Calibration of the STARDUST Navigation Camera

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I. Introduction

The "navigation camera" being carried by the STARDUST spacecraft is intended primarily for navigation to the precise point desired while flying past Comet P/Wild 2 and to gather data necessary to improve scientific knowledge of the cometary environment during the approach to the comet for the sake of spacecraft safety. Its secondary purpose is to gather new scientific data about the cometary nucleus, specifically the nucleus morphology and mineralogical homogeneity, and an imaging science team was created among project Co-Is to prepare for this activity.

The camera is fixed to the spacecraft. It is pointed by use of an attached scan mirror, set at a 45° angle to the optical axis, that rotates about the optical axis. The plane of this scan is changed by rolling the spacecraft about its x-axis, which must remain pointed in the "ram" direction in order to maintain protection of the body of the spacecraft by the dust shield (Whipple bumper). The dust shield blocks the view of the scan mirror in the forward direction, so a periscope was installed in order to look around the dust shield. The front periscope mirror will be "sandblasted" during passage through the comet, but the scan mirror will be protected, and it rotates off of the periscope as the spacecraft approaches the comet nucleus.

Following the "better, faster, cheaper" paradigm of Discovery class missions, the camera lens, filter wheel and shutter are spare Voyager components and the CCD is a Cassini spare. Additional components, while new, have inherited designs, e.g. the 12 to 8 bit compressor (Cassini), the scan mirror motor and electronics (Pathfinder, MISR), and the CCD drivers (Milstar).

The camera lens is a six element Petzval design (the final, field lens, being new), having a 203 mm focal length at a speed of f/3.5. The CCD has 1024 x 1024 imaging elements, each 12 μm on a side, giving the camera a 59 μradian per pixel field of view. Although 12μm square, there is a 1μm channel on each side of every pixel that has no sensitivity, so the photometric area of each pixel is 120 $(\mu m)^2$ rather than 144 $(\mu m)^2$. This is accounted for in the quantum efficiency measurement, however, so it does not have to appear as an additional term in the data reduction equations. The filter wheel has eight positions and carries filters designed specifically to meet STARDUST needs. The transmission data and plotted transmission curves for these filters will be found in Appendix I. The scan mirror reflectance, lens transmission, and CCD quantum efficiency are given in Appendix II. A "grain-of-wheat" calibration lamp is placed about 6 mm in front of the front lens element. This results in non-uniform but extremely repeatable illumination of the CCD, and, run considerably under-voltage, this lamp is very stable and has never been know to fail when operated in this mode. It is a satisfactory relative "field flattener," while absolute calibration will come from standard stars. Data compression is supplied by a 12 to 8 bit square root compression chip. A look-up table for this compression is given in Appendix III. CCD full well is about 100,000 electrons, and the electronics are set to 20 electrons/dn. Uncompressed data are quite linear over the full range from 0 to 4095 dn (81,920 electrons). Readout rate is 300 kpixels/s. The shutter can be set for exposures from 5 ms to 20 s, with a bulb command available for exposures in excess of 20 s. There are no gain state settings.

II. Plans

The calibration intentions of the camera team were the very best. The plans called for three independent calibration runs, with a month separating them, to check the stability both of the camera and the radiometric calibration system. Focus of each filter was to be checked after shake tests and vertical and horizontal modulation transfer function measured. Actual shutter times vs. commanded times were to be checked 50 times for each of three different exposure times and exposure uniformity across the aperture was to be measured. Geometric distortion was to be measured both with and without the periscope.

In fact, a useable power supply for the flight camera electronics was never delivered by the vendor, and, after weeks of delay, an existing power supply had to be flight qualified. Delivery finally occurred months after the camera was originally supposed to arrive at Lockheed Martin Astronautics in Denver, so all testing had to be compressed to an absolute minimum. One set of absolute calibrations was run, described in detail below, camera focus was checked at only one wavelength, and the shutter tests were never carried out beyond checking electronic response times with the exposures commanded. Bore siting of the instrument was carried out in Denver by means of an autocollimator with reference to spaceframe datum plates. Complete details will be found in Appendix XIII. The periscope mirrors were aligned, but no tests were ever carried out with the periscope in the optical path in front of the camera. Geometric calibration will be performed on star fields in flight. A mathematical description of the transformation from inertial vectors to the camera focal plane is given in Appendix IV by Shyam Bhaskaran.

The filter thicknesses were designed to give identical camera focal lengths, given the color curve supplied with the lens. After the camera was delivered to Denver, it was discovered that the units on the color curve were incorrect. As a result, the filters furthest in wavelength from the yellow filter actually used for the focus tests are out of focus. The infrared filter is the worst, the red filter far from great, and the others good to perfect. It would not have mattered much if this had been discovered before delivery to LMA, since it would have taken several months to acquire new filters, and the camera was already weeks overdue. Fortunately the high resolution filter, to be used for closeup nucleus images, is one of the good filters, since its weighted central wavelength of 596 nm is close to that of the yellow filter at 580 nm. Point spread functions for each filter will be found in Appendix V.

III. Photometric Calibration

Photometric calibration of the camera was carried out in the high-bay clean room in building 306 at JPL. David Brown set up a 40-inch integrating sphere and a tungsten lamp, which provided an infinite Lambert plane surface from the viewpoint of the camera.

Variation over the surface is less than ½% at all points used. Radiometric calibration of the lamp was carried out with a calibrated diode and 16 narrow band filters from 350 - 1100 nm. This is identical to the setup that was used for the Cassini wide angle camera. The spectral radiance per ampere is given in the first table in Appendix VI at 14 of those wavelengths. The diode current at each wavelength follows for a diaphragm set to give 1 nA at 700 nm. In order to have a reasonable light level for the range of exposures desired for each flight filter, the diaphragm was opened and closed and the resulting diode current recorded for 700 nm. This diode current at 700 nm for each filter and each temperature is given in the three following tables in Appendix VI. The spectral radiance at each wavelength scales to that at 700 nm in the same ratio as the diode currents given on the first sheet. For example, the actual diode current for the yellow filter in the -30°C run was 18.00 nA, so the values in the final column of the first table in Appendix III all have to be scaled by the ratio 18.00/1.000 to get the actual diode current values for the calibration. These are then multiplied by values for spectral radiance per ampere in the black box to get the spectral radiance values for each calibration.

The camera itself was placed in a large thermal vacuum chamber, and measurements were carried out on successive days at -30°C, -40°C, and -50°C, encompassing the range of temperatures that the camera might encounter in flight. The transmission of the window in the vacuum chamber will be found in Appendix VII. The diode currents measured for each day's calibration run also will be found in Appendix VII. Almost a year into flight, the CCD had been stable at -33°C for many months. When the IMUs (Inertial Measurement Units, the "Gyros") were finally turned off for the first time on Jan. 25, 2000, however, the temperature dropped 7°C in two days. It has since stabilized at about -36°C, fluctuating a few degrees with various recent spacecraft activities. The bias subtracted photometric response of the camera is virtually identical at the three temperatures, but the bias level itself is a strong inverse function of temperature, rising with decreasing temperature. For that reason it is important to take bias frames as near in time to data frames as possible and to bracket a data set with bias frames, if near simultaneous frames are not possible. If the camera temperature is not stable, due to camera or spacecraft activity, it is better to subtract a bias level determined from the BLS pixels (see below) or the mean background level. For a better result when using BLS values, known hot pixels can be corrected first. Cosmic ray hits can be handled similarly. A complete calculation, going from diode current and exposure to the expected dn level, is given in Appendix VIII.

A complete list of calibration files is given in Appendix IX. Although all eight filter were calibrated, a bit less attention was given to the OpNav filter, since it was not expected that it would be used for scientific work. It is not expected that the OpNav filter will be used for compressed frames, which will be taken only during the actual comet encounter, and the uncompressed calibration data were intended primarily to set appropriate exposure times. For each filter, data were taken at four different exposure times in order to check the linearity of the CCD response. It is excellent, as shown in the camera evaluation in Appendix X provided by Justin Maki. The uncompressed response is linear and the compressed response is quadratic, as it should be. The one caution that has to be noted is that **the shutter is not symmetric in its action**. It takes about 2.0 ms longer in one direction than in the other, the longer exposure being the correct one, so there is a 40% difference in successive frames for the shortest 5 ms exposures. This needs to be taken into account for precise photometry. It should also be noted that exposures longer than about one second may not be practical for science images. The spacecraft drift rate is about one pixel per second when in the tightest (025 degree) deadband (which must be used during encounter), so there is no increase in effective exposure for times longer than one second.

Frames taken with the calibration lamp turned on were made at only one exposure level, because the purpose of the cal lamp is to flood the field, with the brightest pixel near saturation. Absolute calibration in space will be provided by observations of cometary standard stars, with the cal lamp providing relative calibration among the pixels. In the broad filters (OpNav & HiRes) and the red filters you can actually see a magnified in-focus ghost image of the cal lamp filament in the lamp-on frames, but again the dn values are quite stable for any given pixel.

The actual frames transmitted to the ground are 1024 rows by 1046 columns for uncompressed images and 1024 rows by 1048 columns for compressed images. The first column is a sync word which always has the value zero. The second column is the row number (0 to 1023), the next eight columns are BLS (BaseLine Stabilization) pixels which are a measure of the background (bias) level, and the eleventh column is the so called FAT pixel, always a large number, which is a part of the image. Then there are 1022 columns of good data followed by another FAT pixel in the 1033 column. The final twelve columes are additional BLS pixels which measure the charge transfer efficiency as the CCD reads out. In sum, each uncompressed frame has 10 columns of non-image data, 1024 columns of data that include two FAT pixels, and 12 more columns on non-image data. A compressed image differs only in requiring two columns each for the sync word and line number, so they have 1048 columns (12 + 1024 + 12). The non-image parts usually are masked off (not included) when images are distributed, but the image does include the FAT pixels.

The periscope was not in the light path during the calibration runs. In fact it was not yet delivered, and the chamber was not big enough to mount it with the camera in any case. Typically images will be taken through the periscope ONLY after we are near the comet and need to look in the forward (ram) direction. Reflectivity curves were made for both periscope mirrors and are included as Appendix XI. Tests were never run with the mirrors installed in their housing, so we can only assume the periscope transmission is equal to the product of the reflectance of the two mirrors.

Information on the format and meaning of data labels that accompany each individual calibration file is given in Appendix XII, by Howard Taylor, the engineer who set the format in consultation with the science team.

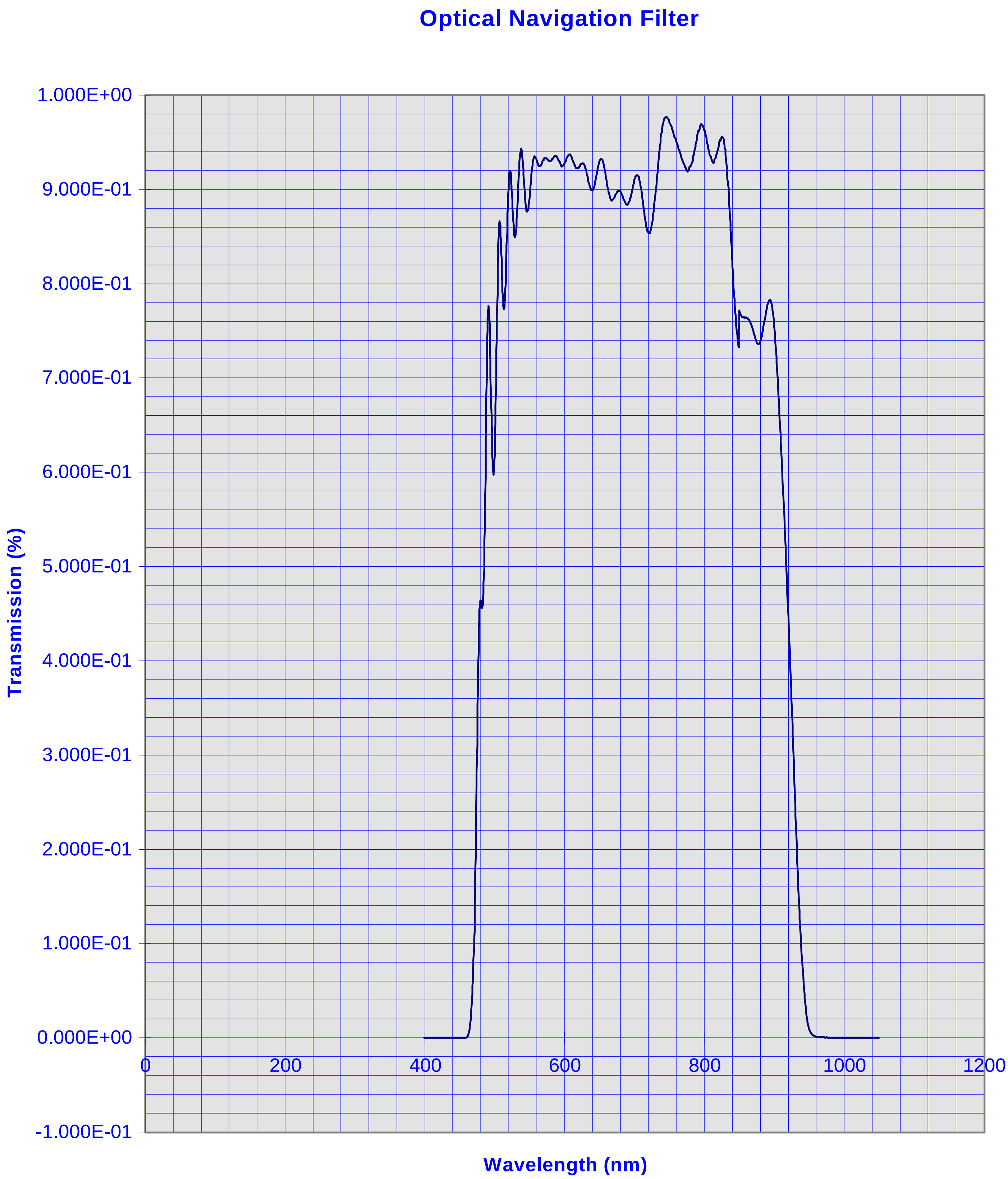
APPENDIX I.

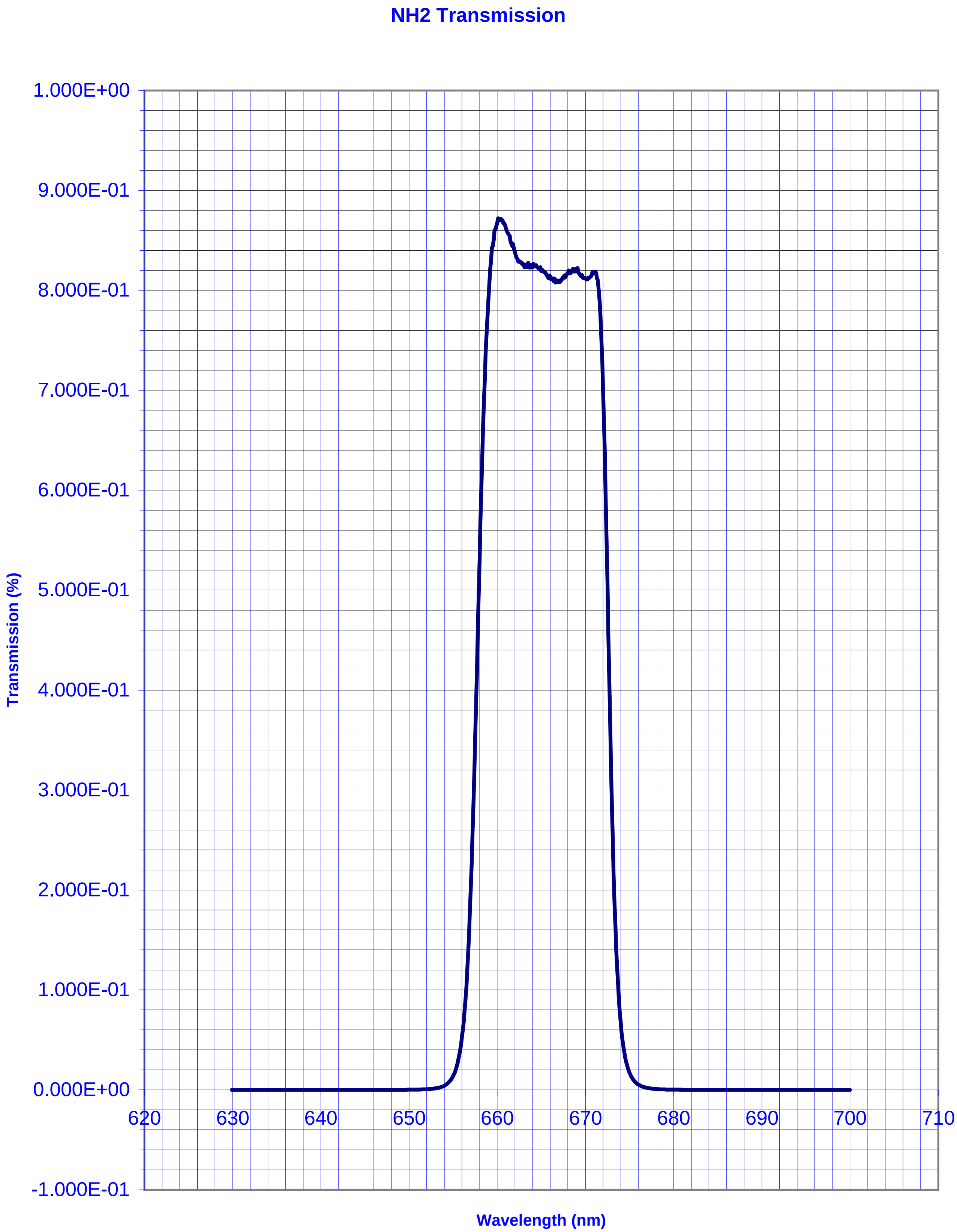
Filter Transmission

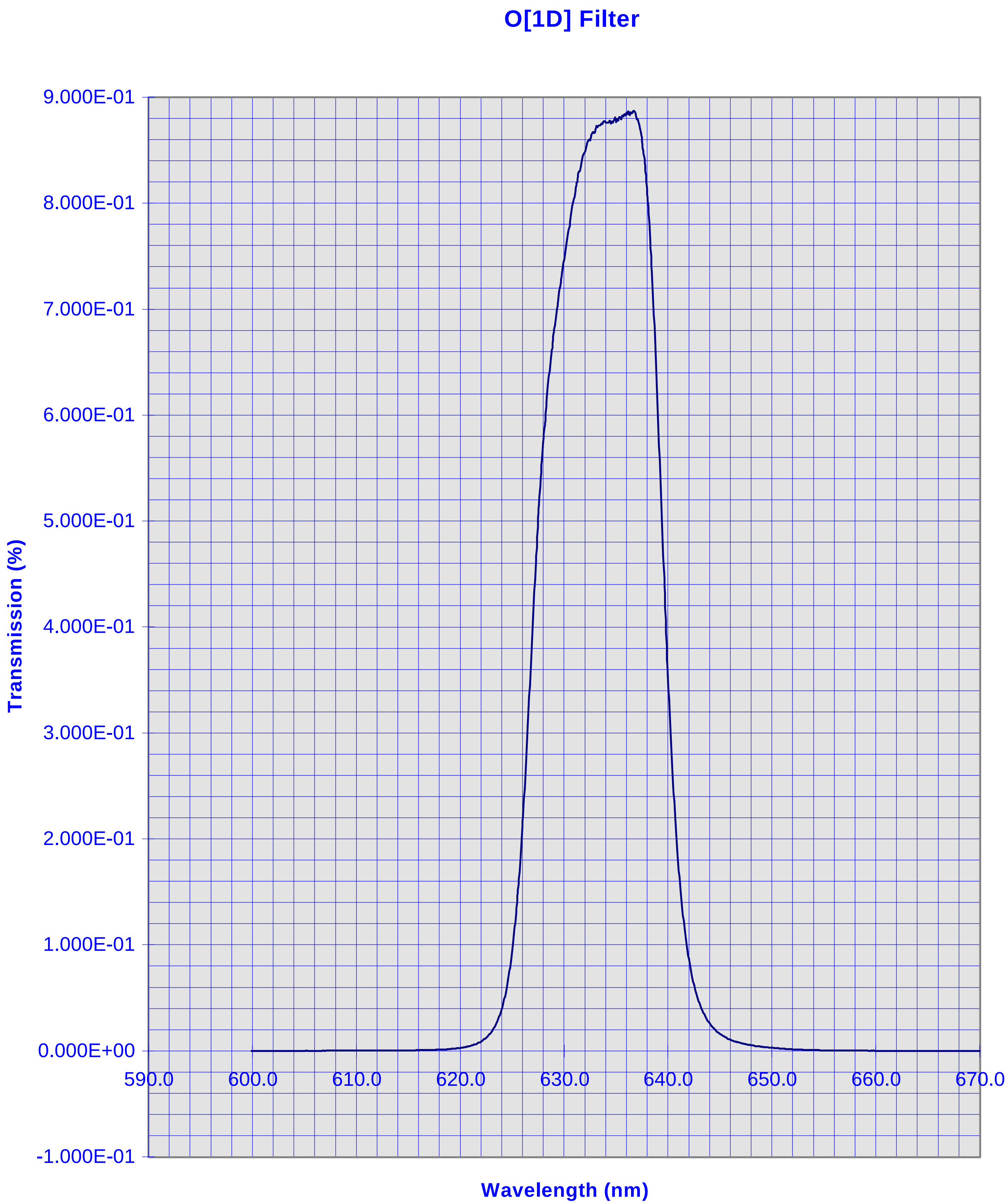
Only filter transmission curves are presented in this printed document. The actual data from which the curves were plotted are contained in the digital archive.

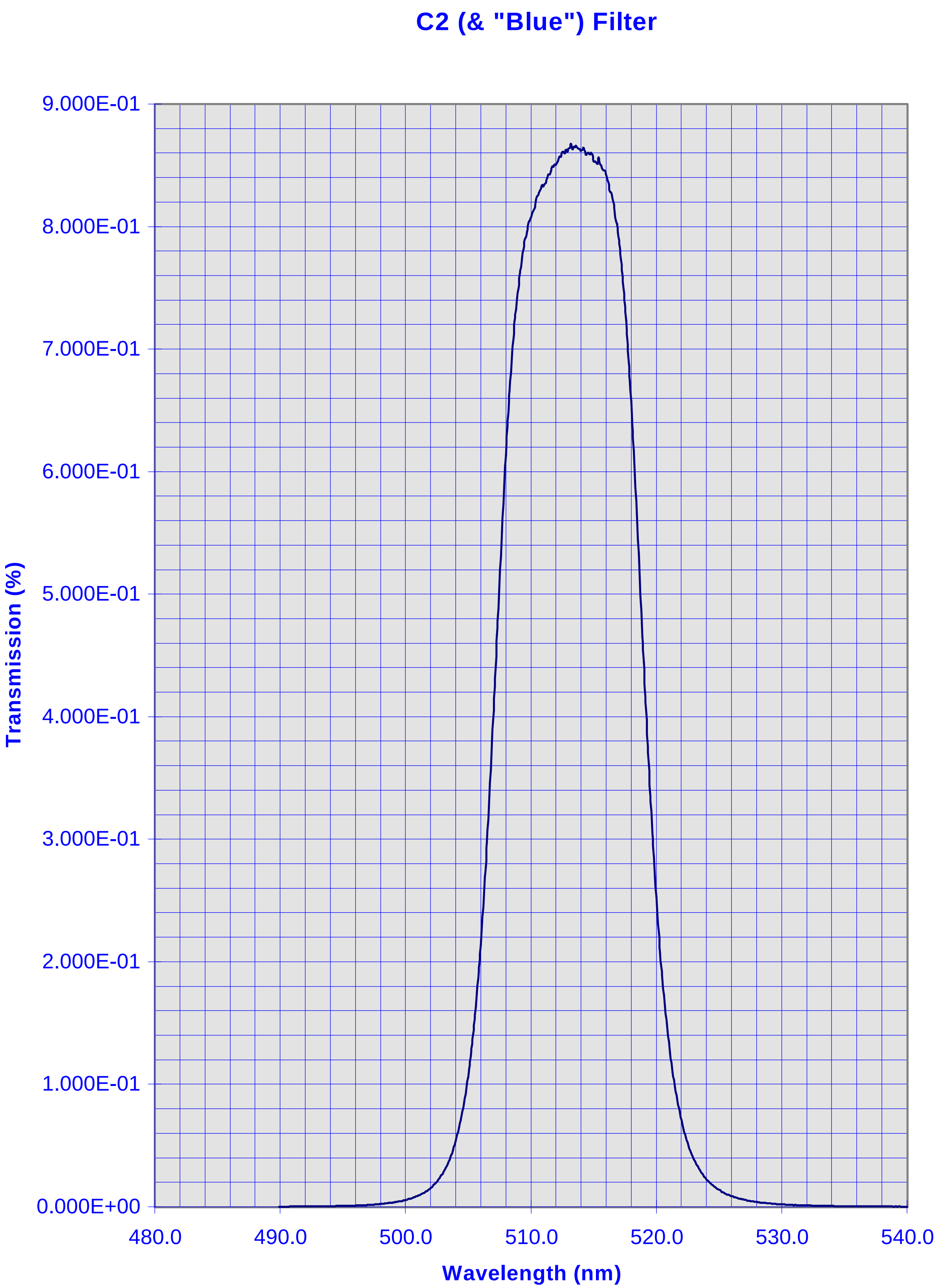
Flight Filter Arrangement

Official	Designations		Transmission Weighted Central Wavelength	Width at Half Transmission
Number	Name		nm	nm
0	OpNav	Navigation Filter	698.8	400
1	NH2	NH_2 Filter	665.1	15
2	Oxygen	$O[^1D]$ Filter	633.6	12
3	C2	C_2 (& Blue) Filter	513.2	12
4	Yellow	Yellow Continuum Filter	580.2	4
5	Red	Red Continuum Filter	712.9	6
6	NIR	Infrared Continuum Filter	874.6	30
7	HiRes	High Resolution Filter	596.4	200

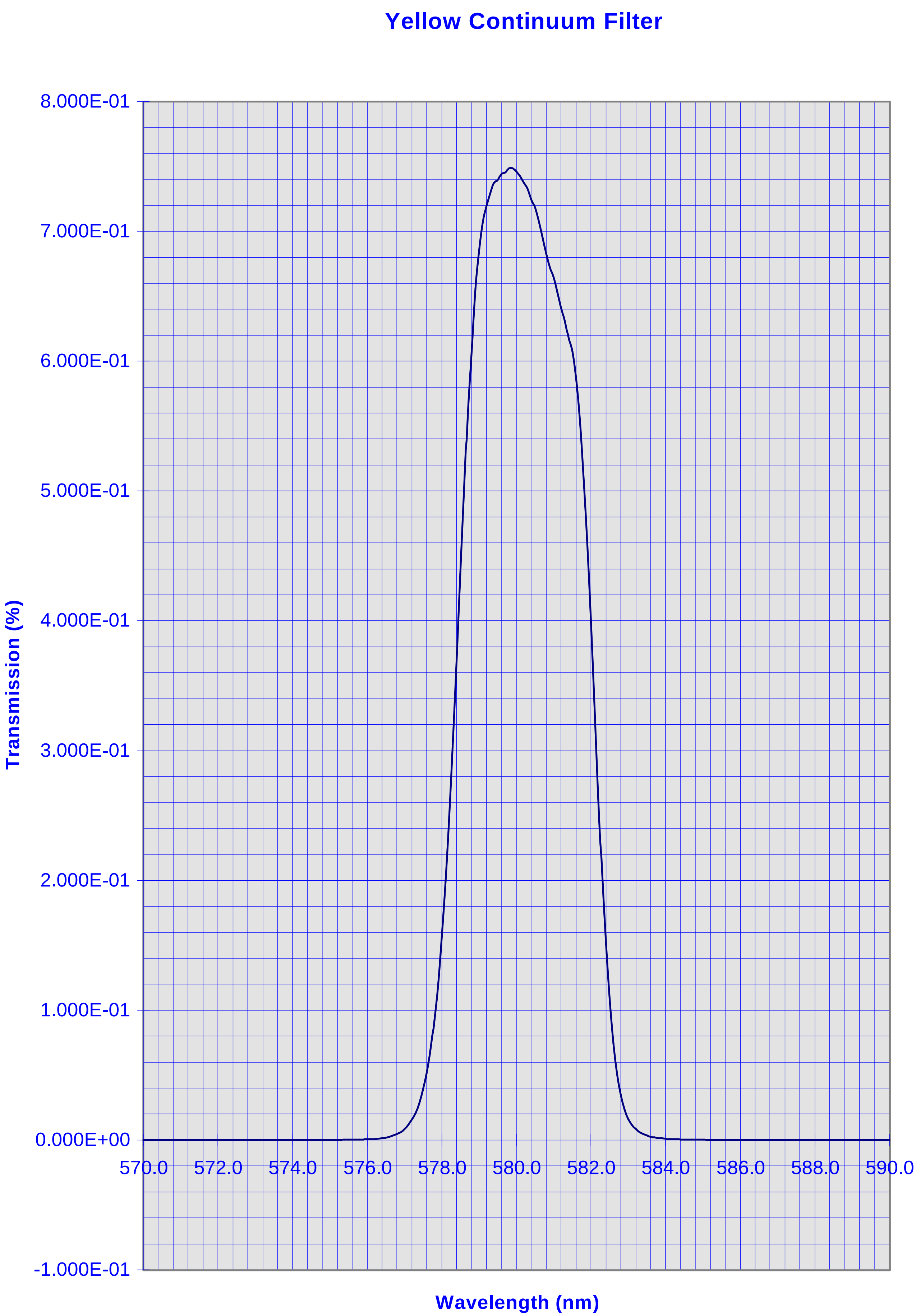

Optical Navigation Filter
1.000E+00
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
0
200
400
600
800
1000
1200
Transmission (%)
Wavelength (nm)


NH2 Transmission
1.000E+00
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
Transmission (%)
620
630
640
650
660
670
680
690
700
710
Wavelength (nm)

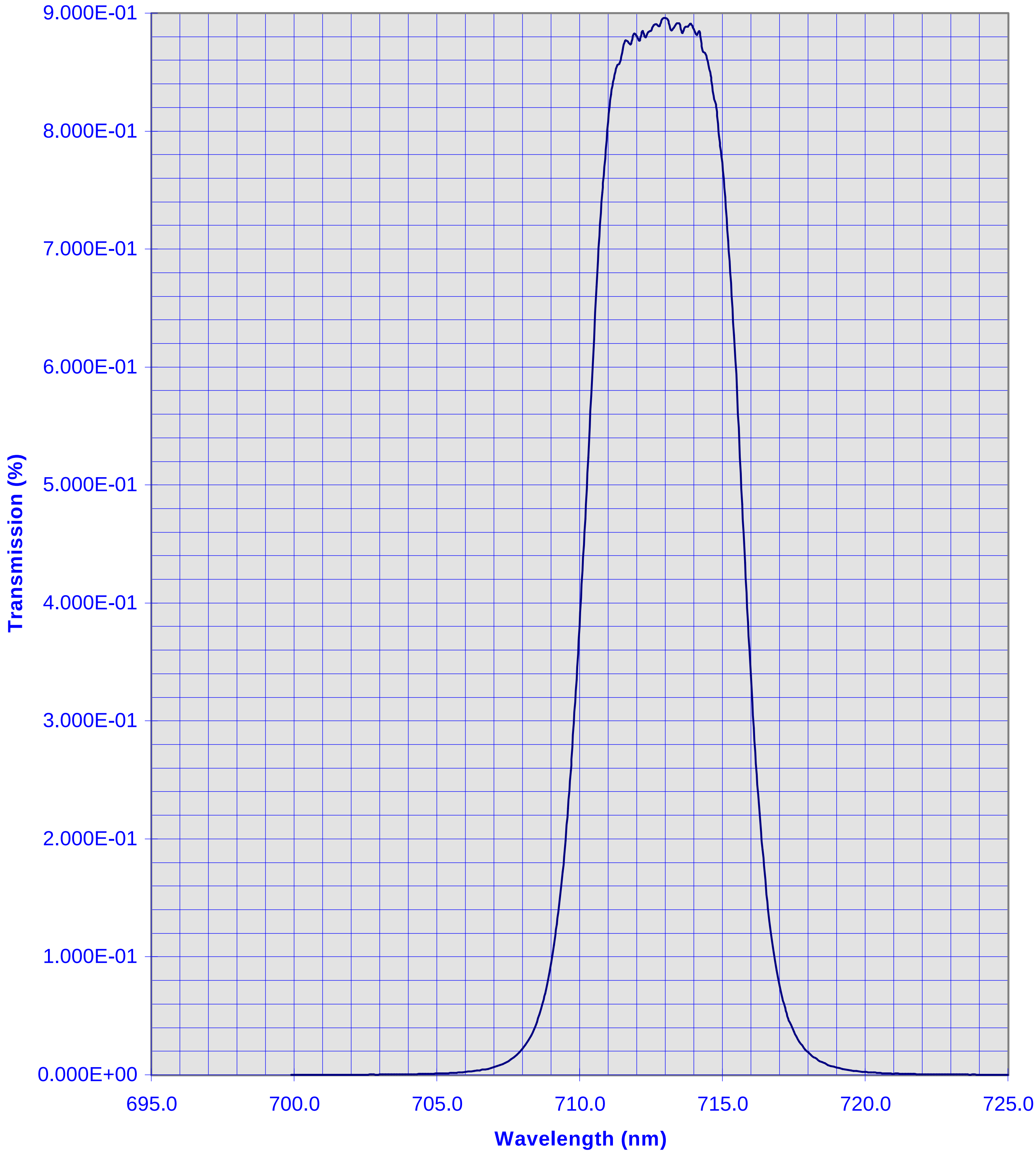

O[1D] Filter
Transmission (%)
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
590.0
600.0
610.0
620.0
630.0
640.0
650.0
660.0
670.0
Wavelength (nm)

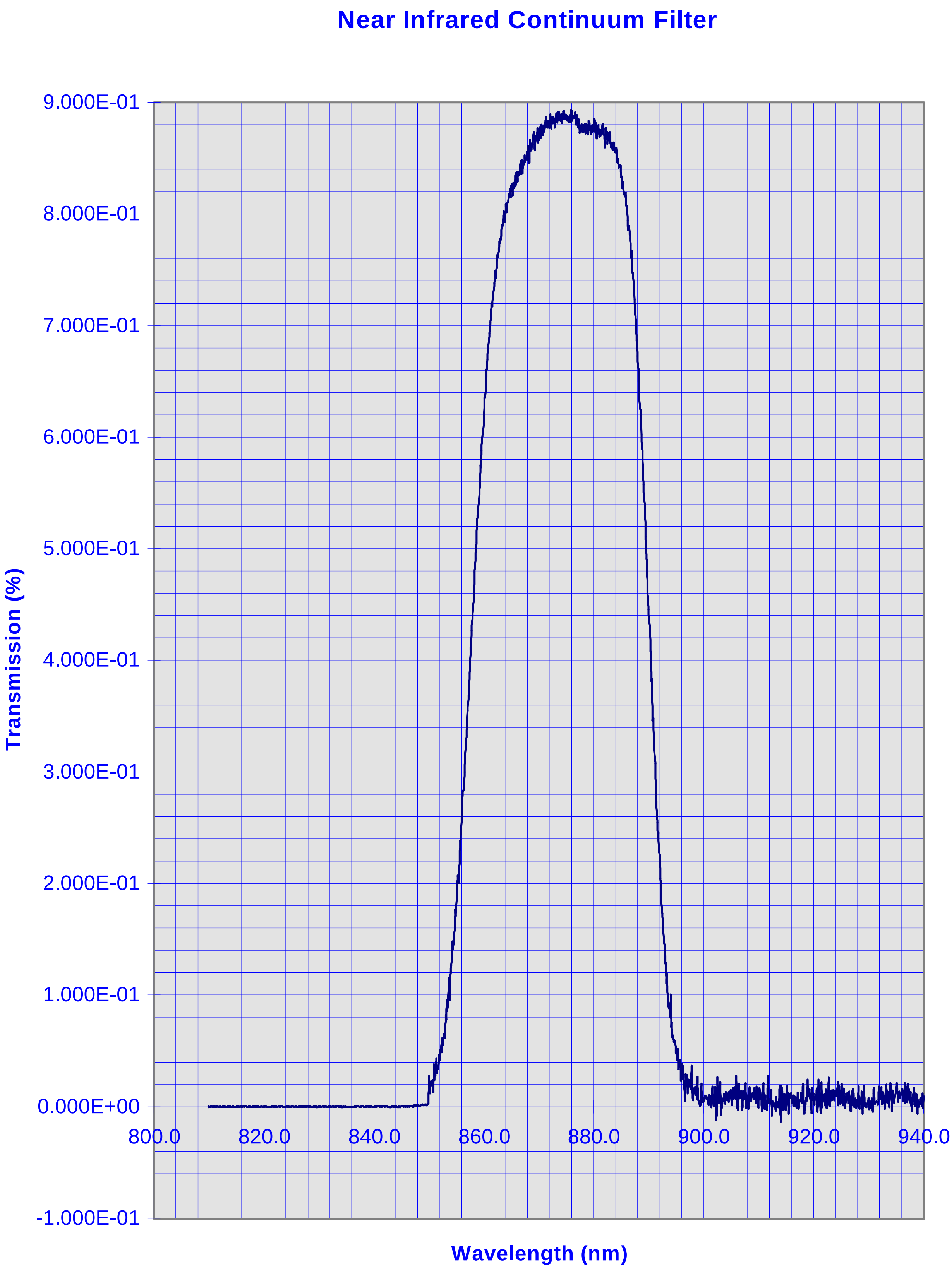


C2 (& "Blue") Filter
Transmission (%)
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
480.0
490.0
500.0
510.0
520.0
530.0
540.0
Wavelength (nm)

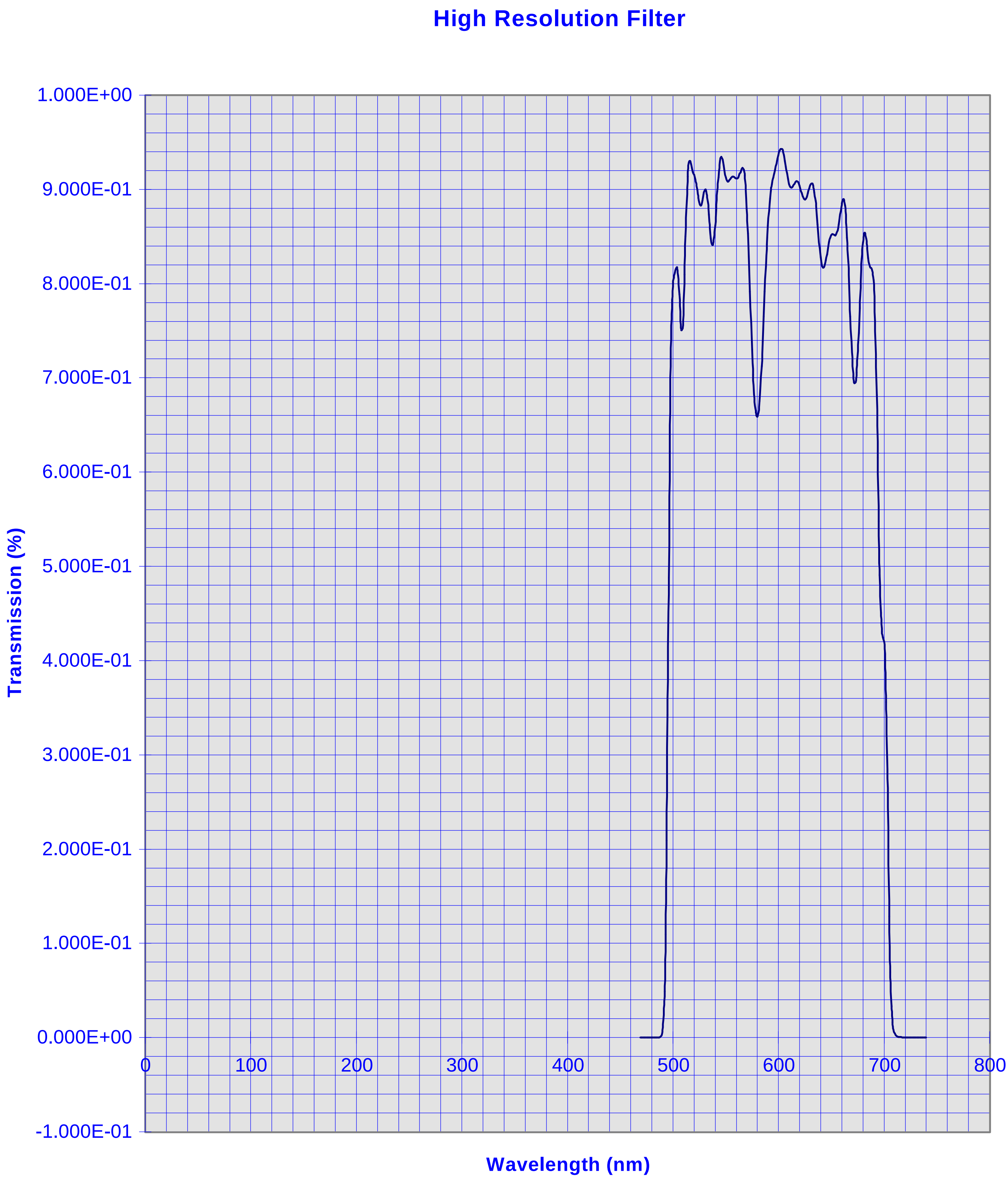

Yellow Continuum Filter
Transmission (%)
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
570.0
572.0
574.0
576.0
578.0
580.0
582.0
584.0
586.0
588.0
590.0
Wavelength (nm)

Red Continuum Filter





Near Infrared Continuum Filter
Transmission (%)
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
800.0
820.0
840.0
860.0
880.0
900.0
920.0
940.0
Wavelength (nm)



High Resolution Filter
Transmission (%)
1.000E+00
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
2.000E-01
1.000E-01
0.000E+00
-1.000E-01
0
100
200
300
400
500
600
700
800
Wavelength (nm)

Data_870_opnav

Wavelength (nm)	Transmission
1050	0.00015
1049	0.00014
1048	0.00014
1047	0.00014
1046	0.00014
1045	0.00016
1044	0.00021
1043	0.00021
1042	0.00014
1041	0.00013
1040	0.00015
1039	0.00015
1038	0.00014
1037	0.00016
1036	0.00017
1035	0.00017
1034	0.00015
1033	0.00012
1032	0.00015
1031	0.0002
1030	0.00018
1029	0.00014
1028	0.00013
1027	0.00014
1026	0.00017
1025	0.00011
1024	0.00014
1023	0.00016
1022	0.00019
1021	0.0002
1020	0.00011
1019	0.00017
1018	0.0002
1017	0.00017
1016	0.00014
1015	0.00018
1014	0.00018
1013	0.00018
1012	0.00017
1011	0.00019
1010	0.00022
1009	0.00015
1008	0.00018
1007	0.00015
1006	0.00014
1005	0.00015
1004	0.00023
1003	0.00013
1002	0.00018
1001	0.00018

1000	0.00019
999	0.0002
998	0.00021
997	0.00027
996	0.00014
995	0.00022
994	0.00021
993	0.00024
992	0.00024
991	0.0002
990	0.0002
989	0.00025
988	0.00023
987	0.00023
986	0.00028
985	0.00017
984	0.00025
983	0.00021
982	0.00028
981	0.00026
980	0.00025
979	0.00028
978	0.00028
977	0.00029
976	0.00031
975	0.00037
974	0.00044
973	0.00028
972	0.00036
971	0.00045
970	0.00046
969	0.00049
968	0.00057
967	0.00058
966	0.00065
965	0.00074
964	0.00077
963	0.00084
962	0.00094
961	0.00107
960	0.00128
959	0.00142
958	0.00168
957	0.00196
956	0.00236
955	0.00284
954	0.0035
953	0.00434
952	0.00528
951	0.00678
950	0.00879
949	0.01106

948	0.01462
947	0.01881
946	0.02398
945	0.03069
944	0.03836
943	0.04663
942	0.0567
941	0.06757
940	0.07865
939	0.09148
938	0.10528
937	0.11925
936	0.13449
935	0.15121
934	0.16804
933	0.18576
932	0.20575
931	0.22543
930	0.24565
929	0.26773
928	0.28897
927	0.30971
926	0.33149
925	0.35194
924	0.37119
923	0.39103
922	0.40972
921	0.42757
920	0.44624
919	0.46458
918	0.48187
917	0.50034
916	0.51903
915	0.53682
914	0.55473
913	0.57287
912	0.58986
911	0.60634
910	0.62376
909	0.63903
908	0.65359
907	0.66906
906	0.68261
905	0.69647
904	0.70972
903	0.7223
902	0.73368
901	0.74444
900	0.75413
899	0.7624
898	0.76938
897	0.77474

896	0.77865
895	0.78116
894	0.78252
893	0.78278
892	0.7817
891	0.77965
890	0.77713
889	0.77404
888	0.76995
887	0.76549
886	0.76132
885	0.75637
884	0.75173
883	0.74819
882	0.74434
881	0.74127
880	0.73881
879	0.73693
878	0.73623
877	0.7358
876	0.7362
875	0.7374
874	0.73942
873	0.74148
872	0.74411
871	0.74653
870	0.74893
869	0.75226
868	0.75412
867	0.75617
866	0.75797
865	0.76
864	0.76132
863	0.76211
862	0.76311
861	0.76329
860	0.76408
859	0.7642
858	0.76362
857	0.76449
856	0.76411
855	0.76397
854	0.76474
853	0.76549
852	0.76705
851	0.76826
850	0.77102
849	0.73348
848	0.74046
847	0.74491
846	0.75183
845	0.76177

844	0.77235
843	0.78012
842	0.79253
841	0.80602
840	0.82124
839	0.83375
838	0.8499
837	0.86232
836	0.87738
835	0.89159
834	0.90445
833	0.91311
832	0.92311
831	0.93234
830	0.94072
829	0.94515
828	0.95224
827	0.95469
826	0.95518
825	0.956
824	0.95348
823	0.9515
822	0.95247
821	0.94893
820	0.94495
819	0.94127
818	0.93842
817	0.93644
816	0.93378
815	0.93246
814	0.93105
813	0.92768
812	0.92975
811	0.92982
810	0.93067
809	0.93499
808	0.93598
807	0.93956
806	0.94228
805	0.9463
804	0.94938
803	0.95418
802	0.9577
801	0.96203
800	0.96301
799	0.96453
798	0.96724
797	0.968
796	0.96865
795	0.96914
794	0.96719
793	0.96441

792	0.96198
791	0.96248
790	0.95791
789	0.95329
788	0.94958
787	0.9451
786	0.94177
785	0.93729
784	0.93571
783	0.93035
782	0.92803
781	0.92527
780	0.92413
779	0.9241
778	0.92107
777	0.92046
776	0.91913
775	0.91991
774	0.92079
773	0.92325
772	0.92448
771	0.92675
770	0.92773
769	0.9304
768	0.93176
767	0.93389
766	0.93629
765	0.93925
764	0.94185
763	0.94233
762	0.94635
761	0.94809
760	0.94995
759	0.9532
758	0.95513
757	0.95573
756	0.95996
755	0.96175
754	0.96379
753	0.96625
752	0.96821
751	0.96956
750	0.97118
749	0.97352
748	0.97528
747	0.97556
746	0.97726
745	0.97696
744	0.97592
743	0.97624
742	0.97383
741	0.97086

740	0.96711
739	0.96144
738	0.95825
737	0.95168
736	0.94359
735	0.93728
734	0.92822
733	0.92015
732	0.91218
731	0.90384
730	0.89613
729	0.88751
728	0.88085
727	0.87347
726	0.86765
725	0.86278
724	0.85918
723	0.85587
722	0.85332
721	0.85367
720	0.85364
719	0.85539
718	0.85706
717	0.86055
716	0.86411
715	0.86957
714	0.87435
713	0.88058
712	0.8859
711	0.89177
710	0.89707
709	0.90213
708	0.90637
707	0.90967
706	0.91306
705	0.91451
704	0.91525
703	0.91447
702	0.91465
701	0.91213
700	0.91047
699	0.90697
698	0.90363
697	0.90049
696	0.89605
695	0.8928
694	0.89074
693	0.88795
692	0.88654
691	0.88457
690	0.8838
689	0.88378

688	0.88419
687	0.88534
686	0.88717
685	0.88849
684	0.89017
683	0.8921
682	0.89444
681	0.89573
680	0.89728
679	0.89786
678	0.89846
677	0.89814
676	0.89827
675	0.89721
674	0.89546
673	0.89472
672	0.89267
671	0.89109
670	0.88995
669	0.88929
668	0.88832
667	0.8884
666	0.88904
665	0.89149
664	0.89388
663	0.89681
662	0.90027
661	0.90372
660	0.90871
659	0.913
658	0.9174
657	0.92223
656	0.92569
655	0.92851
654	0.93133
653	0.93219
652	0.93229
651	0.93169
650	0.92973
649	0.92763
648	0.9239
647	0.92054
646	0.91541
645	0.9127
644	0.90851
643	0.90506
642	0.90209
641	0.89996
640	0.89883
639	0.899
638	0.89937
637	0.90107

636	0.90319
635	0.90577
634	0.90834
633	0.91249
632	0.91555
631	0.91901
630	0.92166
629	0.92397
628	0.9262
627	0.92723
626	0.92784
625	0.92708
624	0.92669
623	0.92692
622	0.92488
621	0.92373
620	0.92291
619	0.92231
618	0.92221
617	0.92291
616	0.92285
615	0.92474
614	0.92612
613	0.92873
612	0.92983
611	0.93232
610	0.93427
609	0.93555
608	0.93678
607	0.93724
606	0.93708
605	0.93582
604	0.93493
603	0.93353
602	0.93173
601	0.9292
600	0.92779
599	0.92615
598	0.92533
597	0.92504
596	0.92452
595	0.9256
594	0.92703
593	0.92944
592	0.93032
591	0.93133
590	0.933
589	0.93455
588	0.93551
587	0.93505
586	0.9355
585	0.93489

584	0.93382
583	0.93268
582	0.93204
581	0.9309
580	0.92995
579	0.92997
578	0.93024
577	0.9302
576	0.93151
575	0.9327
574	0.93272
573	0.93353
572	0.93351
571	0.93335
570	0.93126
569	0.93055
568	0.92819
567	0.92688
566	0.92537
565	0.92483
564	0.92461
563	0.92479
562	0.9267
561	0.92853
560	0.9307
559	0.93287
558	0.93375
557	0.93486
556	0.9337
555	0.93123
554	0.9262
553	0.91931
552	0.91118
551	0.90213
550	0.89319
549	0.88603
548	0.87979
547	0.87728
546	0.87657
545	0.88016
544	0.88694
543	0.89699
542	0.90872
541	0.92083
540	0.93154
539	0.93916
538	0.94326
537	0.94173
536	0.93405
535	0.92316
534	0.90834
533	0.89117

532	0.87527
531	0.86131
530	0.85219
529	0.84915
528	0.85121
527	0.8591
526	0.8731
525	0.88838
524	0.90354
523	0.91509
522	0.91996
521	0.91692
520	0.90543
519	0.88587
518	0.86134
517	0.8338
516	0.8081
515	0.78763
514	0.77563
513	0.77315
512	0.78078
511	0.79691
510	0.81908
509	0.8415
508	0.85882
507	0.86599
506	0.85795
505	0.83535
504	0.79903
503	0.75449
502	0.7051
501	0.6608
500	0.62616
499	0.60406
498	0.59726
497	0.60756
496	0.63212
495	0.6686
494	0.71009
493	0.74848
492	0.77237
491	0.77662
490	0.75779
489	0.7187
488	0.66615
487	0.60779
486	0.5513
485	0.50641
484	0.47618
483	0.45978
482	0.45599
481	0.45957

480	0.46397
479	0.46222
478	0.44857
477	0.42015
476	0.37833
475	0.32537
474	0.26725
473	0.21187
472	0.16355
471	0.1221
470	0.08952
469	0.06519
468	0.0467
467	0.03245
466	0.02188
465	0.01416
464	0.00864
463	0.00486
462	0.00249
461	0.00114
460	0.00047
459	0.00017
458	0.00005
457	0
456	-0.00001
455	-0.00003
454	0.00001
453	-0.00002
452	0
451	-0.00003
450	0
449	-0.00001
448	-0.00002
447	-0.00002
446	-0.00001
445	0.00001
444	0
443	-0.00002
442	0
441	-0.00001
440	-0.00002
439	0.00002
438	-0.00001
437	-0.00001
436	-0.00002
435	-0.00001
434	-0.00001
433	0
432	0
431	0
430	-0.00001
429	-0.00001

428	-0.00003
427	0
426	0.00001
425	0.00001
424	-0.00001
423	0
422	0
421	-0.00002
420	0.00002
419	-0.00001
418	0
417	0
416	0
415	0.00001
414	0
413	-0.00002
412	-0.00001
411	0.00001
410	0
409	-0.00001
408	0
407	0
406	0
405	0
404	0
403	-0.00001
402	-0.00001
401	-0.00001
400	-0.00002
399	-0.00002

Wavelength (nm)	Transmission
700	-0.00001
699.9	0
699.8	-0.00001
699.7	-0.00001
699.6	-0.00001
699.5	0
699.4	-0.00001
699.3	0
699.2	0.00001
699.1	-0.00001
699	-0.00001
698.9	-0.00001
698.8	0
698.7	0
698.6	0
698.5	0
698.4	0
698.3	0
698.2	-0.00001
698.1	0
698	0
697.9	0
697.8	-0.00001
697.7	-0.00001
697.6	0
697.5	0
697.4	0
697.3	0
697.2	-0.00001
697.1	0
697	0.00001
696.9	0.00001
696.8	-0.00001
696.7	0
696.6	0.00001
696.5	0.00001
696.4	-0.00001
696.3	0.00001
696.2	0
696.1	0
696	0
695.9	0
695.8	-0.00001
695.7	0
695.6	-0.00001
695.5	0
695.4	0
695.3	-0.00001
695.2	0
695.1	0

695	-0.00001
694.9	0
694.8	0
694.7	0
694.6	0
694.5	0
694.4	0
694.3	0
694.2	0.00001
694.1	0
694	0
693.9	0
693.8	-0.00001
693.7	0
693.6	0.00001
693.5	0
693.4	0
693.3	-0.00001
693.2	0
693.1	-0.00001
693	0
692.9	0
692.8	-0.00001
692.7	-0.00001
692.6	0
692.5	-0.00002
692.4	0
692.3	-0.00001
692.2	0
692.1	-0.00001
692	-0.00001
691.9	0
691.8	0
691.7	0
691.6	0
691.5	0
691.4	-0.00001
691.3	-0.00001
691.2	0
691.1	0
691	0
690.9	0.00001
690.8	0.00001
690.7	0
690.6	0
690.5	0
690.4	-0.00001
690.3	0.00001
690.2	0
690.1	0
690	0
689.9	0.00001

689.8	0
689.7	-0.00001
689.6	0
689.5	0
689.4	0
689.3	0
689.2	-0.00001
689.1	-0.00001
689	0
688.9	0
688.8	-0.00001
688.7	0
688.6	0
688.5	0
688.4	0
688.3	0
688.2	-0.00001
688.1	0
688	0
687.9	-0.00001
687.8	0
687.7	0
687.6	0
687.5	0
687.4	0
687.3	0
687.2	0.00001
687.1	0.00001
687	0
686.9	0.00001
686.8	0
686.7	-0.00001
686.6	0
686.5	0.00001
686.4	0
686.3	0
686.2	0.00001
686.1	0
686	0
685.9	0
685.8	0.00001
685.7	0.00001
685.6	-0.00001
685.5	0
685.4	0
685.3	0.00001
685.2	0
685.1	0
685	0.00001
684.9	0
684.8	0.00001
684.7	0.00002

684.6	0.00001
684.5	0.00001
684.4	0
684.3	0.00001
684.2	0.00002
684.1	0.00001
684	0.00001
683.9	0.00001
683.8	0.00001
683.7	0.00003
683.6	0.00002
683.5	0.00002
683.4	0.00002
683.3	0.00002
683.2	0.00003
683.1	0.00002
683	0.00001
682.9	0.00003
682.8	0.00002
682.7	0.00003
682.6	0.00002
682.5	0.00003
682.4	0.00003
682.3	0.00003
682.2	0.00004
682.1	0.00003
682	0.00002
681.9	0.00004
681.8	0.00005
681.7	0.00004
681.6	0.00005
681.5	0.00006
681.4	0.00008
681.3	0.00006
681.2	0.00008
681.1	0.00009
681	0.0001
680.9	0.00008
680.8	0.00011
680.7	0.00009
680.6	0.00012
680.5	0.00011
680.4	0.00013
680.3	0.00013
680.2	0.00015
680.1	0.00014
680	0.00016
679.9	0.00018
679.8	0.00019
679.7	0.00023
679.6	0.00023
679.5	0.00023

679.4	0.00026
679.3	0.00028
679.2	0.00031
679.1	0.00033
679	0.00036
678.9	0.00037
678.8	0.00036
678.7	0.00045
678.6	0.00048
678.5	0.0005
678.4	0.00056
678.3	0.00058
678.2	0.00067
678.1	0.0007
678	0.00079
677.9	0.00084
677.8	0.00095
677.7	0.001
677.6	0.00111
677.5	0.00117
677.4	0.0013
677.3	0.00138
677.2	0.00158
677.1	0.00174
677	0.00192
676.9	0.00213
676.8	0.00228
676.7	0.00251
676.6	0.00284
676.5	0.00306
676.4	0.00336
676.3	0.00383
676.2	0.00428
676.1	0.00474
676	0.00527
675.9	0.00578
675.8	0.00646
675.7	0.00731
675.6	0.00813
675.5	0.00909
675.4	0.01024
675.3	0.01171
675.2	0.01304
675.1	0.01509
675	0.0169
674.9	0.01914
674.8	0.02207
674.7	0.02487
674.6	0.02807
674.5	0.0326
674.4	0.03723
674.3	0.04298

674.2	0.0498
674.1	0.05757
674	0.06682
673.9	0.07721
673.8	0.09003
673.7	0.10471
673.6	0.12131
673.5	0.13976
673.4	0.16243
673.3	0.18579
673.2	0.21509
673.1	0.24767
673	0.28442
672.9	0.32457
672.8	0.3665
672.7	0.41104
672.6	0.45663
672.5	0.50296
672.4	0.54716
672.3	0.59214
672.2	0.63229
672.1	0.66827
672	0.70131
671.9	0.72863
671.8	0.75173
671.7	0.77586
671.6	0.78854
671.5	0.80041
671.4	0.81039
671.3	0.81183
671.2	0.81752
671.1	0.81885
671	0.81851
670.9	0.81703
670.8	0.81827
670.7	0.81544
670.6	0.81385
670.5	0.81331
670.4	0.81202
670.3	0.81261
670.2	0.81081
670.1	0.81214
670	0.8116
669.9	0.81256
669.8	0.81238
669.7	0.81245
669.6	0.81535
669.5	0.81413
669.4	0.81516
669.3	0.8171
669.2	0.81766
669.1	0.82244

669	0.82022
668.9	0.82136
668.8	0.81868
668.7	0.81884
668.6	0.8217
668.5	0.81974
668.4	0.81839
668.3	0.81718
668.2	0.81923
668.1	0.82005
668	0.81662
667.9	0.81663
667.8	0.81465
667.7	0.81284
667.6	0.81501
667.5	0.81258
667.4	0.81266
667.3	0.81054
667.2	0.80937
667.1	0.80812
667	0.80999
666.9	0.80812
666.8	0.80888
666.7	0.81014
666.6	0.80768
666.5	0.81186
666.4	0.80923
666.3	0.81205
666.2	0.8111
666.1	0.81098
666	0.81398
665.9	0.81489
665.8	0.81232
665.7	0.81395
665.6	0.81514
665.5	0.81739
665.4	0.8178
665.3	0.8191
665.2	0.81883
665.1	0.82044
665	0.81927
664.9	0.82318
664.8	0.82068
664.7	0.82206
664.6	0.82254
664.5	0.82345
664.4	0.82523
664.3	0.82379
664.2	0.82452
664.1	0.82647
664	0.82281
663.9	0.82457

663.8	0.82587
663.7	0.82257
663.6	0.8233
663.5	0.82758
663.4	0.82338
663.3	0.82581
663.2	0.82438
663.1	0.82312
663	0.82625
662.9	0.82565
662.8	0.82778
662.7	0.82745
662.6	0.82878
662.5	0.82921
662.4	0.82854
662.3	0.83117
662.2	0.83255
662.1	0.83522
662	0.83825
661.9	0.84162
661.8	0.84637
661.7	0.84438
661.6	0.84659
661.5	0.84954
661.4	0.8548
661.3	0.85579
661.2	0.85744
661.1	0.85895
661	0.86173
660.9	0.86497
660.8	0.86689
660.7	0.86705
660.6	0.87013
660.5	0.87052
660.4	0.87175
660.3	0.87028
660.2	0.87001
660.1	0.87204
660	0.86745
659.9	0.86494
659.8	0.86093
659.7	0.86038
659.6	0.85132
659.5	0.84443
659.4	0.84253
659.3	0.8284
659.2	0.82156
659.1	0.80532
659	0.78905
658.9	0.77517
658.8	0.75734
658.7	0.73849

658.6	0.71409
658.5	0.69013
658.4	0.66204
658.3	0.63494
658.2	0.60181
658.1	0.56819
658	0.53192
657.9	0.496
657.8	0.45803
657.7	0.42203
657.6	0.38573
657.5	0.3507
657.4	0.3186
657.3	0.28497
657.2	0.25479
657.1	0.22761
657	0.202
656.9	0.17827
656.8	0.15643
656.7	0.13661
656.6	0.1185
656.5	0.10345
656.4	0.09028
656.3	0.07915
656.2	0.06886
656.1	0.06015
656	0.053
655.9	0.04579
655.8	0.04018
655.7	0.03478
655.6	0.03037
655.5	0.02663
655.4	0.02311
655.3	0.02
655.2	0.01762
655.1	0.01556
655	0.01379
654.9	0.01212
654.8	0.01066
654.7	0.00954
654.6	0.0084
654.5	0.00759
654.4	0.00652
654.3	0.00588
654.2	0.00527
654.1	0.00457
654	0.00417
653.9	0.00365
653.8	0.0034
653.7	0.00303
653.6	0.00268
653.5	0.00247

653.4	0.00222
653.3	0.00198
653.2	0.00181
653.1	0.0016
653	0.00145
652.9	0.00142
652.8	0.00116
652.7	0.00106
652.6	0.00095
652.5	0.00092
652.4	0.0008
652.3	0.00074
652.2	0.00066
652.1	0.00063
652	0.0006
651.9	0.00054
651.8	0.00048
651.7	0.00046
651.6	0.0004
651.5	0.00035
651.4	0.00034
651.3	0.0003
651.2	0.00031
651.1	0.00023
651	0.00024
650.9	0.00022
650.8	0.00021
650.7	0.0002
650.6	0.00018
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650.4	0.00015
650.3	0.00015
650.2	0.00013
650.1	0.00012
650	0.00011
649.9	0.0001
649.8	0.00012
649.7	0.00008
649.6	0.00009
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648.8	0.00007
648.7	0.00005
648.6	0.00005
648.5	0.00005
648.4	0.00006
648.3	0.00004

648.2	0.00005
648.1	0.00003
648	0.00004
647.9	0.00004
647.8	0.00003
647.7	0.00003
647.6	0.00003
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647.4	0.00003
647.3	0.00003
647.2	0.00003
647.1	0.00002
647	0.00003
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646.8	0.00002
646.7	0.00002
646.6	0.00001
646.5	0.00003
646.4	0.00001
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646.2	0.00002
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644.3	0.00001
644.2	0.00001
644.1	0.00001
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643.8	0.00001
643.7	0.00001
643.6	0.00001
643.5	0.00001
643.4	0.00002
643.3	0.00001
643.2	0.00001
643.1	0.00002

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642.8	0.00002
642.7	0.00001
642.6	0.00002
642.5	0.00001
642.4	0.00002
642.3	0.00001
642.2	0.00002
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641.8	0.00002
641.7	0.00001
641.6	0.00001
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641.4	0.00001
641.3	0.00001
641.2	0
641.1	0.00001
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640.7	0.00001
640.6	0.00002
640.5	0.00001
640.4	0.00001
640.3	0.00002
640.2	0.00002
640.1	0.00002
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639.9	0.00002
639.8	0.00002
639.7	0.00002
639.6	0.00002
639.5	0.00001
639.4	0.00001
639.3	0.00002
639.2	0.00002
639.1	0.00001
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638.5	0.00002
638.4	0.00002
638.3	0.00002
638.2	0.00002
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638	0.00002
637.9	0.00002

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637.7	0.00002
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637.4	0.00002
637.3	0.00001
637.2	0.00003
637.1	0.00002
637	0.00002
636.9	0.00002
636.8	0.00002
636.7	0.00002
636.6	0.00002
636.5	0.00002
636.4	0.00002
636.3	0.00002
636.2	0.00002
636.1	0.00002
636	0.00001
635.9	0.00002
635.8	0.00002
635.7	0.00002
635.6	0.00002
635.5	0.00002
635.4	0.00002
635.3	0.00002
635.2	0.00002
635.1	0.00002
635	0.00002
634.9	0.00001
634.8	0.00002
634.7	0.00001
634.6	0.00002
634.5	0.00001
634.4	0.00002
634.3	0.00002
634.2	0.00002
634.1	0.00002
634	0.00002
633.9	0.00002
633.8	0.00002
633.7	0.00002
633.6	0.00002
633.5	0.00002
633.4	0.00002
633.3	0.00002
633.2	0.00002
633.1	0.00002
633	0.00001
632.9	0.00003
632.8	0.00003
632.7	0.00002

632.6	0.00002
632.5	0.00002
632.4	0.00002
632.3	0.00002
632.2	0.00003
632.1	0.00002
632	0.00003
631.9	0.00002
631.8	0.00002
631.7	0.00002
631.6	0.00002
631.5	0.00002
631.4	0.00002
631.3	0.00001
631.2	0.00001
631.1	0.00002
631	0.00002
630.9	0.00002
630.8	0.00002
630.7	0.00002
630.6	0.00002
630.5	0.00002
630.4	0.00002
630.3	0.00002
630.2	0.00002
630.1	0.00002
630	0.00002
629.9	0.00002

Data_875_O1D

Wavelength (nm)	Transmission
670	0.00003
669.9	0.00002
669.8	0.00002
669.7	0.00001
669.6	0.00001
669.5	0.00003
669.4	0.00002
669.3	0.00003
669.2	0.00003
669.1	0.00003
669	0.00003
668.9	0.00002
668.8	0.00003
668.7	0.00001
668.6	0.00002
668.5	0.00002
668.4	0.00003
668.3	0.00002
668.2	0.00002
668.1	0.00002
668	0.00002
667.9	0.00001
667.8	0.00003
667.7	0.00003
667.6	0.00004
667.5	0.00003
667.4	0.00003
667.3	0.00003
667.2	0.00004
667.1	0.00002
667	0.00002
666.9	0.00002
666.8	0.00004
666.7	0.00003
666.6	0.00002
666.5	0.00002
666.4	0.00002
666.3	0.00002
666.2	0.00002
666.1	0.00003
666	0.00003
665.9	0.00002
665.8	0.00003
665.7	0.00002
665.6	0.00005
665.5	0.00003
665.4	0.00003
665.3	0.00003
665.2	0.00003
665.1	0.00003

665	0.00002
664.9	0.00003
664.8	0.00003
664.7	0.00003
664.6	0.00004
664.5	0.00003
664.4	0.00003
664.3	0.00005
664.2	0.00003
664.1	0.00005
664	0.00003
663.9	0.00004
663.8	0.00004
663.7	0.00004
663.6	0.00004
663.5	0.00003
663.4	0.00005
663.3	0.00004
663.2	0.00003
663.1	0.00004
663	0.00003
662.9	0.00005
662.8	0.00005
662.7	0.00004
662.6	0.00004
662.5	0.00005
662.4	0.00004
662.3	0.00003
662.2	0.00006
662.1	0.00005
662	0.00004
661.9	0.00004
661.8	0.00004
661.7	0.00005
661.6	0.00006
661.5	0.00004
661.4	0.00006
661.3	0.00005
661.2	0.00005
661.1	0.00006
661	0.00005
660.9	0.00006
660.8	0.00006
660.7	0.00007
660.6	0.00007
660.5	0.00005
660.4	0.00007
660.3	0.00006
660.2	0.00006
660.1	0.00008
660	0.00007
659.9	0.00008

659.8	0.00009
659.7	0.00007
659.6	0.00009
659.5	0.00006
659.4	0.00007
659.3	0.00008
659.2	0.00009
659.1	0.0001
659	0.00009
658.9	0.00012
658.8	0.0001
658.7	0.00011
658.6	0.00012
658.5	0.00011
658.4	0.00012
658.3	0.00011
658.2	0.00012
658.1	0.00011
658	0.00013
657.9	0.00013
657.8	0.00016
657.7	0.00016
657.6	0.00013
657.5	0.00016
657.4	0.00016
657.3	0.00017
657.2	0.00018
657.1	0.00018
657	0.0002
656.9	0.00018
656.8	0.00023
656.7	0.00021
656.6	0.00021
656.5	0.00025
656.4	0.00025
656.3	0.00024
656.2	0.00026
656.1	0.00027
656	0.00031
655.9	0.00028
655.8	0.00033
655.7	0.00032
655.6	0.00036
655.5	0.00034
655.4	0.00037
655.3	0.00038
655.2	0.0004
655.1	0.0004
655	0.00044
654.9	0.00045
654.8	0.00048
654.7	0.00049

654.6	0.00047
654.5	0.00054
654.4	0.00057
654.3	0.00056
654.2	0.0006
654.1	0.00061
654	0.00064
653.9	0.00067
653.8	0.00066
653.7	0.00073
653.6	0.00079
653.5	0.00079
653.4	0.00086
653.3	0.00084
653.2	0.00092
653.1	0.00094
653	0.00095
652.9	0.00101
652.8	0.00105
652.7	0.00107
652.6	0.00115
652.5	0.0012
652.4	0.00122
652.3	0.00129
652.2	0.00132
652.1	0.00136
652	0.00138
651.9	0.00146
651.8	0.00153
651.7	0.00157
651.6	0.00168
651.5	0.00171
651.4	0.00184
651.3	0.00179
651.2	0.00189
651.1	0.002
651	0.00205
650.9	0.00208
650.8	0.00209
650.7	0.00222
650.6	0.00232
650.5	0.00244
650.4	0.00262
650.3	0.00248
650.2	0.00269
650.1	0.00279
650	0.00278
649.9	0.00294
649.8	0.00305
649.7	0.00308
649.6	0.00327
649.5	0.00333

649.4	0.00341
649.3	0.00349
649.2	0.00359
649.1	0.00373
649	0.00385
648.9	0.00398
648.8	0.00419
648.7	0.00426
648.6	0.00436
648.5	0.0045
648.4	0.00448
648.3	0.00475
648.2	0.00499
648.1	0.00515
648	0.00523
647.9	0.00543
647.8	0.00567
647.7	0.00576
647.6	0.00599
647.5	0.00619
647.4	0.0064
647.3	0.00644
647.2	0.00683
647.1	0.00716
647	0.00742
646.9	0.00764
646.8	0.00794
646.7	0.00817
646.6	0.00842
646.5	0.00868
646.4	0.0089
646.3	0.00929
646.2	0.0098
646.1	0.00997
646	0.01057
645.9	0.01092
645.8	0.01116
645.7	0.01182
645.6	0.01259
645.5	0.0129
645.4	0.01341
645.3	0.01389
645.2	0.01477
645.1	0.01534
645	0.01592
644.9	0.01691
644.8	0.01745
644.7	0.0182
644.6	0.01925
644.5	0.02031
644.4	0.02129
644.3	0.02244

644.2	0.02358
644.1	0.0247
644	0.02585
643.9	0.02759
643.8	0.02876
643.7	0.03053
643.6	0.03206
643.5	0.0344
643.4	0.03612
643.3	0.03831
643.2	0.04028
643.1	0.04305
643	0.04564
642.9	0.0485
642.8	0.05178
642.7	0.05509
642.6	0.05811
642.5	0.06223
642.4	0.06638
642.3	0.07085
642.2	0.07621
642.1	0.08169
642	0.08692
641.9	0.09344
641.8	0.10034
641.7	0.10728
641.6	0.11477
641.5	0.12335
641.4	0.13191
641.3	0.14174
641.2	0.15216
641.1	0.16401
641	0.17608
640.9	0.18946
640.8	0.20344
640.7	0.21872
640.6	0.23573
640.5	0.25224
640.4	0.27042
640.3	0.29014
640.2	0.30984
640.1	0.33142
640	0.35344
639.9	0.37557
639.8	0.40117
639.7	0.42469
639.6	0.45297
639.5	0.47946
639.4	0.50575
639.3	0.53245
639.2	0.55844
639.1	0.58479

639	0.61008
638.9	0.6348
638.8	0.6603
638.7	0.68449
638.6	0.70533
638.5	0.7252
638.4	0.74561
638.3	0.76255
638.2	0.78086
638.1	0.79961
638	0.81069
637.9	0.82364
637.8	0.83275
637.7	0.84385
637.6	0.85087
637.5	0.86037
637.4	0.86637
637.3	0.87029
637.2	0.87485
637.1	0.87923
637	0.879
636.9	0.88397
636.8	0.88607
636.7	0.88734
636.6	0.88551
636.5	0.88486
636.4	0.88593
636.3	0.88322
636.2	0.88655
636.1	0.88423
636	0.88541
635.9	0.88262
635.8	0.88422
635.7	0.88159
635.6	0.88266
635.5	0.87899
635.4	0.88084
635.3	0.88131
635.2	0.87783
635.1	0.87942
635	0.87667
634.9	0.8808
634.8	0.8786
634.7	0.87614
634.6	0.87689
634.5	0.87513
634.4	0.87761
634.3	0.8761
634.2	0.87585
634.1	0.87611
634	0.87591
633.9	0.87751

633.8	0.87677
633.7	0.87466
633.6	0.87506
633.5	0.8737
633.4	0.87351
633.3	0.87273
633.2	0.87159
633.1	0.87285
633	0.86811
632.9	0.86645
632.8	0.86737
632.7	0.86589
632.6	0.86397
632.5	0.8593
632.4	0.85998
632.3	0.85838
632.2	0.85597
632.1	0.85141
632	0.84833
631.9	0.84614
631.8	0.84427
631.7	0.83976
631.6	0.83447
631.5	0.83051
631.4	0.82889
631.3	0.82111
631.2	0.81876
631.1	0.81196
631	0.8059
630.9	0.80168
630.8	0.79772
630.7	0.79219
630.6	0.78536
630.5	0.77735
630.4	0.7723
630.3	0.76639
630.2	0.76006
630.1	0.75336
630	0.74694
629.9	0.74073
629.8	0.73387
629.7	0.72638
629.6	0.72118
629.5	0.71301
629.4	0.70483
629.3	0.69855
629.2	0.69091
629.1	0.6845
629	0.6769
628.9	0.66536
628.8	0.65962
628.7	0.65094

628.6	0.64107
628.5	0.63318
628.4	0.62381
628.3	0.61229
628.2	0.5973
628.1	0.58832
628	0.57463
627.9	0.56193
627.8	0.54938
627.7	0.53239
627.6	0.51525
627.5	0.49904
627.4	0.47962
627.3	0.46298
627.2	0.44404
627.1	0.42387
627	0.40319
626.9	0.3834
626.8	0.36304
626.7	0.34411
626.6	0.32442
626.5	0.30571
626.4	0.28513
626.3	0.2651
626.2	0.24696
626.1	0.22981
626	0.21224
625.9	0.19676
625.8	0.18187
625.7	0.16848
625.6	0.15426
625.5	0.14352
625.4	0.13139
625.3	0.12115
625.2	0.1113
625.1	0.10163
625	0.09344
624.9	0.08548
624.8	0.07859
624.7	0.07202
624.6	0.06636
624.5	0.06004
624.4	0.05504
624.3	0.05095
624.2	0.04673
624.1	0.04268
624	0.03917
623.9	0.03646
623.8	0.03372
623.7	0.03091
623.6	0.02821
623.5	0.02644

623.4	0.02413
623.3	0.02254
623.2	0.02059
623.1	0.01909
623	0.0177
622.9	0.01632
622.8	0.01532
622.7	0.01426
622.6	0.01332
622.5	0.01244
622.4	0.01157
622.3	0.01075
622.2	0.01006
622.1	0.00937
622	0.00858
621.9	0.00805
621.8	0.00764
621.7	0.00724
621.6	0.00673
621.5	0.00627
621.4	0.00596
621.3	0.00564
621.2	0.00523
621.1	0.00506
621	0.00469
620.9	0.0045
620.8	0.00422
620.7	0.00394
620.6	0.00366
620.5	0.00353
620.4	0.00331
620.3	0.00311
620.2	0.00295
620.1	0.00283
620	0.00265
619.9	0.00255
619.8	0.00246
619.7	0.00241
619.6	0.00223
619.5	0.00209
619.4	0.00206
619.3	0.00192
619.2	0.00189
619.1	0.00173
619	0.00166
618.9	0.00158
618.8	0.00157
618.7	0.00142
618.6	0.00138
618.5	0.0013
618.4	0.00124
618.3	0.00117

618.2	0.00118
618.1	0.00116
618	0.00109
617.9	0.00101
617.8	0.00104
617.7	0.00098
617.6	0.00092
617.5	0.0009
617.4	0.00088
617.3	0.00081
617.2	0.0008
617.1	0.00078
617	0.00075
616.9	0.00071
616.8	0.00068
616.7	0.00073
616.6	0.00067
616.5	0.00064
616.4	0.0007
616.3	0.0006
616.2	0.00058
616.1	0.00056
616	0.00053
615.9	0.00054
615.8	0.00055
615.7	0.00051
615.6	0.0005
615.5	0.00052
615.4	0.00047
615.3	0.00049
615.2	0.00045
615.1	0.00043
615	0.00044
614.9	0.00042
614.8	0.0004
614.7	0.00041
614.6	0.0004
614.5	0.00039
614.4	0.00039
614.3	0.00035
614.2	0.00034
614.1	0.00035
614	0.00033
613.9	0.00033
613.8	0.00033
613.7	0.00032
613.6	0.00028
613.5	0.0003
613.4	0.00029
613.3	0.0003
613.2	0.00031
613.1	0.00027

613	0.00027
612.9	0.00027
612.8	0.00029
612.7	0.00027
612.6	0.00028
612.5	0.00026
612.4	0.00024
612.3	0.00027
612.2	0.00024
612.1	0.00024
612	0.00027
611.9	0.00022
611.8	0.00021
611.7	0.00025
611.6	0.00023
611.5	0.0002
611.4	0.00023
611.3	0.00019
611.2	0.0002
611.1	0.00018
611	0.00021
610.9	0.00021
610.8	0.00019
610.7	0.00019
610.6	0.00018
610.5	0.00018
610.4	0.00018
610.3	0.00018
610.2	0.00018
610.1	0.00017
610	0.00018
609.9	0.00018
609.8	0.00018
609.7	0.00014
609.6	0.00015
609.5	0.00016
609.4	0.00014
609.3	0.00016
609.2	0.00015
609.1	0.00015
609	0.00014
608.9	0.00013
608.8	0.00014
608.7	0.00014
608.6	0.00015
608.5	0.00014
608.4	0.00012
608.3	0.00014
608.2	0.00012
608.1	0.00013
608	0.00012
607.9	0.0001

607.8	0.00011
607.7	0.0001
607.6	0.00012
607.5	0.00013
607.4	0.0001
607.3	0.0001
607.2	0.0001
607.1	0.00012
607	0.00008
606.9	0.00011
606.8	0.0001
606.7	0.00008
606.6	0.00008
606.5	0.00008
606.4	0.00008
606.3	0.00008
606.2	0.00008
606.1	0.00007
606	0.00007
605.9	0.00007
605.8	0.00007
605.7	0.00006
605.6	0.00008
605.5	0.00007
605.4	0.00007
605.3	0.00007
605.2	0.00009
605.1	0.00007
605	0.00007
604.9	0.00005
604.8	0.00005
604.7	0.00004
604.6	0.00005
604.5	0.00006
604.4	0.00006
604.3	0.00004
604.2	0.00005
604.1	0.00005
604	0.00004
603.9	0.00006
603.8	0.00006
603.7	0.00005
603.6	0.00004
603.5	0.00006
603.4	0.00005
603.3	0.00005
603.2	0.00004
603.1	0.00003
603	0.00004
602.9	0.00004
602.8	0.00003
602.7	0.00005

602.6	0.00002
602.5	0.00004
602.4	0.00004
602.3	0.00002
602.2	0.00002
602.1	0.00002
602	0.00002
601.9	0.00004
601.8	0.00003
601.7	0.00002
601.6	0.00002
601.5	0.00001
601.4	0
601.3	0.00003
601.2	0.00002
601.1	0
601	0.00003
600.9	0.00001
600.8	0
600.7	0.00002
600.6	0.00002
600.5	0
600.4	0
600.3	0
600.2	0.00002
600.1	-0.00001
600	0
599.9	0

Data_867_c2

Wavelength (nm)	Transmission
540	0.00018
539.9	0.00019
539.8	0.00018
539.7	0.00019
539.6	0.0002
539.5	0.00019
539.4	0.00023
539.3	0.00021
539.2	0.0002
539.1	0.00021
539	0.0002
538.9	0.0002
538.8	0.00024
538.7	0.00025
538.6	0.00025
538.5	0.00023
538.4	0.00022
538.3	0.00025
538.2	0.00026
538.1	0.00027
538	0.00027
537.9	0.00027
537.8	0.00025
537.7	0.00026
537.6	0.0003
537.5	0.0003
537.4	0.0003
537.3	0.00033
537.2	0.00031
537.1	0.00034
537	0.00037
536.9	0.00035
536.8	0.00035
536.7	0.00034
536.6	0.00035
536.5	0.00038
536.4	0.00037
536.3	0.0004
536.2	0.00044
536.1	0.00036
536	0.00039
535.9	0.00042
535.8	0.0004
535.7	0.00041
535.6	0.00045
535.5	0.00047
535.4	0.00051
535.3	0.00046
535.2	0.00051
535.1	0.00051

535	0.00052
534.9	0.00052
534.8	0.00054
534.7	0.00056
534.6	0.00058
534.5	0.00061
534.4	0.00058
534.3	0.00059
534.2	0.00059
534.1	0.00071
534	0.00062
533.9	0.00067
533.8	0.00066
533.7	0.0007
533.6	0.0007
533.5	0.00075
533.4	0.00075
533.3	0.00076
533.2	0.0008
533.1	0.00082
533	0.0008
532.9	0.00088
532.8	0.00082
532.7	0.00093
532.6	0.0009
532.5	0.00095
532.4	0.00101
532.3	0.00103
532.2	0.00106
532.1	0.00106
532	0.0011
531.9	0.0011
531.8	0.00116
531.7	0.00124
531.6	0.00127
531.5	0.0013
531.4	0.00138
531.3	0.00136
531.2	0.00131
531.1	0.00146
531	0.00142
530.9	0.00153
530.8	0.00157
530.7	0.0016
530.6	0.00171
530.5	0.0017
530.4	0.00166
530.3	0.00177
530.2	0.00185
530.1	0.00206
530	0.00201
529.9	0.00203

529.8	0.00208
529.7	0.00217
529.6	0.00216
529.5	0.00235
529.4	0.00248
529.3	0.00239
529.2	0.00257
529.1	0.00268
529	0.00274
528.9	0.00297
528.8	0.00289
528.7	0.00309
528.6	0.00318
528.5	0.00339
528.4	0.00333
528.3	0.00347
528.2	0.00376
528.1	0.0038
528	0.00395
527.9	0.00414
527.8	0.00428
527.7	0.00452
527.6	0.00463
527.5	0.00472
527.4	0.005
527.3	0.0051
527.2	0.00534
527.1	0.0056
527	0.00574
526.9	0.00603
526.8	0.00619
526.7	0.00658
526.6	0.00666
526.5	0.00701
526.4	0.00751
526.3	0.00767
526.2	0.00787
526.1	0.00842
526	0.00874
525.9	0.00917
525.8	0.00969
525.7	0.00994
525.6	0.01045
525.5	0.01079
525.4	0.01145
525.3	0.0121
525.2	0.01248
525.1	0.01337
525	0.01397
524.9	0.01451
524.8	0.01536
524.7	0.01586

524.6	0.01683
524.5	0.01747
524.4	0.01838
524.3	0.01944
524.2	0.02047
524.1	0.02134
524	0.02249
523.9	0.02397
523.8	0.02521
523.7	0.02674
523.6	0.02808
523.5	0.02974
523.4	0.03173
523.3	0.03318
523.2	0.03492
523.1	0.03683
523	0.03902
522.9	0.04115
522.8	0.044
522.7	0.04618
522.6	0.04916
522.5	0.05255
522.4	0.05595
522.3	0.05929
522.2	0.06264
522.1	0.06654
522	0.07065
521.9	0.07595
521.8	0.08039
521.7	0.08532
521.6	0.09103
521.5	0.09678
521.4	0.10346
521.3	0.1096
521.2	0.11728
521.1	0.12538
521	0.13449
520.9	0.14356
520.8	0.15274
520.7	0.1628
520.6	0.17285
520.5	0.18414
520.4	0.19471
520.3	0.20785
520.2	0.22323
520.1	0.23755
520	0.25306
519.9	0.26838
519.8	0.2854
519.7	0.30451
519.6	0.32267
519.5	0.33968

519.4	0.36073
519.3	0.38046
519.2	0.40243
519.1	0.42126
519	0.44464
518.9	0.4652
518.8	0.48706
518.7	0.51073
518.6	0.53317
518.5	0.55574
518.4	0.57635
518.3	0.59744
518.2	0.61695
518.1	0.63864
518	0.65788
517.9	0.67435
517.8	0.68939
517.7	0.70824
517.6	0.72294
517.5	0.7375
517.4	0.74797
517.3	0.76224
517.2	0.77156
517.1	0.78374
517	0.79054
516.9	0.80142
516.8	0.80408
516.7	0.81136
516.6	0.81908
516.5	0.82445
516.4	0.82792
516.3	0.82903
516.2	0.8355
516.1	0.83911
516	0.84196
515.9	0.84542
515.8	0.84565
515.7	0.8465
515.6	0.85004
515.5	0.85059
515.4	0.85655
515.3	0.85099
515.2	0.85241
515.1	0.85333
515	0.85305
514.9	0.85844
514.8	0.86031
514.7	0.85906
514.6	0.86003
514.5	0.86001
514.4	0.85853
514.3	0.86144

514.2	0.86437
514.1	0.86283
514	0.86184
513.9	0.86288
513.8	0.86338
513.7	0.86421
513.6	0.8661
513.5	0.86482
513.4	0.86526
513.3	0.86324
513.2	0.86774
513.1	0.86434
513	0.86353
512.9	0.86093
512.8	0.86281
512.7	0.85981
512.6	0.86112
512.5	0.86099
512.4	0.85669
512.3	0.85723
512.2	0.85423
512.1	0.85231
512	0.85027
511.9	0.85068
511.8	0.84879
511.7	0.84891
511.6	0.84518
511.5	0.84261
511.4	0.84264
511.3	0.83971
511.2	0.83549
511.1	0.83467
511	0.83271
510.9	0.83382
510.8	0.83067
510.7	0.82887
510.6	0.82586
510.5	0.82468
510.4	0.82035
510.3	0.81491
510.2	0.81262
510.1	0.8109
510	0.80746
509.9	0.80475
509.8	0.80358
509.7	0.79629
509.6	0.79168
509.5	0.78911
509.4	0.78177
509.3	0.77491
509.2	0.76698
509.1	0.76045

509	0.74967
508.9	0.7417
508.8	0.73189
508.7	0.7232
508.6	0.70864
508.5	0.69547
508.4	0.68081
508.3	0.66601
508.2	0.64882
508.1	0.63262
508	0.61358
507.9	0.59414
507.8	0.57361
507.7	0.5513
507.6	0.53027
507.5	0.50914
507.4	0.48776
507.3	0.46706
507.2	0.44289
507.1	0.41943
507	0.40029
506.9	0.37908
506.8	0.35688
506.7	0.33571
506.6	0.31631
506.5	0.29775
506.4	0.27764
506.3	0.26105
506.2	0.24427
506.1	0.22881
506	0.21395
505.9	0.19851
505.8	0.18651
505.7	0.17399
505.6	0.16264
505.5	0.15076
505.4	0.14155
505.3	0.13111
505.2	0.12275
505.1	0.1135
505	0.10591
504.9	0.09937
504.8	0.092
504.7	0.08592
504.6	0.08029
504.5	0.07511
504.4	0.0705
504.3	0.06541
504.2	0.06104
504.1	0.05735
504	0.05373
503.9	0.05037

503.8	0.0467
503.7	0.04347
503.6	0.04086
503.5	0.03799
503.4	0.03578
503.3	0.03384
503.2	0.03165
503.1	0.02999
503	0.02753
502.9	0.02627
502.8	0.02491
502.7	0.02337
502.6	0.02176
502.5	0.0207
502.4	0.01941
502.3	0.01836
502.2	0.01717
502.1	0.01604
502	0.01525
501.9	0.01444
501.8	0.01369
501.7	0.01293
501.6	0.01224
501.5	0.01169
501.4	0.01101
501.3	0.01055
501.2	0.00996
501.1	0.00938
501	0.00905
500.9	0.00853
500.8	0.00824
500.7	0.00769
500.6	0.00731
500.5	0.00691
500.4	0.0066
500.3	0.0064
500.2	0.00608
500.1	0.00582
500	0.00542
499.9	0.00523
499.8	0.0049
499.7	0.00467
499.6	0.00454
499.5	0.00432
499.4	0.00406
499.3	0.00391
499.2	0.00376
499.1	0.00359
499	0.00342
498.9	0.00326
498.8	0.00312
498.7	0.00309

498.6	0.00289
498.5	0.00273
498.4	0.00267
498.3	0.00254
498.2	0.00245
498.1	0.00234
498	0.00228
497.9	0.00214
497.8	0.00215
497.7	0.00193
497.6	0.00191
497.5	0.00182
497.4	0.00175
497.3	0.00174
497.2	0.00162
497.1	0.00156
497	0.00151
496.9	0.0014
496.8	0.00138
496.7	0.00132
496.6	0.00123
496.5	0.00125
496.4	0.00122
496.3	0.00115
496.2	0.00113
496.1	0.00109
496	0.001
495.9	0.00102
495.8	0.00089
495.7	0.00092
495.6	0.00085
495.5	0.0009
495.4	0.00081
495.3	0.00083
495.2	0.00072
495.1	0.00074
495	0.00078
494.9	0.00071
494.8	0.00069
494.7	0.00066
494.6	0.00064
494.5	0.00066
494.4	0.00059
494.3	0.0006
494.2	0.00055
494.1	0.00054
494	0.00056
493.9	0.00051
493.8	0.00049
493.7	0.00049
493.6	0.00048
493.5	0.00044

493.4	0.00048
493.3	0.00042
493.2	0.0004
493.1	0.00041
493	0.00037
492.9	0.00038
492.8	0.00037
492.7	0.00037
492.6	0.00037
492.5	0.00033
492.4	0.00032
492.3	0.00034
492.2	0.00032
492.1	0.00031
492	0.0003
491.9	0.00025
491.8	0.00029
491.7	0.00024
491.6	0.00025
491.5	0.00024
491.4	0.00029
491.3	0.00023
491.2	0.00025
491.1	0.00023
491	0.00022
490.9	0.00021
490.8	0.00021
490.7	0.0002
490.6	0.0002
490.5	0.0002
490.4	0.00018
490.3	0.00019
490.2	0.00016
490.1	0.00016
490	0.00017
489.9	0.00017

Data_847_yellow

Wavelength (nm)	Transmission
590	0
589.9	-0.00001
589.8	0.00001
589.7	-0.00001
589.6	-0.00001
589.5	-0.00002
589.4	-0.00002
589.3	0.00002
589.2	0.00003
589.1	0
589	0
588.9	0.00002
588.8	0.00002
588.7	0
588.6	-0.00002
588.5	-0.00001
588.4	-0.00003
588.3	-0.00001
588.2	0
588.1	0
588	0.00001
587.9	0
587.8	0.00002
587.7	0
587.6	0
587.5	0.00001
587.4	-0.00002
587.3	0.00001
587.2	-0.00002
587.1	0
587	0.00001
586.9	-0.00001
586.8	0.00001
586.7	0.00002
586.6	0.00001
586.5	0.00001
586.4	0.00001
586.3	-0.00001
586.2	0.00003
586.1	0.00003
586	0.00002
585.9	0.00004
585.8	0.00004
585.7	0.00003
585.6	0.00004
585.5	0.00006
585.4	0.00008
585.3	0.00009
585.2	0.00005
585.1	0.00011

Data_847_yellow

585	0.00014
584.9	0.00015
584.8	0.00014
584.7	0.00019
584.6	0.00022
584.5	0.00034
584.4	0.00039
584.3	0.00052
584.2	0.00056
584.1	0.0008
584	0.00095
583.9	0.00125
583.8	0.0015
583.7	0.00201
583.6	0.00254
583.5	0.00335
583.4	0.00461
583.3	0.006
583.2	0.00836
583.1	0.0118
583	0.01635
582.9	0.02385
582.8	0.03477
582.7	0.05049
582.6	0.07423
582.5	0.10778
582.4	0.15102
582.3	0.20257
582.2	0.26268
582.1	0.3327
582	0.40035
581.9	0.46054
581.8	0.51077
581.7	0.55521
581.6	0.58632
581.5	0.60723
581.4	0.61737
581.3	0.63139
581.2	0.64125
581.1	0.65321
581	0.66468
580.9	0.67195
580.8	0.68256
580.7	0.69493
580.6	0.70744
580.5	0.71819
580.4	0.72472
580.3	0.73302
580.2	0.73756
580.1	0.74262
580	0.74629
579.9	0.74866

579.8	0.74863
579.7	0.74549
579.6	0.74439
579.5	0.73948
579.4	0.7374
579.3	0.72895
579.2	0.71944
579.1	0.707
579	0.68502
578.9	0.65559
578.8	0.60864
578.7	0.56202
578.6	0.49953
578.5	0.43553
578.4	0.36888
578.3	0.3073
578.2	0.24911
578.1	0.1989
578	0.1573
577.9	0.11975
577.8	0.09231
577.7	0.0691
577.6	0.05188
577.5	0.03889
577.4	0.02839
577.3	0.0209
577.2	0.01578
577.1	0.0116
577	0.00843
576.9	0.00615
576.8	0.00452
576.7	0.0034
576.6	0.00253
576.5	0.00182
576.4	0.00146
576.3	0.00109
576.2	0.00082
576.1	0.00062
576	0.00054
575.9	0.00039
575.8	0.00034
575.7	0.00029
575.6	0.00022
575.5	0.0002
575.4	0.00017
575.3	0.00013
575.2	0.00012
575.1	0.00009
575	0.00007
574.9	0.00008
574.8	0.00007
574.7	0.00011

574.6	0.00004
574.5	0.00004
574.4	0.00003
574.3	0
574.2	0.00004
574.1	0.00004
574	0.00005
573.9	0.00003
573.8	0.00002
573.7	0.00002
573.6	0.00003
573.5	0.00002
573.4	0.00001
573.3	0.00003
573.2	0.00004
573.1	0.00002
573	0.00002
572.9	0.00001
572.8	0.00003
572.7	0.00001
572.6	0.00001
572.5	-0.00001
572.4	0.00003
572.3	0
572.2	0.00004
572.1	0.00004
572	0
571.9	0.00003
571.8	0.00005
571.7	0
571.6	0.00003
571.5	0.00002
571.4	0.00001
571.3	0.00003
571.2	0.00003
571.1	0.00002
571	0.00003
570.9	0.00003
570.8	0.00002
570.7	0.00003
570.6	0.00004
570.5	0.00003
570.4	0.00002
570.3	0.00002
570.2	0
570.1	0.00005
570	0

Data_915_red

Wavelength (nm)	Transmission
725	0.00005
724.9	0.00009
724.8	0.00011
724.7	0.00017
724.6	0.00014
724.5	0.00014
724.4	0.00014
724.3	0.00016
724.2	0.00017
724.1	0.00015
724	0.00014
723.9	0.0002
723.8	0.00024
723.7	0.00017
723.6	0.00024
723.5	0.00022
723.4	0.0003
723.3	0.00021
723.2	0.00027
723.1	0.00024
723	0.00023
722.9	0.00024
722.8	0.00028
722.7	0.00041
722.6	0.00044
722.5	0.00043
722.4	0.0005
722.3	0.0004
722.2	0.00043
722.1	0.0005
722	0.00049
721.9	0.00056
721.8	0.0006
721.7	0.00063
721.6	0.00071
721.5	0.00067
721.4	0.00072
721.3	0.00097
721.2	0.00092
721.1	0.0011
721	0.00102
720.9	0.00121
720.8	0.00127
720.7	0.00129
720.6	0.00124
720.5	0.00162
720.4	0.00171
720.3	0.00189
720.2	0.00215
720.1	0.00211

720	0.0023
719.9	0.00242
719.8	0.00297
719.7	0.00323
719.6	0.00332
719.5	0.00368
719.4	0.00415
719.3	0.00454
719.2	0.00499
719.1	0.00564
719	0.00608
718.9	0.00683
718.8	0.00759
718.7	0.00809
718.6	0.00978
718.5	0.01054
718.4	0.01142
718.3	0.01343
718.2	0.01472
718.1	0.01687
718	0.01917
717.9	0.02147
717.8	0.02522
717.7	0.02789
717.6	0.03231
717.5	0.03645
717.4	0.04219
717.3	0.04777
717.2	0.05673
717.1	0.06486
717	0.0758
716.9	0.08881
716.8	0.10374
716.7	0.1206
716.6	0.14086
716.5	0.16508
716.4	0.19107
716.3	0.22162
716.2	0.25448
716.1	0.29391
716	0.33835
715.9	0.38357
715.8	0.43402
715.7	0.48359
715.6	0.53615
715.5	0.58286
715.4	0.62714
715.3	0.67117
715.2	0.70711
715.1	0.74396
715	0.77333
714.9	0.79279

714.8	0.81889
714.7	0.82969
714.6	0.84684
714.5	0.85639
714.4	0.86554
714.3	0.86846
714.2	0.88451
714.1	0.88152
714	0.88643
713.9	0.89116
713.8	0.8885
713.7	0.88812
713.6	0.88327
713.5	0.89072
713.4	0.89138
713.3	0.88778
713.2	0.88546
713.1	0.89365
713	0.89589
712.9	0.89488
712.8	0.88891
712.7	0.89061
712.6	0.88981
712.5	0.88517
712.4	0.88412
712.3	0.87939
712.2	0.88464
712.1	0.87653
712	0.88058
711.9	0.8824
711.8	0.87371
711.7	0.87572
711.6	0.87647
711.5	0.86896
711.4	0.85803
711.3	0.85495
711.2	0.84449
711.1	0.83083
711	0.80814
710.9	0.77623
710.8	0.74788
710.7	0.71116
710.6	0.66797
710.5	0.62357
710.4	0.57516
710.3	0.52318
710.2	0.4714
710.1	0.42753
710	0.38008
709.9	0.33496
709.8	0.2981
709.7	0.25796

709.6	0.22576
709.5	0.1983
709.4	0.17187
709.3	0.14901
709.2	0.12776
709.1	0.10992
709	0.09429
708.9	0.08093
708.8	0.06914
708.7	0.05976
708.6	0.05146
708.5	0.04467
708.4	0.03865
708.3	0.03308
708.2	0.02916
708.1	0.02559
708	0.02229
707.9	0.01925
707.8	0.01693
707.7	0.01498
707.6	0.01317
707.5	0.01151
707.4	0.01028
707.3	0.00909
707.2	0.0082
707.1	0.00727
707	0.00653
706.9	0.0059
706.8	0.0051
706.7	0.00472
706.6	0.00432
706.5	0.00377
706.4	0.00362
706.3	0.00331
706.2	0.00284
706.1	0.0027
706	0.00238
705.9	0.0021
705.8	0.002
705.7	0.00176
705.6	0.00165
705.5	0.00161
705.4	0.00137
705.3	0.00125
705.2	0.00117
705.1	0.00108
705	0.00109
704.9	0.00095
704.8	0.00087
704.7	0.00083
704.6	0.00077
704.5	0.0007

704.4	0.00065
704.3	0.00059
704.2	0.00057
704.1	0.00059
704	0.00051
703.9	0.0004
703.8	0.00042
703.7	0.0004
703.6	0.00039
703.5	0.0003
703.4	0.00033
703.3	0.00034
703.2	0.00025
703.1	0.0003
703	0.00023
702.9	0.0002
702.8	0.00024
702.7	0.00024
702.6	0.00018
702.5	0.00019
702.4	0.00016
702.3	0.00017
702.2	0.00016
702.1	0.00014
702	0.00009
701.9	0.00014
701.8	0.00015
701.7	0.00013
701.6	0.00012
701.5	0.00009
701.4	0.00012
701.3	0.00009
701.2	0.00014
701.1	0.0001
701	0.00009
700.9	0.00007
700.8	0.00008
700.7	0.00007
700.6	0.00008
700.5	0.00008
700.4	0.00004
700.3	0.00004
700.2	0.00006
700.1	0.00008
700	0.00007
699.9	0.00007

Data_944_nir

Wavelength (nm)	Transmission
940	0.00953
939.9	-0.00138
939.8	0.01167
939.7	0.00053
939.6	0.00781
939.5	0.00597
939.4	0.00273
939.3	0.00433
939.2	-0.00011
939.1	0.00564
939	0.00368
938.9	-0.00623
938.8	-0.0033
938.7	0.01112
938.6	0.00973
938.5	0.00021
938.4	0.01001
938.3	0.01672
938.2	0.01455
938.1	0.00721
938	0.00212
937.9	0.00372
937.8	-0.00392
937.7	0.01285
937.6	0.00923
937.5	0.00403
937.4	0.01547
937.3	0.01192
937.2	0.02048
937.1	0.00595
937	0.00405
936.9	0.0075
936.8	0.01818
936.7	0.00279
936.6	0.02096
936.5	0.00525
936.4	0.00497
936.3	0.00592
936.2	0.00754
936.1	0.01573
936	0.01469
935.9	0.01294
935.8	0.00846
935.7	0.00786
935.6	0.01352
935.5	0.00975
935.4	0.00438
935.3	0.01229
935.2	0.01476
935.1	0.02122

935	0.01551
934.9	0.0097
934.8	0.0098
934.7	0.0031
934.6	0.00682
934.5	0.01131
934.4	0.01441
934.3	0.01317
934.2	-0.00425
934.1	0.01604
934	0.02105
933.9	0.01041
933.8	-0.00074
933.7	0.00403
933.6	0.01315
933.5	0.01143
933.4	0.00338
933.3	0.00629
933.2	0.02002
933.1	0.00691
933	-0.0017
932.9	0.00976
932.8	0.00309
932.7	0.00397
932.6	0.01333
932.5	0.00984
932.4	0.00213
932.3	0.01776
932.2	0.00718
932.1	0.00786
932	0.00693
931.9	0.01786
931.8	0.0066
931.7	0.00181
931.6	0.00398
931.5	0.00402
931.4	0.00495
931.3	0.00404
931.2	0.00275
931.1	0.00531
931	0.01675
930.9	0.01163
930.8	-0.00401
930.7	-0.00043
930.6	0.00722
930.5	-0.00107
930.4	-0.00106
930.3	0.00462
930.2	0.00246
930.1	-0.00236
930	0.00769
929.9	0.00182

929.8	0.00276
929.7	0.00243
929.6	0.00053
929.5	-0.00075
929.4	0.00342
929.3	0.00116
929.2	0.01902
929.1	0.00053
929	0.00243
928.9	-0.00624
928.8	0.00599
928.7	0.01349
928.6	0.00538
928.5	0.00562
928.4	-0.00173
928.3	0.00116
928.2	0.01833
928.1	0.00249
928	0.00469
927.9	0.00598
927.8	0.00214
927.7	-0.00106
927.6	0.0073
927.5	0.00309
927.4	0.00053
927.3	0.00941
927.2	0.0152
927.1	0.00184
927	0.00275
926.9	0.01346
926.8	-0.00425
926.7	-0.00266
926.6	0.00657
926.5	0.01373
926.4	0.00308
926.3	0.01238
926.2	0.01116
926.1	0.01013
926	0.00534
925.9	0.01165
925.8	-0.00043
925.7	0.0015
925.6	0.00246
925.5	0.01623
925.4	0.00148
925.3	0.00568
925.2	0.00627
925.1	0.02018
925	0.00601
924.9	0.00275
924.8	0.01089
924.7	0.01872

924.6	0.00631
924.5	0.00151
924.4	0.02214
924.3	0.00929
924.2	0.01533
924.1	0.00944
924	0.01183
923.9	0.01469
923.8	0.00572
923.7	0.00931
923.6	0.01516
923.5	0.00796
923.4	0.006
923.3	0.00565
923.2	0.01456
923.1	0.0127
923	0.00021
922.9	0.00463
922.8	0.02585
922.7	0.01352
922.6	0.01359
922.5	0.01378
922.4	-0.00139
922.3	0.00053
922.2	0.01553
922.1	0.00117
922	0.01036
921.9	0.00826
921.8	0.00794
921.7	0.00789
921.6	-0.00075
921.5	0.00756
921.4	0.02096
921.3	-0.00496
921.2	0.00695
921.1	0.01857
921	0.00758
920.9	0.02441
920.8	0.00412
920.7	-0.00431
920.6	0.01592
920.5	0.0121
920.4	0.01043
920.3	0.00858
920.2	0.00183
920.1	0.00502
920	0.01178
919.9	0.00691
919.8	0.00621
919.7	0.01652
919.6	-0.00532
919.5	0.00147

919.4	0.00948
919.3	0.01528
919.2	0.01472
919.1	0.00923
919	0.01268
918.9	0.02411
918.8	0.00565
918.7	0.00538
918.6	0.00852
918.5	0.00441
918.4	-0.0056
918.3	-0.00623
918.2	0.01895
918.1	0.02015
918	0.01435
917.9	0.00341
917.8	0.00957
917.7	0.01254
917.6	0.00474
917.5	0.00568
917.4	0.00021
917.3	-0.00172
917.2	0.00309
917.1	0.01287
917	-0.00139
916.9	0.00837
916.8	-0.00011
916.7	0.00119
916.6	0.00903
916.5	0.00021
916.4	0.0028
916.3	0.01016
916.2	0.00699
916.1	0.00344
916	0.00697
915.9	0.01233
915.8	0.00768
915.7	0.01129
915.6	0.00244
915.5	-0.0062
915.4	0.01215
915.3	0.00728
915.2	0.01865
915.1	0.01155
915	-0.00011
914.9	-0.00272
914.8	0.011
914.7	-0.00237
914.6	0.01109
914.5	0.00343
914.4	-0.00274
914.3	0.01341

914.2	0.01681
914.1	0.01848
914	-0.01358
913.9	0.01801
913.8	0.00857
913.7	0.00474
913.6	-0.00044
913.5	0.00413
913.4	0.00443
913.3	0.00119
913.2	0.00886
913.1	-0.00368
913	0.00246
912.9	0.00086
912.8	0.00314
912.7	0.00409
912.6	0.00021
912.5	0.00538
912.4	-0.00797
912.3	0.01446
912.2	0.00942
912.1	0.00727
912	0.00346
911.9	0.00281
911.8	0.01226
911.7	0.02802
911.6	0.00249
911.5	-0.00273
911.4	0.00504
911.3	-0.00174
911.2	0.01017
911.1	-0.00207
911	0.0054
910.9	0.02088
910.8	0.01428
910.7	0.00353
910.6	-0.00434
910.5	0.00734
910.4	0.00698
910.3	0.01091
910.2	0.01674
910.1	0.01213
910	-0.0011
909.9	0.00312
909.8	0.01701
909.7	0.00698
909.6	0.01796
909.5	0.00379
909.4	0.00824
909.3	0.01737
909.2	0.0107
909.1	0.00638

909	0.01211
908.9	0.0093
908.8	0.01205
908.7	0.01028
908.6	0.00509
908.5	0.01026
908.4	0.01778
908.3	0.01127
908.2	-0.00141
908.1	0.00216
908	0.01016
907.9	0.008
907.8	0.00704
907.7	-0.00077
907.6	0.02084
907.5	0.01151
907.4	0.00697
907.3	0.00599
907.2	0.01424
907.1	0.00119
907	-0.003
906.9	0.01262
906.8	0.01413
906.7	0.00769
906.6	0.00833
906.5	0.02064
906.4	0.01427
906.3	-0.00303
906.2	0.01225
906.1	-0.00109
906	0.01413
905.9	0.02788
905.8	0.00706
905.7	0.01769
905.6	0.00934
905.5	0.00703
905.4	0.01329
905.3	0.0164
905.2	0.00186
905.1	0.0048
905	0.00806
904.9	0.01513
904.8	0.00774
904.7	0.01375
904.6	0.00448
904.5	0.00907
904.4	0.01194
904.3	0.00551
904.2	0.00732
904.1	0.00902
904	0.01301
903.9	0.00247

903.8	0.01162
903.7	0.00998
903.6	0.00478
903.5	0.0051
903.4	0.00441
903.3	-0.00109
903.2	0.00838
903.1	-0.00706
903	0.02228
902.9	0.00351
902.8	0.00569
902.7	0.01551
902.6	0.01002
902.5	0.02642
902.4	-0.00173
902.3	-0.01149
902.2	0.01577
902.1	0.01768
902	0.01698
901.9	0.00054
901.8	0.0028
901.7	0.00445
901.6	0.01788
901.5	0.00946
901.4	-0.00044
901.3	0.00382
901.2	0.007
901.1	0.01034
901	0.00185
900.9	0.00185
900.8	0.00512
900.7	0.00809
900.6	0.00768
900.5	0.0071
900.4	0.00903
900.3	0.00871
900.2	0.00999
900.1	0.00609
900	0.00448
899.9	0.00738
899.8	0.00413
899.7	0.00806
899.6	0.02085
899.5	0.01126
899.4	0.00281
899.3	0.00021
899.2	0.00475
899.1	0.00542
899	0.00642
898.9	0.02694
898.8	0.00719
898.7	0.01672

898.6	0.01809
898.5	0.01062
898.4	0.01781
898.3	0.01519
898.2	0.01359
898.1	0.00581
898	0.01199
897.9	0.01881
897.8	0.03684
897.7	0.01899
897.6	0.01574
897.5	0.0209
897.4	0.01827
897.3	0.02448
897.2	0.02106
897.1	0.01177
897	0.02833
896.9	0.02716
896.8	0.02283
896.7	0.0289
896.6	0.00485
896.5	0.02053
896.4	0.02663
896.3	0.03637
896.2	0.02485
896.1	0.03476
896	0.03804
895.9	0.02275
895.8	0.02567
895.7	0.04202
895.6	0.04137
895.5	0.03366
895.4	0.0335
895.3	0.0519
895.2	0.04179
895.1	0.05123
895	0.04743
894.9	0.05038
894.8	0.05752
894.7	0.05997
894.6	0.05783
894.5	0.0636
894.4	0.06107
894.3	0.06359
894.2	0.07592
894.1	0.07161
894	0.10081
893.9	0.07955
893.8	0.09264
893.7	0.08815
893.6	0.09371
893.5	0.10046

893.4	0.10475
893.3	0.11945
893.2	0.11023
893.1	0.12924
893	0.12834
892.9	0.14325
892.8	0.14861
892.7	0.16245
892.6	0.16634
892.5	0.1736
892.4	0.17665
892.3	0.18873
892.2	0.20216
892.1	0.20457
892	0.22377
891.9	0.23002
891.8	0.24545
891.7	0.24166
891.6	0.25443
891.5	0.26172
891.4	0.2743
891.3	0.28018
891.2	0.30767
891.1	0.30992
891	0.32565
890.9	0.34827
890.8	0.34831
890.7	0.34587
890.6	0.38353
890.5	0.38093
890.4	0.40649
890.3	0.40908
890.2	0.42815
890.1	0.43665
890	0.44532
889.9	0.457
889.8	0.46253
889.7	0.48995
889.6	0.49157
889.5	0.50577
889.4	0.51082
889.3	0.53732
889.2	0.54504
889.1	0.55722
889	0.56867
888.9	0.58756
888.8	0.59043
888.7	0.60215
888.6	0.61306
888.5	0.62407
888.4	0.62602
888.3	0.63854

888.2	0.65935
888.1	0.66442
888	0.67272
887.9	0.6876
887.8	0.68614
887.7	0.70237
887.6	0.70877
887.5	0.71065
887.4	0.72319
887.3	0.73681
887.2	0.7468
887.1	0.74698
887	0.75015
886.9	0.76728
886.8	0.76047
886.7	0.77226
886.6	0.77819
886.5	0.78288
886.4	0.78953
886.3	0.78542
886.2	0.79437
886.1	0.8067
886	0.80249
885.9	0.81425
885.8	0.81913
885.7	0.81598
885.6	0.81571
885.5	0.82032
885.4	0.82483
885.3	0.82885
885.2	0.8234
885.1	0.83304
885	0.83249
884.9	0.8434
884.8	0.84298
884.7	0.84386
884.6	0.84143
884.5	0.84935
884.4	0.84554
884.3	0.84829
884.2	0.85636
884.1	0.85908
884	0.85887
883.9	0.85533
883.8	0.85587
883.7	0.86415
883.6	0.86274
883.5	0.85757
883.4	0.86044
883.3	0.86423
883.2	0.85969
883.1	0.86098

883	0.86675
882.9	0.87349
882.8	0.87189
882.7	0.87244
882.6	0.86849
882.5	0.86282
882.4	0.87386
882.3	0.87044
882.2	0.87733
882.1	0.87617
882	0.85979
881.9	0.87022
881.8	0.87179
881.7	0.88069
881.6	0.87913
881.5	0.87666
881.4	0.87102
881.3	0.87456
881.2	0.86981
881.1	0.87546
881	0.86879
880.9	0.87955
880.8	0.87852
880.7	0.87814
880.6	0.86767
880.5	0.87079
880.4	0.8813
880.3	0.8723
880.2	0.87892
880.1	0.88541
880	0.87749
879.9	0.87415
879.8	0.87965
879.7	0.87293
879.6	0.87915
879.5	0.8718
879.4	0.87527
879.3	0.87508
879.2	0.88105
879.1	0.88296
879	0.87131
878.9	0.87958
878.8	0.87551
878.7	0.8795
878.6	0.88075
878.5	0.87212
878.4	0.88074
878.3	0.87936
878.2	0.87356
878.1	0.88021
878	0.87322
877.9	0.8784

877.8	0.88046
877.7	0.87767
877.6	0.87811
877.5	0.87529
877.4	0.87303
877.3	0.88481
877.2	0.87721
877.1	0.88264
877	0.882
876.9	0.88905
876.8	0.88017
876.7	0.88824
876.6	0.89128
876.5	0.88586
876.4	0.88816
876.3	0.8863
876.2	0.88615
876.1	0.88361
876	0.89241
875.9	0.89351
875.8	0.88247
875.7	0.88567
875.6	0.88844
875.5	0.88203
875.4	0.88424
875.3	0.88716
875.2	0.8837
875.1	0.88806
875	0.8889
874.9	0.88502
874.8	0.88842
874.7	0.88497
874.6	0.89218
874.5	0.89192
874.4	0.88475
874.3	0.88936
874.2	0.88146
874.1	0.88933
874	0.88332
873.9	0.88556
873.8	0.88656
873.7	0.89083
873.6	0.8914
873.5	0.88484
873.4	0.88164
873.3	0.88923
873.2	0.89031
873.1	0.88582
873	0.88075
872.9	0.87734
872.8	0.88247
872.7	0.88694

872.6	0.88129
872.5	0.88428
872.4	0.88293
872.3	0.87655
872.2	0.88498
872.1	0.88937
872	0.88204
871.9	0.8767
871.8	0.88344
871.7	0.87743
871.6	0.87838
871.5	0.87805
871.4	0.87828
871.3	0.88729
871.2	0.87952
871.1	0.88125
871	0.87385
870.9	0.87894
870.8	0.87086
870.7	0.87708
870.6	0.87739
870.5	0.87975
870.4	0.86866
870.3	0.86933
870.2	0.87765
870.1	0.8664
870	0.87359
869.9	0.86418
869.8	0.87682
869.7	0.86621
869.6	0.86854
869.5	0.86977
869.4	0.8678
869.3	0.85694
869.2	0.8622
869.1	0.87332
869	0.86821
868.9	0.86249
868.8	0.86158
868.7	0.85799
868.6	0.86302
868.5	0.85662
868.4	0.8663
868.3	0.84946
868.2	0.8452
868.1	0.86093
868	0.8486
867.9	0.85613
867.8	0.84888
867.7	0.84996
867.6	0.8496
867.5	0.84678

867.4	0.85256
867.3	0.84465
867.2	0.84371
867.1	0.83659
867	0.83706
866.9	0.84861
866.8	0.83546
866.7	0.84768
866.6	0.83963
866.5	0.83669
866.4	0.83514
866.3	0.83765
866.2	0.82906
866.1	0.8378
866	0.83517
865.9	0.82638
865.8	0.83662
865.7	0.83093
865.6	0.82718
865.5	0.82315
865.4	0.82744
865.3	0.81662
865.2	0.82699
865.1	0.82562
865	0.82522
864.9	0.81489
864.8	0.82273
864.7	0.81755
864.6	0.8179
864.5	0.81066
864.4	0.81047
864.3	0.80843
864.2	0.80163
864.1	0.80333
864	0.80867
863.9	0.79289
863.8	0.79612
863.7	0.79596
863.6	0.80232
863.5	0.78981
863.4	0.78735
863.3	0.79034
863.2	0.78023
863.1	0.7779
863	0.77396
862.9	0.77731
862.8	0.77214
862.7	0.76799
862.6	0.76173
862.5	0.76308
862.4	0.75196
862.3	0.75025

862.2	0.7423
862.1	0.74903
862	0.73959
861.9	0.73787
861.8	0.7324
861.7	0.72687
861.6	0.7173
861.5	0.71867
861.4	0.72034
861.3	0.70602
861.2	0.70285
861.1	0.69484
861	0.69322
860.9	0.68617
860.8	0.6793
860.7	0.66978
860.6	0.66119
860.5	0.66044
860.4	0.64116
860.3	0.63933
860.2	0.63561
860.1	0.63483
860	0.61534
859.9	0.60331
859.8	0.60083
859.7	0.59671
859.6	0.58782
859.5	0.57284
859.4	0.57501
859.3	0.55548
859.2	0.55184
859.1	0.54411
859	0.53447
858.9	0.52751
858.8	0.52588
858.7	0.50581
858.6	0.50097
858.5	0.49154
858.4	0.48246
858.3	0.4794
858.2	0.45606
858.1	0.44801
858	0.43677
857.9	0.43434
857.8	0.42676
857.7	0.40793
857.6	0.41115
857.5	0.39024
857.4	0.38882
857.3	0.37192
857.2	0.36771
857.1	0.35489

857	0.3439
856.9	0.33239
856.8	0.32849
856.7	0.32061
856.6	0.31238
856.5	0.3
856.4	0.28585
856.3	0.28393
856.2	0.2823
856.1	0.26607
856	0.25499
855.9	0.24652
855.8	0.23905
855.7	0.2382
855.6	0.21975
855.5	0.21262
855.4	0.20028
855.3	0.20698
855.2	0.19396
855.1	0.18517
855	0.17718
854.9	0.17058
854.8	0.17603
854.7	0.15961
854.6	0.15369
854.5	0.14912
854.4	0.14112
854.3	0.14831
854.2	0.13039
854.1	0.12634
854	0.12162
853.9	0.11171
853.8	0.09528
853.7	0.11529
853.6	0.10953
853.5	0.09224
853.4	0.08537
853.3	0.09553
853.2	0.07857
853.1	0.08212
853	0.0646
852.9	0.06173
852.8	0.06493
852.7	0.06532
852.6	0.0554
852.5	0.06137
852.4	0.04874
852.3	0.05518
852.2	0.04867
852.1	0.05155
852	0.04218
851.9	0.04699

851.8	0.04574
851.7	0.03392
851.6	0.03454
851.5	0.03028
851.4	0.04323
851.3	0.03358
851.2	0.02725
851.1	0.03011
851	0.02393
850.9	0.03784
850.8	0.01334
850.7	0.02373
850.6	0.01936
850.5	0.02176
850.4	0.01899
850.3	0.02247
850.2	0.01191
850.1	0.01487
850	0.02746
849.9	0.00257
849.8	0.00251
849.7	0.00124
849.6	0.00121
849.5	0.00178
849.4	0.00198
849.3	0.00168
849.2	0.00182
849.1	0.00218
849	0.00133
848.9	0.00191
848.8	0.00123
848.7	0.00161
848.6	0.0015
848.5	0.00149
848.4	0.00036
848.3	0.00061
848.2	0.00029
848.1	0.00118
848	0.00079
847.9	0.00156
847.8	0.00064
847.7	0.00072
847.6	0.00122
847.5	0.00018
847.4	0.00171
847.3	0.00049
847.2	0.00008
847.1	-0.00004
847	0.00088
846.9	0.00045
846.8	0.00043
846.7	0.00015

846.6	0.00029
846.5	0.00008
846.4	0.00043
846.3	0.00014
846.2	0.00001
846.1	-0.00027
846	0.00097
845.9	0.00022
845.8	-0.00006
845.7	0.00008
845.6	0.00069
845.5	0.00032
845.4	0.00006
845.3	0.00023
845.2	0.00054
845.1	0.0006
845	0.00034
844.9	-0.00005
844.8	-0.00037
844.7	-0.00017
844.6	-0.00005
844.5	0.00017
844.4	-0.00046
844.3	-0.00026
844.2	-0.00011
844.1	0.00027
844	0.00019
843.9	0
843.8	-0.00021
843.7	0.00023
843.6	-0.00006
843.5	-0.00002
843.4	0.00012
843.3	0
843.2	-0.00033
843.1	-0.00005
843	-0.00036
842.9	0.00002
842.8	0.00001
842.7	0.00007
842.6	0.00006
842.5	0.00005
842.4	0.0002
842.3	0.00042
842.2	0.00057
842.1	0.00029
842	-0.00005
841.9	0.00051
841.8	0.00041
841.7	0.00027
841.6	0.00036
841.5	-0.00026

841.4	0.00005
841.3	0.00018
841.2	0.0001
841.1	0.00003
841	-0.00006
840.9	0.00031
840.8	0.00025
840.7	0.00015
840.6	-0.00028
840.5	0.00035
840.4	-0.00008
840.3	0.00036
840.2	0.00001
840.1	-0.00004
840	0.00005
839.9	-0.00023
839.8	-0.00023
839.7	0.00003
839.6	0.0001
839.5	0.00019
839.4	-0.0003
839.3	0.00013
839.2	-0.00029
839.1	-0.00012
839	-0.00029
838.9	0.00033
838.8	-0.00001
838.7	0.00003
838.6	0.00024
838.5	-0.00026
838.4	0.00001
838.3	0.00001
838.2	-0.00005
838.1	-0.00014
838	0.00023
837.9	0.00013
837.8	0.00027
837.7	-0.00004
837.6	-0.00001
837.5	0.00005
837.4	0.00001
837.3	-0.00007
837.2	0.00043
837.1	0.00011
837	0.00039
836.9	0.00004
836.8	0.00008
836.7	-0.00008
836.6	0.00026
836.5	-0.00025
836.4	-0.00012
836.3	-0.0001

836.2	-0.00027
836.1	-0.00002
836	-0.00013
835.9	0.00007
835.8	-0.00012
835.7	-0.00005
835.6	-0.0001
835.5	-0.00002
835.4	-0.00019
835.3	-0.00027
835.2	-0.0003
835.1	-0.00013
835	-0.00012
834.9	0.00031
834.8	0.00002
834.7	-0.00006
834.6	-0.00015
834.5	-0.00019
834.4	0.00012
834.3	-0.00039
834.2	-0.00003
834.1	0.00024
834	0.0002
833.9	-0.00035
833.8	-0.0001
833.7	-0.00007
833.6	0.0004
833.5	0.00006
833.4	0.00046
833.3	0.00031
833.2	-0.00002
833.1	0.00011
833	-0.00005
832.9	0.00005
832.8	-0.00013
832.7	0.00026
832.6	0.00003
832.5	0.00012
832.4	-0.00005
832.3	-0.00001
832.2	-0.00001
832.1	0.00011
832	-0.00003
831.9	0.00021
831.8	-0.00027
831.7	0.0002
831.6	-0.00016
831.5	-0.00013
831.4	-0.00012
831.3	0.00033
831.2	0.00039
831.1	0.00004

831	0.00013
830.9	0.00004
830.8	-0.00009
830.7	0.00021
830.6	-0.00006
830.5	-0.00003
830.4	0.00005
830.3	0.00003
830.2	0.00018
830.1	-0.00001
830	0.00011
829.9	-0.00005
829.8	-0.00001
829.7	-0.00038
829.6	-0.00017
829.5	0.00011
829.4	-0.00027
829.3	0
829.2	0
829.1	0.0006
829	-0.00016
828.9	0.00003
828.8	-0.00032
828.7	0.00004
828.6	-0.0002
828.5	0.00019
828.4	0.00022
828.3	0.00003
828.2	0.00003
828.1	-0.00017
828	0.00029
827.9	-0.00012
827.8	-0.00028
827.7	0.00009
827.6	-0.00008
827.5	-0.00006
827.4	0.00012
827.3	-0.00006
827.2	-0.0001
827.1	0.00009
827	-0.00005
826.9	0.00015
826.8	-0.0001
826.7	0.0001
826.6	-0.00017
826.5	0.0002
826.4	-0.00016
826.3	-0.00006
826.2	-0.00012
826.1	-0.00021
826	-0.00003
825.9	0.00026

825.8	0.00009
825.7	0.00005
825.6	-0.00009
825.5	-0.00003
825.4	-0.00001
825.3	-0.0001
825.2	0.00012
825.1	0.00029
825	-0.00023
824.9	-0.00003
824.8	0.00006
824.7	0.00008
824.6	-0.0001
824.5	0.00023
824.4	-0.00031
824.3	-0.00005
824.2	0.00014
824.1	-0.00027
824	-0.00002
823.9	-0.00017
823.8	0.00003
823.7	0.00006
823.6	-0.00003
823.5	-0.00022
823.4	-0.00024
823.3	0.00014
823.2	0.00015
823.1	0.00001
823	0
822.9	-0.00015
822.8	0.00005
822.7	0.00035
822.6	0.00032
822.5	-0.00008
822.4	0.00006
822.3	0.00019
822.2	0.00006
822.1	-0.00025
822	-0.00026
821.9	0.00026
821.8	0.00008
821.7	0.00008
821.6	-0.00001
821.5	0.00032
821.4	-0.00034
821.3	0.00008
821.2	-0.00003
821.1	-0.00017
821	-0.00019
820.9	0.00001
820.8	-0.00025
820.7	-0.00013

820.6	-0.00001
820.5	-0.00026
820.4	0.00041
820.3	0.00043
820.2	-0.00006
820.1	0.0001
820	-0.00007
819.9	-0.00006
819.8	-0.00007
819.7	-0.00004
819.6	0.00013
819.5	-0.00014
819.4	-0.00012
819.3	0.00007
819.2	-0.00004
819.1	0.00007
819	0.0004
818.9	-0.00001
818.8	-0.00005
818.7	0.00006
818.6	0.0003
818.5	-0.00001
818.4	-0.00017
818.3	0.00011
818.2	-0.00009
818.1	-0.00002
818	0.00011
817.9	-0.00033
817.8	-0.00018
817.7	0.00008
817.6	-0.00019
817.5	0.0003
817.4	-0.00004
817.3	0.00022
817.2	-0.00024
817.1	-0.00019
817	-0.0001
816.9	-0.00008
816.8	0.00016
816.7	0.00024
816.6	0.00023
816.5	0.00005
816.4	-0.0002
816.3	0.00013
816.2	0.0003
816.1	-0.00018
816	-0.00007
815.9	0.00021
815.8	0.0001
815.7	0.00001
815.6	-0.0001
815.5	-0.00009

815.4	0.00011
815.3	-0.0001
815.2	-0.00006
815.1	0.00021
815	-0.00002
814.9	0.00002
814.8	0.00002
814.7	0.00004
814.6	-0.00021
814.5	-0.00007
814.4	0.00015
814.3	0.0001
814.2	-0.0001
814.1	-0.00015
814	0.00008
813.9	0.00016
813.8	-0.00002
813.7	0.00008
813.6	-0.00003
813.5	0.00009
813.4	-0.00014
813.3	-0.00032
813.2	0.00002
813.1	-0.00013
813	0.00005
812.9	0.00023
812.8	0.00003
812.7	-0.00013
812.6	0.0001
812.5	-0.00012
812.4	0.00007
812.3	-0.00024
812.2	-0.00015
812.1	0.00024
812	-0.00007
811.9	-0.00009
811.8	-0.0001
811.7	-0.00003
811.6	-0.00003
811.5	0.00016
811.4	-0.00004
811.3	-0.00021
811.2	-0.00007
811.1	0.00021
811	-0.00002
810.9	0.00023
810.8	-0.0002
810.7	0.00018
810.6	0.00004
810.5	0.00017
810.4	0.00014
810.3	0.00005

810.2	0.00004
810.1	-0.00001
810	-0.00042
809.9	0.00018

Wavelength (nm)	Transmission
740	0
739	-0.00002
738	0.00001
737	-0.00001
736	0.00001
735	-0.00001
734	0.00001
733	0.00002
732	-0.00001
731	0
730	0.00003
729	0.00002
728	0.00001
727	0.00002
726	0.00001
725	0.00001
724	0.00003
723	0.00003
722	0.00005
721	0.00007
720	0.00009
719	0.00013
718	0.00019
717	0.00025
716	0.00034
715	0.00048
714	0.00069
713	0.00106
712	0.0017
711	0.00273
710	0.0047
709	0.00855
708	0.01614
707	0.03345
706	0.0696
705	0.12846
704	0.20327
703	0.28485
702	0.35593
701	0.40083
700	0.41996
699	0.42498
698	0.4308
697	0.45086
696	0.49087
695	0.54772
694	0.61545
693	0.68155
692	0.73804
691	0.77871

690	0.80358
689	0.81372
688	0.8163
687	0.81691
686	0.81985
685	0.82733
684	0.83696
683	0.84773
682	0.85394
681	0.8529
680	0.84391
679	0.82616
678	0.80207
677	0.77398
676	0.74736
675	0.7233
674	0.70536
673	0.69558
672	0.69429
671	0.70172
670	0.71678
669	0.73868
668	0.76525
667	0.79449
666	0.82307
665	0.84857
664	0.86909
663	0.88287
662	0.88953
661	0.88922
660	0.8855
659	0.87753
658	0.8697
657	0.86213
656	0.85664
655	0.85298
654	0.85133
653	0.85171
652	0.85211
651	0.85244
650	0.8518
649	0.8489
648	0.84422
647	0.83771
646	0.83086
645	0.82461
644	0.82051
643	0.81724
642	0.817
641	0.82062
640	0.82791
639	0.83746

638	0.85003
637	0.86291
636	0.87543
635	0.888
634	0.89668
633	0.9031
632	0.90619
631	0.90574
630	0.9044
629	0.90067
628	0.89624
627	0.89207
626	0.89008
625	0.8891
624	0.89076
623	0.89255
622	0.89612
621	0.90013
620	0.90384
619	0.90671
618	0.90837
617	0.90858
616	0.90755
615	0.90594
614	0.90389
613	0.90213
612	0.90207
611	0.90336
610	0.90601
609	0.91119
608	0.91696
607	0.92425
606	0.93025
605	0.93649
604	0.94218
603	0.94299
602	0.94304
601	0.94142
600	0.93673
599	0.93241
598	0.92731
597	0.92157
596	0.91692
595	0.9125
594	0.90599
593	0.89989
592	0.88997
591	0.87726
590	0.86132
589	0.8419
588	0.81791
587	0.79137

586	0.7651
585	0.73836
584	0.71247
583	0.69139
582	0.67516
581	0.66367
580	0.65865
579	0.66014
578	0.66765
577	0.68273
576	0.70297
575	0.72999
574	0.75897
573	0.79165
572	0.82384
571	0.85317
570	0.8792
569	0.89994
568	0.91435
567	0.92089
566	0.92267
565	0.92158
564	0.91813
563	0.91591
562	0.91242
561	0.91174
560	0.91186
559	0.91228
558	0.91302
557	0.91343
556	0.91289
555	0.91204
554	0.91067
553	0.90854
552	0.90799
551	0.90991
550	0.91283
549	0.91883
548	0.92594
547	0.93144
546	0.93481
545	0.93291
544	0.92558
543	0.91251
542	0.89774
541	0.87891
540	0.86178
539	0.84851
538	0.8415
537	0.84131
536	0.84795
535	0.85902

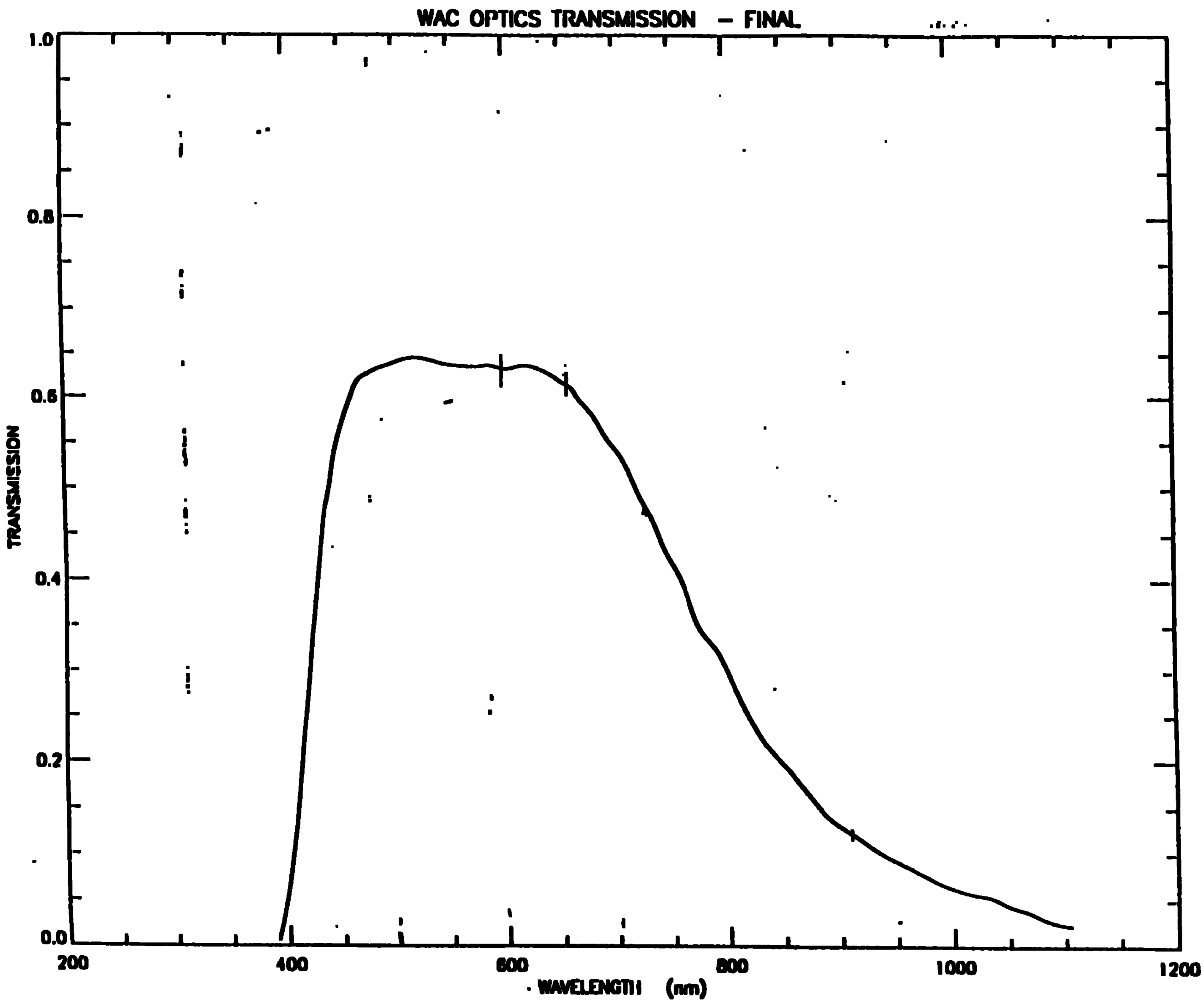
534	0.87305
533	0.88605
532	0.89538
531	0.89989
530	0.89907
529	0.8942
528	0.88834
527	0.88373
526	0.88265
525	0.88621
524	0.8913
523	0.89948
522	0.90721
521	0.91154
520	0.9155
519	0.91865
518	0.92275
517	0.92741
516	0.93025
515	0.9275
514	0.91346
513	0.88739
512	0.85008
511	0.80941
510	0.7734
509	0.75235
508	0.75032
507	0.765
506	0.78839
505	0.80838
504	0.81743
503	0.81627
502	0.81136
501	0.80763
500	0.80053
499	0.77874
498	0.72218
497	0.62157
496	0.48795
495	0.34244
494	0.20914
493	0.10944
492	0.04884
491	0.01844
490	0.006
489	0.00197
488	0.00073
487	0.00028
486	0.00012
485	0.00005
484	0.00003
483	0.00002

482	0
481	0
480	-0.00003
479	0.00001
478	-0.00002
477	-0.00001
476	-0.00002
475	-0.00001
474	-0.00001
473	-0.00001
472	-0.00002
471	-0.00001
470	-0.00004
469	-0.00001

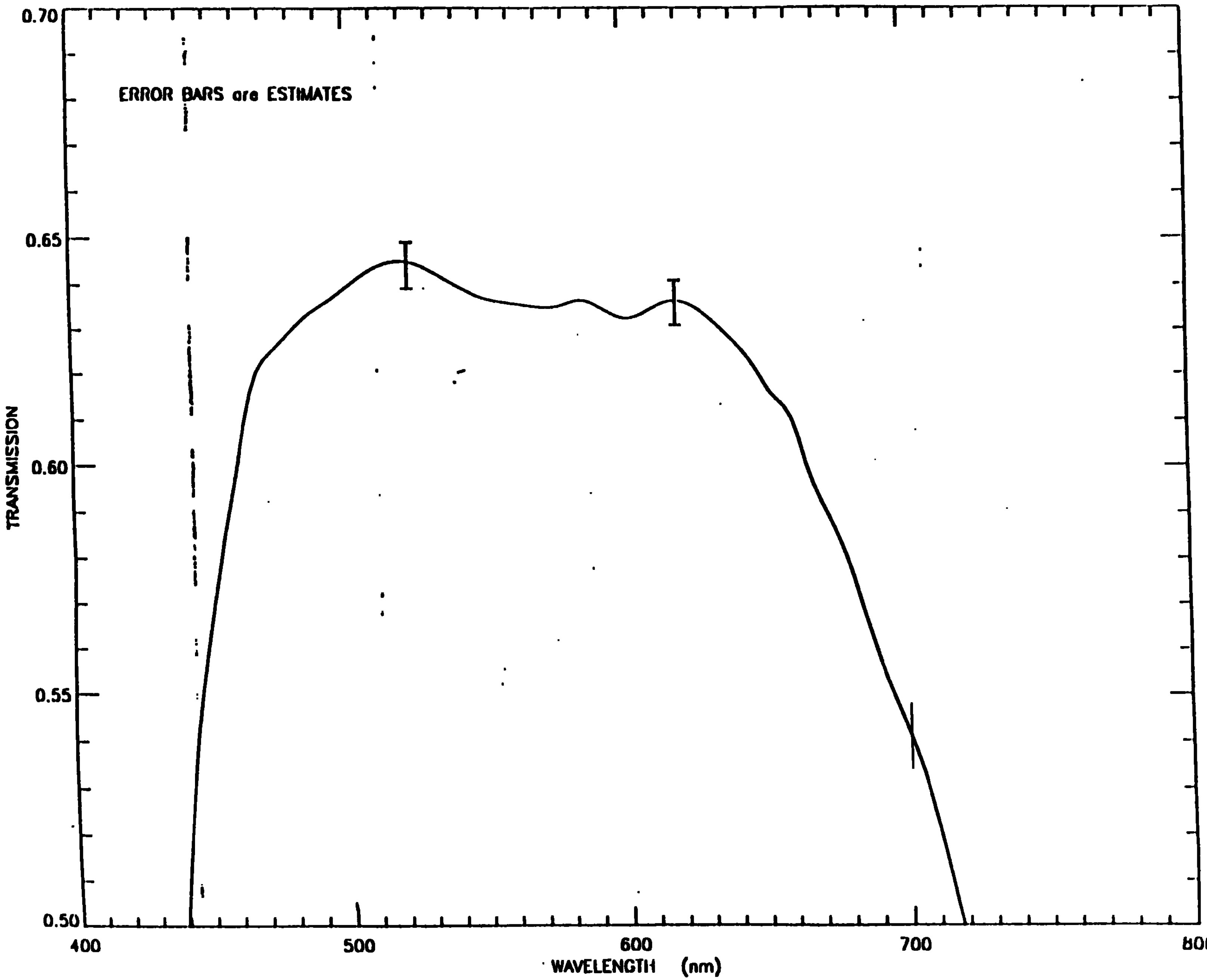
APPENDIX II

System Thruput

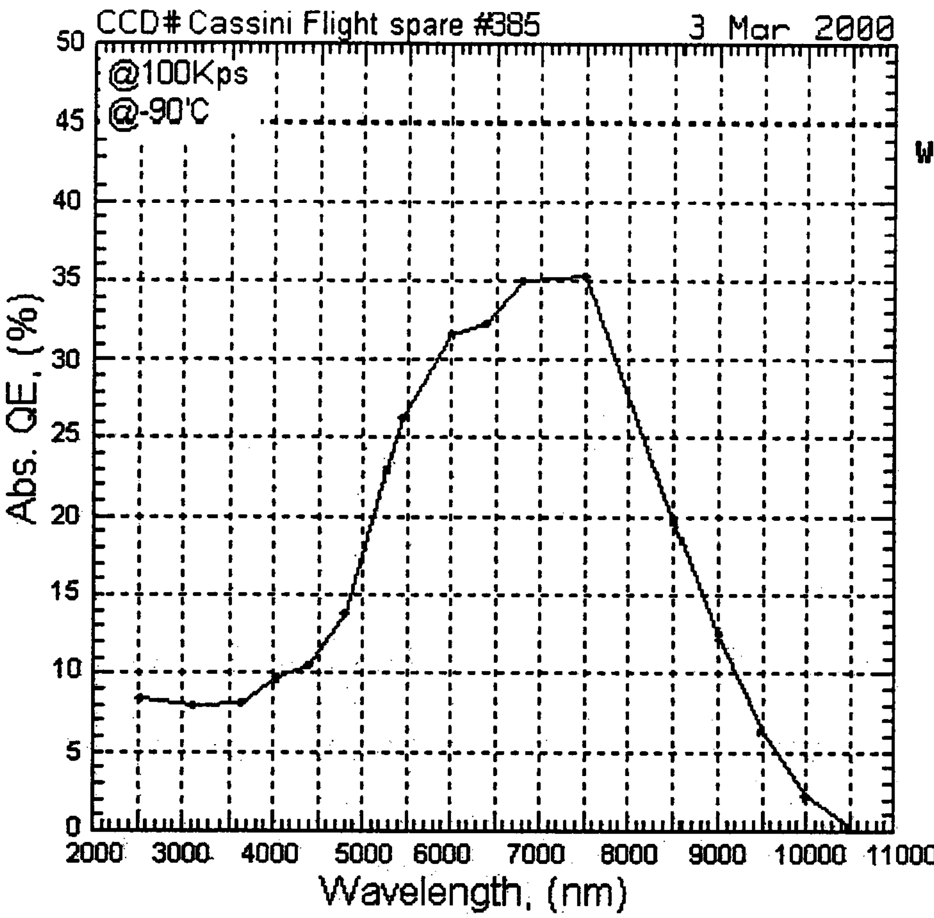
The data in this appendix are largely in analog form, the curves being those delivered with the equipment. The lens transmission data given are actually those for the Cassini lens, both the Cassini and the STARDUST lenses being backup units from the Voyager project. The Cassini lens, however, has a different field flattener and antireflection coating on that field lens, so the STARDUST flight lens may differ slightly in transmission. CCD quantum efficiency measurements are for the STARDUST flight unit. The scan mirror reflectivity curve is that delivered by the manufacturer. However, it extended only from 400 nm to 750 nm. This has been extrapolated to 900 nm using standard data for vacuum deposited evaporated aluminum. Numerical values are given for every 25 nm interval in a final table, and the system thruput is then shown for the case of the OpNav filter. The energy of a photon at that wavelength is also given for use in calculations such as those presented in Appendix VIII.


WAC OPTICS TRANSMISSION - FINAL
TRANSMISSION
0.0
0.2
0.4
0.6
0.8
1.0
200
400
600
800
1000
1200
WAVELENGTH (nm)

WAC OPTICS TRANSMISSION — FINAL



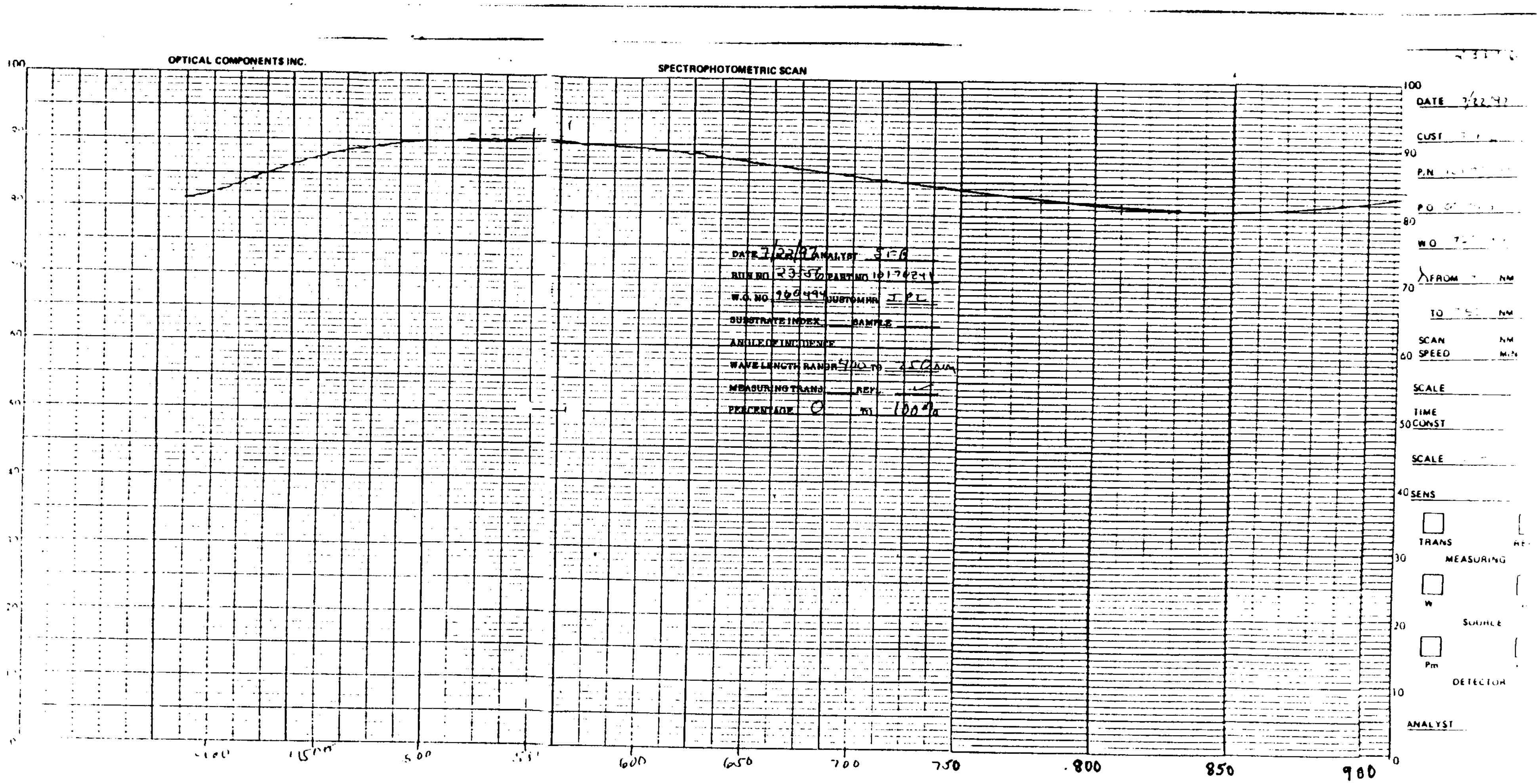
Quantum Efficiency results for Cassini flt. spare #385



QE %

WAVELENGTH	DATA
2540	8.4
3130	8
3650	8.1
4050	9.7
4400	10.5
4810	13.8
5280	23
5455	26.3
6005	31.5
6400	32.3
6805	35
7510	35.3
8520	19.7
9003	12.4
9501	6.3
10000	2.2
10500	.3

Scan Mirror


OPTICAL COMPONENTS INC.
SPECTROPHOTOMETRIC SCAN
DATE 7/22/97 ANALYST SIG
RUN NO 23-56 PART NO 1017624
W.O. NO 960494 CUSTOMER IPL
SUBSTRATE INDEX
SAMPLE
ANGLE OF INCIDENCE
WAVE LENGTH RANGE 400 TO 450 nm
MEASURING TRANS
REFL
PERCENTAGE 0 TO 100%
DATE
CUST
P.N
P.O
W.O
λ FROM
NM
TO
NM
SCAN SPEED
NM MIN
SCALE
TIME CONST
SCALE
SENS
TRANS
MEASURING
W
SOURCE
Pm
DETECTOR
ANALYST
100
90
80
70
60
50
40
30
20
10
0
600
650
700
750
800
850
900

Sample Calculation
Nav Filter
-30 C

Wavelength nm	Optics Transmission %	CCD QE	Nav Filter Transmission	Scan Mirror Al	Thruput		Photon Energy Ws/photon
400	0.067	0.095	0.00	0.820	0.0000		4.970E-19
425	0.400	0.102	0.00	0.850	0.0000		4.678E-19
450	0.565	0.115	0.00	0.874	0.0000		4.418E-19
475	0.629	0.135	0.40	0.890	0.0302		4.185E-19
500	0.639	0.175	0.72	0.900	0.0725		3.976E-19
525	0.644	0.222	0.91	0.903	0.1175		3.787E-19
550	0.637	0.268	0.92	0.905	0.1421		3.615E-19
575	0.634	0.291	0.93	0.900	0.1544		3.457E-19
600	0.632	0.315	0.93	0.895	0.1657		3.313E-19
625	0.634	0.323	0.92	0.886	0.1669		3.181E-19
650	0.618	0.330	0.92	0.875	0.1642		3.058E-19
675	0.586	0.340	0.89	0.864	0.1532		2.945E-19
700	0.542	0.351	0.90	0.857	0.1467		2.840E-19
725	0.486	0.352	0.86	0.849	0.1249		2.742E-19
750	0.419	0.353	0.96	0.840	0.1193		2.651E-19
775	0.340	0.315	0.92	0.828	0.0816		2.565E-19
800	0.298	0.277	0.95	0.819	0.0642		2.485E-19
825	0.229	0.238	0.95	0.811	0.0420		2.410E-19
850	0.196	0.200	0.76	0.810	0.0241		2.339E-19
875	0.157	0.162	0.74	0.813	0.0153		2.272E-19
900	0.130	0.124	0.74	0.822	0.0098		2.209E-19
925	0.109	0.093	0.36	0.835	0.0030		2.149E-19
950	0.092	0.063	0.00	0.850	0.0000		2.093E-19
975	0.760	0.043	0.00	0.855	0.0000		2.039E-19
1000	0.063	0.022	0.00	0.858	0.0000		1.988E-19

APPENDIX III.

Compressed Data Look-Up Table

The STARDUST navigation camera has a square-root compression chip for use in taking science images rapidly during the encounter with P/Wild 2. Various mathematical approximations can be used for rough photometry, but the best possible results can be obtained only with the exact conversions given in this table.

The Compression table used on the Nav-Cam for the Stardust program
note: this algorithm is the same one used on the Cassini program

the input value	***the look-up table Outputs***
12 bit input	8 bit output
4095	255
4094	255
4093	255
4092	255
4091	255
4090	255
4089	255
4088	255
4087	255
4086	255
4085	255
4084	255
4083	255
4082	255
4081	255
4080	255
4079	254
4078	254
4077	254
4076	254
4075	254
4074	254
4073	254
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4071	254
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7	3
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3	1
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1	0
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APPENDIX IV.

Transformation from Inertial Vectors to Camera Focal Plane

by Shyam Bhaskaran

Transformation of Inertial Vectors Into the Camera Focal Plane for the STARDUST Navigation Camera

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February 15, 2000

In order to compute predicts of stars and the comet in the camera FOV, the transformation of an inertial vector into camera pixel and line coordinates is needed. This is a three step process; the first step is to rotate an inertial vector into a camera coordinate frame (the M-N-L frame shown in Figure 1), the second is to project these 3-D coordinates into the 2-D camera focal plane, and then finally scale the result into values of pixel and line. In the following derivation, the notation $\mathbf{R}_1(\theta)$, $\mathbf{R}_2(\theta)$, and $\mathbf{R}_3(\theta)$ will be used to denote positive θ rotations about the x, y, and z axes, respectively.

First, we need the inertial to spacecraft body-fixed rotation matrix, $\mathbf{T}_{IBF}$. This is provided by the ACS system using information from the star tracker or gyroscopes, and is provided in the form of quaternions in the downlink telemetry which can be transformed into rotation matrices. The rotation to the camera M-N-L coordinate system requires several steps. The camera boresight, L, is pointed in the spacecraft $-Y$ axis, which puts the camera M-N plane in the spacecraft X-Z plane. The orientation of M-N is defined with M anti-parallel to X and N antiparallel to Z. If the mirror angle, θ, is $0°$ (i.e., the mirror is pointed along the spacecraft X axis), the reflection effectively transforms M-N-L to M'-N'-L' such that L' is now along X, N' points in $-Z$, and M' along $+Y$ (Figure 2). This transformation can be accomplished via

$$\mathbf{T}_1 = \mathbf{R}_r \mathbf{R}_3(270°)\mathbf{R}_2(90°), \tag{1}$$

where

$$\mathbf{R}_r = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & -1 \\ 1 & 0 & 0 \end{bmatrix}. \tag{2}$$

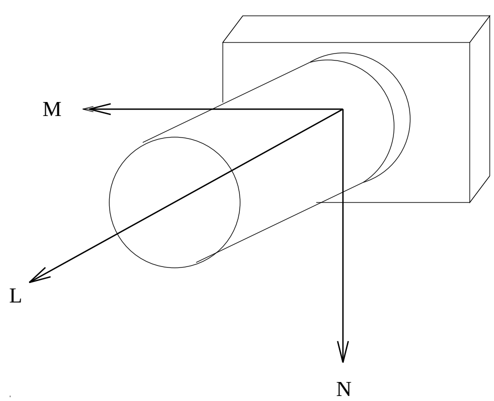

Figure 1: Camera Frame

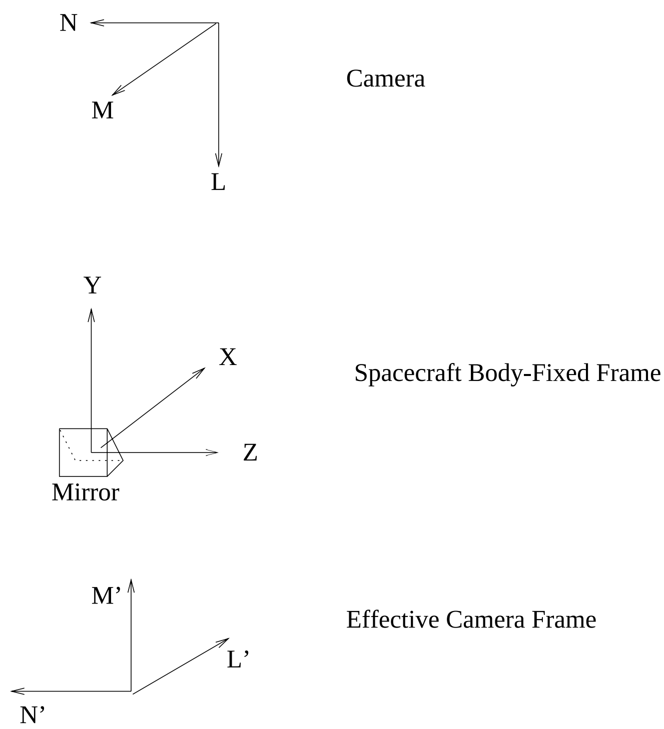

Figure 2: Spacecraft and Camera Coordinate Frames

The matrix, $\mathbf{R}_r$, accounts for the mirror reflection about the X-Z plane which flips M from $-Y$ to Y, with the result that M'-N'-L' is no longer a right-handed coordinate system.

Now, as the mirror swivels about the Y axis with angle θ, L' will sweep through the X-Z plane. In addition, since the camera is fixed while the mirror swivels, the image will appear to rotate about the boresight. This rotation is applied as,

$$\mathbf{T}_2 = \mathbf{R}_3(\theta)\mathbf{R}_2(-\theta), \tag{3}$$

where the second term is a positive rotation about M' (the sign is negative since the coordinate system is not right-handed) to align the boresight, and the first term rotates around the boresight.

Finally, to account for any alignment offsets for camera and mirror mounting, and for misalignments between the star tracker determined attitude and the camera boresight, three further rotations defined by angles ψ, χ, and Ω for rotations about the camera N, M, and L axes, respectively, are included. The alignment offset matrix, $\mathbf{T}_a$ is computed as

$$\mathbf{T}_a = \mathbf{R}_3(\Omega)\mathbf{R}_1(-\chi)\mathbf{R}_2(\psi). \tag{4}$$

Nominally, these angle are zero, but they will be determined empirically in flight from calibration data taken of star clusters. In general, these angles will be functions of θ, the mirror angle, so the calibration data must be taken at discrete steps of the mirror. Values for the angles between the data points will be linearly interpolated.

The total transformation from inertial to the camera frame, $\mathbf{T}_{IC}$ is then

$$\mathbf{T}_{IC} = \mathbf{T}_a\mathbf{T}_2\mathbf{T}_1\mathbf{T}_{IBF}. \tag{5}$$

An inertial LOS unit vector, $\hat{\mathbf{V}}_I$, can then be rotatated into a unit vector in the camera coordinates, $\hat{\mathbf{V}}_C$ by

$$\hat{\mathbf{V}}_c = \begin{bmatrix} V_{c1} \\ V_{c2} \\ V_{c3} \end{bmatrix} = \mathbf{T}_{IC}\hat{\mathbf{V}}_I. \tag{6}$$

Once $\hat{\mathbf{V}}_c$, a LOS vector in camera M-N-L coordinates is obtained, it needs to be transformed into the 2-D camera focal plane. A detailed description of this process can be found in Ref. 1; a brief synopsis will be given here. First, apply the gnomonic projection,

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{f}{V_{c3}} \begin{bmatrix} V_{c1} \\ V_{c2} \end{bmatrix} \tag{7}$$

where

f = the camera focal length, in mm

V_{c1}, V_{c2}, V_{c3} = the components of the line-of-sight unit vector in M-N-L coordinates

x, y = the projection of the LOS vector into focal plane coordinates, measured in mm.

Next, find the bias to x and y, Δx and Δy, caused by optical distortions by:

$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \begin{bmatrix} -yr & xr^2 & -yr^3 & xr^4 & xy & x^2 \\ xr & yr^2 & xr^3 & yr^4 & y^2 & xy \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \nu_5 \\ \nu_6 \end{bmatrix} \tag{8}$$

where $r = x^2 + y^2$, and the ν's are the optical distortion coefficients. The corrected image locations, x' and y', are then

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x + \Delta x \\ y + \Delta y \end{bmatrix}. \tag{9}$$

Finally, the conversion from the rectangular coordinates to pixel and line is:

$$\begin{bmatrix} p \\ l \end{bmatrix} = \begin{bmatrix} K_x & K_{xy} & K_{xxy} \\ K_{yx} & K_y & K_{yxy} \end{bmatrix} \begin{bmatrix} x' \\ y' \\ x'y' \end{bmatrix} + \begin{bmatrix} p_o \\ l_o \end{bmatrix}, \tag{10}$$

where $\mathbf{K}$ is a transformation matrix from mm to pixel/line space, and p_o and l_o are the center pixel and line of the CCD. Currently , the ν's in Eq. (8) and all cross terms in the $\mathbf{K}$ matrix in Eq. (10) are set to zero. The nominal focal length is 200 mm, and K_x and K_y are 83.8133 pixels/mm. During flight, calibration images of dense star fields will be taken and used to accurately determine all these parameters.

References

1. W. M. Owen and R. M. Vaughan, "Optical Navigation Program Mathematical Models" JPL Internal Document JPL-EM 314-513, August 9, 1991.

APPENDIX V.

Point Spread Functions

Each point spread function is presented as a grid of points whose size is given at the top of each sheet, usually near one micron. The yellow and high resolution filters show excellent resolution, the other filters decreasingly so as they differ in wavelength from the yellow in which the camera was focused. This was discussed in the plans section at the beginning of this document.

The digital version of this appendix also contains a pointspread function for a blue continuum filter. This filter was procured for possible flight use, but was not flown.

Filter Wavelength: 445 nm (Blue continuum). Grid spacing: .0007537 mm

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
22			1																1		
23										1	1	1									
24							1	1	1				1	1	1						
25					1	1		1	3	5	5	5	3	1		1	1				
26				1	1	1	4	9	10	9	9	9	10	9	4	1	1	1			
27			1	1	2	8	10	9	10	15	18	15	10	9	10	8	2	1	1		
28			1	1	8	9	10	23	36	43	45	43	36	23	10	9	8	1	1		
29		1		4	10	10	30	45	37	29	28	29	37	45	30	10	10	4		1	
30		1	1	9	9	23	45	31	31	46	51	46	31	31	45	23	9	9	1	1	
31		1	3	10	10	36	37	31	56	40	24	40	56	31	37	36	10	10	3	1	
32	1		5	9	15	43	29	46	40		20		40	46	29	43	15	9	5		1
33	1		5	9	18	45	28	51	24	20	##	20	24	51	28	45	18	9	5		1
34	1		5	9	15	43	29	46	40		20		40	46	29	43	15	9	5		1
35		1	3	10	10	36	37	31	56	40	24	40	56	31	37	36	10	10	3	1	
36		1	1	9	9	23	45	31	31	46	51	46	31	31	45	23	9	9	1	1	
37		1		4	10	10	30	45	37	29	28	29	37	45	30	10	10	4		1	
38			1	1	8	9	10	23	36	43	45	43	36	23	10	9	8	1	1		
39			1	1	2	8	10	9	10	15	18	15	10	9	10	8	2	1	1		
40				1	1	1	4	9	10	9	9	9	10	9	4	1	1	1			
41					1	1		1	3	5	5	5	3	1		1	1				
42							1	1	1				1	1	1						
43										1	1	1									
44			1																1		

Filter Wavelength: 514.1 nm (C2). Grid spacing: .0008708 mm

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2																								
3									1			1					1			1	1	1	1	1
4			1						1			1								1				
5													1	1		1						2	2	1
6						1		1								1	1							
7					1	1							1								1	1	1	1
8										1		1	2		1	1					1	1		
9					1										1						1	1	1	2
10		1	1										1			1	1	1		1	1	1		
11							1			1			1		1	1						1	2	3
12														1	1		2	1		1	1		1	1
13		1	1				1									1	2			1		1	2	2
14				1		1	2		1	1							1	1	1		1	2	1	1
15				1							1			1		1	2	1		1	1	1	2	3
16							1	1		1	1							1	2	2	1	4	3	2
17				1	1		1		1	1		1		1		1	2	2	1	1	2	2	3	8
18		1			1				1		2	2	1	2		2	1	1	2	2	2	3	8	10
19									1		1		1	1	1	2	1	5	4	2	3	3	5	8
20													1		2	1	2	4	2	8	7	6	12	16
21		1	1						1		1	1		1	2	1	2	2	8	12	8	14	14	14

22		1				1	1	1	1		1		1	1	1	2	2	3	7	8	15	23	20	37
23		1		2		1	1	1	1	1		1	2	1	4	2	3	3	6	14	23	26	34	49
24		1		2		1		1		2	1	2	1	2	3	3	8	5	12	14	20	34	41	52
25		1		1		1		2		3	1	2	1	3	2	8	10	8	16	14	37	49	52	74
26					1	1		2		2		2	1	4	2	8	7	16	22	25	47	46	68	84
27								1		1	1	2	1	4	3	6	9	23	23	34	41	54	88	81
28									1	1	1	1	2	3	4	7	11	18	25	47	48	77	87	78
29								1	1	1	1	1	2	3	7	8	12	17	36	57	61	85	75	86
30										1	1	2	3	3	7	8	18	22	38	50	69	87	81	94
31		1		1						1	1	2	2	3	6	9	22	25	36	45	77	90	92	89
32								1	1	1	1	1	2	4	6	10	17	24	43	52	80	84	92	81
33		1				1		1	1		1	1	2	4	6	9	13	24	51	58	80	79	89	78
34								1	1	1	1	1	2	4	6	10	17	24	43	52	80	84	92	81
35		1		1						1	1	2	2	3	6	9	22	25	36	45	77	90	92	89
36										1	1	2	3	3	7	8	18	22	38	50	69	87	81	94
37								1	1	1	1	1	2	3	7	8	12	17	36	57	61	85	75	86
38									1	1	1	1	2	3	4	7	11	18	25	47	48	77	87	78
39								1		1	1	2	1	4	3	6	9	23	23	34	41	54	88	81
40					1	1		2		2		2	1	4	2	8	7	16	22	25	47	46	68	84
41		1		1		1		2		3	1	2	1	3	2	8	10	8	16	14	37	49	52	74
42		1		2		1		1		2	1	2	1	2	3	3	8	5	12	14	20	34	41	52
43		1		2		1	1	1	1	1		1	2	1	4	2	3	3	6	14	23	26	34	49
44		1				1	1	1	1		1		1	1	1	2	2	3	7	8	15	23	20	37
45		1	1						1		1	1		1	2	1	2	2	8	12	8	14	14	14
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47									1		1		1	1	1	2	1	5	4	2	3	3	5	8
48		1			1				1		2	2	1	2		2	1	1	2	2	2	3	8	10
49				1	1		1		1	1		1		1		1	2	2	1	1	2	2	3	8
50							1	1		1	1							1	2	2	1	4	3	2
51				1							1			1		1	2	1		1	1	1	2	3
52				1		1	2		1	1							1	1	1		1	2	1	1
53		1	1				1									1	2			1		1	2	2
54														1	1		2	1		1	1		1	1
55							1			1			1		1	1						1	2	3
56		1	1										1			1	1	1		1	1	1		
57					1										1						1	1	1	2
58										1		1	2		1	1					1	1		
59					1	1							1								1	1	1	1
60						1		1								1	1							
61													1	1		1						2	2	1
62			1						1			1								1				
63									1			1					1			1	1	1	1	1
64																								
Filter Wavelength: 580 nm (Yellow continuum). Grid spacing: .0009827 mm																								
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28									1				1											
29											1													
30									2	2	2	2	2											
31						1		2	2	2	4	2	2	2		1								
32								2	2	26	53	26	2	2										
33							1	2	4	53	##	53	4	2	1									
34								2	2	26	53	26	2	2										
35						1		2	2	2	4	2	2	2		1								

	36									2	2	2	2	2											
	37											1													
	38									1				1											
	Filter Wavelength: 590 nm (Hi Res). Grid spacing: .0009997 mm																								
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43			
	29											1													
	30									1	2	2	2	1											
	31								1	1	1	3	1	1	1										
	32								2	1	25	52	25	1	2										
	33							1	2	3	52	##	52	3	2	1									
	34								2	1	25	52	25	1	2										
	35								1	1	1	3	1	1	1										
	36									1	2	2	2	1											
	37											1													
	Filter Wavelength: 634 nm (O[1D]). Grid spacing: .0010746 mm																								
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	21																		1	1	1	1	1	1	2
	22																		1	1	1	2	1	4	4
	23														1					1	2	1	3	4	3
	24														1		1		1	1	1	3	3	4	8
	25															1	1	1	1	1	4	4	4	9	10
	26															1		1	2	2	4	3	8	10	13
	27																1	2	1	2	3	6	10	12	23
	28																1	1	2	3	4	9	10	19	27
	29														1		1	1	4	3	6	9	13	24	28
	30														1	1	2	1	3	3	8	9	19	26	34
	31			1								1			1	1	2	1	2	4	9	10	23	26	41
	32													1		1	1	2	3	4	9	11	24	27	46
	33					1								1	1	1	1	3	4	4	9	11	24	27	48
	34													1		1	1	2	3	4	9	11	24	27	46
	35			1								1			1	1	2	1	2	4	9	10	23	26	41
	36														1	1	2	1	3	3	8	9	19	26	34
	37														1		1	1	4	3	6	9	13	24	28

38																1	1	2	3	4	9	10	19	27
39																1	2	1	2	3	6	10	12	23
40															1		1	2	2	4	3	8	10	13
41															1	1	1	1	1	4	4	4	9	10
42														1		1		1	1	1	3	3	4	8
43														1					1	2	1	3	4	3
44																		1	1	1	2	1	4	4
45																		1	1	1	1	1	1	2
46																	1		1	1		1	1	2
47																	1	1					1	1
48										1			1									1	1	
49																							1	1
50																					1	1		
51																1								
52						1																		
53																								
54																1								
55									1															
56																								
57																								
58												1												
59																								
60																								
61																								

Filter Wavelength: 640 nm (OpNav). Grid spacing: .0010848 mm

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
3																						1		
4						1		1																
5													1										1	
6																								
7			1										1									1		
8													1			1						1		
9			1																					1
10																	1	1		1	1			
11										2					1								1	1
12														1			1	1						
13																1	1						1	1
14				1		1	1											1	1		1	1	1	1
15											1						1	1		1			1	1
16										1									1	1	1	2	2	1
17							1					1					1	1	1		1	1	1	3
18									1		1	1		1		1			1	1	1	1	3	4
19									1		1		1	1		1		2	2	1	1	1	2	2
20													1		1	1	1	2	1	3	2	2	4	5
21									1					1	1		1	1	3	4	2	4	4	4
22									1				1		1	1	1	1	2	2	5	6	5	11
23		1				1	1						1		2	1	1	1	2	4	6	6	10	15
24				1						1		1	1	1	2	1	3	2	4	4	5	10	11	16
25								1		1		1	1	1	1	3	4	2	5	4	11	15	16	30
26								1				1		1	1	2	2	4	6	7	14	15	26	35
27												1	1	1	1	1	2	6	6	9	12	20	34	38
28											1		1	1	1	2	3	4	7	12	15	30	36	51

	29						1				1	1	1	1	1	3	2	3	3	11	14	21	32	40	63
	30				1						1		1	1	1	3	2	5	5	11	13	26	32	50	69
	31				1	1			1		1		1	1	1	2	3	7	6	10	13	30	34	60	68
	32		1				1		1		1	1	1	1	2	2	3	4	7	12	15	31	35	63	64
	33		1				1		1		1	1	1	1	2	2	3	3	8	15	17	31	35	63	62
	34		1				1		1		1	1	1	1	2	2	3	4	7	12	15	31	35	63	64
	35				1	1			1		1		1	1	1	2	3	7	6	10	13	30	34	60	68
	36				1						1		1	1	1	3	2	5	5	11	13	26	32	50	69
	37						1				1	1	1	1	1	3	2	3	3	11	14	21	32	40	63
	38											1		1	1	1	2	3	4	7	12	15	30	36	51
	39												1	1	1	1	1	2	6	6	9	12	20	34	38
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	41								1		1		1	1	1	1	3	4	2	5	4	11	15	16	30
	42				1						1		1	1	1	2	1	3	2	4	4	5	10	11	16
	43		1				1	1						1		2	1	1	1	2	4	6	6	10	15
	44									1				1		1	1	1	1	2	2	5	6	5	11
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	46													1		1	1	1	2	1	3	2	2	4	5
	47									1		1		1	1		1		2	2	1	1	1	2	2
	48									1		1	1		1		1			1	1	1	1	3	4
	49							1					1					1	1	1		1	1	1	3
	50										1									1	1	1	2	2	1
	51											1						1	1		1			1	1
	52				1		1	1											1	1		1	1	1	1
	53																1	1						1	1
	54														1			1	1						
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	56																	1	1		1	1			
	57			1																					1
	58													1			1						1		
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	61													1										1	
	62						1		1																
	63																						1		
	Filter Wavelength: 665 nm (NH2). Grid spacing: .0011273 mm																								
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	4			1			1		1	1															
	5												1	1									1	2	1
	6									1			1					1							
	7		1	1										1	1							1	2	1	
	8													2	1	1	2					1	2		
	9			1												1	1		1			1		1	2
	10			1		1					1		1	1				1	2		1	2	1	1	1
	11									1	3		1	1		1						1	1	2	2
	12		1												1	1	1	3	2	1	1	1	2	2	1
	13		1		1	1				1	1				1		1	2	1	1	1	1	1	2	3
	14		1		1		1	2		1	1						1	1	2	2	1	2	3	4	3
	15		1				1	1				1	1		1	1	1	3	3	2	3	2	2	3	4
	16							1	1		1	1			1		1	1	1	4	4	3	7	7	6

	17		1					2	1			1	1	1	1	1	1	2	3	4	3	6	8	6	9
	18		1			1				1		3	2	1	3	1	2	2	2	4	5	7	8	13	19
	19								1	2		2	1	2	3	1	3	2	7	8	7	10	12	15	17
	20											1	1	2	2	4	4	4	8	6	11	14	13	19	27
	21									1		1	1	1	3	4	3	5	7	11	18	17	22	29	29
	22		1				1	1	1	2	1	1	1	2	2	3	6	7	10	14	17	22	31	30	32
	23		1		1		2	2		1	1	2	1	3	2	7	8	8	12	13	22	31	37	41	50
	24		1		2		1		1	1	2	2	2	4	3	7	6	13	15	19	29	30	41	48	46
	25				1				2	1	2	1	3	3	4	6	9	19	17	27	29	32	50	46	44
	26					1	1	1	2	1	2	1	3	4	6	7	12	16	20	35	34	46	54	46	51
	27				1	1	1		1	1	2	2	3	4	7	9	11	15	26	37	42	51	47	48	45
	28				1		1		1	1	1	2	3	4	6	10	13	20	26	32	45	47	46	48	34
	29		1				1	1	1	1	2	3	3	5	6	13	16	23	24	33	49	48	51	42	27
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	31		1		2	1	1		2	1	3	2	5	7	8	13	14	30	35	47	43	46	46	26	22
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	34		1		1		1	1	2	1	3	3	4	6	9	13	17	28	29	47	44	49	44	25	23
	35		1		2	1	1		2	1	3	2	5	7	8	13	14	30	35	47	43	46	46	26	22
	36		1		1		1		1	1	2	2	4	6	7	14	15	26	31	42	47	47	50	32	23
	37		1				1	1	1	1	2	3	3	5	6	13	16	23	24	33	49	48	51	42	27
	38				1		1		1	1	1	2	3	4	6	10	13	20	26	32	45	47	46	48	34
	39				1	1	1		1	1	2	2	3	4	7	9	11	15	26	37	42	51	47	48	45
	40					1	1	1	2	1	2	1	3	4	6	7	12	16	20	35	34	46	54	46	51
	41				1				2	1	2	1	3	3	4	6	9	19	17	27	29	32	50	46	44
	42		1		2		1		1	1	2	2	2	4	3	7	6	13	15	19	29	30	41	48	46
	43		1		1		2	2		1	1	2	1	3	2	7	8	8	12	13	22	31	37	41	50
	44		1				1	1	1	2	1	1	1	2	2	3	6	7	10	14	17	22	31	30	32
	45									1		1	1	1	3	4	3	5	7	11	18	17	22	29	29
	46											1	1	2	2	4	4	4	8	6	11	14	13	19	27
	47								1	2		2	1	2	3	1	3	2	7	8	7	10	12	15	17
	48		1			1				1		3	2	1	3	1	2	2	2	4	5	7	8	13	19
	49		1					2	1			1	1	1	1	1	1	2	3	4	3	6	8	6	9
	50							1	1		1	1			1		1	1	1	4	4	3	7	7	6
	51		1				1	1				1	1		1	1	1	3	3	2	3	2	2	3	4
	52		1		1		1	2		1	1						1	1	2	2	1	2	3	4	3
	53		1		1	1				1	1				1		1	2	1	1	1	1	1	2	3
	54		1												1	1	1	3	2	1	1	1	2	2	1
	55									1	3		1	1		1						1	1	2	2
	56			1		1					1		1	1				1	2		1	2	1	1	1
	57			1												1	1		1			1		1	2
	58													2	1	1	2					1	2		
	59		1	1										1	1							1	2	1	
	60									1			1					1							
	61												1	1									1	2	1
	62			1			1		1	1															
	63						1					1	1	1	1		1	1				1	1	1	
	Filter Wavelength: 712.8 nm (Red Continuum). Grid spacing: .0011273 mm																								
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	3	2		1	1	2	5	1	3	3	1	4	6	8	9	5	8	11	7	6	9	13	20	19	14

	4	1	1	6	1	4	8		7	6	1	5	3	2	4	3	3	6	4	3	5	8	6	3	4
	5		1	1		1		1	2		1	1	3	9	6	3	6	9	6	6	8	9	16	28	23
	6	1	2	4	1	3	3	2	4	6	5	4	8	9	6	6	11	16	11	11	13	10	13	19	15
	7		5	8		3	3		5	4	1	2		5	7	2	4	7	6	11	12	11	19	20	18
	8		1		1	2		2	3	2	8	6	6	23	15	9	24	18	13	23	22	27	43	32	21
	9		3	7	2	4	5	3	5	5	7	5	2	7	5	13	19	9	16	17	8	17	27	25	38
	10	1	3	6		6	4	2	5	1	8	4	5	13	10	14	18	27	43	34	31	47	47	46	58
	11	1	1	1	1	5	1	8	7	8	28	13	13	20	9	20	23	22	31	32	35	41	36	38	47
	12	1	4	5	1	4	2	6	5	4	13	4	13	13	17	30	17	29	47	40	44	60	67	75	82
	13	2	6	3	3	8		6	2	5	13	13	21	19	29	34	34	59	58	48	62	68	61	60	64
	14		8	2	9	9	5	23	7	13	20	13	19	19	24	33	35	39	46	60	66	65	74	87	91
	15	1	9	4	6	6	7	15	5	10	9	17	29	24	36	47	42	60	84	76	72	88	92	88	83
	16	1	5	3	3	6	2	9	13	14	20	30	34	33	47	57	55	73	72	63	81	76	58	67	78
	17		8	3	6	11	4	24	19	18	23	17	34	35	42	55	52	64	73	91	##	75	74	88	75
	18		11	6	9	16	7	18	9	27	22	29	59	39	60	73	64	86	85	82	82	68	66	52	32
	19	2	7	4	6	11	6	13	16	43	31	47	58	46	84	72	73	85	57	66	73	57	50	38	33
	20		6	3	6	11	11	23	17	34	32	40	48	60	76	63	91	82	66	85	67	45	48	41	35
	21	2	9	5	8	13	12	22	8	31	35	44	62	66	72	81	##	82	73	67	39	35	40	27	22
	22	2	13	8	9	10	11	27	17	47	41	60	68	65	88	76	75	68	57	45	35	40	40	30	39
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	24		19	3	28	19	20	32	25	46	38	75	60	87	88	67	88	52	38	41	27	30	52	59	54
	25	1	14	4	23	15	18	21	38	58	47	82	64	91	83	78	75	32	33	35	22	39	68	54	44
	26	1	14	5	12	14	29	29	46	59	52	82	66	86	73	70	59	35	43	43	35	63	77	53	52
	27		17	4	15	18	35	36	35	53	56	80	71	84	68	65	61	43	42	43	49	68	62	49	47
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	29	1	19	8	26	12	22	36	39	68	52	84	74	86	78	49	43	26	24	43	58	60	59	45	29
	30		20	4	23	19	30	38	42	65	49	90	65	78	75	47	49	37	36	54	54	56	59	35	24
	31		21	2	28	28	36	37	39	64	54	92	61	76	70	49	57	43	43	59	48	50	52	27	22
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	35		21	2	28	28	36	37	39	64	54	92	61	76	70	49	57	43	43	59	48	50	52	27	22
	36		20	4	23	19	30	38	42	65	49	90	65	78	75	47	49	37	36	54	54	56	59	35	24
	37	1	19	8	26	12	22	36	39	68	52	84	74	86	78	49	43	26	24	43	58	60	59	45	29
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	41	1	14	4	23	15	18	21	38	58	47	82	64	91	83	78	75	32	33	35	22	39	68	54	44
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	46		6	3	6	11	11	23	17	34	32	40	48	60	76	63	91	82	66	85	67	45	48	41	35
	47	2	7	4	6	11	6	13	16	43	31	47	58	46	84	72	73	85	57	66	73	57	50	38	33
	48		11	6	9	16	7	18	9	27	22	29	59	39	60	73	64	86	85	82	82	68	66	52	32
	49		8	3	6	11	4	24	19	18	23	17	34	35	42	55	52	64	73	91	##	75	74	88	75
	50	1	5	3	3	6	2	9	13	14	20	30	34	33	47	57	55	73	72	63	81	76	58	67	78
	51	1	9	4	6	6	7	15	5	10	9	17	29	24	36	47	42	60	84	76	72	88	92	88	83
	52		8	2	9	9	5	23	7	13	20	13	19	19	24	33	35	39	46	60	66	65	74	87	91
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	54	1	4	5	1	4	2	6	5	4	13	4	13	13	17	30	17	29	47	40	44	60	67	75	82
	55	1	1	1	1	5	1	8	7	8	28	13	13	20	9	20	23	22	31	32	35	41	36	38	47
	56	1	3	6		6	4	2	5	1	8	4	5	13	10	14	18	27	43	34	31	47	47	46	58
	57		3	7	2	4	5	3	5	5	7	5	2	7	5	13	19	9	16	17	8	17	27	25	38
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	59		5	8		3	3		5	4	1	2		5	7	2	4	7	6	11	12	11	19	20	18
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	64		2	1		1				1	1	1	2		1	1			2		2	2			1

************Filter Wavelength: 880 nm (NIR Continuum). **************

This filter is far enough out of focus (.666 mm) that it can best be modeled by convolving the image with a uniform ("tophat") blur of diameter 0.197 mm This is the **geometric** blur of an f/3.38 beam at a defocus of .666 mm)

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
							1																		
					1				1						1	1	1	1	1			1			
																			1						
					1				1						1	2	2						1		1
1														1								1	1		
1							1							1	1	1	1	1							
																	1	1					1	1	
2	1		1			1	1	1			1		1	2	2	1	1	1						1	
		1	1			1	1	1			1	1					1	1	1		1	1	1		
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2	2	1	1	2	2	1	1	1	2	2	1	1	2	2	2	2	1		1			2	1		
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47	41	48	61	69	77	80	80	80	77	69	61	48	41	47	37	20	23	15	8	7	3	2	2	1	1
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APPENDIX VI.

Spectral Radiance During Calibration

Absolute radiometry numbers for the STARDUST mission were provided by David Brown, who set up and calibrated all the test equipment.

The STARDUST camera, which has a 3.5 degree field of view, was set up 0.5 m from the integrating sphere during calibration. It therefore viewed only the central 3.05 cm of the 40 inch sphere. The first page of this appendix shows the departures of the sphere from uniformity, less than 0.5% in the area viewed.

40" SPHERE UNIFORMITY

M. Carey
1/12/96

Sheet1

						1.54						
				1.577		1.548			1.56			
		1.561	1.563	1.564	1.564	1.555	1.567	1.567	1.565	1.56	1.553	
		1.561		1.569		1.563			1.572		1.562	
		1.557	1.559	1.564	1.564	1.571	1.573	1.577	1.577	1.573	1.567	1.556
	1.555	1.555		1.56		1.576			1.586		1.572	
1.373	1.555	1.554	1.554	1.559	1.568	1.579	1.588	1.594	1.588	1.574	1.56	1.551
	1.554	1.552		1.557		1.582			1.594		1.578	
		1.553	1.552	1.552	1.555	1.582	1.575	1.587	1.594	1.587	1.58	1.564
		1.552		1.55		1.581			1.594		1.58	
		1.545	1.548	1.548	1.551	1.579	1.57	1.583	1.59	1.586	1.577	
				1.542		1.574			1.595			
						1.567						

↑ UP

						-2.47						
				-0.13		-1.96			-1.20			
		-1.14	-1.01	-0.95	-0.85	-1.52	-0.76	-0.76	-0.89	-1.20	-1.65	
		-1.14		-0.63		-1.01			-0.44		-1.08	
	-1.52	-1.39	-1.27	-0.95	-0.95	-0.51	-0.38	-0.13	-0.13	-0.38	-0.76	-1.46
		-1.52		-1.20		-0.19			0.44		-0.44	
-13.65	-1.52	-1.58	-1.58	-1.27	-0.70	0.00	0.57	0.95	0.57	-0.32	-1.20	-1.77
		-1.71		-1.39		0.19			0.95		-0.06	
	-1.58	-1.65	-1.71	-1.71	-1.52	0.19	-0.25	0.51	0.95	0.51	0.06	-0.95
		-1.71		-1.84		0.12			-0.95		0.06	
		-2.15	-1.96	-1.96	-1.77	0.00	-0.57	0.25	0.70	0.44	-0.13	
				-2.34		-0.32			1.01			
						-0.70						

RADIOMETRIC CALIBRATION OF THE INTEGRATING SPHERE

The integrating sphere system used to calibrate the Stardust camera was the 1-meter sphere developed for use in calibrating the Cassini ISS camera system. It is comprised of a sphere, light source, and radiometer. The light source is a highly stable tungsten source (0.1%). During operation, the source current is kept constant so as to keep the color temperature constant. The sphere radiance is changed by varying the entrance aperture to the sphere. The sphere radiance is measured using the radiometer mounted on the sphere and which constantly monitors the radiance in real time. The radiometer is of the filter type and employs a very stable, temperature-controlled silicon photodetector. The radiometer has been calibrated in two ways:

1) Bottom up: the individual components (filters, detector, geometry) were themselves calibrated and the overall expected detector current was calculated from the sum of the parts.

2) Top down: the radiometer stared at a NIST-traceable, lambertian light source with individual filters installed and the photodetector currents noted for each filter.

A comparison between 1) and 2) was made with average results differing by 1%.

Once the radiometer was calibrated, the sphere was calibrated by setting the appropriate light source current, and letting the source warm up and stabilize for roughly an hour. The aperture size was set, then kept constant, and the various filters inserted in the radiometer, with the detector current being noted for each filter. Dark current was also measured and subtracted. Having the radiometry calibration in hand, the filter currents then directly translated into a spectral radiance. Once the spectral radiance curve (using all filters) was produced, only one filter (700 nm) was needed for setting up and monitoring the system with time. The whole spectral radiance curve scaled with the radiometer current value using the 700 nm filter. Data for the calibration is shown below.

Filter central wavelength(nm)	2/6/1996 calibration spec rad/amp	1/22/1998 correction %	corr factor	1/22/1998 calibration spec rad/amp	Diode Current (nA) Aperture set for 1 nA at 700 nm
400	2.78E+06	3.3	1.033	2.87E+06	0.027
450	2.02E+06	2.5	1.025	2.07E+06	0.100
500	1.18E+06	0.7	1.007	1.19E+06	0.331
550	1.28E+06	1.3	1.013	1.30E+06	0.471
600	1.10E+06	2	1.02	1.12E+06	0.737
650	9.49E+05	1.3	1.013	9.61E+05	1.004
700	1.09E+06	1.5	1.015	1.11E+06	1.000
750	9.79E+05	-0.1	0.999	9.78E+05	1.195
800	8.98E+05	-1.7	0.983	8.83E+05	1.311
850	1.19E+06	-1.5	0.985	1.17E+06	0.974
900	1.44E+06	-2.8	0.972	1.40E+06	0.776
950	2.62E+06	-3.2	0.968	2.54E+06	0.402
1000	6.40E+06	-2.7	0.973	6.23E+06	0.164
1050	1.47E+07	-1.5	0.985	1.45E+07	0.070

NOTE: spectral radiance = watts/m^2/sr/nm
amps are dark corrected radiometer amps

Spectral Radiance

April 8, 1998

-30° C

Filter	Diode Current	Spectral Radiance at 700 nm
	nA	W m^{-2} sr^{-1} nm^{-1}
OpNav	0.994	1.103×10^{-3}
NH2	4.00	4.440×10^{-3}
Oxygen	4.00	4.440×10^{-3}
C2	18.00	19.98×10^{-3}
Yellow	18.00	19.98×10^{-3}
Red	18.00	19.98×10^{-3}
NIR	18.00	19.98×10^{-3}
HiRes	0.981	1.089×10^{-3}

Spectral Radiance

April 9, 1998

-40° C

Filter	Diode Current	Spectral Radiance at 700 nm
	nA	W m^{-2} sr^{-1} nm^{-1}
OpNav	0.777	0.862×10^{-3}
NH2	3.745	4.157×10^{-3}
Oxygen	3.771	4.186×10^{-3}
C2 Uncomp.	16.896	18.75×10^{-3}
C2 Comp.	16.795	18.64×10^{-3}
Yellow Uncomp.	17.184	19.07×10^{-3}
Yellow Comp.	17.293	19.20×10^{-3}
Red	8.754	9.717×10^{-3}
NIR	18.164	20.16×10^{-3}
HiRes	0.920	1.021×10^{-3}

Spectral Radiance

April 10, 1998

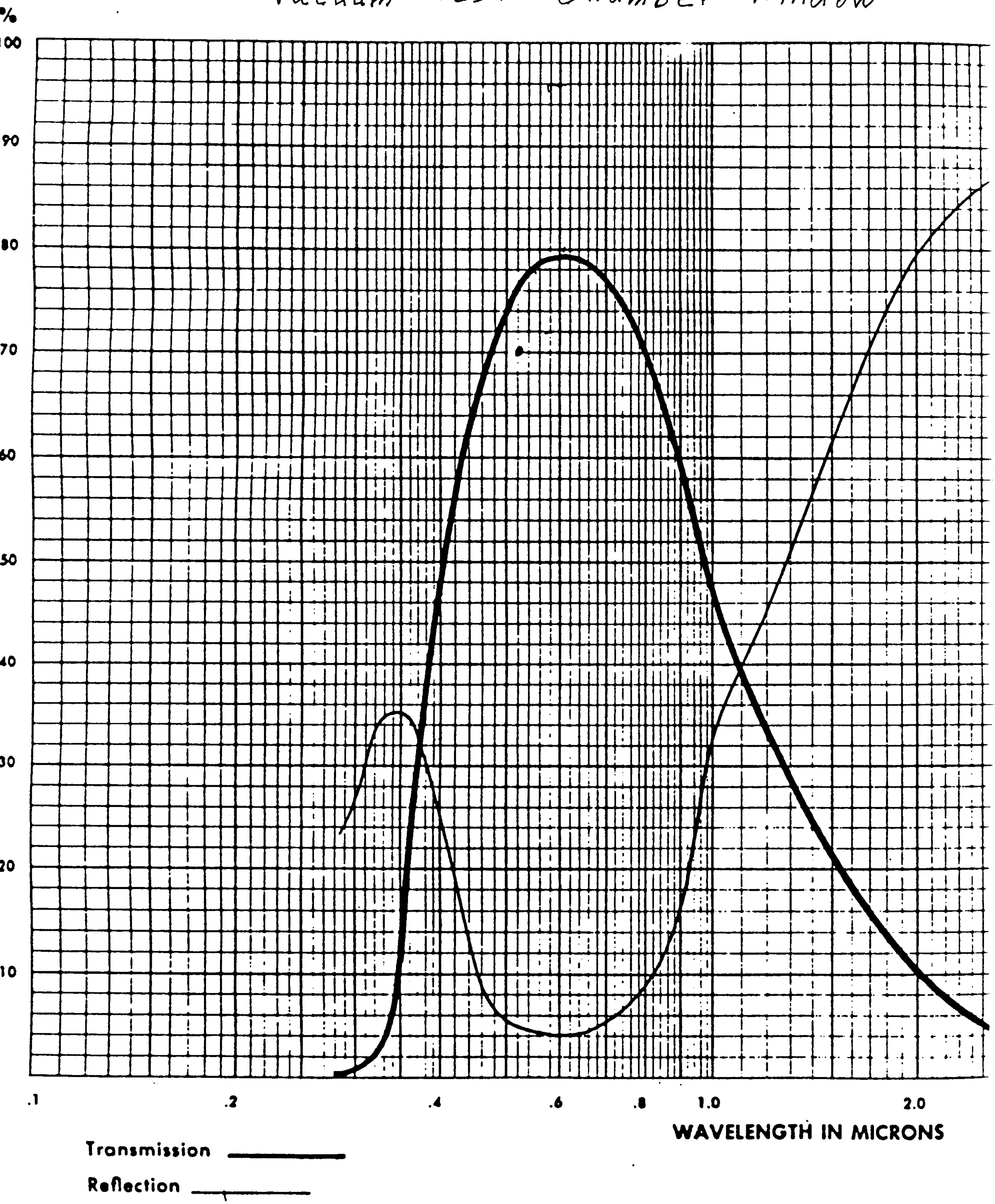
-50° C

Filter	Diode Current	Spectral Radiance at 700 nm
	nA	W m^{-2} sr^{-1} nm^{-1}
OpNav	0.7761	0.861×10^{-3}
NH2	3.745	4.157×10^{-3}
Oxygen	3.751	4.164×10^{-3}
C2 Uncomp.	16.794	18.64×10^{-3}
C2 Comp.	16.807	18.66×10^{-3}
Yellow Uncomp.	17.184	19.07×10^{-3}
Yellow Comp.	17.2	19.09×10^{-3}
Red	8.0	8.88×10^{-3}
NIR	18.164	20.16×10^{-3}
HiRes	0.910	1.010×10^{-3}

APPENDIX VII.

This appendix shows the transmission and reflection curves for the coating of the window of the vacuum chamber in which all calibration runs were carried out, a necessary component for absolute calibration. It was coated with an infrared reflection coating to keep unwanted energy OUT of the chamber. These numbers may not include the transmission of the glass itself, which should be well above 90%.

Vacuum Test Chamber Window



APPENDIX VIII.

Sample Calculation - Radiance to dn

This appendix presents a sample calculation of the dn level anticipated for a 45 ms exposure through the OpNav filter at a temperature of -30°C. The calculated value is 1% high. Since not all of the figures used were those for the actual flight hardware, this discrepancy is not surprising.

Recipe for a Calculation

Pick a filter and a temperature. Example,OpNav at -30ºC

In Appendix VI find the spectral radiance at 700nm for this case, 1.103 x 10^{3}

For other wavelengths, multiply the 700 nm value found above by the numbers in the final column of the page in Appendix VI headed "Radiometric Calibration of the Integrating Sphere." These products are the values of L_e to be used in the equation on the next page.

In the calculation table on the page following the equation, the second column, headed "Flux per pixel," is the product of the first three terms in the equation and the focal ratio term. The other terms are as labeled.

The "bias" is an electronically set background that should not be confused with dark current. Since the STARDUST drift rate is about one pixel per second, there is no point to attempting exposures longer than one second for scientific use. The dark current is roughly 10 electrons or ½ dn per second, which is "lost in the noise" so to speak. Bias is the zero exposure background and must always be subtracted. Dark current is ignored in all calculations.

Conversion from Calibration Absolute Flux to dn for a Pixel

$$dn = \frac{p}{4} L_e A_d \frac{T_h V_h}{(f/\#)^2} \left(\frac{l}{hc}\right) E D_e \Delta l + b(T) - 1$$

where:

- dn is the measured camera pixel dn (from 0 to 4095)
- L_e is the integrating sphere radiance in W m^{-2} sr^{-1} (appendix V)
- A_d is the area of one pixel in m^2 (144 x 10^{-12})
- f/# is the lens focal ratio (3.5)
- ?/hc is the photon energy at wavelength ? (Ws $photon^{-1}$)
  h being Planck's constant & c the speed of light
- ?? is the wavelength interval used in the calculation
- V_h is the transmission of the vacuum chamber window at ? (appendix VII)
- T_h is the system thruput [filter transmission (appendix I) x lens transmission x CCD quantum efficiency (electrons per photon) x scan mirror reflectivity (all in appendix II)] at wavelength ?
- E is the exposure time (s)
- D_e is the dn per electron ratio (set at 0.05)
- b(T) is the bias level at temperature T

The subtracted "one" simply converts to the usual low dn value of zero instead of one.

For compressed files, the dn calculated from the formula above, BEFORE the b(T)-1 term is added, must be entered into the compression look-up table in Appendix III to obtain the dn value expected. THEN the b(T)-1 term can be added, using the b(T) value measured for a compressed file, of course.

Please note that this equation is appropriate for use only with an infinite Lambert plane surface as the radiance source, such as was provided for this calibration by the large integrating sphere.

Sample Calculation
Nav Filter
-30 C

Filter central	**Flux**	**Photon**	**System**	**Window**	**Exposure**	D l	**Photons**
wavelength	**per pixel**	**Energy**	**Thruput**	**Thruput**			**per pixel**
nm	**Watts**	**Ws/photon**	**T_h**	**V_h**	**s**	**nm**	
400	7.153E-16		0.0000				
450	1.908E-15		0.0000				
500	3.610E-15	3.976E-19	0.0725	0.750	0.045	50	1111
550	5.610E-15	3.615E-19	0.1421	0.780	0.045	50	3871
600	7.592E-15	3.313E-19	0.1657	0.795	0.045	50	6791
650	8.854E-15	3.058E-19	0.1642	0.790	0.045	50	8449
700	1.015E-14	2.840E-19	0.1467	0.770	0.045	50	9086
750	1.072E-14	2.651E-19	0.1193	0.737	0.045	50	8004
800	1.062E-14	2.485E-19	0.0642	0.700	0.045	50	4321
850	1.048E-14	2.339E-19	0.0241	0.655	0.045	50	1591
900	9.963E-15	2.209E-19	0.0098	0.590	0.045	50	587
950	9.355E-15		0.0000				
1000	9.384E-15		0.0000				
1050	9.311E-15		0.0000				
					Total	photons	43811
					Total	dn *	2191
				Total dn expected (including 413 dn of bias)			**2604**
					* using 20 photons per dn		
			Measured in the calibration lab			dn	**2584**

APPENDIX IX.

Calibration Files in Archive

A short summary of the calibration files will be found in this appendix. For each filter, temperature, and camera setting (calibration lamp on or off, compressed or uncompressed, and exposure), the number of exposures is given.

STARDUST Camera
Calibration Files

FILTER	Nav Filter (#0)				HiRes Filter (#7)			
	lamp off	lamp off	lamp on	lamp on	lamp off	lamp off	lamp on	lamp on
	uncompressed	compressed	uncompressed	compressed	uncompressed	compressed	uncompressed	compressed
Temperature								
		Exposures (s) - #				Exposures (s) - #		
-30° C	.070 - 3		.020 - 12	.020 - 10	.110 - 4	.080 - 4	.250 - 6	.250 - 5
	.045 - 3		bias - 4	bias - 6	.080 - 4	.050 - 4	bias - 3	bias - 3
	.025 - 3				.050 - 4	.020 - 6		
	.010 - 3				.020 - 4	.005 - 6		
	bias - 4				.005 - 6	bias - 4		
					bias - 4			
-40° C	.070 - 4	.070 - 4		.020 - 11	.110 - 4	.110 - 4	.250 - 5	.250 - 6
	.045 - 4	.045 - 4			.080 - 4	.080 - 4	bias - 3	bias - 4
	.025 - 4	.025 - 6			.050 - 4	.050 - 4		
	.010 - 6	.010 - 8			.020 - 4	.020 - 4		
	bias - 4	bias - 5			.005 - 6	.005 - 9		
					bias - 3	bias - 5		
-50° C	.070 - 4		.020 - 6		.110 - 4	.110 - 4	.250 - 4	.250 - 6
	.045 - 4		bias - 2		.080 - 4	.080 - 4	bias - 3	bias - 4
	.025 - 4				.050 - 4	.050 - 4		
	.010 - 4				.020 - 7	.020 - 6		
	bias - 4				.005 - 6	.005 - 8		
					bias - 4	bias - 4		

STARDUST Camera
Calibration Files

FILTER		IR Filter (#6)					Red Filter (#5)			
		lamp off	lamp off	lamp on	lamp on		lamp off	lamp off	lamp on	lamp on
		uncompressed	compressed	uncompressed	compressed		uncompressed	compressed	uncompressed	compressed
Temperature										
			Exposures (s) - #					Exposures (s) - #		
-30° C		.160 - 4	.160 - 4	.100 - 6	.100 - 6		.270 - 4	.270 - 4	2.0 - 3	1.5 - 3
		.120 - 4	.120 - 4	bias - 3	bias - 3		.190 - 4	.190 - 4	bias - 3	bias - 3
		.070 - 4	.070 - 4				.110 - 4	.110 - 4		
		.025 - 4	.025 - 4				.035 - 4	.035 - 3		
		bias - 4	bias - 4				bias - 4	bias - 4		
-40° C		.160 - 4	.160 - 4	.100 - 6	,100 - 6		.270 - 4	.270 - 4	2.0 - 3	1.5 - 3
		.120 - 4	.120 - 4	bias - 3	bias - 3		.190 - 4	.190 - 4	bias - 3	bias - 3
		.070 - 4	.070 - 4				.110 - 4	.110 - 4		
		.025 - 4	.025 - 4				.035 - 4	.035 - 4		
		bias - 4	bias - 4				bias - 4	bias - 4		
-50° C		.160 - 4	.160 - 4	.100 - 4	.100 - 4		.270 - 4	.270 - 4	2.0 - 3	1.5 - 3
		.120 - 5	.120 - 4	bias - 3	bias - 3		.190 - 4	.190 - 4	bias - 3	bias - 3
		.070 - 4	.070 - 4				.110 - 4	.110 - 4		
		.025 - 4	.025 - 4				.035 - 4	.035 - 4		
		bias - 2	bias - 2				bias - 2	bias - 2		

STARDUST Camera
Calibration Files

FILTER	Yellow Filter (#4)				C_2 (&blue) Filter (#3)			
	lamp off	lamp off	lamp on	lamp on	lamp off	lamp off	lamp on	lamp on
	uncompressed	compressed	uncompressed	compressed	uncompressed	compressed	uncompressed	compressed
Temperature								
		Exposures (s) - #				Exposures (s) - #		
-30° C	.400 - 4	.400 - 4	20 - 3	20 - 3	.360 - 4	.360 - 4	20 - 3	20 - 3
	.280 - 4	.280 - 4			.260 - 4	.260 - 4	bias - 3	bias - 3
	.175 - 4	.175 - 4			.150 - 4	.150 - 4		
	.055 - 4	.055 - 3			.050 - 4	.050 - 4		
	bias - 4	bias - 4			bias - 8	bias - 4		
-40° C	.400 - 4	.400 - 4	20 - 4	20 - 3	.360 - 5	.360 - 4	20 - 3	20 - 3
	.280 - 4	.280 - 4			.260 - 4	.260 - 4	bias - 3	bias - 3
	.175 - 4	.175 - 4			.150 - 4	.150 - 4		
	.055 - 4	.055 - 4			.050 - 4	.050 - 4		
	bias - 4	bias - 4			bias - 4	bias - 4		
-50° C	.400 - 4	.400 - 4	20 - 3	20 - 3	.360 - 4	.360 - 4	20 - 3	20 - 3
	.280 - 4	.280 - 4	bias - 3	bias - 4	.260 - 4	.260 - 4	bias - 3	bias - 3
	.175 - 4	.175 - 4			.150 - 4	.150 - 4		
	.055 - 4	.055 - 4			.050 - 4	.050 - 4		
	bias - 2	bias - 2			bias - 2	bias - 2		

STARDUST Camera
Calibration Files

FILTER			O[^{1}D] Filter (#2)					NH$_2$ Filter (#1)		
		lamp off	lamp off	lamp on	lamp on		lamp off	lamp off	lamp on	lamp on
		uncompressed	compressed	uncompressed	compressed		uncompressed	compressed	uncompressed	compressed
Temperature										
			Exposures (s) - #					Exposures (s) - #		
-30° C		.320 - 4	.320 - 4	2.3 - 4	2.3 - 4		.250 - 4	.250 - 4	1.5 - 4	1.5 - 4
		.225 - 4	.225 - 4	bias - 3	bias - 3		.180 - 4	.180 - 4	bias - 3	bias - 3
		.130 - 4	.130 - 4				.100 - 4	.100 - 4		
		.040 - 3	.040 - 4				.030 - 4	.030 - 4		
		bias - 4	bias - 3				bias - 3			
-40° C		.320 - 4	.320 - 4	2.3 - 4	2.3 - 4		.250 - 3	.250 - 4	1.5 - 4	1.5 - 4
		.225 - 4	.225 - 4	bias - 3	bias - 3		.180 - 4	.180 - 4	bias - 3	bias - 3
		.130 - 4	.130 - 4				.100 - 4	.100 - 4		
		.040 - 4	.040 - 4				.030 - 4	.030 - 4		
		bias - 4	bias - 4				bias - 3			
-50° C		.320 - 4	.320 - 4	2.3 - 4	2.3 - 4		.250 - 3	.250 - 3	1.5 - 4	1.5 - 4
		.225 - 4	.225 - 4	bias - 4	bias - 4		.180 - 4	.180 - 4	bias - 3	bias - 3
		.130 - 4	.130 - 4				.100 - 4	.100 - 4		
		.040 - 4	.040 - 4				.030 - 4	.030 - 4		
		bias - 2	bias - 2				bias - 2	bias - 3		

APPENDIX X.

Camera Evaluation

by Justin Maki

Shortly after the calibration runs were completed, Justin Maki ran a preliminary evaluation of the calibration data base, checking CCD linearity (uncompressed), changes in behavior with temperature, and looking for bad pixels. This is his report.

Stardust Navigation Camera (NC)
Calibration Data Analysis

Justin Maki
Jet Propulsion Laboratory
Section 388, Image Processing Systems Group
16 June 1998

The following report summarizes the results of a quick-look (i.e., two day) analysis of the Stardust Navigation Camera (NC) calibration data.

Summary: The calibration data and preliminary analysis indicate that the camera is functioning nominally and that there are no signs of electronic or other hardware problems.

Analysis

A total of 1,341 images currently reside in the /project/stardust/ directory/database at MIPL.

Note: The raw binary files in /project/stardust contain 1024 x 1046 x 16 bit images (uncompressed images are 12 bits actual, compressed images are 8 bit actual). Of the 1046 rows, rows 0-2 contain DN values of zero. Row 3 contains seemingly spurious values (up a factor of 2 higher/lower than the average). For the analysis done here the first four rows (0-3) were ignored. Therefore, in this context a single "image" is comprised of 1024x1042 pixels.

Bias Frames

83 "zero second exposure" images are listed in table 1, along with the median, mean, standard deviations of the pixels in each image. In general, the statistics are reasonable, with the exception of images numbers 12 and 13, whose standard deviations are 2 times the average standard deviation. These two images each contain a faint "stripe" in the column direction, approximately 10 pixels wide and spanning the height of the image. Several other images around this time (Apr 08, 19:40) also contain this type of stripe.

Table 1. Images used for bias frame analysis.

#	filename	median (DN)	mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
1.	/project/stardust/Cal-980408a/csd9898-145928.pds	70	70.4374	0.881068	-30	on
2.	/project/stardust/Cal-980408a/csd9898-145941.pds	70	70.4326	0.880791	-30	on
3.	/project/stardust/Cal-980408a/csd9898-145953.pds	70	70.4278	0.881598	-30	on
4.	/project/stardust/Cal-980408a/csd9898-150005.pds	70	70.4249	0.881473	-30	on
5.	/project/stardust/Cal-980408a/csd9898-164034.pds	70	70.4363	0.892775	-30	on
6.	/project/stardust/Cal-980408a/csd9898-164048.pds	70	70.4296	0.894894	-30	on
7.	/project/stardust/Cal-980408b/csd9898-182303.pds	70	70.4313	0.893715	-30	on
8.	/project/stardust/Cal-980408b/csd9898-182315.pds	70	70.4238	0.893688	-30	on
9.	/project/stardust/Cal-980408b/csd9898-182327.pds	70	70.4147	0.893937	-30	on
10.	/project/stardust/Cal-980408b/csd9898-182339.pds	70	70.4134	0.898294	-30	on
11.	/project/stardust/Cal-980408c/csd9898-194303.pds	71	70.7066	0.865121	-30	on
12.	/project/stardust/Cal-980408c/csd9898-194318.pds	71	70.6881	1.88479	-30	on
13.	/project/stardust/Cal-980408c/csd9898-194341.pds	71	70.6645	1.85908	-30	on
14.	/project/stardust/Cal-980408c/csd9898-194511.pds	71	70.6000	0.878771	-30	on

#	filename	median (DN)	mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
15.	/project/stardust/Cal-980408c/csd9898-194604.pds	71	70.5761	0.864619	-30	on
16.	/project/stardust/Cal-980408c/csd9898-194619.pds	71	70.5656	0.863789	-30	on
17.	/project/stardust/Cal-980408c/csd9898-194634.pds	71	70.5596	0.864599	-30	on
18.	/project/stardust/Cal-980408c/csd9898-194647.pds	71	70.5536	0.864917	-30	on
19.	/project/stardust/Cal-980409b/csd9899-104150.pds	75	75.2275	0.781806	-40	on
20.	/project/stardust/Cal-980409b/csd9899-104212.pds	75	75.2123	0.780897	-40	on
21.	/project/stardust/Cal-980409b/csd9899-104227.pds	75	75.2010	0.778997	-40	on
22.	/project/stardust/Cal-980409b/csd9899-104242.pds	75	75.1953	0.77972	-40	on
23.	/project/stardust/Cal-980409b/csd9899-111913.pds	75	75.0189	0.776588	-40	on
24.	/project/stardust/Cal-980409b/csd9899-111932.pds	75	75.0196	0.775962	-40	on
25.	/project/stardust/Cal-980409b/csd9899-111950.pds	75	75.0199	0.776302	-40	on
26.	/project/stardust/Cal-980409b/csd9899-112007.pds	75	75.0219	0.776036	-40	on
27.	/project/stardust/Cal-980409b/csd9899-80118.pds	75	74.9729	0.769757	-40	on
28.	/project/stardust/Cal-980409b/csd9899-80139.pds	75	74.9719	0.769872	-40	on
29.	/project/stardust/Cal-980409b/csd9899-80205.pds	75	74.9719	0.769977	-40	on
30.	/project/stardust/Cal-980409b/csd9899-80223.pds	75	74.9702	0.769472	-40	on
31.	/project/stardust/Cal-980409d/csd9899-123436.pds	75	74.9732	0.776862	-40	on
32.	/project/stardust/Cal-980409d/csd9899-123455.pds	75	74.9727	0.777262	-40	on
33.	/project/stardust/Cal-980409d/csd9899-123511.pds	75	74.9702	0.775447	-40	on
34.	/project/stardust/Cal-980409d/csd9899-123530.pds	75	74.9709	0.776908	-40	on
35.	/project/stardust/Cal-980410a/csd98100-110928.pds	79	79.3885	0.733667	-50	on
36.	/project/stardust/Cal-980410a/csd98100-111000.pds	79	79.3833	0.732309	-50	on
37.	/project/stardust/Cal-980410a/csd98100-111021.pds	79	79.3758	0.732506	-50	on
38.	/project/stardust/Cal-980410a/csd98100-111037.pds	79	79.3730	0.730968	-50	on
39.	/project/stardust/Cal-980410a/csd98100-115911.pds	79	79.2656	0.728671	-50	on
40.	/project/stardust/Cal-980410a/csd98100-115938.pds	79	79.2645	0.726788	-50	on
41.	/project/stardust/Cal-980410c/csd98100-133709.pds	79	79.2788	0.730312	-50	on
42.	/project/stardust/Cal-980410c/csd98100-133756.pds	79	79.2763	0.730798	-50	on
43.	/project/stardust/Cal-980410d/csd98100-153352.pds	79	79.2637	0.738477	-50	on
44.	/project/stardust/Cal-980410d/csd98100-153433.pds	79	79.2605	0.738006	-50	on
45.	/project/stardust/Cal-980408a/usd9898-142427.pds	412	411.954	8.84636	-30	off
46.	/project/stardust/Cal-980408a/usd9898-142444.pds	412	411.923	8.84484	-30	off
47.	/project/stardust/Cal-980408a/usd9898-142502.pds	412	411.891	8.84829	-30	off
48.	/project/stardust/Cal-980408a/usd9898-142521.pds	412	411.861	8.84091	-30	off
49.	/project/stardust/Cal-980408a/usd9898-163452.pds	411	410.907	8.27586	-30	off
50.	/project/stardust/Cal-980408a/usd9898-163508.pds	411	410.85	8.29438	-30	off
51.	/project/stardust/Cal-980408b/usd9898-180328.pds	411	410.615	8.29372	-30	off
52.	/project/stardust/Cal-980408b/usd9898-180347.pds	411	410.597	8.29127	-30	off
53.	/project/stardust/Cal-980408b/usd9898-180406.pds	411	410.593	8.28615	-30	off
54.	/project/stardust/Cal-980408b/usd9898-180424.pds	411	410.577	8.29927	-30	off
55.	/project/stardust/Cal-980408c/usd9898-194115.pds	416	416.168	8.27182	-30	off

#	filename	median (DN)	mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
56.	/project/stardust/Cal-980408c/usd9898-194138.pds	415	415.163	8.36732	-30	off
57.	/project/stardust/Cal-980408c/usd9898-194156.pds	414	414.544	8.38860	-30	off
58.	/project/stardust/Cal-980408c/usd9898-194215.pds	414	414.046	8.40539	-30	off
59.	/project/stardust/Cal-980409b/usd9899-73531.pds	456	456.269	8.25097	-40	off
60.	/project/stardust/Cal-980409b/usd9899-73550.pds	456	456.241	8.24970	-40	off
61.	/project/stardust/Cal-980409b/usd9899-73610.pds	456	456.204	8.24774	-40	off
62.	/project/stardust/Cal-980409b/usd9899-73640.pds	456	456.215	8.25422	-40	off
63.	/project/stardust/Cal-980409c/usd9899-105356.pds	458	457.648	8.08925	-40	off
64.	/project/stardust/Cal-980409c/usd9899-105414.pds	457	457.607	8.09067	-40	off
65.	/project/stardust/Cal-980409c/usd9899-105448.pds	458	457.638	8.09456	-40	off
66.	/project/stardust/Cal-980409c/usd9899-113119.pds	457	456.758	8.12141	-40	off
67.	/project/stardust/Cal-980409c/usd9899-113149.pds	457	456.605	8.11432	-40	off
68.	/project/stardust/Cal-980409c/usd9899-113211.pds	457	456.578	8.12331	-40	off
69.	/project/stardust/Cal-980409c/usd9899-113232.pds	457	456.569	8.12293	-40	off
70.	/project/stardust/Cal-980409d/usd9899-123259.pds	456	455.99	8.12424	-40	off
71.	/project/stardust/Cal-980409d/usd9899-123319.pds	456	456.008	8.11287	-40	off
72.	/project/stardust/Cal-980409d/usd9899-123339.pds	456	456.008	8.11457	-40	off
73.	/project/stardust/Cal-980409d/usd9899-123400.pds	456	455.975	8.10129	-40	off
74.	/project/stardust/Cal-980410a/usd98100-104250.pds	502	502.019	7.54089	-50	off
75.	/project/stardust/Cal-980410a/usd98100-104326.pds	502	501.951	7.54673	-50	off
76.	/project/stardust/Cal-980410a/usd98100-104358.pds	502	501.963	7.54845	-50	off
77.	/project/stardust/Cal-980410a/usd98100-104420.pds	502	501.944	7.54348	-50	off
78.	/project/stardust/Cal-980410a/usd98100-115820.pds	502	501.71	7.56945	-50	off
79.	/project/stardust/Cal-980410a/usd98100-115841.pds	502	501.618	7.55824	-50	off
80.	/project/stardust/Cal-980410c/usd98100-133614.pds	502	501.874	7.59743	-50	off
81.	/project/stardust/Cal-980410c/usd98100-133636.pds	502	501.864	7.60950	-50	off
82.	/project/stardust/Cal-980410d/usd98100-153209.pds	502	501.704	7.51723	-50	off
83.	/project/stardust/Cal-980410d/usd98100-153237.pds	502	501.668	7.50522	-50	off

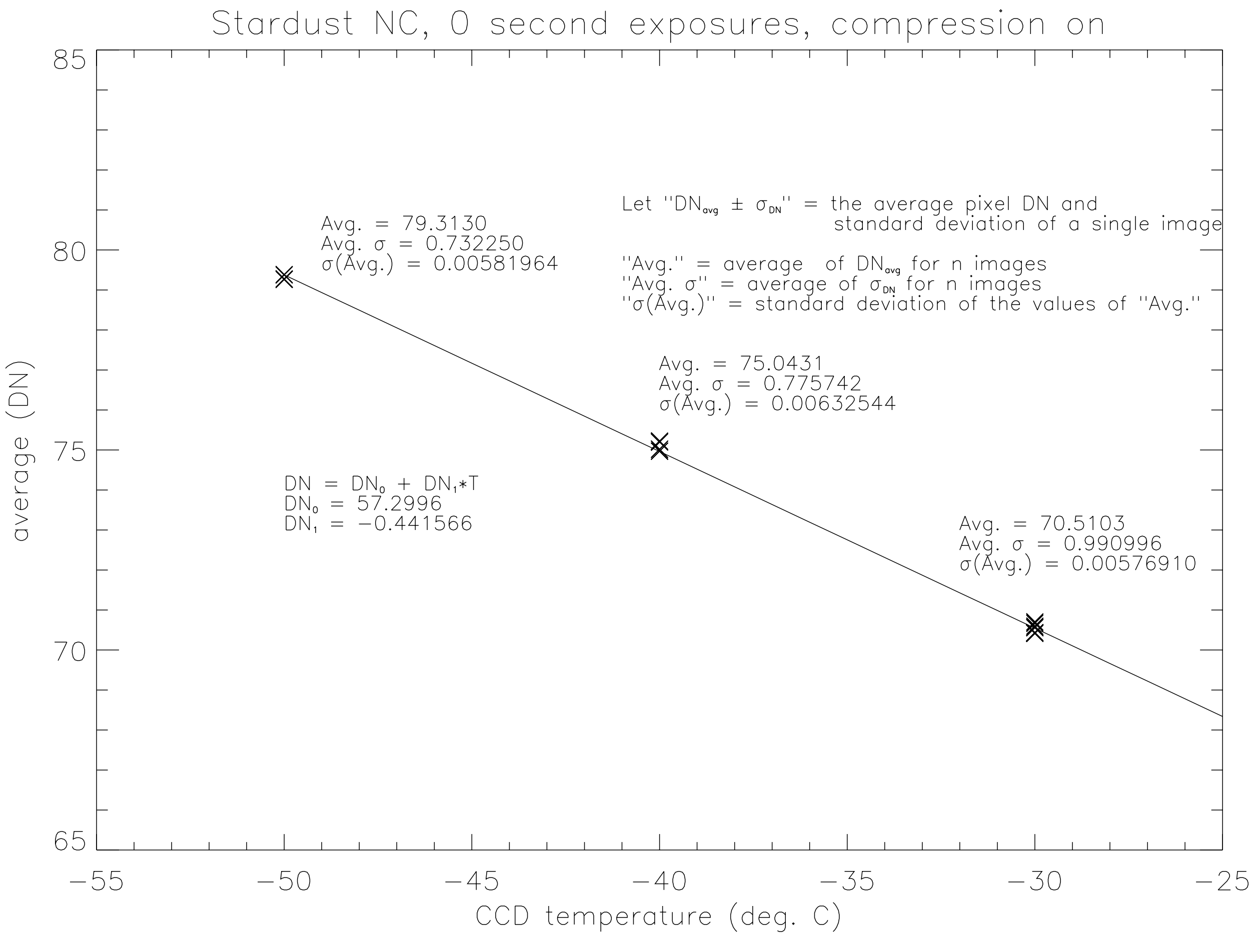


Figure 1. Average bias DN values vs. temperature, compression on.

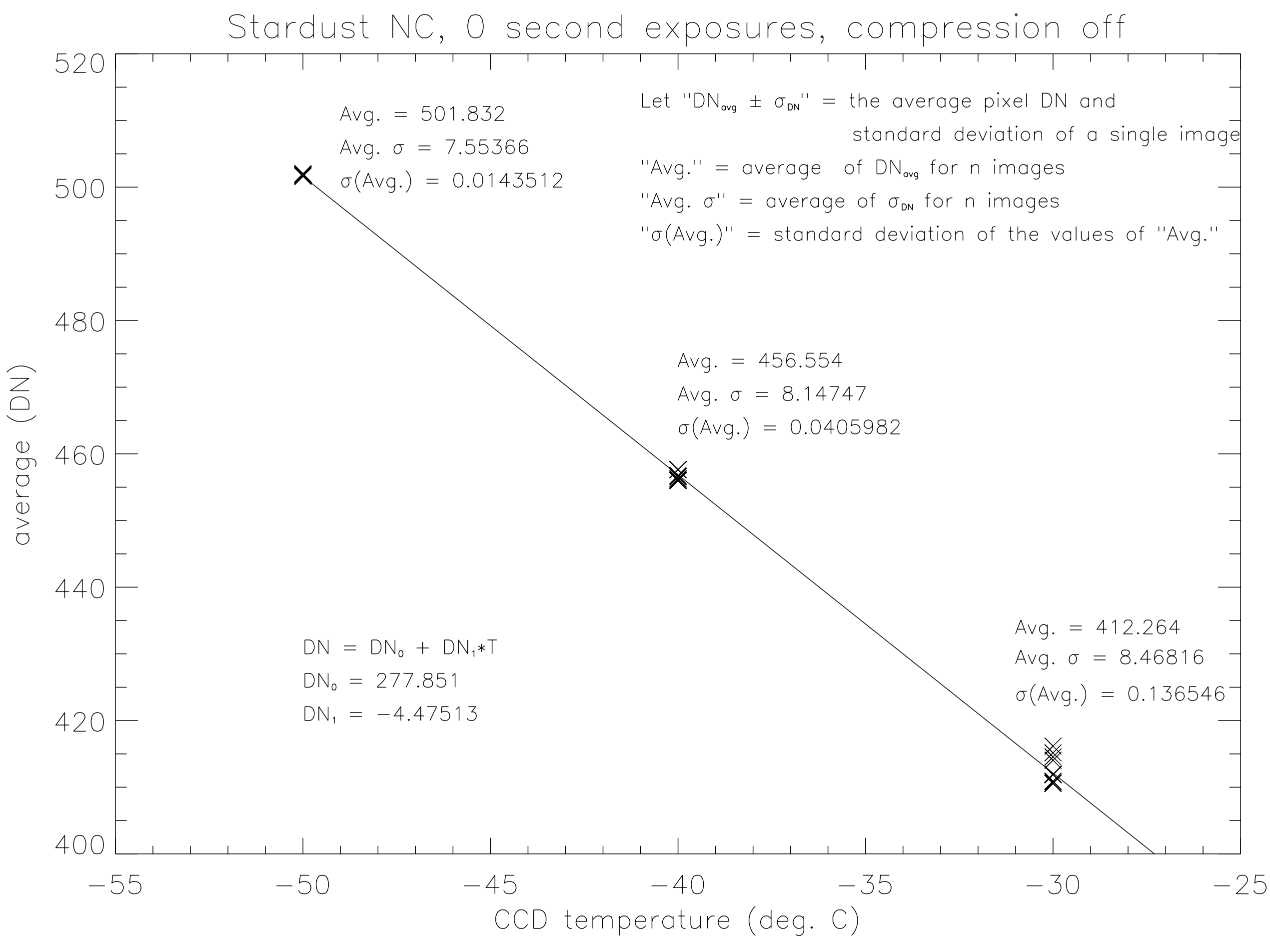


Figure 2. Average bias DN values vs. temperature, compression off.

Spurious Pixels in Bias Frames

A "spurious" pixel is defined as a pixel with a DN value that is more than 3σ from the mean of an image. In the below, the images at each temperature were averaged together to form an average image. Pixels in this average image that lie more than 3σ from the average value of the average image were flagged as spurious and are listed in table 2. Note that most of the spurious pixels lie on the edge of the detector. The non-edge pixels flagged as spurious are not correlated among the temperature sets and are probably due to random events (cosmic rays?).

Table 2a-f. Spurious Pixels

Table 2.a. CCD T = -30°C, compression on

Average DN = 71.1
σ = 1.10

X pixel location	Y pixel location	DN value	sigma from average
0	0	89	16.2702
0	1	82	9.91212
0	2	80	8.09554
0	3	79	7.18724
0	4	78	6.27895
0	5	78	6.27895
0	6	76	4.46236

Table 2.b. CCD T = -30°C, compression off

Average DN = 414.6
σ = 3.60

X pixel location	Y pixel location	DN value	sigma from average
0	0	512	27.086
0	1	499	23.4726
0	2	495	22.3607
0	3	491	21.2489
0	4	472	15.9677
0	5	457	11.7983
0	6	443	7.9069
42	3	400	-4.04531

Table 2.c. CCD T=-40°C, compression on

Average DN = 74.5
σ = 0.50

X pixel location	Y pixel location	DN value	sigma from average
0	0	93	36.9453
0	1	89	28.956
0	2	85	20.9667

0	3	84	18.9693
0	4	83	16.972
0	5	81	12.9773
0	6	80	10.98
0	7	78	6.98535
0	8	77	4.98801
612	1	73	-3.00132
948	1	73	-3.00132
959	1	73	-3.00132

Table 2.d. CCD T=-40°C, compression off

Average DN = 452.5

σ = 4.22

X pixel location	Y pixel location	DN value	sigma from average
0	0	569	27.6379
0	1	550	23.1322
0	2	541	20.9979
0	3	528	17.9151
0	4	508	13.1723
0	5	495	10.0894
0	6	482	7.00658
0	7	470	4.16088
111	301	466	3.21231
357	379	466	3.21231
55	381	466	3.21231
395	466	466	3.21231
984	474	466	3.21231
116	666	466	3.21231
626	797	466	3.21231

Table 2.e. CCD T=-50°C, compression on

Average DN = 79.7

σ = 0.84

X pixel location	Y pixel location	DN value	sigma from average
0	0	92	14.6111
0	1	89	11.0334
0	2	84	5.07043
0	3	84	5.07043
0	4	83	3.87784

Table 2.f. CCD T=-50°C, compression off

Average DN = 505.8

σ = 5.01

X pixel location	Y pixel location	DN value	sigma from average

0	0	552	9.22671
0	1	556	10.0251
0	2	542	7.23084
0	3	536	6.03332
0	4	525	3.83787
171	675	525	3.83787
109	480	490	-3.14765
526	891	490	-3.14765

Images showing spurious pixels (2.5 σ) can be viewed on the web at

http://rushmore.JPL.NASA.GOV/~jnm/stardust/calibration/spurious_pixels/

Linearity

The NC uncompressed images exhibit a linear relationship between the input radiant energy and the output DN (see figures below).

The NC compressed images *do not* exhibit a linear relationship between the input radiant energy and the output DN (see figures below).

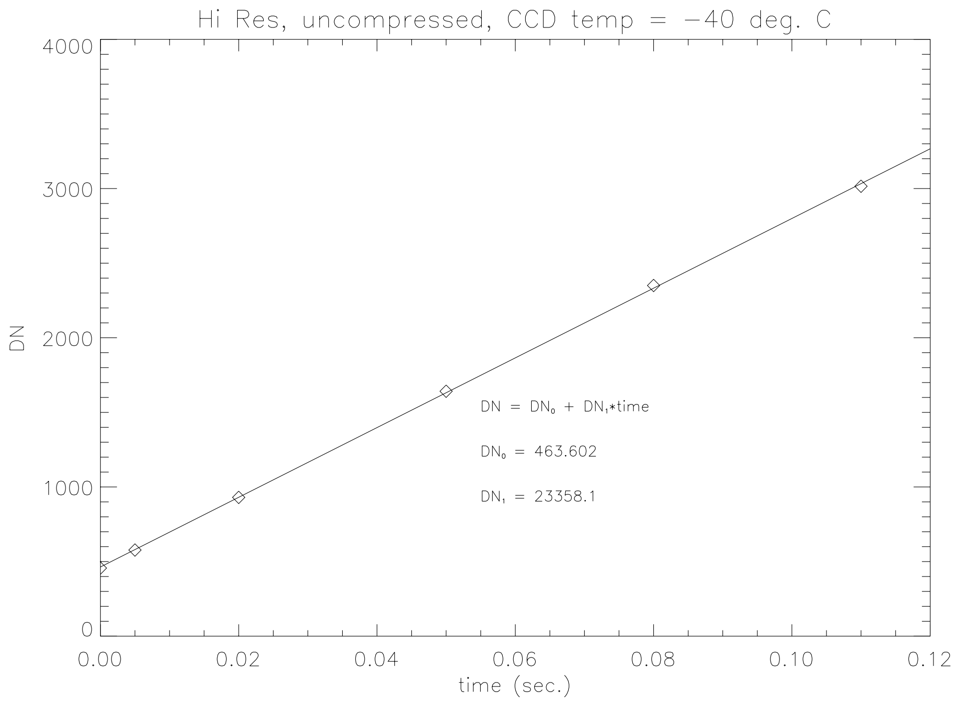
Listed below are the 81 images used in the CCD linearity analysis:

Table 3. List of images used for linearity analysis

#	Filename	Median (DN)	Mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
1.	/project/stardust/Cal-980409b/usd9899-71201.pds	3104	3031.67	358.502	-40	off
2.	/project/stardust/Cal-980409b/usd9899-71351.pds	2131	2087.9	241.31	-40	off
3.	/project/stardust/Cal-980409b/usd9899-71654.pds	1425	1403	171.74	-40	off
4.	/project/stardust/Cal-980409b/usd9899-73201.pds	849	840.181	71.3299	-40	off
5.	/project/stardust/Cal-980409b/usd9899-73531.pds	456	456.269	8.25097	-40	off
6.	/project/stardust/Cal-980409b/csd9899-74257.pds	222	218.837	19.4487	-40	on
7.	/project/stardust/Cal-980409b/csd9899-74512.pds	182	179.872	14.5301	-40	on
8.	/project/stardust/Cal-980409b/csd9899-74622.pds	144	142.088	10.2578	-40	on
9.	/project/stardust/Cal-980409b/csd9899-75000.pds	107	106.617	5.191	-40	on
10.	/project/stardust/Cal-980409b/csd9899-75921.pds	75	74.9855	0.76966	-40	on
11.	/project/stardust/Cal-980409b/usd9899-81533.pds	3086	3015.55	356.046	-40	off
12.	/project/stardust/Cal-980409b/usd9899-81739.pds	2400	2350.21	272.281	-40	off
13.	/project/stardust/Cal-980409b/usd9899-81916.pds	1670	1641.66	195.632	-40	off
14.	/project/stardust/Cal-980409b/usd9899-82250.pds	940	930.278	90.434	-40	off
15.	/project/stardust/Cal-980409b/usd9899-82444.pds	580	577.331	25.3821	-40	off
16.	/project/stardust/Cal-980409b/usd9899-82721.pds	456	456.487	8.25492	-40	off
17.	/project/stardust/Cal-980409b/csd9899-82910.pds	221	217.532	19.2474	-40	on
18.	/project/stardust/Cal-980409b/csd9899-83042.pds	191	188.614	15.5646	-40	on
19.	/project/stardust/Cal-980409b/csd9899-83201.pds	157	155.291	11.7114	-40	on
20.	/project/stardust/Cal-980409b/csd9899-83349.pds	114	113.363	6.22288	-40	on
21.	/project/stardust/Cal-980409b/csd9899-83552.pds	86	86.1759	2.19447	-40	on
22.	/project/stardust/Cal-980409b/csd9899-104150.pds	75	75.2275	0.781806	-40	on
23.	/project/stardust/Cal-980409c/usd9899-104712.pds	3108	3035.53	359.736	-40	off
24.	/project/stardust/Cal-980409c/usd9899-104831.pds	2387	2336.88	270.917	-40	off
25.	/project/stardust/Cal-980409c/usd9899-105022.pds	1508	1484.69	180.674	-40	off
26.	/project/stardust/Cal-980409c/usd9899-105219.pds	777	771.337	58.0342	-40	off
27.	/project/stardust/Cal-980409c/usd9899-105356.pds	458	457.648	8.08925	-40	off
28.	/project/stardust/Cal-980409b/csd9899-110137.pds	221	217.726	19.281	-40	on
29.	/project/stardust/Cal-980409b/csd9899-105953.pds	191	188.179	15.5335	-40	on

#	Filename	Median (DN)	Mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
30.	/project/stardust/Cal-980409b/csd9899-105721.pds	150	147.928	10.8773	-40	on
31.	/project/stardust/Cal-980409b/csd9899-105616.pds	101	100.255	4.16876	-40	on
32.	/project/stardust/Cal-980409c/usd9899-110406.pds	3165	3093.05	365.426	-40	off
33.	/project/stardust/Cal-980409c/usd9899-110551.pds	2361	2312.72	266.677	-40	off
34.	/project/stardust/Cal-980409c/usd9899-110748.pds	1558	1533.7	185.138	-40	off
35.	/project/stardust/Cal-980409c/usd9899-110918.pds	793	787.283	61.952	-40	off
36.	/project/stardust/Cal-980409c/usd9899-111131.pds	457	457.004	8.0811	-40	off
37.	/project/stardust/Cal-980409b/csd9899-111740.pds	222	218.843	19.3962	-40	on
38.	/project/stardust/Cal-980409b/csd9899-111625.pds	190	187.25	15.3876	-40	on
39.	/project/stardust/Cal-980409b/csd9899-111442.pds	151	149.564	11.0579	-40	on
40.	/project/stardust/Cal-980409b/csd9899-111326.pds	104	103.077	4.62973	-40	on
41.	/project/stardust/Cal-980409b/csd9899-111913.pds	75	75.0189	0.776588	-40	on
42.	/project/stardust/Cal-980409c/usd9899-112415.pds	3120	3048.76	363.584	-40	off
43.	/project/stardust/Cal-980409c/usd9899-112631.pds	2363	2314.02	269.034	-40	off
44.	/project/stardust/Cal-980409c/usd9899-112822.pds	1551	1525.74	185.769	-40	off
45.	/project/stardust/Cal-980409c/usd9899-113032.pds	811	805.391	75.9337	-40	off
46.	/project/stardust/Cal-980409c/usd9899-113119.pds	457	456.758	8.12141	-40	off
47.	/project/stardust/Cal-980409b/csd9899-113935.pds	220	216.318	19.136	-40	on
48.	/project/stardust/Cal-980409b/csd9899-113746.pds	190	187.092	15.4169	-40	on
49.	/project/stardust/Cal-980409b/csd9899-113611.pds	151	149.067	11.0431	-40	on
50.	/project/stardust/Cal-980409b/csd9899-113448.pds	105	104.252	5.23804	-40	on
51.	/project/stardust/Cal-980409b/csd9899-113258.pds	75	75.0137	0.777159	-40	on
52.	/project/stardust/Cal-980409d/usd9899-114945.pds	3089	3017.79	361.596	-40	off
53.	/project/stardust/Cal-980409d/usd9899-115135.pds	2422	2371.97	278.202	-40	off
54.	/project/stardust/Cal-980409d/usd9899-115303.pds	1590	1563.71	185.481	-40	off
55.	/project/stardust/Cal-980409d/usd9899-115433.pds	839	831.512	63.5786	-40	off
56.	/project/stardust/Cal-980409d/usd9899-115605.pds	456	456.543	8.1334	-40	off
57.	/project/stardust/Cal-980409d/csd9899-120234.pds	219	215.916	19.1923	-40	on
58.	/project/stardust/Cal-980409d/csd9899-120126.pds	192	189.472	15.846	-40	on
59.	/project/stardust/Cal-980409d/csd9899-120015.pds	153	151.121	11.2318	-40	on
60.	/project/stardust/Cal-980409d/csd9899-115903.pds	107	106.213	4.85831	-40	on
61.	/project/stardust/Cal-980409d/csd9899-115736.pds	75	71.7004	15.4329	-40	on
62.	/project/stardust/Cal-980409d/usd9899-120804.pds	3112	3040.46	359.076	-40	off
63.	/project/stardust/Cal-980409d/usd9899-120934.pds	2326	2278.28	263.028	-40	off
64.	/project/stardust/Cal-980409d/usd9899-121102.pds	1624	1597.91	191.156	-40	off
65.	/project/stardust/Cal-980409d/usd9899-121230.pds	822	815.394	68.8096	-40	off
66.	/project/stardust/Cal-980409d/usd9899-121433.pds	456	456.287	8.12793	-40	off
67.	/project/stardust/Cal-980409d/csd9899-122045.pds	221	217.187	19.1217	-40	on
68.	/project/stardust/Cal-980409d/csd9899-121931.pds	188	185.306	15.1756	-40	on
69.	/project/stardust/Cal-980409d/csd9899-121818.pds	155	152.825	11.4105	-40	on

#	Filename	Median (DN)	Mean (DN)	standard deviation (DN)	CCD temperature (°C)	compression (on/off)
70.	/project/stardust/Cal-980409d/csd9899-121706.pds	105	104.853	4.94937	-40	on
71.	/project/stardust/Cal-980409d/csd9899-121558.pds	75	74.9854	0.776735	-40	on
72.	/project/stardust/Cal-980409d/usd9899-122706.pds	3151	3077.04	366.086	-40	off
73.	/project/stardust/Cal-980409d/usd9899-122834.pds	2352	2302.79	267.424	-40	off
74.	/project/stardust/Cal-980409d/usd9899-123003.pds	1559	1533.63	185.533	-40	off
75.	/project/stardust/Cal-980409d/usd9899-123130.pds	806	798.862	62.0967	-40	off
76.	/project/stardust/Cal-980409d/usd9899-123259.pds	456	455.99	8.12424	-40	off
77.	/project/stardust/Cal-980409d/csd9899-123932.pds	222	217.976	19.3897	-40	on
78.	/project/stardust/Cal-980409d/csd9899-123821.pds	189	186.511	15.4129	-40	on
79.	/project/stardust/Cal-980409d/csd9899-123705.pds	151	149.178	11.0679	-40	on
80.	/project/stardust/Cal-980409d/csd9899-123554.pds	104	103.677	4.63885	-40	on
81.	/project/stardust/Cal-980409d/csd9899-123455.pds	75	74.9727	0.777262	-40	on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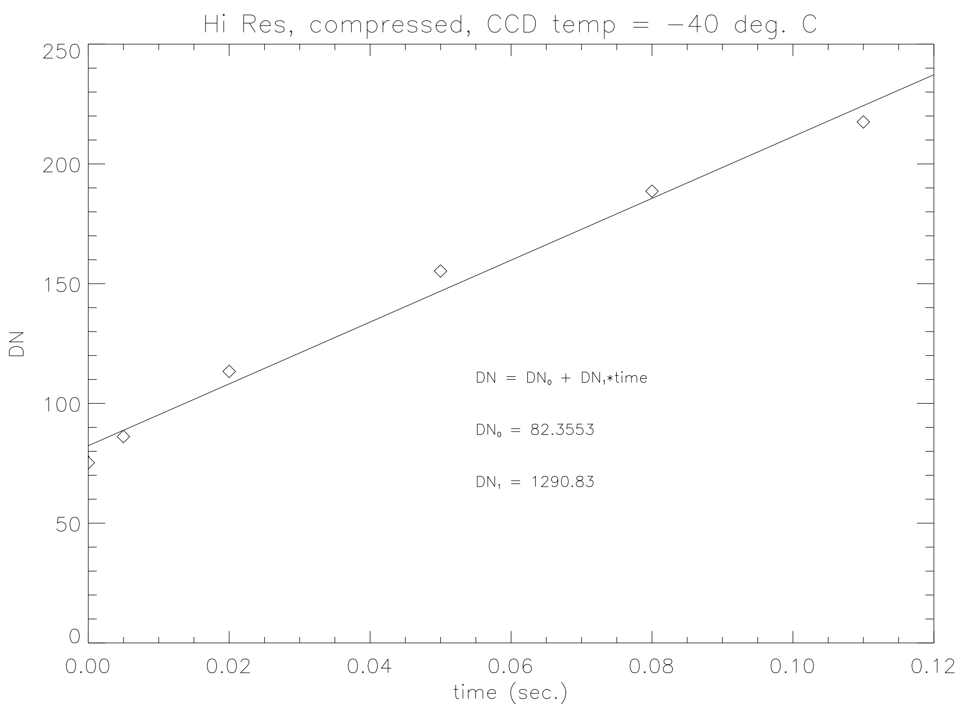
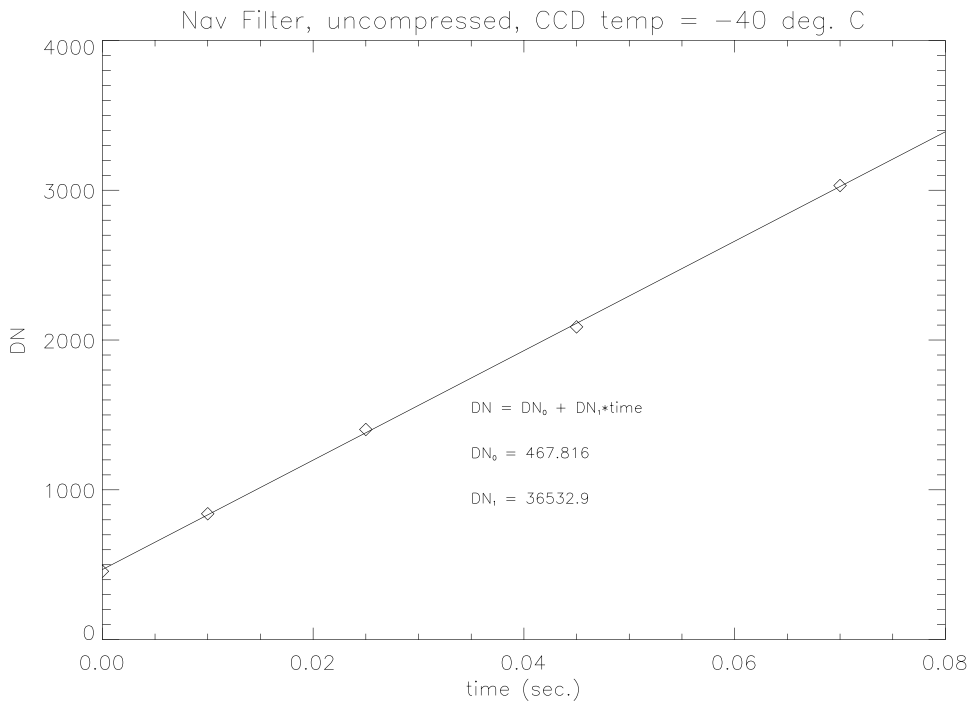
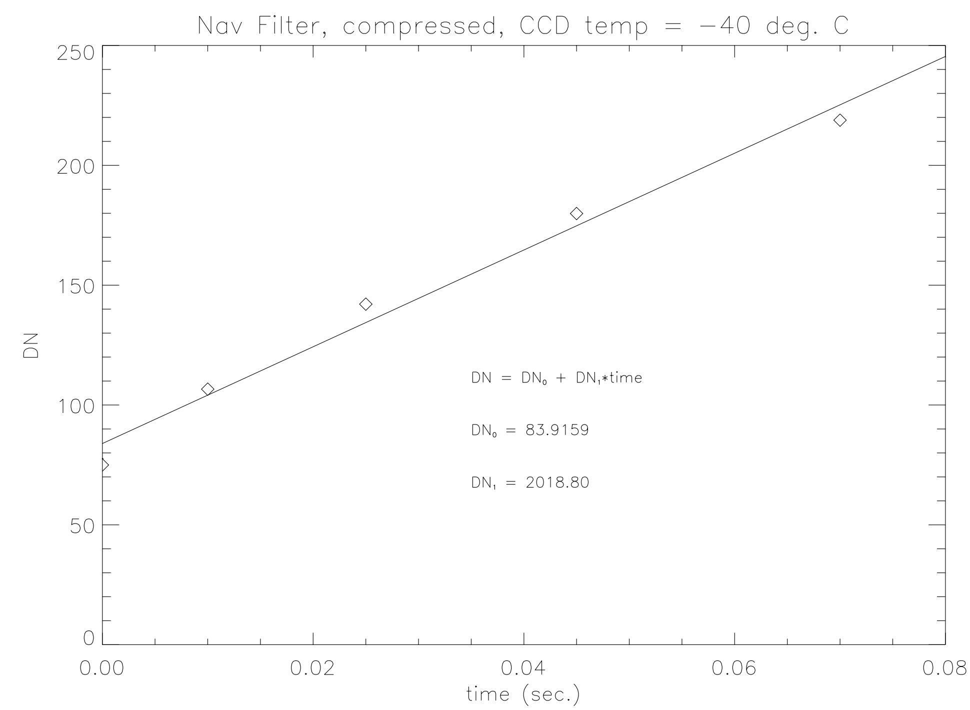
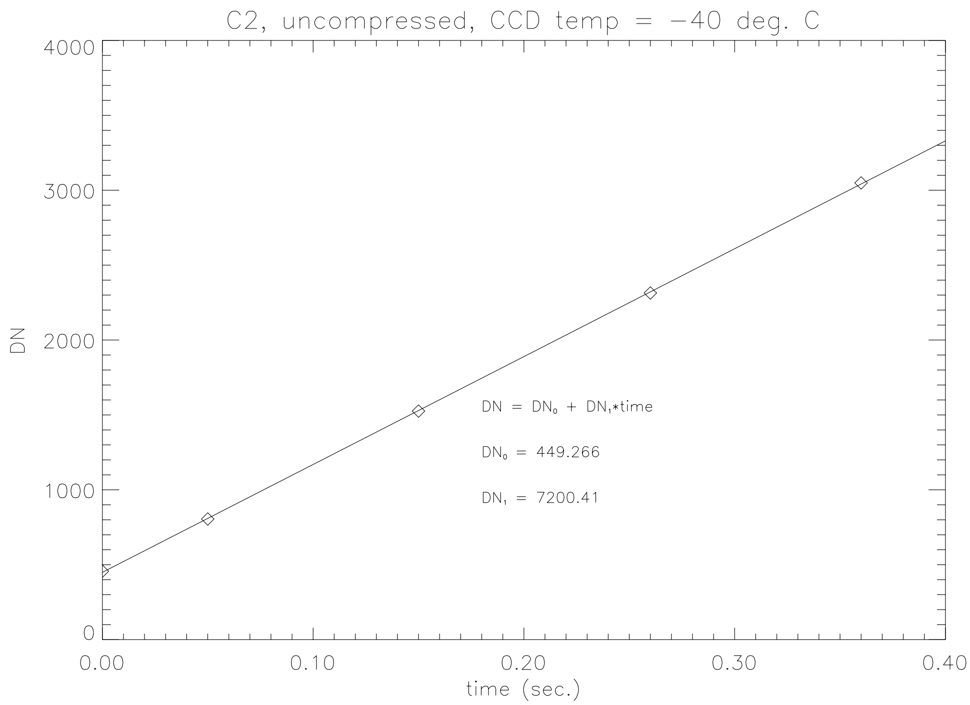
0.02
0.04
0.06
0.08
0.10
0.12

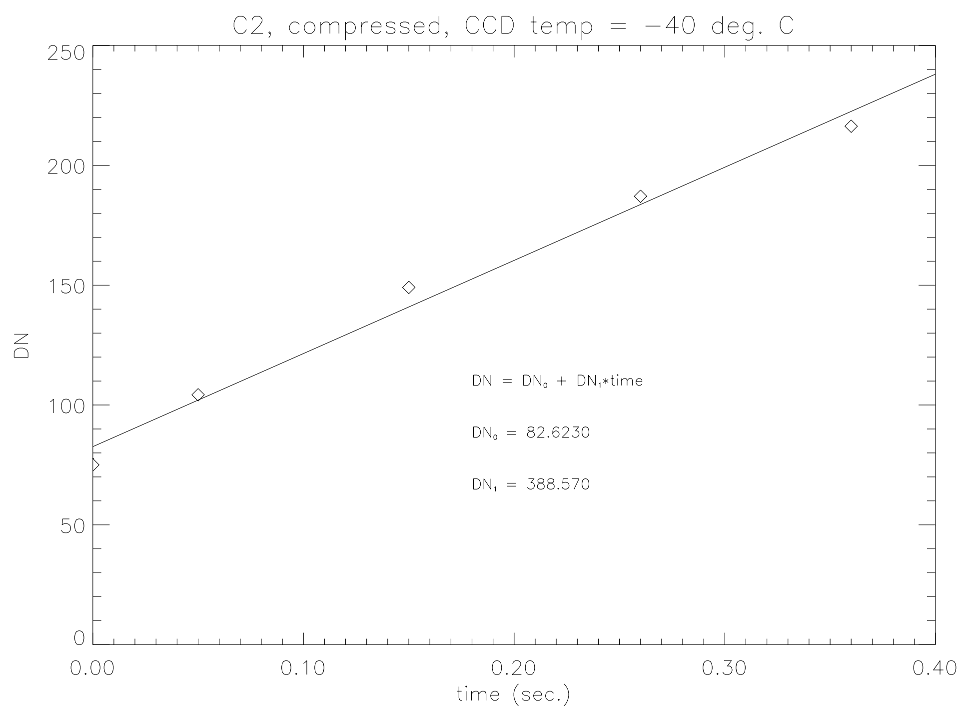

Hi Res, compressed, CCD temp = −40 deg. C
DN = DN₀ + DN₁*time
DN₀ = 82.3553
DN₁ = 1290.83
DN
time (sec.)
0
50
100
150
200
250
0.00
0.02
0.04
0.06
0.08
0.10
0.12


Nav Filter, uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 467.816
DN₁ = 36532.9

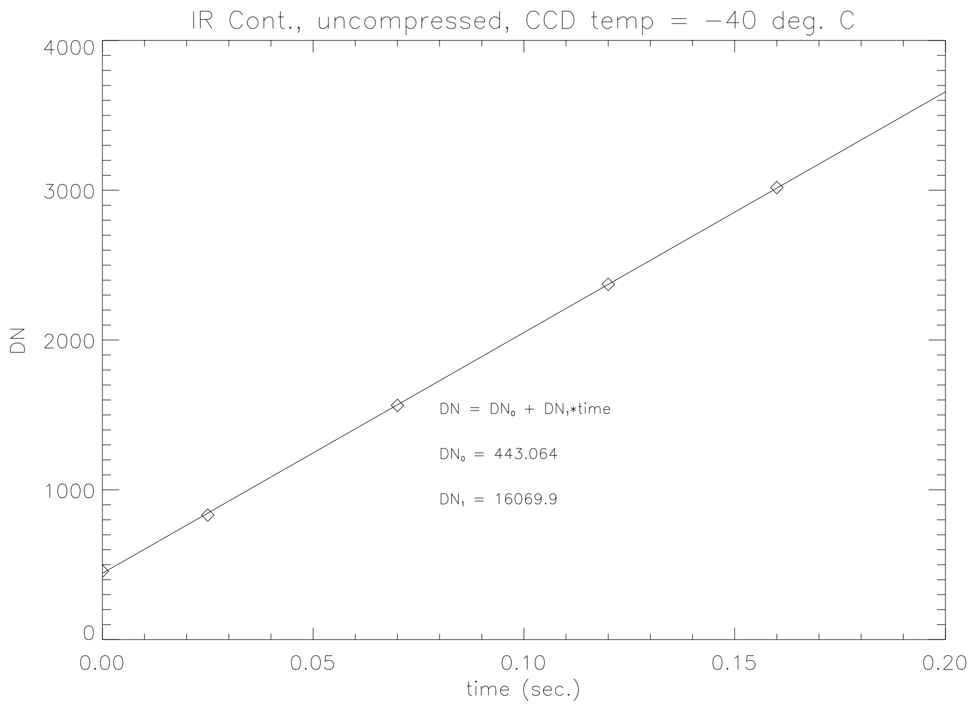

Nav Filter, compressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 83.9159
DN₁ = 2018.80

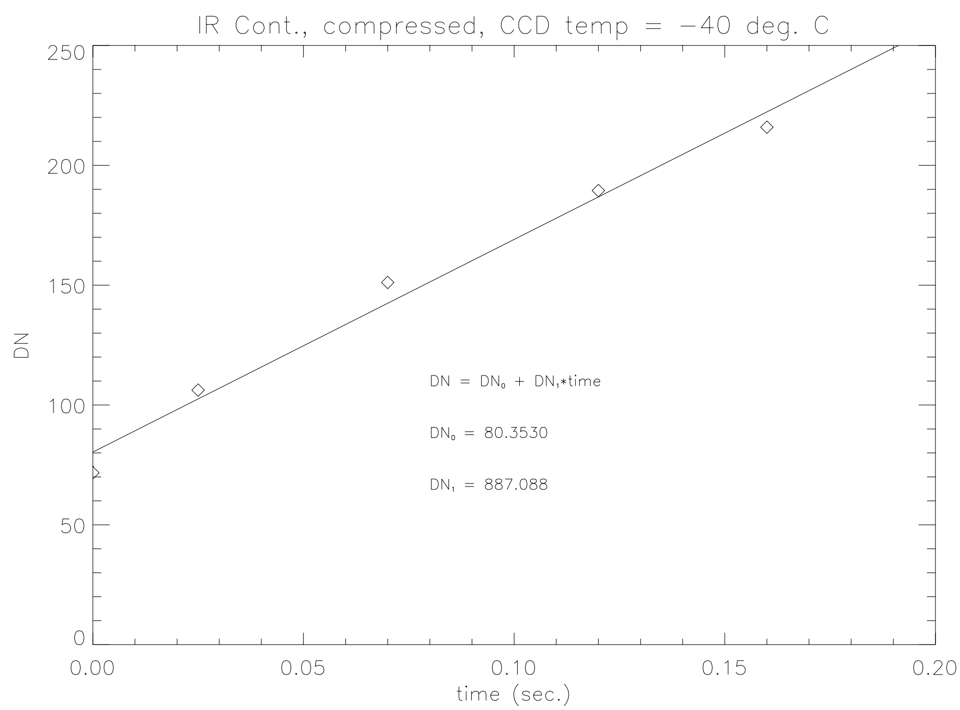


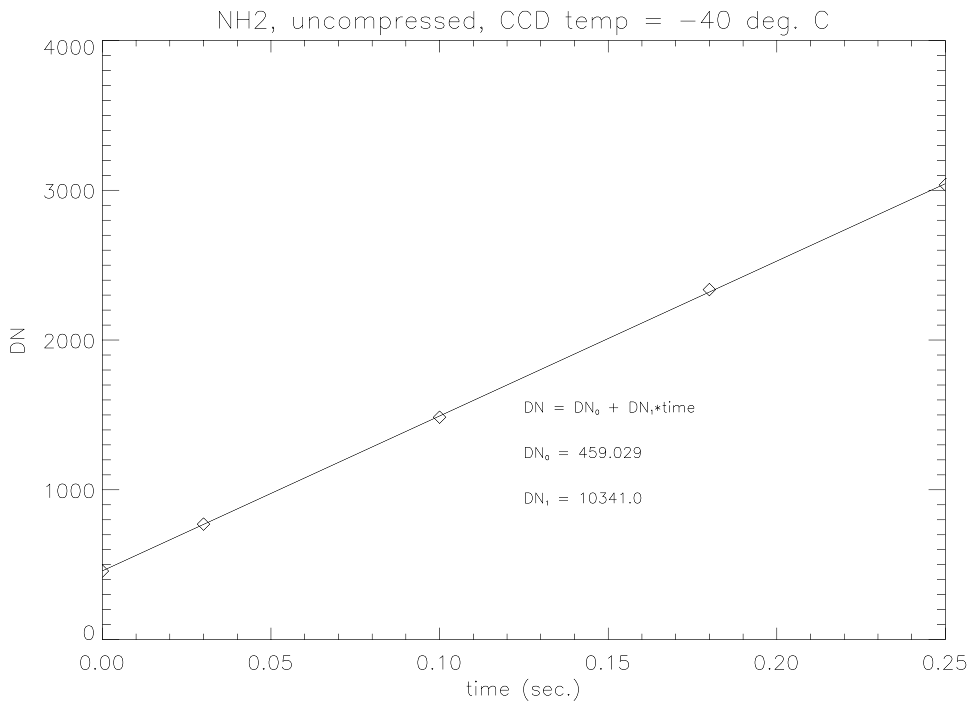
C2, uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN0 + DN1*time
DN0 = 449.266
DN1 = 7200.41

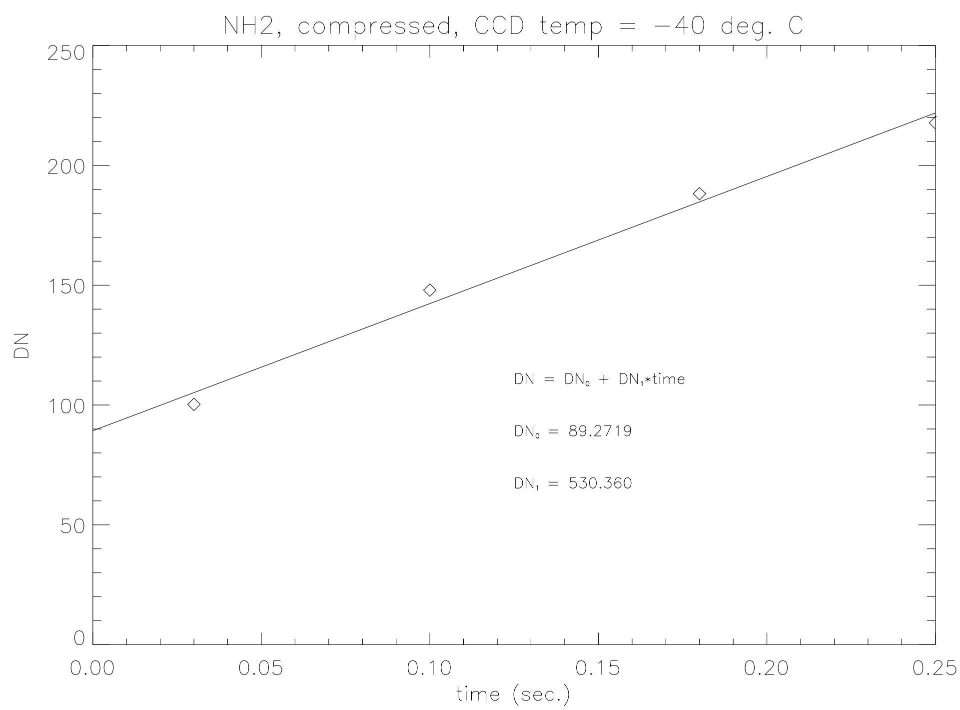


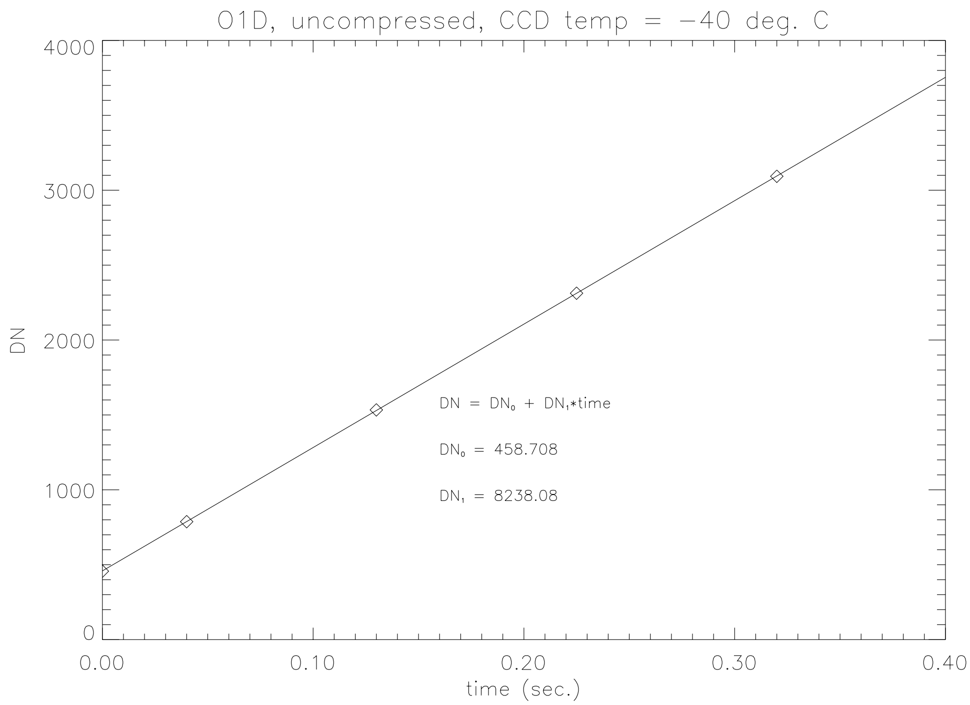
C2, compressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN0 + DN1*time
DN0 = 82.6230
DN1 = 388.570

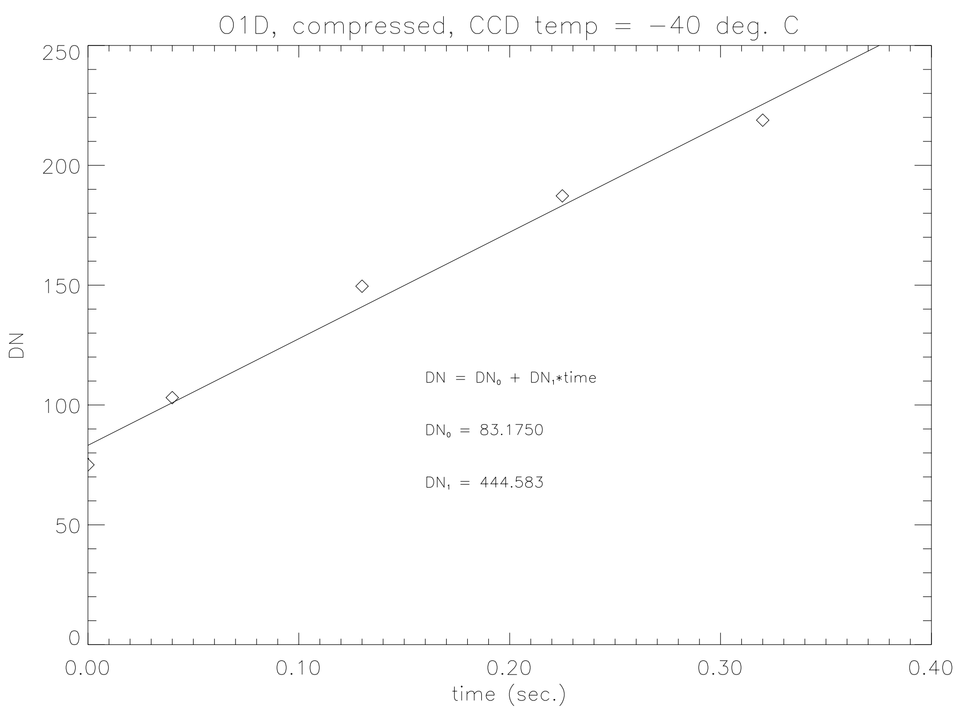

IR Cont., uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
0
1000
2000
3000
4000
0.00
0.05
0.10
0.15
0.20
DN = DN₀ + DN₁*time
DN₀ = 443.064
DN₁ = 16069.9

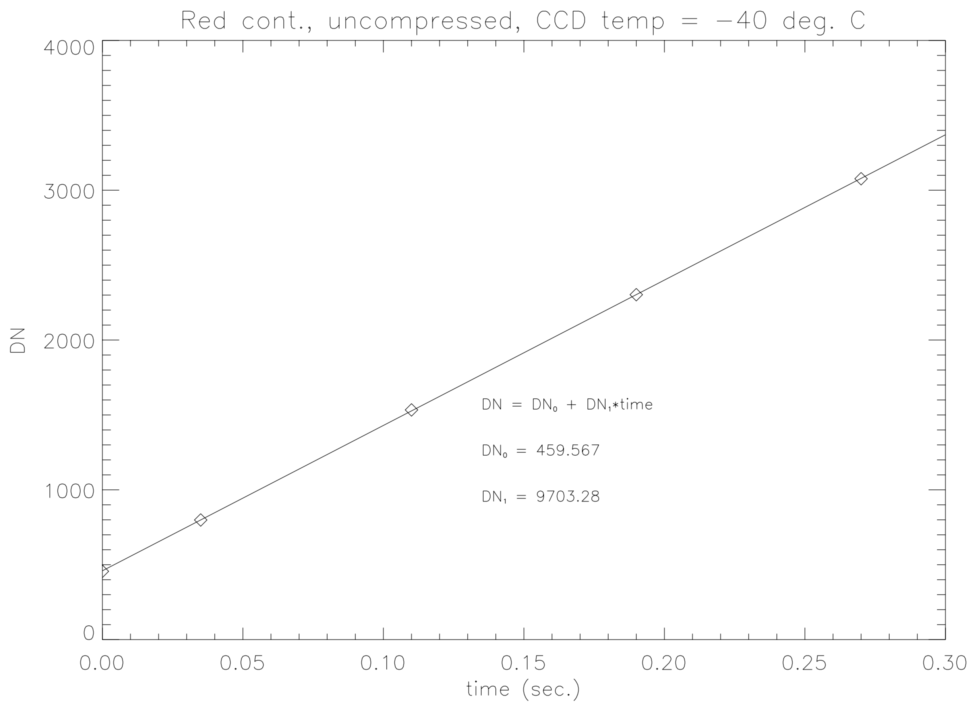

IR Cont., compressed, CCD temp = −40 deg. C
DN
time (sec.)
0
50
100
150
200
250
0.00
0.05
0.10
0.15
0.20
DN = DN₀ + DN₁*time
DN₀ = 80.3530
DN₁ = 887.088


NH2, uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 459.029
DN₁ = 10341.0

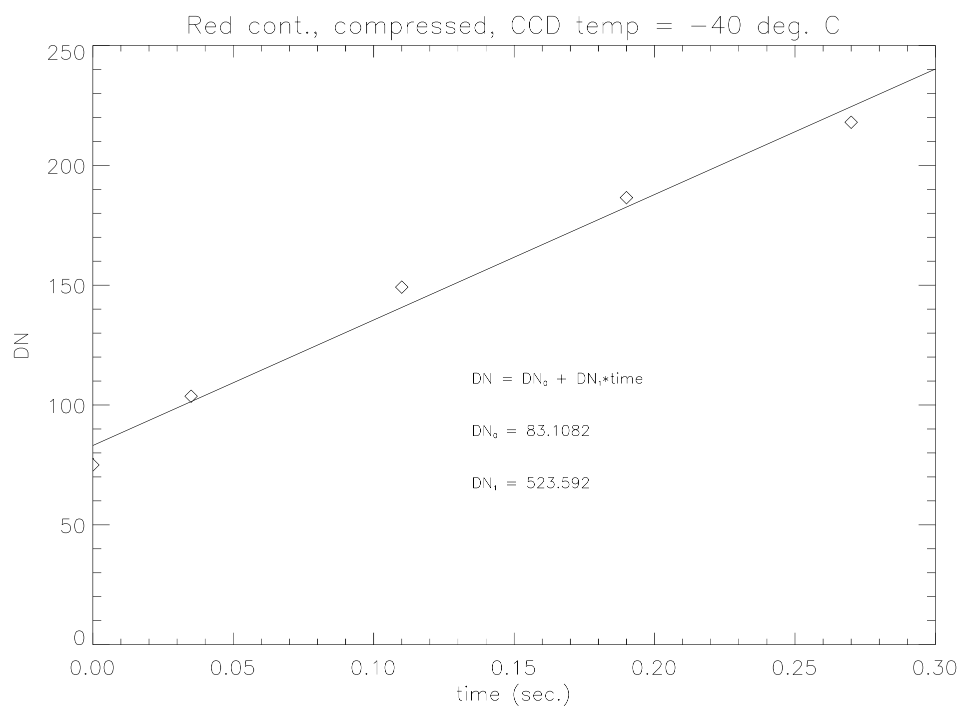

NH2, compressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 89.2719
DN₁ = 530.360


O1D, uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
0.00
0.10
0.20
0.30
0.40
0
1000
2000
3000
4000
DN = DN₀ + DN₁*time
DN₀ = 458.708
DN₁ = 8238.08

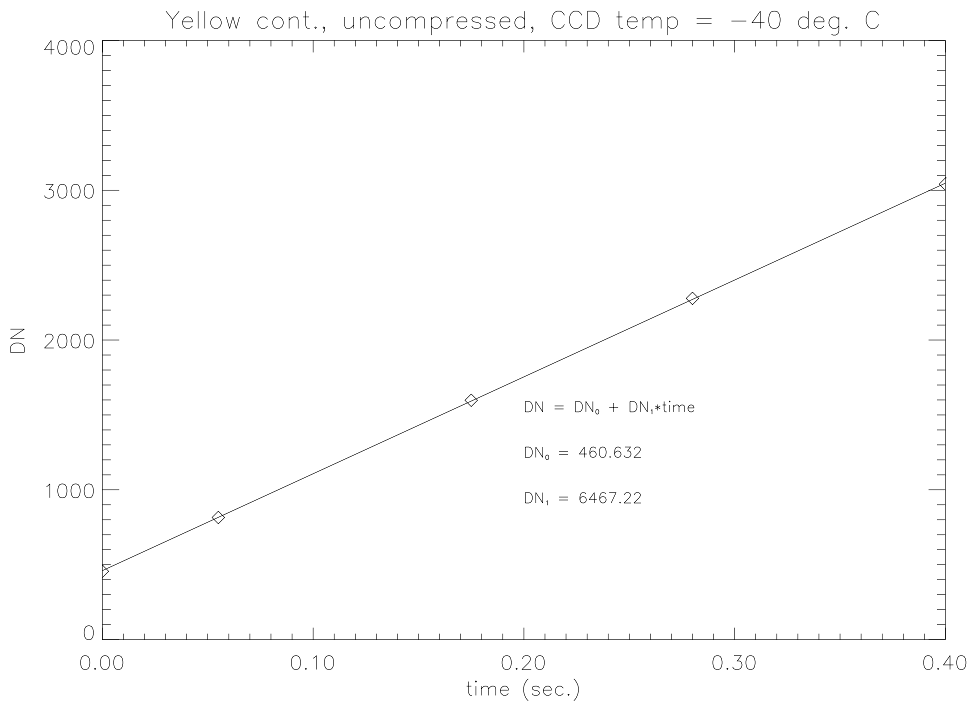

O1D, compressed, CCD temp = −40 deg. C
DN
time (sec.)
0.00
0.10
0.20
0.30
0.40
0
50
100
150
200
250
DN = DN₀ + DN₁*time
DN₀ = 83.1750
DN₁ = 444.583



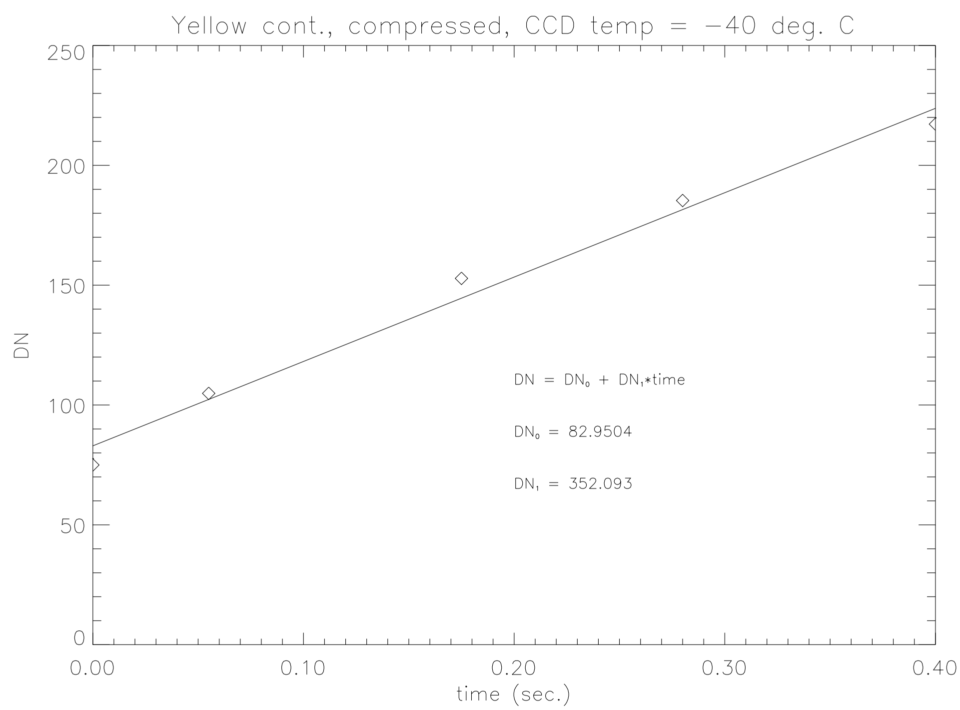
Red cont., uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN0 + DN1*time
DN0 = 459.567
DN1 = 9703.28



Red cont., compressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN0 + DN1*time
DN0 = 83.1082
DN1 = 523.592



Yellow cont., uncompressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 460.632
DN₁ = 6467.22



Yellow cont., compressed, CCD temp = −40 deg. C
DN
time (sec.)
DN = DN₀ + DN₁*time
DN₀ = 82.9504
DN₁ = 352.093

The following figures show the camera DN vs integration time, fit to a quadratic.

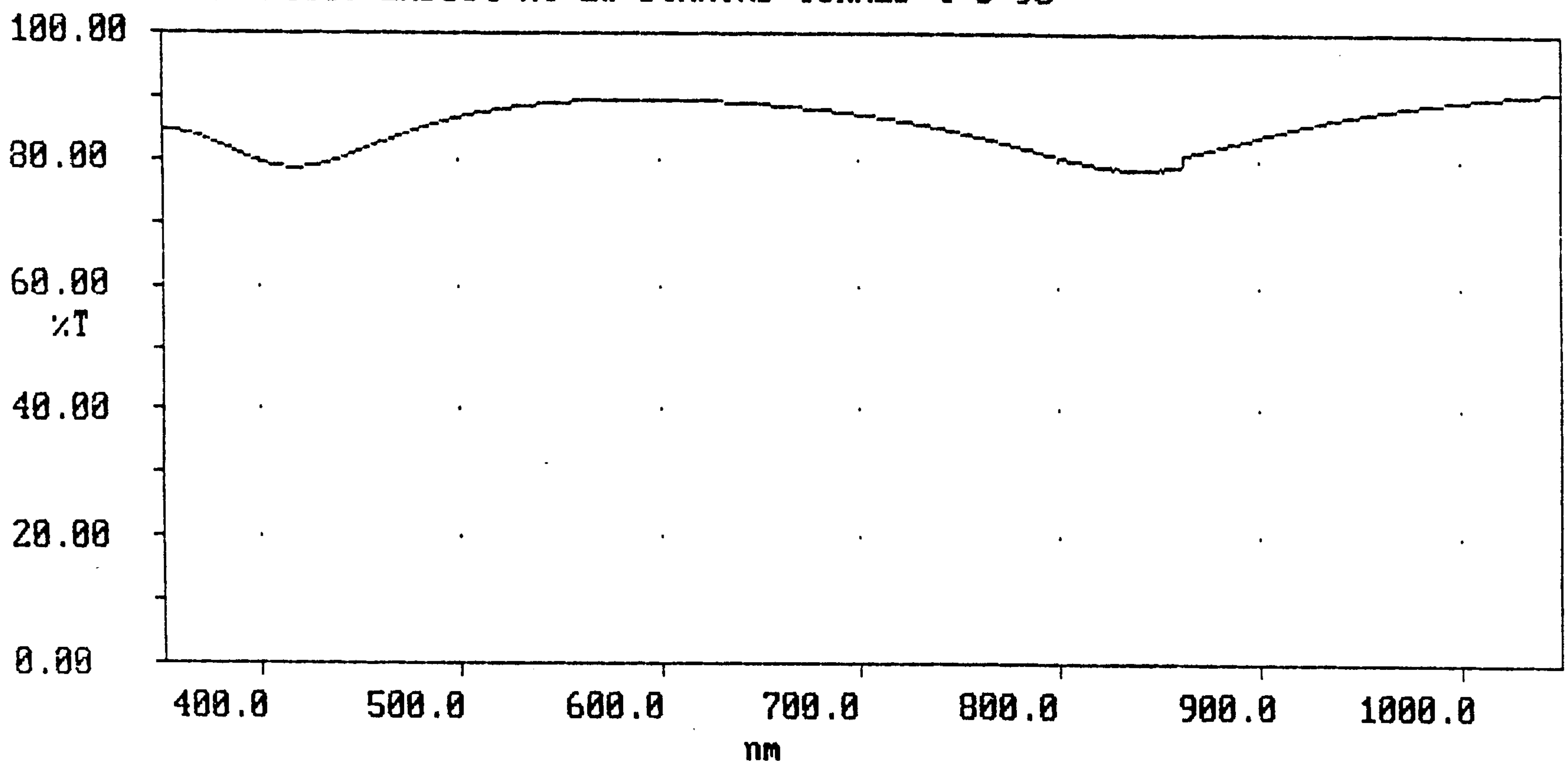
APPENDIX XI.

Periscope Mirror Reflectance

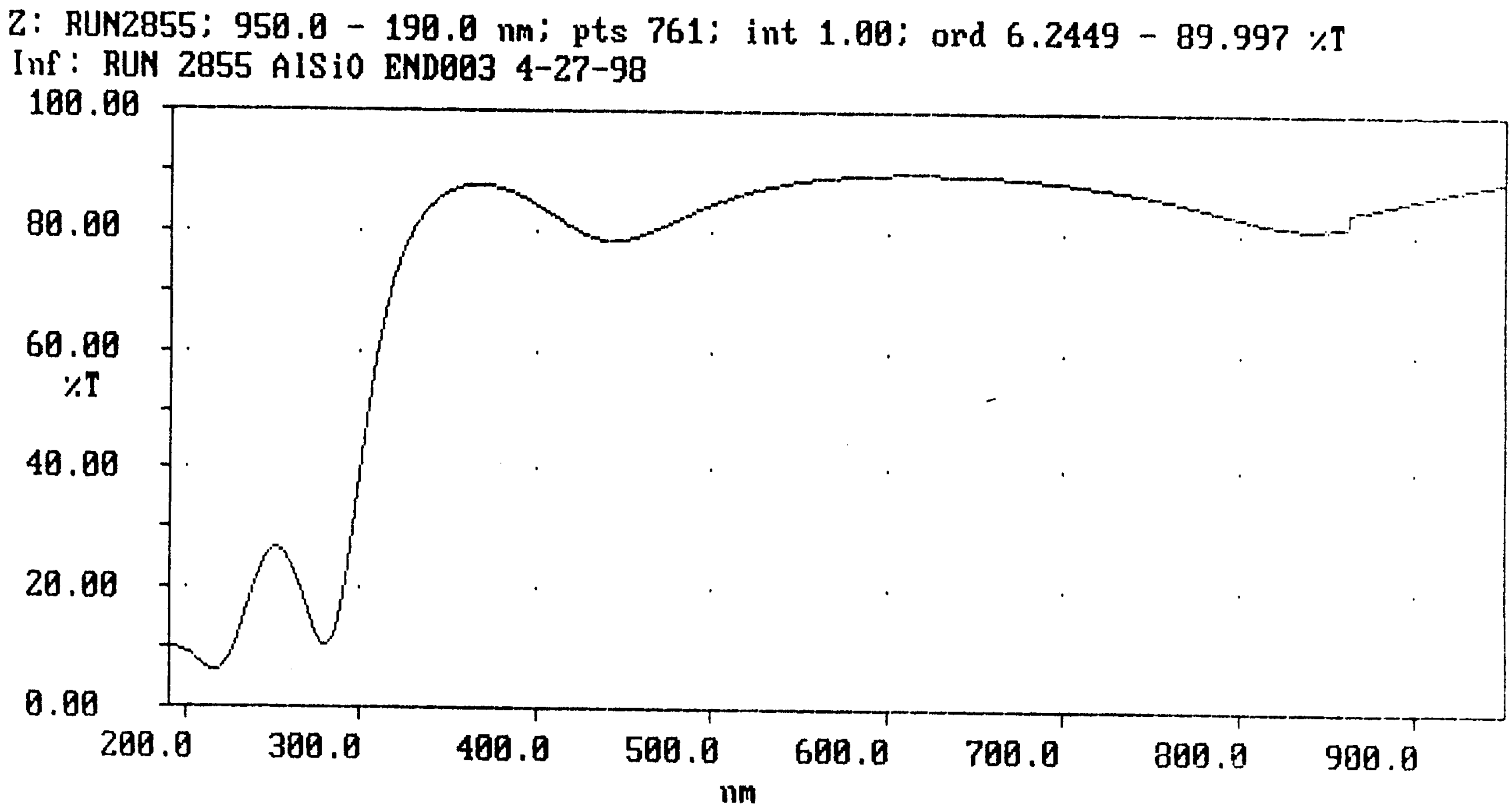
As noted in the main text, the periscope was never tested for transmission after assembly, only for alignment. It must be assumed that the transmission is the product of the reflectance of the two mirrors, given here.

Lower Periscope Mirror

Z: run2853; 1050.0 - 350.0 nm; pts 701; int 1.00; ord 78.698 - 91.145 %T
Inf: Run 2853 AlSiO END004 Al LW DIAMOND TURNED 4-8-98



Upper Periscope Mirror



APPENDIX XII.

File Data Format

by Howard Taylor

The image data are in PDS form. This section describes how that data are arranged within the files, as well as thoroughly describing the content of the PDS attached labels which accompany the image data.

Stardust Navigation Camera Preflight Calibration
Image Data Format

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Archive Overview

The images on the Calibration volume are in standard PDS format. Each file includes an attached PDS label at the beginning of the file, followed by a histogram, and ending with the image itself. The PDS label contains two OBJECT definitions, which describe the storage requirements for both the histogram and image objects. The label also describes the circumstances surrounding the collection of the calibration image. This meta-data is in keyword and value pairs and each of these keywords is described at the end of this document.

Camera Description:

The camera has a 1024x1024 array as the active portion of the CCD. The images that are stored on this volume, however, contain more than just the active portion of the CCD. Each line contains a sync pattern, a line counter, 8 baseline stabilization pixels, the 1024 pixels from the active portion of the CCD, and finally 8 over-clock pixels used to measure the quantum efficiency. The number of rows for each image is always 1024, no matter what compression mode is used, but the number of columns for each image depends on the compression mode used.

Compression Modes:

The navcam images can be either 8-bit or 12-bit data. The 12-bit data is commonly referred to as "uncompressed data", while the 8-bit is referred to as "compressed data". This compression is accomplished by a 12-bit to 8-bit square-root look-up-table compression method, which is implemented in the hardware of the camera electronics. This compression islossy and the estimate of the 12-bit image can be recovered using the look-up table mentioned in Appendix 3 of the Calibration Document. Both the image and histogram portions of the data file require different amounts of storage space, dependent on the compression mode used.

Pixel storage requirements:

In uncompressed mode with 12-bit data, the pixels are expressed in two bytes, as 16 bits per pixel. The upper nibble of the most significant byte is always zero for these images. In compressed mode with 8-bit data, the pixels are expressed in a single byte.

Number of Columns within each Row:

The general form of each line for each image is fixed. The row of data from the camera can be categorized into five different regions:

1. Sync Pattern — Always 2 bytes, with value 0x0000
2. Line Counter — Always 2 bytes, values from 0 to 1023
3. 8 BLS pixels — Baseline Stabilization pixels, either 1 or 2 bytes per pixel *
4. 1024 image pixels — Either 1 or 2 bytes per pixel *
5. 12 over-clock pixels — Used to measure quantum efficiency, either 1 or 2 bytes per pixel *

* The pixels are either 1 or 2 bytes per pixel dependent on the compression mode. Uncompressed, 12-bit images require 2 bytes per pixel, while compressed 8-bit images require 1 byte per pixel.

For the uncompressed, 12-bit data, each row contains 1046 “pixels” of data, which is exactly 2092 bytes. This is 2 bytes for the sync, 2 bytes for the line counter, 8 pixels at 2 bytes per pixel,1024 pixels at 2 bytes per pixel and, finally, 12 pixels at 2 bytes per pixel. In equation form:

$$bytes\_per\_uncompressed\_line = 2 + 2 + 2 * (8 + 1024 + 12) = 2092$$

For the compressed, 8-bit data, each row contains 1048 “pixels” of data, which is exactly 1048 bytes. This is 2 bytes for the sync, 2 bytes for the line counter, 8 pixels at 1 byte per pixel,1024 pixels at 1 bytes per pixel and, finally, 12 pixels at 1 bytes per pixel. In equation form:

$$bytes\_per\_compressed\_line = 2 + 2 + 1 * (8 + 1024 + 12) = 1048$$

Reading with “RAW” image readers:

When using any of the supported PDS readers, this extra data at the beginning and end of the line is not displayed, but when reading these images with a raw raster-scan style reader, this extra data at the beginning and ending of each line must be taken into account.

Values to use when reading images with a RAW readers:

Compression Mode	# Rows	# Columns	Data Type
Compressed	1024	1048	BYTE data
Uncompressed	1024	1046	MSB_Unsigned_integer (16-bit)

Finding the offset to the data within the file:

When trying to read the histogram or image arrays from the file using a RAW reader, the reader must first skip all of the information before the object to be read. As an example, to read the image object using a raw reader, the reader must first skip the PDS attached header, as well as thehistrogram data. To determine the amount of data to skip, examine two keyword pairs from the attached label.

To advance to the beginning of the histogram data, examine the following keywords:

```
RECORD_BYTES         = 2092
^IMAGE_HISTOGRAM     = 3
```

The first keyword defines the number of bytes within each record, while the second keyword indicates at which record the data begins. In this example, the data starts in record #3. This indicates that 2 other records contain data prior to the start of the histogram data. To compute the data offset, account for 2 records of data: in this example, the offset is (3-1)*2092 = 4184.

To advance to the beginning of the image data, examine the following keywords:

```
RECORD_BYTES         = 2092
^IMAGE               = 11
```

As in the previous example, the first keyword defines the number of bytes within each record. The second keyword indicates the record at which the image data begins. To compute the data offset, follow the example above:

Offset = (^image_histogram – 1) *record_bytes.

Ex: Offset = (11 – 1) * 2092 = 20920

Description of an Example Label

```
PDS_VERSION_ID       = PDS3
/*** FILE FORMAT ***/
RECORD_TYPE          = FIXED_LENGTH
RECORD_BYTES         = 2092
FILE_RECORDS         = 1034
/*** POINTERS TO OBJECTS IN FILE ***/
^IMAGE_HISTOGRAM     = 3
^IMAGE               = 11
/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
MISSION_NAME         = "STARDUST"
SPACECRAFT_NAME      = "STARDUST"
DATA_SET_ID          = "STARDUST-CAL-NC-2-PREFLIGHT-V1.0"
OBSERVATION_NAME     = "CALIBRATION AT MINUS 30 DEGRESS C"
OBSERVATION_TYPE     = "-30"
PRODUCT_ID           = "NC370034.IMG"
ORIGINAL_PRODUCT_ID  = "usd9898-144754.pds"
PRODUCER_INSTITUTION_NAME = "JPL/ACT"
PRODUCT_TYPE         = "EDR"
SOFTWARE_NAME        = "ACT DMAPKTDECOM 1.0"
MISSION_PHASE_NAME   = "PREFLIGHT CALIBRATION"
TARGET_NAME          = "CALIMG"
FRAME_SEQUENCE_NUMBER = 34
/*** TIME PARAMETERS ***/
START_TIME           = 1998-04-08T14:47:54
STOP_TIME            = "N/A"
PRODUCT_CREATION_TIME = 2000-02-25T02:06:51
/*** CAMERA RELATED PARAMETERS ***/
INSTRUMENT_NAME      = "NAVIGATION CAMERA"
INSTRUMENT_ID        = "NC"
EXPOSURE_DURATION    = 0.020<S>
CAL_LAMP_MODE_ID     = "OFF"
QUANTIZATION_MODE_ID = "OFF"
FILTER_NUMBER        = "7"
FILTER_NAME          = "HiRes"
CENTER_FILTER_WAVELENGTH = 596.4<NM>
FILTER_FWHM          = 200.0<NM>
/*** CALIBRATION EQUIPMENT PARAMETERS ***/
MEASUREMENT_SOURCE_DESC = "KEITHLY 607 ELECTROMETER"
RADIANCE             = 0.981<NA>
/*** TEMPERATURE PARAMETERS IN <K> ***/
INSTRUMENT_TEMPERATURE = 306.95<K>
FOCAL_PLANE_TEMPERATURE = 243.15<K>
/*** DESCRIPTION OF OBJECTS CONTAINED IN THE FILE ***/
OBJECT = IMAGE_HISTOGRAM
  ITEMS     = 4096
  DATA_TYPE = MSB_UNSIGNED_INTEGER
  ITEM_BITS = 32
END_OBJECT = IMAGE_HISTOGRAM
OBJECT = IMAGE
  LINES              = 1024
  LINE_SAMPLES       = 1024
  SAMPLE_TYPE        = MSB_UNSIGNED_INTEGER
  SAMPLE_BITS        = 16
  SAMPLE_BIT_MASK    = 2#0000111111111111#
  MAXIMUM            = 3063
  MINIMUM            = 603
  LINE_PREFIX_BYTES  = 20
  LINE_SUFFIX_BYTES  = 24
  MEAN               = 859.588
  STANDARD_DEVIATION = 64.9859
  SATURATED_PIXELS   = 0
  CHECKSUM           = 50501490
END_OBJECT = IMAGE
END
```

General notes regarding label

* Strings appear in quotes.
* Integers and PDS Times do not take quotes.
* Lists are enclosed within {} type brackets.
* If a field is unknown, "UNK" may be entered.
* If a field is not applicable, "N/A" may be entered.
* Fields can spill freely, with or without white space, onto following lines.

Definition of Keywords/Values from the PDS Data Dictionary:

PDS_VERSION_ID	The pds_version_id Keywords indicates the version number of the PDS standards documents that is valid when a data product label is created. Values for the PDS_VERSION_ID are formed by appending the integer for the latest version number to the letters 'PDS'. Examples: PDS3, PDS4.
RECORD_TYPE	The record_type keyword indicates the record format of a file. Note: In the PDS, when record_type is used in a detached label file it always describes its corresponding detached data file, not the label file itself. The use of record_type along with other file-related data elements is fully described in the PDS Standards Reference.
RECORD_BYTES	The record_bytes keyword indicates the number of bytes in a physical file record, including record terminators and separators.
FILE_RECORDS	The file_records keyword indicates the number of physical file records, including both label records and data records.
^IMAGE_HISTOGRAM	The image_histogram object represents a pointer to the image histogram. The value is in "RECORD_BYTE" units and indicates that the data starts at the beginning of the record mentioned. As an example, if the pointer value is 4, then the 3 records are populated with other data. If the bytes per record is 2092, the image histogram data starts at byte 6276
^IMAGE	The ^image pointer represents a byte offset to the image data. The value is in "RECORD_BYTE" units. As an example, if the pointer value is 11, and the bytes per record is 2092, the image histogram data starts at byte 20920.
MISSION_NAME	The mission_name element identifies a major planetary mission or project. A given planetary mission may be associated with one or more spacecraft.
SPACECRAFT_NAME	The spacecraft_name element provides the full, unabbreviated name of a spacecraft.
DATA_SET_ID	The data_set_id element is a unique alphanumeric identifier for a data set or a data product. The data_set_id value for a given data set or product is constructed according to flight project naming conventions. In most cases the data_set_id is an abbreviation of the data_set_name. Example value: STARDUST-CAL-NC-2-PREFLIGHT-V1.0. Note: In the PDS, the values for both data_set_id and

data_set_name are constructed according to standards outlined in the Standards Reference.

OBSERVATION_NAME	The observation_name element provides the identifier for an observation or sequence of commands. For this dataset, this keyword has 3 possibilities, based on the day the calibration was completed: 4/08/98 "CALIBRATION AT MINUS 30 DEGRESS C" 4/09/98 "CALIBRATION AT MINUS 40 DEGRESS C" 4/10/98 "CALIBRATION AT MINUS 50 DEGRESS C"
OBSERVATION_TYPE	The observation_type element identifies the general type of an observation. This keyword has 3 possibilities, based on the day the calibration was completed: 4/08/98 "-30" 4/09/98 "-40" 4/10/98 "-50"
PRODUCT_ID	The product_id data element represents a permanent, unique identifier assigned to a data product by its producer. Note: In the PDS, the value assigned to product_id must be unique within its data set. This value represents the actual name of the image file on the archive. The output directory is also available.
ORIGINAL_PRODUCT_ID	The original_product_id element provides the temporary product identifier that was assigned to a product during active flight operations which was eventually replaced by a permanent id (see product_id). In this dataset, this value represents the original filename recorded by the calibration equipment. This name can be linked back to the original calibration log files.
PRODUCER_INSTITUTION_NAME	The producer_institution_name element identifies a university, research center, NASA center or other institution associated with the production of a data set. This would generally be an institution associated with the element producer_full_name. In this dataset, this field has the value "JPL/ACT", described as: JPL = Jet Propulsion Laboratory. ACT = Applied Coherent Technology Corp.
PRODUCT_TYPE	The product_type data element identifies the type or category of a data product within a data set. Examples: EDR, UDR.
SOFTWARE_NAME	The software_name element identifies data processing software such as a program or a program library.
MISSION_PHASE_NAME	The mission_phase_name element provides the commonly-used identifier of a mission phase.
TARGET_NAME	The target_name element identifies a target. The target may be a planet, satellite, ring, region, feature, asteroid or comet. See target_type. In this calibration dataset, the target is "CALIMG".
FRAME_SEQUENCE_NUMBER	The frame_sequence_number element indicates the location within a cycle at which a specific frame occurs. Frames are repeated in

a specific order within each cycle. In this dataset, this value represents a uniquly sequential identifier assigned to each image of the archive.

START_TIME	The start_time element provides the date and time of the beginning of an event or observation (whether it be a spacecraft, ground-based, or system event) in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.
STOP_TIME	The stop_time element provides the date and time of the end of an observation or event (whether it be a spacecraft, ground-based, or system event) in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.
PRODUCT_CREATION_TIME	The product_creation_time element defines the UTC system format time when a product was created. Formation rule: YYYY-MM-DDThh:mm:ss.
INSTRUMENT_NAME	The instrument_name element provides the full name of an instrument. Note: that the associated instrument_id element provides an abbreviated name or acronym for the instrument.
INSTRUMENT_HOST_NAME	The instrument_host_name element provides the full name of the host on which an instrument is based. This host can be either a spacecraft or an earth base. Thus, the instrument_host_name element can contain values which are either spacecraft_name values or earth_base_name values.
INSTRUMENT_ID	The instrument_id element provides an abbreviated name or acronym which identifies an instrument. Note: The instrument_id is not a unique identifier for a given instrument. Note also that the associated instrument_name element provides the full name of the instrument.
EXPOSURE_DURATION	The exposure_duration element provides the value of the time interval between the opening and closing of an instrument aperture (such as a camera shutter).
CAL_LAMP_MODE_ID	The cal_lam_mode_id element provides the value of the calibration lamp mode at the time the image was acquired. This value indicates whether the calibration lamp was on or off at the time the image was acquired.
QUANTIZATION_MODE_ID	The quantization_mode_id element provides the identifier for the quantization mode used when the image was acquired. This value indicates if the original data was quantized at the time the data was acquired. A value of "off" indicates that the data was not quantized, while a value of "on" indicates that the data was quantized. In this dataset, this value indicates that the image was compressed with a hardware square-root compression technique prior to transmission.
FILTER_NUMBER	The filter_number element provides the number of an instrument filter through which an image or measurement was acquired or which is associated with a given instrument mode. Note: that the filter_number is unique, while

the filter_name is not.

FILTER_NAME	The filter_name element provides the commonly-used name of the instrument filter through which an image or measurement was acquired or which is associated with a given instrument mode. Example values: RED, GREEN. See also filter_number.
CENTER_FILTER_WAVELENGTH	The center_filter_wavelength element provides the mid_point wavelength value between the minimum and maximum instrument filter wavelength values.
FILTER_FWHM	The filter_fwhm element provides the measurement for the Full-width, half-max value associated with the filter. This is the width of the filter transmission curve at the point of half of the maximum transmission value.
MEASUREMENT_SOURCE_DESC	The measurement_source_desc element describes the source of light used in a laboratory-generated data set, or the radar transmitter in the case of radar astronomy experiments.
RADIANCE	The radiance element describes the amount of current recorded from the photo-diode detector used to measure the radiance output from the source emitter.
INSTRUMENT_TEMPERATURE	The instrument_temperature element provides the temperature, in degrees Celcius, of an instrument or some part of an instrument.
FOCAL_PLANE_TEMPERATURE	The focal_plane_temperature element provides the temperature of the focal plane array in degrees kelvin at the time the observation was made.
OBJECT = IMAGE_HISTOGRAM	The histogram object is a sequence of numeric values that provides the number of occurrences of a data value or a range of data values in a data object. The number of items in a histogram will normally be equal to the number of distinct values allowed in a field of the data object. (For example, an 8-bit integer field can have 256 values. This would result in a 256-item histogram.) Histograms may be used to bin data, in which case an offset and scaling factor indicate the dynamic range of the data represented. The following equation allows the calculation of the range of each 'bin' in the histogram. 'bin lower boundary' = ('bin element' * scaling_factor) + offset.
ITEMS	The items element defines the number of multiple, identical occurrences of an single object, such as a column. See also: repetitions. Note: In the PDS, the data element ITEMS is used for multiple occurrences of a single object, such as a column. REPETITIONS is used for multiple occurrences of a repeating group of objects, such as a container. For a fuller description of the use of these data elements, please refer to the Standards Reference.
DATA_TYPE	The data_type element supplies the internal representation and/or mathematical properties of a value being stored. See also:

bit_data_type, general_data_type. Note: In the PDS, users may find a bit-level description of each data type in the Standards Reference document.

ITEM_BITS	The item_bits element indicates the number of bits allocated for a particular bit data item. Note: In the PDS, the item_bits element is used when the items element specifies multiple occurrences of an implied item within a BIT_COLUMN object definition.
END_OBJECT	The end_object element terminates the object description.
OBJECT = IMAGE	A regular array of sample values. Image objects are normally processed with special display tools to produce a visual representation of the sample values. This is done by assigning brightness levels or display colors to the various sample values. Images are composed of LINES and SAMPLES. They may contain multiple bands, in one of several storage orders. Note: Additional engineering values may be prepended or appended to each LINE of an image, and are stored as concatenated TABLE objects, which must be named LINE_PREFIX and LINE_SUFFIX. IMAGE objects may be associated with other objects, including HISTOGRAMs, PALETTEs, HISTORY, and TABLEs which contain statistics, display parameters, engineering values, or other ancillary data.
LINES	The lines element indicates the total number of data instances along the vertical axis of an image. Note: In PDS label convention, the number of lines is stored in a 32-bit integer field. The minimum value of 0 indicates no data received.
LINE_SAMPLES	The line_samples element indicates the total number of data instances along the horizontal axis of an image.
SAMPLE_TYPE	The sample_type element indicates the data storage representation of sample value.
SAMPLE_BITS	The sample_bits element indicates the stored number of bits, or units of binary information, contained in a line_sample value.
SAMPLE_BIT_MASK	The sample_bit_mask element identifies the active bits in a sample. Note: In the PDS, the domain of sample_bit_mask is dependent upon the currently-described value in the sample_bits element and only applies to integer values. For an 8-bit sample where all bits are active the sample_bit_mask would be 2#11111111#.
MAXIMUM	The maximum element indicates the largest value occurring in a given instance of the data object.
MINIMUM	The minimum element indicates the smallest value occurring in a given instance of the data object.

LINE_PREFIX_BYTES	The line_prefix_bytes element indicates the number of non-image bytes at the beginning of each line. The value must represent an integral number of bytes.
LINE_SUFFIX_BYTES	The line_suffix_bytes element indicates the number of non-image bytes at the end of each line. This value must be an integral number of bytes.
MEAN	The mean element provides the average of the DN values in the image array.
STANDARD_DEVIATION	The standard_deviation element provides the standard deviation of the DN values in the image array.
SATURATED_PIXELS	The saturated_pixels element provides a count of the number of pixels in the array which at the maximum DN value. For this dataset, the non-quantized data has a maximum value of 4095, while the quantized data has a maximum value of 255.
CHECKSUM	The checksum element represents an unsigned 32-bit sum of all data values in a data object.
END	End of the PDS Label.

APPENDIX XIII.

This appendix gives complete details of the boresighting of the NavCam on the STARDUST spacecraft. Final geometric calibration will be carried out in flight.

JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

September 19, 1998

TO: Distribution

FROM: E. Motts / M. Schwochert

SUBJECT: Addendum to Test Report; Stardust Camera alignment measurement.

Scope

This memorandum is intended as an addendum to a JPL Interoffice Memorandum titled "Test Report; Stardust Camera alignment measurement", dated May 7, 1998 by E. Motts. Further analysis of the subject measurement results are described as an aid to interpretation of the original report. Repotted values and knowledge estimates are slightly revised, but without changing the conclusions of the original report.

Analysis

In discussions following the release of the original report, the following alignment parameter values were requested:

1) the 200 mm optical axis with respect to the Nav Cam Mounting Cube.
2) the mirror rotation axis with respect to the Nav Cam Mounting Cube.
3) the mirror tilt angle with respect to the mirror rotation axis.

Response to item 1) The camera optical axis was found to be well aligned to the mounting interface in the X-Y plane (less than the measurement uncertainty); however the Nav Cam Mounting Mirror (not actually a cube) surface normal is rotated +0.208° with respect to the interface -Y axis. Refer to Figure 1, following. Therefore the angle in the X-Y plane between the optical axis and the Nav Cam Mounting Mirror is determined to be +0.208°

The direction of the camera optical axis in the Y-Z plane was not measured directly but can be derived from measurements of the boresight and scan mirror normal, since the motion of the scan mirror is uniform. This was shown to be uniform to less than 1.3 pixels in any direction which corresponds to 0.004° maximum play or wobble of the scan mirror rotation axis, as stated in 'Stardust Scan Mirror mechanism Acceptance Test Procedure', Section 9.0, dated February 6, 1998. If the scan mirror axis is well aligned to the interface, the camera optical axis can be determined to be rotated 0.102° with respect to the interface Y axis. Refer to Figure 2. The Nav Cam Mounting Mirror normal is rotated 0.190° with respect to the interface

Y axis; therefore the angle between the camera boresight and the Mounting Mirror normal in the Y-Z plane is the difference, 0.088".

Response to item 2) The scan mirror rotation axis is well aligned with the instrument interface Y axis in the X-Y plane; therefore the angle is the same as shown for the Camera Optical Axis in Figure 1, 0.208".

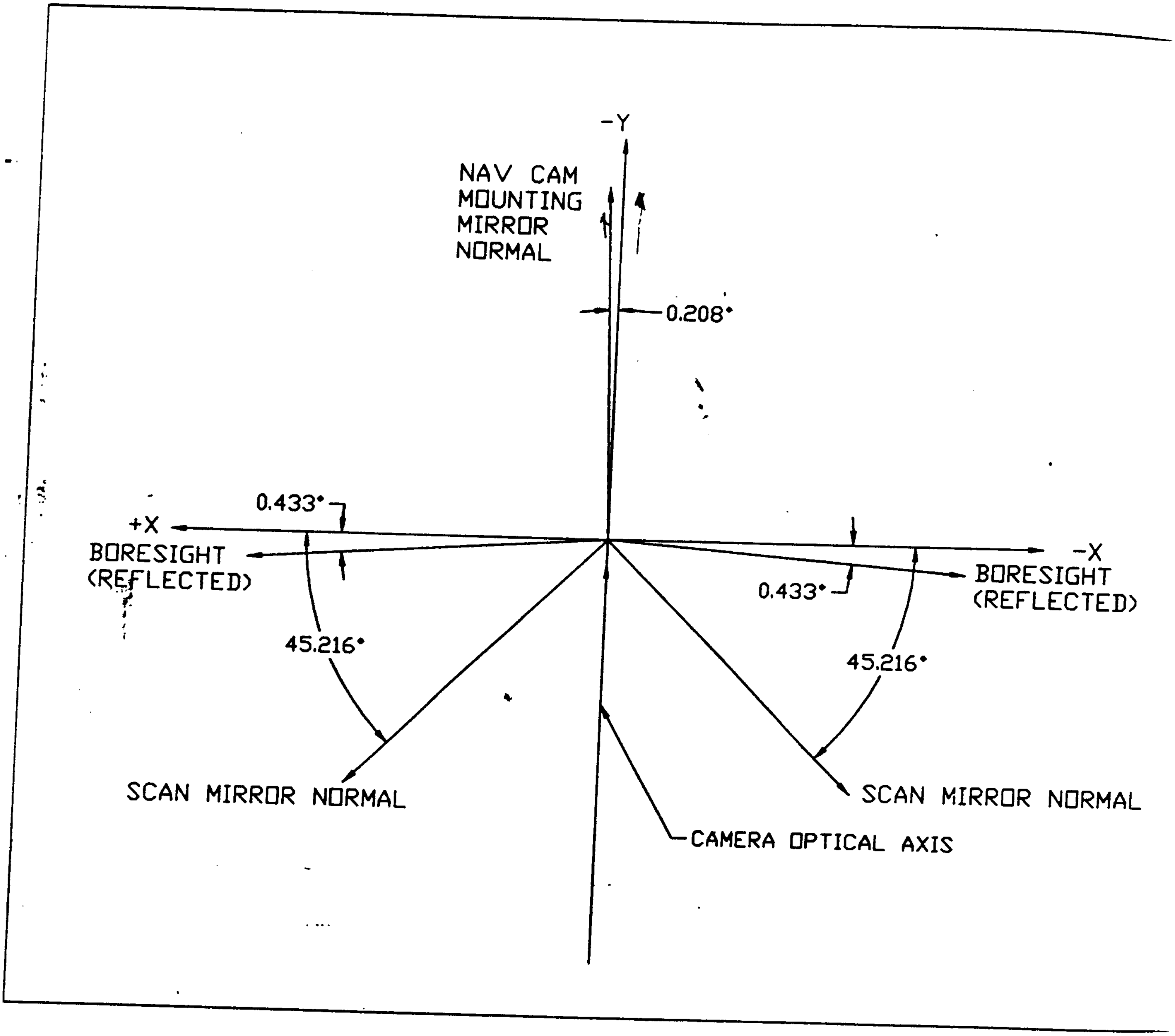
The scan mirror rotation axis is believed to be well aligned with the interface Y axis in the Y-Z plane, based on assembiy techniques used and control of tolerances. Although the alignment in the Y-Z plane was not measured as a part of the test described, it can be assumed that the axis is well aligned, therefore the angle to the Nav Cam Mounting Mirror normal would be 0.190".

Response to item 3) The scan mirror was determined to be rotated 45.216° with respect to the instrument **interface X-Z plane as previously reported, and as shown** in Figures 1 and 2. Again, the scan mirror axis of rotation is thought to be well aligned to the interface Y axis.

With the combined effect of the camera boresight misalignment (0.102" in the Y-Z plane) and the misalignment of the scan mirror (0.216" with respect to its scan axis) the reflected boresight in the -Z direction can be predicted. Refer to Figure 2. The reflected boresight is expected to form an angle of 0.534" with respect to the interface -Z axis

The direction of the reflected boresight in the X-Y plane was measured and reported in the previous IOM, a mean value of 0.433° from the X axis. The values reported in the previous report showed **a** slight skew of 0.013°, as did the values for the scan mirror normals. Since the sign and magnitude of both differences are nearly identical, this should probably be considered as a systematic error. The most likely source would be the theodolite at Station 1, which measured the mirror normal angles. Therefore, the uncertainty assigned to knowledge of the angles between the Nav Cam Mounting Mirror is increased from 0.007° to 0.020°, (three sigma), still less than the Knowledge Requirement of 0.03".

Distribution: S. Bhaskaran
T. Duxbury
G. Fraschetti
M. Schwochert



-Y
NAV CAM
MOUNTING
MIRROR
NORMAL
0.208°
0.433°
+X
BORESIGHT
(REFLECTED)
45.216°
-X
BORESIGHT
(REFLECTED)
0.433°
45.216°
SCAN MIRROR NORMAL
SCAN MIRROR NORMAL
CAMERA OPTICAL AXIS

Figure 1

X

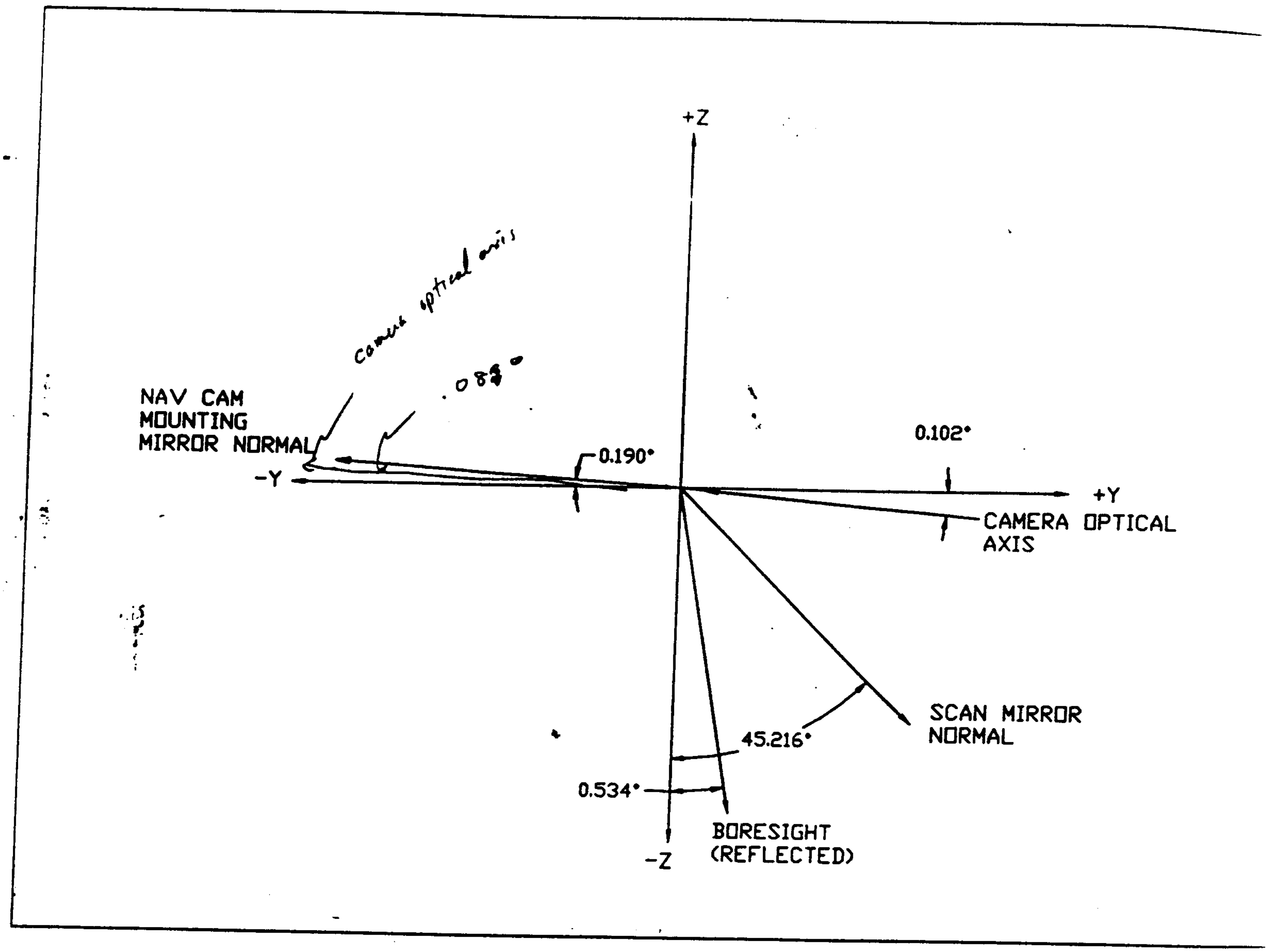

+Z
camera optical axis
.088°
NAV CAM
MOUNTING
MIRROR NORMAL
-Y
0.190°
0.102°
+Y
CAMERA OPTICAL
AXIS
SCAN MIRROR
NORMAL
45.216°
0.534°
BORESIGHT
(REFLECTED)
-Z

Figure 2

3 3 . 1 .

JET PROPULSION LABORATORY INTEROFFICE **MEMORANDUM**

May 7, 1998

TO: Distribution

FROM: E. Motts EM

SUBJECT: **Test** Report; Stardust Camera alignment measurement.

Scope

This report describes **a** test of the Stardust Camera performed on April 13,1998. The objective of the test was to measure the camera boresight direction with respect to the spacecraft interface as represented by the drill fixture. Angles between the interface and the camera alignment mirror ware also determined. The requirements of ICD SD-62200-220, Revision B, ***STARDUST PROJECT Interface Control Document for Navigation Camera (NAVCAM)*** **are** addressed. Measurements were performed by the author with Mark Schwochert, David Thiessen and Darryl Day.

Description of Test Method

Measurements of the horizontal and vertical angles between the camera boresight, the camera scan mirror normal the alignment mirror on the Stardust drill template, the camera minor, and the fixture mirror were performed using **electronic** optical theodolites. The theodolites, two Leica Model T3000A's, were equipped for a&collimation to mirror **surfaces.**

For this test, the Stardust Camera was mounted on its fixture, which was mounted in turn on an optical table. The table was leveled using **a spirit level.**

The theodolite at Station 1 observed the camera mirror, the drill template mirror, and the fixture mirror (sea **Figure 1). Station 3 determined** angles **in the horizontal plane with** respect to **a Davidson Optronics Model D644 referene mirror. Angles in a vertical** plane **were measured with respect to local gravity.**

Determination of the camera scan mirror normal was done by autocollimation using the theodolite at Station 2. The azimuth of Station 2 (the horizontal angle) was set by cross-collimating back to Station 1. Thus, both theodolites could measure **in the same coordinate system.**

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G. Fraschetti	M. Schwochert
E. Hagerott	C. Sepulveda
E.	D. Thiessen

Camera boresight was determined by projecting the Station 2 illuminated reticle into the camera. By imaging the reticle with the camera ground support equipment and adjusting the pointing of the theodolite, the reticle was made to fall on pixel (512, 512) of the camera detector. It was thus determined that the theodolite was boresighted with the camera optics and detector. The theodolite angles so determined were set and recorded three times, to calculate the average readings.

The measurements of the scan mirror normal and the camera boresight were done in two positions; first with the scan mirror at the stop (see Figure 1) and again with the scan mirror rotated through approximately 180° (Figure 2).

Finally, the camera was removed and the drill template was installed in its place. The alignment mirror on the drill template was measured with Station 1 by the same method used for the fixture and camera mirrors. Refer to figure 3.

All data were recorded in the author's laboratory notebook number 7, pages 106 through 111. Data were later tanscribed to a Microsoft Excel spreadsheet, "CAMOM.xls," sheet 1 (see Table 1).

Data Reduction

Raw angles in the Excel spreadsheet were used to create unit vectors of the form r, theta, phi, using right-handed angle conventions for each measured feature (see Table 2). The vector for each mirror represents the normal to the minor surface, pointing away from the surface. Vectors were also created to represent the viewing direction of the camera boresight. Since the raw theodolite angles are in a spherical coordinate system with the horizontal angles (Hz) increasing in a clockwise direction and vertical angles (V) increasing away from zenith, the following algorithms were used for the conversion:

$$r = 1$$

$$theta = 360° - Hz$$

$$Phi = 180° - V$$

. . The vectors were exported to another software package (Leica ManCAT) for rotation into the desired coordinate system, the spacecraft interface coordinate system. Previous measurement data in the desired coordinate system existed for one of the mirrors, the drill template mirror, from measurements performed by the author on August 29, 1997 (see Attachment 1). Therefore, by rotating the coordinate system through two **angles**, the drill template mirror vector was set to the previously measured angles and all vectors were rotated into the spacecraft interface coordinate system. See Figures 4 and 5.

Knowledge Estimate

The 3 sigma knowledge (or uncertainty) estimate is calculated as the sum of all systematic errors added to three times the RSS of the random errors. Systematic errors are those errors that are fixed in magnitude or which do not behave in **a** random manner, but which cannot be precisely quantified **and corrected. Random errors are** due to variations in observation, vibration, atmospheric effects, and the like.

In this test, the systematic errors **are estimated based on experience with these** theodolites and similar istruments. The ramdom errors in observing mirrors are based on the calculated standard deviation **in autocollimating to similar** mirrors. Random error in **observing the boresight is plus** and **minus one-half the worst case range of measured values.**

Table 3 contains two uncertainty estimates; one for angle **to the mirror normals, and** one for the boresight angles. Since there are different error contributions in each type of measurement, the uncertainties are calculated separately.

Test **Restults**

Test results are tabulated in Table 2. As an aid to interpretation of the results, the results are shown graphically in Figures 4 through 6. The coordinate system used is the Spacecraft coordinate system as shown in ICD SD-62200-220, Figure 3.3.1.2.1-1, *NA VCAM Mounting.*

Conclusions:

89.56719 Half cone angle. ±.02 °

As can be seen in Figure 4, the **camera** Boresight deviates from the X-Z **plane by an average of 0.43281 (0.41973° on the +X side and 0.44589 " on the -X side)**. This **angle exceeds the** requirements of ICD SD-62200-220 Revision 8, paragraph 3.3.4.1, Instrument Alignment to the Drill Fixture, which states:

> 'The NAVCAM alignment to the JPL Drill Fixture shall be <= 0.07 degrees about s the X and Z axes."

The uncertainty in the boresight angles is calculated to be ±0.021°, (three sigma). Uncertainty in the minor angles reported is calculated to be ±0.007°, (three sigma).

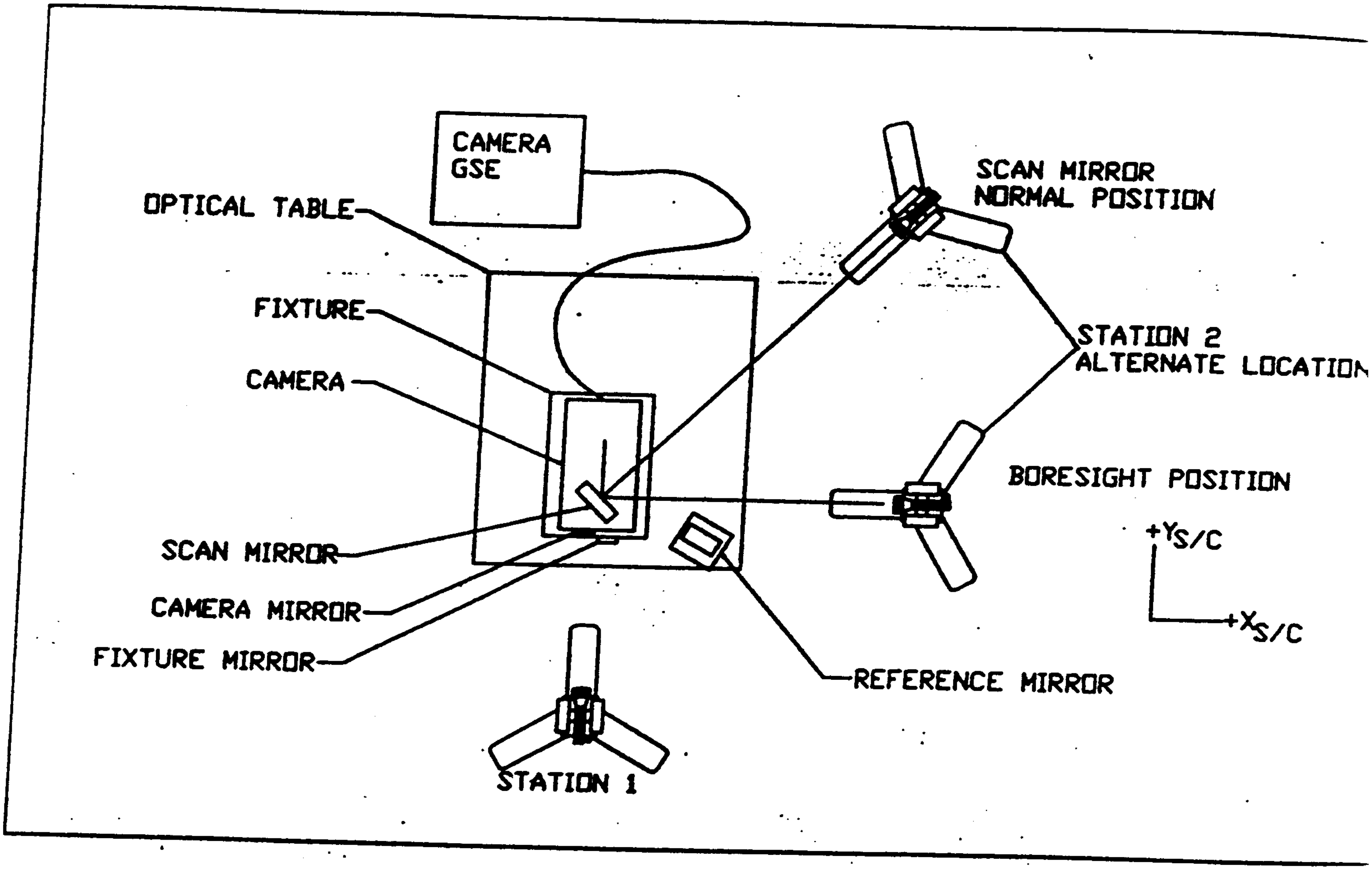

CAMERA
GSE
OPTICAL TABLE
FIXTURE
CAMERA
SCAN MIRROR
CAMERA MIRROR
FIXTURE MIRROR
SCAN MIRROR
NORMAL POSITION
STATION 2
ALTERNATE LOCATION
BORESIGHT POSITION
+Y S/C
+X S/C
REFERENCE MIRROR
STATION 1

Figure 1

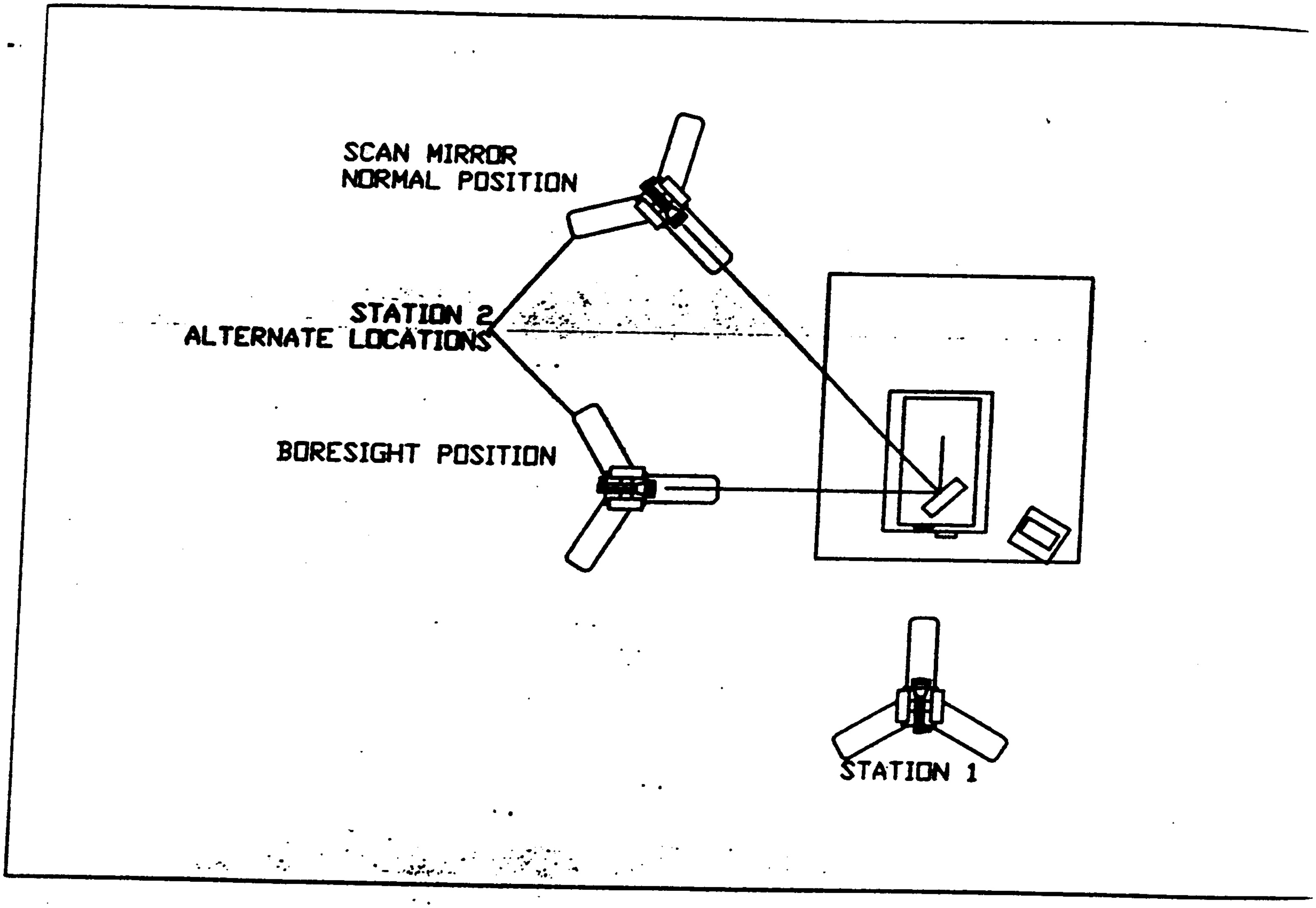

SCAN MIRROR
NORMAL POSITION
STATION 2
ALTERNATE LOCATIONS
BORESIGHT POSITION
STATION 1

Figure 2

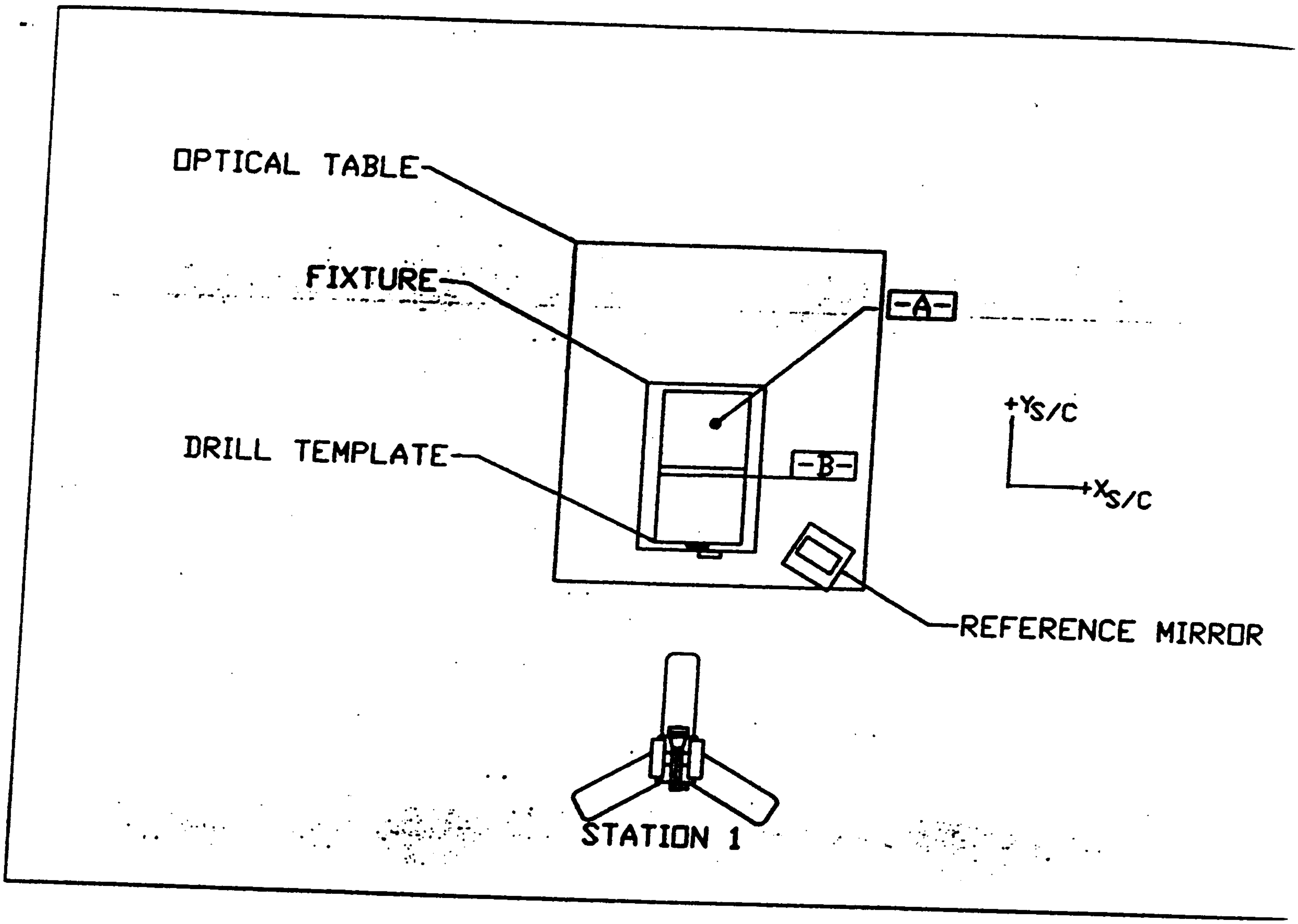

OPTICAL TABLE
FIXTURE
-A-
+Y S/C
DRILL TEMPLATE
-B-
+X S/C
REFERENCE MIRROR
STATION 1

Figure 3

STARDUST CAMERA OPTOMECHANICAL ALIGNMENT TEST
4/13/98

Data from E. Motts Lab Notebook #7, p 40 and 41, and 108 through 111.

Operation:	From Station:	To Station:	Hz	V	Description:
Fixture Mirror to	1	Ref Mir	180.00004	90.08477	Station 1 positioned for Fixture Mirror
Camera Mirror	1	Fixture Mir	164.35057	90.01223	
	1	Ref Mir	180.00003	90.08523	Station 1 positioned for Camera Mirror
	1	Camera Mir	164.06854	90.18290	
Autocollimate to	1	2	193.07800	NA	Station 1 positioned for Camera Mirror
Scan Mirror from W	2	1	13.07828	91.66951	Crosscollimating 1 and 2.
	2	Scan Mir	29.07295	89.86002	Station 2 autocollimating on Scan Mirror
Boresight Camera	1	2	217.85230	NA	Station 1 positioned for Camera Mirror
from W.	2	1	37.85219	92.90416	Crosscollimating 1 and 2.
	2	Pixel 512,512	73.85541	89.89635	Imaged T3000a reticle using camera.
			73.85739	89.89698	Three observations.
			73.85729	89.89661	
Autocollimate to	1	2	127.23641	NA	Station 1 positioned from Camera Mirror
Scan Mirror from E.	2	1	307.23637	90.85140	Crosscollimating 1 and 2.
	2	Scan Mir	299.50513	89.94792	Station 2 autocollimating on Scan Mirror
Boresight Camera	1	2	110.14434		Station 1 positioned for Camera Mirror
from E.	2	1	290.14400	92.14377	Crosscollimating 1 and 2.
	2	Pixel 512,512	254.72118	90.02224	Imaged T3000a reticle using camera.
			254.72264	90.02008	Three observations.
			254.72316	90.02069	
Drill Template	1	Ref Mir	180.00037	90.08483	After above measurements
Mirror	1	Cam Mir	164.06822	90.18683	After above measurements
	1	Ref Mir	179.99999	90.08506	After Camera removal
	1	Ref Mir	180.00023	90.08239	After Drill Template installation
	1	Drill Template	164.37144	90.12267	Autocollimating to Drill Template Mirror
Fixture Mirror	1	Ref Mir	180.00000	NA	Station positioned for Fixture Mirror
	1	Fixture Mir	164.34969	90.00723	Autocollimating to Fixture Mirror

Table 1

STARDUST CAMERA OPTOMECHANICAL ALIGNMENT TEST
4/13/98

Theodolite data:

ID	Hz	V
FIXTMIR1	164.35057	90.01223
CAMMIR1	164.06854	90.18290
SCANW1	29.07295	89.86002
BSW1	73.85670	89.89664
SCANE1	299.50513	89.94792
BSE1	254.72233	90.02100
DRTEMPI	104.37144	90.12287

Normal Vectors, SCC

ID	r	θ	ϕ
FIXTMIR1	1	195.64943	89.98777
CAMMIR1	1	195.93146	89.81710
SCANW1		330.9270s	90.13998
BSW1	1	286.14330	90.10336
SCANE1	1	80.49487	90.05208
BSE1	1	10527767	89.97900
DRTEMPI	1	195.62856	89.87733

From **ManCAT Jobfile Stardust.job:** Rotated to place DRTEMP1 at previous values (from 8/29/97)

ID	r	θ	ϕ
BSE1	1	359.55411	89.97905
BSW1	1	180.41973	90.10341
CAMMIR1	1	9020790	89.81005
DRTEMPI	1	89.90500	89.87028
FIXTMIR1	1	80.92587	89.98072
SCANE1	1	314.77131	90.05708
SCANW1	1	22520348	90.14498

Projected into X-Z plane:

ID	ϕ' (X-Z)
BSE1	89.97905
BSW1	90.10341
SCANE1	90.08105
SCANW1	90.20576

Table 2

STARDUST CAMERA OPTOMECHANICAL ALIGNMENT TEST
4/13/98

Knowledge Estimate:

Error Sources:	R or S	Magnitude
Theodolite Calibration Errors	S	0.00056
Leveling or Azimuth Reference	R	0.00028
Autocollimation to Mirrors	S	0.00014
Boresight to Detector	R	0.00108
Knowledge of Drill Template Mirror	S	0.00490

Propagation of Errors:

Mirrors to Drill Template Interface:		**Magnitude**	**Contribution**
Theodolite Calibration Errors	S	0.00056	0.00056
Leveling or Azimuth Reference	R	0.00028	0.00056
Autocollimation to Mirrors	S	0.00014	0.00028
Knowledge of Drill Template Mirror	S	0.00490	0.00490
Sum of Systematic Errors:			0.00574
RSS of Random Errors, X 3:			0.00188
3 σ Knowledge Estimate:			**0.007**
Knowledge Requirement:			**0.03**

Boresight to Drill Template Interface		**Magnitude**	**Contribution**
Theodolite Calibration Errors	S	0.00088	0.00112
Leveling or Azimuth Reference	R	0.00028	0.00056
Autocollimation to Mirror	S	0.00014	0.00028
Knowledge of Drill Template Mirror	S	0.00490	0.00490
Boresight to Detector	R	0.00108	0.00108
Sum of Systematic Errors:			0.00630
RSS of Random Errors, X 3:			0.01480
3 σ Knowledge Estimate:			**0.021**
Knowledge Requirement:			**0.03**

Table 3

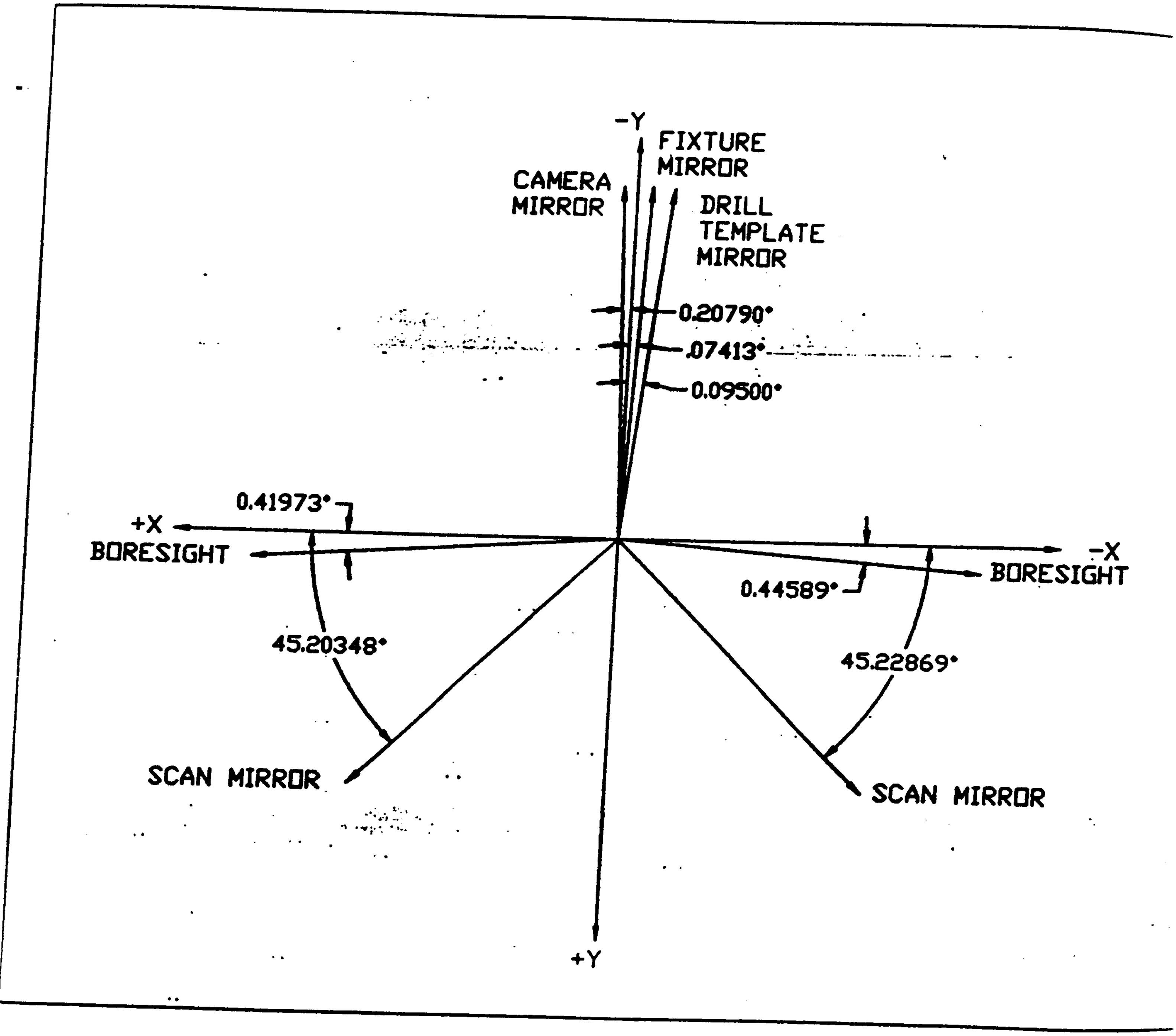

-Y
FIXTURE MIRROR
CAMERA MIRROR
DRILL TEMPLATE MIRROR
0.20790°
.07413°
0.09500°
0.41973°
+X
BORESIGHT
-X
BORESIGHT
0.44589°
45.20348°
45.22869°
SCAN MIRROR
SCAN MIRROR
+Y

Figure 4

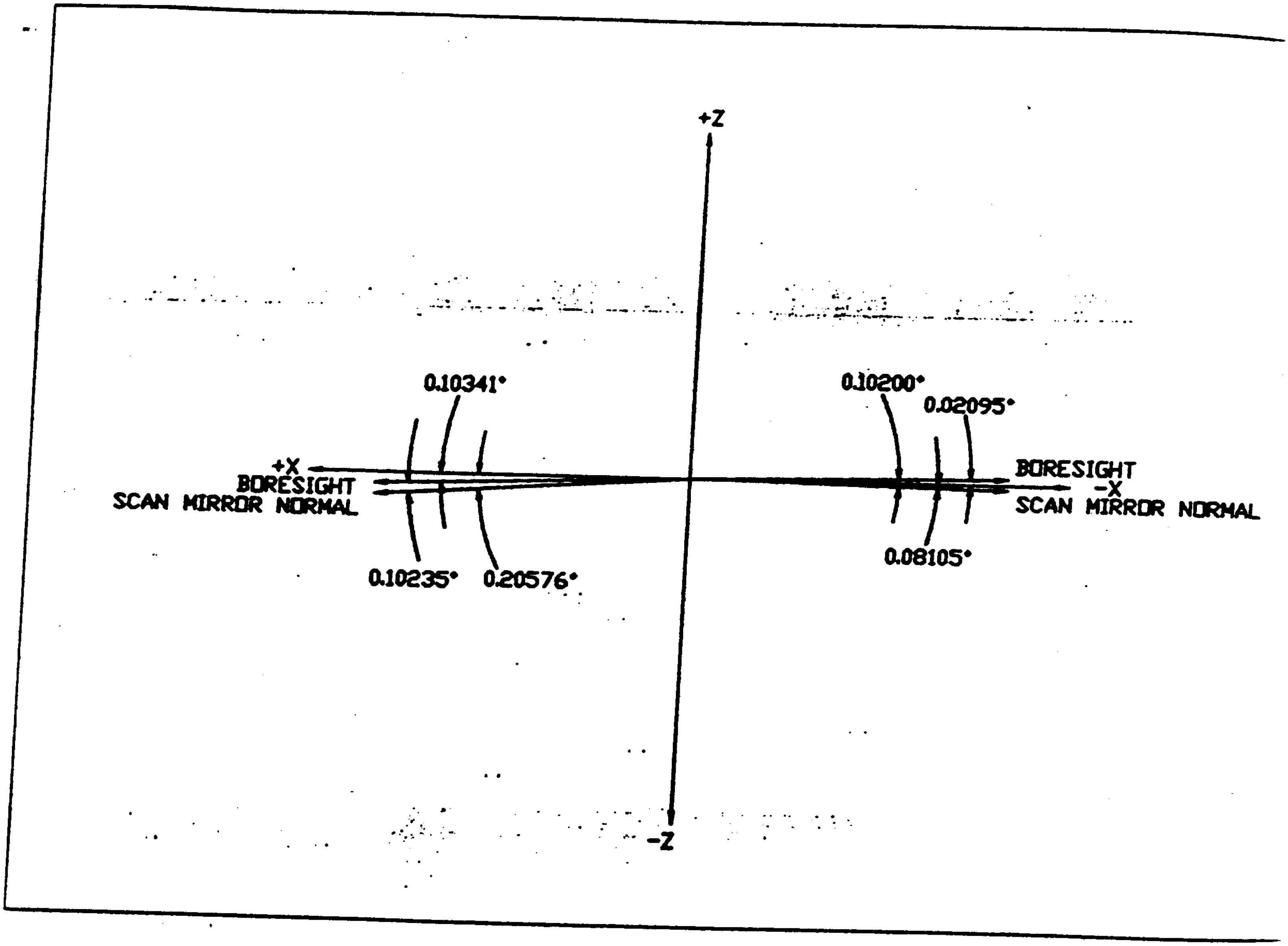

+Z
0.10341°
0.10200°
0.02095°
+X
BORESIGHT
SCAN MIRROR NORMAL
BORESIGHT
-X
SCAN MIRROR NORMAL
0.08105°
0.10235°
0.20576°
-Z

Figure 5

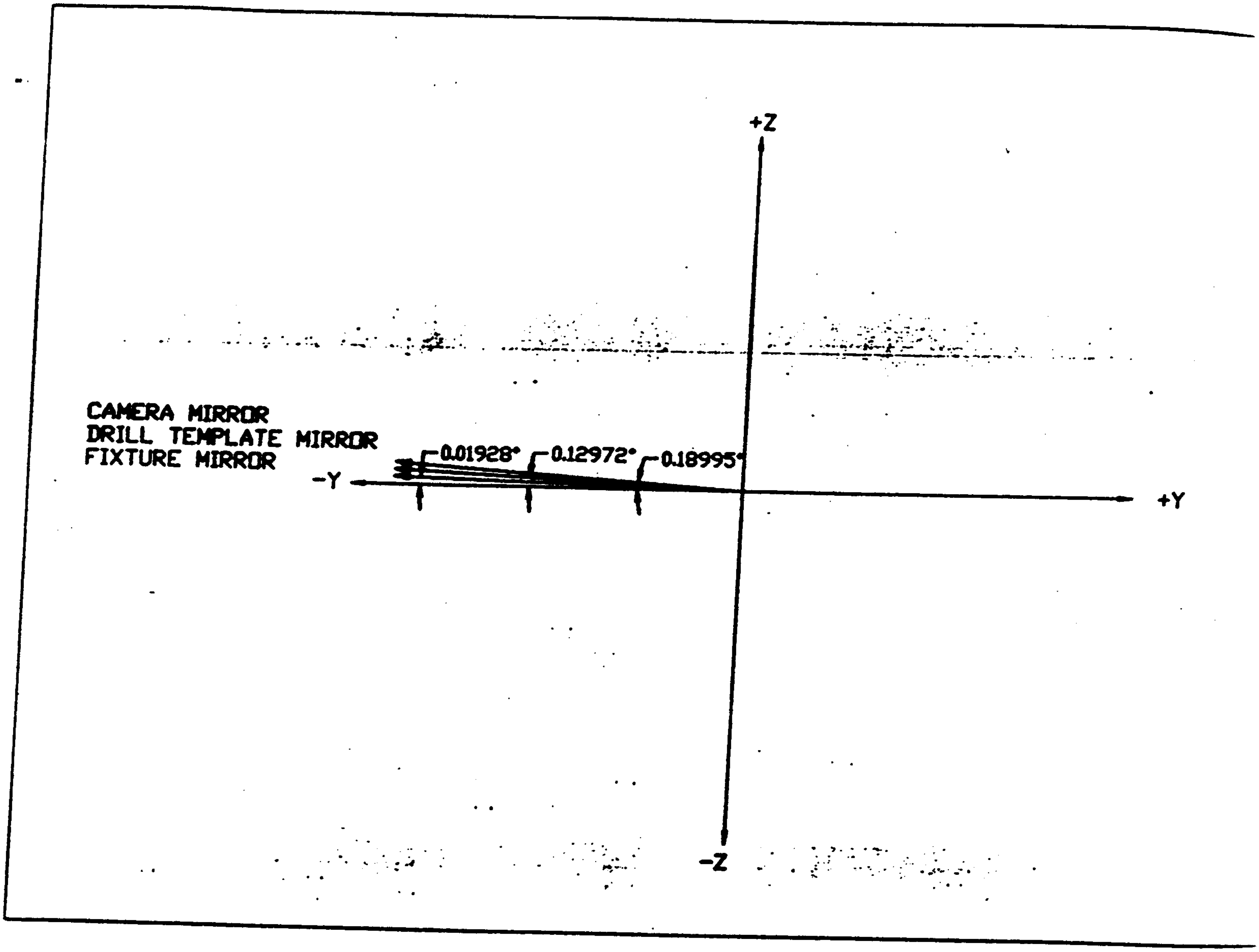

+Z
CAMERA MIRROR
DRILL TEMPLATE MIRROR
FIXTURE MIRROR
0.01928°
0.12972°
0.18995°
-Y
+Y
-Z

Figure 6

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM

August 28, 1997

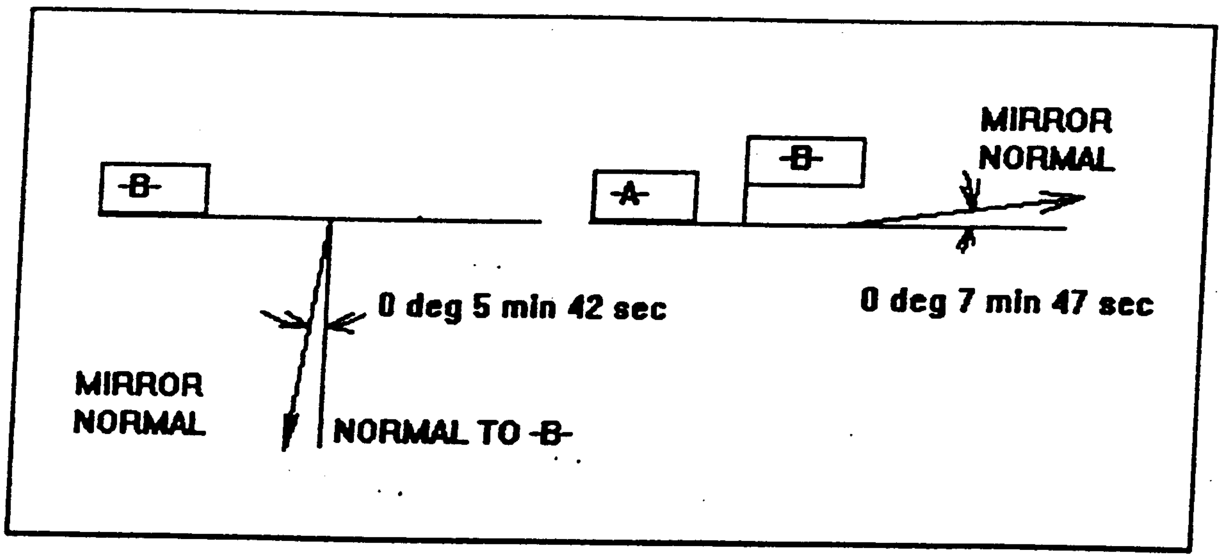
TO: Distribution

FROM: E. Motts

SUBJECT: Alignment Measurement of the Stardust Drill Template.

Measurement of the S/C Drill Template (P/N 10177498-1 A) alignment mirror was accomplished on August 28, 1997. An autocollimator was used to determine the angles of the mirror with respect to datum features -A- and -B-.

The following figure represents the orientation of the mirror normal with respect to the template datum features:



Measurement uncertainty is estimated to be ± 17.5 seconds (3 σ). The uncertainty reported is the root-sum-square of the random errors, including orientation of the drill template on the surface plate, setting of the reference mirror, reading of the autocollimator, and errors in the porroprism.

For additional information on this measurement, please contact me at (818) 354-9573.

Distribution: D. Day
G. Fraschetti
E. Hagerott
M. Schwochert

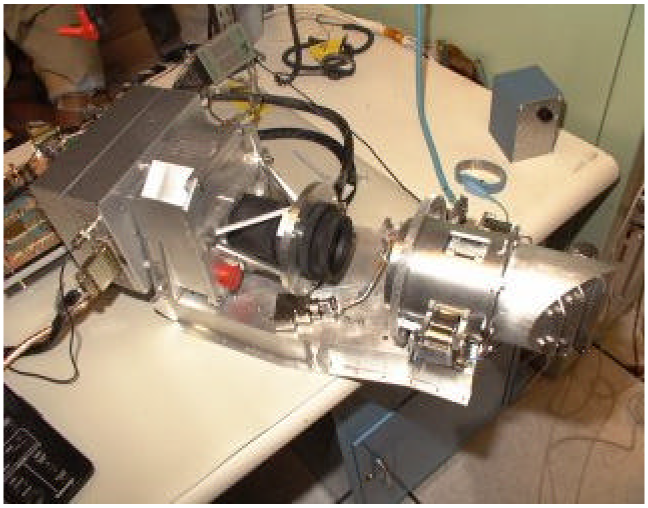
APPENDIX XIV.

Calibration Notebook

by Erick Malaret

This appendix gives complete details of the image processing requirements and validation which were completed for the calibration data for the NavCam on the STARDUST spacecraft. Sample calculations and calibration matrices are also discussed.

STARDUST's NAVCAM GROUND-CALIBRATION (v1.0)



Prepared by

Dr. Erick Malaret
ACT Corp.

Last Revision: April 11, 2000

TABLE OF CONTENT

1.Introduction

This document describes ACT's methodology/results associated with the derivation of ground-based calibration matrices for the NAVCAM. Detail information of the Stardust Navigation Camera (NC) can be found in the first few sections of the "The Stardust Navcam Calibration Report".

2.Stardust Camera Calibration Model

ACT adopted a simplified calibration equation used to characterize the NC as a function of input signal, and all the camera parameters. The readout from pixel x, before image data compression, is a digital number with the following functional dependence,

$$DN_{BC}(x \mid P,t,T,i) = \mathrm{int}\left[t \cdot U_i(x) \cdot \left\{R^P \cdot S_{DNi}\right\} + B_{DN}(T,x) + D_{DN}(x,T) \cdot t\right] \quad \text{(Eq 1)}$$

Since the Stardust NAVCAM camera makes use of a digital look-up-table type of compression, the actual DN value after compression for the same pixel can be expressed as,

$$DN_{AC}(x \mid P,t,T,i) = LUT[DN_{BC}(x \mid P,t,T,i), q] \quad \text{(Eq 2)}$$

where,

$DN_{BC}(x \mid P,t,T,i)$	Digital number readout from pixel x, before image data compression
$DN_{AC}(x \mid P,t,T,i)$	Digital Number readout from pixel x, after image data compression
x	Position of a pixel in the focal plane array
P	Periscope flag. P=1 ➔ periscope is in use P=0 ➔ periscope is not is use
τ	Integration time in milli-seconds. Note: The actual value of the integration time can be slightly different from the commanded value. The PDS file has the correction already included in the header.
T	Electronics Temperature in degrees Kelvin. Note: this is not the CCD temperature
i	Index to filter number.
$U_i(x)$	Spatial non-uniformity associated with the combination of i-th filter and CCD responsivity. The non-uniformity has a spatial mean value of 1.
R	Effective reflectivity of periscope mirrors
$B_{DN}(T,x) + D_{DN}(x,T) \cdot t$	Bias offset at pixel location x. This term is **dependent on temperature**. The value of this term is expressed in digital numbers or counts.
q	Compression Look-up-table id, q=0 ➔ identity LUT q=1 ➔ square root compression LUT

The output of a CCD pixel, attributed to only signal, can be expressed in terms of a spectral integral,

$$\left\{R^P \cdot S_{DNi}\right\} = R^P \cdot \alpha \cdot \int R_\lambda(\lambda)F(\lambda)P(\lambda)O(\lambda)QE(\lambda)d\lambda \equiv I_{EQ} \cdot R^P \cdot \alpha \cdot NQE_i$$

(Eq 3)

The spectral integral folds the spectral radiance, the spectral filter transmisivity, the conversion from energy to a number of photons, spectral optics transmission, and the spectral detector quantum efficiency. This can also be expressed as an equivalent input radiance times the net quantum efficiency. The α_i constant is used for proportionality constant, and the NQE_i

Defining ILUT as the inverse Look-up-table, and from Eq(1,2) it follows,

$$S_{DNi} = \frac{ILUT\left[DN_{AC}(x \mid P,t,T,i),q\right] - B_{DN}(T,x) - D_{DN}(x,T)\cdot t}{t \cdot U_i(x)\cdot R^P} \quad \text{(Eq 4)}$$

The above allows us to express the equivalent band radiance as,

$$\boxed{R_{\lambda\, EQ_i}(x) = \frac{ILUT\left[DN_{AC}(x \mid P,t,T,i),q\right] - B_{DN}(T,x) - D_{DN}(x,T)\cdot t}{t \cdot U_i(x)\cdot R^P \cdot \alpha_i \cdot NQE_i}} \quad \text{(Eq 5)}$$

Hence to obtain the equivalent radiance for pixel x, the following steps are applied,

Step #	Description
0	Apply inverse LUT to measured DN values. This removes the effect of the compression.
1	Subtract dark field fixed pattern, i.e., B_DN(T,x) And Subtract dark count rate times integration time, i.e., D_DN(x,T)*tint
2	Normalize by denominator term in Eq.(5) (except non-uniformity)
3	Normalize by non-uniformity

3.NAVCAM Ground Calibration Matrices

In this section characterization of the NAVCAM camera is done using only measurements done during the ground calibration at JPL. All of the data used in this section is present in the **STARDUST Pre-flight Calibration Archive.** A detail description of the actual measurements done and the data can be found in the PDS archive documents.

Validation of Compression System

From the calibration equation it is clear that compression of the NC is done as the last step of the processing in the camera. This is easily verified when looking at dark field data, compressed and not-compressed. Figure 1 shows two dark field images where the only difference is the application of the compression. For the case of dark field images the response of the CCD is fairly uniform. Hence, the mean value of both the compressed and the un-compressed images should be consistent with the NC LUT mapping.

Mean value of compressed image ➔ 456.2
Mean value of uncompressed image ➔ 74.9
This is in direct agreement with the LUT provided earlier in the **STARDUST Pre-flight Calibration Archive**.

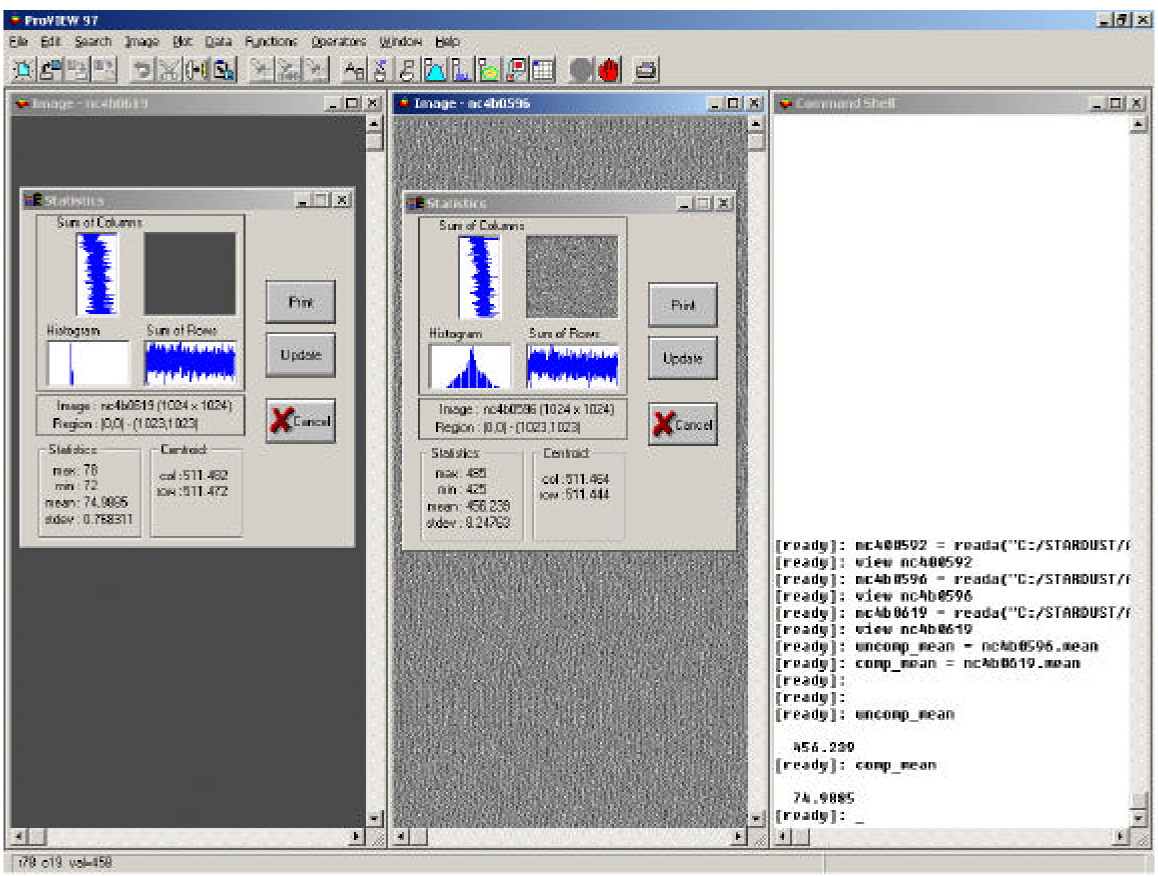


Figure 1 Comparison of uncompressed and compressed image (under no input signal).

Estimation Bias Offset Matrix

The bias offset term in the camera model equation, $B_{DN}(T, x)$, is a function of temperature and pixel location. A full characterization of it was obtained from the pre-flight data .

A script file was written in the ProVIEWMSHELL language to compute to bias level at each of the three temperatures available in the pre-flight data, i.e. –30, -40, and –50 degrees Centigrade (code is provided in the calibration routines section). This was done by averaging up all images in the **STARDUST Pre-flight Calibration Archive** for which:

- there is no input signal (because shutter is closed)
- no compression is applied to the images
- this is done for all the three key temperatures, -30,-40,-50

From the following table and plot it is evident that there is linear relation between CCD temperature and offset bias level.

CCD Temperature	Number of Images Used	Spatial Mean	Spatial Standard Deviation
-30	54	413.27	1.19
-40	36	457.39	1.38
-50	23	502.11	1.58

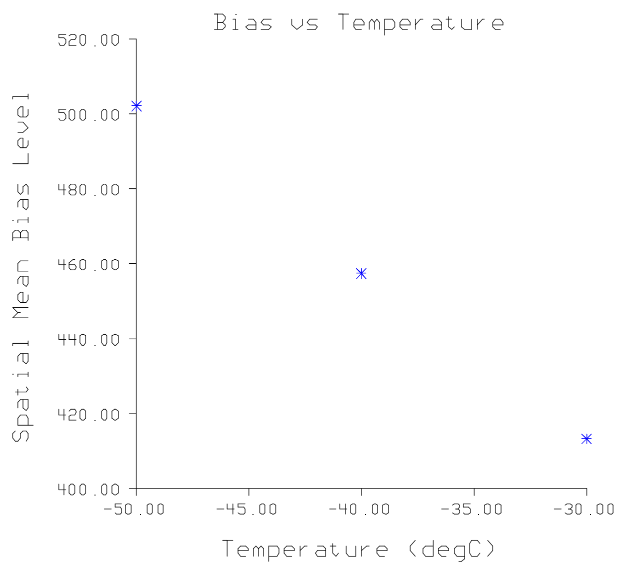


Figure 2 Plot of Spatial Mean Bias level vs. CCD FPA temperature

From the above the average value of the offset bias can expressed as:

$B_{DN}(T, x)$ **= 279.90 –4.44*T,**

where T is the electronics temperature in degrees Centigrade. The spatial fluctuations in the bias offset are less that half a percent with respect to the mean offset bias value. Therefore, in **version 1.0** of the calibration matrices, no spatial dependency will be used.

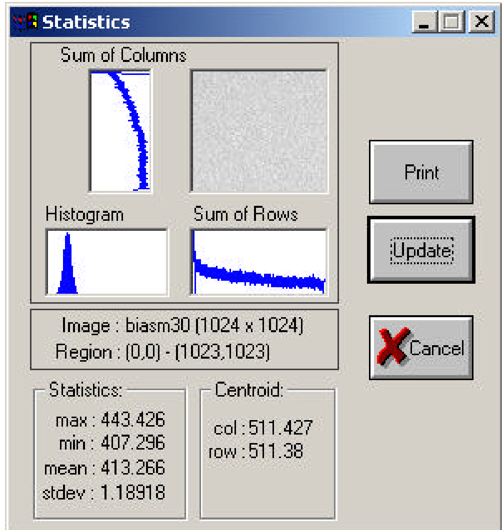


Figure 3 Bias statistical results for run at CCD temperature of -30 degC.

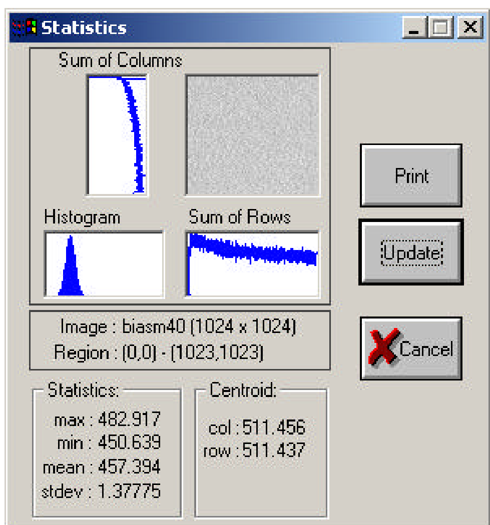


Figure 4 Bias statistical results for run at CCD temperature of -40 degC.

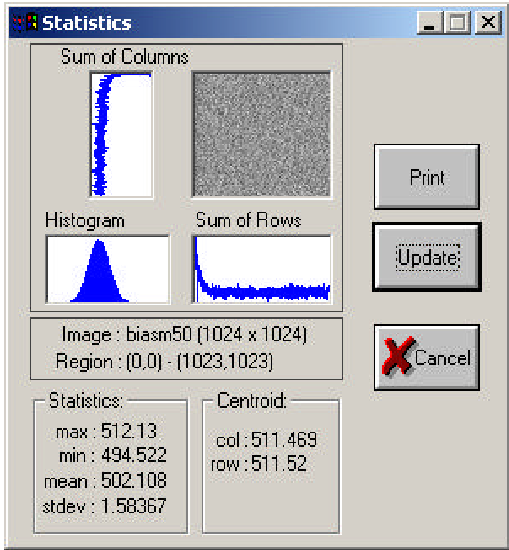


Figure 5 Bias statistical results for run at CCD temperature of -50 degC.

JPL has reported that the bias offset is sensitive to the electronics temperature and not the CCD temperature. During the ground calibration the electronics temperature was not recorded. Another way to estimate the bias offset is by using the Baseline-Stabilization (BLS) pixels embedded in the PDS data files. These pixels are not real physical pixels but their value moves up and down with changes in electronics temperature.

Estimation of Dark Field Matrix

For the NAVCAM camera at an integration time of onesecond , and T=-40deg. C, the dark current contribution (second term) is about 10 electrons, which equals 0.5DN. Therefore, for practical purposes during mission operations, the dark field contribution is negligible and will not be modeled in this version of the calibration equation.

$D_{DN}(x,T) \equiv 0$, **adopted in version 1.0 of the calibration matrices.**

Estimation of Effective Camera Exposure Times

There is a discrepancy in the NAVCAM between commanded camera exposure and effective camera exposure. This can be easily observed on consecutive images measured with same camera parameters and looking at the constant source. The average DN value alternates from image to image.

The **STARDUST Pre-flight Calibration Archive** incorporate the corrected exposure in the field called "EXPOSURE_DURATION"

Estimation of Coherent Noise

Close observation of high and low exposure images reveal the presence of a coherent (or spatially periodic) noise pattern in all of the images observed in the ground data. The image below provides an example of this, where it is evident that the periodic noise shows in the vertical direction. The periodicity of this noise is 42-43 pixels as it has been observed in multiple images. For the particular image in display, the noise has a peak-to-peak of about 20DN on a background with an average of 3200 DN, i.e. 0.6% of the background.

Depending on the magnitude of this noise in the flight data, there may be a need to include a spatial noise removal step in the calibration of the NAVCAM images. Version 1.0 of the calibration does not include any algorithms for spatial noise removal.

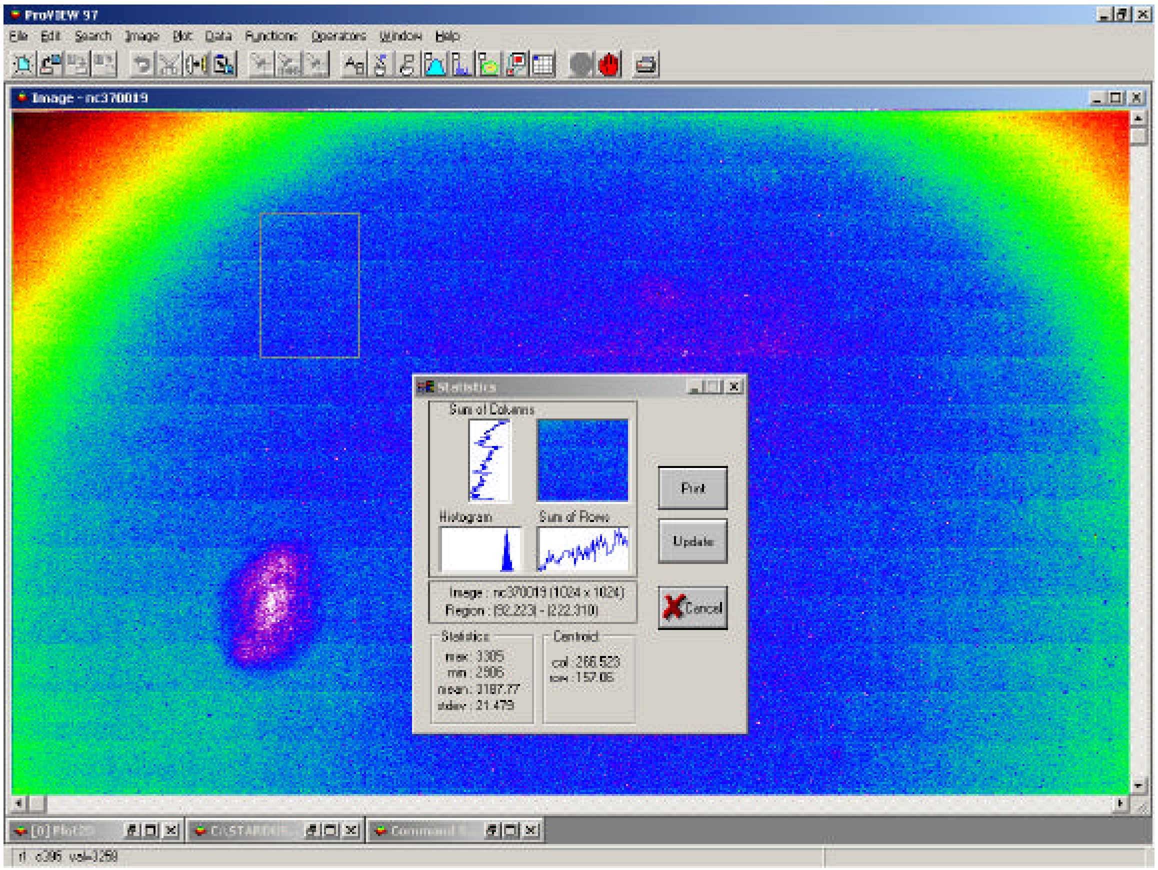


Figure 6 Depiction of spatial periodic noise in image nc370019

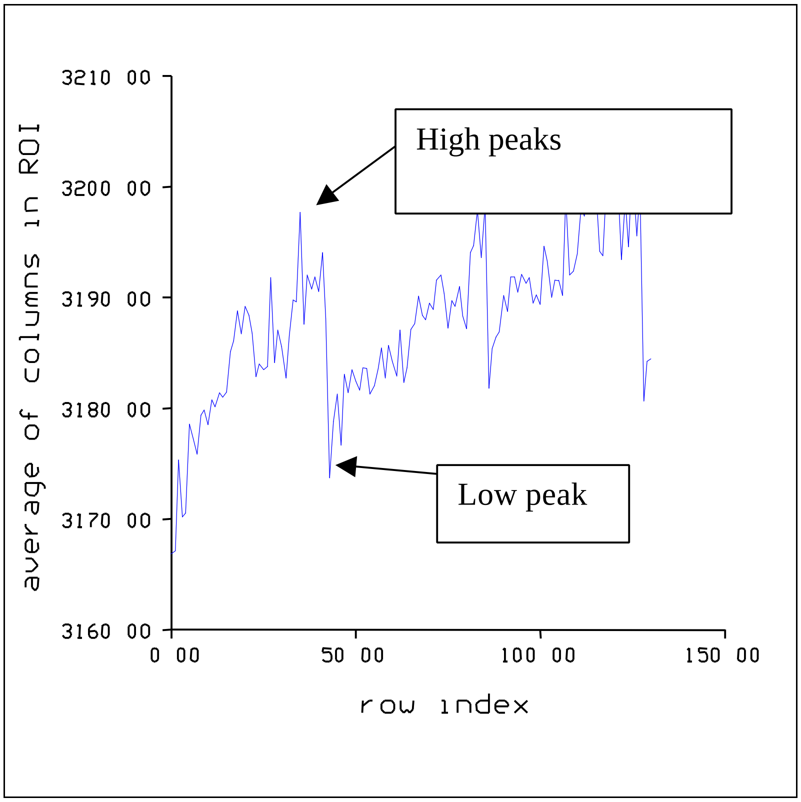


Figure 7 Plot of column average over a sub-region of image nc370019.

Estimation of Non-uniformity Matrices

The following table provides all the images, in the **STARDUST Pre-flight Calibration Archive**, that are used to provide a first order characterization of the non-uniformity function. The ProVIEW script file used is found in the appendix.

Filter Wheel Position	Source Image	Non-uniformity Calibration Matrix File (version 1.0)
0	NC300002.img	nonu_0.img
1	NC310076.img	nonu_1.img
2	NC320107.img	nonu_2.img
3	NC330147.img	nonu_3.img
4	NC340236.img	nonu_4.img
5	NC350276.img	nonu_5.img
6	NC360196.img	nonu_6.img
7	NC370019.img	nonu_7.img

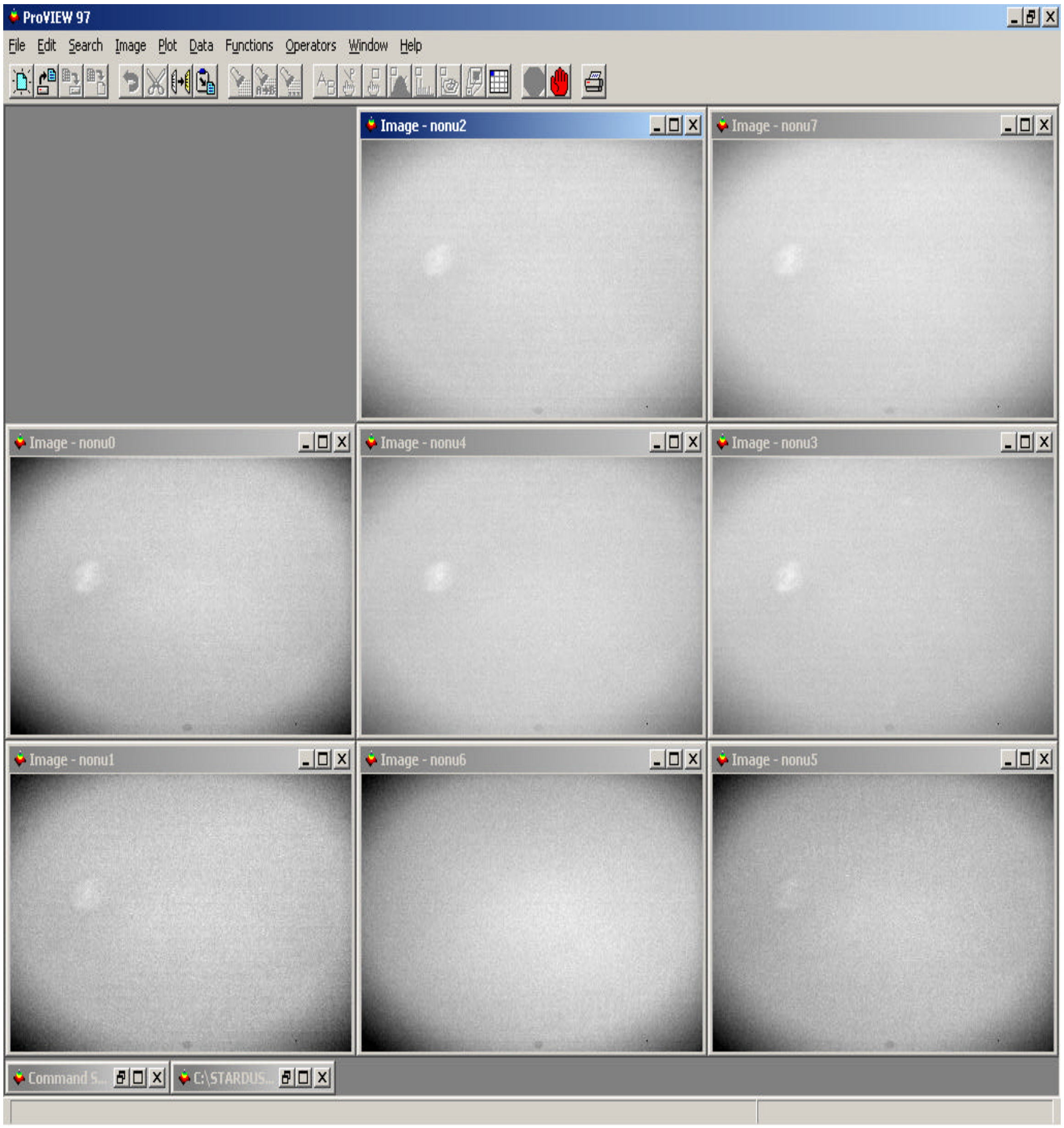


Figure 8 Nonuniformity estimates for each of the filters

Figure 8 shows the non-uniformity estimates for each of the filters. Notice that filter#6 does not show the bright blemish visible in all the other filters.

PSF Estimation

In the **STARDUST Pre-flight Calibration Archive** there are no point source images available. Hence, no estimate of the PSF is included in this version 1.0 of the calibration.

Estimation of NQE_i coefficients

Filter #	**NQE_i -C30**	**NQE_I -C30**	**NQE_I -C30**
0	9.360E+16	7.316E+16	7.016E+16
1	2.030E+16	1.900E+16	1.900E+16
2	1.741E+16	1.641E+16	1.632E+16
3	1.544E+16	1.448E+16	1.440E+16
4	1.486E+16	1.419E+16	1.419E+16
5	1.964E+16	1.911E+16	1.746E+16
6	2.952E+16	2.978E+16	2.978E+16
7	5.139E+16	4.544E+16	4.495E+16

alpha = 4.616E-13

4.Calibration Routines

The following contains routines used in the generation of this document.

Bias_Estimate

```
// This routine will add up all images for which:
//   +there is no input signal (because shutter is closed)
//   +no compression is applied to the images
//   +this is done for all the three key temperatures, -30,-40,-50
// The input to this routine is the Stardust DVD with
// pre-flight calibration data

// compute averages for -30, -40, and -50 degC.
temp = -30
while(temp>=-50){
        $substring = "NC"::int2str(temp.abs/10)::"B*.img"
        $list = findfiles("e:",$substring)
        $list
        i = 0
        N = nlines($list)
        isum = 0
        n = 0
        while(i<N){
                meter($list(i,:),i/N*100)
                x = reada($list(i,:),"pds")
                $compression = "QUANTIZATION_MODE_ID = \"OFF\""
                $x = x.text
                groi = eqindexS($x, $compression)

                PDStemp = str2float(pdskwdstr(x.text,"FOCAL_PLANE_TEMPERATURE"))-273.15
                Tdiff    = PDStemp-temp
                if(groi.ncols && (Tdiff.abs<3) ){
                        // only add up images uncompressed
                        // and with temperatures that do not seem in error
                        isum = isum+x
                        n = n+1  // number of images selected so far
                        groi2 = eqindexS($x, "FOCAL_PLANE_TEMPERATURE")
                        $list(i,:)
                        $x(groi2.imag,:)
                        str2int($x(groi2.imag,:))
                        i::n::N
                }

                i = i+1
        }
        isum = isum/n
        view isum
        meter("",-1)
        writea("uncomp_bias_offset_at_m"::int2str(temp.abs)::"_n"::int2str(n)::".flt",isum,"float")

        temp = temp-10
}

biasm30 = reada("C:/STARDUST/ACT-CAL-DOCS/BIASES/biasm30.flt","float")
view biasm30
biasm30 = reada("C:/STARDUST/ACT-CAL-DOCS/BIASES/uncomp_bias_offset_at_m30_n54.flt","float")
view biasm30
biasm40 = reada("C:/STARDUST/ACT-CAL-DOCS/BIASES/uncomp_bias_offset_at_m40_n36.flt","float")
view biasm40
biasm50 = reada("C:/STARDUST/ACT-CAL-DOCS/BIASES/uncomp_bias_offset_at_m50_n23.flt","float")
view biasm50
M_linetype=0
M_tlabel = "Bias vs Temperature"
M_xlabel = "Temperature (degC)"
M_ylabel = "Spatial Mean Bias Level"
plot0(-30::-40::-50, biasm30.mean::biasm40.mean::biasm50.mean)


x = -30::-40::-50
```

```
y = biasm30.mean::biasm40.mean::biasm50.mean
[yhat,coeff]=polyfit[y,x,1]

"values for a and b are:"
coeff
```

Non-Uniformity_Estimate

```
// nonu_estimate.msh
// This will read the files identified to be representative
// of non-uniformity images for version 1.0 of the ground calibration
//

$files= "NC300002.img"
$files= $files::"\n"::"nc310076.img"
$files= $files::"\n"::"nc320107.img"
$files= $files::"\n"::"nc330147.img"
$files= $files::"\n"::"nc340236.img"
$files= $files::"\n"::"nc350276.img"
$files= $files::"\n"::"nc360196.img"
$files= $files::"\n"::"nc370019.img"

// load each source images
i=0
while(i<8){
        $list = findfiles("e:",$files(i,:))
        $list = smodify($list,"\n","")
        $list = smodify($list,"NC","nc")
        $list = smodify($list,"IMG","img")
        $list = smodify($list,"\\","/")

        $list
        evaltext "x=reada(\""::$list::"\",\"pds\")"

        $x = x.text
        $PDSLamp = pdskwdstr(x.text,"CAL_LAMP_MODE_ID")
        $PDSComp = pdskwdstr(x.text,"QUANTIZATION_MODE_ID")
        PDStemp = str2float(pdskwdstr(x.text,"FOCAL_PLANE_TEMPERATURE"))-273.15
        if(($PDSLamp=="\"OFF\"")&&($PDSComp=="\"OFF\"") ){
                bias_offset = 279.90 -4.44*PDStemp
                xnew = x - bias_offset
                // avoid border of two pixels around the image!!!
                xnewroi = xnew(wdef(2,2,x.nrows-4,x.ncols-4))
                xnewroi = xnewroi/xnewroi.mean
                xnew          = ones(x.nrows,x.ncols)
                xnew(2:,2:) = xnewroi
                xnew          = xnew/xnew.mean
                [xnewmedian]=nxmmedian[xnew,3,3]
                // only use images with lamp and compression off          // only add up images uncompressed
                if(i==0){
                        $outlist = "nonu_"::int2str(i)::"_"::$files(i,:)
                }else{
                        $outlist = $outlist::"\n"::"nonu_"::int2str()::"_"::$files(i,:)
                }
                writea($outlist(i,:),xnew,"float")
                evaltext "nonu"::int2str(i)::"=xnew"
                evaltext "x"::int2str(i)::"=x"
                evaltext "view nonu"::int2str()
        }
        i = i+1
}
```