Recalculate Thermal Analysis
Cases 11, 12, 16, 17
Section 6 of Canberra paper

The parameter for the type of geometry was incorrect in the input file for the numerical diffraction calculations. This showed up in comparing the diffraction patterns computed numerically with the patterns computed analytically (using the method described in SAO Special Report 382).

Section 1.

One inch, uncoated, no dihedral angle offset, analytic

```
 Microradians     Cross section
   0.0000000        2.829377                                                   *
   2.0000000        2.749793                                                 (*
   4.0000000        2.571133                                                     *)
   6.0000000        2.301556                                            (*
   8.0000000        1.976676                                      (*)
  10.0000000        1.635765                               ( *)
  12.0000000        1.318930                         ( * )
  14.0000000        1.054899                    ( * )
  16.0000000        0.863293                (  * )
  18.0000000        0.747862             (   * )
  20.0000000        0.699399            (   * )
  22.0000000        0.699757            (   * )
  24.0000000        0.725381             (  *  )
  26.0000000        0.752660              (  *  )
  28.0000000        0.763108            (    *   )
  30.0000000        0.744123           (     *   )
  32.0000000        0.694121         (      *   )
  34.0000000        0.616657       (      *    )
  36.0000000        0.521101      (      *   )
  38.0000000        0.420431     (     *   )
  40.0000000        0.325316 (    *  )
  42.0000000        0.244006 (   * )
  44.0000000        0.181019 (  *)
  46.0000000        0.136738 ( *
  48.0000000        0.107396 (*)
  50.0000000        0.088534 (*
```

Input file:
Dihedral angle offset 0.00

```
 LIST 1 1 1 0
 00. 5. 00. .00 0001  .00  0.00     .05     2   51  50.
  0.7071   1.0000   .707106781 0.0       0.0      .707106781  .5320 1.461 1.484
.707106781 0.0       0.0      .707106781
   51   -3   32.       40.       100.
   51   -3   32.       40.       100.
```

One inch, uncoated, no dihedral angle offset, numerical, type 2

```
 0.00  2.83006390                                                   *
 2.00  2.76982230                                                  *
 4.00  2.63278828                                               *)
 6.00  2.42097114                                           (*
 8.00  2.15592855                                      (*)
10.00  1.86238553                                 (*)
12.00  1.56855685                           (* )
14.00  1.29708549                     (  * )
16.00  1.06824443                 ( *  )
18.00  0.89362189             (  *  )
20.00  0.77682140           (  *  )
22.00  0.71415554         (   *  )
24.00  0.69563016         (   *  )
26.00  0.70671468         (   *  )
28.00  0.73125038          (  *   )
30.00  0.75445040          (   *   )
32.00  0.76436072         (    *   )
34.00  0.75316040        (     *    )
36.00  0.71700945      (      *    )
38.00  0.65875128     (      *    )
40.00  0.58331456    (      *    )
42.00  0.49773258  (      *    )
44.00  0.40997452  (     *   )
46.00  0.32758910 (    *   )
48.00  0.25568283 (   *  )
50.00  0.19742557 (  * )
```

Input file

Type 2 geometry

```
  51     2 050.0    .05       +00.       00.      +0.00     +0.00     +0.00
0.7071   1.0000    .707106781 0.0       0.0      .707106781   .5320  1.461 0.
                   .707106781 0.0       0.0      .707106781
                                                                           051
1481    0     0   1.00
```

One inch, uncoated, no dihedral angle offset, numerical, type 5

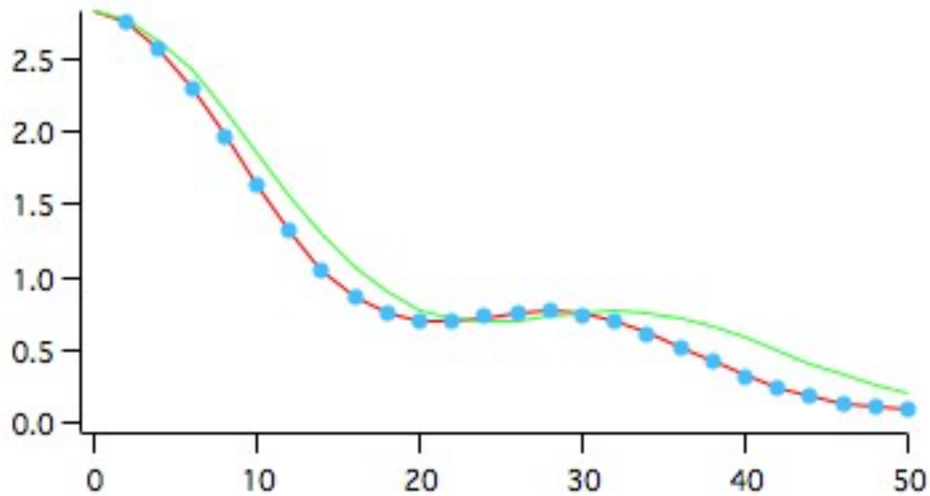
```
  0.00    2.83006390                                                          *
  2.00    2.75010283                                                        (*
  4.00    2.57064001                                                     *)
  6.00    2.29999064                                                (*
  8.00    1.97408465                                          (*)
 10.00    1.63250549                                   ( *)
 12.00    1.31557425                             ( * )
 14.00    1.05209378                       (   *  )
 16.00    0.86157065                   (   *  )
 18.00    0.74750031                 (   *  )
 20.00    0.70033761                (   *  )
 22.00    0.70160148                (   *  )
 24.00    0.72750939                 (  *   )
 26.00    0.75433059                 (   *   )
 28.00    0.76371685                (    *   )
 30.00    0.74321707              (      *    )
 32.00    0.69161631             (      *    )
 34.00    0.61275654           (      *     )
 36.00    0.51630987          (      *    )
 38.00    0.41533465         (      *   )
 40.00    0.32049521 (     *    )
 42.00    0.23991996 (    * )
 44.00    0.17791201 ( * )
 46.00    0.13461603  (*)
 48.00    0.10608308 (*)
 50.00    0.08775320 (*)
```

Input file:
Type 5 geometry

```
   51     5  050.0    .05       +00.       00.      +0.00     +0.00     +0.00
 0.7071   1.0000    .707106781 0.0       0.0      .707106781   .5320  1.461 0.
                    .707106781 0.0       0.0      .707106781
                                                                            051
 1481    0     0   1.00
```

Section 2.

Compare analytic and numerical diffraction calculations - type 2 and type 5
no dihedral angle offset



Red = analytic
Green = numerical type 2
Blue dots = numerical type 5

The effect of the error in the type of geometry was to make the diffraction patterns wider (green curve). The agreement between the numerical (blue dots) and analytic (red) calculations is almost exact.

Section 3.

One inch, uncoated, dihedral = +1.25, analytic

```
 0.0000000       1.027828                                                    *
 2.0000000       0.994669                                                 *)
 4.0000000       0.921546                                             (*
 6.0000000       0.814929                                        *)
 8.0000000       0.693695                                 (*)
10.0000000       0.578077                           (*)
12.0000000       0.486704                      ( *)
14.0000000       0.431411                   ( *)
16.0000000       0.417008                   (*)
18.0000000       0.439232                   ( * )
20.0000000       0.486881                    (   *  )
22.0000000       0.545134                   (       *    )
24.0000000       0.598105                   (         *       )
26.0000000       0.632747                  (            *         )
28.0000000       0.641507               (                *          )
30.0000000       0.621481            (                   *           )
32.0000000       0.578197         (                  *              )
34.0000000       0.519282       (                 *               )
36.0000000       0.455224    (                 *               )
38.0000000       0.396086   (               *               )
40.0000000       0.348511  (              *              )
42.0000000       0.315744 (             *              )
44.0000000       0.297168 (            *             )
46.0000000       0.288758 (            *            )
48.0000000       0.284368  (           *           )
50.0000000       0.278351  (          *           )
```

Input file:

Dihedral angle offset 1.25 arcsec

```
 LIST 1 1 1 0
 00. 5. 00. .00 0001  .00 1.25     .05     2   51  50.
  0.7071   1.0000   .707106781 0.0       0.0       .707106781  .5320 1.461 1.484
.707106781 0.0       0.0      .707106781
   51   -3   32.       40.       100.
   51   -3   32.       40.       100.
```

One inch, uncoated, dihedral = +1.25, numerical, type 2

```
    0.00    1.04403250                                                   *
    2.00    1.01864055                                                  *
    4.00    0.96163166                                               *
    6.00    0.87565830                                          (*
    8.00    0.77233521                                     (*
   10.00    0.66482756                               (*)
   12.00    0.56700970                          ( *)
   14.00    0.48958883                      ( *)
   16.00    0.44054837                    (* )
   18.00    0.42257437                   ( *)
   20.00    0.43342994                   ( * )
   22.00    0.46704132                   (   *  )
   24.00    0.51420229                   (     *    )
   26.00    0.56452609                   (        *     )
   28.00    0.60772887                  (           *        )
   30.00    0.63554420                 (             *          )
   32.00    0.64365473               (               *            )
   34.00    0.63041320            (                  *              )
   36.00    0.59739432          (                  *               )
   38.00    0.55047118        (                  *                )
   40.00    0.49585580     (                  *                )
   42.00    0.44022747    (                *                 )
   44.00    0.38971327  (                *                )
   46.00    0.34884192  (              *               )
   48.00    0.31924113 (             *               )
   50.00    0.30068535 (             *              )
```

Input file

Geometry type 2

```
  51    2  050.0    .05       +00.       00.      +1.25     +1.25     +1.25
0.7071   1.0000    .707106781 0.0       0.0      .707106781   .5320  1.461 0.
                   .707106781 0.0       0.0      .707106781
                                                                           051
1481    0     0   1.00
```

One inch, uncoated, dihedral = +1.25, numerical, type 5

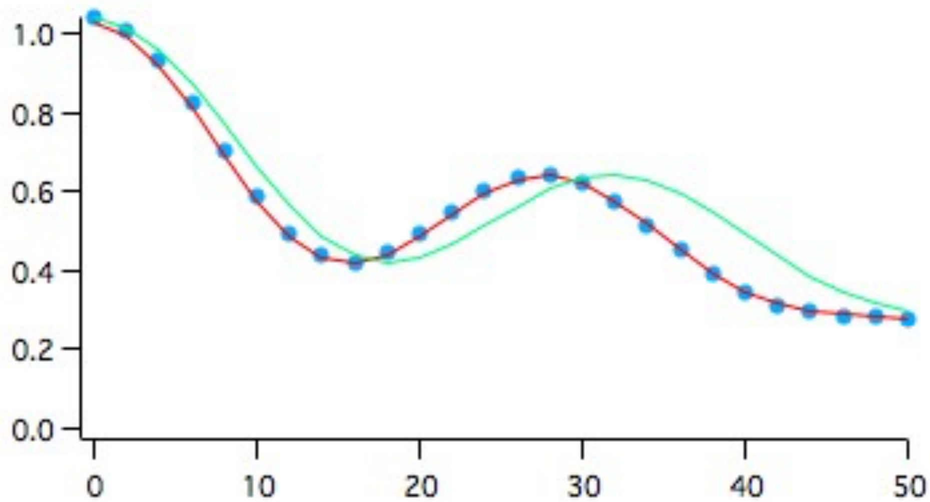
```
    0.00    1.04403250                                                   *
    2.00    1.01037601                                                 *)
    4.00    0.93615724                                             (*
    6.00    0.82795064                                        *)
    8.00    0.70491526                                  *)
   10.00    0.58756452                           ( *)
   12.00    0.49475192                      ( *)
   14.00    0.43840936                   ( * )
   16.00    0.42331611                   ( *)
   18.00    0.44506554                   (  * )
   20.00    0.49225282                   (    *   )
   22.00    0.54986103                   (       *     )
   24.00    0.60188365                  (          *        )
   26.00    0.63524397                 (             *          )
   28.00    0.64252199              (                *             )
   30.00    0.62096349            (                 *              )
   32.00    0.57635069         (                  *               )
   34.00    0.51649326      (                  *                )
   36.00    0.45201202    (                 *                )
   38.00    0.39294868  (                *                )
   40.00    0.34583700  (              *               )
   42.00    0.31373450 (             *               )
   44.00    0.29579633 (            *               )
   46.00    0.28780304 (            *              )
   48.00    0.28349821  (           *             )
   50.00    0.27722673  (          *            )
```

Input file
Geometry type 5

```
  51    5  050.0    .05       +00.       00.      +1.25     +1.25     +1.25
0.7071   1.0000    .707106781 0.0       0.0      .707106781   .5320  1.461 0.
                   .707106781 0.0       0.0      .707106781
                                                                           051
1481    0     0   1.00
```

Section 4.

Compare analytic and numerical diffraction patterns - type 2 and 5
Dihedral = 1.25



Red = analytic
Green = numerical type 2
Blue dots = numerical type 5

The effect of the error in the type of geometry was to make the diffraction patterns wider (green curve). The agreement between the analytic (red) and numerical (blue dots) curves is almost exact.

In order to determine the effect of the error in the parameter for the geometry, the thermal cases 11, 12, 16, and 17 have been recalculated.

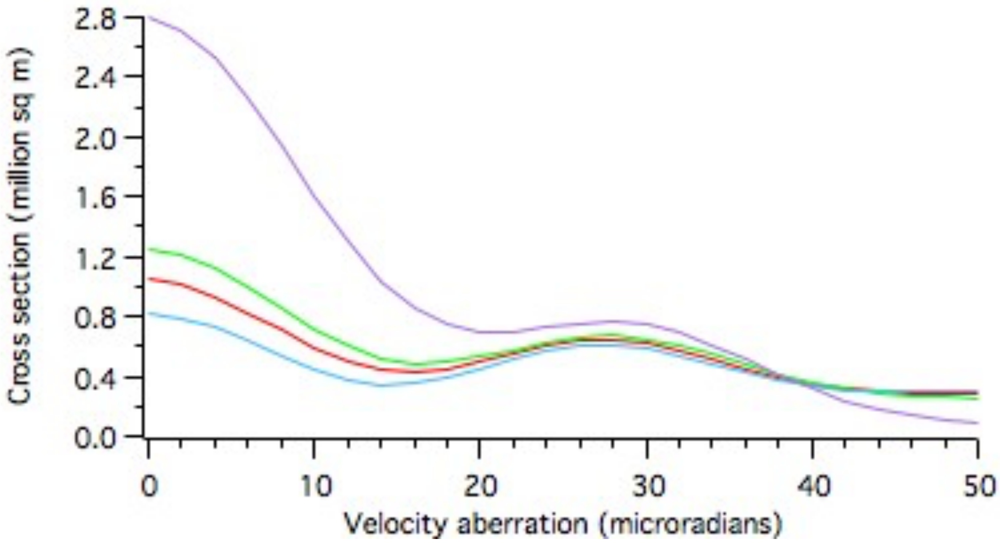
In addition to using the results of the thermal simulations done in Italy, the thermal analysis has been done using my own thermal program Thermal2.

The only parameters supplied for the Italian simulations are the emissivity of the cavity, the temperature of the core, and the computed temperature of the retroreflector, and whether there is conduction through the mount. The value of the conduction is given only as "very high".

In the simulations with program Thermal2 the cube corner is assumed to be facing a zero deg background with no earth albedo, earth infrared, or solar heating. The temperature of the rings is assumed to be the same as the temperature of the core. The emissivity of the cube corner and the retaining rings is assumed to be .9. The emissivity of the cavity is either .07 or .29.

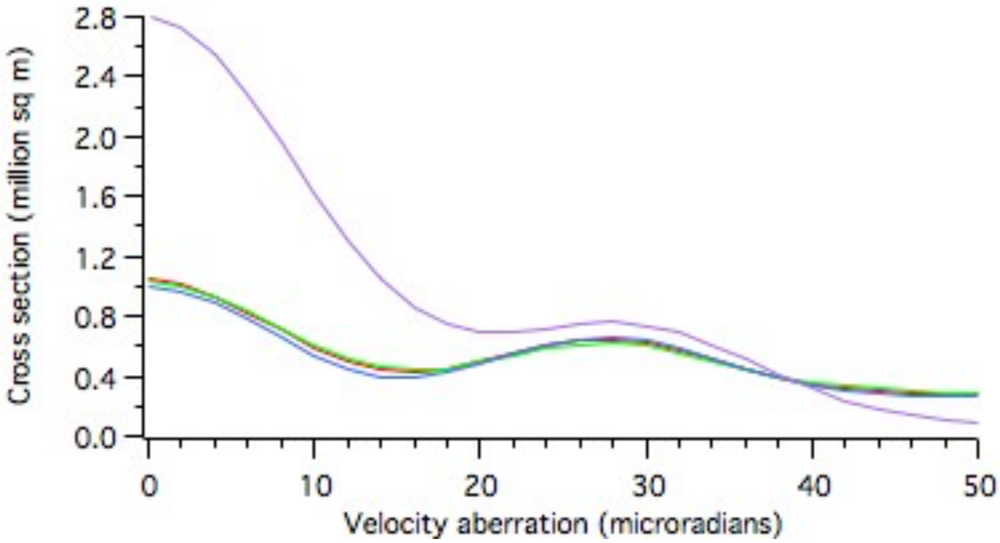
Section 5.

Case 11, Italy program
Floating mount
Cube temperature 259 K, core 303 K, cavity e=.07
Red = dihedral angle 1.25 arcseconds, isothermal
Purple = no dihedral, Green = -1.25, Blue = +1.25, with thermal gradient



microrad	-1.25	0.00	+1.25	diff	fraction
32	0.60496278	0.68983140	0.54032960	.064631	.0937

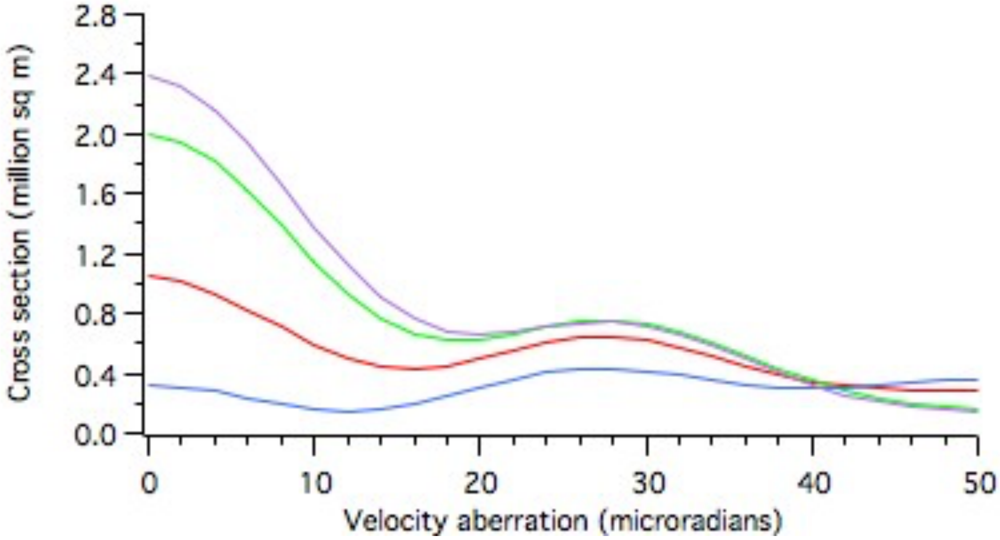
Case 11, Program Thermal2
Cube temperature 250 K



microrad	-1.25	0.00	+1.25	diff	fraction
32	0.55985671	0.68808967	0.58590446	.02604	.0444

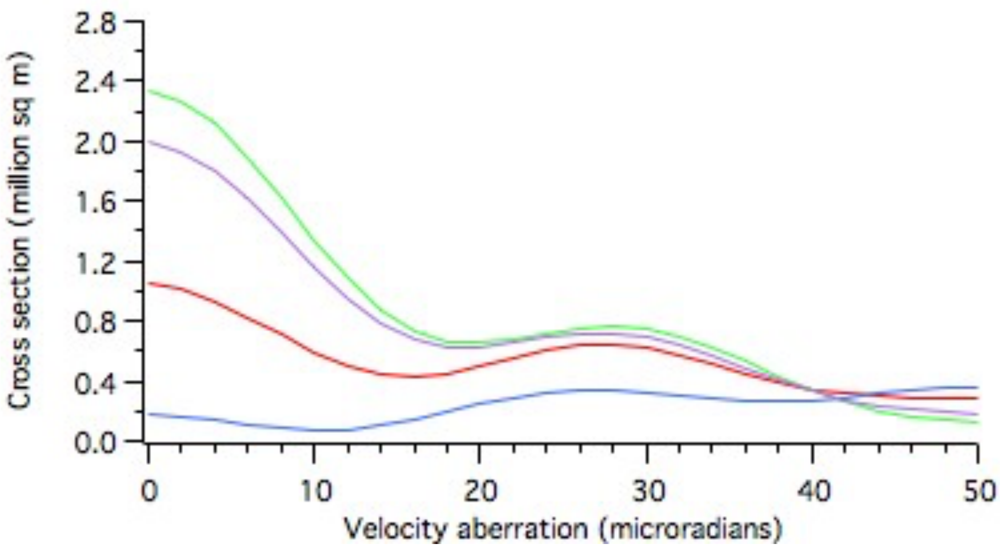
Section 6.

Case 12, Italy Program
Mount conduction .02 watts/deg K
Cube temperature 293 K, core 303 K, emissivity e=.07
Red = dihedral angle 1.25 arcseconds, isothermal
Purple = no dihedral, Green = -1.25, Blue = +1.25, with thermal gradient



microrad	-1.25	0.00	+1.25	diff	fraction
32	0.68581183	0.66692987	0.38626526	.29995	.4373

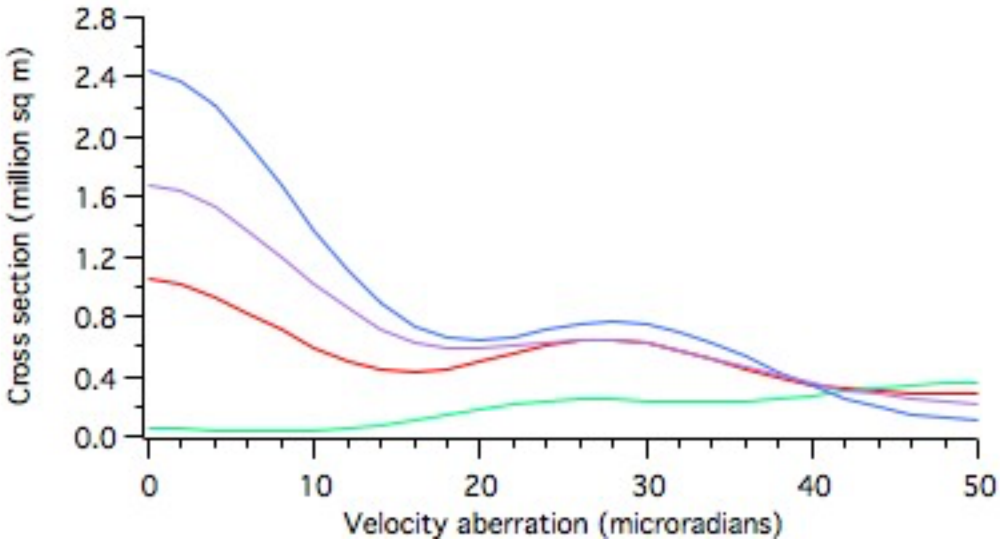
Case 12, Program Thermal2
Cube temperature 293 K



microrad	-1.25	0.00	+1.25	diff	fraction
32	0.69658931	0.64189035	0.30281921	.39377	.5653

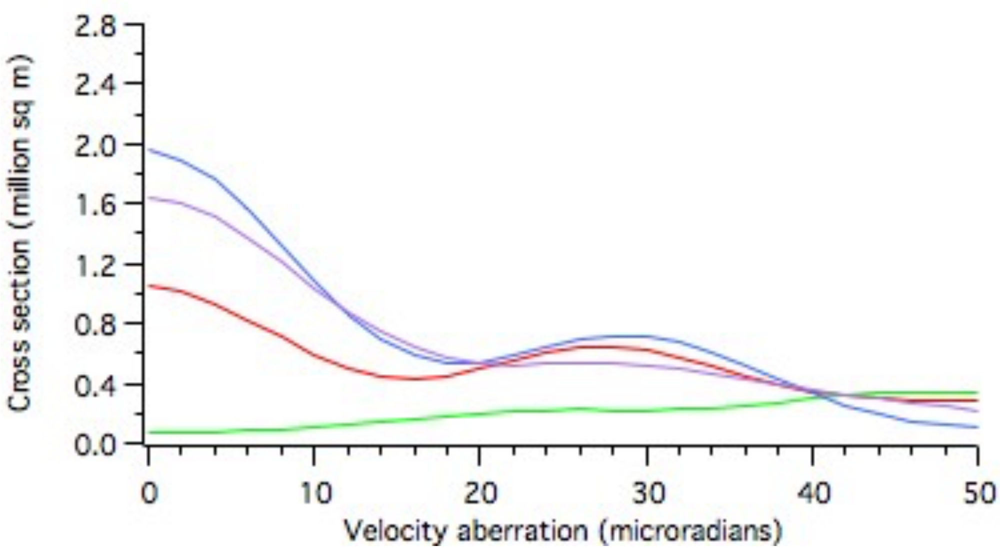
Section 7.

Case 16, Italy Program
Floating mount
Cube temperature 359 K, core 413 K, emissivity e=.29
Red = dihedral angle 1.25 arcseconds, isothermal
Purple = no dihedral, Green = -1.25, Blue = +1.25, with thermal gradient



Microrad	-1.25	0.00	+1.25	Diff	Fraction
32	0.23011767	0.57889062	0.70294644	.472828	.6726

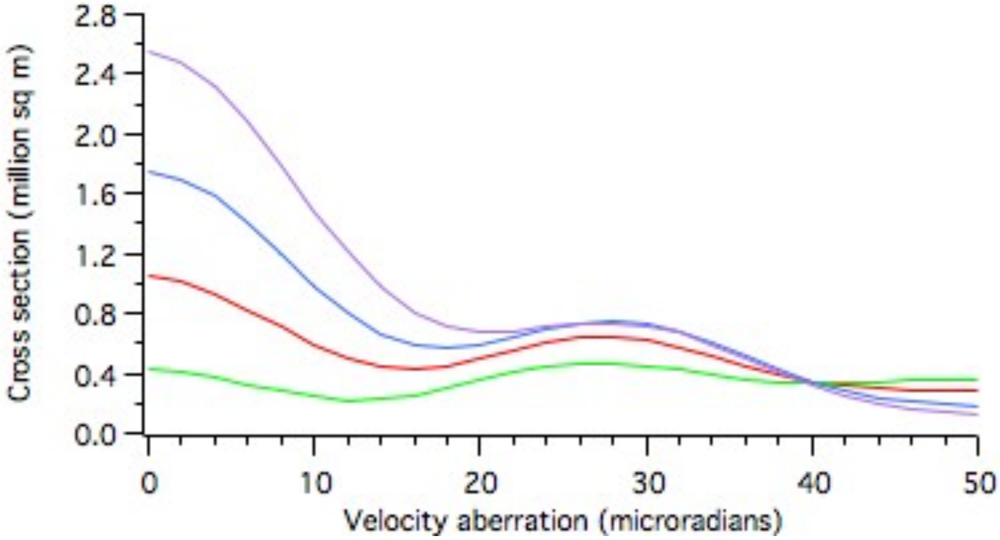
Case 16, Program Thermal2
Cube temperature 359 K



Microrad	-1.25	0.00	+1.25	Diff	Fraction
32	0.22607794	0.49777775	0.67228200	.4462	.6637

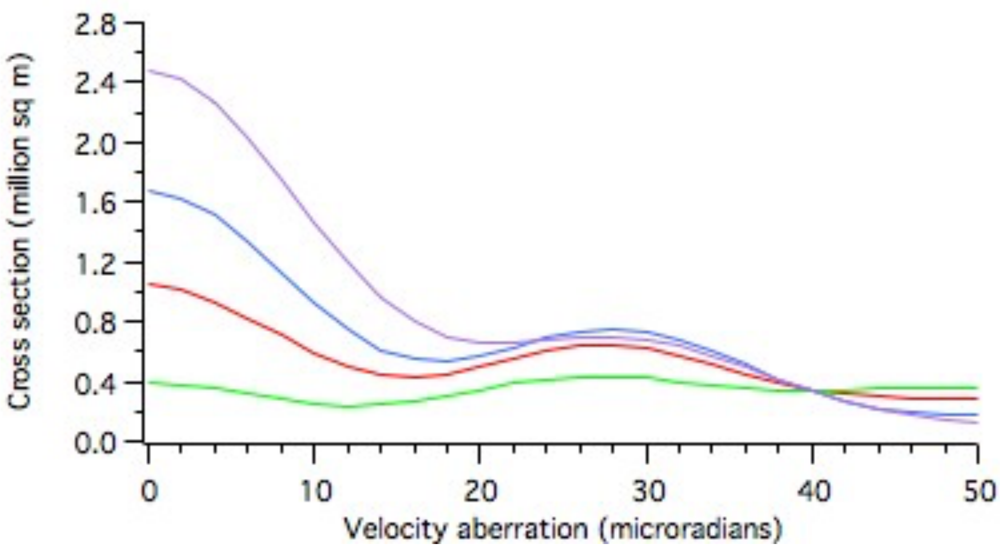
Section 8.

Case 17, Italy Program
Floating mount
Cube temperature 298 K, core 343 K, emissivity e=.29
Red = dihedral angle 1.25 arcseconds, isothermal
Purple = no dihedral, Green = -1.25, Blue = +1.25, with thermal gradient



Microrad	-1.25	0.00	+1.25	Diff	Fraction
32	0.42486459	0.66892016	0.67465670	.2498	.3702

Case 17, Program Thermal2
Cube temperature 298 K

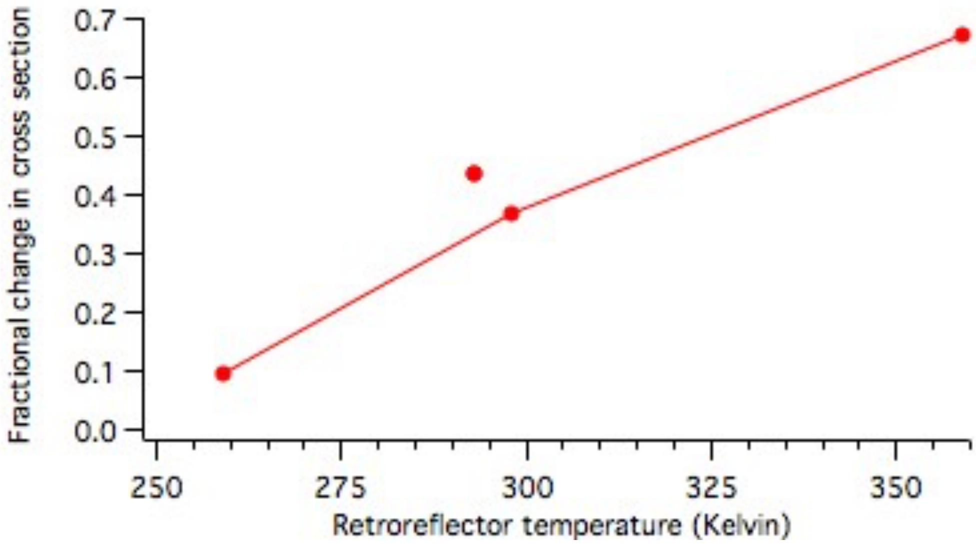


Microrad	-1.25	0.00	+1.25	Diff	Fraction
32	0.39935082	0.64046653	0.68346629	.2841	.4156

Section 9.

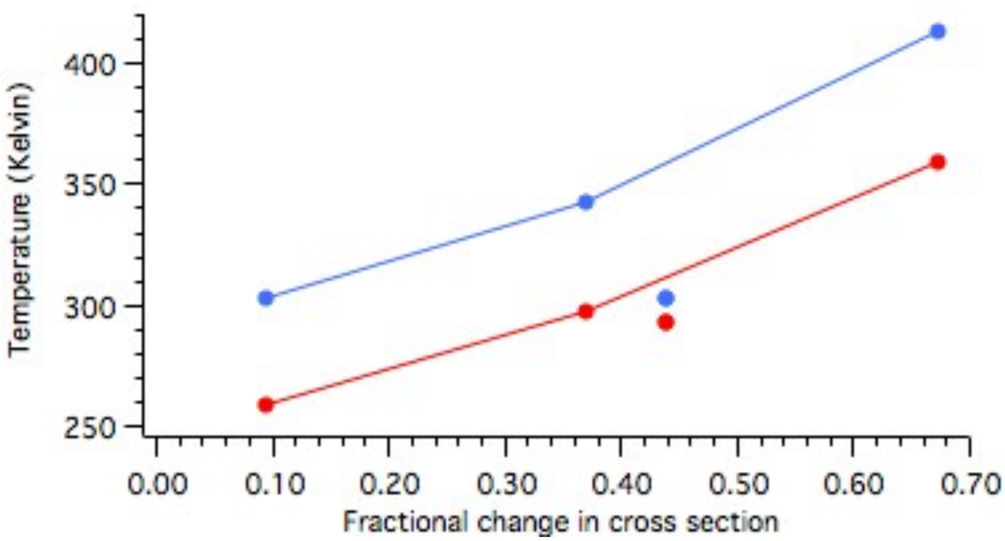
Italy program

Fractional change in cross section vs temperature



Case	Core temperature	Reflector Temperature	Fractional change in cross section
11 radiation only	303	259	.0937
17 radiation only	343	298	.3702
16 radiation only	413	359	.6726
12 conduction + radiation	303	293	.4373

Temperature vs fractional change in cross section

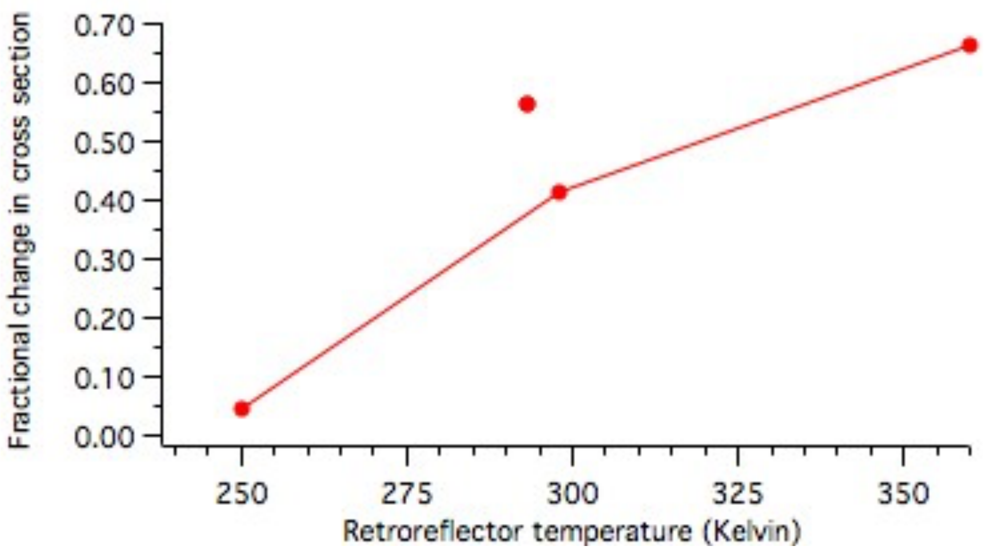


Red = cube temperature, Blue = core temperature, dots = Case 12 with conduction

Section 10.

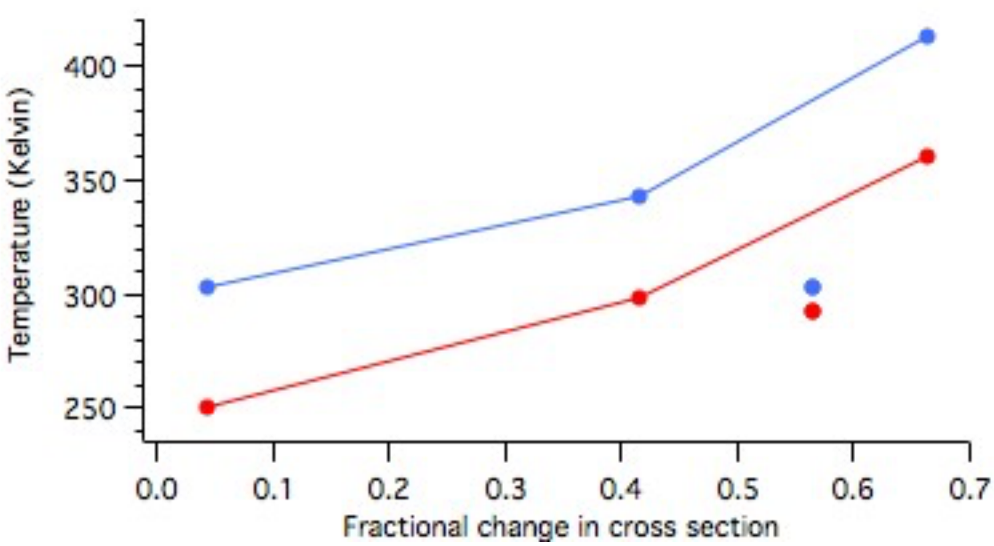
Program Thermal2

Fractional change in cross section vs temperature



Case	Core temperature	Reflector Temperature	Fractional change in cross section
11 radiation only	303	250	.0444
17 radiation only	343	298	.4156
16 radiation only	413	360	.6637
12 conduction + radiation	303	293	.5653

Temperature vs fractional change in cross section



Red = cube temperature, Blue = core temperature, dots = Case 12 with conduction

The figures in sections 9 and 10 show that the change in cross section is directly related to the temperature of the cube corner. In Case 12 where there is conduction, the temperature of the cube corner is close to the temperature of the core. Case 12 is plotted as a dot since is does not lie on the curves for either the core or the cube corner.

The fractional change in cross section becomes very small at around 250 deg K. It would probably approach zero for temperatures below 250 deg K. This has not been studied.

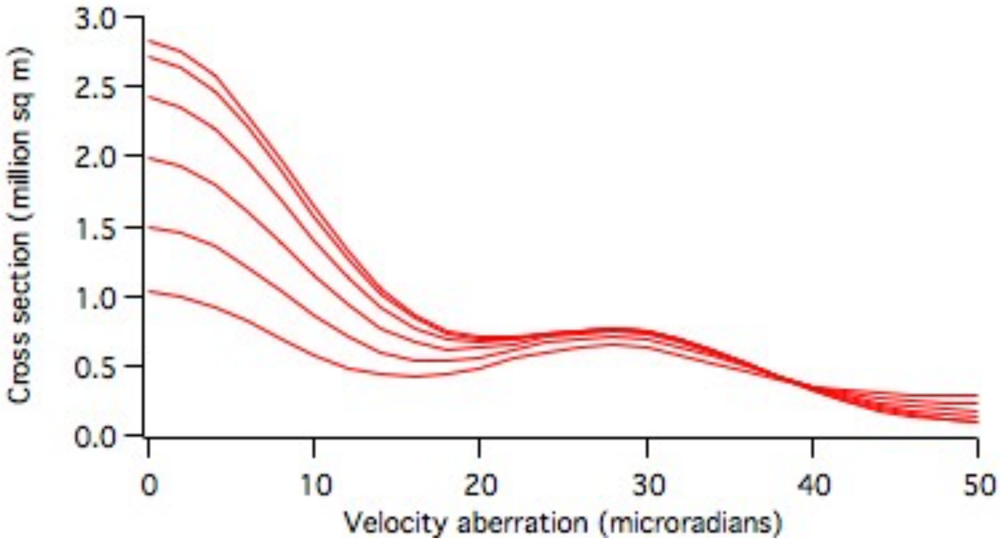
The temperature of the cube corner is related to the temperature of the core. In order to eliminate the thermal effects almost entirely it would be necessary to design the core to run at a very low temperature. This can be done by the use of a very low a/e coating on the core.

The input deck for case 11 is given below. e1 is the emissivity of the core. condM is the conductance (watts/deg) between the mount and the cube corner. t1 is the temperature of the cavity. t2 is the effective temperature of the environment.

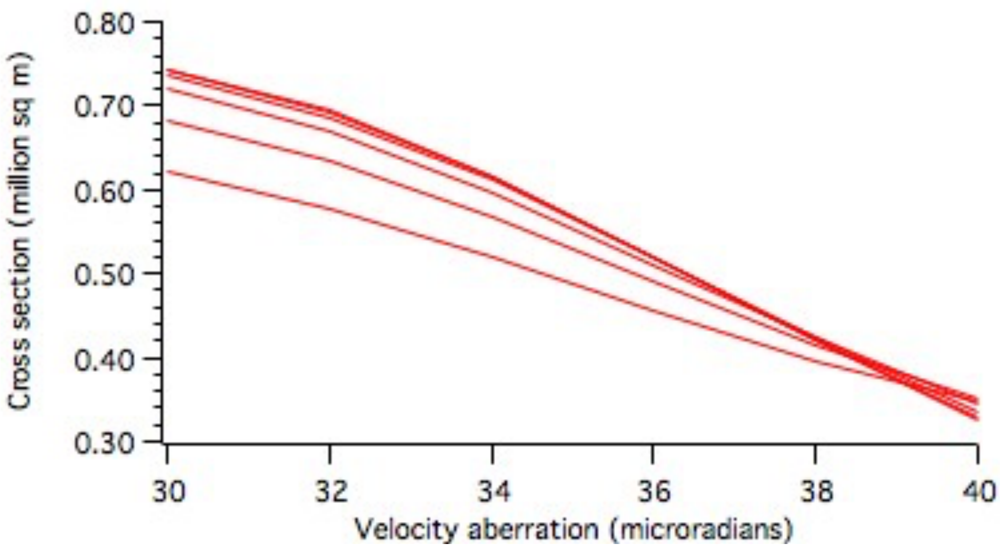
```
     l     m     n iflag iter nsides  (6i6)
    13    13    13     4 20000     6
          t0   alpha      e1      e2      e3      t1      t2  shade(f12.4,6f8.2)
    303.0000     .00    0.07    0.90  0.0000    303.  000.00  00000.
   htcap    cond density   space   dtime   solar  alphaV  alphaF (7f8.2)
   0703.    1.38    2.20    2.59  01.000  0000.0    0.00    0.00
  alphax  alphay  alphaz   condM earthIR   Rside   ringU   ringL (7f8.2)
    0.00    0.00    0.00   0.000   00.00  1.0000  1.0000  0.4000
      t3      e4
   303.0     .90
```

Section 11.

Dihedral angle offset 0.00 to 1.25 arcsec in 0.25 increments



Expanded plot

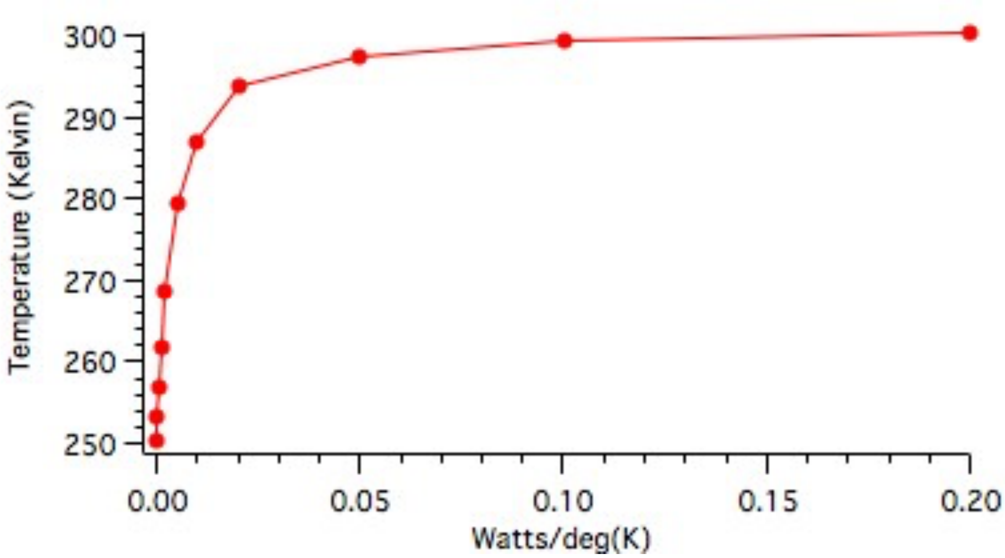


The top curve is with no dihedral angle offset. The bottom curve is with dihedral angle = 1.25 arcsec. The change in the cross section with dihedral angle is quite large at the center of the pattern. However, the change at 32 microradians is only about 16 percent. The change at 39 microradians is almost zero.

The change at 32 microradians is still an important difference. If the dihedral angle and location on the satellite is recorded for each cube corner it is possible to do an analysis to determine the "as-build" range correction as a function of incidence angle on the satellite.

Section 12.

Cube temperature vs mount conductance
Case 12



.

Mount conductance watts/deg K	Cube temperature K
.0000	250.38
.0002	253.31
.0005	257.00
.0010	261.87
.0020	268.69
.0050	279.40
.0100	286.95
.0200	293.76
.0500	297.48
.1000	299.36
.2000	300.38

The mount conductance was not specified. However, a value of .020 watts/deg gives the same temperature 293 K as the Italian thermal analysis.

The results show that a very small amount of conductance can have a very significant effect on the temperature of the retroreflector. The effect of the conductance saturates as the temperature of the cube corner approaches the temperature of the cavity and the mounting rings. The floating mount is essential for keeping the cube corner as cold as possible.