NASA-NIST TSI Workshop Day 2 Summary (R. Willson)

Version 9 (9/23/05)

Introduction (and disclaimer)

The methods of analyzing the capabilities and performances of the various TSI flight instruments are not standardized. Any effort to compare instrument information presented at the TSI Workshop will therefore be somewhat controversial in that the participants tend to view the characterizations of instrumentation other than their own in their own frame of reference. In general the participants were on the same page but there are many layers of detail that make it difficult to compare the presentations. This draft of the Day2 Summary is submitted to the participants and organizers as a straw-man summary that needs their iteration. The goal is to make it as acceptable as possible to all contributors without compromising its validity as a representation of the current state of the art.

The accomplished accuracy for all instruments is listed here as no better than the disagreement of their sensor complement as launched. The philosophy of using this criterion is that each instrument team makes their best effort to launch fully characterized sensors and that the actual disagreement of the sensors on multi-sensor instruments is the minimum realized accuracy of the approach. In other words an objective statement of the art must include the performances of ‘outlying’ sensors that experiment teams might like to ignore. It can be seen that in most cases theoretical accuracy goals were more optimistic than the on-orbit achievements.

A singular issue with most instruments is the absence of a comprehensive treatment of the significant uncertainties that can arise from complex thermal radiative interactions between the sensors and their instrument surround at ambient temperatures (~ 20K). After the metrological uncertainties have been minimized, these are the most important remaining sources of error that prevent ambient temperature instrumentation from achieving S.I. uncertainties significantly below 1000 ppm at the TSI level. The only instrumentation that has demonstrated SI uncertainties at the100 ppm level are those operated in laboratories at temperatures near or below 10 K. The uncertainties caused by thermal radiative interactions propagate as $T^{3}\cdot\delta T$, cannot be measured or modeled adequately, and must therefore be minimized by operation of the sensor at cryogenic temperatures.

Determination of the inherent ability of ambient temperature sensors to define the radiation scale at the TSI level in satellite experiments is a worthwhile and scientifically interesting objective. However, uncertainties of 100 ppm or less would be required to produce a TSI record with sufficient traceability over the multi-decadal to centennial time scales for climate change and solar physics investigations without employing and overlapping, redundant measurement paradigm for the satellite TSI monitors. Until the deployment of instrumentation with sensors operating near liquid He temperatures, 100 ppm uncertainty seems unachievable. The absolute uncertainties of current ambient temperature instrumentation are therefore less important for a long term TSI climate change database than their ability to provide highly precise and traceable results over their mission lifetimes.

VIRGO/DIARAD flight performance and degradation (Crommelynck & Dewitte)

1. Measurement goals:

   a. Accuracy: ~ 500 ppm (source: The DIARAD type instruments, principles and error estimates, Crommelynck &. Dewitte, Day1 presentation)
   b. Precision/Traceability: tbd
   c. Sensitivity: tbd

2. Measurement accomplishments:

   a. Accuracy: > 4100 ppm (from R/L as-launched ratio, Dewitte, DIARAD Repeatability, p.2.)
   b. Precision/Traceability: tbd
   c. Sensitivity: tbd

DIARAD Sensor	launched agreement	Units
R (+ 5.0)	1371.3	W/m2
L	1365.7	W/m2
Difference	4100	ppm

3. Measurement approach:

   a. Cavity: Cylindrical, flat bottom
   b. Absorptive agent: Diffuse black
   c. Mode: ACR operation, DC cavity electrical substitution heating
   d. Field-of-view shutter effect calibrated and modeled
   e. Sensor thermal radiative field errors not addressed in presentation

4. Degradation:

   a. ~ 50 ppm/yr or 0.5 W/m2 degradation over 8 years (366 ppm)
   b. Calibrated using multi sensor redundancy
   c. Linear fit to pre- and post- SOHO 1998 hiatus is a less convincing argument for claimed continuity than a more complex fit to the post-hiatus results might provide

5. DIARAD comments:

   a. Crommelynck:

      i. The correction of the thermal radiative effects of the baffle above the precision aperture of the cavity is indeed very important in particular for a lightweight radiometer orbiting around the Earth. For DIARAD and SOLCON or SOVA1 the correction is automatic due to the *side by side on a common heat sink* design of the two cavities operated differentially it explains the uncertainty 470 and 600 ppm numbers in Greg's table
      ii. Claus (Frohlich) can perhaps give his comments for his SOVA2 instrument on EURECA.

    iii. At the L1 Lagrange point the situation is much easier as the temperature is quite stable. The regular open/close measurements are required also for the same reason but are not sufficient.
    iv. About the cone difference: Between the left and right sides of DIARAD there is a difference of 5.7 W/m2. The right side is considered to be an outlier with respect to accuracy based on the 6.3 (level-mean)/sigma (see the presentation of Steven "Flight and ground comparisons"). We use DIARAD right since the beginning of the mission only to monitor the drift of DIARAD left. Unfortunately we do not know the reason why the right side reads more and we have never tried to introduce an implicit correction for it.
    v. Off-sun pointing was done with the shuttle flights as you know. But on SOHO this is not the case because of the rest of the payload, therefore on DIARAD the temperature of the shutter is measured and the required correction applied as shown in my presentation (note that the underside of our shutters are black). Here we require some detailed formulations from Claus before and after the successive failures. In particular after and independently from the DIARAD measurements with up to now no identified temperature measurements.
    vi. The DIARAD diffraction correction has been calculated by NIST.
    vii. Back-to-back sensor designs have to deal with longitudinal temperature gradients.

b. Willson:

    i. DIARAD sensors:
        1. aperture is stainless 2 – 3 mm thick
        2. FOV1 ~ 1 deg half angle – close to ACR’s
        3. How does DIARAD determine effective cavity absorptance?
        4. cylindrical cavity section is 0.5 mm diam silver
    ii. The DIARAD/SOLCON/SOVA1 'side-by-side' sensor design compares the inside view of a shutter with that of the sun in a ~3K background, as seen through their solar fields of view. The 'back-to-back' designs (ACRIM, PMO, ERBE, and ERB) compare the solar field of view with the heat sink.
    iii. For the solar field of view, the differential effect of importance is the radiative exchange difference between the shutter and a ~ 3K solar field of view without the sun. None of the TSI experiments provides this without pointing away from the sun and all (except VIRGO) have invoked this measurement mode at some point in their missions.
    iv. The multi-sensor satellite TSI instruments ACRIM2, DIARAD and TIM have each had sensors whose performances fall well outside the bounds of uncertainty predicted for them. However, since they were launched with the assumption of proper sensor calibration we're stuck with our worst sensors' performances in any objective assessment of the state of the art (in my view).

VIRGO flight performance and degradation (Frohlich)

PMO6V:

1. Measurement goals:

   a. Accuracy: ~ 1200 ppm (source: PMO6V on VIRGO/SOHO, Frohlich, Day1 presentation)

6. Measurement accomplishments:

   a. Accuracy: ~ 1200 ppm
   b. Precision/Traceability: tbd
   c. Sensitivity: tbd

   The 'day-1' level-1 ratio A/B is 1.0004227 which is 633 ppm higher than on ground with 0.9997897. For the '1-day' irradiance the level-2 values are 1365.04 and 1365.90 Wm-2 for A and B (input from Claus Frohlich).

PMO6 Sensor	**'as-launched' agreement**	**Units**
A	1365.04	W/m2
B	1365.90	W/m2
Difference	633	ppm

2. Measurement approach:

   a. Cavity: Inverted conical, cylindrical surrounding collector
   b. Absorptive agent: Specular black paint
   c. Mode: ACR operation, DC cavity electrical substitution heating
   d. Shutters failed on launch. Sensor covers used on timescales ~ 8 hrs to provide minimal shuttering for differential operations.
   e. Field-of-view shutter effect calibrated and modeled
   f. Sensor thermal radiative field errors not addressed in presentation but addressed in comments below

3. Degradation:

   a. Total degradation ~ 3000 ppm (1996 – 2005)
   b. Calibrated using multi sensor redundancy
   c. SOHO hiatus difference = ~ 300 ppm
   d. Slope change during late 1996 to mid 1997 looks normal for cavities

4. PMO6V comments:

   a. Frohlich
      i. As to the PMO6V: the difference value between A and B at the beginning of the mission should be stated correctly (in Day1 Summary – correct value shown here in table above).
      ii. Diffraction is included (the value calculated by Brusa long time ago is slightly less (about 0.01%) than what Eric calculated)

        iii. IR correction of the sky around the sun is taken into account together with the thermal model which accounts for the detailed temperature distribution within the muffler and the temperature of the shutter (or cover for the 8-h open operation) into account.
        iv. On VIRGO the treatment of PMO6V-A is adequate, the one for PMO6V-B needs to be checked (especially the temperature of the cover which degrades during the mission) and may have to be changed. It may explain some of the deviations we observe relative to DIARAD.
        v. On SOVA2 the thermal corrections were more approximate (just from memory), the details need to be checked - but it does not seem to be of importance to the discussions here, although it is important for the PMO6 radiometry.
    b. Willson

        i. Claus (Frohlich) assumes the air/vac difference is equivalent to the sum of non-equivalences. This view is not held by the other experimenters/presenters.
        ii. PMO6V degradation slope change after mid 1997 looks linear (Is there a non-exposure related contribution?)

DIARAD:

1. Claus Frohlich’s analysis of SOHO hiatus difference ~ - 200 ppm (0.3 W/m2)

2. Claus Frohlich’s analysis of DIARAD total degradation ~ 600 ppm (1996 – 2005)

3. DIARAD comments

    a. Claus Frohlich:

        i. DIARAD SOHO Hiatus difference: For PMO6V and DIARAD a first difference is determined by comparison with the backup. Then the ratio PMO6V-A/DIARAD both at level 1.8 data is calculated, from this ratio the non-exposure dependent correction for DIARAD is determined (exponential function plus step over SOHO hiatus) and finally the differences of each radiometer is adjusted to agree with ACRIM2 over this time period.
        ii. DIARAD total degradation: It includes the correction from the comparison L/R which is apart from the linear versus more complicated function the same as IRMB. More importantly it includes the exponential correction for the non-exposure dependent changes, which cannot be determined from L and R alone, but need comparison with PMO6V.

ACRIM1 Flight Comparisons and Degradation Calibrations (Willson)

ACRIM1:

1. Measurement goals:
   1. Accuracy: ~ 1000 ppm
   2. Precision/Traceability: not specified
2. Measurement accomplishments:
   1. Accuracy: > 1021 ppm (from Willson, Day1 Talk, p. 25.)
   2. Precision/Traceability: < 5 ppm/yr
3. Measurement approach:
   1. Cavity: conical
   2. Absorptive agent: Specular black paint
   3. Mode: ACR operation, DC cavity electrical substitution heating
   4. Field-of-view shutter effect calibrated and modeled
   5. Sensor thermal radiative field effects modeled
4. Degradation:
   1. Total degradation over mission (9.75 years) ~ 600 ppm
   2. Calibrated by comparisons w/sensor C with residual uncertainty < 5 ppm/yr
   3. 3 sensor calibrations limited by ~ 150 ppm uncertainty during spin mode
   4. Pre- and post- spin mode comparisons → ~ 150 ppm degradation
   5. exposure of sensors during spin mode > 50% of pointed mode
5. ACRIM1 comments: Solar observing time per LEO orbit: 55 minutes

ACRIM2:

1. Measurement goals:
   1. Accuracy: ~ 1000 ppm
   2. Precision/Traceability: < 10 ppm/yr
2. Measurement accomplishments:
   1. Accuracy: > 4090 ppm (from Willson, Day1 Talk, p. 25.)
   2. Precision/Traceability: < 7.5 ppm/yr
3. Measurement approach:
   1. Cavity: conical
   2. Absorptive agent: Specular black paint
   3. Mode: ACR operation, DC cavity electrical substitution heating

   d. Field-of-view shutter effect calibrated and modeled
   e. Sensor thermal radiative field effects modeled

4. Degradation:

   a. Total degradation < 1500 ppm during 1991 – 2001 mission
   b. Calibrated by comparisons w/sensor C, residual uncertainty < 7.5 ppm/yr
   c. No sensor changes across 1992 UARS solar panel event ~ 1 month

5. ACRIM2 comments:

   a. Solar observing time per LEO orbit: 35 minutes
   b. ACRIM2 power bus interrupted mid 2002, resumed for several months during late 2002, then failed permanently
   c. Switched from sensor B to A as monitoring sensor in 1999. Sensor A results inherently more noisy than B.
   d. Solar observing time/LEO orbit: 35 min

ACRIM3:

1. Measurement goals:

   a. Accuracy: ~ 1000 ppm
   b. Precision/Traceability: < 10 ppm/yr

2. Measurement accomplishments:

   a. Accuracy: > 2068 ppm (from Willson, Day1 Talk, p. 25.)
   b. Precision/Traceability: < 3 ppm/yr

3. Measurement approach:

   a. Cavity: conical
   b. Absorptive agent: Specular black paint
   c. Mode: ACR operation, DC cavity electrical substitution heating
   d. Field-of-view shutter effect calibrated and modeled
   e. Sensor thermal radiative field effects modeled

4. Degradation:

   a. Total degradation: 330 ppm during 2000 – 2005 minimum mission
   b. Calibrated by comparisons w/sensor C, residual uncertainty < 3 ppm/yr

5. ACRIM3 comments

   a. Solar observing time/LEO orbit: 65 min
   b. ACRIMSAT/ACRIM3 approved by NASA Senior Review for extended mission FY06 – 09.
   c. No significant loss of data during 1st 5 yr ‘minimum’ mission.
   d. ACRIM3 instrument engineering vital signs indicate > 10 yrs life left

   e. ACRIMSAT satellite engineering vital signs indicates > 15 yrs life left
   f. ACRIMSAT LEO orbit (700 km polar) good for > 30 yrs

6. ACRIM general comments:

   a. Lee (questions):
      i. How do you correct for the degradations of your ACRIM sensors?
      ii. Are the raw 1980-1989 Solar Maximum Mission (SMM) ACRIM I TSI measurements available to the scientific community?
      iii. Can the raw 1980-1989 Solar Maximum Mission (SMM) ACRIM I TSI measurements be reduced without any special procedures to obtain the same SI scale TSI results/trends that you have published?

   b. Willson (responses to Lee's questions):
      i. The degradation and correction of ACRIM sensors has been presented and published many times and was described at the meeting in July. Best references are:
         1. ACRIM1: Willson, R. C., and H. S. Hudson, The Suns luminosity over a complete solar cycle, Nature, 351, pp 42-44, 1991
         2. ACRIM2: Willson, R.C., Total Solar Irradiance Trend During Solar Cycles 21 and 22, SCIENCE , VOL. 277, pp 1963-1965, 1997
         3. ACRIM3: Willson, R.C., A.V. Mordvinov, Secular total solar irradiance trend during solar cycles 2123, GRL, V. 30, NO. 5, pp. 1199-1202, 2003
      ii. ACRIM measurements are and have always been readily available and have been used by many in both research and citation.
      iii. ACRIM1 observations are produced in a straightforward manner using a published algorithm: Willson, R.C., (1979), Active cavity radiometer type IV, J. Applied Optics, 18, p.179

SORCE/TIM flight comparisons, performance, and degradation (Kopp)

1. Measurement goals:

   a. Accuracy: < 100 ppm
   b. Precision/Traceability: 10 ppm/yr
   c. Sensitivity: 1 ppm

2. Measurement accomplishments:

   a. Accuracy: > 660 ppm (from ratio C/D, Kopp TIM Stability p.8, includes linearity corrections applied after launch.)
   b. Precision/Traceability: 10 ppm/yr
   c. Sensitivity: no data presented

3. Measurement approach:

   a. Large cylindrical/conical cavity

b. NiP diffuse black
c. Phase sensitive detection
d. Pulse width modulated cavity electrical substitution heating
e. Primary aperture provides view limiting, large separation from cavity
f. Field-of-view shutter effect calibrated and modeled
g. Sensor thermal radiative field errors not addressed in presentation

4. Degradation:

   a. 50 ppm/yr, calibrated using multi sensor redundancy to 10 ppm/yr
   b. Photodiode reflectance calibration (not clearly contributory at precision level)

5. TIM comments:

   a. Willson:

      i. Have some corrections been applied to the 'as-launched' values found here?
      ii. Does the photodiode retro-reflectance measurement add information or uncertainty?

Shuttle TSI flight comparisons, performance, and degradation (Dewitte)

1. Adjustment of flight results to the SAAR scale:

INSTRUMENT	SAAR Adjustment
SOVA1L	1.000799
DIARAD L	1.000295
SOLCON R	.999823
SOVA 1R	.999764
SOLCON L	.999228
DIARAD R	.996253
ACRIM2	1.001295
SOVA2	.999703
PMO6VB	1.000661
ACRIM3	1.000404
TIM	1.004137
ERBS	1.000536
ACRIM1	.999026
ERB	.995867

ERBS/ERBE flight performance and degradation (Lee)

1. Measurement goals:

   a. Accuracy: ~ 2000 ppm
   b. Precision/Traceability: tbd

2. Measurement accomplishments:

   a. Accuracy: Single sensor instrument – cannot assess
   b. Precision/Traceability: tbd

3. Measurement approach:

   a. Cavity: conical (ACR V)
   b. Absorptive agent: Specular black paint
   c. Mode: ACR operation, DC cavity electrical substitution heating
   d. Field-of-view shutter effect calibrated and modeled
   e. Sensor thermal radiative field errors not addressed in presentation

4. Degradation:

   a. Total degradation: single sensor instrument cannot self-calibrate
   b. Non-solar drifts of up to1000 ppm/yr are observed in ERBE results

5. ERBS/ERBE comments:

a. Lee:

    i. The minor ERBS corrections affects the ERBS TSI absolute measurements at the 0.01% [0.3 Watts-per-squared meters] level. The corrections have not bearings on the ERBS measurement precisions. The corrections are outlined below. The corrections were discussed at the workshop.
    ii. The raw ERBS telemetry data are available to you and the scientific community for analyses. To reduce the data, there are no special tricks or conditions required to use the raw data. Anyone can derive the same TSI results that I have presented. Anyone can apply corrections without distorting the measurements. No tricks required.
    iii. The ERBS data are not corrected for the diffraction which amounts to a 0.99988 factor, 0.3 Watts-per-squared meters correction out of 1365 Watts-per-square meters, less than 0.01% on the absolute scale.
    iv. The ERBS solar monitor response is within 0.01% of its full scale measurement. This correction impacts the absolute ERBS TSI measurements at the 0.3 Watts-per-squared meters level.
    v. The ERBS response degradation with time is not detectable; and considerably lower than the response degradations of the SMM ACRIM I, UARS ACRIM II, and ACRIMSAT ACRIM reference sensors.

b. Willson:

    i. Does an ATBD or an equivalent document for ERBE? Neither the few ERBS/ERBE publications nor the presentations I've heard have presented a 'first principle' analysis of an ERBE algorithm, accuracy, precision.
    ii. It would be interesting and potentially useful to review the ERBE TSI measurement starting on a basic level, revise its algorithm if appropriate and reprocess ERBE raw data. The objective would be to decrease some of the unexplained TSI variations in its record and improve the database.
    iii. According to Eric Shirley's talk (Day3) the ERBE diffraction correction is 0.02 %, about twice the value quoted by Lee. What is the source of Lee's stated 0.01 % effect (5.a.iii above) and why is it different by a factor of 2?
    iv. Lee's ERBE Workshop talks showed the running values of sampled signal through a typical measurement. It was apparent that the TSI sensor was not settled out at full scale by the time data sampling occurred (30 - 32 seconds after shutter operation as I recall). If the sensor's response were within 0.01 % of full scale as Lee claims, the settle-out residual likely wouldn't have been detectable on the scale of the charts.
    v. Unsettled sensor performance could be caused by the fact that the ACR type V sensor ERBE uses is slower than the ACR IV used in the ACRIM1 experiment (both ACRIM1 and ERBE were built by TRW). The ACR types IV and V sensors (as all other versions) were developed by my group at JPL and we understand them well. We used the ACR type V in our space shuttle ACRIM and

    UARS/ACRIM2 instrumentation and have considerable experience with its response time and performance. The ACRIM team would not expect the ACR type V sensor with the TRW circuitry to settle out adequately within 30 seconds of shutter operation.
vi. The ACR V sensor's operation on ERBE should be examined carefully to evaluate the effects of unsettled performance on both its TSI scale and uncertainties.
vii. An experimental test of the ERBE response and its impact on TSI measurements could be made at JPL which has operational instruments with both ACR IV and V sensors.
viii. Lee's statement 'The ERBS response degradation with time is not detectable' cannot be verified experimentally because ERBE has no independent means of calibrating degradation. Past efforts to support it relied on poorly understood solar proxy models or ground based observations and utilized unverifiable assumptions regarding exposure dependent effects for the sensor.
ix. Solar observing time is very limited (~ 3 min every 14 days) which contributes to data uncertainties.
x. ERBE is not solar pointed – the sun drifts through ERBE's TSI sensor field of view. This can cause variations that might be large relative to cosine effects because of non-uniform responsivity along the cavity's length. The ACR type V sensors are not designed for off-axis observations.
xi. Significant uncalibrated degradation has been detected in ERBE results, especially in early years and during 'ACRIM Gap'.

Nimbus7/ERB flight performance and degradation (Synthesis by Willson)

1. Measurement goals:

    a. Accuracy: ~ 5000 ppm (design requirement)
    b. Precision/Traceability: tbd

2. Measurement accomplishments:

    a. Accuracy: Single sensor instrument – cannot assess
    b. Precision/Traceability: tbd

5. Measurement approach:

    a. Cavity: Inverted conical, cylindrical surrounding reflective collector (similar to VIRGO/PMO6)
    b. Absorptive agent: Specular black paint
    c. Mode: Passive normal monitoring operation, ACR calibration every 14 days, DC cavity electrical substitution heating
    d. No shutters – calibrates against space view w/o sun
    e. Sensor thermal radiative field errors not addressed

3. Degradation:

    a. Total degradation: single sensor instrument cannot self-calibrate

  b. Non-solar drifts observed in ERB results are significantly smaller in amplitude than those seen in the ERBS/ERBE results
  c. Re-analysis of database near end of mission removed many thermal drift effects and solar pointing errors

4. ERB comments:

  a. Willson:

    i. Limited solar observing time: ~ 5 minutes every orbit, 3 of 4 days, contributes to data uncertainty.
    ii. Not solar pointed – sun drifts through sensor field of view. Adds possible errors due to non-uniform cavity responsivity.
    iii. Residual uncalibrated degradation detected in results even after efforts of Hoyt et al.
    iv. Infrequent ESR operation likely provides errors due to sensor temperature drift.
    v. Comparisons with ACRIM indicate higher precision of ERB, relative to ERBE, likely due to in part to ERB's larger observing time (~ 200 times greater than ERBE's).
    vi. Comparisons with ACRIM indicate less uncalibrated drifting of ERB sensitivity, relative to ERBE.

JPL/TMO ground comparisons and significance for flight TSI Results (Willson)

1. JPL Table Mtn. Observatory (TMO) Solar Test Facility (STF) would provide a definitive end-to-end test, simulating the spaceflight environment with the sun as the source for representative ACRIM, TIM and VIRGO instrumentation.

2. TMO/STF experimental resources

   a. Large solar tracker
   b. Solar pointed, flight rated 1 meter high-vacuum chamber w/3 windows
   c. Flight rated clean room
   d. Laboratory environment w/data acquisition facilities
   e. Accommodations on-site for 24 persons
   f. Unique solar observational advantages
      i. 7500 feet elevation
      ii. Adjacent to the Mojave Desert (very dry overlying atmosphere)
      iii. High incidence of transparent skies (> 10000 W/m2)
      iv. Clear, dry skies provide minimal solar aureole

3. Simultaneous testing of TIM, ACRIM and VIRGO w/sun as the source

4. Air/vacuum differences can be measured

5. Solar aureole effects can be minimized by:

   a. Providing common fields of view with external apertures
   b. Monitoring the aureole and modeling its effect on the instruments

6. Test planning and review of results using TMO accommodations and conference facilities

Day2 Discussion

1. The TSI Workshop did not resolve the ACRIM/VIRGO – TIM 0.4 % scale difference

2. Further experimental work must be conducted

3. Two complementary testing programs should be implemented

   a. Power and diffraction testing using the NIST trap diode/laser facility
   b. End-to-end spaceflight equivalence test w/sun as source using JPL TMO/STF

4. NIST trap diode/laser testing

   a. Power test

      i. Under-fill ACRIM, VIRGO and TIM primary apertures
      ii. Test for linearity and non-equivalences against trap diode's SI calibration

   b. Diffraction test

      i. Over-fill view limiting apertures
      ii. Observe diffraction effects for each instrument geometry
      iii. Compare with power test results to test predicted diffraction effects

5. TMO/STF solar testing

   a. JPL TMO/STF solar pointed vacuum chamber can test ACRIM, VIRGO and TIM instrumentation simultaneously.
   b. Sun as the source at > 1000 W/m2
   c. High vacuum thermally controlled environment near spaceflight conditions
   d. Adaptation of instruments to common field of view to minimize aureole effects

6. Cost of testing

   a. NIST testing ~ 50 K$
   b. JPL TMO/STF testing ~ 50 K$

7. Testing schedule

   a. NIST: November 2005
   b. TMO/STF: May 2006