The Solar Bolometric Imager

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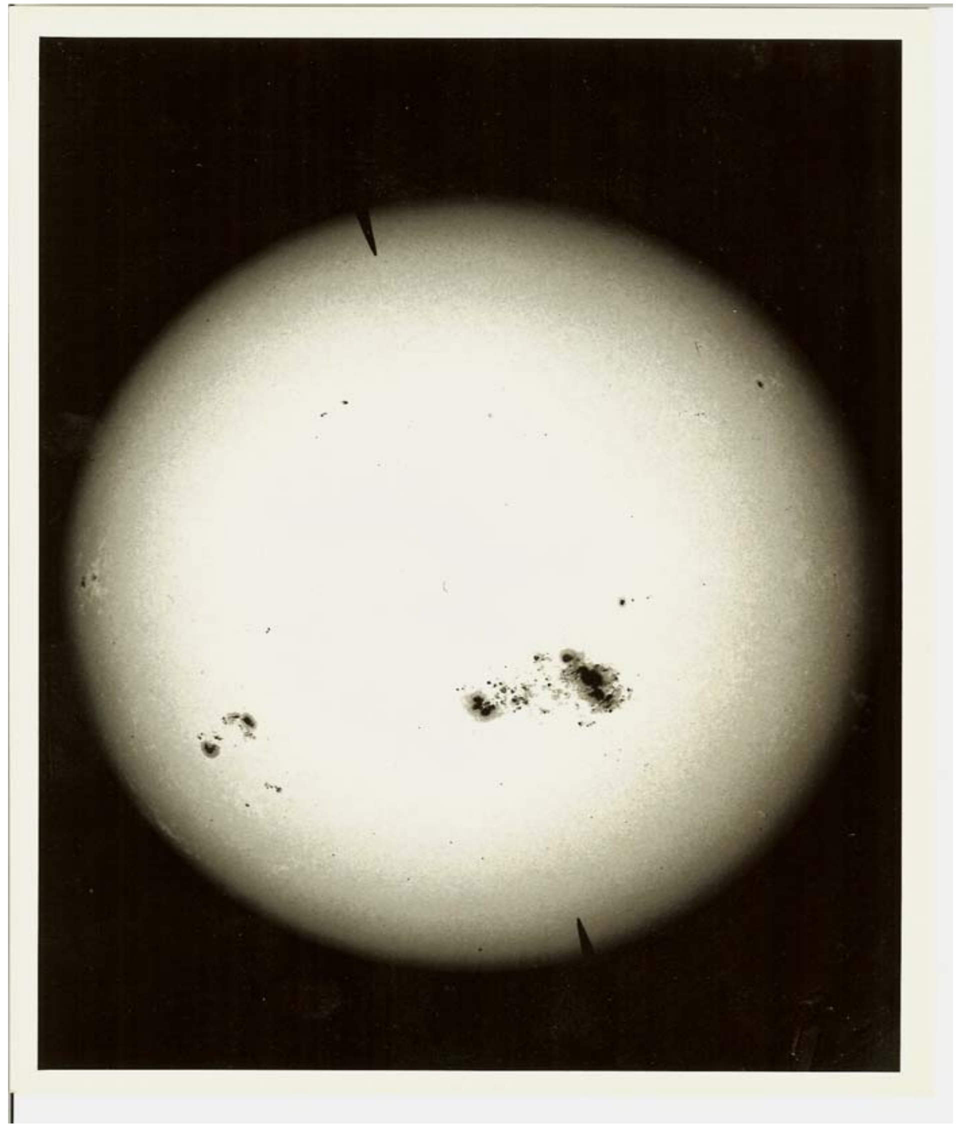
Science Background

- Why do dark sunspots and bright faculae cause variations of solar luminosity (i.e. why doesn't disturbed convective heat flux simply flow around them)?
- What does total solar irradiance (TSI) variation tell us about solar, stellar convection and the solar magnetic cycle?
- Are there other, lower – amplitude thermal inhomogeneities contributing to total solar irradiance (TSI) variation on climatically important time scales?

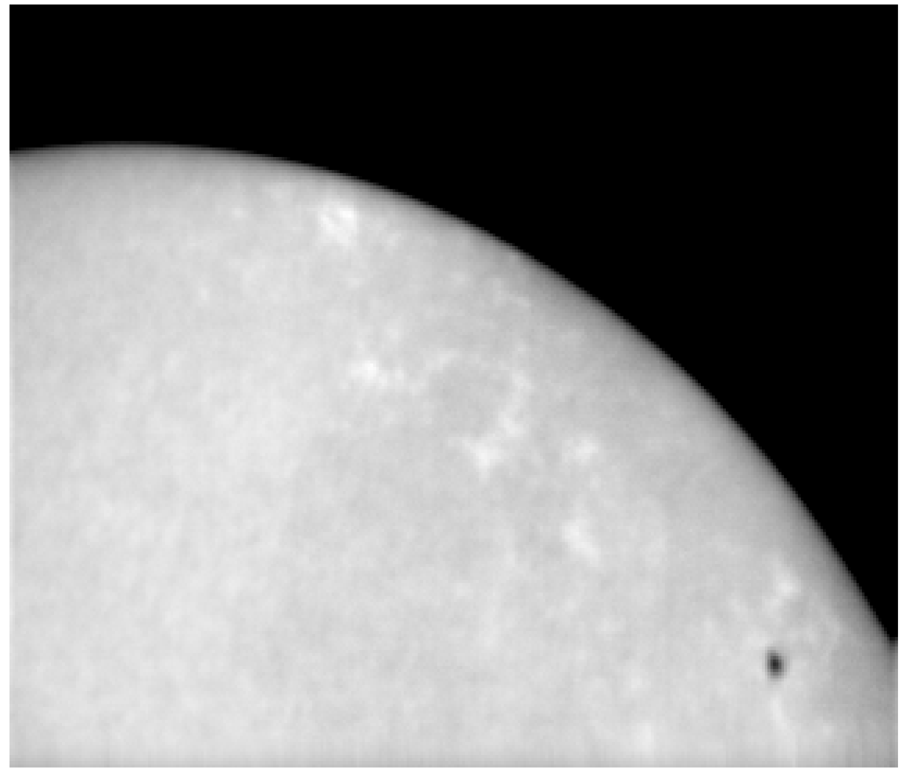


What is the Solar Bolometric Imager?

- The SBI *images* the solar photosphere with *non- selective spectral response* over 0.2 – 2.6 micron i.e. 94% of the total solar irradiance (TSI).
- SBI is complementary to pyrheliometers like ACRIM, which provide *highly reproducible* TSI measurements over the same wavelength range, but no angular resolution.
- SBI is optimized for measuring *brightness contrast* of photospheric structures. Does not require absolute accuracy, nor long term reproducibility.

What does the SBI Do?

- Its *broad – band*, *non – selective response* and its ~2 arc sec *angular resolution*, enable the SBI to *directly measure* the *contributions to TSI variation* from photospheric structures of different T_c, such as faculae, network, umbrae, penumbrae, thermal shadows, and other brightness inhomogeneities.
- A *separate, 100 nm passband channel at 750 nm* (i.e. located on the red slope of the solar spectral irradiance curve) offers imaging optimized for sensitivity to the smallest detectable variations in T_b .

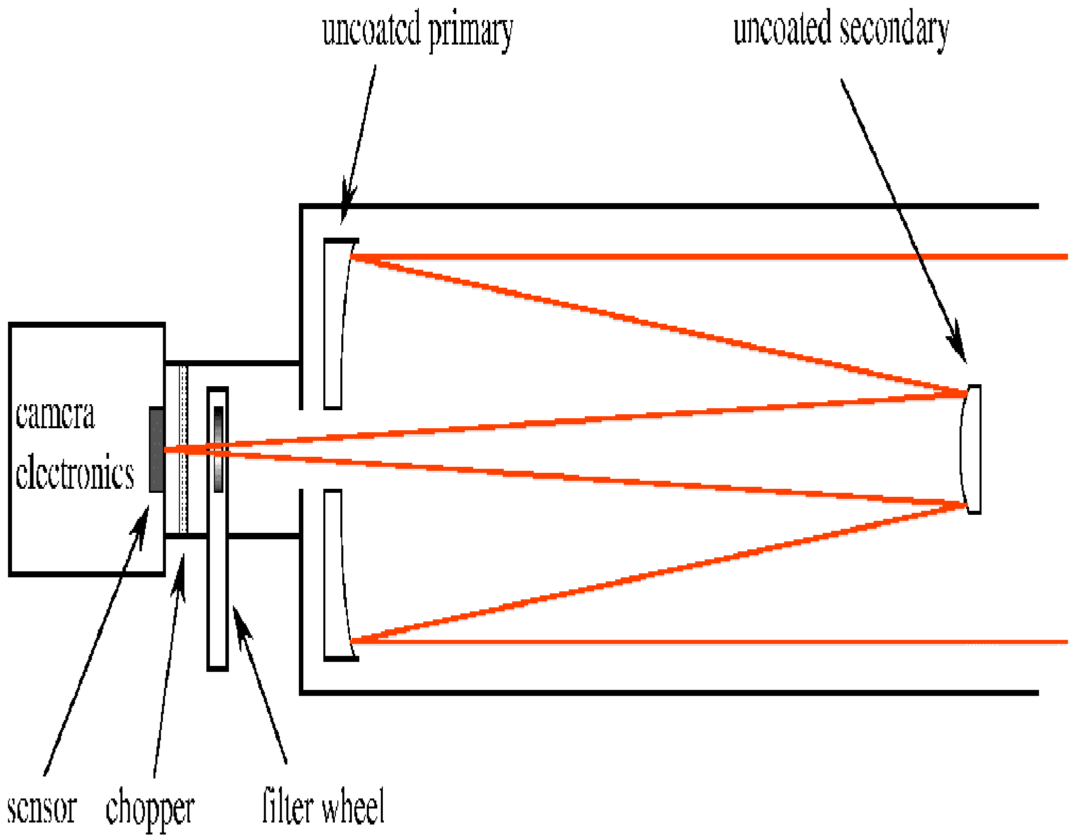


SBI System Requirements

- Telescope achromatic over similar wavelength range (0.2μm to 2.6 μm) as flight ESR's (accepts >95% of TSI).
- Spectrally constant system response to +/- 10% over this range
- Focal plane irradiance < 1 mW/cm^2
- Angular resolution <5 arcsec over spectral range
- Acceptable scattered light (< 2-3 % @40 arc secs off solar limb)
- Operable in vacuum, over temperature range: –50 °C → +70 °C

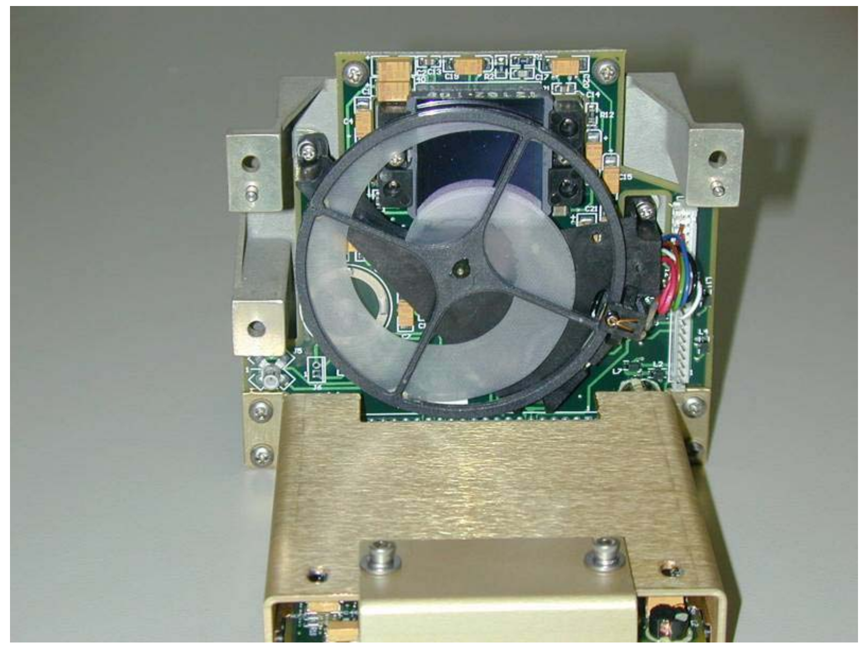
Optical Design

- Telescope: 30cm aperture all-reflecting, folded(Dall-Kirkham), f/12.
- Uncoated (bare glass) primary and secondary mirrors enable direct solar imaging in integrated light.



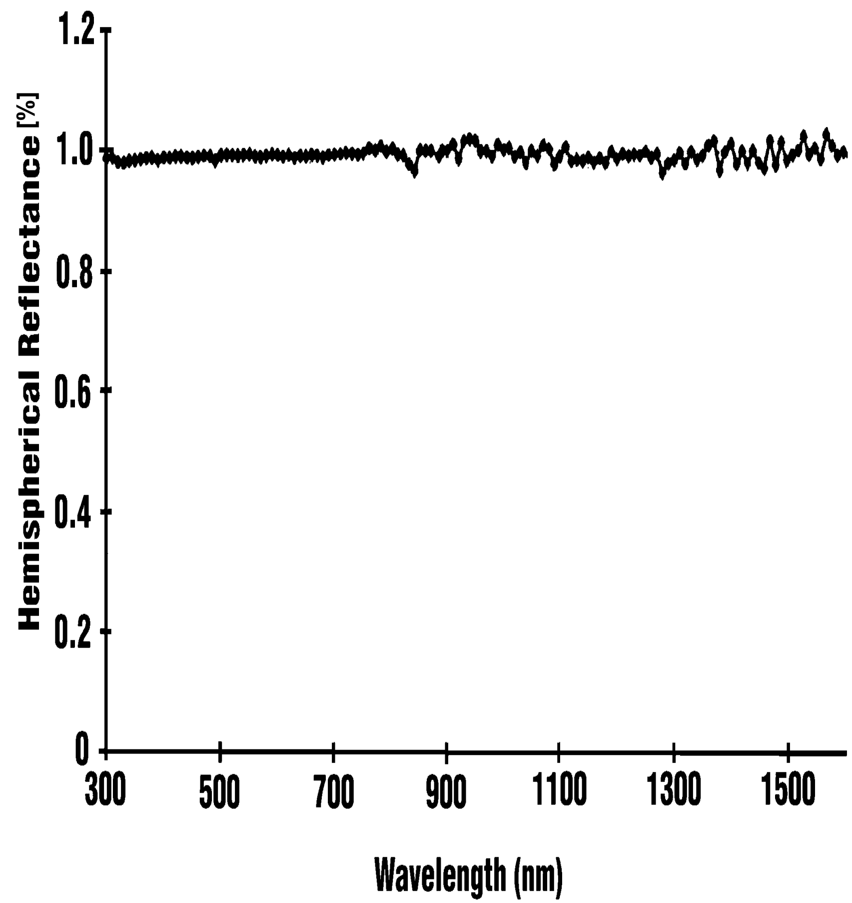
Camera

- Barium strontium titanate (bst) ferroelectric detector(TI/Raytheon “Nightsight”)
- 320 x 240 active pixels
- Chip gold – blacked at NIST for spectrally flat response
- On-chip thermal regulation to bst Curie temperature (~ 30 °C)
- AC coupled – requires optical chopper



Spectral reflectance of gold - blacked detector

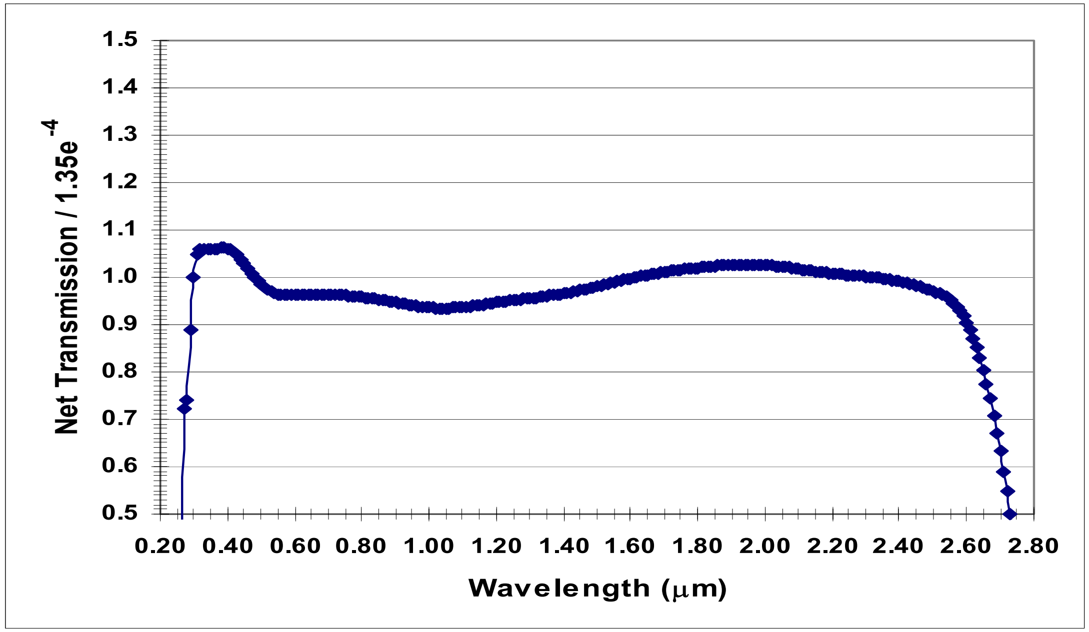
- Gold blacking produces spectrally constant response to +/- 5% from UV to NIR (NIST measurement).
- MTF ~ 70% of original detector



System Spectral Transmission

System transmission *calculated* from measured spectral transmission/reflection curves of individual elements.

Spectrally flat to +/- 10% over 0.3 – 2.6 microns.

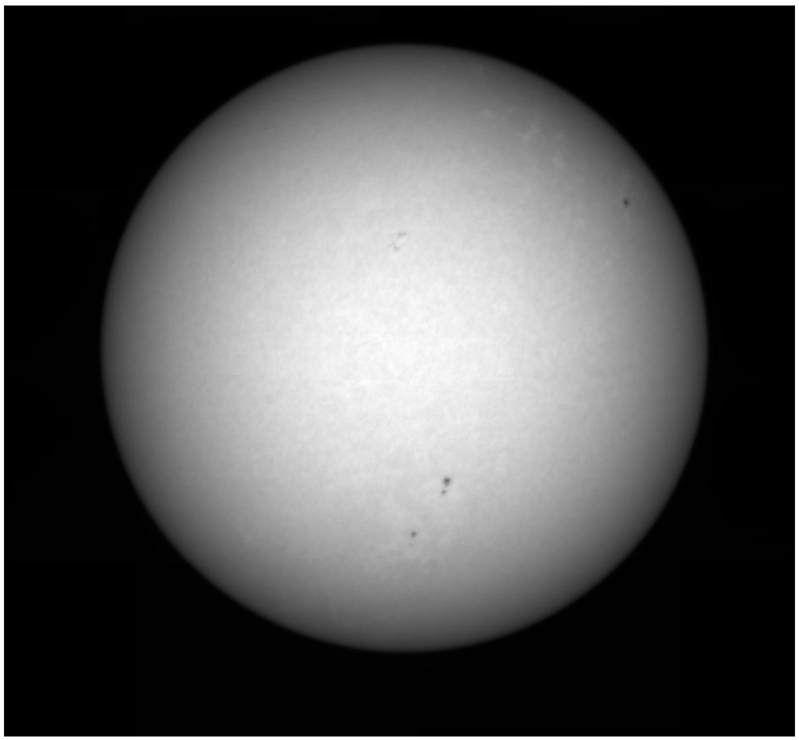


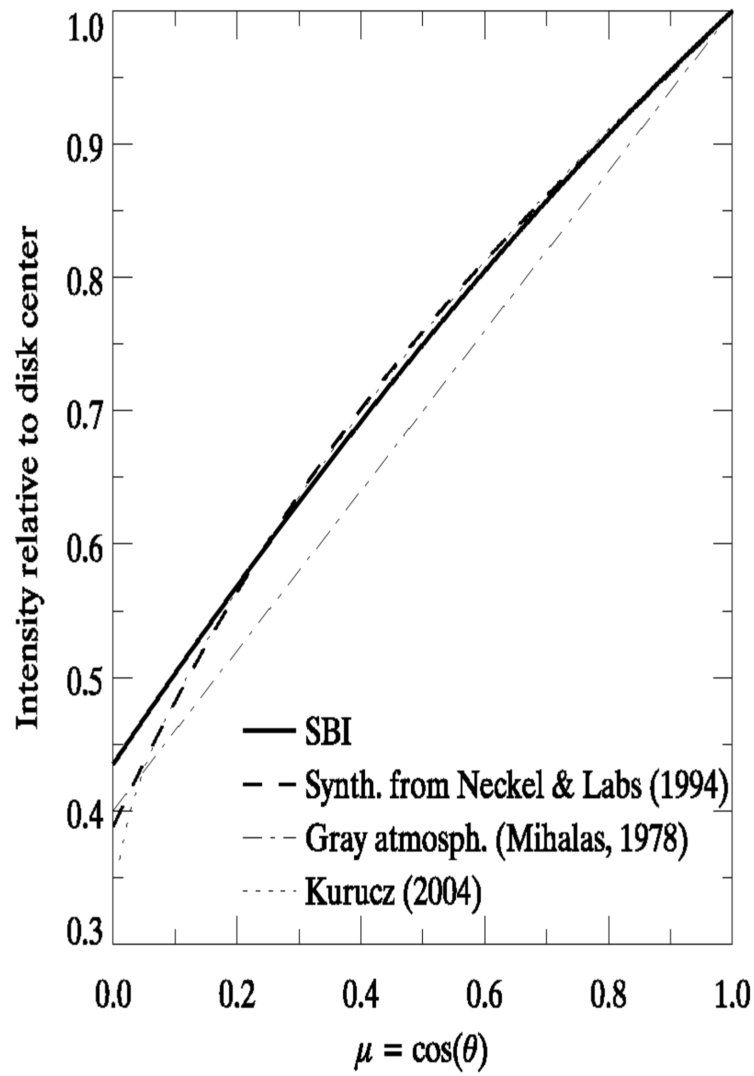
- Plan to *measure* overall system spectral transmission in laboratory, e.g.:
  - 200nm – 400nm PMT sensor
  - 350nm – 1100nm PMT sensor
  - 800nm – 1700nm Ge detector
  - 1000nm – 2600nm Indium Antimonide detector

Frame grabber

- Buffered chip signal → analog differential line driver.
- 14 bit A/D conversion
- IDE interface to computer
- Software performs frame differencing
- Adjustment of BST bias Voltage (0-15V) for fine gain control

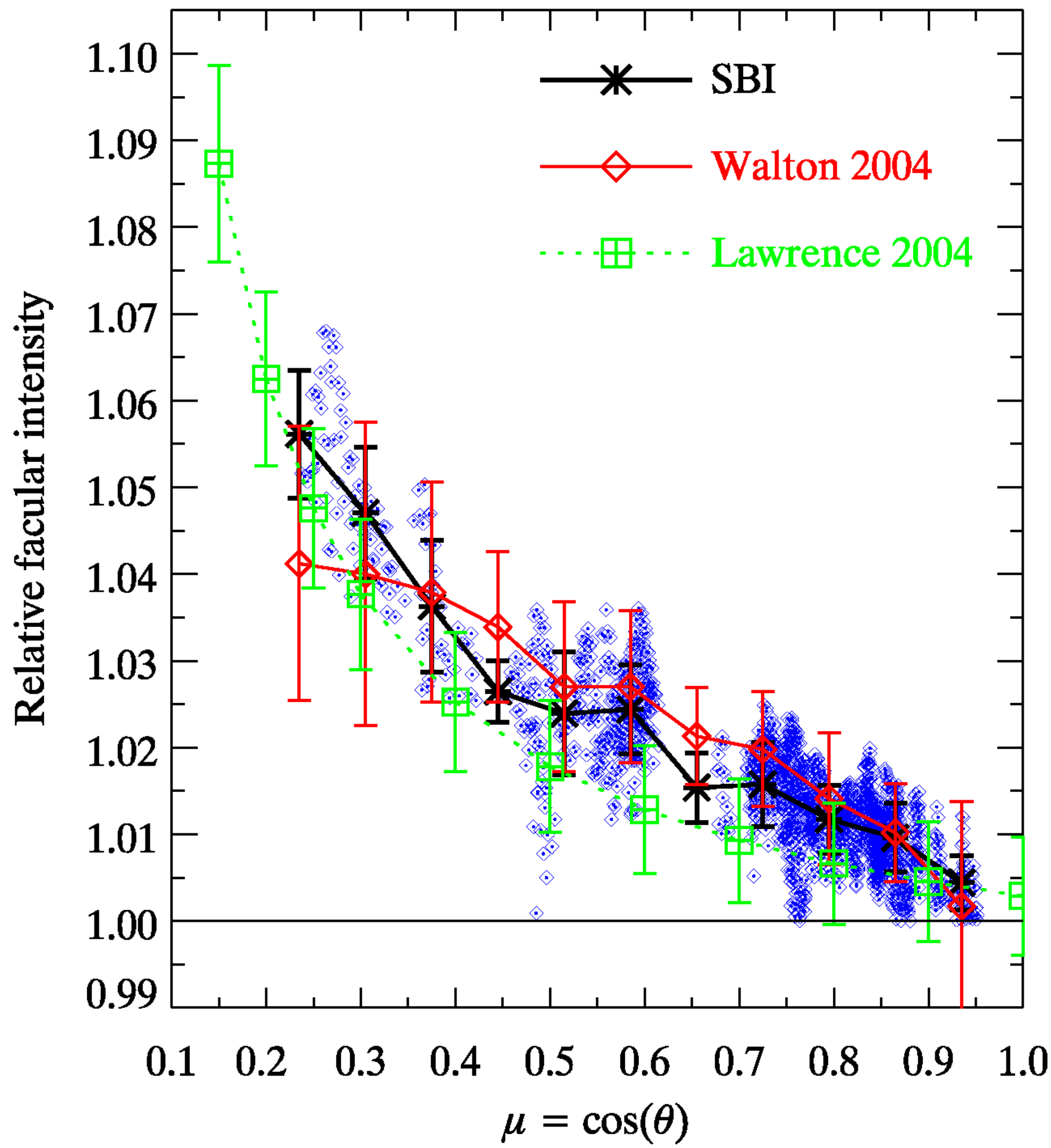
Results of first SBI flight: 1.Broad - band photospheric limb darkening



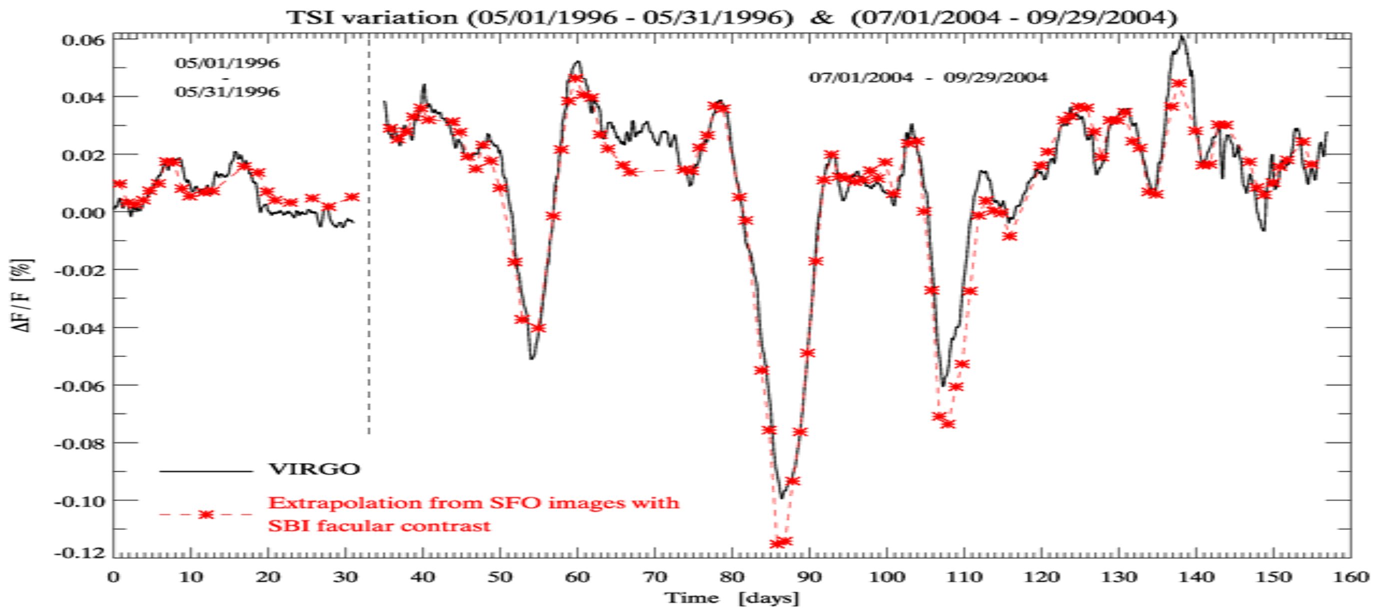


Results from the first flight: 2.Broad - band facular contrast

Agrees well with red, green narrow-band contrasts measured at similar angular resolution (ref. 1), and corrected assuming black body emission (ref. 2).



1. J. Lawrence, Sol. Phys. 116, 17, 1988.
2. J. Lawrence, S. Walton, priv. comm., 2004.



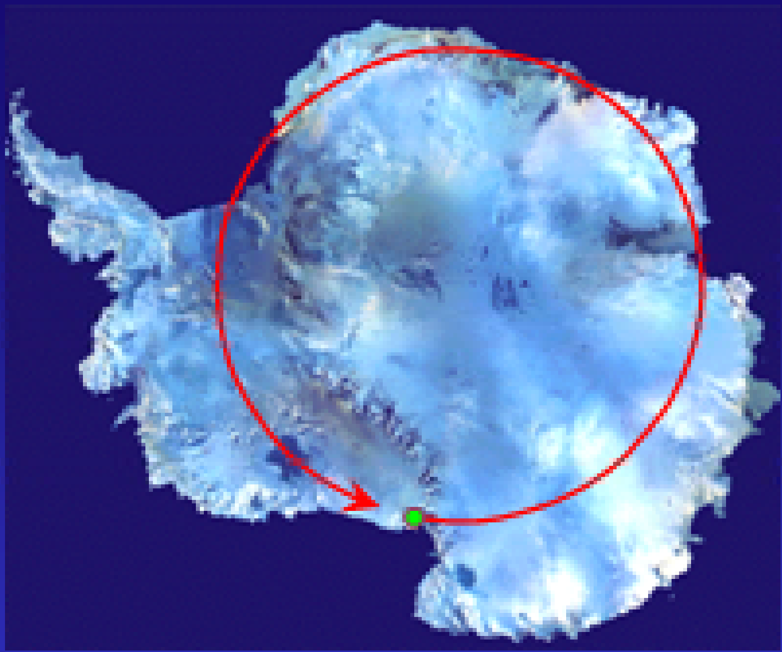
Results (cont'd): 3.TSI reconstruction using the SBI facular contrasts: Reconstruction and radiometry not only *correlate*, but also agree in *amplitude* to approximately +/-5% rms (Foukal, Bernasconi and Walton, in preparation). **Theoretical Consequences:** This amplitude agreement i) argues against "convective stirring" (Parker, 1995) or other significant T_b variations, at least on rotational time scales; ii) favors the thermal impedance model of sunspot – induced luminosity variation (Spruit,1982, Foukal et al., 1983) over energy storage in magnetic fields(Wilson, 1981), or downdrafts (Schatten et al 1983).

6. Goals for Antarctic Flight

- Improve accuracy of facular, umbral and penumbral contrast by measuring features over full range of limb distance and magnetic flux. Thus improve discrimination between competing dynamical models of solar luminosity variation on *rotational* time scales.
- Use temporal filtering to attenuate p-mode and granular noise, and so extend facular contrast threshold to enhanced network. Thus, to test whether its area variation accounts for TSI variation over the *11- yr cycle,* or whether other activity – related heat flux variations might contribute.
- Using the 750 nm and broad –band channels, and both spatial and temporal p-mode and granular noise attenuation, search for low – amplitude T_b inhomogeneities outside spots, faculae, on scales from supergranules, and active region "thermal shadows", to pole – equator differences. Thus, provide new heat flow constraints for dynamical models of large – cell convection, meridional circulation,and latitudinal differential rotation.

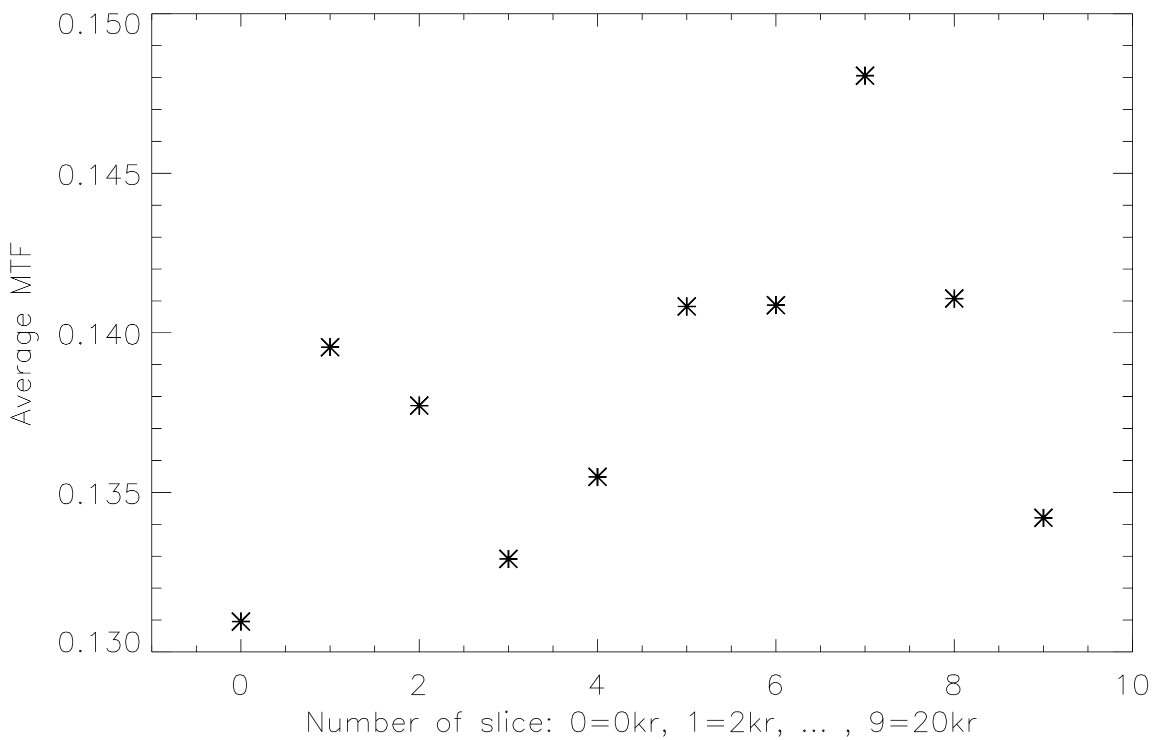
Flight profile

Balloon flight planned for Antarctic summer season 2006/6007 at about minimum of solar cycle.



- Launch from McMurdo station at 78° Latitude North
- Desired altitude: ~36 km
- Desired flight duration: 27 days
- Realistic flight duration: 15 days
- On-board storage space: 1,400 GB
- ~ 24 h line of sight high data rate communications via NSBF's UHF radio
- Over the horizon communication via TDRSS satellite link
- Minimum science data downloaded in-flight
- Recovery of all data (and payload) at end of mission

SBI in space: radiation hardness of BST detector



- No significant MTF dependence on radiation exposure up to 20 krad
- Array sensitivity decreases above 10 kilorads (by~5% /krad) up to 20 krad
- Compatible with NASA guidelines for 4-yr mission@ 600 km, 28 deg inclination.

Solar Irradiance Space Mission

- Pyrheliometers to measure TSI continously
- **Optimum use of SBI -** simultaneously measures TSI contribution of specific umbrae, penumbrae, faculae causing TSI variation.
- Avoids main errors of TSI reconstruction: i)area measurements; ii) contrast dependences on magnetic flux, of solar magnetic structures
- Achieves optimal sensitivity for photometric detection of large –scale solar convection, meridional circulations, thermal shadows, etc.