Implications of the RHESSI solar limb measurements

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Abstract: The solar aspect sensors of the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) allow us to study the precise shape of the Sun in a 17nm bandpass filter at about 670nm. The measurement is analogous in some ways to Dicke's original oblateness measurements. Interpreted strictly as limb position, the individual measurements have a precision of a few milli arcsec (mas), and we have been obtaining about 100 points per second since launch in February 2002. We find the oblateness of the Sun (the difference of equatorial and polar radius) in July-September 2004 to have been 7.98±0.14 mas, consistent with the expectation from the surface rotation rate. To obtain this result we made use of the (positive) correlation we observed between the RHESSI radius value and the brightness of the EIT 28.4nm limb. This correlation establishes a relationship between facular brightening and apparent radius.On-disk data show that facular contrast has a maximum at intermediate values of mu and decreases again at the extreme limb. The behavior of the contrast at the extreme limb is not well understood at present, but the limb observation show that it cannot go exactly to zero. We discuss this in the context of the "hot wall" and cloud models of faculae and plage, noting that the hot wall model would predict zero contrast at the limb..

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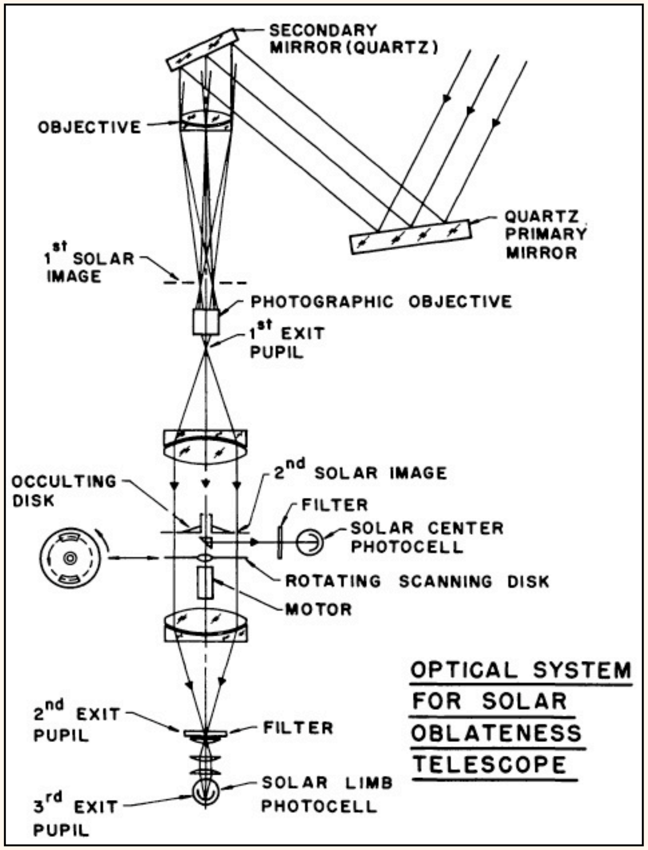
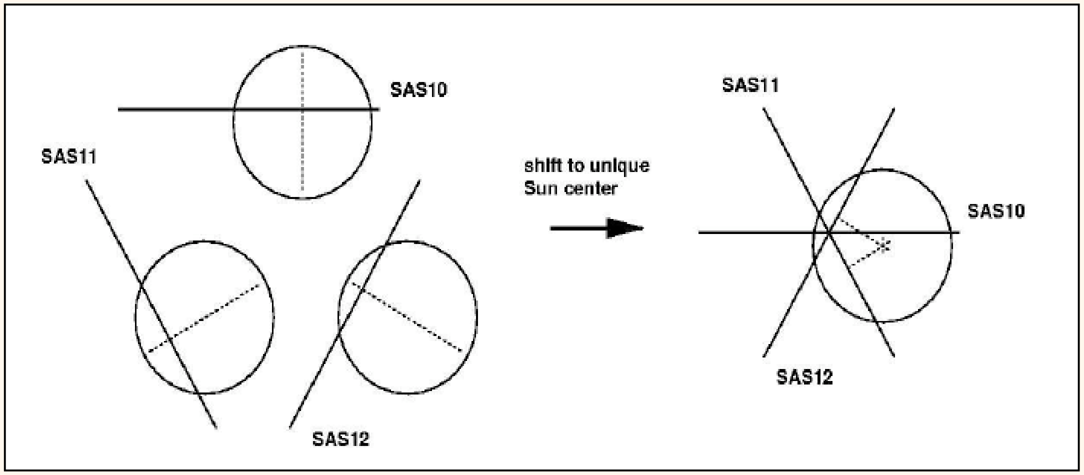
Rotating telescopes and RHESSI

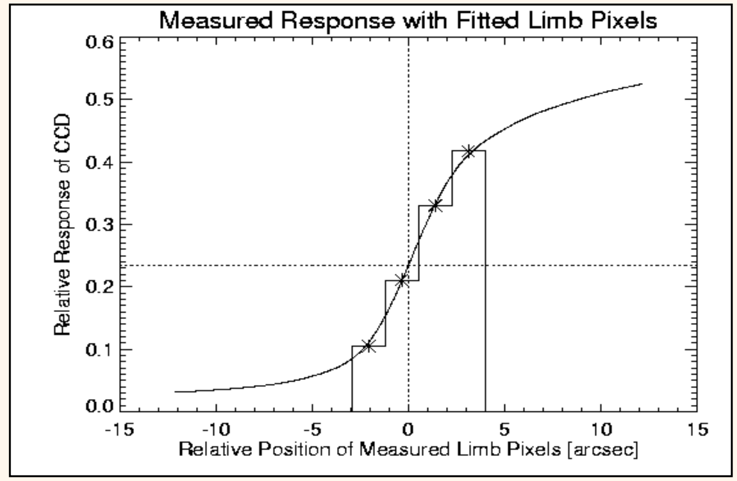


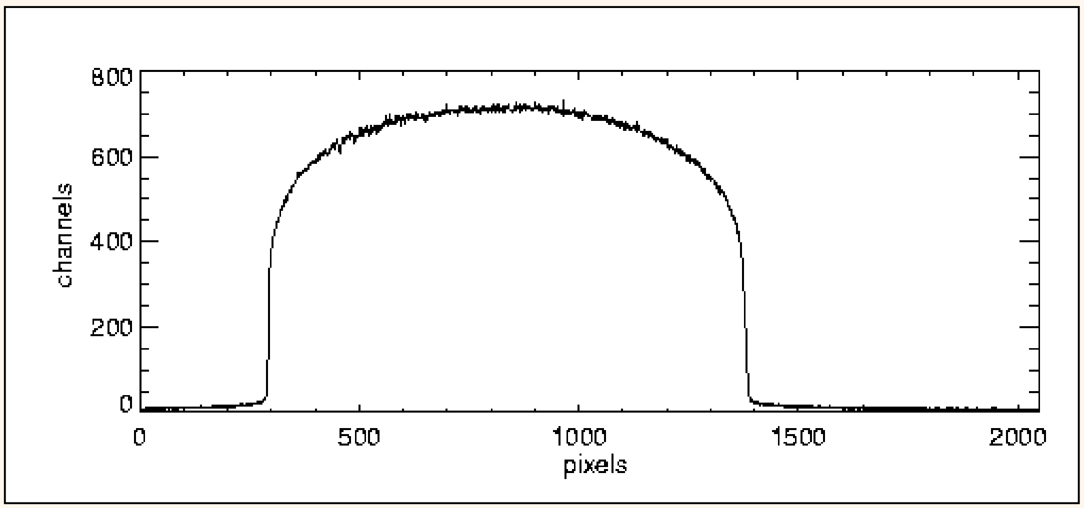
Dicke & Goldenburg 1974
In contrast, the entire RHESSI spacecraft rotates

- Rotation makes photometry *differential* in nature
- Rapid rotation cancels out subtle spacecraft temperature variations
- RHESSI needs instantaneous aspect information at the sub arcsec level hence lots of data

RHESSI’s Solar Aspect System







- Sensor: 2048-pixel linear CCD, 1.73 arc sec/pixel
- Optics: simple 4 cm lenses
- Spectral band: 670 nm x 12 nm FWHM
- Data: ~6000 line images/day
- Data: ~100 limb pixel sets per sec, or about 10^{10} total to date

Potential SAS observables

Thermal

- Granulation ?
- Convective motions ?
- p-modes !
- g-modes ???
- r-modes ??
- Oblateness !
- Higher-order shape terms ?
- Gravitational moment J2 !
- “ “ J4 ??
- Global temperature variation ?
- Facular Limb-darkening function ! (this poster)
- Planetary tides

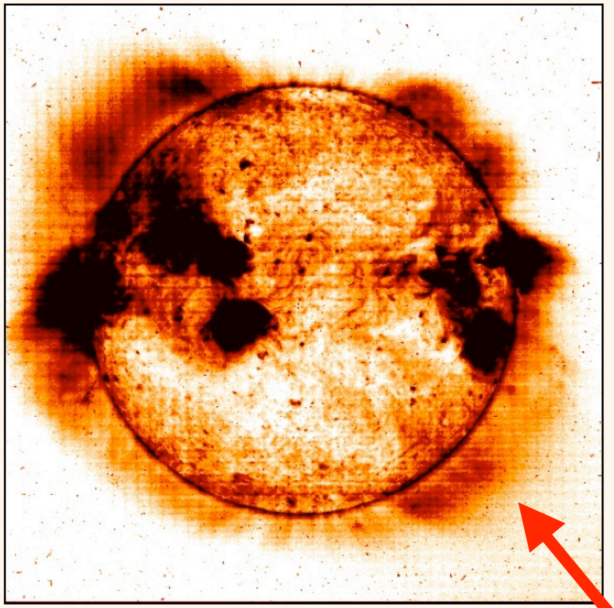
Magnetic

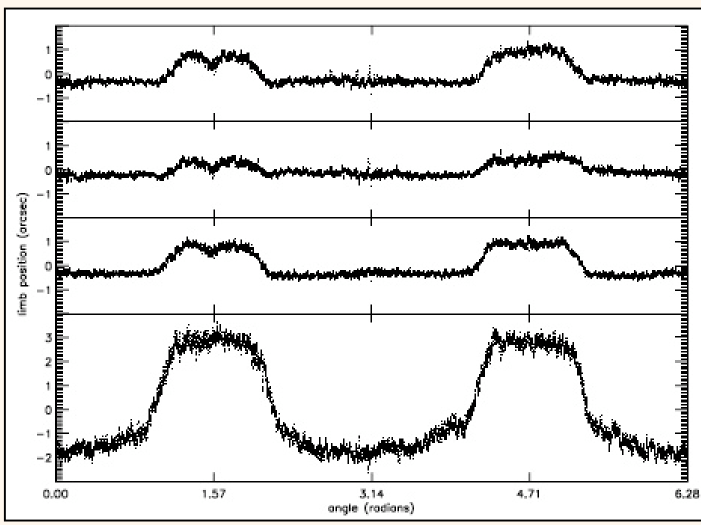
- Sunspots !
- Faculae !
- Polar faculae ?
- Active network !
- Flares ?
- Prominences ?
- Coronal holes ?

Legend:
! => detected
? => likely to be detected
?? => maybe
??? => we wish!

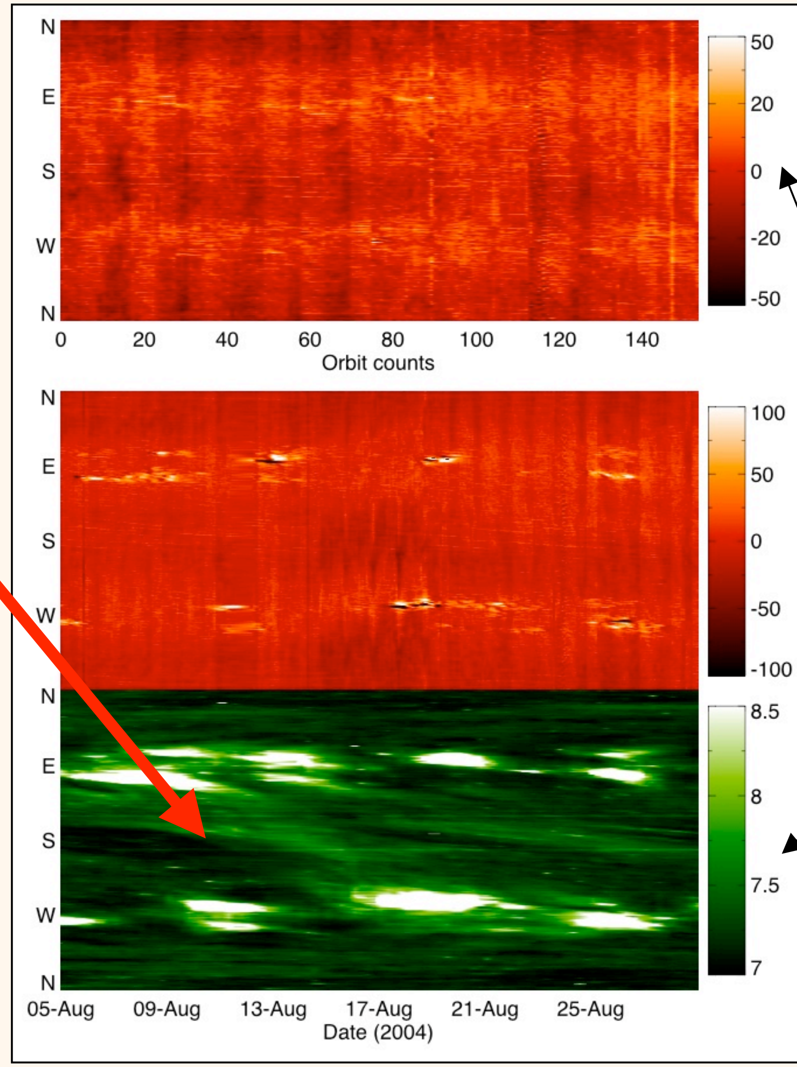
The EUV and RHESSI limb synoptics

284Å
(EIT)





Auchère et al. 1997



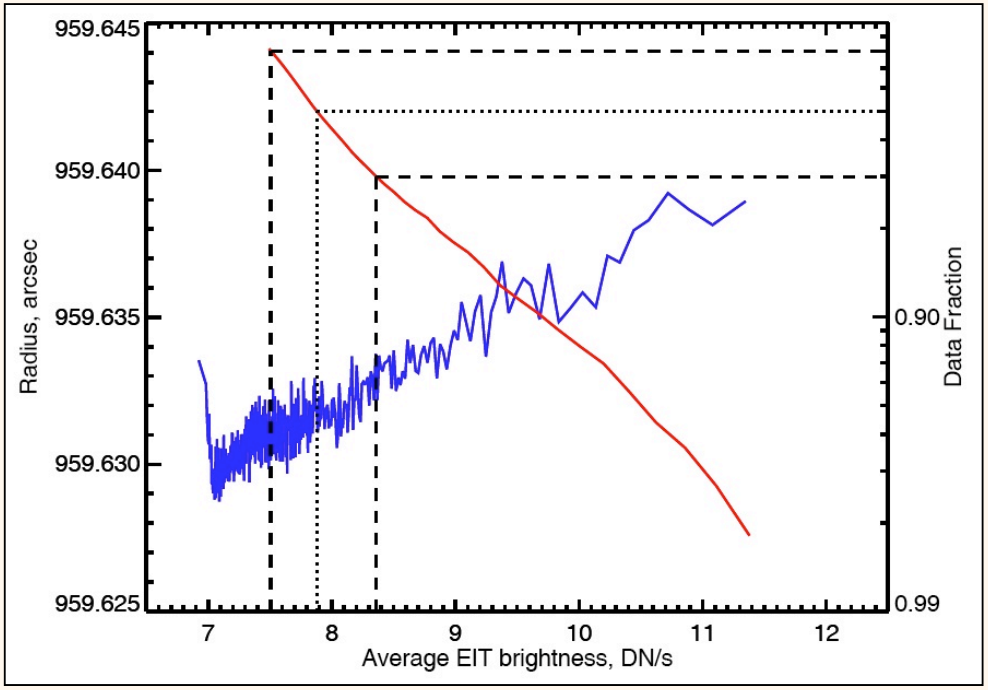
Timewise selection

mas

Arbitrary two weeks

DN/s

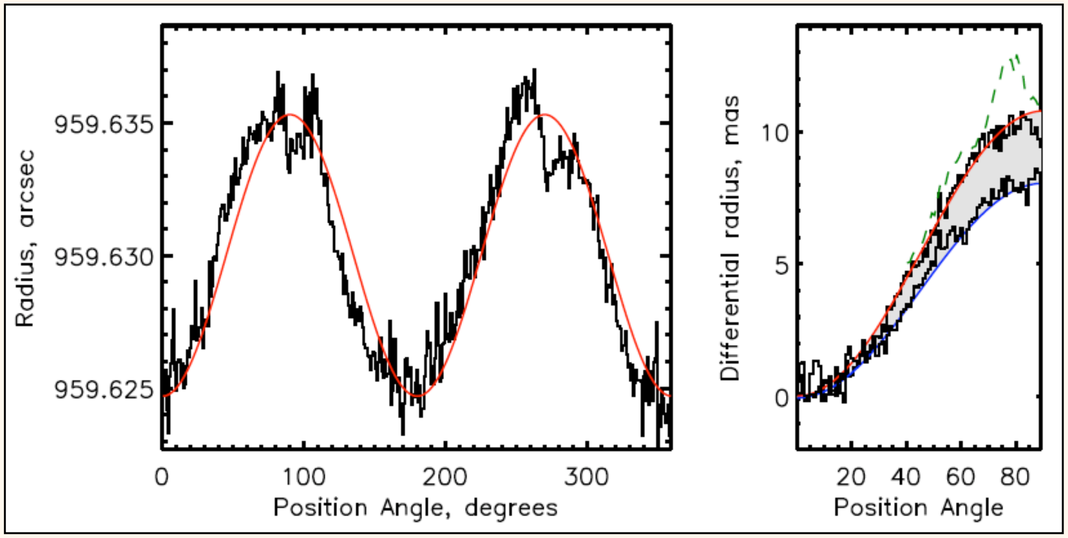
RHESSI radius vs EUV brightness

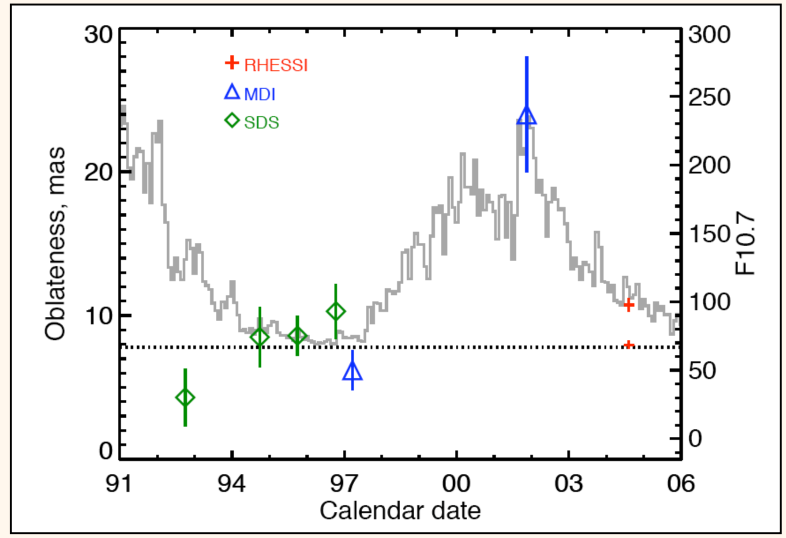


- Blue line, left axis shows the RHESSI/EUV correlation
- Red line, right axis shows cut level for oblateness study
- Empirically, at least, 284Å is a good magnetic proxy

We use the same EIT data as a reference for limb-brightening and global temperature studies involving disk images

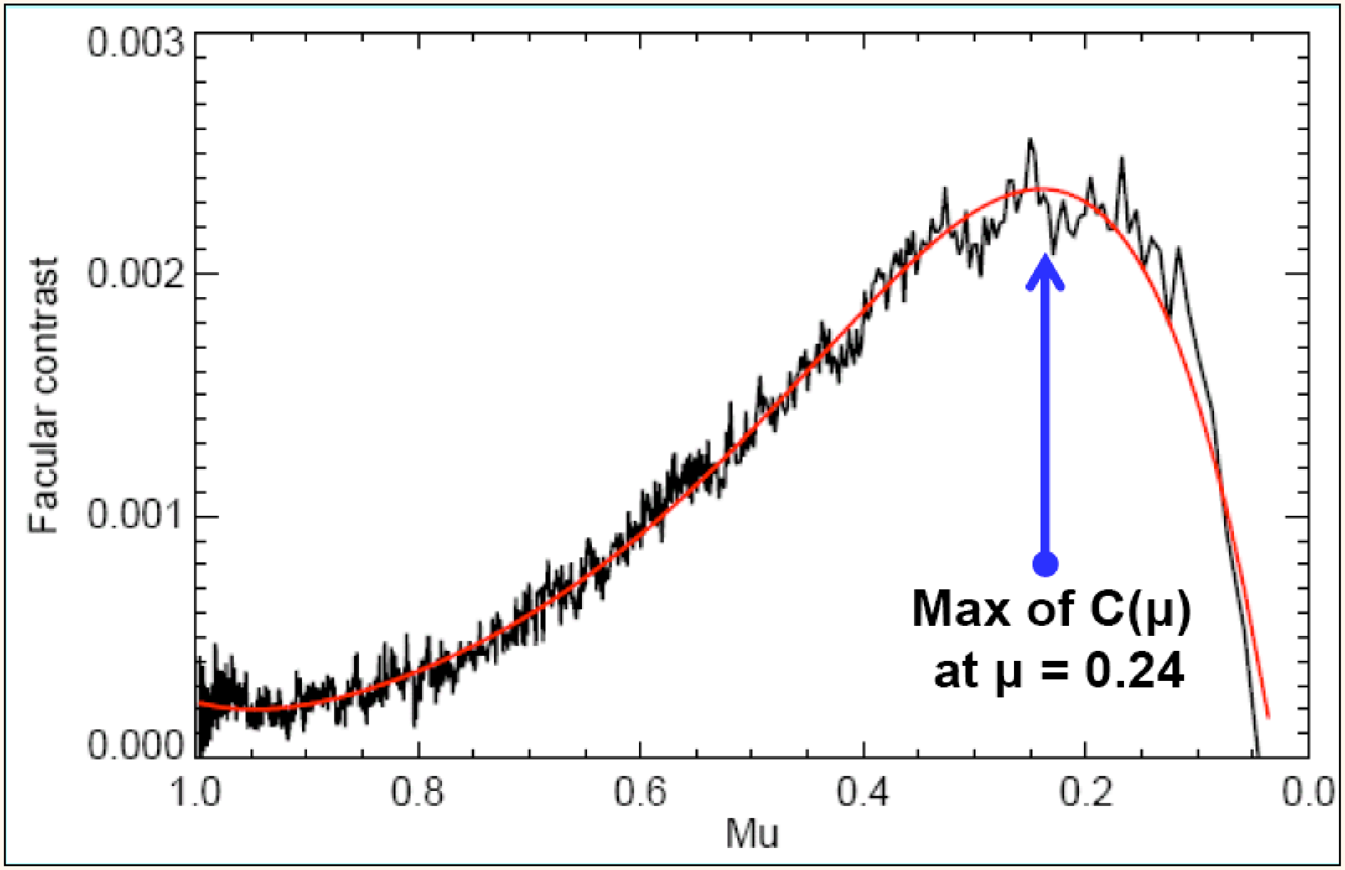
Oblateness results from 2004





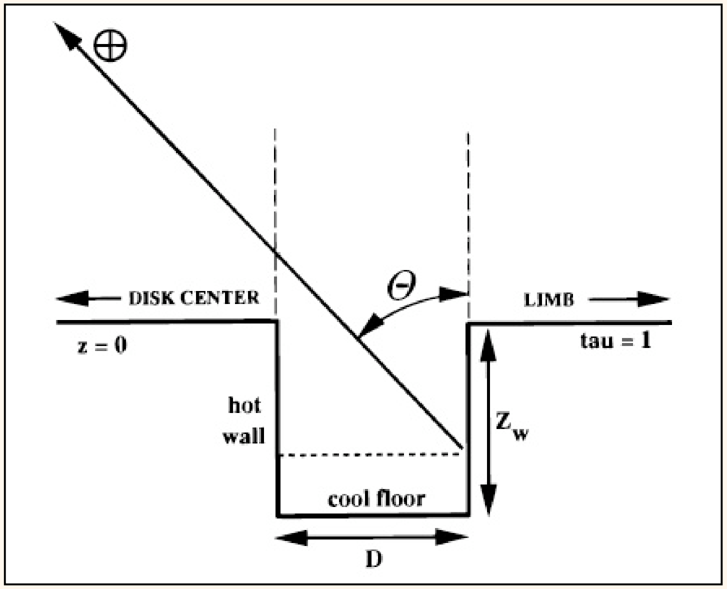
Synopsis: Statistical errors are much improved over previous observations. RHESSI finds an oblateness of 8.01 ± 0.14 mas on the hypothesis of negligible background temperature quadrupole term other than from rotational dimming (Von Zeipel's theorem) - Fivian et al., *Science, submitted*

Facular contrast result



Synopsis: The facular contrast fits the hot-wall well, as found e.g. by Topka et al. (1997) and Ortiz et al. (2002) but directly, rather than as normalized to B/μ. Note the finite level at $\mu = 1$.

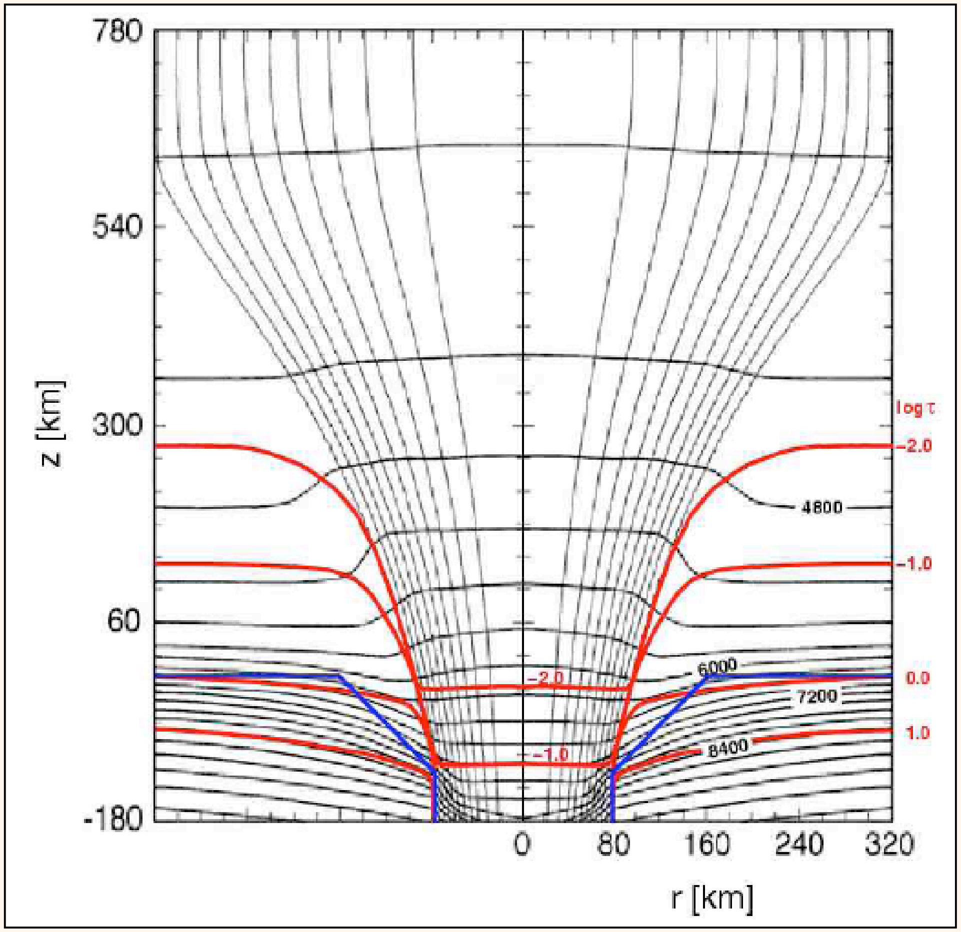
Hot-wall-plus-cloud model wanted



Topka et al., 1997

- The magnetic flux tube responsible for the “hot wall” also induces coronal heating
- We have no good quantitative description of this yet
- Ca K is often used as a plage measure, but it is a chromospheric feature
- We use 284Å (SOHO/EIT) instead
- The limb near faculae is elevated (see panel 5)

Numerical simulations of flux tubes



From Steiner & Stenflo, 1998. The red contours show opacity, with the scale on the right. At least for a vertical flux tube there appears to be no obvious “cloud” or vertical protrusion.

Conclusions

- The RHESSI optical observations offer some interesting new solar astrometry and photometry via its rotating optics
- We have found that the EUV brightness can be used as a sensitive proxy for faculae or facula-like features, at the limb and on the disk
- Using this proxy, we find (a) that the hot-wall model works well on the disk, with a 6th-order polynomial yielding $\mu_{max} = 0.24$.
- The extreme limb remains a problem. We need a model that combines hot wall and cloud, apparently

SOT, STEREO, SDO, RHESSI, and the limb

Future program: By driving the statistical error in the oblateness measurement down to 0.14 mas, we find ourselves at a small fraction of the photospheric scale height or of any known feature scale. Yet the robustness of the RHESSI measurements means that we can in principle study the structures of the limb. We note that the network itself is resolved by the RHESSI angular resolution, so that we can in principle study the "helioid" figure determined in cell centers. It would be very nice to coordinate future SOT observations with RHESSI in order to do this. The effective RHESSI time resolution is low, and so it may be that lower-resolution SDO images would be better. In either case we speculate that we can use STEREO to define the limb network for this purpose. We encourage this kind of study.