

# Reconstruction of TSI from Broad Band Facular Contrast Measurements by the Solar Bolometric Image

**Pietro N. Bernasconi**

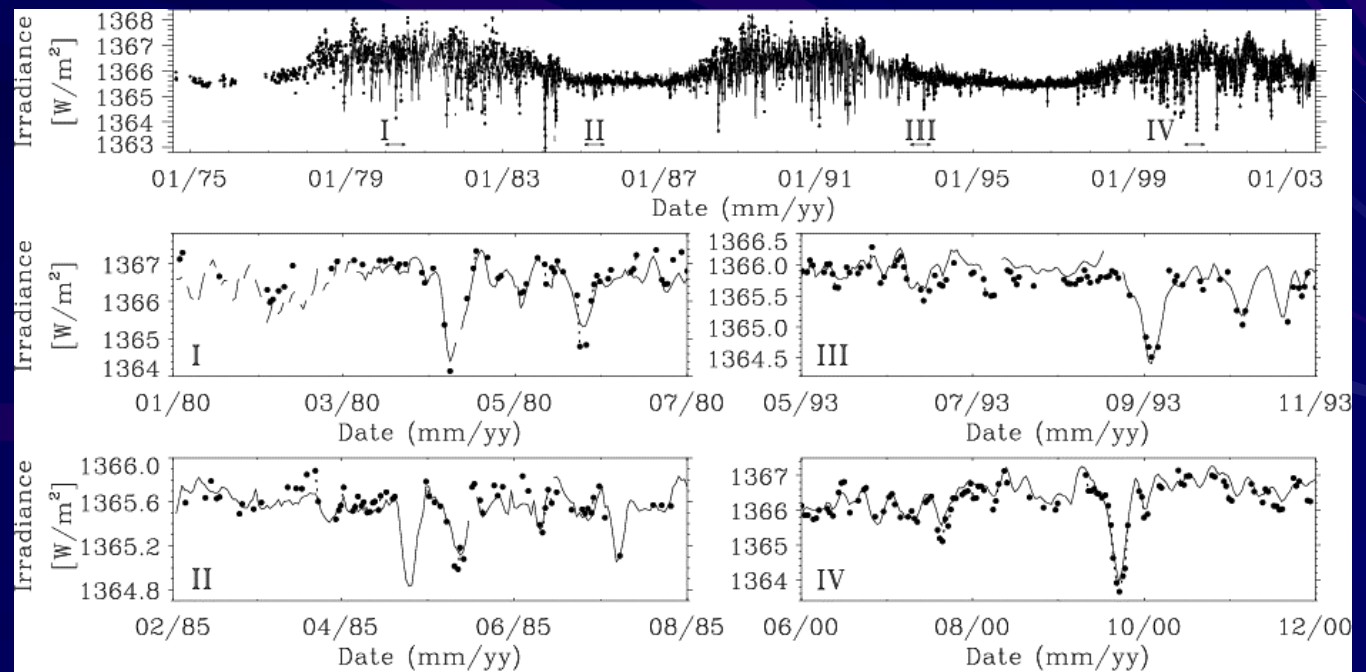
JHU/Applied Physics Laboratory, [pietro.bernasconi@jhuapl.edu](mailto:pietro.bernasconi@jhuapl.edu)

**Peter V. Foukal**

Heliophysics Inc., [pvfoukal@comcast.net](mailto:pvfoukal@comcast.net)

# Introduction

- Variations in TSI correlate well with changes in projected area of photospheric magnetic structures:
    - Dark spots decrease TSI
    - Bright faculae in AR & network increase TSI
  - Modeling of TSI based solely on contribution from *identified* photospheric magnetic sources reports very high correlation coefficients:  $r > 0.9$
- ⇒ TSI variability arises from brightness structures associated spatially & temporally with magnetic structures (flux tubes)



Wenzler et al. 2007,  
A&A 460, 583

$$r = 0.96$$

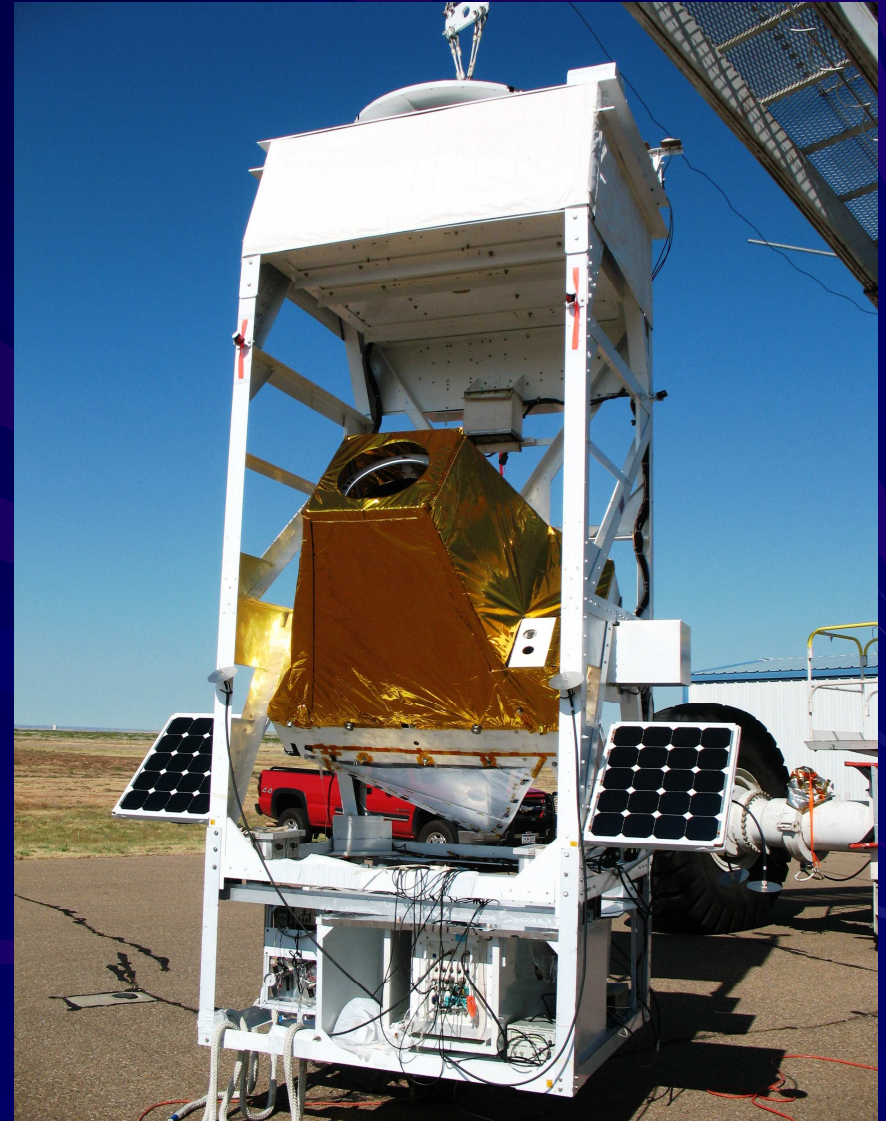
# Are all TSI contributions accounted for ?

---

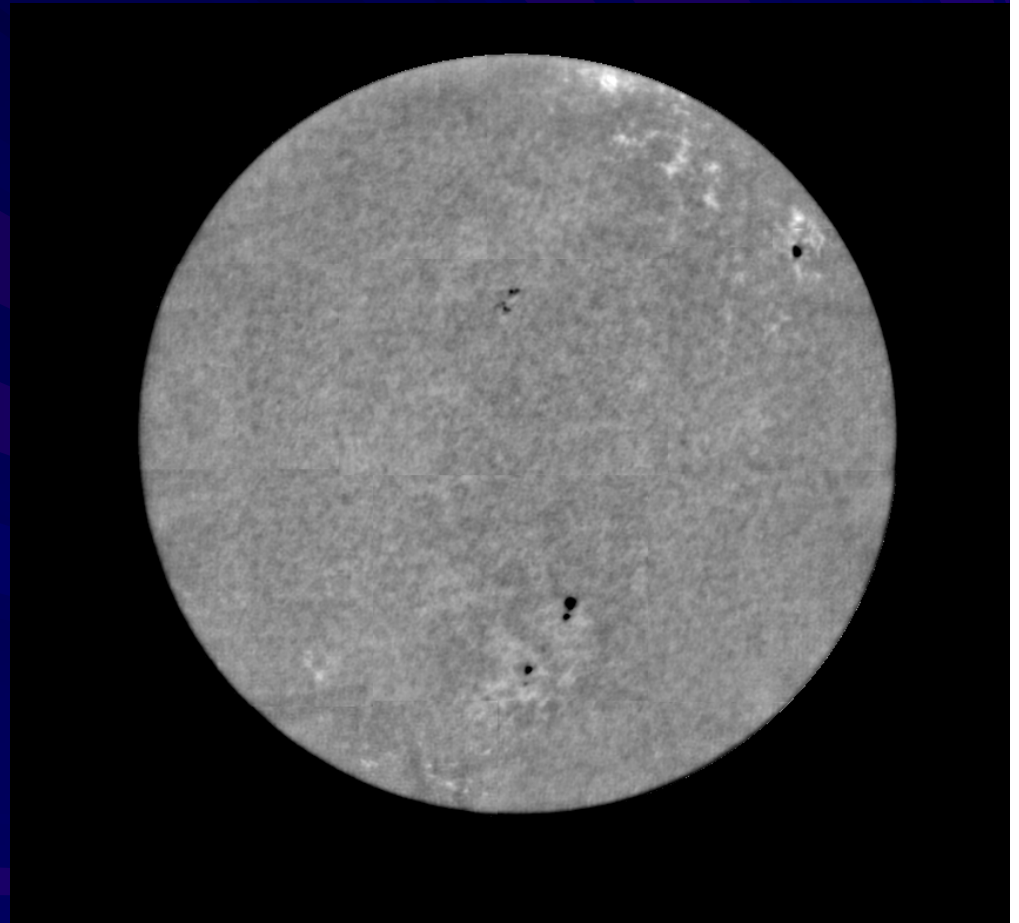
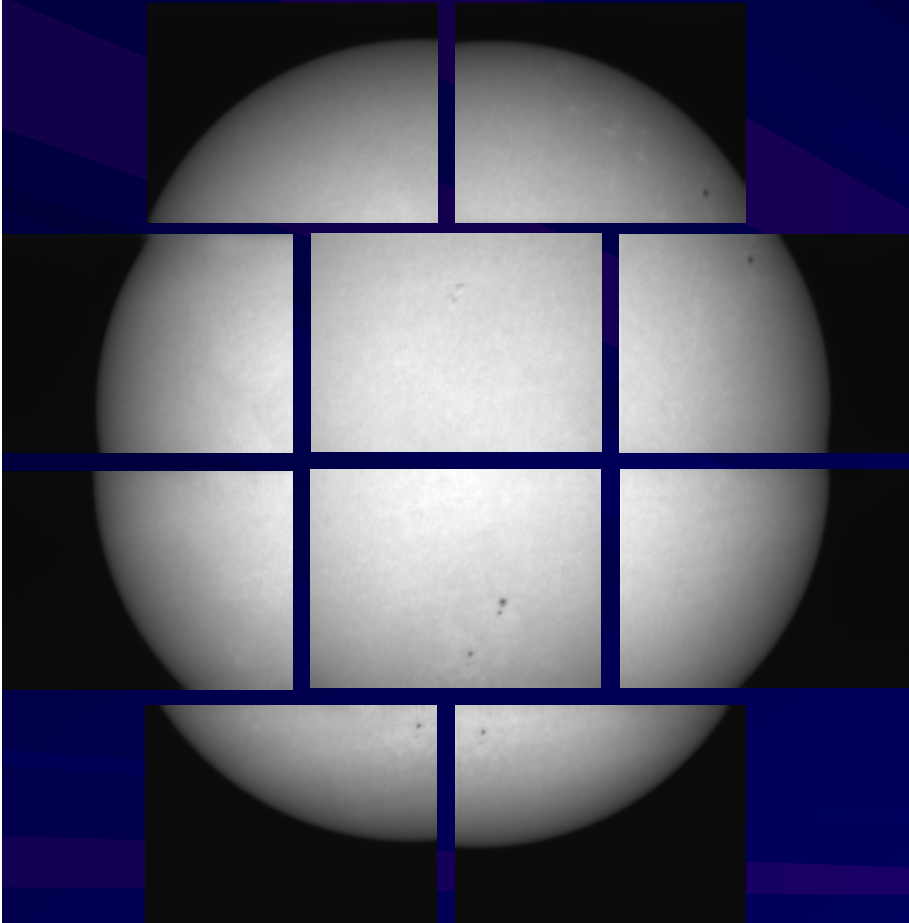
- Correlation analysis alone can not discriminate between:
  - TSI variation from changes of projected areas of spots & faculae
  - TSI variation contribution from brightness structures immediately surrounding flux tubes
- All past and current TSI models rely, in one way or another, on fitting the facular contrast to match as closely as possible the measured TSI variation
- Possible extra-flux-tube structures could be:
  - Bright rings around sunspots (Fowler et al., 1983; Rast et al., 1999)
  - Low-level brightness around ARs associated with predicted “convective stirring” (Parker, 1995)
- Extra-flux-tube contributions would be important on solar-rotational to multidecadal time scales
- Evidence of appreciable convective stirring could reopen the possibility of slower TSI variations large enough to drive climate on centennial to millennial time scales
- TSI modeling based on actual measurements of the bolometric contrast of spots & faculae can determine if other sources of TSI variability have been overlooked

# Solar Bolometric Imager

- Recently, the Solar Bolometric Imager (SBI) imaged the photosphere in broad band from the stratosphere (~35 Km altitude)
    - Novel 30 cm aperture telescope with an 320x240 element BST thermal detector
    - 3 arcsec pixels
    - *Spectrally constant response* between 0.30 – 2.6  $\mu\text{m}$  (i.e. including ~ 94% of TSI) (ref. 1).
  - Sept 1, 2003 SBI balloon flight
    - Provided the *first broad band measurement of facular contrast* (ref. 2).
  - Sept 13, 2007 second SBI balloon flight at Sun minimum.
    - Will provide first precise measurements of network bolometric brightness
1. Bernasconi *et al.*, *Advances in Space Research* 33, 1746, 2004.
  2. Foukal *et al.*, *ApJ. Letts.* 611, 57, 2004.

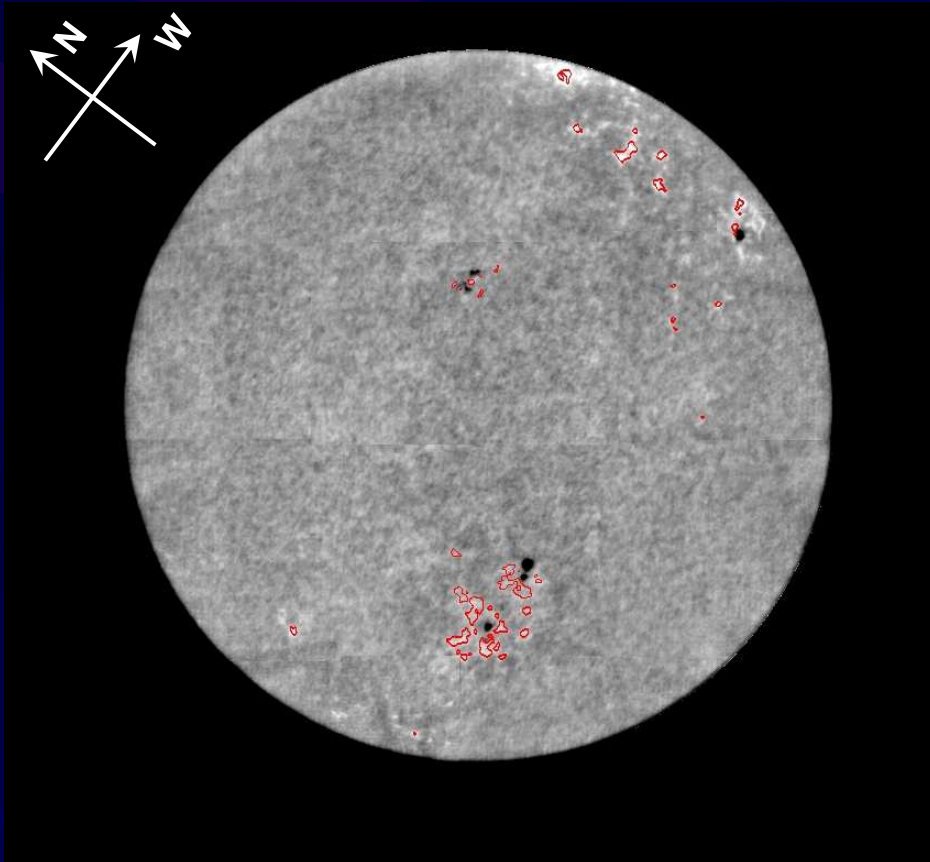


# SBI Bolometric Images



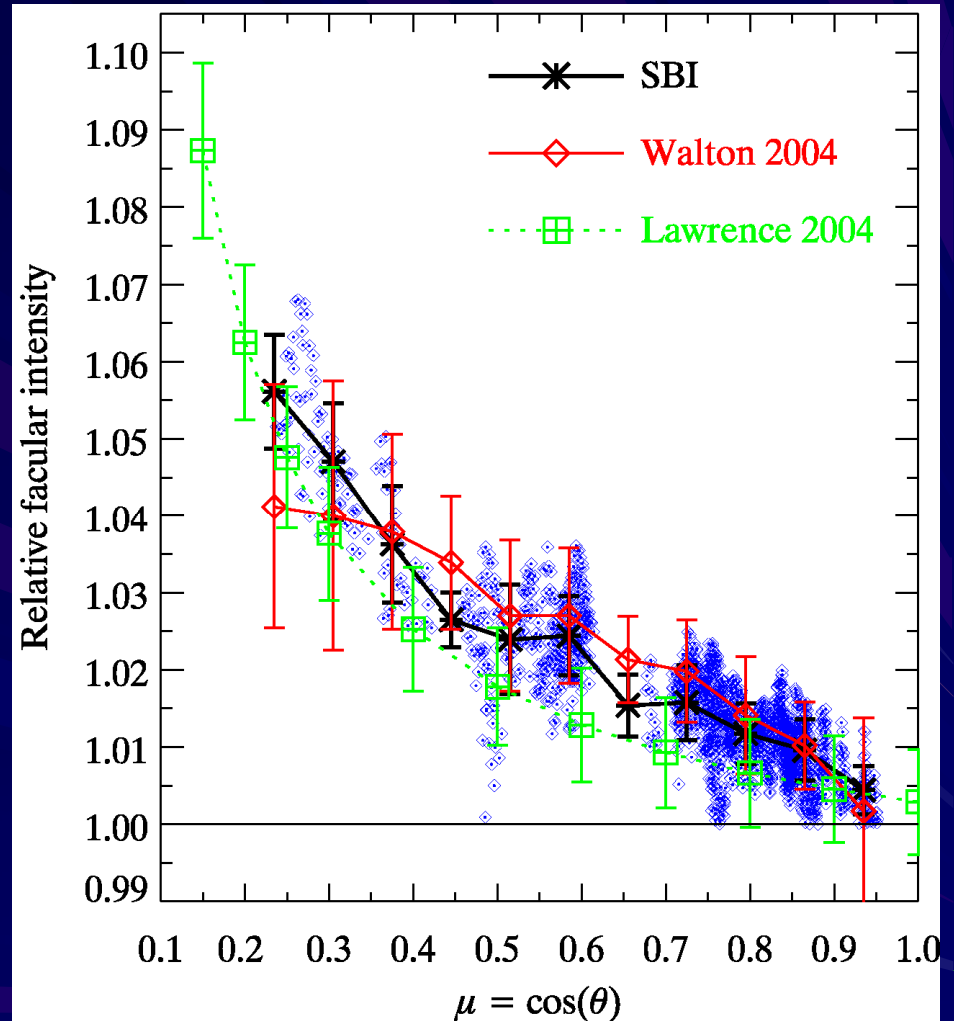
September 1, 2003

# Measured Facular Bolometric Contrast



September 1, 2004

Identification of faculae on SBI contrast image



Center-to-limb variation of facular contrast (Foukal et al. 2004, ApJ. 611, L57)

# TSI Model

- 1) Determine areas and locations of faculae and sunspots umbrae and penumbrae from SFO Ca II K and Red images
- 2) Compute contribution to TSI variation from Faculae, Umbrae, Penumbrae:

$$\partial S_{X_i} / S = A [C_X(\mu) - 1] L(\mu)$$

A = Fractional proj. area of feature

$C_X(\mu)$  = Photometric contrast of:

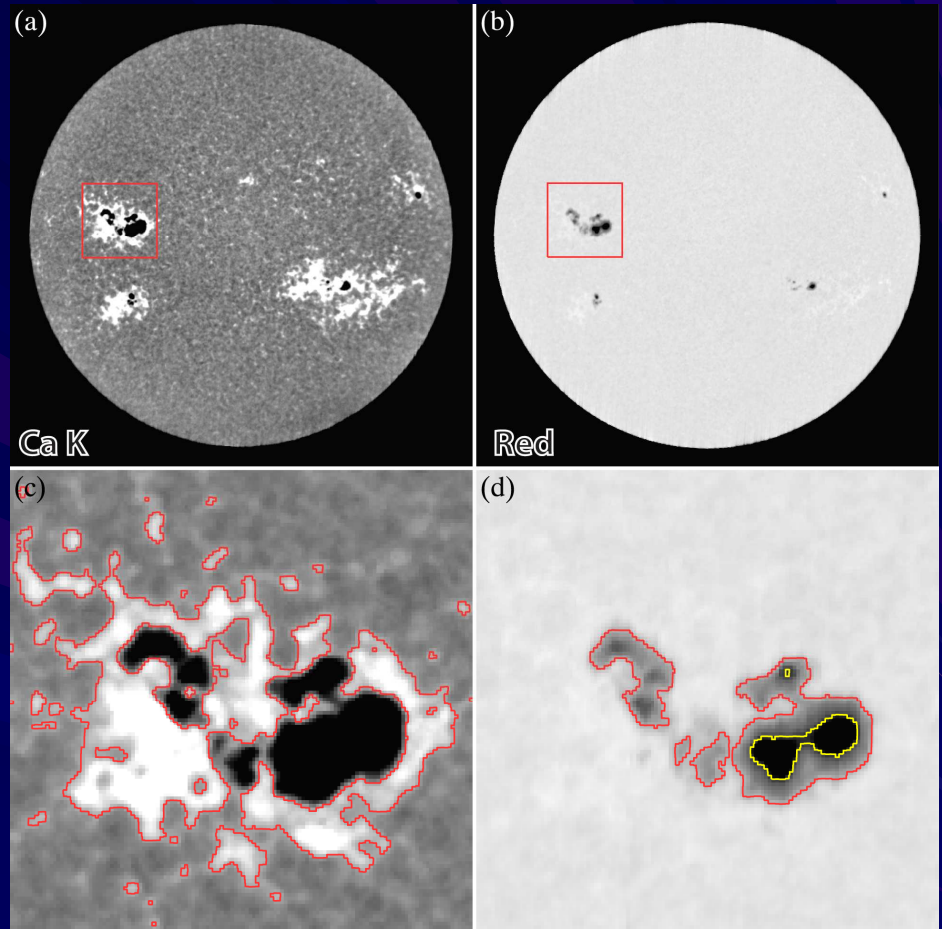
Umbra:  $C_U(\mu) = 1.76$

Penumbra:  $C_P(\mu) = 1.23$

Facula:  $C_F(\mu)$

$L(\mu)$  = Limb darkening (from SBI bolometric measurements)

- 3) Sum all contributions to obtain daily TSI variation



Photometric thresholds for:

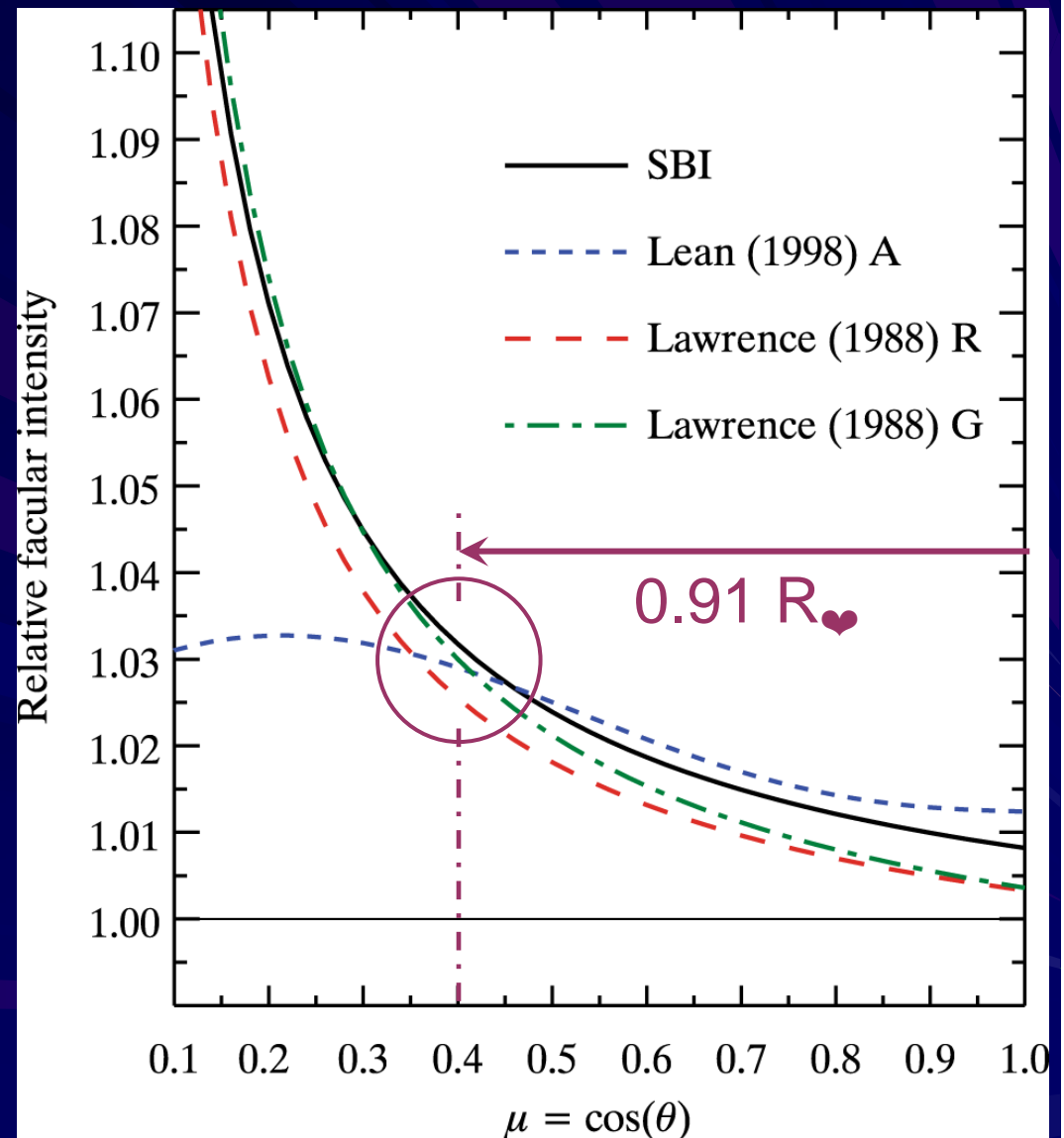
Umbra:  $I_U < 0.68$  Red

Penumbra:  $0.68 < I_P < 0.91$  Red

Facula:  $I_F > 1.05$  Ca II K

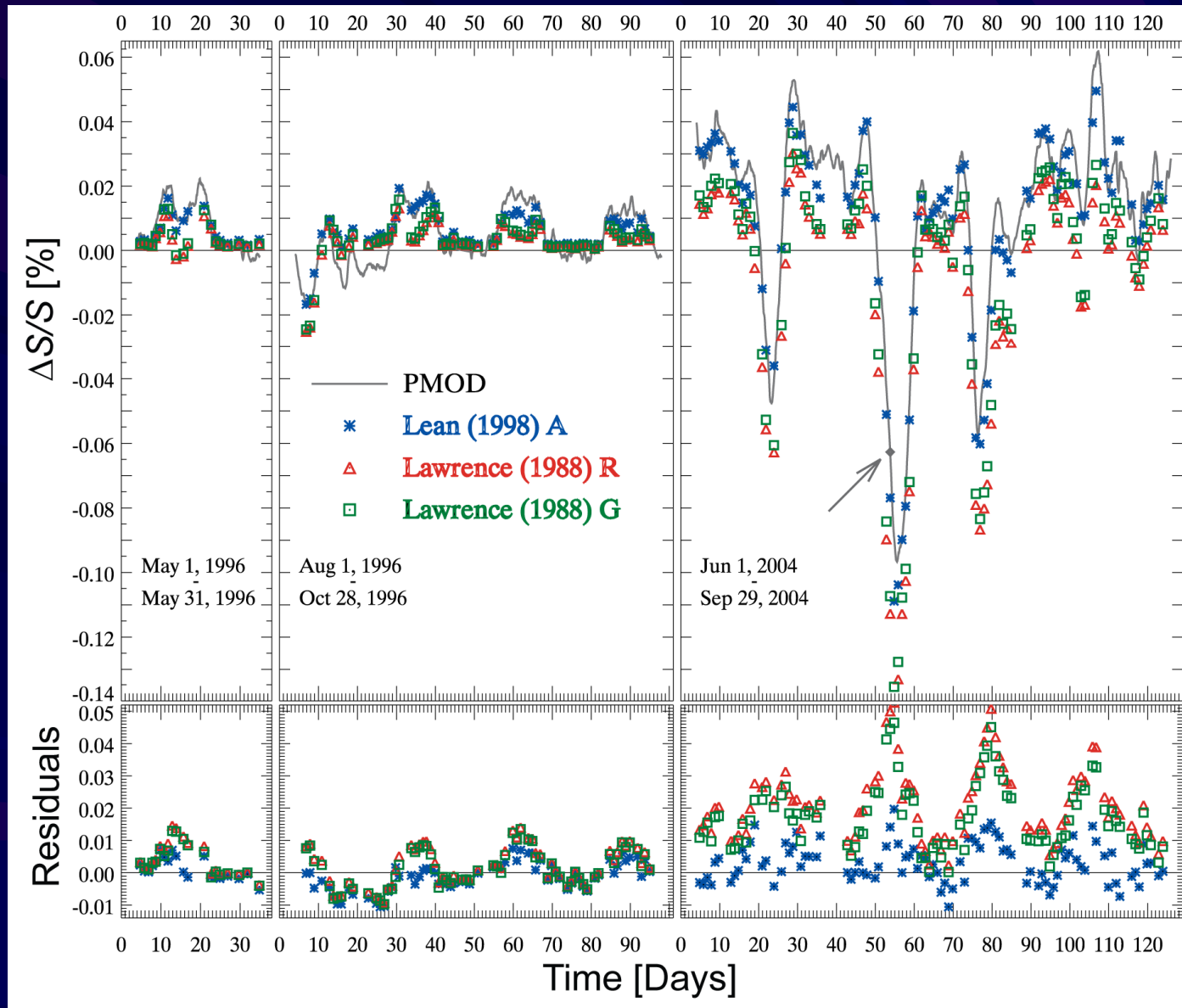
# Facular Contrast

- Use 4 different center-to-limb facular contrasts curves
- SBI:
  - Broad-band (300nm–2600 nm) contrast measurements
  - Foukal et al. 2004, ApJ 611, L57
- Lean (1998) best fit #A:
  - Best fit for reconstruction of measured TSI.
  - Lean et al. 1998, ApJ 492, 390
- Lawrence (1988) R & G:
  - Monochromatic (0.15 nm BP) photometric measurements in:
    - Red (524.5 nm)
    - Green (626.4 nm)
  - Lawrence 1988, Sol.Ph. 116, 17

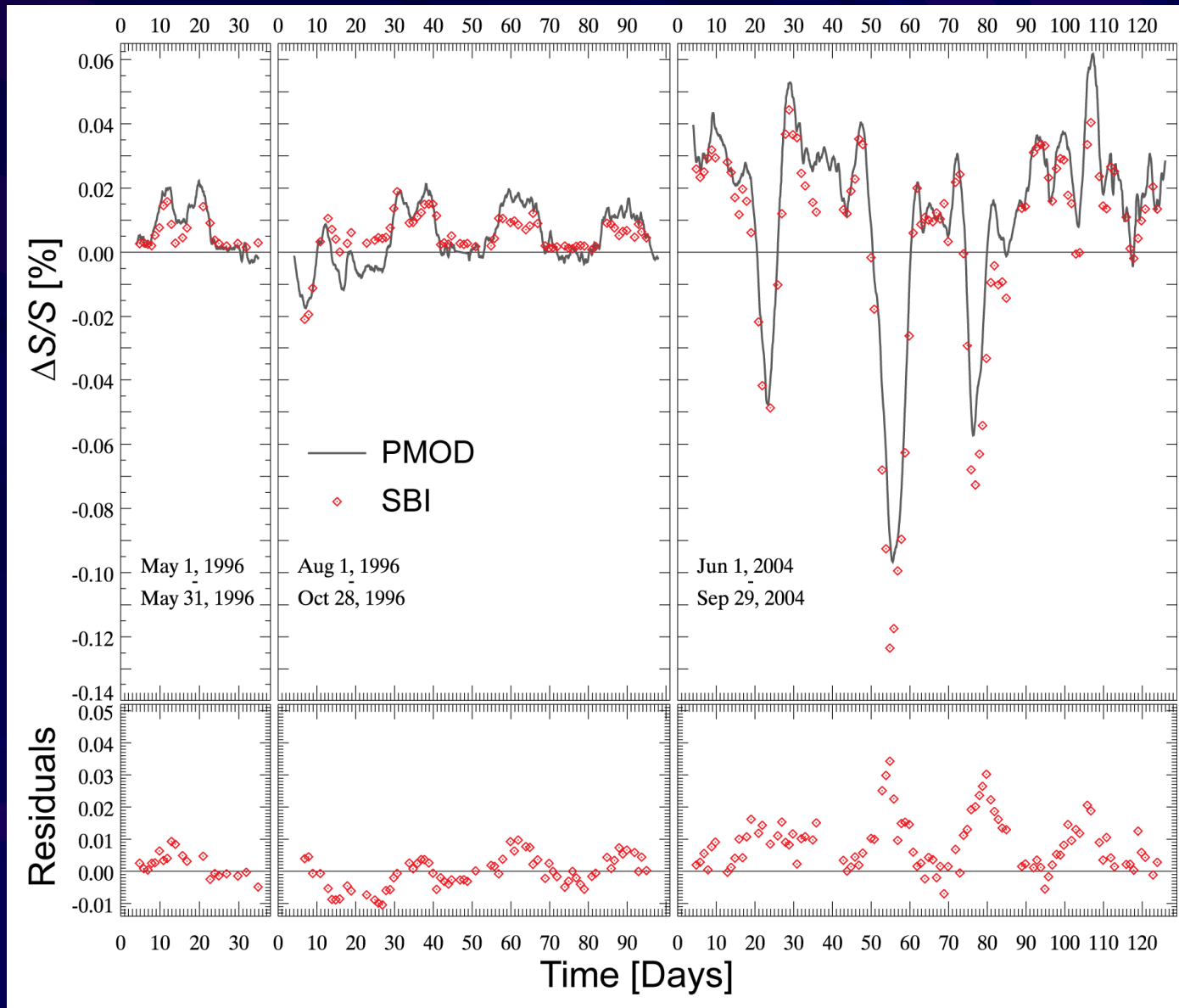




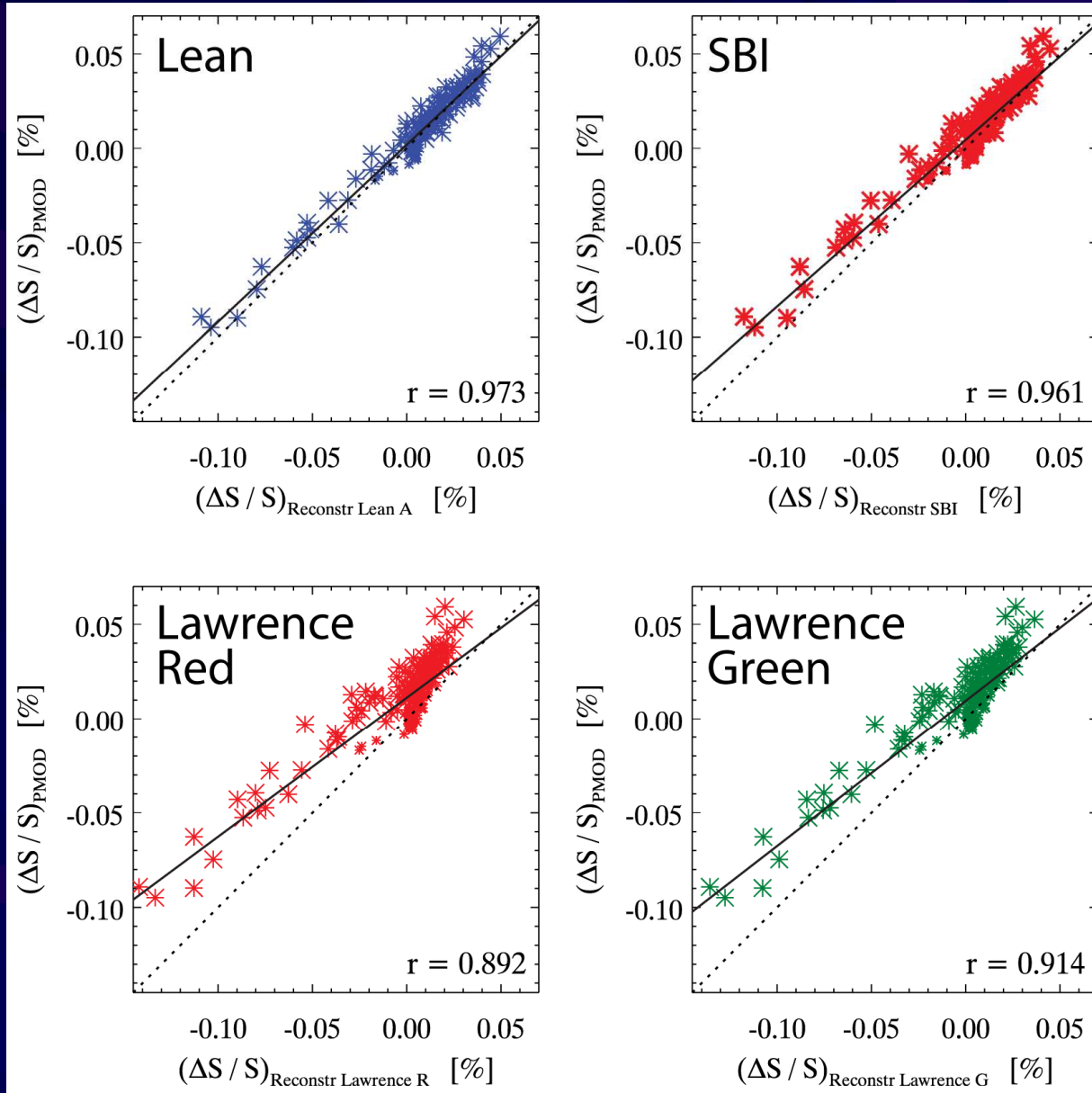
# Reconstructions



# SBI reconstruction



# Scatter Plots

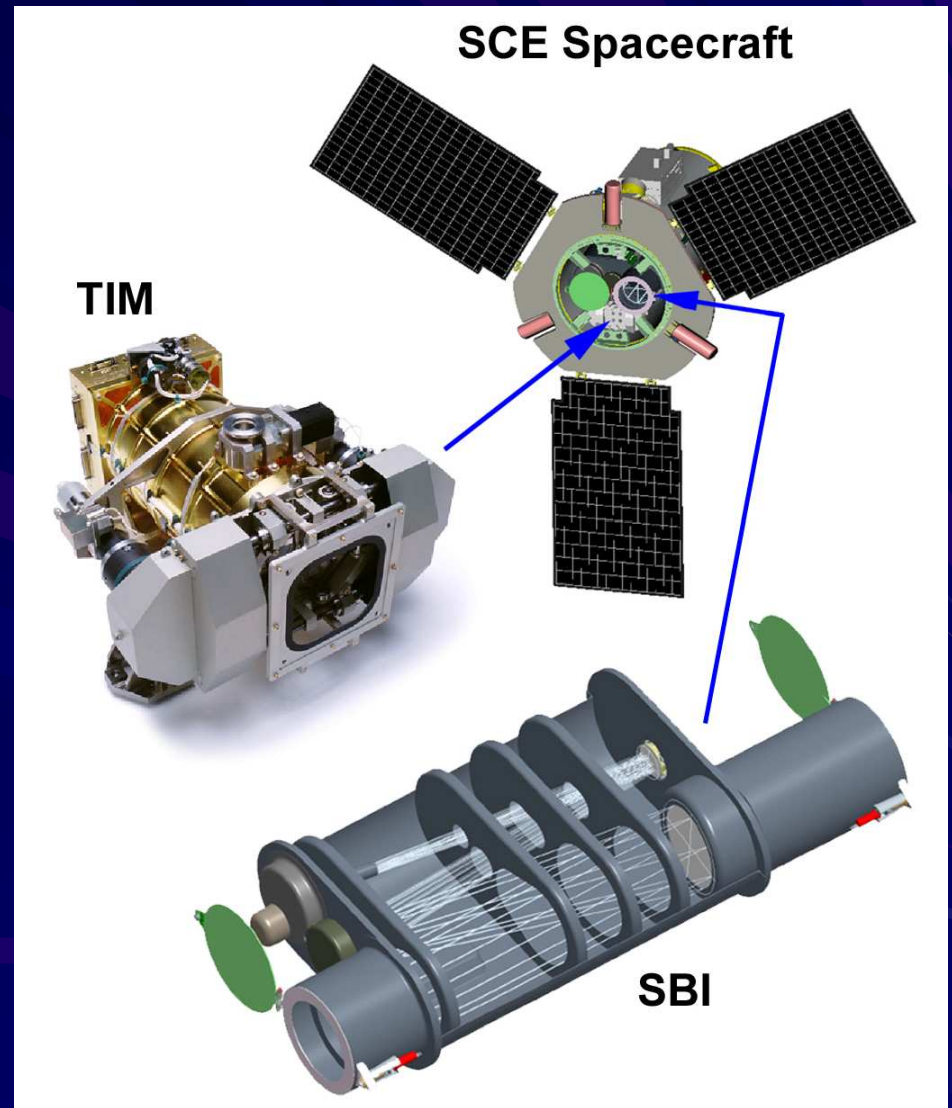


# Results & Conclusions

- Reconstruction with SBI data is first to use actual measured broadband facular contrasts
  - Agrees to about 10% with TSI record
- High facular contrast is needed at  $\mu > 0.4$  to agree with radiometry
- Shape of facular contrast curve at  $\mu > 0.4$  has great impact
- Consistently positive residuals ( $TSI_{P_{MOD}} - TSI_{model}$ )
  - May indicate possible presence of extra-flux-tube TSI contributions from bright structures not included in reconstruction
- Details in Foukal & Bernasconi, 2008, Sol. Phys. 248, 1
- To conclusively determine whether the positive residuals we see are really caused by extra-flux-tube bright structures, imaging of areas and contrasts of spots, faculae, and network with SBI over at least several months will be necessary.

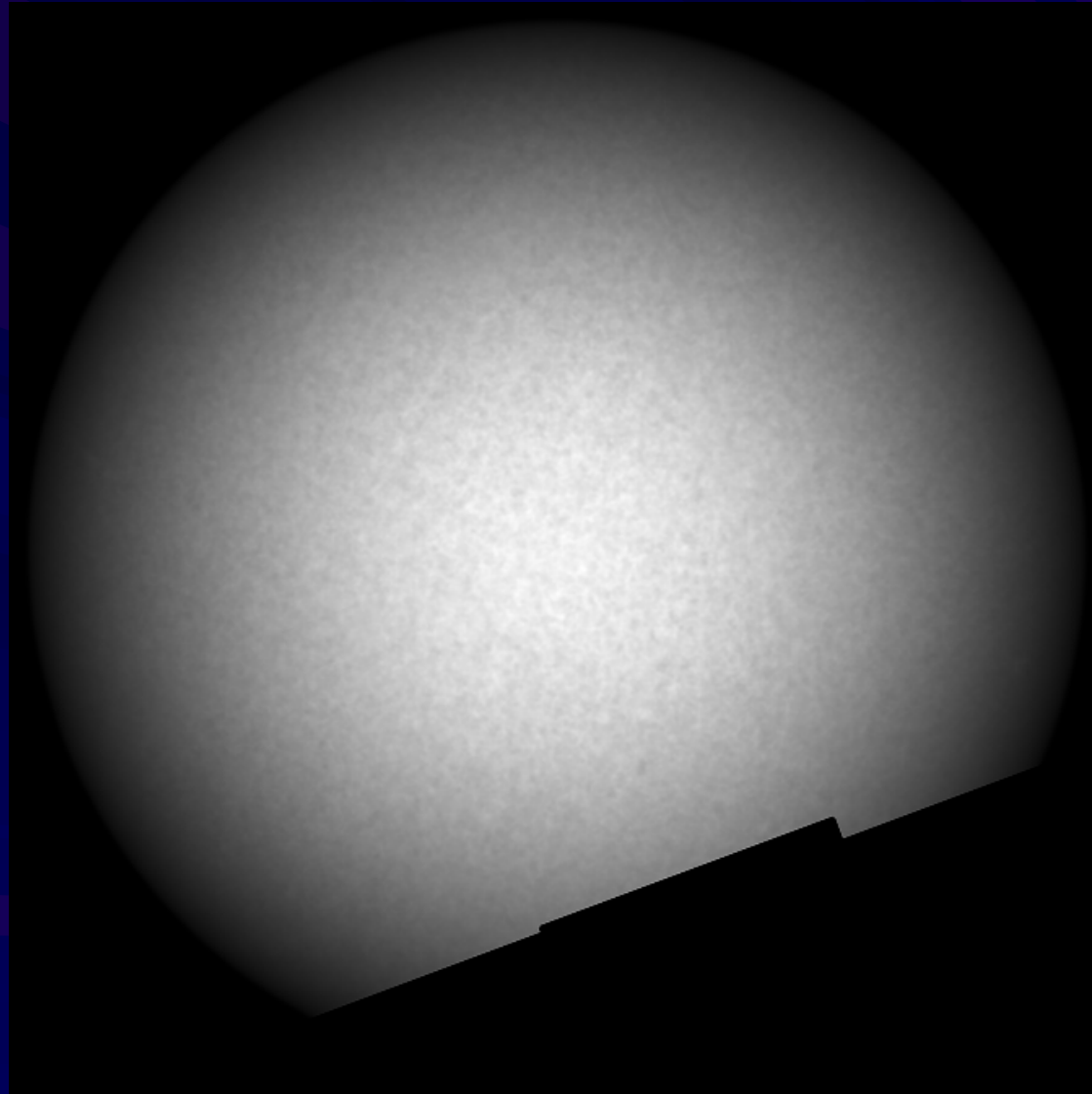
# Solar Climate Explorer

- SMEX class mission
- Suite of 2 instruments
  - Solar Bolometric Imager
  - Total Irradiance Monitor
- Baseline mission duration: 2 years
- Targeted mission lifetime: 6 years
- Objectives:
  - Understand the physical mechanisms responsible for TSI variation
  - Advance understanding of convection, meridional flow, and dynamo activity in the Sun and Sun-like stars
  - Accurately reconstruct and predict TSI variation from decadal to millennial timescales to improve our knowledge of TSI forcing on Earth's climate

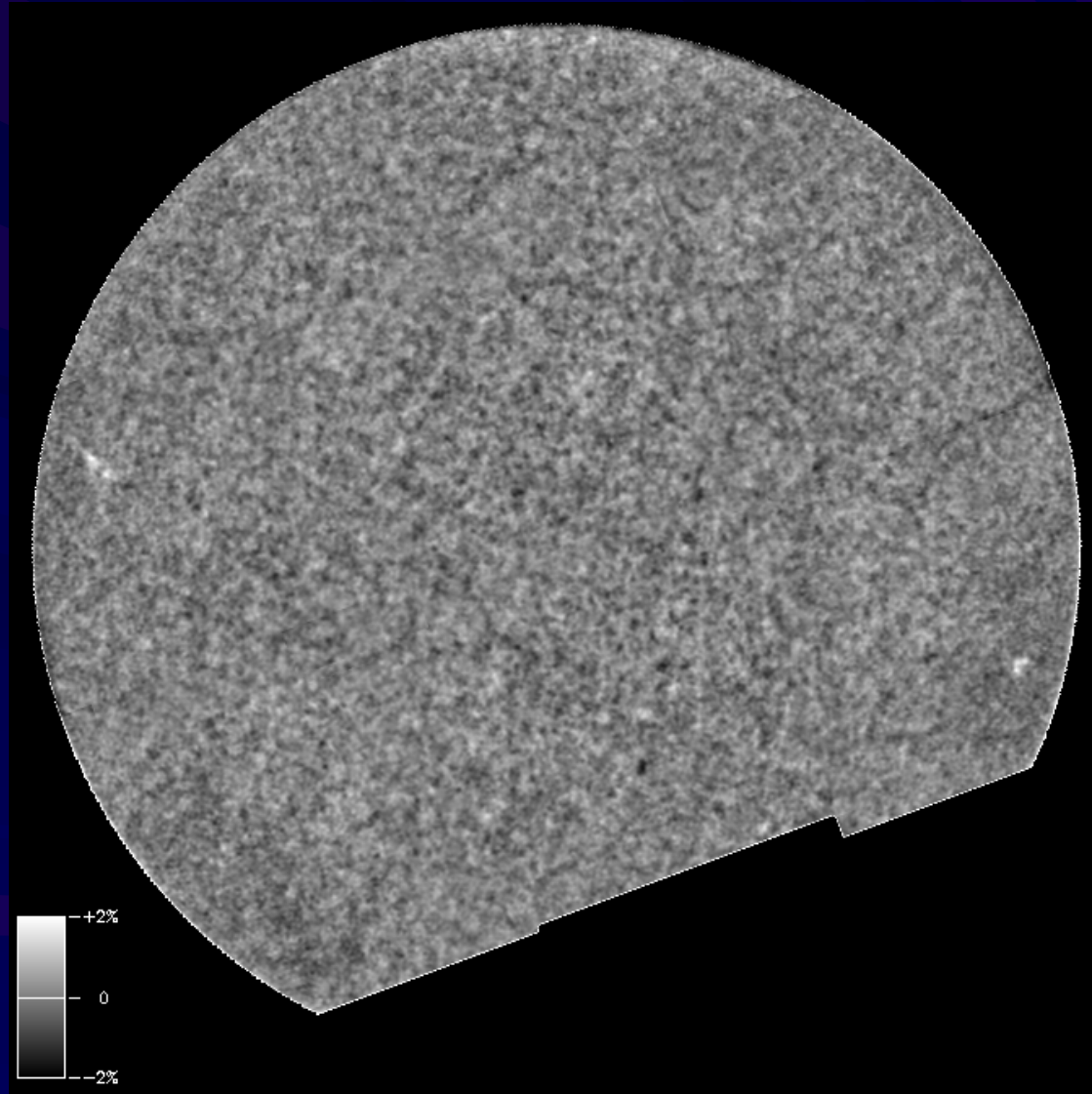


# September 13, 2007 SBI images

---

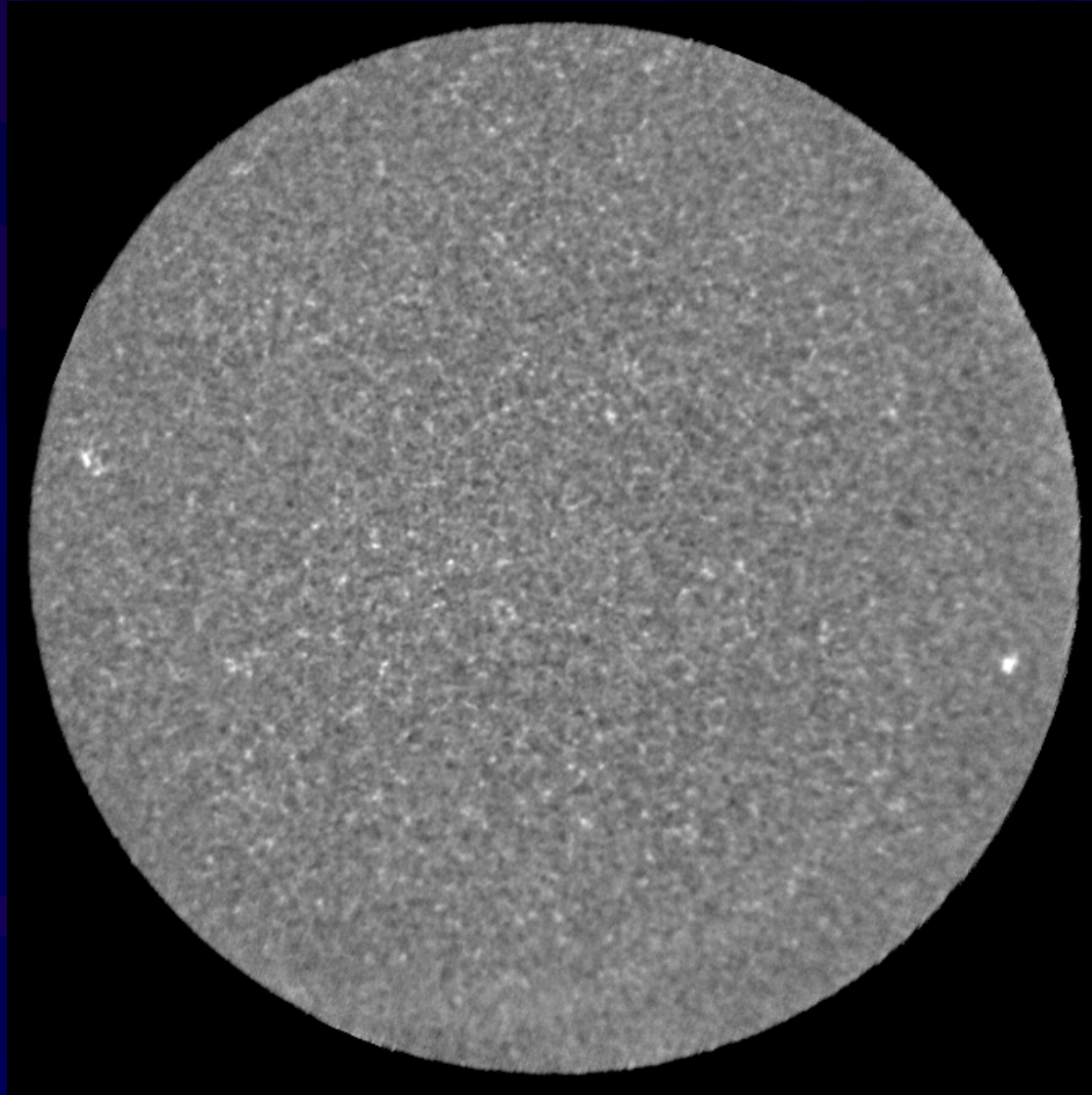


# SBI Limb Darkening Removed



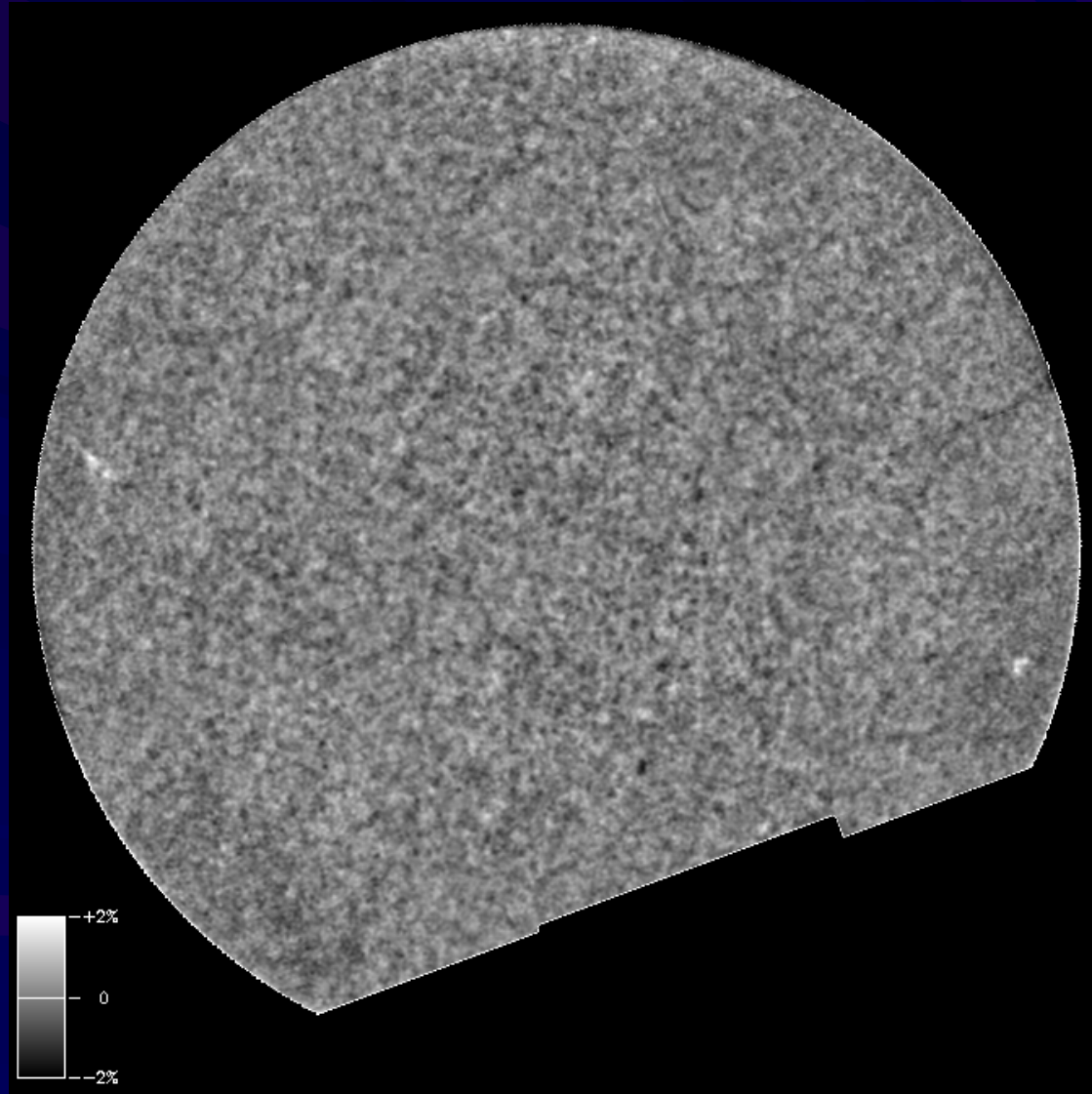
# San Fernando CallK

---

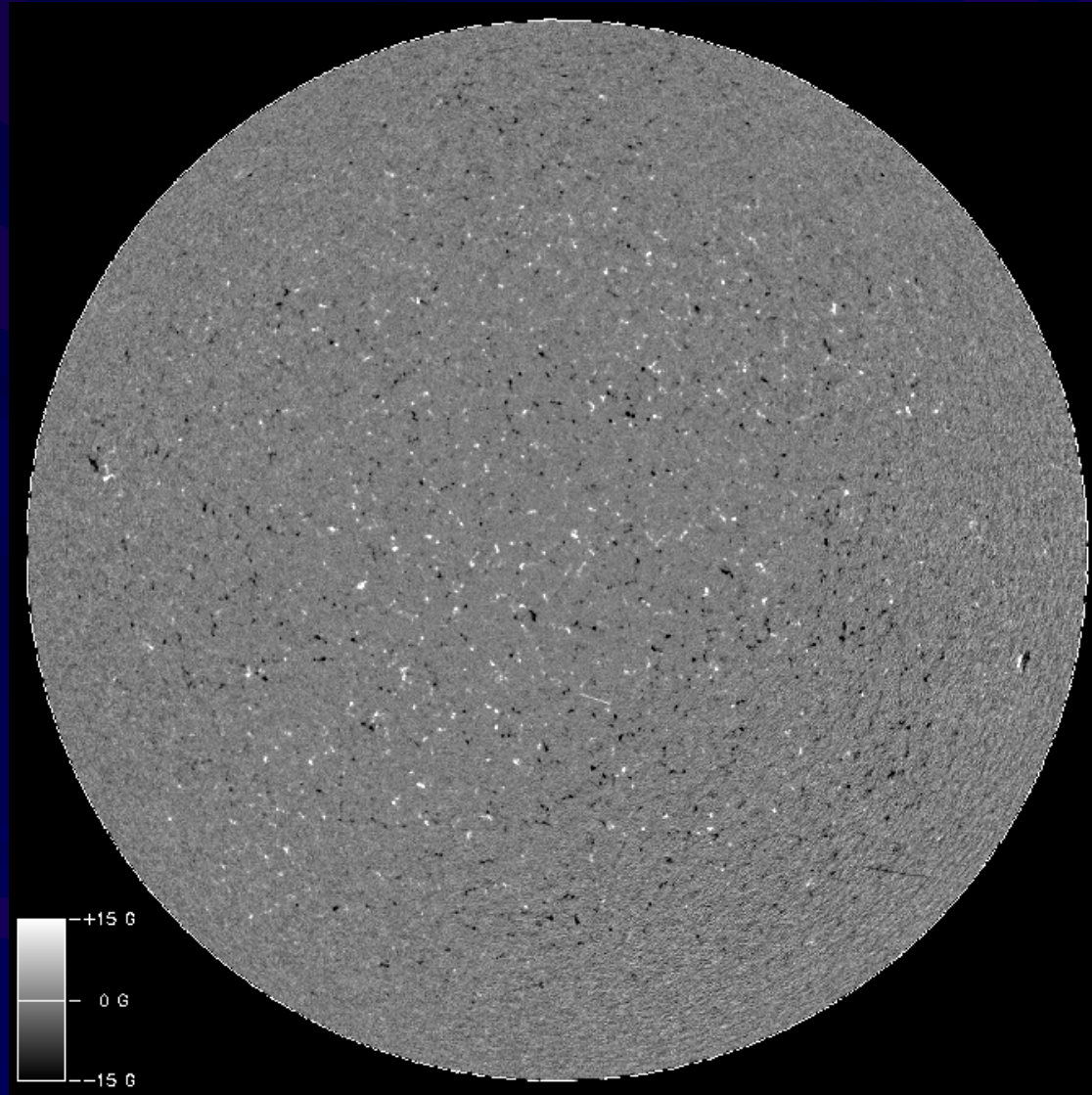




# SBI Limb Darkening Removed

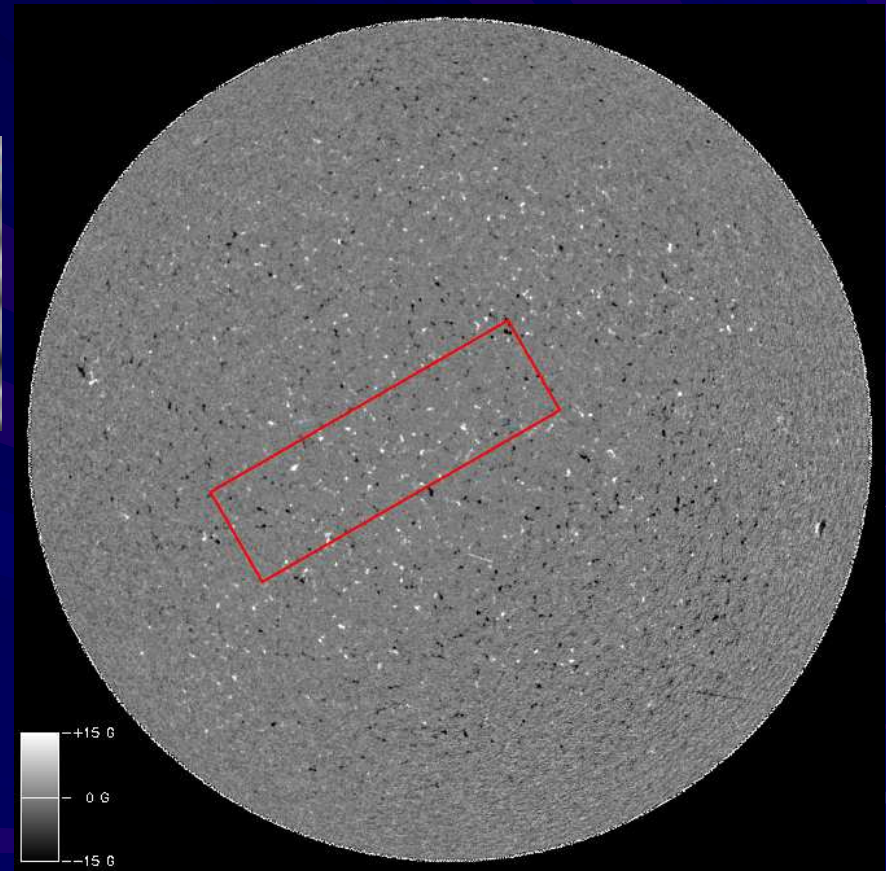
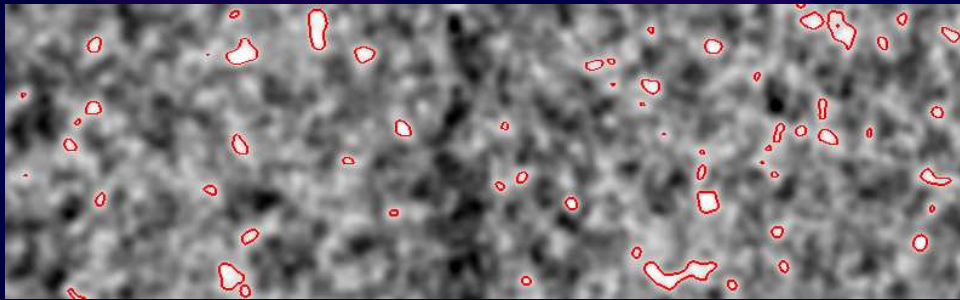


# MDI LOS magnetogram



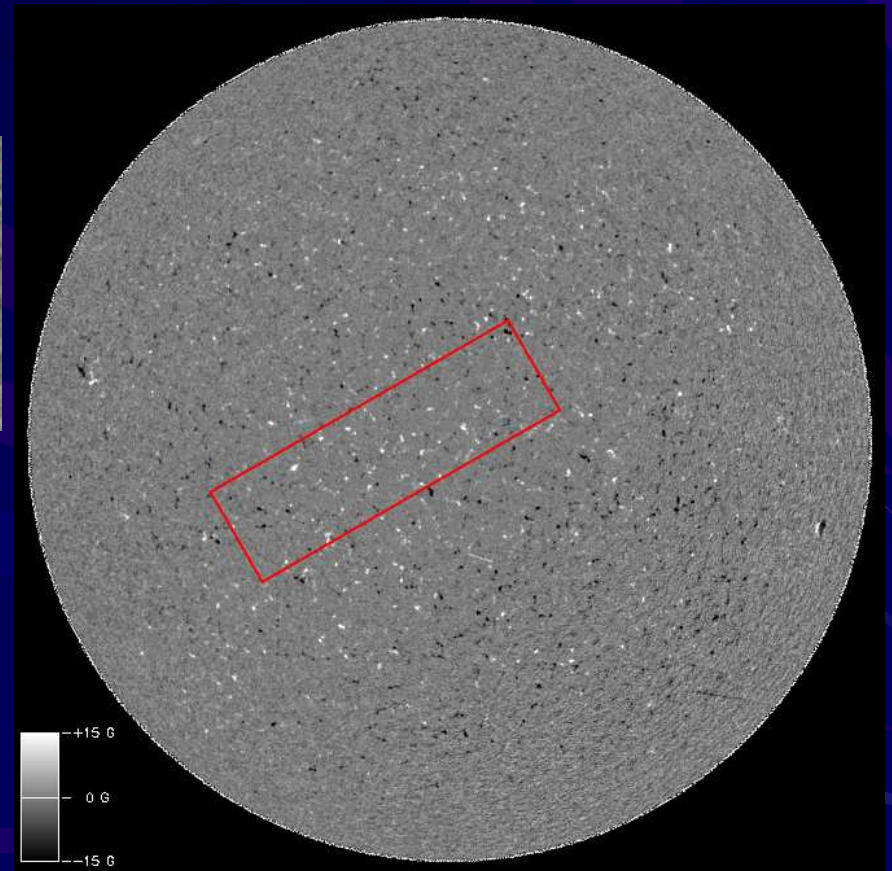
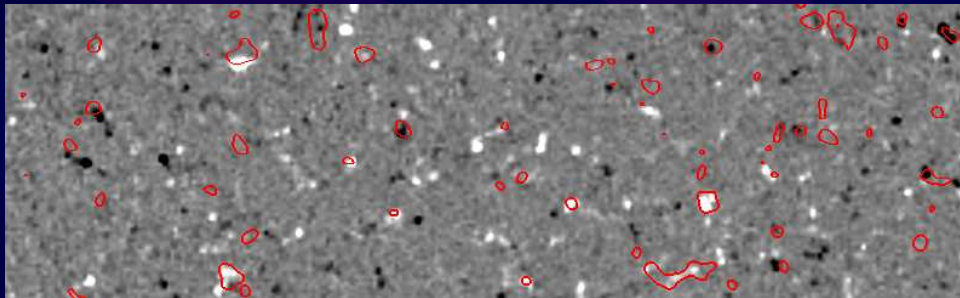
# Bolometric contrast of network

SBI 1 hour average



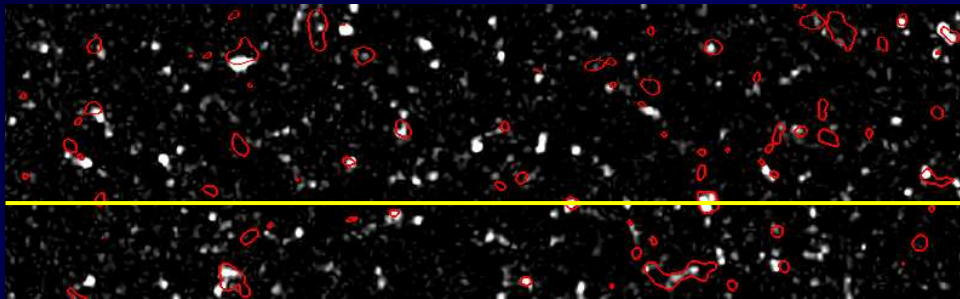
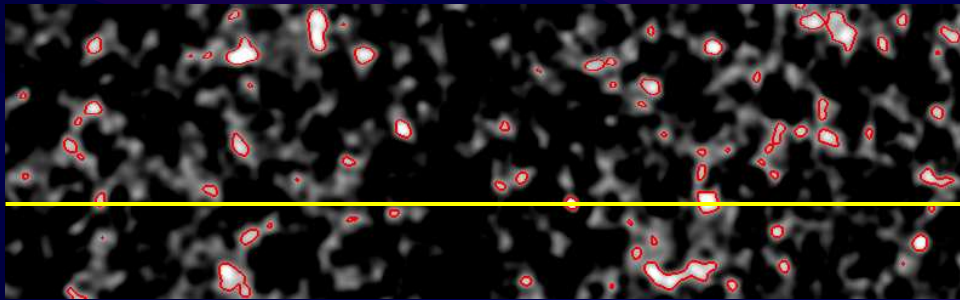
MDI LOS

MDI 30 mins before



MDI LOS

SBI contrast > 0%



$|MDI| > 1 \text{ G}$

