Morphology and time evolution of dark facular regions in Cycle 23 and 24

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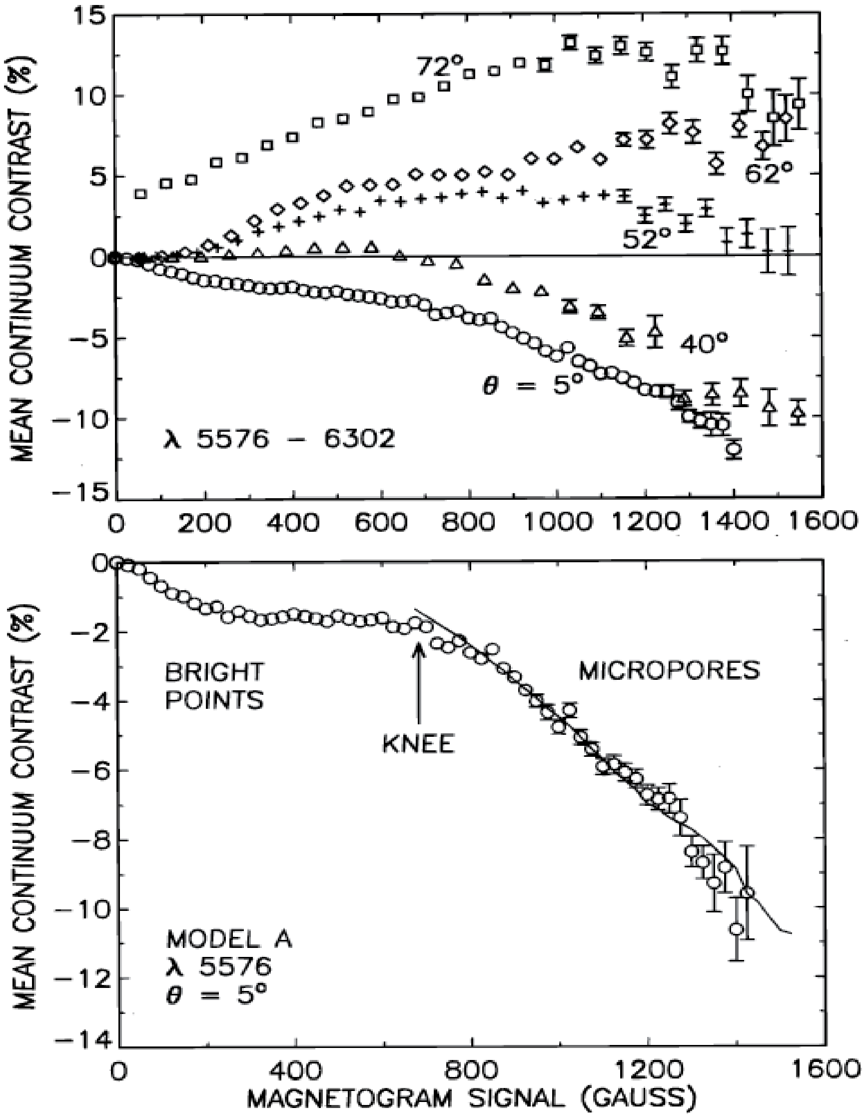
- **Outline:**
  - **Literature review on observations of dark facular regions**
  - **Solar cycle length observation record from the Mauna Loa Precision Solar Photometric Telescope (PSPT)**
  - **Analysis of high spatial resolution Helioseismic and Magnetic Imager (HMI) and Atmospheric Imaging Assembly (AIA)**

Observations of Dark Facular Regions

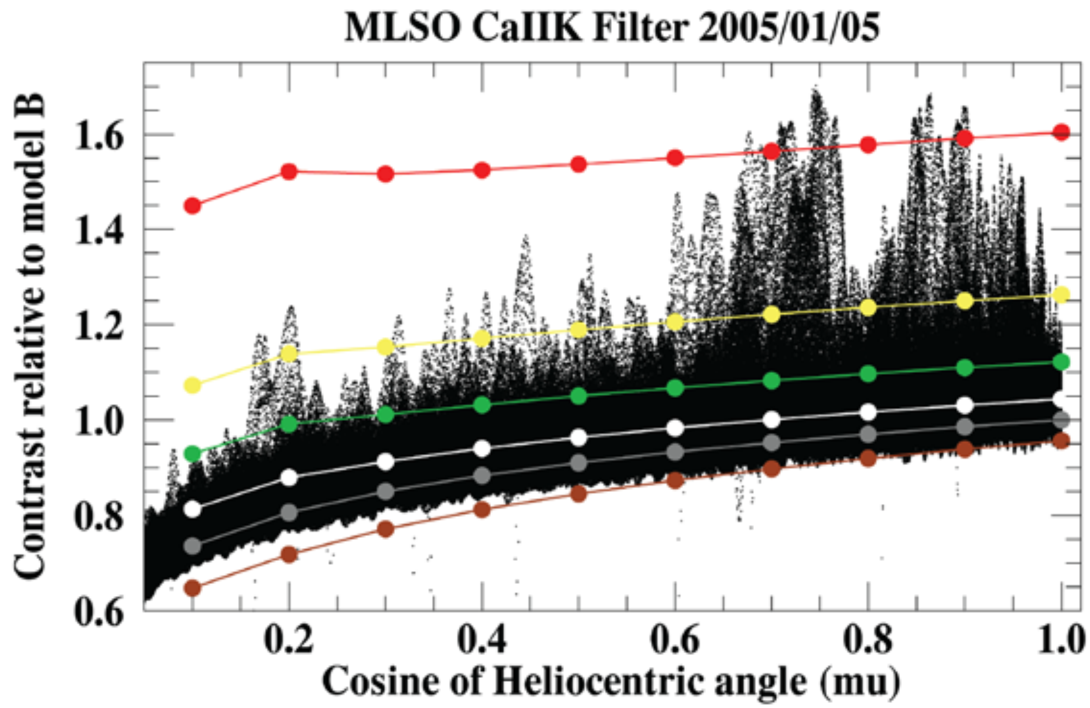


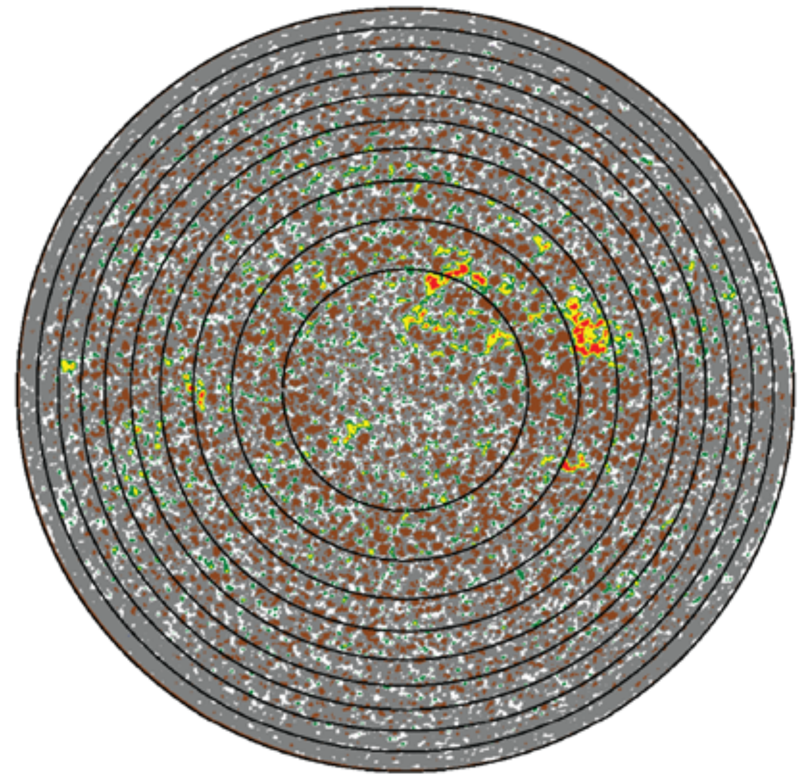
- **Topka et al., ApJ, 1997:**
  - Studied dark regions embedded in solar structures identified as facula & plage in active regions.
  - Continuum intensity of facular area in solar active regions near disk center and outside of sunspots and pores is ~3% lower than 'quiet Sun' at 500nm.
  - Result is likely to be dependent on spatial resolution and dark regions will appear darker in higher spatial resolution images.
- **Lawrence et al., ApJ, 1993**
  - Demonstrates results will be wavelength dependent and correlates positively with H^- opacity.
- **Foukal et al., 1989 & 1990**
  - Dark facular regions observed in the infrared at 1.6μm reproduce the Topka et al. 1997 observations in the visible.

Question: Can these dark facular regions be detected in PSPT?

- **Advantages:**
  - Analysis can be done on nearly full solar cycle
  - Full disk images with 1 arc-sec pixels
  - Consistent observations and data processing
- **Disadvantages:**
  - Does not have co-temporal/spatially aligned magnetograms
  - Feature identification performed on relatively low contrast ground-based images

PSPT Image processing/SRPM spectral synthesis





$$\bar{I}_{m,\mu}(\lambda_0) = \int I_{m,\mu}(\lambda_0)\Phi(\lambda - \lambda_0)\,d\lambda$$

- $I_{m,\mu}$ = The m^th model intensity.
- $\Phi(\lambda)$ = Instrument bandpass profile.
- μ = $\cos(\theta)$, θ=heliocentric angle.

$$I_a = \frac{\sum_{n=1}^{All\ Pixels} I_{m_n,\mu_n}}{Number\ of\ Pixels}$$

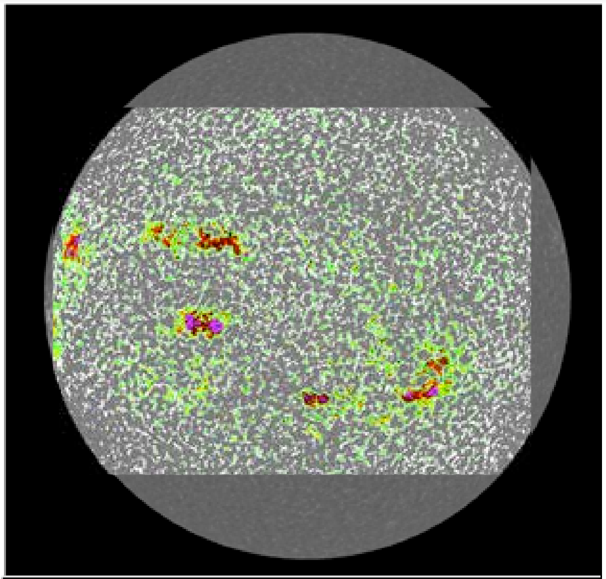
- I_a = Average disk intensity found from spline interpolation to account for CLV and normalized to total number of pixels.

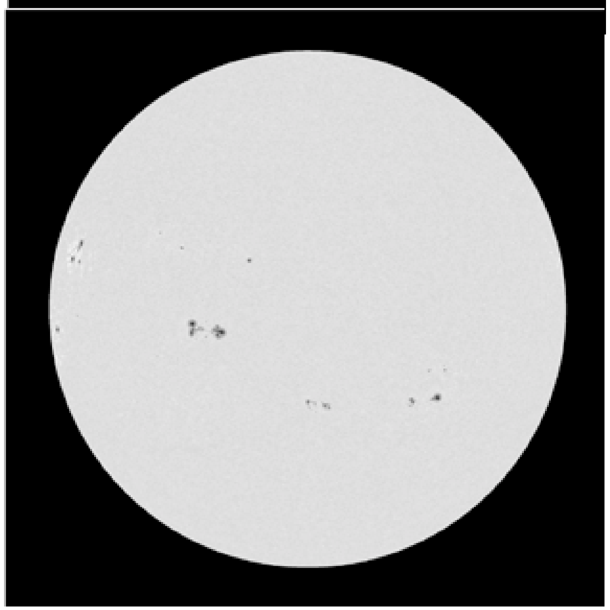
$$R = \Omega_{Sun} I_a$$

- R = Irradiance calculated at 1 AU.
- Ω_{Sun} = Solid angle subtended by solar disk.

- R Sunspot penumbra
- S Sunspot umbra
- P Facula
- H Plage
- F Enhanced network
- D Quiet-Sun network
- B Quiet-Sun internetwork
- A Dark quiet-Sun internetwork

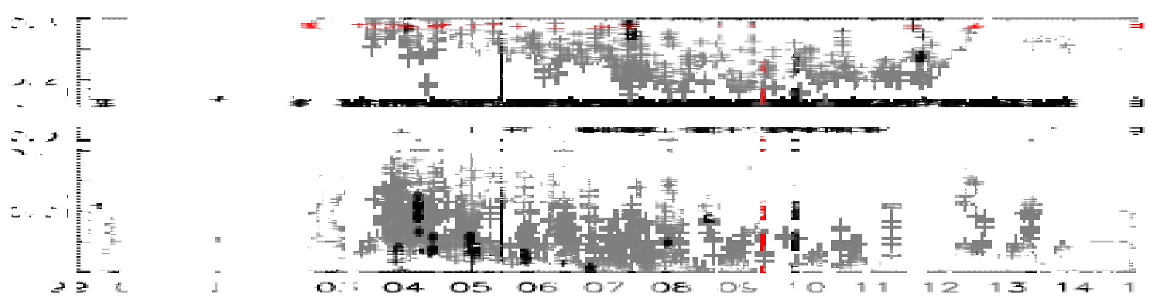
../2015/SIST_2015/presentations/SIST_meetingJuly2016/Illustrator/allimg_vs_mu.ai



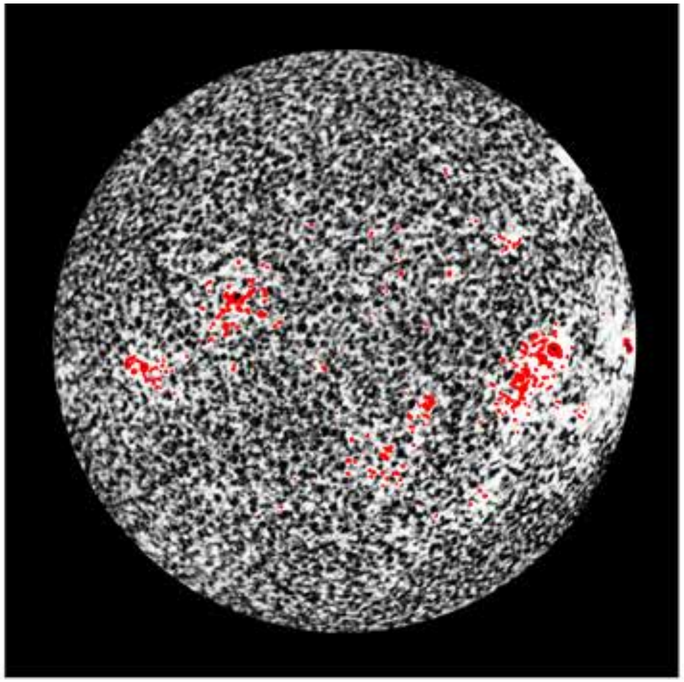


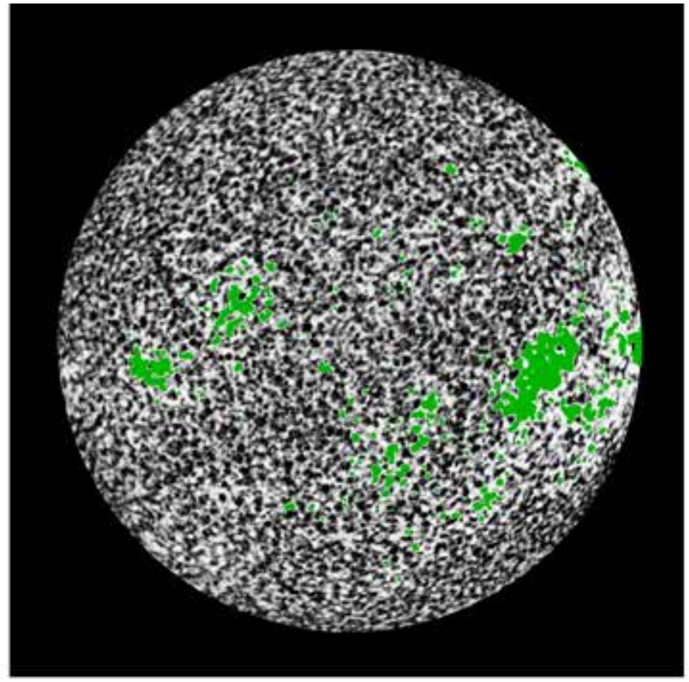
Not all faculae are created equal

- Some faculae and plage have negative contrast at the PSPT red continuum wavelength (607nm)
- The position of dark faculae on the disk is not a simple function of heliocentric angle
- The fraction of dark faculae decreases into the last minimum

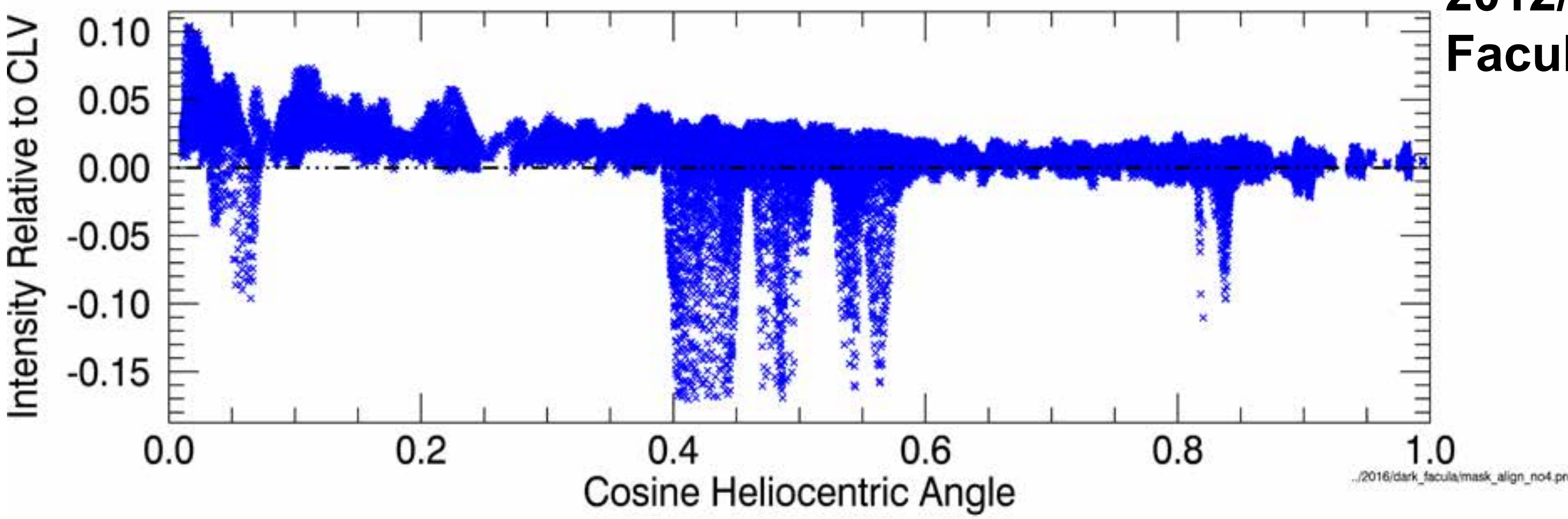


PSPT Image processing/SRPM spectral synthesis

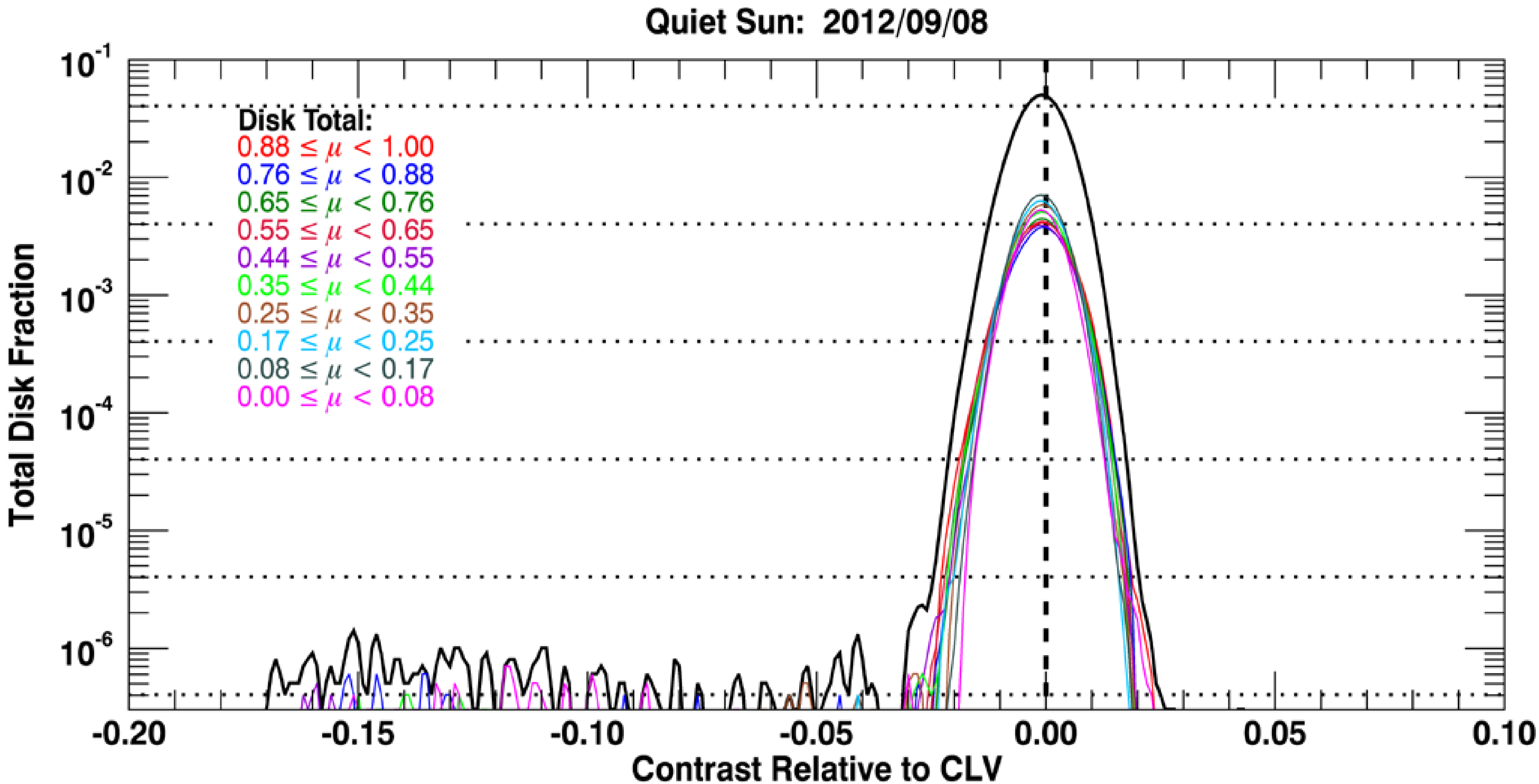




2012/09/08
Facula+Plage



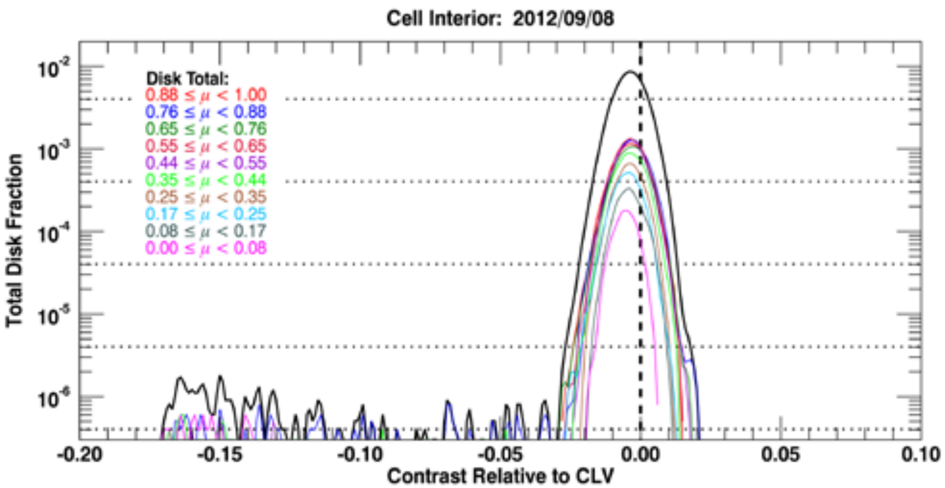
PSPT Contrast Histograms 20120908

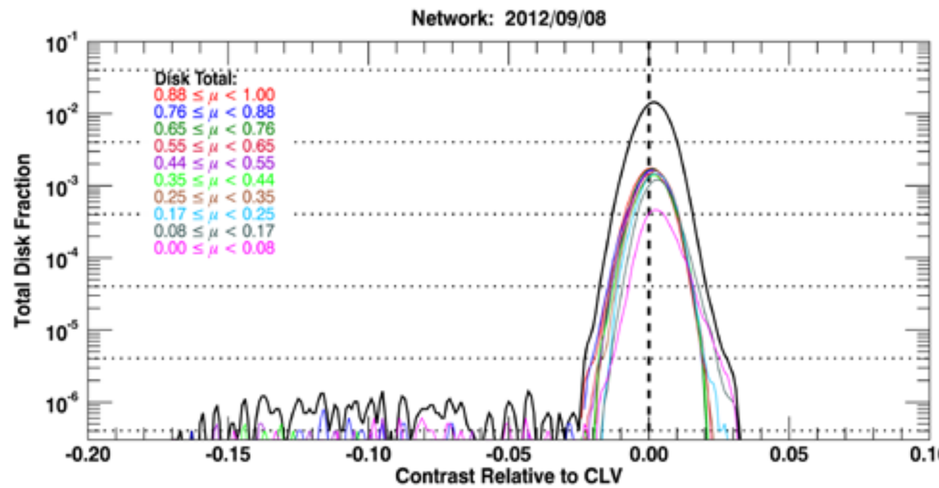


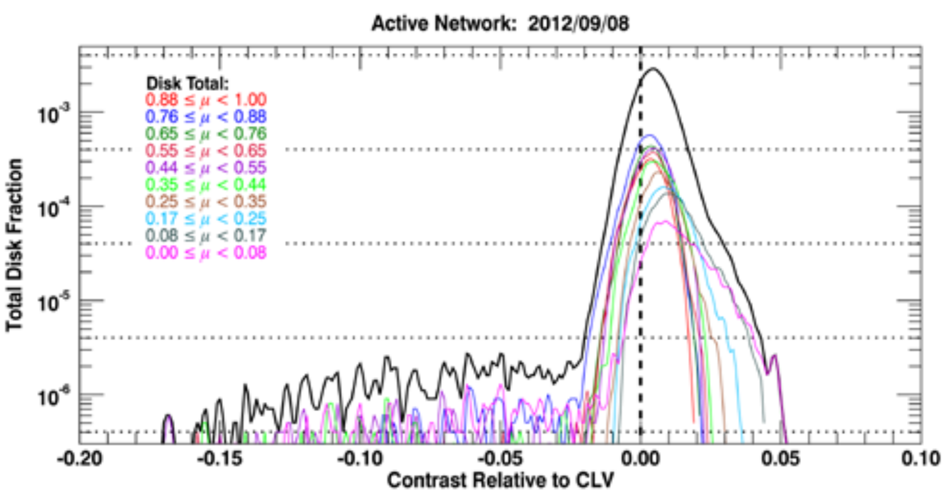
SORCE

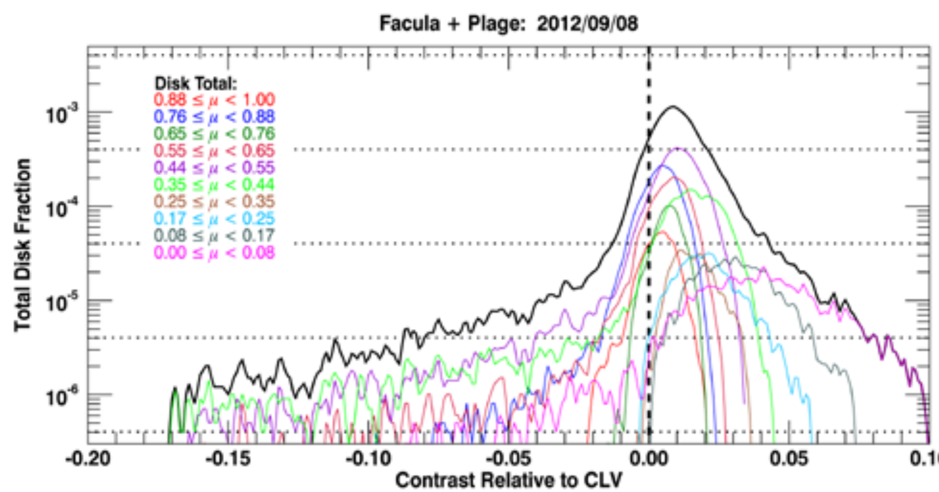
PSPT Contrast Histograms 20120908

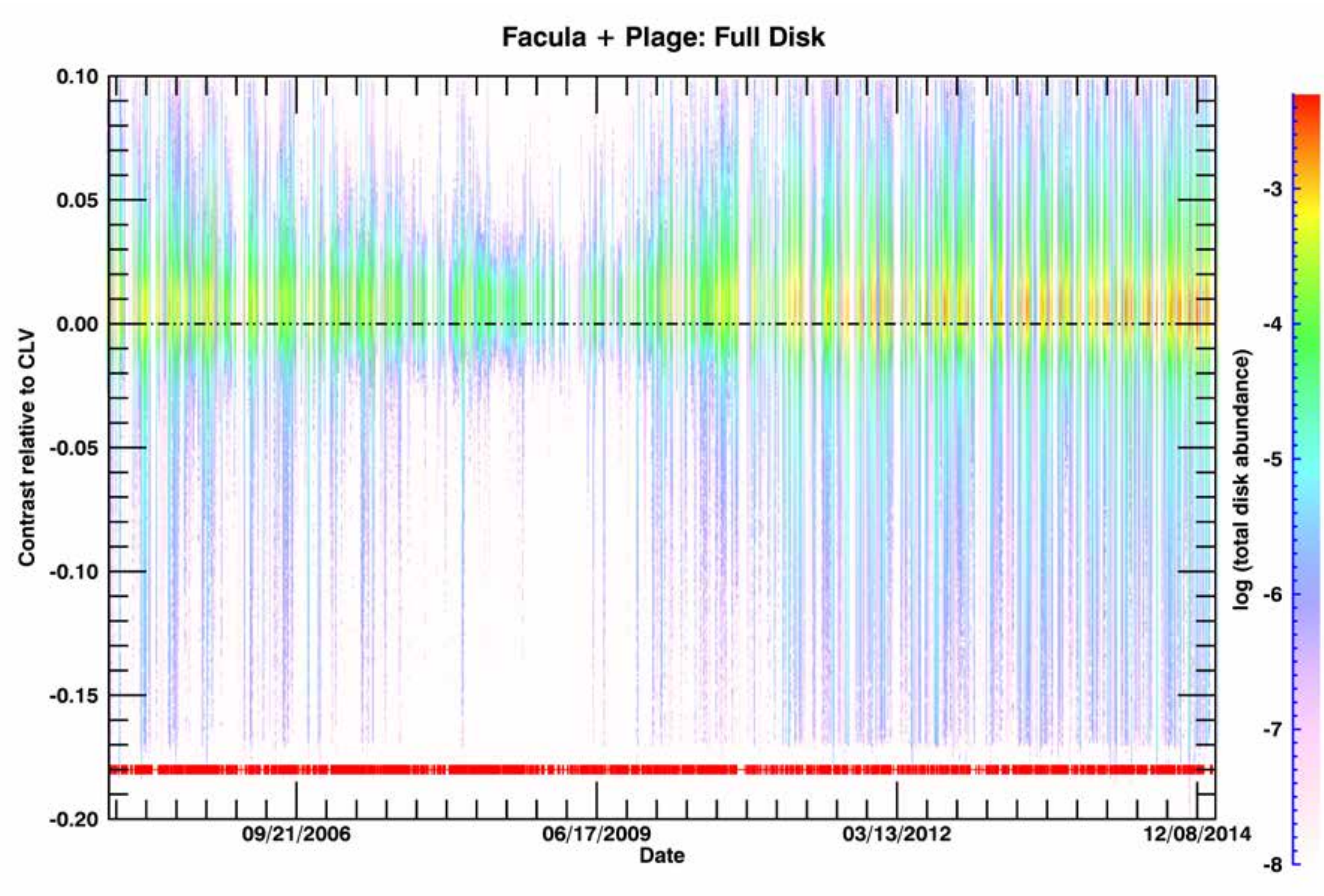
LASP









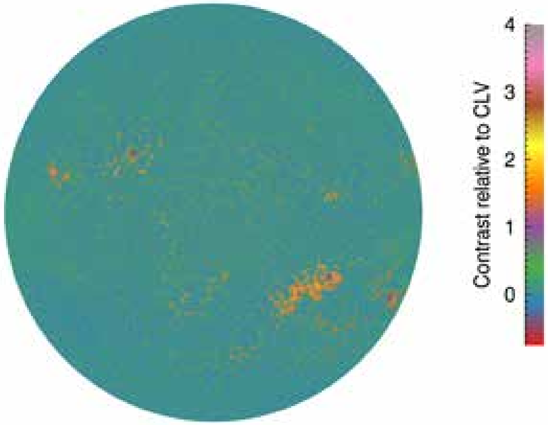

Facula + Plage: Full Disk
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
Contrast relative to CLV
09/21/2006
06/17/2009
03/13/2012
12/08/2014
Date
-3
-4
-5
-6
-7
-8
log (total disk abundance)

Summary & Conclusions from PSPT Analysis

- **Feature brightness performed on 10 disk positions for each of 7 solar features.**
  - **Dark features appear in every feature type but with the widest distribution in the facula + plage, and active network components.**
- **Time series of dark features show a distinct increase in area that is in-phase with proxies of solar activity.**
- **Large numbers of relatively weak bright pixels are responsible for the brightening seen nearing the solar limb.**
- **Smaller numbers of significantly darker pixels are seen throughout the solar disk but produce the largest contribution near disk center.**

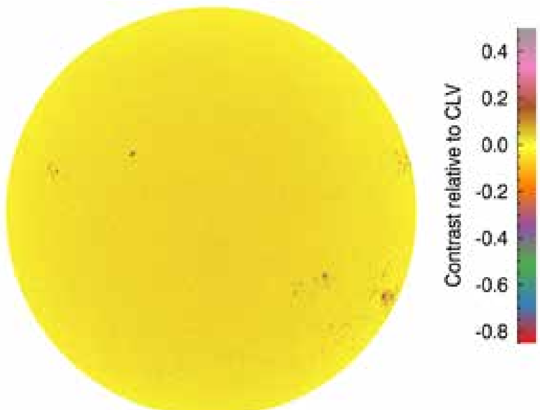
HMI – AIA analysis

Question: Can the PSPT result be verified or improved using the higher spatially resolved HMI intensity images with co-registered magnetograms?



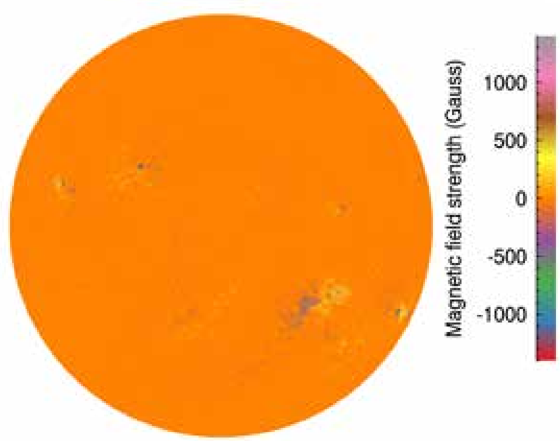
AIA 170nm

- Spatial sampling = 0.612 arc-sec/pixel – co-temporal with HMI
- CLV removed via Legendre-Fourier fitting function
- Very high contrast wrt CLV (eases feature identification)
- Construct feature masks matching PSPT masks
- Image stretched to match HMI (via heliocentric coordinate interpolation)



HMI 617.3nm

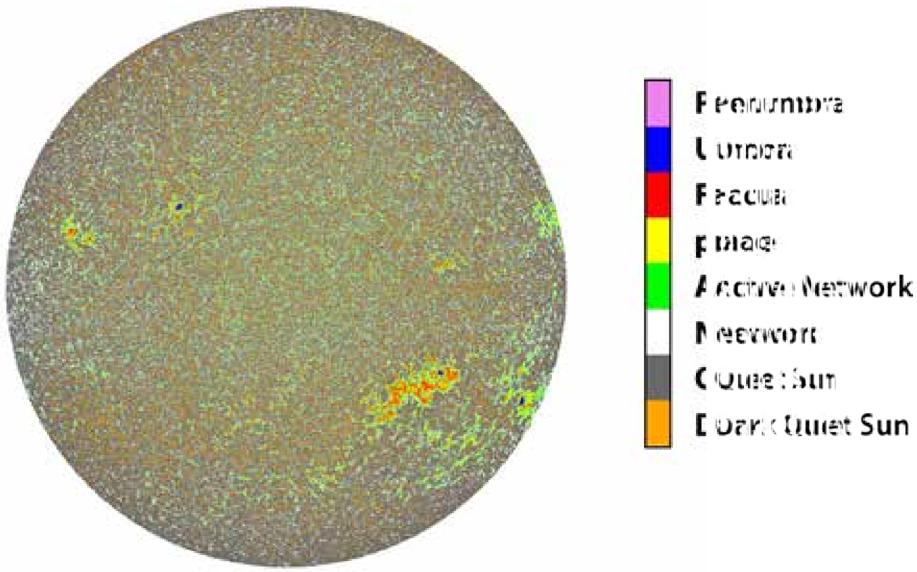
- Spatial sampling = 0.504 arc-sec/pixel
- Scattered light contribution removed via Lucy-Richardson deconvolution – enhances image contrast
- CLV removed via Legendre-Fourier fitting function



HMI magnetogram

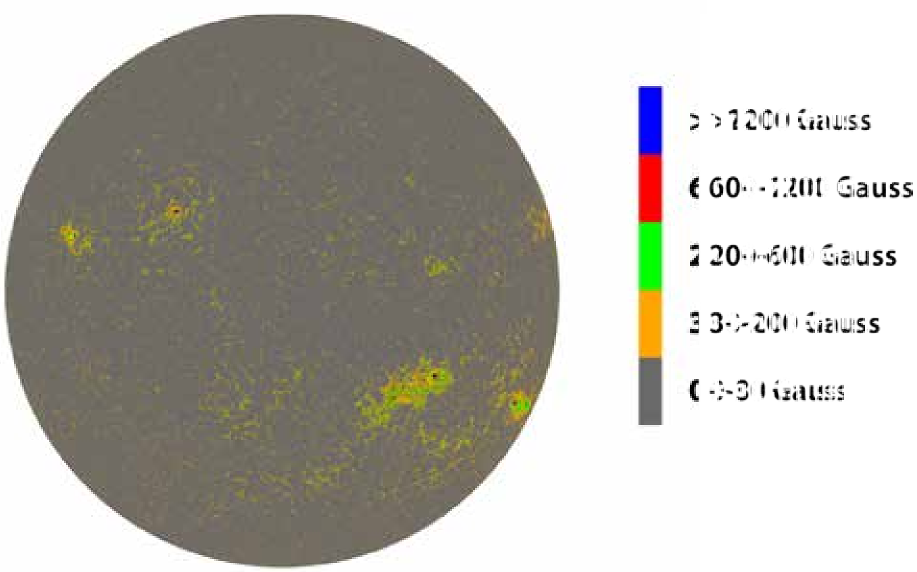
- Spatial sampling = 0.504 arc-sec/pixel
- Scattered light removal enhances magnetic field contrast
- Construct mask based on magnetic field strength
- Can mask HMI contrast images via magnetic field strength instead of through feature identification

SORCE HMI Magnetogram & AIA Feature Masks



AIA 170nm Feature Mask

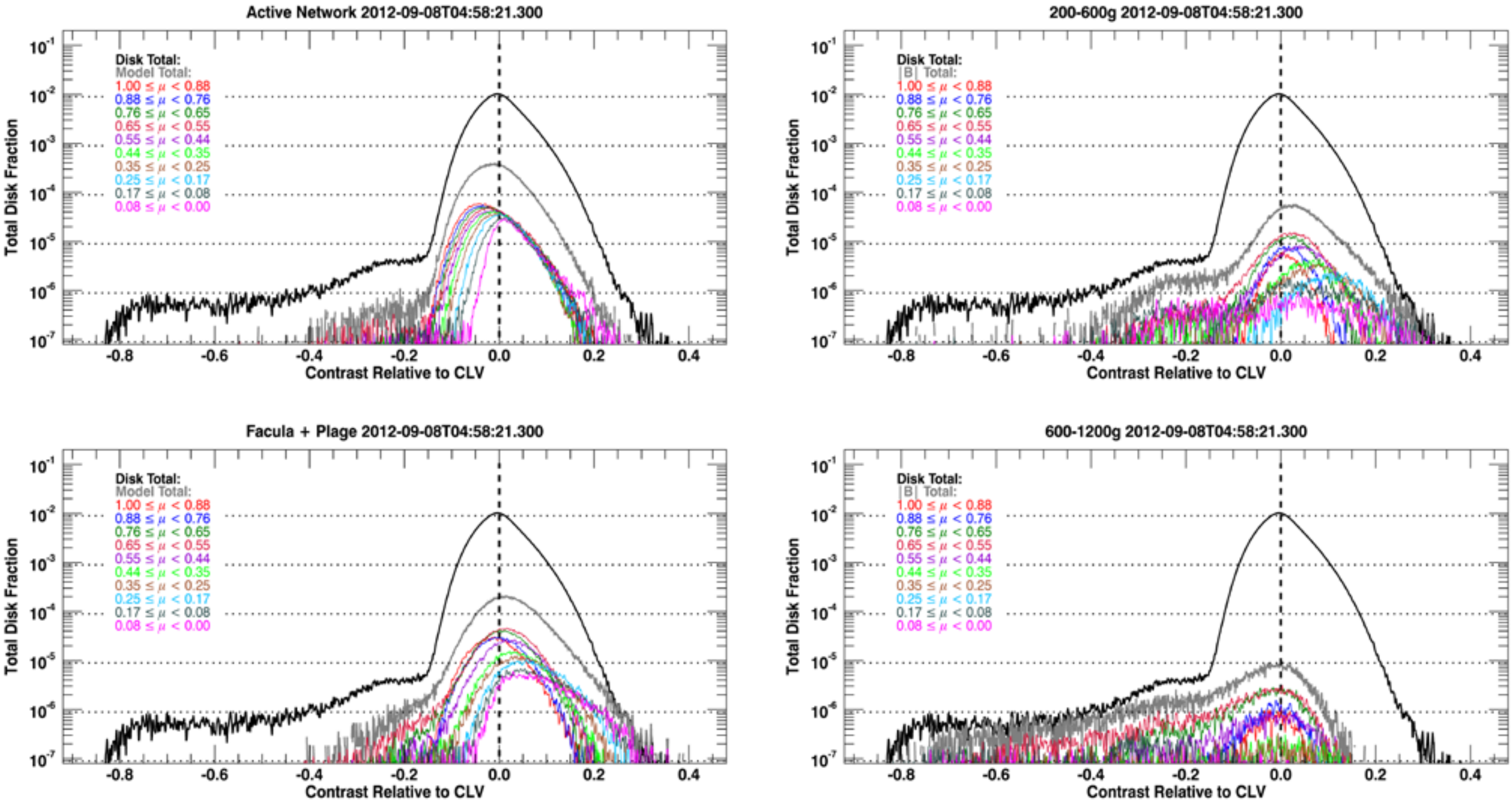
- Has same equivalent total feature area as PSPT SRPM masks
- AIA 1700 produces meaningful sunspot areas



HMI Magnetogram Mask

- Magnetic field thresholds set to discriminate between bright points and micro-pore field strengths described in Topka et al. 1997.

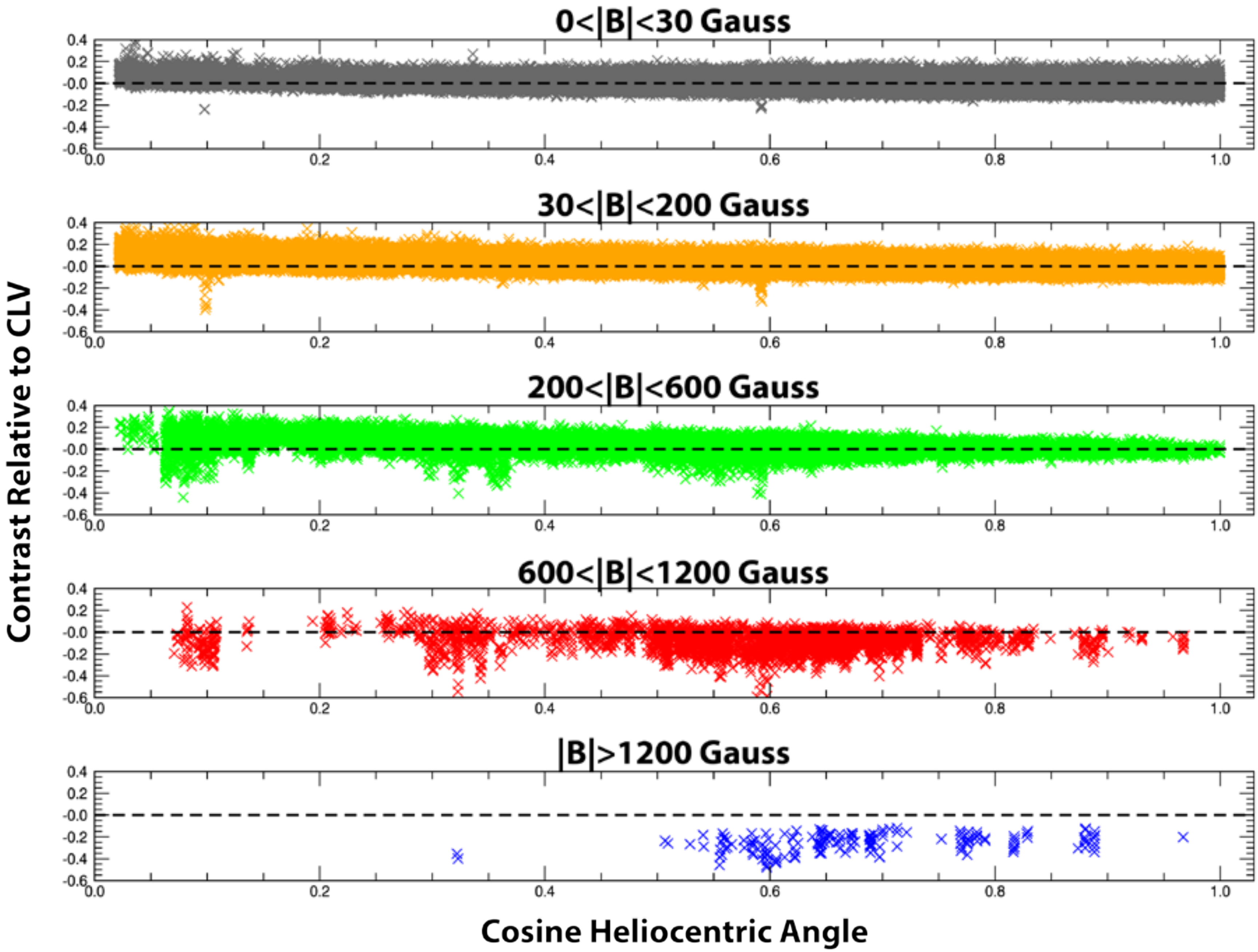
Bin by |B| & Plage feature type



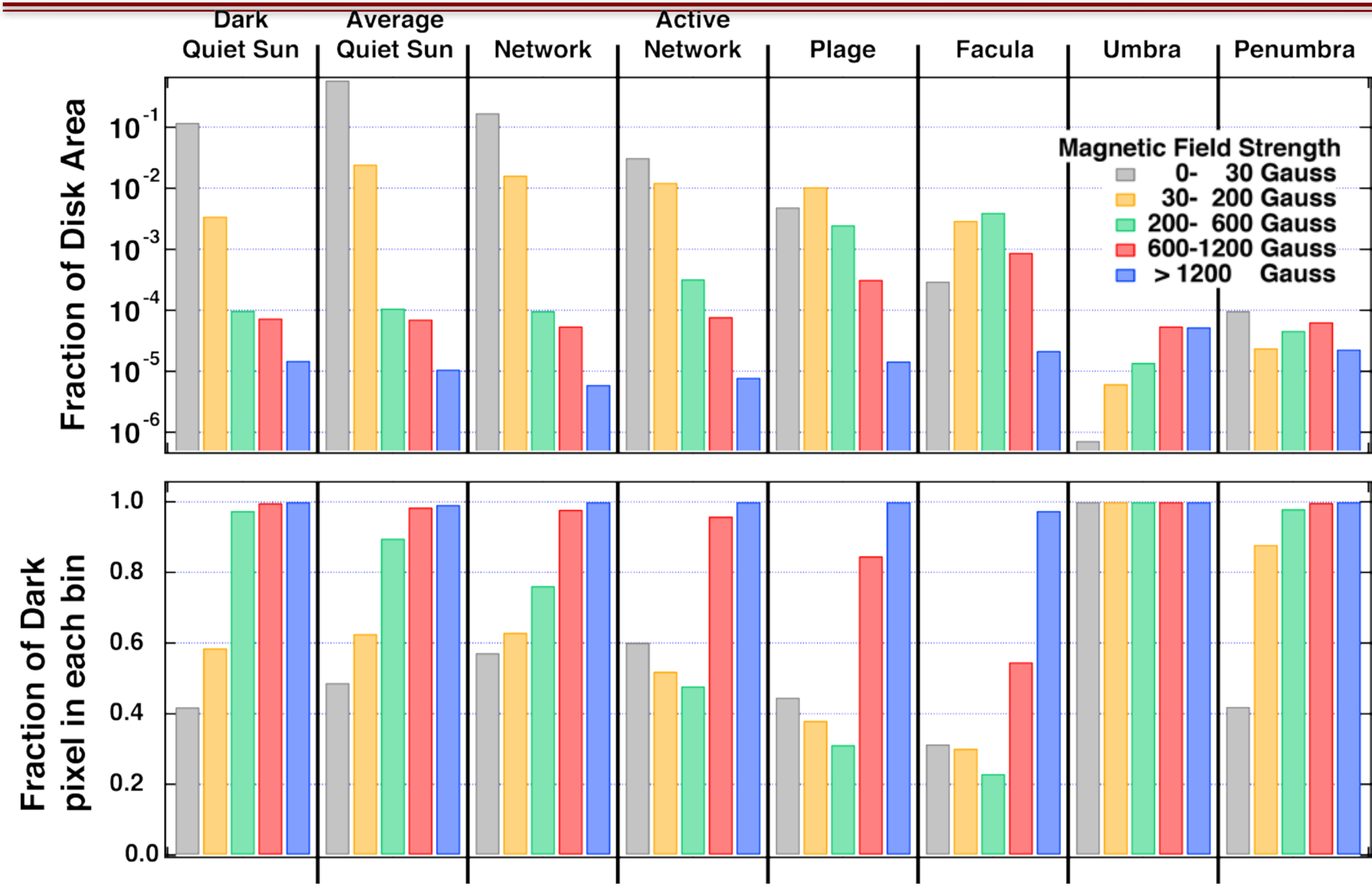
Increasing feature brightness

Increasing magnetic field strength

Plage feature type binned by |B|



Bin by |B| & feature type



Full Disk Statistics

Summary & Conclusions from HMI Analysis

- Magnetic field strength alone cannot uniquely assign the brightness of a given HMI pixel.
- Low magnetic field strength pixels contribute substantially facular and network brightness. There is no such thing as quiet Sun.
- Pixels that are in the 200<|B|<600 Gauss range show a distinct brightening near the limb resembling the structure seen in facula identified in PSPT. This field range is predominately bright relative to the CLV. For 600<|B|<1200 Gauss , it is predominately dark.
- Higher spatial resolution HMI images suggest about 40-50% of facular pixels appear to dark in the visible wavelength range.
- Bright and dark pixels are highly interleaved in solar regions that can be identified as facular structures.