Interpreting ultra-precise small-angle double-differential Stellar Astrometry: Lessons from the Sun

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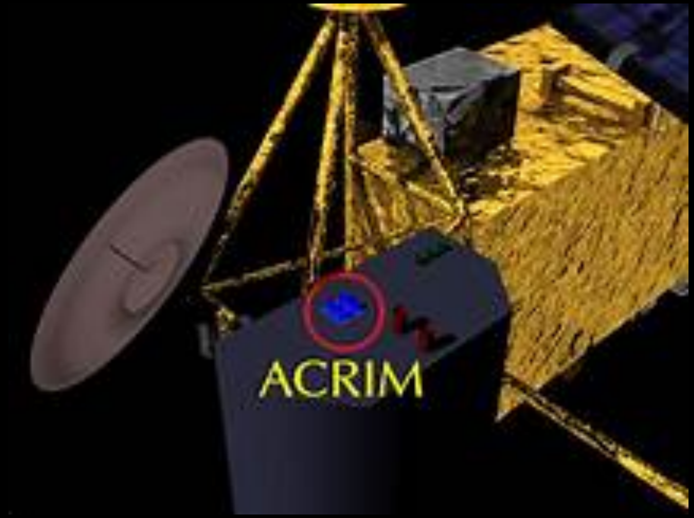
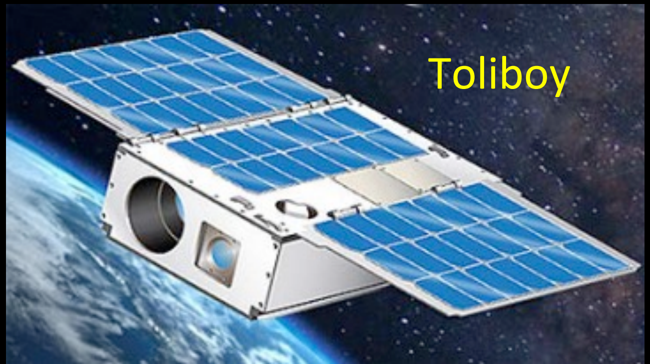
- **Optical centroid changes due to non-uniform surface brightness variations:**
  - **Magnetism**
  - **Reynolds stress from turbulence and stellar rotation**
- **“Effective wavelength” changes**
  - **Stellar effective temperature variations**

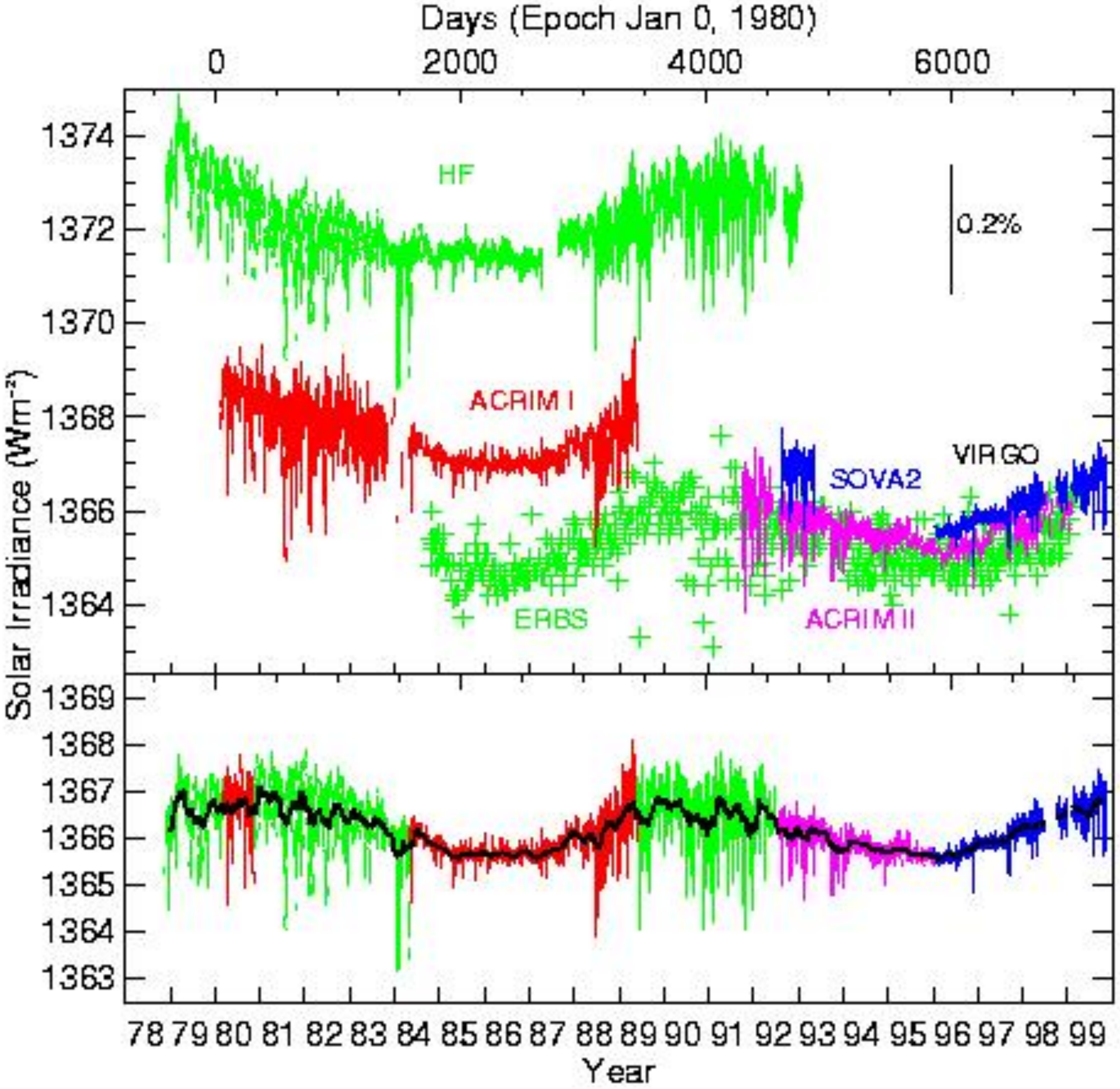
Other precise Solar satellite photometry : SOHO, ACRIM

- Magnitudes – benchmark: 5 M_{Earth} around aCen, 10 x 10^{-6} arcsec
  - Diffraction limit of 10cm aperture at 500nm is 1 arcsec
  - 1R_{sun} at D_{aCen} has 6 x 10^{-3} arcsec angular diameter
  - 0.1% total brightness change at limb of Sun is 3 x 10^{-6} arcsec centroid change
  - Depending on optical passband, 1 deg K stellar temperature change (uncorrected) could create a "few hundred"x 10^{-6} arcsec spurious centroid shift

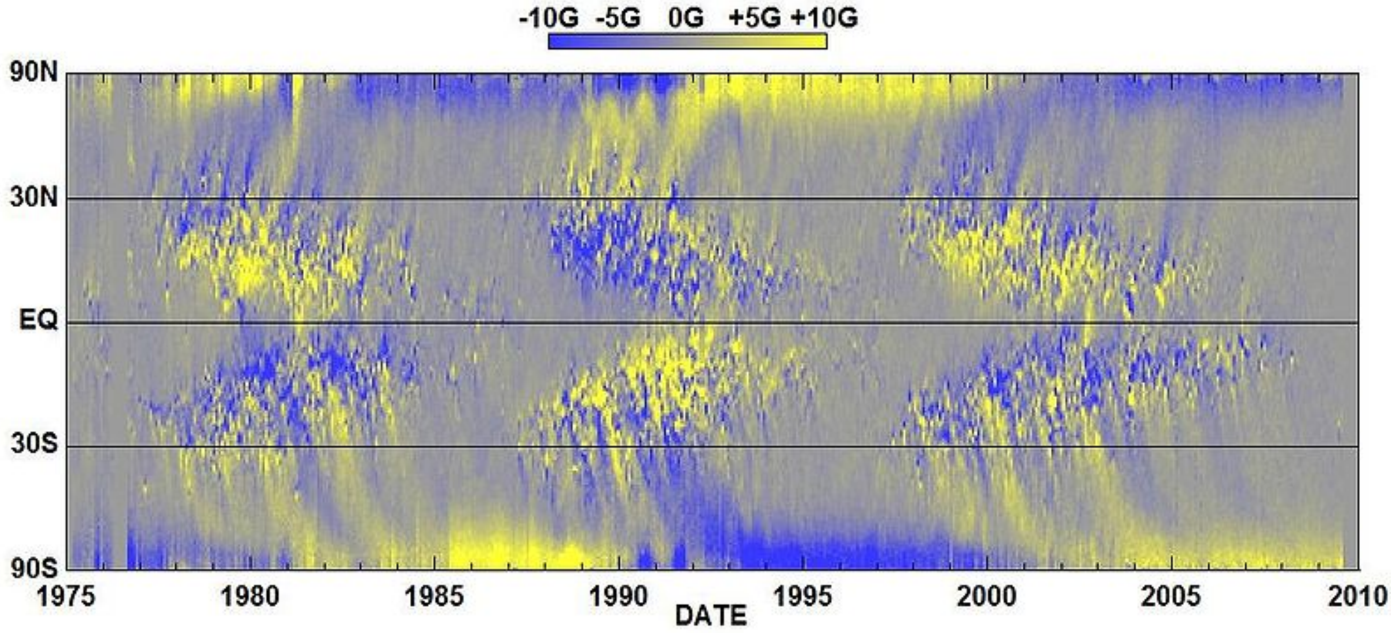




Solar Irradiance changes...

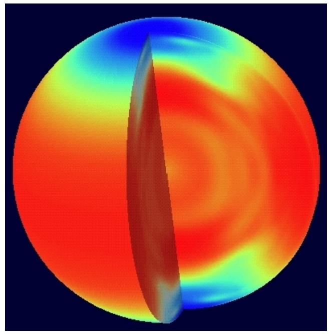


Solar Magnetism: Summary

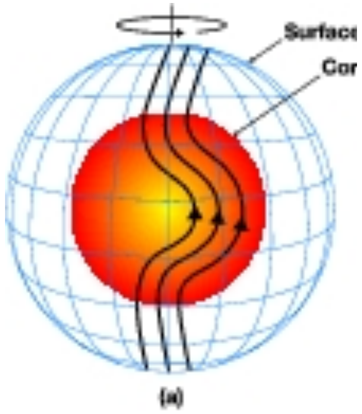


Hathaway/NASA/MSFC 2009/09

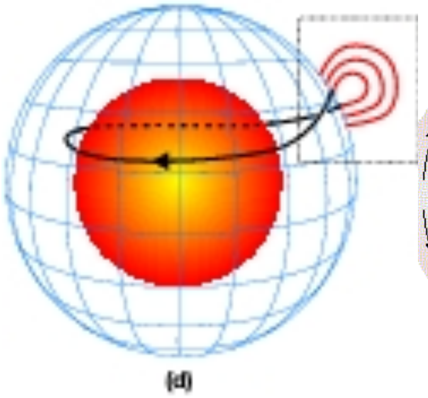
Differential rotation



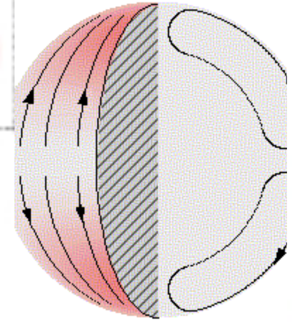
Poloidal → Toroidal field



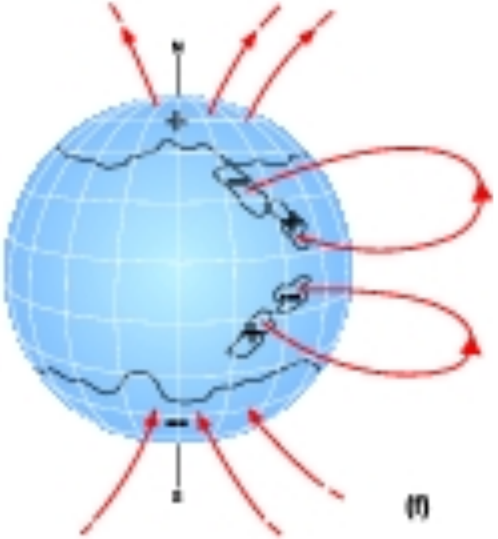
Flux expulsion



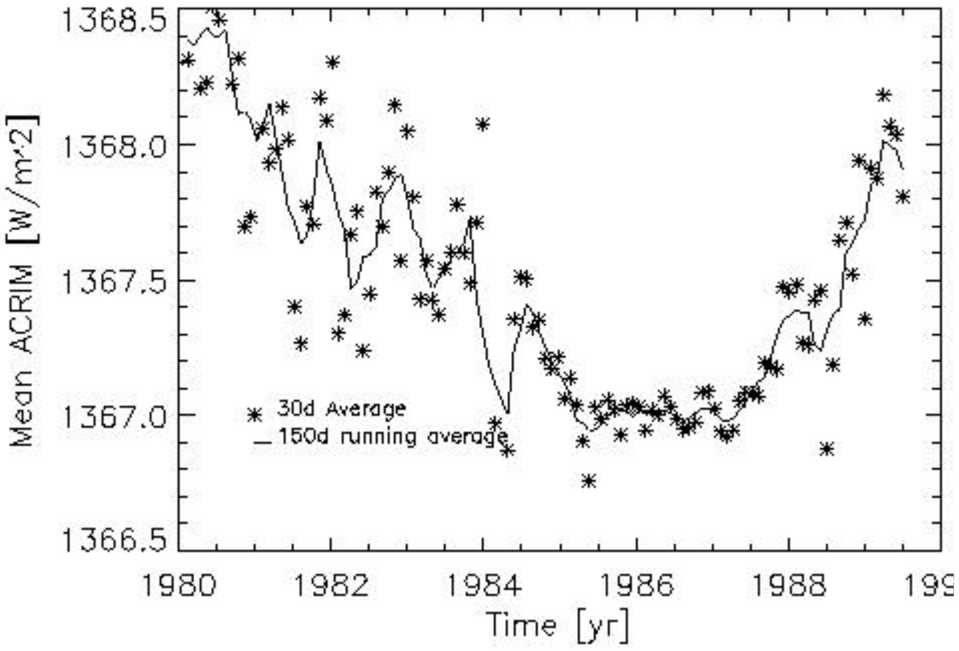
Meridional circulation

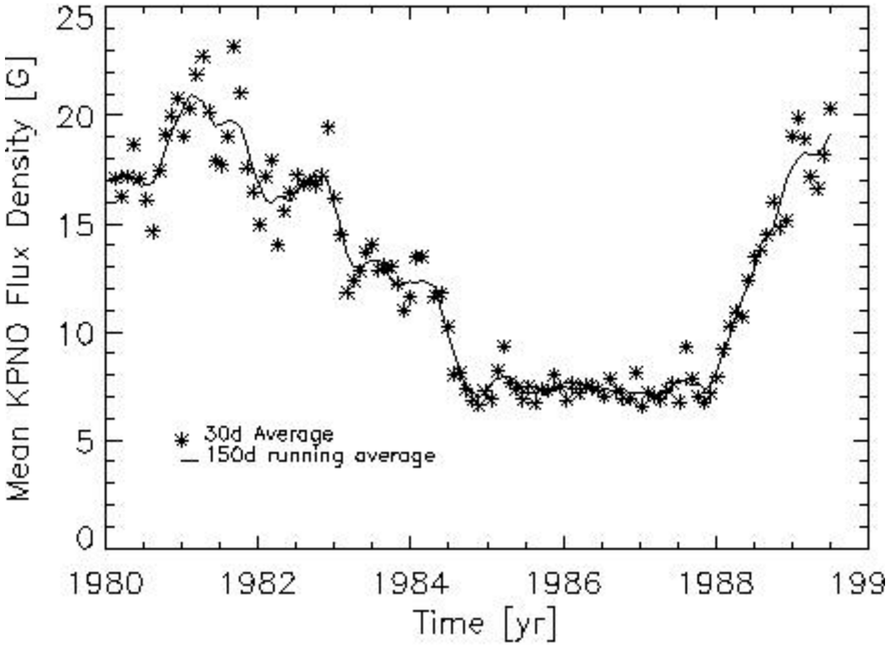


Diffusion, → Poloidal

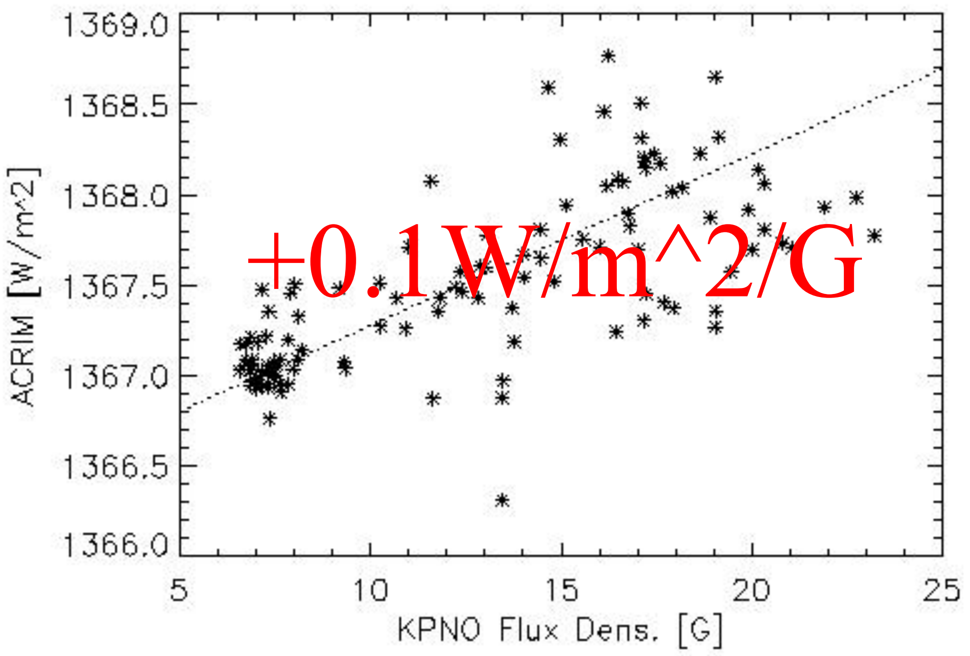


Magnetism is directly associated with most solar brightness variations

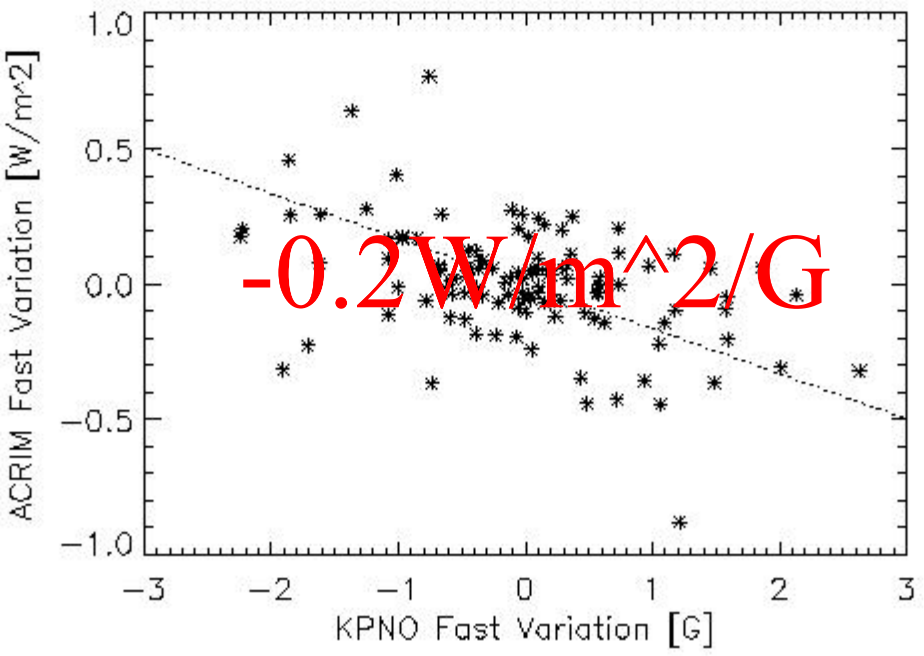




Irradiance changes and solar magnetism

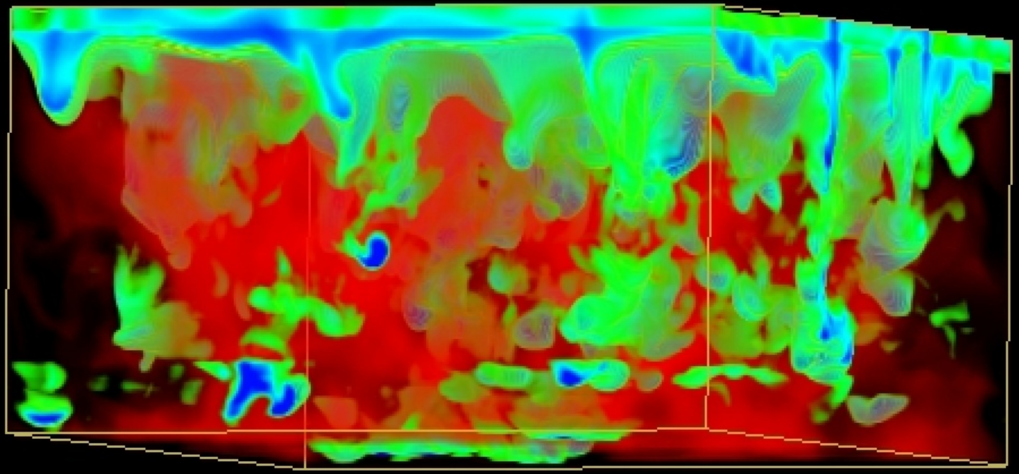


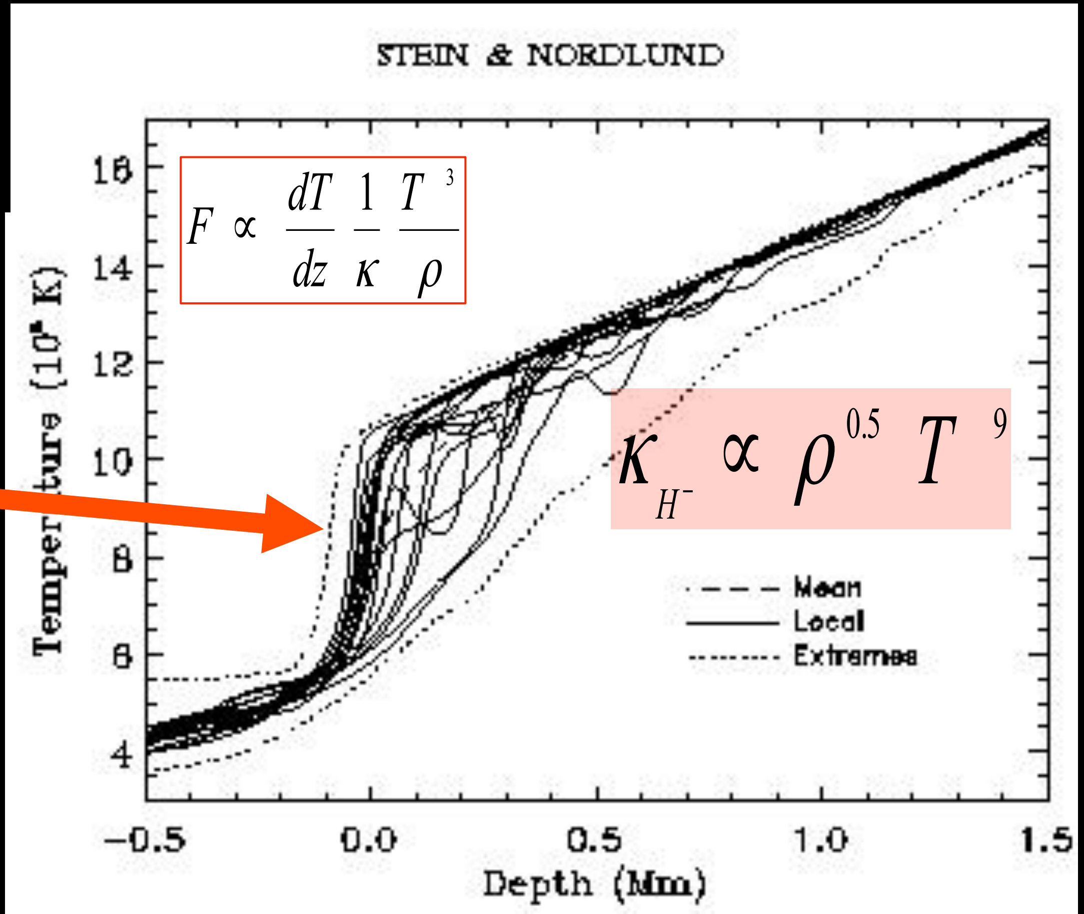
The slow variations using 30d averages are plotted here



This plot shows the residual from the 150d moving means.

Dynamic Radiative Photosphere, Convection and Radiation

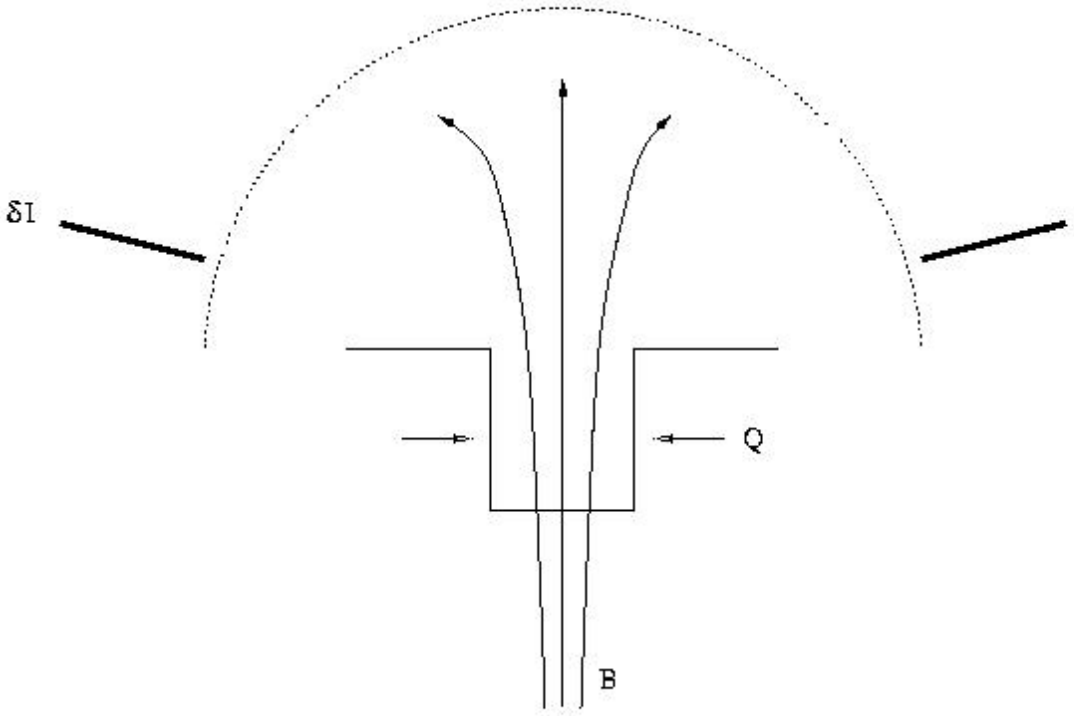




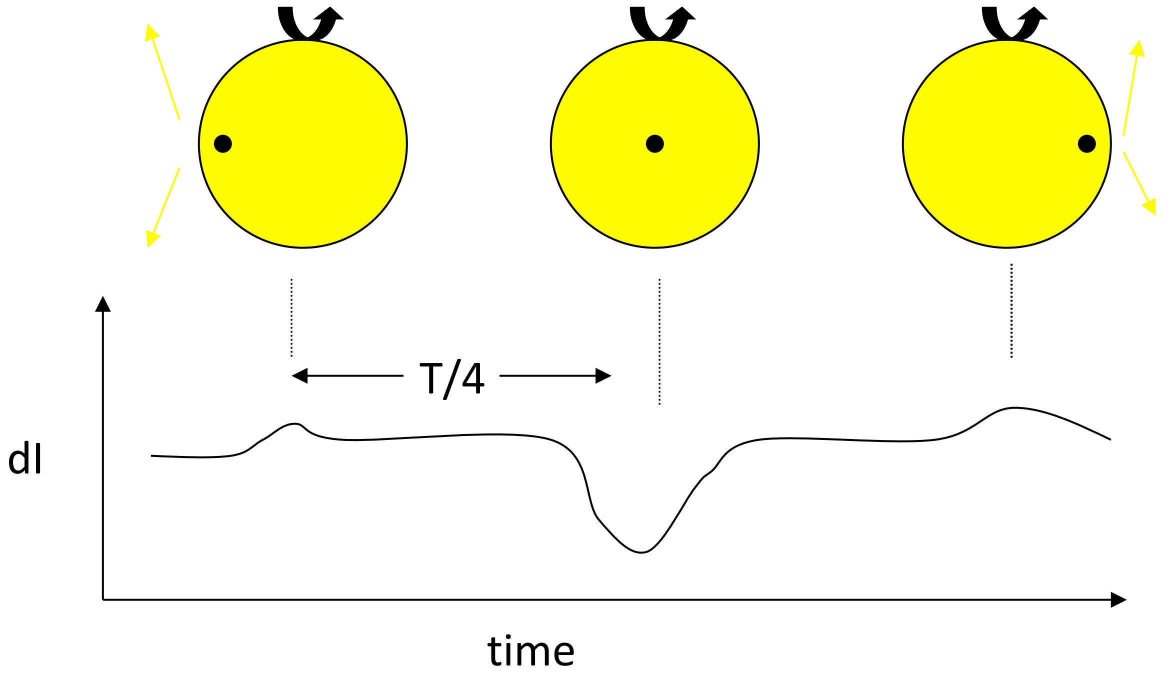
"few km" thick transition from opaque to transparent

Spots and faculae create flux changes by angular redistribution of local luminosity

1. Magnetic brightness perturbations largest edge on

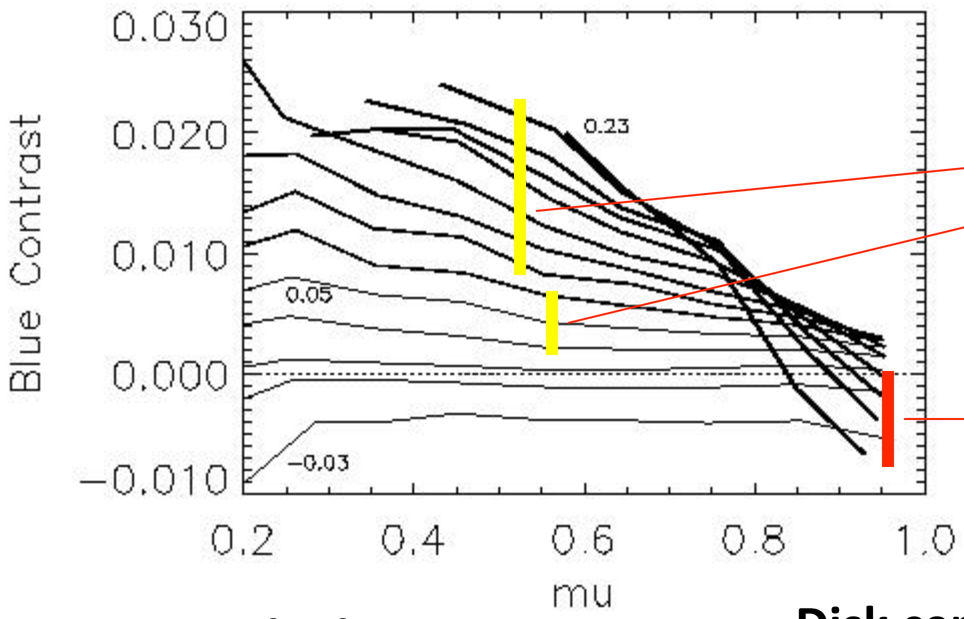


2. Magnetic brightness have short-term anticorrelation



Solar rotation creates angular variation in active region irradiance …

Continuum blue flux contrast vs. vertical orientation and magnetic flux (CaK flux)



The integrated disk brightness change due to bright faculae is 38% of the faint faculae

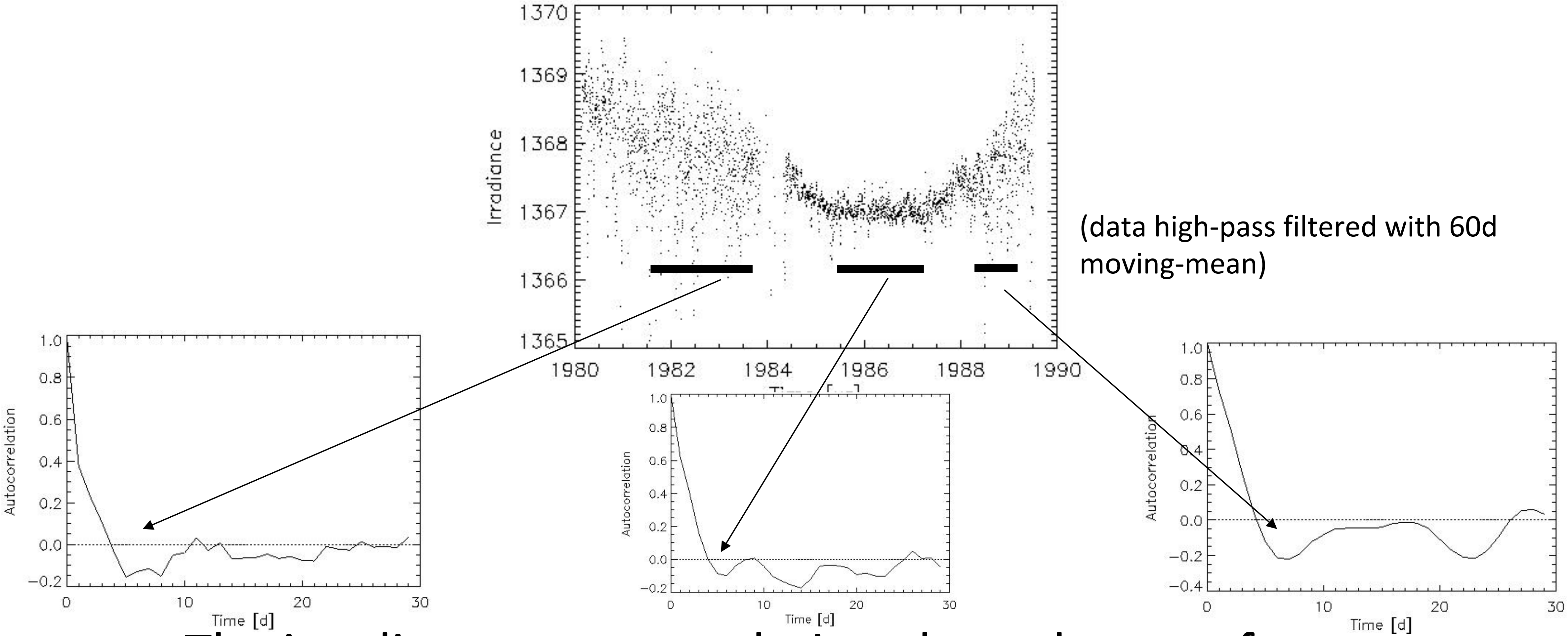
“Bright” faculae are dark, at any wavelength near disk center

near limb

Disk center

Data from the Precision Photometric Solar Telescope

Apparent solar brightness change is flux redistribution

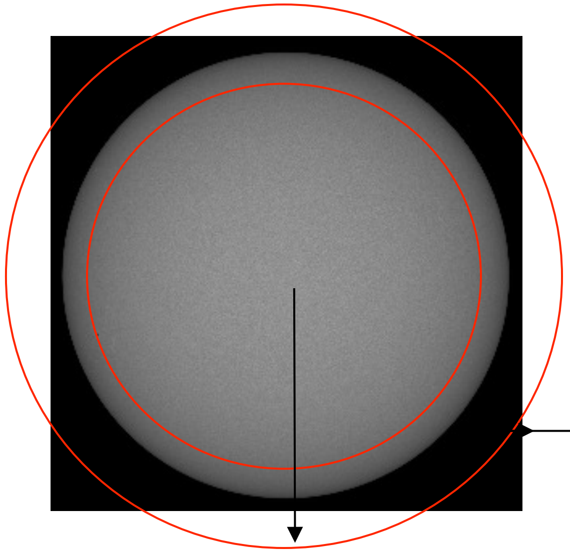


(data high-pass filtered with 60d moving-mean)

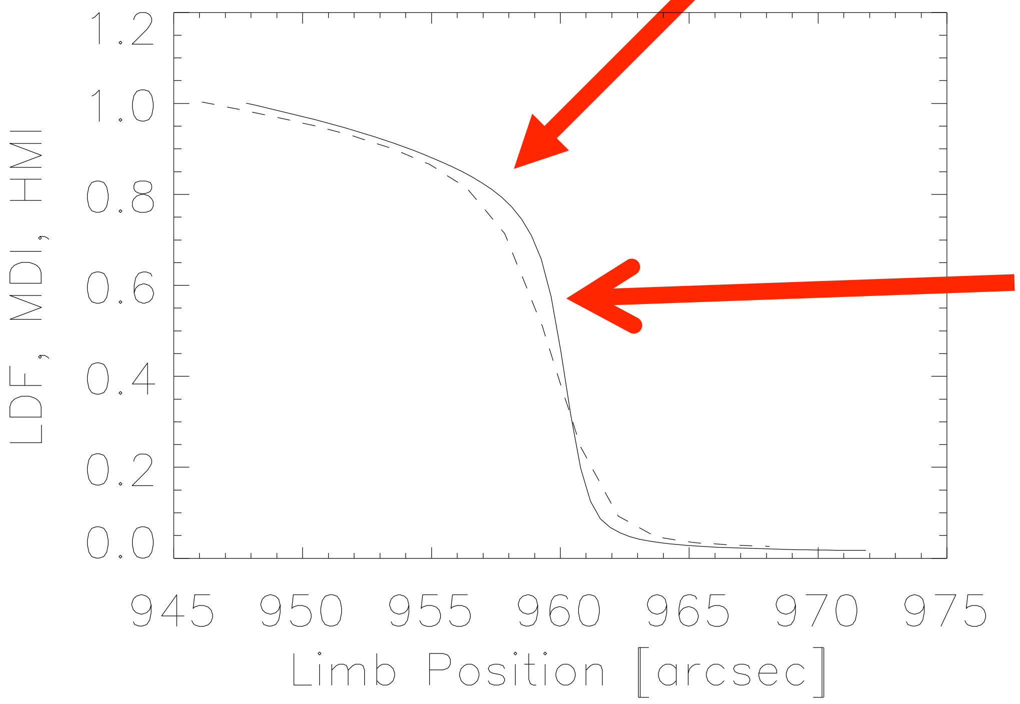
The irradiance autocorrelation shows how surface magnetic fields (faculae and sunspots) redistribute flux

HMI: Microarcsecond Solar Limb Astrometry
Where's the limb?
Distinguishing brightness and limb position

$$I(\theta, r) = \bar{I}(r - \beta(\theta))(1 + \alpha(\theta))$$

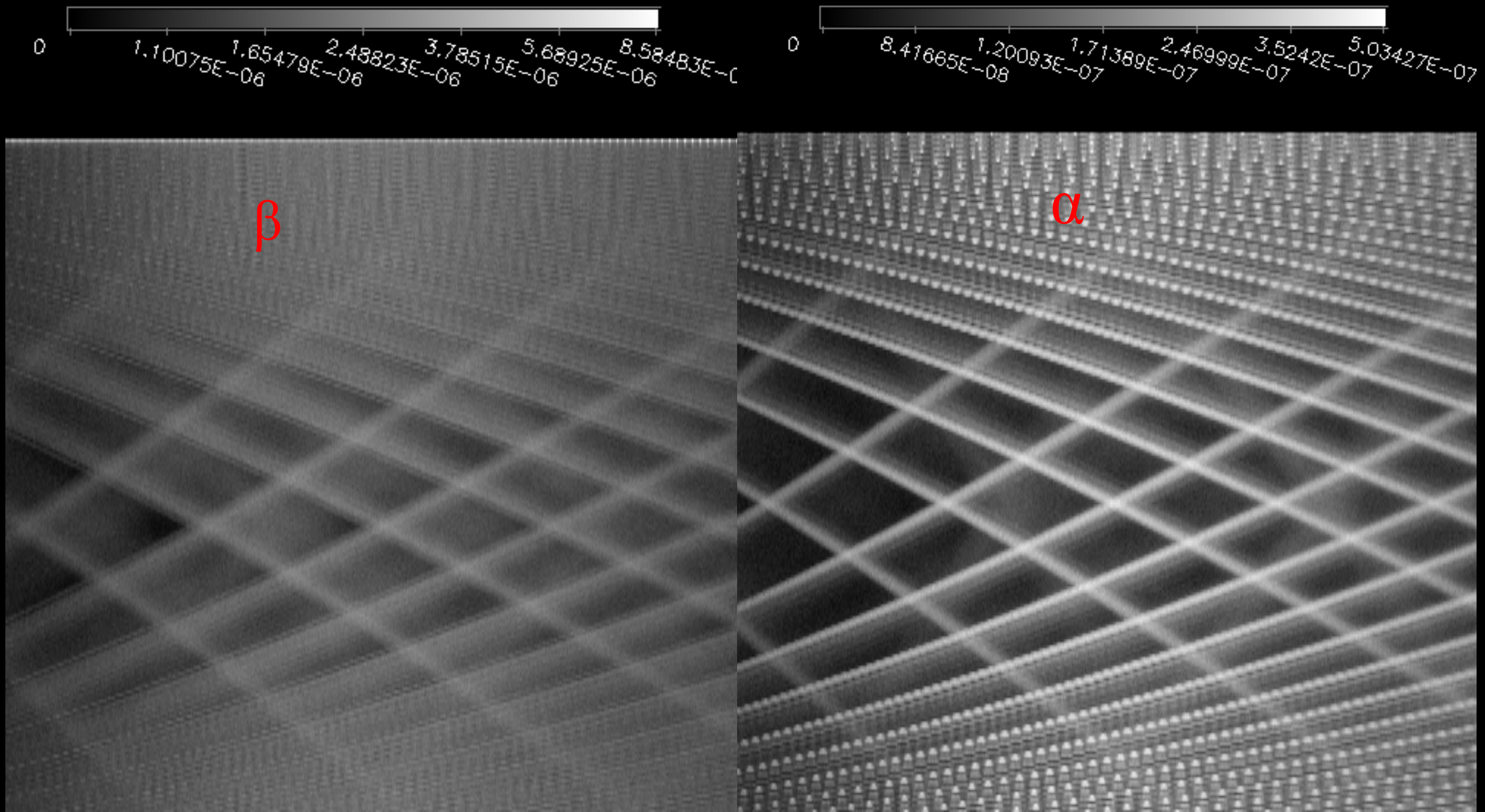


50 pixel annulus



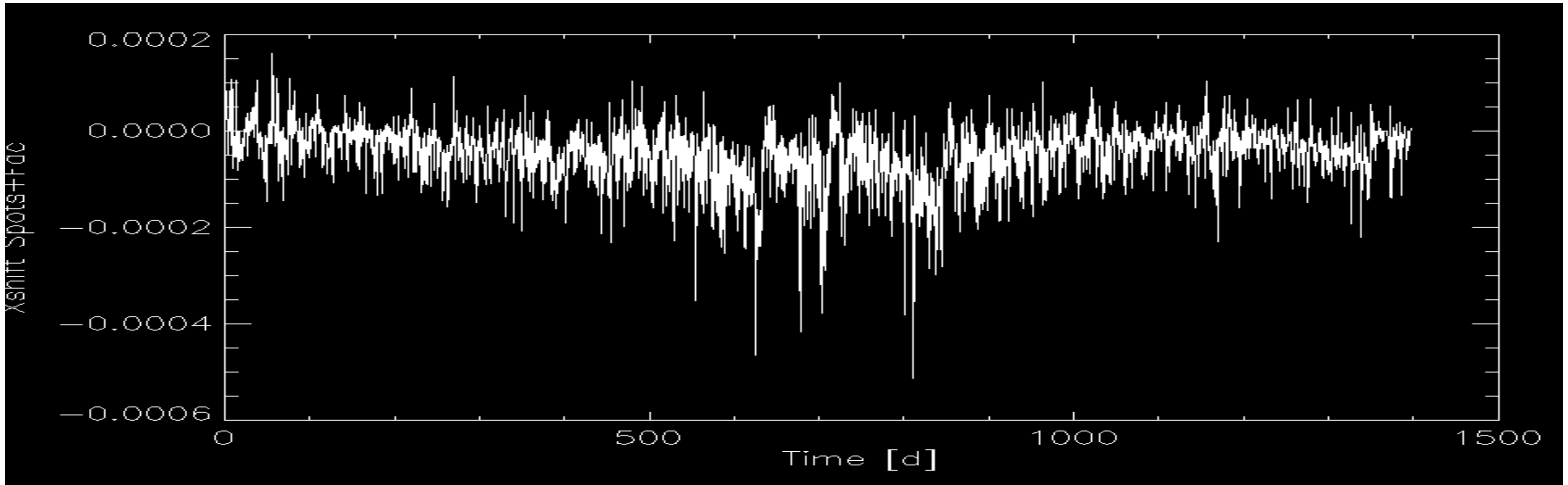
SDO/HMI: 0.5"/ pix

Solar microarcsecond astrometry: Spatial-temporal power spectra for p-mode oscillations

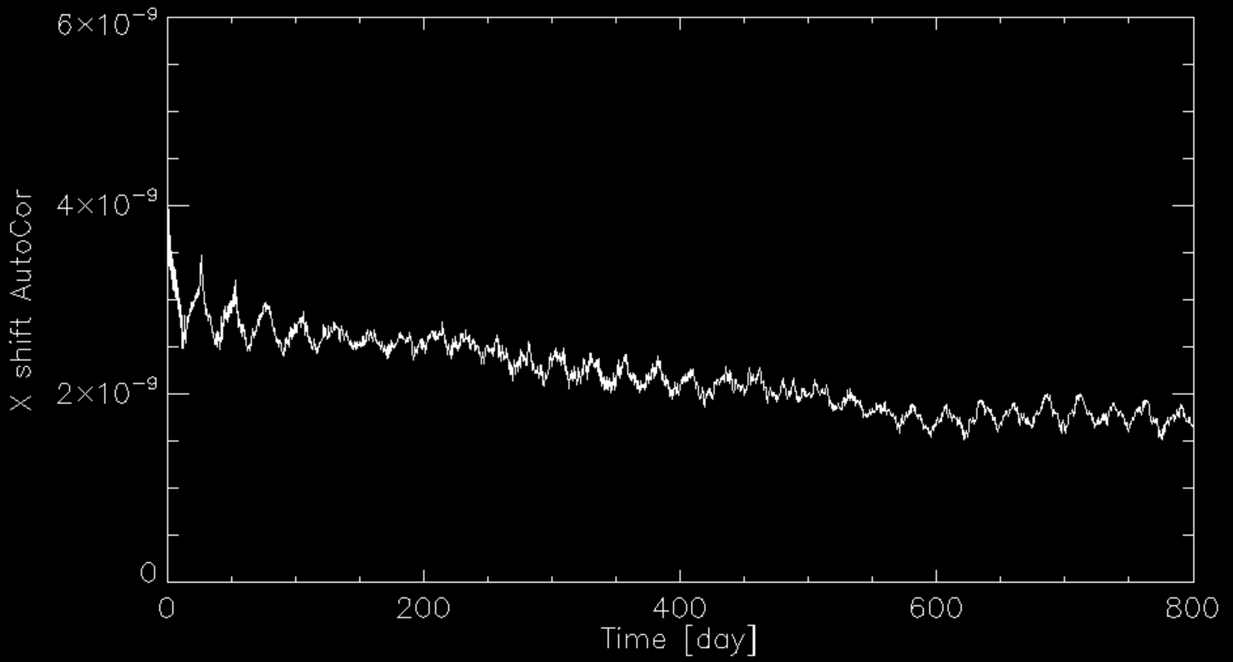


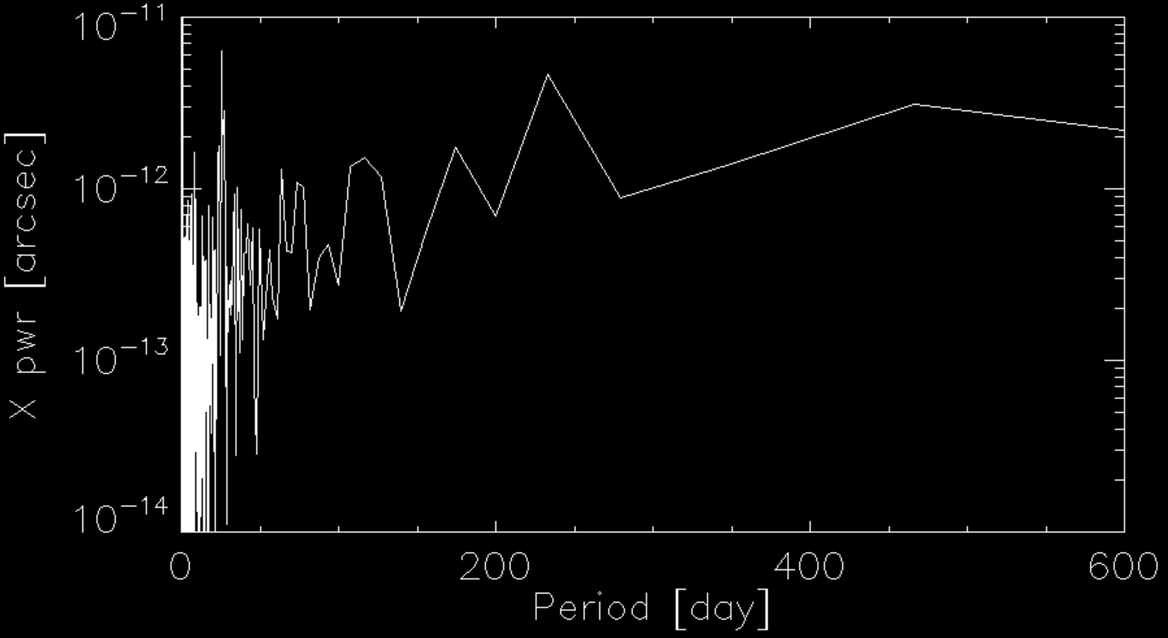
1% Solar limb brightness variations in time from 4 years of HMI α(ϴ,t)

4 yr



Spots and faculae: Long coherence time, and about 1microarcsec power amplitude in 1 year observation of centroid shift near 1 year period





Sun has more than active region faculae and sunspots – these create significant stellar effective wavelength changes and large apparent astrometric separation changes in aCen or 61Cyg

The Limb solar temperature

Ground non-facular and facular brightness measurements

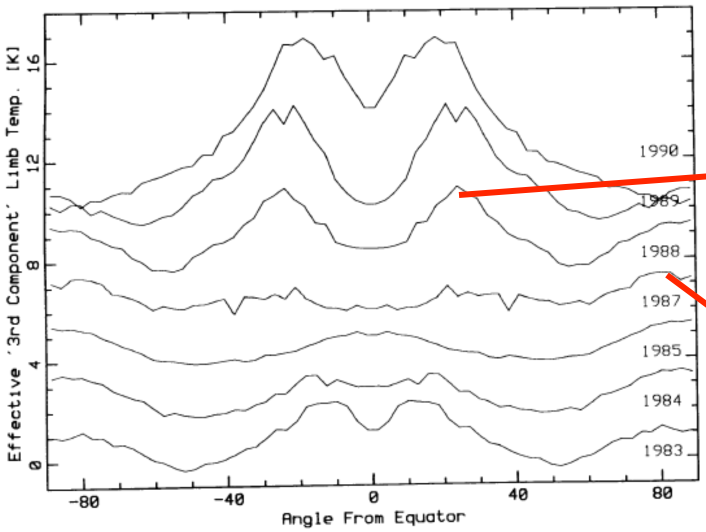
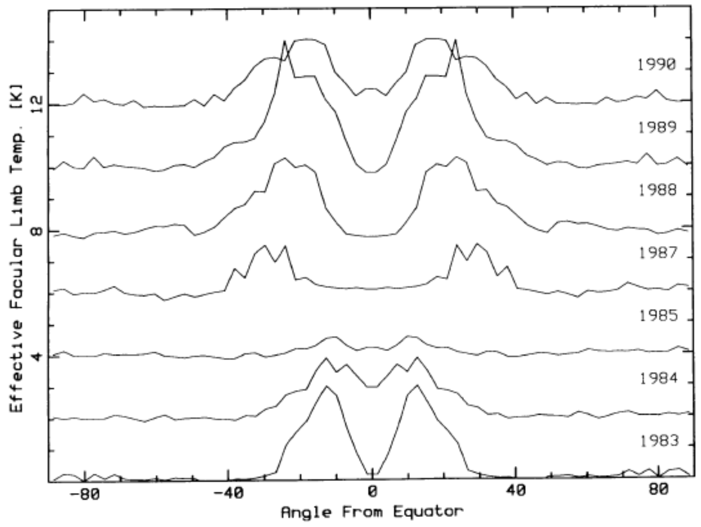


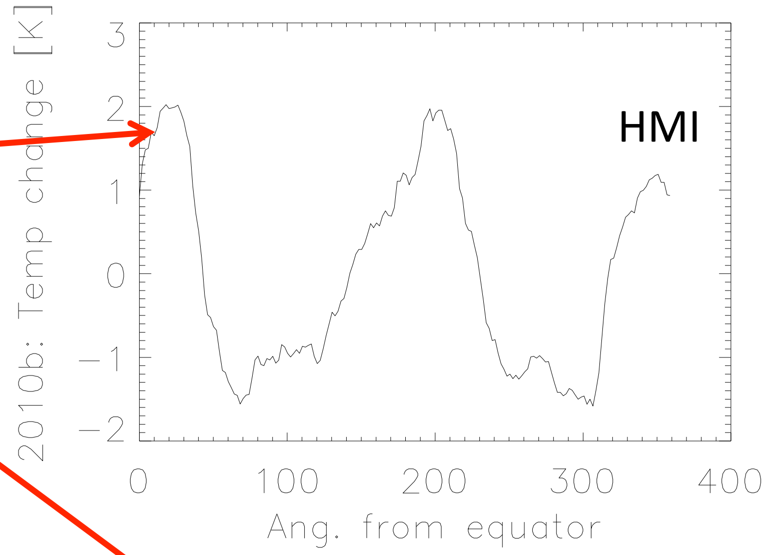
FIG. 2.—Effective limb brightness of the nonfacular or "smooth" flux contribution 1983–1990. Successive plots are displaced vertically by 2 K.

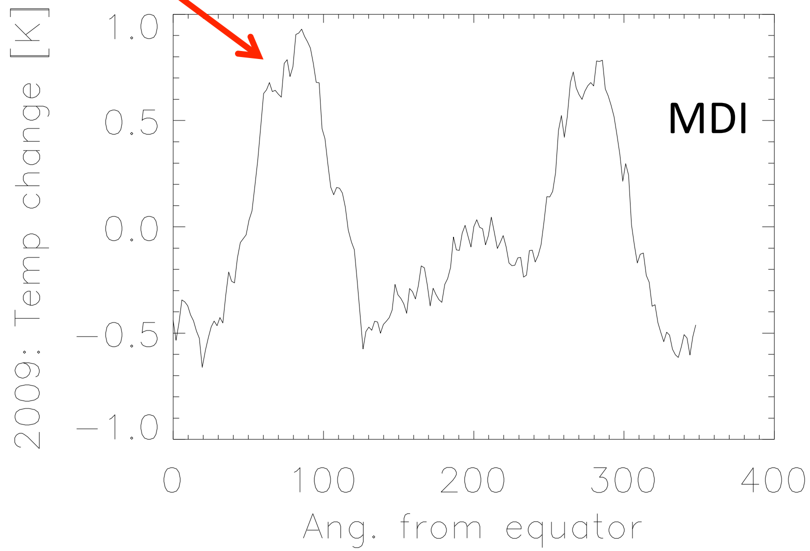
L36 KUHN &



(Kuhn, Libbrecht, Dicke 1985)

Satellite non-facular brightness measurements





The effective temperature of the Sun fluctuates by about 1K on short and long timescales. aCen stellar temperature changes should be measured continuously to 1% or better

Final thoughts….

- To interpret aCen astrometry for exoplanet signals we should understand aCenA/B stellar activity variability with continuous measurements of…
  - Magnetic field Stokes-V polarimetry in photospheric lines
  - Effective temperature from multi-wavelength continuum brightness flux
  - Proxy chromospheric flux measurements, i.e. in CaII K

Interpreting Alpha Cen Astrometry using lessons from the Sun

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