What are Starspots?

Starspots are cooler, darker regions of the sun or stars surrounded by photospheric granules, or parcels of convecting plasma. Solar starspots (sunspots) consist of two parts:
- Umbra: dark, central region
- Penumbra: lighter, outer region

Granules in photosphere ("surface")

How do Starspots Form?

- Faraday’s Law and Ohm’s Law explain why starspots are cooler:
  \[ i = \frac{d\phi}{dt} \]
  \[ i = \frac{\dot{\mathcal{E}}}{R} \]
- If \( R \neq 0 \) and \( \dot{\mathcal{E}} \) is finite, then \( \dot{\mathcal{E}} \) is not possible, so we must have \( \dot{\mathcal{E}} = 0 \). This implies that the change in \( \Phi \) is zero. Plasma is trapped on field lines.
- Due to \( \mathcal{E} \times B \) forces, magnetic field lines act as strings under tension. Hence, plasma parcels cannot move side-to-side and convection is inhibited, cooling the area.
- The Stefan-Boltzmann Law explains why starspots appear darker:
  \[ i = qT^4 \]
  - This fourth-power dependence on temperature makes the cooler spots appear dark in comparison to the photosphere.

How are Starspots Formed?

- Starspots consist of two parts:
  - Penumbra: lighter, outer region
  - Umbra: dark, central region

Instrumentation

- 0.2-m Meade Schmidt-Cassegrain telescope
- SBIG ST-8XE CCD Camera and CCDSoft
- Photometric filters: B (Blue), V (Visual), R (Red), I (Infrared)

Image Processing

- Systematic errors must be removed from raw images before analysis.
- Vignetting: Darkening of an image around corners due to the uneven illumination by the optics.
- Dark current noise: Thermal excitation of pixels; increases with higher temperature

Why LO Pegasi?

- Has large starspots
- Is favorably placed for observation from November
- Has a short rotational period

Photometry

- Using Mira Pro 7, differential aperture photometry was performed on the images to produce light curves showing the brightness variations of LO Pegasi.

Inversion

- A Light-curve Inversion algorithm is used to generate a surface plot of LO Pegasi based on variations in brightness.
- Many factors are taken into account by the algorithm, including:
  - Limb darkening: Darkening of the limb (edge) of a star. Most pronounced through the B filter, least pronounced through the I filter.
  - Noise: The algorithm is sensitive to noise. Hence, we include a smoothing function which causes the algorithm to favor dark spots and an overall smoother surface.*

Light-curve Inversion Algorithm

- Divide the stellar surface into spherical rectangles of nearly equal areas: \( N \) latitude bands and \( M \) longitude bands
- \( J_{mn} \) refers to the specific intensity along the outward normal of the \( m \)th patch of the \( n \)th latitude band
- \( J_{mn}' \) refers to the integrated intensity observed at time \( t \)
- Our task is to find the set of \( J_{mn}' \), which best represents the surface from the light curve
- \( E \) is the objective function which the algorithm is trying to minimize:
  \[ E(J, B) = \sum (J_{mn}' - J_{mn} - B_{mnb}) \]
- \( G \) is the goodness of fit function:
  \[ G(B) = \sum \left( \frac{J_{mn}' - J_{mn}}{\sigma_{mn}} \right)^2 \]
- Below, \( S \) is the smoothing function and \( c_j \) is the bias parameter:
  \[ S = \sum_{j=1}^{J} c_j \left( 1 + \frac{x}{J} \right) \]
- \( S \) suppresses noise artifacts in the reconstruction of the stellar surface.

Results

- 2006
- 2007
- 2008
- 2009
- 2010

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