Starspots on LO Pegasi, 2006-2014

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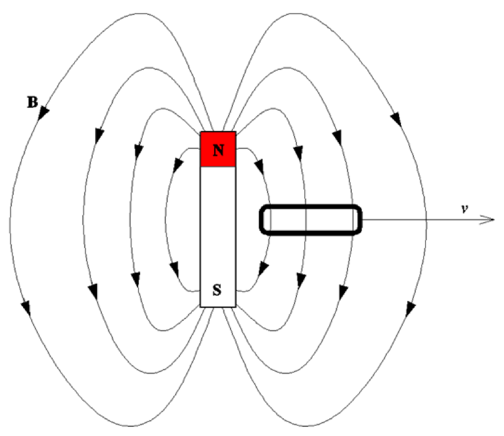
Starspots

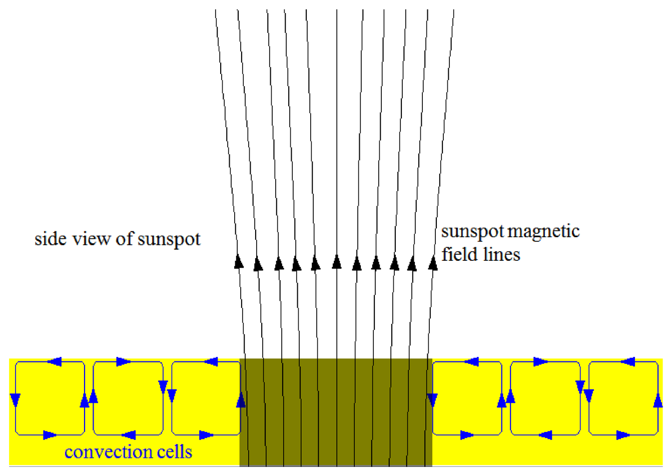
Starspots are cool, dark regions on the stellar surface that exhibit strong magnetic activity. On the Sun, they are called sunspots. They arise because the stellar gas is ionized to form an electrically conducting plasma.

Ohm's law: $I = \frac{\varepsilon}{R}$ Faraday's law: $\varepsilon = -\frac{d\Phi_B}{dt}$

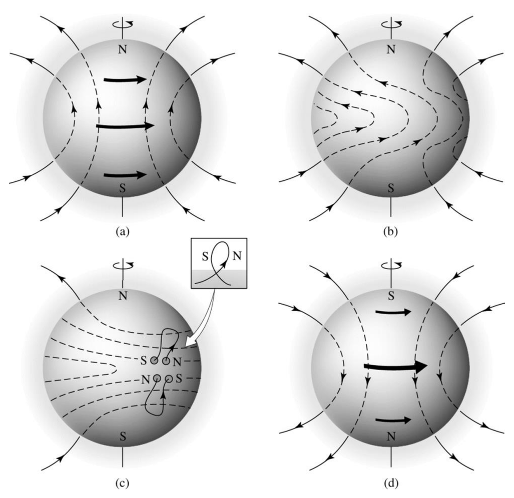
In a perfect conductor, $R = 0$, so that ε must also be 0, resulting in a constant flux through any loop. In that limit, the field lines would move with conducting loop pictured below. This is called *flux freezing*.



In a star, the field lines and plasma are constrained to move together via flux freezing. In spots, **B** is vertical and several thousand gauss in magnitude, and **v×B** forces produce strong *magnetic tension* that causes the field lines to resist bending. This means that plasma cannot move horizontally, suppressing convection inside spots. As a result, radiative diffusion dominates as the primary means of energy transport in spots, while convection dominates in the surrounding surface. Radiative diffusion is not as efficient as convection in the star's outer layers, leading the spot to be cooler and darker than its surroundings.



In the *Babcock Model*, differential rotation and flux freezing "wind up" the field from a polodial configuration at minimum activity (top two figures below). Magnetic flux tubes are less dense than their surroundings, making them buoyant. Spots form at the footpoints where flux tubes rise through the surface (bottom left). The field is reversed at the next minimum (bottom right).



Instrumentation

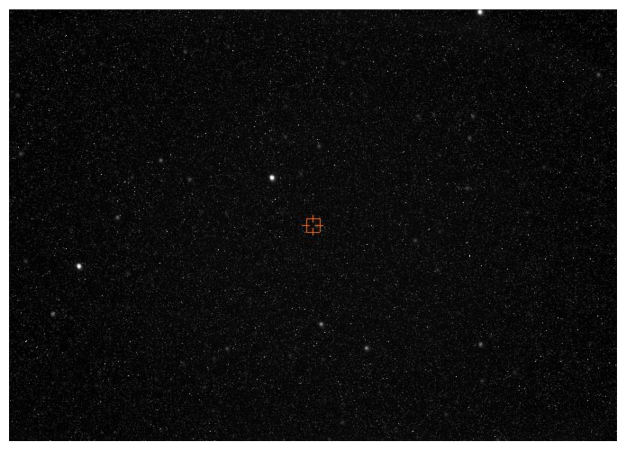
- Meade 14-inch LX600 Telescope
- Quantum Scientific Imaging Model 632 CCD Camera
- Astrodon B (blue), V (visual), R (red), and I (infrared) Standard Photometric Filters

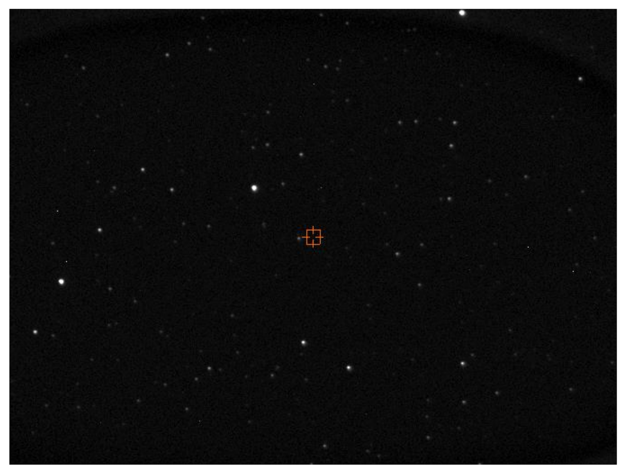
Meade Instruments Corp.

Quantum Scientific Imaging, Inc.

Data Analysis

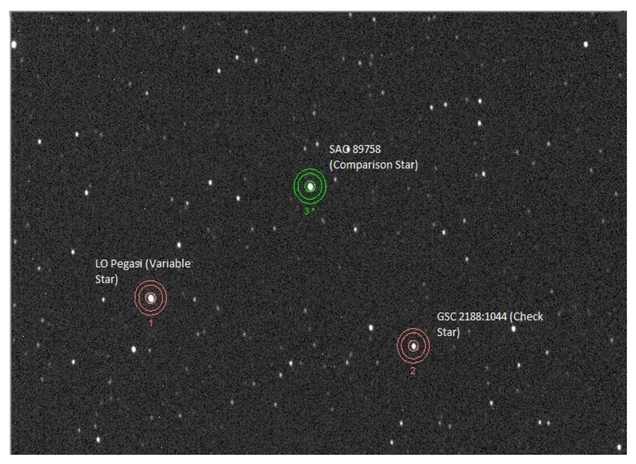
To nearly eliminate thermal noise in an image, we subtract a *dark frame* obtained with the shutter closed. We also divide by a *flat field frame*, which is an image of a uniformly bright field. This compensates for *vignetting*, the fact that the center of the image is better-illuminated than the edges by the telescope optics.





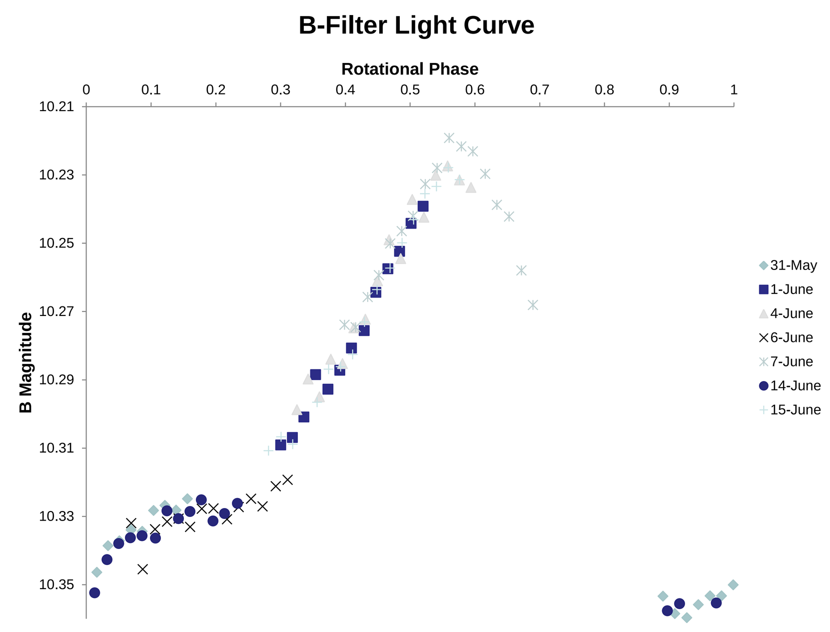
Top: Raw unprocessed image
Bottom: The same image after processing

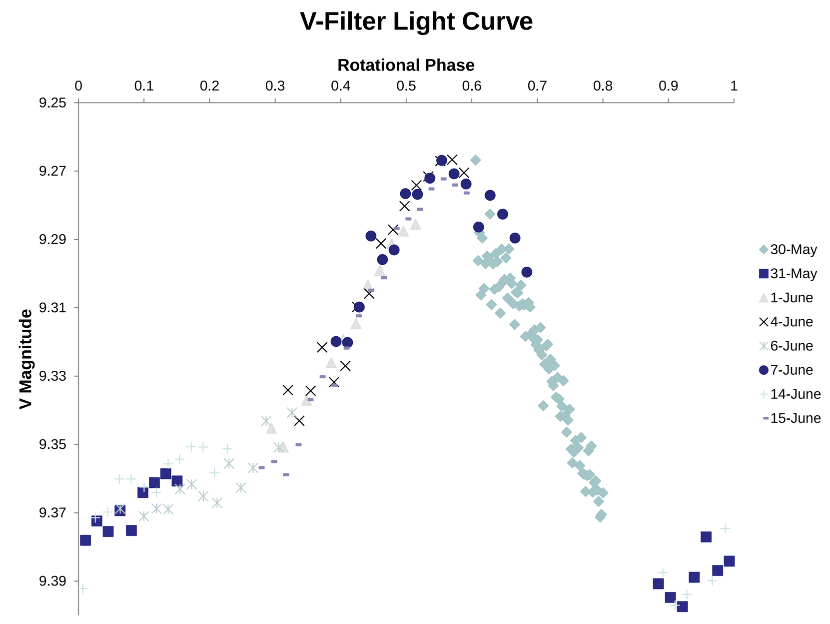
Differential aperture photometry was then performed using *Mira Pro* software to obtain the brightness as a function of time of our target star, LO Pegasi, using SAO 89758 as the comparison star and GSC 2188:1044 as the check star.

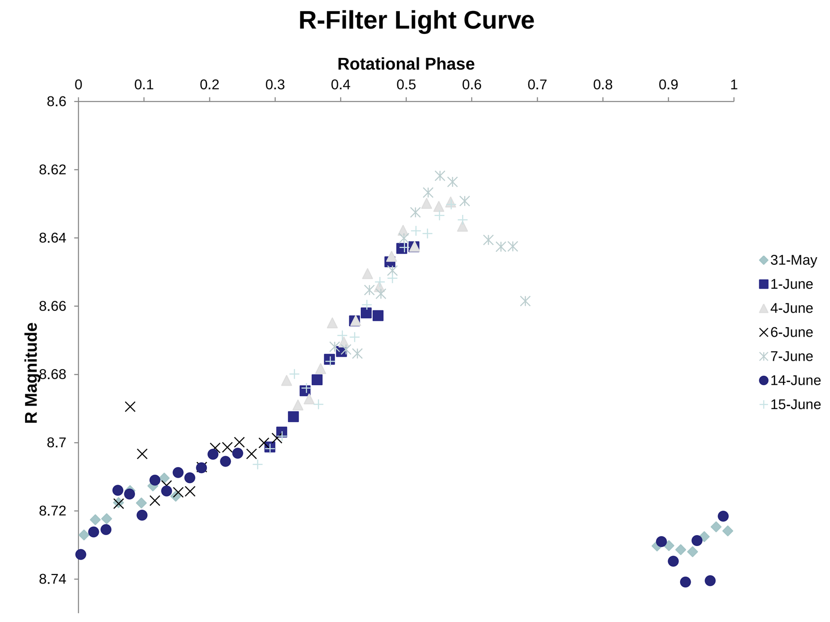


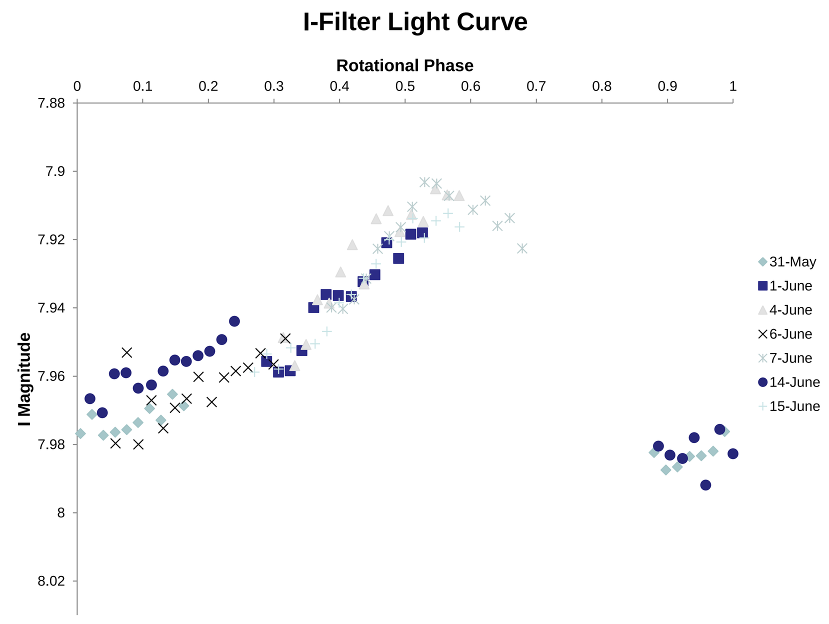
2014 Light Curves

LO Pegasi is a spectral type K star that is a "young solar analog." Its rapid rotation creates strong magnetic fields and large starspots. As the star's rotation carries starspot features in and out of view, the star's observed brightness varies with the same period as the star's rotation. By using *Peranso* time-series analysis software, we determined LO Pegasi's rotational period to be 10.1538 ± 0.0009 hours.





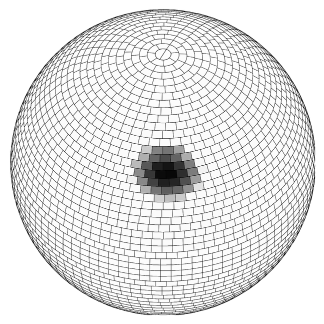




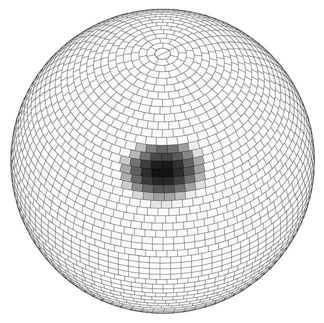
Surface Images via Light-curve Inversion

A Light-curve Inversion (LI) algorithm developed by one of us (Harmon) was used to convert variations in brightness into surface images of LO Pegasi. The algorithm exploits differences in the degree of limb darkening through different filters to improve the latitude resolution of the inversions.

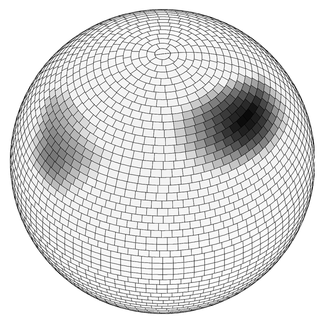
The images below show the results for 2006-2011 and 2014. In 2012-2013, the average brightness and amplitude of the light curves were much lower than in the other years, suggesting the presence of a large, nearly circular spot centered on the visible rotation pole, which could not be imaged by LI. Images obtained by another method called Doppler imaging also indicate a polar spot on LO Pegasi that is likely permanent. Thus, the spots shown in the 2006-2011 images are in reality likely appendages of a polar spot. LI has recently been modified to image polar spots by taking into account long-term variations in average brightness, but there was not time to complete a detailed analysis for inclusion here. An image for an arbitrary assumed polar spot radius in 2014 is shown; further work will elucidate the variation in its radius from 2006-2014.



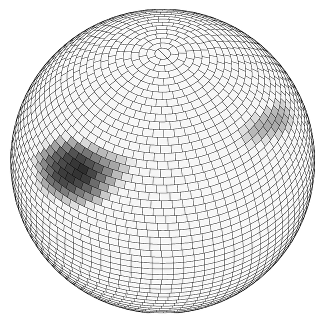
2006



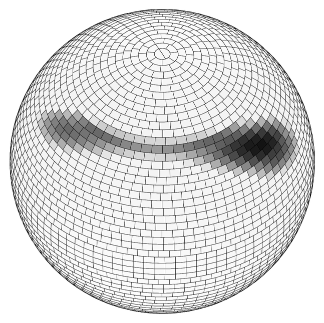
2007



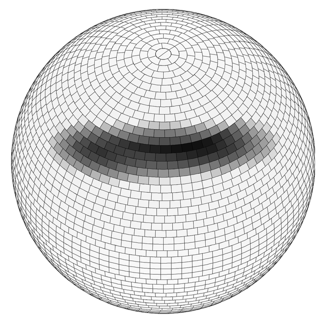
2008



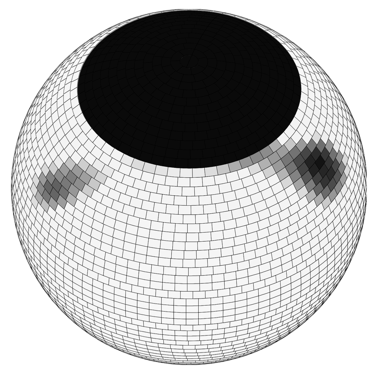
2009



2010



2011



2014

Acknowledgments

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