Stellar Surface Imaging of LO Pegasi via Light-curve Inversion

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Goal

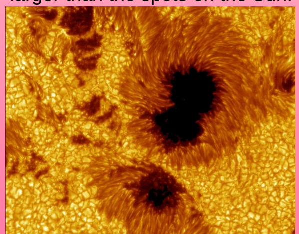
Our goal was to study dark starspots on the surface of the K8 main-sequence star LO Pegasi. Because stars other than the Sun are so far away from us, even the Hubble Space Telescope images them as mere pinpoints. Thus, in order to map the starspots on LO Pegasi, we had to use an indirect method. We acquired digital images of LO Pegasi during June and July, 2008 through B, V, R, and I photometric filters using a 0.2-m Meade Instruments LX200 Schmidt-Cassegrain telescope and Santa Barbara Instruments Group ST-8XE CCD camera. We then performed differential aperture photometry on our images to create light curves of the star and employed a technique called Light-curve Inversion to map the surface based on the variations in the star's brightness produced by the starspots as they are carried into and out of view by the star's rotation.

Why is this important?

Starspots, like sunspots, are regions of enhanced magnetic field strength compared to the rest of the stellar surface. Understanding how starspots are formed and move on the surface of the star can give us a greater insight into the dynamo process which generates the magnetic field of this star and thus more insight into our own Sun's magnetic behavior.

What is a Starspot?

It is a spot of cooler, darker plasma (ionized gas, mostly hydrogen) on the photosphere (surface) of the star. A sunspot consists of a dark center called the *umbra* and a filamentary halo called the *penumbra*. Sunspots can be over 50,000 kilometers across and can last up to a few months. They are a few hundred Kelvin cooler than the surrounding photosphere and thus appear darker. Starspots that are large enough to be studied with present technology are much larger than the spots on the Sun.



An image of a sunspot from the Swedish Solar Telescope. The darkest areas are umbrae and the halos around them are penumbrae.

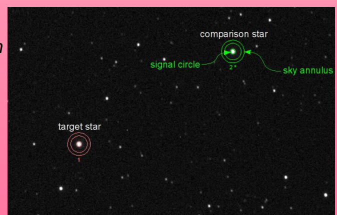
Starspots are caused by bundles of magnetic field lines that suppress convection in the photosphere. Convection is the constant churning of plasma within the star and is how energy is primarily transported within the photosphere. The hot gas rises to the surface, loses heat to space, cools off and sinks to hotter layers where the process begins again. Where the magnetic field lines protrude through the photosphere, they restrict the plasma from moving side to side and so convection is inhibited, the plasma cools and a starspot is formed.

Procedure

We used *Mira Pro* software from Mirametrics to perform differential aperture photometry on our digital images. Aperture photometry is the method of drawing a circle, called a signal circle, around the star using the software and having the software count how many star photons were captured within that circle. By counting the photons from the star we can determine the star's brightness. Because the sky is not completely dark, there are also photons from the sky that are counted within the signal circle and should not be counted as part of the star's brightness. To account for this, we draw another annulus around the signal circle that captures only sky photons. This allows *Mira Pro* to determine how many sky photons there are per pixel so it can subtract the sky photons from the total photons in the signal circle so we are left with only star photons being counted within the signal circle.

The brightness of LO Pegasi changes throughout its 10.17-hr rotation period because of its starspots. If a spot is in the field of view of Earth, the total brightness of the star will decrease because the spot is not as bright as the surrounding photosphere. To measure the brightness of our star, we compare it to another star on the images of known brightness. The field of view of our images is comparable to the size of the full Moon, so that all stars in the images are close to LO Pegasi on the sky. Changes in atmospheric transparency thus affect the apparent brightnesses of LO Pegasi and the comparison star nearly equally, so that use of the comparison star automatically compensates for the effects of such changes. We also measure the brightness of another star on the frame called the check star to make sure that the comparison star is not of variable intensity itself. The comparison and check stars should have a constant brightness ratio.

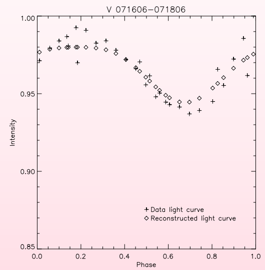
An image on which we are performing aperture and differential photometry using LO Pegasi and the comparison star.



We then created graphs of LO Pegasi's brightness vs. rotational phase. The rotational phase is the fraction of a rotation through which the star has turned since an arbitrary starting time, neglecting the integer part, and thus varies between 0 and 1. The light curves are then analyzed to map the starspots via the Light-curve Inversion program. See Conrad Moore's presentation for more details

Results

Below are three light curves and images of LO Pegasi from two previous summers followed by light curves and images obtained this summer. It is easy to see the light curve has changed in shape and size over the past few years to become deeper and wider. This indicates the spots are becoming more spread out and larger.



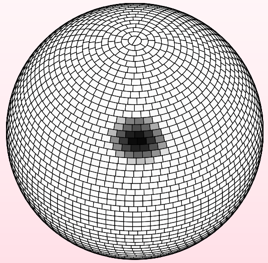
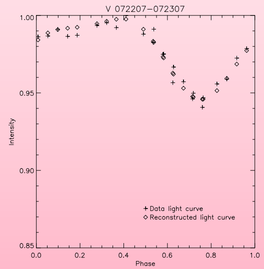


Image and light curve from July 16 – July 18, 2006.



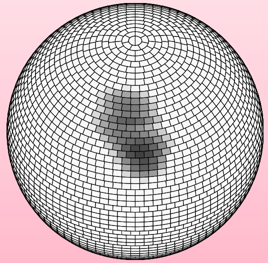
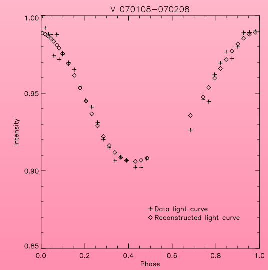


Image and light curve from July 22 – July 23, 2007.



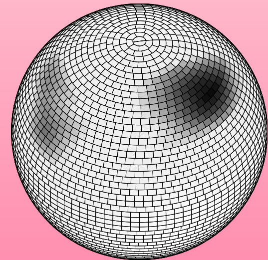
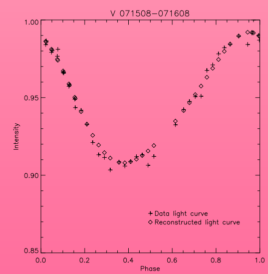


Image and light curve from July 1– July 2, 2008.



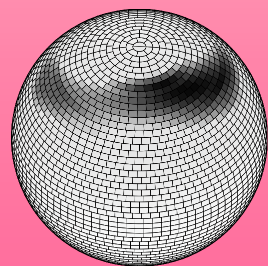


Image and light curve from July 15 – July 16, 2008.

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