Keplerian Periodicity in the Photometric Variability of VV Serpentis

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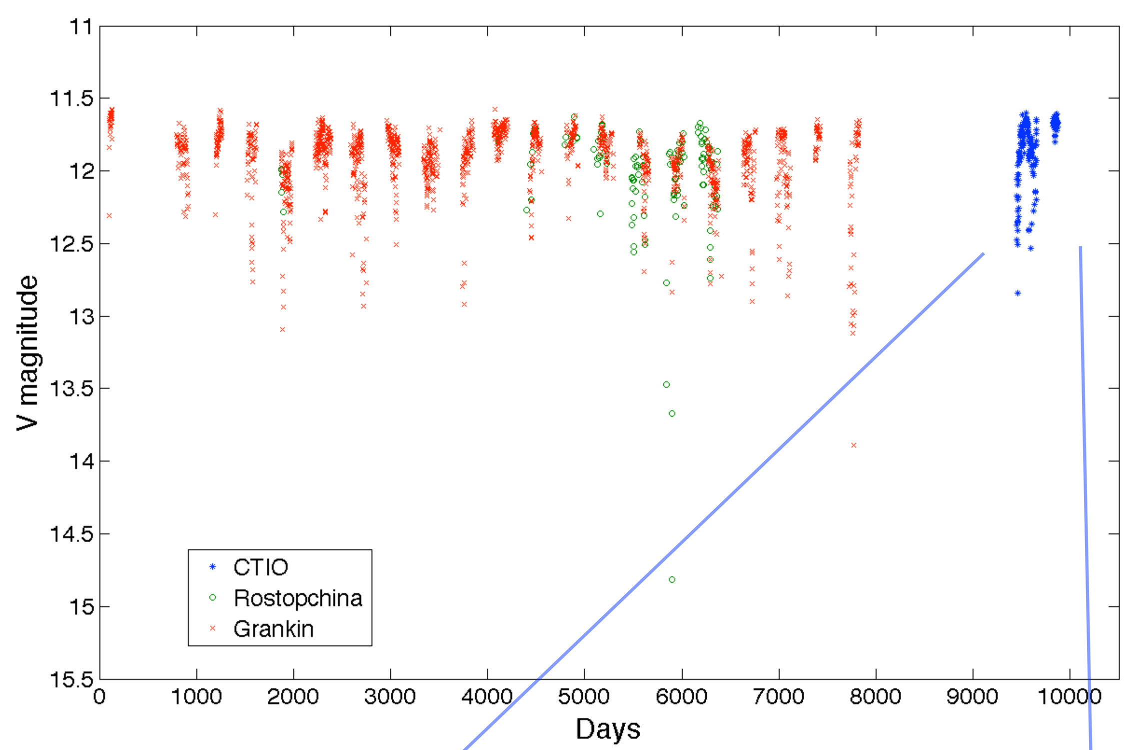
Abstract

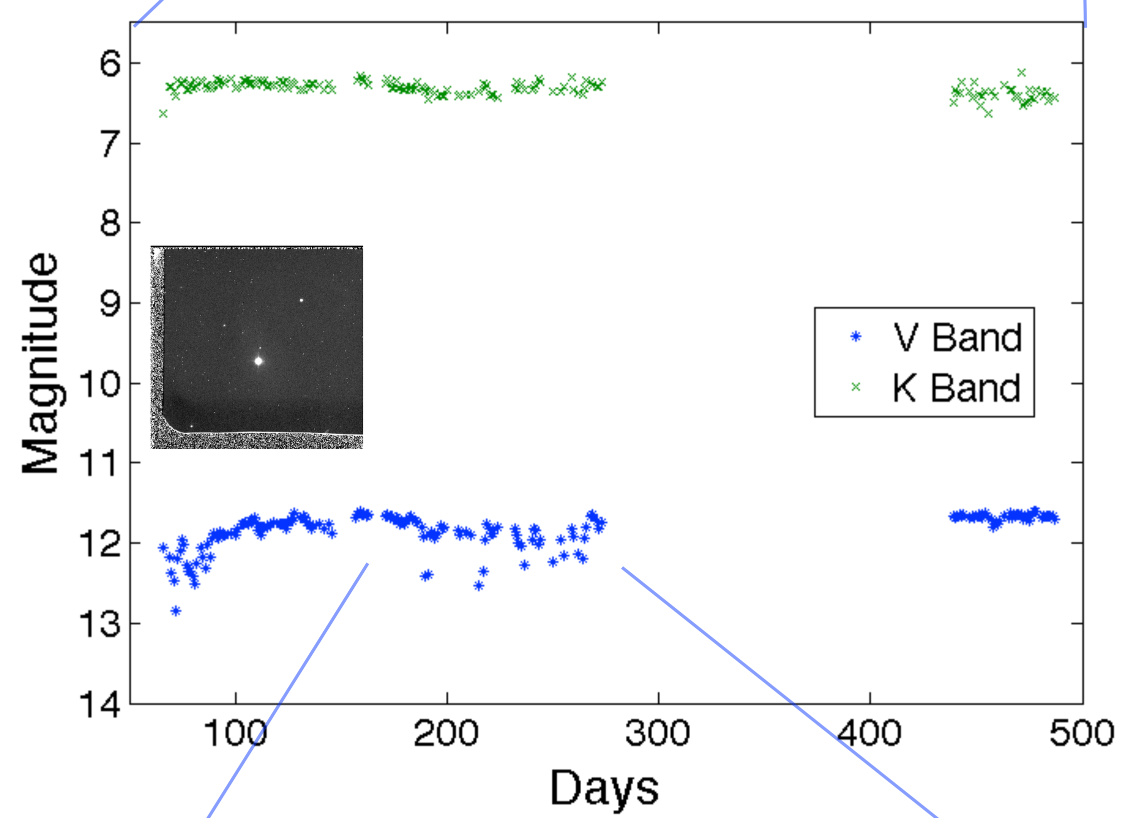
We present the results of our long-term photometric monitoring effort of VV Serpentis, a Herbig Ae star with an edge-on disk that is known to undergo periodic extinction events. We combine our 177 nights of data from the ANDICAM simultaneous visible/IR imager with two data sets from the literature to create a large, statistically significant, 1834 night data set spanning 23 observing seasons. A Lomb-Scargle analysis of this data set shows a broad peak in the periodigram at 30-35 days. This period corresponds to the Keplerian orbital period of the inner rim of the disk, suggesting that the periodic extinction events are caused by protoplanetary structure, which is expected to form in the same inner regions of the disk.

VV Serpentis

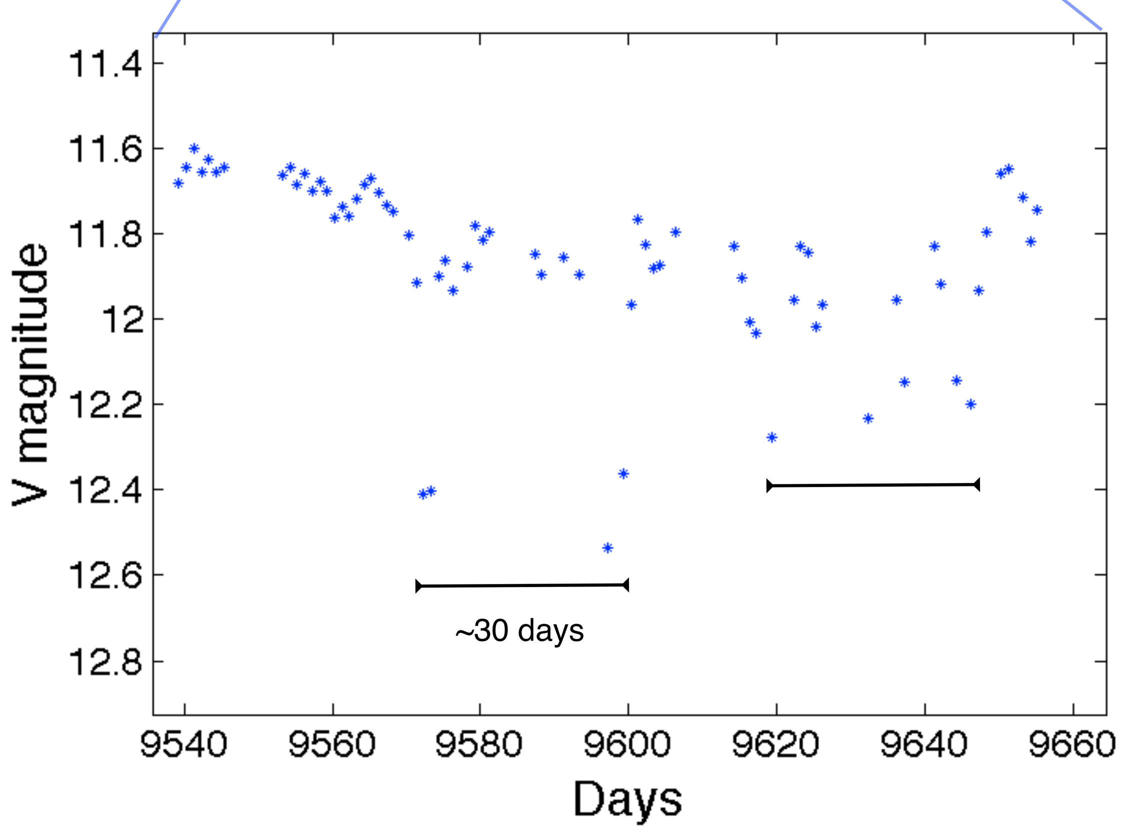
- A nearby (~260 pc) Herbig Ae star related to the Serpens Cloud.
- VV Ser is a UX Ori star, a subgroup of young stars that are variable as a result of dust occultations. Particularly strong occultations (~1.5-2 magnitudes in V) are general accompanied by a "bluing effect" as a result of scattered light from the disk accounting for a larger fraction of the observed flux.
- SED modeling (Pontoppidan et al. 2007) confirms that VV Ser has a nearly edge-on (i~70°), self-shadowed dusty disk that is dominated by its puffed-up inner rim.
- Host star mass estimated to be ~3M⊙ with spectral type of B9 from SED modeling.
- Photometrically and spectroscopically variable on time scales of minutes to years.



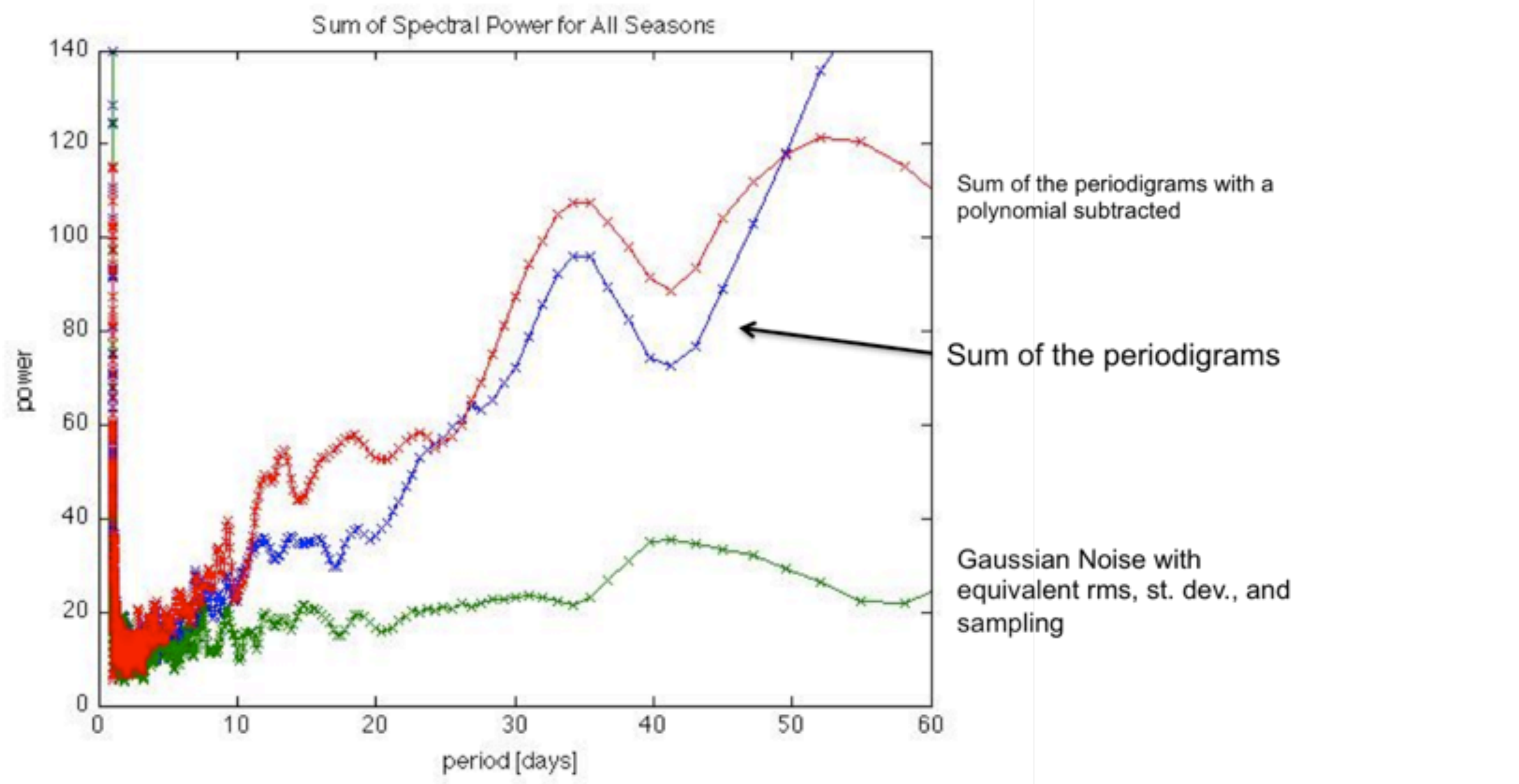
We combined our data from the CTIO telescope in Chile (shown in blue) with that of two other groups to obtain a massive 23 season, 1834 night light curve. The red data is from the ROTOR program at the Maidanak Observatory (Artmemenko, Grankin, and Petrov 2010). The green data is from the Crimean Astrophysical Observatory (Rostopchina et al. 2001)



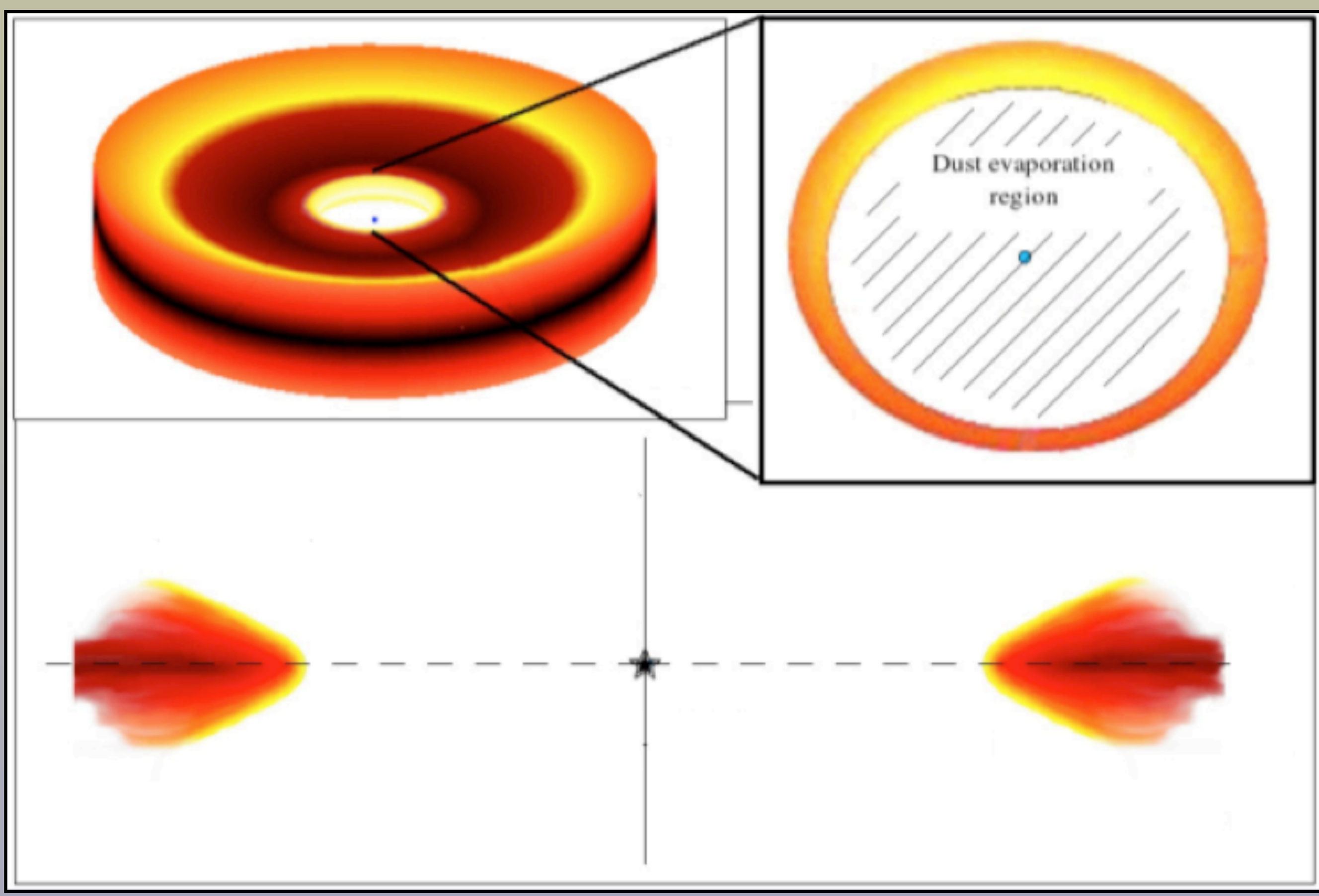
Data of VV Ser from ANDICAM on the CTIO 1.3m in Chile.



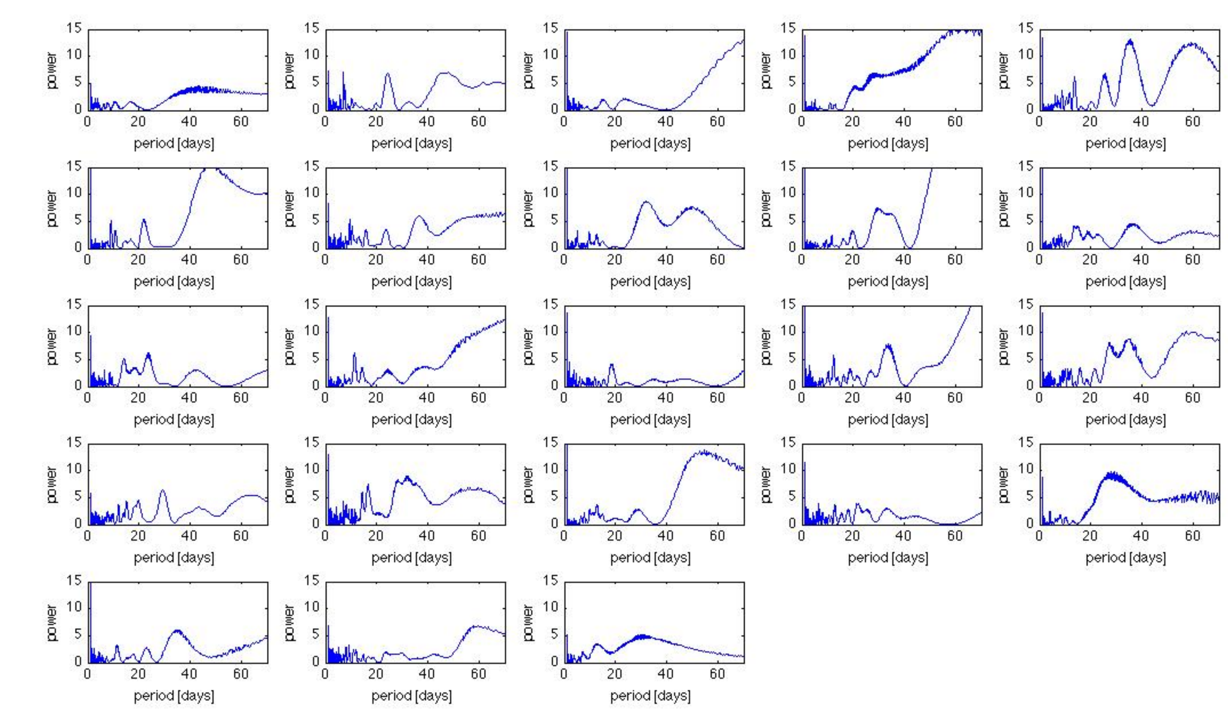
Zoomed in section of V-band data showing sharp (few day) extinction events with characteristic ~30 day period.



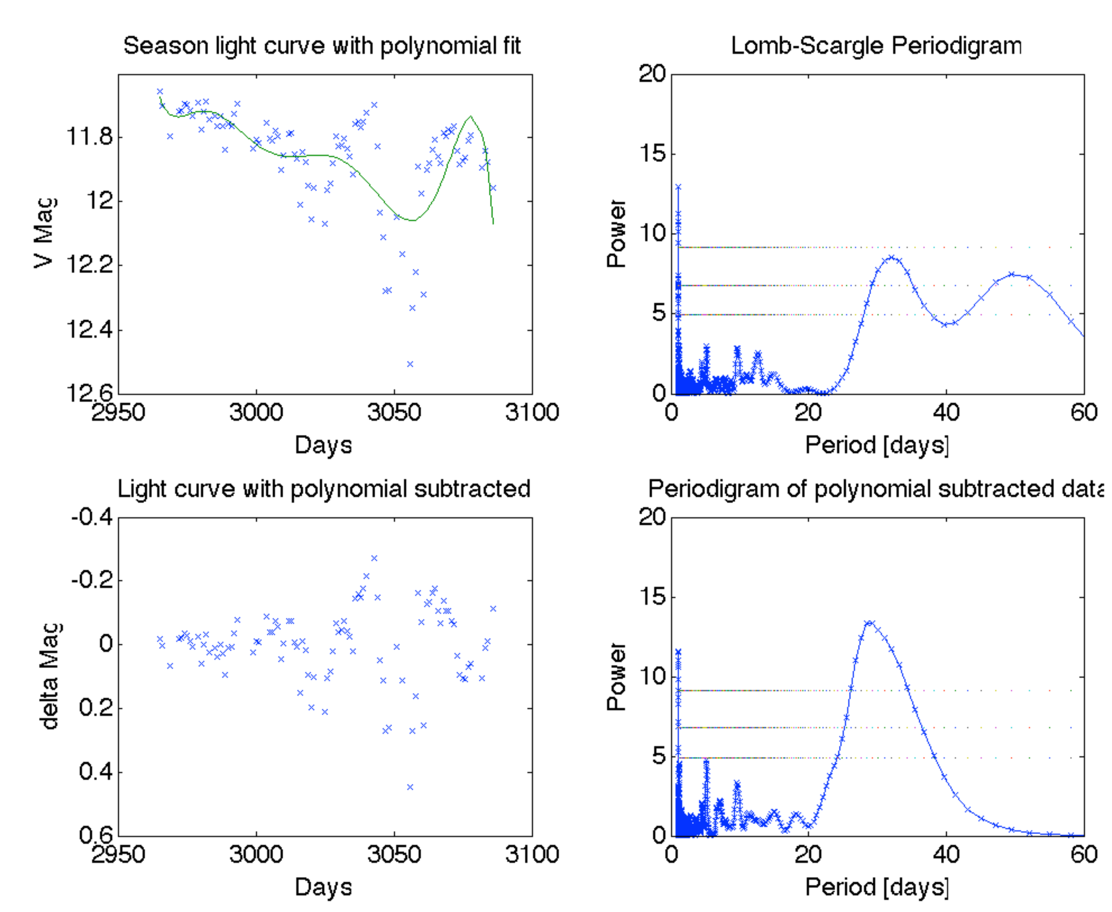
Periodigram of the full 23 seasons of data. The blue curve shows a peak at 35 days, roughly the Keplerian orbital period of the puffed up inner rim radius of a 3 M⊙ star. The red curve is the same data with polynomial fits subtracted from the data prior to generating the periodigram. The green curve is the periodigram of Gaussian noise with equivalent rms, standard deviation, and sampling as the real data.



Sketch showing the geometry of VV Ser's disk. Top left shows a protoplanetary disk with an inner puffed up rim that casts a shadow over the outer part of the disk. Top right shows the inner puffed up rim and the inner photodissociation region. Lower sketch shows a cross section of the inner puffed up rim. In the case of VV Ser, the line of sight passes through the edge-on disk. Protoplanetary clumps are predicted to be in the puffed up inner rim. Figure adapted from Isella et al, 2008.



Individual Lomb-Scargle periodigrams of all 23 observing seasons of data.



An example of a polynomial subtracted from the light curve of one season. Top left is the light curve of the season with a polynomial fit and the corresponding periodigram (top right). Lower left, the light curve with the polynomial subtracted and the corresponding periodigram (lower right). The peak in the periodigram around 30-35 days becomes stronger, while the lower frequency power disappears. Horizontal lines in the periodigram show 50%, 10%, and 1% confidence levels.

Interpretations

- A 35 day period around a 3 solar mass star corresponds to a Keplerian orbital radius of 0.3 AU
- This is consistent with Eisner et al 2004, which measured an inner rim radius of 0.3-0.4 using Keck interferometry
- In our Toy model, a 2 day extinction event at this orbital radius corresponds to a "clump" diameter of ~0.1 AU
- For a 0.6 magnitude extinction event and assuming ISM grains, we calculate a column density of ~1.1 x10^{21} [H/cm^2]
- This corresponds to a mass of ~3.3x10^{21}, which is roughly the mass of an asteroid

References

Alonso-Albi, T., Fuente, A., Bachiller, R., Neri, R., Planesas, P., Testi, L., Berne, O., Joblin, C. 2009, A&A, 497, 117

Artemenko, S. A., Grankin, K. N., & Petrov, P. P. 2010, Astronomy Reports, 54, 163

Baisch, S., Götz, H. R., Bokelmann 1999, Computers & Geosciences, 739, 750

Bertout, C. 2000, A&A, 363, 984

Chavarria-K., C., de Lara, E., Finkenzeller, U., Mendoza, E. E., and Ocegueda, J. 1988, A&A, 197, 151

Eisner, J. A. & Kulkarni, S. R. 2001, ApJ, 550, 871

Eisner 2004, J. A., Lane, B. F., Hillenbrand, L. A., Akeson, R. L. & Sargent, A. I. 2004, ApJ, 613, 1049

Grady, C. A., Sitko, M. L., Bjorkman, K. S., Perez, M. R., Lynch, D. K., Russell, R. W., & Hanner, M. S. 1997, ApJ, 483, 449

Grankin, K. N., Yu, S., Melnikov, J., Bouvier, et al. 2007, A&A, 461, 827

Grinin, V. P., Rostopchina, A. N., & Shakhovkoi, D. N. 1998, Astronomy Letters, 24, 802

Herbst, W., Herbst, D. K., Grossman, E. J., & Weinstein, D. 1994, AJ, 108, 1906

Isella, A., Testi, L., Natta, A. 2008, A&A, 451, 951

Natta, A., Prusti, T., Neri, R., Wooden, D., Grinin, V. P., & Mannings, V. 2001, A&A, 371, 186

Herbst, W. & Shevchenko, V. S. 1999, AJ, 118, 1043

Press, W. H., Flannery, B. P., Teukolsky, S. A., Vetterling, W. T. 1992, Numerical Recipes in C

Pontoppidan, K. M., Dullemond, C. P., Blake, G. A., Boogert, A. C. A., van Dishoeck, E. F., Evans, N. J., II, Kessler-Silacci, J., & Lahuis, F. 2007, ApJ, 656, 980

Rostopchina, A. N., Grinin, V. P., & Shakhovskoi, D. N. 2001, Astronomy Reports, 45, 51