# Mini Solar Systems in Formation: Modeling of Circumsecondary Disk Eclipses


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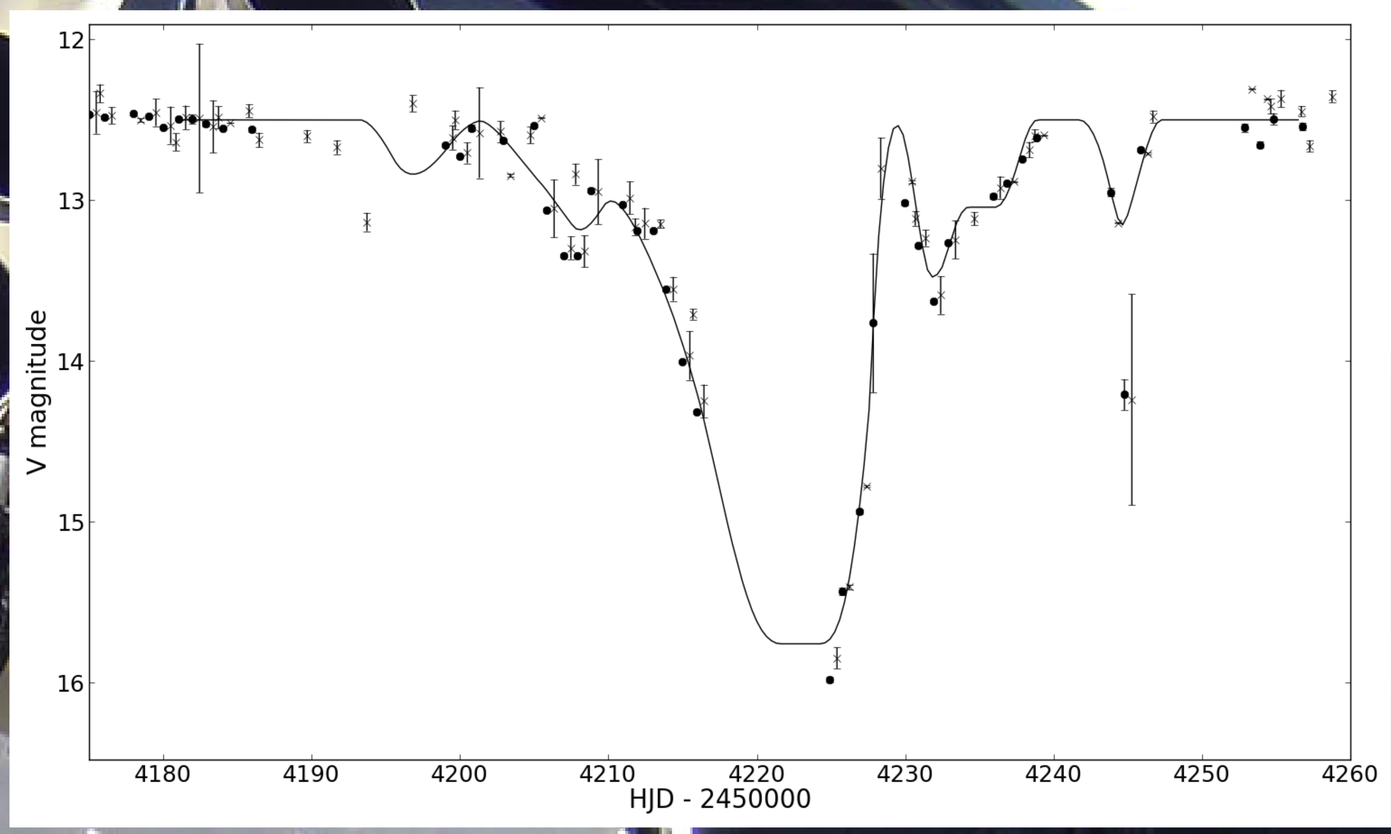
1 SWASP J140747.93-394542.6 (hereafter referred to as J1407), a ~0.9 solar mass pre-main sequence K5 star and a member of Sco Cen, exhibited a long (~54 day), deep (>3.3 mag), and complex eclipse centered on 29 April 2007 (Mamajek et al. 2012). We present here a model of the event as a circumsecondary disk eclipsing the star.

## Significance

An eclipse by a secondary companion alone cannot cause a drop in brightness of this length, depth, or complexity. Systematically eliminating other plausible causes, the group came to the conclusion that the dimming of the star was due to an eclipse by a secondary companion with an extended ring system that had significant substructure due to the possible formation of satellites (Mamajek et al. 2012). Kenworthy et al. (in prep) have found an upper limit of 14 Jupiter masses for a secondary in an orbit of 5.2-25.2 AU, indicating that the companion is likely of planetary mass. J1407 is one of a very small number of known eclipsing circumsecondary disks, and so far the only one that has exhibited any hint for the presence of exosatellites. Thus far, the properties of the debris ring system and constraints on the mass of the companion are consistent with the eclipsing body being the first candidate "protoexosatellite disk system." We are working to further characterize this system and test this idea.

Model light curve fitted to observed data

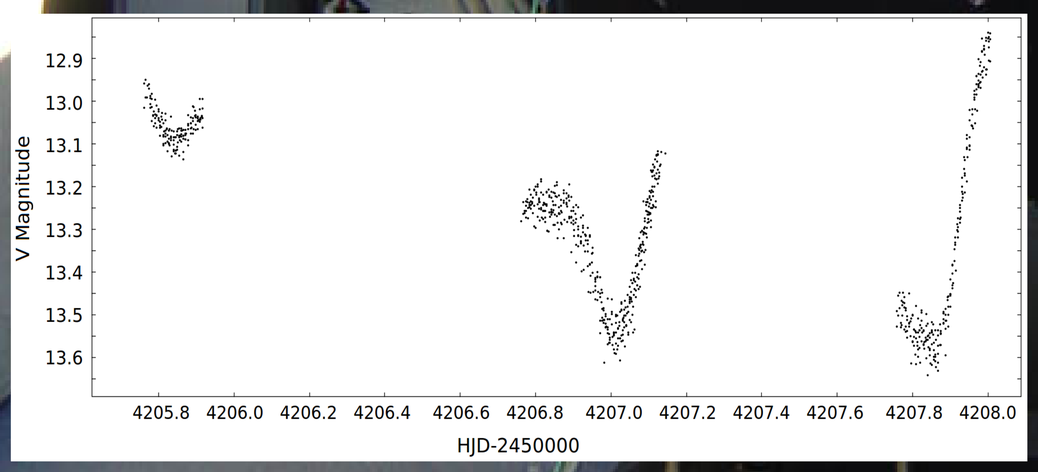



## J1407 Best Fit Model

The model that best fit the observed light curve was a flat debris disk with four rings, inclined at an angle of 5° to the orbital plane and 10° to the observer's line of sight. The orbital plane was inclined by an angle of 0.036° to the observer's line of sight. All of these values are for an orbital period of 9862 days, and will change if the period is found to be different.

## Eclipse Substructure

At both the beginning and the end of the eclipse, the light curve of J1407 exhibited a great deal of substructure that was not seen elsewhere. It is possible that this substructure is indicative of substructure in the disk rings, which may be determined by further refinement of the model.




Graphic model of disk and rings

### Disk and Ring Properties

- Main Disk: $R_{in}$=0.2 $R_{sun}$, $R_{out}$=15.8 $R_{sun}$, $\tau_{vert}$=0.52
- 1st ring: $R_{in}$=18.2 $R_{sun}$, $R_{out}$=19.4 $R_{sun}$, $\tau_{vert}$=0.02
- 2nd ring: $R_{in}$=19.4 $R_{sun}$, $R_{out}$=23.4 $R_{sun}$, $\tau_{vert}$=0.16
- 3rd ring: $R_{in}$=23.4 $R_{sun}$, $R_{out}$=31.0 $R_{sun}$, $\tau_{vert}$=0.09
- 4th ring: $R_{in}$=41.0 $R_{sun}$, $R_{out}$=45.0 $R_{sun}$, $\tau_{vert}$=0.12

## Discussion

Canup & Ward 2002 have examined the formation conditions of the Galilean satellites, and J1407 is the closest analogue we have found to a young moon-forming Jupiter. Further study can provide valuable insight into the formation of the ring and moon systems of giant planets. Observing such eclipses is the only method currently available to directly study extrasolar planet and satellite systems, and is invaluable to understanding the history of our own Solar System.

## Future Work

- Improve model to account for disk substructure and different disk materials
- Monitor J1407 for future eclipses
- Search for and model other disk eclipses similar to J1407
- Incorporate flared accretion disk back into the model


### References

- Canup, R. M. & Ward, W. R. 2002, AJ, 124, 3404
- Kenworthy, M. A., Lacour, S., Mamajek, E. E., Kraus, A., & Ireland, M., in prep.
- Mamajek, E. E., Quillen, A. C., Pecaut, M., Moolekamp, F., Scott, E. L., Kenworthy, M. A., Collier Cameron, A. C., & Parley, N. 2012, AJ 143, 72



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