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# A Transiting Extrasolar Ring System: Indirect Evidence for Exosatellite Formation?

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## Abstract

In May 2007, the young (16 million year) star 1SWASP J140747.93-394542.6 ("J1407") underwent a complex series of eclipses that lasted 56 days, during which time it showed rapid variations of up to 50% in times of less than four hours. After ruling out other plausible alternatives, we conclude that there is an unseen secondary companion, J1407b, which hosts a giant ring system that fills a significant fraction of the Hill sphere. We present our exoring model, our search for J1407b, and discuss the future prospects for finding more of these systems in archival data.

## 1 The light curve

The young star 1SWASP J140747.93-394542.6 ("J1407") is a 16-million-year-old pre-main sequence star in Scorpius-Cantaurus OB Assocation ("Sco-Cen"), the nearest OB association. The SuperWASP and ASAS programs show that the star J1407 had a series of extremely complex eclipses over a two-month span in early 2007 (Mamajek et al. 2012), with $\sim$ 95% of the star's light blocked out near the minimum (see Figure 1). The star J1407 shows no evidence for accretion nor any circumstellar disk blueward of the WISE4 IR band, ruling out several simple hypotheses for these light curve fluctuations. Variability due to the presence of star spots and the star's rapid rotation is seen at a level of 5% with a derived rotational period of 3.2 days (van Werkhoven et al. 2014).

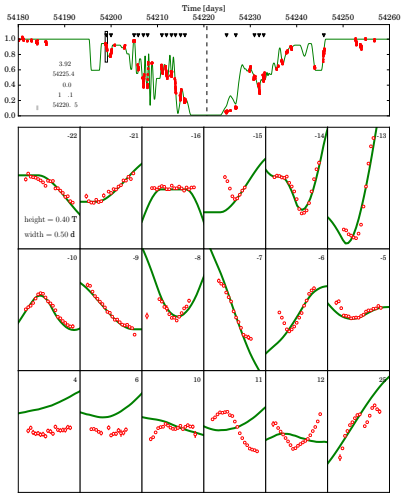


Figure 1: The lightcurve towards J1407.

## 2 Giant Exoring Model

We hypothesise that there is an unseen substellar companion J1407b (Kenworthy et al. 2015) in a near edge-on orbit to our line of sight. The eclipses have been modeled as due to a set of (at least 30) concentric dust rings with total mass of approximately 1 Earth mass, with radii ranging from approximately 30-90 million km (see Figure 2) that are in orbit around J1407b. Our non-detection of J1407b places strong upper limits on its mass with $20-40 M_{Jup}$ being the most likely range and with an orbital period of $10-30$ years (Kenworthy et al. 2015). There is at least one very clean gap in the ring system at radius $\sim 0.4 AU$ which may be cleared by a sub-Earth-size exosatellite (see Figure 3; Mamajek et al. 2012; Kenworthy and Mamajek 2015). While popularly described as a "super-Saturn" with "rings", given the age of the system, and the size and inferred mass of the rings, it seems plausible that we are detecting a circumplanetary (or protoexosatellite) disk. The disk would appear to fill a non-negligible fraction of its

Hill radius, and the appearance of gaps would suggest that system is in the process of spawning exosatellites.

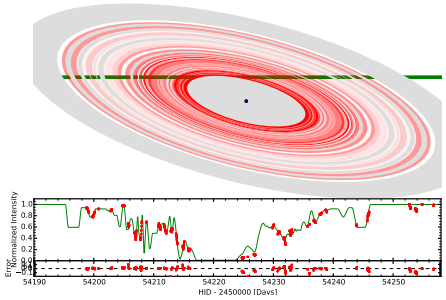


Figure 2: Ring model for J1407 lightcurve. The diameter of the rings is 1.6 AU. The green line shows the path of J1407 behind the ring system. Optical depth is represented by different shades of red. Grey areas indicate regions with no photometric coverage.

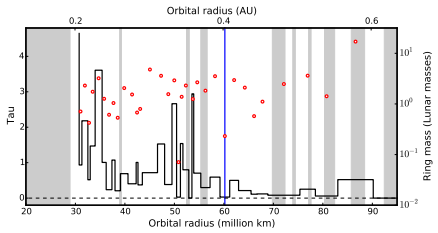


Figure 3: Optical depth versus radial distance from J1407b. The blue line indicates a ring cap clearing which we attribute to a Mars-mass exosatellite in orbit around J1407b. Grey areas indicate regions with no photometric coverage.

I will summarize the current knowledge about the J1407 system including archival and on-going photometric searches for additional eclipses, imaging and Doppler constraints on the companion of the ringed companion, and future prospects for discovering eclipsing disks girding young exoplanets and substellar objects.

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