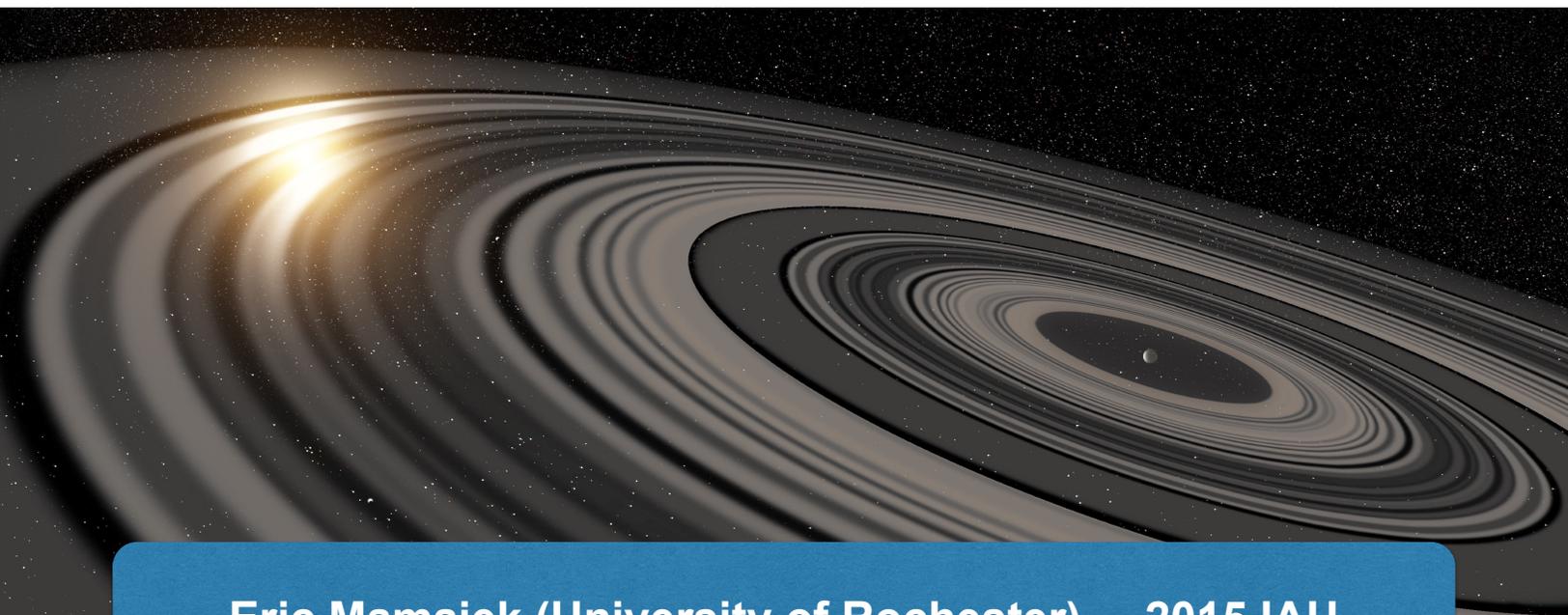


A Transiting Extrasolar Ring System: Indirect Evidence for Exosatellite Formation?

Credit: Ron Miller



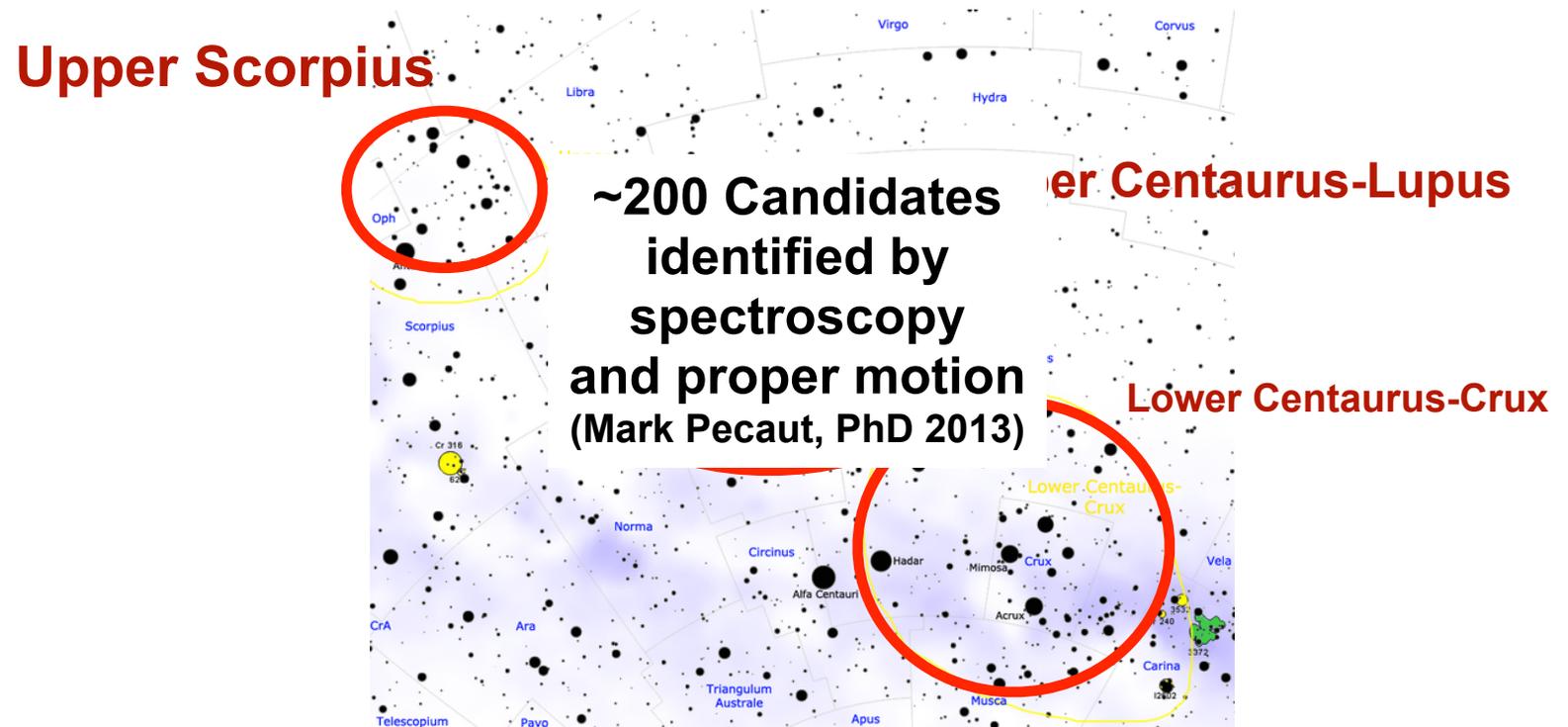
Eric Mamajek (University of Rochester) 2015 IAU

Collaborators: ***Matt Kenworthy*** // E. Scott // S. Lacour // M. Ireland // A. Kraus // A. Triaud // F.J. Hamsch // D. Reichart // T. van Werkhoven // J. Birkby // D. Cameron // M. Pecaut

papers on J1407 eclipses

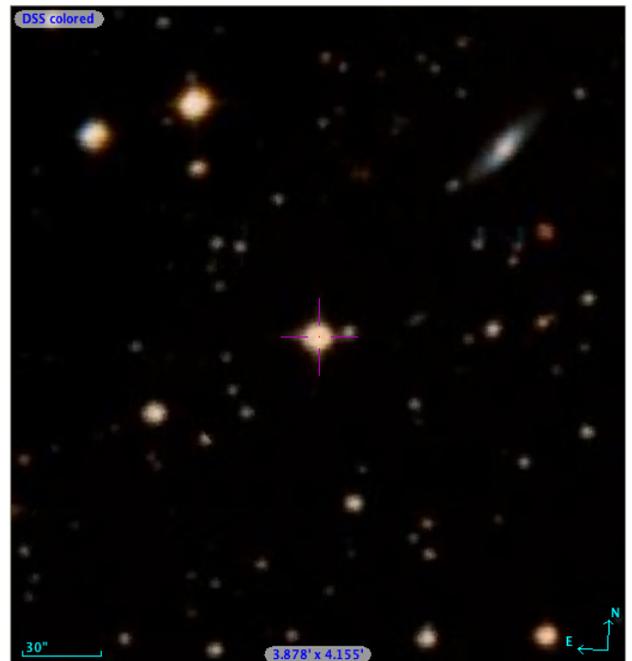
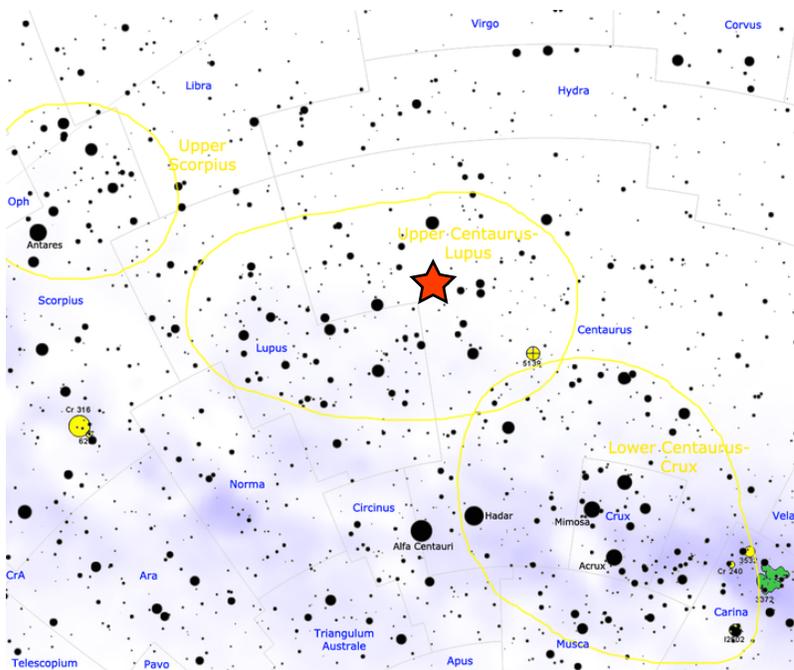
- Mamajek et al. (2012, AJ, 143, 72)
- van Werkhoven, Kenworthy, Mamajek (2014, MNRAS, 441, 2845)
- Kenworthy et al. (2015, MNRAS, 446, 411)
- Kenworthy & Mamajek (2015, ApJ, 800, 126)

Young pre-MS stars in an OB Association



Pre-MS Candidate J1407

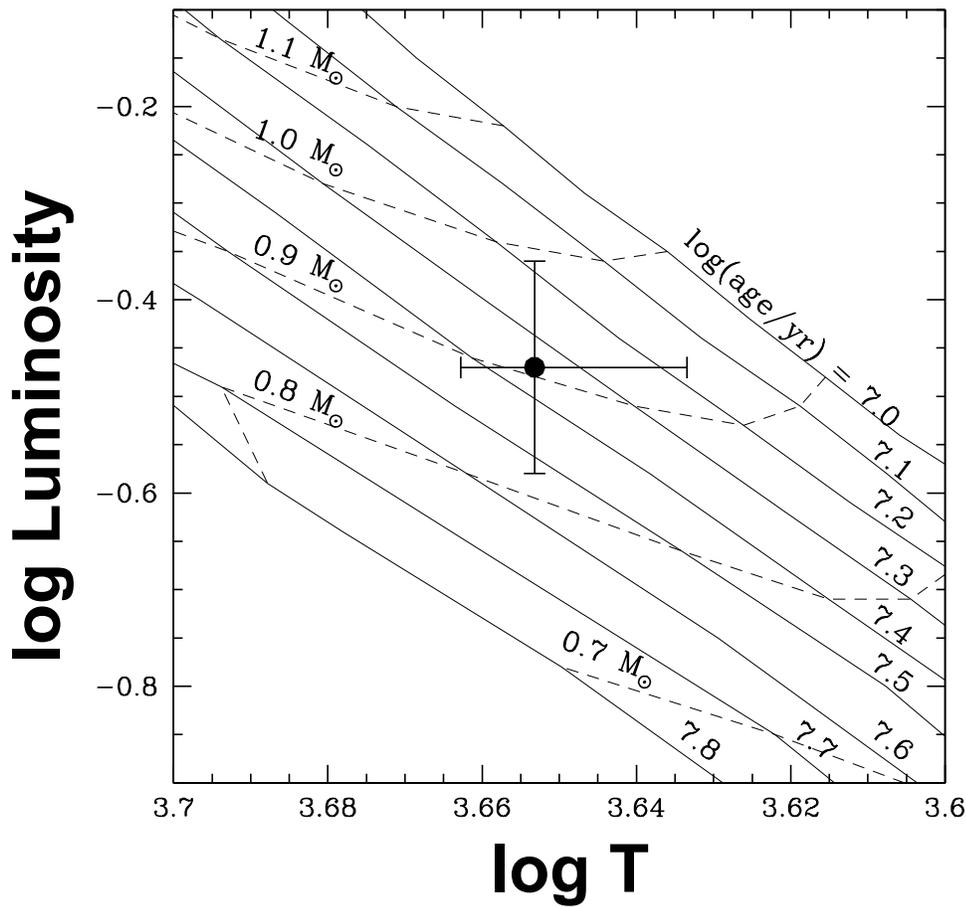
(1SWASP J140747.93-394542.6)



$d = 133 \pm 12$ pc (kinematic distance)

Mamajek et al. (2012)

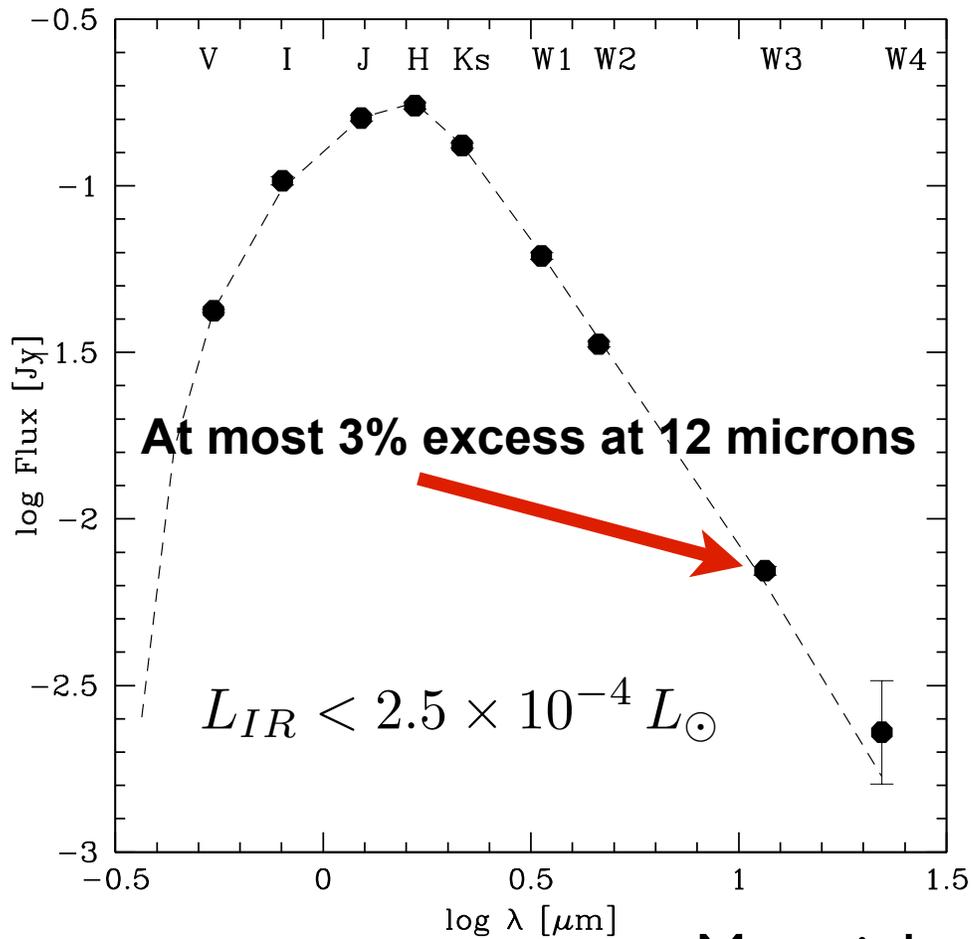
Photometry consistent with UCL subgroup age (~16 Myr)



Baraffe et al. (1998)
isochrones

Mamajek et al. (2012)

The star J1407: lightly reddened “naked” pre-MS K5



Mamajek et al. (2012)

Planet dims star by a few percent for a few hours



Star Brightness

100%
99%
98%



Time (hours)

HD 209458 b transit
by H. Deeg

Super Wide Angle Survey for Planets **(SWASP)**



**SuperWASP South
(@SAAO,
Sutherland, S Africa)**

**Rapid photometry (30 sec) using
several wide angle cameras**

Searching for hot Jupiter transits

Pollacco et al. 2006, Butters et al. 2010

All Sky Automated Survey (ASAS)



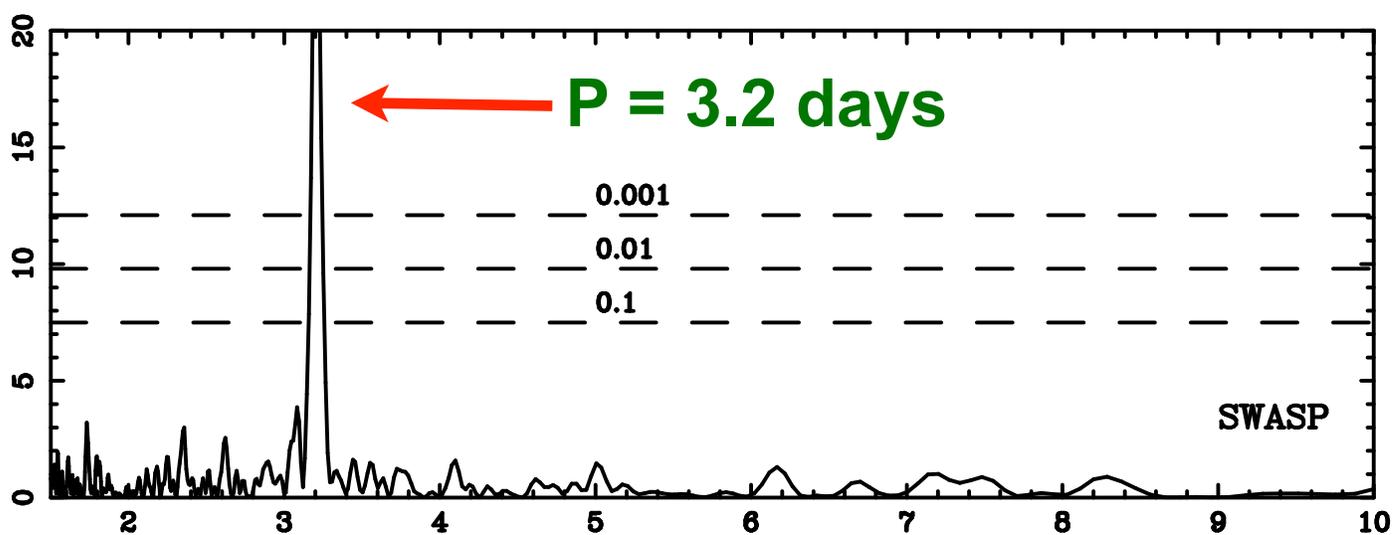
**Maps whole sky about
once every three days**

**Long term photometric monitoring
for variables**

**SuperWASP South
(LCO, Chile)**

Pojmanski 2002, Pojmanski et al. 2005

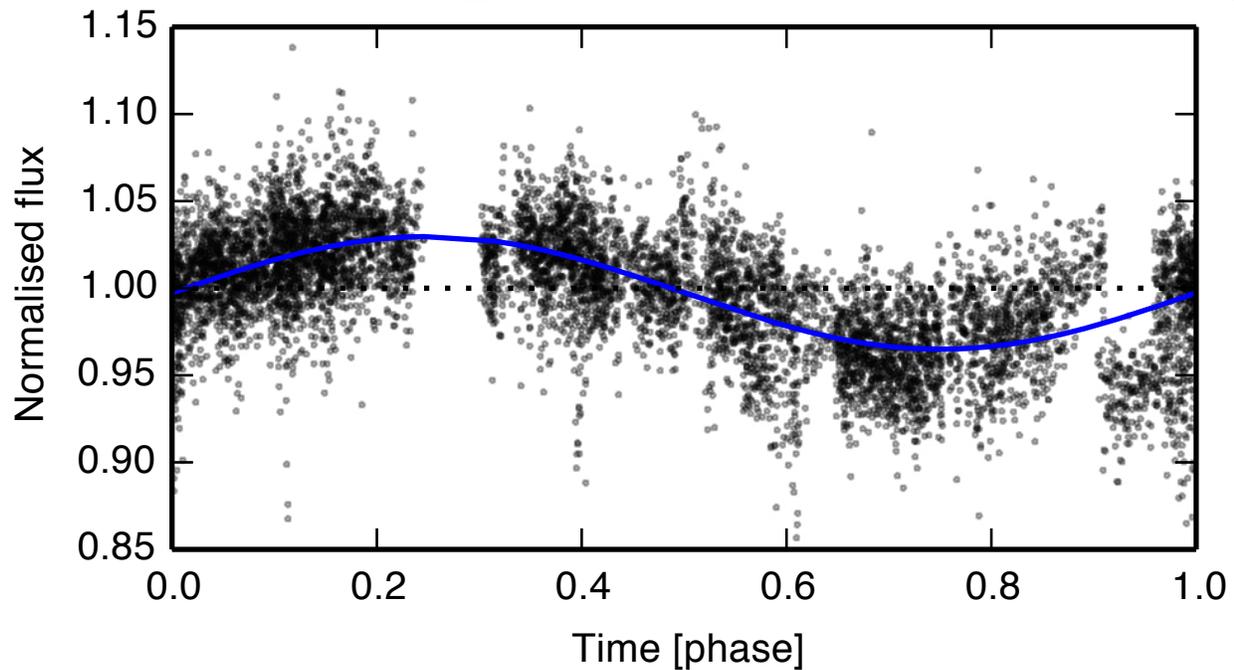
Pre-MS Candidate J1407



12.7 mag, K5 pre-MS star

Mamajek et al. (2012)

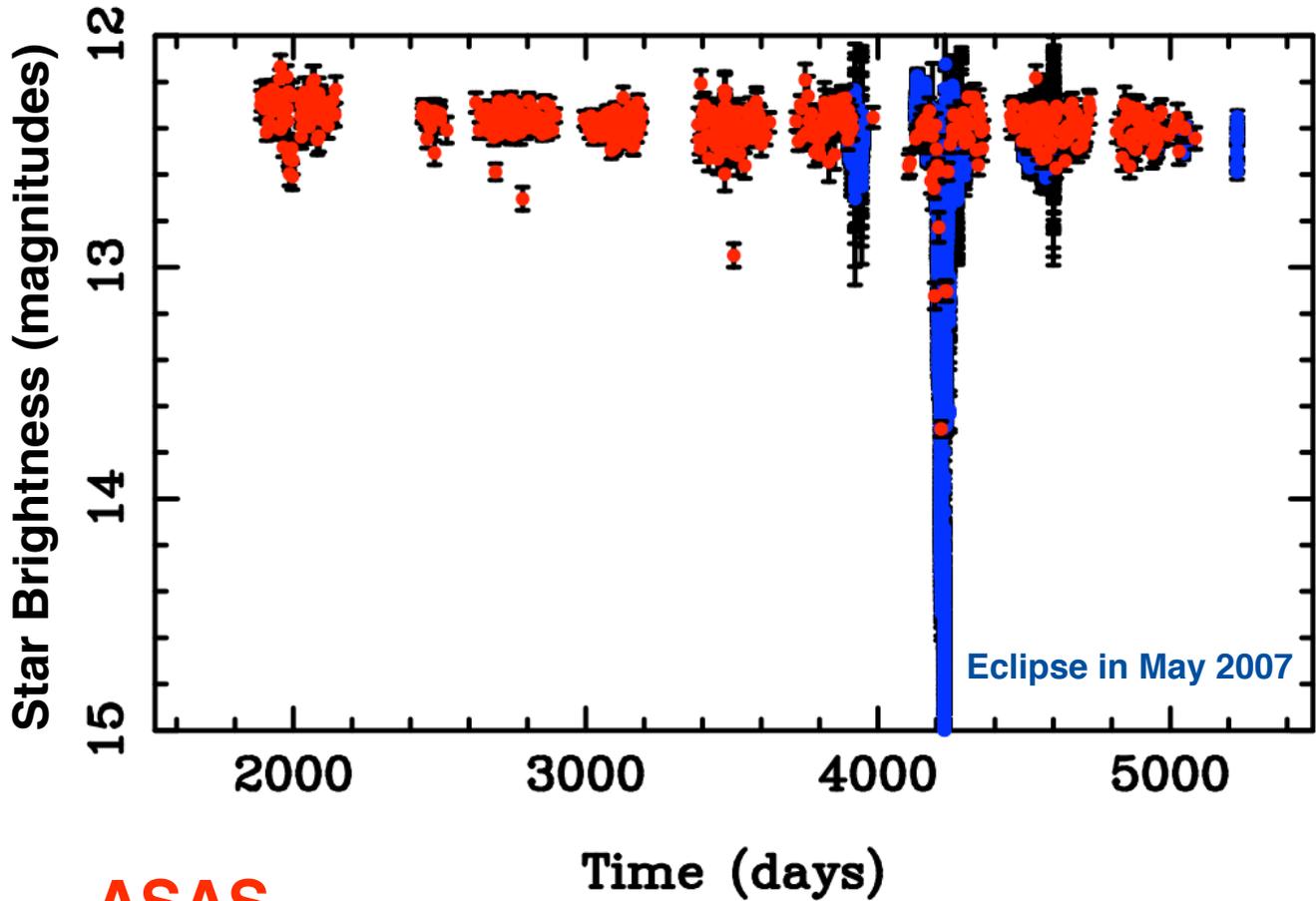
Removing stellar variability



period $P = 3.2011(2)$ d

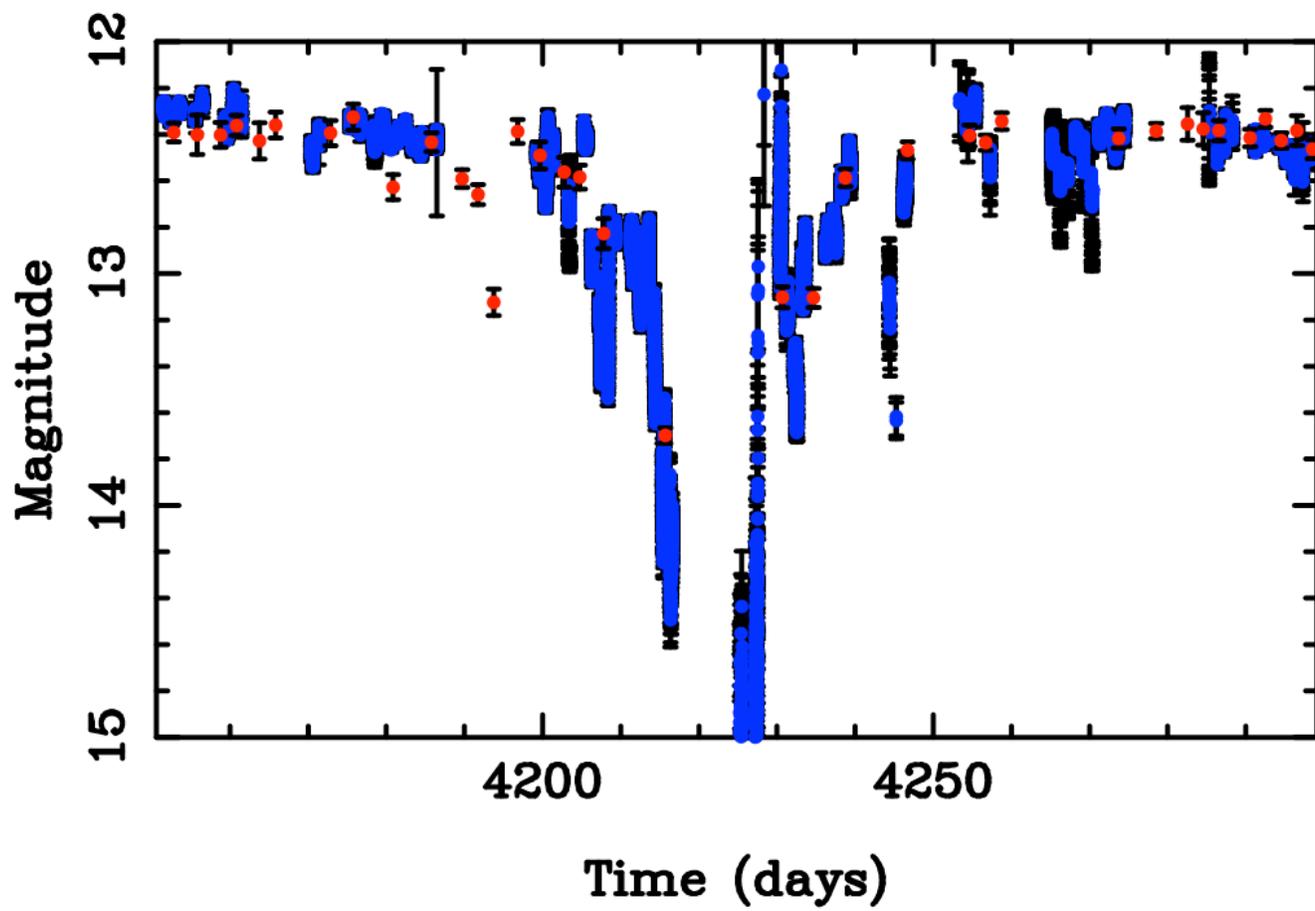
van Werkhoven et al. (2014)

J1407 Lightcurve

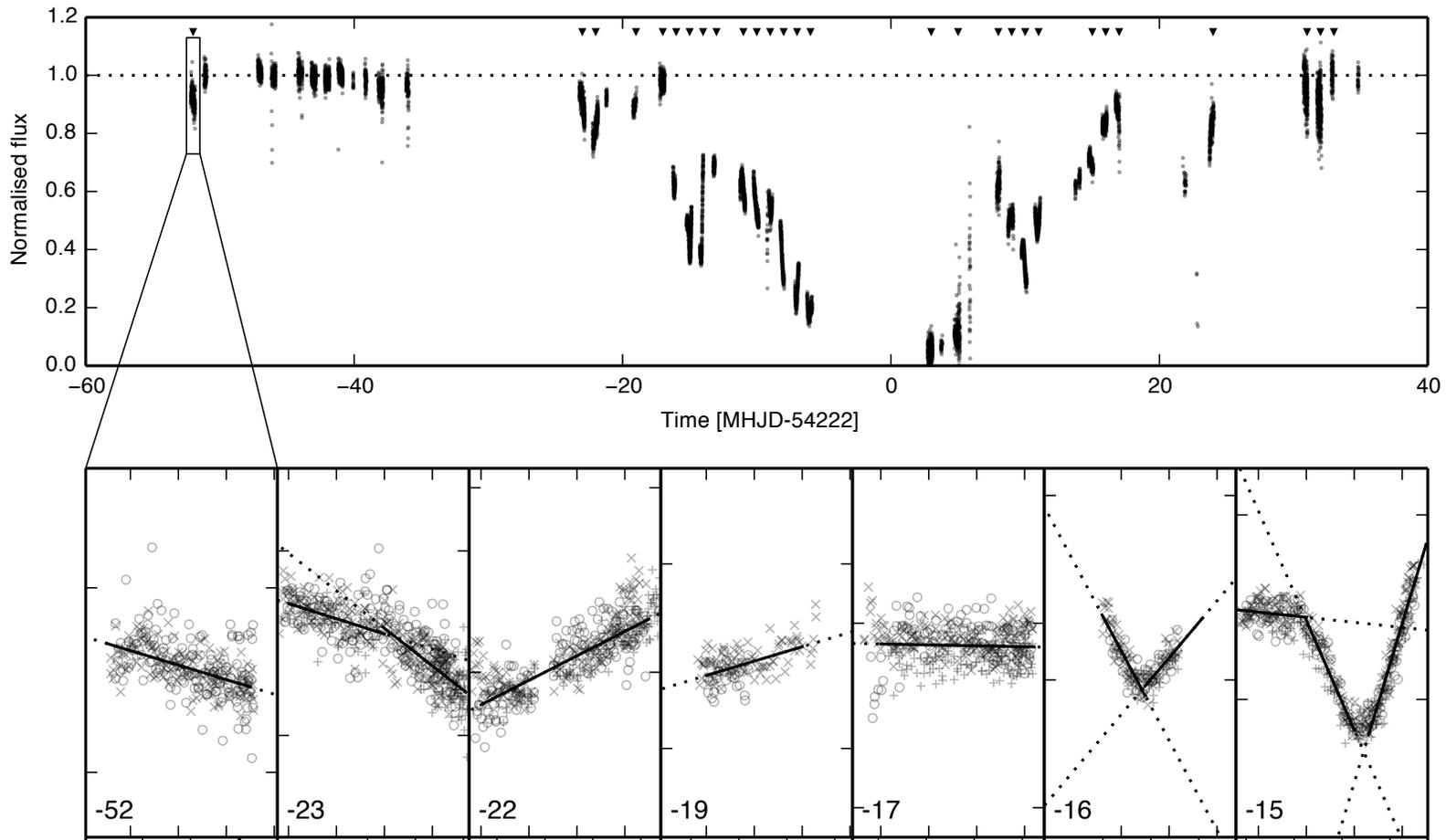


ASAS

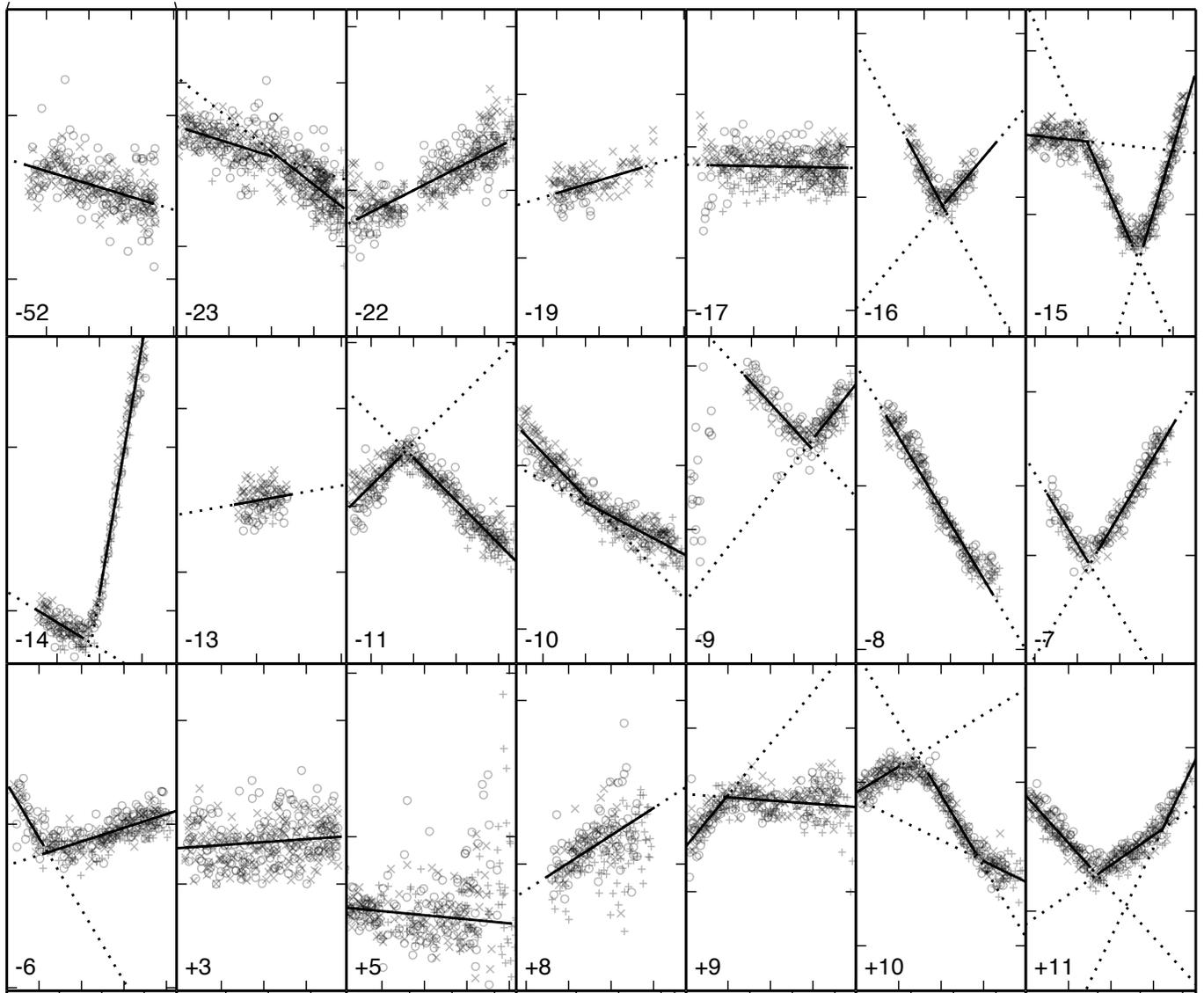
SuperWASP



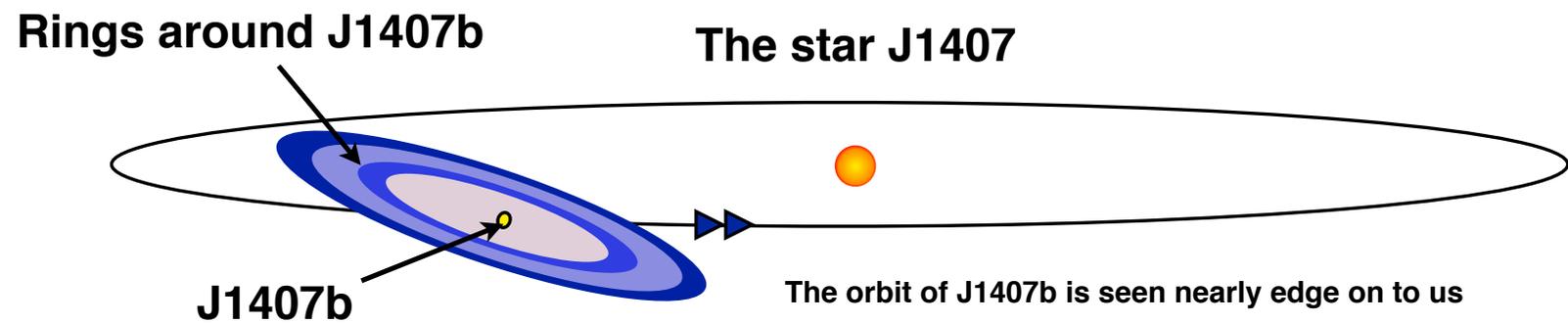
Eclipse duration of 56 days



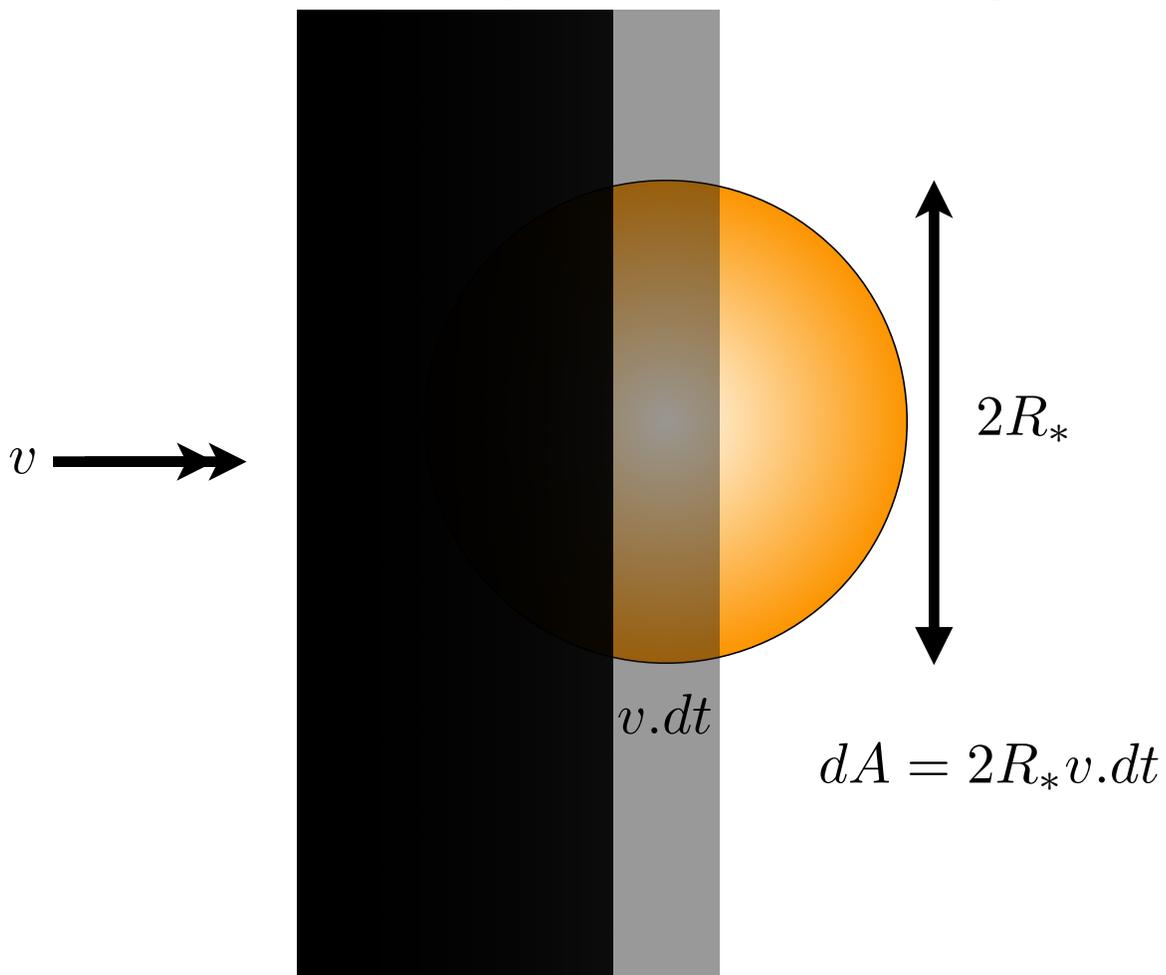
van Werkhoven et al. (2014)



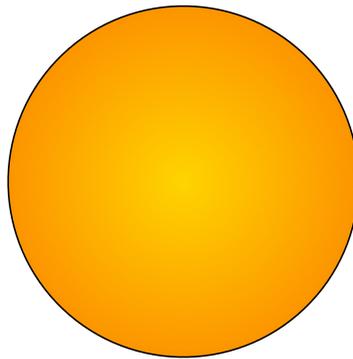
Eclipse by a large ring system



Geometry of Eclipsing ring

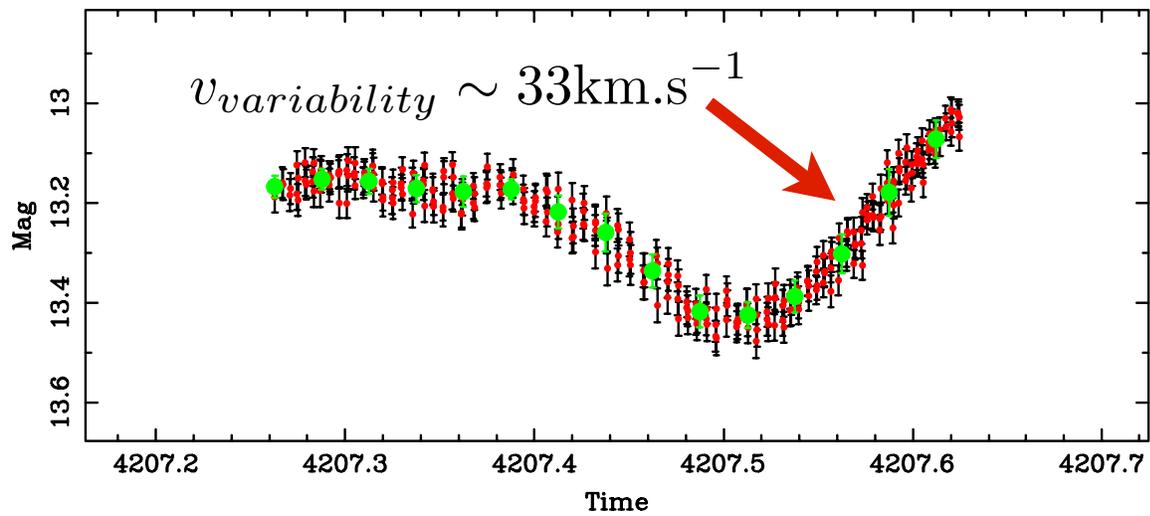


Eclipsing by a ring system



$$R_* = 0.9R_{\odot}$$

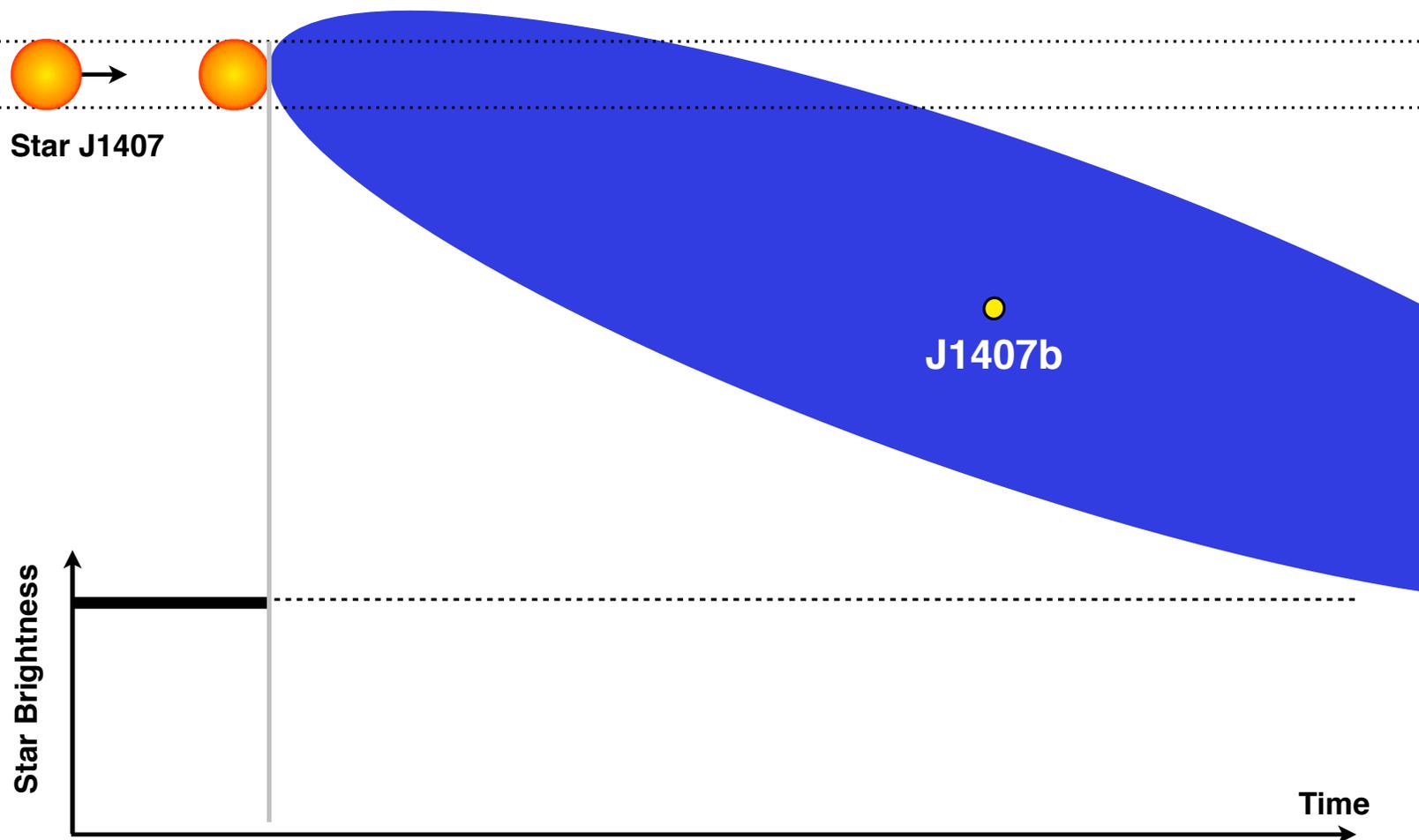
Day 4207



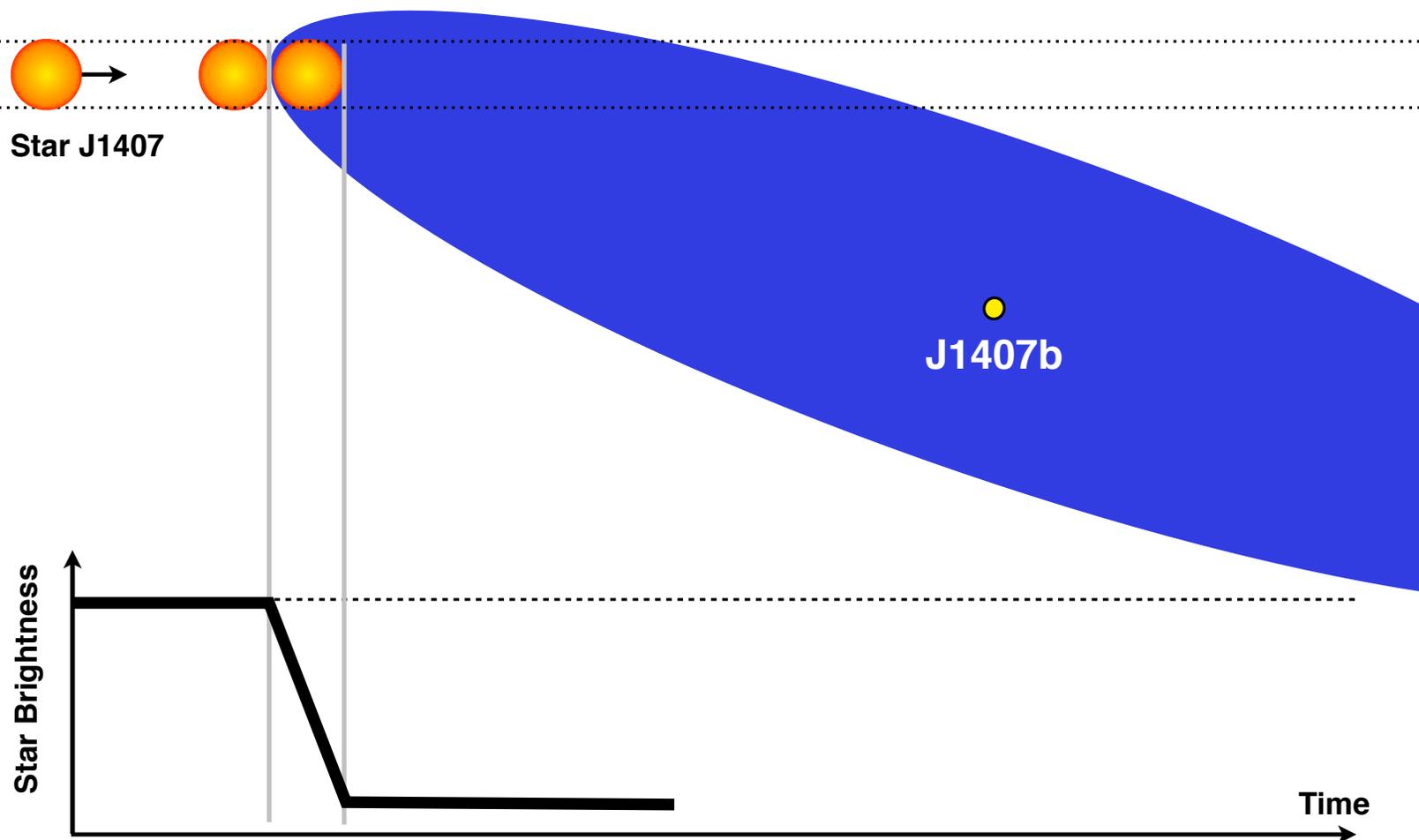
Estimating the size of the object

$$33 \text{ km}\cdot\text{s}^{-1} \times 56 \text{ days} \sim 0.8\text{AU}$$

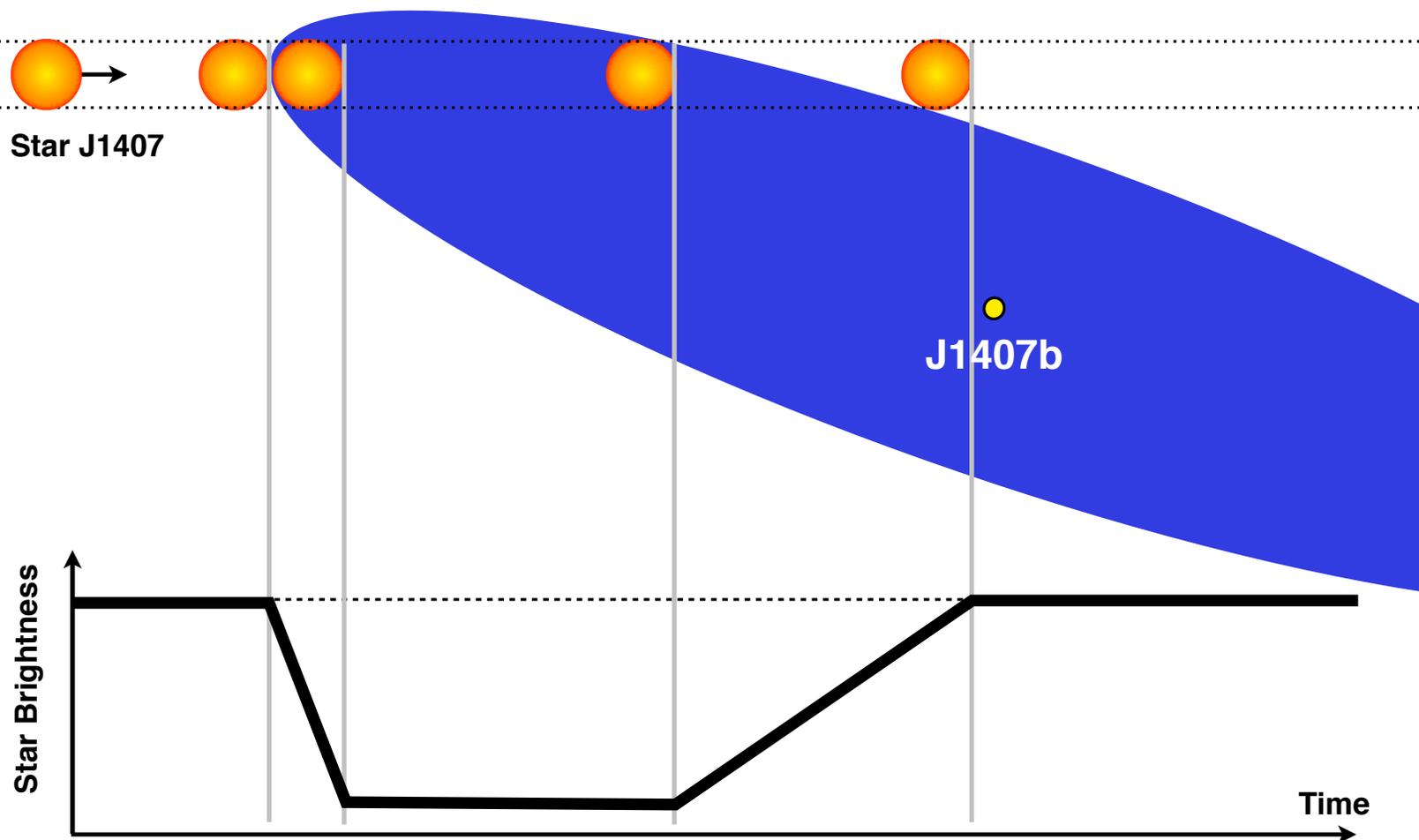
How the rings change the light curve of J1407



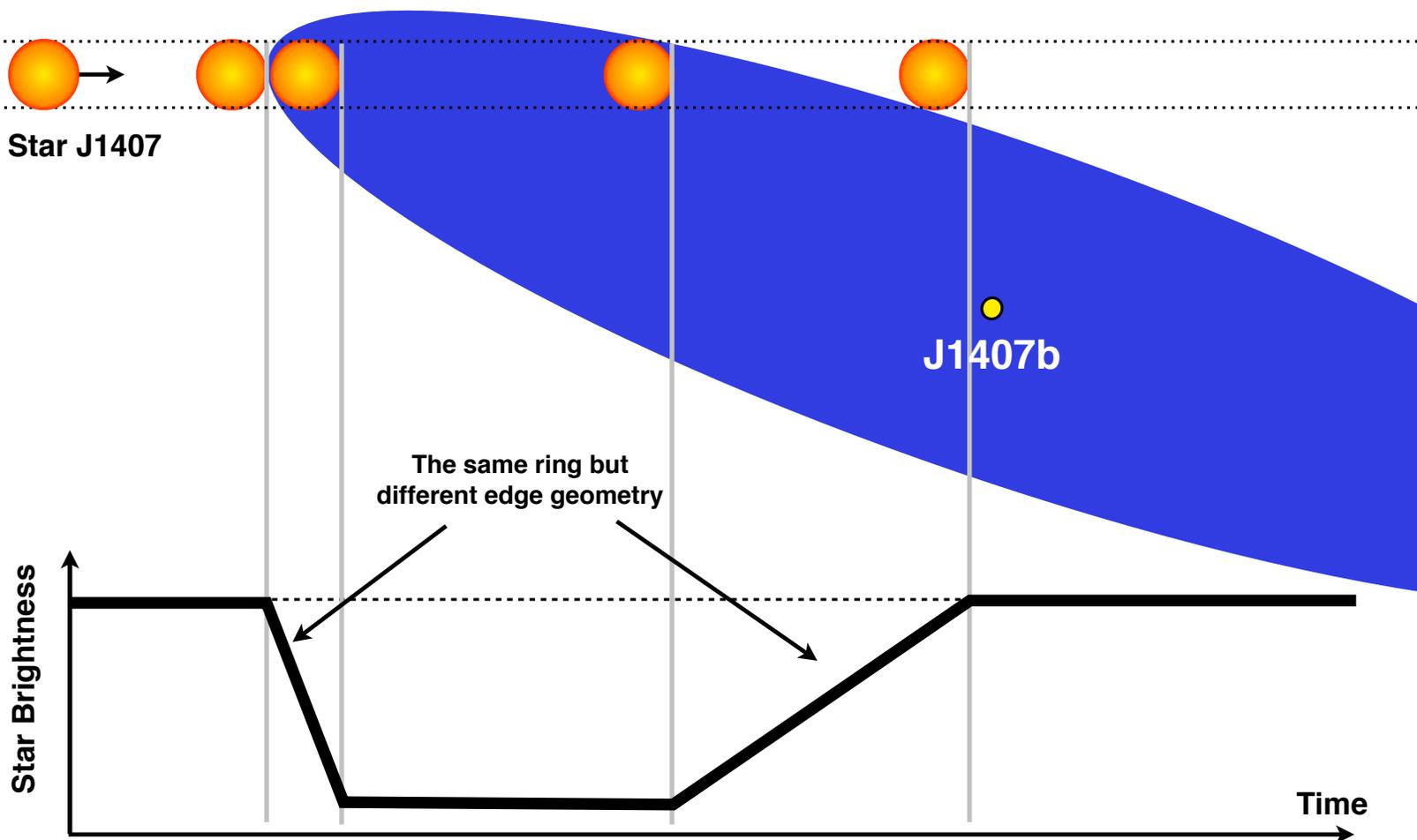
How the rings change the light curve of J1407



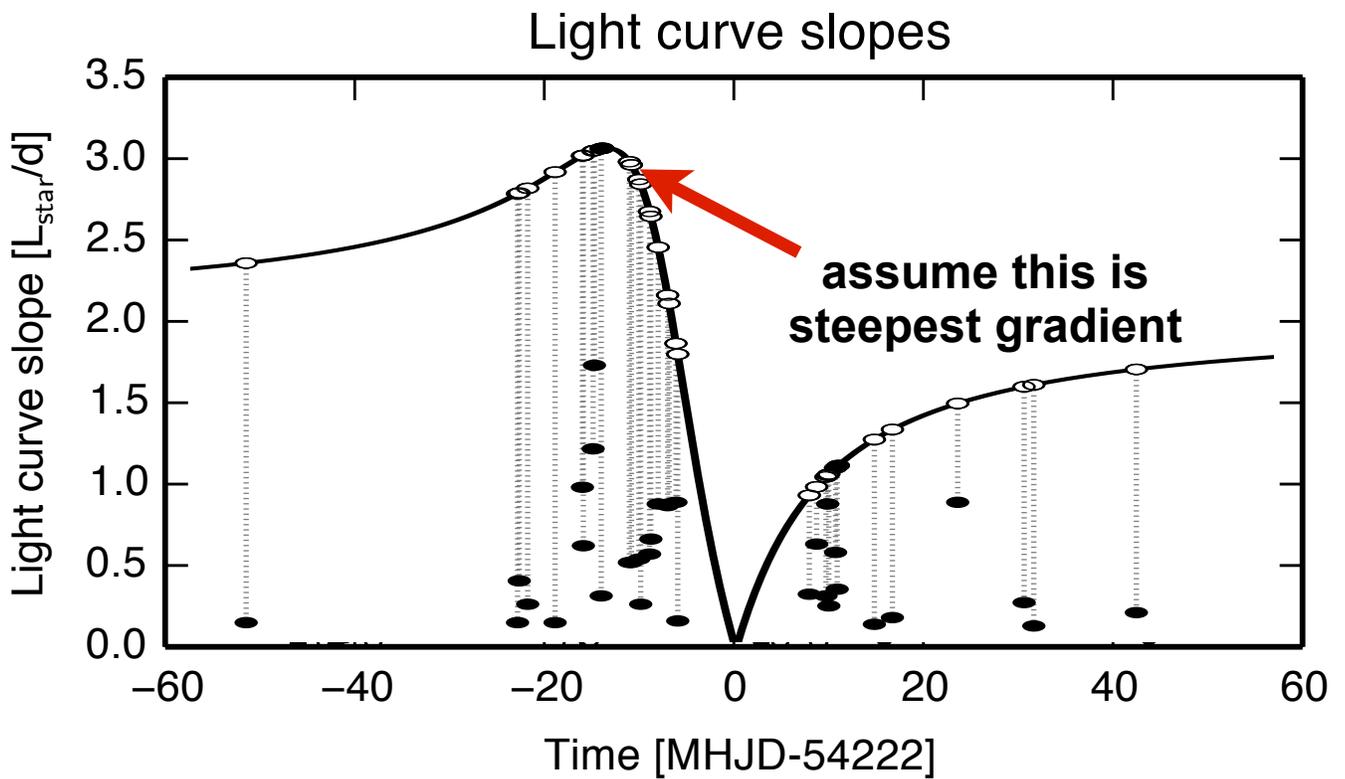
How the rings change the light curve of J1407



How the rings change the light curve of J1407



Rings smoothed by star's disk gives the ring plane geometry

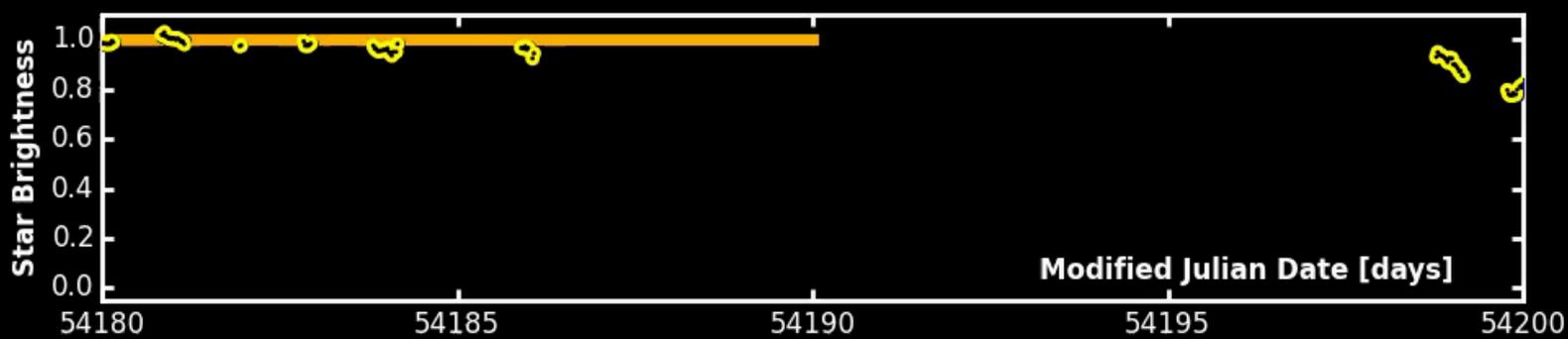


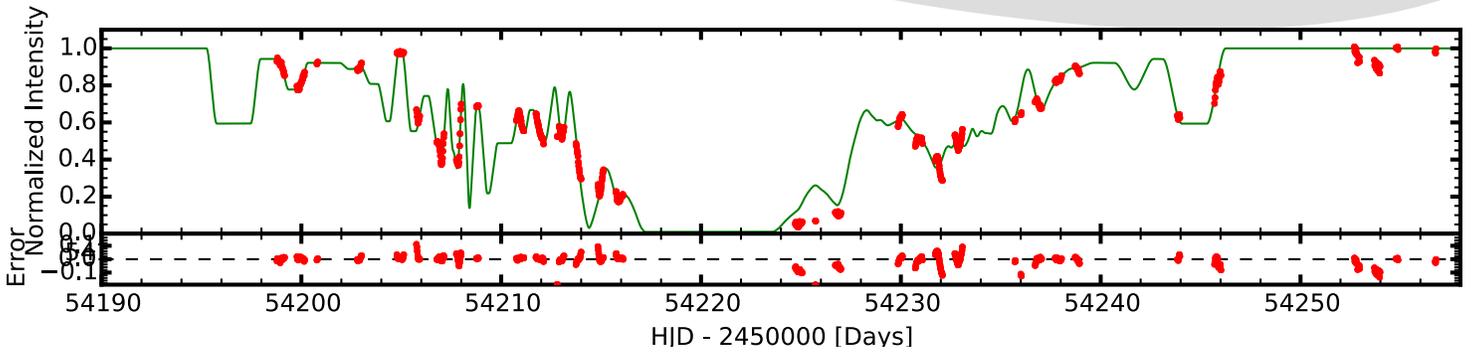
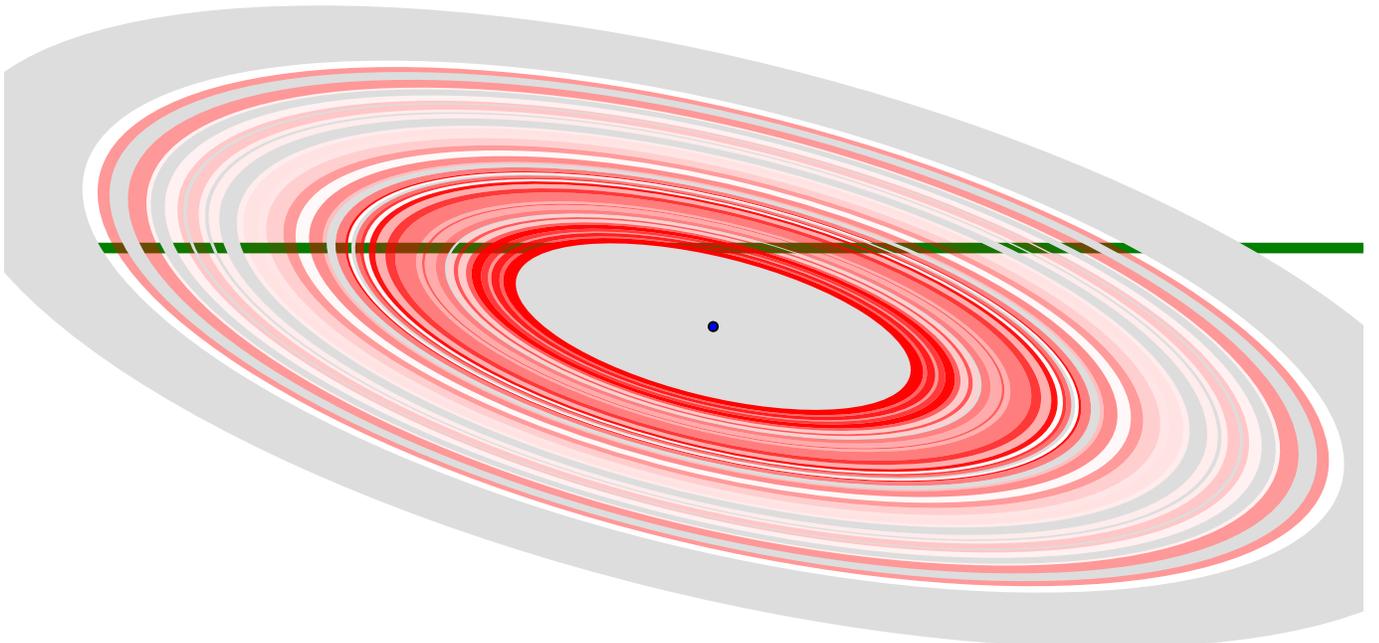
van Werkhoven et al. (2014)

2007-03-31

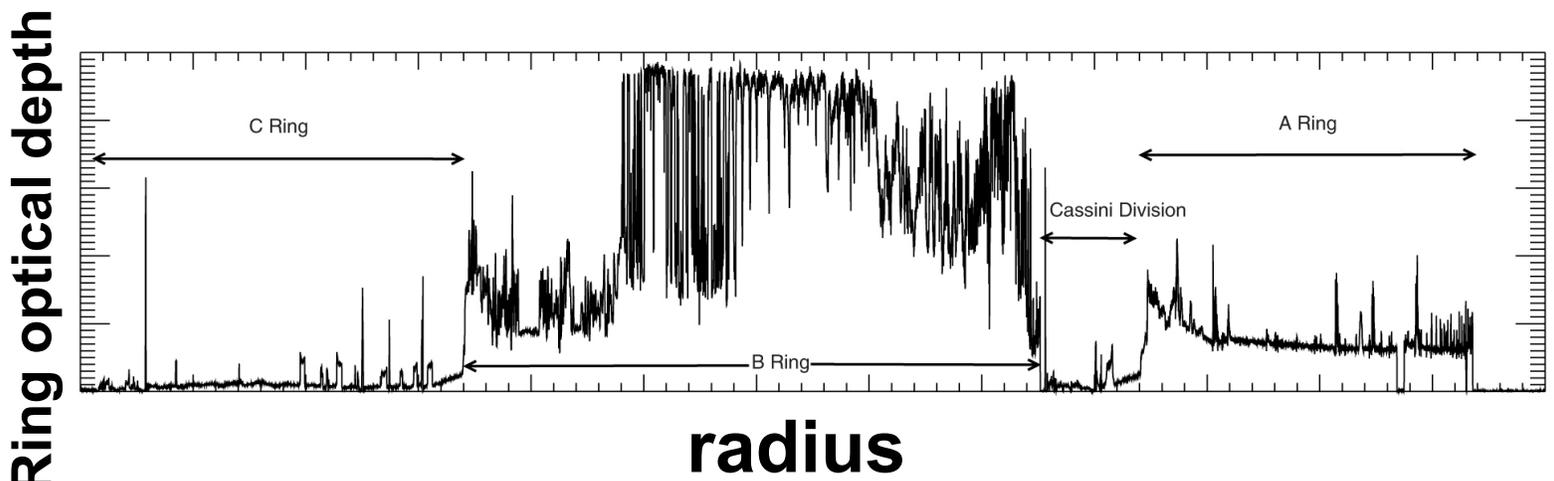


The star J1407



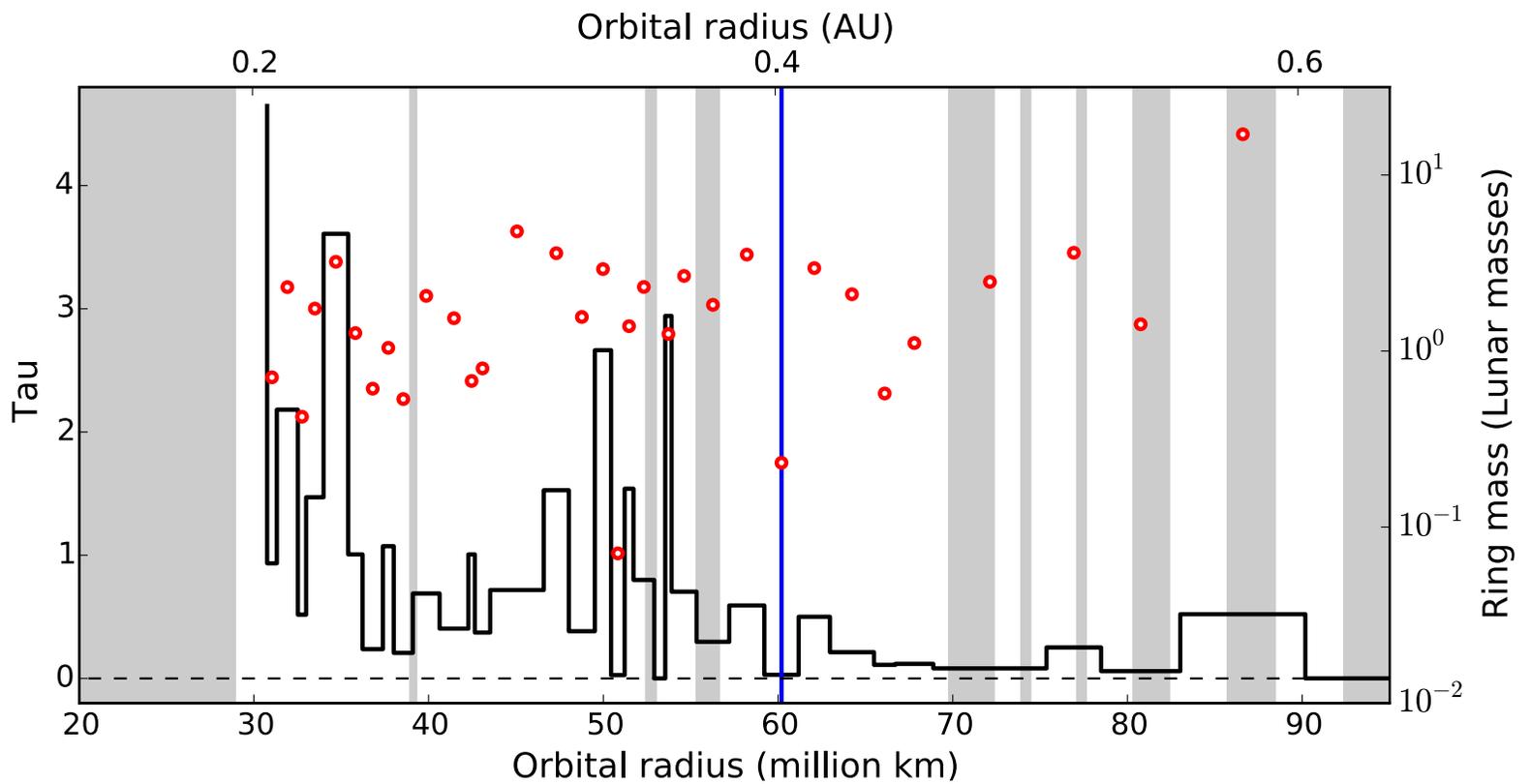


Saturn's rings

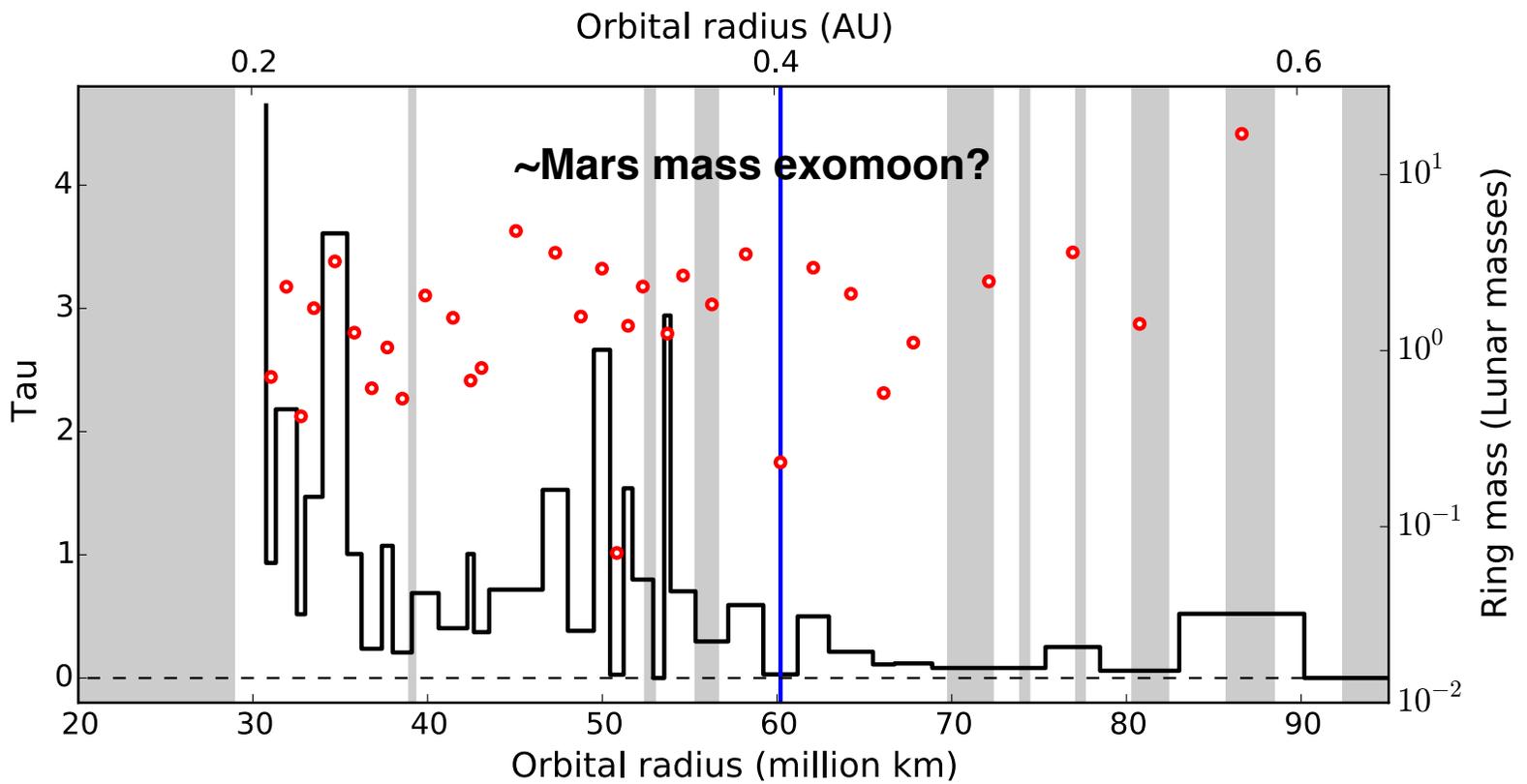


Tiscareno review 2013
and Colwell 2009

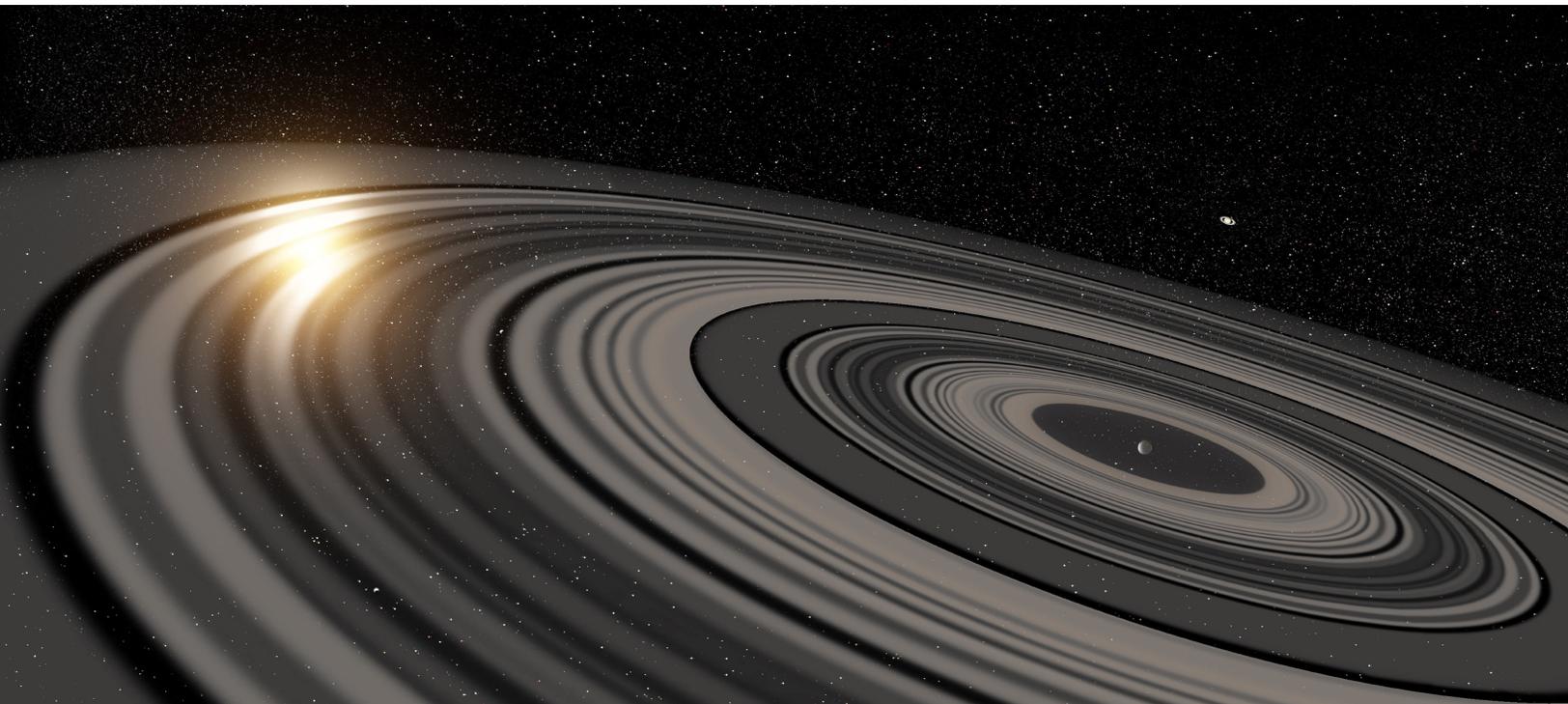
Mass of J1407b's rings: $\sim 0.6 M_{\text{Earth}}$



...and are we seeing clearing out with an exomoon?

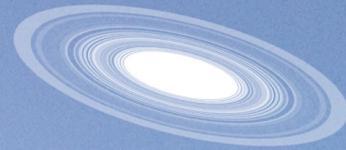


“Ring system” 200 times bigger than Saturn’s rings



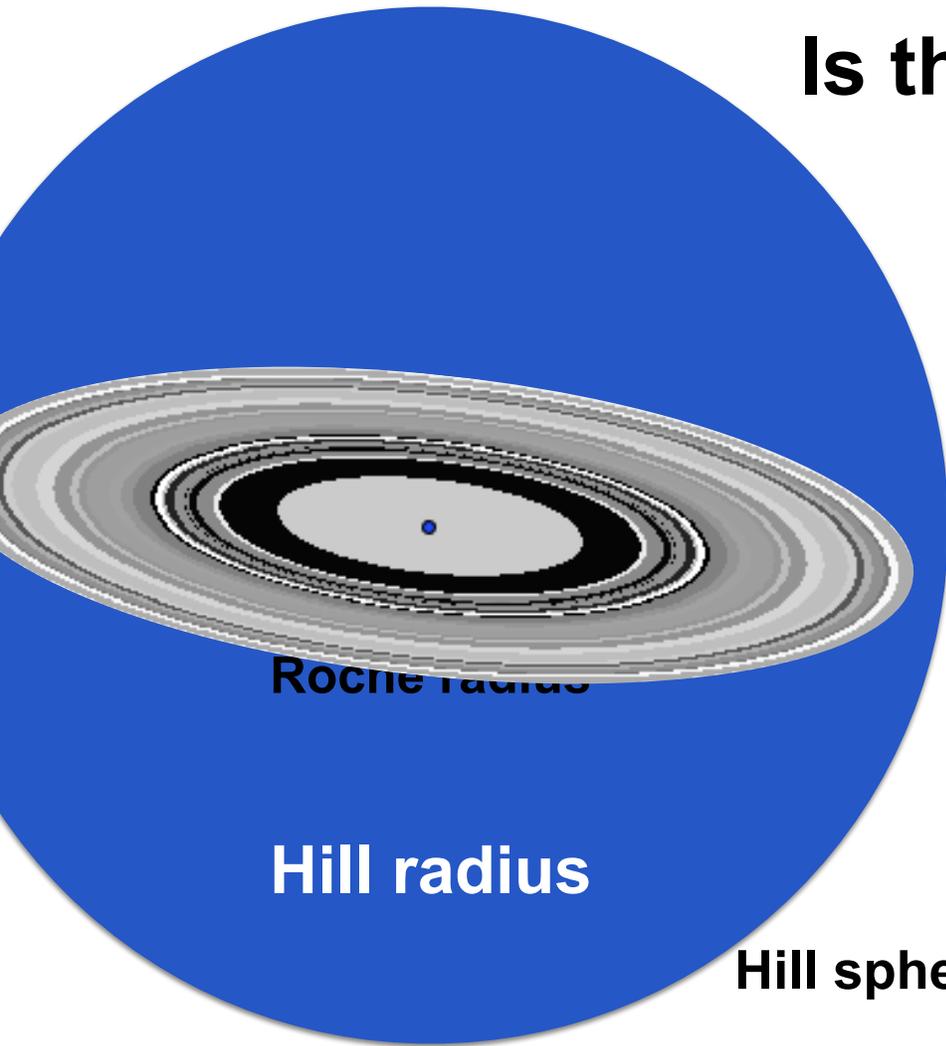
**...but clearly a different beastie given size and mass:
Protoexosatellite disk?**

If you put the rings around Saturn....



...we'd be able to see it at twilight from Earth!

Is this possible?



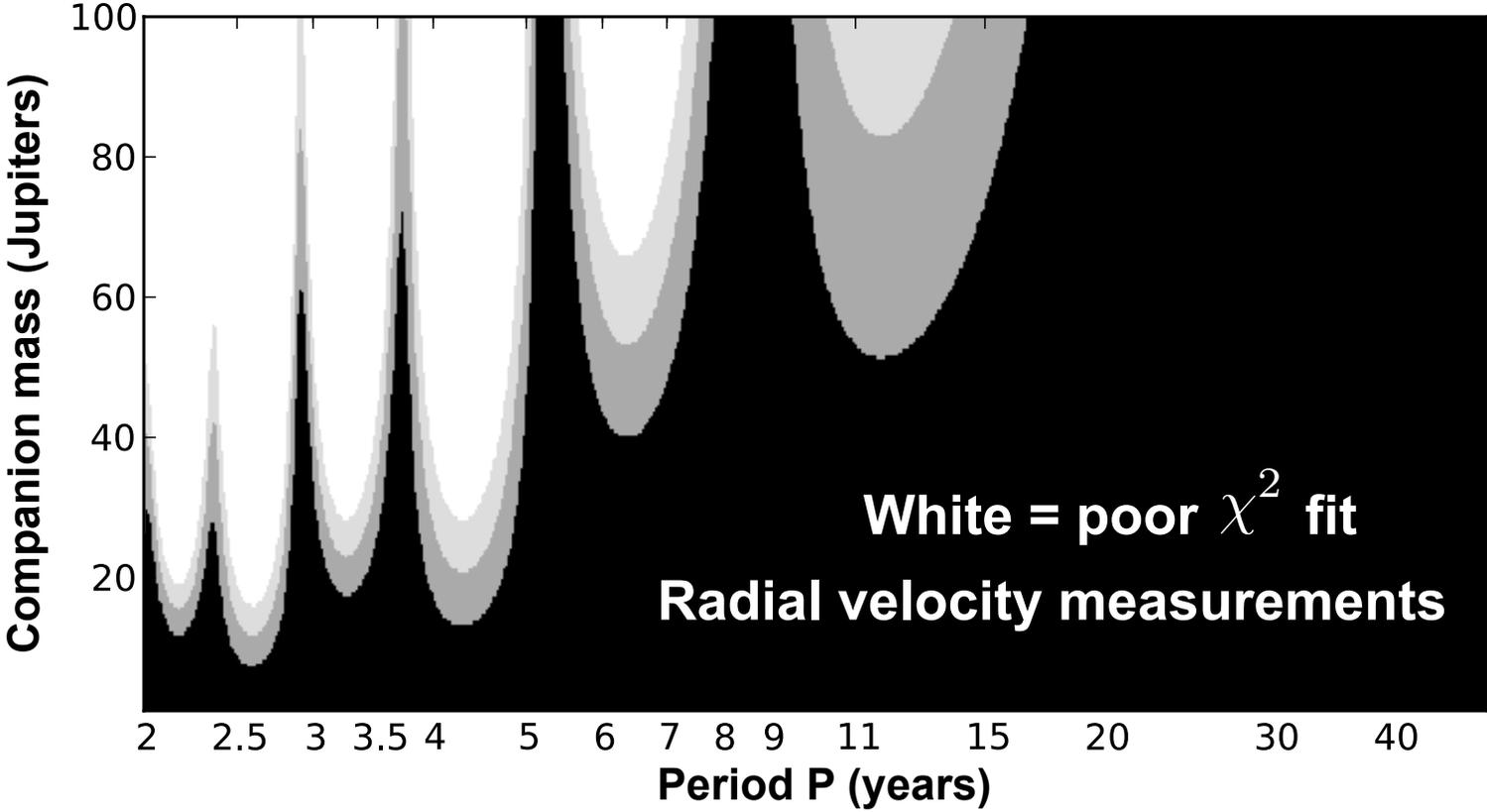
Rocne radius

Hill radius

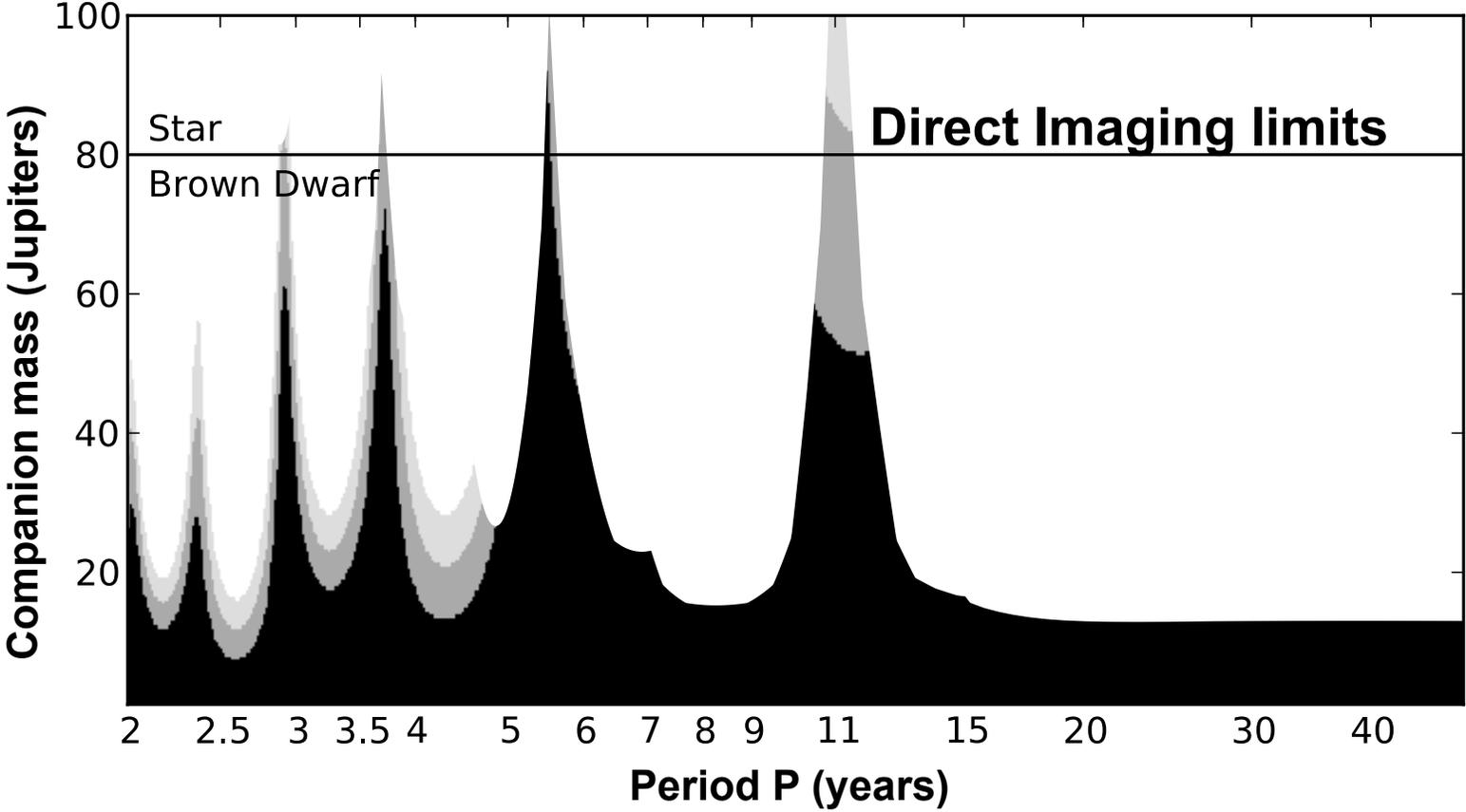


Hill sphere filling fraction is ξ

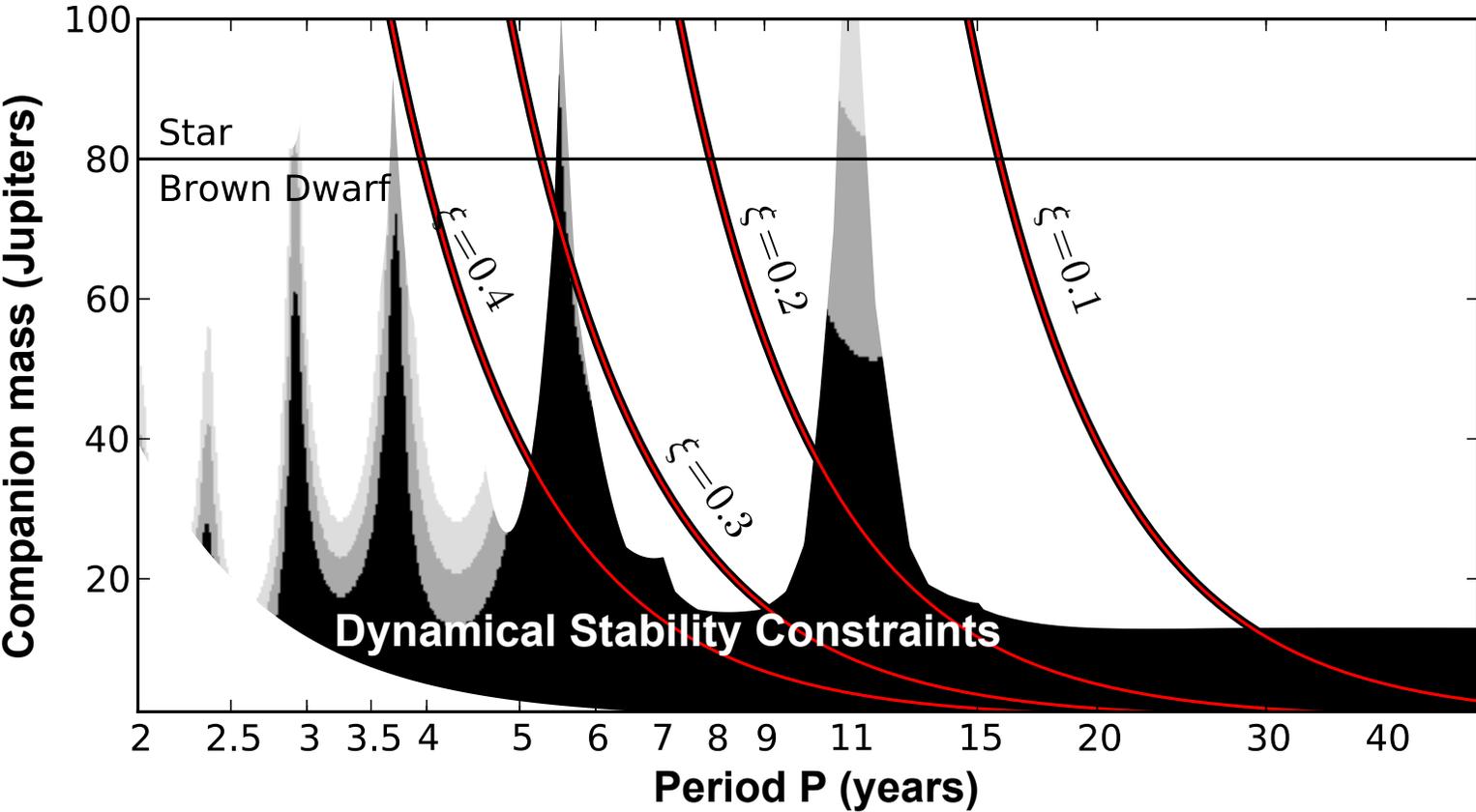
Finding J1407b Mass and Period



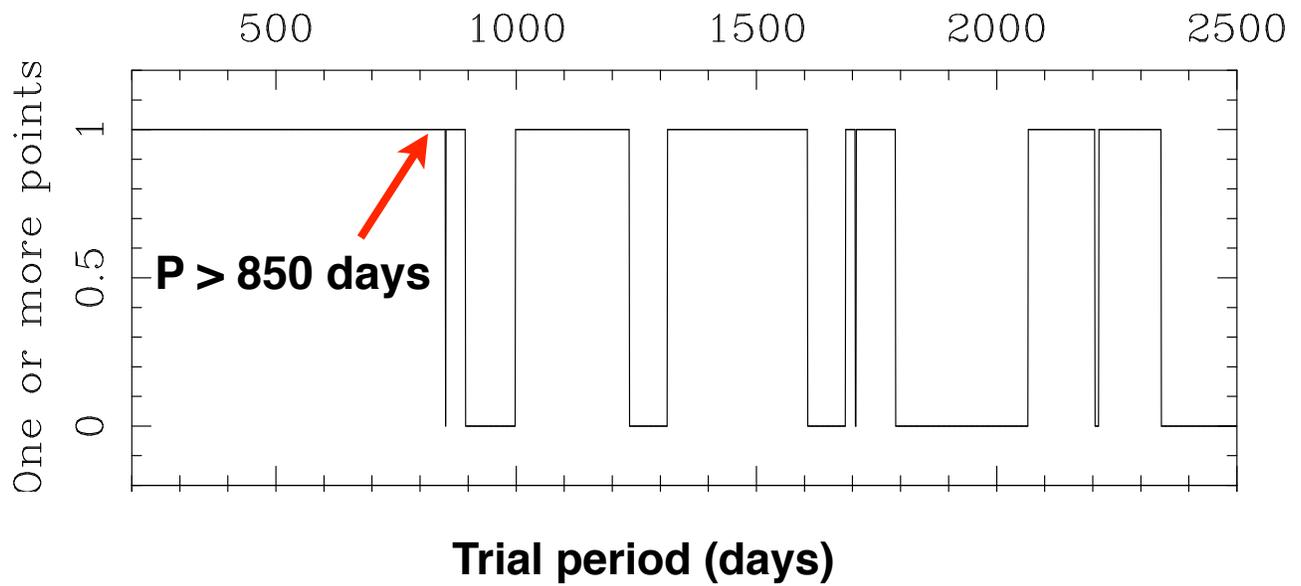
Finding J1407b Mass and Period



Finding J1407b Mass and Period

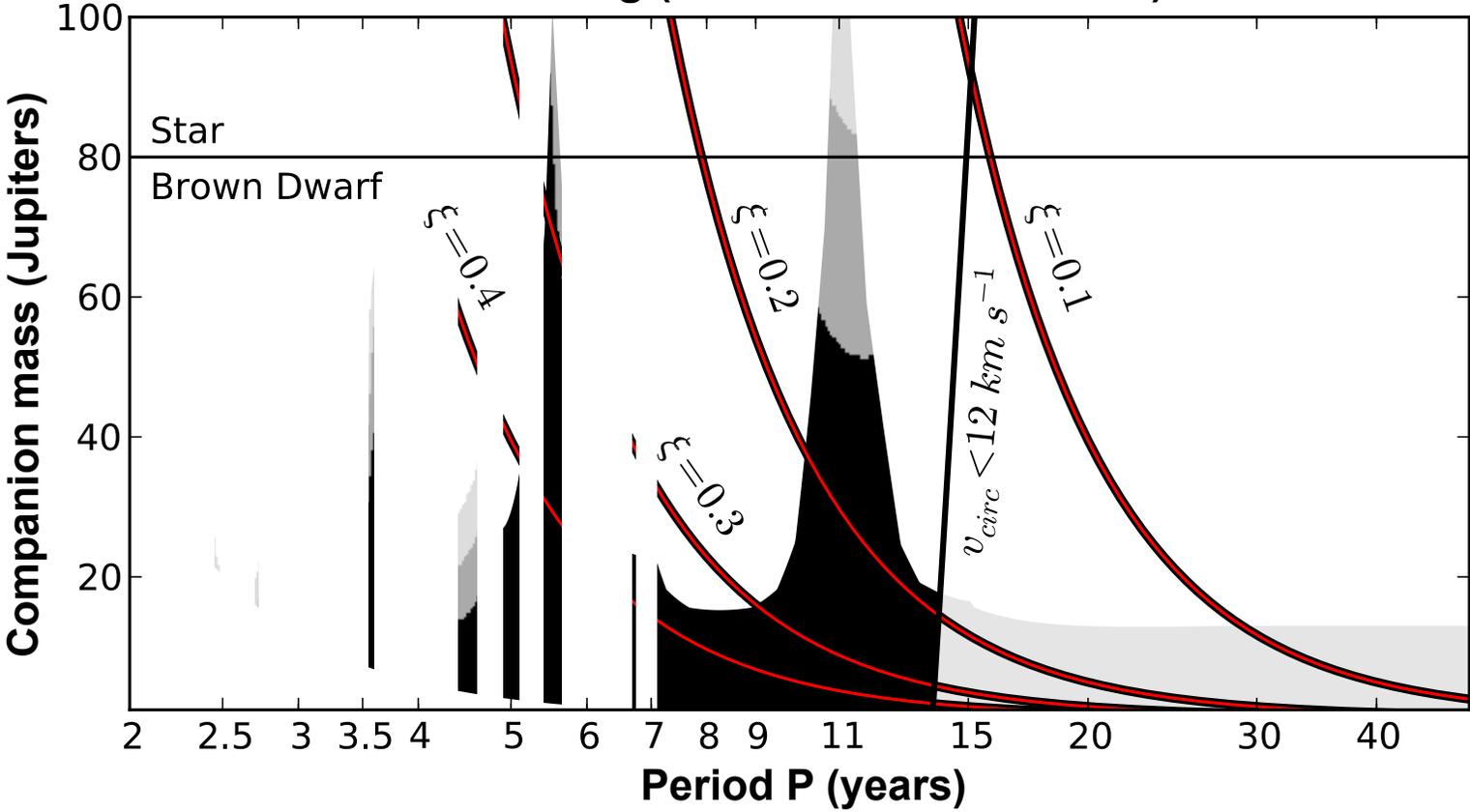


Hunt for periodicity

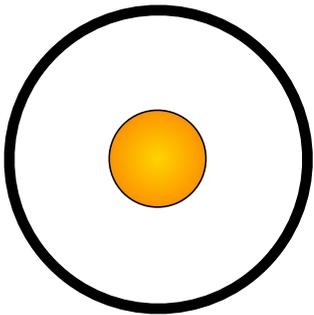


Finding J1407b Mass and Period

Photometric monitoring (PROMPT from E. Scott)

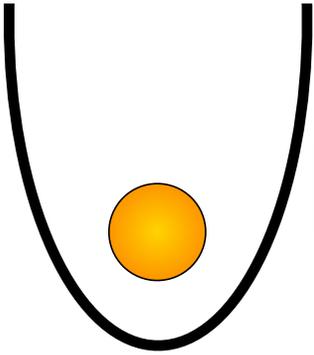


Problem

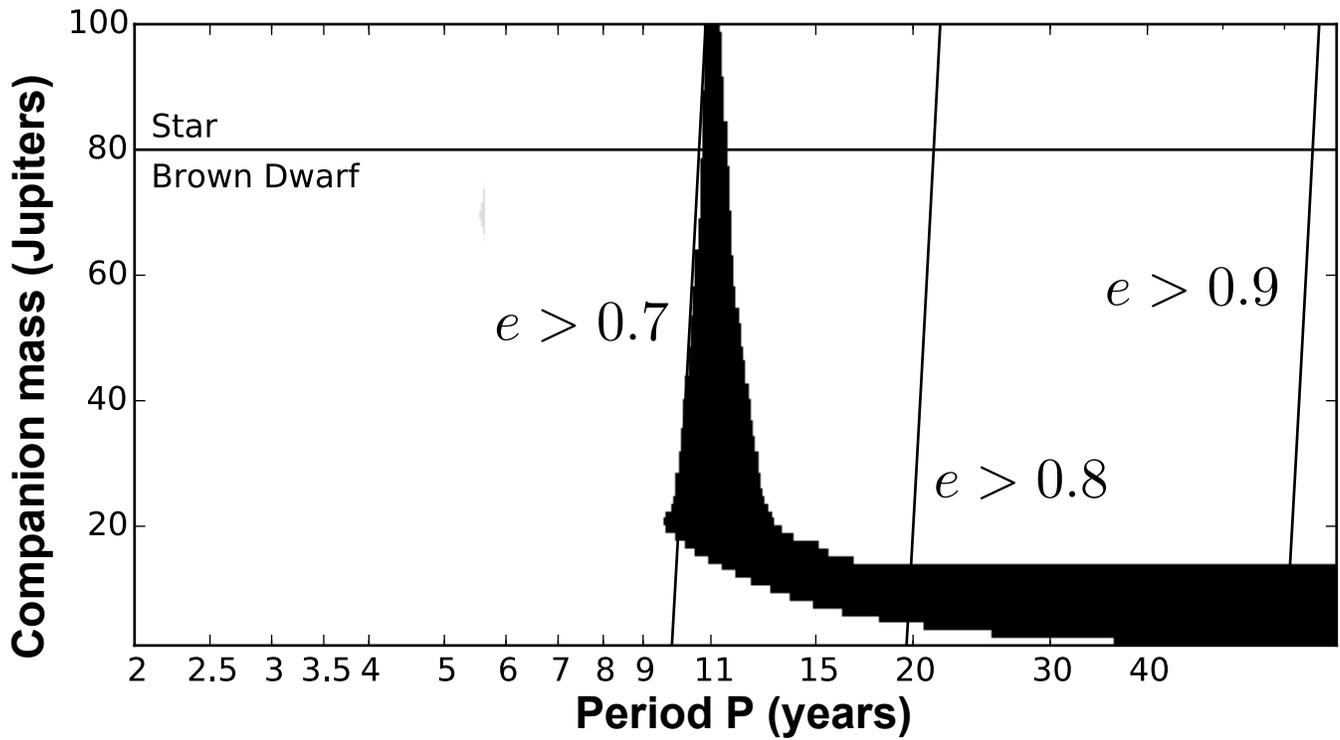


$$v_{circ} < 20 \text{ km.s}^{-1}$$

BUT $v_{variability} \sim 33 \text{ km.s}^{-1}$

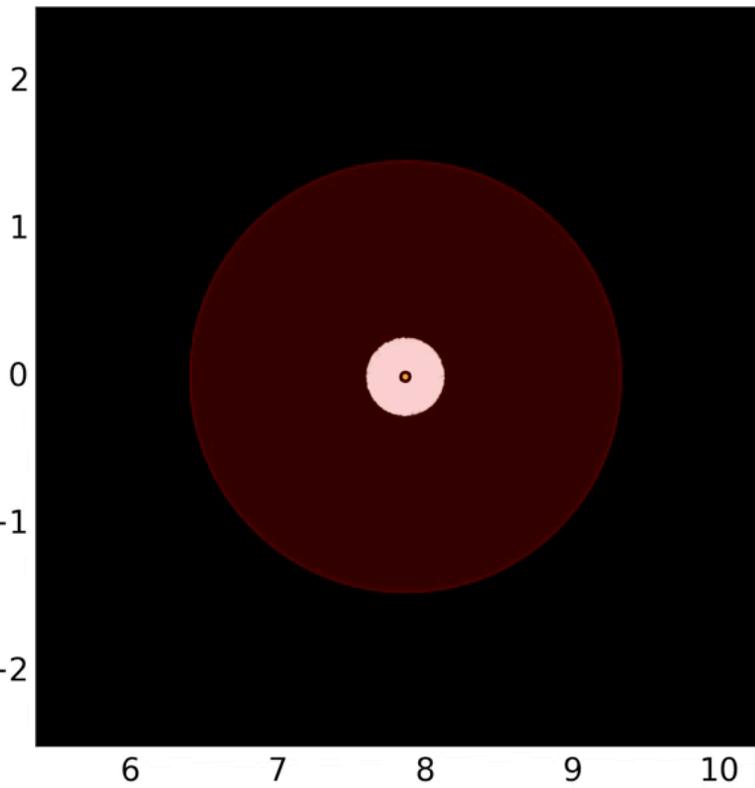


Eccentric orbits

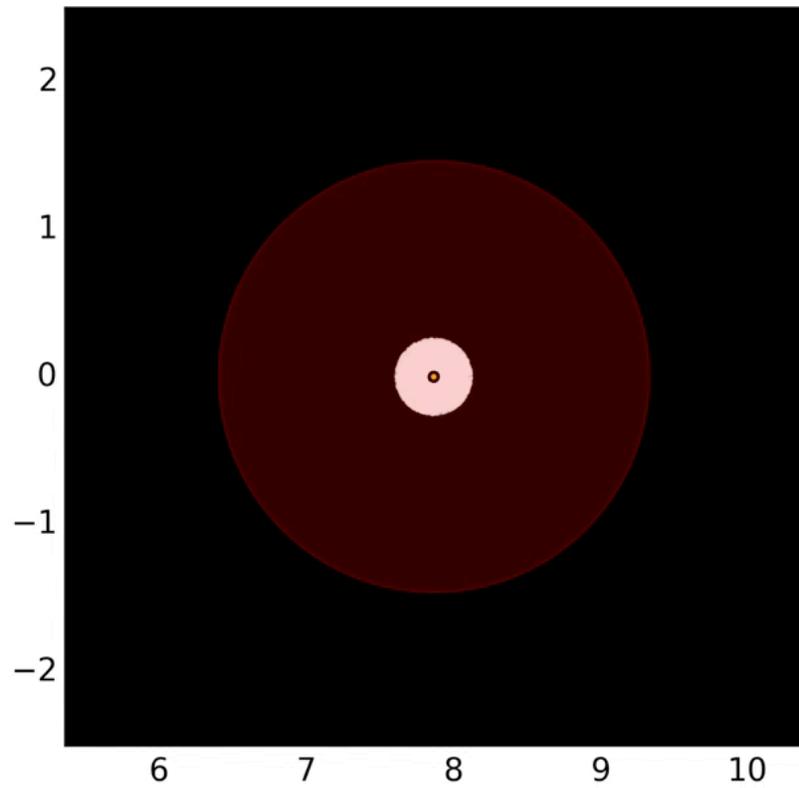


Retrograde Hill rings survive for much longer

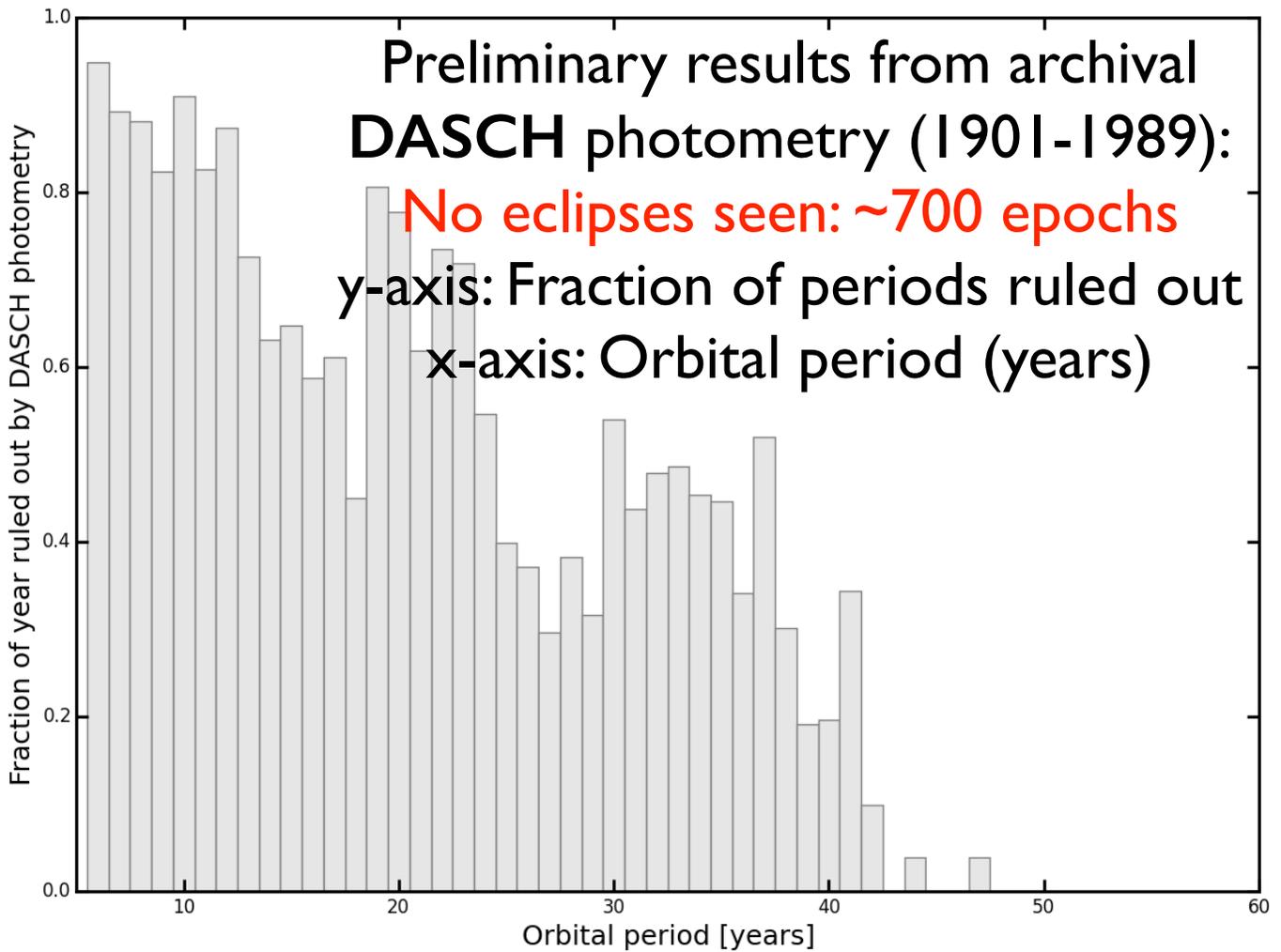
Prograde

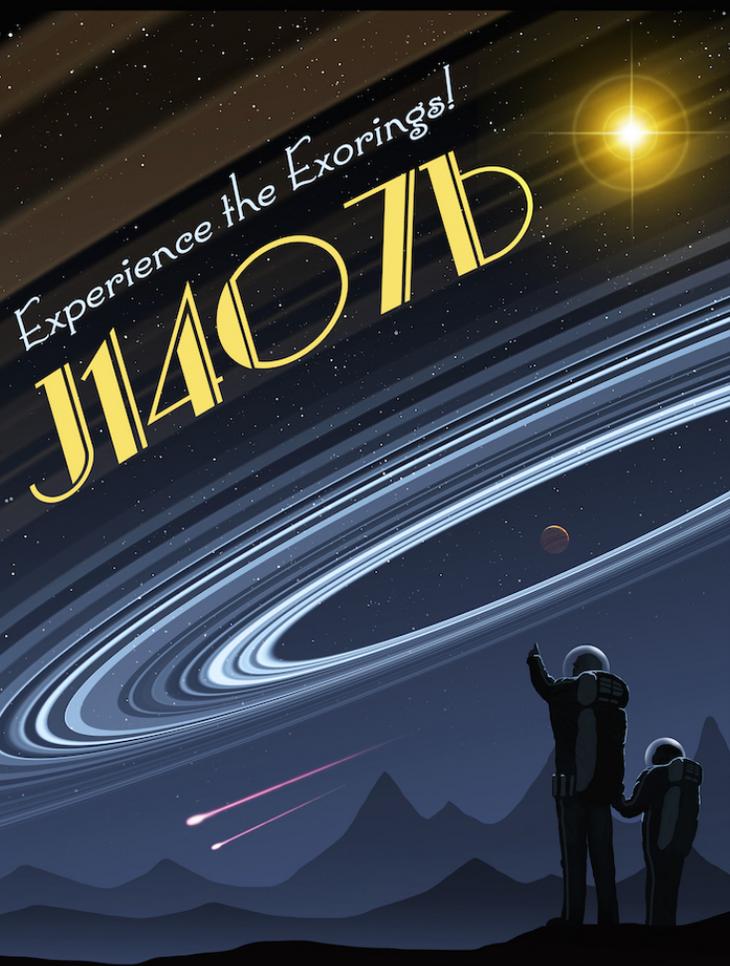


Retrograde



Rieder and Kenworthy, in prep.





*J1407b is easily reachable from the ScoCen Terminus.
Bi-weekly jumps to Mamajek Orbital Station, and then daily gliders to Fort Anja.*

(c) Mark Garlick

Conclusions

- What the heck is J1407 “b”?
- Rings probably fill large fraction of Hill sphere of substellar object
- No sign yet of additional eclipses (past or present)
- Search of thousands of young stars: no J1407ish eclipses
- Looking for the rings using ALMA and ZIMPOL

Papers and code at:
<http://bit.ly/j1407b>