WASP-18b phase curve

Shporer, Wong, et al. 2018, in prep.

Avi Shporer
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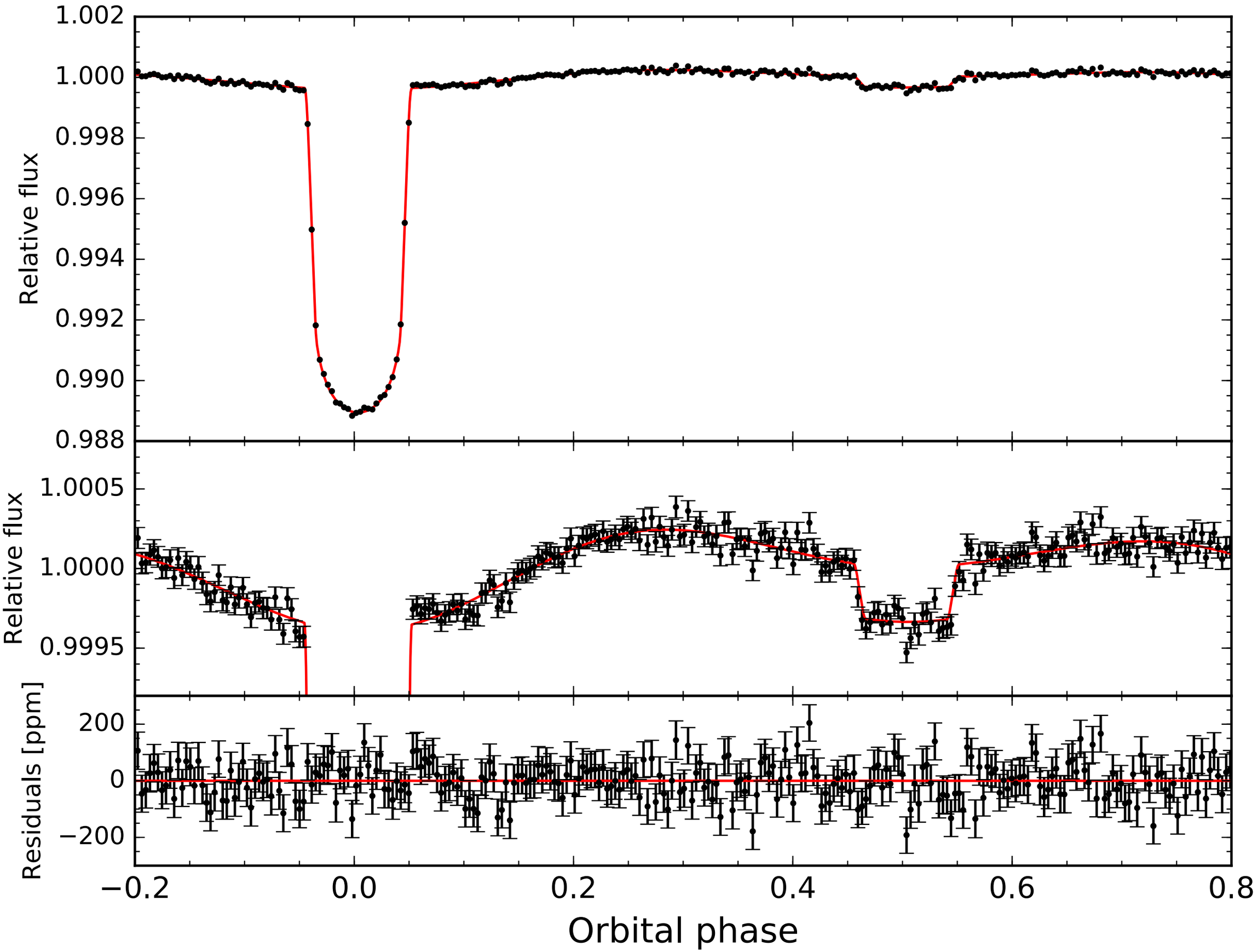
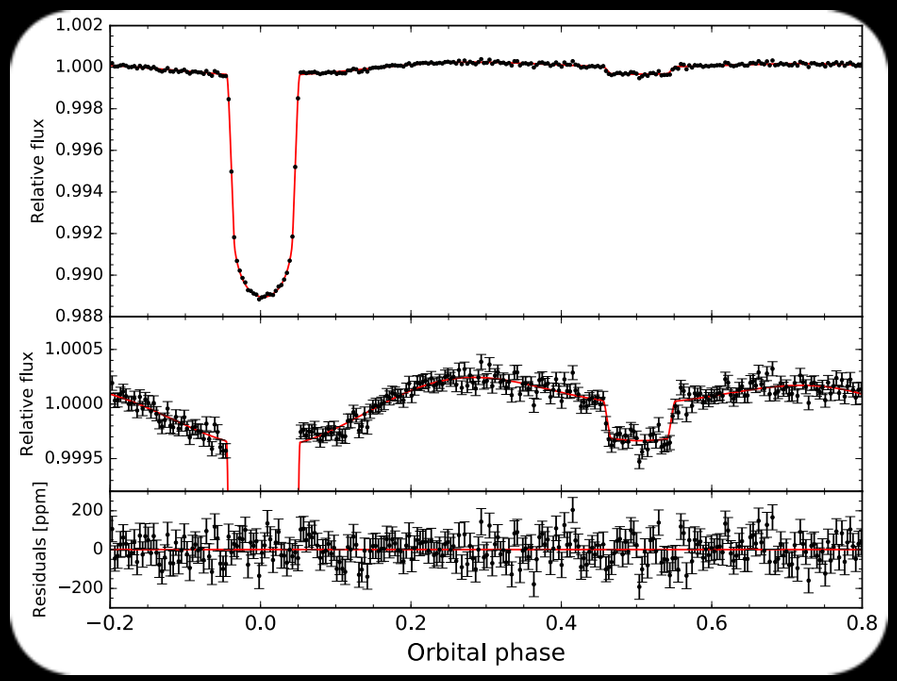
Image credit: Tunc Tezel, The World At Night


1.002
1.000
0.998
0.996
0.994
0.992
0.990
0.988
Relative flux
1.0005
1.0000
0.9995
Relative flux
200
0
−200
Residuals [ppm]
−0.2
0.0
0.2
0.4
0.6
0.8
Orbital phase

Photometric variability along the orbit:
Phase curves

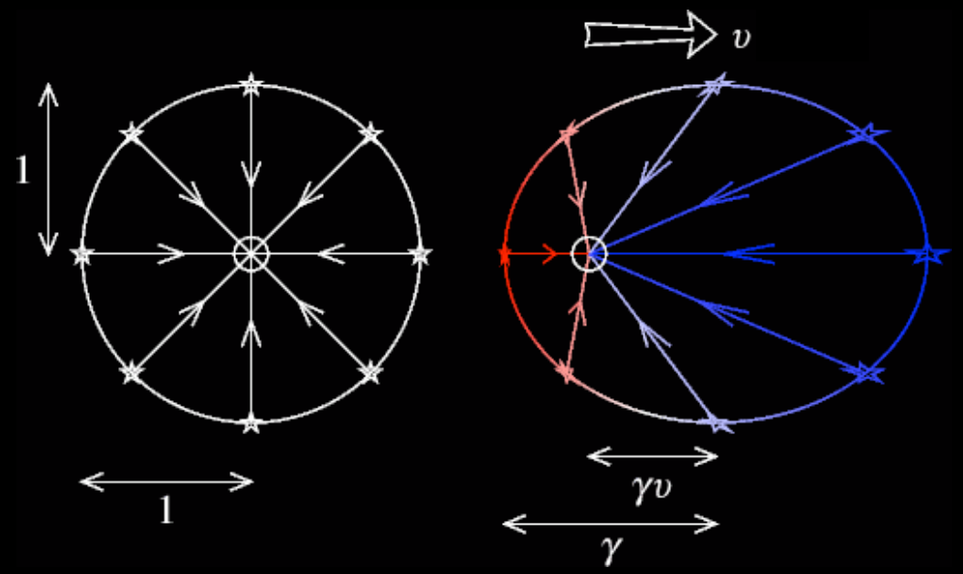
Gravitational: Beaming
Tidal ellipsoidal deformation

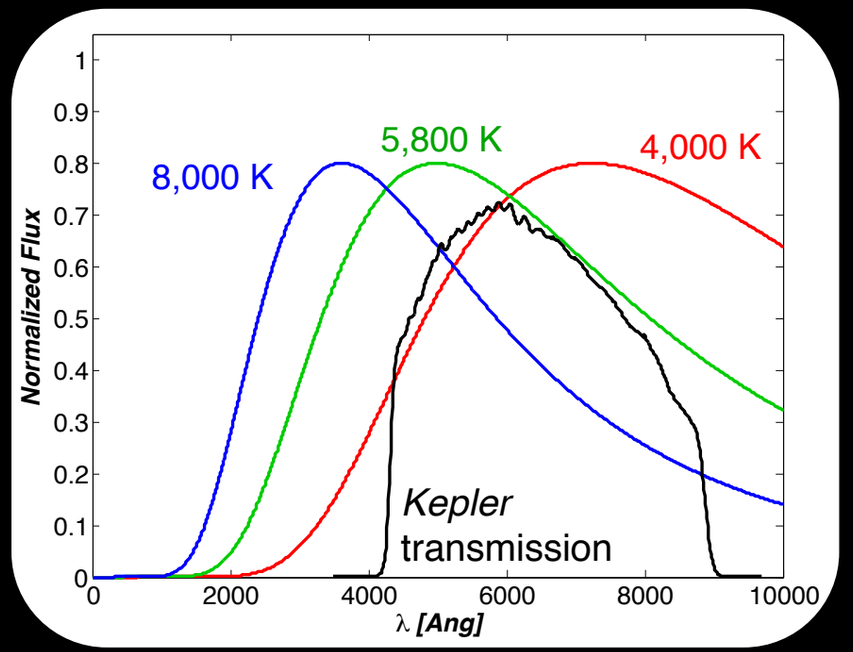
Atmospheric: Reflected light
Thermal emission (heating)



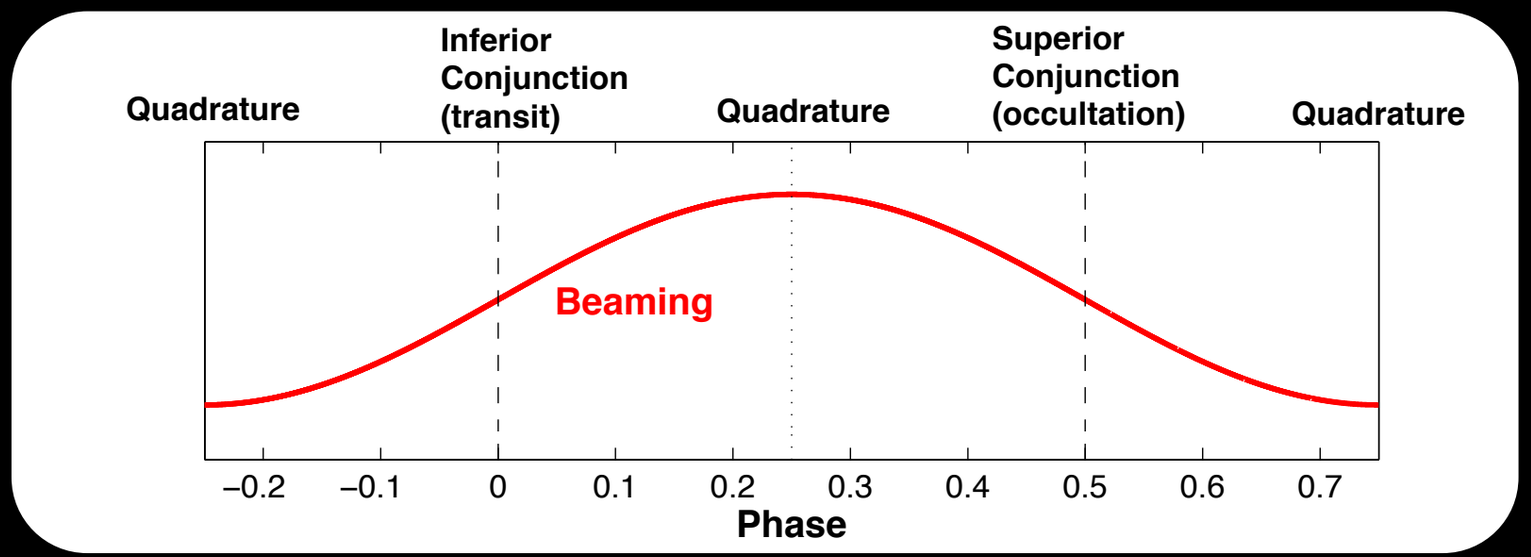
The Beaming Effect
aka Doppler Boosting

- Aberration
- Arrival rate
- Doppler shift



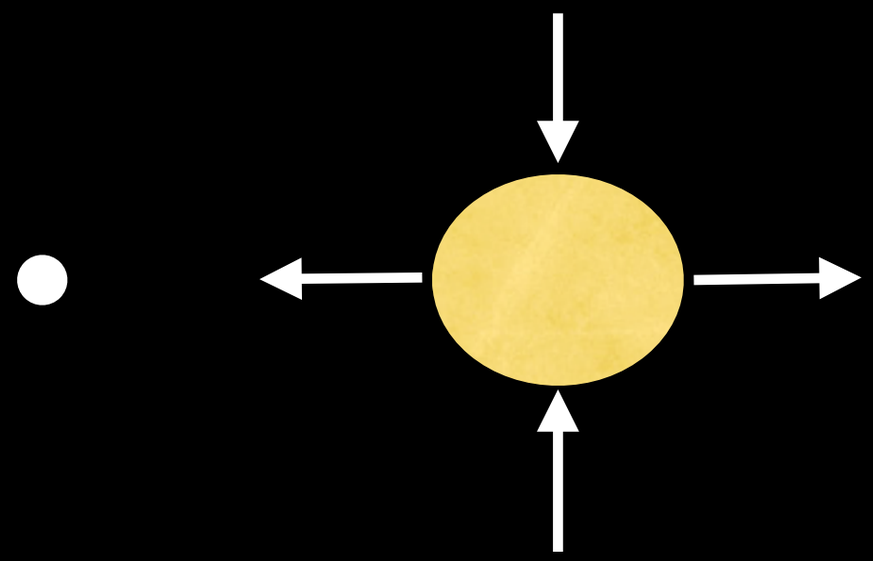


velocity-dependent flux ⇨ Photometric variation following orbital motion

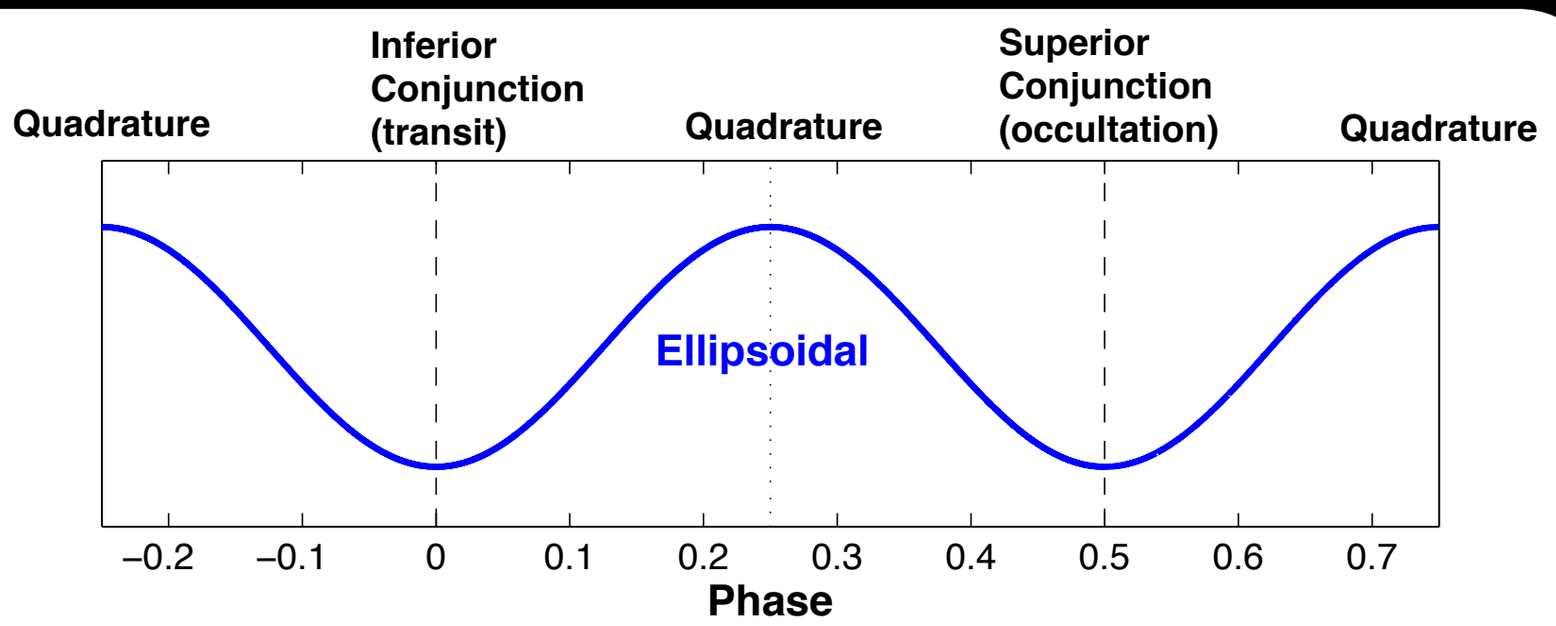


$$A_{\rm beam} = \alpha_{\rm beam} 4 \frac{K_{RV}}{c}$$

Tidal Ellipsoidal Deformation

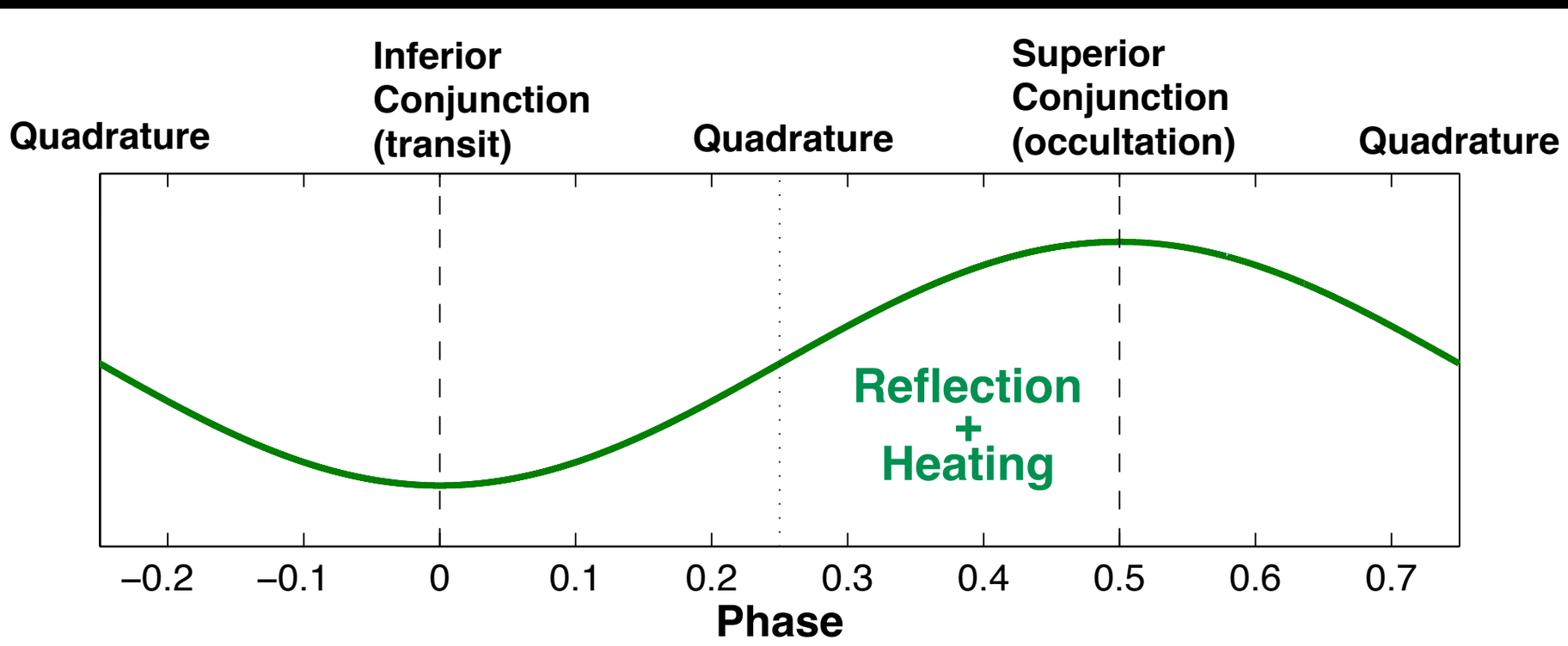


$$A_{\rm ellip} = \alpha_{\rm ellip} \frac{M_2 \sin i}{M_s} \left(\frac{R_s}{a} \right)^3 \sin i$$



Atmospheric: Reflection + Heating

$$A_{\rm refl} = \alpha_{\rm refl} 0.1 \left(\frac{R_2}{a}\right)^2 \sin i$$



Gravitational

Beaming

$$A_{\rm beam} = \alpha_{\rm beam} \frac{4}{c} \frac{M_2 \sin i}{(M_s + M_2)^{2/3}} \left(\frac{2\pi G}{P} \right)^{1/3}$$

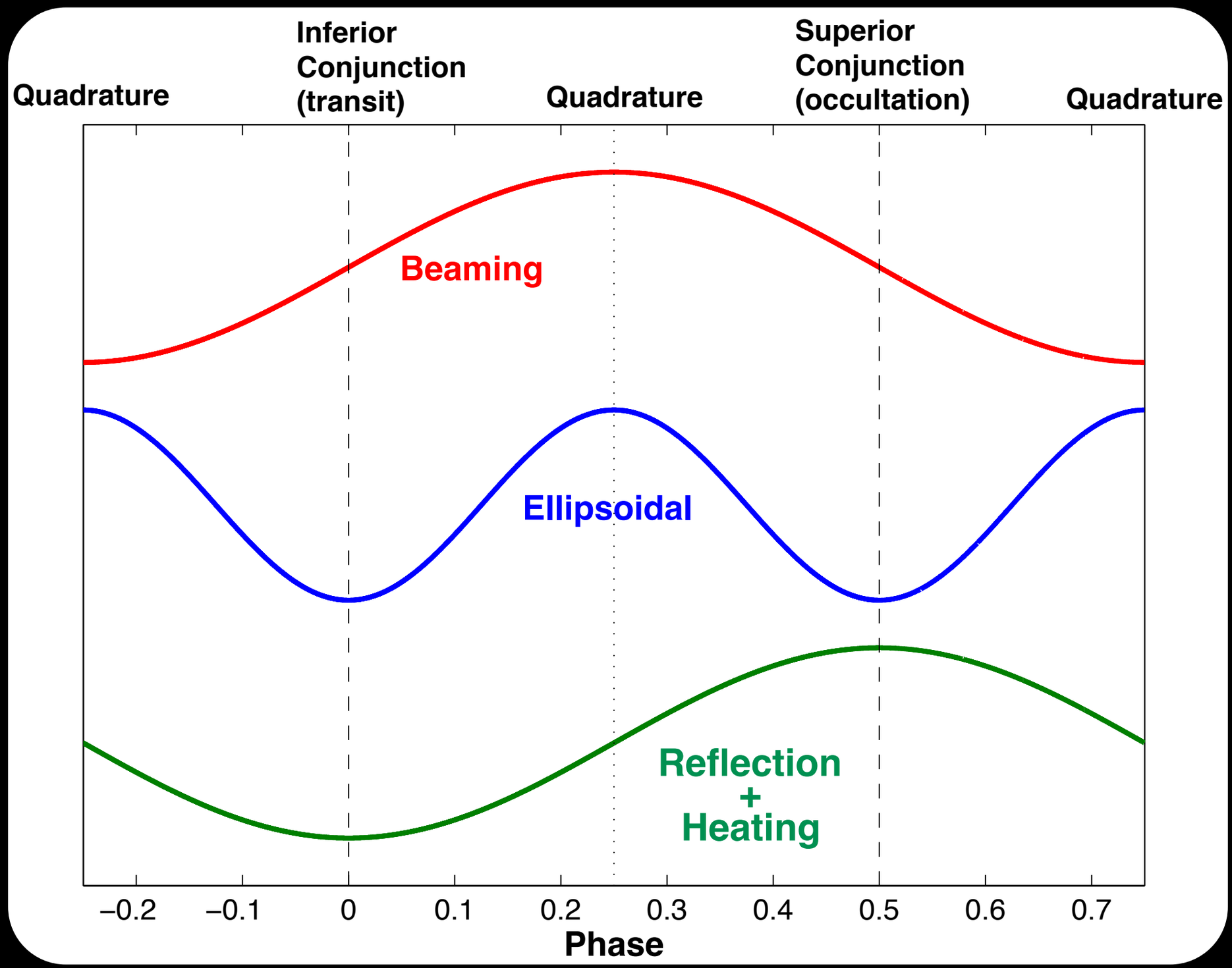
Tidal Ellipsoidal Deformation

$$A_{\rm ellip} = \alpha_{\rm ellip} \frac{M_2 \sin^2 i}{M_s} \left(\frac{R_s}{a} \right)^3$$

Atmospheric

Reflection+heating

$$A_{\rm refl} = \alpha_{\rm refl} 0.1 \left(\frac{R_2}{a} \right)^2 \sin i$$



sin(ϕ)

cos(2ϕ)

cos(ϕ)

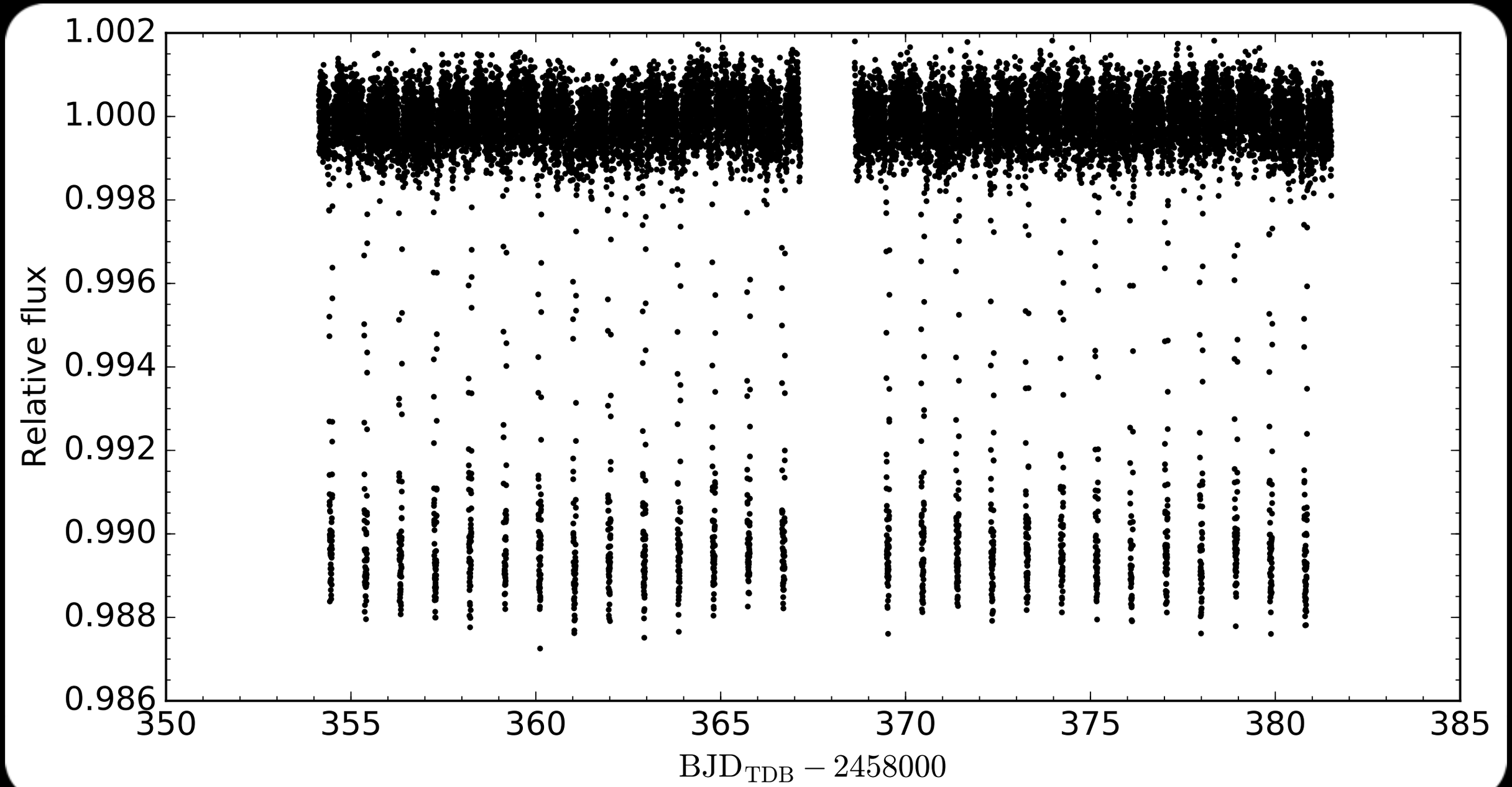
Unique period+phase for each component

WASP-18b:

P = 0.94 day
M_p = 10.5 ± 0.5 M_{Jup}
R_p = 1.20 ± 0.05 R_{Jup}

T_{eff} = 6,431 ± 48 K
M_s = 1.46 ± 0.29 M_{Sun}
R_s = 1.26 ± 0.04 R_{Sun}
K_{RV} = 1,816.6 ± 6.2 m/s

TESS Sector 2



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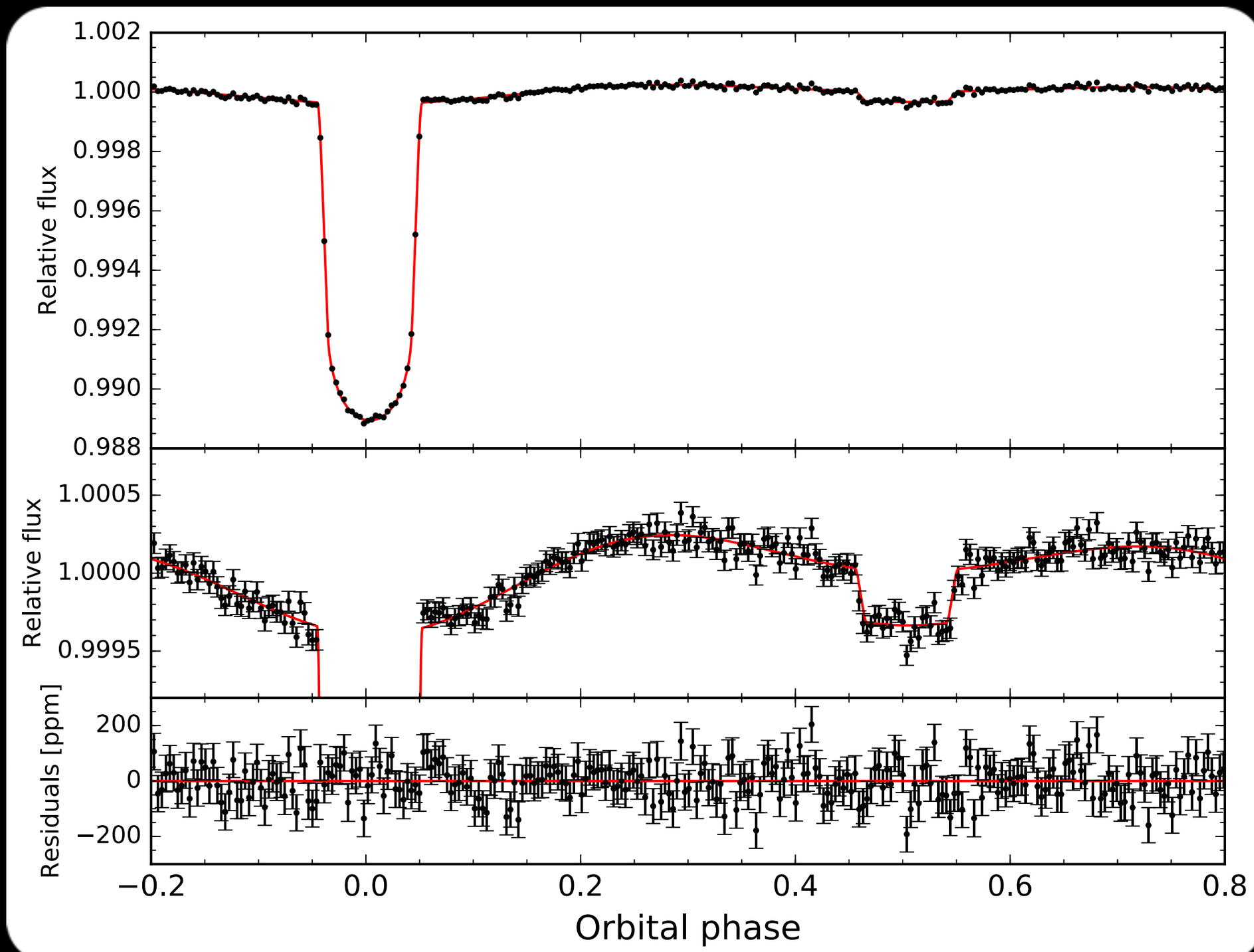

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WASP-18b Phase Curve
I

Measured:
A_{beam} = 24.2 ± 5.7 ppm
A_{ellip} = 194.1 ± 7.3 ppm

Expected:
A_{beam} = 18 ± 2 ppm
A_{ellip} = 186 ± 25 ppm

Both amplitudes agree with expectations

But not always:
KOI-74 - van Kerkwijk et al. 2010; Bloemen et al. 2012
KIC 10657664 - Carter et al. 2011
TrES-2 - Barclay et al. 2012
HAT-P-7 - Esteves et al. 2013
Kepler-76 - Faigler et al. 2013
Kepler-13A - Shporer et al. 2011, 2014; Mazeh et al. 2012; Esteves et al. 2013
KIC 9164561 - Rappaport et al. 2015

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WASP-18b Phase Curve
II

2nd eclipse = Thermal emission + Reflected light

2nd eclipse = 355 ± 21 ppm
Expected thermal emission: 326 ppm → $A_g < 0.093$ (2σ)

Night side = 2nd eclipse - 2 x A_{refl}
Measured: A_{refl} = 190.6 ± 7.9 ppm → Night side < 44 ppm (2σ)

A_{beam} = 24.2 ± 5.7 ppm
A_{refl} = 190.6 ± 7.9 ppm → Phase shift < 3.2 deg (2σ)

Shporer, Wong, et al. 2018, in prep.

WASP-18b Phase Curve Summary

A_{beam} = 24.2 ± 5.7 ppm
A_{ellip} = 194.1 ± 7.3 ppm
Agree with expectations

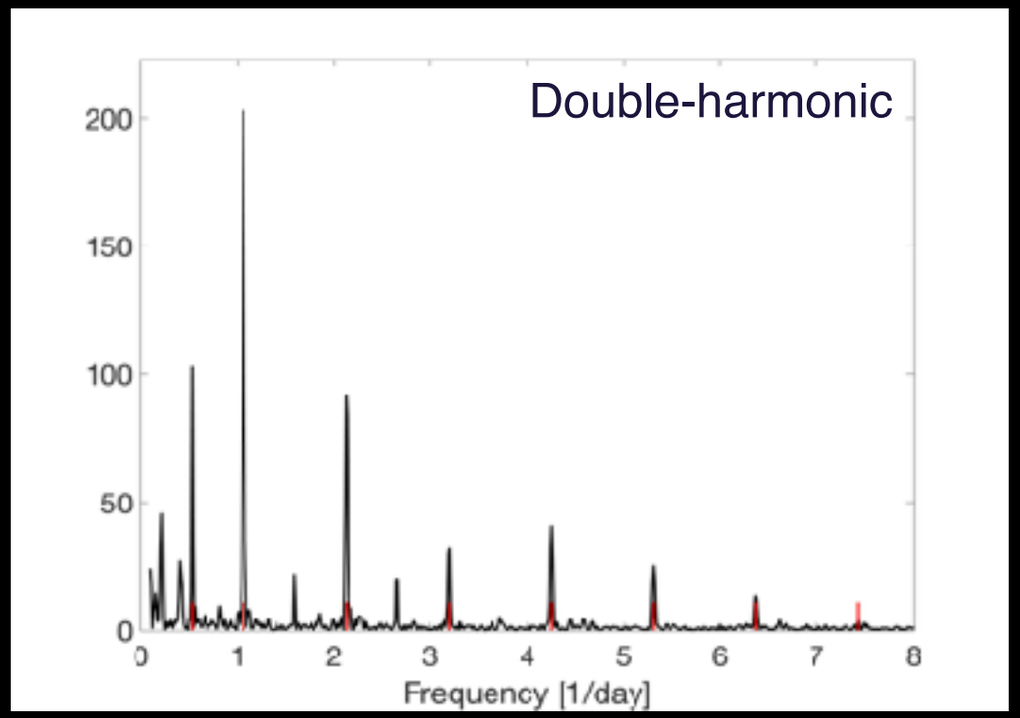
2nd eclipse = 355 ± 21 ppm
$A_g < 0.093$ (2σ)
Night side < 44 ppm (2σ)
Phase shift < 3.2 deg (2σ)

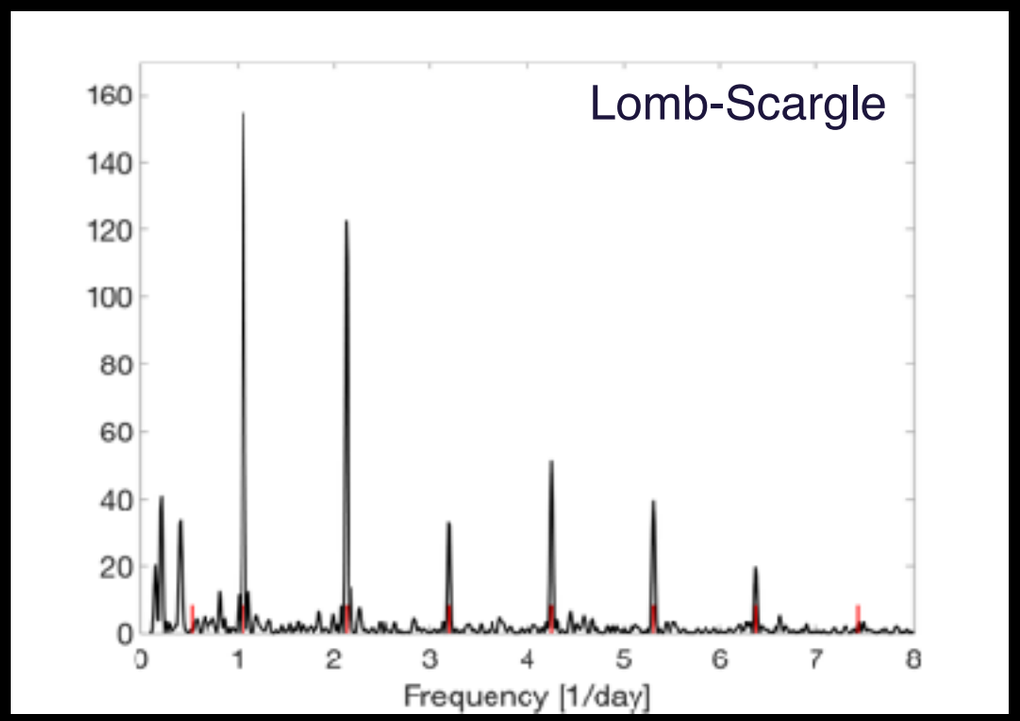
Low albedo, inefficient day-night circulation, no phase shift
➡Consistent with highly-irradiated gas-giant planets

First of a sample of atmospheres characterized by TESS

Shporer, Wong, et al. 2018, in prep.

Period analysis while removing in transit+eclipse data





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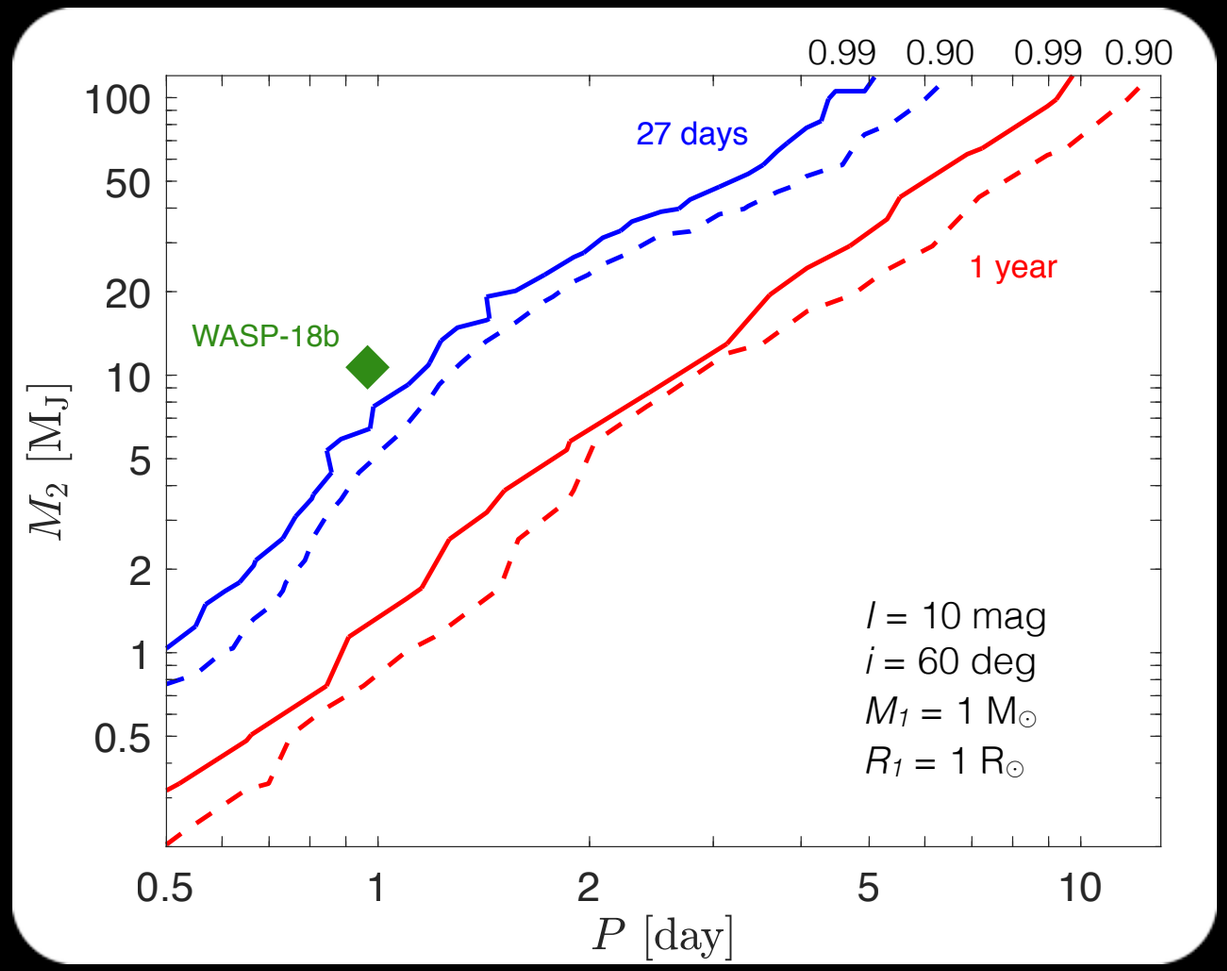
Injection and recovery simulation



Shporer 2017

WASP-18b phase curve

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