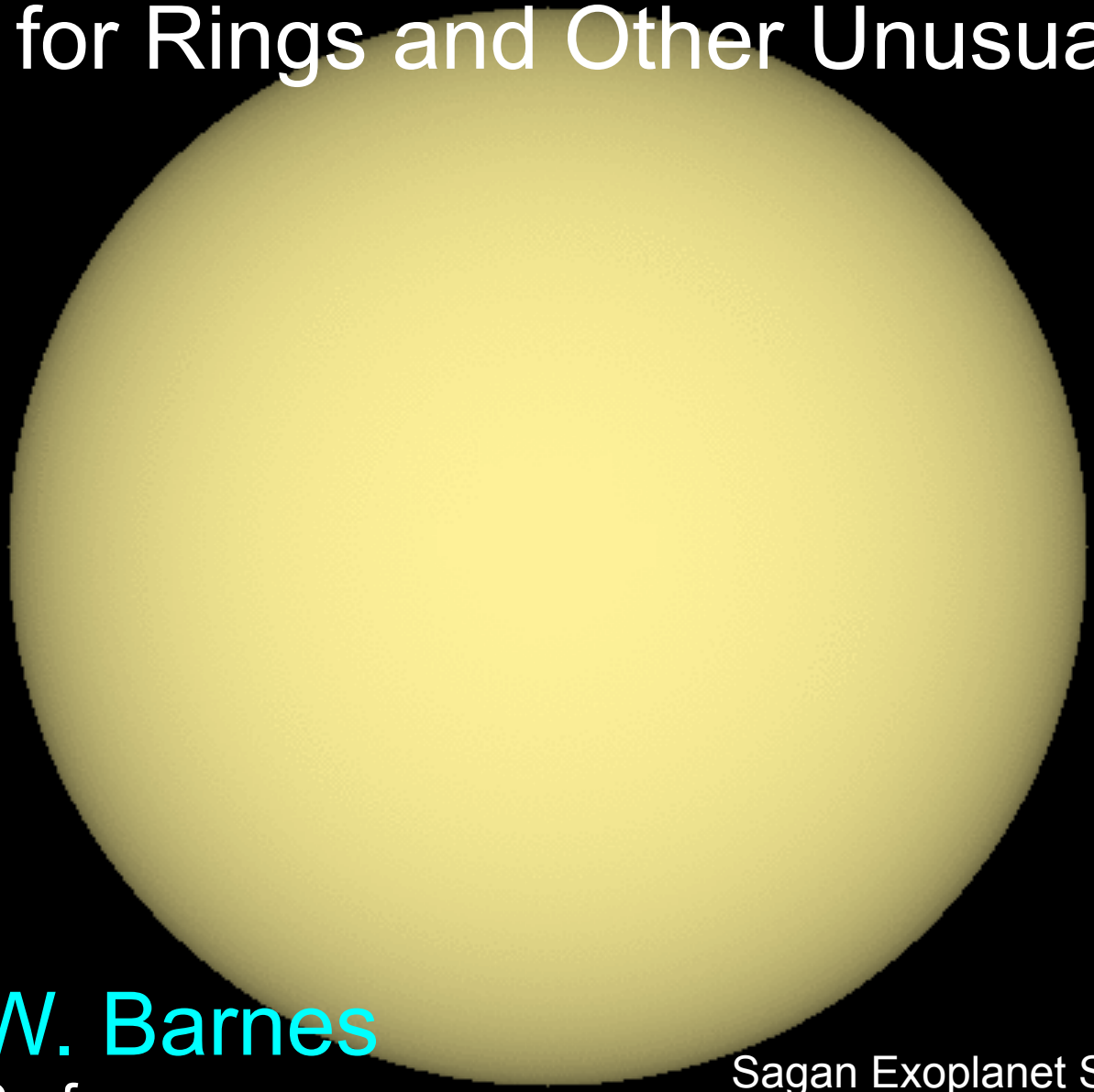
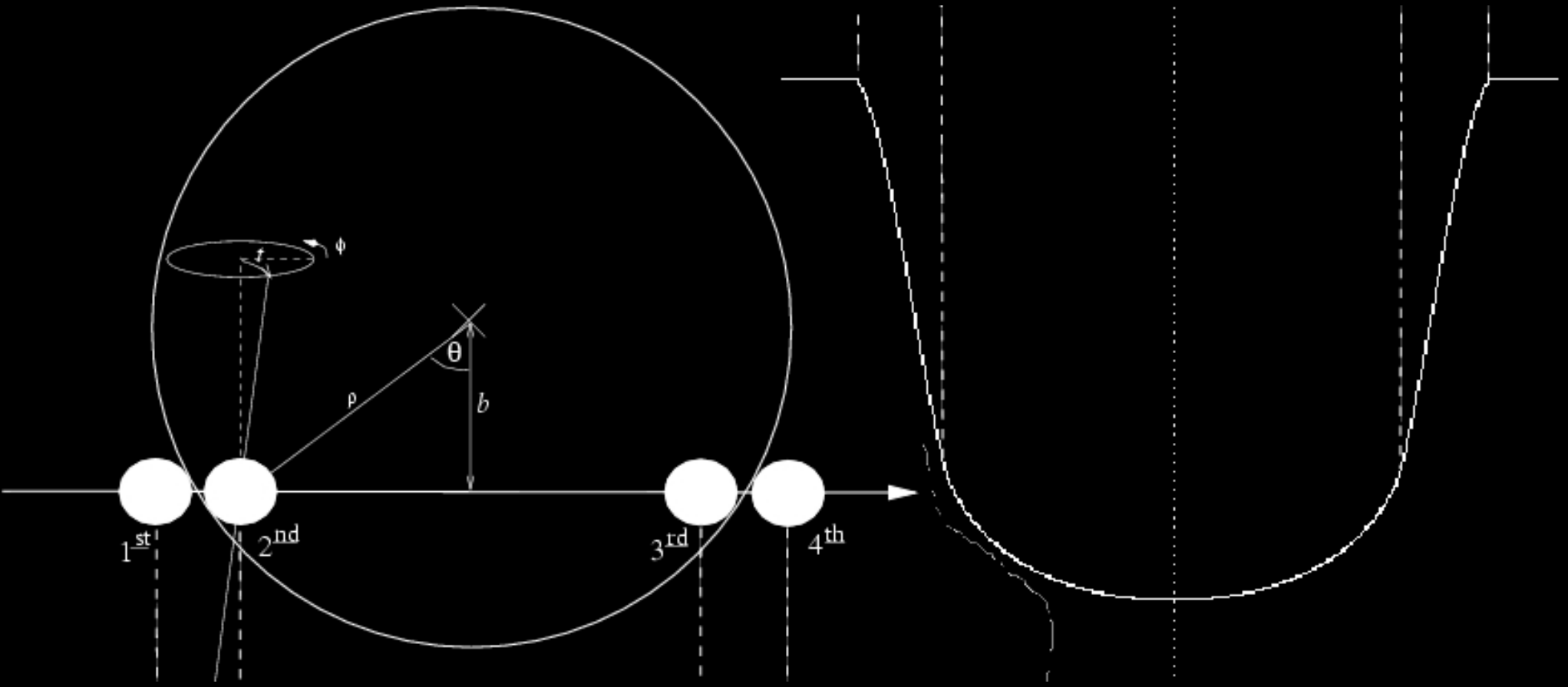
Looking for Rings and Other Unusual Features



Jason W. Barnes
Assistant Professor
Department of Physics
University of Idaho

Sagan Exoplanet Summer Workshop
Caltech, Pasadena, CA
2012 July 23-27

The “Usual” Features

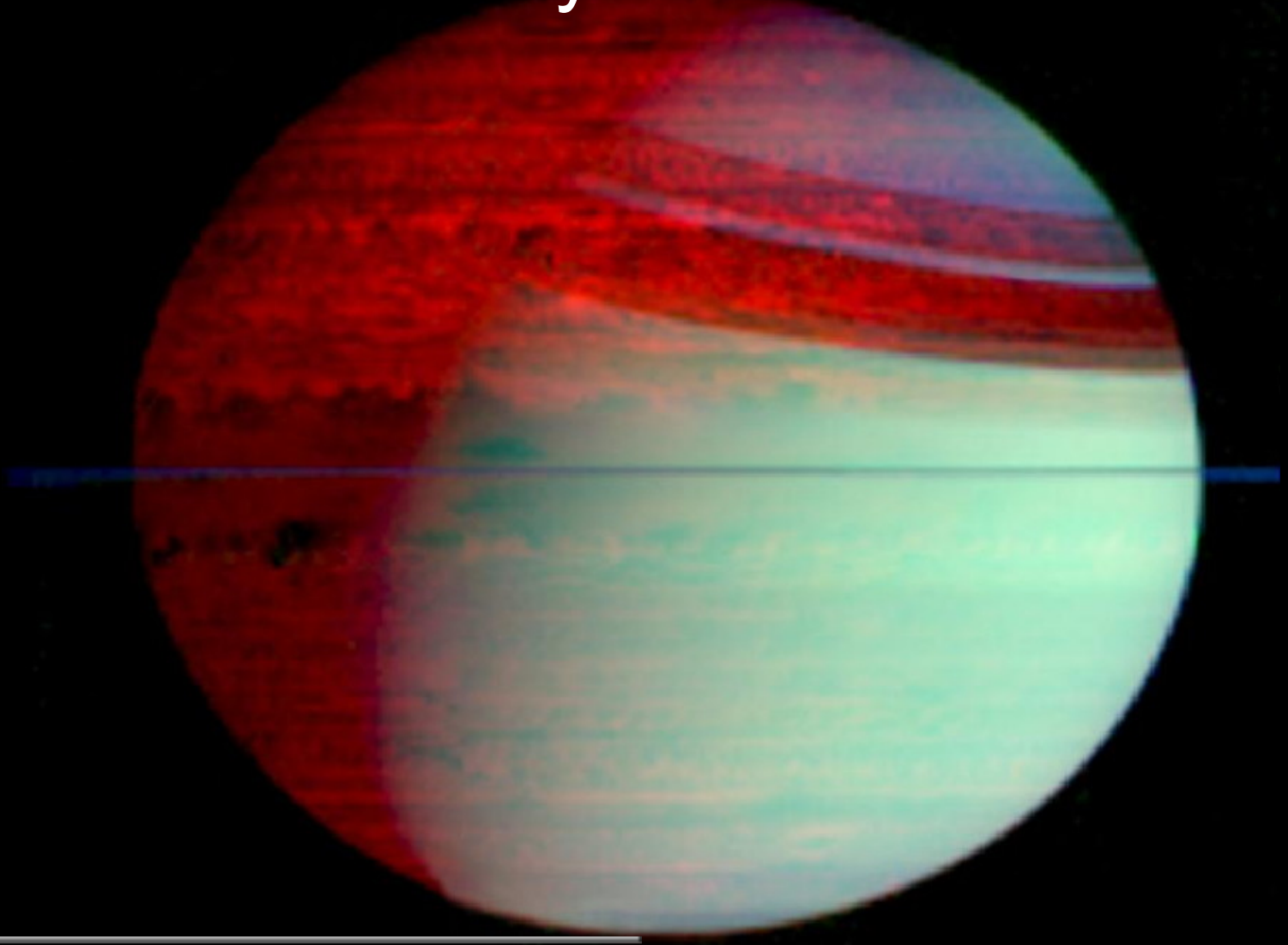


Rp/R*, R*, b, limb-darkening
(baseline, center)

Depth, duration, ingress, curvature
(baseline, center)

e.g., Seager & Mallen-Ornelas (2003 ApJ)

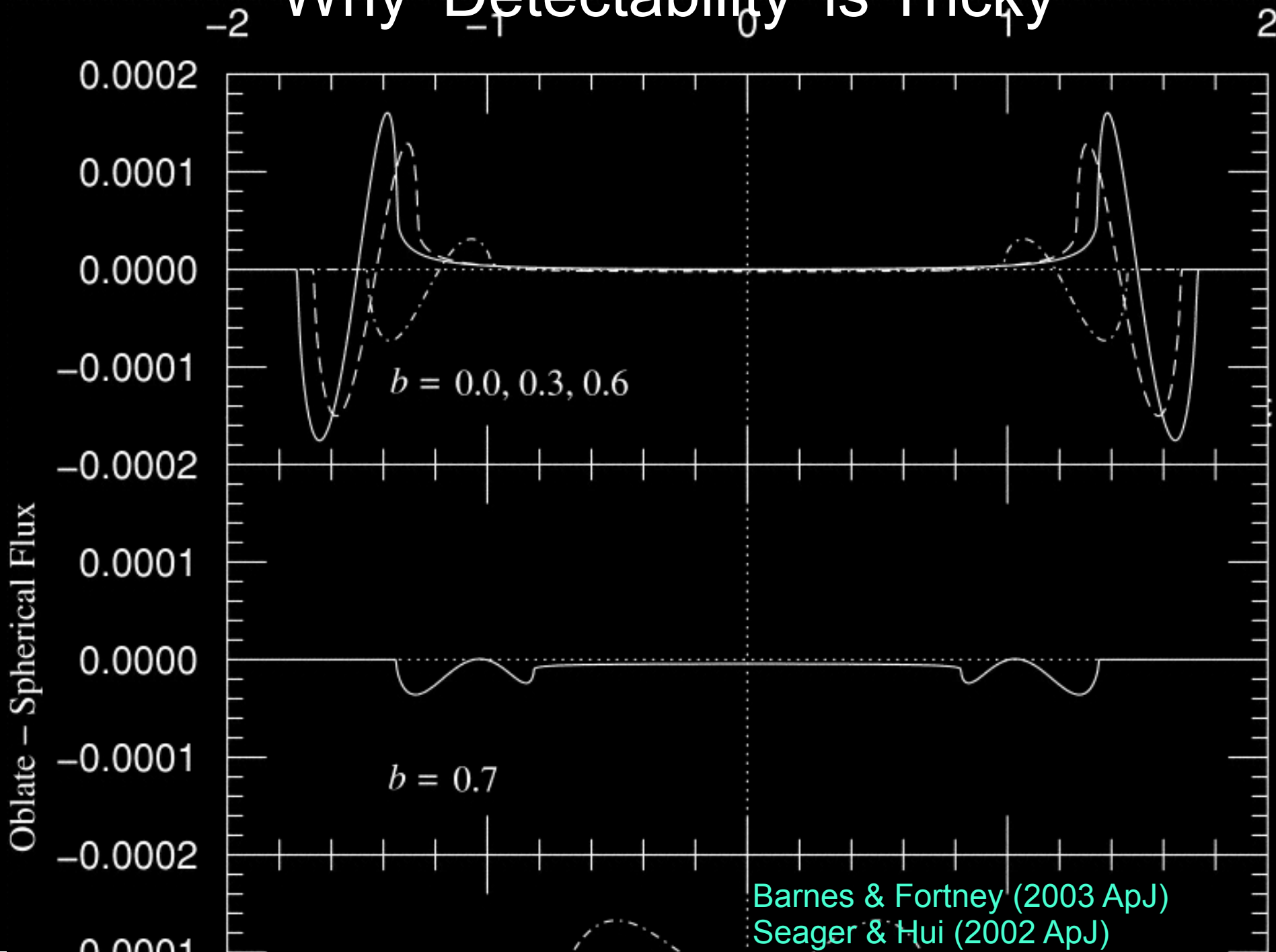
Planetary Oblateness



$$\Omega = \sqrt{\frac{fGM_p}{R_{\rm eq}^3}\left[\frac{5}{2}\left(1-\frac{3}{2}\mathbb{C}\right)^2+\frac{2}{5}\right]}$$

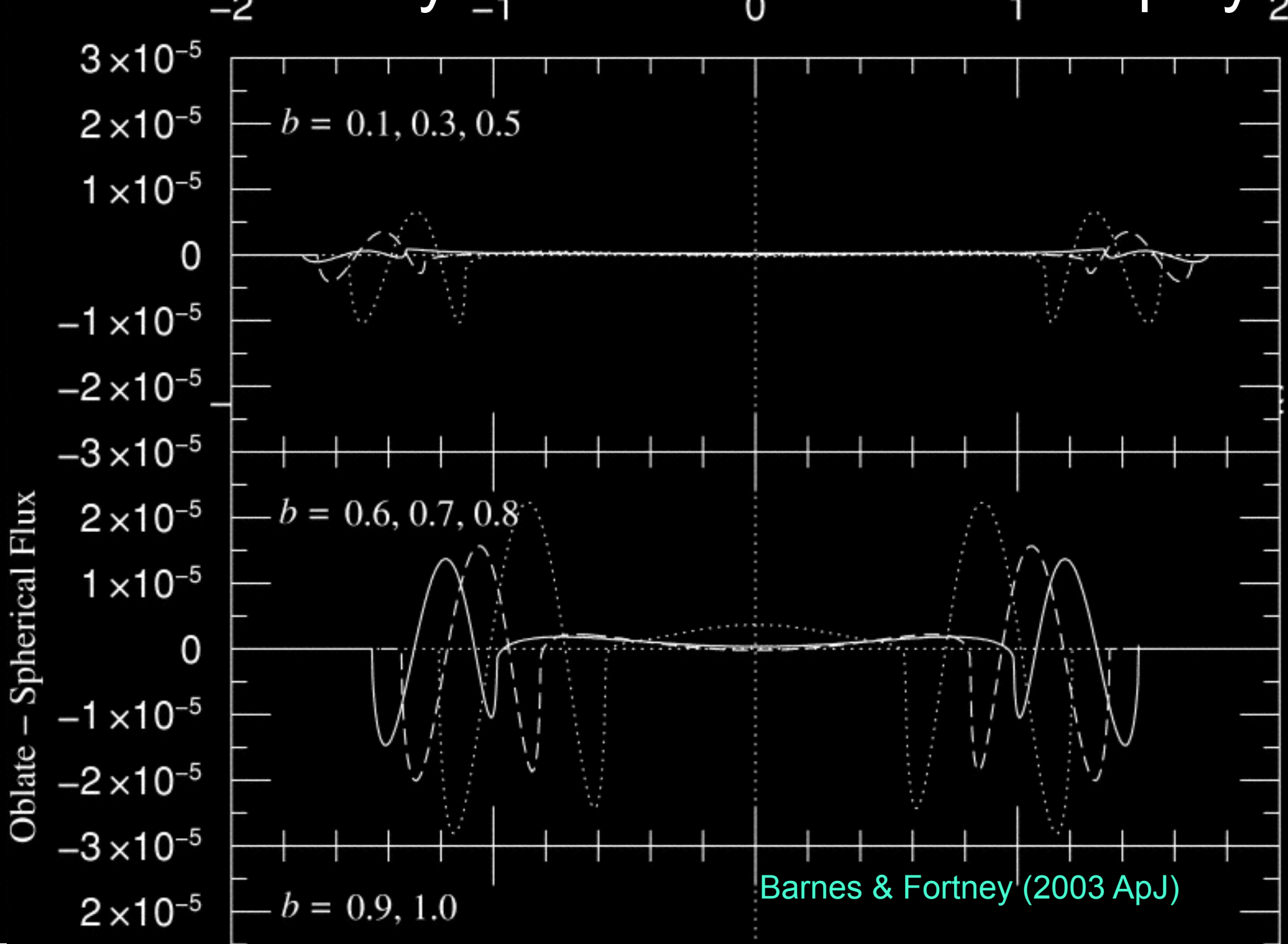
Barnes & Fortney (2003 ApJ)

Why ‘Detectability’ is Tricky

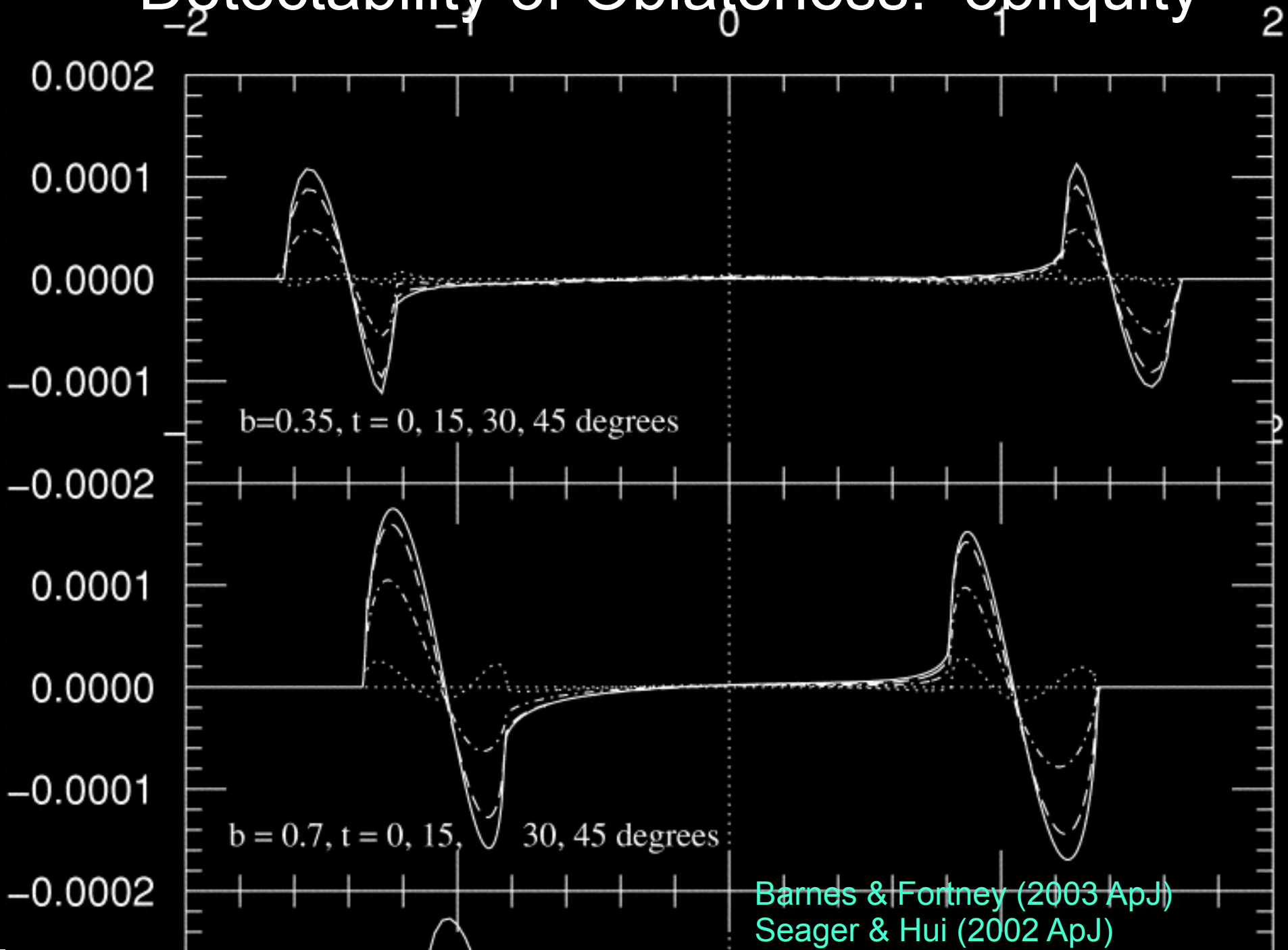


Barnes & Fortney (2003 ApJ)
Seager & Hui (2002 ApJ)

Detectability of Oblateness: no obliquity

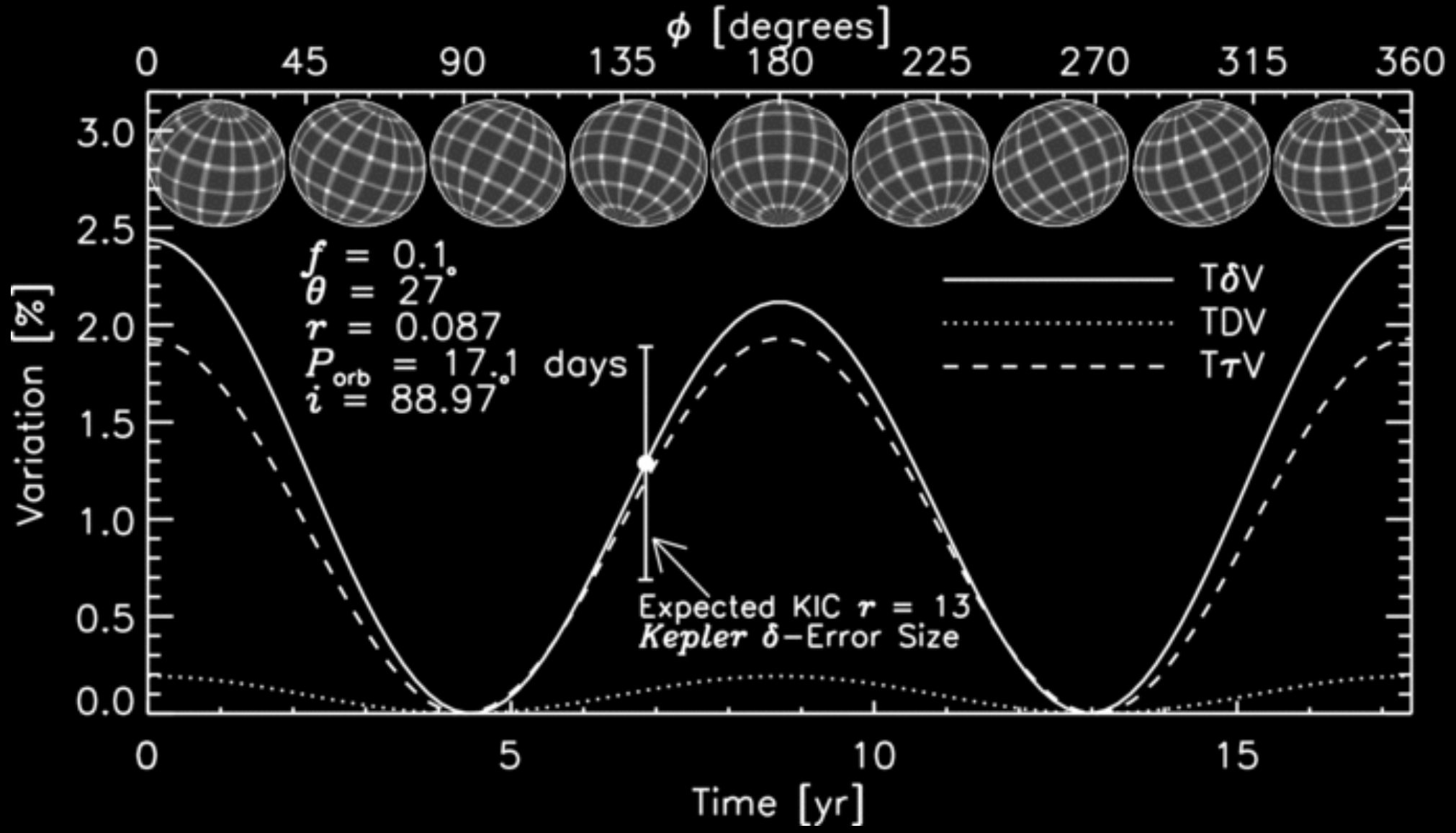


Detectability of Oblateness: obliquity



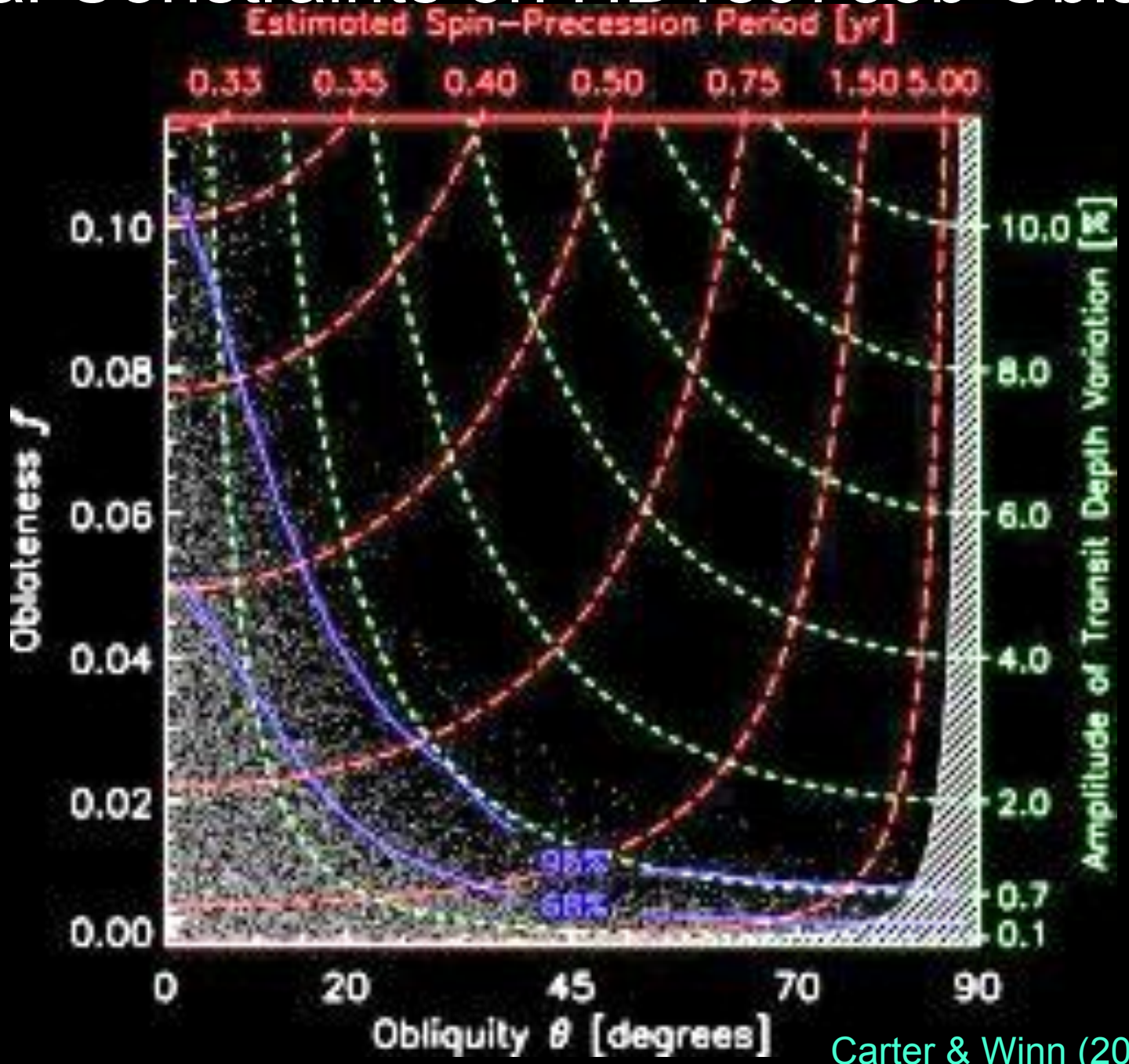
Barnes & Fortney (2003 ApJ)
Seager & Hui (2002 ApJ)

Detectability of Oblateness: precession



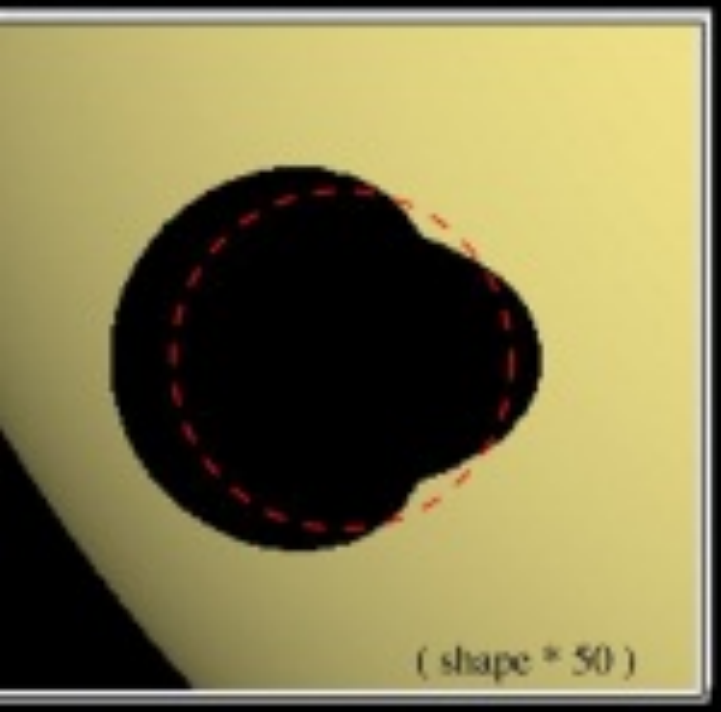
Carter & Winn (2010b ApJ)

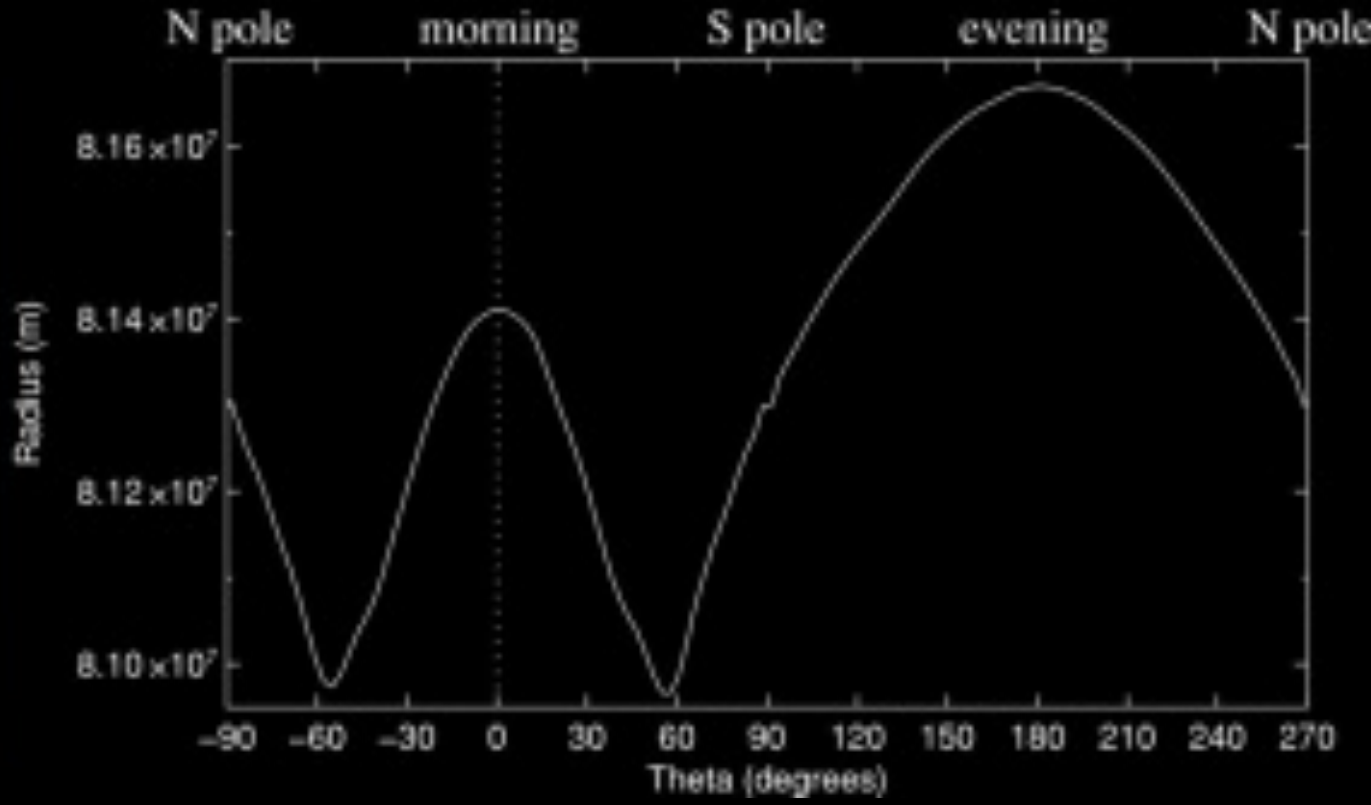
Empirical Constraints on HD189733b Oblateness



Carter & Winn (2010a ApJ)

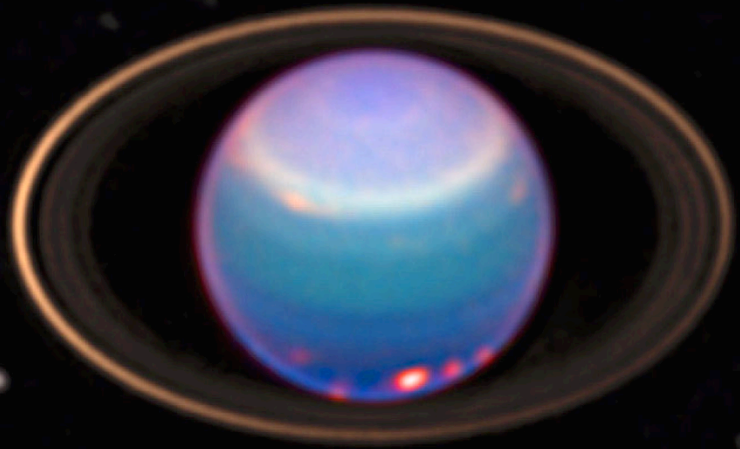
Winds can Mimic Oblateness

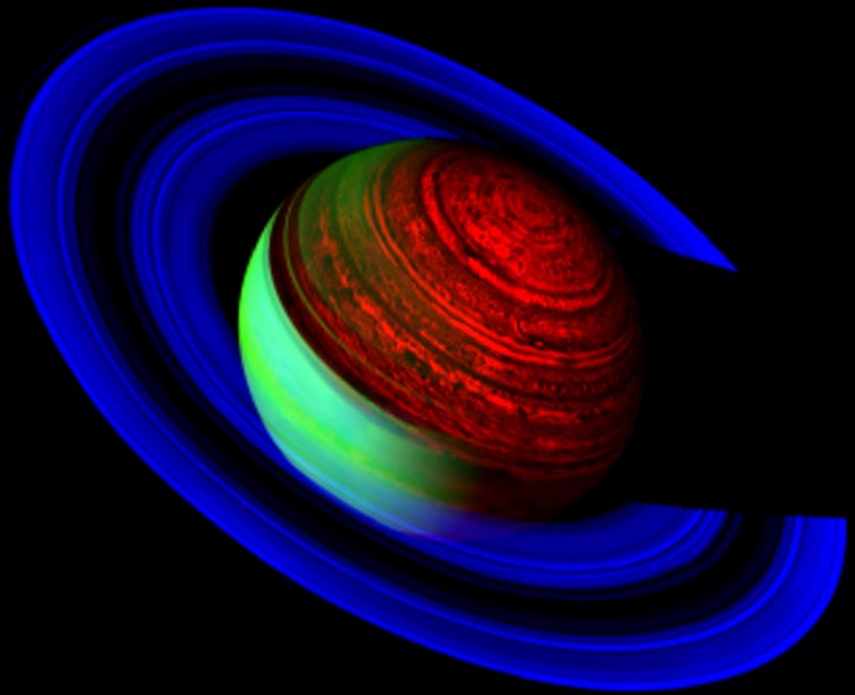


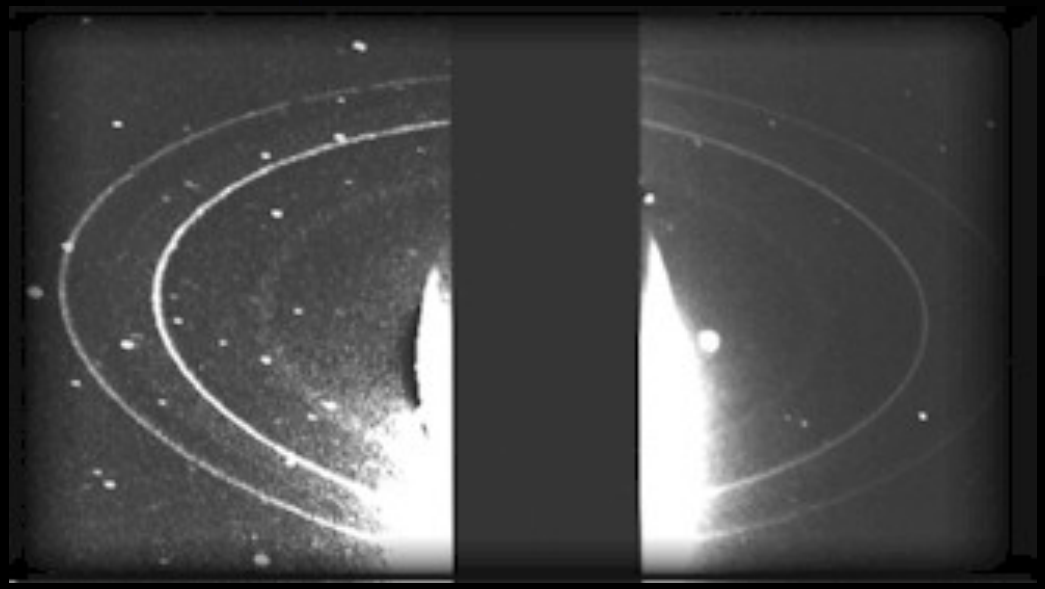


Barnes et al (2009 ApJ)

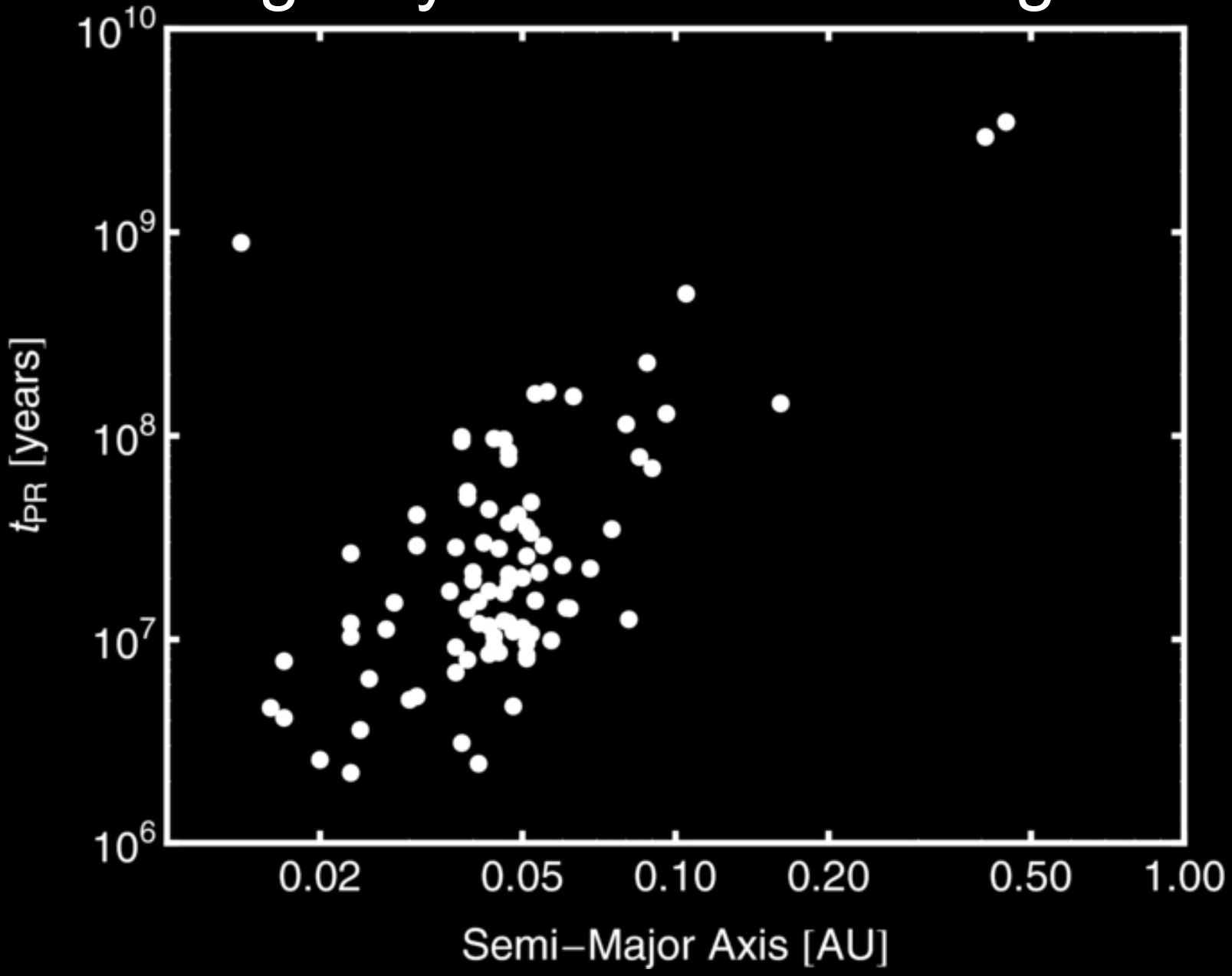
Rings in the Solar System





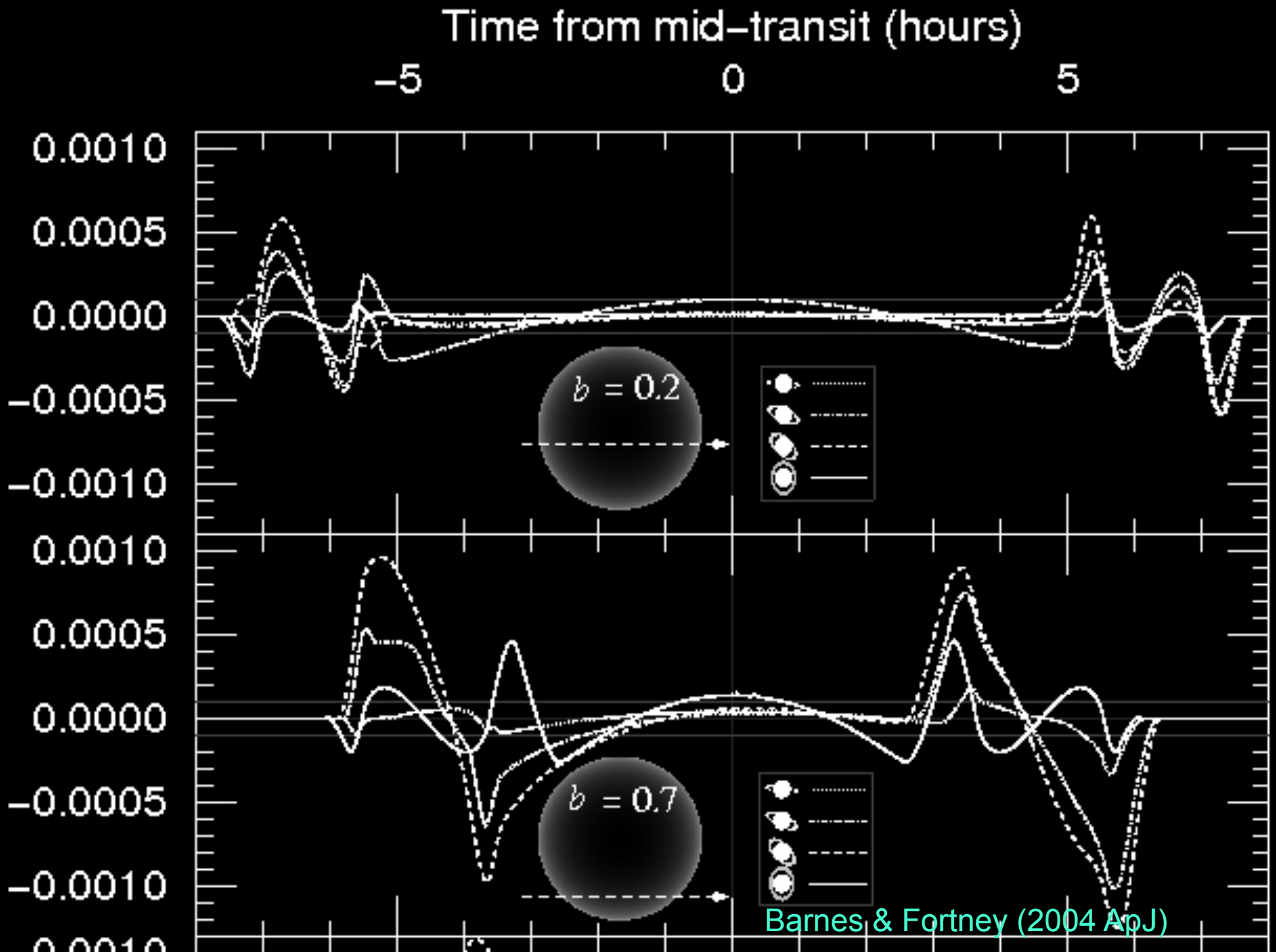


Longevity of Extrasolar Rings



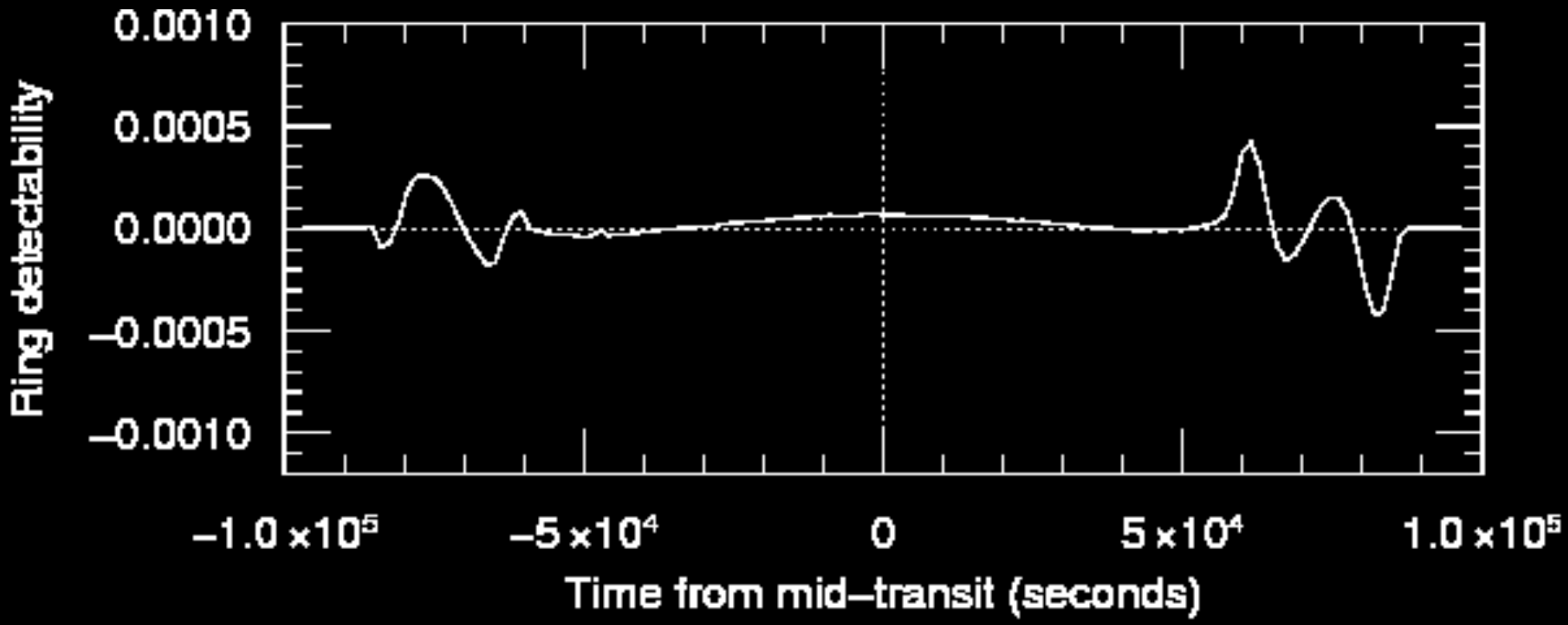
Schlichting & Chang (2011 ApJ)

Detectability of Ring Systems



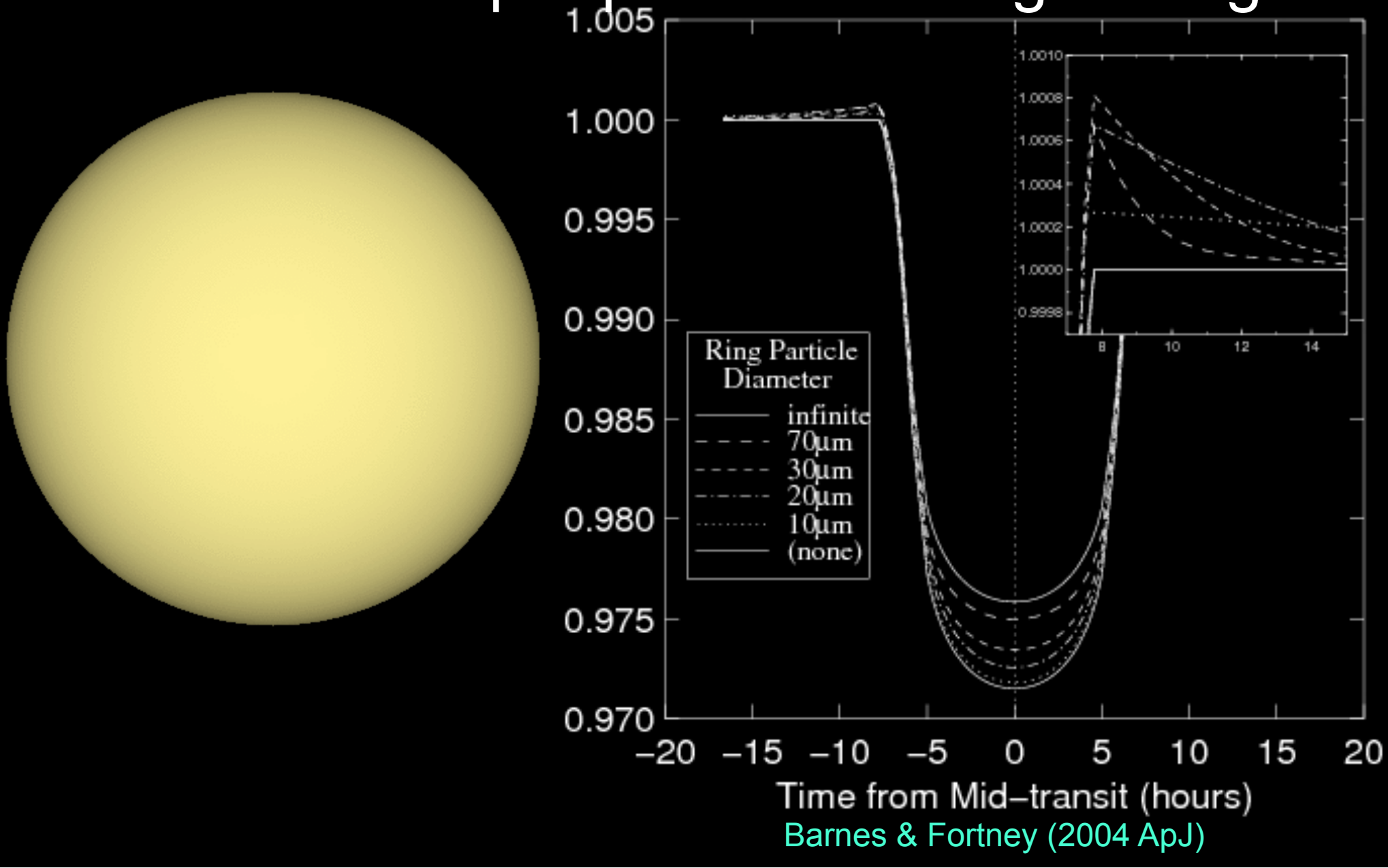
Barnes & Fortney (2004 ApJ)

Detectability of Saturn



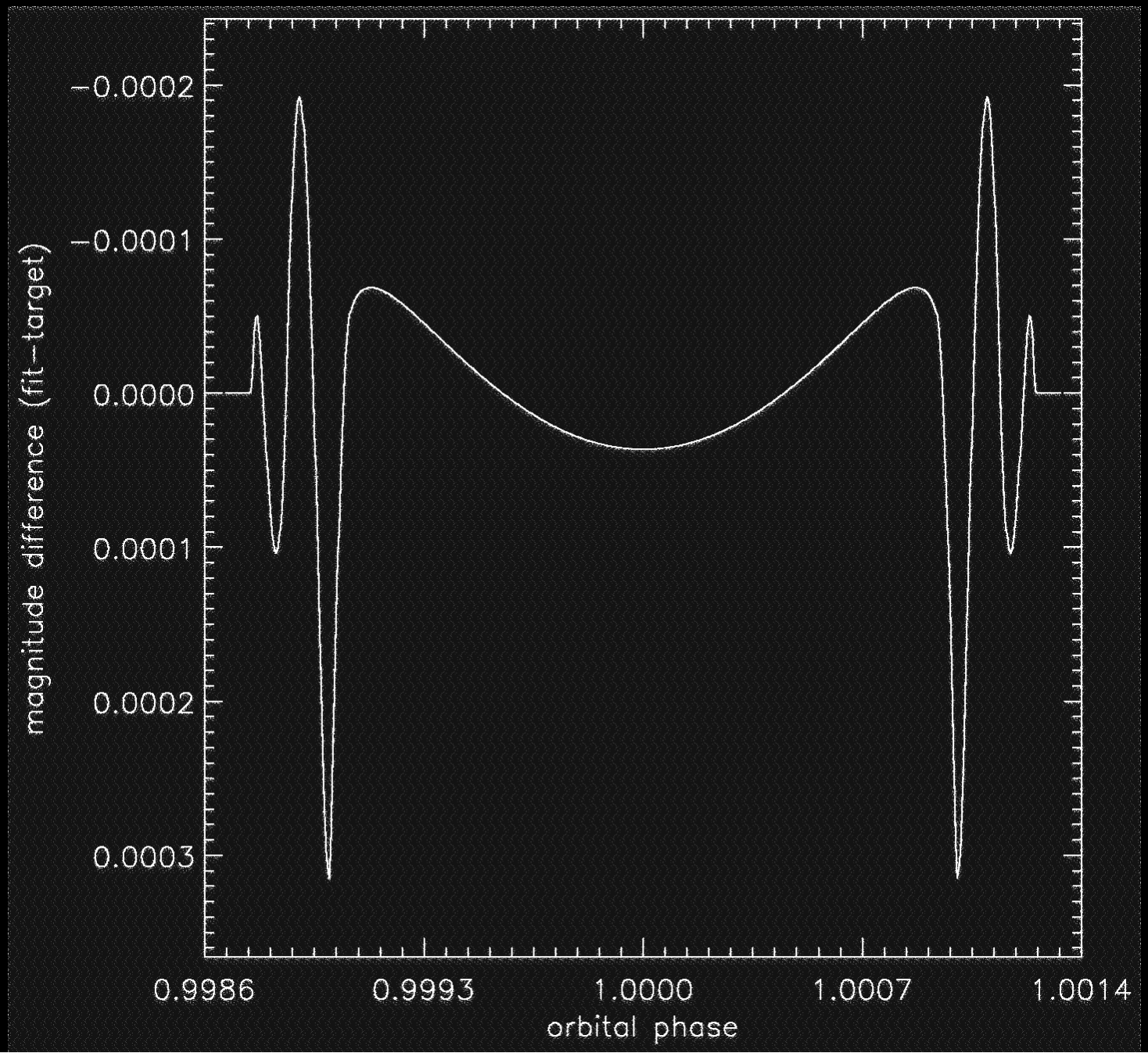
Barnes & Fortney (2004 ApJ)

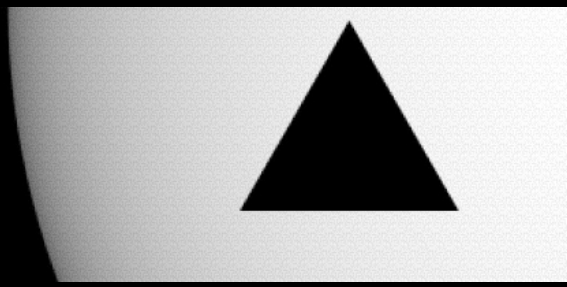
Ring Particle Diffraction can lead to pre/post transit brightening



Barnes & Fortney (2004 ApJ)

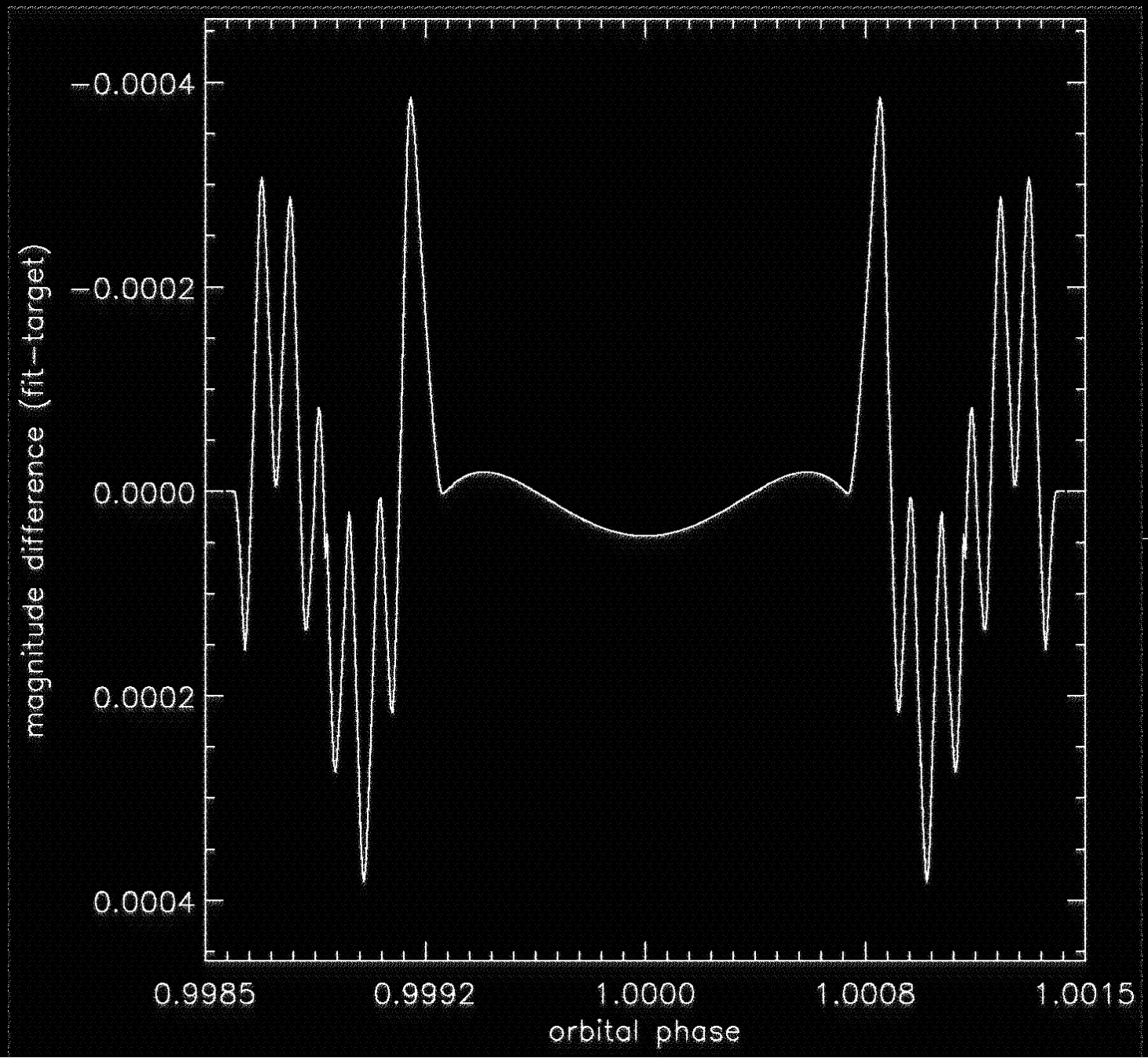
Signatures of Artificial Objects (aliens?)

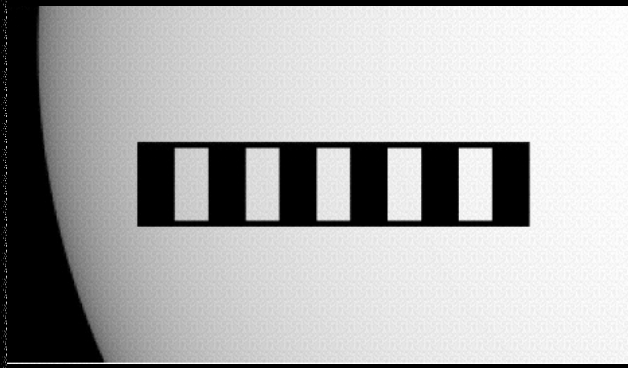




Arnold (2005 ApJ)

Signatures of Artificial Objects (aliens!)



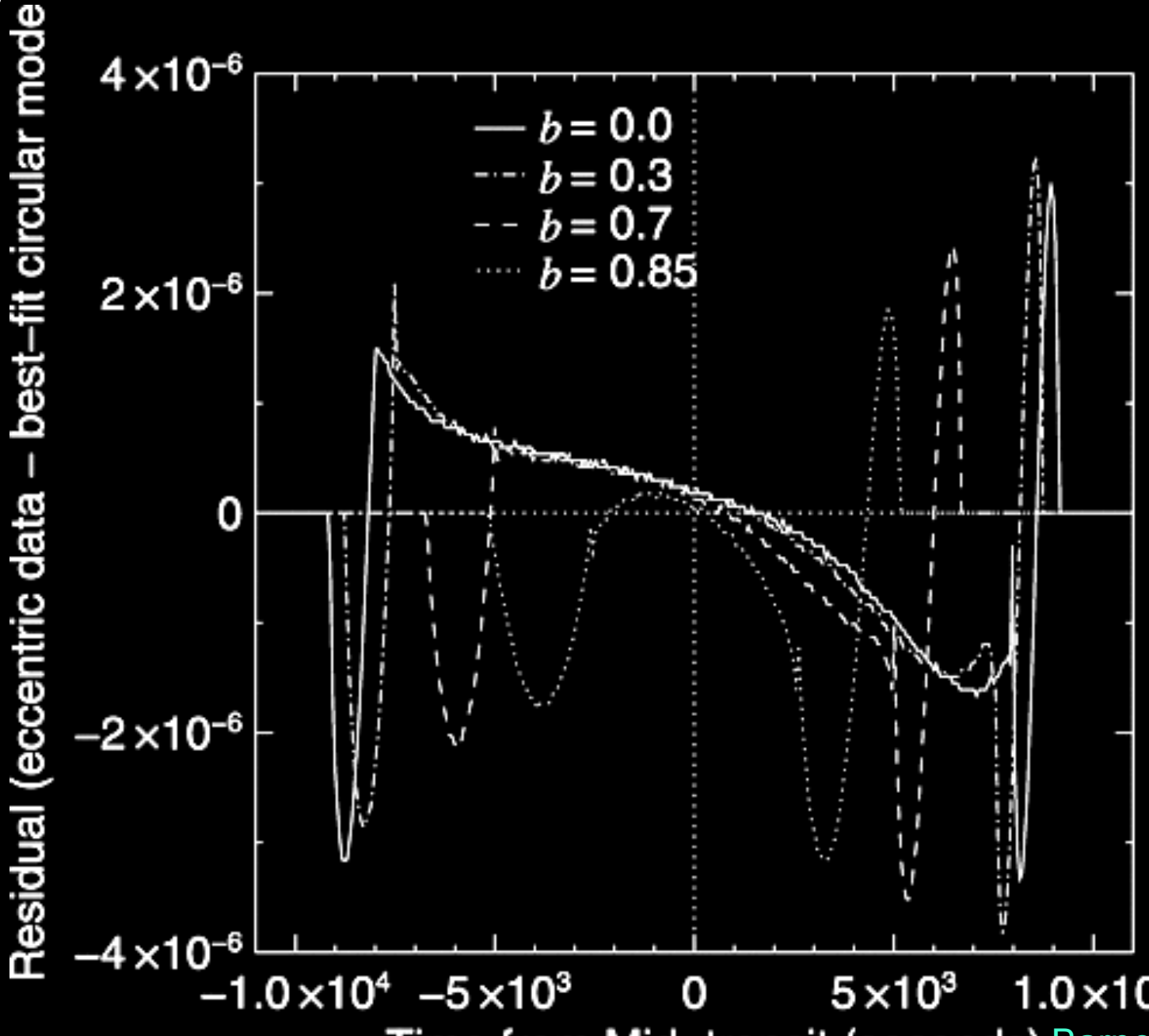


Arnold (2005 ApJ)

Lightcurve Deviations for Eccentric Orbits

Barnes (2007 PASP)

Lightcurve Deviations for Eccentric Orbits



Barnes (2007 PASP)

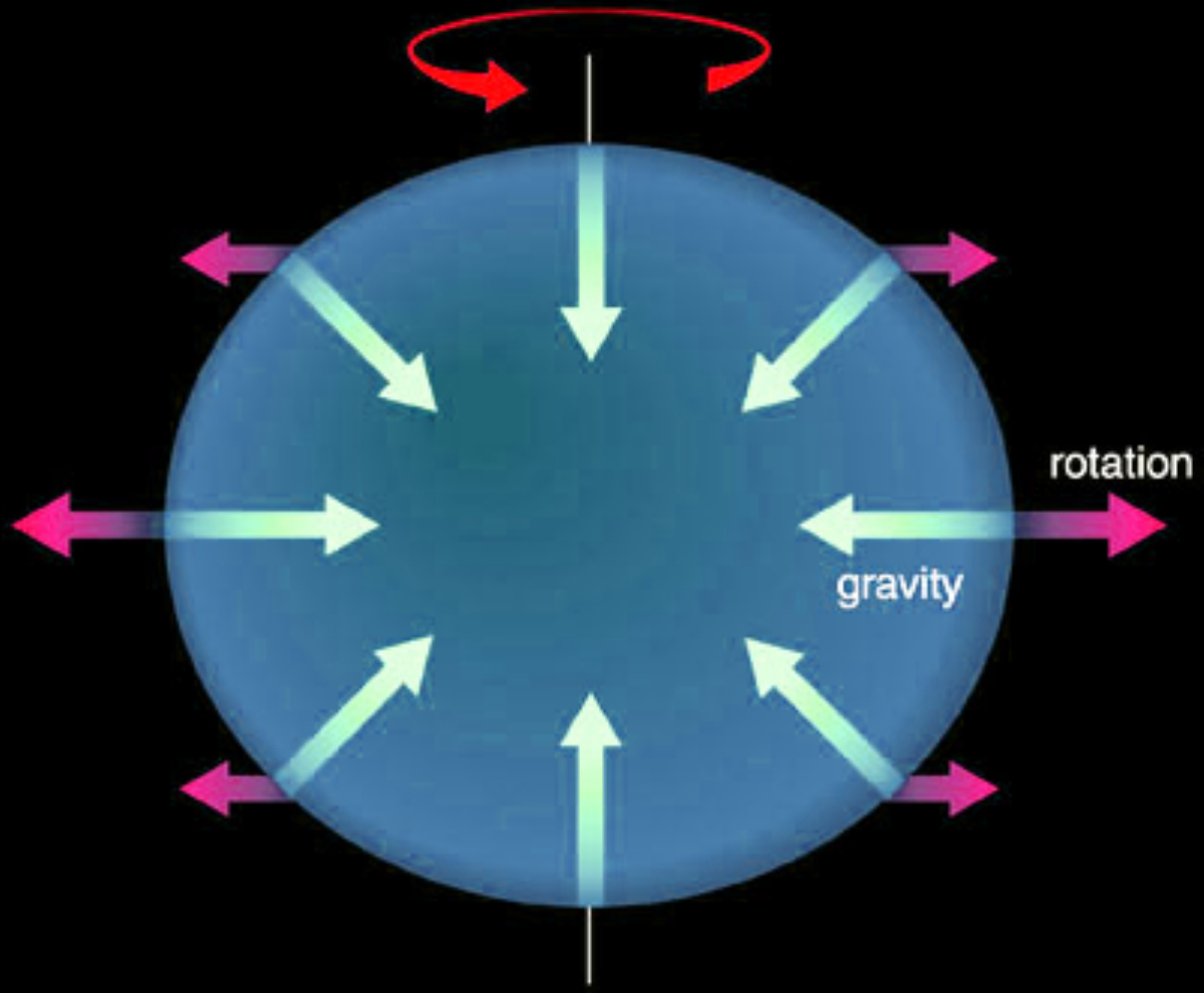
Gravity Darkening

$T = T_{pole}\,(g/g_{pole})^{1/4}$

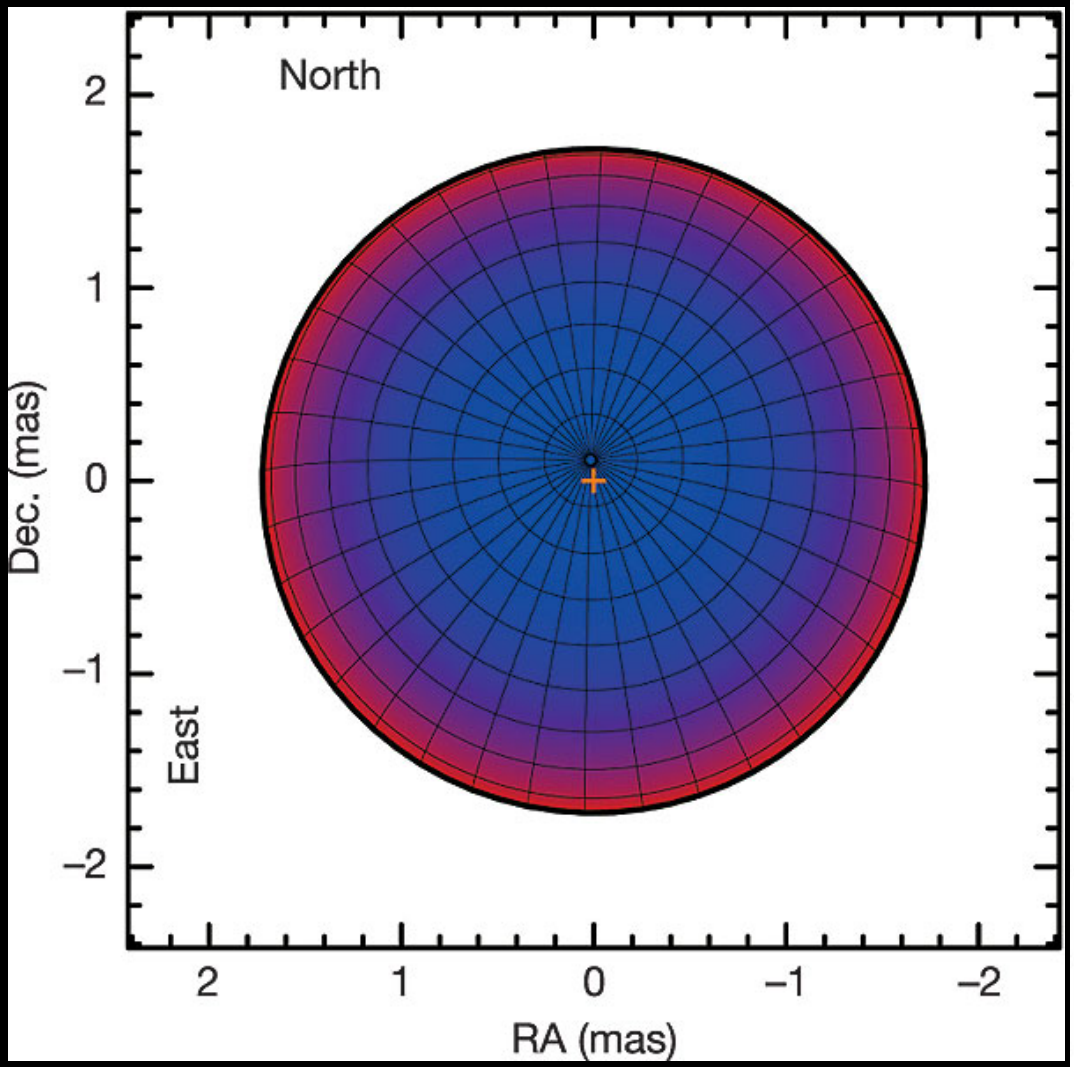
von Zeipel (1924)

$F = \sigma T^4$

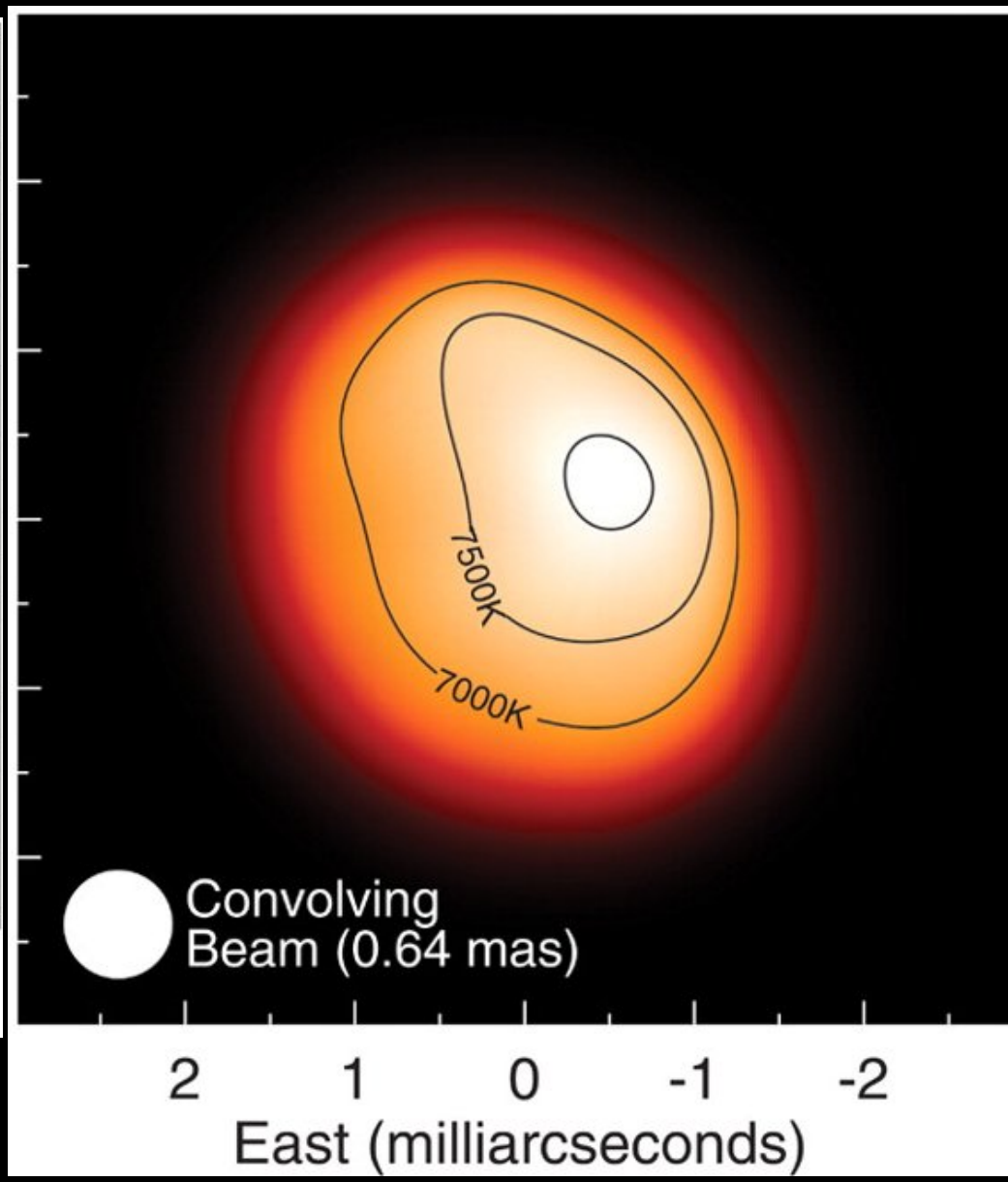
$F = F_{pole}\,(g/g_{pole})$



Optical Interferometric Imaging of Fast-Rotators

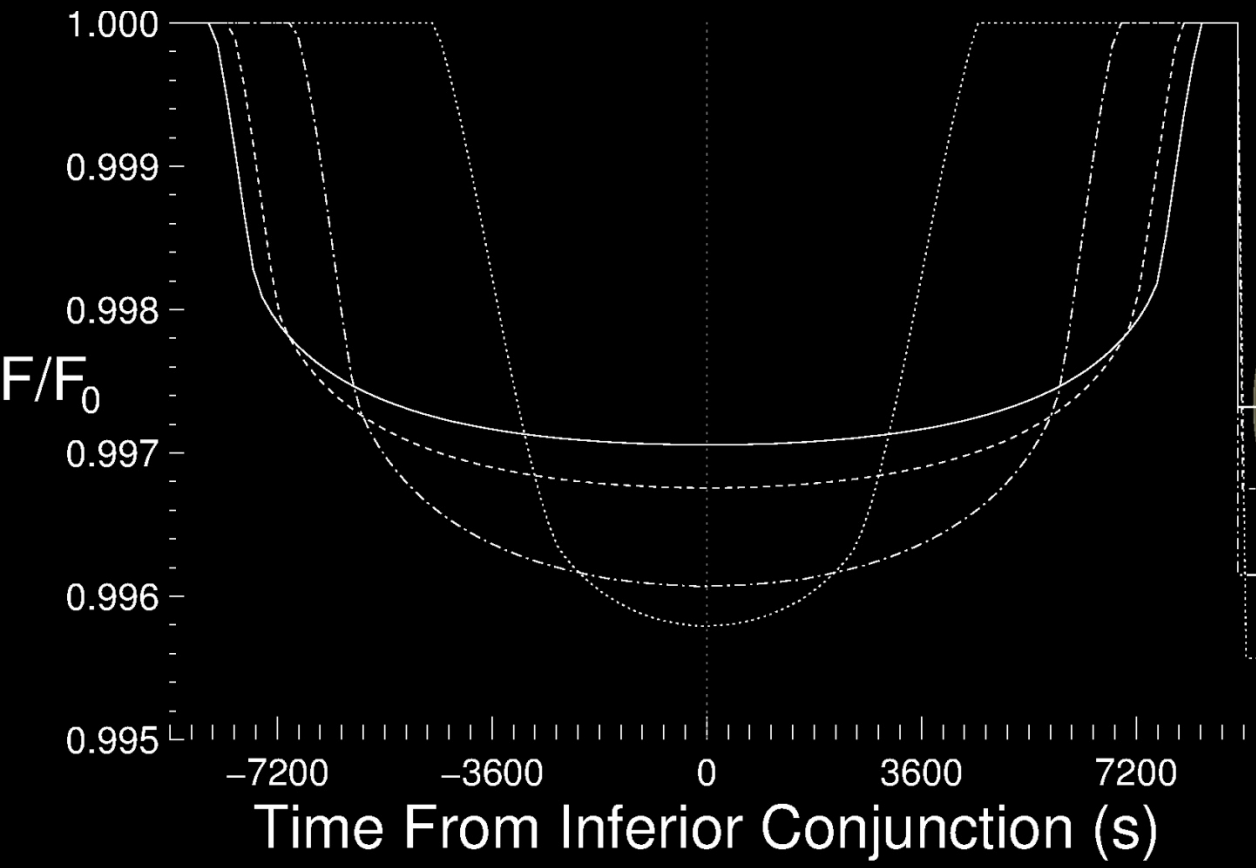


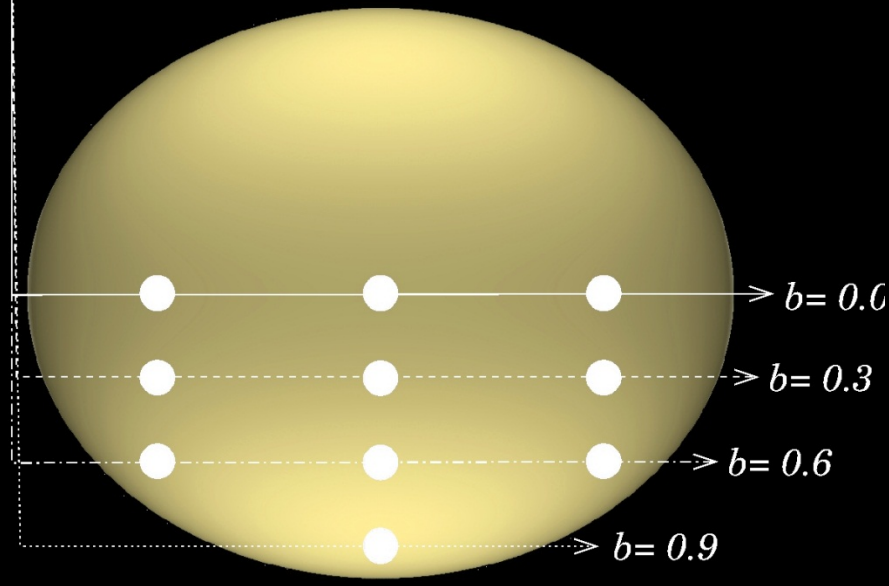
Vega (Alpha Lyrae) model
Peterson *et al.* 2006



Altair (Alpha Aquilae) image
Monnier *et al.* 2007

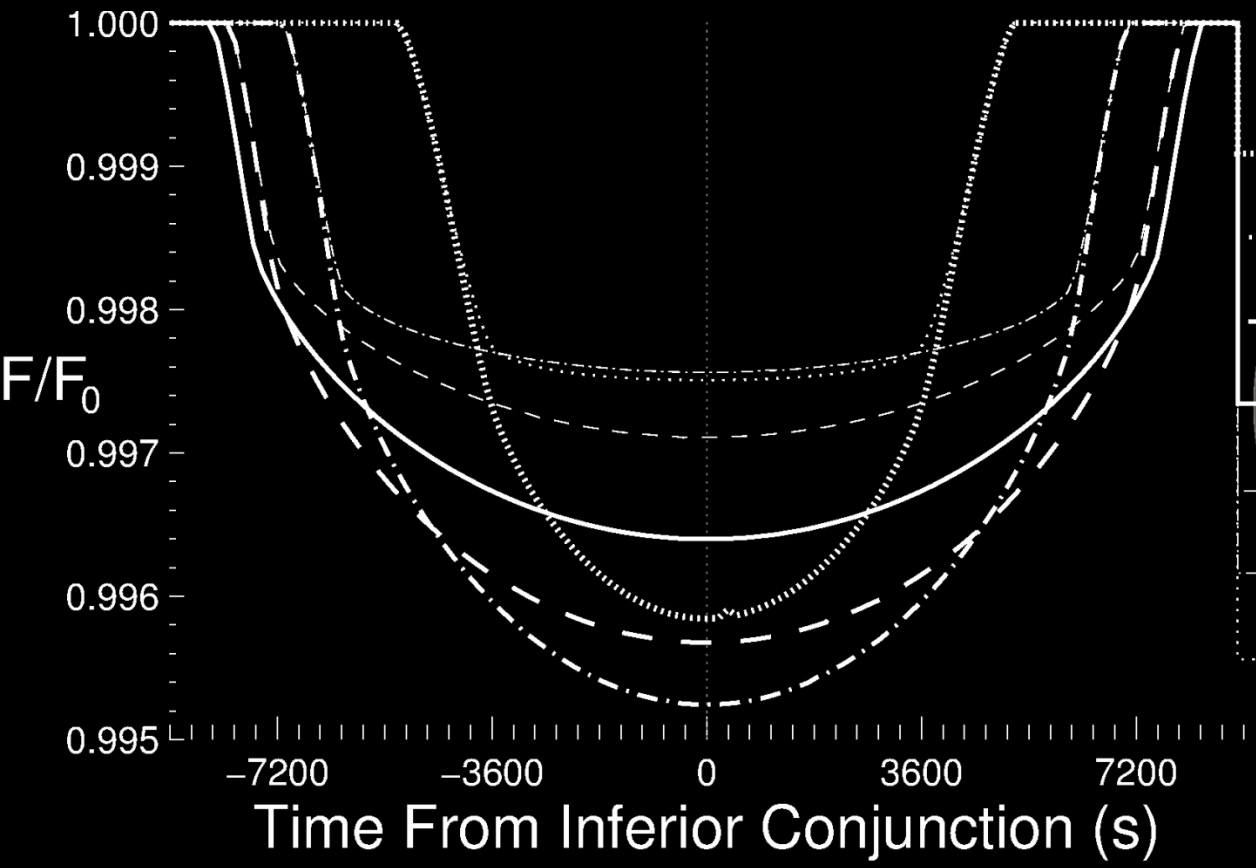
Star Obliquity 0, spin-orbit aligned

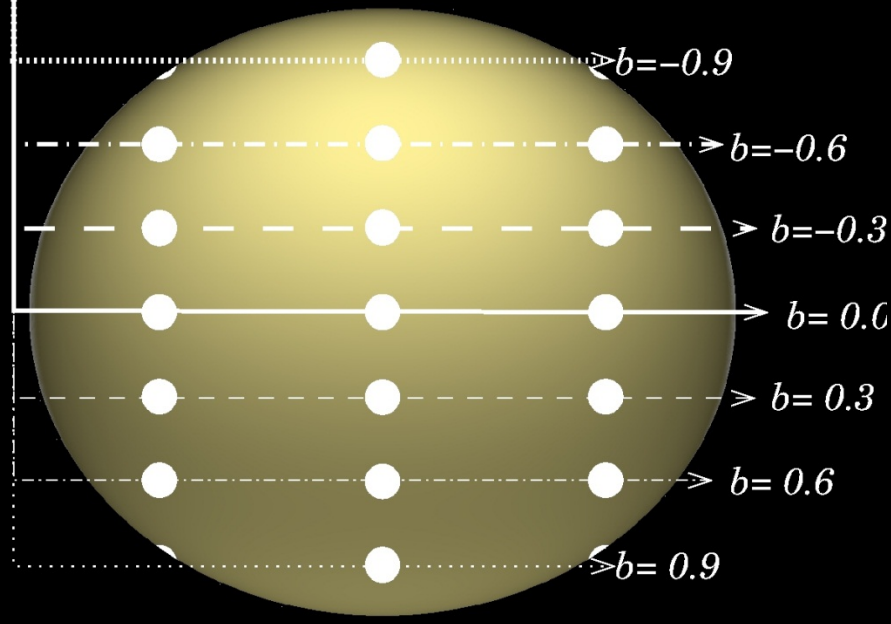




Barnes (2009 ApJ)

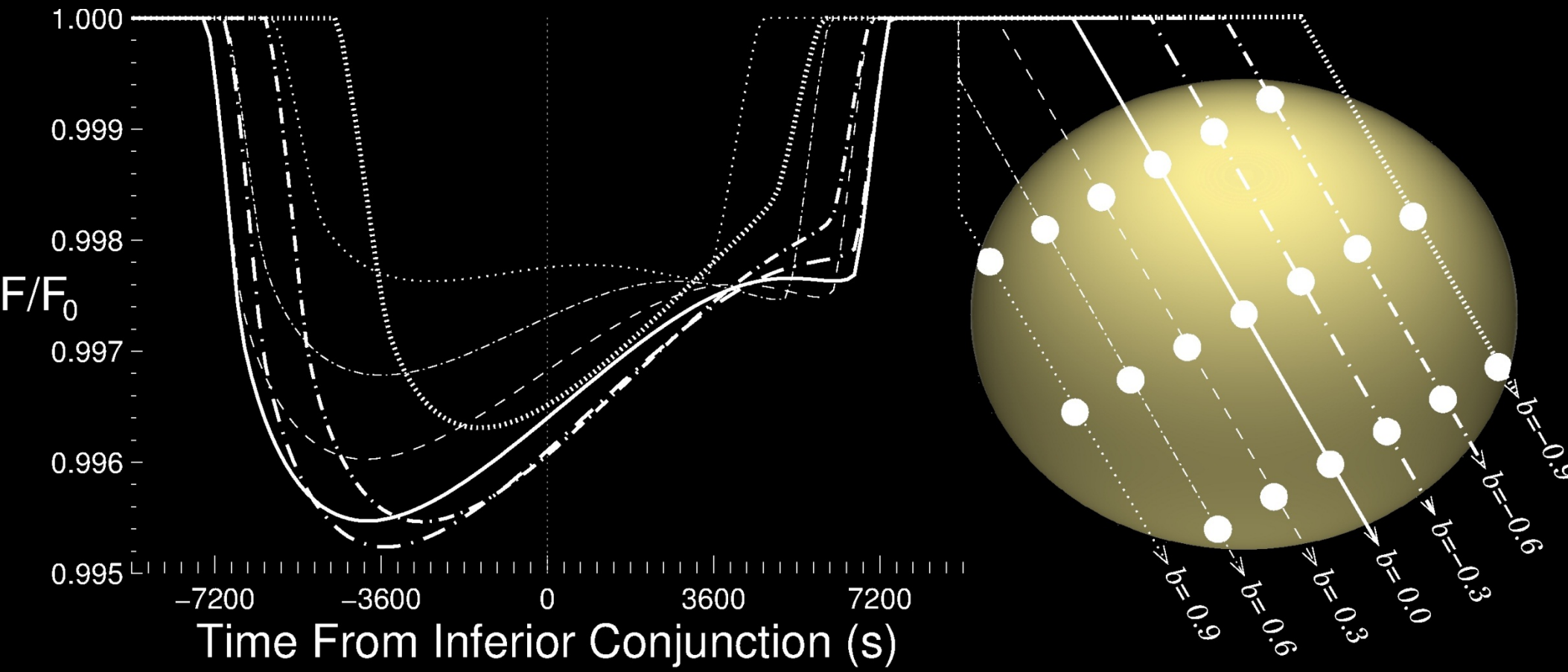
Star Obliquity 30, misaligned





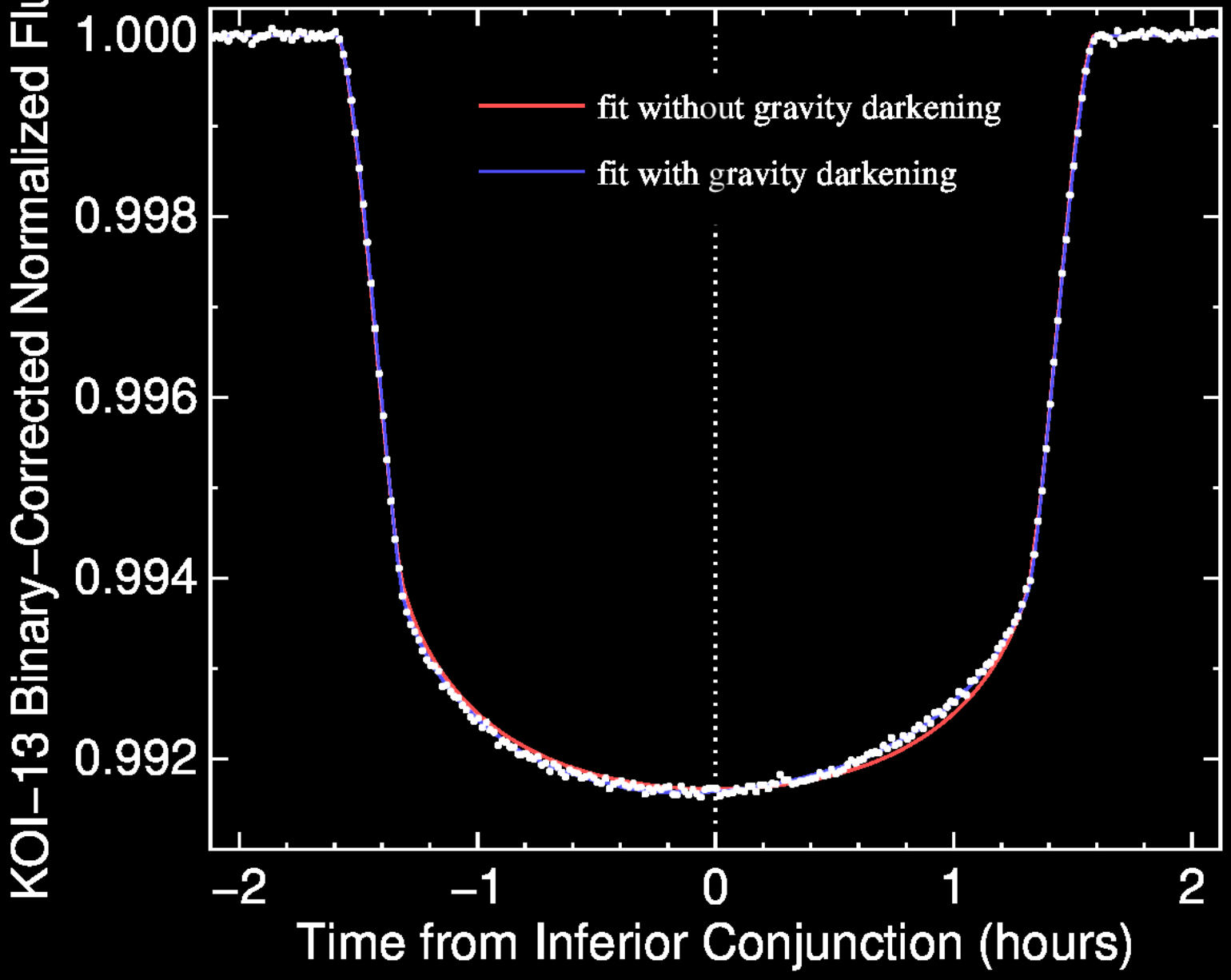
Barnes (2009 ApJ)

Star Obliquity 30, misaligned



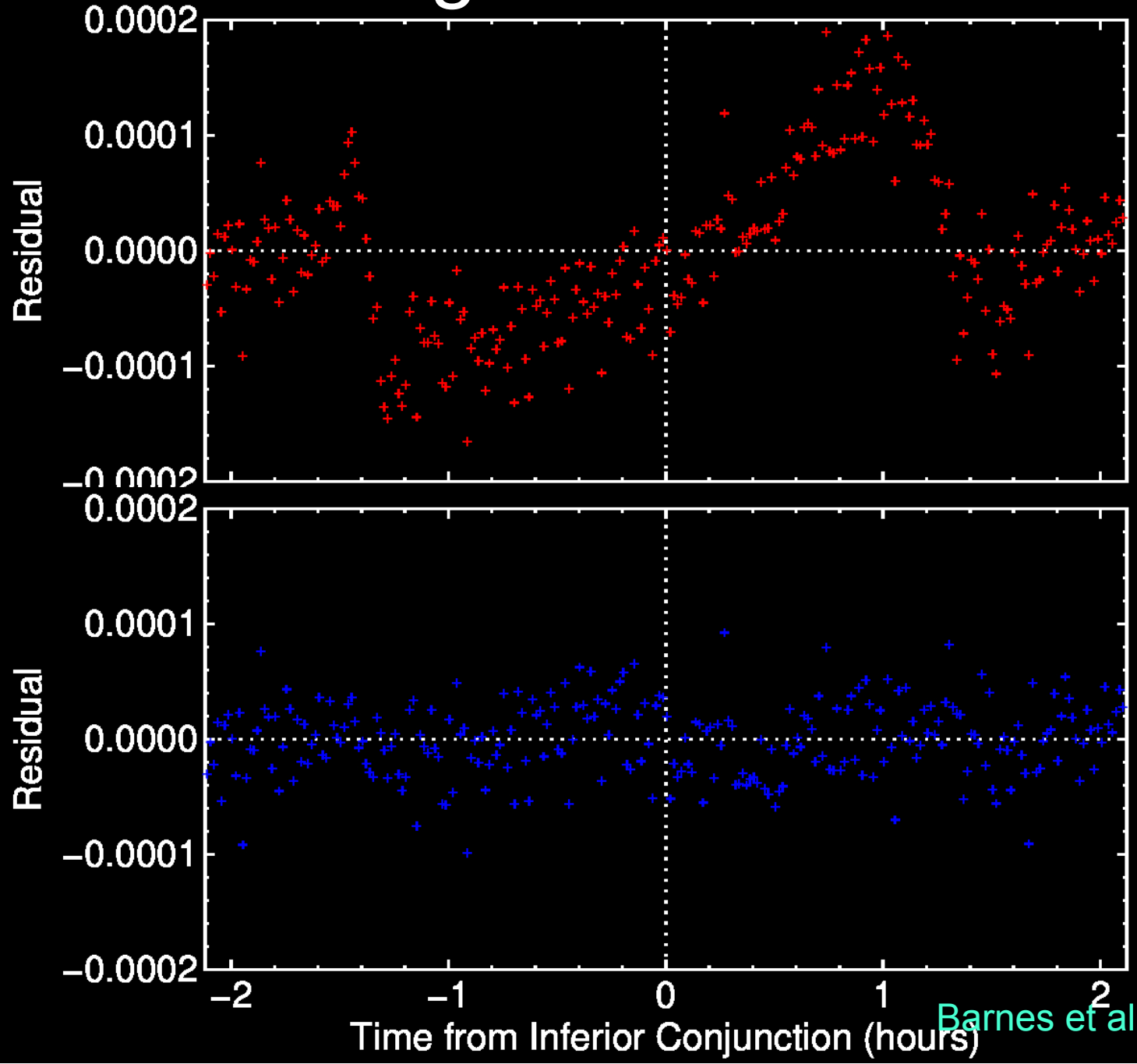
Barnes (2009 ApJ)

KOI-13 Lightcurve Fits



Barnes et al. (2011 ApJS)

KOI-13 Lightcurve Residuals



Barnes et al. (2011 ApJS)

KOI-13 Transit Best-Fit Parameters

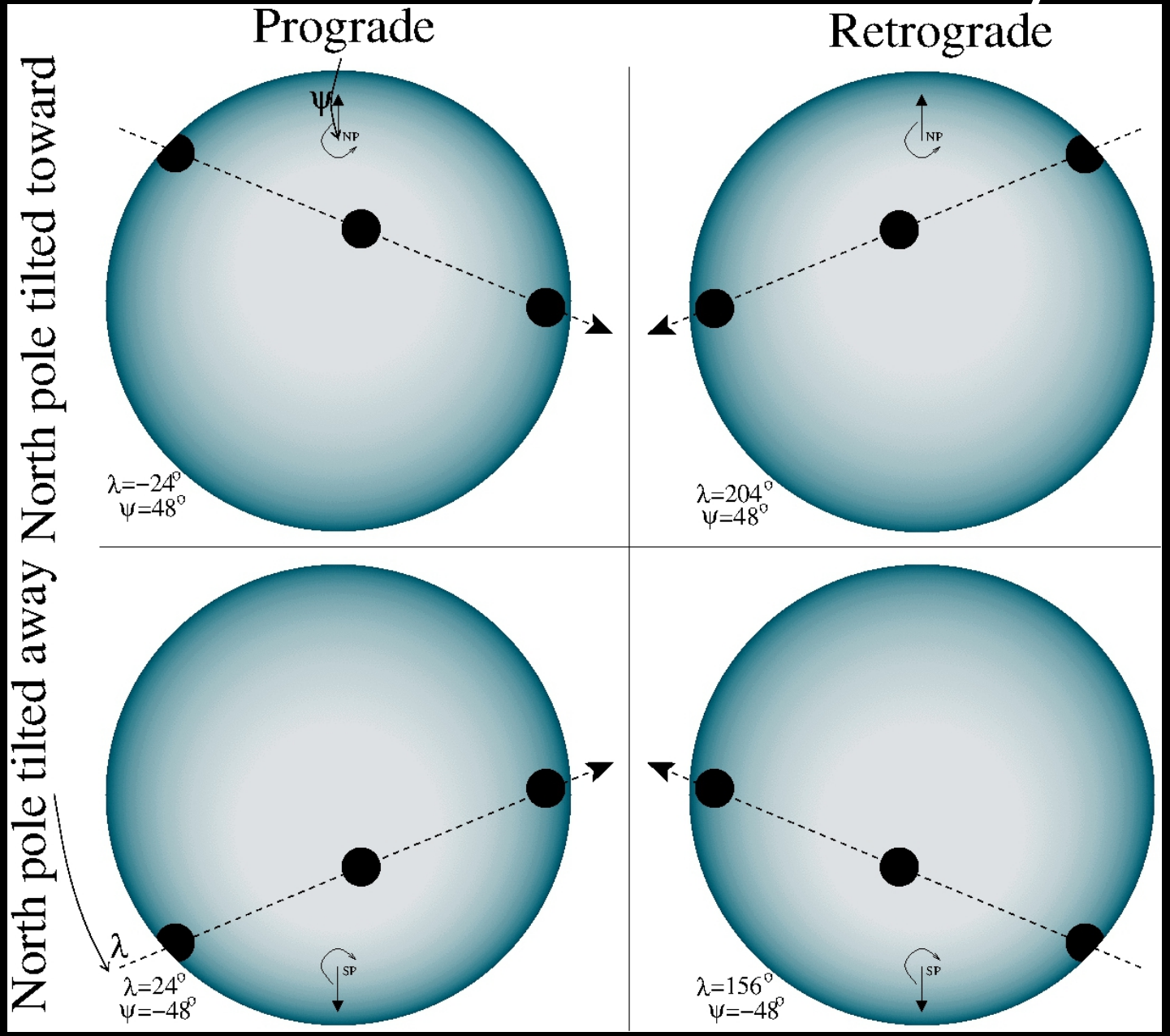
TABLE 1

BEST-FIT TRANSIT PARAMETERS FOR THE KOI-13.01 SYSTEM.

Parameter	Best-Fit Values $M_* = 1.83\ M_\odot$	$M_* = 2.05\ M_\odot$
$\chi^2_{\rm reduced}$	1.409	1.419
R_*	$1.694 \pm 0.013\ R_\odot$	$1.756 \pm 0.014\ R_\odot$
$R_{\rm p}$	$1.393 \pm 0.015\ R_{\rm Jup}$	$1.445 \pm 0.016\ R_{\rm Jup}$
$\frac{R_{\rm p}}{R_*}$	0.084508	0.084513
i	$85.9° \pm 0.1°$	$85.9° \pm 0.4°$
b	0.31962	0.31598
c_1	0.49 ± 0.03	0.48 ± 0.03
T_0	4628032 ± 3 s	4628033 ± 3 s
M_*	$(0.9 \pm 0.6\ M_\odot)$	
λ	$24° \pm 4°$	$23° \pm 4°$
ψ	$-45° \pm 4°$	$-48° \pm 4°$
φ	$54° \pm 4°$	$56° \pm 4°$
$P_{\rm rot*}$	22.5 hr	22.0 hr
f_*	0.018	0.021

Barnes et al. (2011 ApJS)

KOI-13 Transit Geometry



Barnes et al. (2011 ApJS)

Summary: Possible Causes of Funny-Shaped Lightcurves

- Planetary Oblateness
  - Detectable signal (10^{-4}) when high obliquity, high oblateness
  - Low signal (10^{-5}) when low obliquity
  - Watch for precession in close-in planets
- Winds
  - Tiny signal – can mimic oblateness signature for big E-W jets
- Rings
  - Potentially Large signal (10^{-3}) for thick, extended, Saturn-like rings
  - Diffraction can lead to pre- and post-transit brightening – but be careful
- Artificial objects
  - Would extraterrestrial civilizations communicate with transits? Look for weird stuff
- Eccentricity
  - Unfortunately microscopic signal (10^{-6}) even in best cases
- Gravity darkening
  - Possibly huge signal (10^{-2}); detected at 10^{-4} level for KOI-13.01