

Continuing Observations of PTFO 8-8695b, a 3Myr-old T-Tauri Planet Candidate

Julian van Eyken
NExSci/Caltech

D. R. Ciardi (PTF Orion P.I.),¹ J. W. Barnes,⁴ T. M. Brown,^{3,14} D. Dragomir,³ J. Eastman,¹⁵ C. A. Beichman,¹ G. van Belle,⁵ K. von Braun,^{5,6} S. Carey,¹ C. Crockett,⁷ J. J. Fortney,⁸ S. B. Howell,⁹ B. K. Jackson,¹⁰ C. Johns-Krull,¹¹ S. R. Kane,¹² T. Lister,³ J. McLane,^{13,5} P. Plavchan,¹⁶ L. Prato,⁵ A. Shporer,¹ J. R. Stauffer,¹ and the PTF collaboration

¹Caltech, ²U.C. Santa Barbara, ³LCOGT, ⁴U. Idaho, ⁵Lowell Observatory, ⁶MPIA-Heidelberg, ⁷US Naval Observatory, Flagstaff, ⁸U.C. Santa Cruz, ⁹NASA Ames, ¹⁰Carnegie Institution for Science, ¹¹Rice Univ., ¹²San Francisco State Univ., ¹³N. Arizona Univ., ¹⁴U. Colorado, Boulder, ¹⁵CfA, ¹⁶Missouri State Univ.

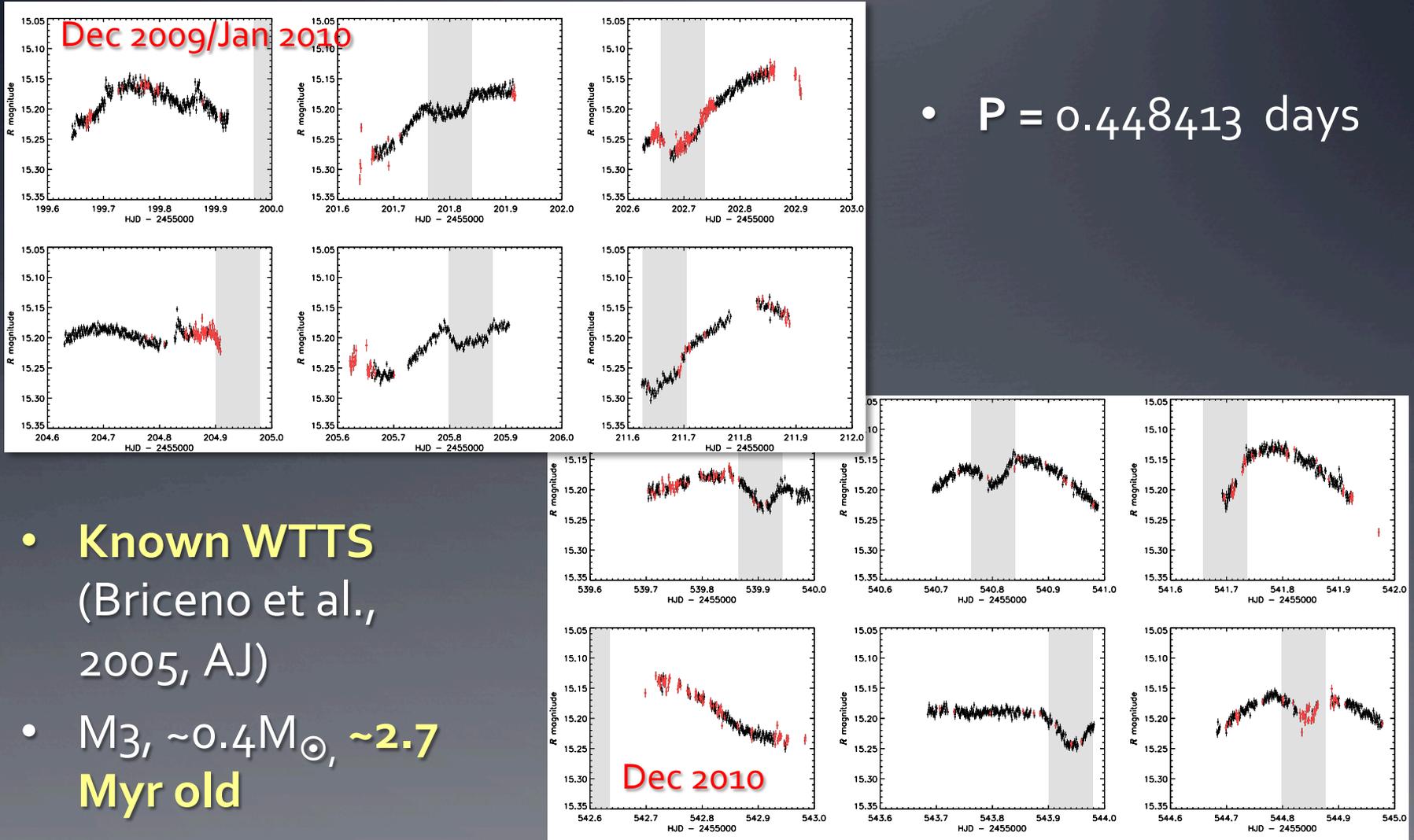
Caltech, May 2015

PTF Orion – 2009/2010

- Young transit search in 7-10Myr 25-Ori association
- Part of Palomar Transient Factory survey
- ~80 s cadence, R-band
- ~7,000 exposures, ~110,000 light curves

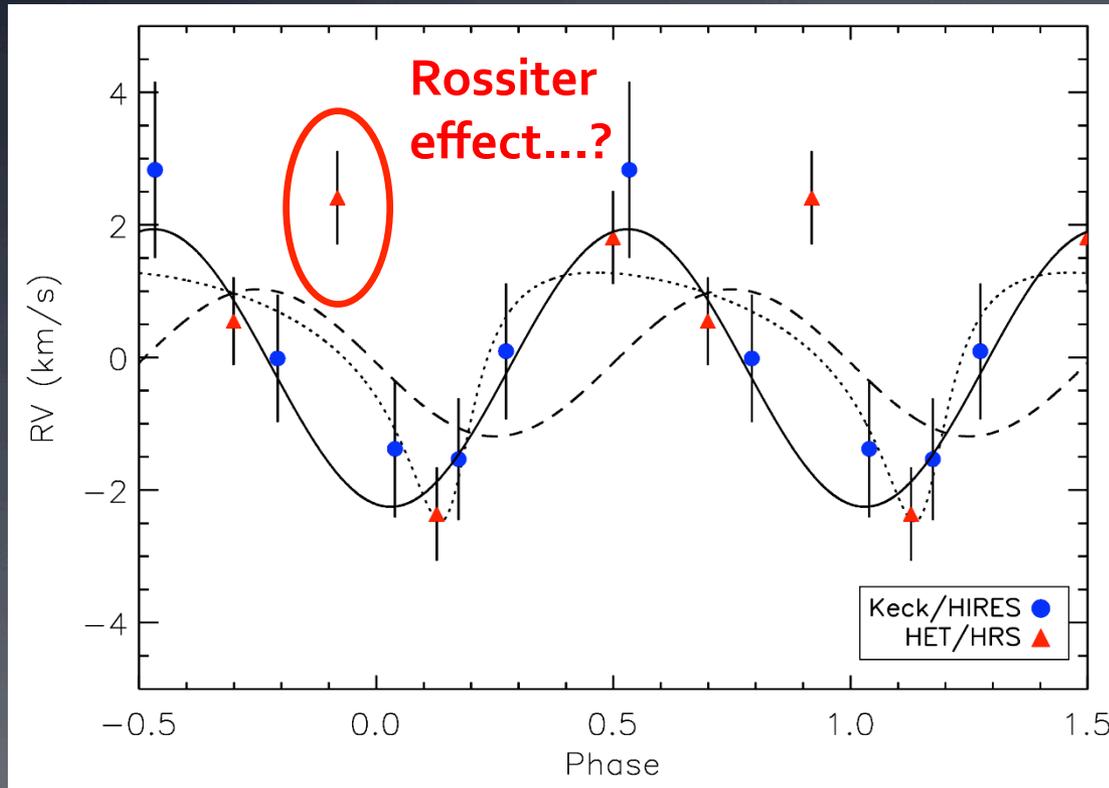


PTFO 8-8695



Original Keck+HET RV follow-up

RV Folded on Transit Period



— — Circular fit, fixed to transit phase

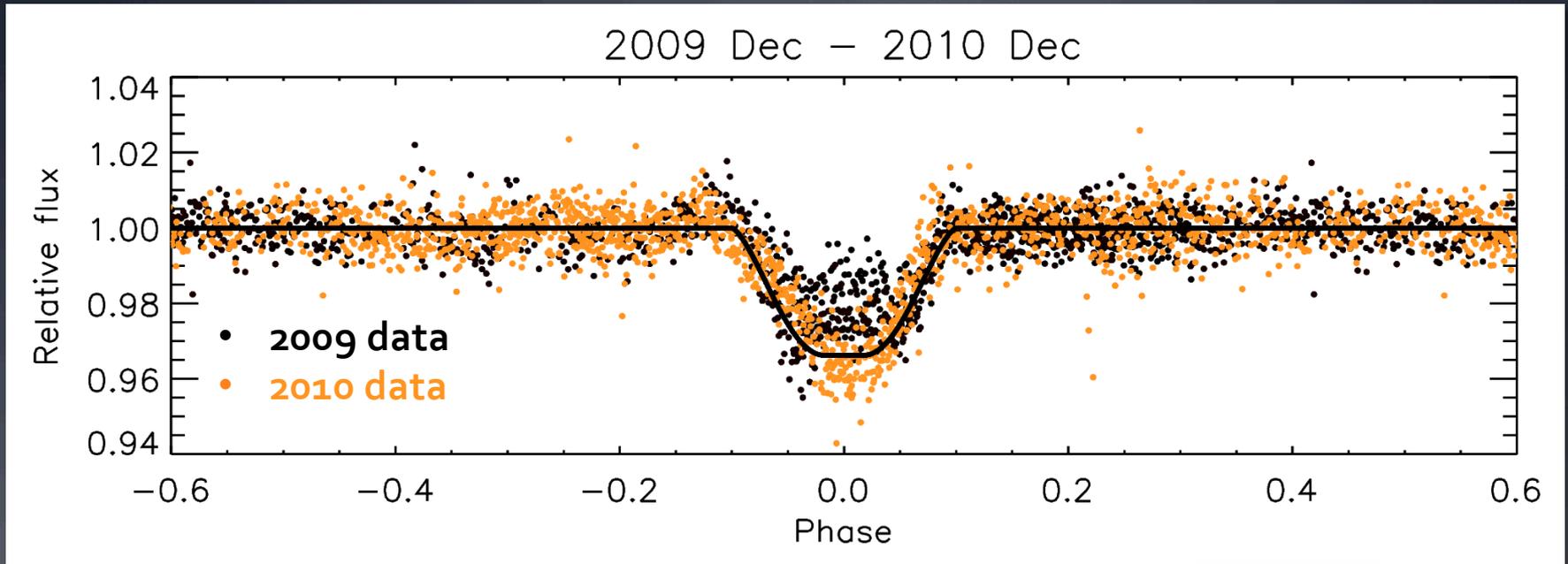
⋯⋯⋯ Eccentric fit, fixed to transit phase – *maybe unlikely?*

— Sinusoidal (circular) fit, floating phase

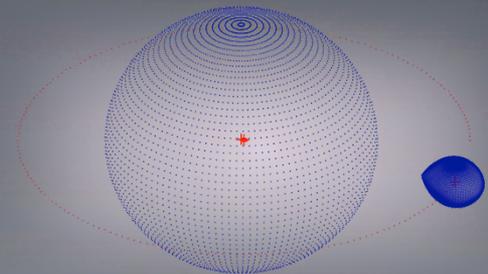
- *Signal probably dominated by star spots since out of phase*
- Upper limit, $M_p \sin i \leq 4.8 \pm 1.2 M_{Jup} \Rightarrow M_p \leq 5.5 \pm 1.4 M_{Jup}$

Whitened and Folded Light Curve

Stellar variability removed:

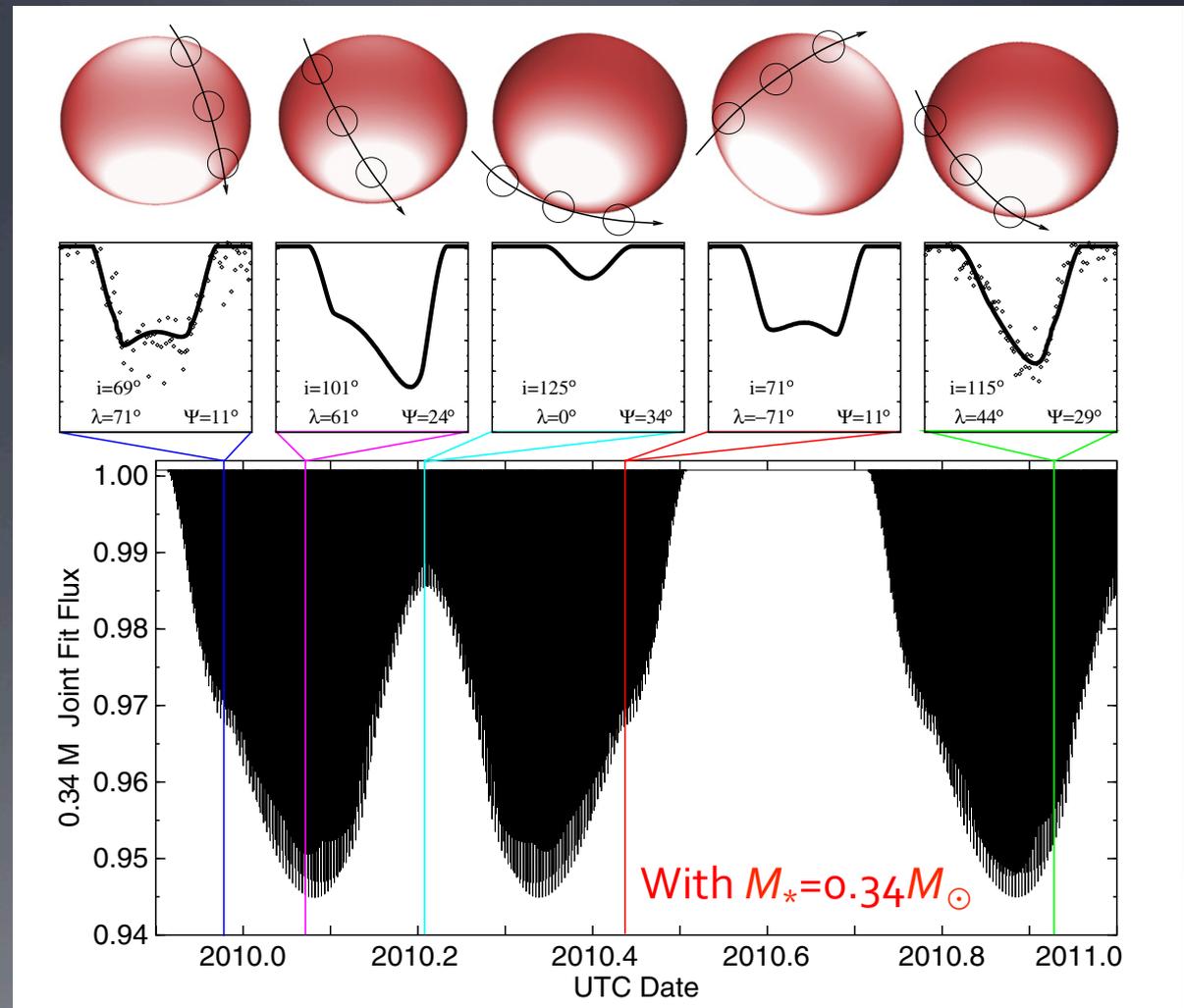


- Transit shape is v. difficult to model with star spots
- Periodogram analysis suggests stellar co-rotation
- But - second year looks *more grazing but deeper*



Grav. darkening + precession

- $J_{\text{star}} \sim J_{\text{orbit}} \Rightarrow$
star and orbit
both precess
- Can find
simultaneous fit
of all data
- **Transits are
expected to
disappear at
times!**



(Barnes et al. 2013)

Current best vital stats (Barnes et al. 2013)

- High obliquity
- *V. near Roche limit*

φ = angle
between J_*
and J_{orbit}



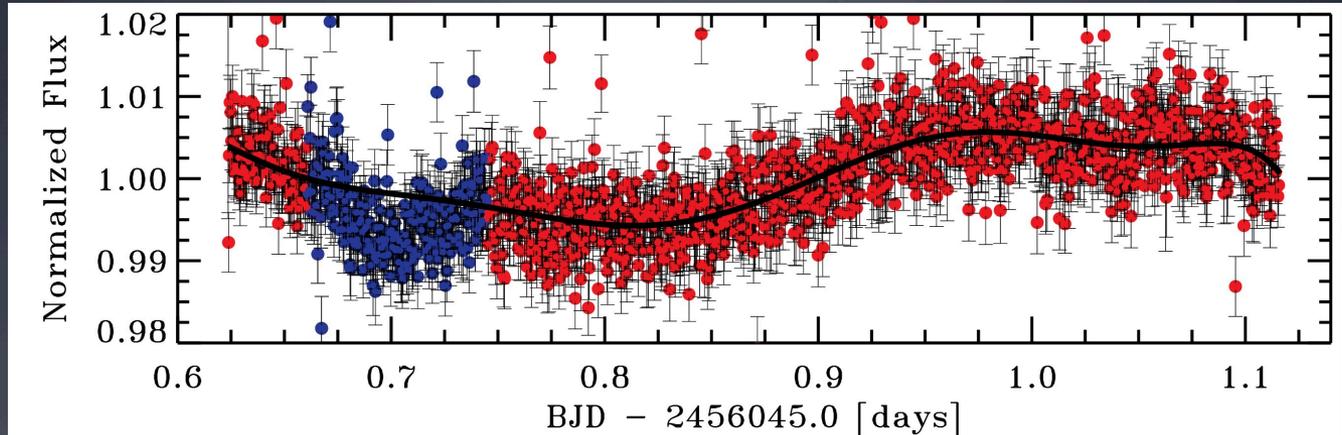
Table 3
Best-fit Parameters from the Self-consistent, Joint Fit of the 2009 and 2010 van Eyken et al. (2012) Lightcurves

	Parameters for Joint Fits	
	0.34 M_{\odot}	0.44 M_{\odot}
R_*	$1.04 \pm 0.01 R_{\odot}$	$1.03 \pm 0.01 R_{\odot}$
R_p	$1.64 \pm 0.07 R_{\text{Jup}}$	$1.68 \pm 0.07 R_{\text{Jup}}$
P	0.448410 ± 0.000004 days	0.448413 ± 0.000001 days
t_0	60848500 ± 100 s	60848363 ± 38 s
i	$114^{\circ}8 \pm 1^{\circ}6$	$110^{\circ}7 \pm 1^{\circ}3$
λ	$43^{\circ}9 \pm 5^{\circ}2$	$54^{\circ}5 \pm 0^{\circ}5$
ψ	$29^{\circ}4 \pm 0^{\circ}3$	$30^{\circ}3 \pm 1^{\circ}3$
M_p	$3.0 \pm 0.2 M_{\text{Jup}}$	$3.6 \pm 0.3 M_{\text{Jup}}$
φ	$69^{\circ} \pm 3^{\circ}$	$73^{\circ}1 \pm 0^{\circ}6$
φ_*	18°	$20^{\circ}2$
φ_p	51°	$52^{\circ}9$
$P_{\dot{\Omega}}$	-292.6 days	-581.2 days
f	0.109	0.083
χ_r^2	2.17	2.19

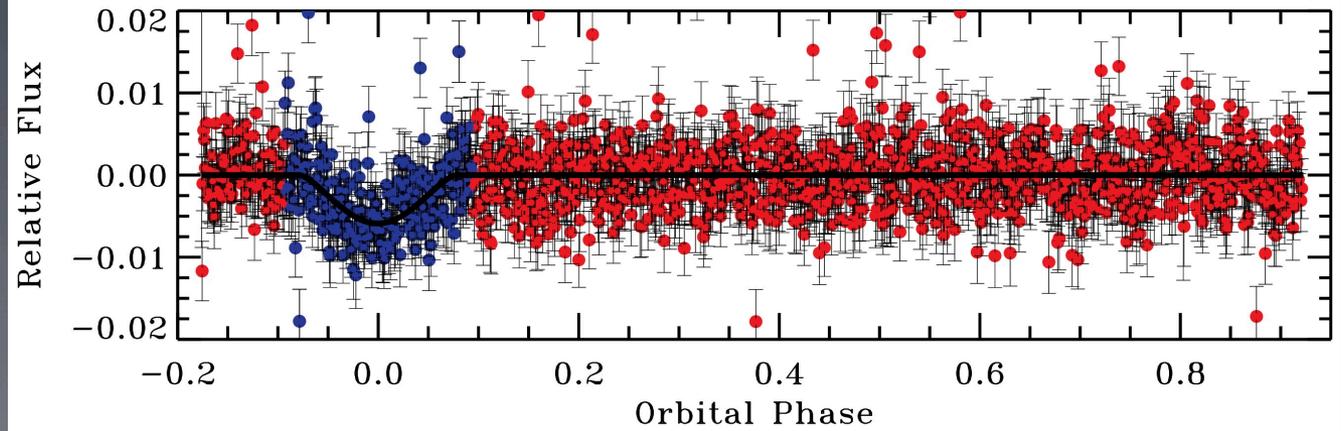
Notes. Epochs t_0 are measured in seconds after 2009 January 1 00:00 UTC (JD 2454832.5). The orbital period is P .

More followup - Spitzer 4.5 μm (April 2012)

Stellar light
curve

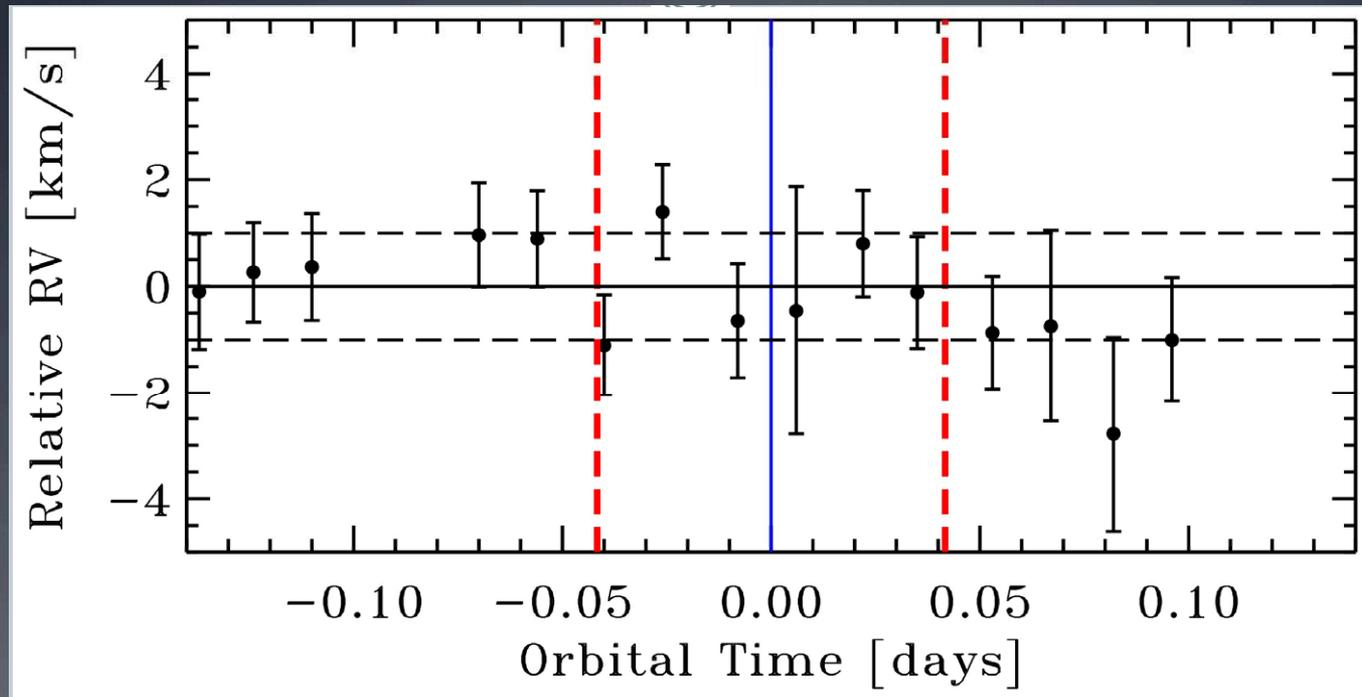


Variability
removed



Ciardi et al., ApJ submitted

Followup data, Keck NIRSPEC (Dec 2012)

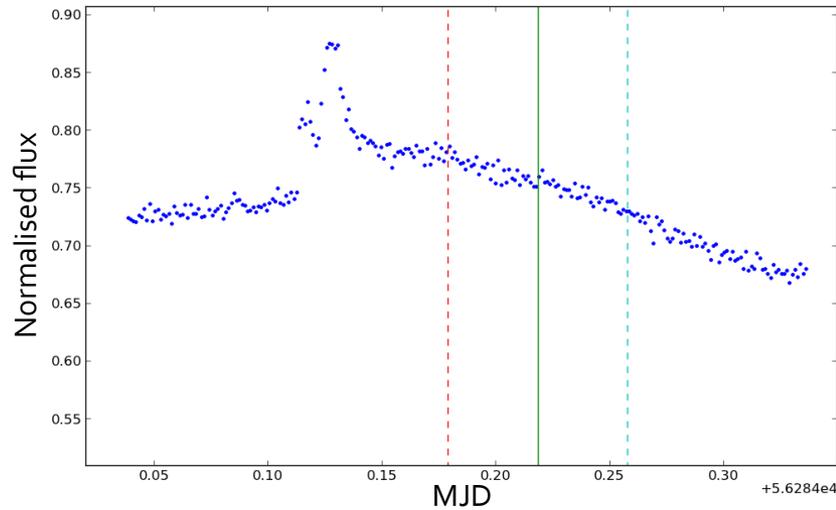


Ciardi et al., ApJ submitted

.... no obvious RM....

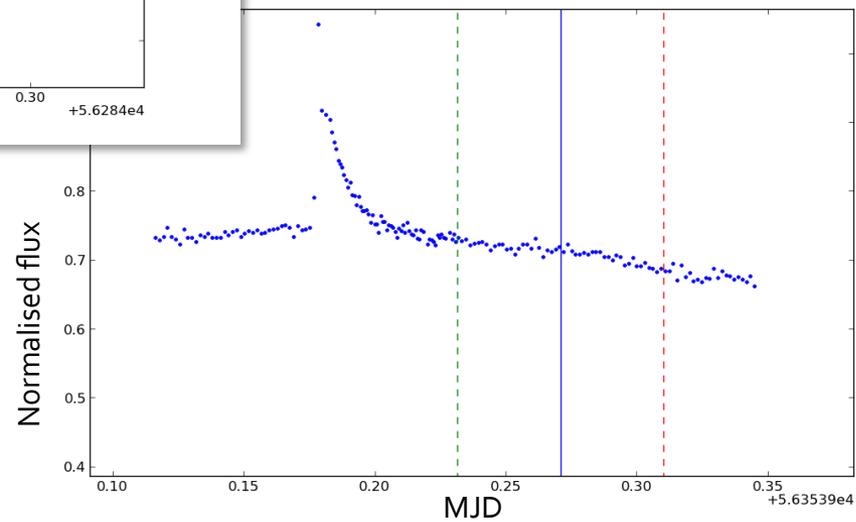
2012 LCOGT followup

Dec 2012



Flares, but -
no transits...?!

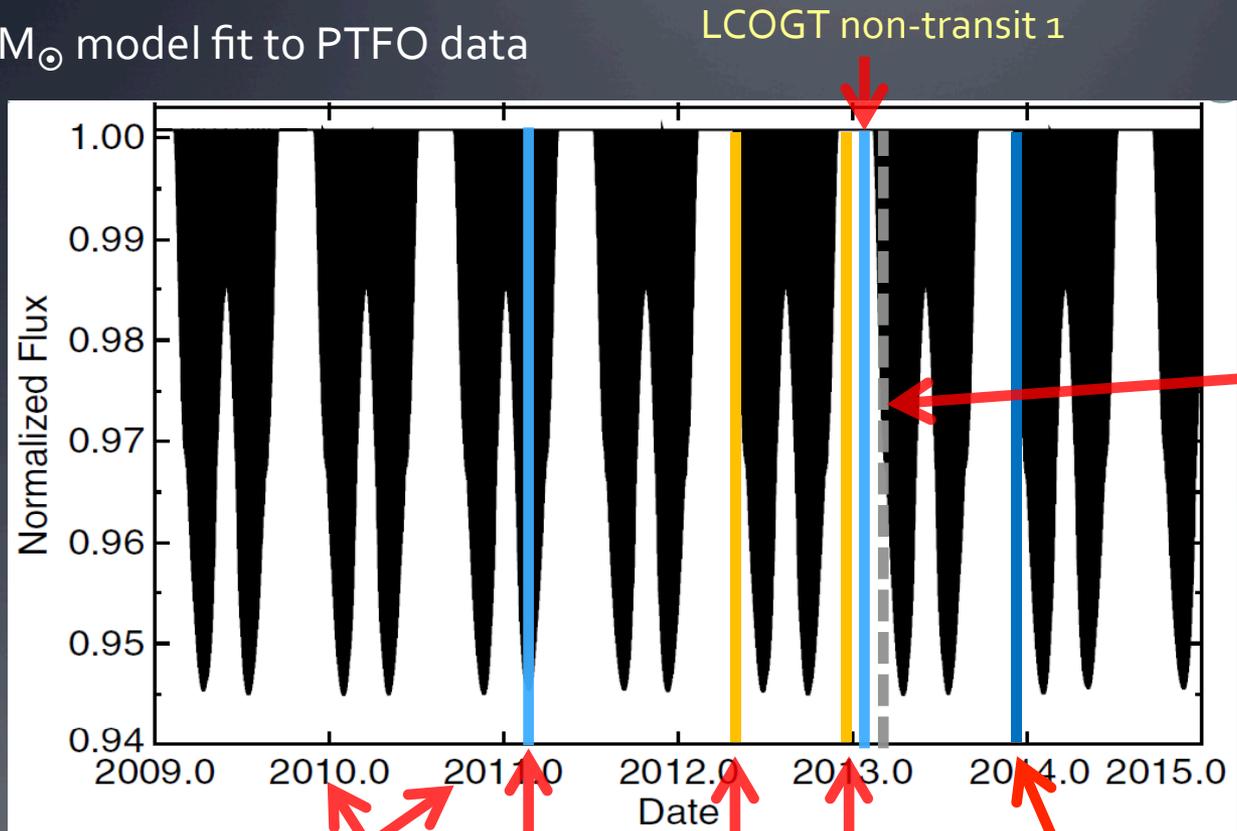
Mar 2013



(MJD = JD-2400000.5)

It all fits.... (almost)

$M_* = 0.34M_{\odot}$ model fit to PTFO data



PTFO Orion data

Suspected RM data point

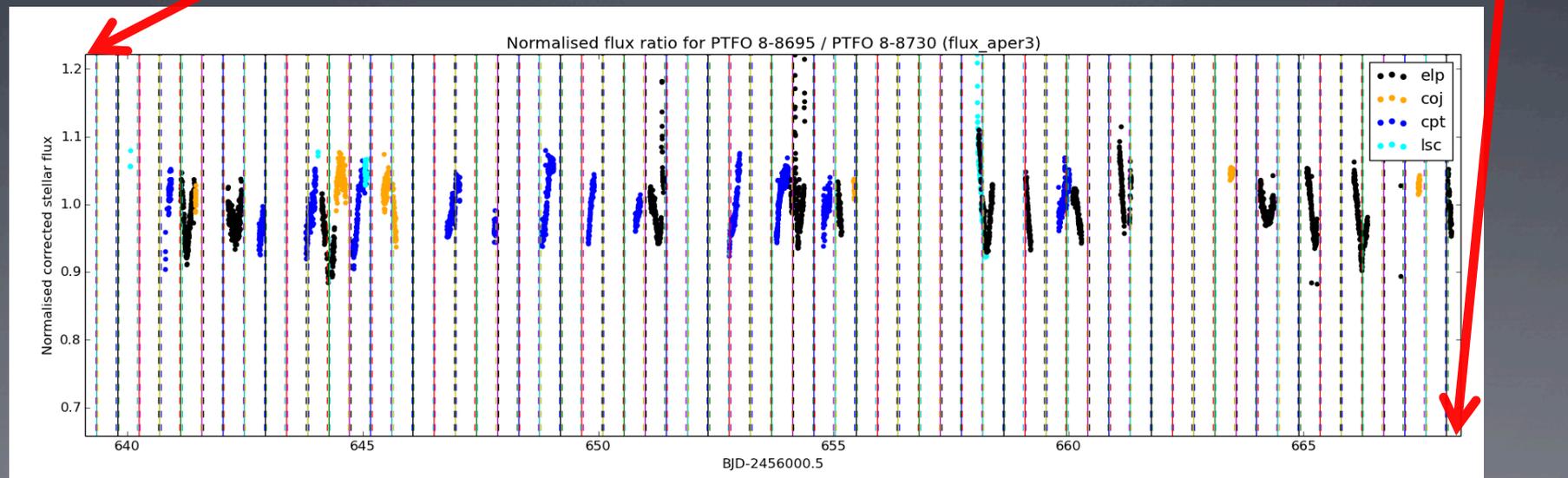
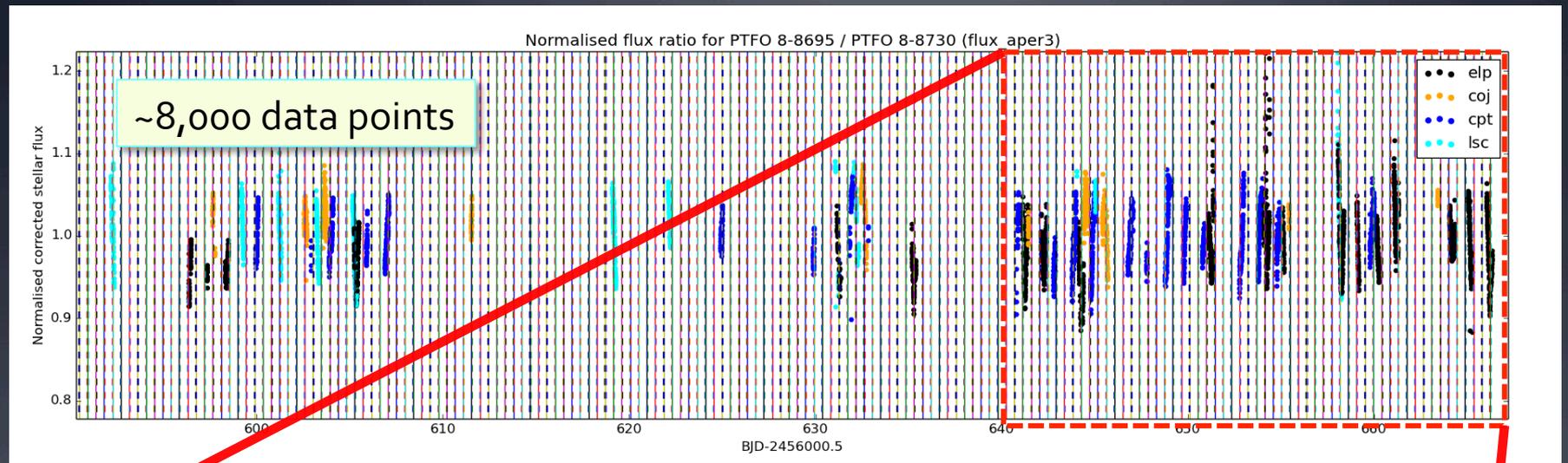
Shallow Spitzer transit

RM non-detection

Latest LCOGT...

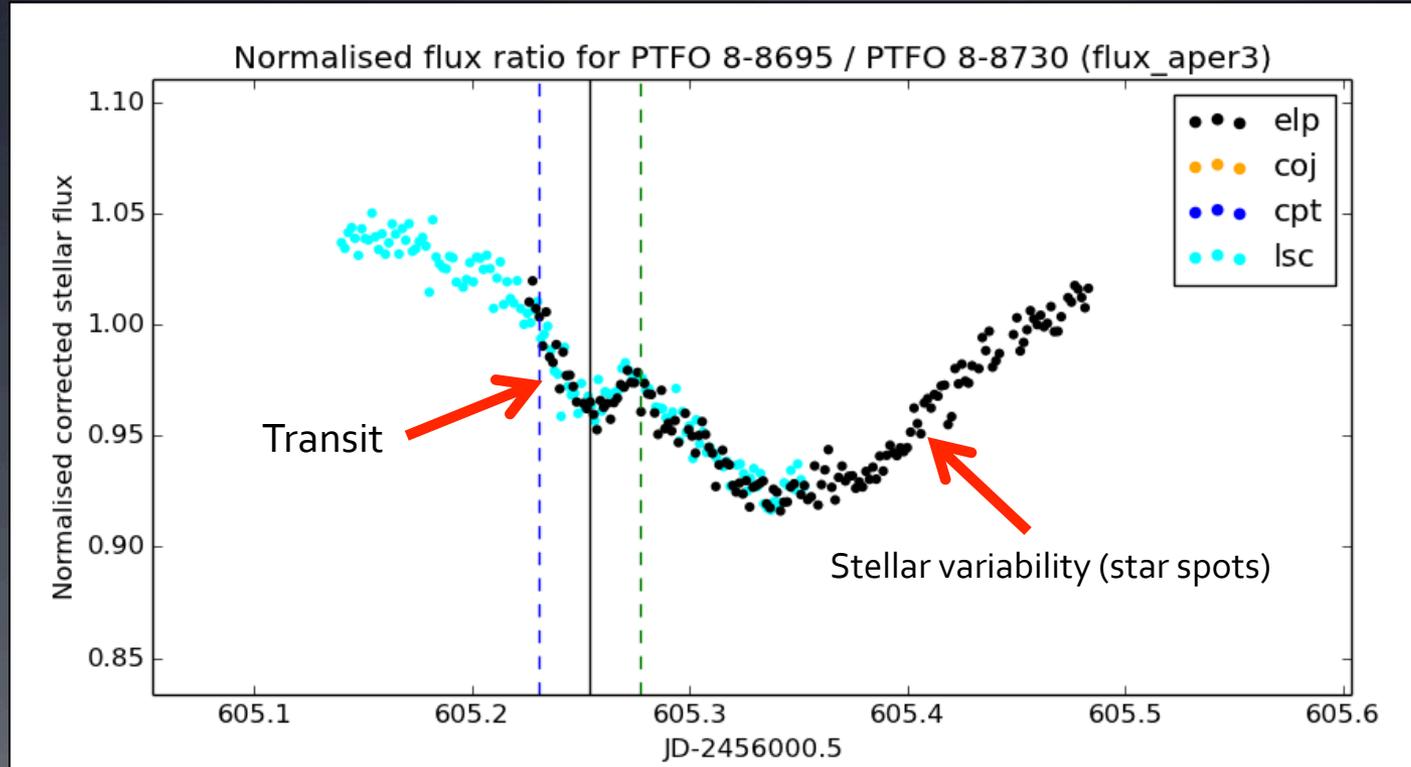
LCOGT non-transit 2 :-s

LCOGT follow-up Nov 2013-Jan 2014



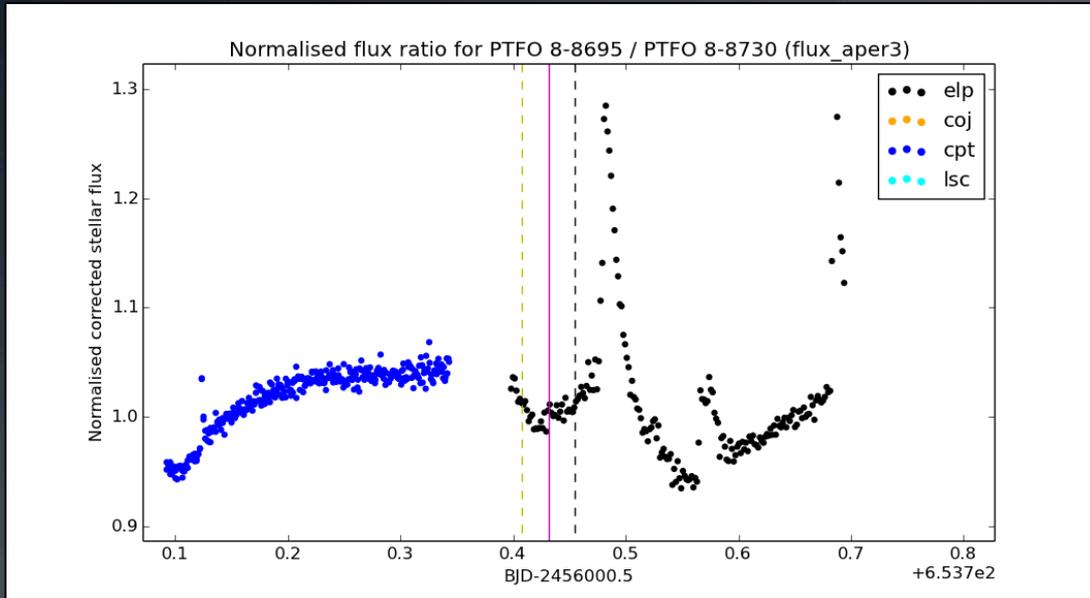
The Transits Return....

Nov 2013



- Raw photometry straight from LCOGT/IPAC archive, differenced against nearby stable star
- Transit duration $\sim 1/2$ its previous value

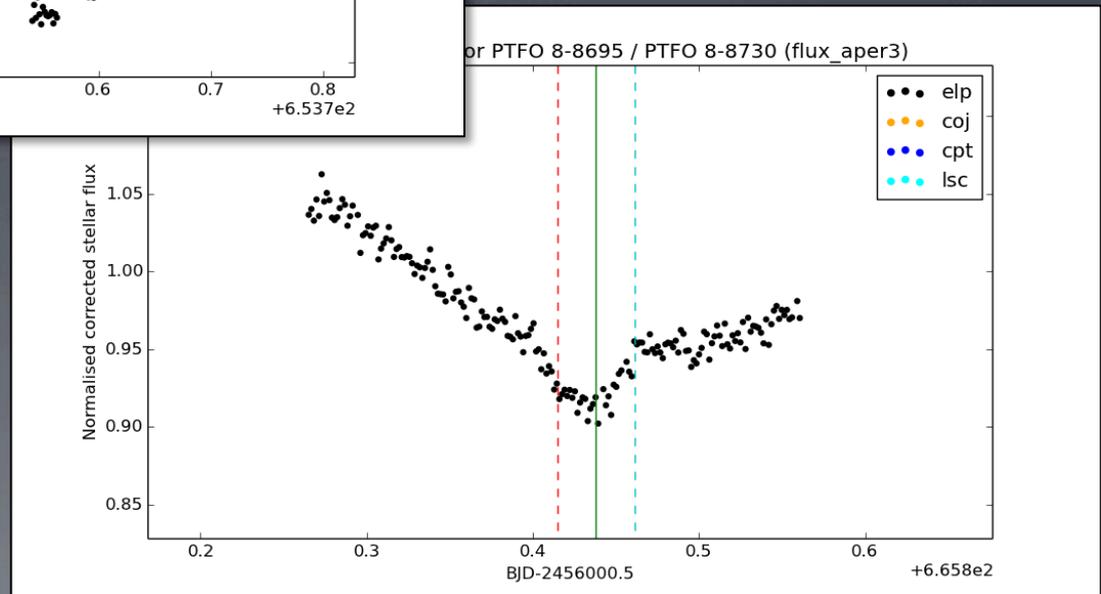
Later in season



Flares(!)

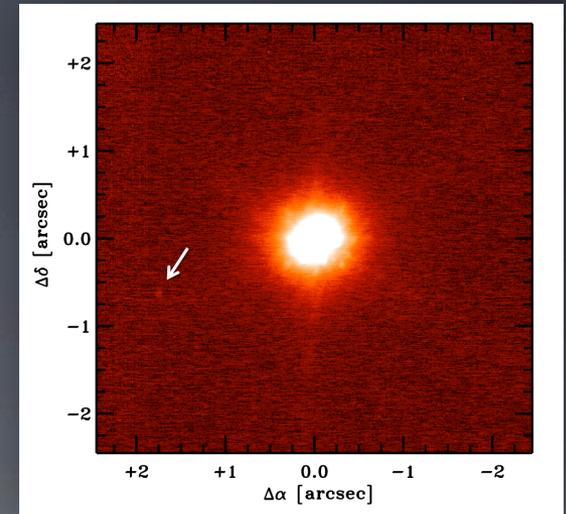
Transits longer –
shape evolving
through season?

Need to push all through
the fits again, refine the
model.



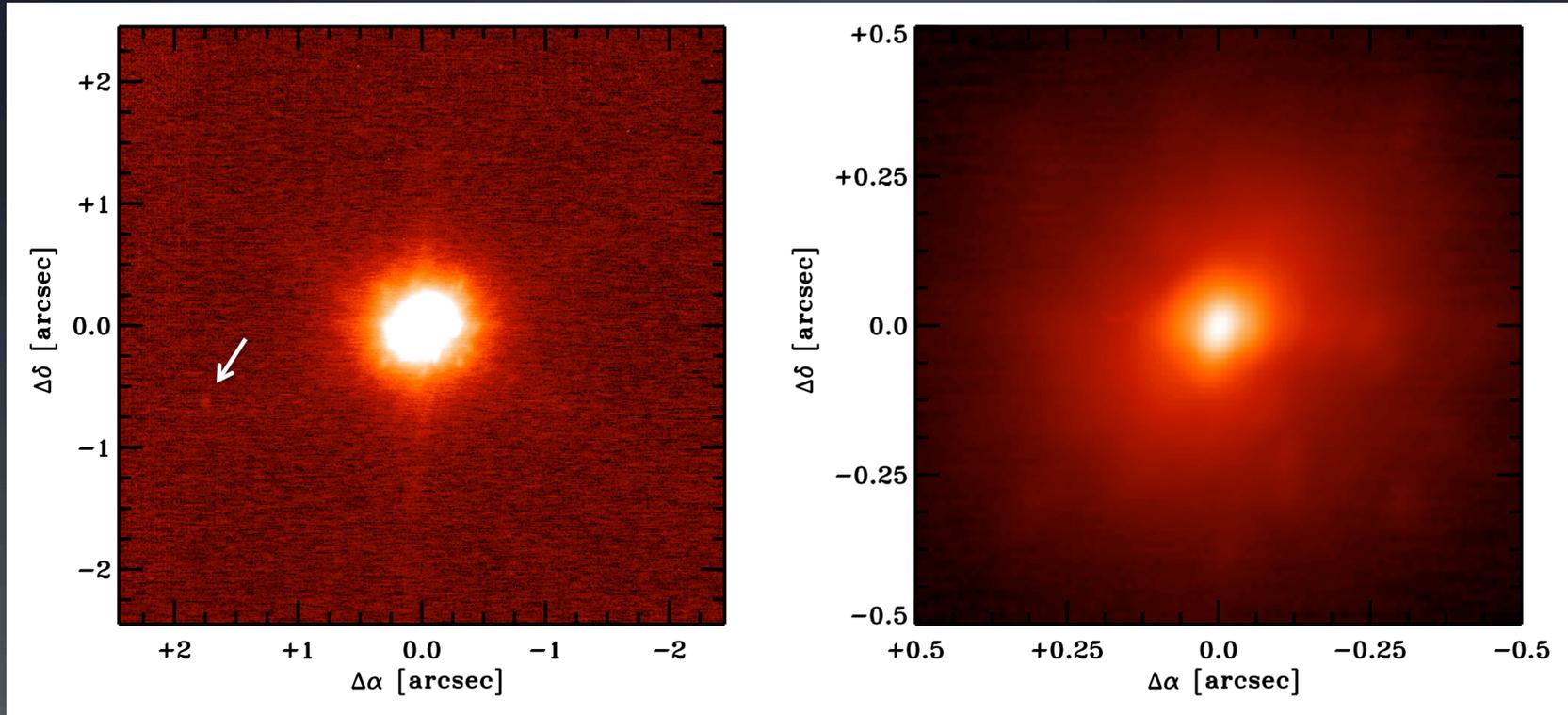
Summary/to-do

- ~ 2.7 Myr-old, $P \approx 0.45$ d, hot Jupiter
- Precessing, grav. darkened model fits data
- Transits disappear and reappear
- Poss. losing mass/evaporating
- Strong flaring – maybe accretion events?
- $H\alpha$ profile wing consistent with emission at planet orbit radius
- LCOGT data to be properly reduced + more from 2014/15 season. Total 5 yr baseline will help constrain models.
- Stellar $v \sin i$ should change with time
- Follow-up visual companion with:
 - - Further AO
 - - DARKNESS (MKID-based high contrast imager with P1640)
- Multi-band photometry?
- Orbital decay? Change in ephemeris?
- Star-planet interactions?



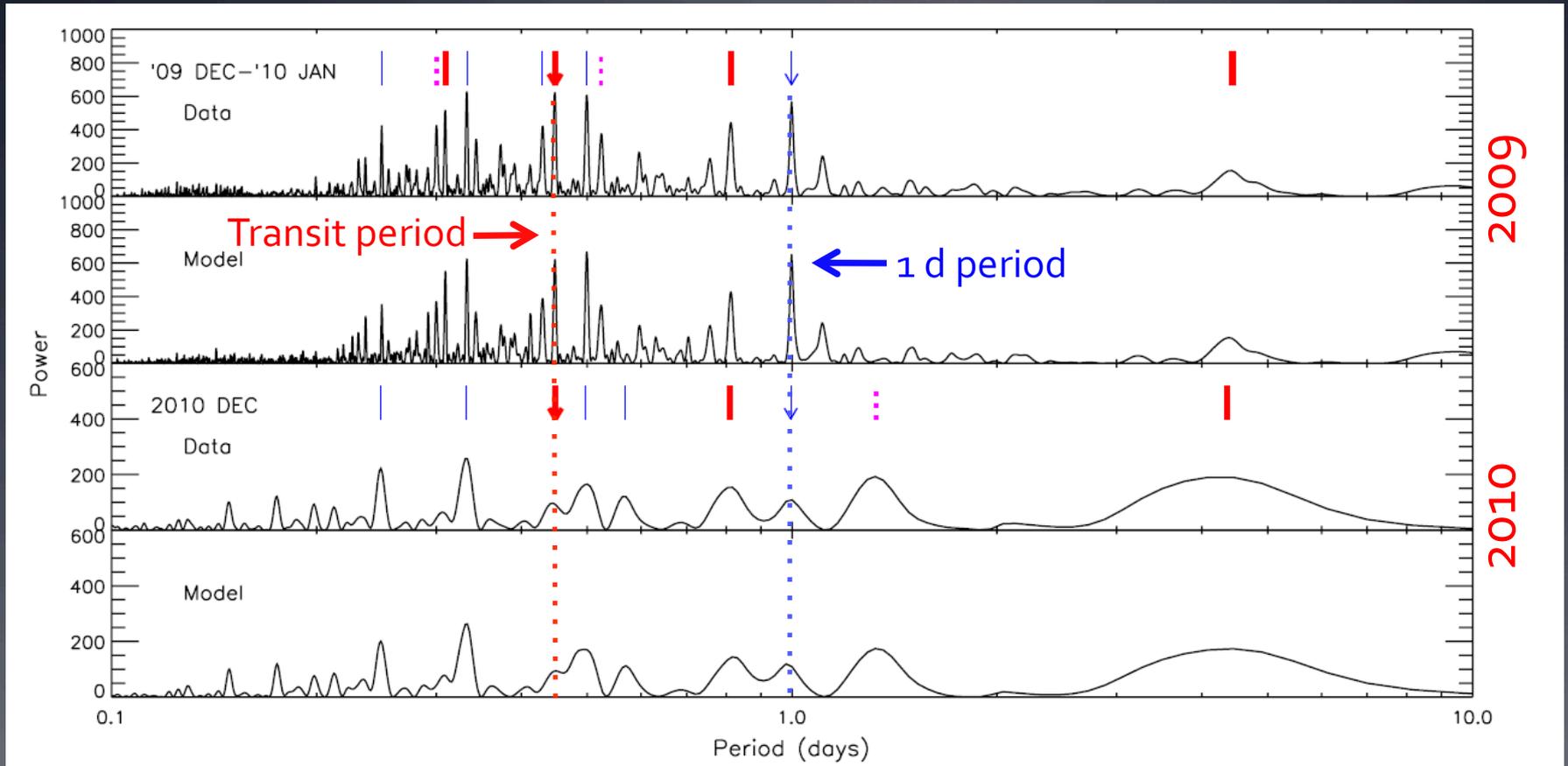
Extra slides

Keck AO follow-up



- Single faint additional source (left)
- 1.8" separation, 6.96mag fainter
- *Source cannot account for transits*

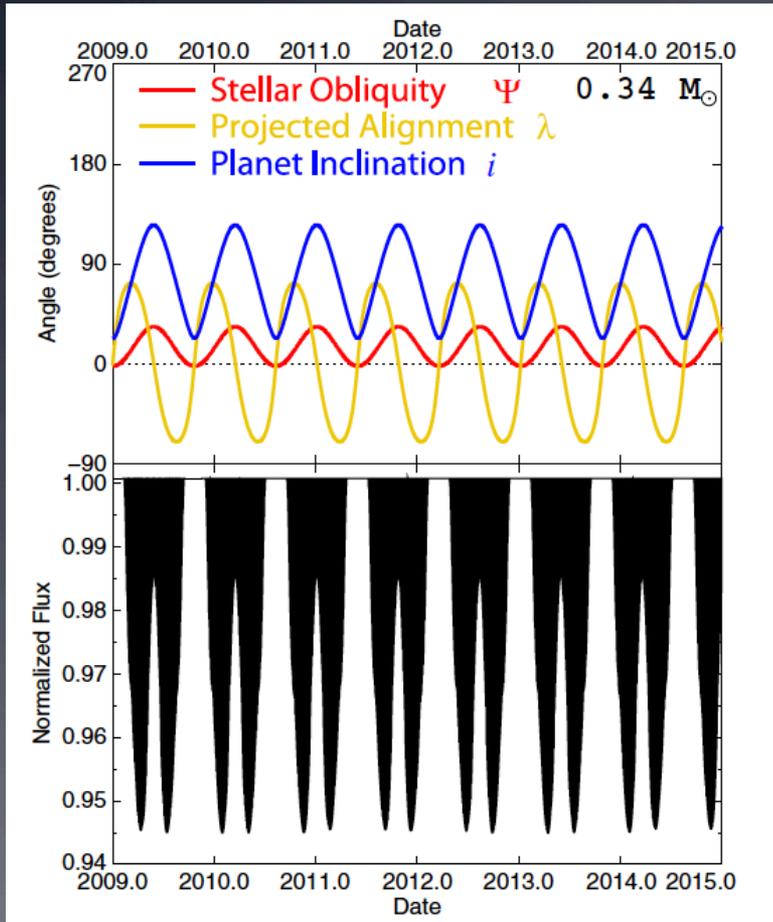
Periodogram analysis



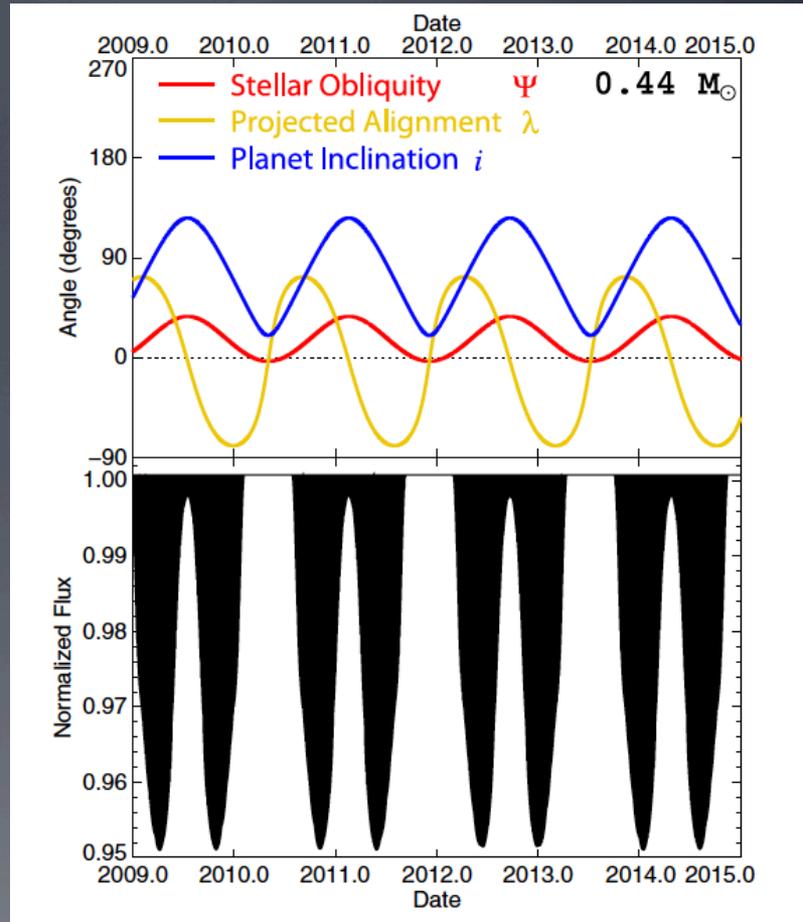
- 1 day is probably obs. window artifact; all other peaks are aliases
- Effect of transit in models is small + no other periodicities evident
- => **Star/orbit co-rotation** – *prob. not background binary*

Model predictions (Barnes et al. 2013)

For $M_* = 0.34 M_\odot$

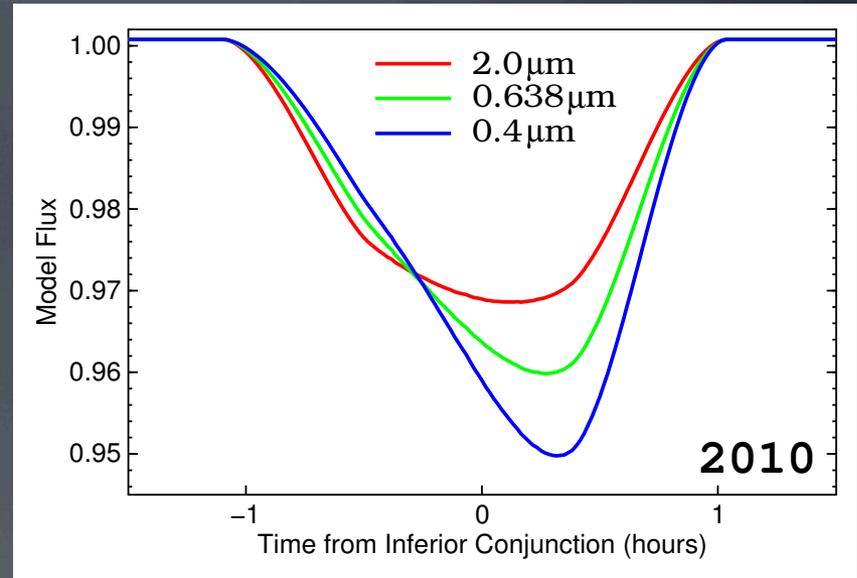
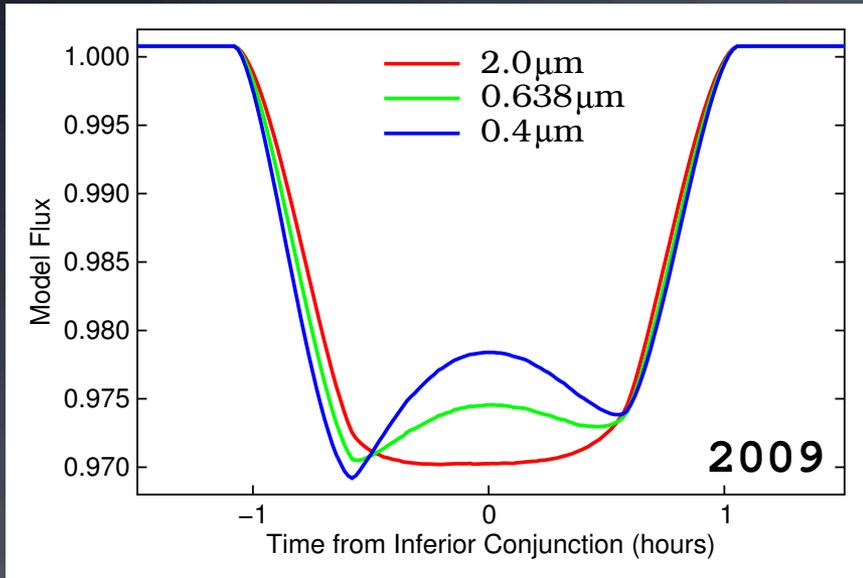


For $M_* = 0.44 M_\odot$



- Further transit (or no-transit) observations can better constrain M_*

Multi-band photometry model of PTFO 8-8695



- Gravitationally darkened transits are asymmetric and chromatic
- Measurement of a model-consistent chromatic effect with ARCONS would provide compelling evidence for our interpretation

Planet in context with other exoplanets

