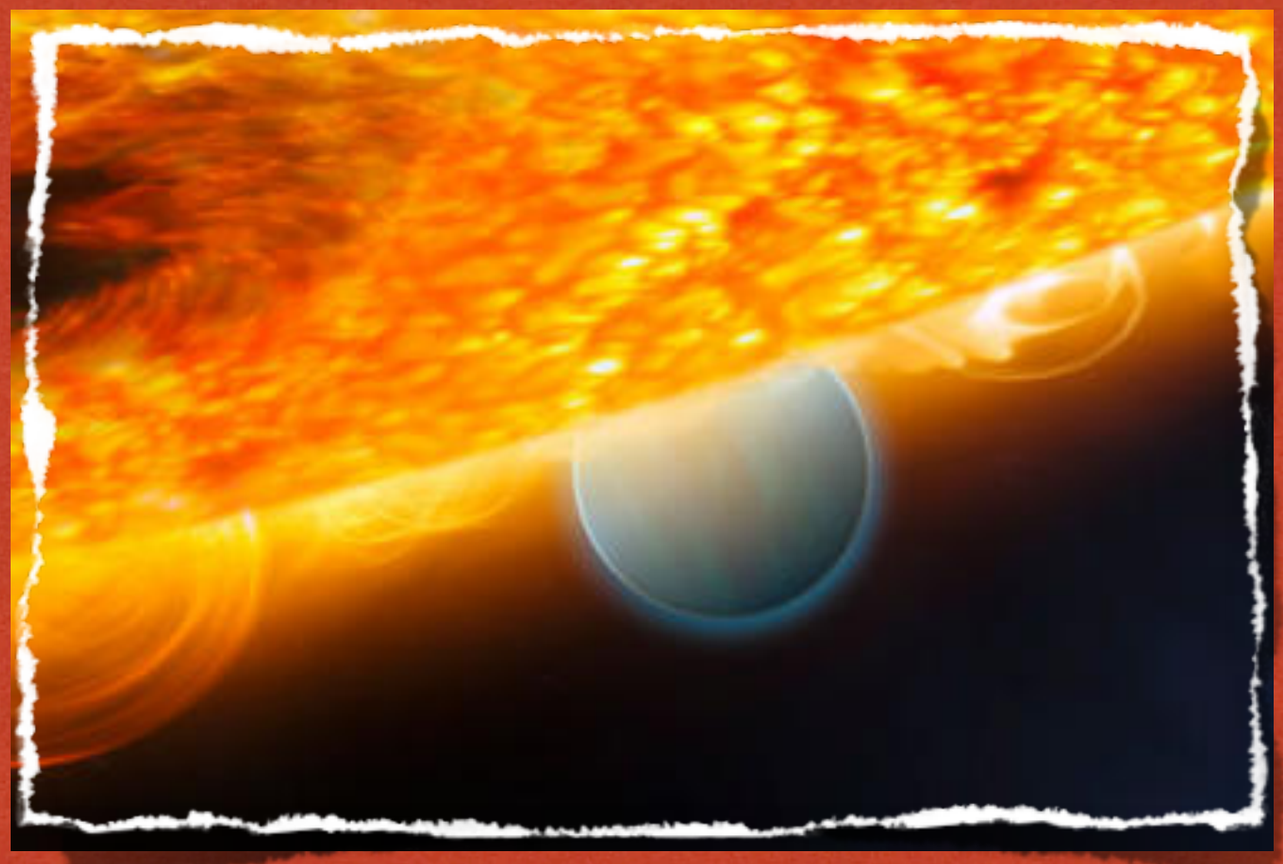
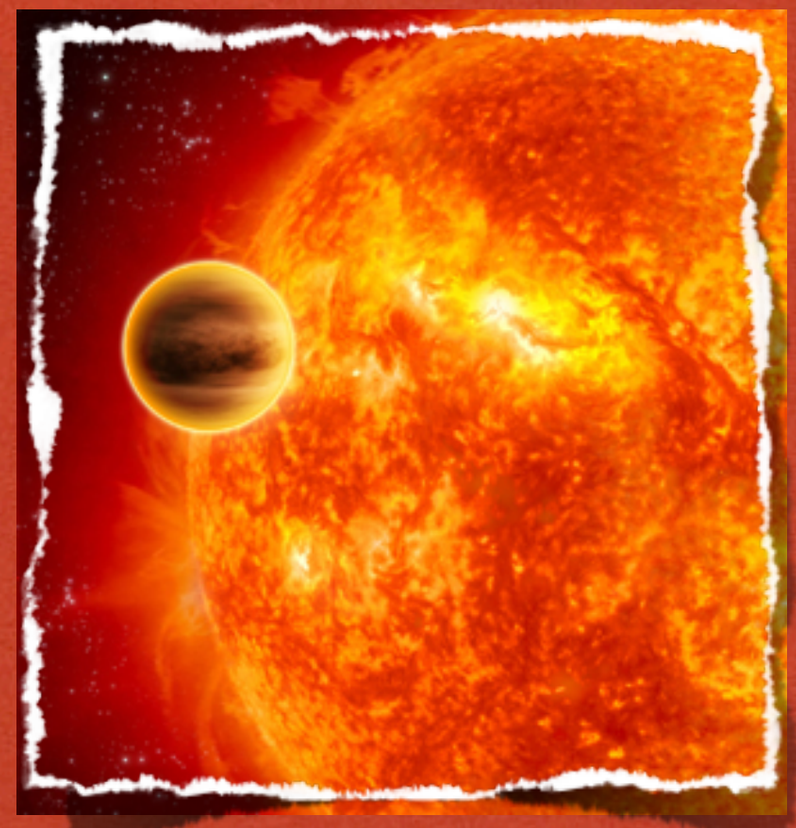
R. Dawson, CfA

APPLICATIONS OF BAYESIAN STATISTICS TO THE ORIGIN OF HOT JUPITERS



M. Kornmesse/NASA

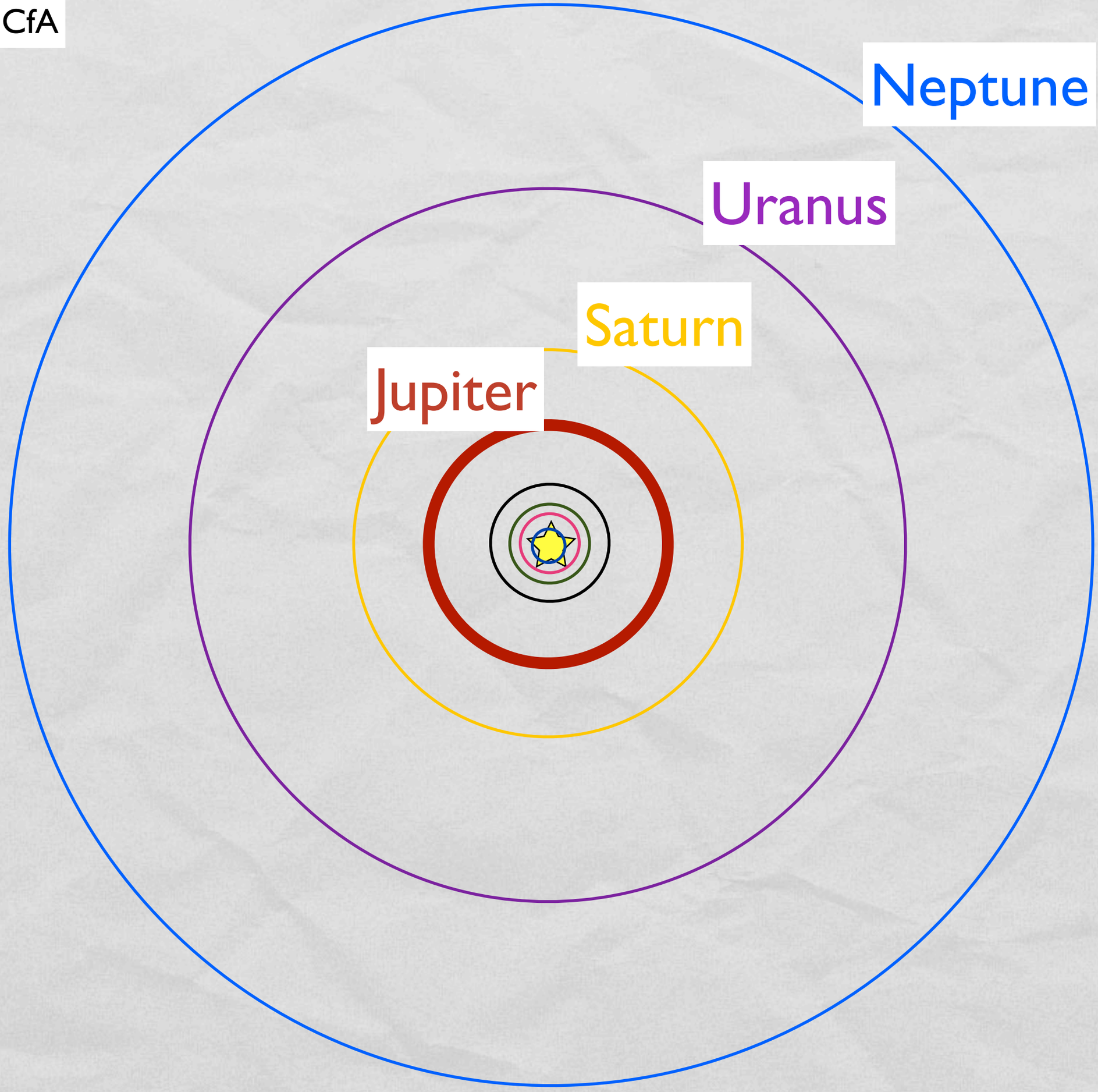


Christophe Carreau/ESA

Bekki Dawson
Harvard-Smithsonian Center for Astrophysics

John Johnson, Ruth Murray-Clay, Timothy Morton, Justin Crepp, Daniel Fabrycky, Andrew Howard

R. Dawson, CfA



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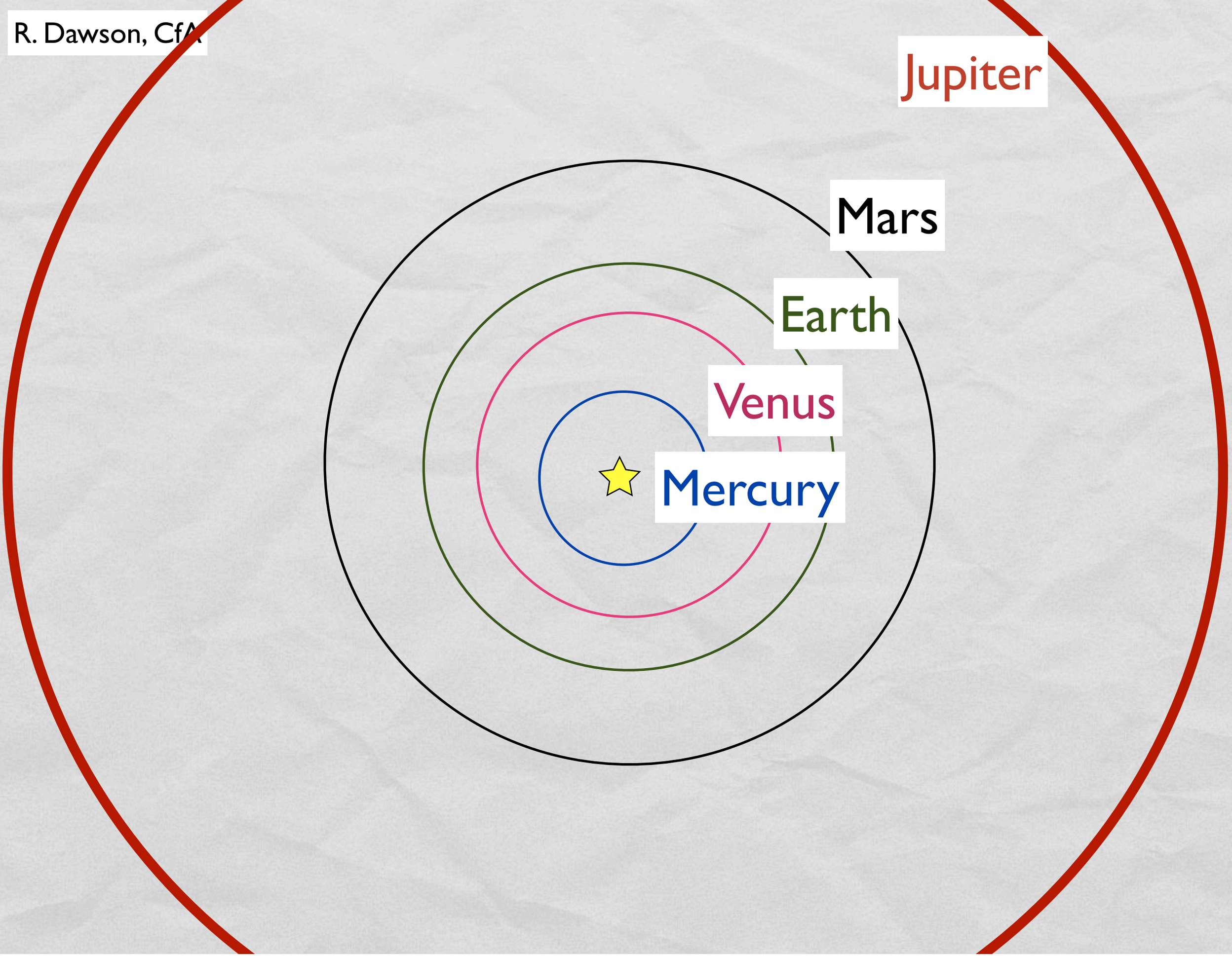


Jupiter

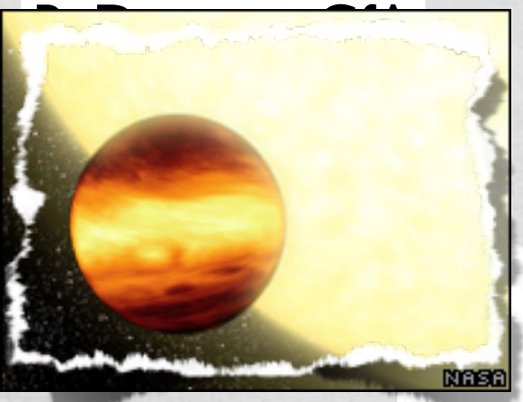
Mars

Earth

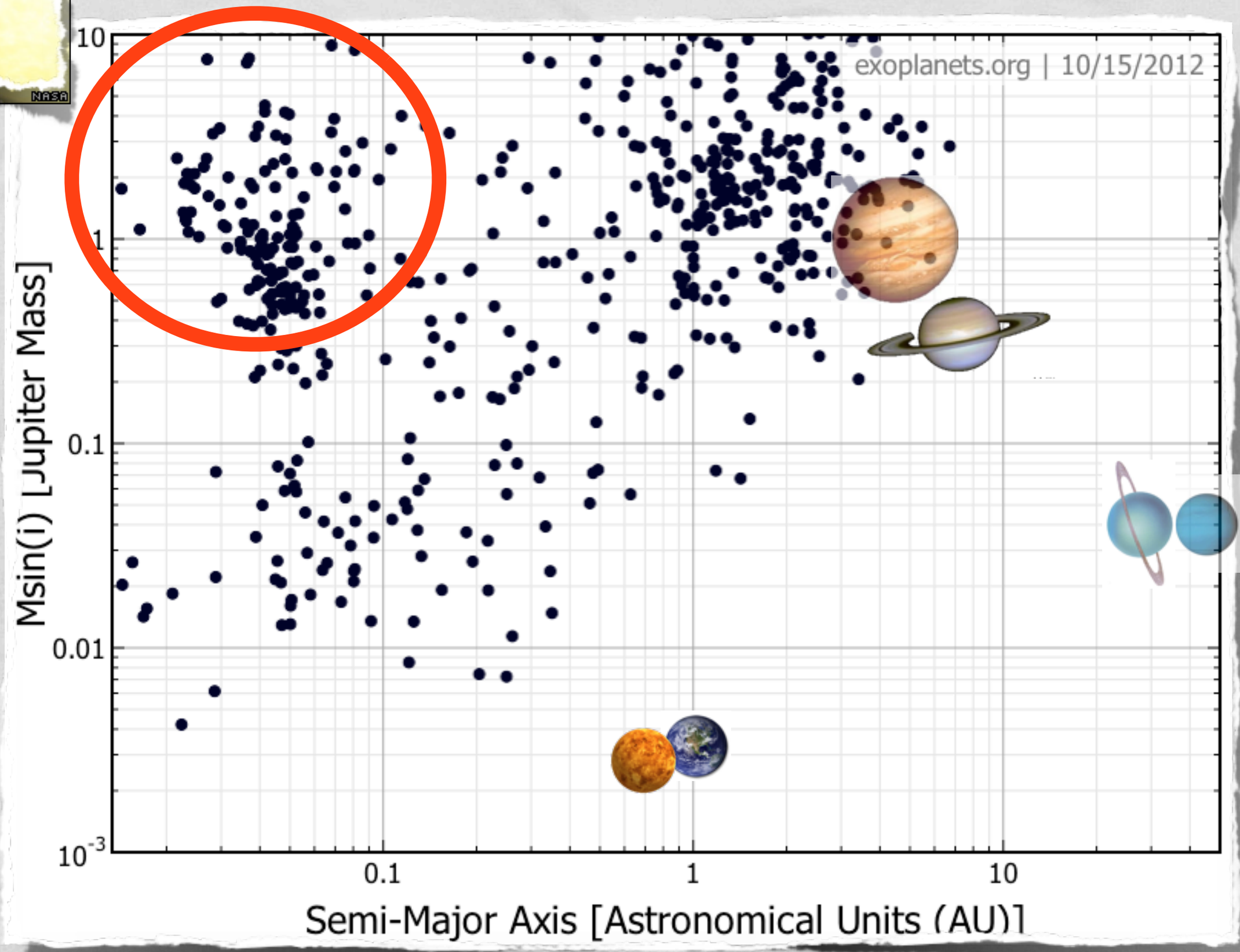
Venus

Mercury

Hot Jupiter



Hot Jupiters



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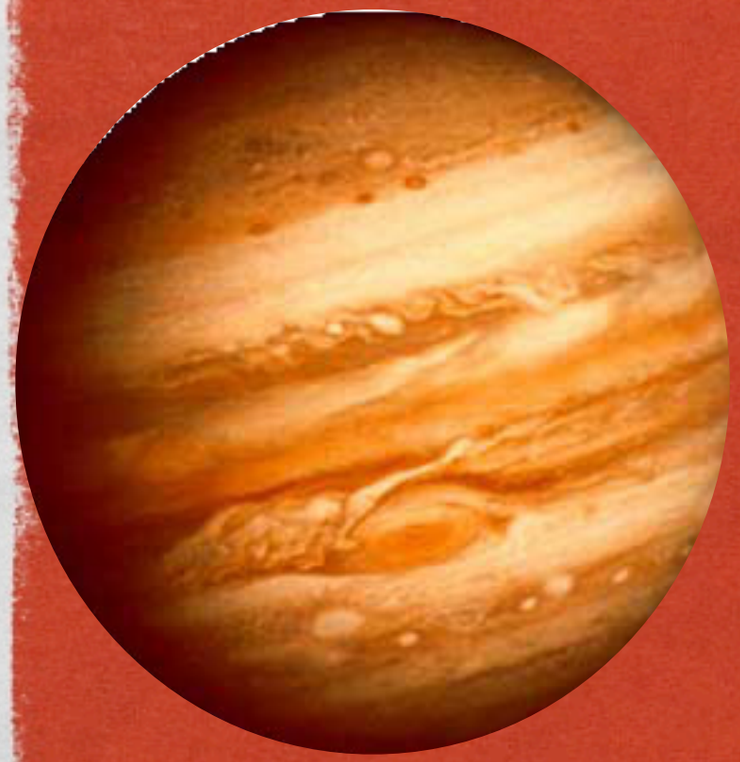
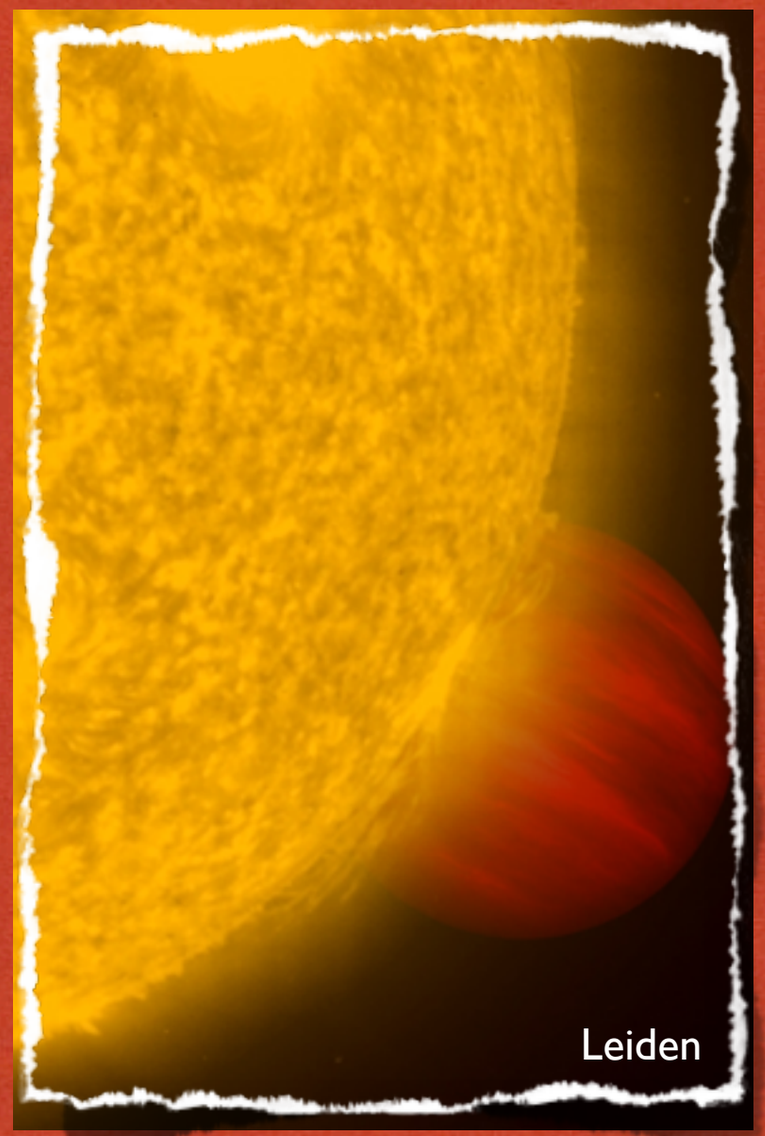


+ ? =



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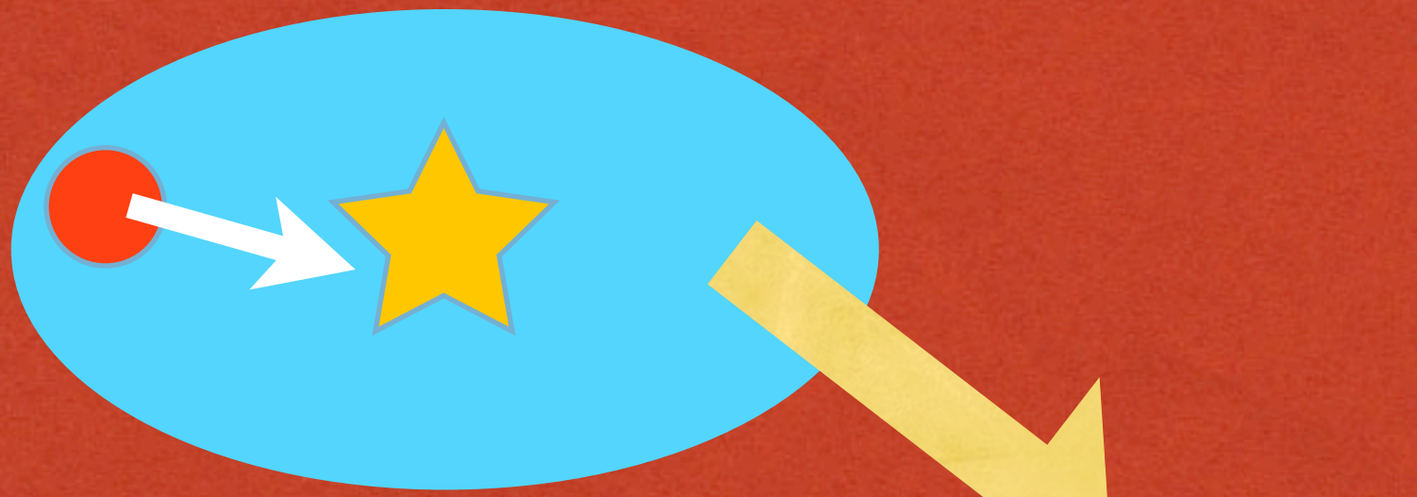
THE ORIGIN OF HOT JUPITERS: TWO CLASSES OF MIGRATION THEORY

Smooth disk migration



e.g. Goldreich & Tremaine 80
Ward 97
Alibert+ 05
Ida & Lin 08
Bromley & Kenyon 11

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THE ORIGIN OF HOT JUPITERS: TWO CLASSES OF MIGRATION THEORY

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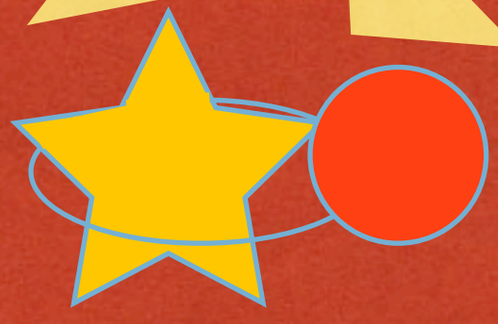
High eccentricity migration



e.g. Rasio & Ford 96
Wu & Murray 03
Fabrycky & Tremaine 07
Ford & Rasio 08
Chatterjee+ 08
Naoz+ 11
Wu & Lithwick 11

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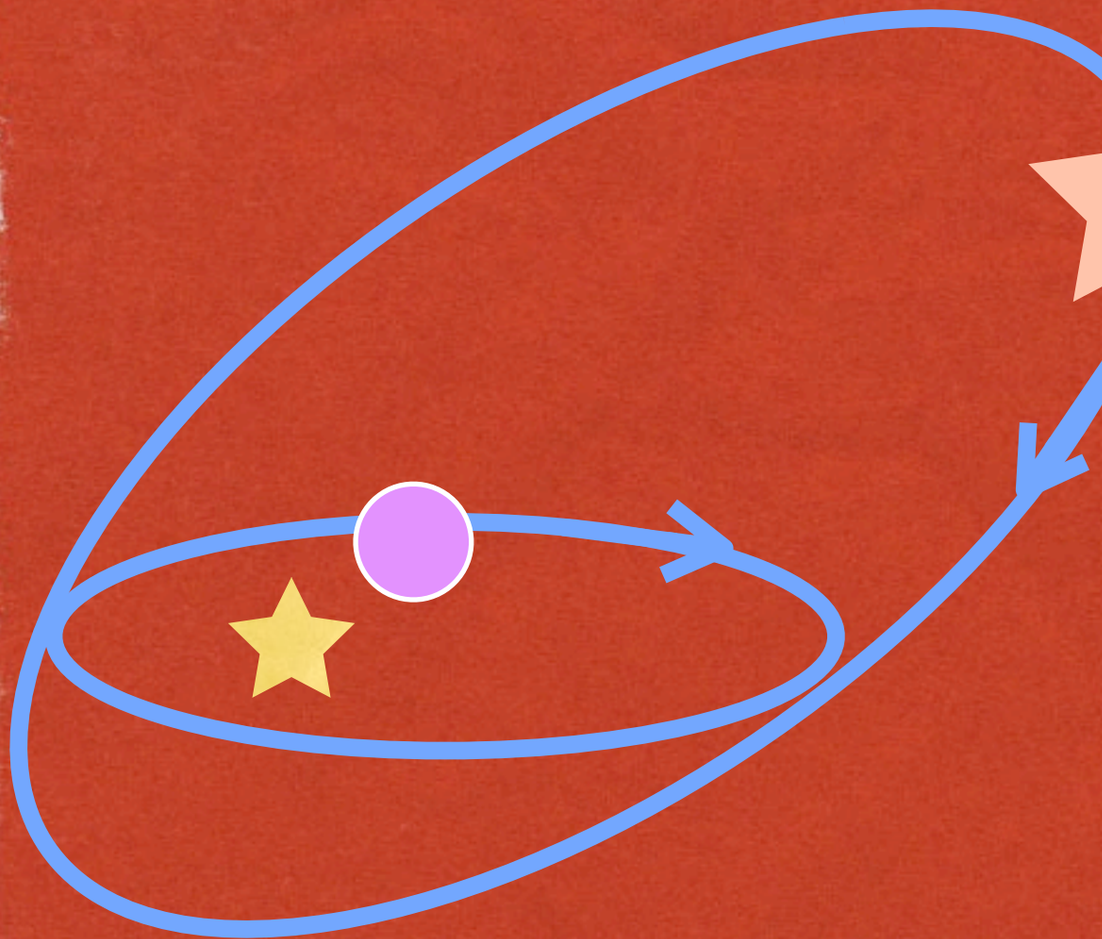
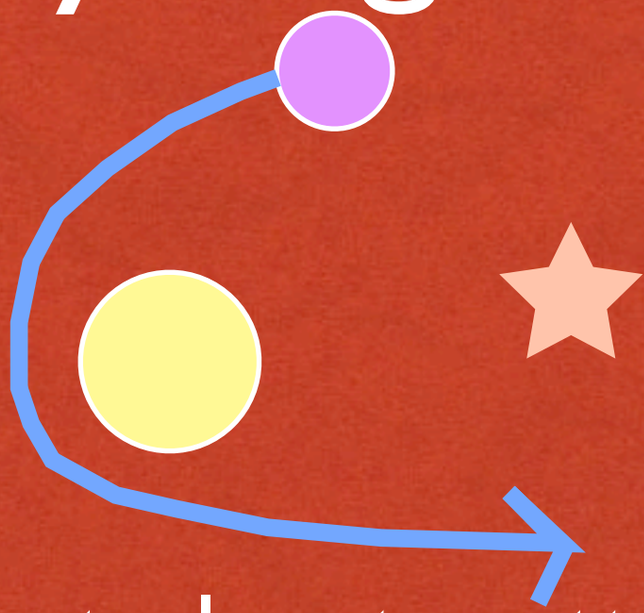
Perturbations from a companion cause high eccentricity migration



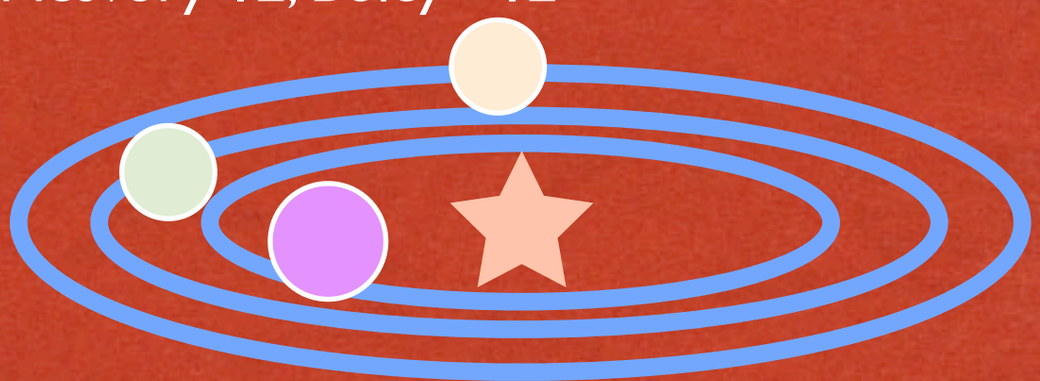
Stellar or planetary Kozai

e.g. Wu and Murray 03, Fabrycky & Tremaine 07, Naoz+11, 12



Planet-planet scattering

e.g. Rasio & Ford 96, Chatterjee+ 08, Ford & Rasio 08, Matsumura+ 12, Beauge and Nesvory 12, Boley+ 12



Secular chaos Wu and Lithwick 11

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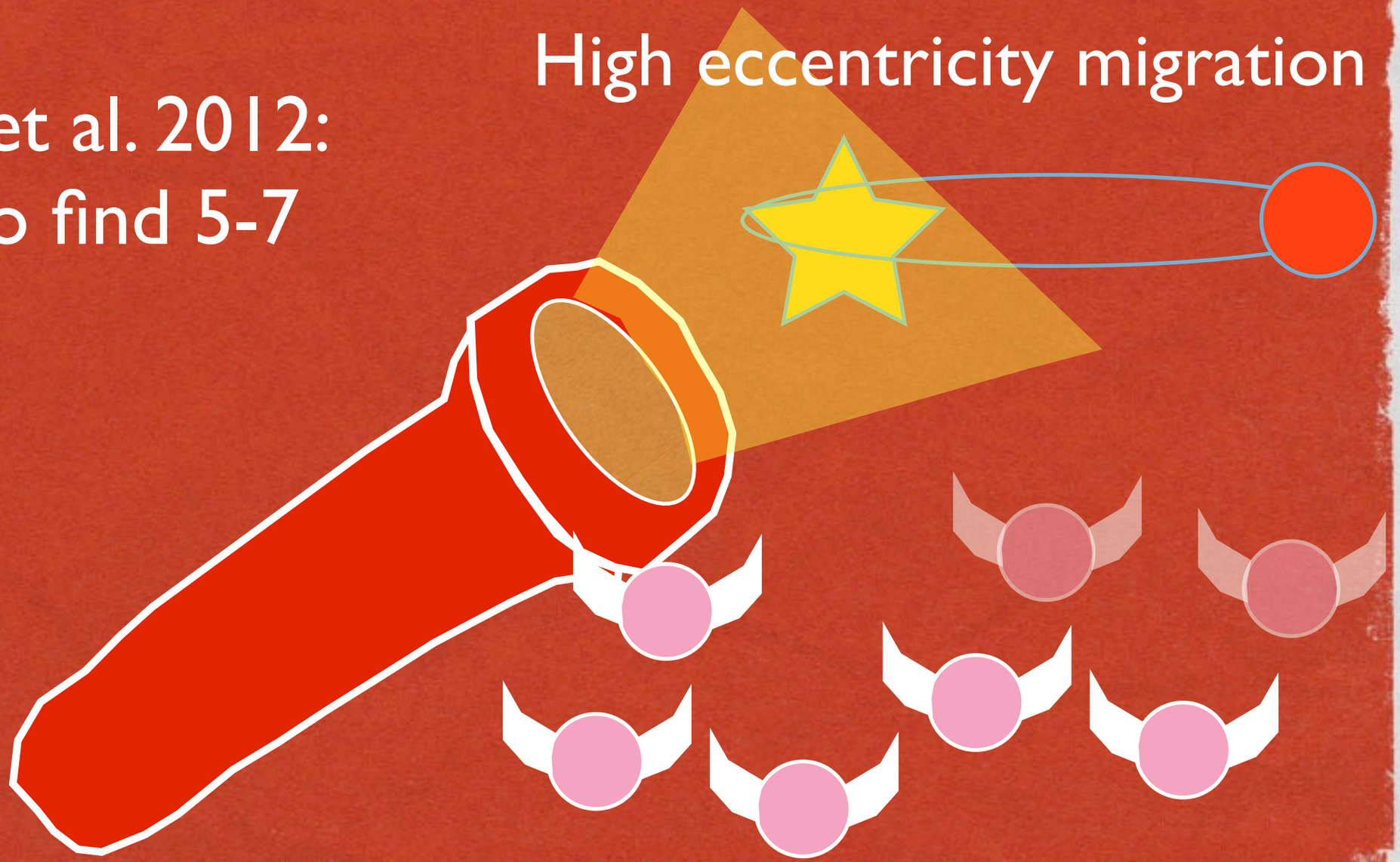
We're searching for the putative supereccentric progenitors of hot Jupiters

Socrates et al. 2012:
Expect to find 5-7

High eccentricity migration



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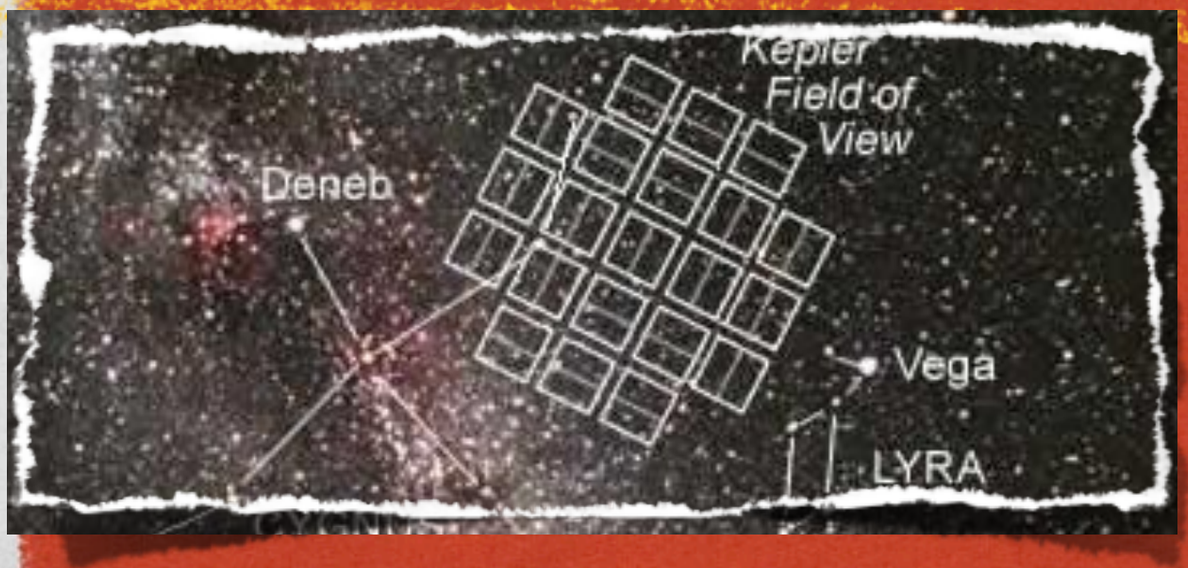
SEARCHING FOR SUPER-ECCENTRIC PROTO-HOT JUPITERS IN 2 STEPS



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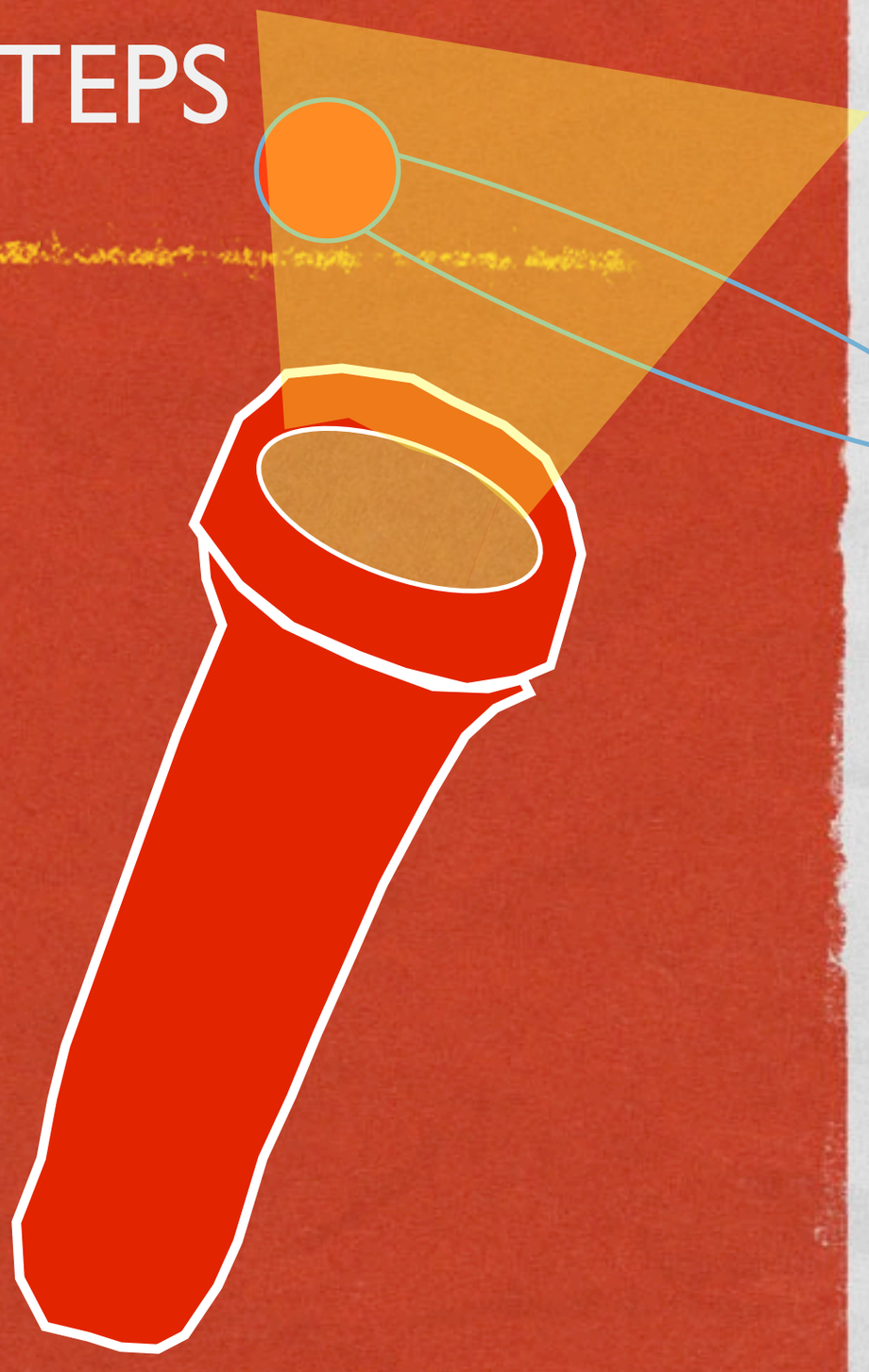

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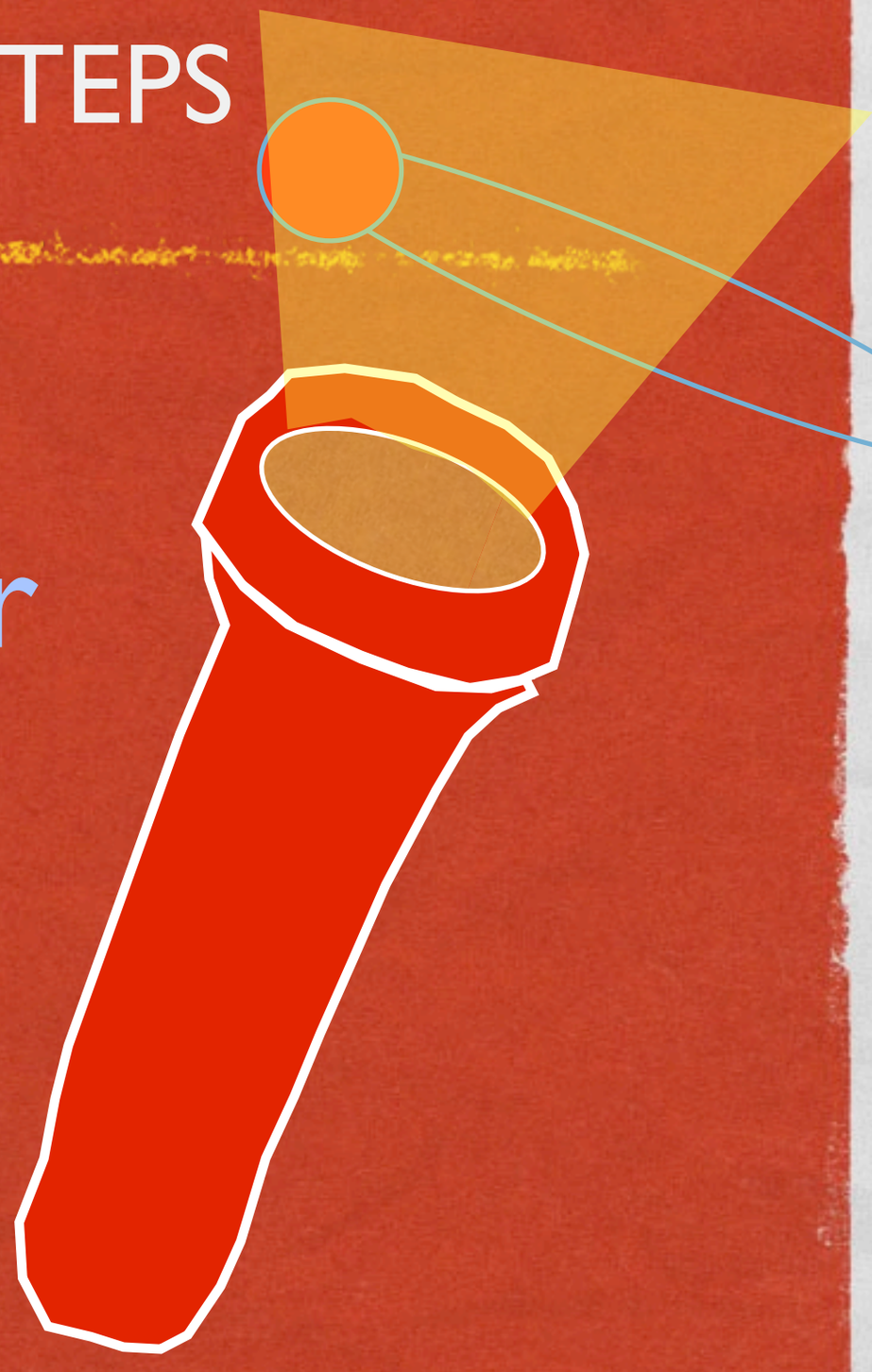
SEARCHING FOR SUPER-ECCENTRIC PROTO-HOT JUPITERS IN 2 STEPS

1. Kepler



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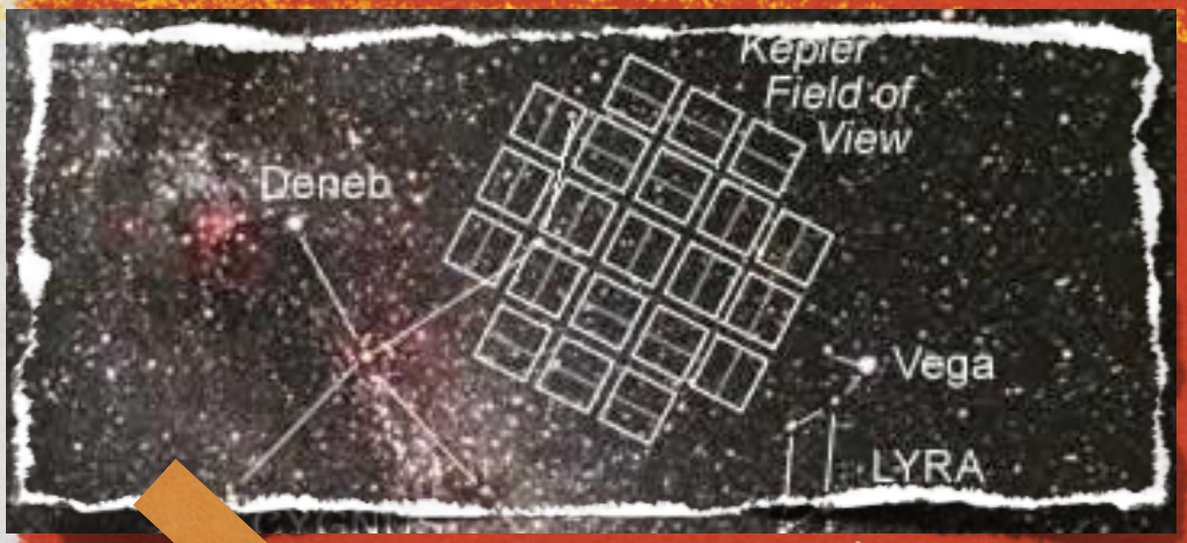
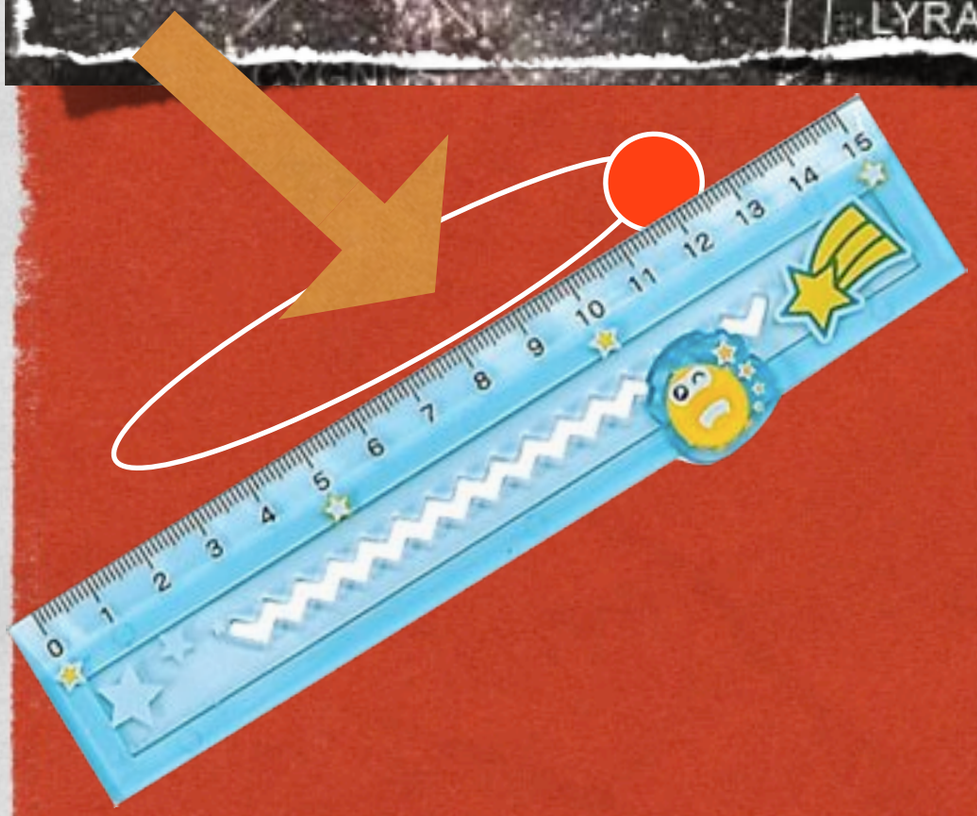
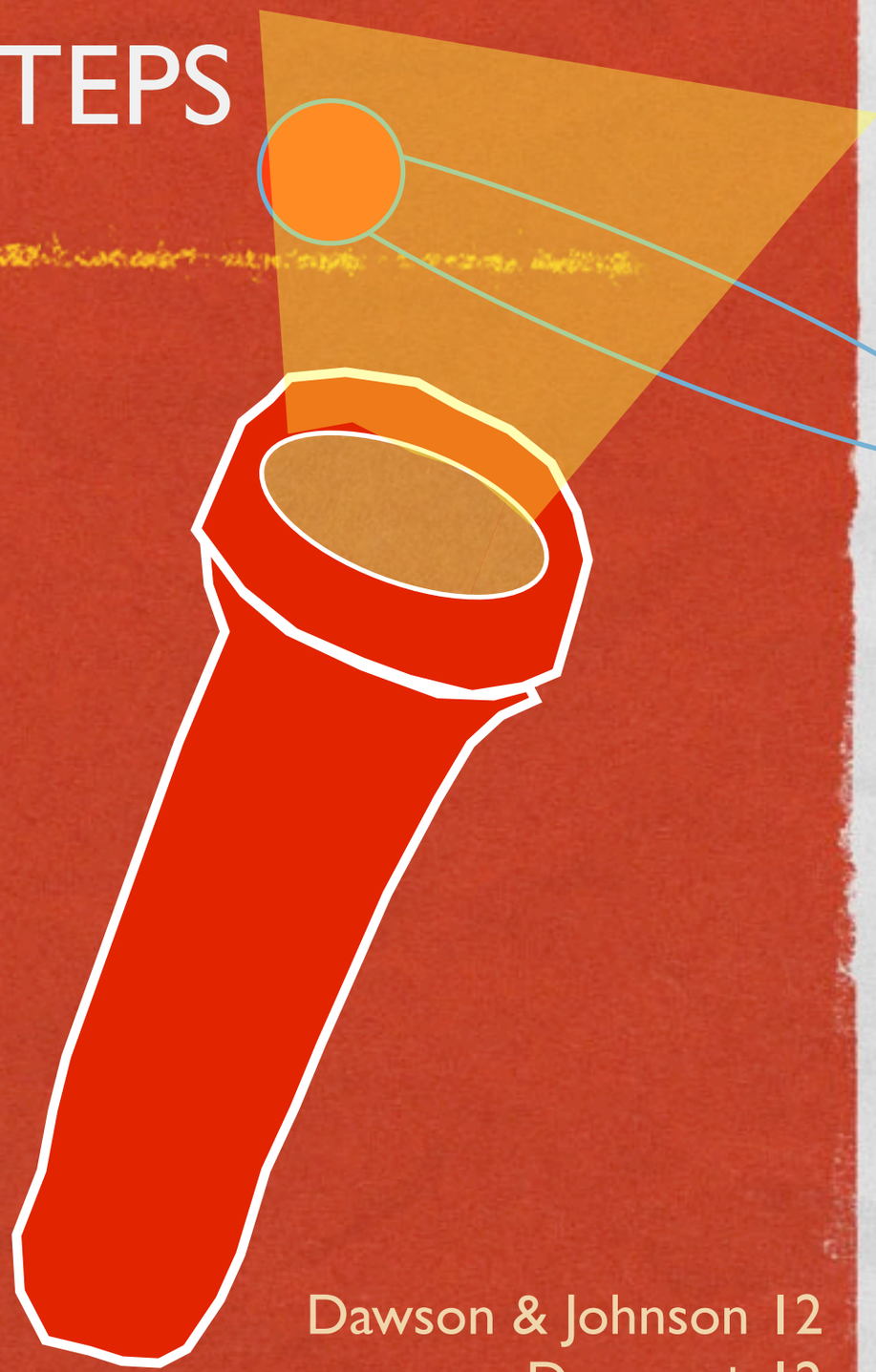
SEARCHING FOR SUPER-ECCENTRIC PROTO-HOT JUPITERS IN 2 STEPS





1.

2.

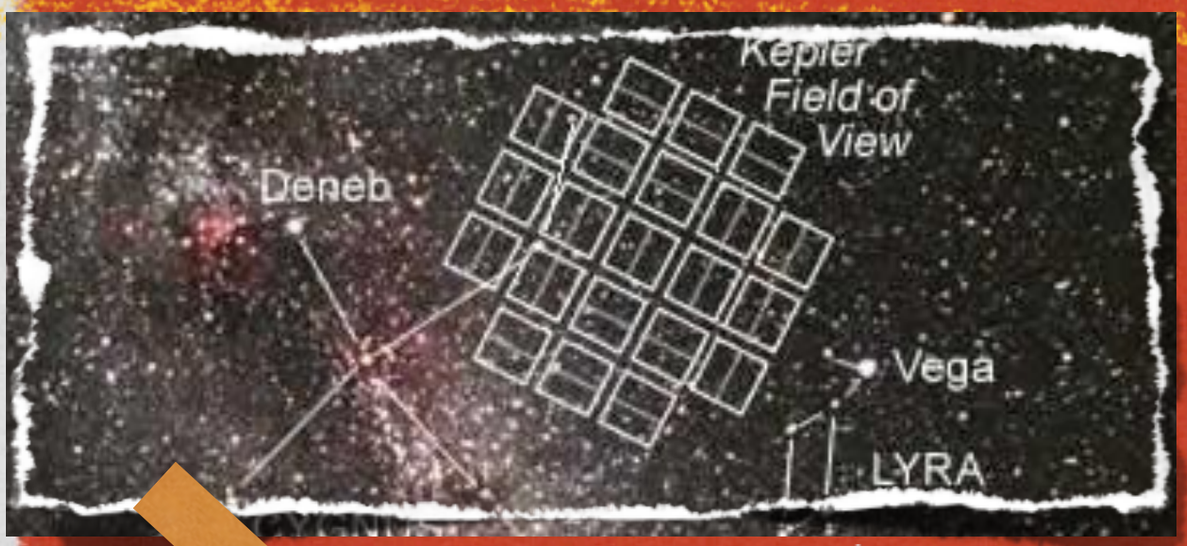


Dawson & Johnson 12
Dawson+ 12

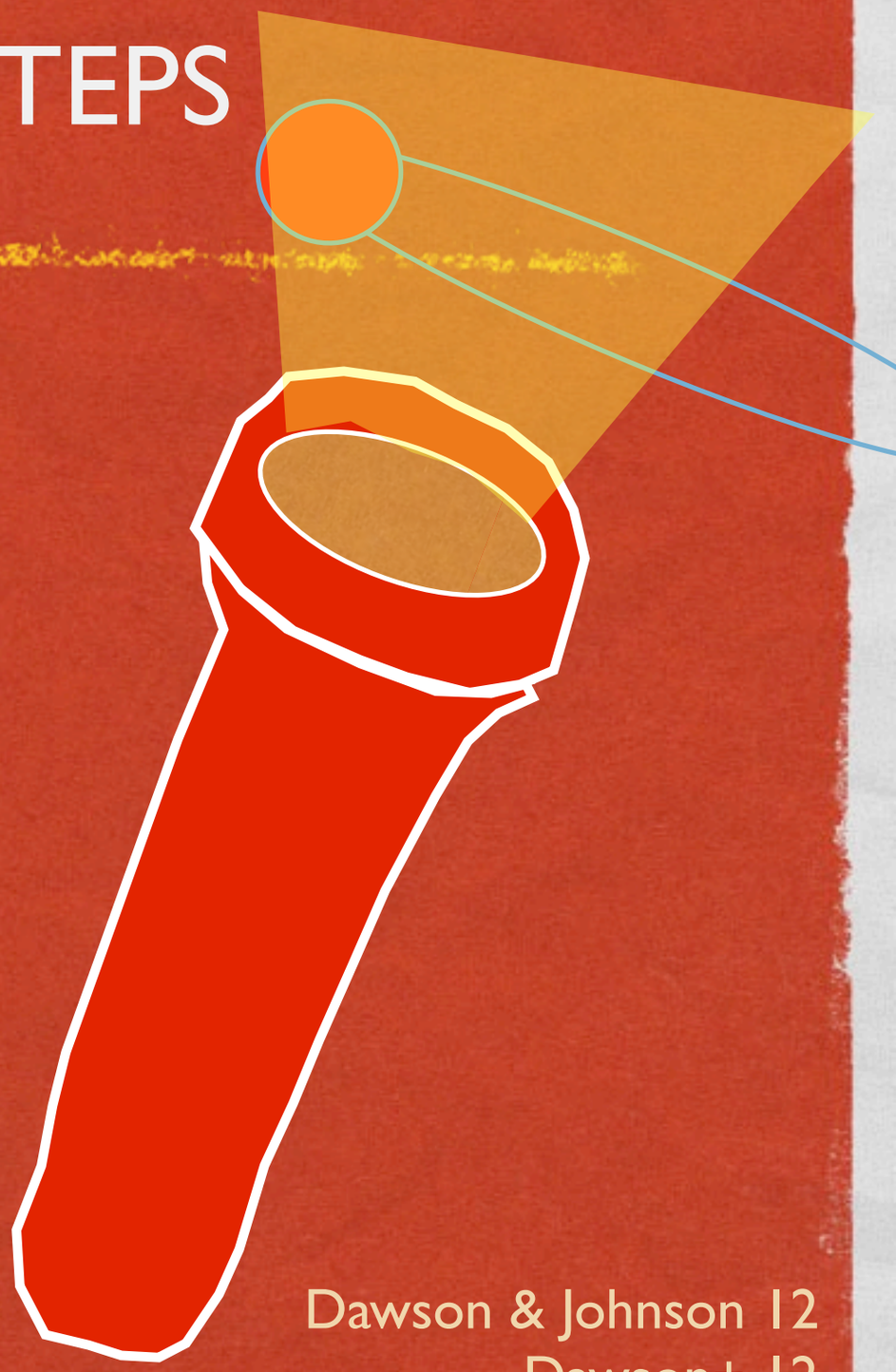
Johnson, Dawson, + in prep

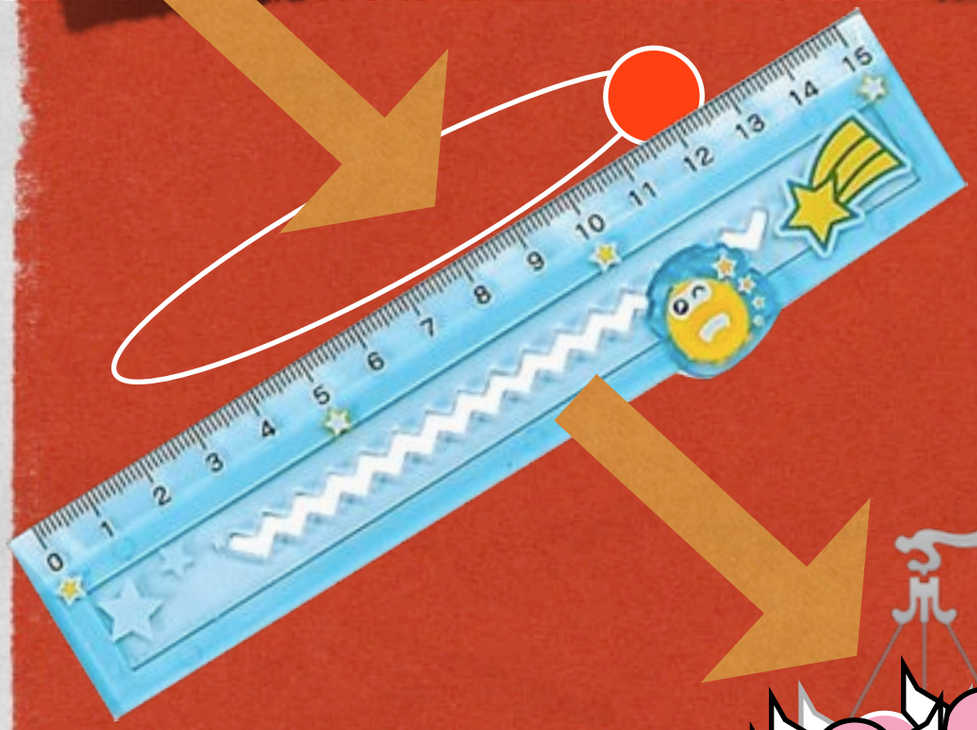
R. Dawson, CfA

SEARCHING FOR SUPER-ECCENTRIC PROTO-HOT JUPITERS IN ~~2~~ 3 STEPS



1.





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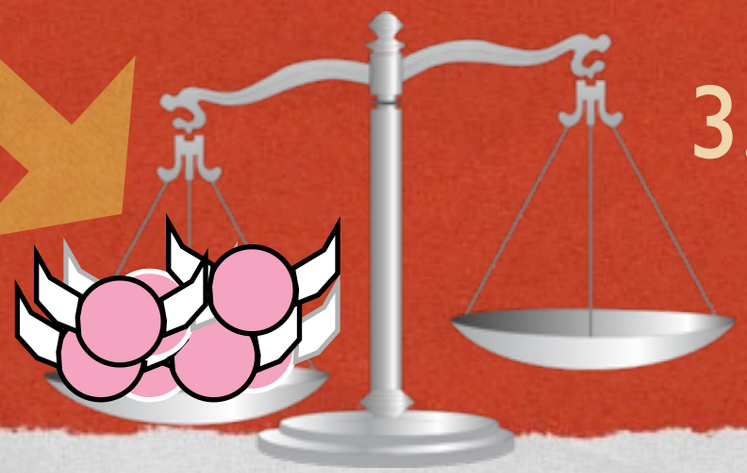
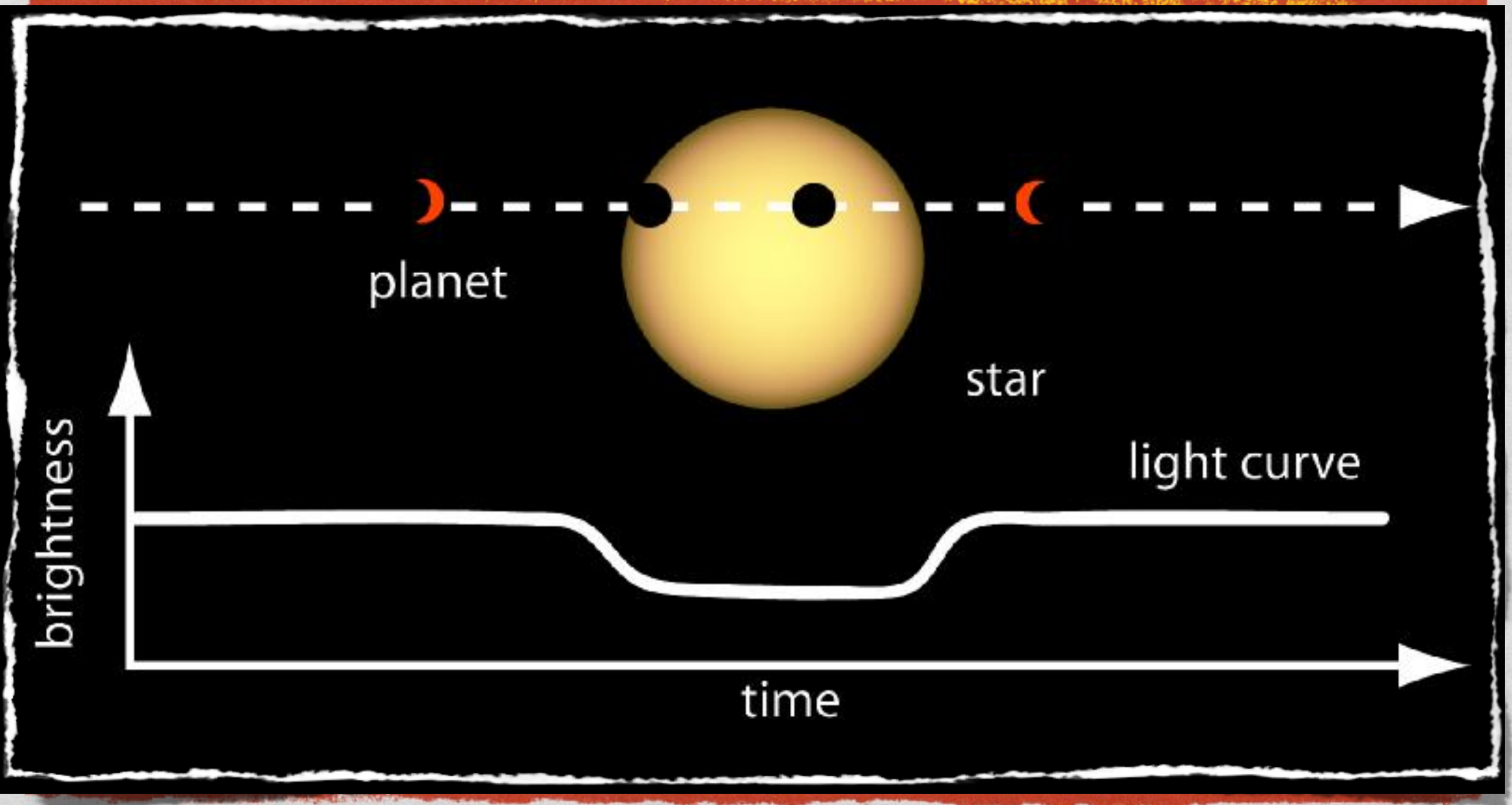


3.

Dawson & Johnson 12
Dawson+ 12
Dawson, Murray-Clay, & Johnson in prep
Johnson, Dawson, + in prep

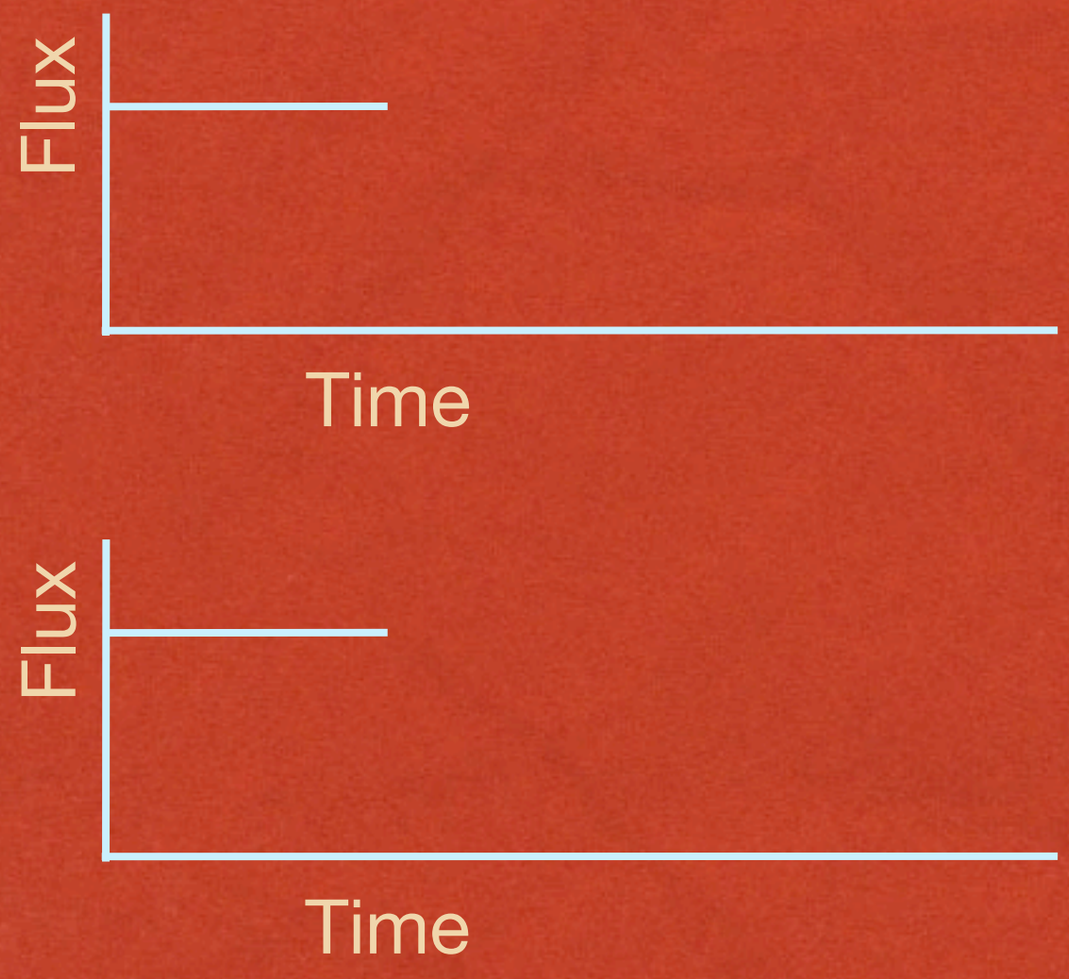
R. Dawson, CfA

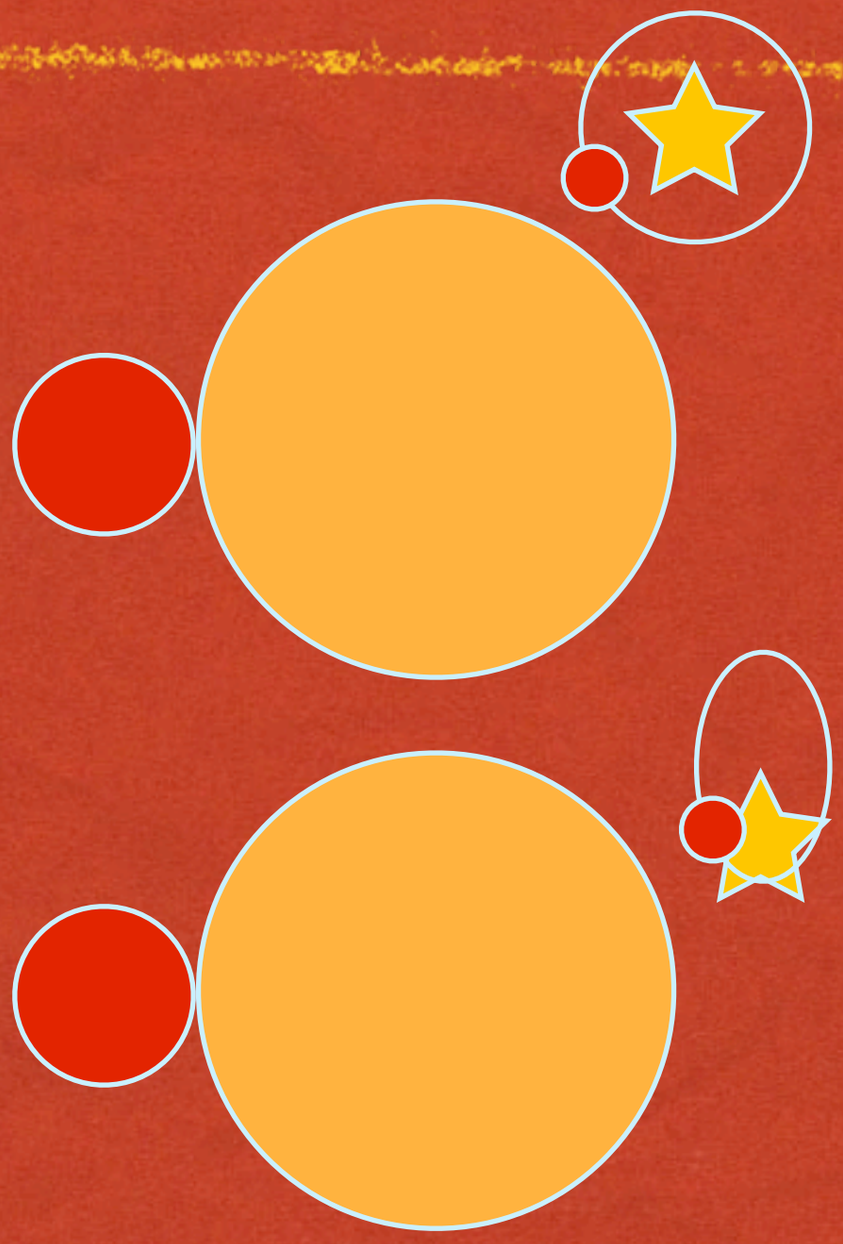
PLANETARY TRANSITS DETECTED BY KEPLER



R. Dawson, CfA

MEASURING ECCENTRICITY FROM PHOTOMETRY: THE "PHOTOECCENTRIC EFFECT"





Dawson & Johnson 2012

R. Dawson, CfA

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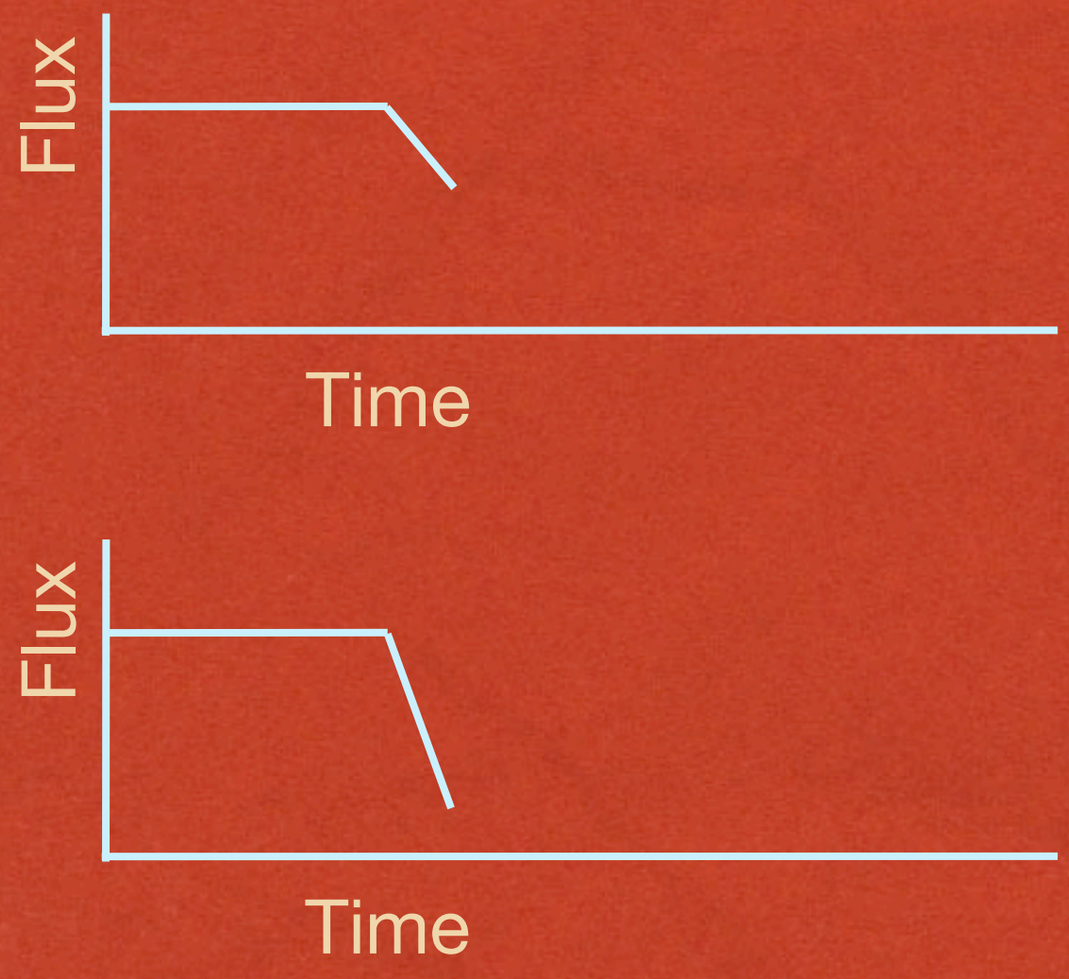

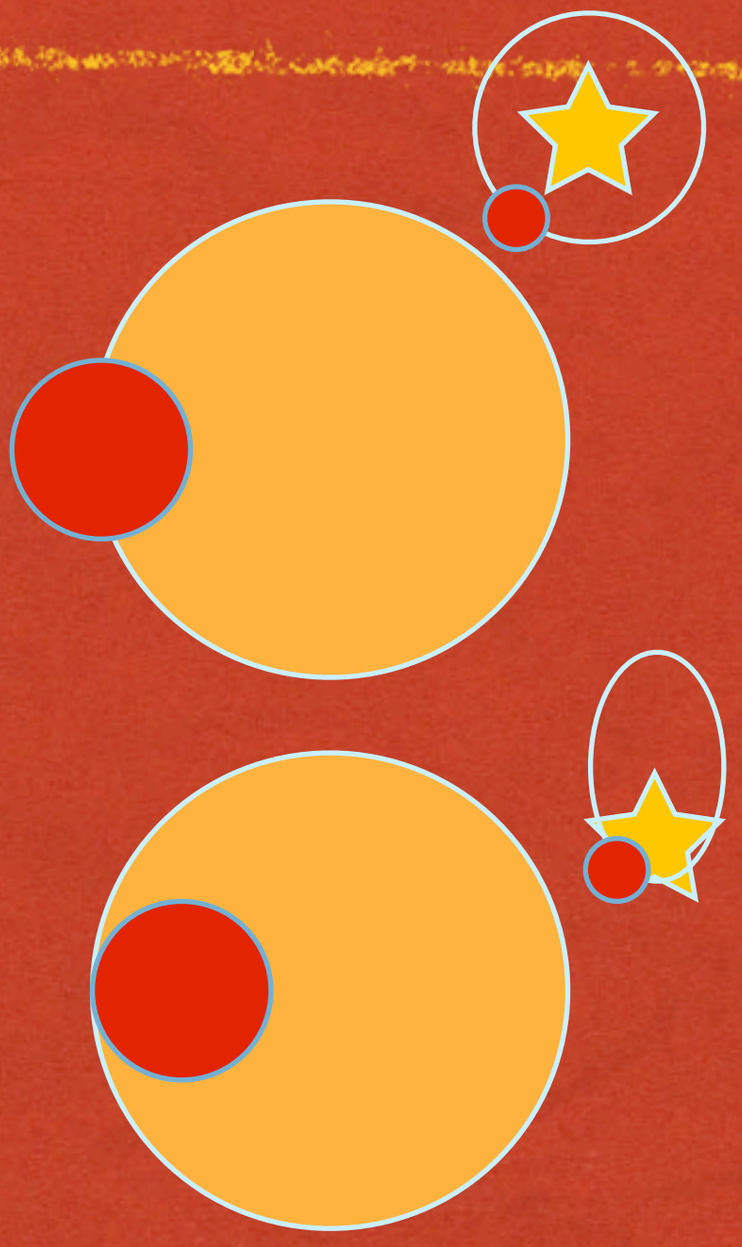

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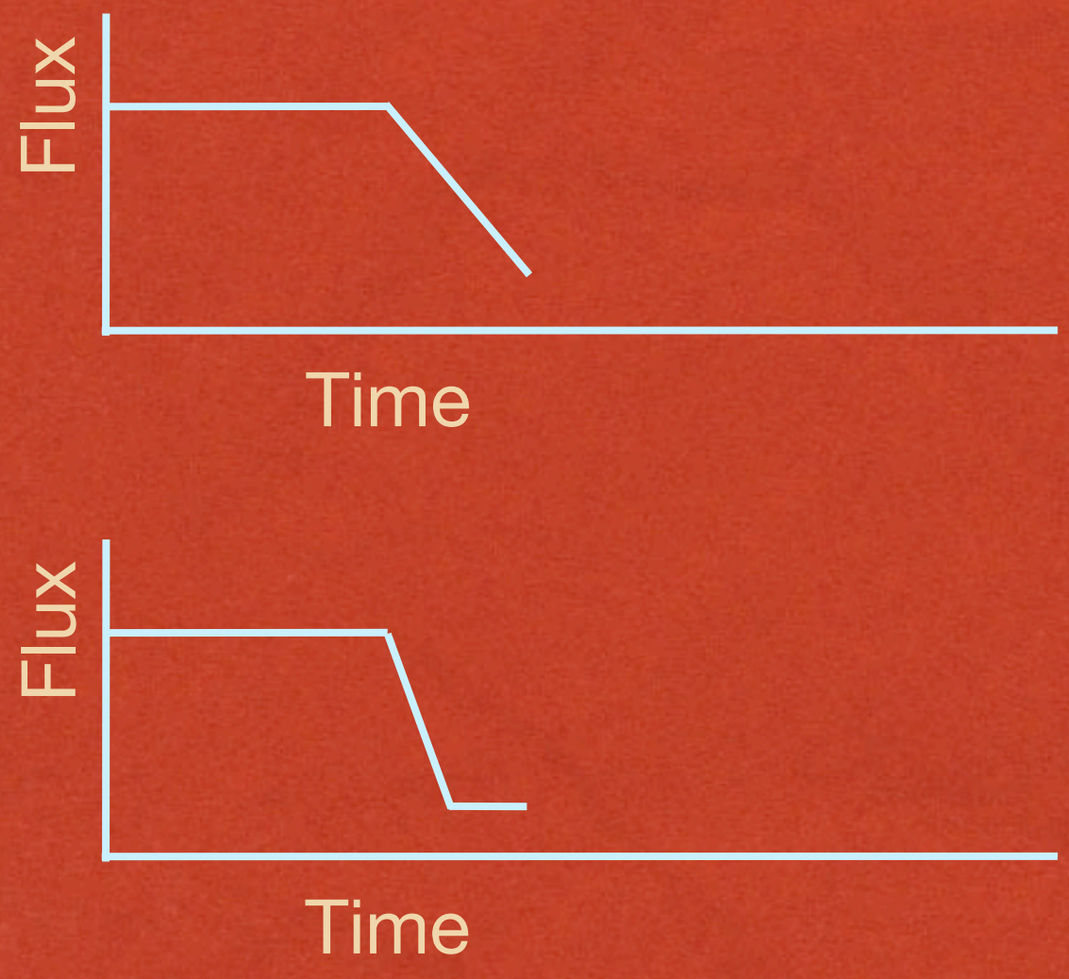

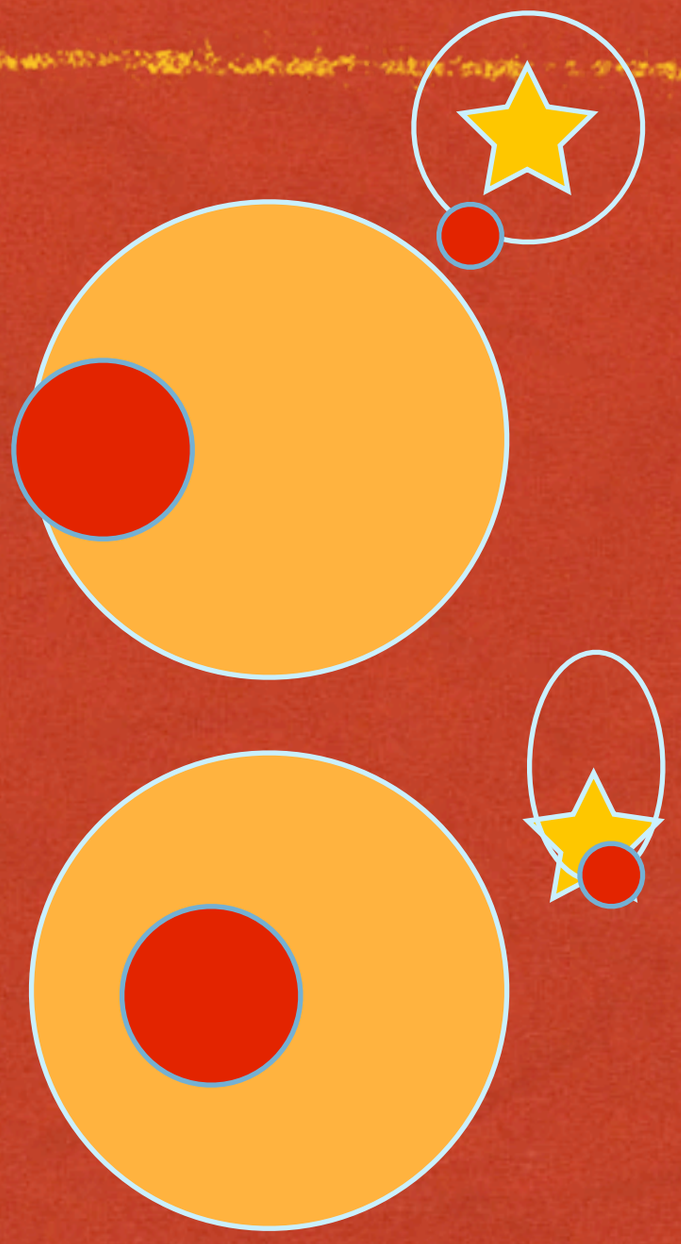

Dawson & Johnson 2012

R. Dawson, CfA

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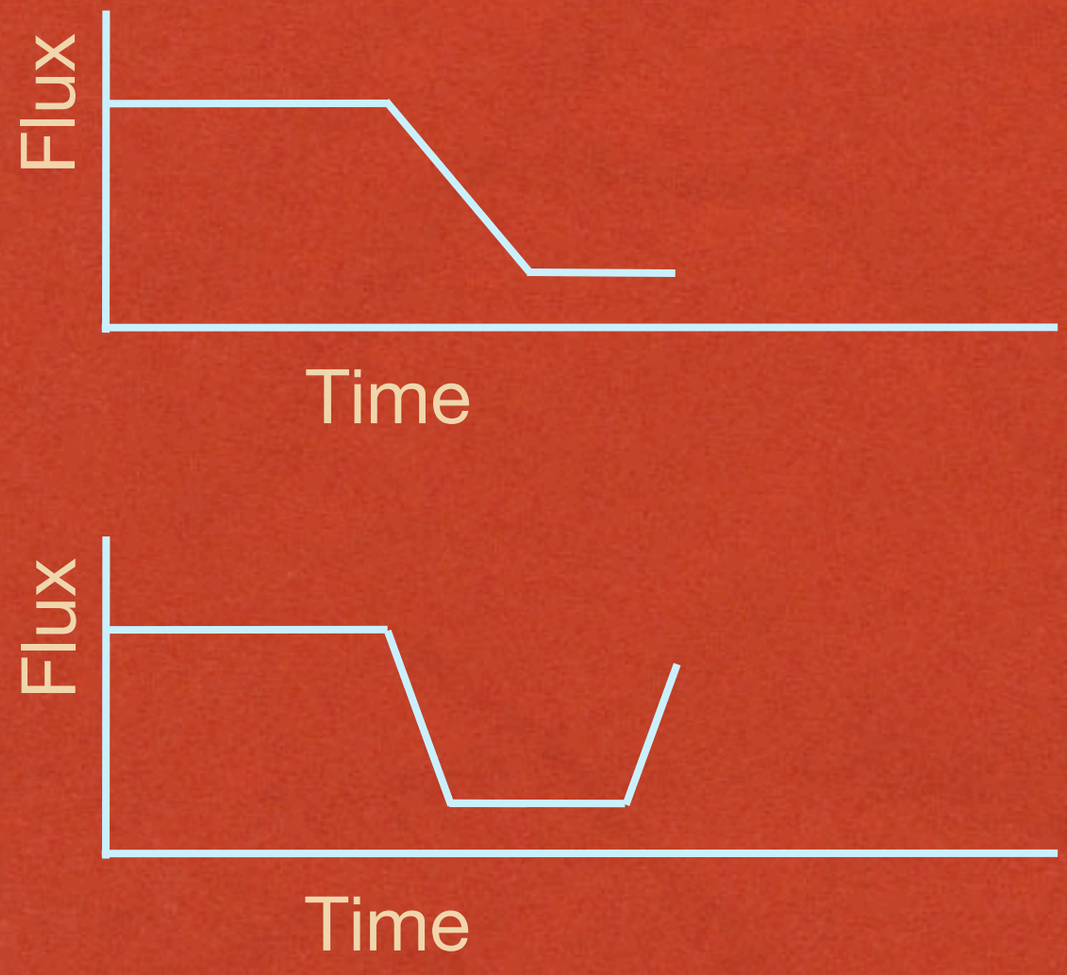

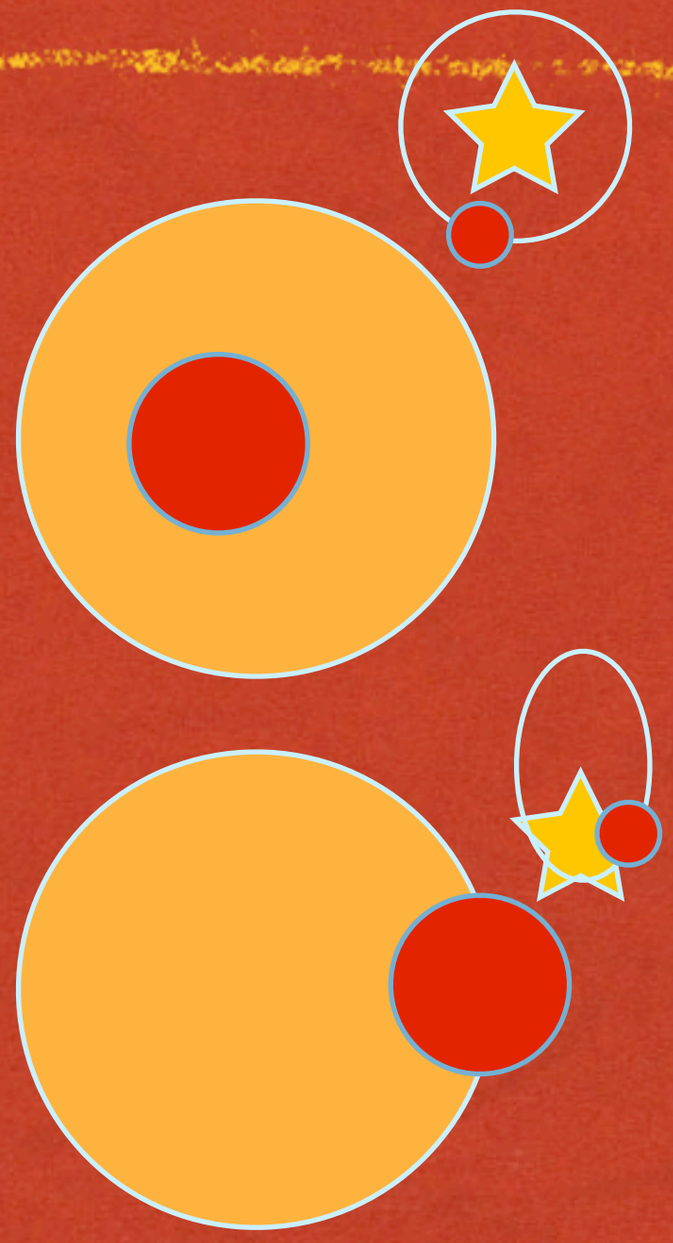

Dawson & Johnson 2012

R. Dawson, CfA

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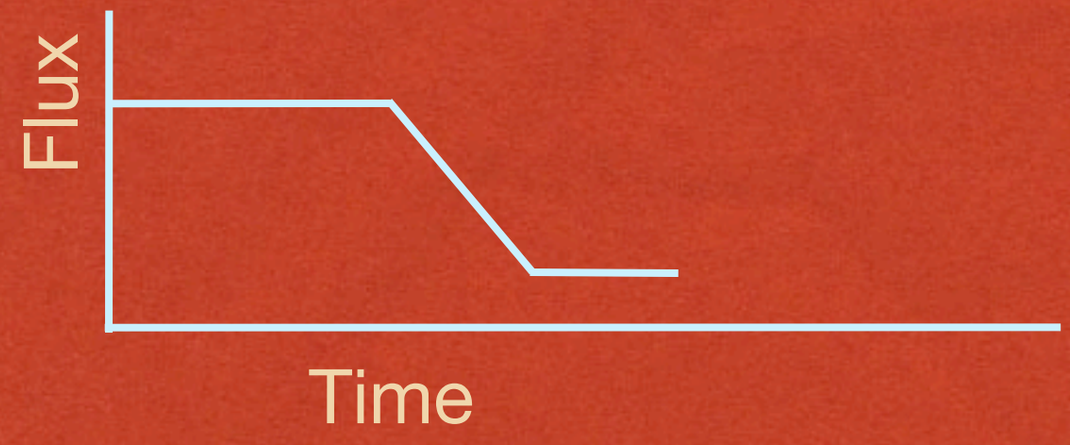

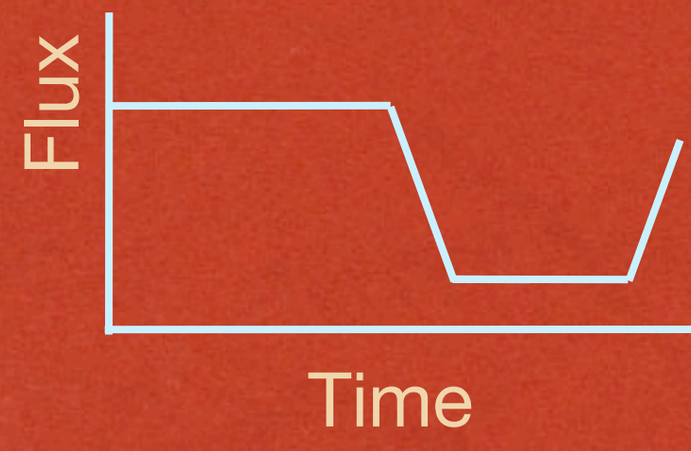

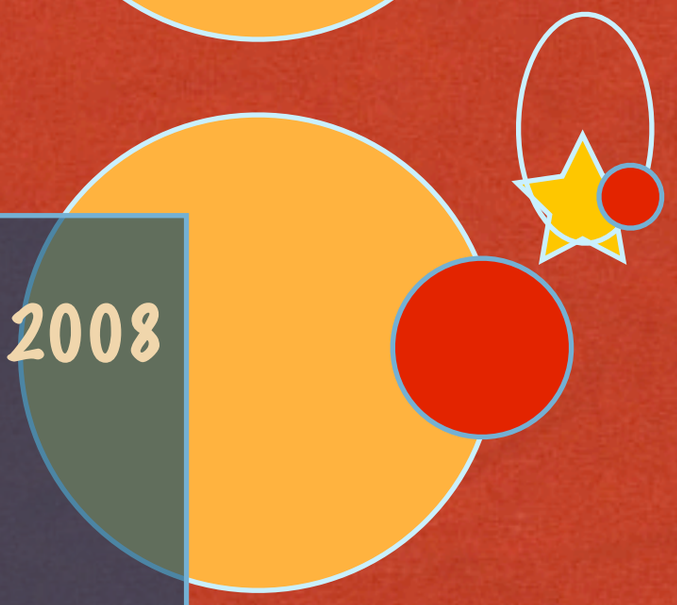

Burke 2007
Ford, Quinn, Veras 2008
Barnes 2008
Moorhead+ 2011
Kipping+ 2012
Kane+ 2012
Plavchan+ 2012

Dawson & Johnson 2012

R. Dawson, CfA

ECCENTRICITY MEASUREMENT POSSIBLE DESPITE PARAMETER DEGENERACIES

$$\rho_\star g^3 = \left[\frac{2\delta^{1/4}}{\sqrt{T_{14}^2 - T_{23}^2}}\right]^3 \left(\frac{3P}{G\pi^2}\right)$$

Light curve observables

Dawson & Johnson 2012

ECCENTRICITY MEASUREMENT POSSIBLE DESPITE PARAMETER DEGENERACIES

$$\rho_\star g^3 = \left[\frac{2\delta^{1/4}}{\sqrt{T_{14}^2 - T_{23}^2}}\right]^3 \left(\frac{3P}{G\pi^2}\right)$$

Transit speed/ circular speed:

Light curve observables

Dawson & Johnson 2012

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Transit speed/ circular speed:

$$g(e,\omega) = \frac{1 + e\sin\omega}{\sqrt{1-e^2}}$$

Light curve observables

Dawson & Johnson 2012

ECCENTRICITY MEASUREMENT POSSIBLE DESPITE PARAMETER DEGENERACIES

Host star density

$$\rho_\star g^3 = \left[\frac{2\delta^{1/4}}{\sqrt{T_{14}^2 - T_{23}^2}}\right]^3 \left(\frac{3P}{G\pi^2}\right)$$

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Dawson & Johnson 2012

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Transit speed/ circular speed:

Light curve observables

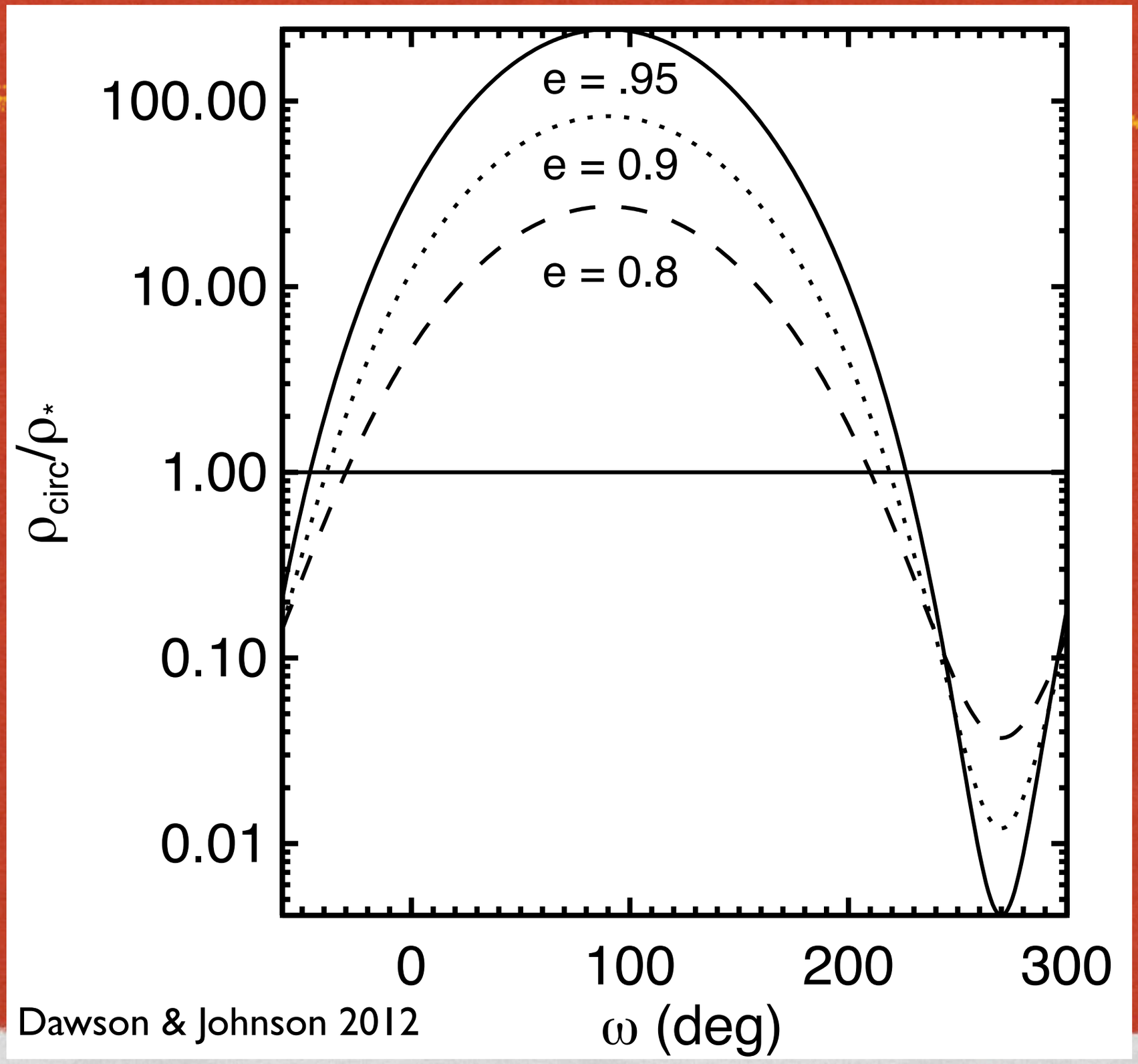
$\rho_{\rm circ}$

if assume g = 1

Dawson & Johnson 2012

R. Dawson, CfA

LIGHT CURVE OF A HIGHLY ECCENTRIC PLANET --> UNREALISTIC STELLAR DENSITY



Dawson & Johnson 2012

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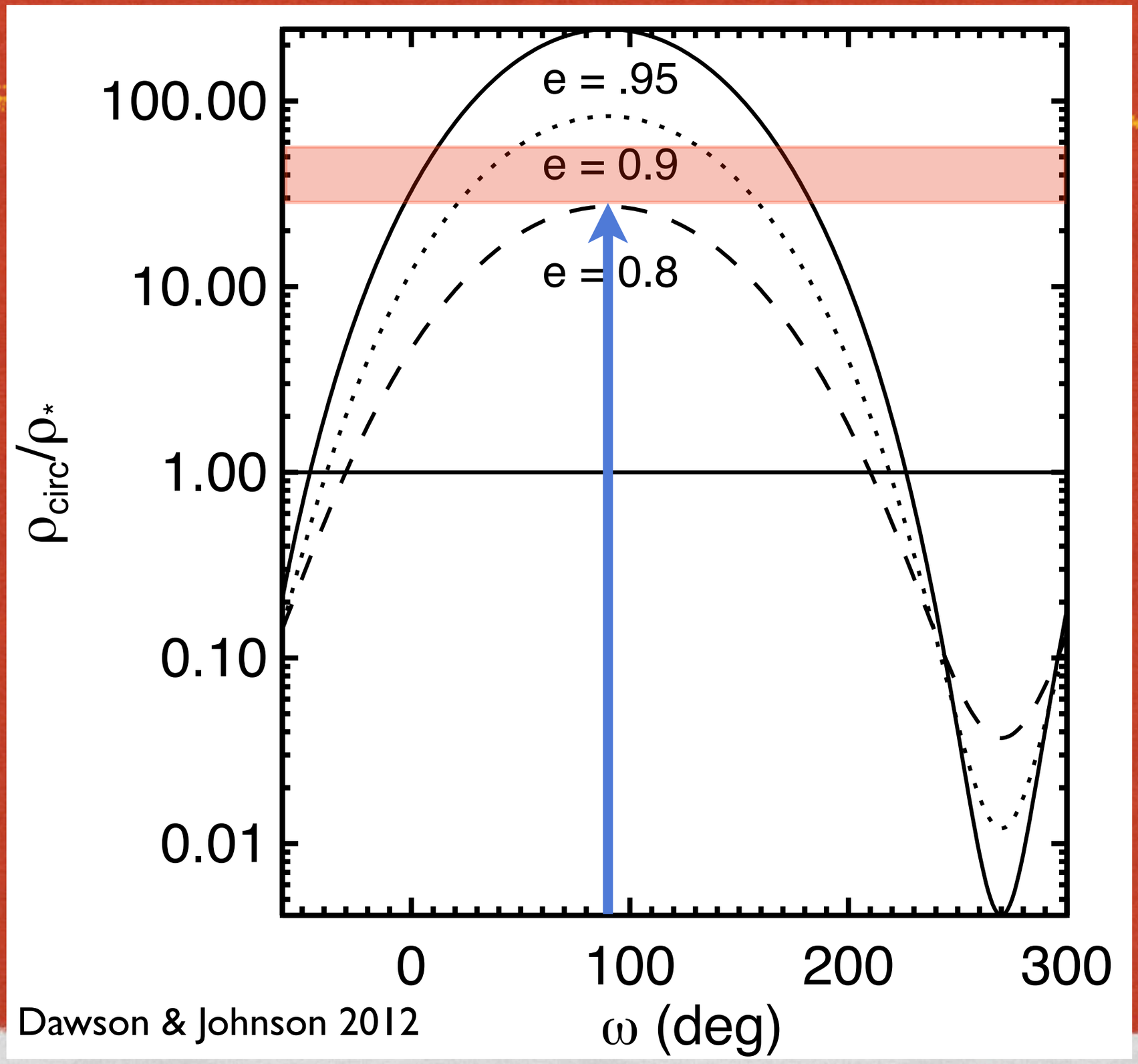
LIGHT CURVE OF A HIGHLY ECCENTRIC PLANET --> UNREALISTIC STELLAR DENSITY



Dawson & Johnson 2012

A BAYESIAN APPROACH

$$\text{prob}(e, \omega, \rho_\star, X|D) \propto \text{prob}(D|e, \omega, \rho_\star, X)\text{prob}(e, \omega, \rho_\star, X)$$

Model | data Data | model model

$$\text{prob}(e, \omega, \rho_\star, X|D) \propto \text{prob}(D|e, \omega, \rho_\star, X)\text{prob}(\rho_\star)$$

$$\text{prob}(e|D) \propto \int\int\int \text{prob}(D|e, \omega, \rho_\star, X)\text{prob}(\rho_\star) dX\, d\rho_\star\, d\omega$$

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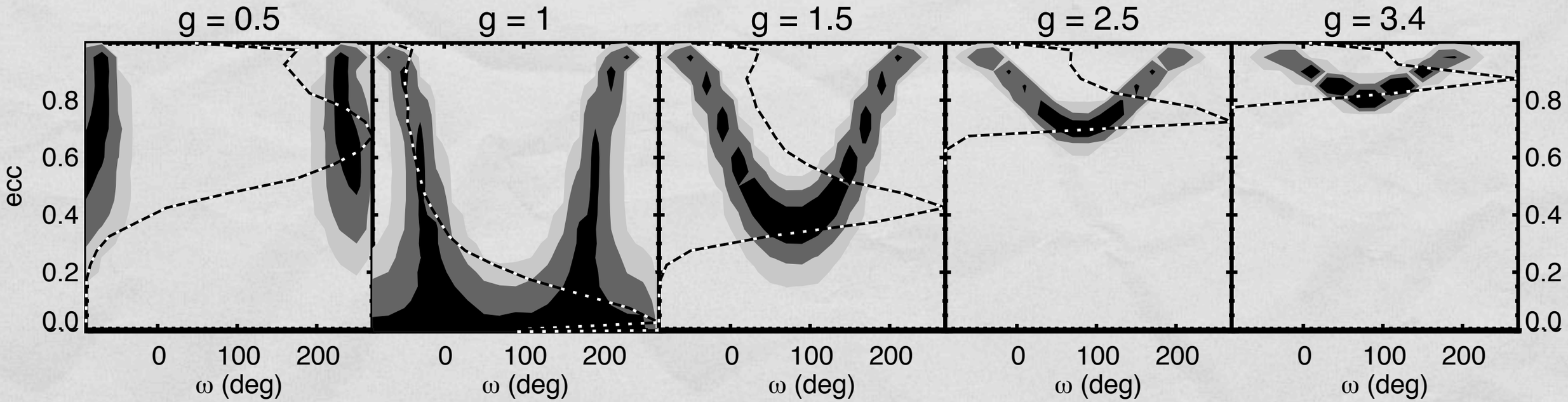
Moving faster



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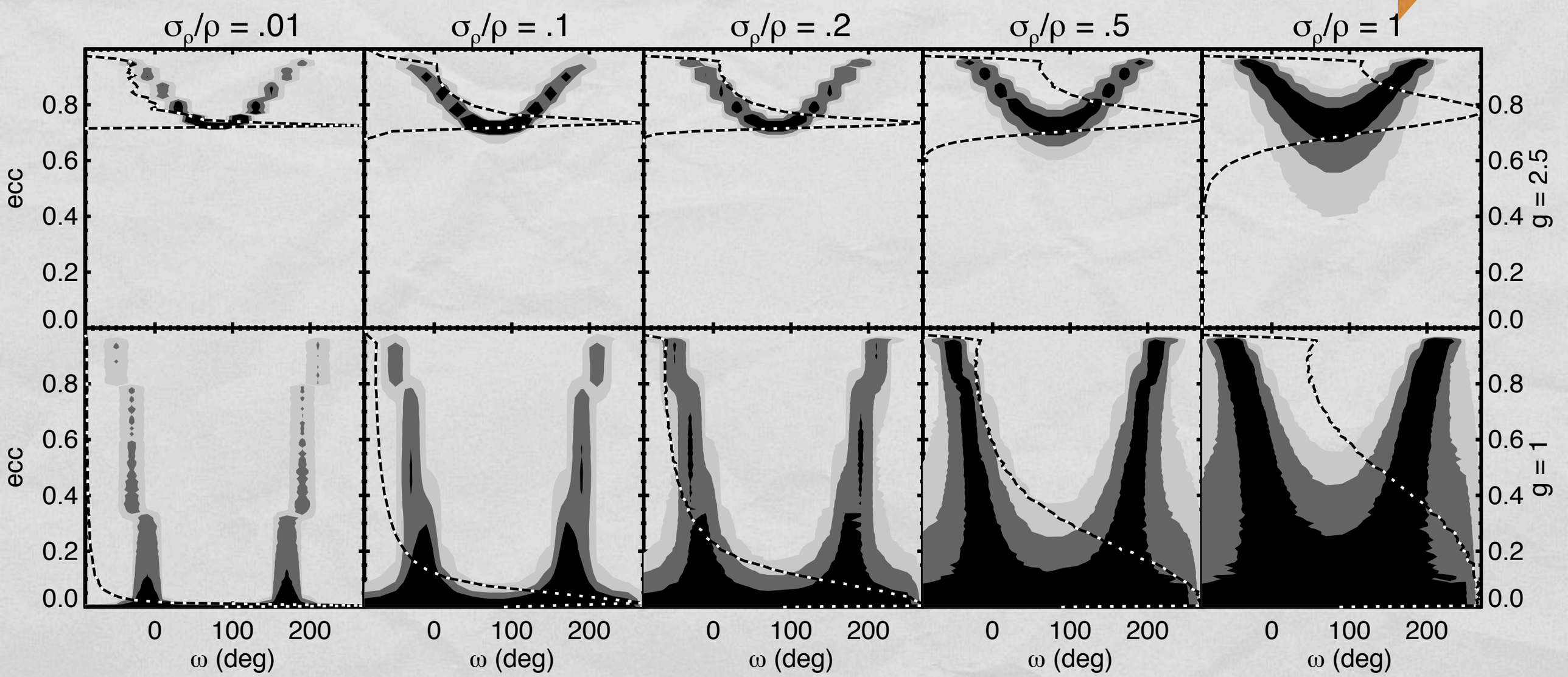
Star's true density more uncertain



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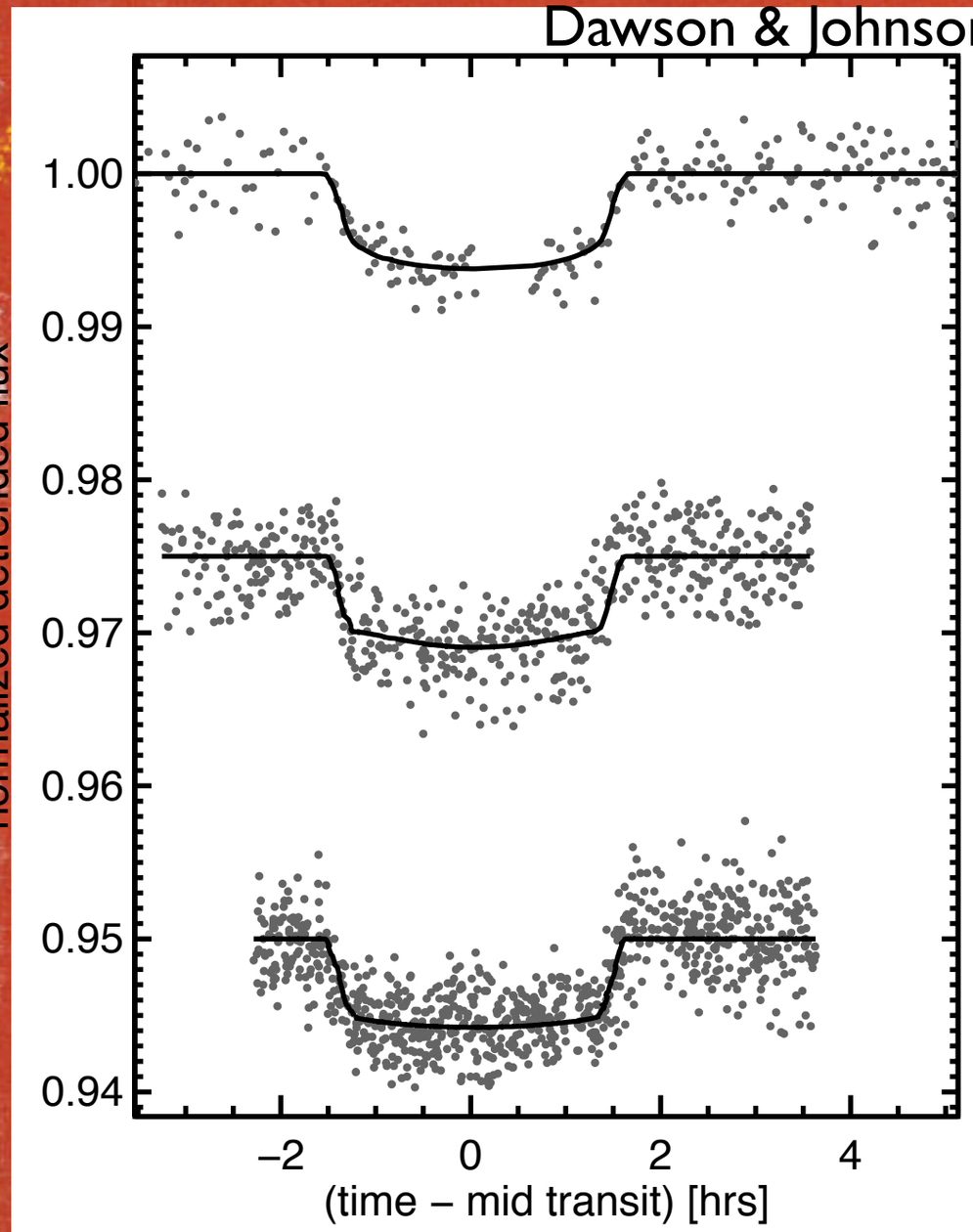
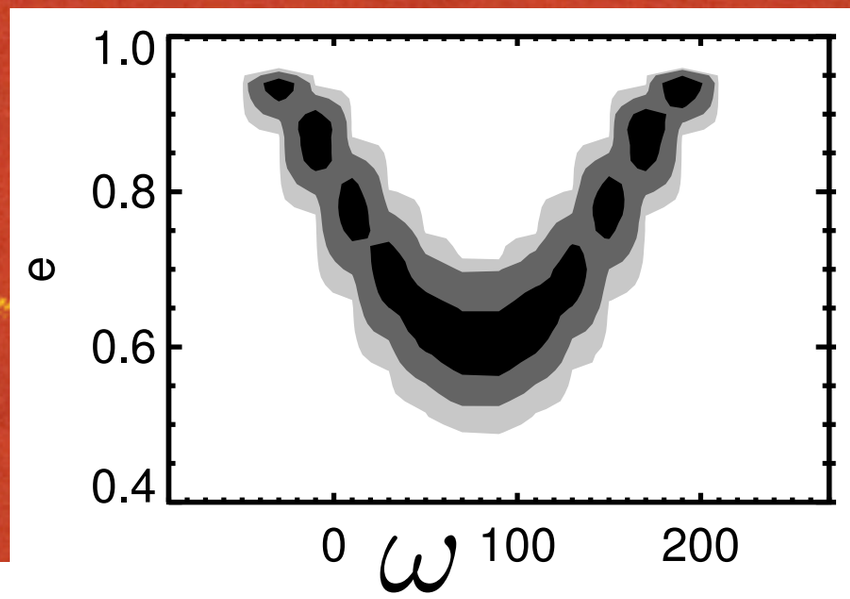
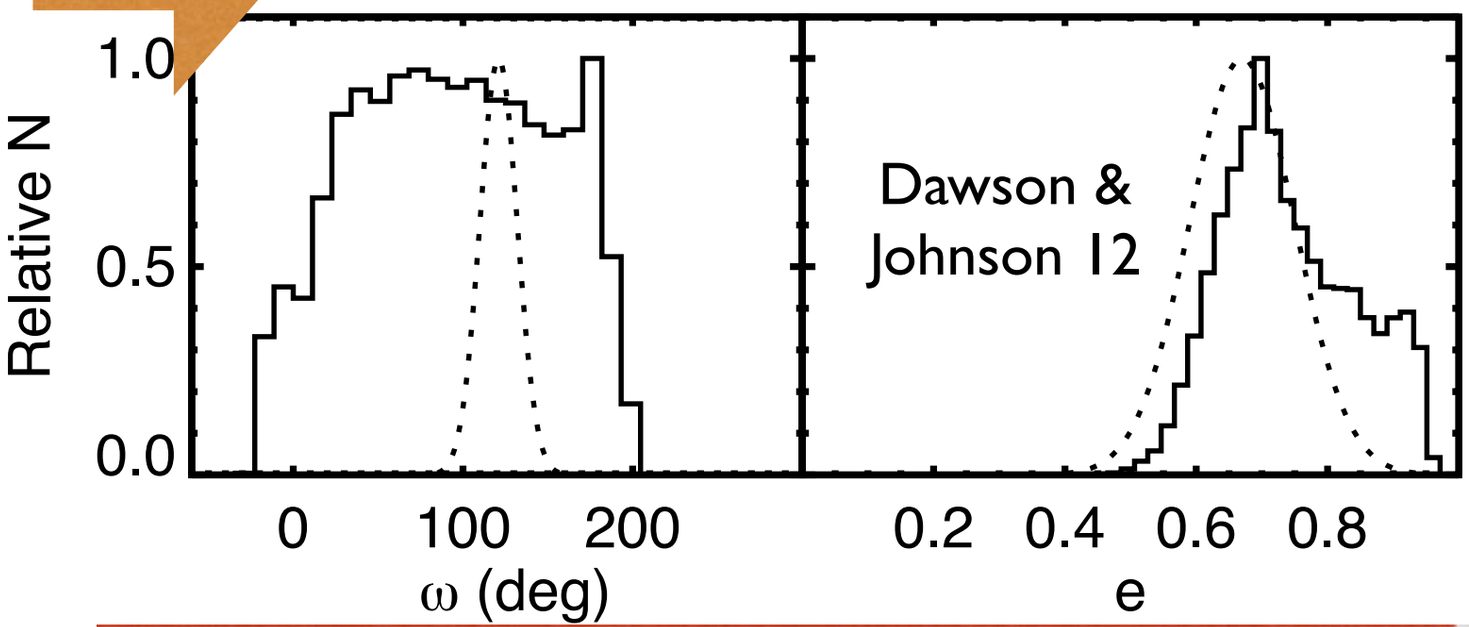
TEST CASE: HD 17156B







[Lightcurves from Barbieri+ 09, Winn+ 09]

Fischer et al. 07

Dawson & Johnson 12 (photometry alone)

$e = 0.67 \pm 0.08$

$e = 0.71^{+0.16}_{-0.09}$

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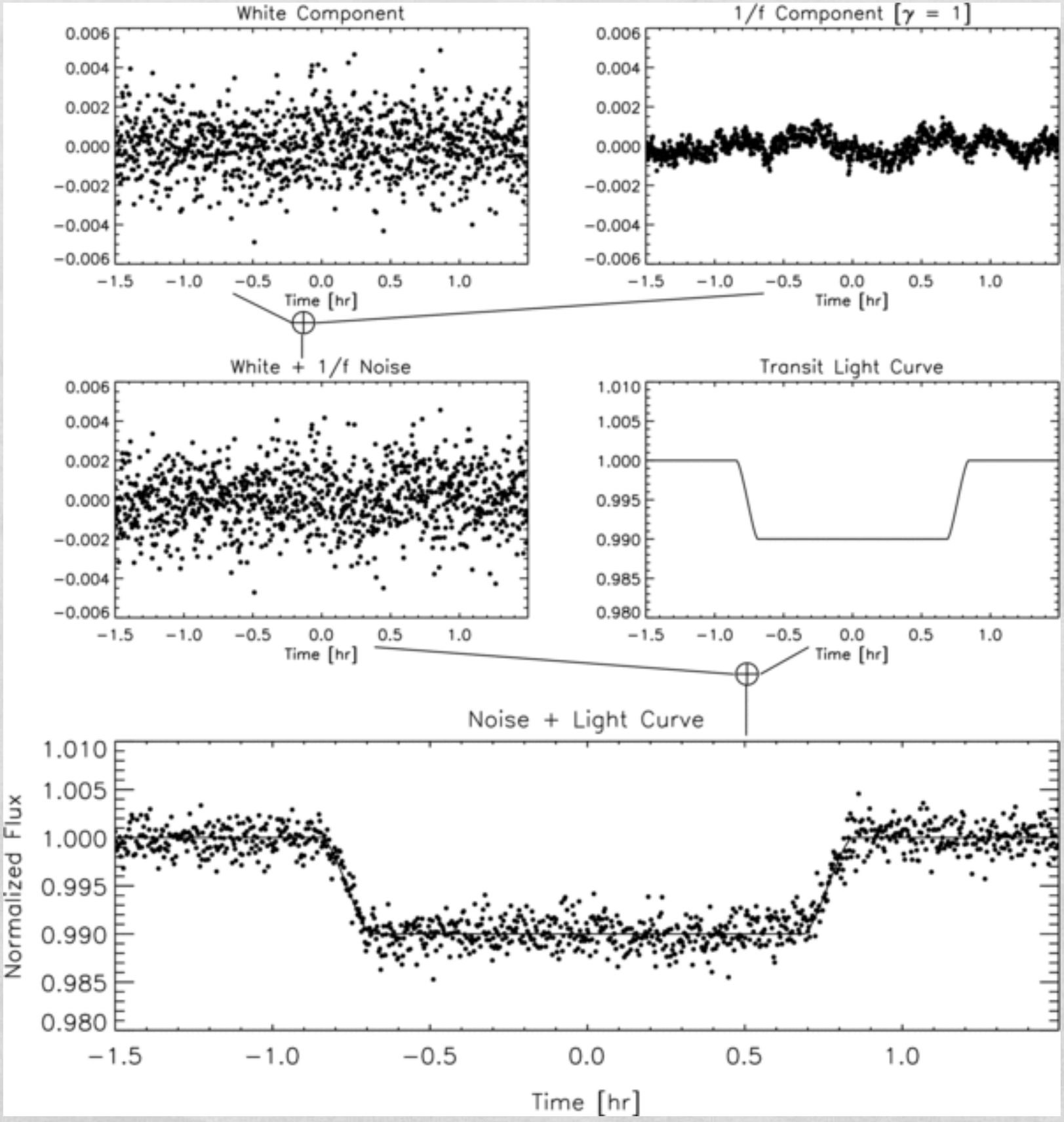
FITTING NOISY LIGHT-CURVES WITH WAVELET NOISE

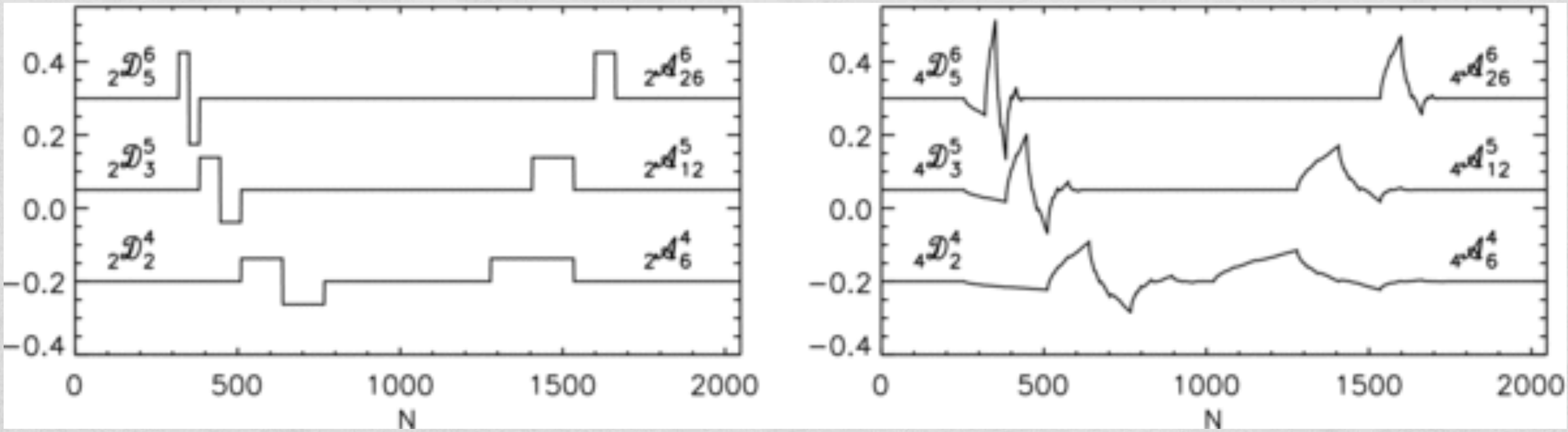
Carter & Winn 2009



Carter & Winn 2009

Compute residuals

Apply wavelet transform



Compute wavelet likelihood

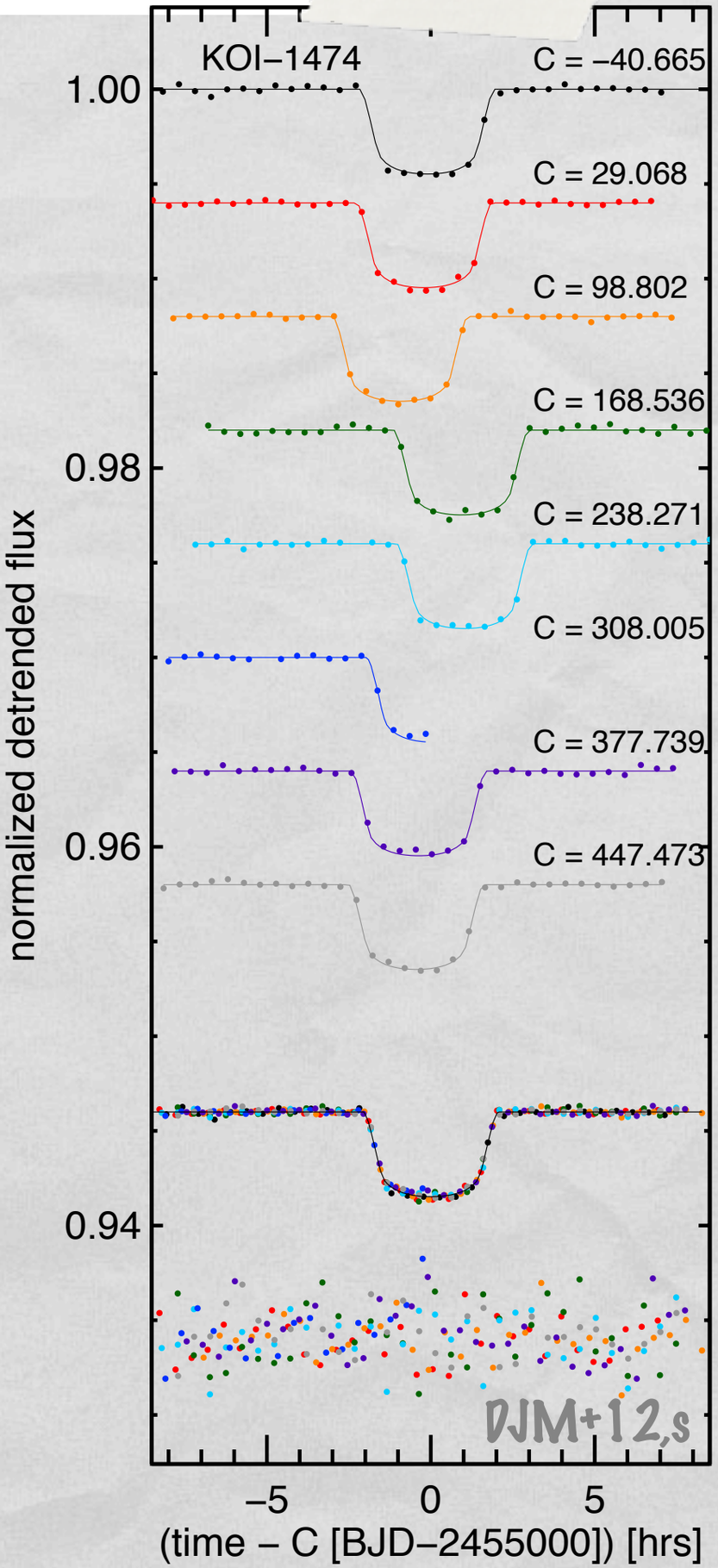
$$\sigma_W^2 = \sigma_r^2 2^{-\gamma m} + \sigma_w^2,$$

$$\sigma_S^2 = \sigma_r^2 2^{-\gamma} g(\gamma) + \sigma_w^2,$$

$$\mathcal{L} = \left\{ \prod_{m=2}^{M} \prod_{n=1}^{n_0 2^{m-1}} \frac{1}{\sqrt{2\pi\sigma_W^2}} \exp\left[-\frac{\left(r_n^m\right)^2}{2\sigma_W^2} \right] \right\}$$

$$\times \left\{ \prod_{n=1}^{n_0} \frac{1}{\sqrt{2\pi\sigma_S^2}} \exp\left[-\frac{\left(\bar{r}_n^1\right)^2}{2\sigma_S^2} \right] \right\},$$

R. Dawson, CfA



KOI 1474.01

Period = 69.7340 days

$e = 0.81^{+0.10}_{-0.07}$

Dawson+ 2012

R. Dawson, CfA

CHARACTERIZING HOST STAR KOI 1474

Model | data

$$\mathrm{prob}(M_\star, \tau_\star, Z | T_{\mathrm{eff,spec}}, [\mathrm{Fe/H}]_{\mathrm{spec}}, \log g_{\mathrm{spec}}, I) \propto$$
$$\mathrm{prob}(T_{\mathrm{eff,spec}}, [\mathrm{Fe/H}]_{\mathrm{spec}}, \log g_{\mathrm{spec}} | M_\star, \tau_\star, Z, I) \mathrm{prob}(M_\star, \tau_\star, Z | I)$$

Data | model

Stellar evolution model

Takeda et al. 2007

Model

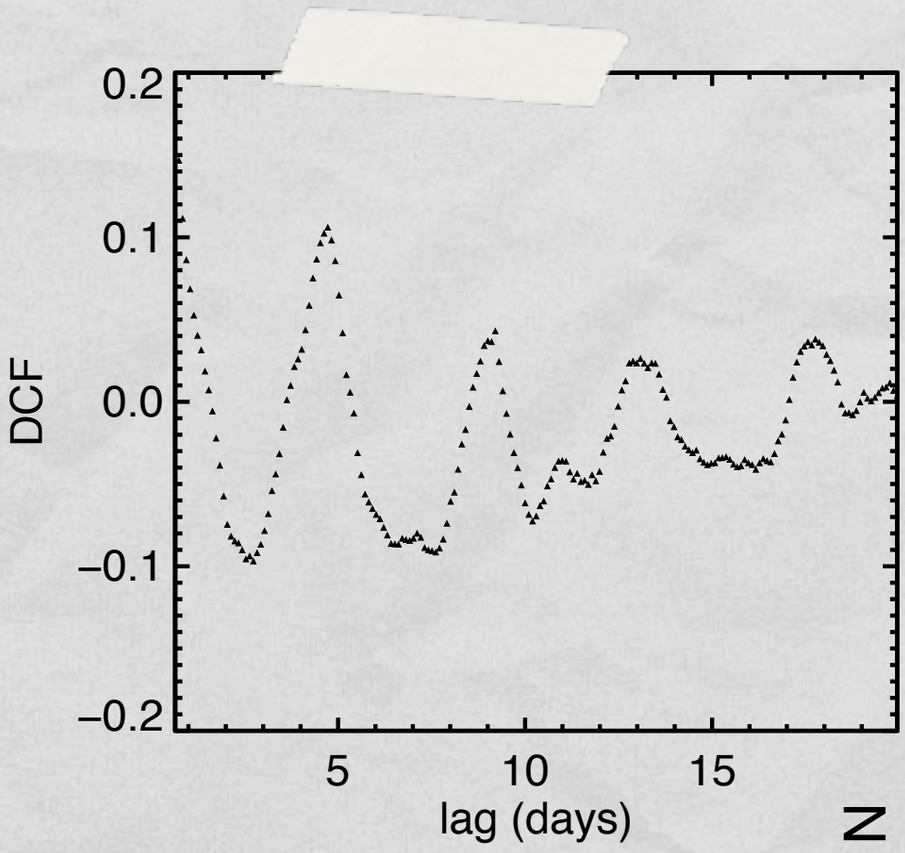
TRILEGAL population synthesis

Girardi et al. 2000, 2002, 2005

Dawson+ 2012

R. Dawson, CfA

HOW I WONDER WHAT YOU ARE...



Rotation period
4.6 +/- 0.4 days

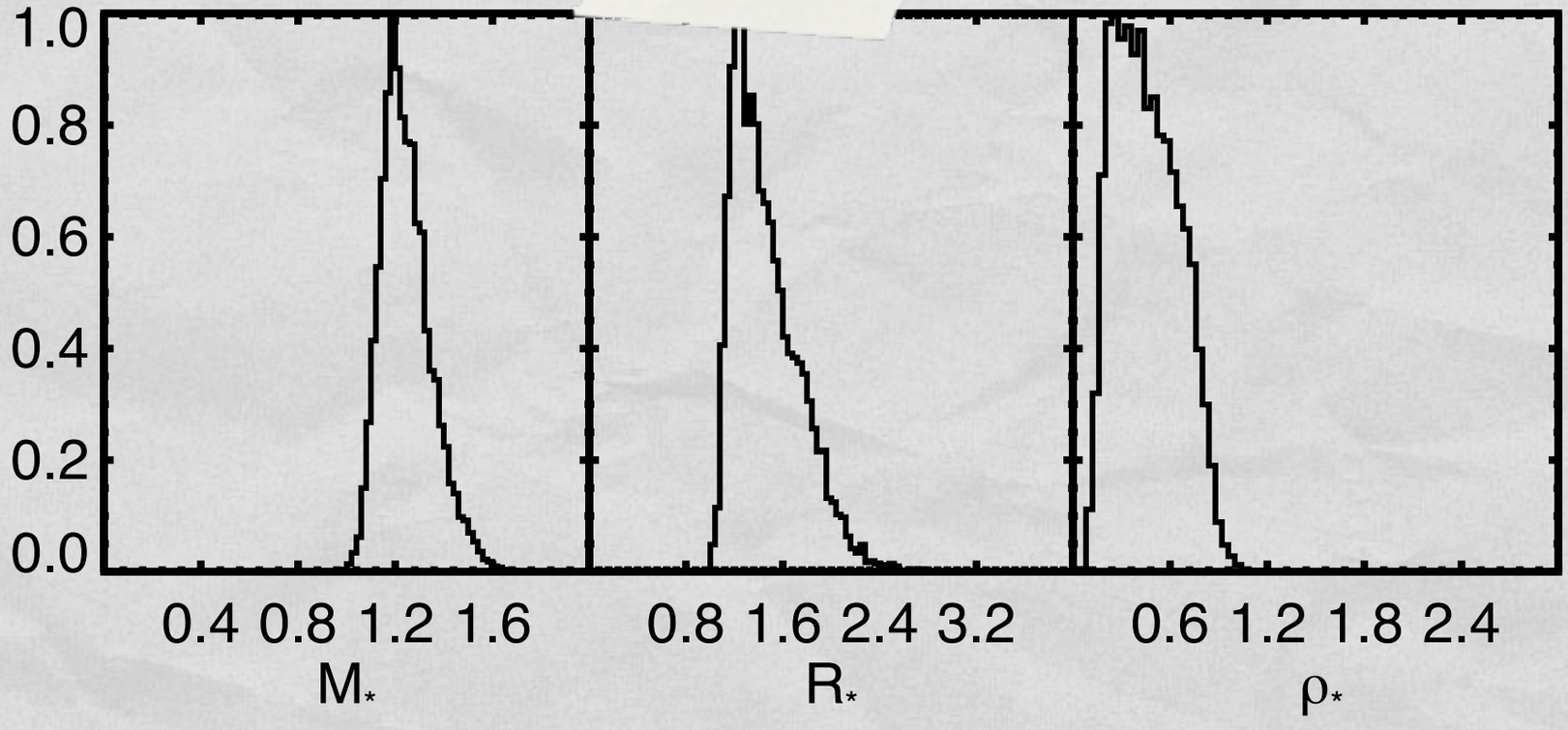
Dawson+ 2012

$$T_{\rm eff} = 6240 \pm 100{\rm K}$$

$$M_\star = 1.22^{+0.12}_{-0.08} M_\odot$$

$$R_\star = 1.40^{+0.37}_{-0.21} R_\odot$$

$$\rho_\star = 0.44^{+0.26}_{-0.20} \rho_\odot$$



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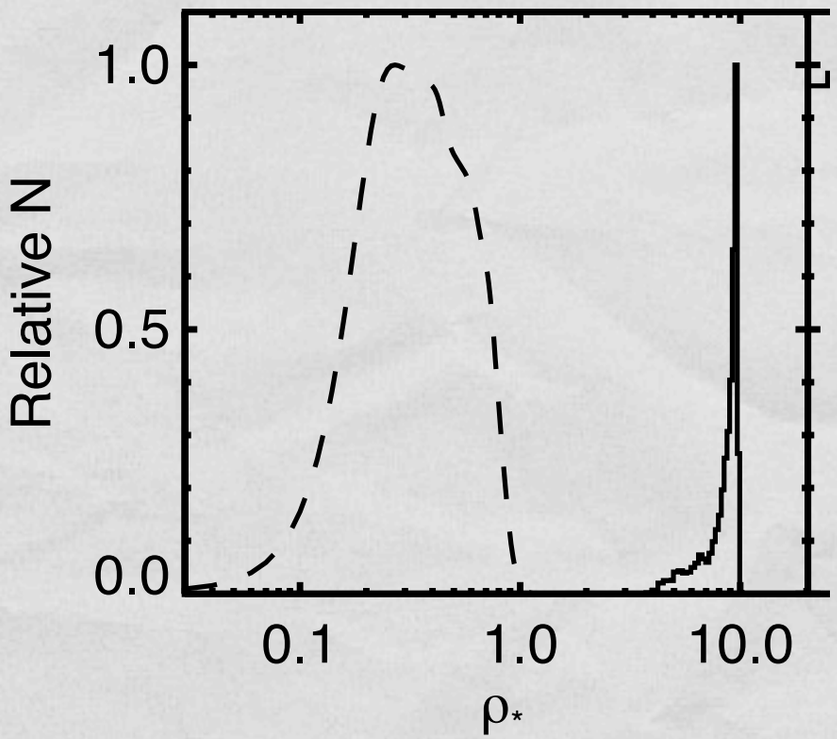

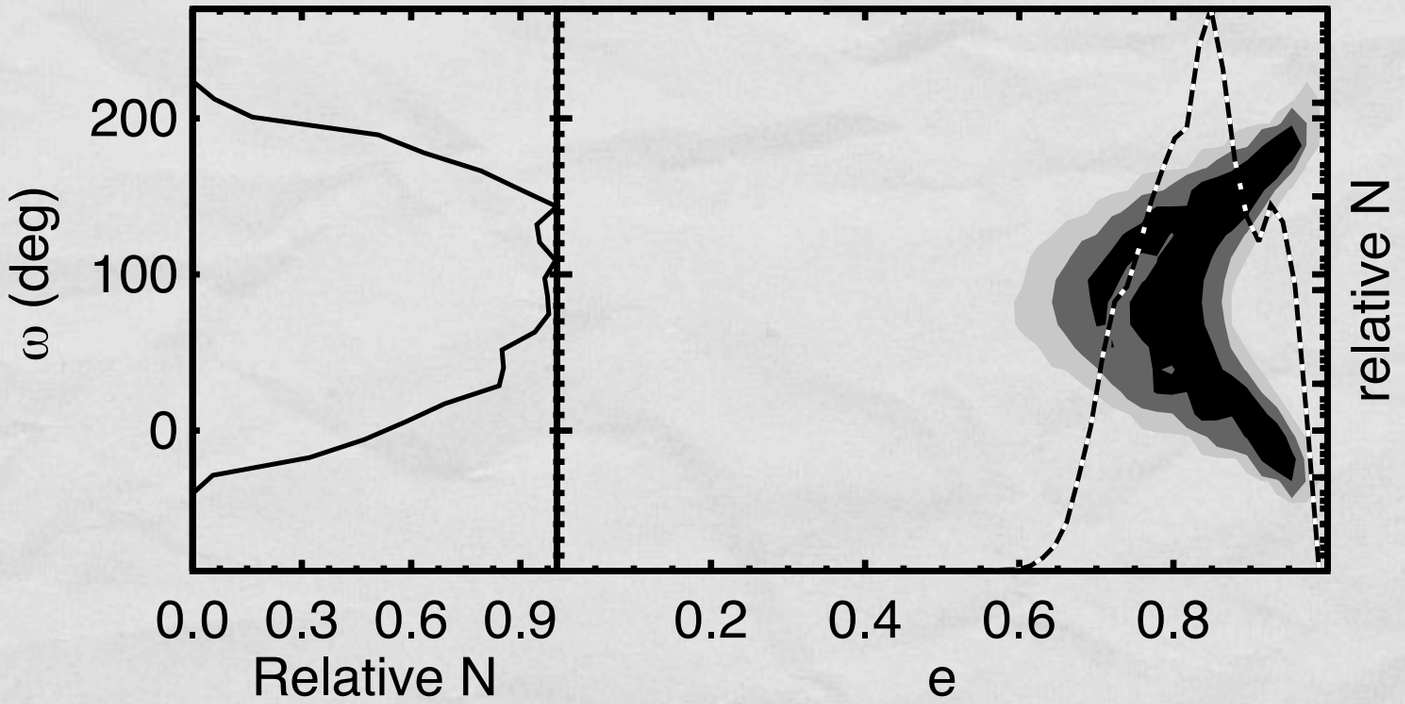

Period =

69.7340 days

$e = 0.81^{+0.10}_{-0.07}$

KOI 1474.01'S HIGHLY-ECCENTRIC ORBIT

Dawson+ 2012

R. Dawson, CfA

Speaking @ CfA on 11/13 -->

PLANET OR FALSE POSITIVE?

Timothy Morton,
Caltech

planet (pl)

eclipsing binary (eb)

background planet (bgpl)

hierarchical eclipsing binary (eb)

background eclipsing binary (bgeb)

R. Dawson, CfA

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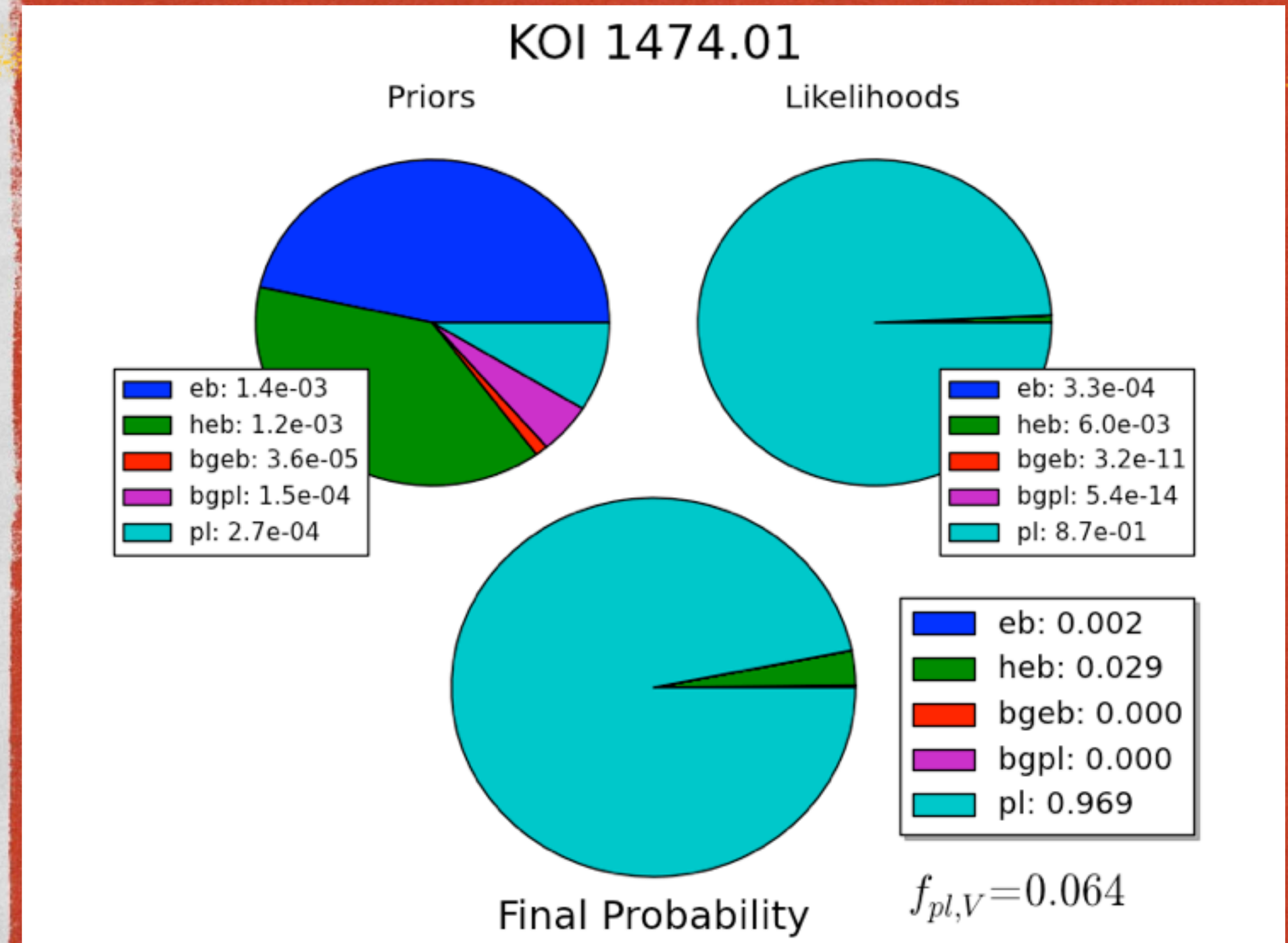
PLANET OR FALSE POSITIVE?

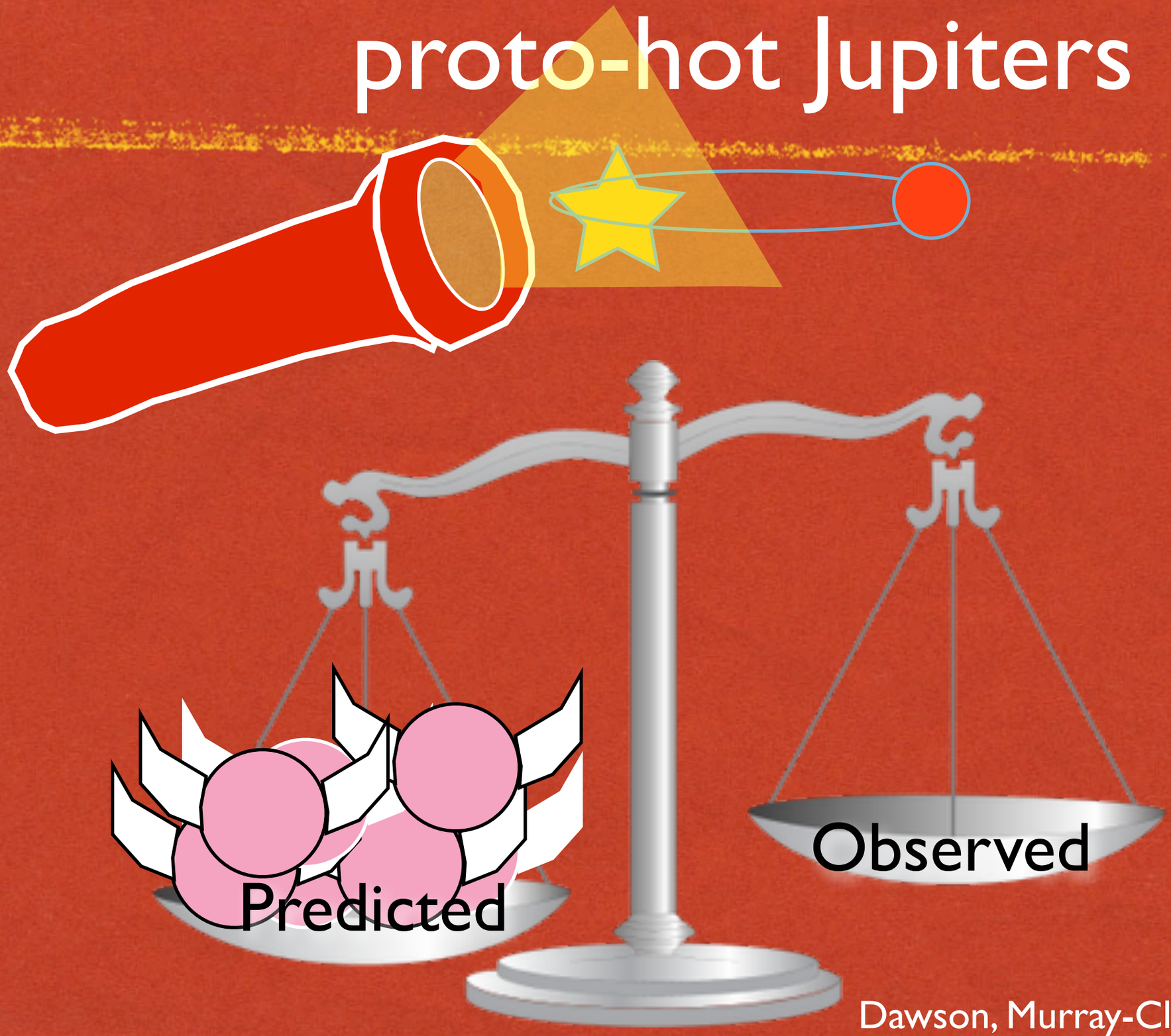
Timothy Morton,
Caltech



Dawson+ 2012

R. Dawson, CfA

A paucity of super-eccentric proto-hot Jupiters



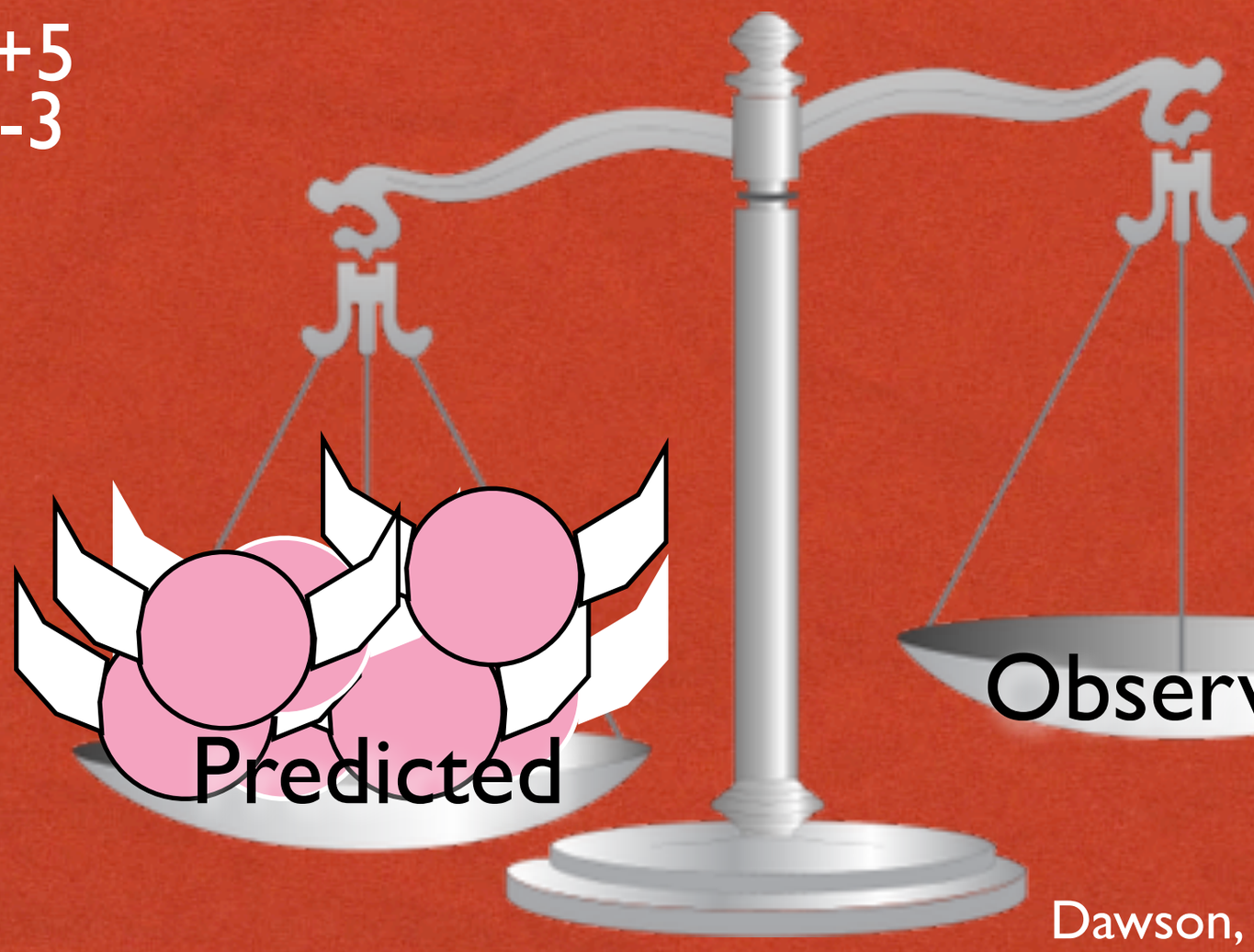
Dawson, Murray-Clay, Johnson, in prep

R. Dawson, CfA

A paucity of super-eccentric proto-hot Jupiters

We account for incompleteness, Poisson counting uncertainties

7^{+5}_{-3}

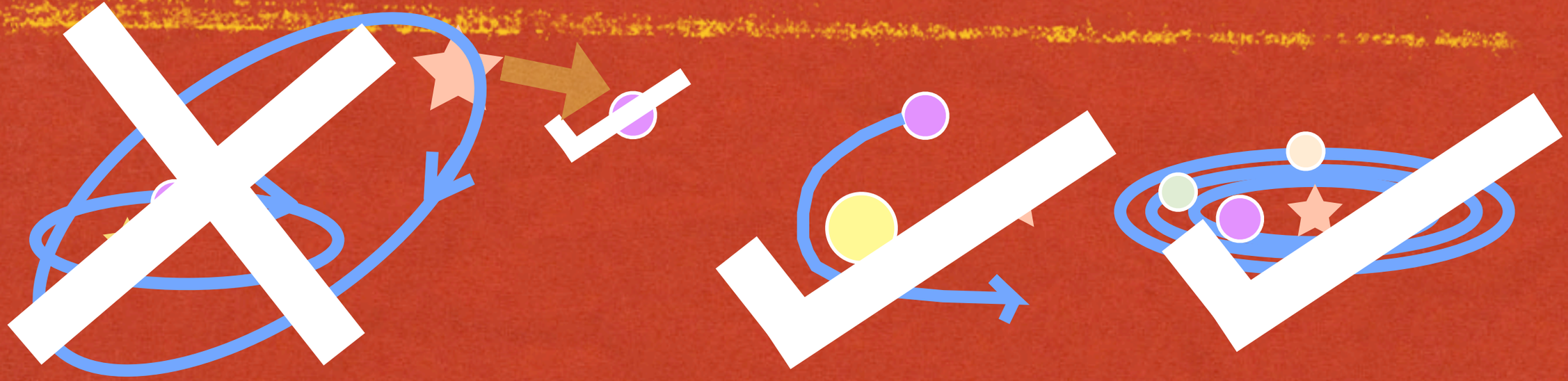


1^{0}_{-1}

Dawson, Murray-Clay, Johnson, in prep

R. Dawson, CfA

IMPLICATIONS FOR MIGRATION MODELS

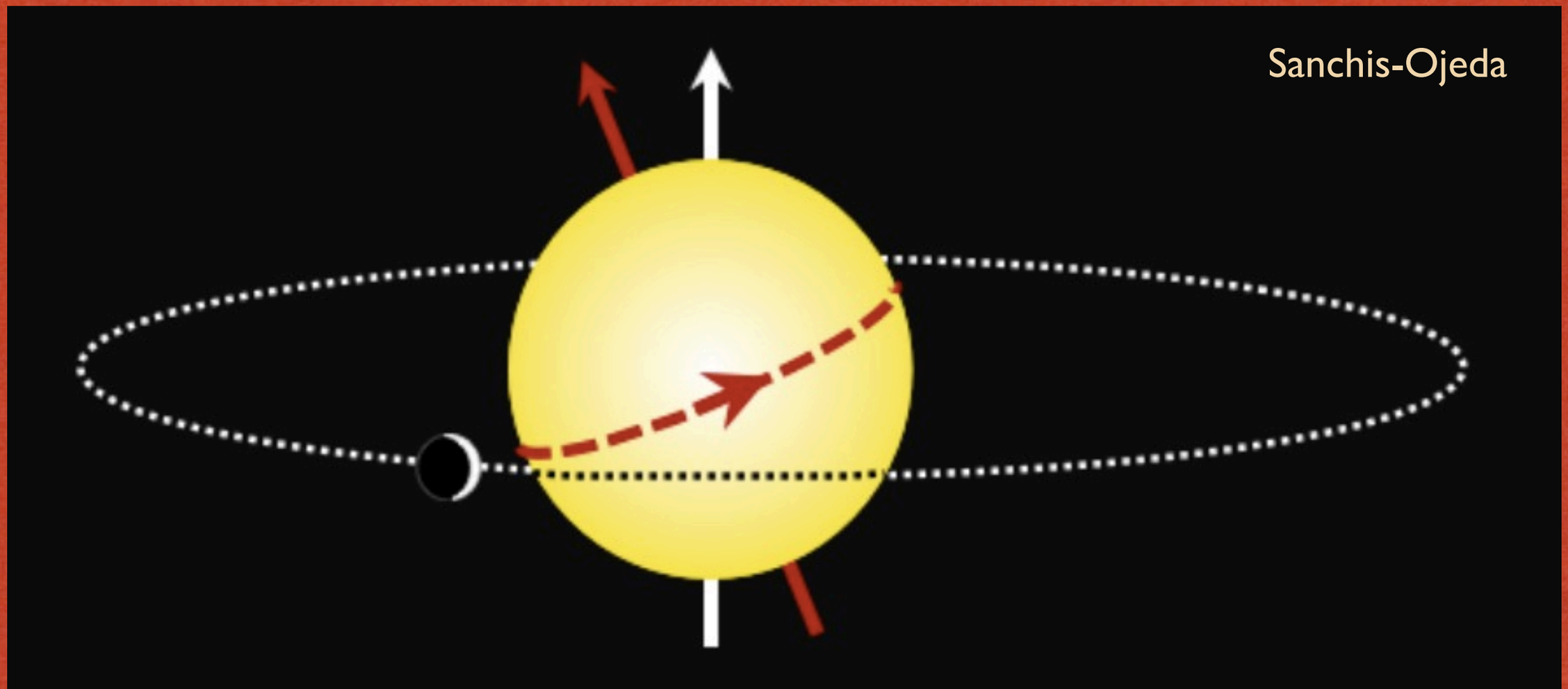


- Inconsistent with most hot Jupiters being produced by stellar perturbers
- Planetary perturbation models that avoid a high-eccentricity stage are possible
- Disk migration still a possibility

Dawson, Murray-Clay, Johnson, in prep

R. Dawson, CfA

SPIN-ORBIT ALIGNMENT



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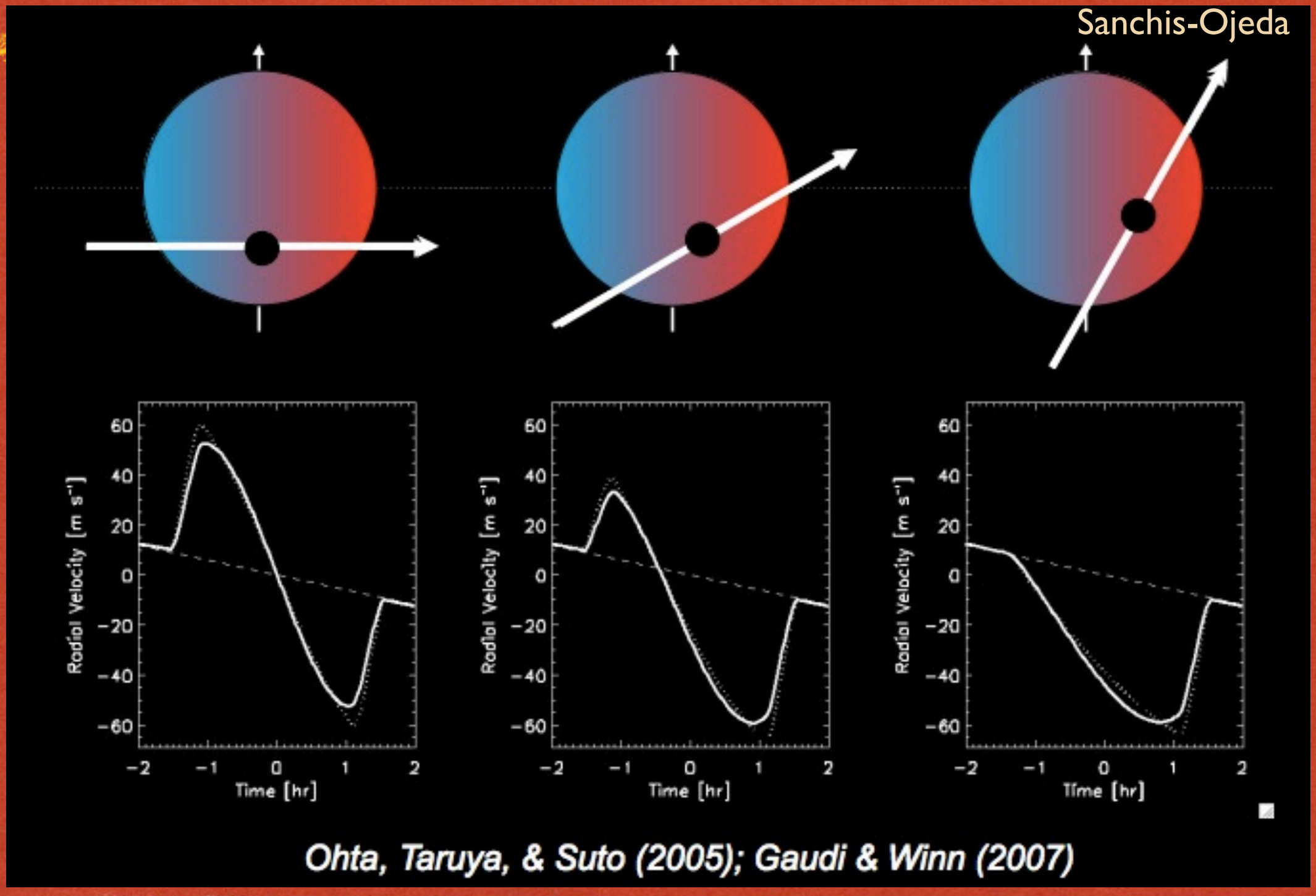
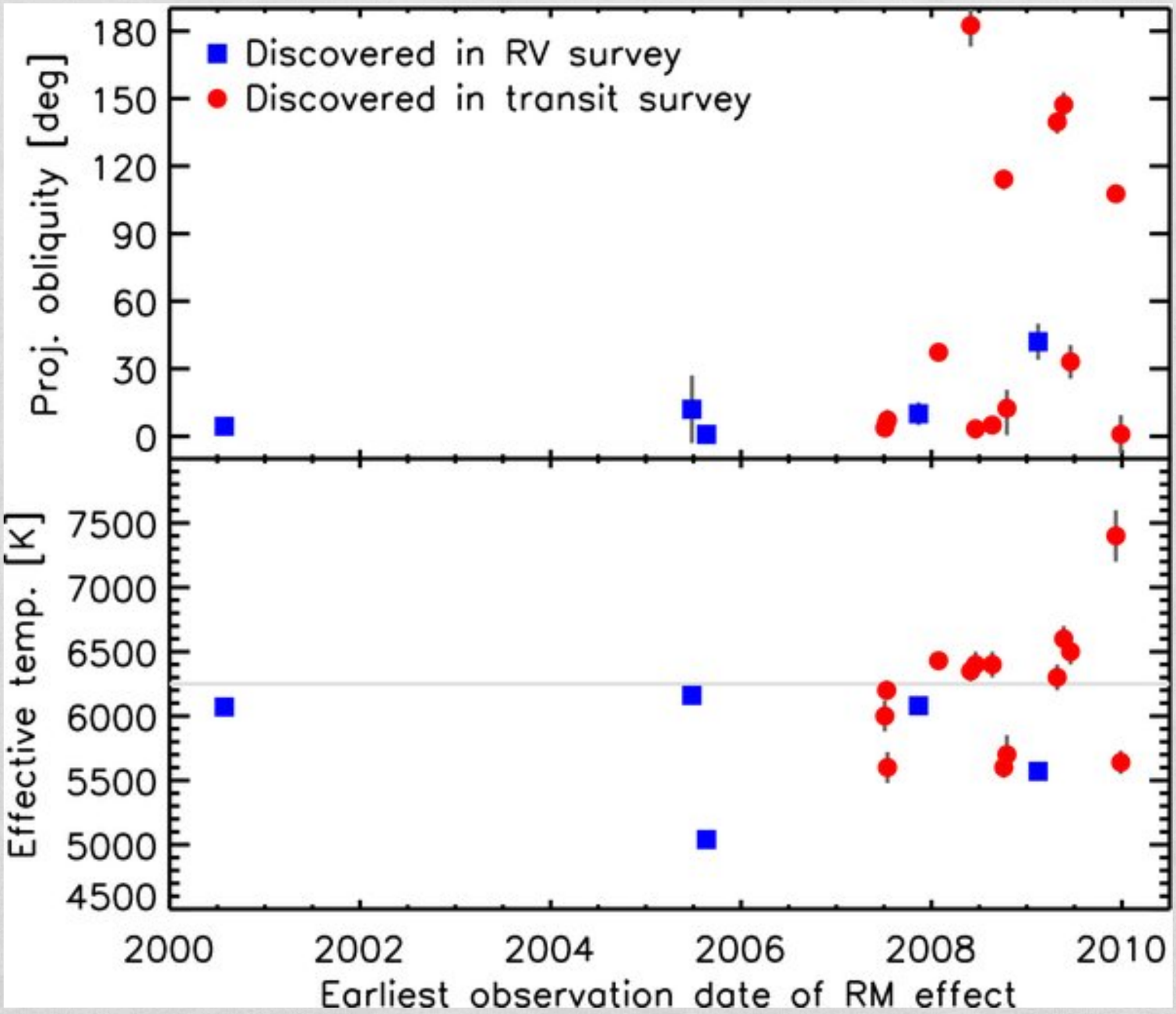
PROJECTED ANGLE MEASURED BY DOPPLER EFFECT



Ohta, Taruya, & Suto (2005); Gaudi & Winn (2007)

R. Dawson, CfA

Winn+ 2010



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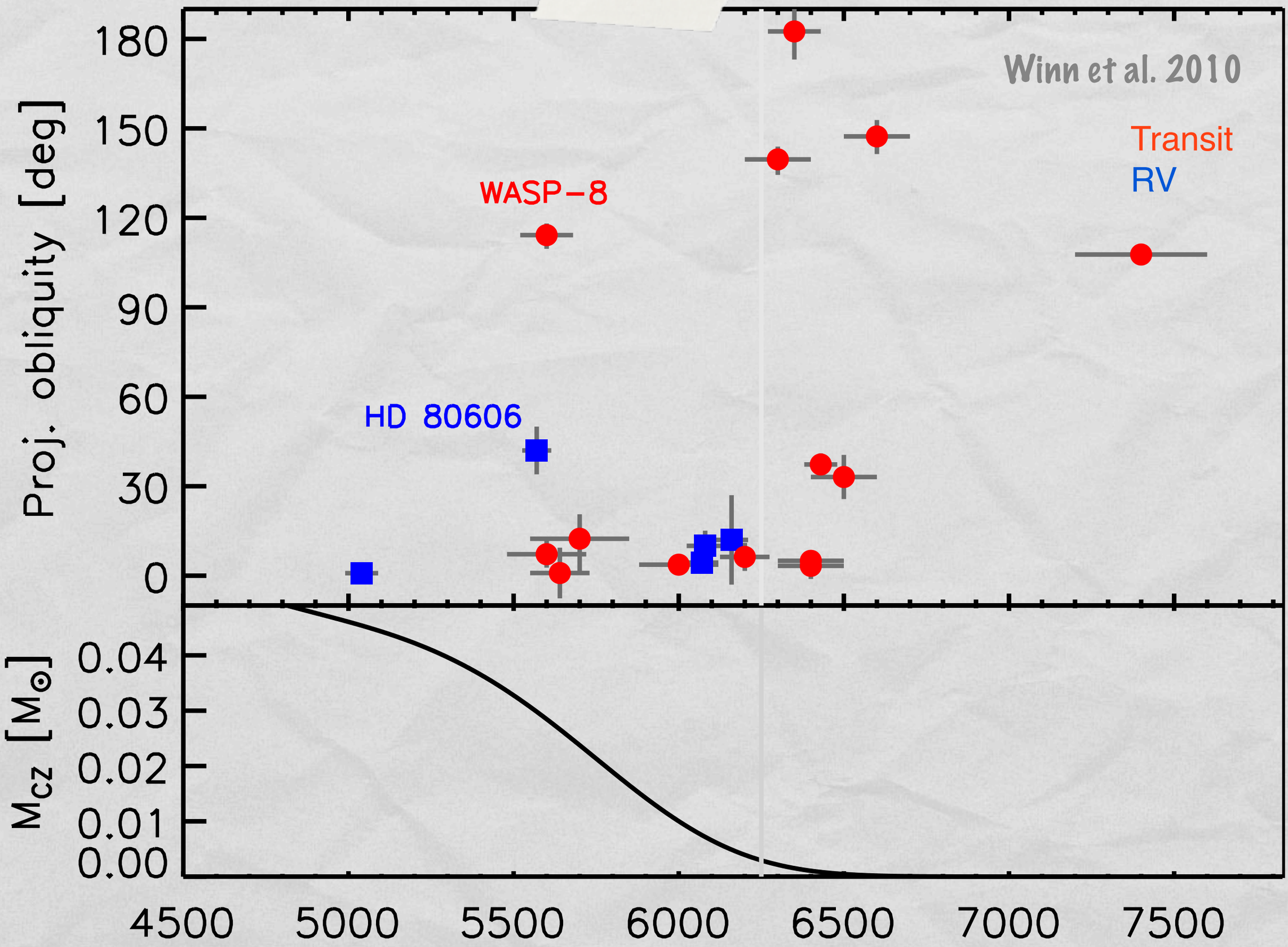
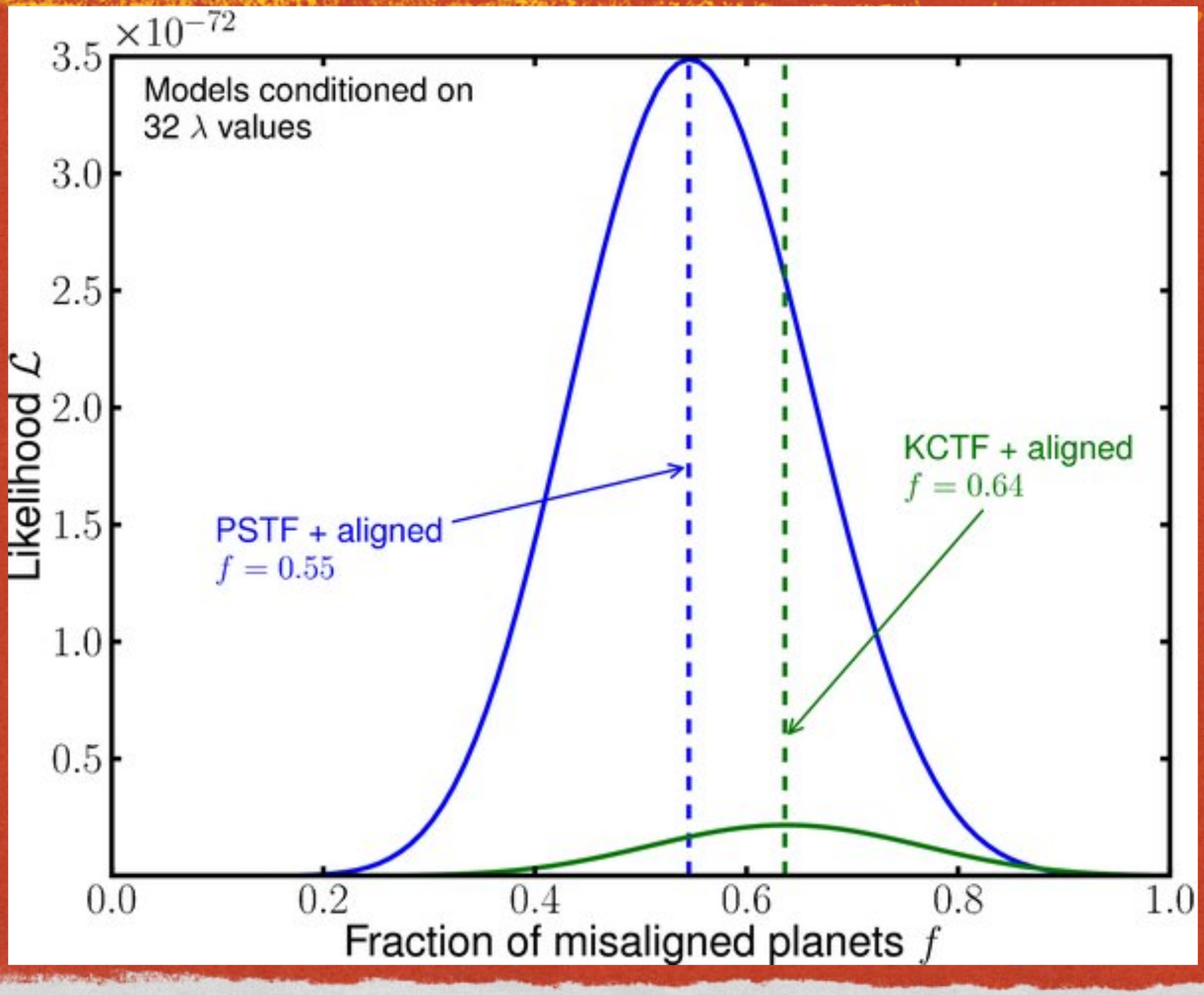

Winn et al. 2010
Transit
RV
WASP-8
HD 80606
Proj. obliquity [deg]
180
150
120
90
60
30
0
M_{cz} [$M_\odot$]
0.04
0.03
0.02
0.01
0.00
4500
5000
5500
6000
6500
7000
7500

Speaking @ CfA on 11/13 -->

$$P_{f,\mathcal{M}}(f|\{\lambda\}) = \frac{\mathcal{L}_{\mathcal{M}}(\{\lambda\}|f)p(f)}{\int_0^1 \mathcal{L}_{\mathcal{M}}(\{\lambda\}|f)p(f)df},$$

Timothy Morton, Caltech



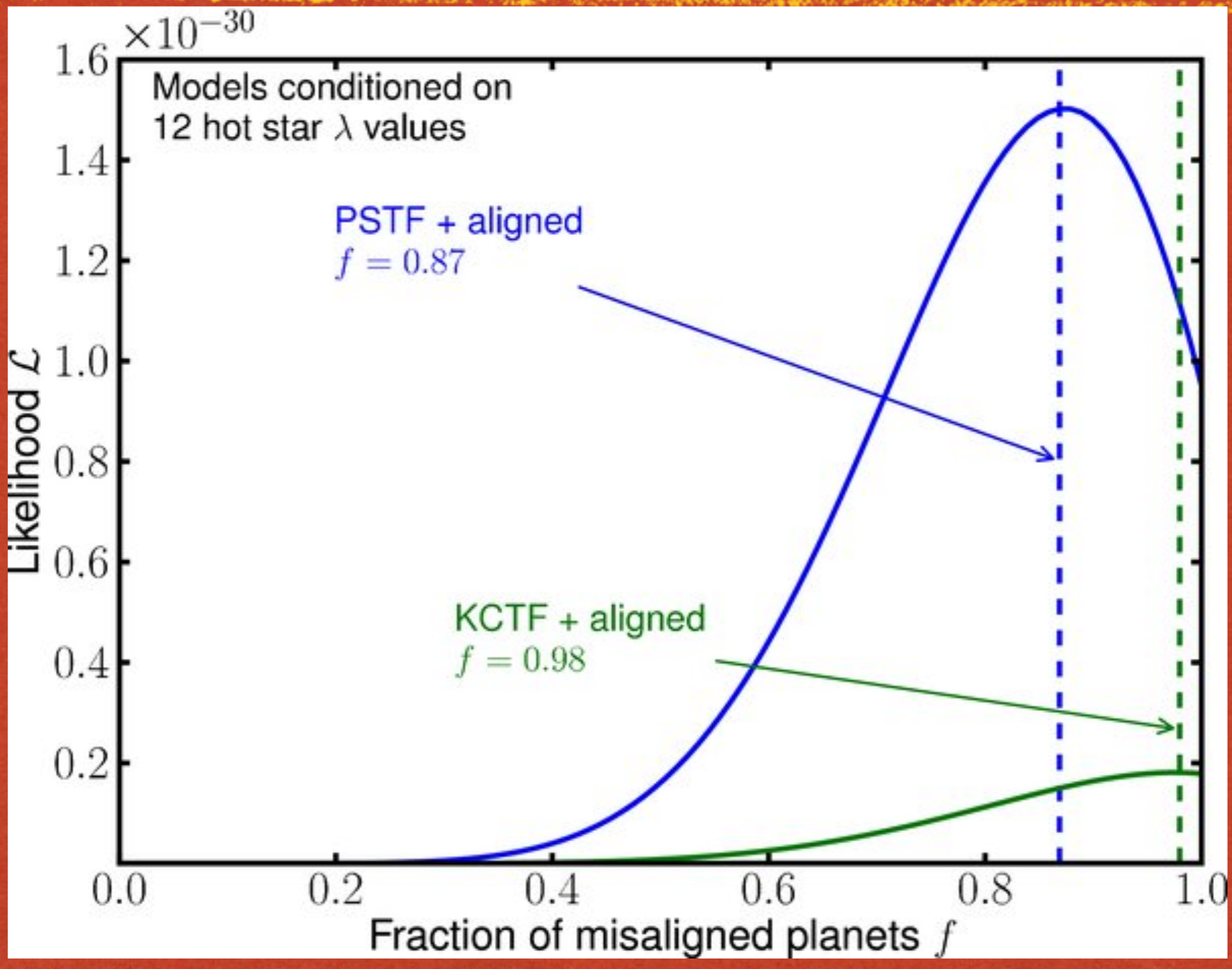
Morton & Johnson 2011

R. Dawson, CfA

Speaking @ CfA on 11/13 -->

HOT JUPITERS ORBITING HOT STARS MAY ALL BE MISALIGNED

Timothy Morton, Caltech



Morton & Johnson 2011

R. Dawson, CfA

SUMMARY

- We developed the "photoeccentric effect" Bayesian approach to measure the eccentricities of transiting planets from their light curves for the first time
- We identified KOI-1474.01 as an eccentric planet being perturbed by a nearby companion
- We found a paucity of super-eccentric proto-hot Jupiters, favoring stellar rather than planetary perturbers