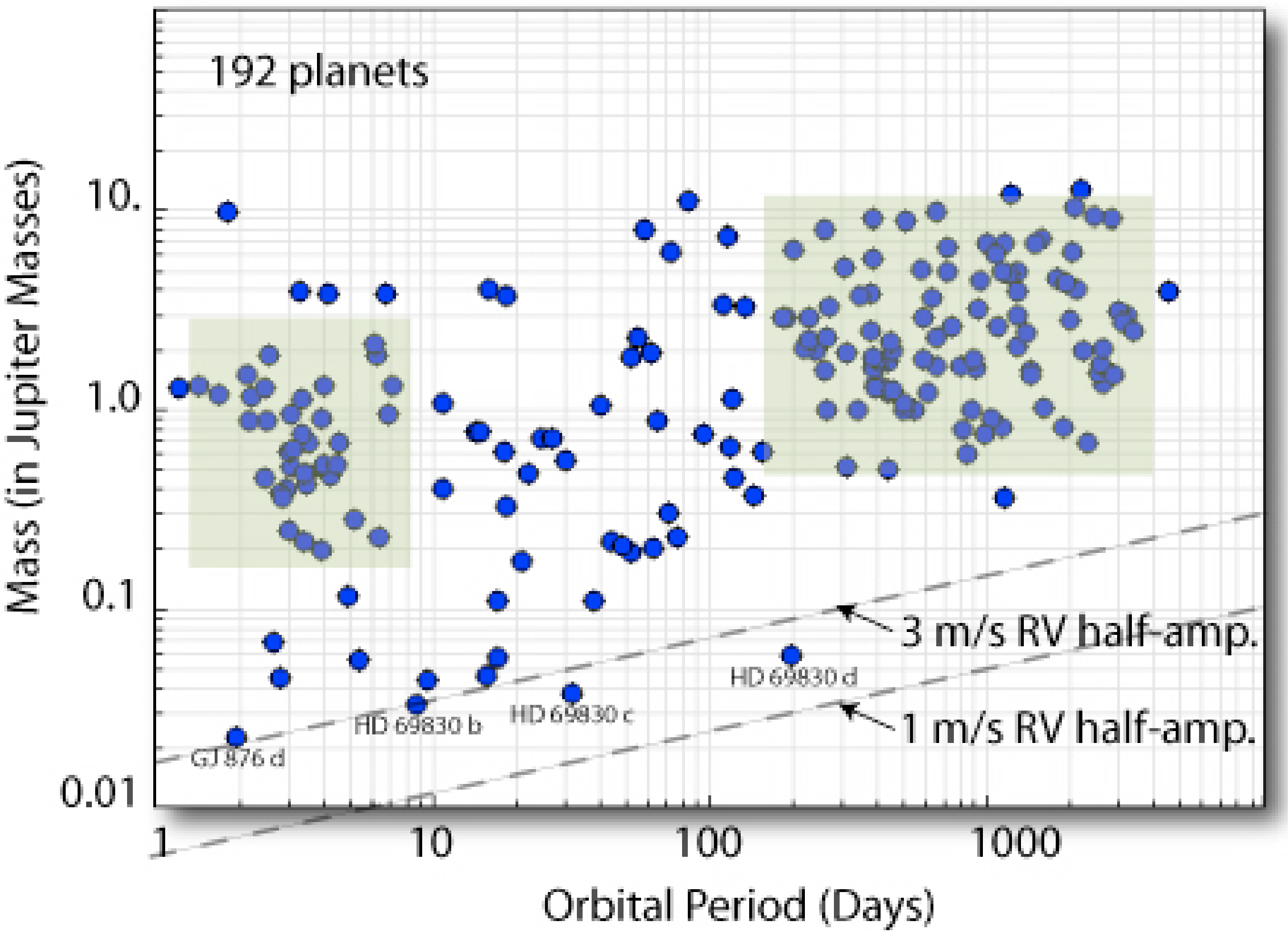
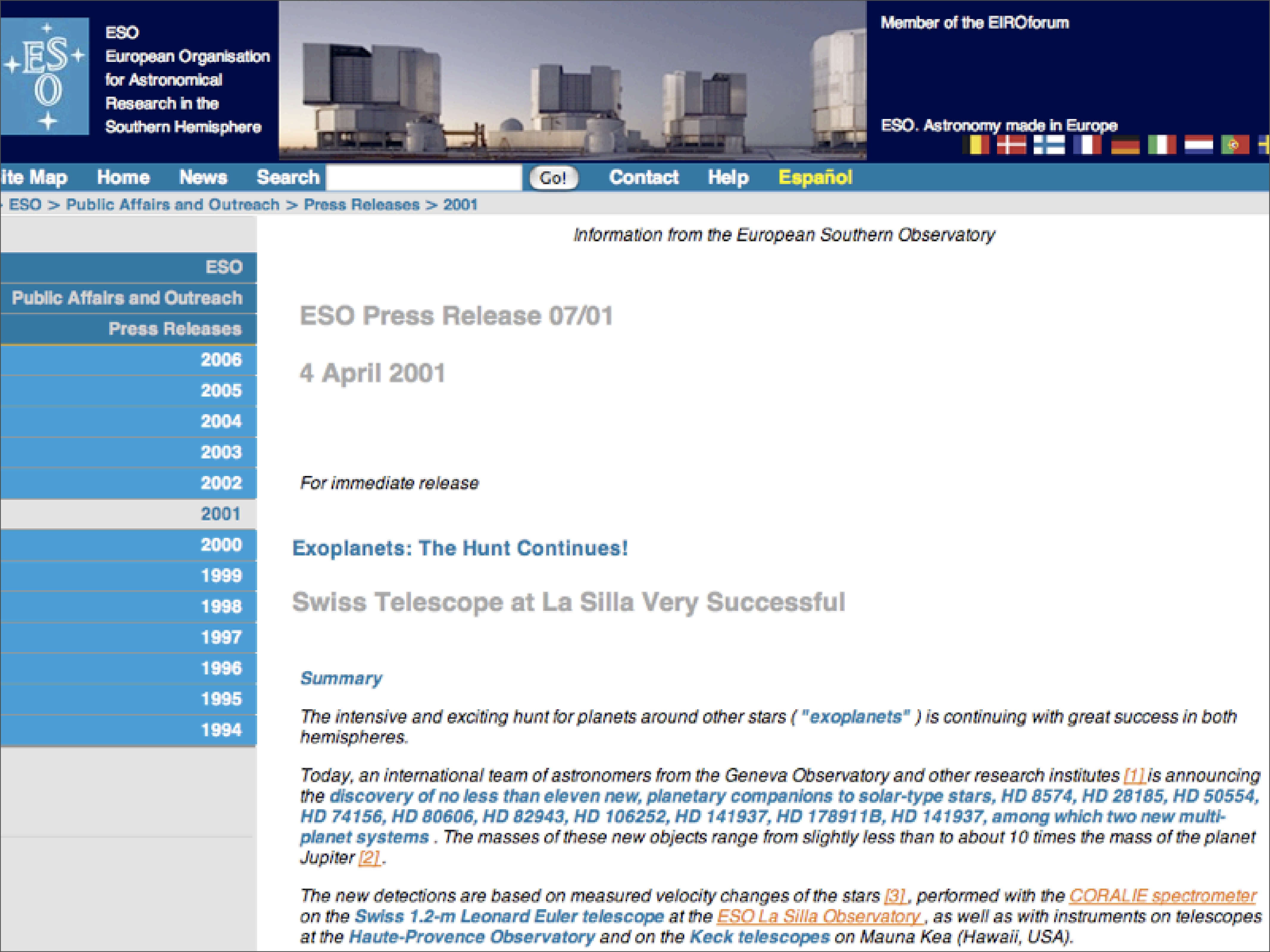
hd 80606 b

greg laughlin
jonathan langton
ucsc



The success of the planet detection programs has enabled the comparative study of populations of planets, as well as the detailed investigation of individual systems of particular interest.



Information from the European Southern Observatory

ESO Press Release 07/01

4 April 2001

For immediate release

Exoplanets: The Hunt Continues!

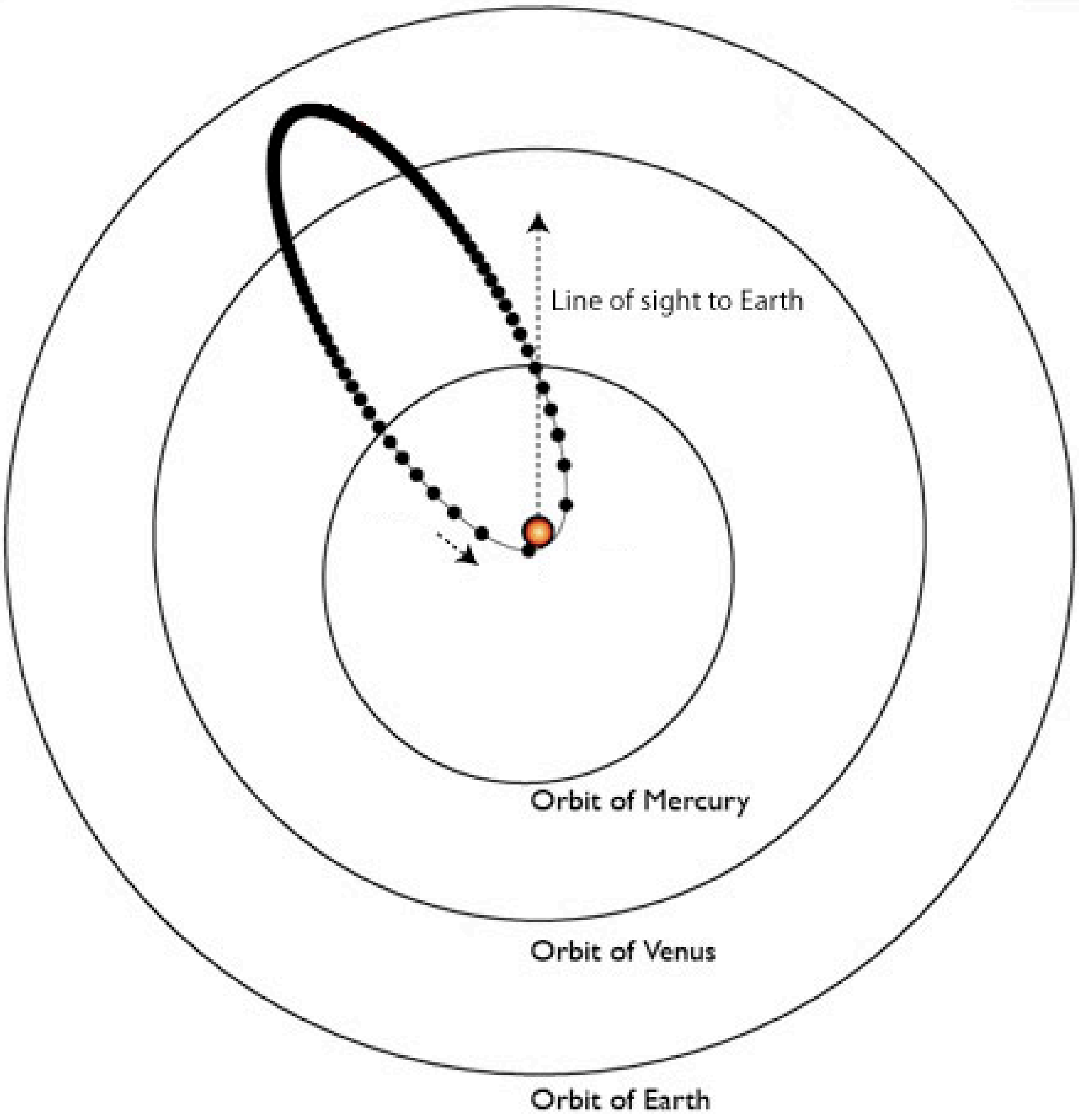
Swiss Telescope at La Silla Very Successful

Summary

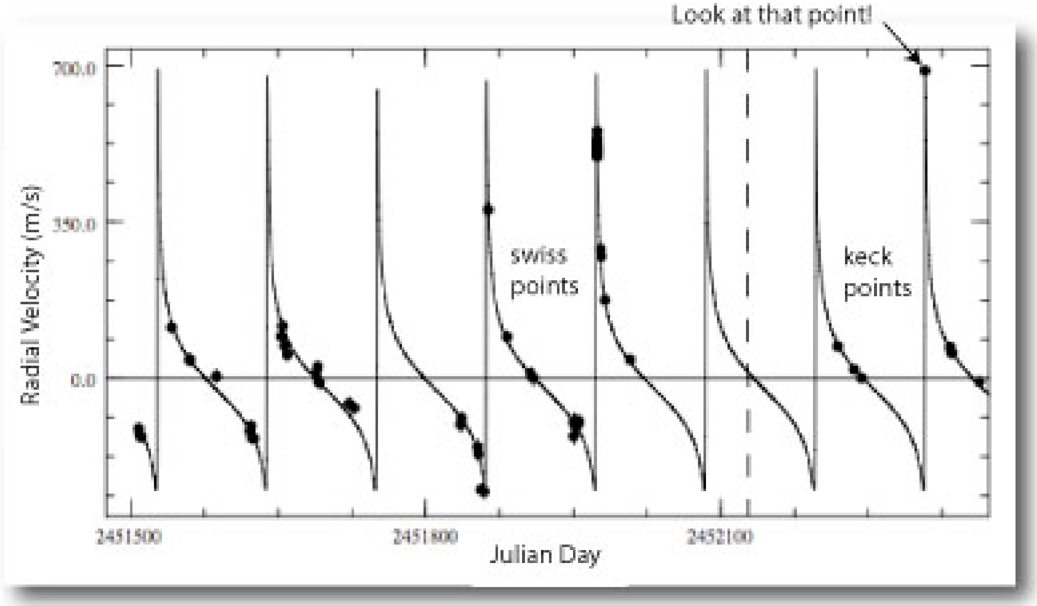
The intensive and exciting hunt for planets around other stars ("exoplanets") is continuing with great success in both hemispheres.

Today, an international team of astronomers from the Geneva Observatory and other research institutes [1] is announcing the discovery of no less than eleven new, planetary companions to solar-type stars, HD 8574, HD 28185, HD 50554, HD 74156, HD 80606, HD 82943, HD 106252, HD 141937, HD 178911B, HD 141937, among which two new multi-planet systems . The masses of these new objects range from slightly less than to about 10 times the mass of the planet Jupiter [2].

The new detections are based on measured velocity changes of the stars [3], performed with the CORALIE spectrometer on the Swiss 1.2-m Leonard Euler telescope at the ESO La Silla Observatory , as well as with instruments on telescopes at the Haute-Provence Observatory and on the Keck telescopes on Mauna Kea (Hawaii, USA).

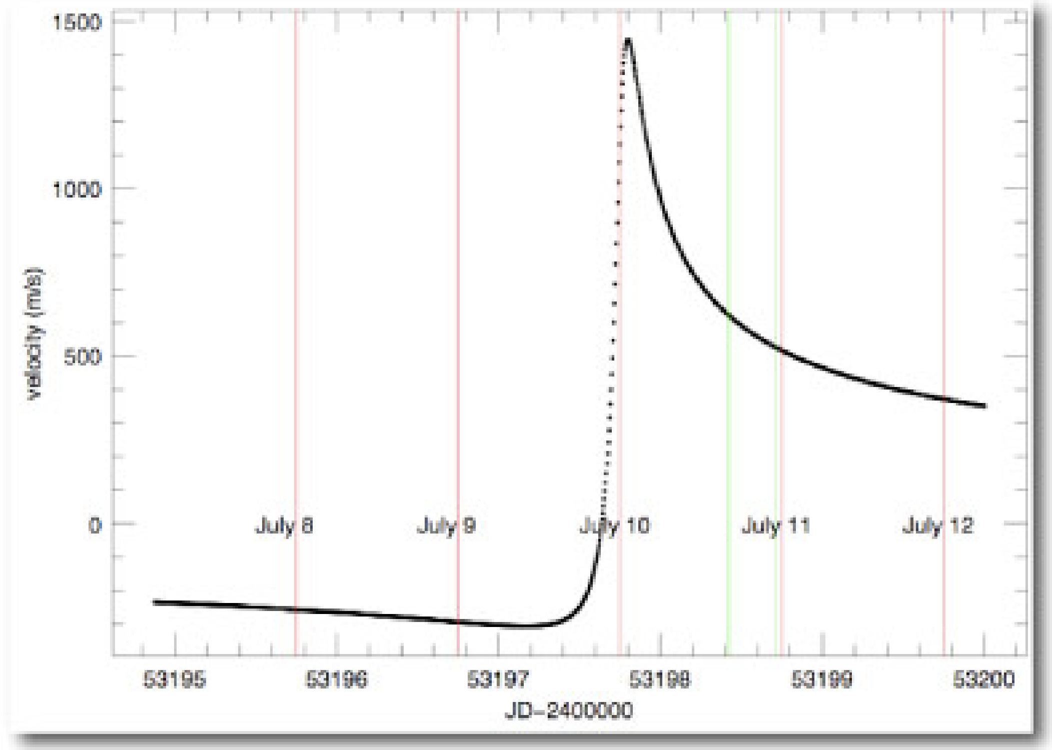


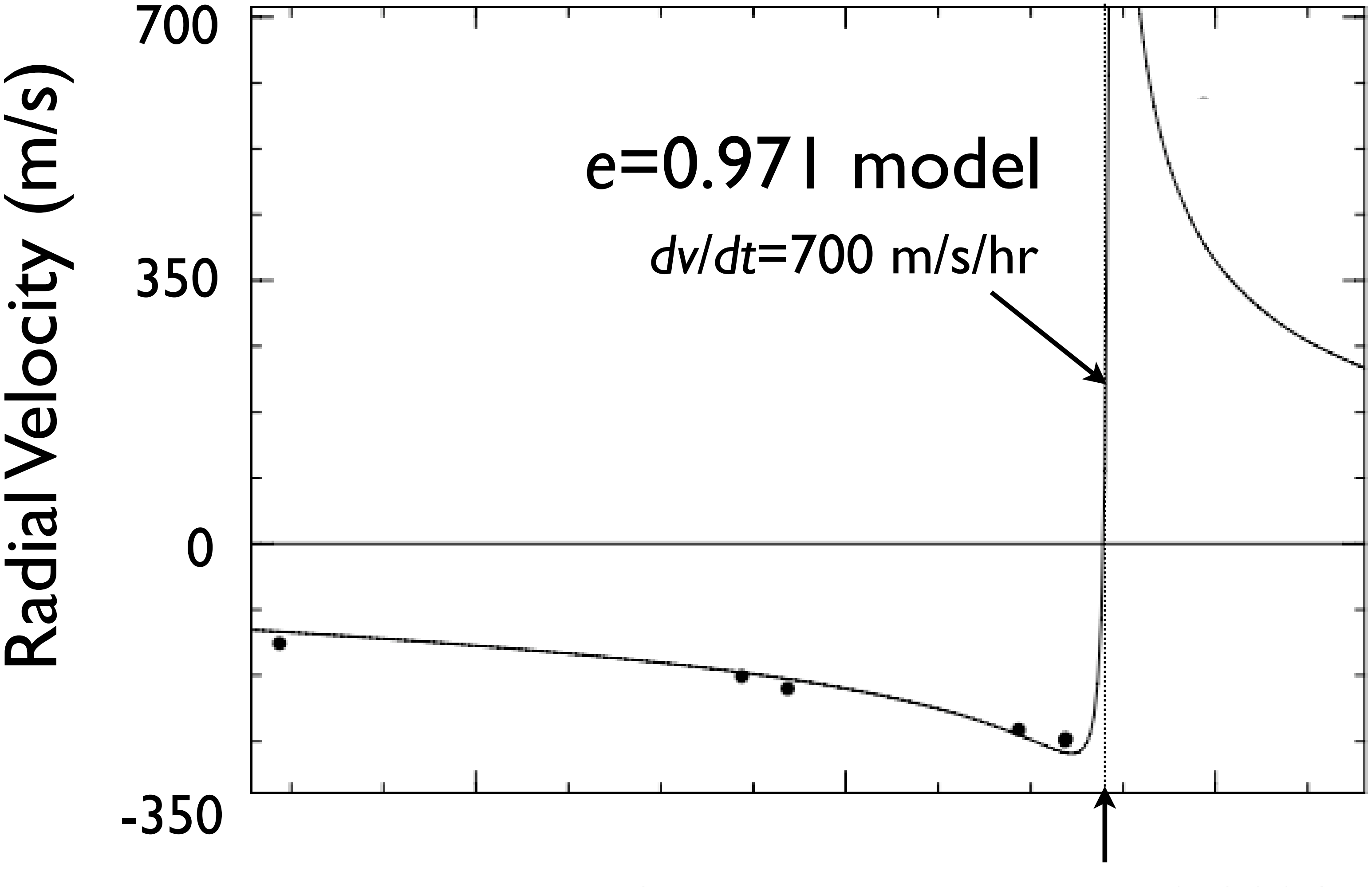
HD 80606b has a P=112 day orbital period, a semi-major axis, a=.45 AU, e=0.937, Msin(i)=4 Mjup, and a periastron distance, a(1-e)~7 stellar radii. A "lukewarm Jupiter" is being hauled in periodically for detailed inspection...



The early Keck observations suggested an eccentricity of e=0.971 +/- 0.017! This would have put periastron passage at a remarkable 2.5 stellar radii.

Serendipitously, California-Carnegie Keck time was scheduled for 5 successive nights in July 2004. HD 80606 was just visible at dusk (dec=+60, HA>5) during these nights. The best fit to the radial velocity data predicted that the periastron swing would occur on July 10th.

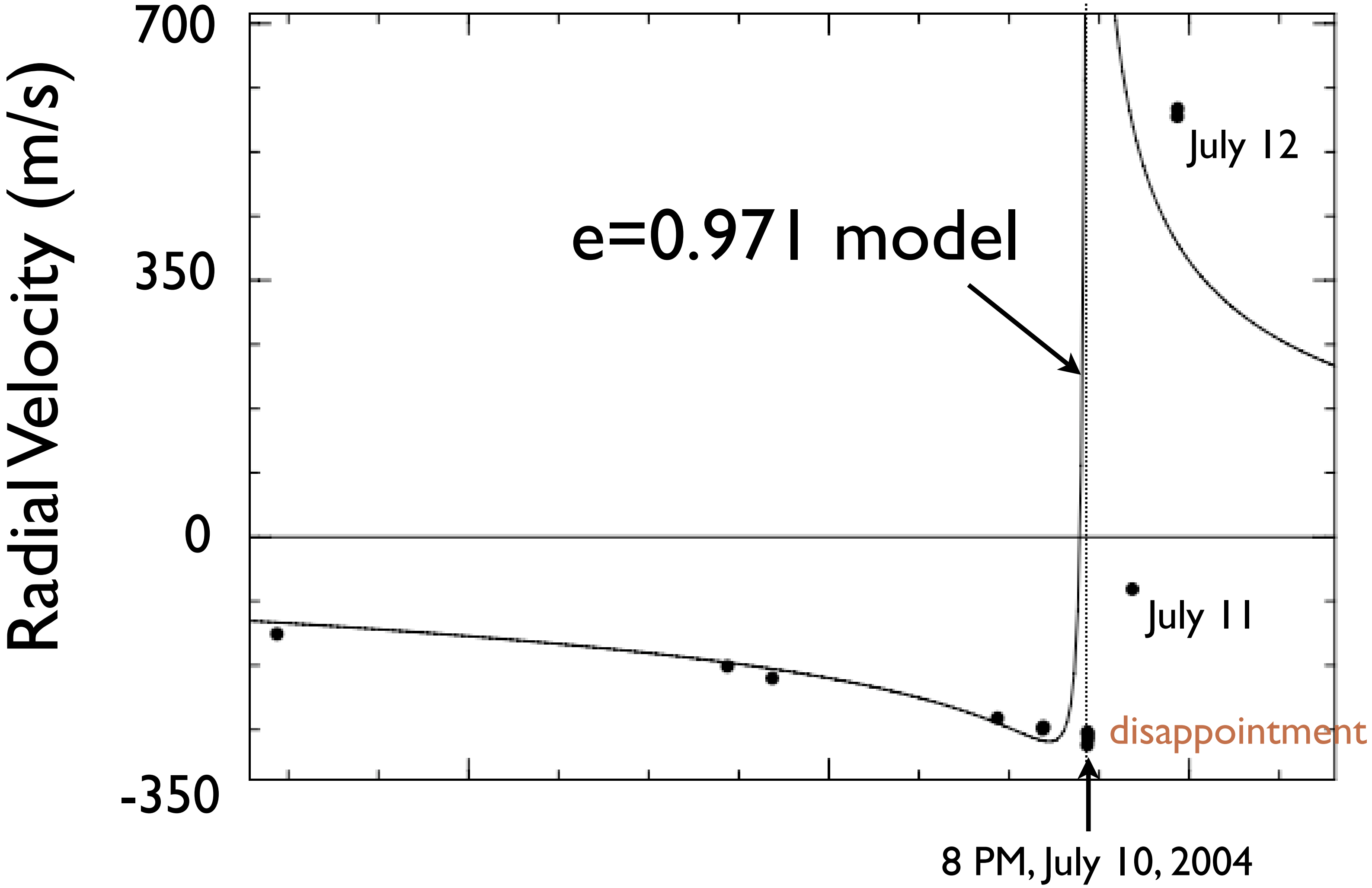




e=0.971 model

dv/*dt*=700 m/s/hr

8PM Hawaii time, July 10, 2004



e=0.971 model

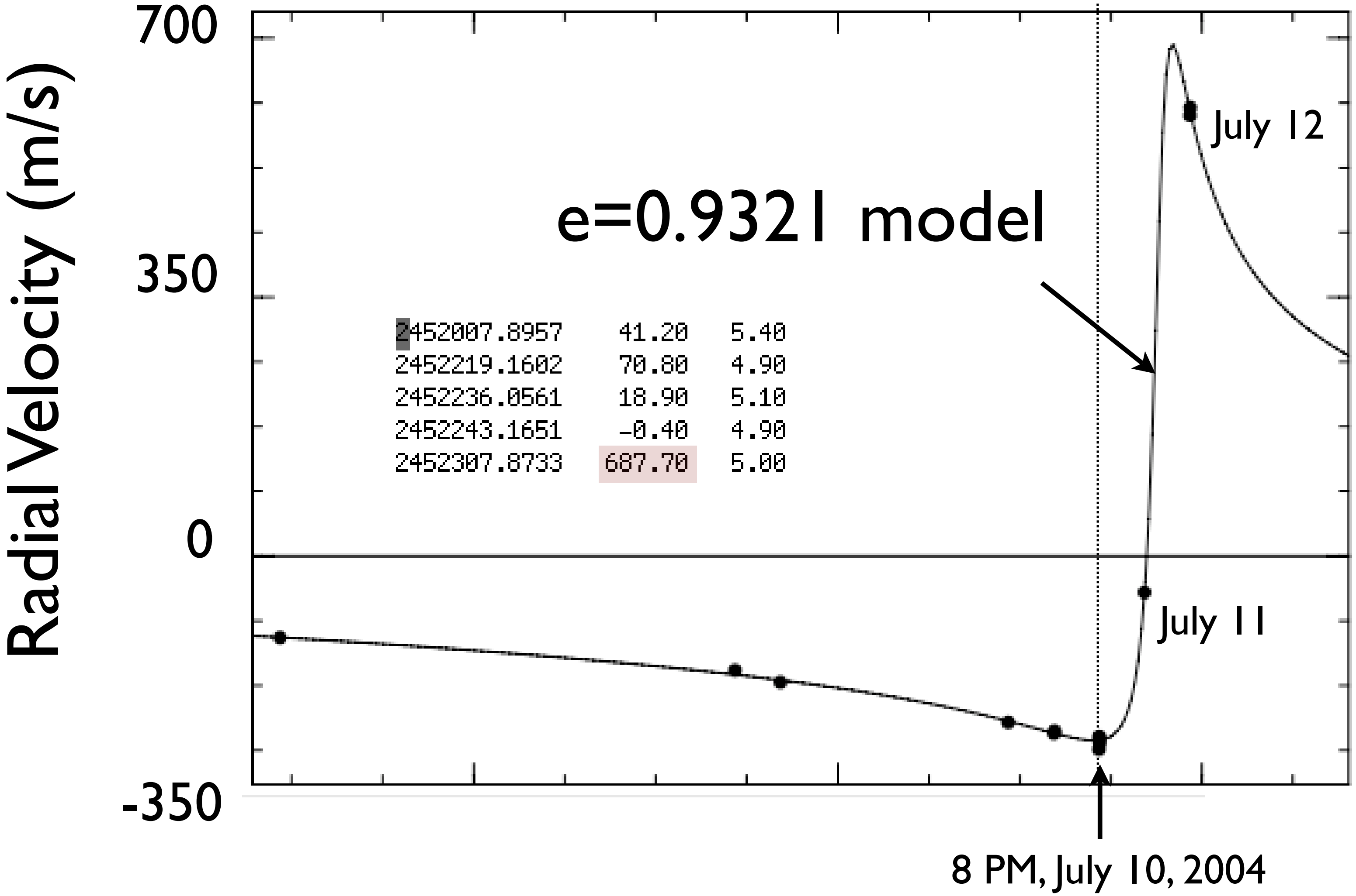
July 12

July 11

disappointment

8 PM, July 10, 2004

The best fit to the data has an eccentricity of "only" 0.9321. A random observation has a less than 1 in 2000 chance of seeing radial velocity as high as 687 m/s (5th Keck velocity).



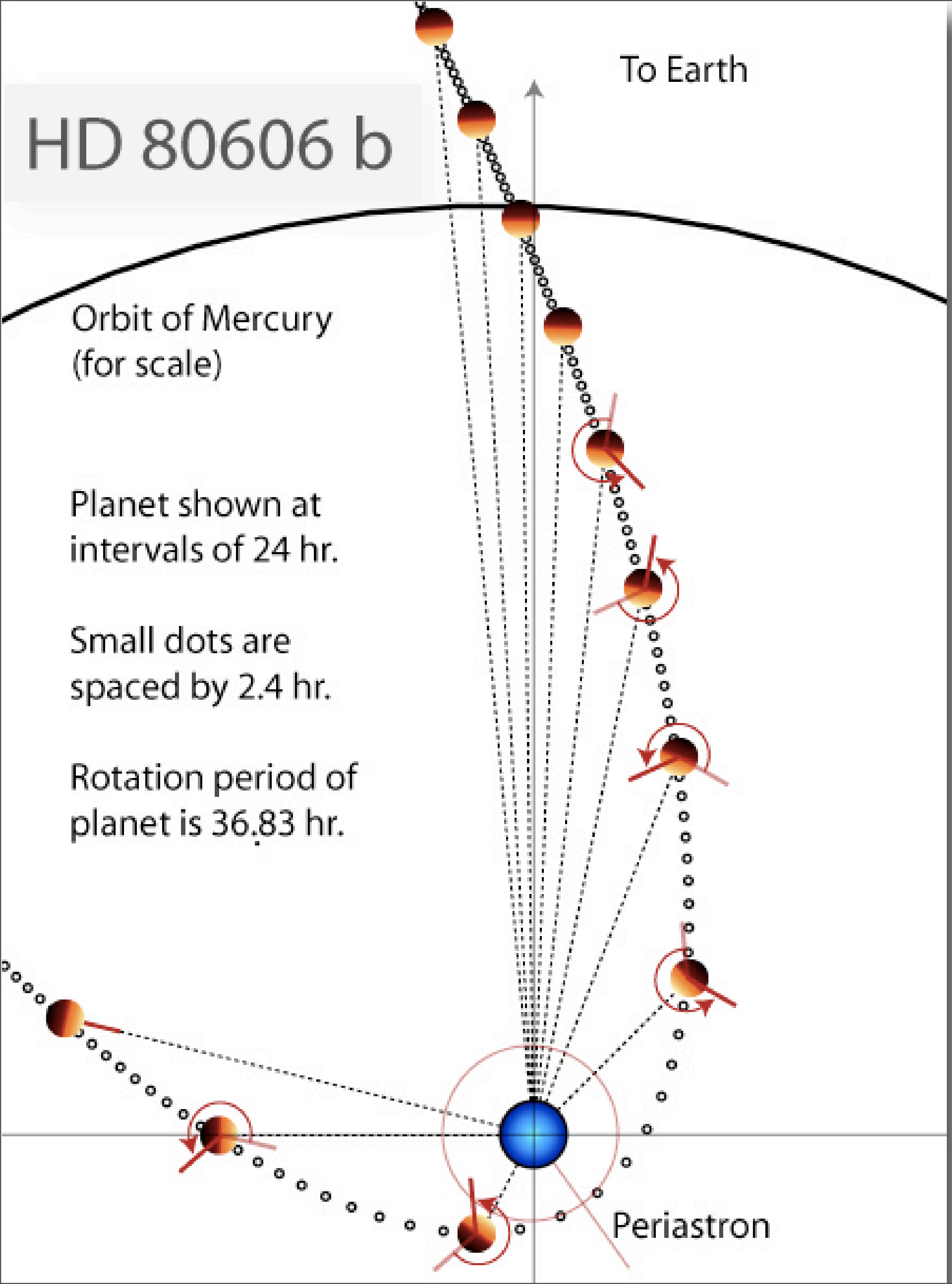
e=0.9321 model

July 12

July 11

8 PM, July 10, 2004

```
2452007.8957     41.20    5.40
2452219.1602     70.80    4.90
2452236.0561     18.90    5.10
2452243.1651     -0.40    4.90
2452307.8733    687.70    5.00
```

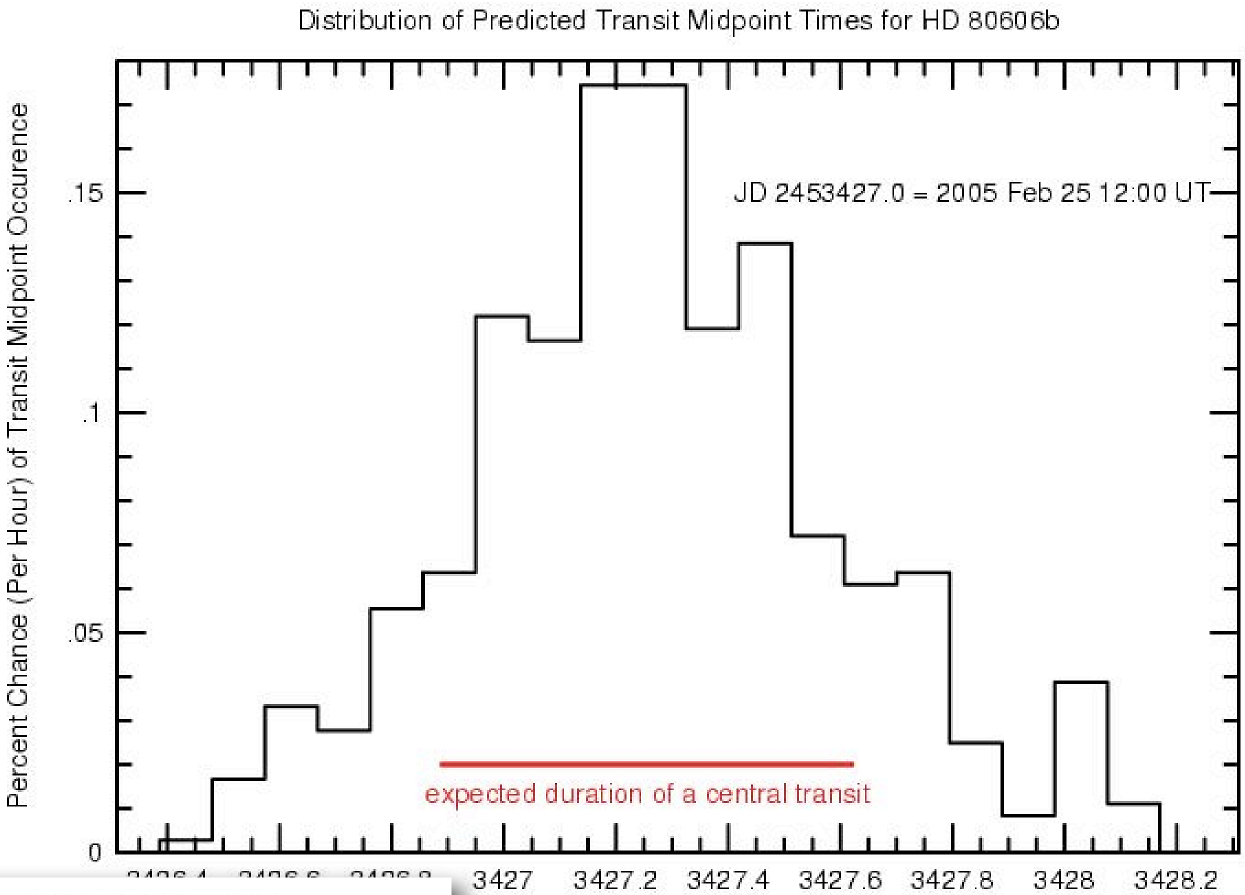


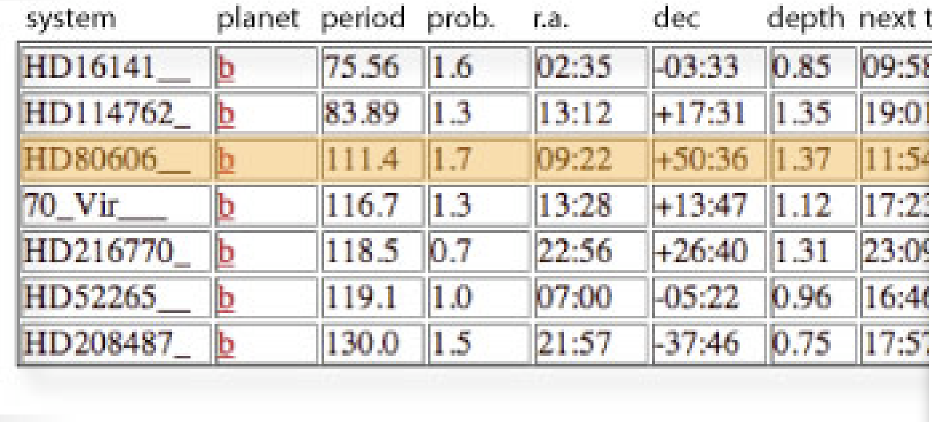
For a tidal quality factor $Q{\sim}10^6$ (appropriate to giant planets) strong tidal forces during the close approaches will bring the planet into *pseudo-synchronization* (Hut 1981) on a timescale of a few Myr. The spin frequency is thus ~82% of the instantaneous orbital frequency of the planet as it goes through periastron:

$$P_{\mathrm{SPIN}} = \frac{(1+3e^2+\frac{3}{8}e^4)(1-e^2)^{3/2}}{1+\frac{15}{2}e^2+\frac{45}{8}e^4+\frac{5}{16}e^6} P_{\mathrm{ORBIT}}$$

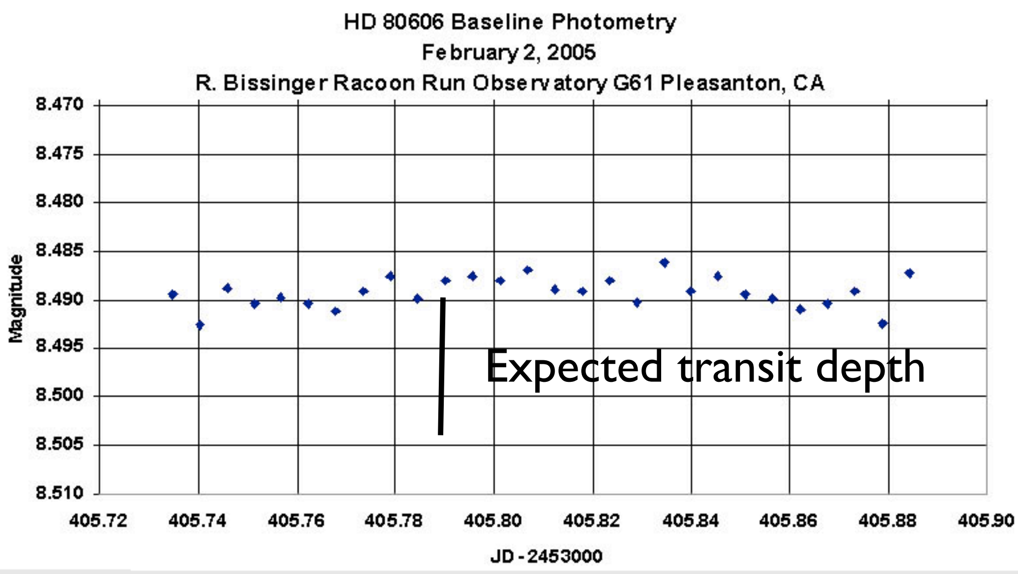
Transits?

Ron Bissinger



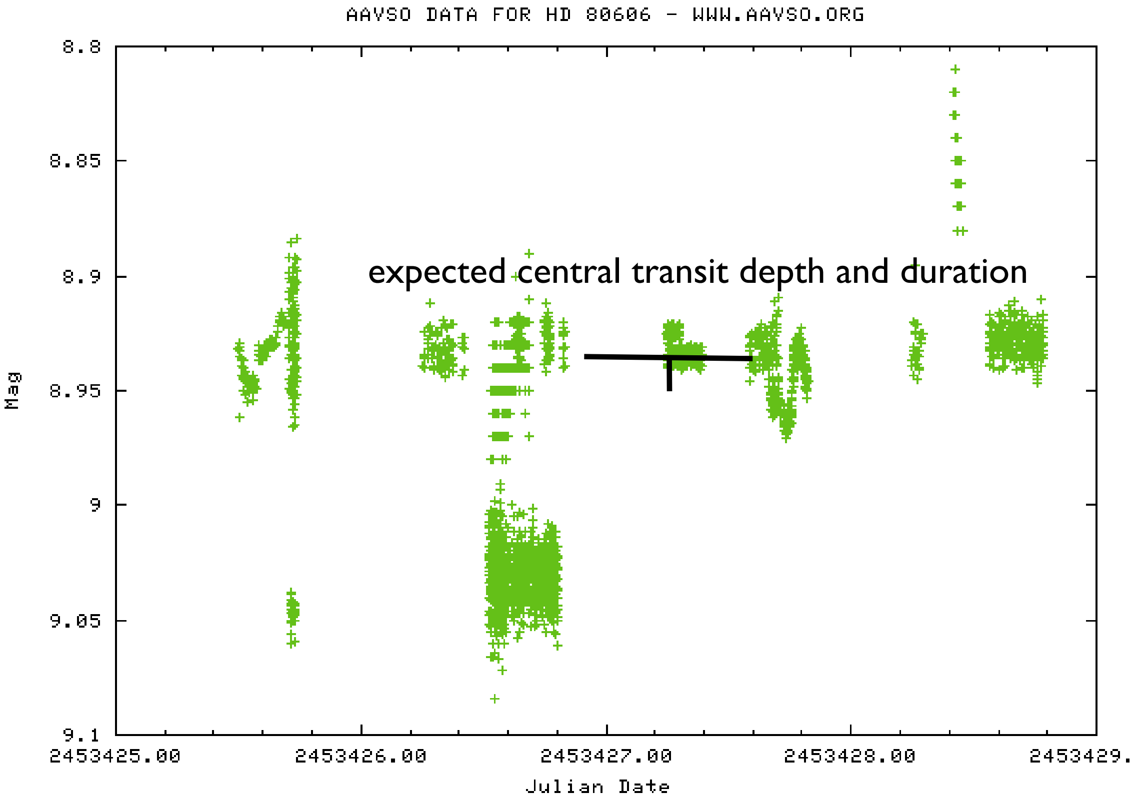


system	planet	period	prob.	r.a.	dec	depth	next transit
HD16141__	b	75.56	1.6	02:35	-03:33	0.85	09:5
HD114762_	b	83.89	1.3	13:12	+17:31	1.35	19:0
HD80606__	b	111.4	1.7	09:22	+50:36	1.37	11:5
70_Vir___	b	116.7	1.3	13:28	+13:47	1.12	17:2
HD216770_	b	118.5	0.7	22:56	+26:40	1.31	23:0
HD52265__	b	119.1	1.0	07:00	-05:22	0.96	16:4
HD208487_	b	130.0	1.5	21:57	-37:46	0.75	17:5

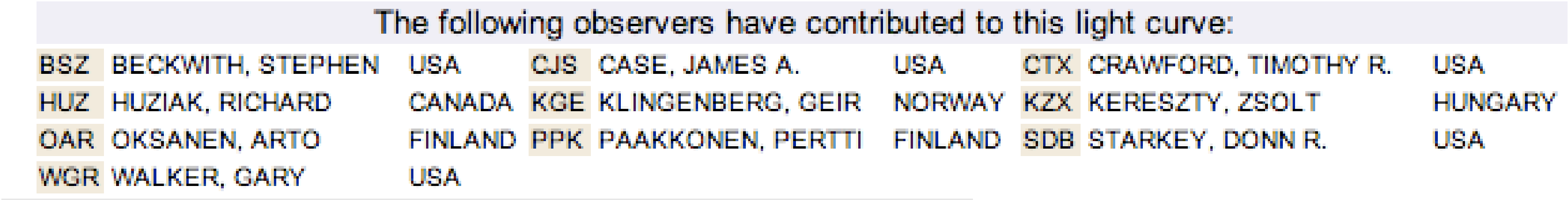


HD 80606 is a good candidate star for amateur astronomers.

Transitsearch-AAVSO observers submitted 3596 photometric measurements during HD 80606's JD 2453427. (Feb, 2005) transit opportunity. No hint of a transit was seen. Additional campaigns must be done to fully rule out a transit.



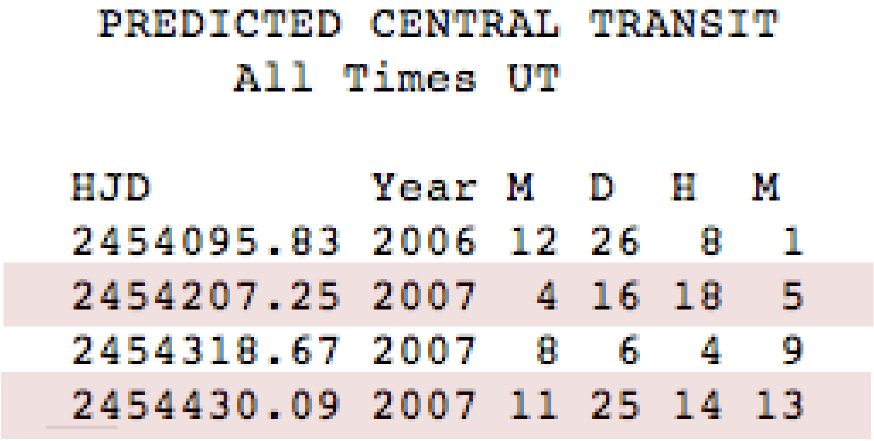
expected central transit depth and duration



The following observers have contributed to this light curve:

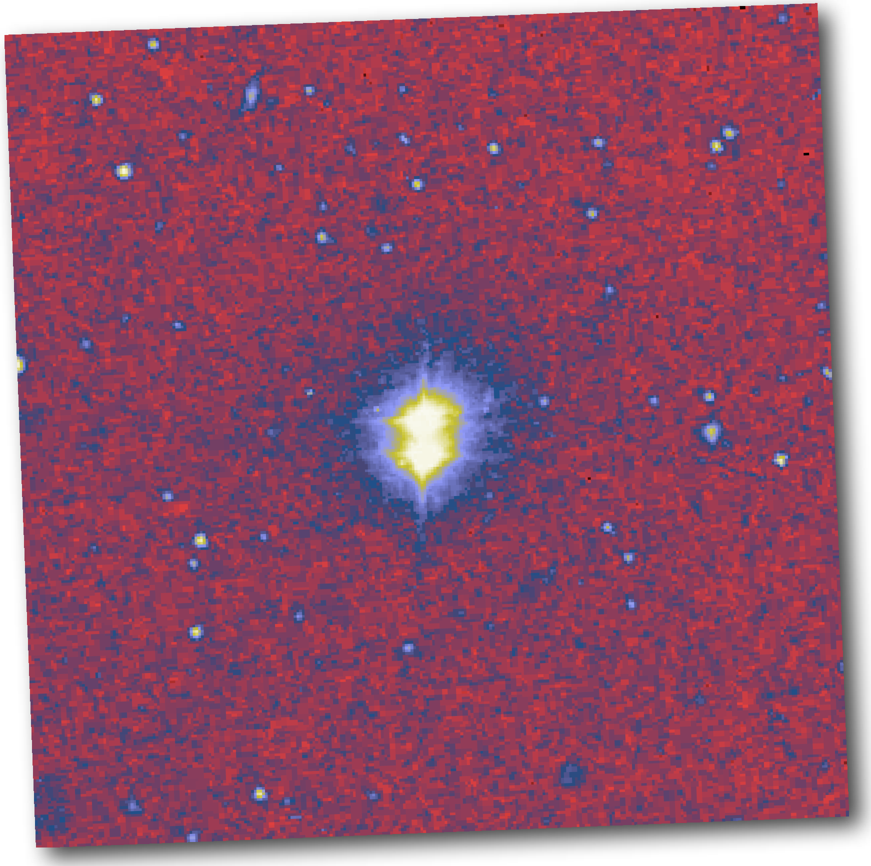
BSZ	BECKWITH, STEPHEN	USA	CJS	CASE, JAMES A.	USA	CTX	CRAWFORD, TIMOTHY R.	USA
HUZ	HUZIAK, RICHARD	CANADA	KGE	KLINGENBERG, GEIR	NORWAY	KZX	KERESZTY, ZSOLT	HUNGARY
OAR	OKSANEN, ARTO	FINLAND	PPK	PAAKKONEN, PERTTI	FINLAND	SDB	STARKEY, DONN R.	USA
WGR	WALKER, GARY	USA						

HD 80606 Campaign Poster



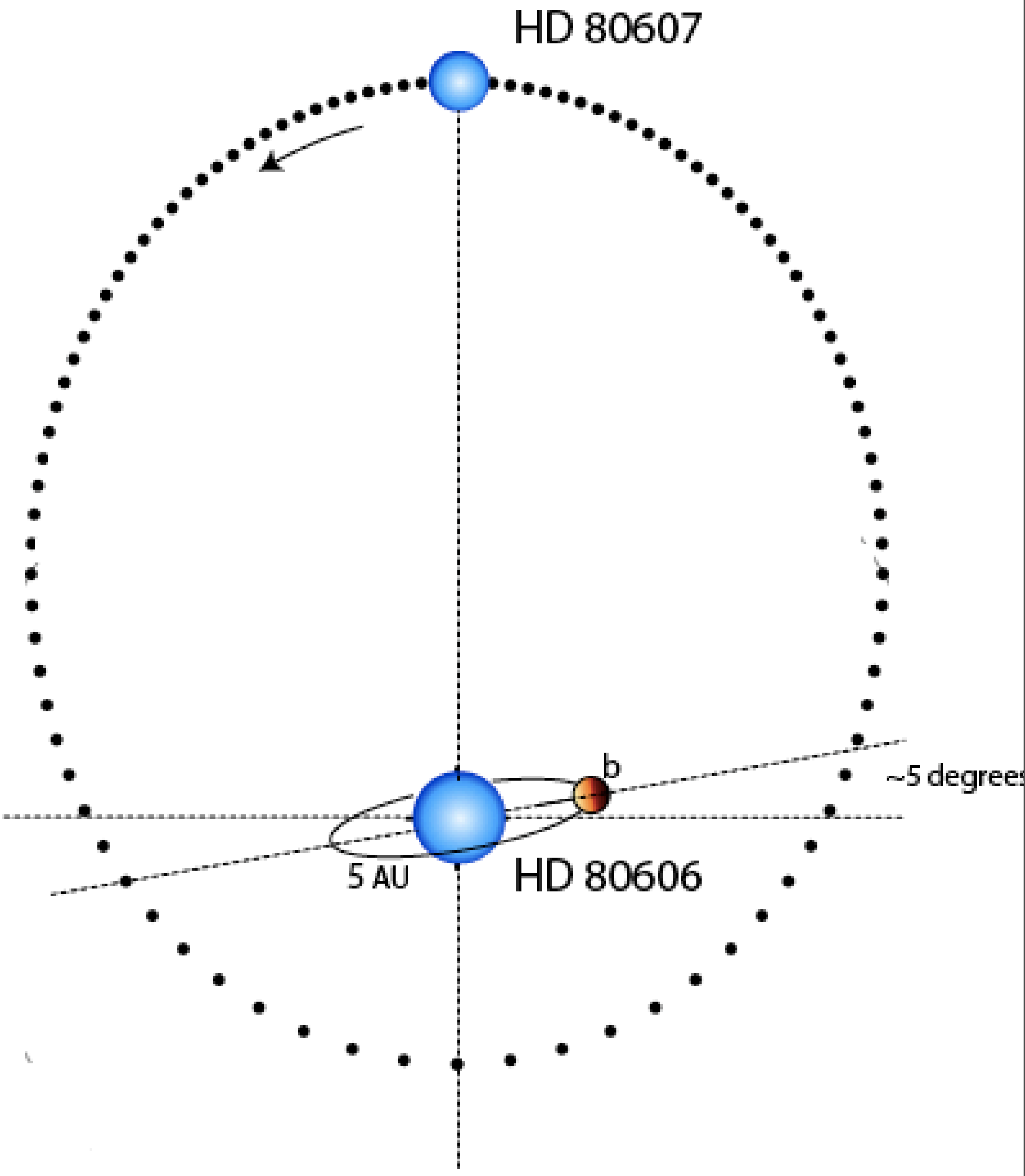
```
      PREDICTED CENTRAL TRANSIT
           All Times UT

 HJD          Year M  D  H  M
 2454095.83 2006 12 26  8  1
 2454207.25 2007  4 16 18  5
 2454318.67 2007  8  6  4  9
 2454430.09 2007 11 25 14 13
```



HD 80606 & HD 80607

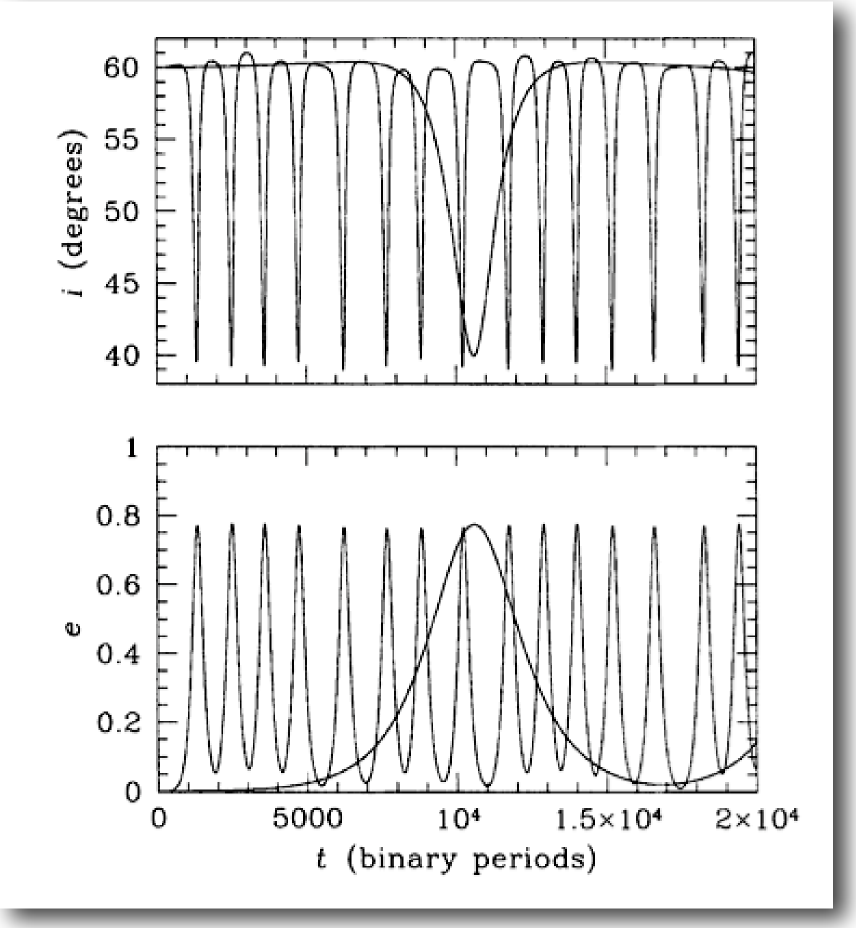
~1000 AU Separation



In the Wu & Murray (2003) theory, the planet forms in a disk at ~5AU with a modest eccentricity of e~0.1 The disk is within 5 degrees of being perpendicular to the e~0.5 binary orbital plane.

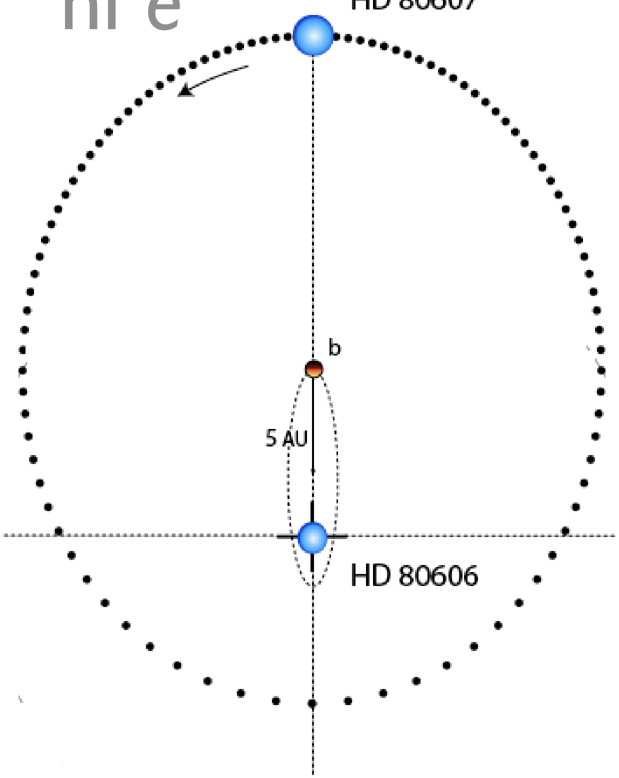
The Kozai effect

If we neglect the mass of the planet, then the planet conserves $\Theta = (1 - e_p^2)^{1/2} \cos I$ during its motion. (This *Kozai integral* is related to the Jacobi energy and the Tisserand relation in the circular restricted 3-body problem.)

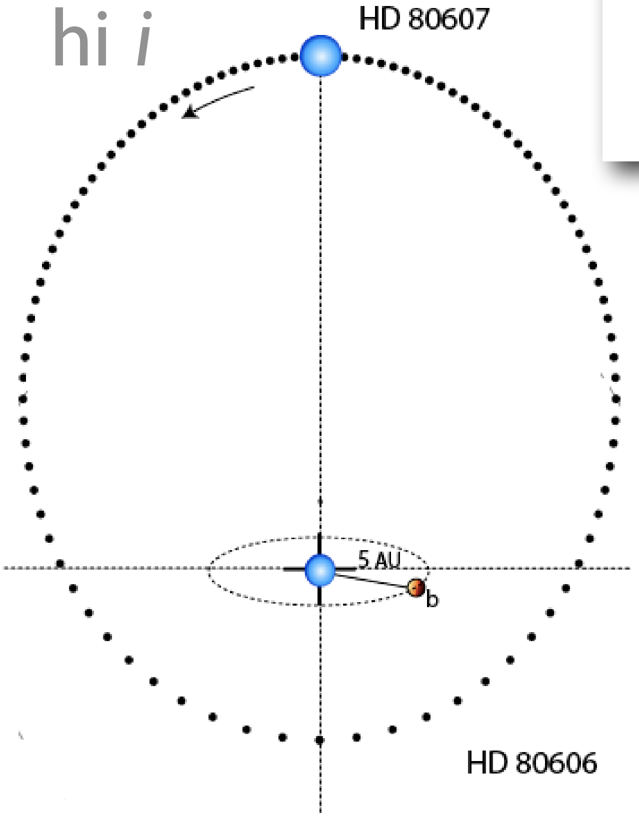


Holman et al. 1997 model for the *e*=0.67 planet orbiting 16 Cyg B

hi e

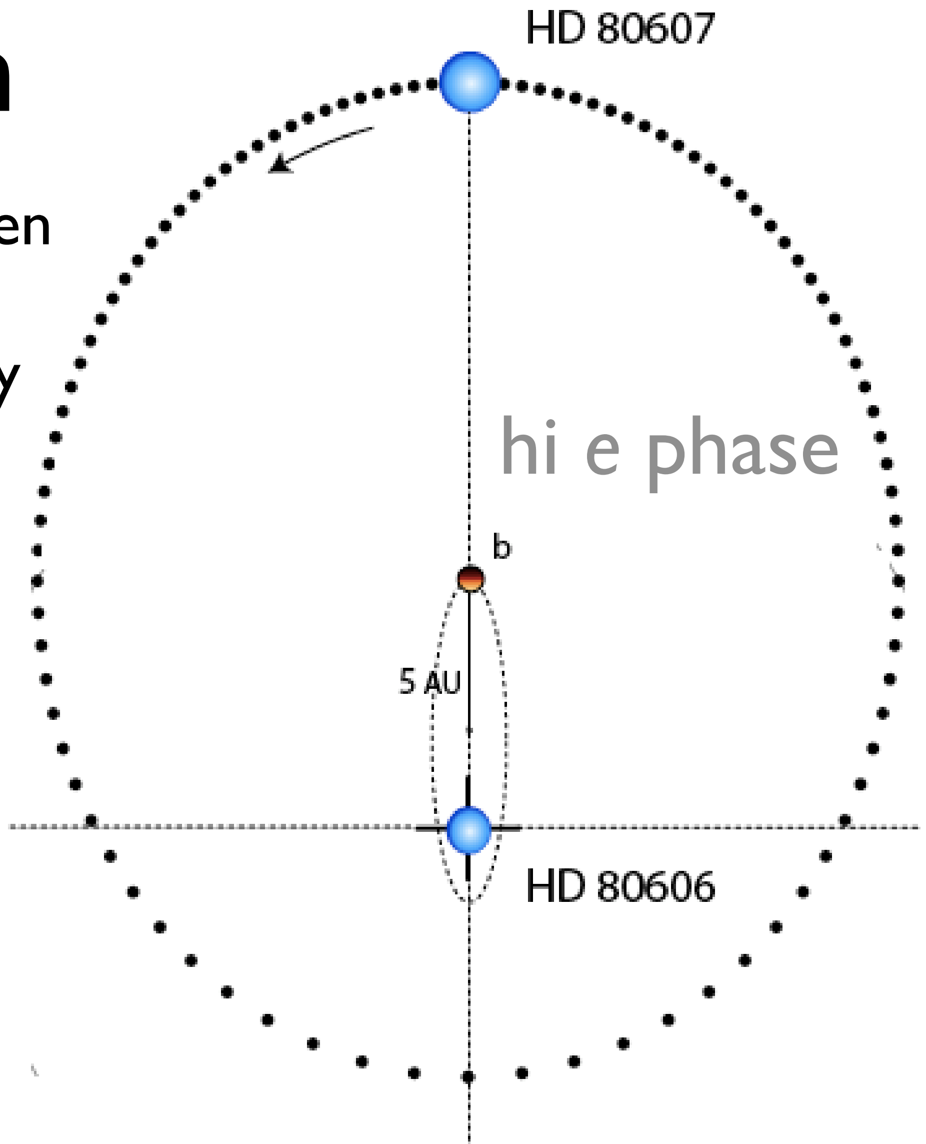


hi *i*



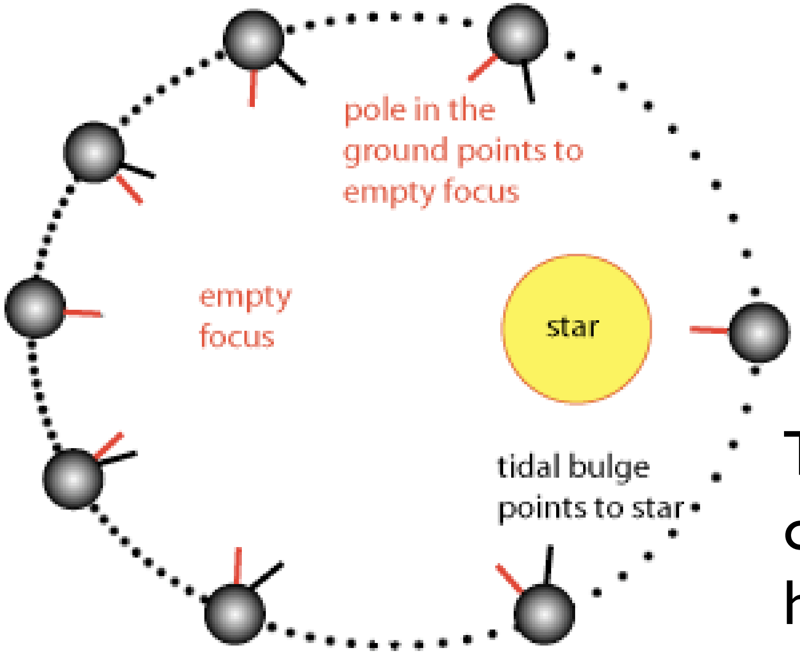
Numerical integrations show that if the initial inclination of the planetary to binary orbit is greater than *I=39*.5 deg, then large oscillations in e and *I* occur over secular time scales.

Tidal Circularization



If we neglect the mass of the planet, then the component of the planet's angular momentum perpendicular to the binary plane is conserved:

$$J = (GM_\star a_p)^{1/2} M_p (1 - e_p^2)^{1/2}$$



Tidal dissipation in the planet robs the orbit of energy, and hence decreases *a* when e is high. Conservation of *J* enforces a constant *a*(1-e) at each successive hi-e cycle.

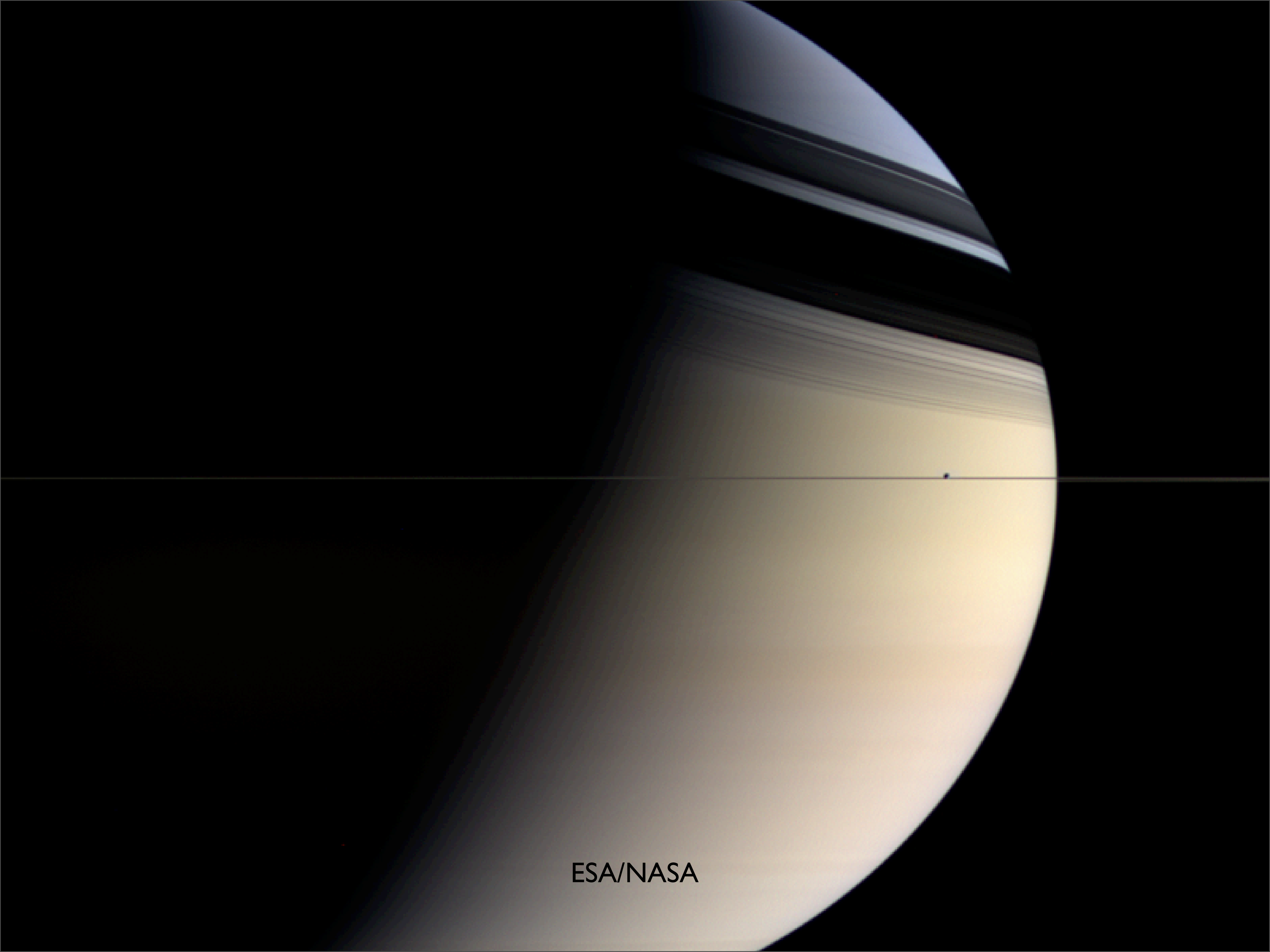
Computational “imaging” of extrasolar planets

1. Spitzer allows for observations of the infrared flux coming from these planets. Corot and Kepler should allow for optical reflection as a function of phase to be observed.

2. There’s an intrinsic value to having the best possible views of these planets.

HD 209458 b

ESA/NASA



ESA/NASA

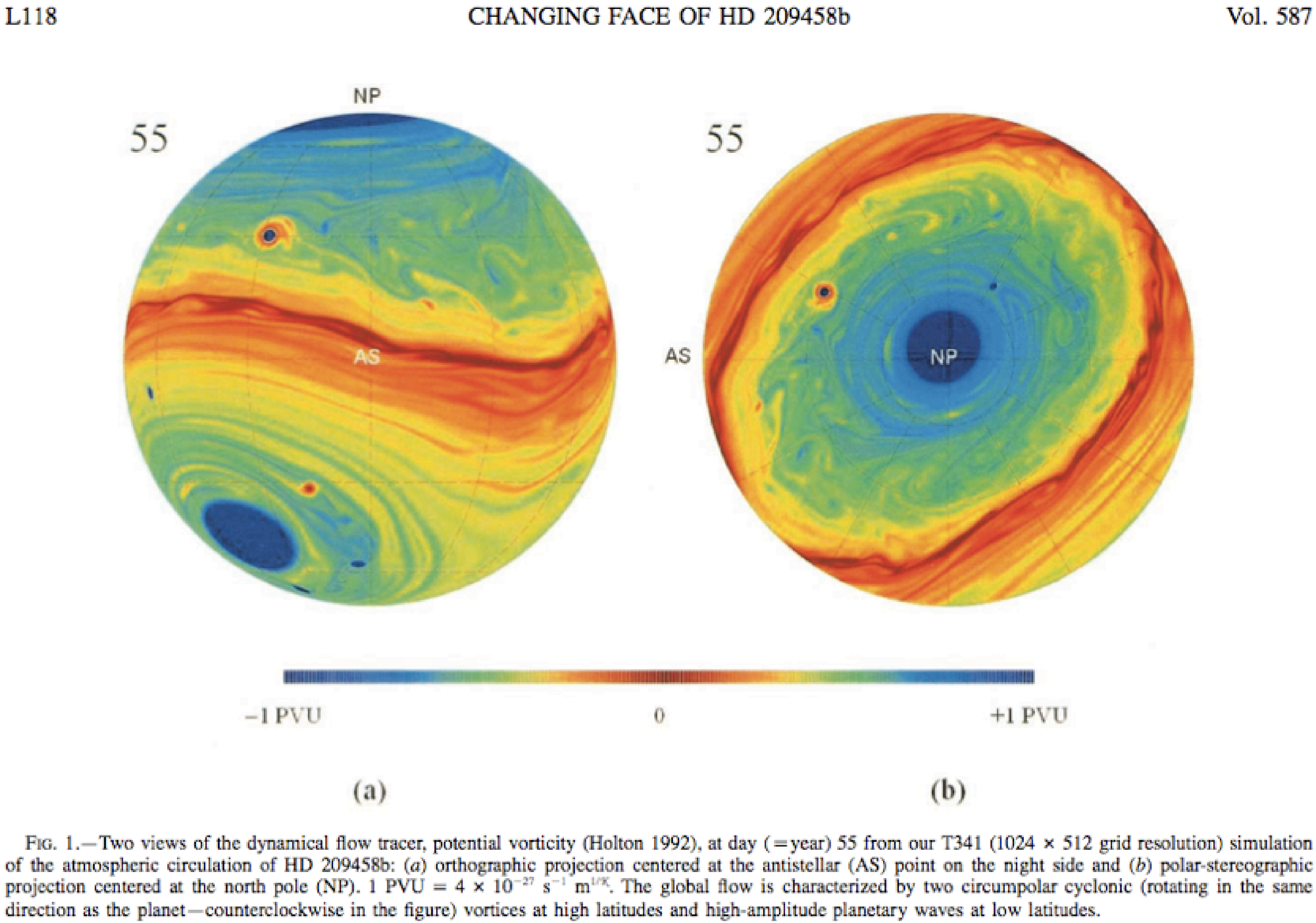
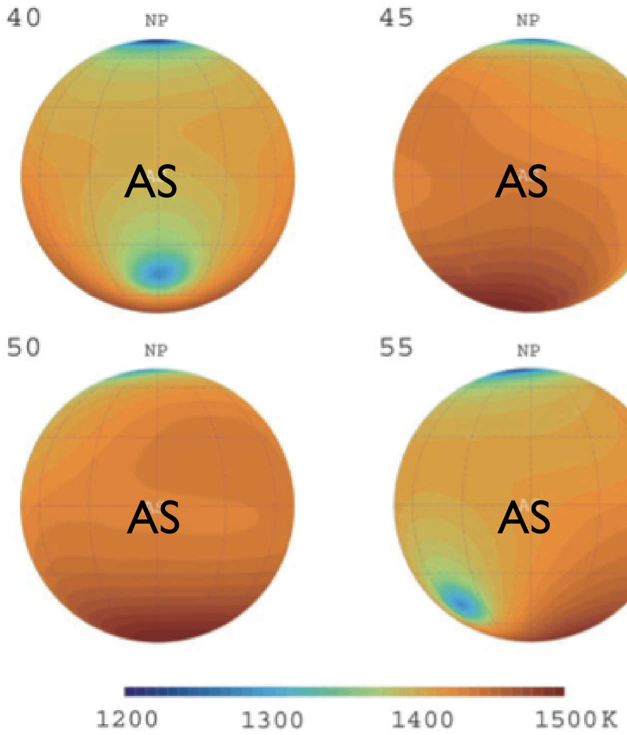
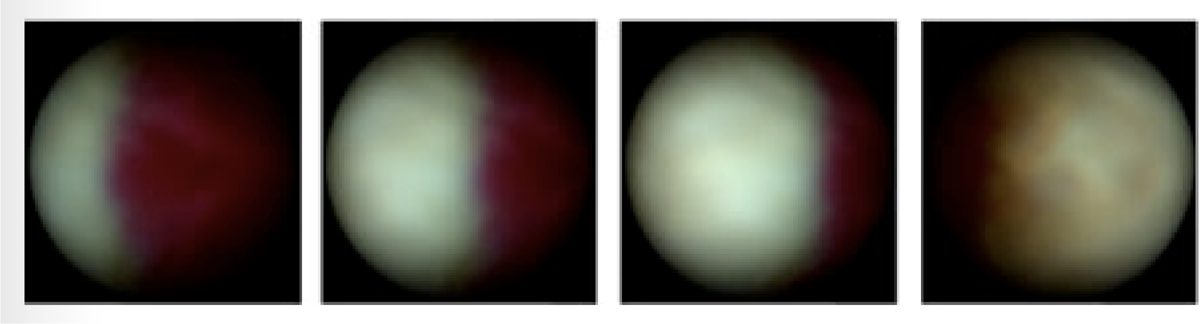

L118 CHANGING FACE OF HD 209458b Vol. 587

FIG. 1.—Two views of the dynamical flow tracer, potential vorticity (Holton 1992), at day (=year) 55 from our T341 (1024 × 512 grid resolution) simulation of the atmospheric circulation of HD 209458b: (*a*) orthographic projection centered at the antistellar (AS) point on the night side and (*b*) polar-stereographic projection centered at the north pole (NP). 1 PVU = 4×10^{-27} s^{-1} $m^{1/K}$. The global flow is characterized by two circumpolar cyclonic (rotating in the same direction as the planet—counterclockwise in the figure) vortices at high latitudes and high-amplitude planetary waves at low latitudes.

Cho et al. 2003



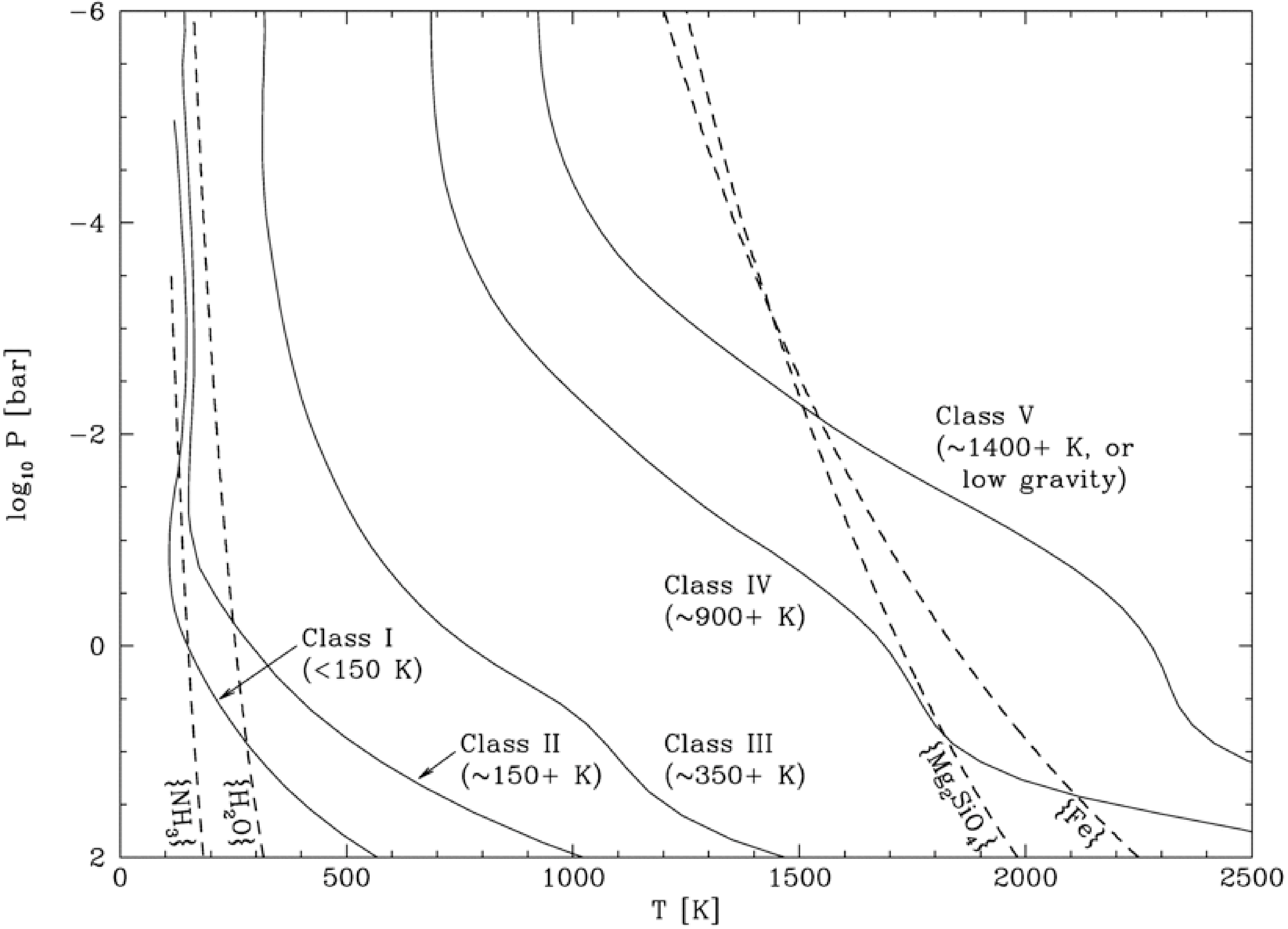


Fortney et al. 2006 (Cooper-Showman Model)

Cho et al.

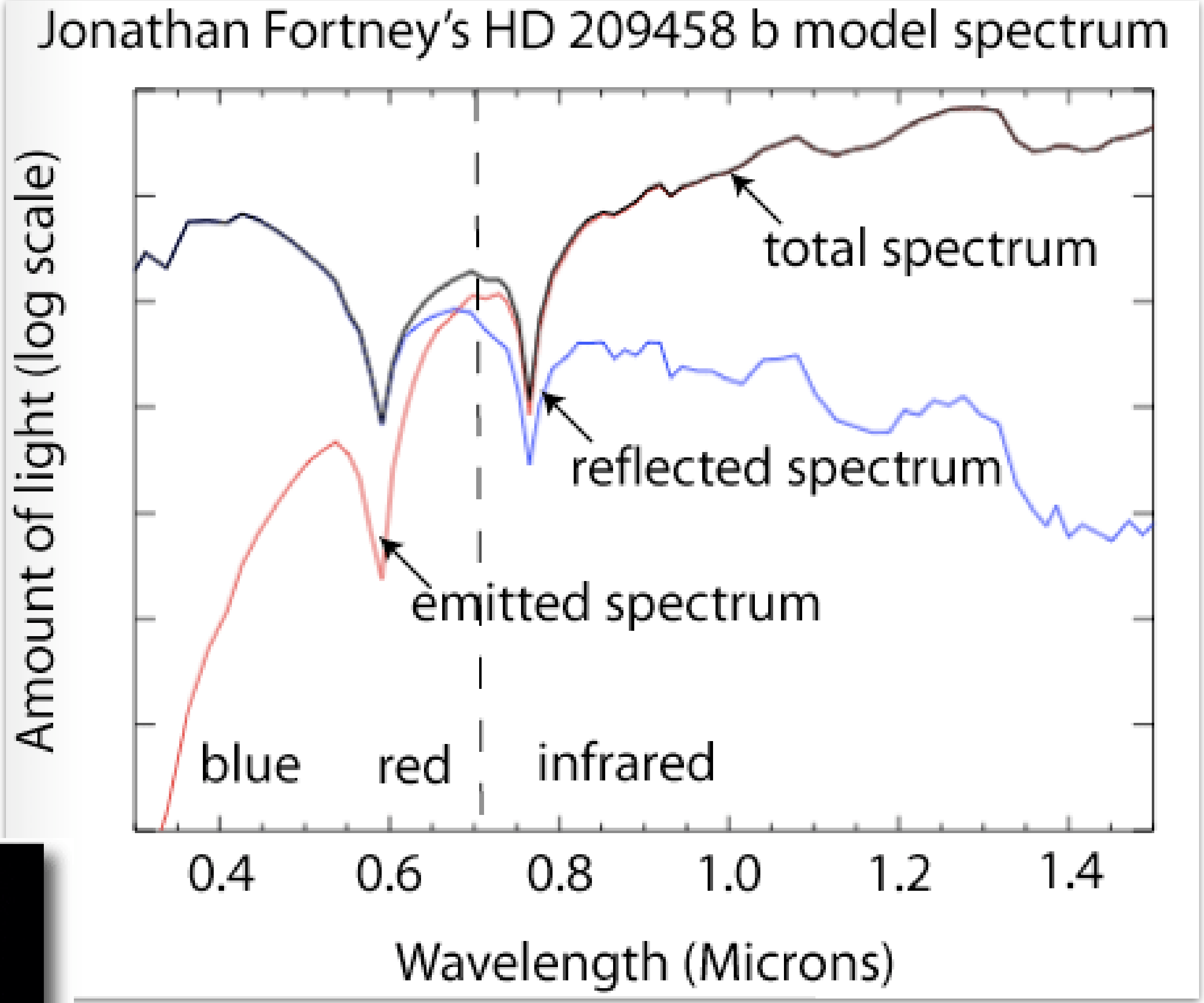
No consensus yet on what the flow patterns should look like at the photosphere of HD 209458b. Cho et al. with a high-resolution 2D “shallow water” model predict cold polar vortices and an equatorial jet. Cooper & Showman (2005) use lower-resolution full 3D model and predict a superrotating jet and a late afternoon “hotspot” at the photospheric level.

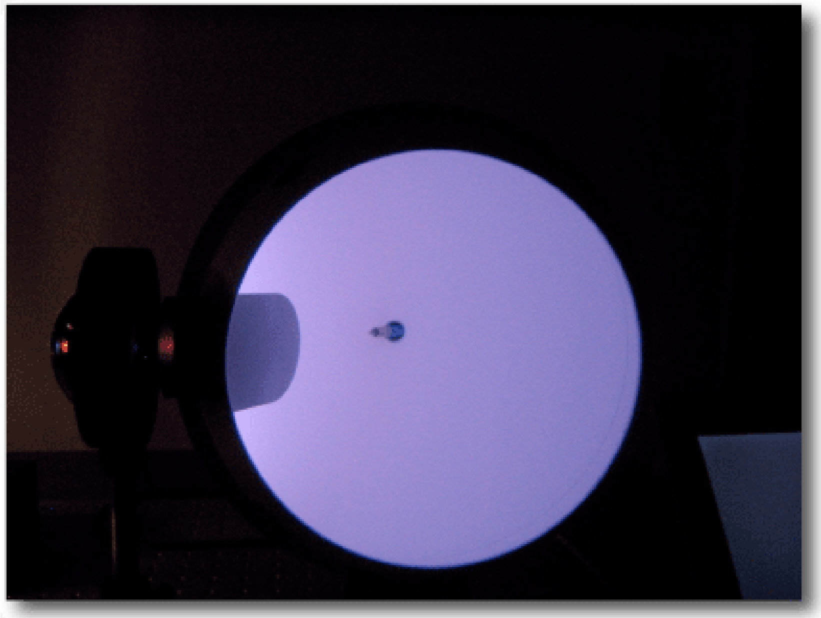
Our immediate goal is to get an understanding of why these simulations differ, and to do simulations for observationally testable scenarios.



Burrows et al. 2003

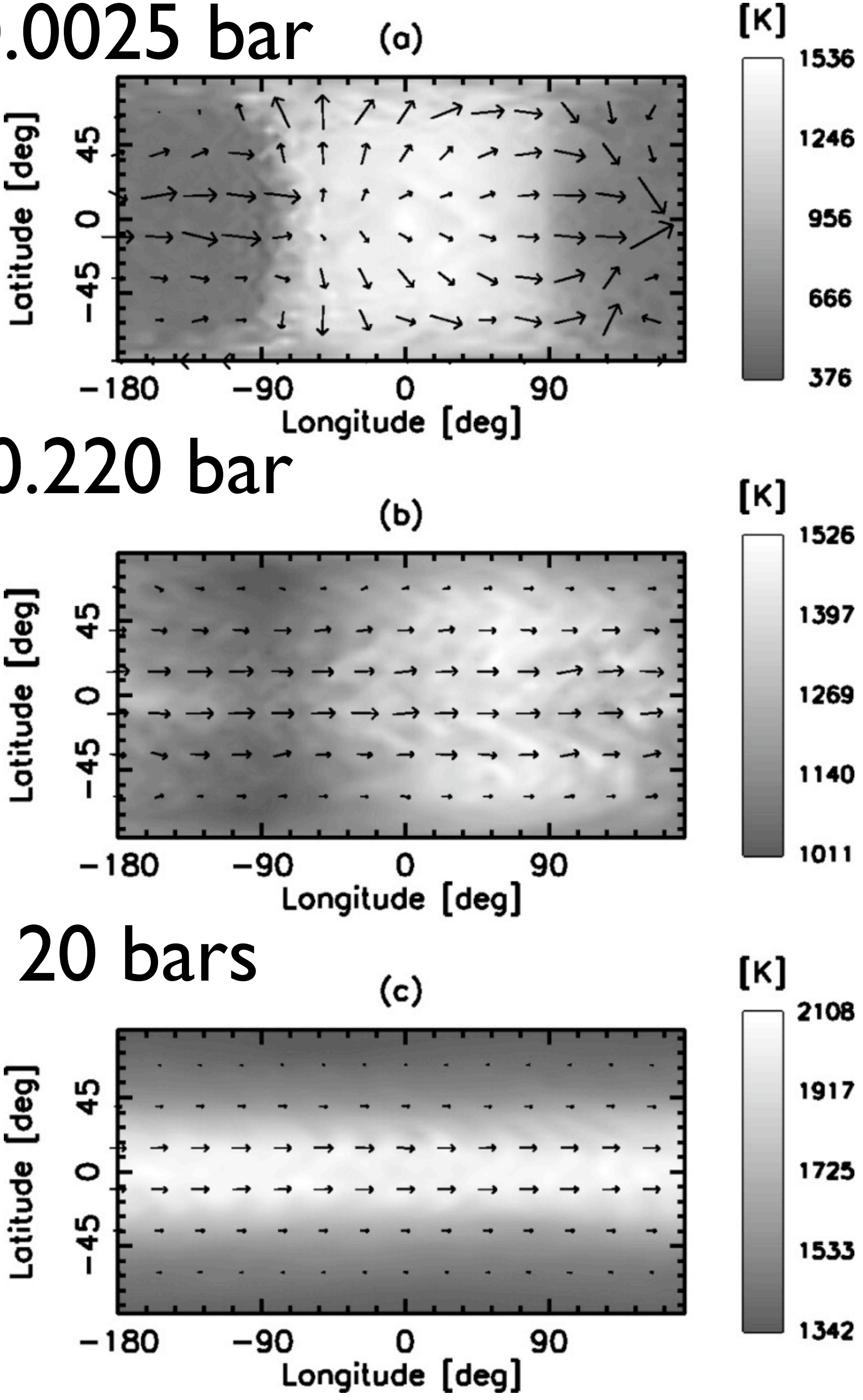
Spectrum of a hot Jupiter is a combination of reflected and thermal flux. Albedos are predicted (and found) to be very low. A~0.15



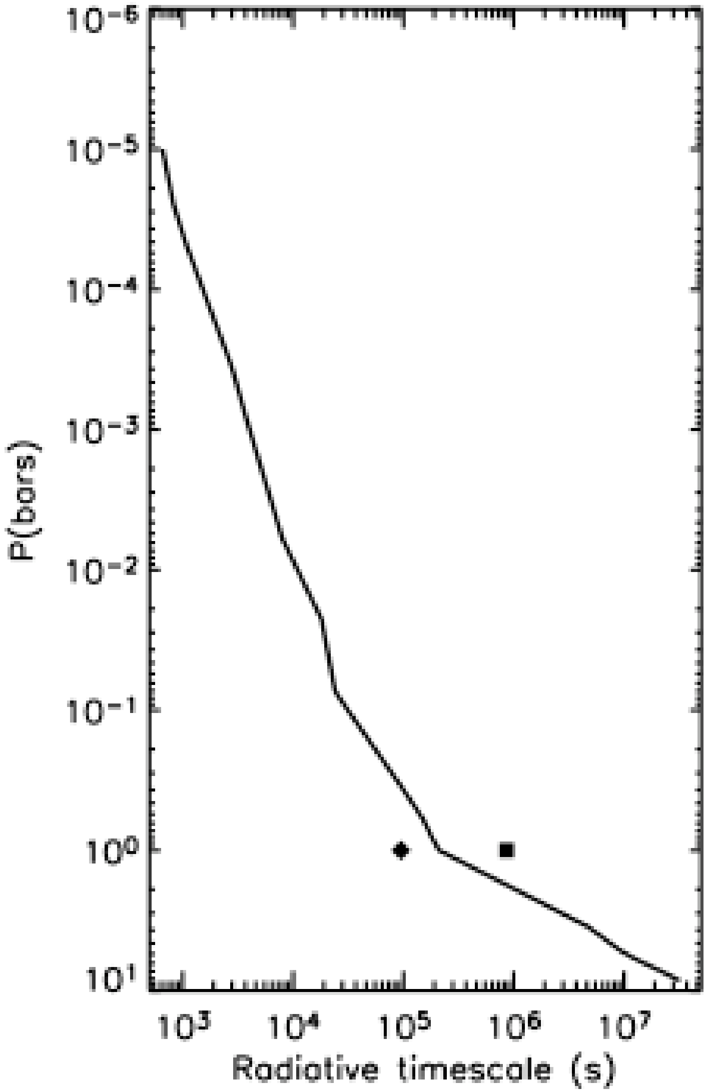


Resulting optical color obtained in an integrating sphere (originally built to simulate the Martian lighting environment). [John Moore (Arizona)]

Appearance of the planet will depend on the radiative time constant appropriate to the photosphere.



Cooper & Showman (2006)



Iro et al. 2005

Following Cho et al., we built a spectral-method code to model the dynamics using the so-called shallow water equations:

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -g \nabla h - f \mathbf{k} \times \mathbf{v}$$

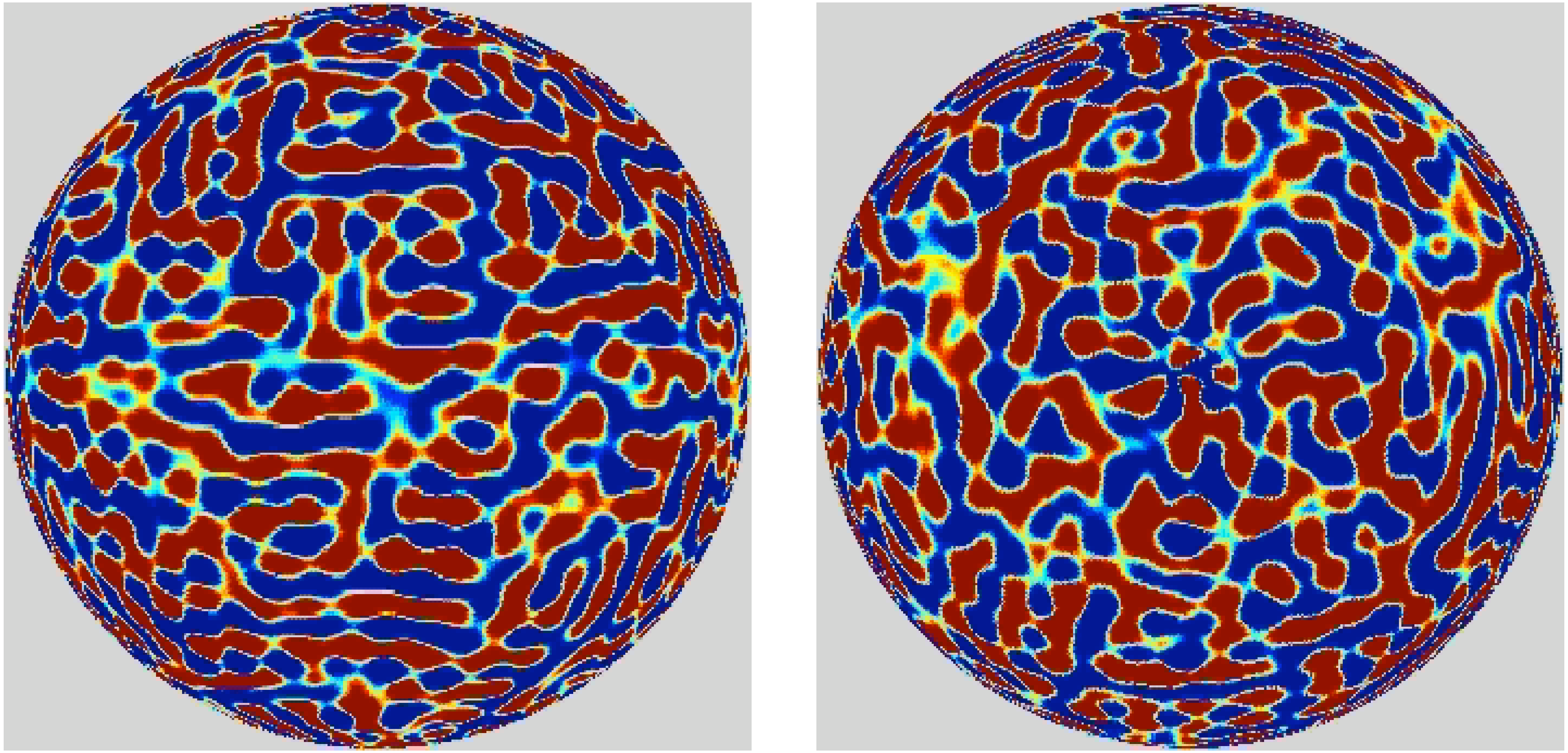
$$\frac{\partial h}{\partial t} + \mathbf{v} \cdot \nabla h = -\mathcal{K} h \nabla \cdot \mathbf{v} - (h - h_E)/\tau_d$$

Height, *h* of the fluid layer is proportional to temperature. Departures are from a forced equilibrium height profile across the planet, e.g. for synchronous rotation:

$$h_E = \eta \cos\phi \cos\lambda \qquad \mathcal{K} = R/c_p$$

τ_d = radiative time constant for "Newtonian" cooling

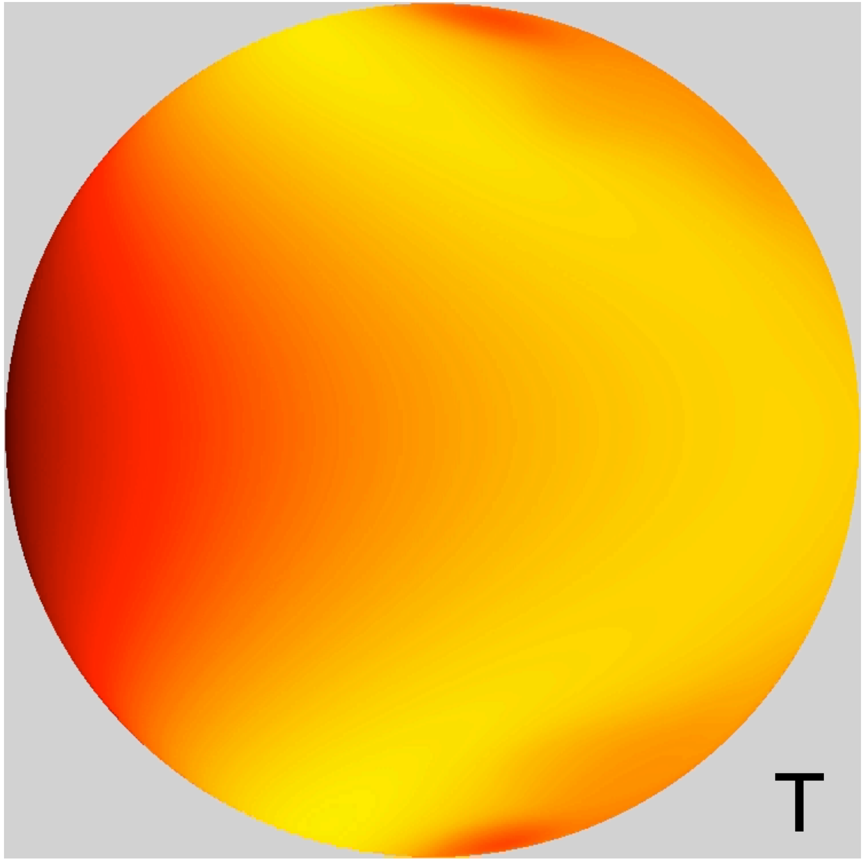
η = day-night equilibrium temperature difference



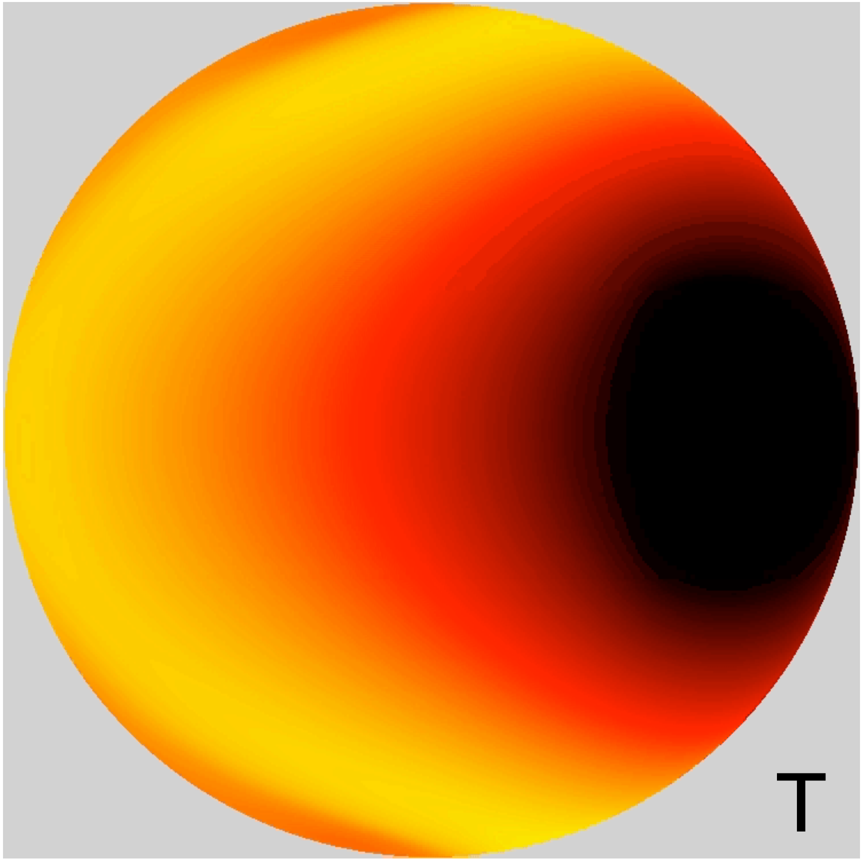
Equatorial View $\nabla \times \mathbf{v}$ Polar View

P=3.52 d, R=1.3 Rjup, M=0.69 Mjup, 384x193 res, t=40 rotations
Evolution of a random velocity field on a planet with no forcing.

Conclusion -- Cho simulations are largely driven by initial conditions. They use a radiative time constant of 10 days. Results of Iro et al. 2005 suggest 8 hours at photosphere is more realistic.



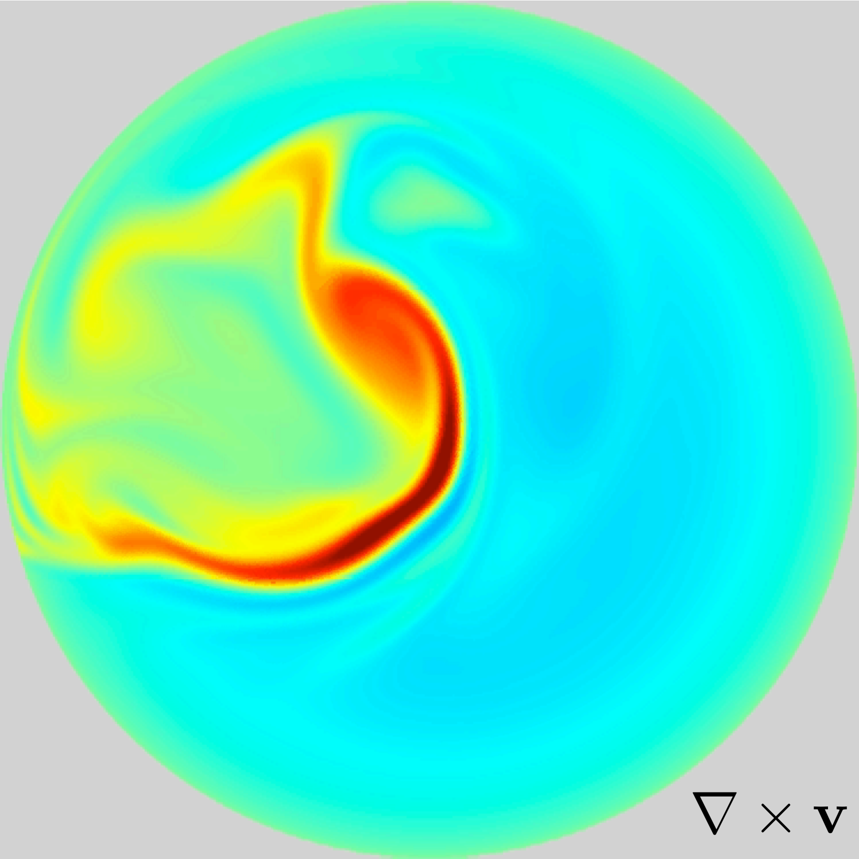
Dayside View



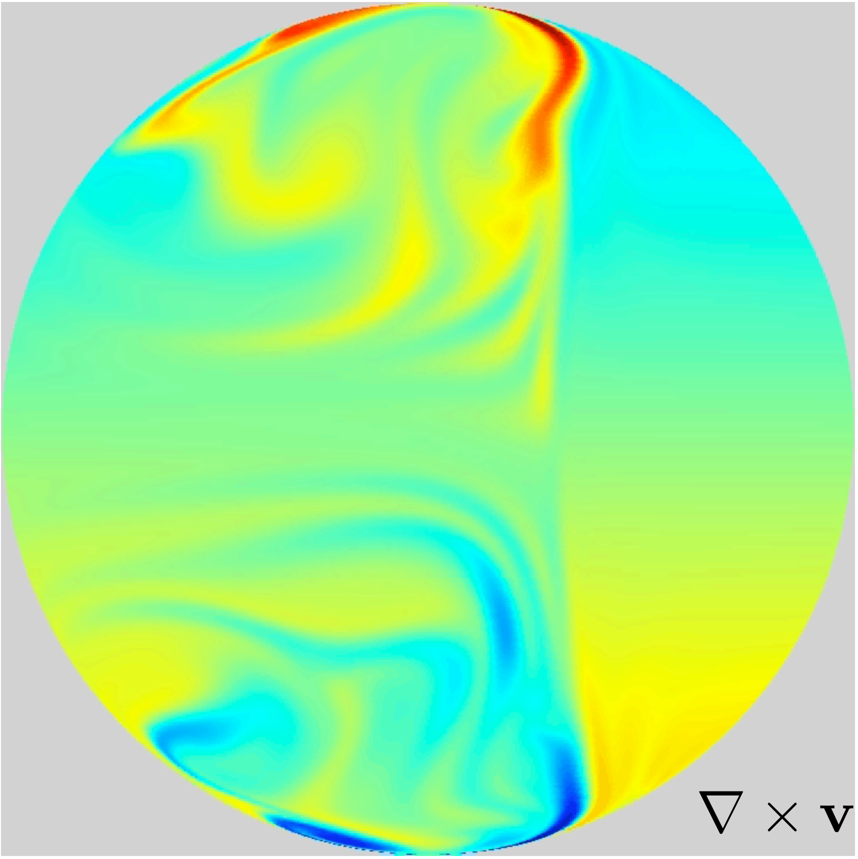
Nightside View

Based on the results of Iro et al. 2005, we assume a photospheric radiative time constant of 8 hours, and a day-night equilibrium temperature difference of 800K. The system is allowed to evolve for 250 rotational periods, and then plotted for 4 rotations.

Flow pattern is qualitatively similar to Cooper & Showman (2005) at the assumed photospheric level of 220 mbar.



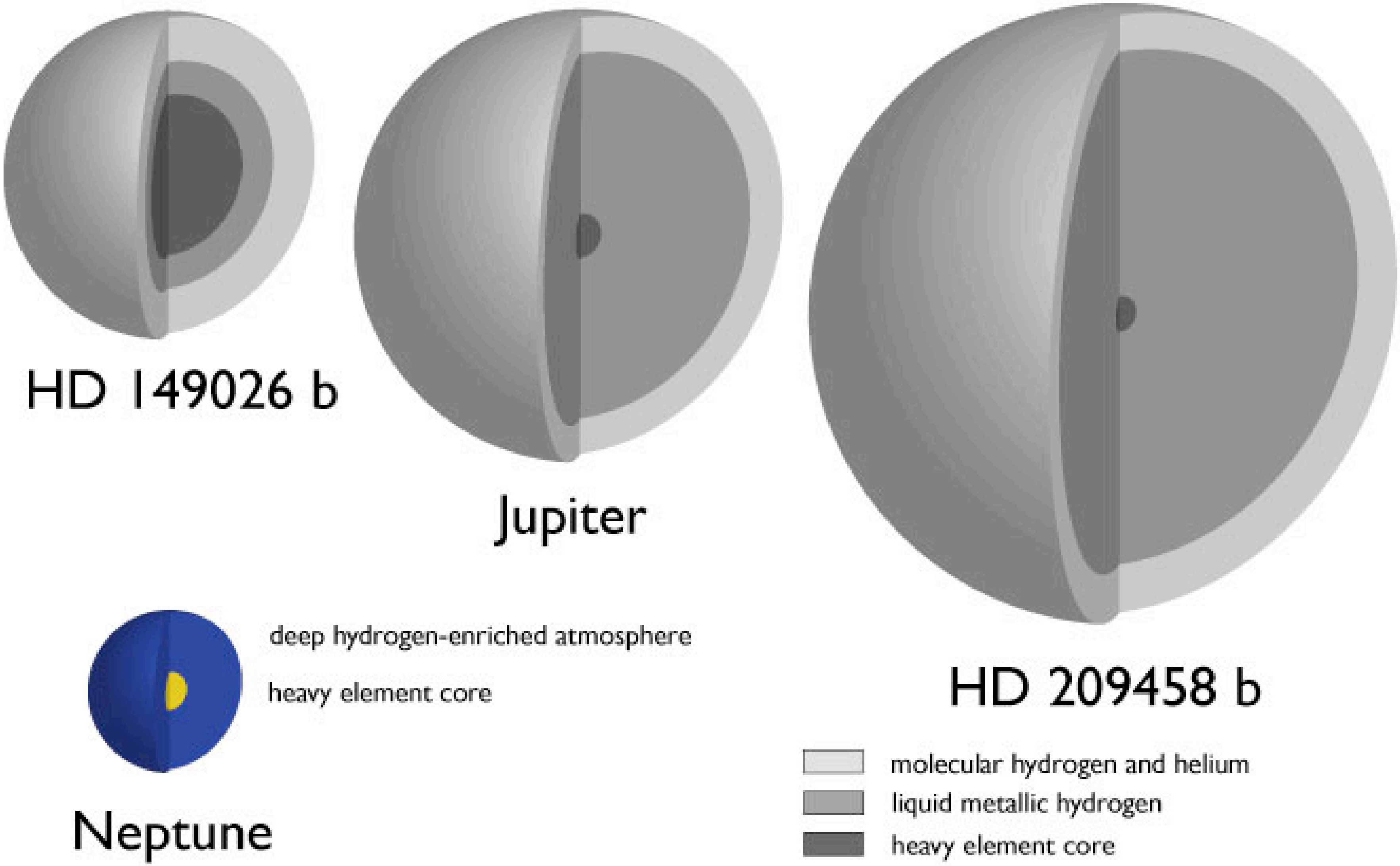
North Pole View



Equatorial View

Because of the radiative time constant used, our overall velocity flow pattern for HD 209458b is more similar to the Cooper Showman model, and predicts a significant day-night side variation.

The size of HD 209458 b and several other known transiting planets is a real problem.



OBLIQUITY TIDES ON HOT JUPITERS

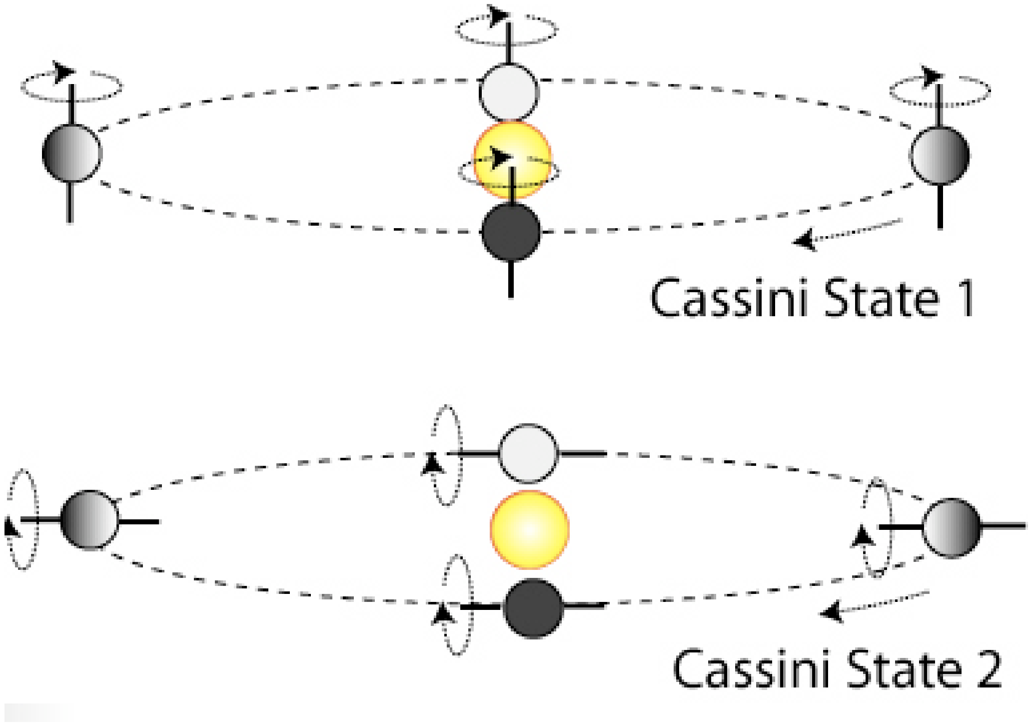
Joshua N. Winn[1] and Matthew J. Holman
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

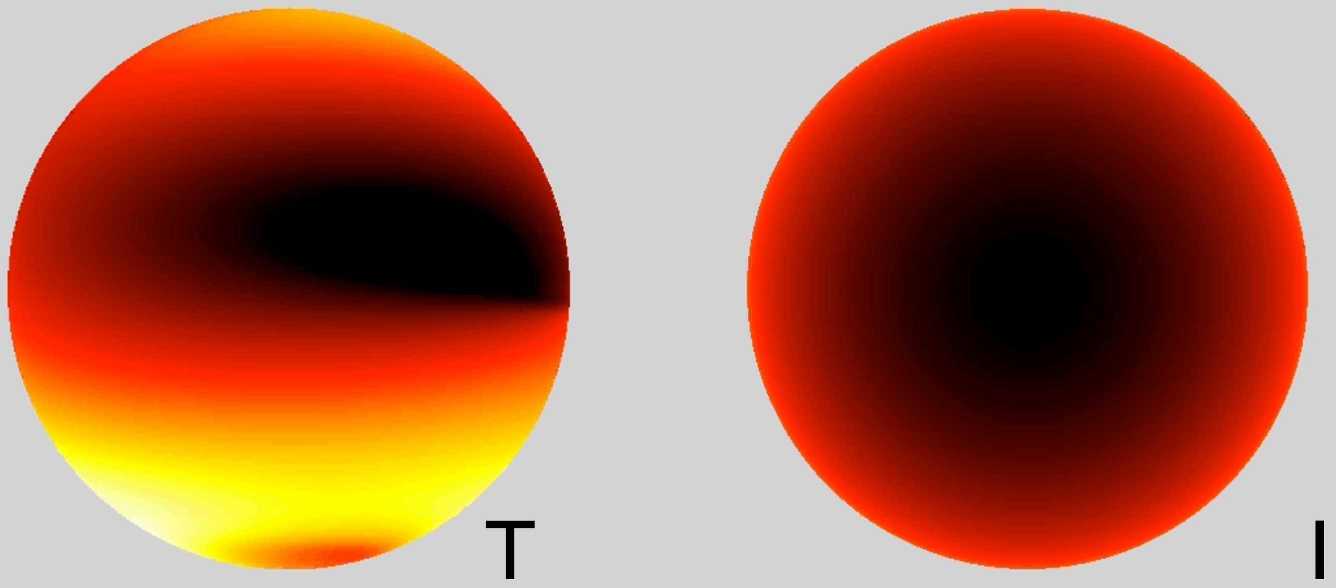
Received 2005 May 13; accepted 2005 June 20; published 2005 July 15

ABSTRACT

Obliquity tides are a potentially important source of heat for extrasolar planets on close-in orbits. Although tidal dissipation will usually reduce the obliquity to zero, a nonzero obliquity can persist if the planet is in a Cassini state, a resonance between spin precession and orbital precession. Obliquity tides might be the cause of the anomalously large size of the transiting planet HD 209458b.

Subject headings: celestial mechanics — planetary systems: formation — planets and satellites: formation — stars: individual (HD 209458)

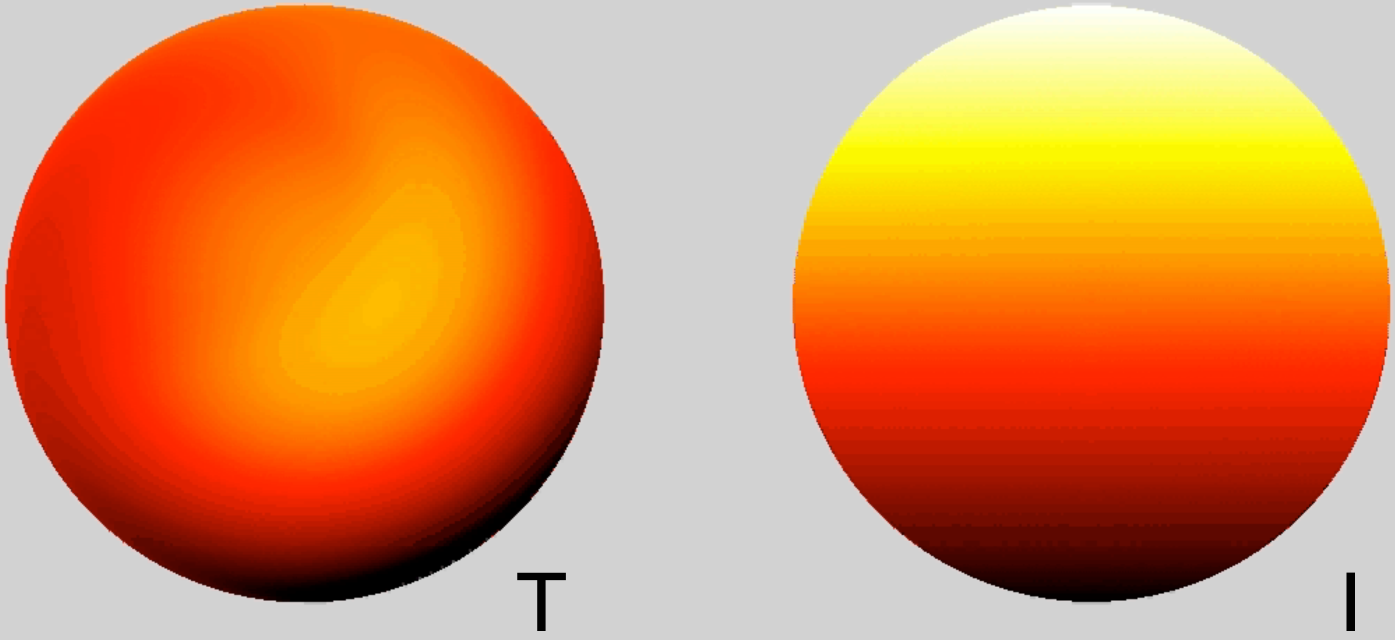




Equator view
Antistellar Pivot

Irradiation Pattern

The irradiation pattern for a planet in Cassini State 2 is totally different, and leads to a different hydrodynamic response in the atmosphere.

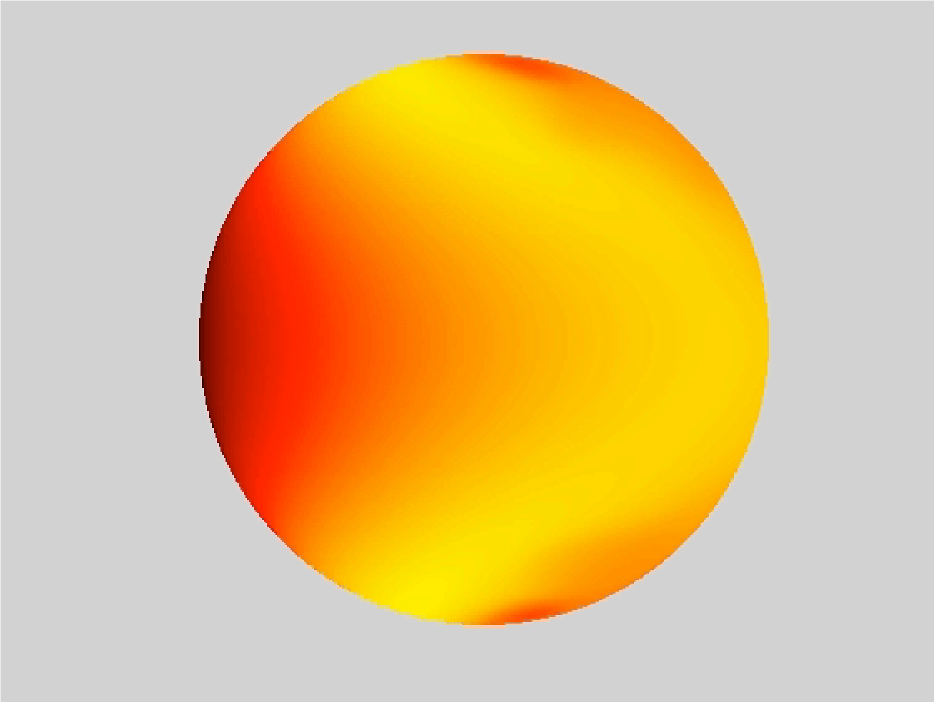


Polar view

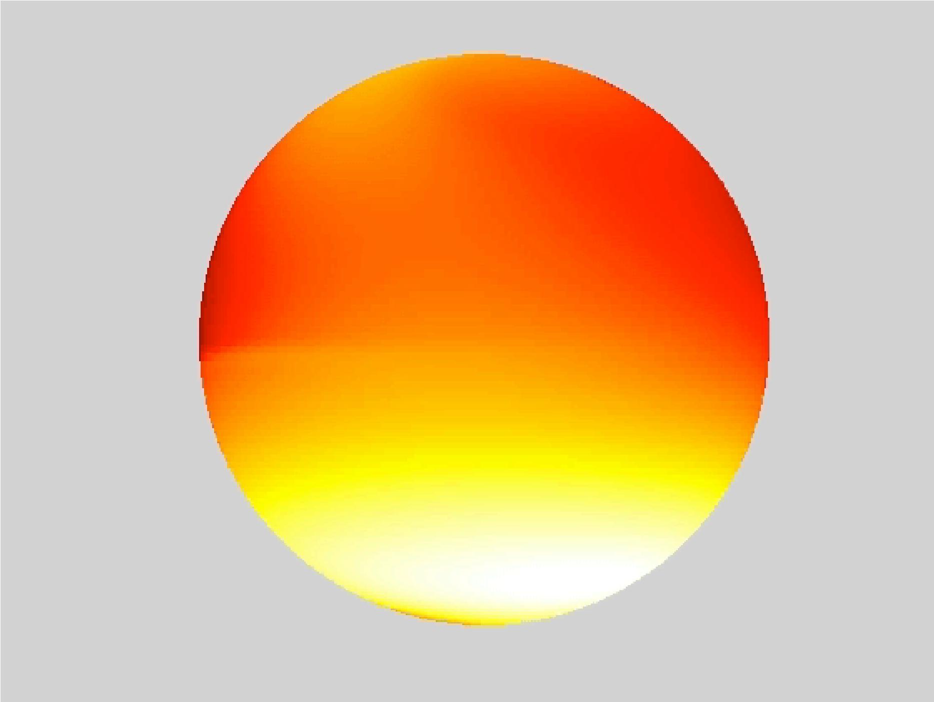
Irradiation Pattern

The irradiation pattern for a planet in Cassini State 2 is totally different, and leads to a different hydrodynamic response in the atosphere.

View from Earth

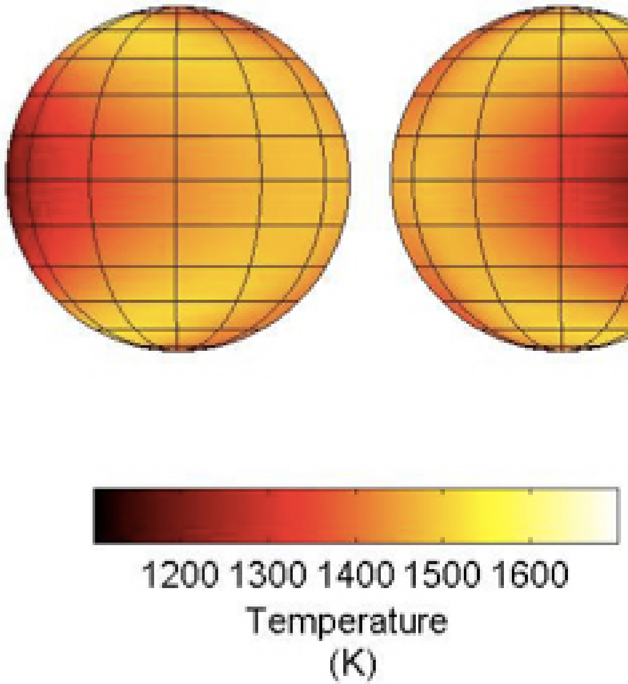


Cassini State 1

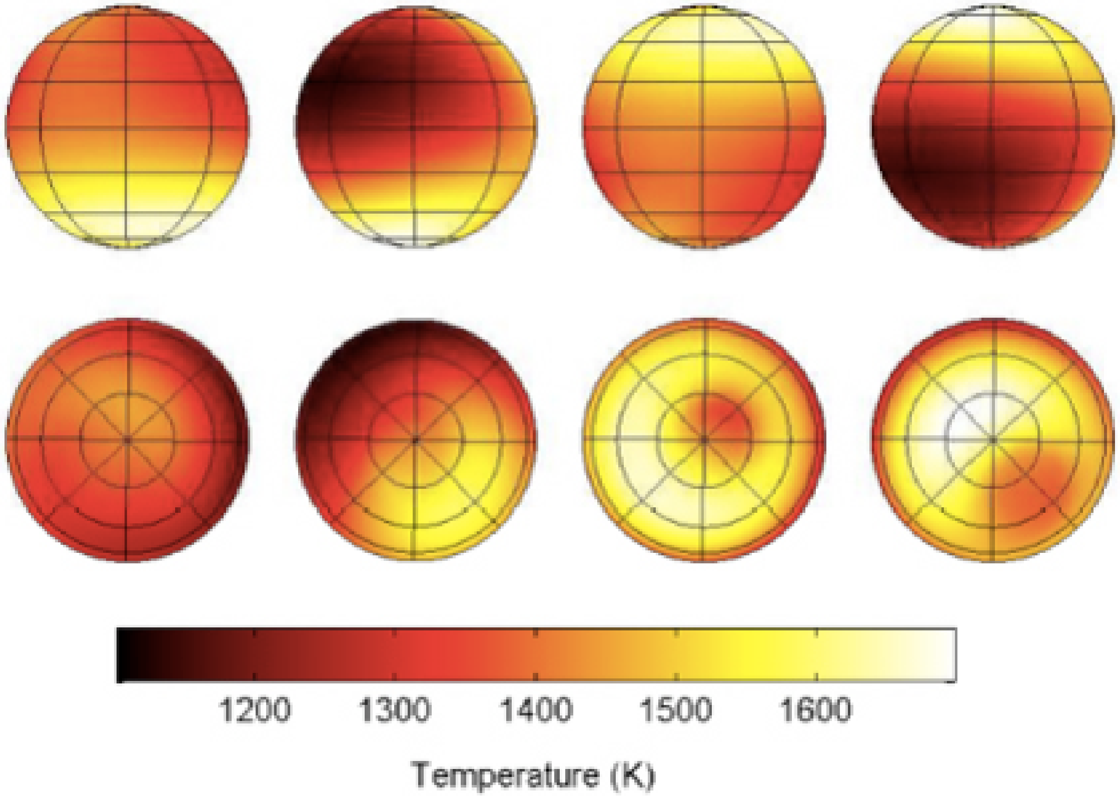


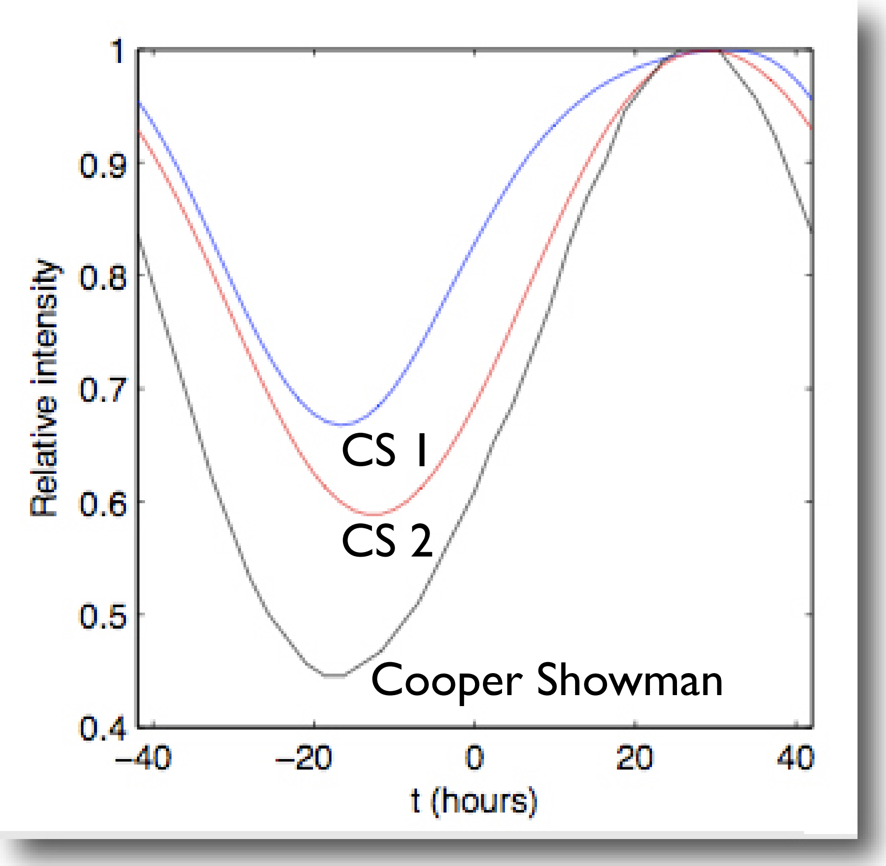
Cassini State 2
(equatorial alignment)

CS 1



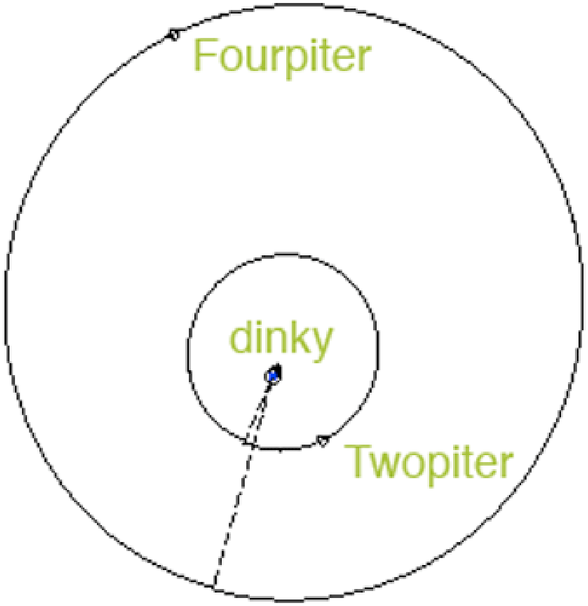
CS 2

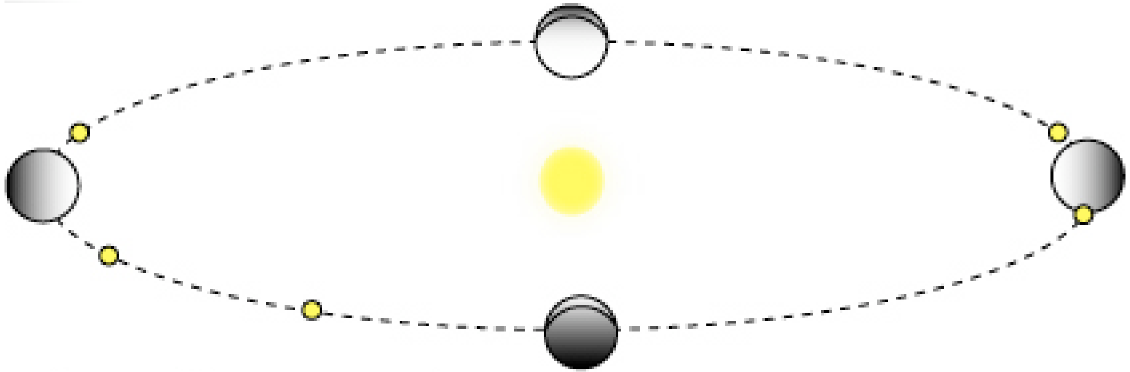




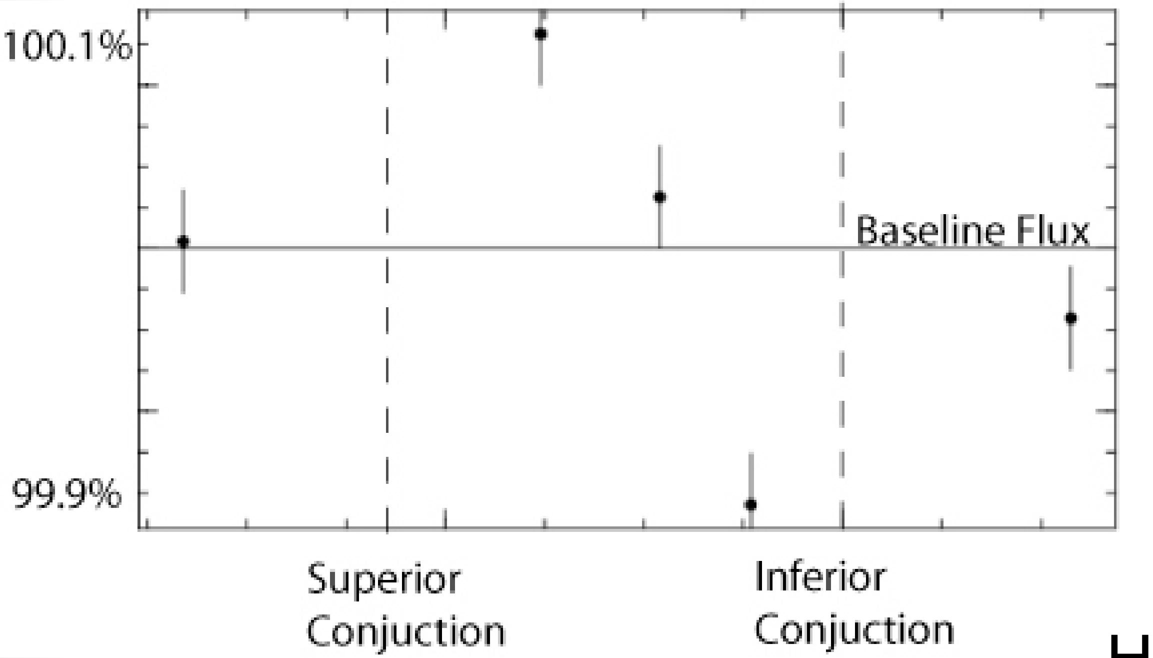
Despite the large difference in the flow patterns on the surface for the CS1 and CS2 cases, the light curves are depressingly similar. Our CS1, CS2 and Cooper-Showman all predict a flux minimum 60 deg east of the anti-stellar point

Spitzer observes Upsilon Andromedae b

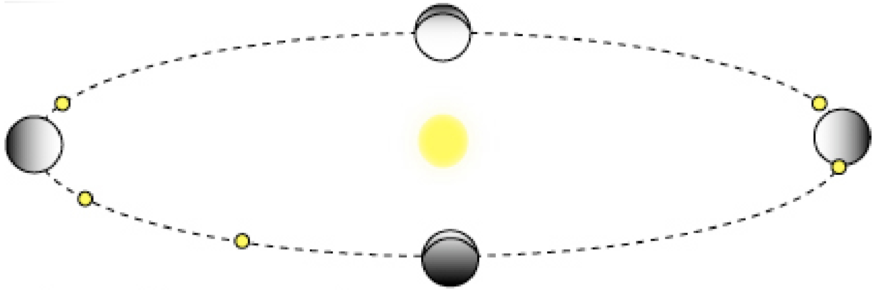




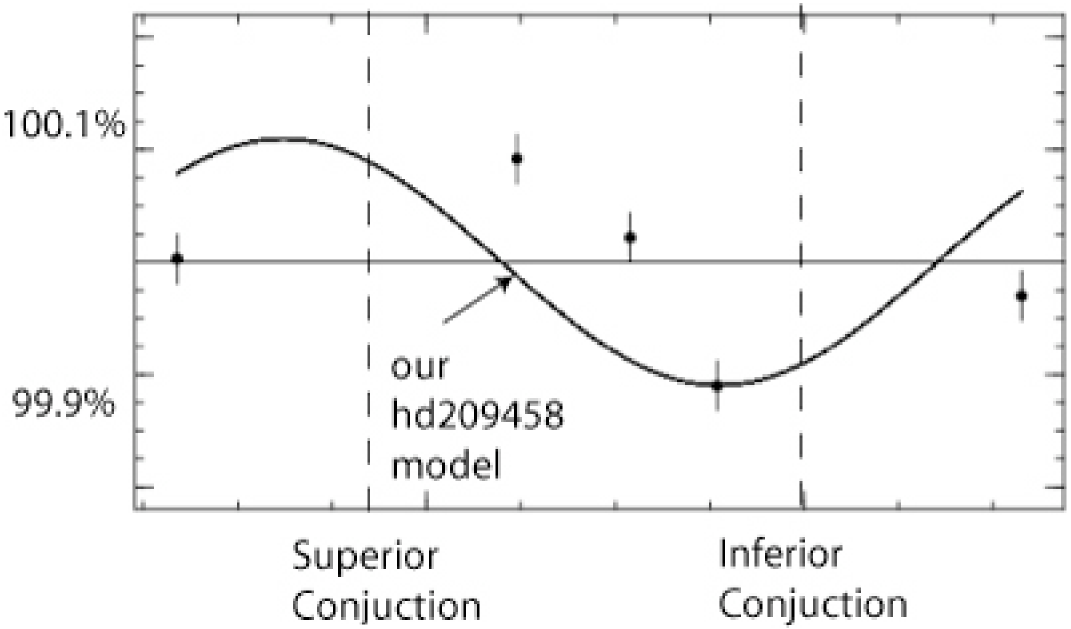
observations were made at the 5 phases marked by yellow circles.

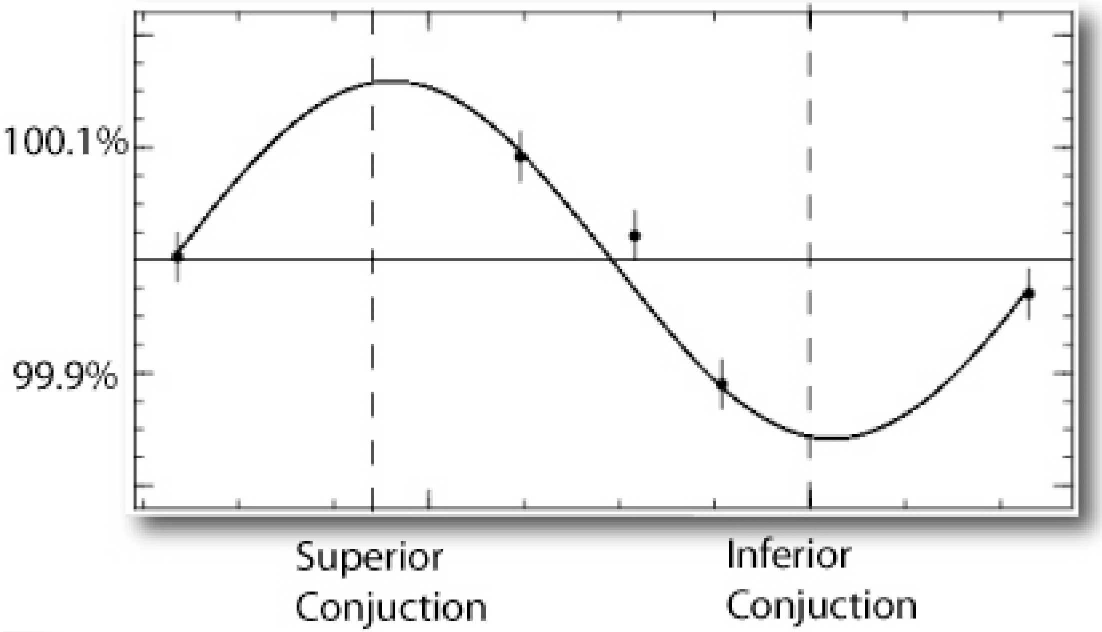


Harrington et al. 2006



observations were made
at the 5 phases marked
by yellow circles.

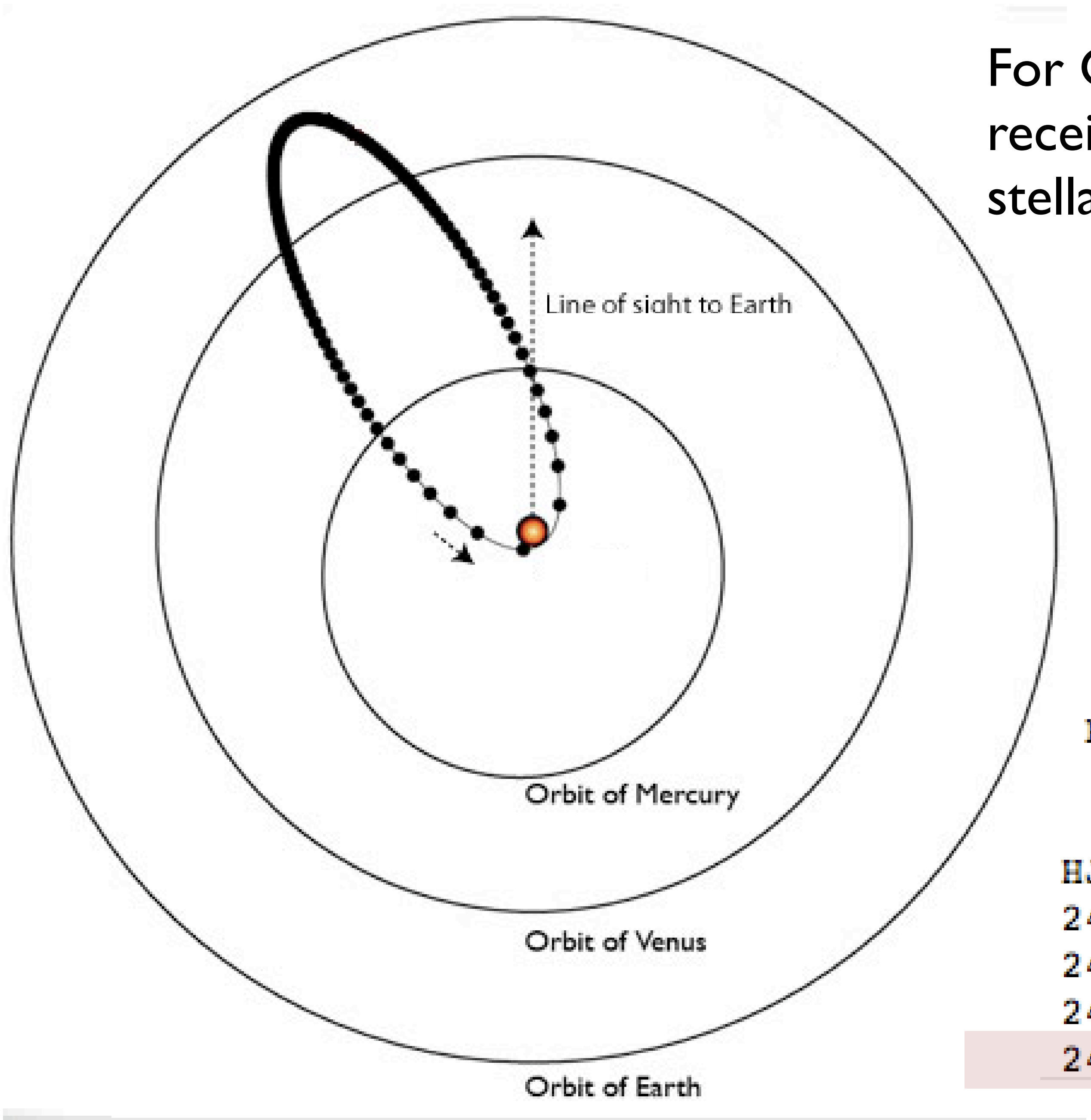




Our CS1, and CS2 and the Cooper-Showman models do not fit the Ups And 24-micron lightcurve. The 24-micron results suggest a large day-night side temperature difference and a short radiative time constant -- of order ~1 hour!

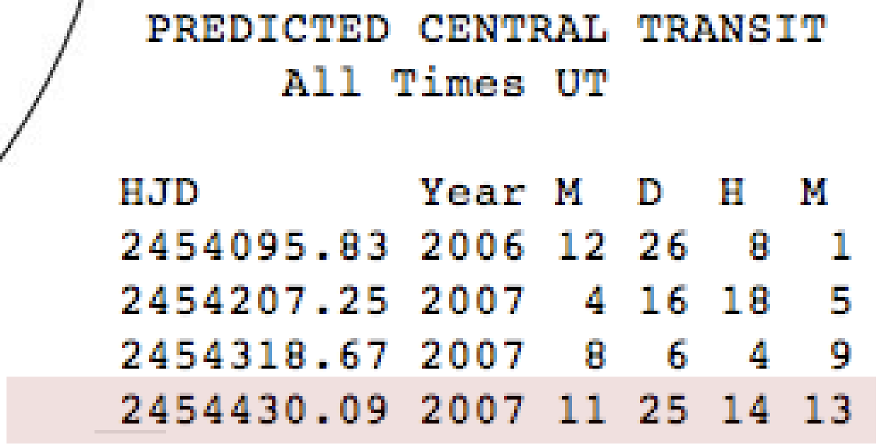
In contrast, however, Cowan et al. 2007 find no day/night side variations at 3.6, 4.5 and 8 microns for HD 179949 and 51 Peg.

Spitzer observations of HD 80606 b can potentially give us the radiative time constant in the planetary atmosphere.



For Q=300,000, the planet receives roughly equal tidal and stellar energy inputs. Teq~400K

Nov. 21, 2007 periastron is visible to Spitzer



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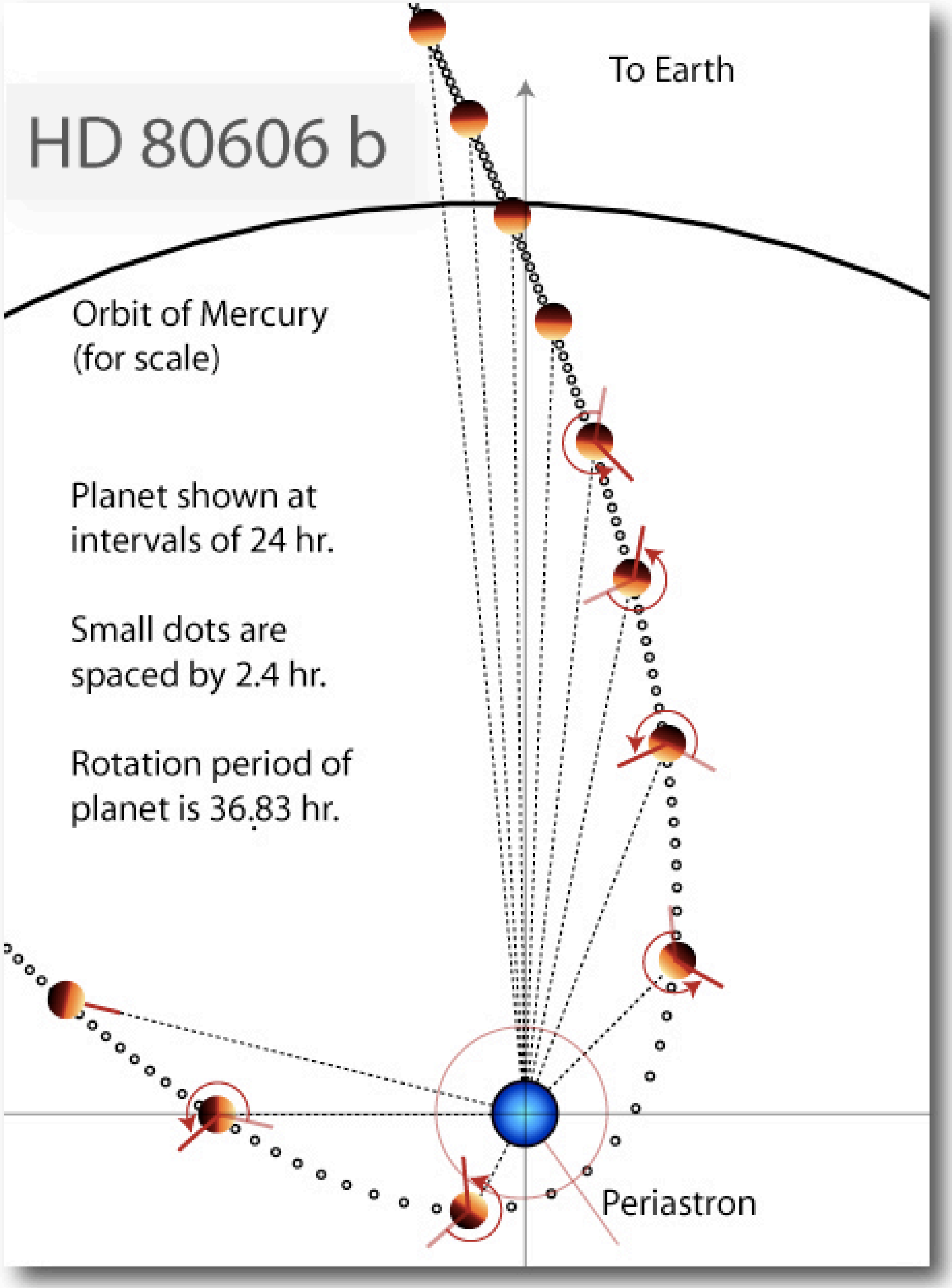
  PREDICTED CENTRAL TRANSIT
       All Times UT

HJD         Year M  D  H  M
2454095.83 2006 12 26  8  1
2454207.25 2007  4 16 18  5
2454318.67 2007  8  6  4  9
2454430.09 2007 11 25 14 13
```

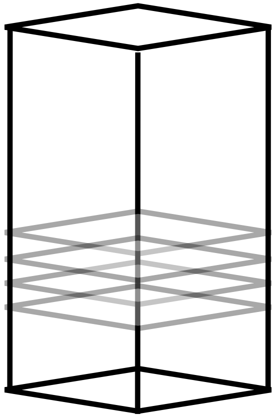
Move to a 2D compressible hydro formulation



Planet shown at intervals of 24 hr.

Small dots are spaced by 2.4 hr.

Rotation period of planet is 36.83 hr.

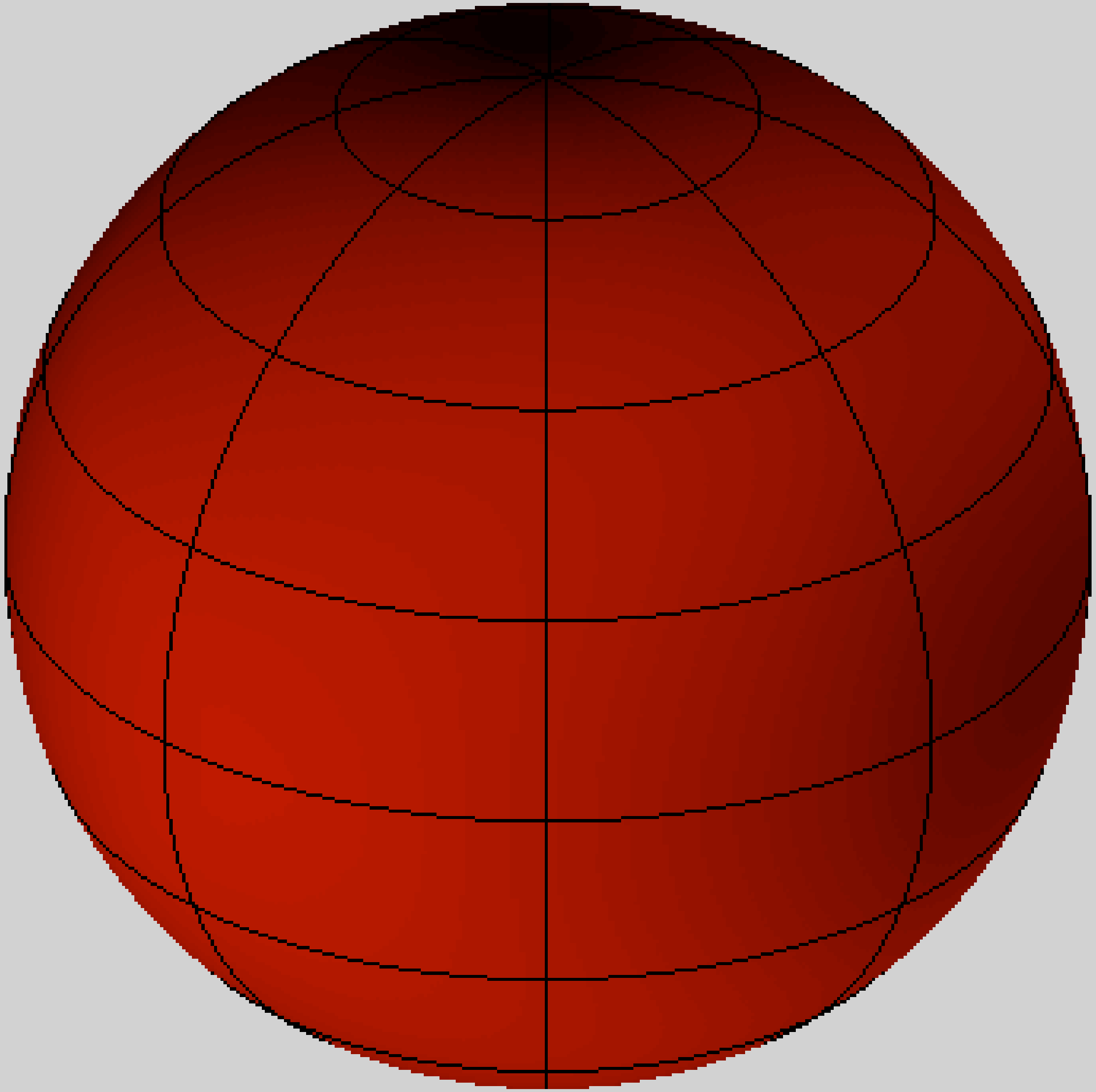


Assume that a parameterizable column density sigmac in the atmosphere responds to stellar heating.

$$
\begin{aligned}
\frac{\partial T}{\partial t} &= -\mathbf{v}\cdot\nabla T-(\gamma-1)T\nabla\cdot\mathbf{v} \\
\frac{\partial \mathbf{v}}{\partial t} &= -\mathbf{v}\cdot\nabla\mathbf{v}-\frac{RT}{\rho}\nabla\rho-R\nabla T-f\mathbf{k}\times\mathbf{v} \\
\frac{\partial \rho}{\partial t} &= -\mathbf{v}\cdot\nabla\rho-\rho\nabla\cdot\mathbf{v}.
\end{aligned}
$$

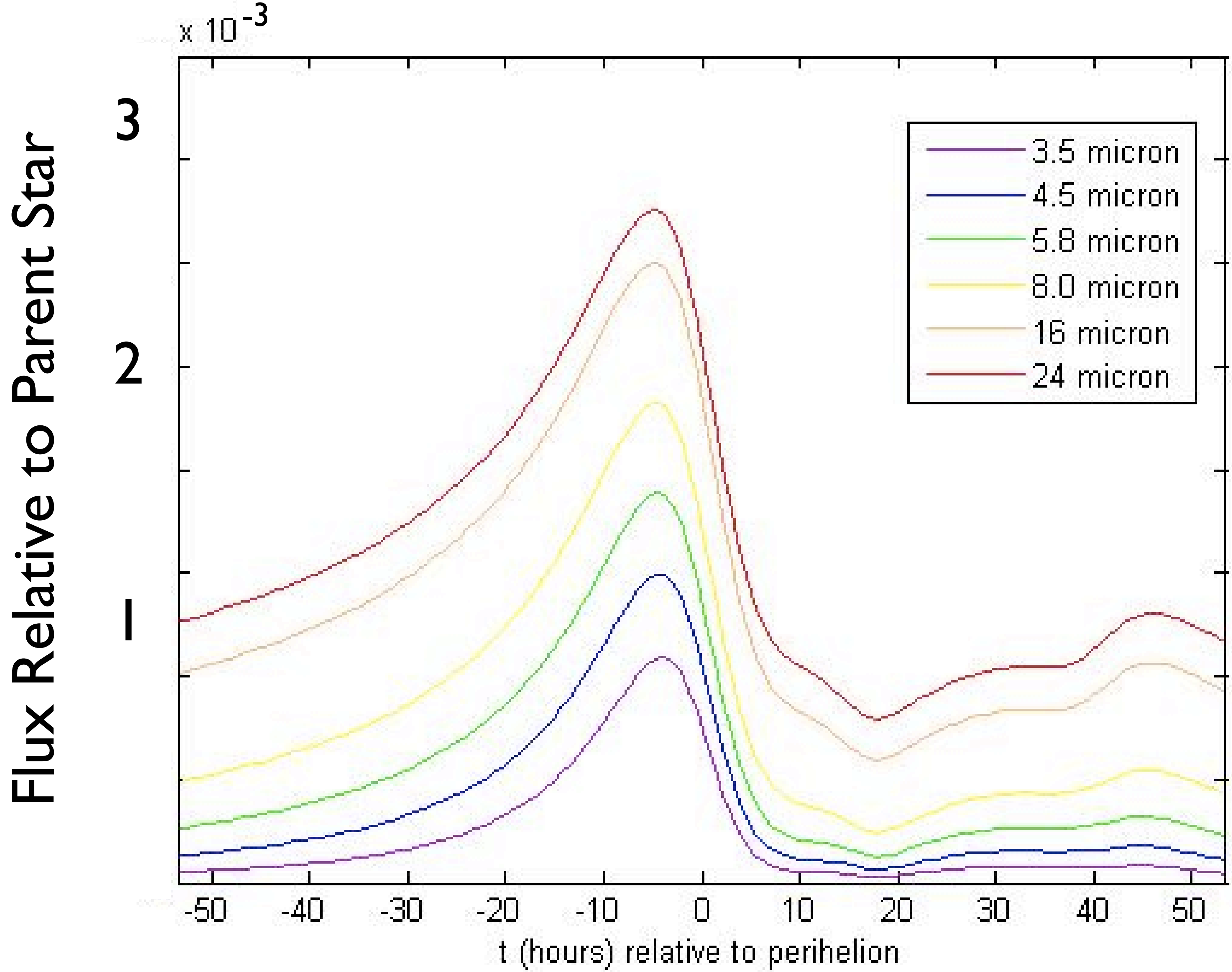
$$\sigma_c C_p \dot{T} = \sigma(T_{eq}^4 - T^4)$$

$$\sigma T_{eq}^4 = \left((1-A_B)\frac{L_* X(\sigma_c)}{4\pi a^2}\right)\cos\alpha + \sigma T_{tidal}^4$$

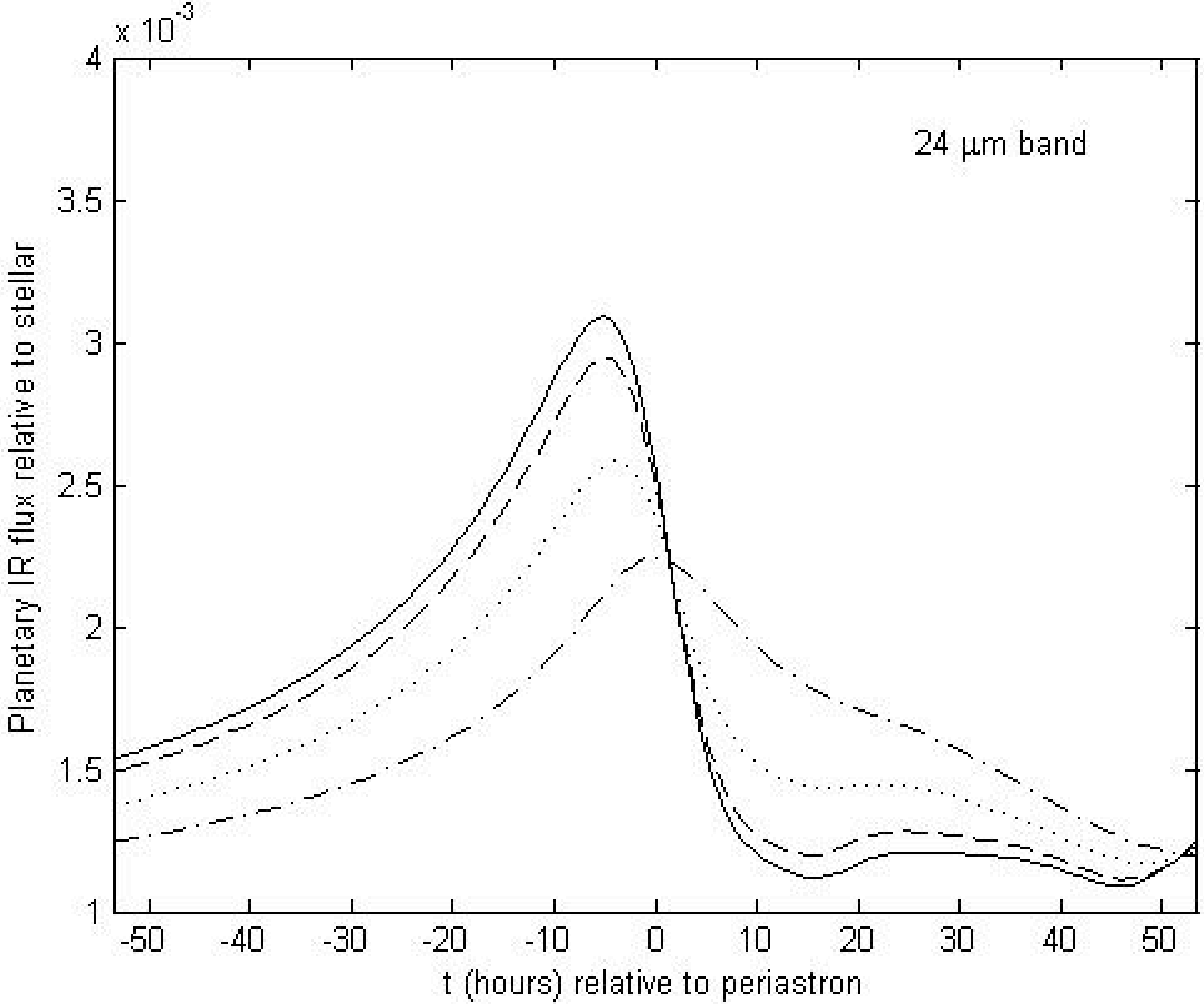


View from Earth (sigma = 20 gm/cm^2)

Run model for 2 orbits, then animate +/- 50 hours surrounding periastron.



Predicted light curves in Spitzer Bands



24-micron flux as a function of sin(i)

We're currently writing a GO-4 proposal with Drake Deming of GSFC to observe the Nov. 21, 2007 periastron passage of HD80606b. Over the next year, we'll be working to improve the hydrodynamical modeling prior to (hopefully) seeing observational data from Spitzer.