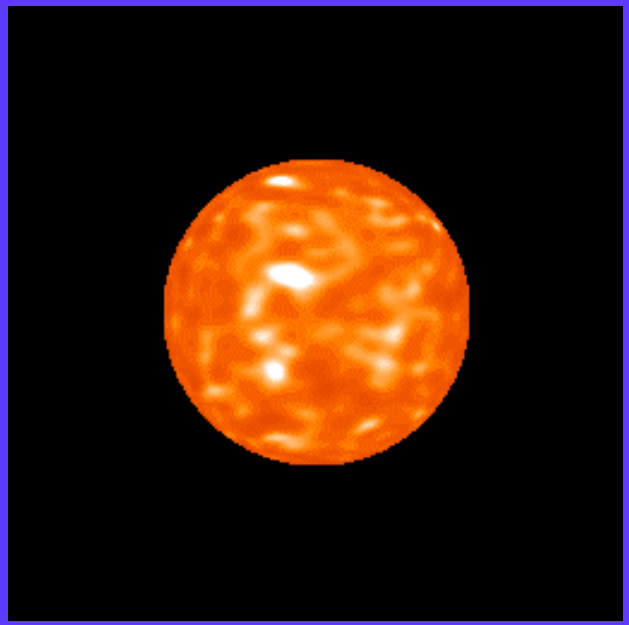
Searching for the scattered light from the transiting planet HD209458b

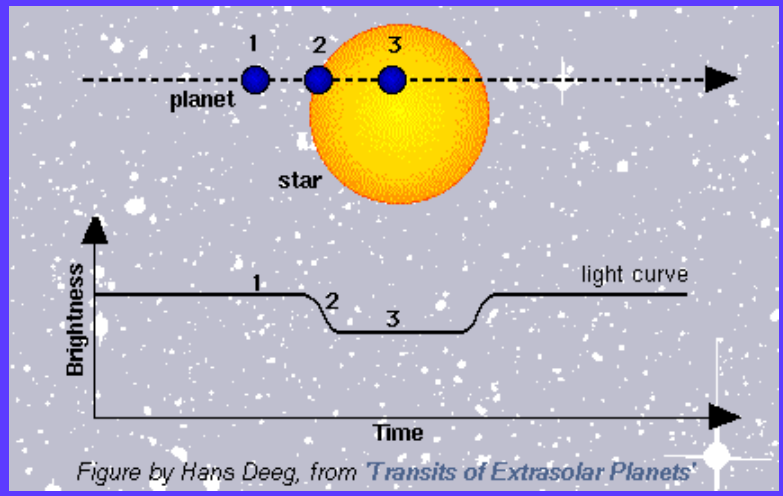


Department of Physics
University of Tokyo
Yasushi Suto

16:00- October 18, 2002

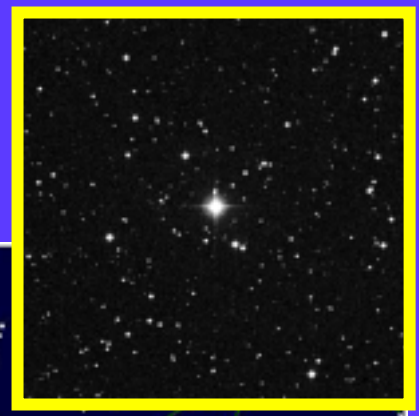
Extrasolar Planet Meeting@RESCEU

Transit method for the extrasolar planet search

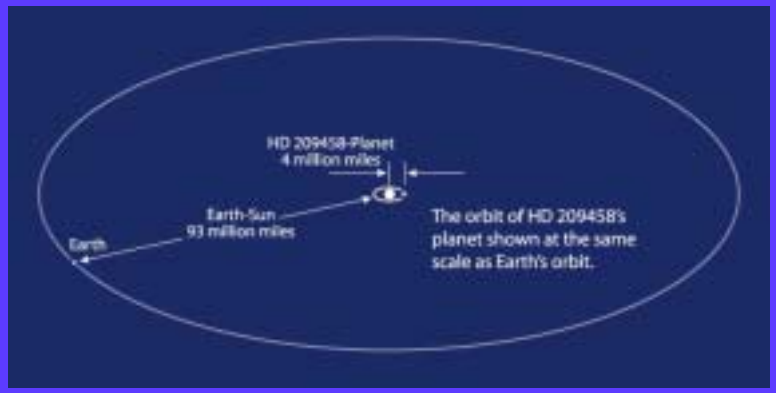


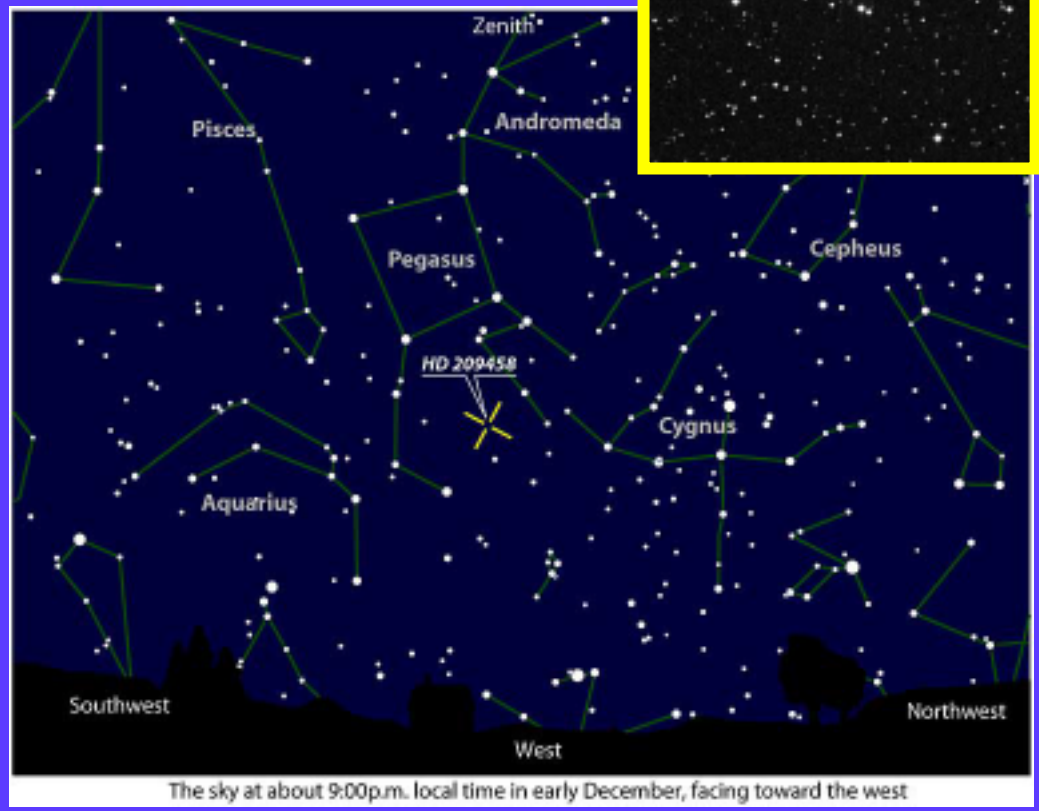
- inclination angle is determined (or only observable for edge-on system, i.e., when $i \sim 90$ deg.)
- size of the planet can be estimated
- complementary to the radial velocity method
- Low probability: **10%** $(0.05AU/a_{orbit})(R_{star}/R_{Sun})$
- Small flux variation: **~1%** $(R_{planet}/R_{Jupiter})^2(R_{Sun}/R_{star})^2$
- Sensitive to the CIGP (close-in-giant-planets)

HD209458: the unique star with a transit planet



- V=7.65
- G0V
- d=47pc



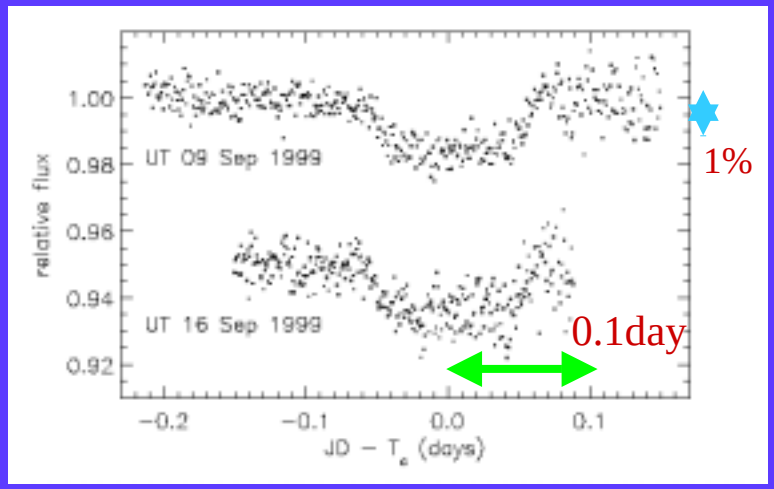


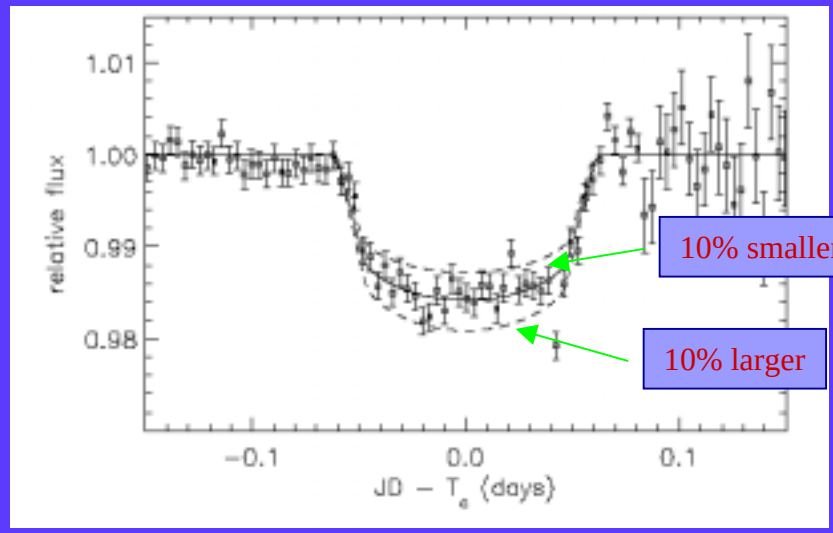
The sky at about 9:00p.m. local time in early December, facing toward the west

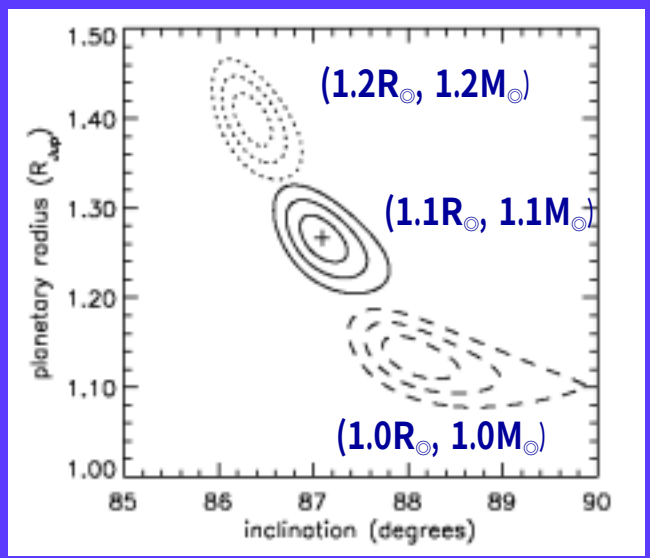
Detection of Planetary Transits Across a Sun-like Star

Charbonneau, D., Brown, T.M., Latham, D.W., & Mayor, M.
2000, ApJL, 529, L45

Light curve of HD209458







Fitting parameters: Rs, Ms, c_λ, R_p, *i*

C_λ limb darkening parameter $B_\lambda(\mu)=1-c_\lambda(1-\mu)$

Rs, Ms, c_λ estimated from stellar model (metallicity, temperature, color, luminosity)

Henry et al. 1999 (IAU Circ. 7307)
Henry et al. 2000 ApJ, 529, L41
Charbonneau et al. (2000)

Parameters for the HD209458 system

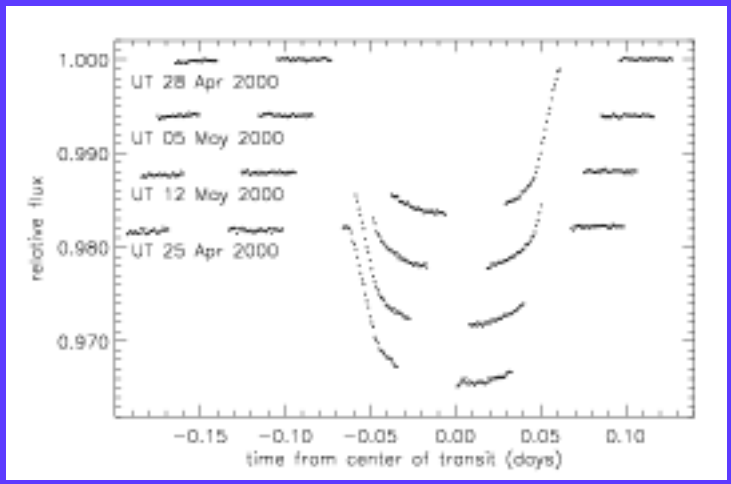
Table 1: Orbital Solution for HD 209458.

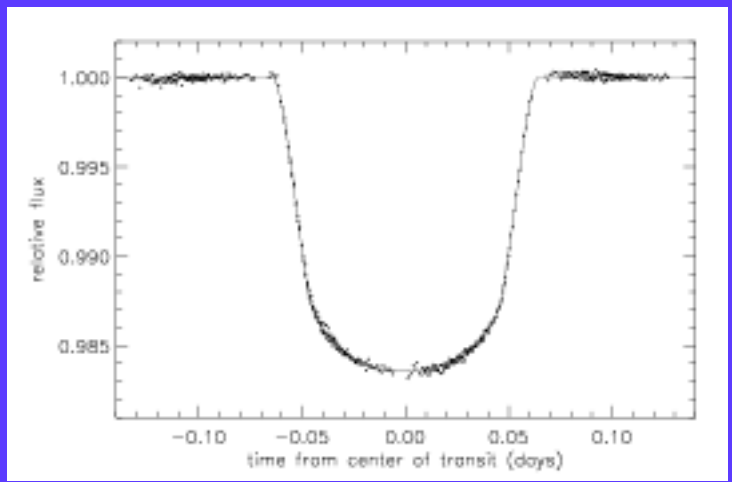
Period	3.52433 ± 0.00027	days
γ	-14.7652 ± 0.0016	$\mathrm{km\,s^{-1}}$
K	85.9 ± 2.0	$\mathrm{m\,s^{-1}}$
e	0	FIXED
T_c	$2,451,430.8238 \pm 0.0029$	HJD
$M_p \sin i$	$0.685 \pm 0.018\ (M_*/1.1M_\odot)^{2/3}$	M_{Jup}

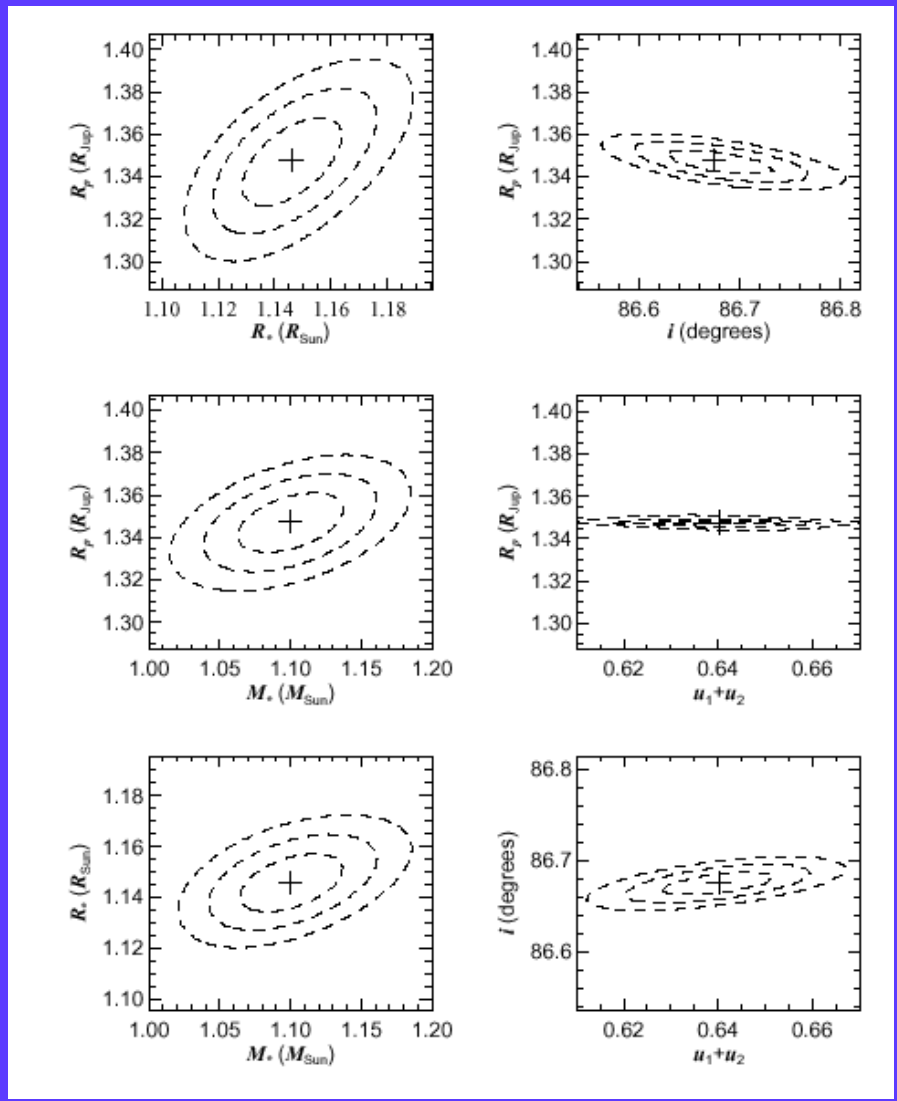
Table 2: The Mass and Radius of HD 209458

Model			$\log g$ vs. $T_{\rm eff}$			M_V vs. $B-V$		
Code	Z	Y	Age (Gyr)	M_* ($M_\odot$)	R_* ($R_\odot$)	Age (Gyr)	M_* ($M_\odot$)	R_* ($R_\odot$)
Geneva	0.02	0.30	4.6	1.15	1.33	6.3	1.08	1.29
Bertelli	0.02	0.27	5.0	1.11	1.31	4.0	1.09	1.30
Claret	0.02	0.28	5.3	1.12	1.31	7.9	1.05	1.27
Yale	0.02	0.27	5.7	1.11	1.31	7.3	1.06	1.28
Yale	0.02	0.30	6.0	1.05	1.27	7.7	1.01	1.25
Geneva	0.008	0.264	9.8	0.94	1.20	12.3	0.91	1.30

HST observation of HD209458







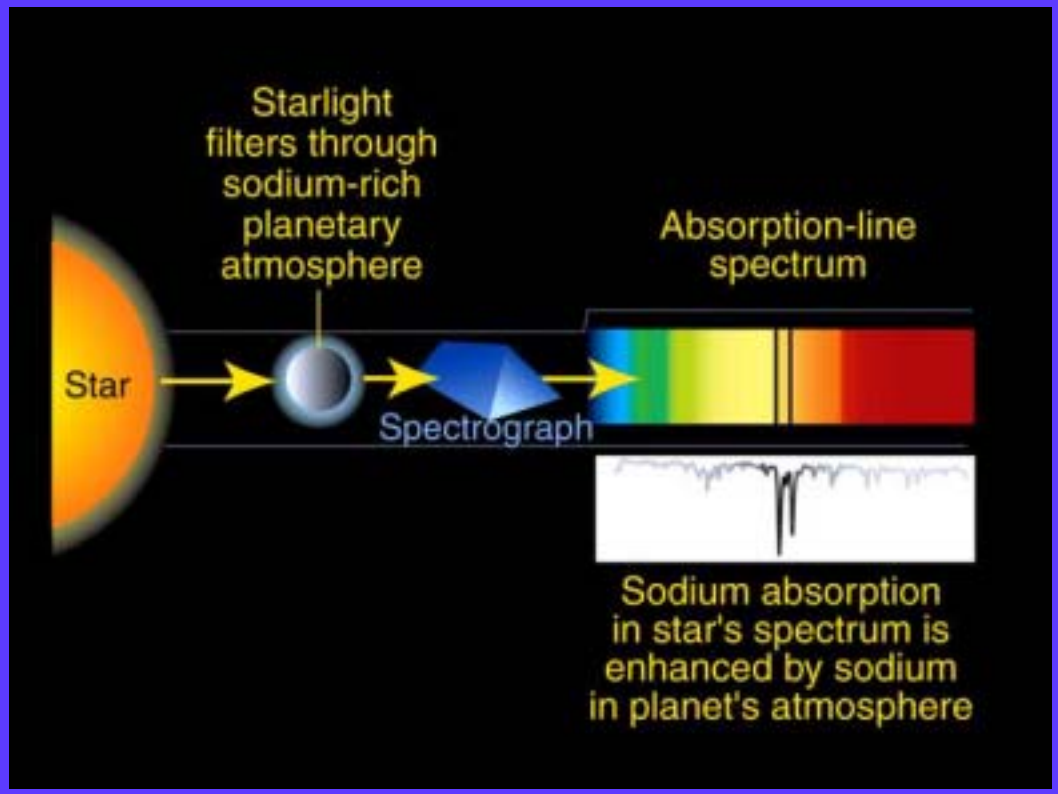
Brown et al. (2001)

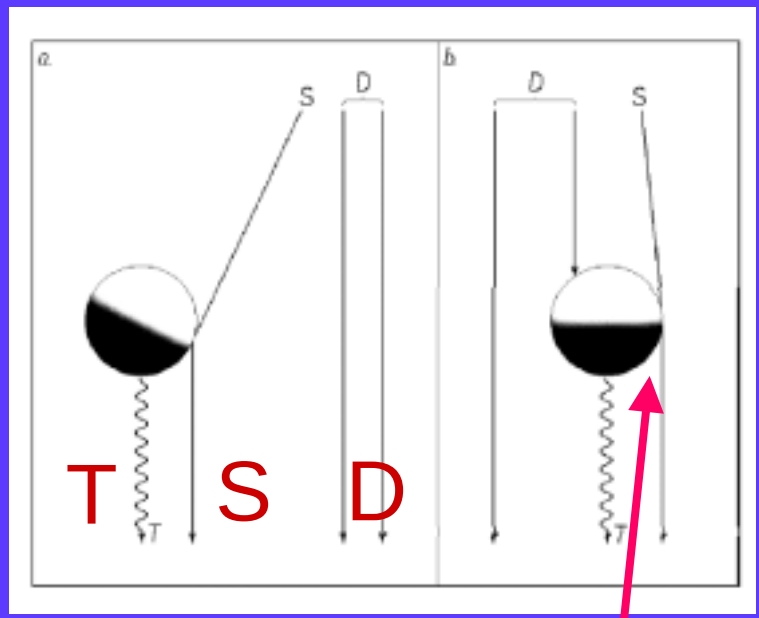
Implications for HD209458b

HD209458 G0V V=7.58 (d=47pc)
HD209458b Orbital Period 3.52474 ± 0.00004 days
viewing angle 86.68±0.14 deg
Mass 0.63 $M_{Jupiter}$
Size 1.347±0.060 $R_{Jupiter}$

- M_p=0.63 M_J, R_p=1.3 R_J :roughly consistent with a theoretical model for CIGP (e.g., Guillot et al. 1996)
- ρ =0.4 g/cm^3 < Saturn's density
- g=970 cm/s^2
- Tp = 1400(1-A)1/4 K A:albedo Ts=6000K
- $v_{thermal}$ ~ 6 km/s < 42 km/s=v_{escape}

Detection of an extrasolar planet atmosphere



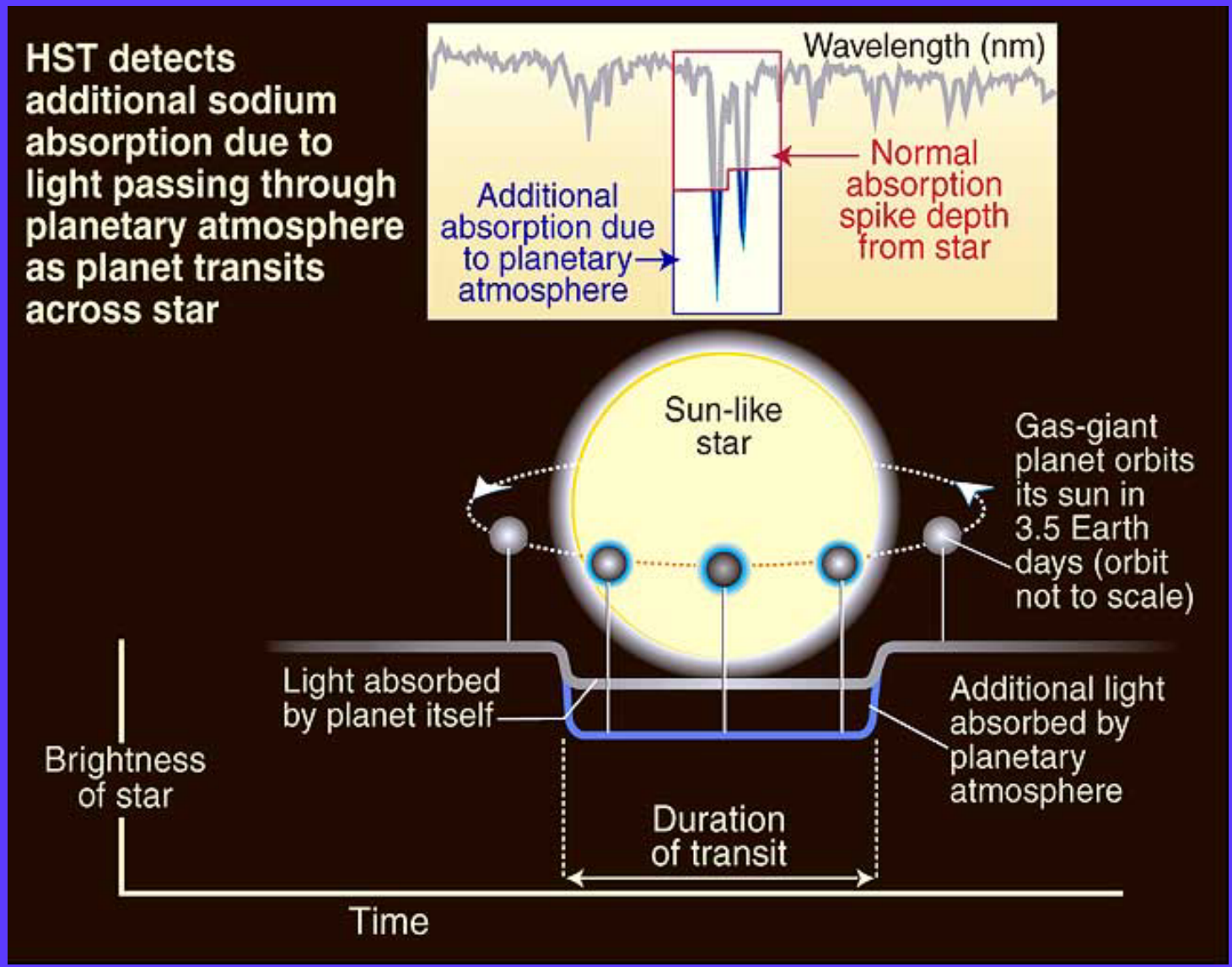


Absorption due to the planetary atmosphere

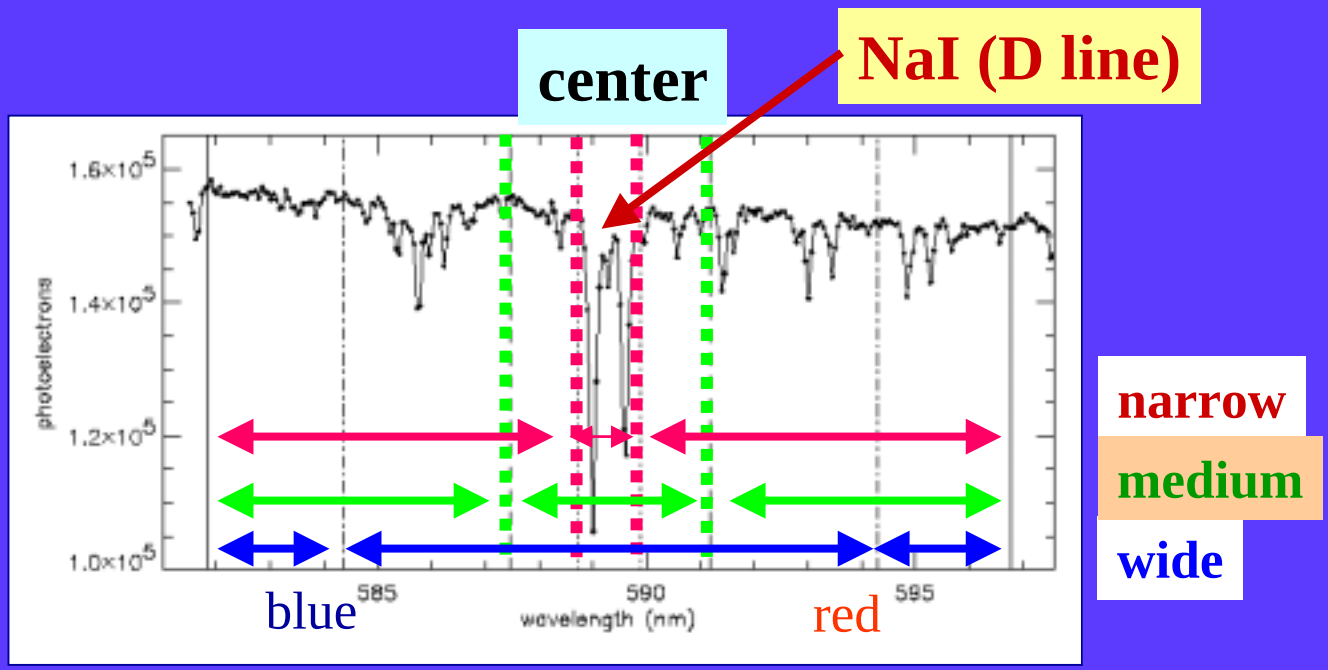
Charbonneau, D., Brown, T.M., Noyes, R.W., & Gilliland, R.L. 2002, ApJ, 568, 37

S: scattered light
D: direct light
T: thermal radiation

Schematic detection method of atmospheric absorption

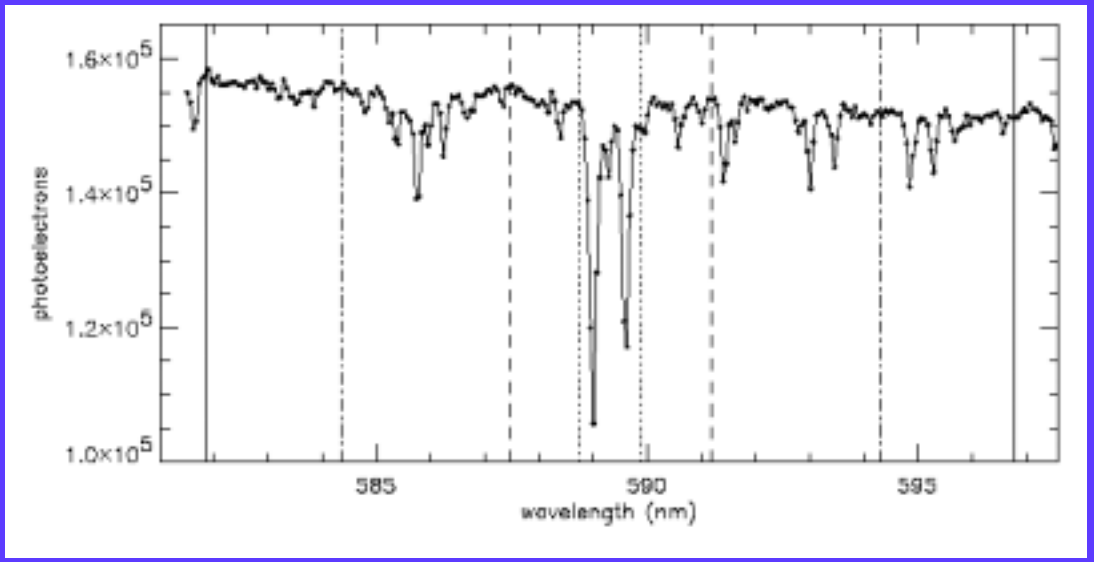


HST spectrum for HD209458



width	blue (nm)	center (nm)	red (nm)
narrow	n_b: 581.8–588.7	n_c: 588.7–589.9	n_r: 589.9–596.8
medium	m_b: 581.8–587.4	m_c: 587.4–591.2	m_r: 591.2–596.8
wide	w_b: 581.8–584.3	w_c: 584.3–594.3	w_r: 594.3–596.8

Detection of additional Na absorption



HST spectrum

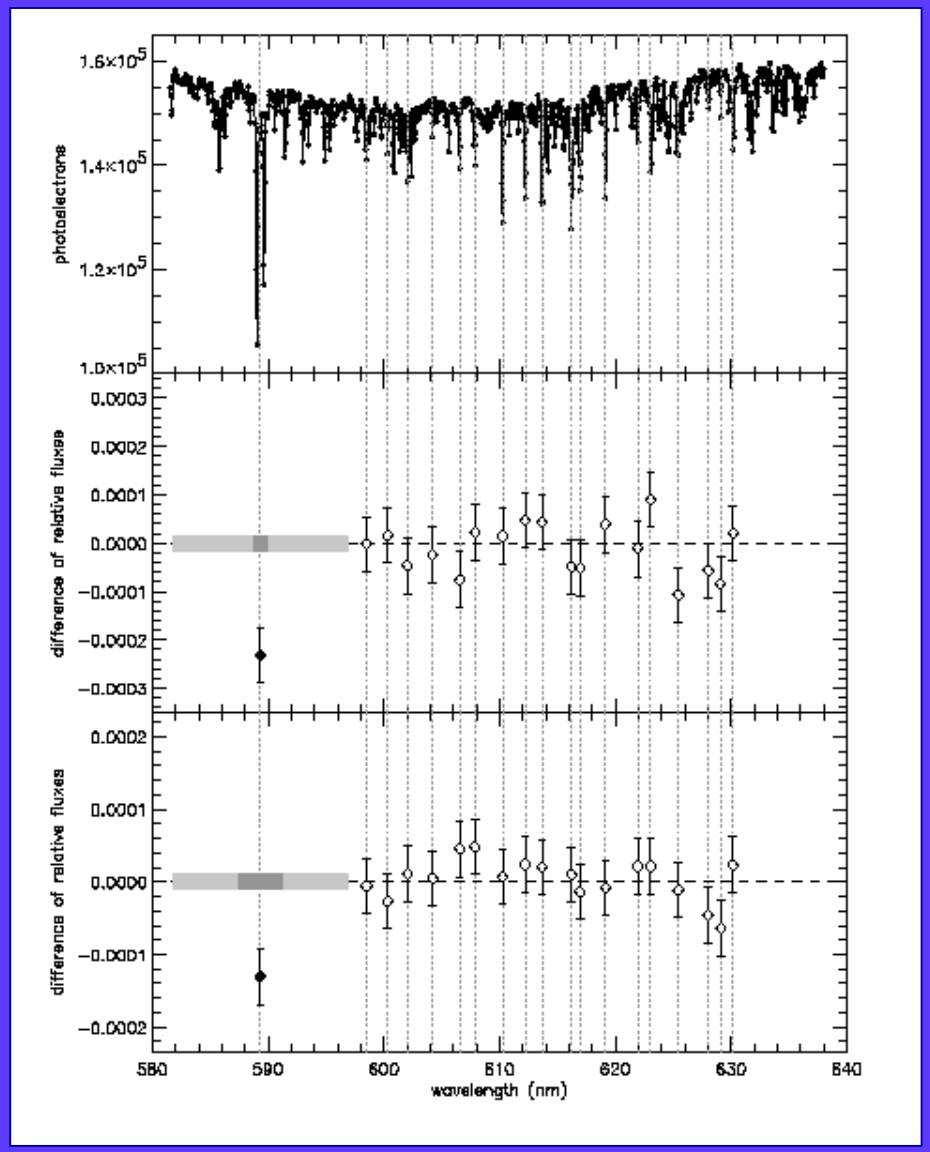
absorption index

$$
\begin{aligned}
n_{Na}(t) &= n_c(t) - [n_b(t) + n_r(t)] / 2 \\
m_{Na}(t) &= m_c(t) - [m_b(t) + m_r(t)] / 2 \\
w_{Na}(t) &= w_c(t) - [w_b(t) + w_r(t)] / 2.
\end{aligned}
$$

$$
\begin{aligned}
\Delta n_{Na} &= \overline{n_{Na}(t_{in})} - \overline{n_{Na}(t_{out})} = (-23.2 \pm 5.7) \times 10^{-5} \\
\Delta m_{Na} &= \overline{m_{Na}(t_{in})} - \overline{m_{Na}(t_{out})} = (-13.1 \pm 3.8) \times 10^{-5} \\
\Delta w_{Na} &= \overline{w_{Na}(t_{in})} - \overline{w_{Na}(t_{out})} = (-\ 3.1 \pm 3.6) \times 10^{-5}.
\end{aligned}
$$

Large difference between in- and out-of-transits for the region around the Na line !

Detected only for the Na line wavelengths



difference of relative fluxes

(Logically natural) steps toward direct detection of extrasolar planets

- Radial velocity modulation of the star
- Shadowing of the stellar light due to transit
- Additional absorption features due to the planetary atmosphere during the transit
- **Total flux variation of the star+planet system due to the orbital phase-dependent scattered light component (current attempt)**
- **Direct imaging of planet, i.e., separation of the planetary component from the stellar light (final goal)**

Subaru observation

“Spectro-photometric search for scattered light from HD209458b”

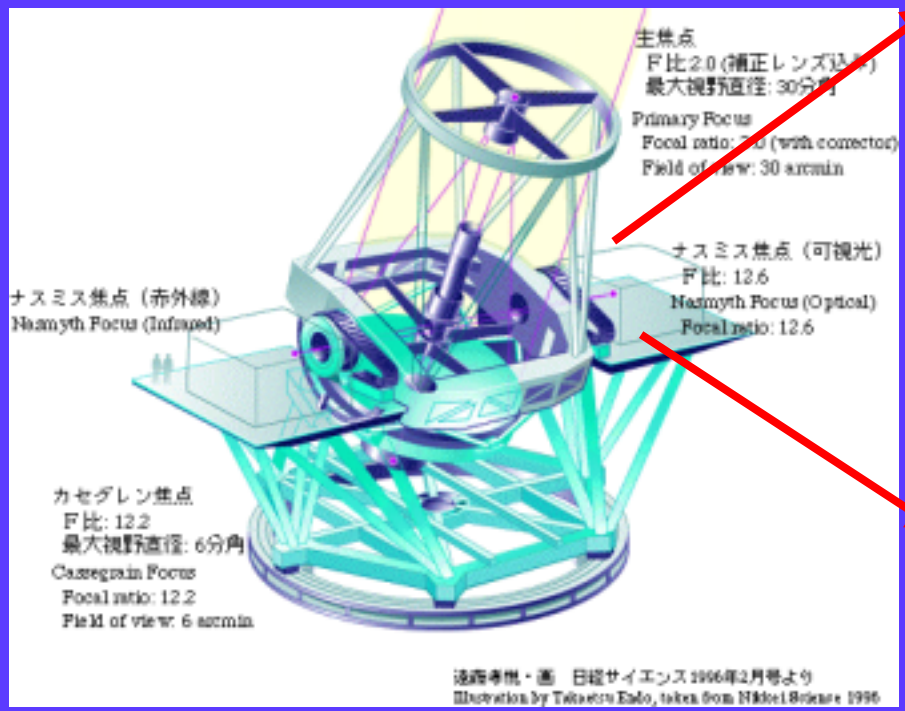
S02B-16 on October 24 and 26, 2002

Yasushi Suto (Univ. of Tokyo)

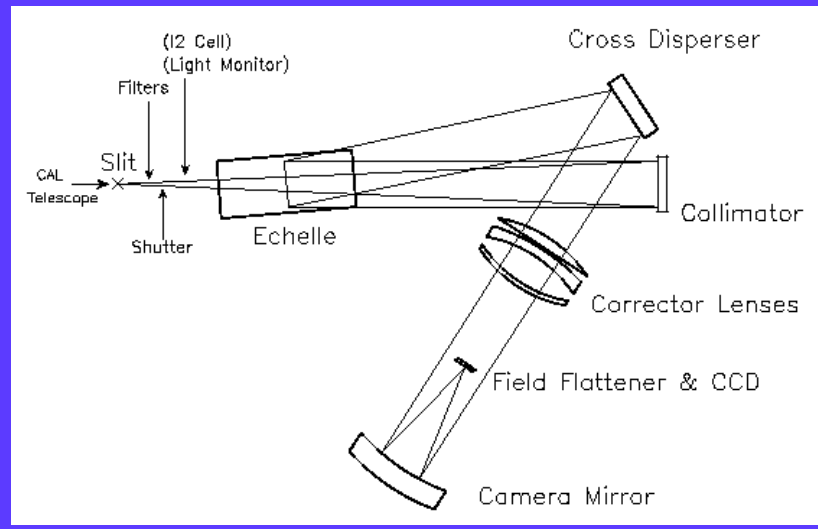
Toru Yamada (National Astronomical Obs. Japan)

Edwin L. Turner (Princeton Univ.)

HDS at Subaru

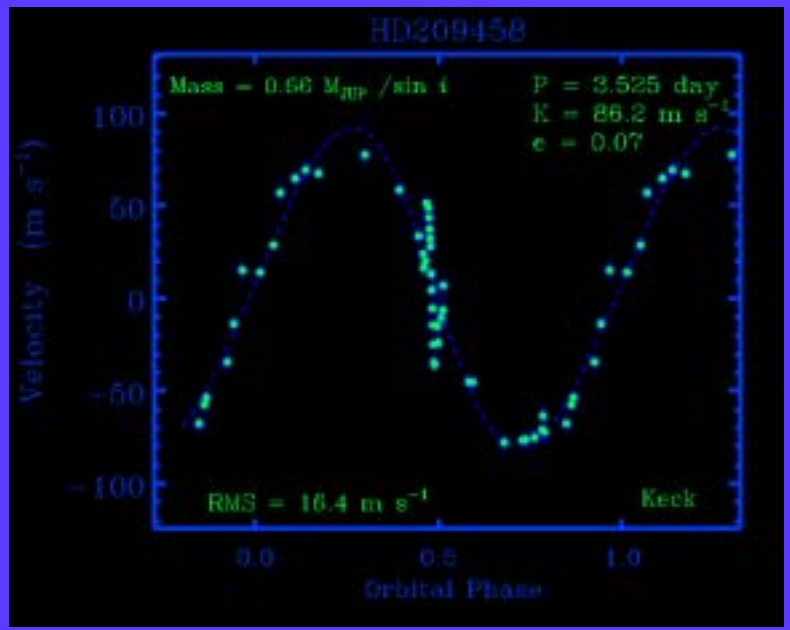


CCD: 4.1k x 2k x 2
13.5μm/pixel, 0.12”/pixel
Gain: 1.7e$^-$/ADU
Readout time: 70sec
Saturation level: 50000e$^-$



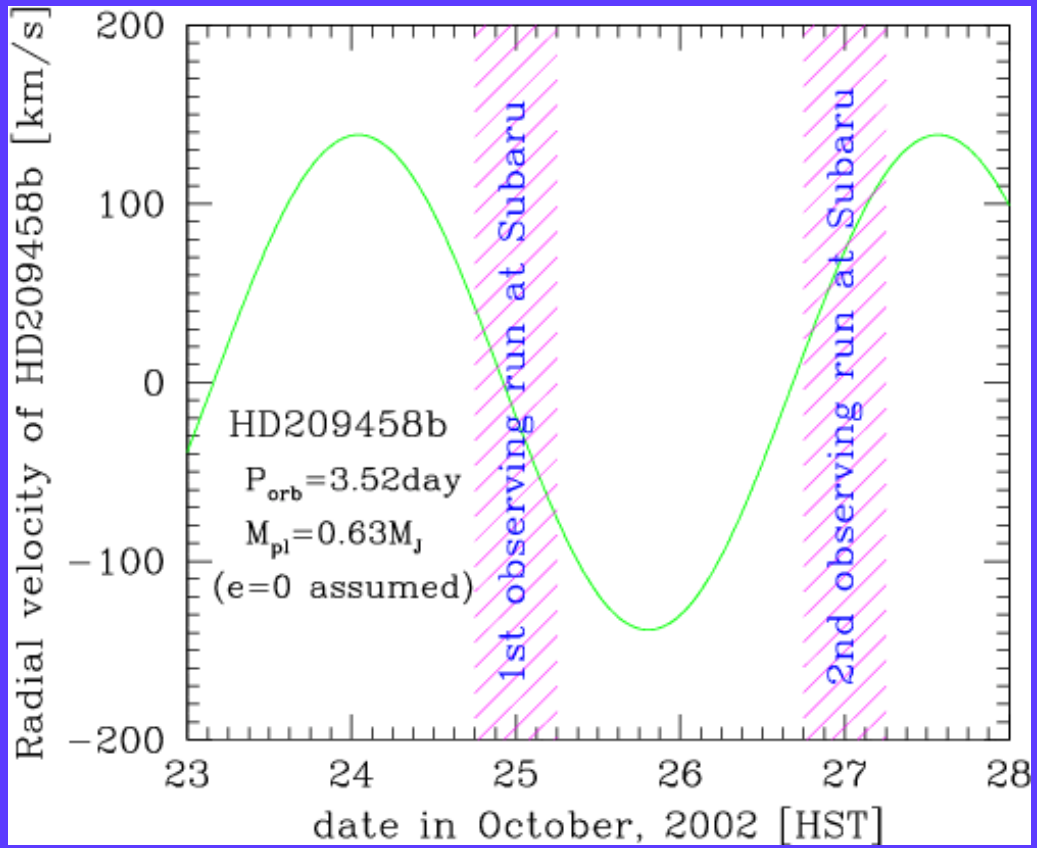
Radial velocity curve

HD209458 (parent star)



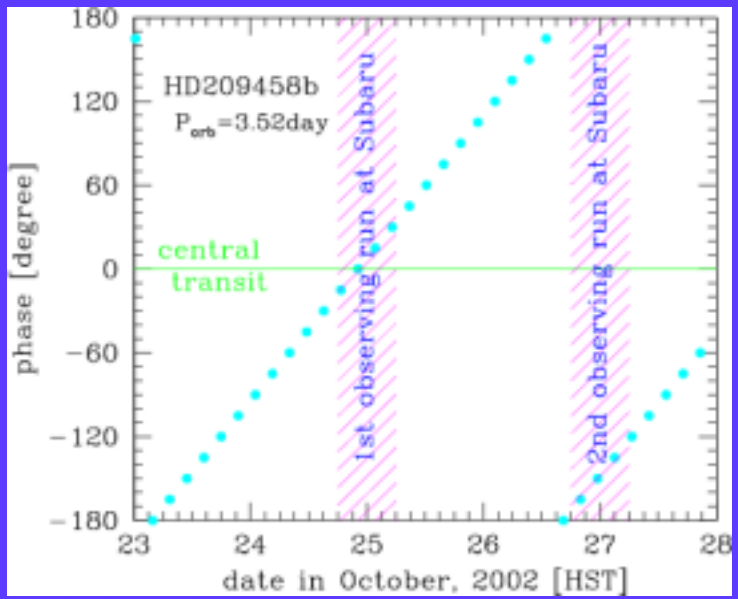
$$K_{pl}(\Phi) = \left(\frac{2\pi G M_*}{T_{orbit}}\right)^{1/3} \frac{\sin i}{(1+M_{pl}/M_*)^{2/3}} \cos\Phi$$

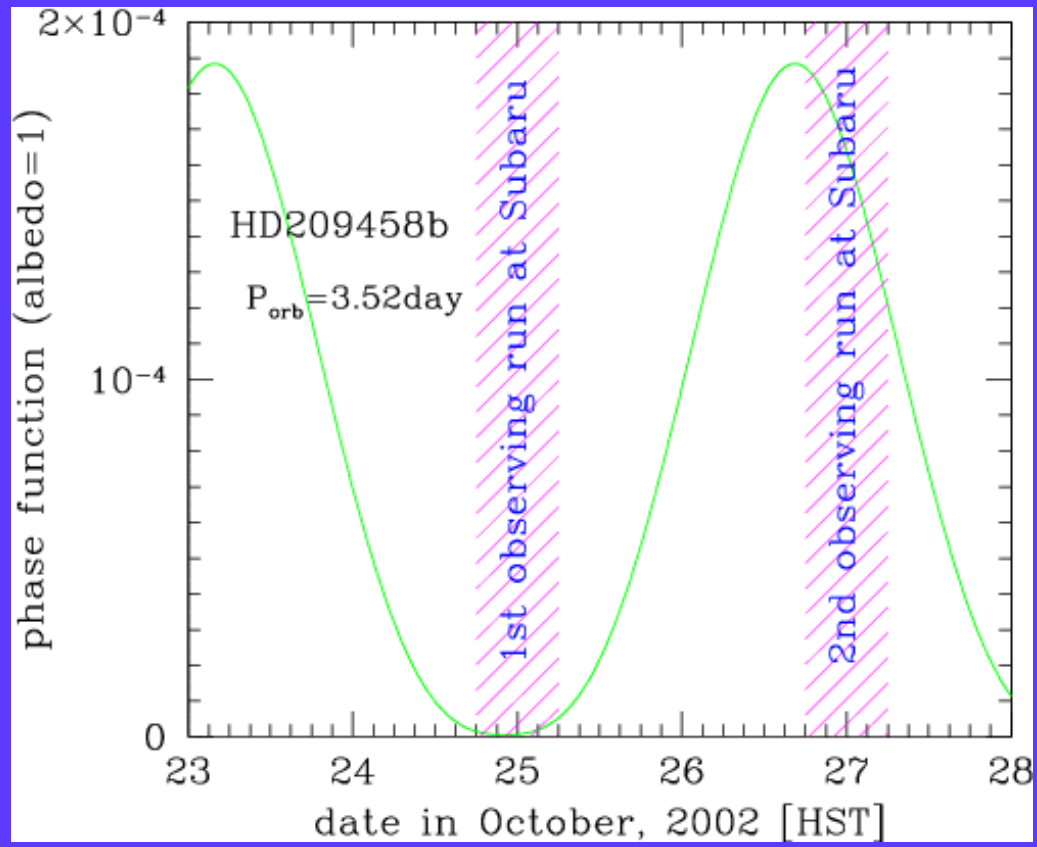
$$\approx 144 \cos\Phi \text{ km/s}$$



HD209458b
(a transiting planet)

Phase function





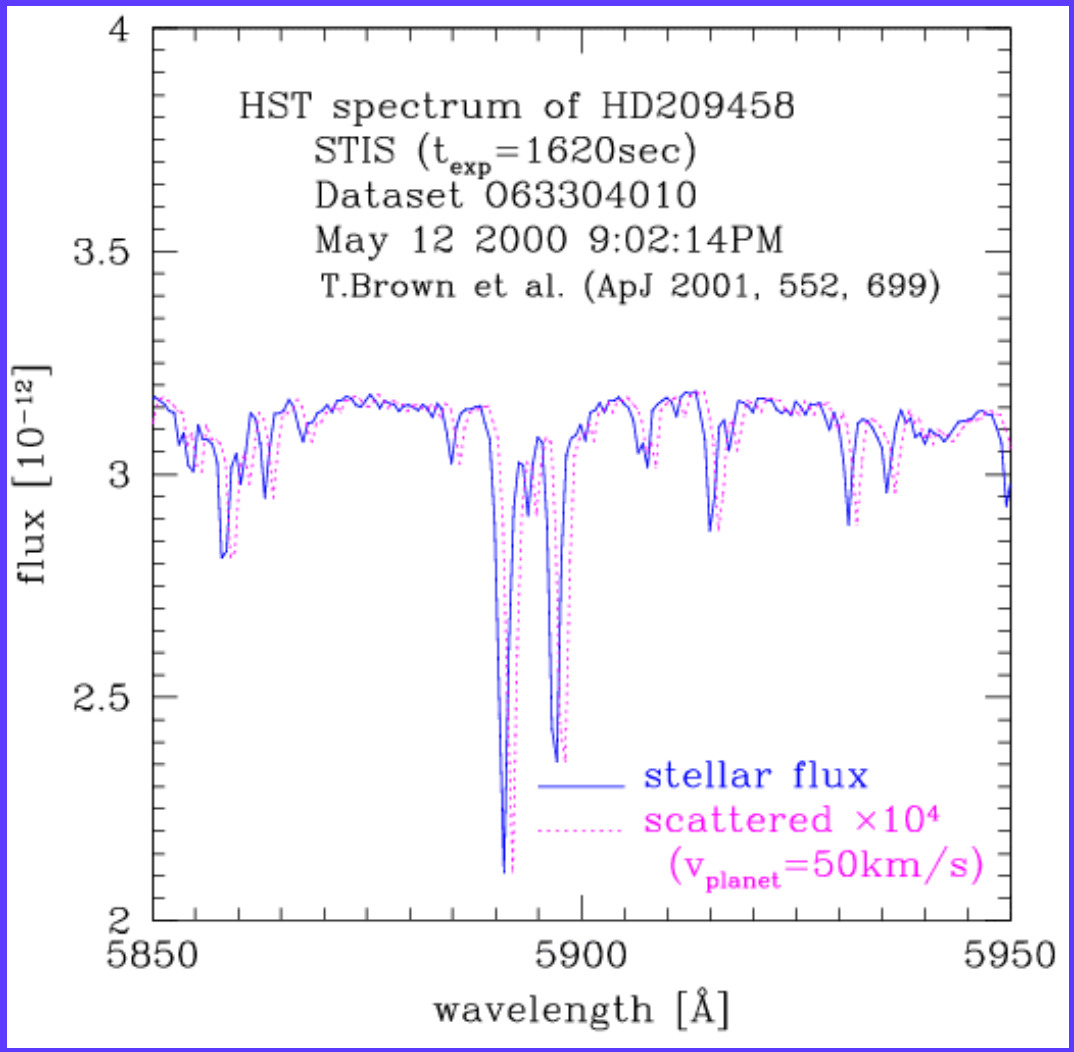
The Lambert law :

$$f(\Phi, i) = \varepsilon\phi(\alpha) = p\left(\frac{R_p}{a}\right)^2\left[\frac{\sin\alpha + (\pi-\alpha)\cos\alpha}{\pi}\right]$$

$$\cos\alpha = -\sin i \sin 2\pi\Phi$$

$\Phi = 0$: maximum radial velocity of the star

Strategy for scattered light search with HDS



- Statistical search for the scattered components Doppler-shifted at $V_p(t)$ from the stellar absorption lines.

Prospects

- Chance favors the prepared mind.

But there are other prepared minds…
at http://www.astro.caltech.edu/~dc/frames.html

David Charbonneau In Transit
(i.e. upcoming travel, talks and observing runs)

Oct 16 - Oct 18	Palomar	observing @ Palomar 60"
Oct 23 - Oct 25	***Hawaii***	***observing @ Keck II***
Dec 2	U. of North Carolina	colloquium