Extrasolar planets

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Extrasolar planets

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F. Pont (Exeter)
C. D. Parkinson (JPL)
S. K. Sirothia (NCRA-TIFR)

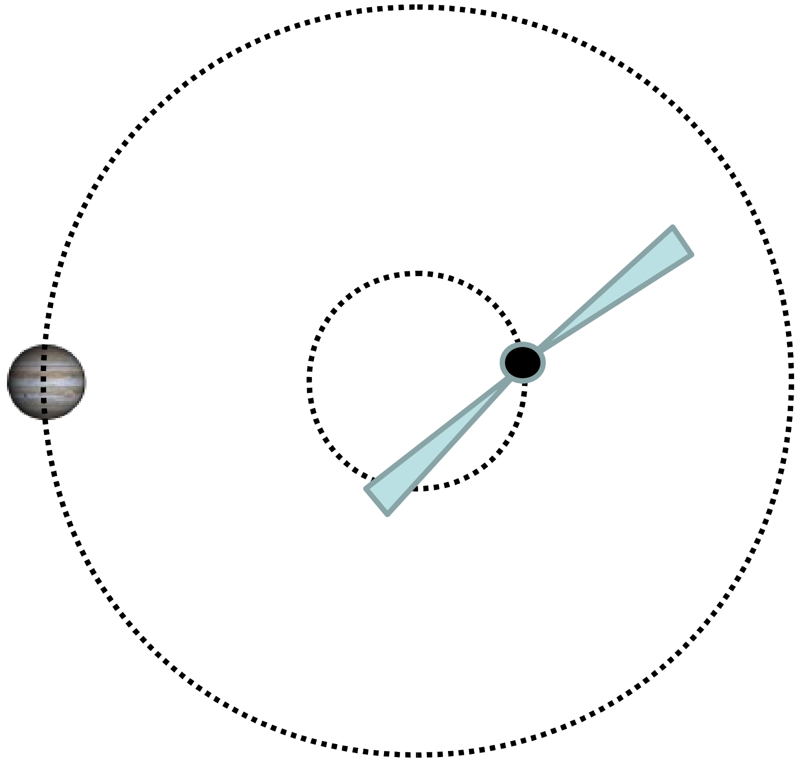
Outline

- Detection of extrasolar planets
- Observation of atmosphere using transits
- Evaporation of hot-Jupiters
- Atmosphere of HD189733b
- A sunset seen from an extrasolar planet

Detection techniques

Timing technique

- Measure accurate pulses/oscillations from the star
- Light travel time of pulse changes with orbit of planet



Wolszczan & Frail 1992

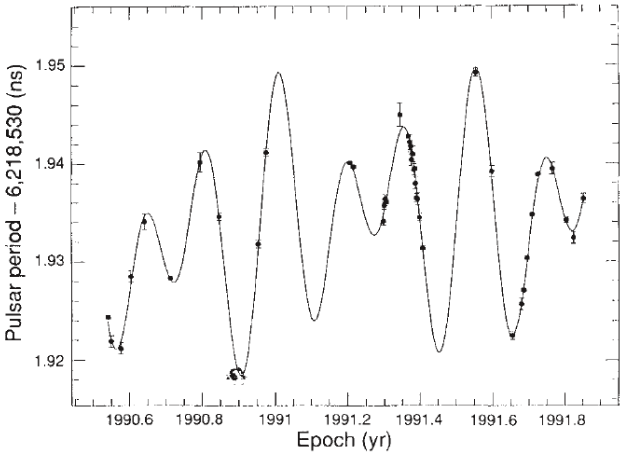
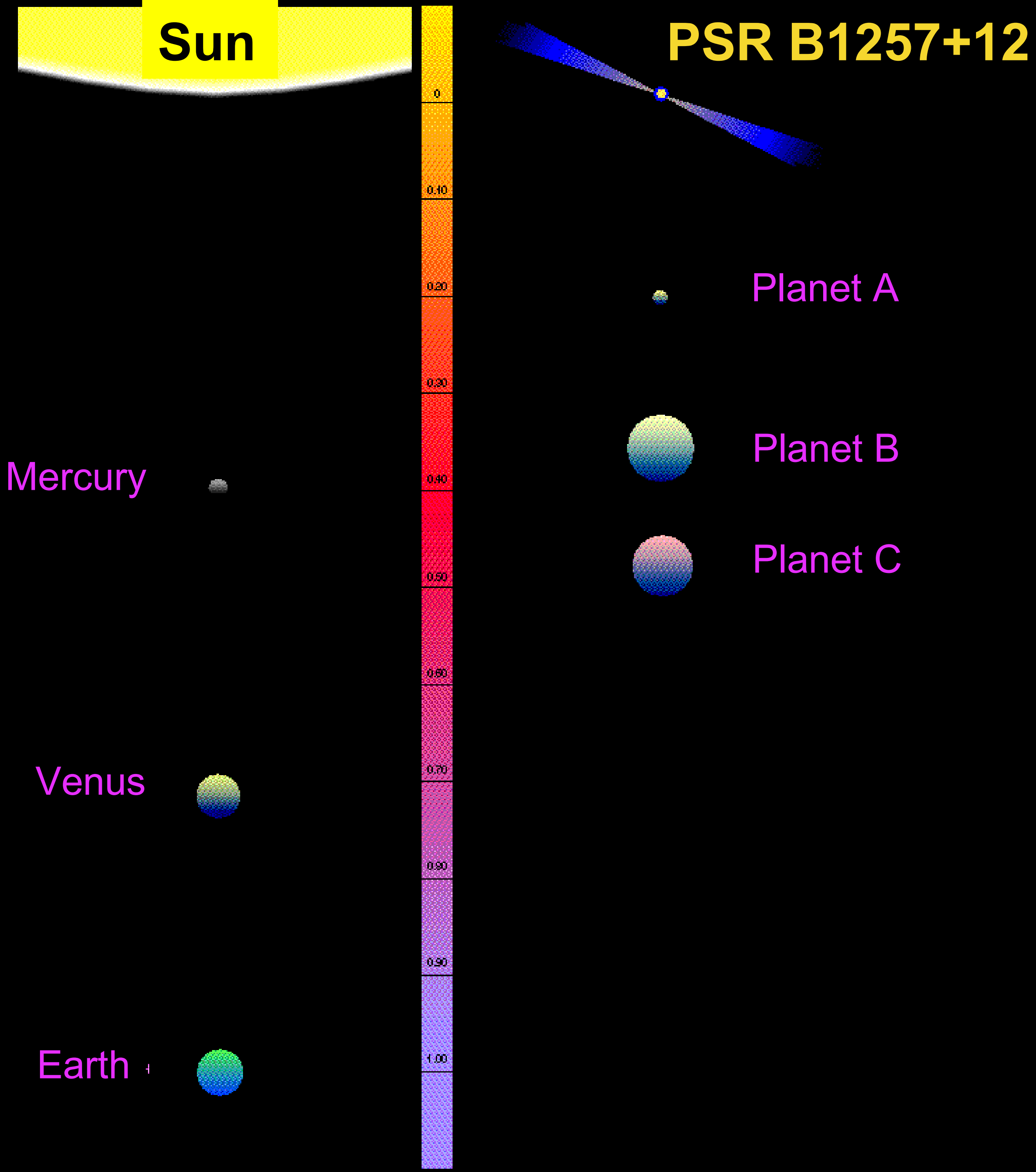


FIG. 3 Period variations of PSR1257+12. Each period measurement is based on observations made on at least two consecutive days. The solid line denotes changes in period predicted by a two-planet model of the 1257+12 system.



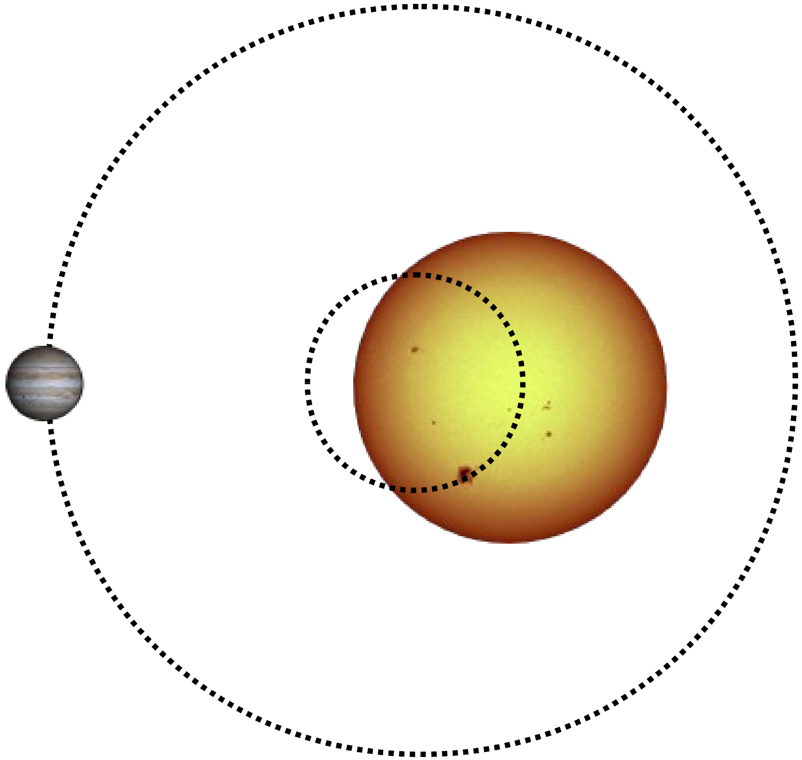
Sun
PSR B1257+12
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Planet A
Planet B
Planet C
Mercury
Venus
Earth

Detection techniques

Radial velocity

Measurement using Doppler shift on stellar spectrum : Reflex motion of the star because of the planet gravity

➔ Period and Mass of the planet (M sin i)



Detection techniques

Radial velocity

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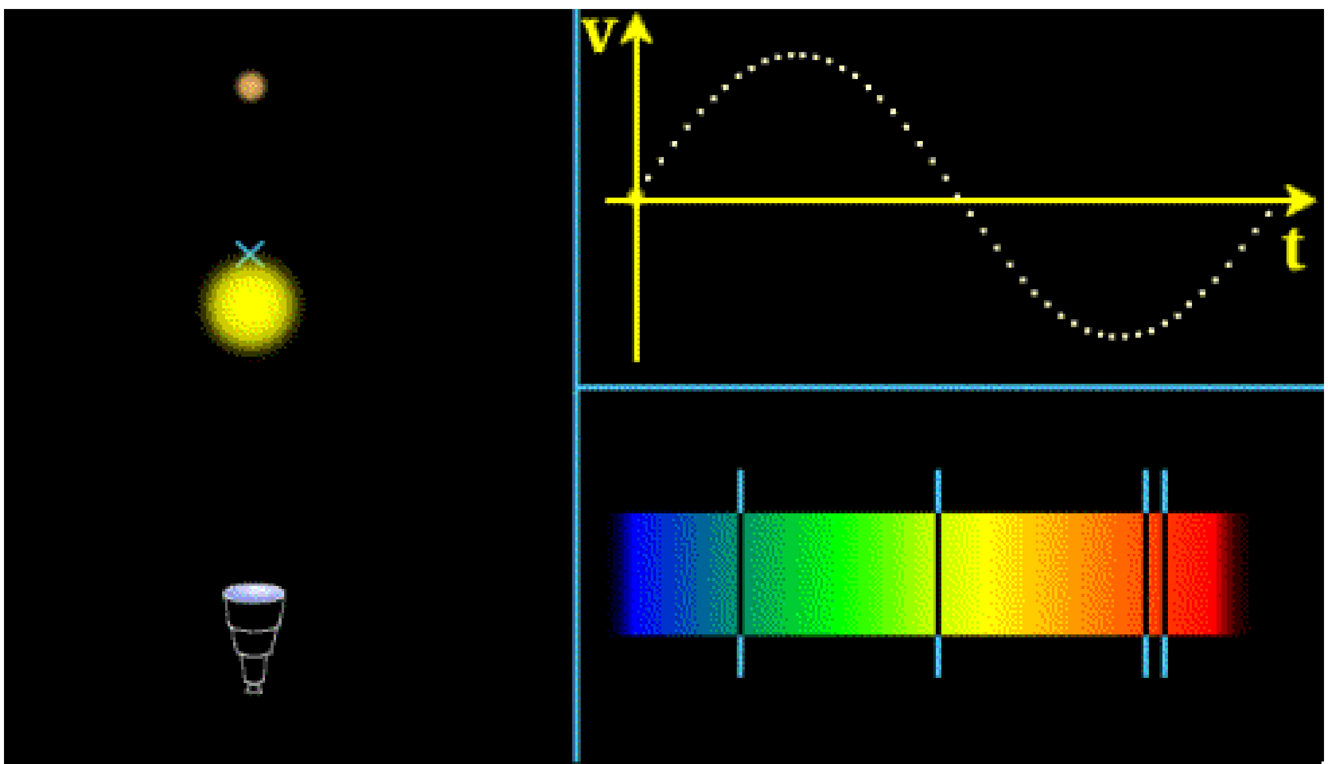
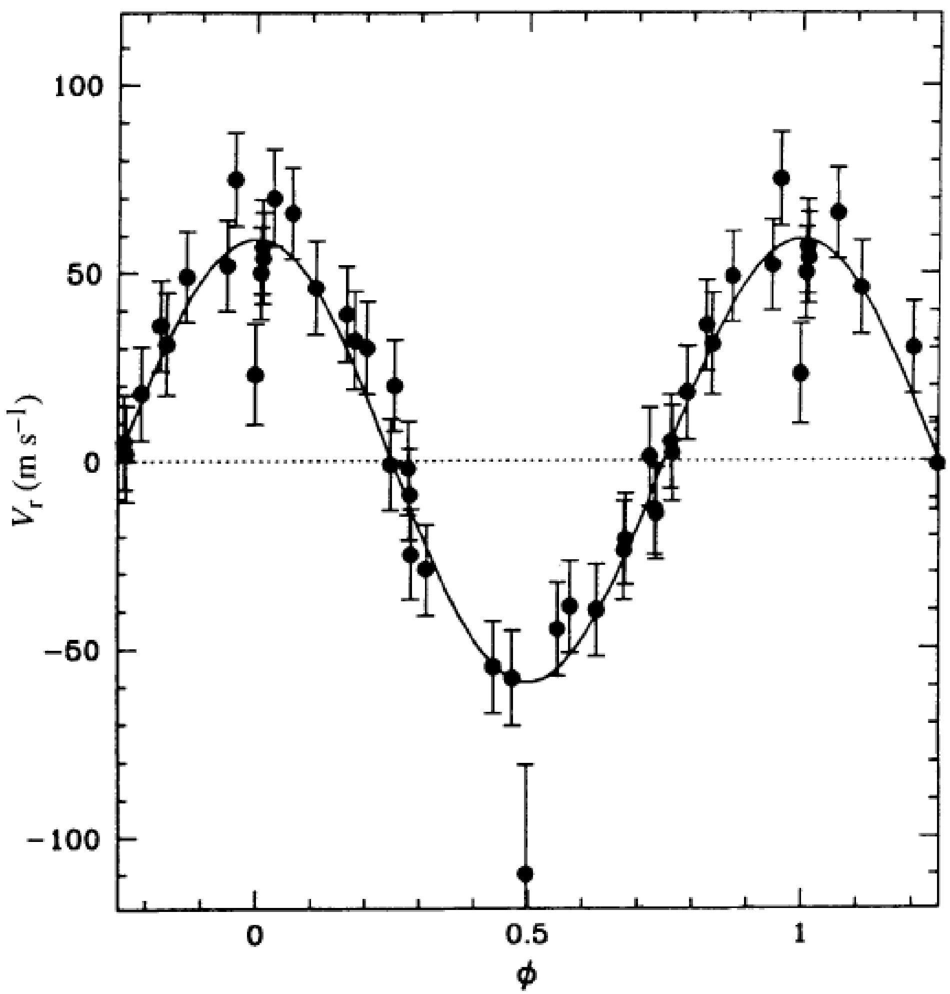


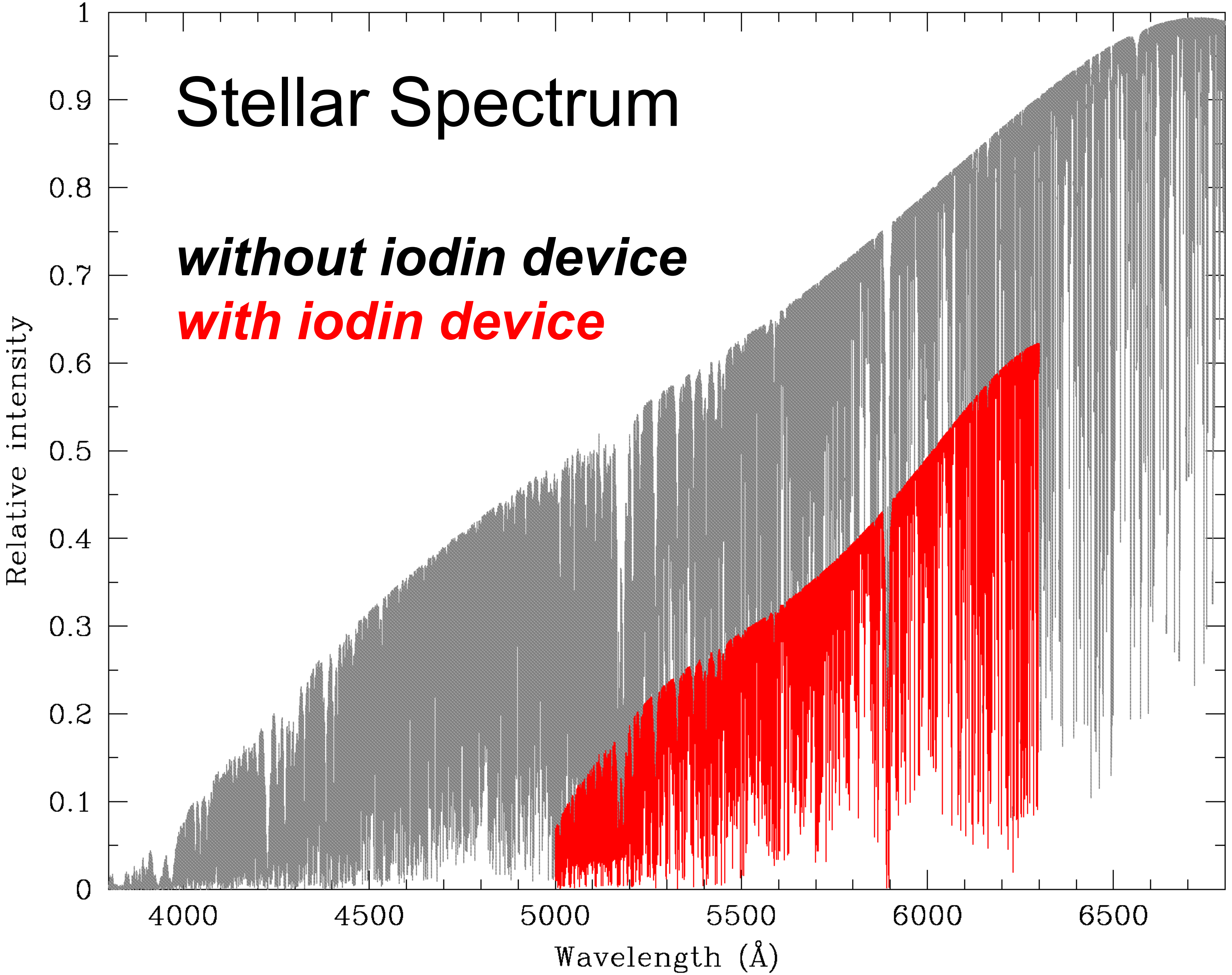
$$\frac{\delta\lambda}{\lambda} = \frac{\delta v}{c}$$

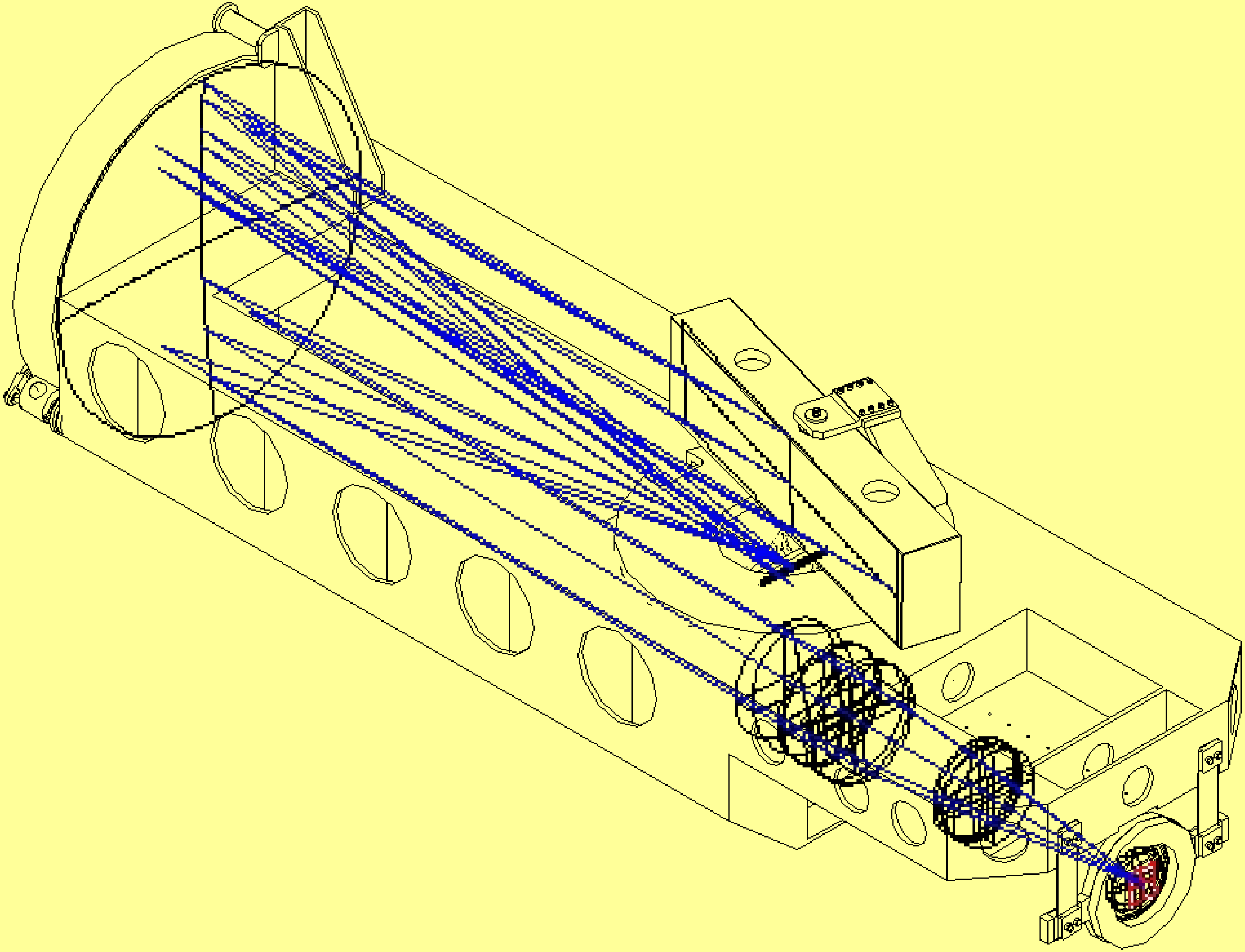
Discovery of 51 Peg b

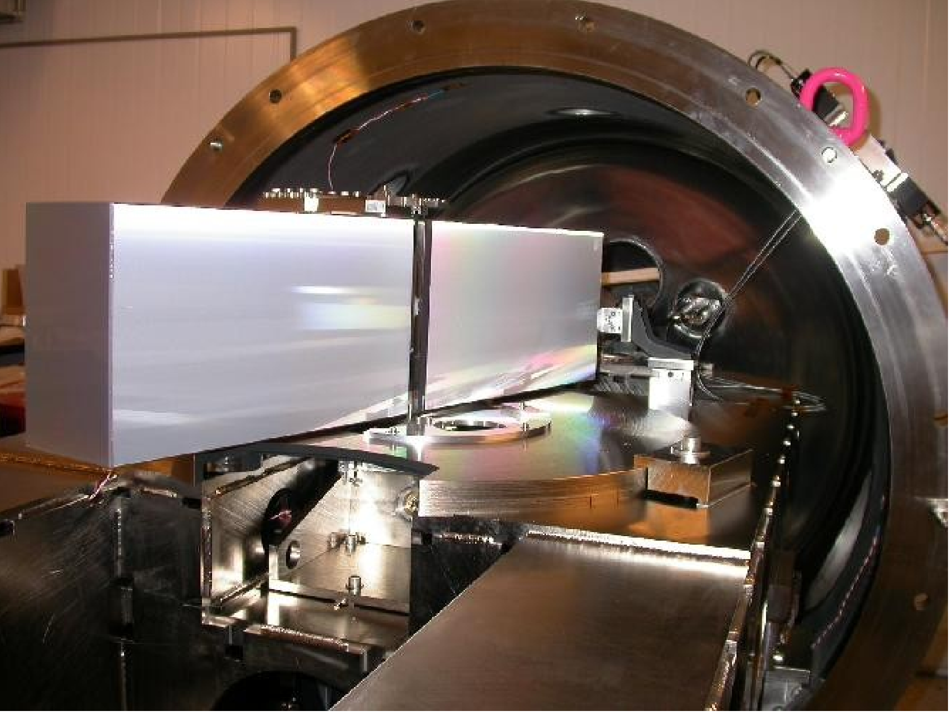
(Mayor & Queloz 1995)

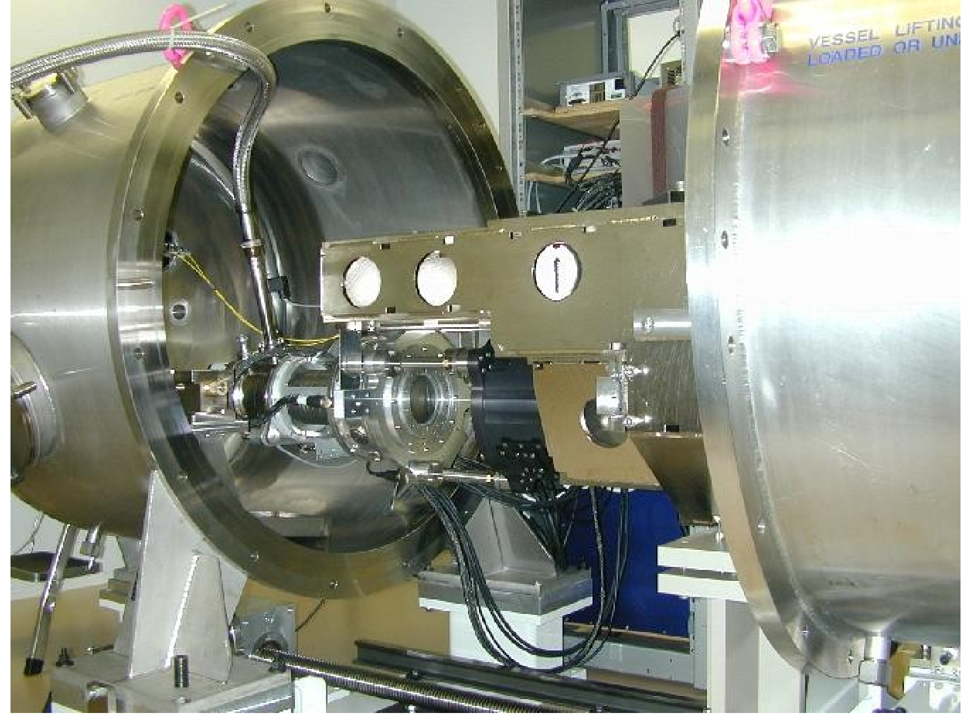
$M_p = 0.47\ M_{Jup}$, $a_p = 0.05$ AU, P = 4.2 days !

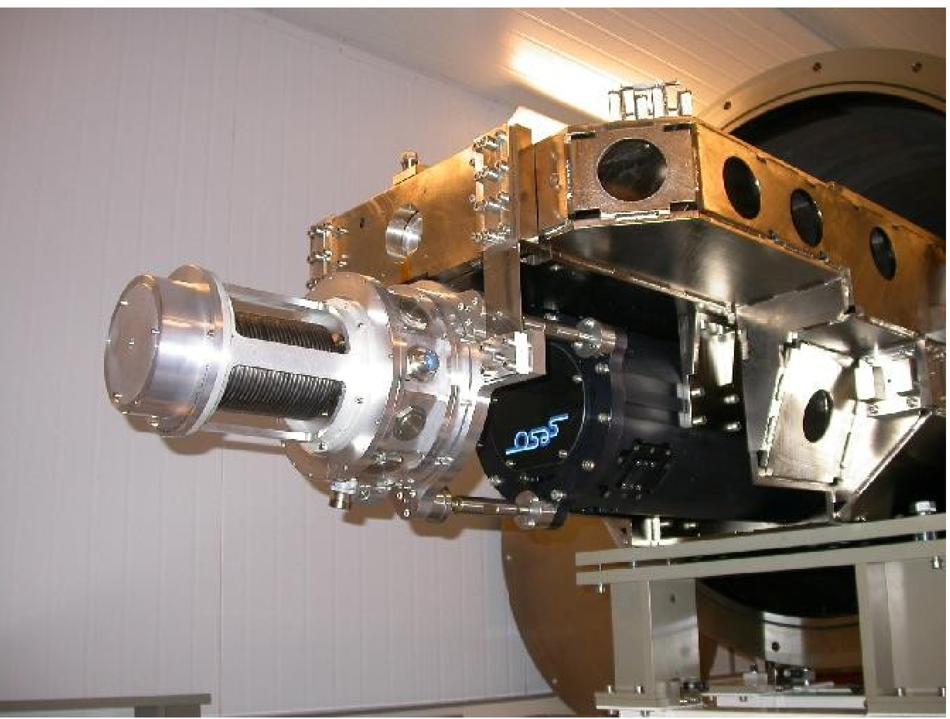



Stellar Spectrum
without iodin device
with iodin device
Relative intensity
Wavelength (Å)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
4000
4500
5000
5500
6000
6500





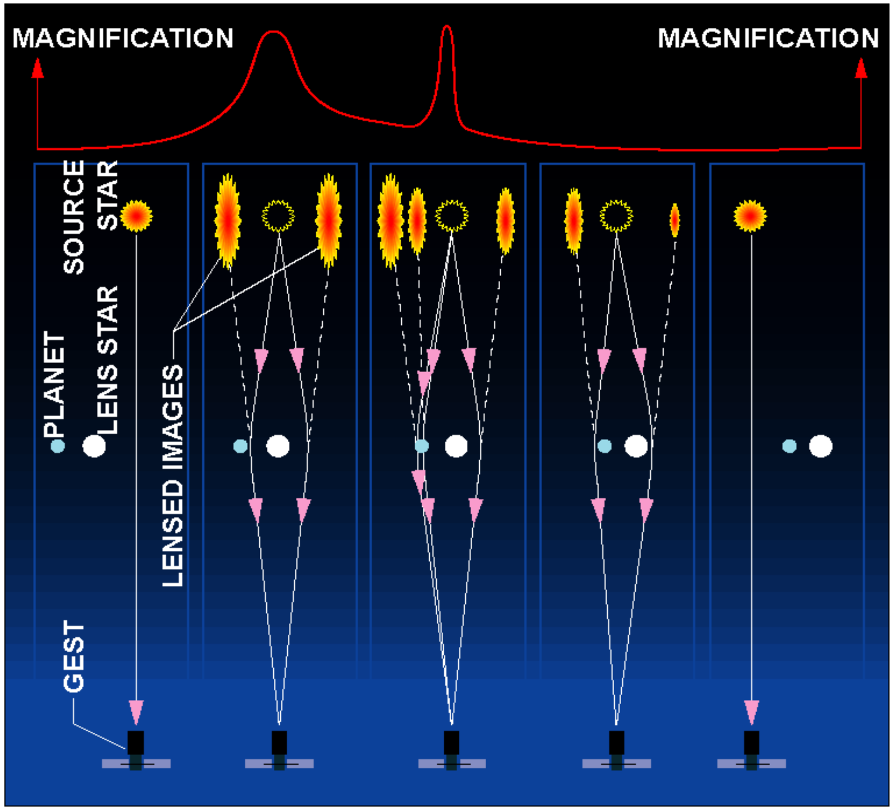

VESSEL
LOADED OR



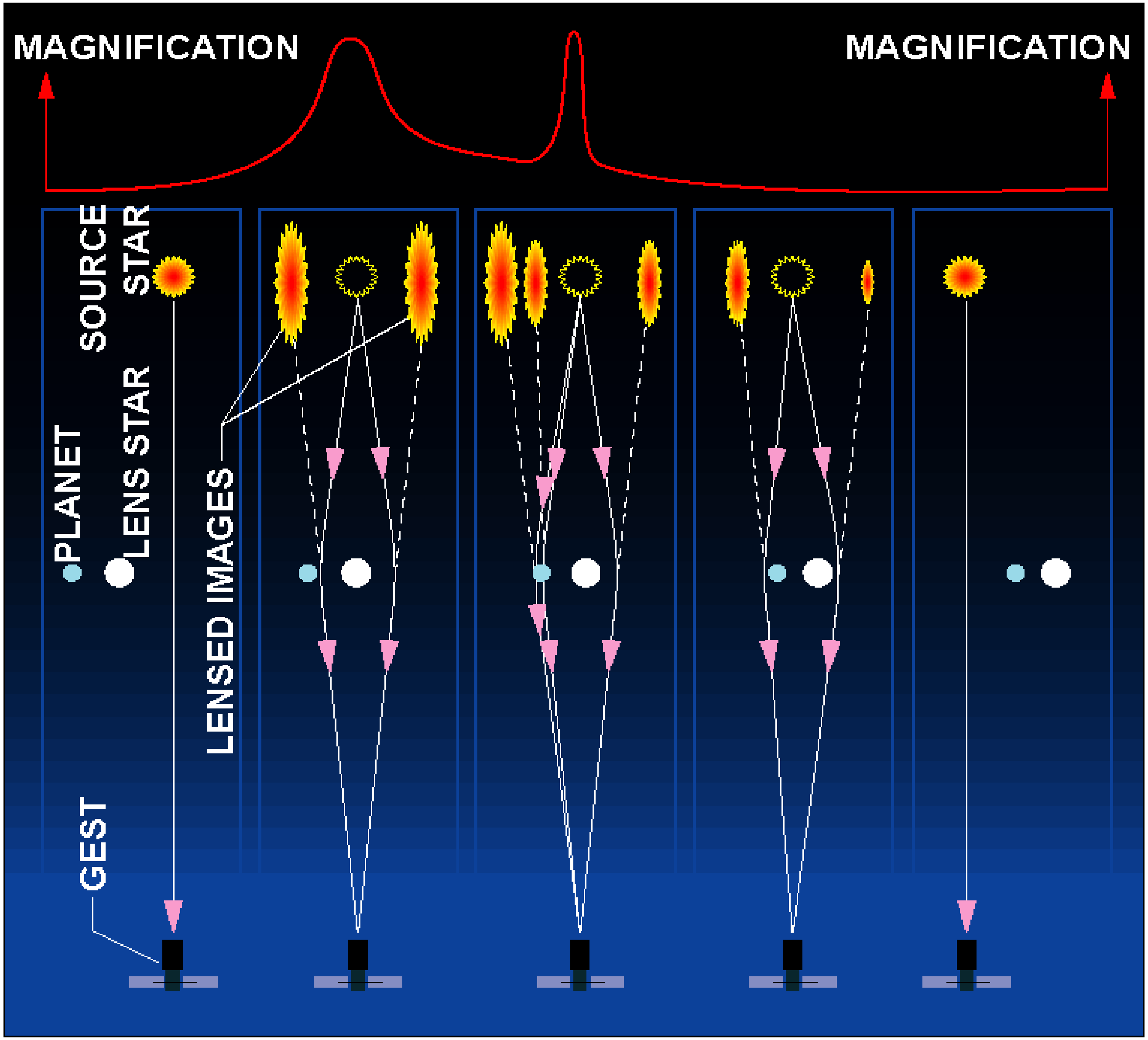
Detection techniques

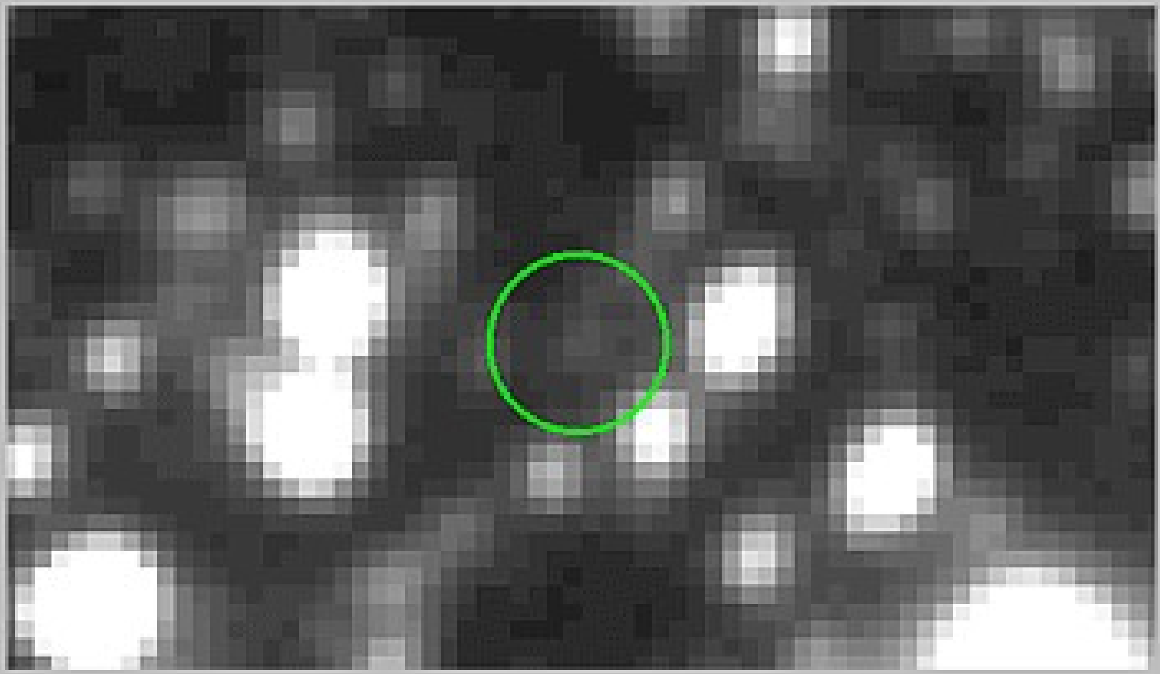
Gravitational lensing : using the bending of the light of a field star caused by the planet gravity

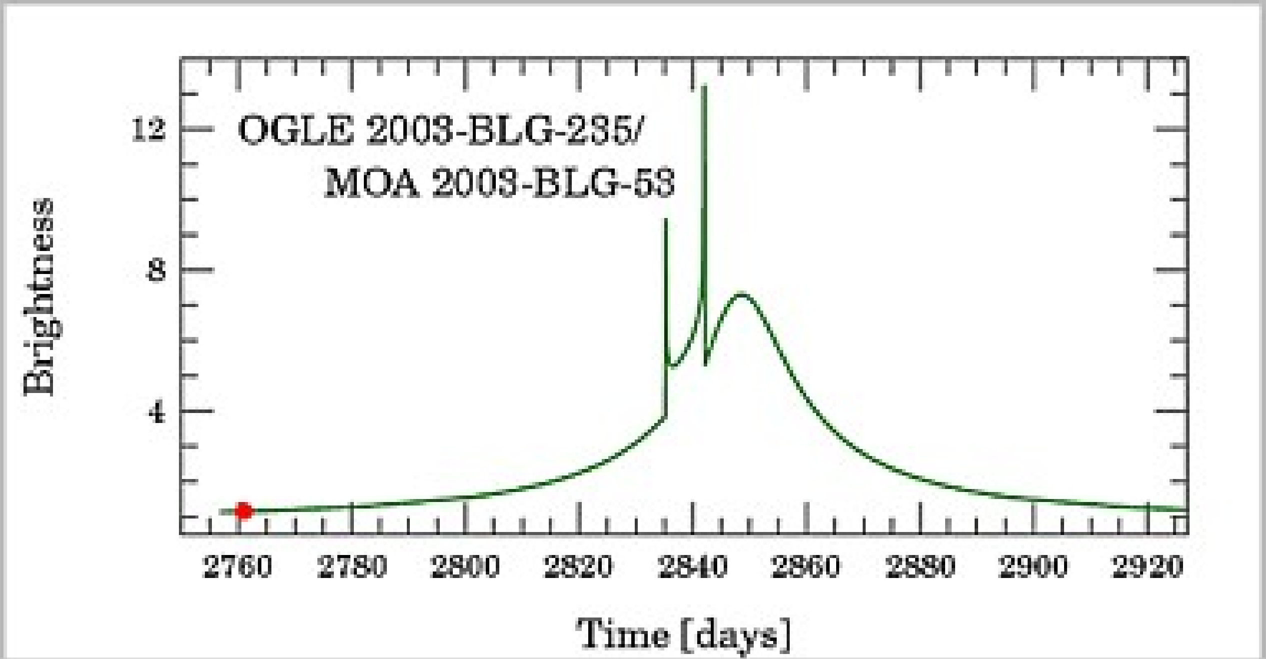
➔ Mass of the planet



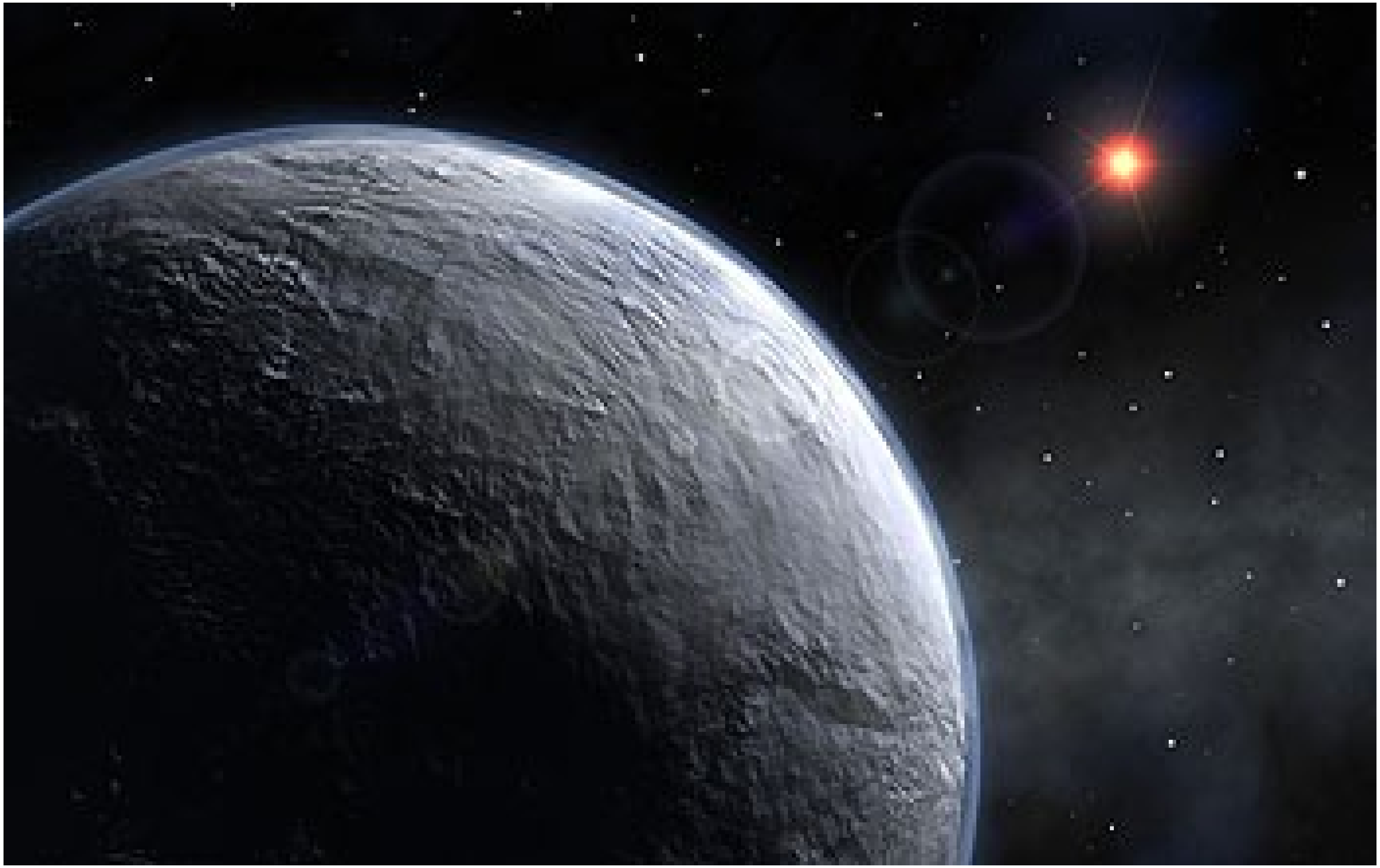
Gravitational micro-lensing

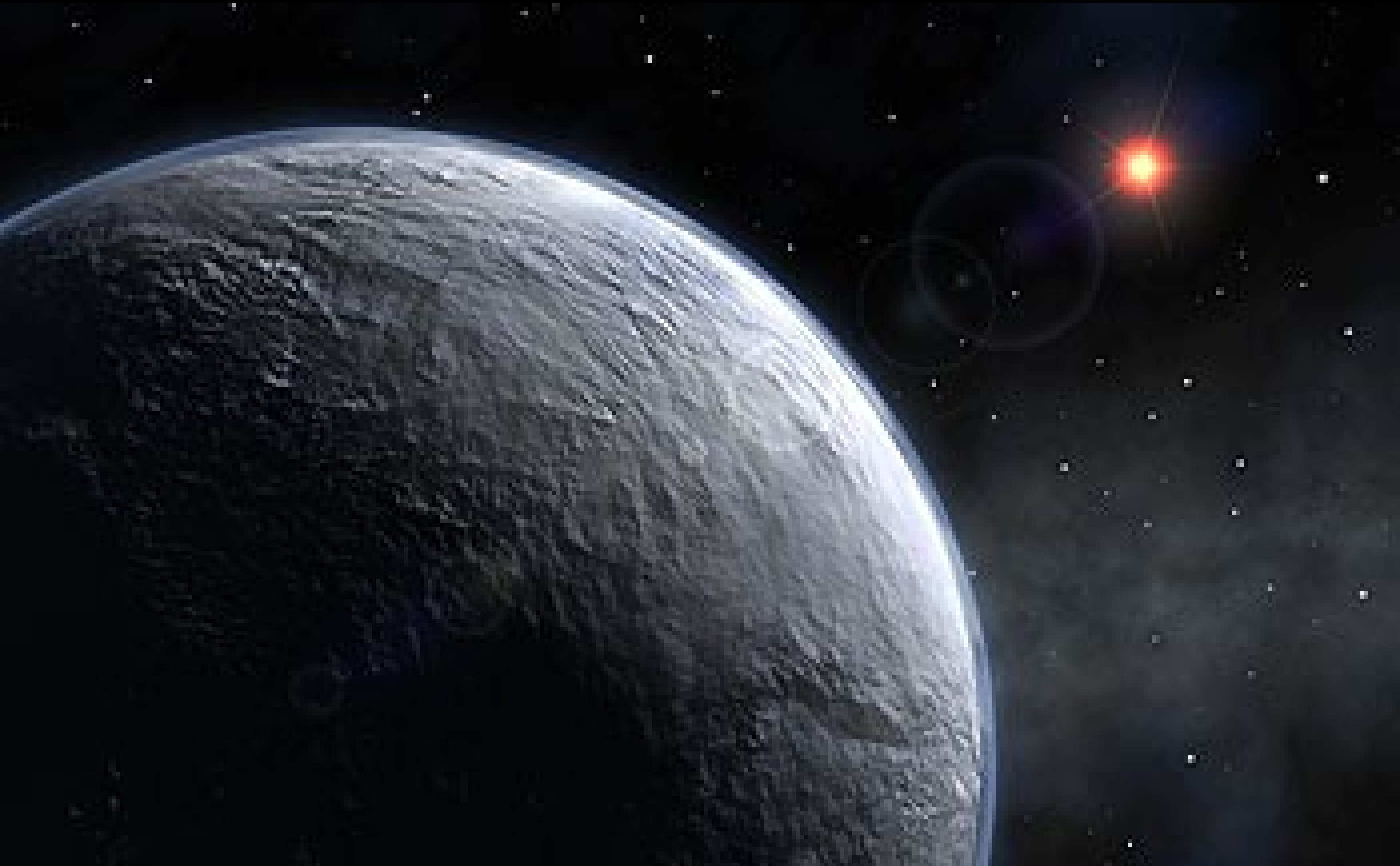


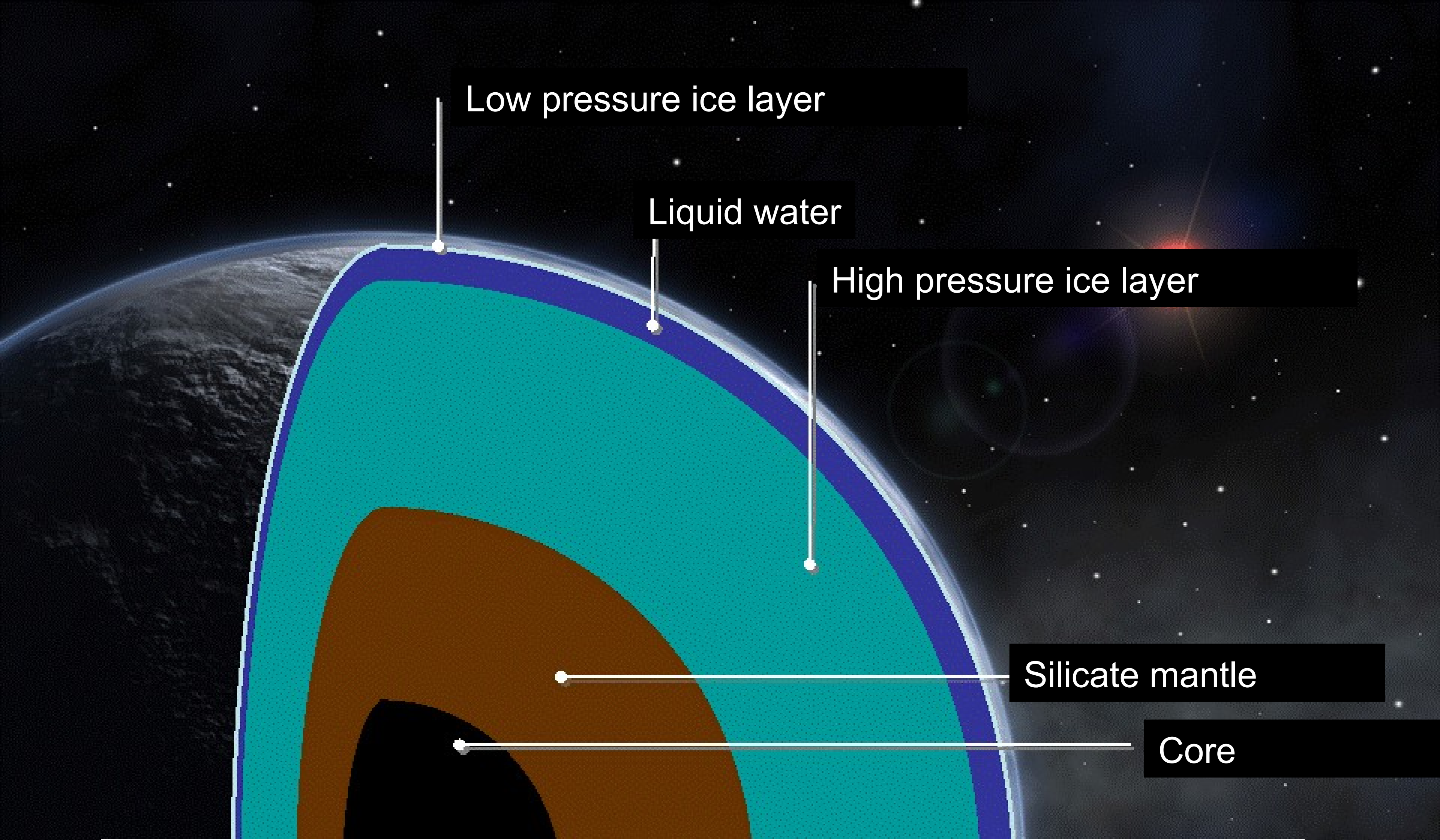



OGLE 2003-BLG-235/
MOA 2003-BLG-53
Brightness
Time [days]
4
8
12
2760
2780
2800
2820
2840
2860
2880
2900
2920

OGLE-2005-BLG-390Lb
M_p ~ 6 Earth mass, a_p ~2.5 AU







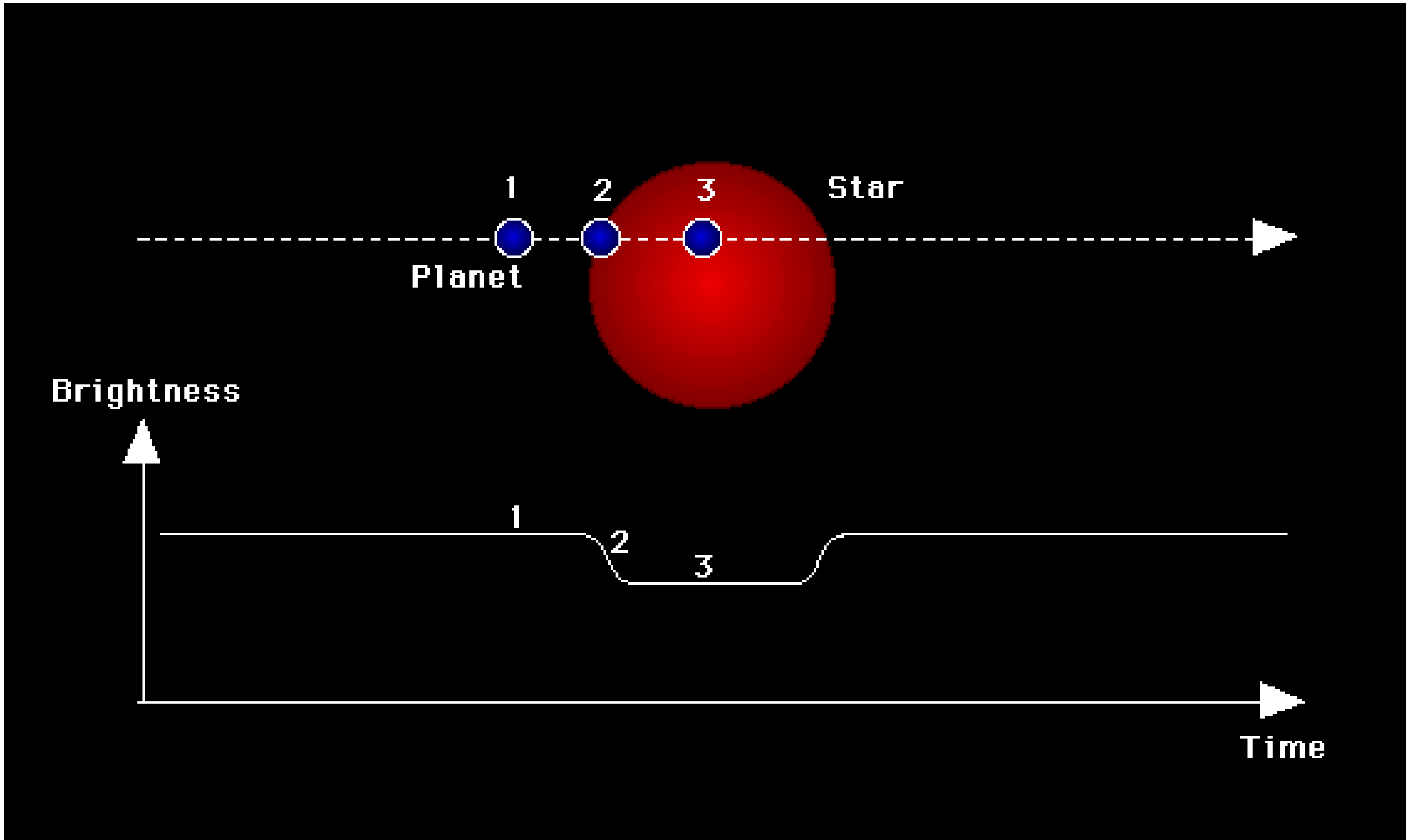
Liquid water below an ice shell during billions of years

Detection techniques

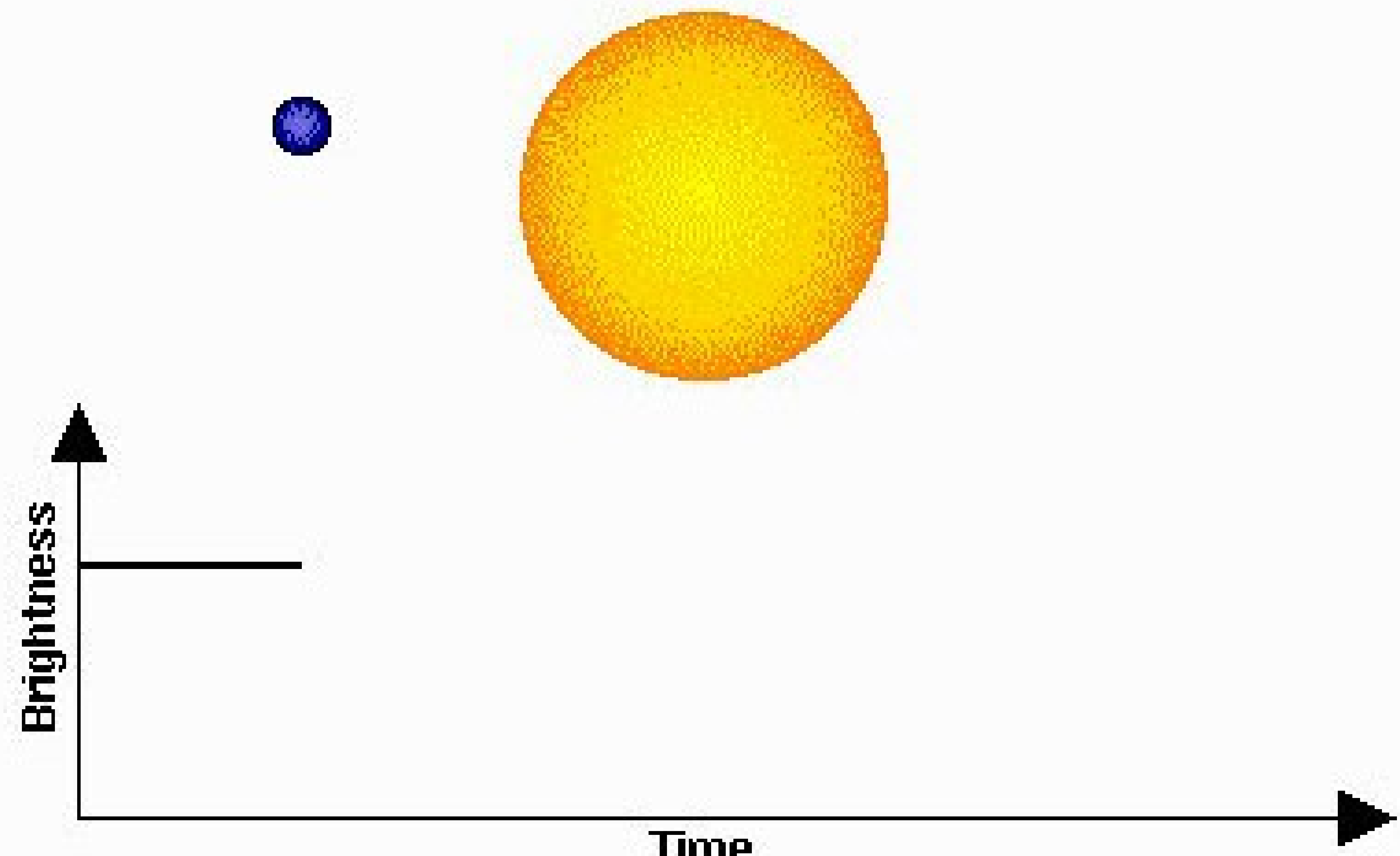
Transit photometry : Survey of large number of field stars

→ use the shadow of the planet on the parent star light

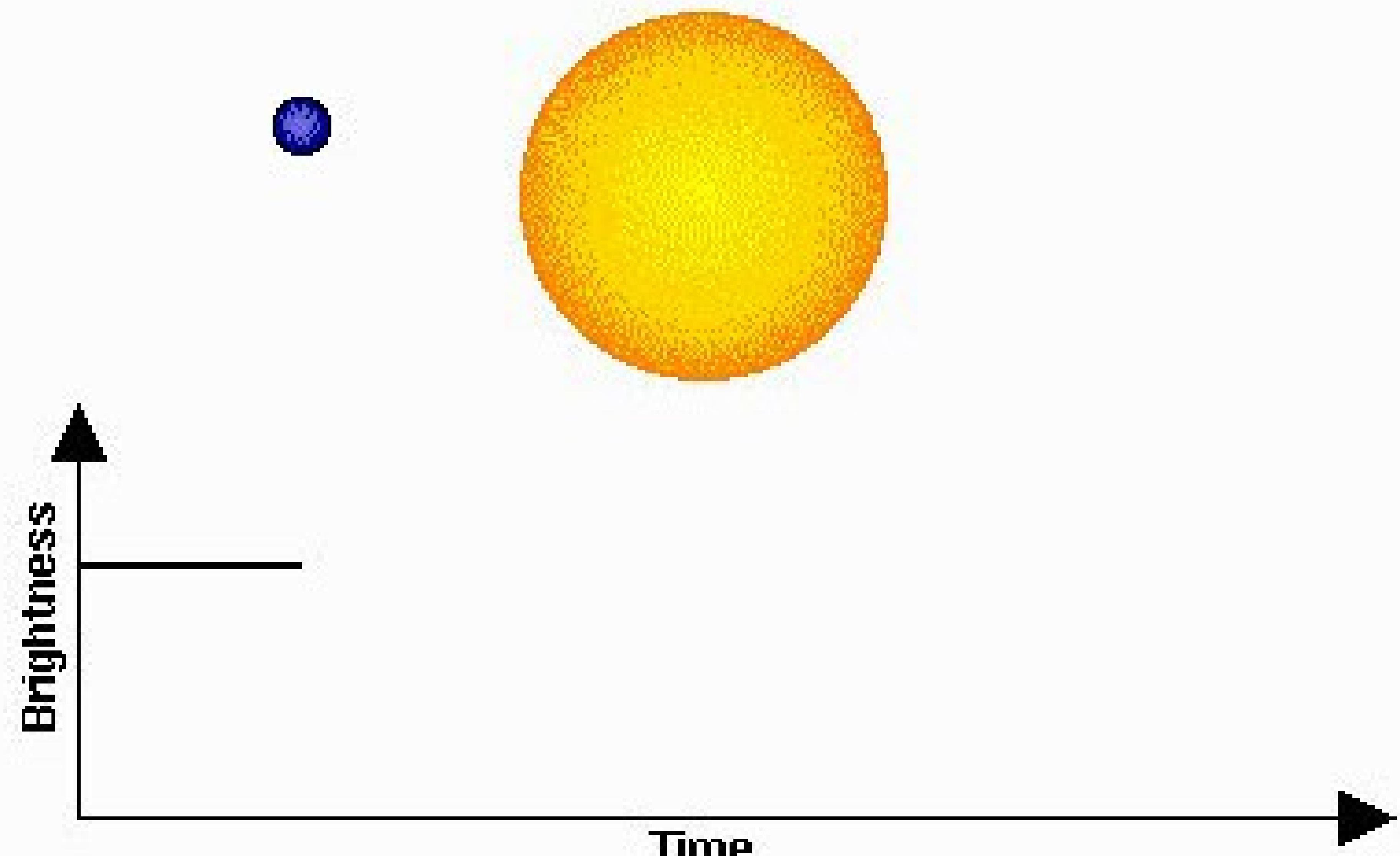
➔ Radius of the planet



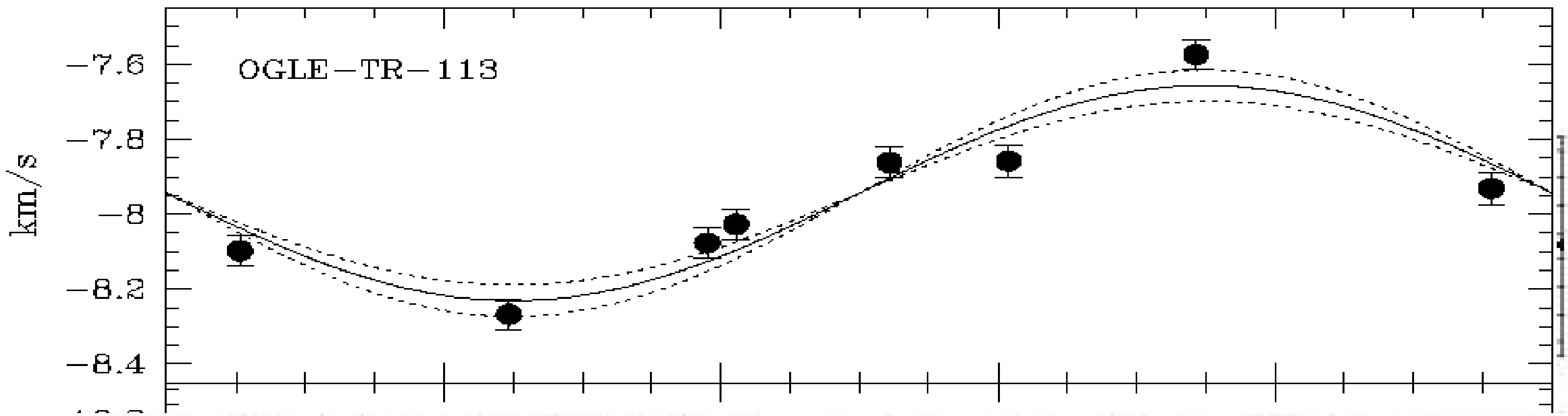
Transit photometry

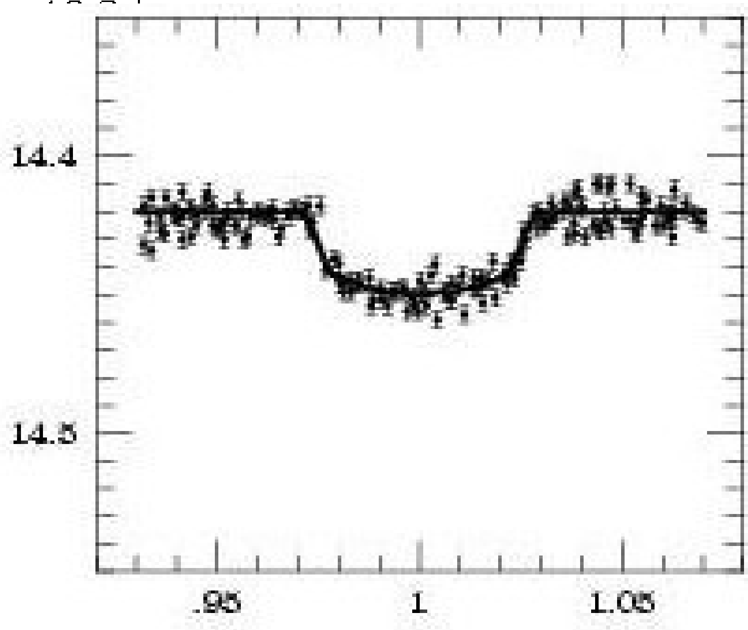


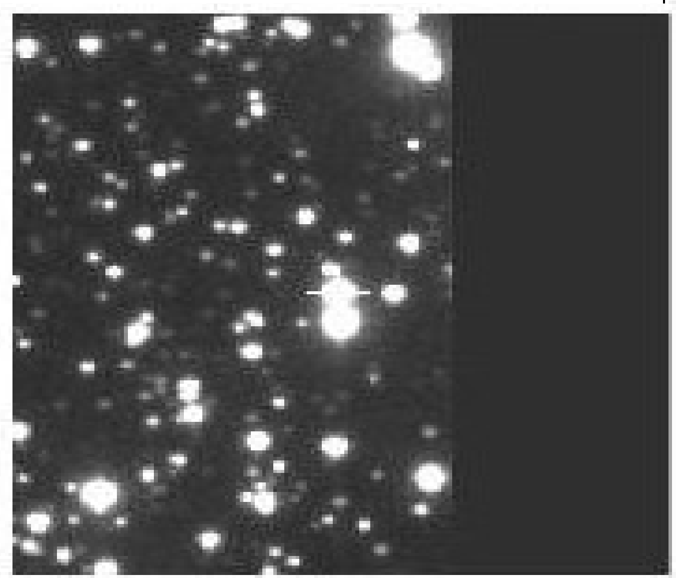
Transit photometry



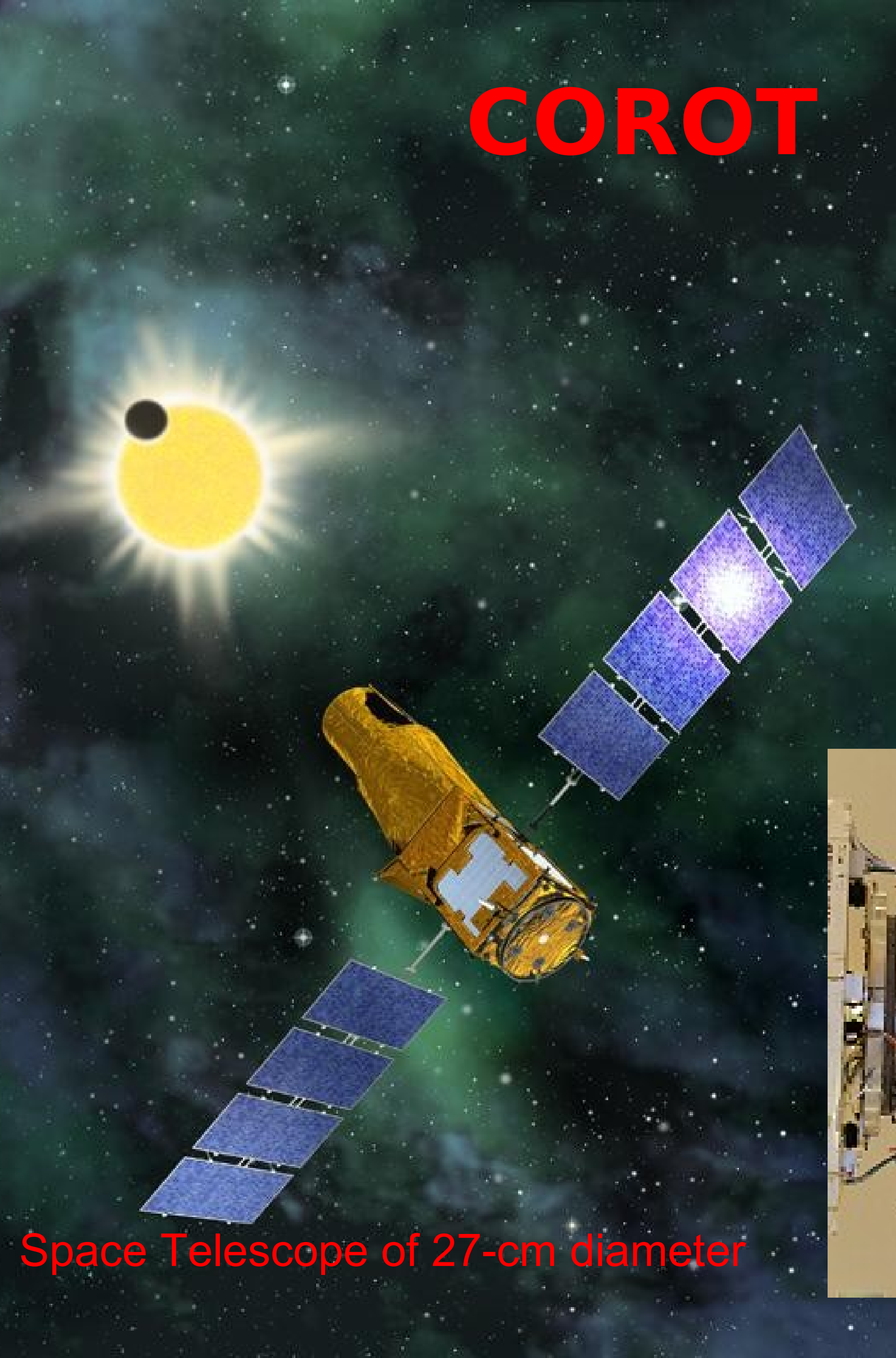
OGLE team discovered « very-hot-Jupiters »
ex: OGLE-113: M_p = 1.35 M_{Jup} , a_p = 0.0228 AU !





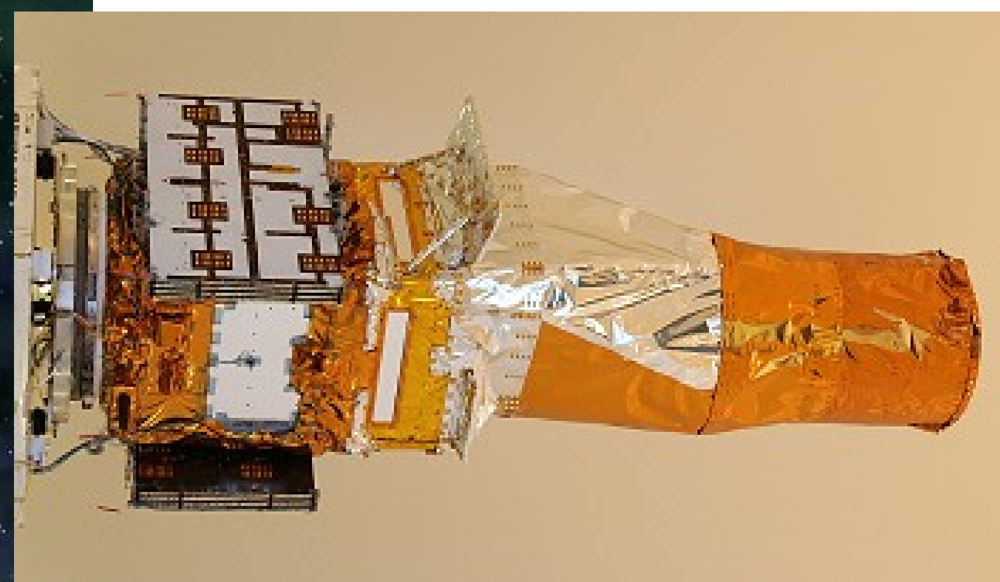


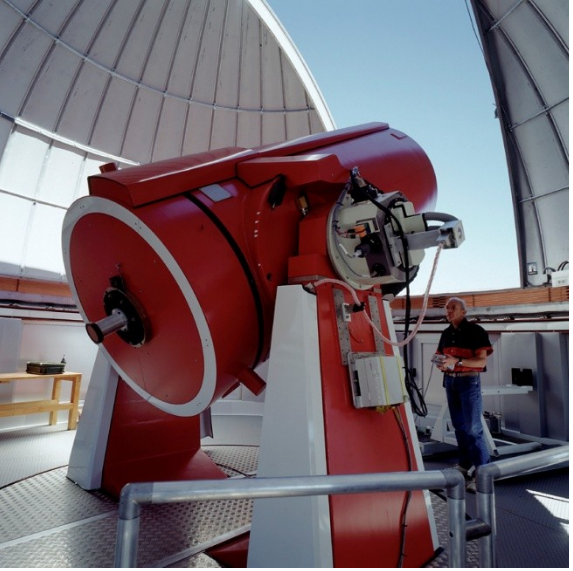
COROT



Space Telescope of 27-cm diameter

Planet detection using wide-field space photometry

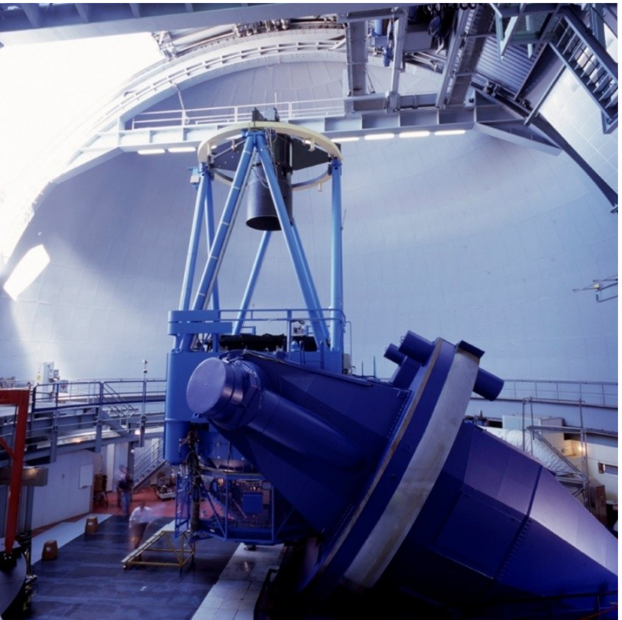




CORALIE
1.2m La Silla

SOPHIE
1.93m OHP

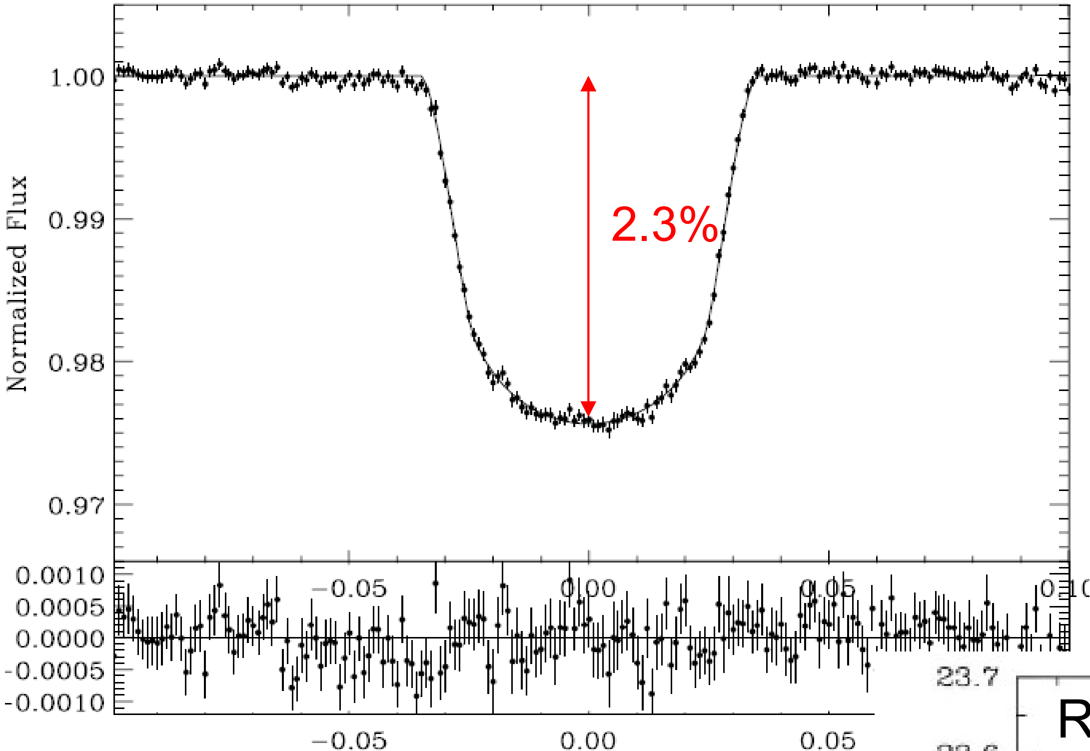
Need for radial velocity follow-up



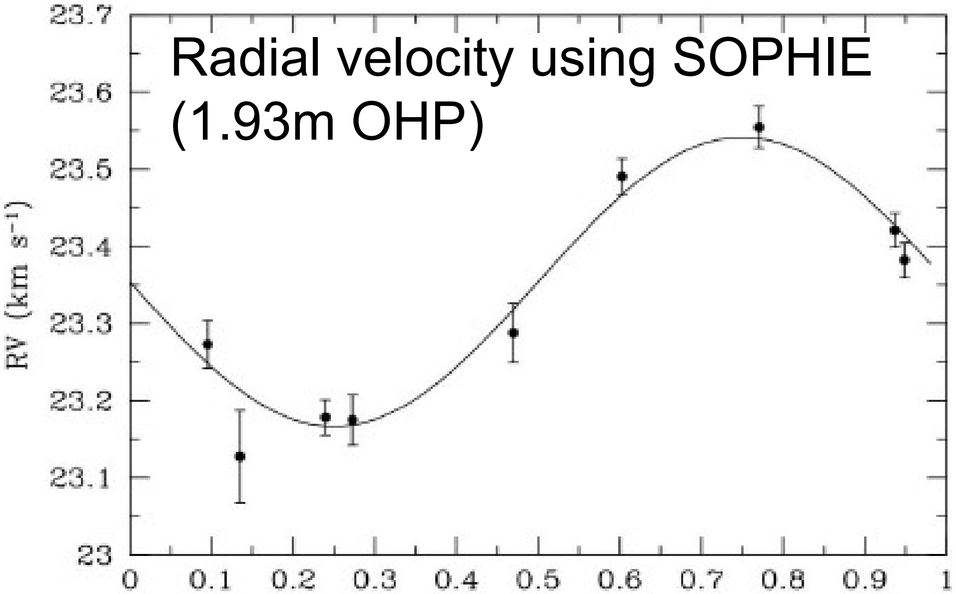
HARPS
3.6m La Silla

FLAMES
8.2m Paranal

COROT_1b



P = 1.509 jours
M_p = 0.99 $M_{Jupiter}$
R_p = 1.47 $R_{Jupiter}$



Detection techniques

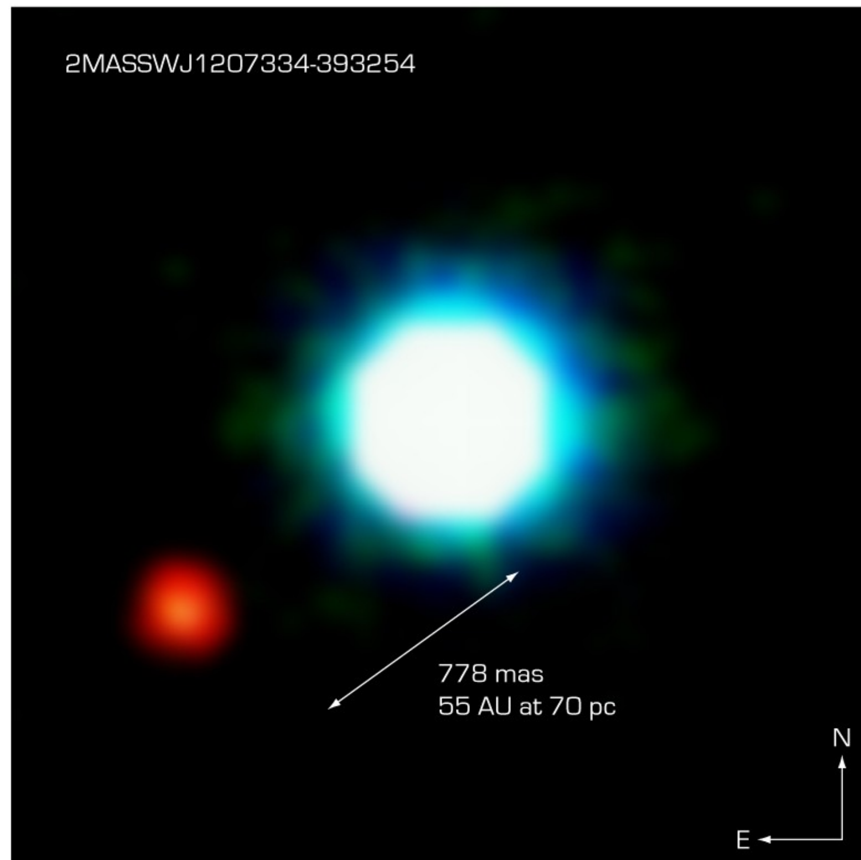
Direct imaging : 3 new systems discovered in 2008.

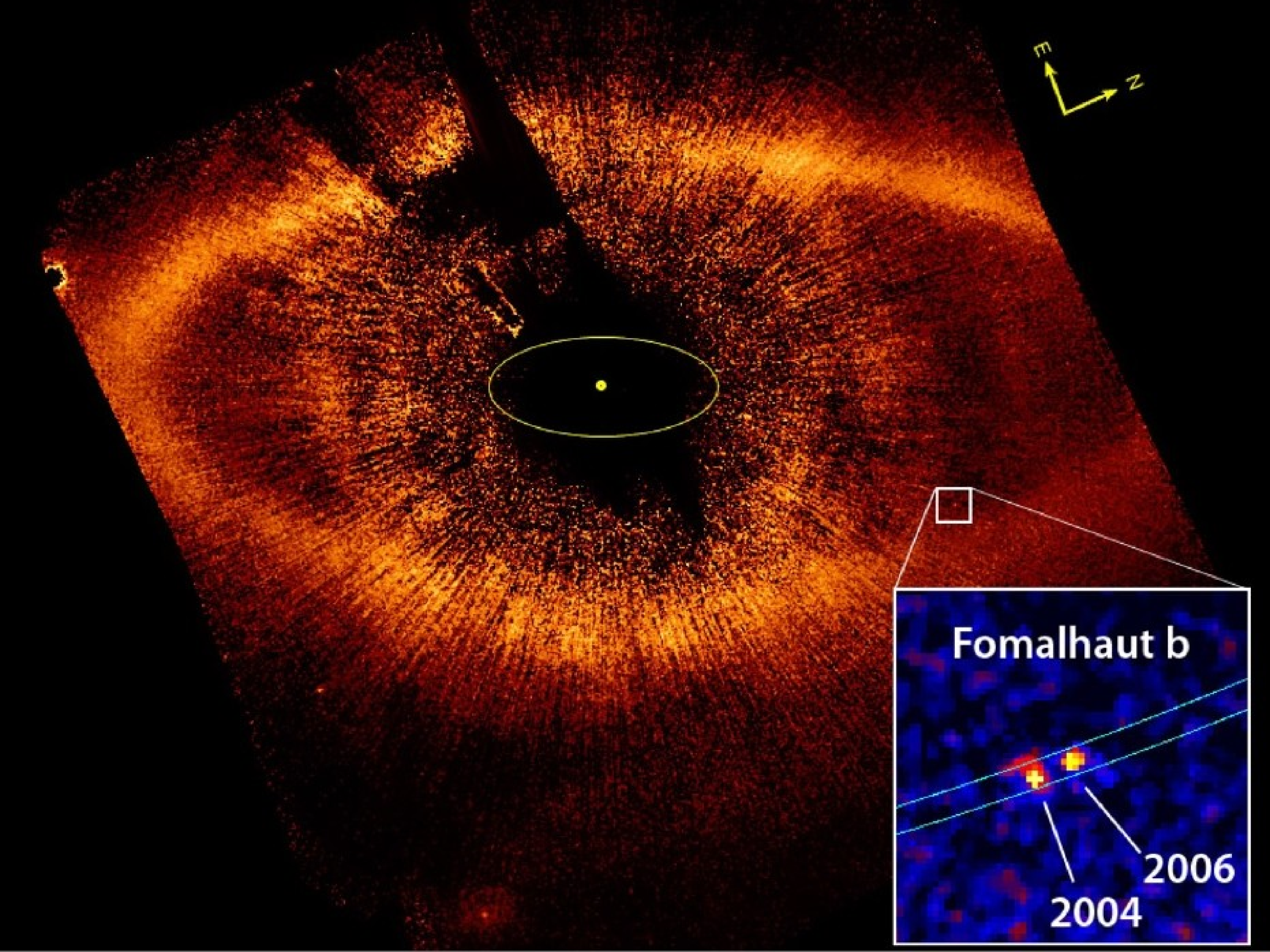
Possible only for big (and young) planets far from their parent star.

2M-1207: discovered in 2004.

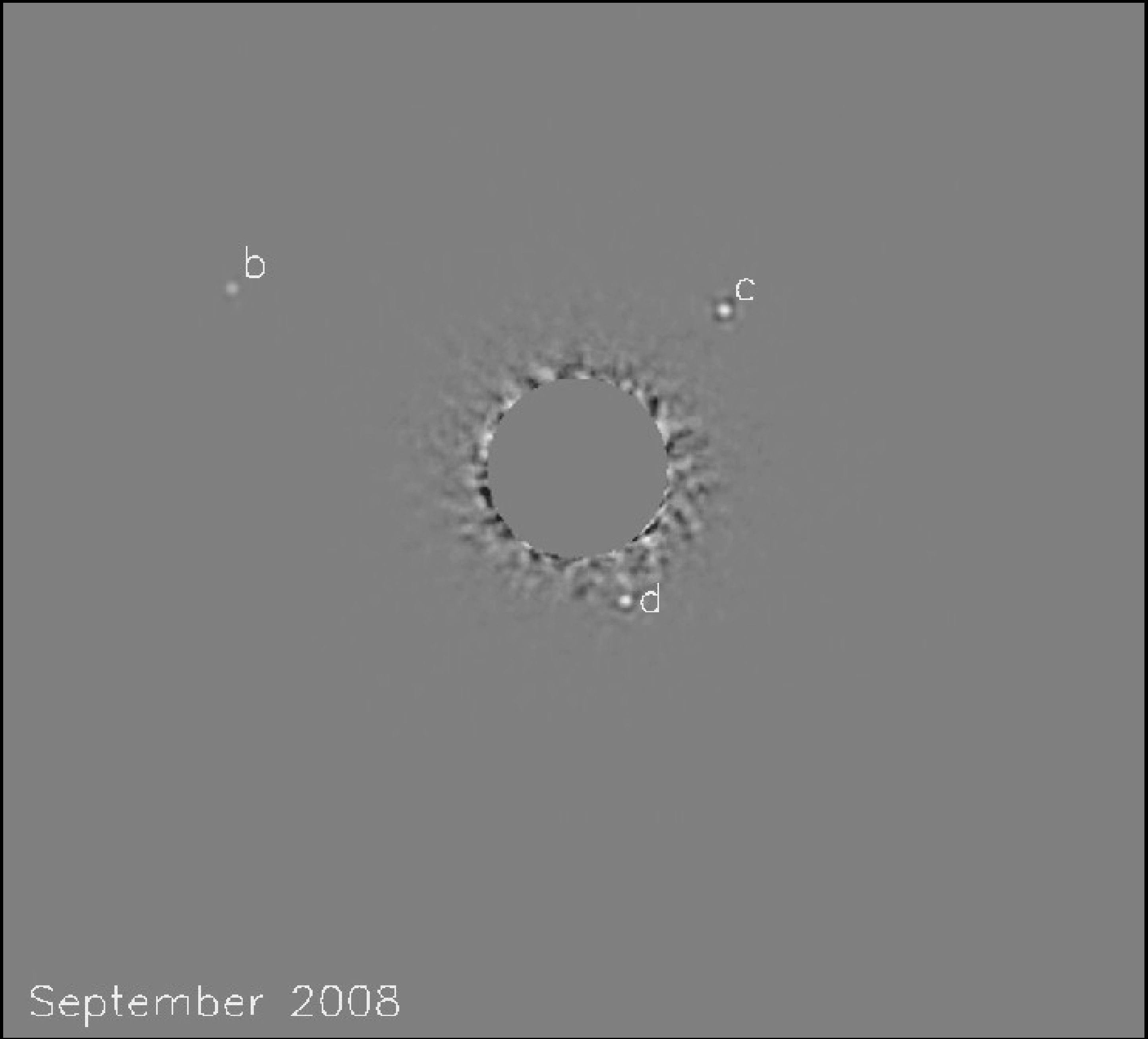
A 5 Jupiter mass object
orbiting a 25 Jupiter mass Brown Dwarf:

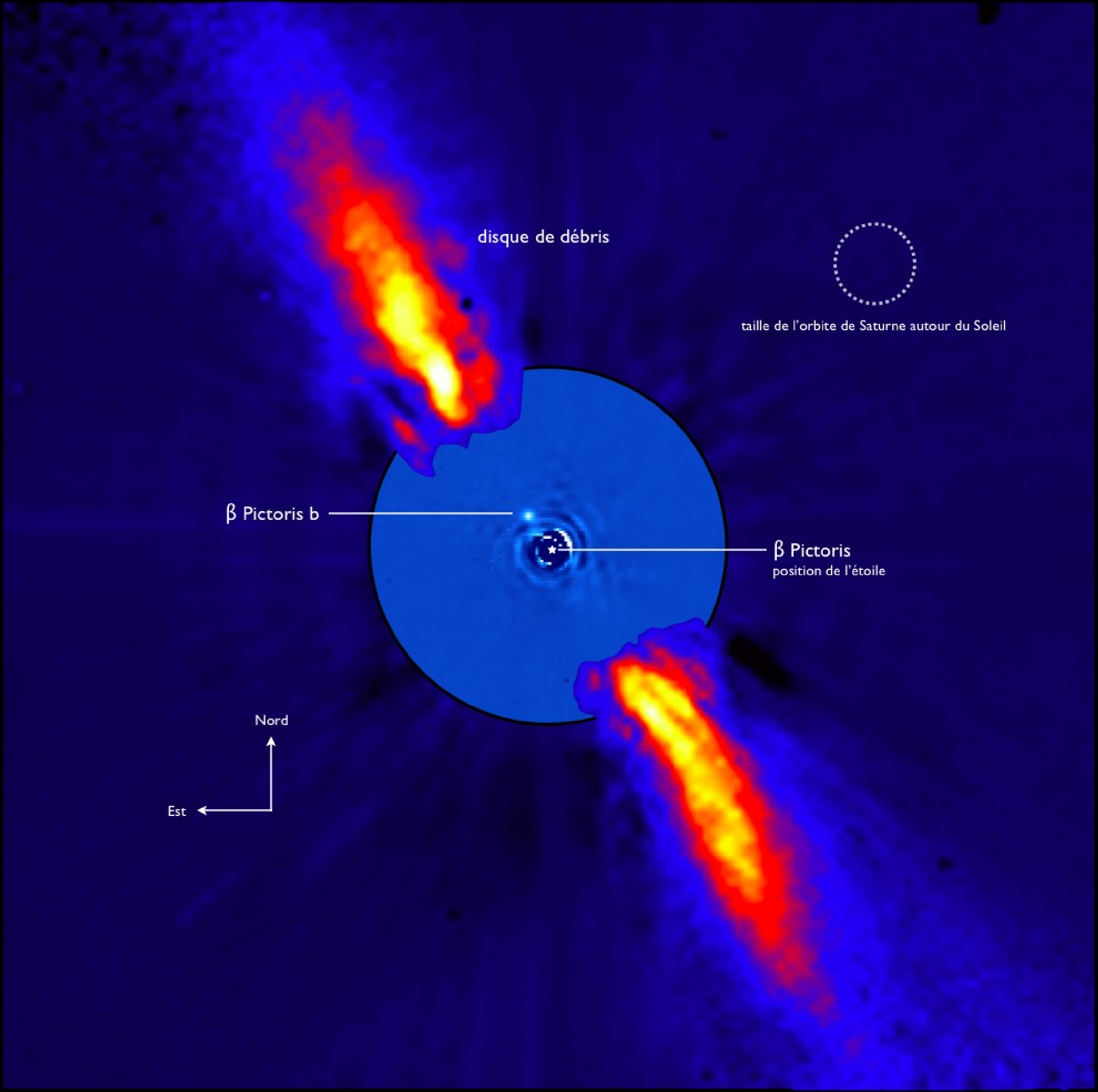
Is it a planet ?



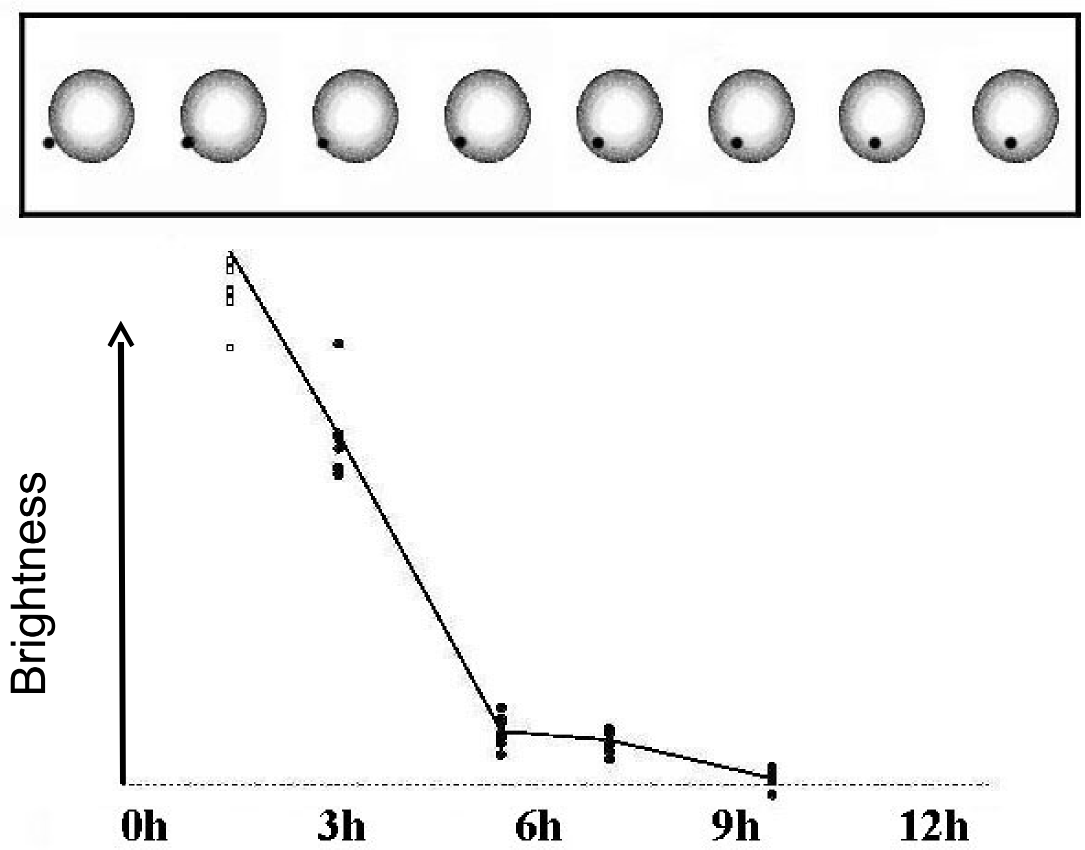

E
N
Fomalhaut b
2006
2004

Planetary system of HR 8799



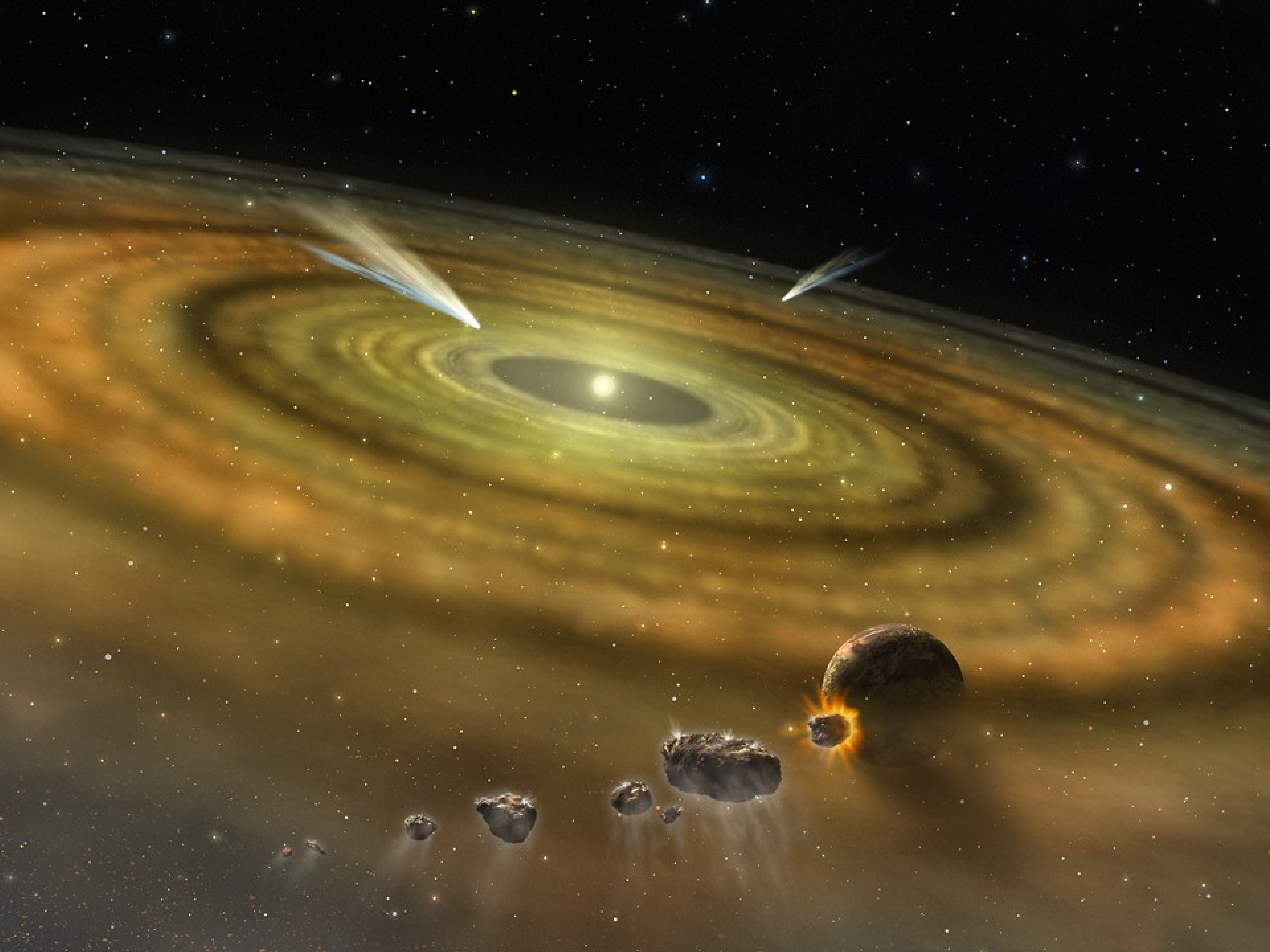

disque de débris
taille de l'orbite de Saturne autour du Soleil
β Pictoris b
β Pictoris
position de l'étoile
Nord
Est

β Pictoris:



November 10, 1981

1981 photometric event could be due to the transit of an extrasolar planet.
(Lecavelier et al. 1994, 1995)

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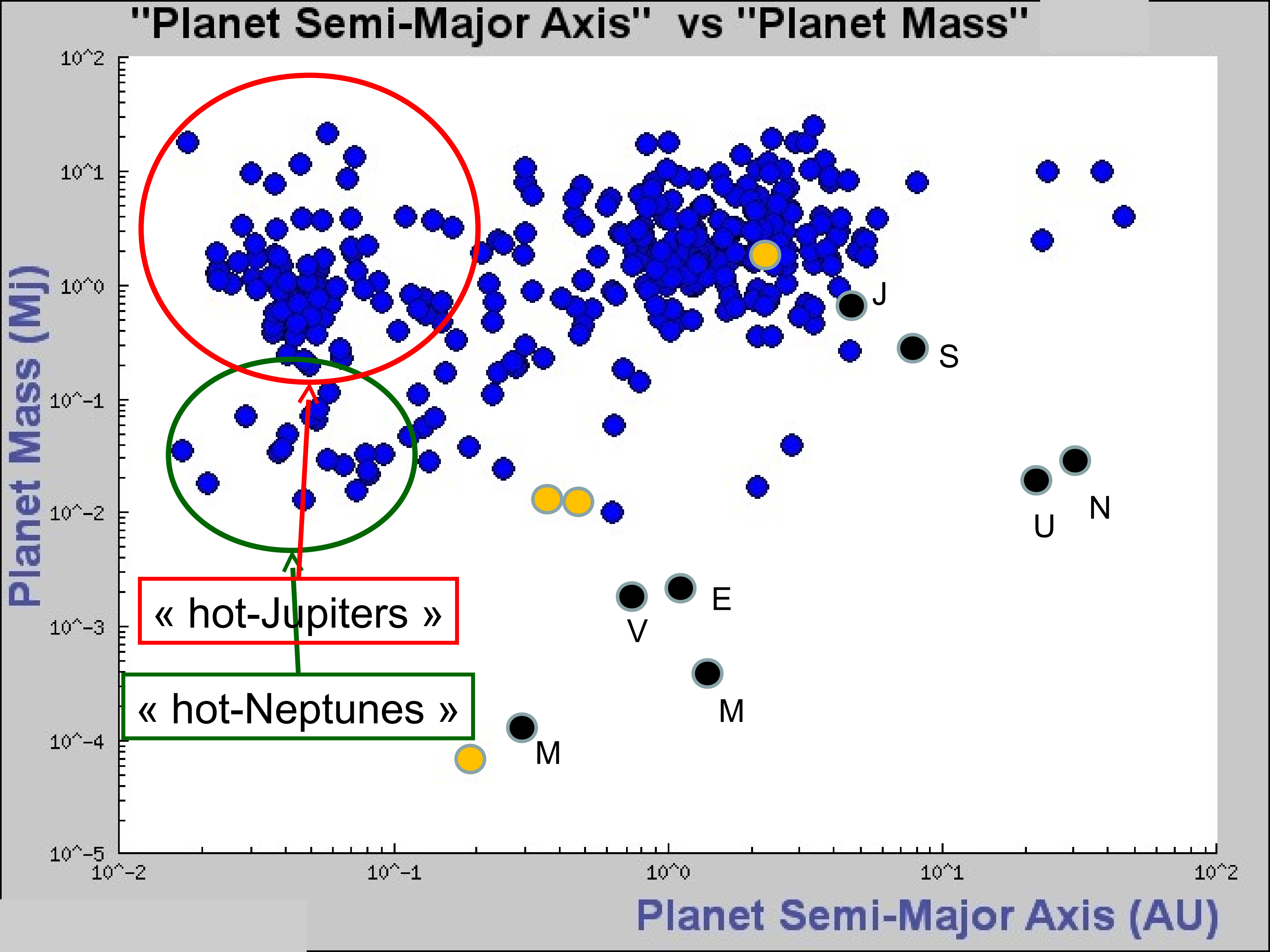
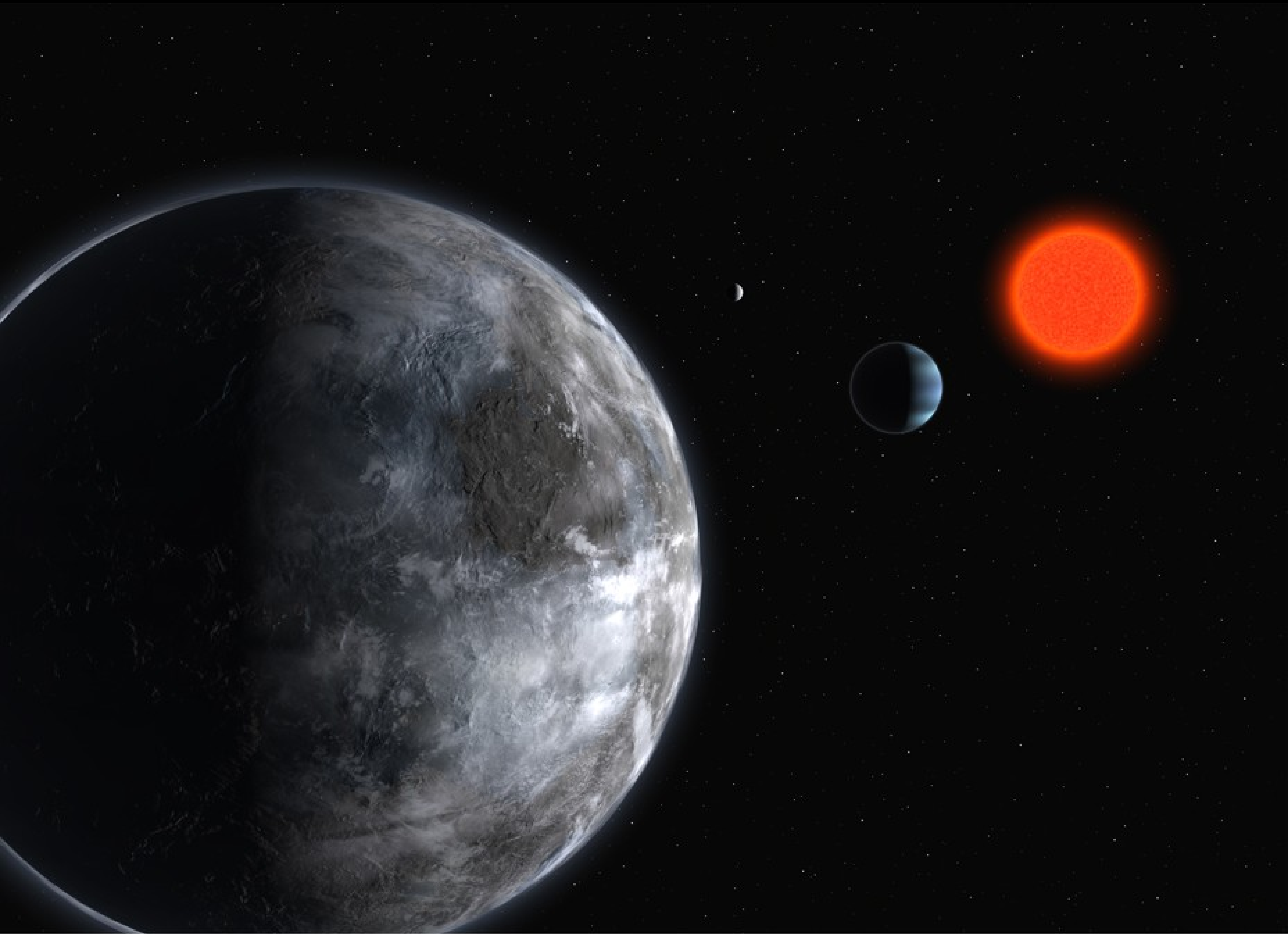

"Planet Semi-Major Axis" vs "Planet Mass"
Planet Mass (Mj)
Planet Semi-Major Axis (AU)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-2
10^-1
10^0
10^1
10^2
J
S
U
N
E
V
M
M
« hot-Jupiters »
« hot-Neptunes »

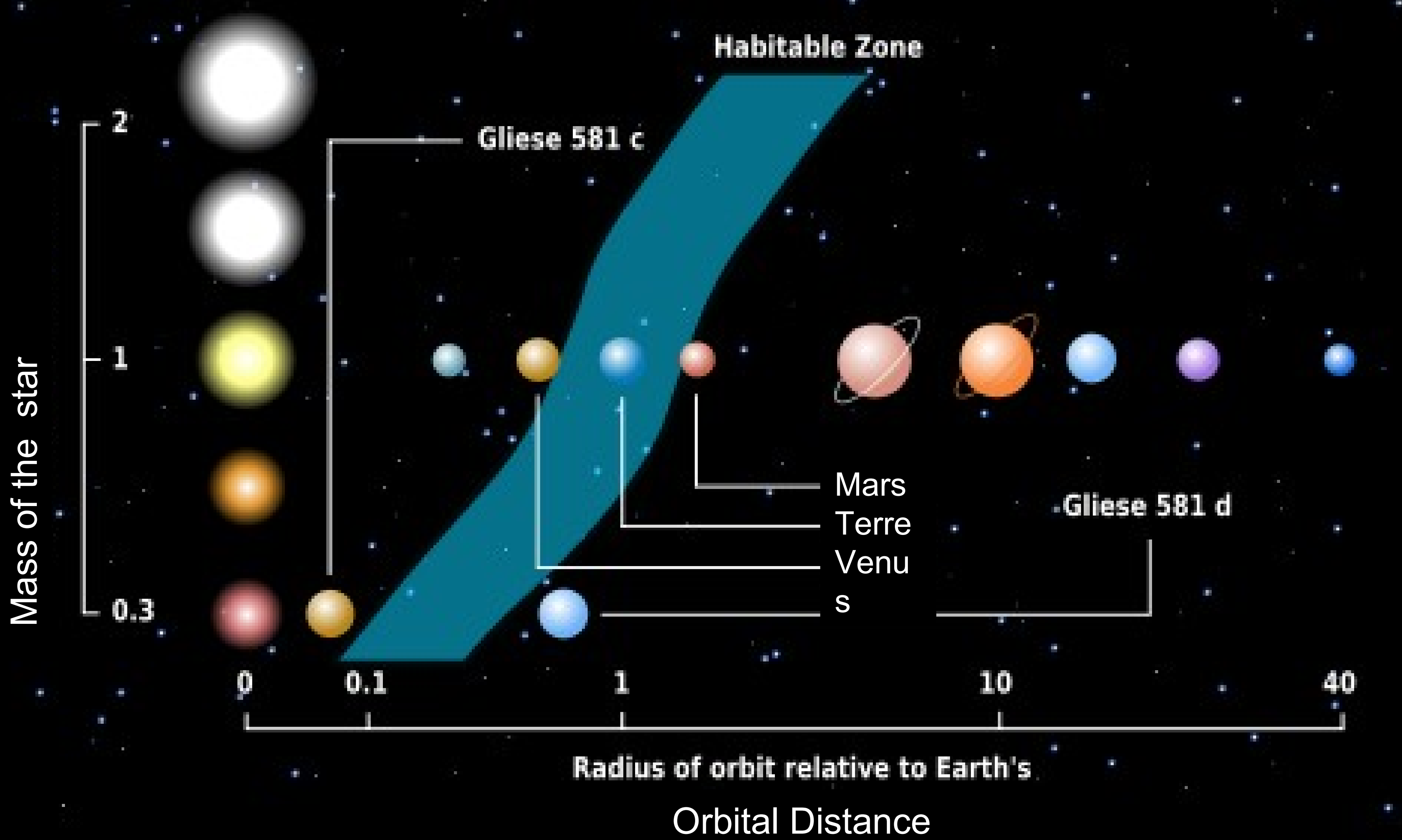
An "Earth-like" planet : Gliese 581 c

- Orbit in 13 days
- 11 millions kilometers from the star
- Low mass star ➔
  Star light on planet ~ Sun light on the Earth
- 5 Earth-mass ➔ Solide rocky planet

An “Earth-like” planet : Gliese 581 c

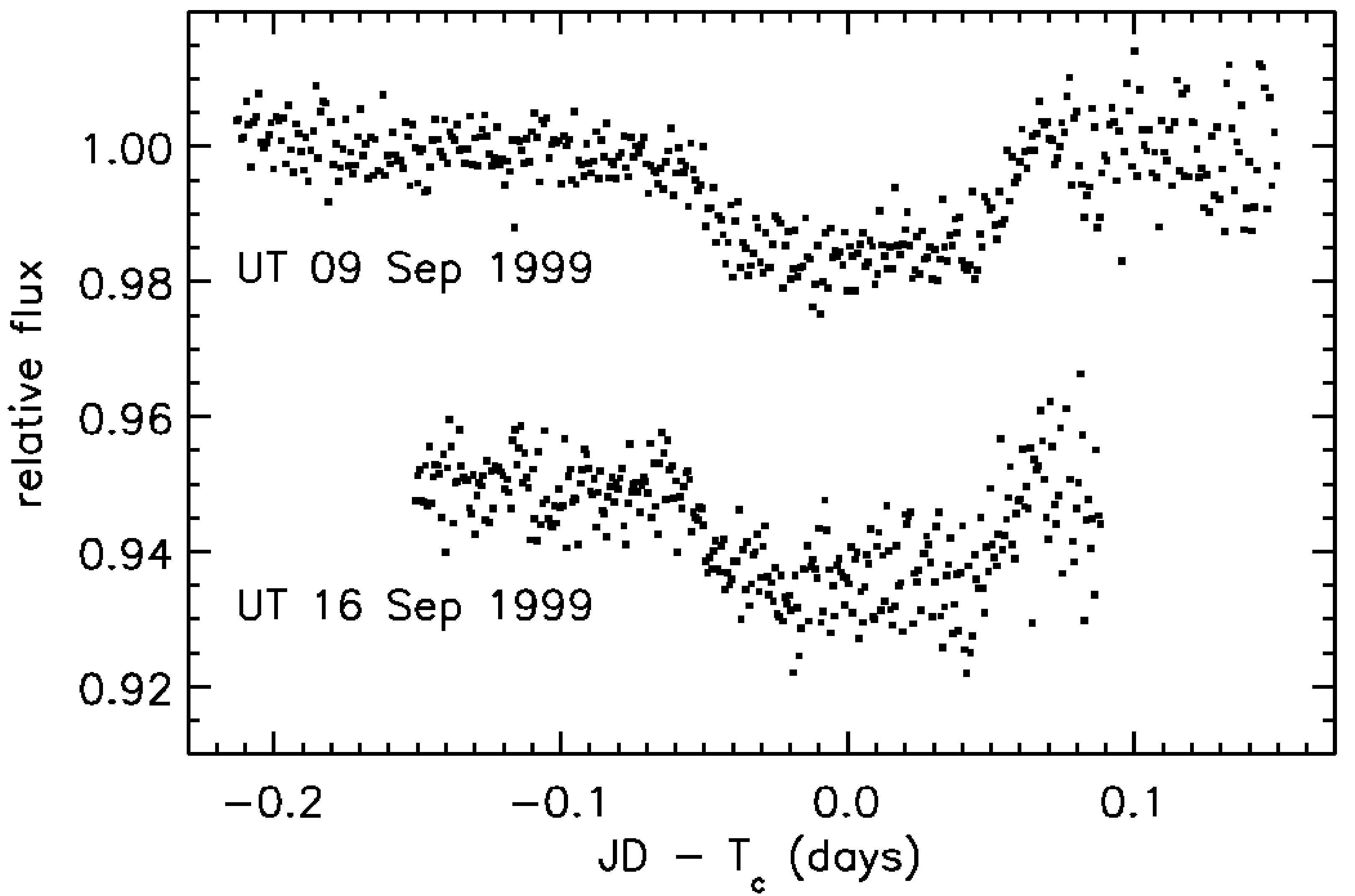


“Habitable Zone”

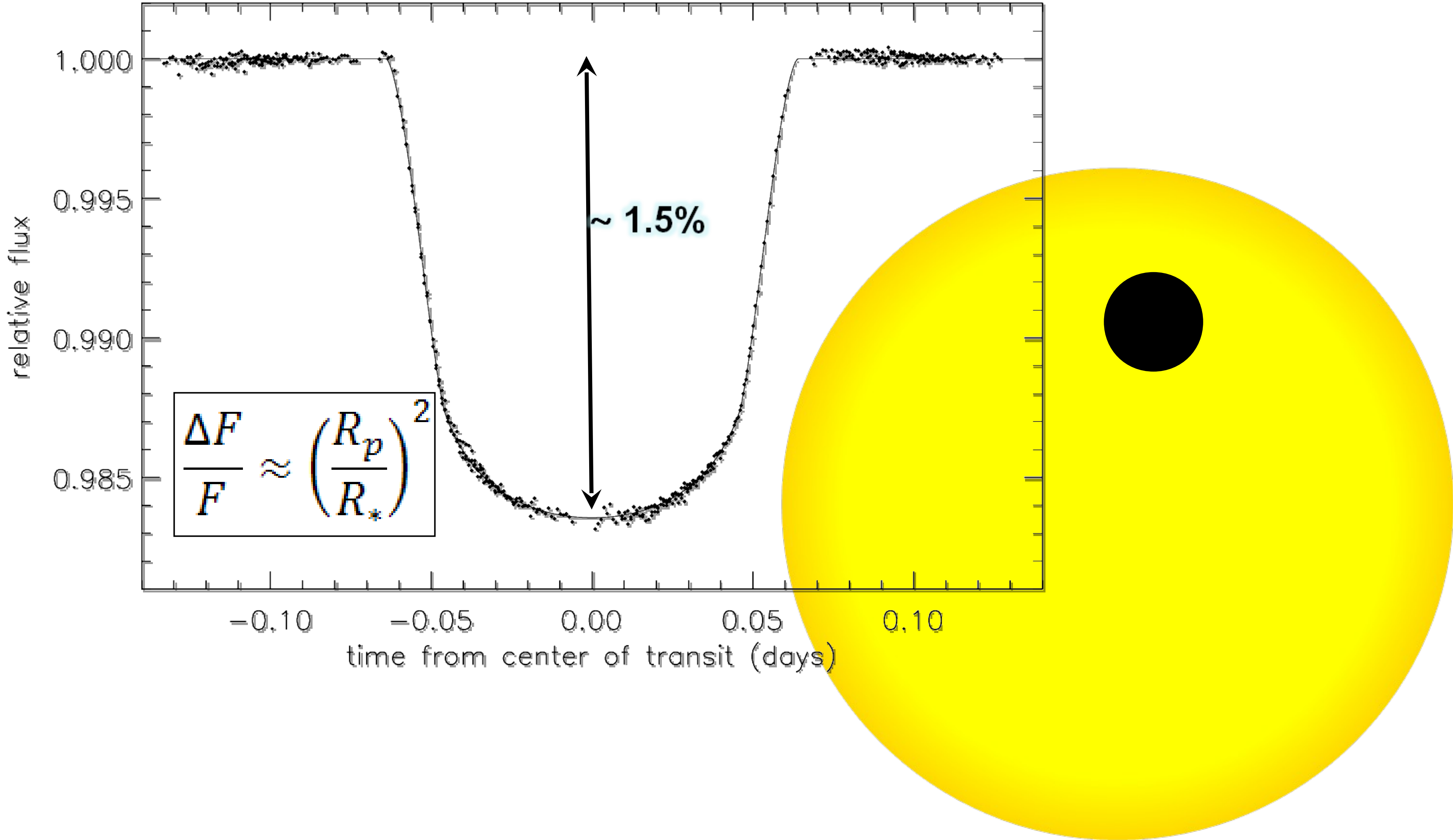


Transit of HD 209458b

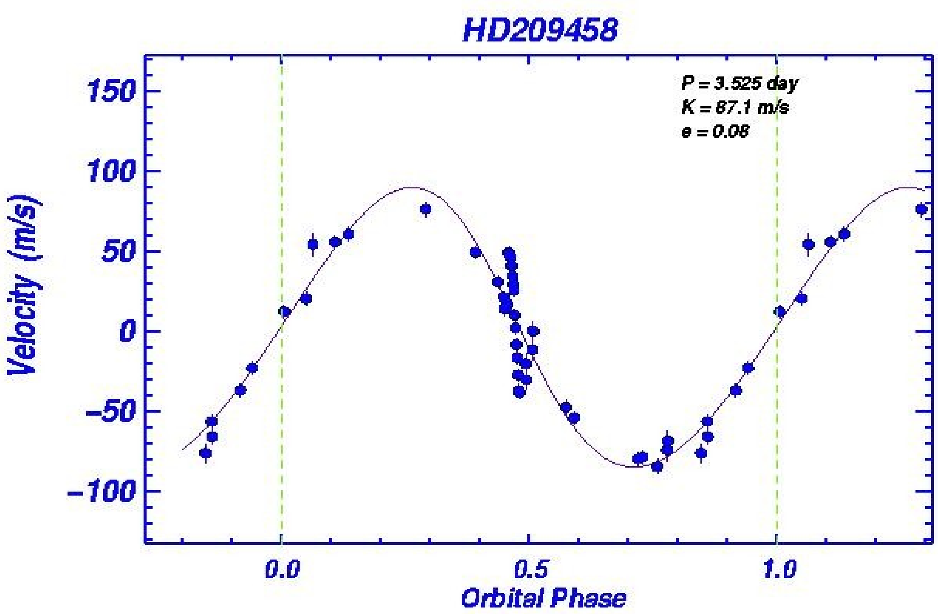
(Charbonneau et al. 2000)

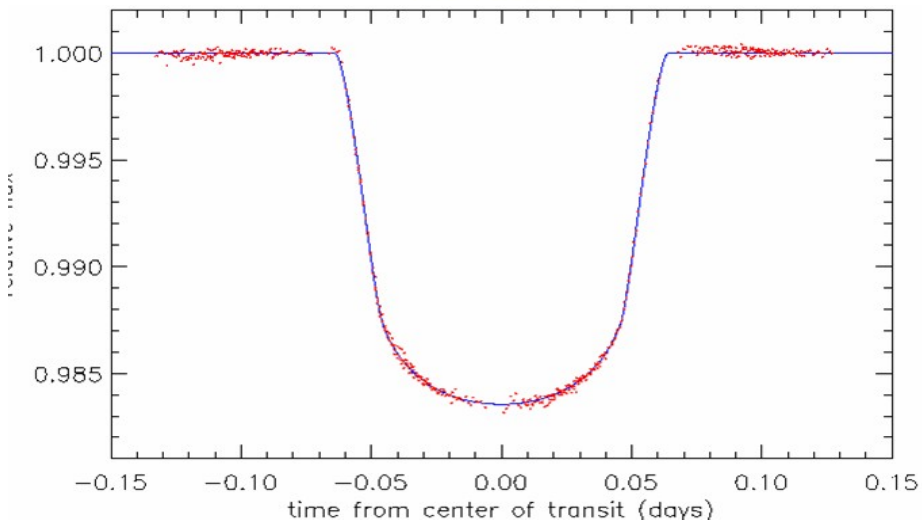


Transit depth → Planet radius



Radial velocity / Transit photometry





HD 209458b

Period = 3.524738 days

Mass = 0.66 ±0.01 $M_{Jupiter}$

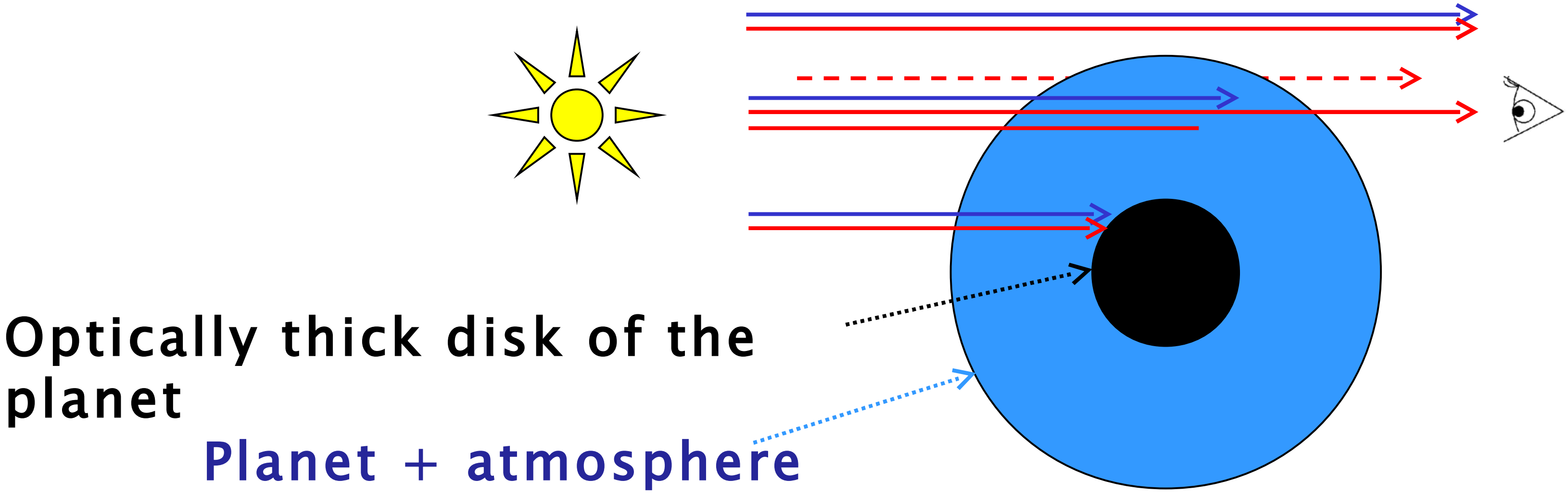
Radius = 1.32 ±0.02 $R_{Jupiter}$

Density = 0.38 ±0.01 g/cm^3

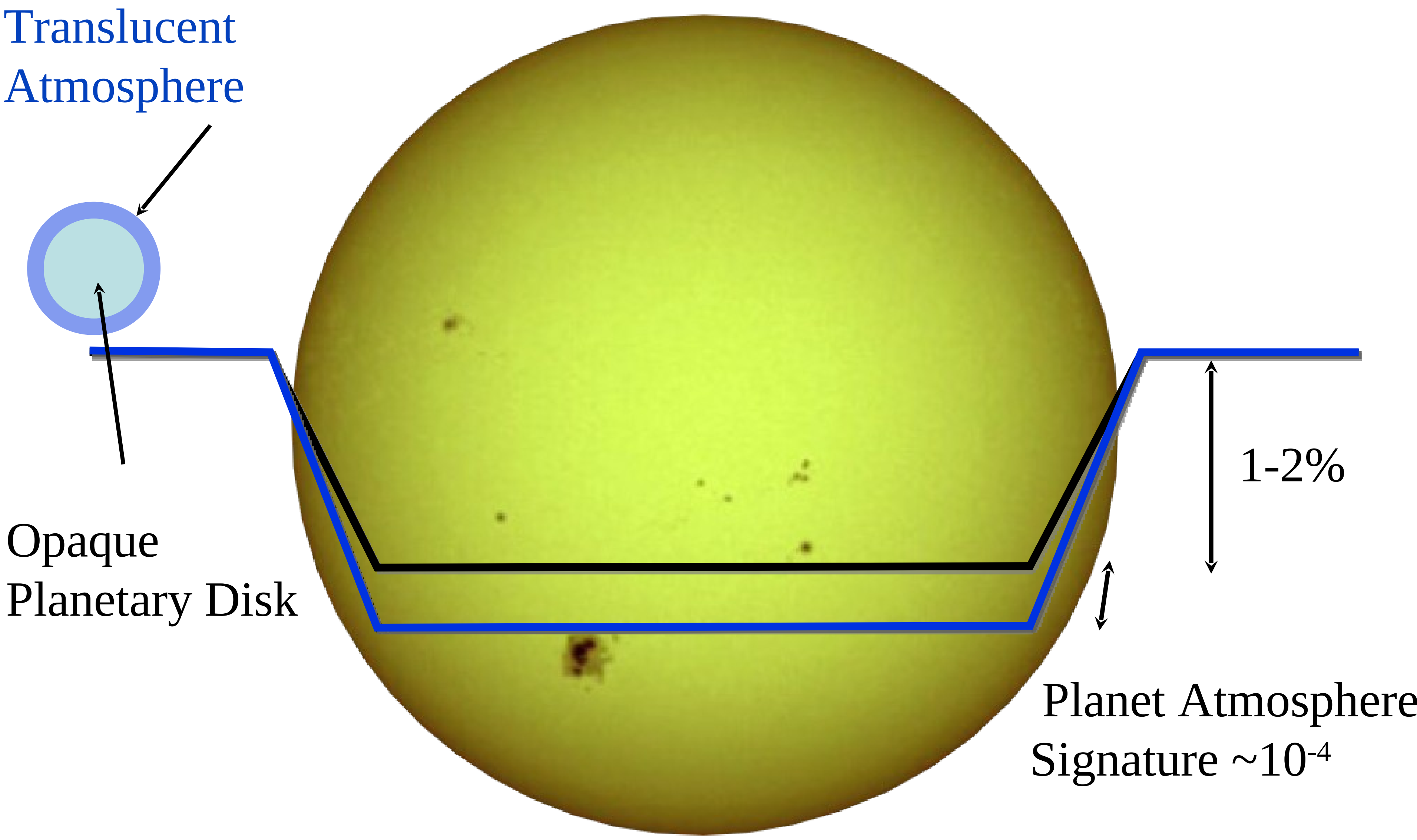
Spectroscopic transits of atmospheres

Because of the atmosphere,
light absorption is as a function of wavelength (λ)

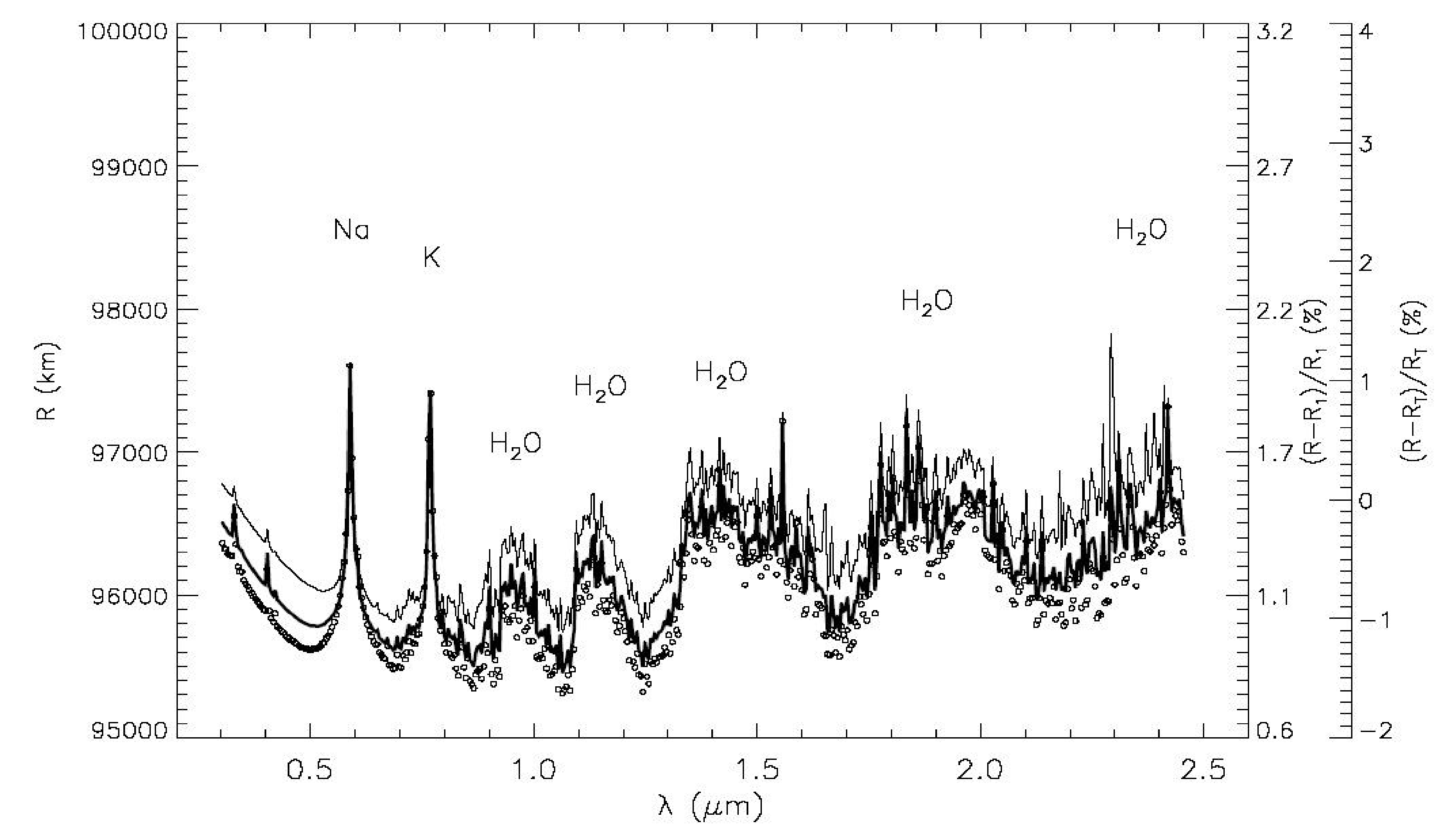
The planet looks larger when observed at highly absorbed wavelengths → $R_P \equiv R_P(\lambda)$



Seager & Sasselov 2000, ApJ 537, 916
Hubbard et al. 2001, ApJ 560, 413
Brown 2001, ApJ 553, 1006


Translucent
Atmosphere
Opaque
Planetary Disk
1-2%
Planet Atmosphere
Signature ~10-4

Radius as a function of wavelength for a Hot-Jupiter



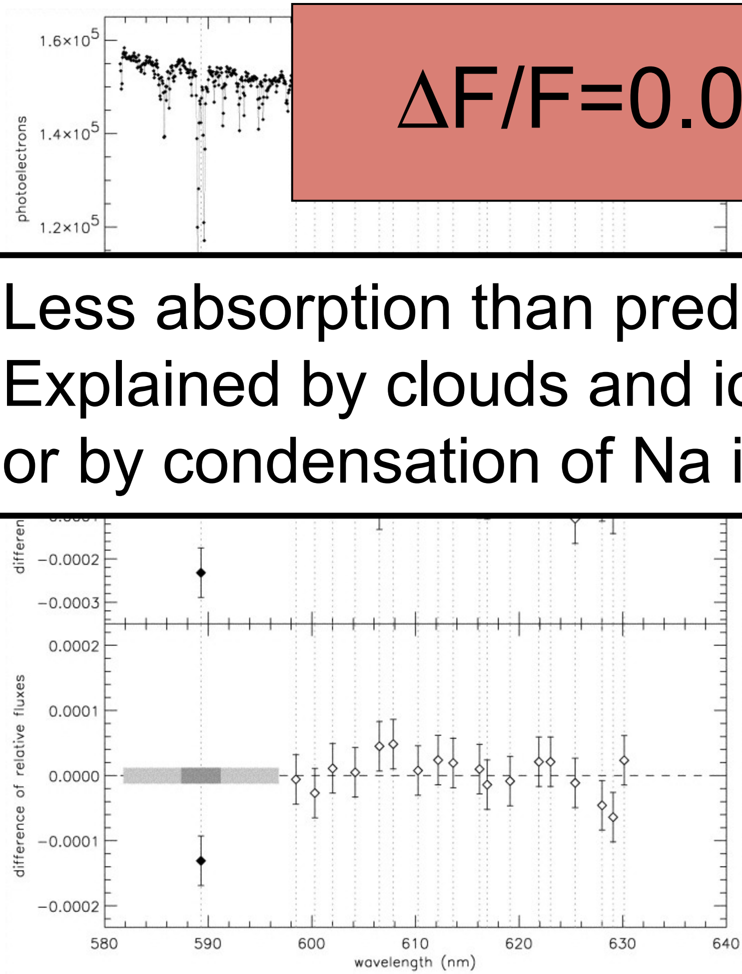
(Hubbard et al. 2001)

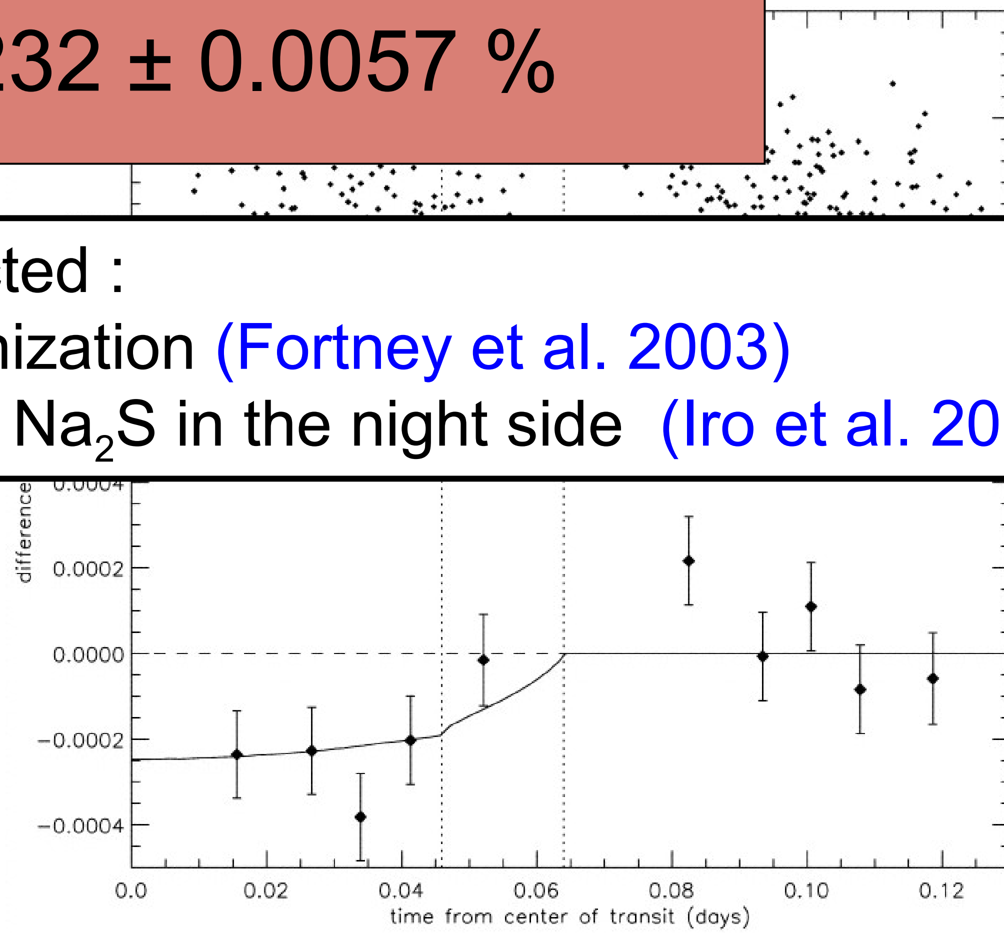
NaI in HD 209458b:
1st detection of an extrasolar atmosphere

(Charbonneau et al. 2002)

$\Delta F/F = 0.0232 \pm 0.0057$ %

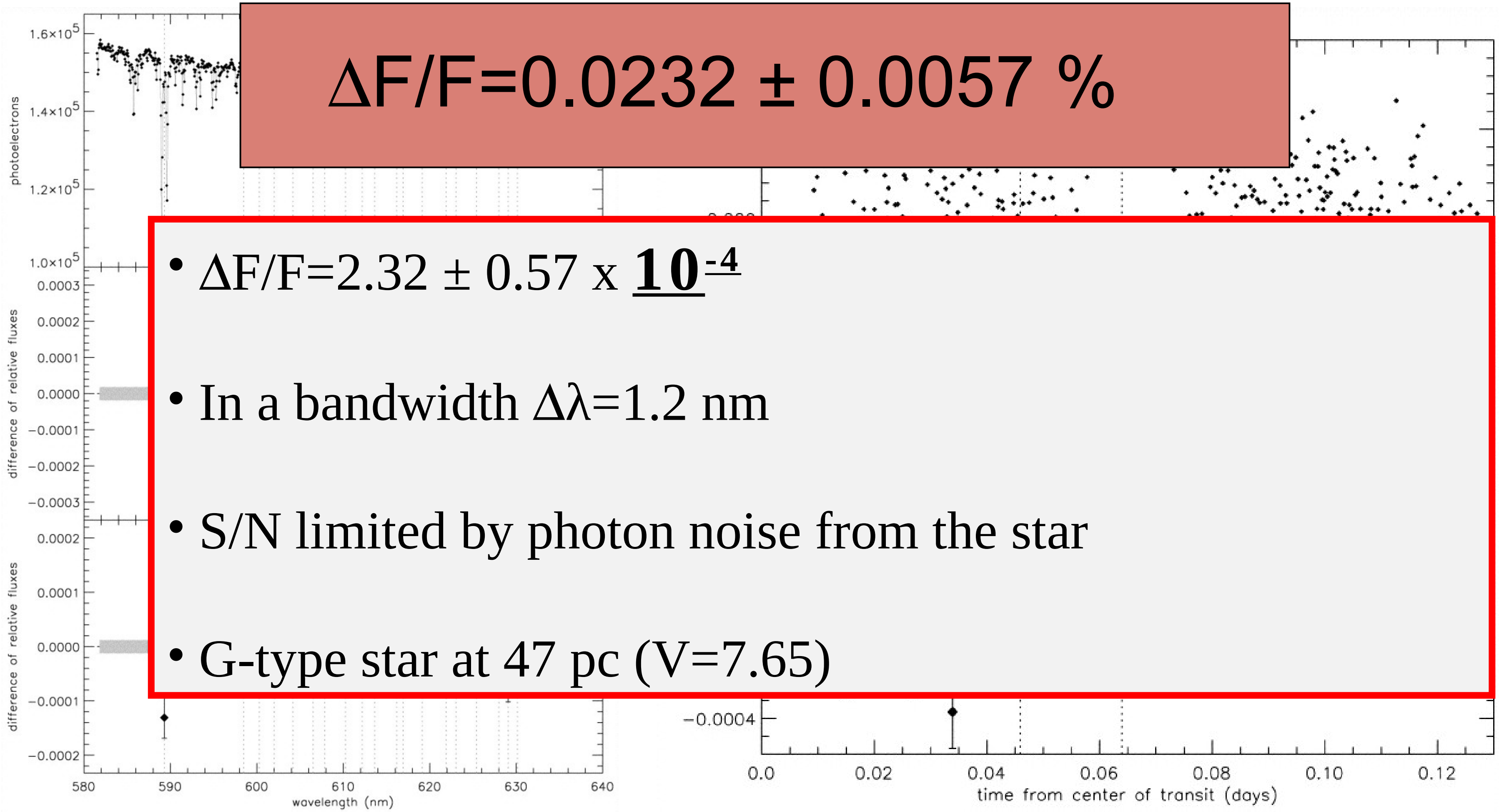
Less absorption than predicted :
Explained by clouds and ionization (Fortney et al. 2003)
or by condensation of Na in Na_2S in the night side (Iro et al. 2005)





NaI in HD 209458b: 1st detection of an extrasolar atmosphere

(Charbonneau et al. 2002)

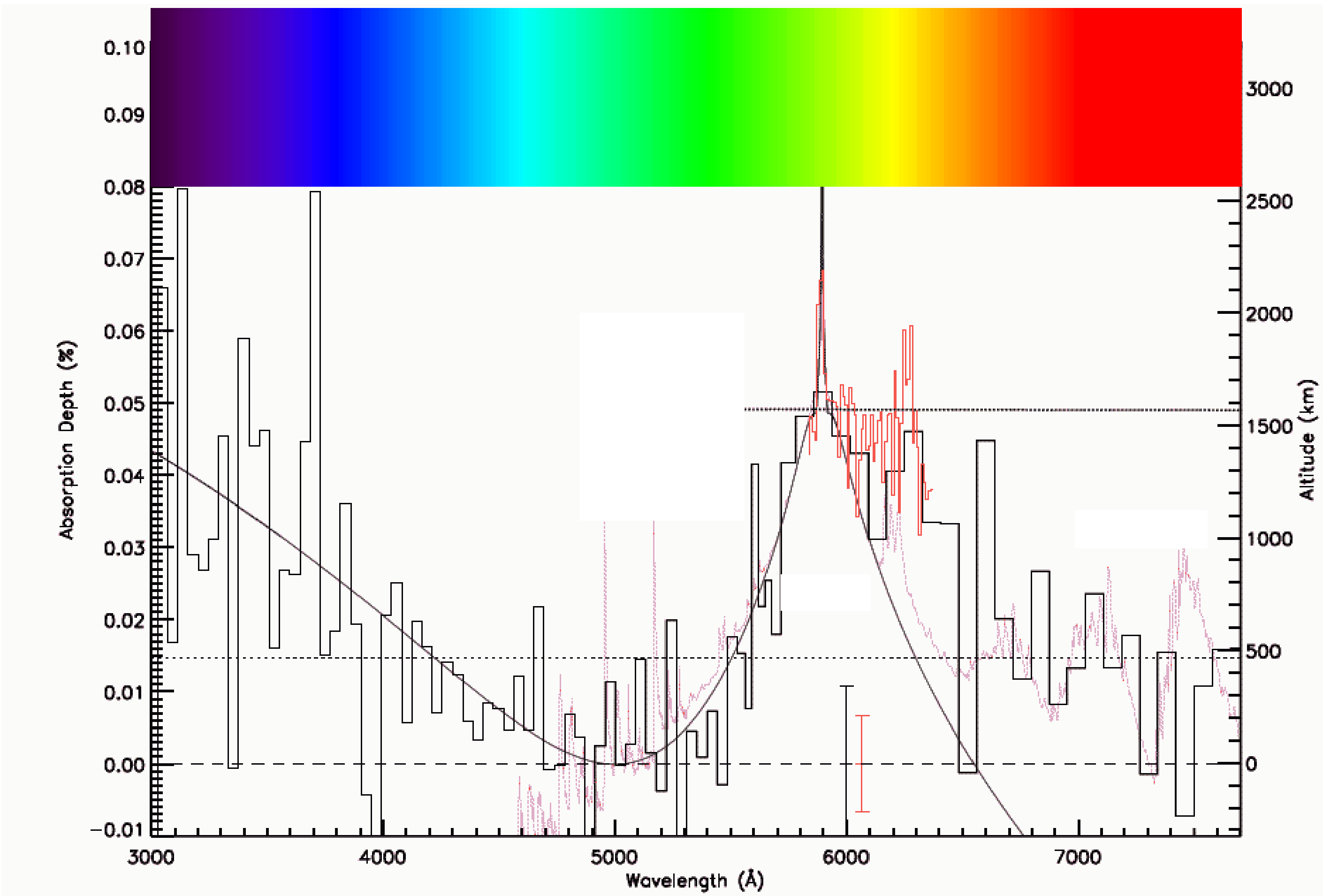


$\Delta F/F = 0.0232 \pm 0.0057$ %

- $\Delta F/F = 2.32 \pm 0.57 \times \mathbf{10^{-4}}$
- In a bandwidth $\Delta\lambda = 1.2$ nm
- S/N limited by photon noise from the star
- G-type star at 47 pc (V=7.65)

HD209458b (Osiris):
Atmosphere spectrum from near-UV to near-IR

(Sing et al. 2008a, 2008b, Desert et al. 2008, Lecavelier et al. 2008)



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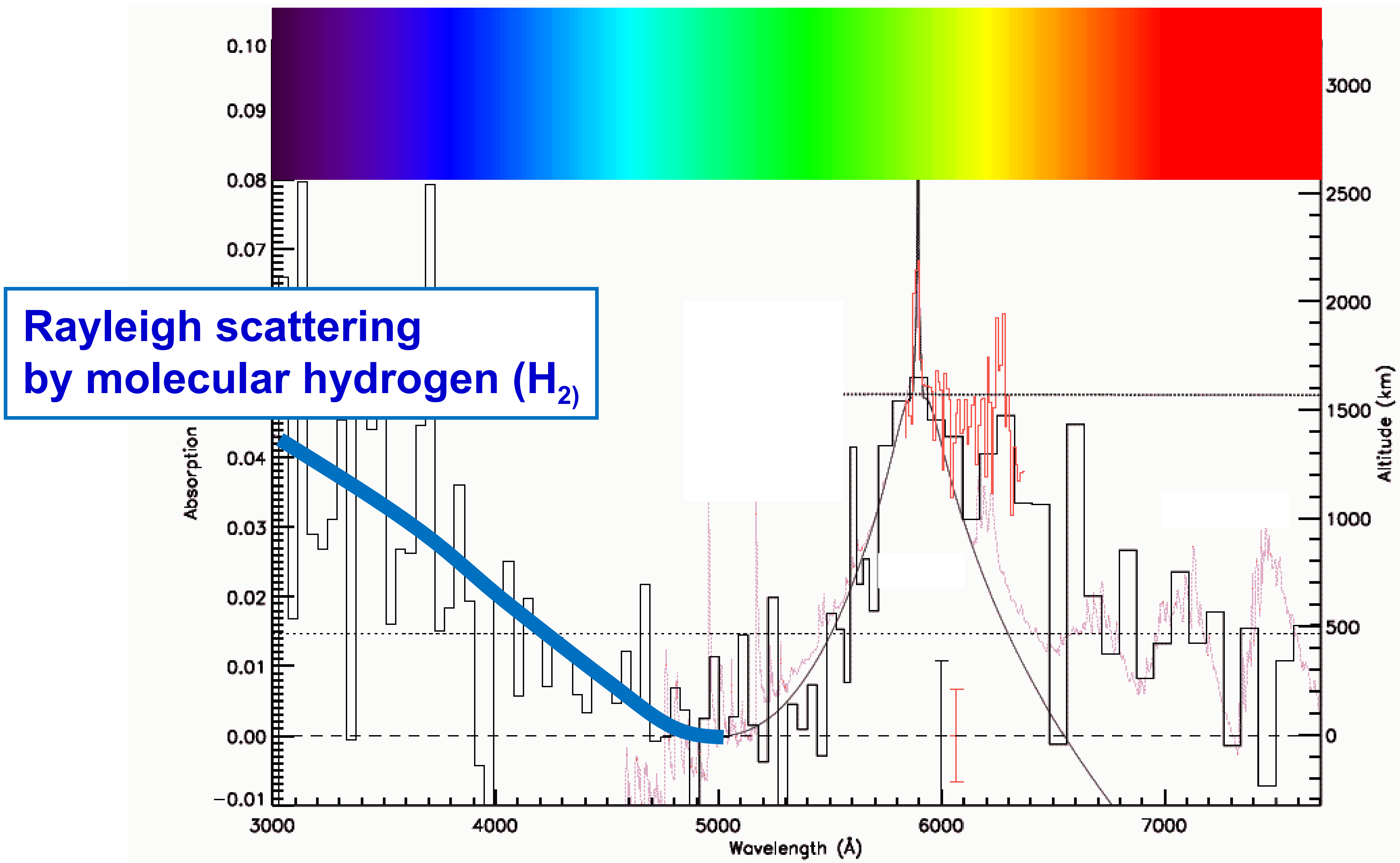

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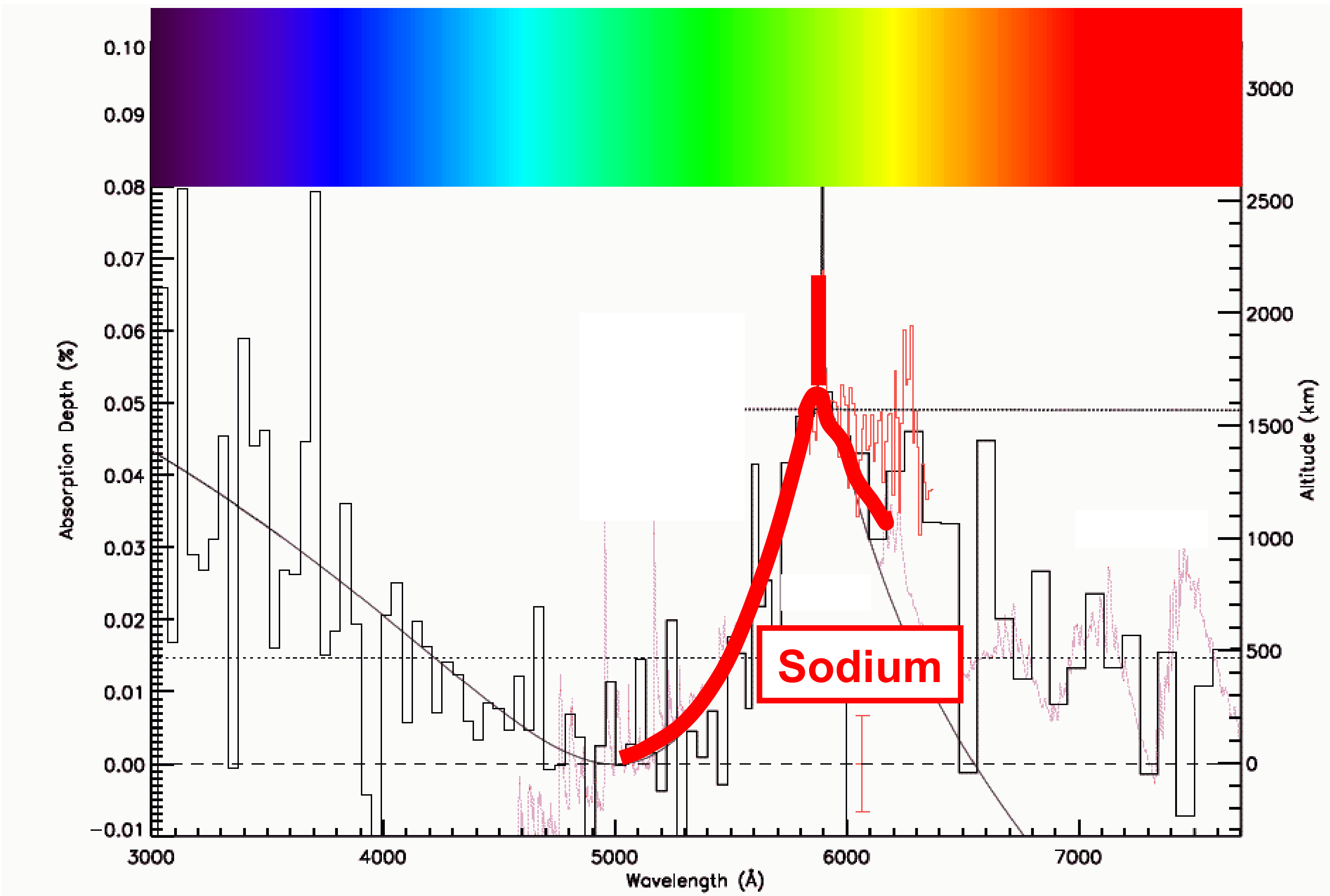
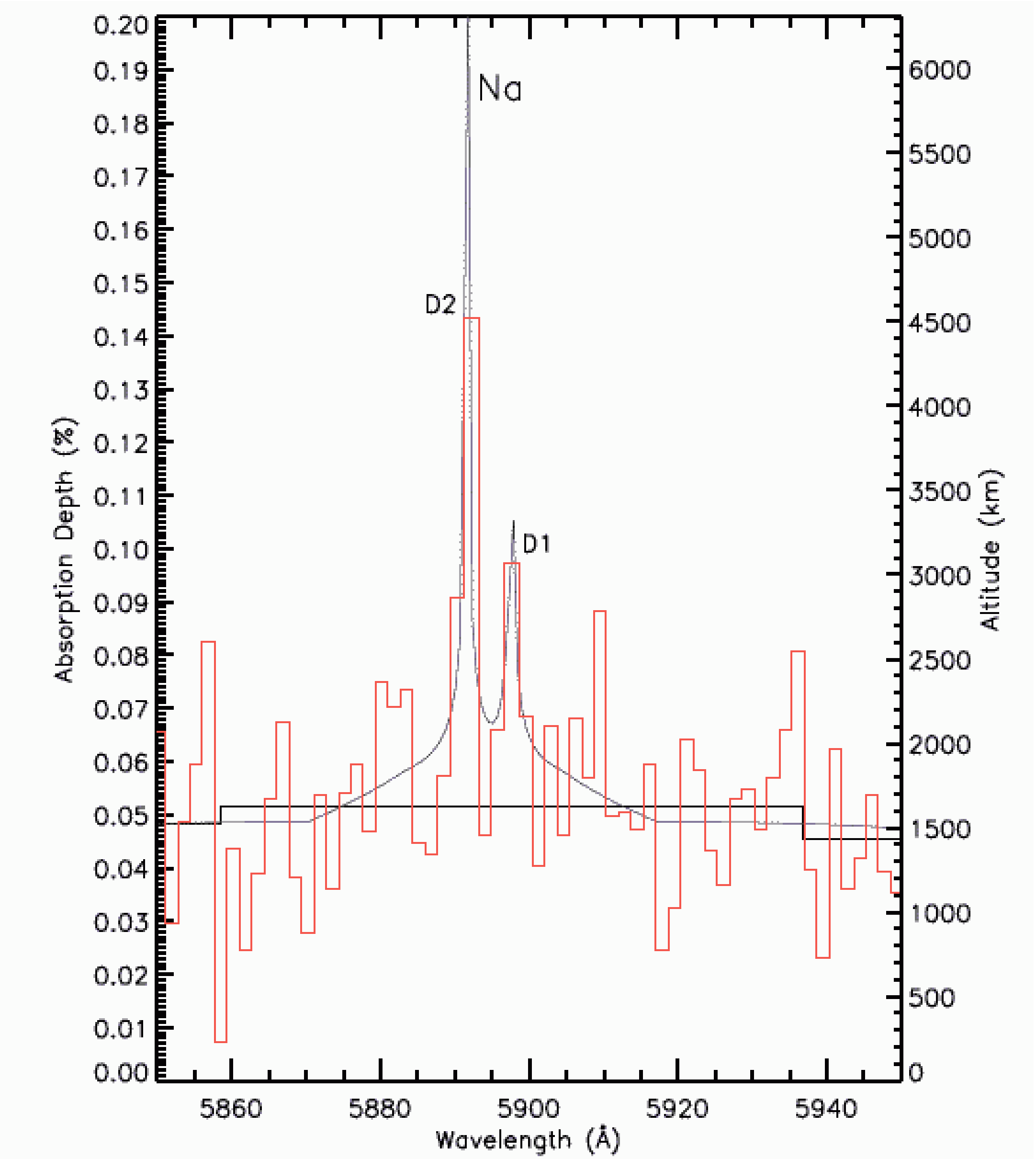


Core of the sodium doublet

(Sing et al. 2008a, 2008b)



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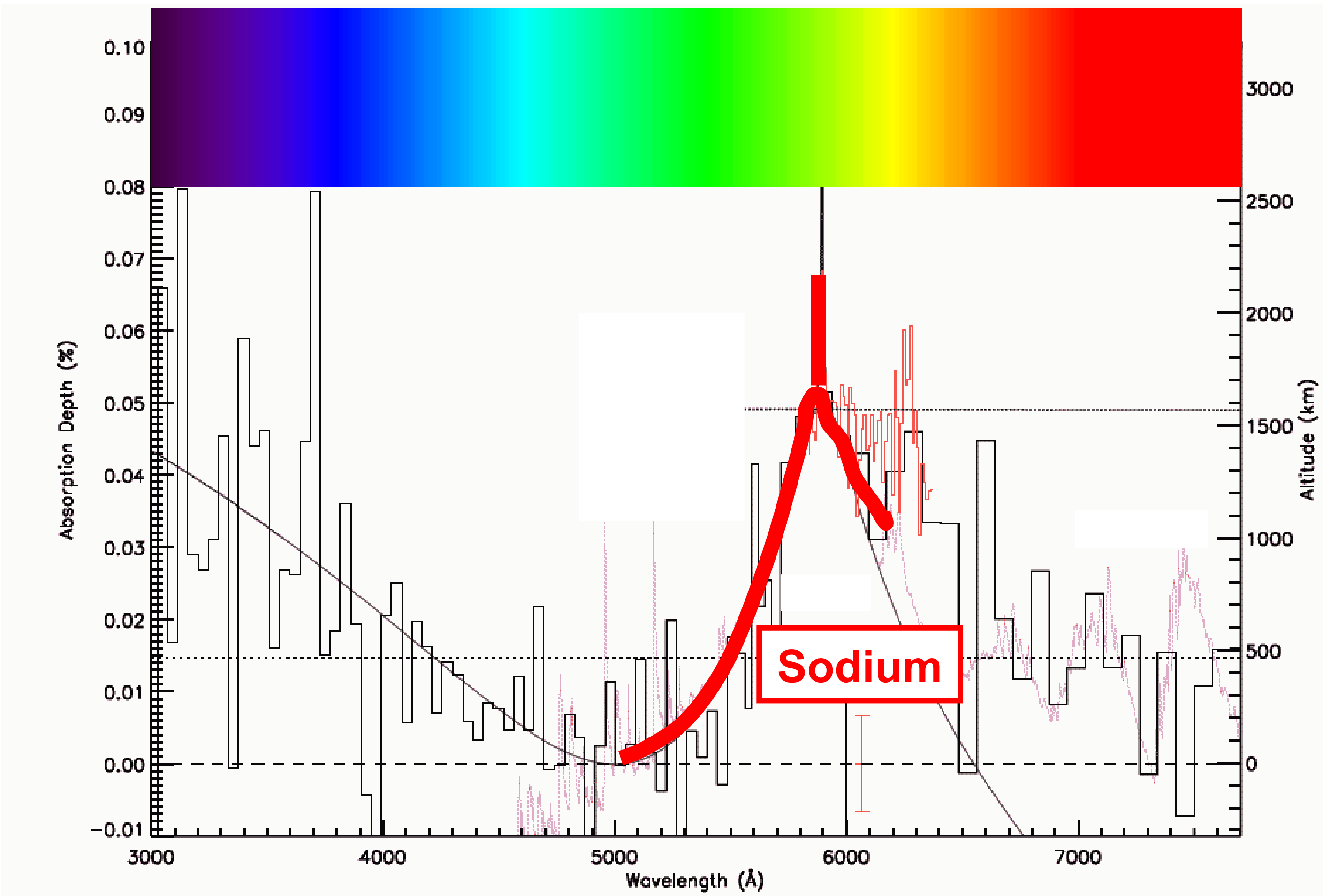

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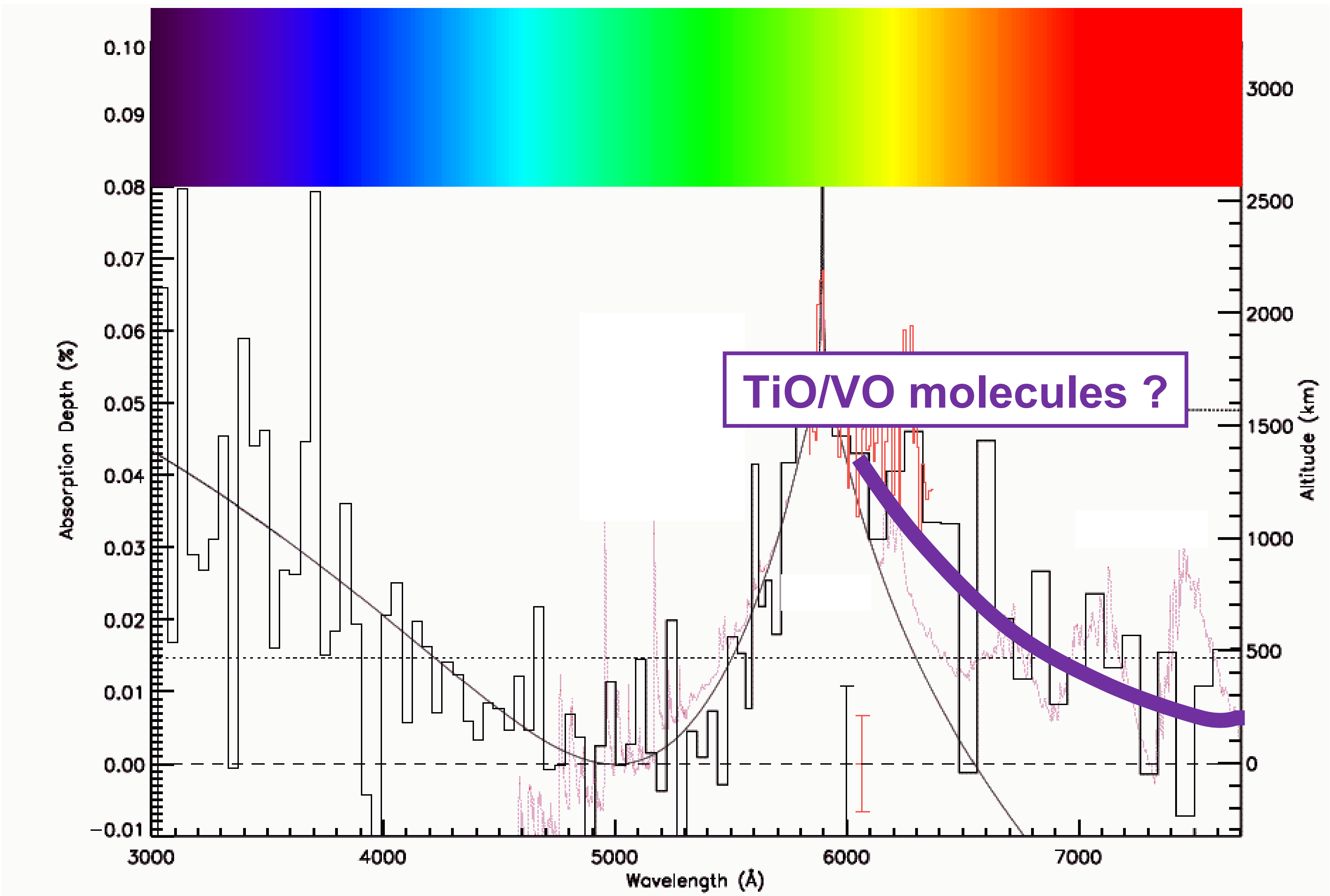
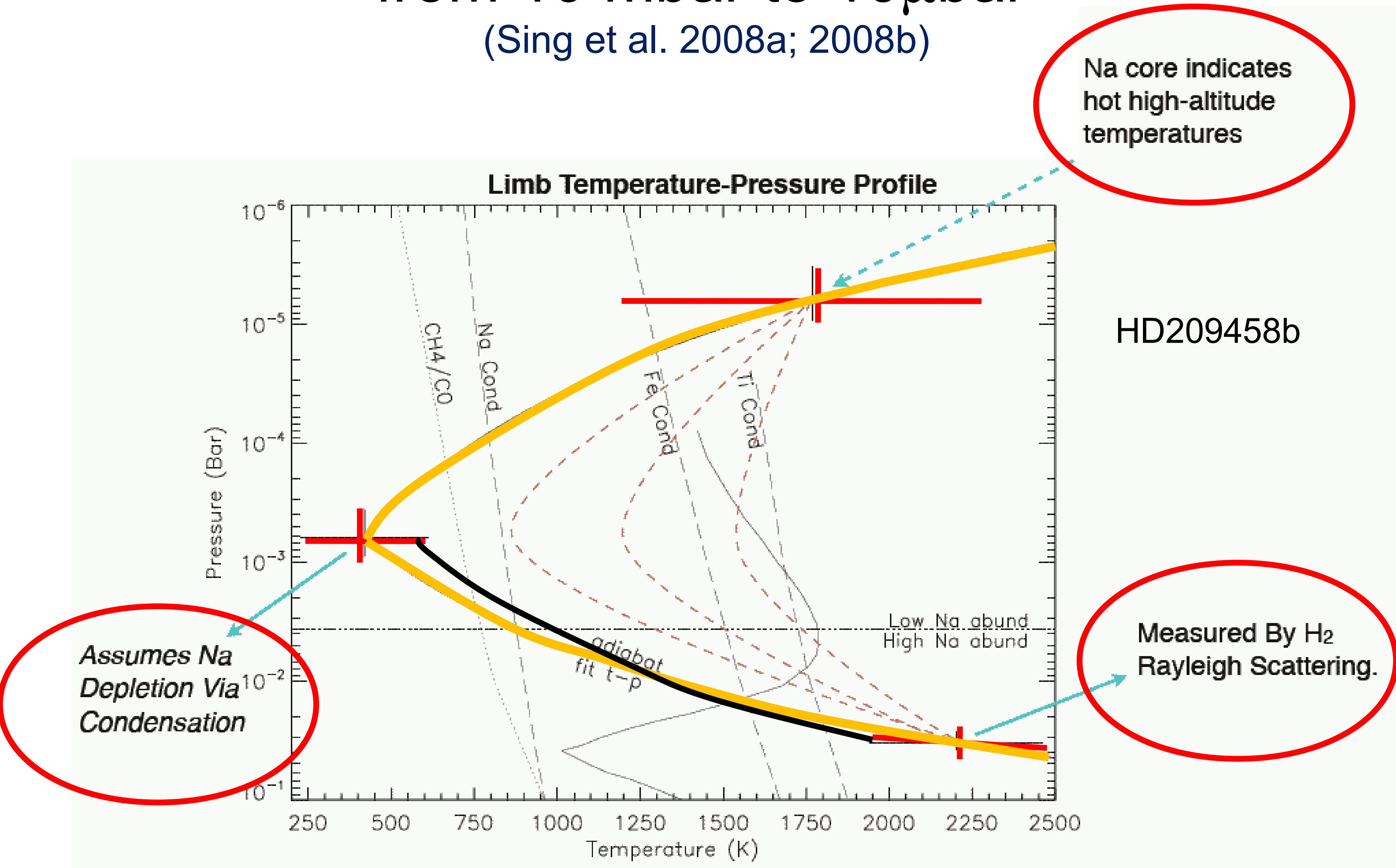


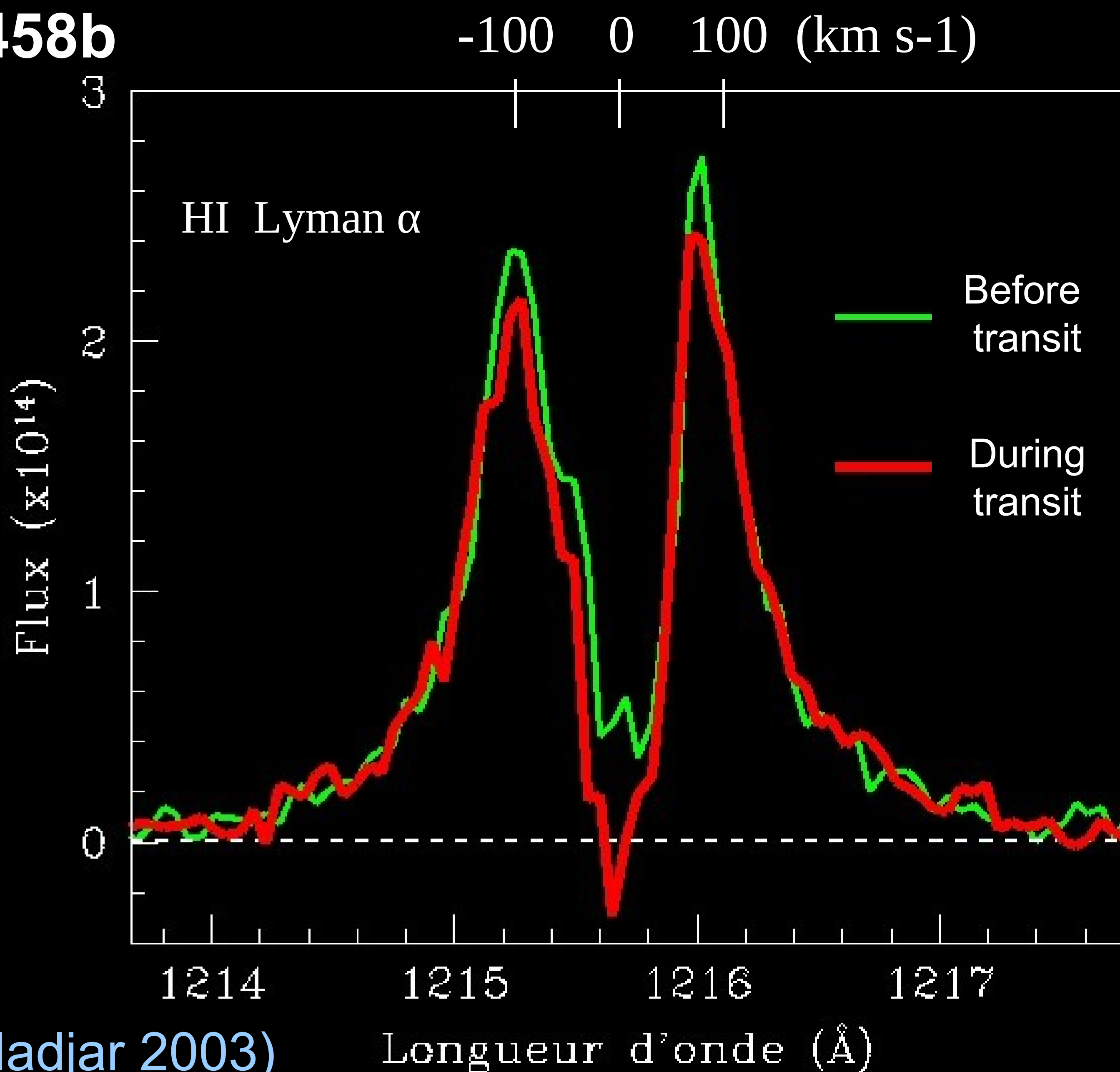
Temperature-Pressure Profile from 10 mbar to 10μbar

(Sing et al. 2008a; 2008b)

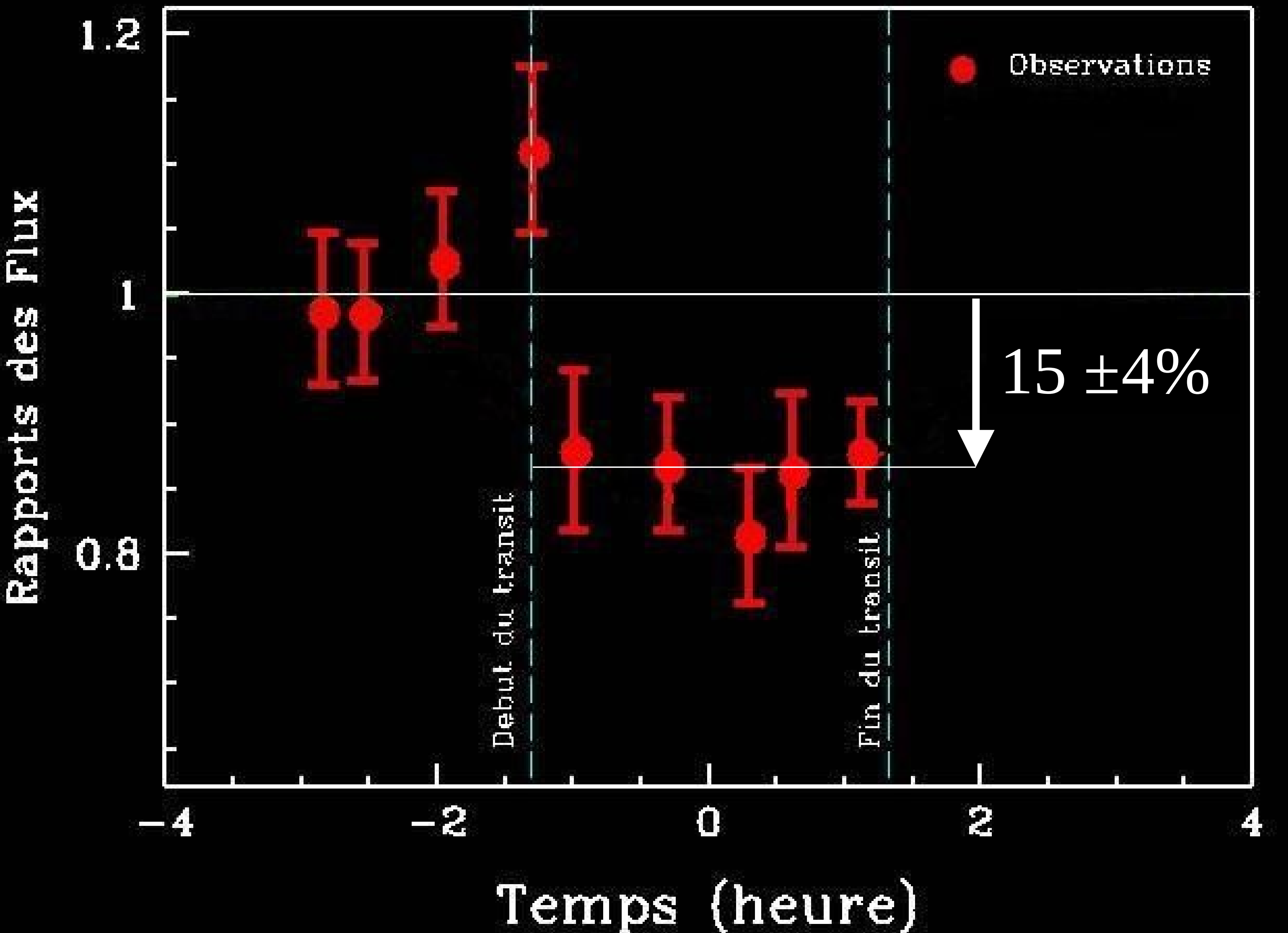


Hydrogen in Lyman-alpha

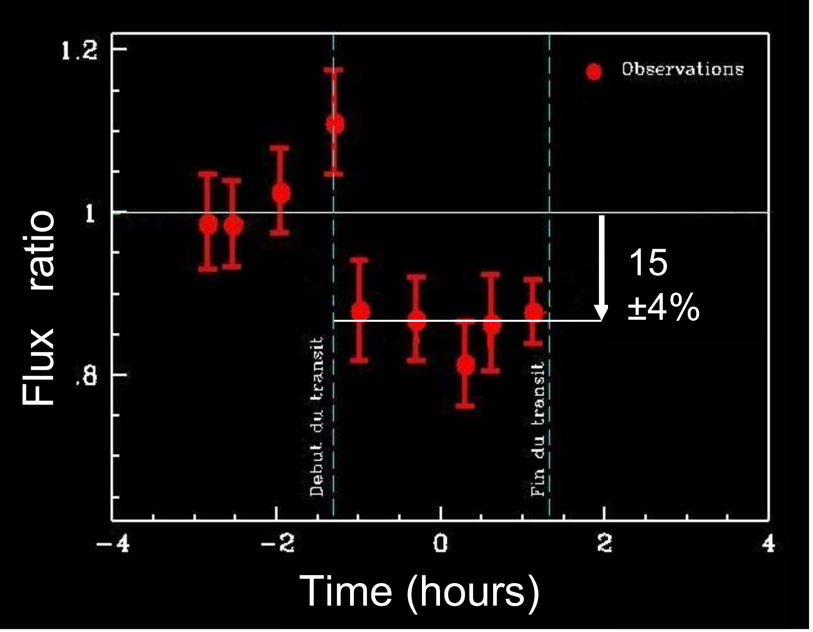
HD 209458b



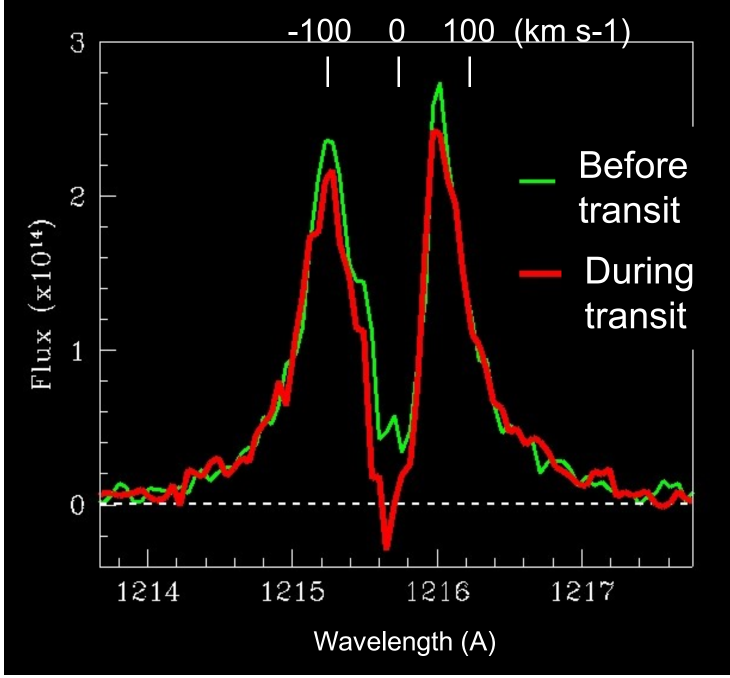
(Vidal-Madjar 2003)



Observations
1.2
1
0.8
Rapports des Flux
15 ±4%
Debut du transit
Fin du transit
−4
−2
0
2
4
Temps (heure)



2 constraints:



- Absorption of 15%

HD209458b radius 1.35 R_{Jupiter} → Absorption = 1.4 %

Filled Roche Lobe 3.6 R_{Jupiter} → Absorption = 10 %

Hydrogen 4.3 R_{Jupiter} → Absorption = 15 %

→ Beyond the Roche Lobe ➔ **Hydrogen is escaping**

- Absorption: $|V_{\mathrm{blue}}| \geq$ 100 km/s

V_{esc} = 43 km/s

→ Beyond the escape velocity ➔ **Hydrogen is escaping**

➔ The planet is evaporating

Estimation of the escape rate

(Vidal-Madjar et al. 2003; Lecavelier des Etangs et al. 2004, 2009)

N-body Particle simulation:

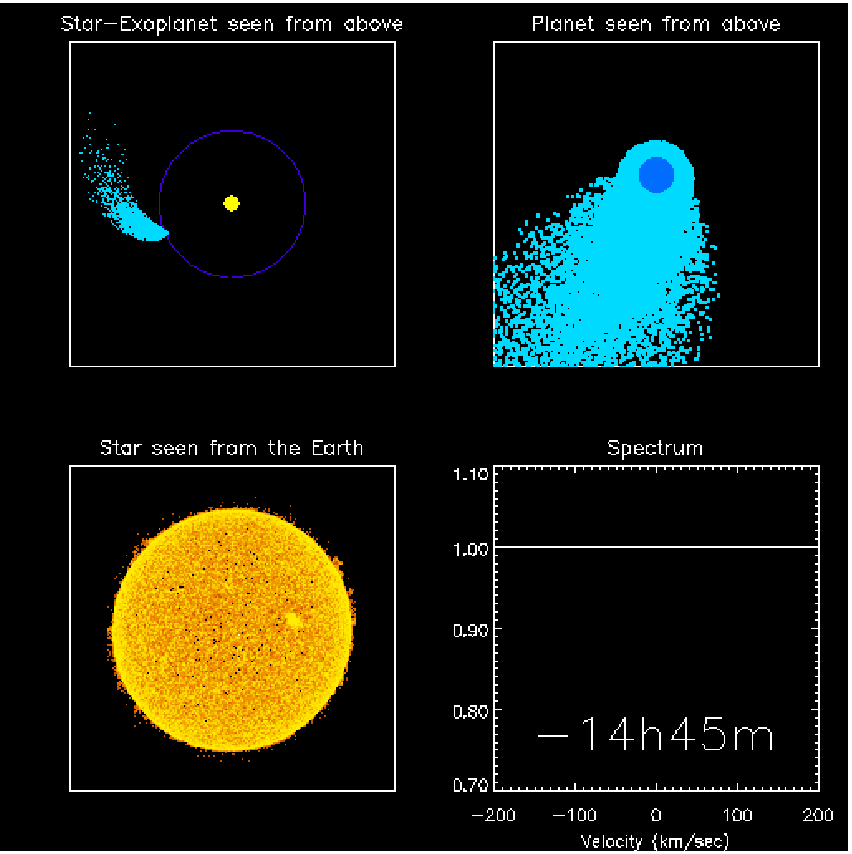
- Both planetary and stellar gravity taken into account
- Hydrogen atoms sensitive to stellar radiation pressure:

  - radiation pressure as a function of the radial velocity
  - extinction of Ly-α within the escaping hydrogen cloud
- Neutral hydrogen ionized by EUV photons

Estimation of the escape rate

(Vidal-Madjar et al. 2003; Lecavelier des Etangs et al. 2004, 2009)

N-body Particle simulation:



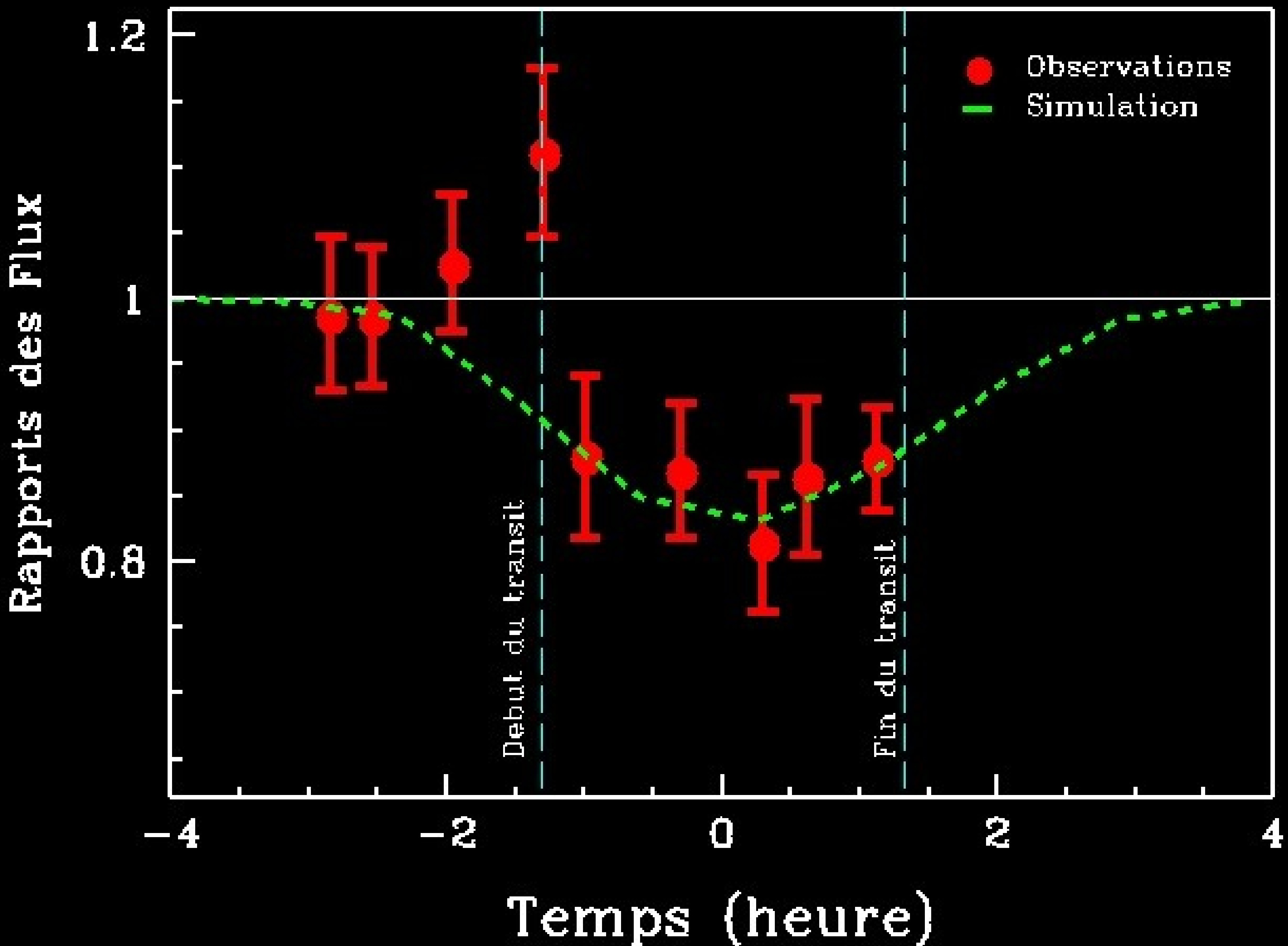
$\Delta F/F = 15\%$:

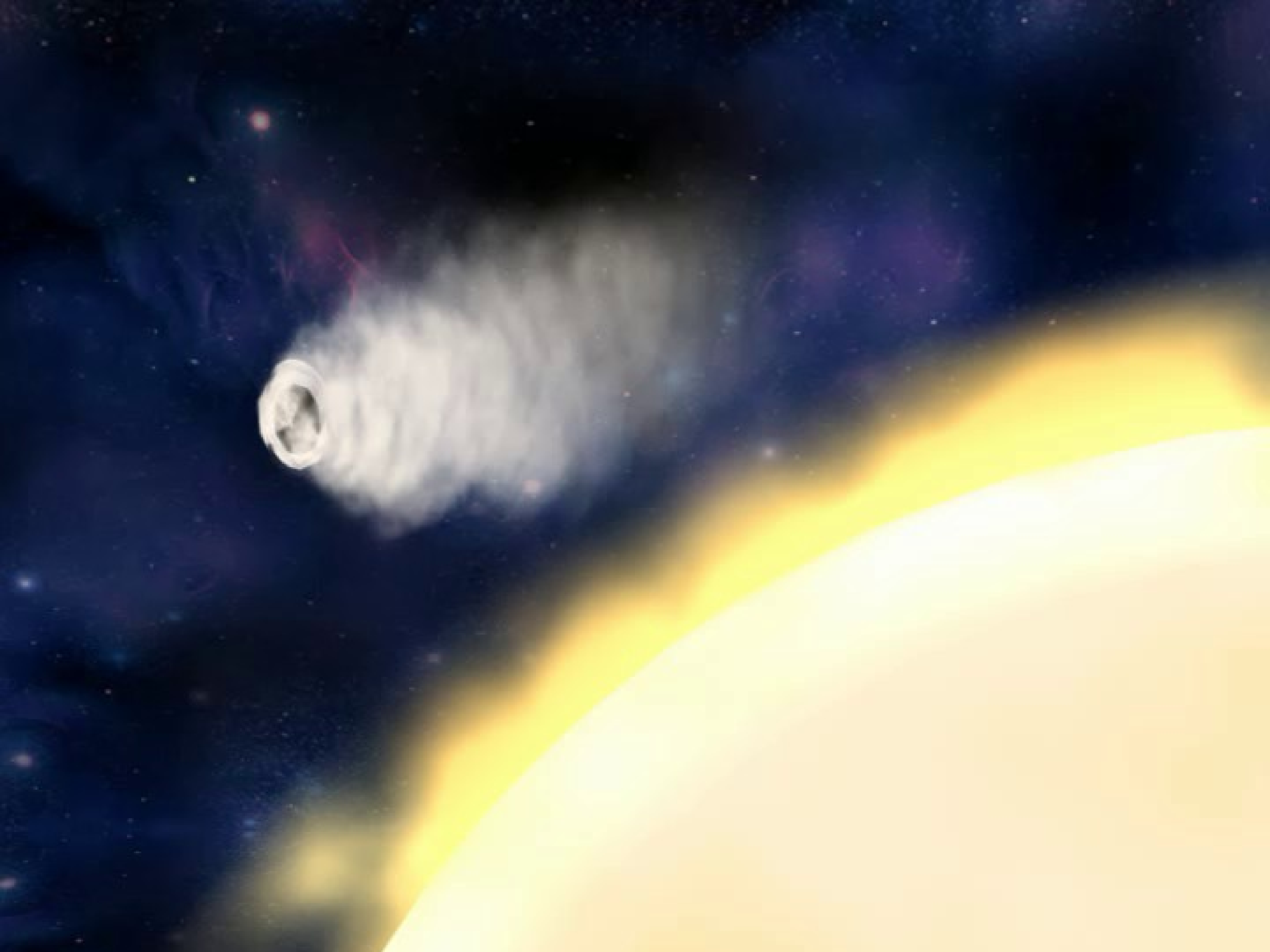
F_{EUV} =1 solar: $dM/dt \sim 10^{9.5}$ g/s

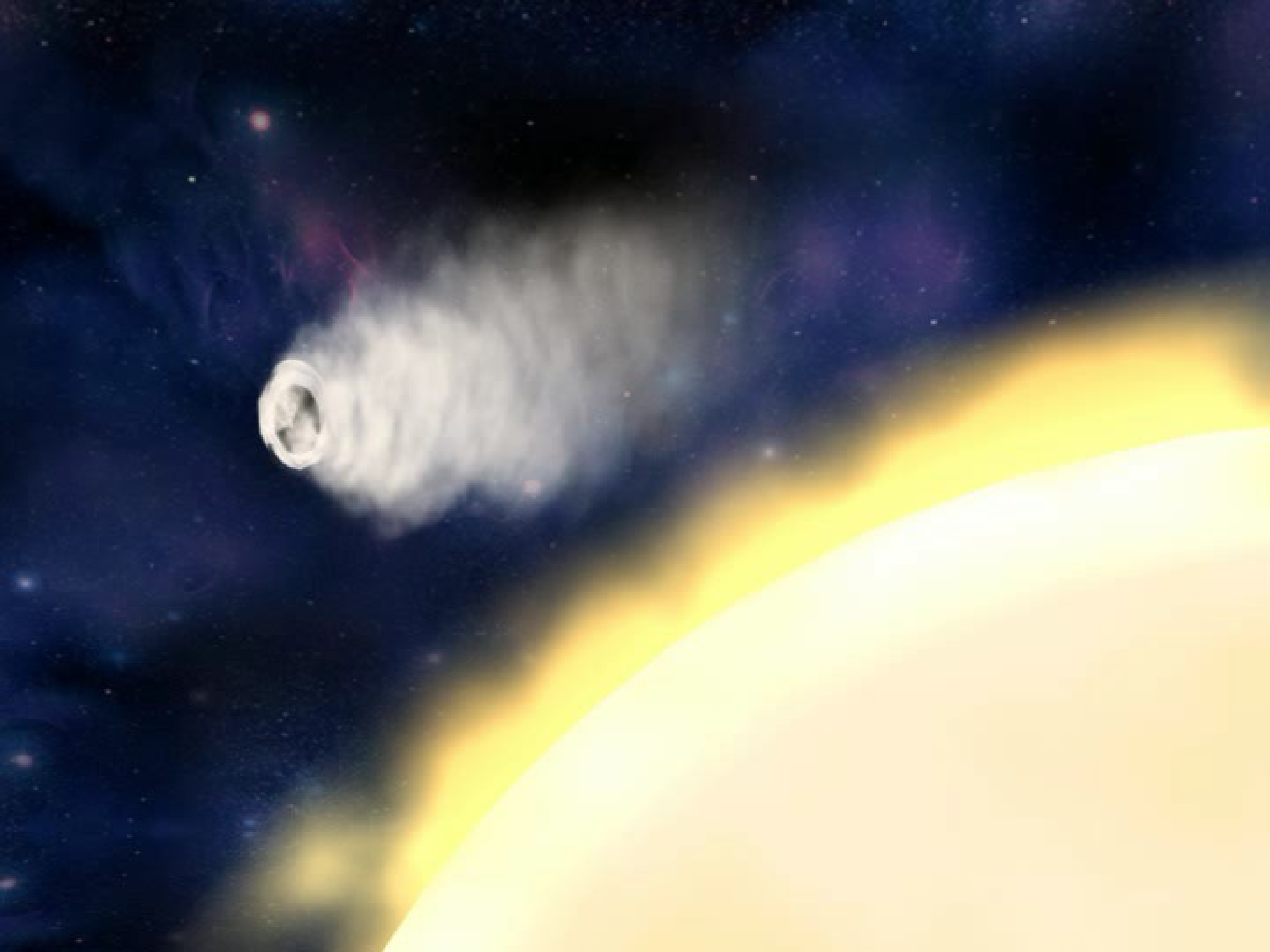
F_{EUV} =2 solar: $dM/dt \sim 10^{10.5}$ g/s

F_{EUV} =4 solar: $dM/dt \sim 10^{11.5}$ g/s

Escape rate $\geq 10^{10}$ g/s

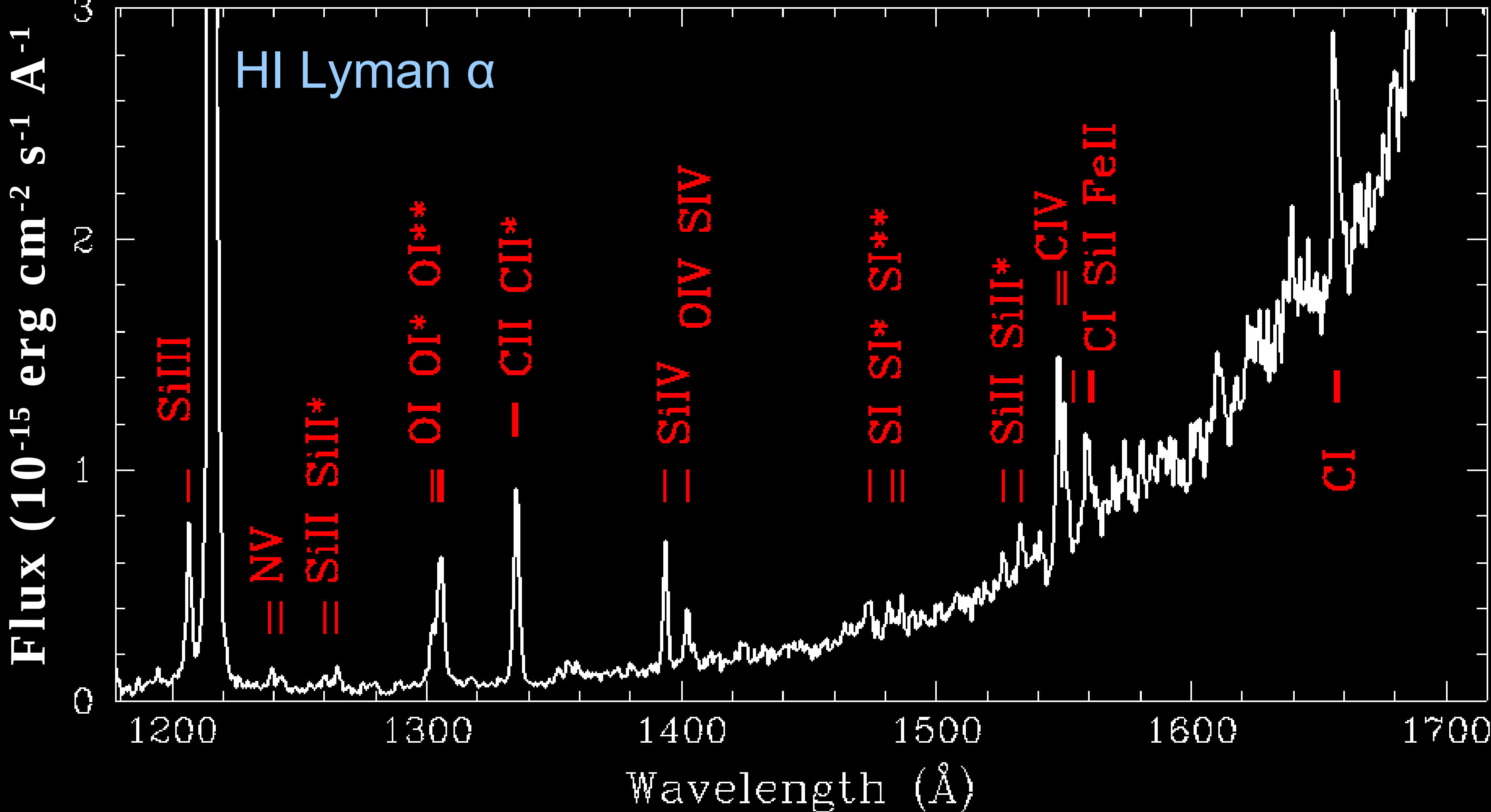




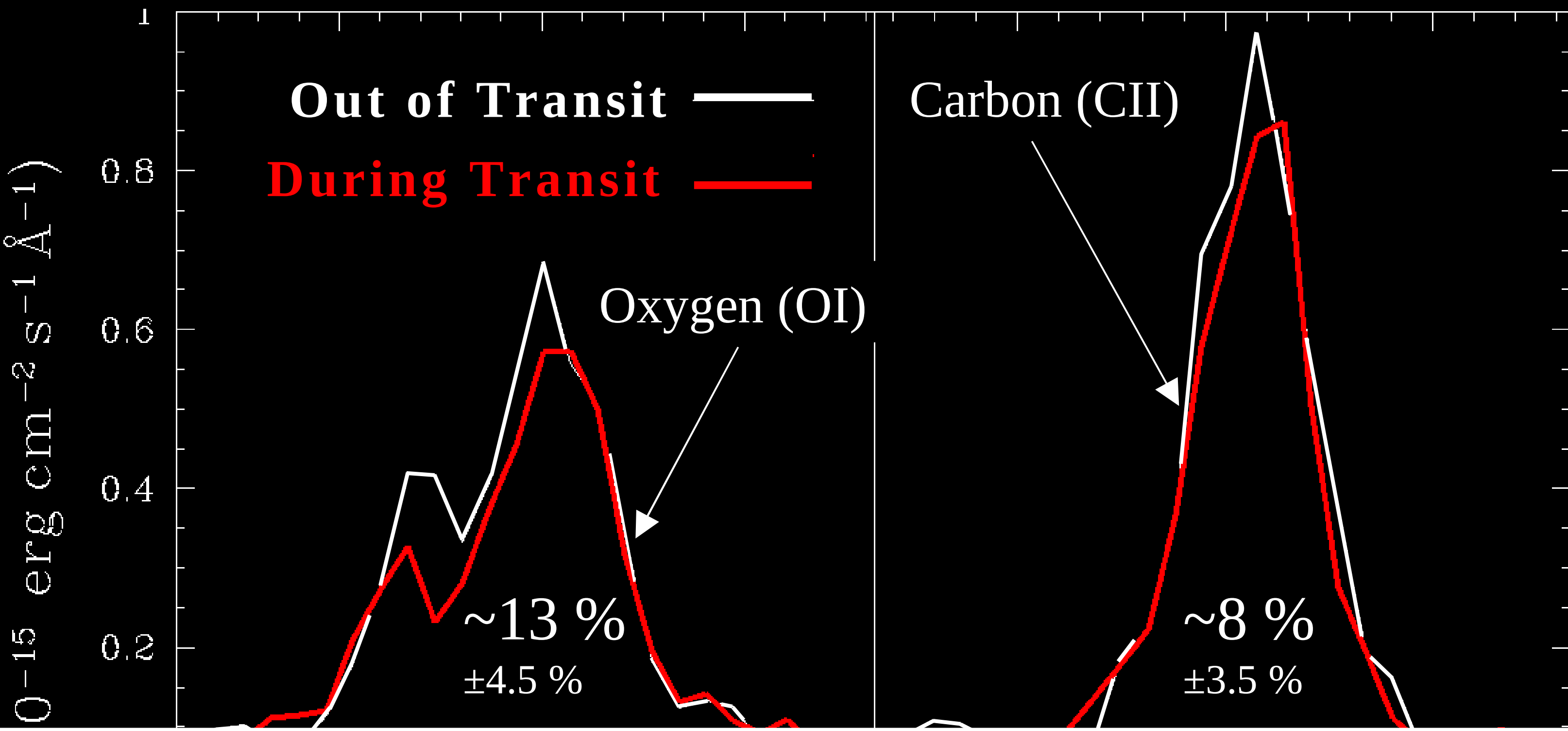


Broad band HST observations in UV

(Vidal-Madjar et al. 2004)



Detection of Carbon and Oxygen



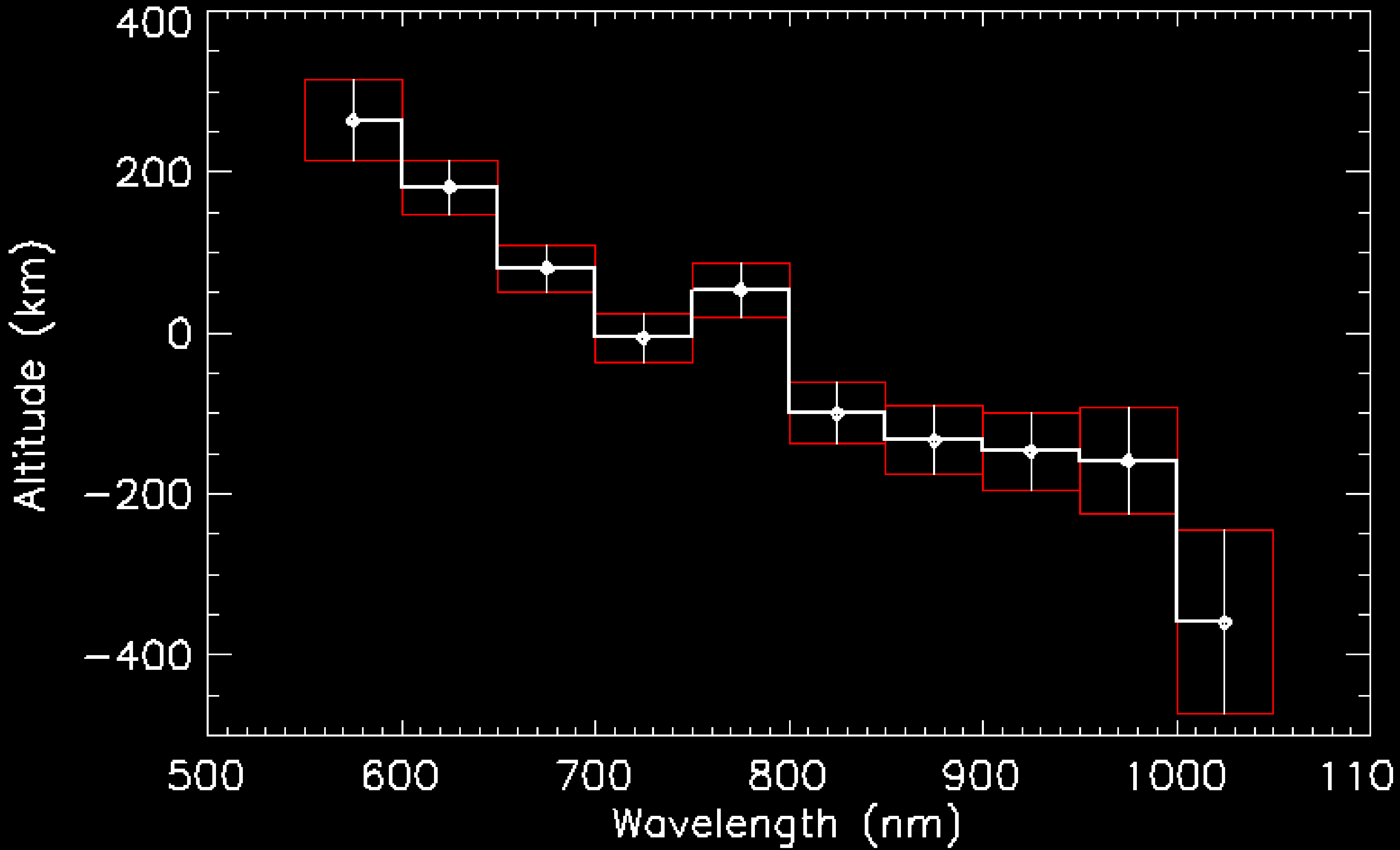
➔ Blow-off of the atmosphere (hydrodnamical escape)

HD 189733b : an exceptional target for extrasolar atmosphere studies

discovered at « Observatoire de Haute Provence »
(Bouchy *et al.*, octobre 2005)

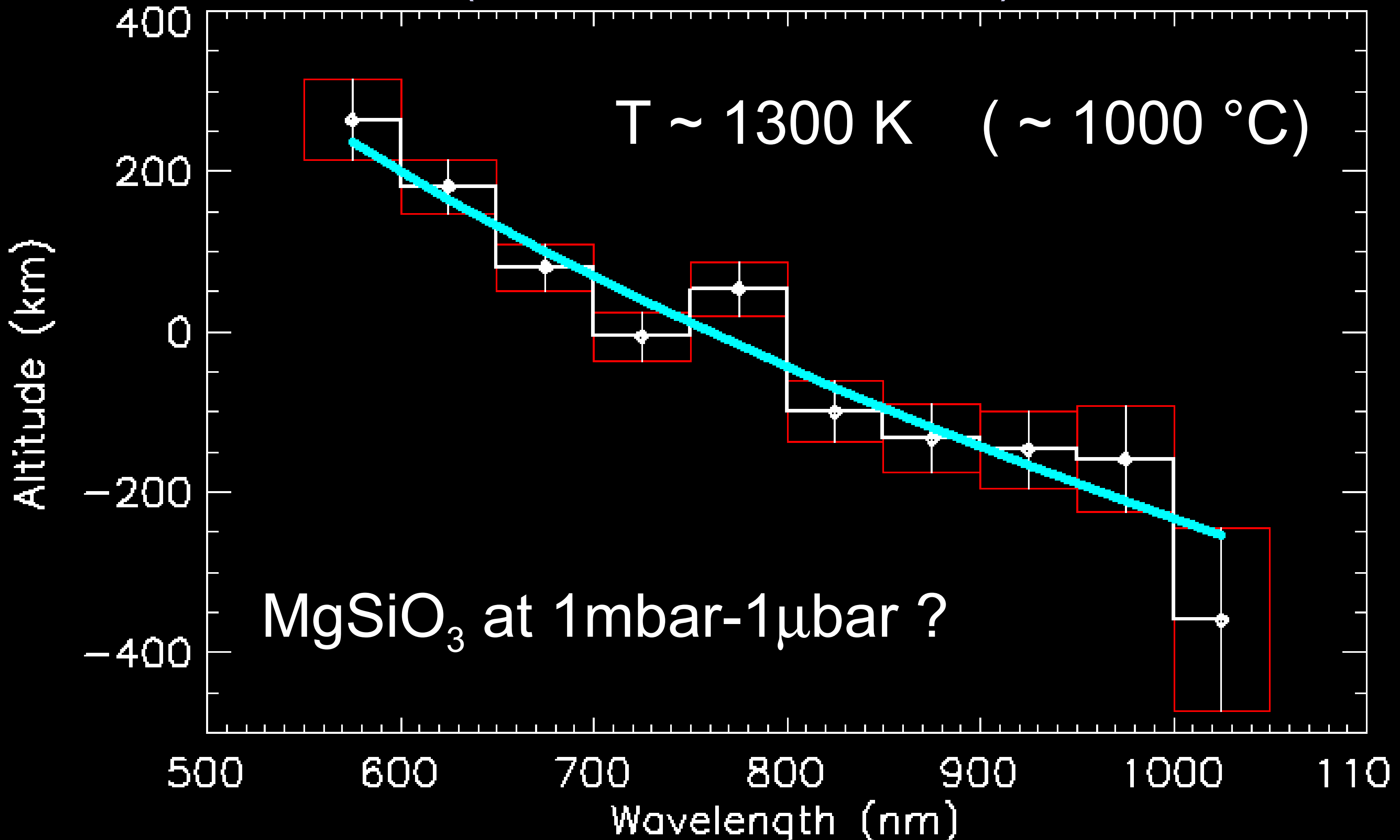
Absorption spectrum of HD189733b : Haze

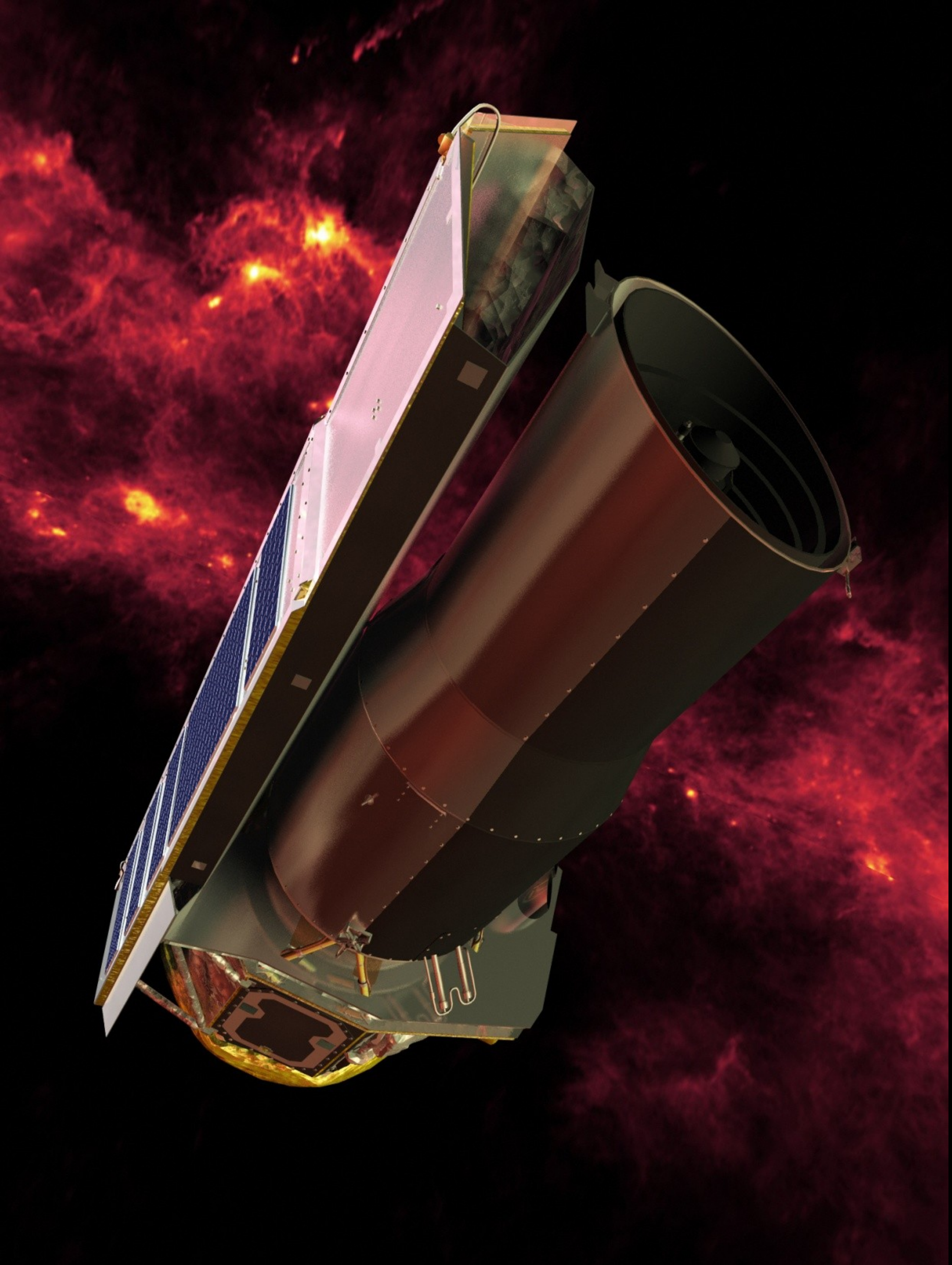
(Lecavelier et al. 2008a)



Absorption spectrum of HD189733b : Haze

(Lecavelier et al. 2008a)



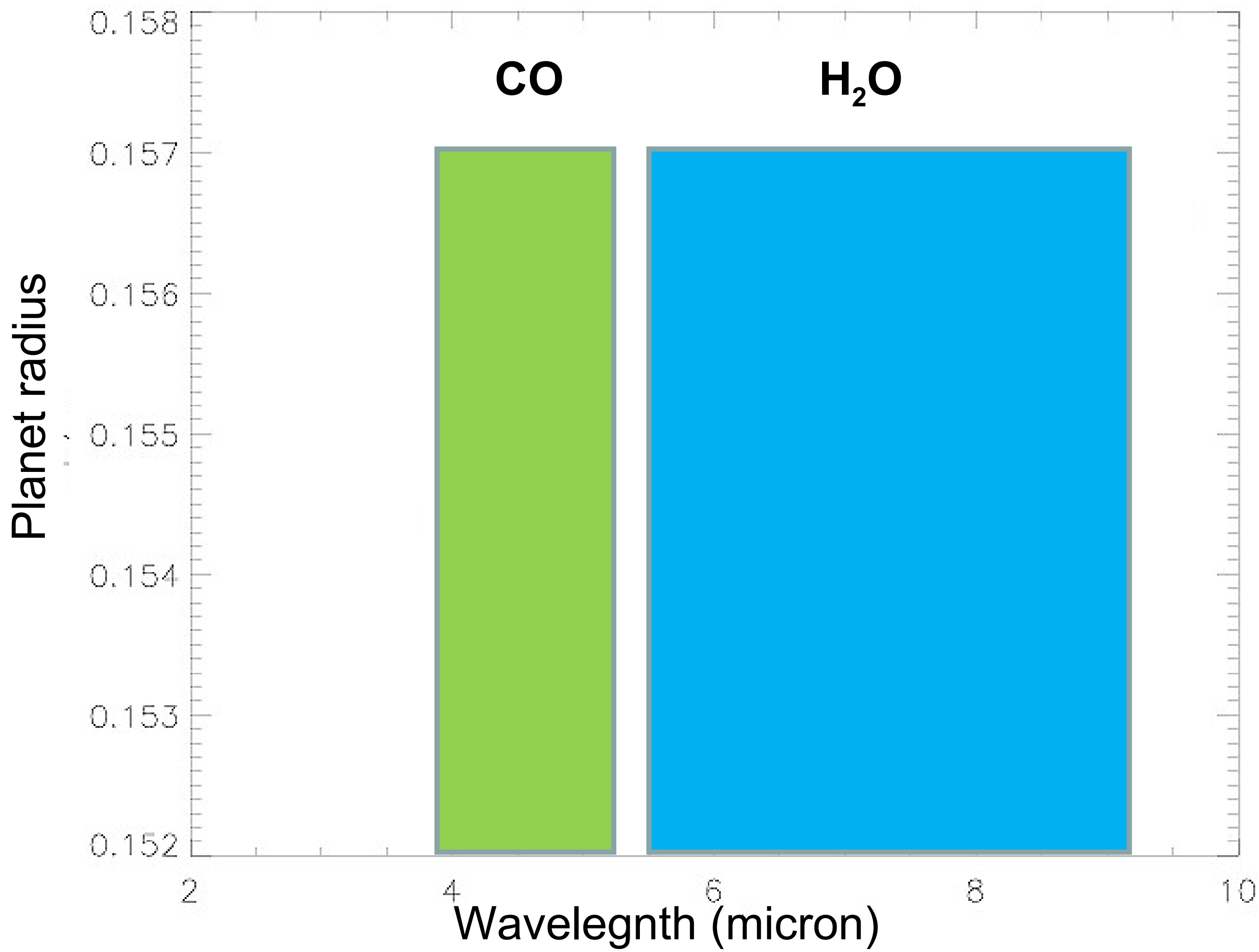


Emission and
Absorption
from extrasolar
planets atmosphere

with
The *Spitzer* infrared
space observatory

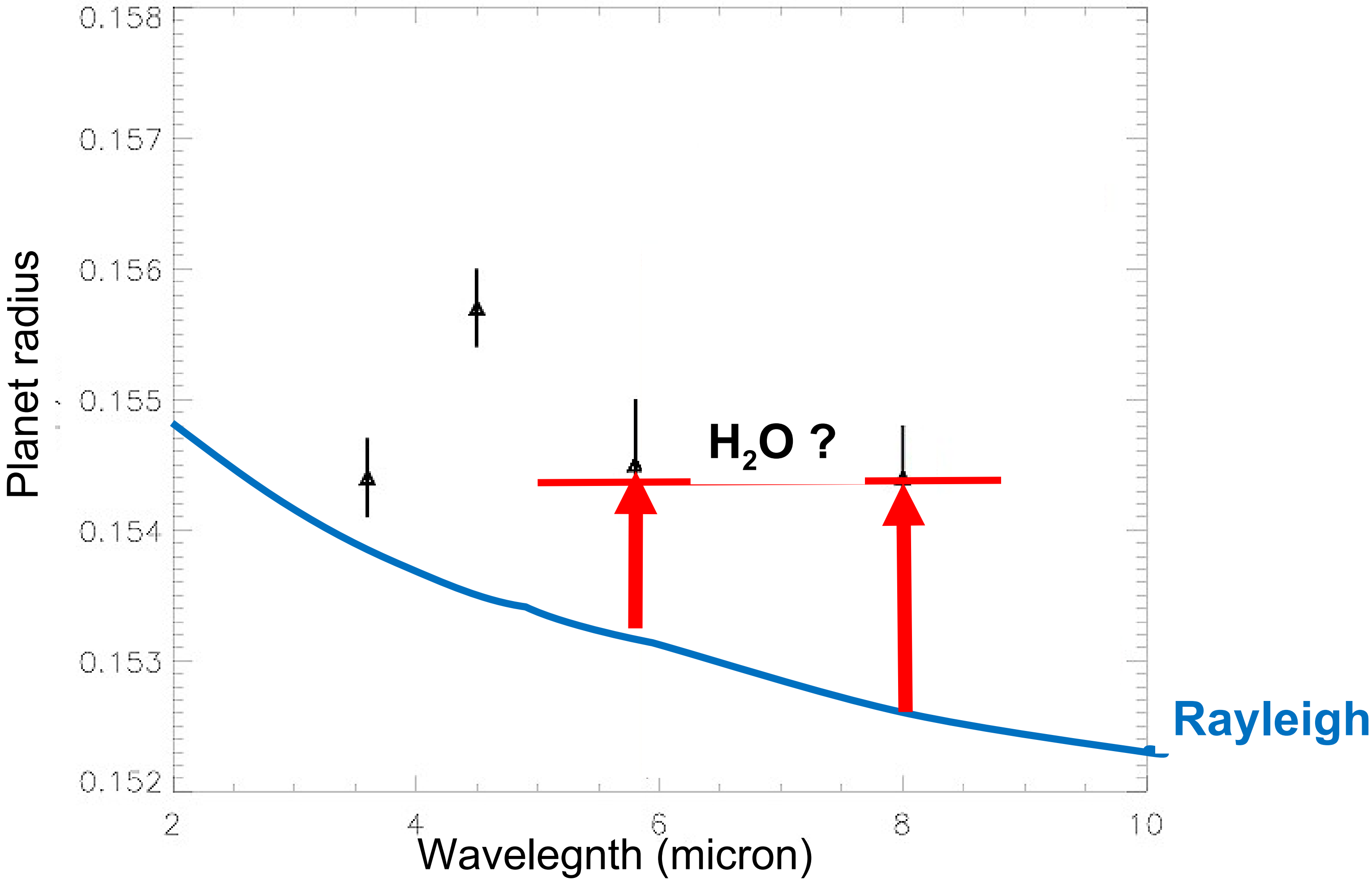
Spitzer observations of HD189733b

(Désert et al. 2008)



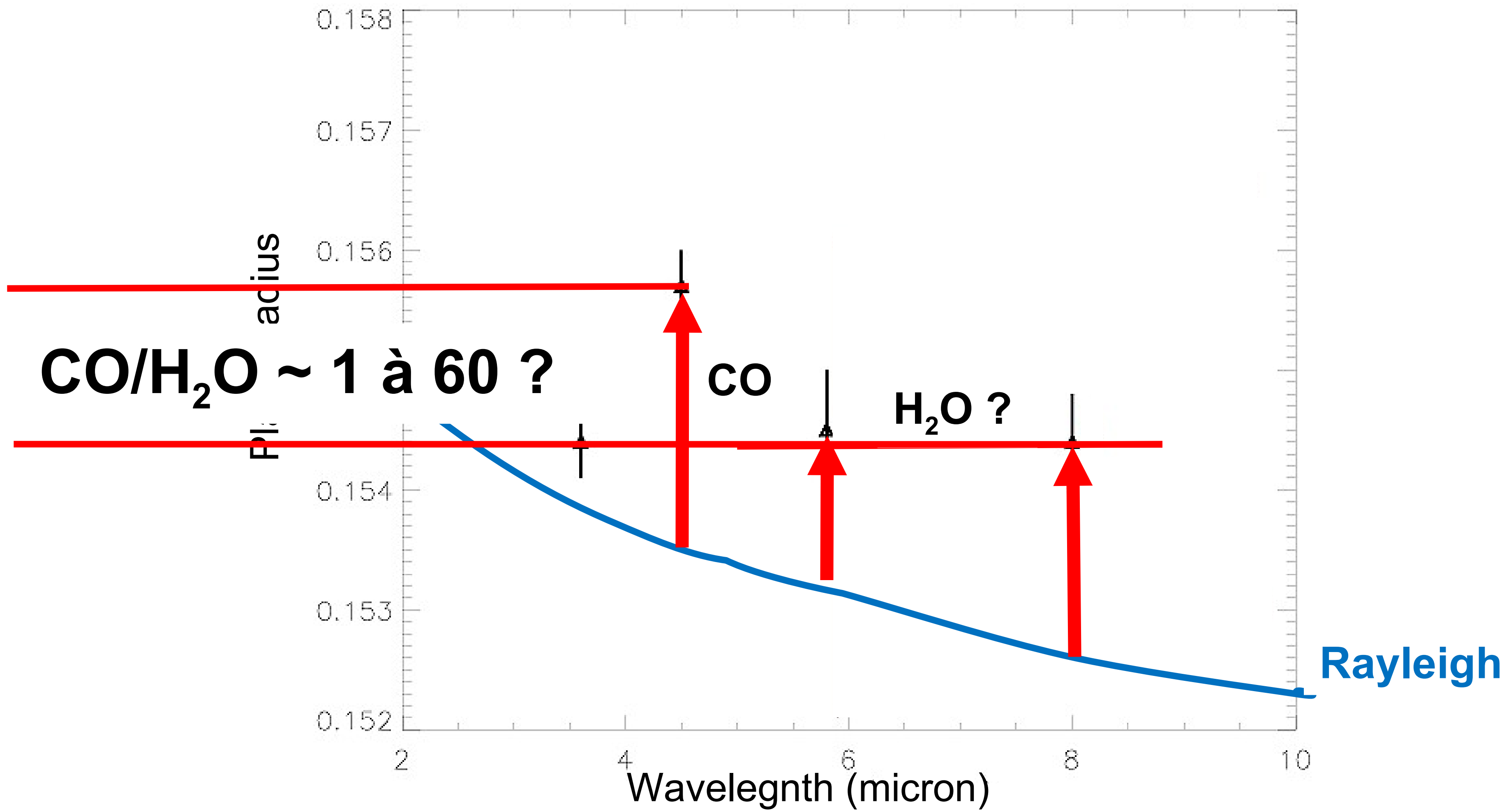
Spitzer observations of HD189733b

(Désert et al. 2008)

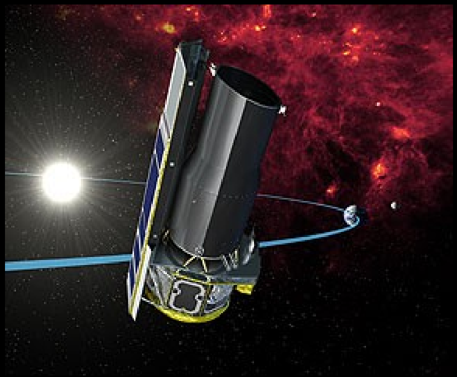


Spitzer observations of HD189733b

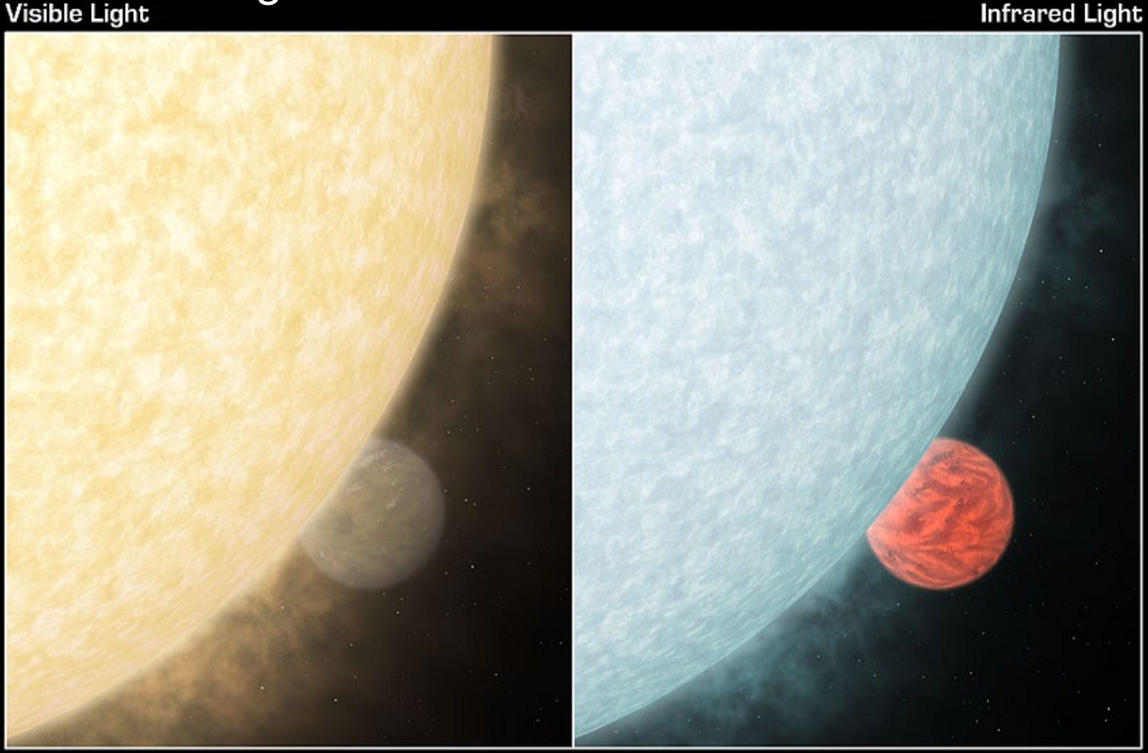
(Désert et al. 2008)

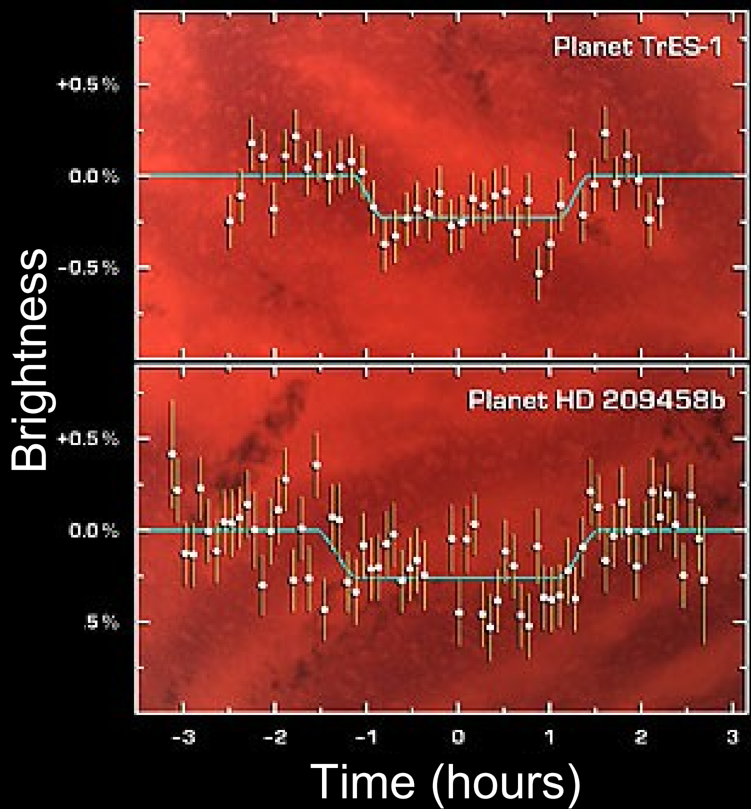


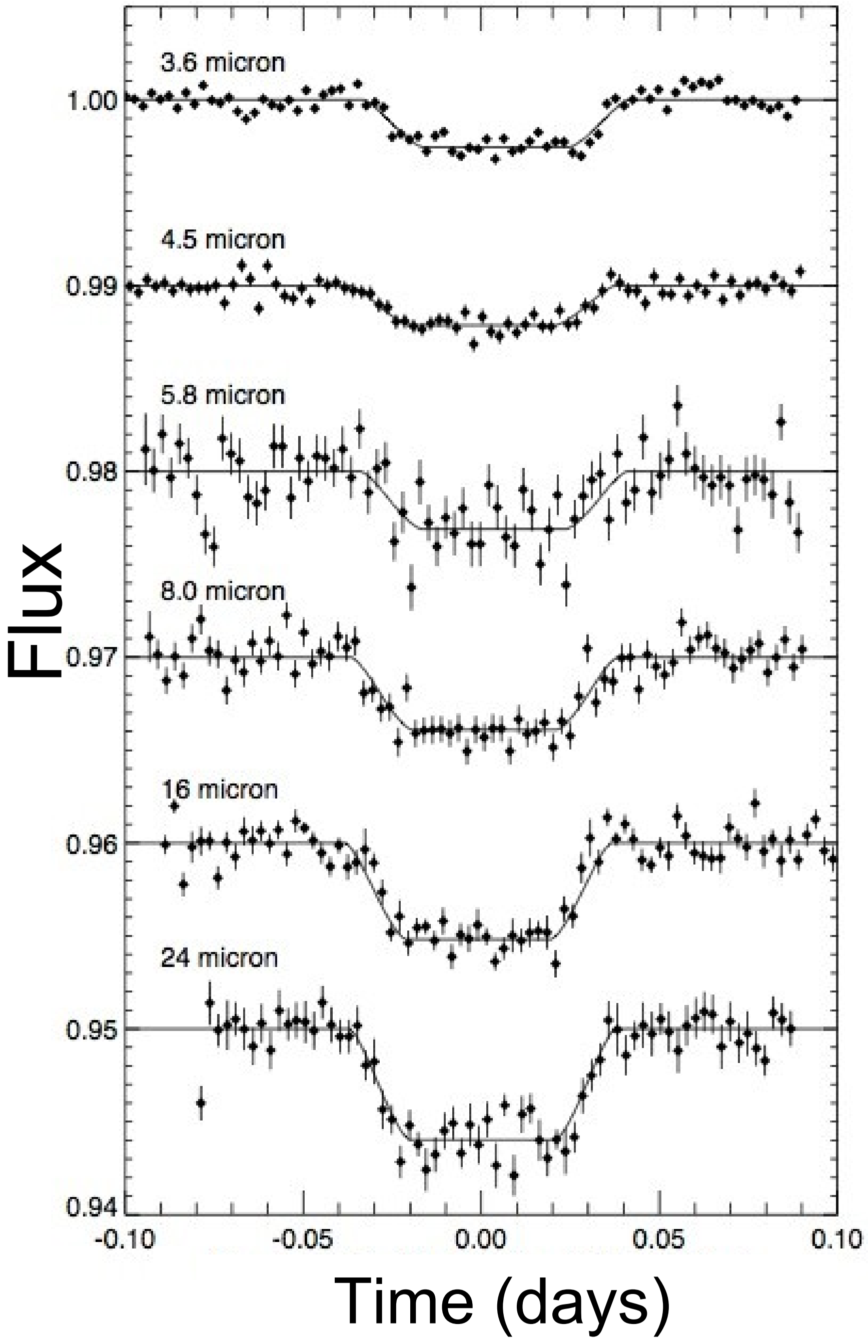
Secondary eclipses Observed with Spitzer



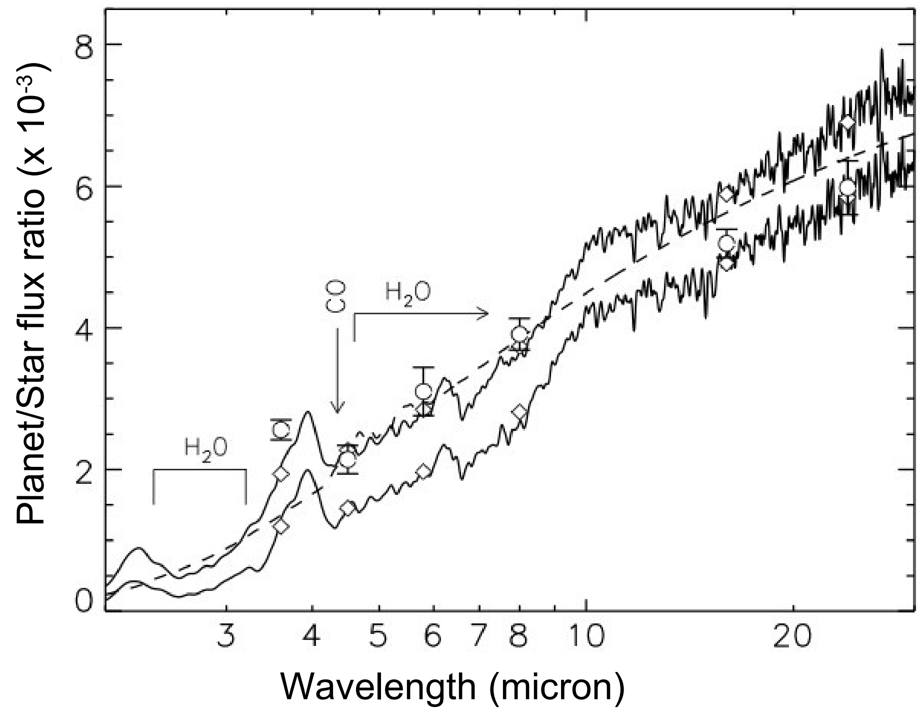
Reflected light in the Visible   Thermal emission in the IR







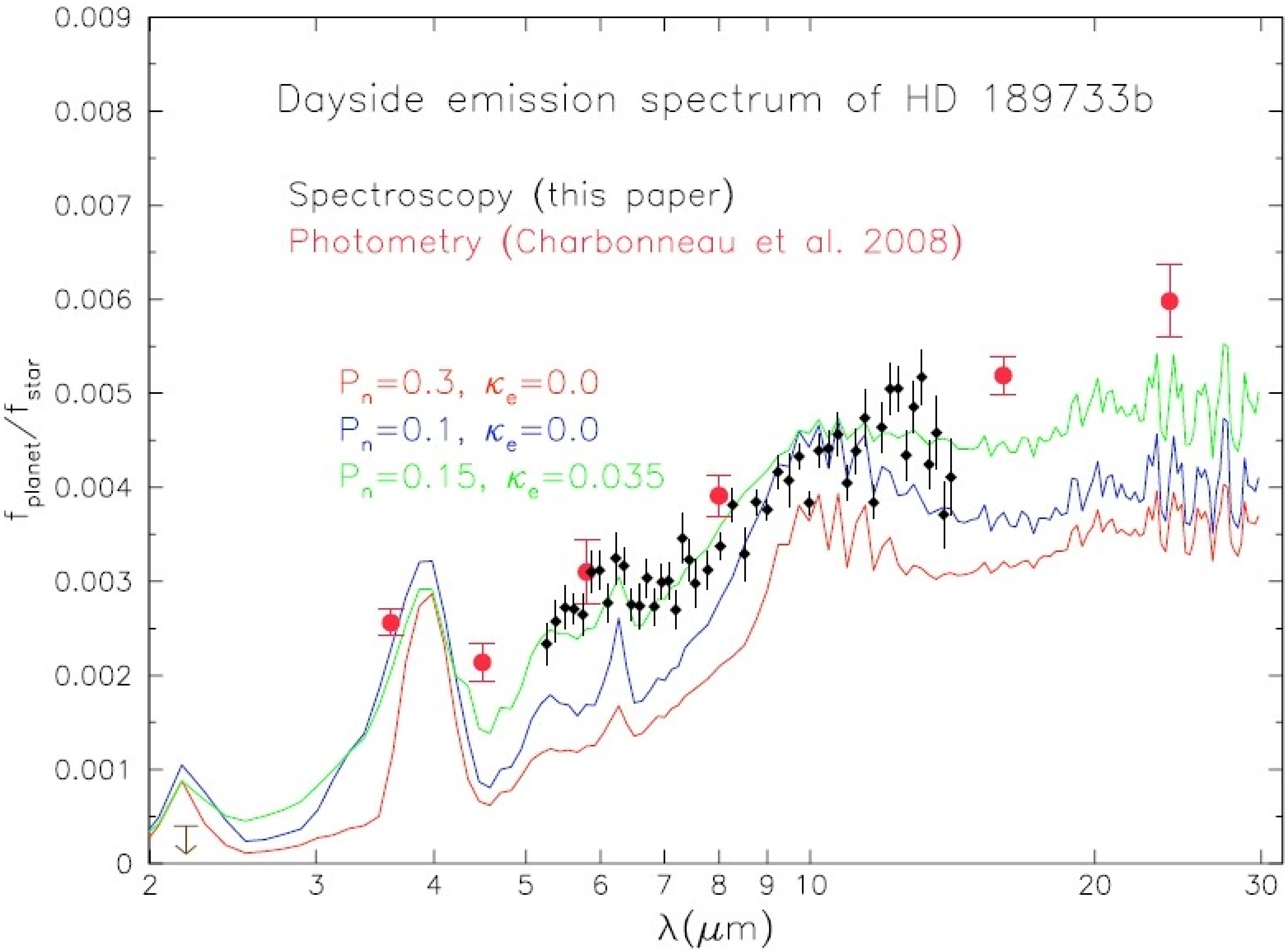
Emission Spectrum of HD189733b from secondary transit observations



(Grilllmair et al., Nature, 2008)

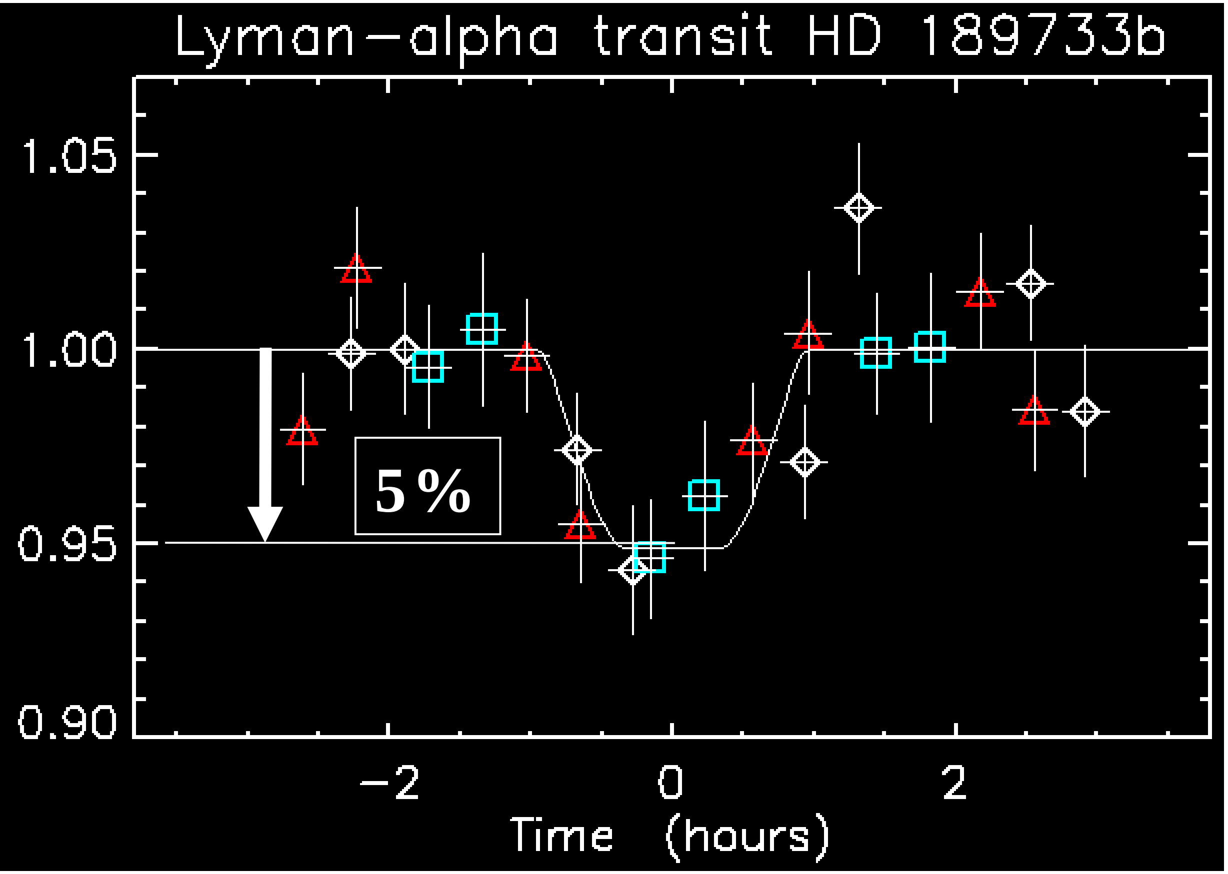
Eclipses of HD189733b with Spitzer infrared space telescope

(Grillmair et al. 2008)



HST/ACS Lyman-α observation of HD 189733b

(Lecavelier et al. 2009)



Results:

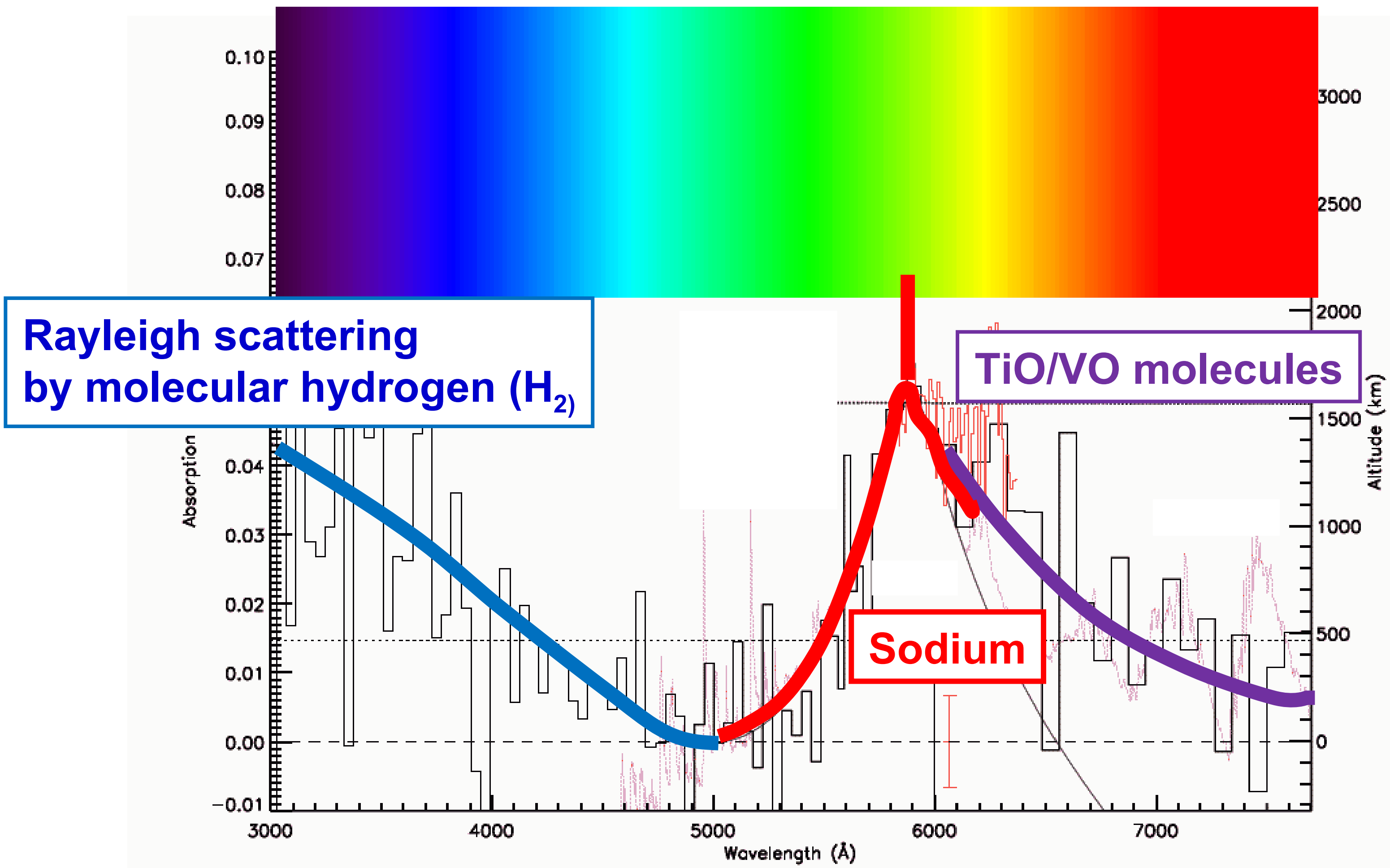
- Depth ~ 5.1 ± 0.7 %

⇒ dM/dt ~ 10^7-10^{10} g/s

New detection of the evaporation of an extrasolar planet.

HD209458b (Osiris): Atmosphere spectrum from near-UV to near-IR

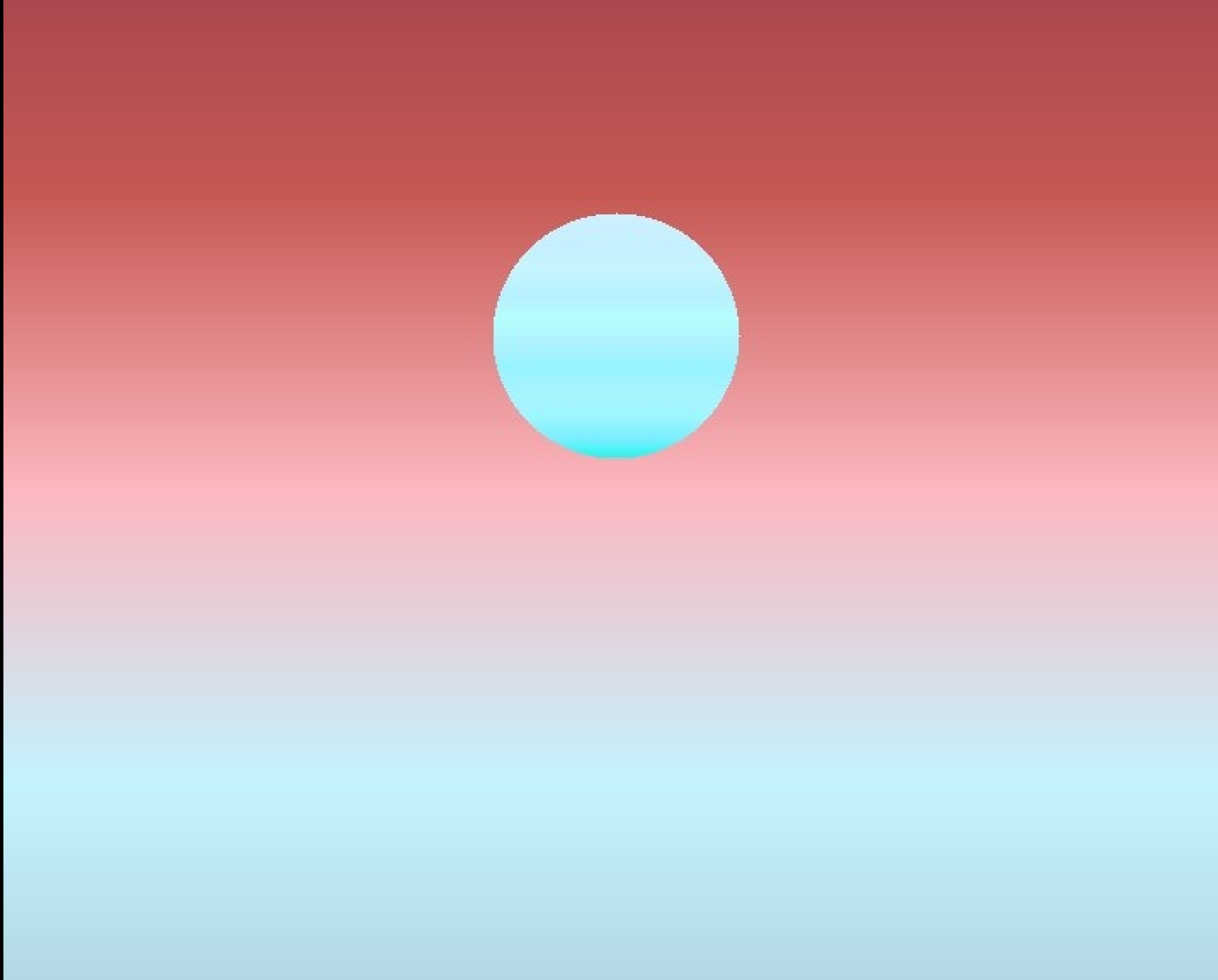
(Sing et al. 2008a, 2008b, Desert et al. 2008, Lecavelier et al. 2008)



HD 209458 b (Osiris): Atmospheric transmission is known from 3000 to 7500 Å

➔ Colors in the sky of Osiris can be calculated !!

A sunset seen from “Osiris”



The end