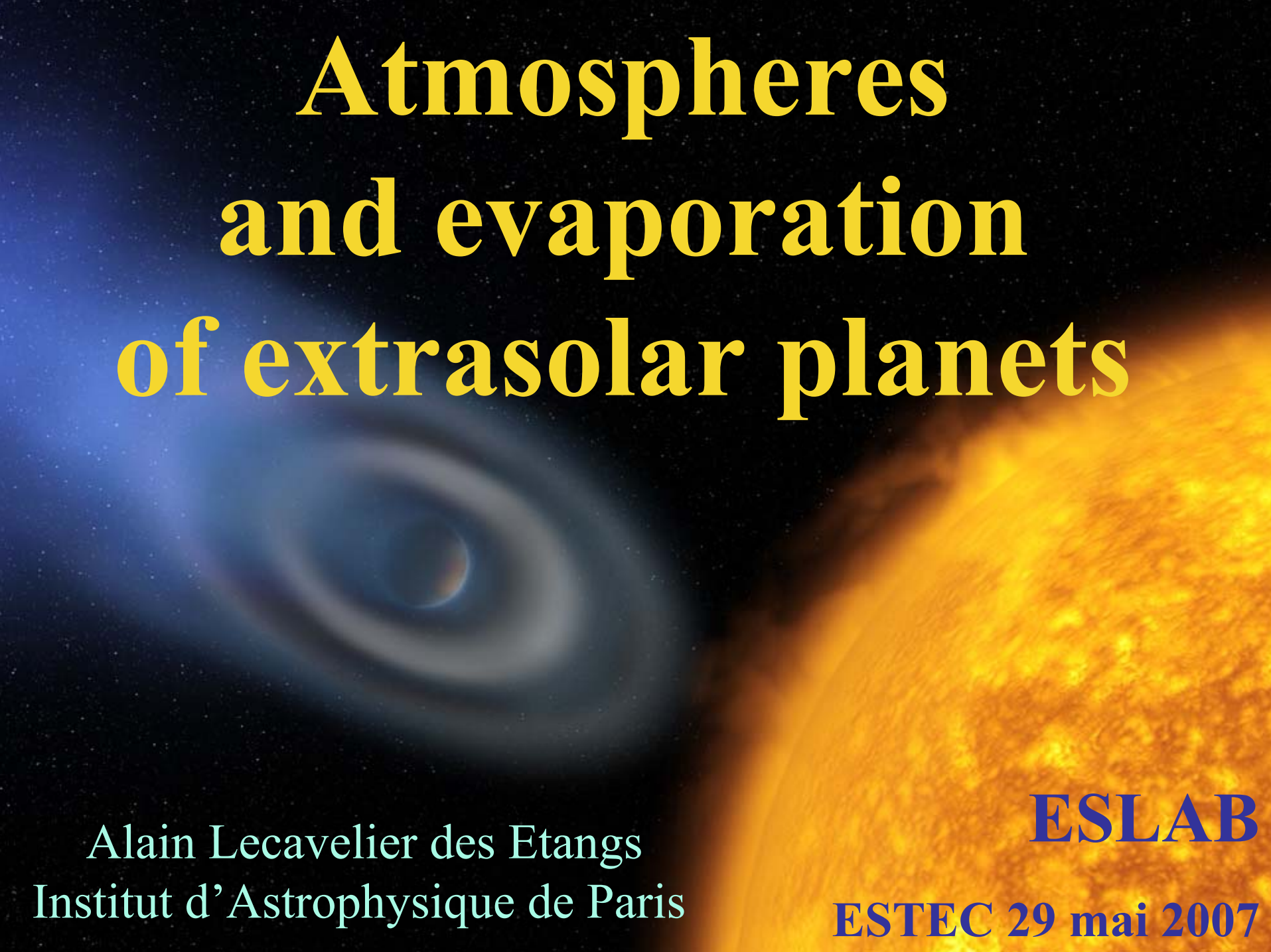
Atmospheres and evaporation of extrasolar planets



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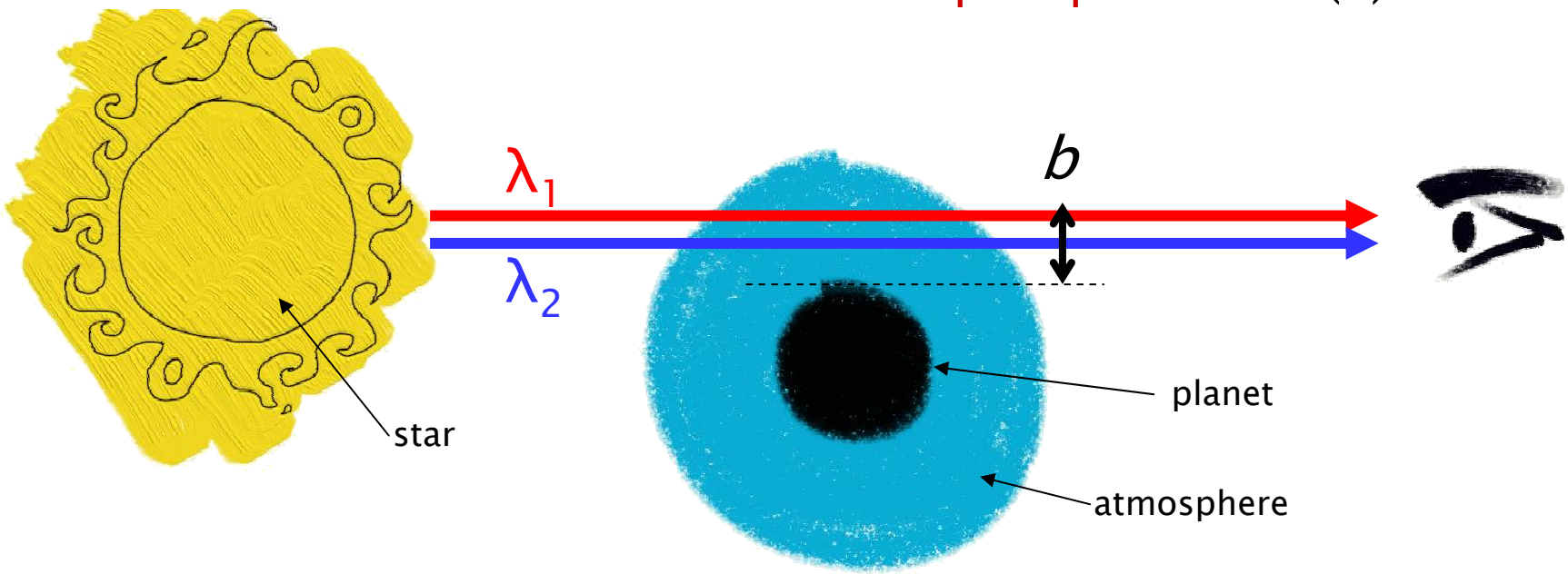
Institut d'Astrophysique de Paris

ESLAB

ESTEC 29 mai 2007

Absorption spectroscopy during transits

Light is absorbed
as a function of wavelength (λ)
and impact parameter (*b*)



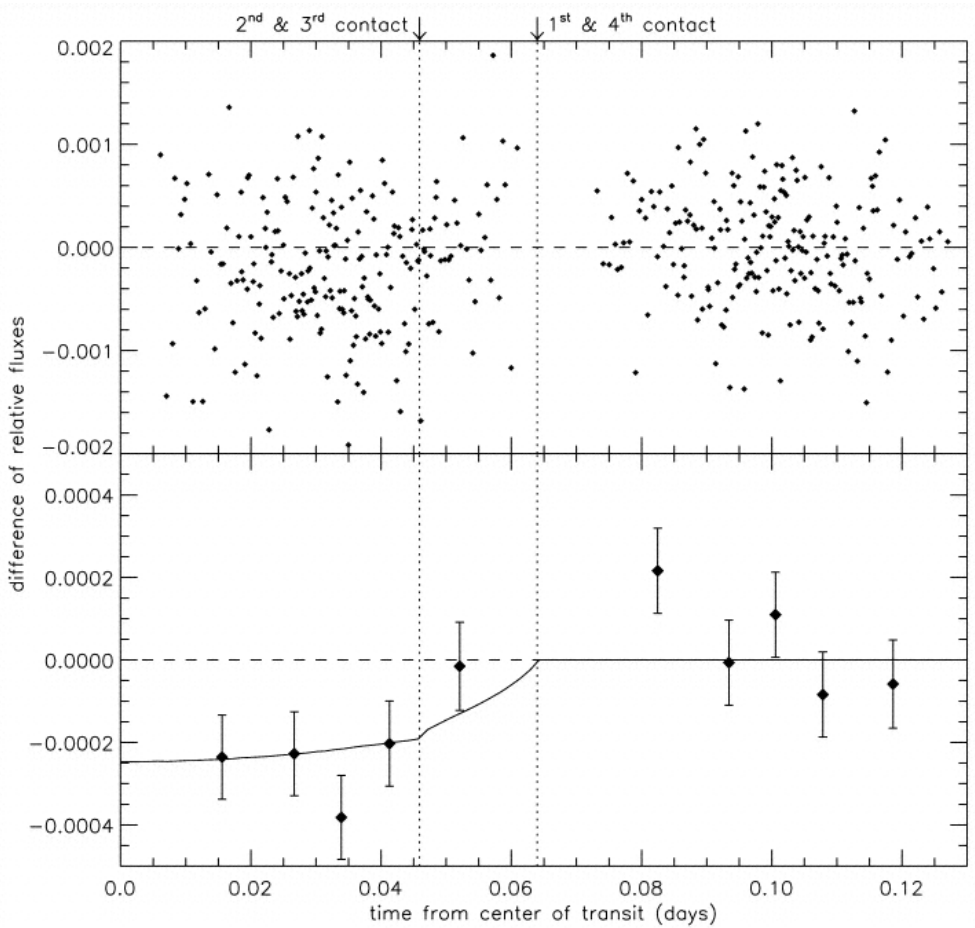
The planet looks larger when observed at highly absorbed wavelengths → $R_P = R_P(\lambda)$

Seager & Sasselov (2000)
Hubbard et al. (2001)
Brown (2001)

HD 209458b:

first detection of an extrasolar planet atmosphere (Na I)

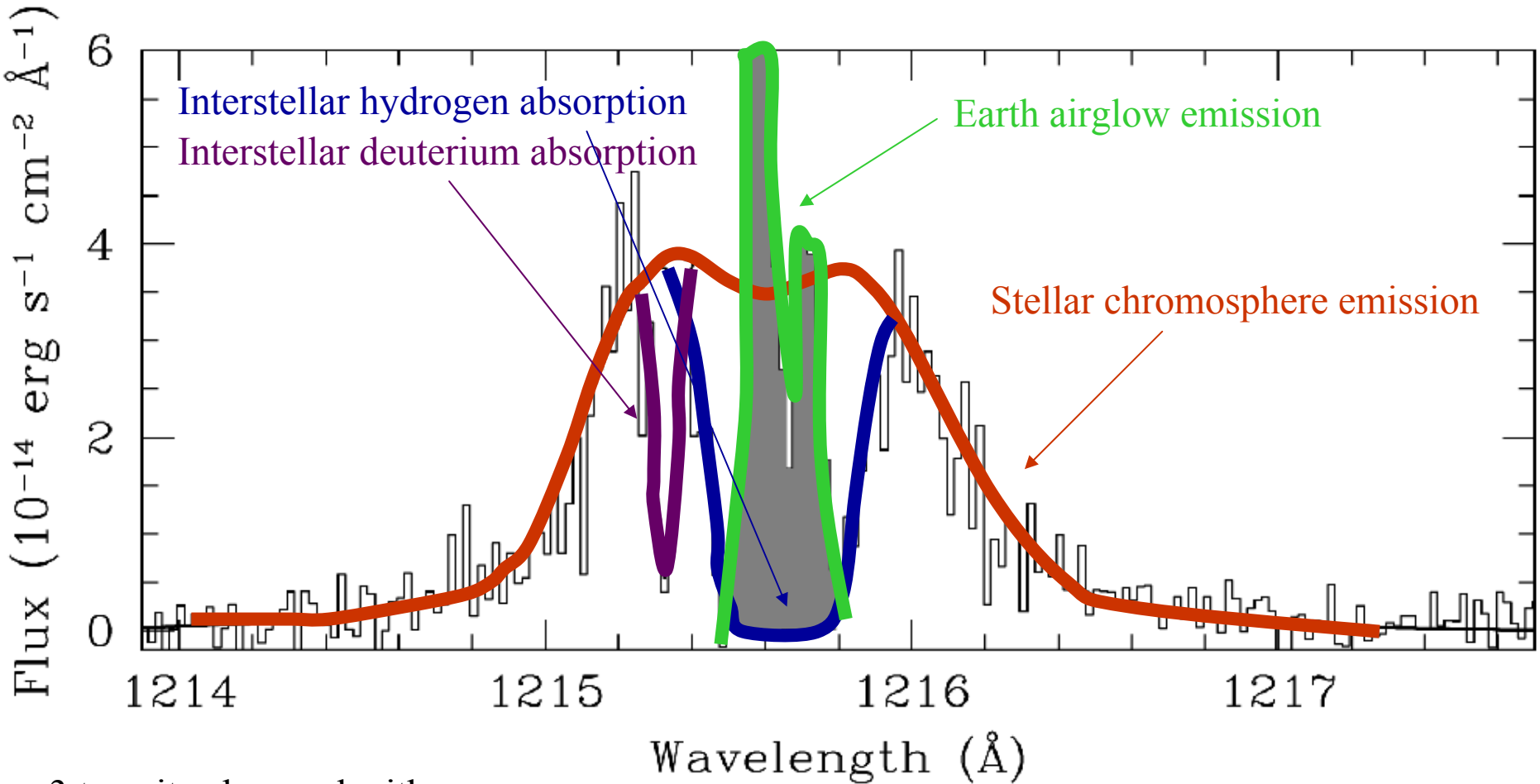
(Charbonneau et al. 2002)



0.0232 ± 0.0057 %

4 σ detection

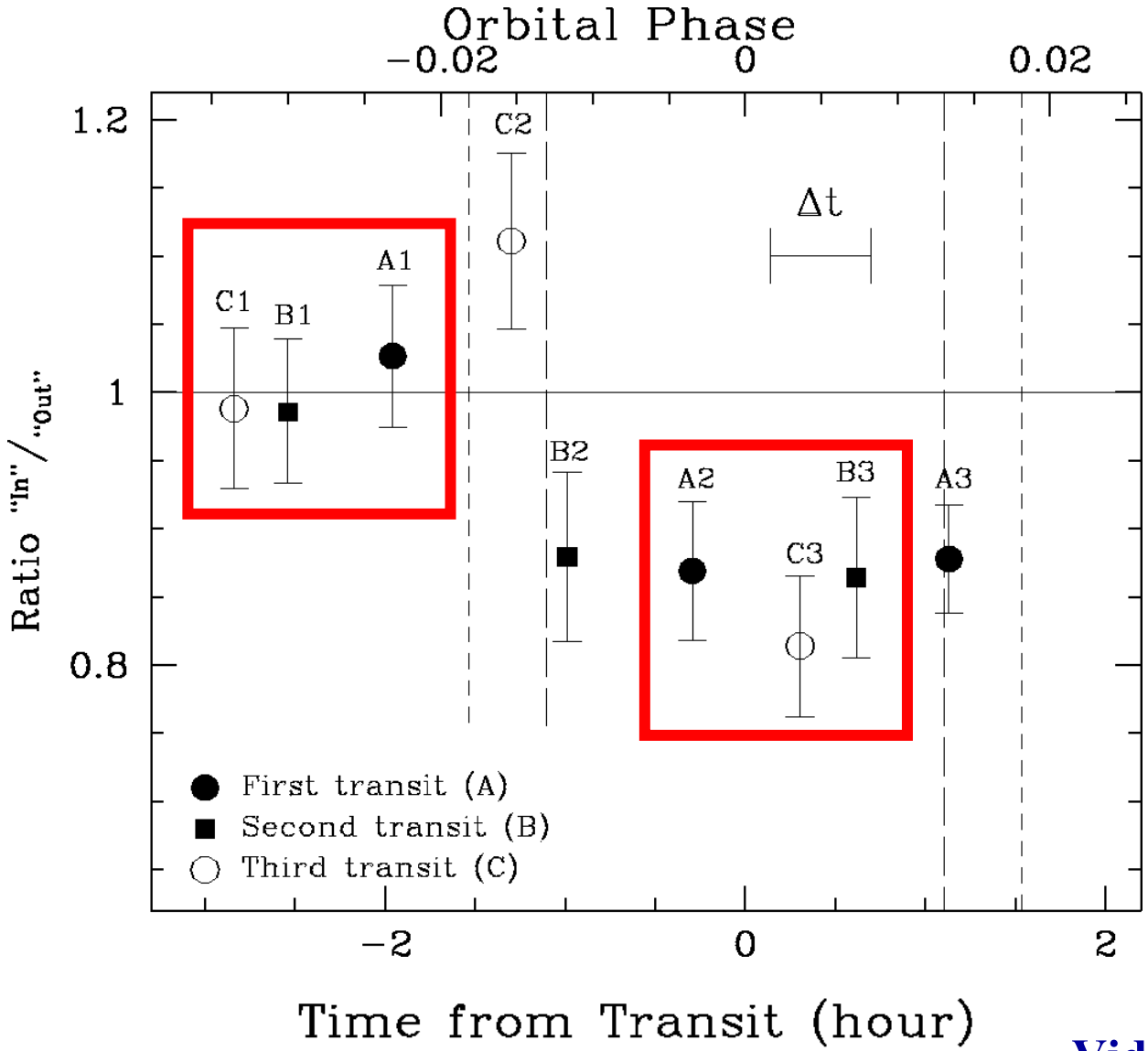
HST observations of HD 209458 at Lyman α



3 transits observed with
HST + STIS in autumn 2001

Vidal-Madjar et al. (2003)

HST observations of HD 209458 at Lyman α



Absorption:
15 ± 4 %

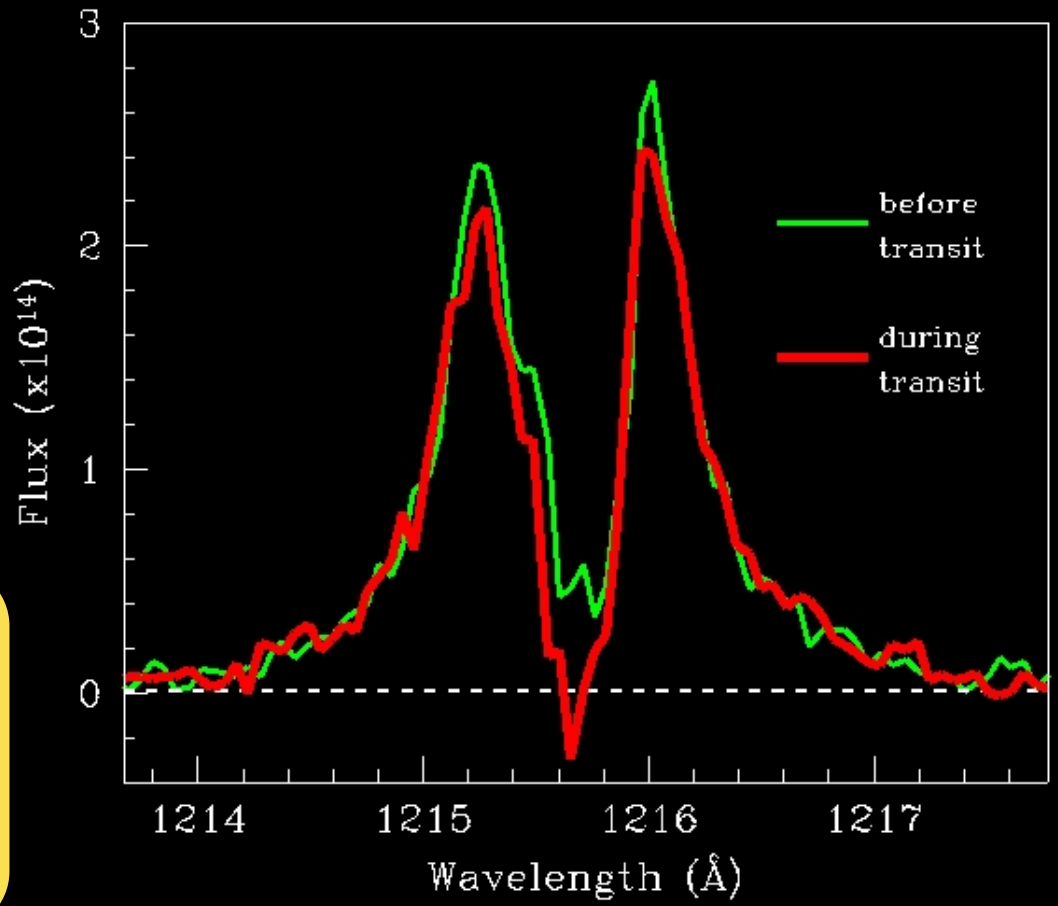
3.8 σ detection

Vidal-Madjar et al. (2003)

HD 209458b transit:
15 % absorption in HI

HUGE !!

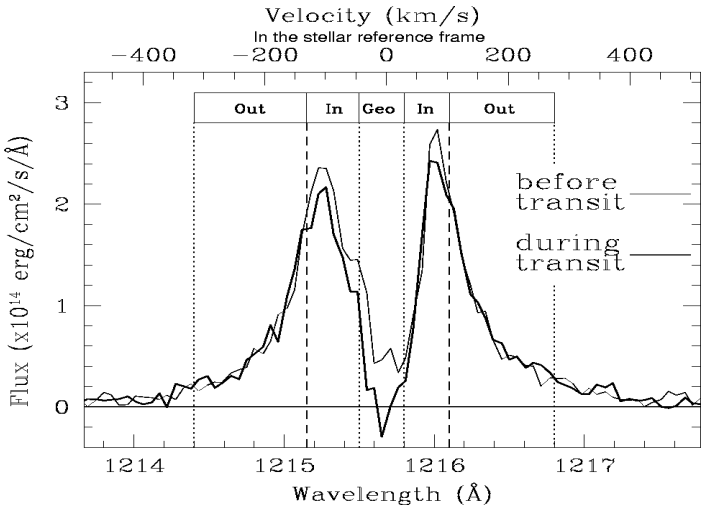
HI detection with
HST + STIS
(Vidal-Madjar et al. 2003)



Confirmation of the HI absorption from new HST + STIS observations
(Vidal-Madjar et al. 2004)

- HD 209458b only ($1.32\ R_J = 95000$ km) → 1.6 % absorption
  Filling up the Roche lobe ($2.7\ R_{HD209} = 3.6\ R_J$) → 10 % absorption
  15 % absorption → $3.2\ R_{HD209} = 4.2\ R_J = 300{,}000$ km

→ Beyond the Roche Lobe => **hydrogen escapes**



- Absorption: from –130 km/s to 100 km/s
  V_{esc} (surface) = 54 km/s

→ Beyond the escape velocity => **hydrogen escapes**

=> The planet is evaporating

Vidal-Madjar et al. (2003)

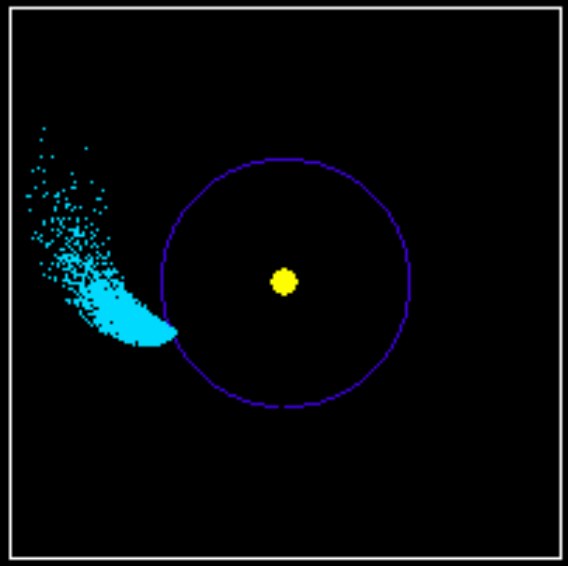
Escape rate estimation

(Vidal-Madjar & Lecavelier 2004; Lecavelier et al., in prep.)

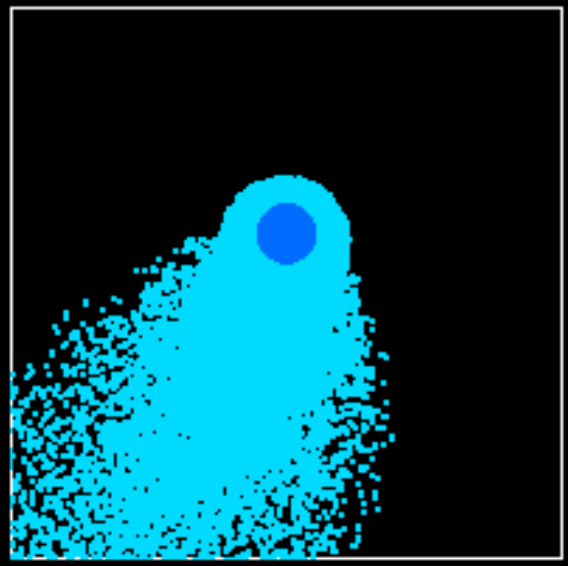
Particle simulation:

- Hydrogen atoms sensitive to stellar radiation pressure
- Both planetary and stellar gravity taken into account
- Neutral hydrogen ionized by EUV photons (lifetime ~ 6 hours)

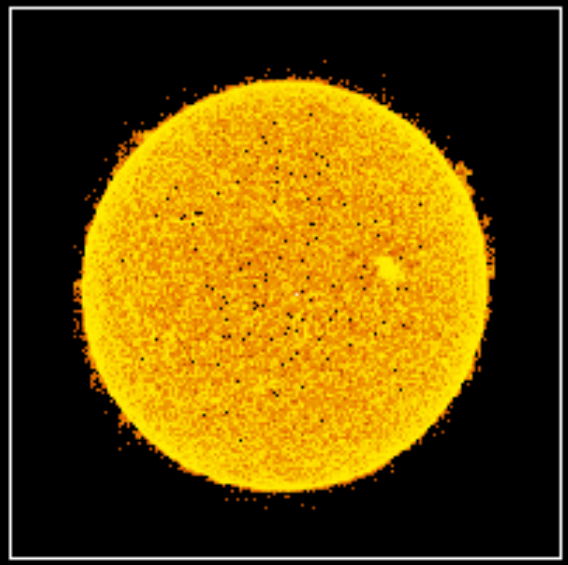
Star−Exoplanet seen from above



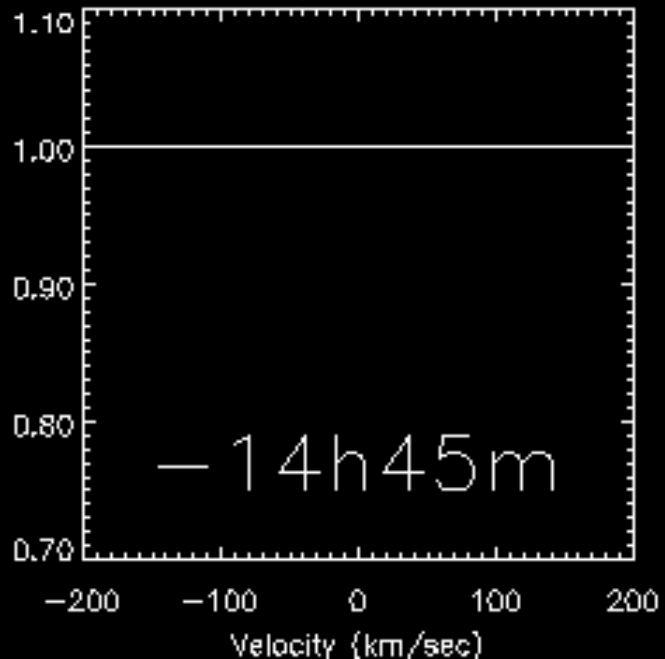
Planet seen from above



Star seen from the Earth



Spectrum



Escape rate estimation

(Vidal-Madjar & Lecavelier 2004; Lecavelier et al., in prep.)

Particle simulation:

- Hydrogen atoms sensitive to stellar radiation pressure
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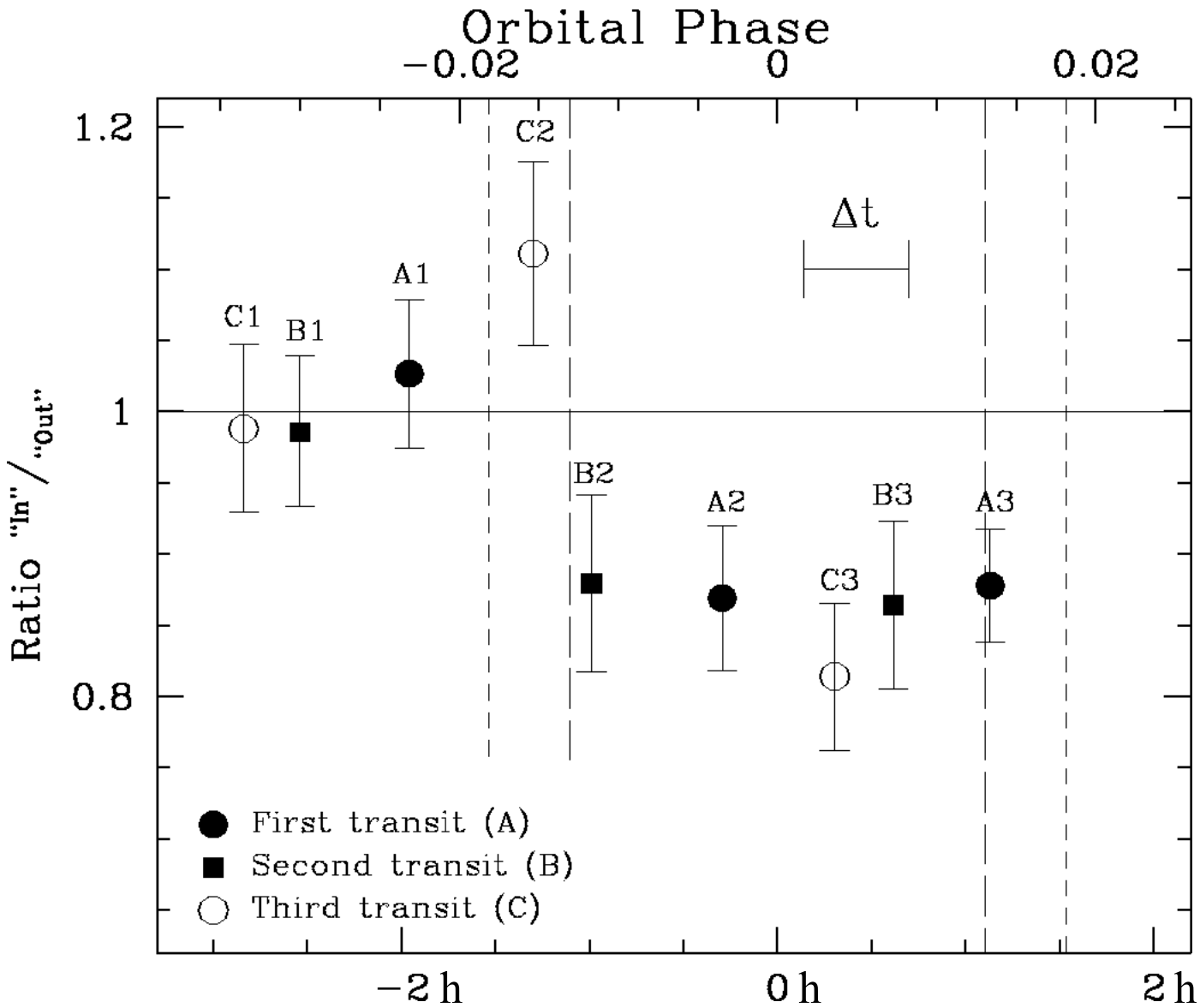
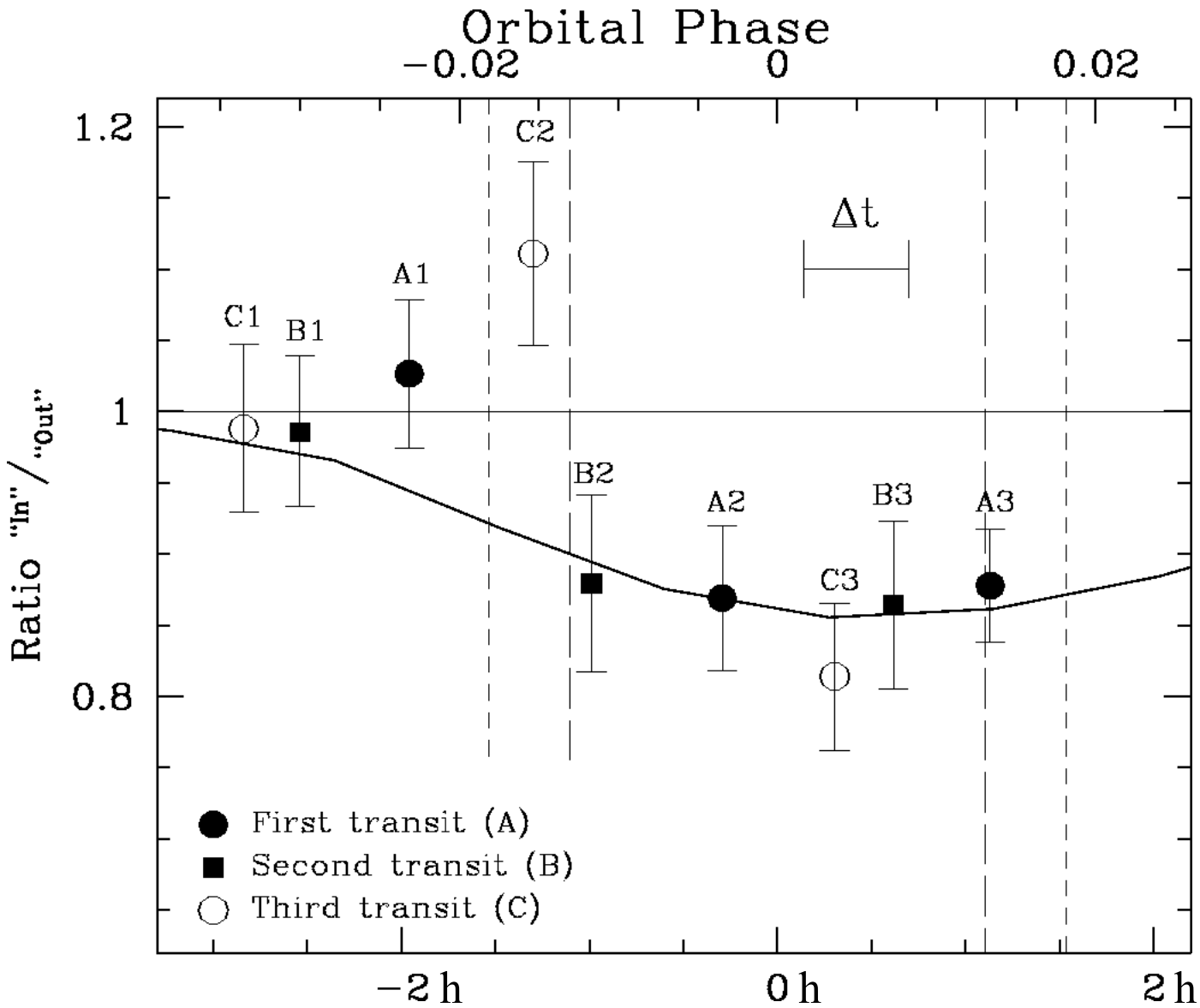
- Neutral hydrogen ionized by EUV photons (lifetime ~ 6 hours)

15% absorption → Escape flux: ~ 10^{10} g/s

Burrows & Lunine, *Nature* 378, 333 (1995) ➔ escaping (H_2^+, H^+, HI) ~ 10^{10} g/s


Orbital Phase
−0.02
0
0.02
1.2
1
0.8
Ratio "In" / "Out"
C2
Δt
A1
C1
B1
B2
A2
B3
A3
C3
First transit (A)
Second transit (B)
Third transit (C)
−2 h
0 h
2 h



=> Evaporation rate > 10^{10} g s^{-1}

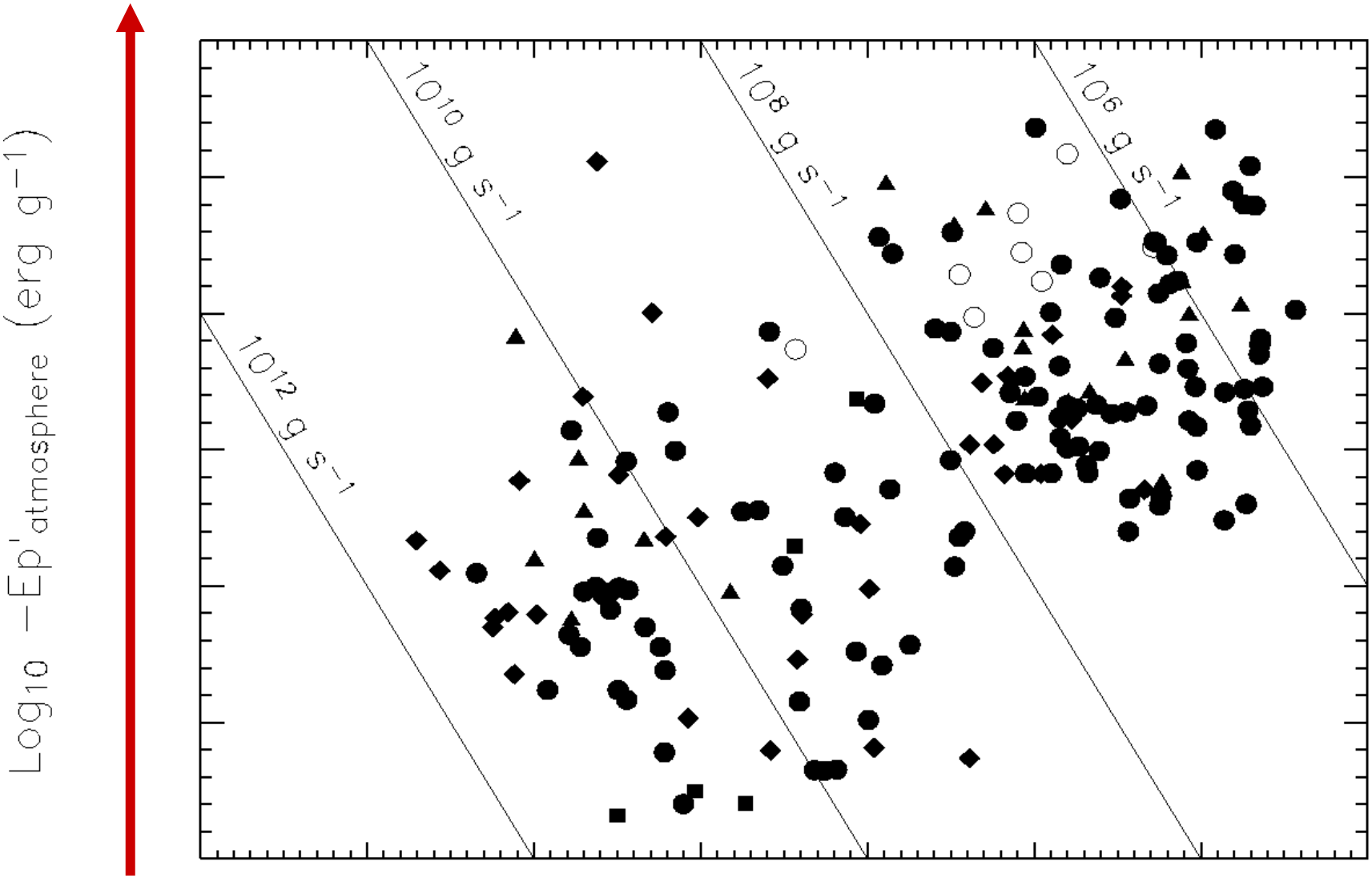
Vidal-Madjar et al. (2003)

Numerous models to understand the evaporation

- Lammer et al. 2003
- Lecavelier des Etangs et al. 2004, 2007
- Baraffe et al. 2004, 2005, 2006
- Yelle 2004
- Jaritz et al. 2004
- Tian et al. 2005
- Hubbard et al. 2005
- Garcia-Munoz 2006

The energy diagram

~ mass



~ distance

~ period

Lecavelier des Étangs (2007)

Signature of hot hydrogen in HD 209458b

Ballester, Sing & Herbert (2007)

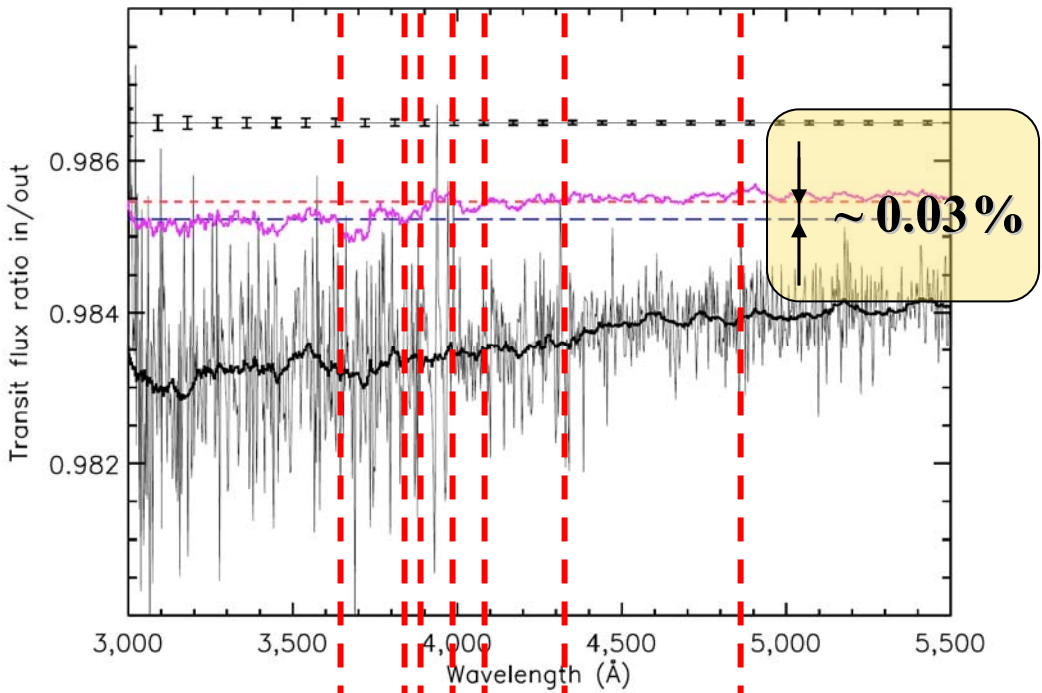
Balmer jump and continuum

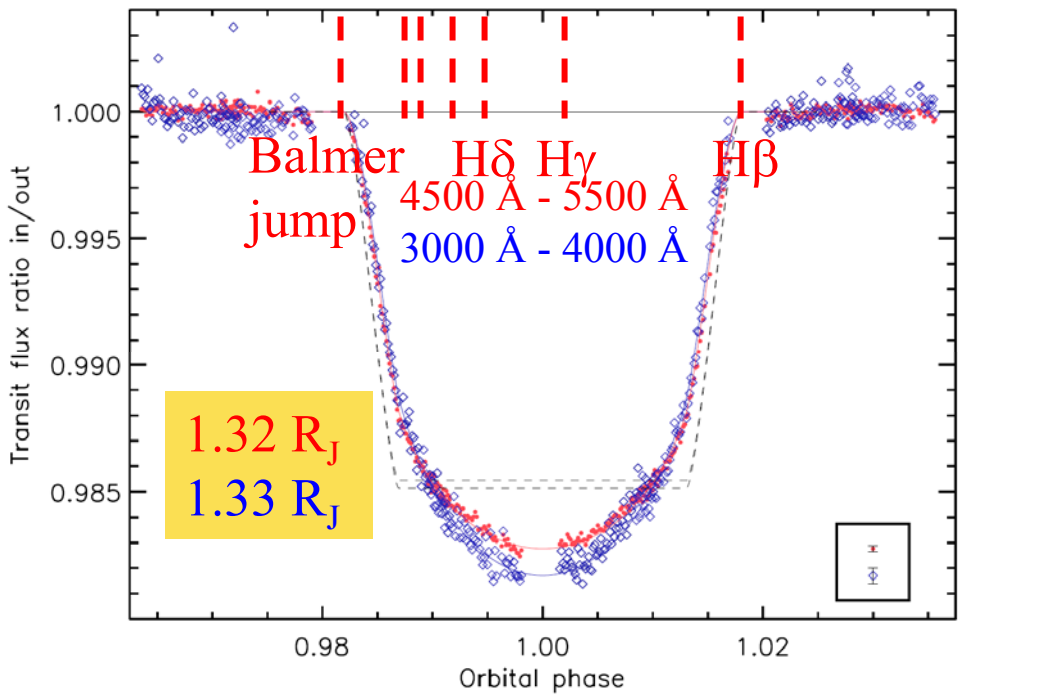
excited state ($n = 2$) of neutral H

$T \approx 10\,000$ K

HST+STIS (archive data from Knutson, Charbonneau et al. 2007)

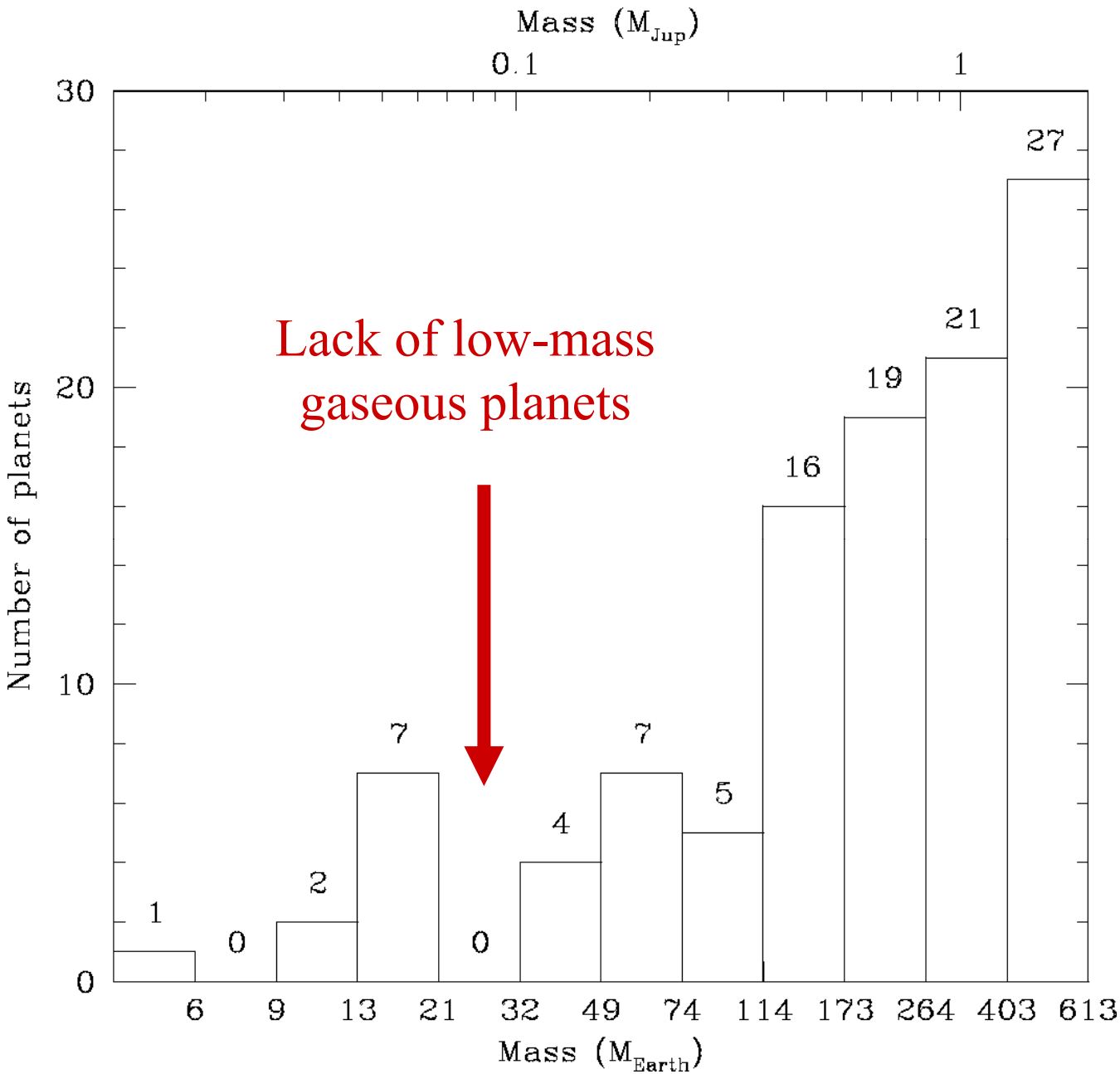
QuickTime™ et un décompresseur TIFF (non compressé) sont requis pour visionner cette image.



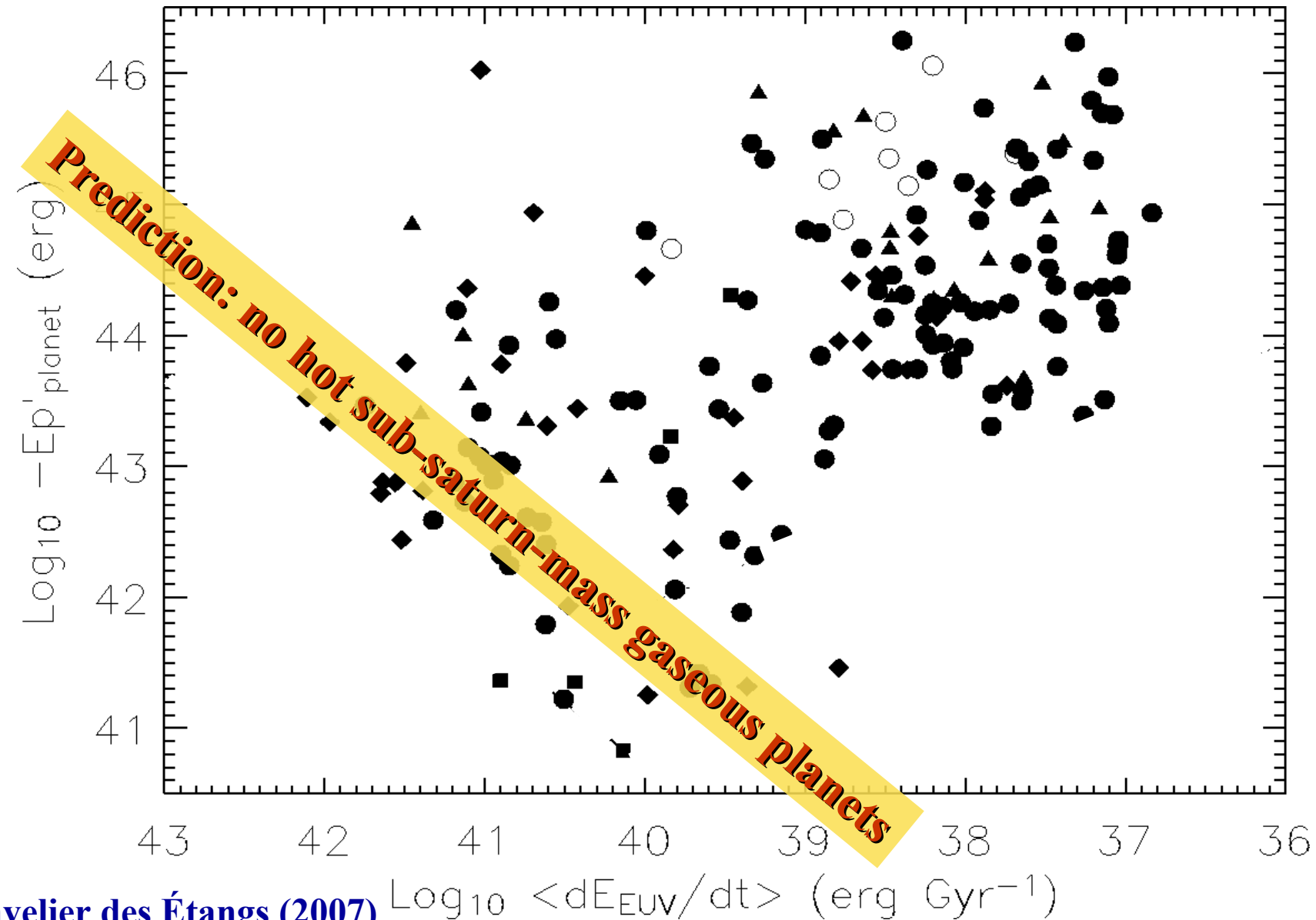


Remnants of evaporation?

- « Hot Neptunes »
  (hot hydrogen-poor Neptune-mass planets)
- « Massive Earths »
  (solid core)

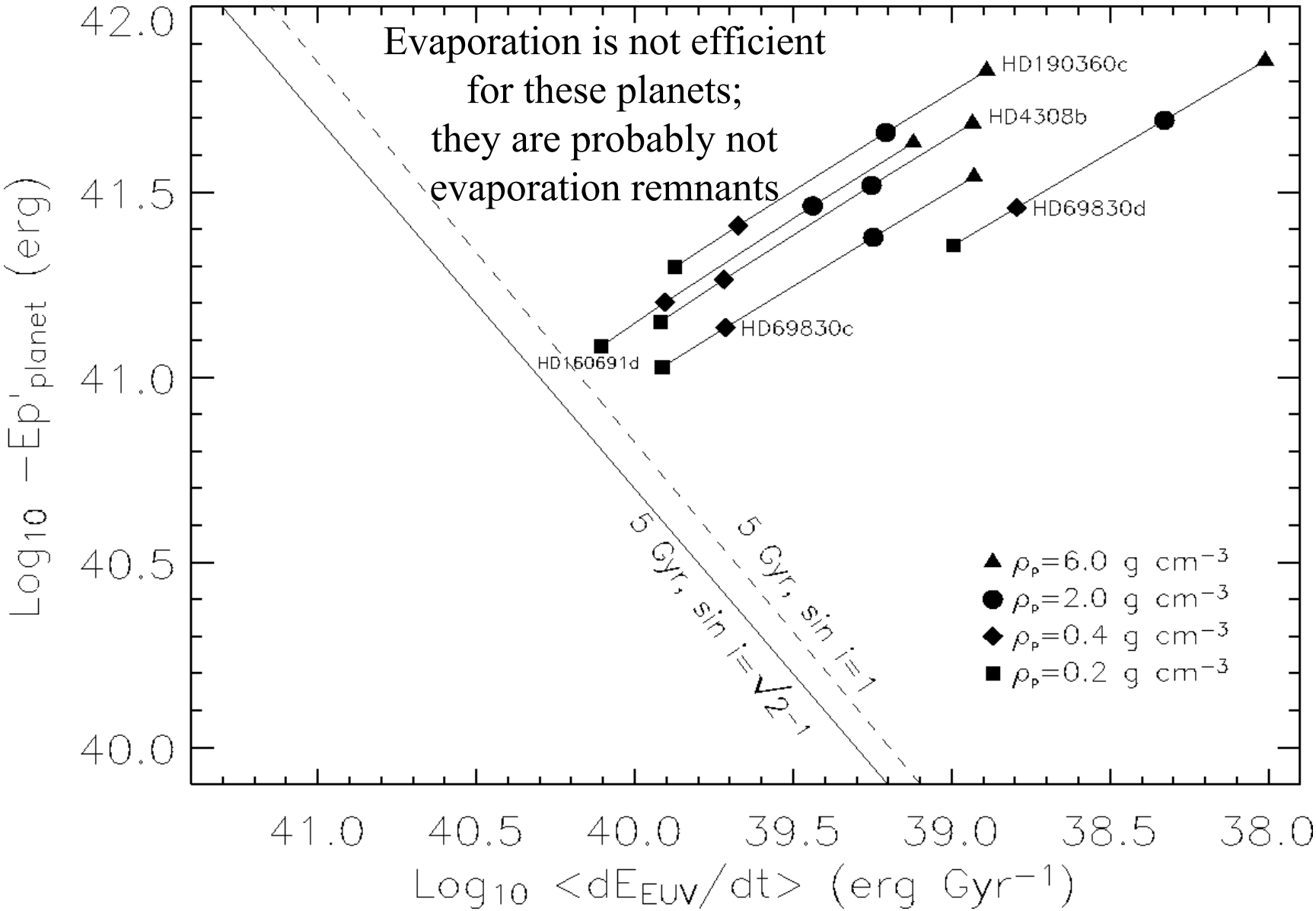

Mass (M_{Jup})
0.1
1
30
20
10
0
Number of planets
Lack of low-mass
gaseous planets
1
0
2
7
0
4
7
5
16
19
21
27
6
9
13
21
32
49
74
114
173
264
403
613
Mass (M_{Earth})

The energy diagram



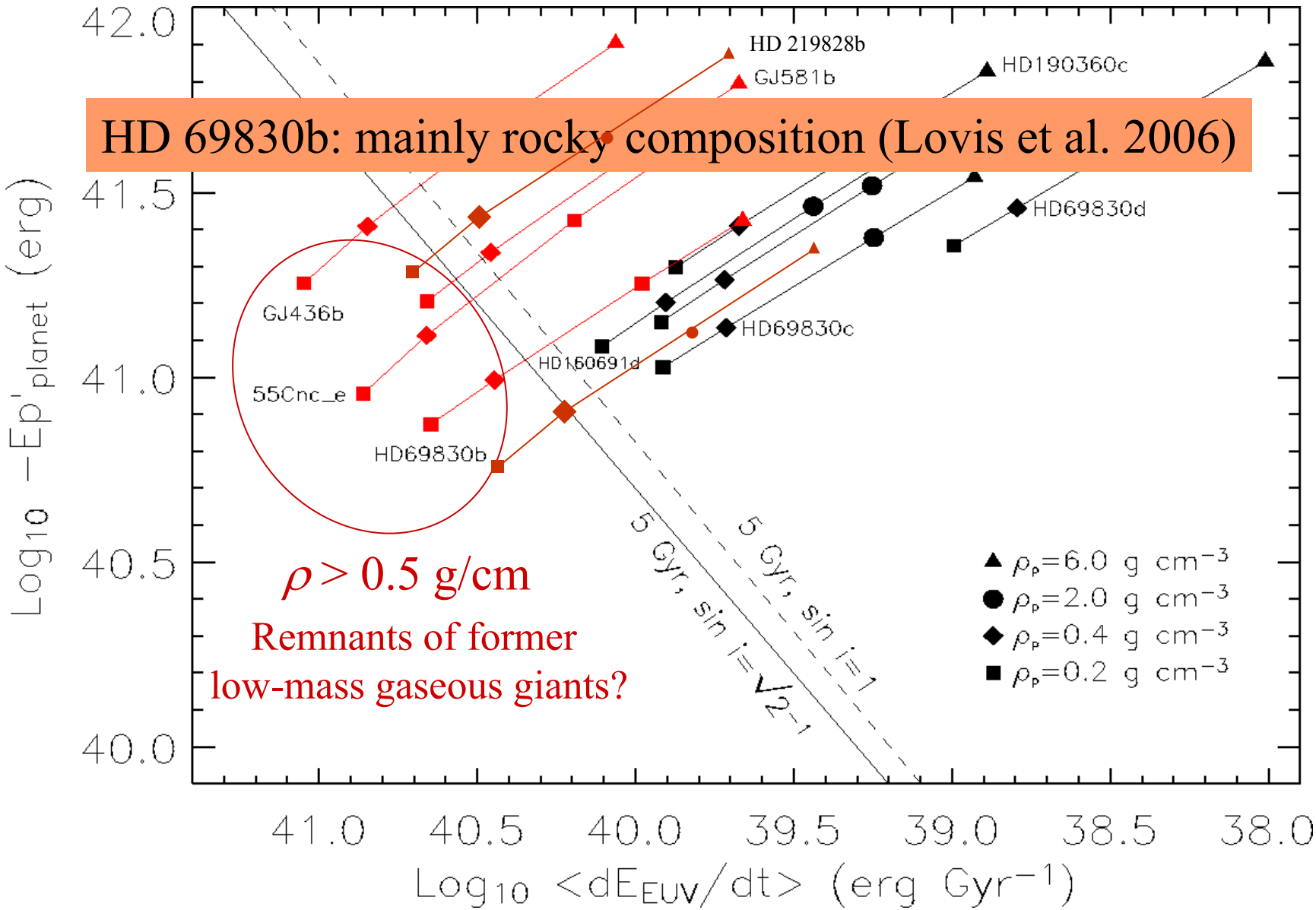
Lecavelier des Étangs (2007)

Hot Neptunes in the energy diagram



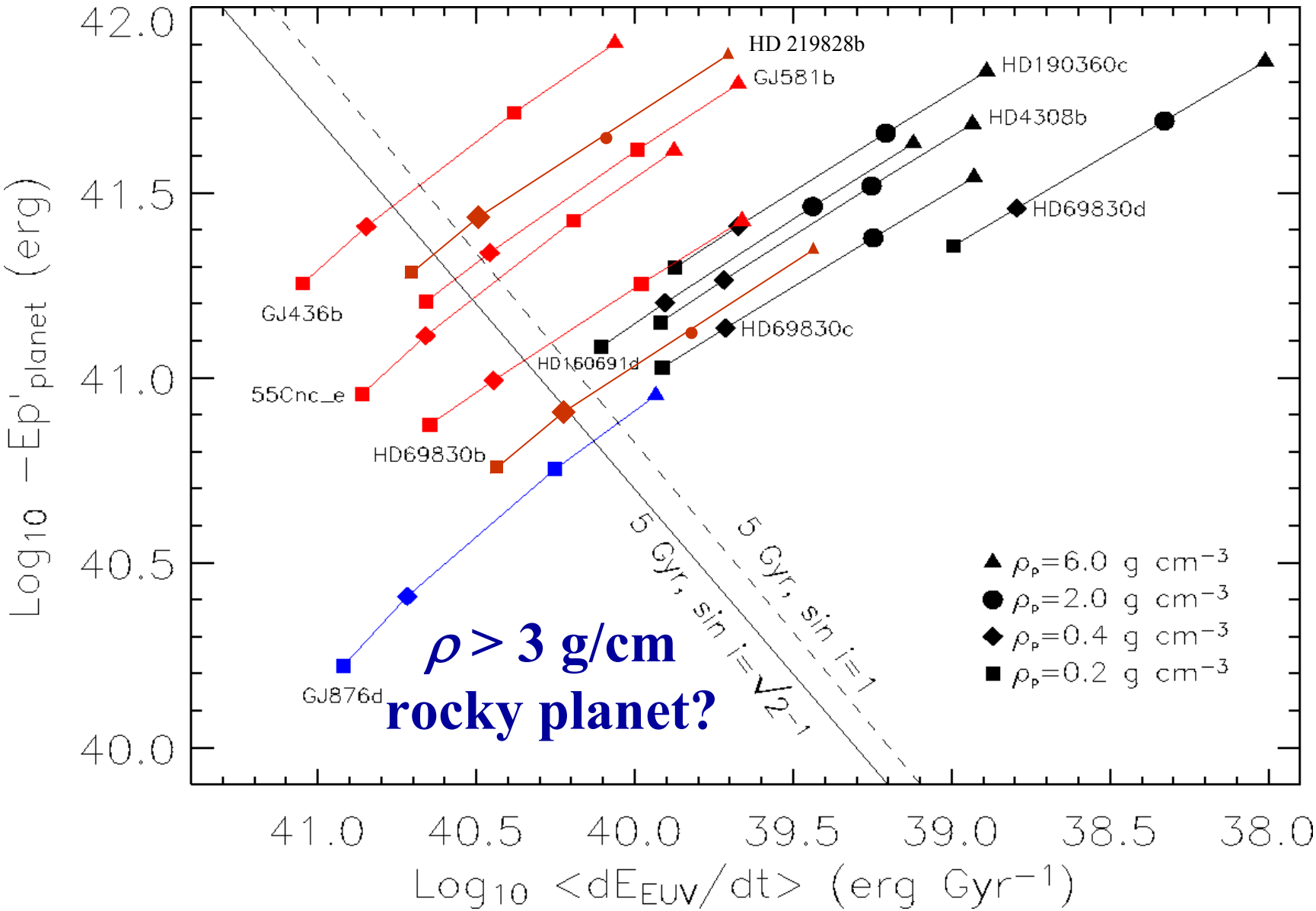
Lecavelier des Étangs (2007)

Hot Neptunes in the energy diagram



Lecavelier des Étangs (2007)

Hot Neptunes in the energy diagram



Lecavelier des Étangs (2007)

Back to the observations…

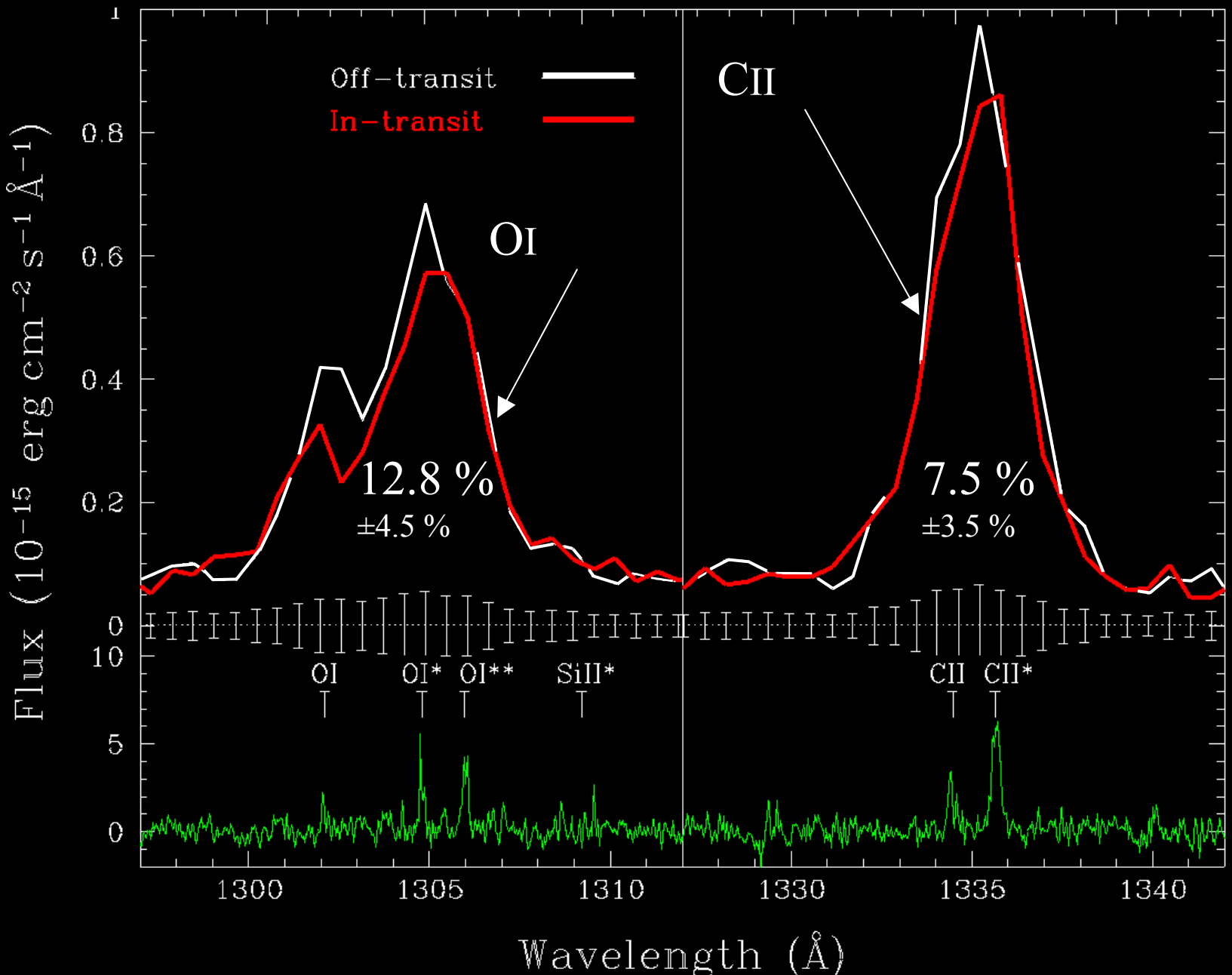
In the atmosphere of HD 209458b, Hubble Space Telescope absorption spectroscopy allowed the detection of:

- sodium (Charbonneau et al. 2002)
- hydrogen (Vidal-Madjar et al. 2003; 2004)
- excited hydrogen (Ballester et al. 2007)

and also

- carbon and oxygen (Vidal-Madjar et al. 2004)

Carbon and oxygen detections



Consequences

- Oxygen and carbon are present in the upper atmosphere of HD 209458b, up to the Roche lobe
- They are dragged up by the hydrogen flow:

➔ **HYDRODYNAMIC ESCAPE (« BLOW-OFF »)**

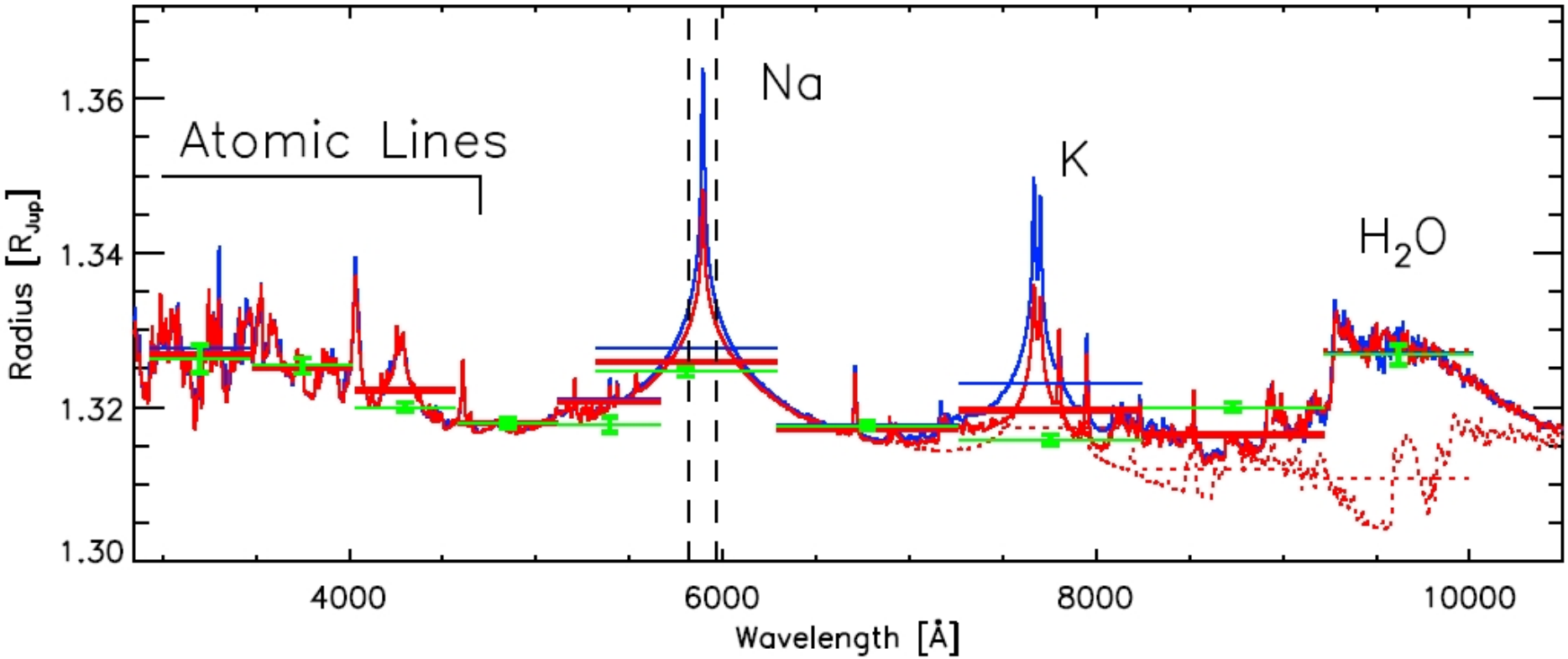
Detection of water ?

(Barman 2007)

- Re-interpretation of Knutson et al.' (2007) STIS measurements.
- ➔ Detection of water ?

Detection of water ?

(Barman 2007)



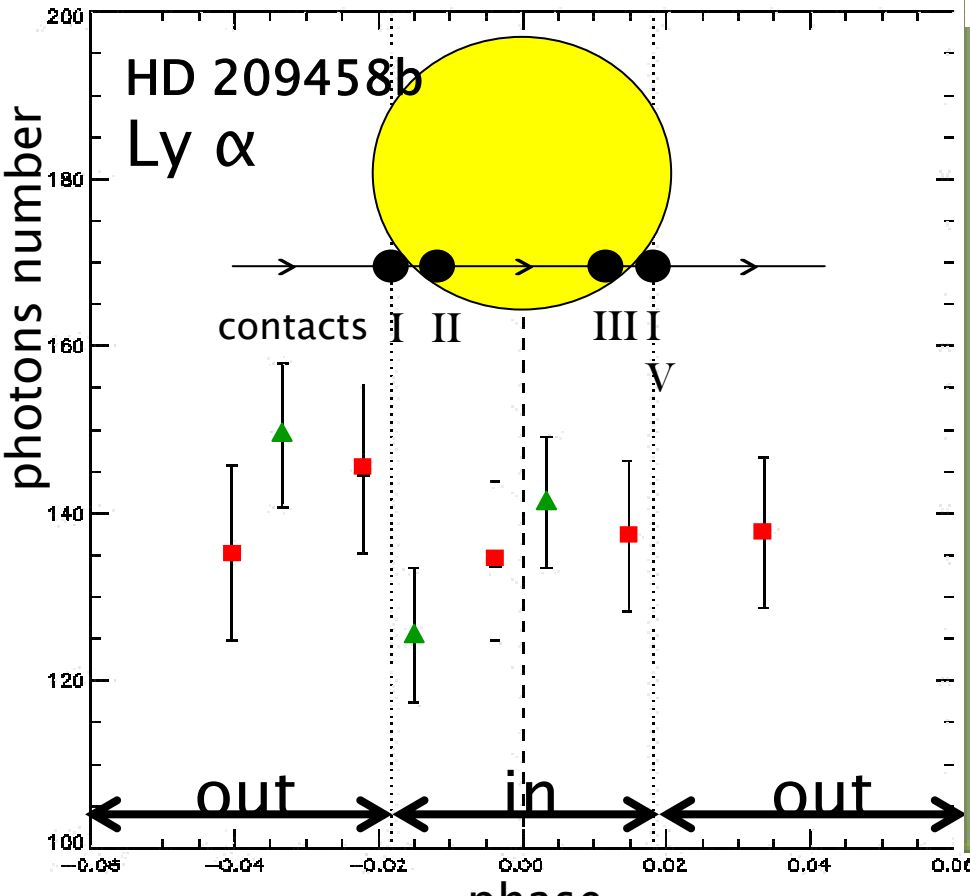
Next… ACS ?

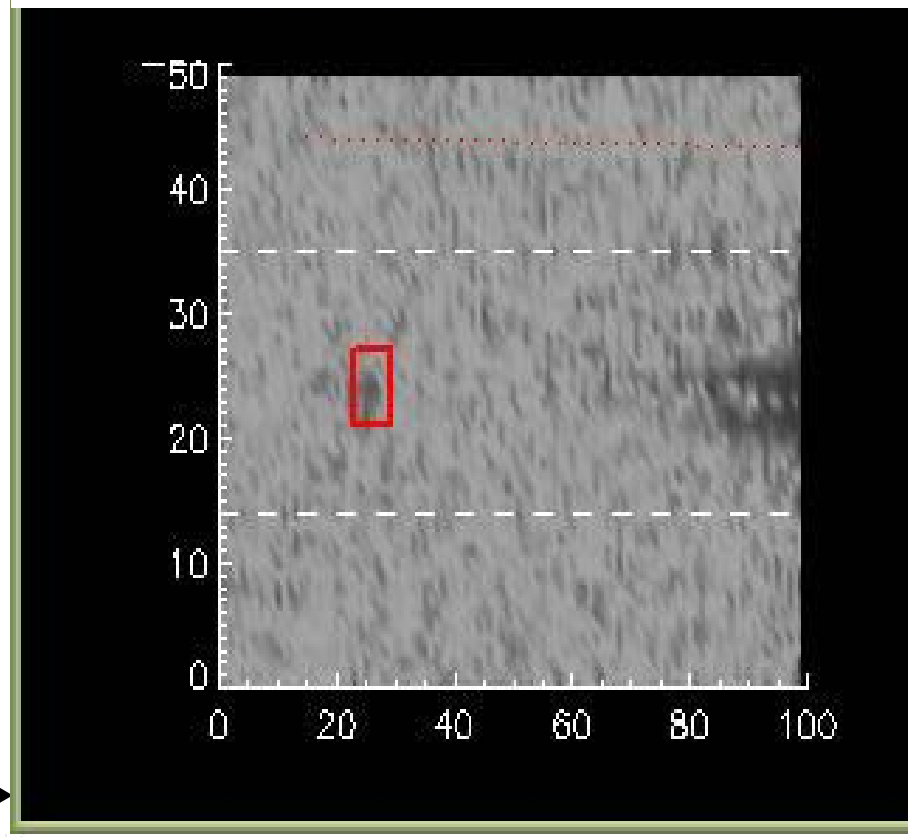
- Switch from STIS to ACS (SBC FUV-camera of ACS is still working)
- ACS is almost as efficient as STIS for transits in Ly-α

Next… ACS ?

HST/ACS Observations of HD209458b

Ehrenreich et al. (in prep.)





Next… ACS ?

- Switch from STIS to ACS (SBC FUV-camera of ACS is still working)
- ACS is almost as efficient as STIS for transits in Ly-α

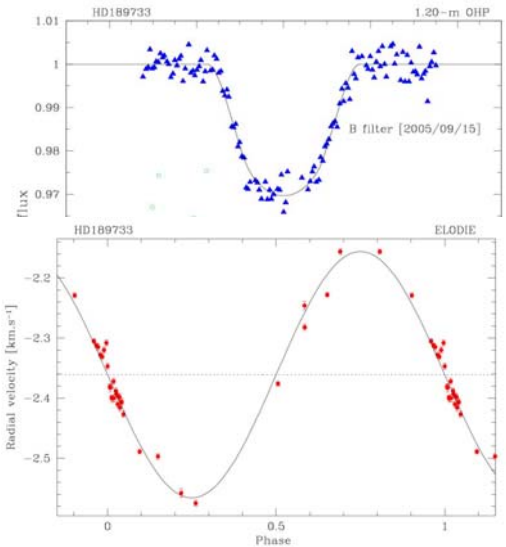
- BUT
  - "red-leak" in ACS filter
  - lack of resolution:

  ➔ only bright isolated emission line.

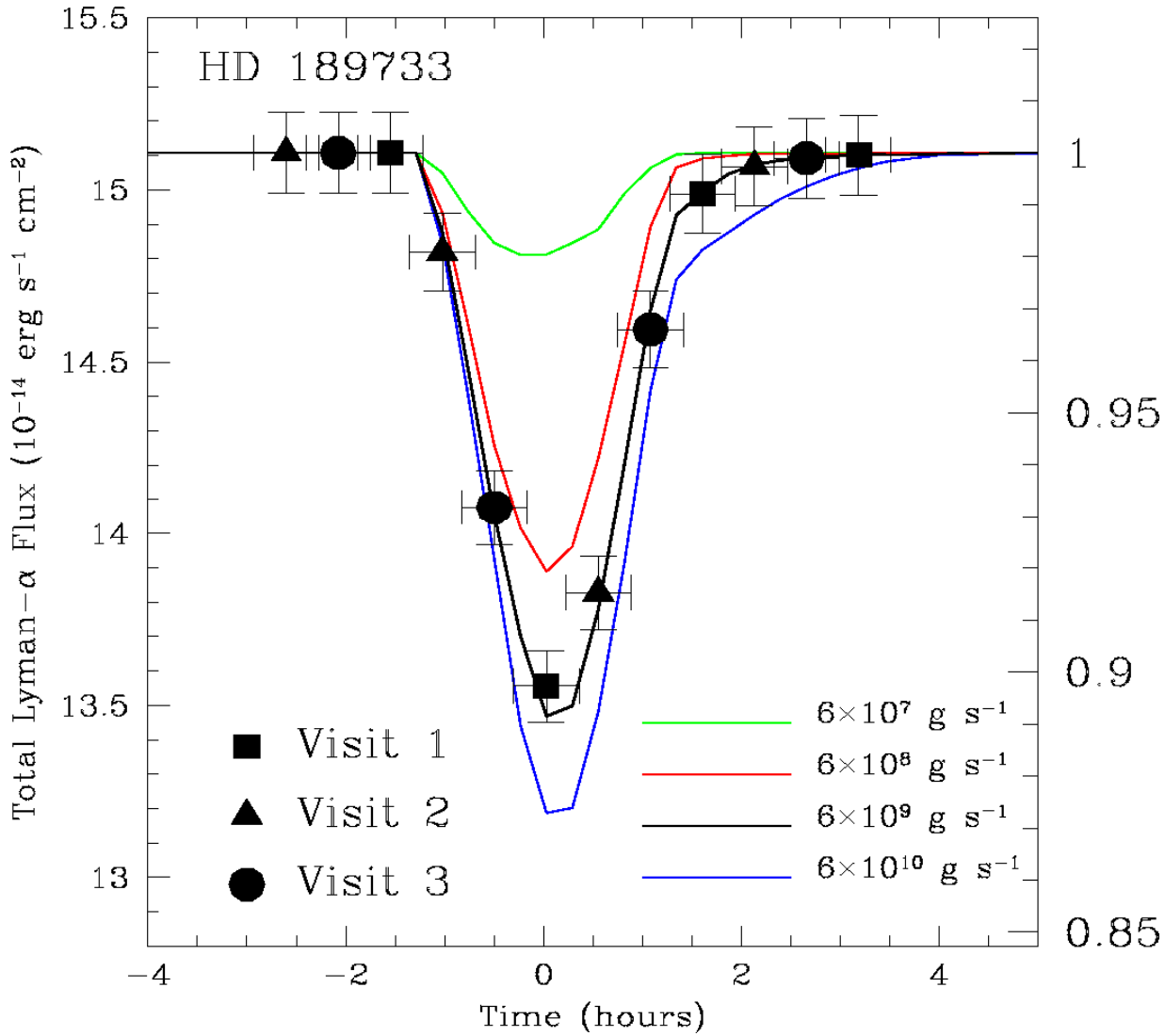
- C and O detections should be confirmed (2.5σ)
- A lot to be done in absorption against the stellar continuum (H_20, etc.)

- STIS back thanks the Space Shuttle Servicing Mission 4?

HD 189733b:
ACS Observations scheduled for June 2007



Bouchy et al. (2005)



Thank you !