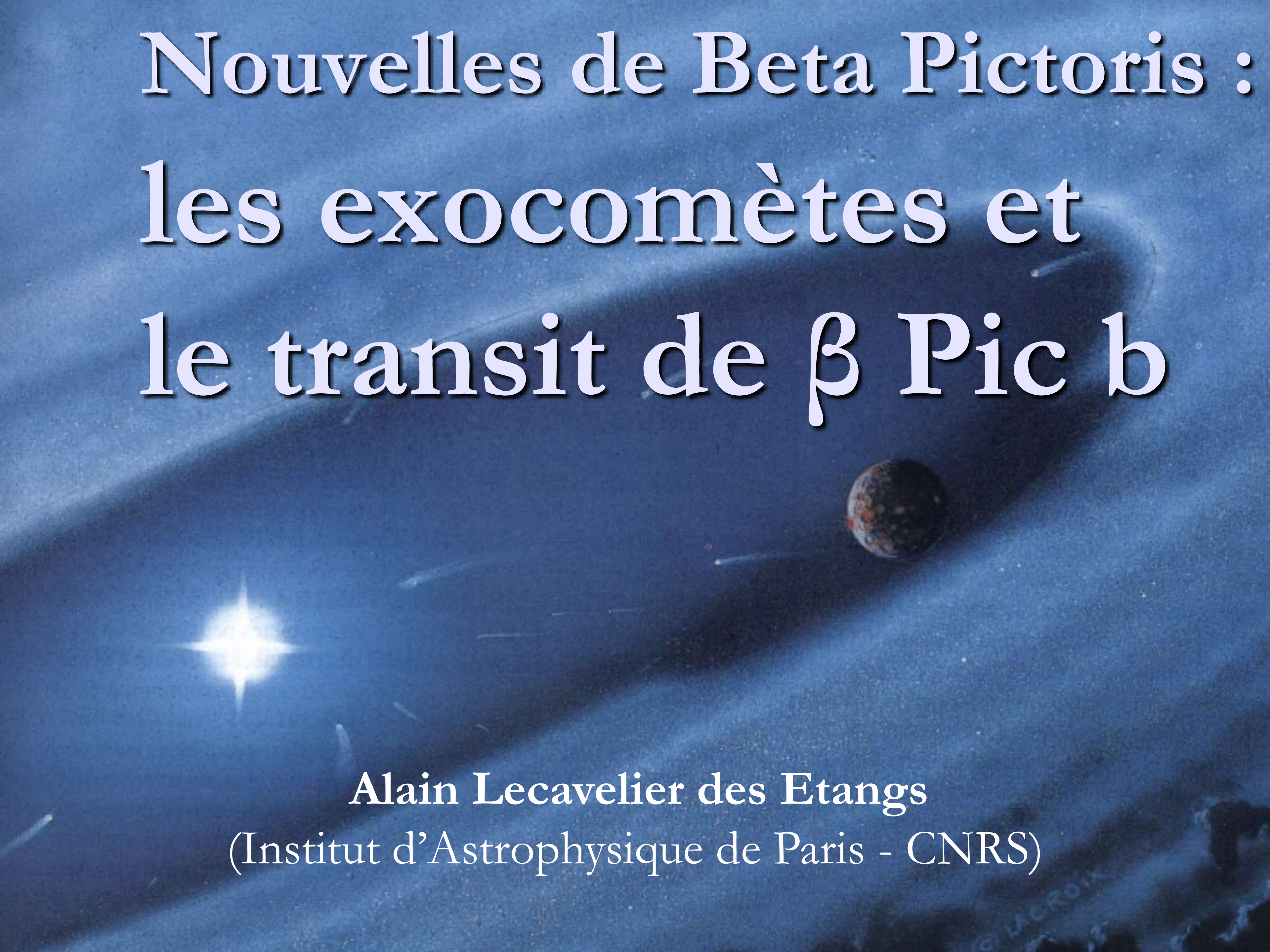
Nouvelles de Beta Pictoris :

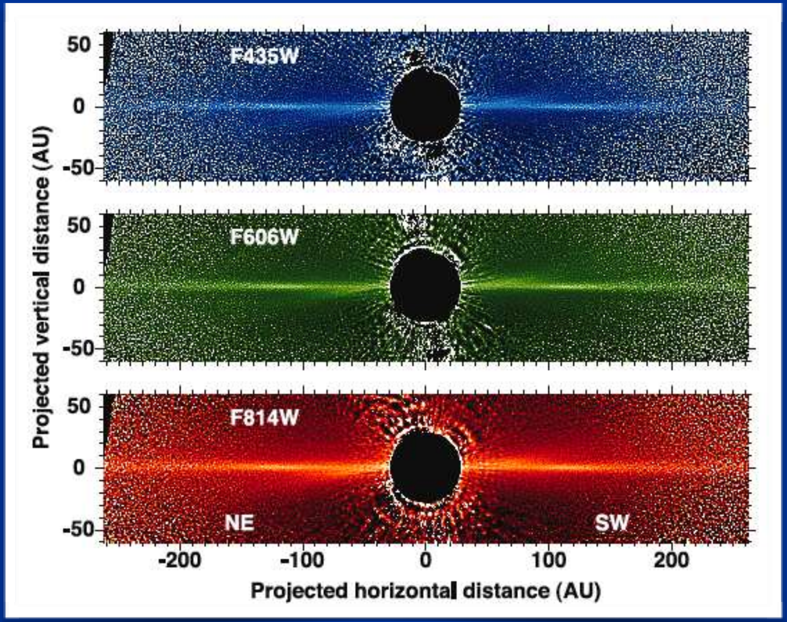
les exocomètes et le transit de β Pic b



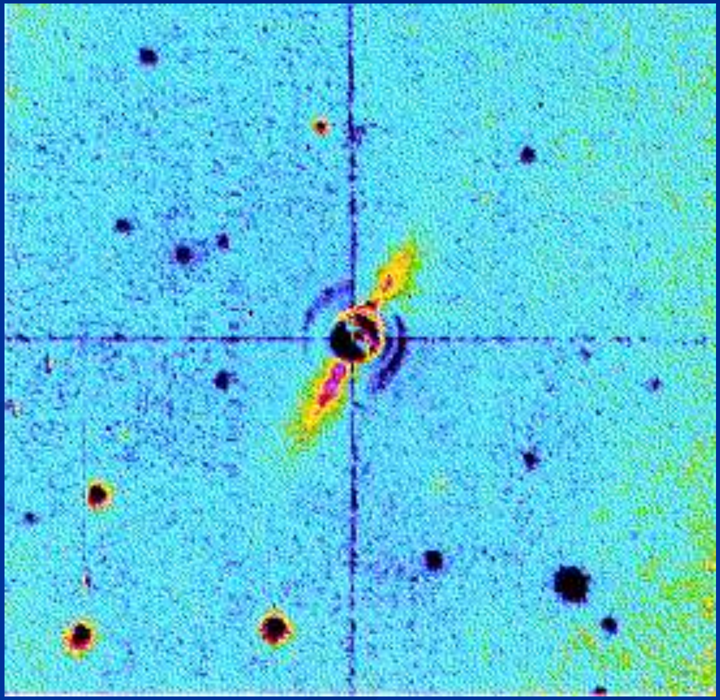
Alain Lecavelier des Etangs
(Institut d'Astrophysique de Paris - CNRS)

β Pic : a young planetary system

- A5V main sequance star, d=19,3 pc, **V = 3.85**
- Age = **21 million years**
- Seen **exactly edge-on**
  - ➔ Signatures of the disk in absorption
  - ➔ Transit of exocomets



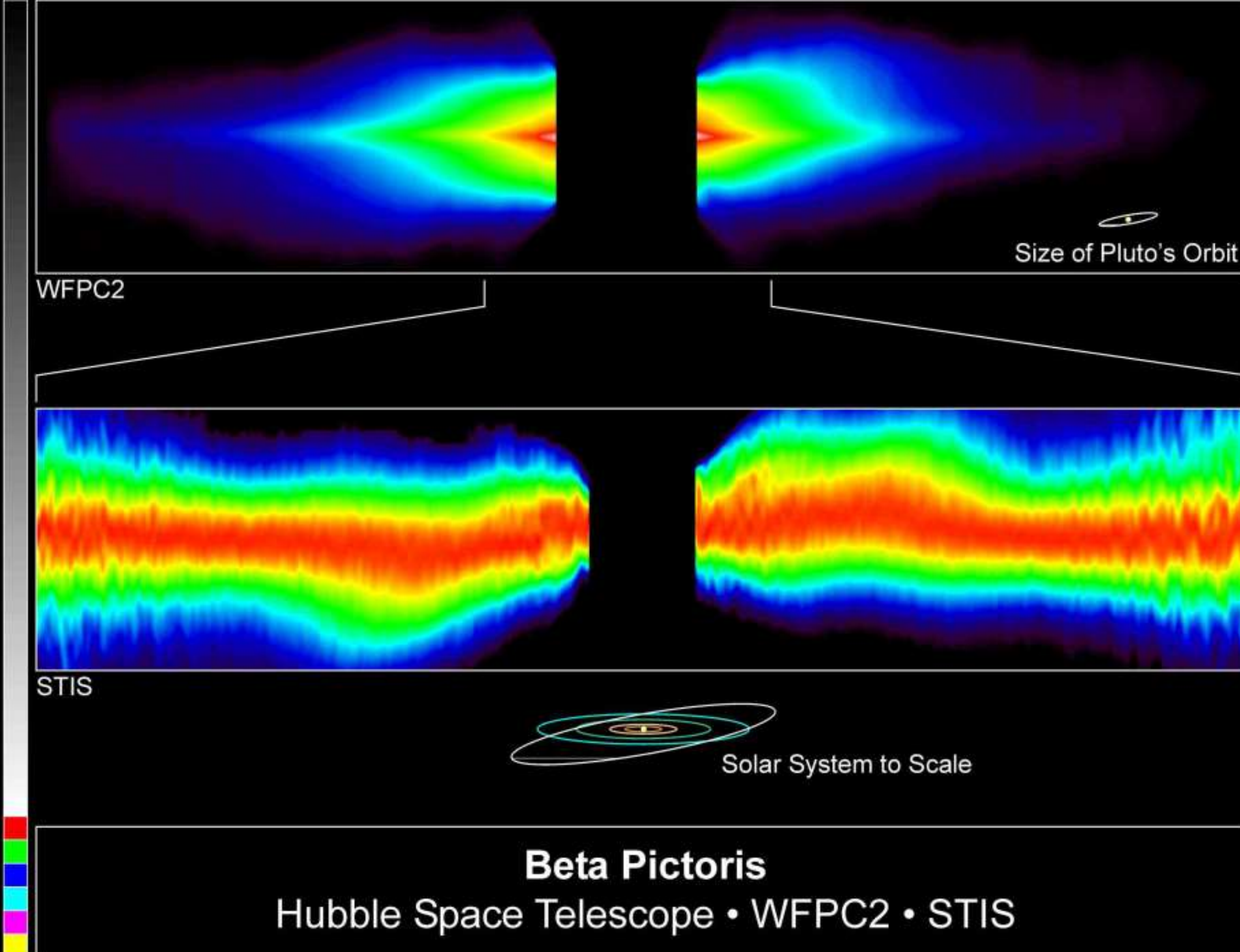
Golimowski et al. 2006



Smith & Terrile 1984

β Pic : a complete planetary system

- Gas
- Dust
- Planetesimals
- Exocomets
- Planet(s)



PRC98-03 • January 8, 1998 • ST ScI OPO • A. Schultz (Computer Sciences Corp. and ST ScI), S. Heap (NASA Goddard Space Flight Center) and NASA

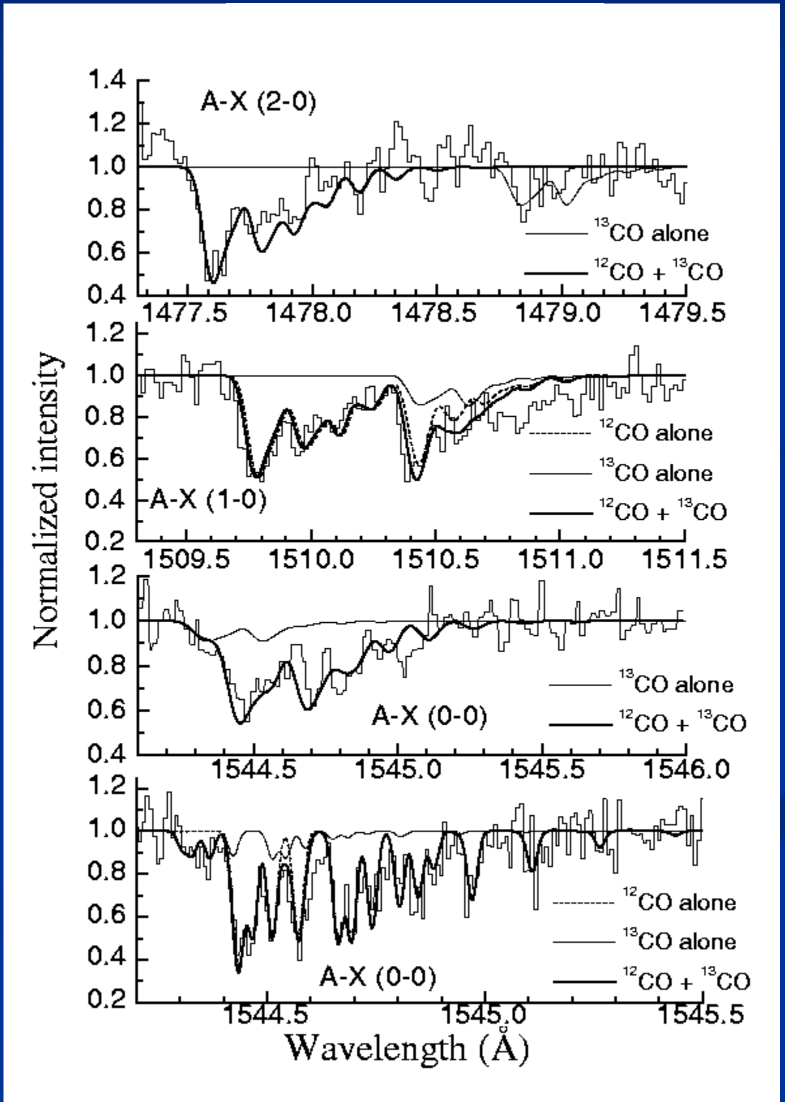
CO in the disk of β Pic

Vidal-Madjar et al. (1994); Jolly et al. (1998); Roberge et al. (2000)

- CO detected in absorption observed in bands at 1400-1500 Å *Vidal-Madjar et al. (1994)*

- Population of energy levels
  ➔ gas at ~ 25 K

- ^{12}CO / ^{13}CO < 20 (~ 15)



Discovery of exocomets

Ferlet et al. (1987); Beust et al. (1990-2004)

- Ferlet et al. (1987)

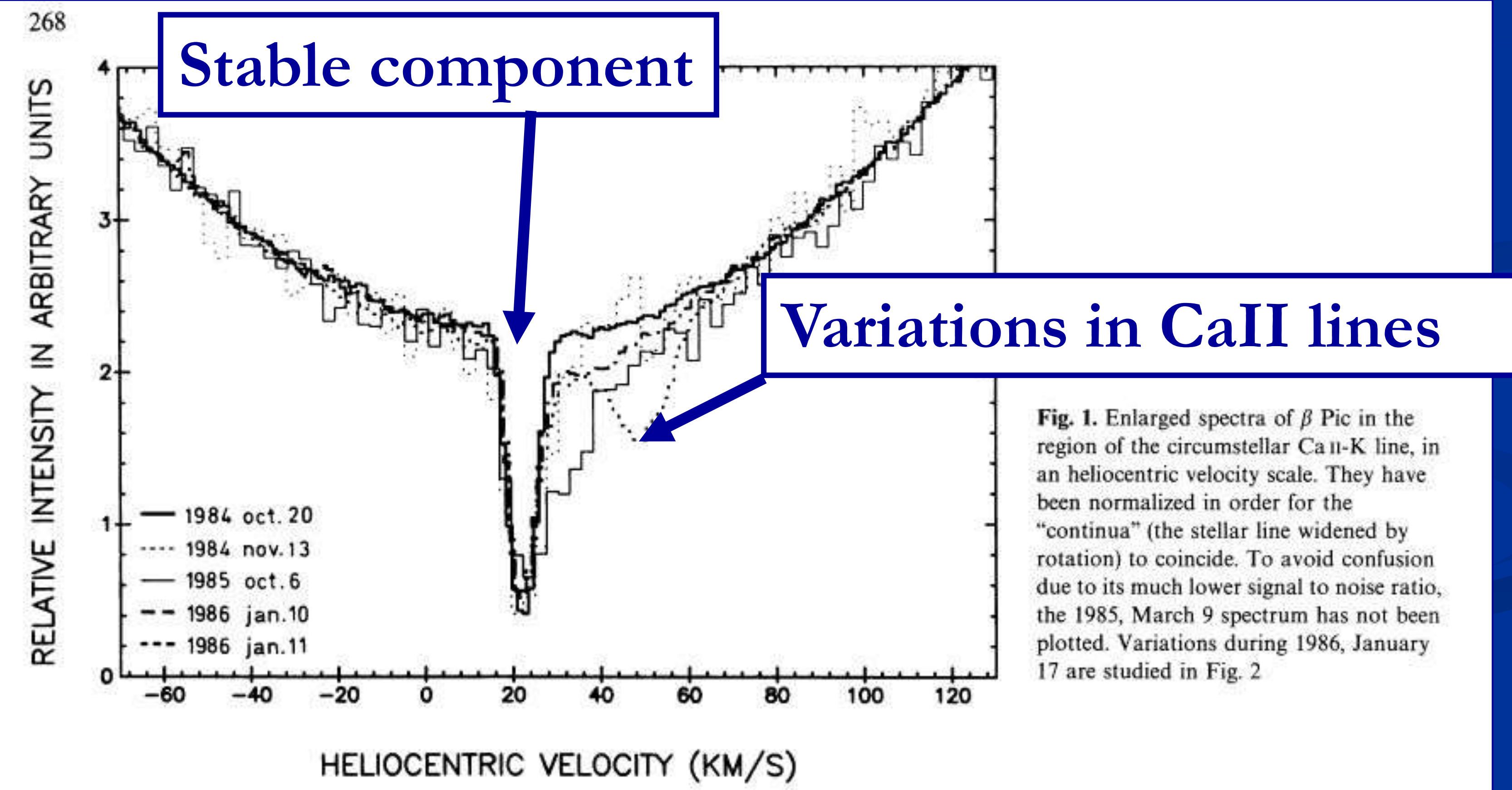
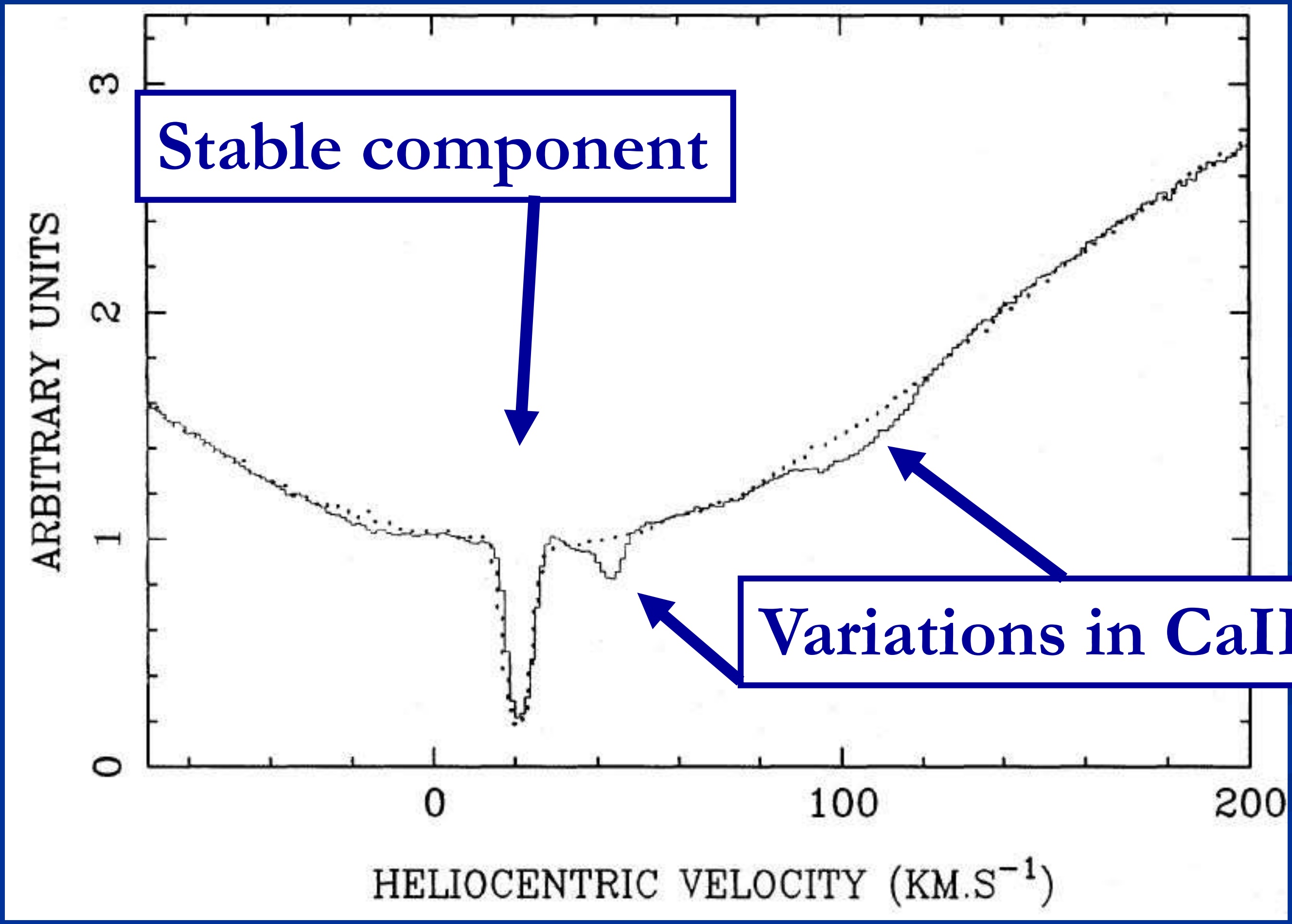


Fig. 1. Enlarged spectra of β Pic in the region of the circumstellar Ca II-K line, in an heliocentric velocity scale. They have been normalized in order for the "continua" (the stellar line widened by rotation) to coincide. To avoid confusion due to its much lower signal to noise ratio, the 1985, March 9 spectrum has not been plotted. Variations during 1986, January 17 are studied in Fig. 2

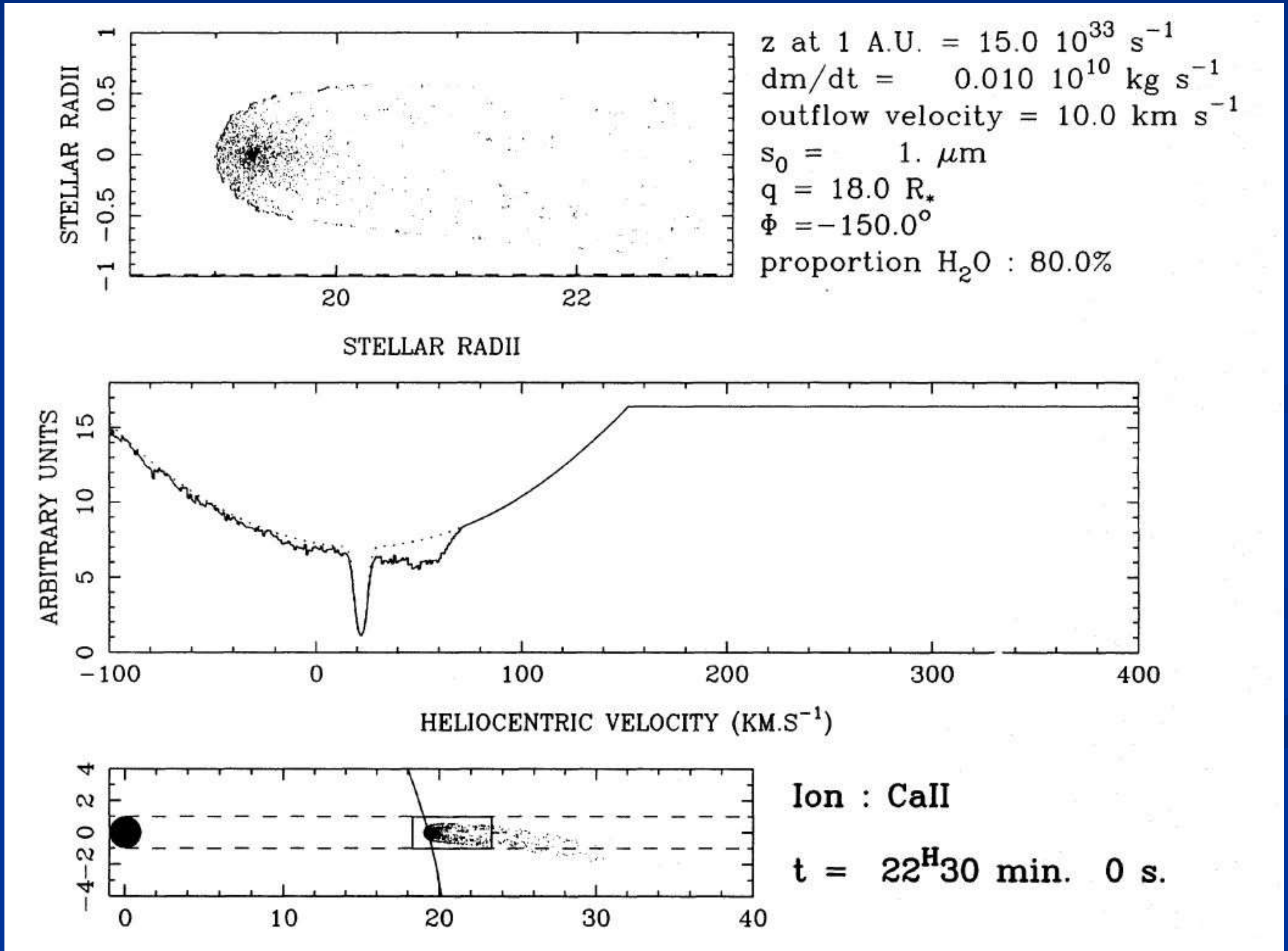
Observation of exocomets

Ferlet et al. (1987); Beust et al. (1990-2004)

- Beust et al. (1990)



Nuerical simulations of exocomets (Beust et al. 1990-2004)



Nuerical simulations of exocomets (Beust et al. 1990-2004)

The FEB scenario (Falling Evaporating Bodies) explain main characteristics of variable gas :

- Radial velocity of the gas
- Variability
- Size of the gaseous clouds
- Temperature of the hot gas
- Presence of over-ionized species (Al++)

Nature, 23 October 2014, Vol 514, p. 462

LETTER

doi:10.1038/nature13849

Two families of exocomets in the β Pictoris system

F. Kiefer[1,2,3], A. Lecavelier des Etangs[1,2], J. Boissier[4], A. Vidal-Madjar[1,2], H. Beust[5], A.-M. Lagrange[5], G. Hébrard[1,2] & R. Ferlet[1,2]

Detection of exocomets in variable CaII lines at 3934 and 3968Å

Statistical analysis of more than 1000 spectra, ~500 exocomets

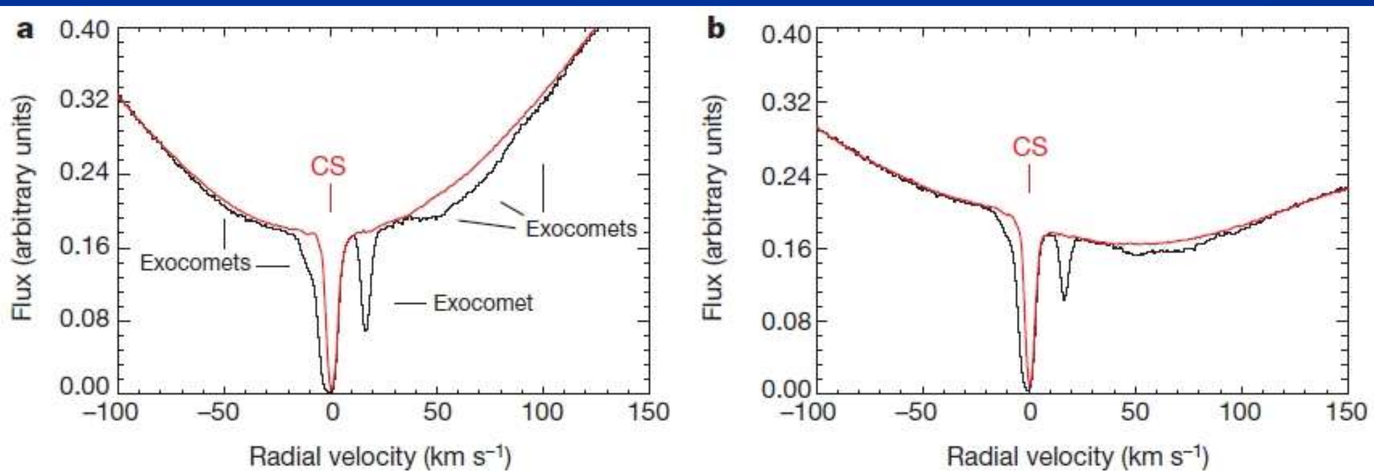
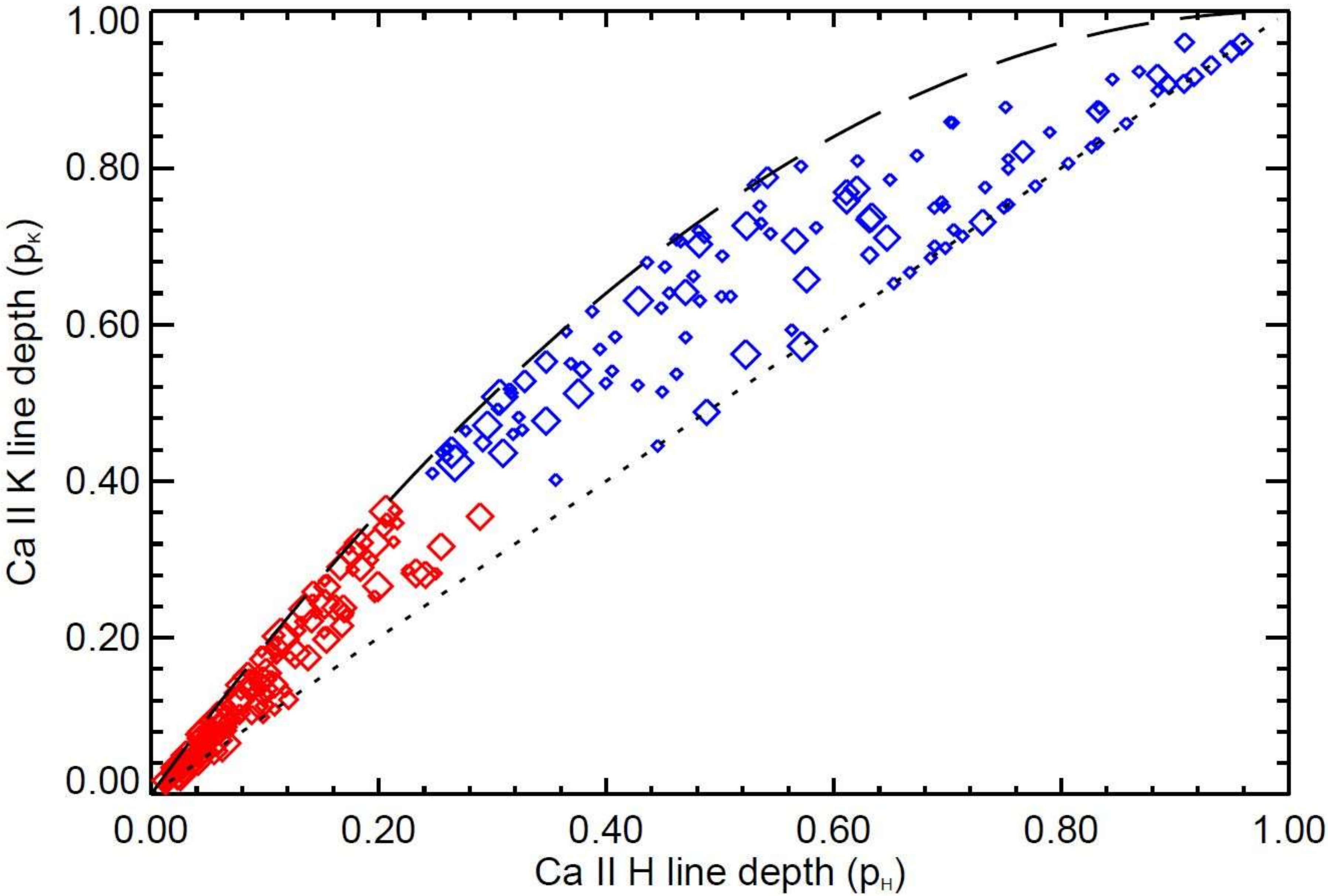
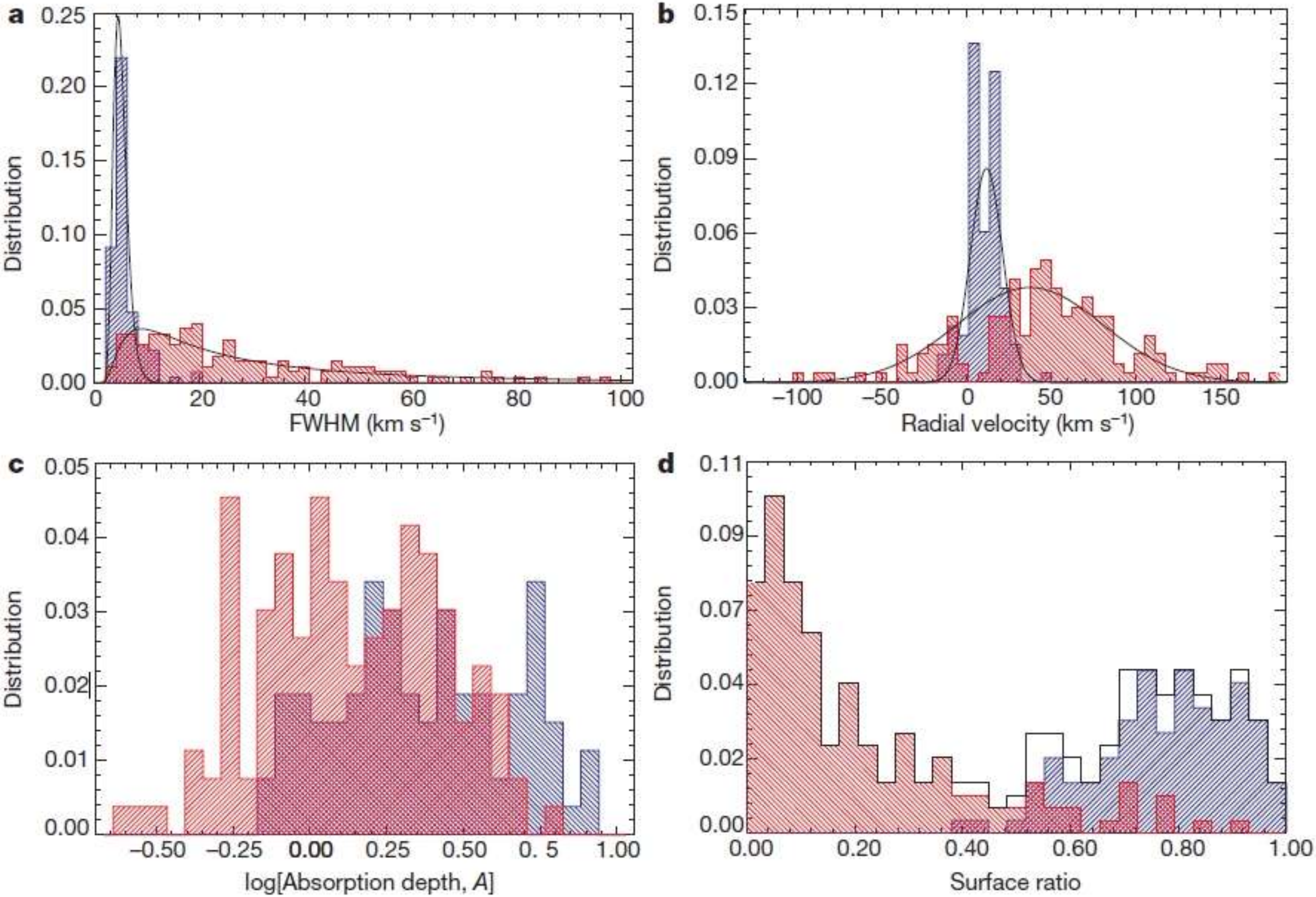


Figure 1 | A typical Ca II spectrum of *β* Pictoris. **a**, Ca II K-line (3,934 Å). **b**, Ca II H-line (3,968 Å). A typical Ca II spectrum of *β* Pic (black line) collected on 27 October 2009 is shown together with the derived *β* Pic stellar spectrum (red line) used as the reference spectrum free of variable absorption features. Radial velocities are given with respect to the star's rest frame. CS indicates the circumstellar disk contribution, while solid black lines indicate the changes in flux caused by the transiting exocomets. Each transiting exocomet produces an absorption signature detected at the same radial velocity in both Ca II lines.

Two families of CaII line depths



Two families of variable absorption lines



Two families of exocomets « sizes »

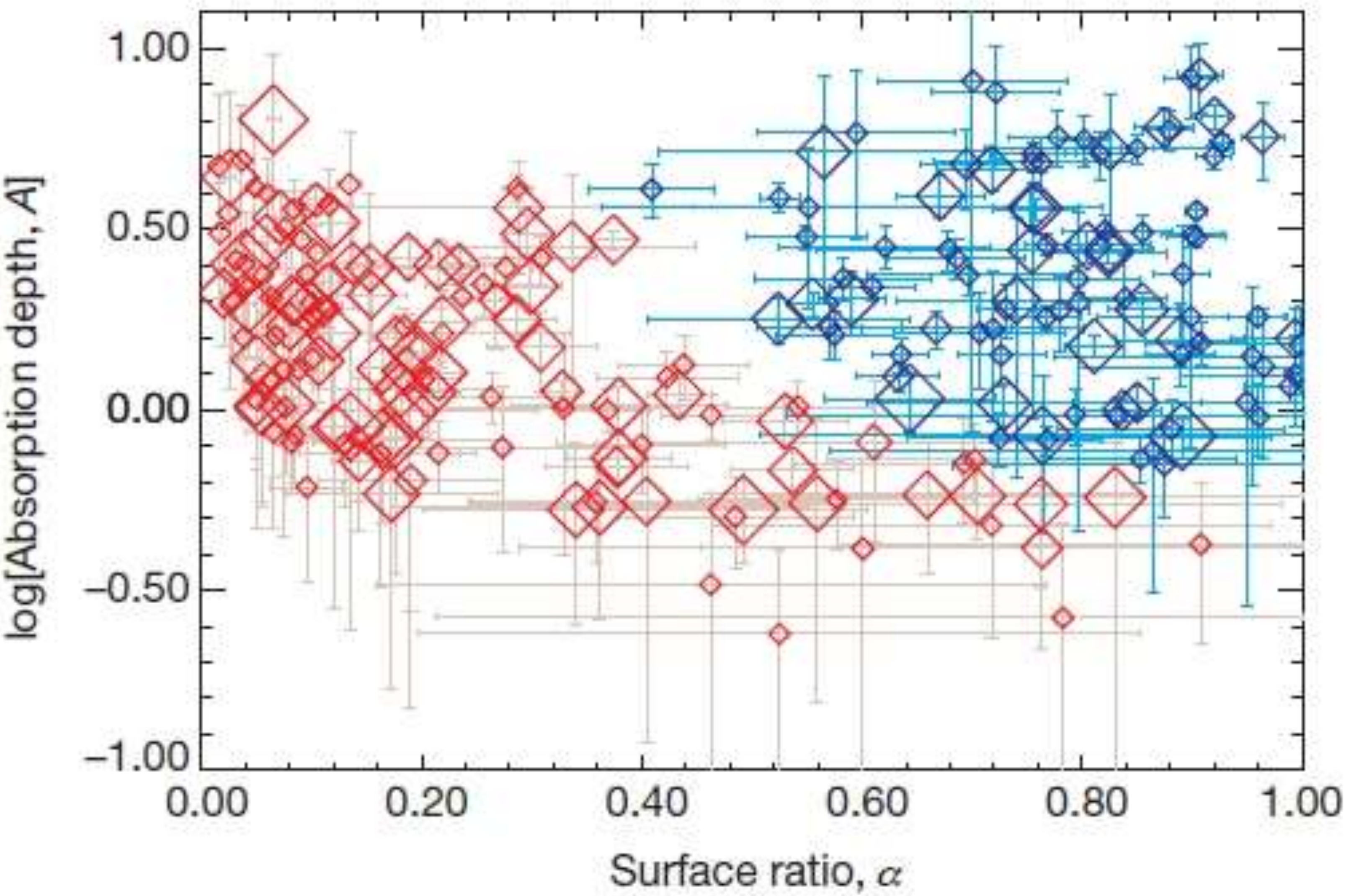
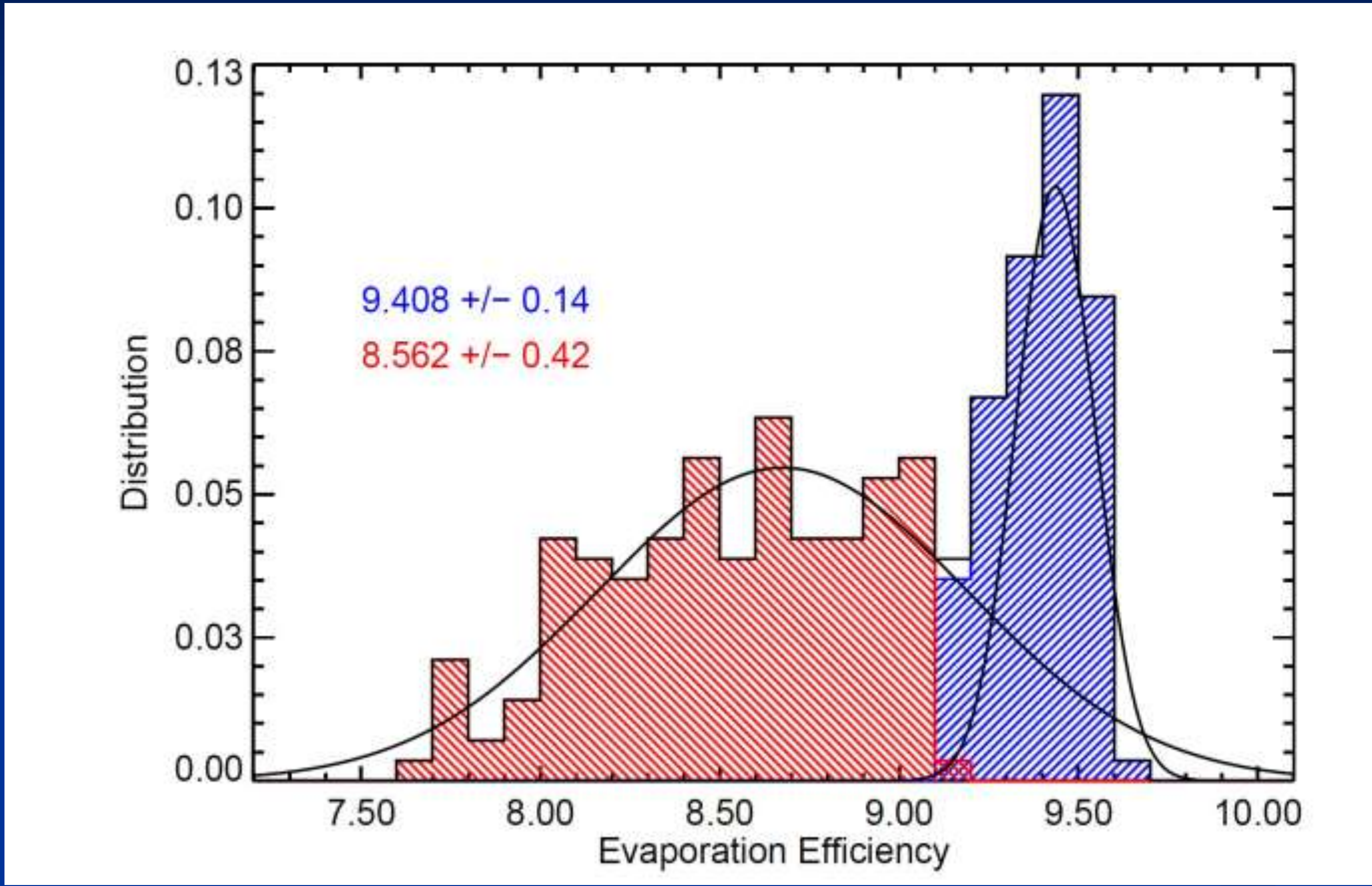


Figure 2 | Coma absorption depths as a function of surface ratio for transiting exocomets. The absorption depths A (a dimensionless number) of

Evaporation efficiency



$$\eta = \log \frac{Z_{H_2O} L_{H_2O} + \frac{1}{2}\dot{M} v_n^2}{F_\star(d)}$$

η = log (Evaporation Efficiency)

$$= \log \frac{\text{Energy used for evaporation}}{\text{Energy received bfrom the star}}$$

Two families of orbital properties

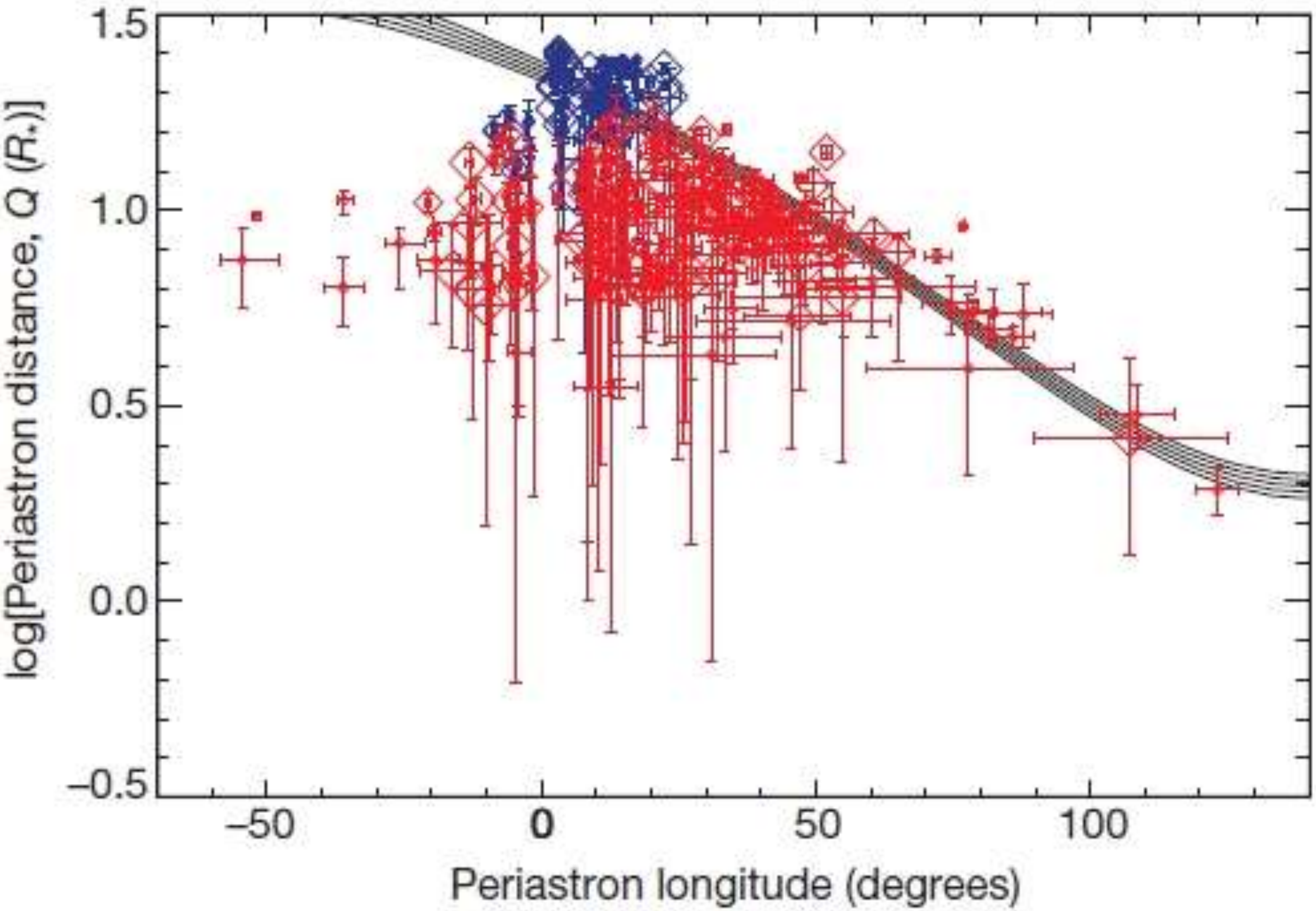
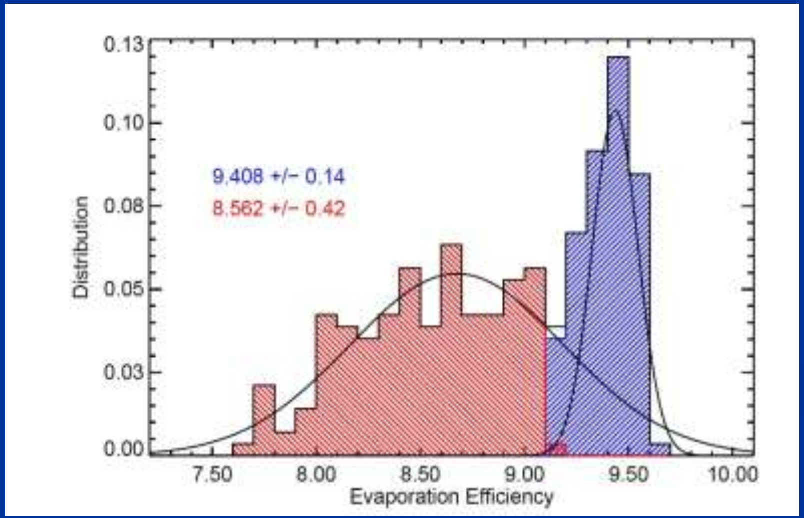


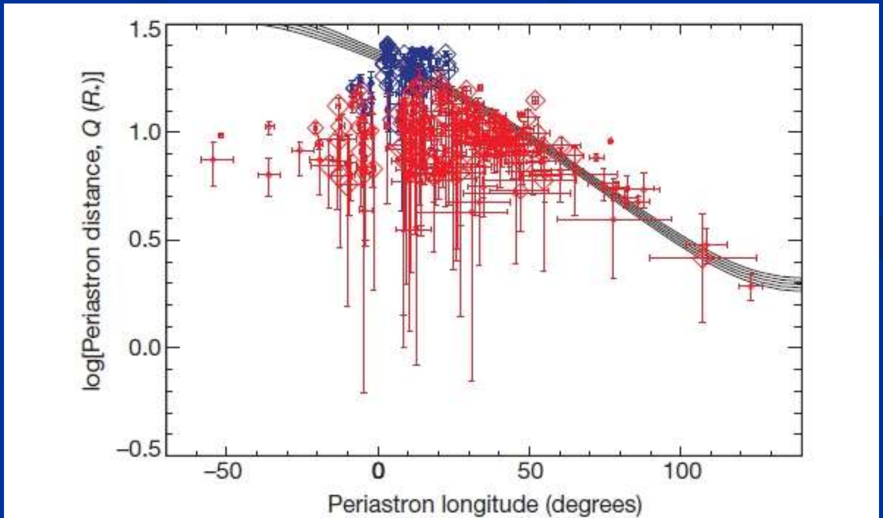
Figure 4 | Periastron distance versus periastron longitude. The exocomets

Two families of exocomets

(Kiefer et al., Nature 514, 2014)

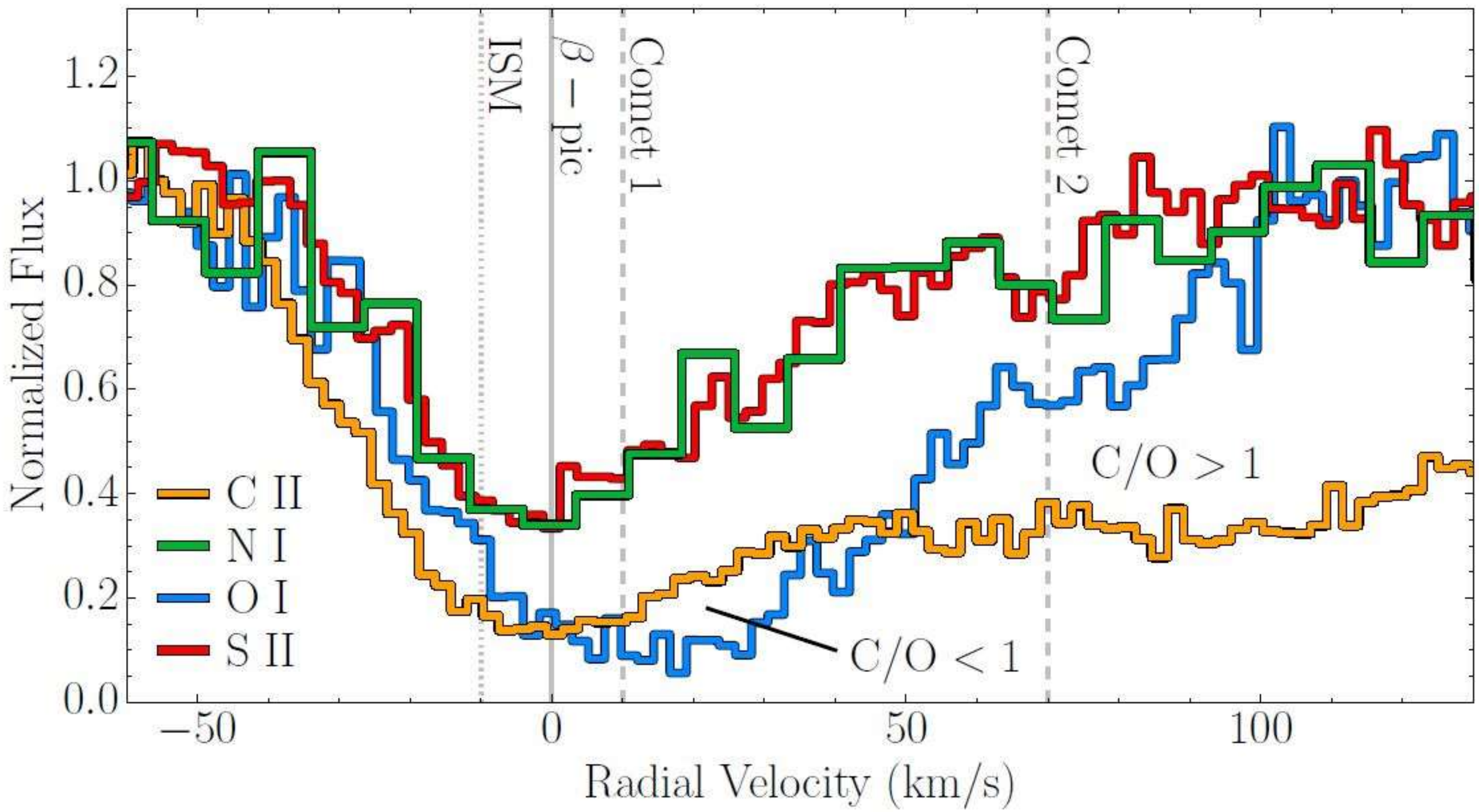
- One family of young comets on a single orbit, likely produced by the recent break-up of one or a few larger objects (in blue)
- One family of older objects trapped in resonance with a massive planet (β Pic b ?) (in red)





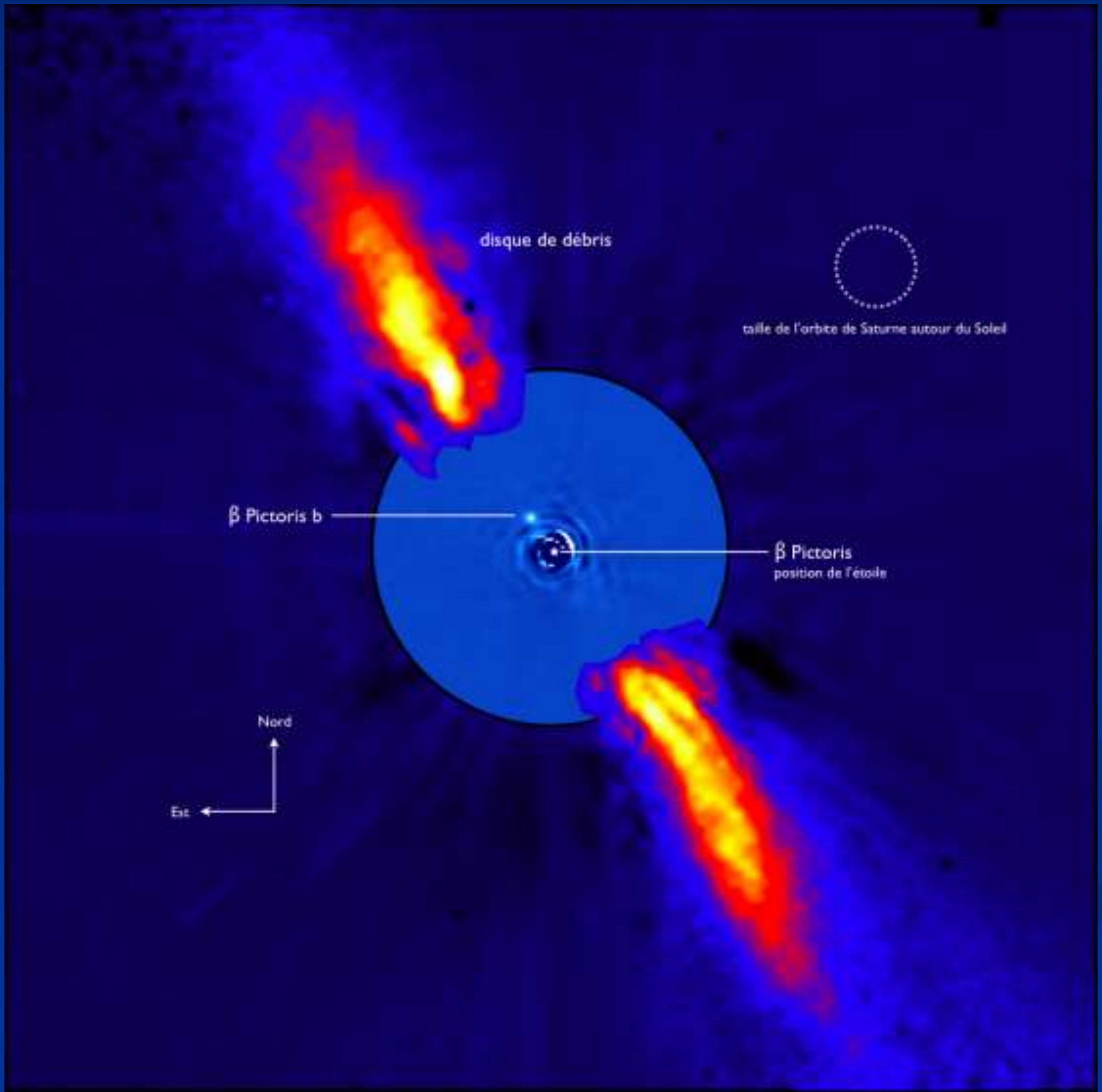
New observations of exocomets in the far-UV with HST/COS
(Paul Wilson et al.)

Different C/O ratio for the 2 families of exocomets ??

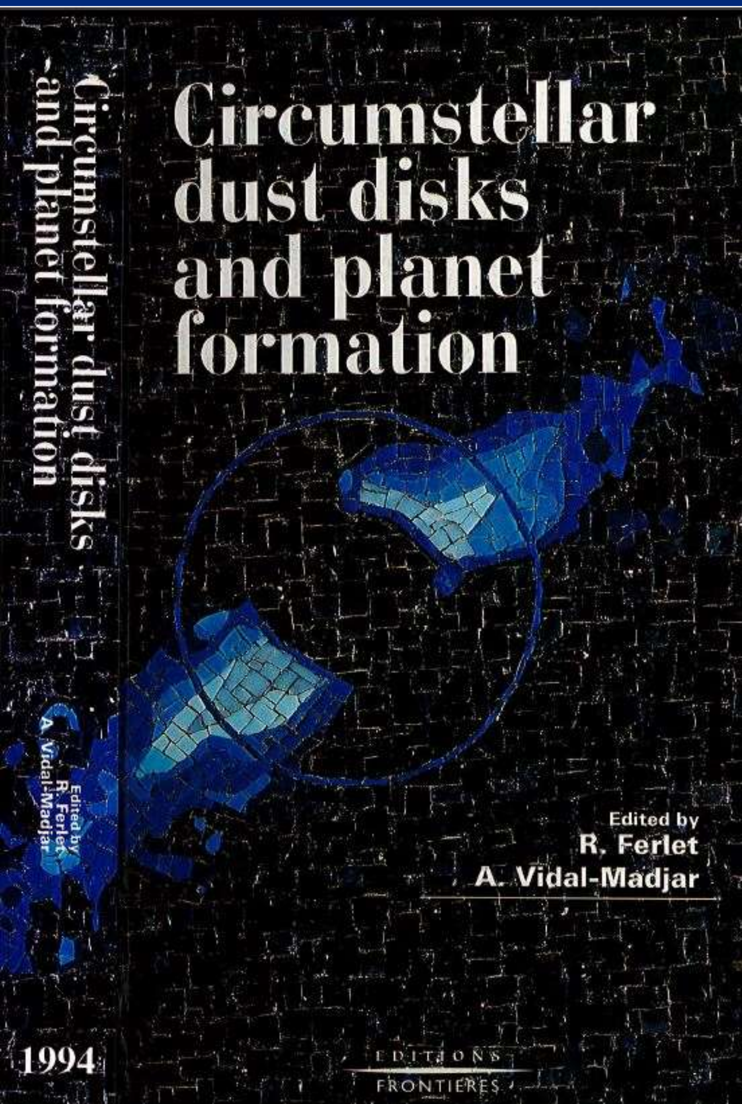


The planet :: β Pic b

Image of Beta Pic b in 2003
(Lagrange et al. 2009)



Circumstellar dust disk and planet formation conference (1994)



FOREWORD

During a full week, Paris was at the center of all circumstellar disks

The subject chosen for the tenth anniversary of the annual meetings[1] of the Institut d'Astrophysique de Paris of the Centre National de la Recherche Scientifique (CNRS), LES DISQUES DE POUSSIERES CIRCUMSTELLAIRES ET LA FORMATION DES PLANETES – "CIRCUMSTELLAR DUST DISKS AND PLANET FORMATION" was and still remains at the forefront of astronomical research.

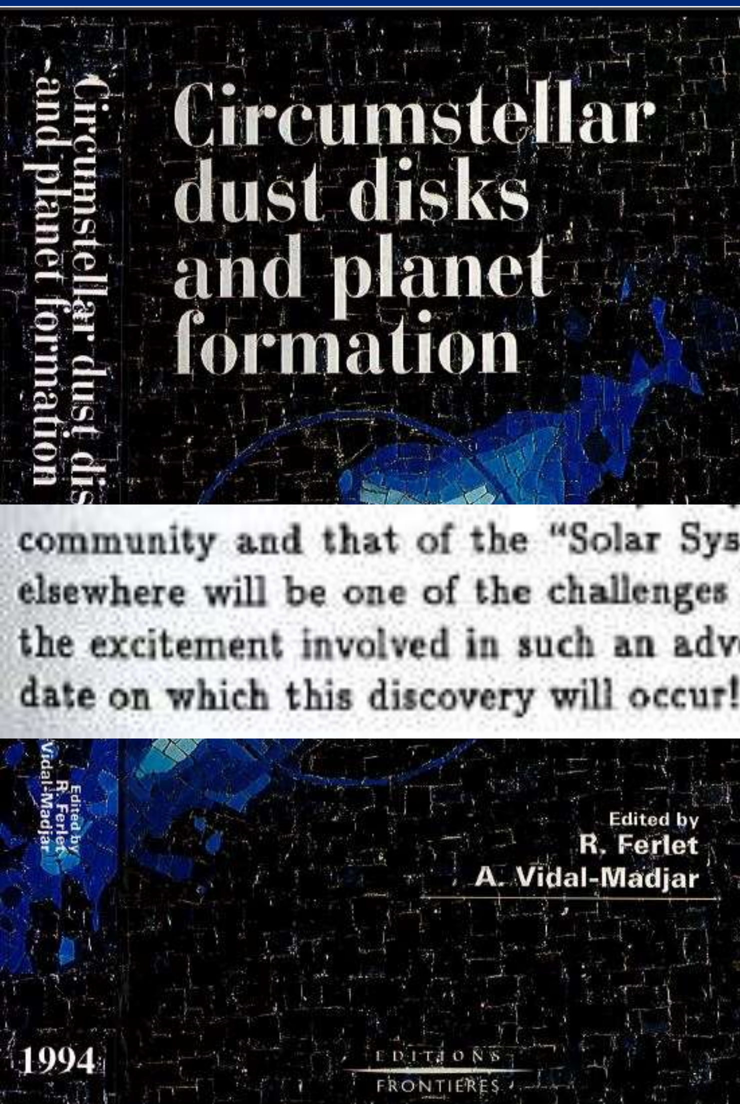
A large number of teams in the world are involved in the study of disks around very young stars as well as around main sequence stars, and this field of research is in rapid expansion. Since 1984 when the dusty disk around the star β Pictoris was imaged for the first time, many detailed multi–wavelengths spectroscopic observations including those by the Hubble Space Telescope, have led to a detailed characterization of this disk, in which kilometer size small bodies have been indirectly detected. Recent photometric observations, of what is already thought to be the prototype of a planetary system in formation, or even already formed, suggest the presence of at least a giant planet which has already condensed. It seems now possible to be able to directly test some predictions of dynamical models of planet formation for the first time.

Although the IRAS satellite discovered infrared excesses, interpreted as due to dust envelopes, in many nearby stars, the case of β Pictoris remains unique. In fact, disks around main sequence stars are far less luminous than those observed for most of the T–Tauri stars, especially if they are not seen edge–on from the Earth. The differences between these systems resulting either from planetary accretion or from ejection of matter, can in fact provide constraints or processes of planet formation.

The Paris Conference therefore dealt with finding possible links between differents types of disks, and studying their evolution toward planetary systems, as well as putting forward the implications for processes of planetary growth. A a matter of fact, one of the major issues in these studies is to understand the formation of our own Solar System. That is why another original point of the IAP Meeting was to define possible analogies between the β Pictoris system and our own, in order to more precisely constrain the wonderful story, which led to the still unique exemple of the solar planets.

As many as eighty seven attendees from the whole world (Australia, Canada, USA, India, Japan, Eastern countries and EEC countries) met in Paris from the 4th to the 8th of July 1994 to confront their views. This was undoubtedly an opportunity to realize the need for pluridisciplinary links between theoreticians and observers, and, what is more unusual, between specialists from the "stellar" community and that of the "Solar System". The discovery of planets around β Pictoris and /or elsewhere will be one of the challenges in the next decade. If a consensus was easily reached about the excitement involved in such an adventure, on the contrary the participants did not agree on the date on which this discovery will occur!

Circumstellar dust disk and planet formation conference (1994)



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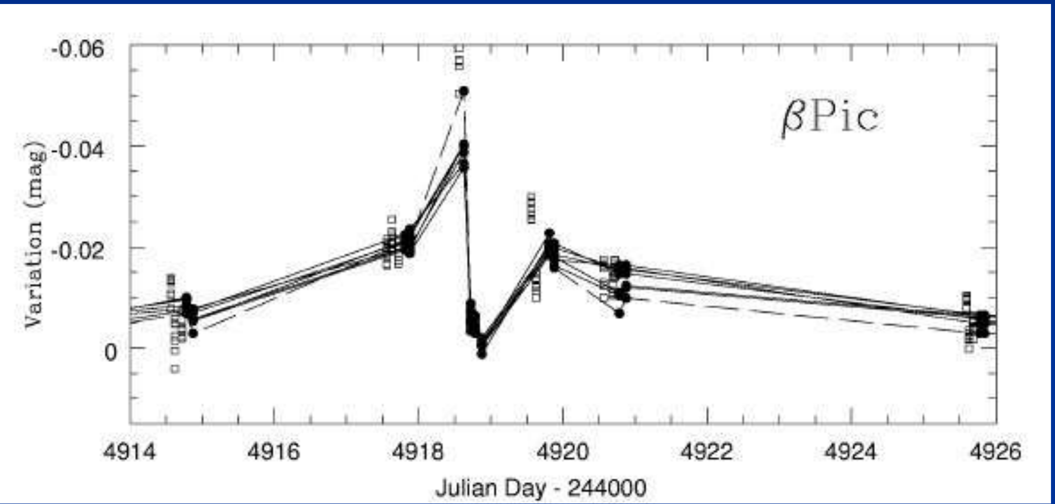
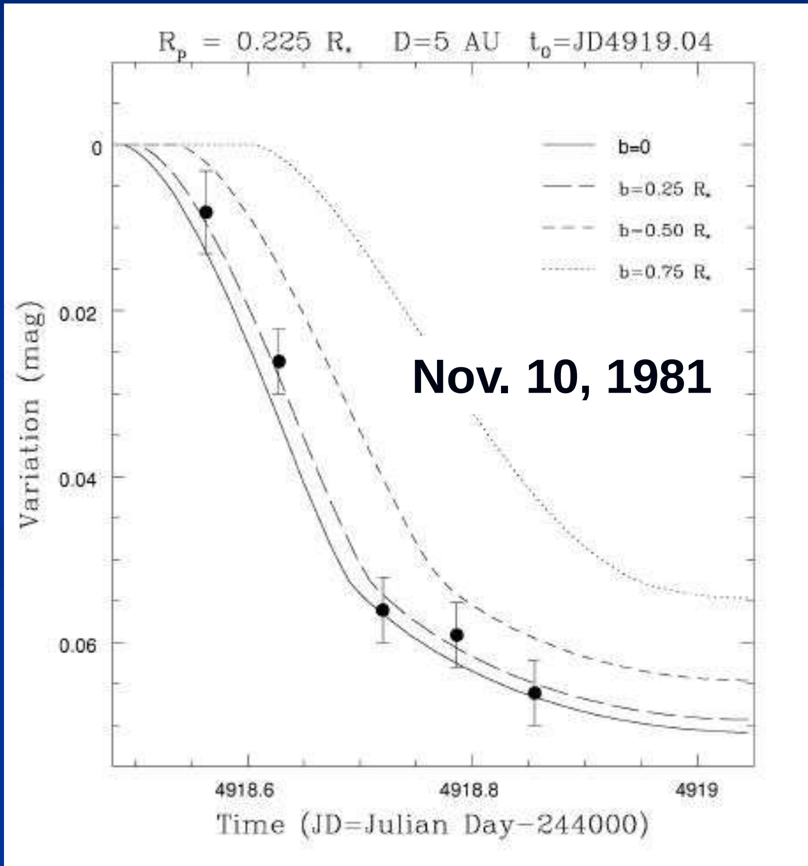


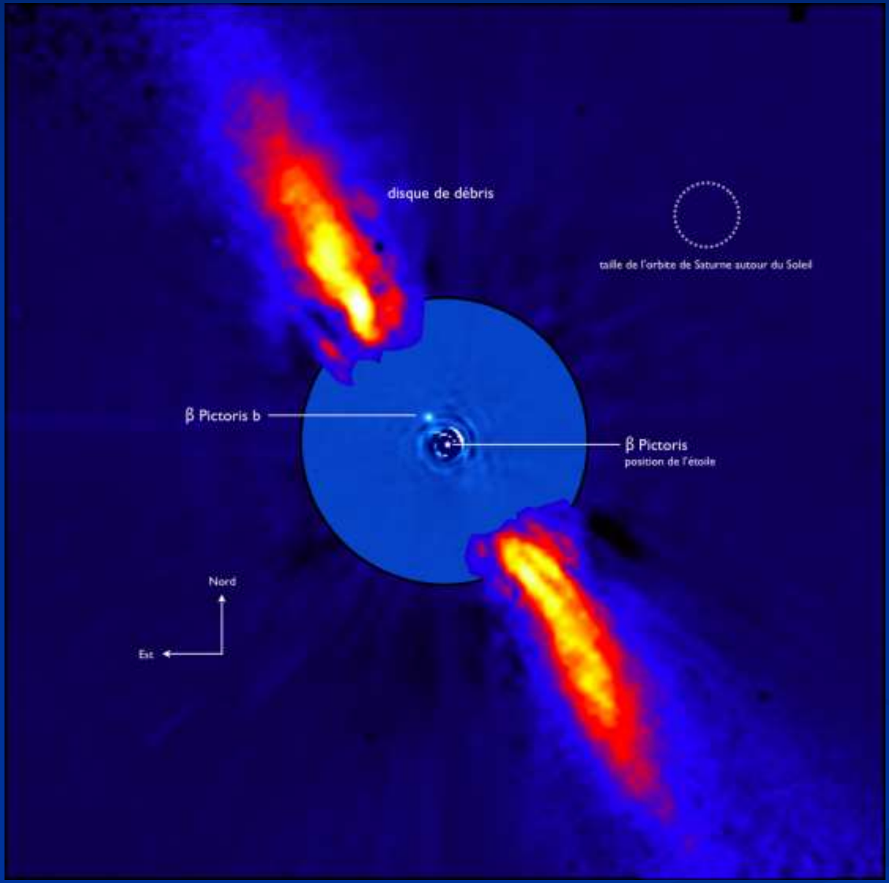
Photometric variations on days time scale related to a hole of obscuring dust around the planet



Photometric variations on hours time scale related to the transit of a planet (with limb-darkening !)

Image of Beta Pic b in 2003

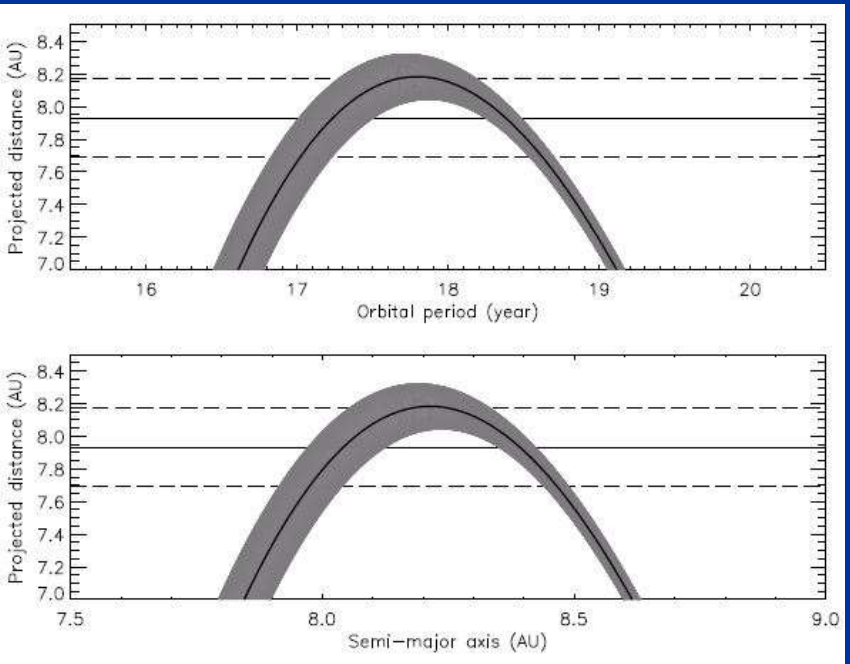
(Lagrange et al. 2009)

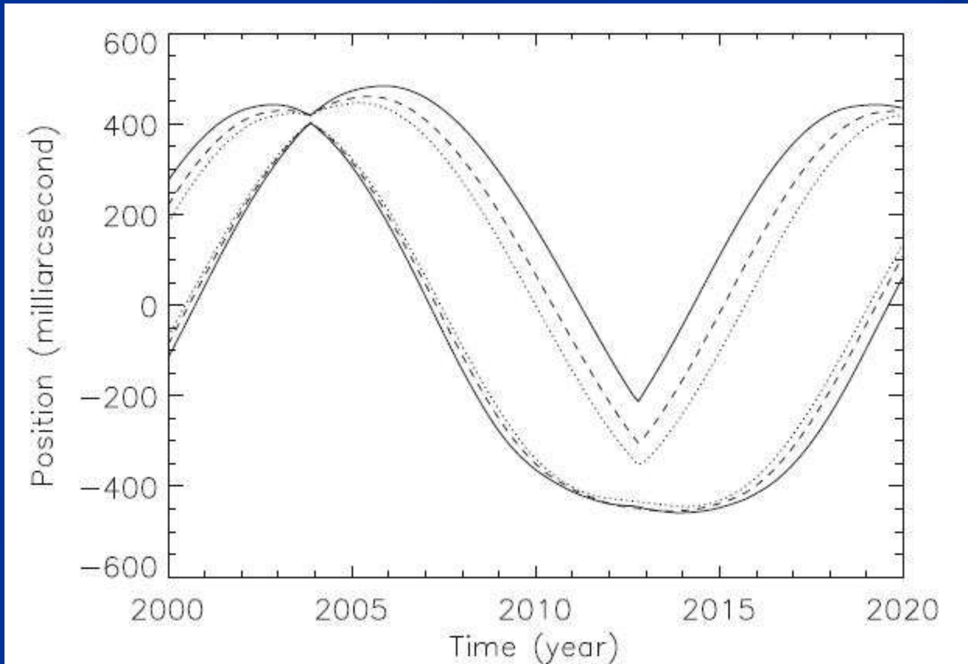


Could it be the transiting planet of 1981 ??

Prediction using the 2003 position
(Lecavelier des Etangs & Vidal-Madjar 2009)

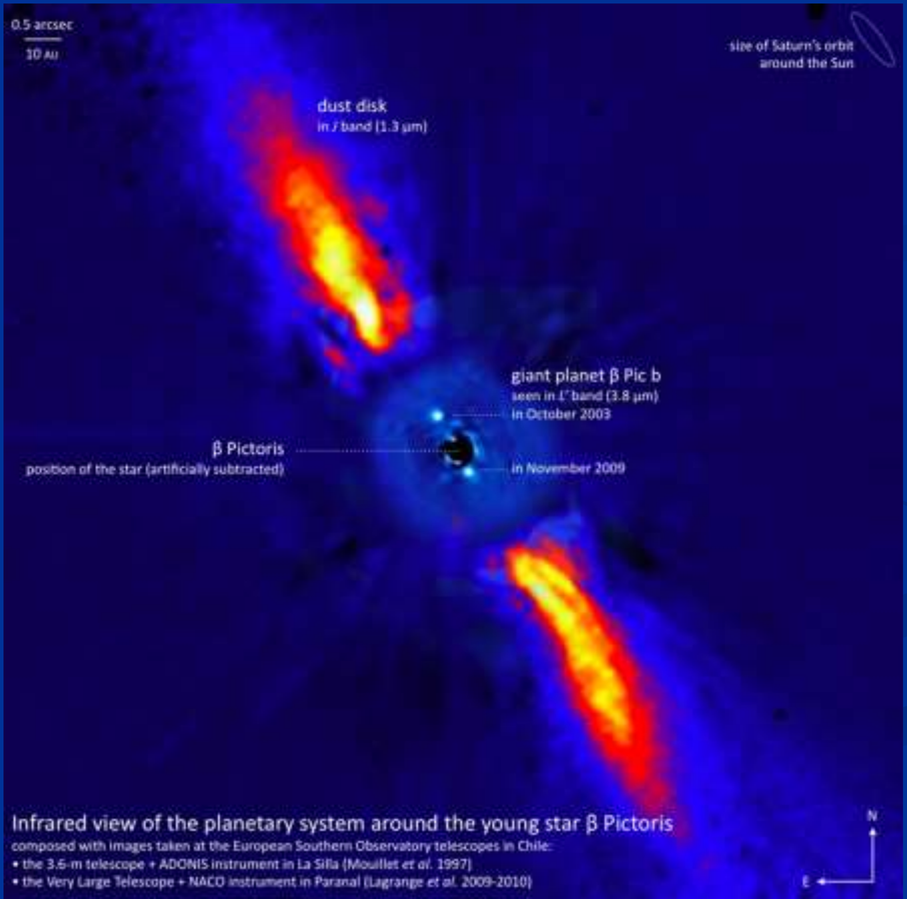
- If this is the same planet::
  → orbital period is 17-19 years
  → observed closed to quadrature in 2003
  → Next quadrature (in the other side) predicted in 2012-2015





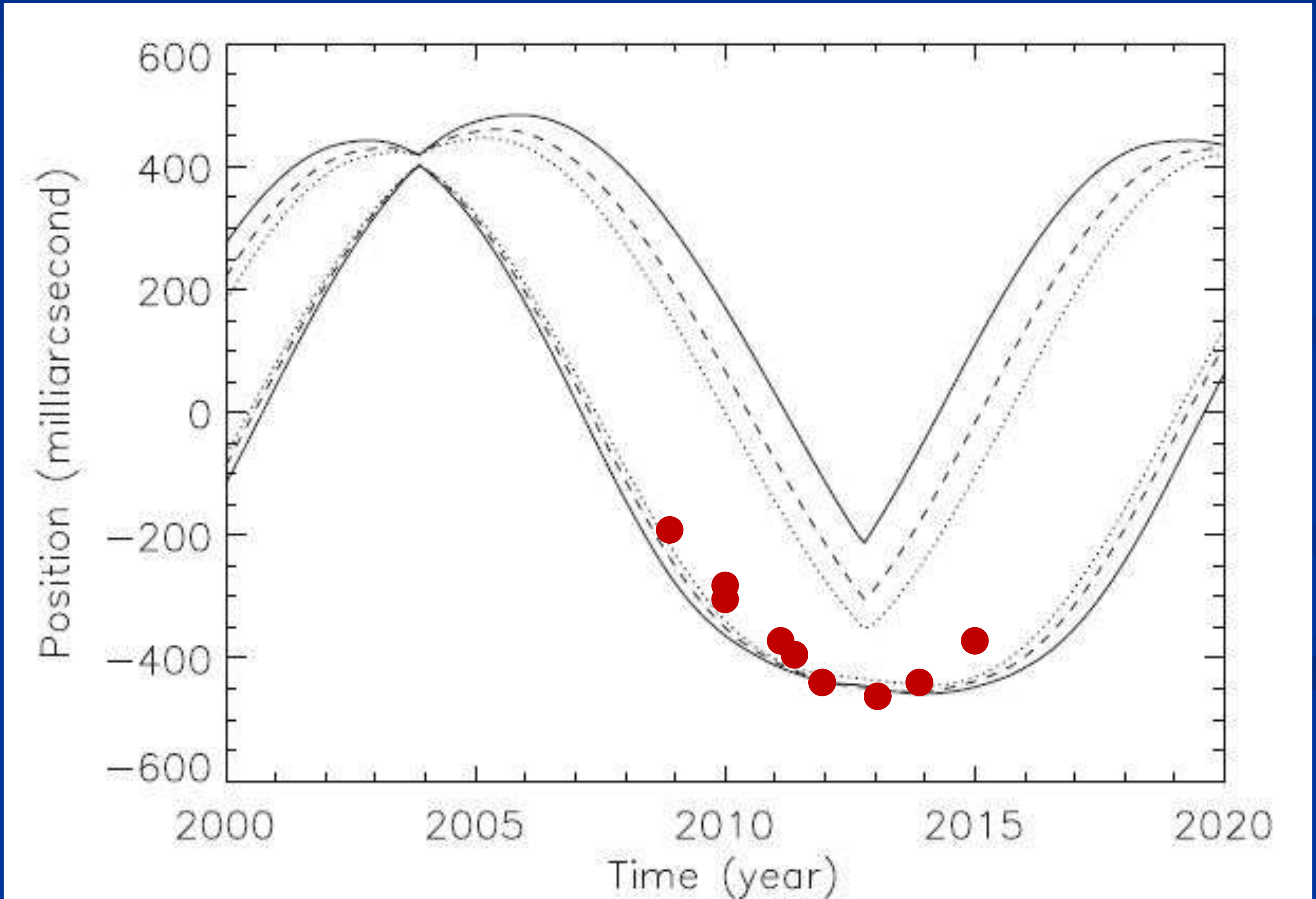
Observations of November 2009
(Lagrange et al. 2010)

- In 2009, the planet appears in the other side in agreement with the predictions.



Observations of Nov 2009 - Jan 2015

- The planet position is in agreement with the predictions.

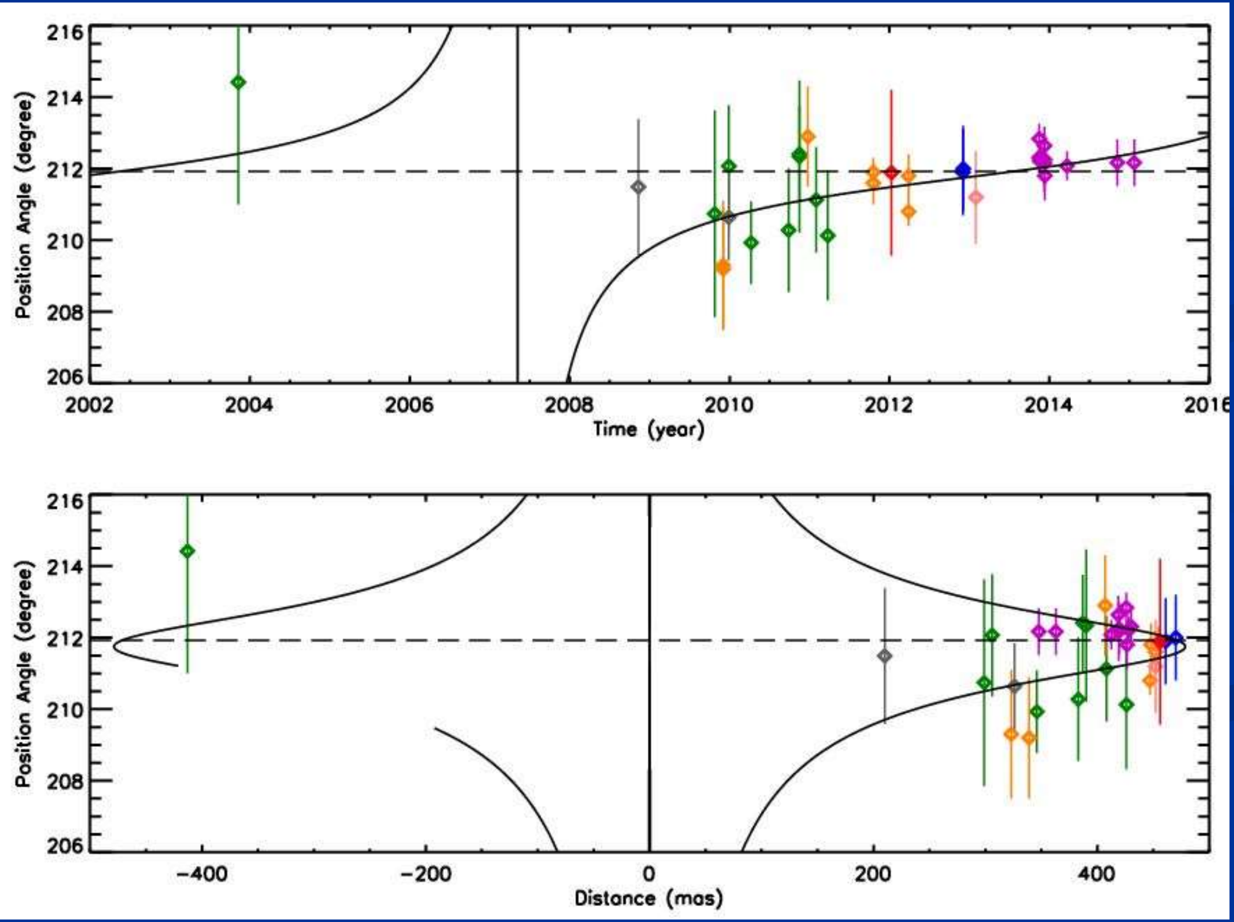


Does β Pic b transits ??

- Millar-Blanchaer et al. (2015) → $i=89.0° \pm 0.3°$

Does β Pic b transits ??

- Millar-Blanchaer et al. (2015) → i=89.0° ± 0.3°



Does β Pic b transits ??

- Millar-Blanchaer et al. (MB 2015) → i=89.0° ± 0.3°
- No
  if Position Angle measurements of MB have no systematics
- Yes
  if 0.5° systematics in PA measurements of MB 2015:
  → Bonnefoy et al. 2014 & Macintosh et al. 2014
  have PA lower by 0.5° on the same data as MB 2015.

Observations of Nov 2009 – Jan 2015

- What are the new constraints on the planet and the transit ?

MCMC statistics:

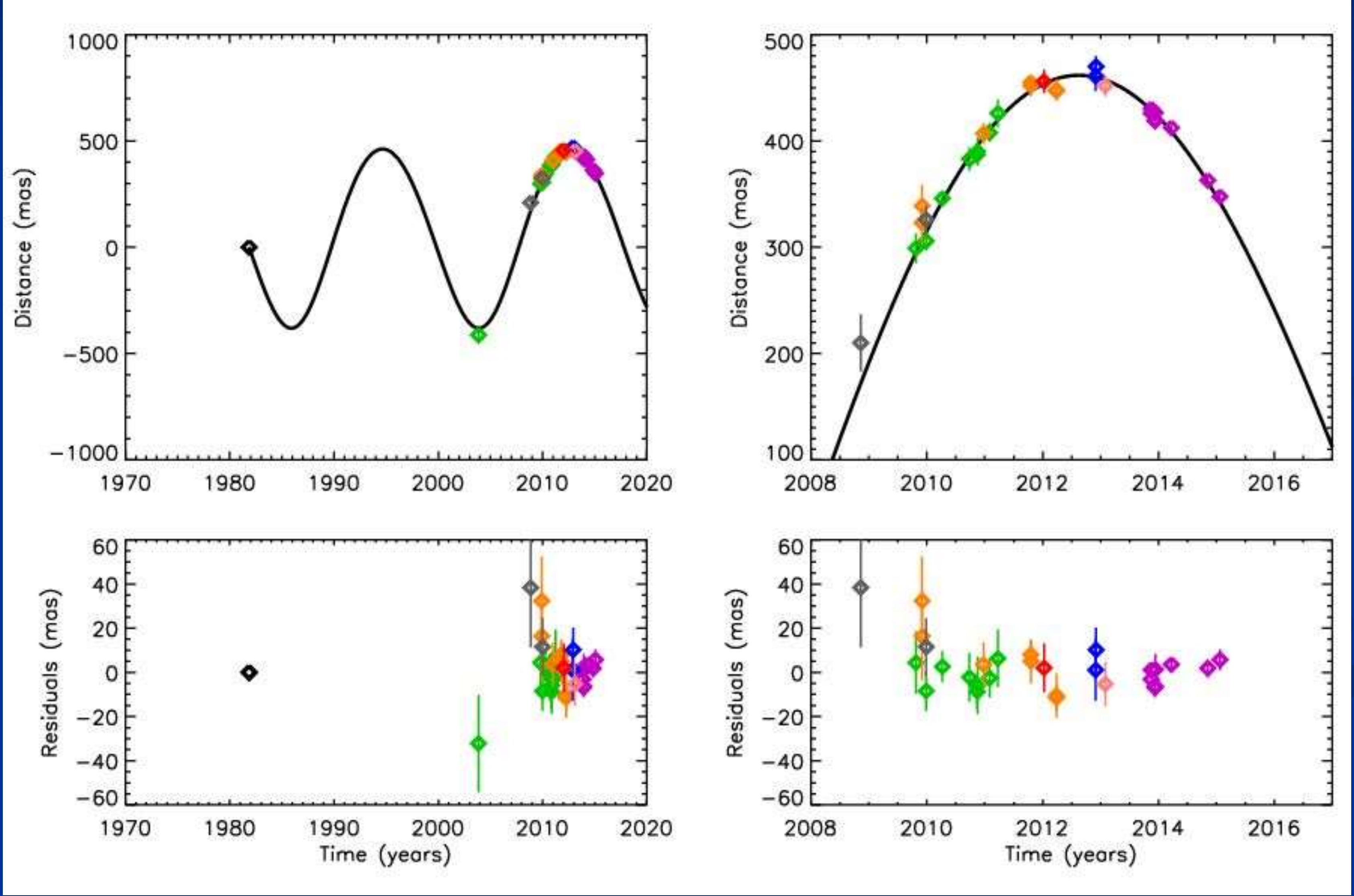
fit to - 32 Astrometric position measurements

- 1 Planet's radial velocity measurement (Snellen et al. 2014)

→ two families of orbits : e~0.1 and e~0.3

Observations of Nov 2009 - Jan 2015

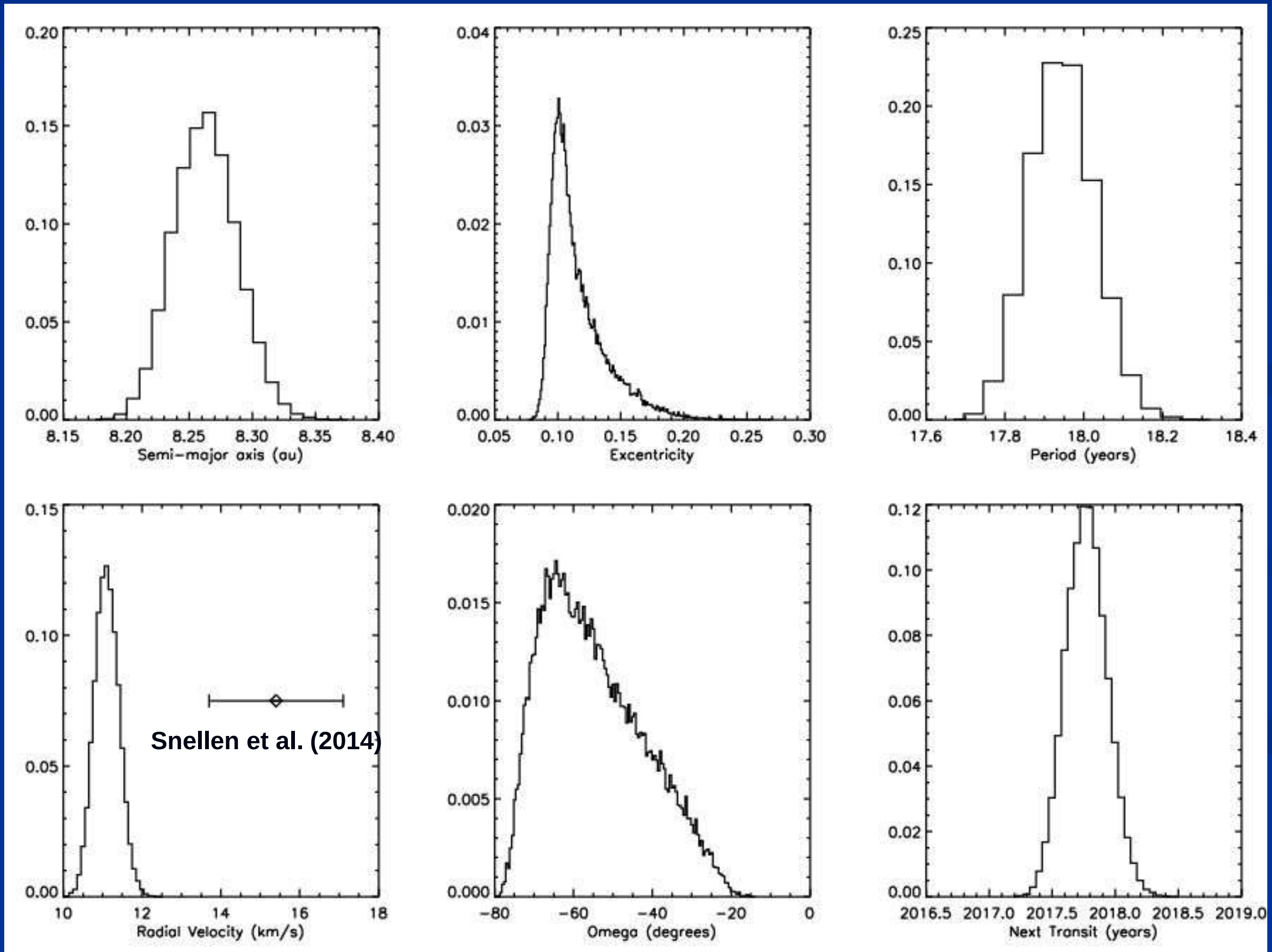
Low eccentricity orbit (e~0.1, Period~18 years, χ^2=36.5/30)

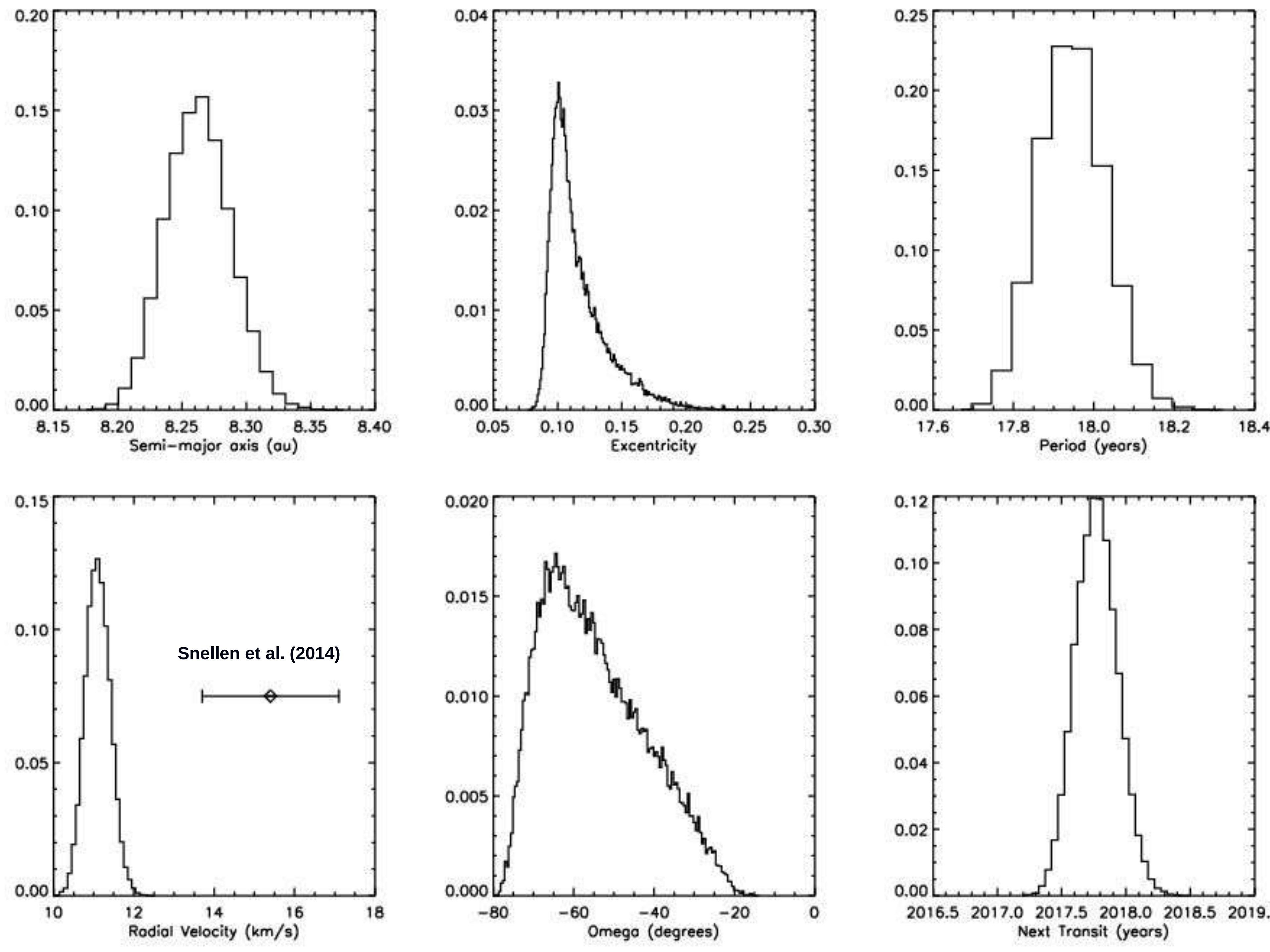


Observations of Nov 2009 - Jan 2015

Low eccentricity orbit (e~0.1, Period~18 years)

Next transit in :: 1st July 2017 - 15th Feb 2018 (2 σ)

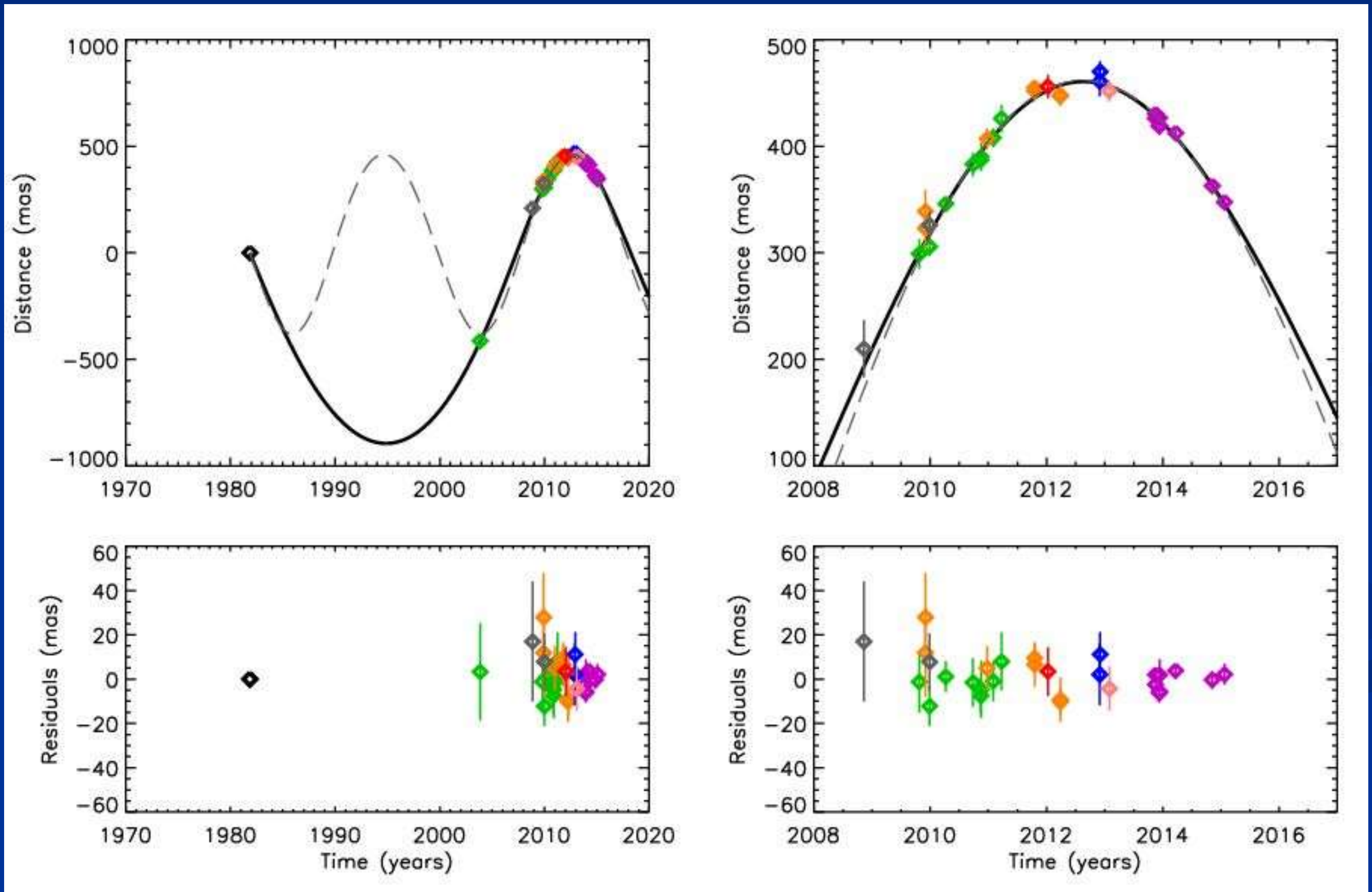




Semi-major axis (au)
Excentricity
Period (years)
Radial Velocity (km/s)
Snellen et al. (2014)
Omega (degrees)
Next Transit (years)

Observations of Nov 2009 - Jan 2015

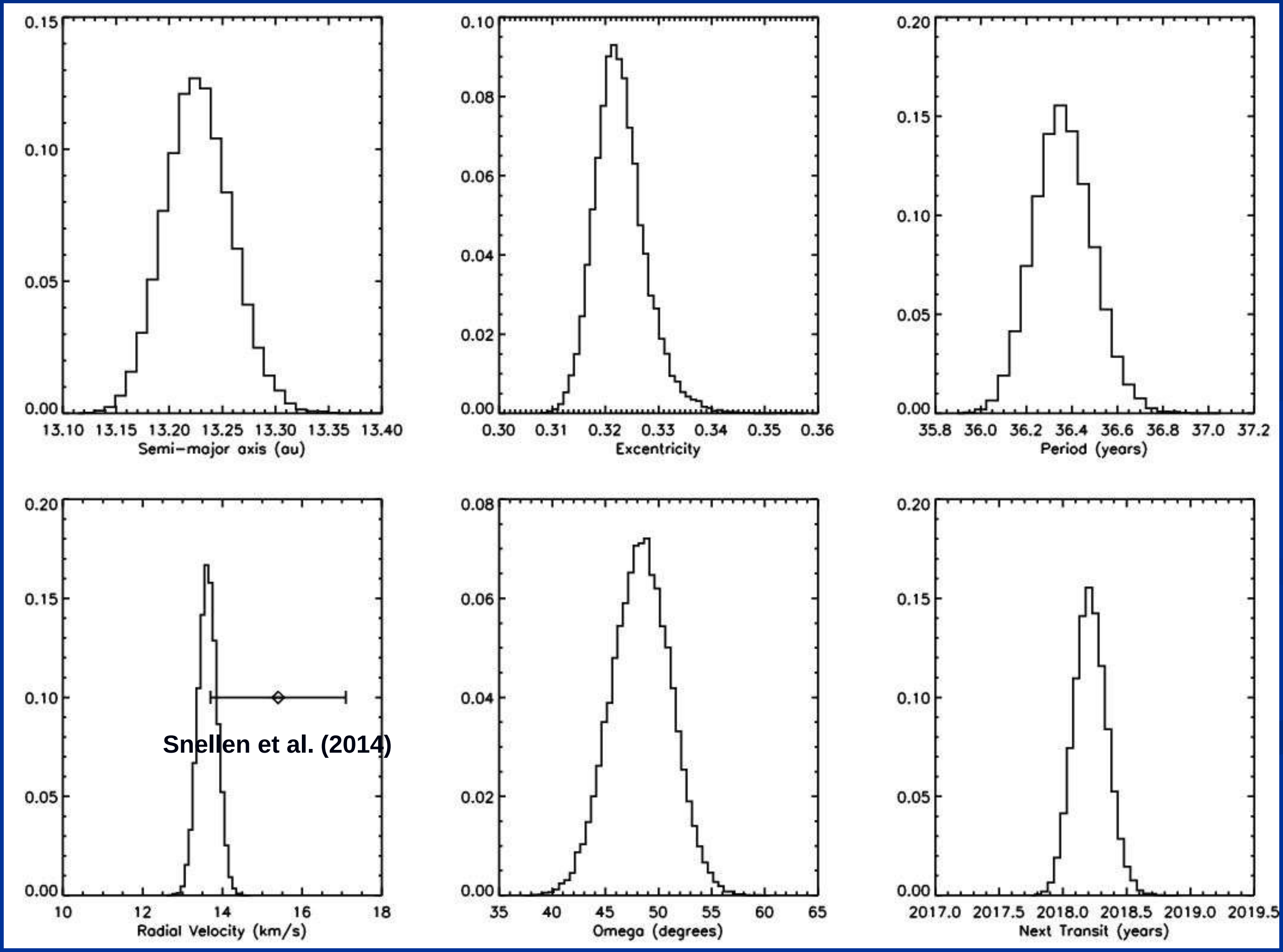
High eccentricity orbit (e~0.3, Period~36 years , χ^2=23.8/30)

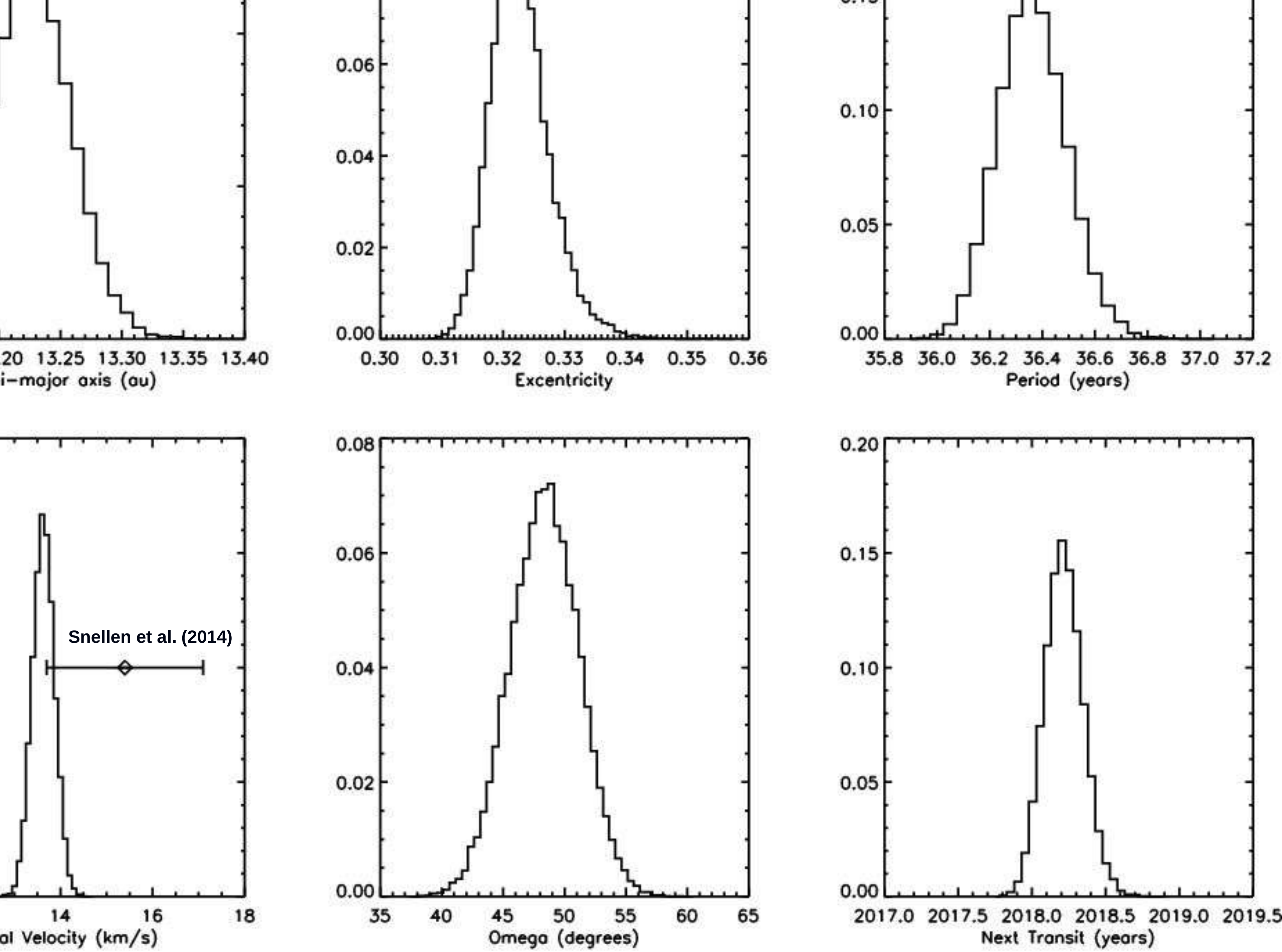


Observations of Nov 2009 - Jan 2015

High eccentricity orbit (e~0.3, Period~36 years)

Next transit in :: 1st Jan 2018 - 30th Jun 2018 (2 σ)





0.06
0.04
0.02
0.00
0.30 0.31 0.32 0.33 0.34 0.35 0.36
Excentricity
0.10
0.05
0.00
35.8 36.0 36.2 36.4 36.6 36.8 37.0 37.2
Period (years)
.20 13.25 13.30 13.35 13.40
i–major axis (au)
Snellen et al. (2014)
14 16 18
al Velocity (km/s)
0.08
0.06
0.04
0.02
0.00
35 40 45 50 55 60 65
Omega (degrees)
0.20
0.15
0.10
0.05
0.00
2017.0 2017.5 2018.0 2018.5 2019.0 2019.5
Next Transit (years)

PICSAT

→ high accuracy photometry (10^{-3})

PI : Sylvestre Lacour

- Based on a CubSat platform.
- Lounch could be as early as end of 2016

Conclusion

β Pic b can be a transiting planet !!

Transit of a young planet in front of a 3.8 magnitude star !

Transit observations have been proven to be extremely powerful to scan the planet environment and atmosphere::
→ Rings, Satellites, etc.

***Rendez-vous* in 2017-2018**

Thank you