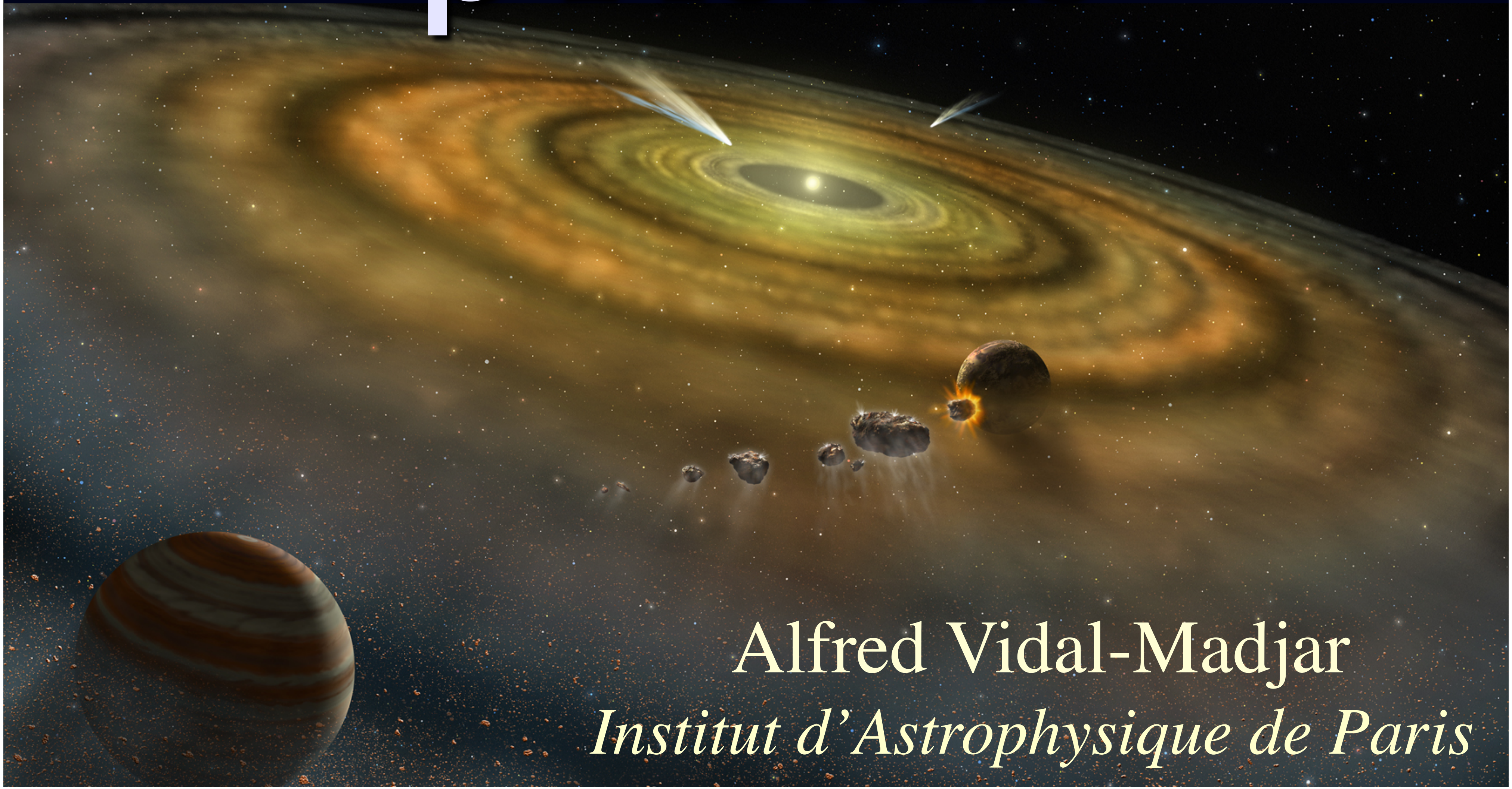
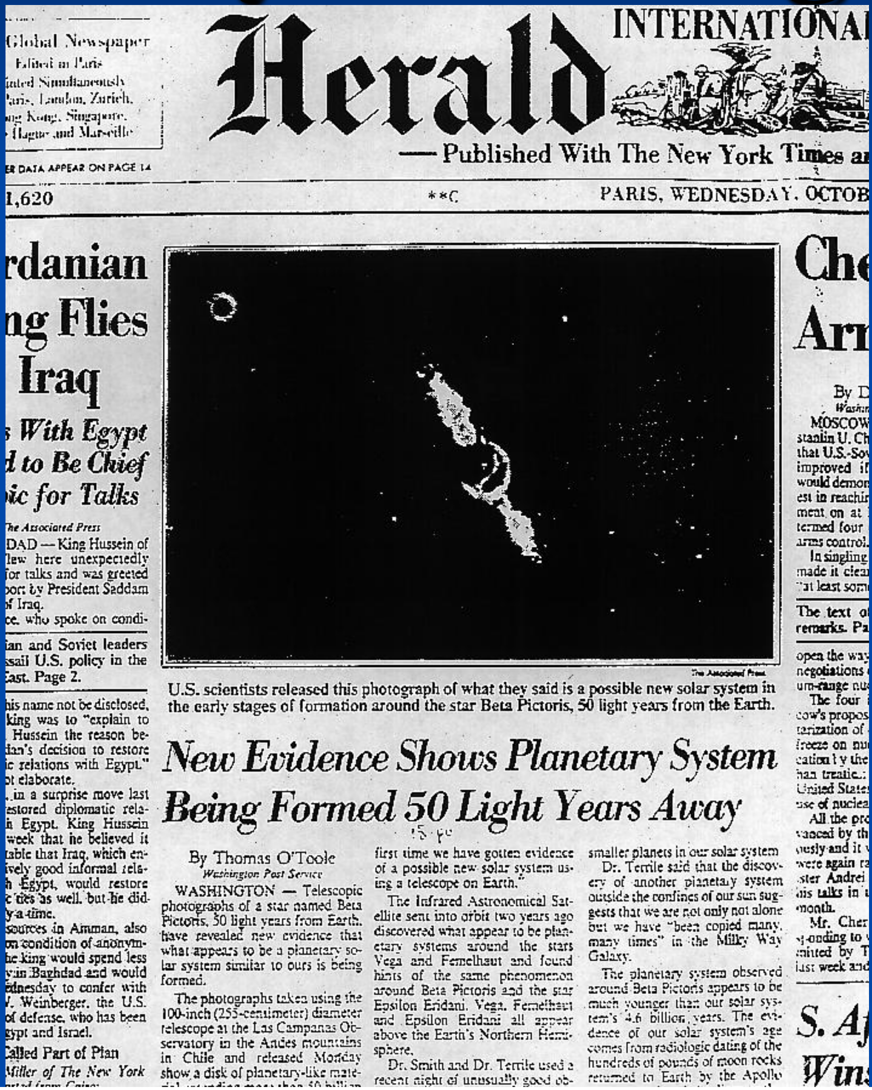
Circumstellar gas in β Pictoris



Alfred Vidal-Madjar

Institut d'Astrophysique de Paris

IRAS discovery of circumstellar dust around main sequence stars, followed by « an » edge-on disk image…



INTERNATIONAL Herald

— Published With The New York Times

PARIS, WEDNESDAY, OCTOB

U.S. scientists released this photograph of what they said is a possible new solar system in the early stages of formation around the star Beta Pictoris, 50 light years from the Earth.

New Evidence Shows Planetary System Being Formed 50 Light Years Away

By Thomas O'Toole
Washington Post Service

WASHINGTON — Telescopic photographs of a star named Beta Pictoris, 50 light years from Earth, have revealed new evidence that what appears to be a planetary solar system similar to ours is being formed.

The photographs taken using the 100-inch (255-centimeter) diameter telescope at the Las Campanas Observatory in the Andes mountains in Chile and released Monday show a disk of planetary-like mate-

first time we have gotten evidence of a possible new solar system using a telescope on Earth."

The Infrared Astronomical Satellite sent into orbit two years ago discovered what appear to be planetary systems around the stars Vega and Femelhaut and found hints of the same phenomenon around Beta Pictoris and the star Epsilon Eridani. Vega, Femelhaut and Epsilon Eridani all appear above the Earth's Northern Hemisphere.

Dr. Smith and Dr. Terrile used a recent night of unusually good ob-

smaller planets in our solar system.

Dr. Terrile said that the discovery of another planetary system outside the confines of our sun suggests that we are not only not alone but we have "been copied many, many times" in the Milky Way Galaxy.

The planetary system observed around Beta Pictoris appears to be much younger than our solar system's 4.6 billion years. The evidence of our solar system's age comes from radiologic dating of the hundreds of pounds of moon rocks returned to Earth by the Apollo

Seen by Roger Ferlet and myself in the flight to ESO-La Silla, Chile, triggered our curiosity…
Lew Hobbs at Mc Donald Observatory went through the same excitement…
We of course all observed for the first time β Pic and never stopped since then !

Gas around β Pic

- Stable and variable

Stable and variable gas

(Sletteback, 1975; Hobbs et al. 1985; Vidal-Madjar et al. 1986; Ferlet et al. 1987)

- Ferlet et al. (1987)

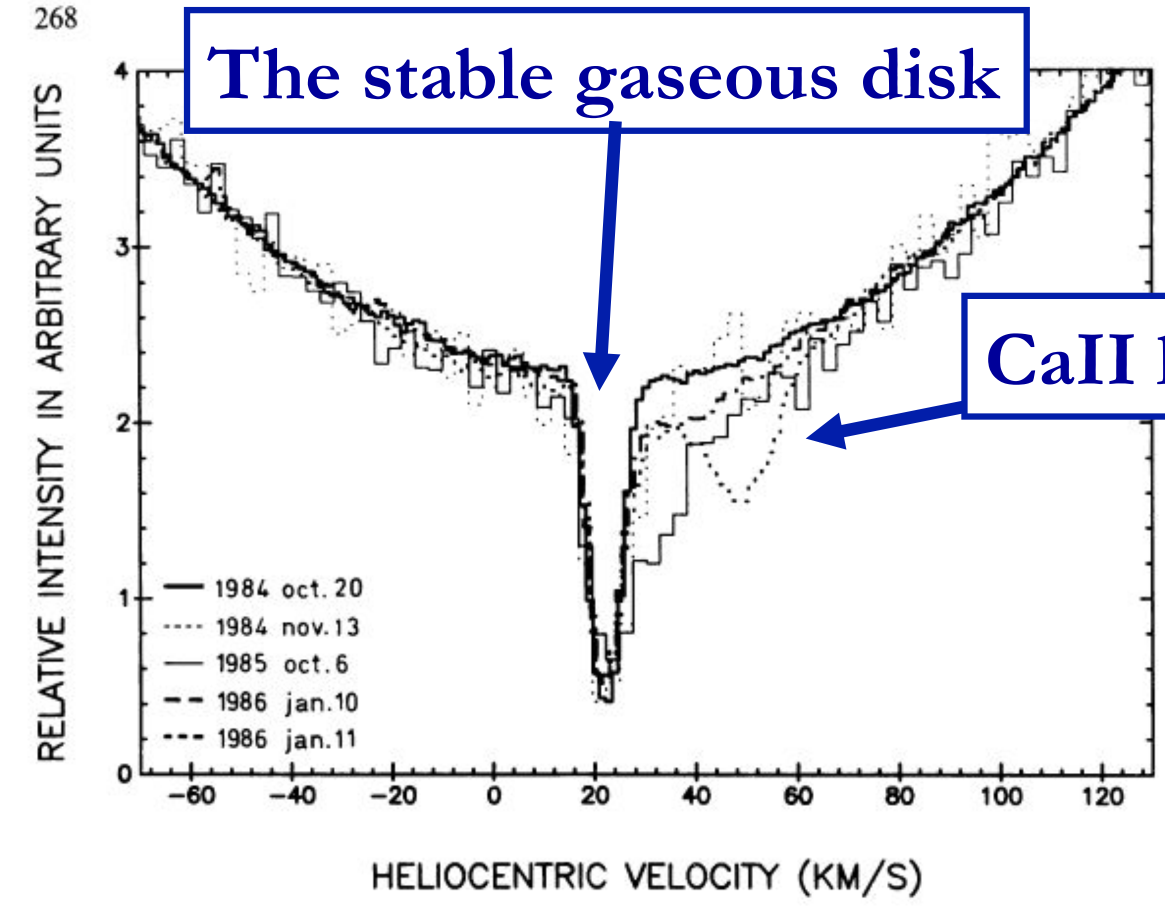
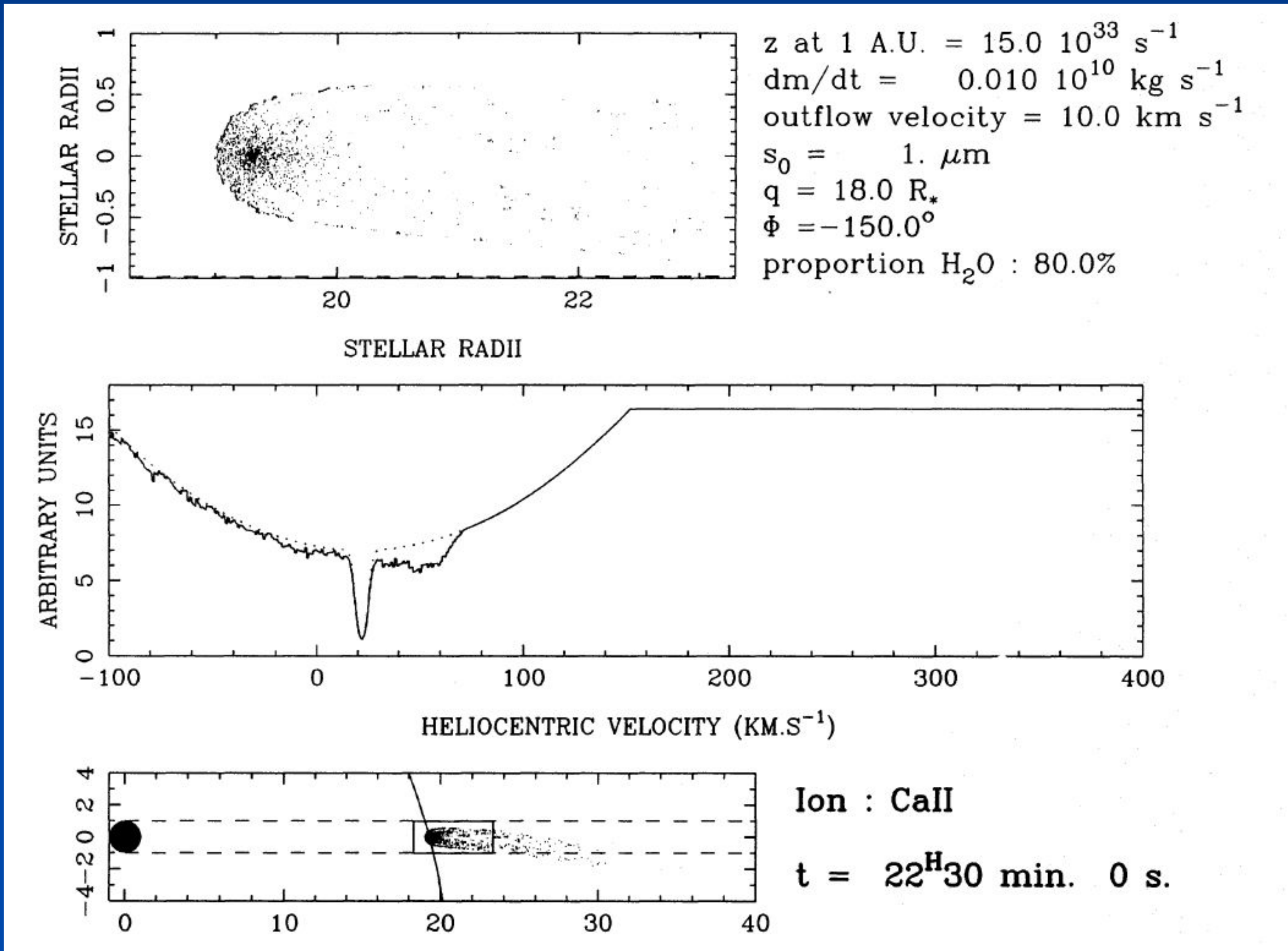


Fig. 1. Enlarged spectra of β Pic in the region of the circumstellar Ca II-K line, in an heliocentric velocity scale. They have been normalized in order for the "continua" (the stellar line widened by rotation) to coincide. To avoid confusion due to its much lower signal to noise ratio, the 1985, March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

Numerical simulation of infalling comets

Beust et al. 1990-2004



Numerical simulation of infalling comets

(Beust et al. 1990-2004; Beust & Valiron 2007)

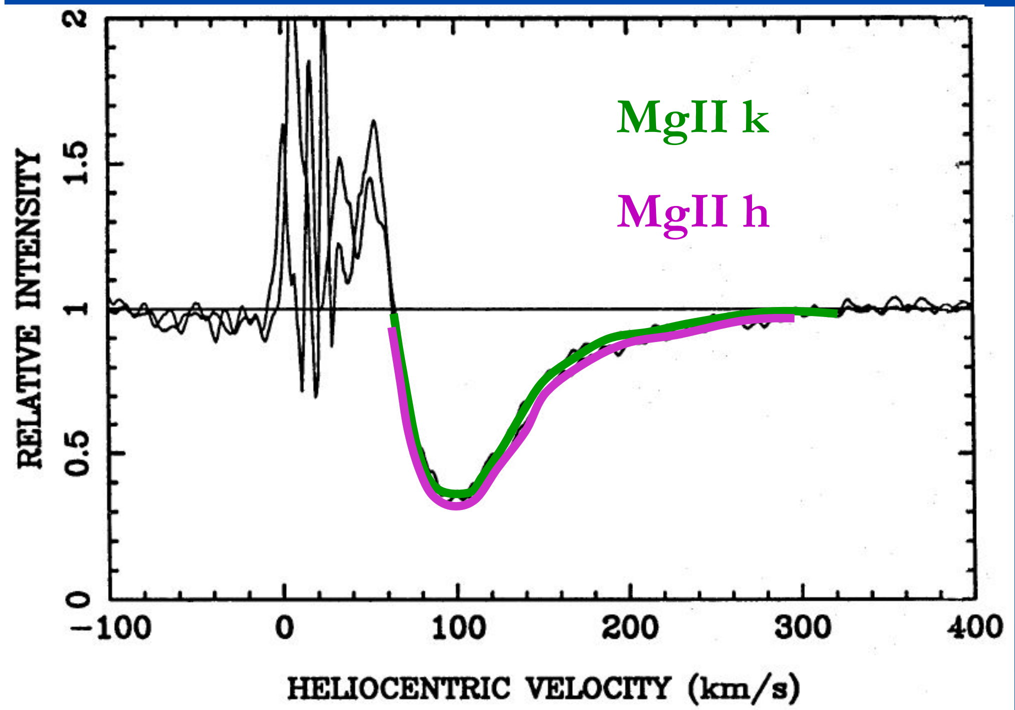
The FEB scenario (Falling Evaporating Bodies) explains many gas characteristics as :

- Radial velocity of infalling gas
- Variability
- Clumpiness
- Temperature of hot gas
- Highly ionized species
- Composition

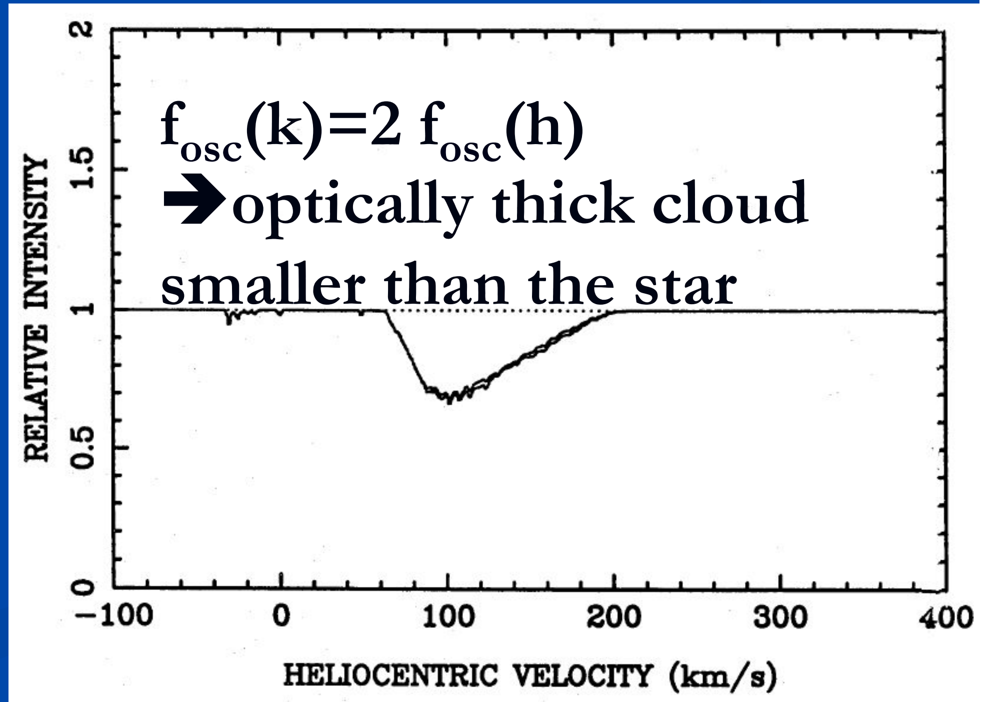
Confirmation of the comets scenario with HST

Vidal-Madjar et al. (1994)

- Many lines detected in the UV (FeII, MgII, CrII, ZnII, etc.)
- e.g., the MgII doublet → gas cloud smaller than the star



Observed absorption in the two MgII lines



Theoretical prediction

Gas around β Pic

- Stable and variable
- When ?

Dust and gas dynamics

- Dust and gas produced close to the star are pushed on eccentric orbits by radiation pressure (β ~70 in the case of Ca II, Lagrange et al. 1998)
- Life time of dust and gas could be short when compared to the age of the system (as short as 200 years for CO!)
- → Dust and gas should be produced now
- → Dust and gas could be observed far from their production place

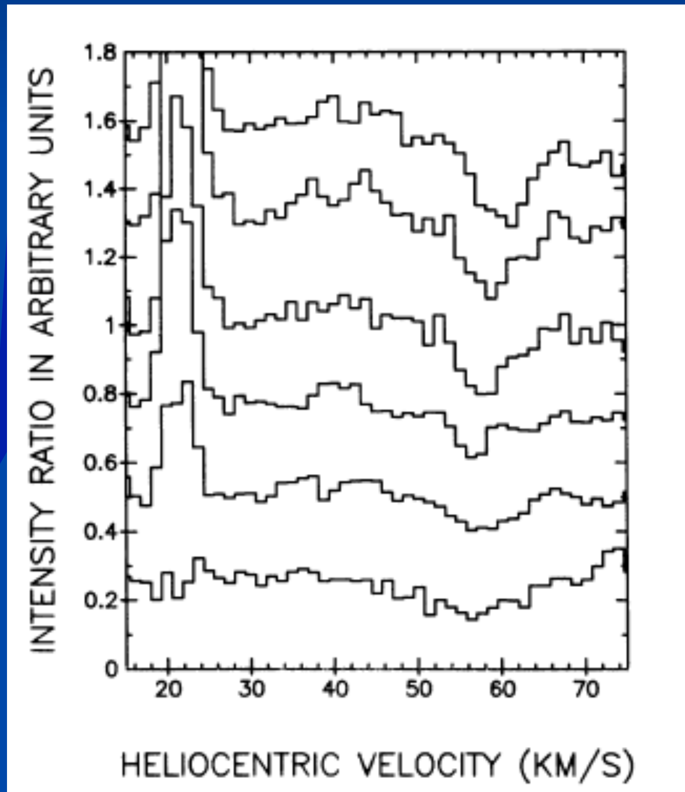
Gas around β Pic

- Stable and variable
- When ?
- Where ?

Comets

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

- Ferlet et al. (1987)



Free fall acceleration

d ~ 0.2 AU

$\Delta v/\Delta t$ which is of the order of $0.5\,\mathrm{m\,s^{-2}}$ (see Fig. 2), a value which corresponds roughly to a distance of 0.2 au above the stellar

Distance of the Ca II stable gas

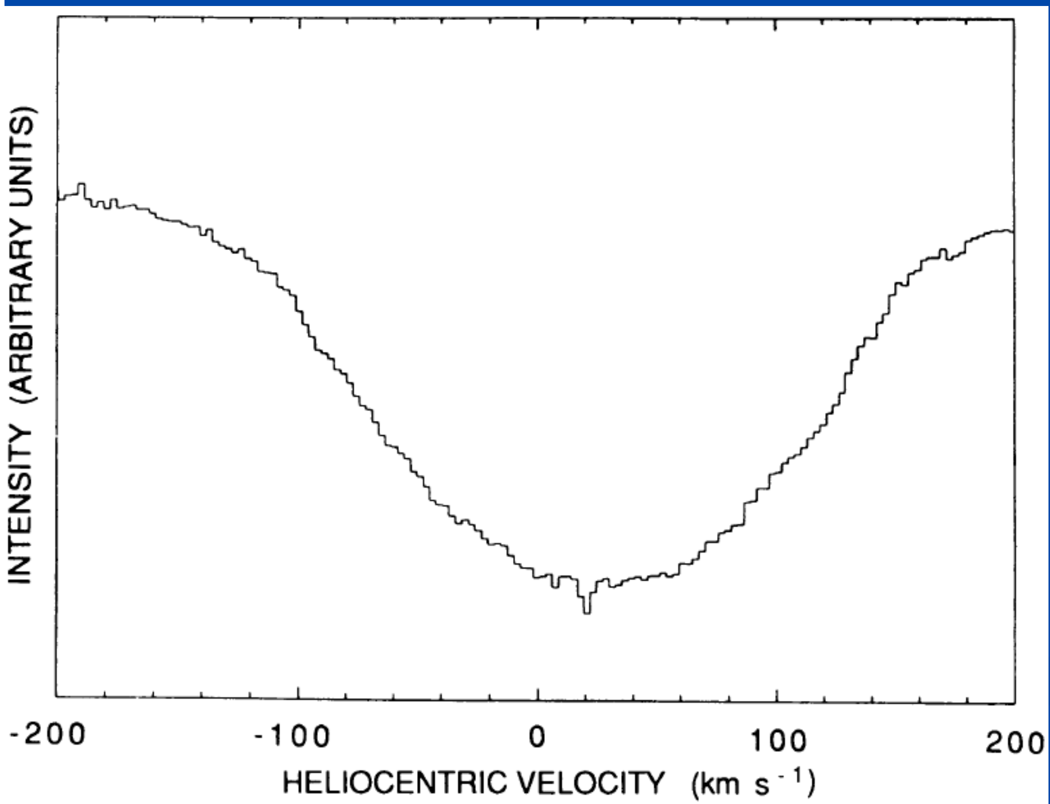
- Hobbs et al. (1988)

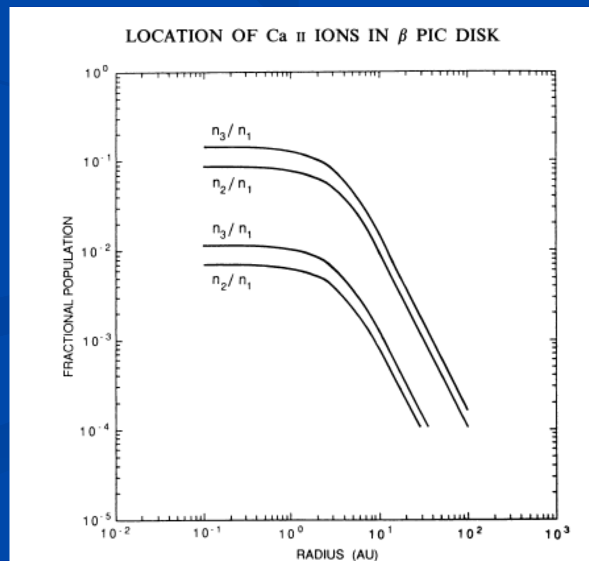
Ca II 8542Å line from metastable level

$N_{8542}/N_{3933} \sim 0.05$

→

stable gas at ~ 1 AU.

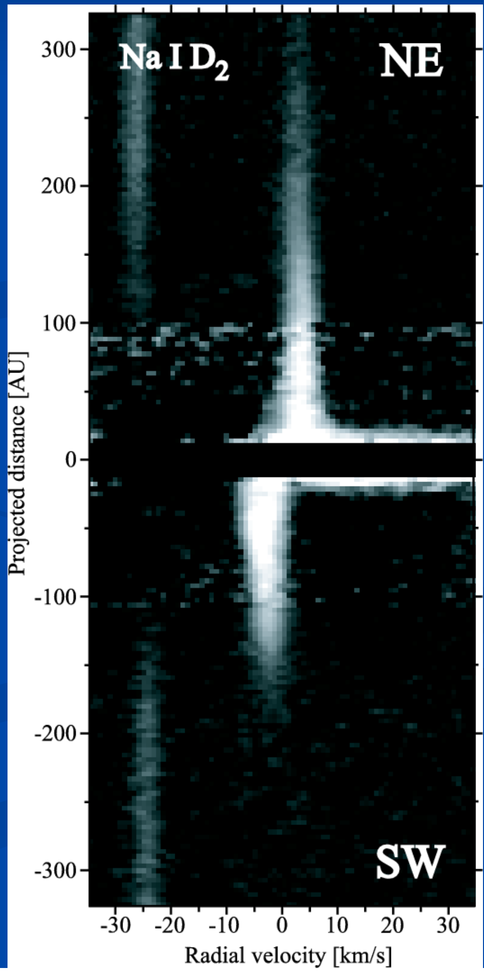




Observation of gaseous emission lines in β Pic disk

Brandeker et al. (2004)

- The gas is in keplerian rotation
- and extends to at least 300 AU
- *N*(Na I) ~ 3.e+10 cm−2, compatible with absorption studies.
- Neutral and ionized species not at the same locations within the disk



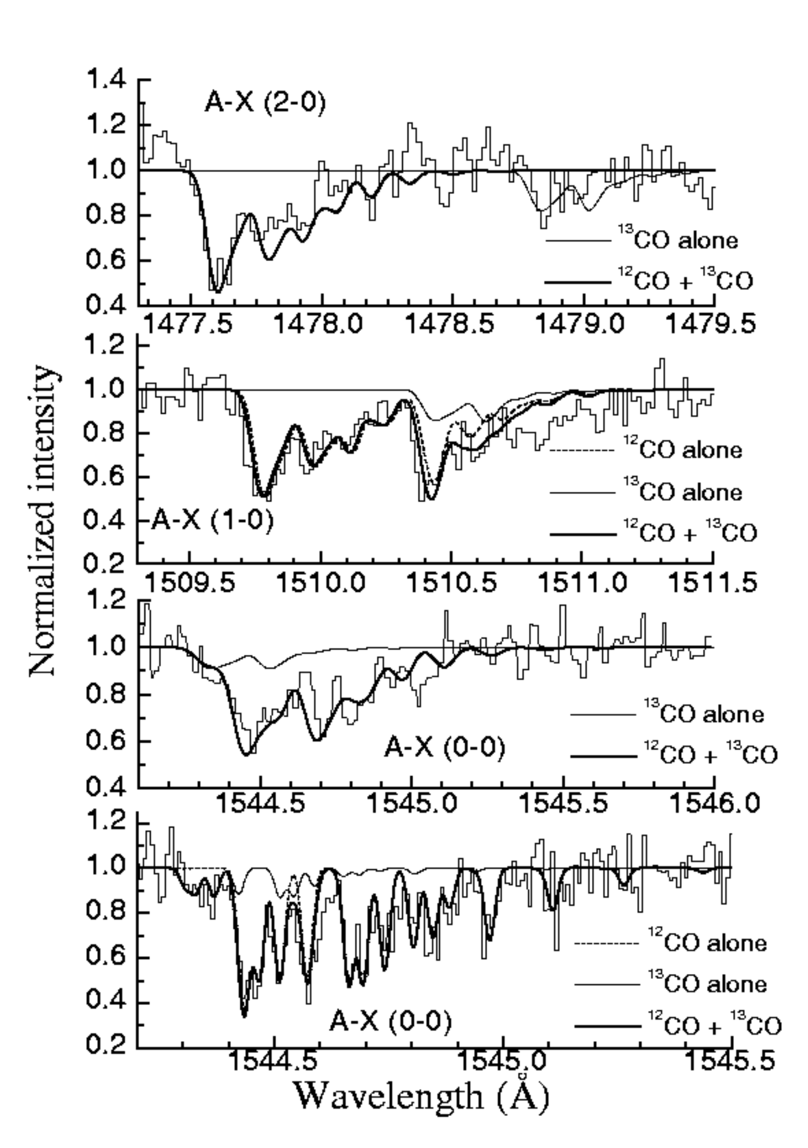
CO in the β Pic disk

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

- CO is detected in absorption using electronic bands at 1400-1500 Å

- CO level population ➔ gas at ~ 25 K implies CO gas at about 100AU.

- ^{12}CO / ^{13}CO < 20 (~ 15)
  ($^{12}C/^{13}C$) local ISM ~ 60 - 70
  ($^{12}C/^{13}C$) Solar System ~ 89

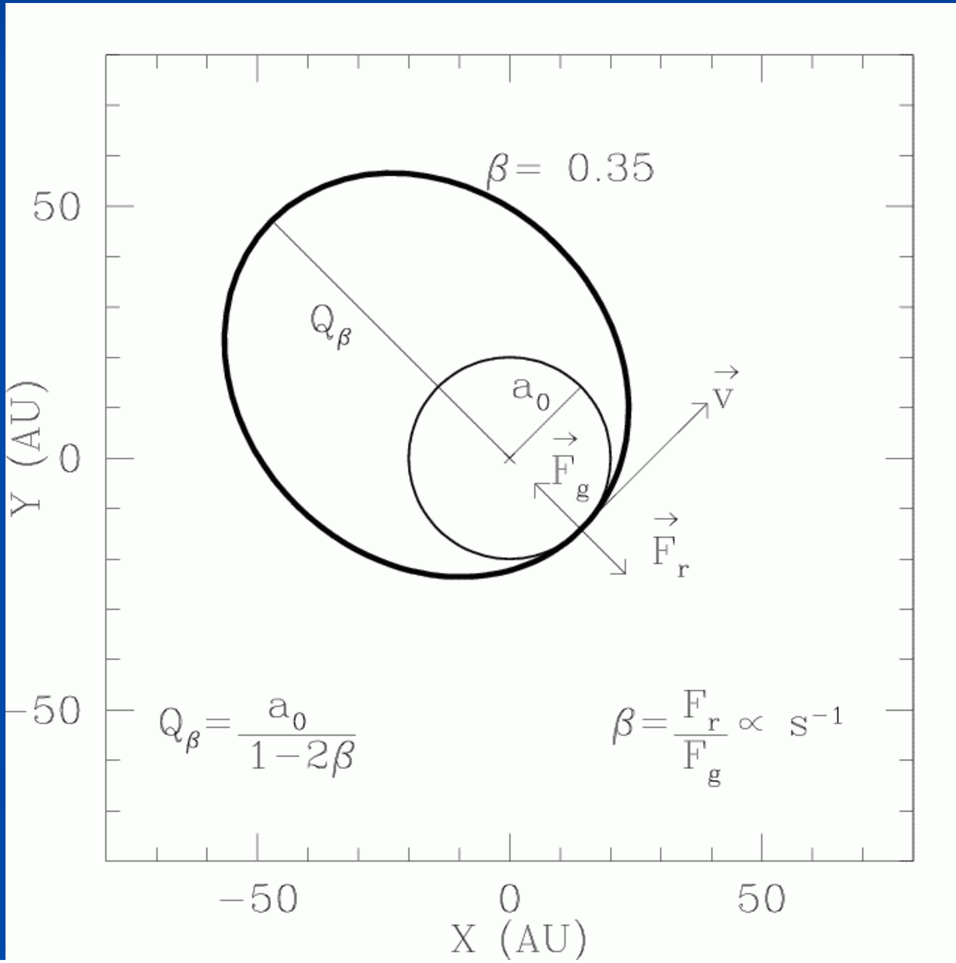


Evaporating Kuiper Belt objects as a possible source of dust and gas

(Lecavelier des Etangs et al. 1996 ; Lecavelier des Etangs 1998)

- Dust produced in inner parts can be seen in outer parts.
Scattered light following F α r $^{-5}$.

- Bodies trapped in resonance with a migrating Neptune-like planet can significantly evaporate, producing a dust and gas disk with characteristics similar to the observed ones
(CO, asymetries, etc.)

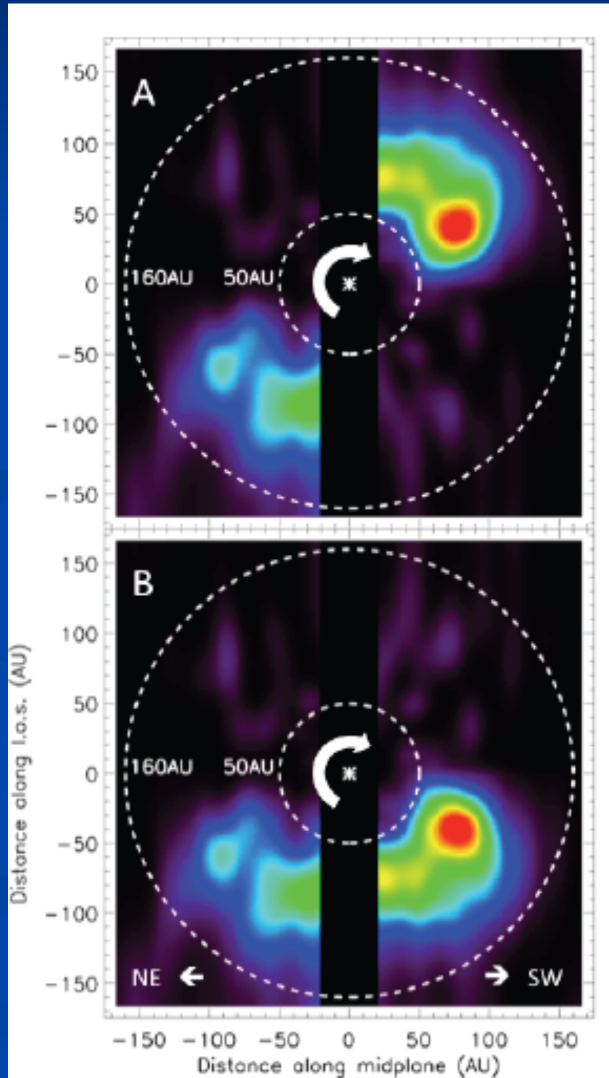


CO in the β Pic disk

Dent et al. (2014)

- ALMA observation of CO at 870 μm

- Clumpy ; compatible with absorption detection (10% in front of star)

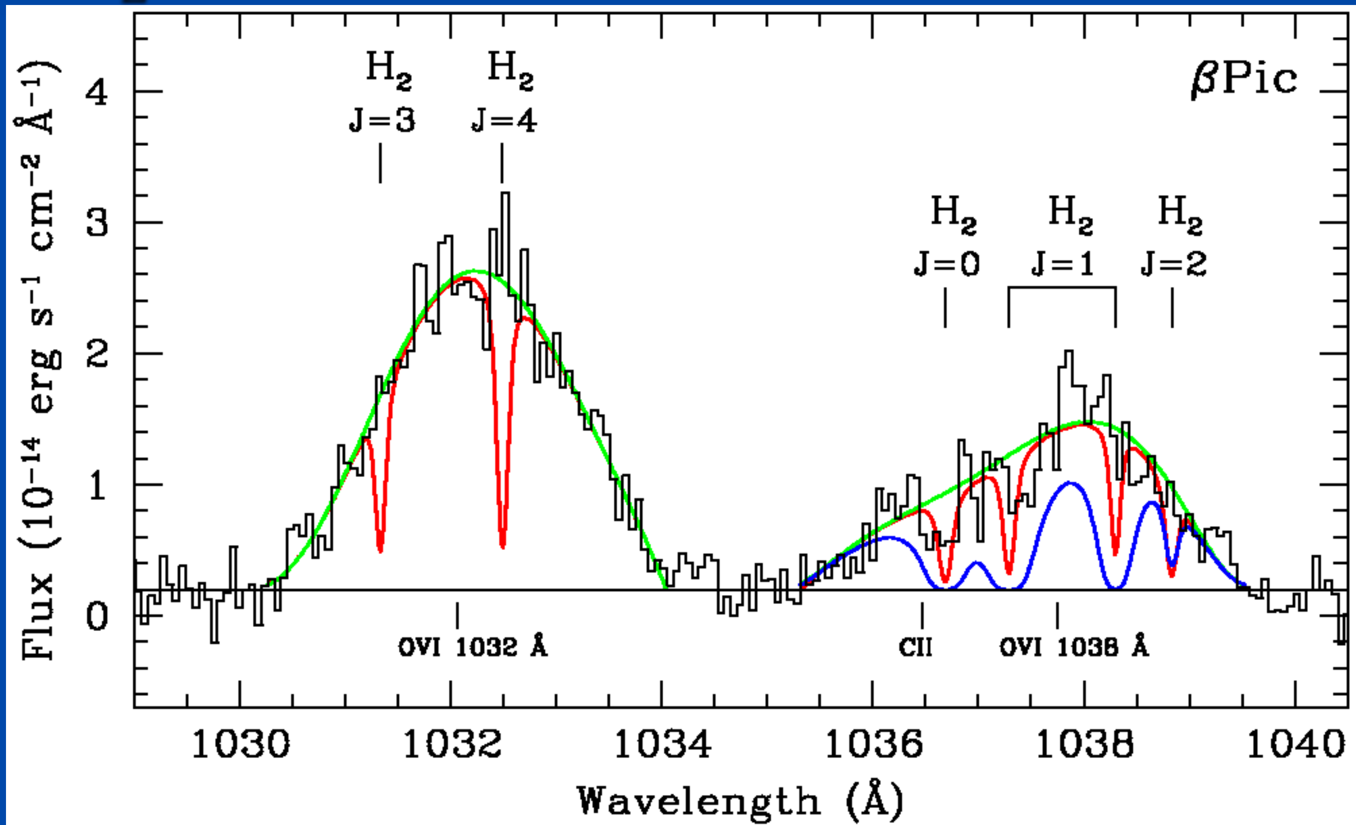


Gas around β Pic

- Stable and variable
- When ?
- Where ?
- What ?

Search for H_2 in the β Pic disk
(Lecavelier et al. 2001)

- FUSE observations → $N(H_2) < 10^{18}$ cm^{-2}
- → $CO/H_2 > 6. 10^{-4}$



Lecavelier des Etangs et al. 2001, Nat. 412, 706

Search for H_2 in the β Pic disk

(Lecavelier et al. 2001)

- FUSE observations → $N(H_2) < 10^{18}$ cm^{-2}
- → $CO/H_2 > 6.\ 10^{-4}$
- → CO is not protected from UV radiations by H_2
- → CO has a short lifetime (< 200 years)
- CO needs a permanent source :
  the CO in β Pic must originate from frozen source :

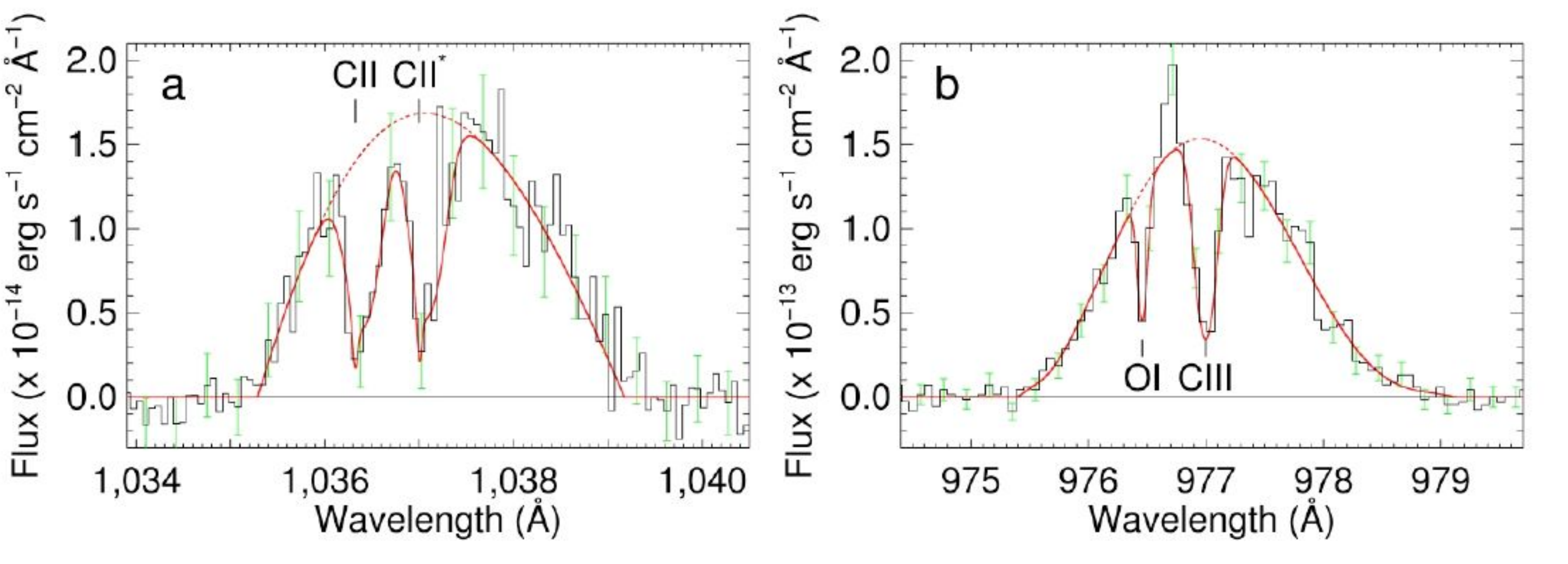
Evaporation of frozen bodies (comets) could produced CO in β Pic.

(Lecavelier des Etangs et al. 1996 ; Lecavelier des Etangs 1998; Dent et al. 2014)

Solving the stability of the β Pic gas disk ?

- FUSE observations allowed detection of C+, C++, and OI in the β Pic disk

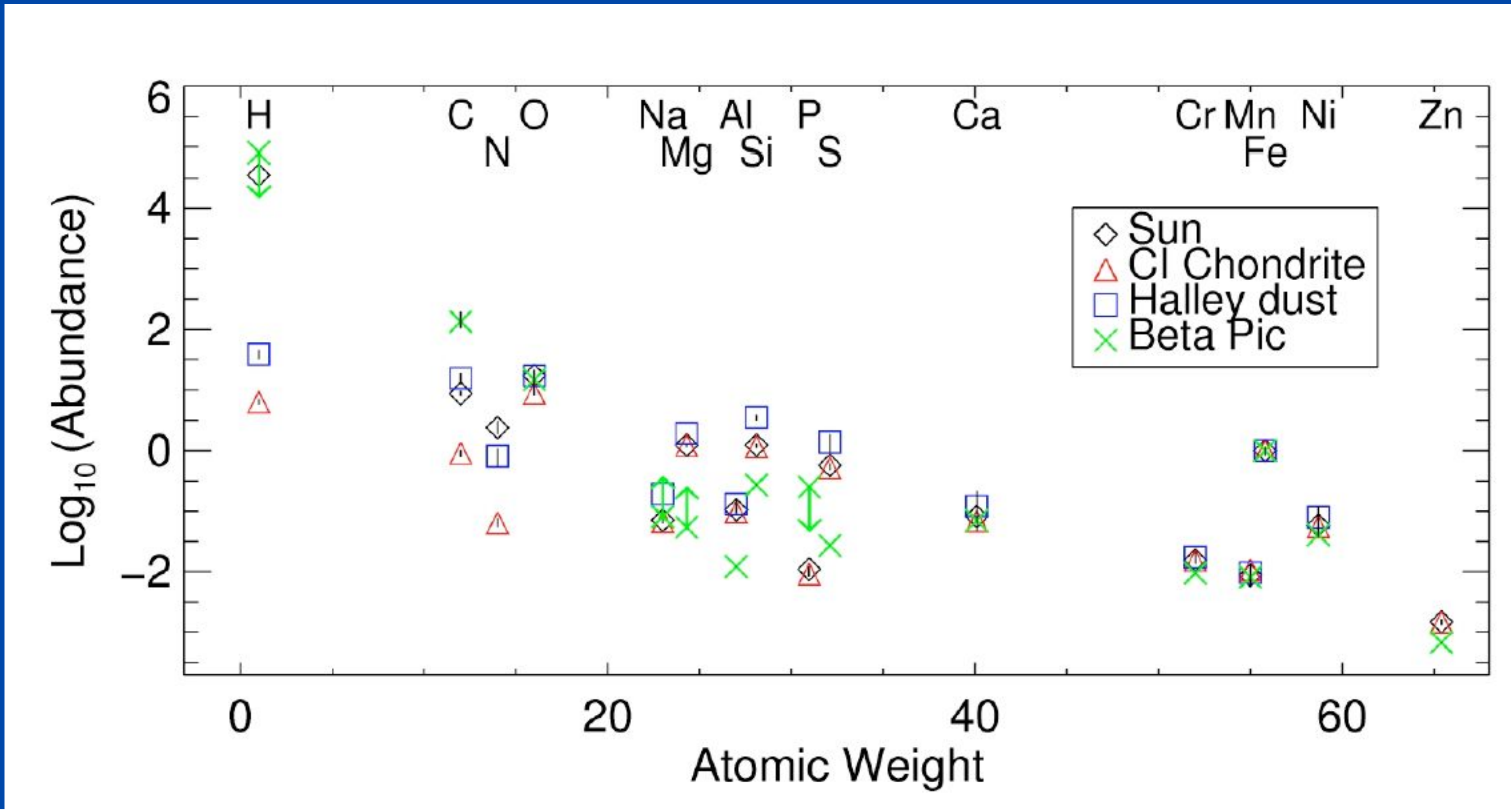
(Roberge et al. 2006)



The gaseous disk of β Pic

Lagrange et al. (1998), Roberge et al. (2006)

- Inventory of gaseous species using UV (-opt) absorption spectroscopy



Solving the stability of the β Pic gas disk ?

- β Pic gas should be rapidly blown away by radiation pressure (Lagrange et al. 1998)
- Possible braking gas : H I in a ring compatible with N (HI) < 1.e+19 cm-2 (Freudling et al. 1995; Lagrange et al. 1998)
- Observations of a stable gas disk in Keplerian rotation (Olofsson et al. 2001, Brandeker et al. 2004)
- Coulomb interraction more efficient for braking gas : C II best candidate ?

(Roberge et al. 2006; Fernandez et al. 2006; Castaldi et al. 2014)

Gas around β Pic : Conclusions

(see also Vidal-Madjar, Lecavelier des Etangs & Ferlet 1998 review)

- Stable and variable

how stable is the « stable » gas ? stabilized by C II ?

exocomets discovered in 1987, before exoplanets !

- When ?

gas continuously produced now (like in early Solar System?)

- Where ?

at least two distinct and independent regions :

one nearby at ~ 0.1 - 1 AU and the other at ~ 80 - 100 AU

- What ?

hydrogen poor (?) and carbon rich : asteroidal and cometary material

Thank you !