Falling Evaporating Bodies in the β Pictoris system

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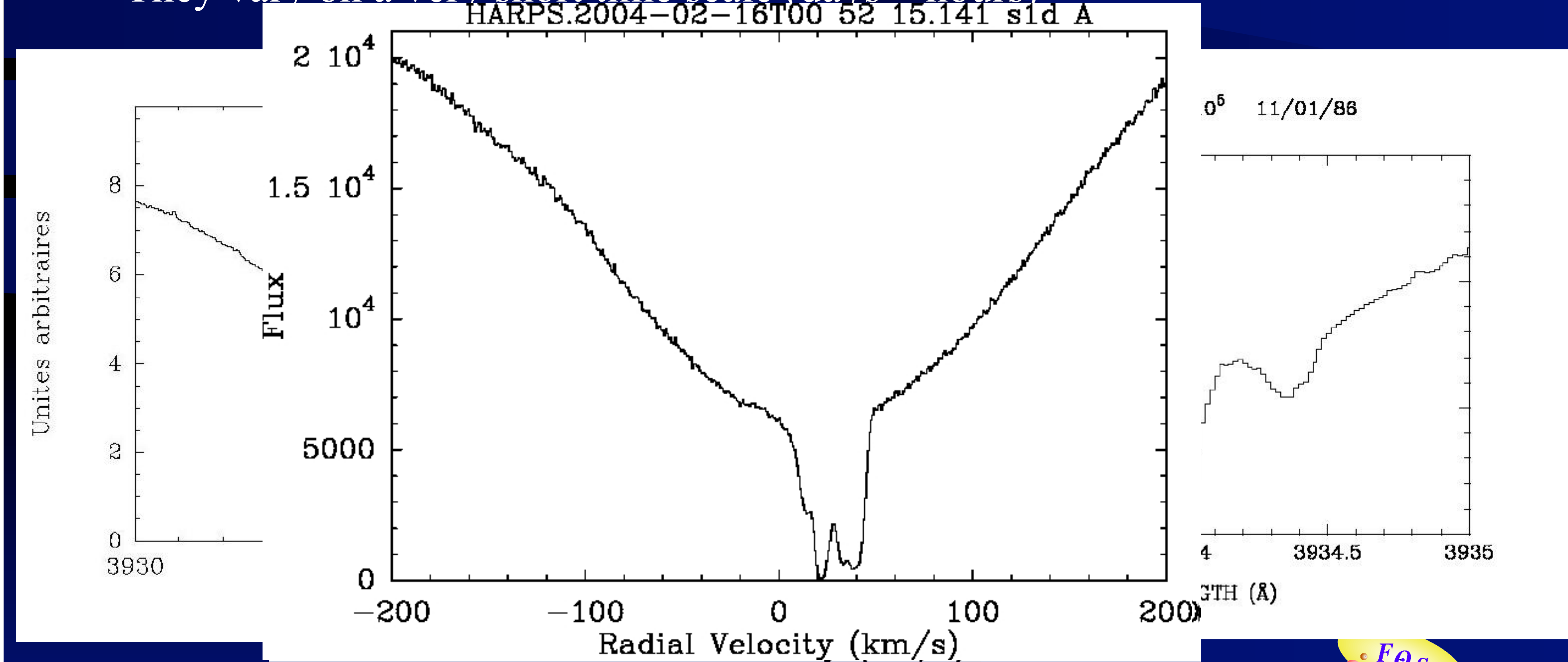
Falling Evaporating bodies in the β Pictoris disk
Extrasolar cometary activity ?

I. Gas and spectral variations in the β Pic spectrum
II. The *Falling Evaporationg Bodies* (FEBs) scenario
III. Dynamical issue : Mean-motion resonances
IV. Link with β Pic b
V. Open issues
VI. FEBs elsewhere than in β Pic

Gas in the β Pictoris disk

- Circumstellar gas is detected in absorption in the spectrum of the star (thanks to edge-on orientation) since ~1985 ! Thousands of such events
- Apart from a stable component, transient additional, Doppler-shifted components are frequently observed.
- They vary on a very short time scale (days – hours)



Characteristics of the transient events

- Detected in many spectral lines, but not all (Ca II, Mg II, Al III…) : only moderately ionized species (Lagrange et al.1987)
- Most of the time reshifted (tens to hundreds of km/s), but some blueshifted features (Crawford et al. 1998)
- The higher the velocity, the shorter the variation time-scale
- Comparison between features in doublet lines → saturated components that do not reach the zero level → The absorbing clouds do not mask the whole stellar surface (Lagrange et al. 1988)
- ~Regularly observed for 30 years : they are frequent but their bulk frequency is erratic

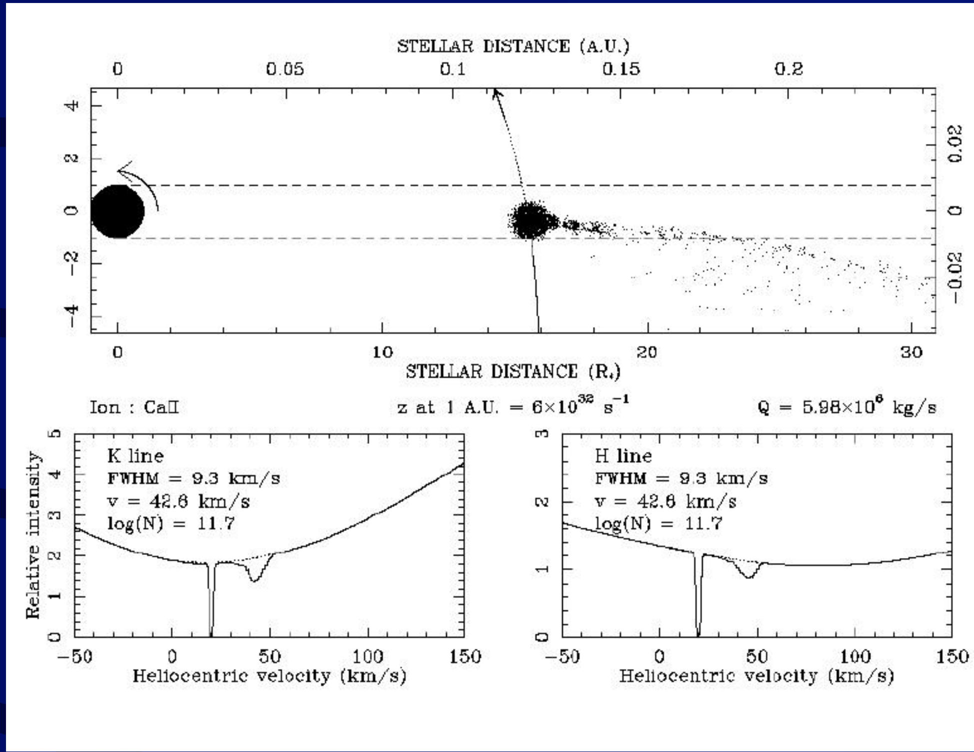
The FEBs
(*Falling Evaporating Bodies*) scenario

(Beust et al. 1990, 1995, 1998…)

- Each of these events is generated by an evaporating body (comet, planetesimal) that crosses the line of sight.
- These objets are star-grazing planetesimals (<0.5 AU).
- At this short distance the dust sublimates → metallic ions in the coma.
- This model naturally explains :
  - The infall velocities : projection of the velocity onto the line of sight → close to the star
  - The time variability : time to cross the line of sight
  - The limited size of the clouds = size of the coma
  - The chemical issue : not all species are concerned
  - The mere presence of the ions : Most of these species undergo a radiation pressure from the star that overcomes stellar gravity

Simulating the FEBs scenario

- We compute the dynamics of metallic ions in the FEBs coma and the resulting absorption components.
- The ions are subject to the radiation pressure and to a drift force by the other species
- The different kinds of variable features (high velocity, low velocity…) are well reproduced if we let the periastron distance vary.
- The longitude of periastrons are not randomly distributed (predominance of redshifted features)

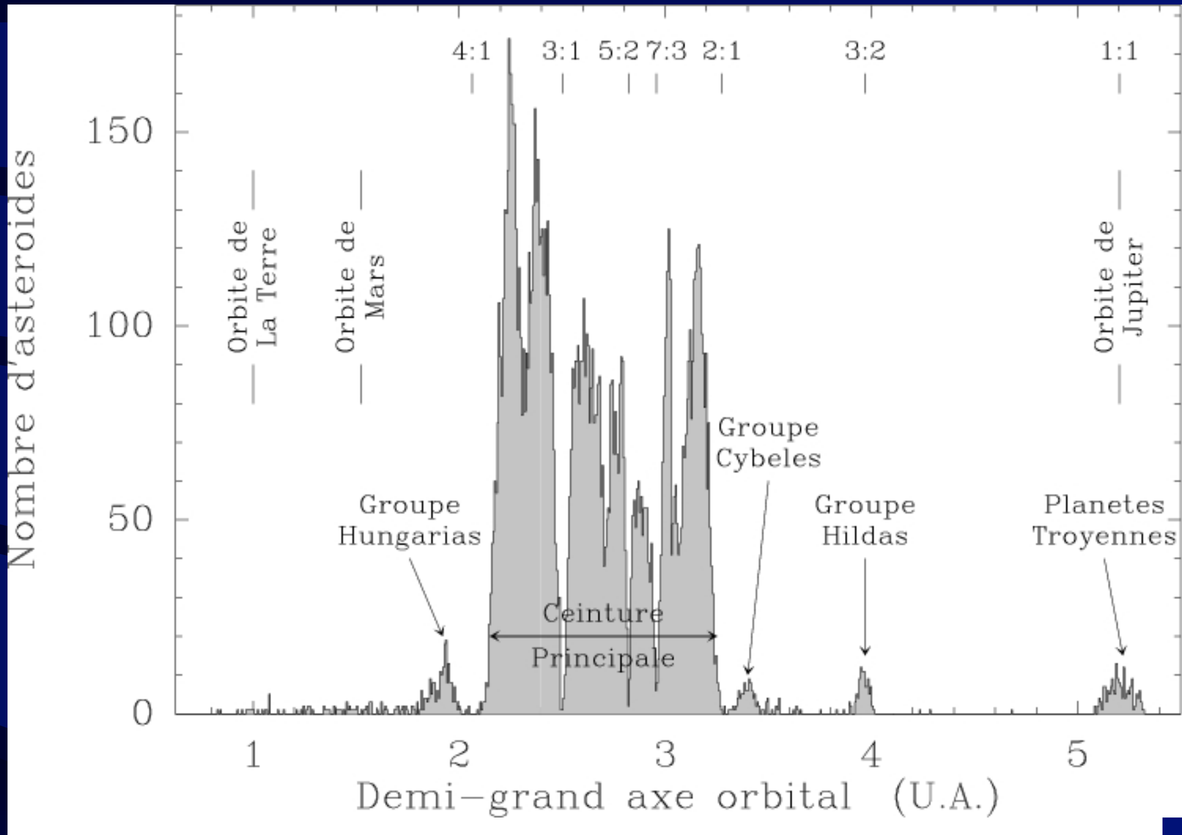


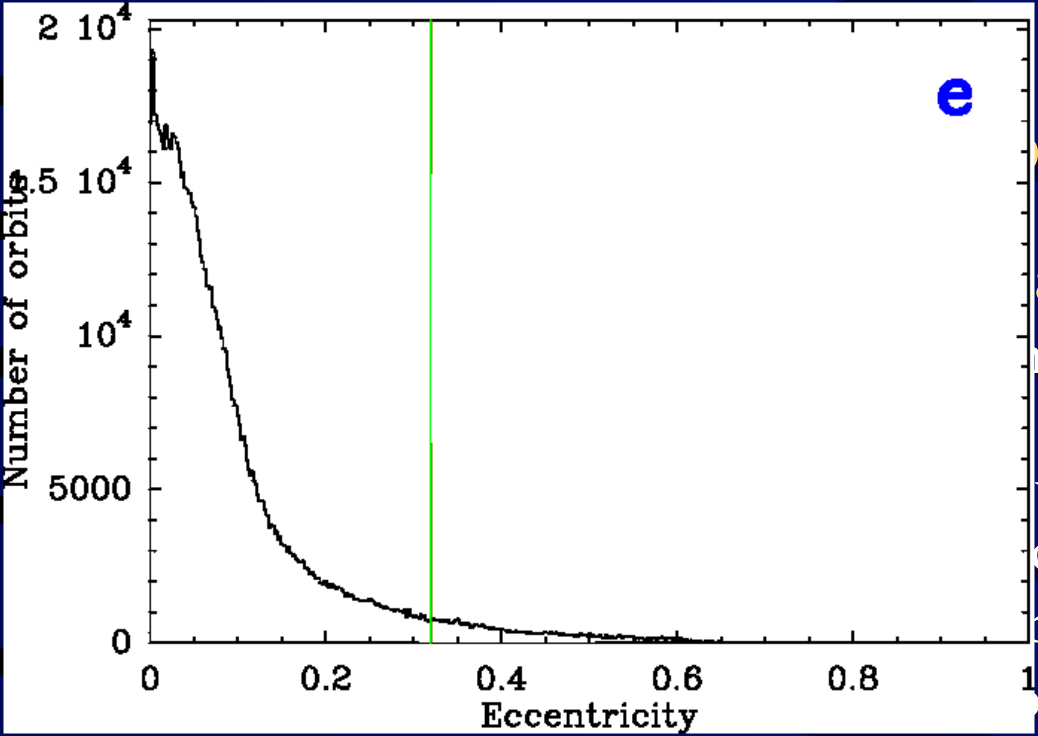
- Question : why so many star-grazers ? What is their dynamical origin ?
- How do you decrease periastron values downto ~zero (increase eccentricities)
- Requirement : Planetary perturbations (Kozai or MMRs ⇒ preferred)

The mean-motion resonance model

(Beust & Morbidelli 1996, 2000, Thébault et al 2001, 2003; Freistetter et al. 2007)

- Bodies trapped in some mean-motion resonances with a Jovian planet (4:1,3:1) see their eccentricity grow up to ~1 ⇨ FEBs!
- One requirement : The planet needs to have a moderate (>0.05) eccentricity.
- The orientation of the FEBs orbits is constrained ⇨ explains the blue/red-shift statitics.
- A similar phenomenon gave birth to the Kirkwood gaps in the Solar asteroid belt.





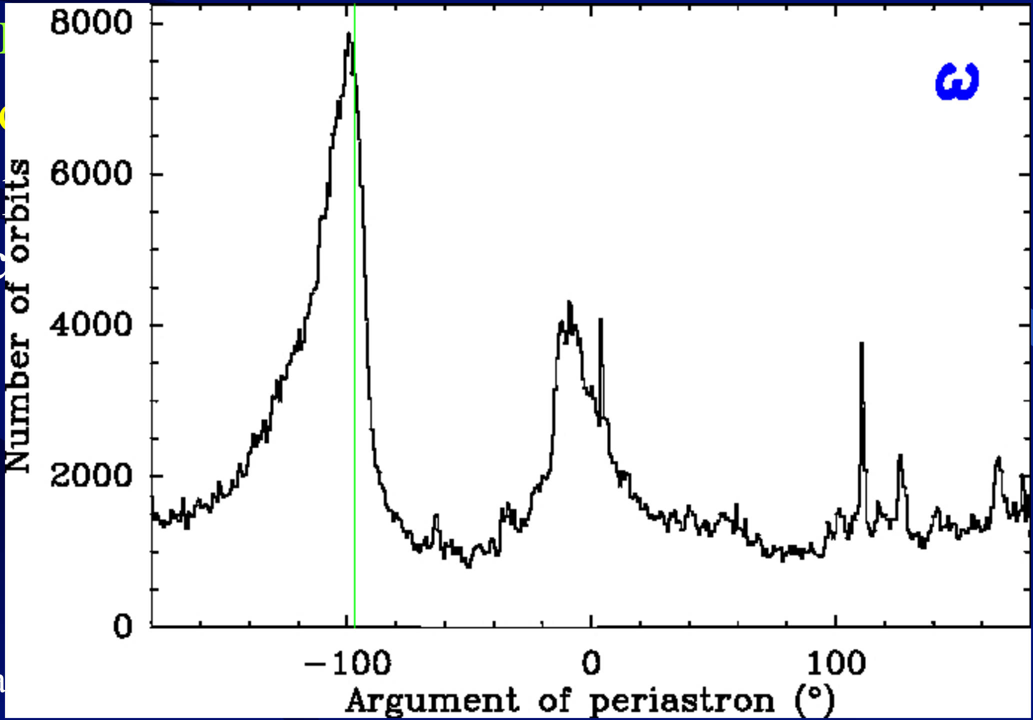
… Pic b ?

…ance model :

…g the star between

…with a suitable periastron
…of sight (~ -70°±20°)
…biting *inside*
…biting near the main resonances

- **Could β Pic b be that pla…**
  - Size/mass: ok ✓ ; distance: …
  - Eccentricity & longitude of …
  - Inner planetary system : unc…
- To be investigated:
  - Constraints on mass, orbital … periastron
  - Presence of other planets in …

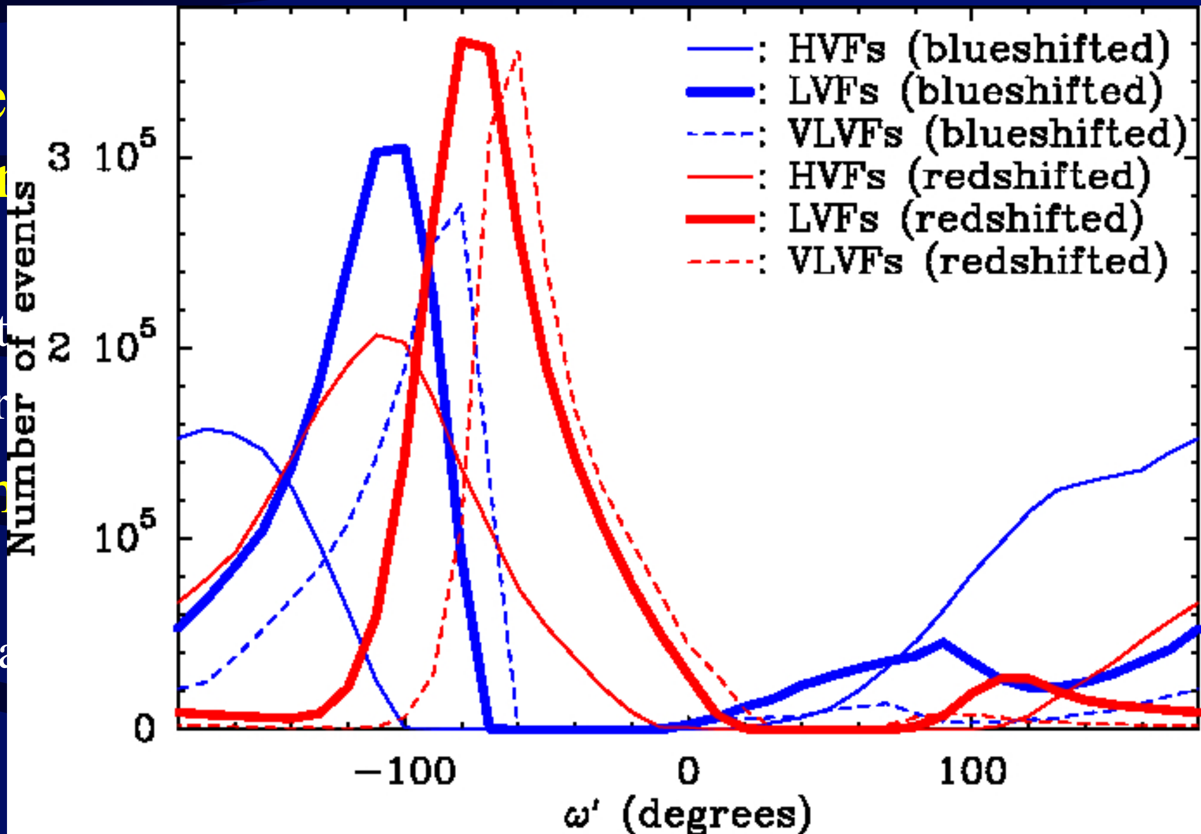


Open issues

- The physics of sublimation / dynamics of ions. Carbon can help the gas to be self-braking (Roberge et al. 2006)
- The quantity of matter involved / rates of sublimation
- The potential duration of the phenomenon until resonances are cleared. How do we refill the resonances ?
- Fragmentation issues ?
  - Many components seem to be lasting several days long (correlation up to 2-3 weeks, Tobin & Beust 2004)
  - 1 passage across the line of sight = 6-7 hours at most
  - Interpretation : many successive bodies on the same orbit ⇨ Fragmentation processes (cf. Shoemaker-Levy 9)
  - Dynamical issue : regroupment of fragments in continuous streams favoured by trapping in the resonance with the planet… (Beust)

FEBs elsewhere than in β Pic ?

- There are many othe
  FEBs ? It depends o
  - disk orientation
  - planet periastron orient
  - age vs FEB duration pr
- Some interesting can
  variations
  - HD 172555 (Kiefer et a
  - HD 21620, HD 42111,
    2013)
  - HR 10, HR 2174, 51 Oph (Lecavelier des Etangs et al. 1997)
  - Some white dwarfs ? (Stone et al. 2014)
  - Some Herbig stars (AB Aur: Grady et al. 1999). But the presence of a strong stellar winds may prevent FEB signatures to be detected (Beust et al. 2001) ?



Conclusions

- The FEB scenario explains most of the characteristics of the observations.
- It implies a giant planet that could fit β Pic b. The orbit needs to be better specified to conclude
- FEB activity is a source of dust and gas in the inner part of the system ⇨ a way to sustain a population of hot dust.
- FEBs are not restricted to β Pic : other examples + solar system….
- Still open questions : duration of the phenomenon (~10^7 yrs ?) / fragmentation issues / refilling of the resonances (collisions, but also migration, etc…) / Amount of material needed ?

Duration of the phenomenon

- The resonances clear out quickly (< 1 Myr) ⇨ Need for refilling to sustain the process
- Collisions between planetesimals are a good candidate to refill the resonances (Thébault & Beust 2001)
- But the disk gets eroded ⇨ loss of material (Thébault, Augereau & Beust 2003)