Circumstellar gas in \( \beta \) Pictoris

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

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 $\beta$ 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 CaII-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

\[ z \text{ at } 1 \text{ A.U.} = 15.0 \times 10^{33} \text{ s}^{-1} \]
\[ \frac{\text{dm}}{\text{dt}} = 0.010 \times 10^{10} \text{ kg s}^{-1} \]
\[ \text{outflow velocity} = 10.0 \text{ km s}^{-1} \]
\[ s_0 = 1. \mu \text{m} \]
\[ q = 18.0 \text{ R}_\odot \]
\[ \Phi = -150.0^\circ \]

proportion \( H_2O : 80.0\% \)

Ion: CaII

\[ t = 22^230 \text{ min. } 0 \text{ s.} \]
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
Many lines detected in the UV (FeII, MgII, CrII, ZnII, etc.)
- e.g., the MgII doublet $\Rightarrow$ gas cloud smaller than the star

Confirmation of the comets scenario with HST
Vidal-Madjar et al. (1994)

Variations in the MgII doublet

- Observed absorption in the two MgII lines
- Theoretical prediction

$\text{f}_{\text{osc}}(k) = 2 \text{f}_{\text{osc}}(h)$
$\Rightarrow$ optically thick cloud smaller than the star
Gas around $\beta$ 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 ($\beta \sim 70$ 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 $\beta$ Pic

- Stable and variable
- When?
- Where?
Comets
Ferlet et al. (1987); Beust et al. (1990-2004)

- Ferlet et al. (1987)

Free fall acceleration
\( d \sim 0.2 \text{ AU} \)

\( \Delta v/\Delta t \) which is of the order of 0.5 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

$\frac{N_{8542}}{N_{3933}} \sim 0.05 \rightarrow$ stable gas at $\sim 1$ 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
- \( N(\text{Na I}) \sim 3.\times10^{10} \text{ cm}^{-2} \), 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

Jolly et al. 1998
Roberge et al. 2000
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 $F \propto r^{-5}$.

- 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, asymmetries, 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 $\beta$ Pic

- Stable and variable
- When?
- Where?
- What?
Search for $\text{H}_2$ in the $\beta$ Pic disk
(Lecavelier et al. 2001)

- FUSE observations $\Rightarrow$ $N(\text{H}_2) < 10^{18}$ cm$^{-2}$
- $\Rightarrow$ $\text{CO}/\text{H}_2 > 6 \times 10^{-4}$

Lecavelier des Etangs et al. 2001, Nat. 412, 706
Search for $\text{H}_2$ in the $\beta$ Pic disk

(Lecavelier et al. 2001)

- FUSE observations $\Rightarrow N(\text{H}_2)< 10^{18} \text{ cm}^{-2}$
- $\Rightarrow \text{CO}/\text{H}_2 > 6 \times 10^{-4}$
- $\Rightarrow \text{CO is not protected from UV radiations by H}_2$
- $\Rightarrow \text{CO has a short lifetime} (< 200 \text{ years})$
- CO needs a permanent source:
  the CO in $\beta$ Pic must originate from frozen source:

Evaporation of frozen bodies (comets) could produced CO in $\beta$ Pic.

(Lecavelier des Etangs et al. 1996; Lecavelier des Etangs 1998; Dent et al. 2014)
Solving the stability of the $\beta$ Pic gas disk?

- FUSE observations allowed detection of C+, C++, and OI in the $\beta$ Pic disk

(Roberge et al. 2006)
The gaseous disk of $\beta$ Pic
Lagrange et al. (1998), Roberge et al. (2006)

- Inventory of gaseous species using UV (-opt) absorption spectroscopy
Solving the stability of the $\beta$ Pic gas disk?

- $\beta$ 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)
- Coulomb interaction 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 !