Exocomets

and Their Impact on Planets in the Habitable Zone

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

With inputs from Théo Vrignaud

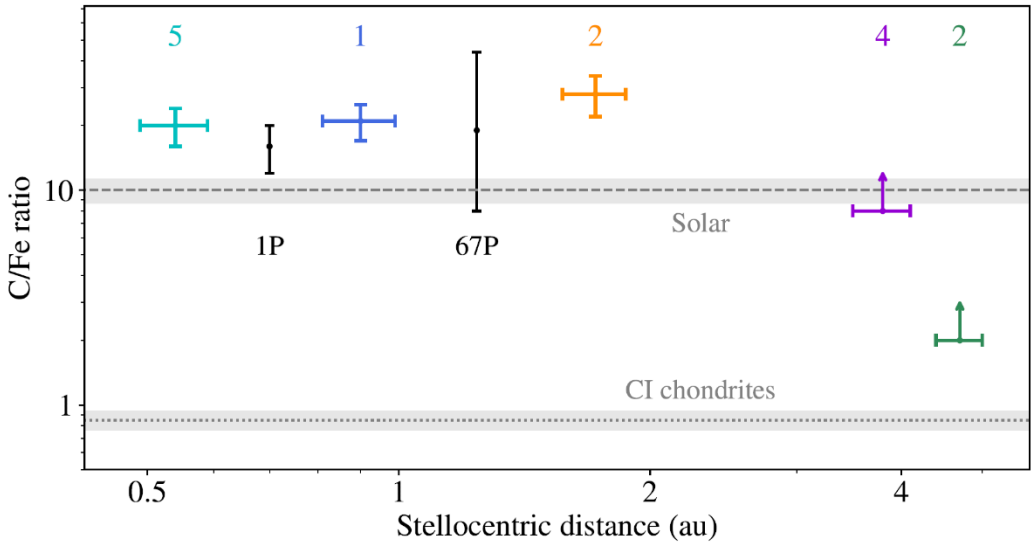
The C-to-Fe ratio as a probe of exocomet origins

In preparation

Théo Vrignaud[1] and Alain Lecavelier des Etangs[1†]

- Analyzing new HST data, we estimate for the first time **volatile/refractory ratios in 3 exocomets.**
- **We found high ratio C/Fe ratio (~20–30)** similar to the ones of Solar system comets (1P and 67P)

➔ **Exocomets can transport volatile into the habitable zone**



Detection of small bodies as comets

- Comets = small bodies with evaporation signature

(evaporation of volatile, from a body on an eccentric orbit)

➔ Small bodies can be detected when they are comets !!

- Detection of the coma and/or tail
  - ➔ up to several millions' kilometers in size
  - ➔ detection through
    - **transit observations** in extrasolar systems

Detection of small bodies as comets

- Detection
  of the two components
  - Gas (spectroscopy)
  - Dust (photometry)

- Exocomets can be detected in **spectroscopy**
  through **the transit signature of the gaseous coma**
- Exocomets can be detected in **photometry**
  through **the transit signature of the dust tail**

Transits of exocomets

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Discovery of the 1st exocomets

Ferlet et al. (1987); Lagrange et al. (1988) Beust et al. (1990-2004)

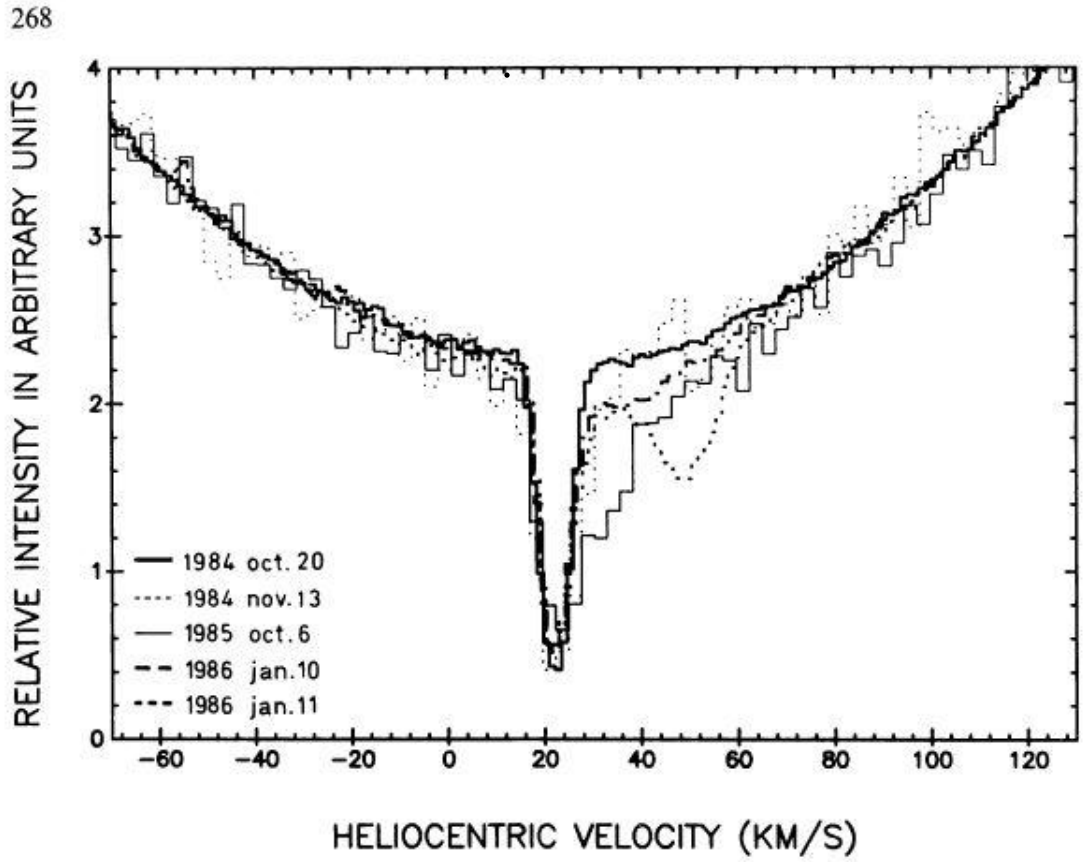

Fig. 1. Enlarged spectra of β Pic in the region of the circumstellar Ca II-K line, in an heliocentric velocity scale. They have been normalized in order for the "continua" (the stellar line widened by rotation) to coincide. To avoid confusion due to its much lower signal to noise ratio, the 1985, March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

(Ferlet et al. 1987)

Spectroscopic transits of exocomets
in the young planeary system of β Pictoris

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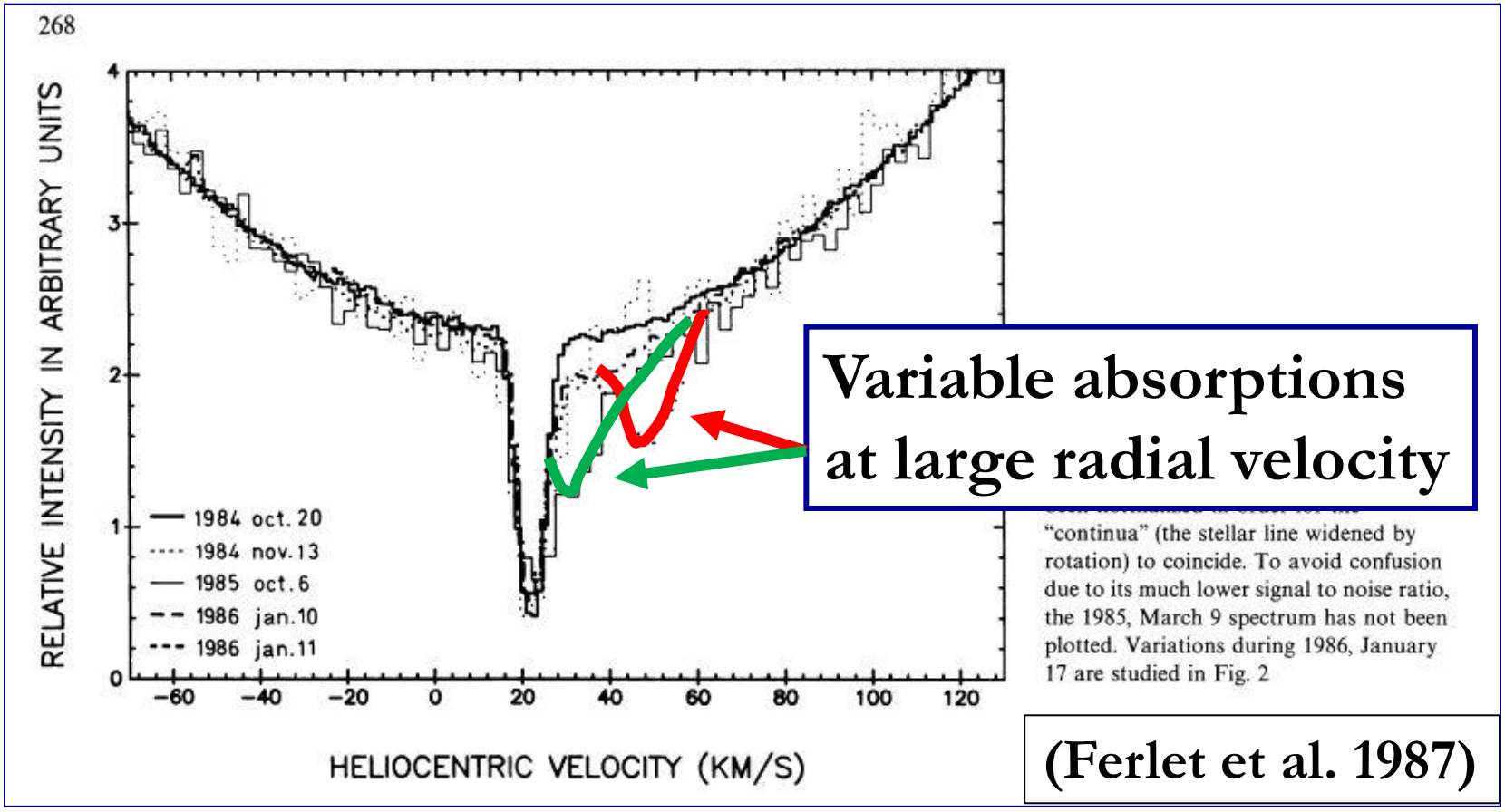

Spectroscopic transits of exocomets
in the young planeary system of β Pictoris

➔ After more than 30 years of observation

- The exocomets scenario is widely accepted
  to interpret the spectroscopic transits
- The orbital properties are known for β Pic exocomets
- The cometary gas is observed in details
- Scenarios are proposed for the exocomets dynamical origin

Nonetheless,

- *Only a few exocometary systems identified*
- *Physical properties of the nucleus (size) remained unknown*
- *Chemical composition remained unknown*

Transits of exocomets

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Photometric detection of exocomets

Lecavelier, Vidal-Madjar & Ferlet (1999) ; Lecavelier (1999)

Astron. Astrophys. 343, 916–922 (1999)

ASTRONOMY AND ASTROPHYSICS

Photometric stellar variation due to extra-solar comets

A. Lecavelier des Etangs, A. Vidal-Madjar, and R. Ferlet

Institut d'Astrophysique de Paris, CNRS, 98bis Boulevard Arago, F-75014 Paris, France

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

NOVEMBER II 1999, PAGE 15

Astron. Astrophys. Suppl. Ser. **140**, 15–20 (1999)

A library of stellar light variations due to extra-solar comets

A. Lecavelier des Etangs[1]

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Photometric detection of exocomets

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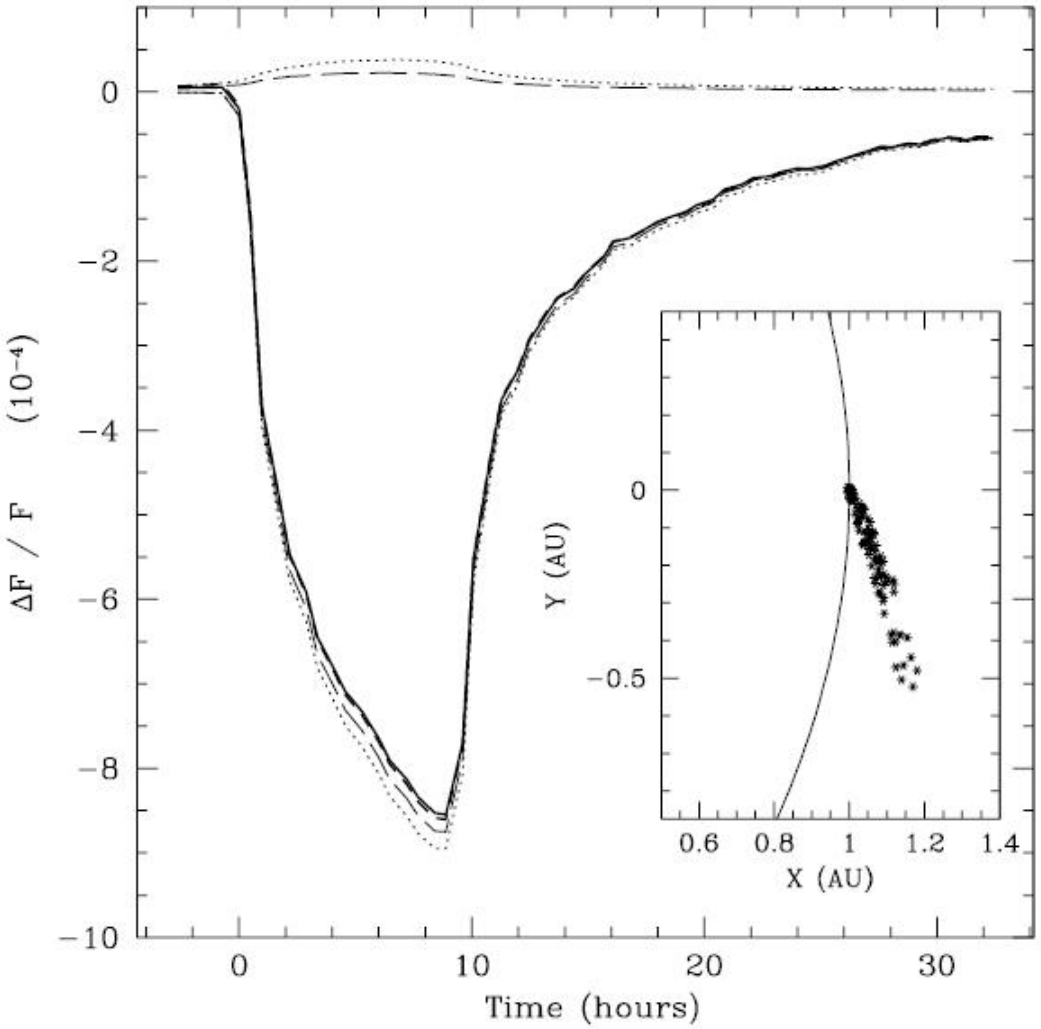
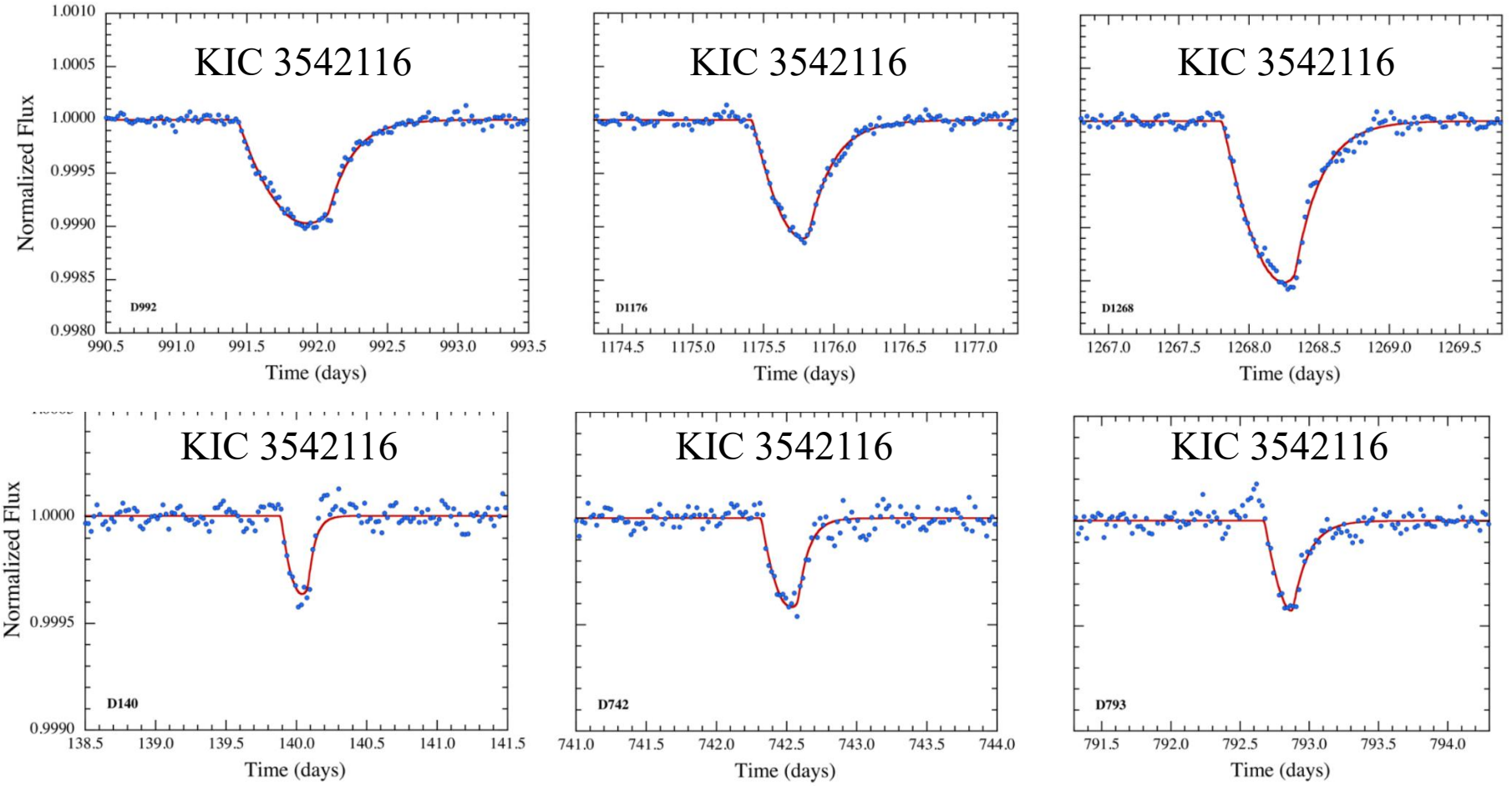


Simulation with production rate P = $2 \cdot 10^6$ kg/s and periastron q = 1 ua

Detection of exocomets with Kepler in KIC 3542116 and KIC 11084727

Rappaport et al. (2018)



Photometric detection with TESS

Zieba et al. (2019)

LETTER TO THE EDITOR

Transiting exocomets detected in broadband light by TESS in the β Pictoris system★

S. Zieba[1], K. Zwintz[1], M. A. Kenworthy[2], and G. M. Kennedy[3]

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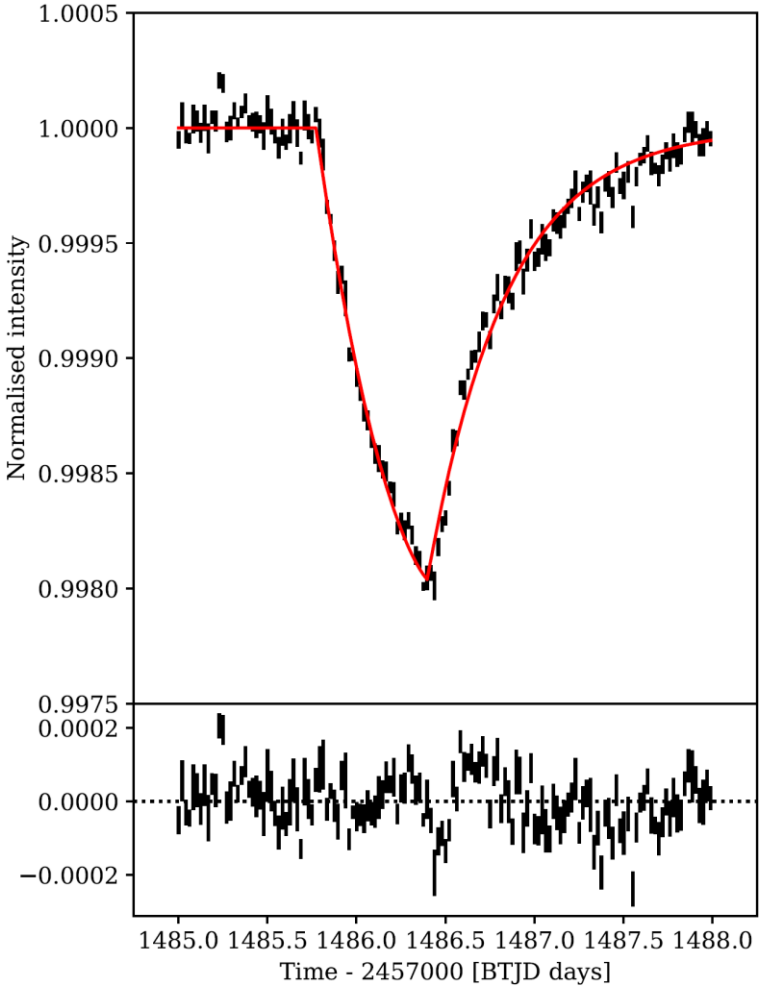
ABSTRACT

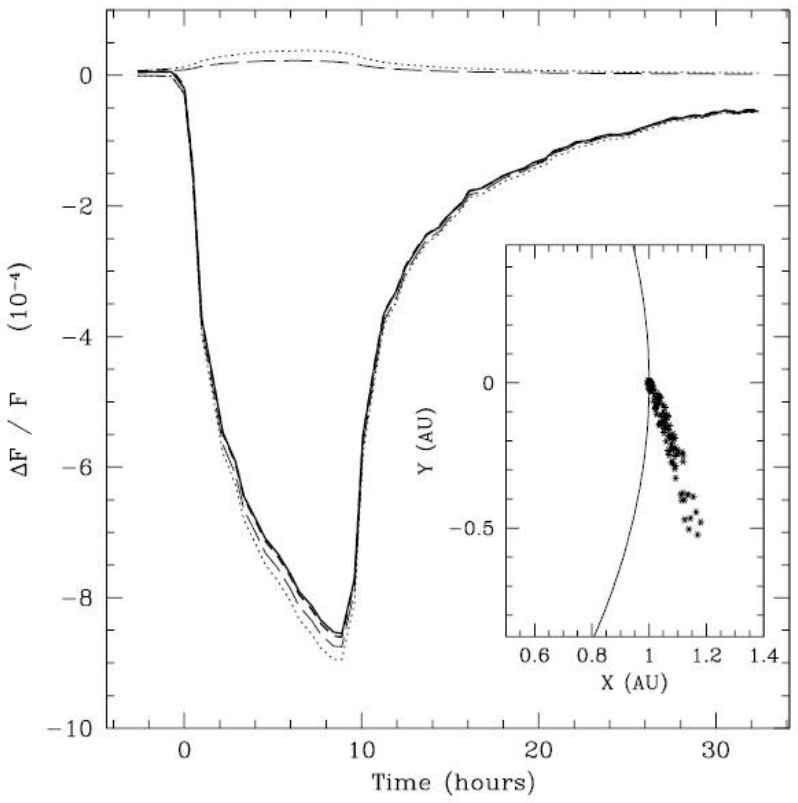
Aims. We search for signs of falling evaporating bodies (FEBs, also known as exocomets) in photometric time series obtained for β Pictoris after fitting and removing its δ Scuti-type pulsation frequencies.
Methods. Using photometric data obtained by the TESS satellite we determined the pulsational properties of the exoplanet host star β Pictoris through frequency analysis. We then pre-whitened the 54 identified δ Scuti p-modes and investigated the residual photometric time series for the presence of FEBs.
Results. We identify three distinct dipping events in the light curve of β Pictoris over a 105-day period. These dips have depths from 0.5 to 2 millimagnitudes and durations of up to 2 days for the largest dip. These dips are asymmetric in nature and are consistent with a model of an evaporating comet with an extended tail crossing the disc of the star
Conclusions. We present the first broadband detections of exocomets crossing the disc of β Pictoris, complementing the predictions made 20 years earlier by Lecavelier Des Etangs et al. (1999, A&A, 343, 916). No periodic transits are seen in this time series. These observations confirm the spectroscopic detection of exocomets in calcium H and K lines that have been seen in high resolution spectroscopy.

Photometric detection with TESS



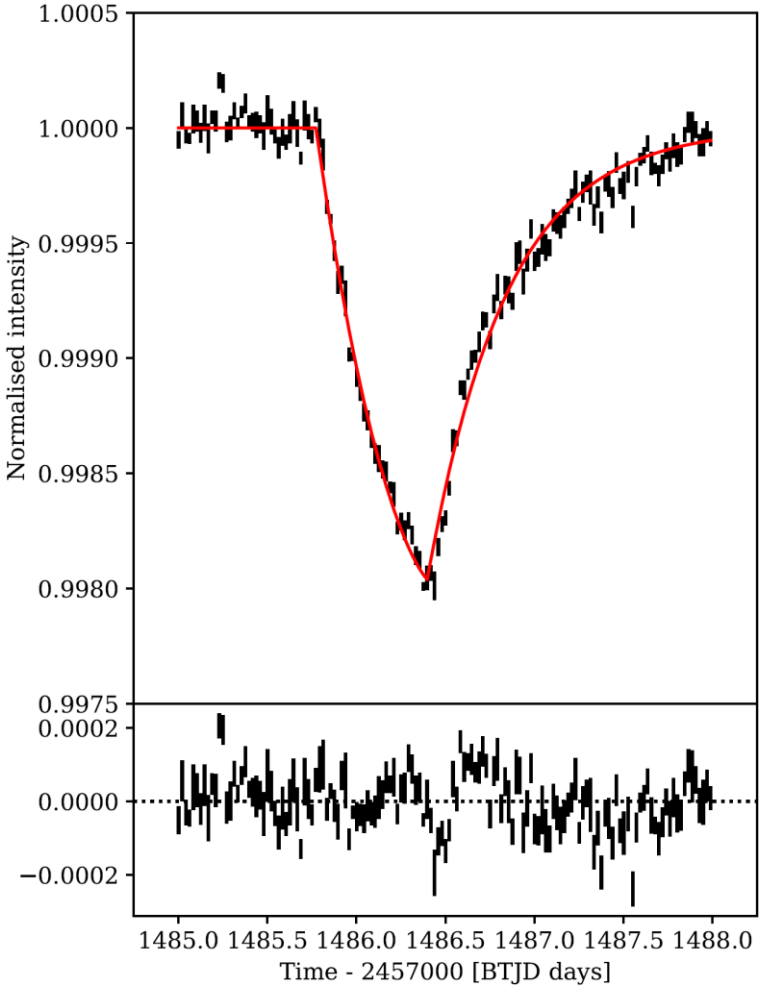
TESS Observation (2019)

Photometric detection with TESS



Simulation (1999)

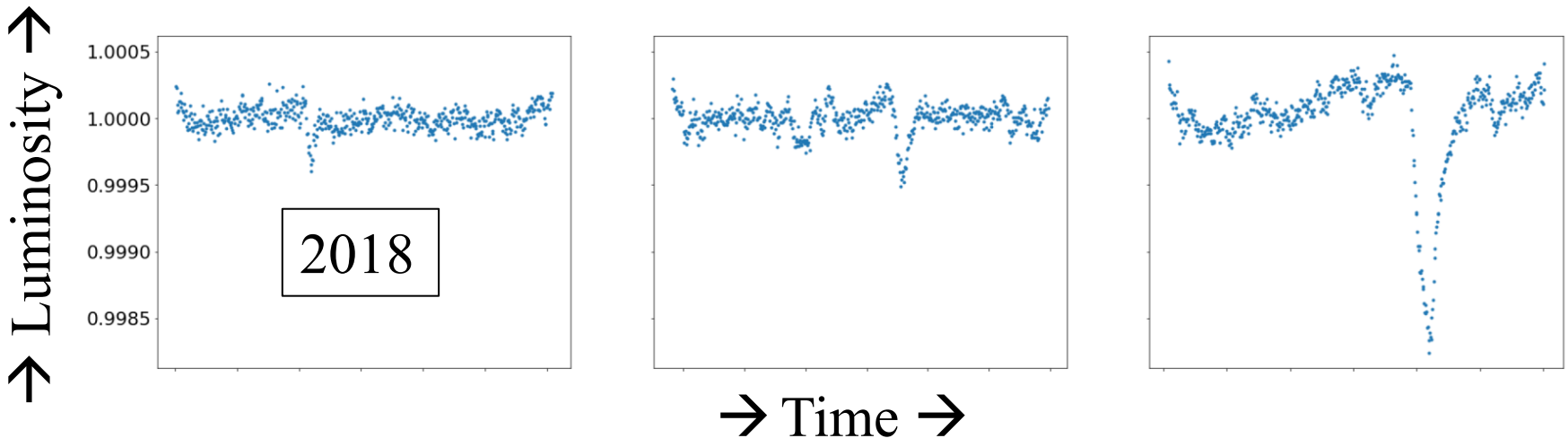
with P = $2 \cdot 10^6$ kg/s and q = 1 ua



TESS Observation (2019)

New exocomets discovered with TESS observations

Lecavelier et al. (2022), see also Pavlenko et al. (2022)



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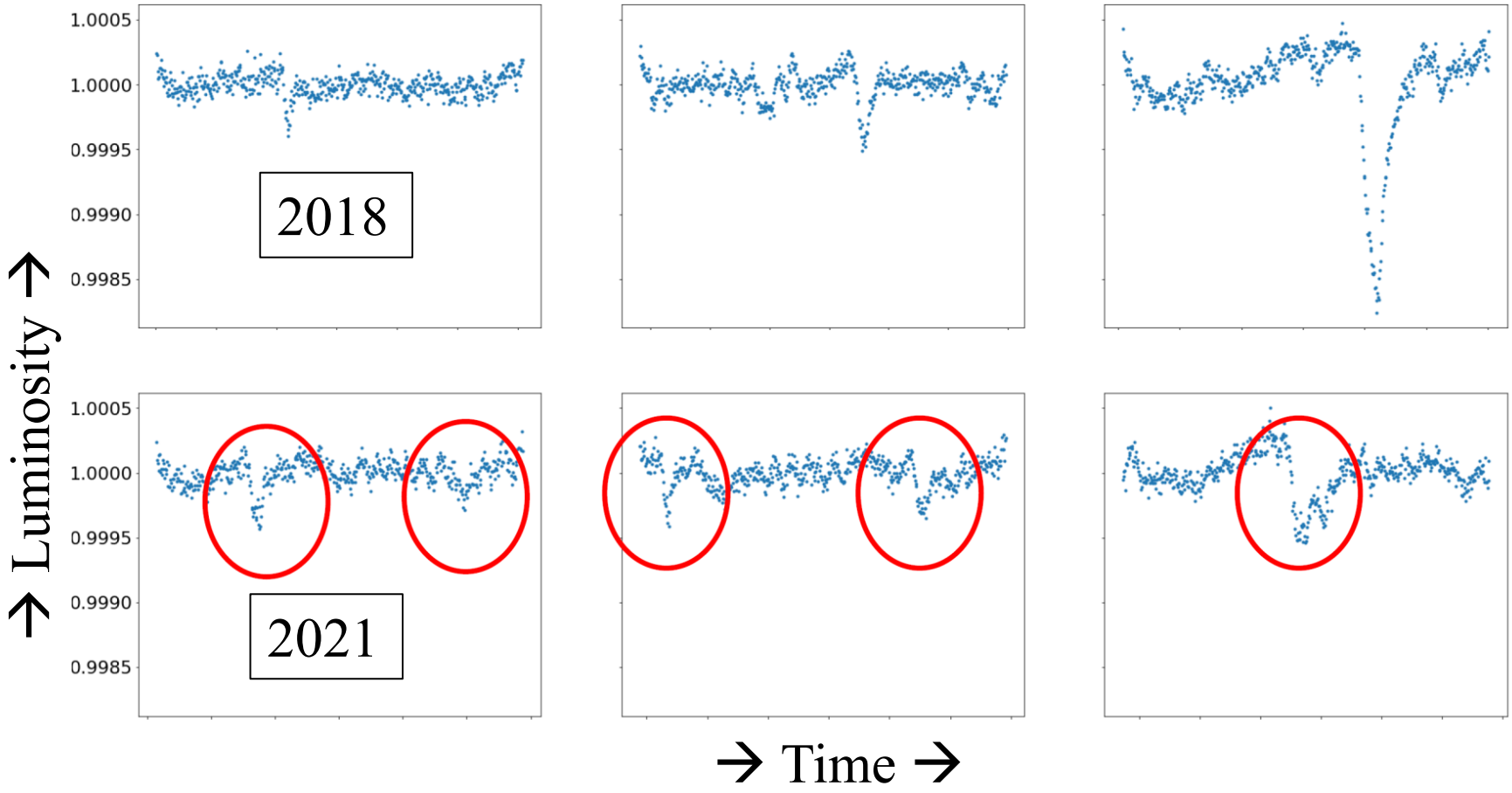

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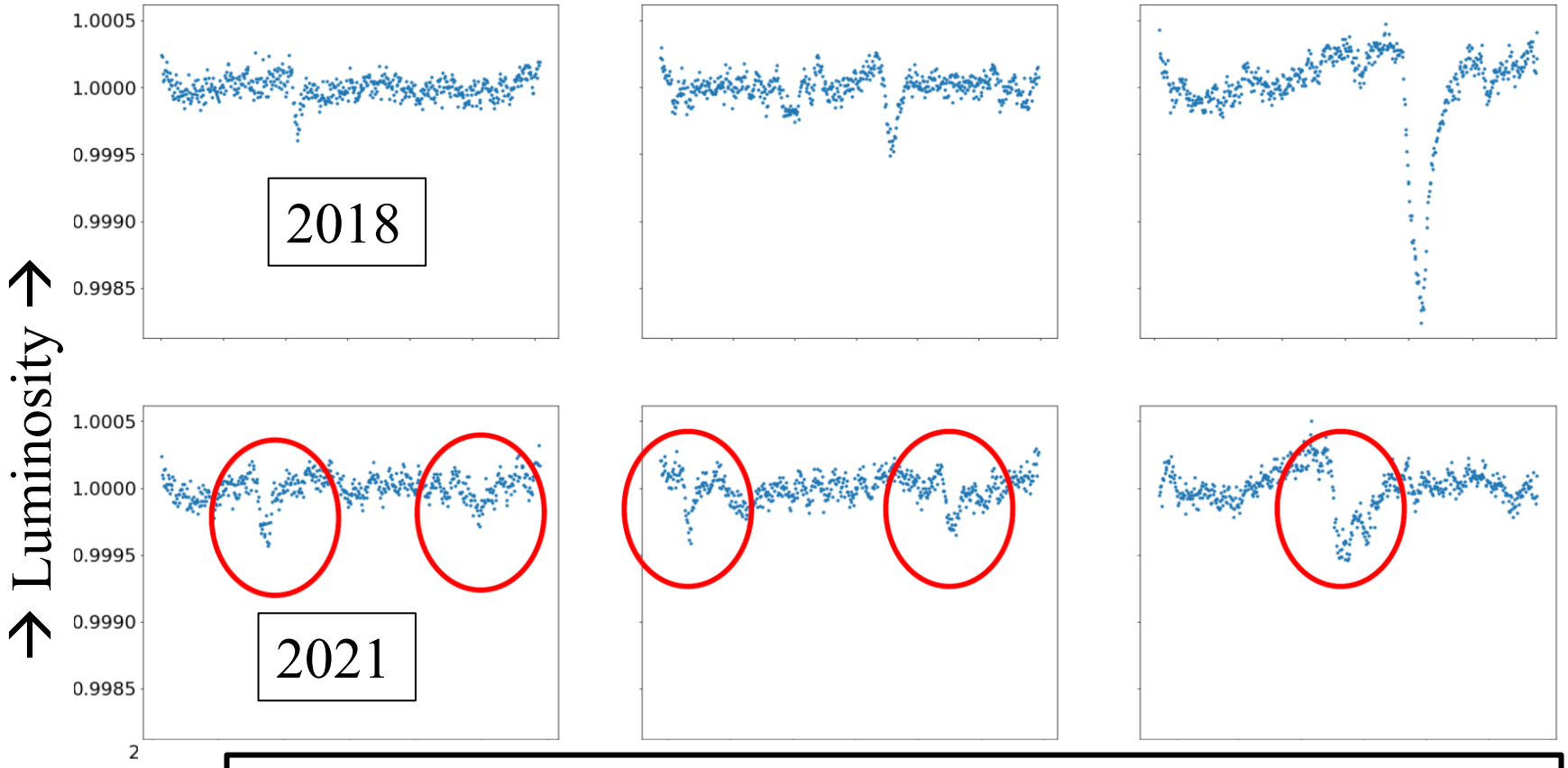
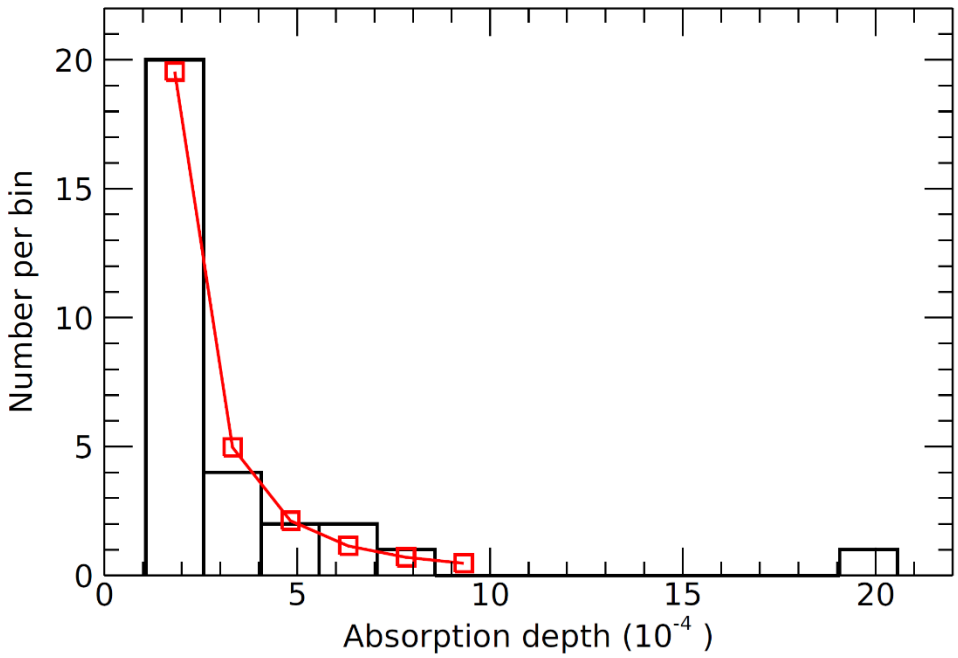


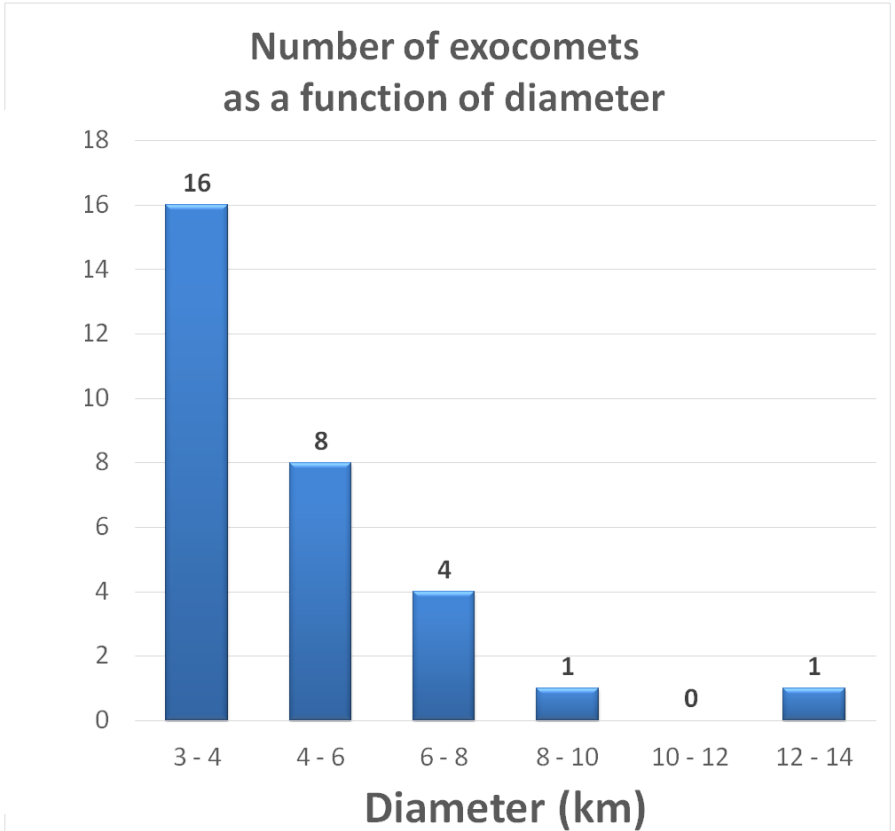
Detection de 30 exocomets in 156 days of observations

Exocomets size distribution in the β Pictoris planetary system

Lecavelier, Cros, Hébrard et al. (2022)

30 exocomets detected in 156 days of TESS observations





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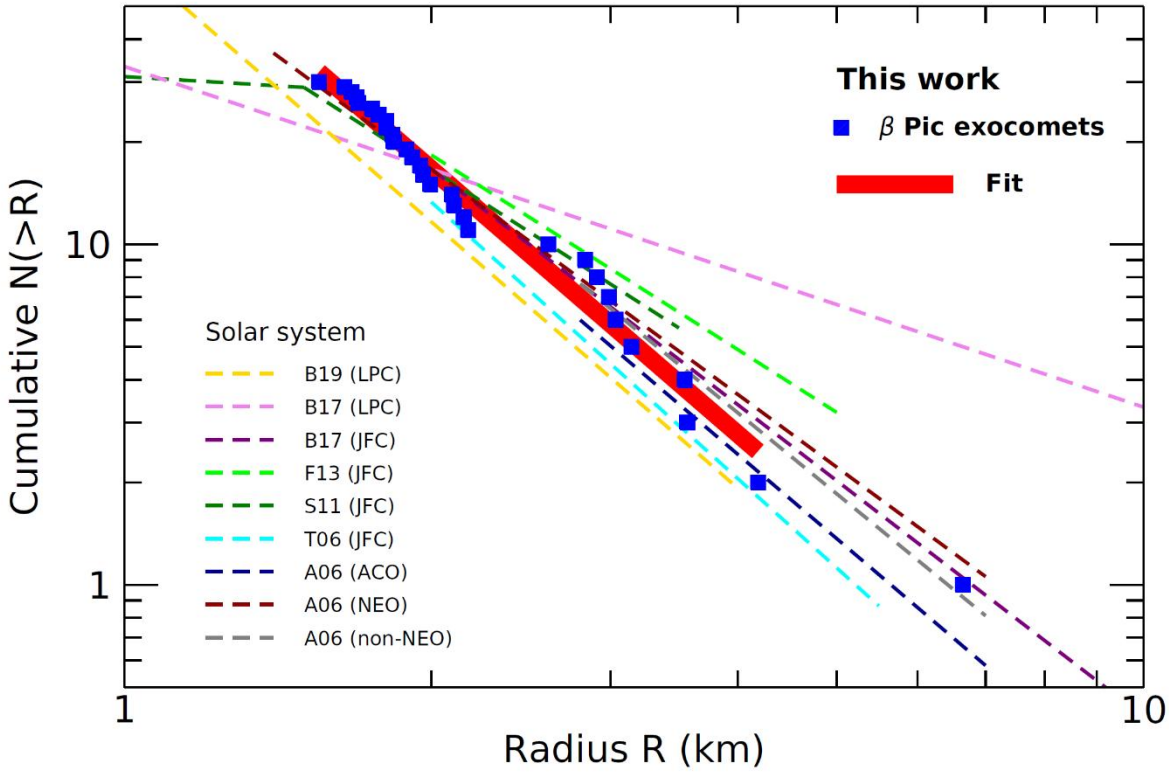
Exocomets size distribution in the β Pictoris planetary system

Alain Lecavelier des Etangs[1]✉, Lucie Cros[1,2], Guillaume Hébrard[1,3], Eder Martioli[1,4], Marc Duquesnoy[5], Matthew A. Kenworthy[6], Flavien Kiefer[1,5], Sylvestre Lacour[5], Anne-Marie Lagrange[5], Nadège Meunier[7] & Alfred Vidal-Madjar[1]

- Size distribution : $dN(R) \propto R^{-3.6}$
- Same as in Solar System !
- Signature of collisional history

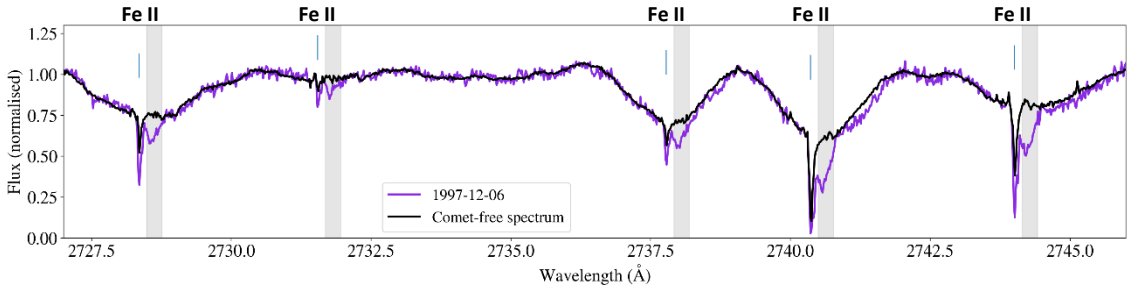


Exocomets characterization with archival HST data

The population of excited levels of Fe+, Ni+ and Cr+

(Vrignaud & Lecavelier, 2024)

- Detection of of **94 Fe II lines** in 1997-12-06 comet



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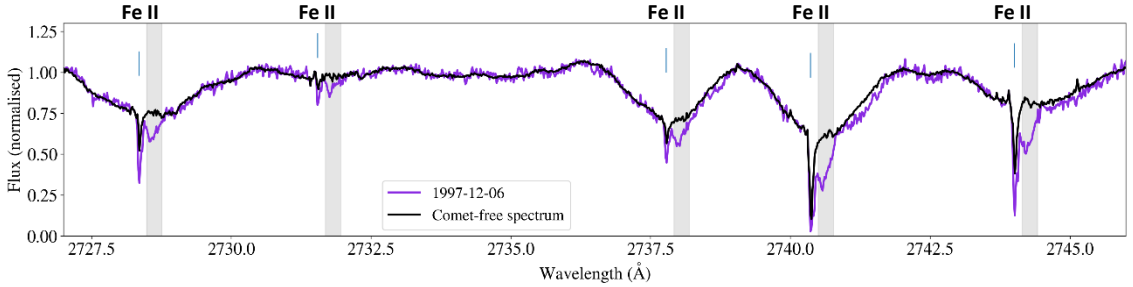
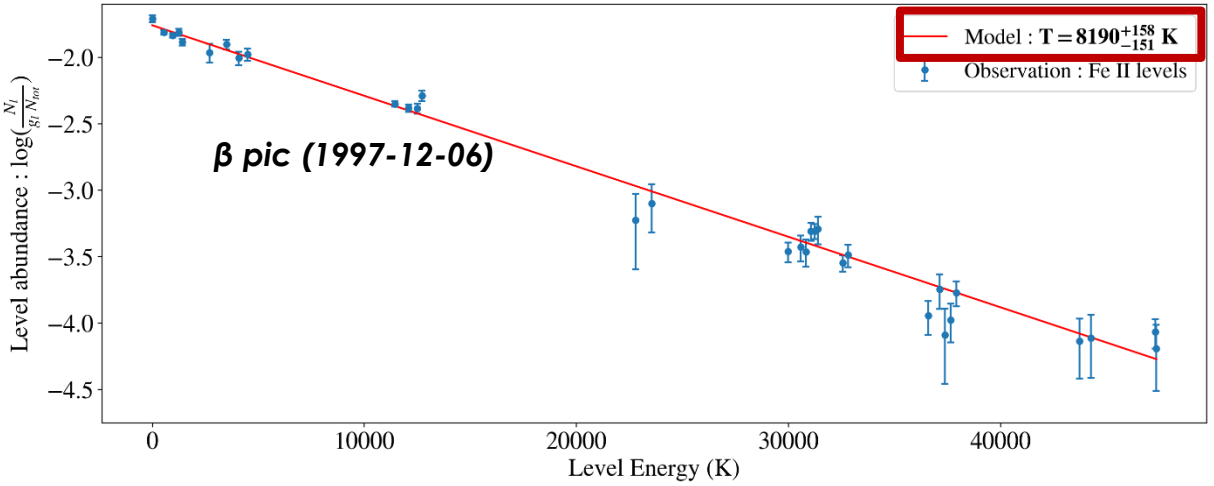


- **The excitation diagram of Fe+ in the comet**



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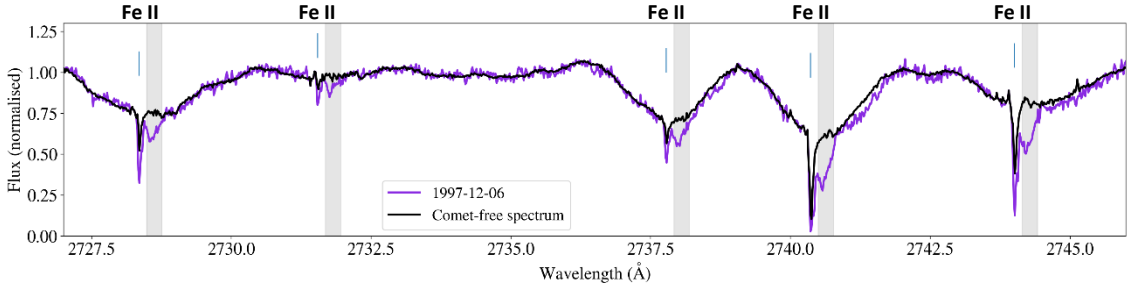
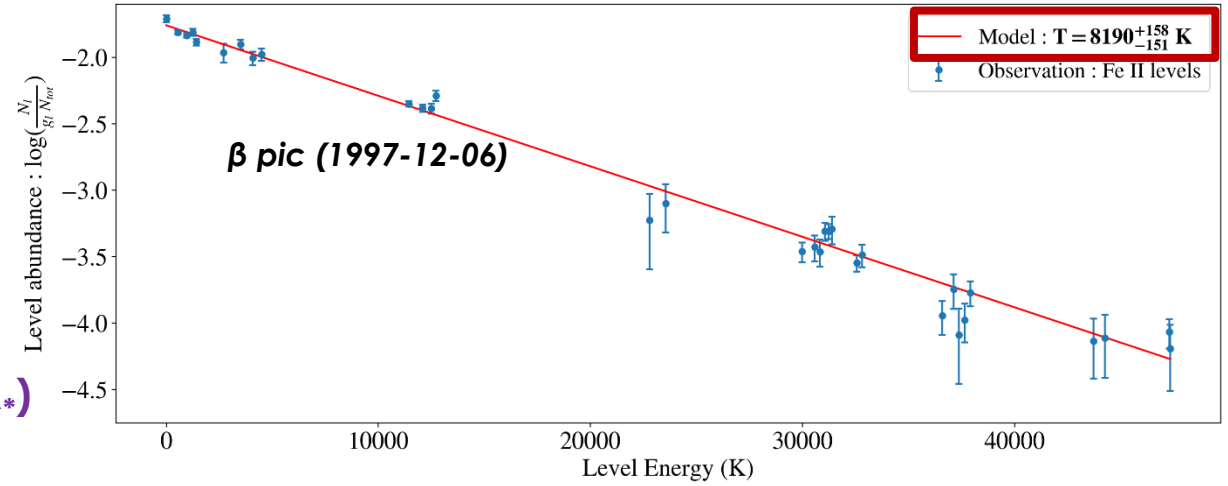


- **The excitation diagram of Fe+ in the comet**

T ~ 8000K
~ Stellar effective temperature !

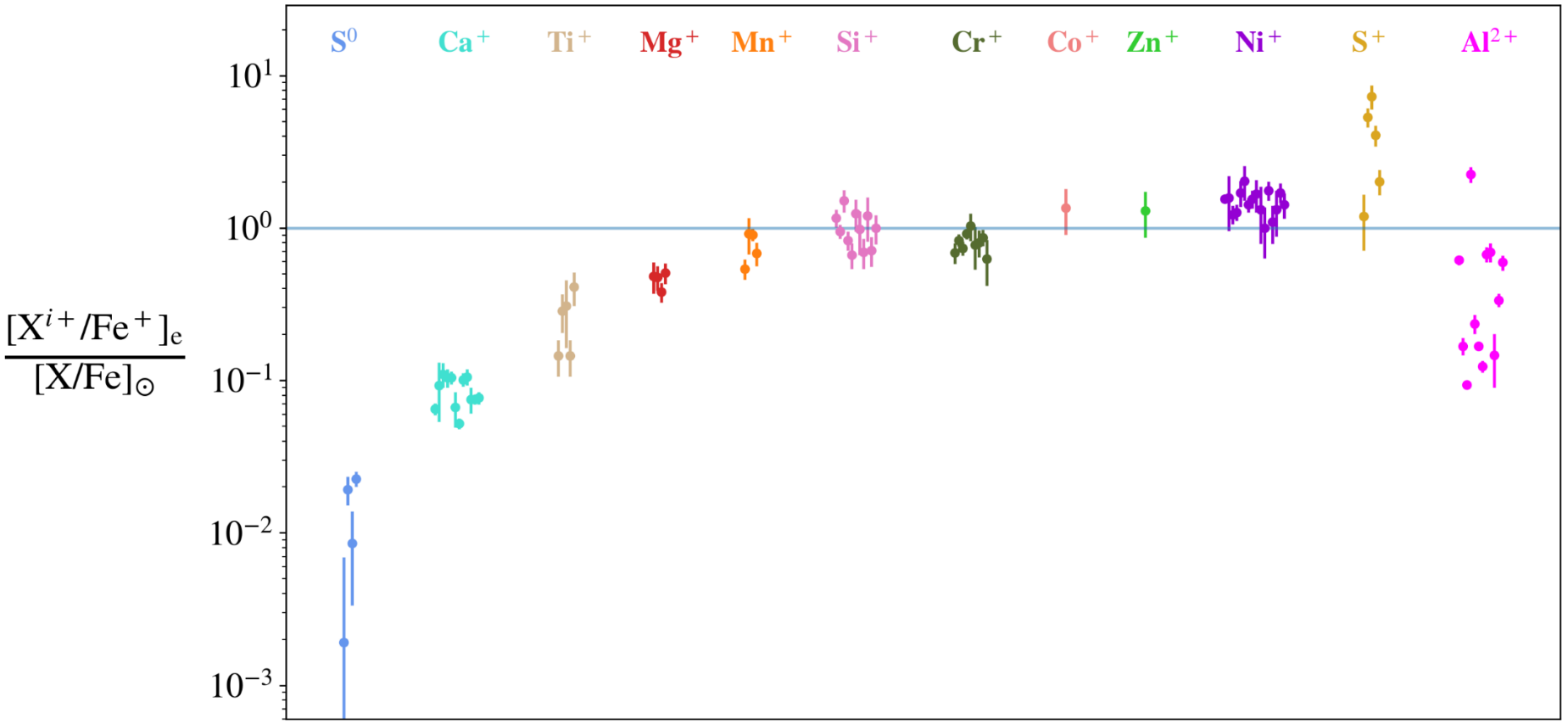
- **The gaseous tail of the comet is in a radiative regime**
- **Low density (< 10^6 cm^{-3})**
- **Close transit distance (<50 R_*)**



Ions abundances in 30 β Pic exocomets

from HST archival data (1997-2024)

(Vrignaud & Lecavelier 2025)



New 2025 HST observations to measure β Pic exocomets composition (Vrignaud et al. 2024)

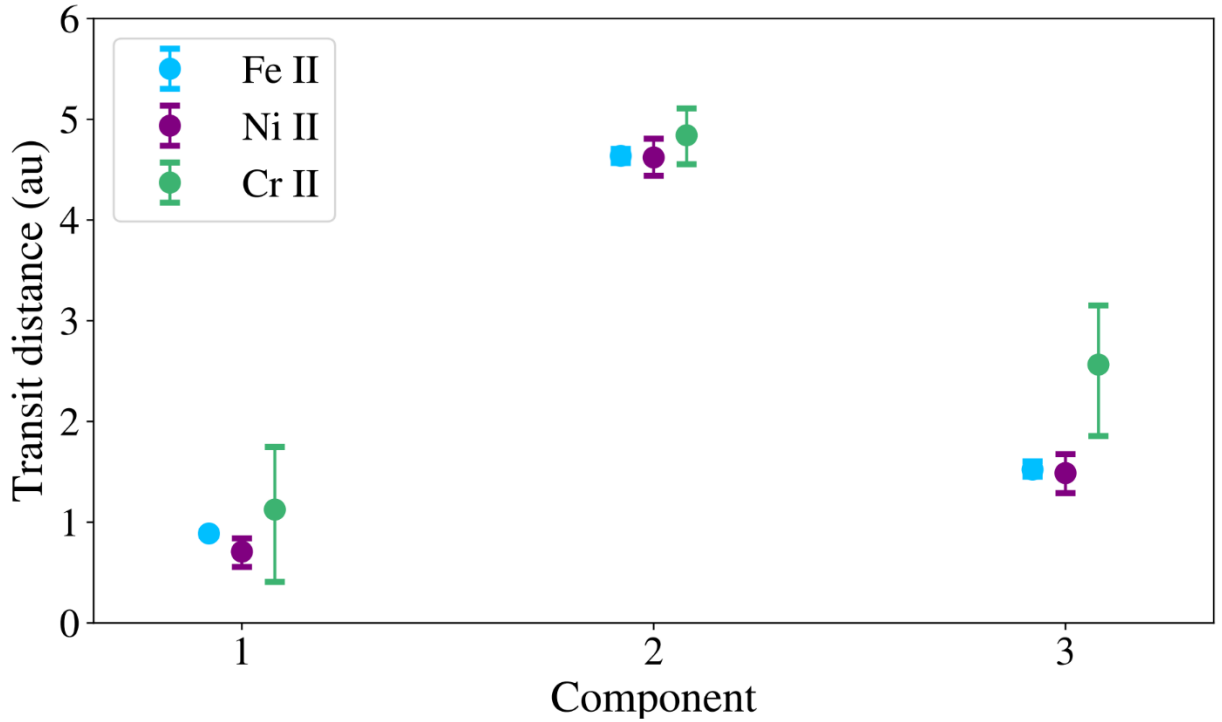
- **Wide wavelength coverage from 1200 Å to 2900 Å**
  ➔ simultaneous coverage of **Fe, C**, S, Ti, Mg, Mn, Si Cr, Co, Zn, Ni, Al

- **4 visits** → warranty exocomets transit detections
  → Executed in April, September, October 2025

Large distance for the cometary tails
(Vrignaud & Lecavelier 2025)

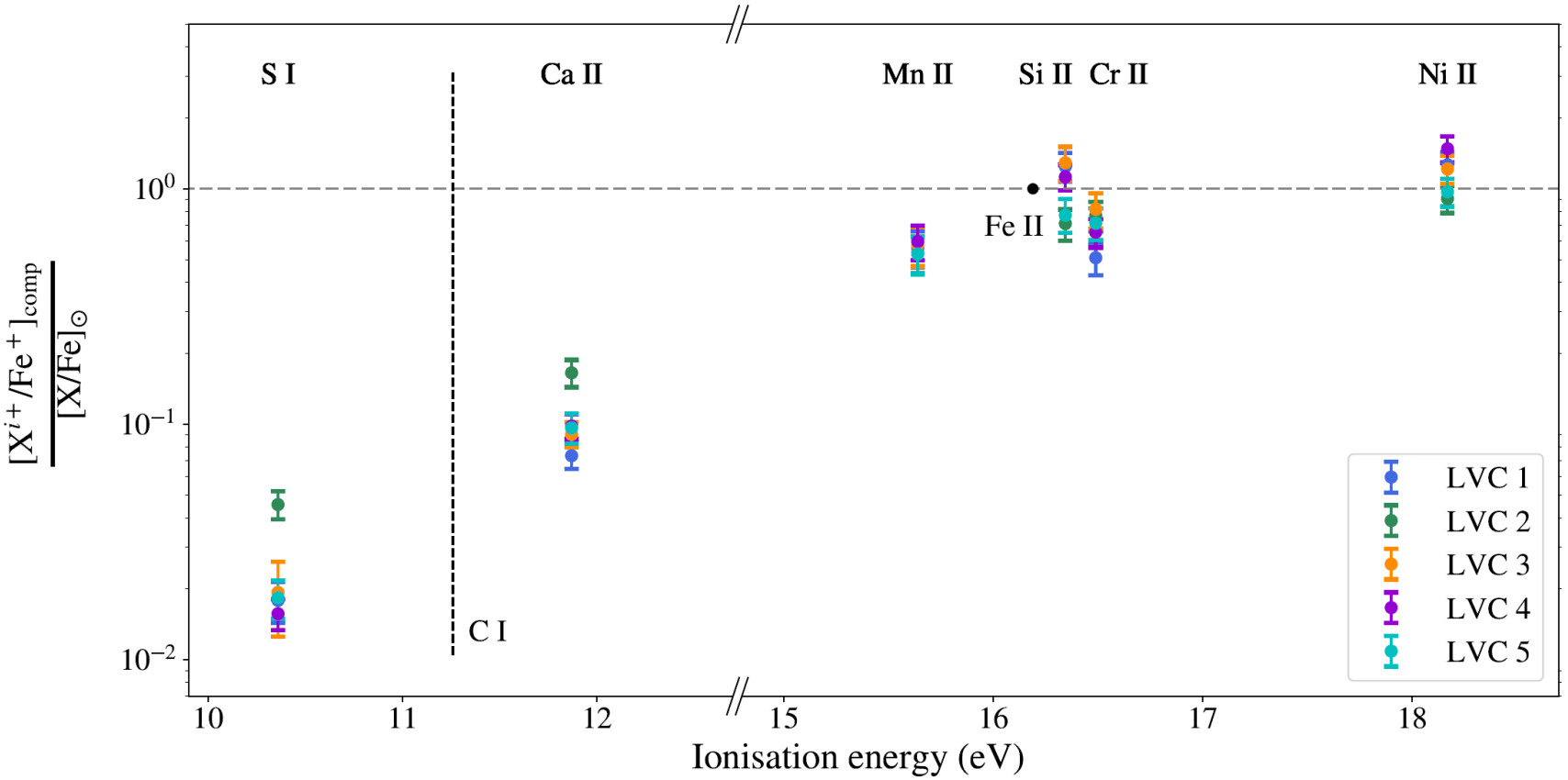
- Measurements of the tail distance using excitation levels population
  ➔ independent estimates for Fe^+, Ni^+ and Cr^+

- Exocometary tails transit at **unexpected large distances** to the star,
  up to ~5 au !!



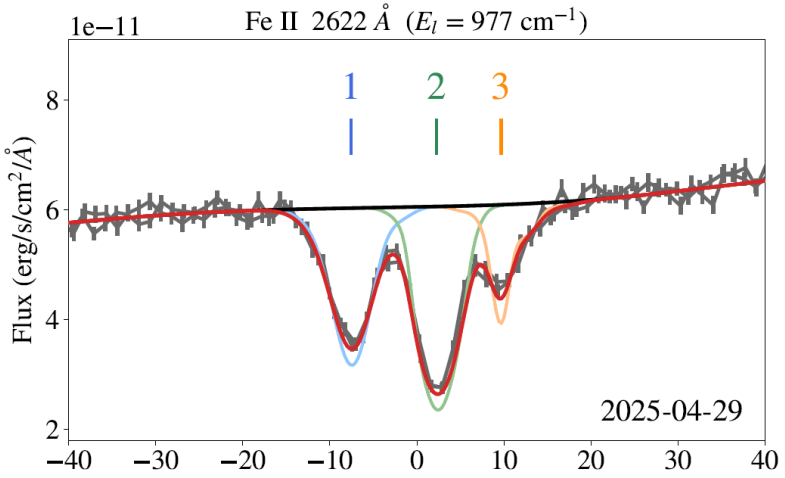
Composition measurement for 5 exocomets
(Vrignaud & Lecavelier 2026, in preparation)

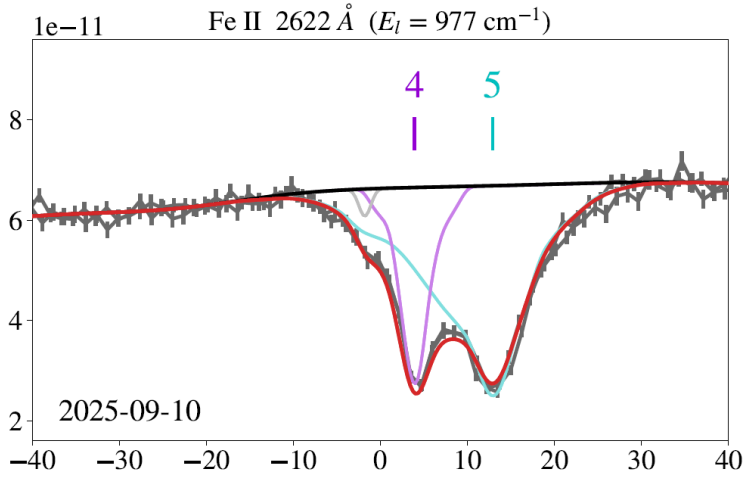
- **Solar abundances** for the refractory species
- Clear relationship between ionization level and ionization potential
  ➔ **derivation of the total species abundances**

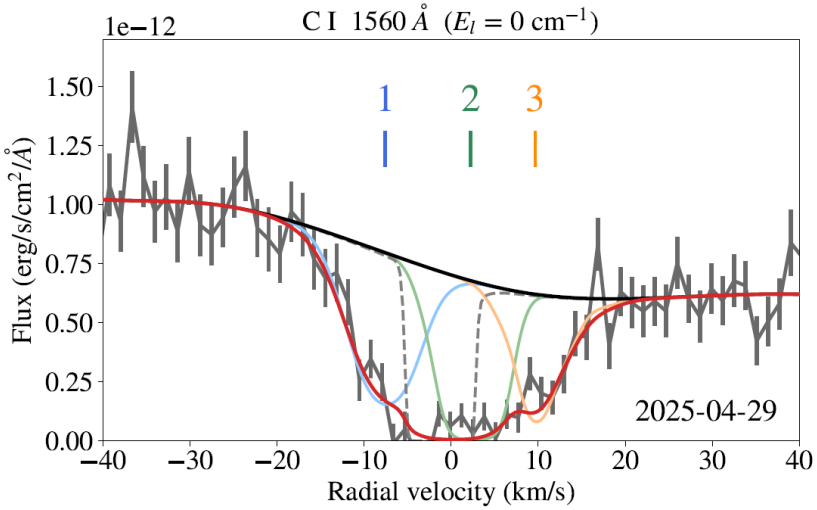


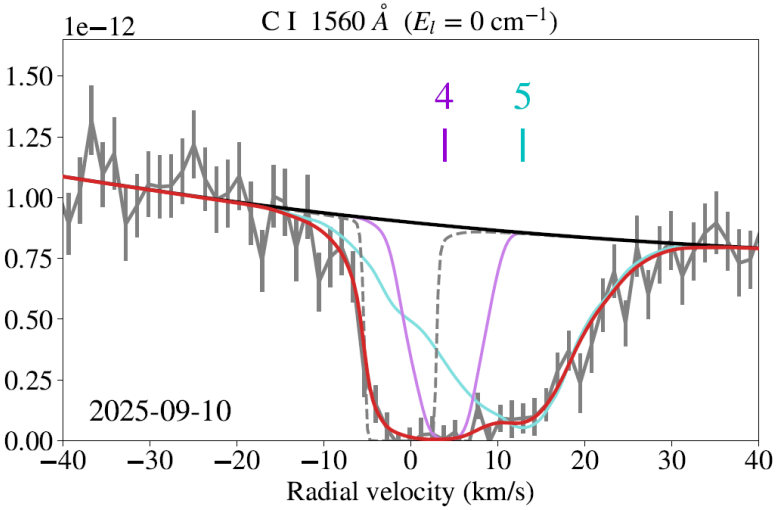
Simultaneous detection of Fe and C

(Vrignaud & Lecavelier 2026, in preparation)









Observations of April and September 2025

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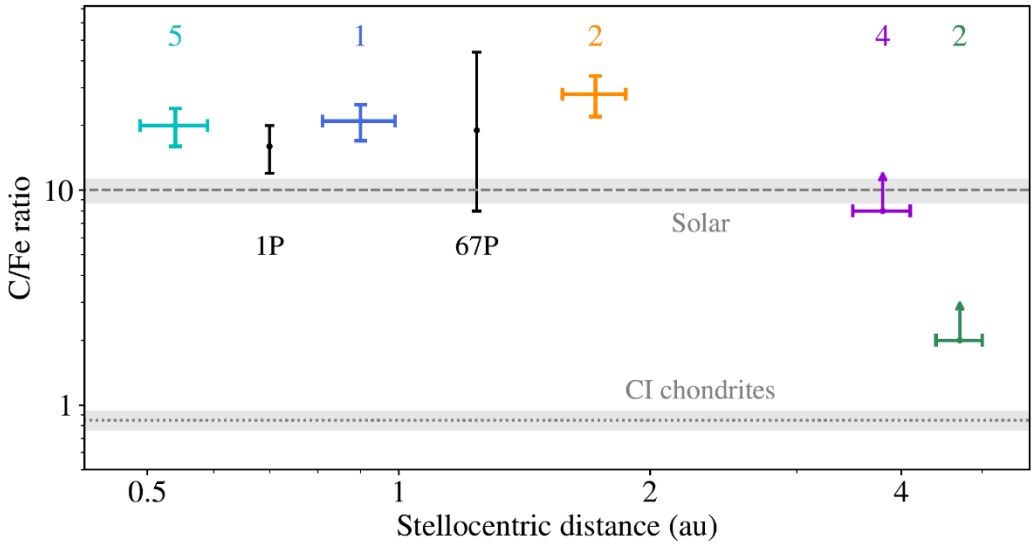


Thank you !