The EXPLORE.DDD (Dusty Debris Disk) CHEOPS program

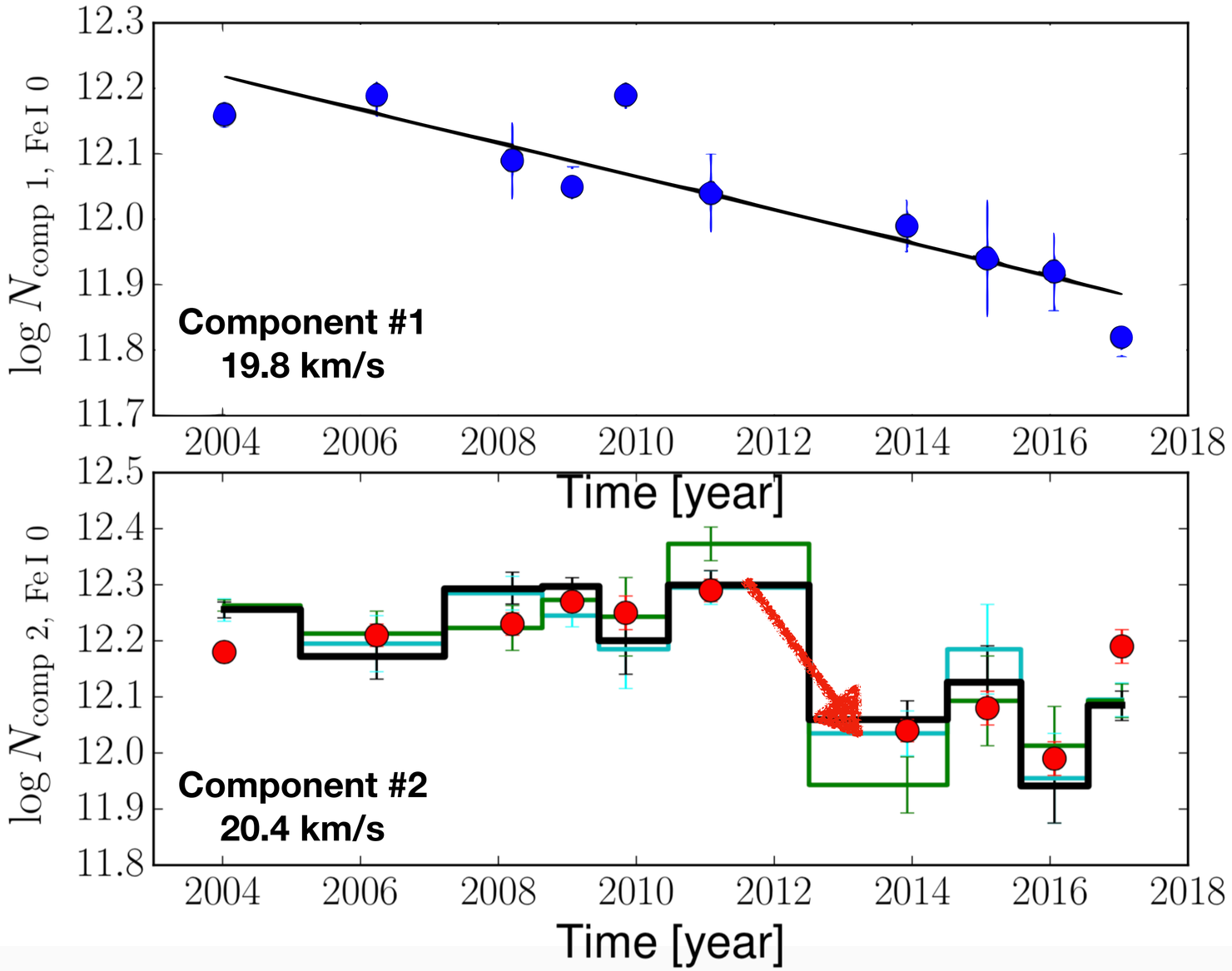
- **Searching for inhomogeneities in young debris disk:**
  - ✦ Traces of Toomre instability vortices;
  - ✦ Transiting clumpses;
  - ✦ Exocomets.

- (post) planet formation conditions in young systems;

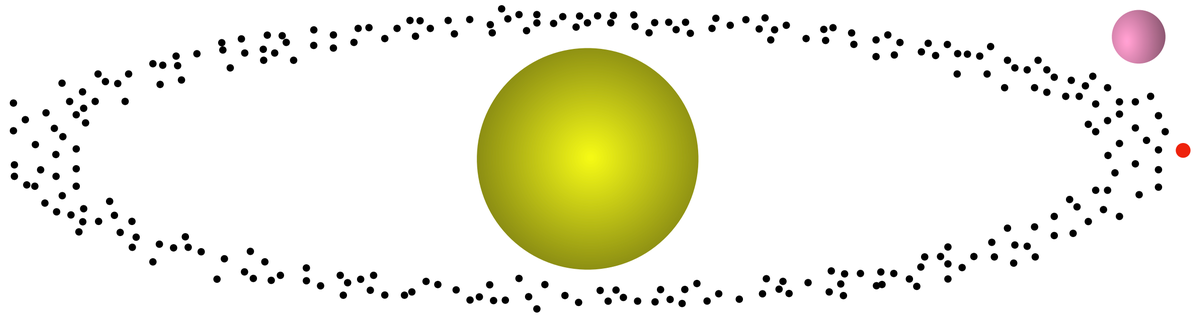
- Planetesimal collisions / planet formation / small primitive bodies in disk;

- **Direct objective**:
  - ✦ "Long" photometric monitoring (several contiguous days) at targets with known (quasi) edge-on disks;
  - ✦ Searching for transient signatures;
  - ✦ HD172555, 49 Ceti, HR10, AU Mic...

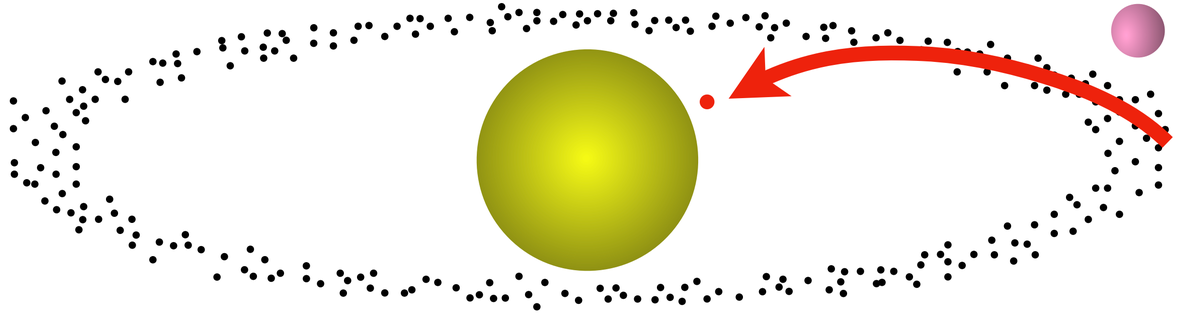
Variations in the Beta Pic disk circumstellar line of Fe I



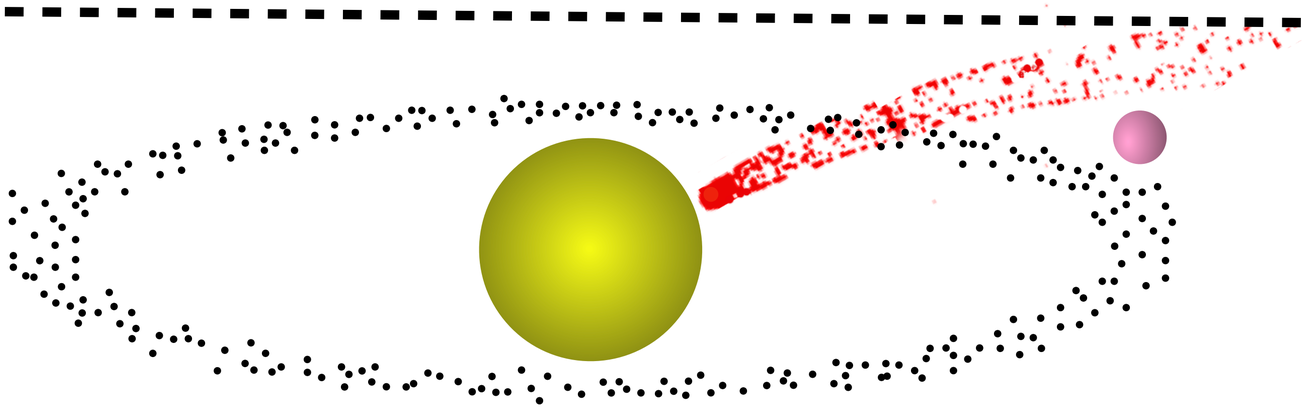
Kiefer+ 2017



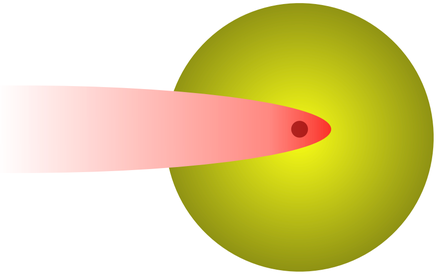
Small body in belt
Interacting with **planet**

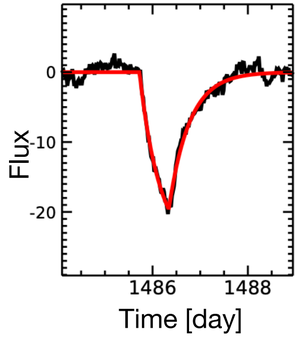


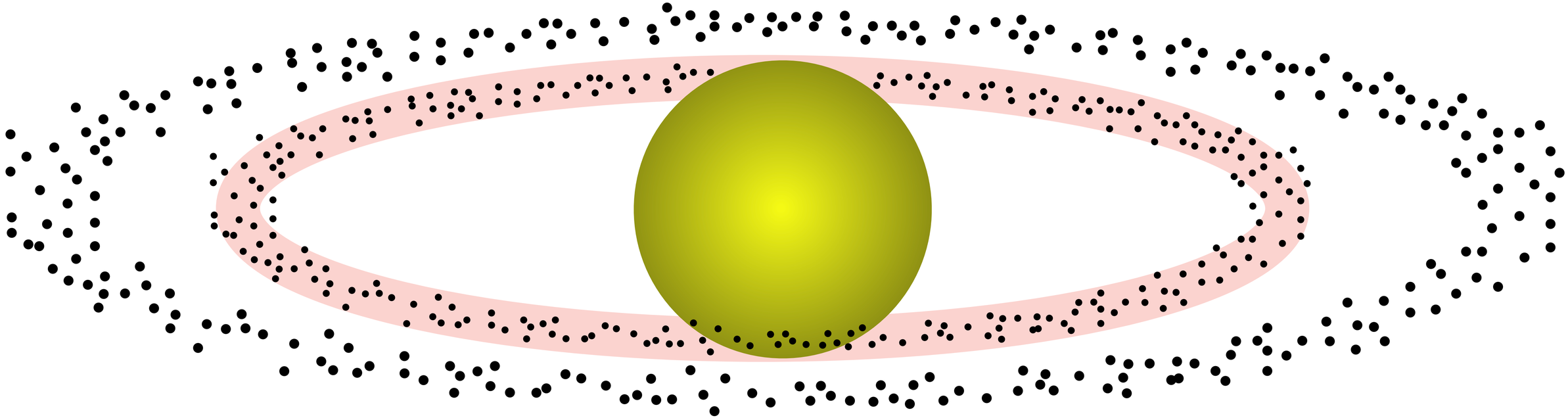
Small body migrating inward
e.g. mean-motion resonance



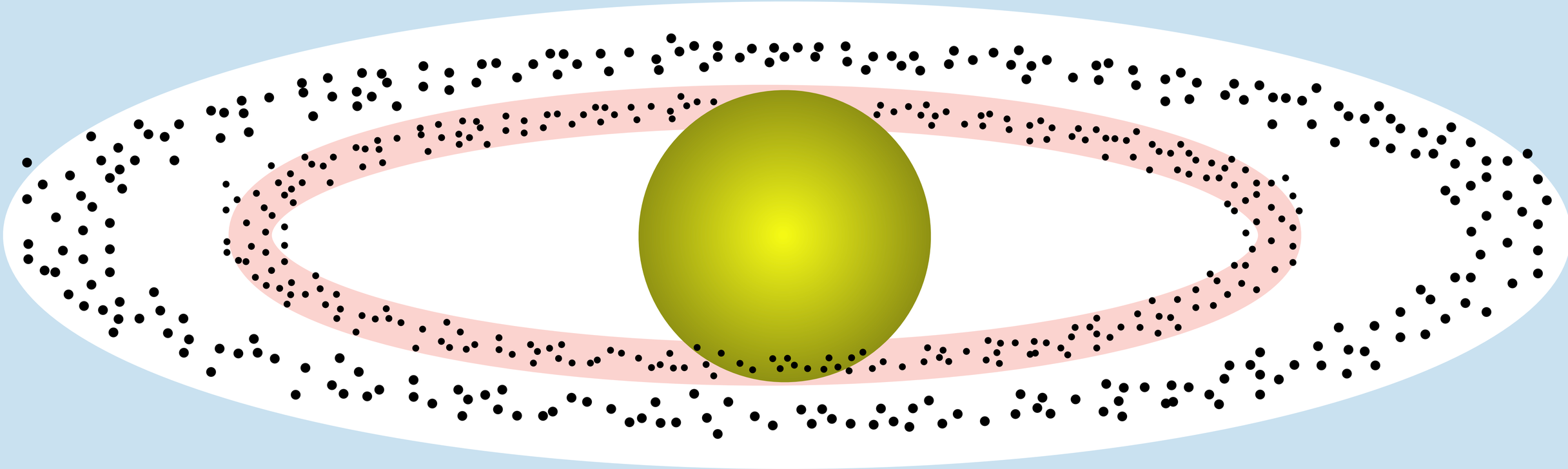
Small body becoming **exocomet**







- **Warm** primitive disk:
  - ➡ Cannot survive more than 5-10 Myr;
- **Warm** secondary disk:
  - ➡ Can be replenished by comets evaporation / disintegration;



- **Warm** primitive disk:
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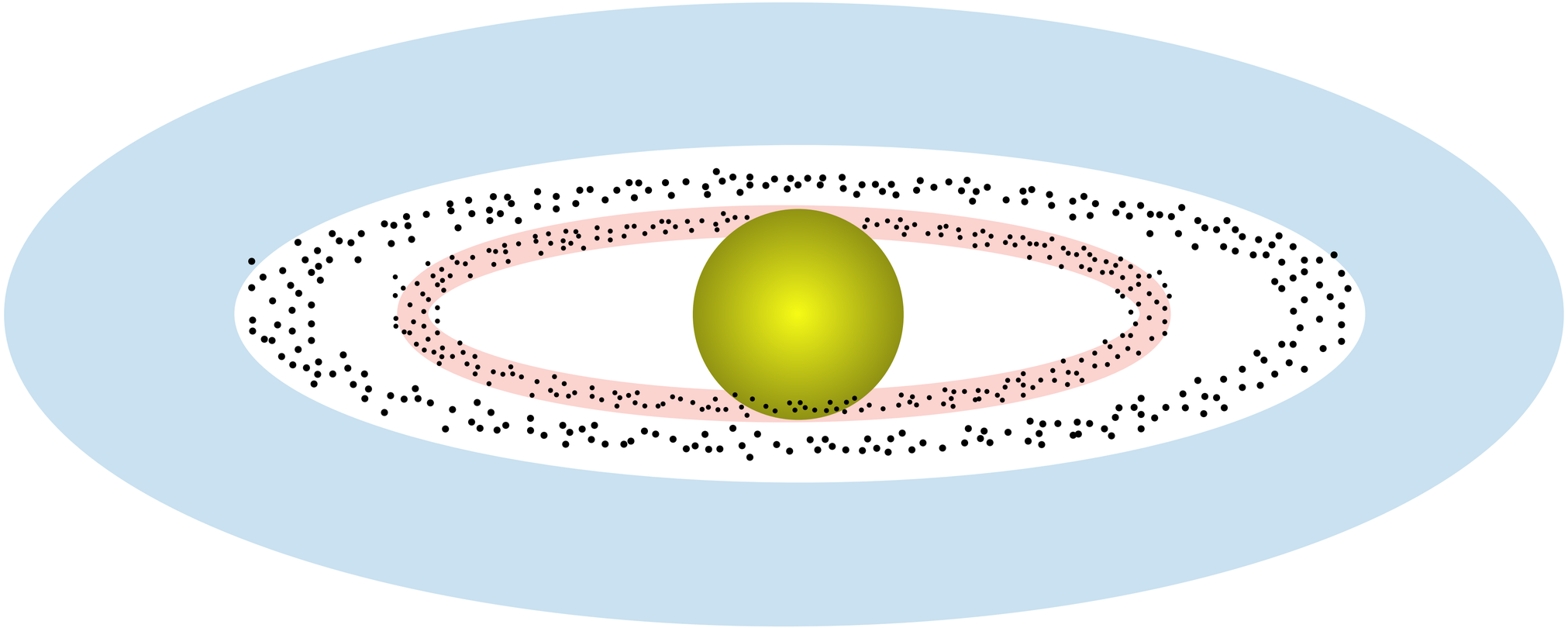
- **Cold** (exterior) disks:
  - ➡ Icy bodies collisions / evaporation ? ~ Kuiper-like objects



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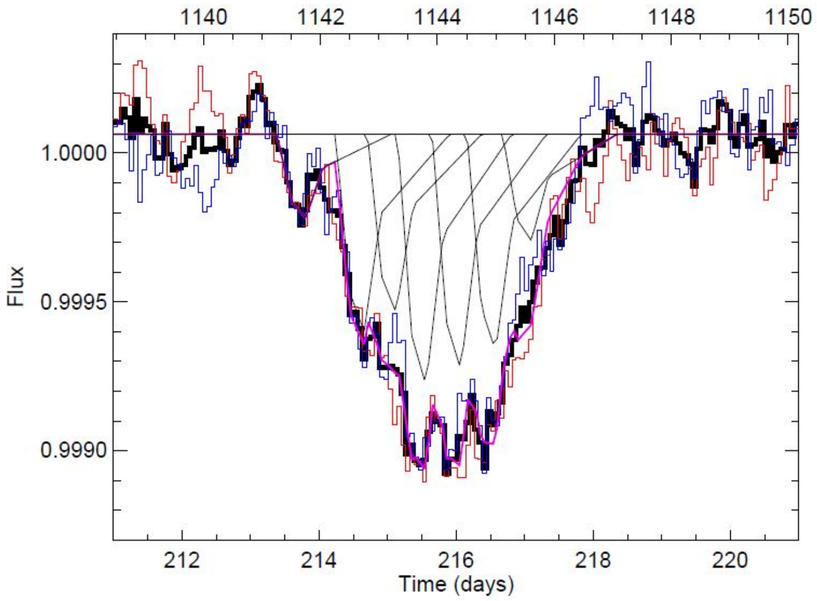
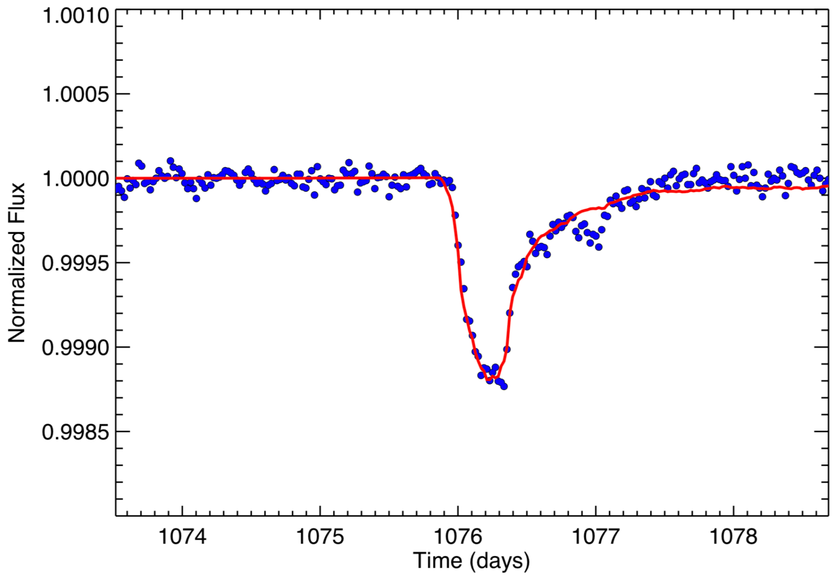
First detections of exocomets in transit photometry !

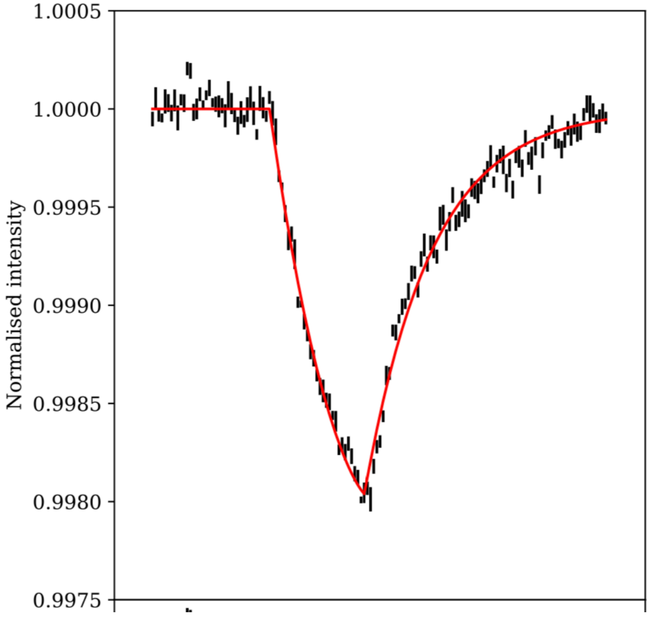
KIC 8462852 - Kiefer+ 2017



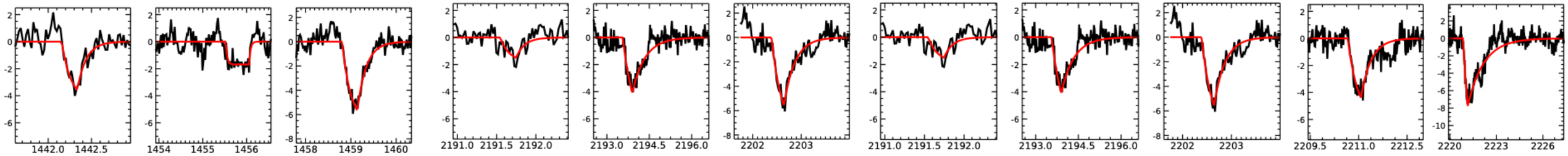
KIC 3542116 - Rappaport+ 2018



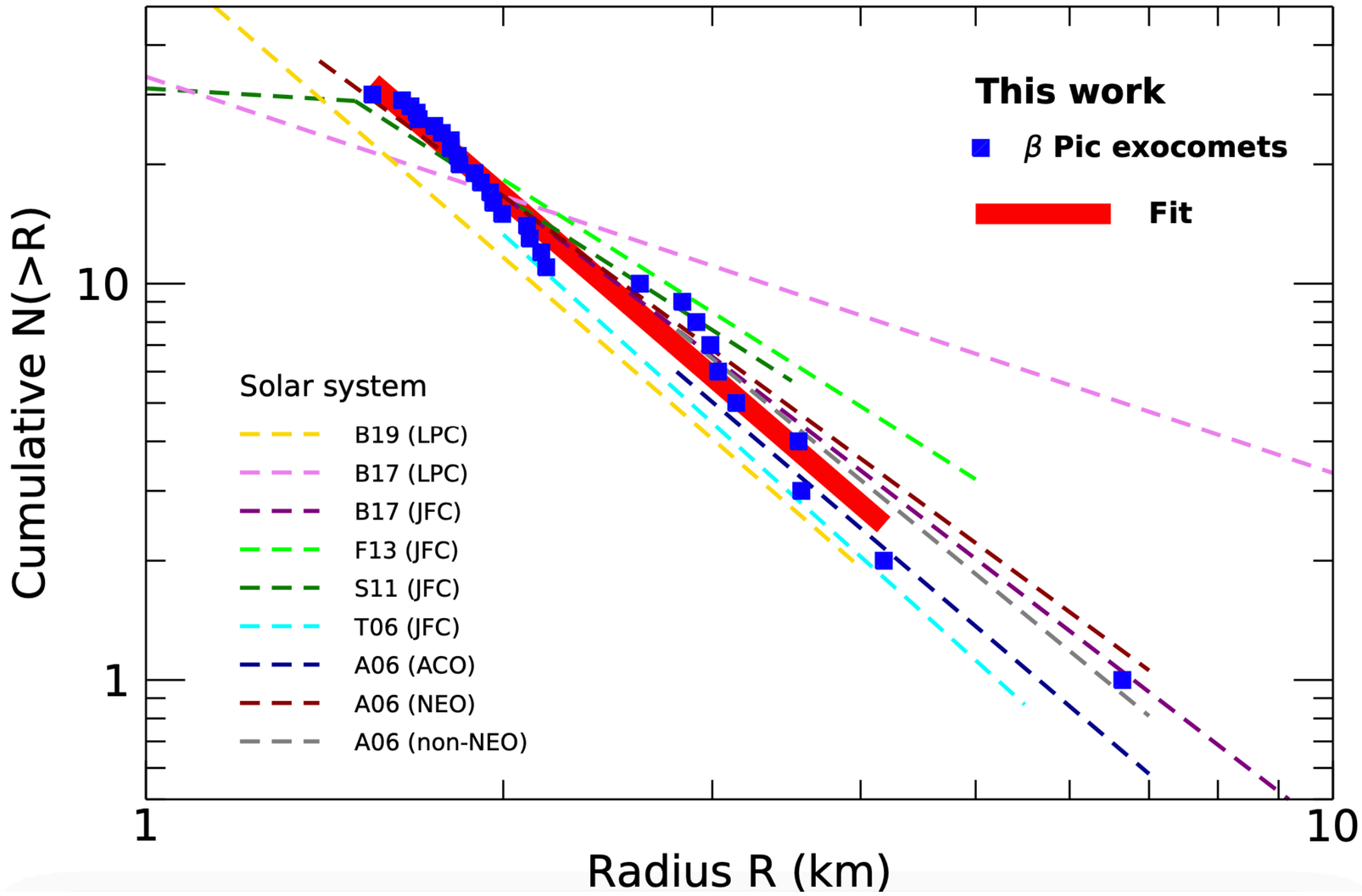
Beta Pic - Zieba+ 2018



Beta Pic - Lecavelier+ 2022



Distribution of comet nucleus size in an extrasolar system

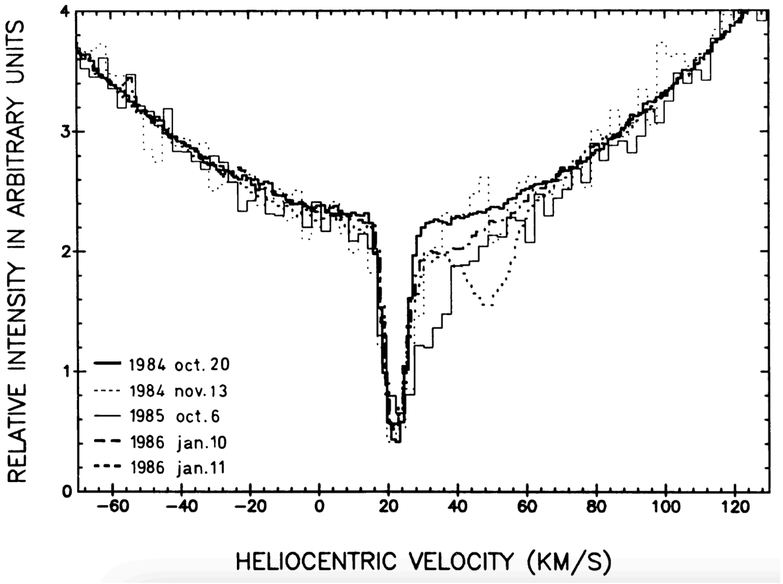


- Solar-system like distribution of size $dN \sim R^{-3.5}\, dR$;
- Small bodies system in collisional equilibrium.

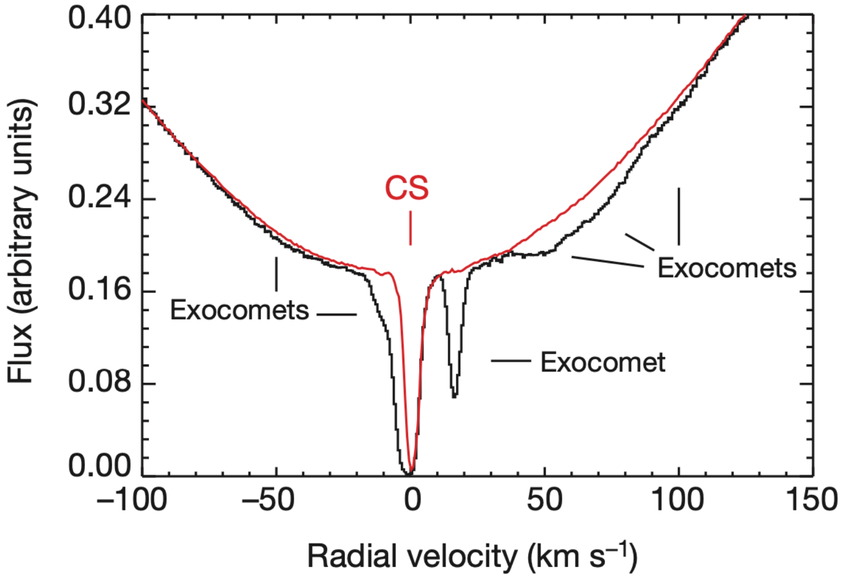
Lecavelier+ 2022

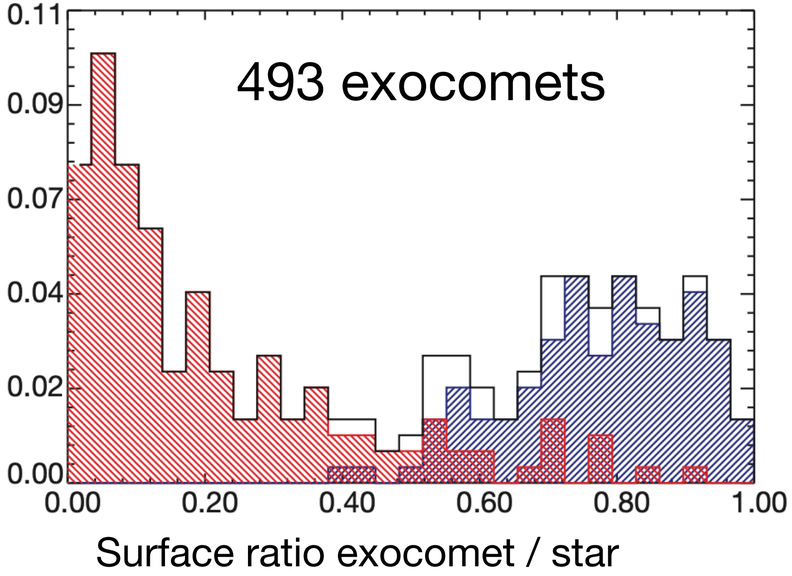
By the way, exocomets have been detected a long time ago already thanks to... spectroscopy !

Ferlet+ 1987

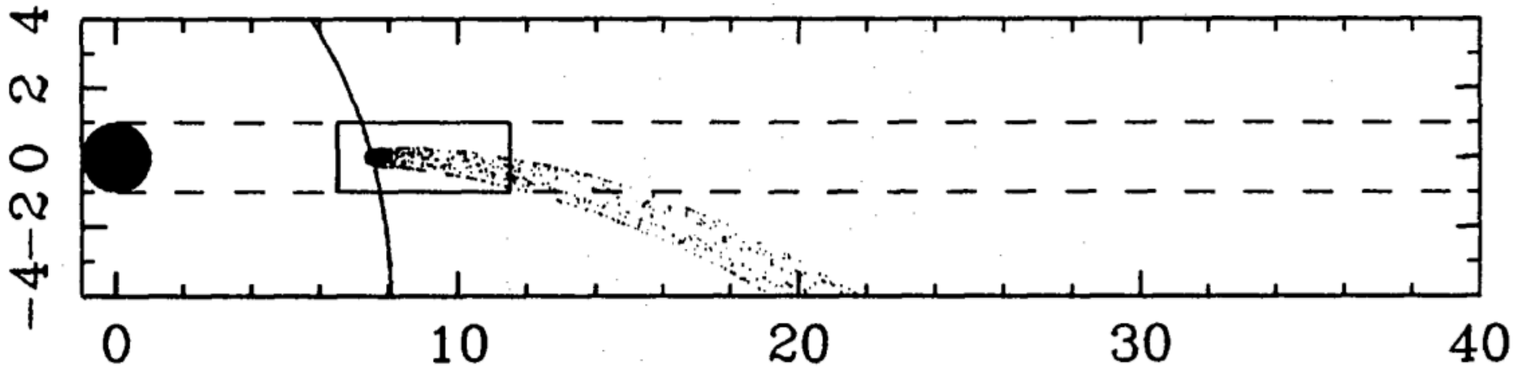


Kiefer+ 2014



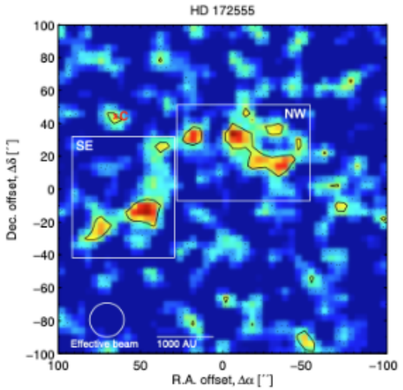


Beust+ 1990

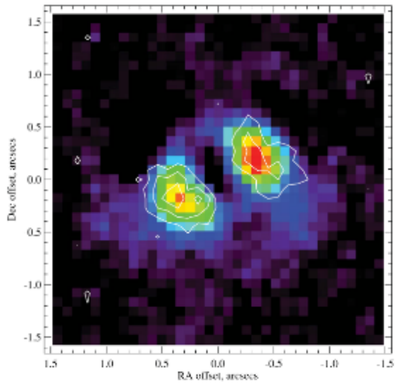


Hint of a photometric transit of an exocomet in the CHEOPS lightcurve of HD 172555 - F. Kiefer, V. van Grootel, A. Lecavelier, G. Szabó, A. Brandeker et al. (EXPLORE.DDD)

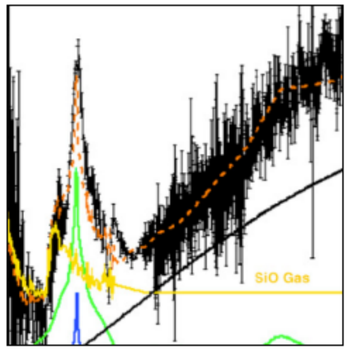
cold dust disk -> 1000 au
Nilsson+ 2009



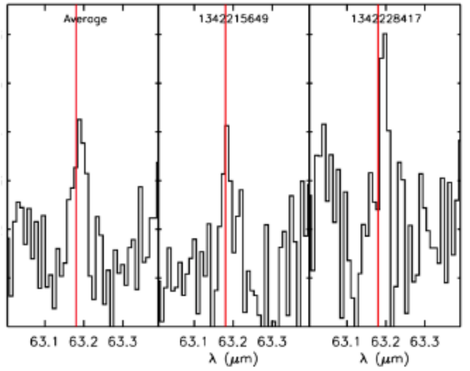
Hot dust disk ~ 10 au
Smith+ 2012



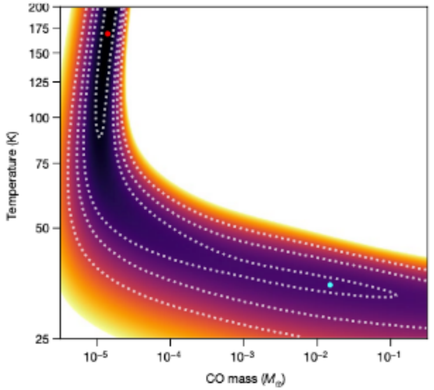
Large amounts of SiO
Lisse+ 2009



Large amounts of [OI]
Riviere-Marichalar+ 2012

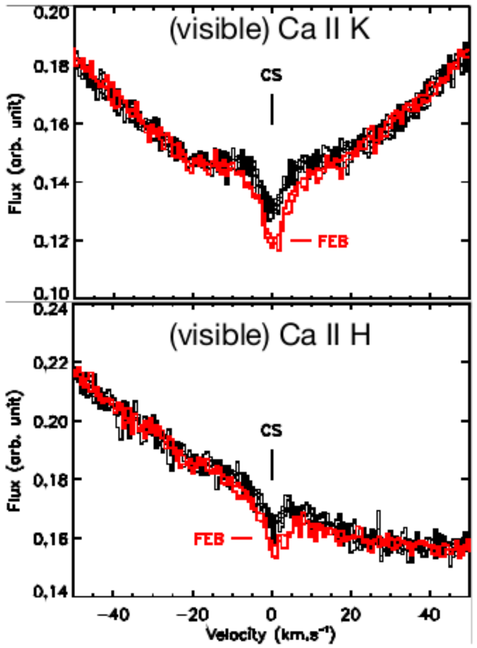


Hot CO detection
Schneiderman+ 2021

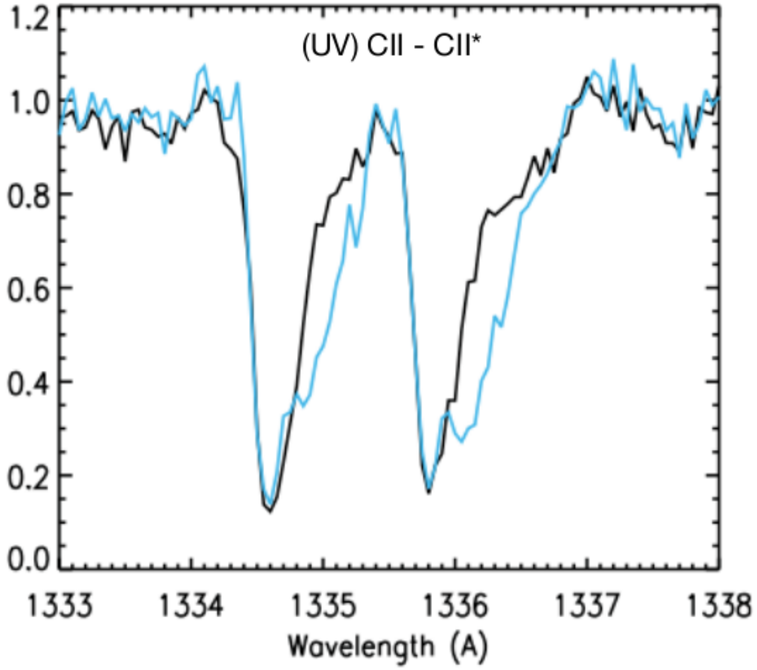


Transient spectral features likely due to exocomets

Kiefer et al. 2014



Grady et al. 2018



- >75° edge-on circumstellar gas disk,
- Same age as Beta Pictoris (BPMG ~ 20 Myr),
- Same spectral type as Beta Pictoris,
- Direct detection of transient events (exocomets),
- Anomalous quantities of O, CO, SIO and hot dust.

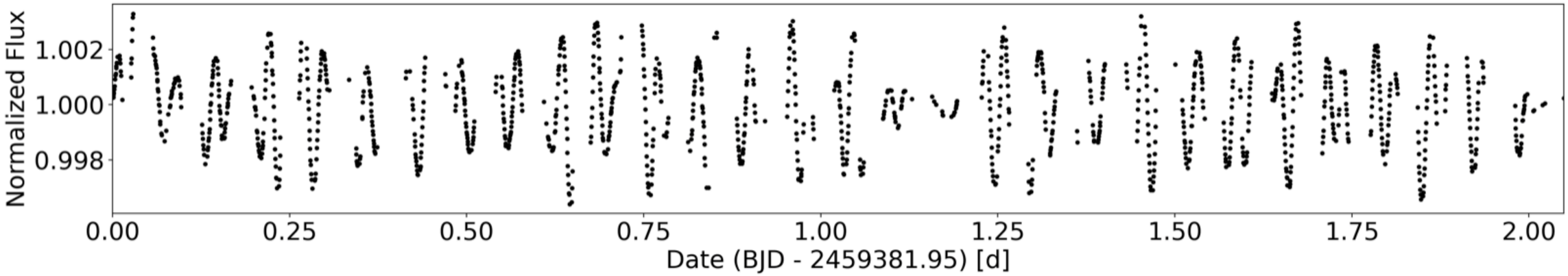
- Icy planetesimal direct and indirect detections,
- Hints of a hypervelocity planetesimal collision (Lisse+ 2009),
- This system may be experiencing a period of heavy bombardment, with frequent collisions of planetesimal bodies which could explain the high mass of localized dust at 1000 AU (Nilsson+ 2009).

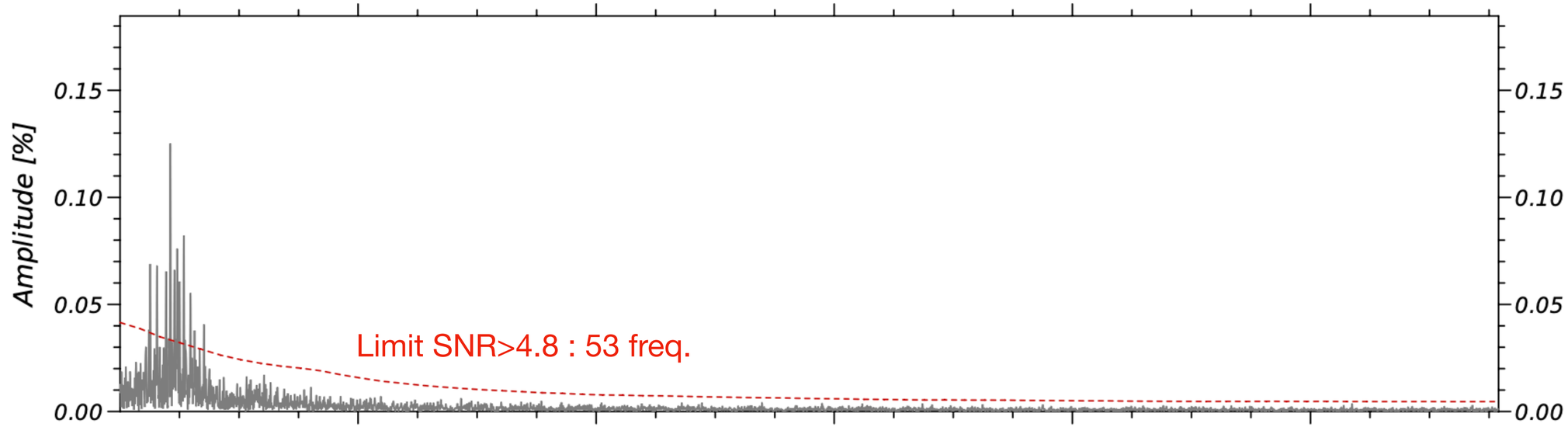
Hint of a photometric transit of an exocomet in the CHEOPS lightcurve of HD 172555 - F. Kiefer, V. van Grootel, A. Lecavelier, G. Szabó, A. Brandeker et al. (EXPLORE.DDD)

- No TESS data (unknown photometric variability).
- One CHEOPS visit: Delta-Scuti-like pulsation pattern.

Main issues: Pulsation analysis & Frequency cleaning + transient identification

2 days of +/- continuous monitoring = not well constrained frequencies w/ < 3 day, but 1 transient

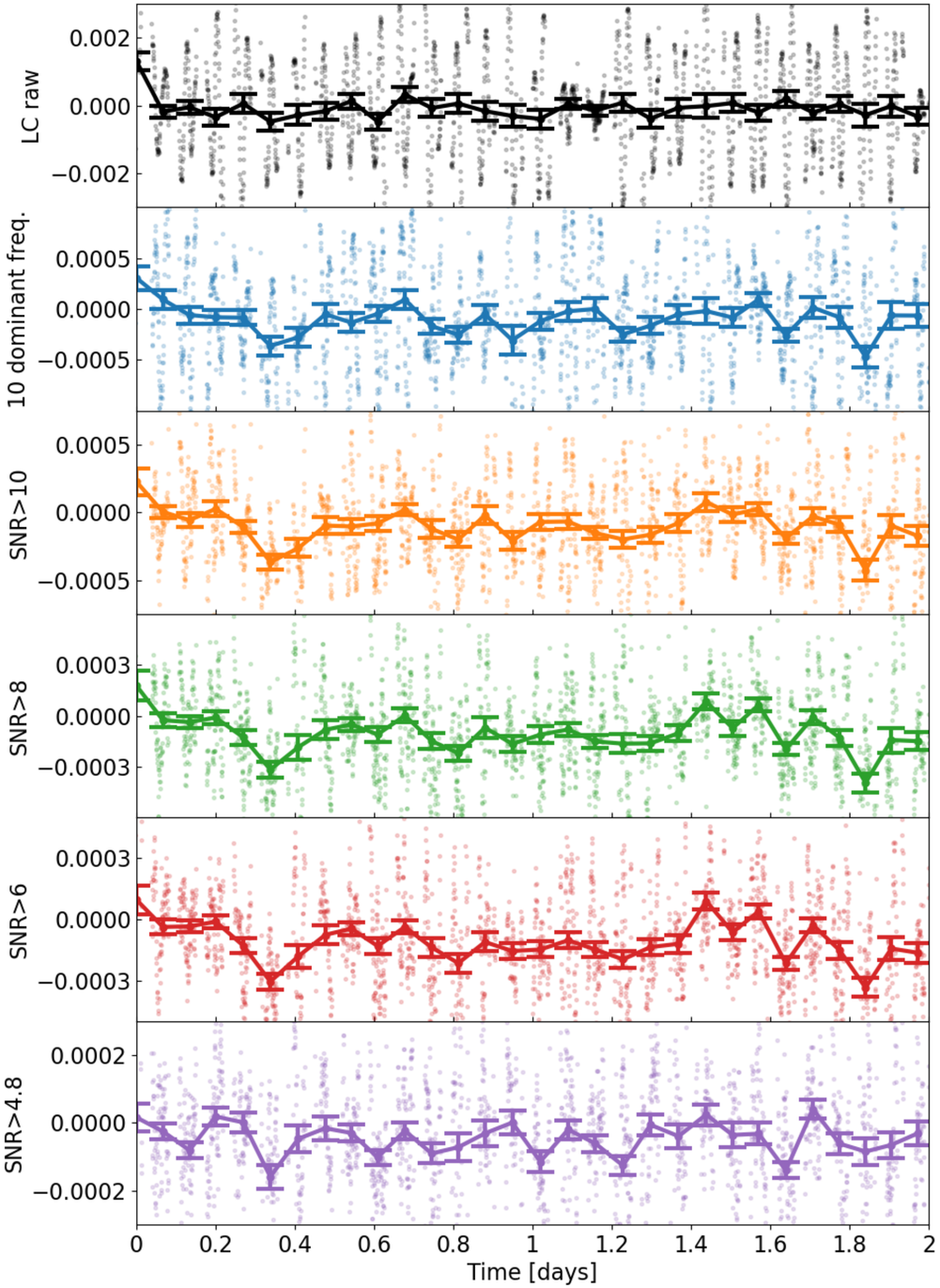




Removing delta-Scuti pulsations with increasing precision

Raw

SNR>4.8

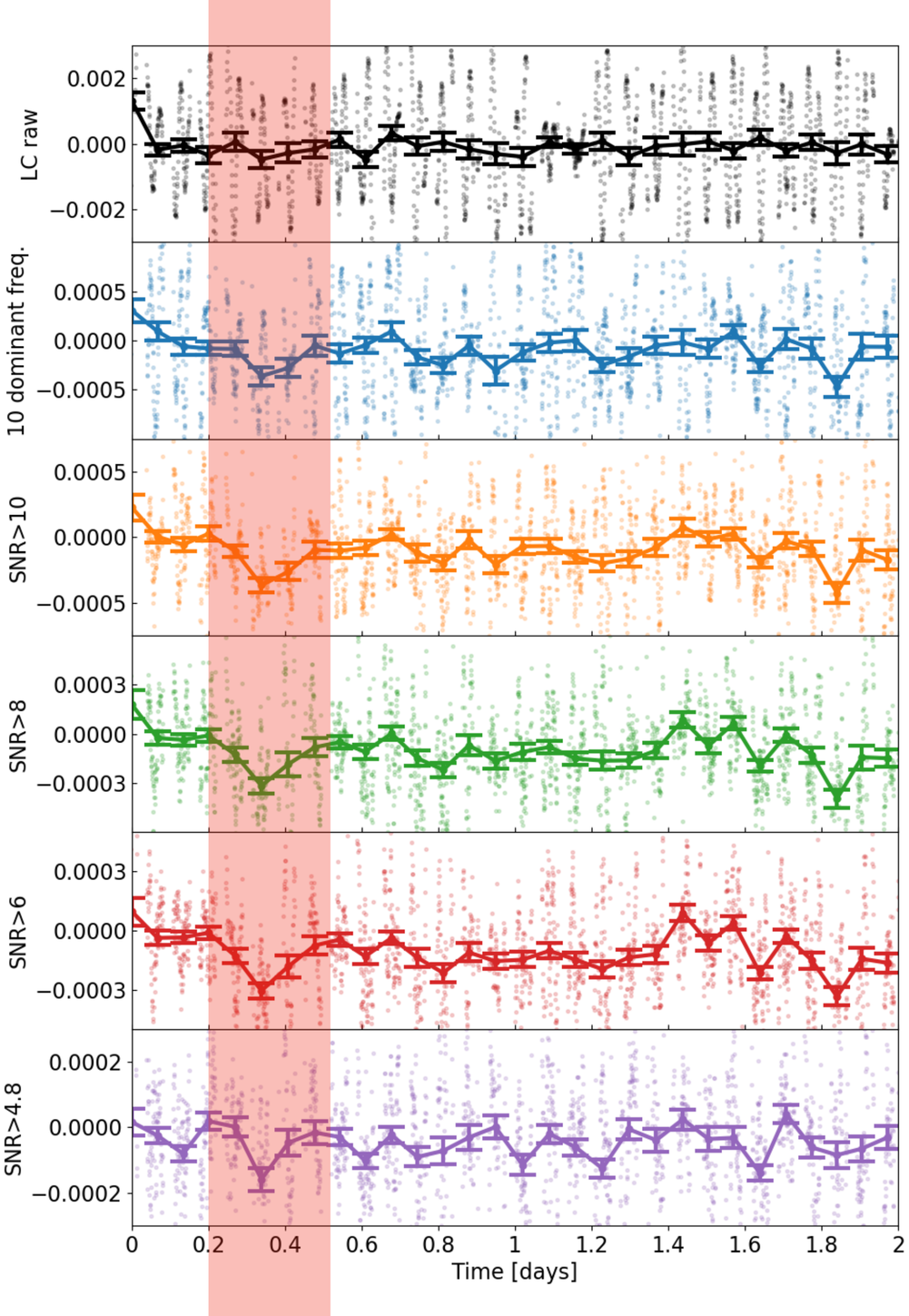


Removing delta-Scuti pulsations with increasing precision

Raw

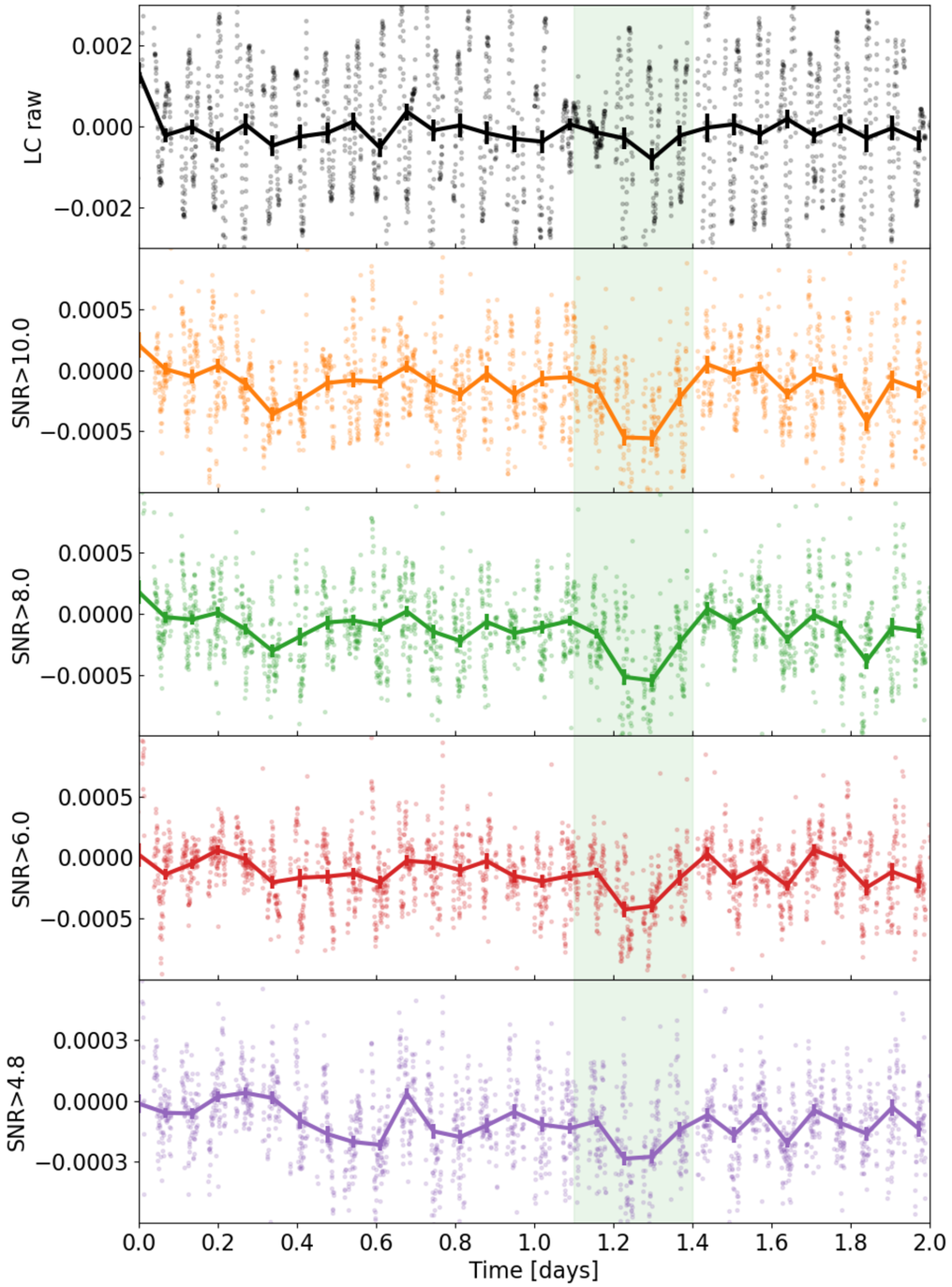
SNR>4.8

Hint of a transient



Injection of exocomet transit curve in raw LC + delta-Scuti removal

- Survives the removal;
- But absorbed with the increasing precision...



Injected depth

544 ppm

Fitted depth

680 ± 80 ppm

580 ± 40 ppm

460 ± 50 ppm

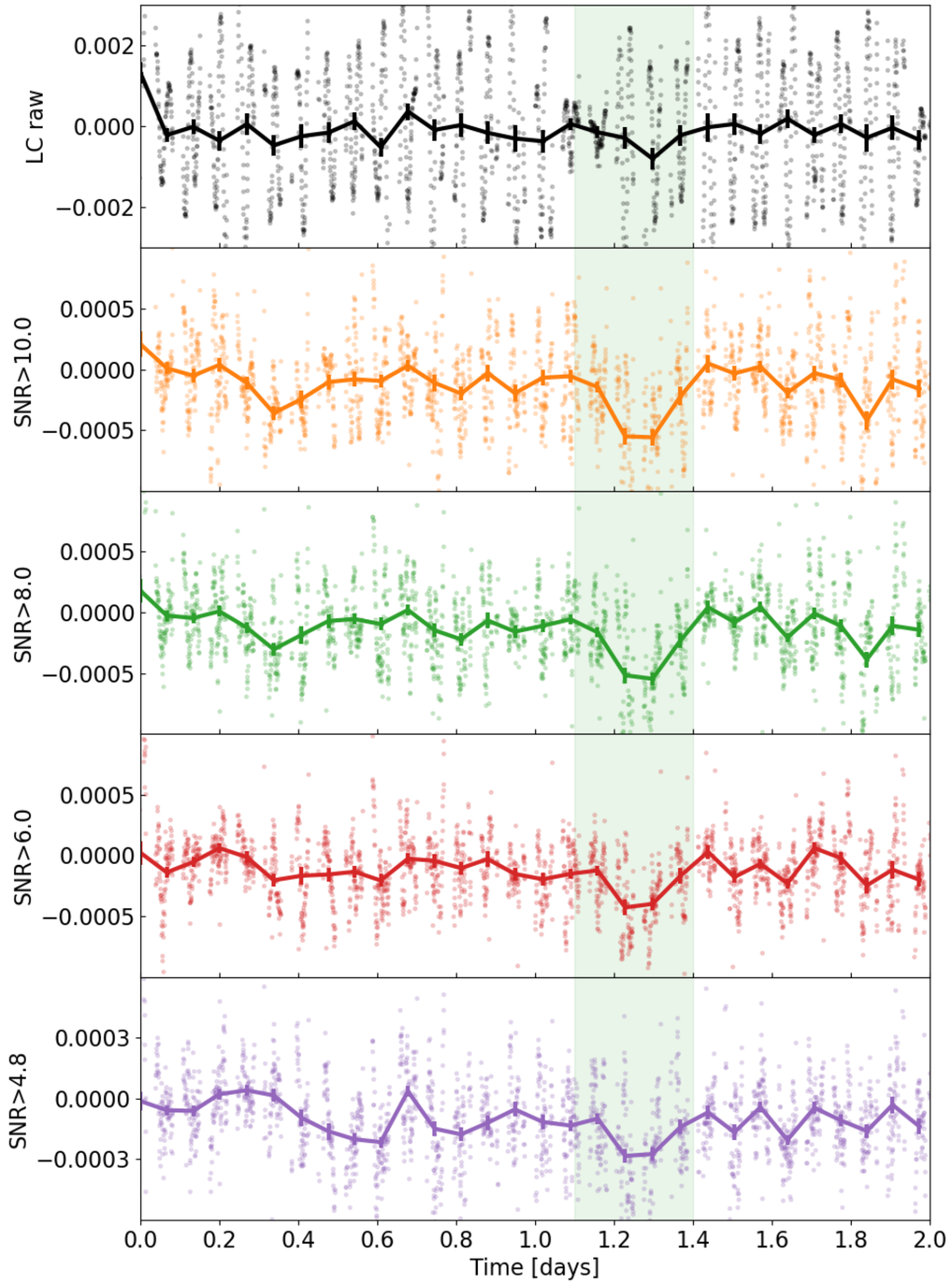
510 ± 130 ppm

Injection of exocomet transit curve in raw LC + delta-Scuti removal

- Survives the removal
- But absorbed with the increasing precision

SNR=8

the best compromise



Injected depth

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Fitted depth

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580 ± 40 ppm

460 ± 50 ppm

510 ± 130 ppm

Hint of one exocomet transit in delta-Scuti residuals

Fit of exocomet transit model (Lecavelier+ 2022)

AD = 336 ± 148 ppm

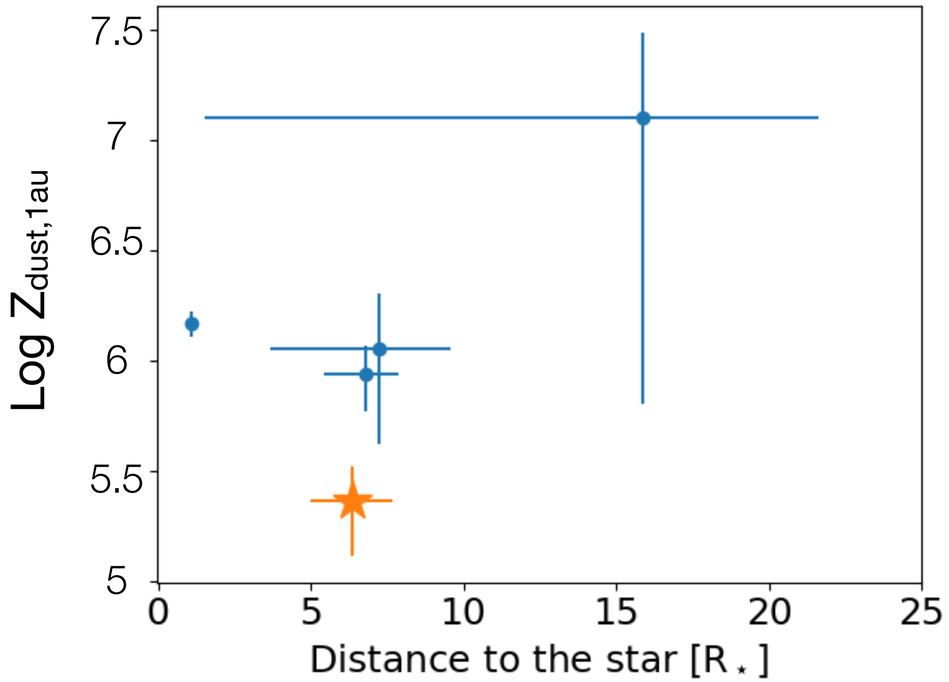
q_{peri} = 0.047 ± 0.010 au

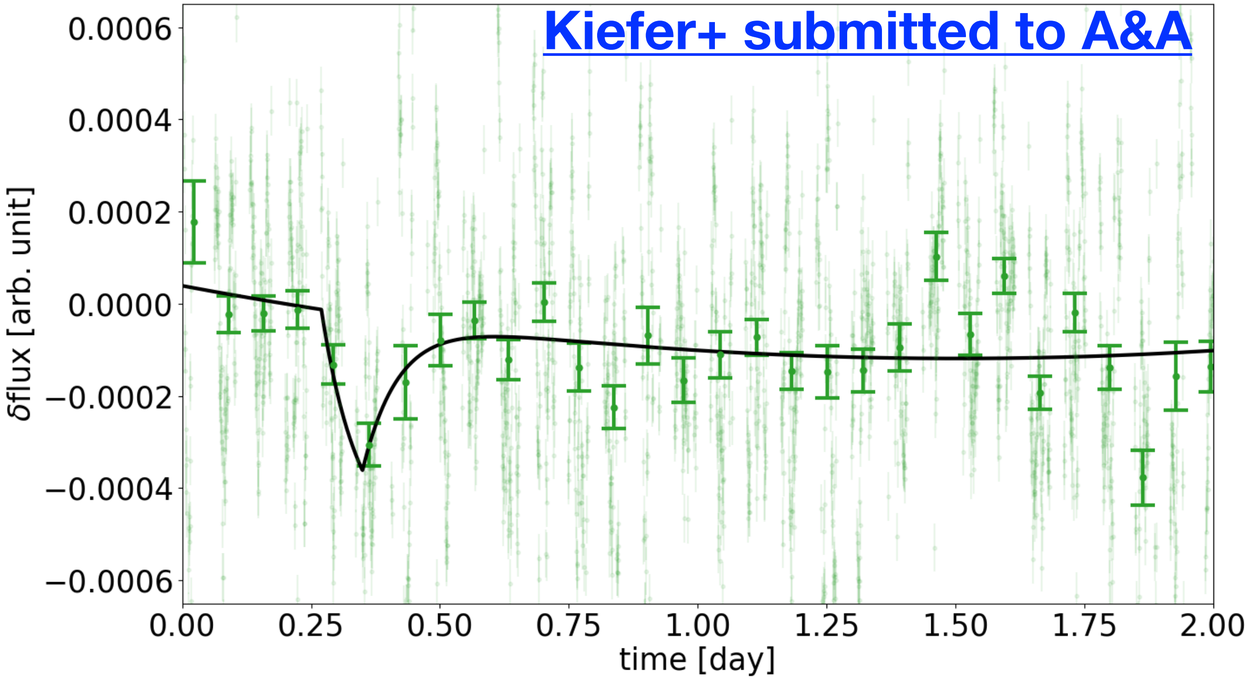
$Z_{dust,\ 1au}$ = 0.92 ± 0.41 . 10^5 kg/s

Other HD172555 exocomets (spectro, Kiefer+ 2014)

- $Z_{dust,1au}$ ~ 4.10^5 kg/s
- q_{peri} ~ 0.01-0.1 au

Same population





Scaling relations w/ Hale-Bopp

(R_{nucl}=30 km; $Z_{dust,1au}$=2.10^6 kg/s; $L_\odot$~0.1 L_{HD172})

R_{nucl} = 2.4 ± 0.5 km

Comparable to R_{nucl} of extrasolar & solar comets:

- β Pic exocomets: 1.5 to 6.7 km;
- Jupiter Family comets: 2-6 km;
- Oort cloud comets: 1-20 km.

Conclusion

- Detection of a photometric exocomet transit in another young system with a **known disk, HD172555**;
- Also the first with CHEOPS...
- Exocomets observed in spectroscopy in this system;
- Spectroscopic and photometric exocomets belong to the same class of objects (size, production rate, periastron, etc);
    - ➡ They could be observed simultaneously in spectroscopy and photometry;
    - ➡ **This has never been done;**
    - ➡ Could allow unprecedented characterisation of chemical species in the coma and the surface of an extrasolar comet!