Transiting Exocomets and What They Tell Us About Their Host Systems

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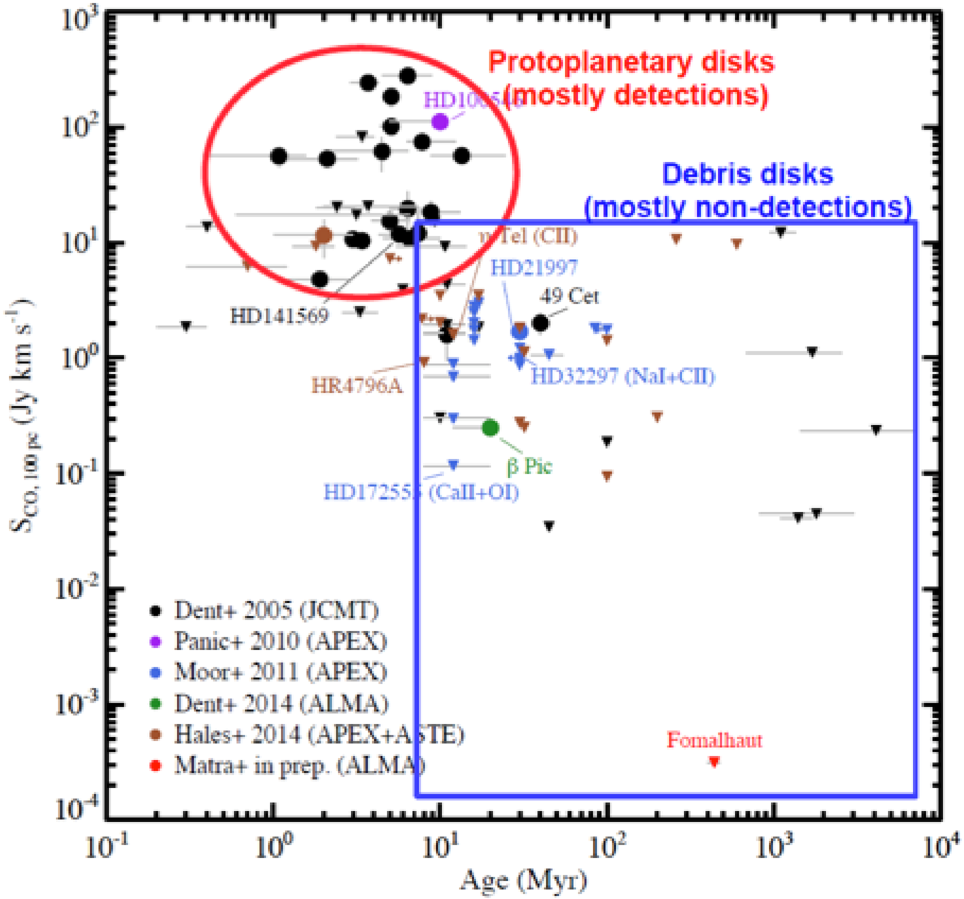
Talk Roadmap

- The Case of β Pictoris
- Questions which can't be answered from β Pic alone
- 49 Cet and HD 172555
- Using transiting exocomets as an indicator of Jovian-mass bodies

Gas in Circumstellar Disks

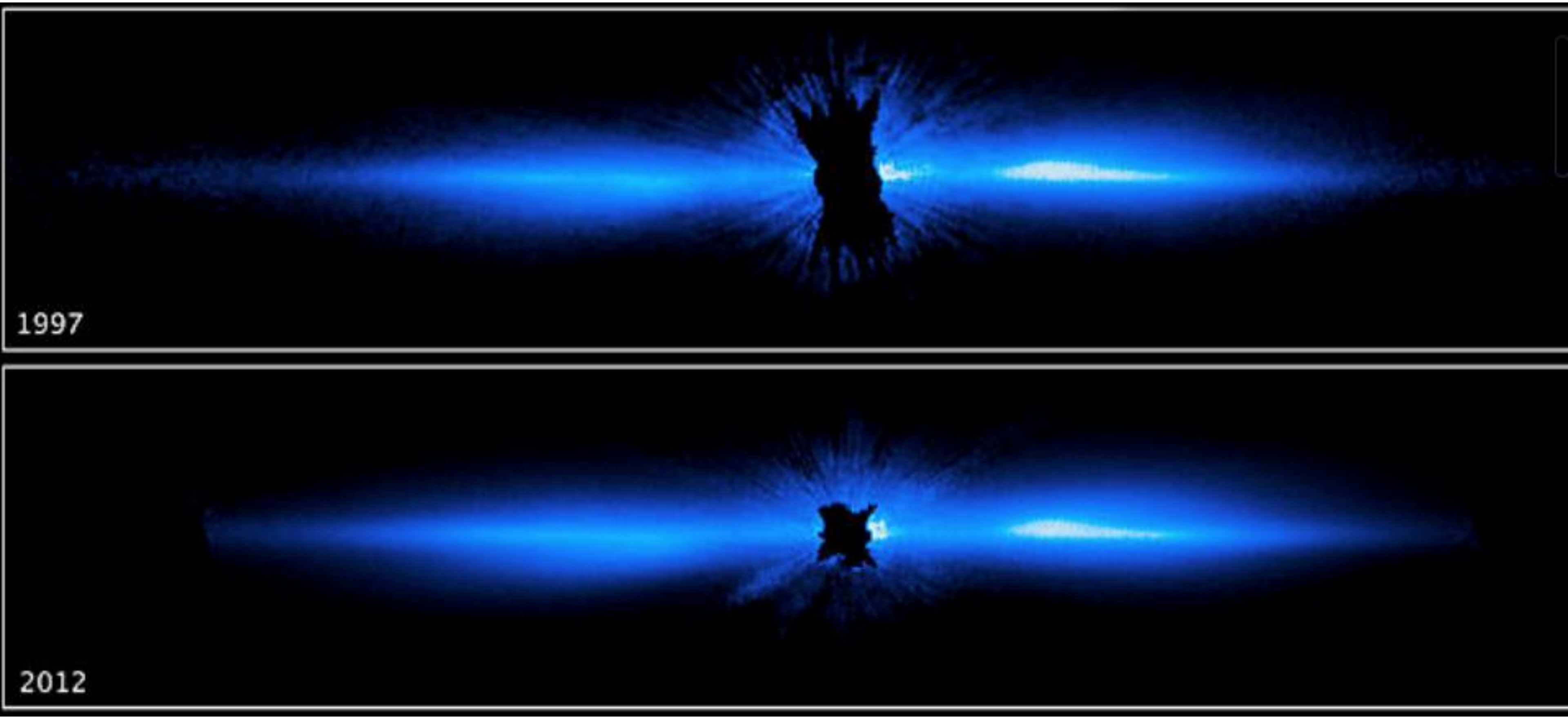


Holland – talk at IPAC 2015

β Pic

- A5V star (T_{eff}=8100±200 K)
- Young moving group member (23±3 Myr, Bell & Mamajek 2015)
- 2 component disk – outer disk at ~120 AU, viewed edge-on, inner disk to ~40 AU tilted by 5° with respect to the outer disk (Golimowski et al. 2006)
- Gas: molecular, atomic and a range of ionization stages of abundant elements

The Case of β Pic

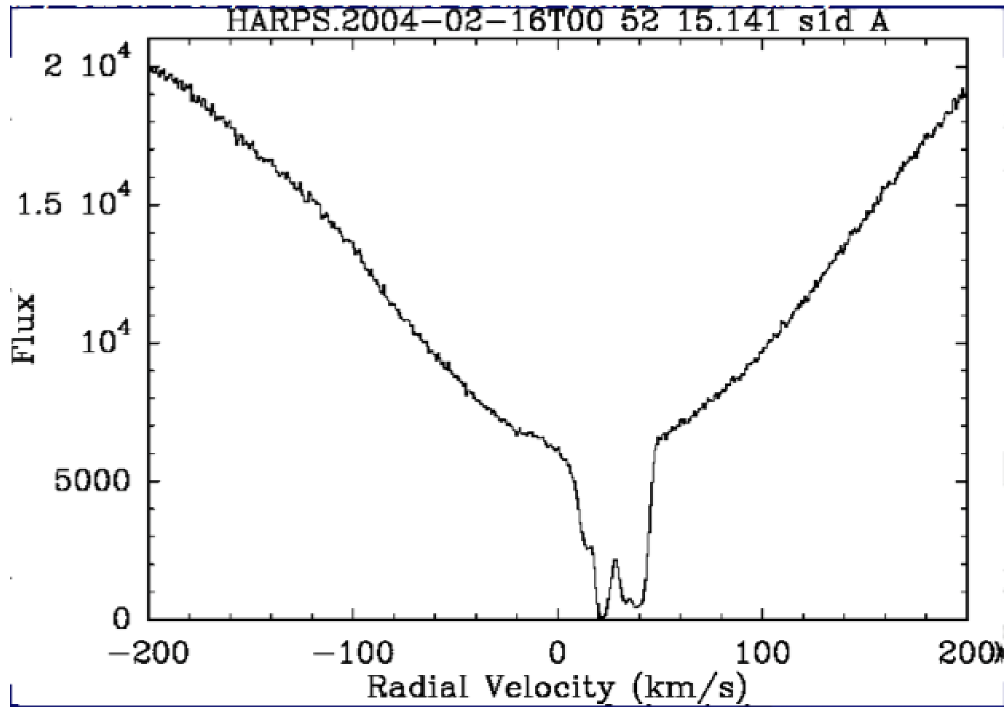


- IR excess detected by IRAS
- edge-on debris disk first imaged by Smith & Terrile 1984
- no variability over 15 years Apai + 15
- inner disk inclination with respect to outer disk is 5˚   (Golimowski et al. 2006)

Gas in the β Pic System

• star identified as A-shell star due to features superposed on rotationally broadened photospheric spectrum - Slettebak 1975 in Ca II and Na I

• same transitions used to probe ISM, so natural to go to UV where high oscillator-strength transitions of first few ionization stages of cosmically abundant elements are located



Beust 14

What we learn from Line of Sight UV Spectroscopy

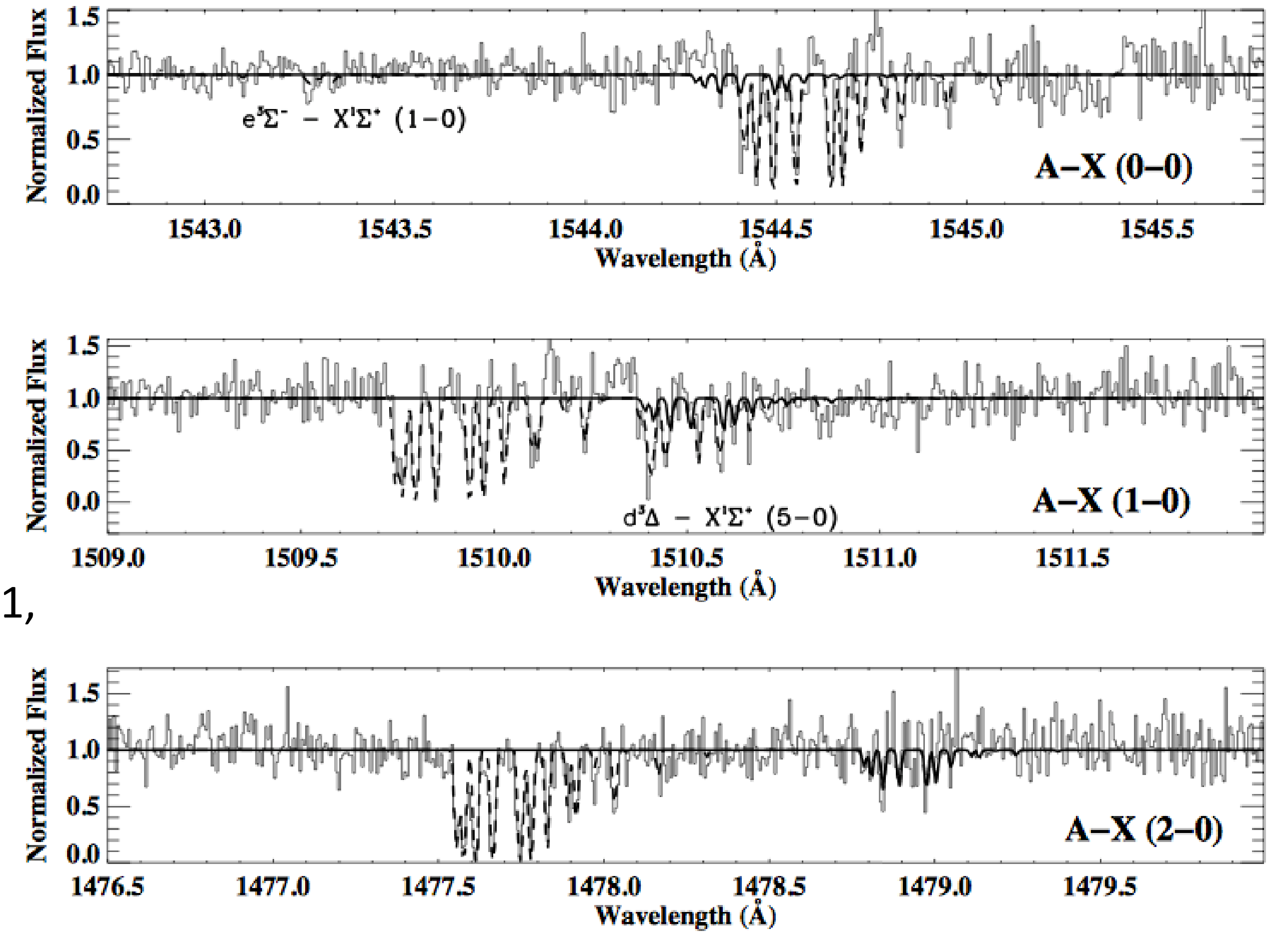
- CO absorption at system velocity Roberge + 2000

- CO restricted to 50 au<r<160 au (Dent 2014)

- $N(H_2) \le 1E18$ cm^{-2} Lecavelier des Etangs +01, $CO/H_2 > 6E-4$

- low optical depth + radiation field of star – lifetime is <200 years

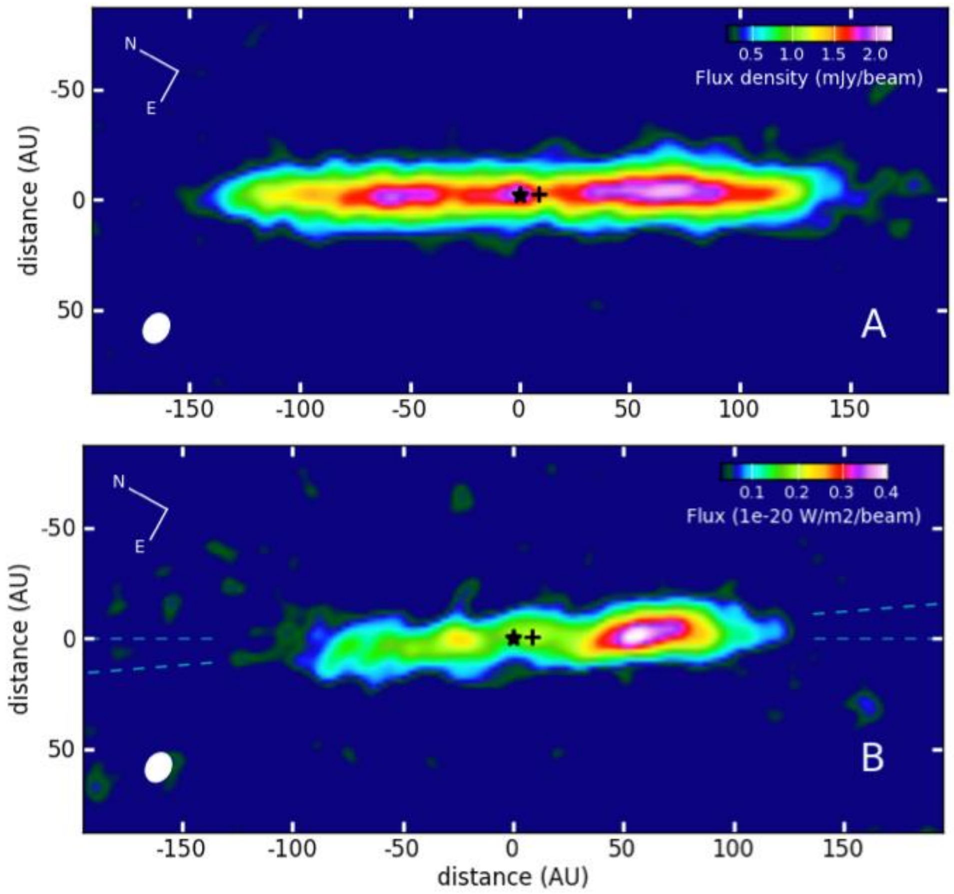
- gas not primordial, sequestered in planetesimals



Roberge + 2000

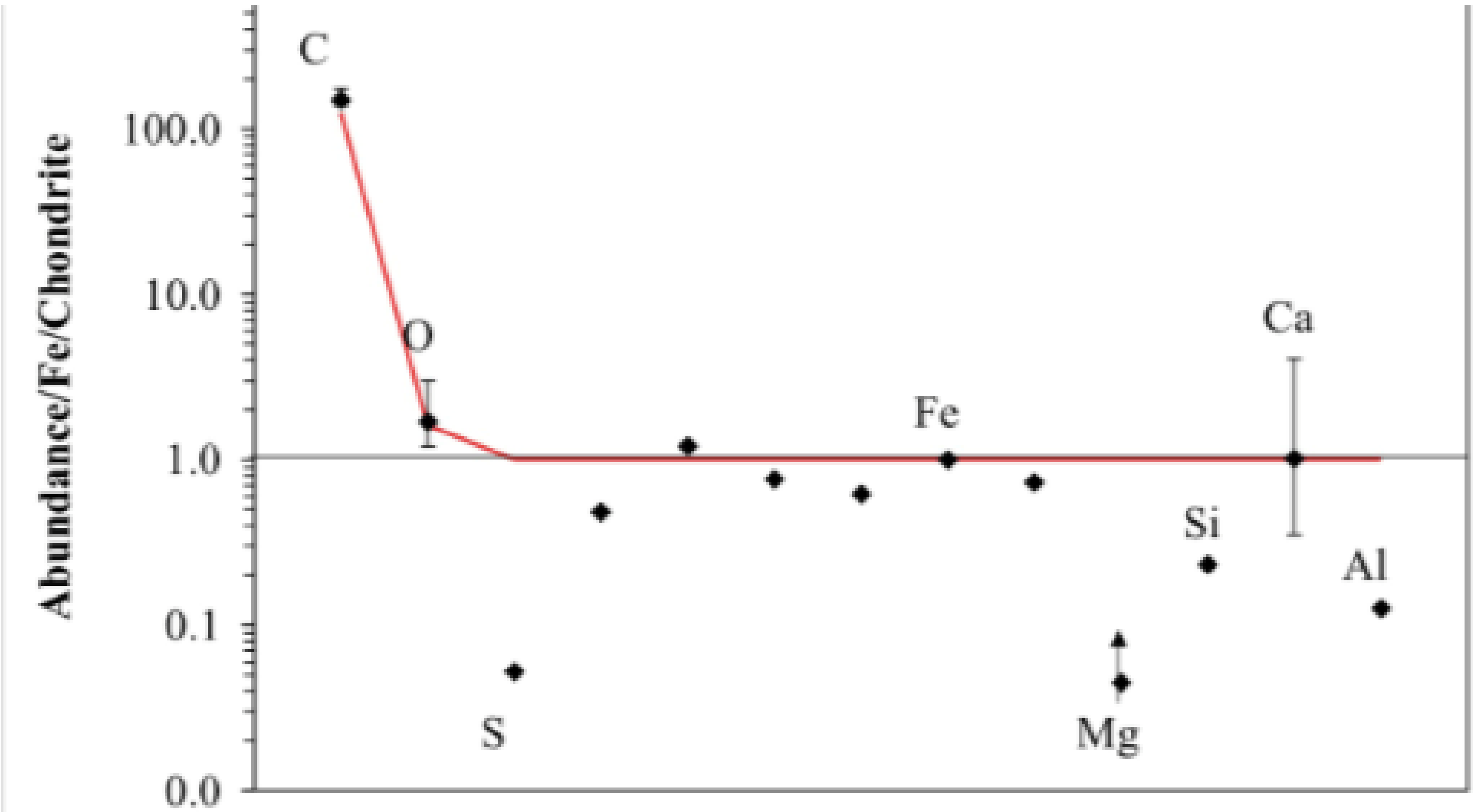
Edge-on Disk

- Constrain location of planetesimal belt from mm imagery.
- Mm dust avoids region around beta Pic b (Dent 2014, and see talk from Thirty years of beta Pic conference)
- CO asymmetrically distributed
- Pericenter offset seen with ALMA



Dent+15

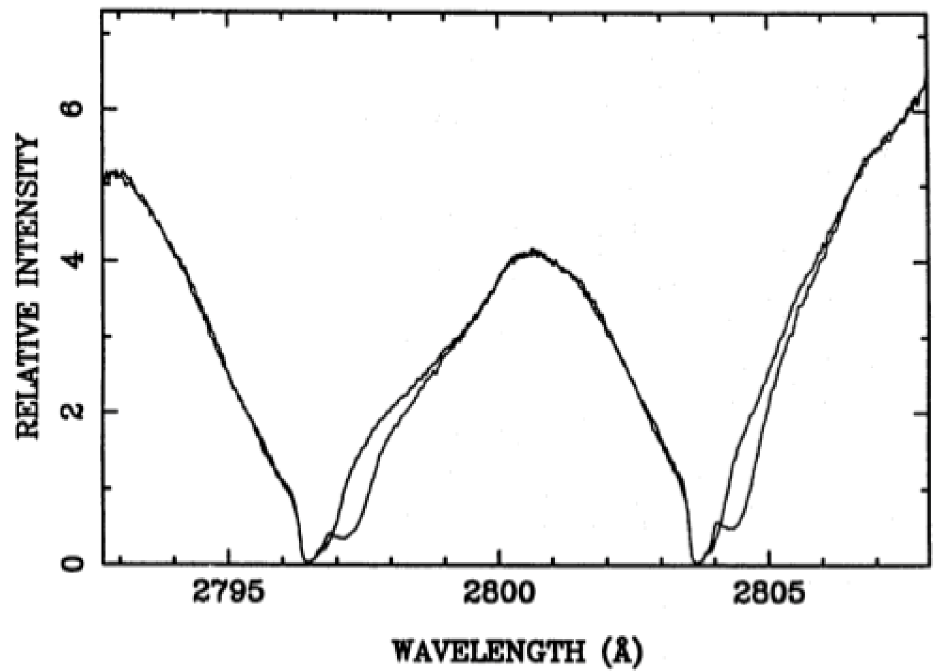
Stable Atomic and Ionic Gas

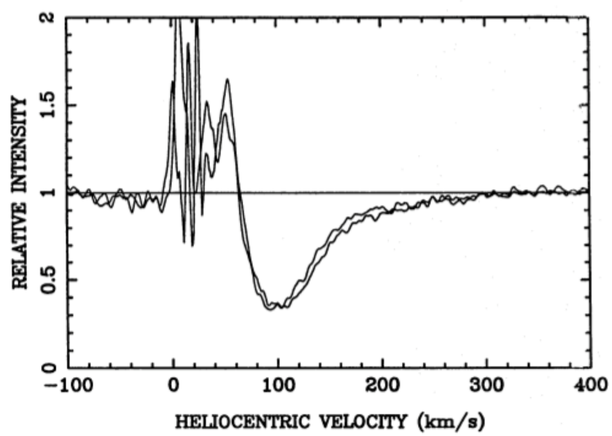


Roberge+06

High Velocity Gas

- typically redshifted, although blue-shifted events are known - Crawford + 98
- Higher the velocity, the faster the variablity
- absorption optically thick, but does not fully cover the stellar disk Lagrange 1988
- 30 years of data





Vidal-Madjar 1994

Interpretation: Falling Evaporating Bodies

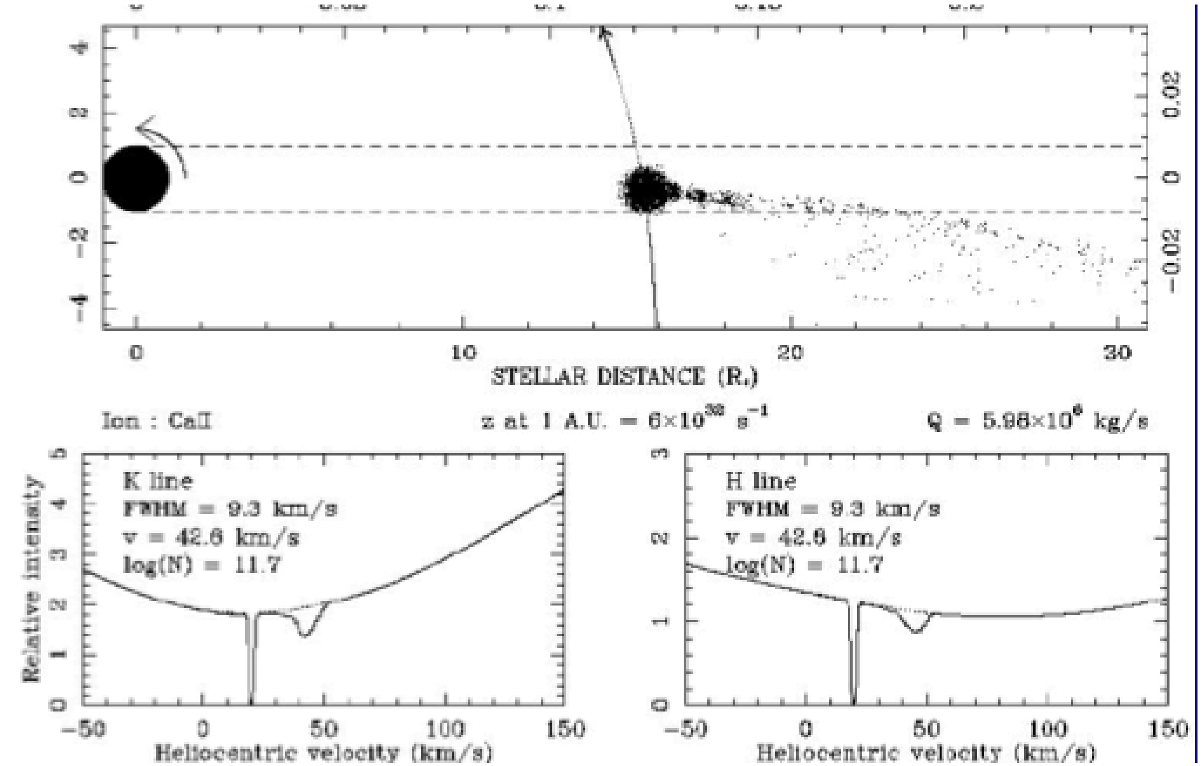
- Work of Beust and collaborators (1990, 1995, 1998) , see talk from Thirty Years of β Pic conference (2014)
- Each event generated by a transiting evaporating body
- Transit durations indicate r<0.5 AU – dust sublimates

Simulations

• assume we are tracking metallic ions in coma of evaporating body – subject to radiation pressure and drift forces by other species

• velocity distribution fit if assume that periastron varies

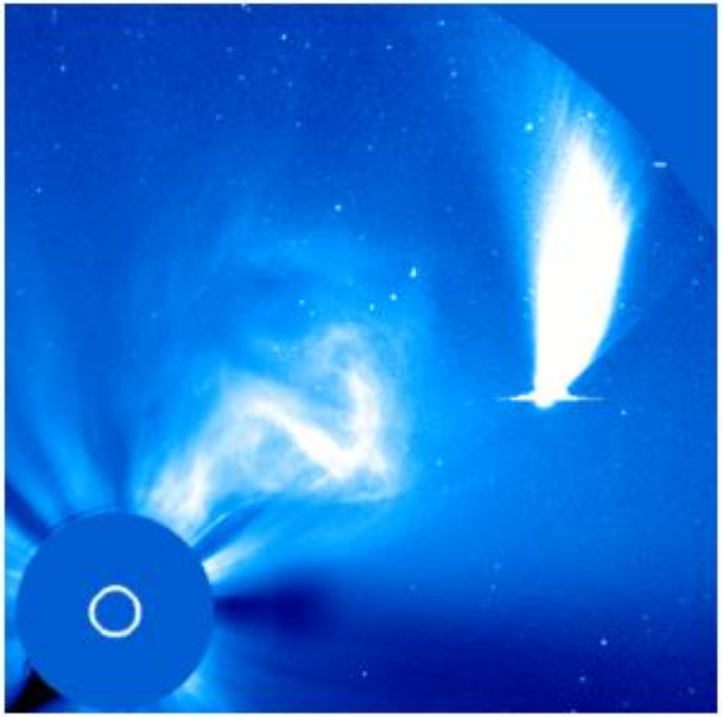
• longitude of periastron not random
• need high eccentricities
• long duration events => fragmentation



• mechanisms: Kozai or
Mean Motion Resonances – favored
* implies Jovian mass planet, eccentricity ~0.05 required

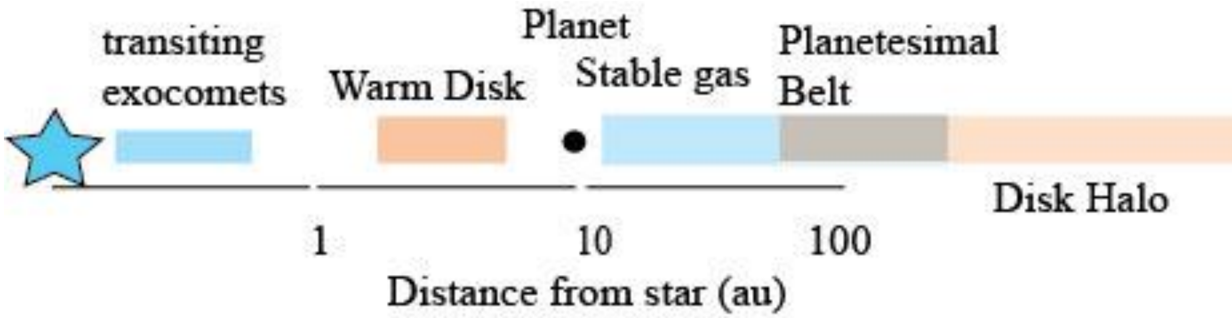
Solar System Analogs

- SOHO comets
- Jupiter-family comets
- Parent populations from asteroid belt with resonant structure (Kirkwood gaps in our Asteroid belt)



Comet C/2002 V1 (NEAT) in LASCO C3

A Cartoon View of the β Pic System



To Observer =>

- Long-term synoptic spectroscopy has revealed
  - bodies and stable gas are carbon-rich
  - no current Solar System analog
- Seeing signatures of resonant structure in parent body disk
- if common, may be a source of near-stellar dust which can complicate searches for terrestrial planets with WFIRST or TMT, but also is an indirect probe of planetary systems

Link to β Pic b?

- Existence of a planet predicted >10 years before imaging detection
- plausible, but need refined orbit for the planet
- β Pic b directly imaged, one other imaged in same moving group (51 Eri b)
- Other A to early F star members of βPic Moving Group more distant – require smaller IWA imaging observations for planet detection

Questions which can't be answered from β Pic alone – search for other edge-on systems

- β Pic well dated – latest 23$\pm$3 Myr
- Single system doesn't tell you how long the phenomenon continues, and whether the chemistry inferred for the gas is typical or anomalous

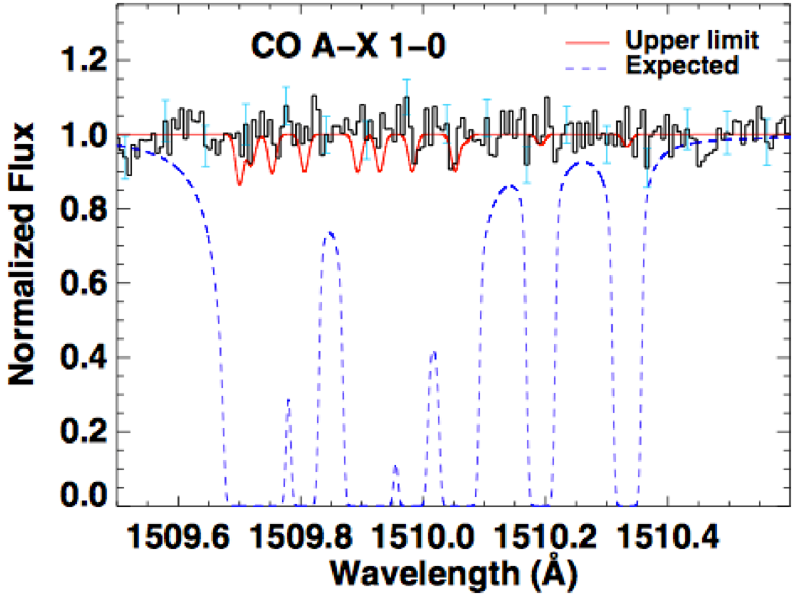
Searching for High Inclination Systems

- Need other edge-on systems
- High-contrast imaging in NIR and thermal imaging in mid-IR or sub-mm
- Or search for variable gas features in Ca II (approach taken by Welsh & Montgomery 2013; Montgomery & Welsh 2012) or in archival UV data –
  - detections, but often for systems with unknown or uncertain ages (e.g. Eiroa et al. 2016) – harder to interpret
  - Limited to stars earlier than ~F2-3 for UV follow-up (flux availability, low stellar activity, rapid stellar rotation), and d≤100 pc to have minimal confusion with ISM at low velocity

Adventures with 49 Cet

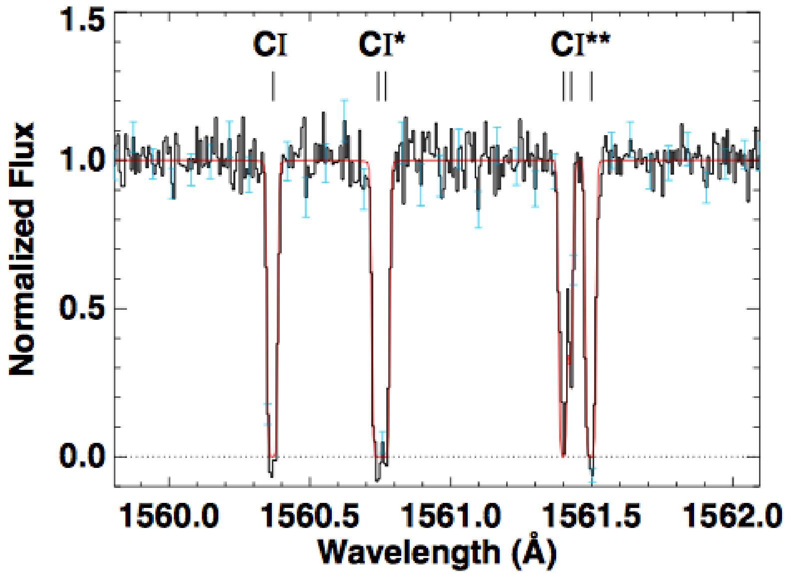
- High L_{IR}/L_* disk, resolved with Herschel, SMA, ALMA, and at N
- Argus association membership – 40 Myr Zuckerman & Song 2012
- Size of disk (*Herschel*, Roberge +13), and young age indicate planetesimal ring is likely to be stirred by a planet (Moór +15)
- System has gas, seen at far-IR and mm-wavelengths
- High inclination indicated from mid-IR (Wahhaj + 07), SMA and thermal imagery (Hughes +08), and coronagraphic imaging (Choquet et al. 2017)

Gas toward 49 Cet



No CO in line of sight Roberge+14

Neutral atomic carbon – atypical of diffuse ISM –Roberge+14

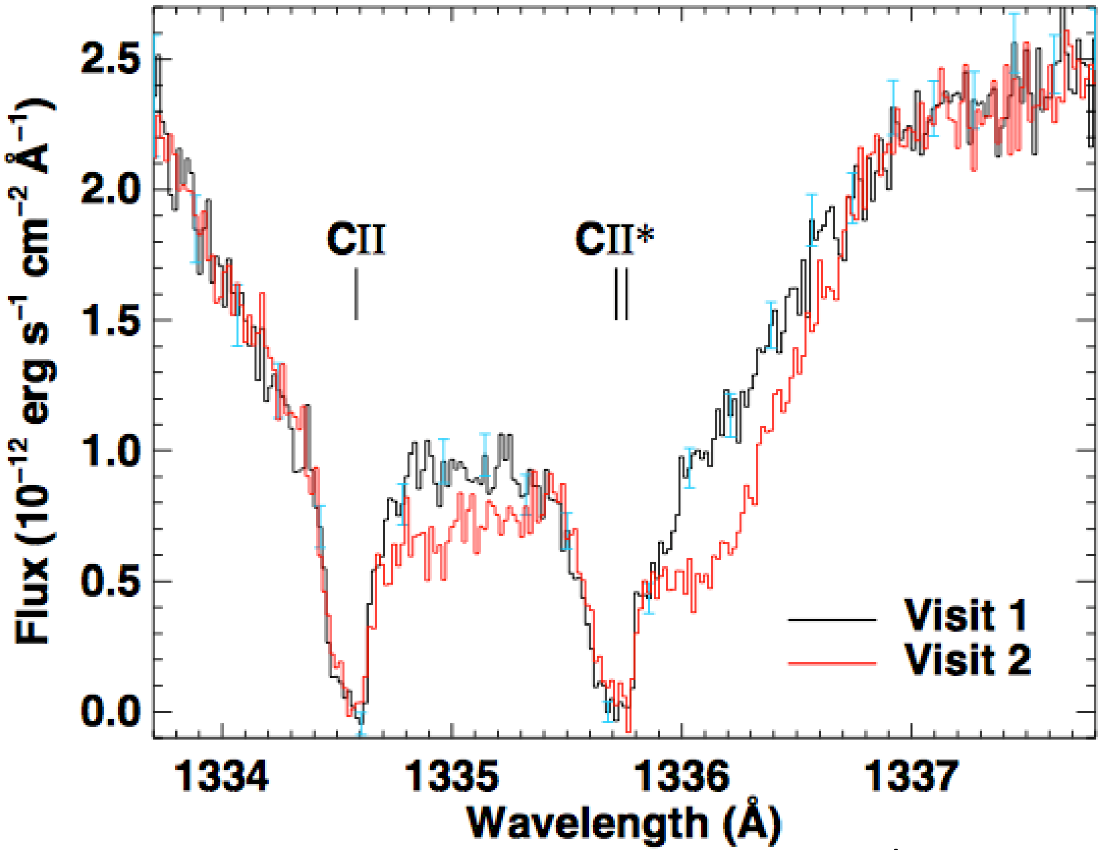


Transiting Exocomets

- Non-detection of infall events in other species

- C/O is 3x solar

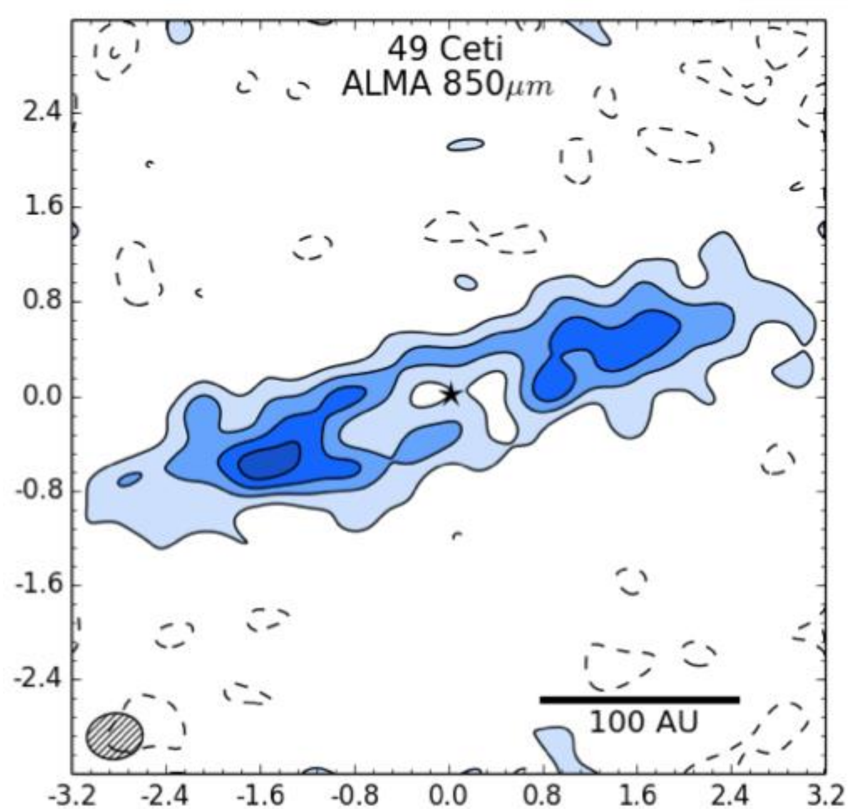
- in addition to the infall event seen
In C II, C IV also shows a blue-shifted event



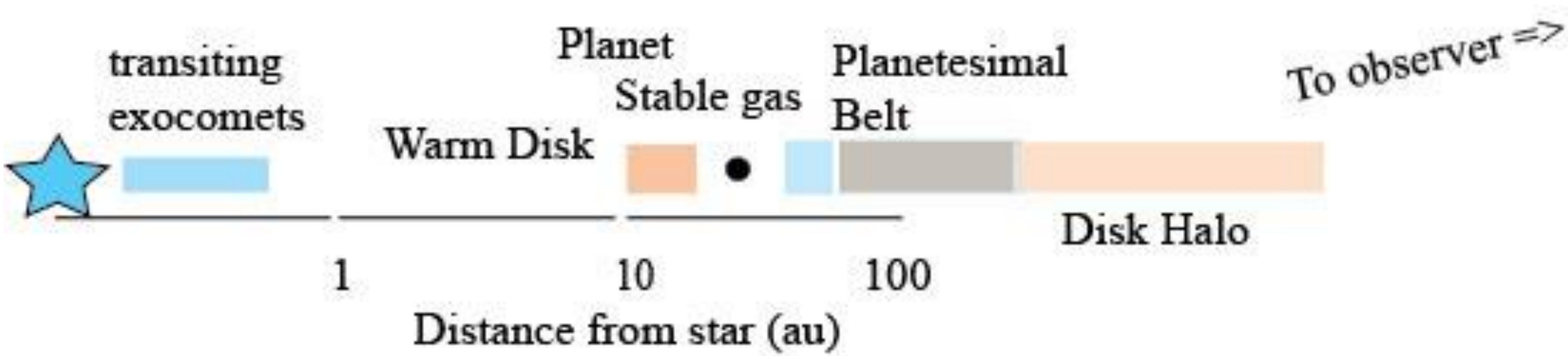
Miles + 15

System Inclination

- Absence of LOS CO absorption is puzzling if i=90° , Solution: higher angular resolution – ALMA or HST
- New inclination is i=73° (Choquet et al. 2017) not restricted to exactly edge-on systems, but LOS spectroscopy may not sample all disk components



49 Cet in Cartoon

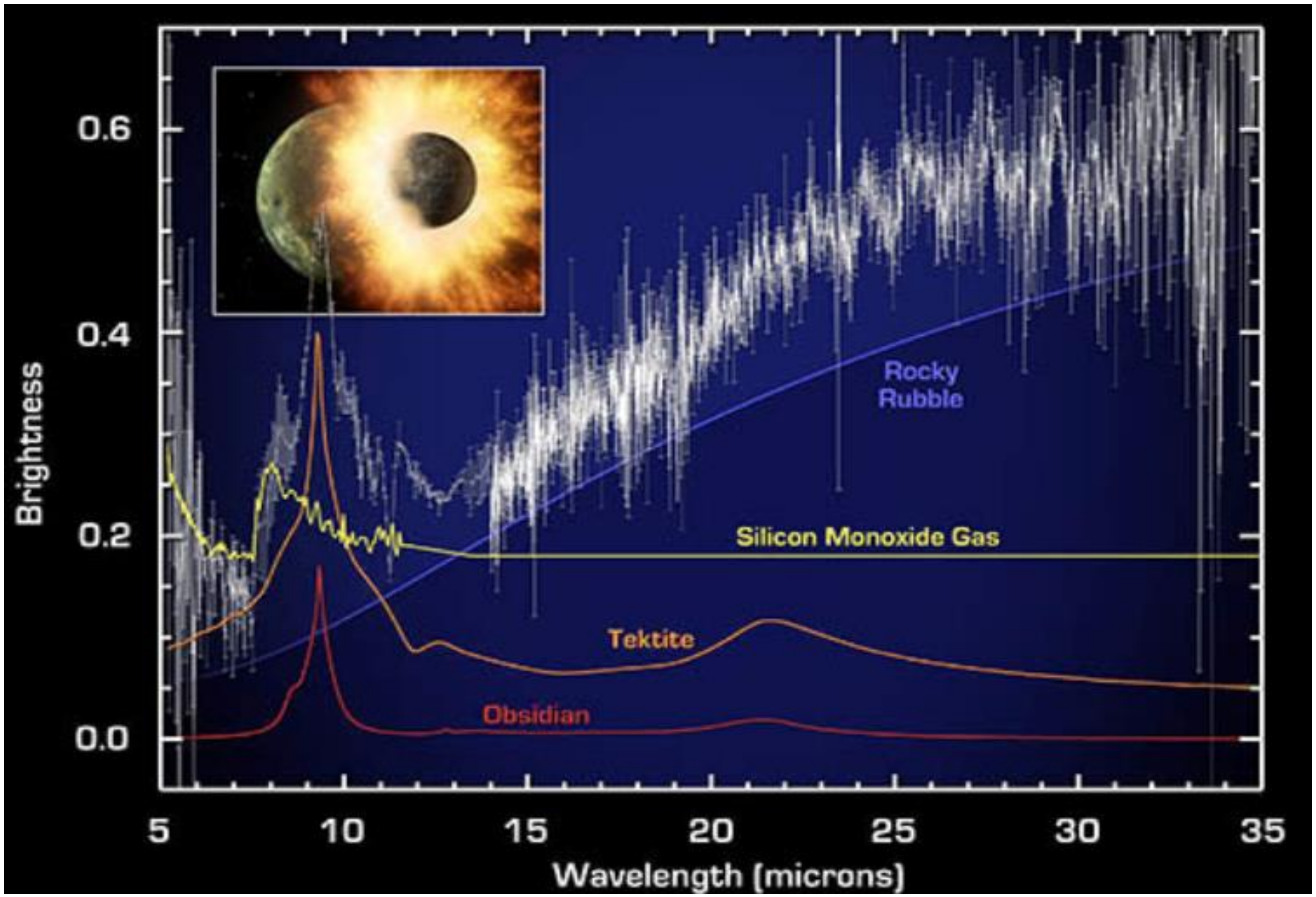


In this system our line of sight is 17° out of the mid-plane, and we miss material In the planetesimal belt or halo in line of sight observation. 2 belt structure (Roberge+12; assuming bb grains, 175K component is at 11 AU; 62K at 84 AU

HD 172555

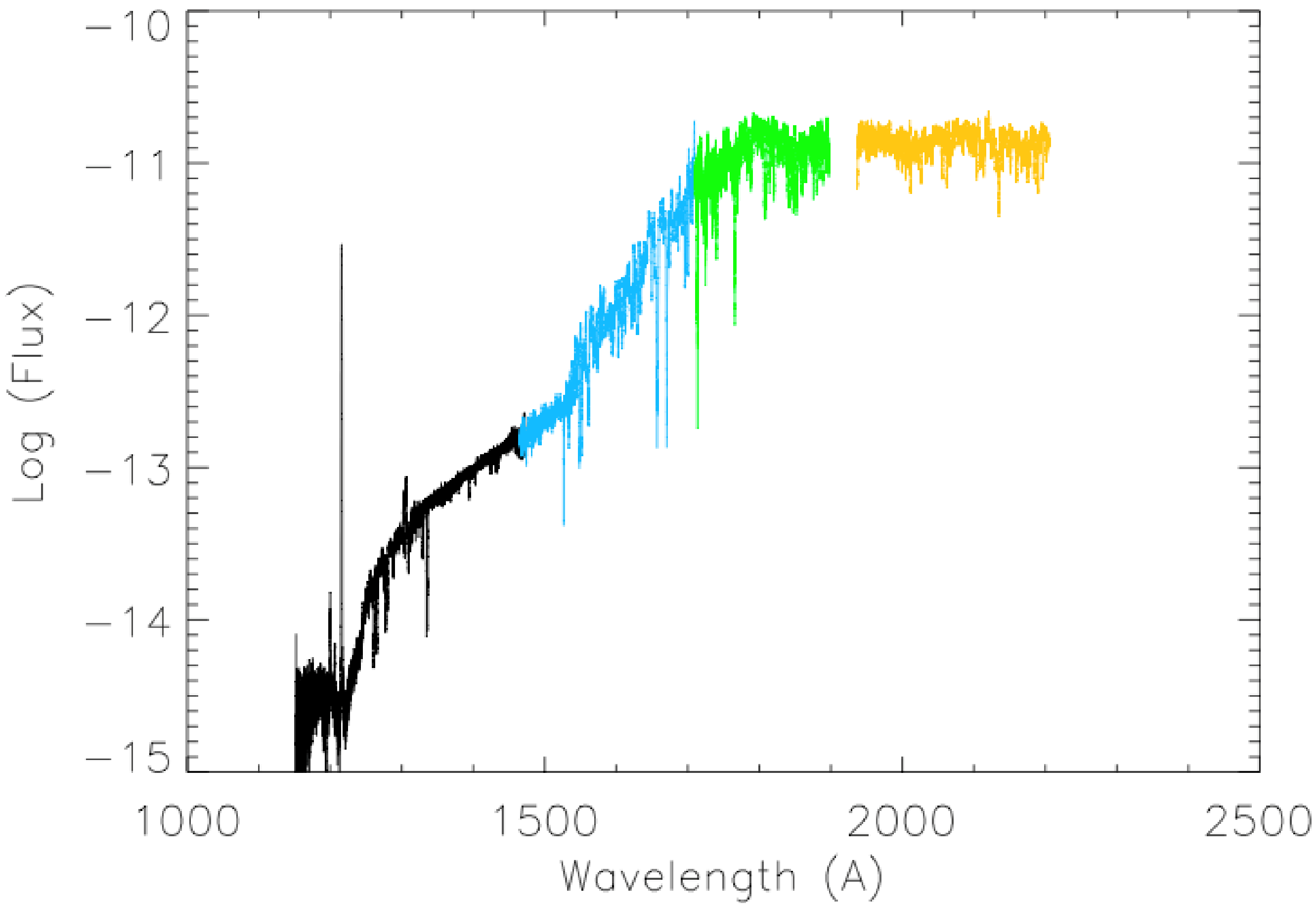
- Star is co-moving with CD -64° 1208 (Feigelson +06)
- member BPMG, A6V, T_{eff}=7800±200 K d=29.2 pc (Riviere-Marichalar + 2012)
- [O I] detection with Herschel Riviere-Marichalar+12 - unusual, most gas detections are [C II]
- Small disk imaged (Smith +12) to ~24 au, inferred inclination i>48°

History of hypervelocity impact?

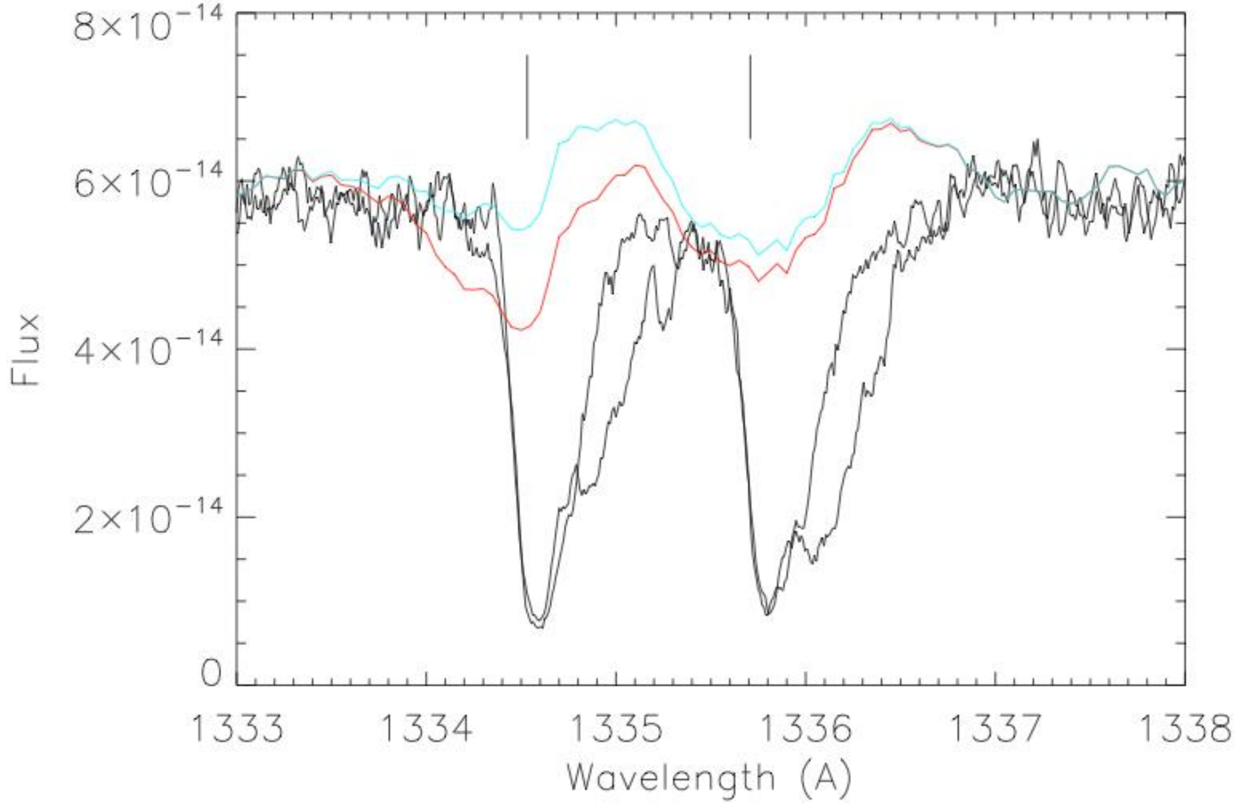


Lisse + 09

UVSED

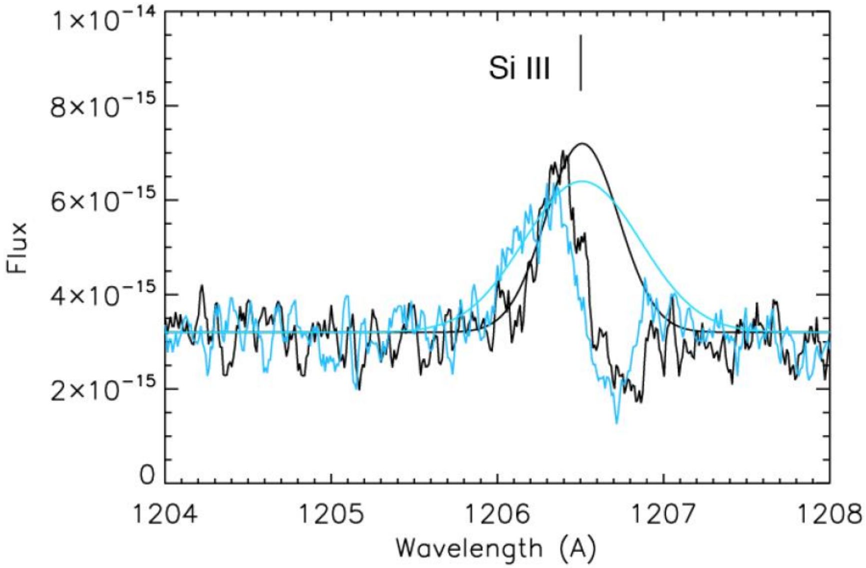


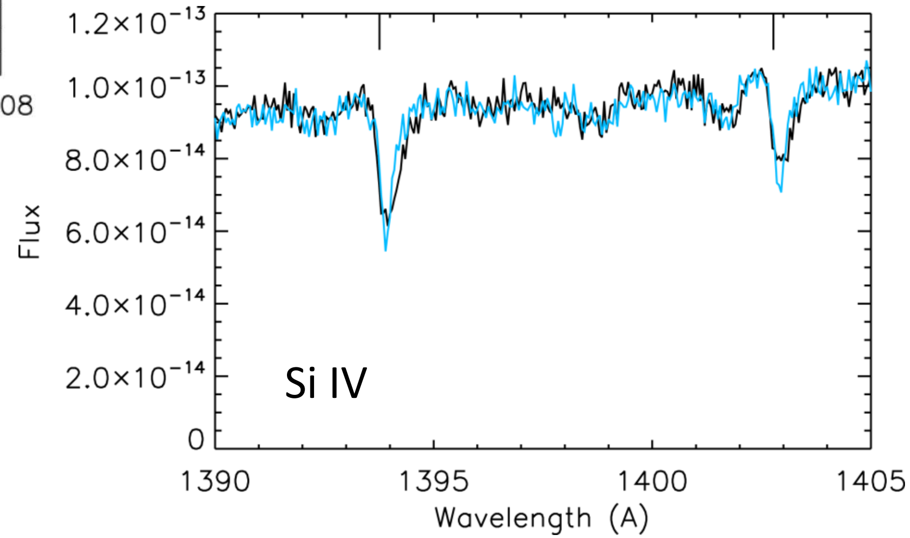
Transiting Exocomets



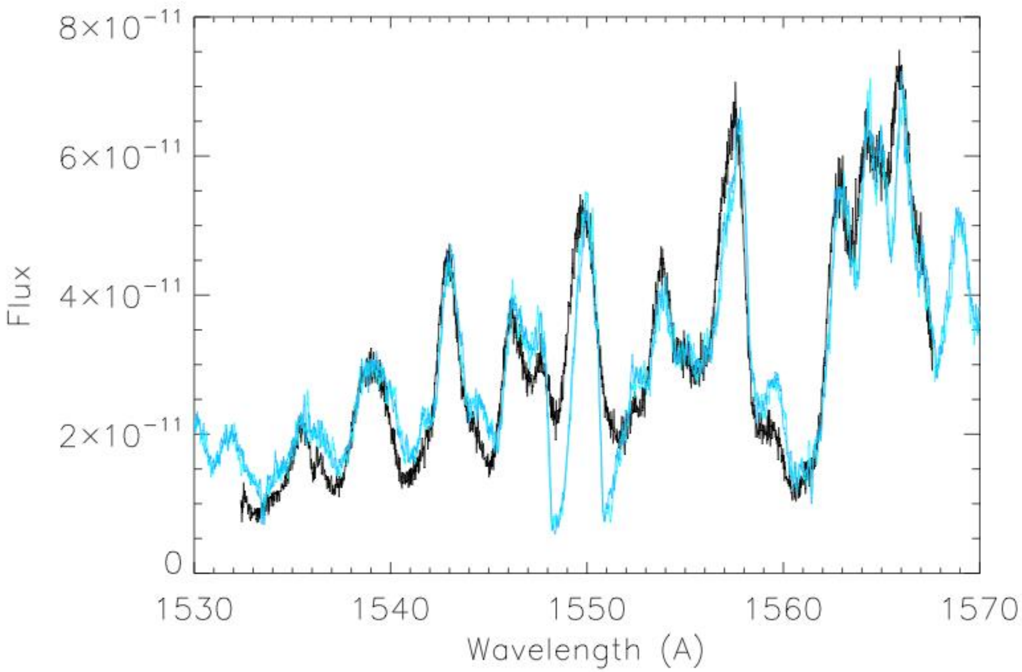
C II COS ~6 days separation max. velocity +160 ±10 km/s
Excess signal compared to α Cep on blue wing 1334.5 line
Indicates chromospheric emission

Si III and Si IV





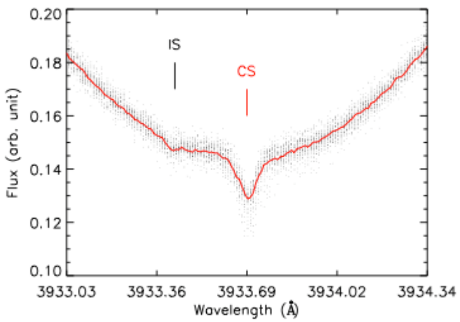
C IV

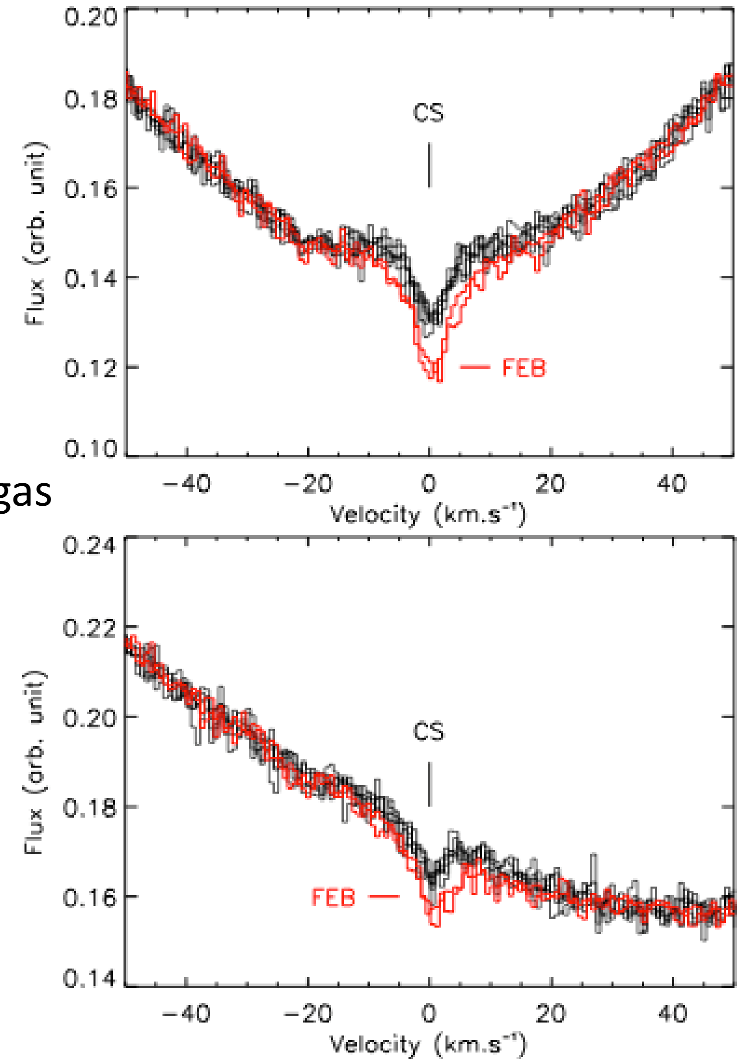


C II not the only
Carbon ion seen.

Comparison with
Altair – not perfect
But good enough to
Show excess absorption
In C IV to v>300 km/s

HD 172555 - Ca II



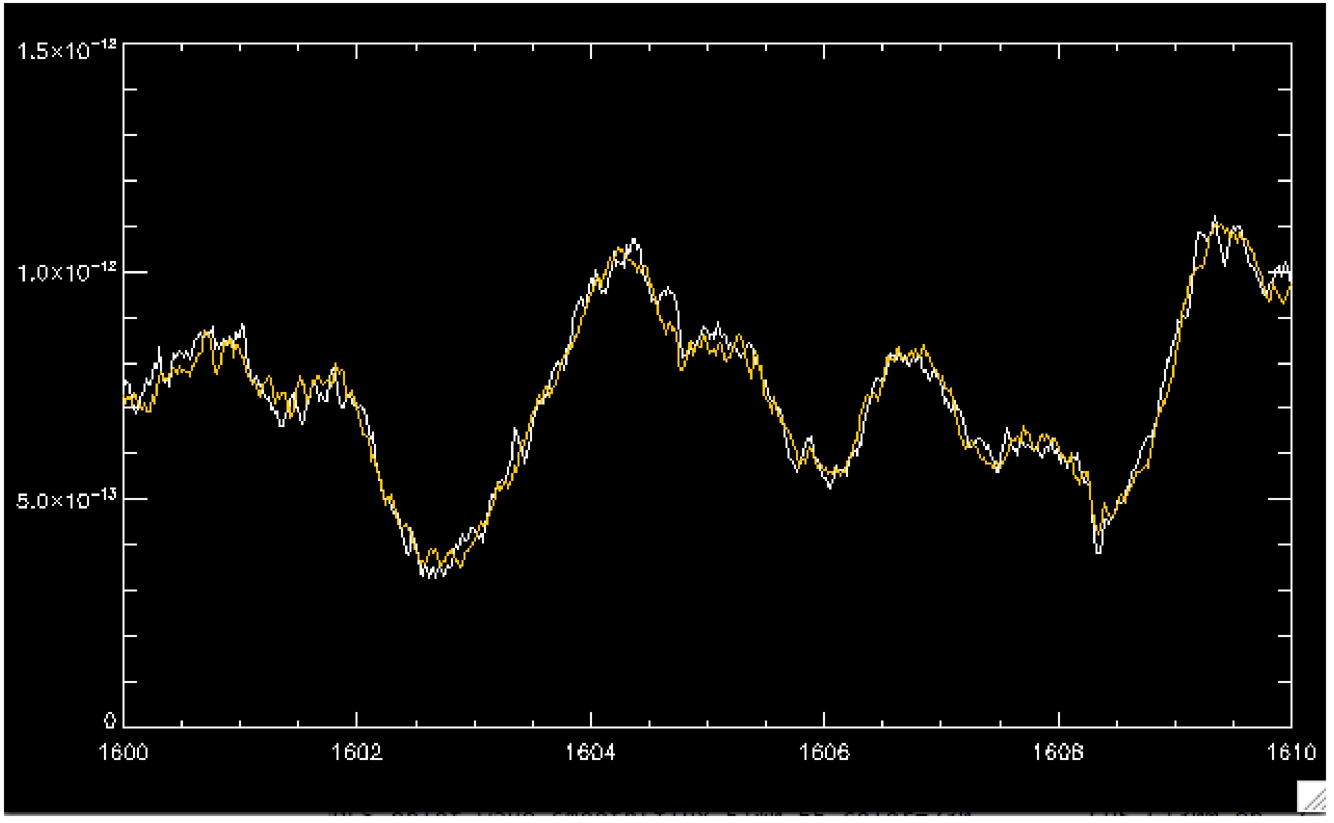


- CS absorption well separated from IS feature
- Variable low velocity gas seen in Ca II; no stable gas component as seen in β Pic or 49 Cet
- 4 episodes seen in HARPS data - Kiefer +14

- Al II 1670 falls in order gap in STIS E140M data.
- did not detect FEB in contemporary Ca II data or in Al III in our STIS E230H data

UV Low Velocity Gas

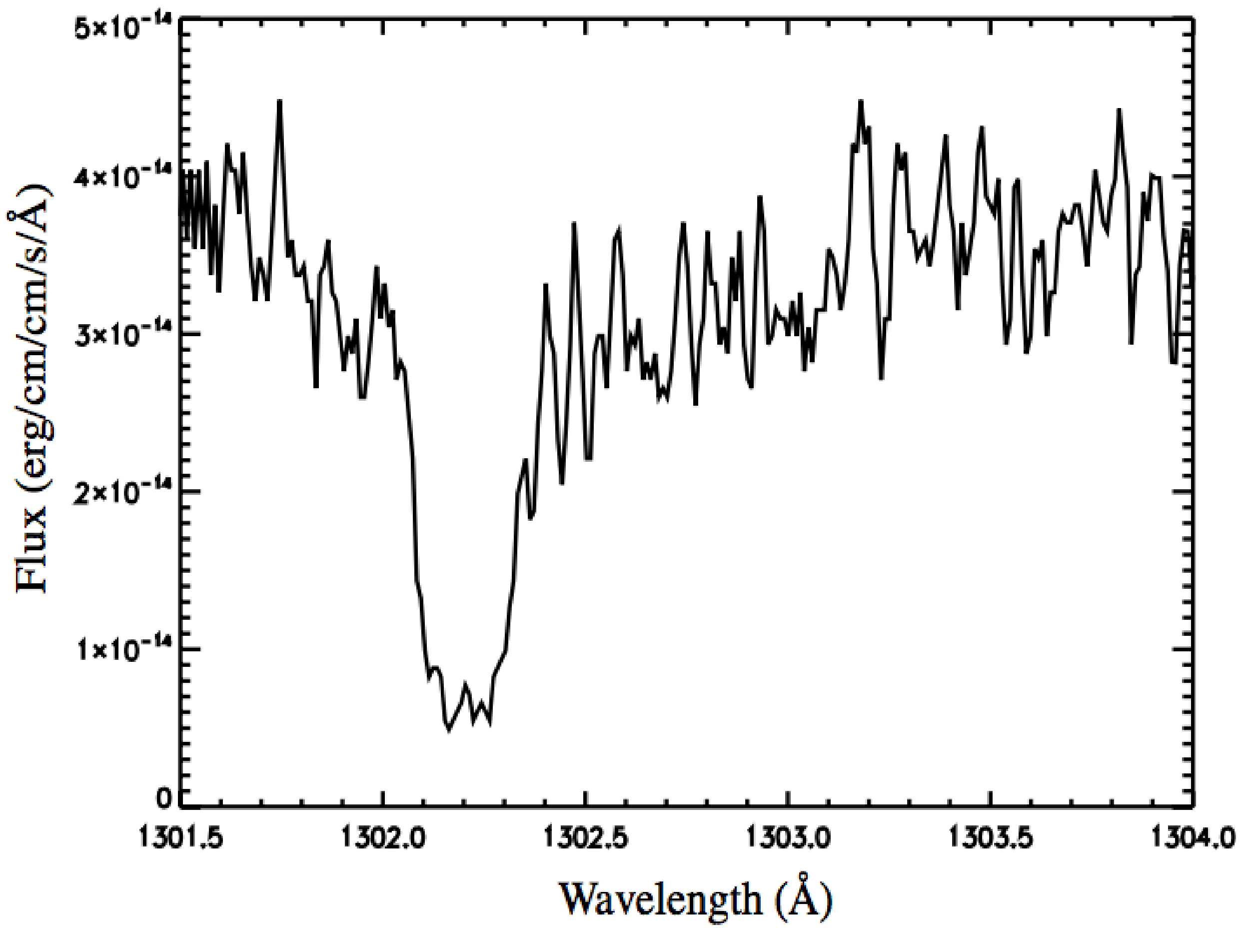
- IS absorption in Si II, Fe II 1608, no significant absorption in CI, Al III



OI – an indicator of water?

- Recent work on β Pic has demonstrated the presence of O I and H I absorption (Wilson et al. 2016) in high velocity gas – likely end product of water dissociation
- So, we searched our data for similar signatures – complicated by our COS spectra not being taken at opposition, and on the dayside of the orbit - airglow

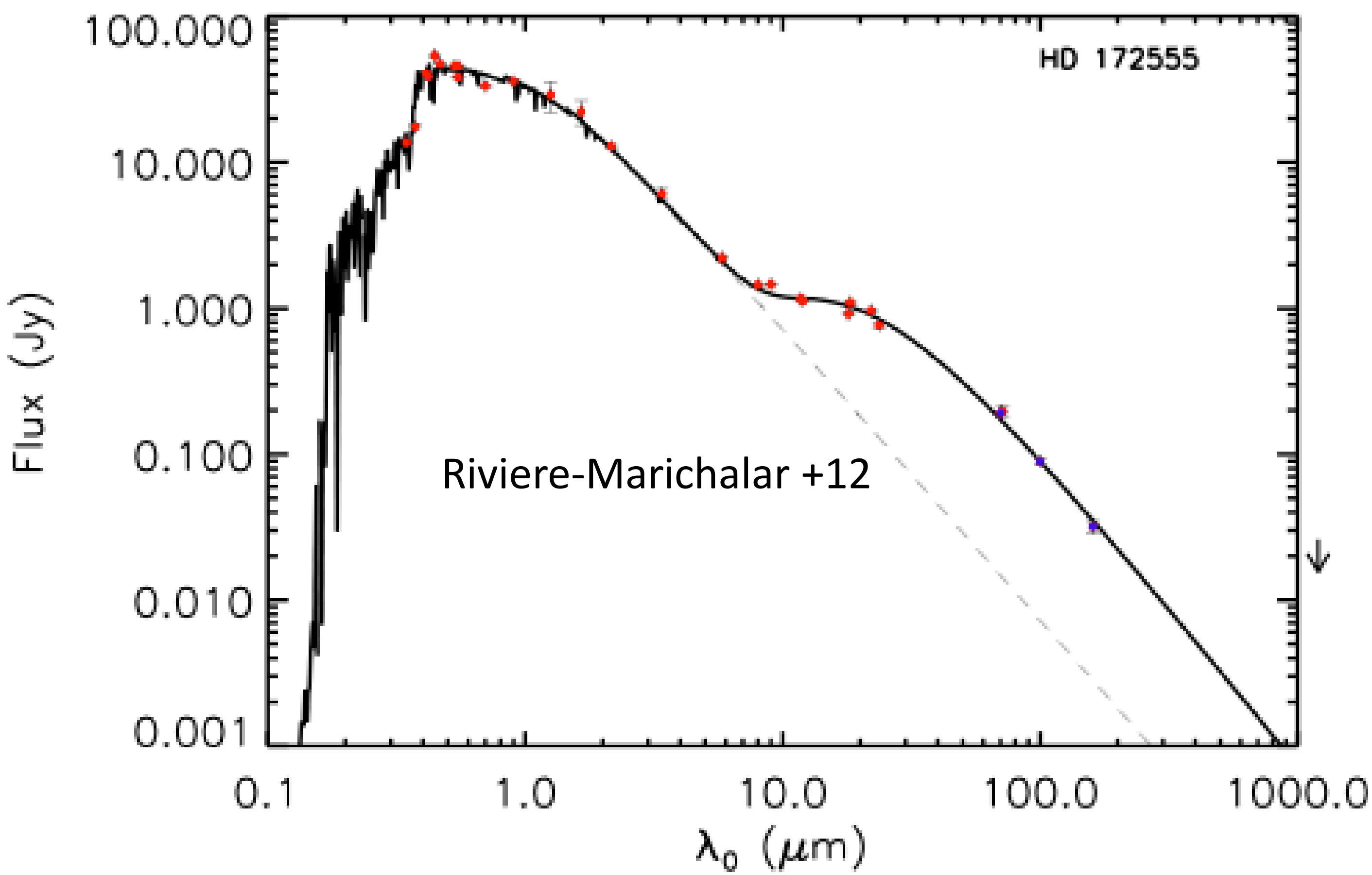
OI detection for HD 172555



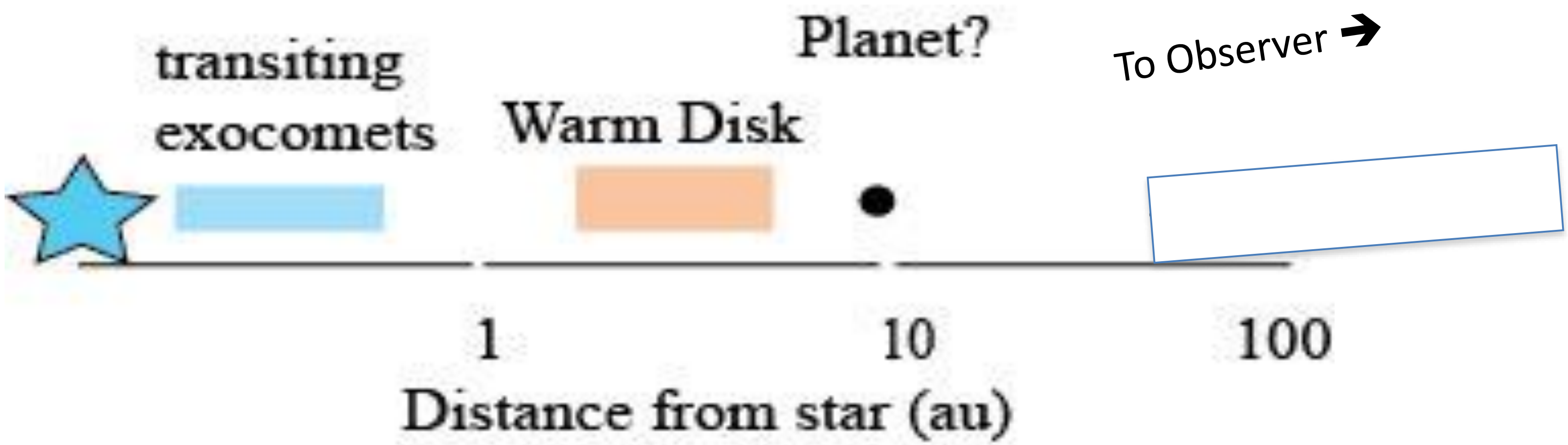
Current Limits to Analysis

- Spectral comparison objects sparse and with incomplete wavelength coverage need to match T_{eff} and level of stellar activity
- S/N of the available HD 172555 data – 5 order of magnitude drop in signal at $\lambda \leq 2000$ Å makes orbit investment to achieve usable S/N challenging

SED consistent with single, warm belt (280 K) at r≥4 au, more likely r>8 au



HD 172555 the Cartoon



- Kuiper belt evidently not required, but then miss stable gas component and molecular gas
- warm debris disk may be required to detect star-grazing bodies

What Have We Learned?

- Transiting exocomets unexpectedly common in βPMG and potentially other young systems
- Can be seen at 40 Myr and potentially to epoch of LHB - span epoch of Earth and Moon formation and early terrestrial history
- If have a common origin in high-eccentricity bodies perturbed into star-grazing orbits by Jovian-mass planets, may have a novel technique for finding exoplanets.
- If have sufficient spectral data, can obtain independent estimates of perturber location

Jovian-mass planet frequency in BPMG A stars:

- 5 stars, 2 low v sin i (not suitable for this technique)
- 2 systems with transiting exocomets known,
- Planet frequency for A- early F stars – 25% from direct imaging, up to 37% from infall activity
- Implication is that Jovian-mass bodies are common, and for the BPMG most probable location(s) are r~10-20 AU – gap in exoplanet searches, with limited coverage by JWST, but one which can be filled using EELT or TMT

Adding to the Planet Sample

- Need larger searches at Ca II, coupled with efforts to date the stars where transiting exocomet features are seen
- UV data critical in probing high velocity infall, and measuring abundances. Have access to this wavelength range with HST, but this ends between 2020 and 2024
- Future mission proposals (e.g. LUVOIR) can fill this gap but likely only in 2030s and beyond.
- Smaller IWA exoplanet searches (≤0.1”) at L’ needed. N and Q band imaging also needed (JWST for outer planet searches), EELT, Giant Magellan, and TMT

Summary

- Transiting exocomets may offer a novel indirect detection technique for giant planets; available data suggest that they are common, and occur in systems without surviving Kuiper belt analogs
- Probe of composition of minor bodies if have access to UV spectroscopy
- Larger numbers of stars needed to do disk tomography
- Complements mid-IR high-contrast imaging studies and far-IR to mm-wavelength searches for gas farther out in system