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THE PROPERTIES OF THE GAS AROUND BETA PICTORIS

Gas evolution in disks

10 – 100 $M_{Jupiter}$ **few M_{Lunar} (dust)**

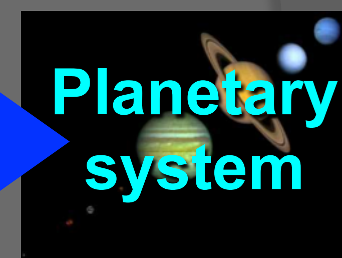
Total Mass

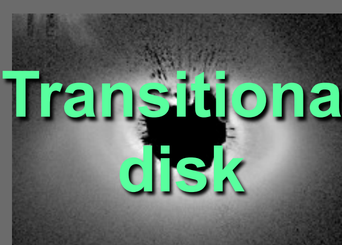
10 – 100 $M_{Jupiter}$ **?**

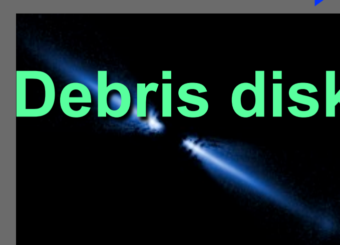
Gas Mass

Time (Myr)

1 5 10 ~ 1 Gyr





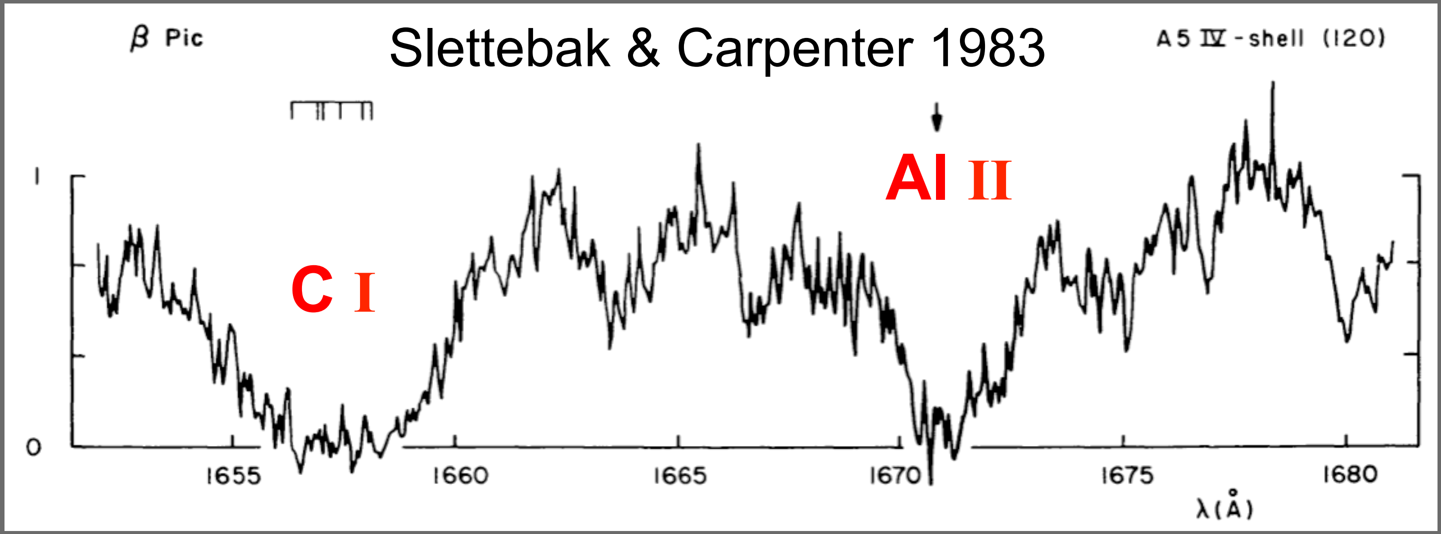


Observation

T Tauri & Herbig Ae/Be stars **Main sequence stars**

The early clues: shell stars

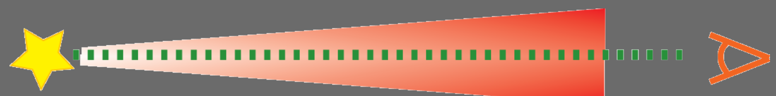
- "Grab bag" of stars w/ narrow absorption lines



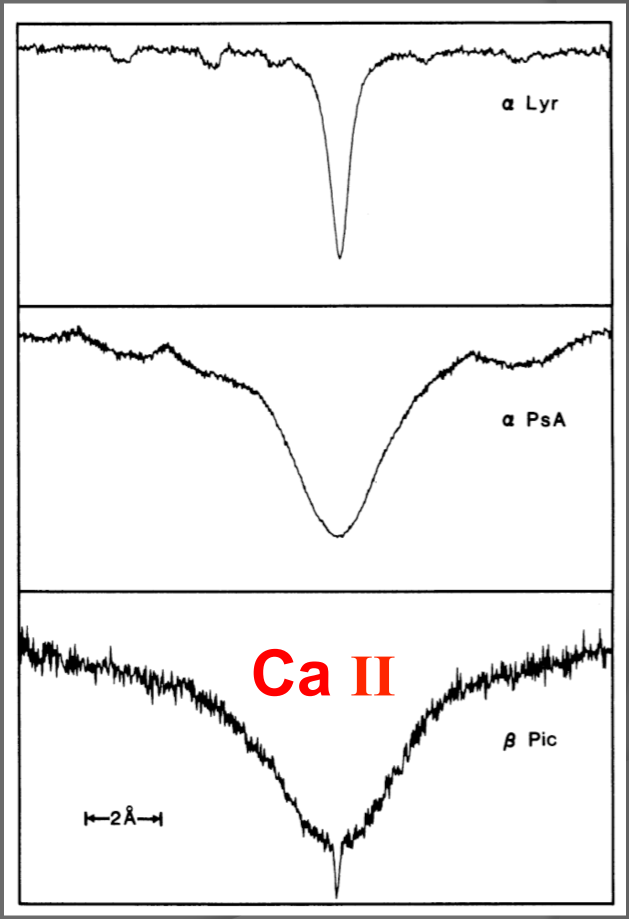
- Beta Pic classed as shell star (Slettebak 1975, 1982)
- Beta Pic circumstellar gas discovered before the dust! (Aumann 1984, Smith & Terrile 1984)

Gas absorption toward Beta Pic

- Optical / UV absorption spectroscopy



- Lines too strong to be interstellar
  (e.g. Vidal-Madjar et al. 1986)
- Many lines & species not seen in local ISM
  (e.g. Lagrange et al. 1998)



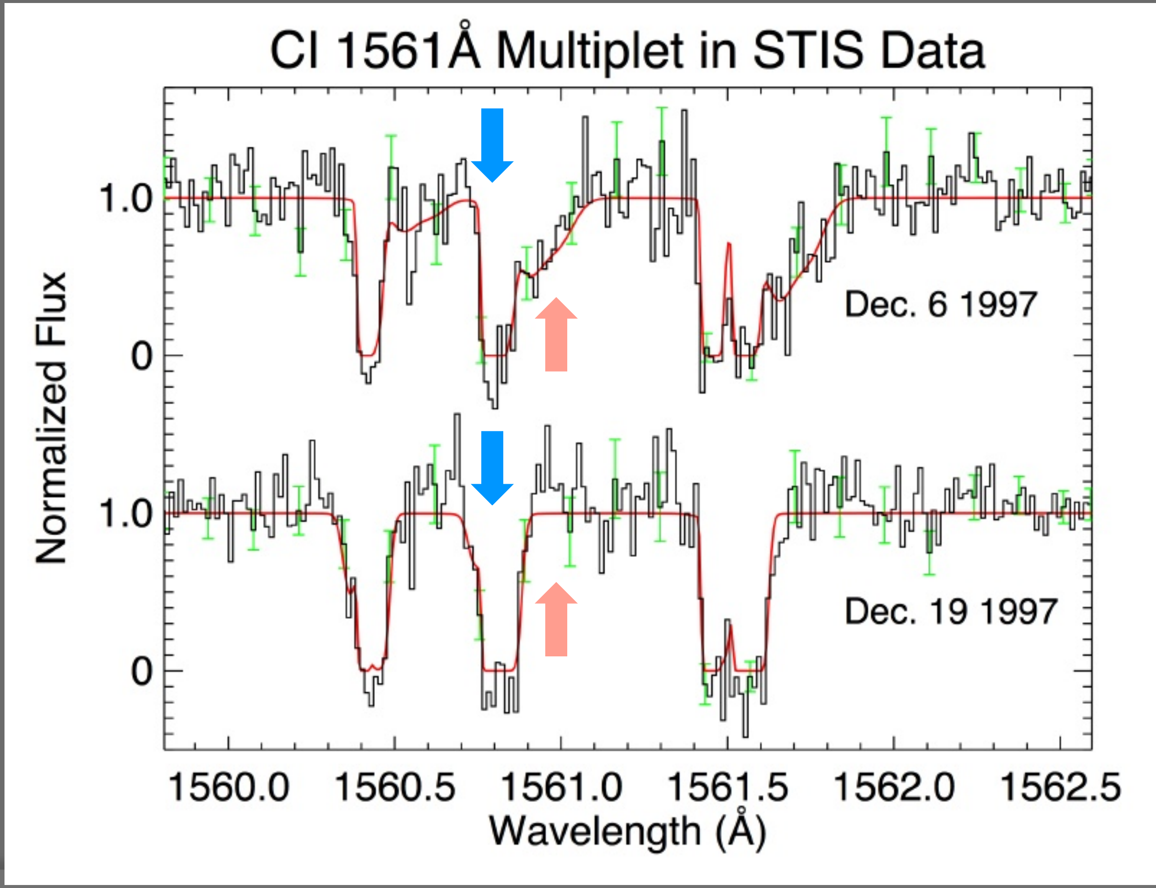
Hobbs et al. 1985

TALK: Vidal-Madjar

The absorption components

Narrow unvarying features at $v = v_\star$: stable gas

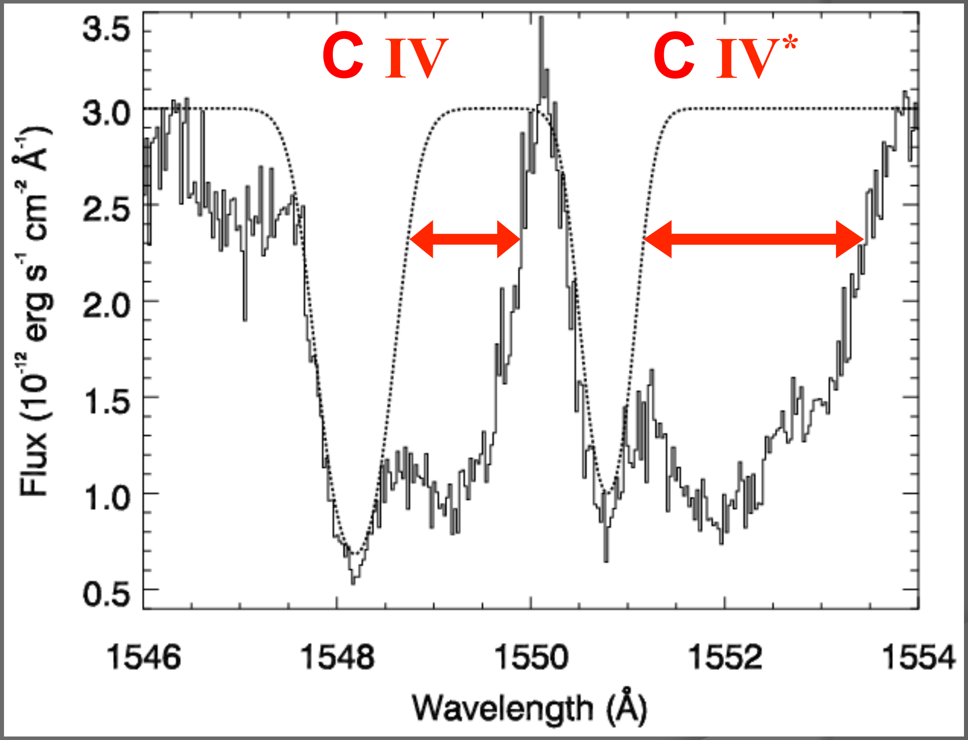
Variable shifted features : FEBs = star-grazing planetesimals



Roberge et al. (2000)

Star-grazing planetesimals

- Usually redshifted, 10s to 100s of km/s
- Variable on timescales as short as hours
- Highly ionized species : hot, dense gas
- Variable gas is clumpy



Bouret et al. (2002)

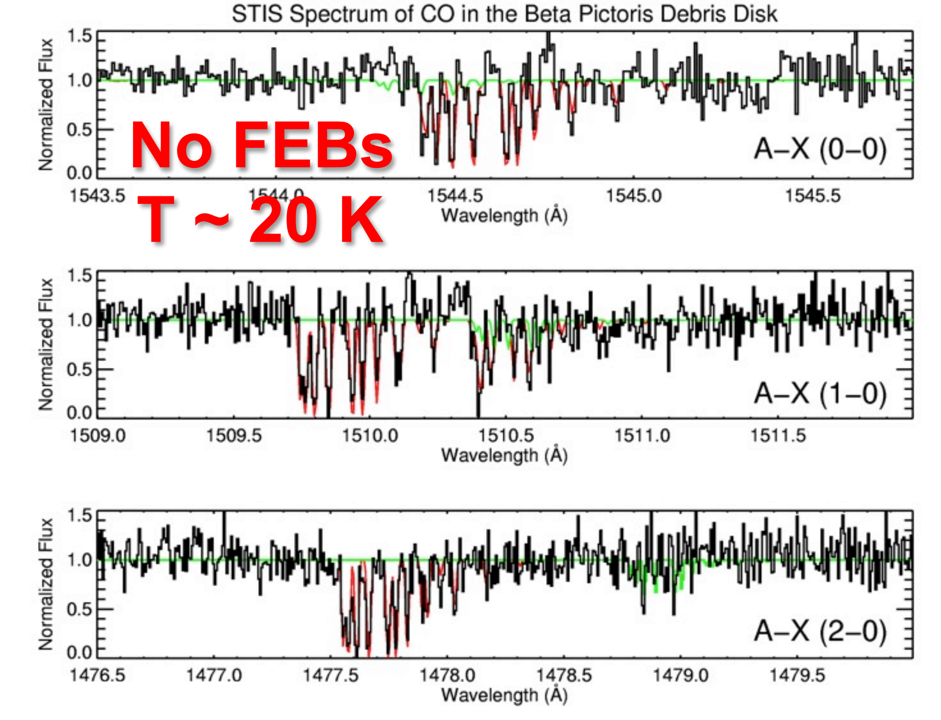
e.g. Lagrange et al. (1986), Ferlet et al. (1987), Lagrange et al. (1988), Beust et al. (1990), Vidal-Madjar et al. (1994)

TALKS: Beust, Kiefer

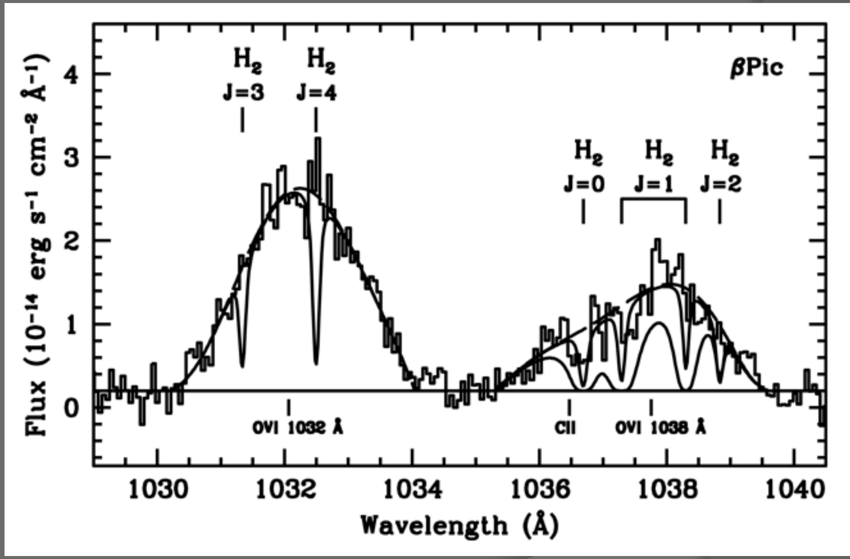
Molecular gas

- Undetectable CO emission (e.g. Zuckerman et al. 1995) … until ALMA

CO absorption (e.g. Deleuil et al. 1993) … but no H_2



Roberge et al. (2000)



Lecavelier des Etangs et al. (2001)

Primordial gas gone

Summary: the nature of the gas

- Stable gas is not interstellar
  - Too strong, wrong velocity, lines from excited levels
- Relatively low gas abundance, primordial gas gone
  - No sub-mm CO emission, no H_2
- Recently produced secondary gas !
  - No shielding of stable gas from UV radiation
  - Species with short ionization / dissociation lifetimes
- Possible production processes: comet evaporation, grain-grain collisions, photodesorption

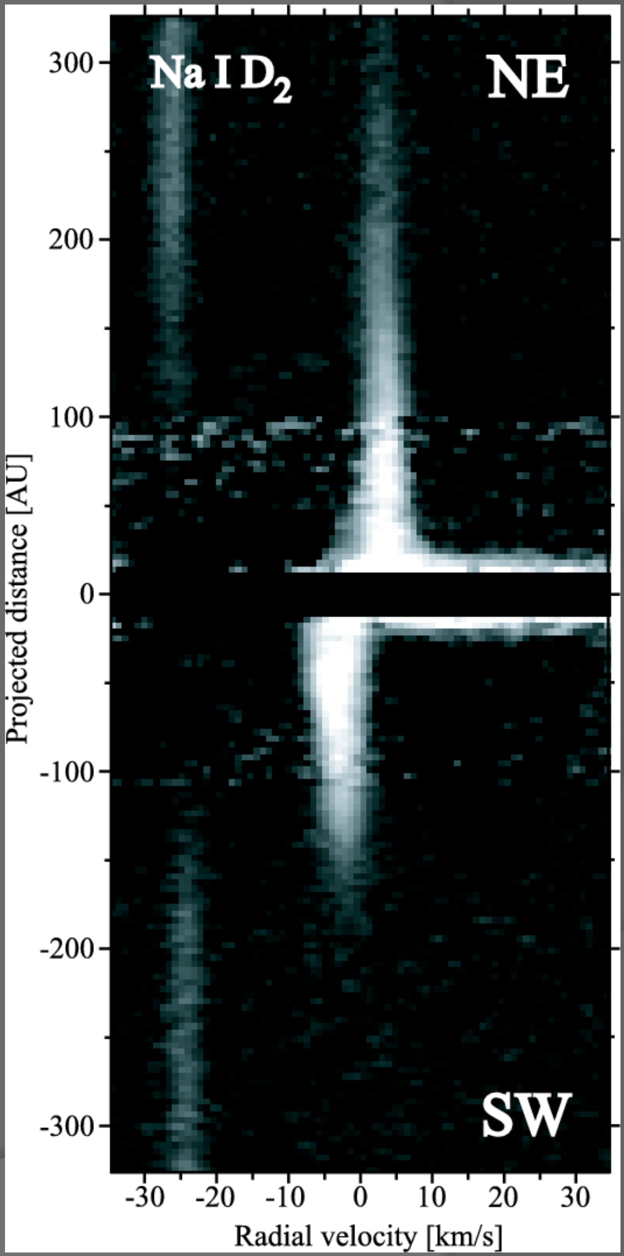
Gas dynamics problem

- Radiation pressure should blow away much stable gas
- Need braking gas
- Hydrogen torus close to star? (Lagrange et al. 1998)
- Not enough H or H_2, unless all stable gas is close to the star
  (Freudling et al. 1995, Lecavelier des Etangs et al. 2001)

Rotating gas disk

- Spatially resolved optical spectra of resonantly scattered atomic emission (e.g. Olofsson et al. 2001)
- Gas in Keplerian rotation out to 100s of AU
- Need a LOT more braking gas

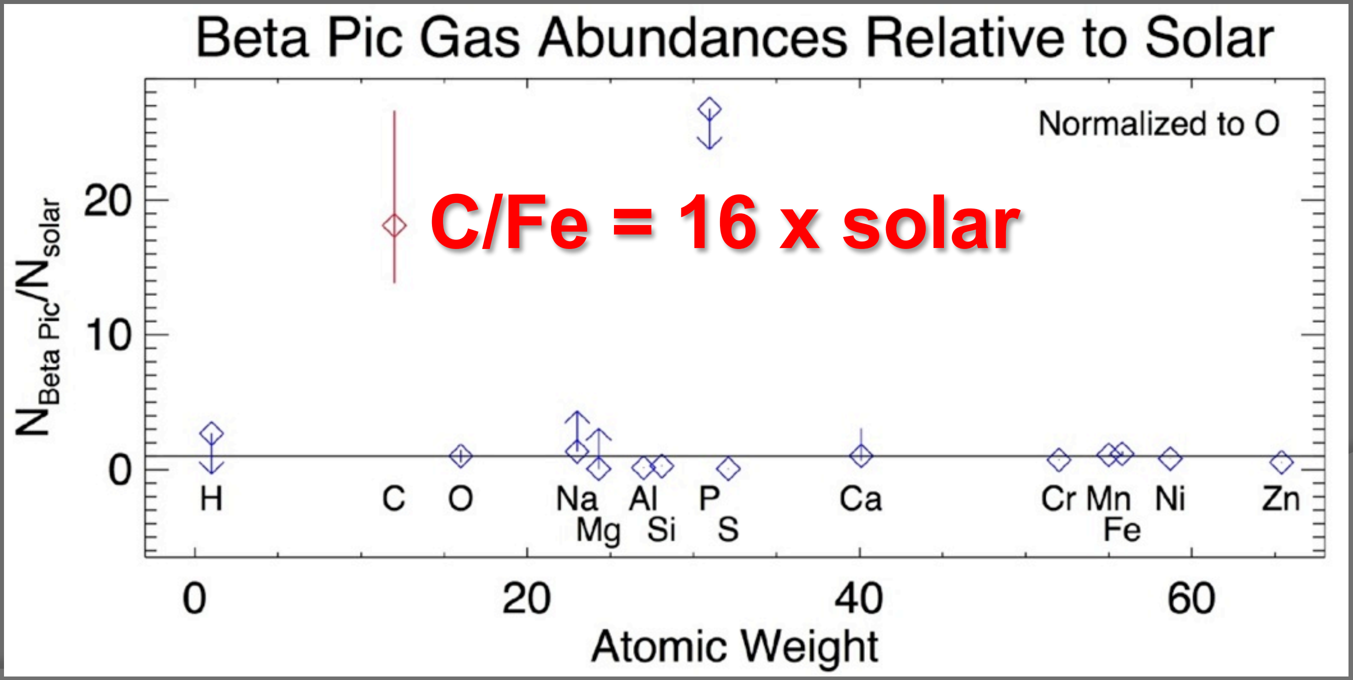
TALK: Brandeker



Brandeker et al. (2004)

Dynamics problem solved: carbon

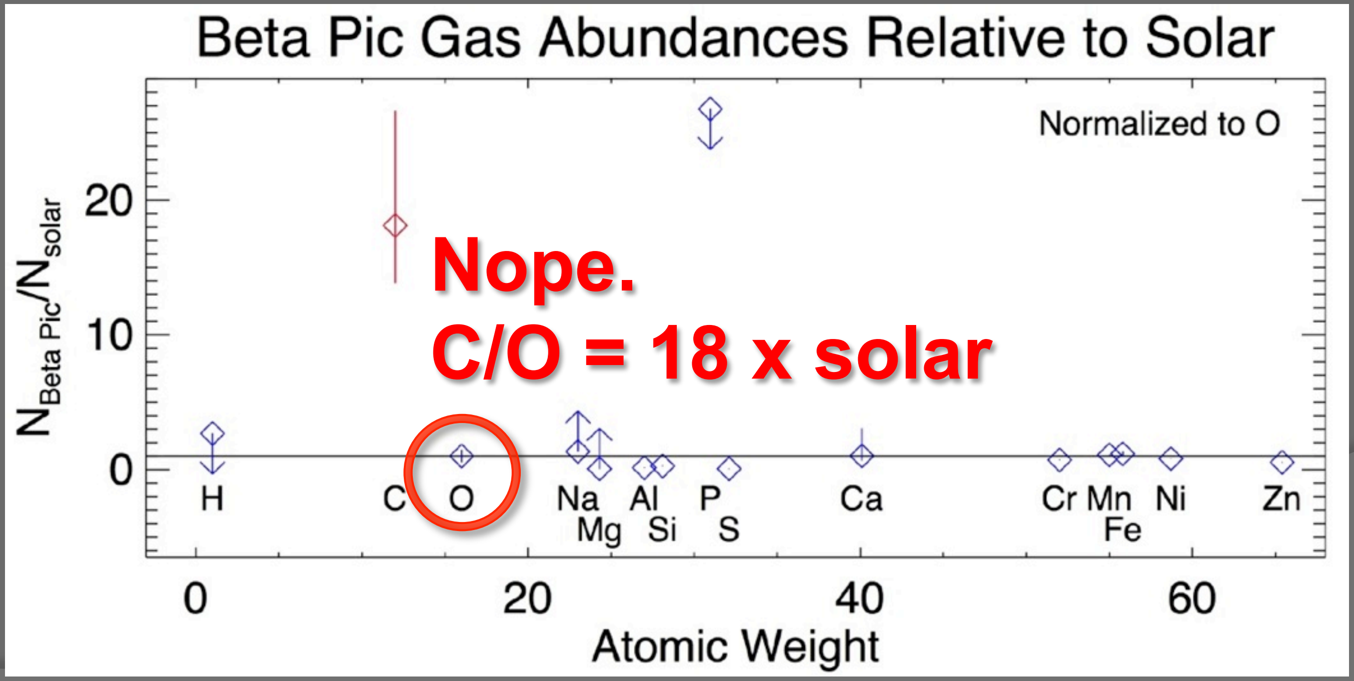
- Coulomb breaking: ions couple into single fluid
  (Fernandez, Brandeker, & Wu 2006)
- If C > 10 x solar, gas will self-break



Roberge et al. (2006)

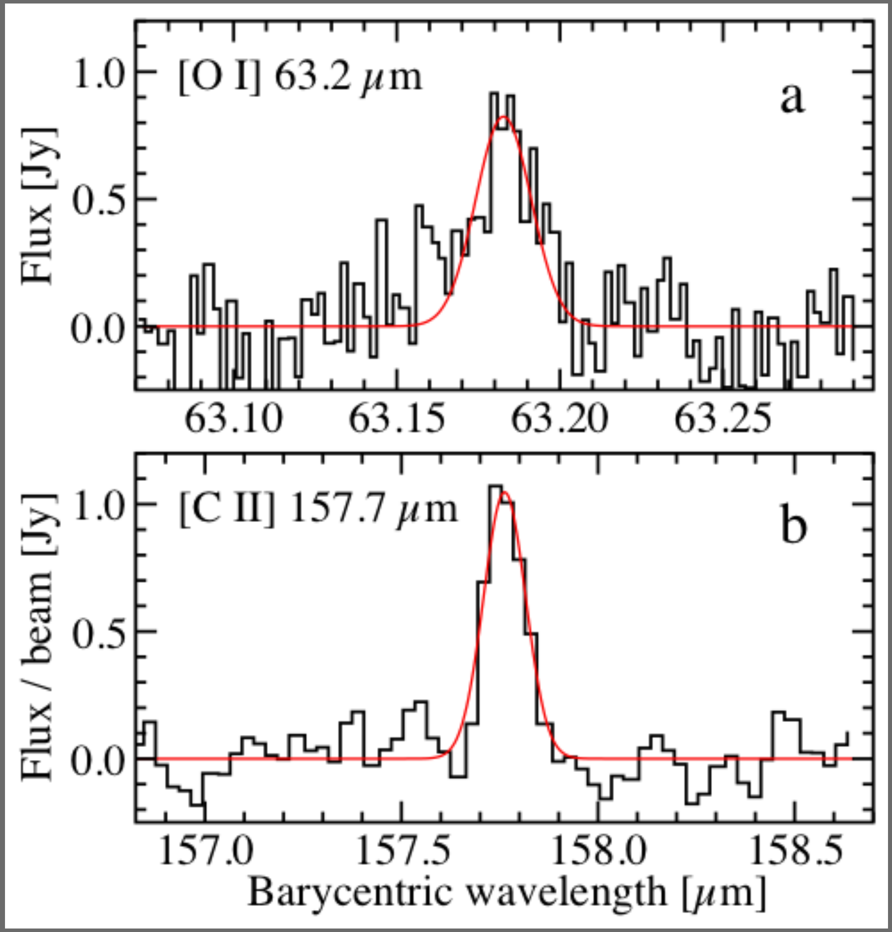
Elemental abundance problem

- Depletion of elements feeling strong radiation pressure could cause carbon overabundance
- But oxygen should also be overabundant



Roberge et al. (2006)

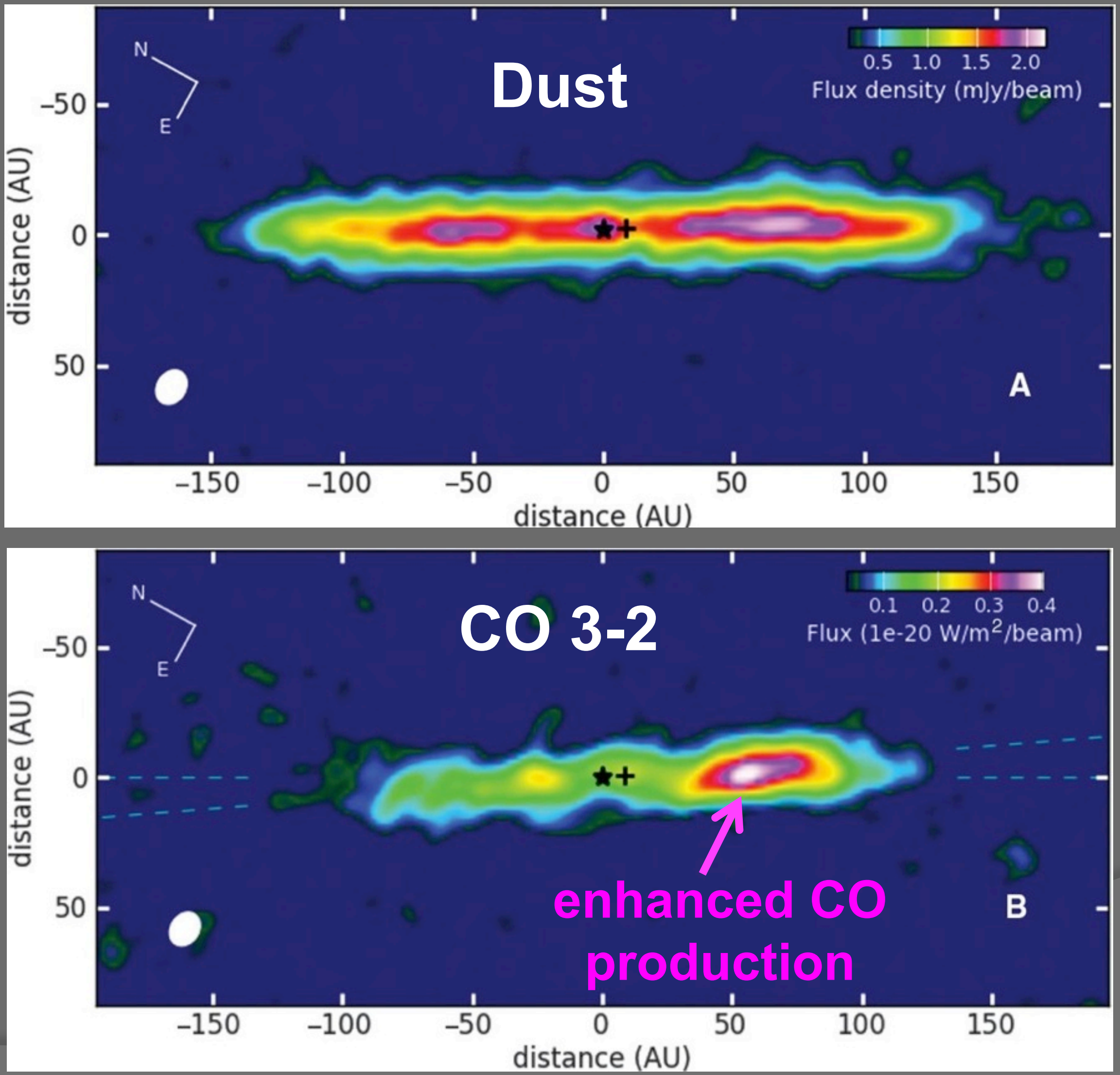
Far-IR oxygen & carbon emission



Brandeker et al., submitted

- C/Fe ~ 400 x solar
- C/O ~ solar
- Rich in carbon AND oxygen
- Caused by differential depletion?
- Overproduction of C and O slightly favored (Xie, Brandeker, & Wu 2013)

The ALMA era: asymmetric CO

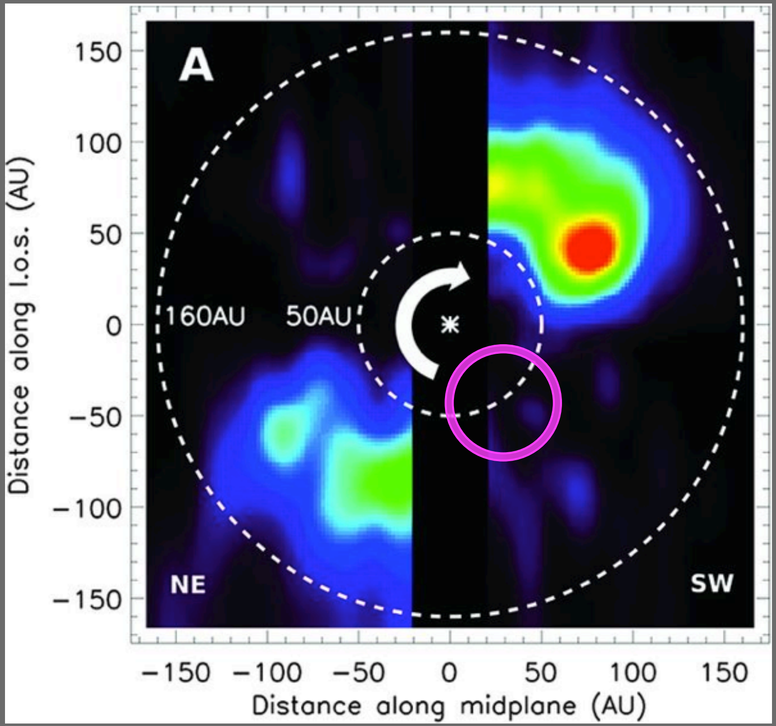


Dent et al. (2014)

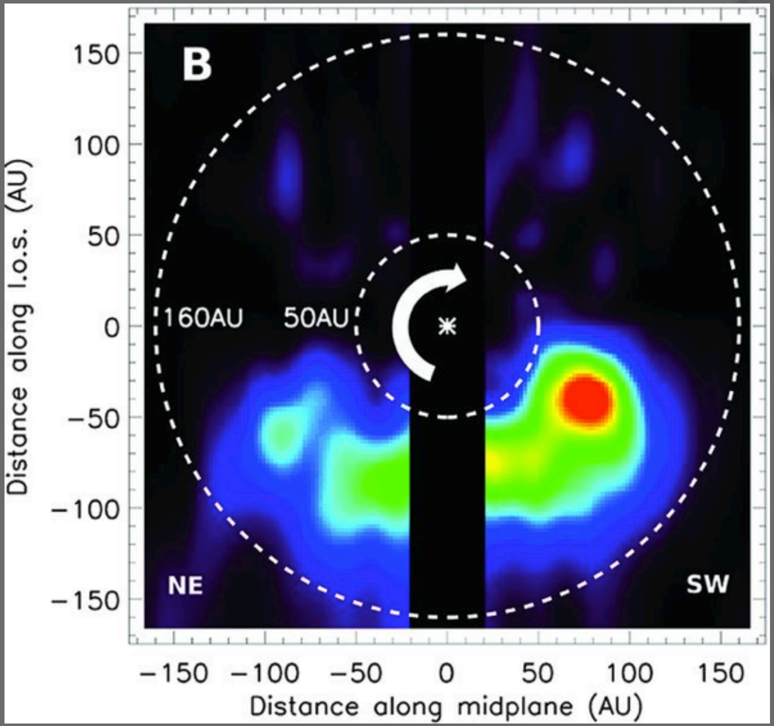
TALK: Dent

CO clumps

De-projected views from above the Beta Pic disk



Comet swarms in mean-motion resonance with planet



Recent collision of Mars-mass icy bodies

Dent et al. (2014)

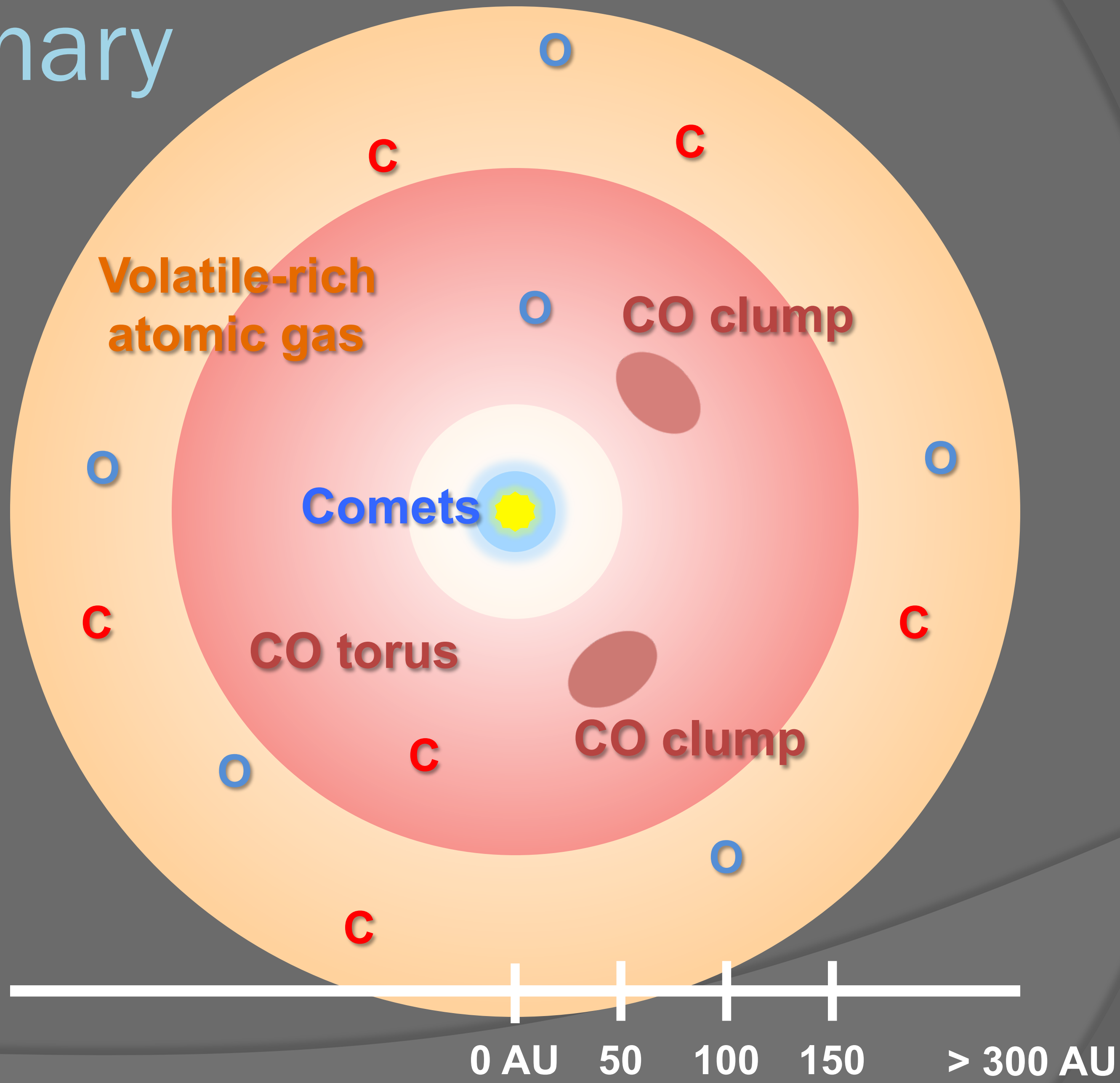
Plus tenuous CO torus at 50 – 160 AU

TALKS: Wyatt, Jackson

Relationship between CO and C

- Absorption measurements said not enough CO to be sole source of carbon
  - C I ionization time and CO dissociation time both ~ 120 years. Expect equal amounts in equilibrium
  - In the line-of-sight, CO is ~ 2% of C I (Roberge et al. 2000)
  - Postulated additional source of carbon
- Now know most CO is not in the line-of-sight
- Enough to supply whole disk? Upcoming ALMA C I map will tell

Summary



O
C
C
Volatile-rich
atomic gas
O
CO clump
O
O
Comets
C
C
CO torus
CO clump
O
C
O
C
0 AU
50
100
150
> 300 AU

Questions

- What do the gas abundances mean?
  - Revisit UV spectroscopy of O and Si in particular
- What is causing the CO clumps?
  - Somebody look for a planet at ~ 60 AU !
- Is Beta Pic representative of debris gas?
  - Roughly 8 debris disks with gas, plus similar number of candidates
  - Analysis of 49 Ceti far-UV spectra and ALMA CO map in progress (Roberge et al. ; Hughes et al.)