ALMA resolves C I emission from the β Pic debris disk ...and new C I data from HD 32297

Gianni Cataldi

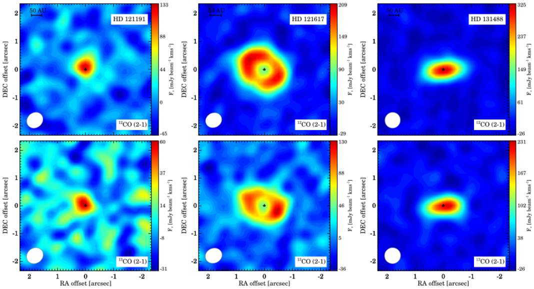
Subaru telescope, NAOJ
JSPS postdoctoral fellow

Outline

1. Short introduction: gaseous debris disks
2. The β Pic debris disk: new insights from ALMA C I data
3. New C I data from HD 32297

Gaseous debris disks

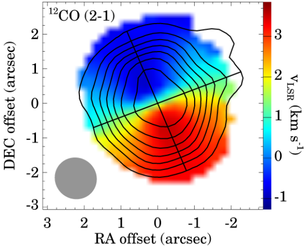
- debris disk are generally gas-poor
- some debris disks contain detectable amounts of gas
- currently ∼20 examples
- mostly around young (∼10s of Myr) A-stars
- primordial or secondary origin?



Moór et al. (2017)

Primordial scenario

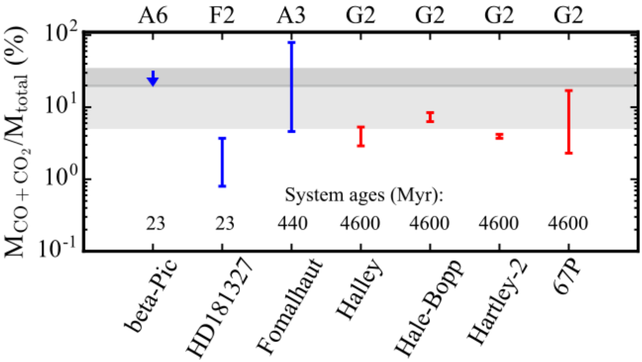
- leftover from protoplanetary phase
- prime example: HD 21997 (30 Myr; large CO mass; gas and dust *not* co-spatial)
- implications for primoridal disk lifetime—some disks can retain gas longer than previously anticipated
  - inefficient gas loss?
- late stage gas accretion by planets?
- influence on dust dynamics?



CO emission from 30 Myr old HD 21997 (Kóspál et al. 2013)

Secondary scenario

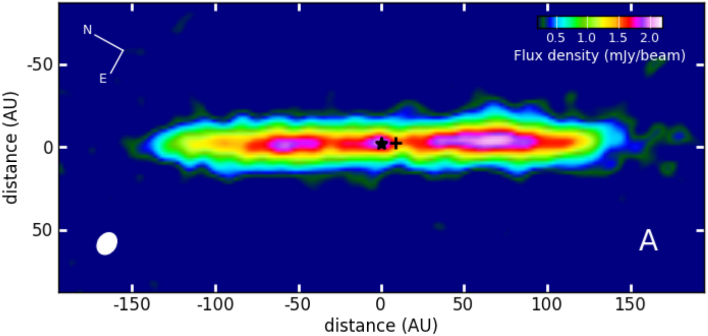
- gas lifetime shorter than age of the system (CO photodissociation)
- gas produced from collisions or outgassing of solid bodies
- ... CO formation? (talk by Kazunari Iwasaki)
- secondary gas allows constraints on parent body composition
- so far, composition consistent with solar system comets



Matrà et al. (2017)

β Pictoris: basic data

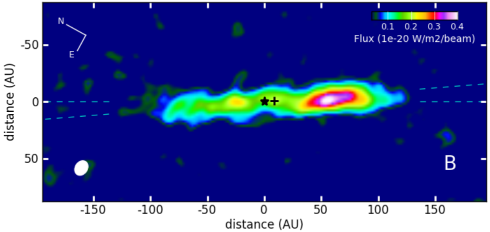
- young (23 ± 3 Myr) main-sequence A-star
- edge-on debris disk with planetesimal belt at ~100 AU and gas
- gas secondary since CO quickly (within ~50 yr) photodissociated
  $\Rightarrow$ must be replenished continuously (colliding comets)



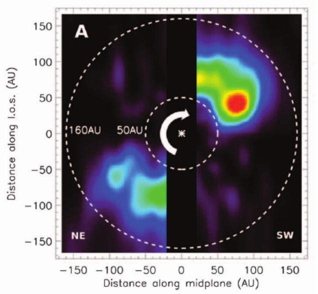
submm continuum Dent et al. (2014)

ALMA resolves CO

- clump: location of enhanced collision rate and thus CO production
- unseen, outward-migrating giant planet trapping cometary bodies in resonance (Wyatt 2003, 2006)



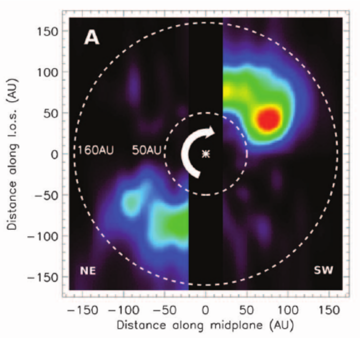
CO 3–2 (Dent et al. 2014)



Dent et al. (2014)

C vs CO in planet migration scenario

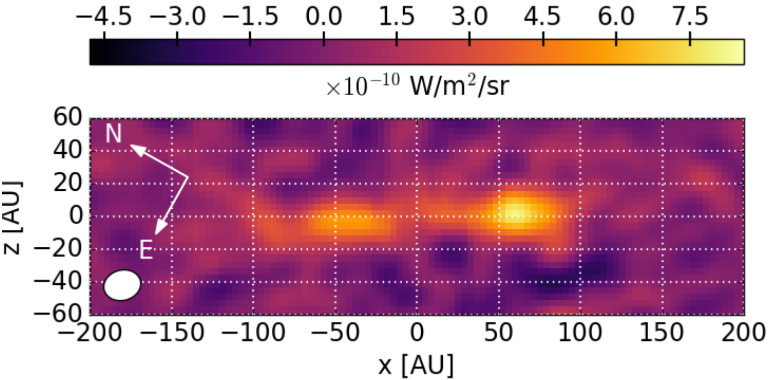
- clump orbits with planet ⇒ time-integrated gas production is symmetric
- CO lifetime short (tracer of instant collision rate) ⇒ traces the clump
- . . . but C traces long term evolution ⇒ should be symmetric



Dent et al. (2014)

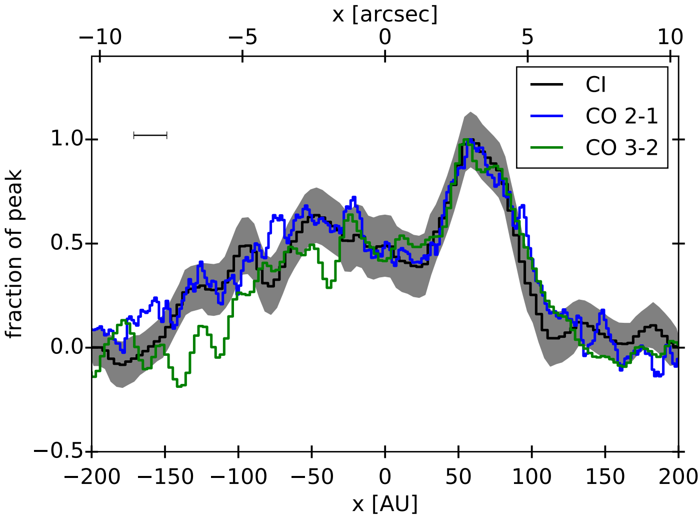
New ALMA band 8 data: C I

- low S/N due to antenna configuration and weather



Cataldi et al. (2018)

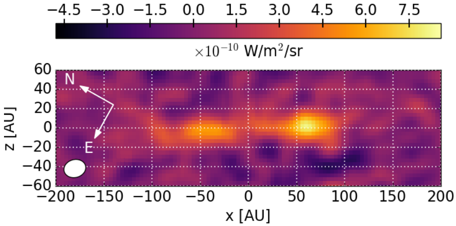
horizontal emission profile



Cataldi et al. (2018)

additional information extracted from the data

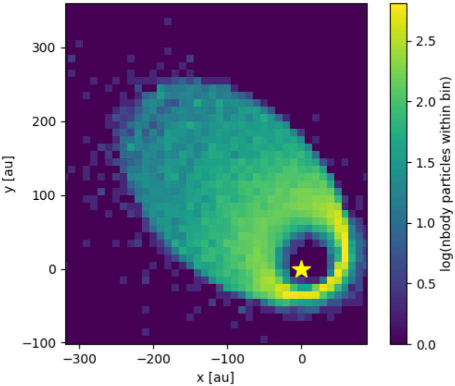
- estimate total C mass: $\sim 10^{-3}\,M_\oplus$ ($\sim$Pluto mass)
- estimate time since C production started:
  - C produced only from CO photodissociation
  - C not removed from the system (no accretion disk)
- gas production started $\sim 10^4$ years ago—very recent!
- gas-producing events must happen relatively frequently



Cataldi et al. (2018)

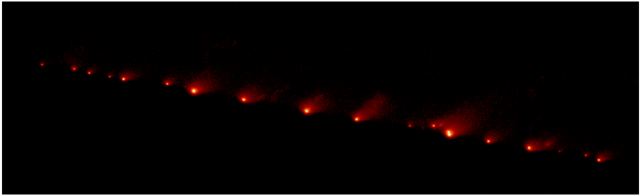
Consequences

- planet scenario excluded
- need some mechanism to explain simultaneous CO and C asymmetry
- eccentric disk?



Tidal disruption

- tidal disruption most suitable mechanism to get eccentric disk
  - giant collision: too infrequent
- tidal disruption of Moon/Mars-sized body by Neptune?
- preliminary modeling promising
- might be applicable to other disks with asymmetries

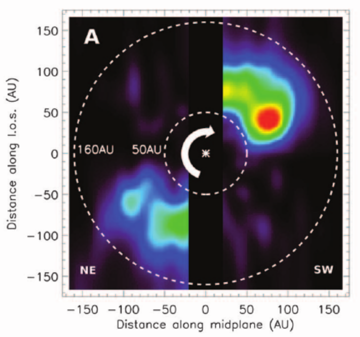


Comet Shoemaker—Levy 9 tidally disrupted by Jupiter.

Image credit: NASA, ESA, and H. Weaver and E. Smith (STScI)

Tidal disruption: difficulties

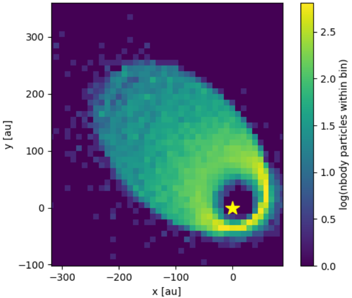
- more frequent than giant collisions, but still too infrequent compared to 10^4 years gas disk age
- radial width of the clump (radiation pressure on CO-rich grains?)
- number density of parent bodies realistic? (requires $\gtrsim$1000 Moons floating in the disk)
- more detailed modeling necessary (Cataldi & Wu, in prep.)



Dent et al. (2014)

Tidal disruption modeling

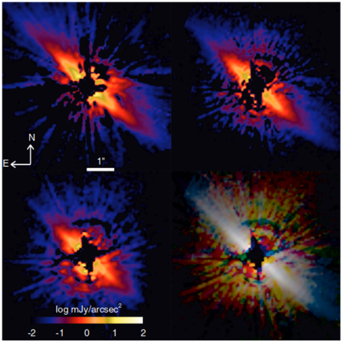
- N-body simulation of tidal disruption
- calculate collision rates in every location of the disk
- infer dust luminosity evolution (typical lifetime of the event)
- compute expected gas density profile and compare to data



N-body simulation of tidal disruption event (Cataldi & Wu, in prep.)

HD 32297

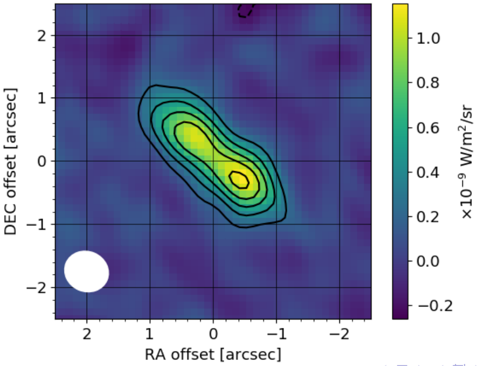
- HD 32297: A-star, <30 Myr old
- C II detected by Herschel (Donaldson+13), CO resolved by ALMA (MacGregor+18)
- might have ~1000× more CO than β Pic



Debes et al. (2009)

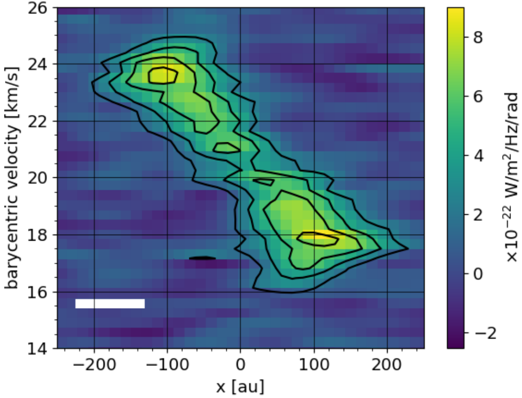
new ALMA C I data

- 18 min on source
- high S/N (compared to β Pic)
- combine with C II data from *Herschel* to estimate total C mass
- compare C and CO spatial distribution
- compare C/CO ratio to other gaseous debris disks



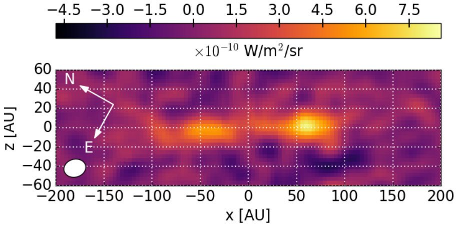
HD 32297: pv diagram

- clearly a ring
- no significant asymmetry apparent



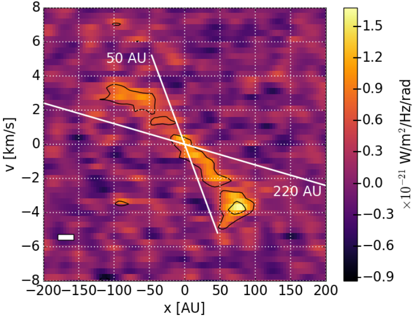
Summary

- C I around β Pic shows the same clumpy asymmetry as CO
- consequence: clump is not due to a planet
- C gas production started only $\sim 10^4$ years ago
- we propose that the disk is eccentric
- tidal disruption event? more modeling underway!
- new, high S/N C I map from HD 32297 currently being analyzed

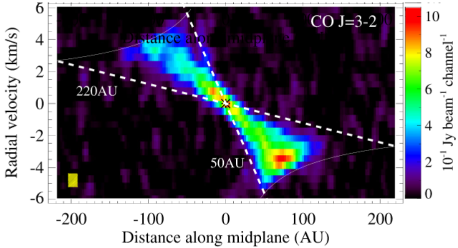


Cataldi et al. (2018)

pv-diagram



C I



CO 3–2 (Matrà et al. 2017)