ALMA does Circumstellar Disks

A User's Perspective on Early Science and Beyond

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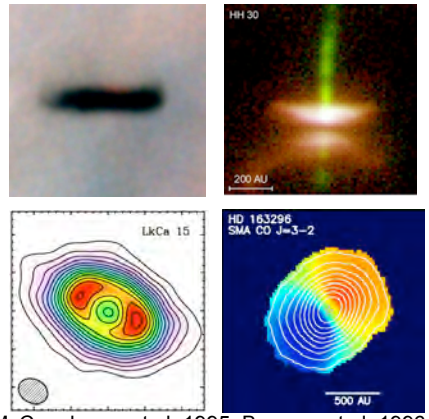
CfA

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

"Protoplanetary" to "Debris"



McCaughrean et al. 1995; Burrows et al. 1996
Andrews; et al., in prep Isella et al. 2007

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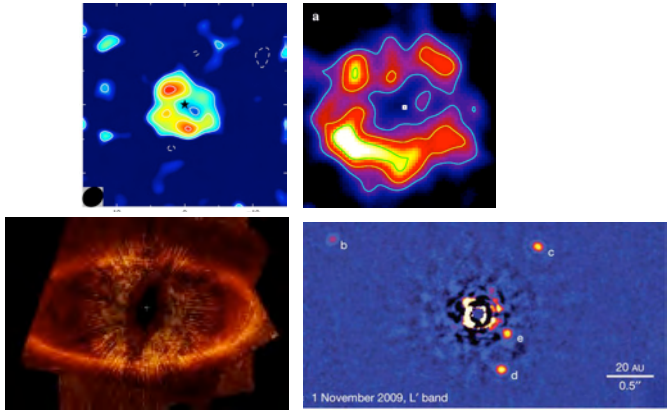


Corder et al 2009; Greaves et al. 2005
Kalas et al. 2008; Marois et al. 20010

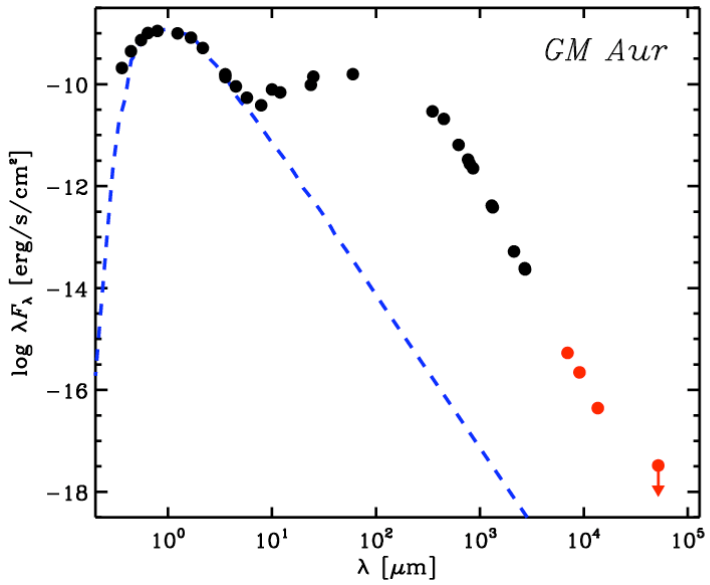
- ~1 to 10 Myr
- gas and trace dust
- dust sticking, growing into planetesimals
- <0.001 to 0.1 M_{Sun}

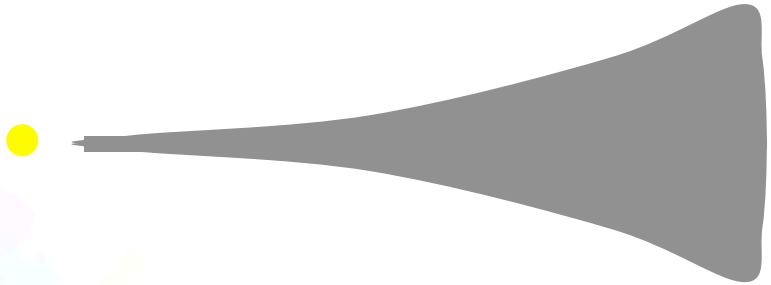
- ~10 Myr to Gyrs
- dust and trace gas
- planetesimals colliding, creating dust
- <1 M_{Moon}

What physics drives evolution? When, where, how do planets form?

ALMA *images* dust and gas at key long wavelengths 0.3 to 9 mm

Relevance of Millimeter Wavelengths



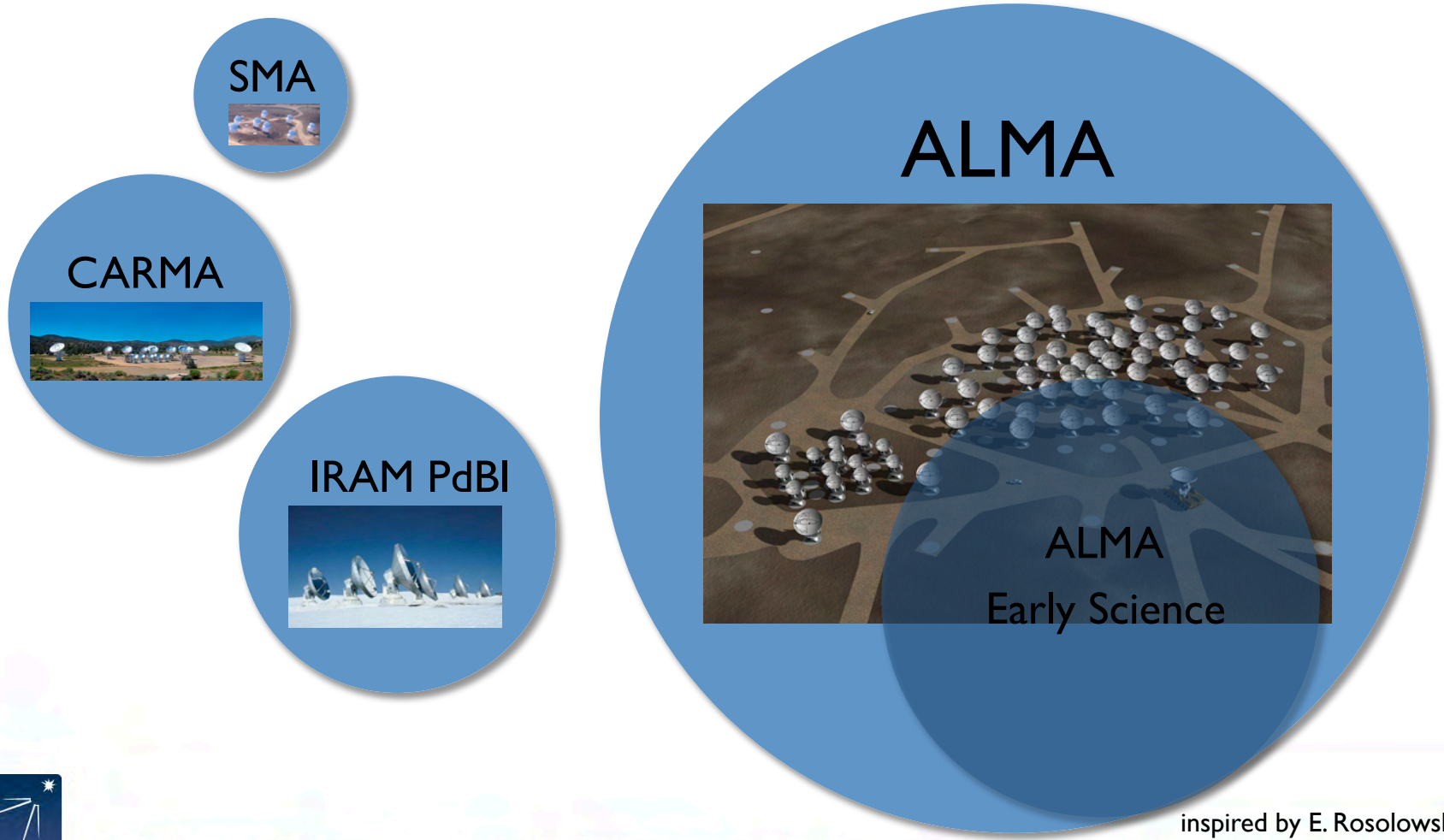


- avoid high dust opacities
  mass tracer
- many accessible lines
  physical diagnostics, chemistry
- heterodyne gives R >10^6
  kinematics
- sensitive to cold material
  including mid-plane, outer disk
- contrast with star
  planet-forming region

- subarcsec imaging with high sensitivity *ALMA!*

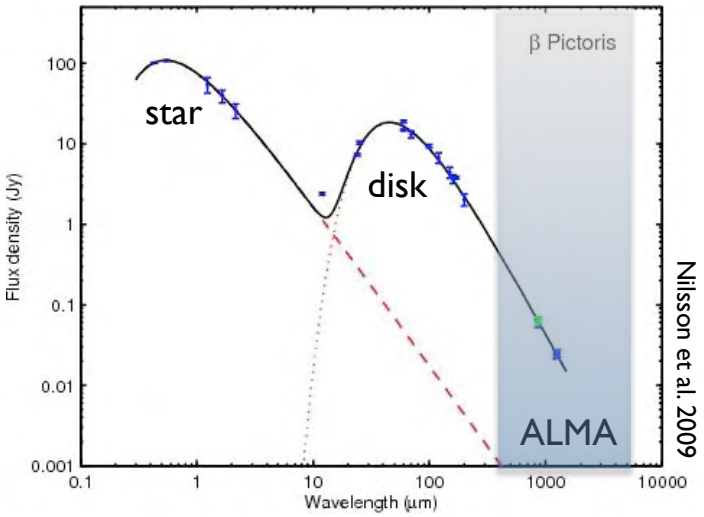
ALMA: Large, Sensitive, Fast!

→ *much deeper* individual spectro-imaging studies *and* statistical views



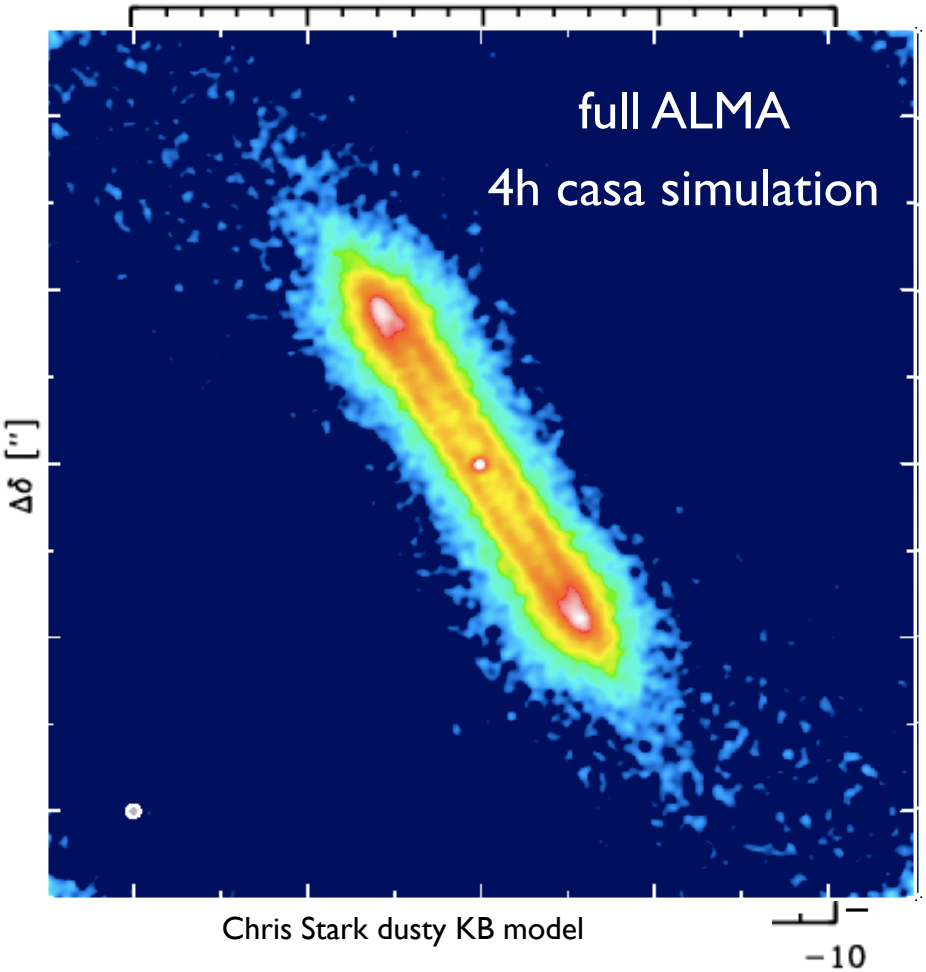
inspired by E. Rosolowsky

Debris Disk Structure



Nilsson et al. 2009

- small dust ≠ large dust
- 10's are 1-10 mJy at 850 μm
- early science ΔS ~1 mJy/√min
- full ALMA 3x better
  and longer baselines
- asymmetries and planets?

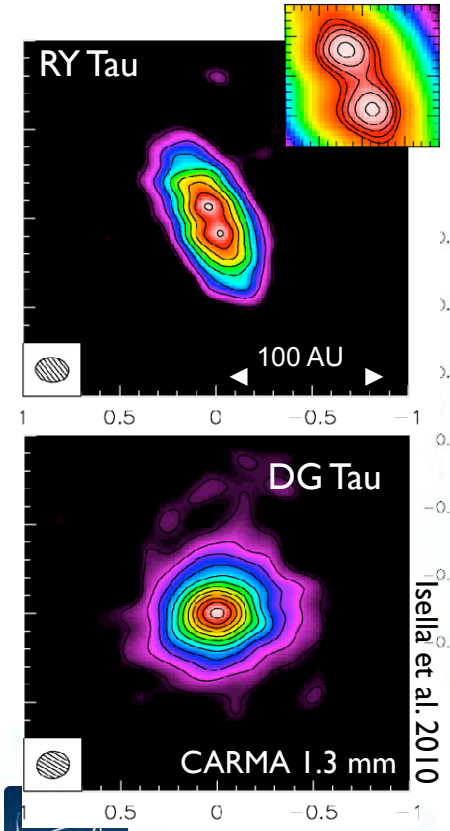


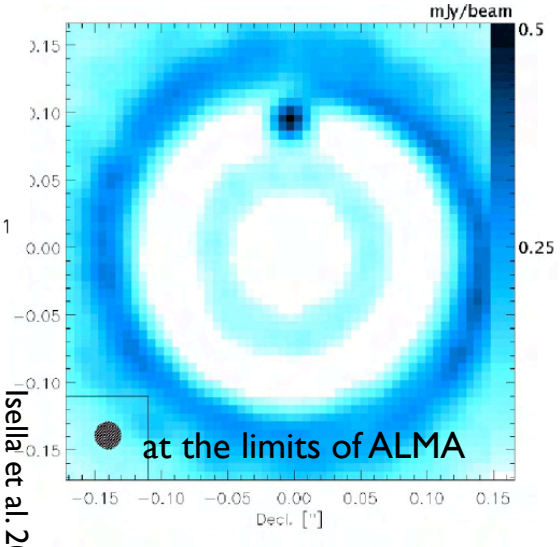
Chris Stark dusty KB model

Protoplanetary Disk Dust

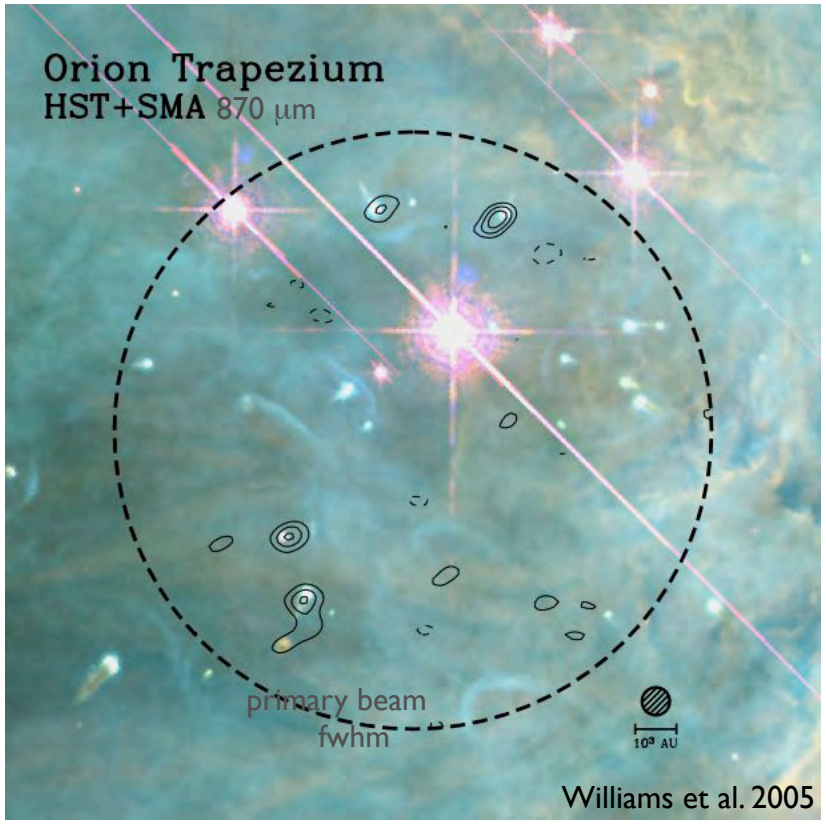
- 100's at 150 pc
- 0.005 M_{sun} ~80 mJy at 850 μm

→ structure, holes, gaps, planets!





Isella et al. 2010

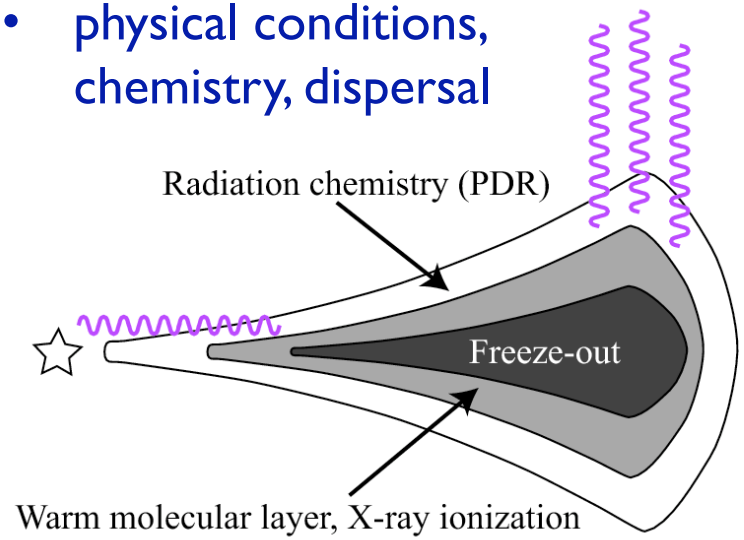


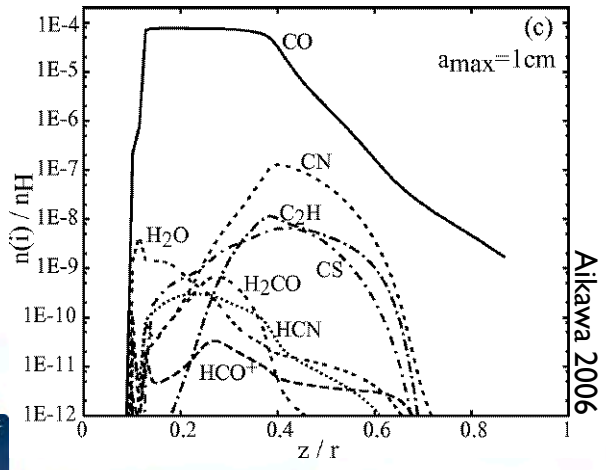
- 1000's within 1 kpc
- reach 1-10 Myr clusters

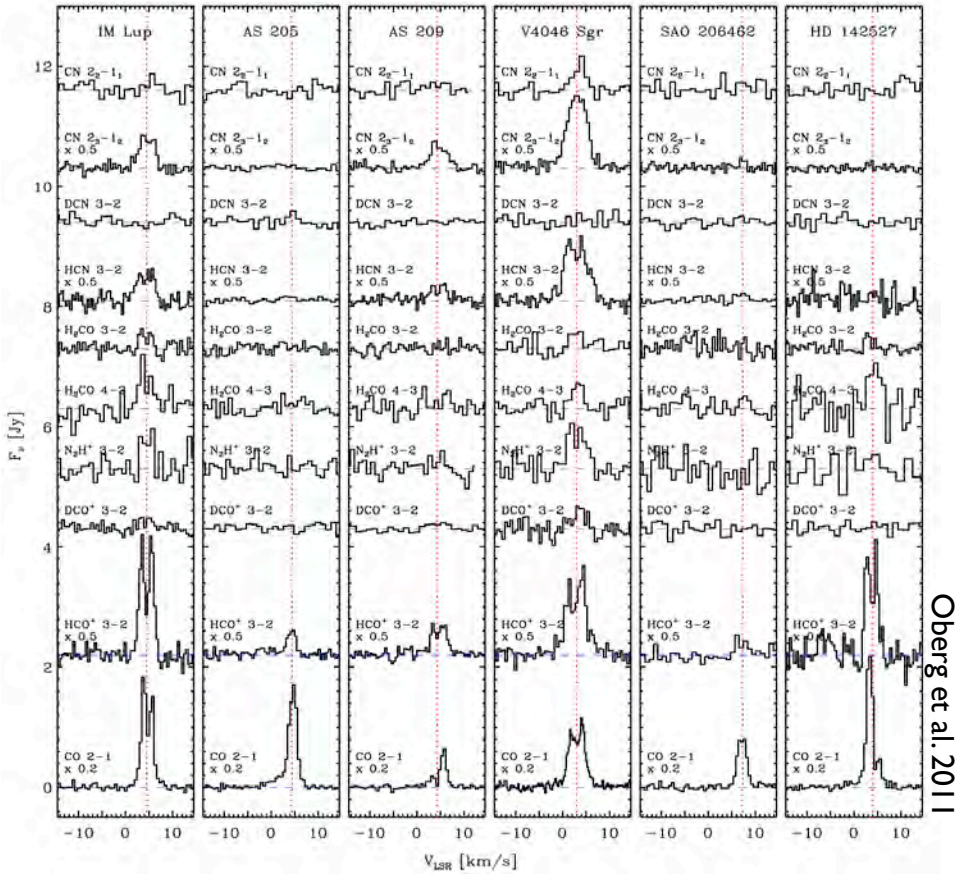
→ mass evolution, statistics

Protoplanetary Disk Gas: Chemistry

- physical conditions, chemistry, dispersal





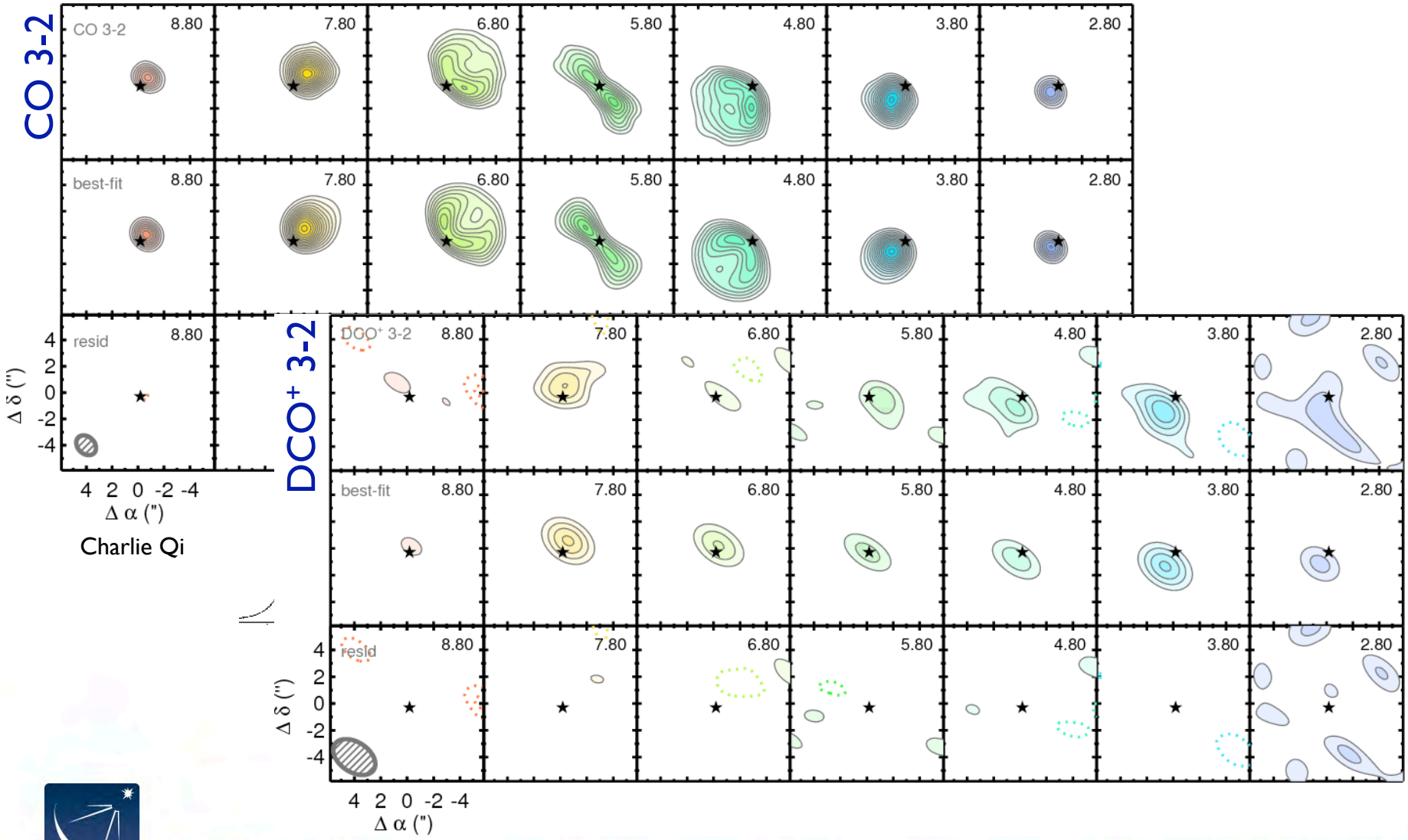


CO 2-1 10 Jy km/s

DCO^+, H_2CO, N_2H^+, … 1 Jy km/s

- early science ΔS ~0.05 Jy km/s /$\sqrt{min}$

Protoplanetary Disk Gas: Kinematics



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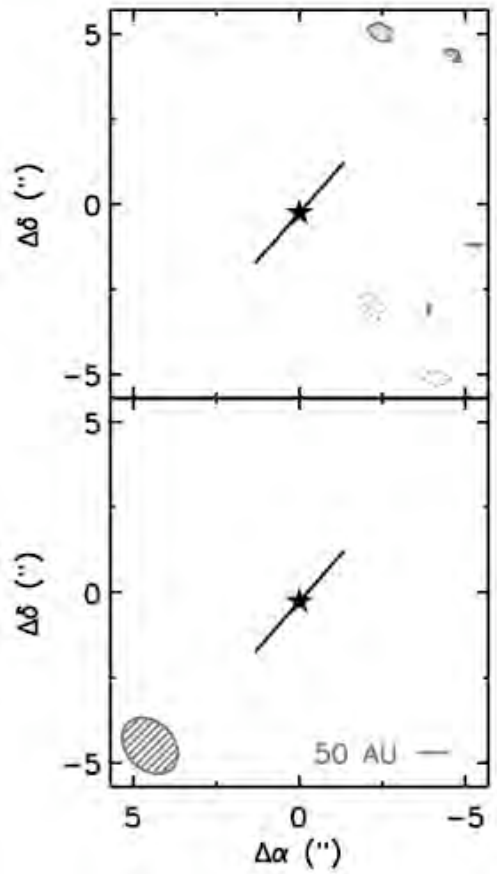
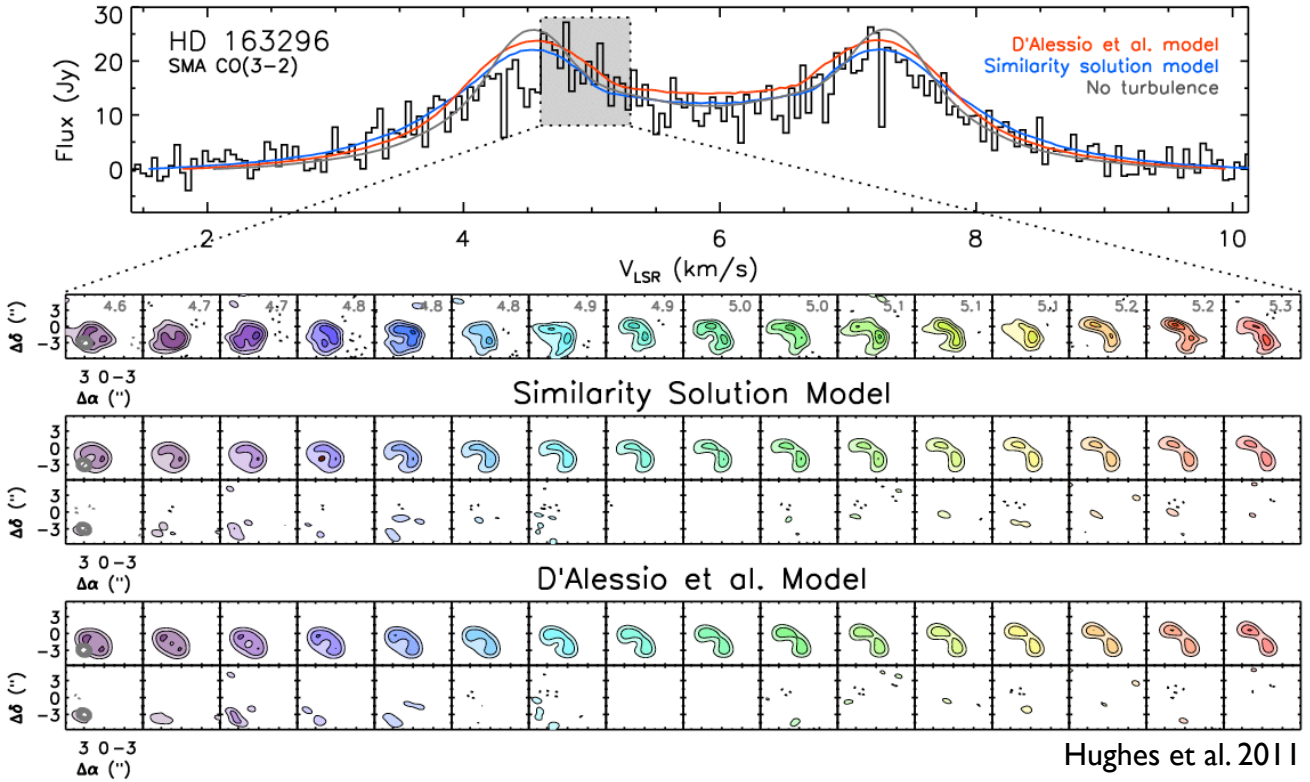


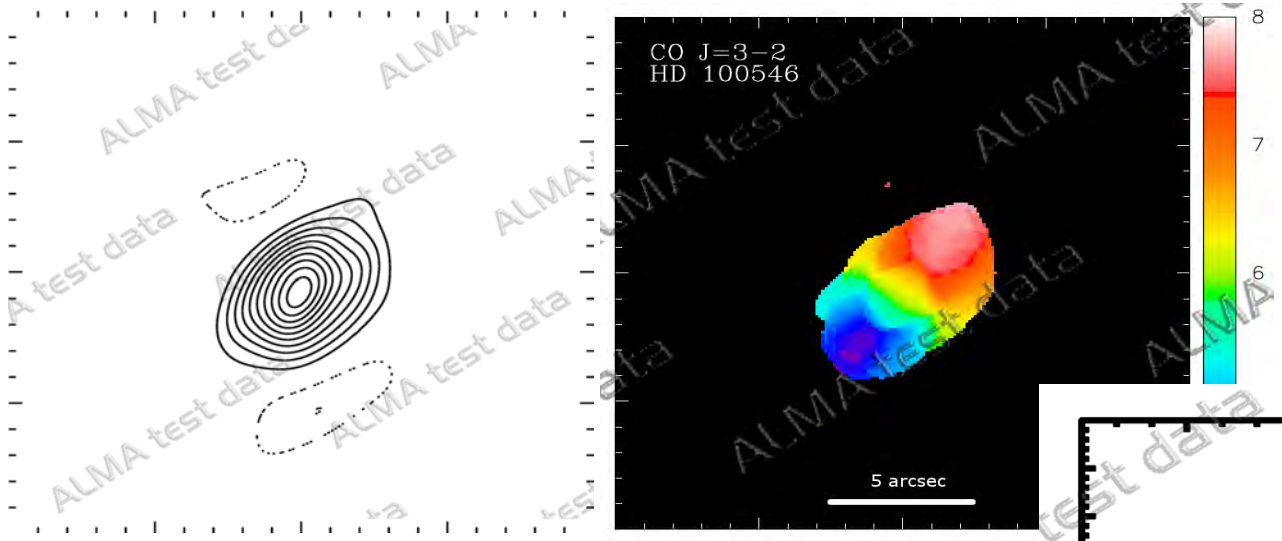
- accretion mechanism: turbulence?
- e.g. HD 163296 CO 3-2 at 44 m/s

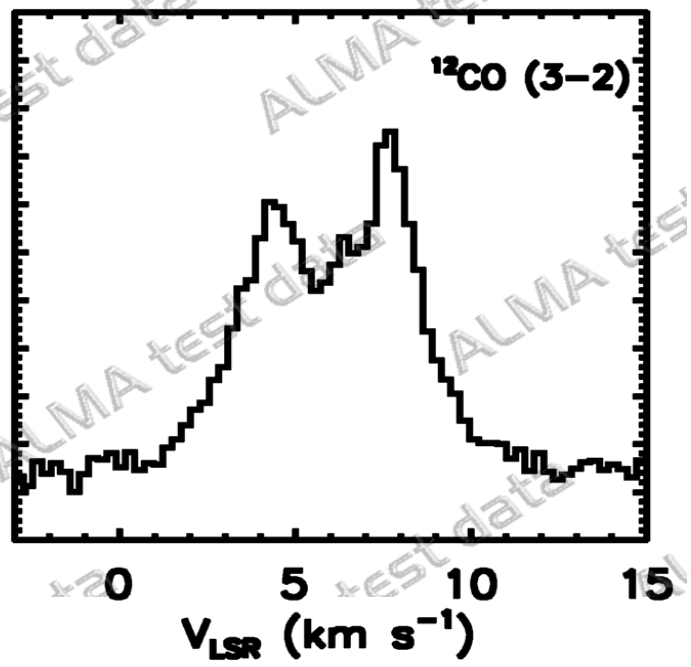


Hughes et al. 2011

Poster 63

ALMA Commissioning: HD 100546





Concluding Remarks

- ALMA offers unprecedented sensitivity at millimeter wavelengths
  - already at start of Early Science
- many fundamental issues to address, e.g. circumstellar disks
  - reach Solar System scales for 100's to 1000's of sources
- expect a lot of surprises