ALMA does Circumstellar Disks

A User’s Perspective on Early Science and Beyond

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“Protoplanetary” to “Debris”

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

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

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
Debris Disk Structure

- 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?
Protoplanetary Disk Dust

- 100’s at 150 pc
- $0.005 \, M_\text{sun} \sim 80 \, \text{mJy at 850 } \mu\text{m}$
  $\rightarrow$ structure, holes, gaps, planets!

- 1000’s within 1 kpc
- reach 1-10 Myr clusters
  $\rightarrow$ mass evolution, statistics
Protoplanetary Disk Gas: Chemistry

- physical conditions, chemistry, dispersal

Radiation chemistry (PDR)

Freeze-out

Warm molecular layer, X-ray ionization

\[ \Delta S \sim 0.05 \text{ Jy km/s} / \sqrt{\text{min}} \]

CO 2-1, DCO\(^+\), H\(_2\)CO, N\(_2\)H\(^+\), ...

10 Jy km/s, 1 Jy km/s

- early science \( \Delta S \sim 0.05 \text{ Jy km/s} / \sqrt{\text{min}} \)
Protoplanetary Disk Gas: Kinematics

Charlie Qi

ALMA Workshop, Victoria, January 2011
Protoplanetary Disk Gas: Kinematics

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