Transition Disk Chemistry in the Eye of ALMA

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Outline

I. Transition Disks: Introduction
II. Model Framework
III. First Results Using CB 26: Test Case Disk
IV. Chemical Results: Implications
V. Observables - The Power of ALMA
I. Circumstellar Disks in Transition

- Circumstellar disks observed ➔ sites of planet formation.
  - Once a protoplanet is massive enough it can dynamically alter the disk ➔ gaps, holes, etc.
  - The initial stages of planet formation involves grain growth and reduction of opacity
- Disks with gaps are called “Transition Disks.”
- Disk chemistry will respond to the change in physical conditions ➔ set initial chemical conditions at the point of planet formation.
- Prediction: The clearing of the inner-disk directly reveals the dense (and normally cold) gas rich midplane to the star.
  - Is this an observable effect? Must first be able to resolve this...
- ALMA has the power to resolve the gap ➔ can directly probe evolving region.

Thalmann et al. 2010: imaging the wall in LkCa 15; consistent with SED disk models ➔ the result of forming protoplanets?

Nearest SFR:

Resolving the Gap

Molecular Clouds
HII Regions
Star Clusters
Maximal resolving power today ~500m Baseline

CO 2-1: 230 GHz

Resolving the Gap

Nearest SFR:

50 AU
100 AU
20 AU

TAURUS-AURIGA
PERSEUS
ORION
CHAMELEON
OPHIUCHUS
Nearest SFR:
1 AU
5 AU

Full ALMA: 12km Baseline

CO 2-1: 230 GHz

Resolving the Gap
III. Chemical Model “Recipe”

- **DISK PHYSICS**
  - Size, Mass
  - Disk Structure: e.g. D’Alessio disks (along with many other SED motivated models).

- **DISK CHEMISTRY**
  - Dust (e.g. Weingartner & Draine), composition and settling.
  - Shape of the UV field, continuum and line (Bethell), stellar and ISRF.
  - Relevant chemical network (Fogel et al. 2011): ~6000 Reactions, ~600 Species.

- **END PRODUCTS:** Observables? Can calculate resulting line emission: LIME (Brinch et al. 2010).
III. UV-Field: Continuum

- UV drives the chemistry through processes such as photodissociation and photodesorption.

- Dependent on dust composition (opacity) and dust settling $\Rightarrow$ many young disks highly settled.

- Transition disks structurally evolved $\Rightarrow$ require full M.C. radiative transfer treatment.

- Include a separate treatment for Ly $\alpha$ photons which behave differently (Bethell & Bergin 2011; Fogel et al. 2011).
IV. CB 26: An Overview

- Disk at the edge of a Bok Globule CB 26, 10° North of Taurus/Auriga dark cloud, D ≈ 140 pc.

Circumstellar disk - edge on.

- $R \approx 200\text{AU}^2$
- $R_{\text{gap}} \approx 45\text{AU}^2$
- $M_{\text{disk}} \approx 0.1\ M_{\text{sol}}^1$
- $L^* > 0.5\ L_{\text{sol}}^3$
- $M^* \approx 0.5 \pm 0.1\ M_{\text{sol}}^1$
- $M_{\text{dust}} \approx 3e^{-3}\ M_{\text{sol}}^2$

- Specific model but typical T Tauri parameters used for model calculation → can generalize results.

1 Launhardt & Sargent 2001; 2 Sauter et al. 2009; 3 Stecklum et al. 2004
Sauter et al. 2009 used spatially resolved maps in the NIR and mm along with the object’s SED to create a consistent physical model for the system.

\[ \alpha = 2.2 \pm 0.1 \]
\[ \beta = 1.4 \pm 0.1 \]

**IV. CB 26 Model**

- Midplane illuminated by star
- \(~\) Pluto’s orbit.
Dense midplane normally cold (~15K) at large distances from star.

Wall heated to T = 30-50K, species that would typically be frozen out at the midplane can be sufficiently heated → desorb from grains.

Sauter et al. 2009 used spatially resolved maps in the NIR and mm along with the object’s SED to create a consistent physical model for the system.

IV. CB 26 Model

Stellar heating
Chemical model results: gas phase molecules at the wall!
LIME Results: $^{18}$O: J=2-1

Pre-ALMA

0.57” Res - 140pc with a 500m baseline

\[ i = \frac{\pi}{2\sqrt{2}} \approx 60^\circ \]
LIME Results: C$^{18}$O: J=2-1

ALMA-Era

0.02" Res - 140pc with a 12km baseline

$i = \frac{\pi}{2\sqrt{2}} \approx 60^\circ$
C^{18}O: J = 6-5
a = 0.01"  v = 658.6GHz
D = 140pc

"Ideal" ($\tau_{\text{dust}} \ll 1$) observation.

Actual observations will be dependent on inclination angle. Dust optically thick near the midplane.

Edge on disk obs. at 0.5 mm with column $R = 200$AU, density $\sim 1 \times 10^{14}$ g/cm$^3$.
$\tau_{\text{dust}, 0.5\text{mm}} > 1$ for $z < 15$AU.

No significant dust obstruction for midplane emission for $i \sim 0$-75°. This corresponds to $\sim$93% of disks observed on the sky.

However, only the case for nearly edge on systems.
ALMA provides us with the ability to significantly increase the resolved sample size of planet-forming disks.

Will allow us to gain a full picture of the evolutionary process of disk dispersal and planet formation.

High sensitivity allows us to go both deeper, and to use new tracers not previously employed due to sensitivity limitations.

Wall will distinctly light-up at high J states - can selectively probe the transition region.

The interface between the inner gap and outer disk (the wall) in transition disks should be a chemically active and interesting region that sets the initial conditions for protoplanet chemistry.

The future: warm molecular rings!