ALMA DISK SURVEYS
WHAT DOES CO TELL US ABOUT?

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GAS MASS & DISTRIBUTION

disk dynamics and evolution
BULK GAS

warm molecular layer
molecules survive in the gaseous phase

hot surface
molecules are photo-dissociated
gas is in the atomic/ionized phase

icy midplane
molecules are frozen onto grains
BULK GAS

- **warm molecular layer**: molecules survive in the gaseous phase
- **icy midplane**: molecules are frozen onto grains
- **hot surface**: molecules are photo-dissociated, gas is in the atomic/ionized phase

- **$^{12}$CO optically thick lines**: $	au = 1$ surface at low column densities ($10^{15}$ cm$^{-2}$)
BULK GAS

- **warm molecular layer**: molecules survive in the gaseous phase
- **icy midplane**: molecules are frozen onto grains
- **hot surface**: molecules are photo-dissociated; gas is in the atomic/ionized phase

13CO and C^{18}O optically thin lines allow us to trace the bulk of the gas.
BULK GAS - MASS

- Warm molecular layer: molecules survive in the gaseous phase
- Hot surface: molecules are photo-dissociated, gas is in the atomic/ionized phase
- Icy midplane: molecules are frozen onto grains

CO PHOTO DISSOCIATION isotope-selective

CO FREEZE-OUT onto grains

Phisical-chemical models - DALI
Visser et al. 2009; Williams & Best 2014;
Woitke et al. 2016
4 Figure 2. 890 µm continuum images of the 61 Lupus disks detected in our ALMA Cycle 2 program (i.e., excluding Sz 82, which was observed by Cleeves et al., in prep), ordered by decreasing continuum flux density (see Table 2). Images are 2000 × 2000 in size. The typical beam size is shown in the first panel.
Figure 2. 890 µm continuum images of the 61 Lupus disks detected in our ALMA Cycle 2 program (i.e., excluding Sz 82, which was observed by Cleeves et al., in prep), ordered by decreasing continuum flux density (see Table 2). Images are 200 x 200 in size. The typical beam size is shown in the first panel.

**LUPUS**

PI: J. P. Williams  
cycle 2/3, band 6/7  
0.2” - 0.3”  
15-20 au radius @150 pc

88 sources  
61 detected in the continuum (890 µm)  
35 in $^{13}$CO (3-2)  
10 in C$^{18}$O (3-2)
LUPUS
PI: J. P. Williams
Cycle 2/3, band 6/7
0.2” - 0.3” beam
15-20 au radius @150 pc

Resolution
0.2” - 0.3” beam

Sensitivity
0.2 - 0.4 mJy beam$^{-1}$

On source integr. time
30 sec – 1 min

Ansdell et al., 2016; 2018
CHAMAELEON I

PI: I. Pascucci
cycle 2, band 7
0.7” - 0.5”

93 sources
66 detected in the continuum (890 $\mu$m)
17 in $^{13}$CO (3-2)
1 in C$^{18}$O (3-2)

Pascucci et al., 2016
Long et al. 2017
CHAMELEON I

PI: I. Pascucci
cycle 2, band 7
0.7” - 0.5”

Resolution
0.7” - 0.5” beam
Sensitivity
0.2 -1 mJy beam^{-1}
σ-ORIONIS

PI: J. Williams
Cycle 3, band 6
0.31” x 0.25” →
120-95 au radius @385 pc

92 sources
37 detected in the continuum (890 µm)
6 in \(^{12}\text{CO} (3-2)\)
4 in \(^{13}\text{CO} (3-2)\)

Amsdell et al., 2017
σ-ORIONIS

Pl: J. Williams
cycle 3, band 6
0.31” x 0.25”
120-95 au radius @385 pc

Resolution
0.31” x 0.25” beam

Sensitivity
0.15 mJy beam⁻¹

On source integr. time
1.2 minutes

Amsdell et al., 2017
Resolution
0.1” beam

Sensitivity
10 mJy beam$^{-1}$
(0.2 km/s)

On source integr. time
4-10 minutes

32 targeted disks
11 clear detections down to $^{13}$CO
3 sources affected by cloud contamination

Long et al., in prep.
CHA I → deeper observations

PI: G. Rosotti

Resolution
0.3” x 0.2” beam

Sensitivity
~ 1 mJy beam\(^{-1}\)
(0.7 km/s)

On source integr. time
20 minutes

<table>
<thead>
<tr>
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<th>targeted disks</th>
<th>clear detections down to C(^{18})O</th>
<th>sources affected by cloud contamination</th>
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Rosotti, Miotello, et al., in prep
ALMA surveys were too shallow
1. ALMA surveys were too shallow
2. CO is much fainter than expected
DISK MASSES

13CO-based gas/dust ratio

dust masses

gas masses

Miotello et al., 2017
DISK MASSES

$^{13}$CO-based gas/dust ratio

CHAMAELEON I

Long et al., 2017
DISK MASSES

CHAMAELEON I + LUPUS

De Simone, Miotello & Testi
(in prep.)
LOW GAS/DUST OR HIGH VOLATILE C DEPLETION?

sign of disk evolution

1. physical evolution
   gas is dissipated
   $M_{\text{gas}} < M_{\text{jup}}$
   giant planet formation is quick or rare

2. chemical evolution
   volatile carbon is locked up in large icy bodies or turned into more complex species

Ansdell et al., 2016
Miotello et al., 2017
Manara et al., 2016
LOW GAS/DUST OR HIGH VOLATILE C DEPLETION?

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2. chemical evolution
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HYDROGEN DEUTERIDE
An alternative to measure disk masses (Bergin et al. 2013; McClure et al. 2016)
HYDROGEN DEUTERIDE
An alternative to measure disk masses

CO-based mass is 2 orders of magnitude lower than HD-based disk mass.
$C_2H$ in TW Hya

strong emission lines

Kama et al., 2016
Trapman, Miotello, et al., 2017

consistent with two orders of magnitude carbon depletion and $C/O>1$
C$_2$H rings

Hydrocarbons in TW Hya

IM Lup (Cleeves et al. 2018)

Bergin et al. (2016)
Kastner et al. (2015)

TW Hya
C$_2$H strong emission
CO fainter than expected
settling
C and O volatile depletion
\([\frac{[C]}{[O]} > 1]\)
(CO\(_2\), CH\(_3\)OH ices in large bodies)

Hogerheijde et al. 2011; Du et al. 2017; Krijt et al. 2018; Eistrup et al. 2016; 2018; Yu et al. 2017a,b; Bosman et al. 2017, 2018; Schwarz et al. 2018
radial drift
\[
\frac{[C]}{[O]} > 1
\]

Some free C not in CO

hydrocarbon chemistry starts
UV-photon-dominated PDR

$\frac{[C]}{[O]} > 1$

hydrocarbon emission is boosted
C$_2$H in Lupus

follow up ALMA Cycle 4 program in Band 6 (PI: Miotello)

search for anti-correlation of C$_2$H and $^{13}$CO line luminosity in a subsample of Lupus disks with CO-based g/d ratios between 1 and 100

Miotello et al., to be submitted
C$_2$H in Lupus

Possible ON/OFF switch of hydrocarbon emission led by C/O $\geq 1$

Step-function
Led by C/O ratio

Miotello et al., to be submitted
C$_2$H in Lupus

Possible ON/OFF switch of hydrocarbon emission led by C/O $\geq 1$

- $C_2H$ is bright as bright as $^{13}CO$ when it is detected

Step-function
Led by C/O ratio

Miotello et al., to be submitted
tentative anticorrelation between $\text{C}_2\text{H}$ emission and CO-based g/d ratio

Limited by low-number statistics
C$_2$H in Lupus

Volatile C and O depletion and C/O>1 can explain the observed $^{13}$CO and C$_2$H fluxes.
C$_2$H in Lupus

C$_2$H ring-like emission seems disconnected from continuum substructures

Similarly to CN, location of C$_2$H rings is not connected either with continuum rings or dips

Miotello et al., in prep.
DSHARP - Huang et al., 2018
Cazzoletti et al., 2018
van Terwisga et al. 2018
CO emission is faint sign of disk evolution
CO emission is faint sign of disk evolution

Physical or chemical evolution?
Figure 2. 890 µm continuum images of the 61 Lupus disks detected in our ALMA Cycle 2 program (i.e., excluding Sz 82, which was observed by Cleeves et al., in prep), ordered by decreasing continuum flux density (see Table 2). Images are 200 × 200 in size. The typical beam size is shown in the first panel.

$C_2H$ hints at chemical evolution. Fast gas dispersal is not yet ruled out.