Millimetre Science with the AT

Astrochemistry with mm-Wave Arrays

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mm-Arrays: Important Features

- Spatial Filtering
- Transform to image plane
- Cross Correlation
(Sub)Millimeter Astrophysics

- Thermal emission from cool dust, gas
- High frequency non-thermal tail
- Uniquely high spectral resolution possible

Orion KL, CSO
Late Type Stars and mm-Arrays

IRC+10216

Plateau de Bure (6 15 m’s)

2 µm AO image
Young Stars & Arrays

What size ranges are present?

<table>
<thead>
<tr>
<th>Component</th>
<th>Size (AU)</th>
<th>Taurus (&quot;)</th>
<th>Orion (&quot;)</th>
<th>Chemical Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-stellar core</td>
<td>&gt;10,000</td>
<td>&gt; 70</td>
<td>&gt; 20</td>
<td>Ions, Long-chains (HC₅N, DCO⁺, ...)</td>
</tr>
<tr>
<td>Cold envelope</td>
<td>5000</td>
<td>35</td>
<td>10</td>
<td>Simple species, Heavy depletions (CS, N₂H⁺, ...)</td>
</tr>
<tr>
<td>Warm inner envelope</td>
<td>500</td>
<td>3</td>
<td>1</td>
<td>Evaporated species, High-T products (CH₃OH, HCN, ...)</td>
</tr>
<tr>
<td>Hot core (high-mass only?)</td>
<td>500</td>
<td>...</td>
<td>2</td>
<td>Complex organics (CH₃OCHO, CH₃CN, ... vib. excited mol.)</td>
</tr>
<tr>
<td>Outflow: direct impact</td>
<td>&lt;100–500</td>
<td>&lt;0.7–4</td>
<td>&lt;0.2–1</td>
<td>Si- and S-species (SiO, SO₂, ...)</td>
</tr>
<tr>
<td>Outflow: walls, entrainment</td>
<td>100–1000</td>
<td>0.7–7</td>
<td>0.2–2</td>
<td>Evaporated ices (CH₃OH, ...)</td>
</tr>
<tr>
<td>Disk</td>
<td>100</td>
<td>0.7</td>
<td>0.2</td>
<td>Ions, D-rich species, Photoproducts (HCO⁺, DCN, CN, ...)</td>
</tr>
<tr>
<td>PDR, compact H II regions</td>
<td>100–3000</td>
<td>...</td>
<td>0.2–7</td>
<td>Ions, Radicals (CN/HCN, CO⁺)</td>
</tr>
</tbody>
</table>

Hogerheijde 1998, after Shu et al. 1987
Absorption Spectroscopy w/mm-Arrays

IRAM 30m

ρOph

PKS1830

High z features

Arrays filter out extended cloud!
SIRTF

- IRAC (mid-IR cameras, 3.6, 4.5, 5.8, 8.0 μm)
- MIPS (far-IR cameras, 24, 70, 160 μm, R=20 SED mode)
- IRS (5-40 μm long slit, R=150, 10-38 μm echelle, R=600)

01 Dec 2002 launch

- GTO observations
- Legacy program
- General observations
SIRTF – Mapping Large Clouds

Evans et al.
Legacy Team

Perseus, Cha, Lupus, Oph, Serpens + Isolated cores
Ideally, single dish should be ~twice array dish diameter for good (u,v) overlap…

Use Mopra to start, good single dish pointing essential.
Heterogeneous Arrays:

CARMA = BIMA + OVRO + SZ Array (8 3.5m telescopes)

SUP submitted
2002 road
2003 move OVRO
2004 move BIMA
2005 full operations
Chemistry and Massive Stars:

- Embedded at main sequence
- Large area heated, shocked
- Extensive chemistry
Orion as a Hot Core Test Case:

Bright lines, complex spatial structure!
The Dynamic Envelopes Around YSOs

- Dust + Gas = n(R), T(R), f(R)
- Polarization (B field support)?
A simple model for L1489 IRS

Inclined, flared disk, in Keplerian rotation and with possible inward motions:

\[ \frac{dR}{d\phi} = \frac{L_\text{uni}}{M_\star R} \]

\[ \frac{dT}{d\phi} = \frac{34 \text{ K} R^{-0.4}}{R} \]

\[ V_R = \sqrt{\frac{M_\star}{M_\odot}} \]

\[ V_W = -V_\odot \]

\[ M_\star = 0.65 \text{ M}_\odot \]

\[ M_d = 0.02 \text{ M}_\odot \]

\[ V_{in} = 1.3 \text{ km/s at 100 AU} \]

Hogerheijde 2001
Complementary IR Envelope/Disk Studies

CO M-band, infall to ~0.1 AU in L1489.

Keck

VLT

NIRSPEC
R=25000
Molecules in the Outflows from Young Stars

mm-arrays can be used to study all outflow phases, even those that are highly extincted. Velocity resolution critical!
Chemistry in YSO Accretion Disks. I

- Line shapes constrain disk orientation, size
- T Tauri, HAe disks well isolated
- Line ratios constrain n,T,chemistry (1 map+spectra)

DM Tau, PdBI
Chemistry in YSO Accretion Disks. II

LkCa 15 Disk, OVRO

Photochemistry near the disk surface?

Disk transport timescales?
Complementary IR Envelope/Disk Studies

CO emission at 4.7 μm, 0.1-10 AU gaps? Other species?

Keck

NIRSPEC
R=25000

VLT
Planetary Science with Millimeter Arrays. I.

Mars Opposition - March 1997

HST WFPC2-
   Color composite¹
   Surface features

HST WFPC2-
   Blue filter (410 nm)¹
   Cloud structure

OVRO - Integrated HDO
   Emission (1.3 mm)²
   Water vapor distribution

¹ P. James (U. Toledo), T. Clancy (SSI), S. Lee (U. Colorado), and NASA
² M. Gurwell (CfA), D. Muhleman (Caltech)
Planetary Science with Millimeter Arrays. II.

Titan’s Atmosphere - December 2000

Keck I - Near IR
Adaptive Optics

Cloud/haze structure
and surface features

OVRO -
Integrated CH$_3$CN
Emission (239.1 GHz)$^2$

OVRO -
Integrated HC$_3$N
Emission (236.5 GHz)$^2$

Latitudinal (seasonal?) variation of
molecular abundances in the upper atmosphere

$^1$ 3-color image from J,H, and K’ AO images (Keck AO team)

$^2$ M. Gurwell (CfA), D. Muhleman (Caltech)
Comets with mm-Arrays

Comae are LARGE, so good zero spacing flux or models mandatory! Jets, however, are compact.

Hale-Bopp Jets, OVRO
Future Submm Arrays - ALMA

64 12m’s
SIS, 8 GHz IF
Construction
FY02 approved.

2011
Atmospheric transmission at Chajnantor, $pwv = 0.5$ mm

![Graph showing atmospheric transmission with frequency bands marked.

AT/WW 2 July 99]
Future Submm Arrays – ALMA. II

ALMA will be incredibly sensitive – Disk images will be possible in continuum to a resolution of <1 AU!

Little is known about the Southern sky at high angular resolution…
Conclusions

- Wealth of opportunities for the ATCA, start with small sources that exploit the excellent sensitivity (disks, absorption line studies…), then move toward mosaics as the system improves.

- Make aggressive use of public datasets on nearby clouds and galaxy (2MASS, SIRTF) and on the new submillimeter single dish capabilities in Chile.

- ATCA not just an ALMA pathfinder, excellent complementary science even after 2011.