NEARBY GALAXIES AND ALMA

Jean Turner, UCLA
nearby galaxies

close-up views of star formation & nuclear fueling on scales of GMCs and star clusters

- where & how do galaxies form stars?
- where does gas spend most of its time?
- where does gas come from?
- what is AGN fueling about?
- what does “feedback” look like?
but early ALMA offers challenges for nearby, BIG galaxies
Herschel: fIR dust emission in M51
ALMA Early Science vs full ALMA: imaging

Messier objects are best done with full ALMA and ACA

M51 Herschel PACS 70+160 microns combined (ESA, PACS team, + JT Photoshop)

15 March 2011

Caltech ALMA Community Day, IPAC
M51 has been mapped in CO

Figure 7. CARMA and NRO45 combined CO ($J = 1-0$) map of M51 with robust $= -2$.

Figure 8. Same as Figure 7, but with robust $= +2$.

CARMA + NRO  Koda et al. 2011

15 March 2011

Caltech ALMA Community Day, IPAC
M51 CO pointings

Figure 7. CARMA and NRO45 combined CO ($J = 1-0$) map of M51 with robust = -2.

Figure 8. Same as Figure 7, but with robust = +2.

CARMA + NRO  Koda et al. 2011
Messier objects best done with full ALMA, ACA

Pety, Gueth, & Guilloteau 2001
dust continuum has the same problem as CO: very extended

free-free continuum is OK: bright & compact but relatively weak.
- detectable in 1 and 3mm bands
- extinction-free tracer of star formation
ES bands & resolution good for nearby galaxies

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Antennas</td>
<td>Sixteen 12 m antennas</td>
</tr>
<tr>
<td>Maximum Baseline Lengths</td>
<td>0.25 km maximum baseline</td>
</tr>
<tr>
<td>Angular Resolution (&quot;&quot;)</td>
<td>0.8” × (300/ν GHz) × (0.25 km / max. baseline)</td>
</tr>
<tr>
<td>12m Primary beam (&quot;&quot;)</td>
<td>20.3” × (300/ν GHz)</td>
</tr>
<tr>
<td>Receiver Bands Available</td>
<td>Bands 3, 6, 7, &amp; 9</td>
</tr>
</tbody>
</table>

5 Mpc: ~6-30 pc                      FOV: ~200-900 pc
50 Mpc: ~60-300 pc                   FOV: 2000-9000 pc
high CO transitions are compact

ALMA test image: CO(2-1) and CO(6-5) with 5 antennas

E/k(J=7) ~110K

15 March 2011
Caltech ALMA Community Day, IPAC
ALMA can spatially separate hot & cold gas

Rotational diagrams for CS indicate two temperatures 800-900K observed in ammonia even in quiescent galaxies (IC 342) Mauersberger et al. 2003

30 m, Bayet et al. 2011
detected extragalactic molecules

<table>
<thead>
<tr>
<th>Species</th>
<th>Detected Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ (+1)</td>
<td>H₂O, H₂CO, c-C₃H₂, CH₃OH, CH₃CCH</td>
</tr>
<tr>
<td>OH</td>
<td>HCN (+2), H₂CS, CH₃N, CH₃CN</td>
</tr>
<tr>
<td>CO (+3)</td>
<td>HNC (+2), NH₃, CH₂NH</td>
</tr>
<tr>
<td>CH</td>
<td>HCO, HNCO, NH₂CN</td>
</tr>
<tr>
<td>CS (+2)</td>
<td>HCO⁺ (+3), C₃H</td>
</tr>
<tr>
<td>CH⁺</td>
<td>H₂S, HOCO⁺</td>
</tr>
<tr>
<td>CO⁺</td>
<td>SO₂</td>
</tr>
<tr>
<td>NO</td>
<td>C₂H</td>
</tr>
<tr>
<td>CN</td>
<td>HOC⁺</td>
</tr>
<tr>
<td>NS</td>
<td>C₂S</td>
</tr>
<tr>
<td>SiO</td>
<td>N₂H⁺ (+1)</td>
</tr>
<tr>
<td>SO (+1)</td>
<td>OCS</td>
</tr>
<tr>
<td>LiH</td>
<td>H₃⁺</td>
</tr>
</tbody>
</table>

* NGC 253’s chemistry closely resembles that of Sgr B2(M) (B. Turner 1989)

* 35 (+ 4 tentatively) detected species

* 13 (+ 2 tentatively) detected rare isotopic substitutions

Compiled: Martín et al 2006; Updated by Meier
3mm & 2mm surveys

NGC 253

Martín et al. 2006, 30m

Snell et al. 2011, FCRAO 14m
1mm spectrum, Arp 220

Martín et al.

Fig. 6.— Detailed view of the spectral line survey. Spectral resolution of the observed data is smoothed to 20.5 MHz (25 – 30 km s$^{-1}$ across the covered range). The LTE model of the identified molecular species is represented in thick continuous line. Identified molecular features are indicated.
imaging chemistry

CO is not the whole story! Molecular abundances are sensitive tracers of galactic environment.

<table>
<thead>
<tr>
<th>N$_2$H$^+$</th>
<th>HNC</th>
<th>HC$_3$N</th>
<th>C$_2$H</th>
<th>C$_{34}$S</th>
<th>HNCO</th>
<th>CH$_3$OH</th>
</tr>
</thead>
</table>

OVRO, Meier & Turner 2005

IC 342 central 300 pc $\lambda$=3mm
imaging chemistry

IC 342 central 300 pc $\lambda=3$ mm

$N_2H^+$  HNC  $HC_3N$  $C_2H$  $C^{34}S$  HNCO  $CH_3OH$

quiescent gas  dense gas  PDR molecule: high radiation fields  grain chemistry; tracers of gentle shocks?

OVRO, Meier & Turner 2005

15 March 2011
imaging chemistry

IC 342 central 300 pc $\lambda=3\text{mm}$

$N_2H^+$, HNC, HC$_3$N, C$_2$H, C$^{34}$S, HNCO, CH$_3$OH

quiescent gas

star formation tracer

dense gas

PDR molecule: high radiation fields

grain chemistry; tracers of gentle shocks?

M82 is a “giant PDR”

OVRO, BIMA Meier & Turner 2005, 2010
Garcia-Burillo +02, Mauersberger & Henkel 1991, Henkel et al. 1991

15 March 2011
Caltech ALMA Community Day, IPAC
gas & star formation

Gao & Solomon 2004

HCN is better correlated with $L_{\text{IR}}$ than is CO

15 March 2011

Caltech ALMA Community Day, IPAC
gas & star formation

Gao & Solomon 2004

HCN is better correlated with L_{IR} than is CO

-is this because it is tracing dense gas?

-or is it an excitation effect? IR pumping
two dense gas tracers in IC342

HCN follows free-free emission faithfully
how to fuel AGN

inner 30" of NGC 6951

gas response to large-scale stellar bar causes gas inflow to 400 pc

but not any closer in

smaller stellar oval likely candidate for inflow in nuclear region

NGC 6951 (Sy 2, 23 Mpc, 1"=110 pc) inner 4 kpc

IRAM PdBI, NUGA project van der Laan et al. 2011

15 March 2011 Caltech ALMA Community Day, IPAC
The Feedback of Activity in AGN: NGC1068

- Prototypical nearby Seyfert 2
- 'Abnormal' chemistry: large HCN/CO intensity ratio in circumnuclear disk (CND)
- New 30m survey of the CND of NGC1068 confirms XDR scenario

(Usoro et al 2004)

No ongoing star formation in the CND ($T_{age} >= 2 \times 10^8$ yrs; Davies et al 2007)
PDR vs XDR

X-rays penetrate deeply and uniformly into clouds, enhancing chemical abundances of many species.
what is feedback? Arp 220

two nuclei

two counter-rotating CO disks

1'' ~ 360 pc

OVRO: Sakamoto et al. 1999

15 March 2011

Caltech ALMA Community Day, IPAC
what is feedback? Arp 220

high res 870μ continuum → compact, luminous western source

1'' ~ 360 pc
0.3'' ~ 100 pc

Fig. 2.— Molecular-line spectra at the two nuclei of Arp 220. Continuum has been subtracted. The right ordinate is the fractional absorption depth $\tau_L$ with respect to the continuum intensity of each nucleus, and can be converted to optical depth via $\tau_L = -\log(-L)$. The 1σ noise is 32, 12, and 28 mJy beam$^{-1}$ for HCO+(4-3), (3-2), and CO(3-2), respectively. The CO(3-2) spectra overlaid in black are from 0''75-resolution data in Sakamoto et al. (2008). The systemic velocity that we estimated for each nucleus is shown by a dashed line.

Sakamoto et al. 2009
Caltech ALMA Community Day, IPAC

15 March 2011
what is feedback? Arp 220

~100 km/s molecular outflow, potentially 100 M_☉/yr
early ALMA & nearby galaxies

early ALMA will be great for

- imaging of hot & dense gas
- extragalactic chemistry & radiative feedback from star formation
- AGN chemical diagnostics (PDRs, XDRs, shocks)
- kinematics of everything
- AGN fueling at the ~50 pc scale (NGC 4945, Circinus)

full ALMA will give high resolution & sensitivity for

- pc-scale gas structures in starburst galaxies & AGN
- extended disks of "normal" spiral galaxies in dust & CO