ALMA Science Highlights

Jongsoo Kim
ALMA Town-hall meeting at KASI
March 20, 2019
# ALMA Full Operations Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Antennas</strong></td>
<td>50×12 m (12-m Array), plus 12×7 m &amp; 4×12 m (ACA)</td>
</tr>
<tr>
<td><strong>Maximum Baseline Lengths</strong></td>
<td>0.16 - 16 km</td>
</tr>
<tr>
<td><strong>Angular Resolution (&quot;)</strong></td>
<td>~0.2” × (300/ν GHz) × (1 km / max. baseline)</td>
</tr>
<tr>
<td><strong>12 m Primary beam (&quot;)</strong></td>
<td>~20.6” × (300/ν GHz)</td>
</tr>
<tr>
<td><strong>7 m Primary beam (&quot;)</strong></td>
<td>~35” × (300/ν GHz)</td>
</tr>
<tr>
<td><strong>Number of Baselines</strong></td>
<td>Up to 1225 (ALMA correlators can handle up to 64 antennas)</td>
</tr>
<tr>
<td><strong>Frequency Coverage</strong></td>
<td>All atmospheric windows from 84 GHz - 950 GHz</td>
</tr>
<tr>
<td><strong>Correlator: Total Bandwidth</strong></td>
<td>(with extension to ~30 GHz when Band 1 is deployed)</td>
</tr>
<tr>
<td><strong>Correlator: Spectral Resolution</strong></td>
<td>16 GHz (2 polarizations × 4 basebands × 2 GHz/baseband)</td>
</tr>
<tr>
<td><strong>Polarimetry</strong></td>
<td>As narrow as 0.008 × (300/ν GHz) km/s</td>
</tr>
<tr>
<td></td>
<td>Full Stokes parameters</td>
</tr>
</tbody>
</table>
Level One Science Aims

• The ability to detect spectral line emission from CO or C\(^+\) in a normal galaxy like the Milky Way at a redshift z=3, in less than 24 hours of observation.

• The ability to image gas kinematics in a solar-mass protostellar / protoplanetary disk at a distance of 150 pc, enabling one to study the physical, chemical, and magnetic field structure of the disk and detect the tidal gaps created by planets undergoing formation.

• The ability to provide precise images at an angular resolution 0.1\(^\circ\).}

→ ASAC reported that the aims were essentially achieved for the last five Cycles.
DSHARP

- Cycle 4 LP
- High-resolution (35 mas) survey of 240 GHz (1.25mm) continuum and $^{12}\text{CO}$ J=2-1 emission from 20 nearby PPDs
- 10 articles published in ApJL focus issue
PHANGS; Cycle 5 LP
(Physics at High Angular Resolution in Nearby Galaxies)

- 74 galaxies; 750h ALMA time
- Understand star formation changes on the size, age, and internal dynamics
Sgr A*, First VLBI with ALMA

- GMVA (VLBA, GB, YS, PV, EB) + ALMA (37 phased antennas) at 86 GHz (3.5mm), 5.76h integration time with ALMA
- 87 μas (factor of 2 improvement)
- Unscattered source has a major-axis size of 120 μas (12 μas Schwarzschild radii)
Extraplannar $^{13}$CO in a Ram-pressure-stripped Galaxy

이범현, 정애리 2018, ApJL

The elongation of ram-pressure-stripped features in the same direction as the ICM wind is commonly observed in a range of wavelengths, and also in simulations (Tonnesen & Bryan 2010; Abramson & Kenney 2014). Compared to the main disk at the same radii, the central velocities of clumps are generally offset to the lower side, toward the Virgo center ($\sim 1100$ km s$^{-1}$, Mei et al. 2007), as expected for the gas stripped due to ram pressure (e.g., Kenney et al. 2004). In addition to the overall molecular gas morphology seen in the previous single-dish observations, all of these characteristics of clumps strongly support the impact of ICM winds on the molecular gas.

The distribution of the line ratio between $^{12}$CO and $^{13}$CO, $R_{^{12}CO}/^{13}CO$, across the extraplanar clumps is intriguing. $R_{^{12}CO}/^{13}CO$ within the main disk falls well within the range observed in nearby galaxies (Paglione et al. 2001; Vila-Vilaro et al. 2015). Meanwhile, $R_{^{12}CO}/^{13}CO$ of our extraplanar clumps is comparable to the disk ratio. For comparison, the intergalactic molecular gas pulled out during galaxy–galaxy interactions shows much higher $R_{^{12}CO}/^{13}CO$ (e.g., $\sim 50$ in the bridge of UGC 12914/5, Braine et al. 2003; $>25$ in the tidal tail of Stephan’s Quintet, Lisenfeld et al. 2004).

Figure 1. Top: ALMA CO intensity maps. The contour levels are $(1, 4, 9, 16, 25, 36, 49) \times 0.065$ Jy km s$^{-1}$ beam$^{-1}$ for $^{12}$CO and $(1, 4, 9, 15, 24, 35, 47) \times 0.009$ Jy km s$^{-1}$ beam$^{-1}$ for $^{13}$CO. The large blue ellipse and green circles represent the $K$-band size and primary beam of ALMA, respectively. The synthesized beam is shown in the bottom-left corner. Small black arrows on the left panel indicate the orientation of each clump, determined by fitting a 2D Gaussian. A thick black arrow shows the ICM wind direction (Abramson et al. 2016). Magenta and cyan contours represent the H I ($0.03$ Jy km s$^{-1}$ beam$^{-1}$) and single-dish CO ($1.7, 3.5, 6.5$ Jy km s$^{-1}$ beam$^{-1}$) data, respectively. Bottom: CO spectra derived from a tight box around the clumps with a 5 km s$^{-1}$ resolution. Blue and red lines show the CO flux density of individual clumps, and the light blue and gray backgrounds represent the main disk profile of $^{12}$CO and $^{13}$CO, respectively. The axis corresponds to the scale of $^{12}$CO, whereas $^{13}$CO spectra are magnified by a factor of 8. In the case of the main disk (background), the flux is scaled down by a factor of 0.15 for both lines.

Figure 2. Line ratio, $R_{^{12}CO}/^{13}CO$ distribution. Both $^{12}$CO and $^{13}$CO maps were imaged at $\sim 45$ resolution to increase S/N. The ratio ranges from 3 to 32, with a mean of $10.39 \pm 3.64$. The blue ellipse and black arrow are the same as in Figure 1.

COMs in V883 Ori
이정은+, 2019, NA

- V883 Ori, A FU Ori star with mass of 1.2 Msun
- ALMA band 7, 0.03" continuum, 0.2" for COM emission
ALMA Development Roadmap

**ORIGINS OF GALAXIES**
Trace the cosmic evolution of key elements from the first galaxies (z>10) through the peak of star formation (z=2–4) by detecting their cooling lines, both atomic (\[\text{CII}, \text{OIII}\]) and molecular (CO), and dust continuum, at a rate of 1-2 galaxies per hour.

**ORIGINS OF CHEMICAL COMPLEXITY**
Trace the evolution from simple to complex organic molecules through the process of star and planet formation down to solar system scales (~10-100 au) by performing full-band frequency scans at a rate of 2-4 protostars per day.

**ORIGINS OF PLANETS**
Image protoplanetary disks in nearby (150 pc) star formation regions to resolve the Earth forming zone (~ 1 au) in the dust continuum at wavelengths shorter than 1mm, enabling detection of the tidal gaps and inner holes created by planets undergoing formation.
ALMA paper productivity

Extrapolation
ALMA proposals and papers

- ’17→’18
- Submitted proposal: 32→49
- Accepted proposal: 10→11
- Published paper: 7→13