JCMT CO(3-2) Mapping of M31

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CO(3-2) in the circumnuclear region of M31

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- M31: distance: 780 kpc, i.e. 1” ≈ 4 pc, nearest large spiral, hosts an extremely quiescent SMBH, with little AGN activity and star formation in the central region (~0.4 solar mass/yr). It has a much larger bulge and less obvious spiral arms, with most of the star formation occurring in a 10 kpc ring.

- Previous surveys show limited neutral gas detections in the circumnuclear region. (e.g. Braun 2009, Nieten 2006)
CO morphology and line ratio

Color map: dust mass surface density.
White contour: CO(3-2). Black contour: CO(1-0).

$\text{CO(3-2)/CO(2-1)} \sim 0.8$

$\text{CO(3-2)/CO(1-0)} \sim 0.9$
Molecular gas temperature and density in the central region

- $A_v \sim 1$, $n(H_2) \sim 10^3 - 10^4 \text{ cm}^{-3}$.
- Large velocity gradient (LVG) assumption with RADEX code:
  - $\text{CO}(3-2)/\text{CO}(1-0)$ ($R_{31}$) $\sim 0.90$:
    - $T_k > 20 \text{ K}$ and $n(H_2) > 4 \times 10^3 \text{ cm}^{-3}$;
  - $\text{CO}(3-2)/\text{CO}(2-1)$ ($R_{32}$) $\sim 0.8$:
    - $T_k > 30 \text{ K}$ and $n(H_2) > 2 \times 10^3 \text{ cm}^{-3}$.

HARP and SCUBA-2 High-Resolution Terahertz Andromeda Galaxy Survey (HASHTAG)

- JCMT large program: first ground-based submillimeter continuum survey of the Andromeda. (273.6 hr)
- SCUBA-2: 450 μm (25 pc) and 850 μm (50 pc) very cold dust survey for entire M31.

PI: Matthew Smith
Observing Manager: Yu Gao
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HARP CO observations

- HARP CO(3-2) observations: Eleven 2’ x 2’ jiggle fields, one 4’ x 4’ raster field (55.3 hours in total). Mean rms: 0.016 K $T_A^*$
  1. Five regions covered by Herschel and optical IFU spectroscopy
  2. Two regions where it has been suggested that there is a component of very cold gas
  3. Four in the area observed by PHAT, CARMA and the IRAM CO(1-0)/CO(2-1)
- For now: focusing on the CO(3-2)/CO(1-0) ratio.
CO Spectra of the disk

Black: CO(1-0), red: CO(3-2)

Color map: dust, black contour: CO(3-2), white contour: CO(1-0)

Credit: Matt Smith
**CO(3–2)/CO(1–0) ratio ($R_{31}$)**

- Nuclear region: $\sim 0.8$
- Mean ratio of the 10 kpc ring: 0.27
- Mean ratio of the inner disk: 0.14

Nucleus: $\sim 0.8$, Disk: $\sim 0.23$.

Galactic center: $\sim 0.7$, Galactic disk: $\sim 0.4$

(Oka et al., 2012)
$T_{\text{dust}}$ vs. $R_{31}$

- Spearman’s rank correlation coefficient: $\rho \sim 0.55$
- p-value < 0.001
Correlation with star formation rate (SFR) surface density

- CO(3-2) has tighter correlation with SFR surface density than CO(1-0).
- A sub-linear KS relation: power-law index 0.49.
Ongoing follow-up programs

Follow-up IRAM 30m CO(1–0) and JCMT CO(3–2) mapping of the nuclear region:

- Help reveal the origin of the nuclear spiral.
- Complementary of HASHTAG CO observations.

Left: dust surface density map (Groves 2012). Right: Hα map. Dashed ellipse marks the nuclear ring.
Prospects

• Retrieve CO(2-1) of the 4 fields and further analyze the ratios.

• Combine previous CII data of M31 center and the 5 fields in the disk with CO(3-2) data, to determine the dark gas fraction and gas properties.

• CO(3-2) contamination to dust continuum.

• ......
Summary

- $R_{31}$ ratio is higher in the central region (0.8) than in the disk (0.14), and rise again in the 10 kpc ring (0.27).

- $R_{31}$ has a significant correlation with dust temperature.

- SFR surface density has a tighter relationship with CO(3–2) than CO(1–0).

- The KS relation derived using CO(3–2) has a sub-linear power-law index of 0.49.