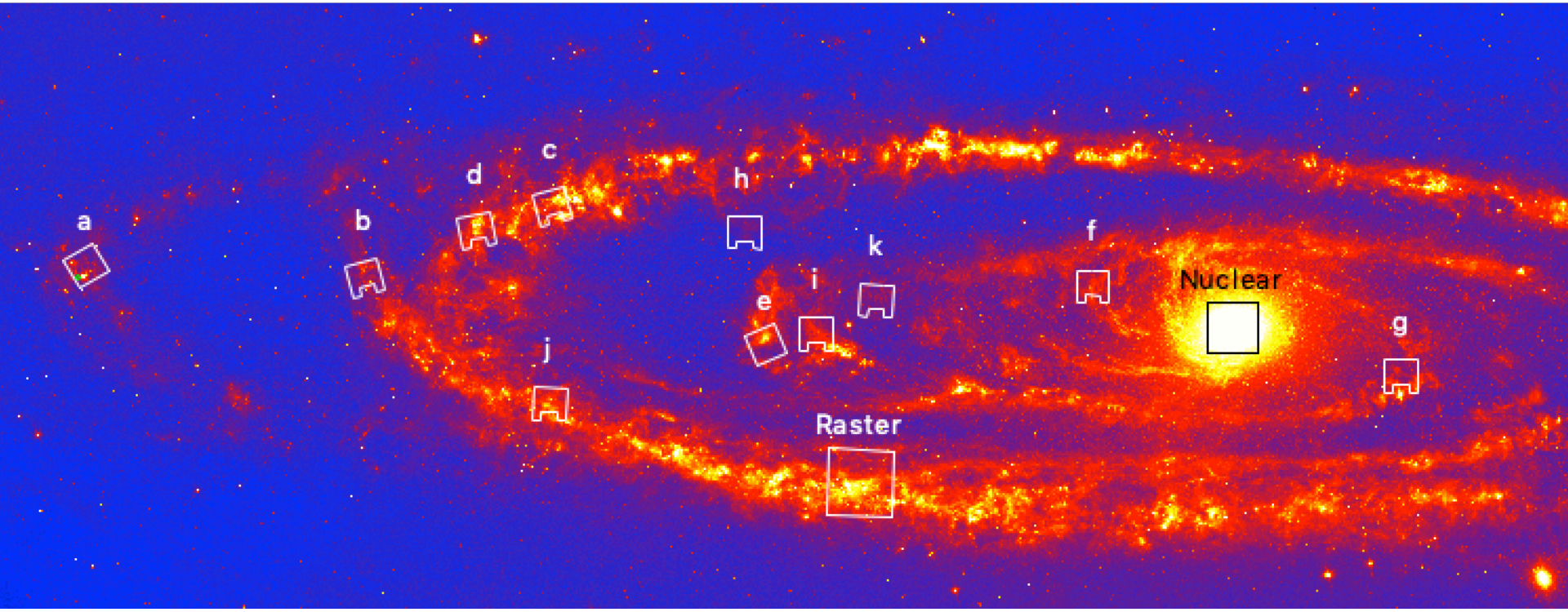
JCMT CO(3-2) Mapping of M31



Zongnan Li (Nanjing University)

Collaborators: Zhiyuan Li, Yu Gao (PMO), Matthew Smith (Cardiff University)

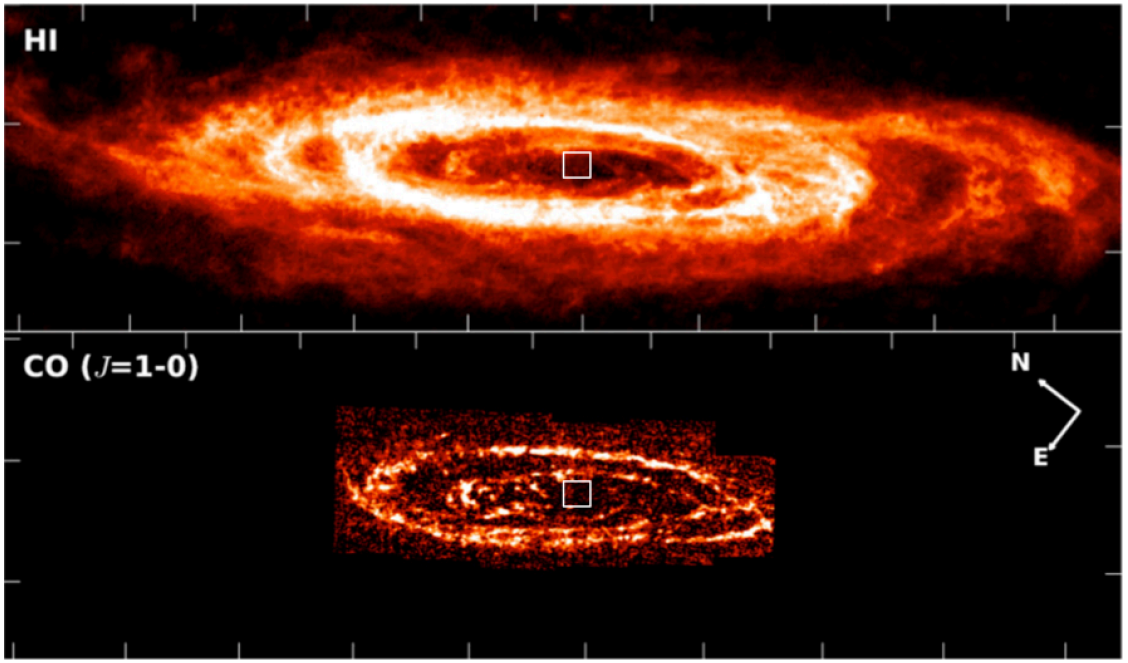
JCMT workshop, Taipei

2019.11.6

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

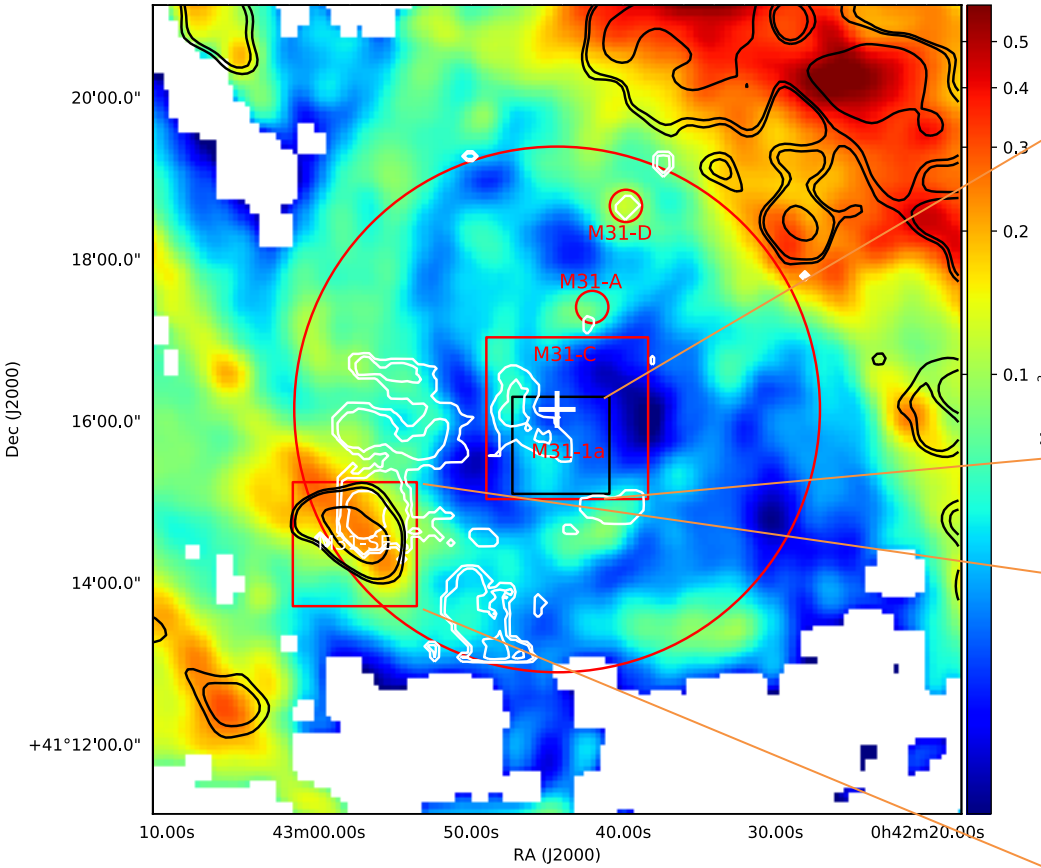
PI: Zhiyuan Li

- 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.

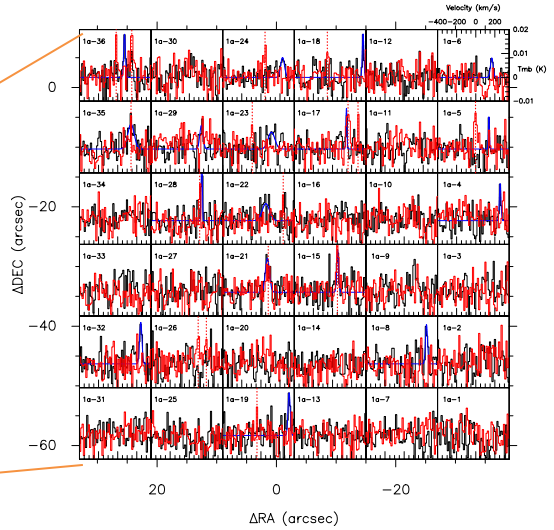


- Previous surveys show limited neutral gas detections in the circumnuclear region. (e.g. Braun 2009, Nieten 2006)

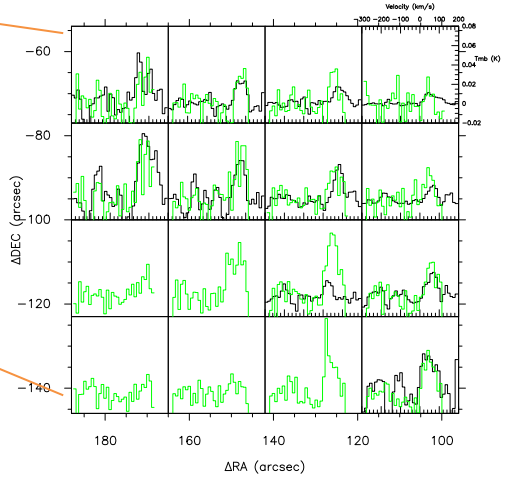
CO morphology and line ratio



CO(3-2)/CO(2-1)~0.8



CO(3-2)/CO(1-0)~0.9



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

Molecular gas temperature and density in the central region

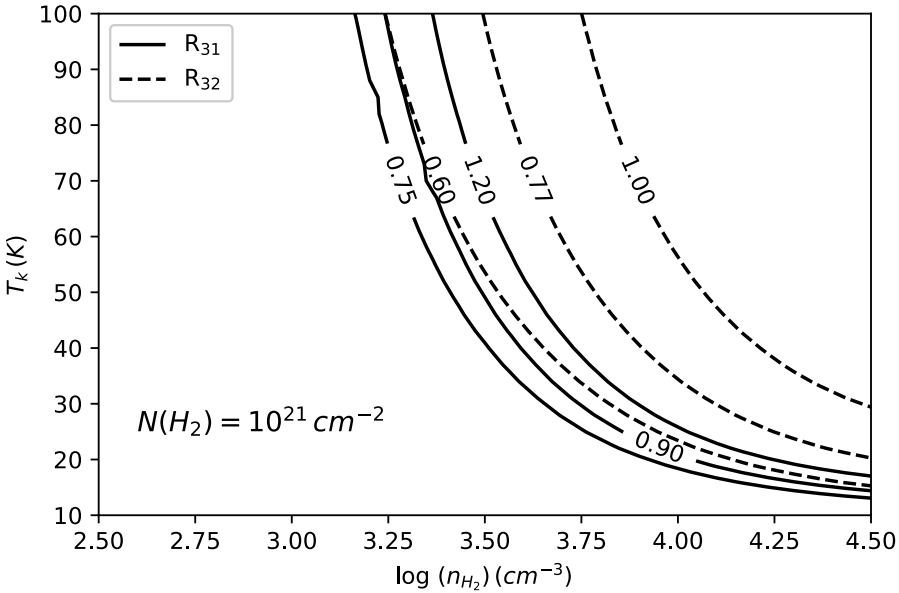
- A_v ~1, n(H_2)~ 10^3 – 10^4 cm^{-3}.
- Large velocity gradient (LVG) assumption with RADEX code:

CO(3-2)/CO(1-0) (R_{31}) ~ 0.90 :

T_k > 20 K and n(H_2) > 4 x 10^3 cm^{-3};

CO(3-2)/CO(2-1) (R_{32}) ~ 0.8 :

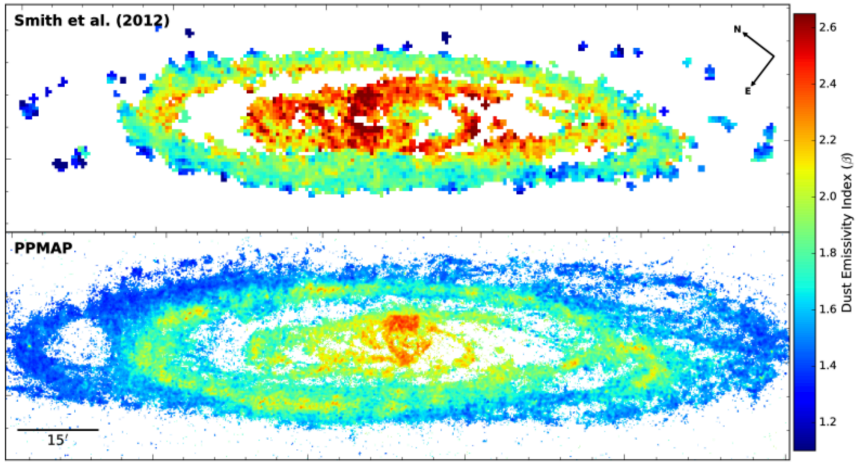
T_k > 30 K and n(H_2) > 2 x 10^3 cm^{-3}.



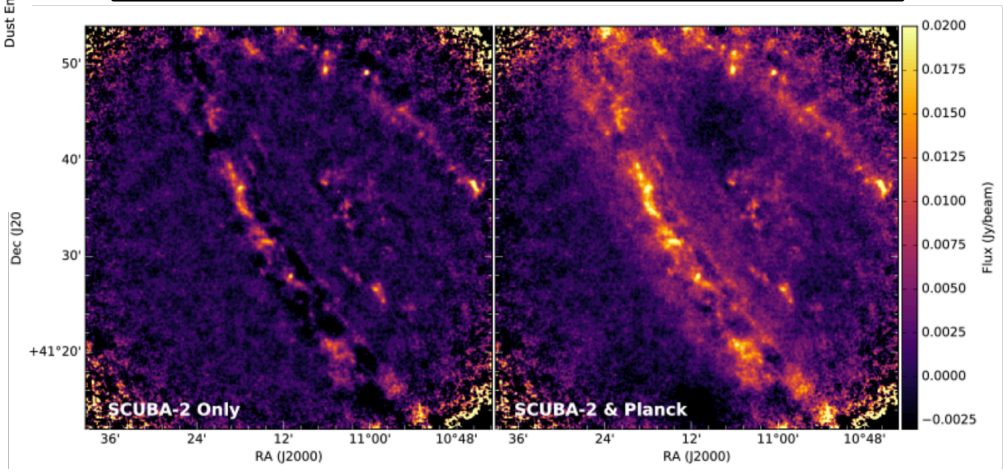
Li et al. 2019, MNRAS, 484, 964

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
Spectroscopy data reduction lead: Zhiyaun Li

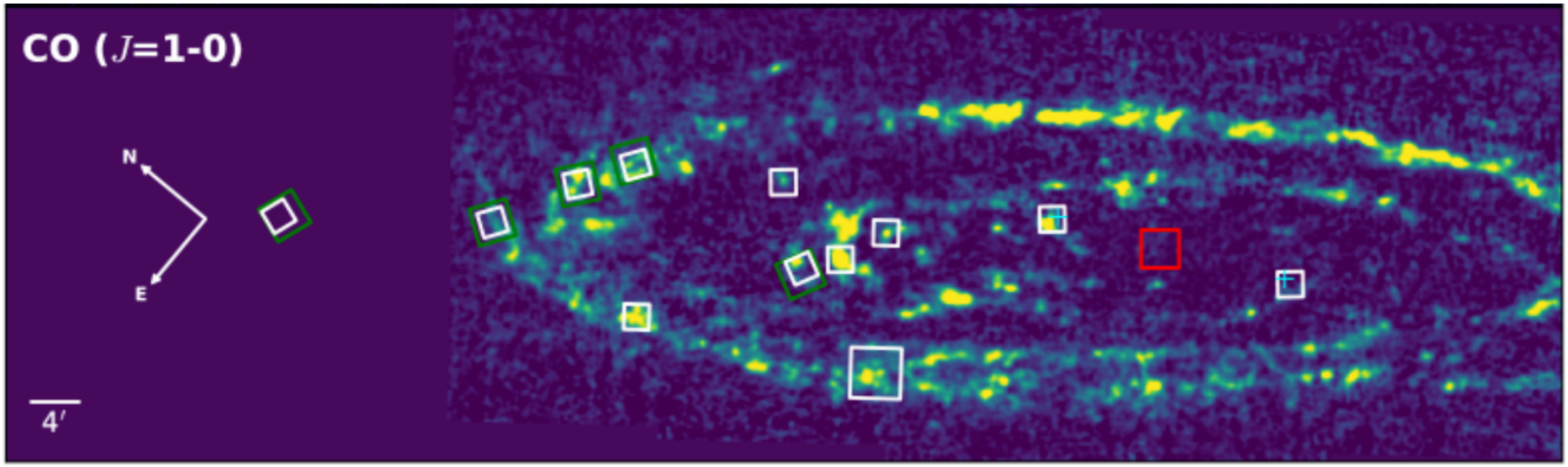


HARP CO observations

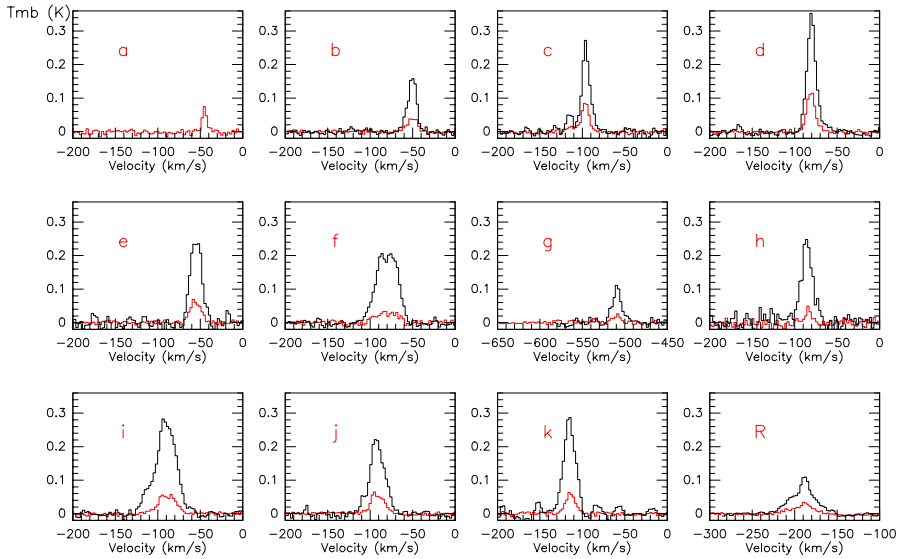
- HARP CO(3-2) observations: Eleven 2’ x 2’ jiggle fields, one 4’ x 4’ raster field (55.3 hours in total). Mean rms: 0.016 K T_A^*

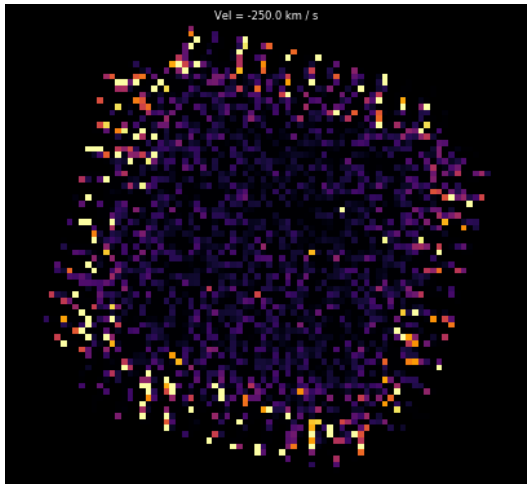
1. Five regions covered by Herschel and optical IFU spectroscopy
2. Two regions where it has been suggested that there is a component of very cold gas
3. Four in the area observed by PHAT, CARMA and the IRAM CO(1-0)/CO(2-1)

- For now: focusing on the CO(3-2)/CO(1-0) ratio.



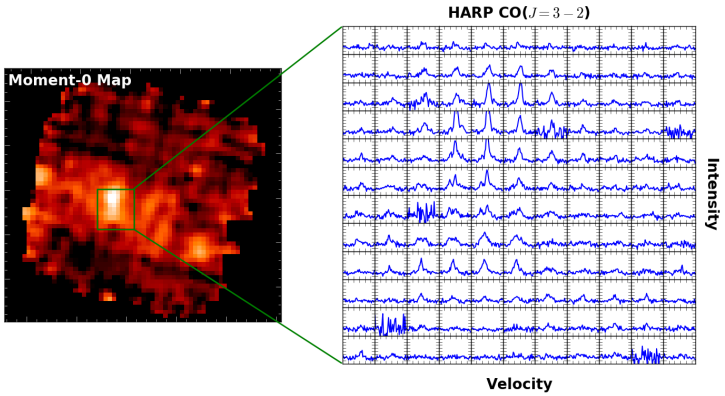
CO Spectra of the disk

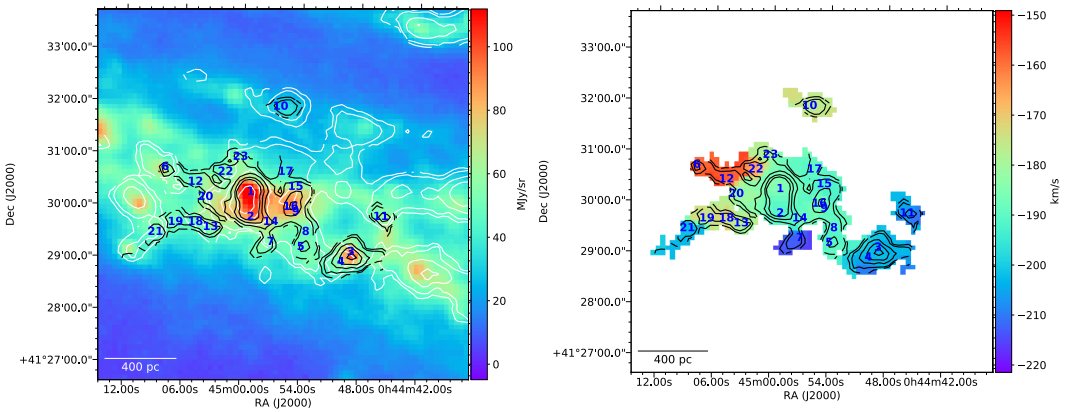




Credit: Matt Smith

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

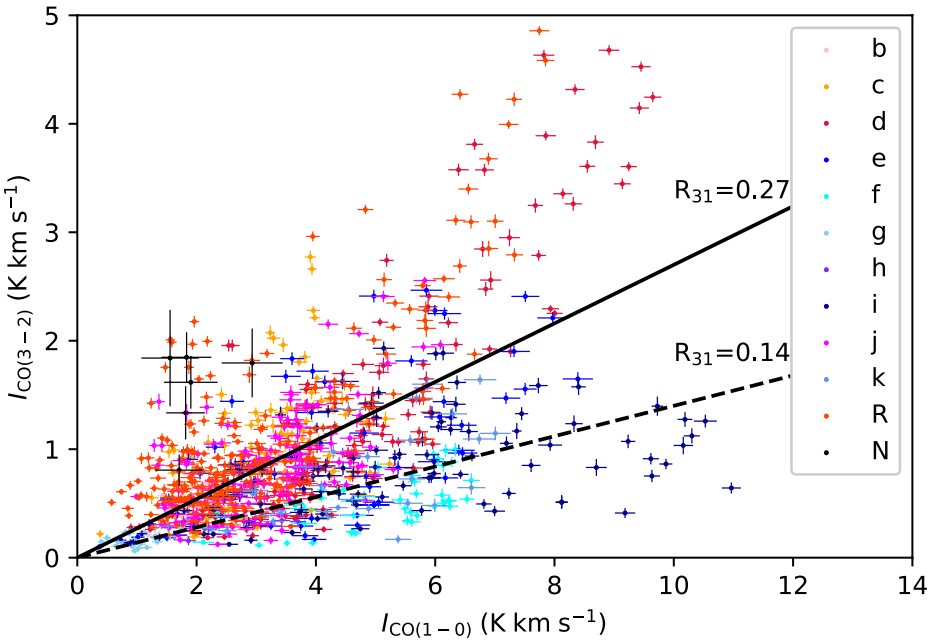


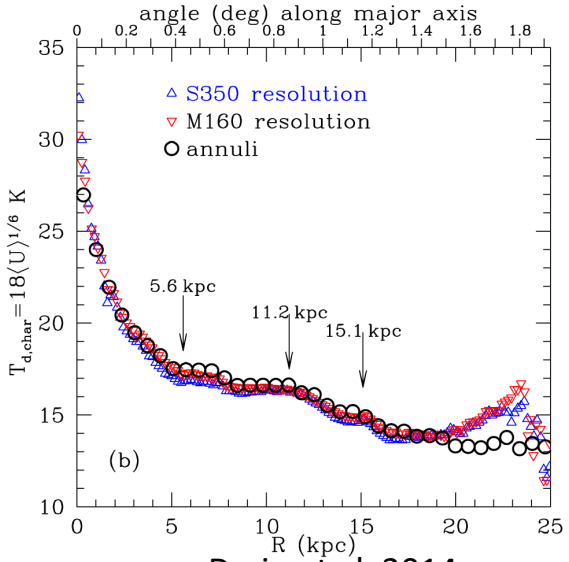


Color map: dust, black contour: CO(3-2), white contour: CO(1-0)

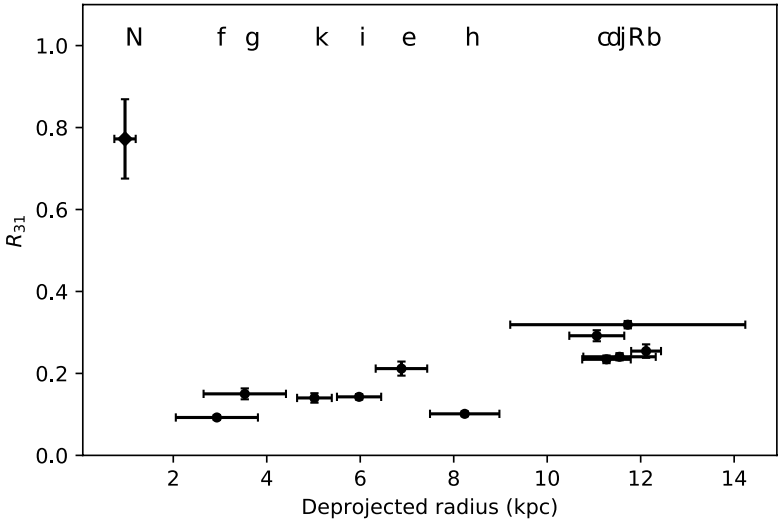
CO(3-2)/CO(1-0) ratio (R_{31})

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





Drain et al. 2014

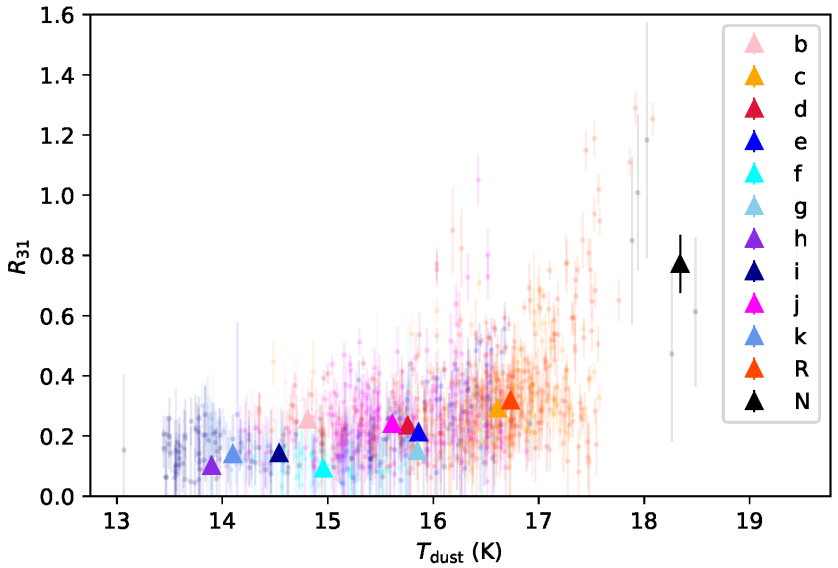


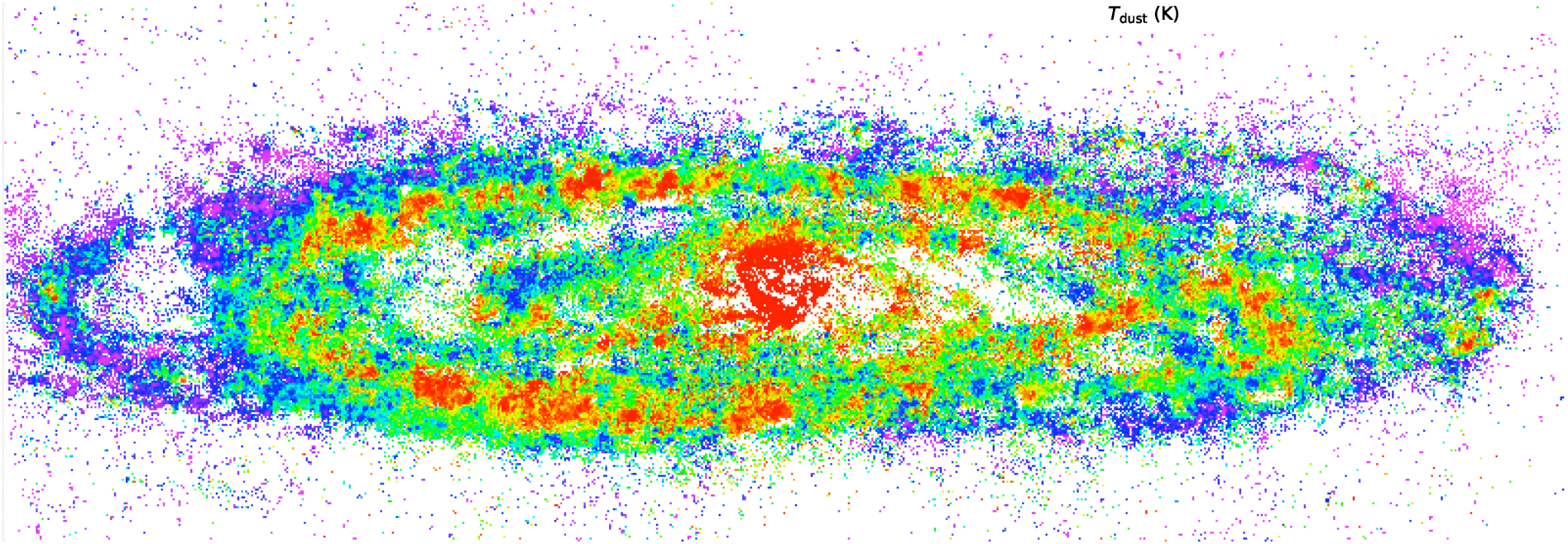
Nucleus: ~0.8, Disk:~0.23.

Galactic center: ~0.7, Galactic disk: ~0.4 (Oka et al., 2012)

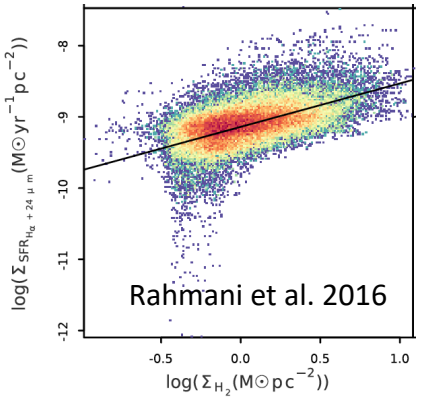
T_{dust} vs. R_{31}

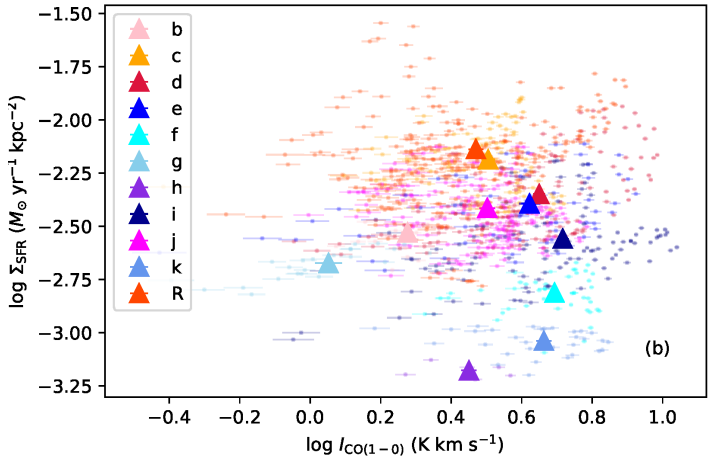
- Spearman's rank correlation coefficient: ρ ~ 0.55
- p-value < 0.001

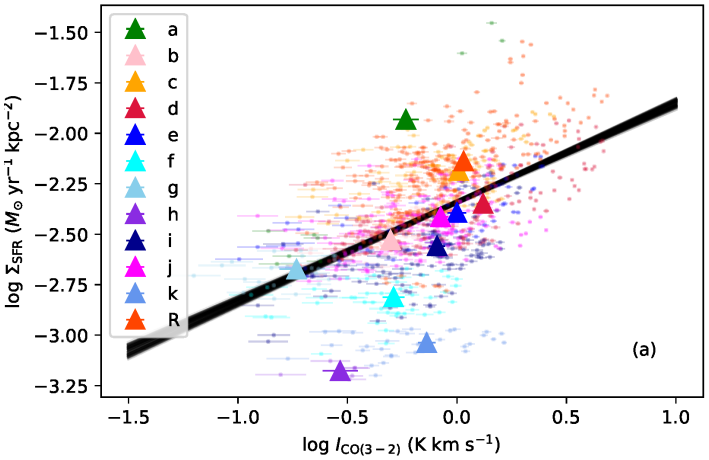




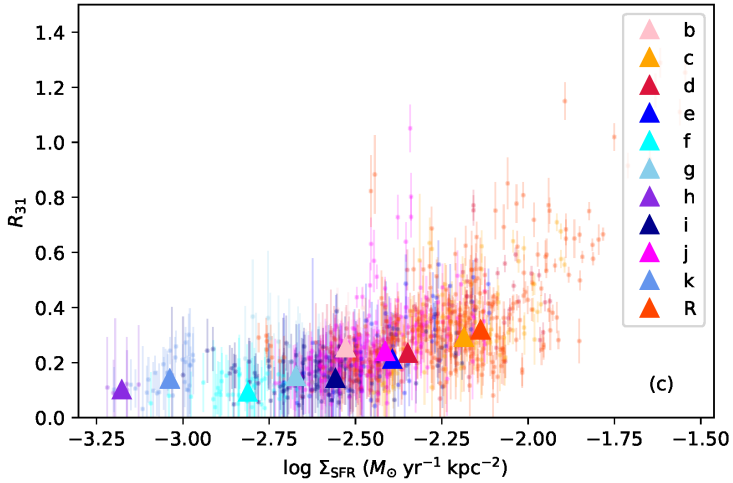
Correlation with star formation rate (SFR) surface density







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



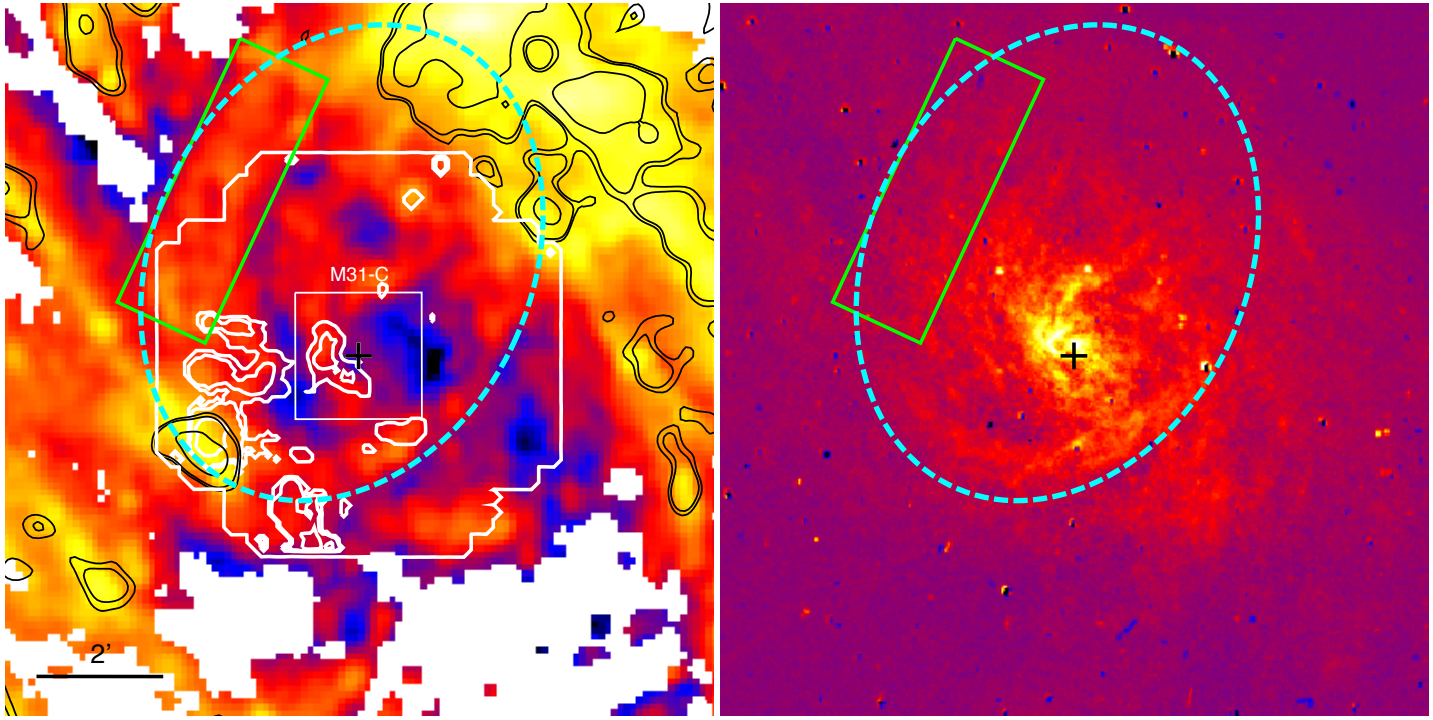
R_{31} vs. SFR surface density

$\rho \sim 0.69$

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.