



***ALMA Science Archive (ASA) -
(Extremely biased) examples of archive-based science***

Toshiki Saito - NAOJ ALMA Project



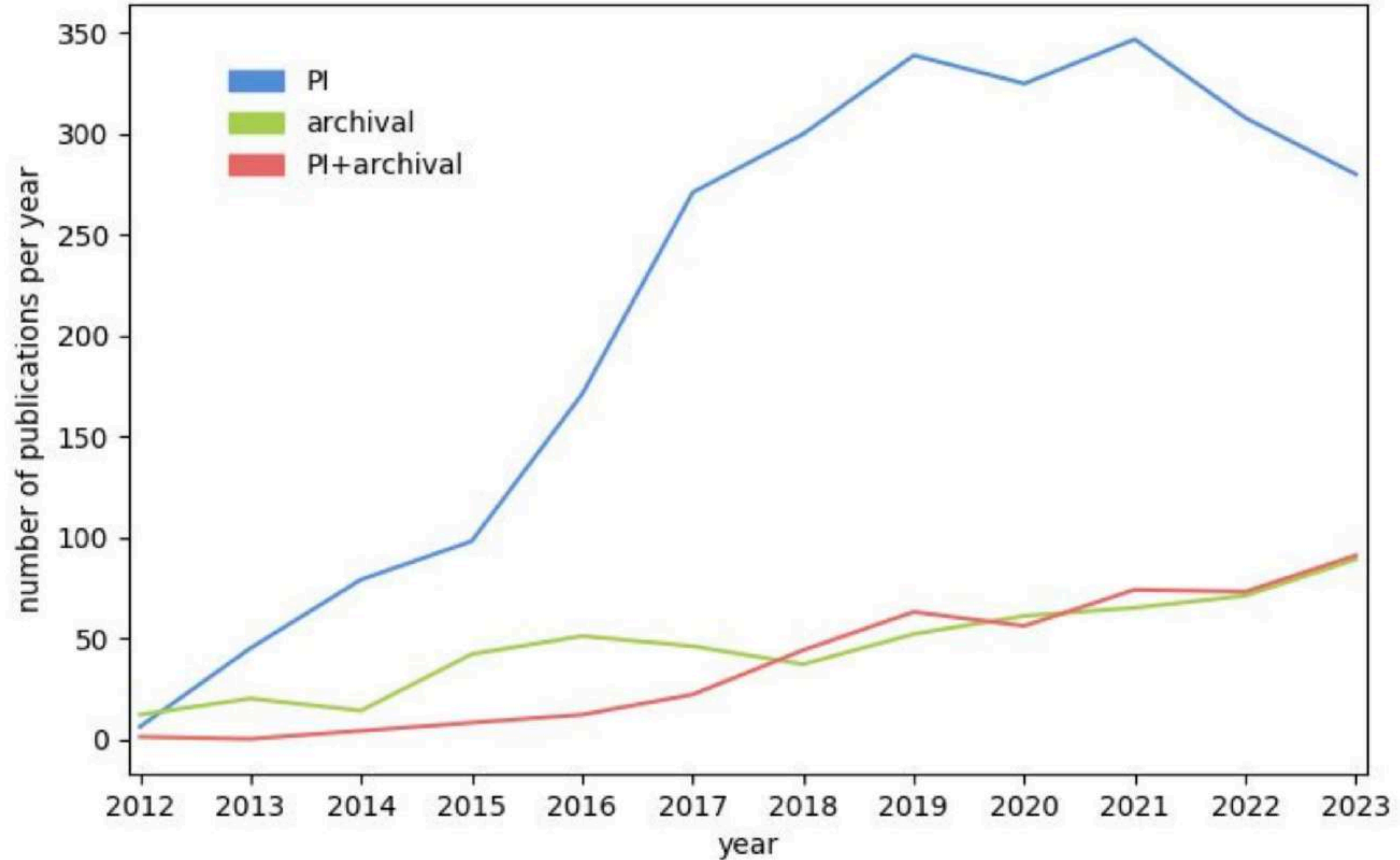
This talk will...

- make new users feel comfortable to start archive-based science by describing some (extremely biased) examples.
- introduce four extragalactic **examples collecting large-program-sized data** from the archive.
 1. A single line for many galaxies I (*Ledger et al. 2024*)
 2. A single line for many galaxies II (*Saito et al. in prep.*)
 3. Many lines and deep continuum for a single galaxy (*Watanabe et al. in prep.; Okubo et al. in prep.; Nagashima et al. in prep., ...*)
 4. A large patchy deep field (*Liu et al. 2019ab*)

ALMA archive is a treasure island!

Refereed ALMA publications (total: 3577)

→ See also Pei-Ying's talk!



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1. A single line for many galaxies I

A single line for many galaxies I (Ledger, Saito et al. 2024)

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ROYAL ASTRONOMICAL SOCIETY





MNRAS **527**, 2963–2990 (2024)

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Stored in the archives: Uncovering the CN/CO intensity ratio with ALMA in nearby U/LIRGs

B. Ledger , ¹★ T. Saito, ² D. Iono ^{2,3} and C. D. Wilson  ¹

¹*Department of Physics and Astronomy, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4M1, Canada*

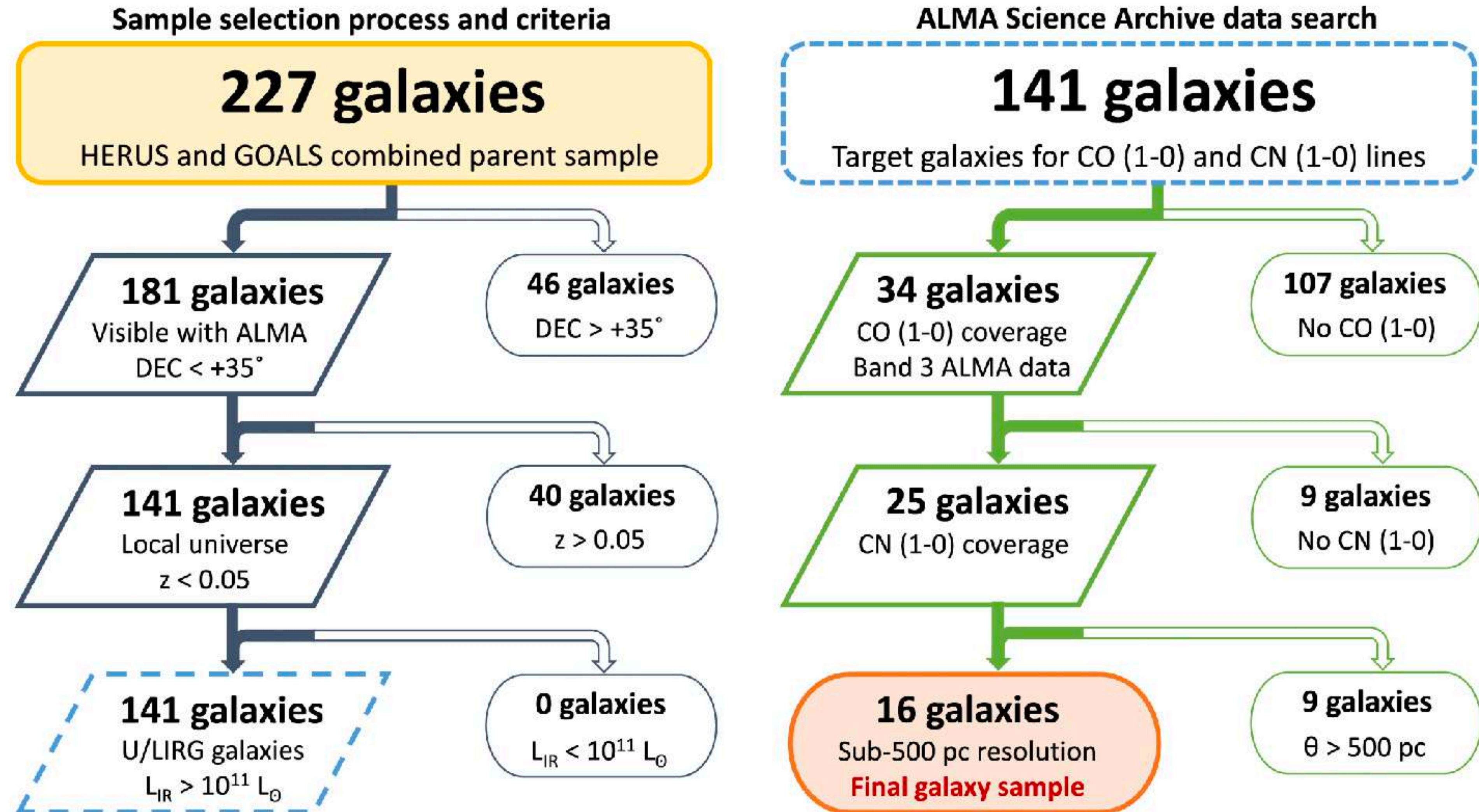
²*National Astronomical Observatory of Japan, National Institutes of Natural Sciences, 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan*

³*Department of Astronomical Science, The Graduate University for Advanced Studies, SOKENDAI, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan*

Ledger et al. 2024, MNRAS, 527, 2963; Ledger et al. in prep.

1. A single line for many galaxies I

A single line for many galaxies I (Ledger, Saito et al. 2024)



Ledger et al. 2024, MNRAS, 527, 2963; Ledger et al. in prep.

1. A single line for many galaxies I

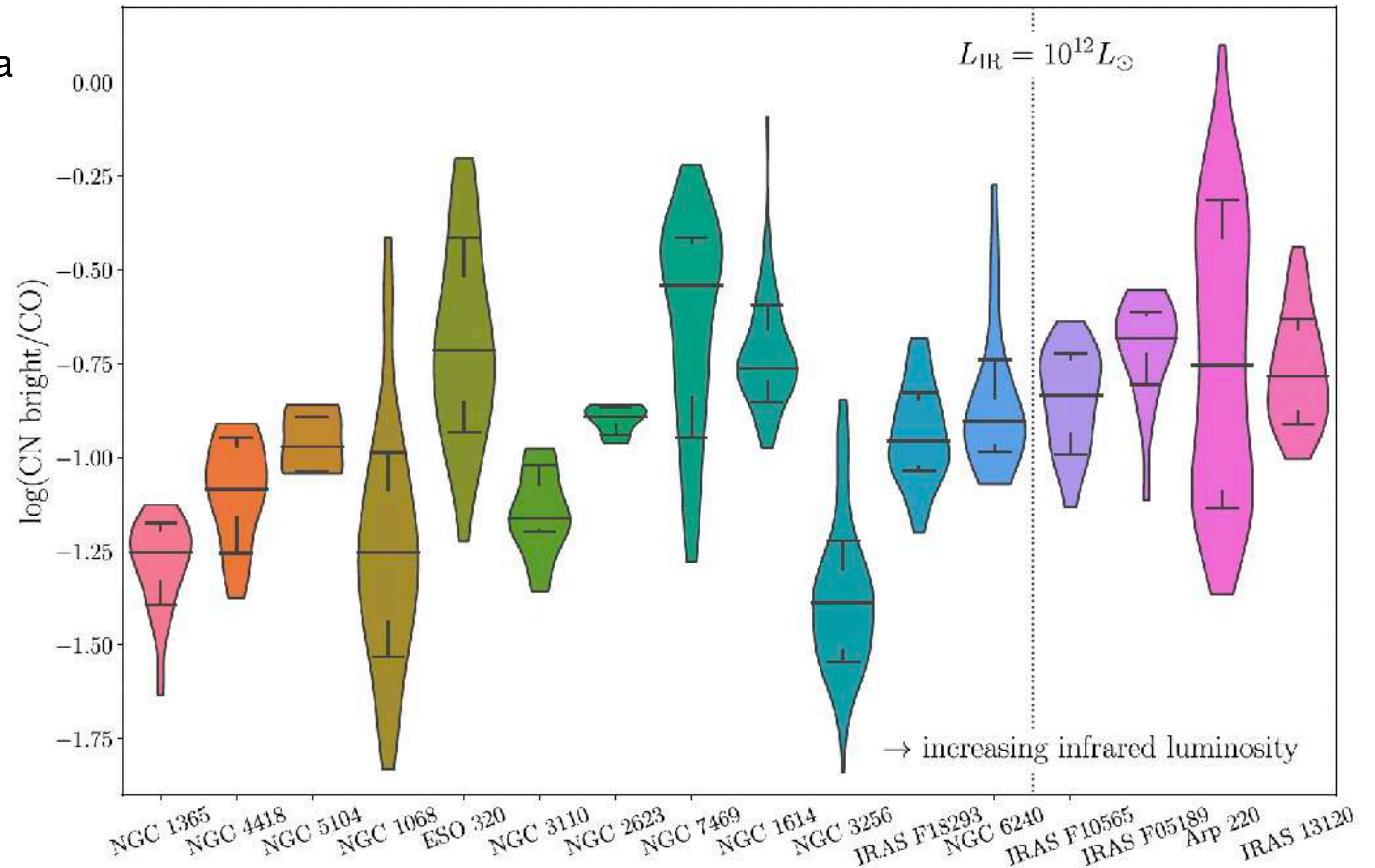
A single line for many galaxies I (Ledger, Saito et al. 2024)

An archive-based project that achieved medium-sized program.

- 16 galaxy sample
- **16** (our own and) archival projects
- Total 12m observing time ~ **34 hours**
- scriptForPI.py + manual flags for earlier cycle data
- PHANGS-ALMA imaging pipeline processed

Any project targeting CO(1-0) in principle covers CN lines. Our data will be getting larger automatically and forever.

Galaxy ^a	CO and CN project code
IRAS 13120-5453	2015.1.00287.S
Arp 220	2015.1.00167.S
IRAS F05189-2524	2012.1.00306.S
IRAS F10565+2448	2019.1.01664.S
NGC 6240	2015.1.00003.S
IRAS F18293-3413	2015.1.01191.S
NGC 3256	2018.1.00223.S
NGC 1614	2013.1.00991.S
	2013.1.01172.S
NGC 7469	2013.1.00218.S
	2017.1.00078.S
NGC 2623	2015.1.01191.S
NGC 3110	2013.1.01172.S
ESO 320-G030	2016.1.00263.S
NGC 1068	2012.1.00657.S
	2018.1.01684.S
NGC 5104	2015.1.01191.S
NGC 4418	2016.1.00177.S
NGC 1365	2015.1.01135.S



Ledger et al. 2024, MNRAS, 527, 2963; Ledger et al. in prep.

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Archival CO(2-1) survey for nearby (U)LIRGs at 150 pc resolution

A single line for many galaxies II (Saito et al. in prep.)

An archive-based project that achieved large program size.

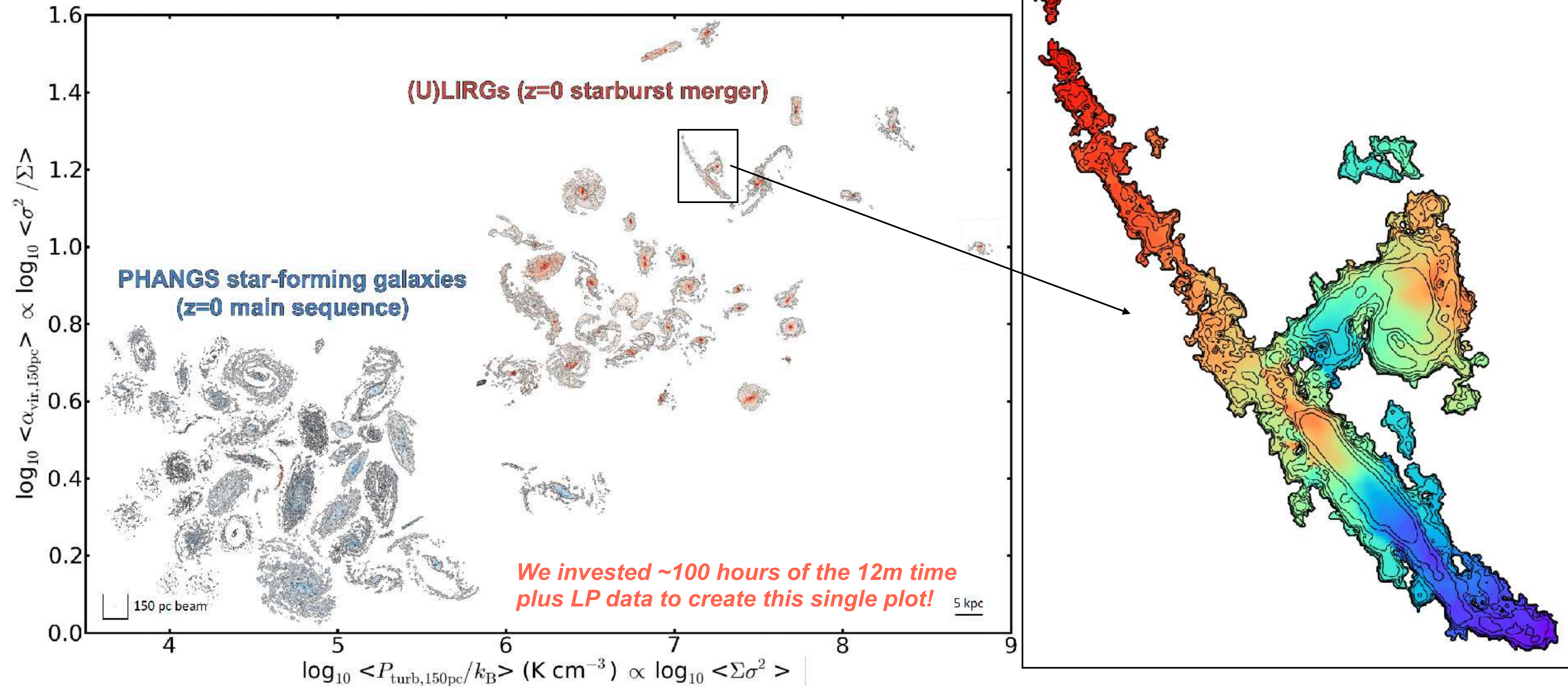
- 34 galaxy sample
- **25** (our own and) archival projects
- Total 12m observing time ~ **105 hours**, 7m time ~ **250 hours** (+ TP time)
- Selection criteria:
 1. Nearby (U)LIRGs in Armus et al. 2009 (i.e., the GOALS sample)
 2. Band 6 projects that cover CO(2-1)
 2. Spatial resolution better than 150 pc (=0.1"-0.4" at (U)LIRG distances)
 3. Short-spacing data if present
- **The largest (U)LIRG sample in the world as of now thanks to archive!**
- **We also use the PHANGS-ALMA large program data as the control sample.**

Projects in use:

*2013.1.01172.S, 2015.1.00003.S,
2015.1.00113.S, 2015.1.00263.S,
2015.1.00287.S, 2015.1.00370.S,
2015.1.00714.S, 2015.1.00804.S,
2015.1.00902.S, 2016.1.00170.S,
2016.1.00777.S, 2016.2.00055.S,
2017.1.00042.S, 2017.1.00255.S,
2017.1.00297.S, 2017.1.00395.S,
2017.1.00767.S, 2017.1.01158.S,
2018.1.00473.S, 2018.1.00486.S,
2018.1.00503.S, 2018.1.00699.S,
and 2019.2.00227.S.*

Archival CO(2-1) survey for nearby (U)LIRGs at 150 pc resolution

A single line for many galaxies II (Saito et al. in prep.)



This talk will...

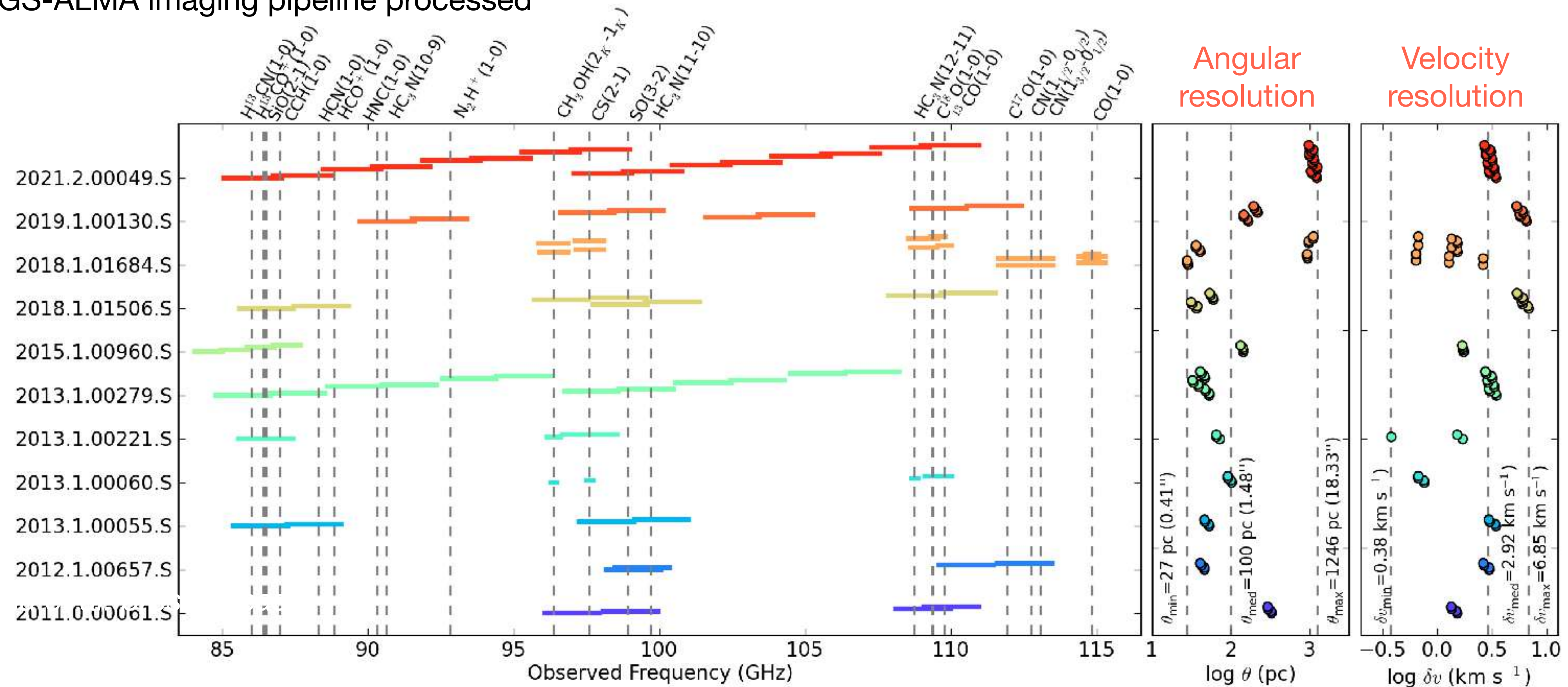
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Collecting ALMA projects for a single galaxy

Many lines and deep continuum for a single galaxy (Saito et al. 2022b; Watanabe et al. in prep.; Nagashima et al. in prep.)

An archive-based project that achieved **nearly large program size without large-program-size efforts.**

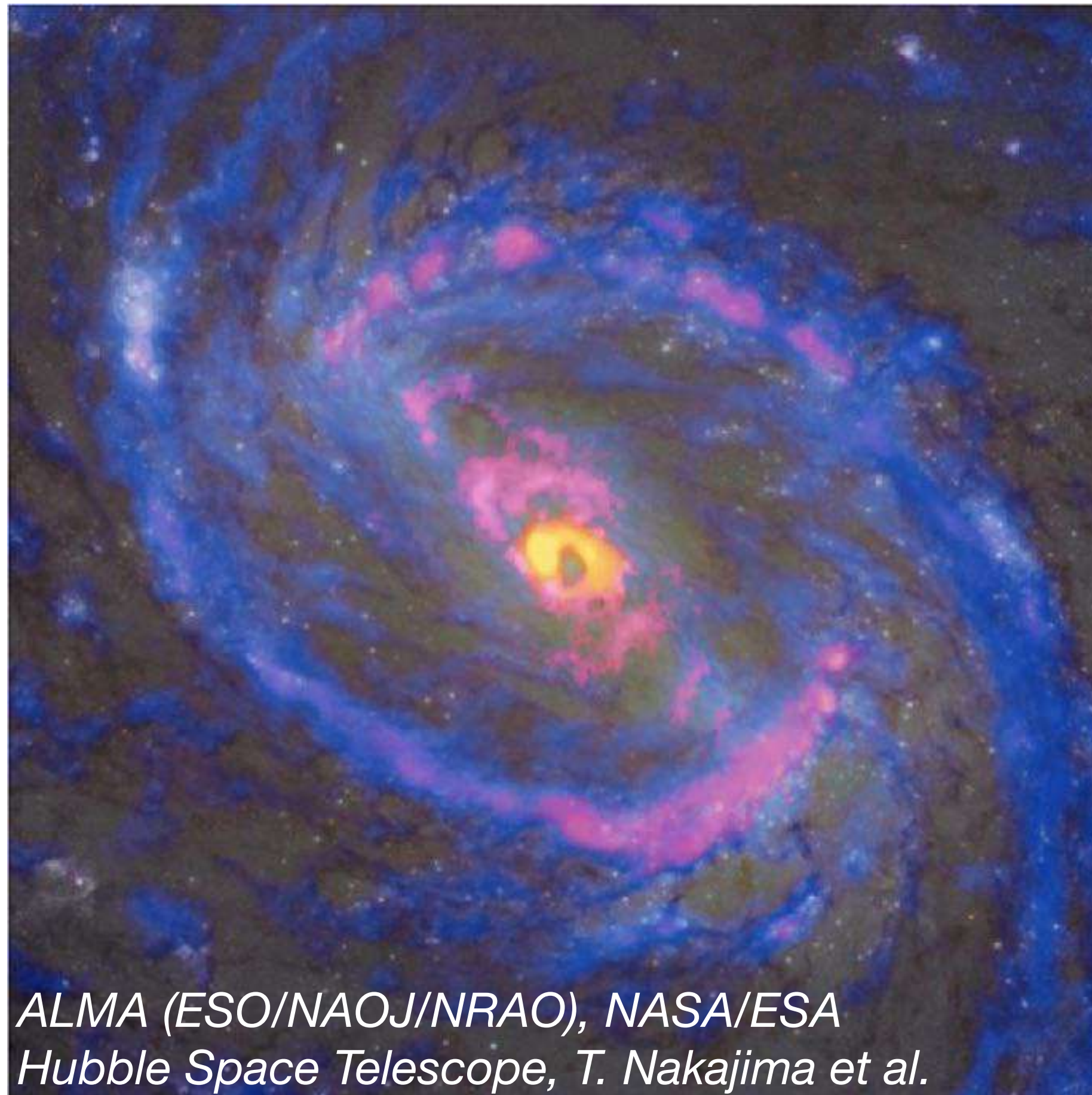
- Total 12m observing time ~ **40 hours**
- Total 7m observing time ~ **43 hours** (+ TP time)
- scriptForPI.py + manual flags for early cycle data
- PHANGS-ALMA imaging pipeline processed



Collecting ALMA projects for a single galaxy

Many lines and deep continuum for a single galaxy (Saito et al. 2022b; Watanabe et al. in prep.; Nagashima et al. in prep.)

HST+ALMA $^{13}\text{CO}/\text{CN}/\text{H}^{13}\text{CN}$



*ALMA (ESO/NAOJ/NRAO), NASA/ESA
Hubble Space Telescope, T. Nakajima et al.*

8 projects utilizing this Band 3 data...

- Nakajima et al. 2023, ApJ, 955, 27 (poster)
- Saito et al. 2022a, ApJL, 927, 32
- Saito et al. 2022b, ApJ, 935, 155

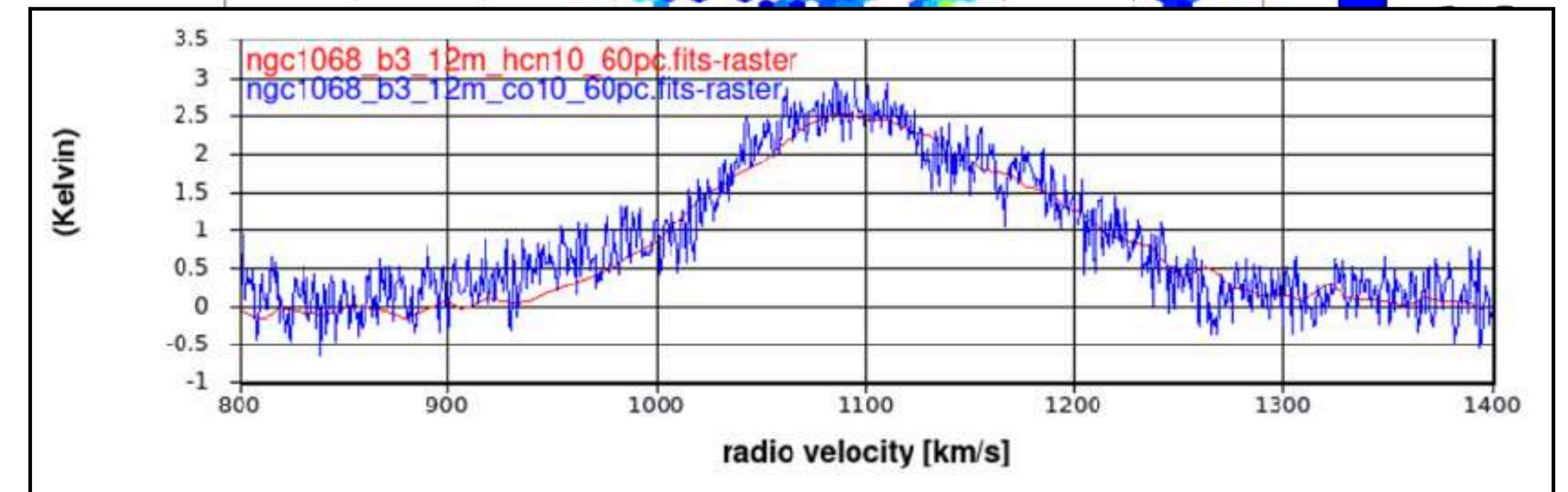
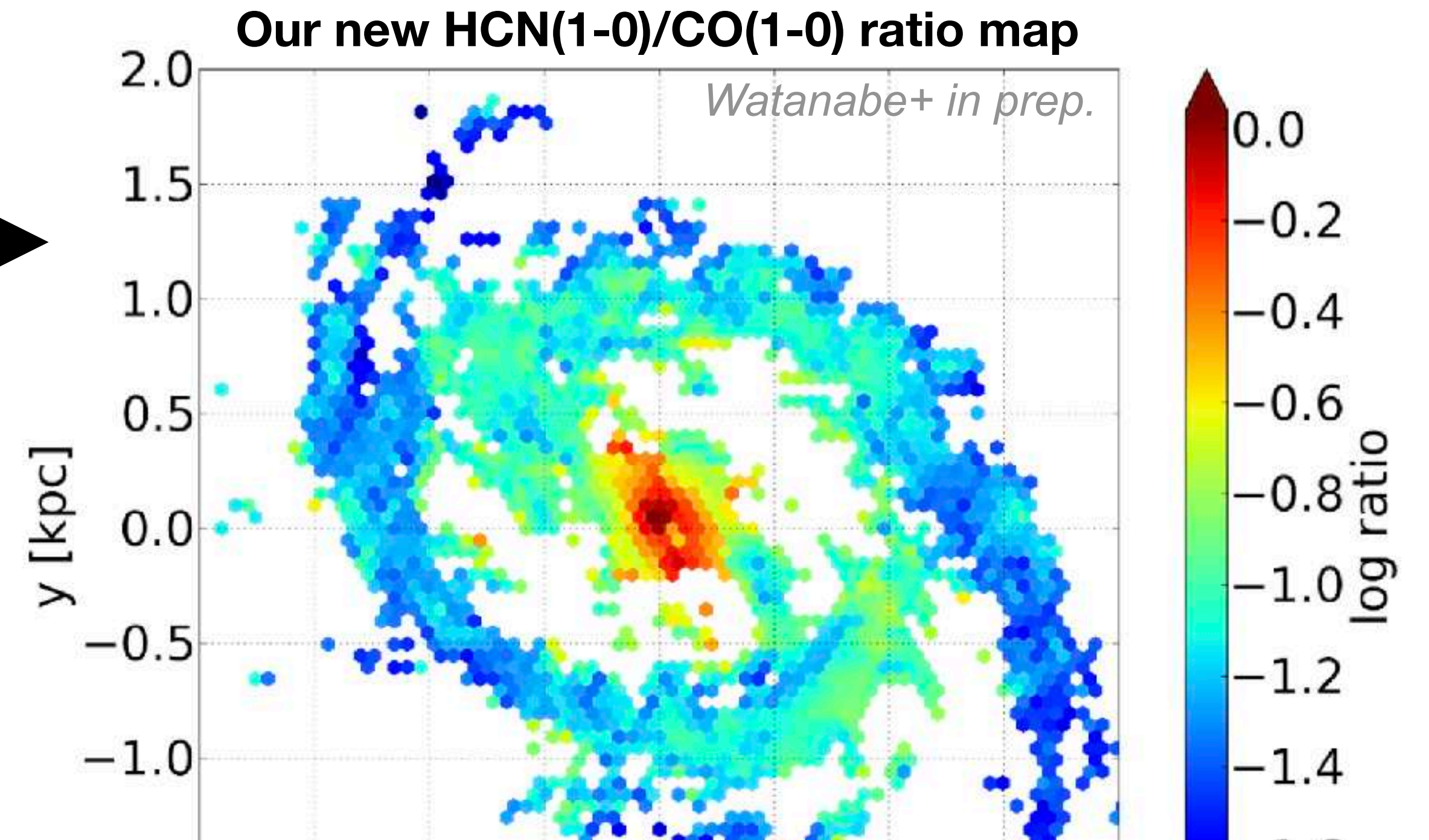
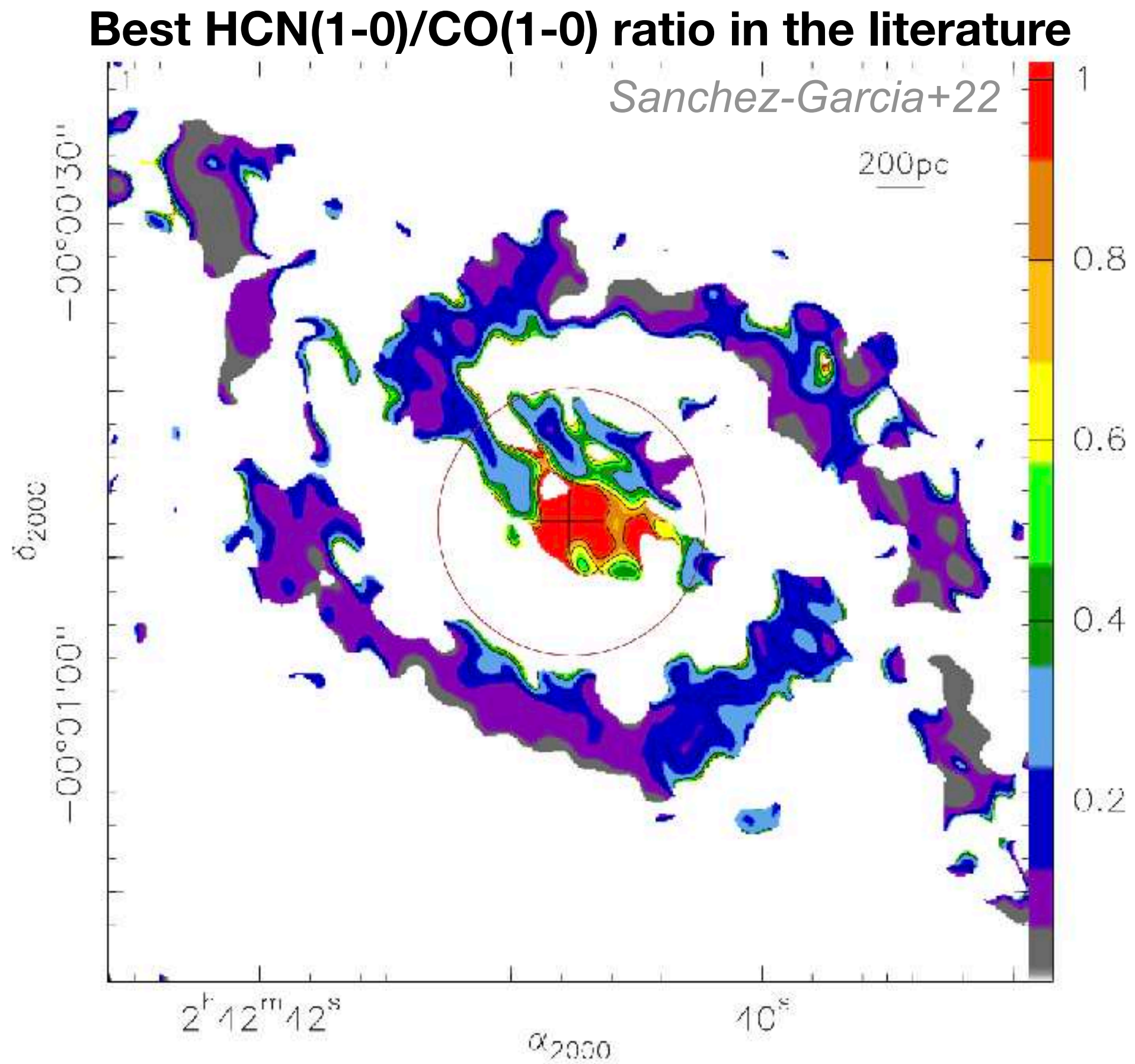
- Ikarashi et al. in prep. (talk on Wednesday)
- Watanabe et al. in prep. (poster)
- Okubo et al. in prep. (poster)
- Nagashima et al. in prep. (talk yesterday)
- Takamatsu et al. in prep.
- and many more potential projects...

We do the same for Bands 4-to-9!

55-pc-resolution HCN(1-0) map of NGC 1068

Many lines and deep continuum for a single galaxy (Watanabe et al. in prep.)

→ See Watanabe-san's poster!



Ultra-deep 100 GHz continuum map of NGC 1068

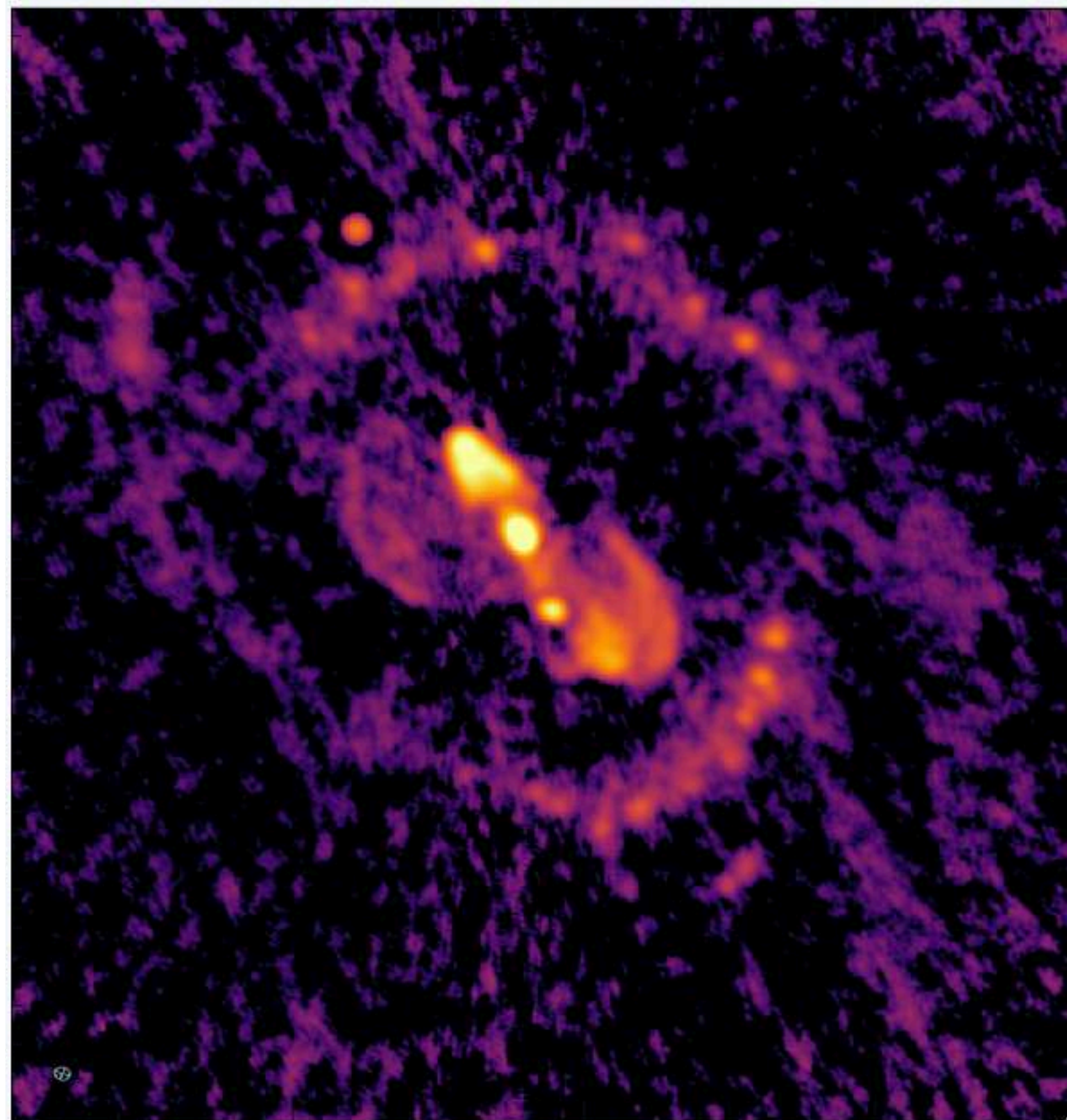
Many lines and deep continuum for a single galaxy (Nagashima et al. in prep.)

The 100 GHz continuum map with $16 \mu\text{Jy}/\text{beam}$ sensitivity at 55 pc resolution and 30 GHz bandwidth. **We achieved ALMA2030-like quality.**

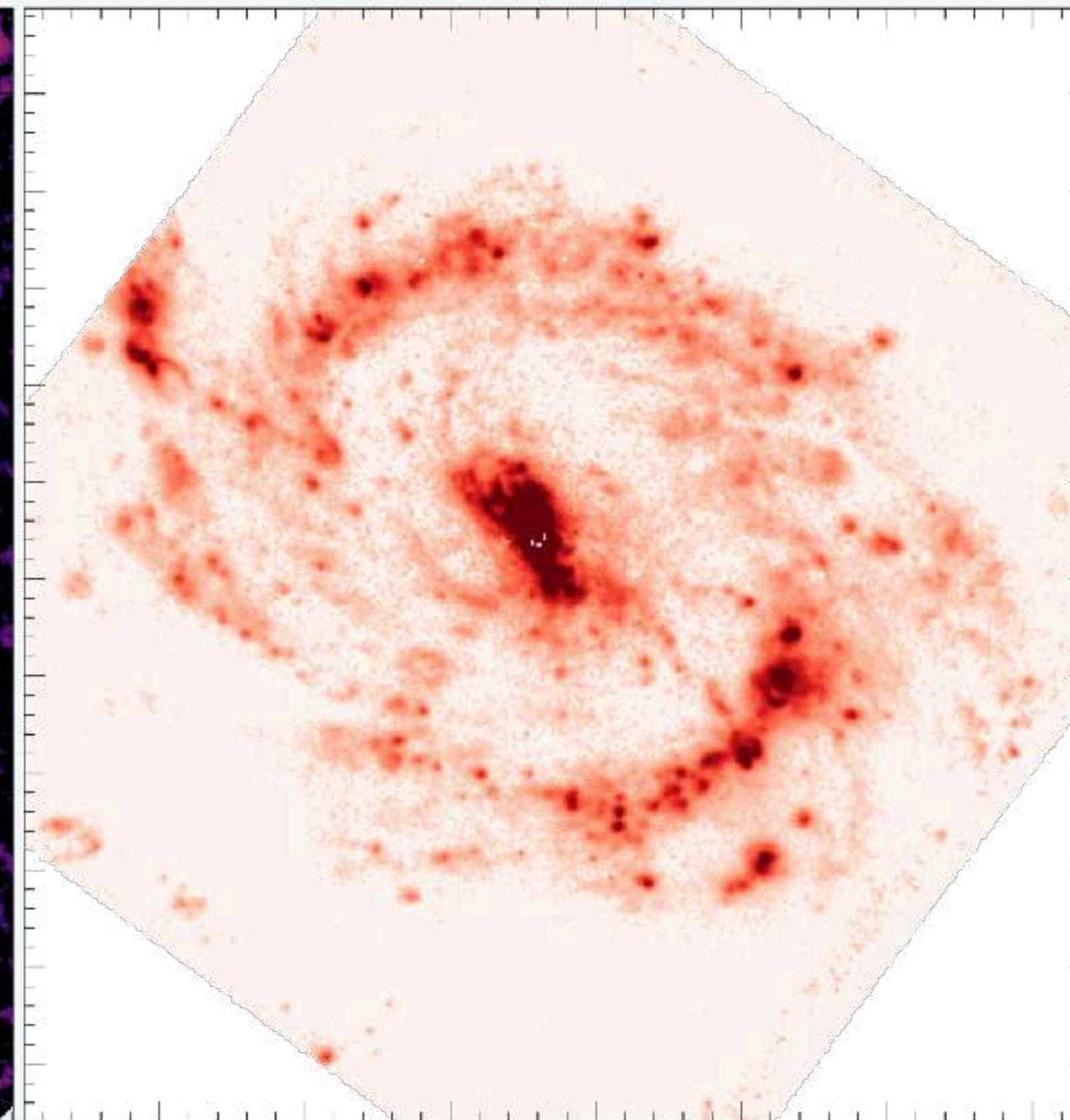
This deep free-free map looks like the bright Paschen alpha map taken by HST!

→ [See Nagashima-san's talk!](#)

ALMA 12m+7m 100 GHz continuum



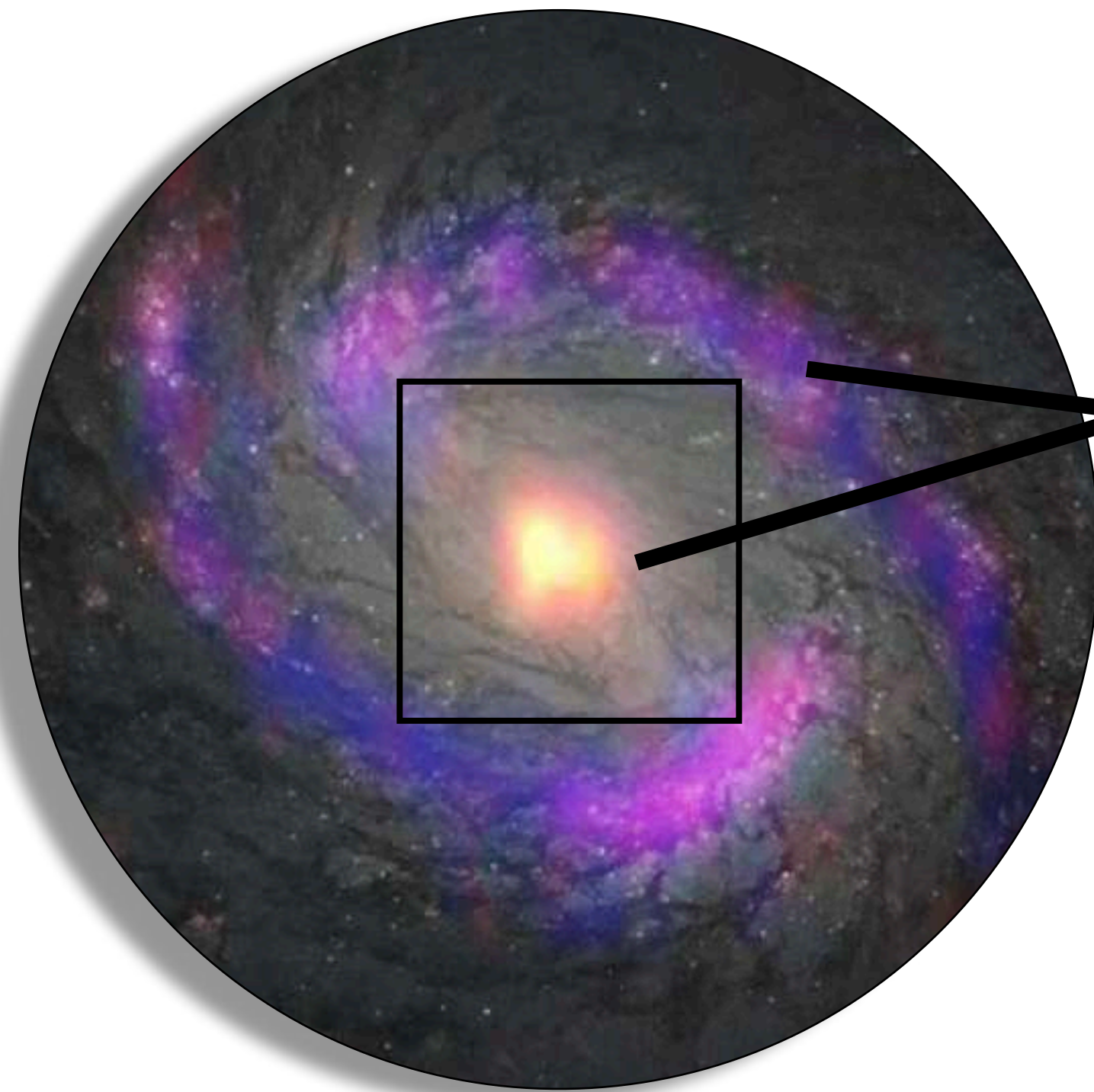
HST/NICMOS Paa line



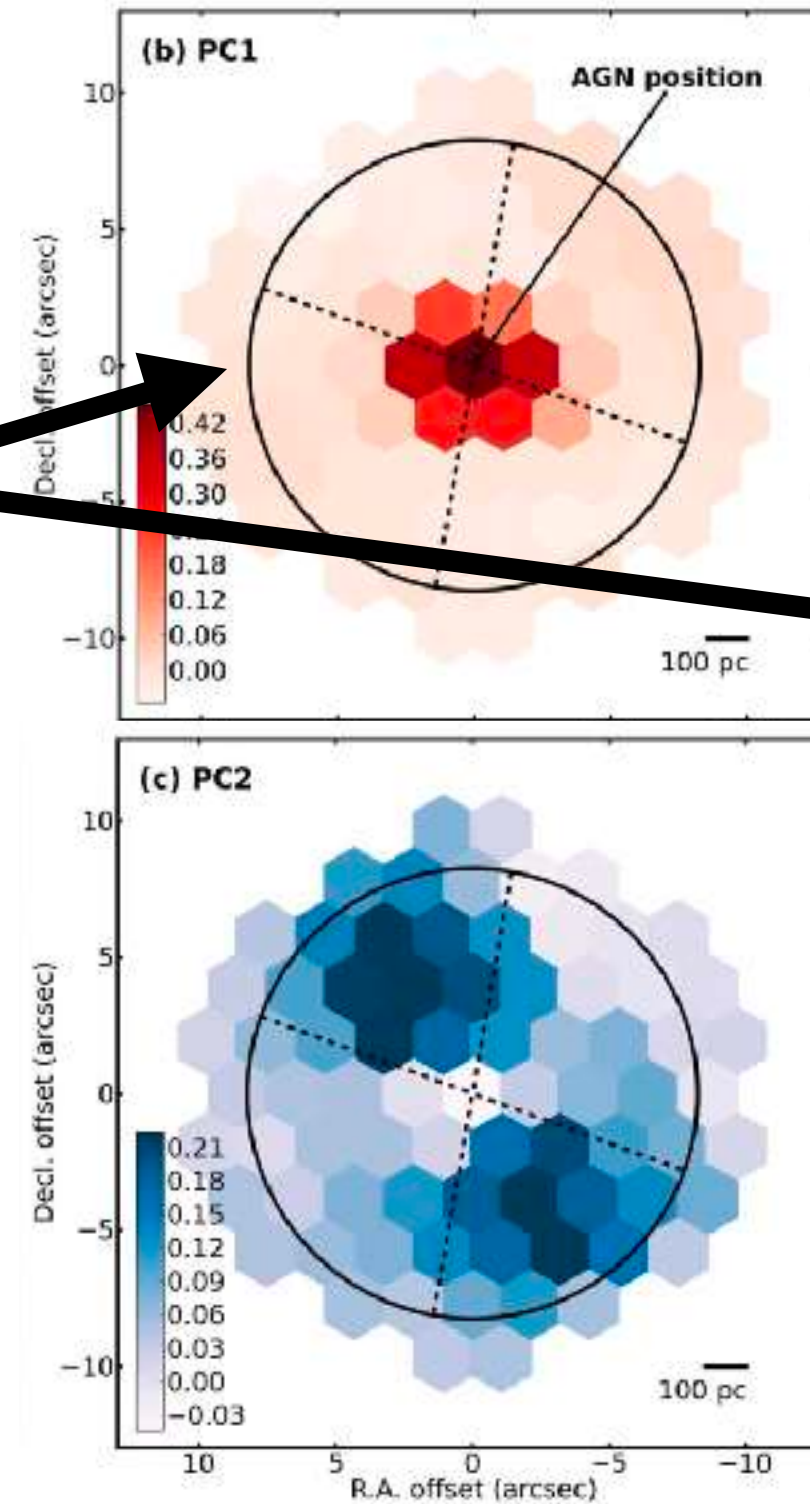
Classifying molecular lines with machine learning

Many lines and deep continuum for a single galaxy (Saito et al. 2022b; Okubo et al. in prep.)

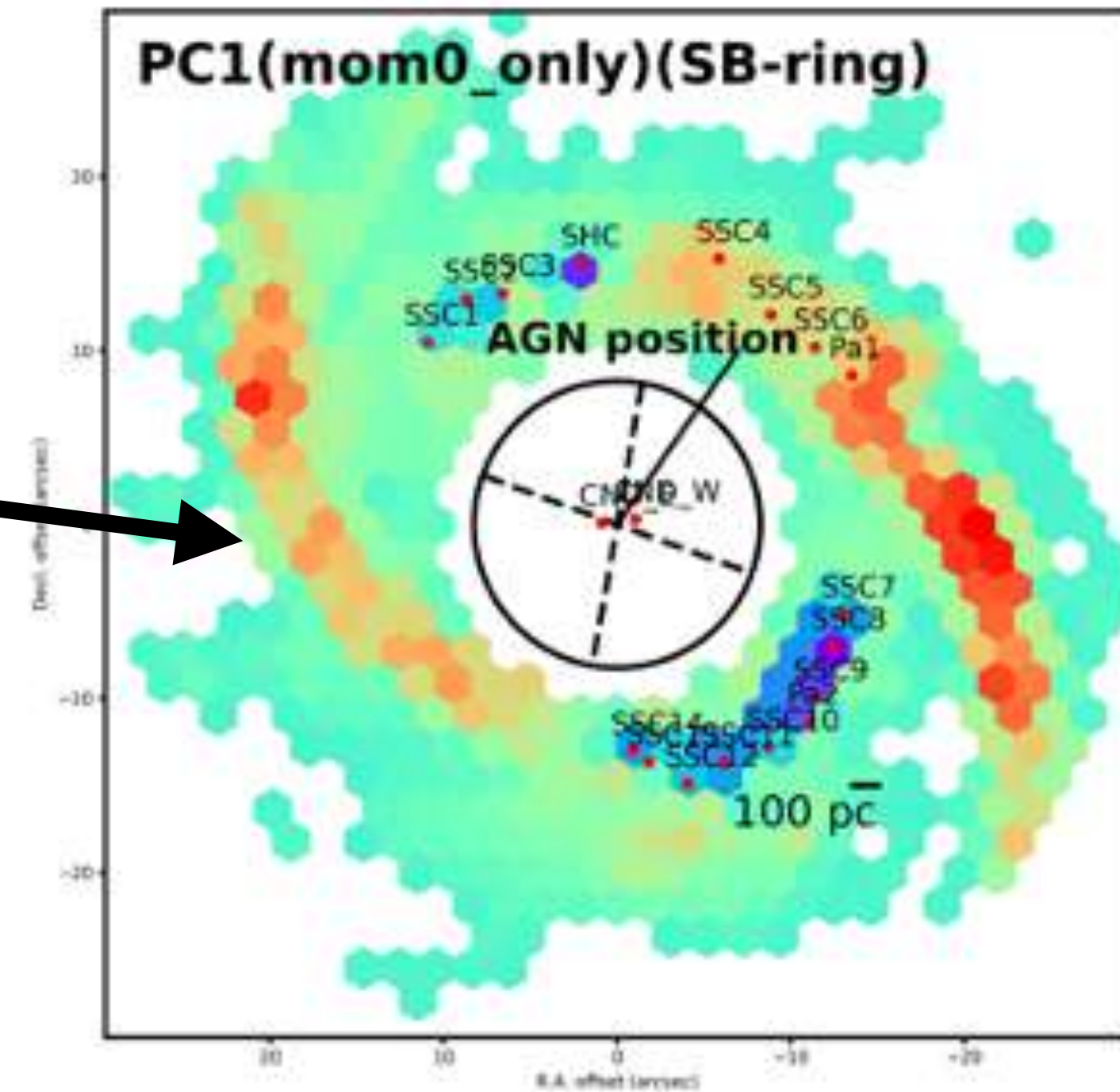
→ See Okubo-san's poster!



PCA for the central kpc
(Saito et al. 2022b)



PCA for the starburst ring
(Okubo et al. in prep.)



















We have utilized many molecular line datasets based on the archive, and succeeded in classifying them into two categories. Each project focuses on some specific molecular lines (we avoid PI science goals).

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Automated Mining of the ALMA Archive in the COSMOS Field (A³COSMOS). I. Robust ALMA Continuum Photometry Catalogs and Stellar Mass and Star Formation Properties for ~ 700 Galaxies at $z = 0.5\text{--}6$

Daizhong Liu¹ , P. Lang¹ , B. Magnelli² , E. Schinnerer¹ , S. Leslie¹, Y. Fudamoto³, M. Bondi⁴, B. Groves⁵ ,
E. Jiménez-Andrade², K. Harrington², A. Karim² , P. A. Oesch³ , M. Sargent⁶ , E. Vardoulaki², T. Bădescu², L. Moser²,
F. Bertoldi² , A. Battisti⁵ , E. da Cunha⁵ , J. Zavala⁷ , M. Vaccari^{4,8} , I. Davidzon⁹ , D. Riechers¹⁰ , and
M. Aravena¹¹ 

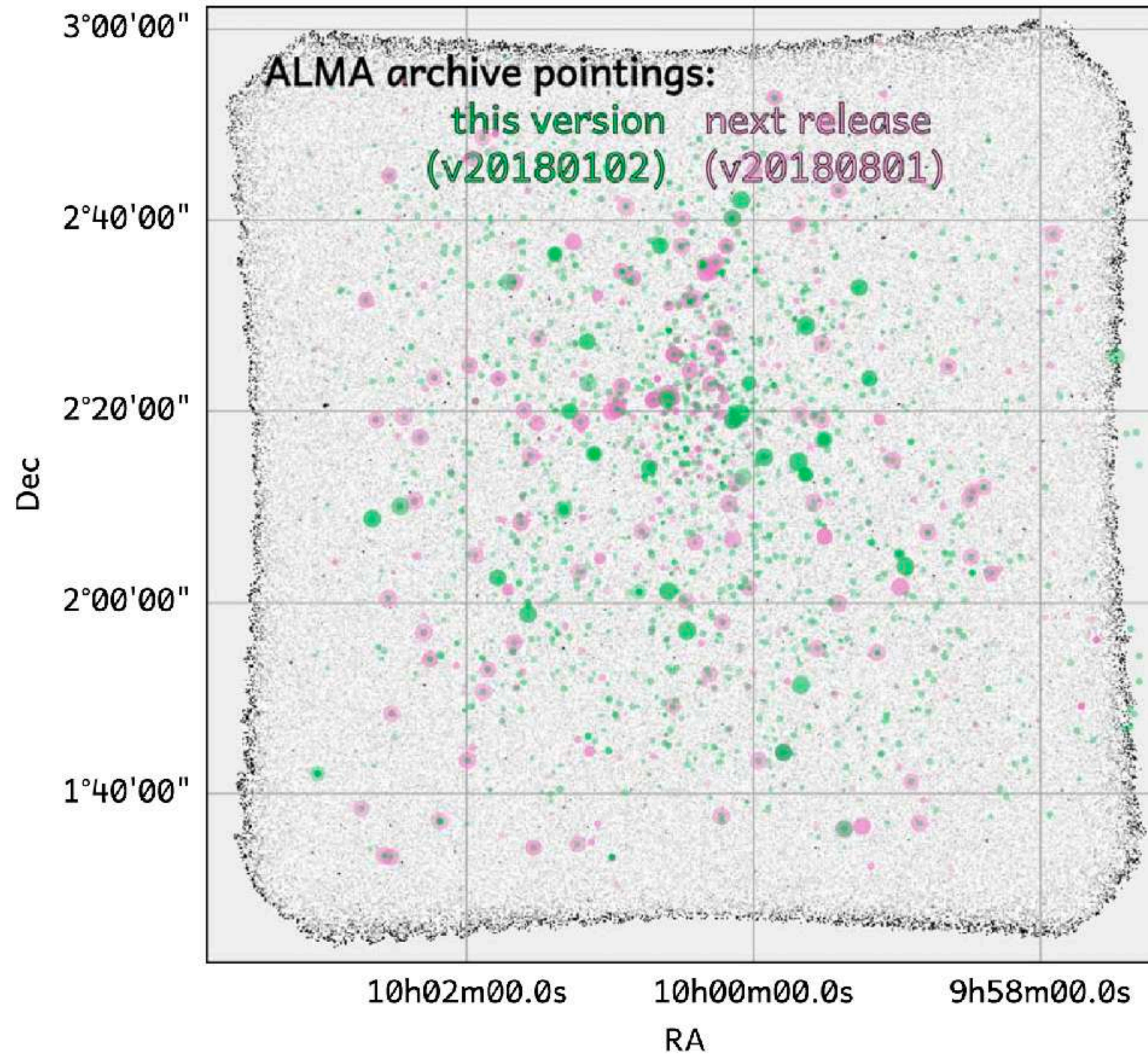
Data mining for the COSMOS field

More than 1500 individual ALMA pointings they collected...

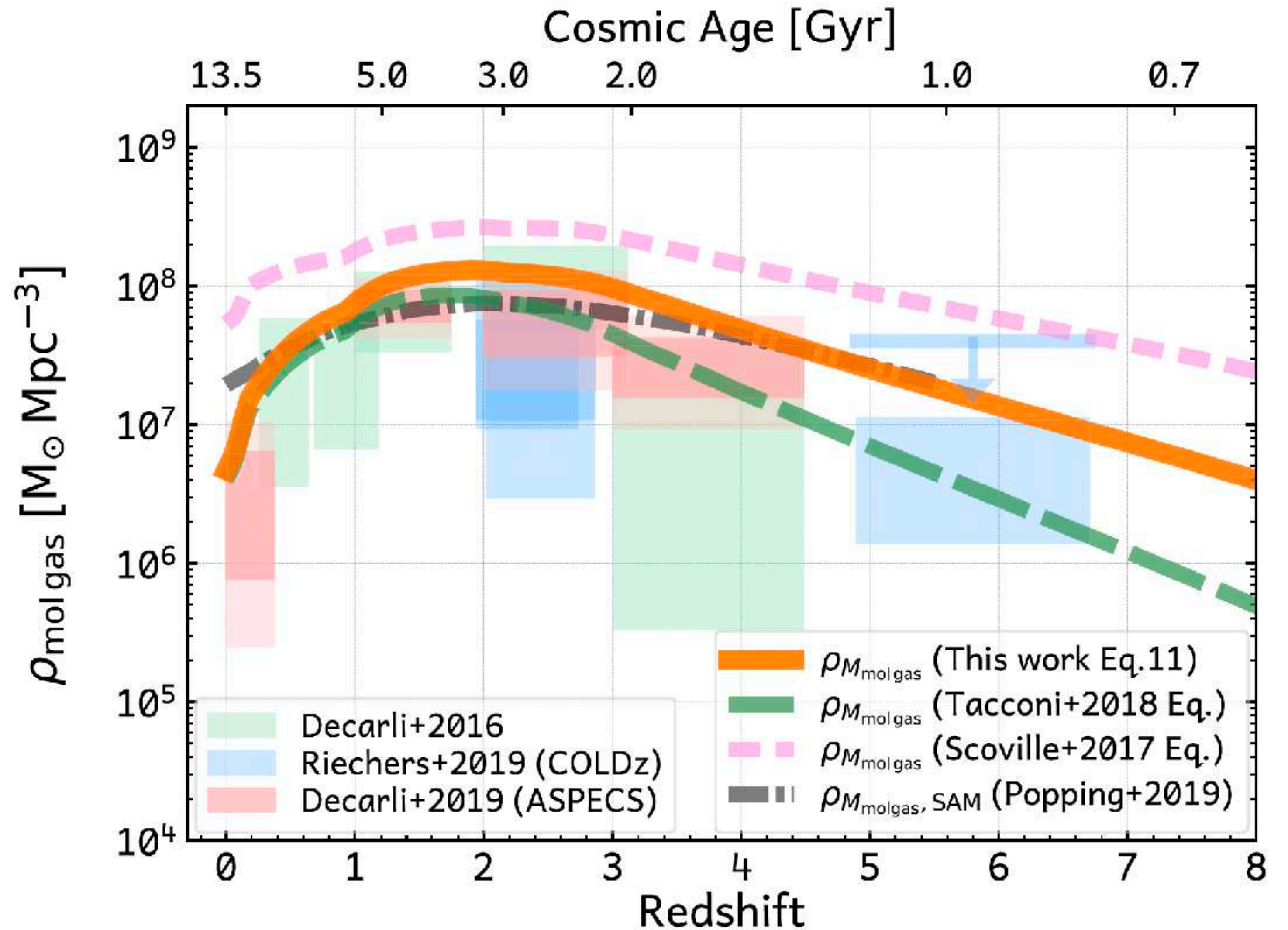
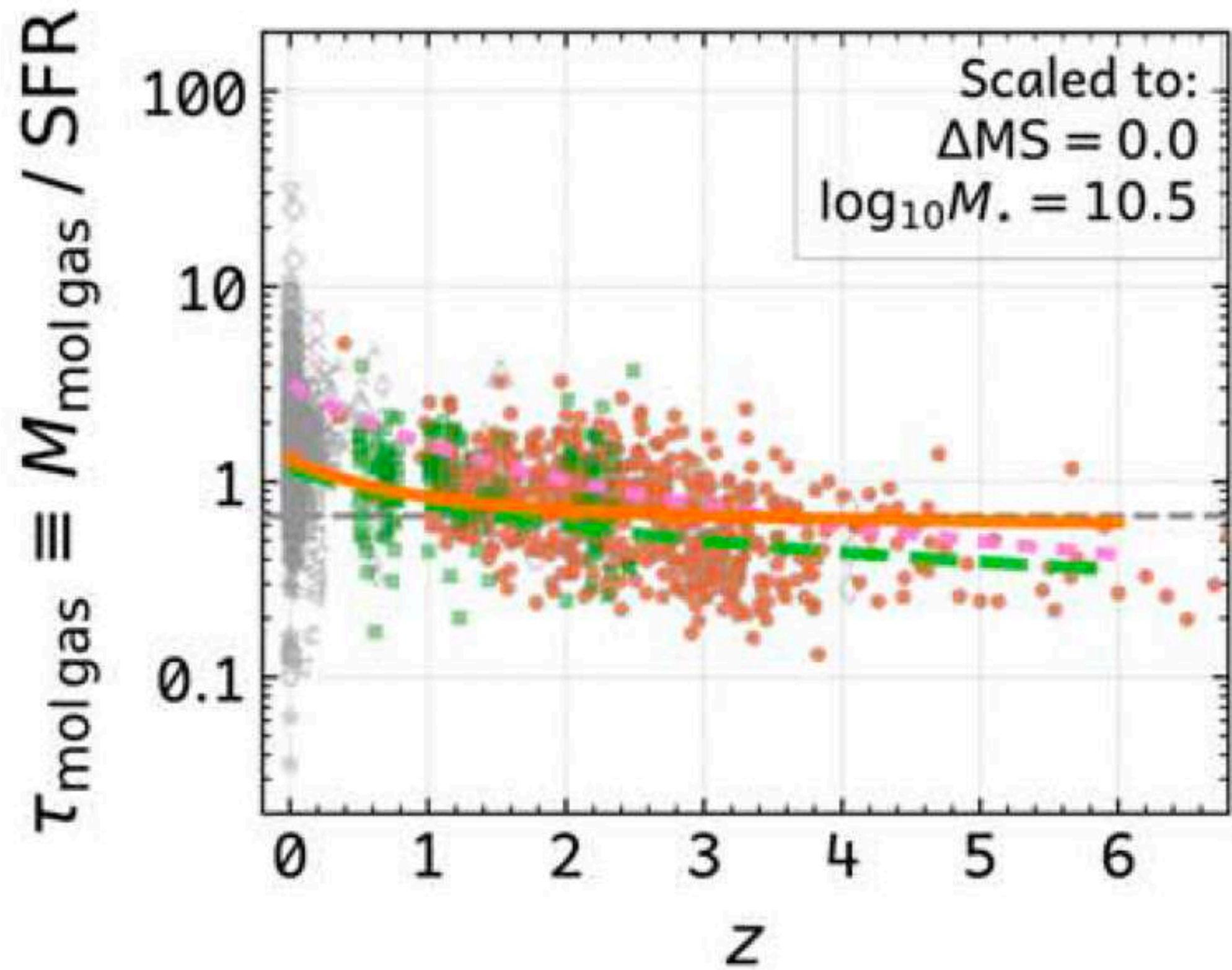
Table 1
Information per ALMA Band

Info Type	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9
Number of images	34	6	2	633	857	1	1
Sum beam area (arcmin ²) ^a	26.639	2.294	0.329	79.511	54.729	0.044	0.016
Mean beam size (arcsec)	2.164	1.098	1.548	1.202	0.772	0.526	0.305
Mean rms noise (mJy beam ⁻¹)	0.039	0.025	0.090	0.077	0.160	0.034	1.757
PYBDSF $S/N_{\text{peak}} > 5.40$	24	5	3	371	524	1	2
GALFIT $S/N_{\text{peak}} > 4.35$ ^b	20 (7)	10 (7)	2 (2)	452 (342)	553 (461)	1 (1)	1 (1)

Data mining for the COSMOS field



Cosmic molecular gas density evolution



Summary

- make new users feel comfortable to start archive-based science by describing some (extremely biased) examples.
- introduce four extragalactic **examples collecting large-program-sized data** from the archive.

1. A single line for many galaxies I (*Ledger et al. 2024*)

~34 hours 12m time!

2. A single line for many galaxies II (*Saito et al. in prep.*)

~105 hours 12m time and ~250 hours 7m time!

3. Many lines and deep continuum for a single galaxy (*Watanabe et al. in prep.; Okubo et al. in prep.; Nagashima et al. in prep., ...*)

~40 hours 12m time and ~43 hours 7m time!

4. A large patchy deep field (*Liu et al. 2019ab*)

>1500 pointings with Bands 3-to-9!

- Takehome messages

- when using the archive, think about how you can **avoid conflicting with the PI** science and maximize science outcome. Archive search is also good for proposal preparation.

- **increasing the completeness by archive** is a good starting point.

- Cover more galaxies or positions.

- Cover more lines or SED data points.

- Recover fainter structures.