

The Brick Line Survey

star formation in an extreme environment



Image credit: NASA/JPL-Caltech/S.
Stolovy (*Spitzer* Science Center/Caltech)

Alyssa Bulatek (she/her)
Committee: Adam Ginsburg, Desika Narayanan,
Jaehan Bae, and John Stanton (UF Chemistry)

September 15, 2023
Candidacy Presentation

Overview and introduction

Defining some acronyms

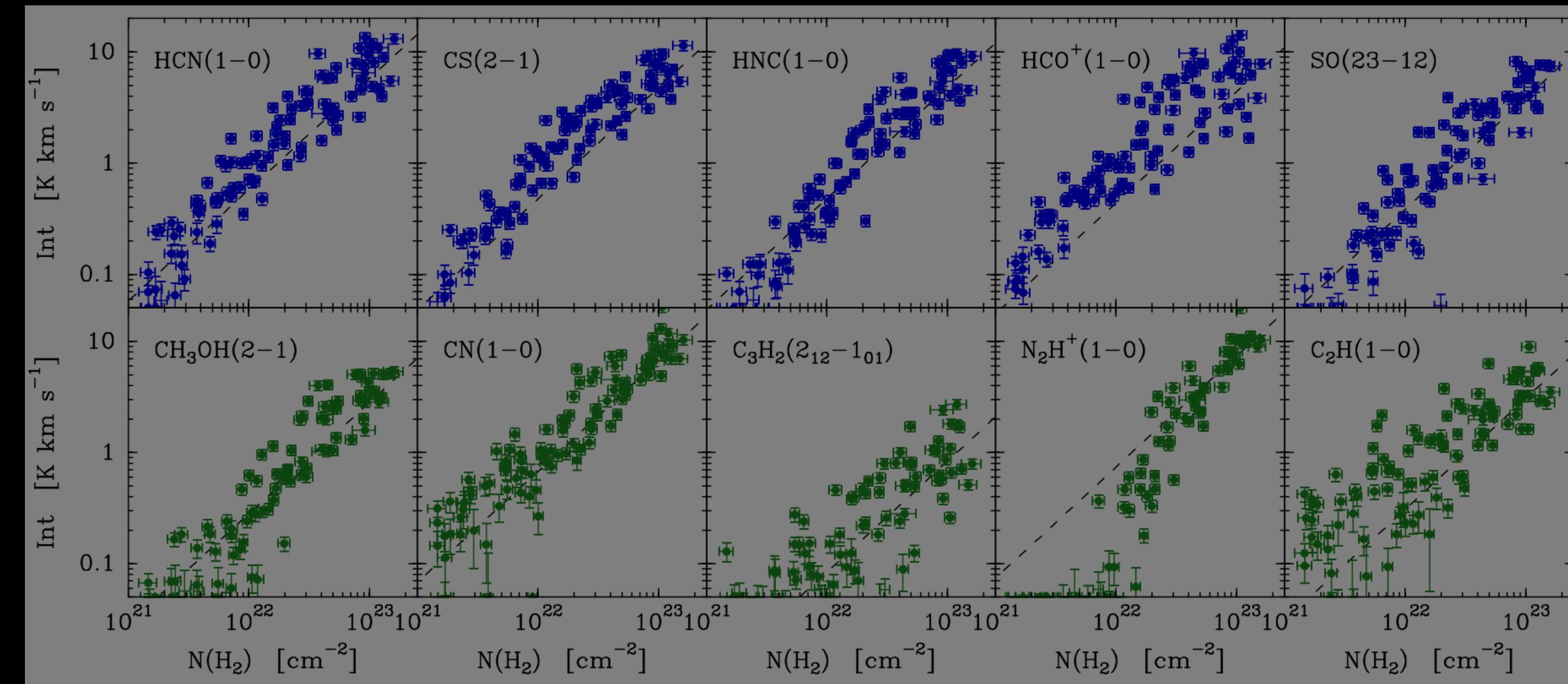
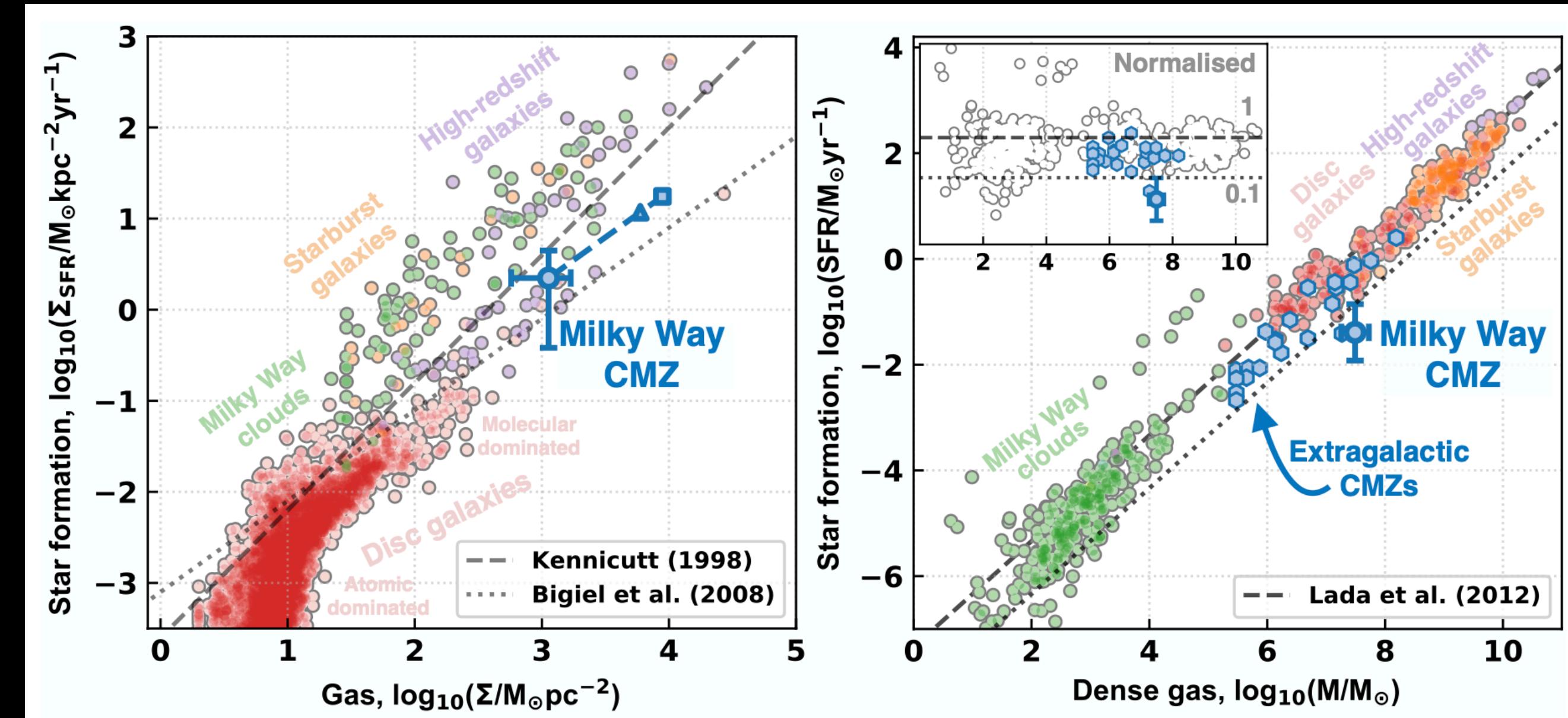


- **Star formation** = SF
- **Interstellar medium** = ISM
- **Galactic Center** = GC: the inner part of the Milky Way
- **Central Molecular Zone** = CMZ: molecular material within $R_{Gal} \approx X00$ pc
- **Cosmic Microwave Background** = CMB
- **Atacama Large Millimeter/submillimeter Array** = ALMA
- **James Webb Space Telescope** = JWST
- **next generation Very Large Array** = ngVLA
- **Brick Line Survey** = BLS

Open questions in Galactic Center star formation

- How do stars form in the Galactic Center?
- Why is star formation in the GC different than in the Galactic disk?
- What are the initial conditions for SF in the GC?
- What role do chemistry, turbulence, and gas kinematics play in GC SF?
- Why is The Brick forming so few stars?

Henshaw+2023



Tafalla+2021

CMZ Quantities

Henshaw+2023

Physical Quantity	CMZ	Solar Neighbourhood	Extragalactic CMZs	$z \sim 2$
Distance [kpc] ^(a)	8.2	0.1 - 0.5	3500 - 20000	$\sim 10^6$ ($z \sim 2$)
SFR [$M_{\odot} \text{yr}^{-1}$] ^(b)	0.07 (0.012-0.14)	0.002	0.001-0.08	1-100
Σ_{gas} [$\log_{10}(M_{\odot} \text{pc}^{-2})$] ^(c)	3.1 (2.8-3.2)	1.5	0.6-3	1.5-3.5
Σ_{SFR} [$\log_{10}(M_{\odot} \text{yr}^{-1} \text{kpc}^{-2})$] ^(d)	0.3 (-0.4-0.6)	-2.5	-3-0	-1.5-1.5
Σ_{*} [$\log_{10}(M_{\odot} \text{pc}^{-2})$] ^(e)	3.9	1.5	3.4-3.9	1-4
t_{dep} [Gyr] ^(f)	0.5 (0.4-1.5)	1	0.3-2.6	0.2-1
t_{dyn} [Myr] ^(g)	5	220	4-40	?
$B[\mu\text{G}]$ ^(h)	10-1000	1-100	?	?
Metallicity, Z ⁽ⁱ⁾	2	1	~ 2	0.2-0.6
CRIR [$\log_{10}(s^{-1})$] ^(j)	-15 to -13	-17 to -15	?	?
Linewidth, $\sigma(10\text{pc})$ [km s^{-1}] ^(l)	12	3	10	20-70
Linewidth scaling, b ^(m)	0.7	0.5	?	?
IMF slope, α ⁽ⁿ⁾	≤ 2.35	2.35	?	?
DGMF, $f(n > 10^4)$ ^(o)	0.95	0.03	?	?
T_{gas} [K] ^(p)	50-100	10-30	50-250	?
T_{dust} [K] ^(q)	20-50	10-30	30-45	?
$P_{\text{ext}}/k_{\text{B}}$ [K cm $^{-3}$] ^(r)	$\gtrsim 10^7$	$\gtrsim 10^5$	10^6 - 10^8	?

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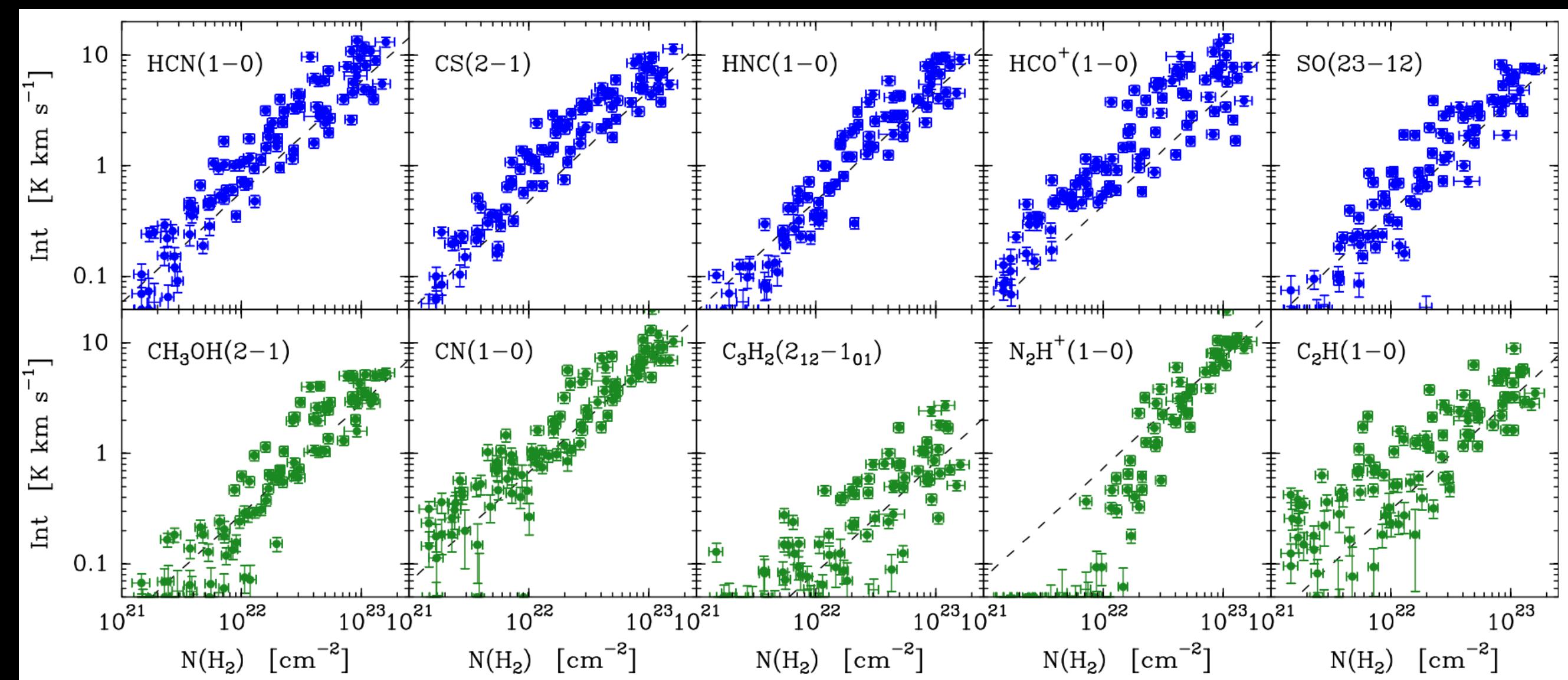
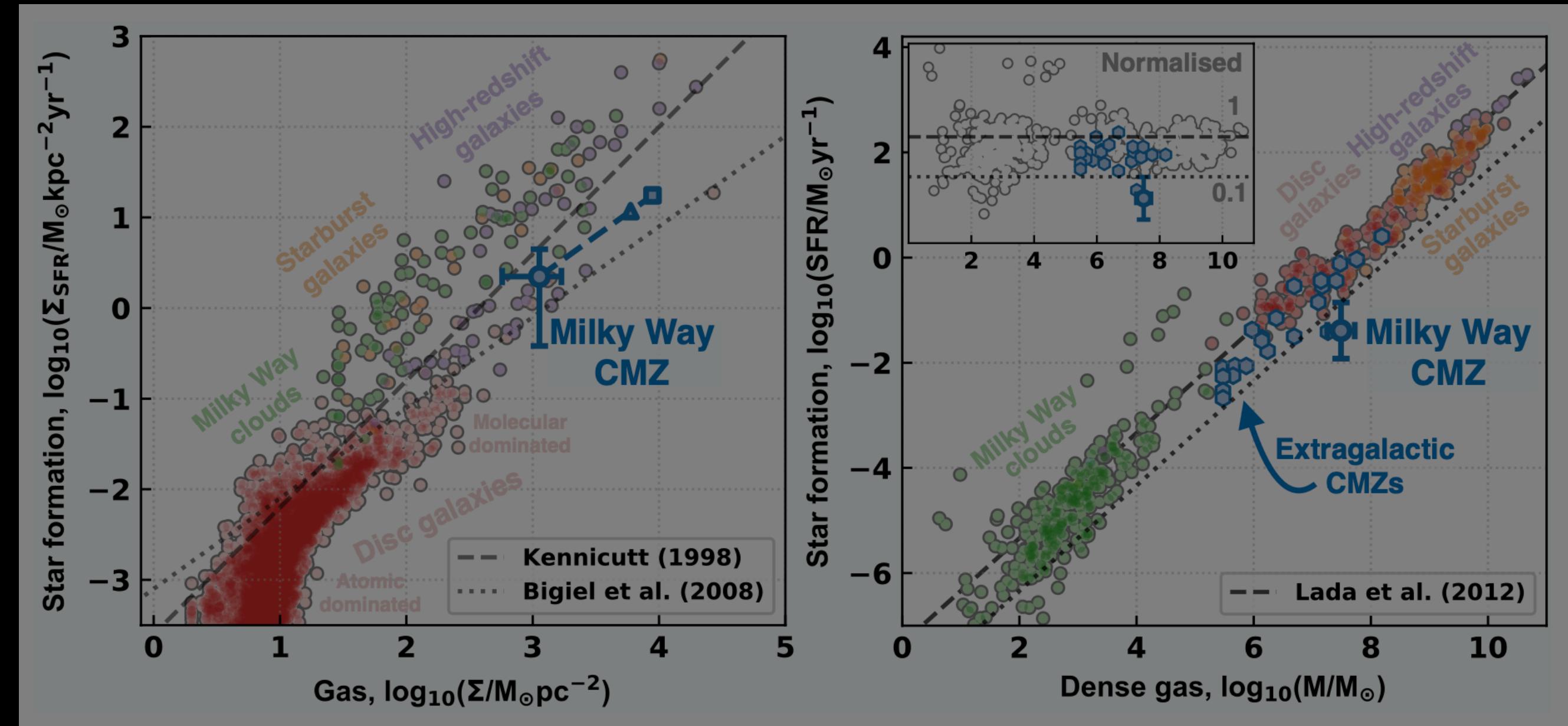
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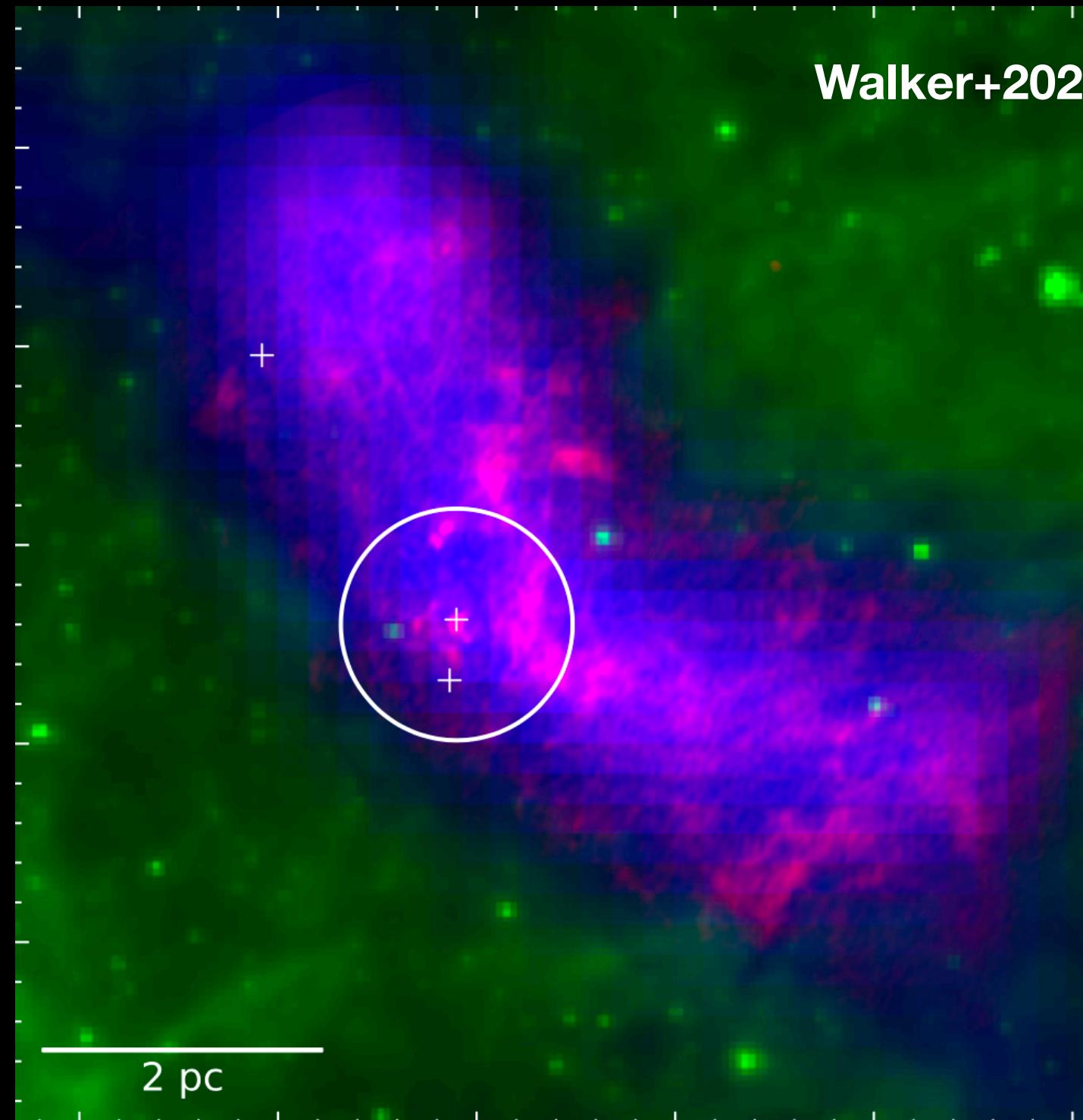
Henshaw+2023



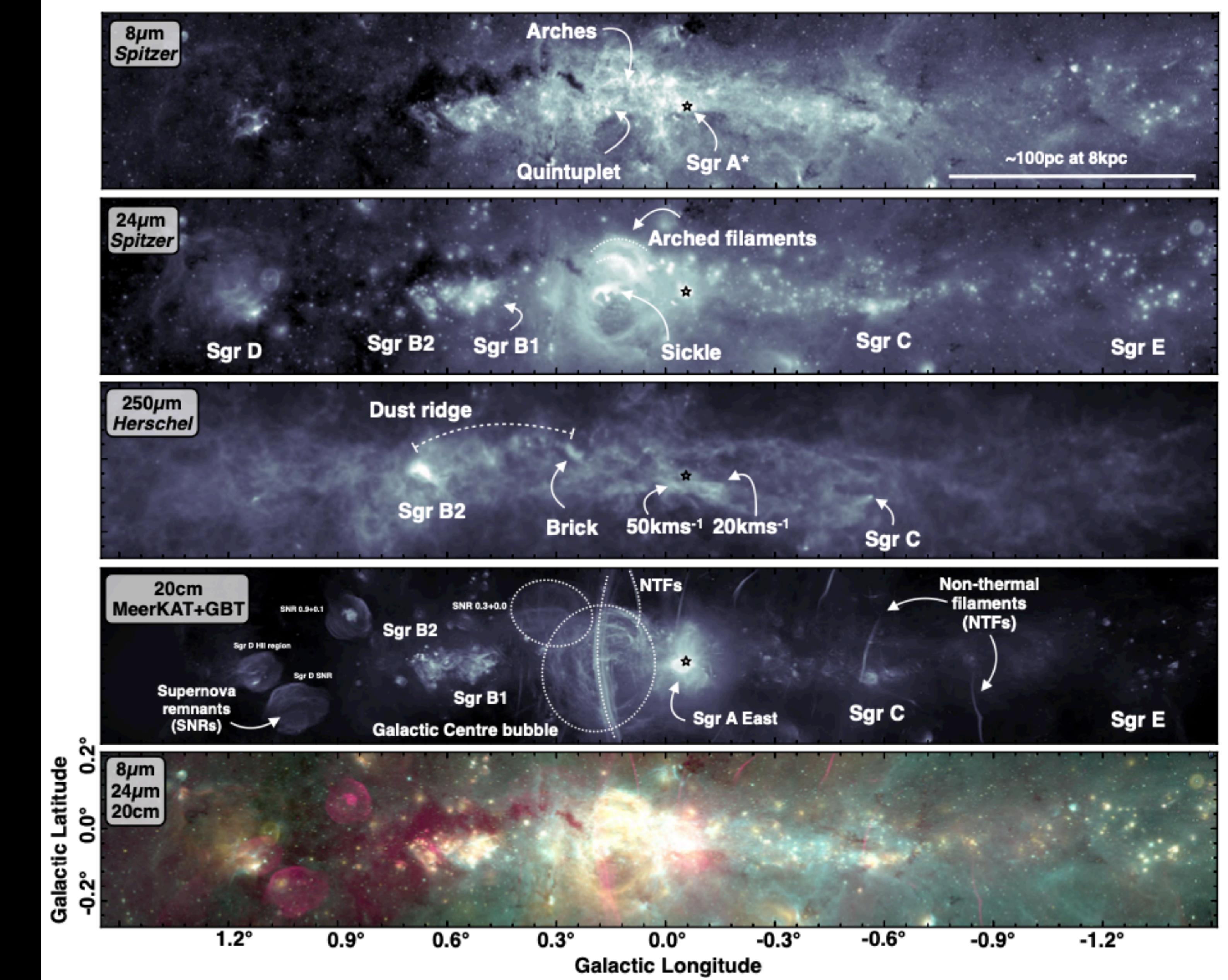
Tafalla+2021

G0.253+0.016

The Brick



red: ALMA 3mm dust continuum
green: Spitzer 8 μm emission
blue: *Herschel* dust column density



Thesis timeline



Thesis timeline

August 2023
Paper I: Methanol
Dasar in The Brick
(accepted)



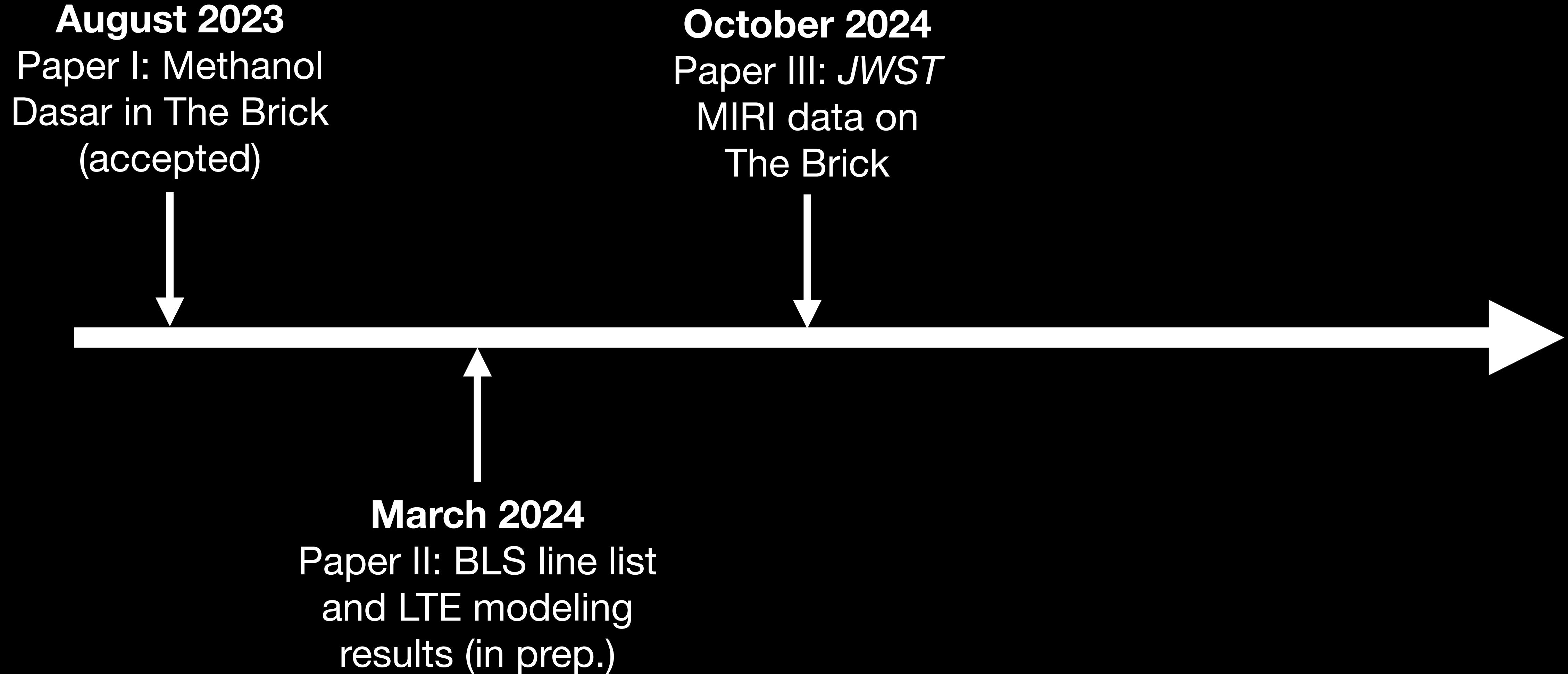
Thesis timeline

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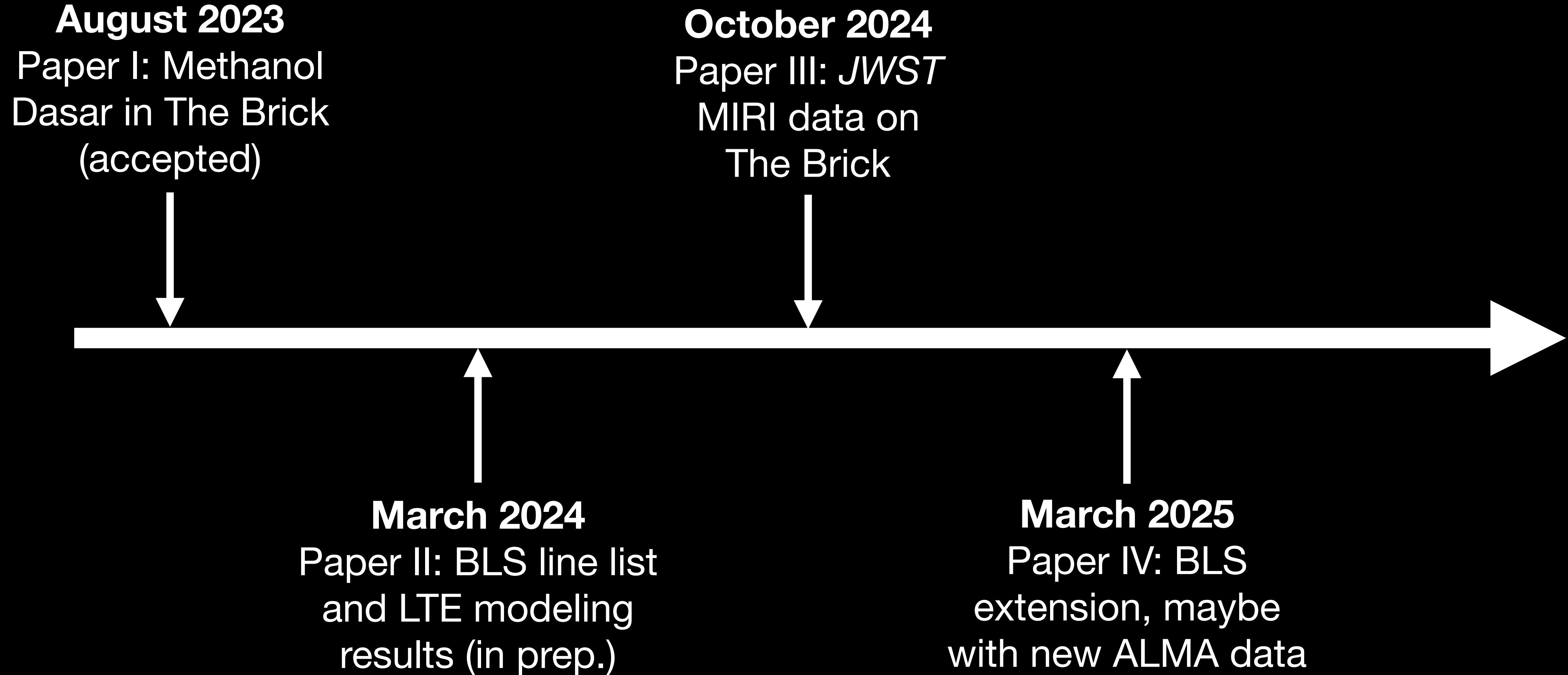


March 2024
Paper II: BLS line list
and LTE modeling
results (in prep.)

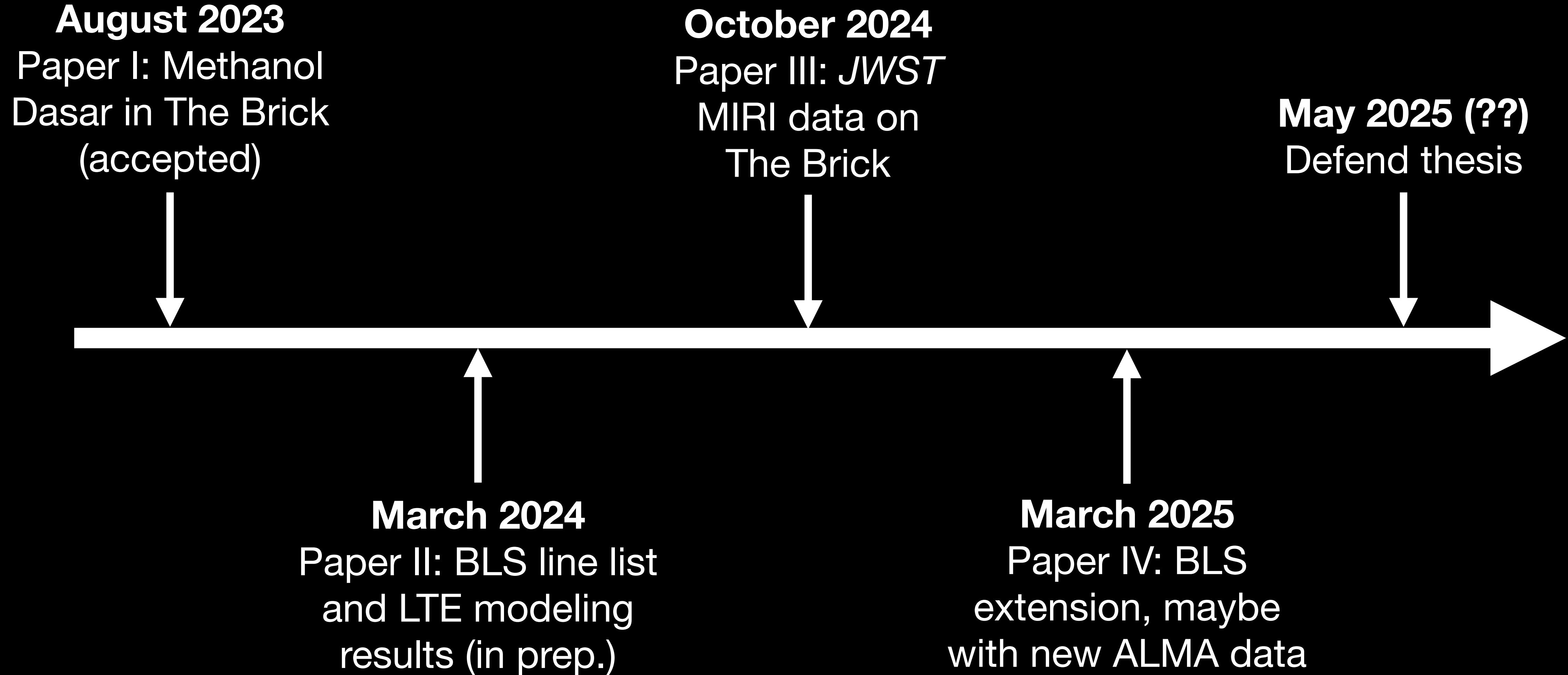
Thesis timeline



Thesis timeline



Thesis timeline



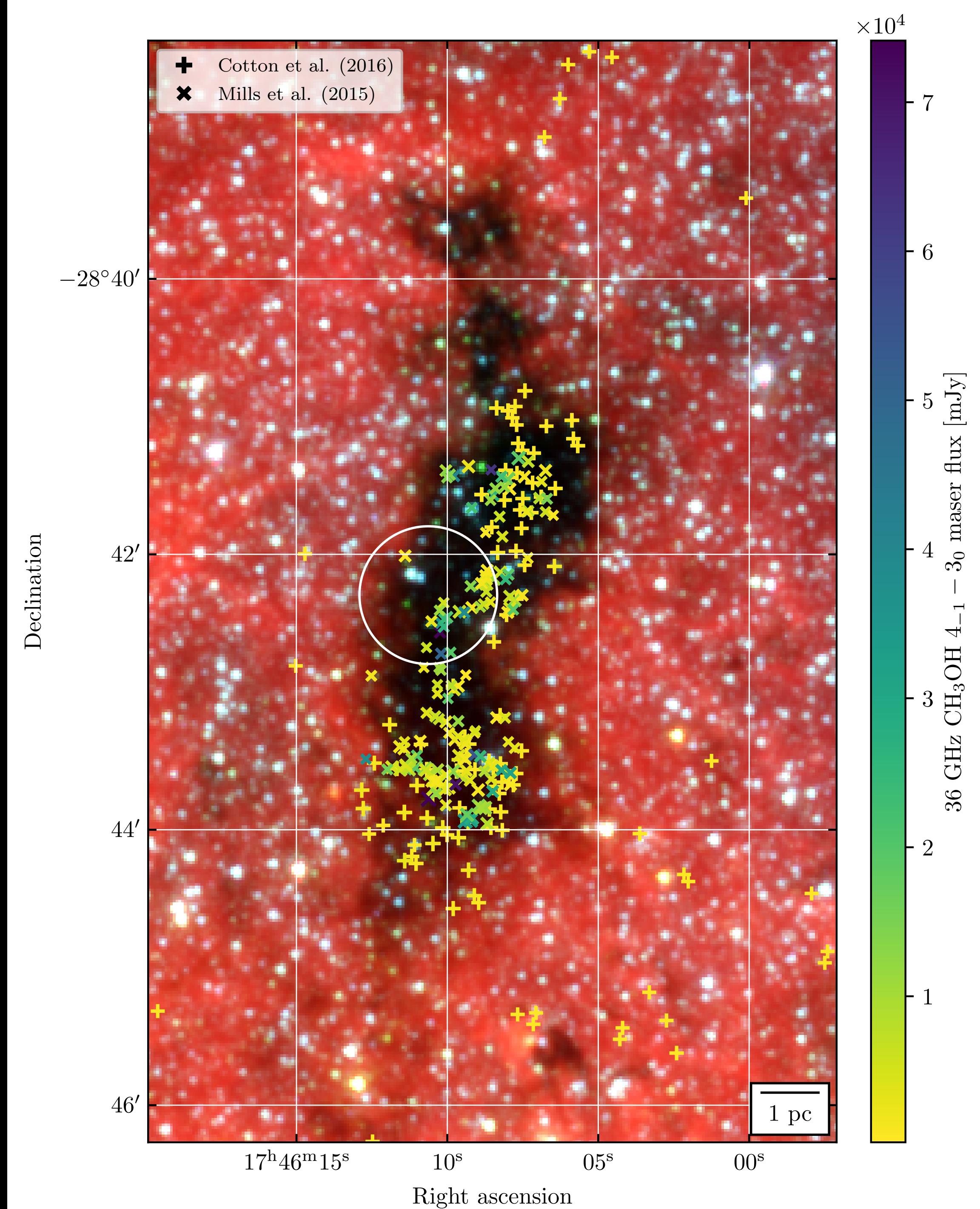
What I have done, and
what I am doing

Years 1 and 2

The Brick Line Survey

Masters Project

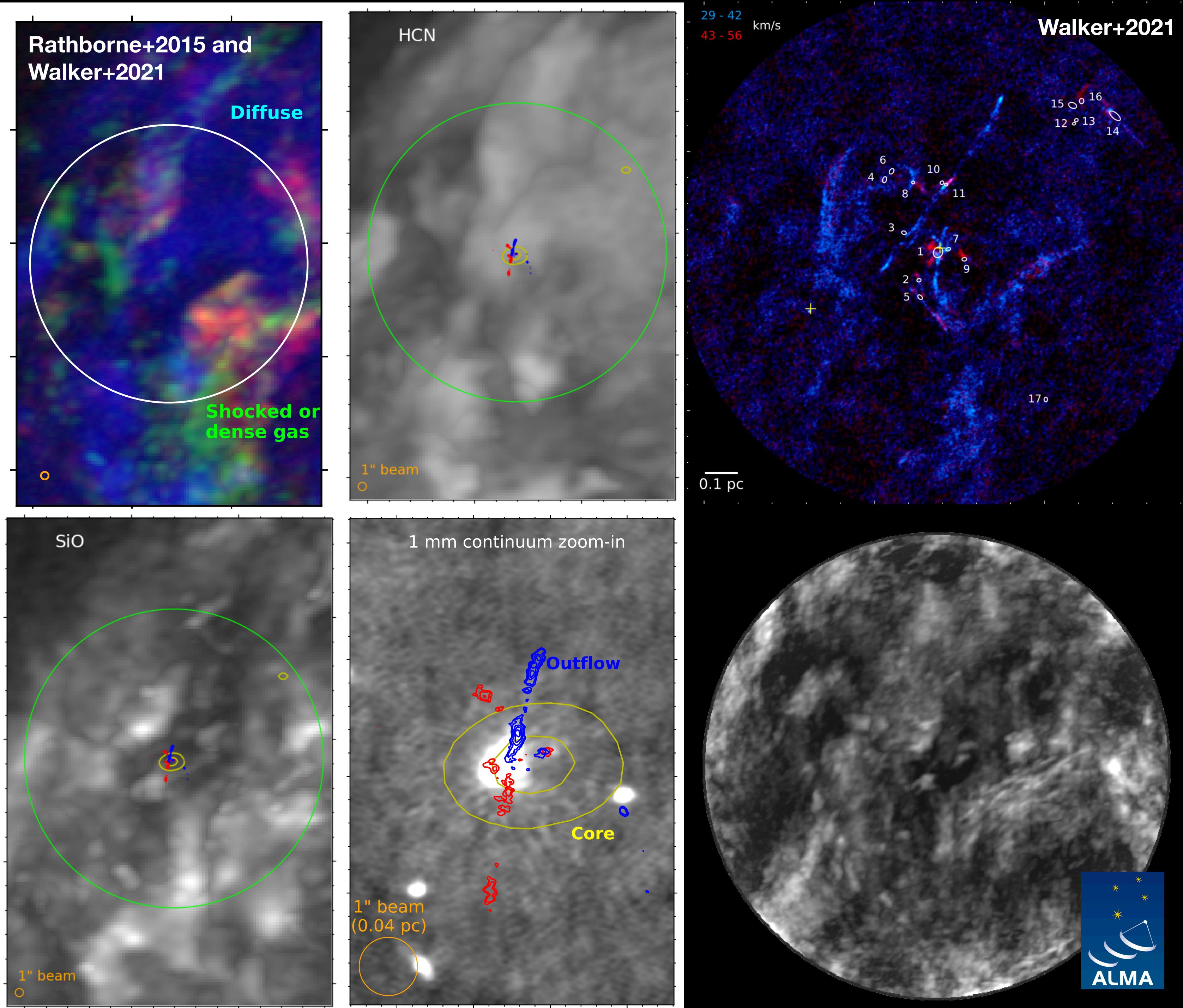
- Which spectral lines trace what physical processes in the Galactic Center?
- ALMA Bands 3, 4, 6
- 1'' angular res.,
~0.25 K sensitivity
in 1 km/s channel
- LAS = 5'' – 10''



The Brick Line Survey

Masters Project

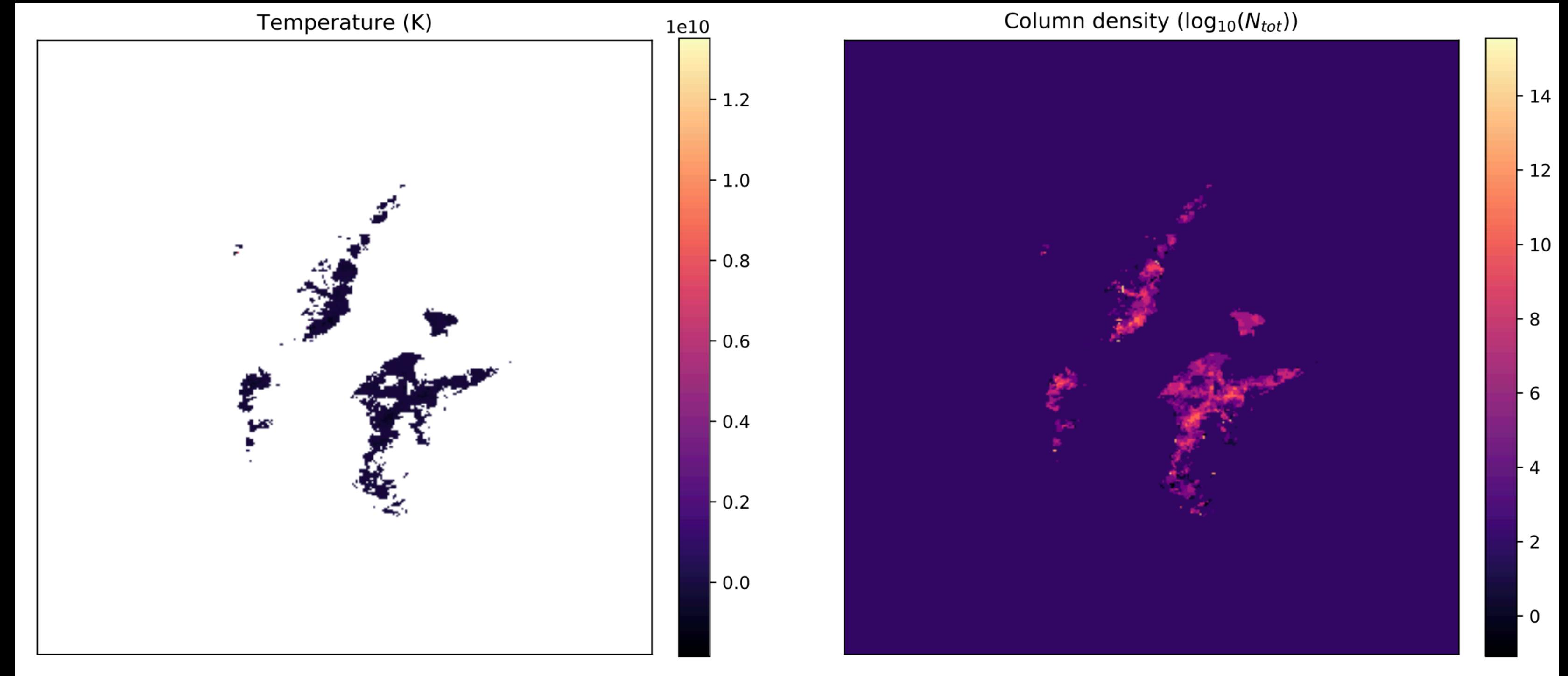
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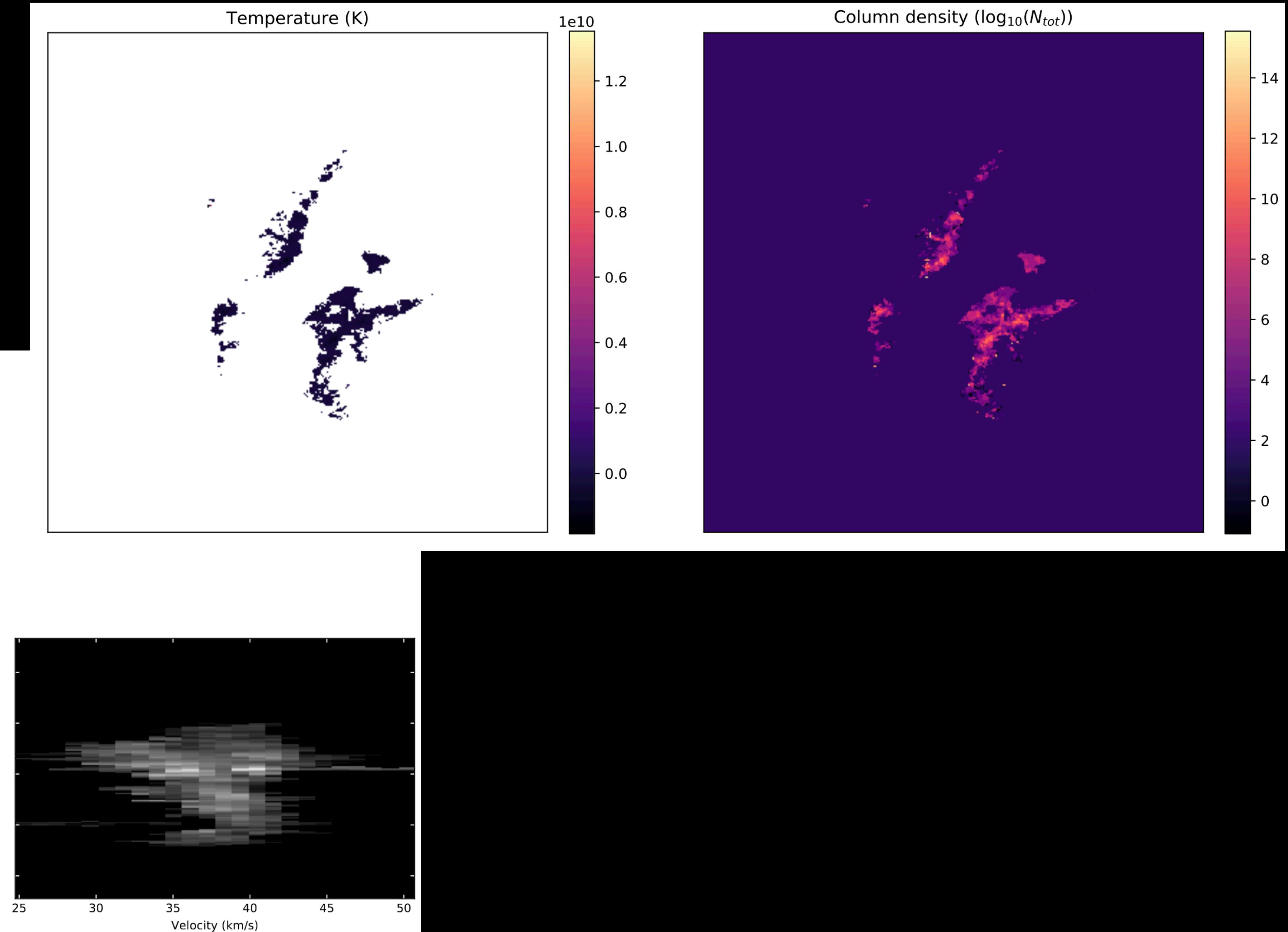
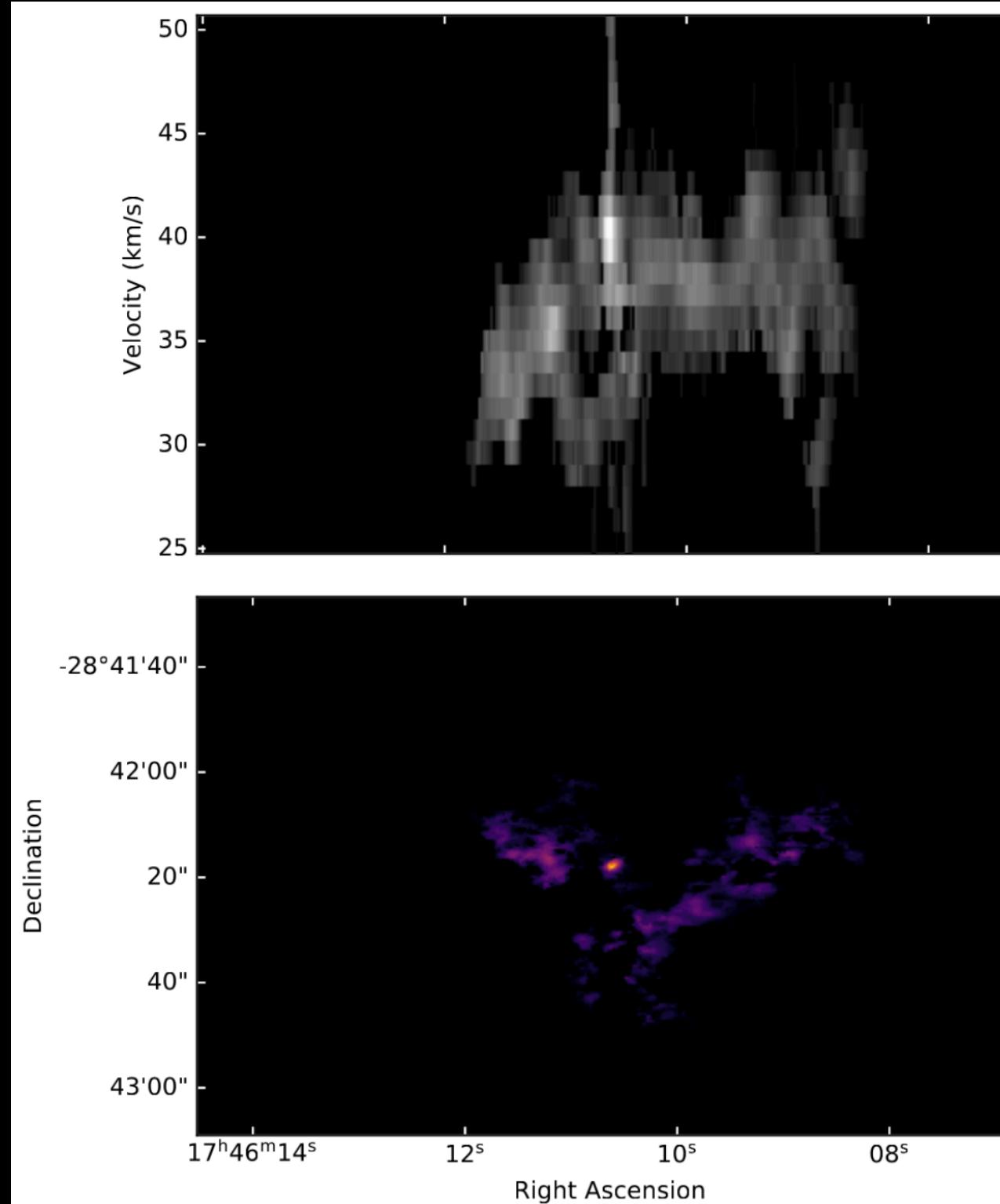
The Brick Line Survey

Masters Project

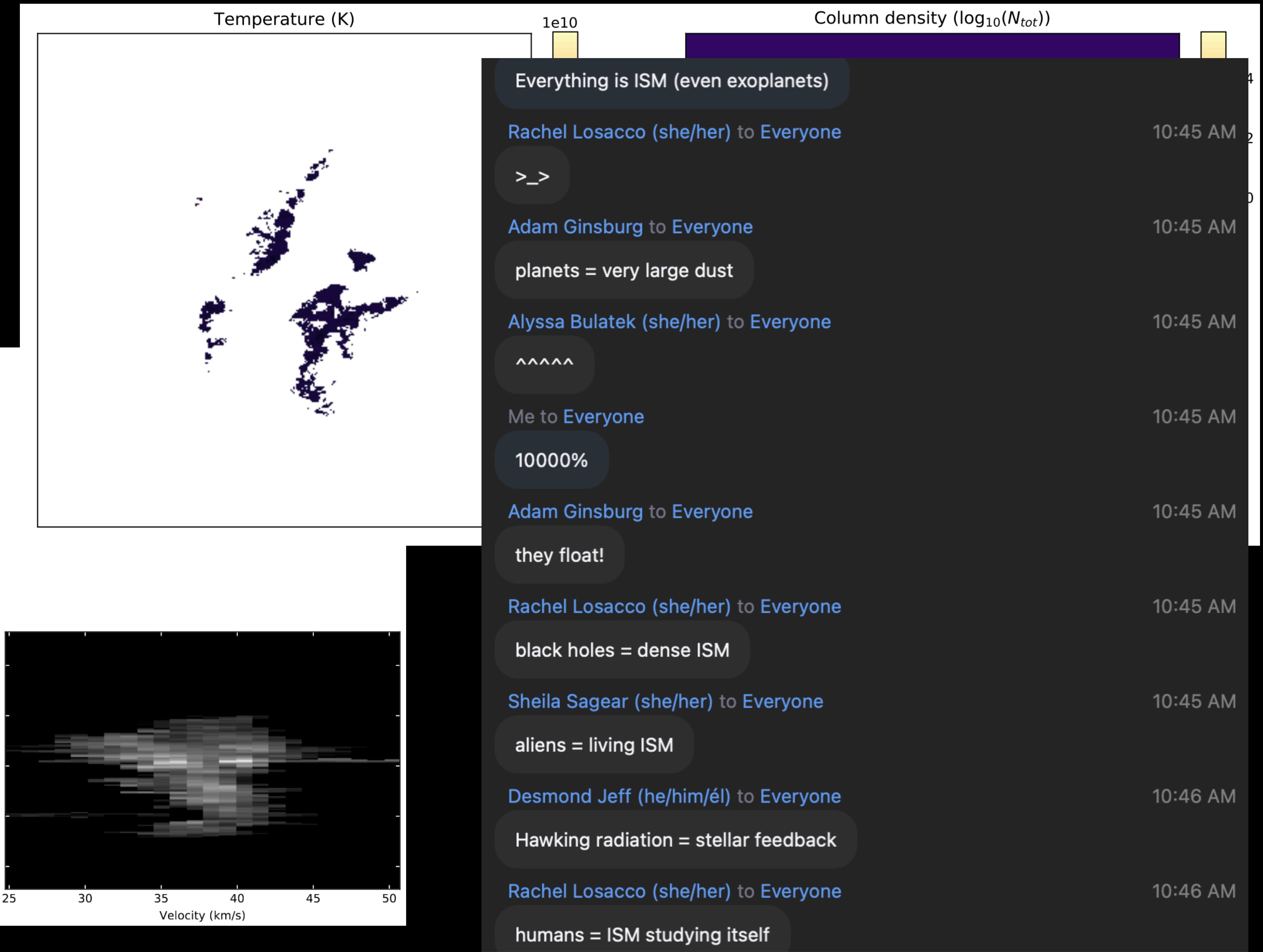
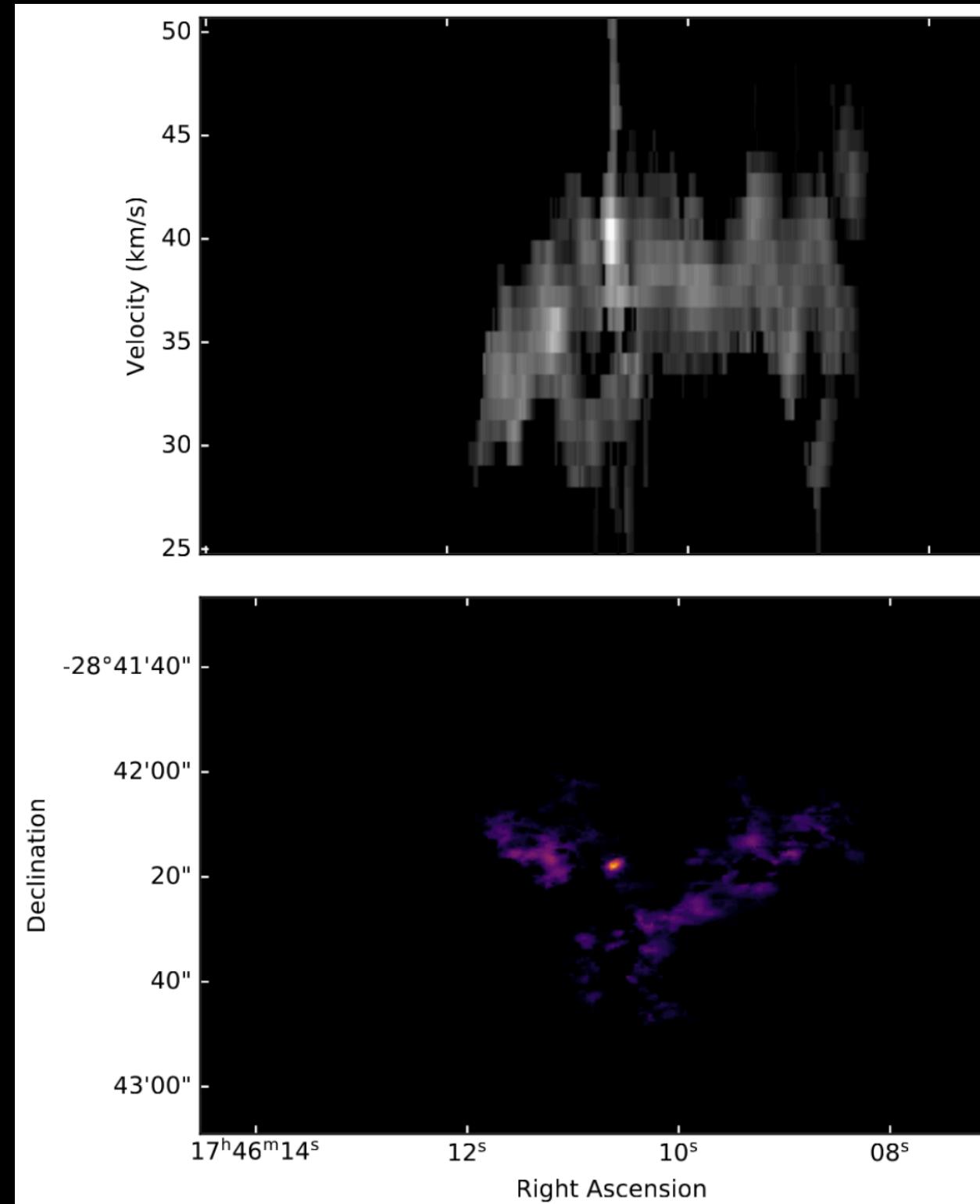
The Brick Line Survey Masters Project



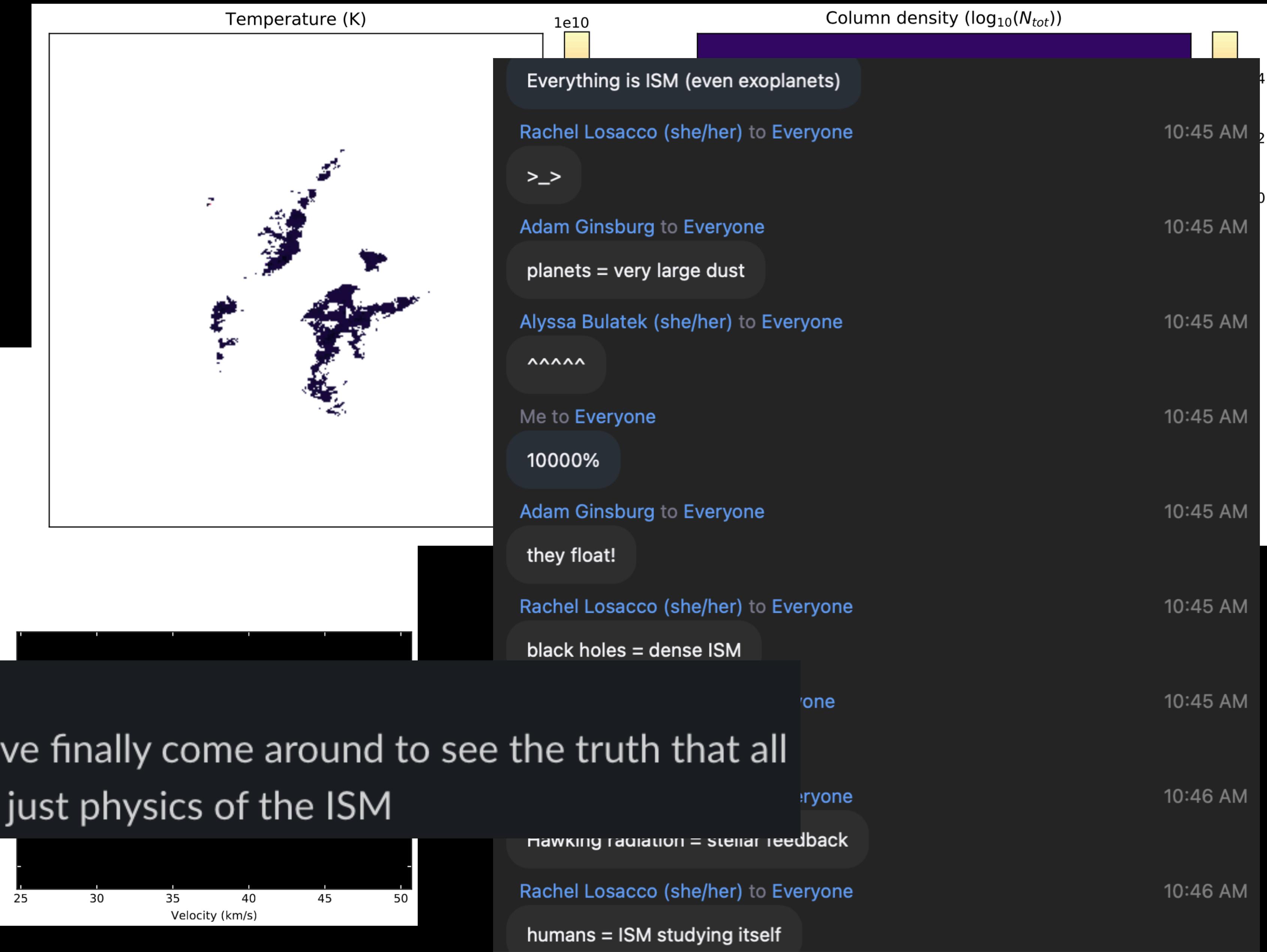
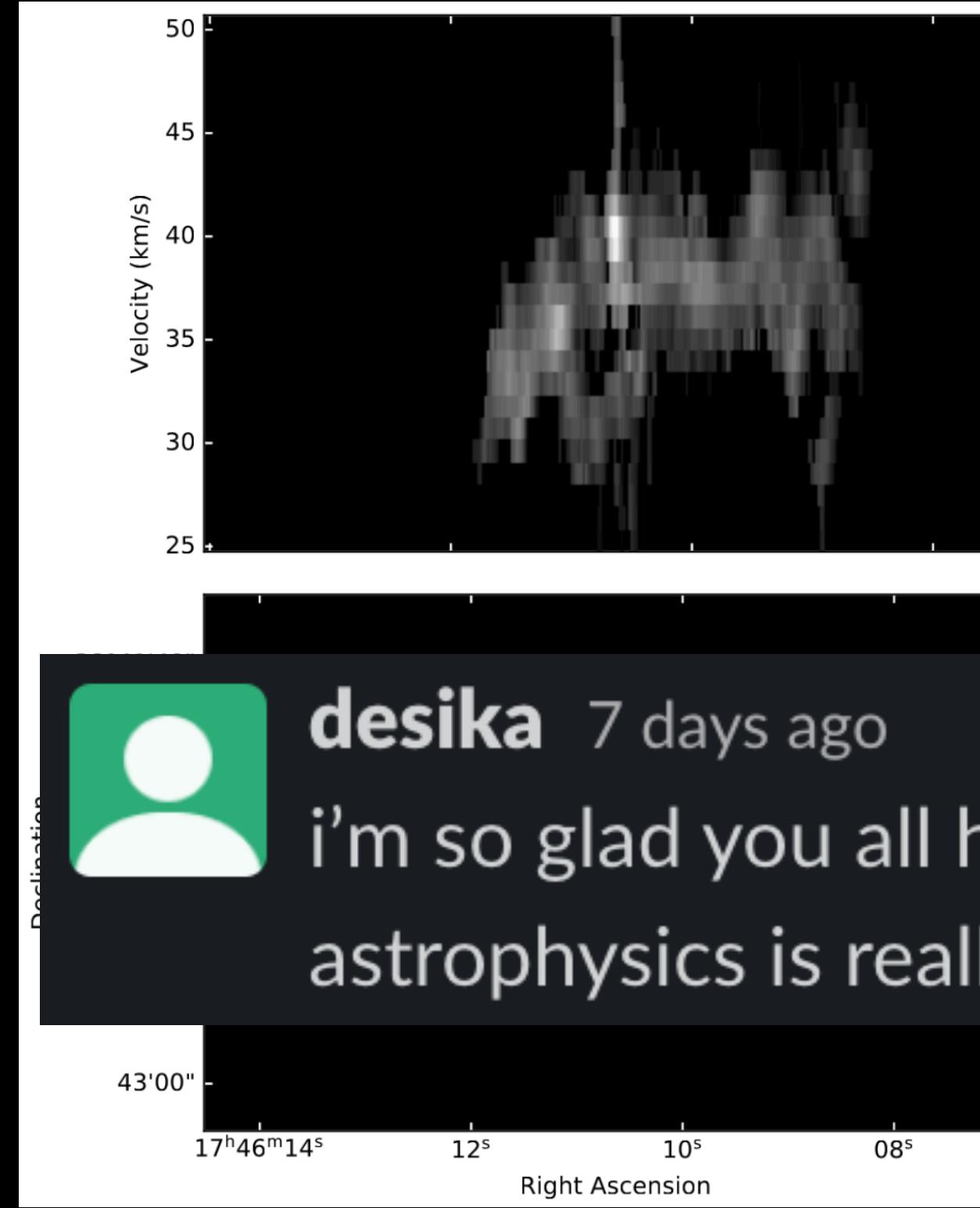
The Brick Line Survey Masters Project



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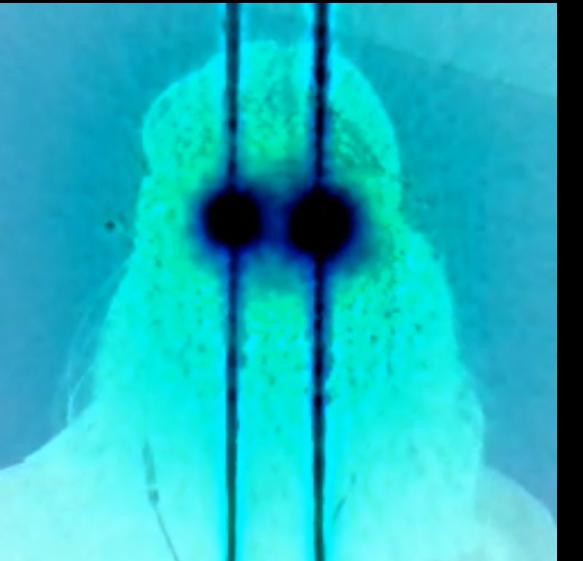
The Brick Line Survey Masters Project



Year 3

Methanol Dasar in The Brick

Paper I (accepted)



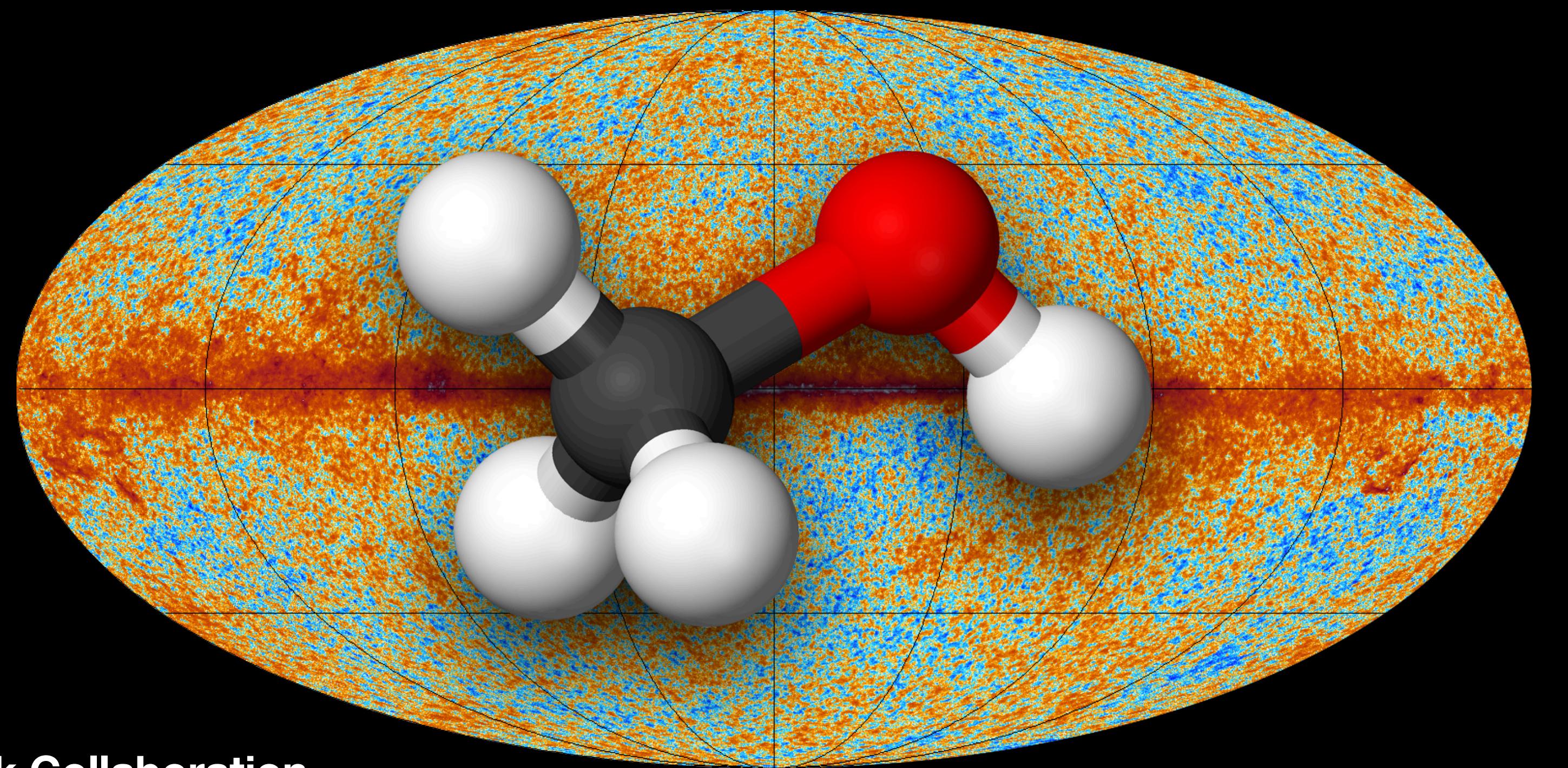
- MASER = Microwave Amplification by Stimulated Emission of Radiation
 - Population inversion: excess population of molecules in upper energy state
 - A photon knocks a molecule out of the upper state
 - Needs source of coherent amplification
- DASAR = Dark "Amplification" by "Stimulated" Absorption of Radiation
 - Pump drives molecules into lower energy state, that then absorb photons

$$\frac{N_u g_l}{N_l g_u} = \exp\left(\frac{-\Delta E}{k_B T_{ex}}\right)$$

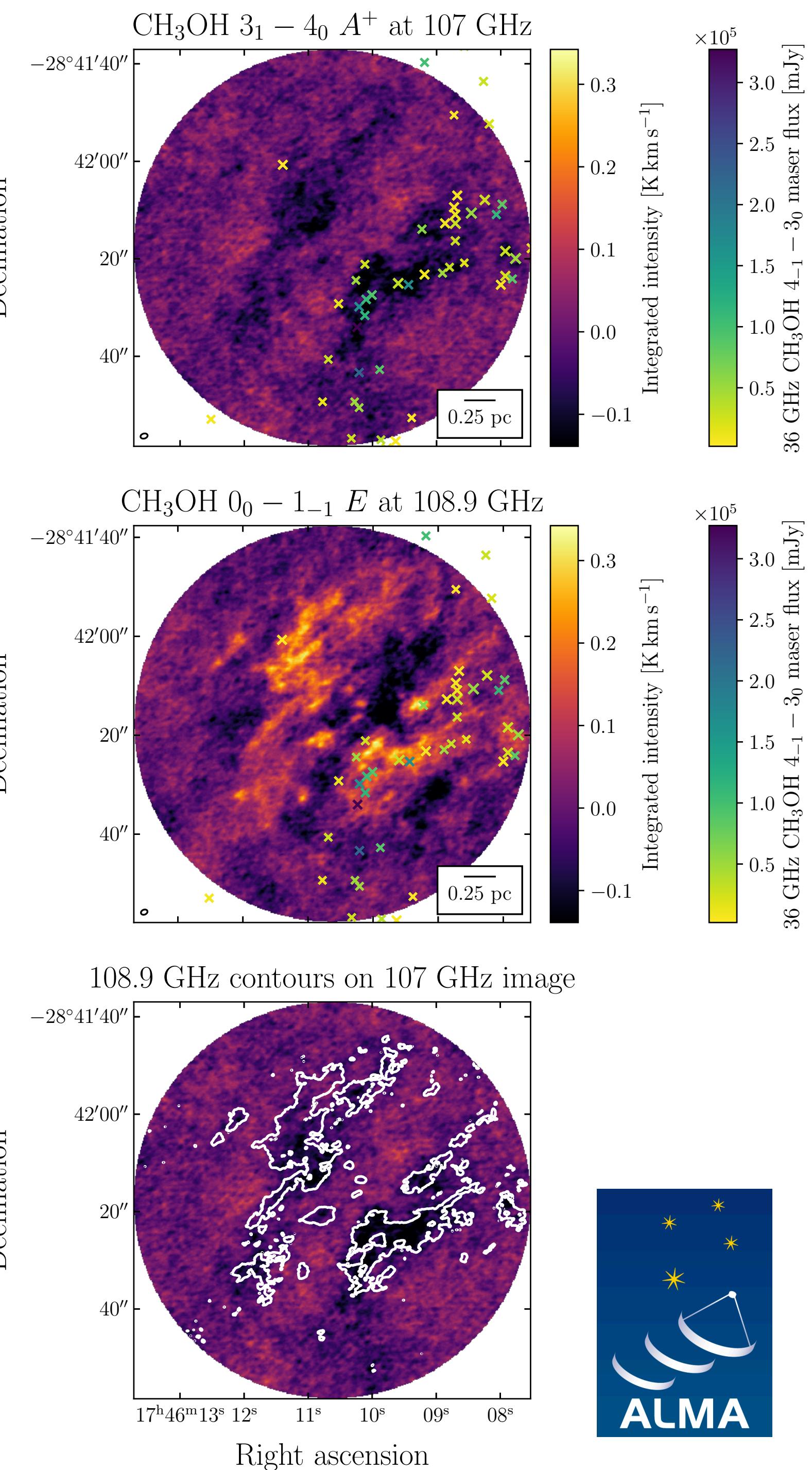
Methanol Dasar in The Brick

Paper I (accepted)

- If the pump gets T_{ex} cold enough, the molecule could even absorb the CMB!



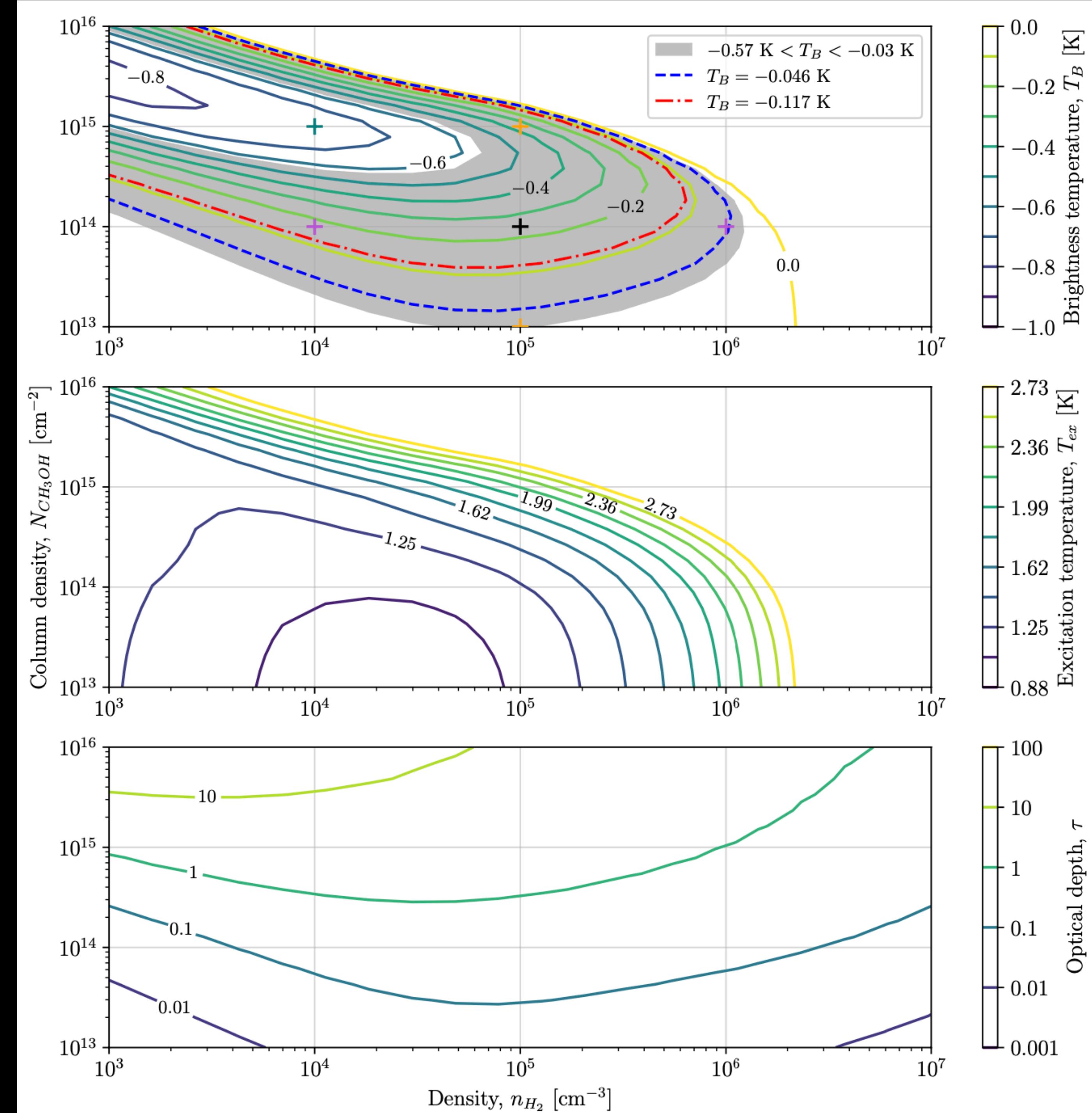
Planck Collaboration
accessed via IRSA



Methanol Dasar in The Brick

Paper I (accepted)

- Modeled dasing volume density, column density, and temperature using RADEX
- Evaluated the use of this line for detecting/measuring dasing regions in high-redshift galaxies
 - Preference for edge-on spirals
 - The ngVLA will be able to observe this line (and others) in starburst galaxies up to at least $z = 5$



The 107 GHz methanol transition is a dasar in G0.253+0.016

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²*Center for Astrophysics and Space Astronomy, Department of Astrophysical and Planetary Sciences, University of Colorado, 389 UCB, Boulder, CO 80309-0389, USA*

³*Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany*

⁴*Astron. Dept., Faculty of Science, King Abdulaziz University, P.O. Box 80203, Jeddah 21589, Saudi Arabia*

⁵*Xinjiang Astronomical Observatory, Chinese Academy of Sciences, 830011 Urumqi, PR China*

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Submitted to ApJ

ABSTRACT

We present observations of population anti-inversion in the $3_1 - 4_0$ A^+ transition of CH₃OH (methanol) at 107.013831 GHz toward the Galactic Center cloud G0.253+0.016 (“The Brick”). Anti-inversion of molecular level populations can result in absorption lines against the cosmic microwave background (CMB) in a phenomenon known as a “dasar.” We model the physical conditions under which the 107 GHz methanol transition dases and determine that dasing occurs at densities below 10^6 cm⁻³ and column densities between 10^{13} and 10^{16} cm⁻². We also find that for this transition, dasing does not strongly depend on the gas kinetic temperature. We evaluate the potential of this tool for future deep galaxy surveys. We note that other works have already reported absorption in this transition (e.g., in NGC 253), but we provide the first definitive evidence that it is absorption against the CMB rather than against undetected continuum sources.

Keywords: astrophysical masers, Galactic Center, molecular clouds, radio lines: ISM

1. INTRODUCTION

Microwave amplification by stimulated emission of radiation, called a “maser,” occurs when two energy levels in a population of particles are inverted or contain a non-thermal distribution of particles. Particles are “pumped” into the

upper state until it is over-populated, driving a population inversion. The level populations are summarized by the excitation temperature using the following relation.

$$\frac{N_u g_l}{N_l g_u} = \exp\left(\frac{-\Delta E}{k_B T_{ex}}\right) \quad (1)$$

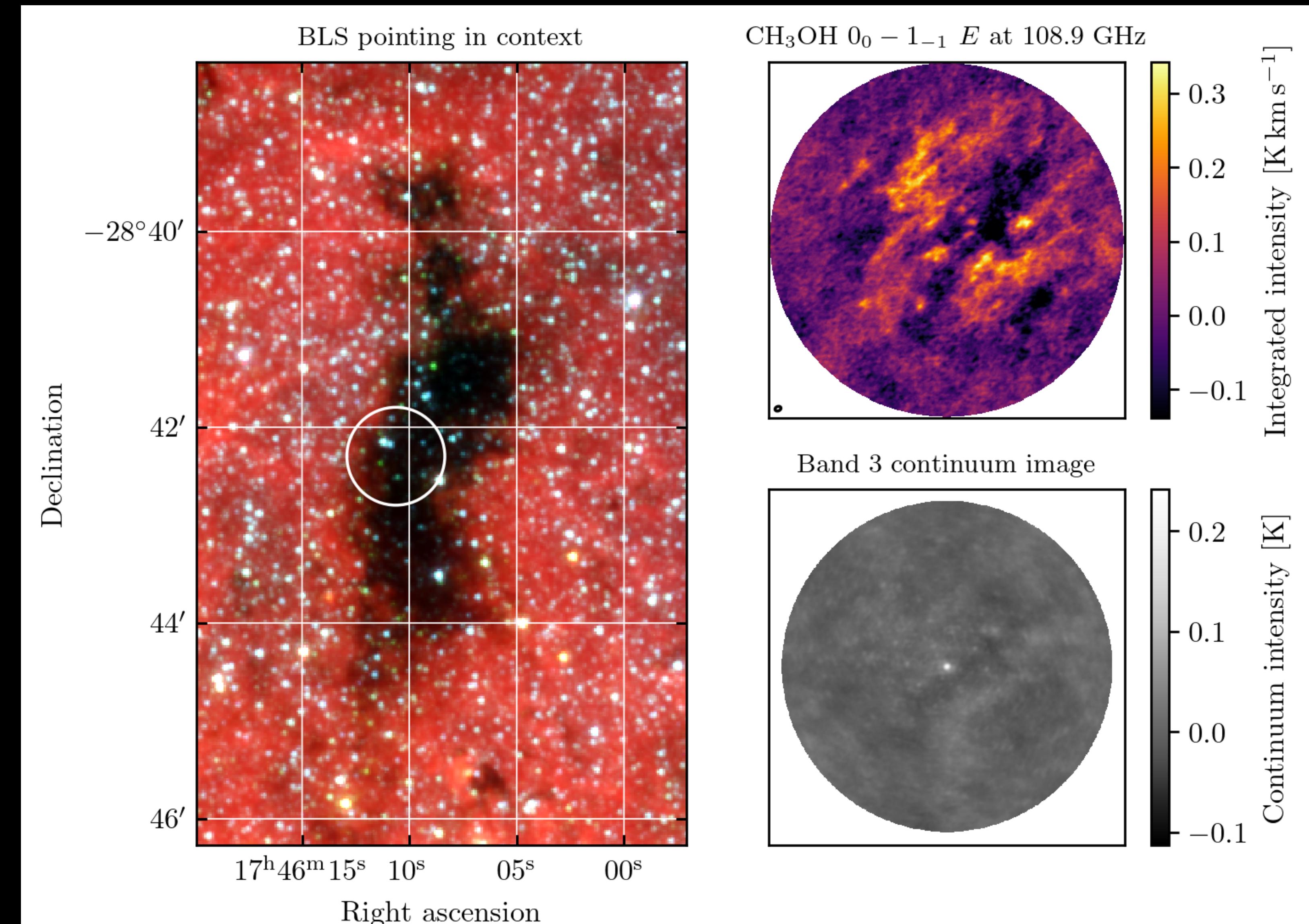
Here, N_u and N_l are the number of particles in the upper and lower energy states respectively, and g_u and g_l are the statistical weights

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BLS I: A line survey of a hot molecular core in The Brick

Paper II (in prep.)

- Complete list of all spectral lines present in the hot core
- LTE modeling results for T, N_{tot} for each molecule
- Working with a high school student on Python, LTE modeling

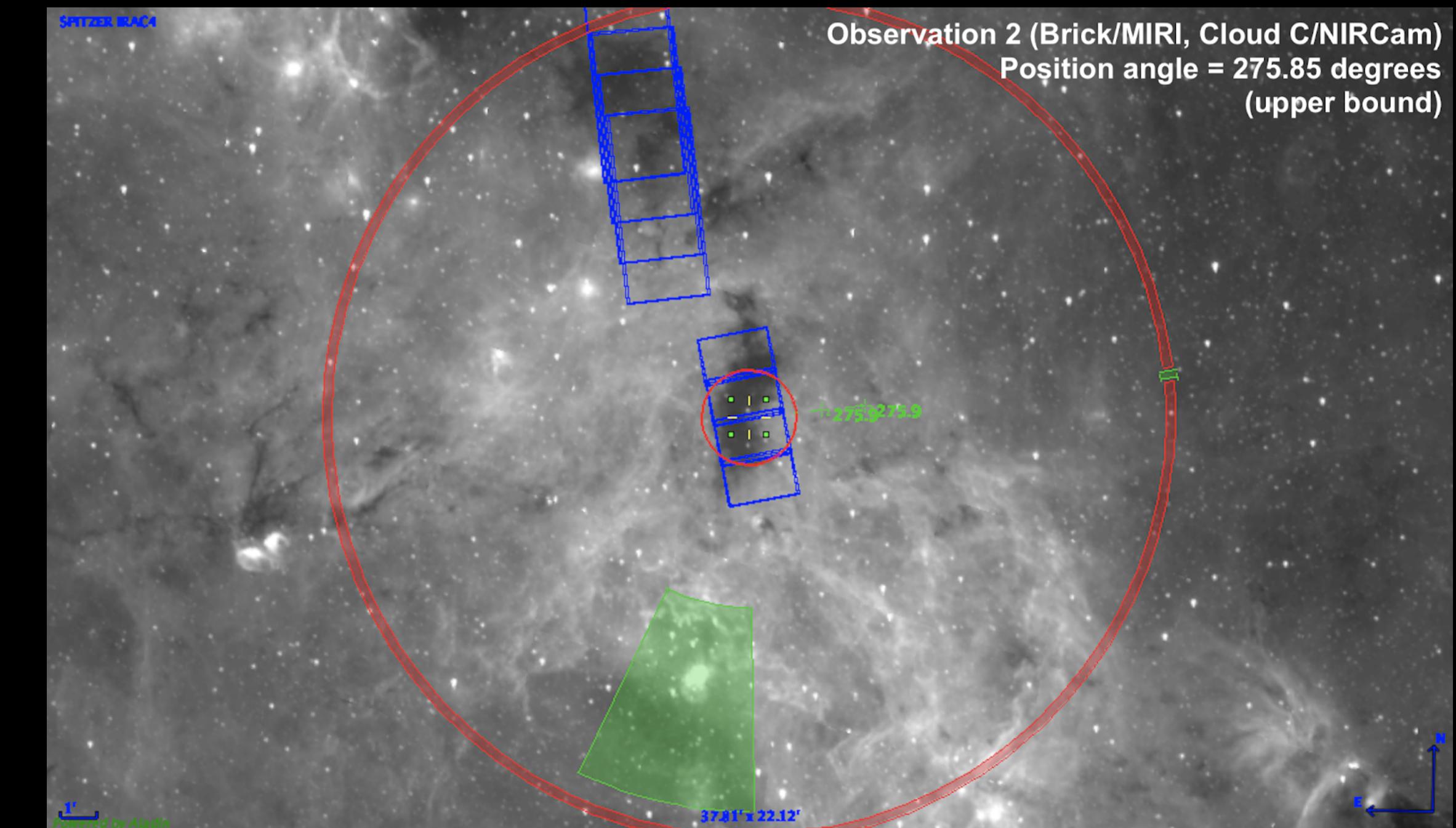
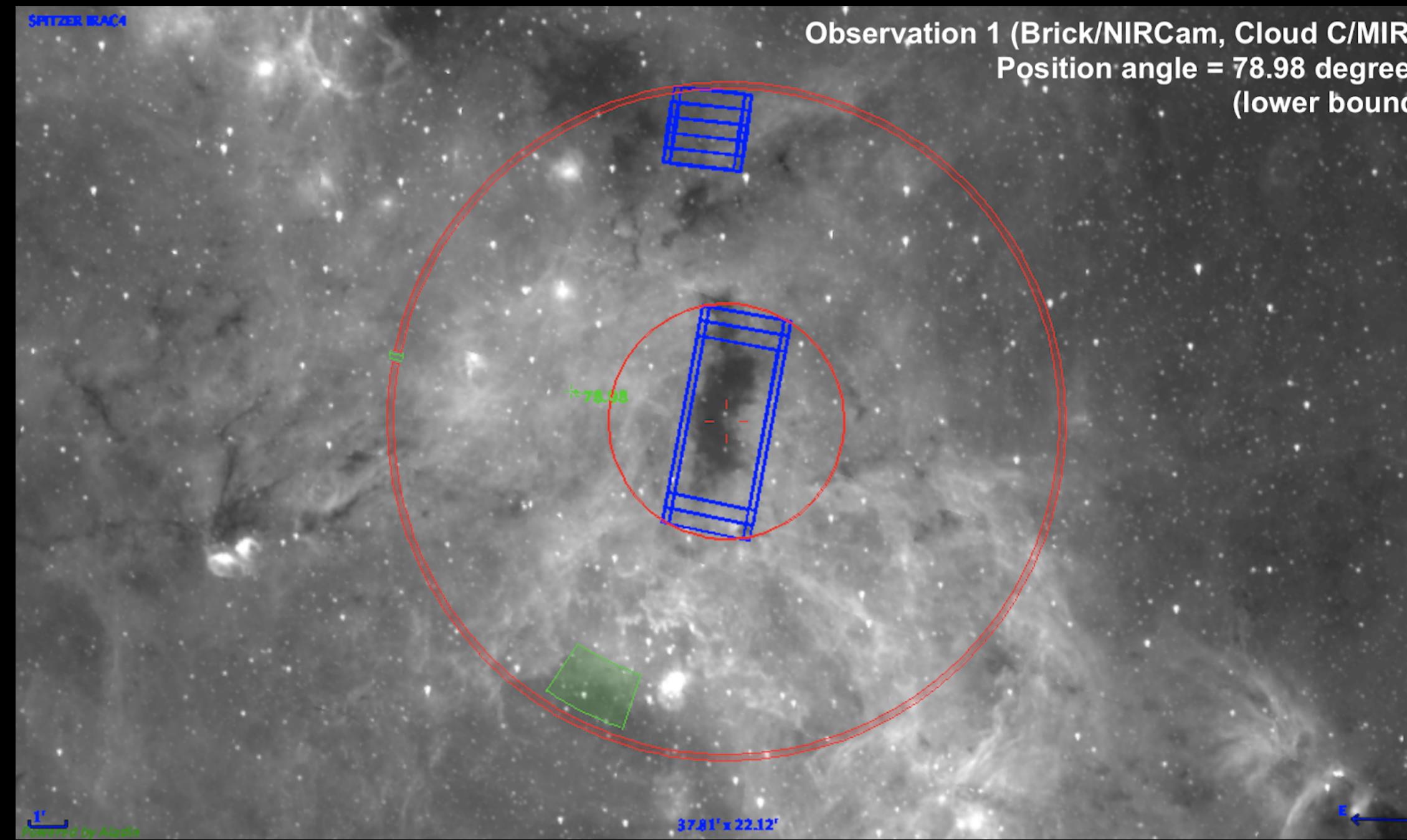


The rest of the thesis



BLS II: JWST MIRI data on The Brick

Paper III

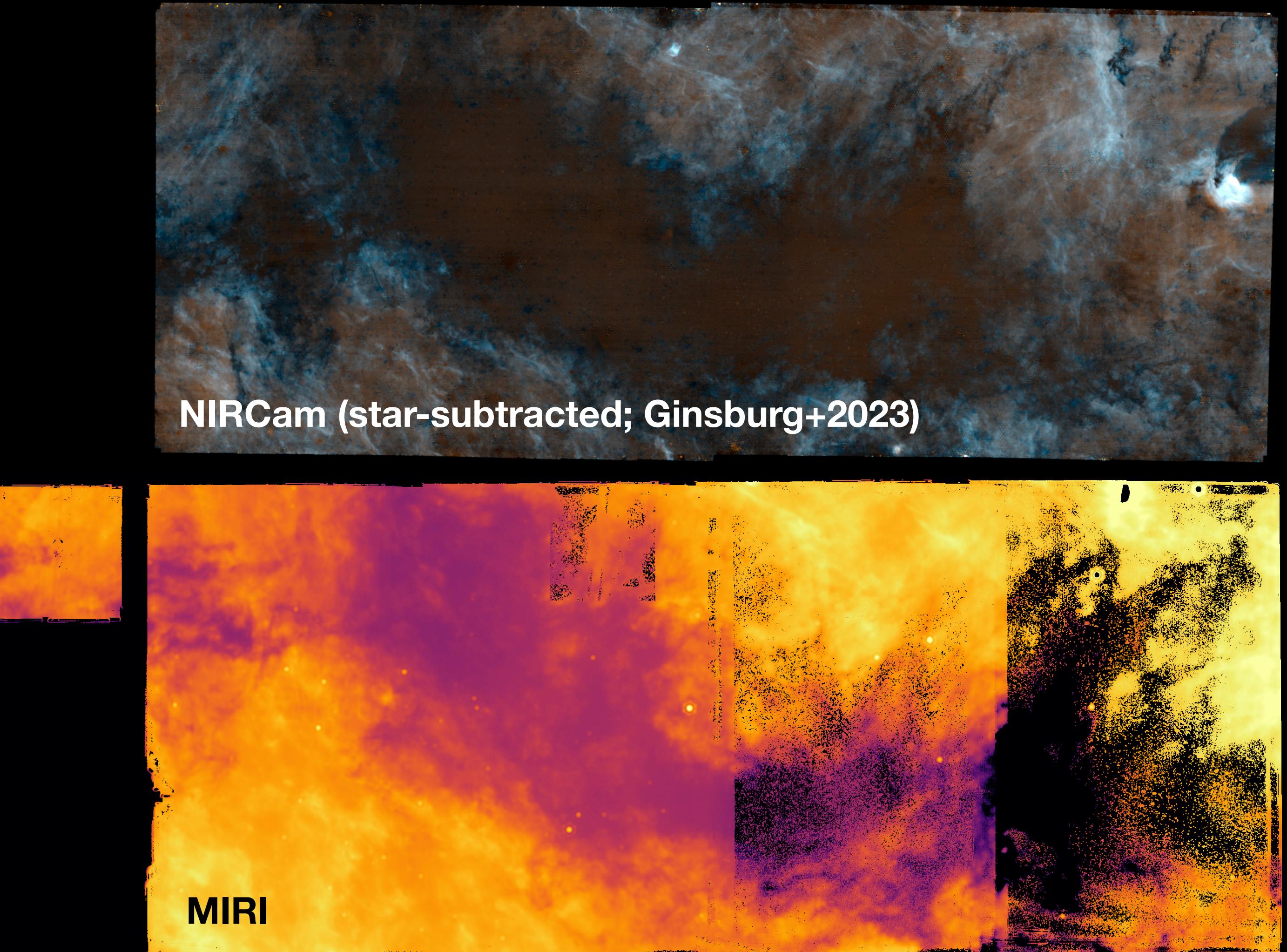




BLS II: JWST MIRI data on The Brick

Paper III

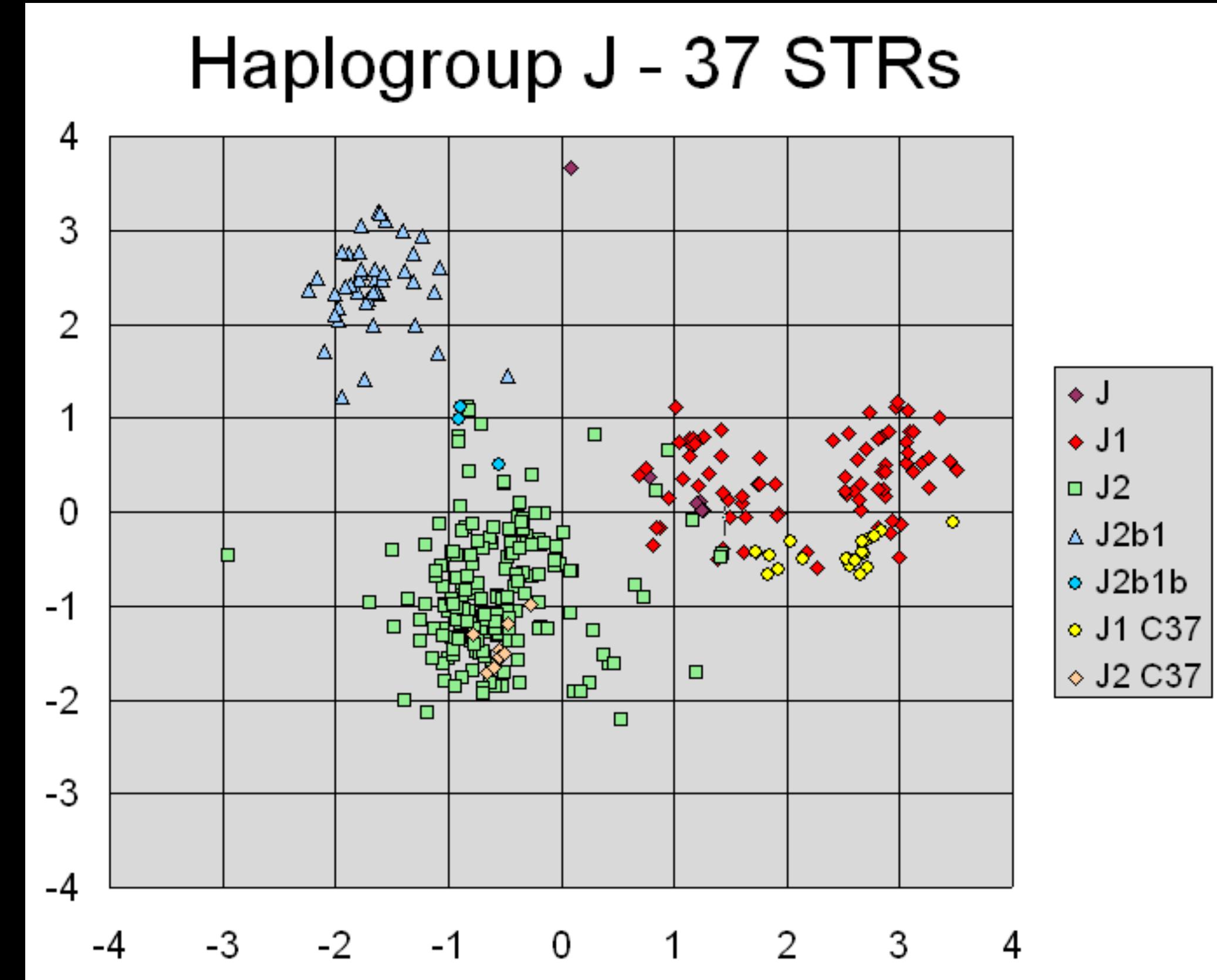
- Reduce MIRI data
 - Solve pipeline issues
(background matching)
- Catalog 26 μm sources in the data
- Spectrally classify those sources (search for YSOs)
- Discussion (depending on what the sources are)



BLS III: BLS extension

Paper IV

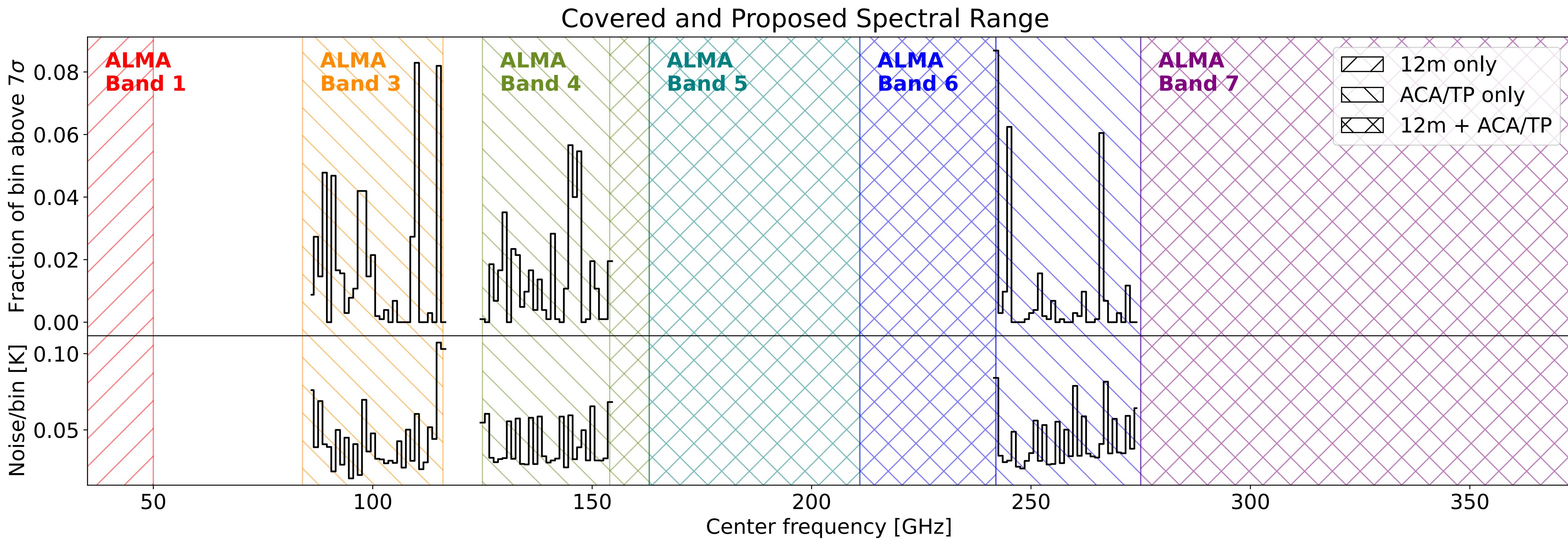
- Answering the "which what" question using the catalog built in Paper I
- Associate new tracers with ISM processes
 - Morphologically, or with e.g. PCA
- First steps:
 - Isolate regions (core, outflow, shocks)
 - Repeat spectral extraction and LTE modeling
 - Compare spectral contents of regions
 - Make conclusions



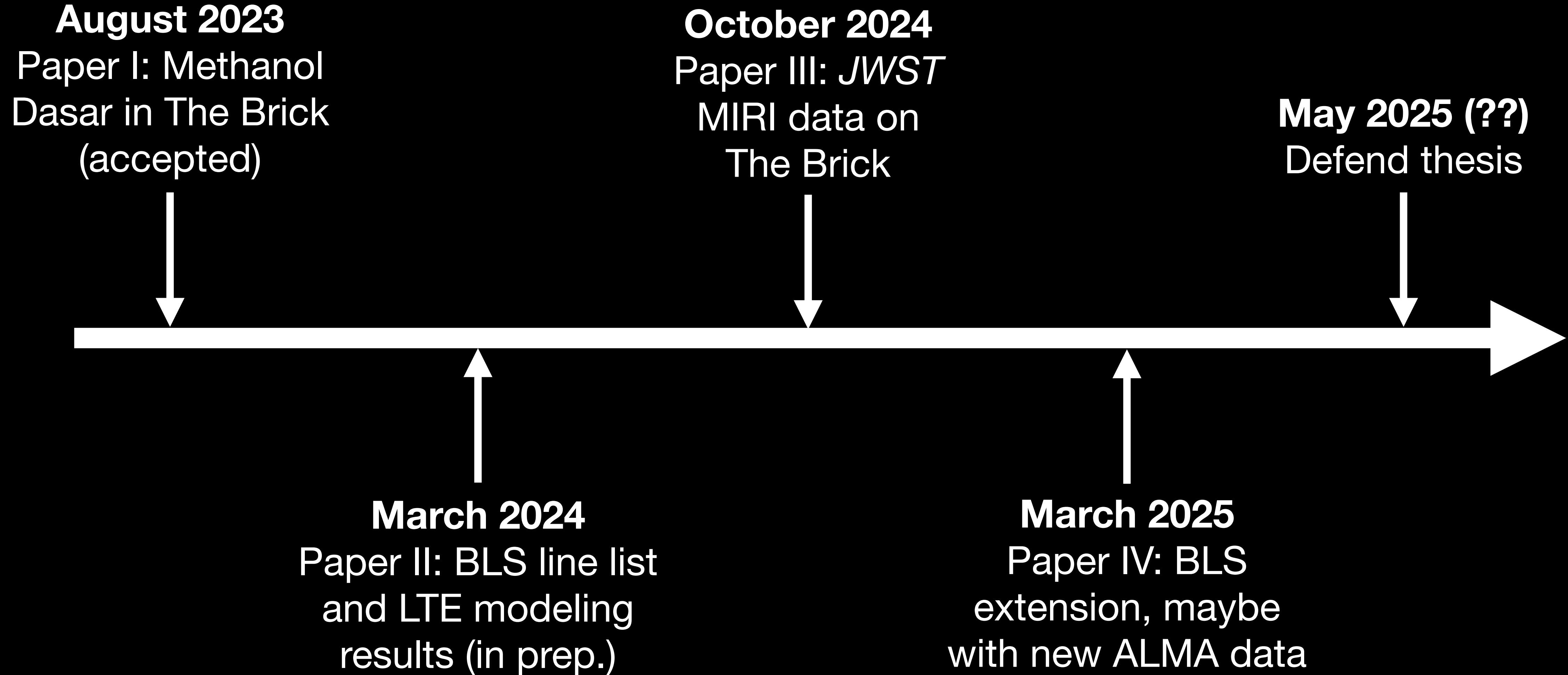
BLS III+ In my dreams

- ALMA Cycle 8, 8S, 9, 10 proposals

- See more lines of more molecules, refine model spectra
- Cover larger angular scales with ACA/TP



Thesis timeline



Other projects

A. The ALMA CMZ Exploration Survey

- Backup paper IV

B. Searching for OB Stars in The Brick

- Henshaw+2022, Jiang+202X

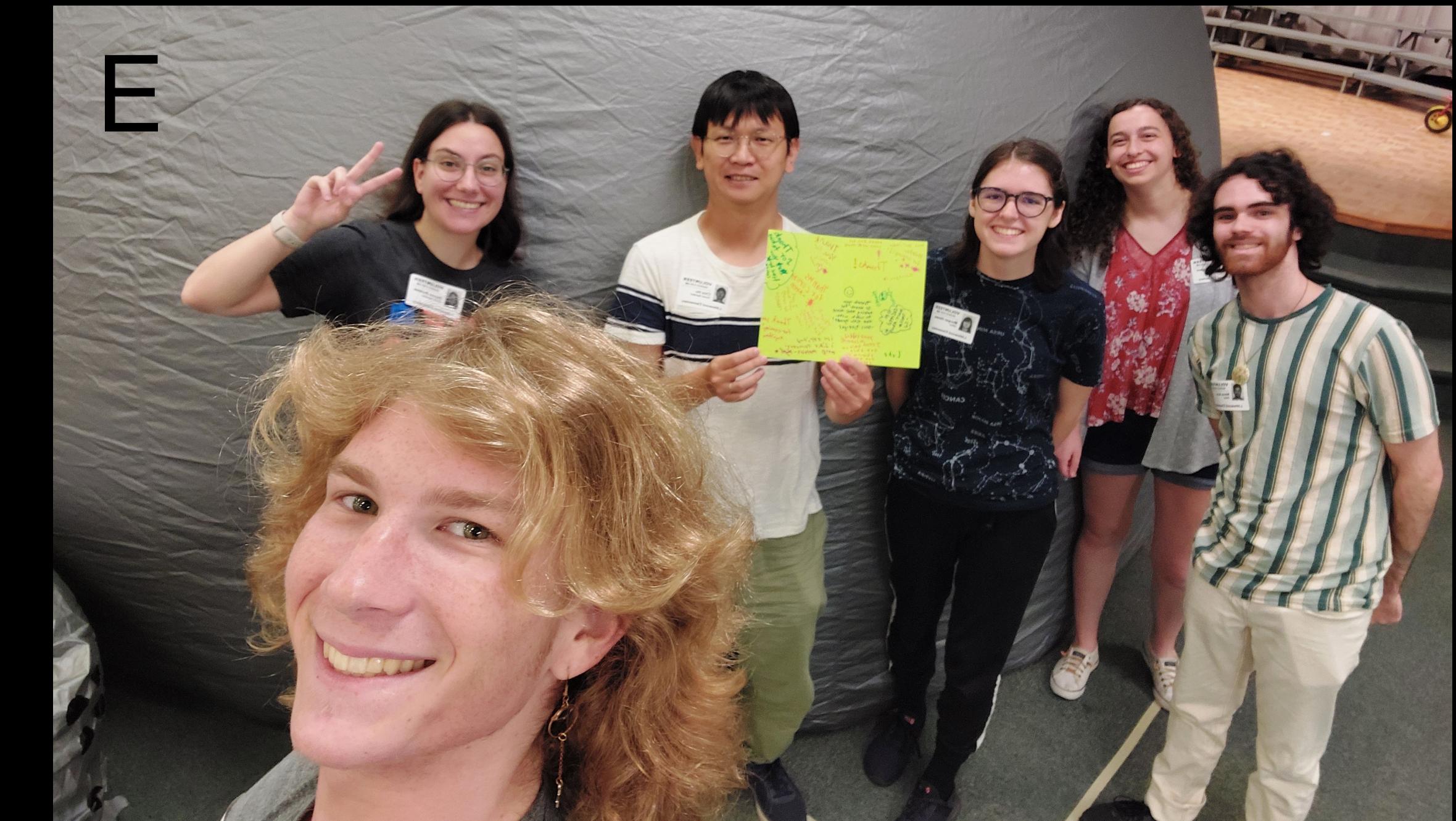
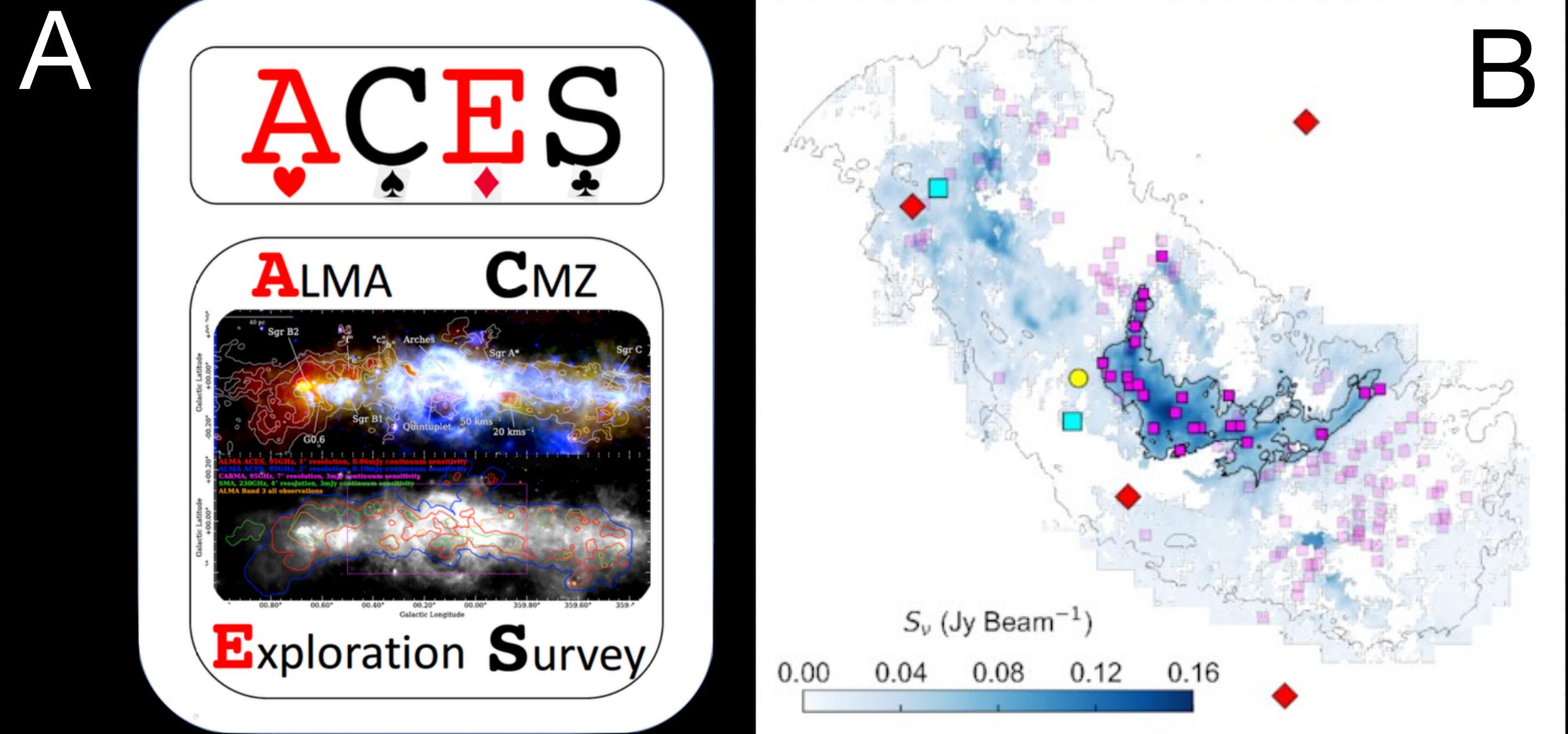
C. JWST NIRCam data on The Brick

- Ginsburg+2023

D. learn.astropy: contributing to open-source software tutorials

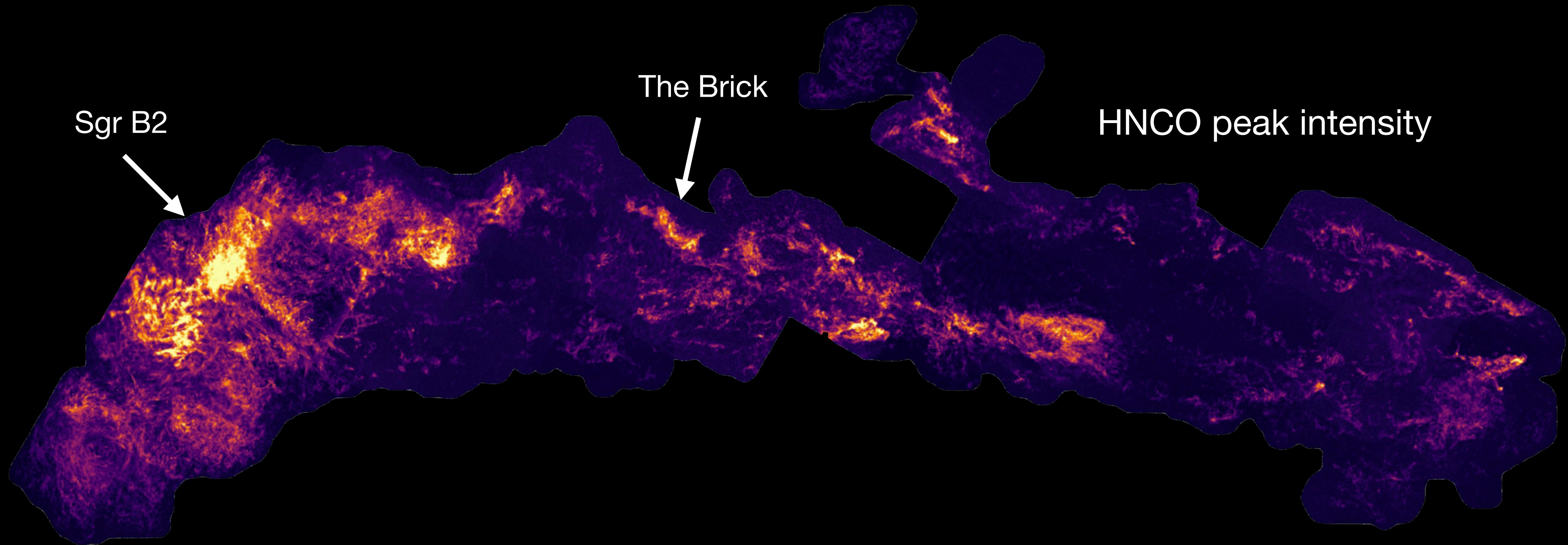
E. Astronomy outreach in the department

- UF Astro Mobile Planetarium (UF AMP)



The ALMA CMZ Exploration Survey

Backup Paper IV



Mosaic made by Dan Walker

Thank you!



**Image credits appear next to images;
all uncredited images were either made
by me or are in the public domain.**

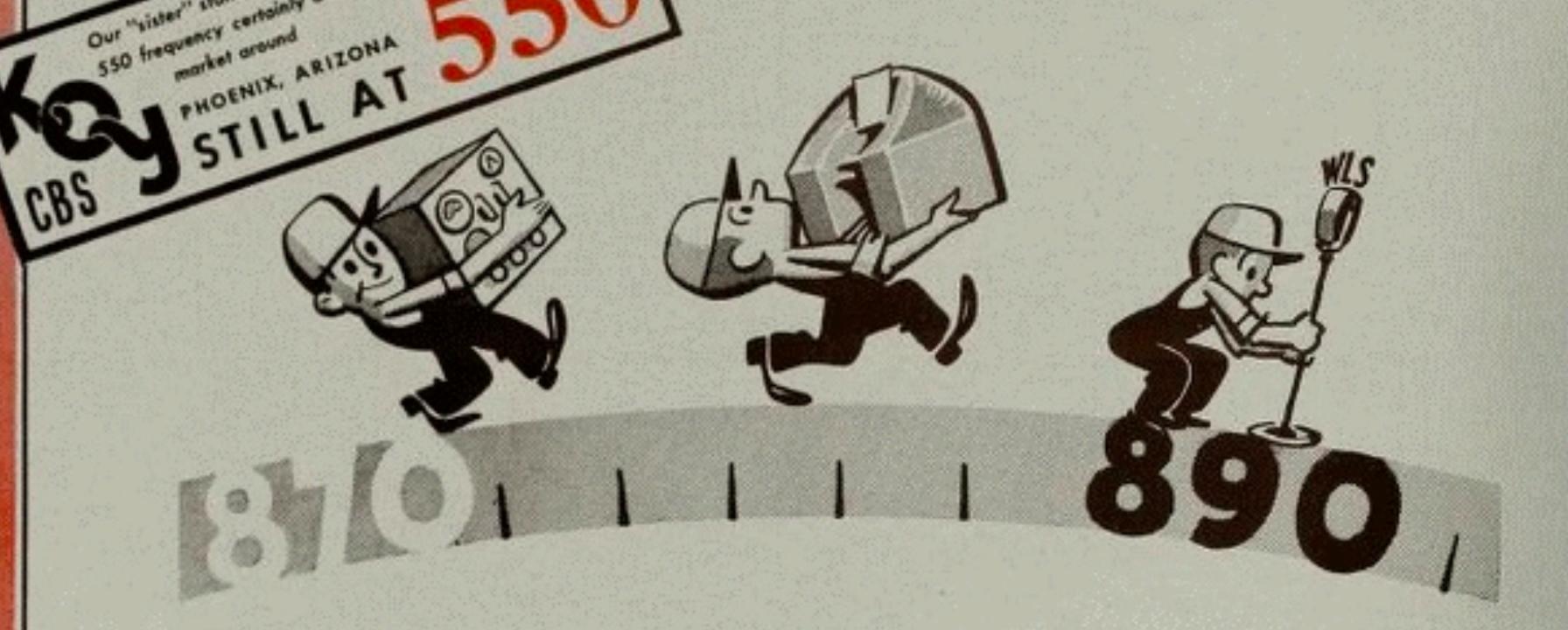
**Also, Mitski has a new
album out today.**



March 24, 1941



Our "sister" station in Arizona stays on 550, and that market certainly does a job in the big, buying
KQY CBS PHOENIX, ARIZONA STILL AT 550



A cartoon illustration showing three men in hats and overalls carrying large pieces of equipment across a horizontal frequency dial. The dial has "870" on the left and "890" on the right. The man on the left carries a large box labeled "PUB". The man in the middle carries a large box labeled "WLS". The man on the right carries a tall pole labeled "WLS".

WE'RE MOVING TO 890

WLS "Moving Day," March 29th, (we go from 870 to 890) has been amply publicized, to insure no "listener loss" to advertisers—nor missed service to listeners. Three full page, two-color advertisements in Prairie Farmer, totaling more than 1,020,000 circulation, largely in the WLS four-state, Major Coverage Area, have impressed the new location on Mid-West farm homes—and merchants. In addition, on several pages in the March 22 issue mention was made of the new WLS frequency. For Chicago listeners a total of eight full-column ads in the Chicago Times have told the same story. A full page back cover ad in Radio Varieties spread the news farther, and every daily and weekly newspaper in the four-state area received a news story, written from the WLS angle, but telling the full reallocation story. 15,000 cards explaining the change were distributed to visitors to the WLS National Barn Dance and studios. We supplied servicemen with WLS tabs for push button sets, to assure the station being represented on every radio. WLS and Prairie Farmer are using stickers on all outgoing mail. And to complete the job of getting the story to everyone, we are using every possible moment on the air to announce the new frequency and explain the reasons for the change. So, when WLS moves up to 890, we'll have our same full-size, loyal audience moving right along with us—for they all *know* that we're moving... why we're moving... and where, too!



The PRAIRIE FARMER STATION
BURRIDGE D. BUTLER
President
GLENN SNYDER
Manager

50,000 WATTS NBC AFFILIATE
REPRESENTED BY JOHN BLAIR & COMPANY