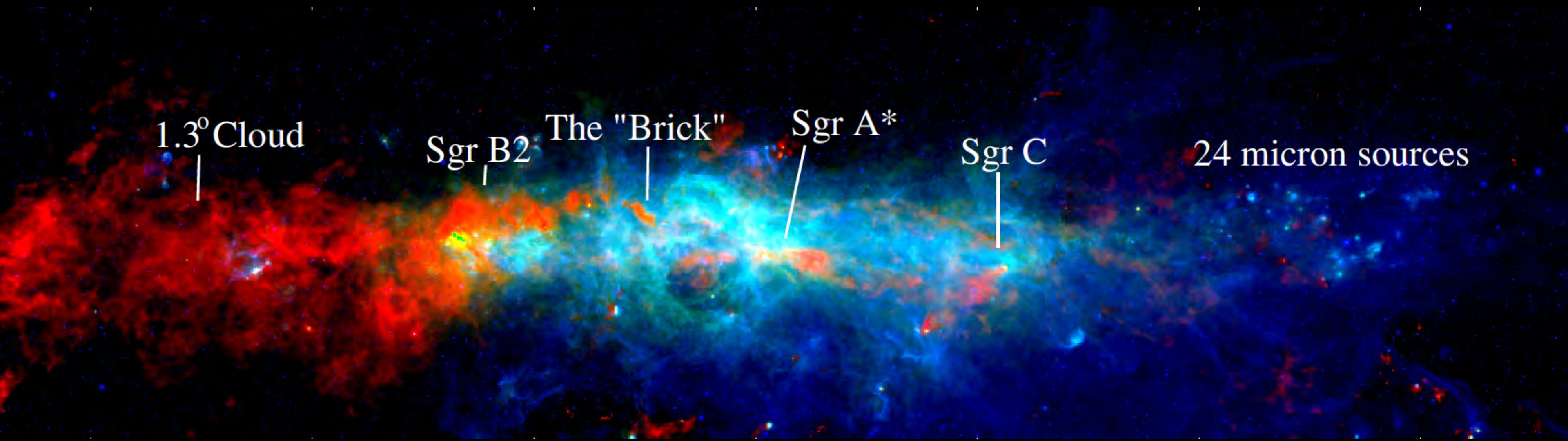
SMA Legacy Survey of the Central Molecular Zone



CARA BATTERSBY

Eric Keto (CfA), Qizhou Zhang (CfA), Xing 'Walker' Lu (CfA), Mark Graham (Southampton), Jens Kauffmann (Bonn), Thushara Pillai (Bonn), John Bally (CU-Boulder), Steve Longmore (Liverpool), Daniel Walker (Liverpool), Diederik Kruijssen (MPA), Adam Ginsburg (ESO), Nimesh Patel (CfA), Volker Tolls (CfA), Luis C. Ho (Peking Univ.)

Red $N(H_2)$ (Battersby+ in prep.), Green 70 micron (Hi-GAL, Molinari +2011), Blue: 8 micron (GLIMPSE, Benjamin+20003)

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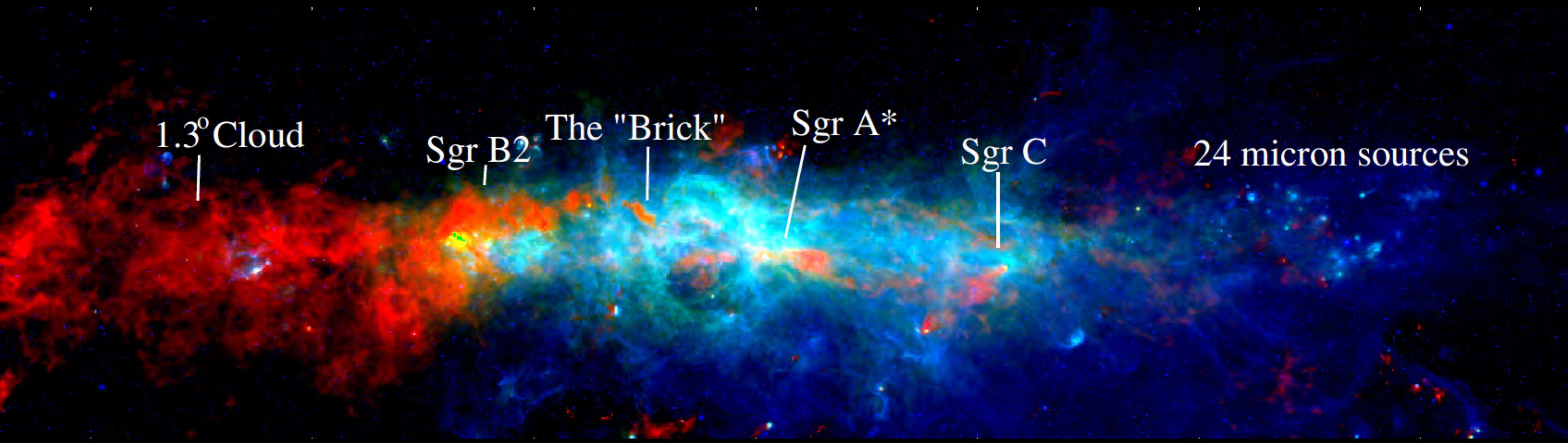

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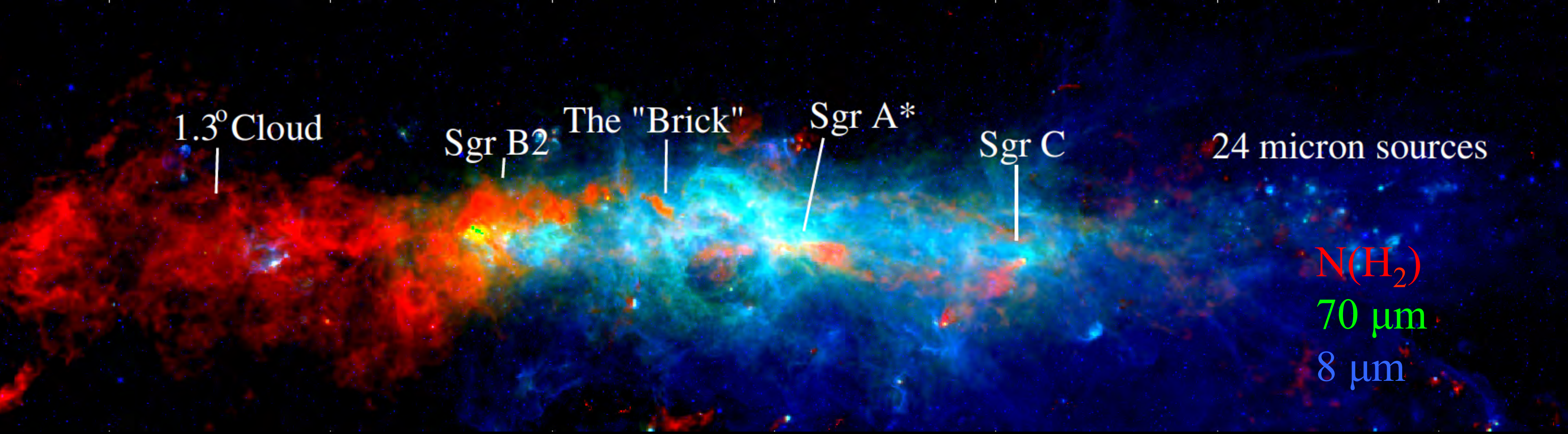

Team:

CfA: Cara Battersby, Eric Keto, Qizhou Zhang, Xing ‘Walker’ Lu, Mark Graham (Southampton), Nimesh Patel, Volker Tolls

Bonn: Jens Kauffmann, Thushara Pillai

University of Colorado, Boulder: John Bally

Liverpool: Steve Longmore, Daniel Walker

MPA: Diederik Kruijssen

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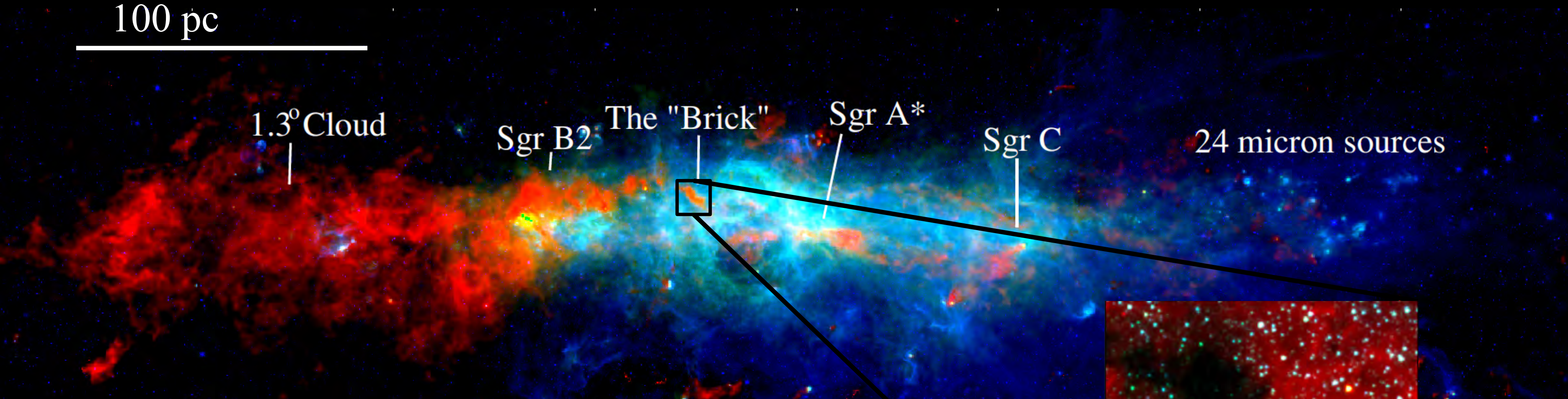
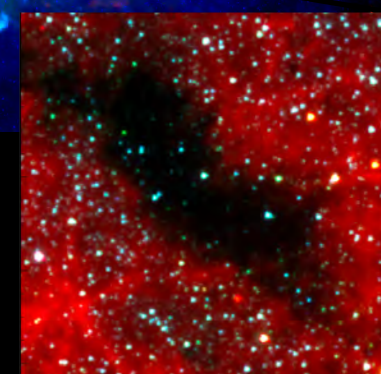
Peking University: Luis C. Ho

$N(H_2)$
70 µm
8 µm



Almost no signs of active star formation!
$1.3 \times 10^5\ M_\odot$ in < 3 pc



“The Brick”
$T \sim 20$ K
$M \sim 10^5\ M_\odot$
$\Sigma_{H2} \sim 1$ g cm^{-2}

Longmore et al. 2012; Rathborne et al. 2014;
Johnston et al. 2014, etc. etc. etc.

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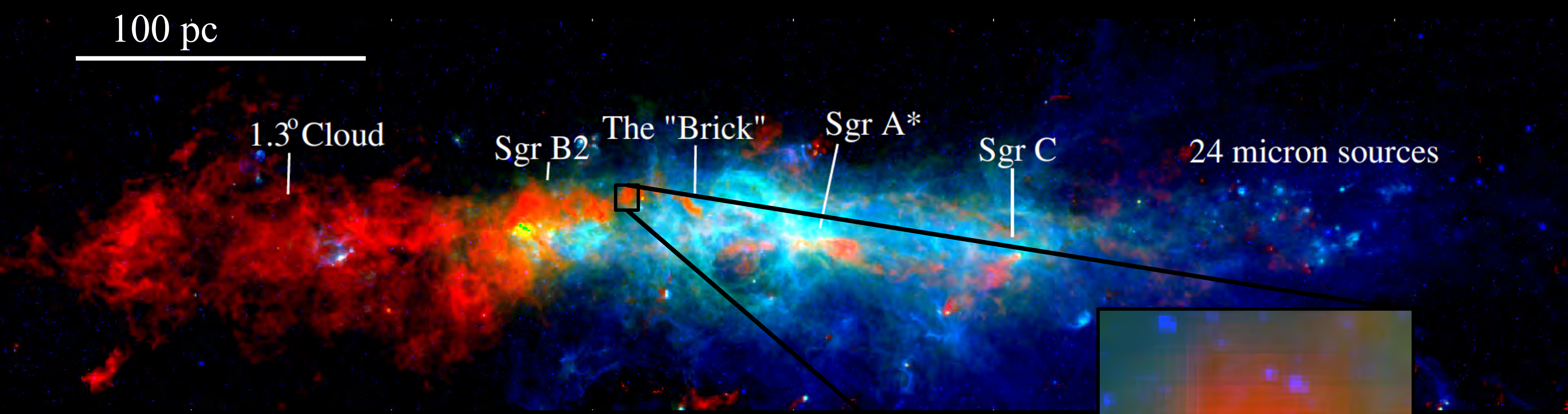
70 µm
8 µm



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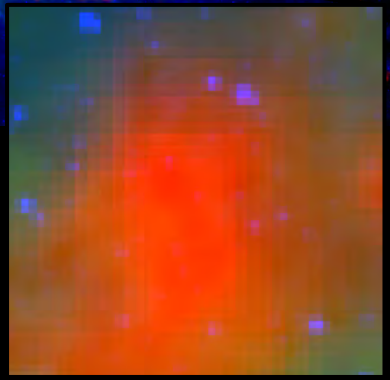


"Bricklet D"

$T \sim 20$ K

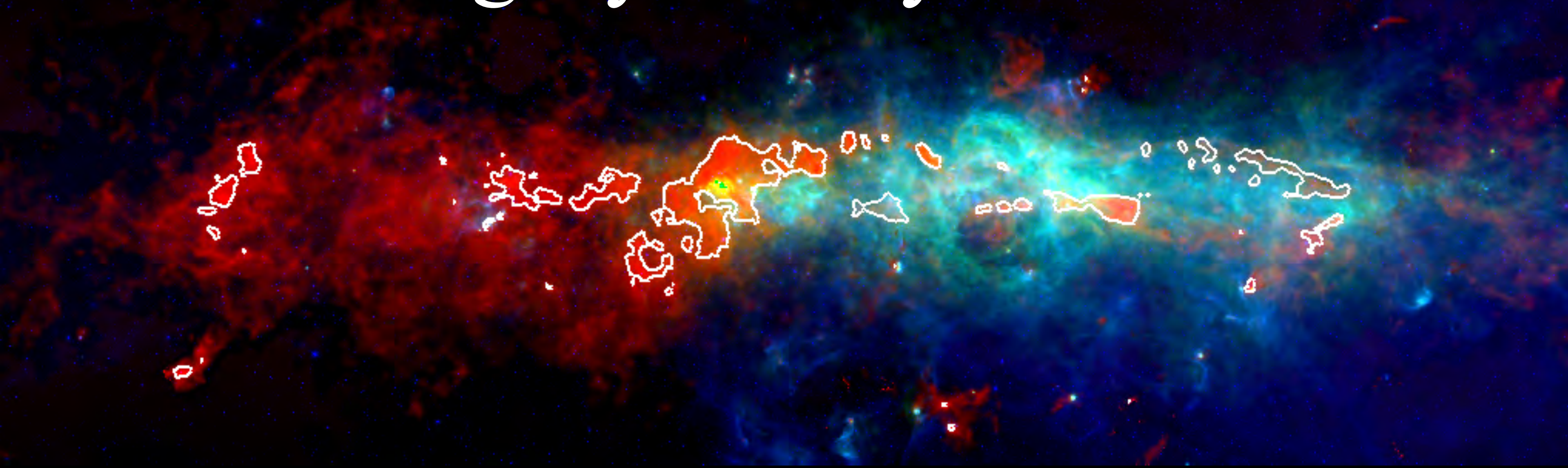
$M \sim 10^5\ M_\odot$

$\Sigma_{H2} \sim 1$ g cm^{-2}

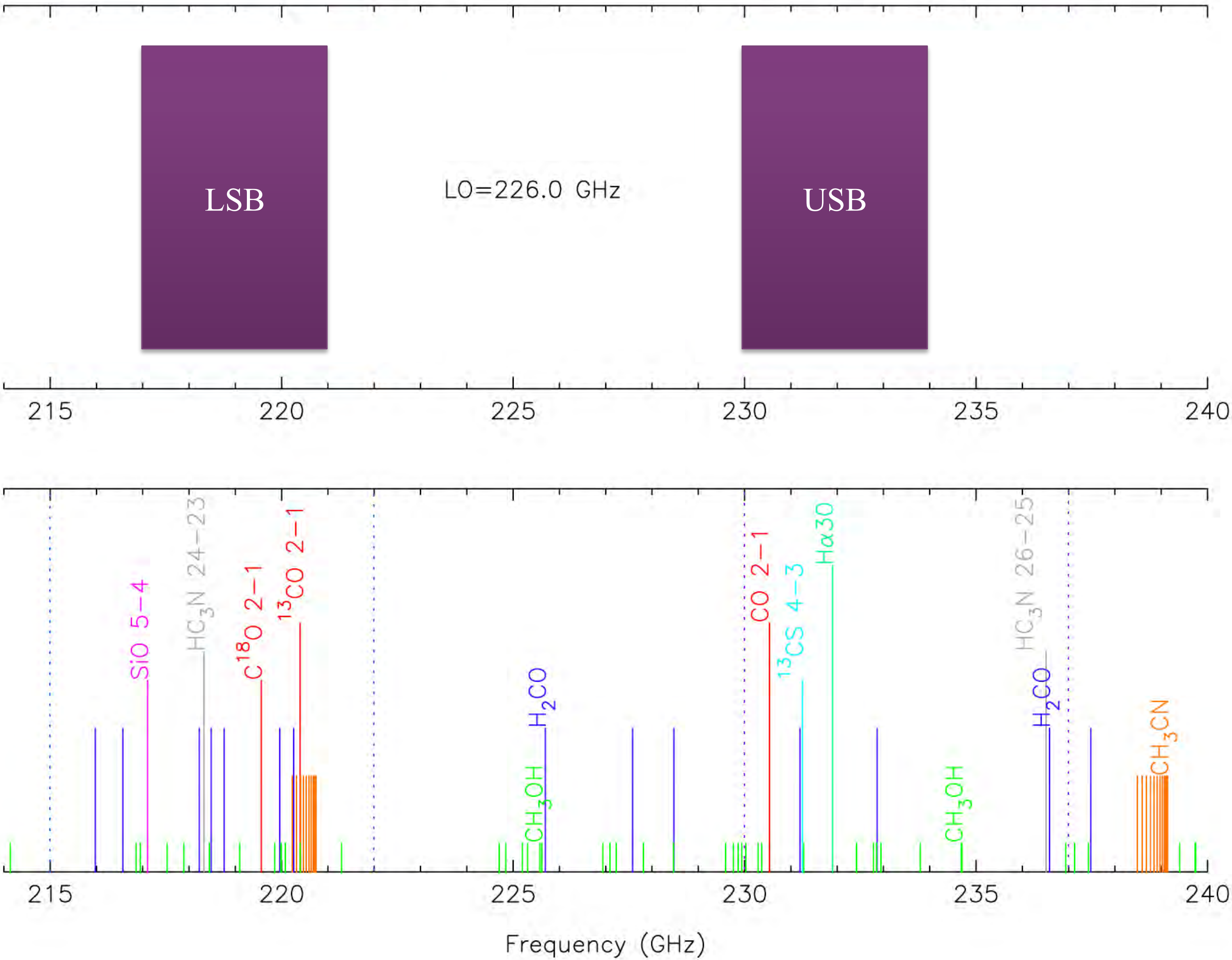
SMA Legacy Survey of the Central Molecular Zone

- Large primary beam, high angular resolution, large bandwidth → detect (pre-) star-forming cores
- First sub-pc (0.2 pc) survey of dense, molecular gas in the CMZ → 1.3 mm dust continuum + spectral line

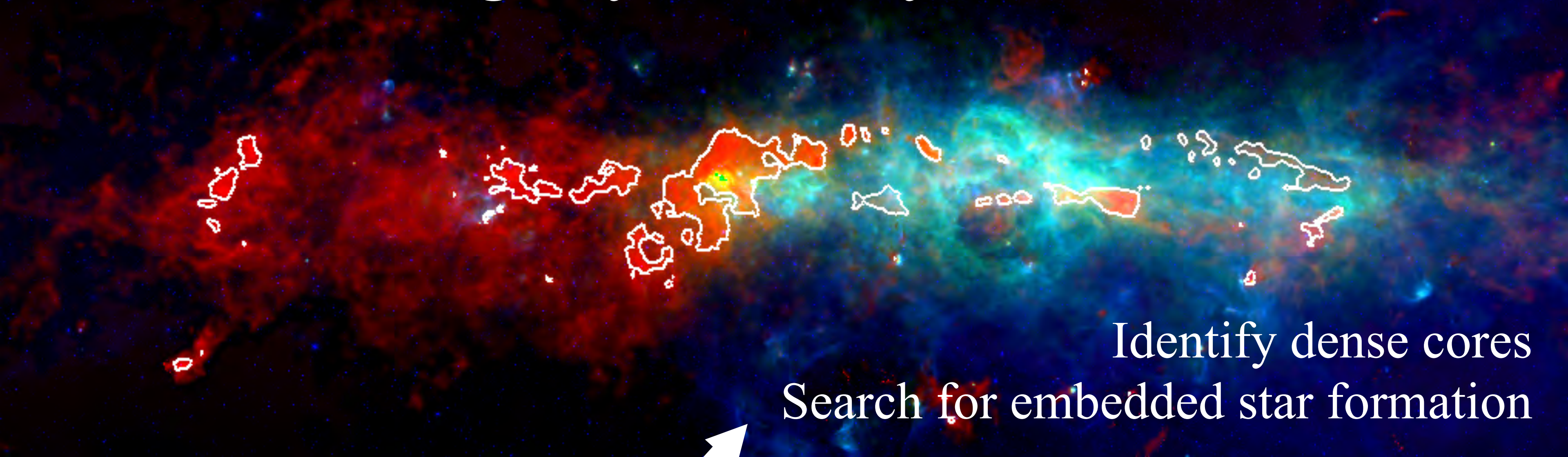
SMA Legacy Survey of the CMZ



- 230 GHz (1.3 mm)
- 240 arcmin^2 (above $N(H_2) = 10^{23}$ cm^{-2} or 3×10^{22} cm^{-2})
- 4'' (0.2 pc) resolution, $\Delta v \sim 1.1$ km/s
- dust continuum + spectral lines (H_2CO, ^{12}CO, ^{13}CO, $C^{18}O$, SiO, CH_3OH, CH_3CN, etc.): 8 GHz bandwidth
- 3 mJy RMS continuum, 0.4 K
- 500 hours (50 subcompact, 450 compact/custom)
- Complement with single-dish (APEX, CSO) observations


LSB
LO=226.0 GHz
USB
215
220
225
230
235
240
SiO 5−4
HC3N 24−23
C18O 2−1
13CO 2−1
CH3OH
H2CO
CO 2−1
13CS 4−3
Hα30
CH3OH
HC3N 26−25
H2CO
CH3CN
215
220
225
230
235
240
Frequency (GHz)

SMA Legacy Survey of the CMZ



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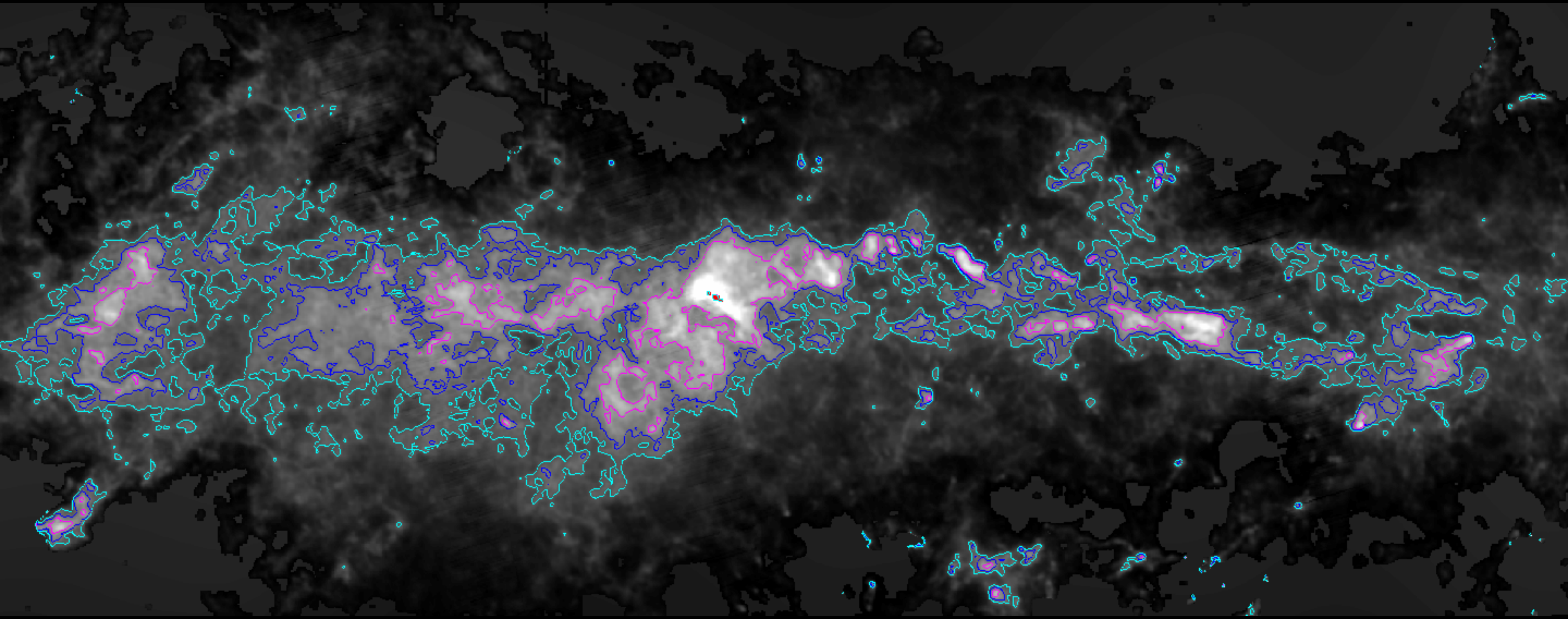
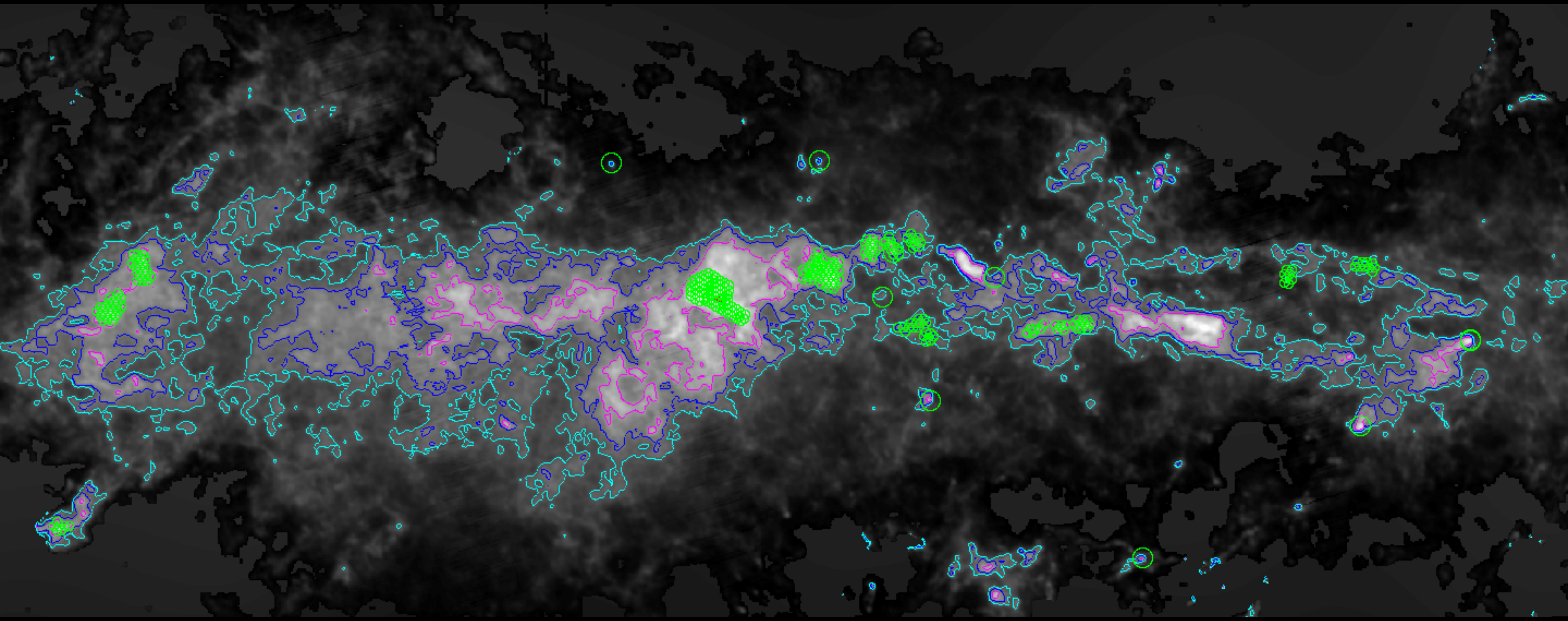
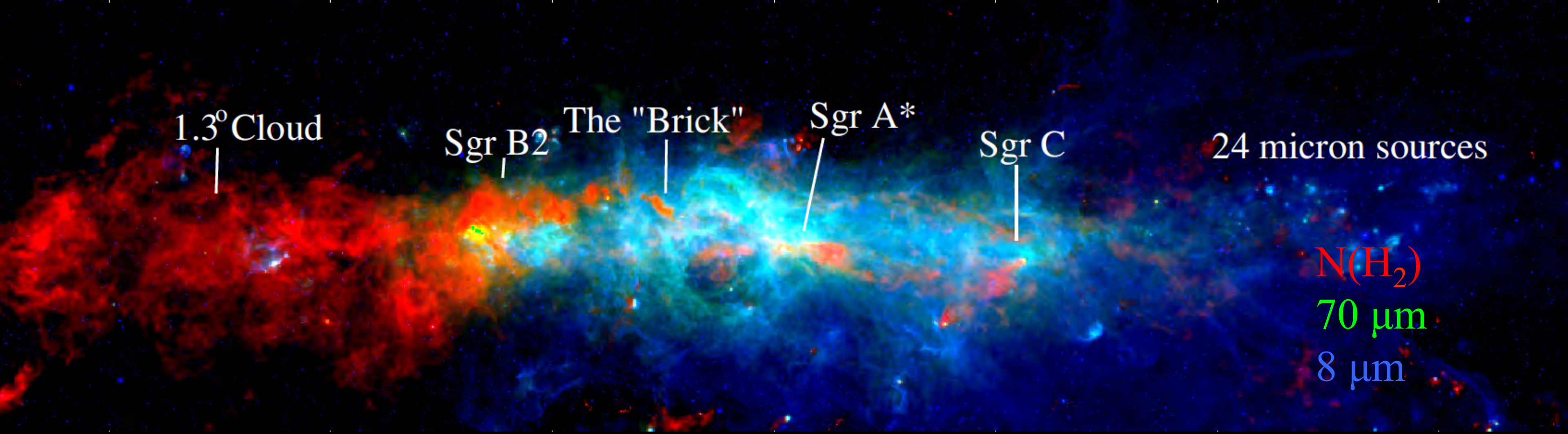


Column Density Map with contours at
3, 5, 10 x 10^{22} cm^{-2}
(cyan, blue, magenta)

Observed regions with green mosaics





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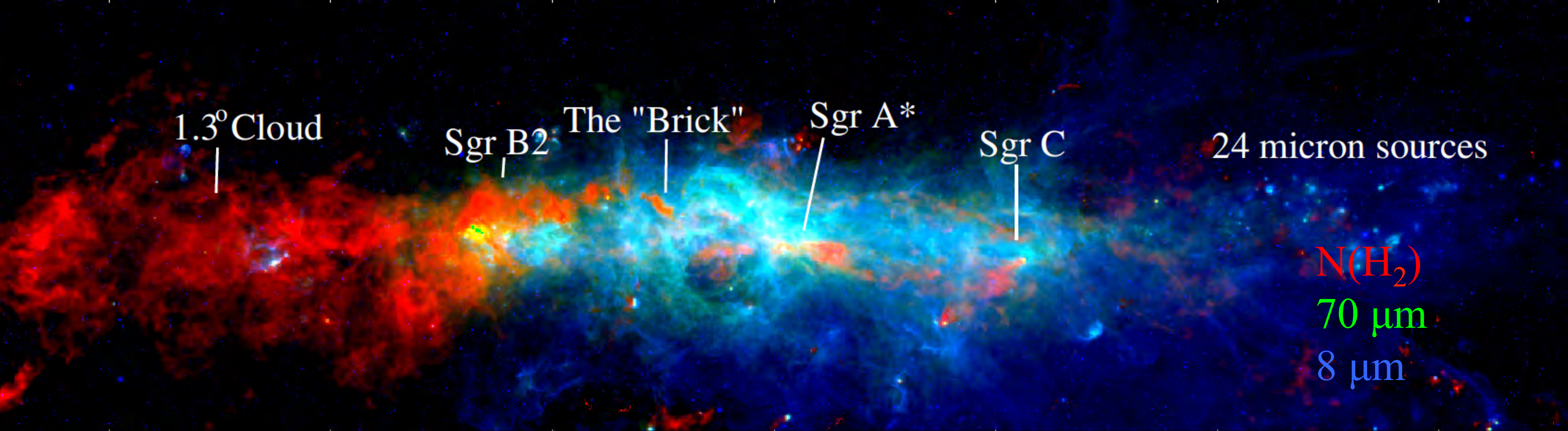

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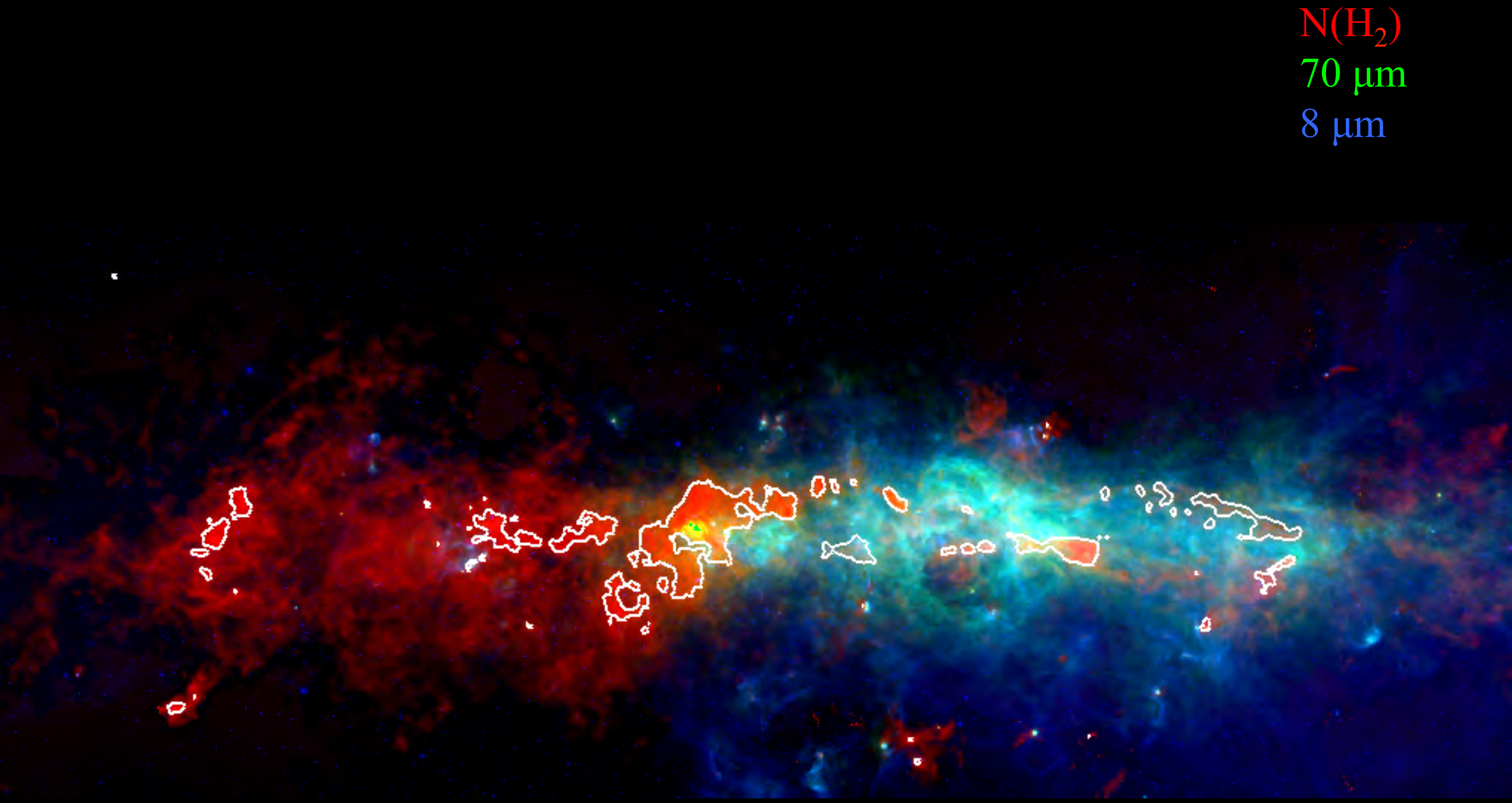
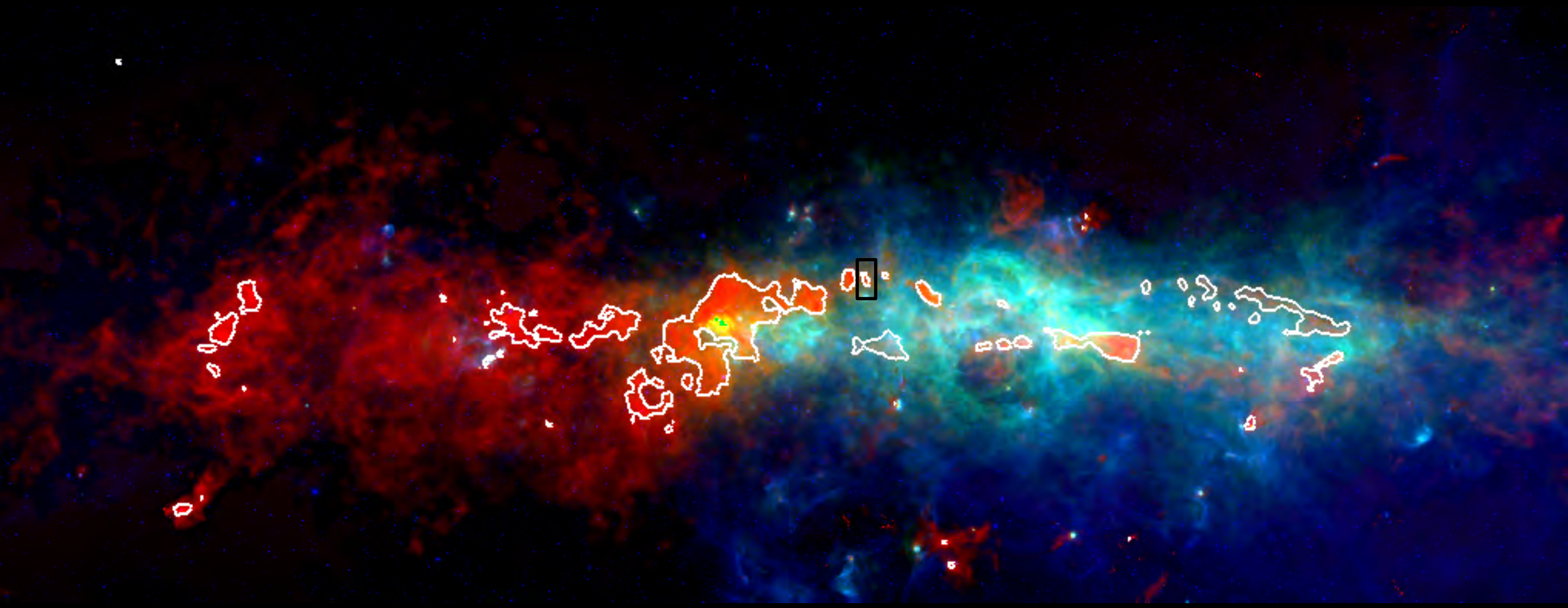


N(H2)
70 µm
8 µm


N(H_2)
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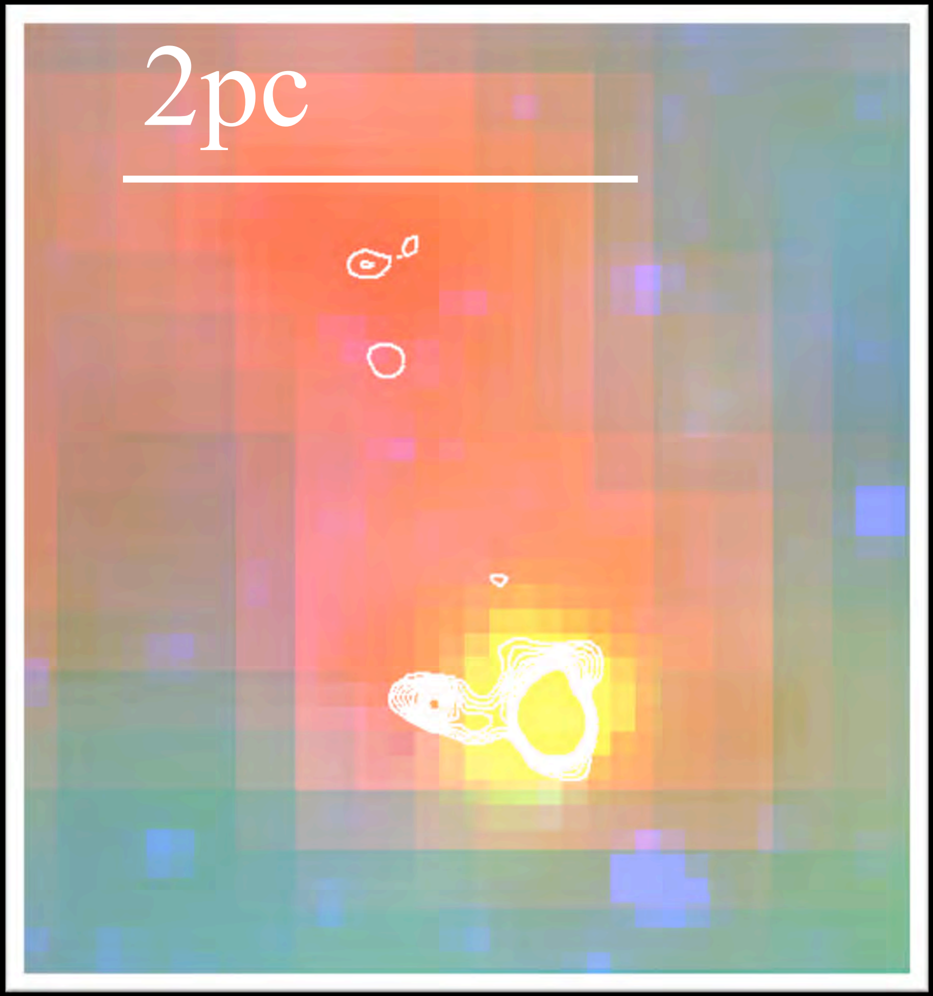
8 μm



$N(H_2)$
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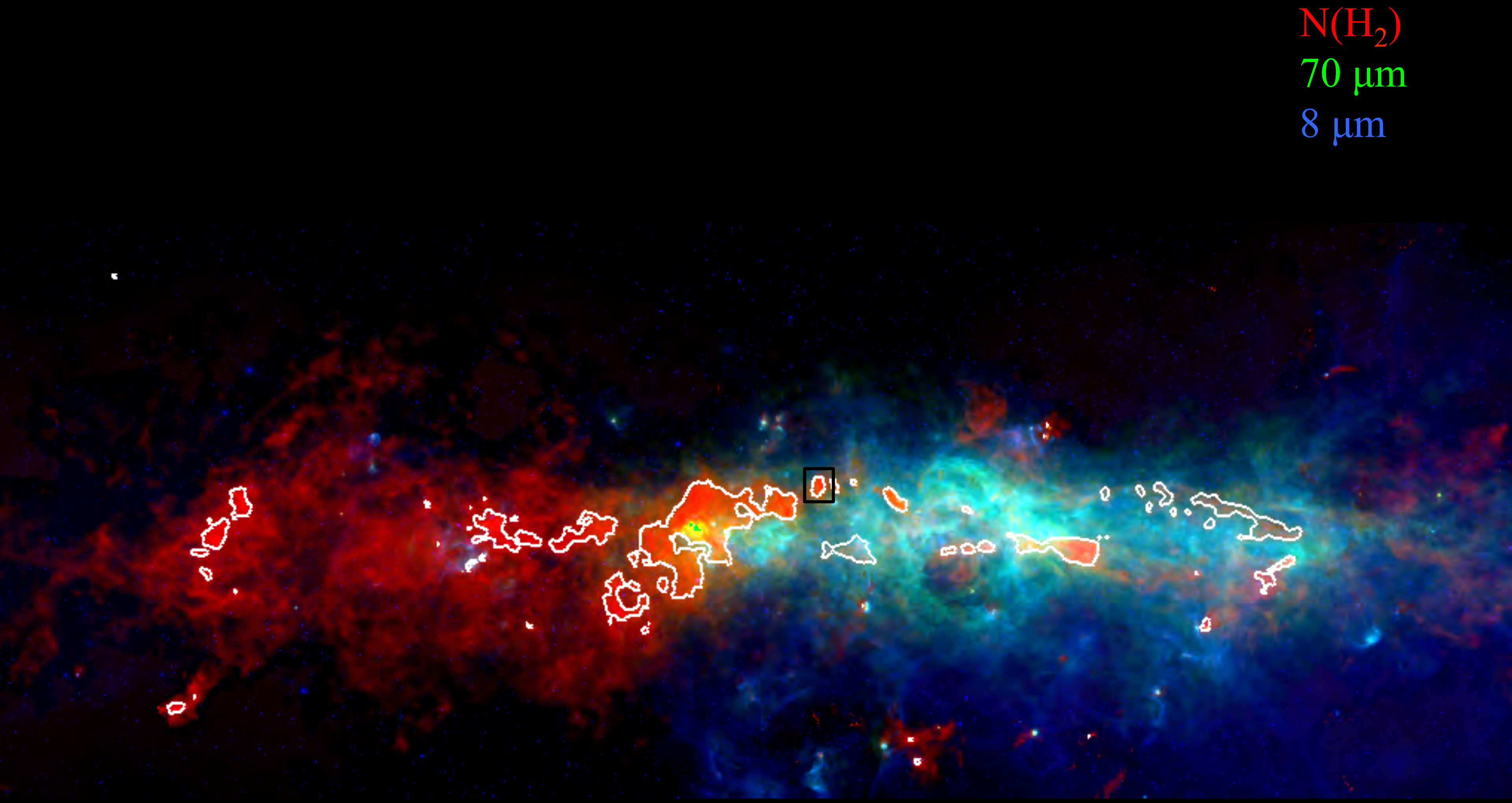
8 µm

1.3 mm dust continuum Dan Walker, in prep.



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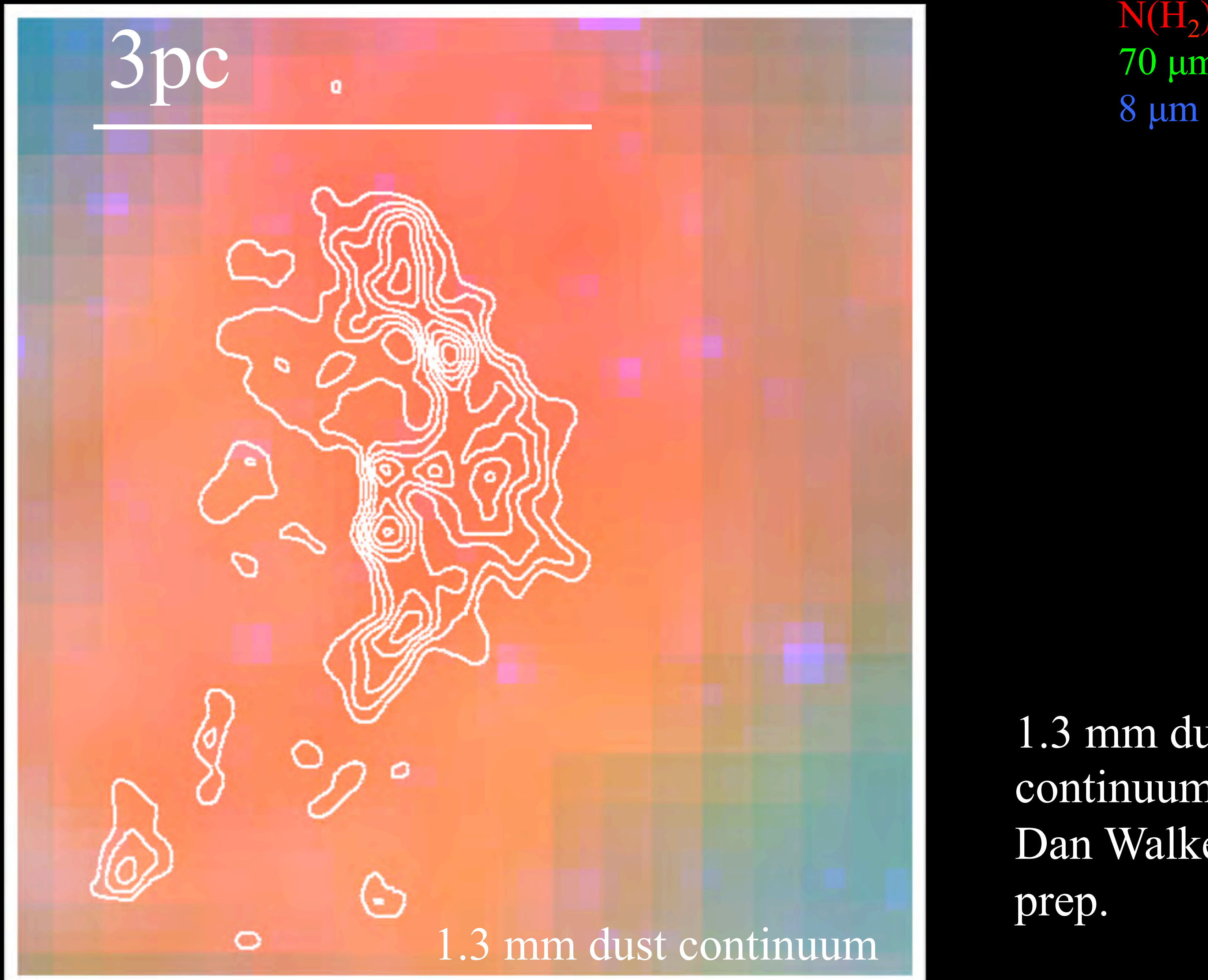
8 µm



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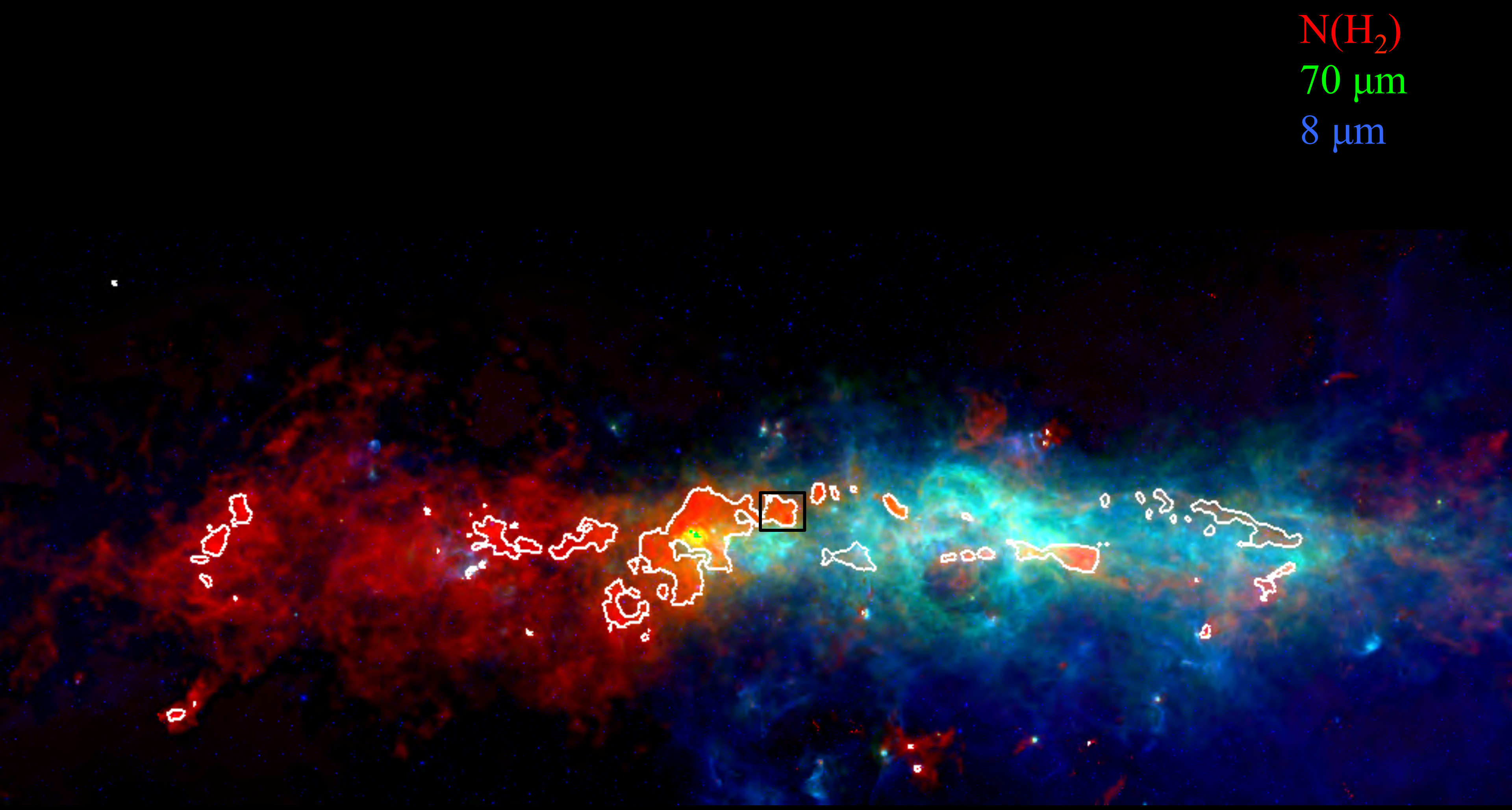

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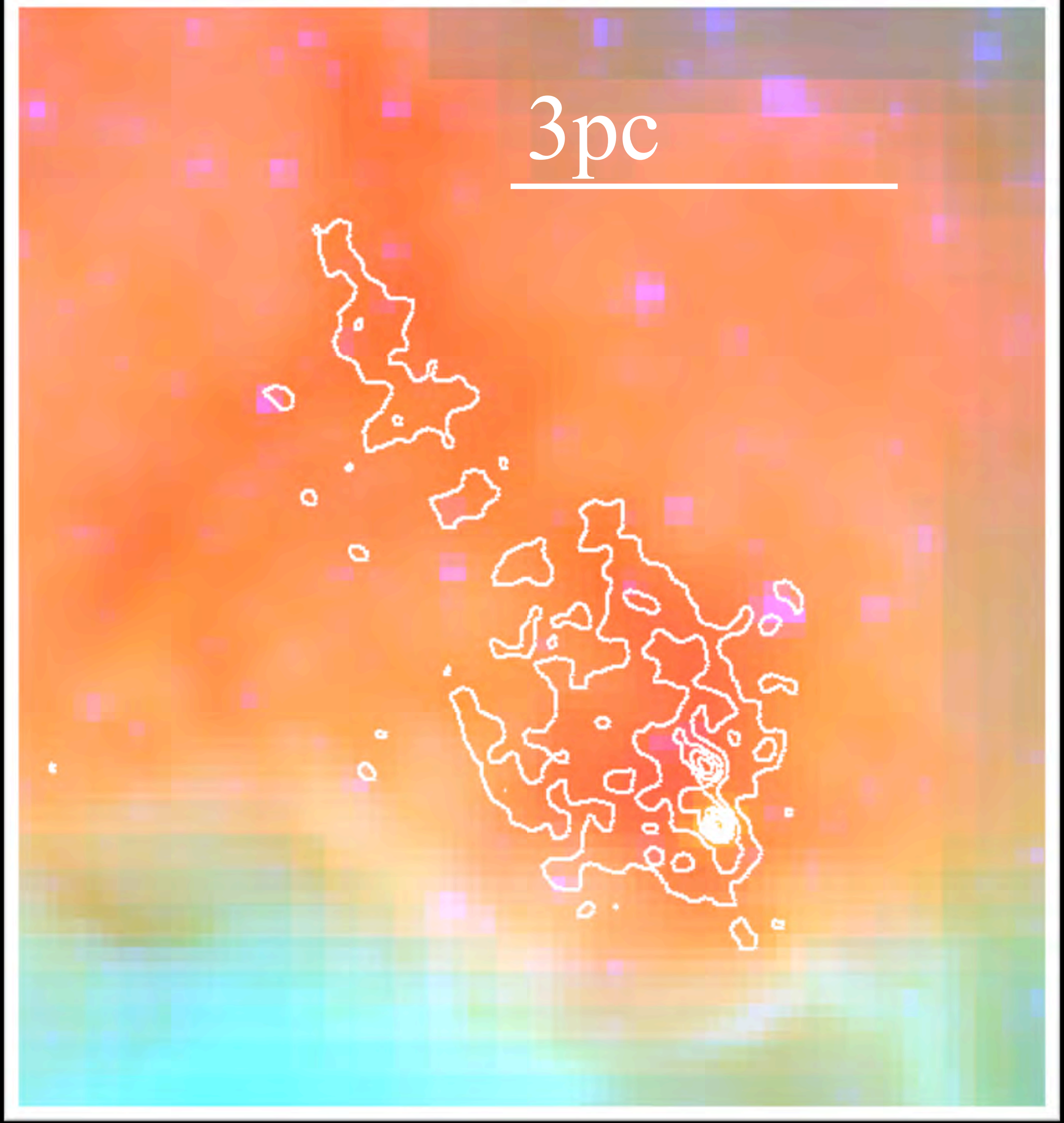
8 µm



N(H_2)
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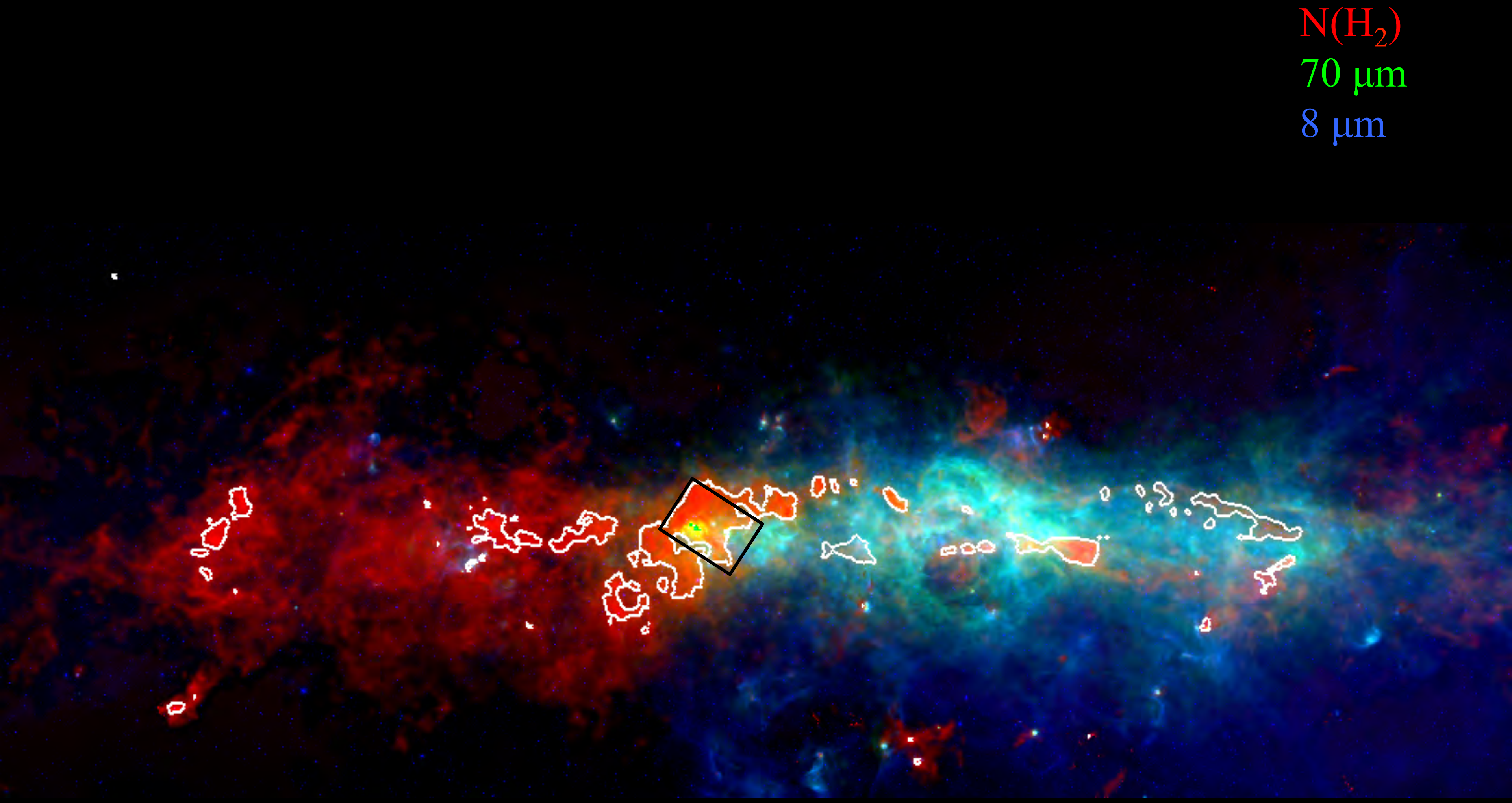
8 µm

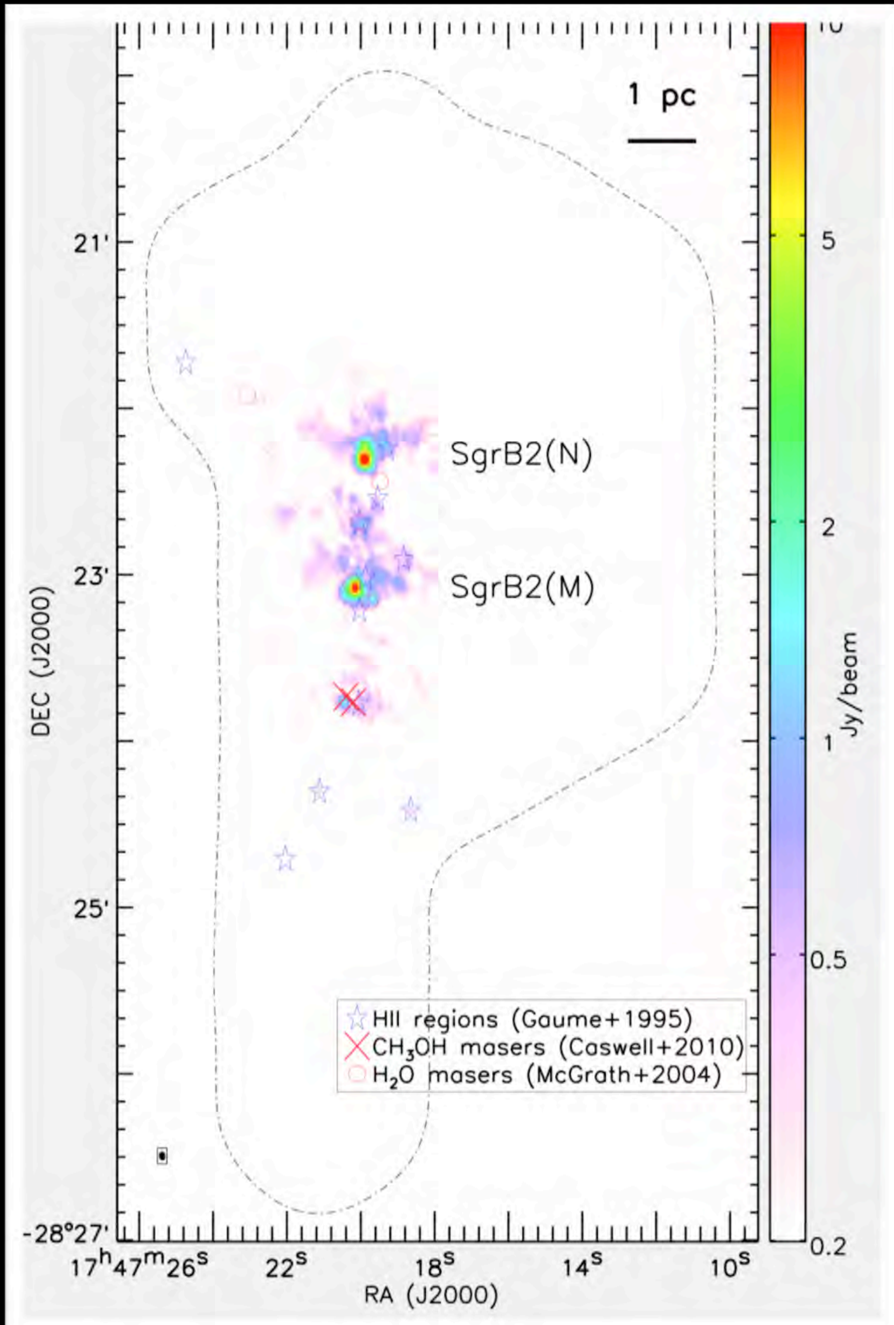
1.3 mm dust continuum
Dan Walker, in prep.



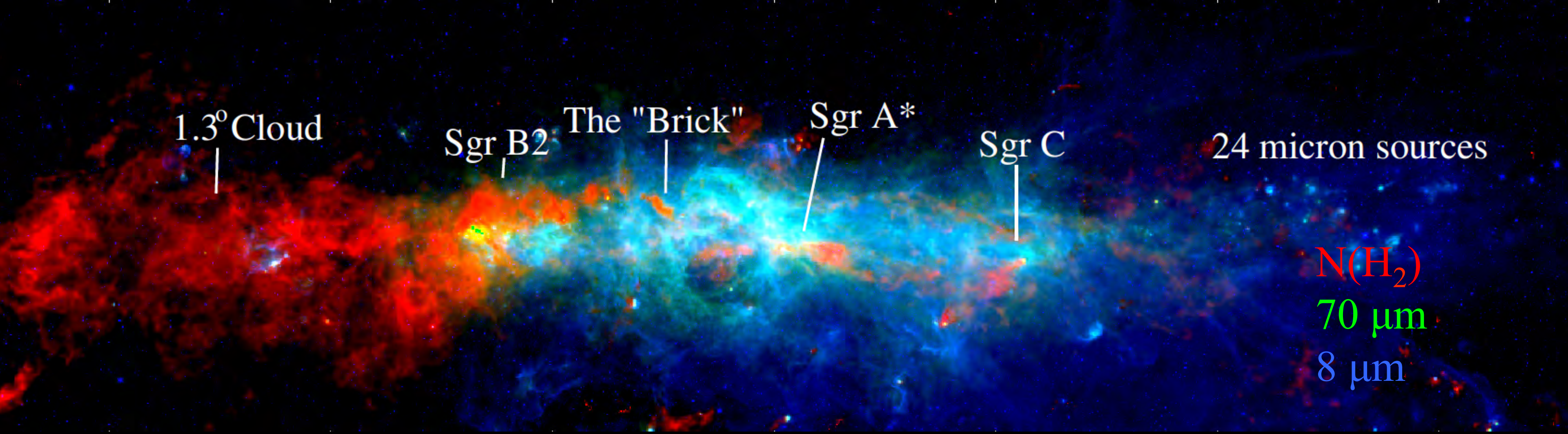
N(H2)
70 µm
8 µm

Sgr B2

N(H_2)
70 μm
8 μm



1.3 mm dust continuum
Xing 'Walker' Lu, in prep.



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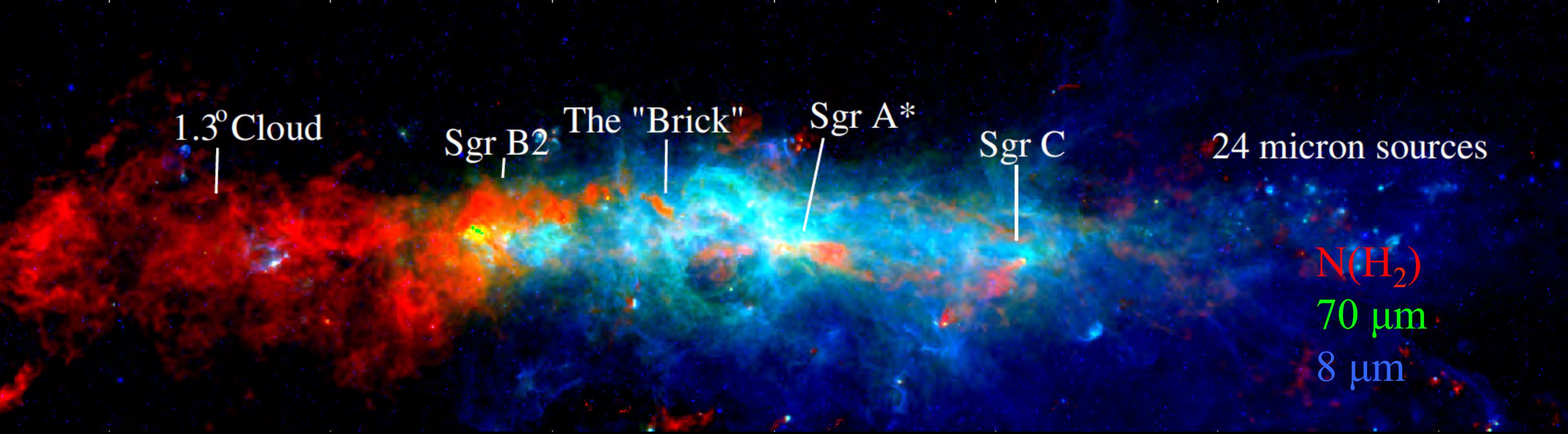

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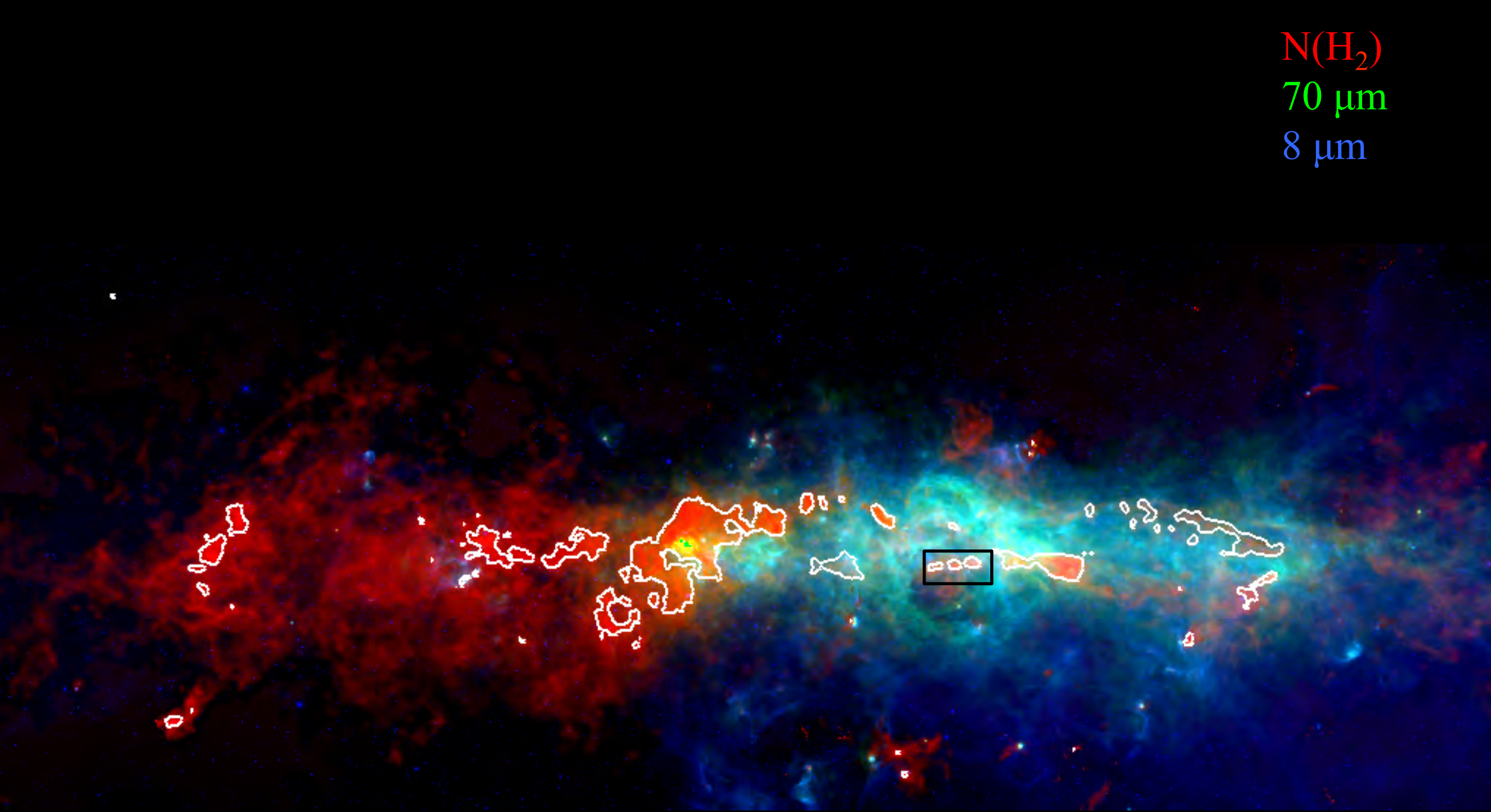

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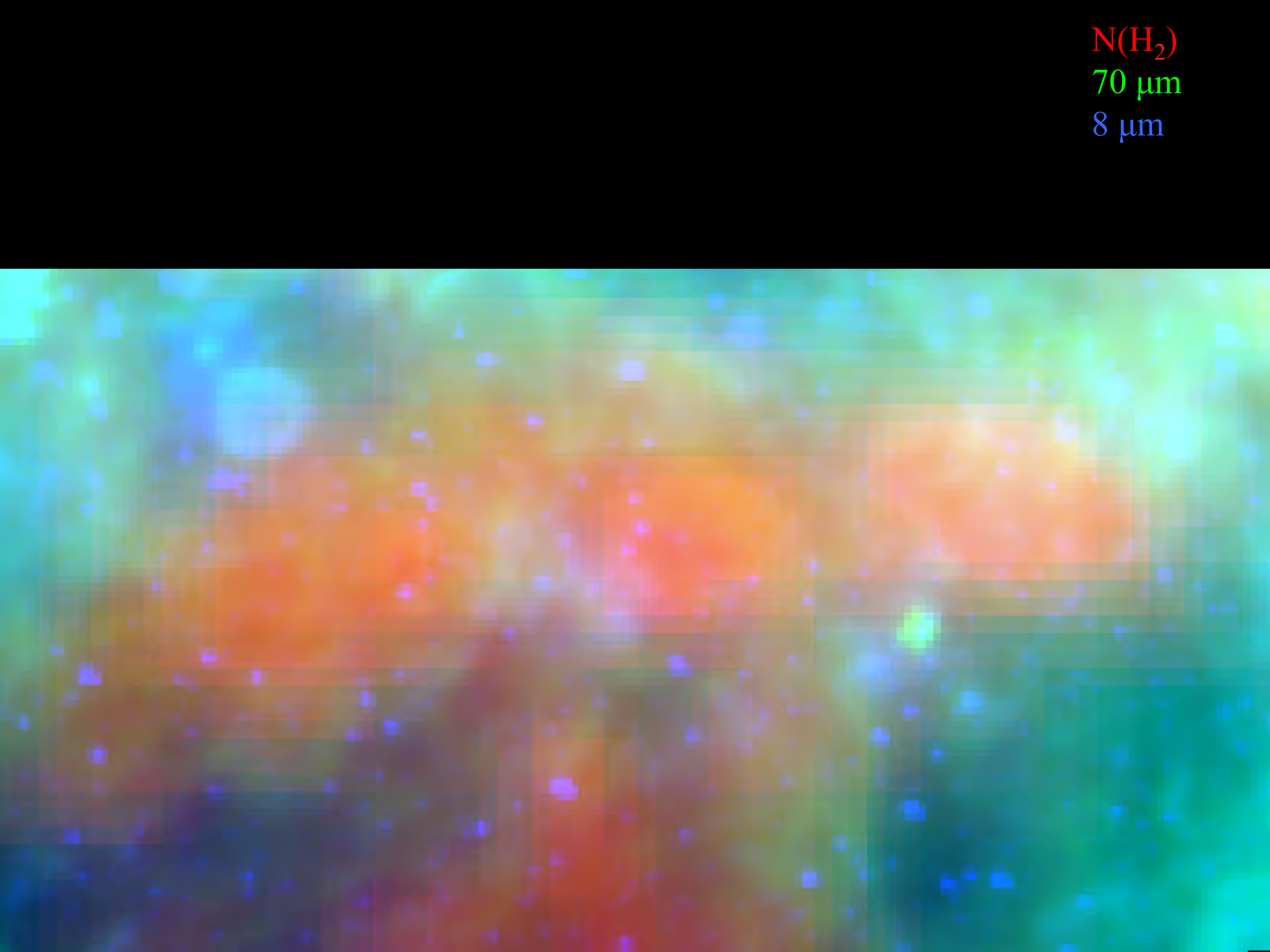
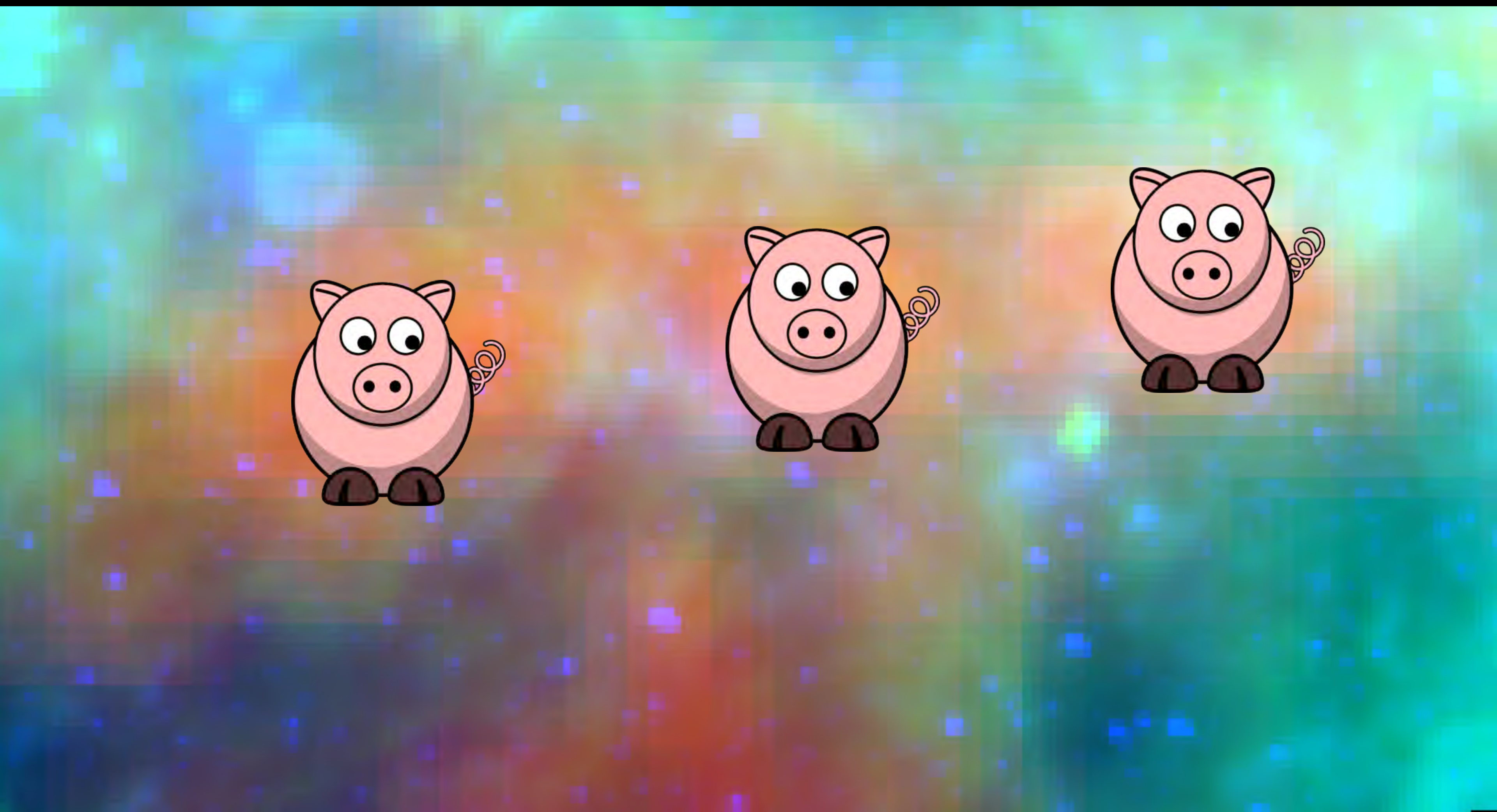
8 µm

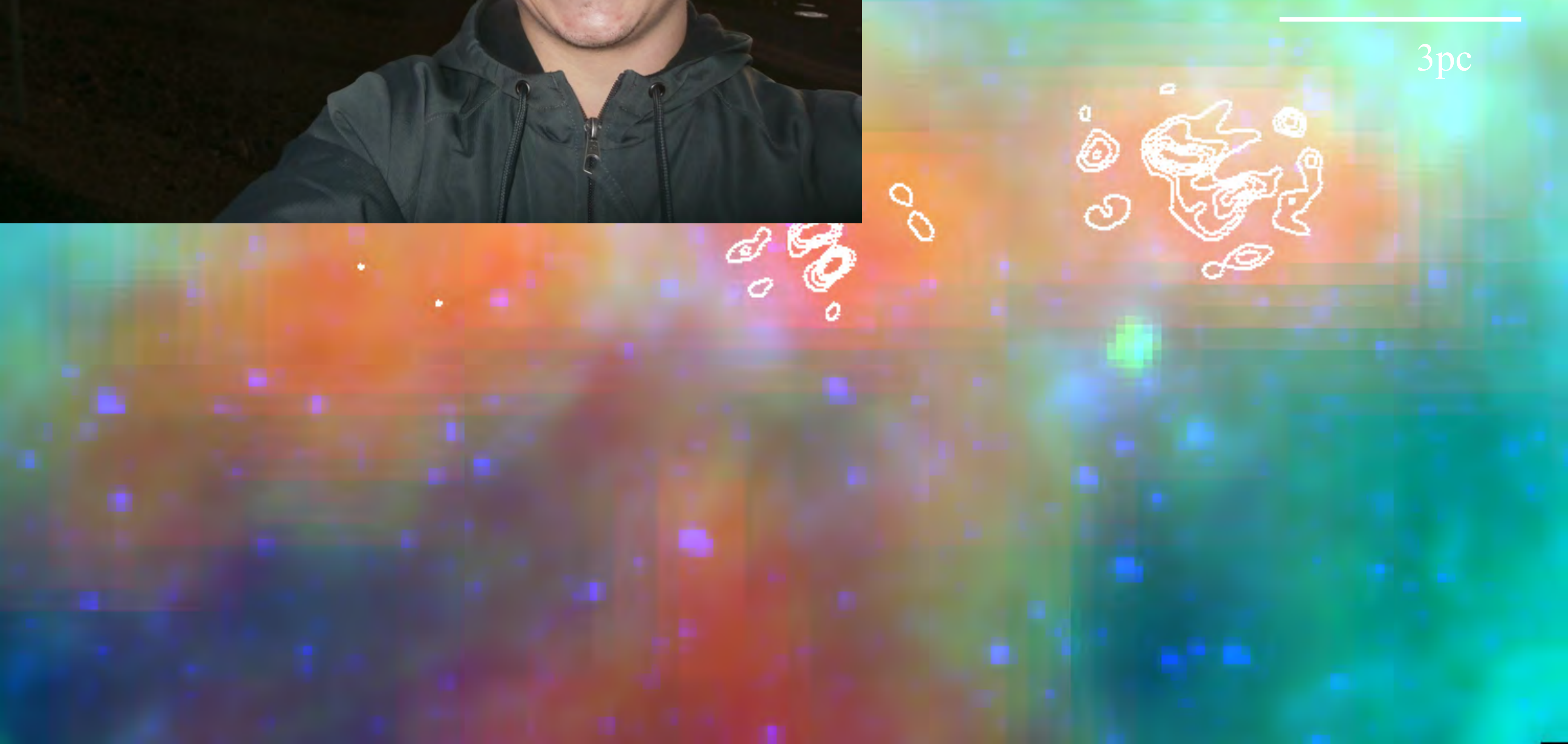

N(H2)
70 µm
8 µm

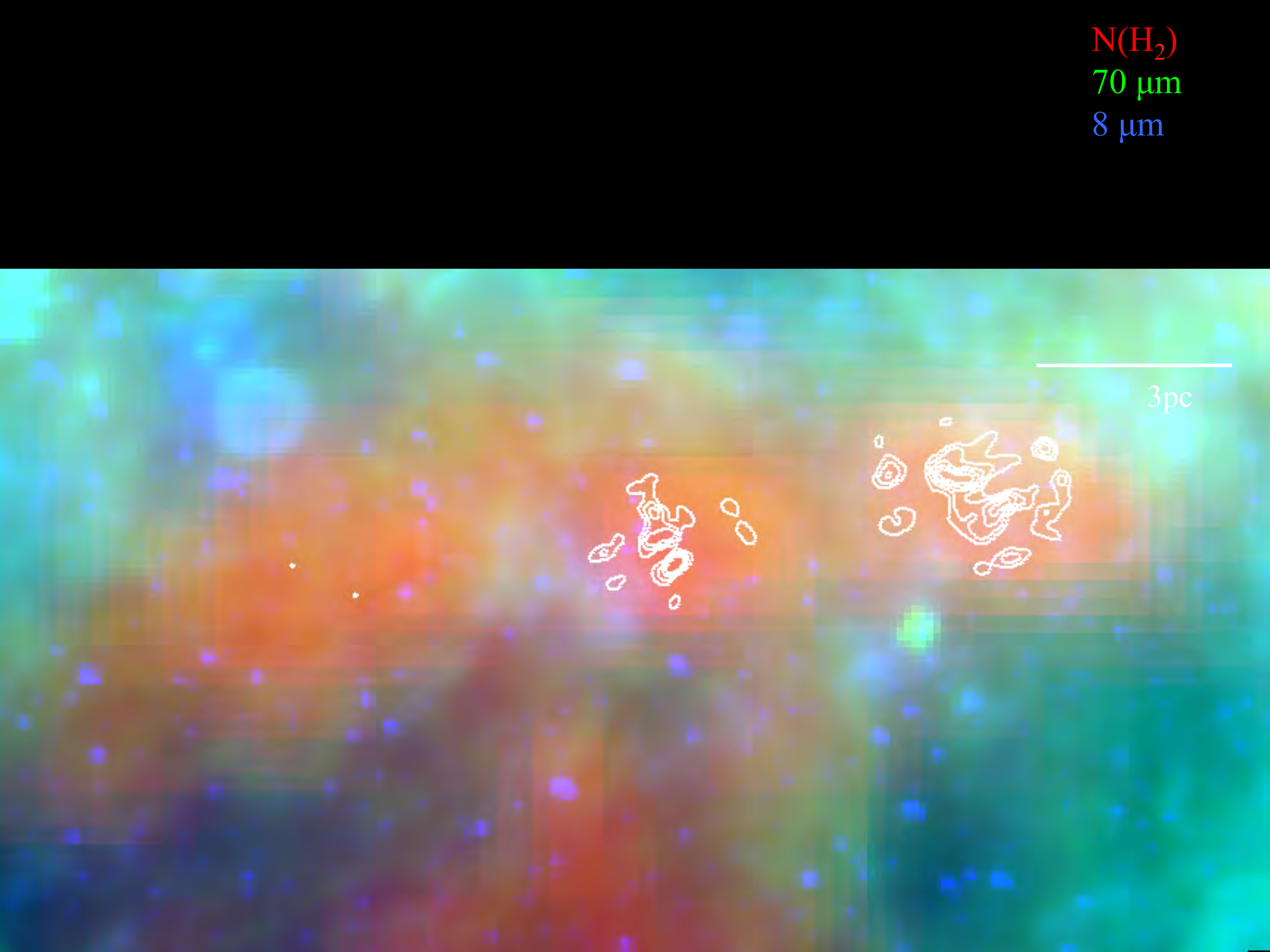


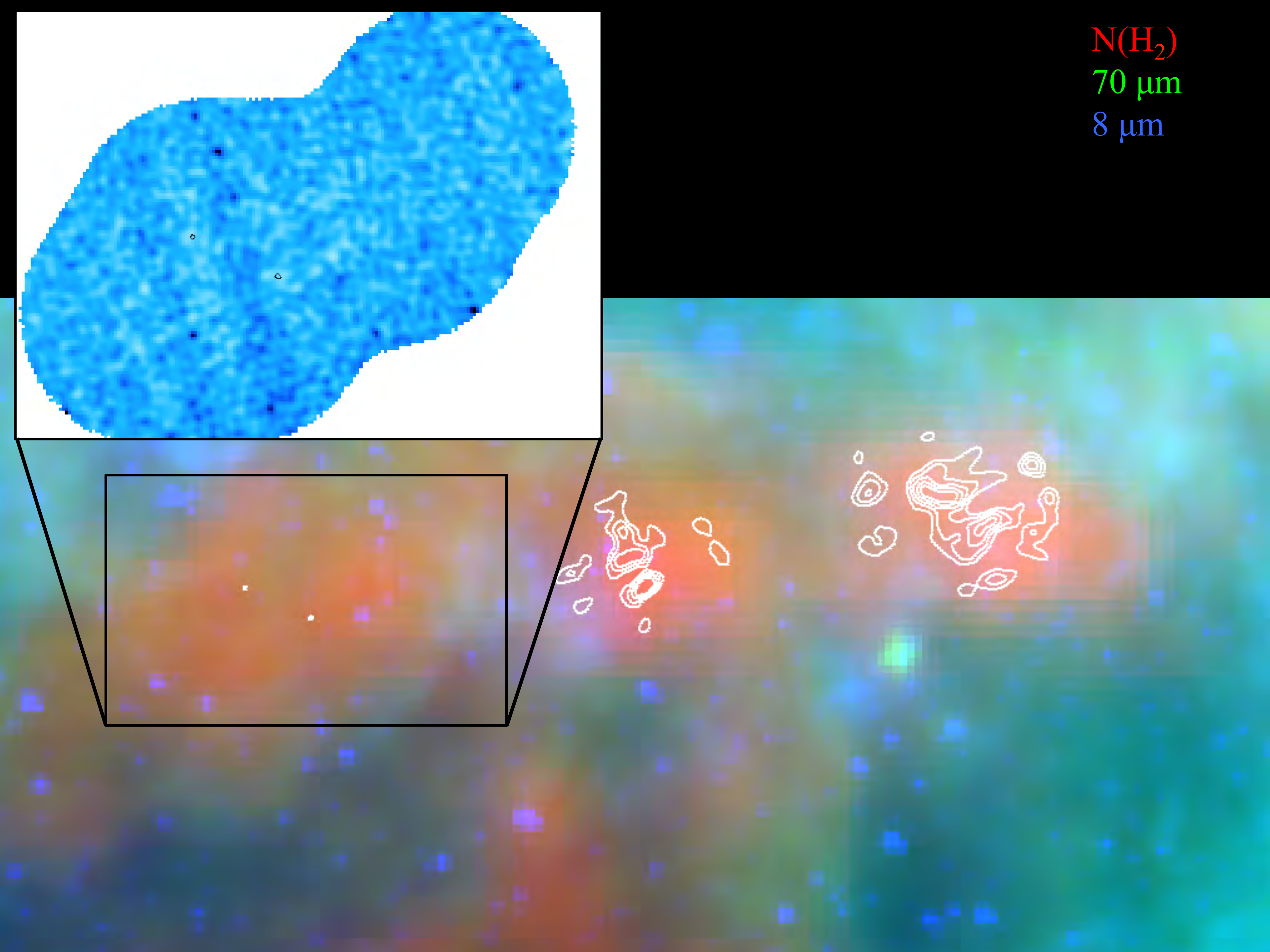


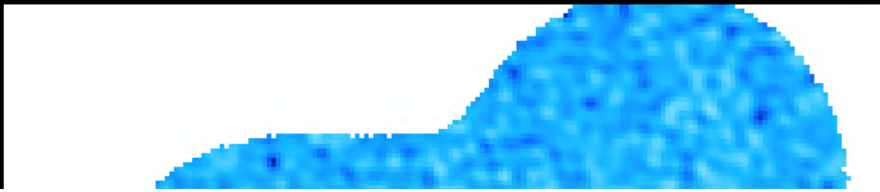
3pc

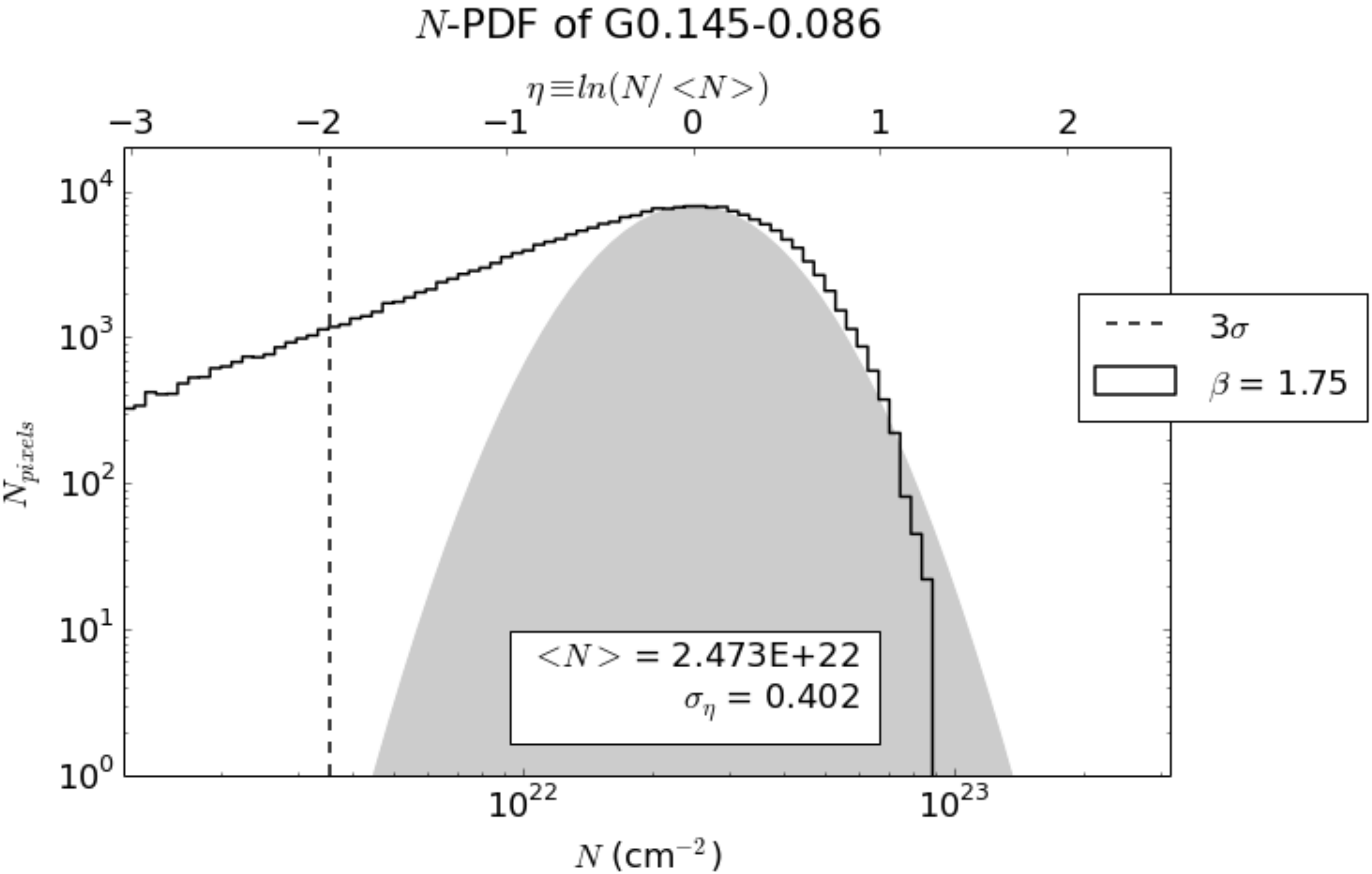
Mark Graham
Southampton Master's Student

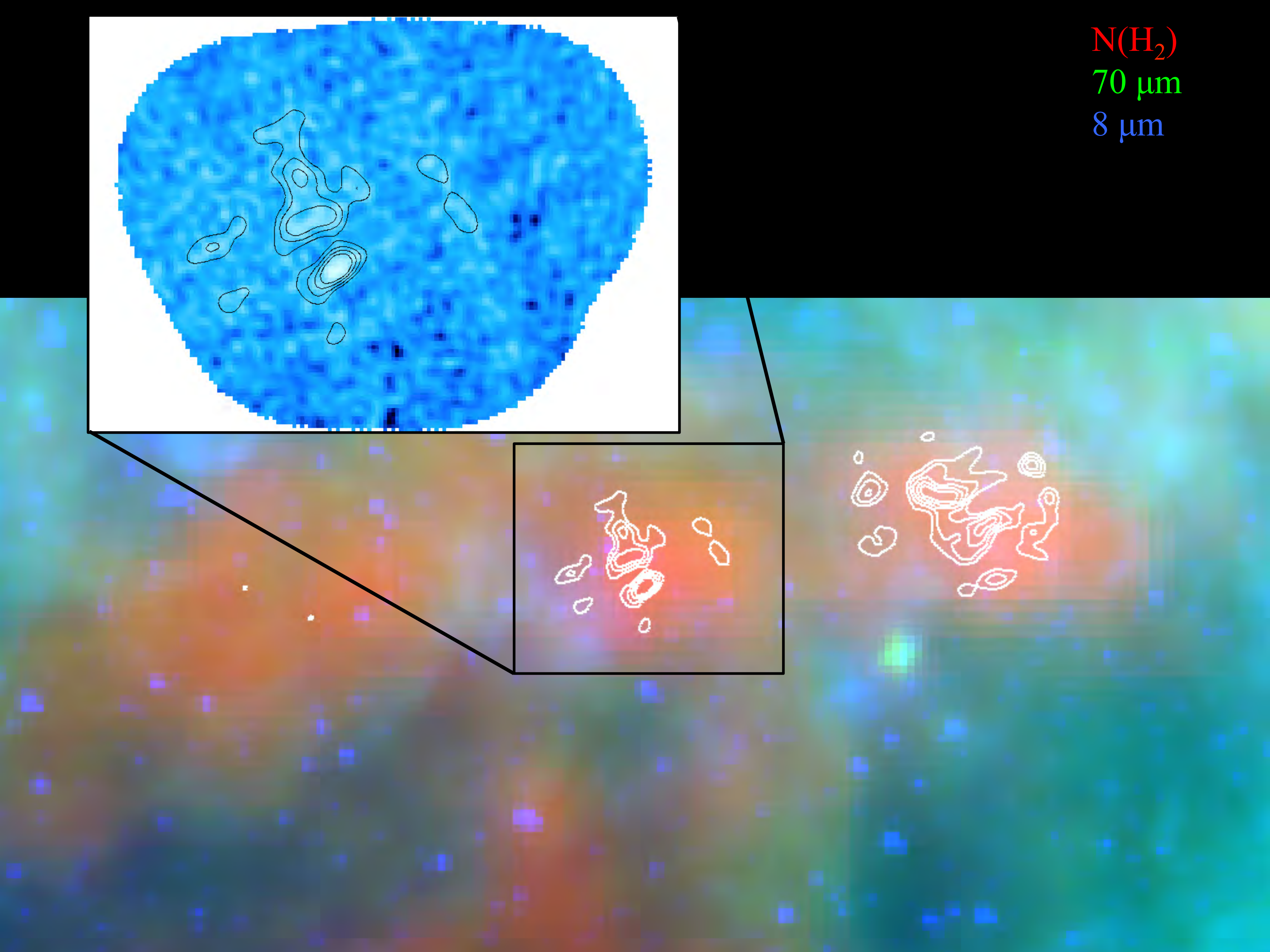


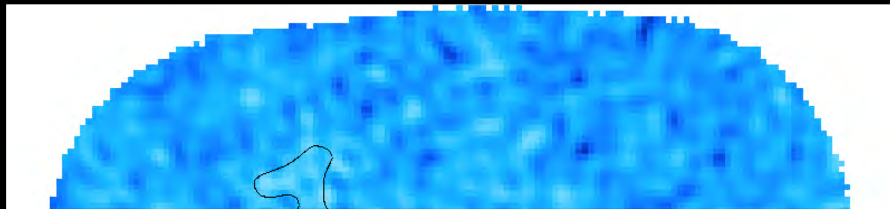

N(H2)
70 µm
8 µm
3pc

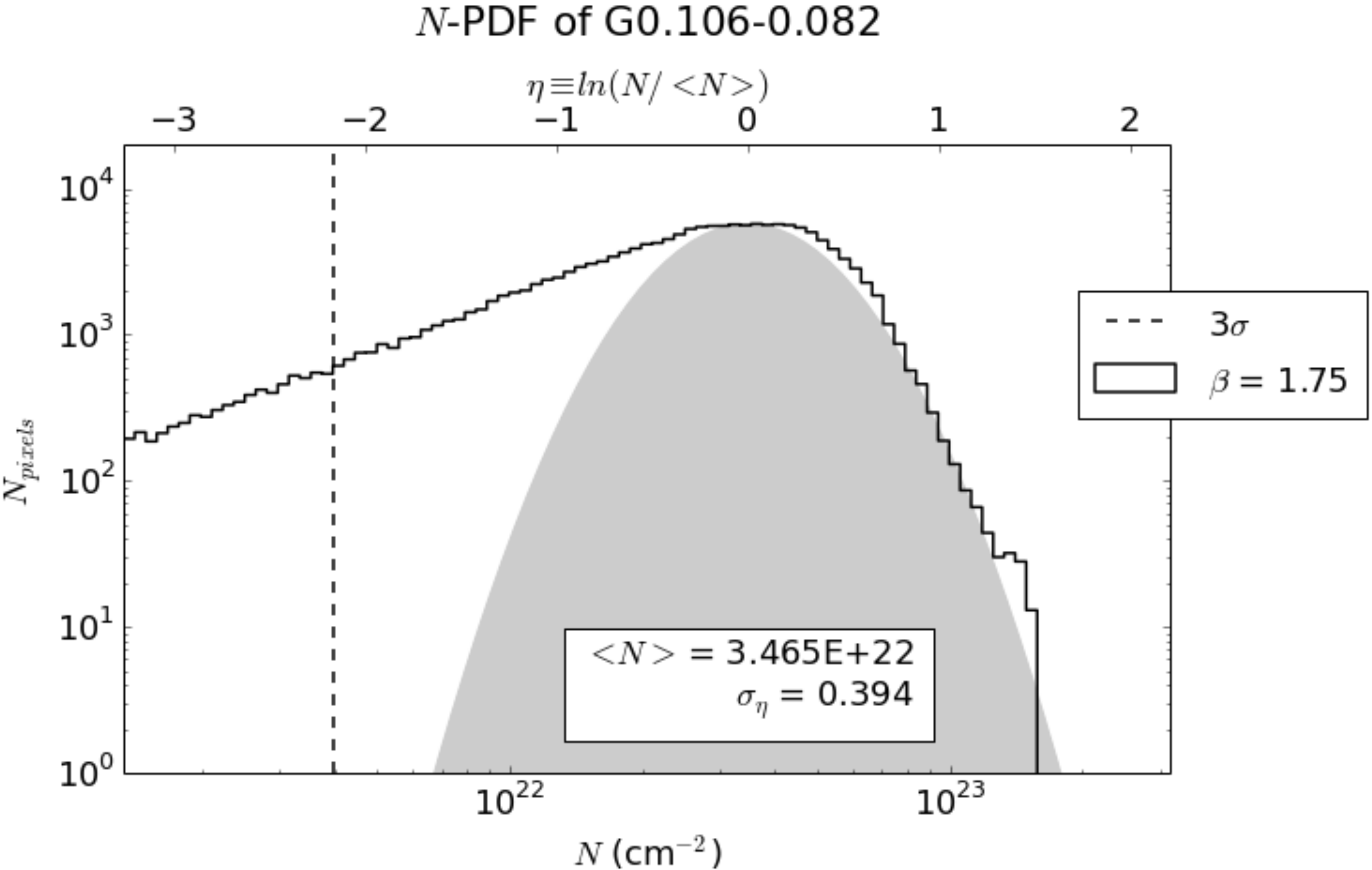

N(H2)
70 μm
8 μm



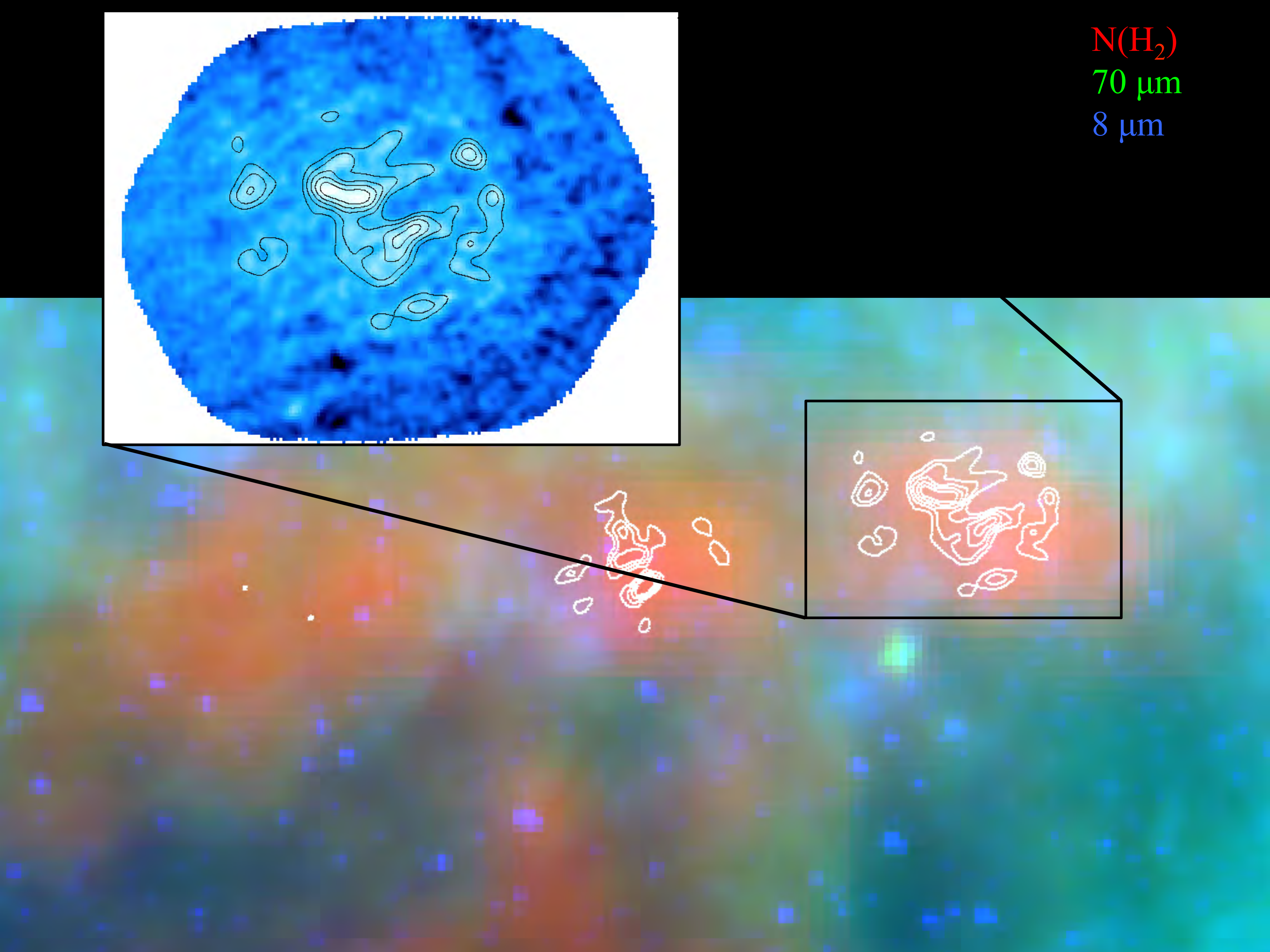

N-PDF of G0.145-0.086
$\eta \equiv ln(N/<N>)$
−3
−2
−1
0
1
2
10^4
10^3
10^2
10^1
10^0
N_{pixels}
10^{22}
10^{23}
N (cm^{-2})
3σ
β = 1.75
$<N>$ = 2.473E+22
σ_η = 0.402


N(H$_2$)
70 μm
8 μm

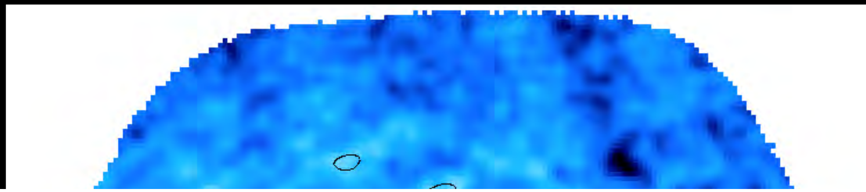


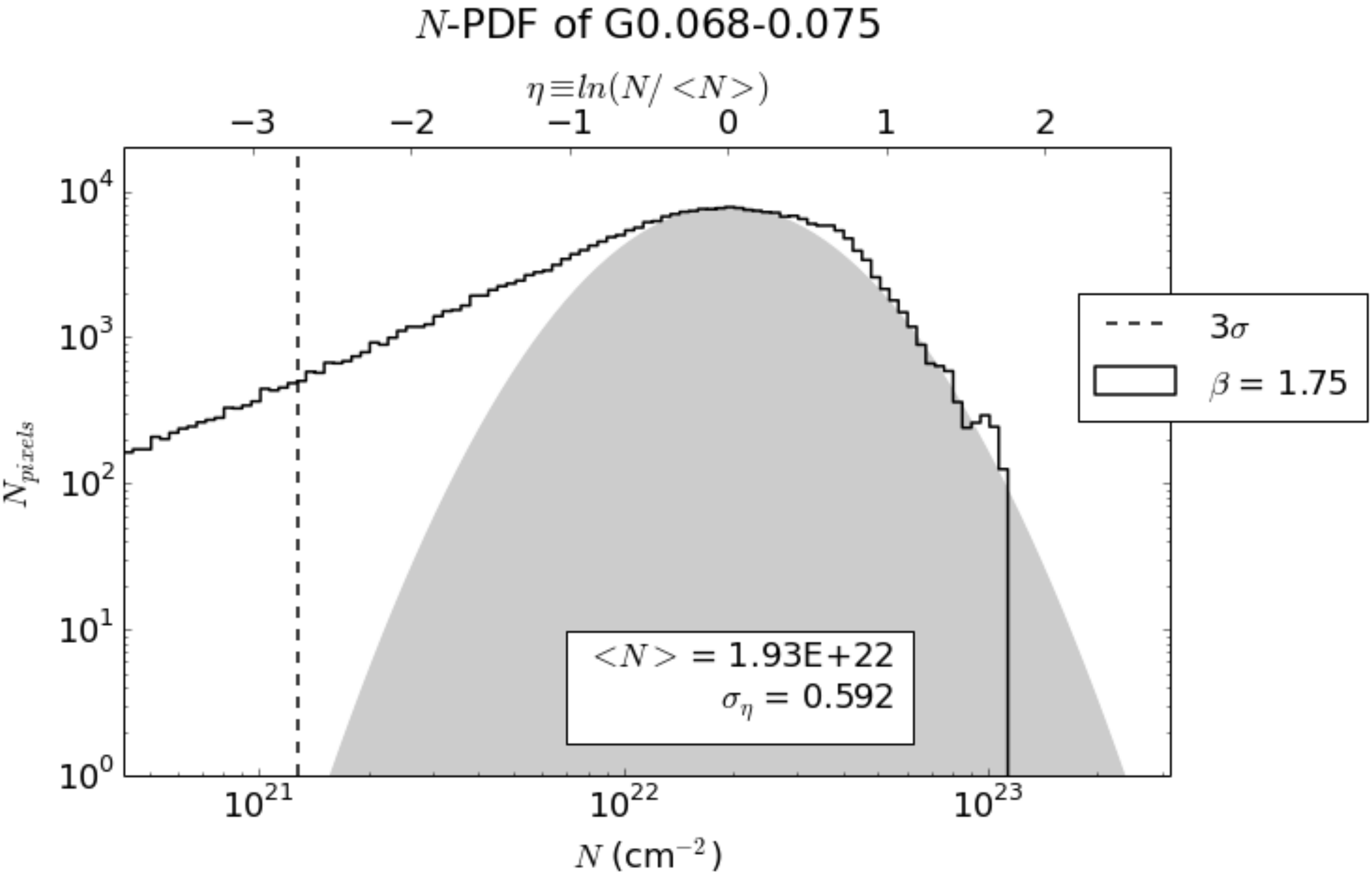


N-PDF of G0.106-0.082
$\eta \equiv ln(N/<N>)$
−3 −2 −1 0 1 2
N_{pixels}
10^0 10^1 10^2 10^3 10^4
10^{22} 10^{23}
N (cm^{-2})
3σ
β = 1.75
<N> = 3.465E+22
σ_η = 0.394

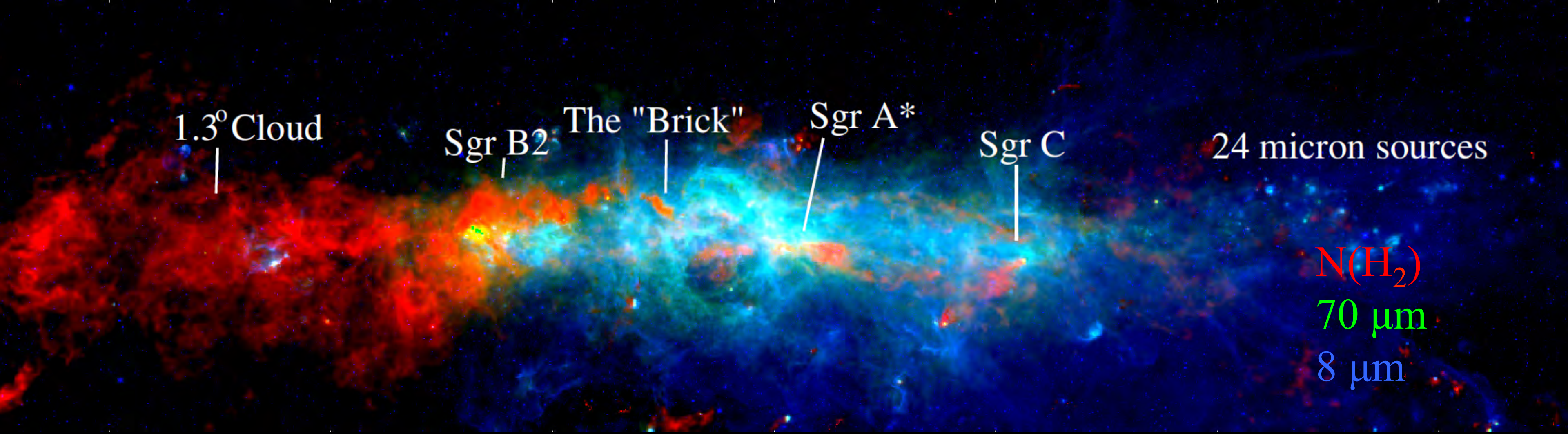


N(H2)
70 µm
8 µm





N-PDF of G0.068-0.075
$\eta \equiv ln(N/<N>)$
−3
−2
−1
0
1
2
10^4
10^3
10^2
10^1
10^0
N_{pixels}
3σ
β = 1.75
<N> = 1.93E+22
σ_η = 0.592
10^{21}
10^{22}
10^{23}
N (cm^{-2})



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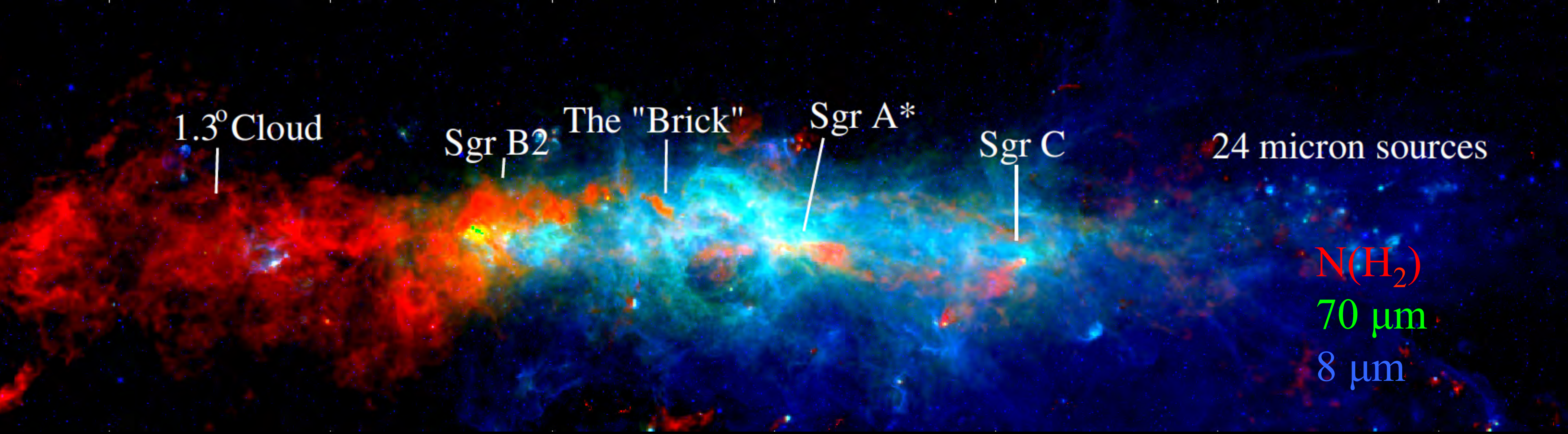

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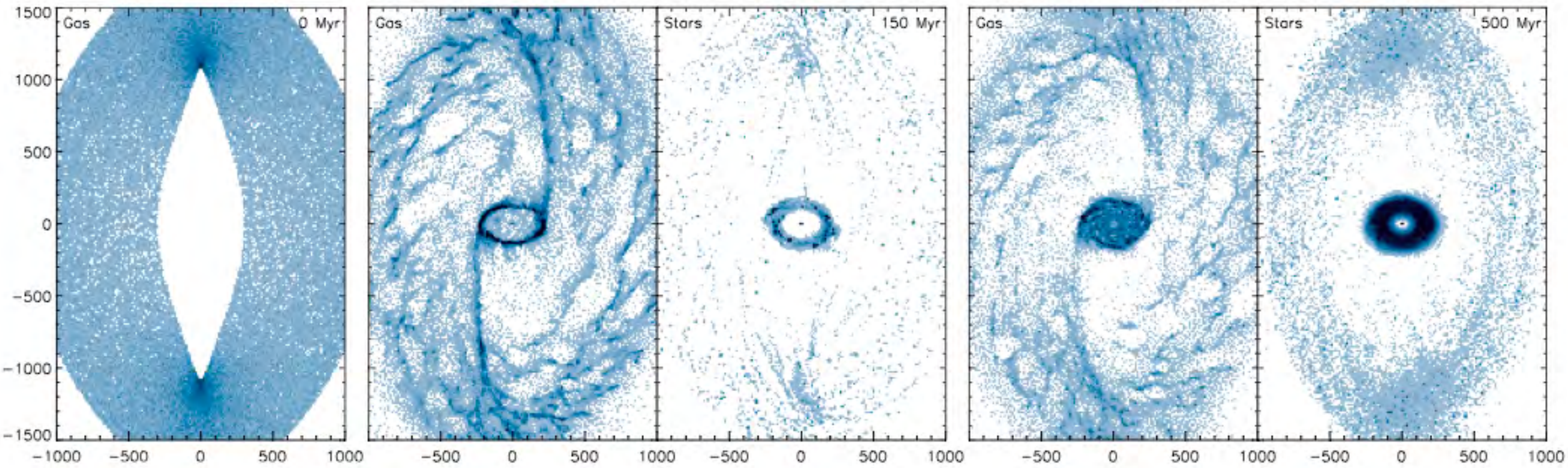
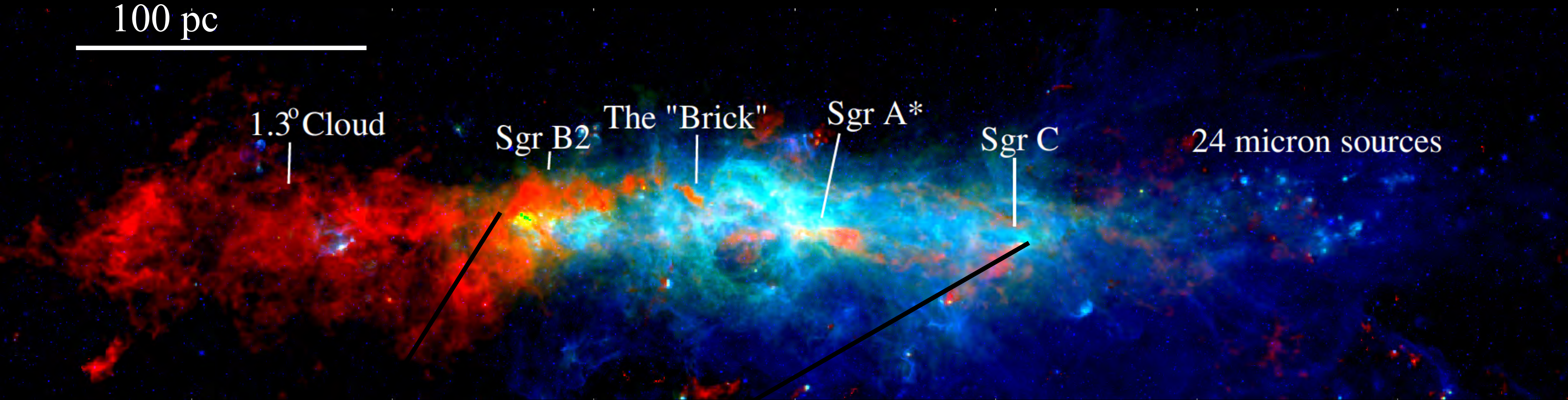
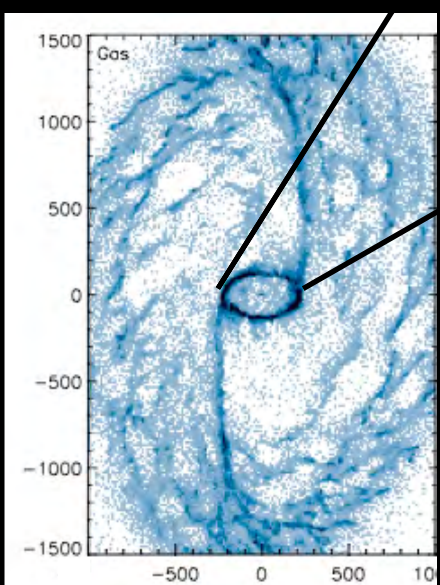


Figure 1: *A model from Kim et al. (2011) illustrating the migration of gas in a barred galaxy from x1 orbits onto x2 orbits to form a 100 – 500 pc radius circum-nuclear ring which co-rotates with the bar. Angular momentum dissipation drives gas towards the nucleus where the gravitational potential of the galaxy may compress it. As the critical density for gravitational collapse is reached, star formation may ignite in the inner ring.*

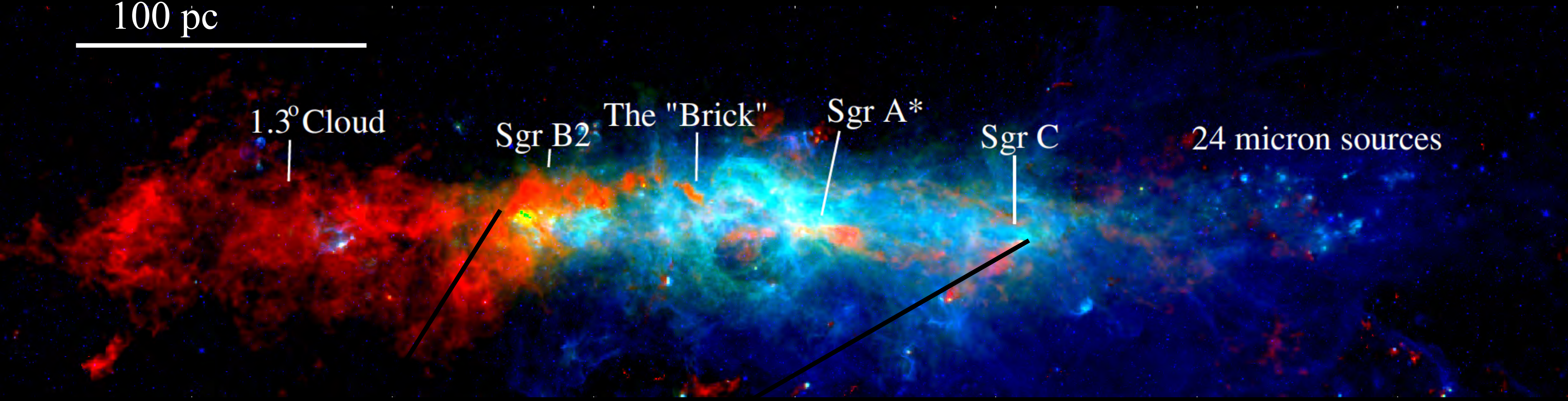


$N(H_2)$
70 μm
8 μm

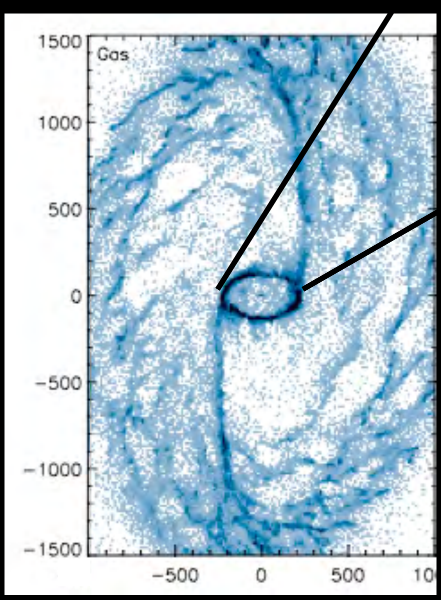


?

Simulation from Kim et al. (2011). Migration of gas in a mildly barred galaxy



$N(H_2)$
70 μm
8 μm



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Simulation from Kim et al. (2011). Migration of gas in a mildly barred galaxy


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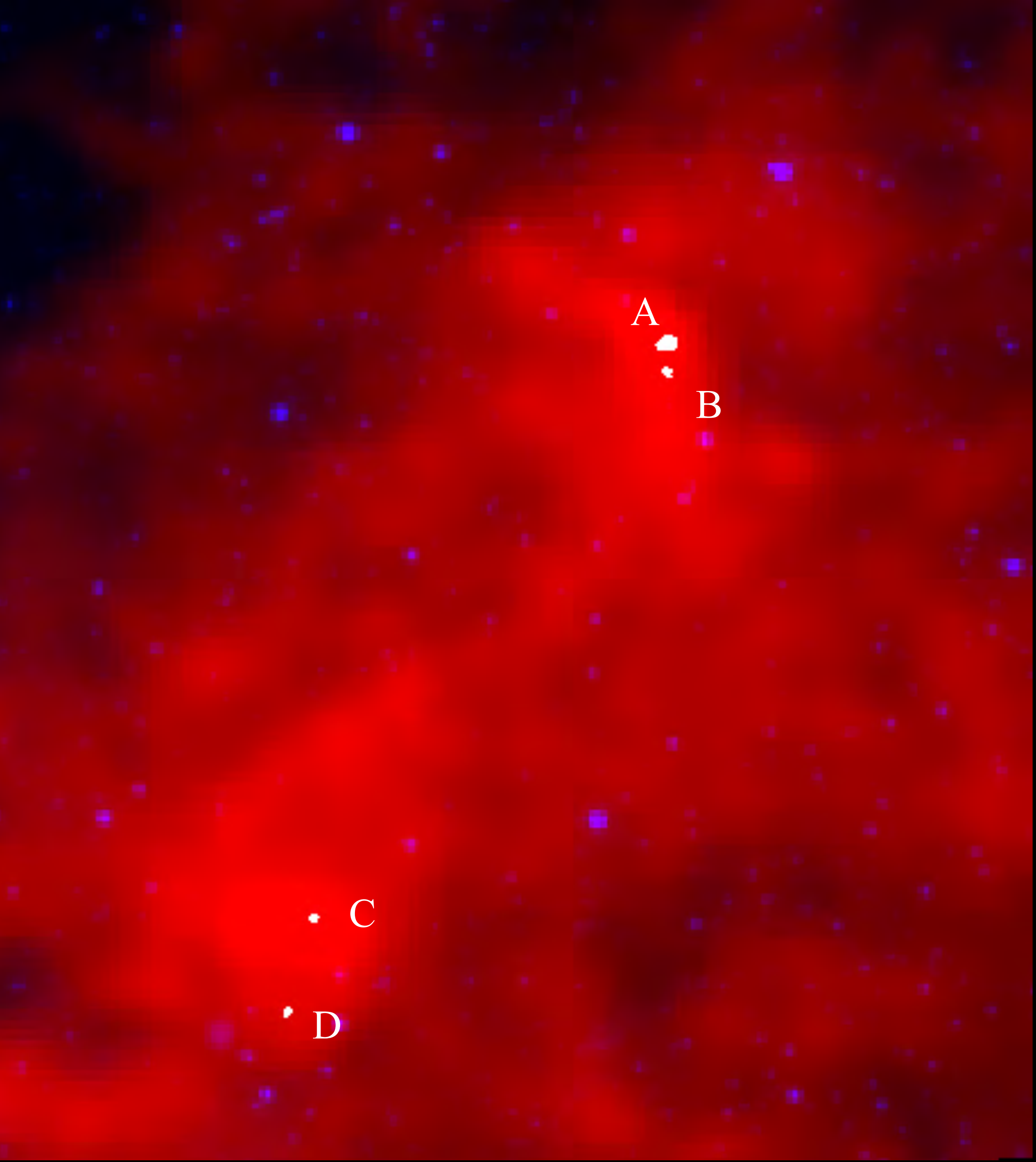
8 µm

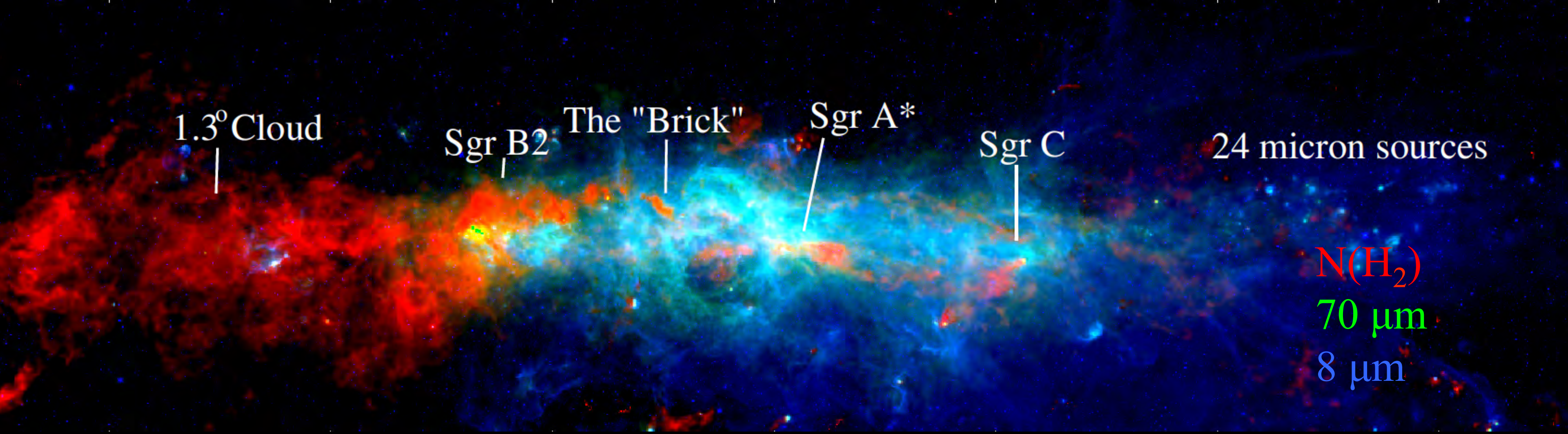


N(H_2)
70 µm
8 µm

Preliminary Core mass estimates, assuming 20 K

A: 400 $M_\odot$
B: 150 $M_\odot$
C: 140 $M_\odot$
D: 130 $M_\odot$

We are seeing interesting structures AND a LOT of variation between regions that otherwise look similar



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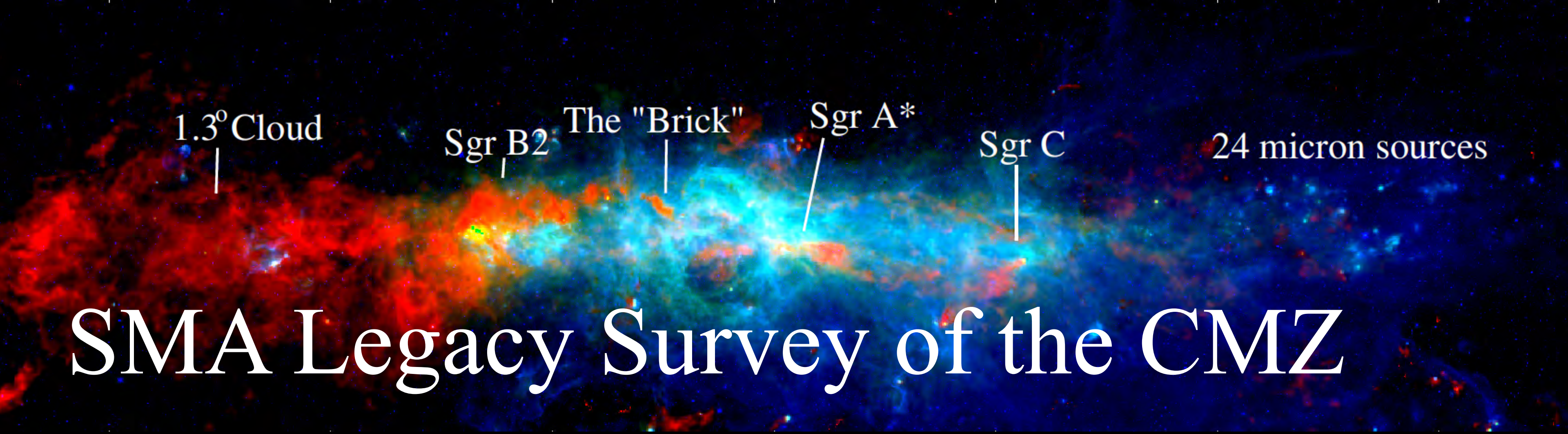


SMA Legacy Survey of the CMZ

Current Projects Overview

Survey overview, dense core catalog: Battersby and Keto

Column Density PDFs: Graham and Battersby

X1 orbit analysis: Bally

Cloud Structure and SFRs with the extended Press-Schecter Formalism: Keto

Deeply Embedded High-mass Star Formation in the CMZ Clouds: Lu and Zhang

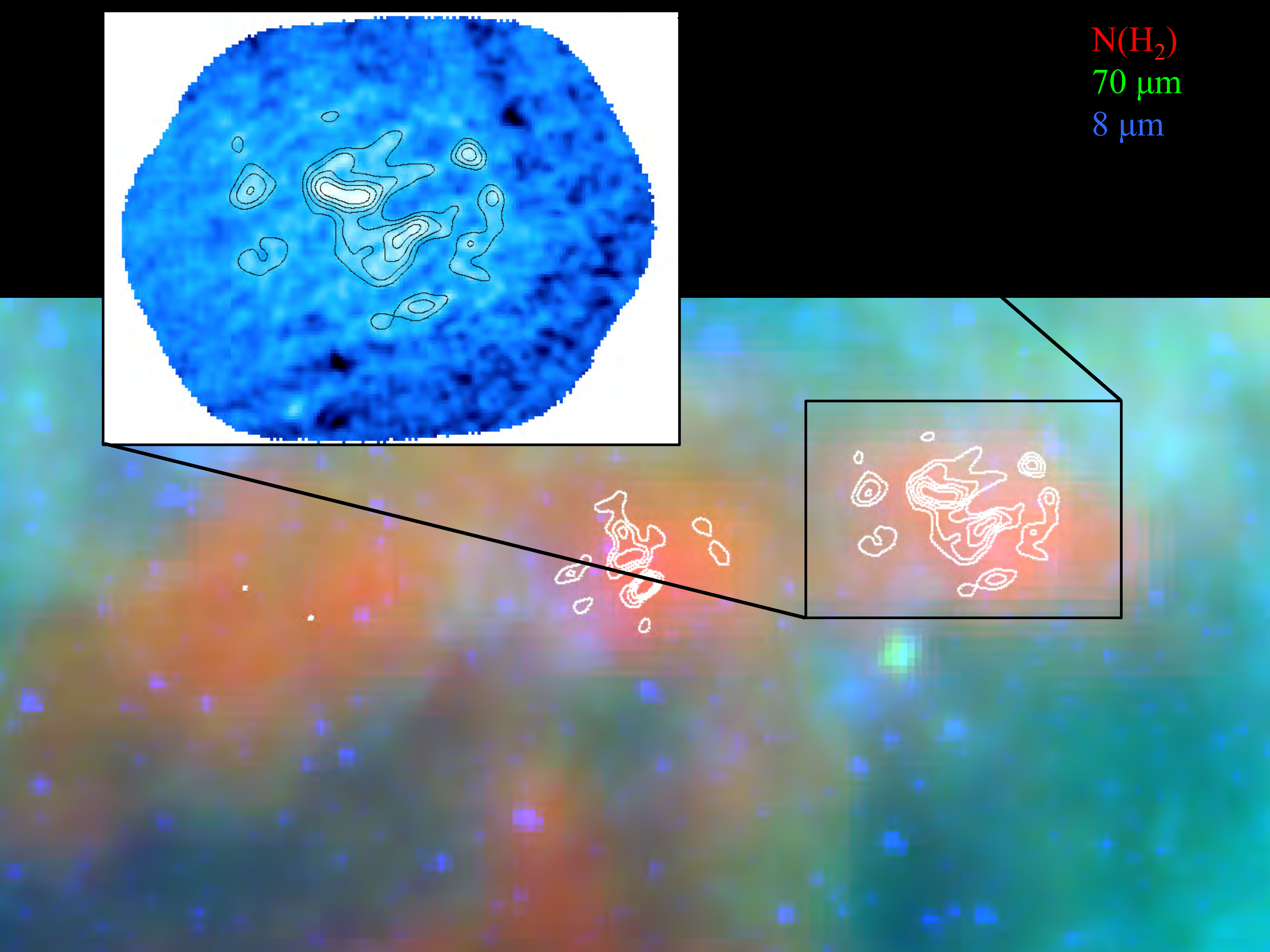
Testing models of CMZ morphology: Kruijssen

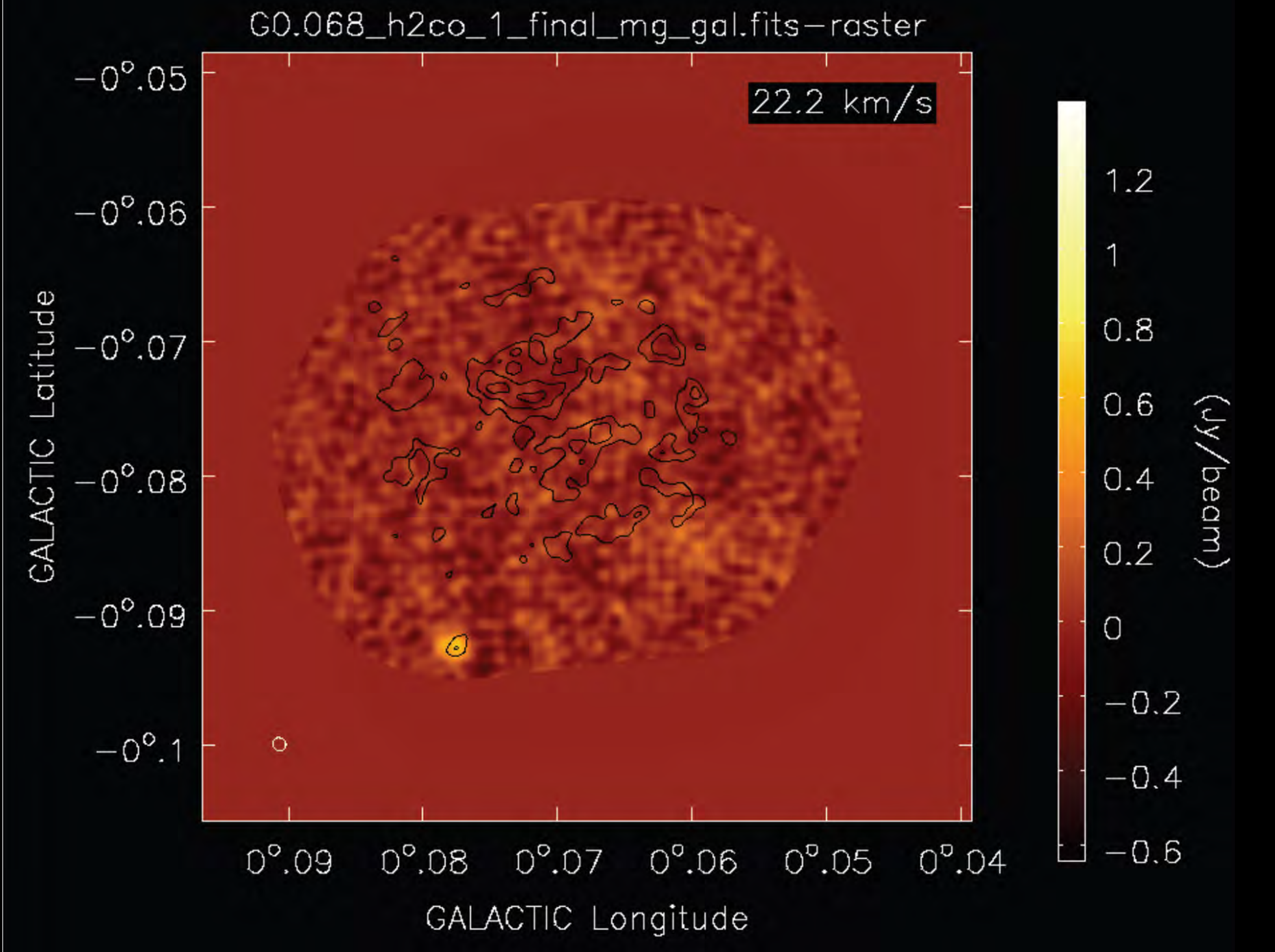
Temperature Structure of CMZ Clouds: Kauffmann and Pillai

Isolated Massive Star Formation in the Galactic Center: Pillai

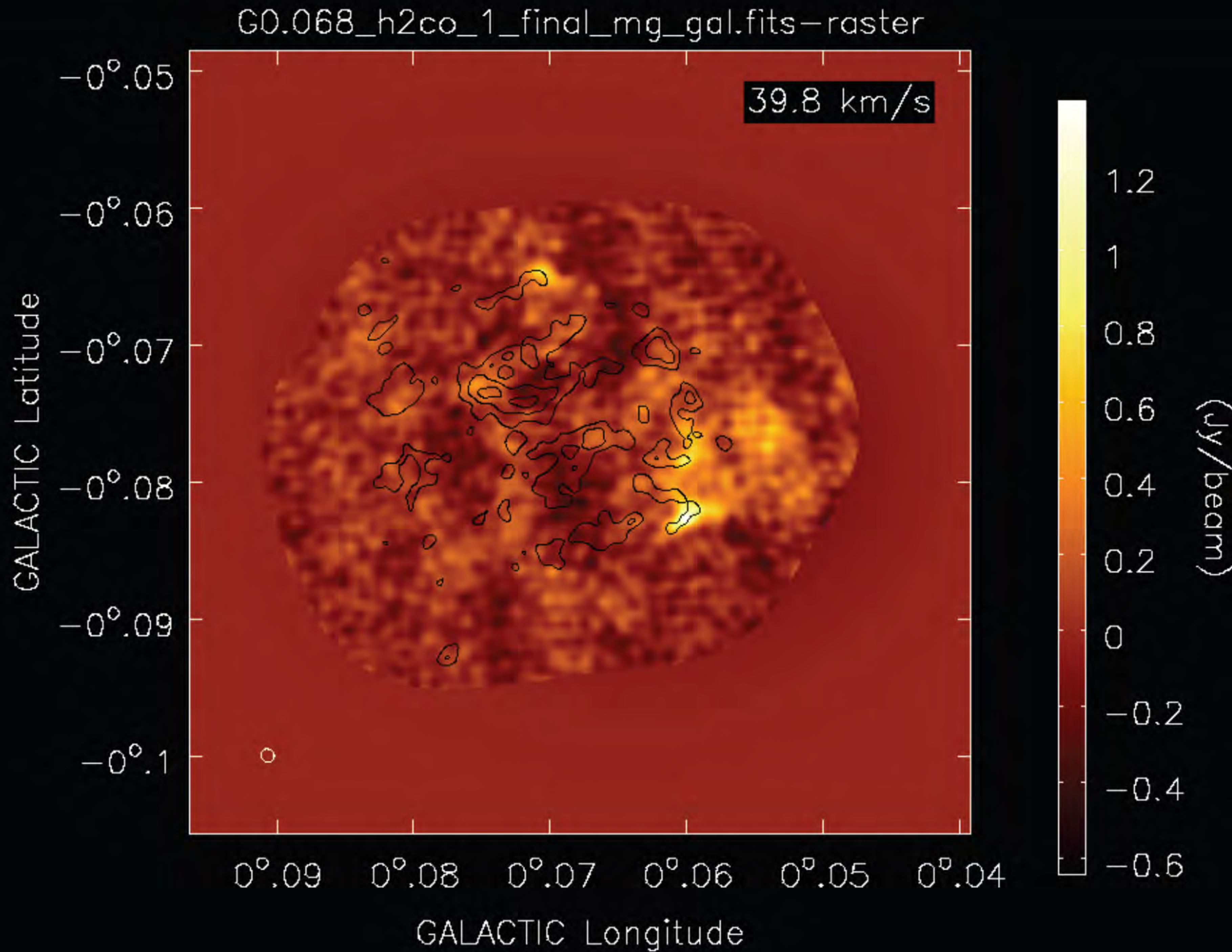
Bricklets -- evolution of YMCs in the dust ridge: Walker and Longmore

Metal cores in the CMZ: Longmore

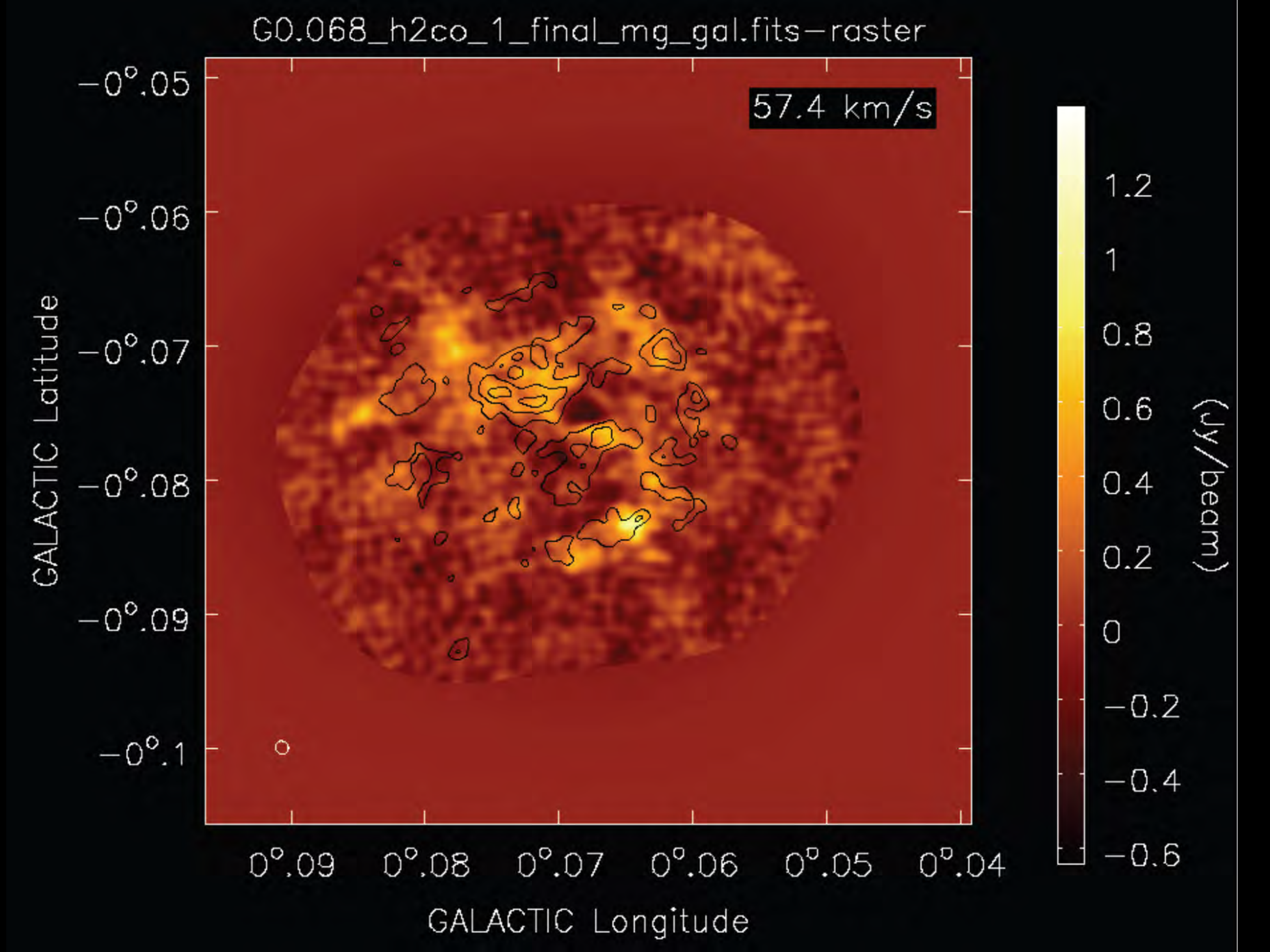

N(H2)
70 μm
8 μm

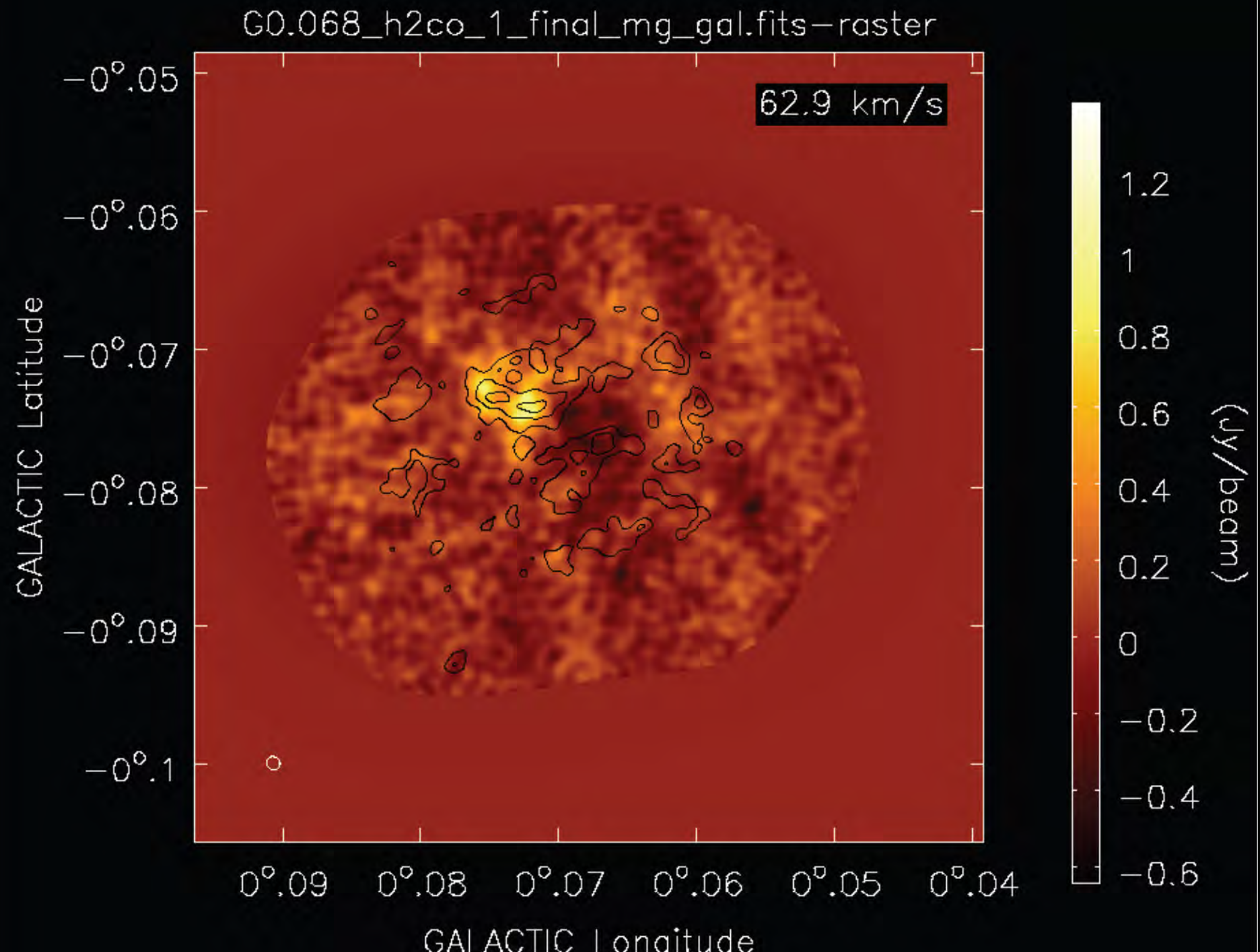


G0.068_h2co_1_final_mg_gal.fits-raster
22.2 km/s
−0°.05
−0°.06
−0°.07
−0°.08
−0°.09
−0°.1
GALACTIC Latitude
0°.09
0°.08
0°.07
0°.06
0°.05
0°.04
GALACTIC Longitude
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
(Jy/beam)

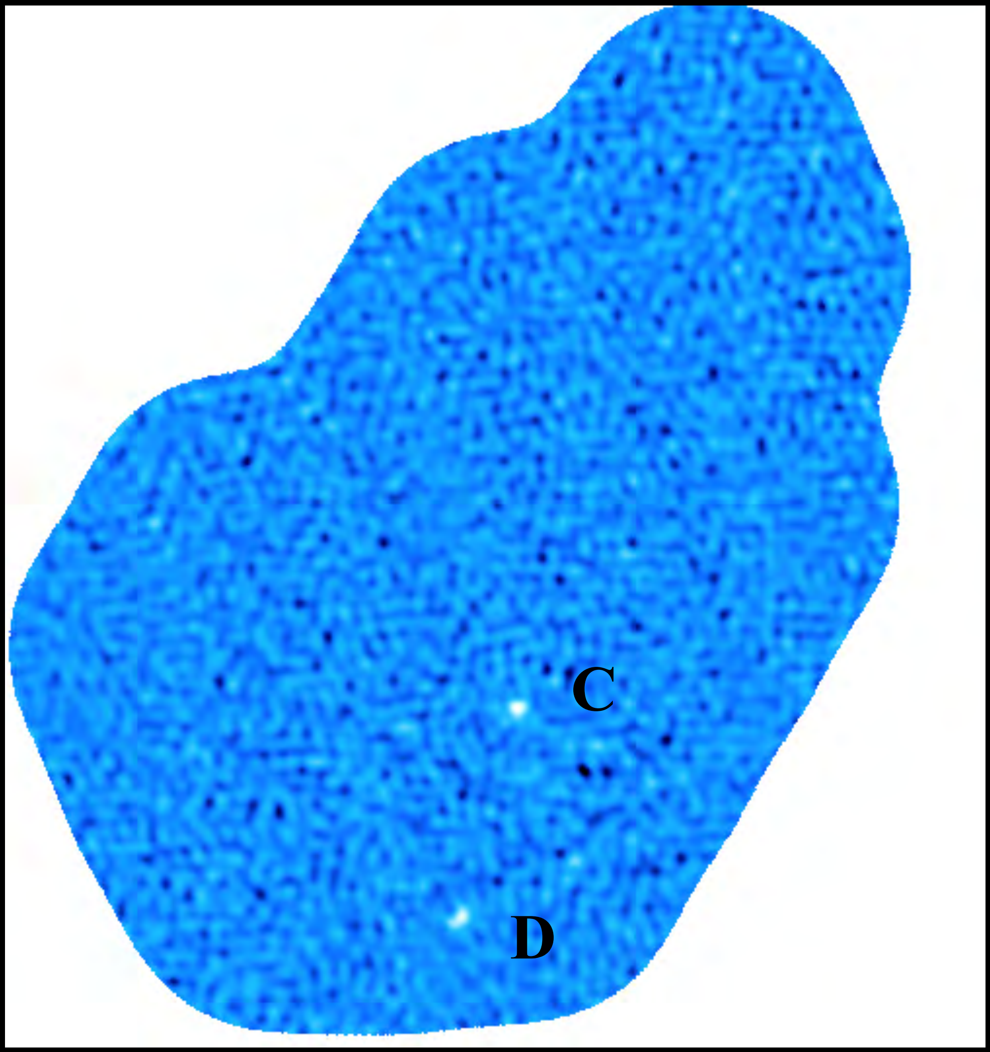


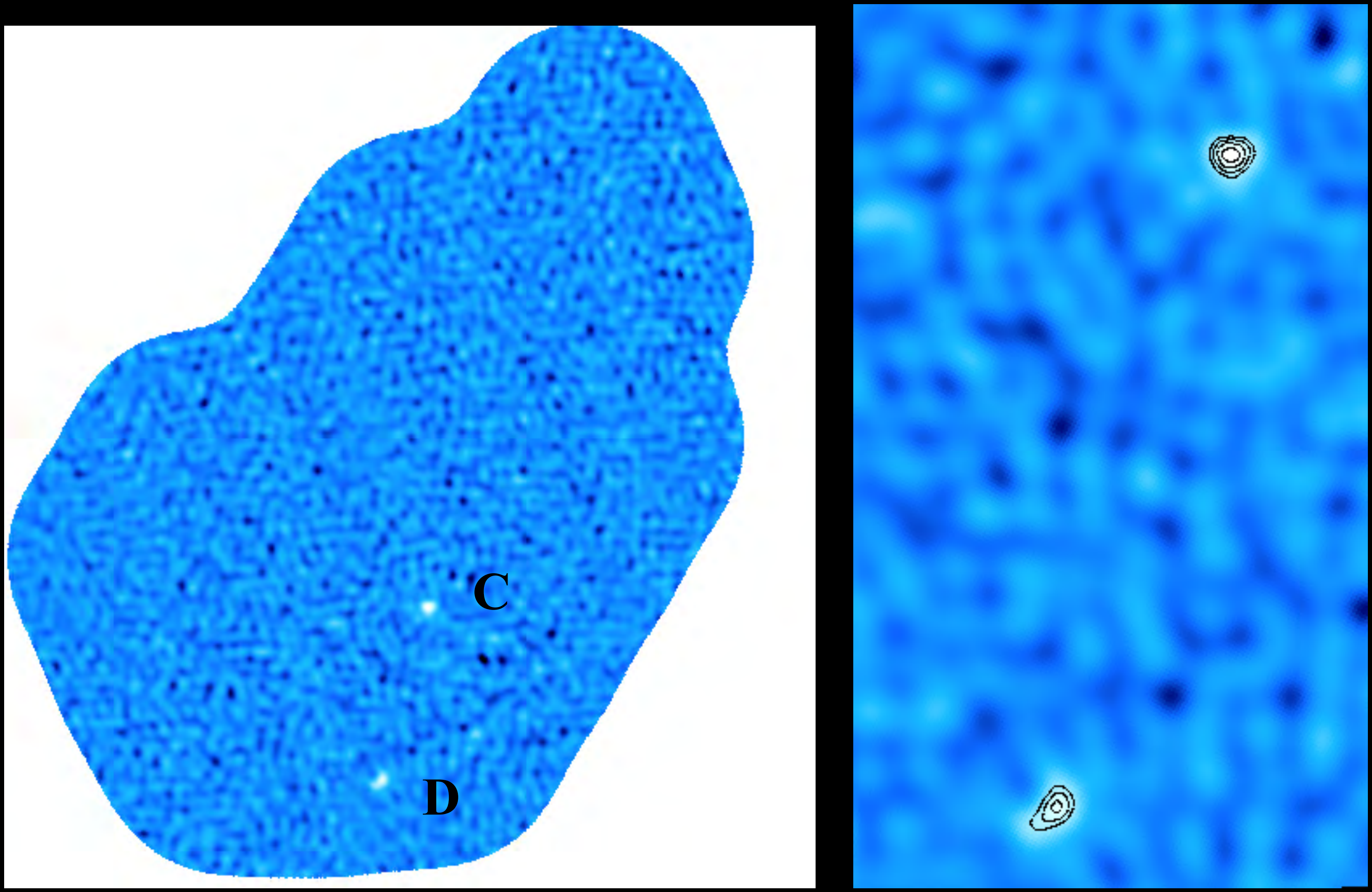
G0.068_h2co_1_final_mg_gal.fits−raster
39.8 km/s
−0°.05
−0°.06
−0°.07
−0°.08
−0°.09
−0°.1
GALACTIC Latitude
0°.09
0°.08
0°.07
0°.06
0°.05
0°.04
GALACTIC Longitude
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
(Jy/beam)

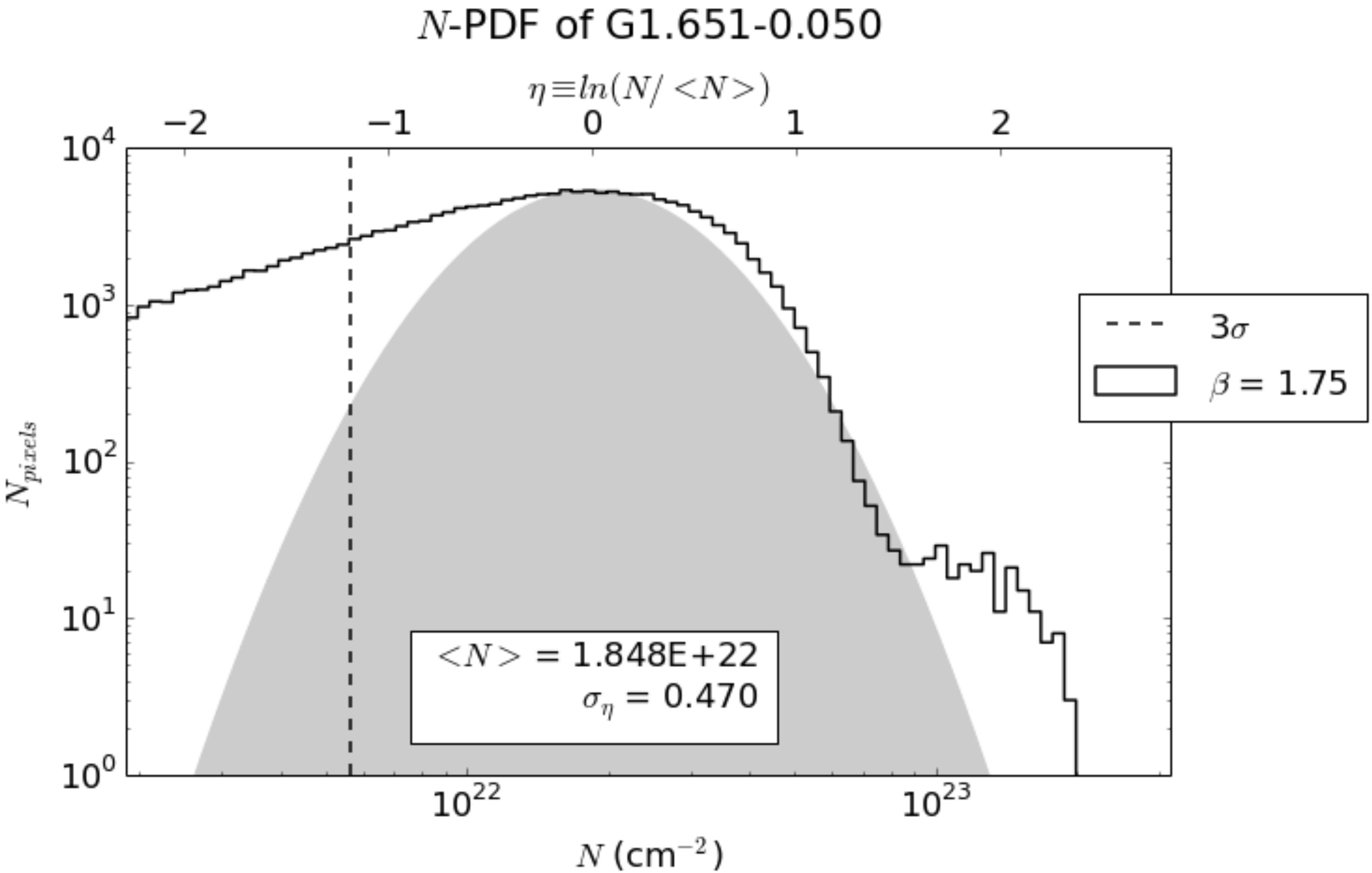

G0.068_h2co_1_final_mg_gal.fits-raster
57.4 km/s
GALACTIC Latitude
GALACTIC Longitude
-0°.05
-0°.06
-0°.07
-0°.08
-0°.09
-0°.1
0°.09
0°.08
0°.07
0°.06
0°.05
0°.04
(Jy/beam)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6



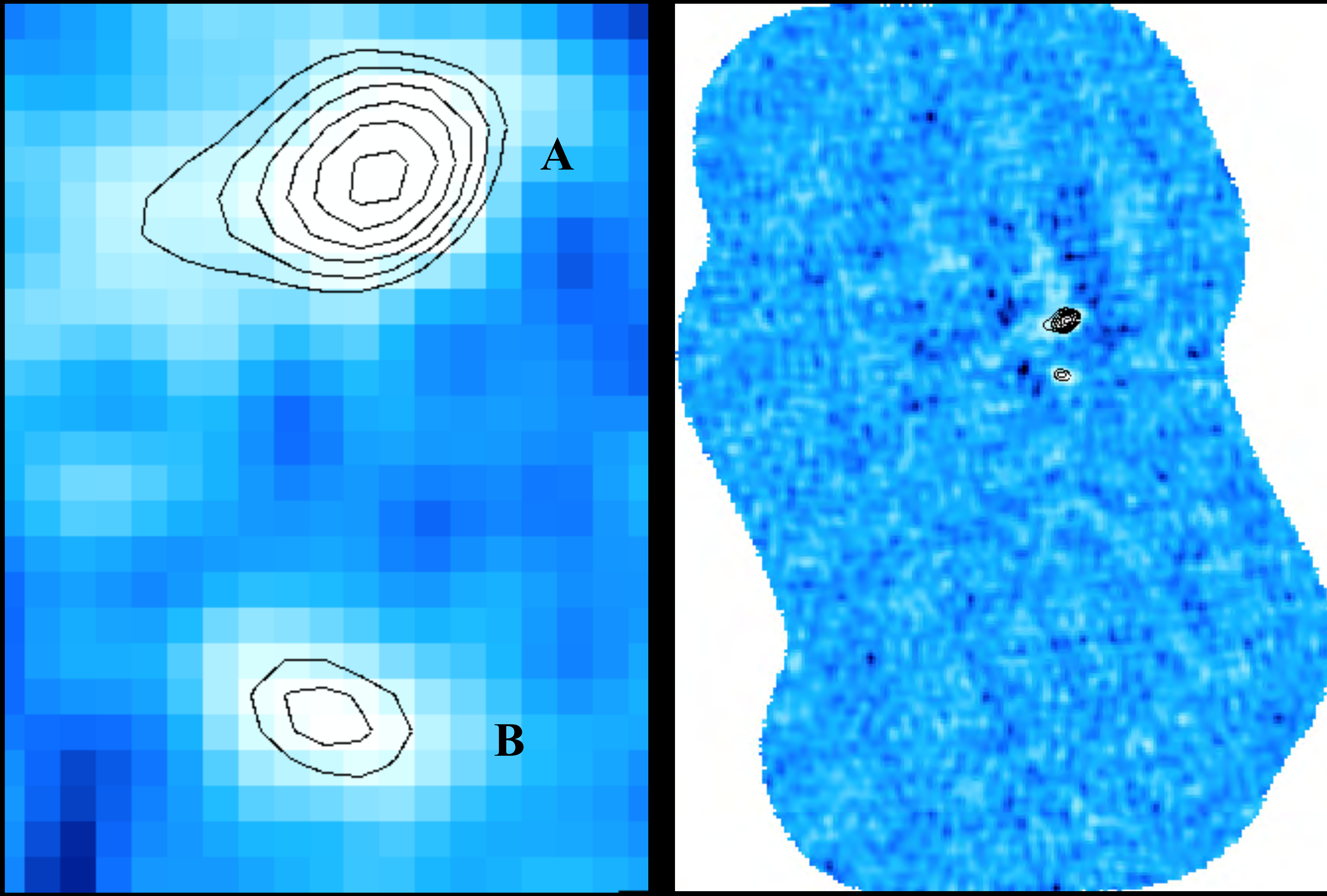
G0.068_h2co_1_final_mg_gal.fits-raster
62.9 km/s
−0°.05
−0°.06
−0°.07
−0°.08
−0°.09
−0°.1
GALACTIC Latitude
0°.09
0°.08
0°.07
0°.06
0°.05
0°.04
GALACTIC Longitude
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
(Jy/beam)


C
D

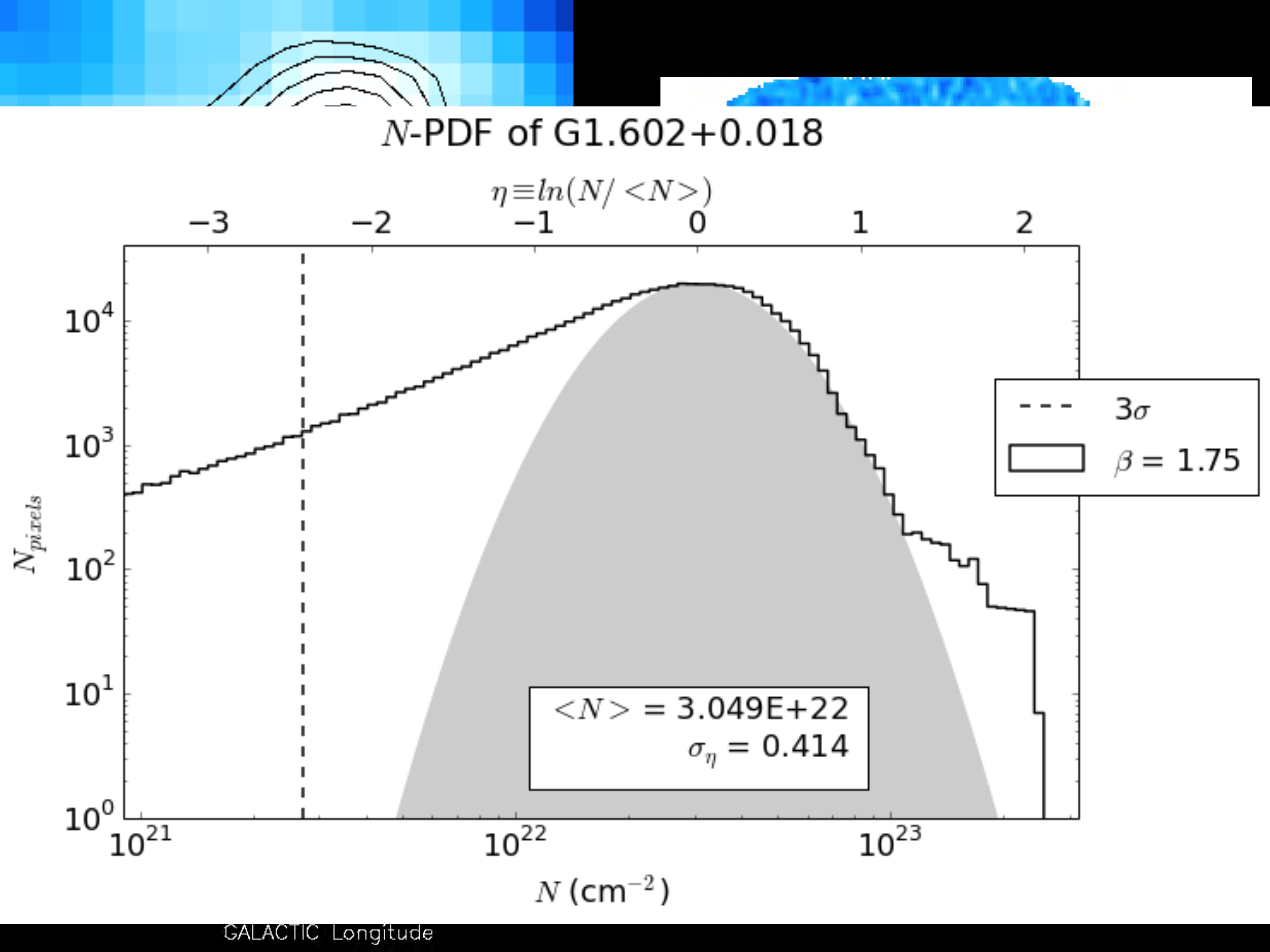

C
D



N-PDF of G1.651-0.050
η ≡ ln(N/ <N>)
−2
−1
0
1
2
10^4
10^3
10^2
10^1
10^0
N_pixels
3σ
β = 1.75
<N> = 1.848E+22
σ_η = 0.470
10^22
10^23
N (cm^−2)

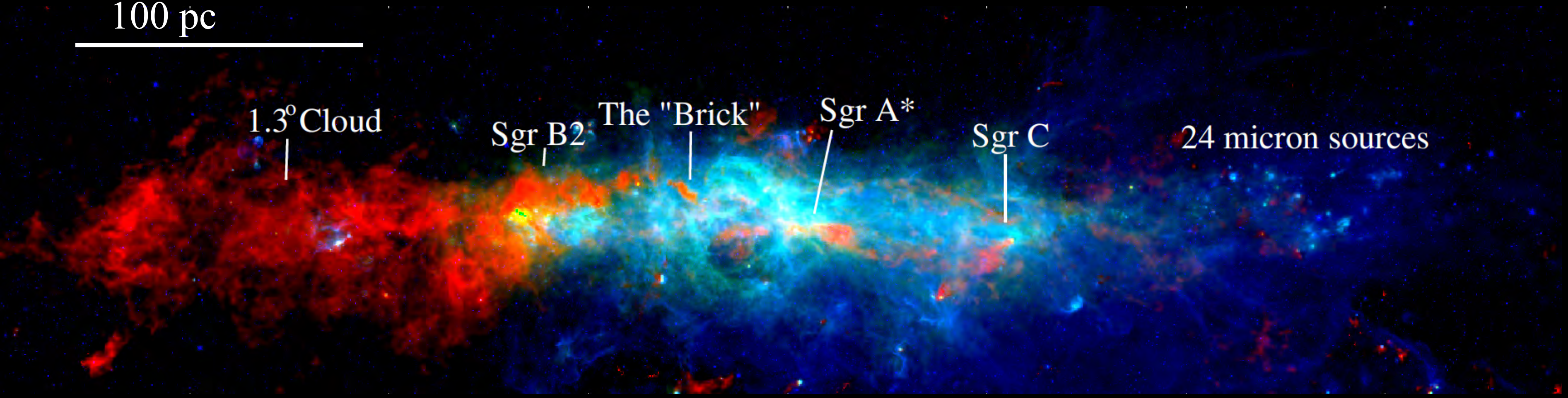


A
B



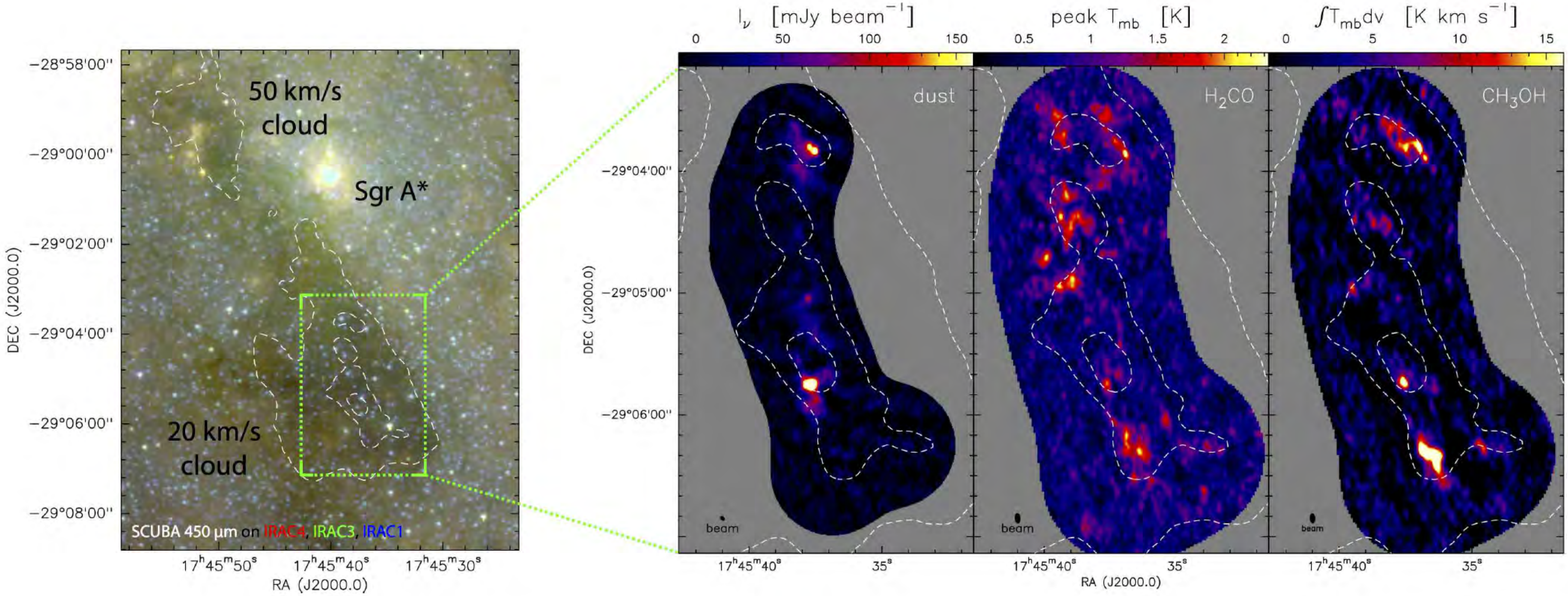
N-PDF of G1.602+0.018
η≡ln(N/ <N>)
−3
−2
−1
0
1
2
10^4
10^3
10^2
10^1
10^0
N_pixels
3σ
β = 1.75
<N> = 3.049E+22
σ_η = 0.414
10^21
10^22
10^23
N (cm^−2)
GALACTIC Longitude

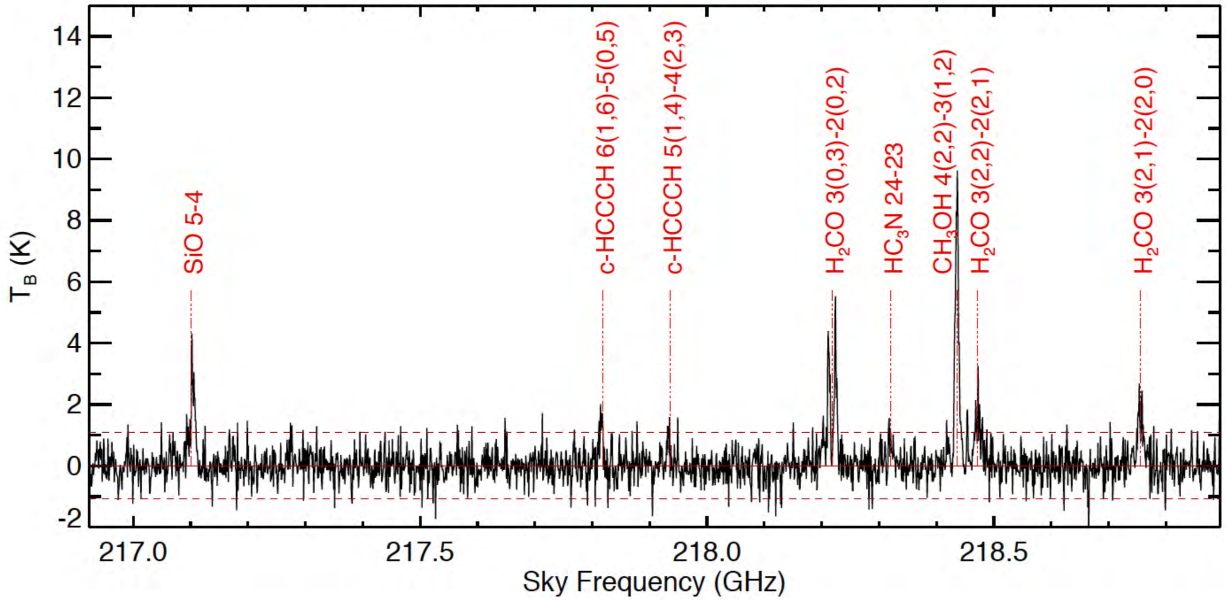
The Wild West of Star Formation



$\Delta v \sim$ 10x higher
n ~ 10-100x higher
High temperatures, ubiquitous exotic molecules

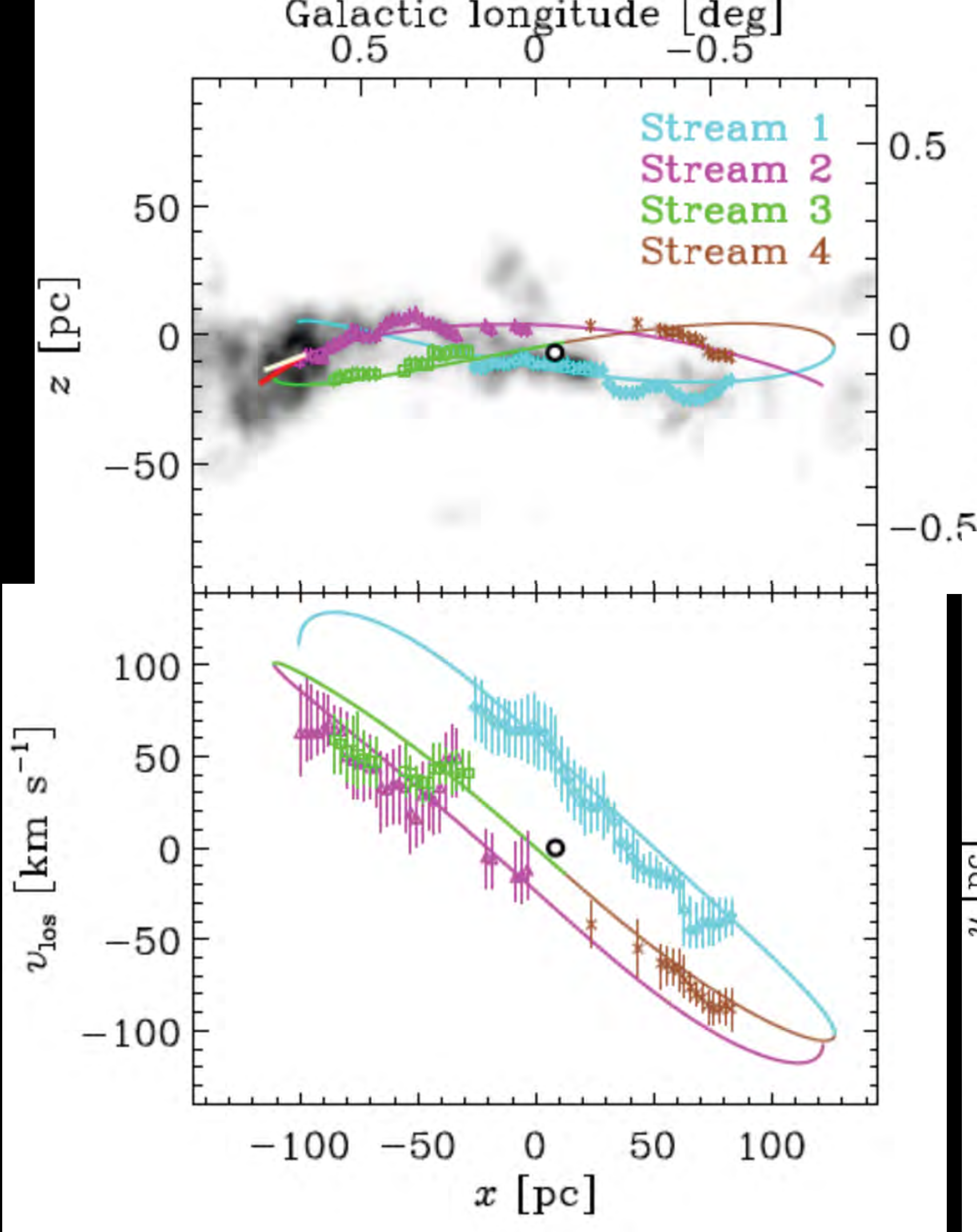
$N(H_2)$
70 μm
8 μm

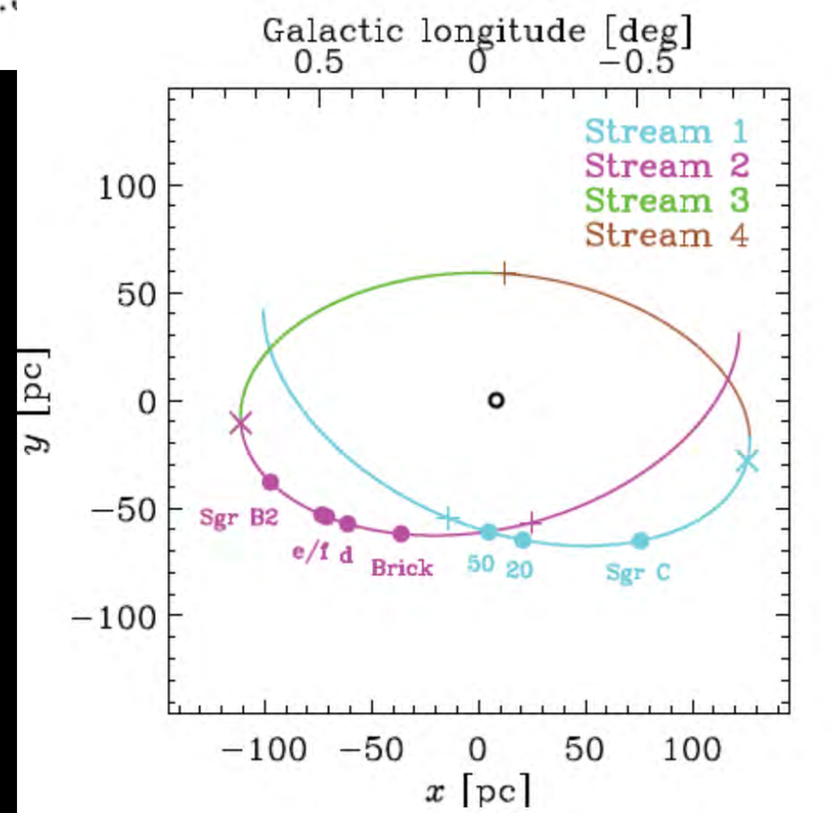


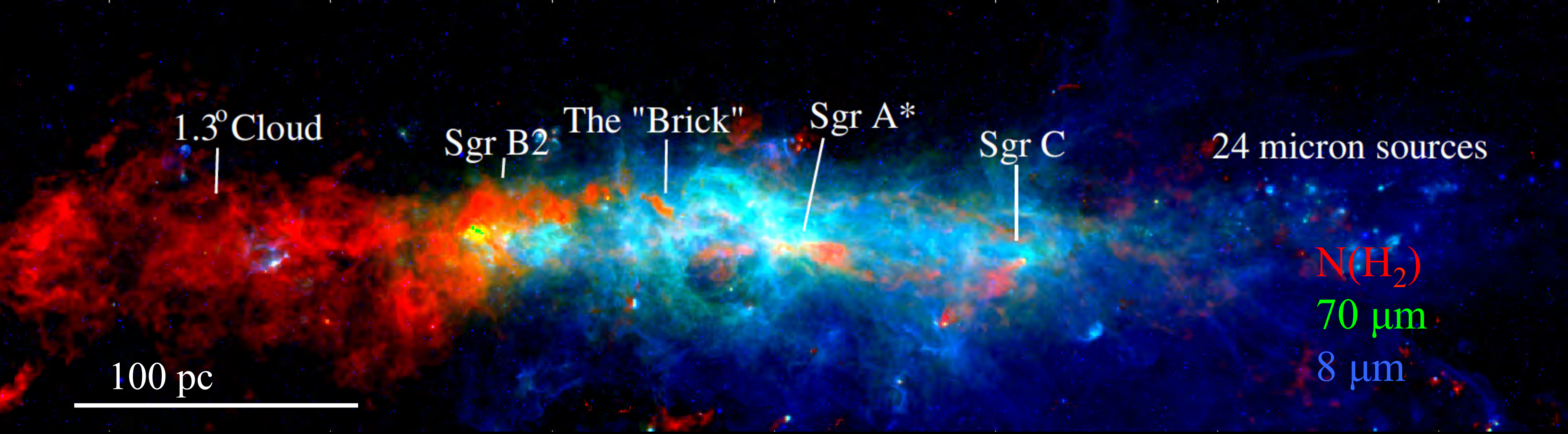


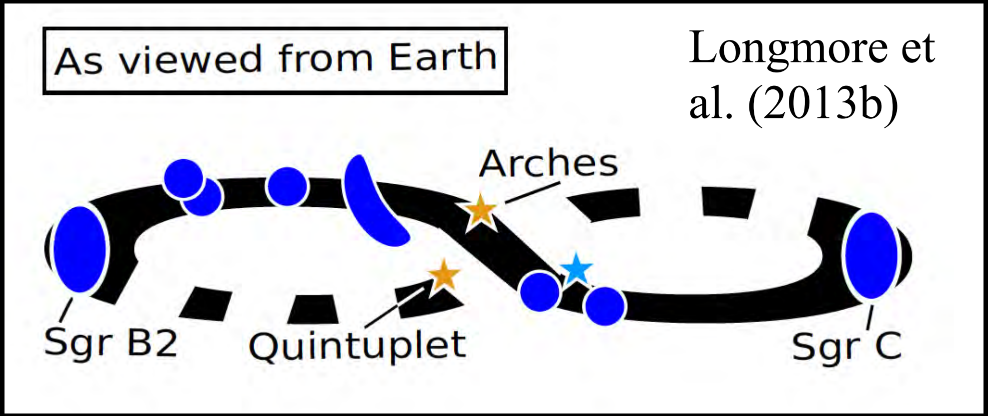
Pilot – PI: Xing (Walker) Lu

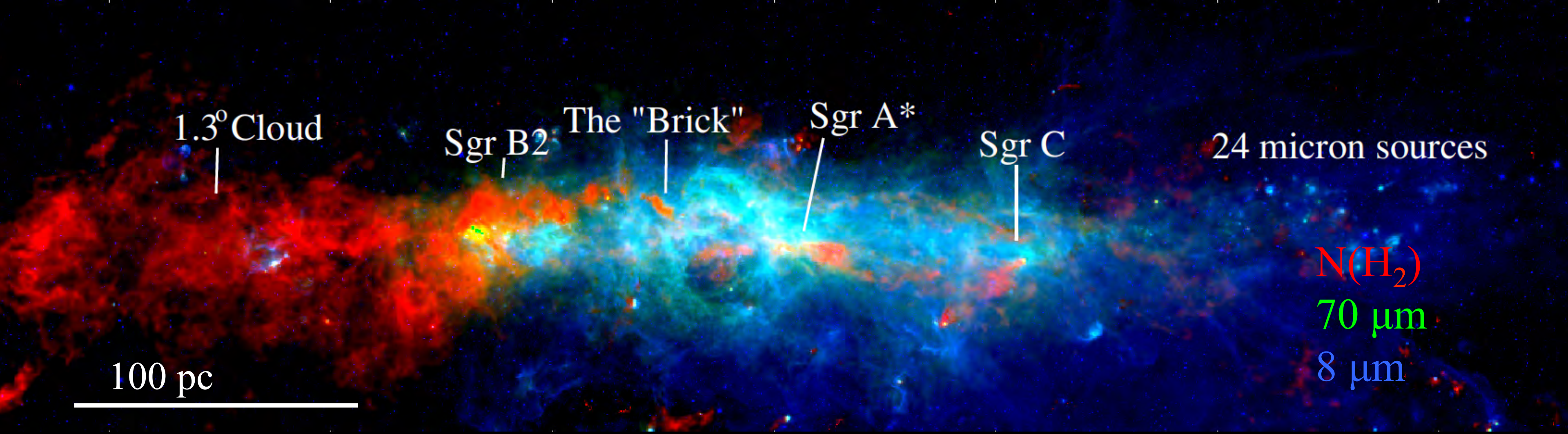
New orbital models from Co-Is Kruijssen and Longmore (Kruijssen et al. 2015)



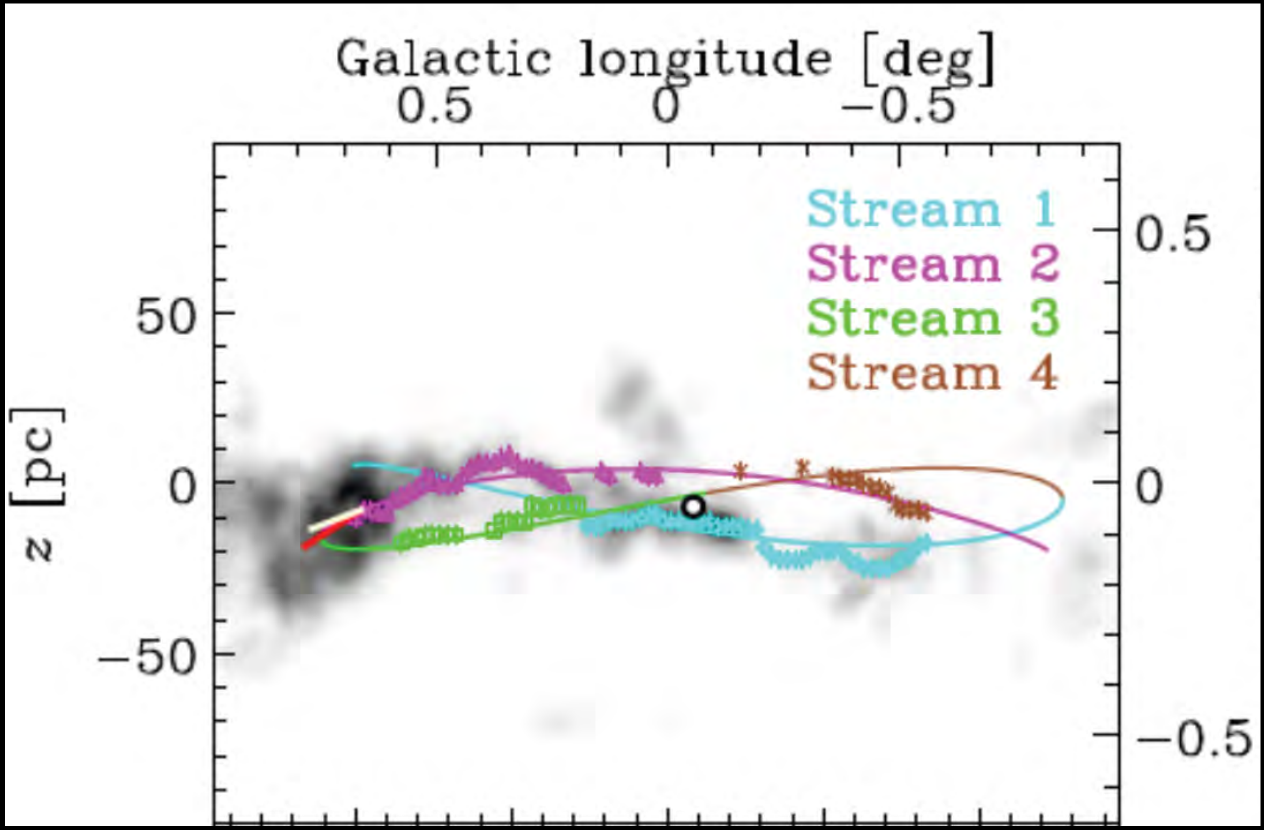


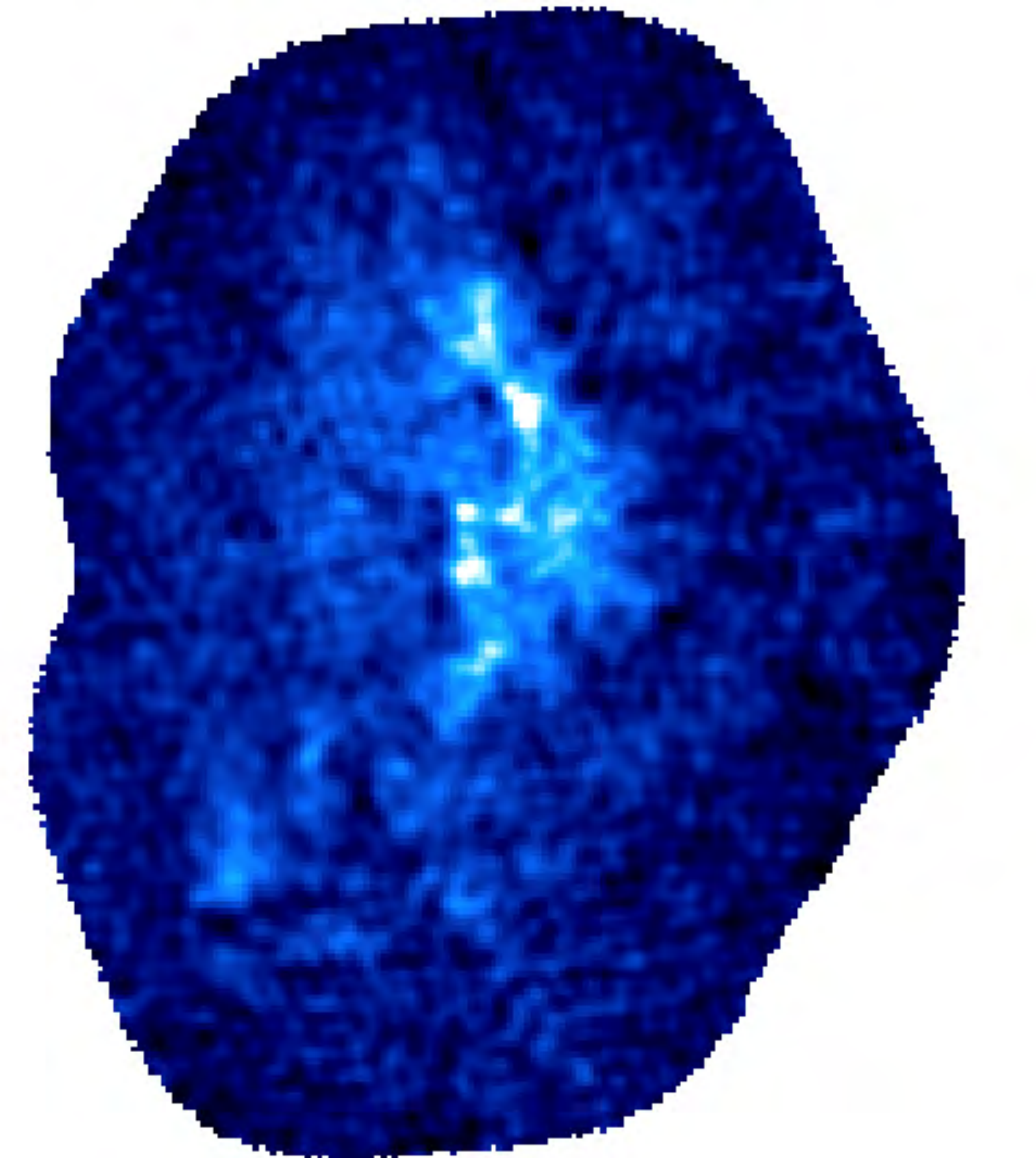

1.3° Cloud
Sgr B2
The "Brick"
Sgr A*
Sgr C
24 micron sources
N(H2)
70 µm
8 µm
100 pc


As viewed from Earth
Longmore et al. (2013b)
Arches
Sgr B2
Quintuplet
Sgr C



New orbital models (Kruijssen+ 2015)





Dan Walker, in prep.