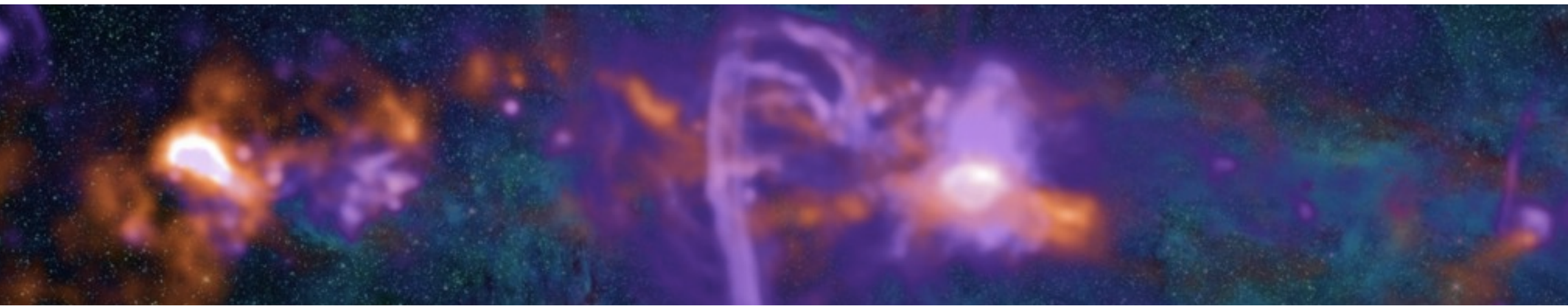
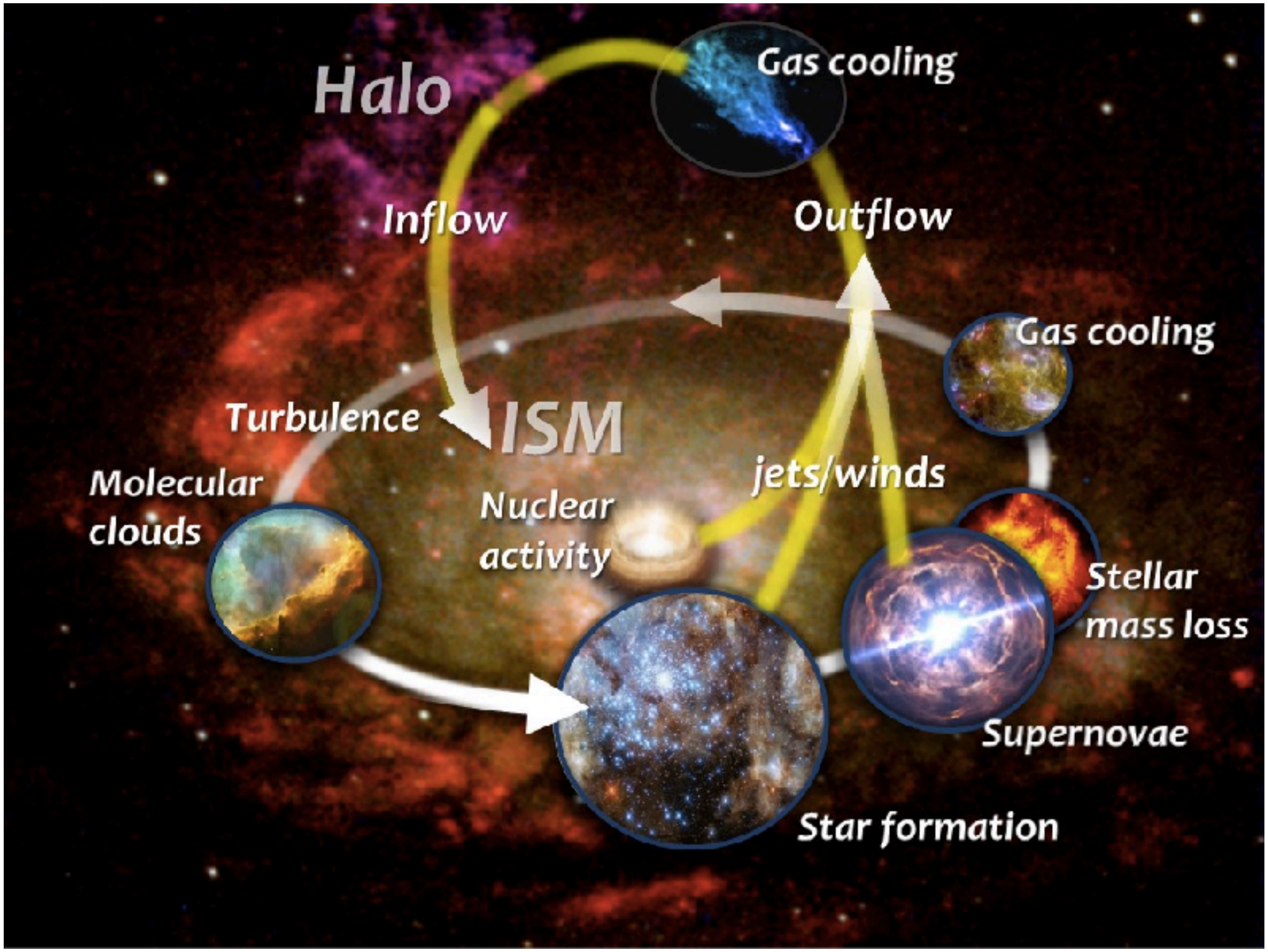
Gas Flows in Galaxy Centers from kiloparsec to subparsec scales

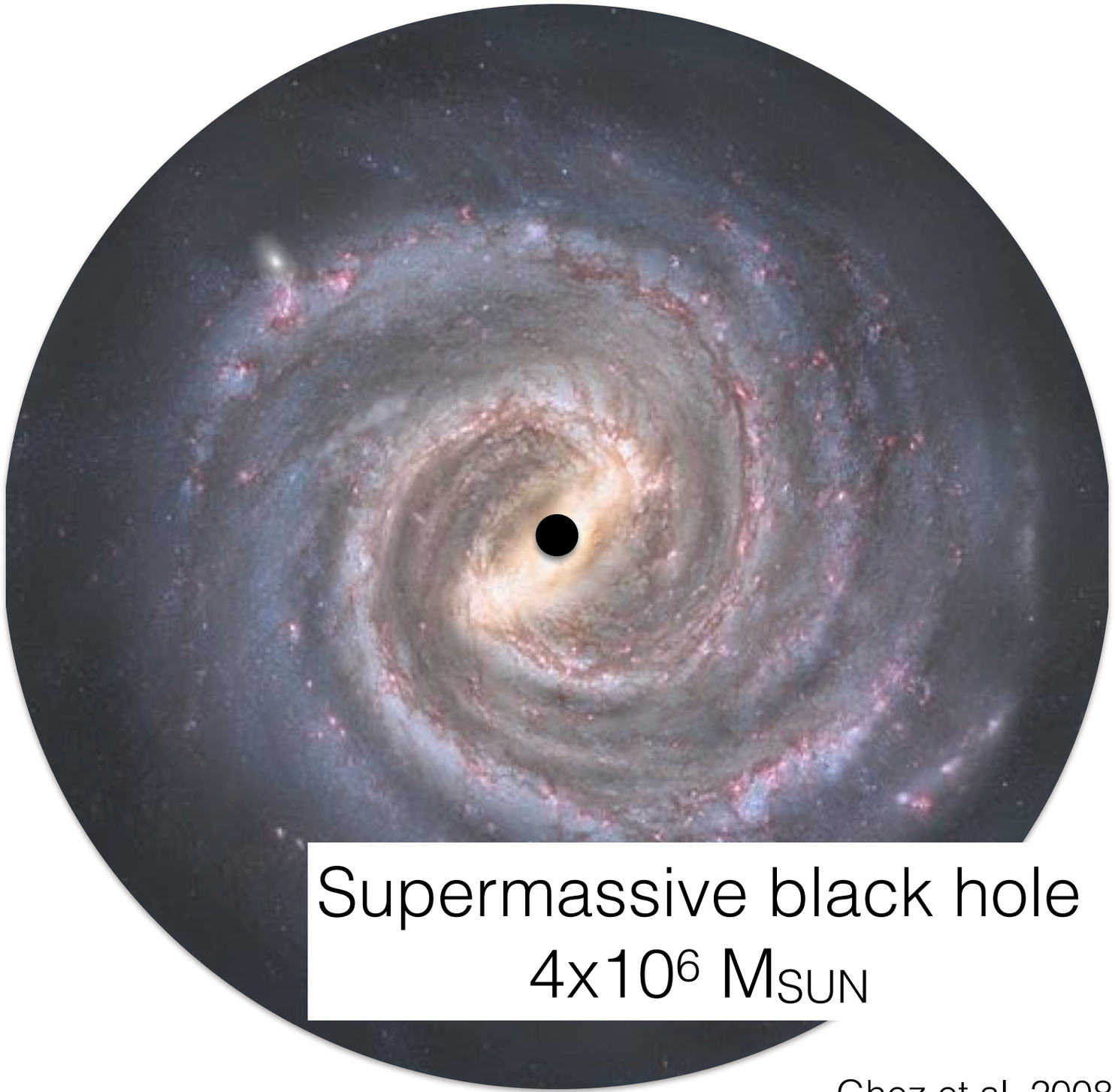


Elisabeth A.C. Mills (University of Kansas)

The Baryon Cycle in Galaxies:

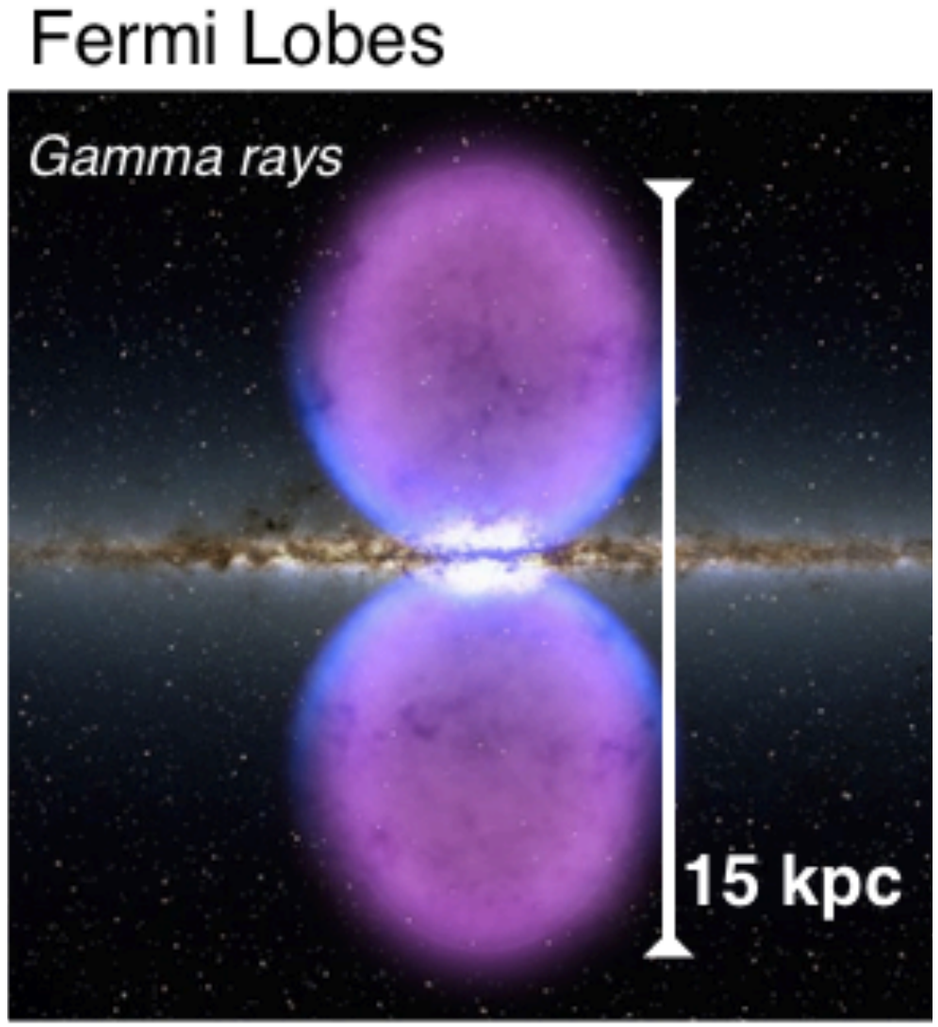


The Milky Way: The Nearest Nucleus



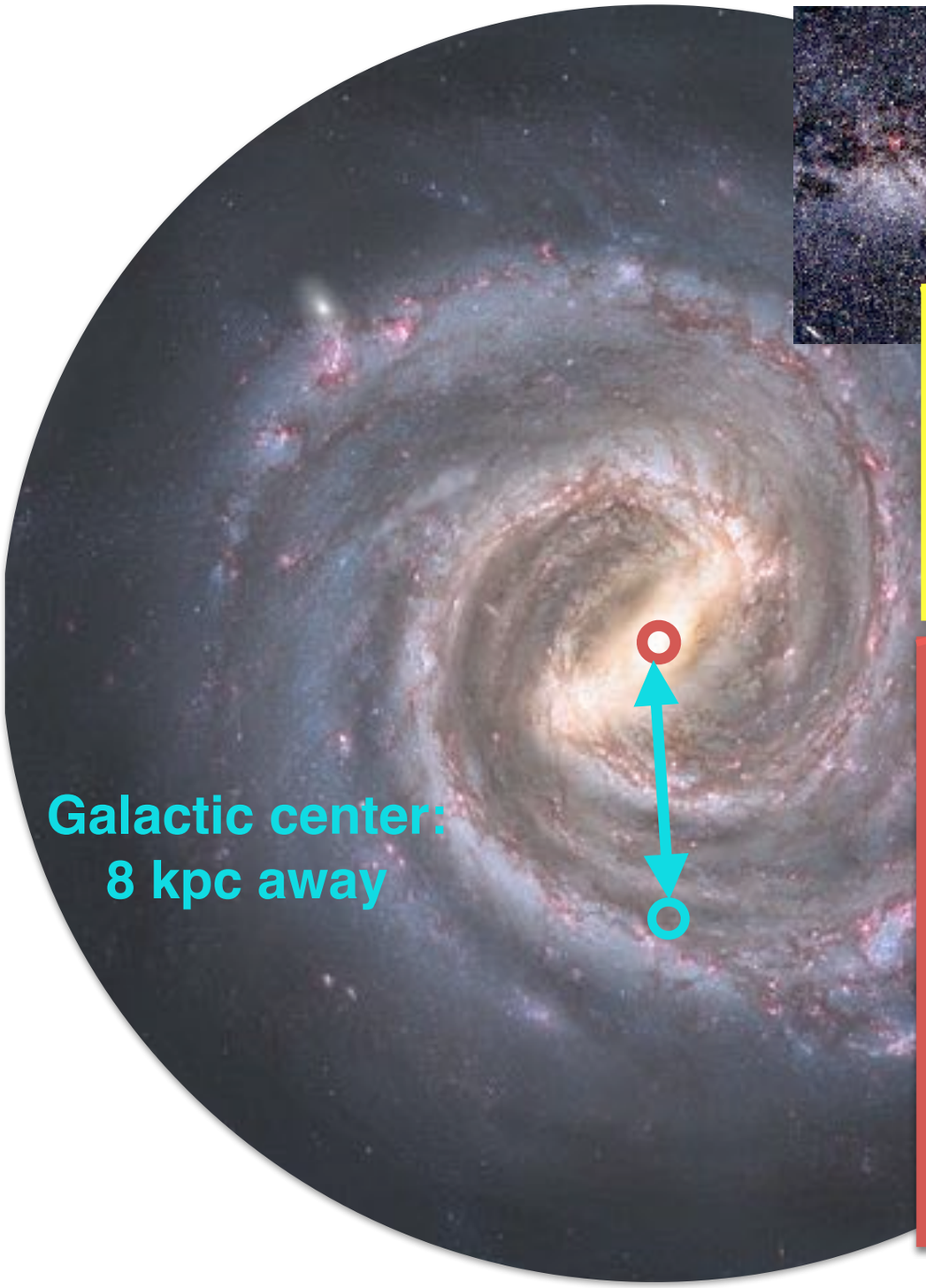
Supermassive black hole
$4 \times 10^6 M_{SUN}$

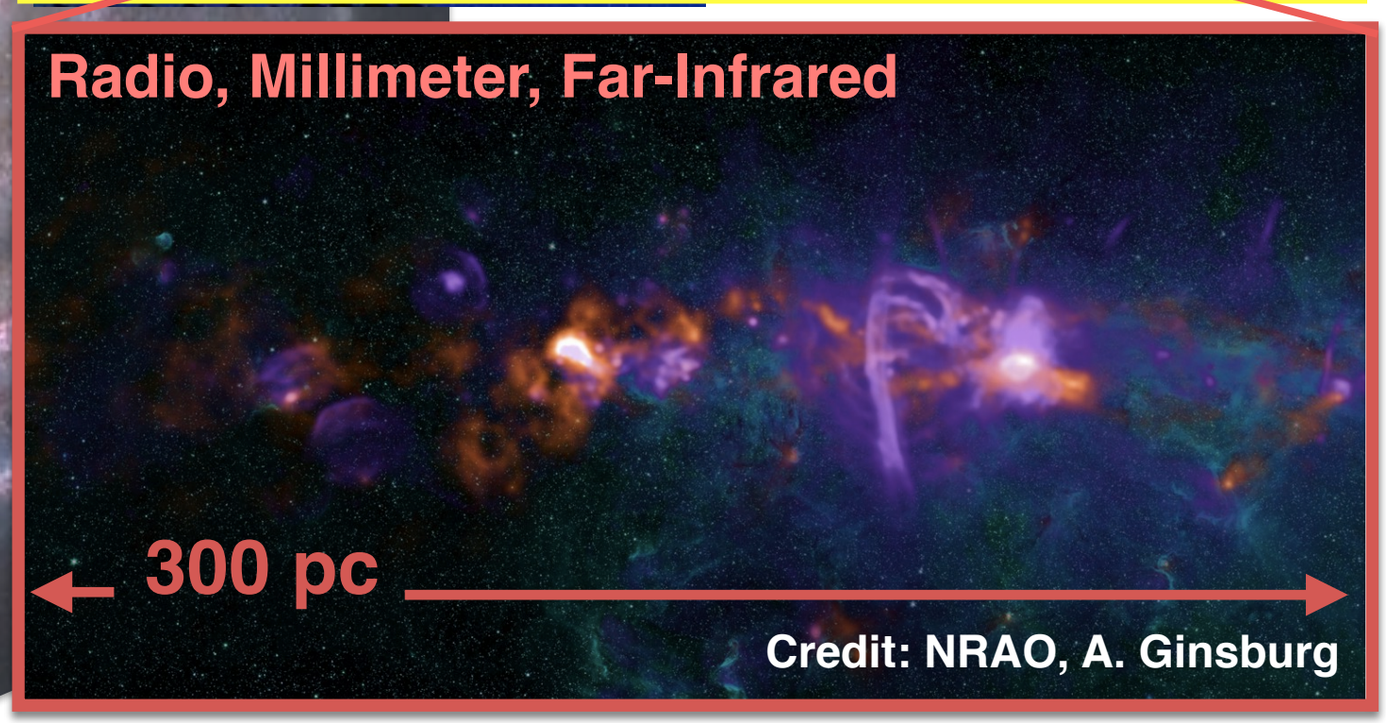
Ghez et al. 2008



Su, Slatyer, and Finkbeiner 2010

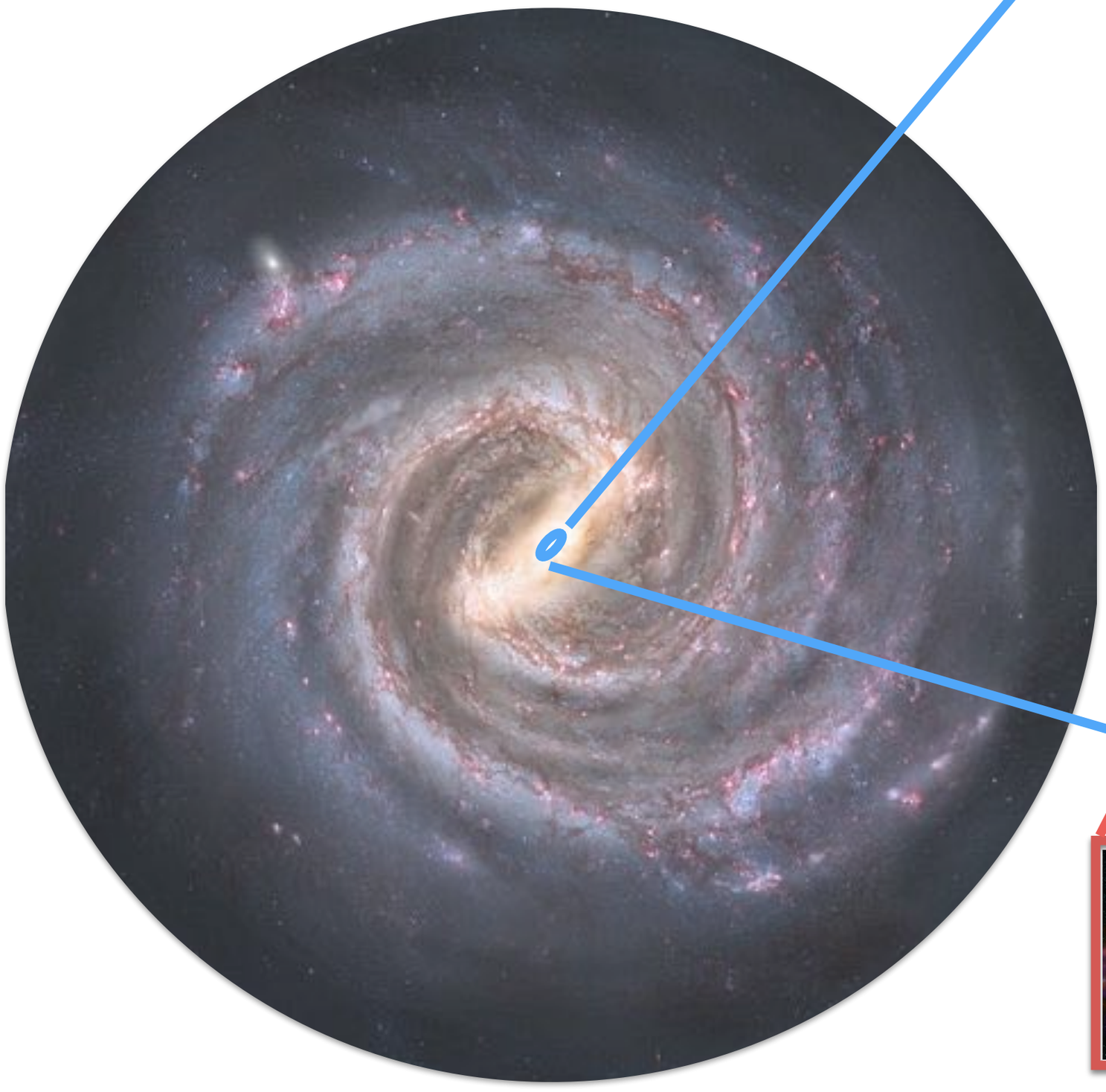
The Milky Way: The Nearest Nucleus



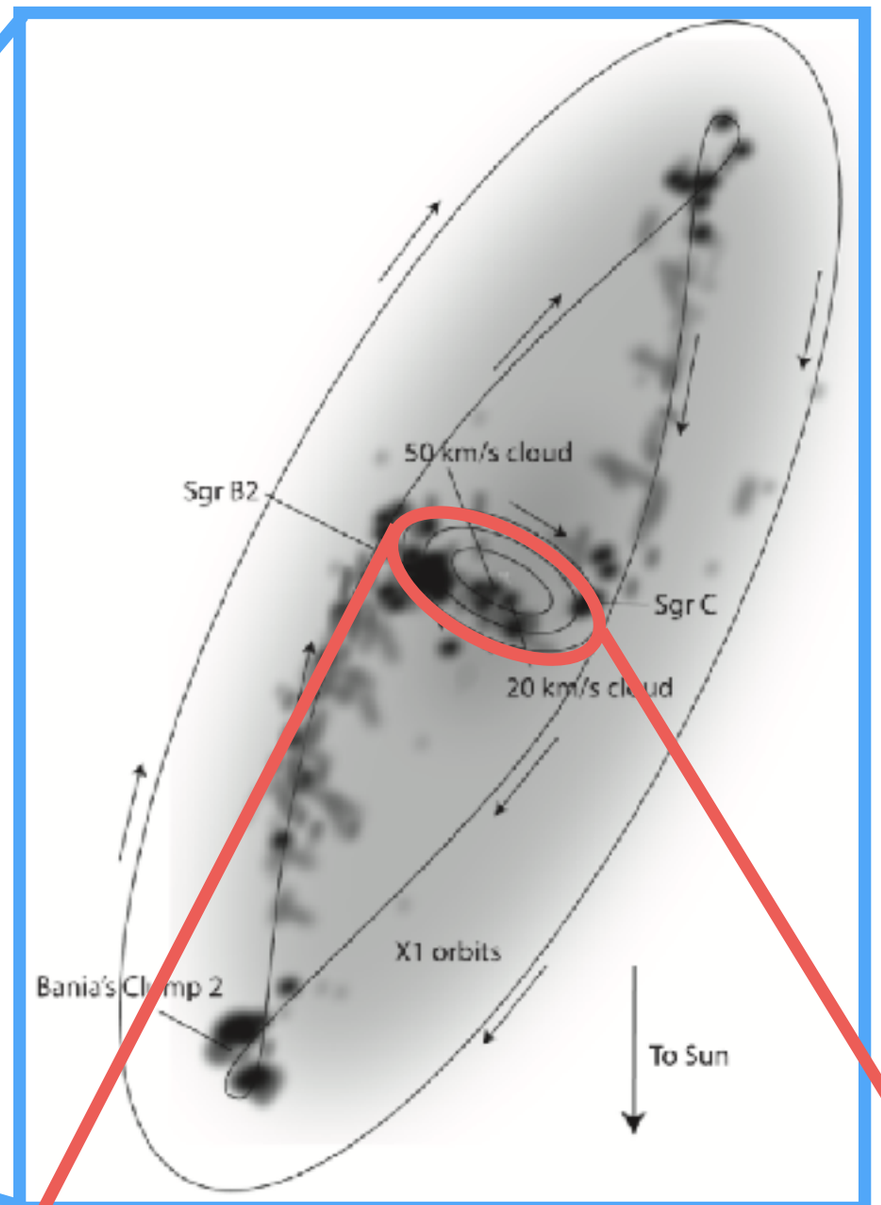


To figure out where the gas is going, we first need to know where the gas is **NOW**.

Our point of view makes this complicated.



what we wish we could see

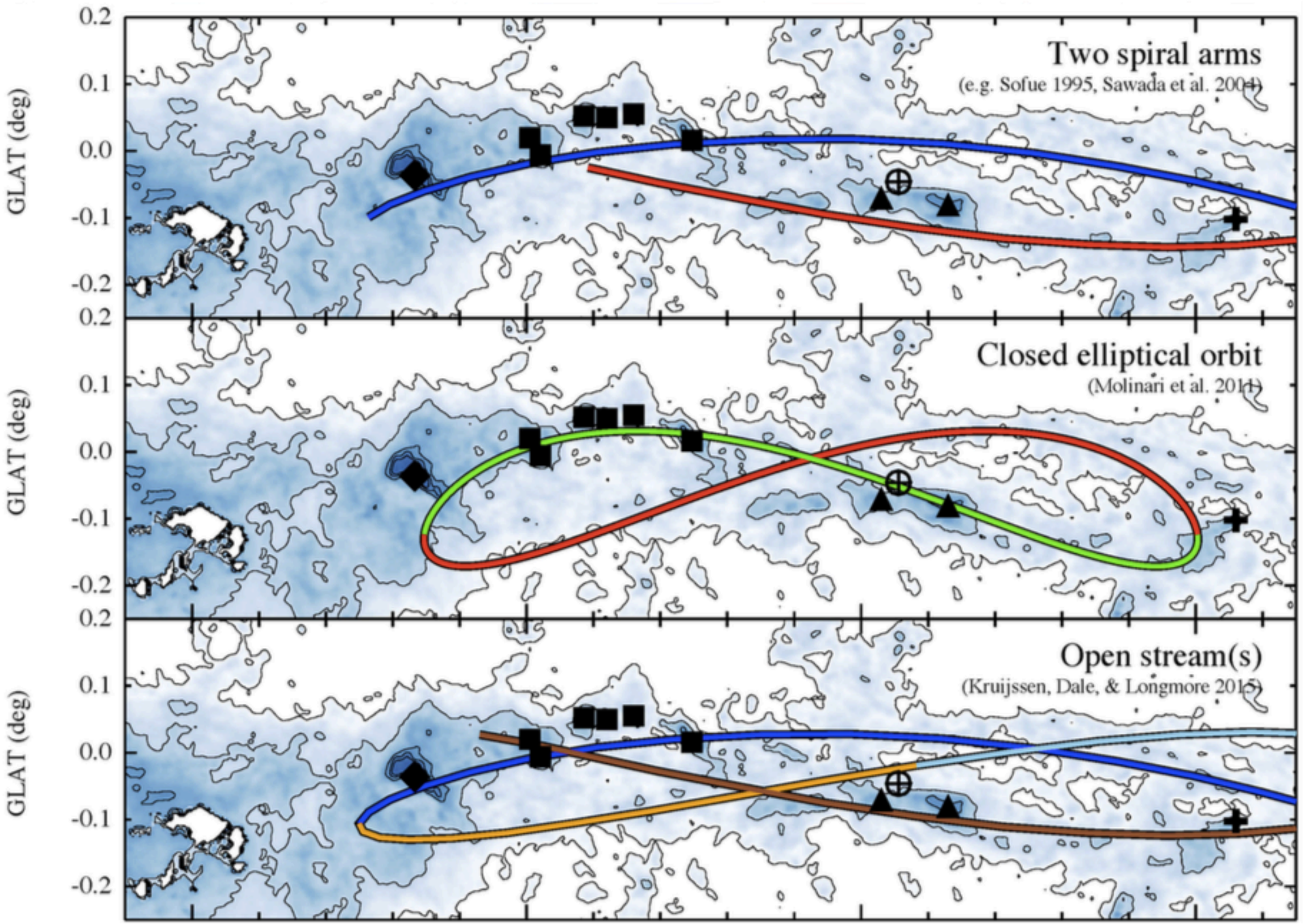


1 kpc

what we actually see

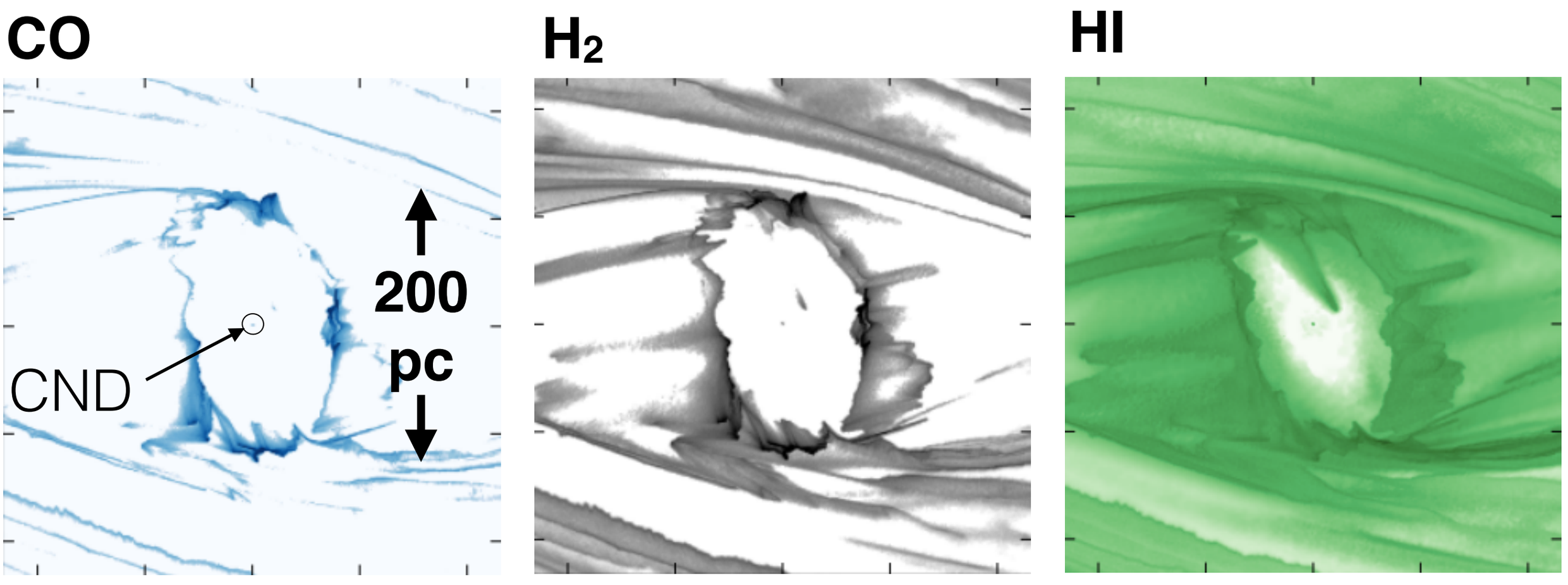
200 pc

There are a lot of possibilities.



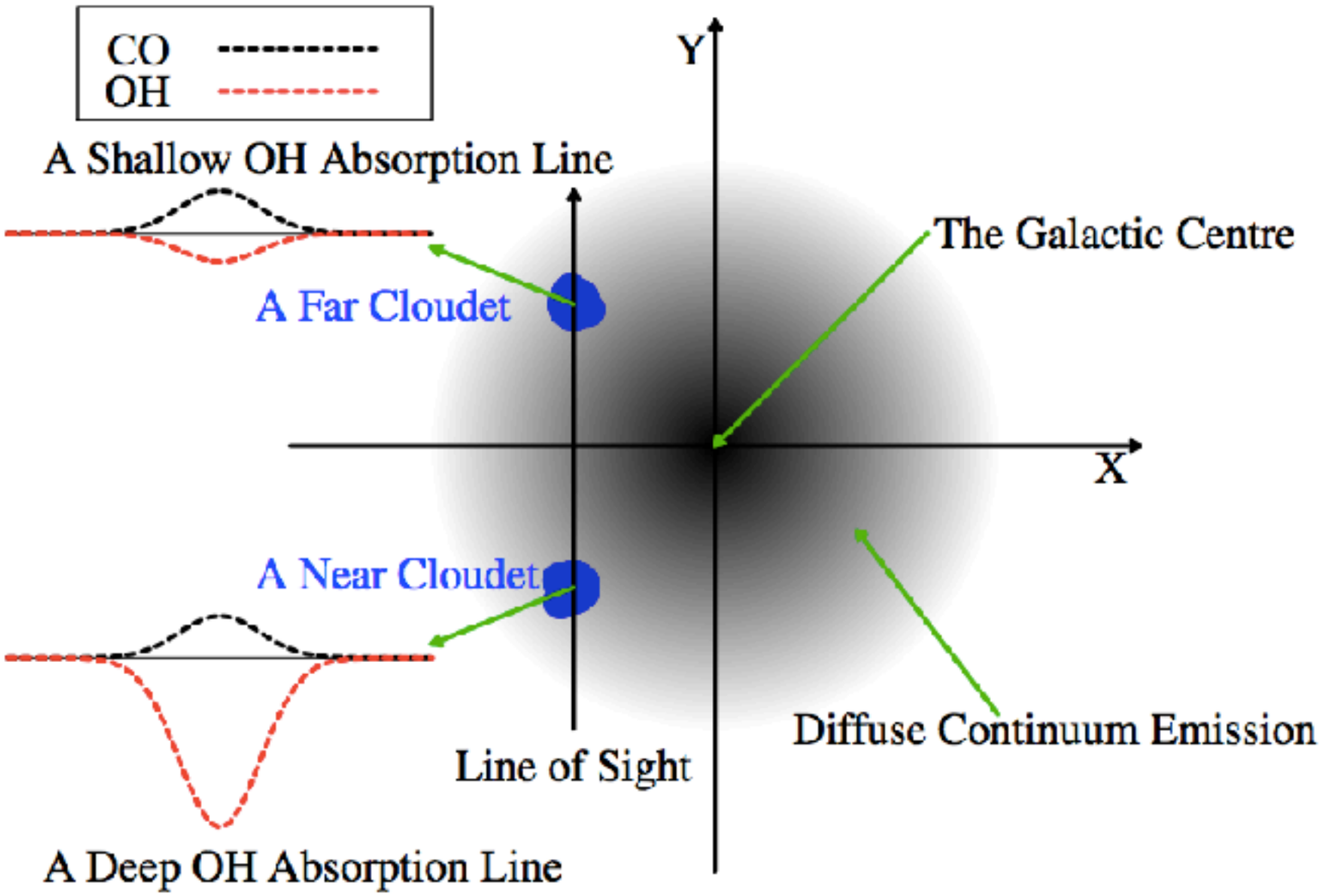
Henshaw et al. (2016)

SOFIA can help by filling in some of the gaps



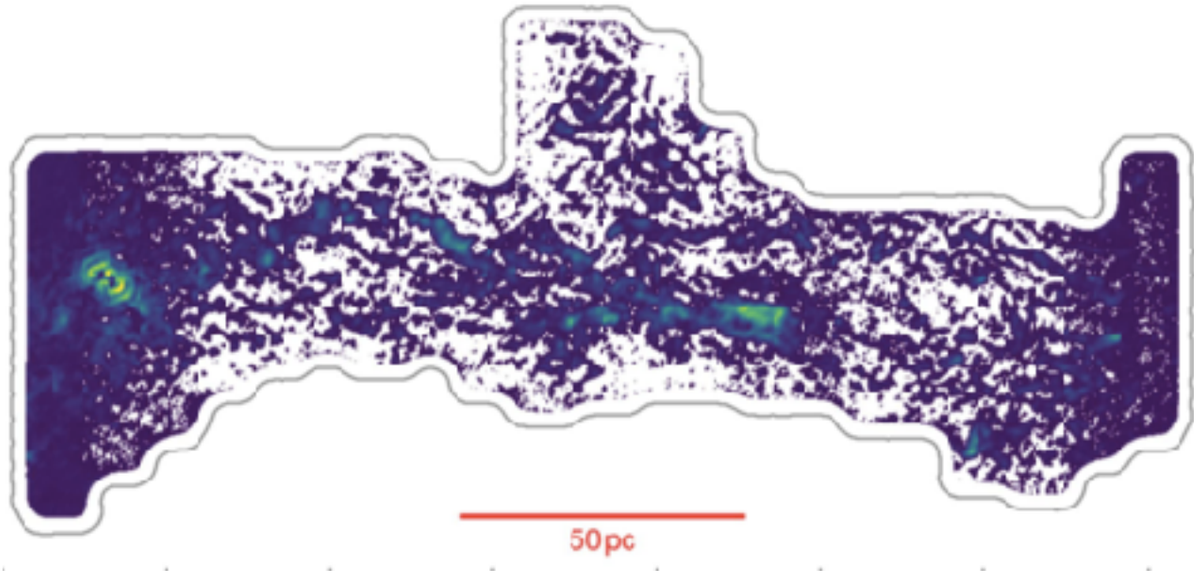
Sormani et al. (2018)

Absorption is another powerful tool for 3D localization

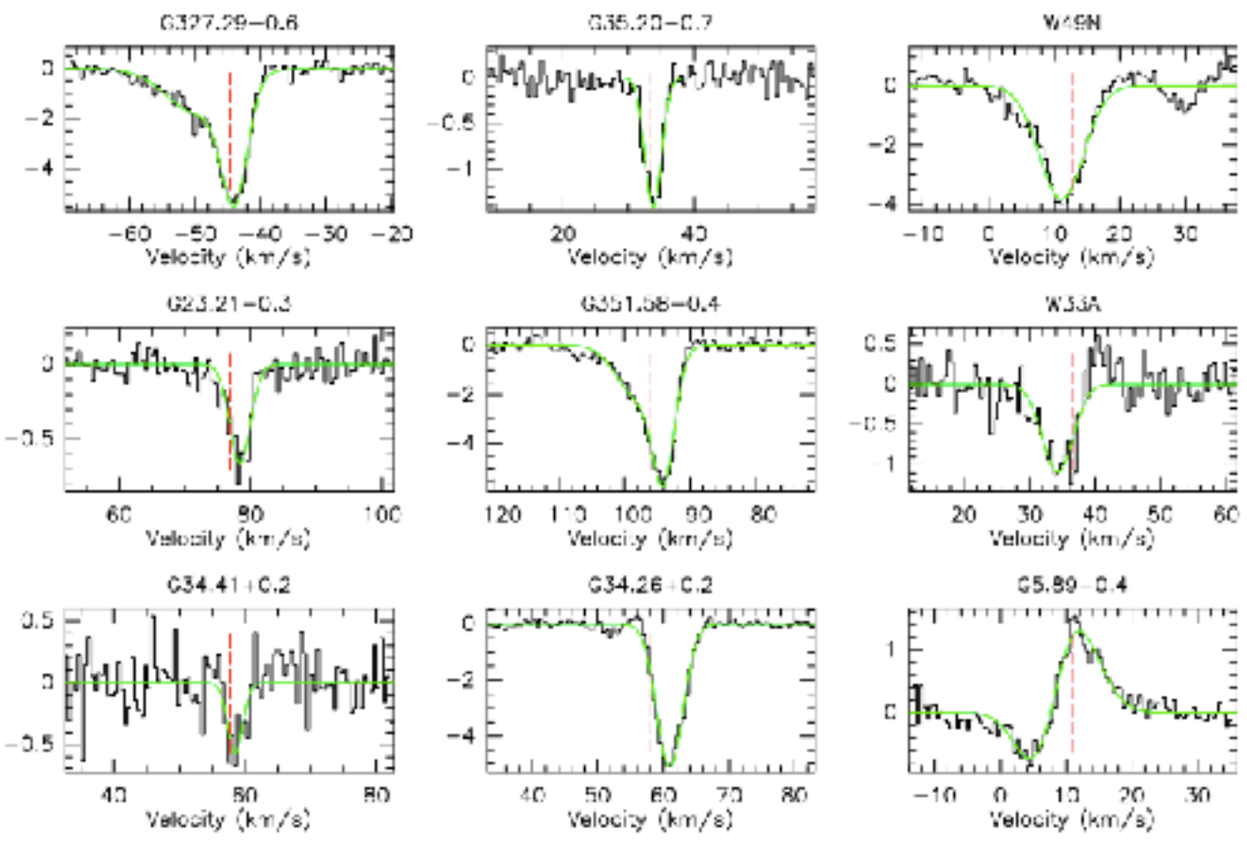


Yan et al. (2017),
Sawada et al. (2004)

SOFIA's unique access to THz ammonia lines can provide information on 3D positions and bulk motions

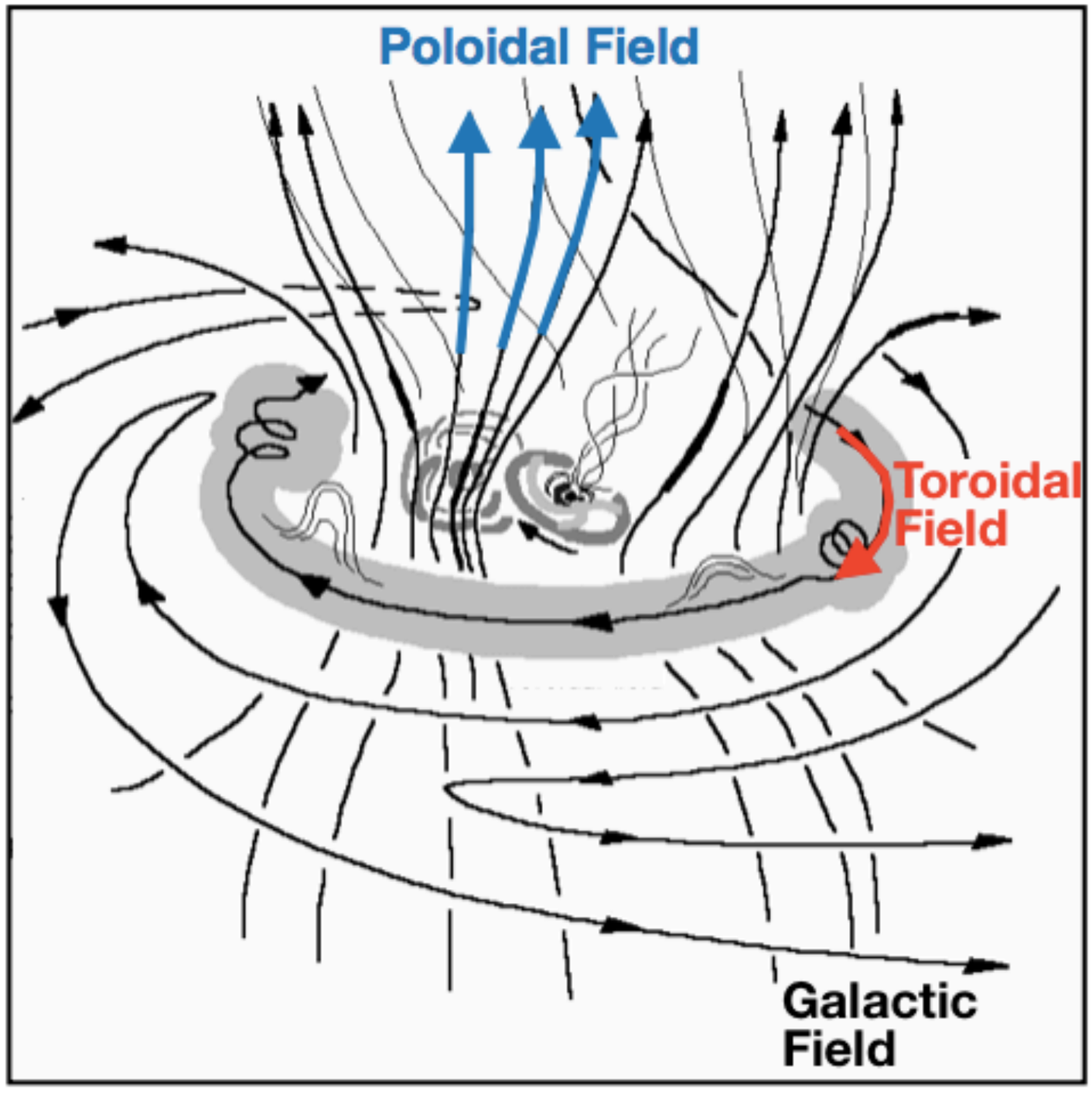


Galactic center
cm-NH_3 (Krieger et al. 2017)



Infall in high mass protostars
THz-NH_3 (Wyrowski et al. 2016)

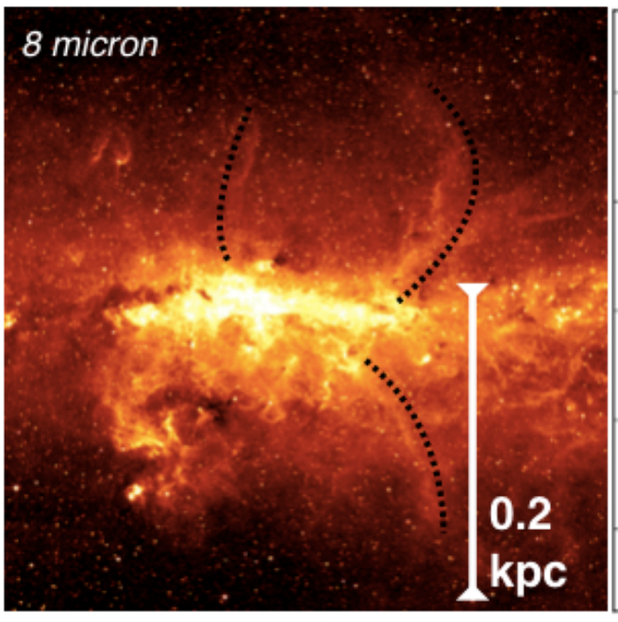
Magnetic fields can also trace the gas flow, both inward and outward.



Sofue and Lang 1999

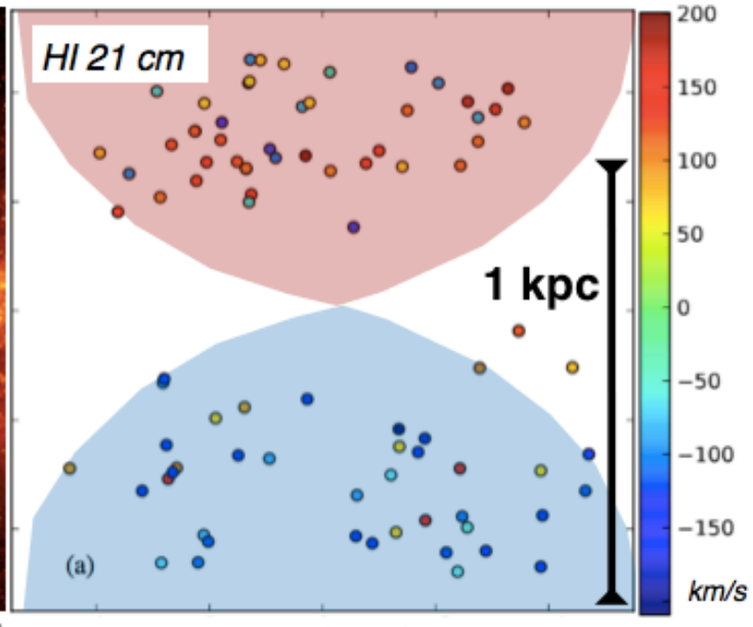
A poloidal field could trace material entrained in a current outflow, and make connections to ‘fossils’ of past events.

Radio/Infrared Lobes



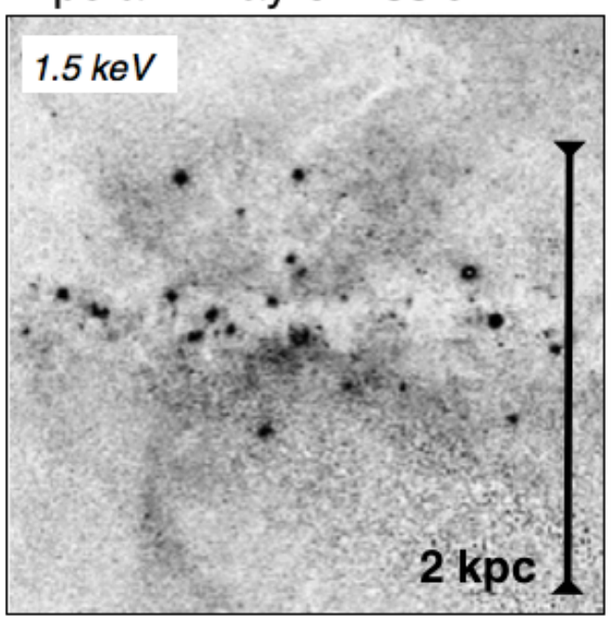
Sofue and Handa 1984

Neutral Outflow



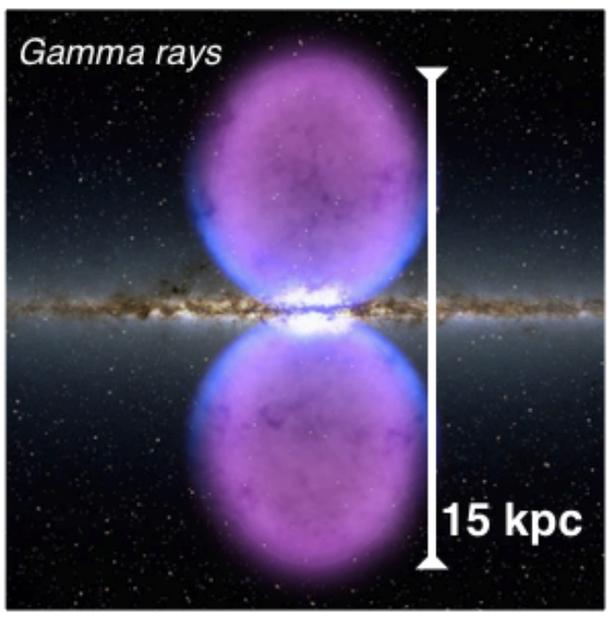
McClure-Griffiths et al. 2013

Bipolar X-ray emission



Bland-Hawthorn et al. 2003

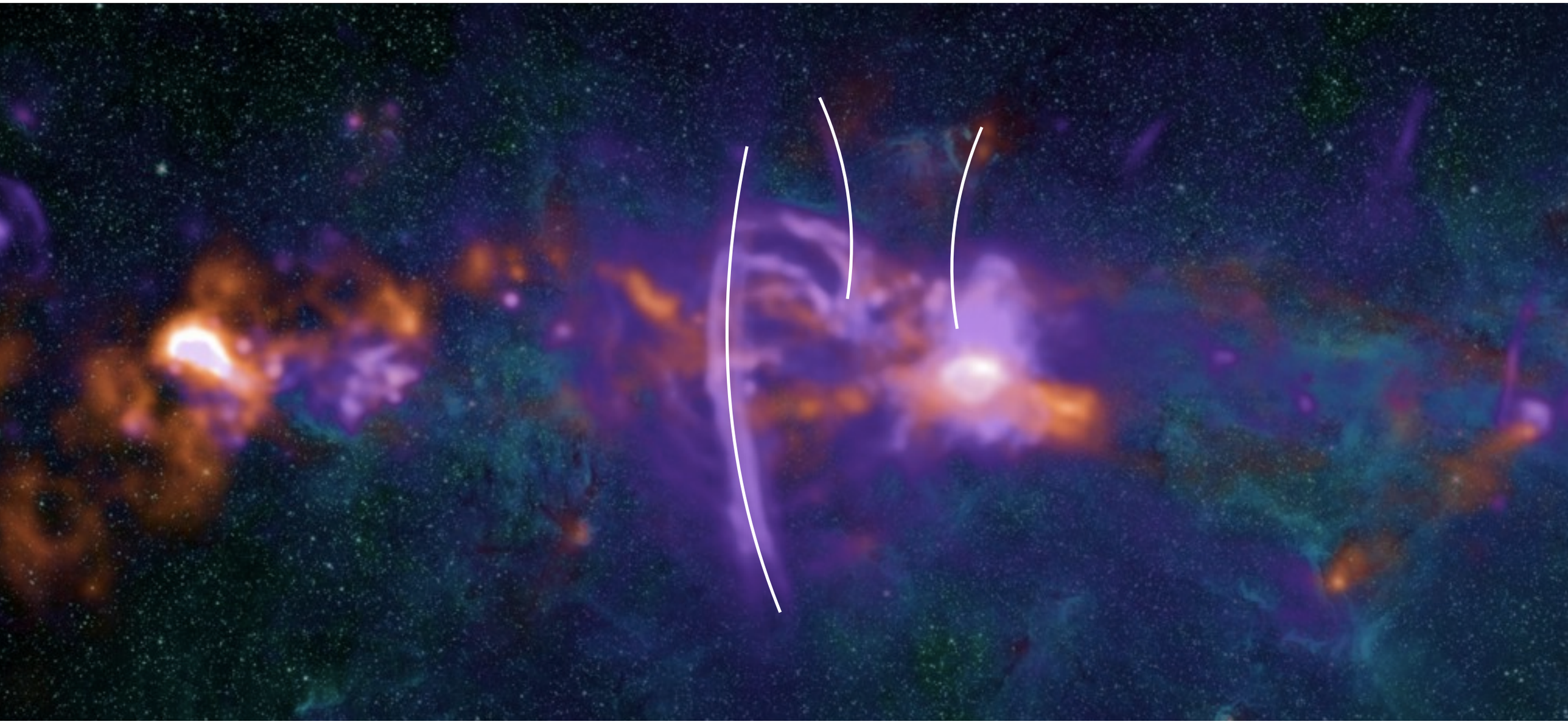
Fermi Lobes



Su, Slatyer, and Finkbeiner 2010

Radio : hot gas, plasma

Poloidal field



Yusef-Zadeh and Morris (1987)

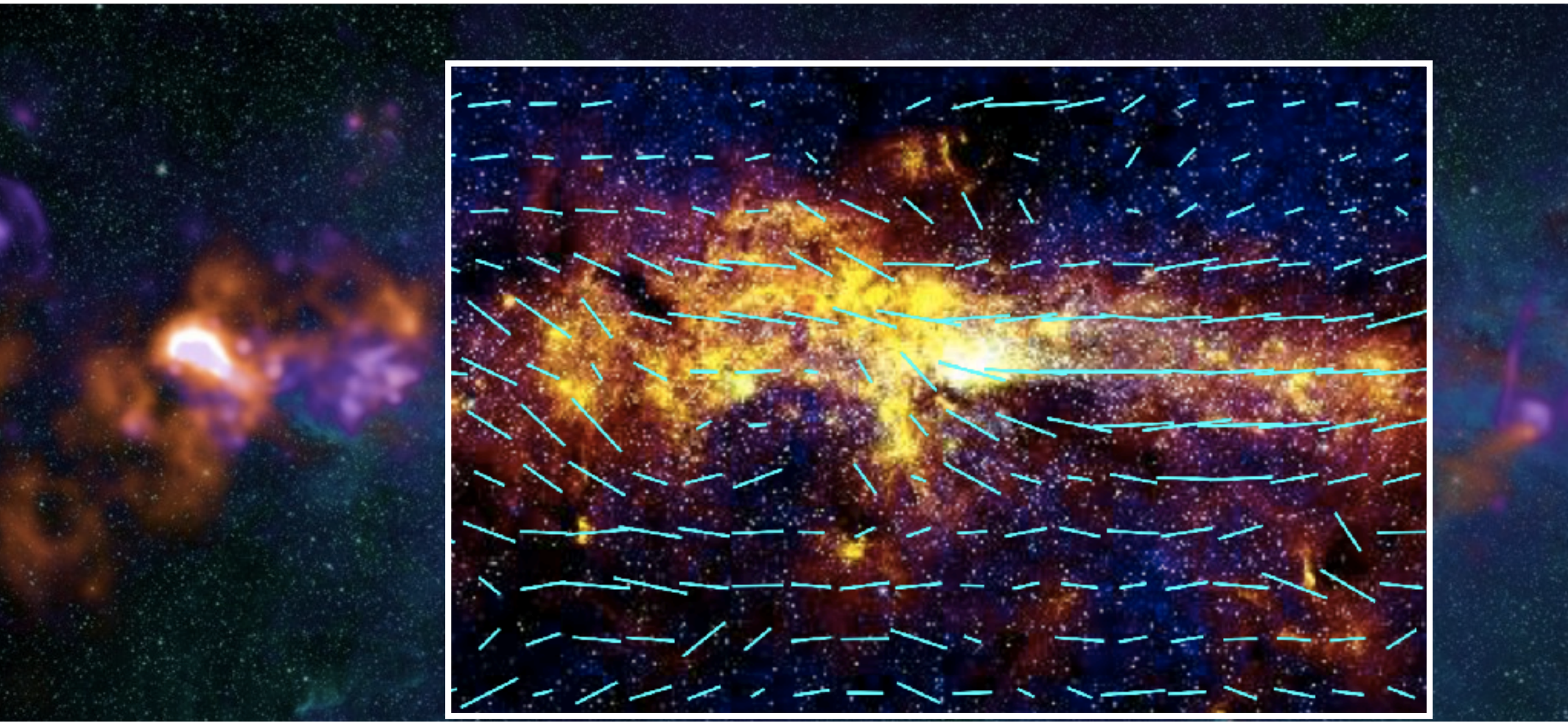
Radio : hot gas, plasma

Poloidal field

MeerKAT

Infrared : polarized starlight

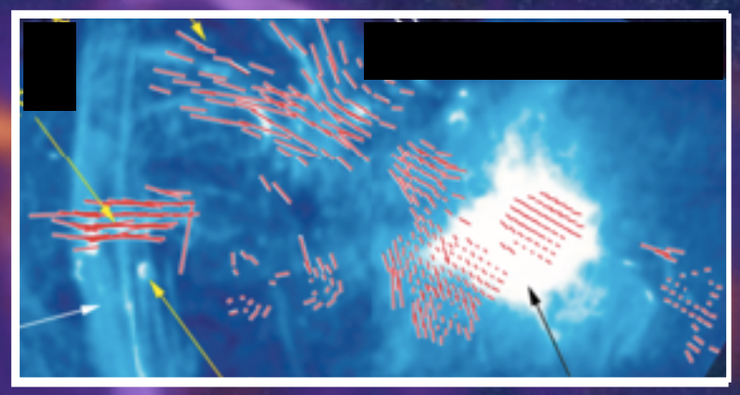
Largely Toroidal field



Nishiyama et al. 2010

Millimeter : cold dust/gas

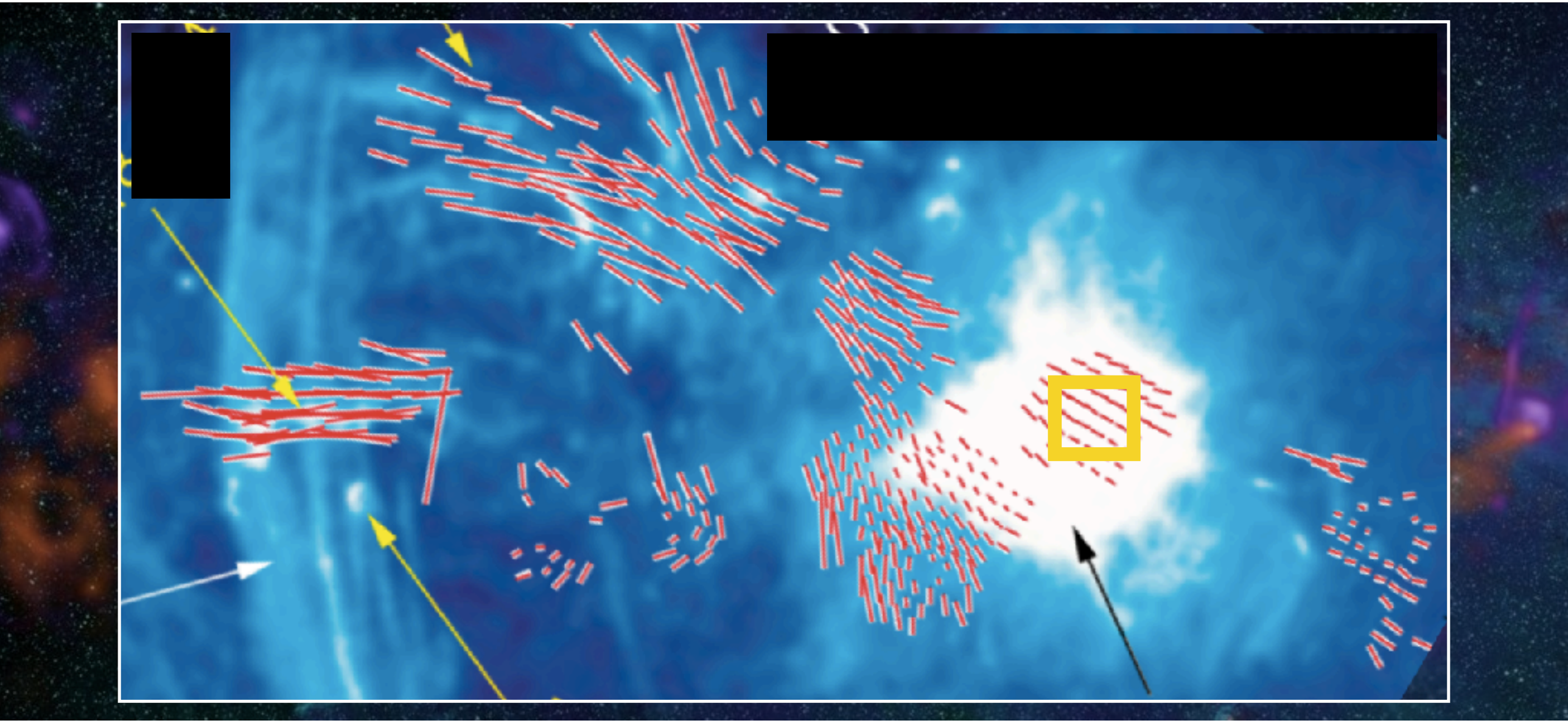
Toroidal field



Chuss et al. 2003

Millimeter : cold dust/gas

Toroidal field



Chuss et al. 2003

With HAWC+, SOFIA can look for changes in the magnetic field direction from the cool medium traced at long wavelengths to the hot medium traced at short wavelengths

Circumnuclear Disk

How representative is the Milky Way's center?

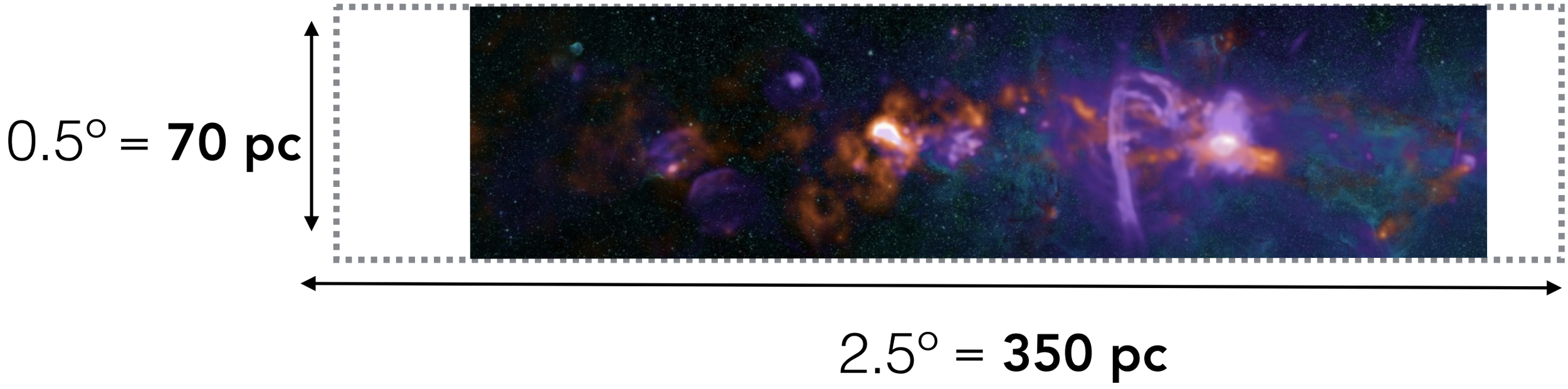
When doing these studies with SOFIA, need to be able to make valid comparisons to other galaxies.

M51; 7.1 Mpc

NGC253; 3.5 Mpc

[CII] with SOFIA:	16″~ 560 pc	16″ ~ 280 pc
[CII] with 9m OST:	4″ ~ 140 pc	4″ ~ 70 pc

RADIO/MM/IR CONTINUUM



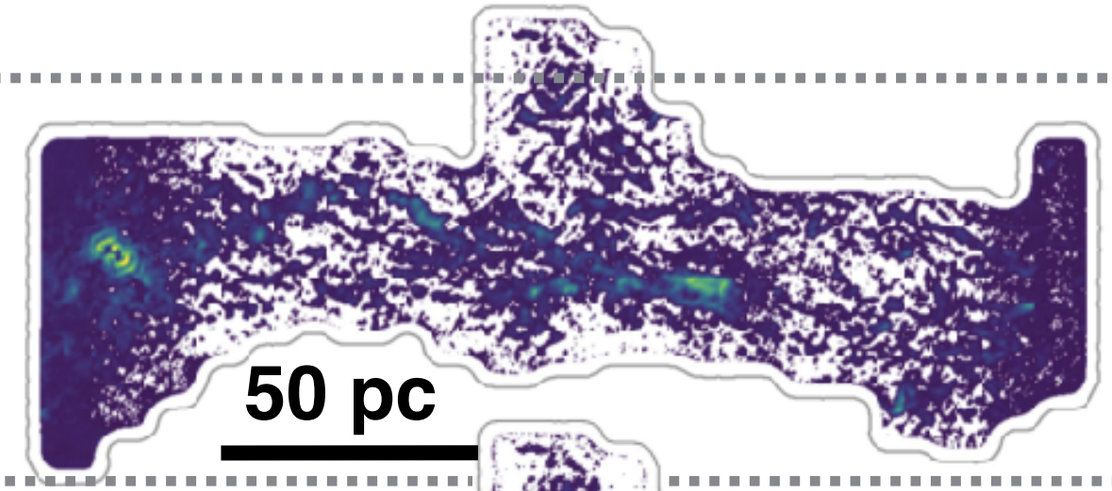
We are making huge progress in parsec-scale line surveys over 100s of pc

RADIO

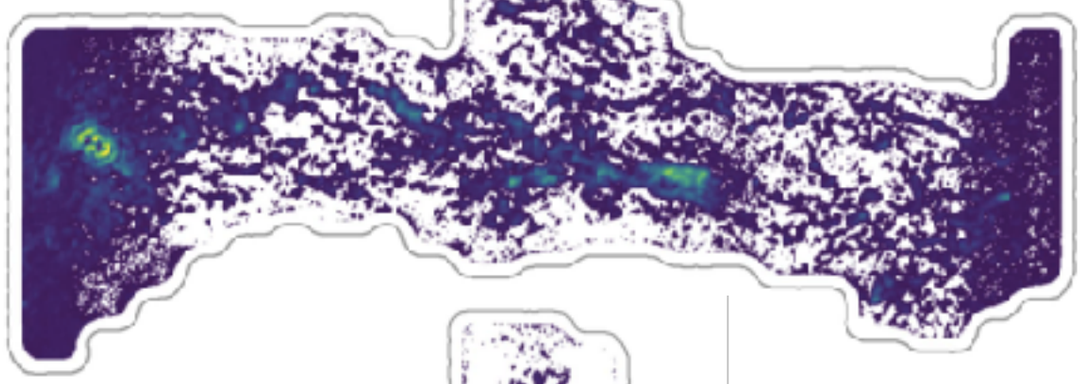
1.2 cm / 25 GHz

23″
0.9 pc

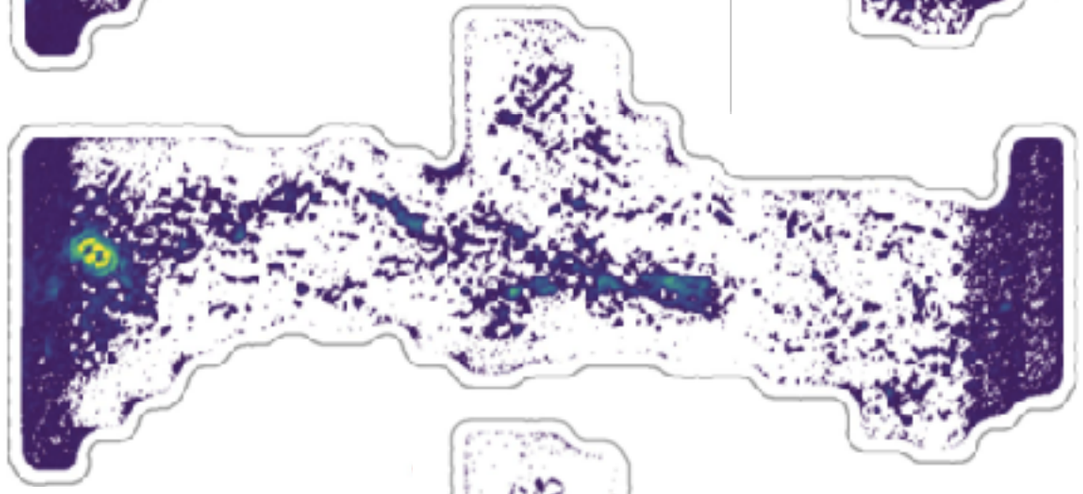
NH_3 (1,1)



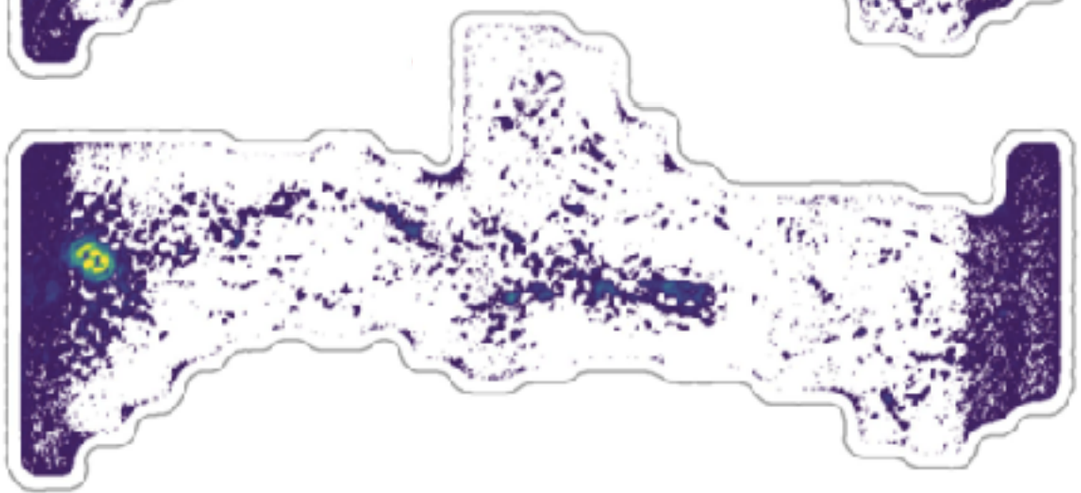
NH_3 (2,2)



NH_3 (3,3)



NH_3 (4,4)



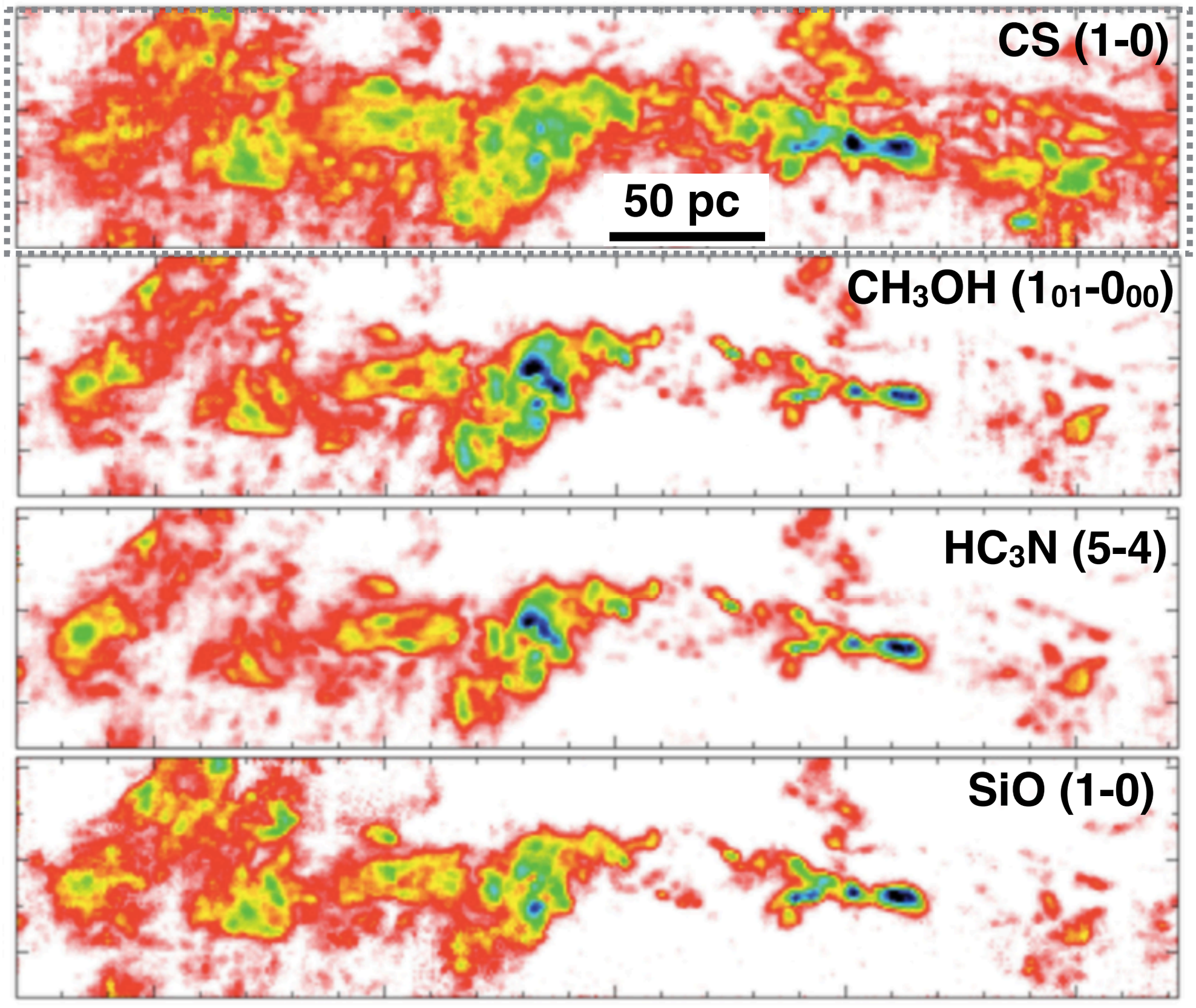
20 lines

Krieger et al.
(2017)

RADIO/MM

7 mm / 50 GHz

65″
2.5 pc



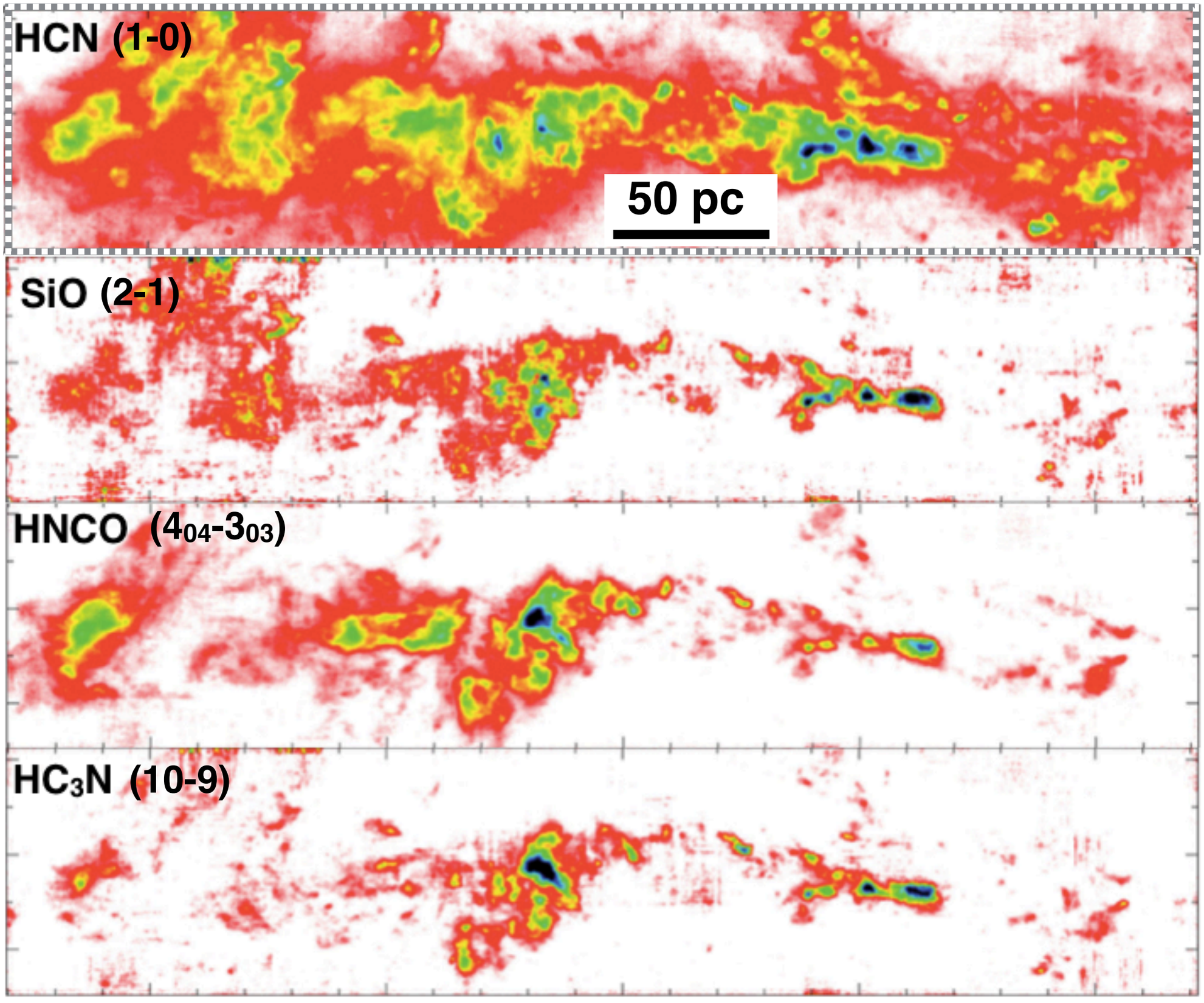
24 lines

Jones et al. (2013)

MILLIMETER

3 mm / 90 GHz

39″
1.5 pc



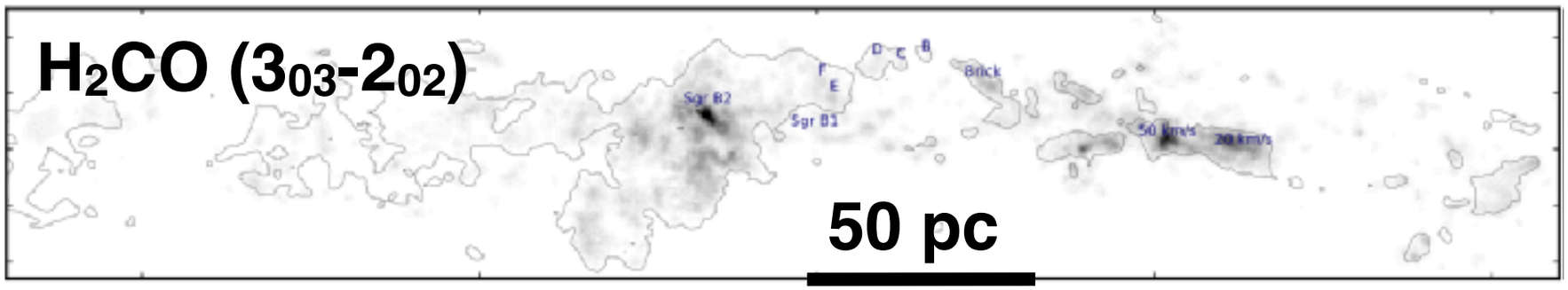
20 lines

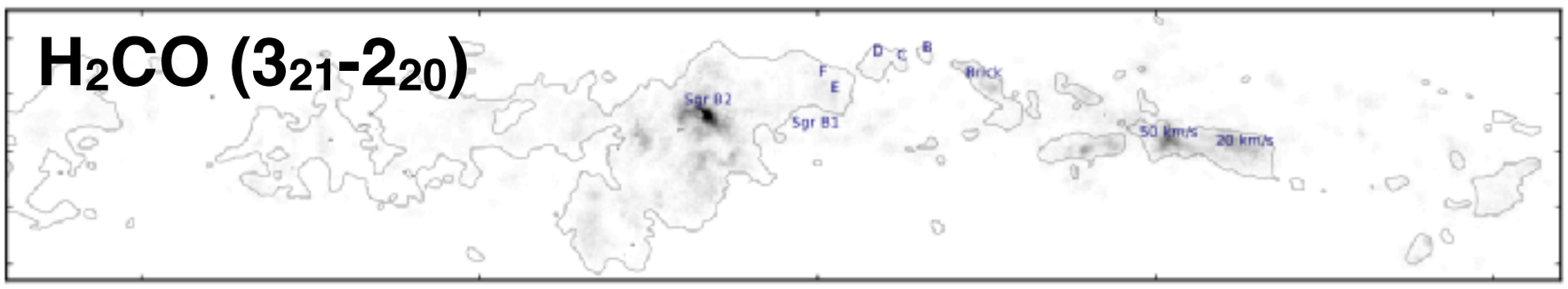
Jones et al. (2012)

MILLIMETER

1 mm / 220 GHz

30″
1.2 pc





11 lines

Ginsburg et al. (2016)

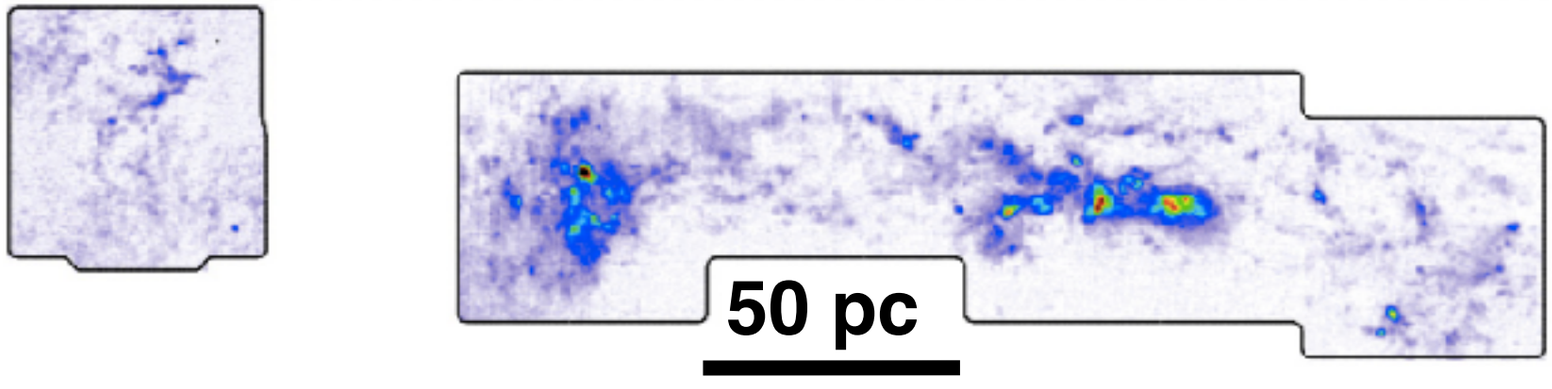
Also: SEDIGISM: a Galactic plane survey at 230 GHz

SUBMM

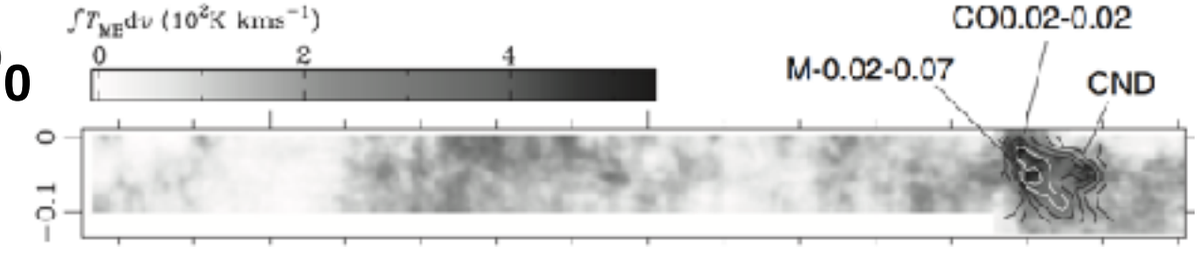
600-850 μm / 350-500 GHz

17/22″
0.7/0.9 pc

HCN
(4-3)



[CI] $^3P_1$-$^3P_0$



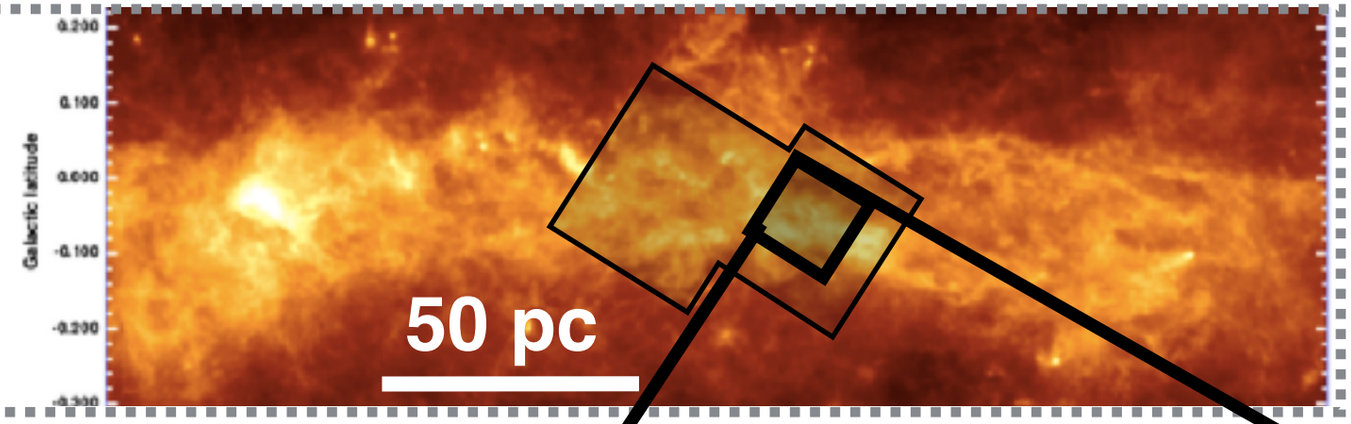
2 lines

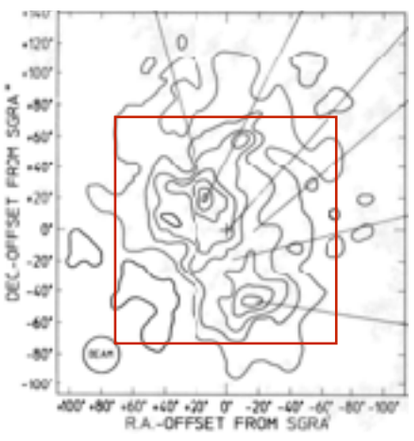
Tanaka et al.
(2011,2018)

FAR-IR

22″
0.9 pc

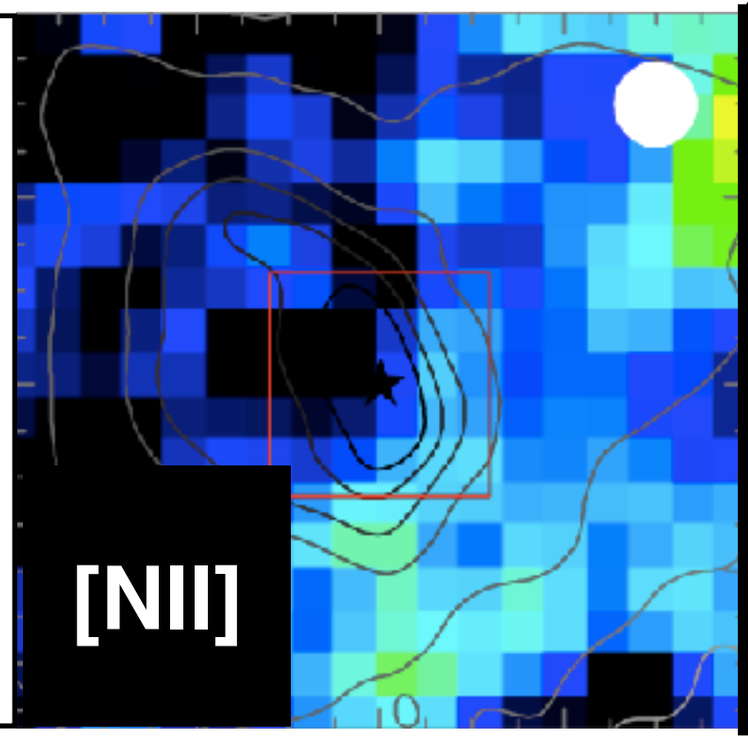
250 μm
continuum

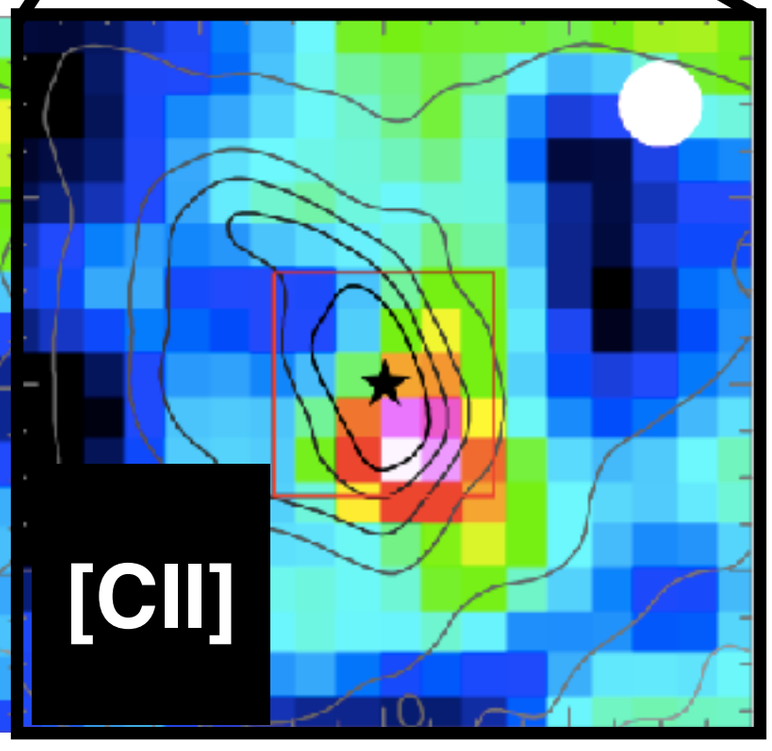




[OI]

Jackson et al. (1993)





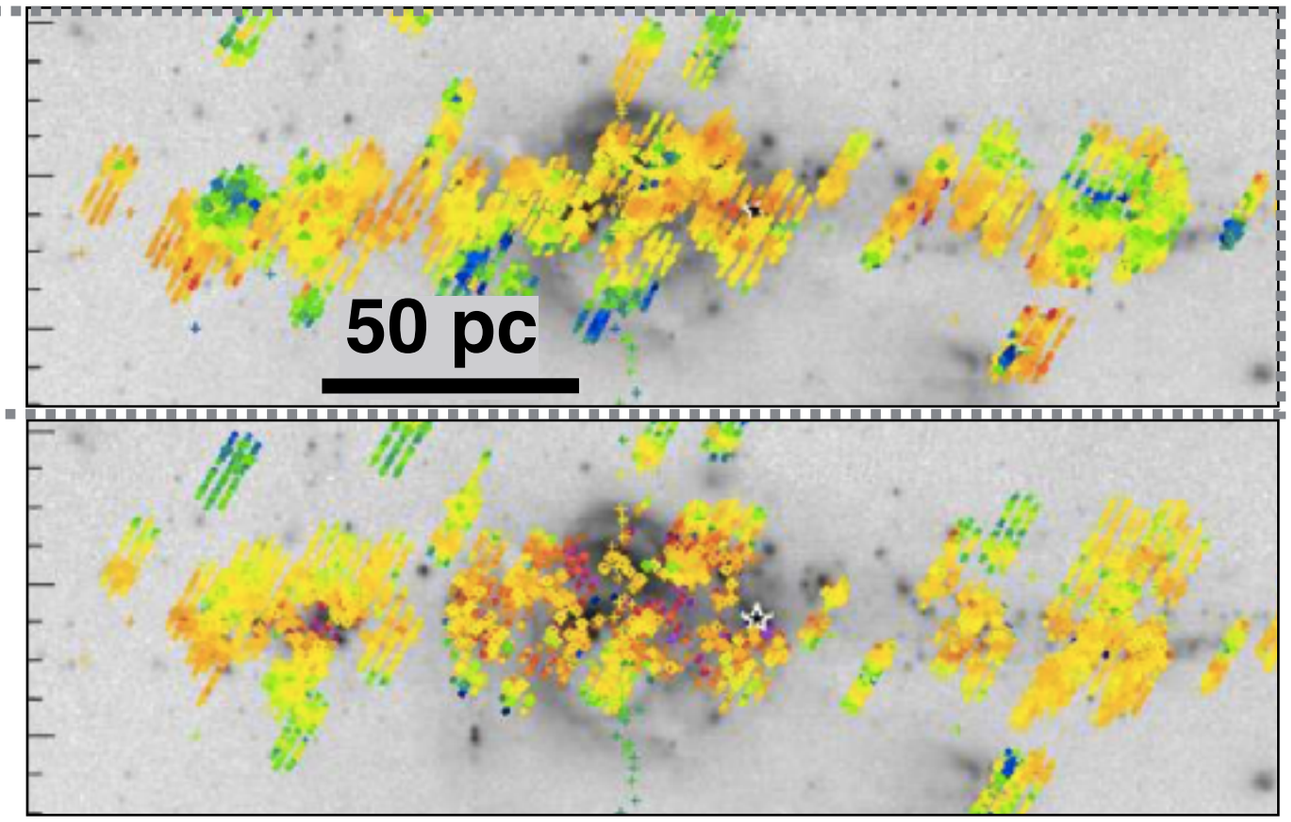
Garcia et al. (2016)

MID-IR

5-34 μm

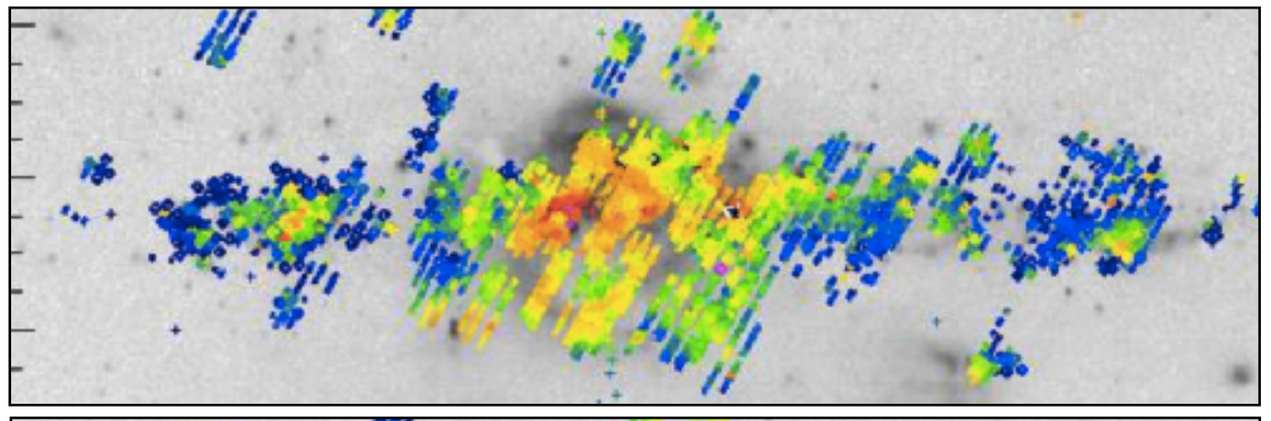
4-10″
0.1-0.4 pc

H_2 S(0)
28 μm

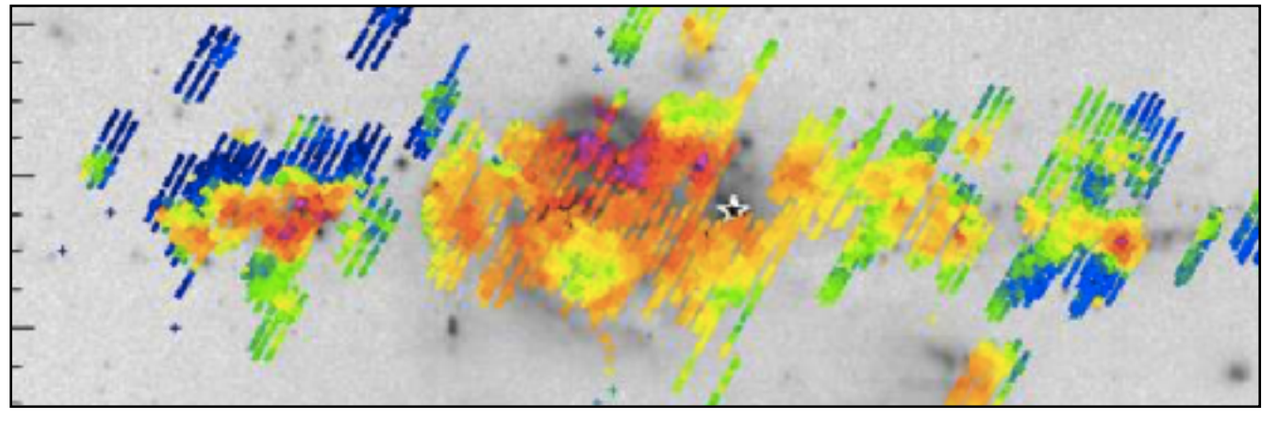


H_2 S(1)
17 μm

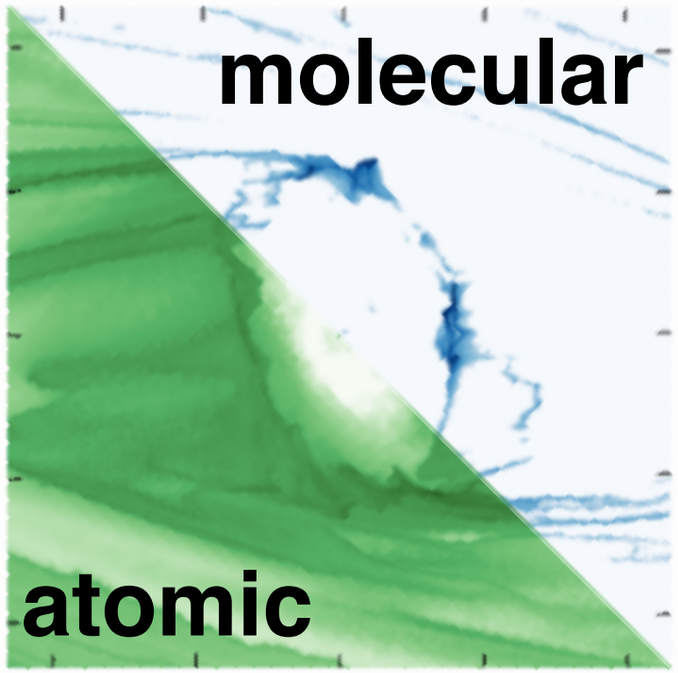
[Ne III]
15 μm

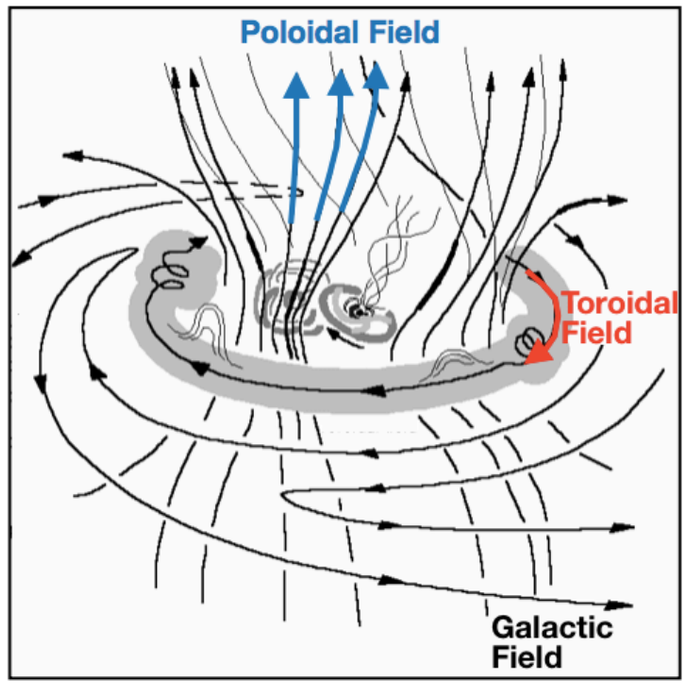


[S III]
33 μm

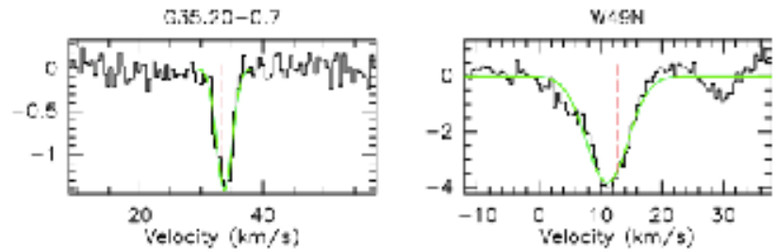


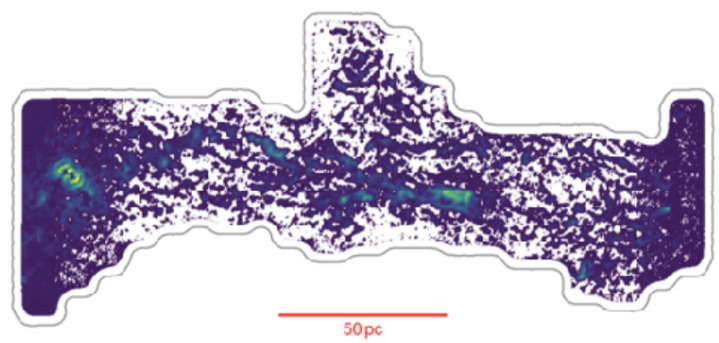
26 lines
Simpson (2018)



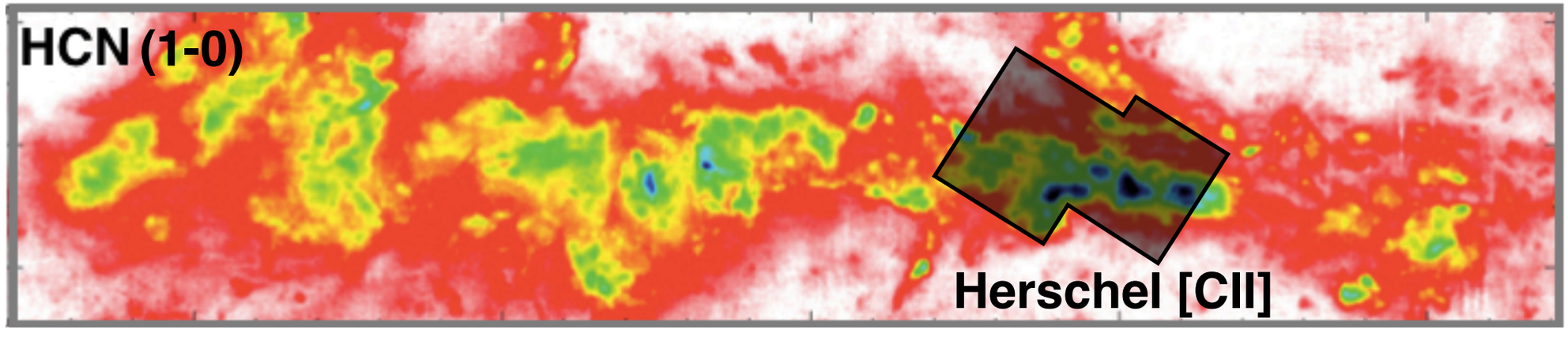


Sofue and Lang 1999





SOFIA can give us critical 3D information by tracing gas flows in the diffuse medium through atomic species, dust polarization, and absorption profiles



To make the best comparisons with other galaxies and put these detailed studies in context, we need to be aiming to map areas >100's pc in size

Cautions for the future:

- Small groups and Instrument teams have dominated SOFIA Galactic center science.
- These teams lack diversity.
- These teams often lack current/active domain experts, especially experts in current theoretical work & other wavelengths.
- While SOFIA has limited time to observe the Galactic center, a lot of Galactic center data has still not been published.

SOFIA's full impact in this area has not been realized.

Future instrument calls must emphasize large, diverse science teams and facilitate increased community access.