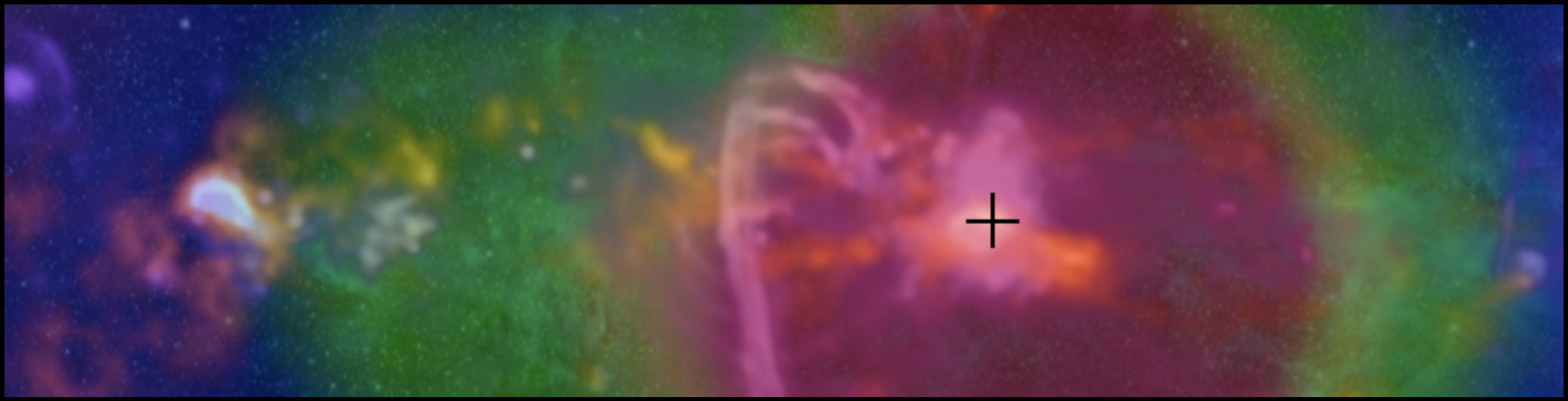
From Low to High Energy: Current frontiers in the Galactic center

10.18.18

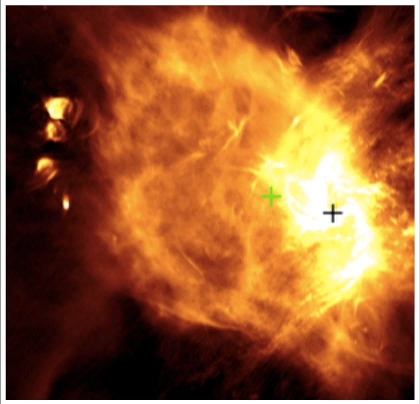
Fermi Symposium

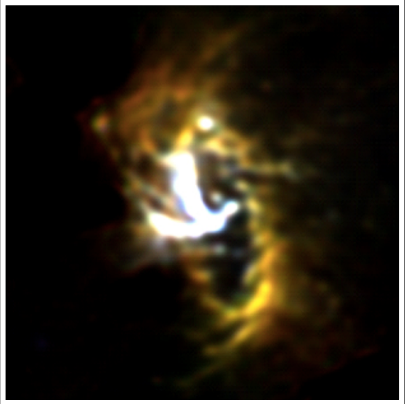
Elisabeth A.C. Mills (Brandeis University)

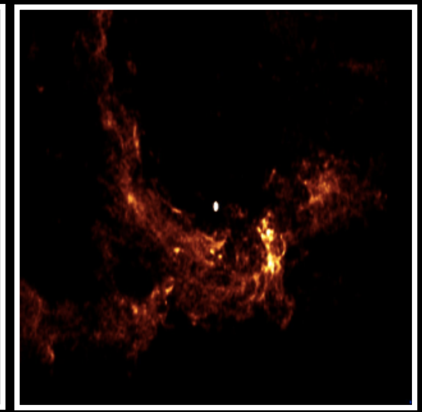
Introduction: The Galactic center environment

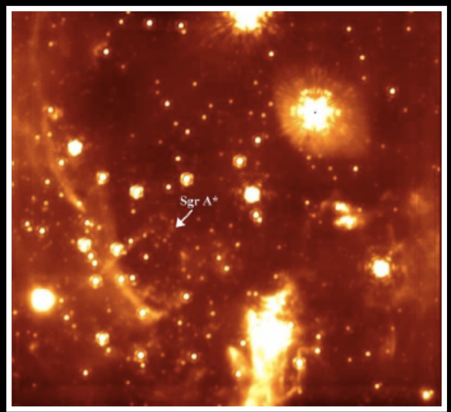


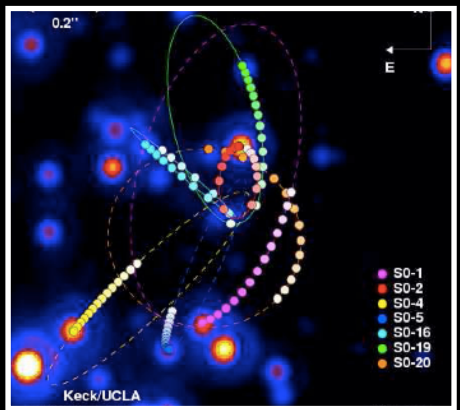
What are the physics that govern conditions in the ISM?

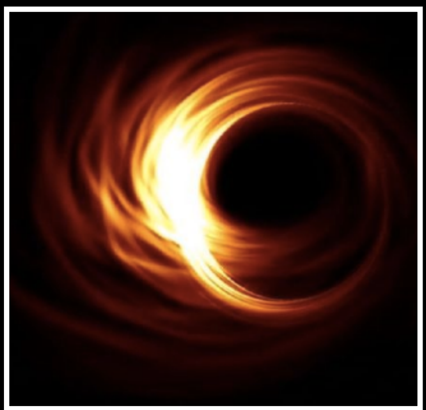




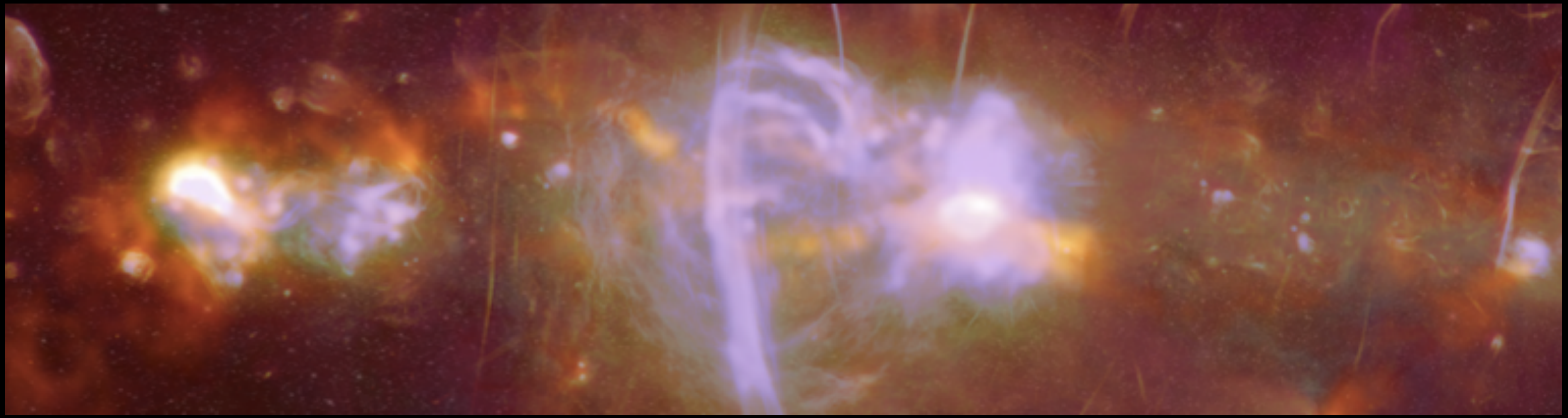








What is the 3D distribution of the ISM?



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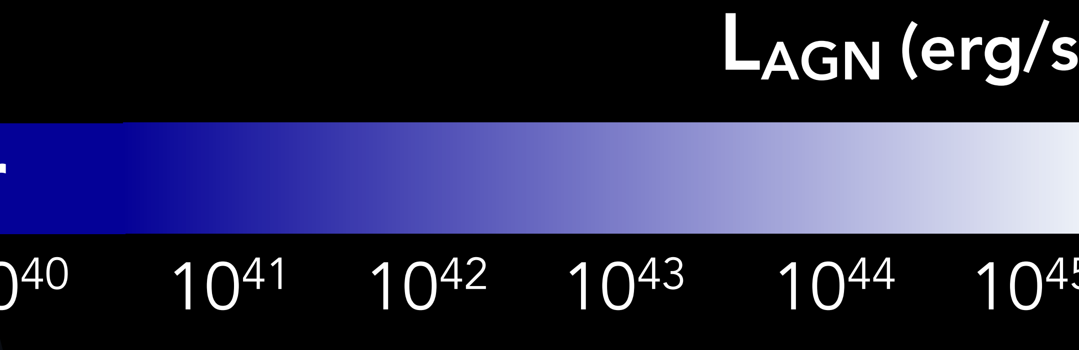
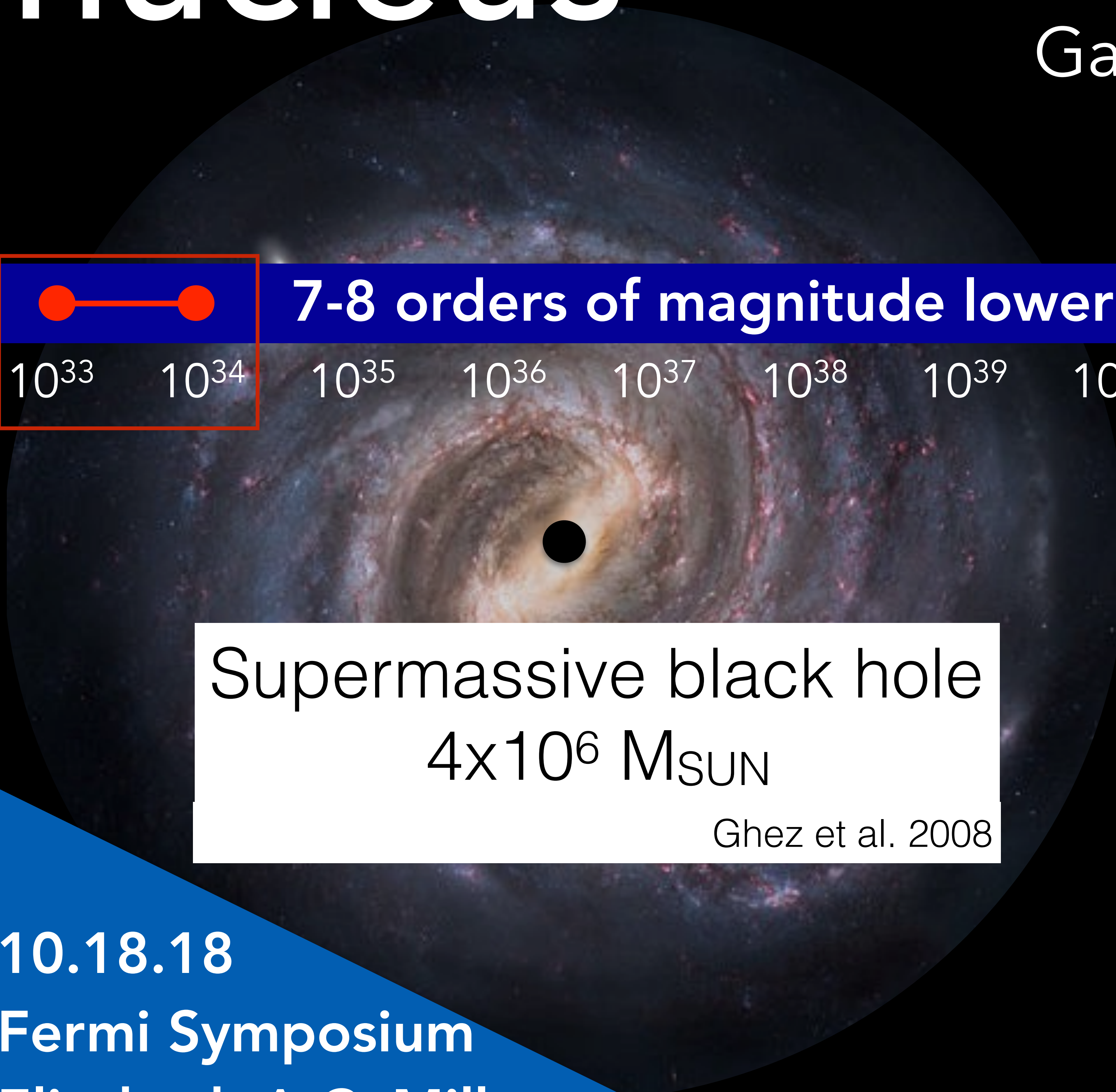
What is the magnetic field geometry?

The nearest galaxy nucleus

Galactic Center vs. Seyferts:





(range of Seyfert properties from a sample by Diamond-Stanic & Rieke 2012)

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The nearest galaxy nucleus

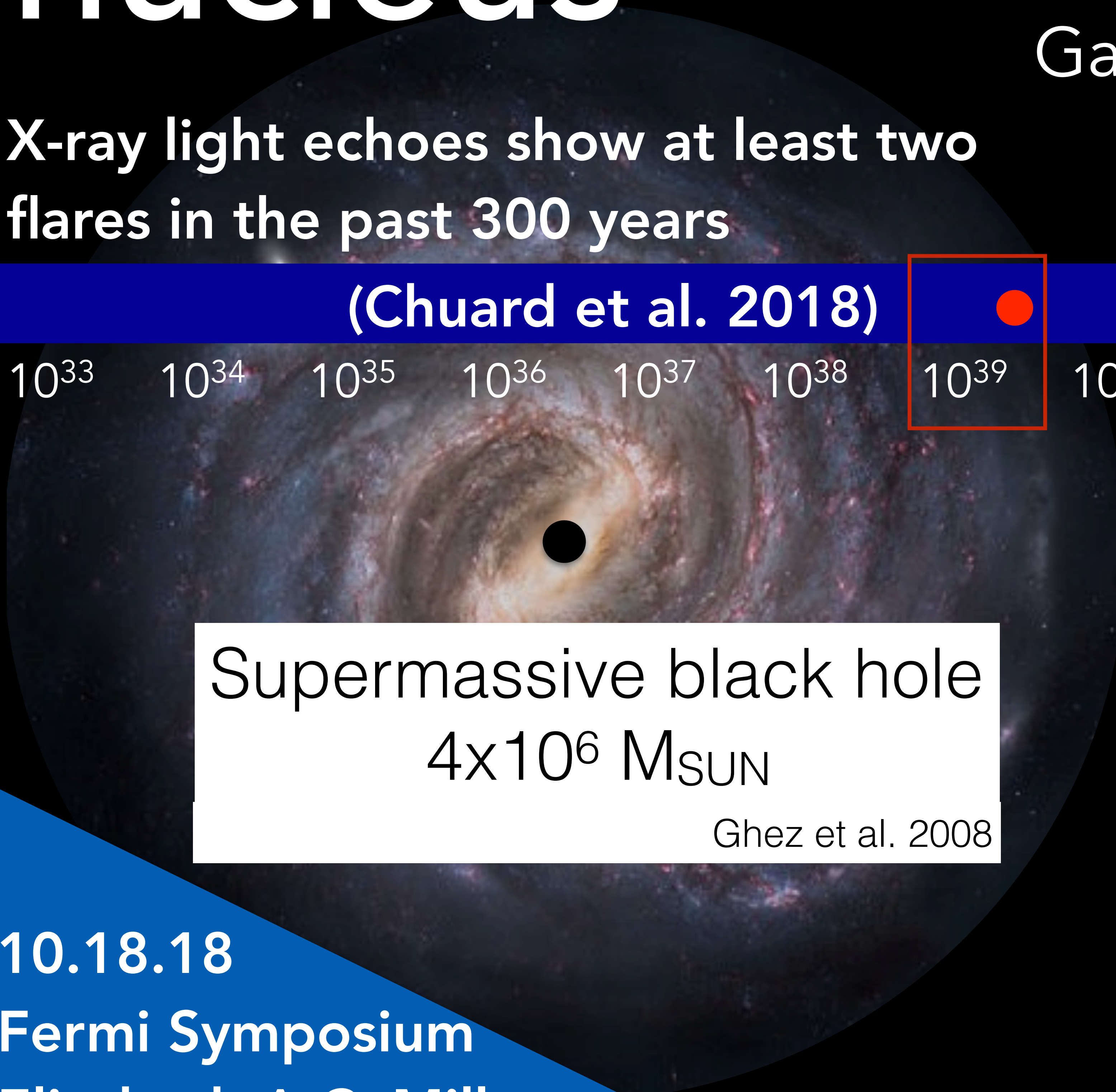
Galactic Center vs. Seyferts:

X-ray light echoes show at least two flares in the past 300 years

L_{AGN} (erg/s)

(Chuard et al. 2018)

10^{33} 10^{34} 10^{35} 10^{36} 10^{37} 10^{38} 10^{39} 10^{40} 10^{41} 10^{42} 10^{43} 10^{44} 10^{45}

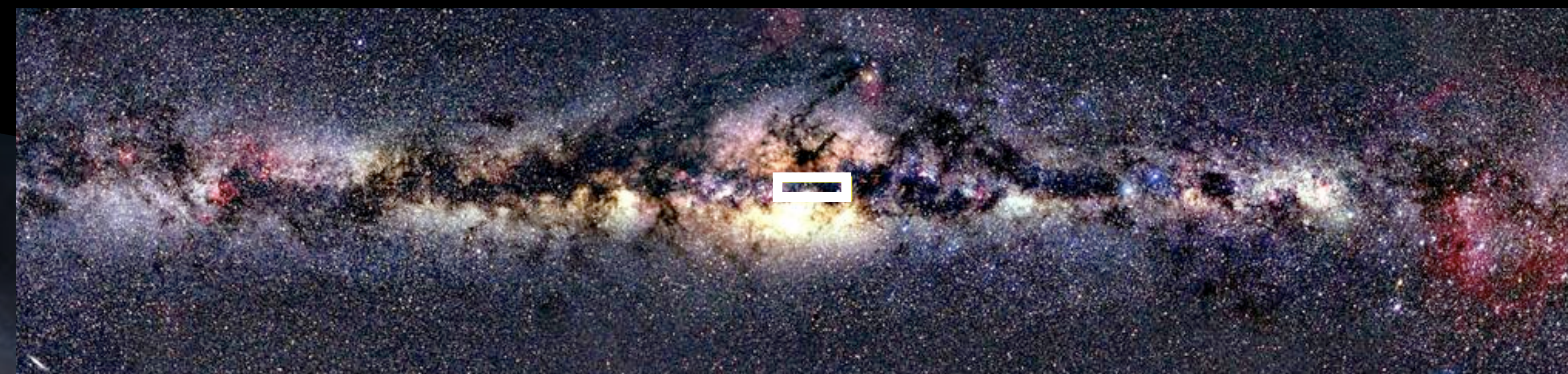


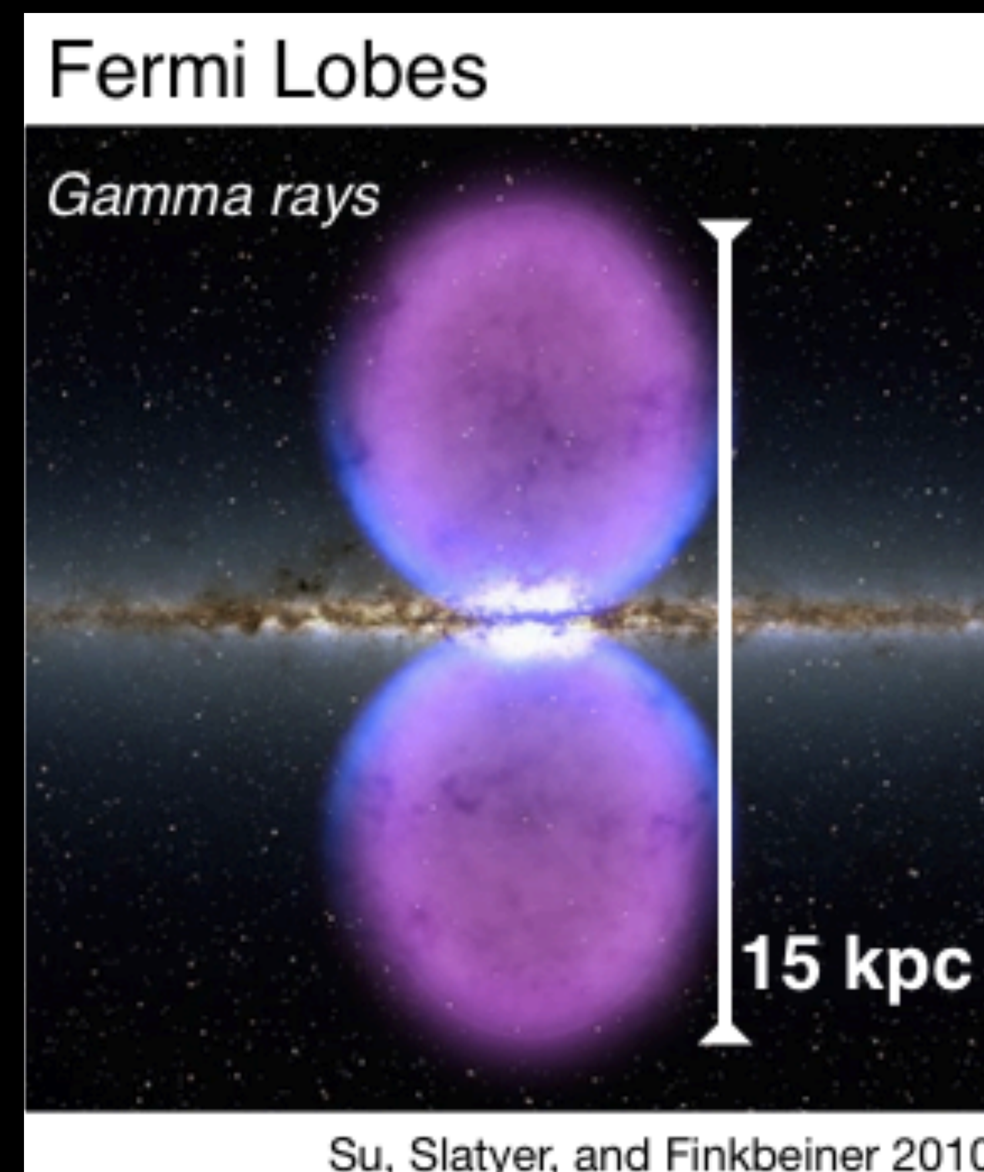
Supermassive black hole
4×10^6 M_{SUN}

Ghez et al. 2008

(range of Seyfert properties from a sample by Diamond-Stanic & Rieke 2012)

The nearest galaxy nucleus





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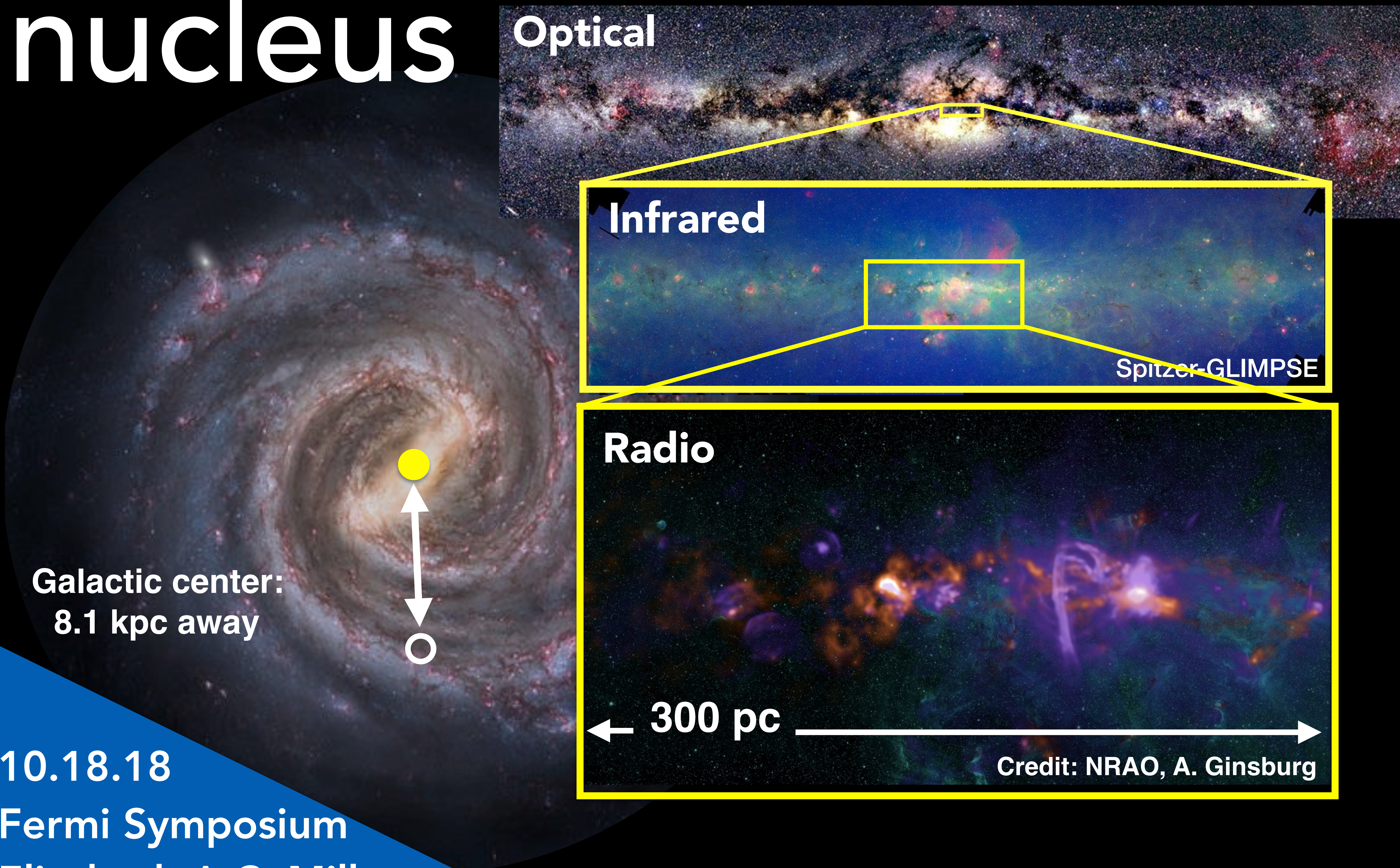
The nearest galaxy nucleus



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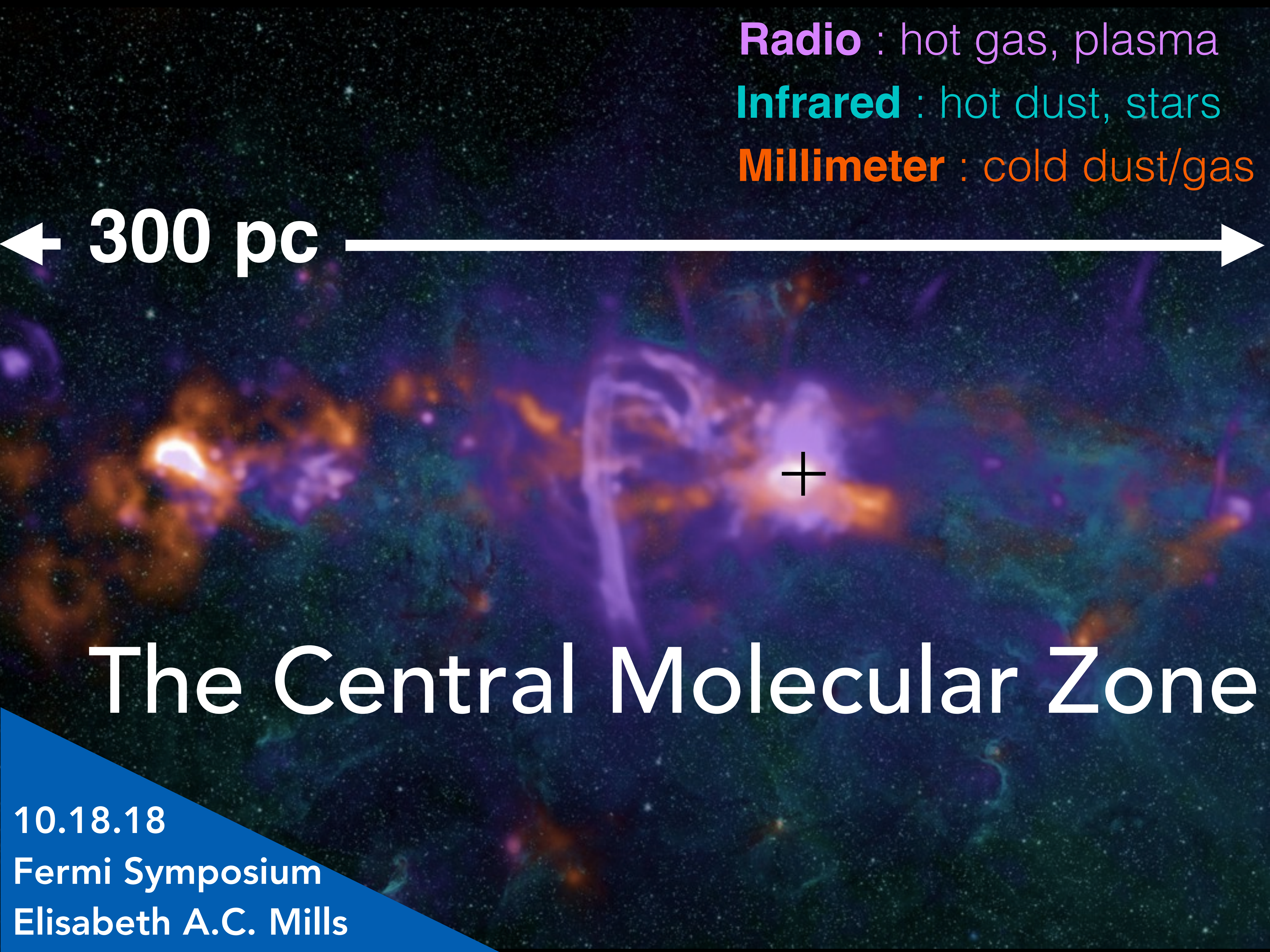

The Central Molecular Zone

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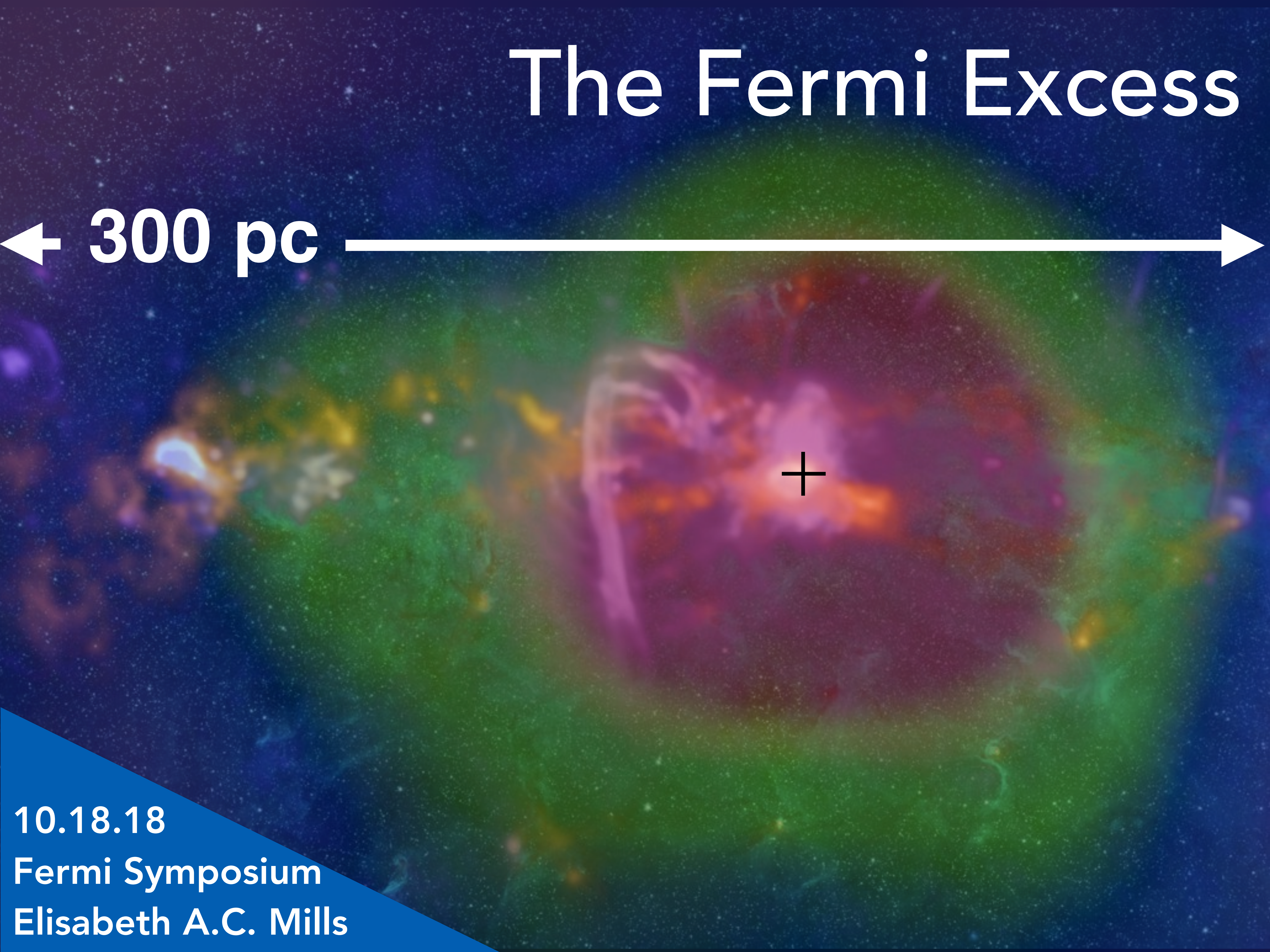
The Fermi Excess



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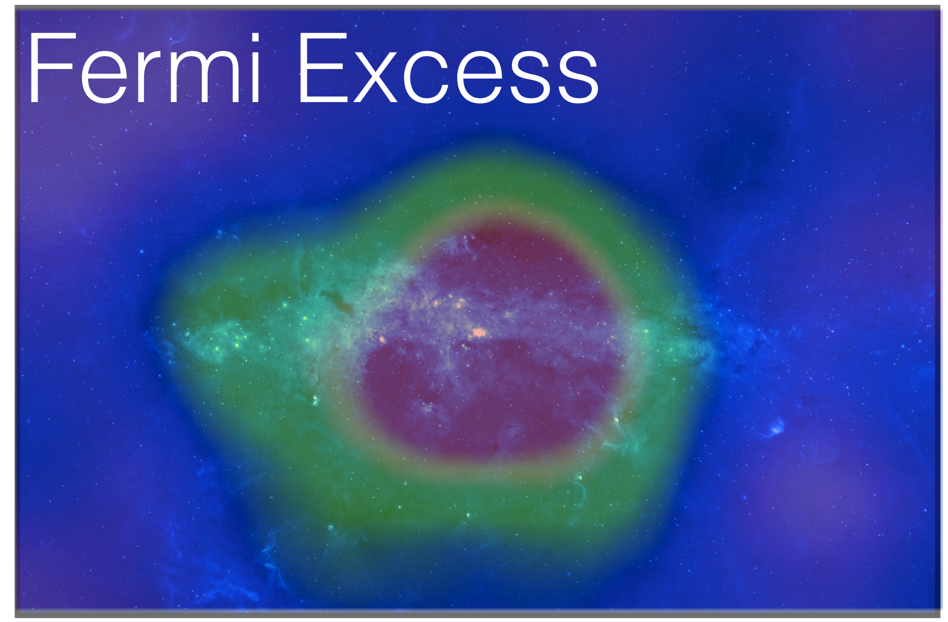
1×10^9 M$_{SUN}$ of stars

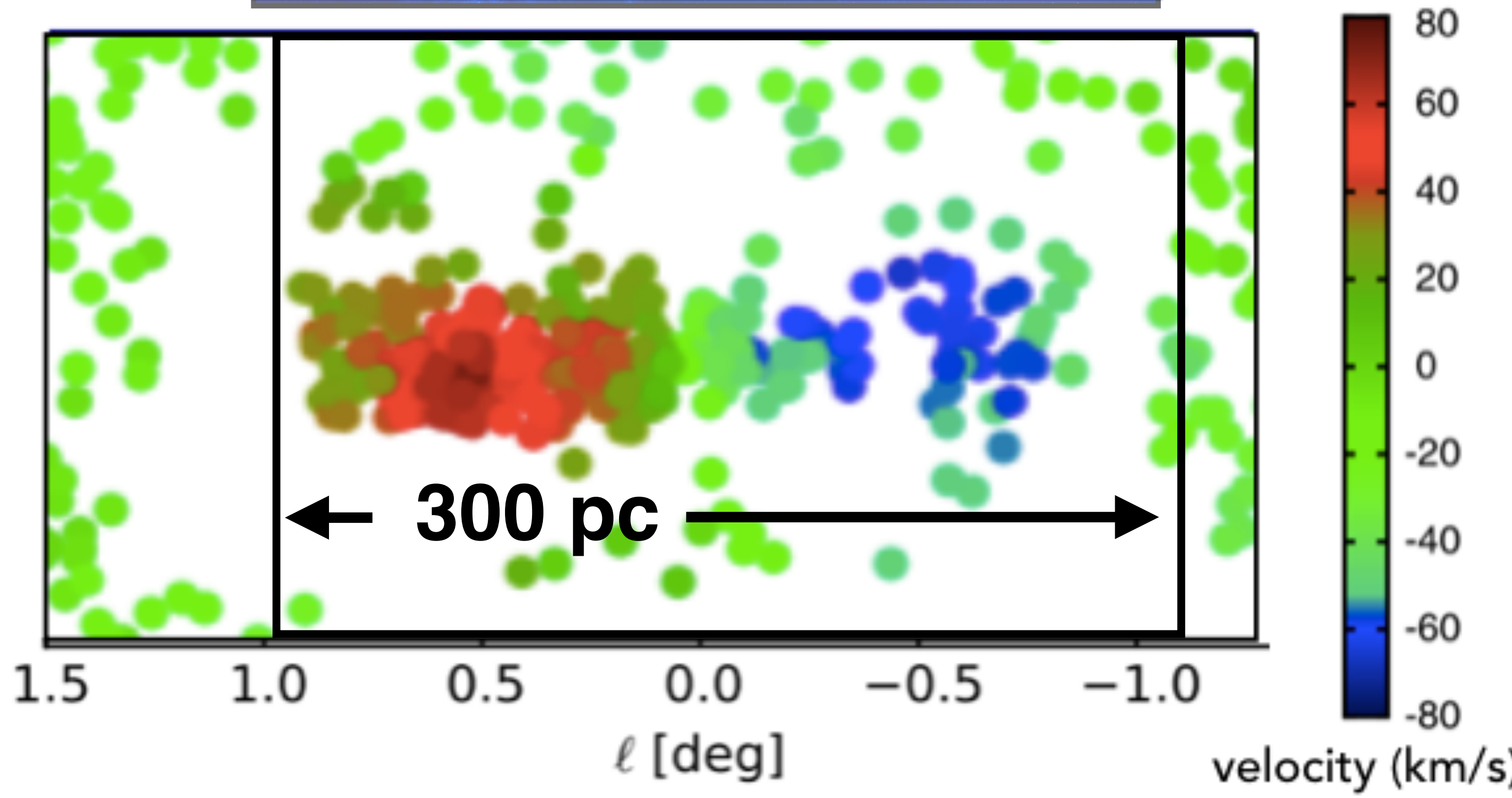
(Launhardt et al 2002)

Infrared : hot dust, stars

~2% of total Milky Way: 6×10^{10} M$_{SUN}$ of stars (McMillan 2011)

The Nuclear Stellar Disk





Schonrich et al. 2015 (APOGEE)

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0.05-0.15 M_{SUN} yr^{-1} of new stars

(Launhardt et al 2002)

Radio : hot gas, plasma

3-10% of total Milky Way:
1.45-2 M_{SUN} yr^{-1} of new stars

(Robitaille & Whitney 2010, Chomiuk & Povich 2011, Licquia & Newman 2015)

Star formation rate

IRAS: **0.08 M_{SUN}/yr**
(Crocker et al. 2011)

WMAP: **0.06 M_{SUN}/yr**
(Longmore et al. 2012)

24 µm: **0.07 M_{SUN}/yr**
(Yusef Zadeh 2009)

24 µm YSOs: **0.14 M_{SUN}/yr**
(Yusef Zadeh 2009)
(**0.05 M_{SUN}/yr**, Koepferl et al. 2015)

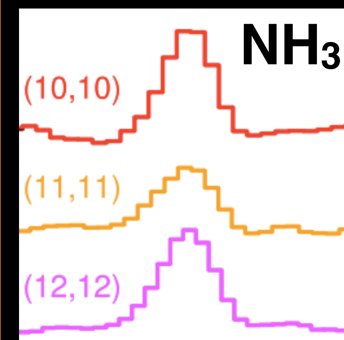
3x10^7 M_{SUN} of molecular gas

(Dahmen et al 1998)

~4% of total Milky Way: 8x10^8 M_{SUN} of stars (Nakanishi & Sofue 2006)

Millimeter : cold dust/gas

Hot T= 50 -300 K



Galactic Disk: T~10-20 K

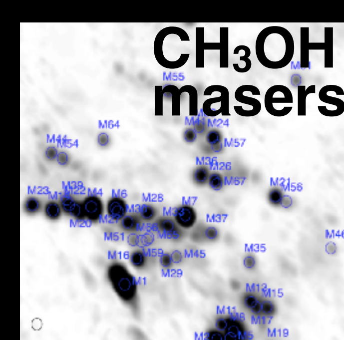
Mills + Morris 2013

Dense n > 10^3 -10^6 cm^{-3}

Galactic Disk: n~10^2 cm^{-3}

Mills et al. 2013, Mills et al. 2018

Turbulent Δv~15-50 km s^{-1}



Galactic Disk: Δv~2-5 km s^{-1}

Mills et al. 2015

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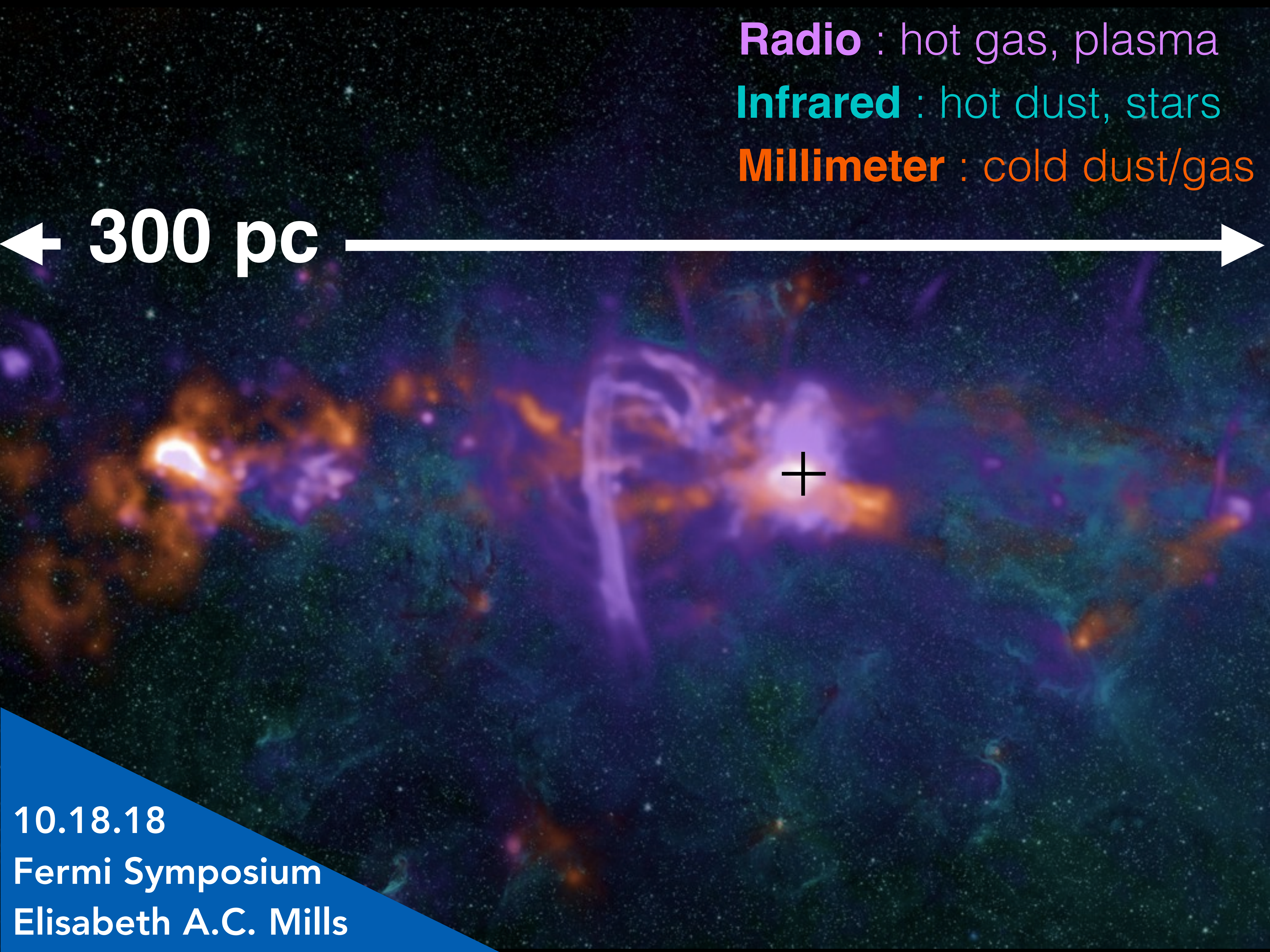
Radio : hot gas, plasma
Infrared : hot dust, stars
Millimeter : cold dust/gas
300 pc
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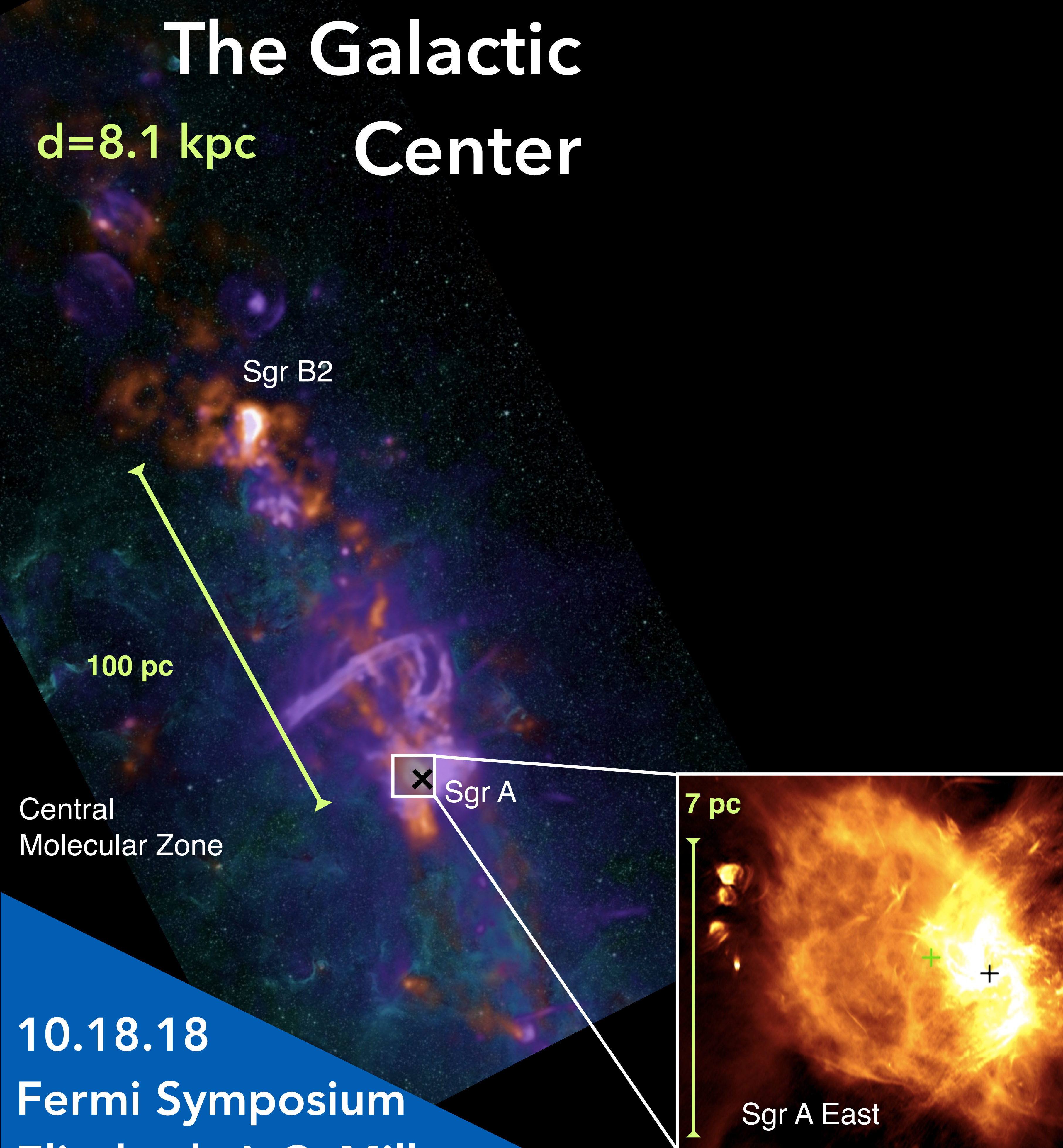
The Galactic Center



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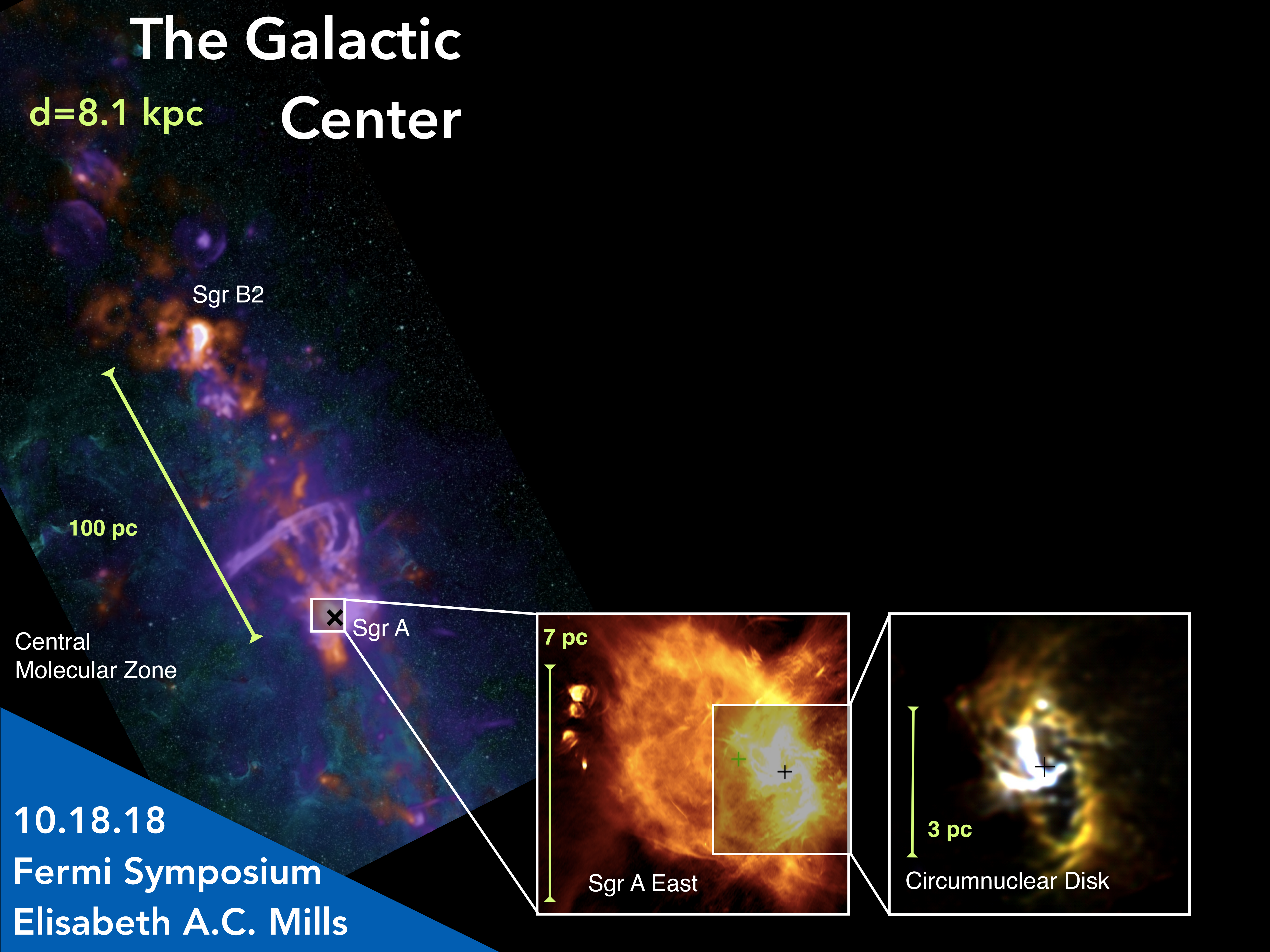
The Galactic Center
d=8.1 kpc
Sgr B2
100 pc
Sgr A
Central
Molecular Zone
7 pc
Sgr A East
3 pc
Circumnuclear Disk
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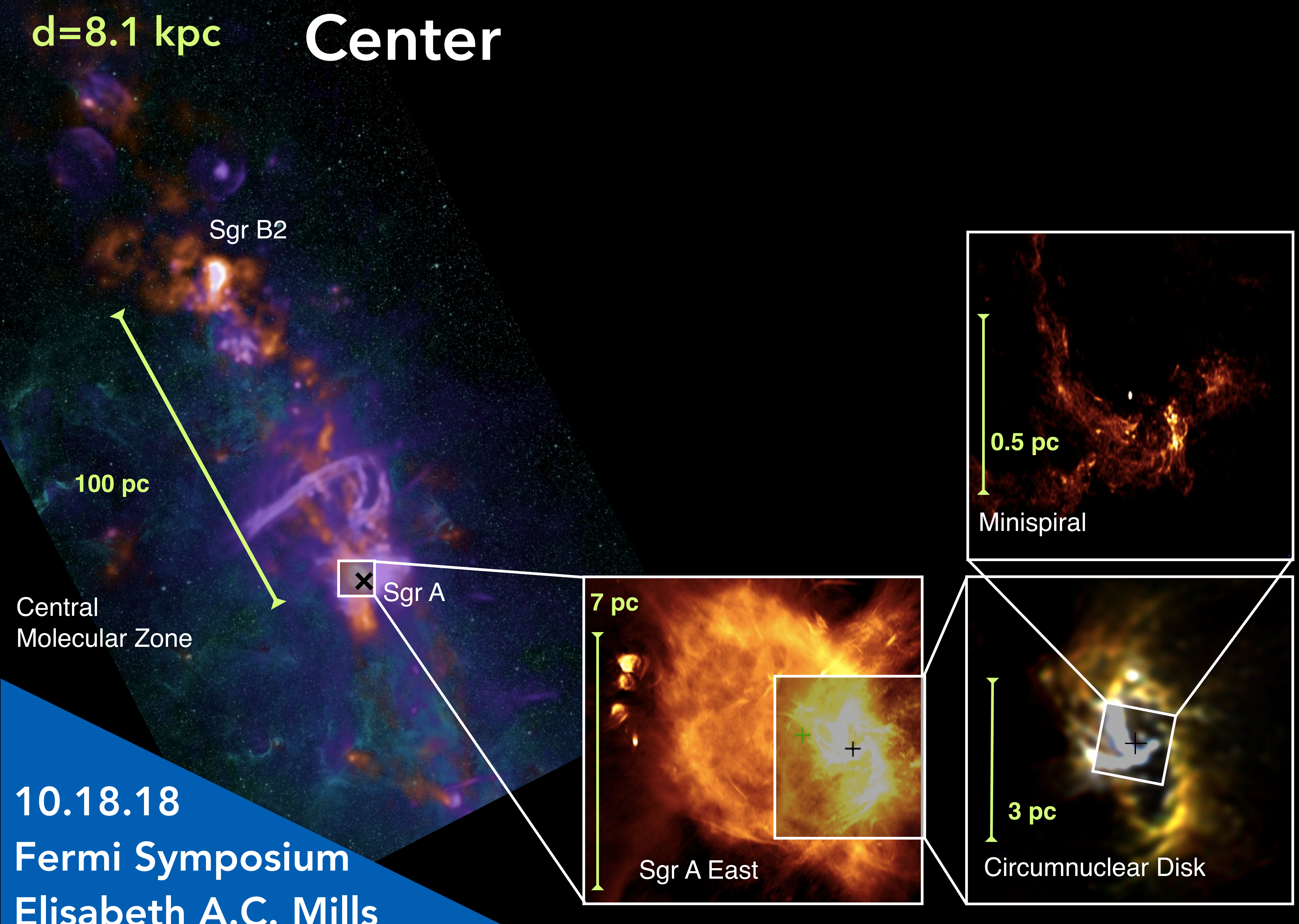
The Galactic Center



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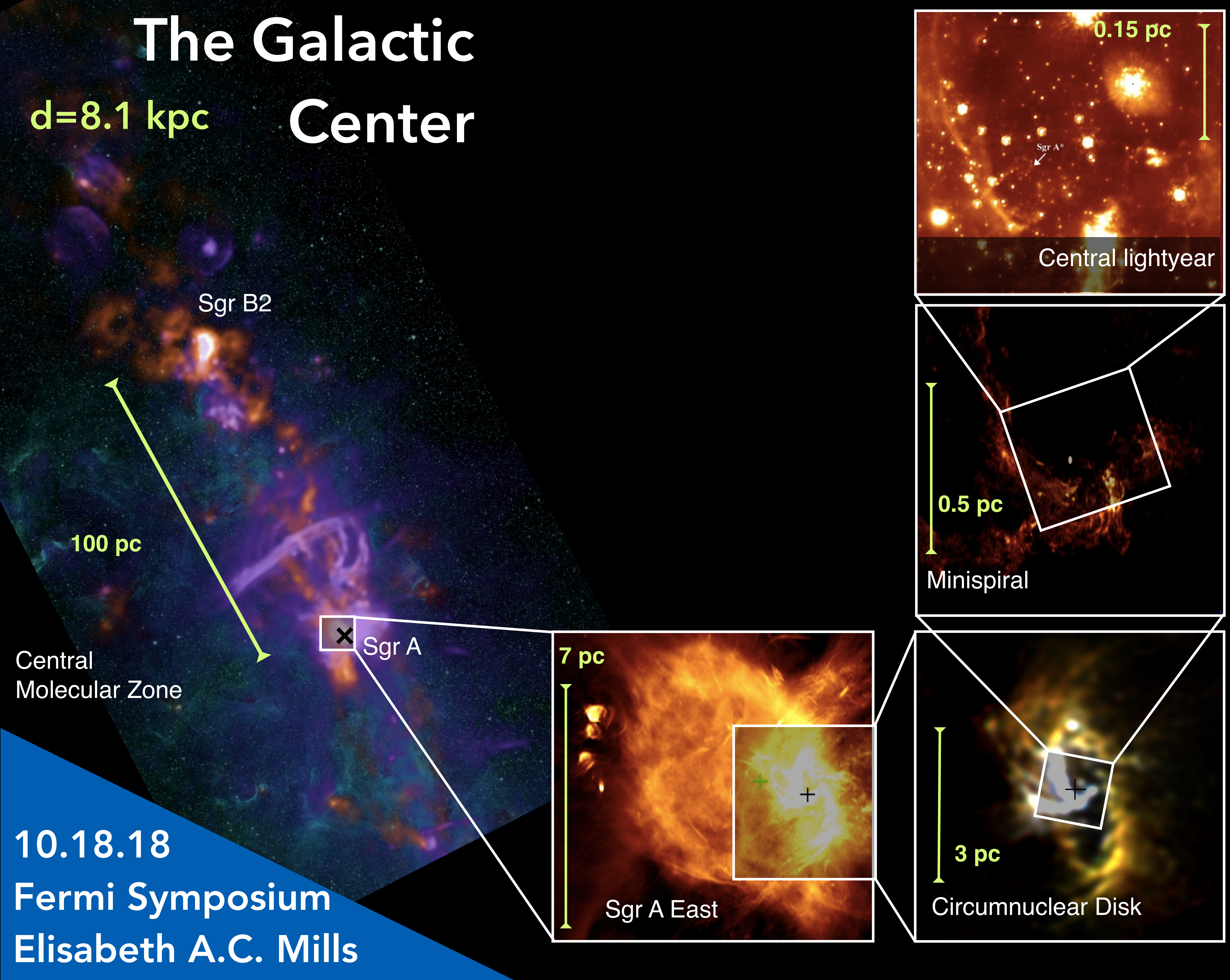
The Galactic Center



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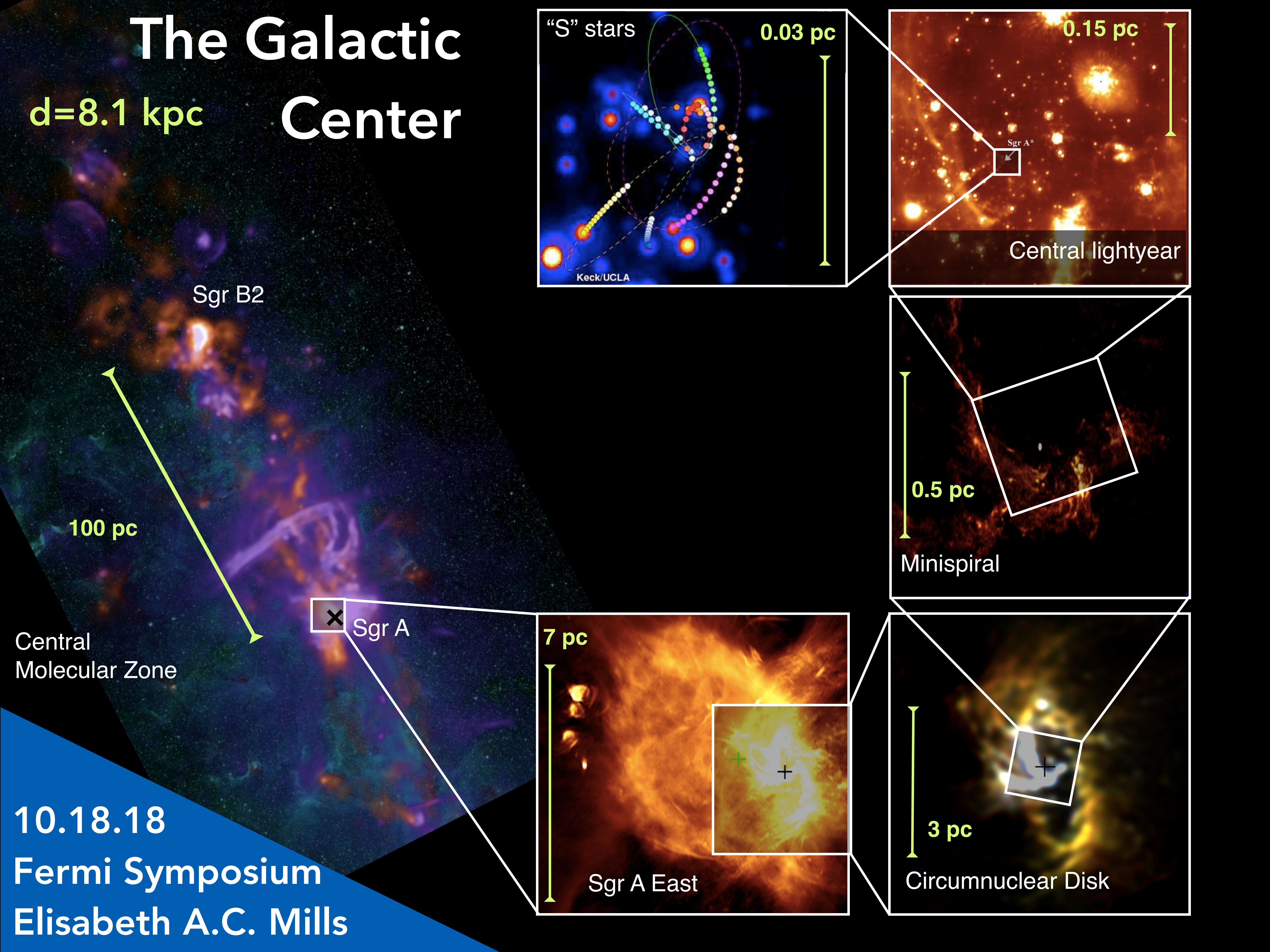
The Galactic Center



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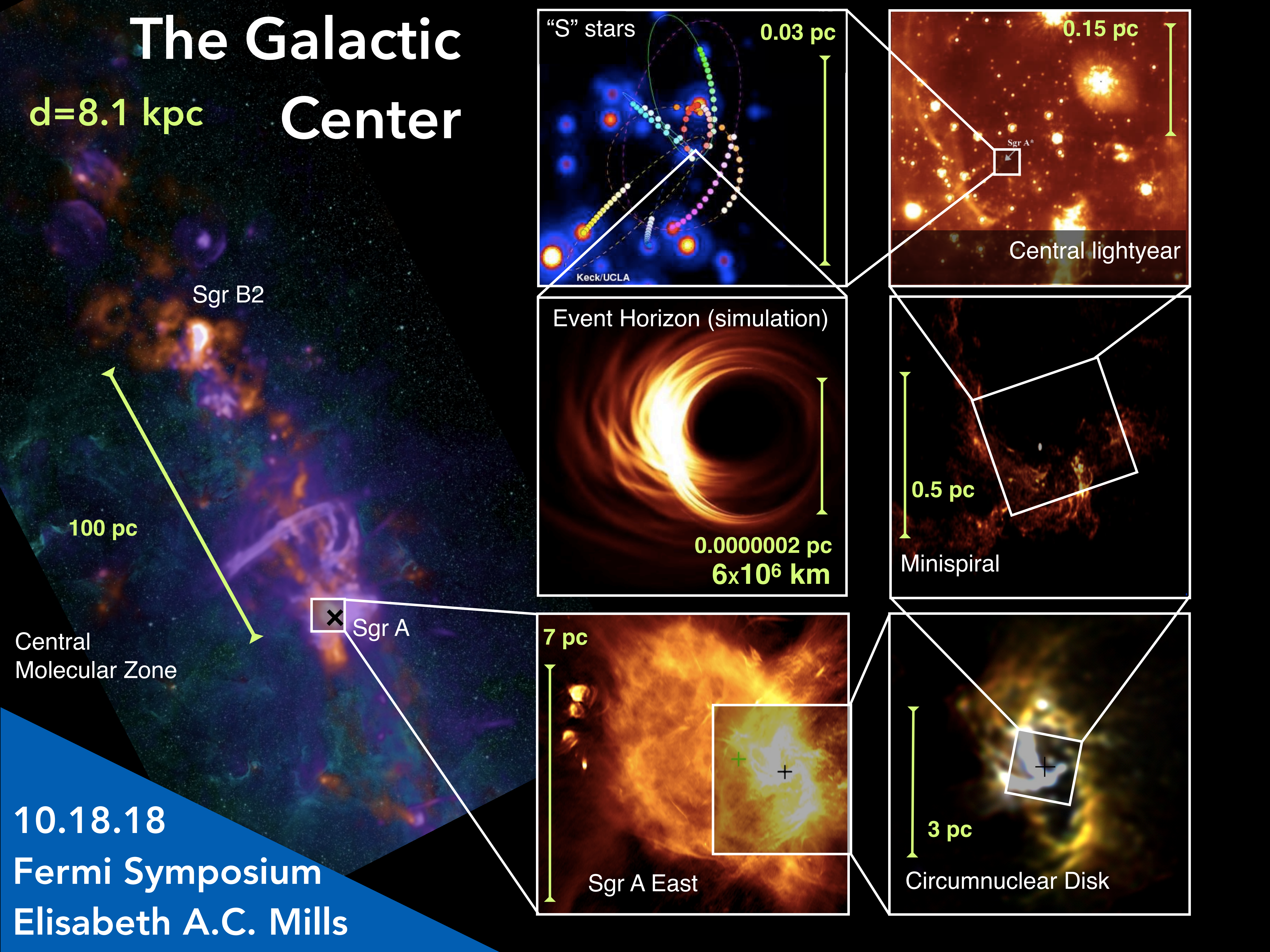
The Galactic Center
d=8.1 kpc
Sgr B2
100 pc
Sgr A
Central Molecular Zone
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"S" stars
0.03 pc
Keck/UCLA
0.15 pc
Sgr A*
Central lightyear
Event Horizon (simulation)
0.0000002 pc
6x10^6 km
0.5 pc
Minispiral
7 pc
Sgr A East
3 pc
Circumnuclear Disk

What sets the gas properties - the journey or the destination?

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Cosmic Ray Heating?

Local CR ionization rate: $\zeta \sim 10^{-16}$ s^{-1} (Indriolo et al. 2014)

Galactic center estimates: $\zeta \sim 10^{-16}$ -10^{-13} s^{-1} (Goto et al. 2013, Harada et al. 2013, Yusef Zadeh et al. 2013c)

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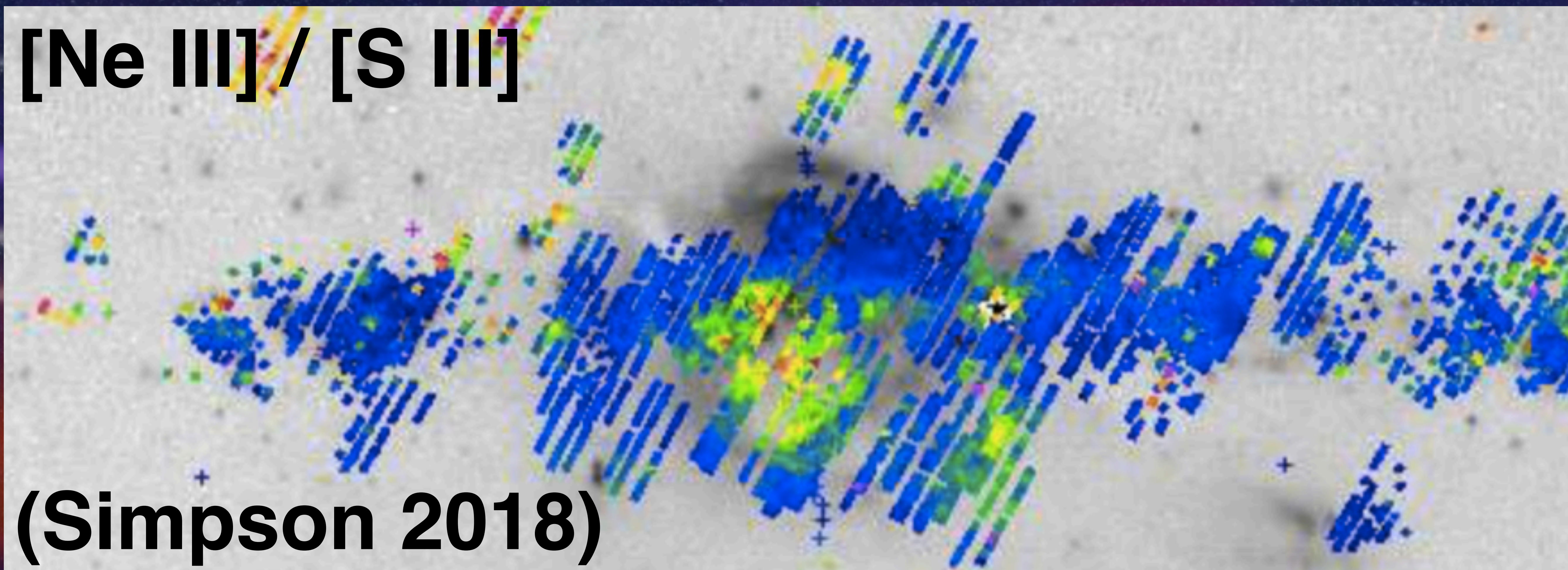
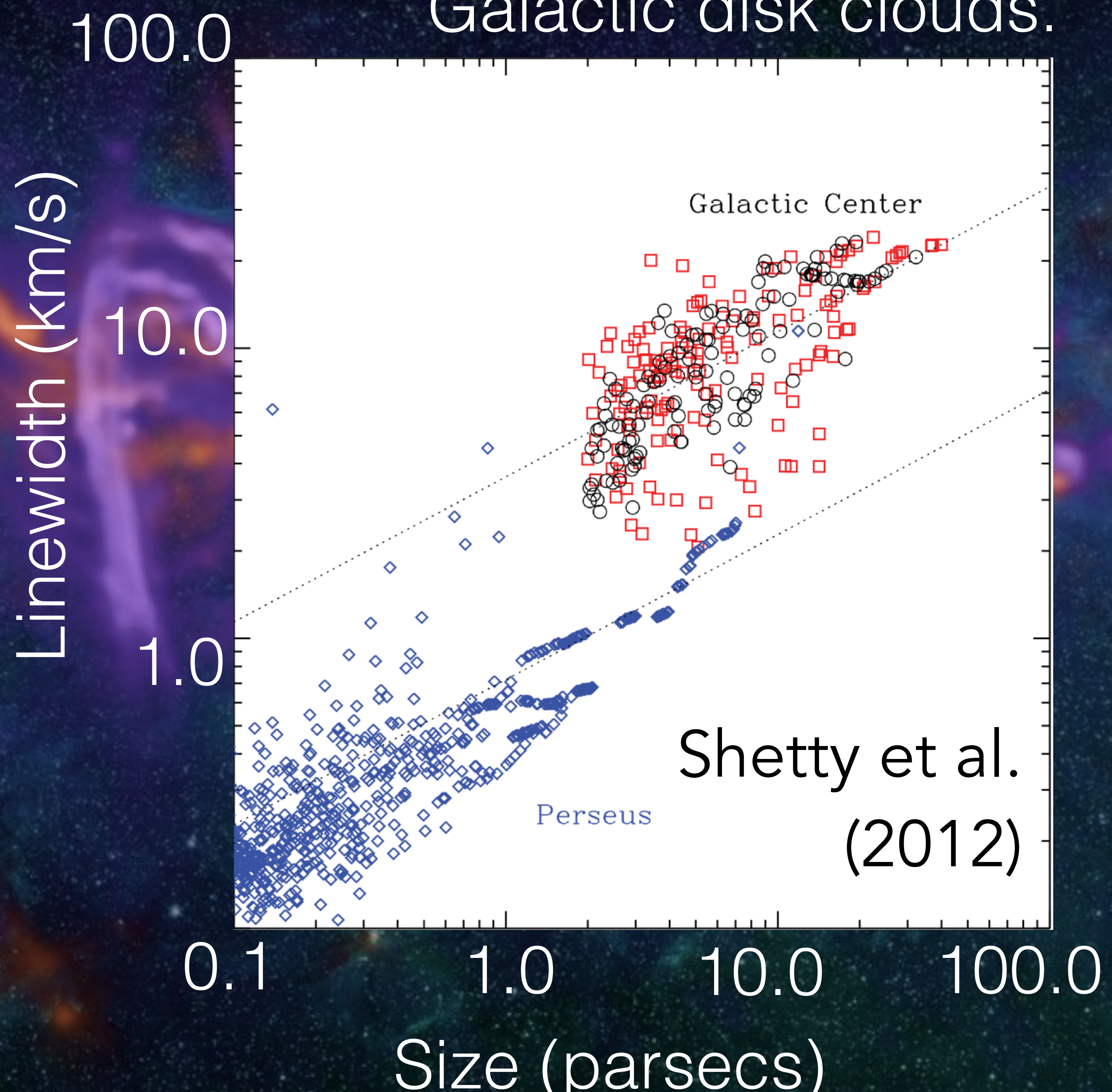


Diffuse HESS excess (Aharonian et al. 2006)

Shock Heating?

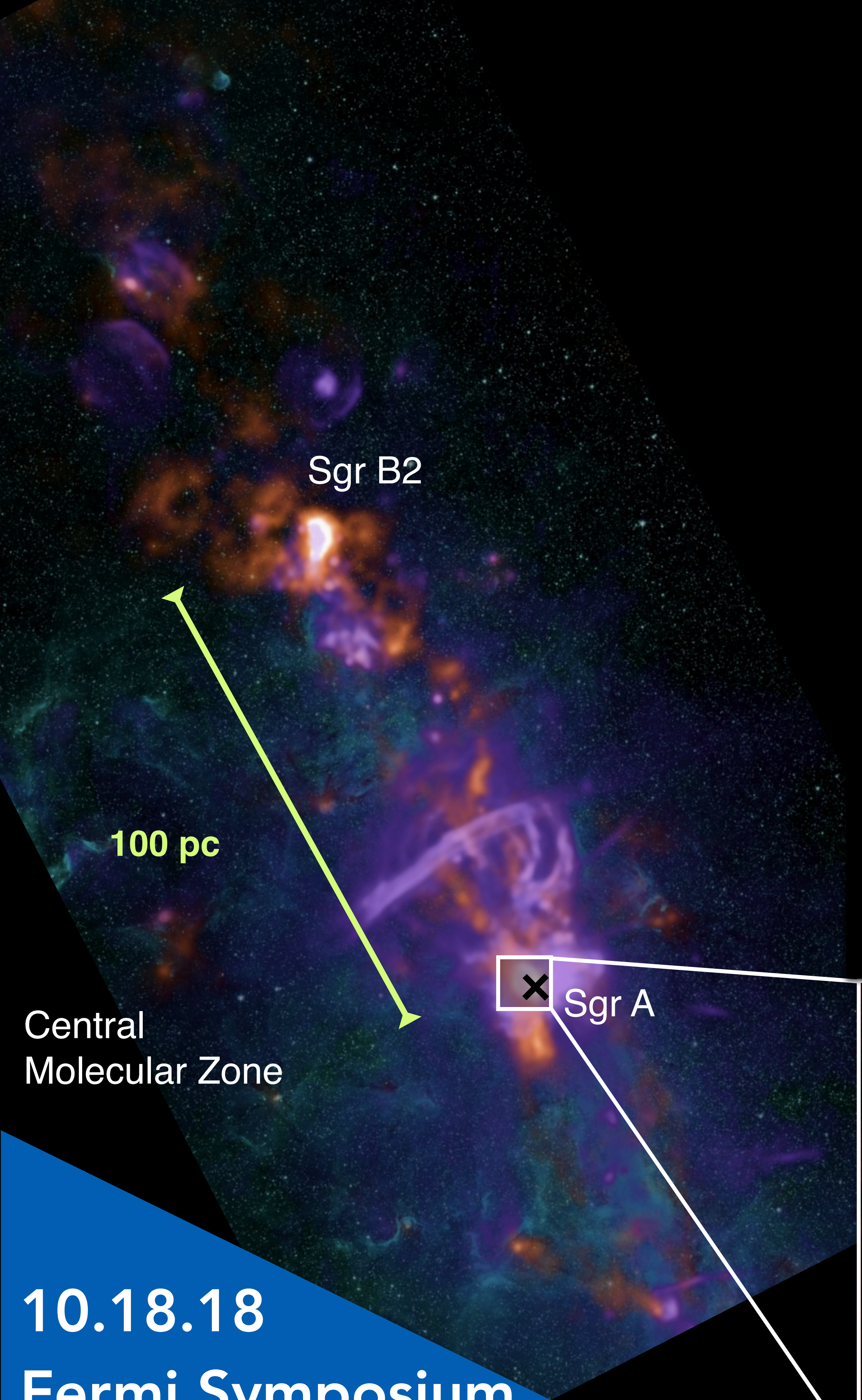
Galactic center clouds are more turbulent than Galactic disk clouds.

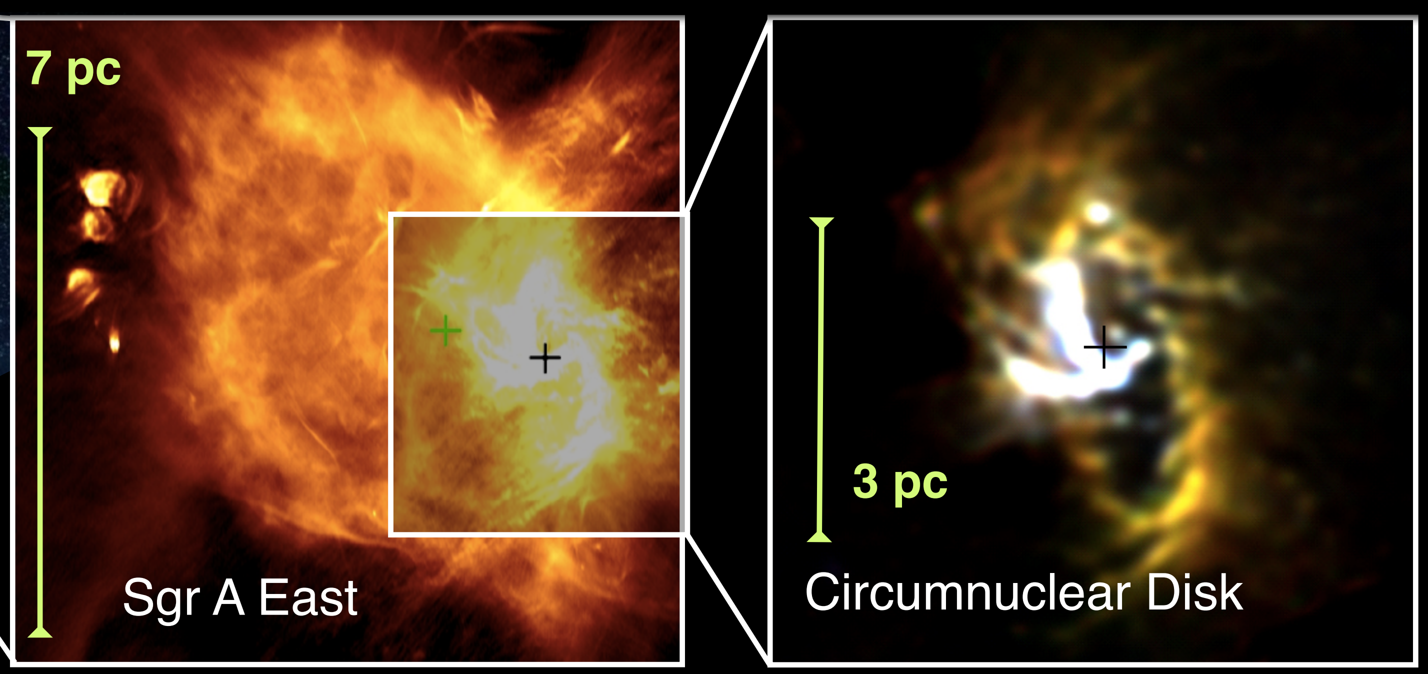


A larger fraction of warm H_2 is seen in the gas within 3 pc of the black hole, and gas at radii > 30 pc,

Favors radially-dependent heating driven by shocks.

(Mills et al. 2017b)





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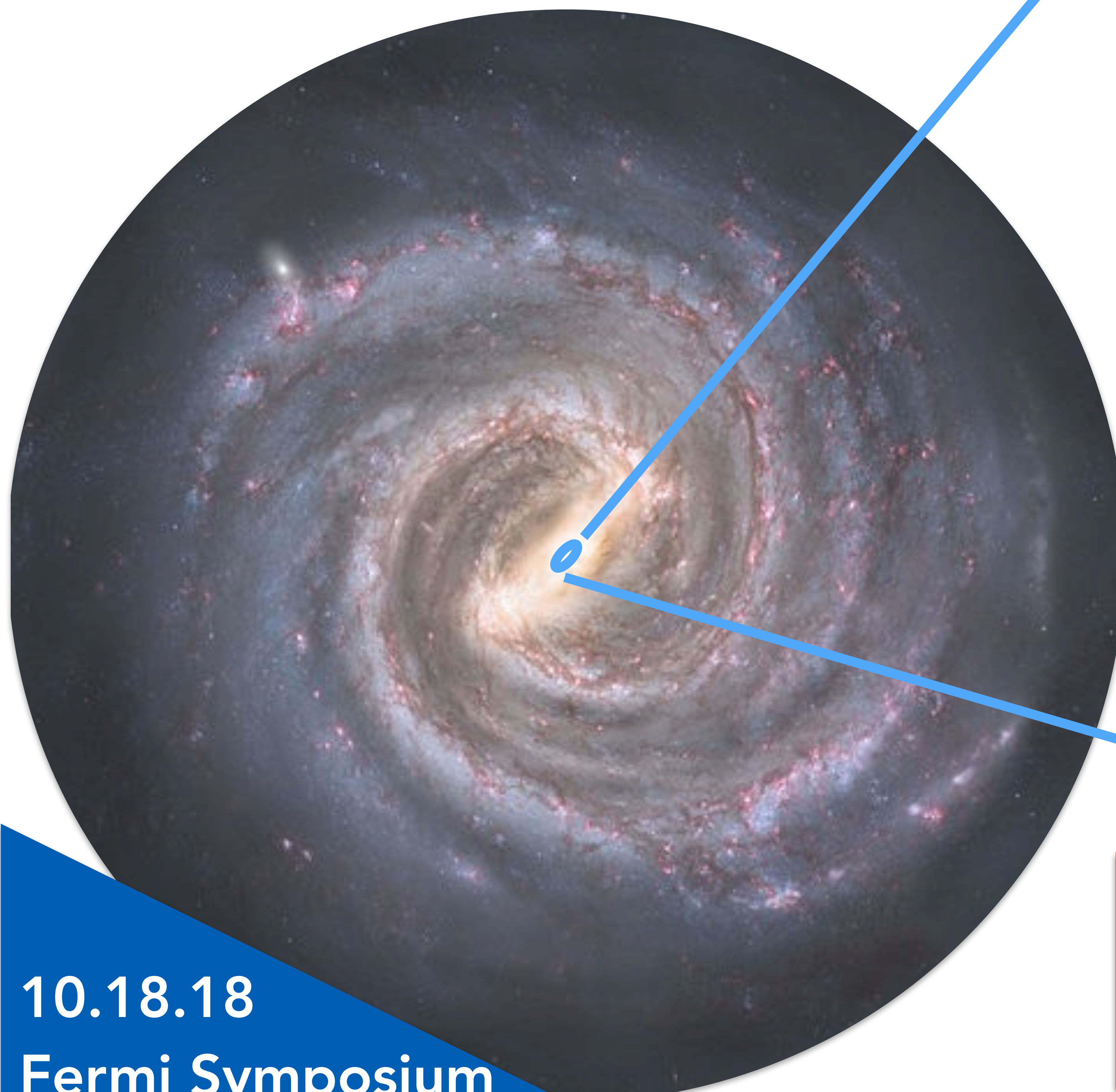
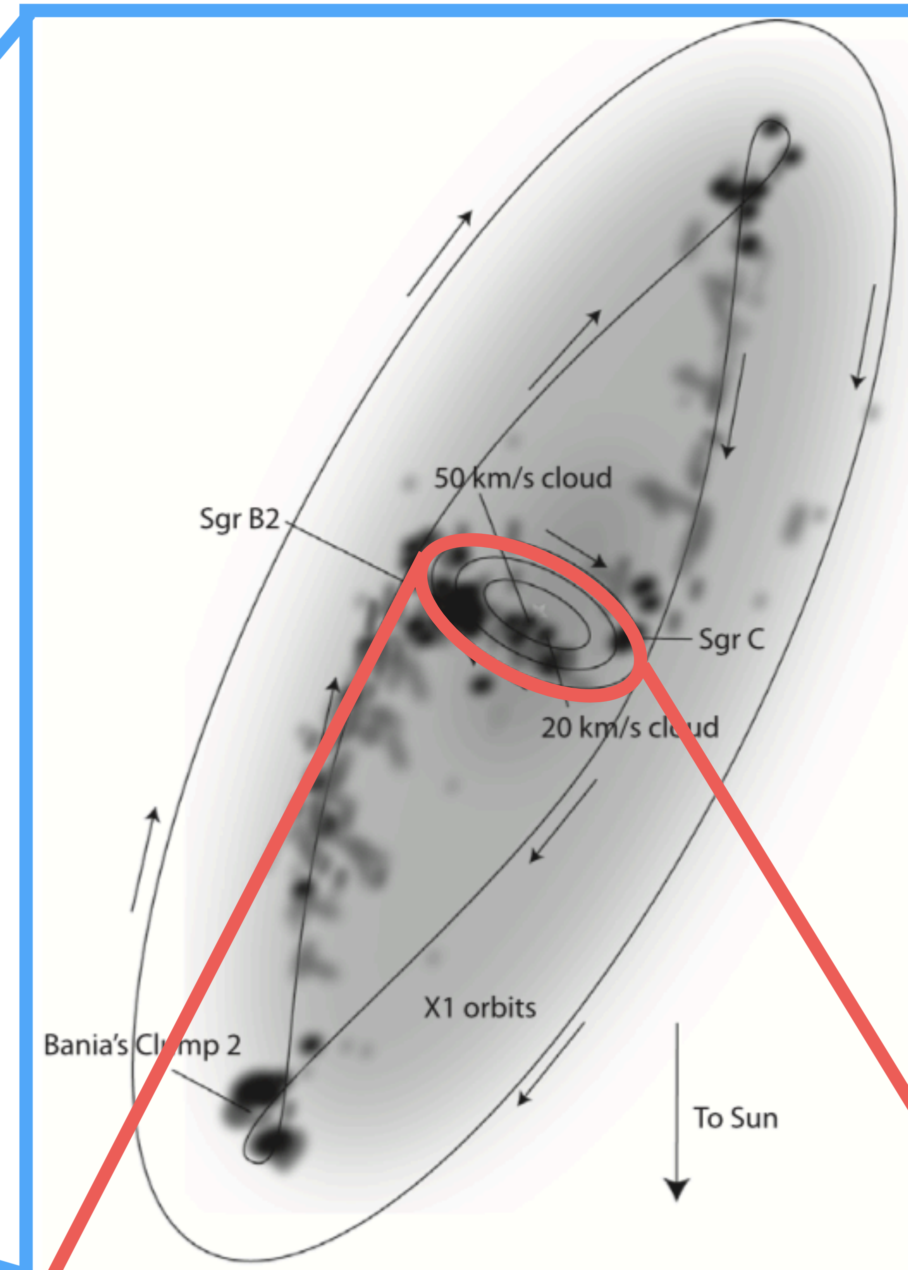
What is the 3D distribution of the gas?

Our point of view makes this complicated.

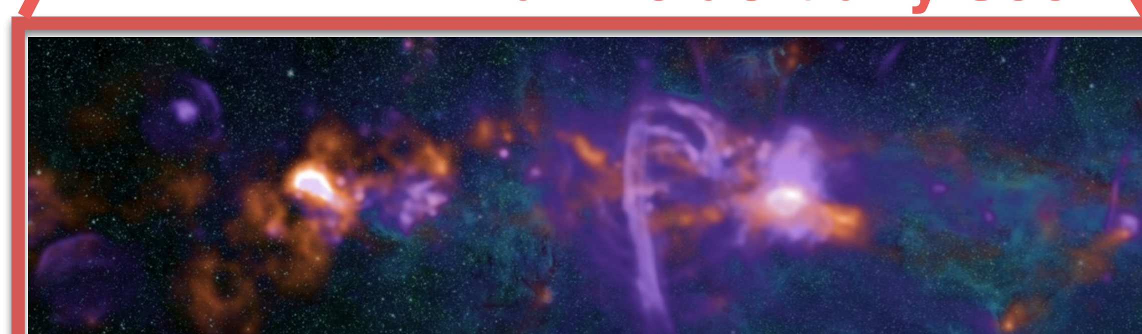


what we wish we could see



1 kpc

what we actually see



200 pc

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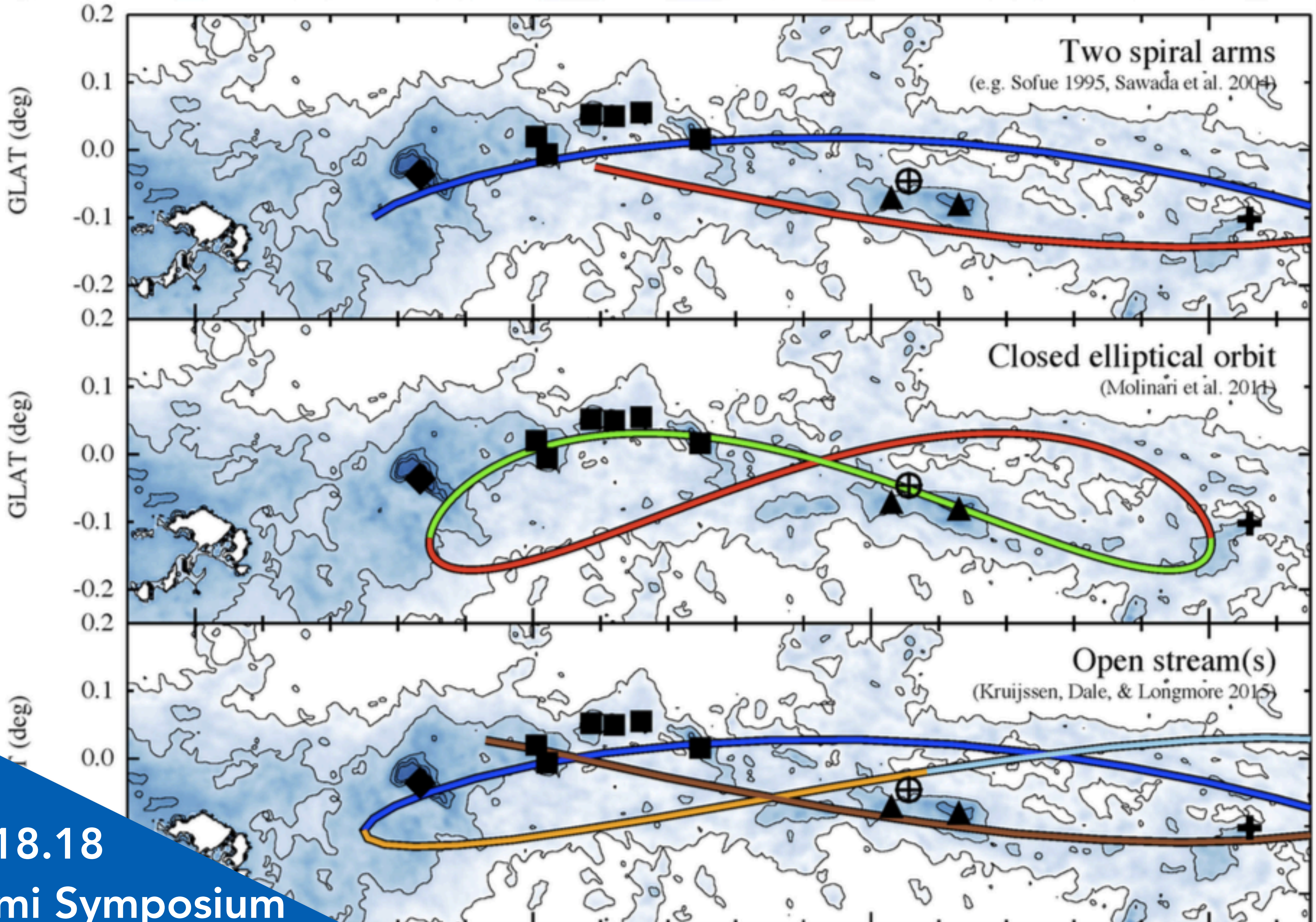
There are a lot of possibilities.

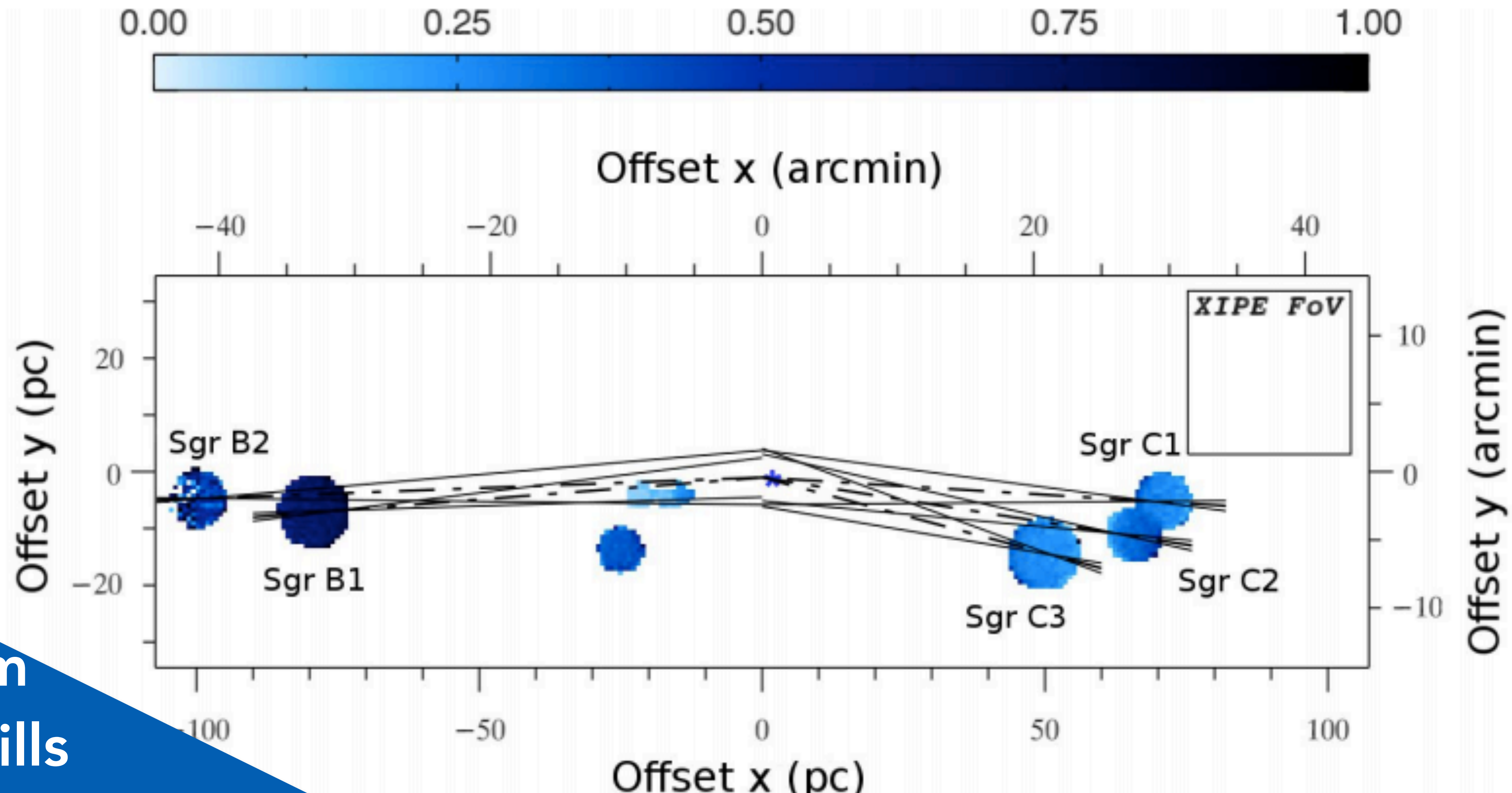


Henshaw et al. (2016)

X-rays may provide strong diagnostics

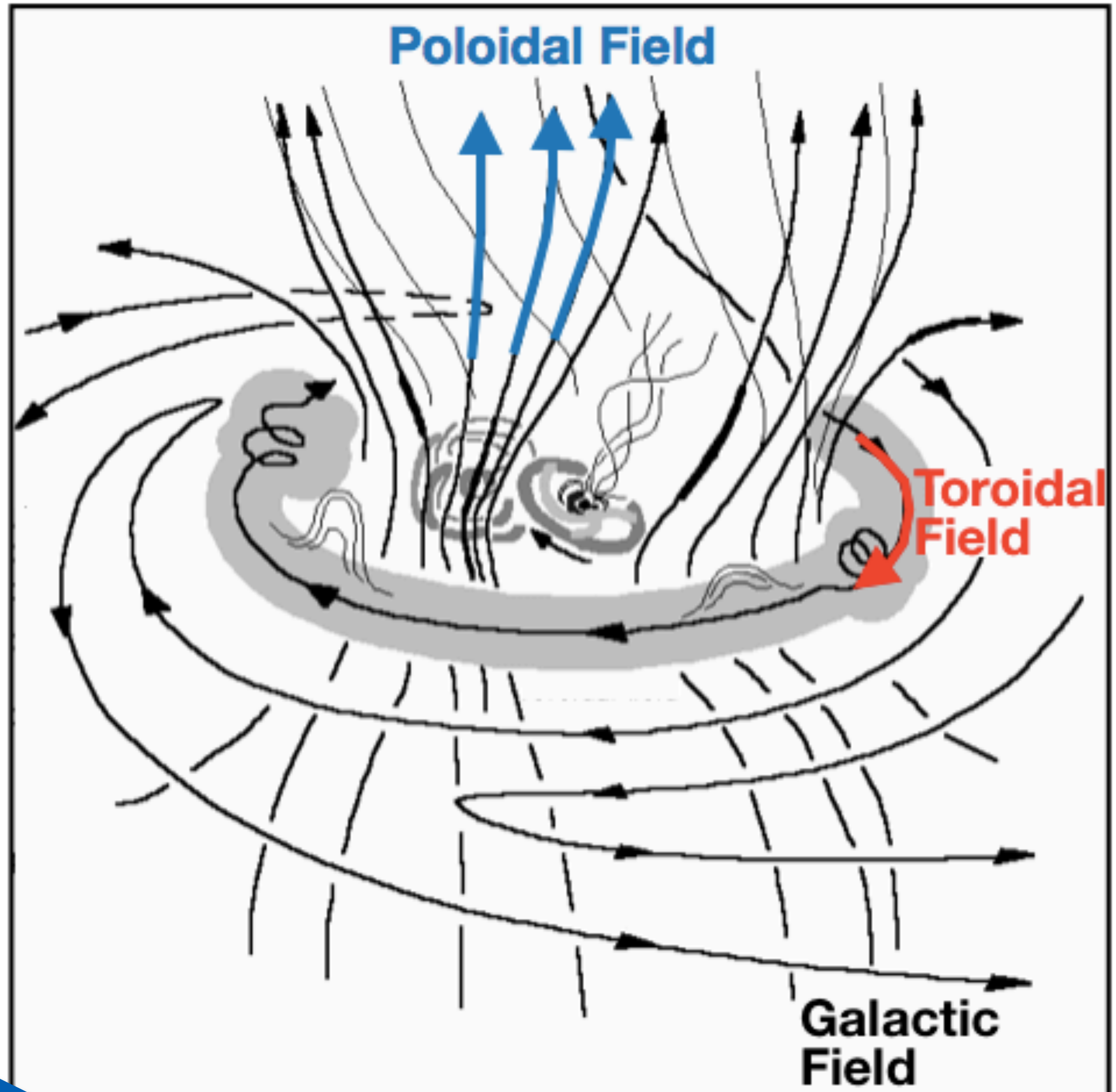
- **Light echoes (Ponti et al. 2010)**
- **Polarimetry (Marin 2014)**
- **Dust scattering Halos (Corrales et al. 2017)**

Marin 2014



What is the magnetic field geometry?

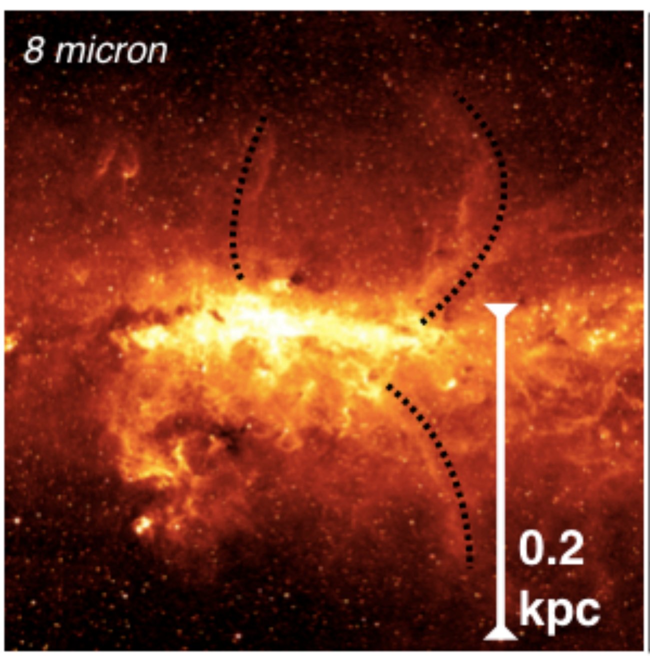
Magnetic fields can trace the gas flow, both inward and outward.



Sofue and Lang 1999

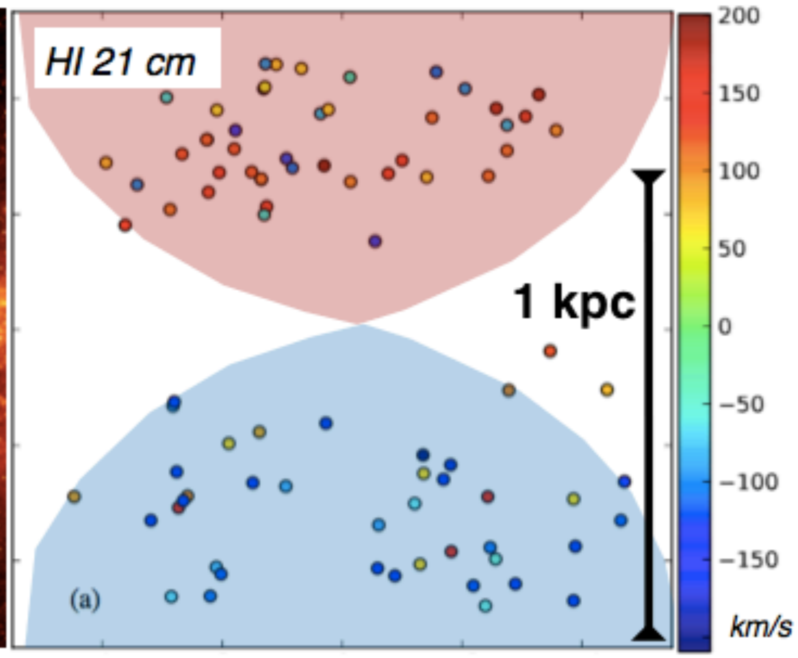
A poloidal field could trace material entrained in a current outflow, and make connections to ‘fossils’ of past events.

Radio/Infrared Lobes



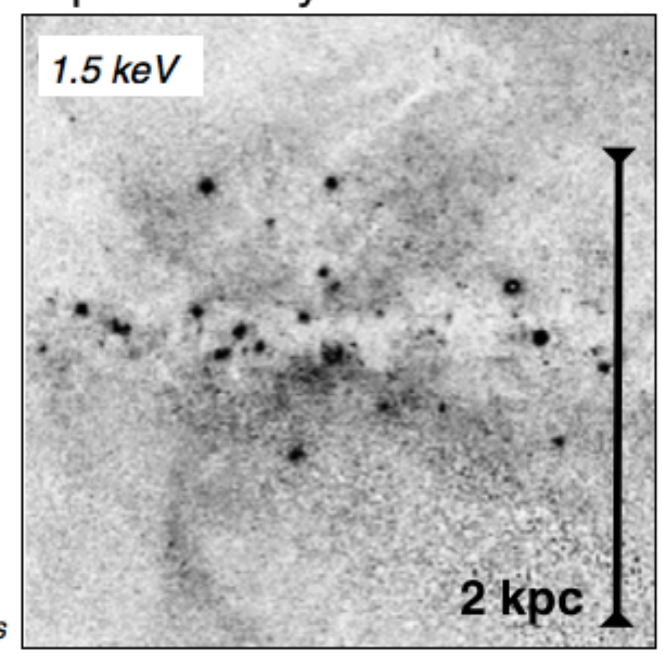
Sofue and Handa 1984

Neutral Outflow



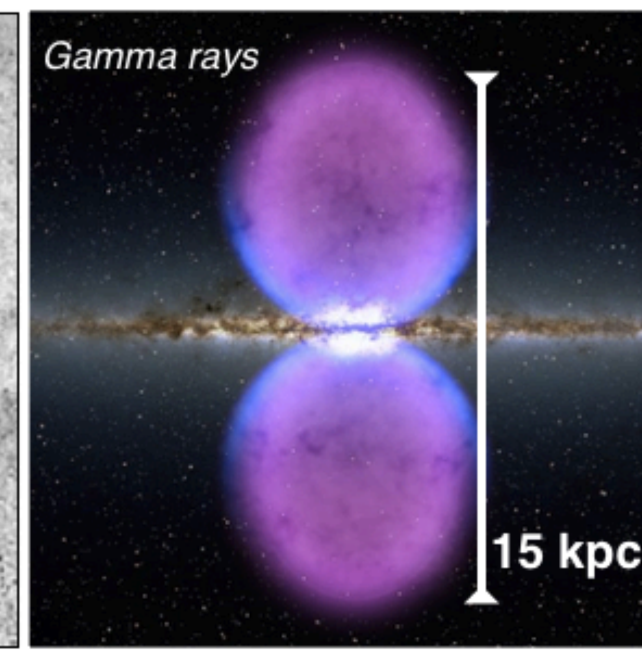
McClure-Griffiths et al. 2013

Bipolar X-ray emission



Bland-Hawthorn et al. 2003

Fermi Lobes



Su, Slatyer, and Finkbeiner 2010

Radio : hot gas, plasma

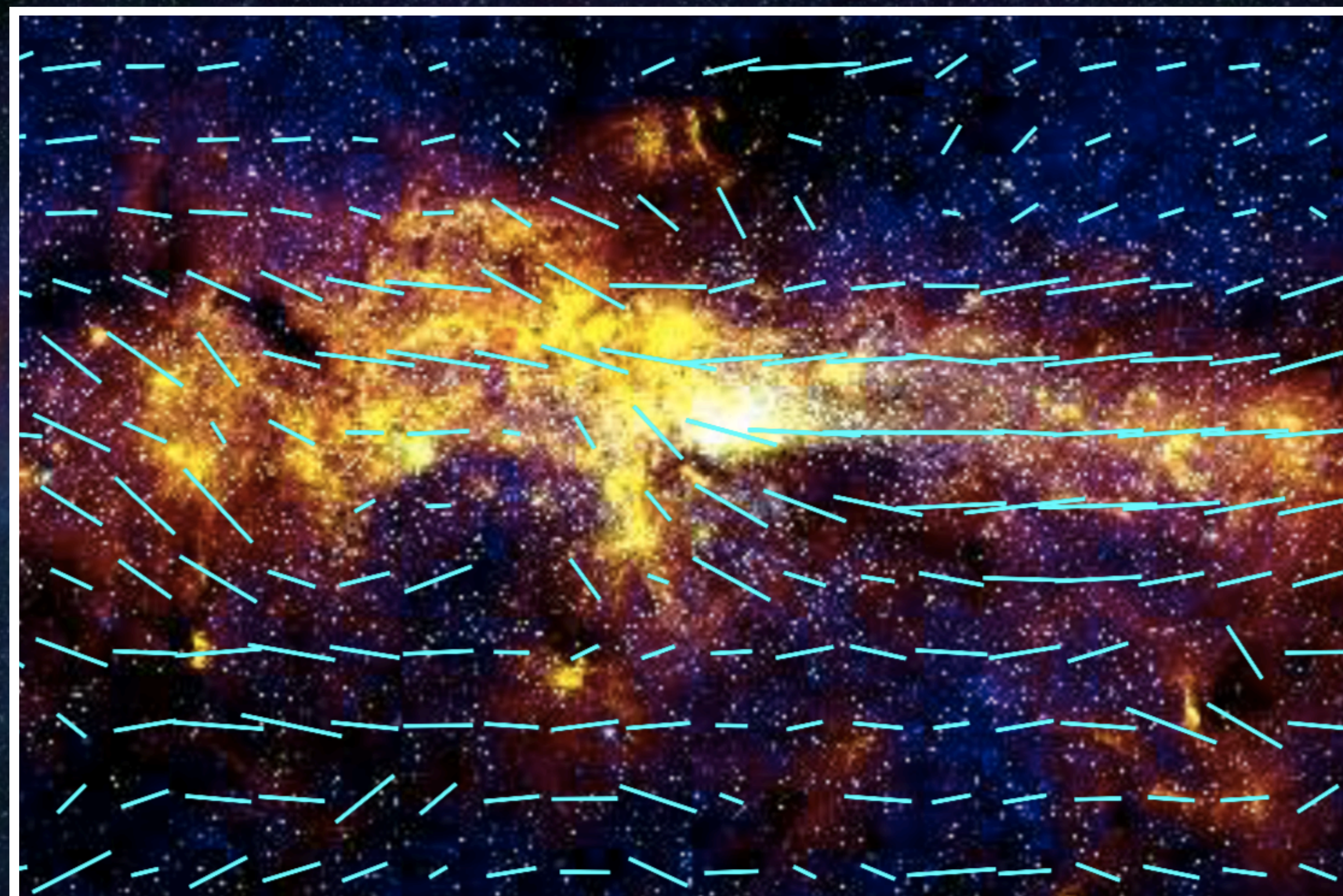
Poloidal field

Yusef-Zadeh and Morris (1987)

Radio : hot gas, plasma

Infrared : polarized starlight

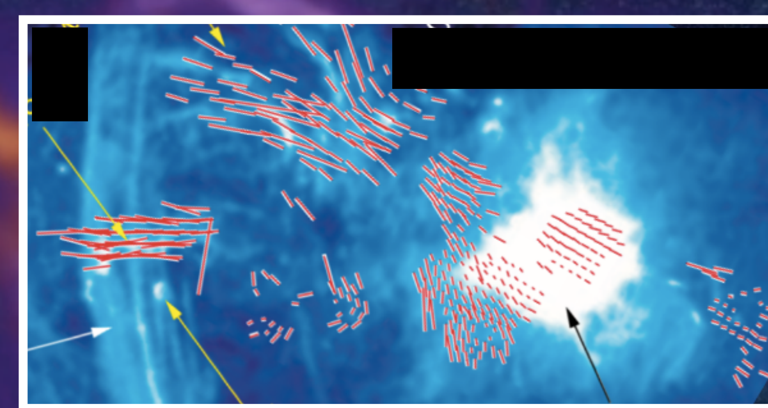
Largely Toroidal field



Nishiyama et al. 2010

Millimeter : cold dust/gas

Toroidal field



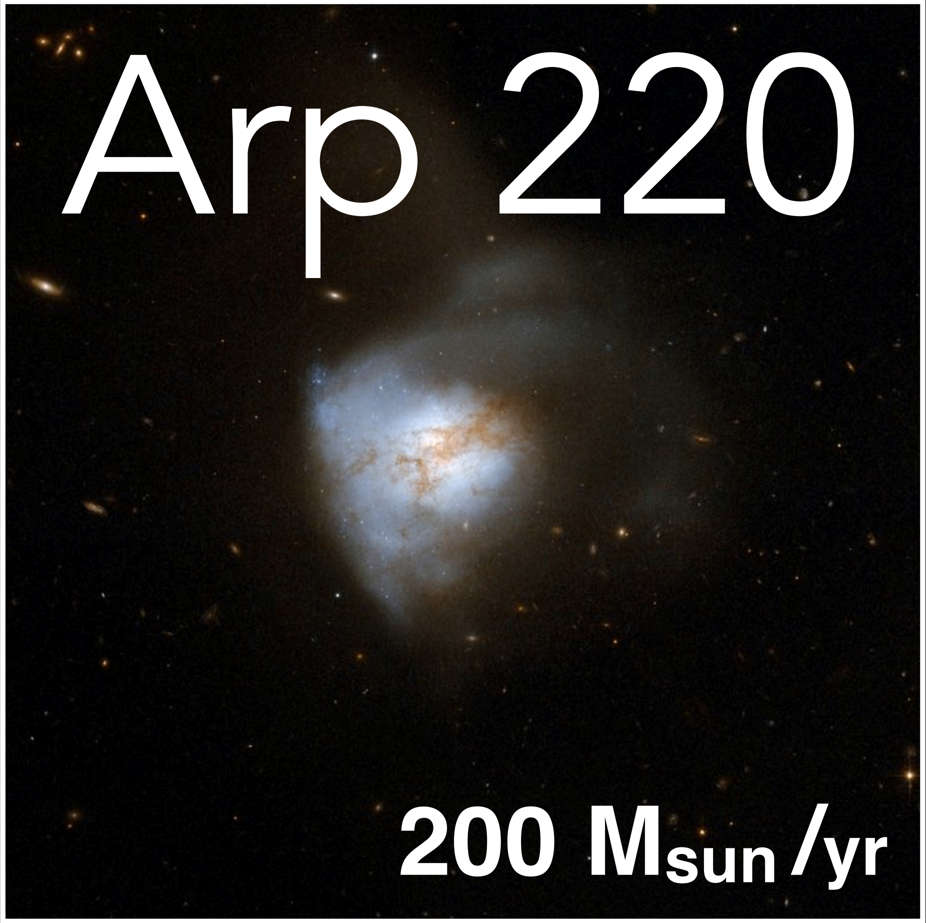
Chuss et al. 2003

Milky Way Physics Likely Not Representative

Barred Spiral
Total mass: 10^{11} M_{sun}

Black hole mass: 5×10^{6} M_{sun}

Nuclear Starburst
Star Formation Rate: 2.8 M_{sun} /yr



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