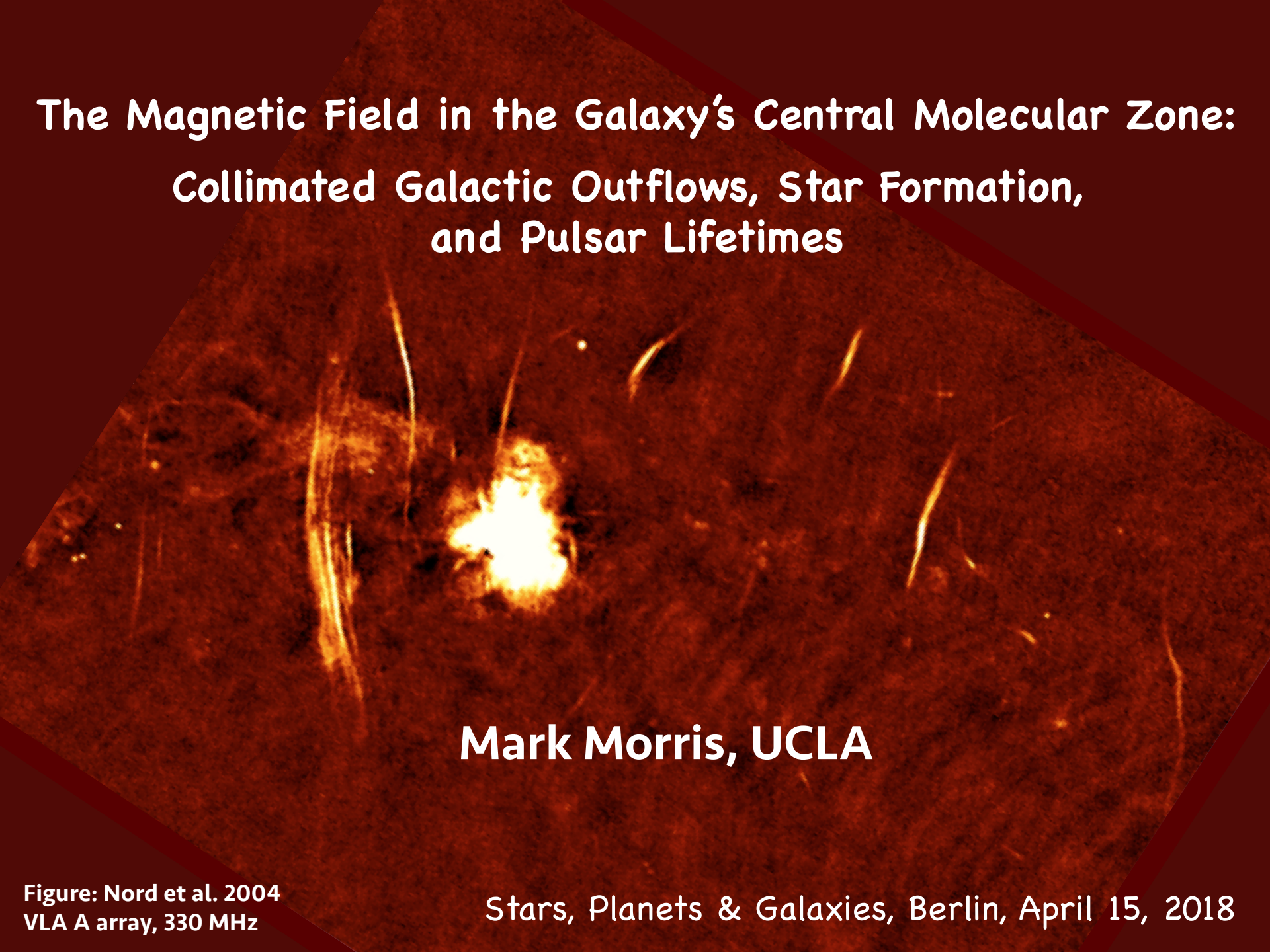
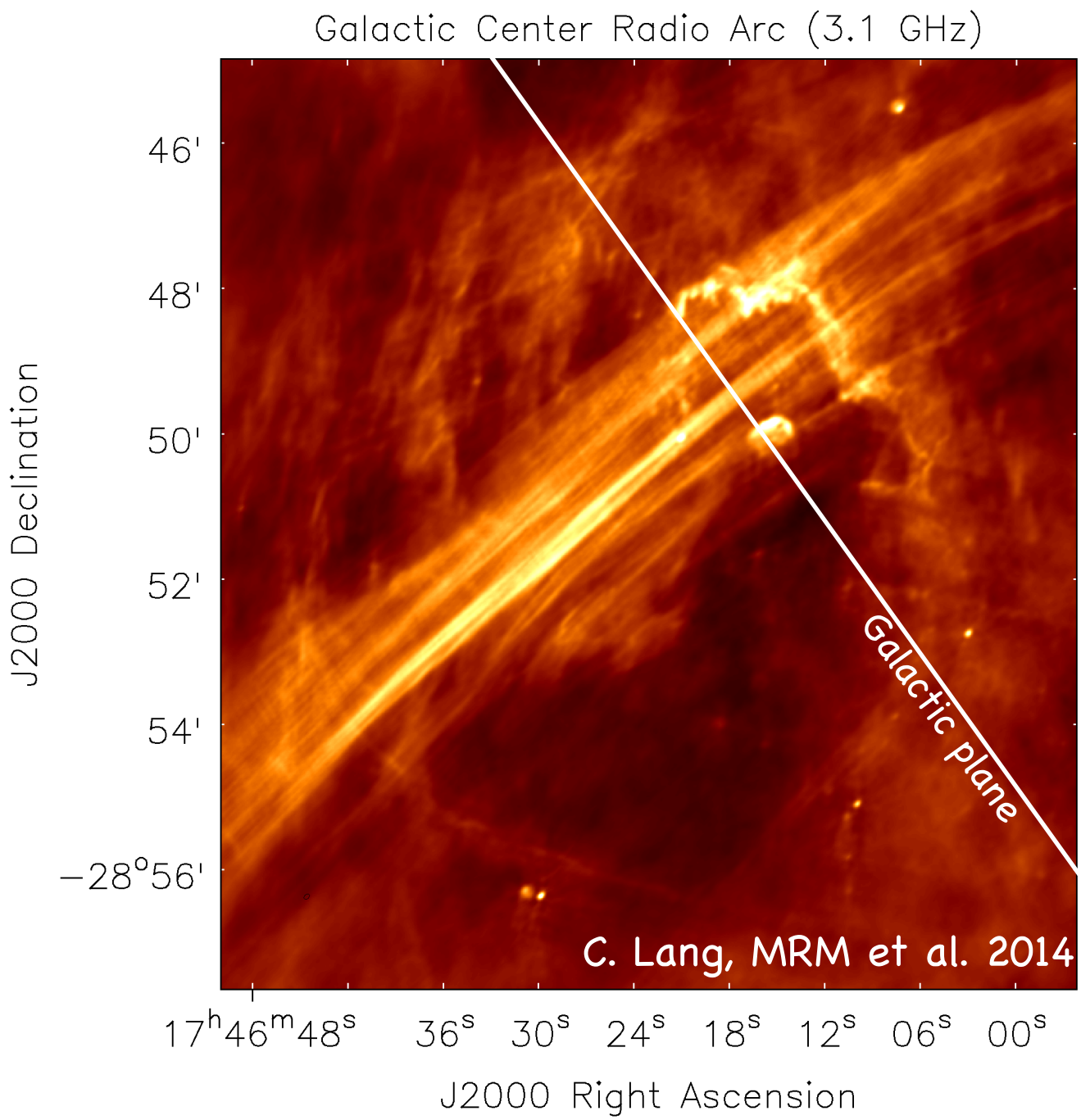
The Magnetic Field in the Galaxy's Central Molecular Zone: Collimated Galactic Outflows, Star Formation, and Pulsar Lifetimes



Mark Morris, UCLA

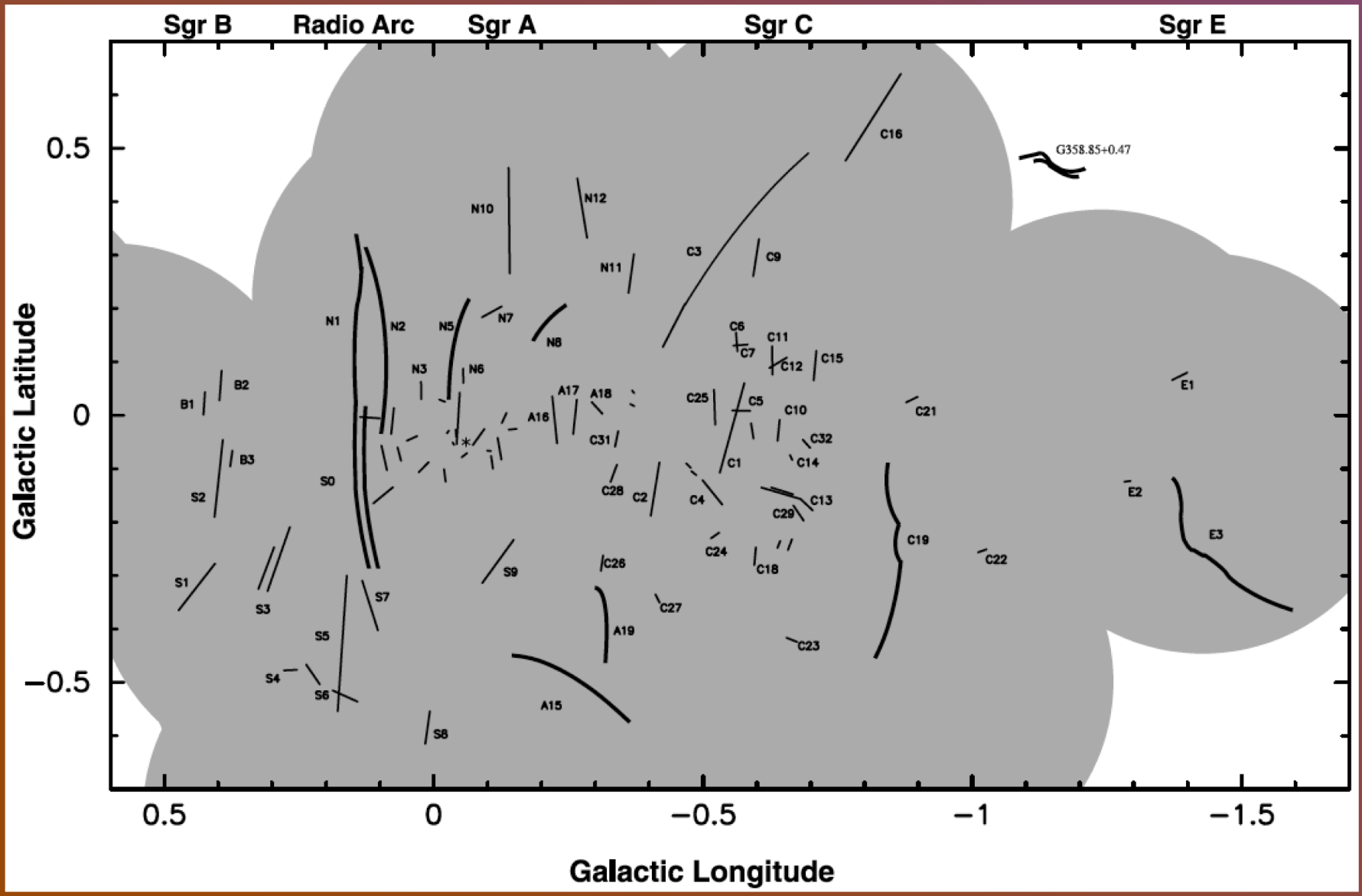
Figure: Nord et al. 2004
VLA A array, 330 MHz

Stars, Planets & Galaxies, Berlin, April 15, 2018


Galactic Center Radio Arc (3.1 GHz)
46'
48'
50'
52'
54'
−28°56'
J2000 Declination
Galactic plane
C. Lang, MRM et al. 2014
17h46m48s
36s
30s
24s
18s
12s
06s
00s
J2000 Right Ascension

Non-thermal Radio Filaments at λ20cm

Yusef-Zadeh, Hewitt, and Cotton 2004



→ Indication of a predominantly vertical, or dipolar field

Vertical columns, from dust emission

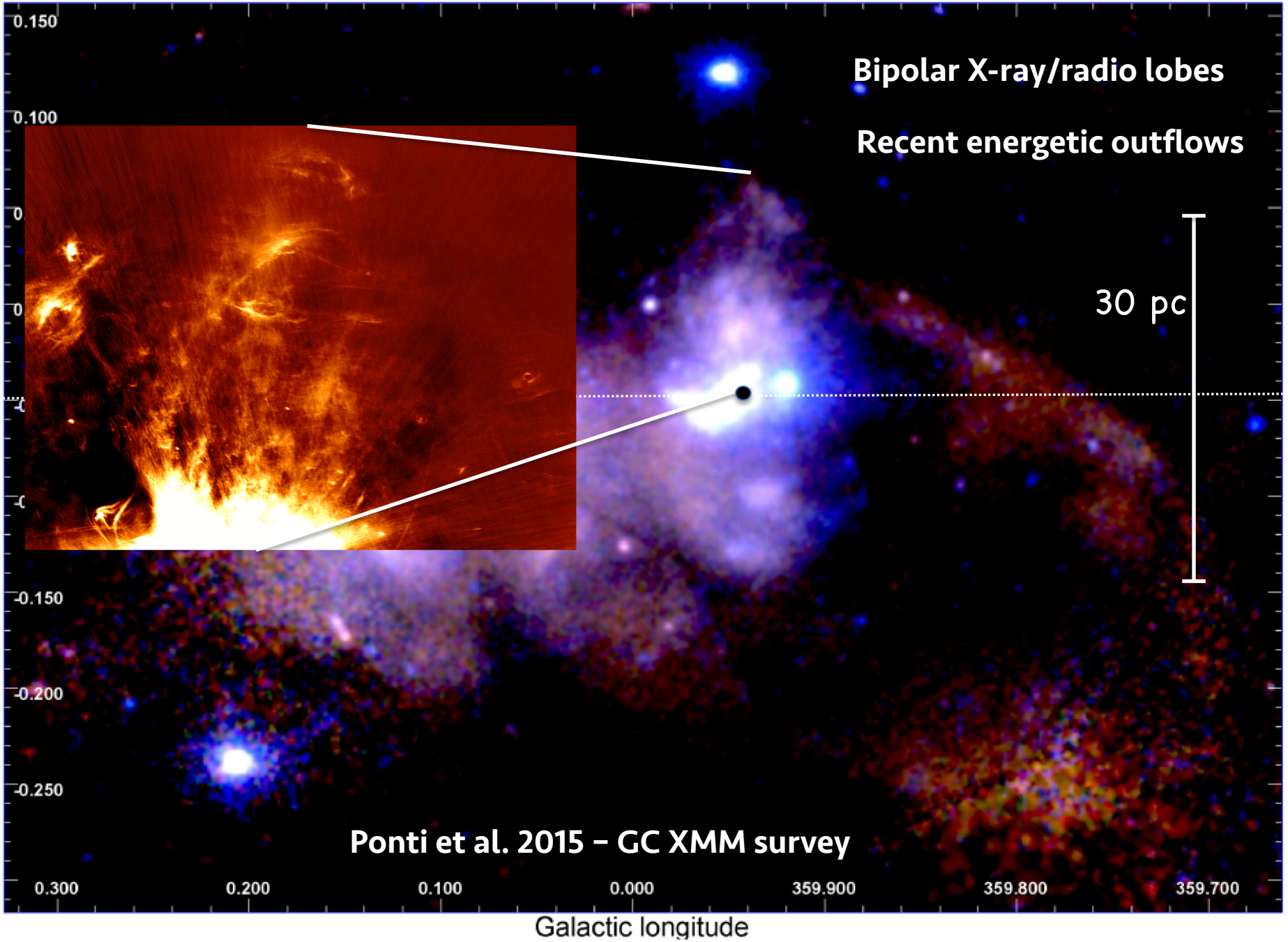
IRAC 8 μm – S. Stolovy

Point #1 →

The vertical (dipole) magnetic field collimates outflows from the Galactic center (in concert with the density gradient)

Bipolar cavities of hot gas can be seen on 3 different scales above the Galactic center:

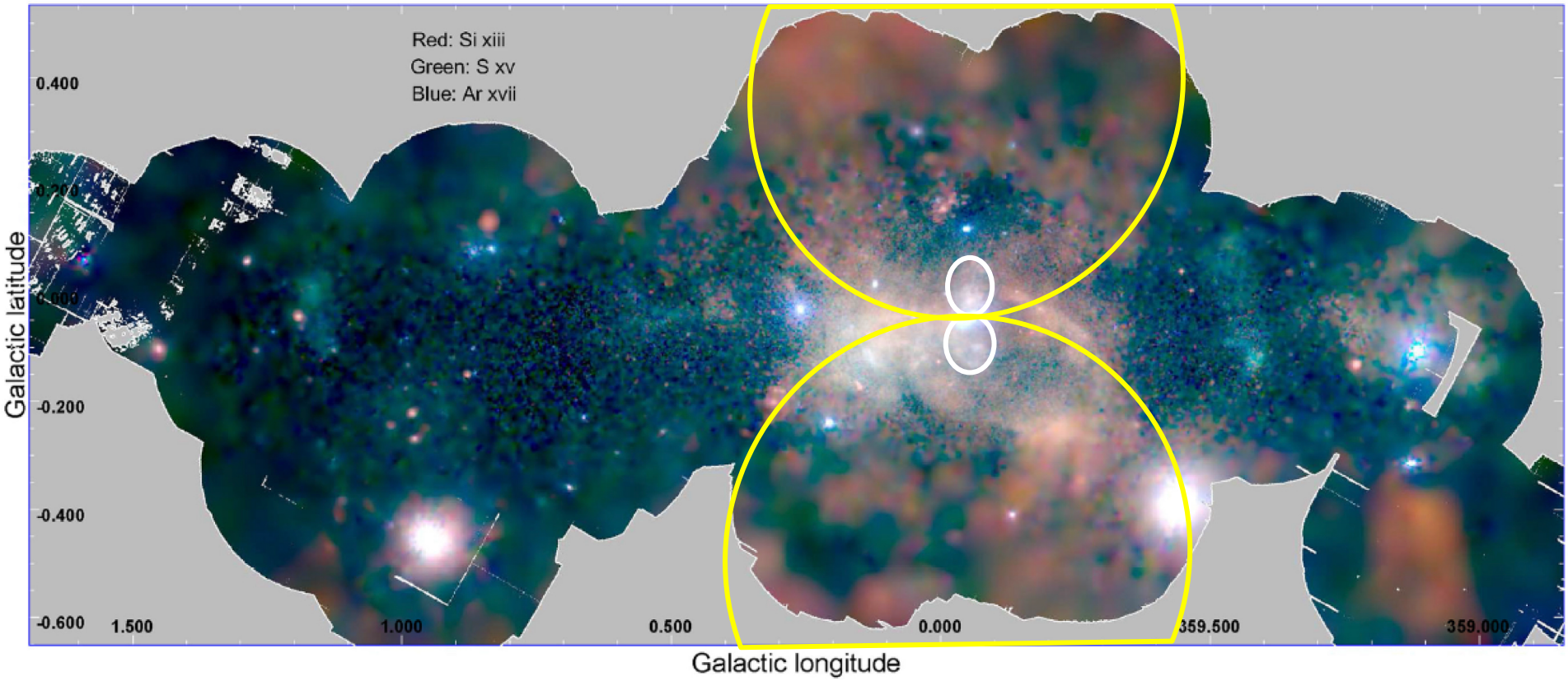
- The bipolar X/radio lobes (~15 pc)
- The Galactic Center Lobe (~150 pc) (but one-sided?)
- The Fermi Bubbles (~ 8 kpc)


Bipolar X-ray/radio lobes
Recent energetic outflows
30 pc
Ponti et al. 2015 – GC XMM survey
Galactic latitude
Galactic longitude
0.150
0.100
0
0
-0.150
-0.200
-0.250
0.300
0.200
0.100
0.000
359.900
359.800
359.700

The Galactic Center Lobes -- 150 pc

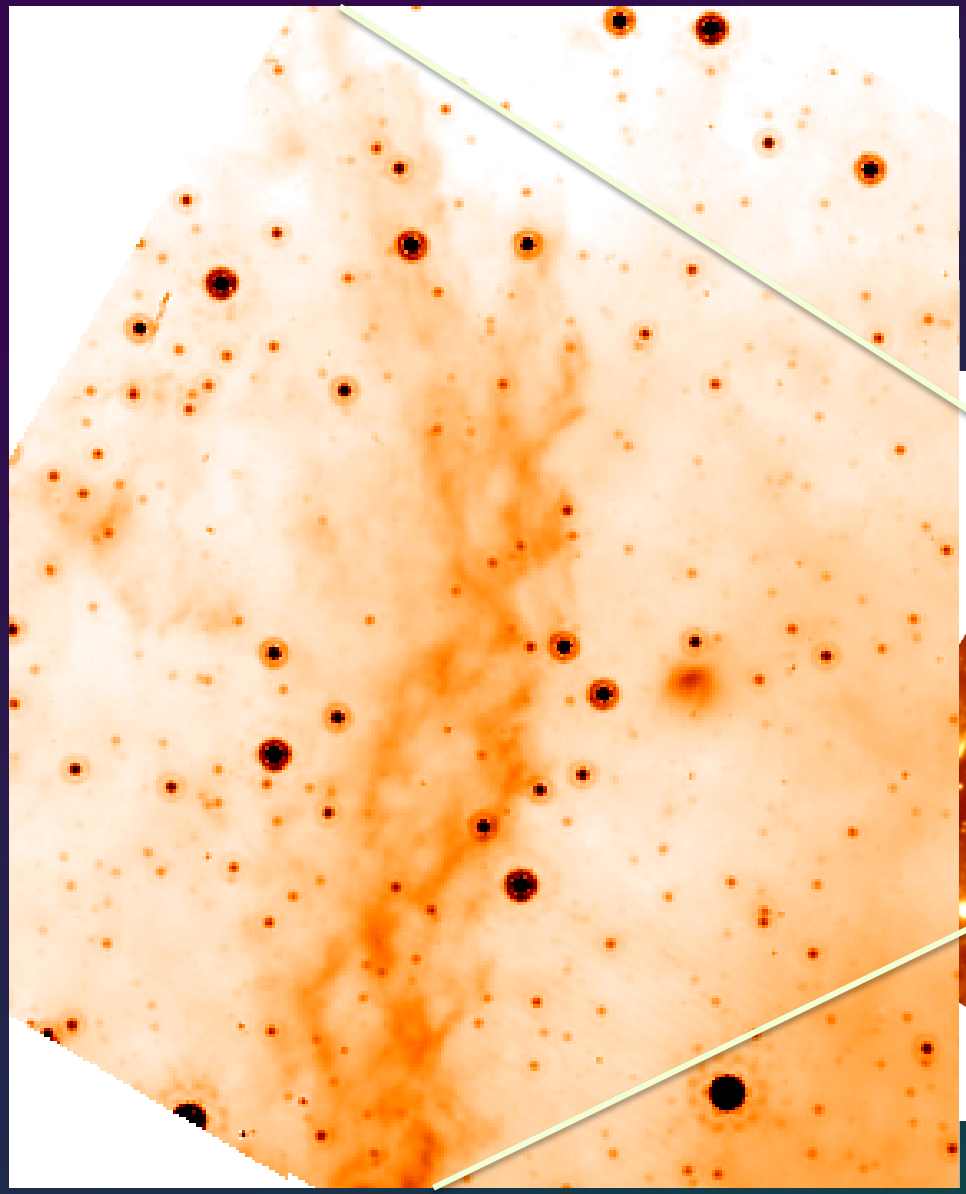
(as viewed in X-rays with XMM)

Note sharp edges – these are bubbles

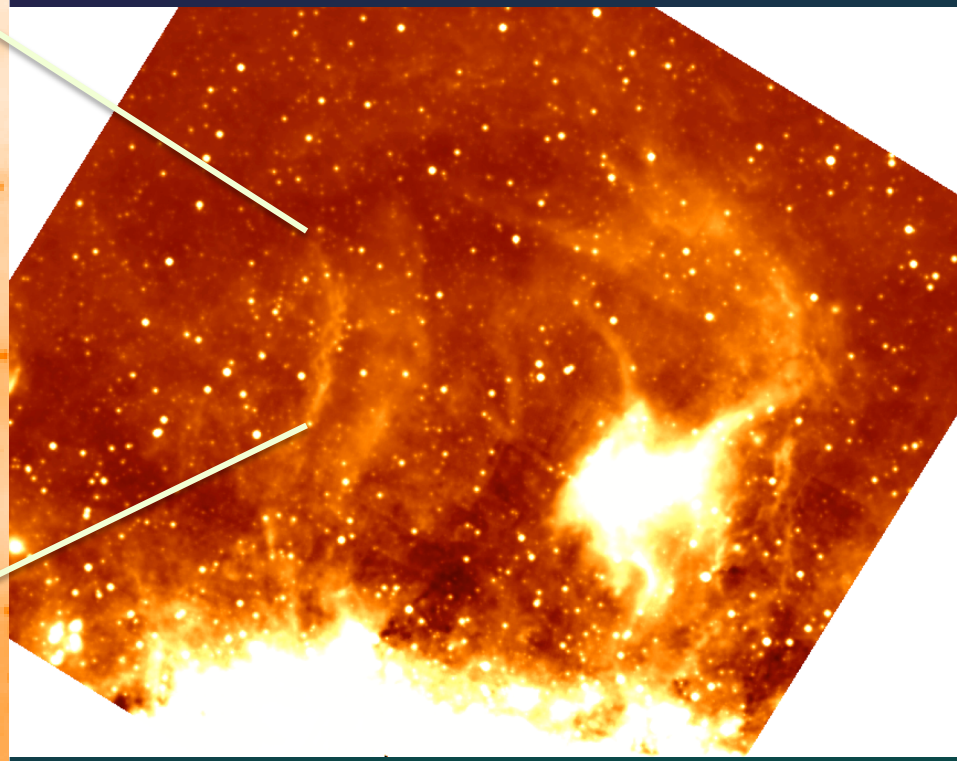


Ponti, MM, et al. 2015

The "Galactic Center Lobe" - 150 pc



WISE - 24 μm



← Double Helix Nebula (MM+ 2006)

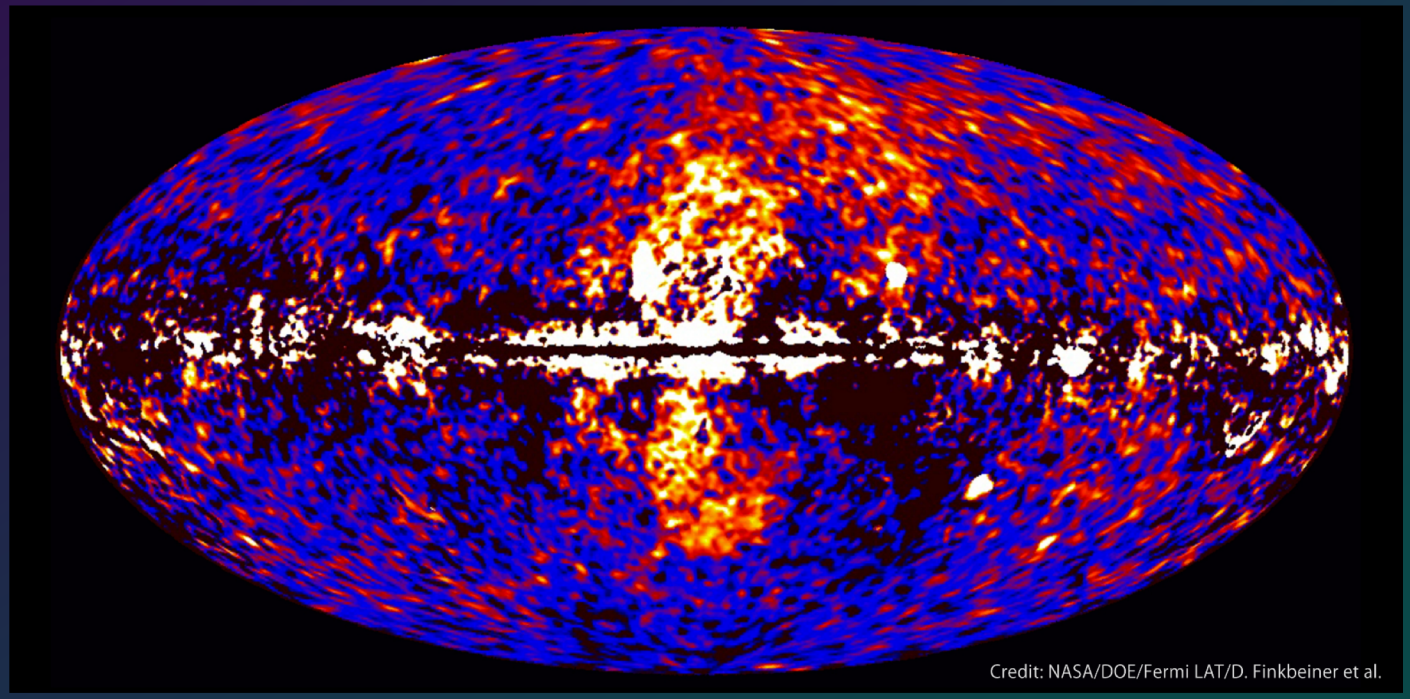
Fermi Bubbles – 8 kpc

A uniform vertical magnetic field over the CMZ →

- Strongly anisotropic diffusion of cosmic rays
- Relatively small cosmic ray residence time
- Feeding of cosmic rays into the Fermi lobes

(Crocker & Aharonian 2011)

adds to collimation by the Galactic density gradient.



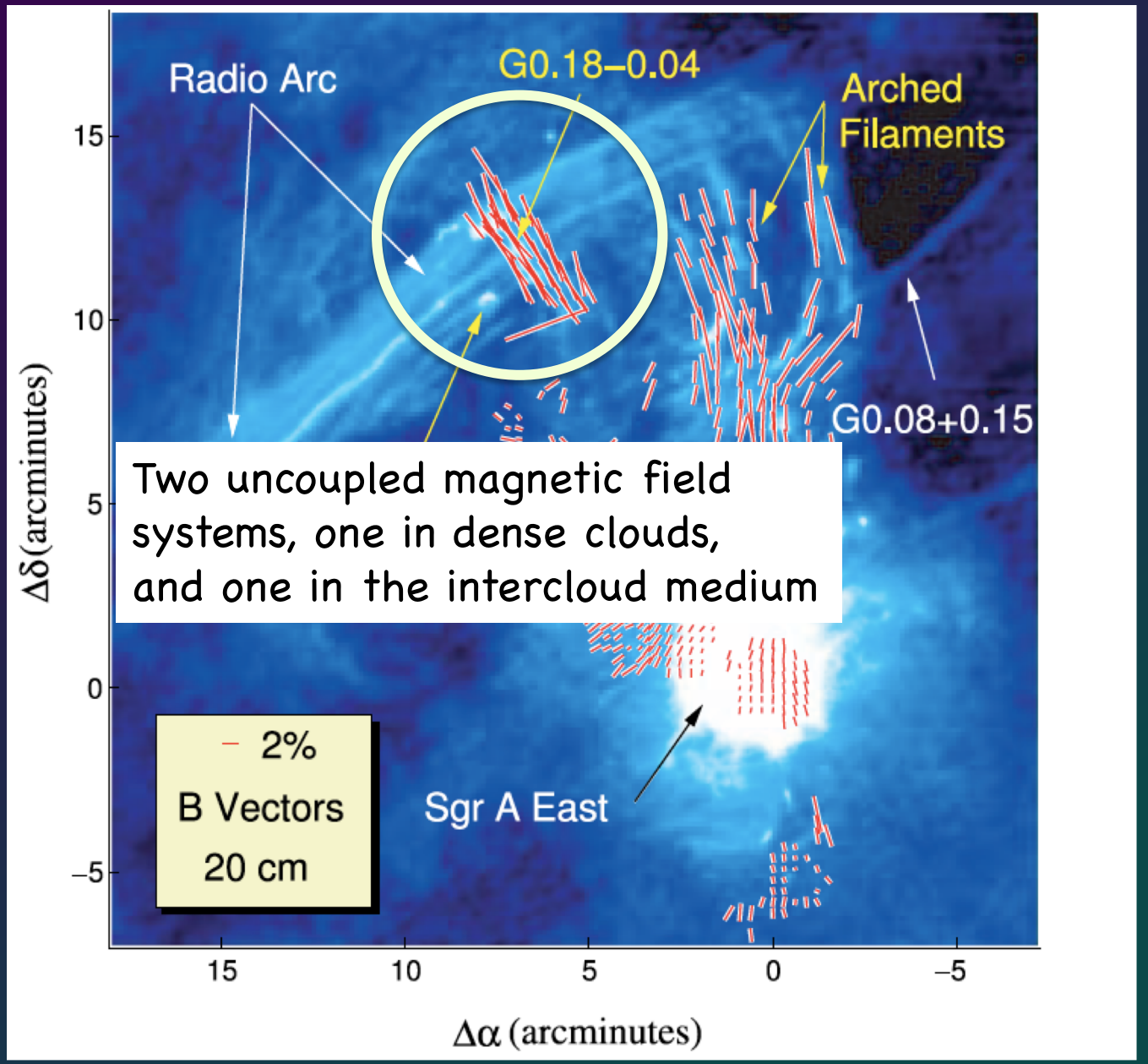
Su, Slatyer & Finkbeiner 2010

Point #2:

The magnetic field in clouds of the central molecular zone is affected by tidal shear, so it follows elongated cloud morphologies.

The new instrument HAWC+ on SOFIA is obtaining spectacular results on polarized emission from magnetically aligned dust grains.

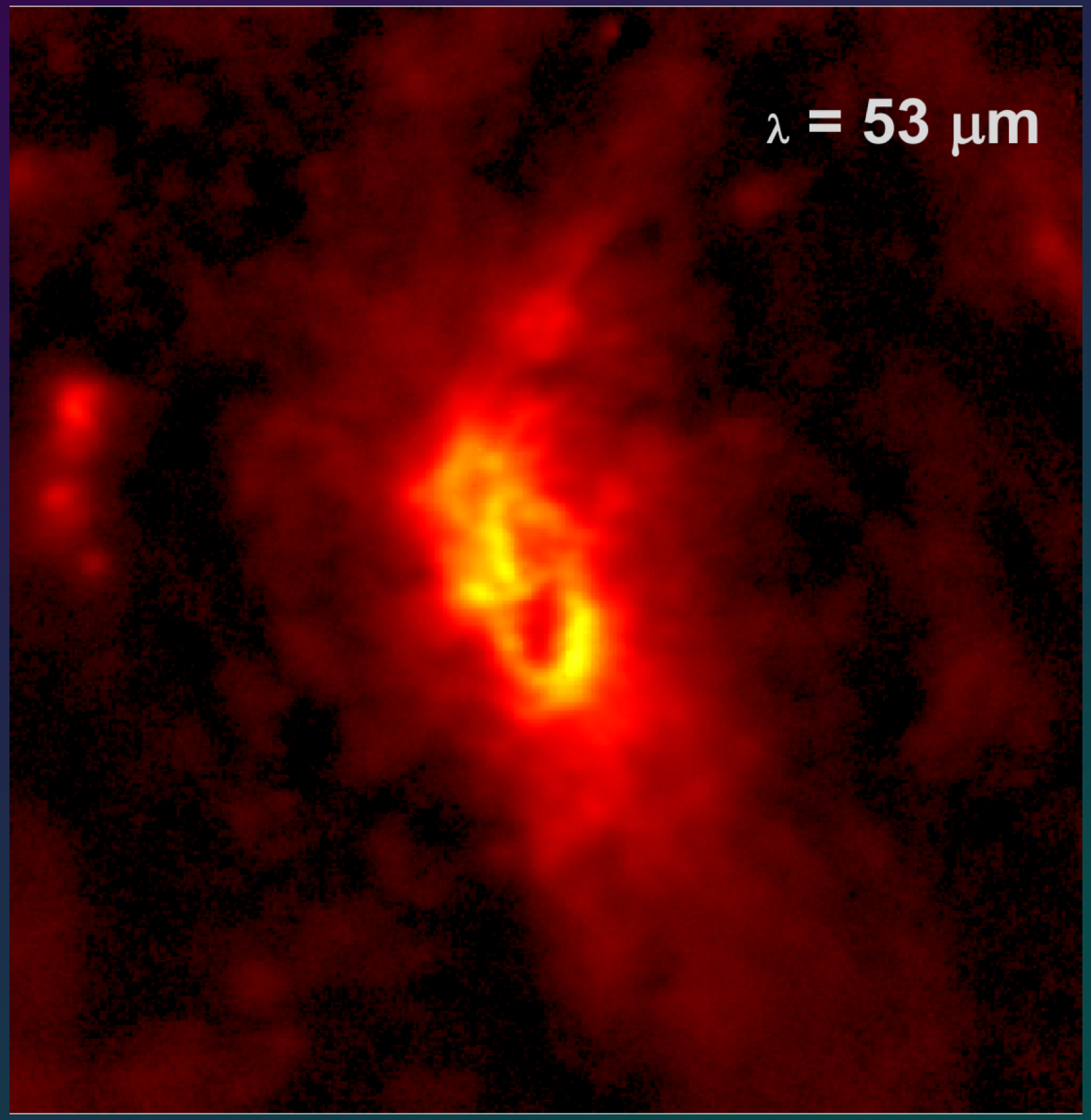
Chuss et al. 2003 (KAO observations)



HAWC+ image of the circumnuclear disk –

Polarization results to be announced (Dowell et al.)

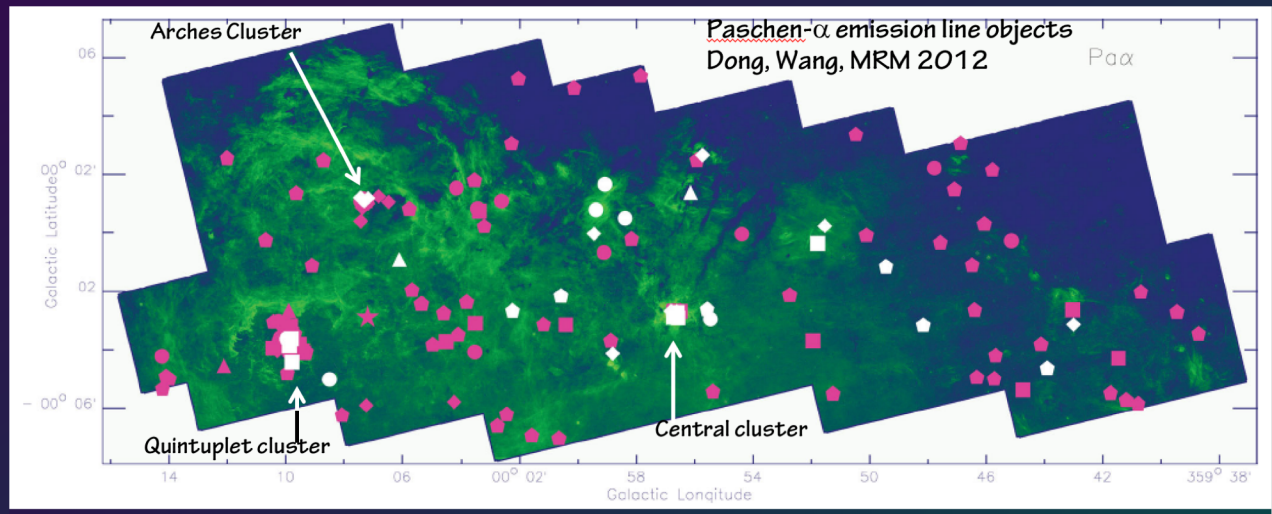
→ indicate a highly ordered, and thus strong, magnetic field in clouds



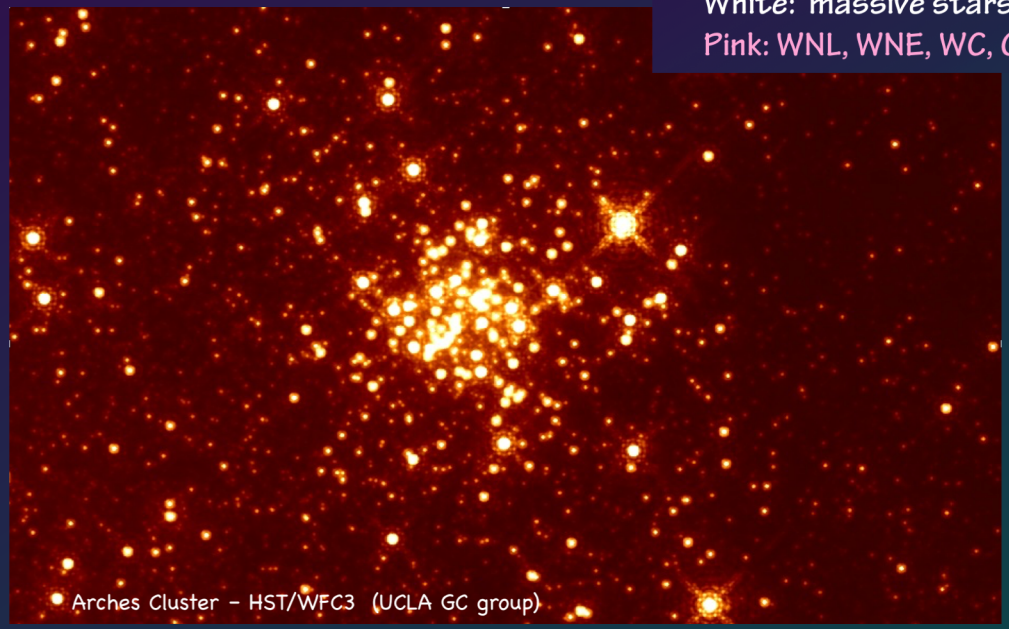
Point #3 (a speculation):

- Indications are that the magnetic field in Galactic center clouds is strong – milligauss

- Stars form abundantly in the central molecular zone



White: massive stars with X-ray counterparts, presumably colliding-wind binaries
Pink: WNL, WNE, WC, OB supergiants, LBVs



speculation → Galactic center stars are substantially more highly magnetized than those in the disk

→ Questions raised:

- Can stars even form in a cloud with a strong magnetic flux without ridding themselves of the field through processes such as ambipolar diffusion?
- If a strongly magnetized star can form, can it retain its magnetic flux against the formation of buoyant magnetic bubbles that carry away flux?
- Or does dynamo action in stellar convection zones regenerate, maintain, and amplify the field?
- Are Zeeman measurements possible with foreseeable IR instrumentation, given the distance?

Carrying the speculation one step further →

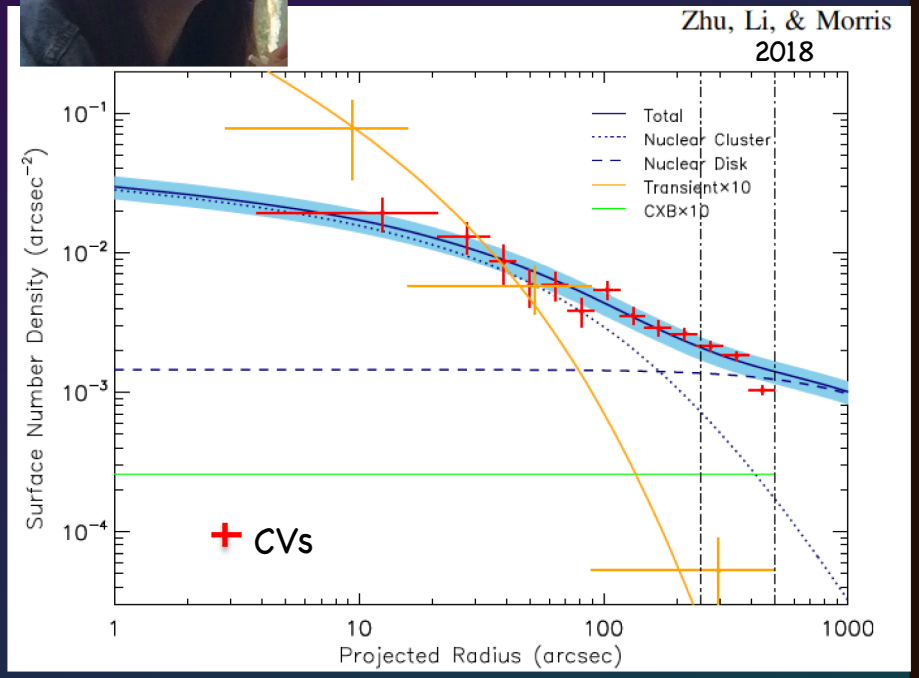
Neutron star remnants of massive star evolution in the Galactic center are highly magnetized – they are predominantly magnetars !

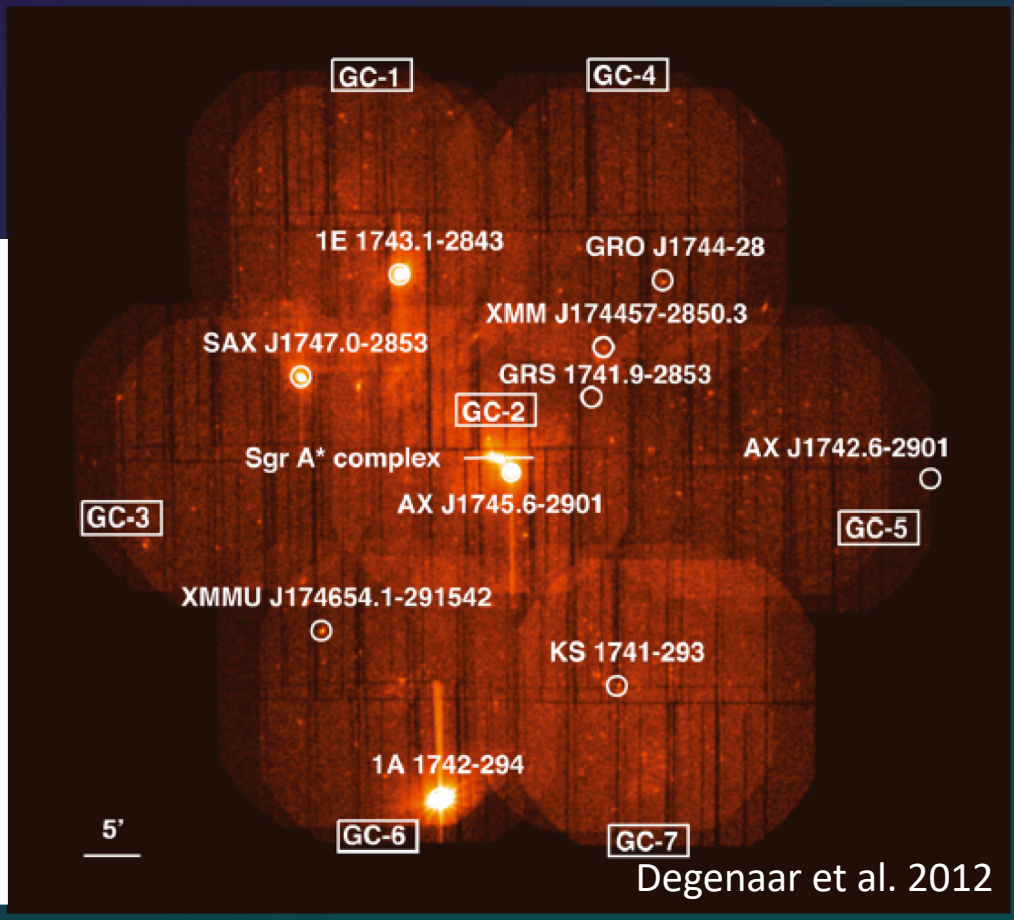
If so, this solves the missing Galactic center pulsar problem

- No surprise that there are neutron stars in the Galactic center. They manifest themselves in close binary systems as transients – bursting low-mass X-ray binaries

- Like black hole LMXBs (Hailey et al. 2018), they are more concentrated toward the Galactic center than field stars

Zhenlin Zhu

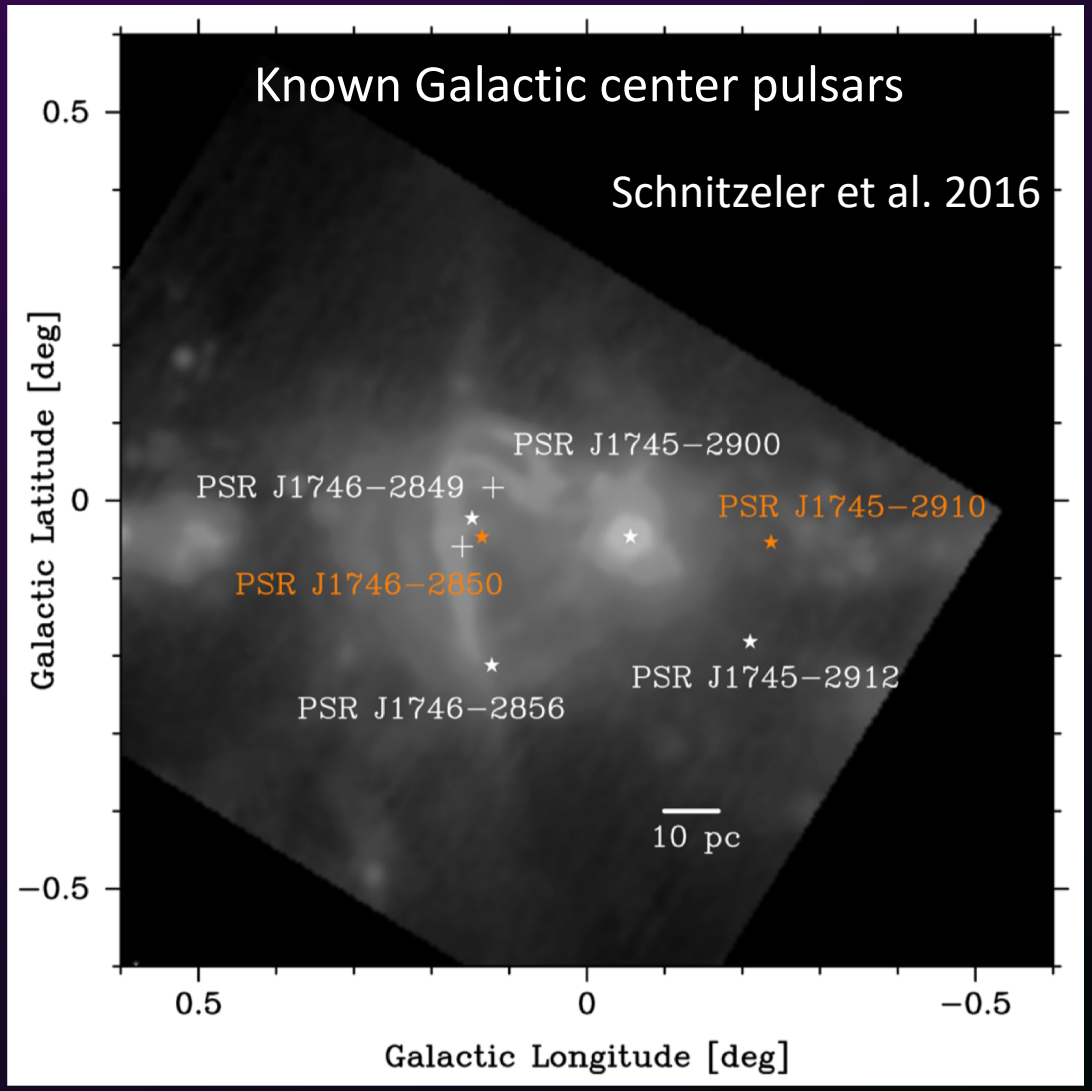




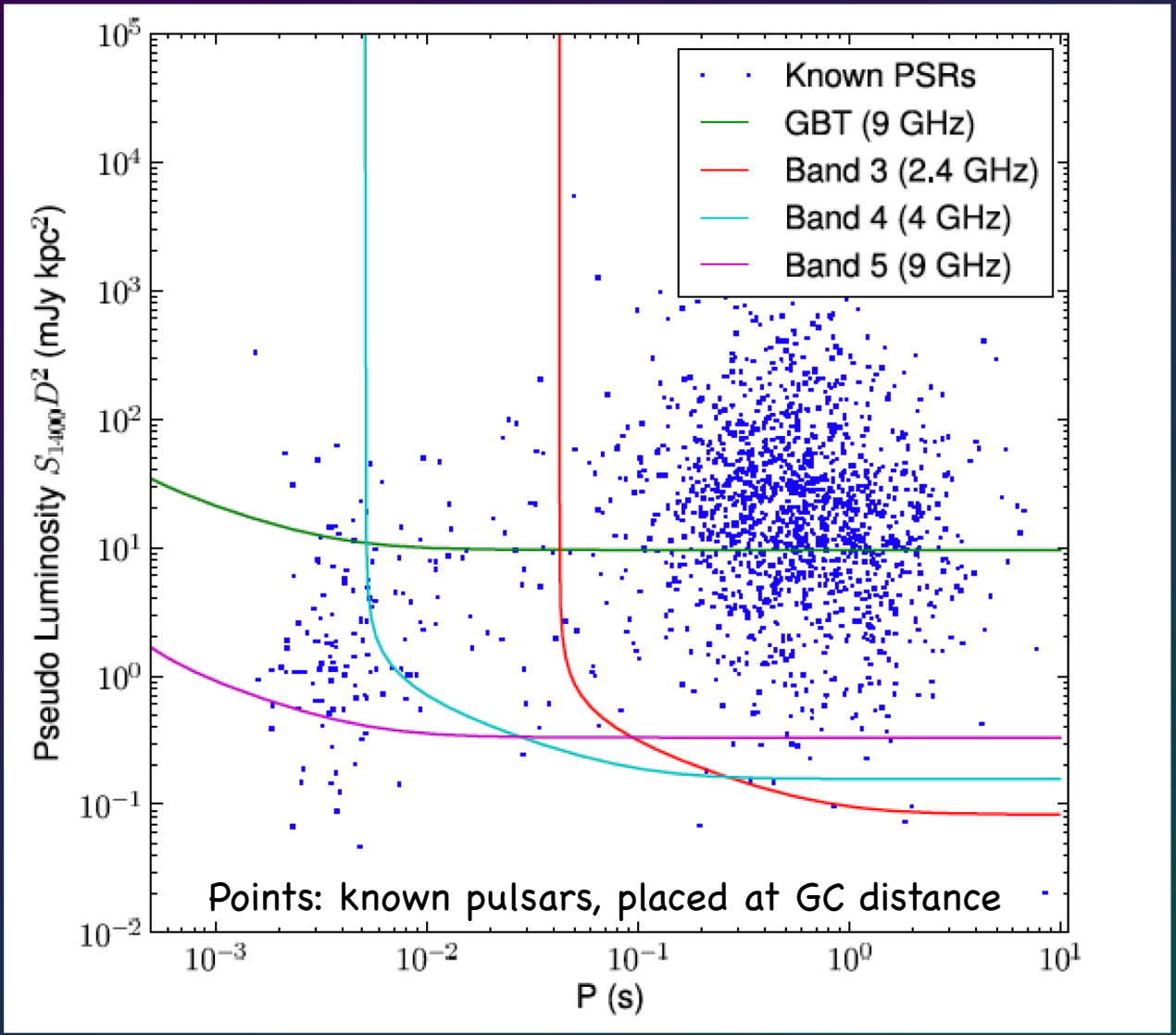
Degenaar et al. 2012

Pulsar demographics in the Galactic center:

- very few, given the star formation rate and the typical 10^7-yr spin-down time
- Ascribed to an inordinately large line-of-sight dispersion measure
- But then the magnetar PSR J1745-2900 was discovered as it underwent an X-ray burst in April 2013 (Degenaar+ 2013)
- The dispersion measure was unprecedented, but the pulsar WAS detectable in radio and X-rays (Eatough et al. 2013; Rea et al. 2013) indicating that other pulsars should be detectable UNLESS this one was being seen through a fortuitous window
- So where are they? there's one other pulsar that has magnetar characteristics, so likely 2 known in the GC, out of a total of ~30 known magnetars



Limitations to pulsar detection → pulse broadening and dispersion delay



SKA sensitivity analysis -- Eatough+2014

→ The implication of this hypothesis is that Galactic center pulsars should have a lifetime ~ 100 times less than pulsars stars in the Galactic disk

→ The issue of the dispersion measure is at least an aggravating factor

→ The few pulsars that are seen in the Galactic center could themselves be relatively highly magnetized

Conclusions:

- The effect of a strong magnetic field on the evolution of massive stars may be profound
- Continued pulsar searches, especially with the Square Kilometer Array, will elucidate this issue