The *Fermi* Bubbles – Possible Nearby Laboratory for AGN Jet Activity

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Einstein Fellows Symposium
Oct. 29, 2014

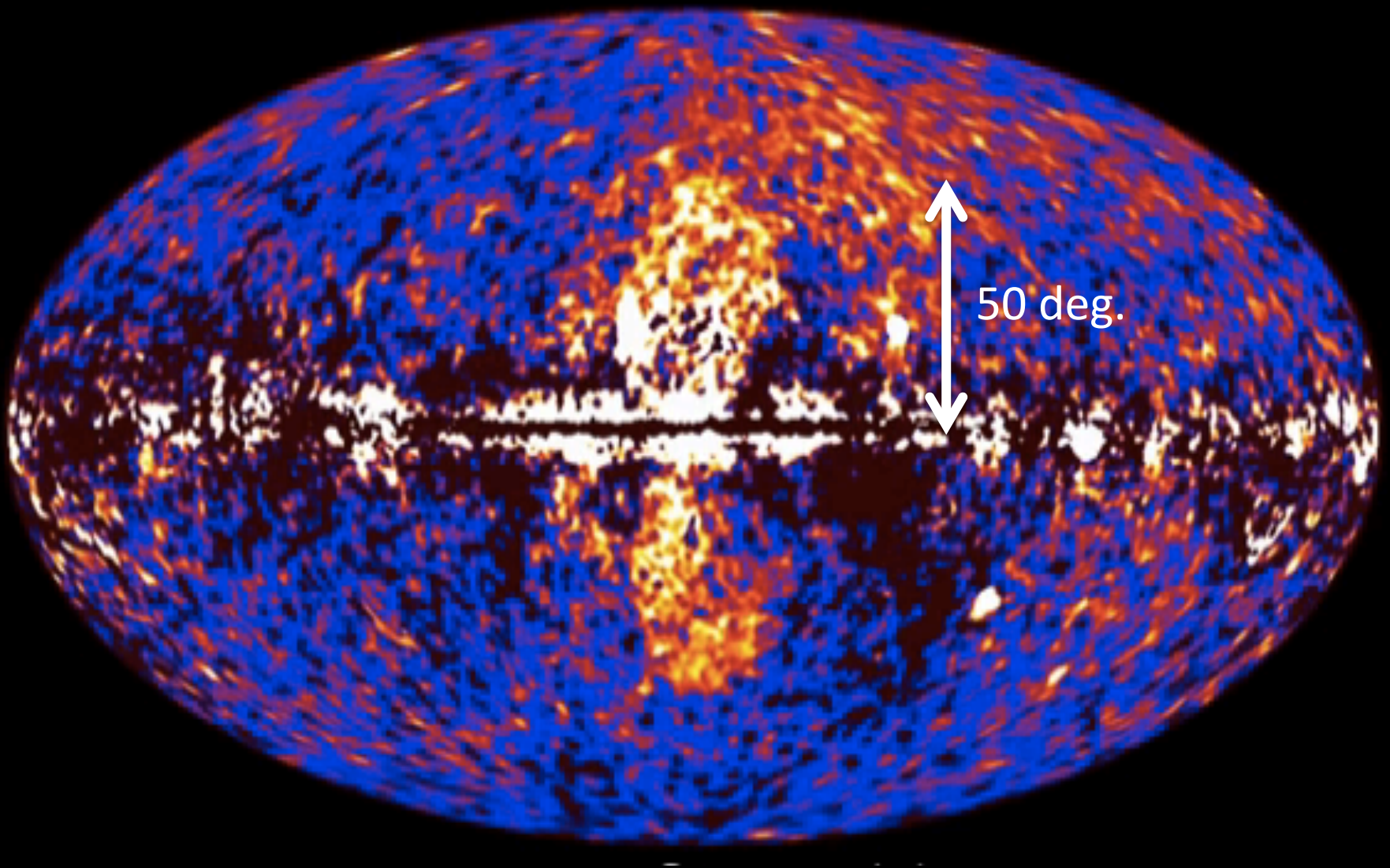
Yang et al., 2012, ApJ, 761, 185 (astro-ph//1207.4185)
Yang et al., 2013, MNRAS, 436, 2734 (astro-ph//1307.3551)

Mateusz Ruszkowski

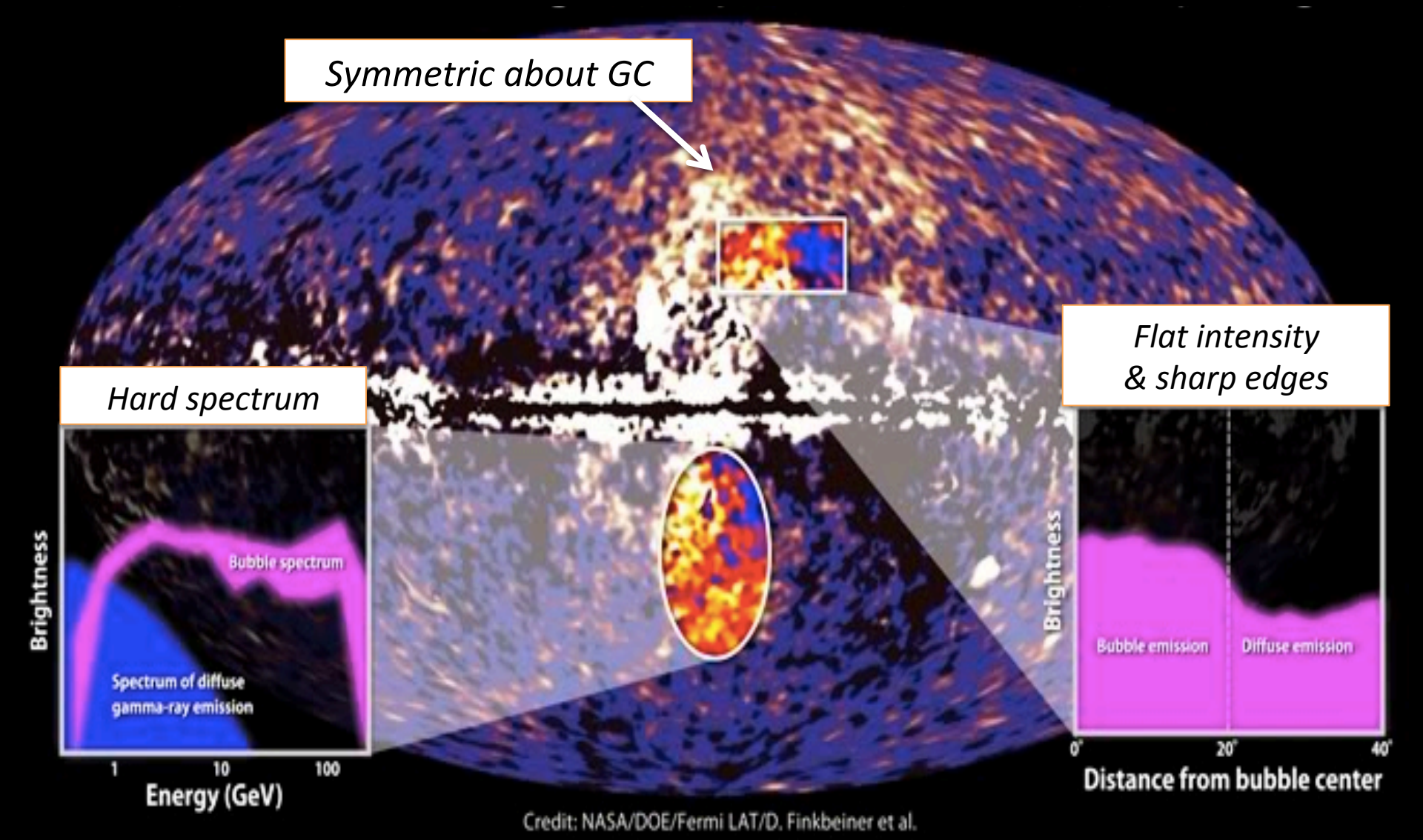
Ellen Zweibel

Paul Ricker

Gamma-ray bubbles by *Fermi* (Su 2010)

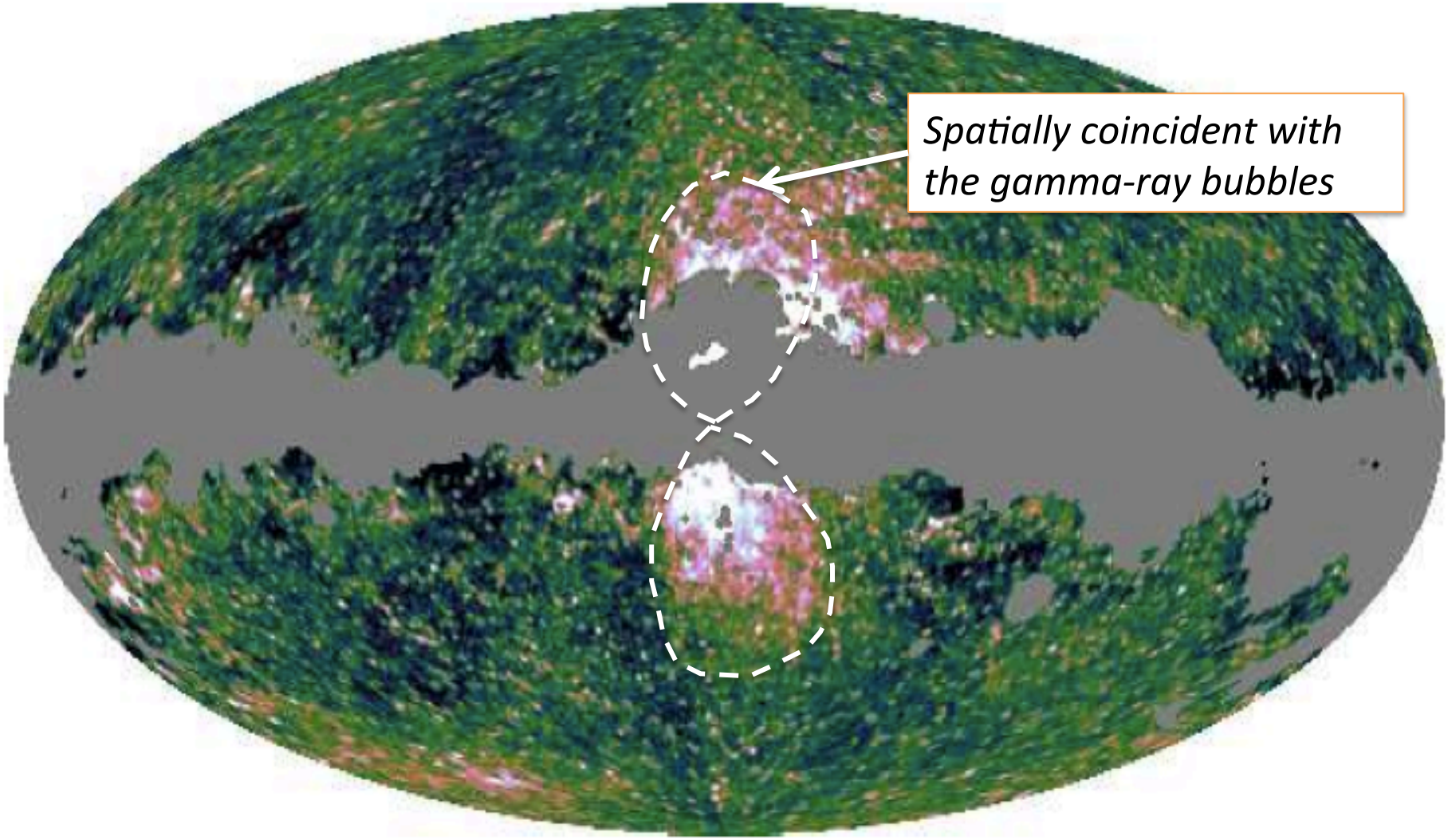


Gamma-ray bubbles by *Fermi* (Su 2010)

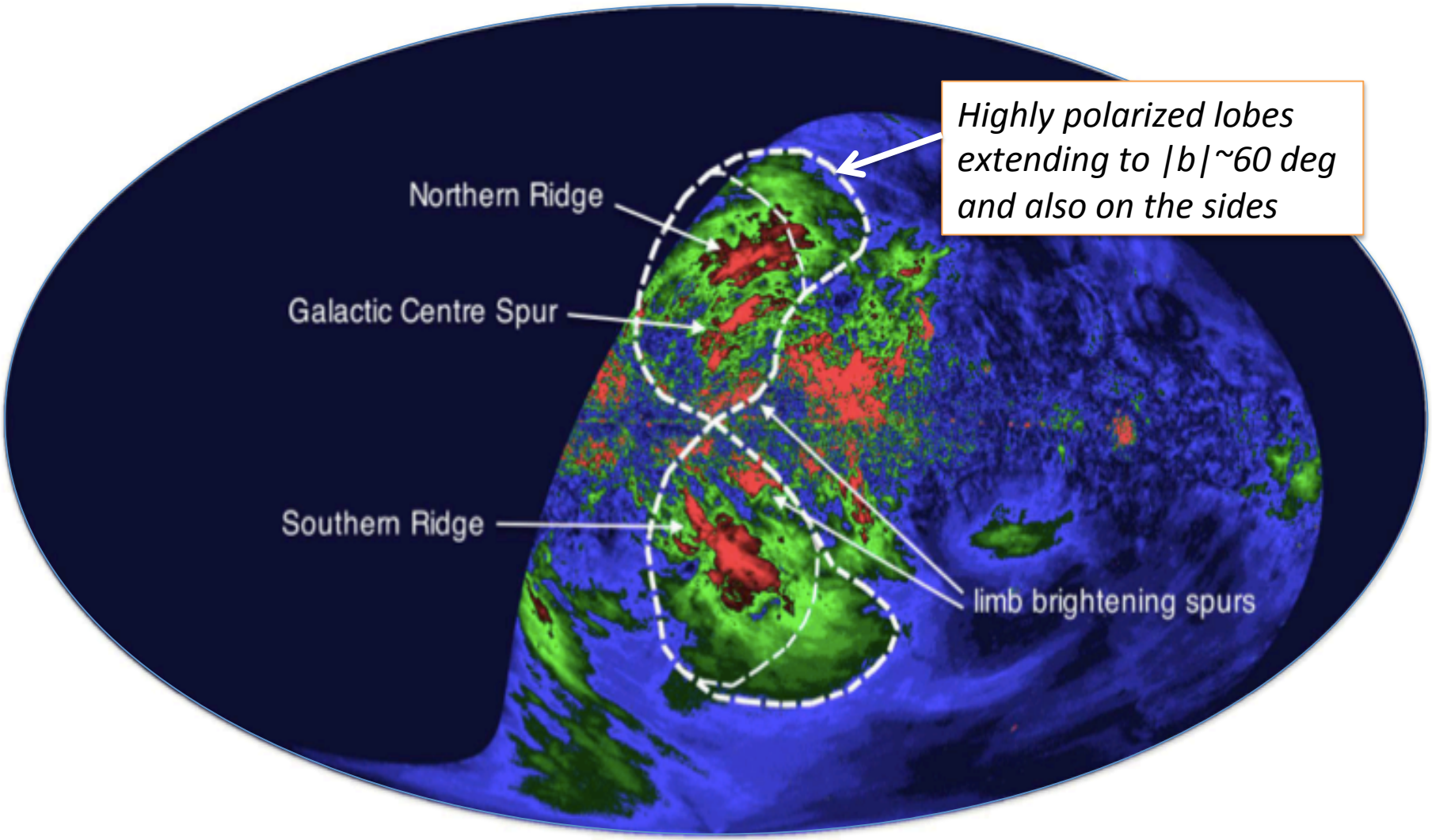


Microwave haze by *WMAP & Planck*

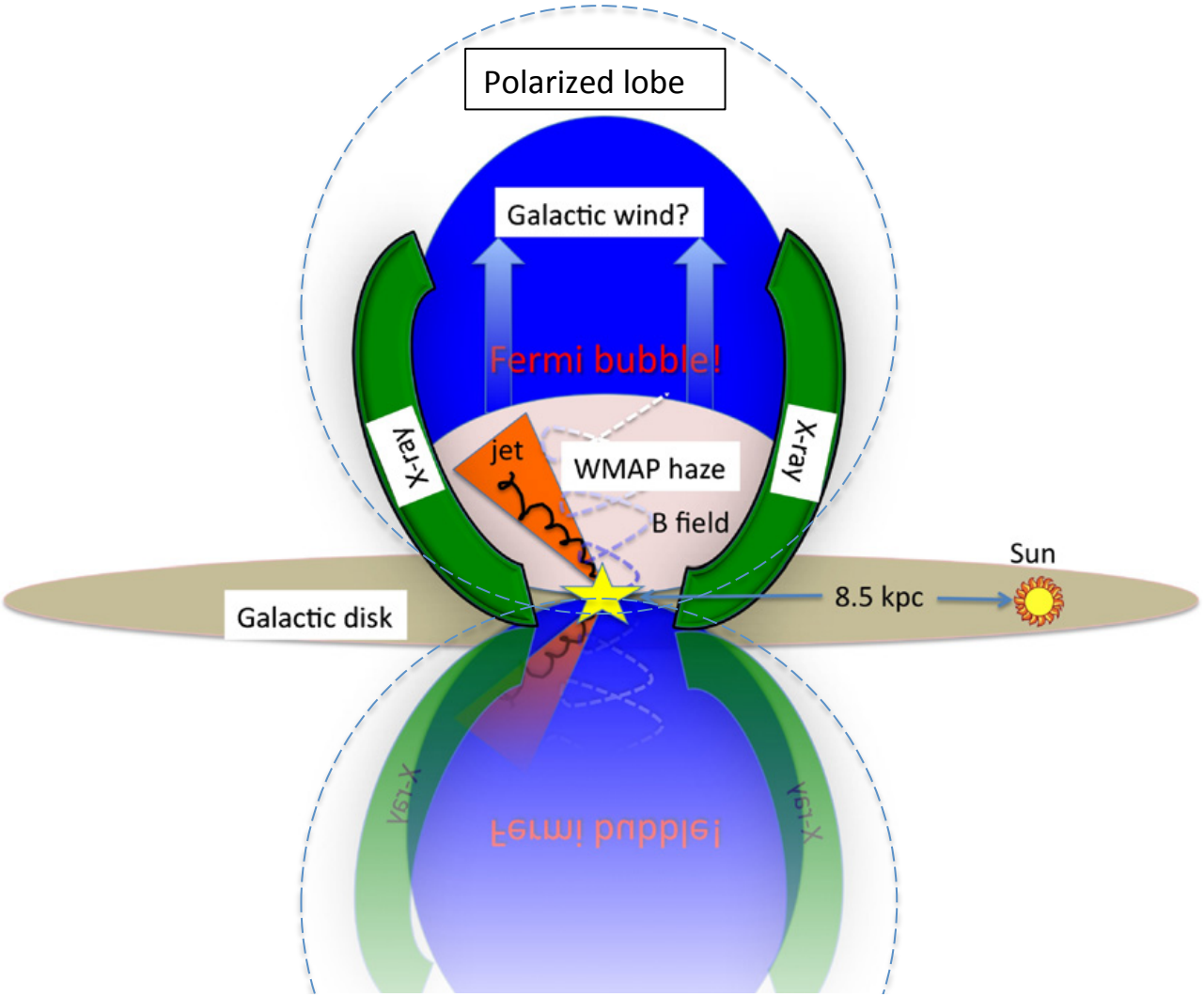
(Finkbeiner 2004, Dobler 2008; Planck Collaboration 2012)



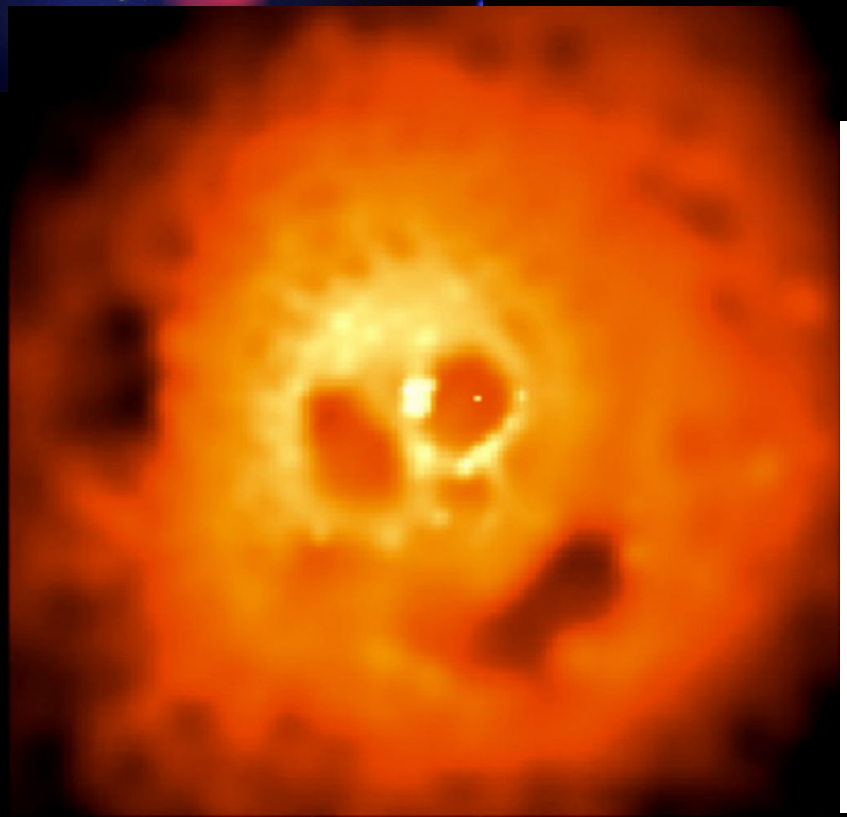
Polarized lobes at 2.3 GHz by *S-PASS* (Carretti 2013)

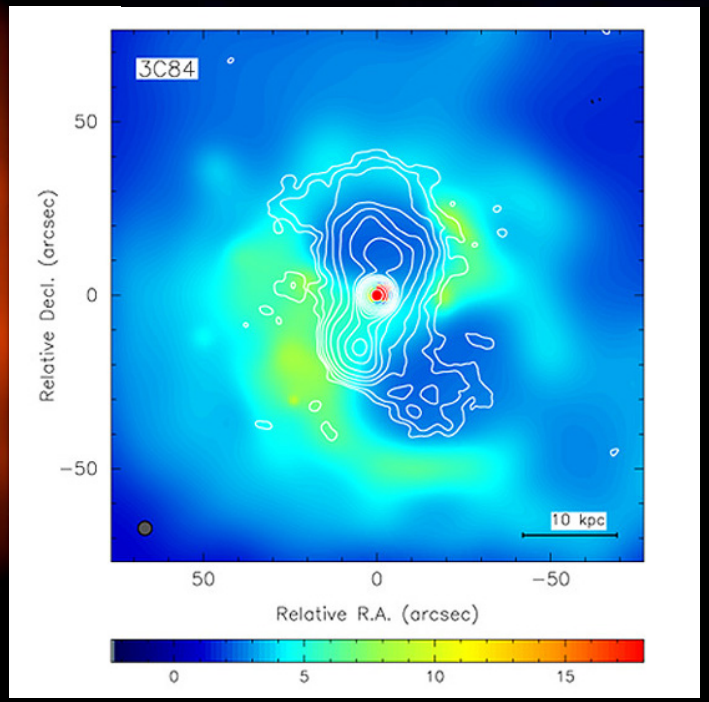


A schematic view



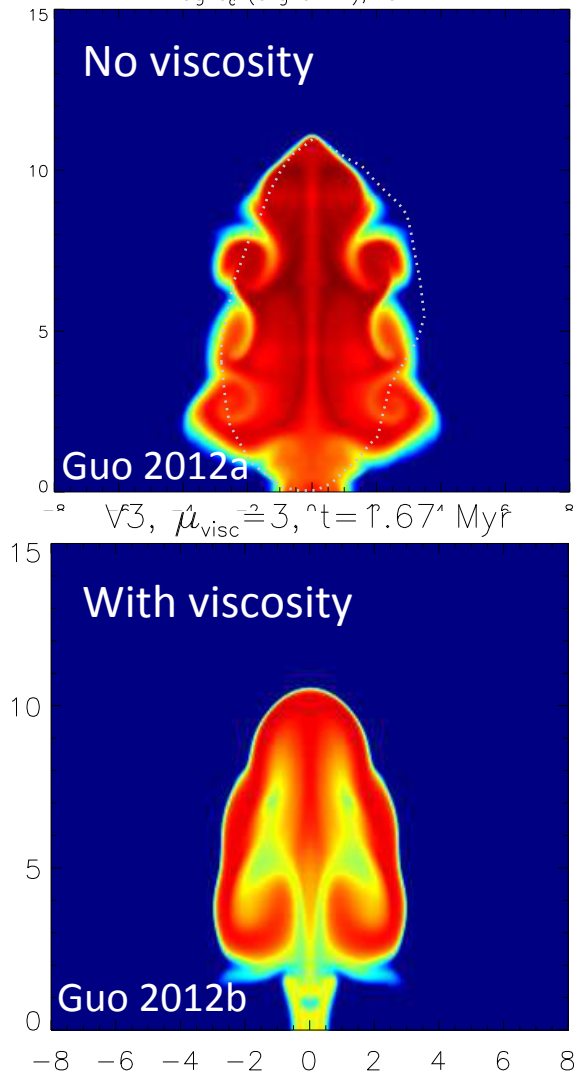
AGN jet-inflated bubbles?





Forming Fermi bubbles by CR jets

CR energy density

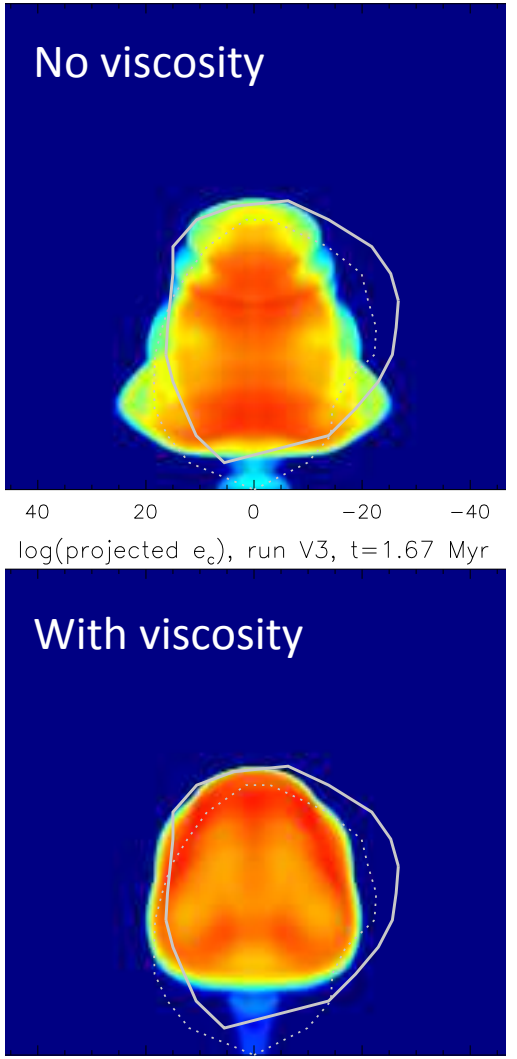


- 2D, hydro simulations including *CR pressure*, *advection* and *diffusion*
- Plausible to form bubbles within 2-3 Myr
- Axial ratio reproduced

- Large-scale instabilities
- Edge-darkened surface brightness

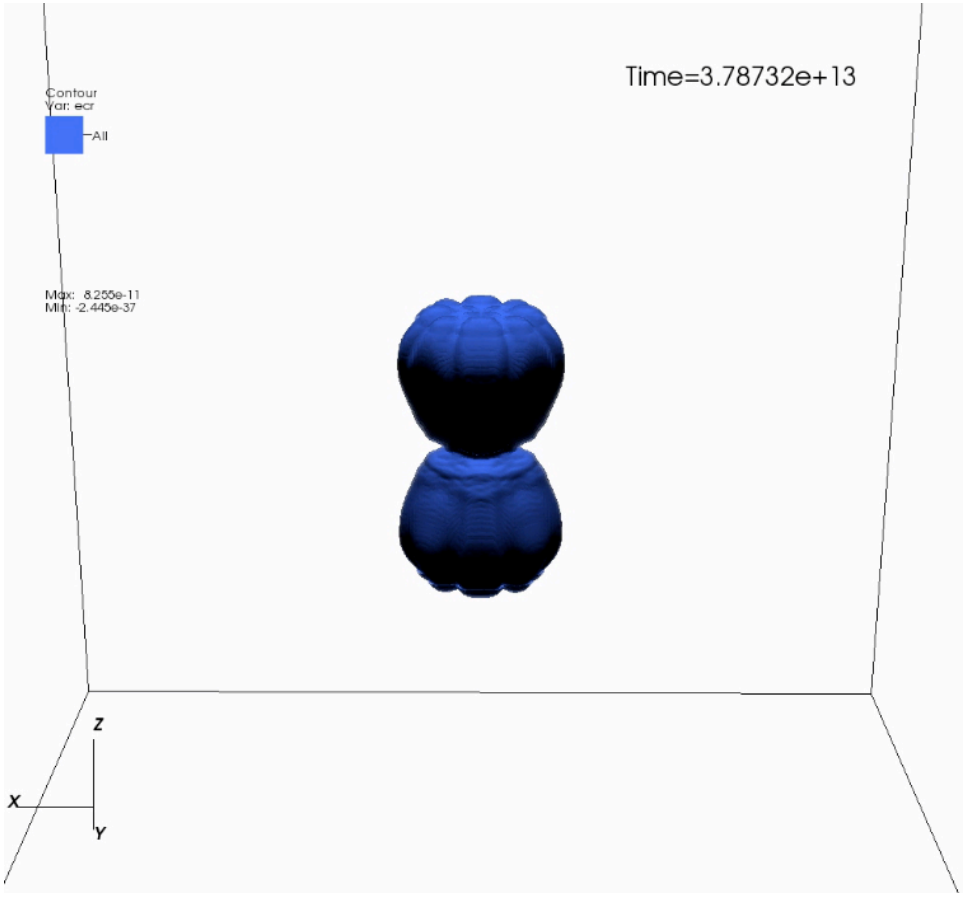
=> Viscosity may be at work

Projected CR energy density

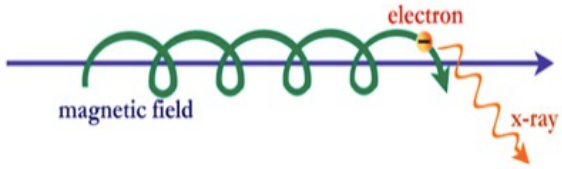


Our Simulations

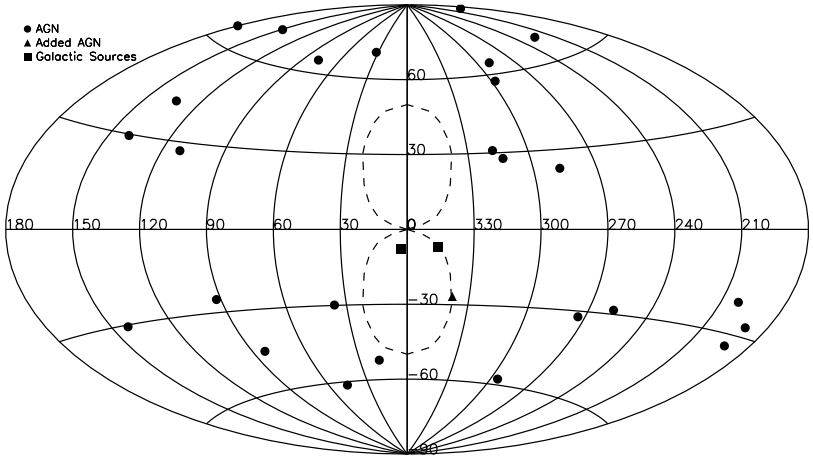
(1) 3D MHD



(2) Anisotropic CR diffusion



(3) Constraints on n_e and T from X-ray absorption lines

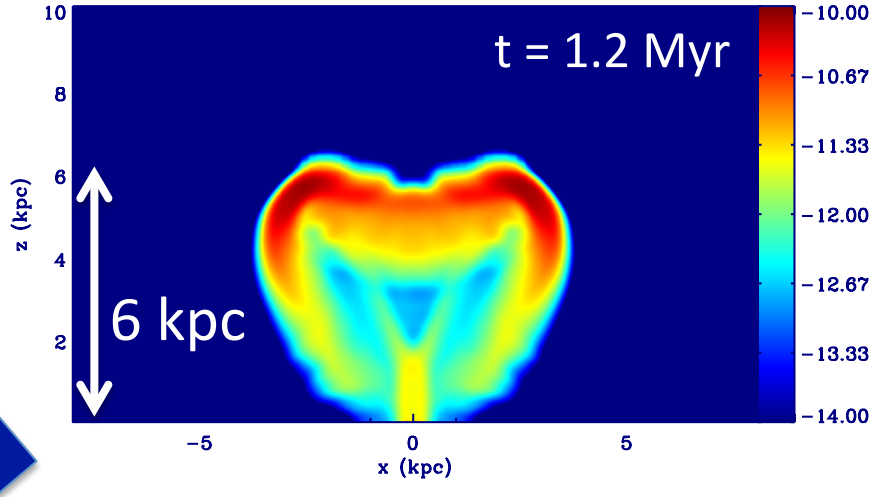


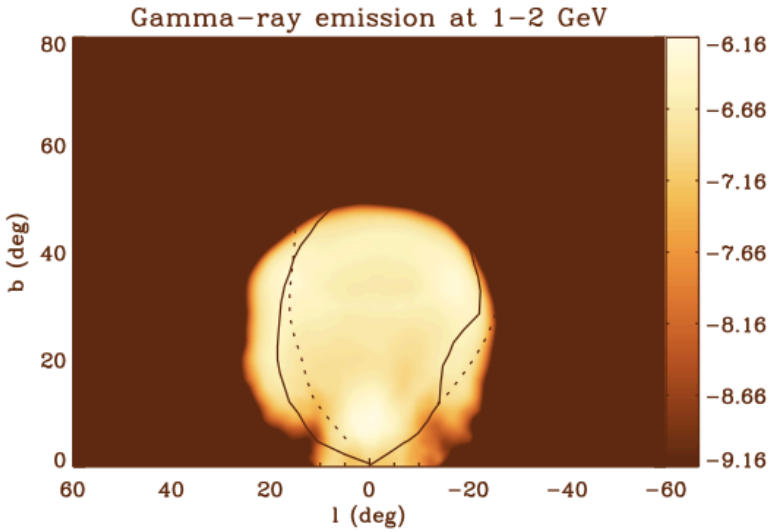
Miller+ 2013

Intrinsic CR properties (Yang+12)

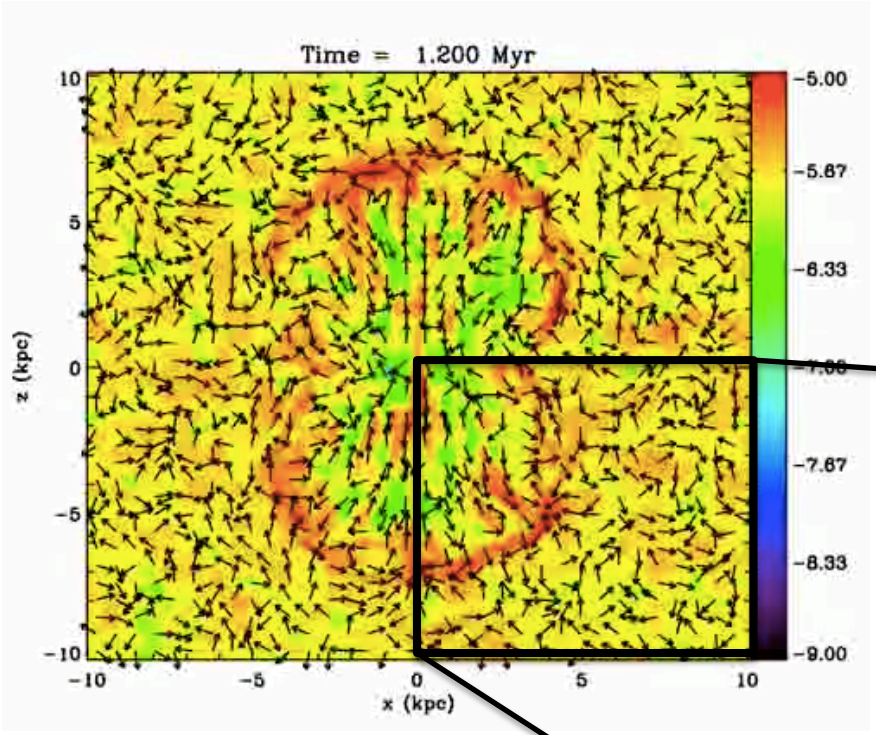
1. Hard spectrum
2. Smooth surface
3. Flat intensity
4. Sharp edges

Slice of CR energy density

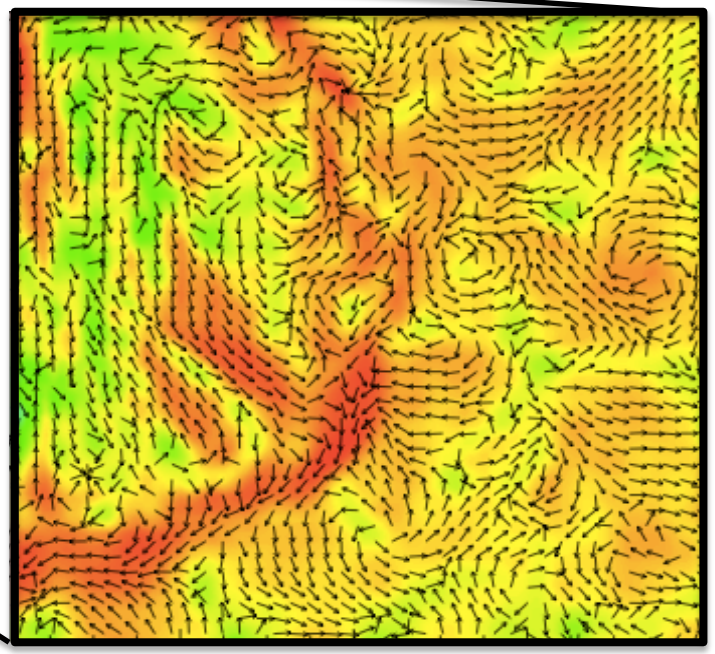




Magnetic draping

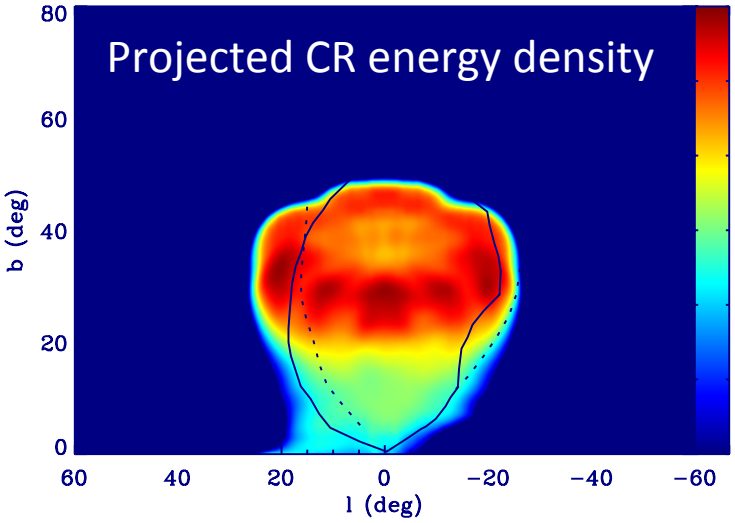


B fields amplified and aligned with bubble surface



Intrinsic CR properties (Yang+12)

Sharp edges



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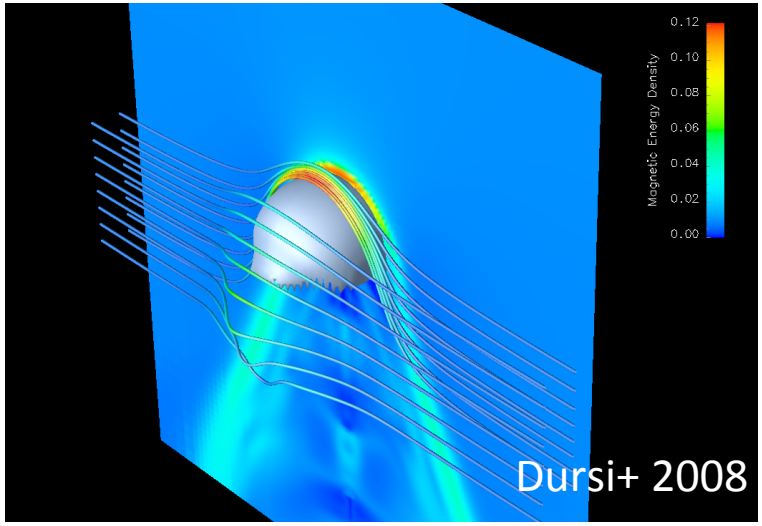
Magnetic draping effect



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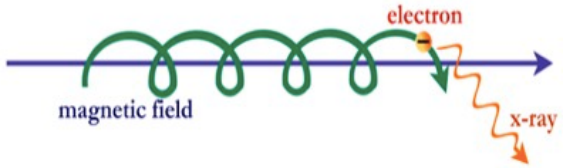
Anisotropic diffusion



Intrinsic CR properties (Yang+12)

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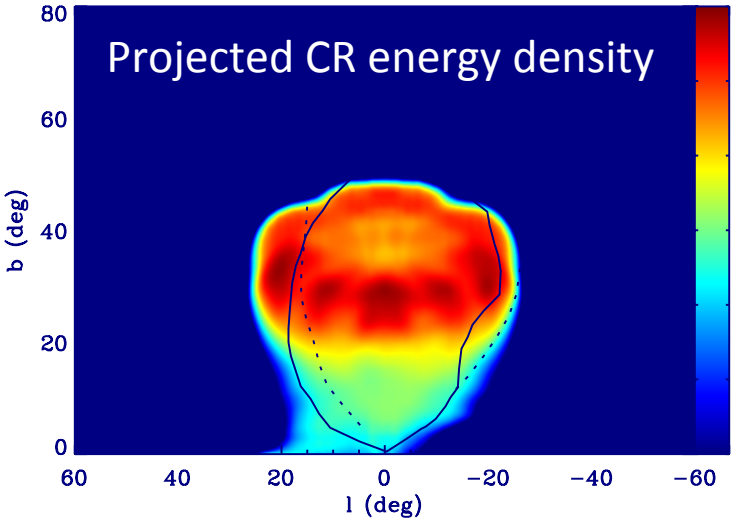
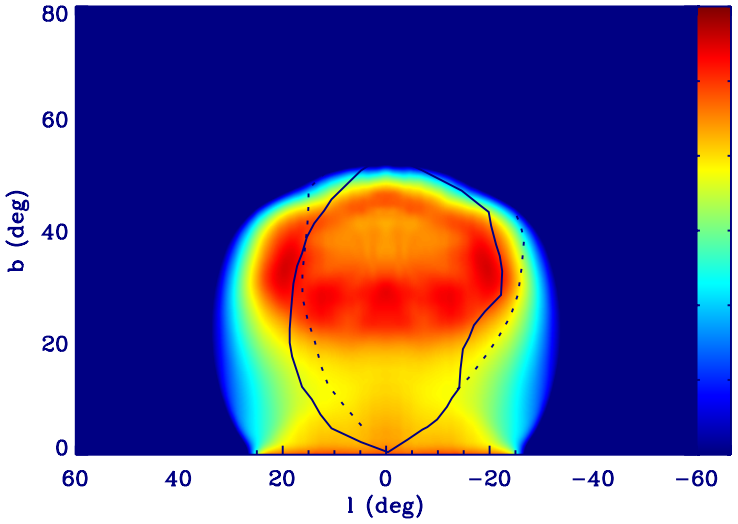
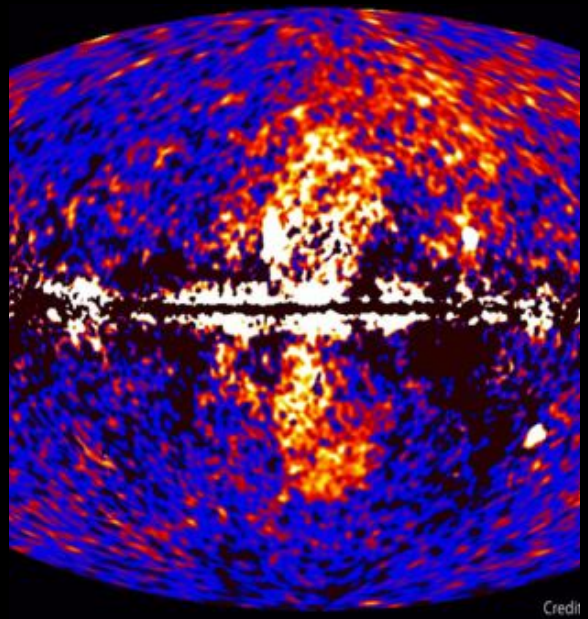
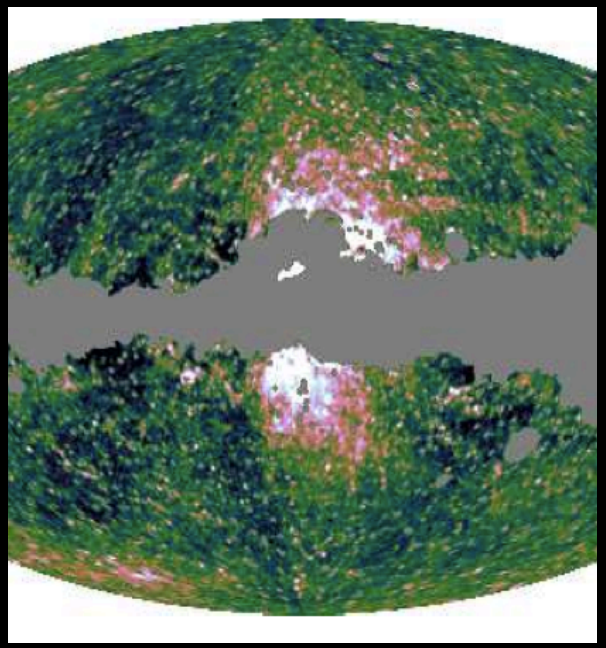


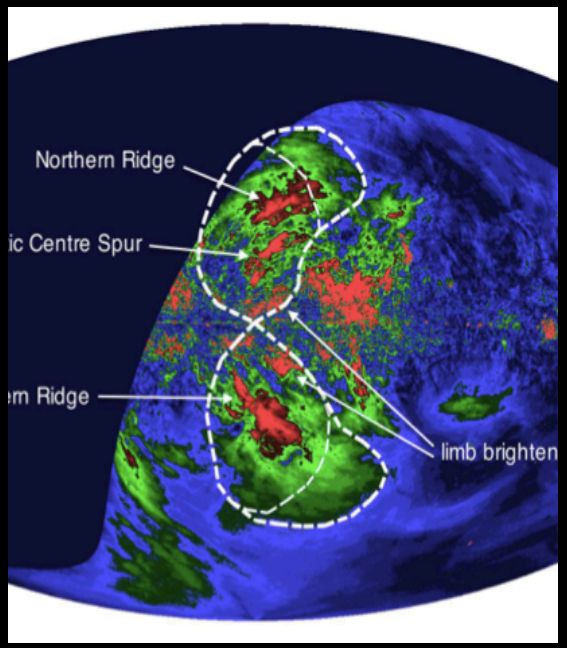
Edges are much smoother
if diffusion were isotropic



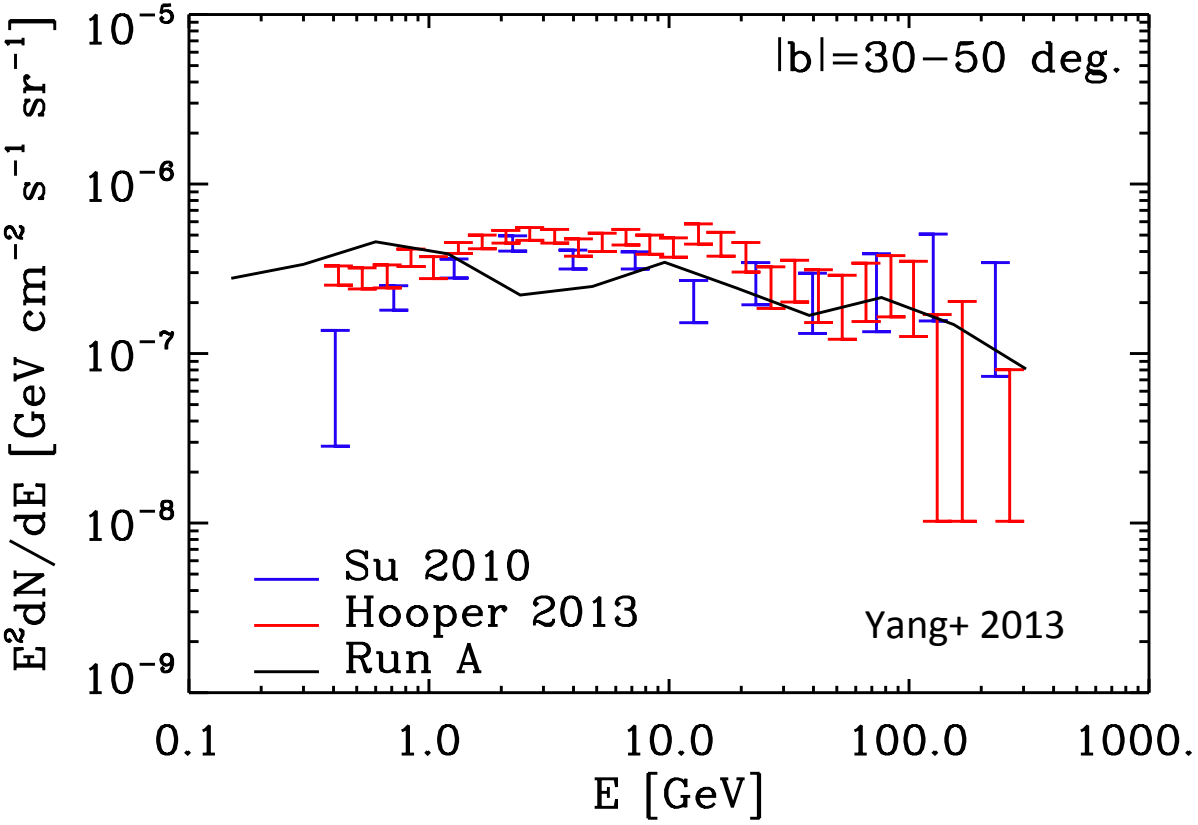
Q: Can we explain the gamma-ray, microwave, and polarization observations by leptonic AGN jets? (Yang+13)





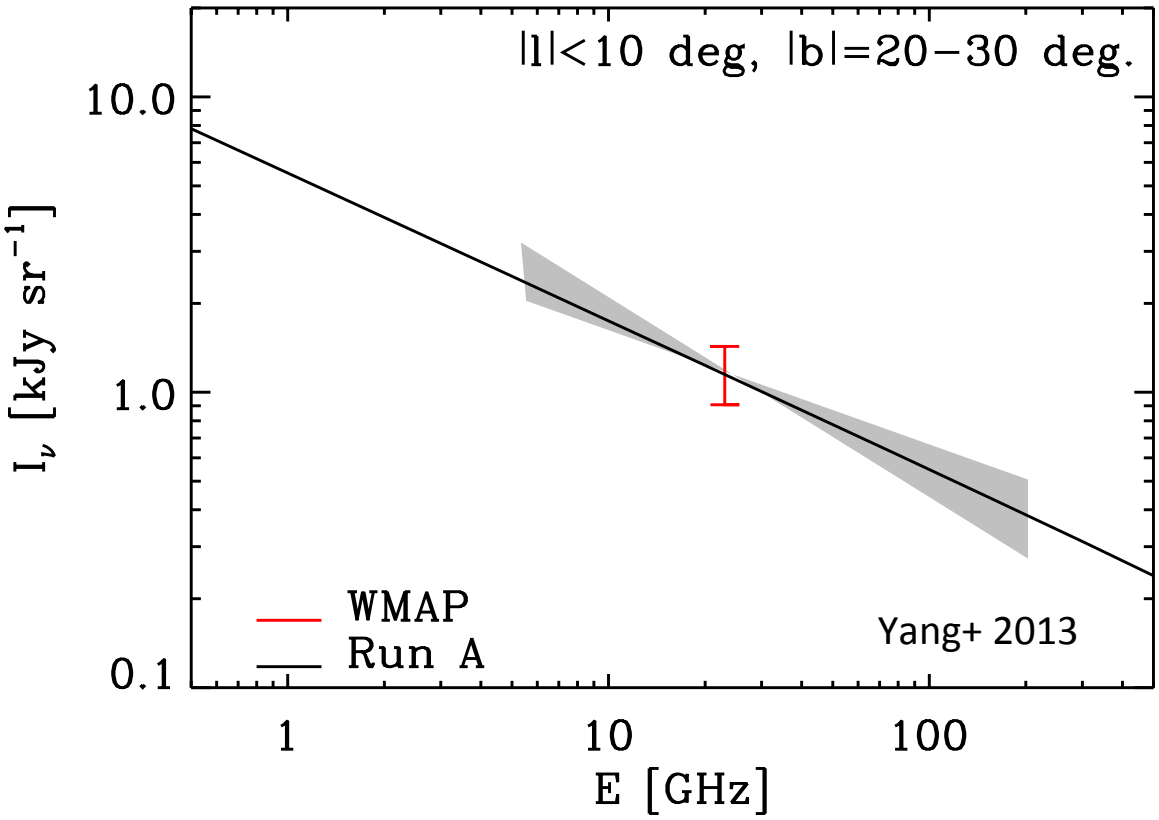


Gamma-ray spectrum



Assuming CRe + GALPROP's ISRF

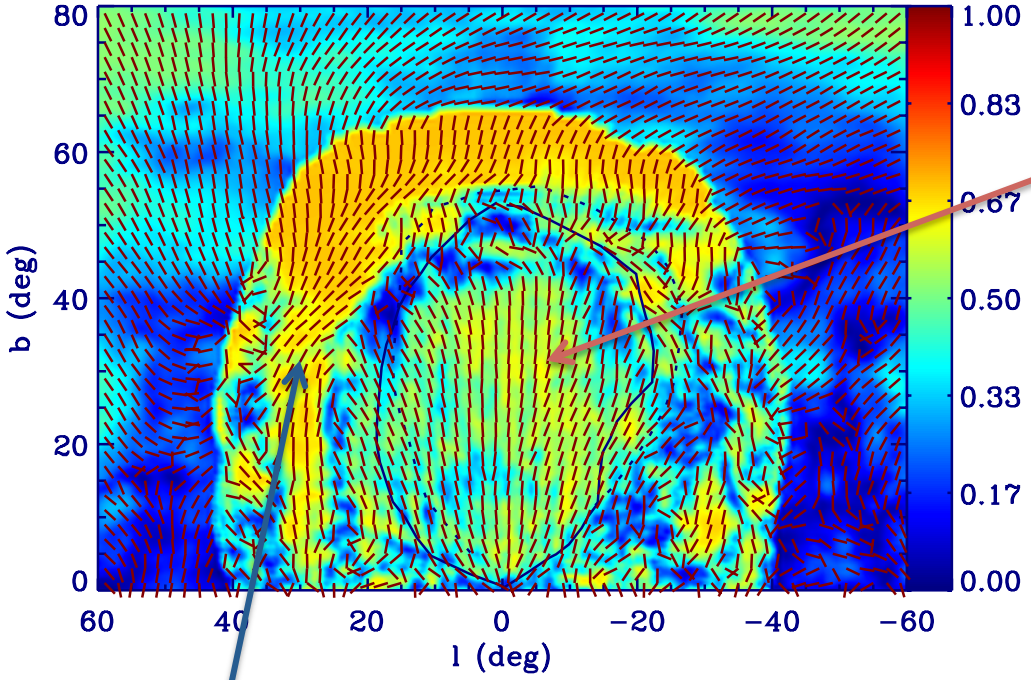
Microwave spectrum



Assuming CRe & B(bubble)~B(ambient)?

-> Bubble field is mixed in and amplified by ISM turbulence

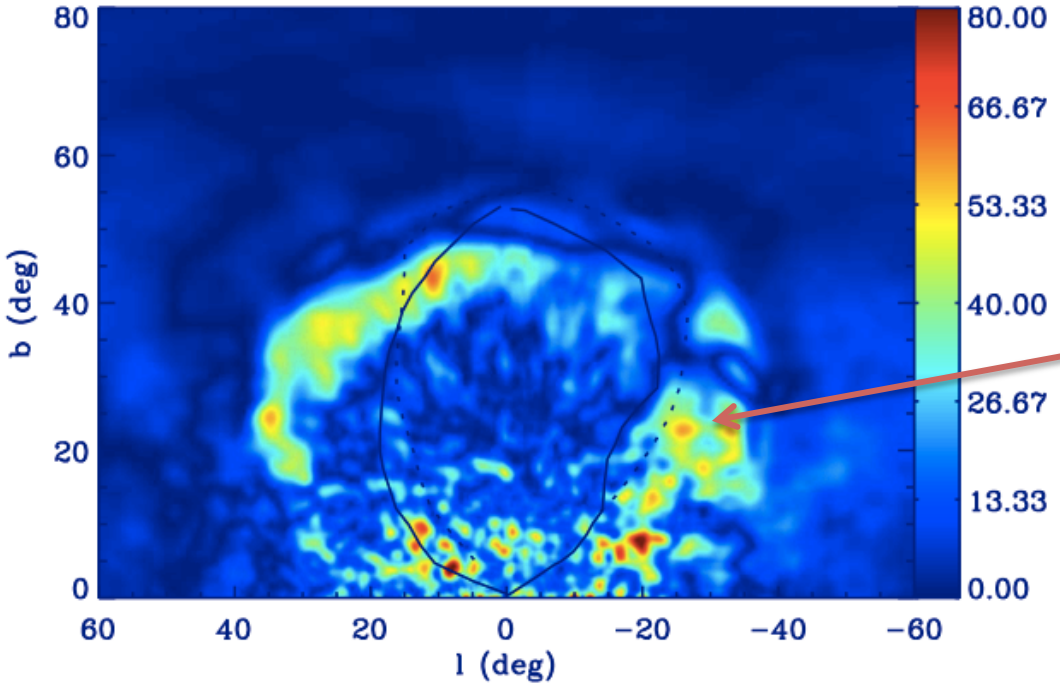
Polarization fraction & Sky-projected B fields



Radial magnetic field lines

- Ordered fields due to **magnetic draping**
- Consistent with larger extension of the 2.3 GHz polarized lobes

Rotation measure



Magnetic draping and shock compression

$$\mathrm{RM} = 812 \int n_\mathrm{e} \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{l} \ \mathrm{rad\ m^{-2}}$$

Summary of the AGN jet scenario

- ✓ Morphology
- ✓ Flat intensity
- ✓ Hard spectrum *due to short formation time*
- ✓ Sharp edges *by draping + anisotropic diffusion*
- ✓ Microwave haze *given turbulence-amplified B*
- ✓ S-PASS polarized lobes
- ✓ Enhanced RM around bubbles *predicted*

Implication for bubble composition

- ❖ Required CRe only ~ 3e-4 of simulated CRs
- ➢ *Bubble pressure dominated by CRp or thermal gas*

Future Prospects

- Modeling CR spectrum

  -> Spatially uniform hard spectrum with high-E cutoff ?!

FLASH now equipped with CR adv. diff. streaming. spectral evolution!