Fermi Bubbles as AGN Laboratories: Supersonic Jets with Anisotropic Cosmic Ray Diffusion (arxiv: 1207.4185)

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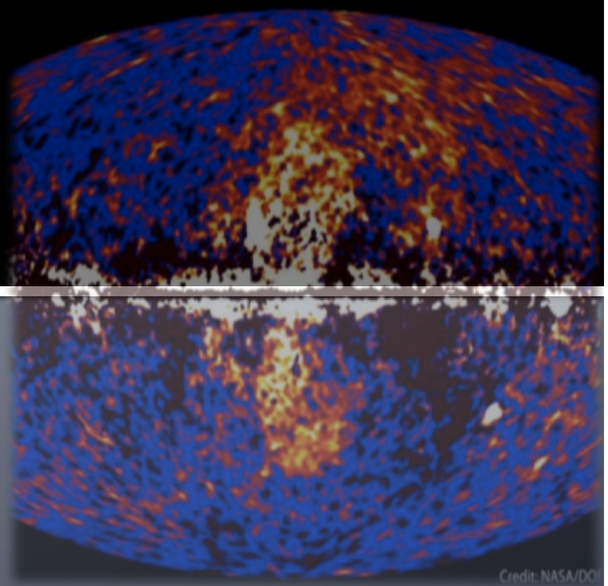
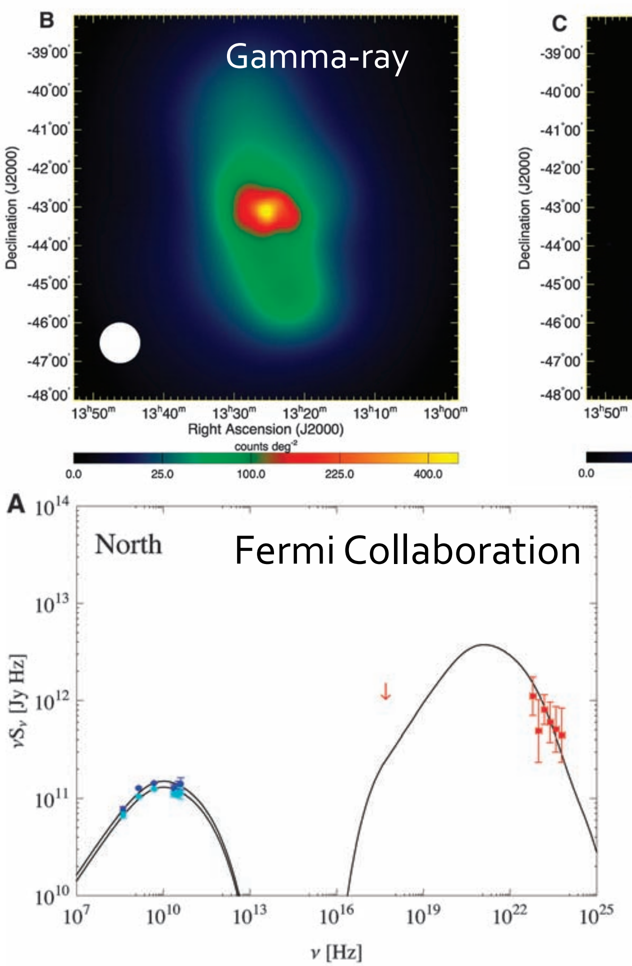


2nd ICM theory & computation workshop
University of Michigan
August, 30, 2012

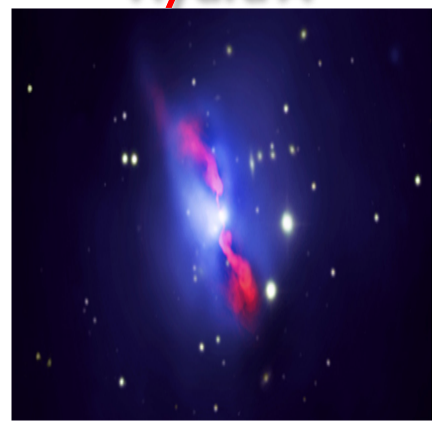
Nonthermal emission from AGN lobes/bubbles

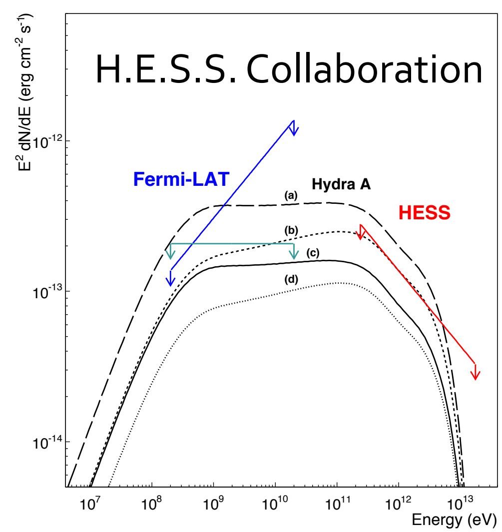
Centauras A



- $U_{CMB} \sim 10 U_B$
- 0.1-1TeV e-

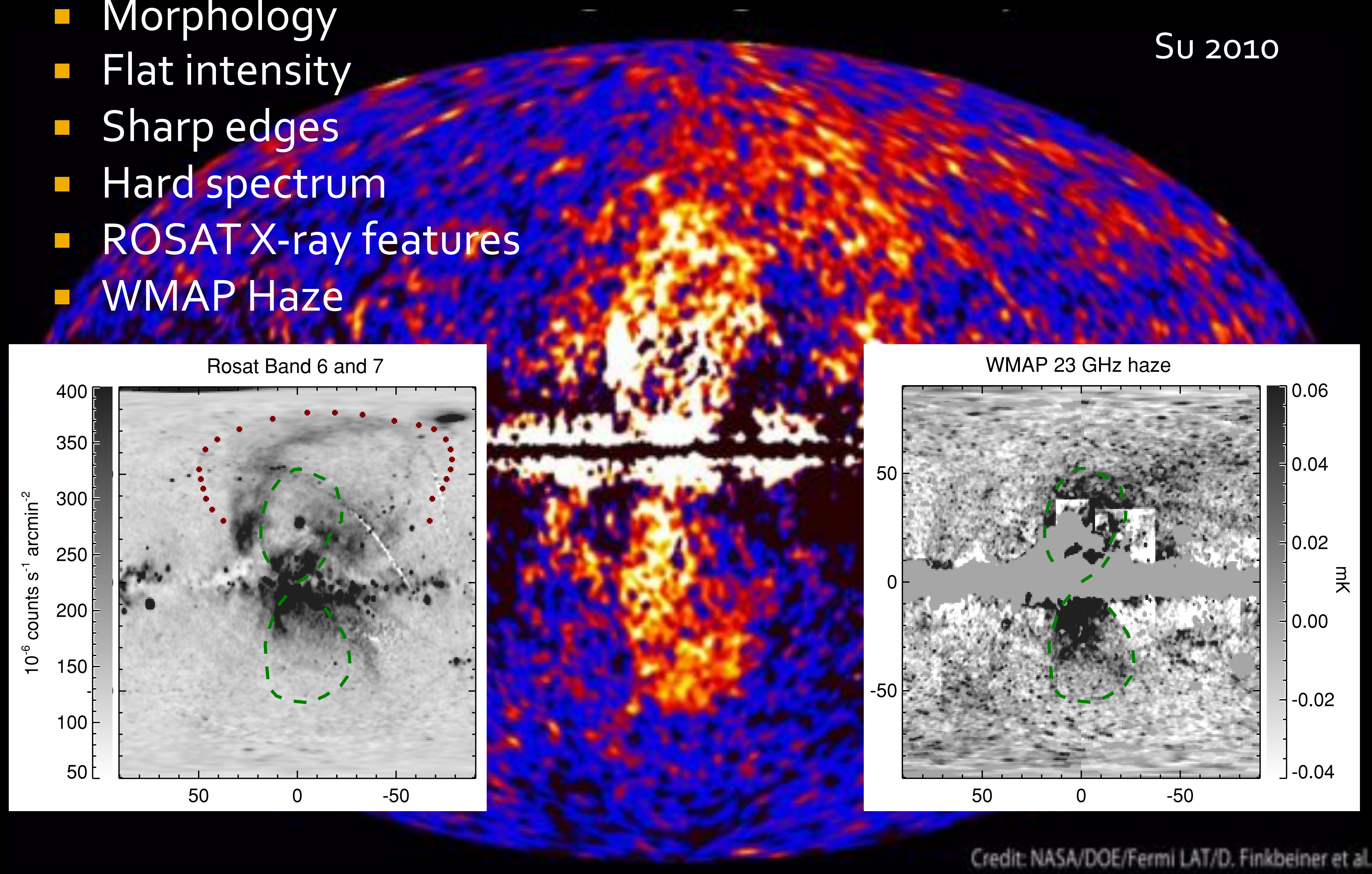
Hydra A





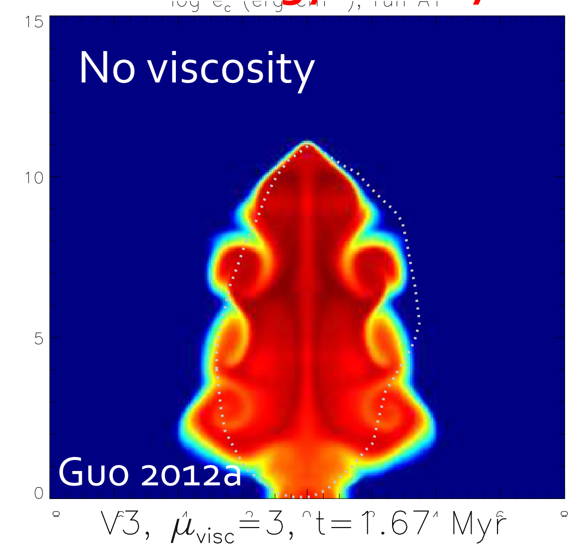
Fermi bubbles – possible evidence for past jet activity of Sgr A*

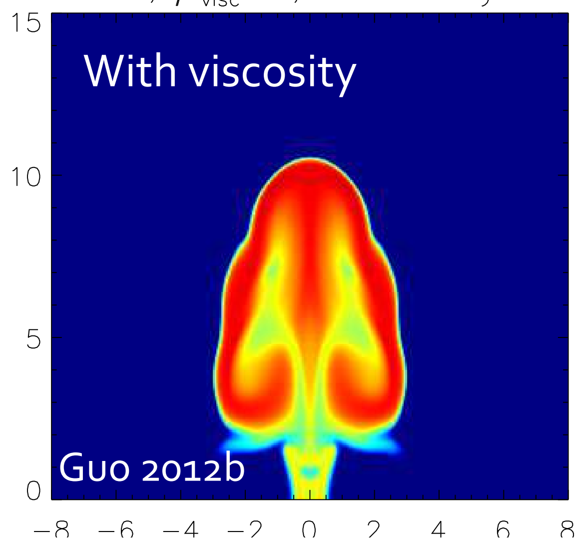
- Morphology
- Flat intensity
- Sharp edges
- Hard spectrum
- ROSAT X-ray features
- WMAP Haze



Forming Fermi bubbles by CR jets

CR energy density



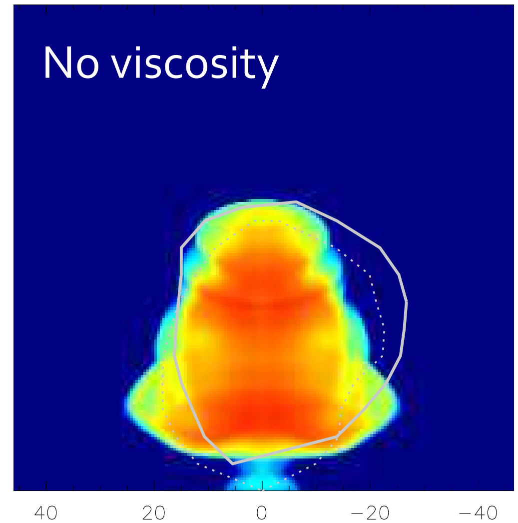


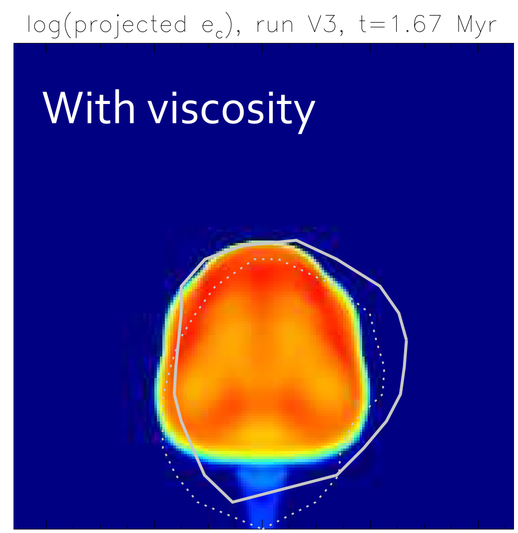
- 2D, hydro simulations including *CR pressure*, *advection* and *diffusion*
- Plausible to form bubbles within 2-3 Myr
- Axial ratio reproduced

- Large-scale instabilities
- Edge-darkened surface brightness

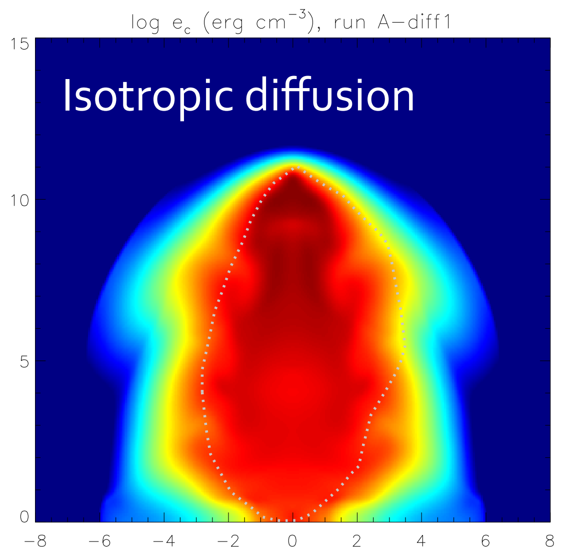
=> Viscosity may be at work

Projected CR energy density

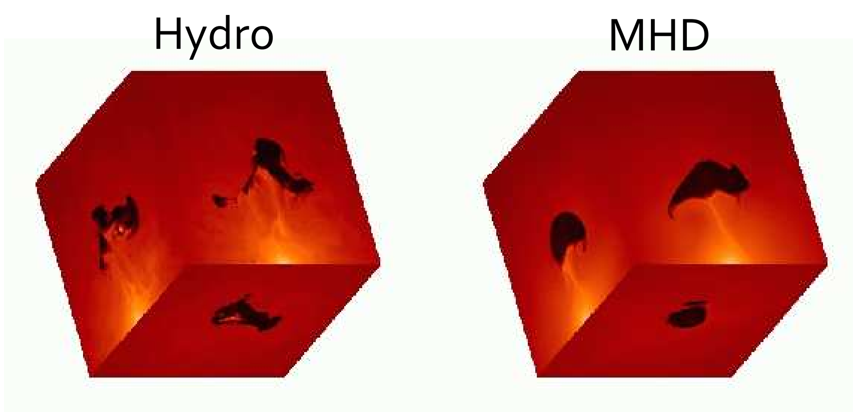




Why are the bubble edges sharp?



- Sharp edges imply suppression of CR diffusion across bubble surface
- Due to magnetic draping + anisotropic CR diffusion?



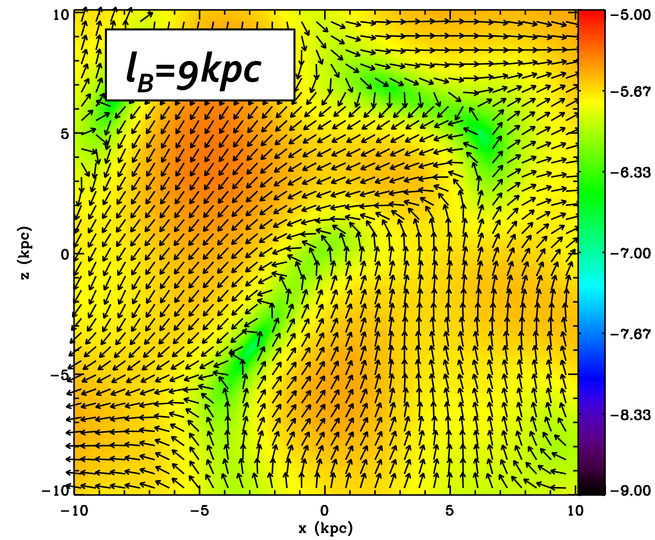
Ruszkowski 2007, 2008

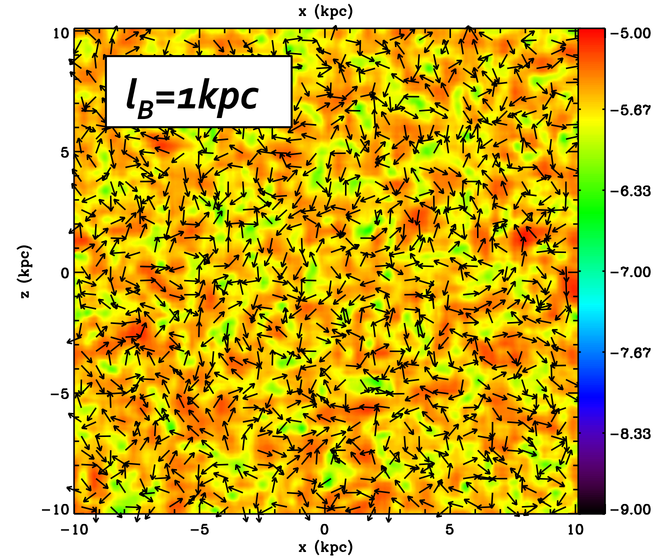
3D MHD simulations of CR jets with anisotropic CR diffusion

- FLASH, unsplit staggered mesh MHD solver, *new* CR module
- Included physics
  - CR pressure and advection
  - Ambient tangled (*mean*) magnetic fields
  - Injected magnetic fields (f_B=1e-3; Sutter 2012, Li 2006)
  - Anisotropic CR diffusion ($\kappa_{||}$=4e28 or 1.2e29 cm²/s)
- Jet parameters:

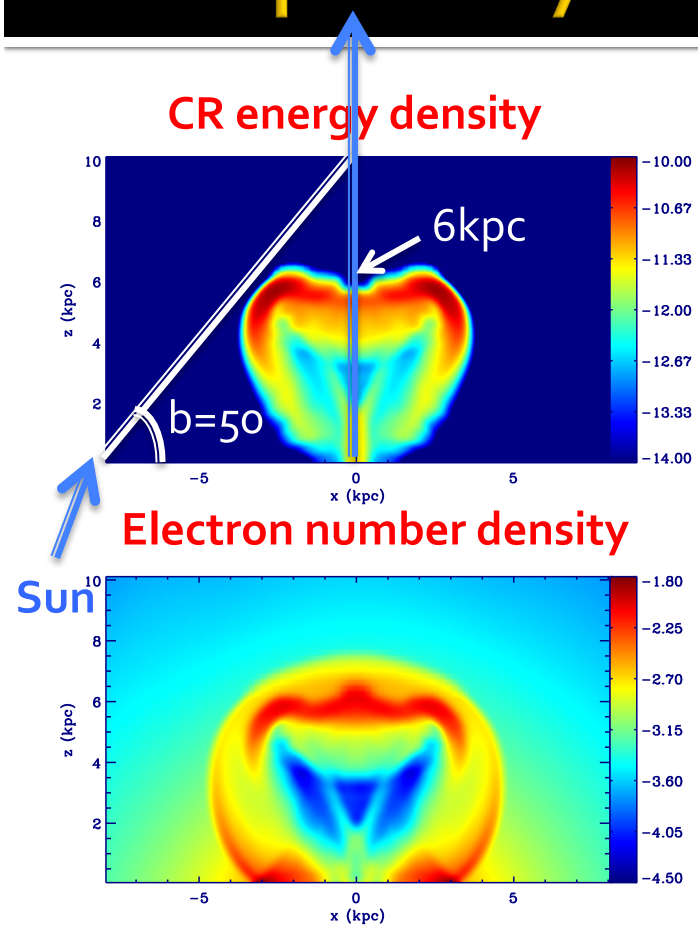
  η_j=0.05, P_{jth}=1.06e-9, P_{jcr}=8.3e-10,

  R_j=0.5kpc, v_j=0.025c, t_j=0.3Myr
- Observational constraints
  - Initial gas density profile (Miller 2012)
  - Bubble temperature ~ a few 10⁷ K (Miller 2012) => R_j, v_j
  - Limb-brightened X-ray image => η_j, t_j
  - Bubble axial ratio => P_{jth} + P_{jcr}

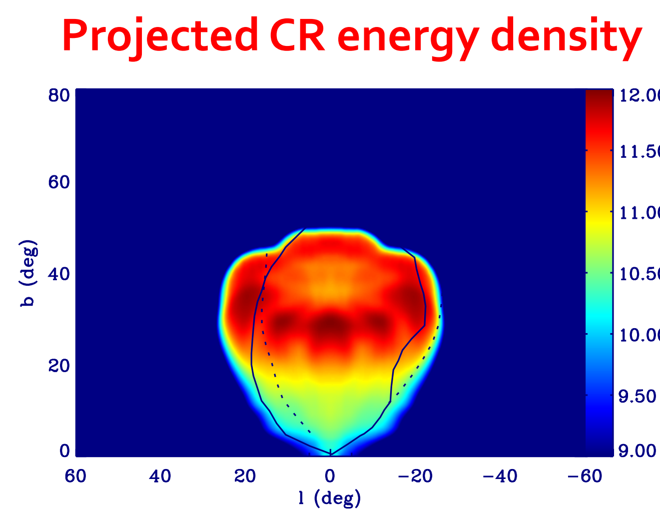




Supersonic jet-inflated Fermi bubbles – the pure-hydro case



- Projection of 3D bubbles => short bubble formation time ~ 1.2 Myr
- Naturally satisfy age constraint from IC cooling time of high-energy electrons
- No sufficient time for instabilities to develop

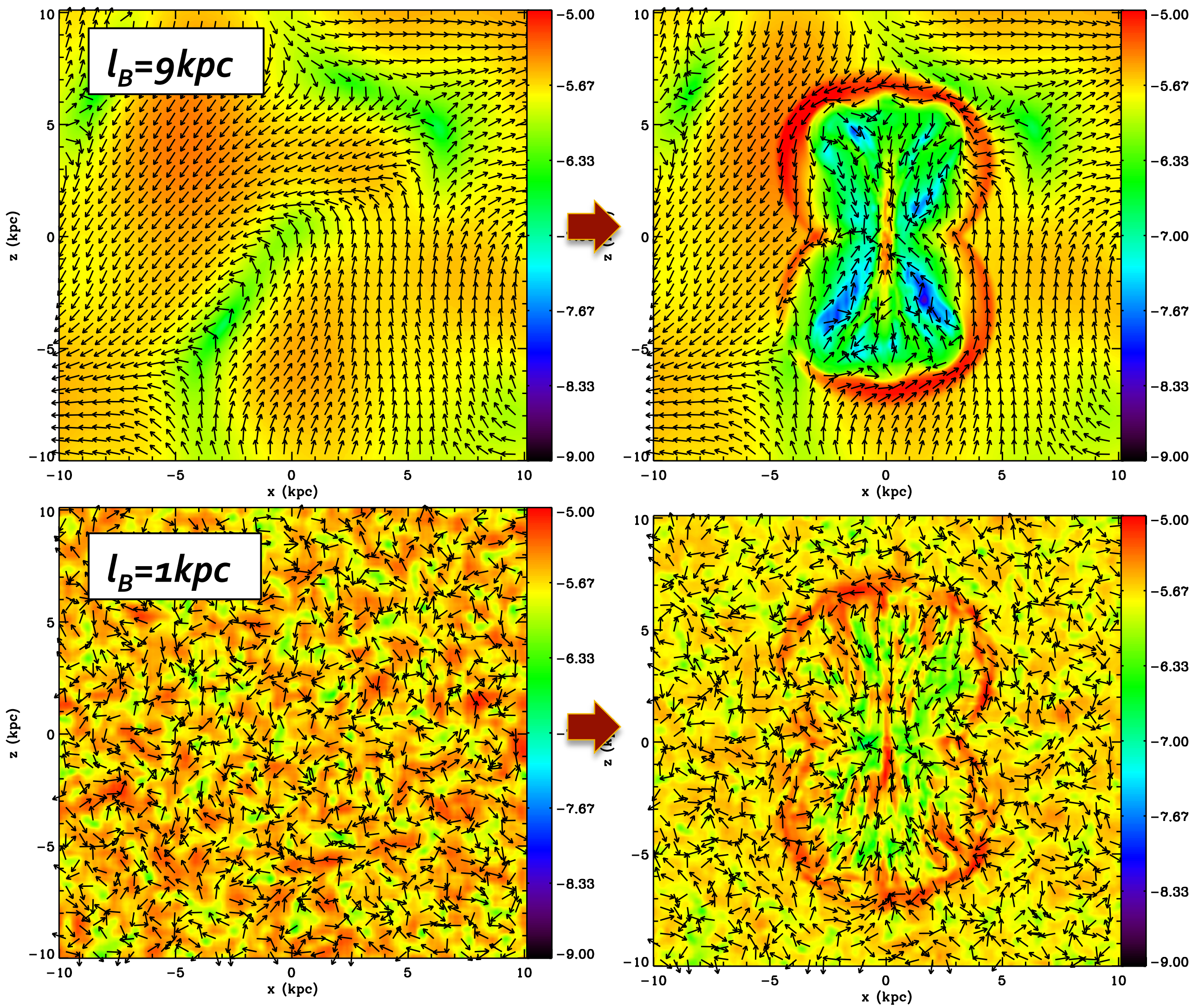


- Edge-brightened CR distribution

=> nearly flat surface brightness (in longitude)

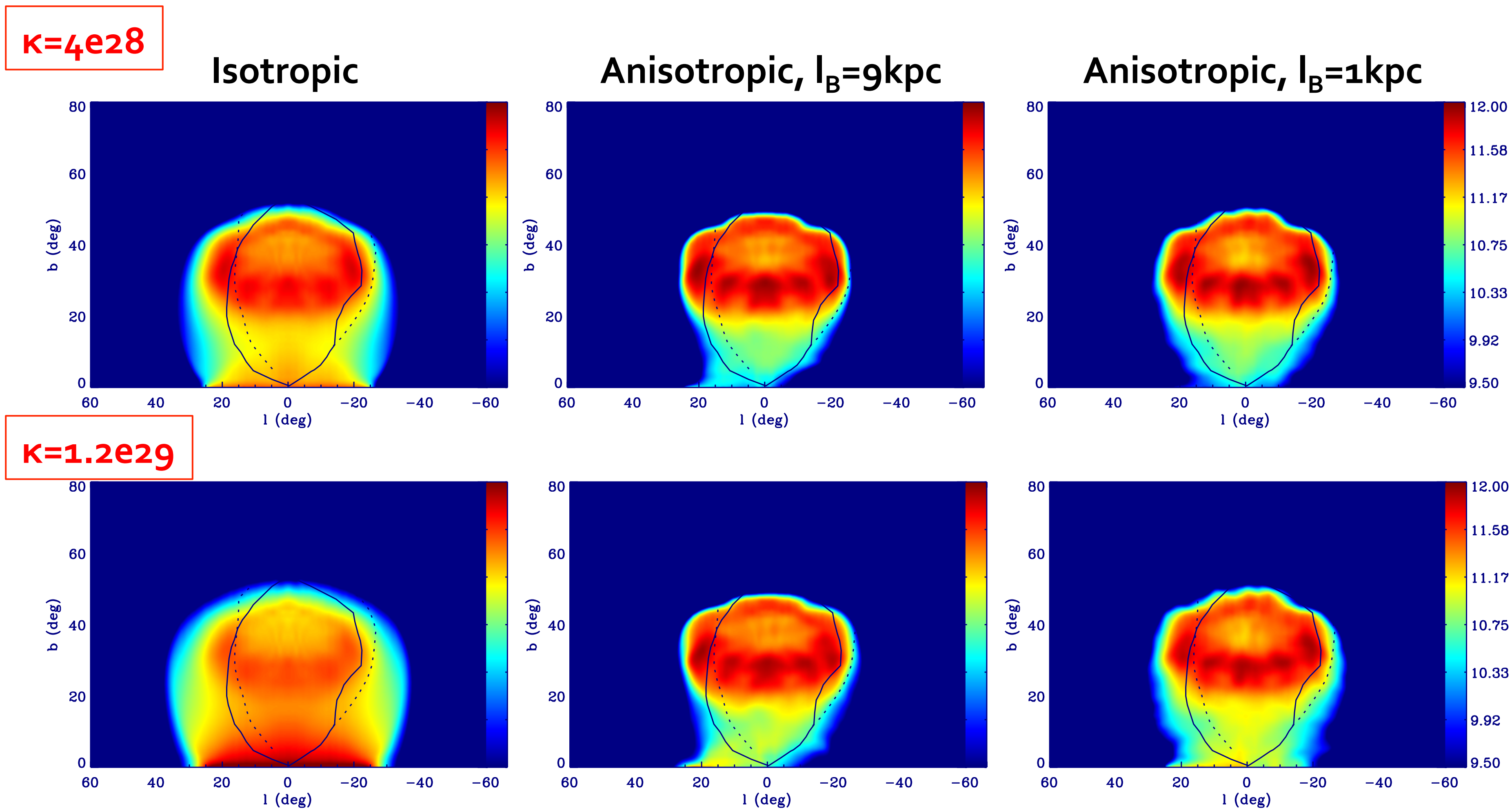
Yang 2012

Magnetic draping due to supersonic bubble expansion



- B fields amplified and aligned with bubble surface
- Draping more effective for fields initially parallel to bubble surface
- Draping more effective when $l_B > R_{bub}$

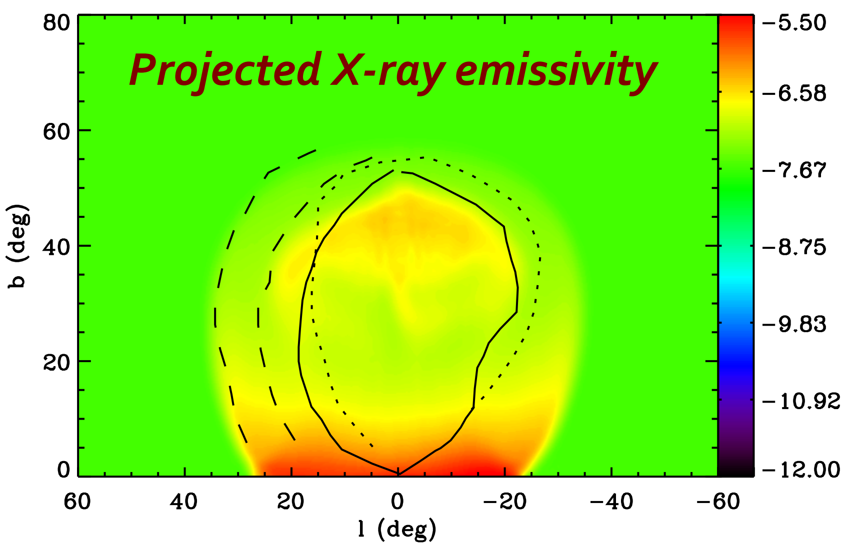
Anisotropic CR diffusion + magnetic draping => sharp bubble edges

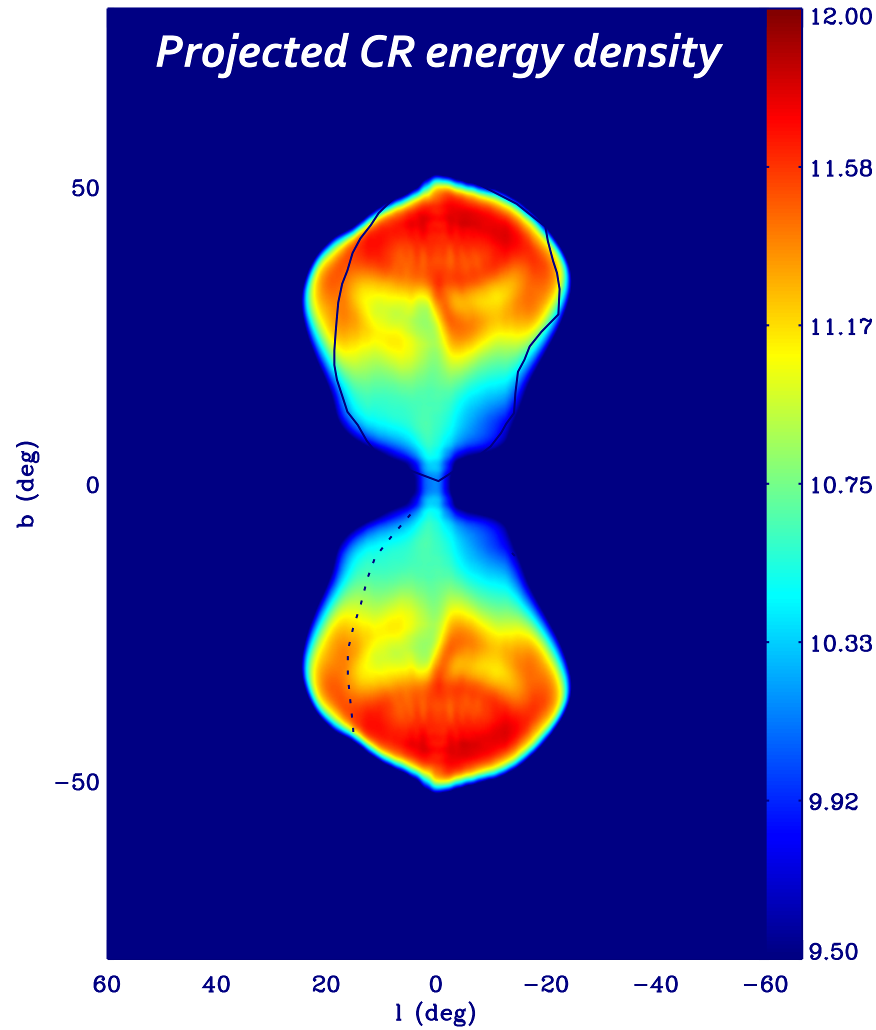


- Bubble shape traces underlying B field if CR diffusivity is large

Slight bends of the Fermi bubbles

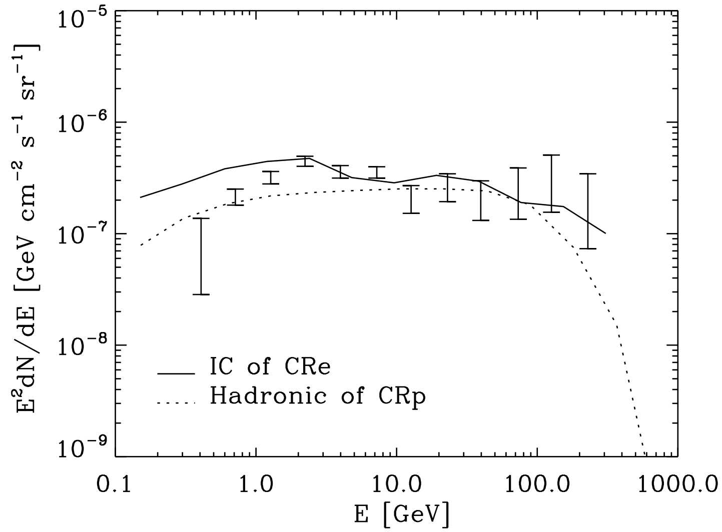
- *Not*: Ram pressure from IGM, jet precession, BH motion
- Both jets tilted to the *east* by 10^o for $0 < t < 0.1t_j$, possibly due to SN ram pressure

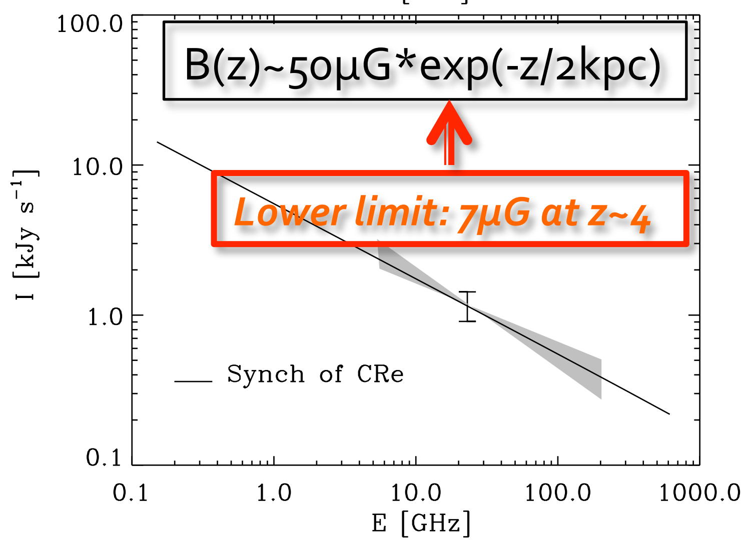




Leptonic or hadronic? (preliminary)

Spectra averaged over |l|<10°, 20°<b<30°





- Either P_{CRe} ~ 5e-4 P_{sim} or P_{CRp} ~ P_{sim} could produce the observed gamma-ray
- Since P_{2nde} < 1e-6 P_{sim}, synchrotron is dominated by primary CRe

⇒ Gamma-ray is also dominated by CRe

⇒ $P_{CRp} << P_{sim}$

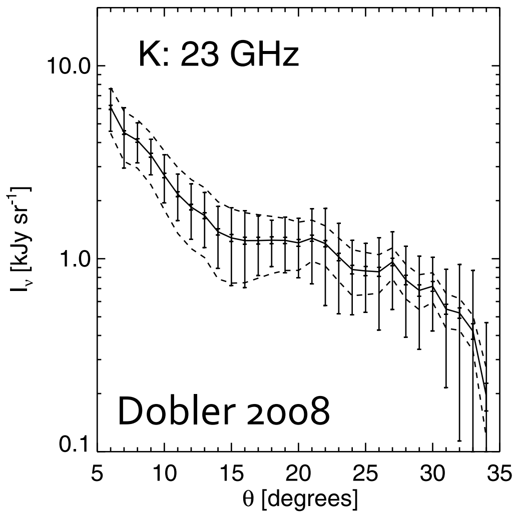
⇒ $P_{sim} = P_{CRe} + P_{CRp} + P_{th}$ (thermal pressure dominates inside the bubbles)

Uncertainties

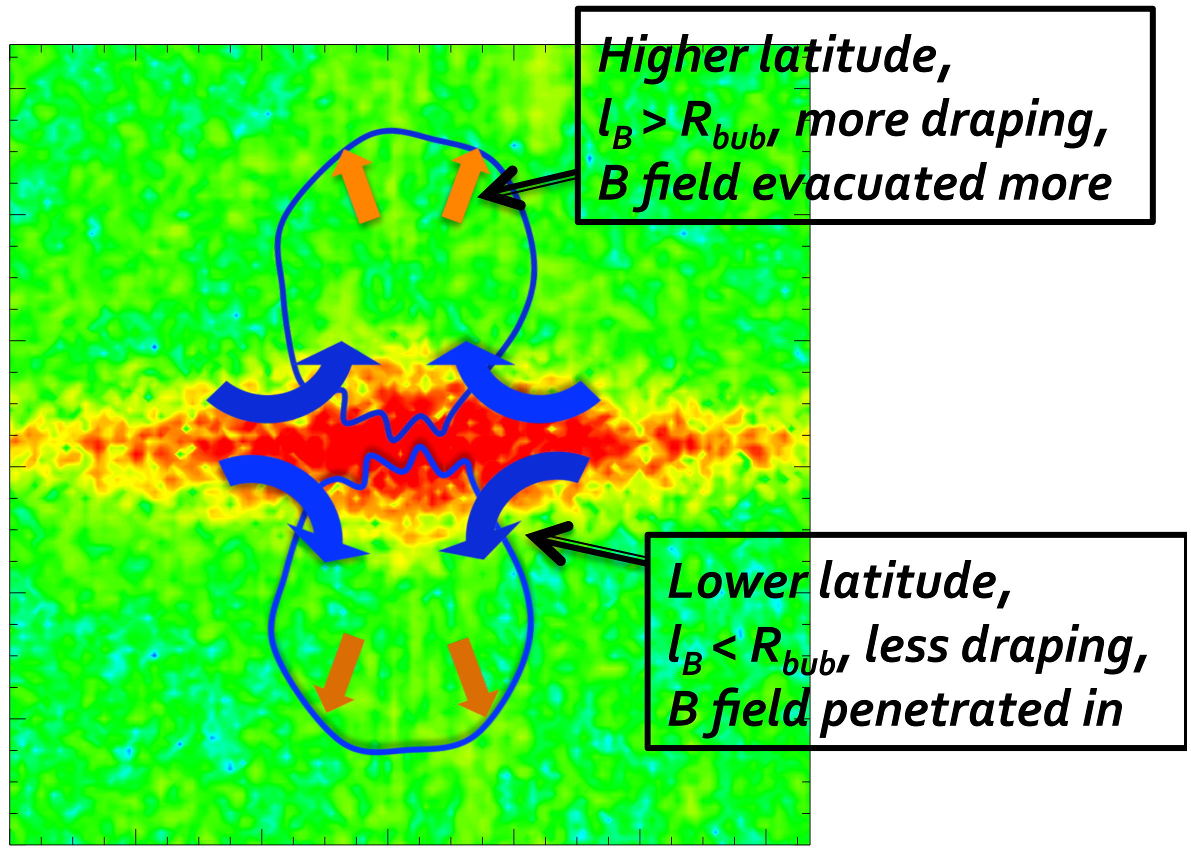
- Spectrum of CRe
- B fields inside the bubbles

How to get large enough strength and gradient of B fields inside the bubbles?

WMAP haze intensity decays away from GC



B(z)~50μG*exp(-z/2kpc)



Summary and future work

- Primary features of the Fermi bubbles are reproduced by our 3D MHD simulations, providing evidence for past AGN jet activity at the GC
- Fermi bubbles are invaluable laboratories to study physics of CRs and B fields, and the compositions of AGN bubbles

- CRe cooling due to IC and synchrotron losses
- CR acceleration by shocks, MHD turbulence, or fast magnetic reconnection