The Fermi Bubbles:

An AGN Feedback Event in the Milky Way?

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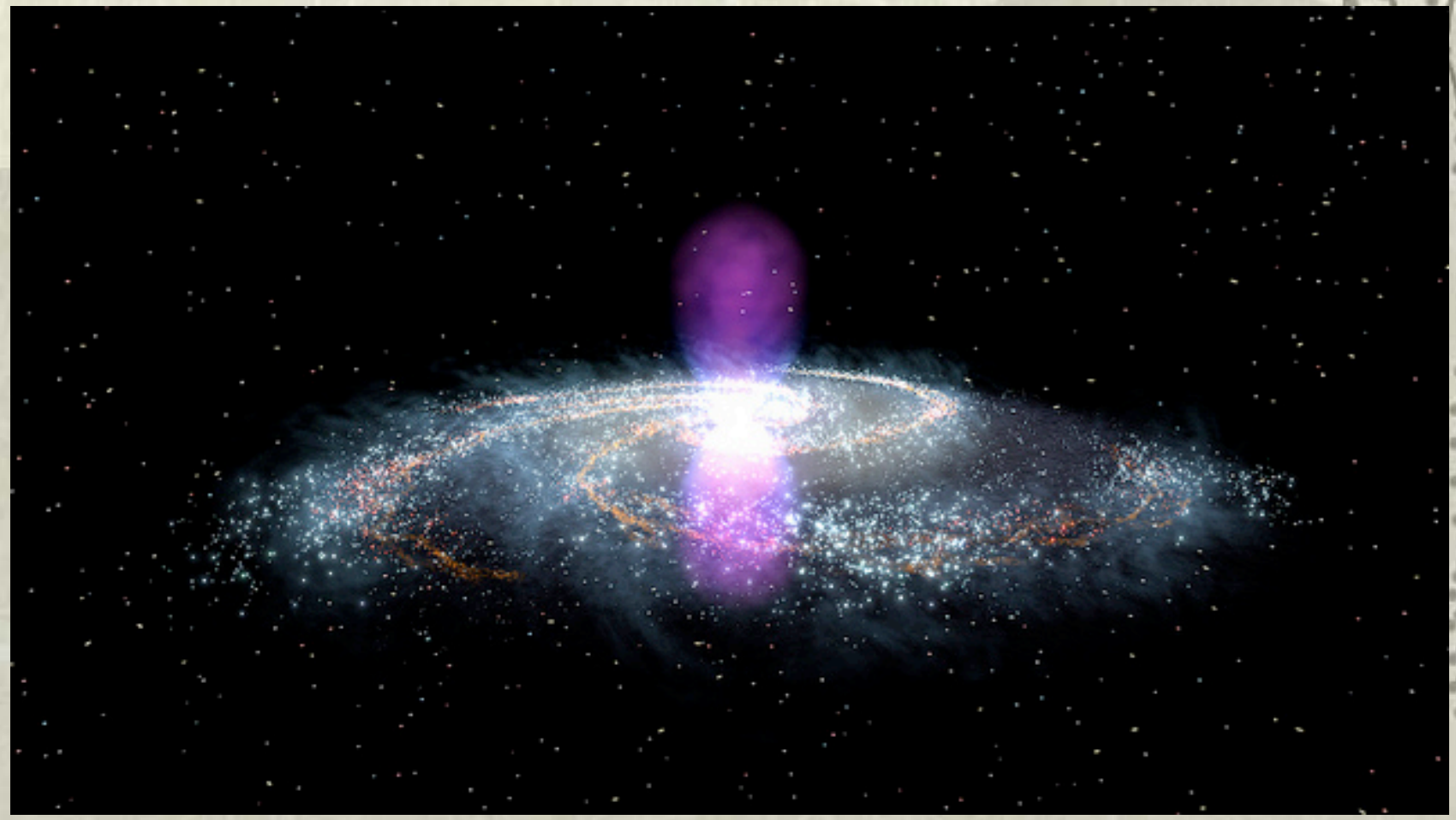
Guo & Mathews, 2011b, arXiv:1103.0055
Guo, Mathews, Dobler, & Oh, 2011, to be submitted soon

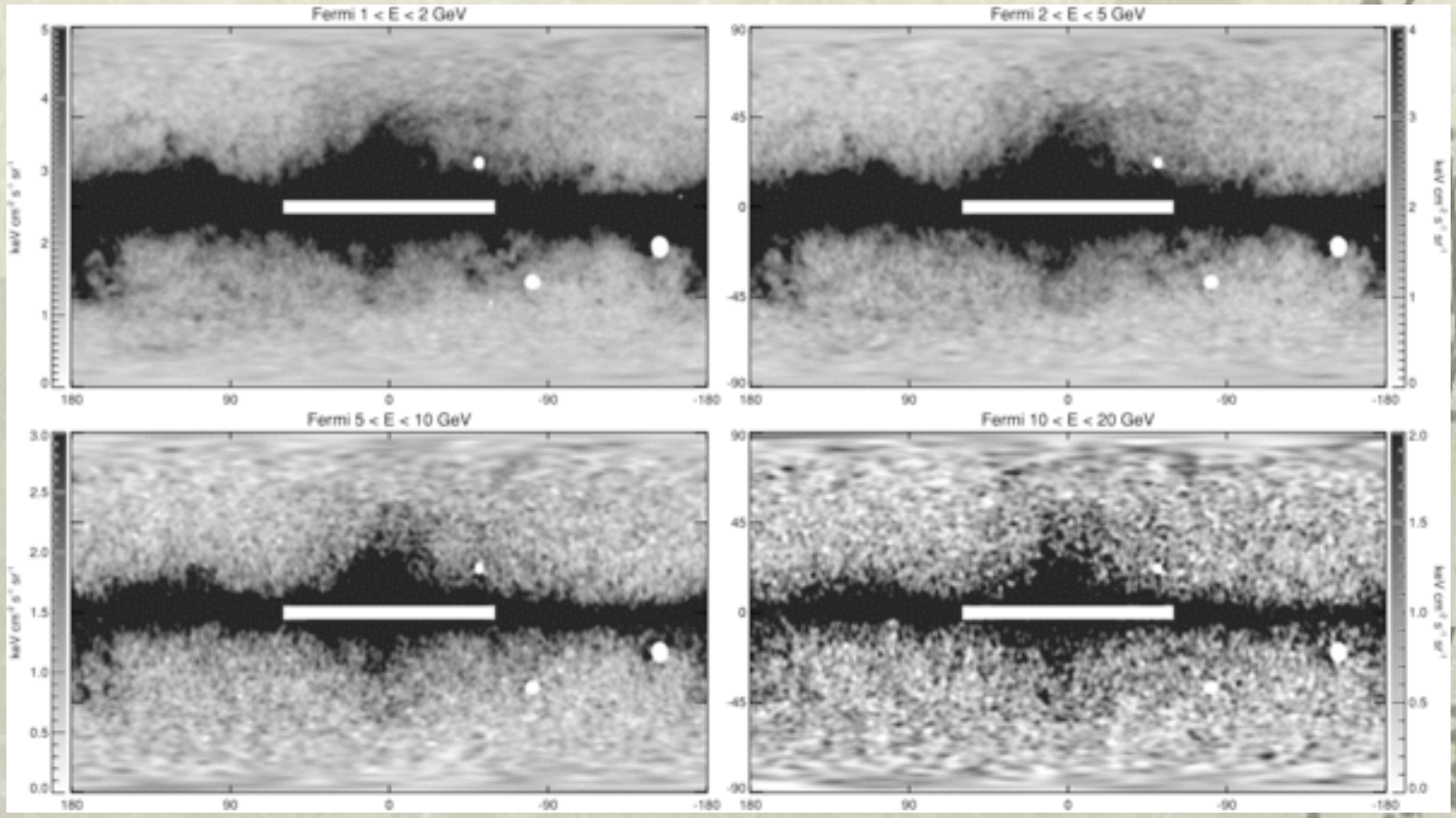
Santa Cruz Galaxy Workshop, Santa Cruz, 08/12/2011

The Fermi Bubbles in the Milky Way



(NASA image)

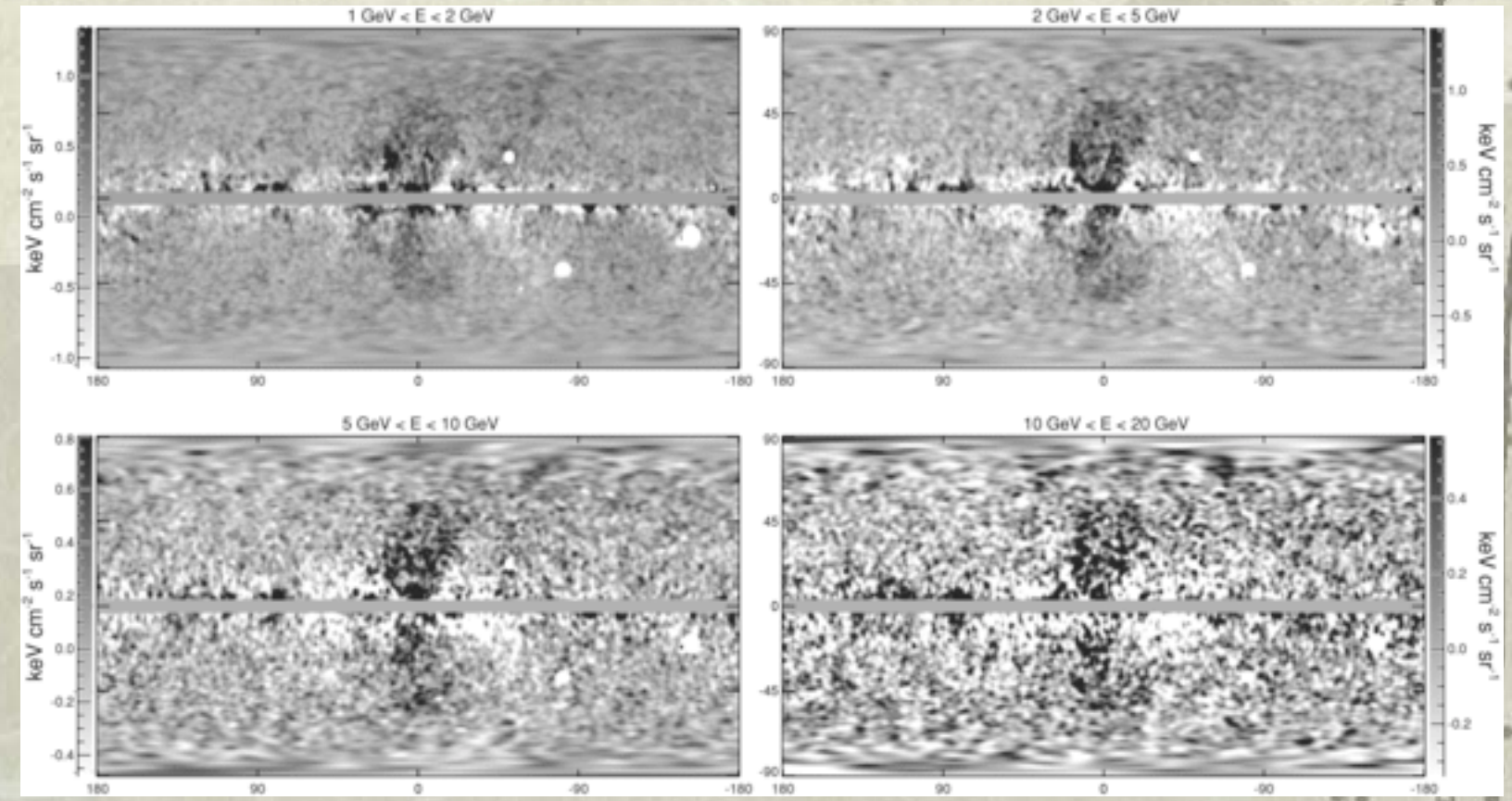
What the Fermi Telescope observed is



All-sky Fermi-LAT 1.6 year maps in four energy bins

Su, Slatyer, and Finkbeiner, 2010

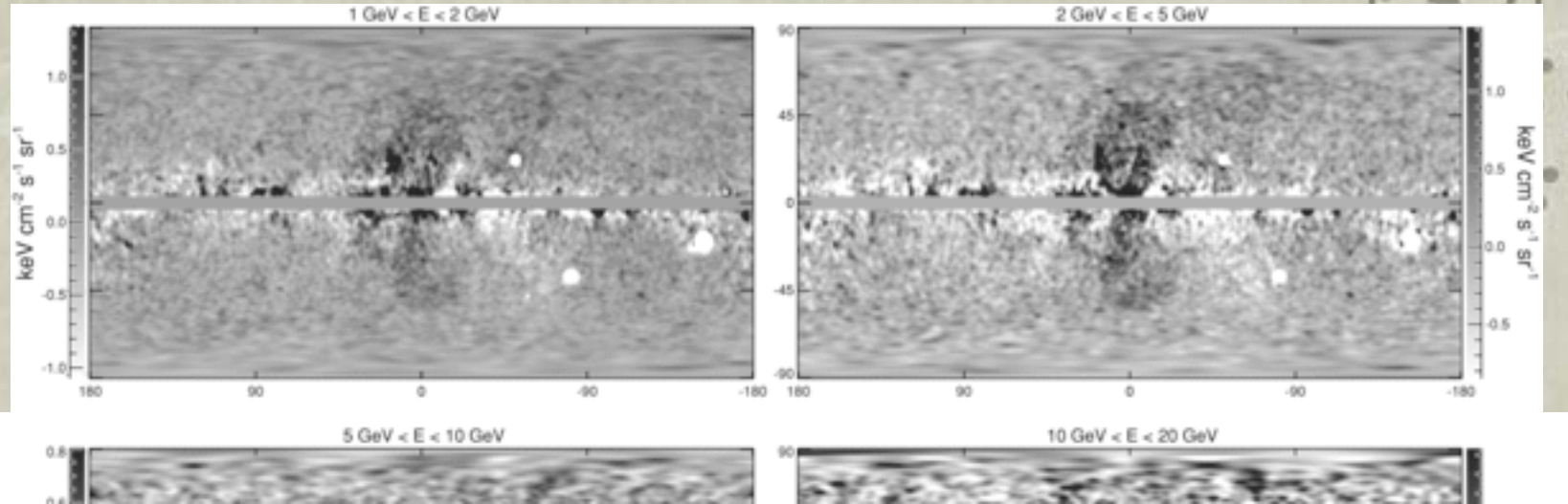
Fermi Bubbles: residual gamma ray emission



Su, Slatyer, and Finkbeiner, 2010

Observational Features of the Fermi Bubbles

- Symmetric about the Galactic plane, with one above and the other below the Galactic Center
- Roughly uniform gamma-ray surface brightness
- Sharp edges
- Hard and spatially-uniform spectrum dN/dE ~ E^{-2} between 1 < E < 200 GeV



Gamma-ray Emission Mechanisms

- Relativistic cosmic-ray protons

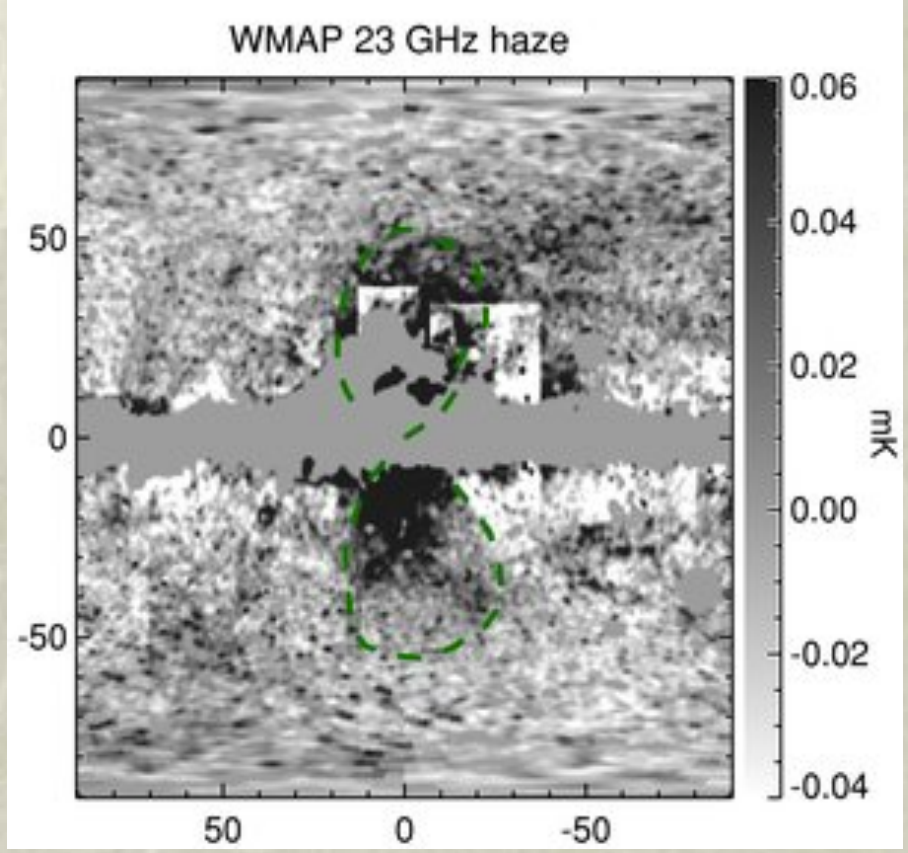
  CRp + thermal nucleus → pions

  neutral pion → 2γ

- Relativistic cosmic-ray electrons

  Inverse-Compton upscattering of starlight or CMB photons

The Fermi Bubbles in Microwave?



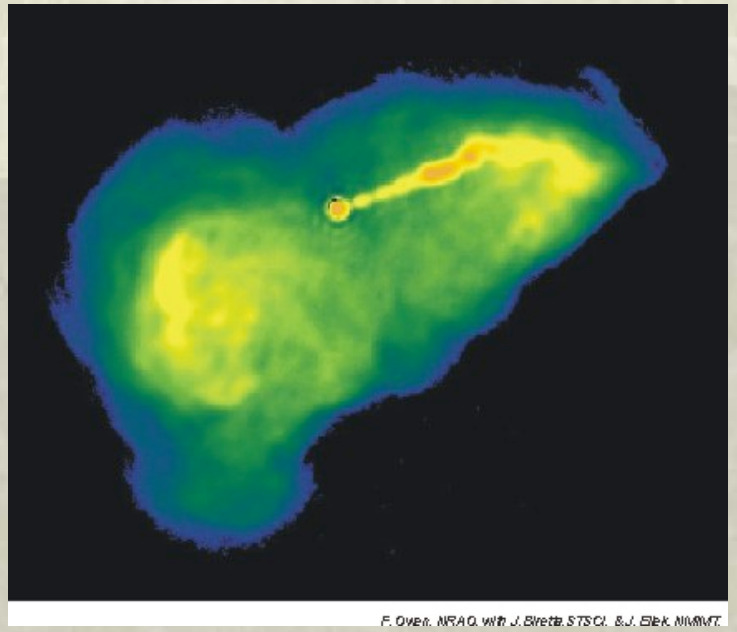
Finkbeiner 2004; Su et al 2010

Synchrotron emission of CR electrons?

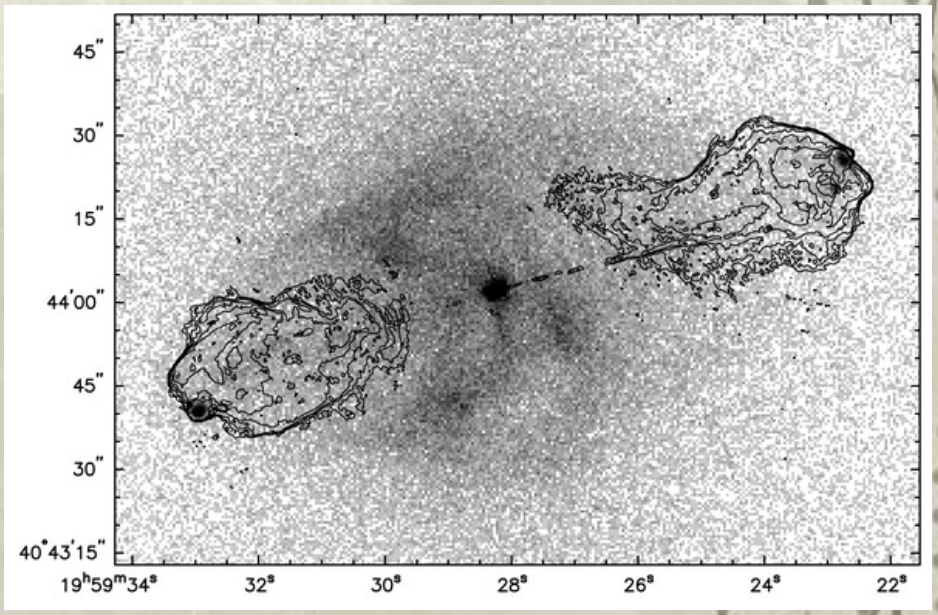
Possible Explanations

- Diffused CR electrons from the Galactic disk? -- ×
- Dark matter annihilations? --- seems unlikely
- Galactic or AGN winds from the Galactic Center?
  – Possible, but stellar/starburst winds are probably too slow: the required CR transport speed is around 10000 km/s.
- AGN jet activity --- our work

Motivation: AGN jets carry CRs and produce CR bubbles



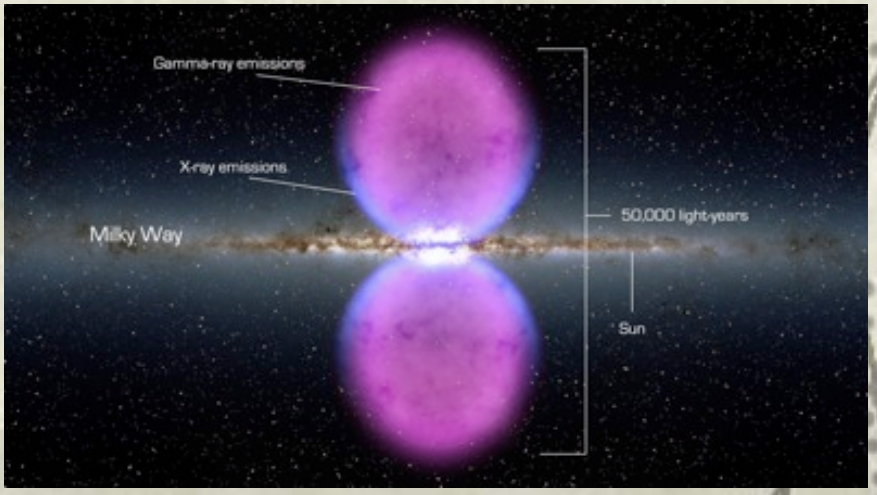
M87 at 20 cm, VLA image



Cygnus A at 6 cm, Wilson et al 2006

- Radio bubbles due to synchrotron emission of CR electrons are seen in both ellipticals and Seyfert spirals.

Objective

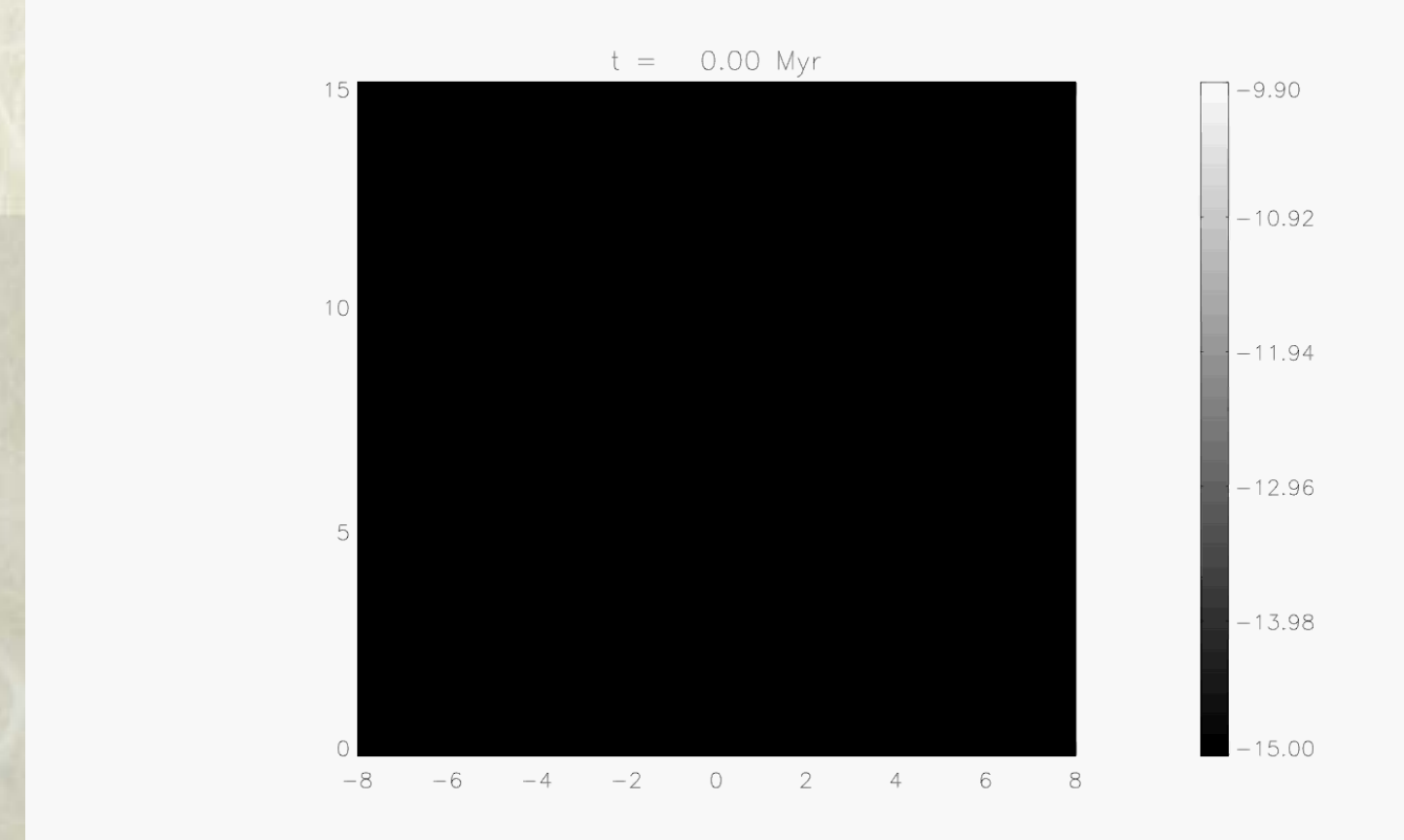


- Identity physical mechanisms relevant for the Fermi bubbles
- Can the Fermi bubbles be produced by a recent AGN jet event?
- Constrain the properties of the AGN event

Methodology

- Hydrodynamic jet simulations with CR dynamics
- Simulations include hydrodynamics, CR transport, CR dynamics, Galactic potential well and a two-fluid jet originated from the GC

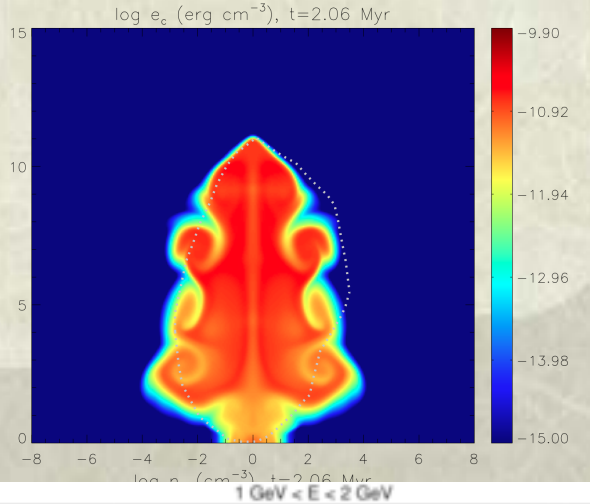
Results -- A successful run



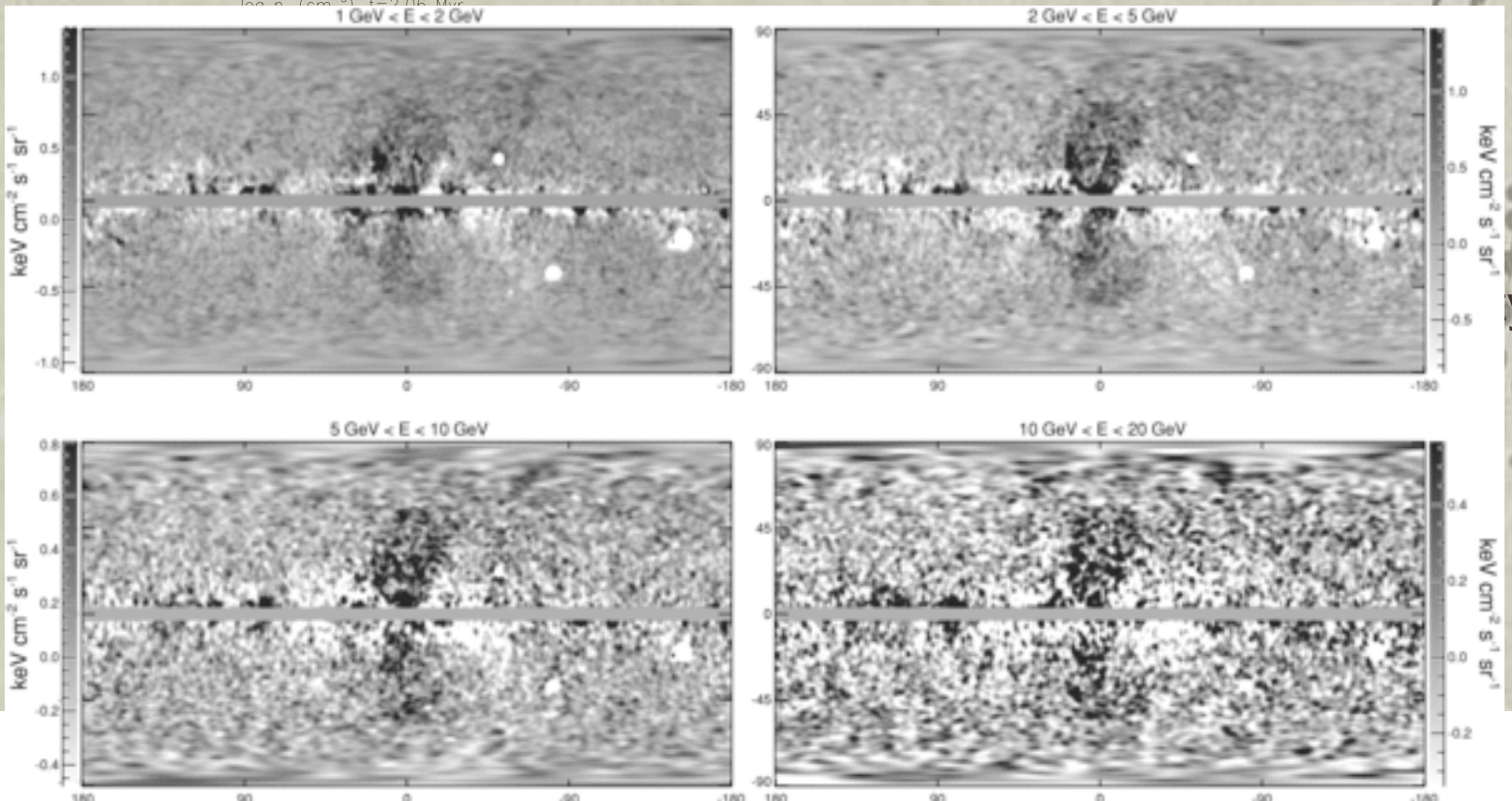
Log (CR energy density)

Guo & Mathews 2011b

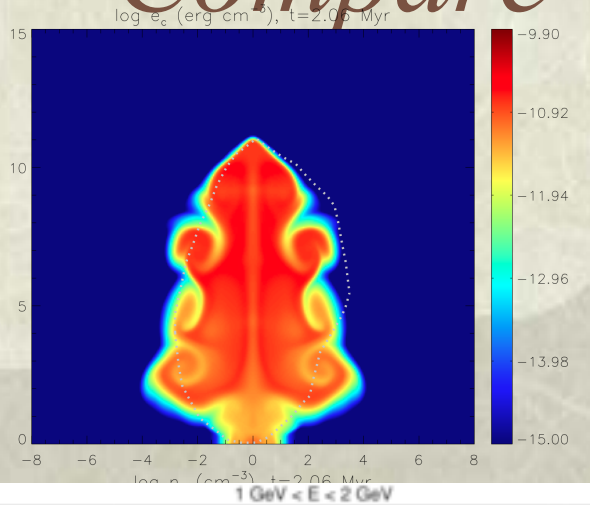
Compare with observations



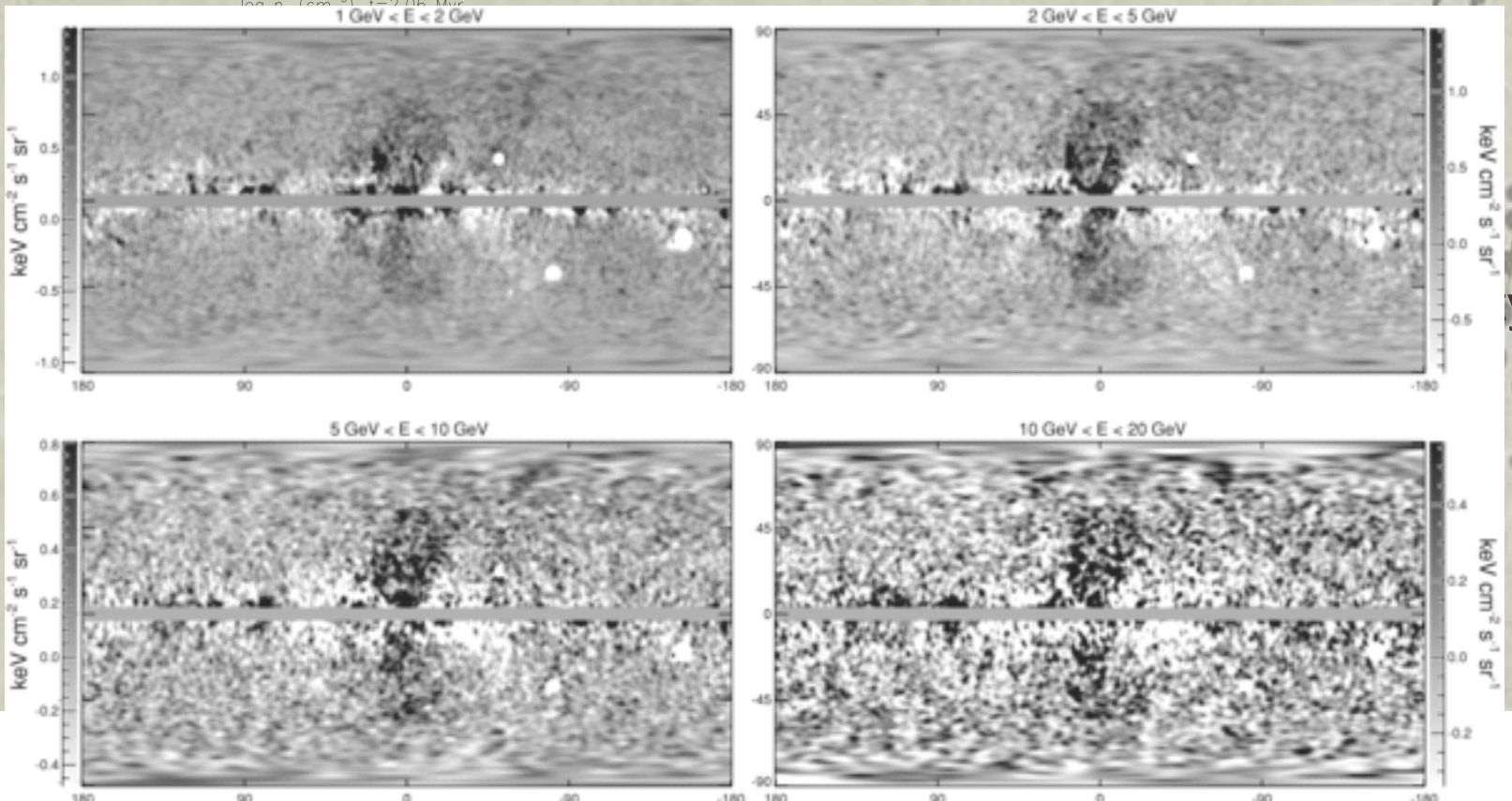
Features reproduced: short age ~ 1 – 3 Myr, location, size, shape, sharp edges, spatially-uniform hard spectrum



Compare with observations



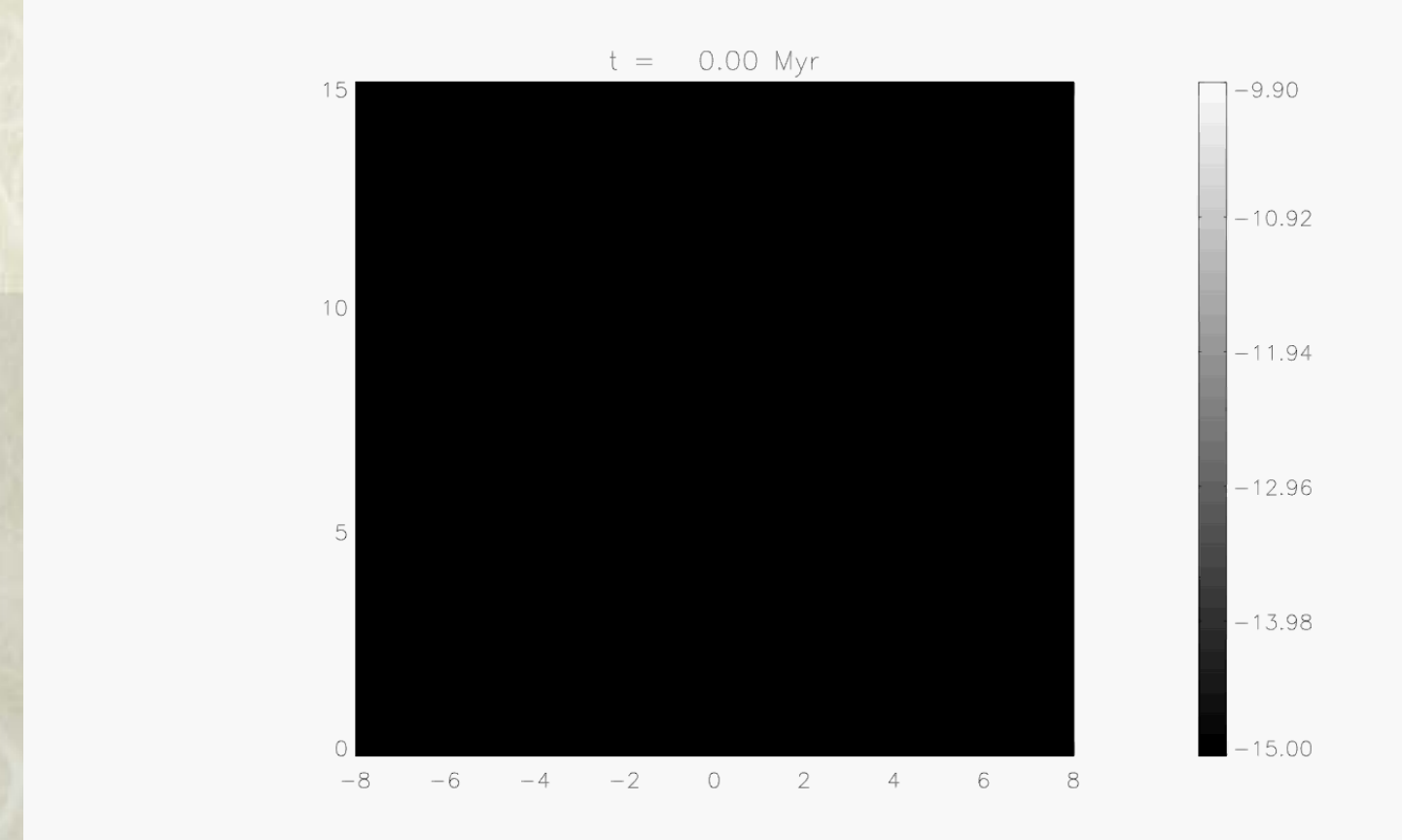
Inconsistencies: surface irregularities and limb darkening in surface brightness



What do these inconsistencies mean?

- They do not necessarily mean that our jet scenario for the Fermi bubbles is wrong
- They may be smoking-gun signatures of additional physics
- Surface irregularities induced by Kelvin-Helmholtz instabilities point toward the role of viscosity or magnetic tension
- Flat gamma ray intensity distribution suggests an edge-favored CR distribution

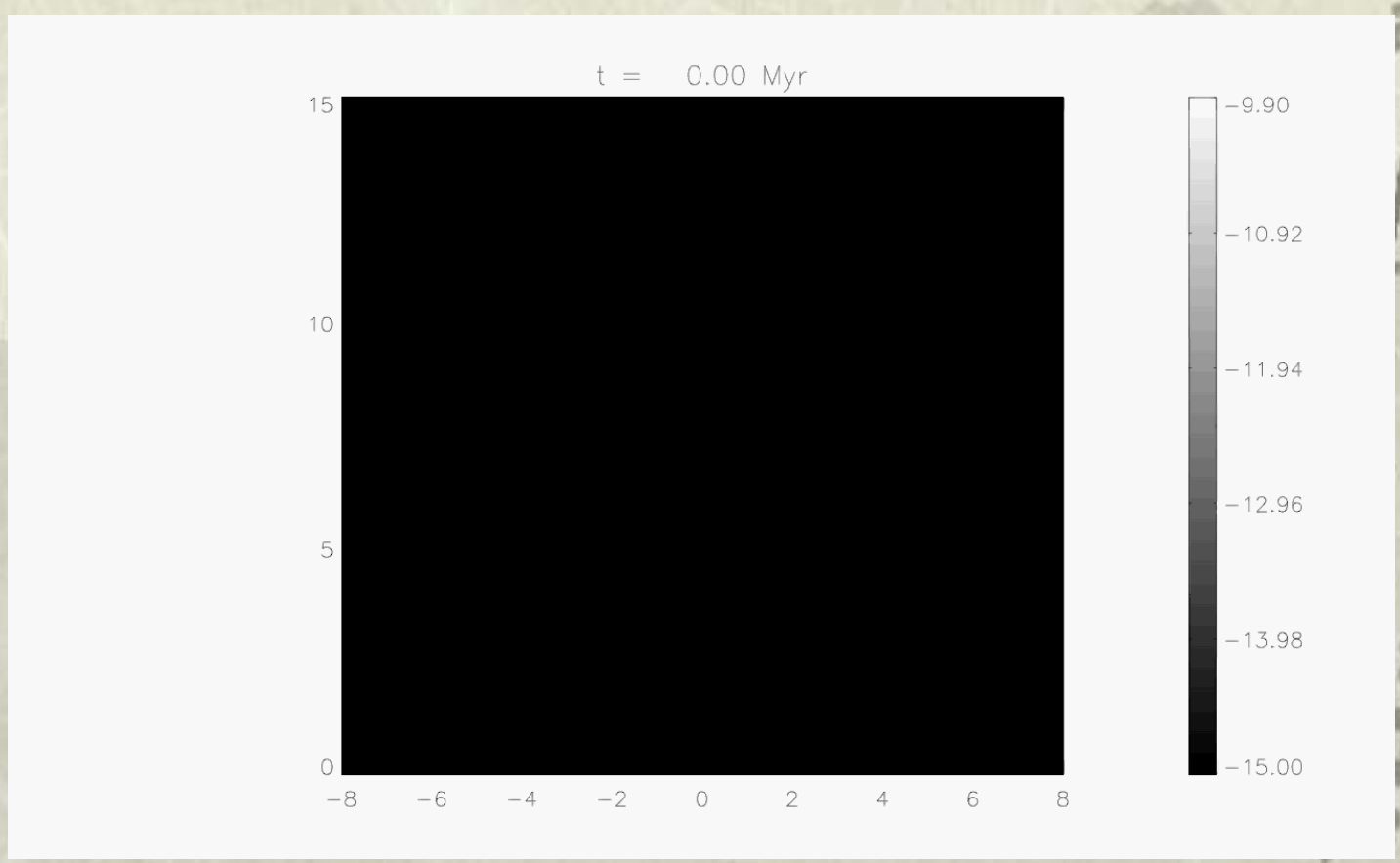
Simulations with Viscosity



Viscosity coefficient = 3 g/cm/s, much less than the Spitzer viscosity

Guo et al 2011, in prep

When viscosity is lower

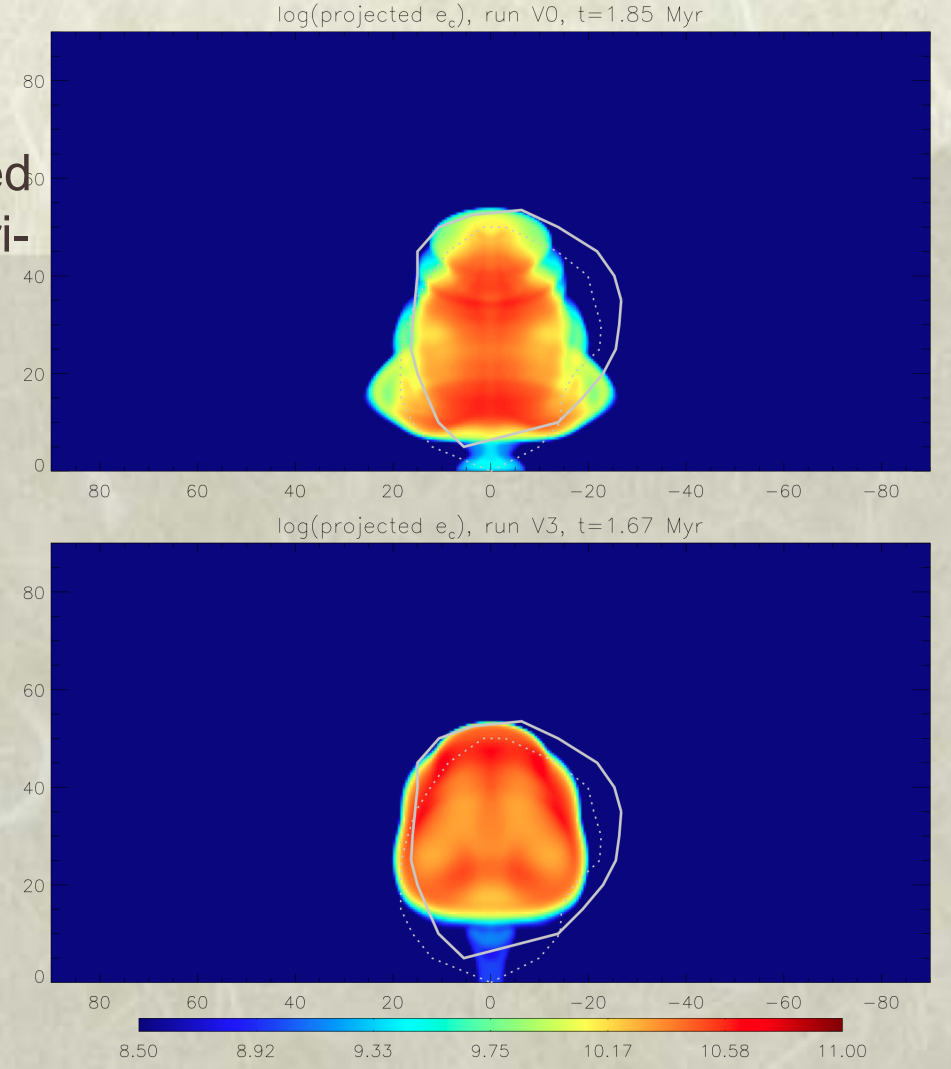


Viscosity coefficient = 1 g/cm/s

Guo et al 2011, in prep

Flat Gamma Ray Surface Brightness

Projected CR distri-bution

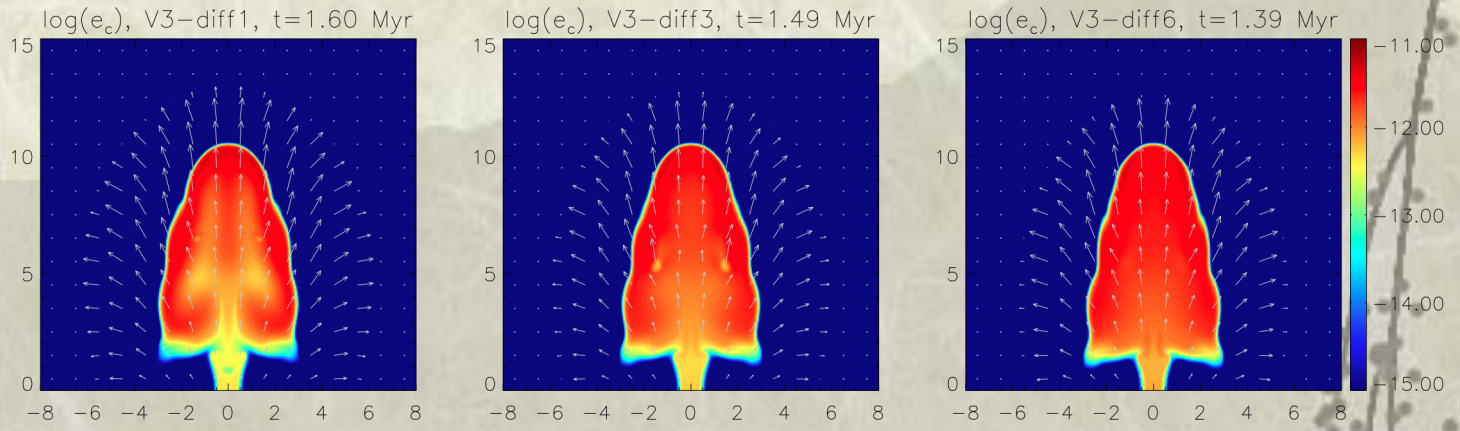


Non-viscous run
Surface irregularities
Center-brightened

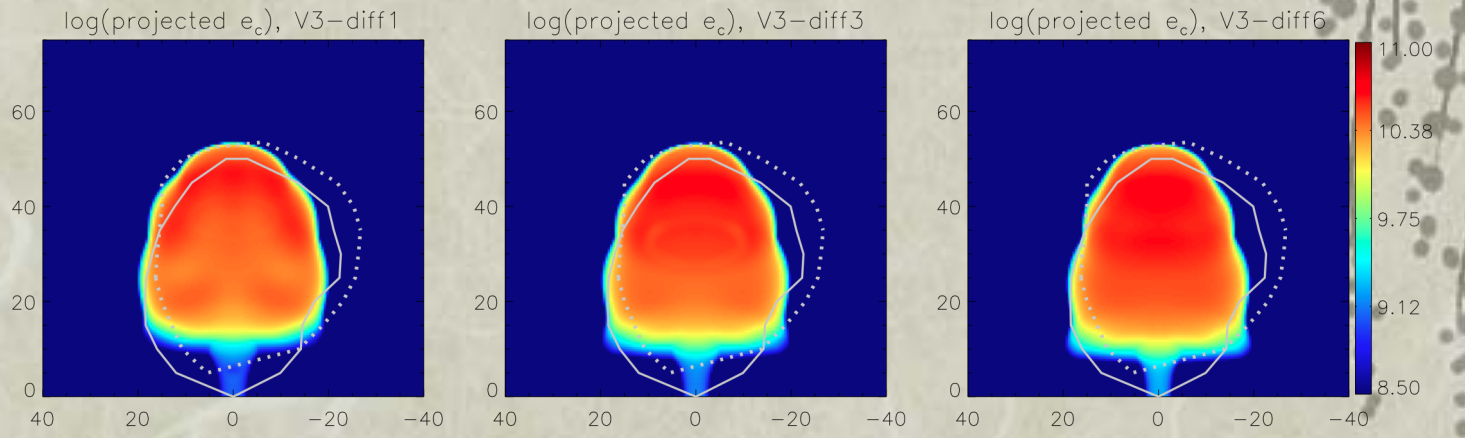
Viscous run
Smooth edges, but limb brightened

CR diffusion also plays a role

CR distribution

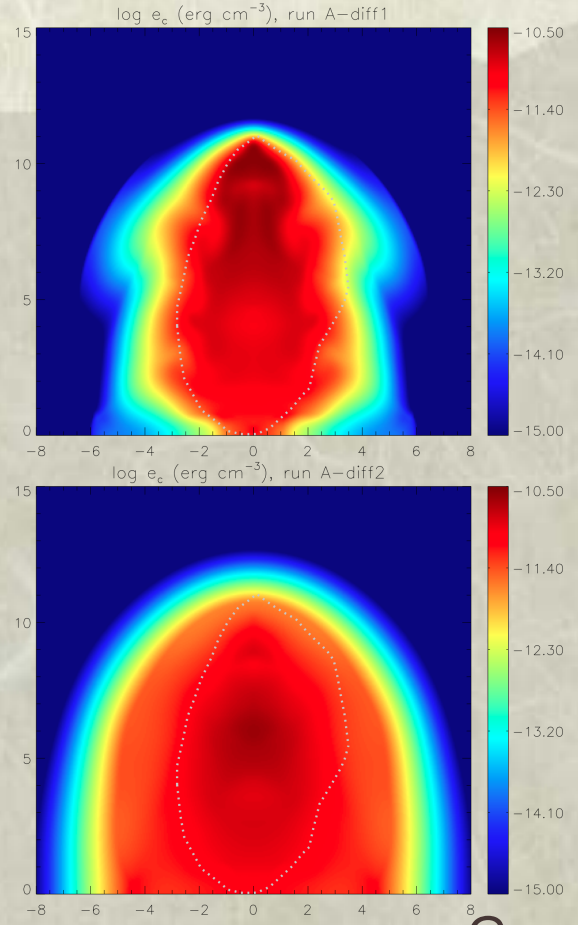


Projected CR distribution



➔ ➔ CR diffusivity increases ➔ ➔

However, CR diffusion across the bubble edges must be suppressed significantly, probably due to the alignment of magnetic fields with bubble surface



D= 3 × 10^{28} cm^2/s

D= 3 × 10^{29} cm^2/s

Guo & Mathews 2011b

What's Next?

- Consolidate the result – other evidence for a recent powerful AGN event at the Galactic Center a few Myrs ago?

- Further constrain the jet properties

- Astronomical implications: Do AGN jet events happen regularly in the Galaxy? What triggers AGN jet events? What is the duty cycle? How does the jet activity affect the evolution of the Galactic bulge and the Galaxy (or more generally disk galaxies)? Can it explain the tight correlations between black holes and bulges and the low stellar fraction in disk galaxies? Have we seen Fermi bubbles in other disk galaxies?