

# The Origin and Implications of the Fermi Bubbles

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Guo & Mathews, 2012, ApJ in press (arXiv:1103.0055)

Guo, Mathews, Dobler, & Oh, 2012, ApJ in press (arXiv:1110.0834)

Santa Cruz Galaxy Workshop, Santa Cruz, 08/16/2012

# Disk Galaxies



NGC 5866



M31

# Physical Processes Governing Galaxy Evolution

(1) Gravity

(2) Radiative Cooling

(3) Star Formation

(4) Stellar Feedback



NGC 3953

# Physical Processes Governing Galaxy Evolution

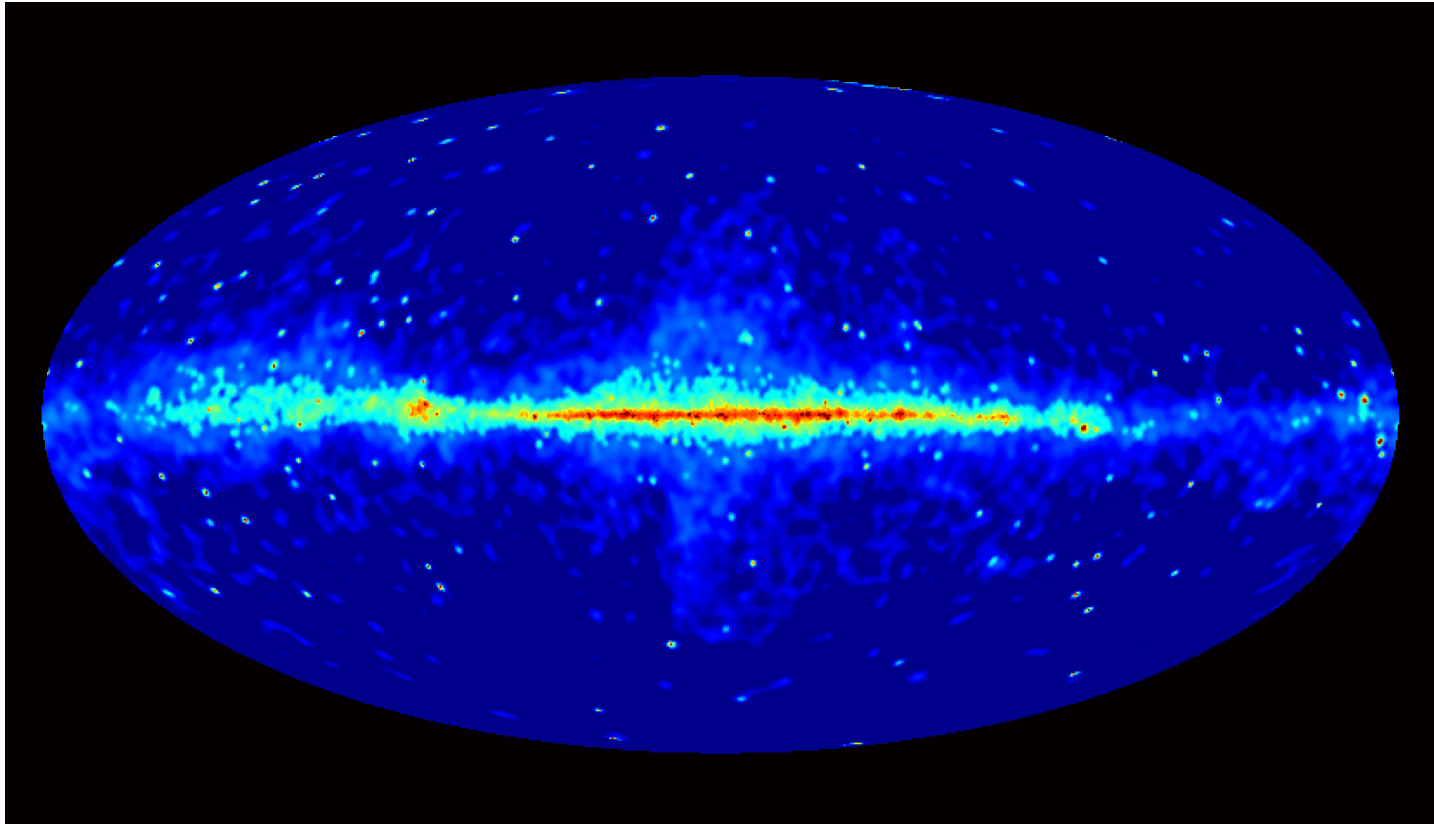
- (1) Gravity
- (2) Radiative Cooling
- (3) Star Formation
- (4) Stellar Feedback



NGC 3953

Are we missing any important physical processes?

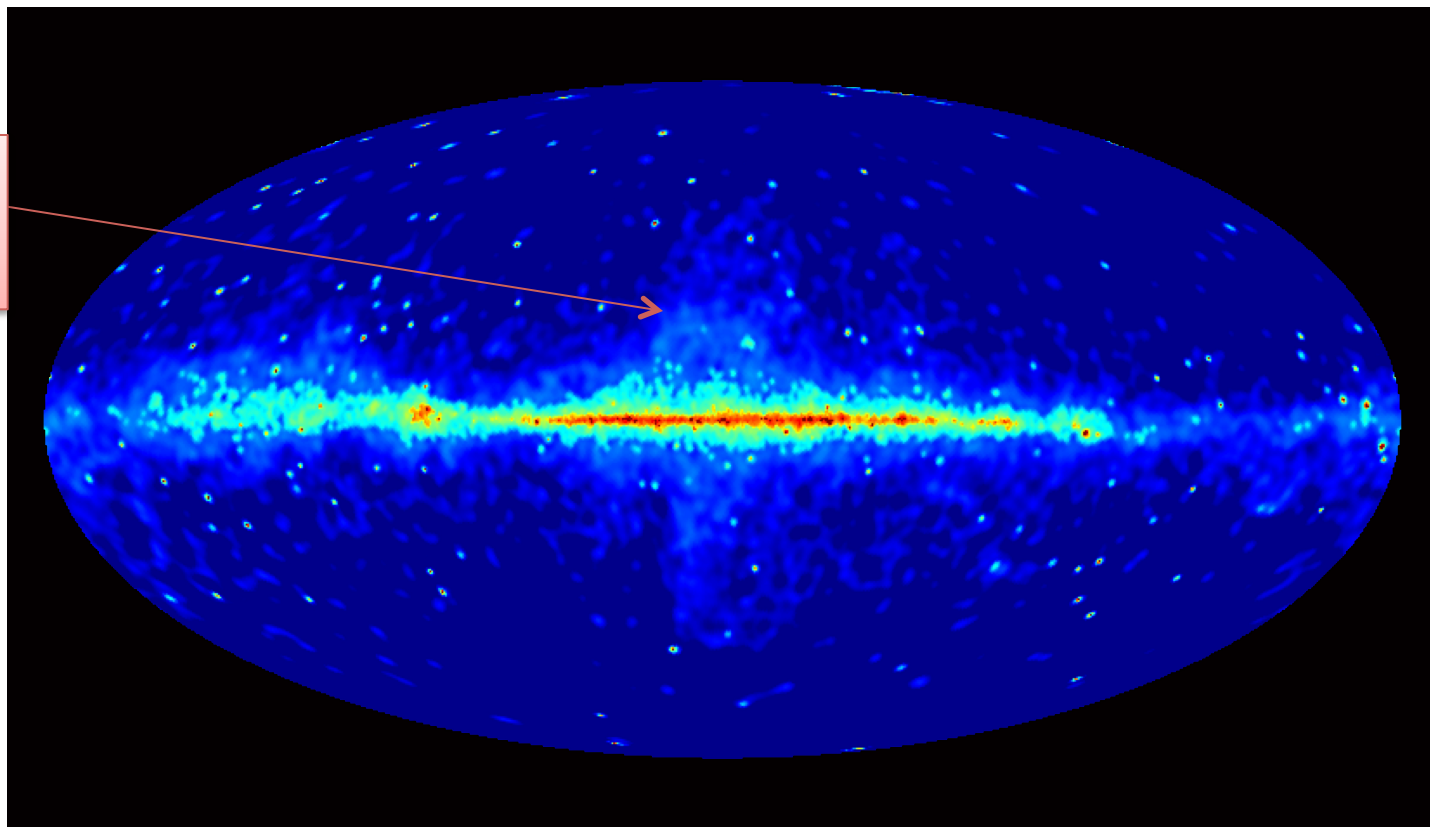
# The Milky Way in Gamma Ray



The All-sky *Fermi* View at  $E > 10$  GeV  
NASA image based on the three-year *Fermi* Data

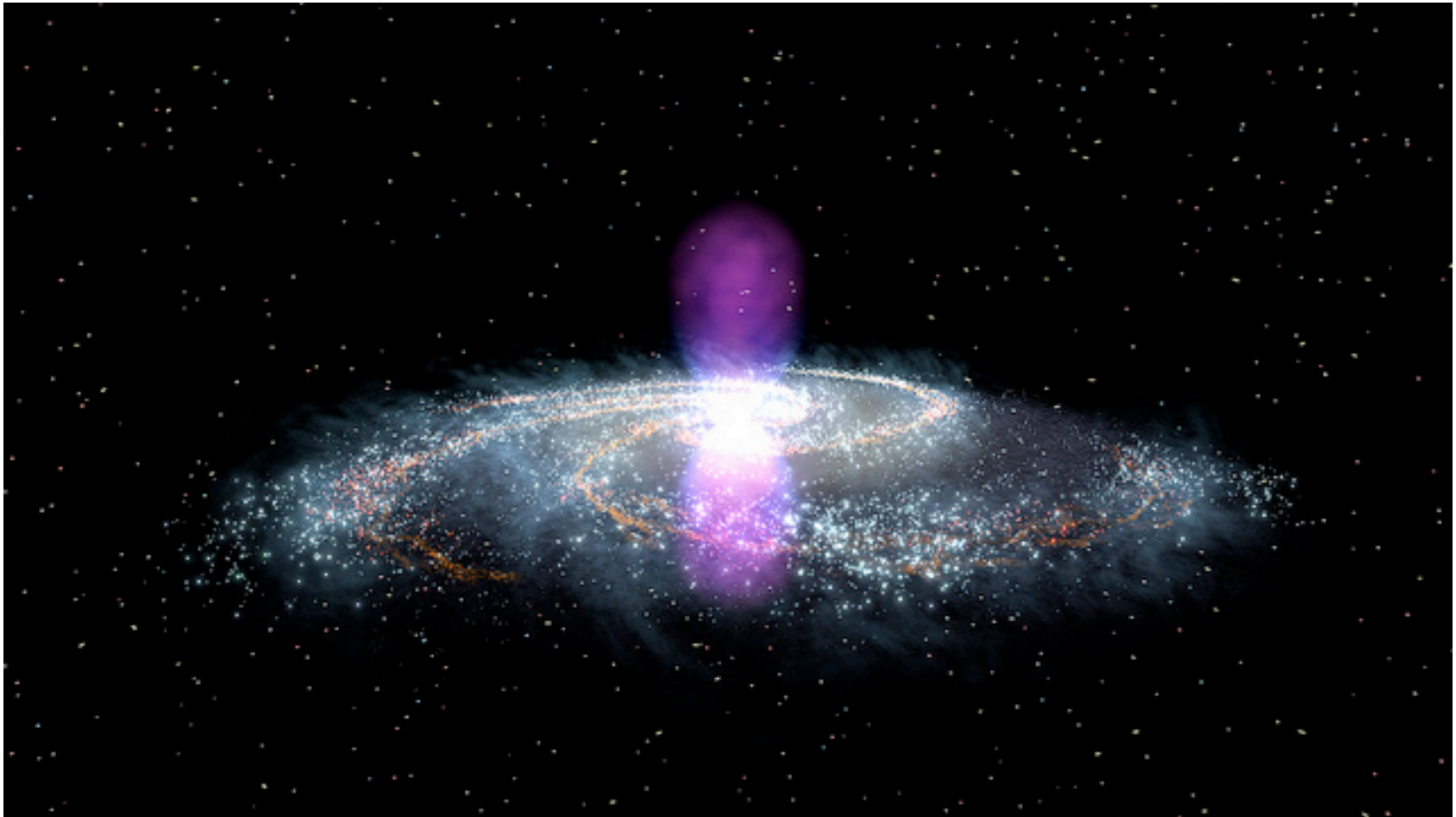
# The All-sky *Fermi* View at $E > 10$ GeV

A diffuse  
gamma-ray  
bubble!



(NASA image based on the three-year *Fermi* Data)

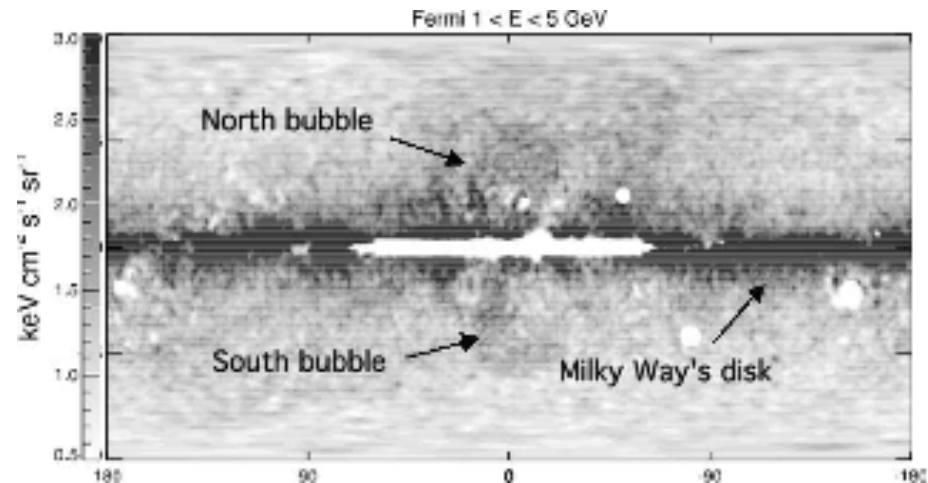
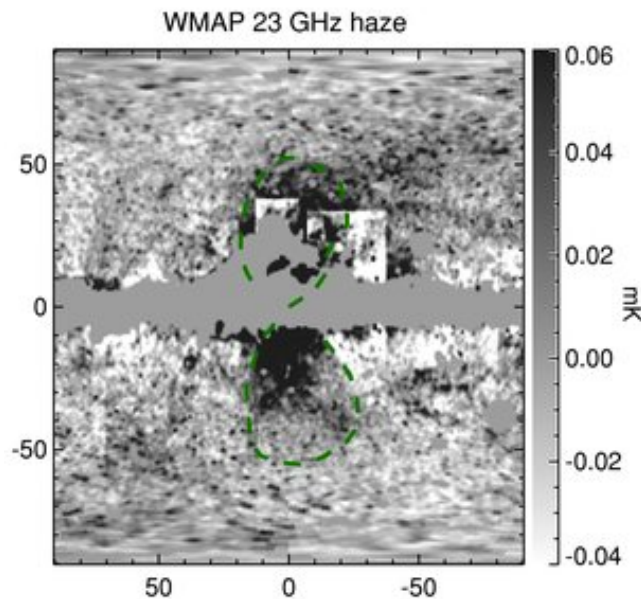
# An Artist's View of The Fermi Bubbles



(NASA image)

# The origin of the Fermi bubbles

- Dark matter annihilations? (Dobler et al 2011)  
in conflict with (1) bilobular morphology  
(2) Sharp edges



The Fermi bubbles

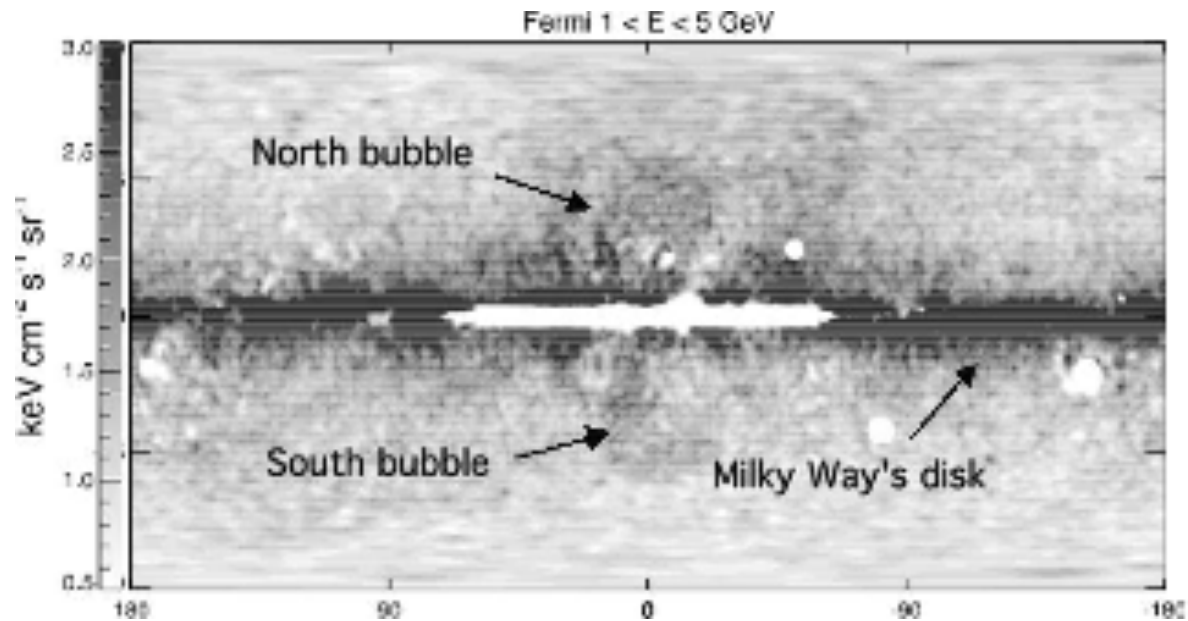
The WMAP Haze: the Fermi bubbles in Microwave

Finkbeiner 2004



# The origin of the Fermi bubbles

Similar events in other galaxies?

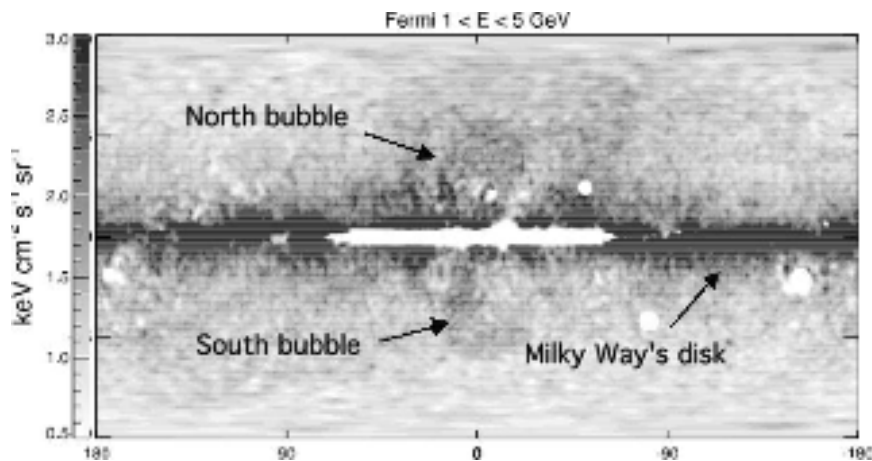


The Fermi bubbles (Su+2010)

# The origin of the Fermi bubbles

Similar events in other galaxies?

- Galactic winds from the Galactic Center? (Crocker & Aharonian 2011)



The Fermi bubbles (Su+2010)

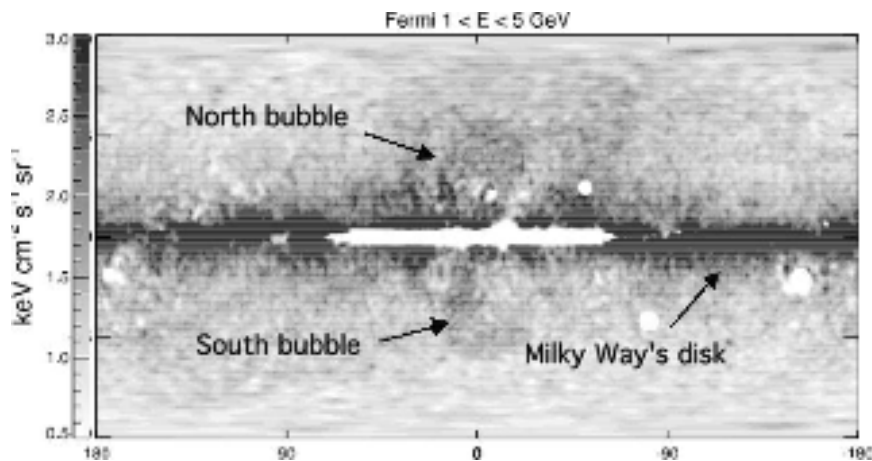


M82, Credit: [NASA](#), [ESA](#), and The [Hubble Heritage](#) Team ([STScI/AURA](#))

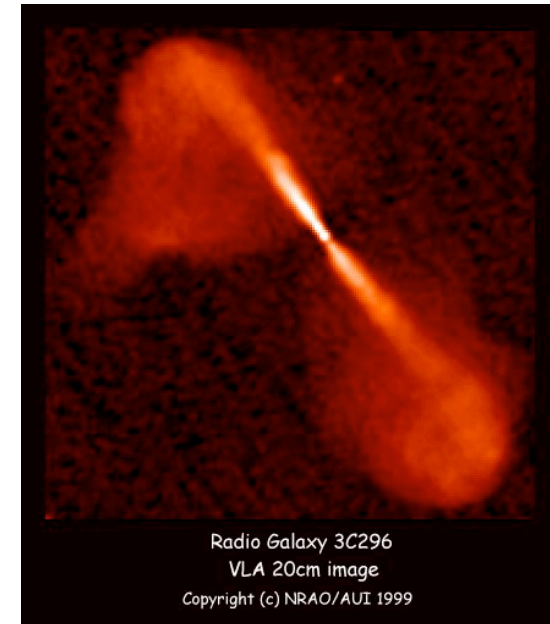
# The origin of the Fermi bubbles

## Similar events in other galaxies?

- AGN bubbles produced by AGN jets? (Guo & Mathews 2012; Guo + 2012)



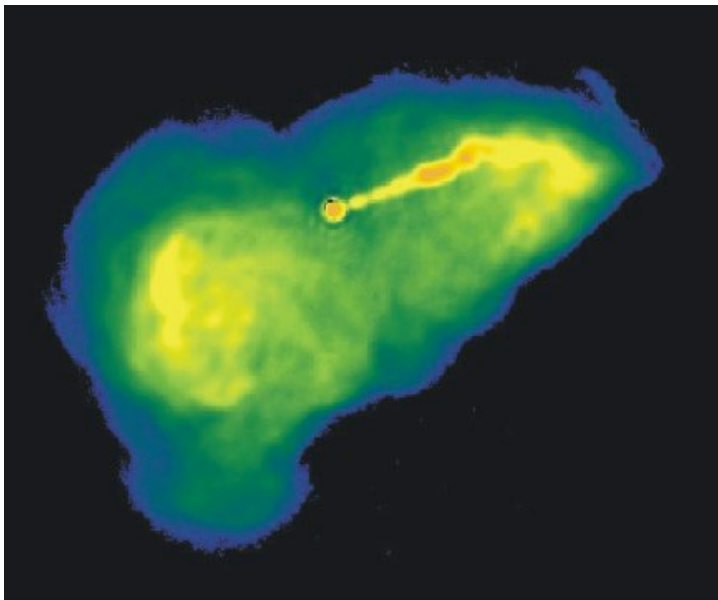
The Fermi bubbles (Su+2010)



20 cm radio image of 3C296  
(Image courtesy of NRAO/AUI)

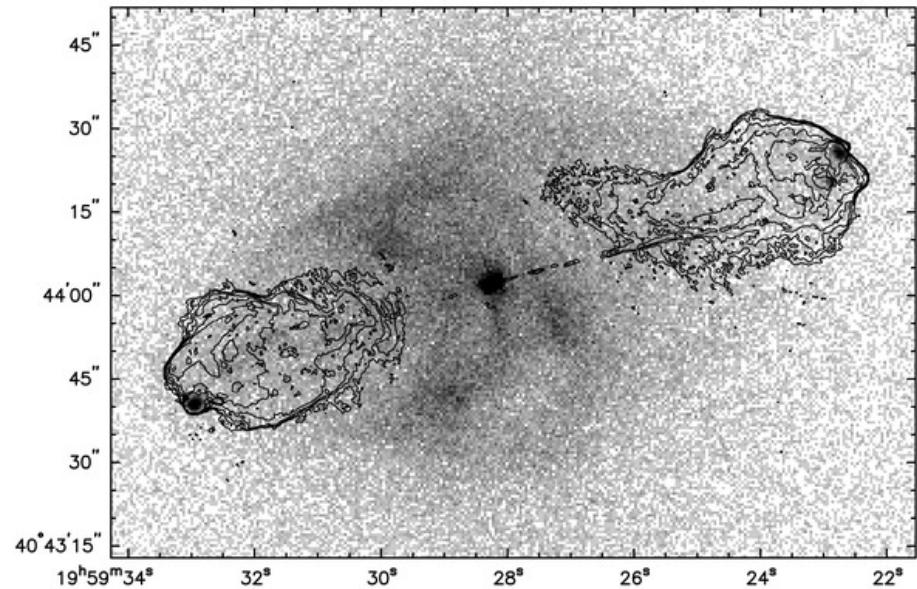
# The origin of the Fermi bubbles

AGN jets carry cosmic rays and produce CR-filled bubbles



*F. Ovechkin, NRAO, with J. Blreth, STS Cl. & J. Eisele, NIMMT.*

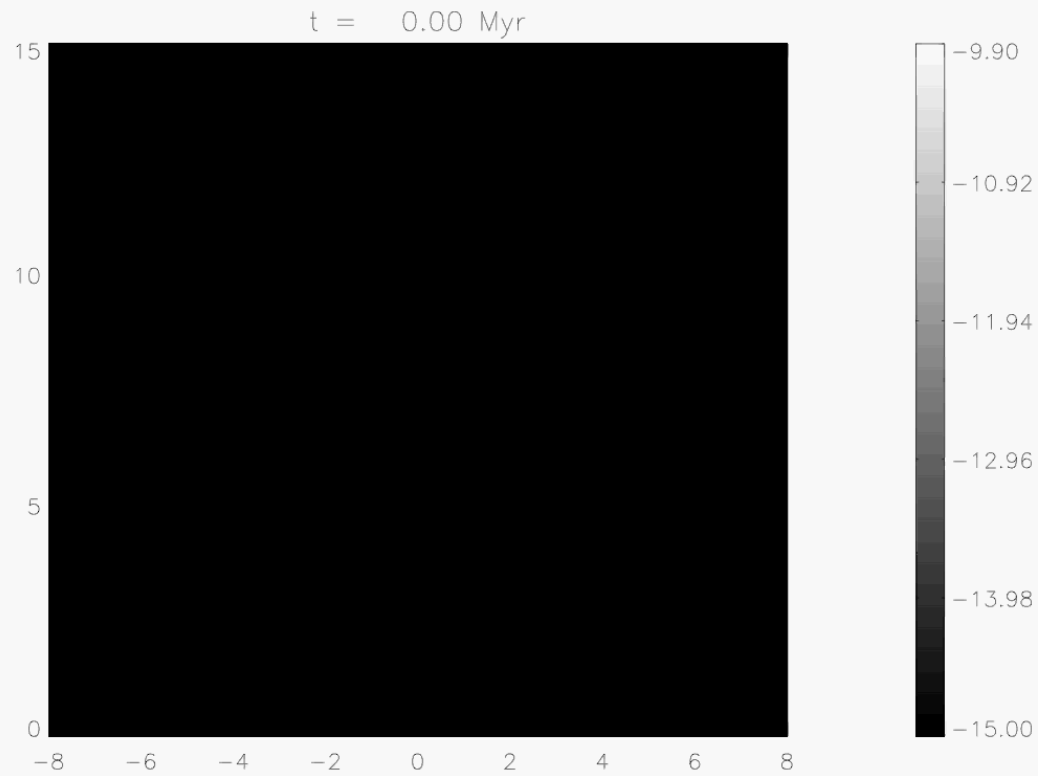
M87 at 20 cm, VLA image



Cygnus A at 6 cm, Wilson et al 2006

Were the Fermi bubbles really produced by a recent AGN jet event?

# A typical run – A1



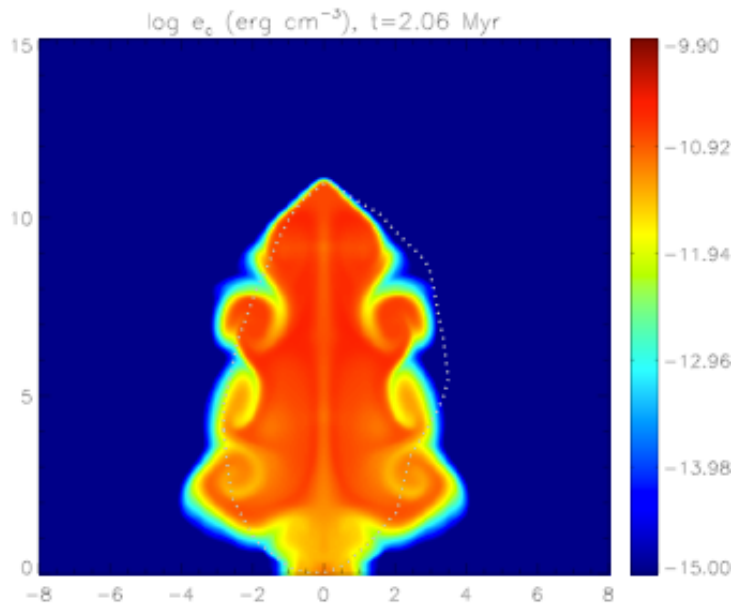
Log (CR energy density)

**Guo & Mathews 2012**

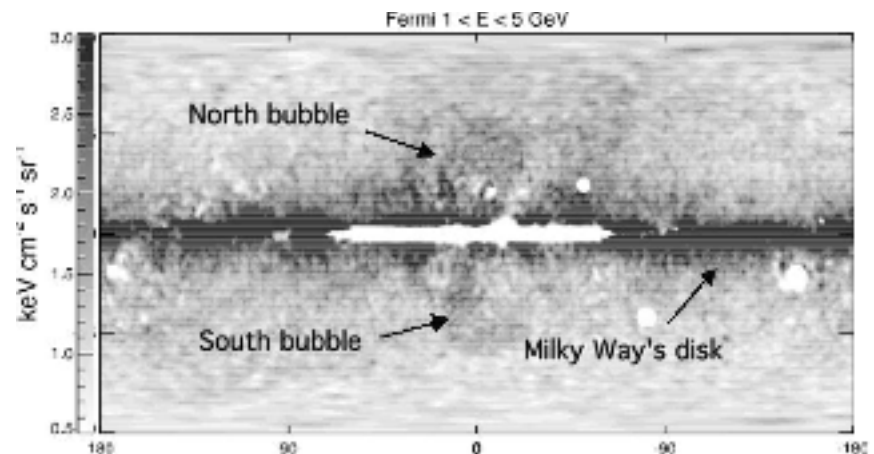
Were the bubbles really produced by a recent jet event?

A recent jet event reproduces many bubble features: location, size, shape, sharp edges

CR particle distribution

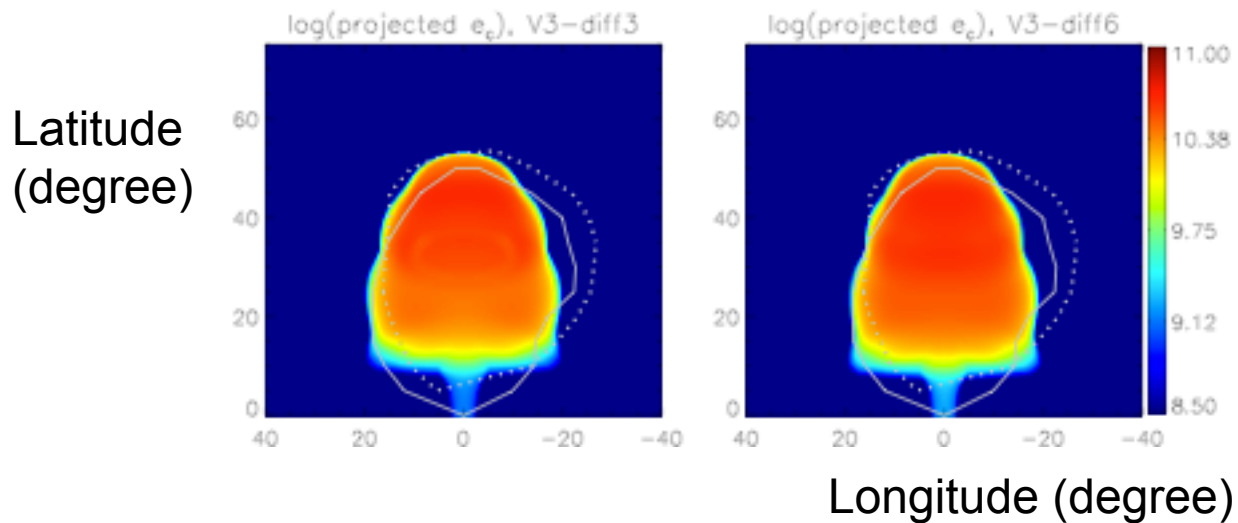


Guo & Mathews 2012



Su, Slatyer, and Finkbeiner, 2010

## Surface irregularities may be removed by shear viscosity

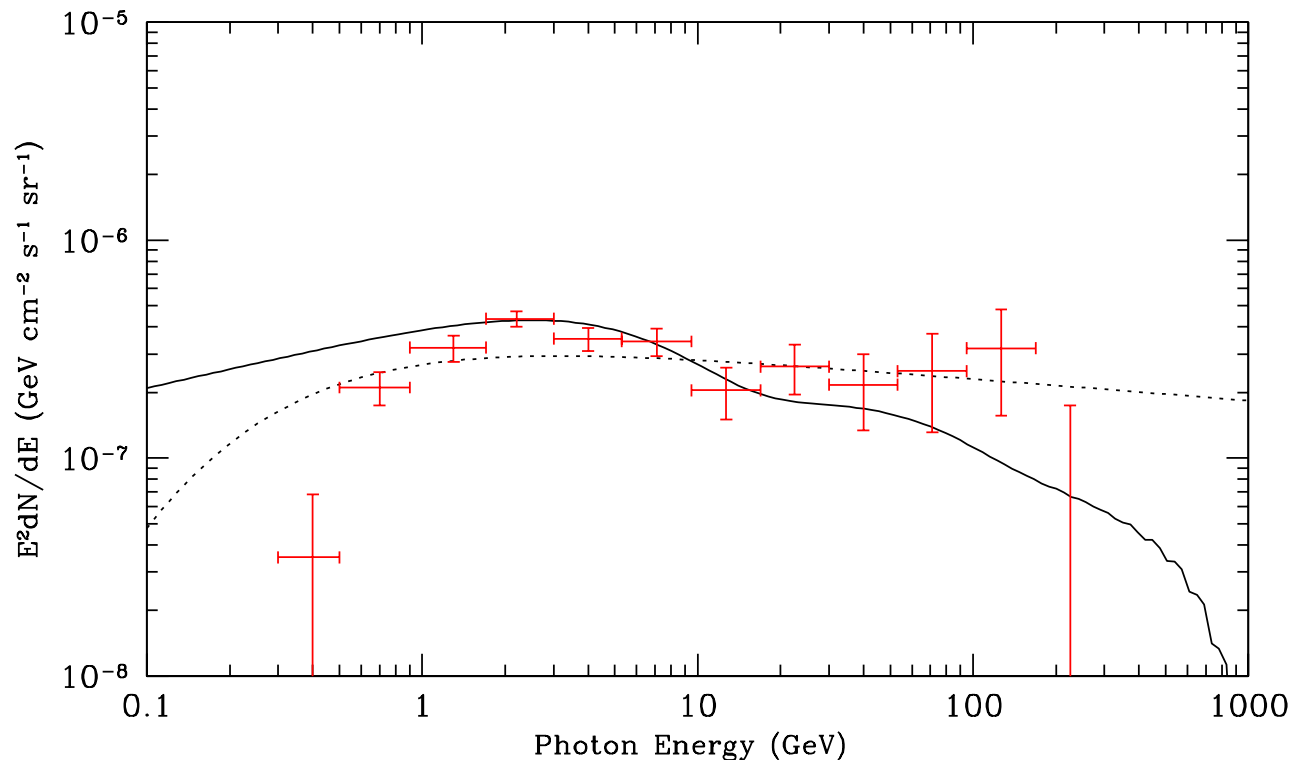


The line-of-sight projected CR energy density in **Galactic coordinates** (Guo et al '12).

CR diffusion is allowed in the bubble interior.



## How do our model compare with *Fermi* observations?



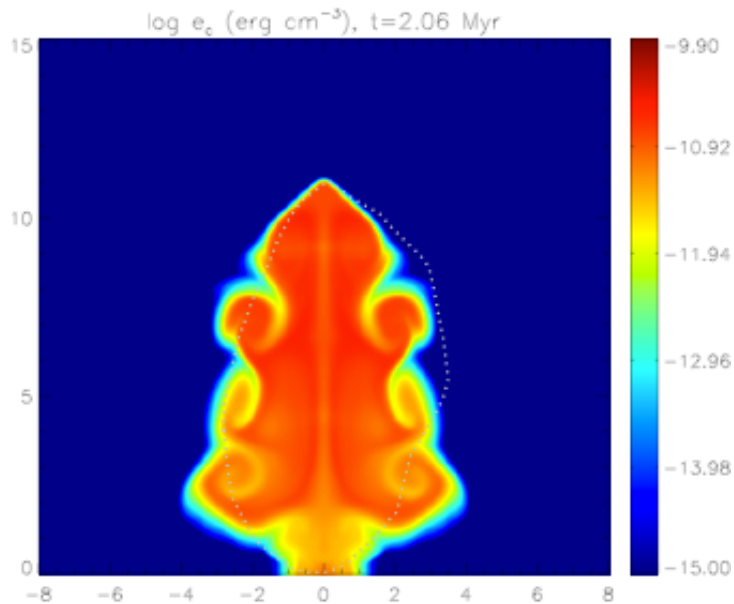
The average spectrum of the Bubbles

**Leptonic Scenario (solid line):** the required CR electron pressure to produce the observed gamma-ray flux is negligible compared to the total bubble pressure

**Hadronic Scenario (dashed line):** the required CR proton pressure is much higher, probably dominating the total bubble pressure.

What are the energetics and age of the bubble event?

CR particle distribution

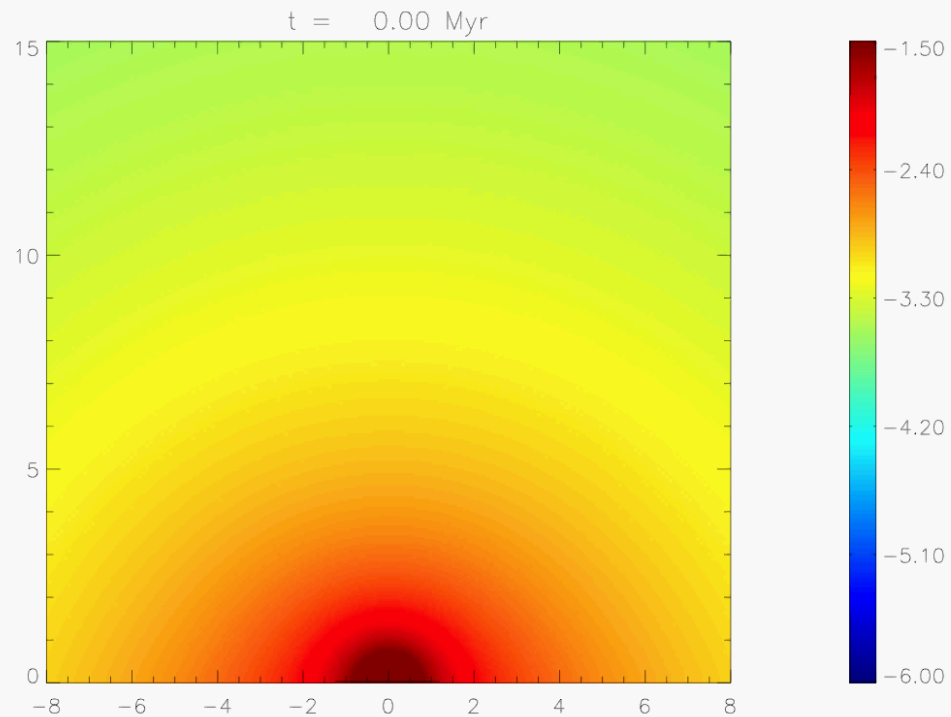


Guo & Mathews 2012

- (1) Energetics  $\sim 10^{55} - 10^{57}$  erg  
**Age  $\sim 1 - 3$  Myr**  
**Jet duration  $\sim 0.1 - 0.5$  Myr**  
Total mass that SMBH accreted:  
 $\sim 100 - 10000 M_{\text{sun}}$

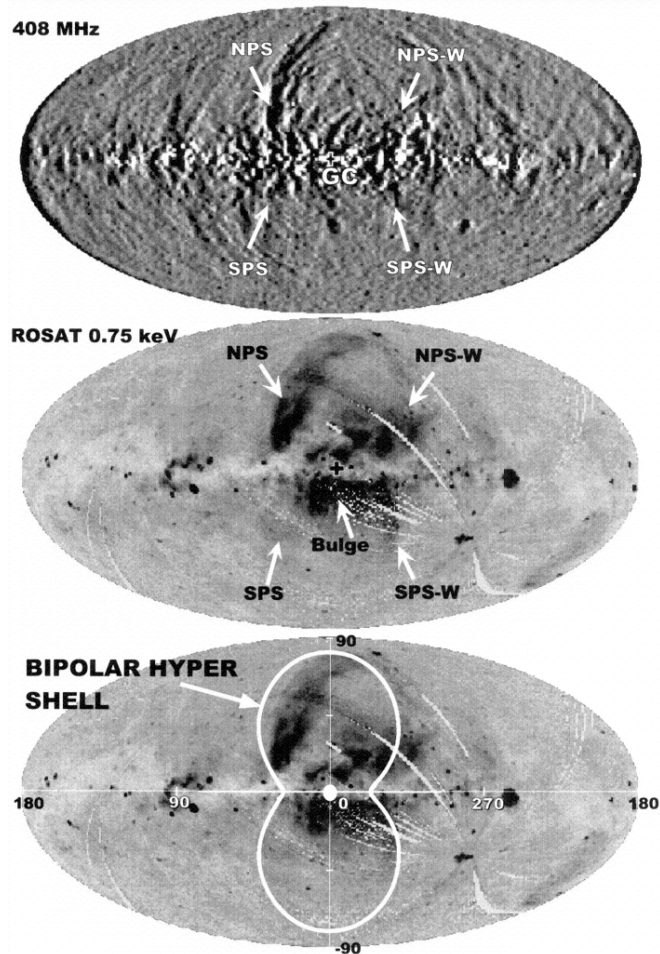
# Why is the Fermi bubble event relevant for galaxy evolution?

## Thermal gas distribution

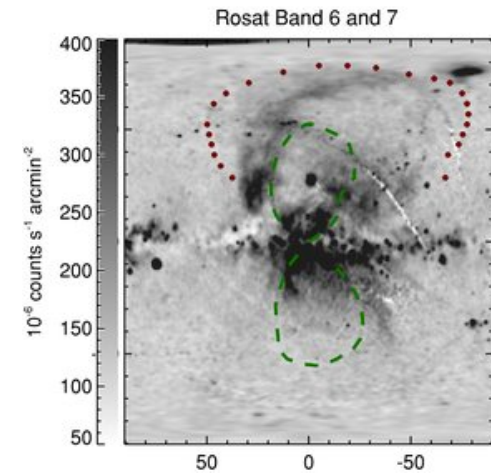
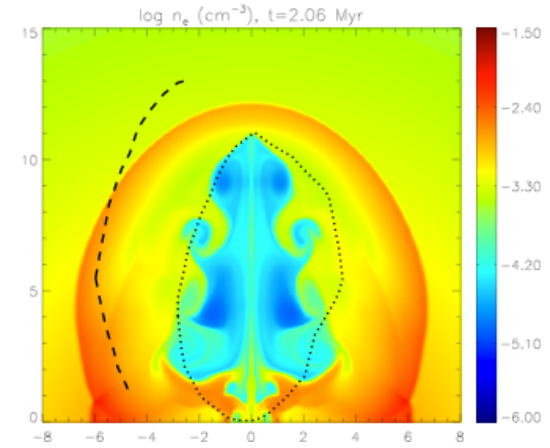


The bubble event produces shocks and outflows in the galactic halo

# Have the shocks been observed?



Sofue 2000

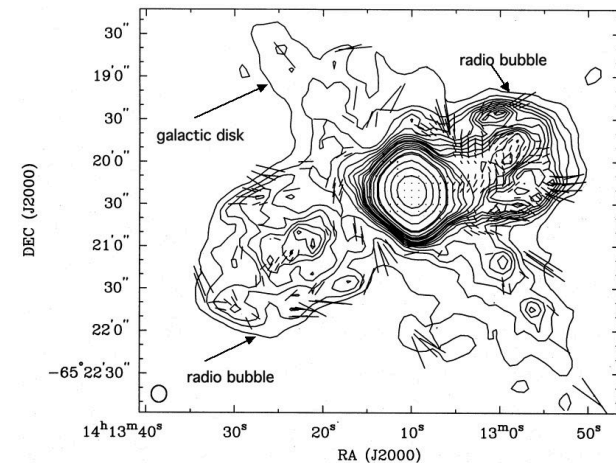
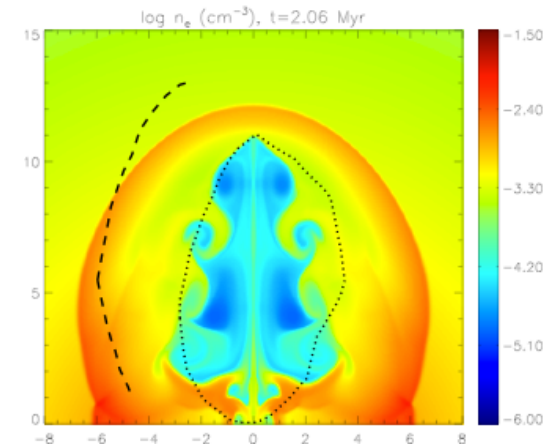


ROSAT X-ray map and the bubbles<sub>20</sub>

# Why is the Fermi bubble event relevant for galaxy evolution?

The bubble event produces shocks and outflows in the galactic halo  
→ **baryon cycle in the circumgalactic medium**

If such AGN jet event happens regularly in galaxies, it may significantly slow down the growth of the galaxy.



The Circinus galaxy at 13 cm  
(Elmouttie et al 1995)

# Summary: The Fermi Bubbles

- The Fermi bubbles can be created with a recent AGN jet activity about 1 – 3 Myr ago, which lasted for  $\sim 0.1 - 0.5$  Myr.
- The estimated energy of the event is  $\sim 10^{55} - 10^{57}$  ergs, depending on the gas densities in the Galactic halo.
- The jet activity produces a strong shock, which heats and compresses the hot halo gas, potentially explaining the ROSAT X-ray features
- Such AGN jet events may be common in both disk and elliptical galaxies. AGN jets may play a significant role in galaxy evolution.

