# Simulating the Fermi Bubble

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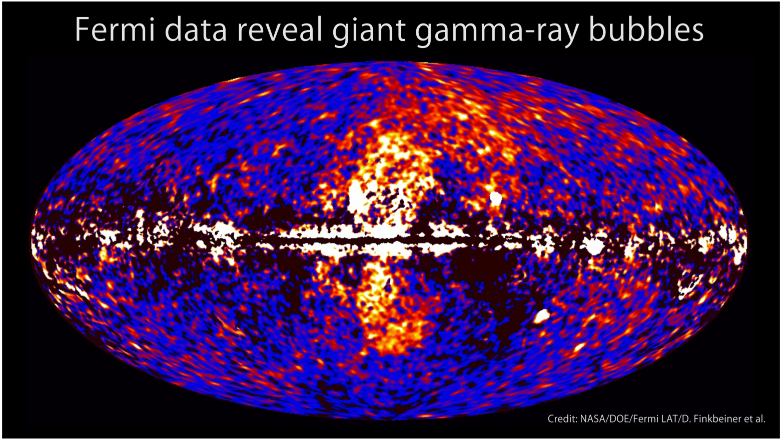
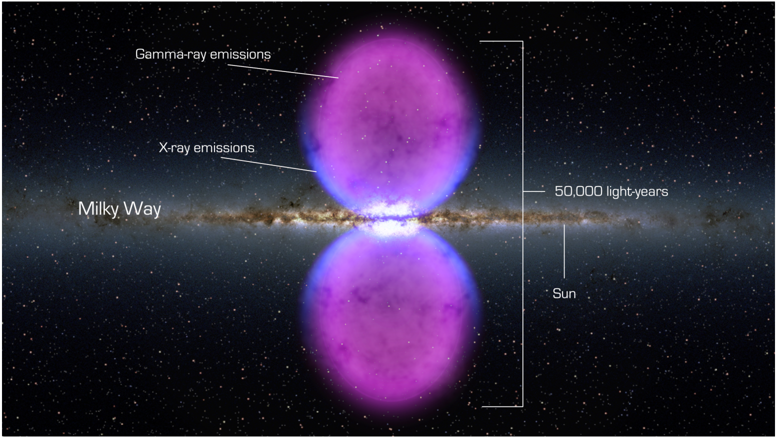
# Outline

- Background and Motivation
- Our Model
- Our Numerical Scheme
- Results
- Future Work

# Detection of the Fermi Bubbles

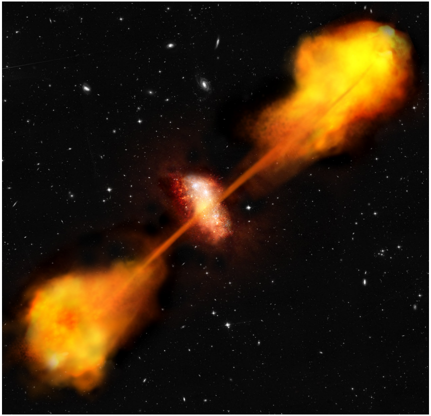
- On June 11, 2008, NASA launched the Fermi Gamma-Ray Telescope
- On November 2010, two gamma-ray / x-ray bubbles were detected in the center of the Milky Way
- These bubbles extend symmetrically $\approx$ 10 kpc above and below the Galactic center, with a width $\approx$ 8.4 kpc
- These bubbles emit gamma-rays at energies between $1 \lesssim E_\gamma \lesssim 100$ GeV, with x-rays emitted at the edge of the bubbles.
- These bubbles have approximately uniform surface brightness.


Fermi data reveal giant gamma-ray bubbles
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.


Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun

# Astrophysical Jets

- Phenomena in which matter is ejected along the axis of rotation of a an accretion
- Gigantic astrophysical jets are launched from accretion disks around the central black holes in active galactic nuclei
- The mechanism that drive these jets remains contraversial



- Illustration of radio galaxy in early Universe
- Material emmited via two symmetric jets, with two lobes at the ends of the jets
- Detected 25 February, 2013; Satellite: Herschel
- Copyright: ESA/C. Carreau/ATG medialab

# Our Goals

- We believe that the Fermi Bubbles are the result of an astrophysical jet pulse that occured millions of years ago
- We hope to uncover
  - How old the Fermi Bubbles are
  - Gain a better understanding of the mechanisim that powers the Fermi Bubbles

# Approximation

- The outflow velocity of the Fermi Bubbles $\mathcal{O}(10^4 \frac{km}{s})$
  - This ammounts to about a 1.01 $\gamma$ value
  - Special Relativistic Effects can be ignored
- Therefore we can use non-relativistic models to simulate the Fermi-Bubbles
- We Model the Fermi-Bubbles through the Euler Gas-Dynamic Equations

# Euler Gas-Dynamic Equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

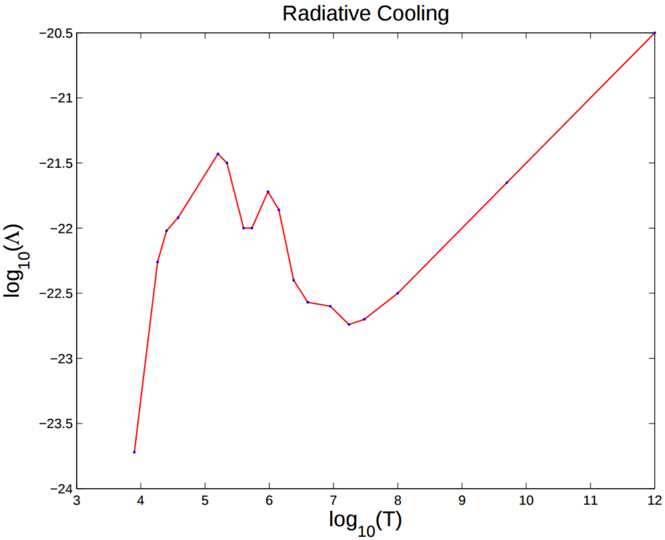
$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} + \nabla P = 0$$

$$\frac{\partial E}{\partial t} + \nabla \cdot (\mathbf{u}(E + P)) = -n^2 \Lambda(T)$$

Energy density & pressure (polytropic gas with $\gamma = 5/3$)

$$E = \frac{3}{2} n k_B T + \frac{1}{2} \rho u^2$$

$$P = n k_B T$$


Radiative Cooling
−20.5
−21
−21.5
−22
−22.5
−23
−23.5
−24
3
4
5
6
7
8
9
10
11
12
$\log_{10}(\Lambda)$
$\log_{10}(T)$

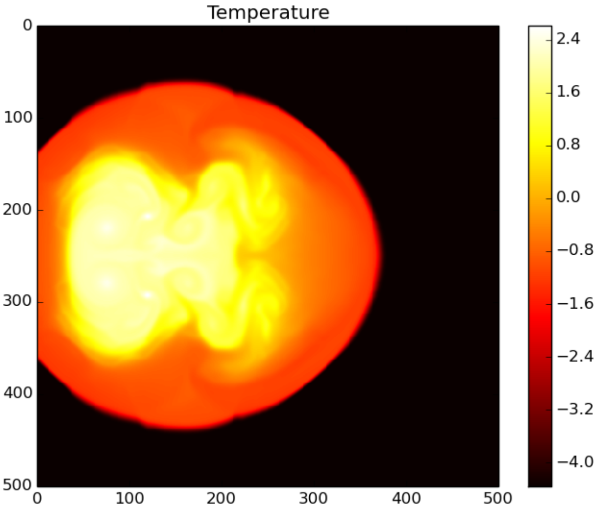
# Our Numerical Method: the $3^{rd}$ Order WENO Scheme

- High-Order Finite Difference Upwind Method for nonlinear hyperbolic differential equations
- Solves for solutions to nonlinear hyperbolic conservation laws containing sharp discontinuities such as shock waves and contacts
- We use a 13 X 13 $kpc^2$ grid to model the bubble, with a total run time of 6.3 million years

# Fermi Bubble Parameters

| Units | Bubble | Ambient | Computational Units |
|---|---|---|---|
| $\rho\ \frac{H}{cm^3}$ | $\rho$=0.06 | $\rho$=60 | $\bar{\rho}$=$10^{-2}$ |
| $P$ kg$\frac{km}{s^2}$ | $P$=1.38·$10^{-4}$ | $P$=1.38·$10^{-4}$ | $\bar{P}$=1.67·$10^{-8}$ |
| u $\frac{km}{s}$ | $u$=3·$10^4$ | $u$=0.0 | $\bar{u}$=$10^3$ |

Table : Fermi Bubble Parameters


Temperature
0
100
200
300
400
500
0
100
200
300
400
500
2.4
1.6
0.8
0.0
−0.8
−1.6
−2.4
−3.2
−4.0

# Further Projects to be investigated

- Further improve the initial conditions of the simulation
- Simulate a 3-D model of the Fermi Bubble
- Create a movie of the Fermi Bubble

# Acknowledgements & References


## Acknowledgements

- Dr. Carl Gardner
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- Friends and Family

## References

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2. Guo, F. & Mathews, W. G., The Fermi Bubbles. I. Possible Evidence for Recent AGN Jet Activity in the Galaxy (2012)
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