Origin of the Fermi/erosita bubbles

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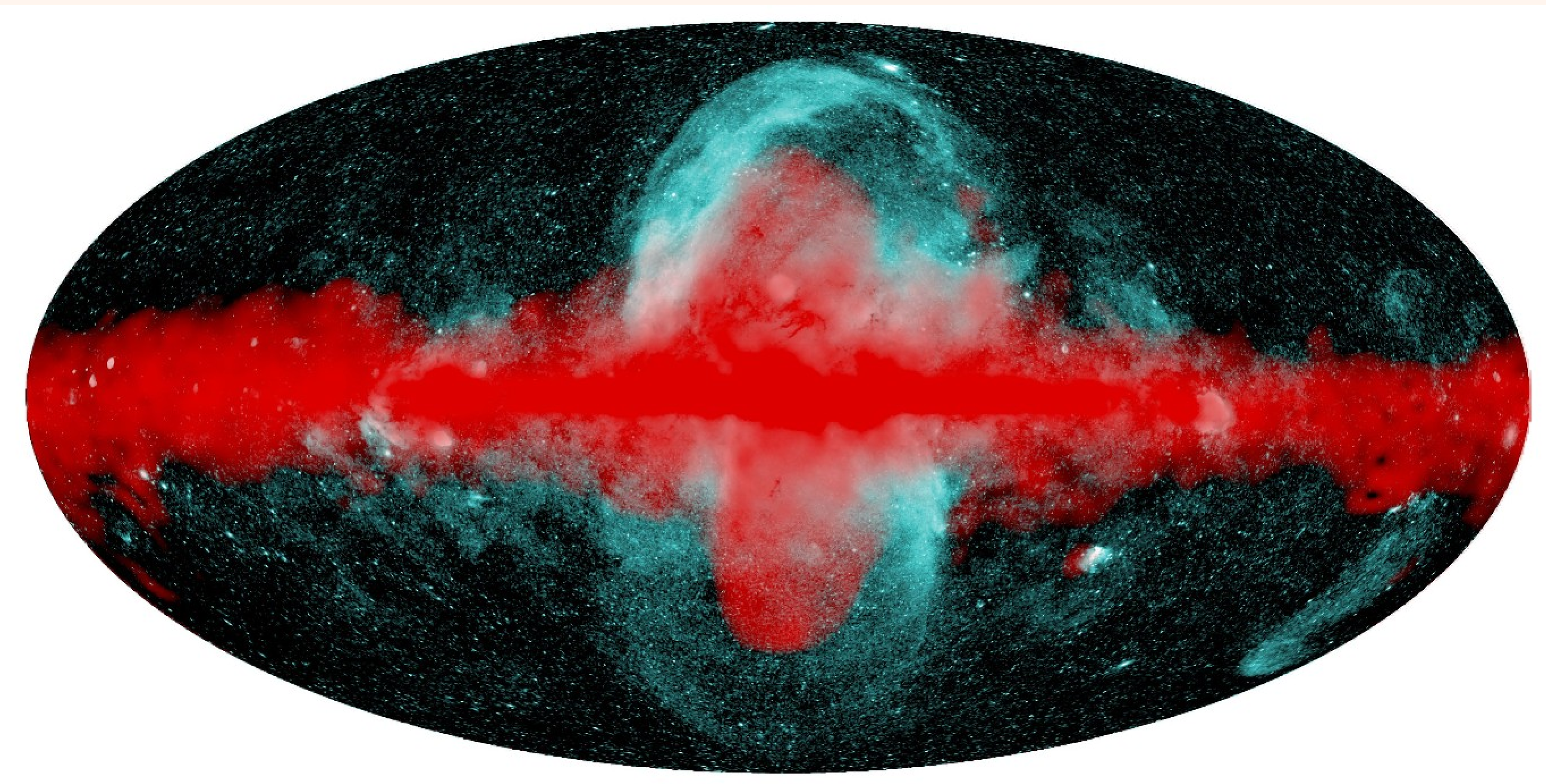
Introduction

Fermi Bubbles are two giant (~50°) gamma-ray (0.1-500 GeV) bubbles observed toward the Galactic center. The bubbles are symmetric about the Galactic plane as well as about the Galactic pole, and each measure about ~8 kpc in size. Complementary features are also observed in radio (~23 GHz) emission and kinematics of the embedded warm clouds.

A recent x-ray sky map from eROSITA has revealed a pair of x-ray bubbles, known as the eROSITA bubbles, that are even larger than the Fermi Bubbles. The location, size, and morphology of the eROSITA bubbles implicate a relation between the Fermi Bubbles and eROSITA bubbles. Further observation of the Fermi/eROSITA bubbles (FEBs) in x-ray spectra and emission lines (*viz.* O VIII and O VII), indicate that the temperature of the eROSITA bubbles is about $3-4\times10^6$ K and the total energy of the system of bubbles is $\approx 10^{56}\,erg$.

Despite several attempts to explain the origin of these bubbles, the main questions remain unsolved, *namely*,

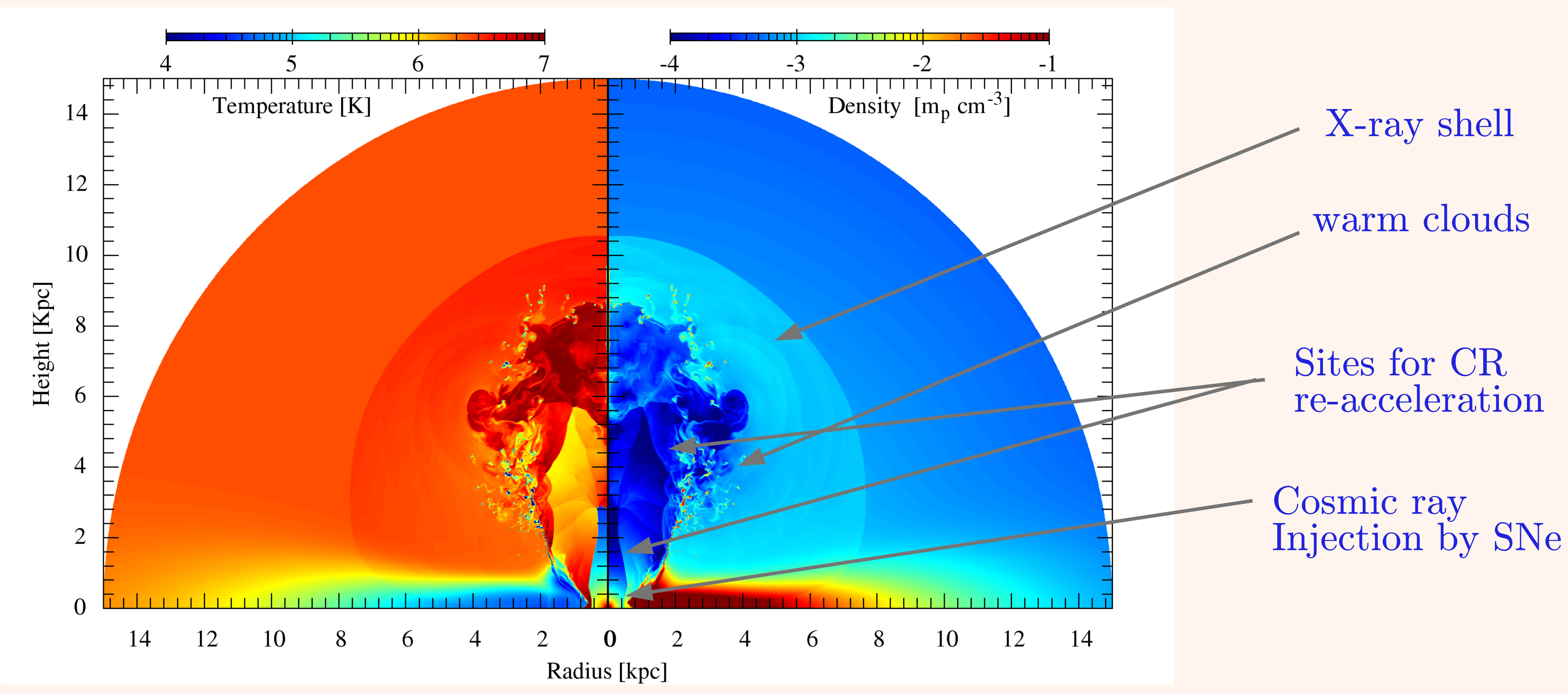
- What is the origin of the Fermi/eROSITA bubbles? Is it driven by star-formation driven or the central super massive black hole?
- What is the age of this system of bubbles?



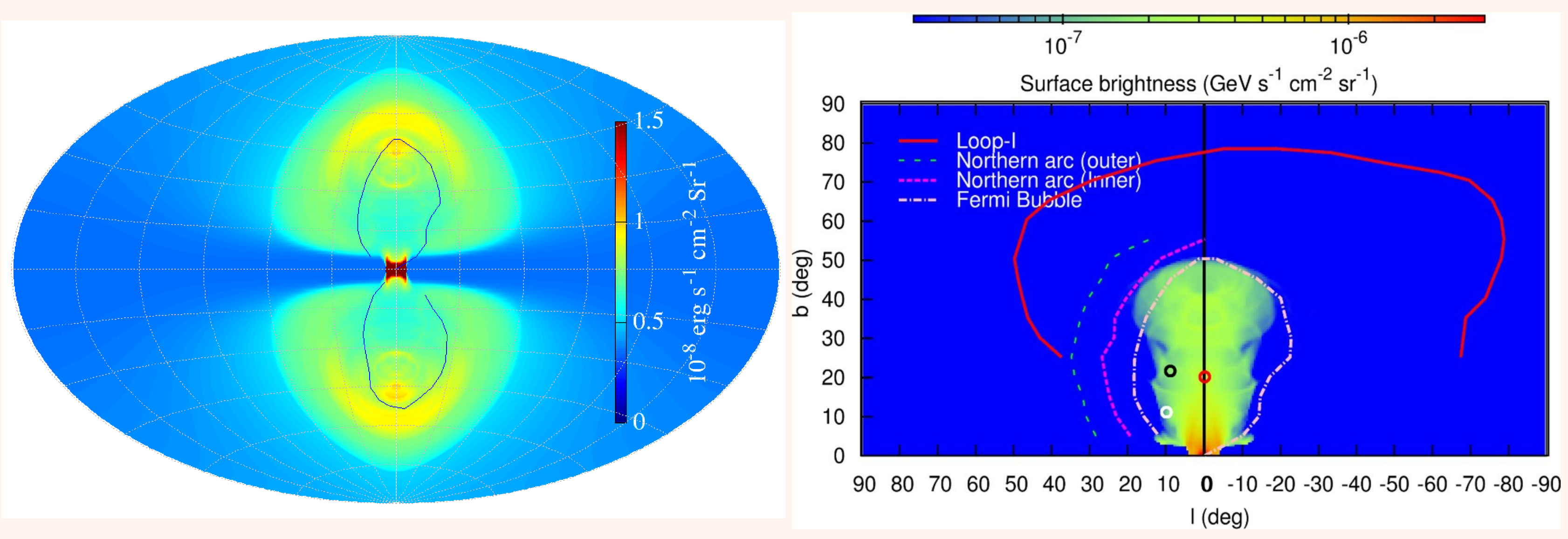
Composite image of the Fermi/eROSITA bubbles. Red shows the gamma ray emission observed using Fermi and cyan shows the x-ray (0.6-1 keV) sky map observed using eROSITA.

A star-formation-driven system

The center of the Milky way is forming stars at a rate of $\pm 0.1-0.8\,M_\odot\,yr^{-1}$ which is capable of driving a galactic wind to ~10 kpc distance and is one of the possible energy sources for powering the FEBs.



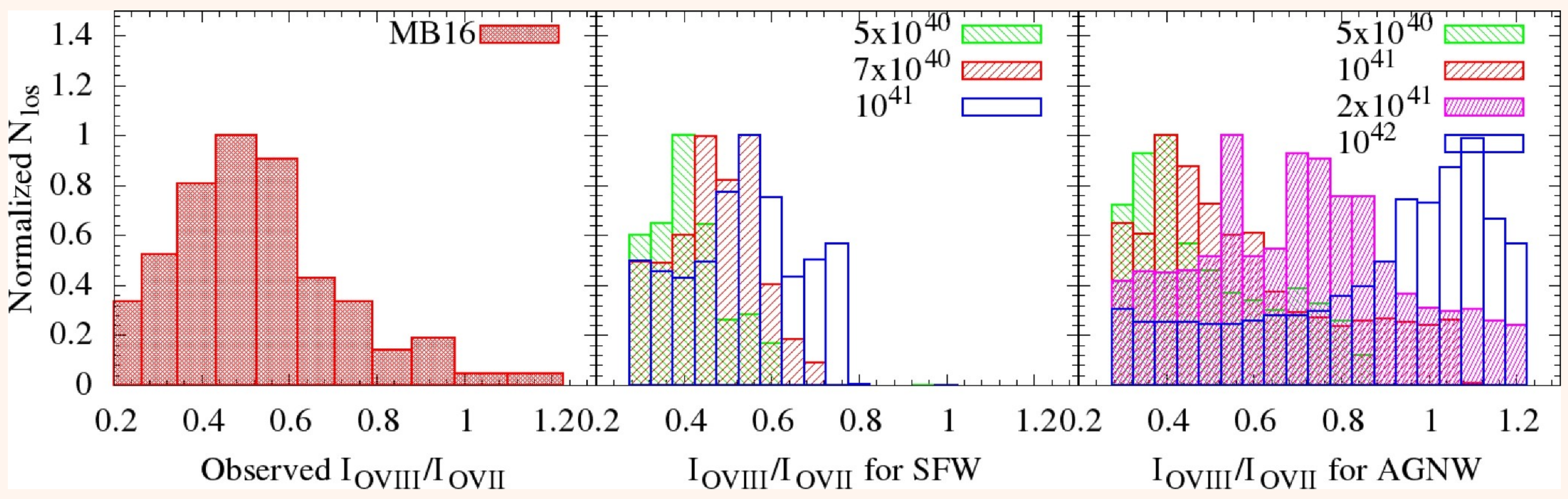
Hydrodynamical simulations of the Fermi/eROSITA bubbles as a result of star-formation driven wind at t = 27 Myr.



Left: Synthetic x-ray sky map in 0.5-2.0 keV band, resembling eROSITA bubbles, The blue line shows the observed edge of the Fermi Bubbles. Right: Synthetic Gamma-ray sky map at 10 GeV assuming Inverse compton scattering of CMB radiation field. Different lines show the observed edges of different features on the sky.

- Star-formation driven winds can explain the system of bubbles at the Galactic center. The required star formation rate is $\approx 0.3-0.5\,M_\odot\,yr^{-1}$, with an age of 27 Myr.
- The model reproduces the Fermi Bubble brightness and morphology. The gamma ray is assumed to originate from IC scattering of CMB by freshly accelerated cosmic ray electrons inside the contact discontinuity.
- The morphology, brightness, and spectra of the x-ray observations are also reproduced. The x-ray is assumed to originate from the shock-heated circumgalactic medium that is swept up by the wind to produce a x-ray emitting shell.
- The model reproduces the kinematics of warm clouds (~10^4K) inside the Fermi Bubbles. Warm clouds are naturally produced at the bubble-shell interface and have line-of-sight velocities of ±200 km s^{-1}.

X-ray line intensities



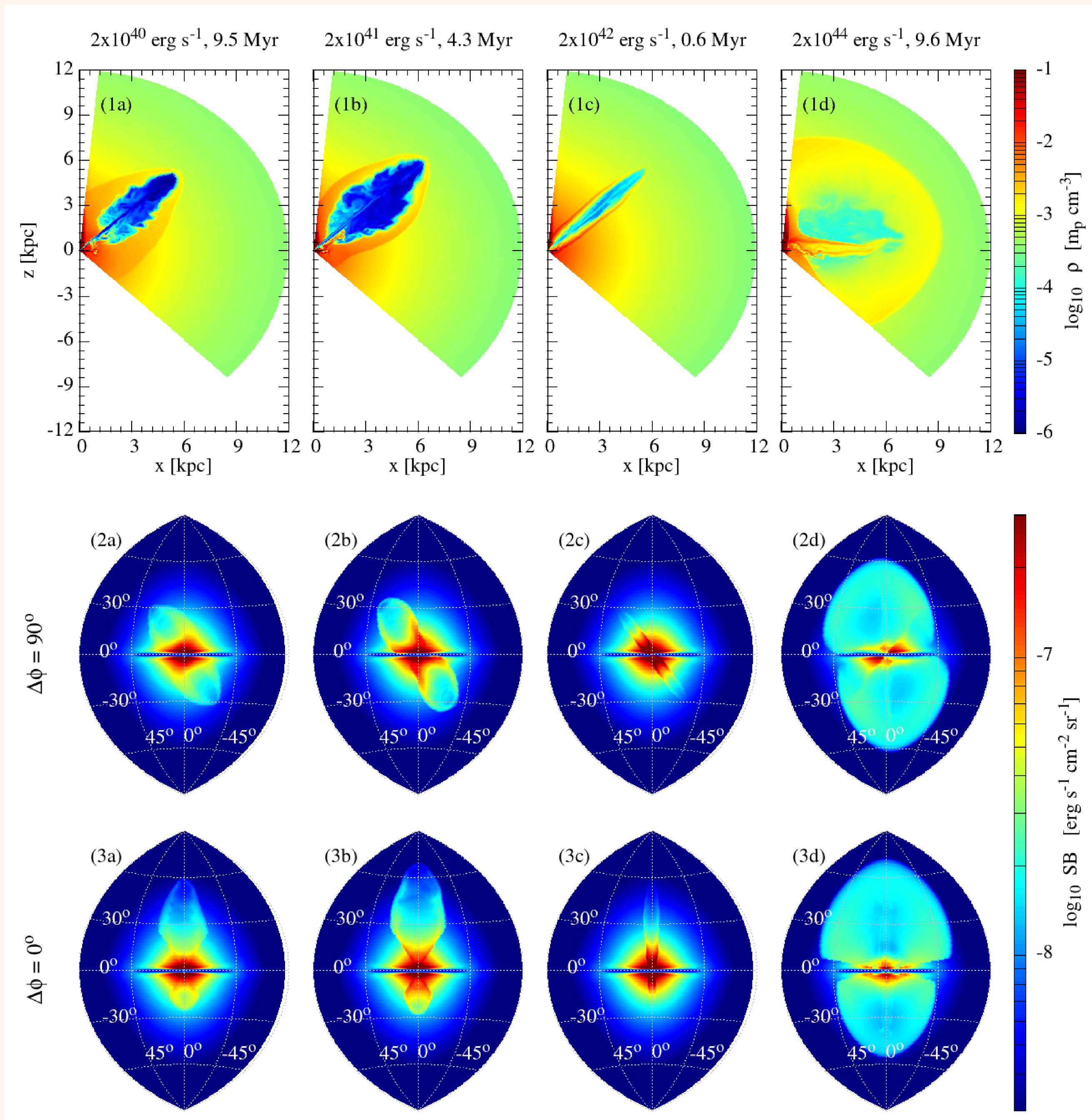
Synthetic x-ray line intensities from simulations of star-formation driven wind (middle panel) and AGN driven wind (right panel) for various mechanical power for the energy source. The left panel shows the observed line intensity ratio of OVIII and OVII.

The x-ray line intensities indicate the temperature of the shock and hence constrain the strength of the energy source.

- The mechanical power of the energy source is limited to $\approx 10^{40.5-41}\,erg\,s^{-1}$ irrespective of the driving mechanism, i.e. SNe or AGN.
- The required active duration for the source is $\approx 10^{56}$ erg/10^{41} erg s^{-1} ≈ 30 Myr.

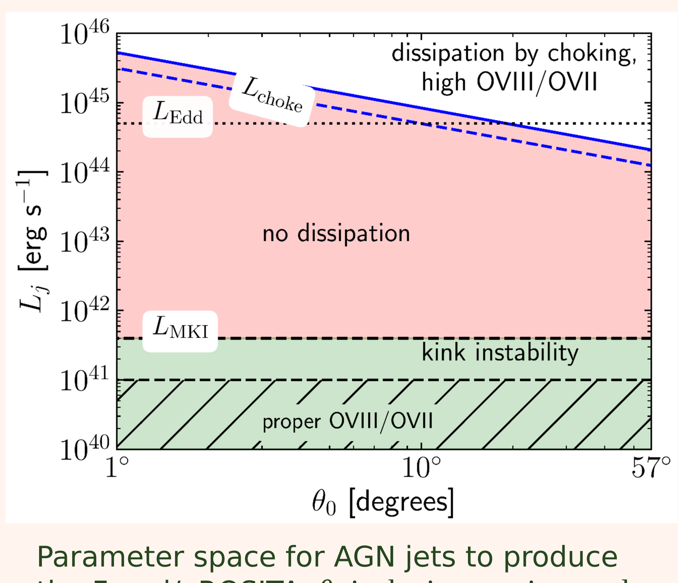
An AGN-driven system

Milky Way contains a supermassive black hole (≈ $4\times10^6\,M_\odot$) at the Galactic center. Although the black hole (BH) is currently quiet, it could have had higher activity in the past. The angular momentum directions of stellar and gaseous structures near the BH are tilted by ~25-50° from the Galactic pole. Therefore, any possible jet activity would have been directed significantly away from the Galactic pole. Such a jet is required to be dissipated to produce the symmetric FEBs.



Top panel: Hydrodynamical simulations of the jets that are directed 45° away from the Galactic pole. Middle Panel: Projected x-ray brightness map in 0.5-2.0 keV band when viewed from the side. Bottom panel: X-ray Map when viewed from the plane of the jet.

- Collimated hydrodynamical jets do not dissipate within the ISM and, therefore, can not produce the symmetric FEBs. Only the jets that are choked early can produce the symmetric bubble features.
- Bubbles from the short-duration and powerful jets are not consistent with x-ray line constraints.
- Dissipation is possible easily for magnetically dominated jets, wide-angle accretion winds, or TDE-driven winds. The processes can generate the symmetric FEBs, however, the mechanical power should be ≈ $10^{40.5-41}$ erg s^{-1} for consistent x-ray emission.



Parameter space for AGN jets to produce the Fermi/eROSITA. θ_0 is the jet opening angle.

Conclusions

- A star formation rate of ≈0.3=0.5 $M_\odot yr^{-1}$ at the center of the MW can explain the observed FEBs shape and brightness in X-ray and gamma-rays. The warm cloud kinematics are naturally produced at the bubble-shell interface due to thermal instability.
- For AGN jet-driven bubbles, dissipation of the jet is essential (either via choking or other instabilities) for producing symmetric FEBs.
- X-ray observations constrain the mechanical power for the energy source to be ≈ $10^{40.5-41}$ erg s^{-1}, irrespective of star-formation-driven or AGN-driven bubbles.

References

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