High Energy Phenomena at the Galactic Center: Fermi Bubbles and Sgr A Lobes

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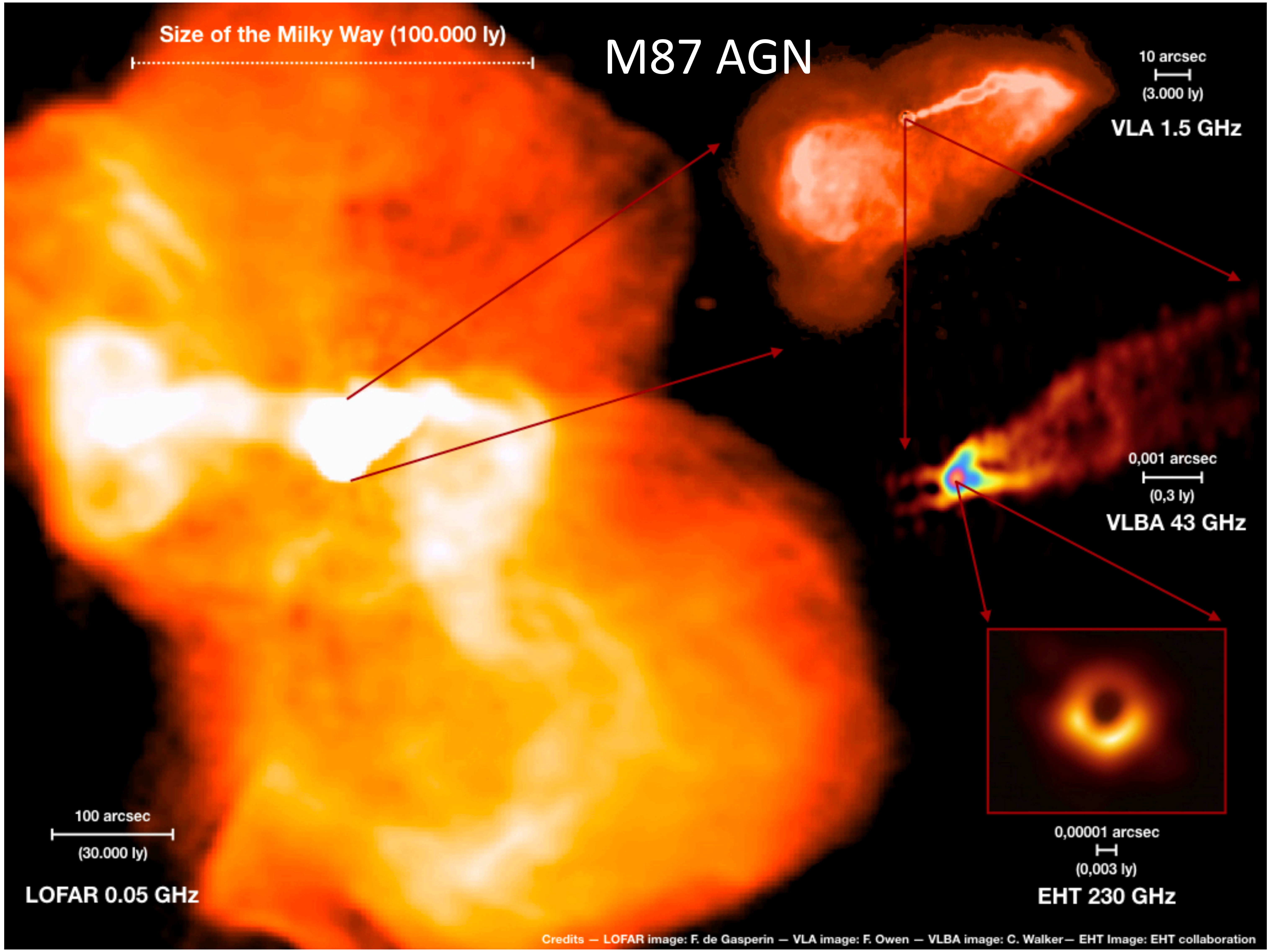
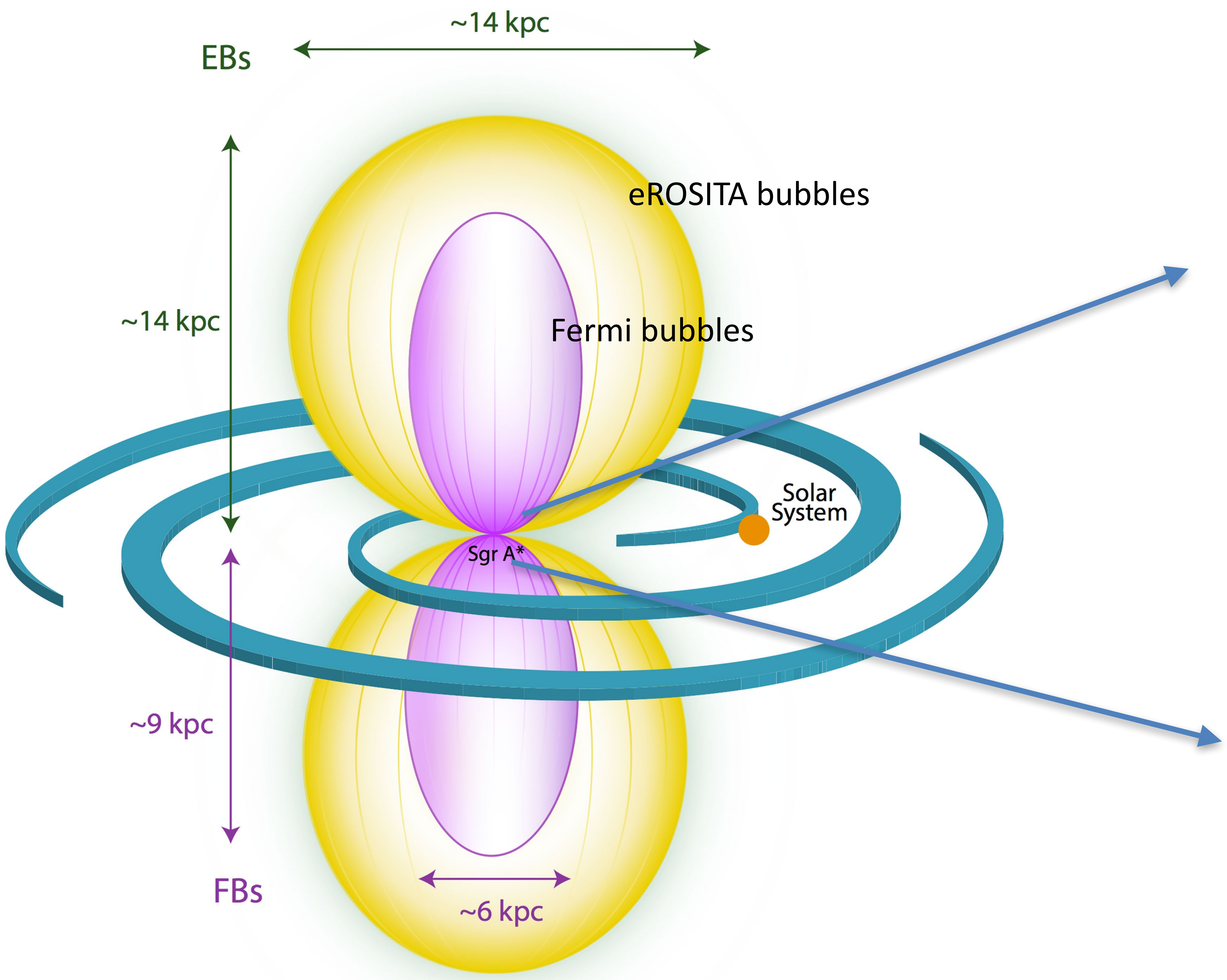
Cosmic Rays: acceleration, transport, impact

Cosmic ray accelerators:

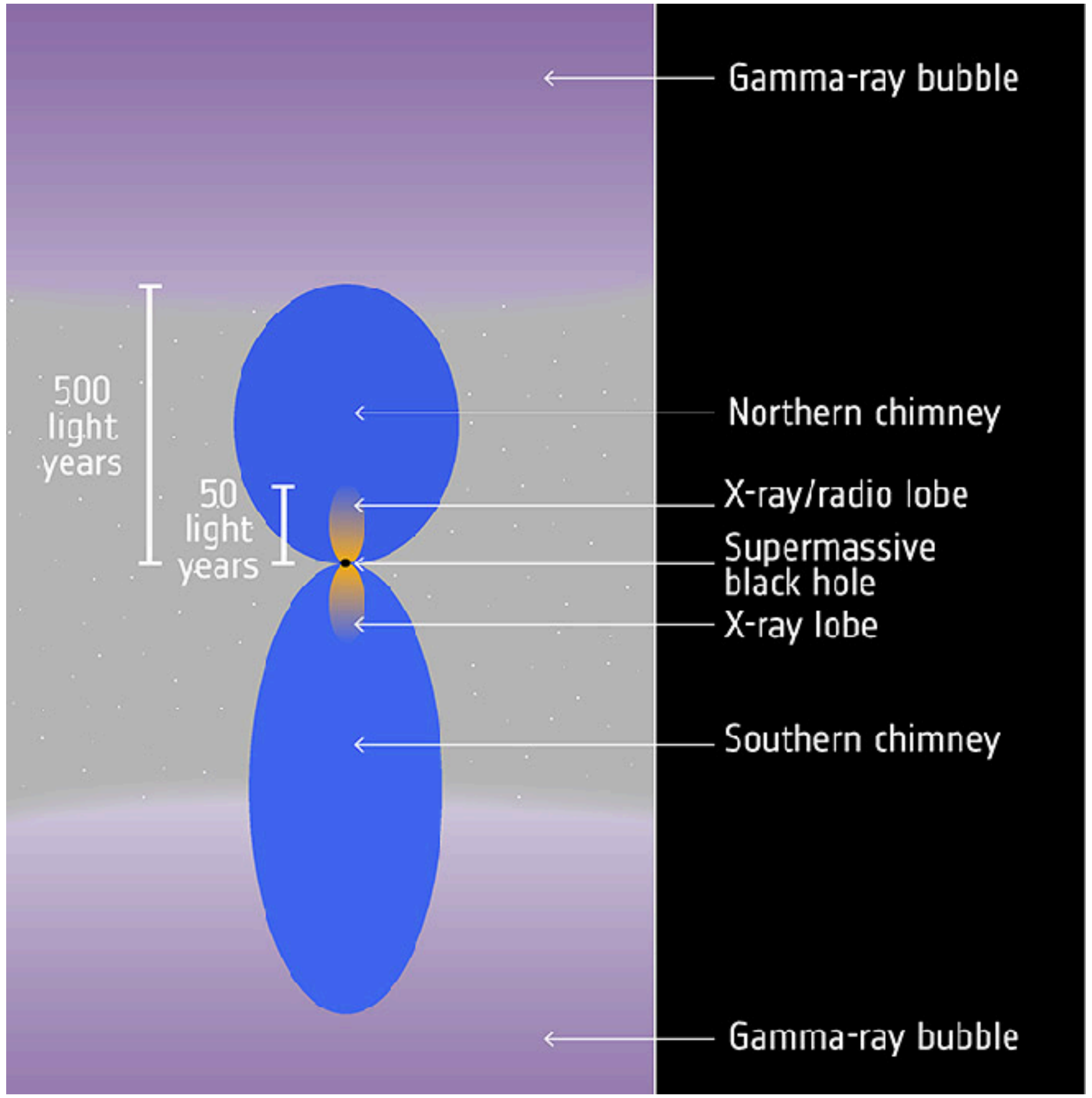
- Supernovae
- Pulsar Wind Nebulae
- Young stellar clusters
- Compact binaries
- **starburst: clustered supernovae**
- **AGN: accretion, jets, outflows**



Energetic Outbursts at the Galactic Center



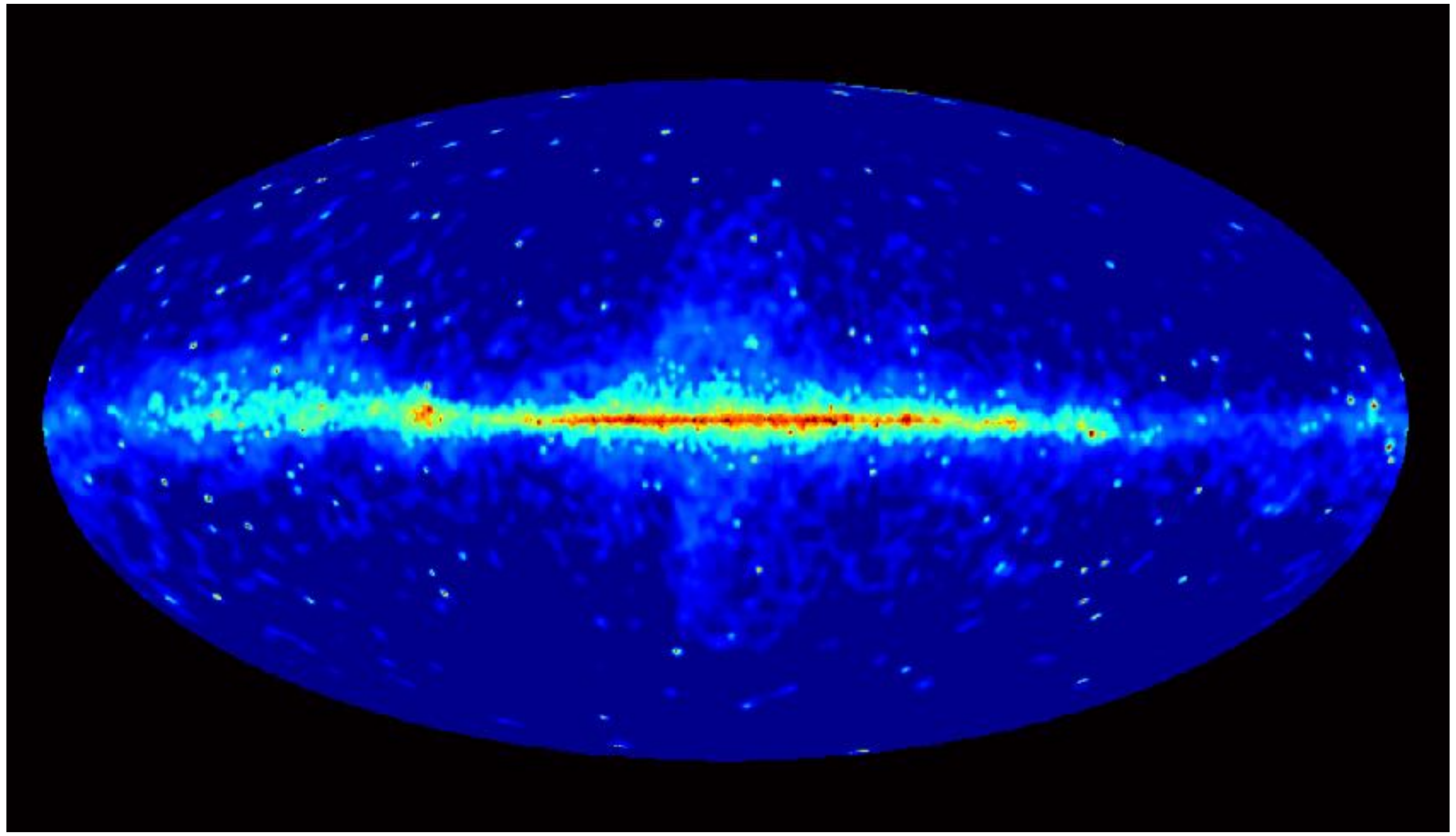
eROSITA and Fermi bubbles Predehl + 2020 Nature

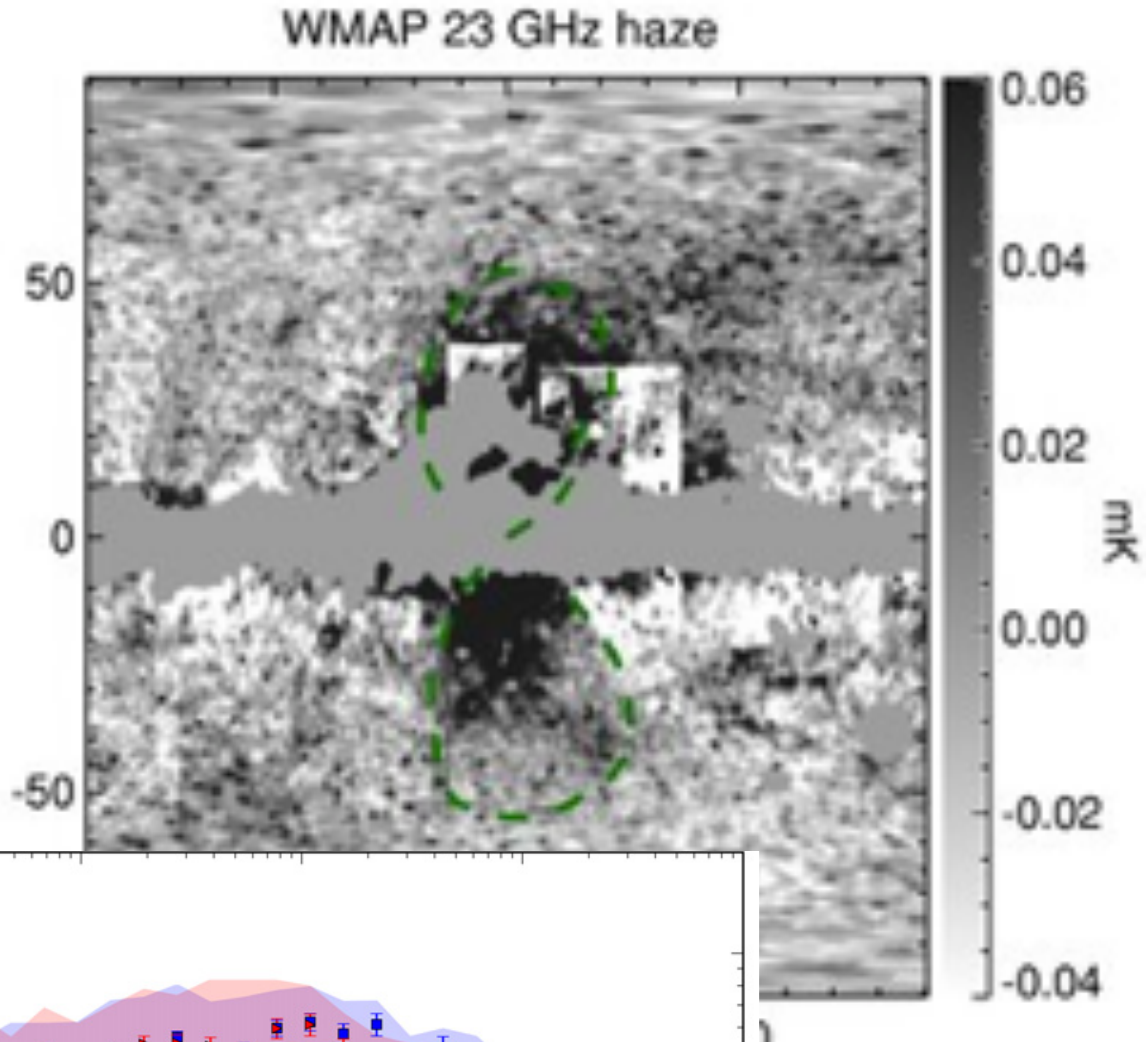


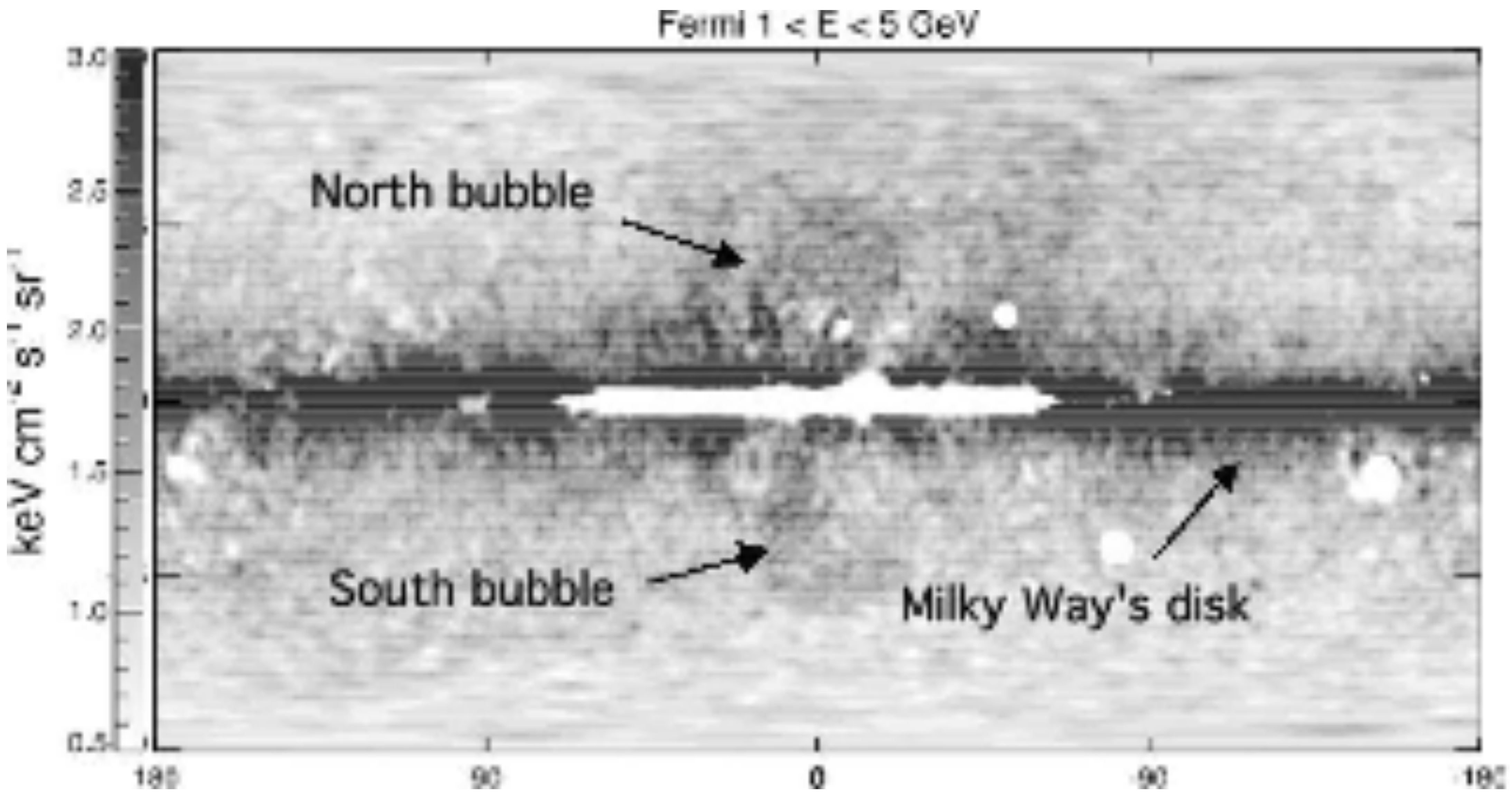
Galactic center Chimneys and the central Sgr A Lobes (Ponti+2019)

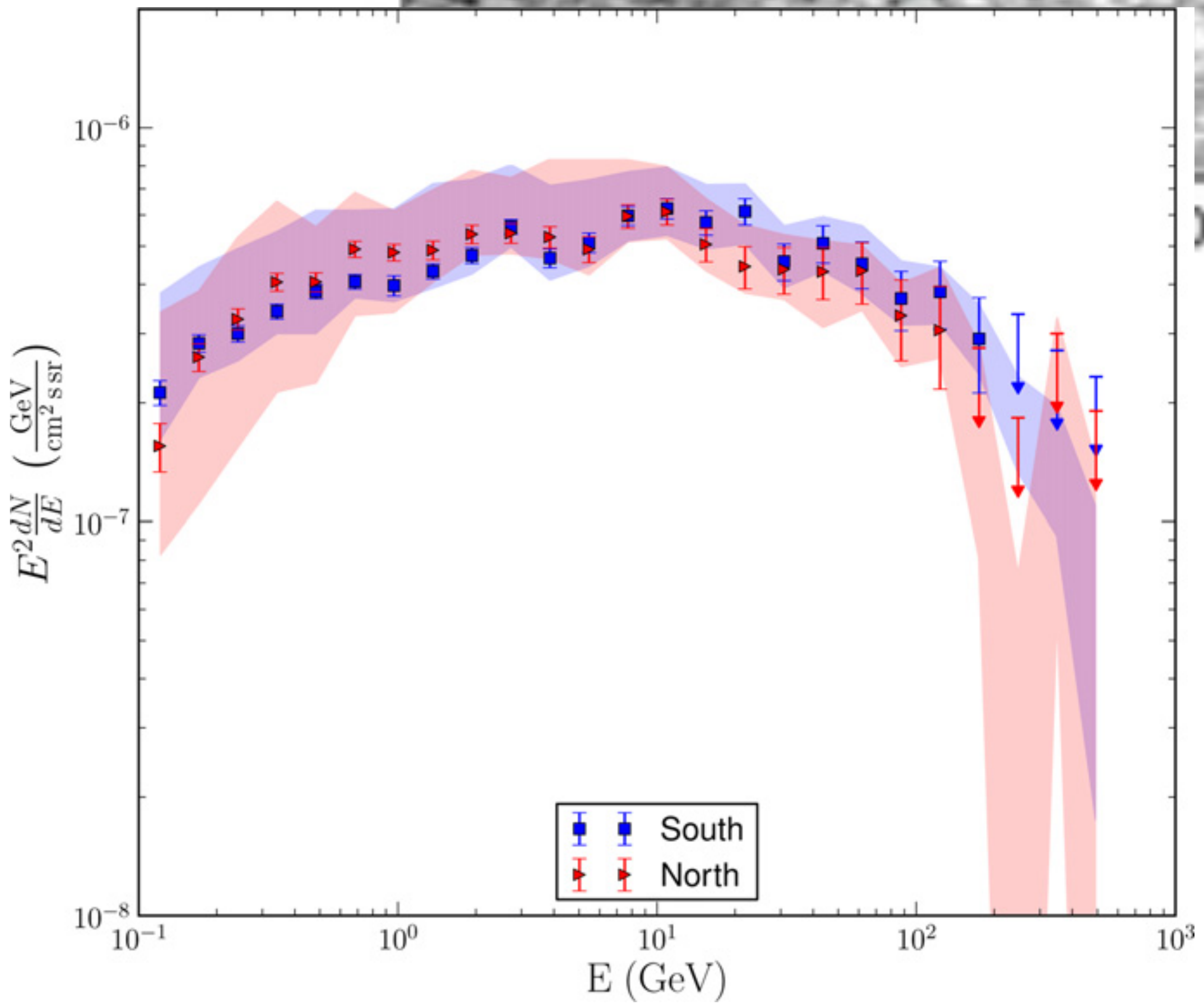
- **Starburst: clustered supernovae**
- **AGN: accretion, jets, outflows**

Fermi Bubbles in Gamma Ray and Microwave









(Su + 2010)

eROSITA Bubbles

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Article | Published: 09 December 2020

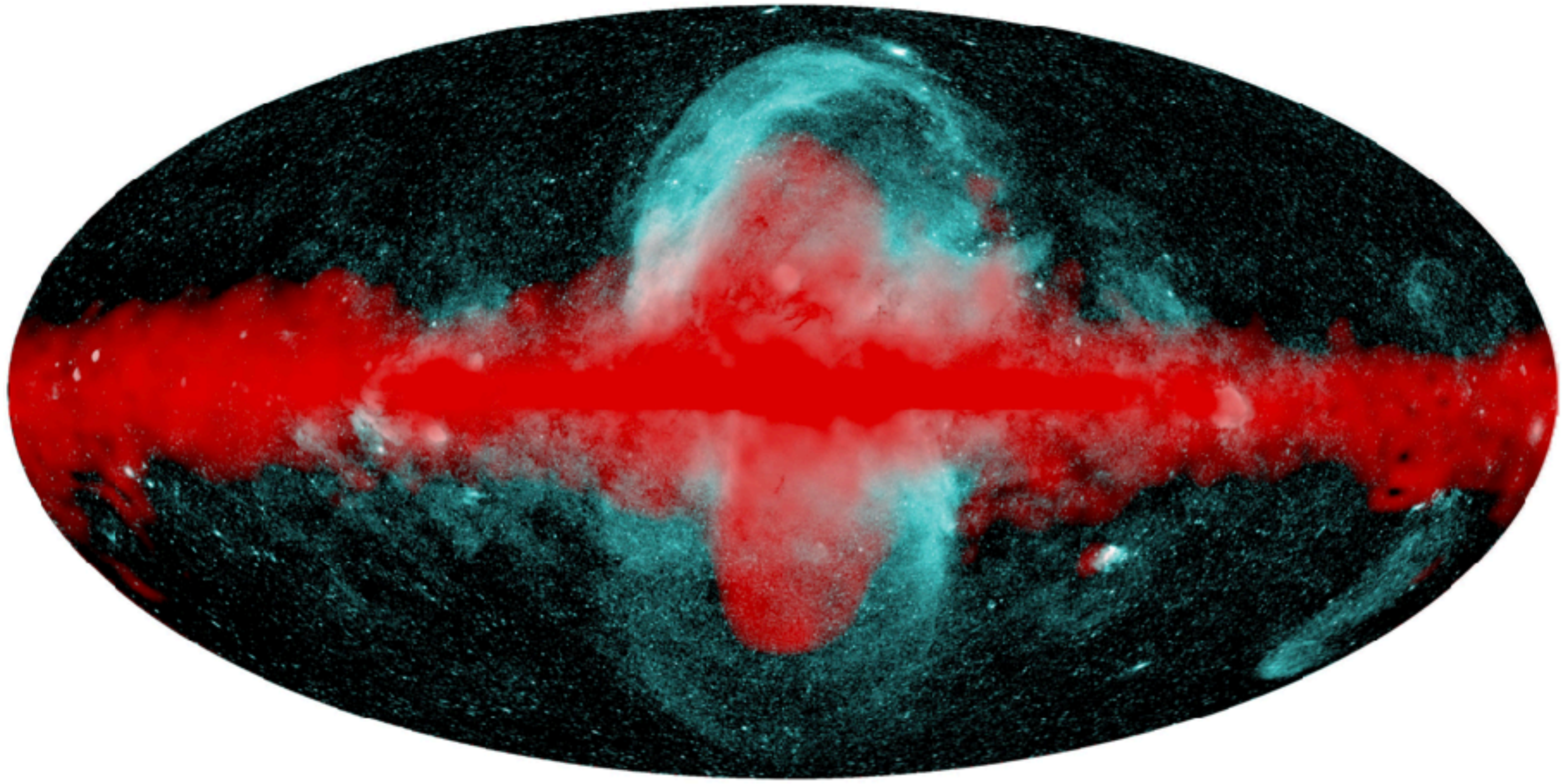
Detection of large-scale X-ray bubbles in the Milky Way halo

17-1

Publ. Astron. Soc. Japan (2020) 72 (2), 17 (1–14)
doi: 10.1093/pasj/psz139
Advance Access Publication Date: 2020 January 31

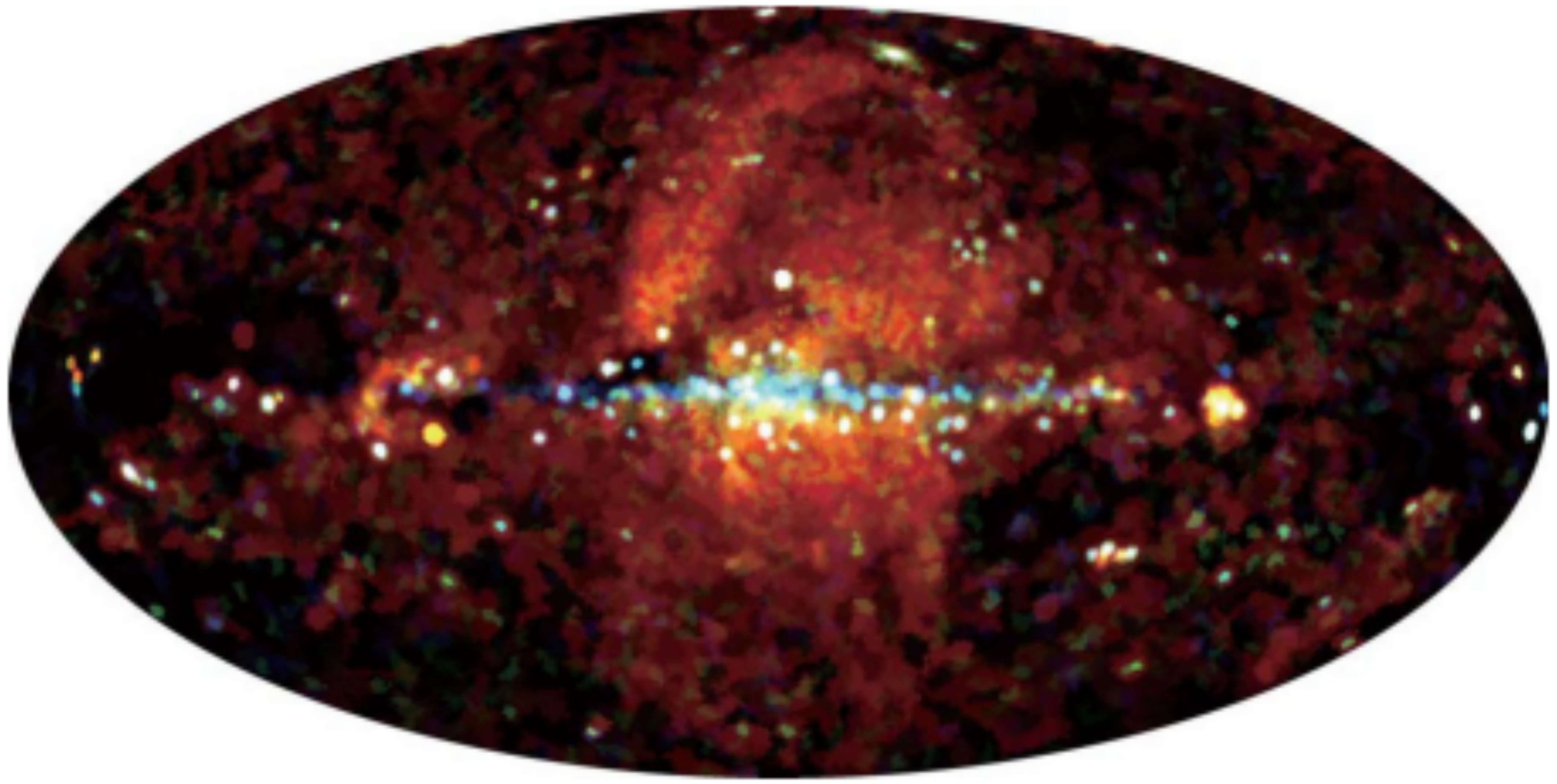
MAXI/SSC all-sky maps from 0.7 keV to 4 keV

Satoshi Nakahira,[1,2,*] Hiroshi Tsunemi,[3] Hiroshi Tomida,[1]
Shinya Nakashima,[2] Ryuho Kataoka,[4,5] and Kazuo Makishima[6]



0.6-1 keV in cyan

eROSITA bubbles (Predehl + 2020)
red — Fermi gamma-ray map

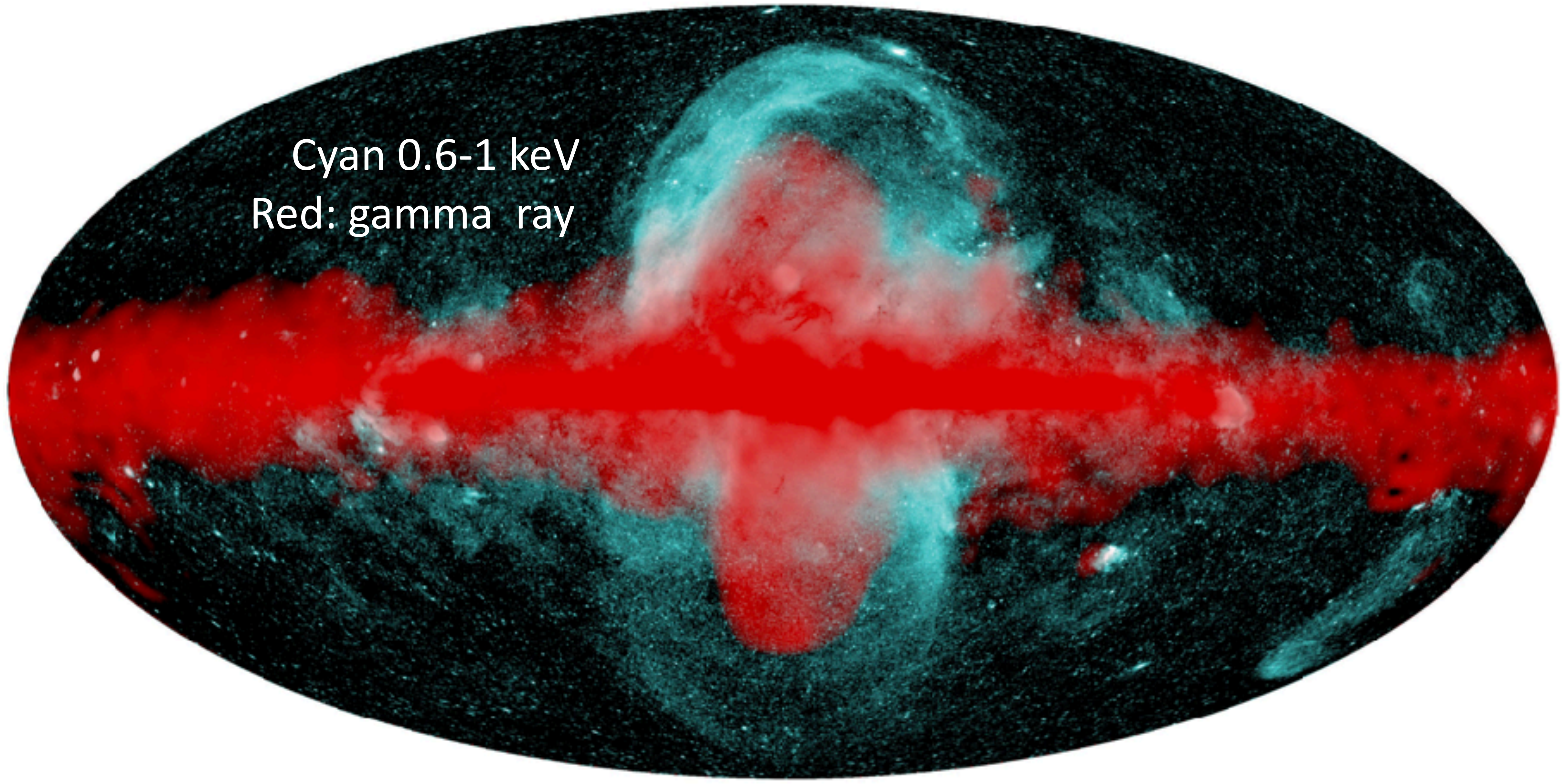


MAXI (0.7-1 keV; red), Nakahira + 2020

Galactic Center Chimneys and Central 15-pc Sgr A Lobes

Ponti et al 2019 Nature

Mysteries about Fermi and eROSITA Bubbles



eROSITA bubbles (Predehl + 2020)

- Fermi and eROSITA bubbles:

(1) Gamma ray emission mechanisms

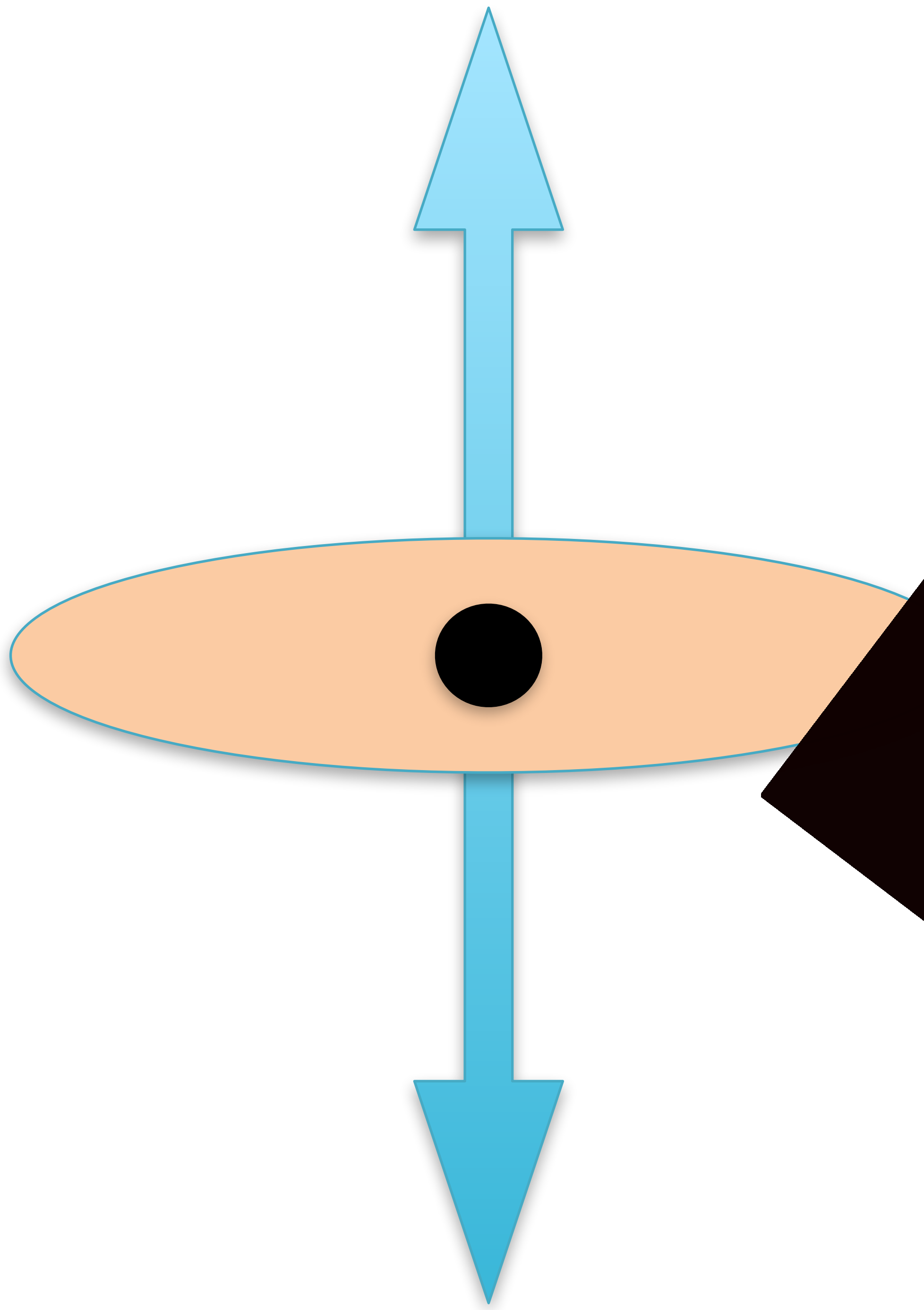
(2) Origins

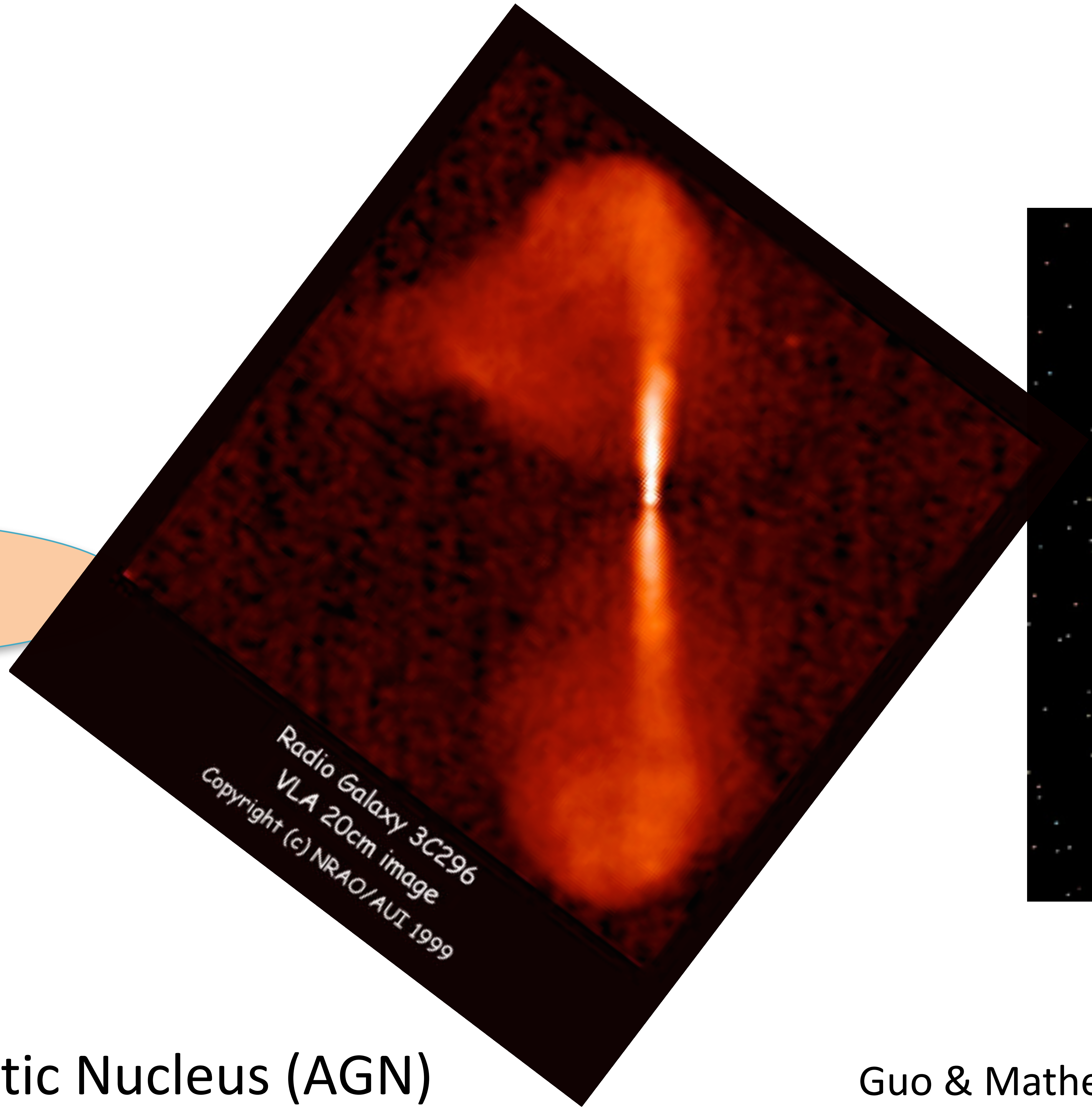
- How do they contribute to the Galactic cosmic ray population at various energies?

- Do Fermi and eROSITA bubbles are the same event?

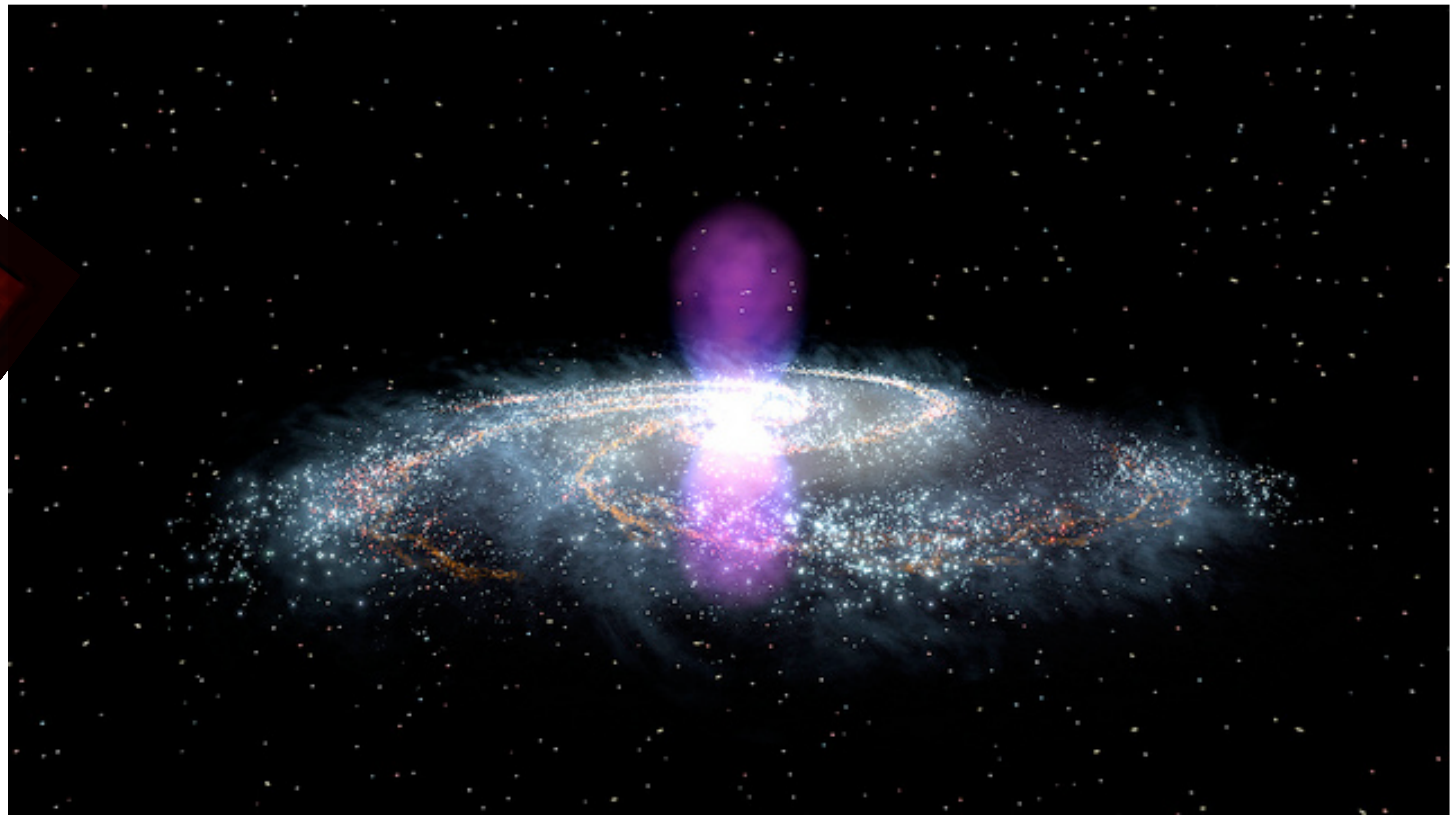
Scenario one: one unified model for Fermi and eROSITA bubbles

Bipolar Jets





Active Galactic Nucleus (AGN)



Fermi Bubbles

Guo & Mathews 2012; Guo + 2012, ApJ; Guo 2017； Zhang & Guo 2020, 2021

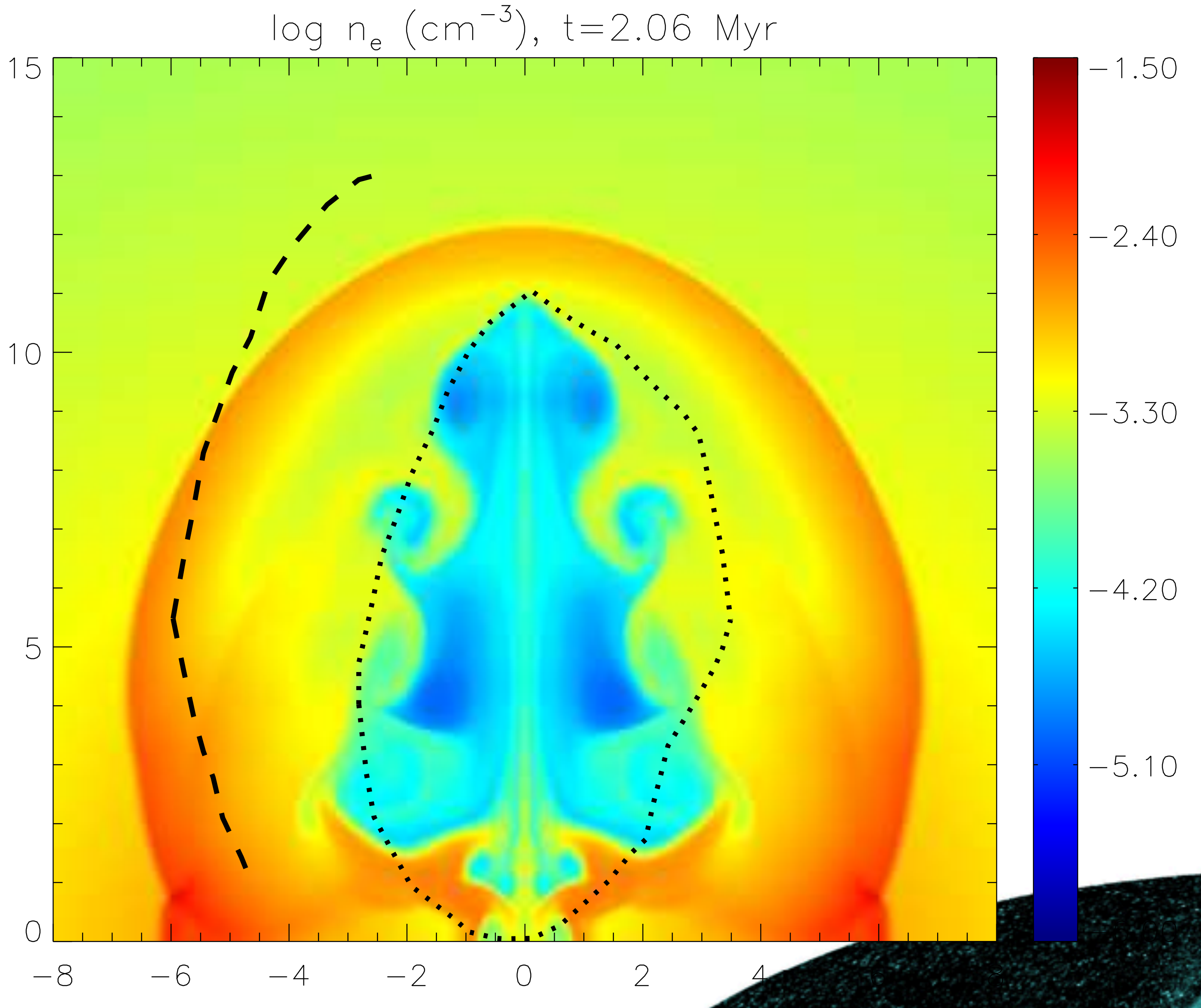
- other AGN models: Quasar outflow model, hot accretion flow - outflow model

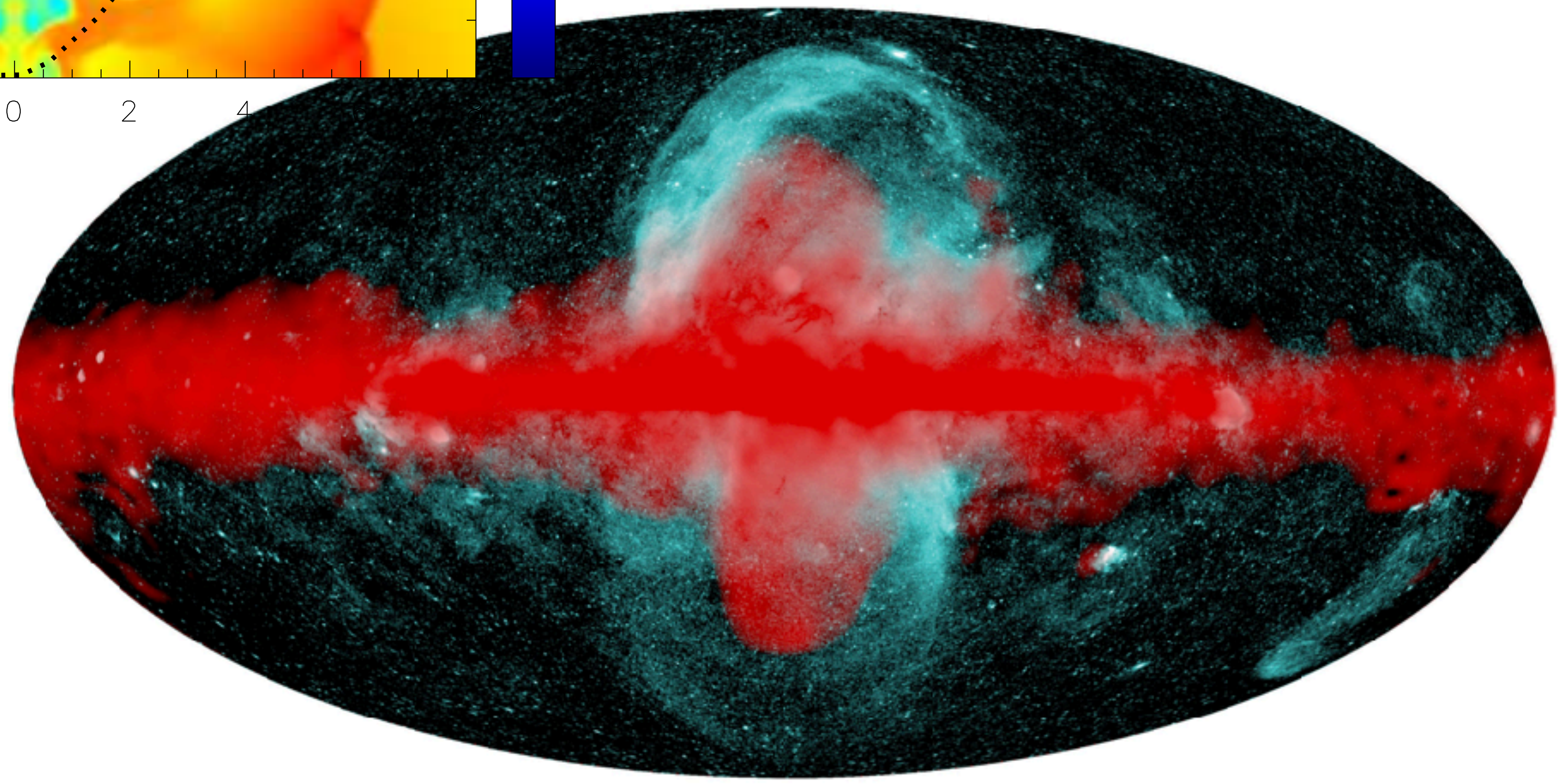
Scenario one: one unified model for Fermi and eROSITA bubbles

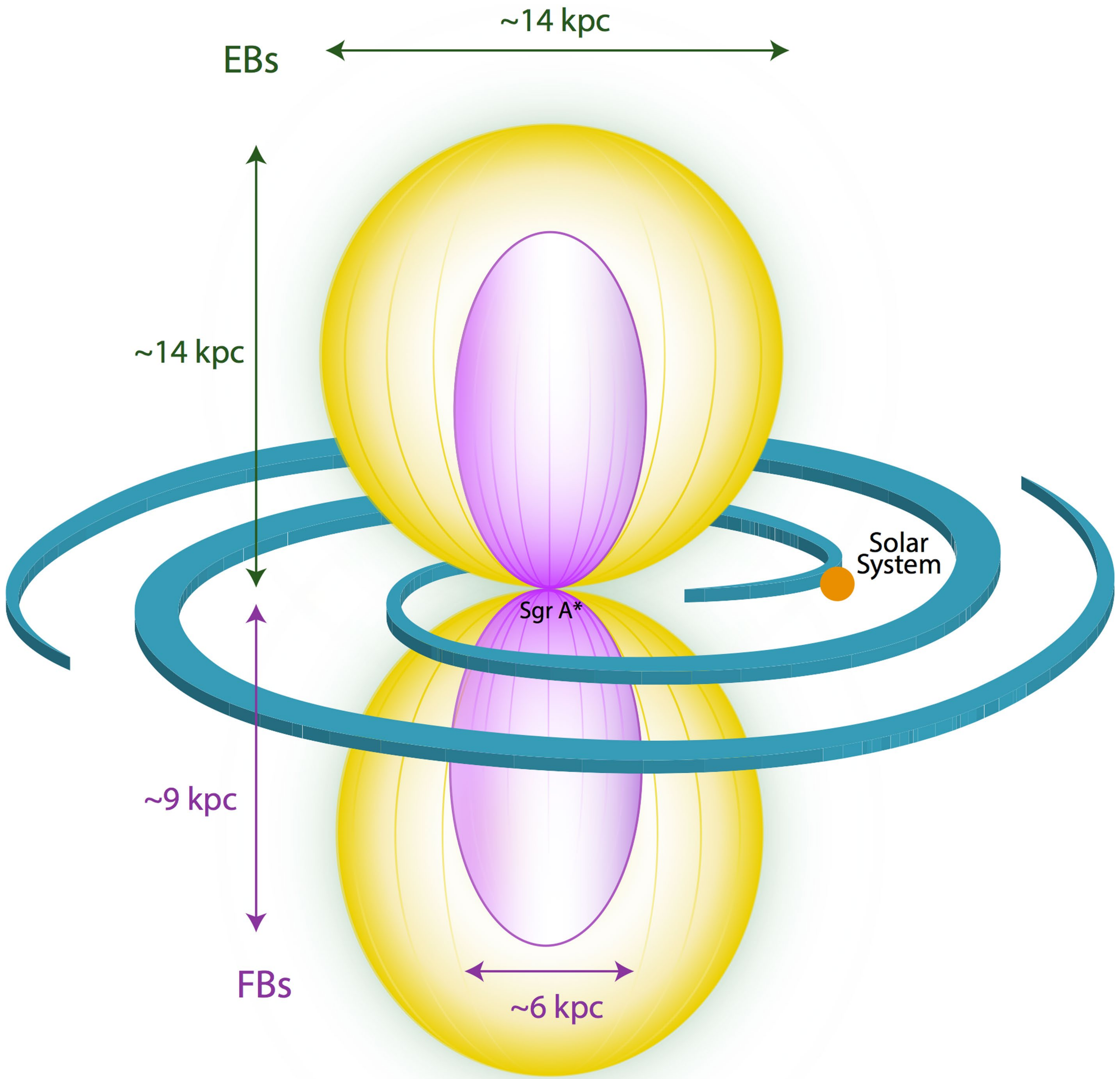
Bubble age ~ 1-2 Myr

Fermi Bubbles： jet ejecta bubbles in the Milky Way

eROSITA bubbles: shocked bubbles in the circumgalactic medium

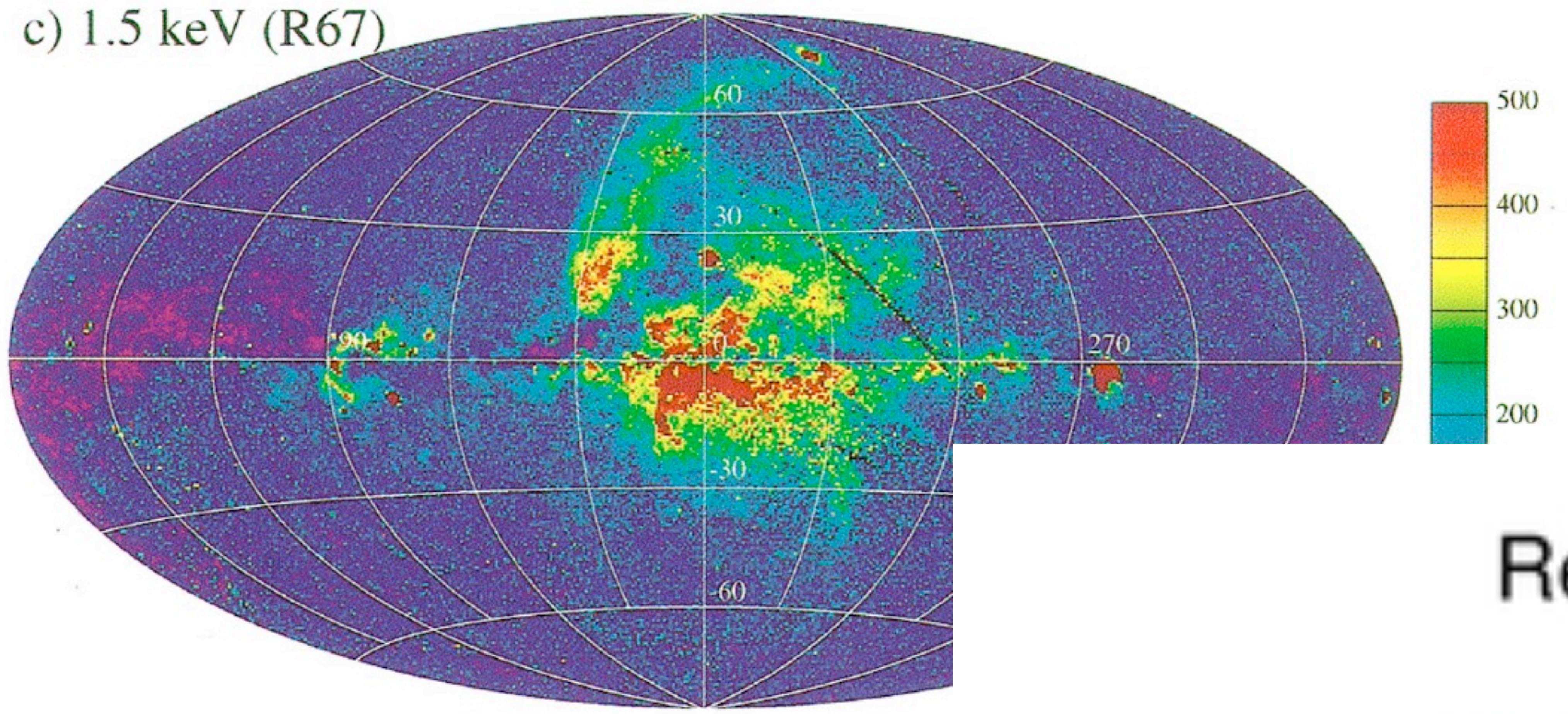


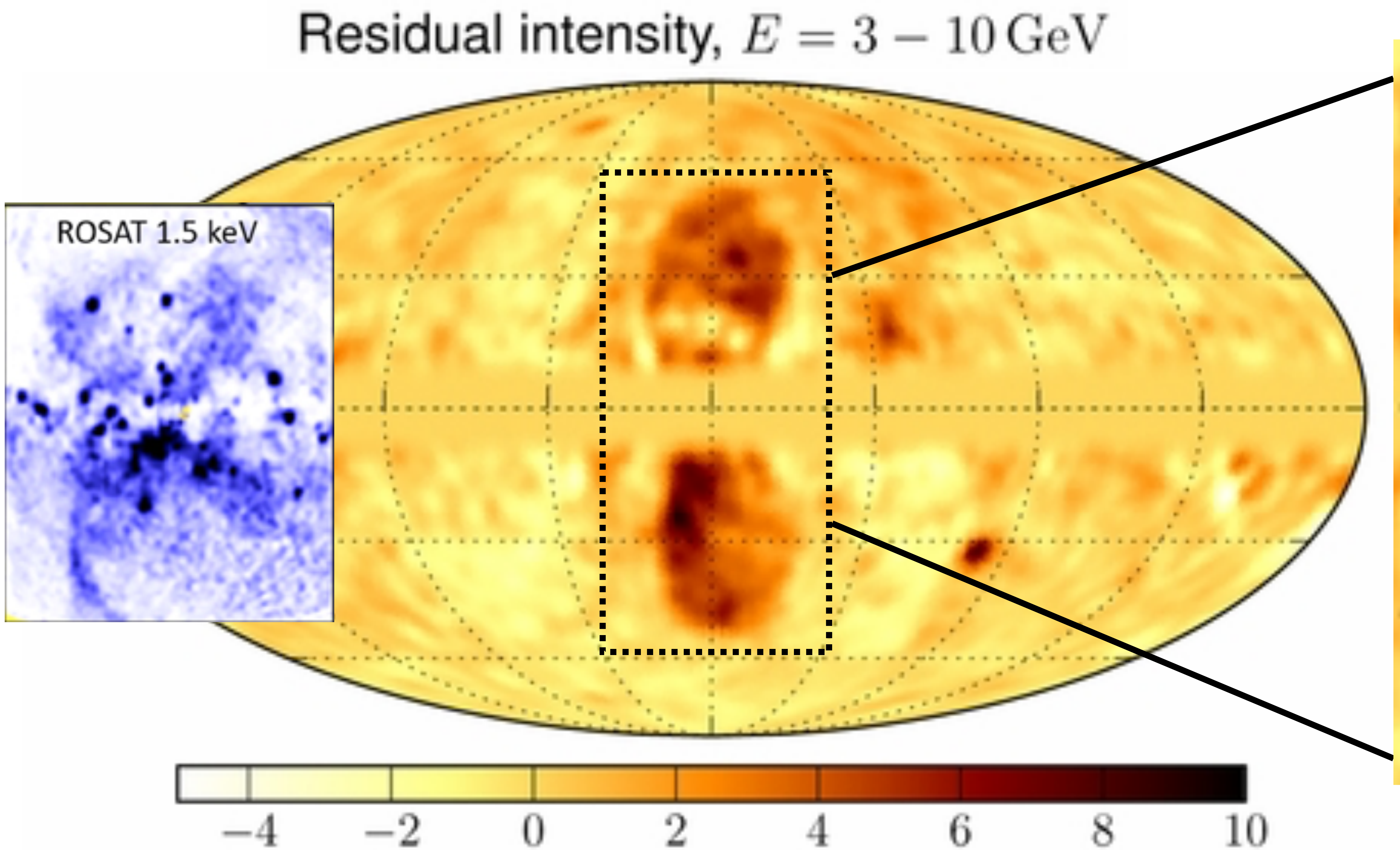




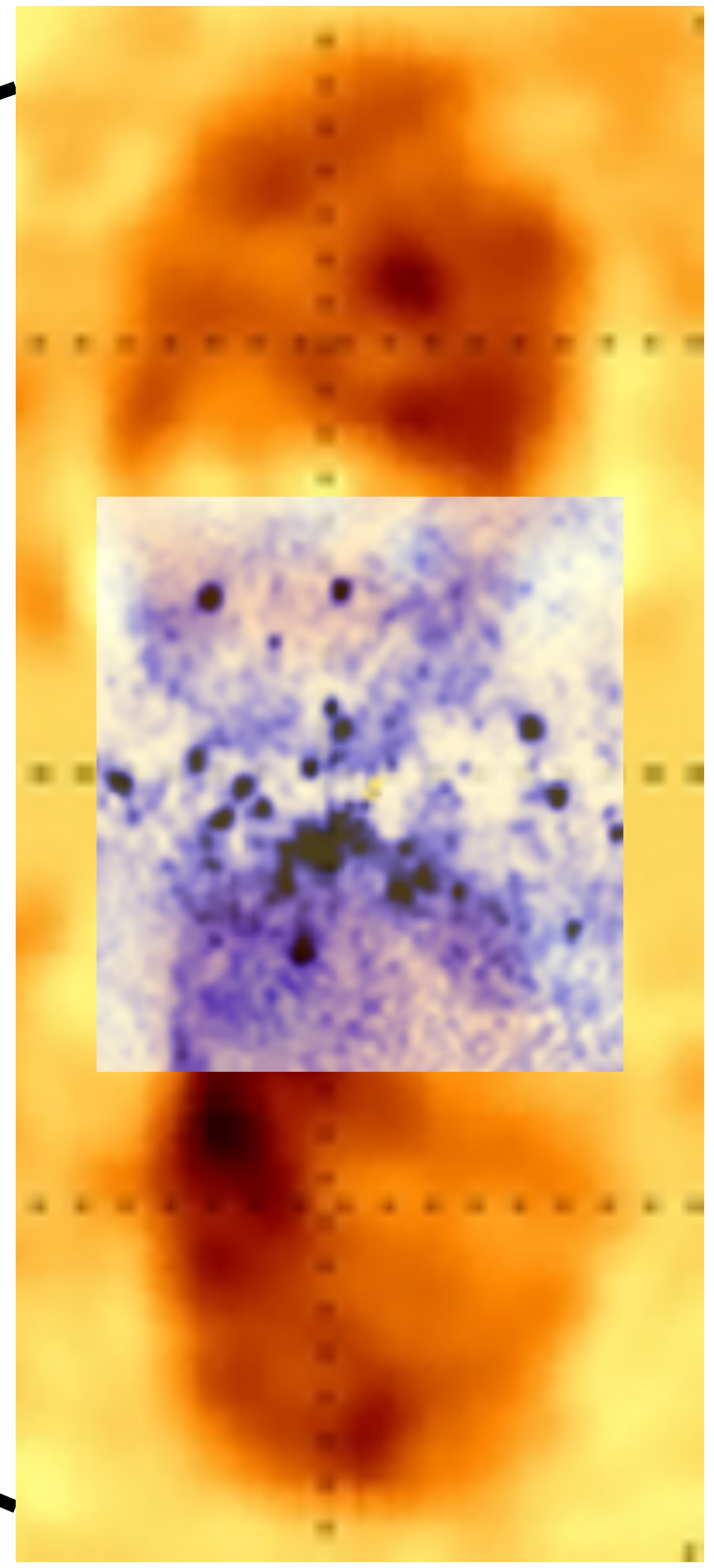
Fermi bubbles (red) and eROSITA Bubbles (cyan)

Problem: bipolar X-ray outflows in ROSAT map





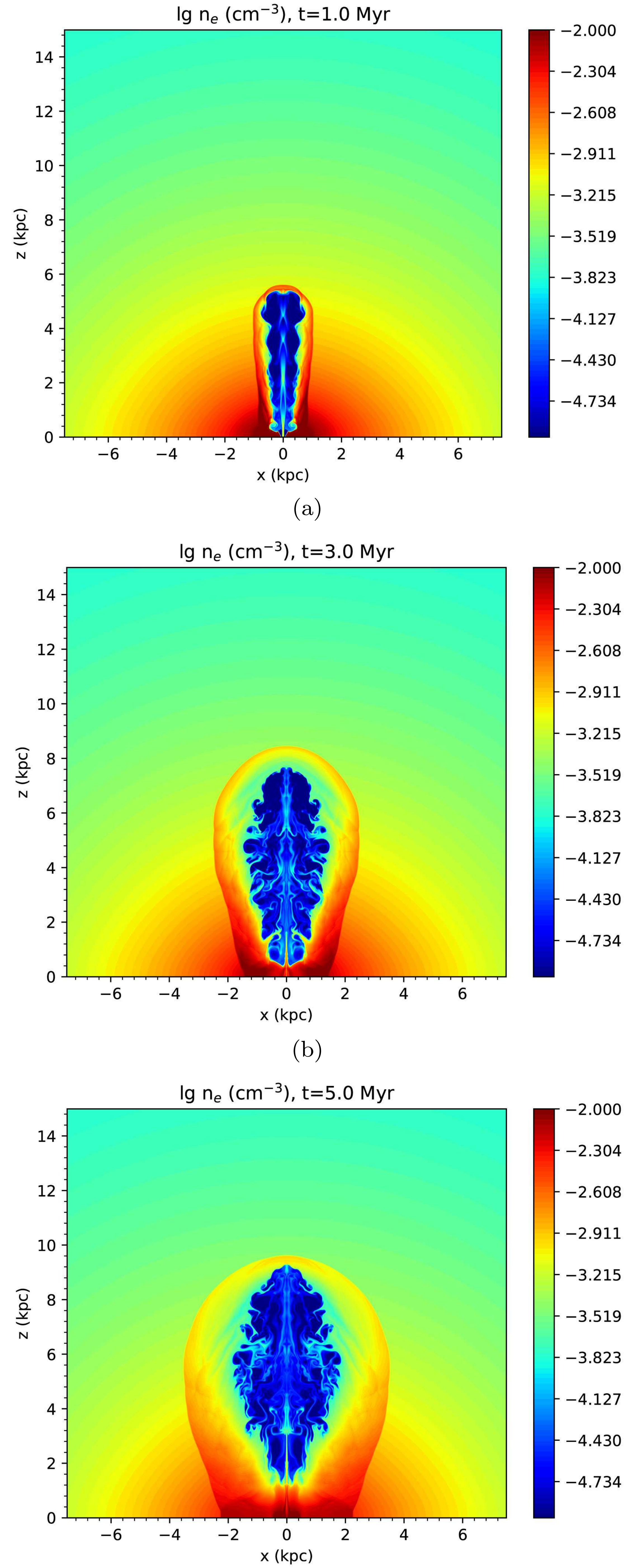
Composite



Scenario two: separate models for Fermi and eROSITA bubbles

The Jet-Shock Model of Fermi bubbles

Bubble age ~ 5 Myr



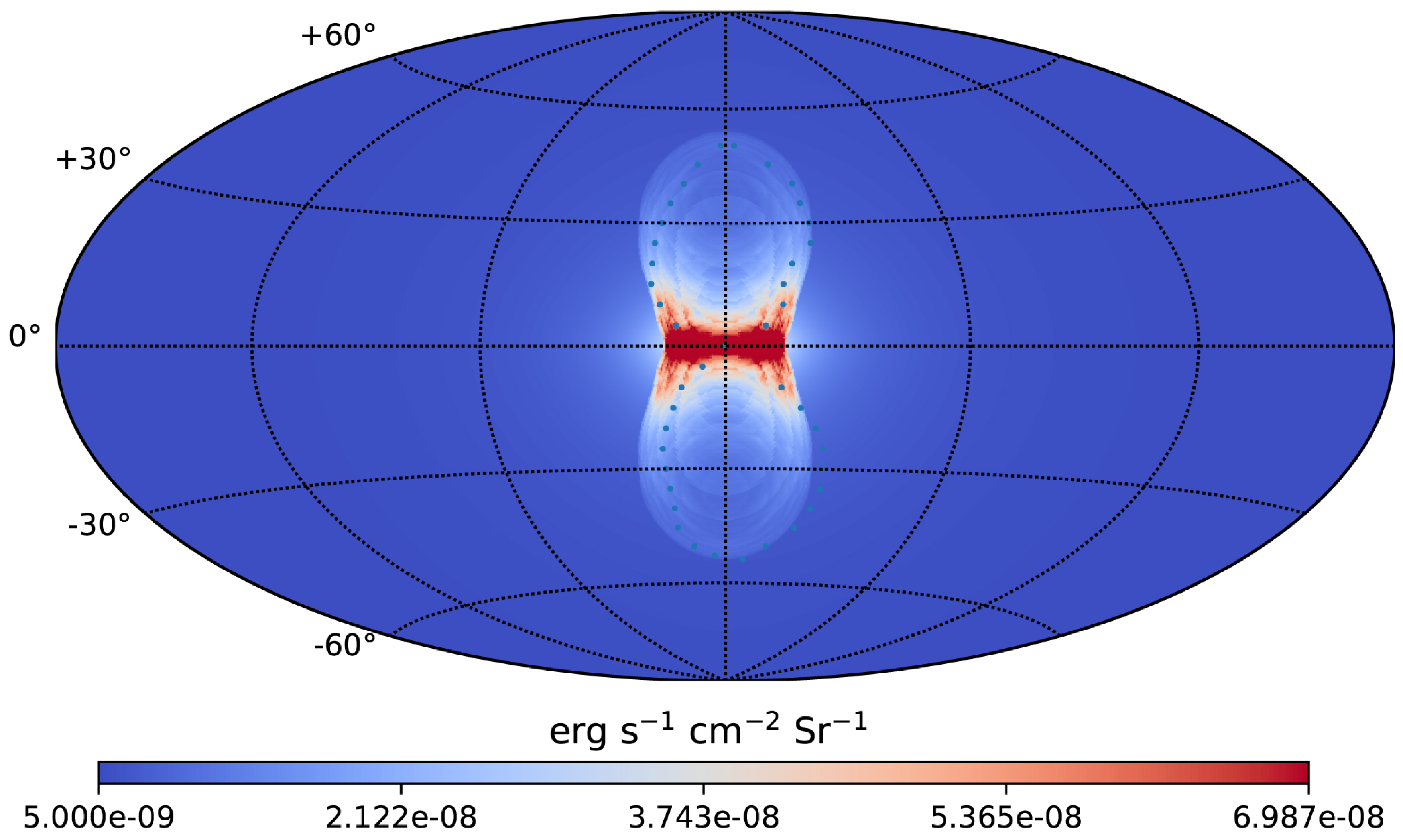
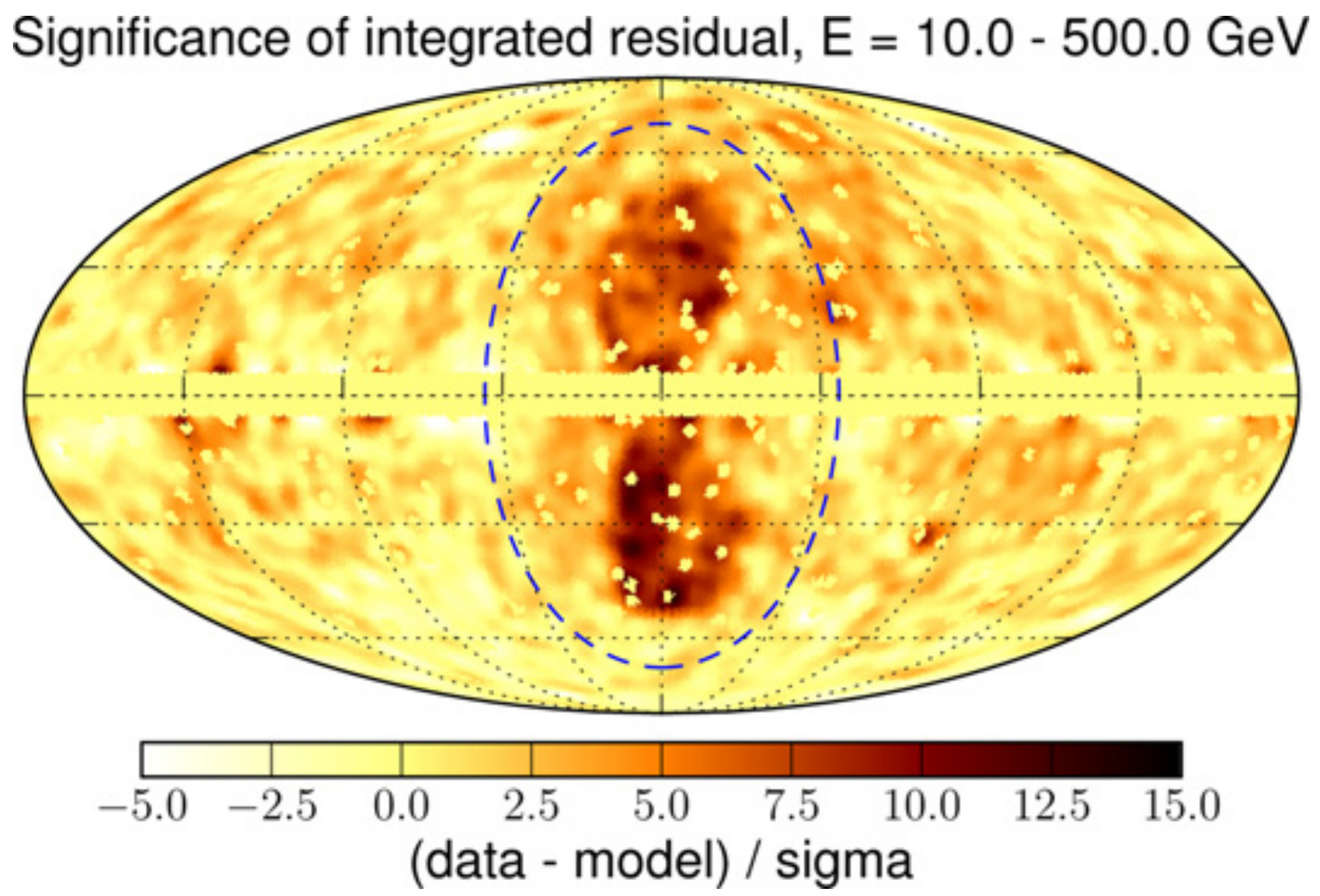


Figure 9. Synthetic X-ray (0.7–2 keV) surface brightness map in Galactic coordinates with a Hammer-Aitoff projection for run A at t = 5 Myr. The dots represent the edge of the observed Fermi bubbles.



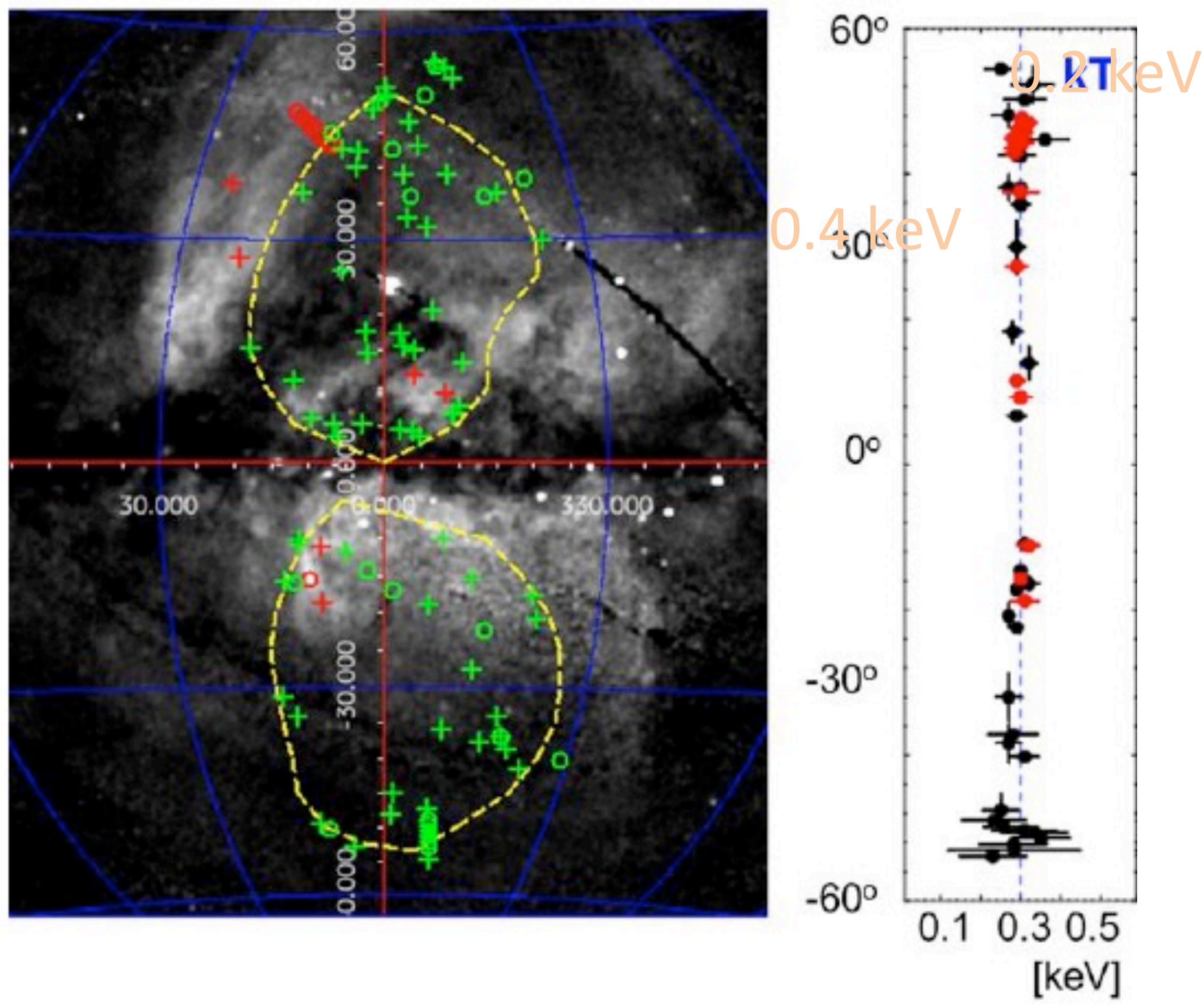
Zhang & Guo, 2020, 2021

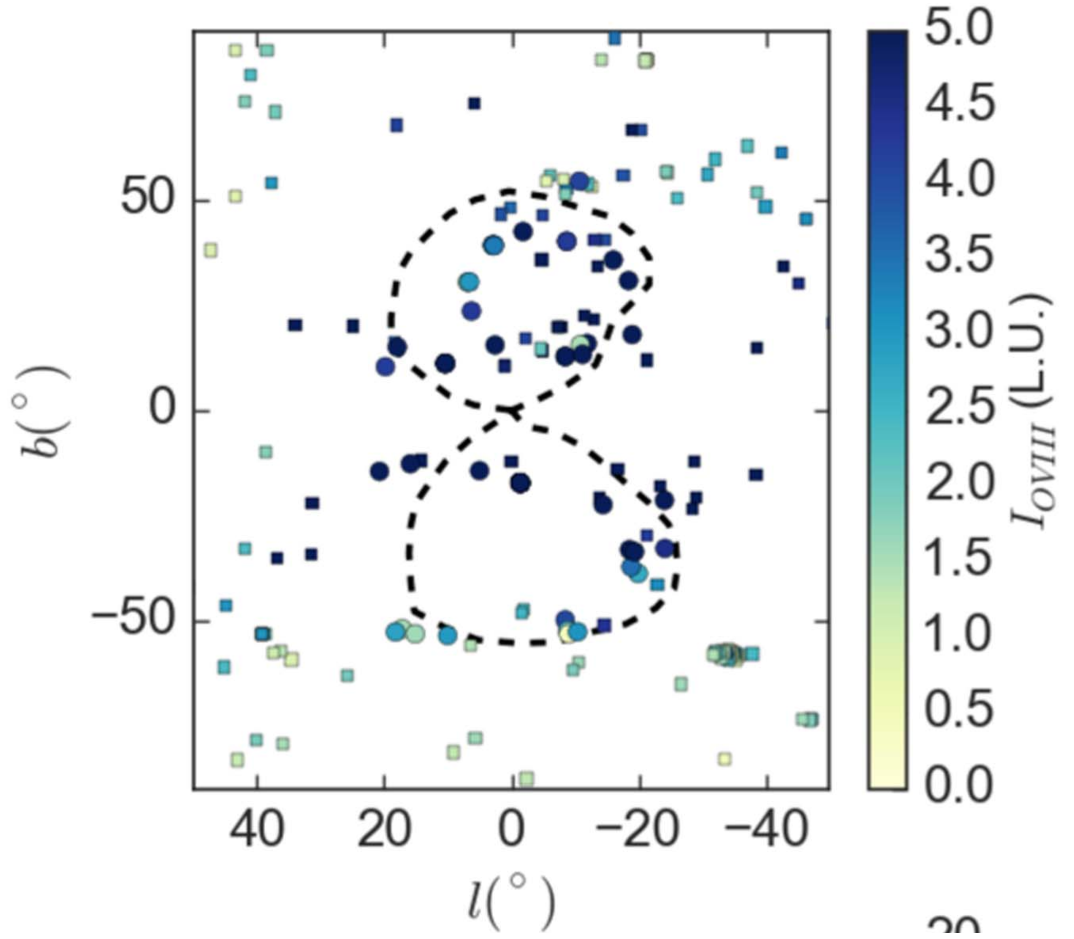
Consistent with Other Potentially Relevant Observations

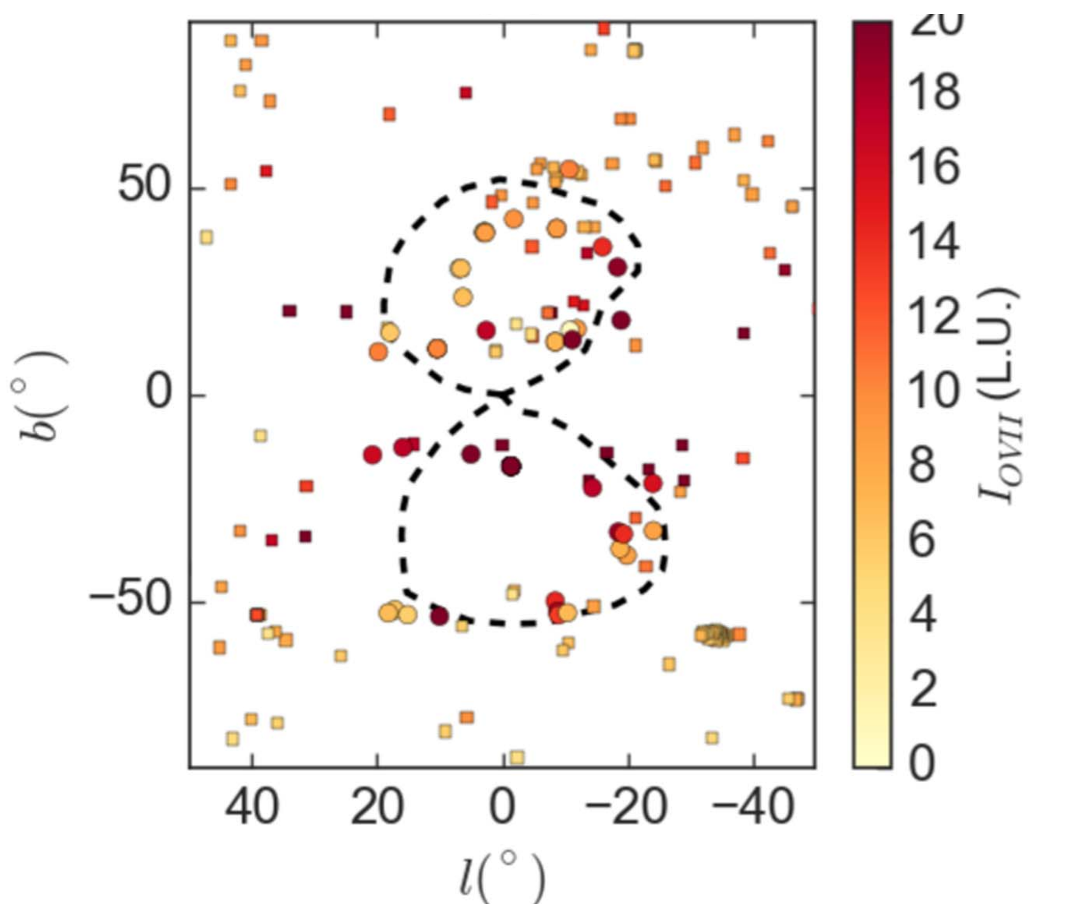
Miller et al.(2016) found the bubble temperature is kT~0.40 keV, gas density ~0.001 cm^{-3}

Bordoloi et al.(2017) found the bubble age is 5-9 Myr from UV absorption line studies of HVCs towards the bubbles.

Sgr A$*$ is orbited by over a hundred massive stars with ages ~ 6±2 Myr

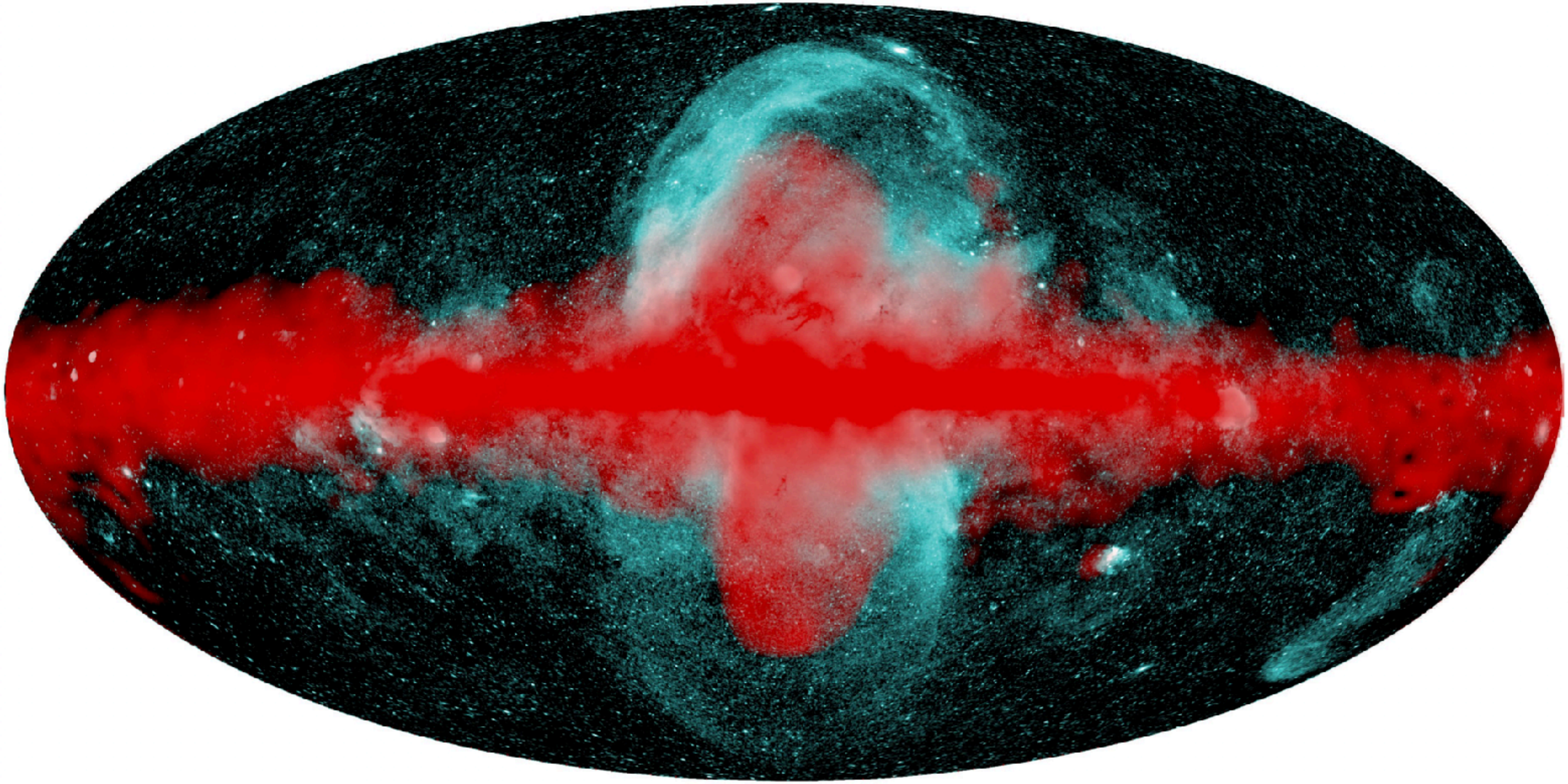






Miller et al.(2016)

Scenario II needs a separate model for eROSITA Bubbles



See Zhang & Guo, 2021

Particle Acceleration at the Shock Front

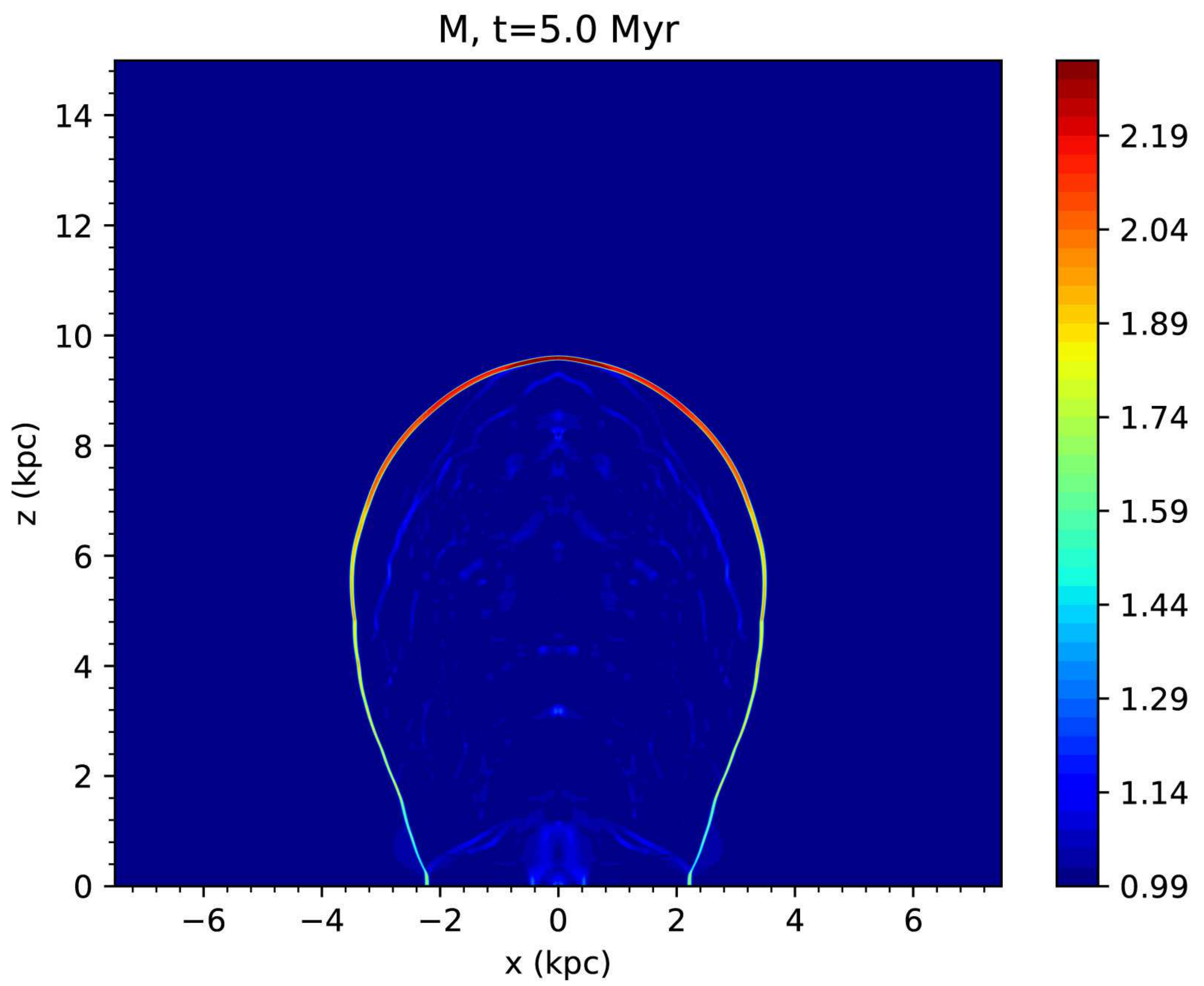


Figure 11. Mach number of the forward shock in Run A at t = 5 Myr. The Mach number increases from low to high latitudes, with an approximate value of about $M \sim 2$.

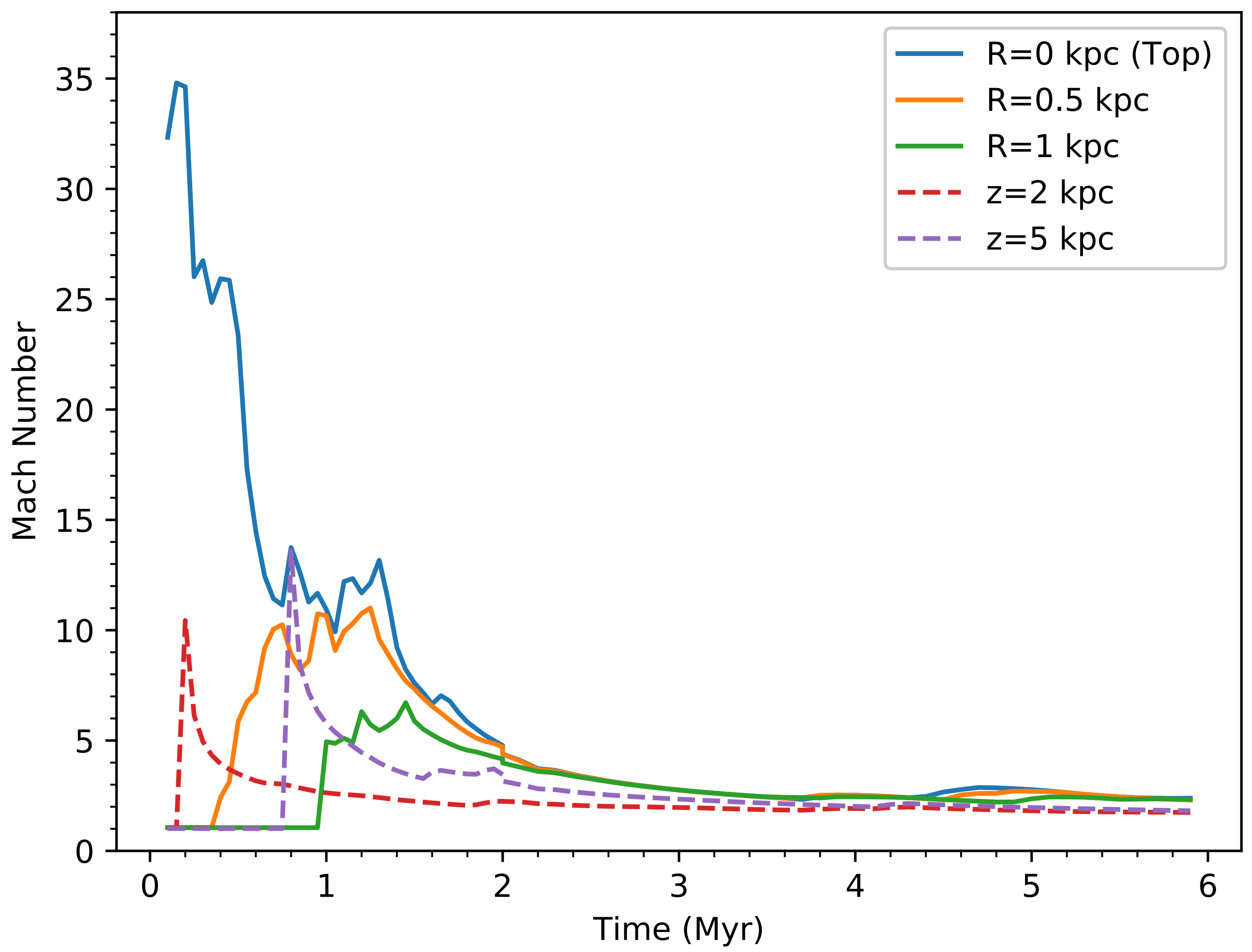
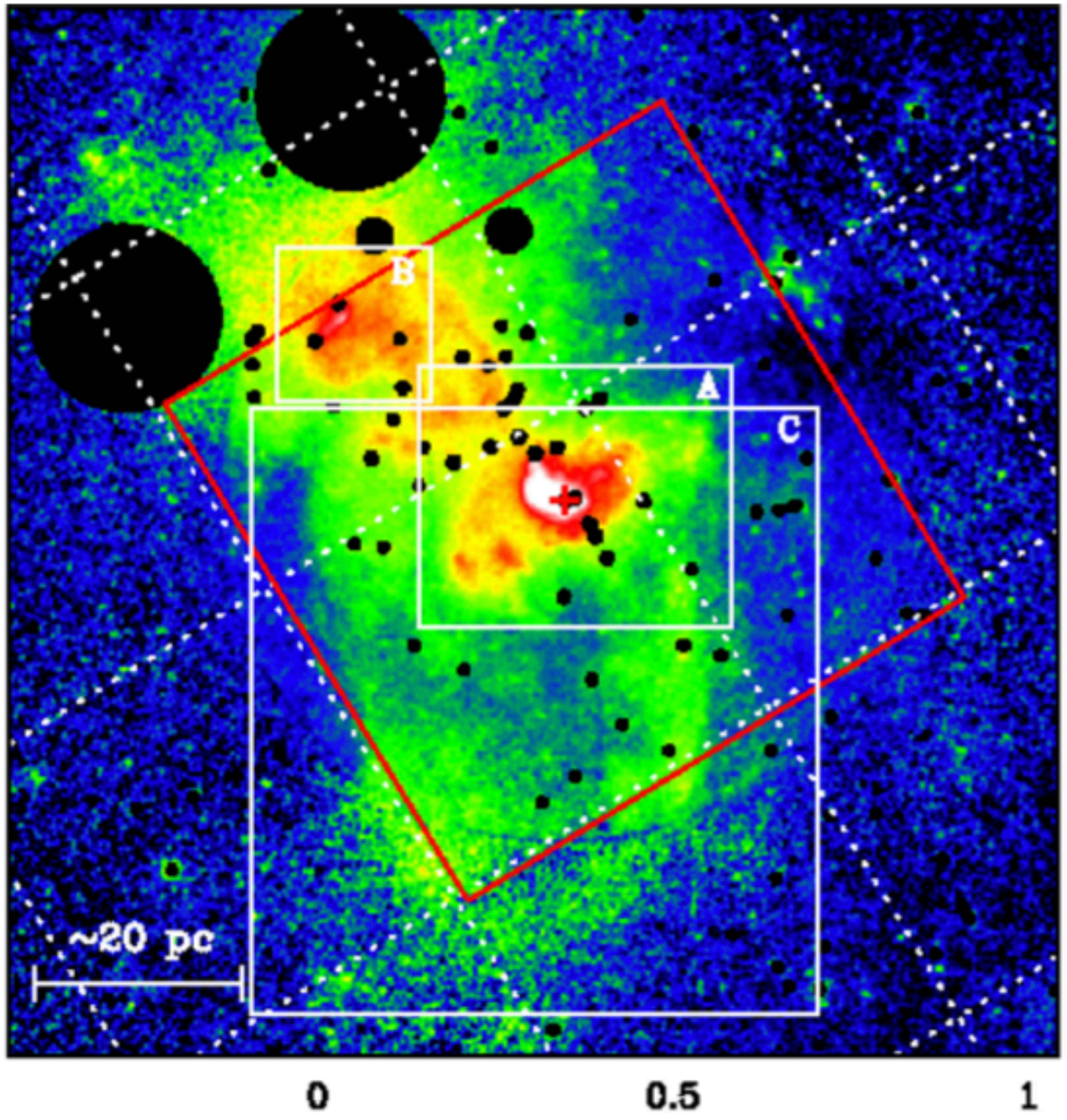


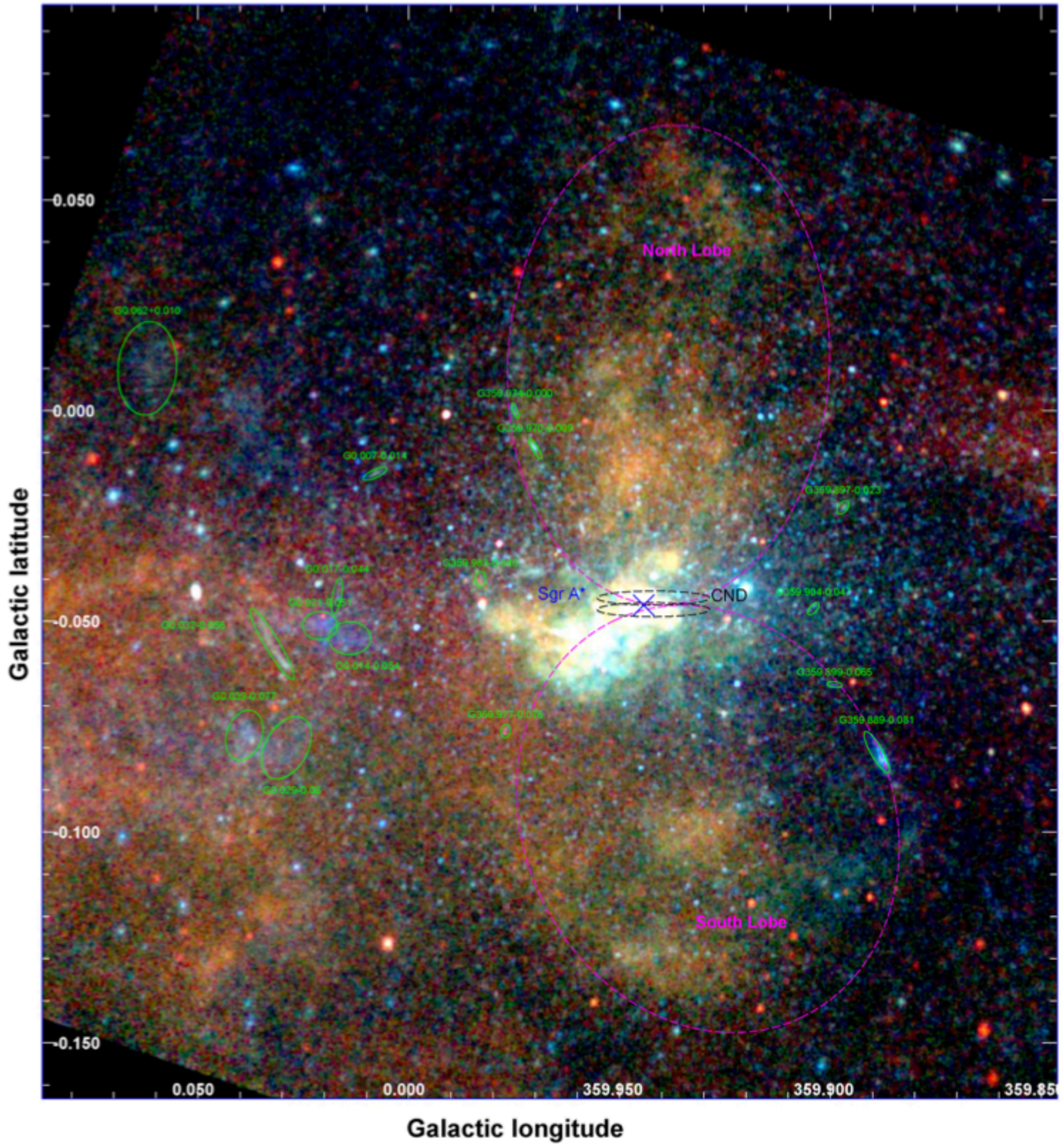
Figure 12. Temporal evolution of the Mach number of the forward shock in Run A. From top to bottom, the solid lines refer to the Mach number evolution at $R = 0$ (the bubble top), 0.5 kpc, and 1 kpc respectively, in the bubble surface. The dashed lines refer to the Mach number evolution at $z = 2$ kpc (red), and 5 kpc (purple) in the bubble surface.

Re-acceleration of low-energy cosmic rays in the inner halo by the shock may be required to explain the gamma ray emission

15-parsec-sized Sgr A Lobes



XMM-Newton 2-4.5 keV
Heard & Warwick 2013

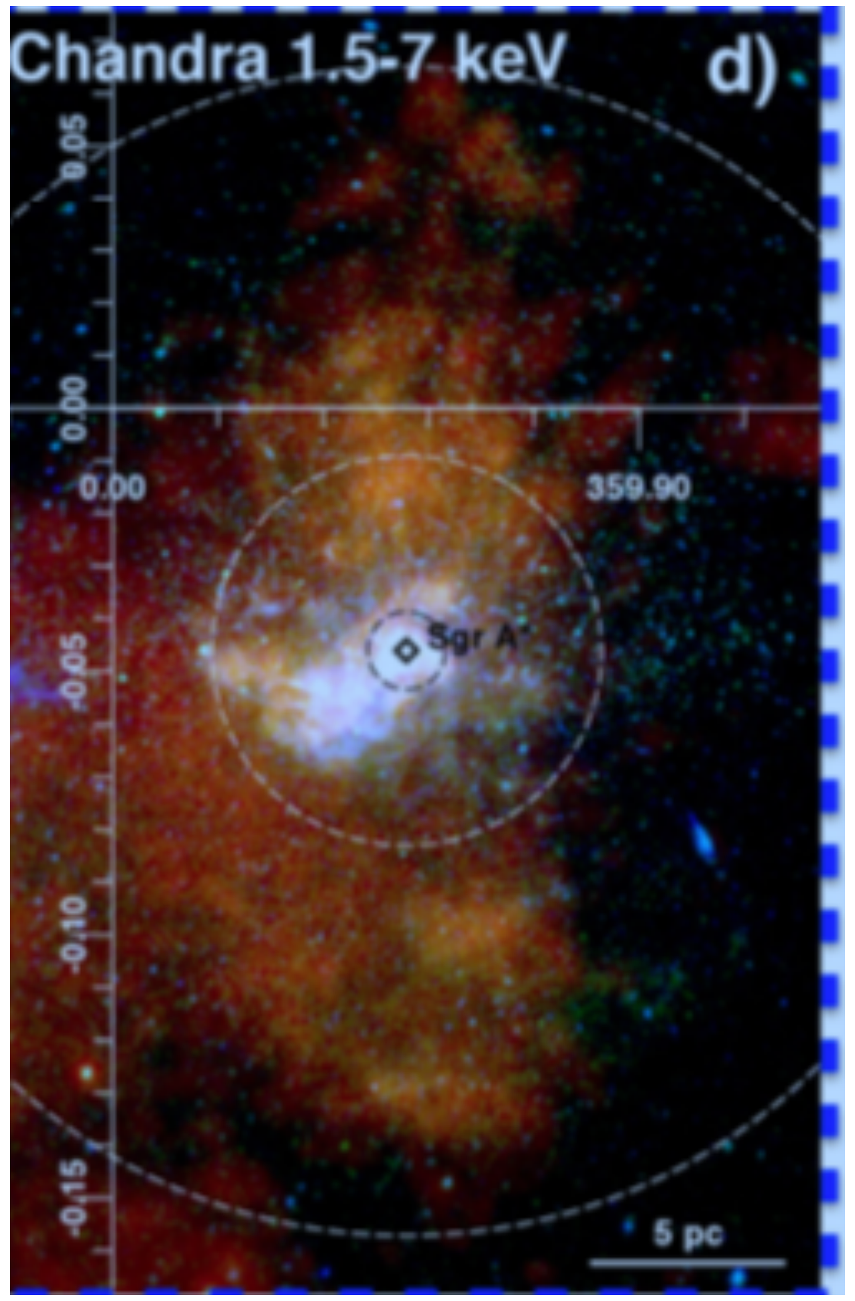


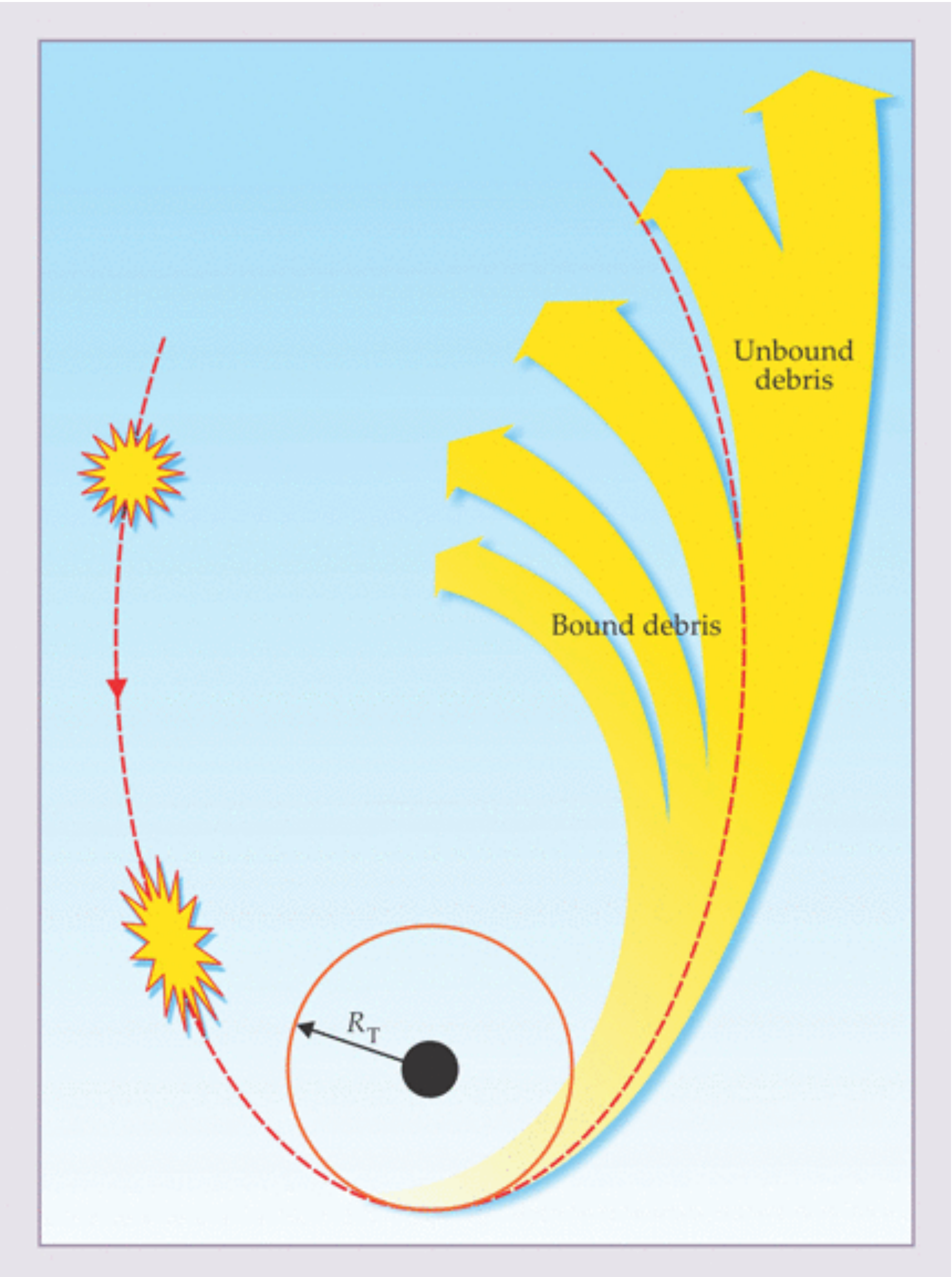
Chandra X-rays
Ponti et al 2015, 2019

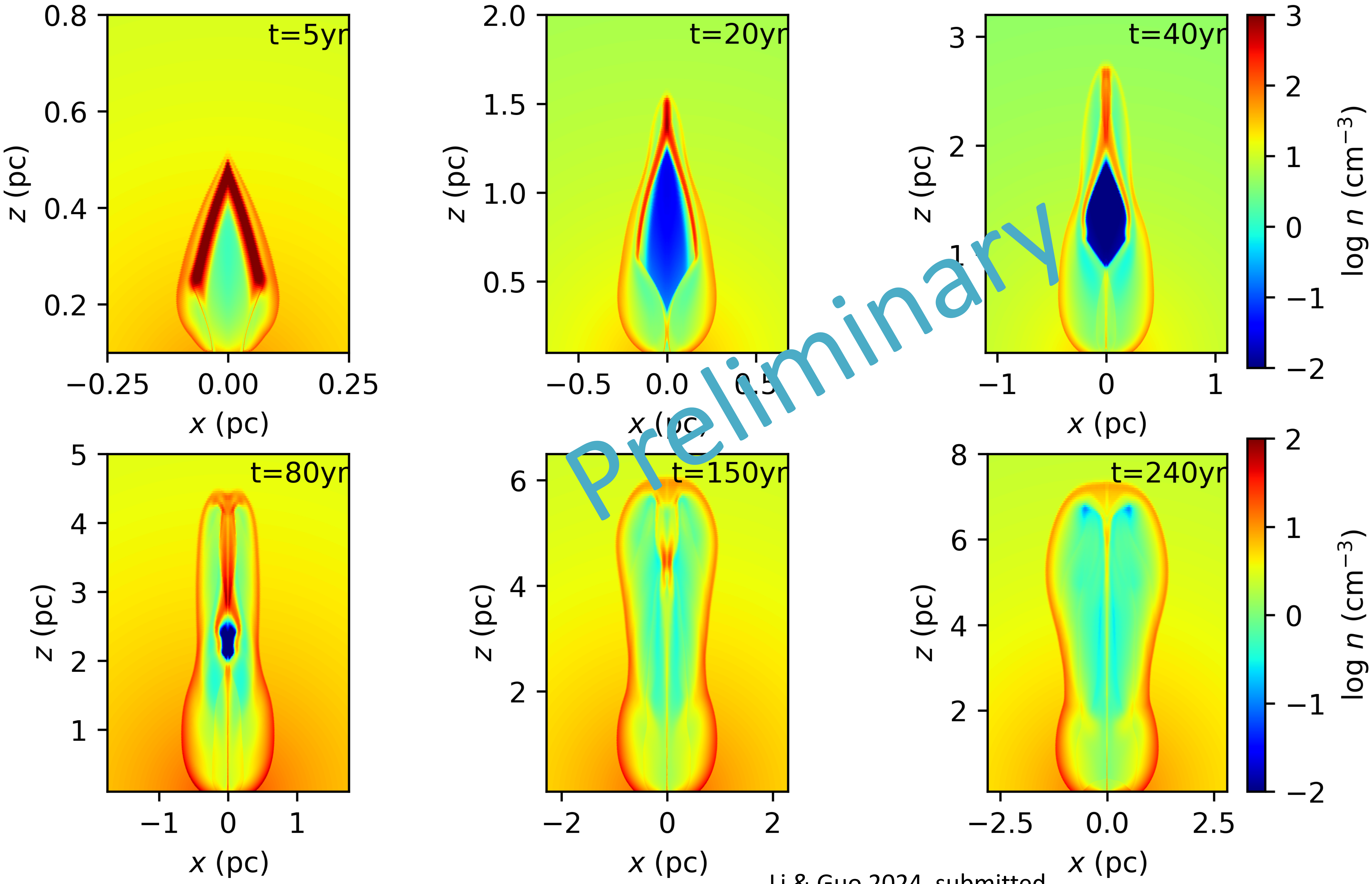
density: a few /cc
T ~ 1 keV
mass ~ few solar mass
energy: 10^{50}-10^{51} erg

The Sgr A lobes: Are they triggered by a pair of TDE Jets in the recent past?

declining power for 0.5 yr

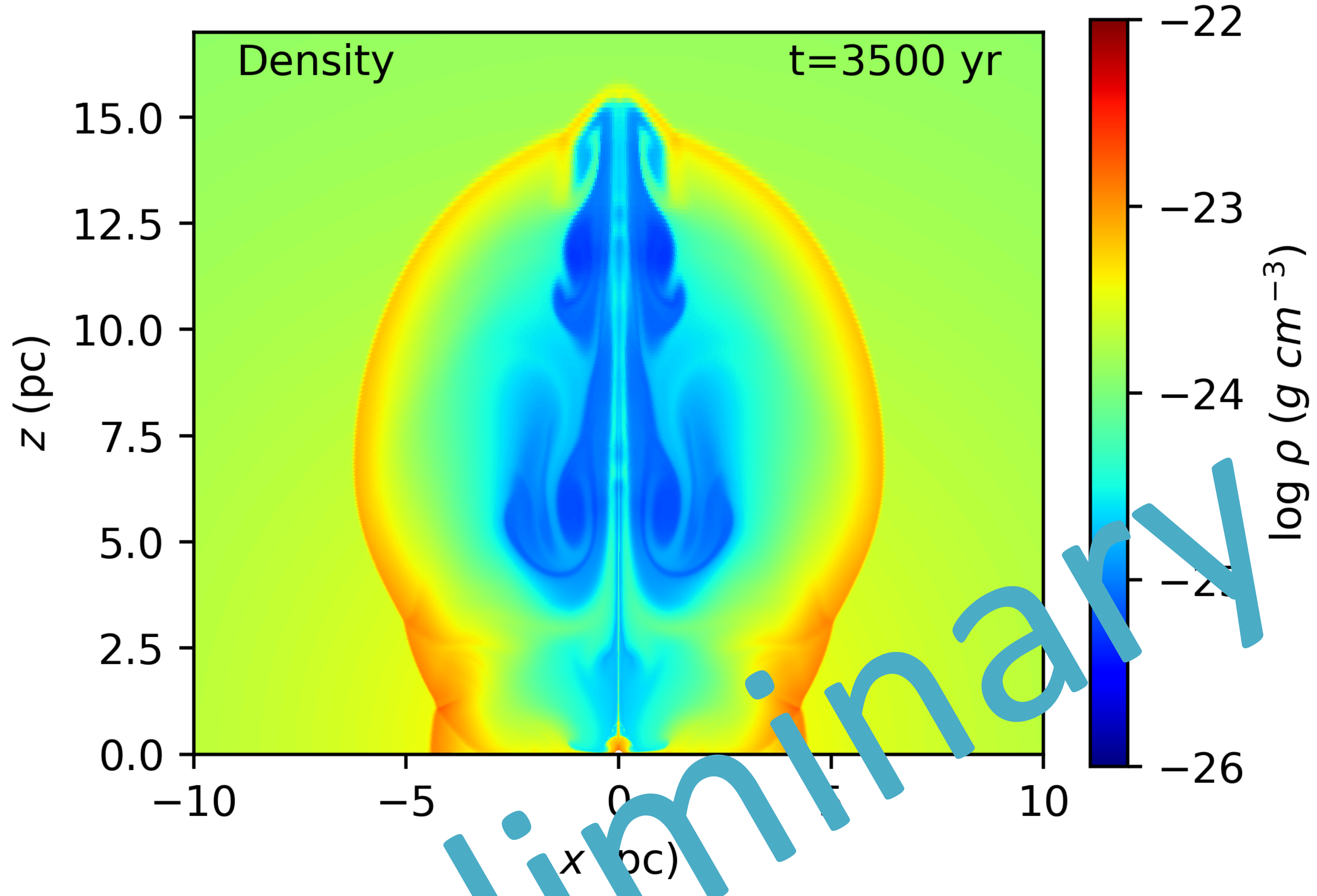


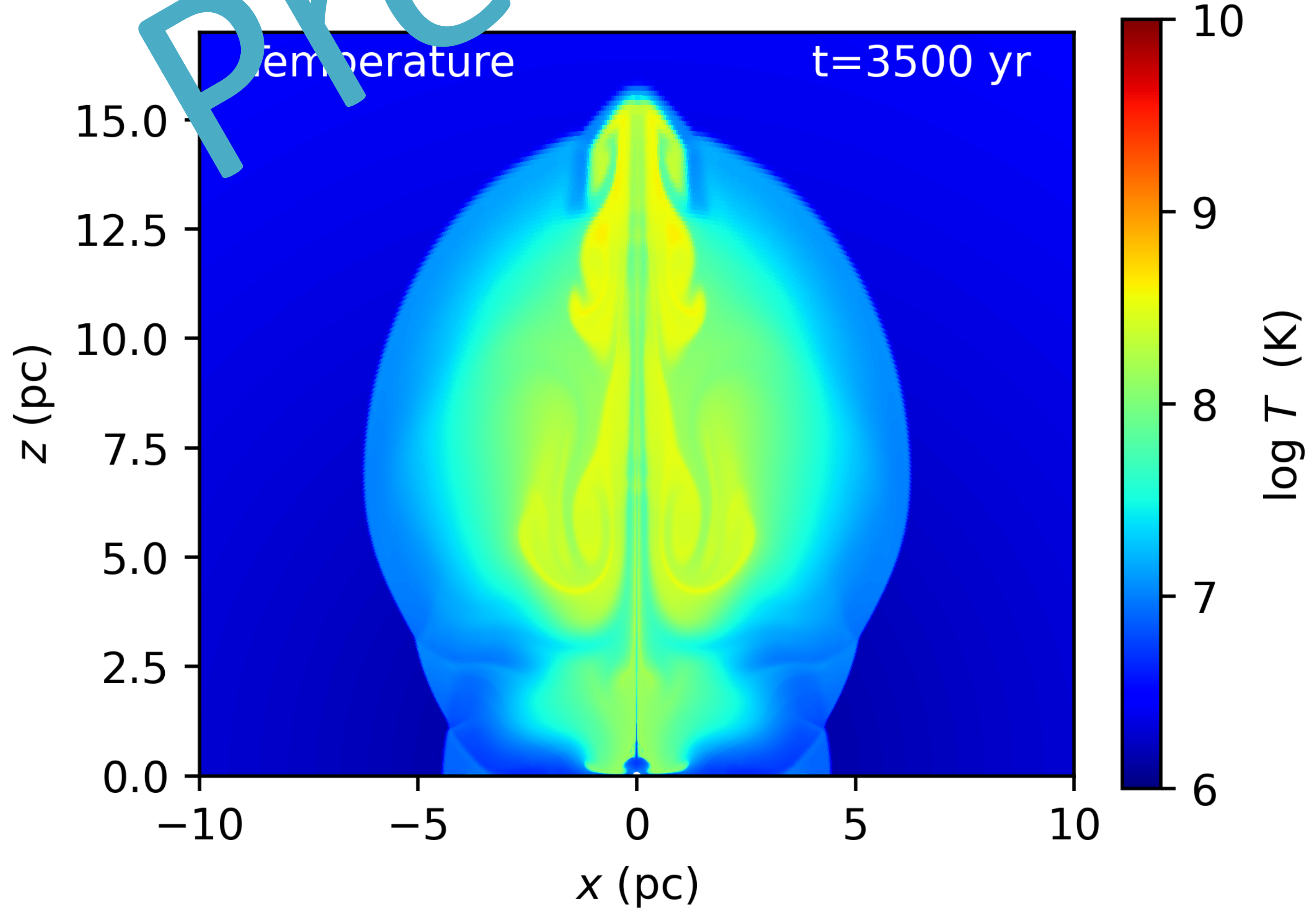




Li & Guo,2024, submitted

The Central Sgr A lobes driven by light thin jets from a TDE event at the Galactic center about 3500 years ago

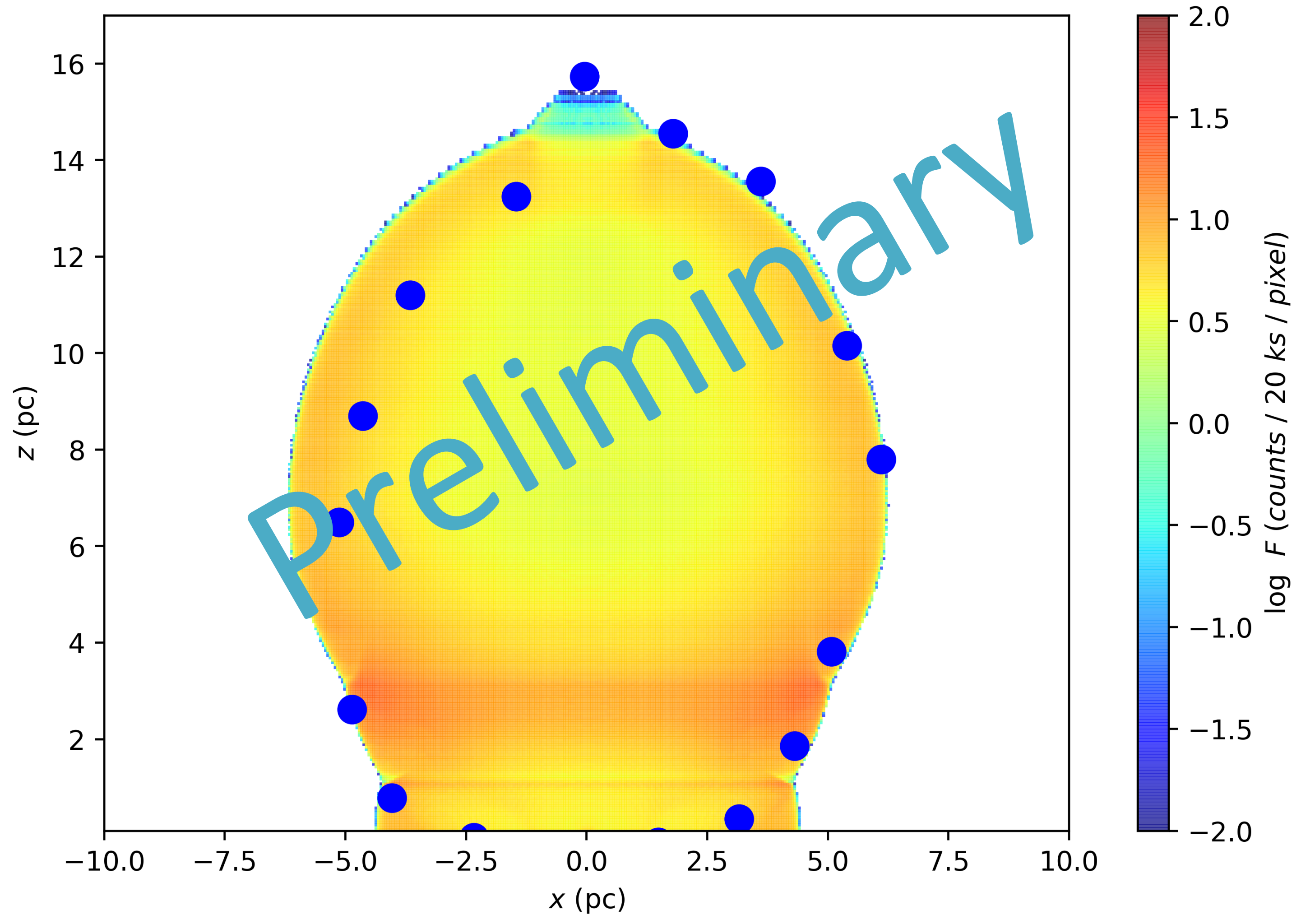


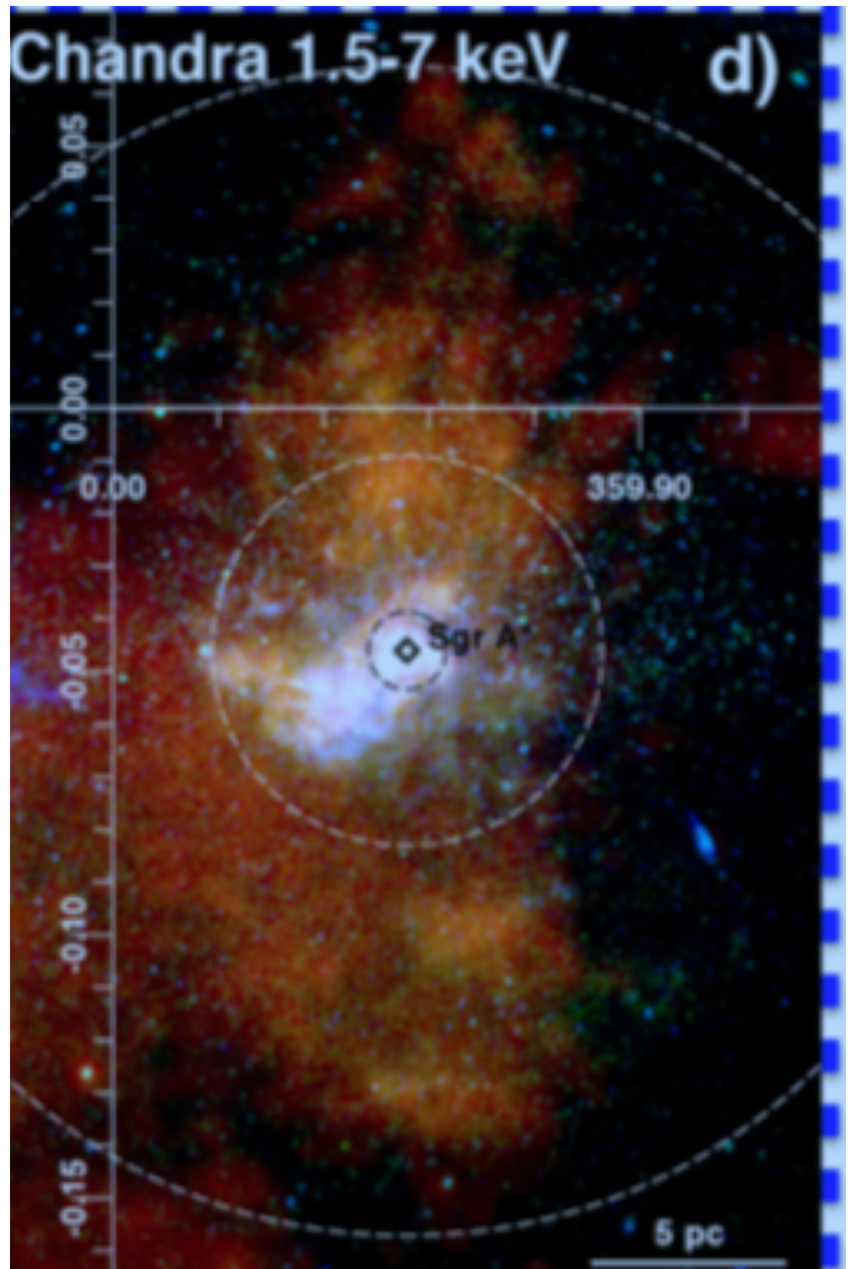


Density and temperature distribution at t=3500 year

X-ray Surface Brightness

2-4.5 keV





Model fits the observed morphology, gas density, temperature, and X-ray surface brightness distribution quite well

Average lobe temperature ~ 1 keV
Average lobe density ~ 5.9 per cc

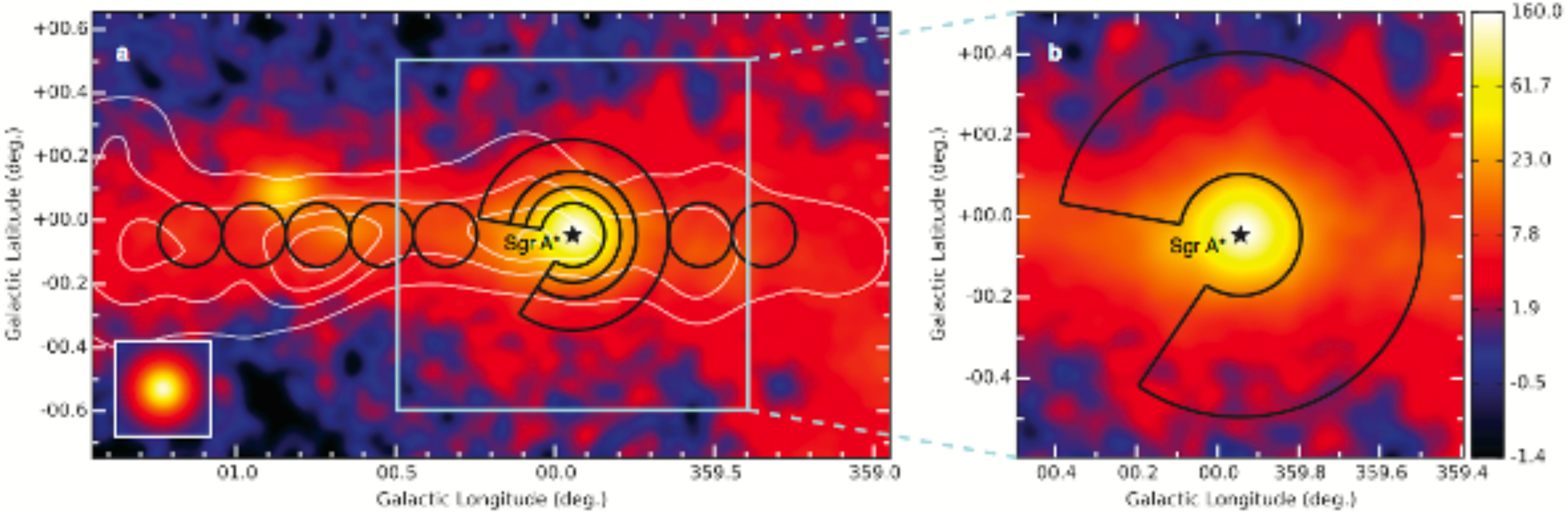
Total injected mass 0.05 solar mass
total injected energy 1 X 10^{51} erg

Consistent with TDE rate in our Galaxy

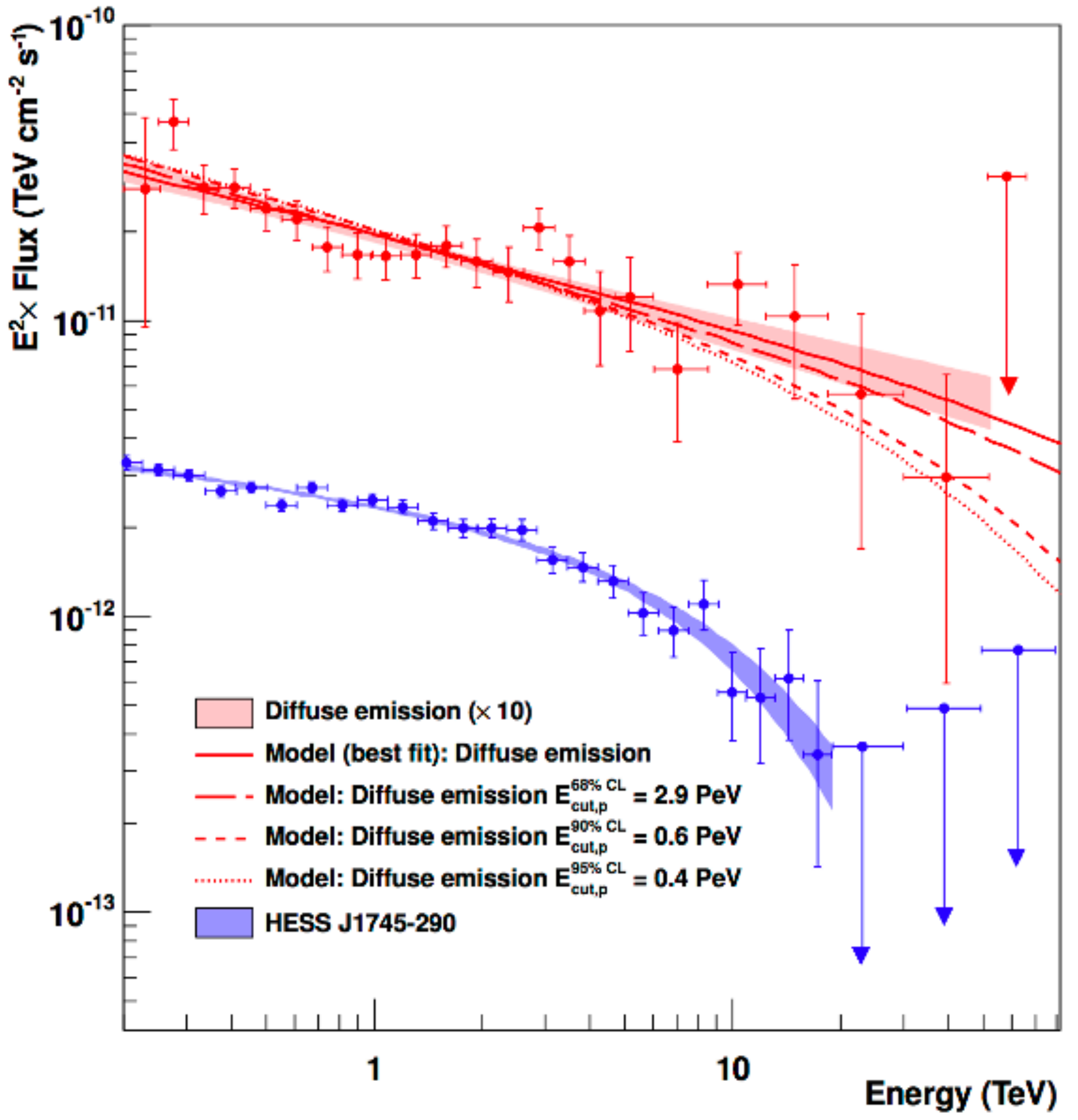
Jet direction should be along the Galactic rotation axis, similar to the AGN jet model for the Fermi bubbles

Li & Guo,2024

Potential Connection with the Galactic Center PeVatron



HESS 2016 Nature



Summary & Outstanding Problems

- The AGN jet-shock model explains the common origin of Fermi bubbles and bipolar X-ray outflows
- The central Sgr A lobes may be due to a TDE jet event at the Galactic Center about 3500 years ago
- Does the shock model produce cosmic rays radiating the observed radio and gamma emissions of the Fermi bubbles?
- Could the Sgr A lobes explain the Galactic center Pevatron?
- How are cosmic rays accelerated in the Fermi bubbles?
- Stay tuned for our future work on eROSITA bubbles, the Galactic center chimneys, M82 winds, and LHAASO observations of the Fermi/eROSITA bubbles region, etc