Fermi Bubbles and Other High Energy Phenomena at the Galactic Center

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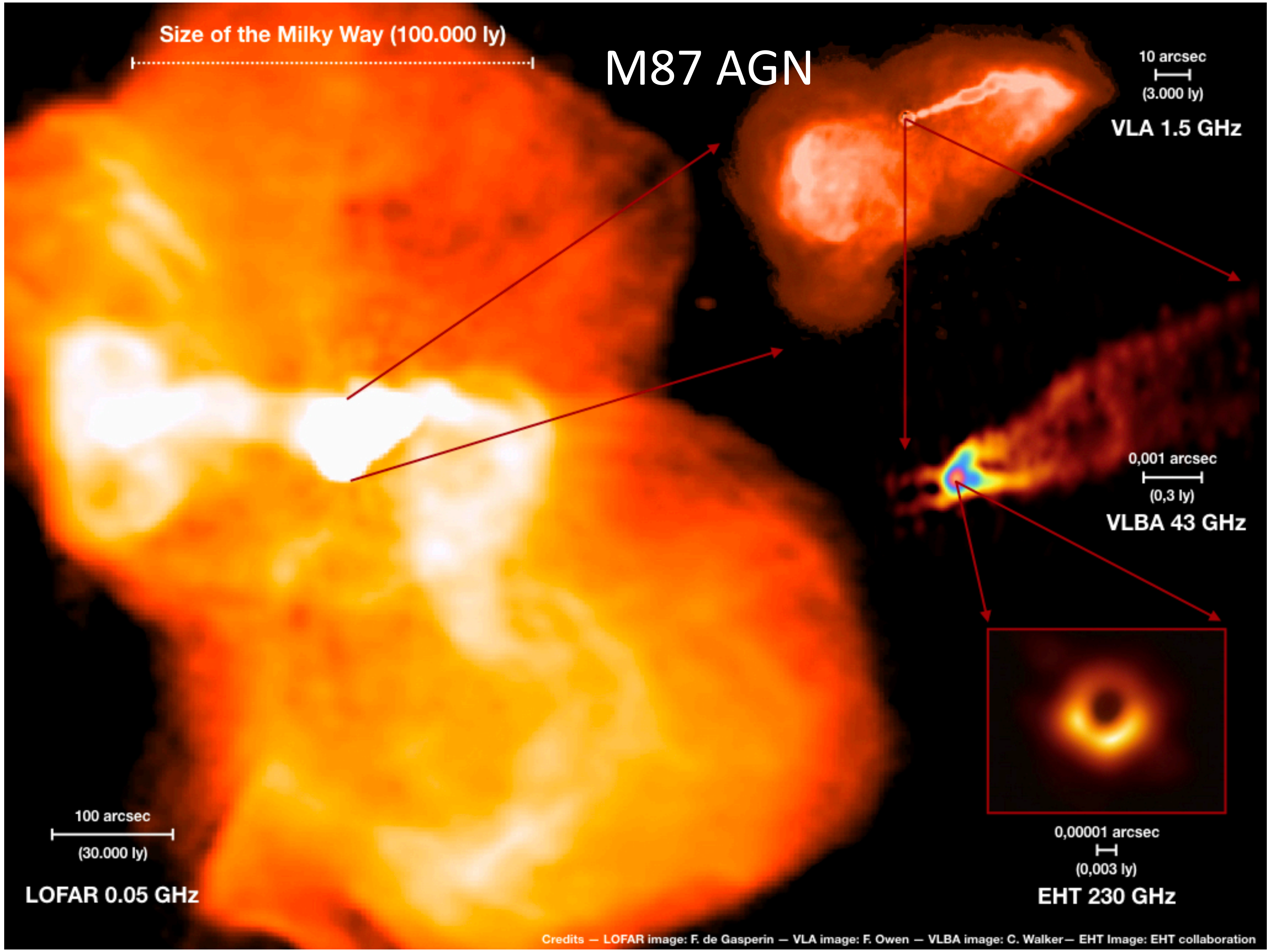
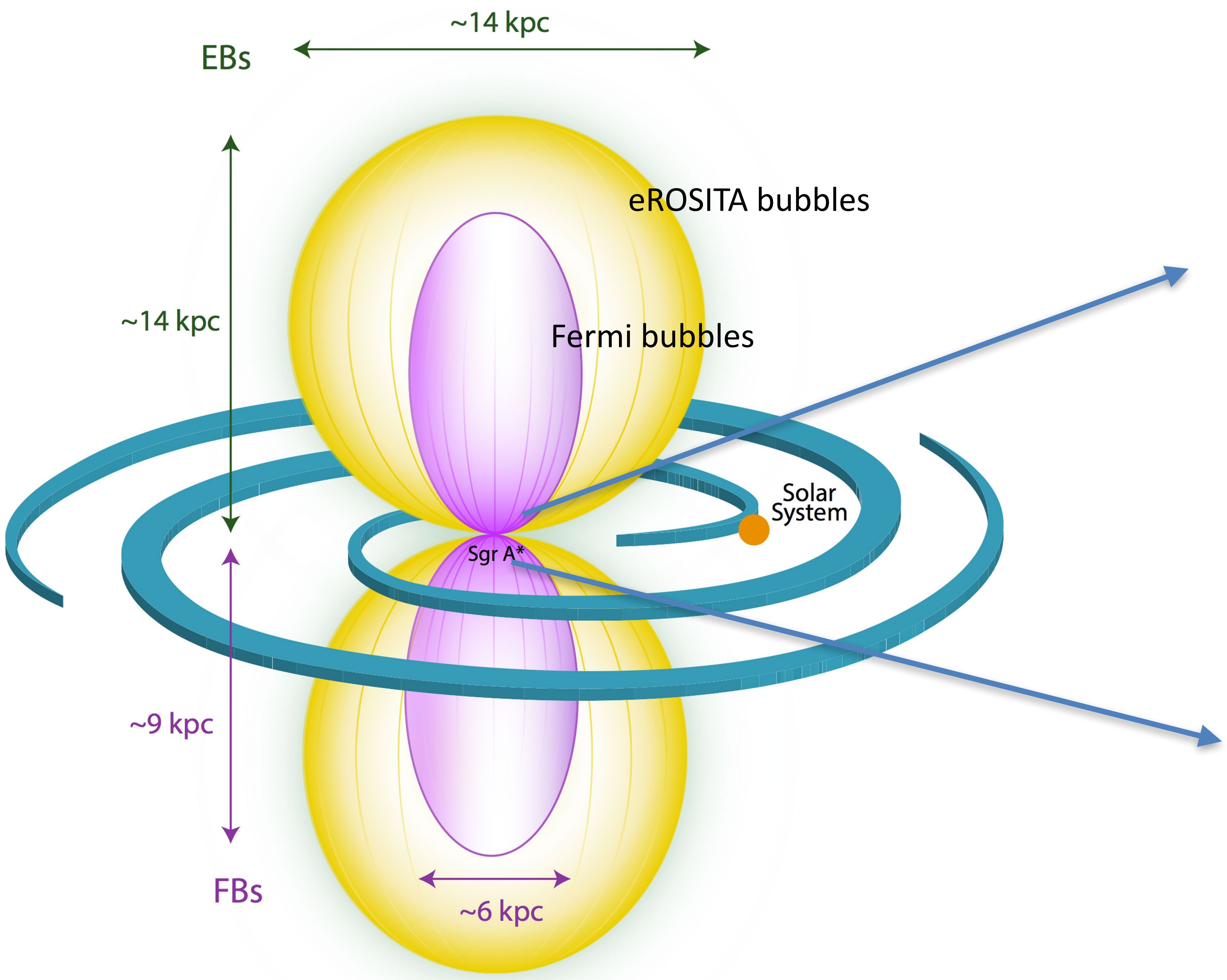
Cosmic Rays: acceleration, transport, impact

Cosmic ray accelerators:

- Supernova remnants (shocks)
- Pulsar Wind Nebulae
- Young stellar clusters
- binaries
- **clustered supernovae (starburst)**
- **AGN: accretion, jets, outflows**

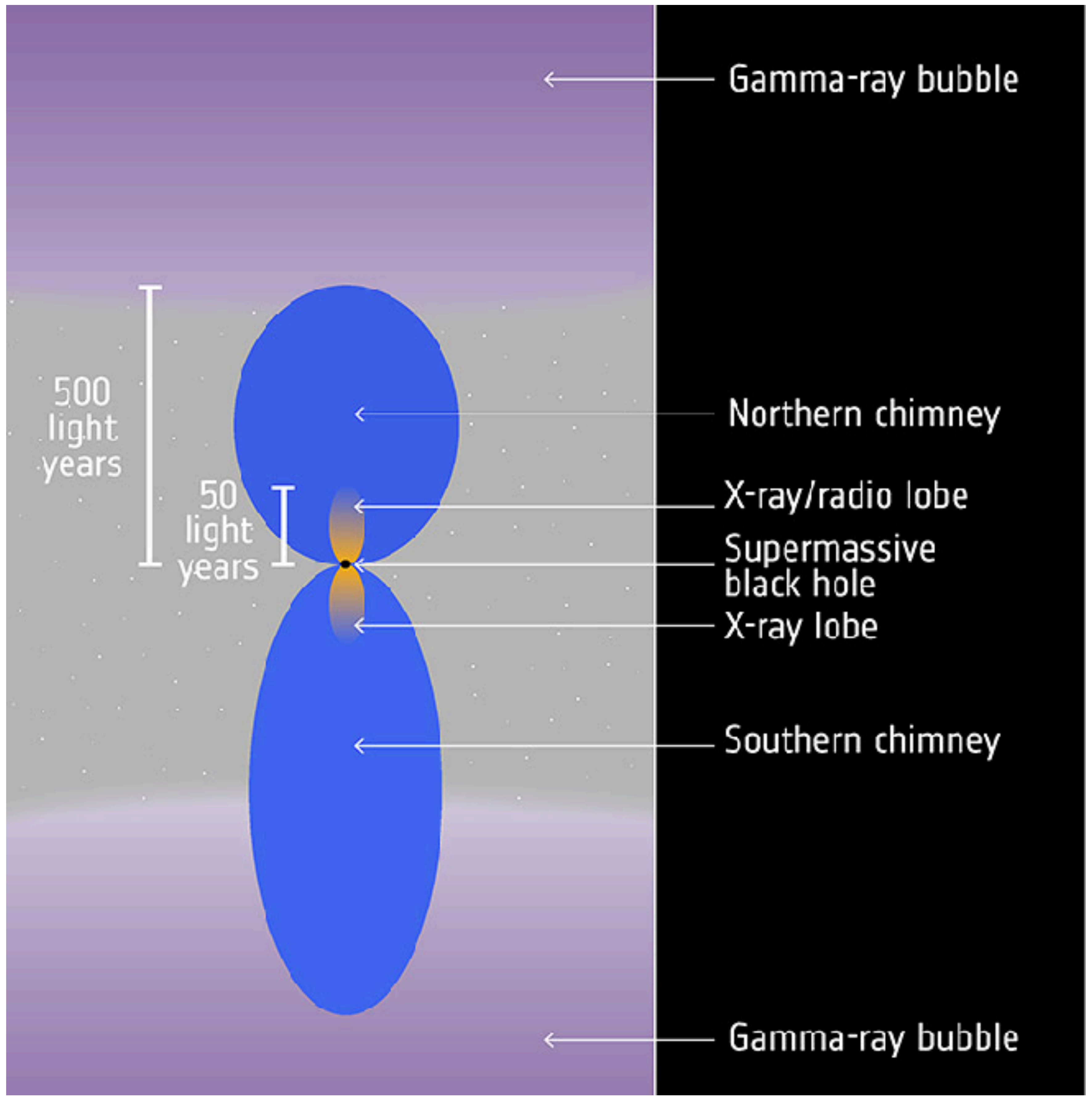


Energetic Outbursts at the Galactic Center



eROSITA and Fermi bubbles

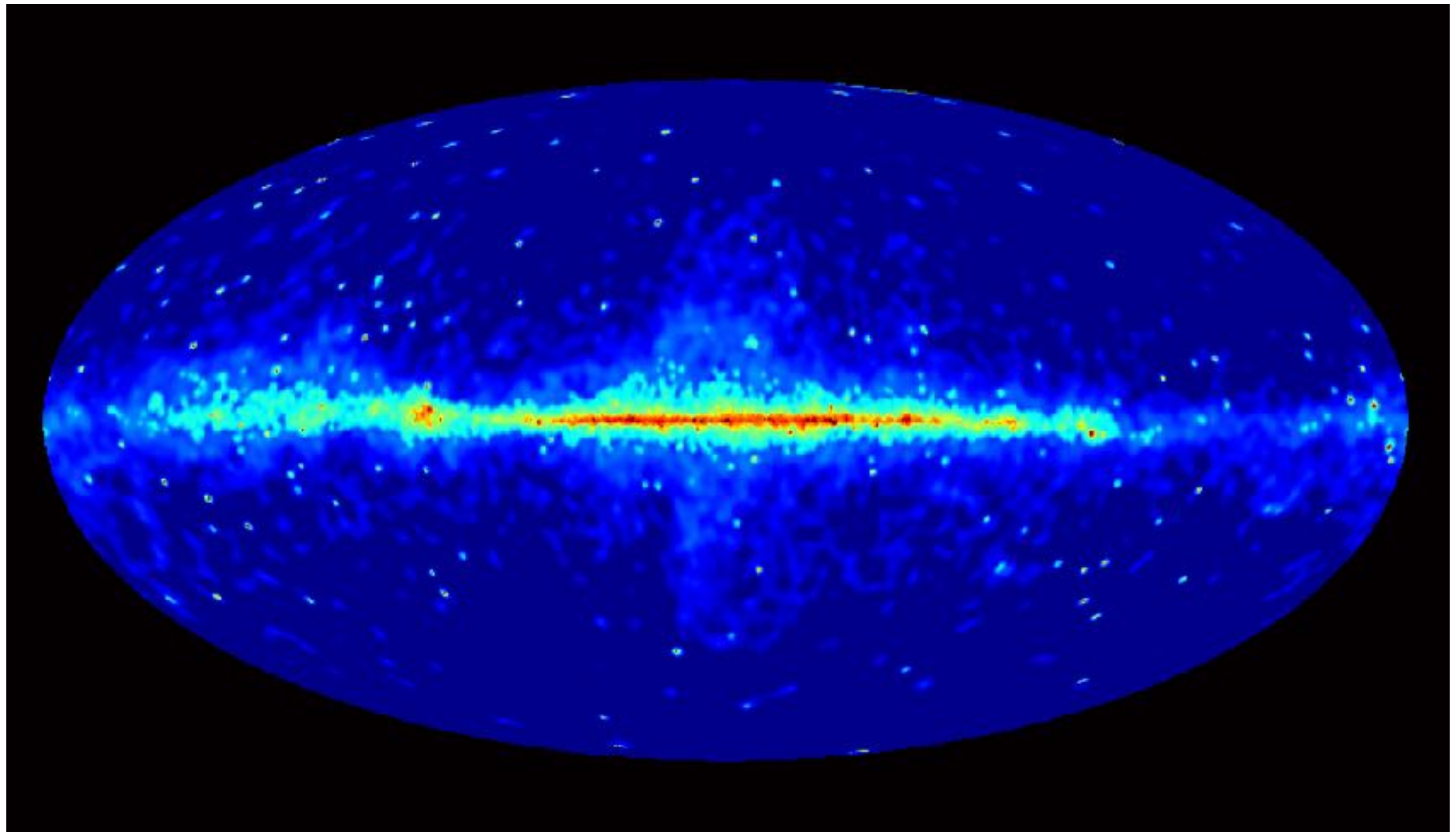
Predehl + 2020 Nature

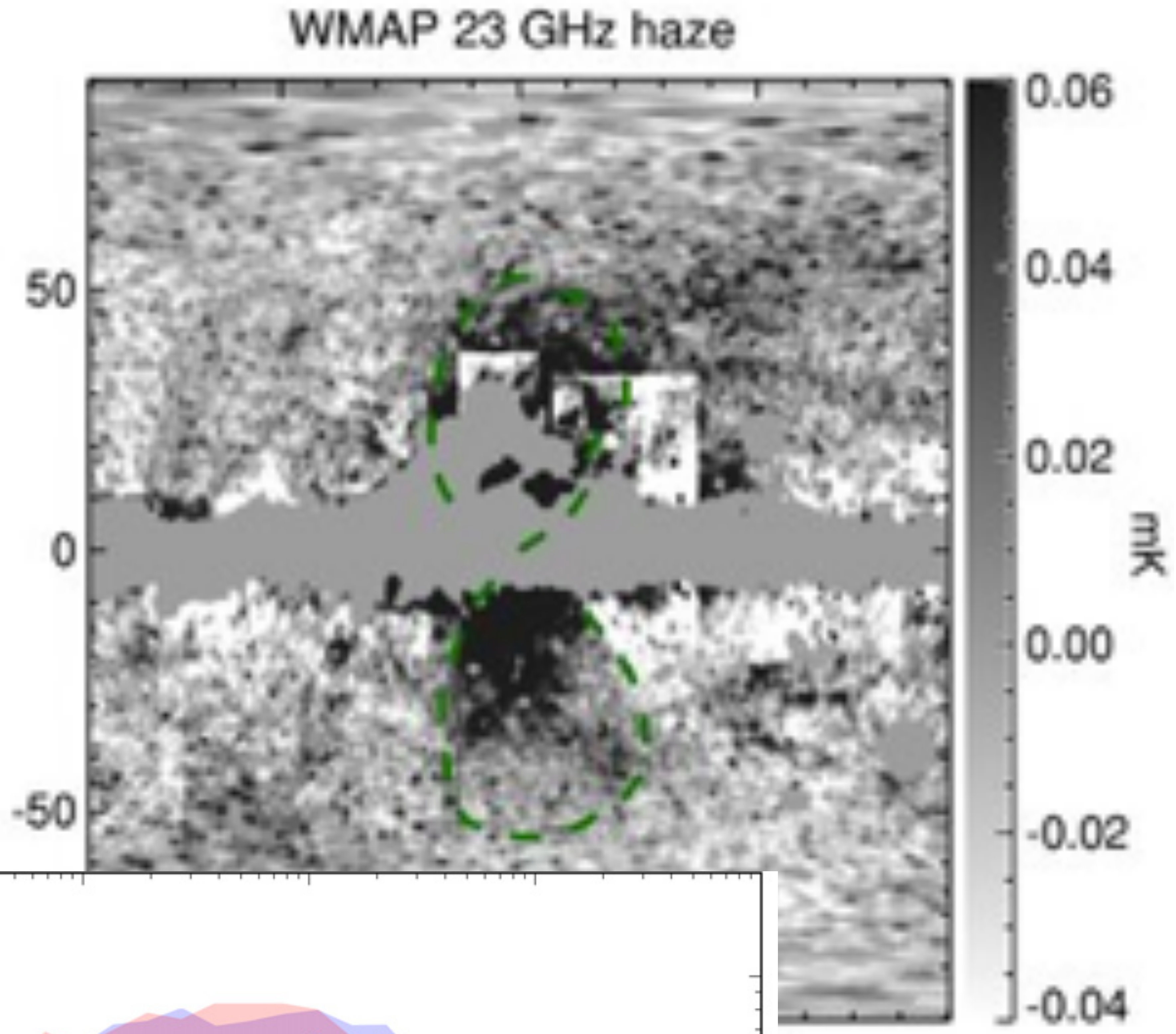


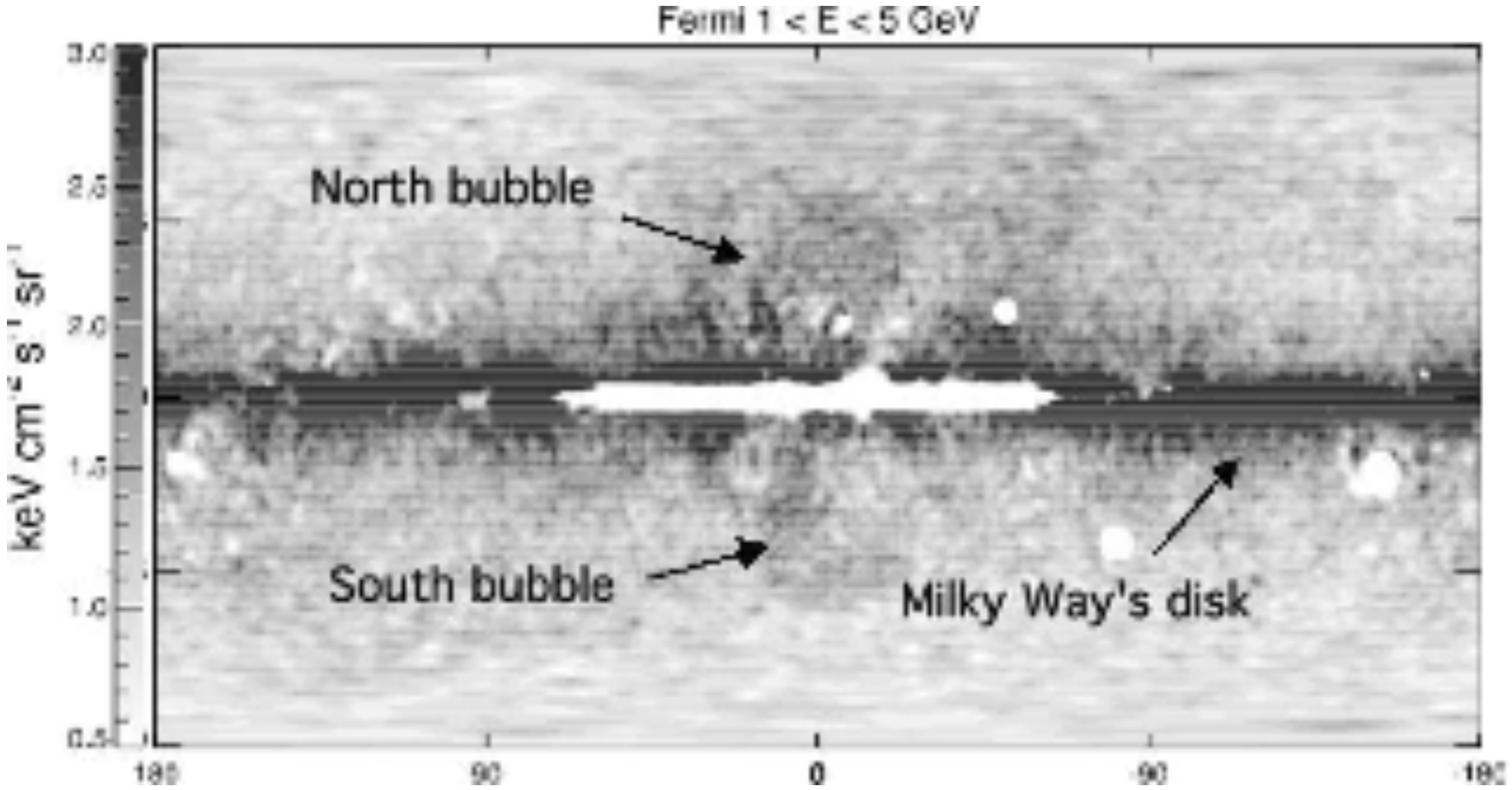
Galactic center lobes and the central X-ray lobes

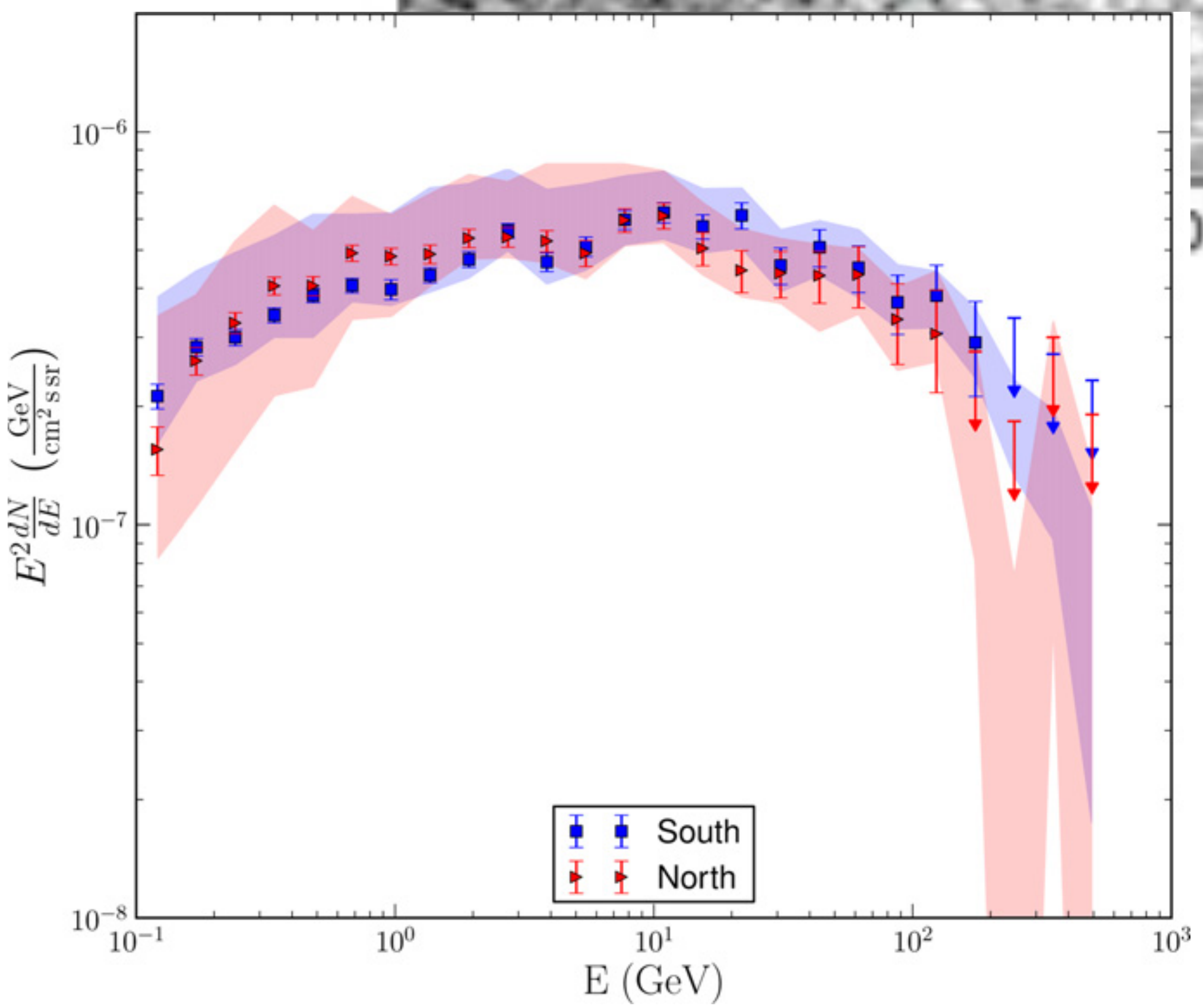
- **clustered supernovae (starburst regions)**
- **AGN: accretion, jets, outflows**

Fermi Bubbles in Gamma Ray and Microwave









(Su + 2010)

eROSITA Bubbles

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Article | Published: 09 December 2020

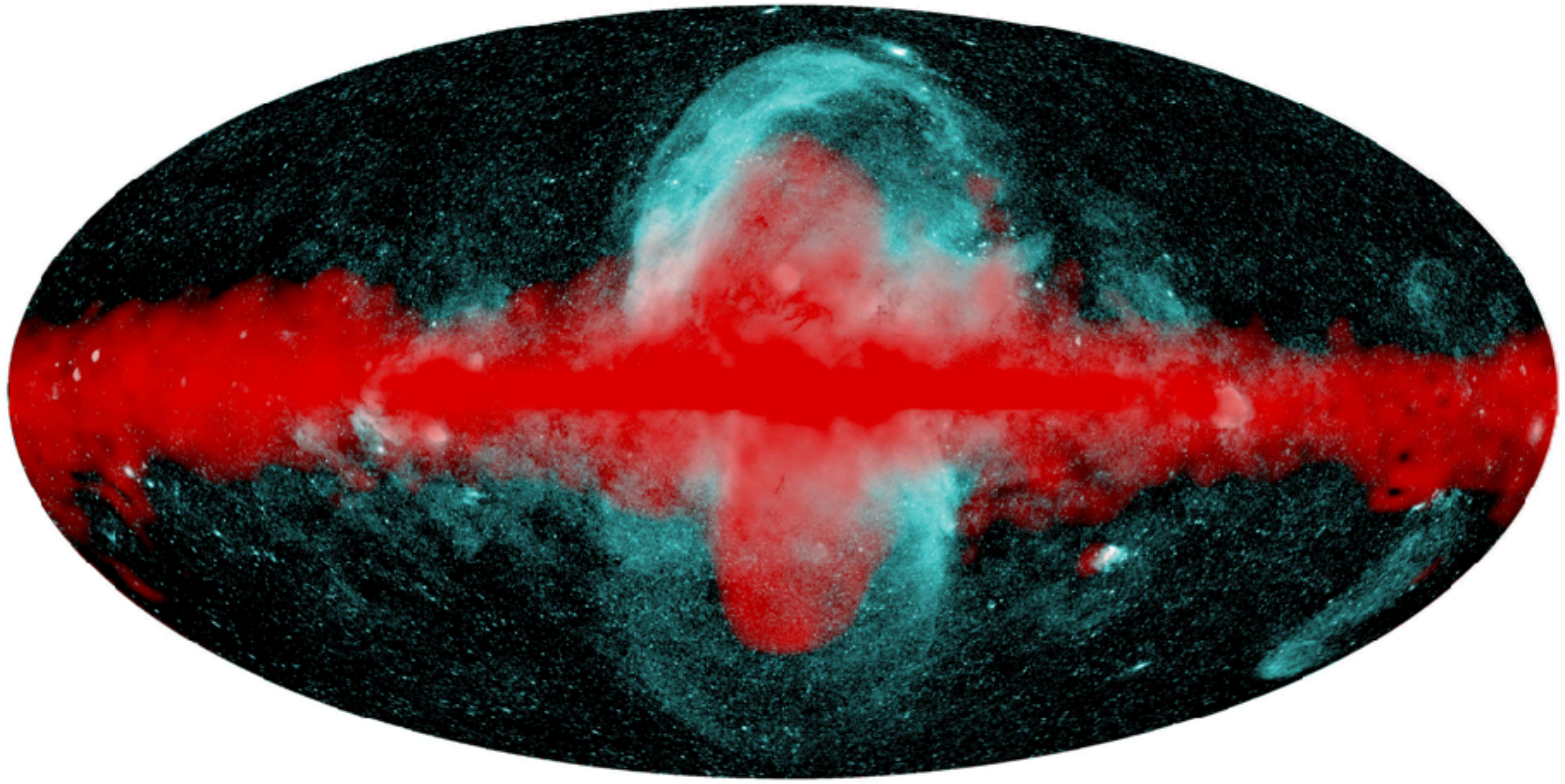
Detection of large-scale X-ray bubbles in the Milky Way halo

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

17-1

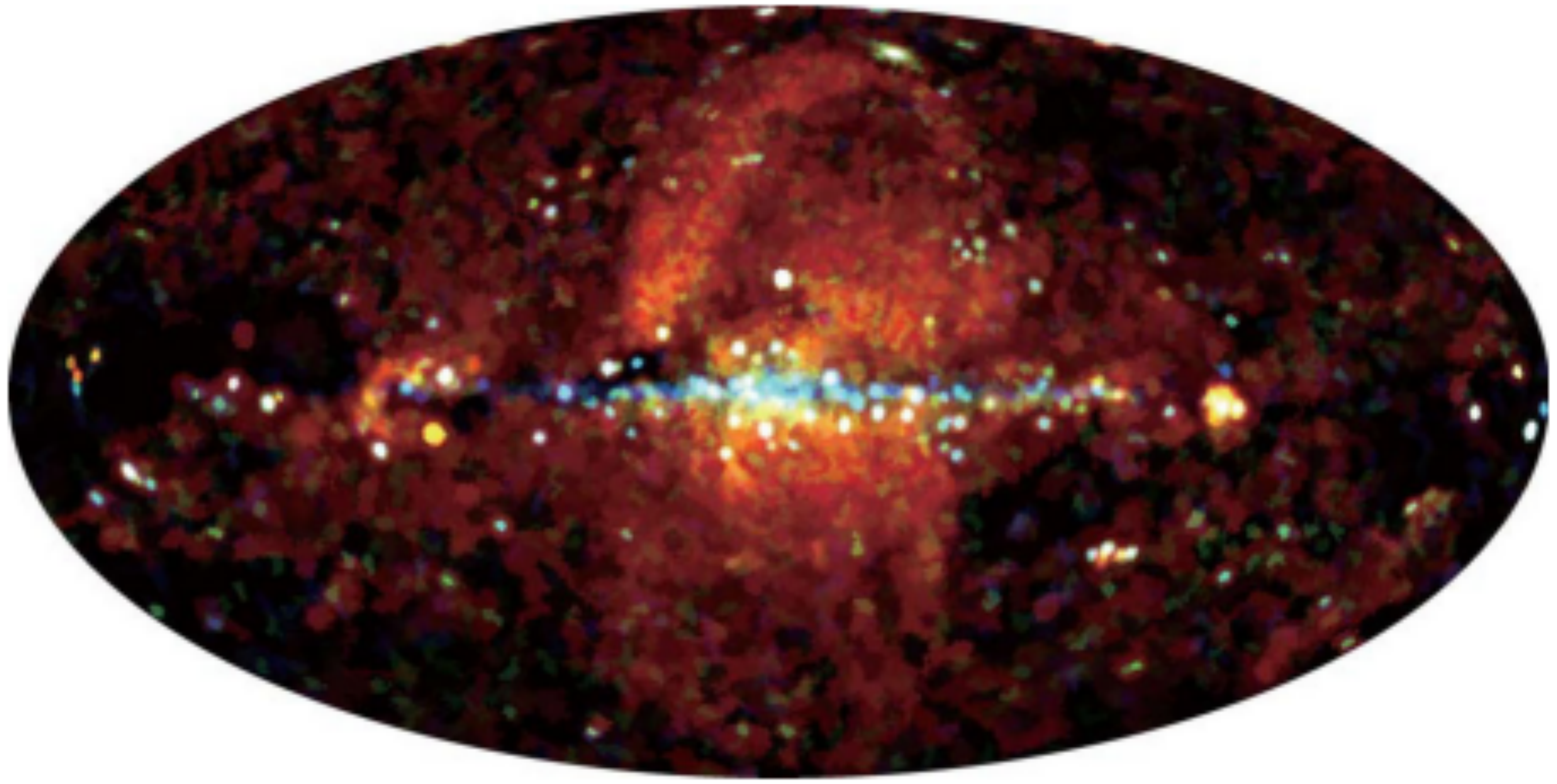
MAXI/SSC all-sky maps from 0.7 keV to 4 keV

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

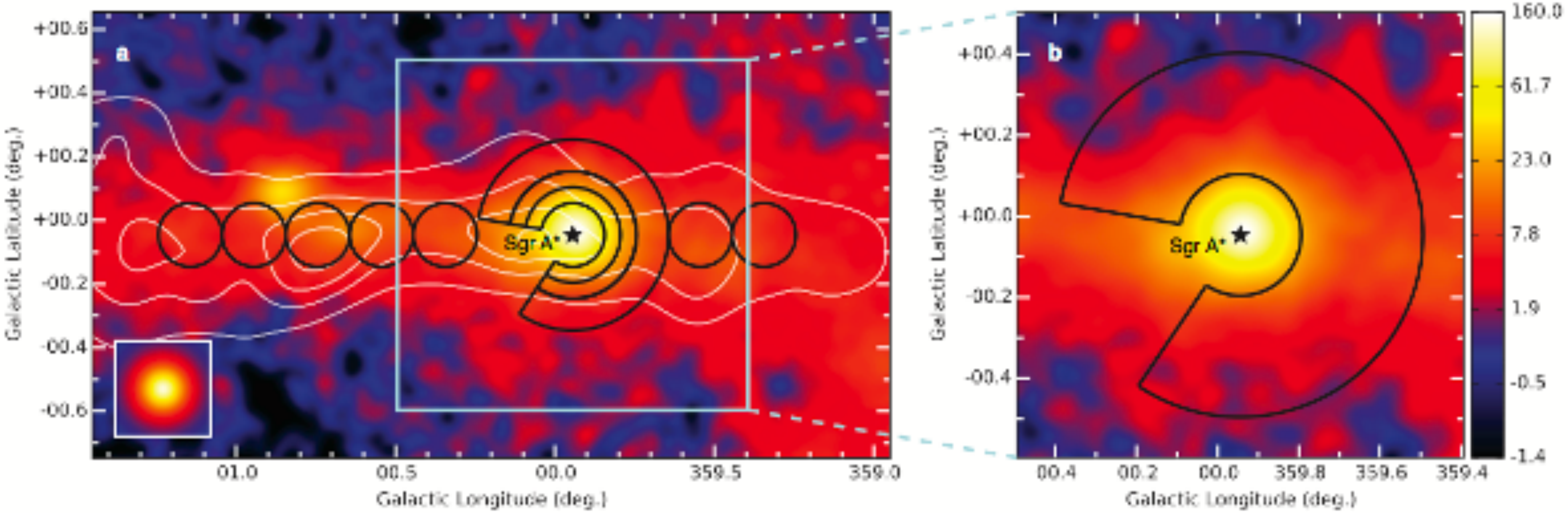


MAXI (0.7-1 keV; red), Nakahira + 2020

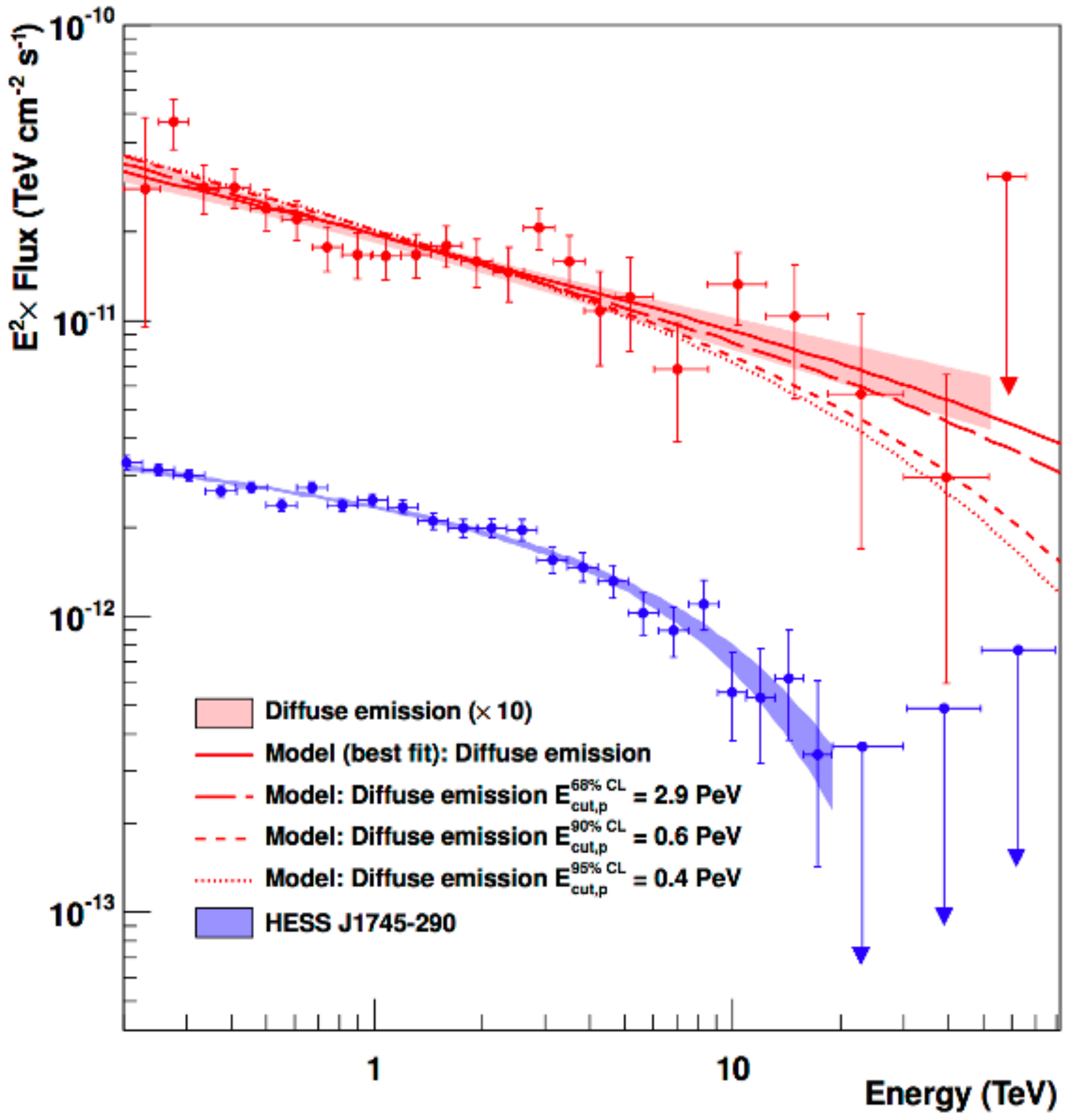
X-ray Chimneys and Central 15-pc X-ray lobes

Ponti et al 2019 Nature

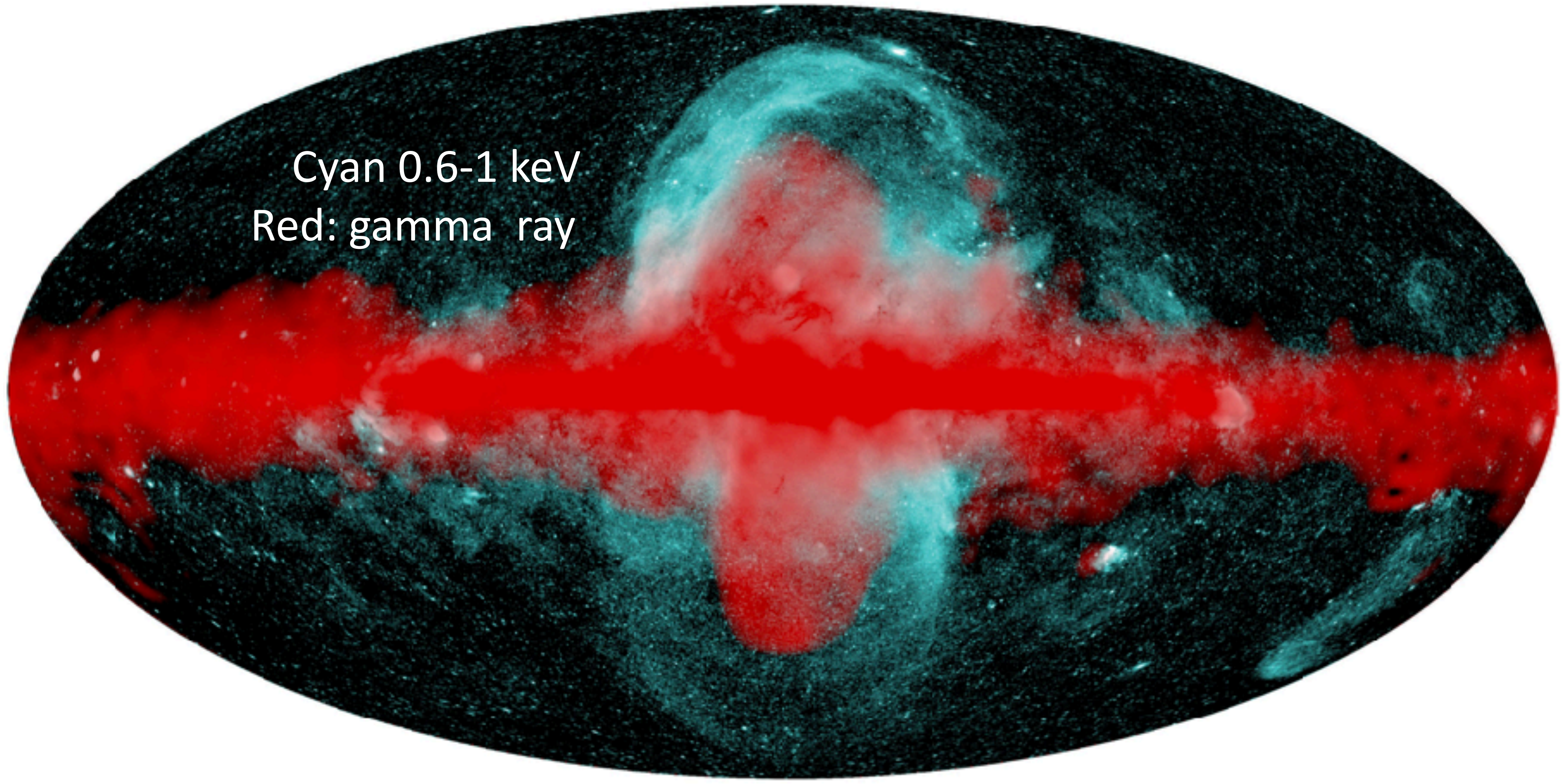
The Galactic Center PeVatron



HESS 2016 Nature



Mysteries about Fermi and eROSITA Bubbles



eROSITA bubbles (Predehl + 2020)

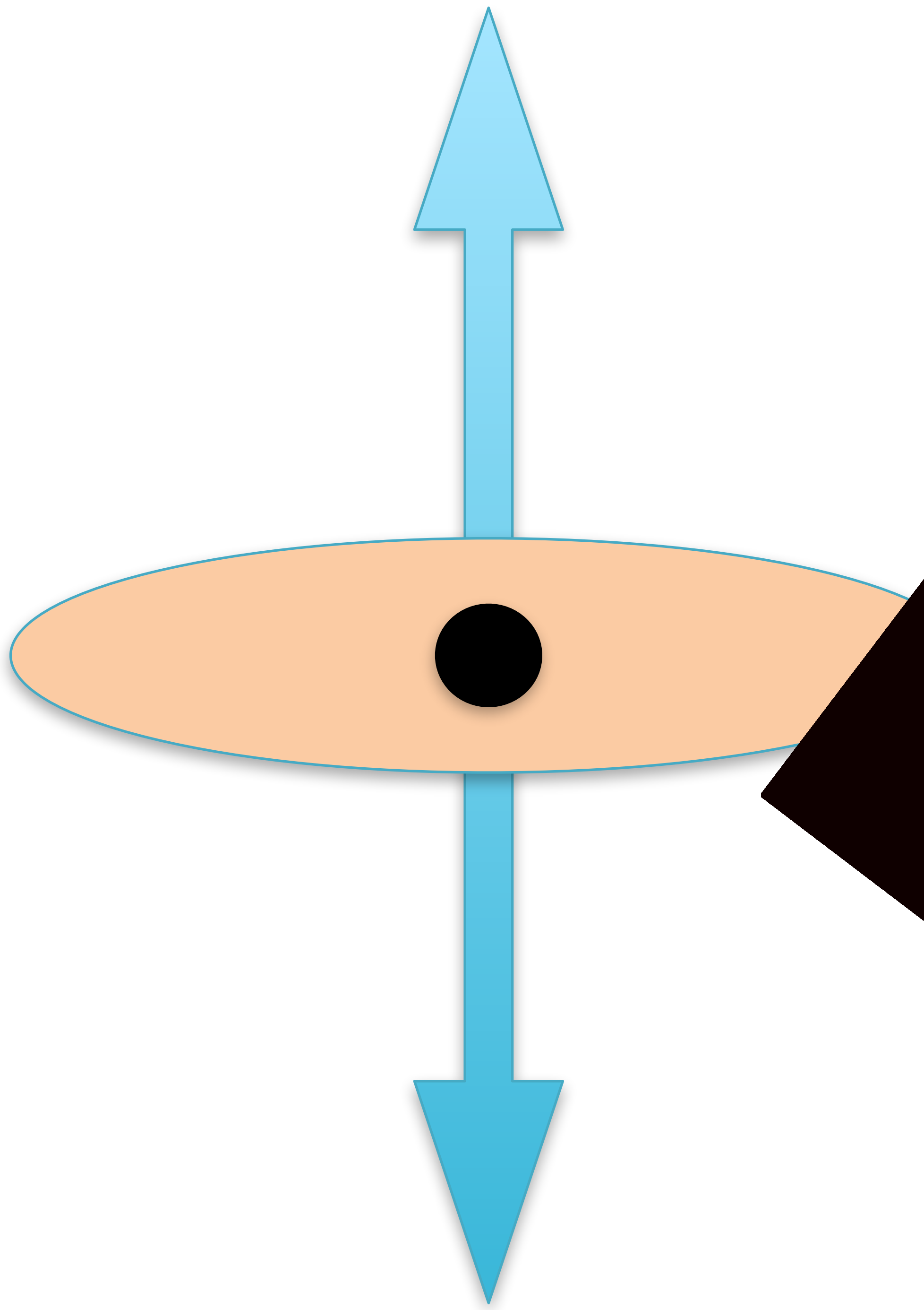
- Fermi and eROSITA bubbles:
(1) Gamma ray emission mechanisms
(2) Origins

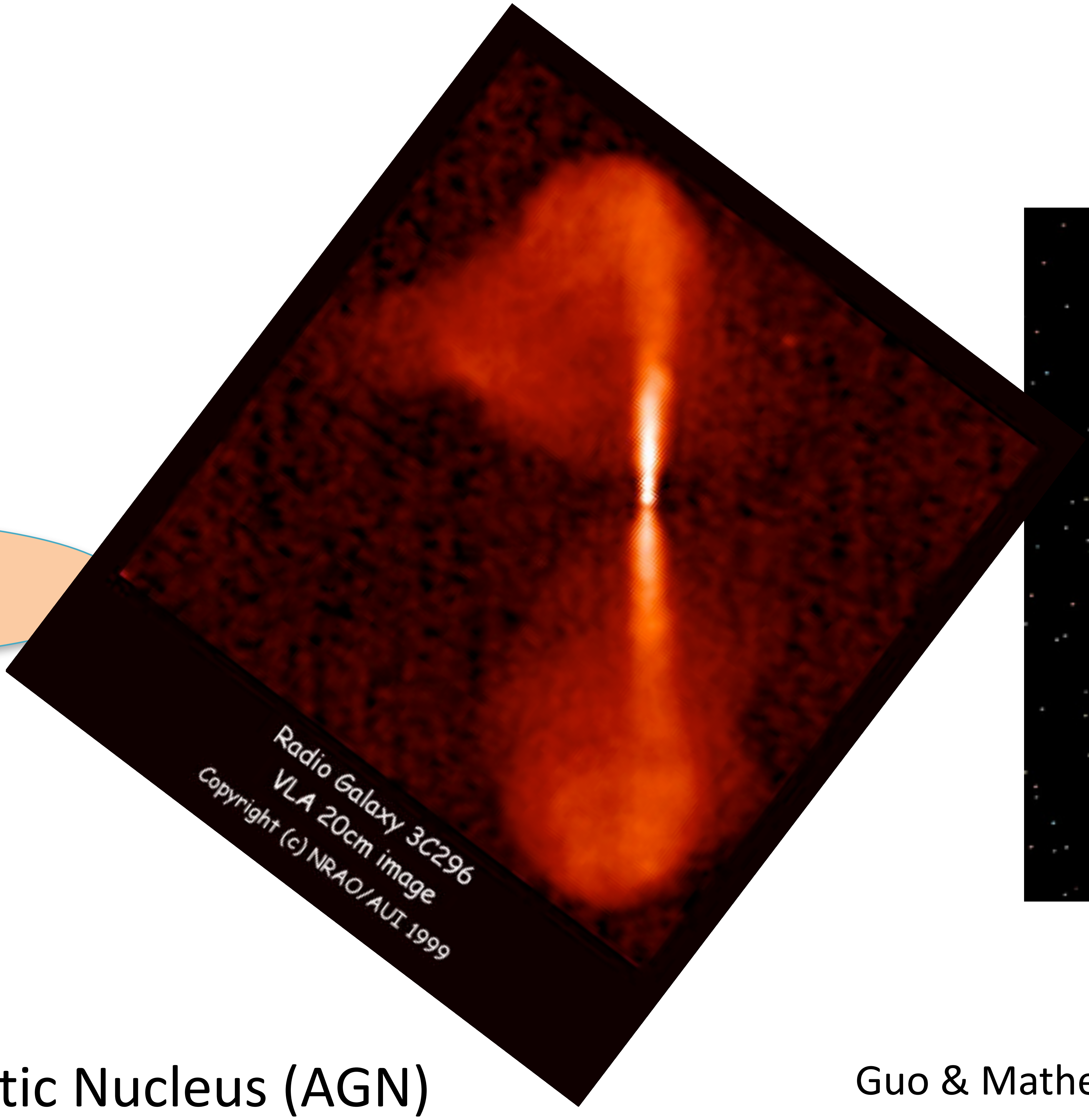
- How do they contribute to the Galactic cosmic ray population at various energies?

- Do Fermi and eROSITA bubbles are somehow related with each other? or simply one same event?

Scenario one: one unified model for Fermi and eROSITA bubbles

Bipolar Jets





Active Galactic Nucleus (AGN)

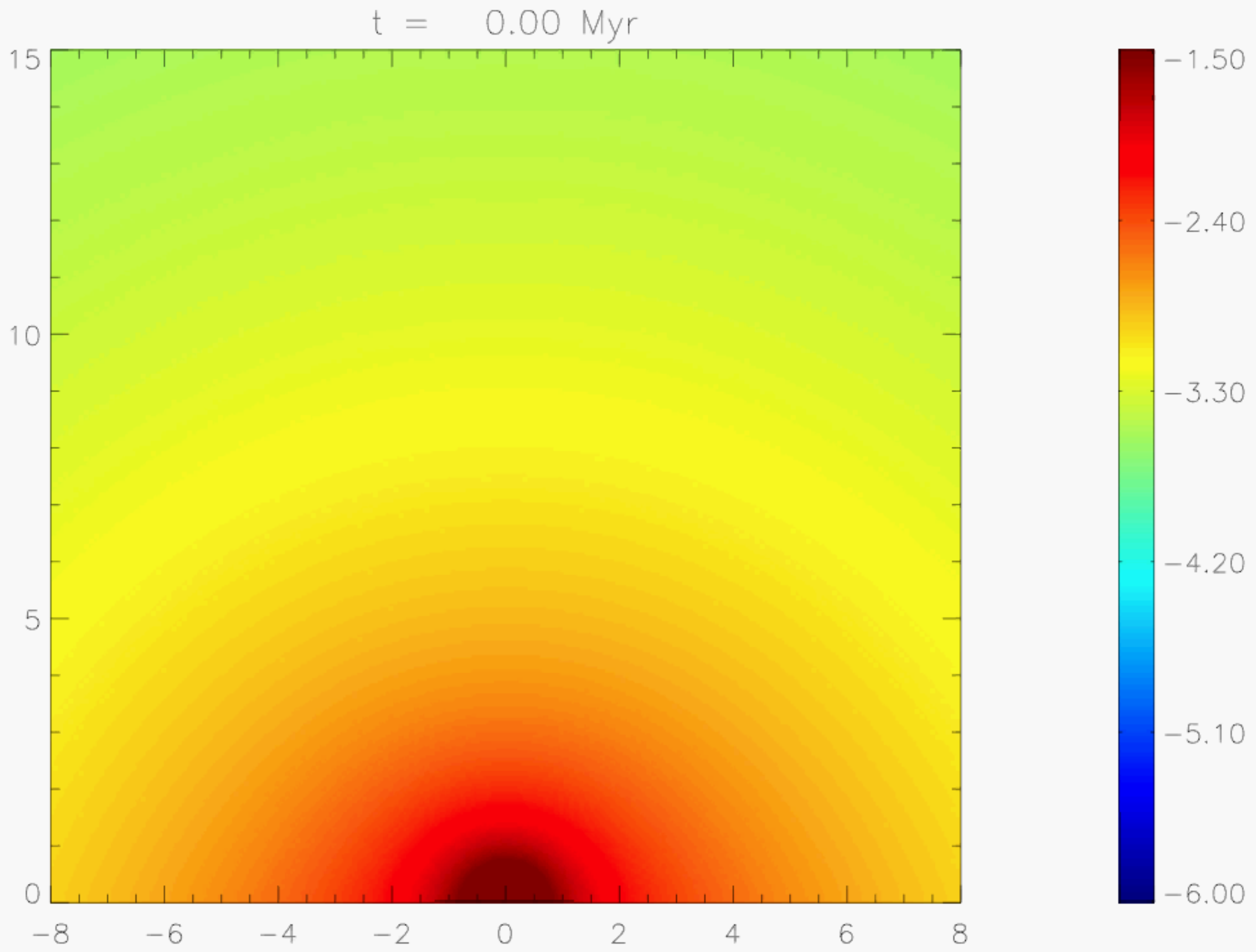
Fermi Bubbles

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

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

Prediction： Forward Shock in the CGM

Producing a forward shock in the circumgalactic medium (CGM) in the Galactic halo



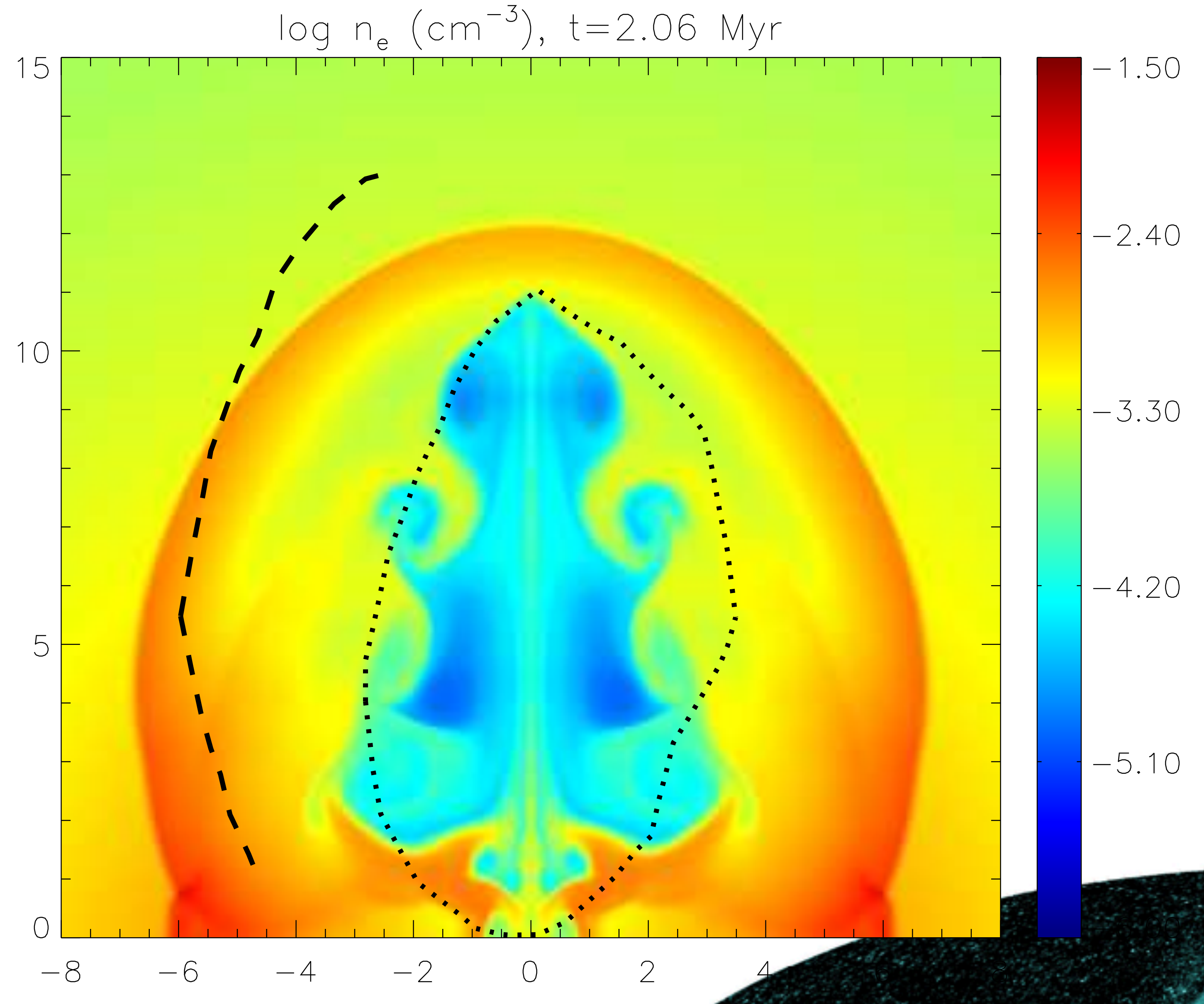
thermal gas density distribution

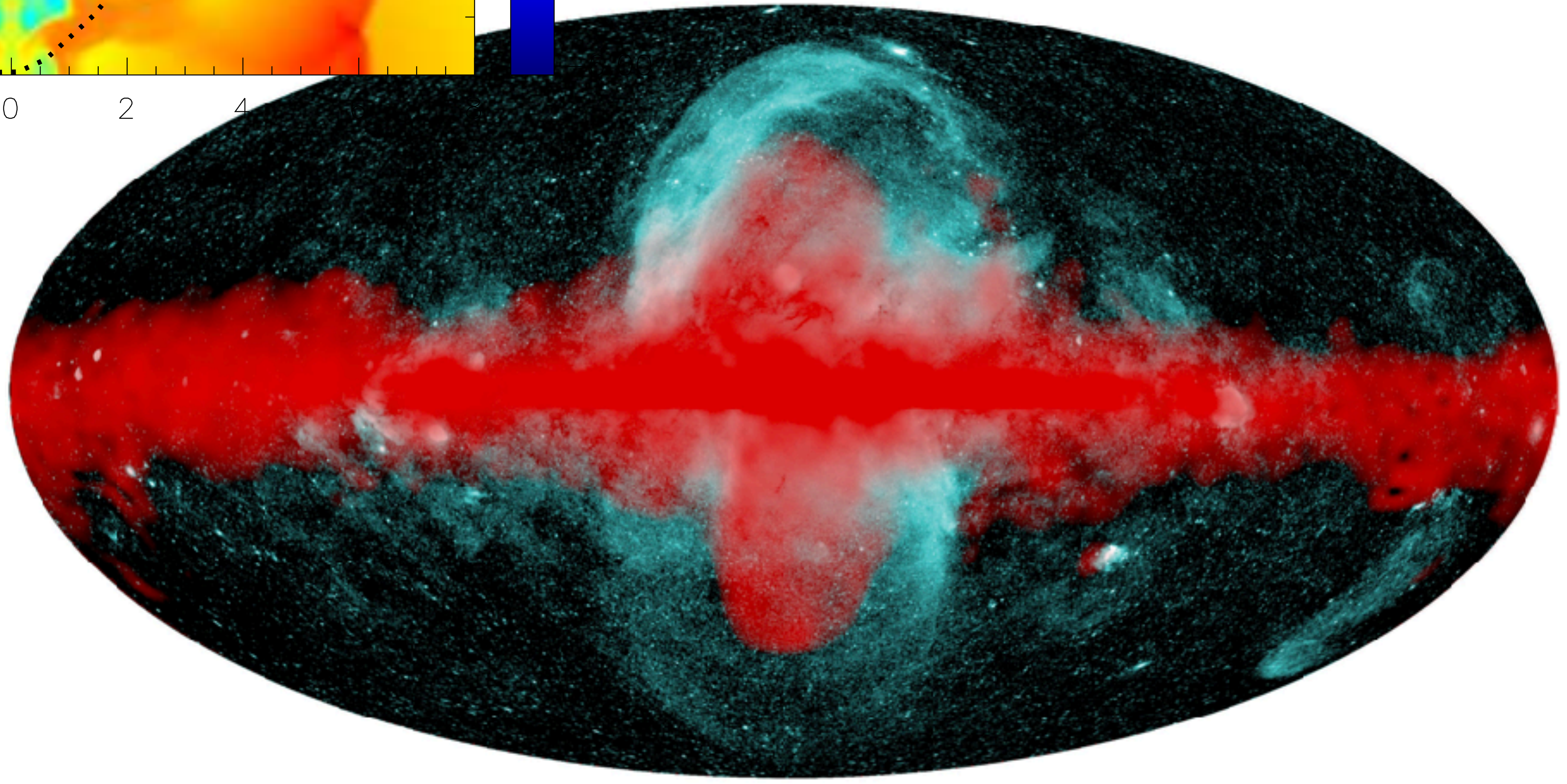
Guo & Mathews, ApJ， 2012a, 2012b

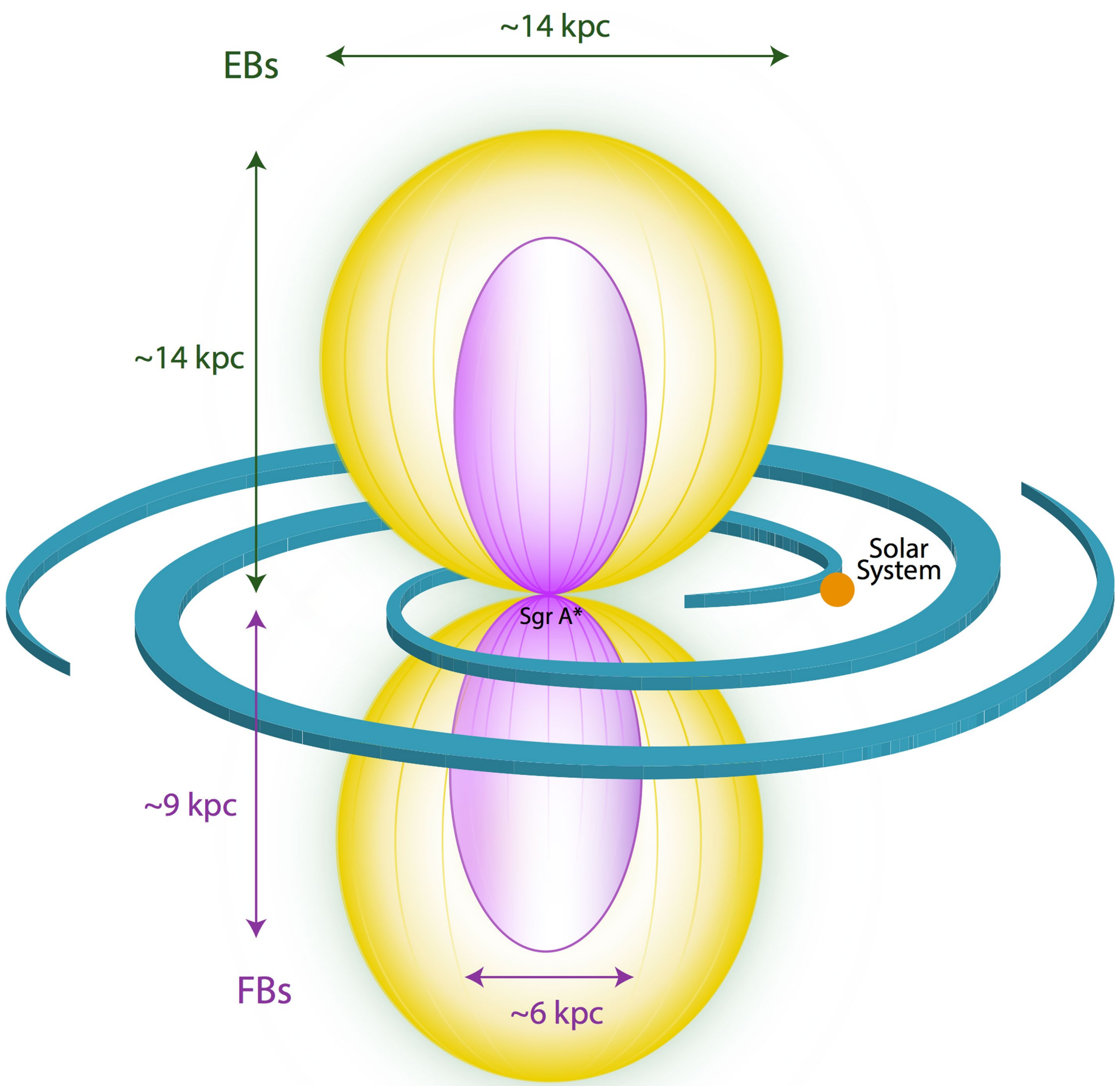
Scenario one: one unified model for Fermi and eROSITA bubbles

Fermi Bubbles：   jet ejecta bubbles in the Milky Way

eROSITA bubbles: shocked CGM bubbles of the Fermi bubble event in the halo

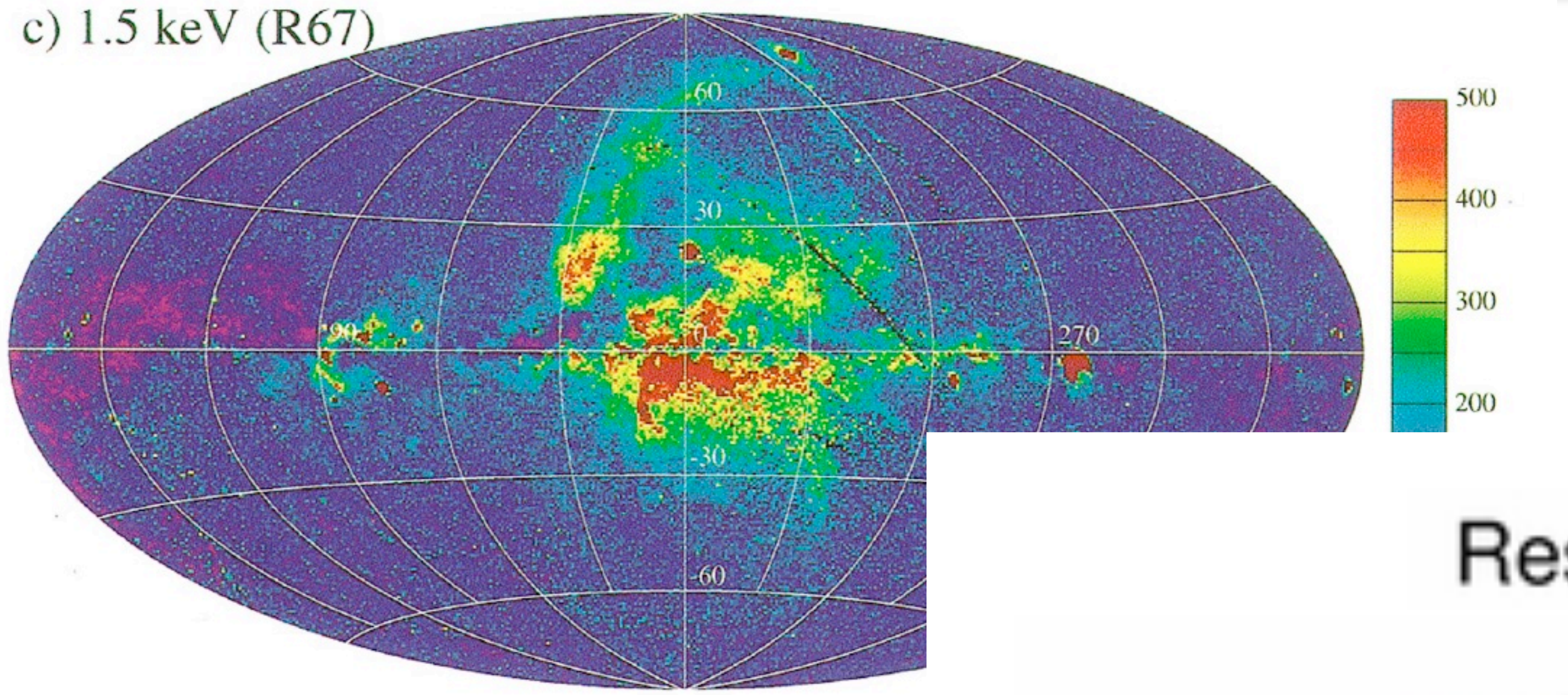


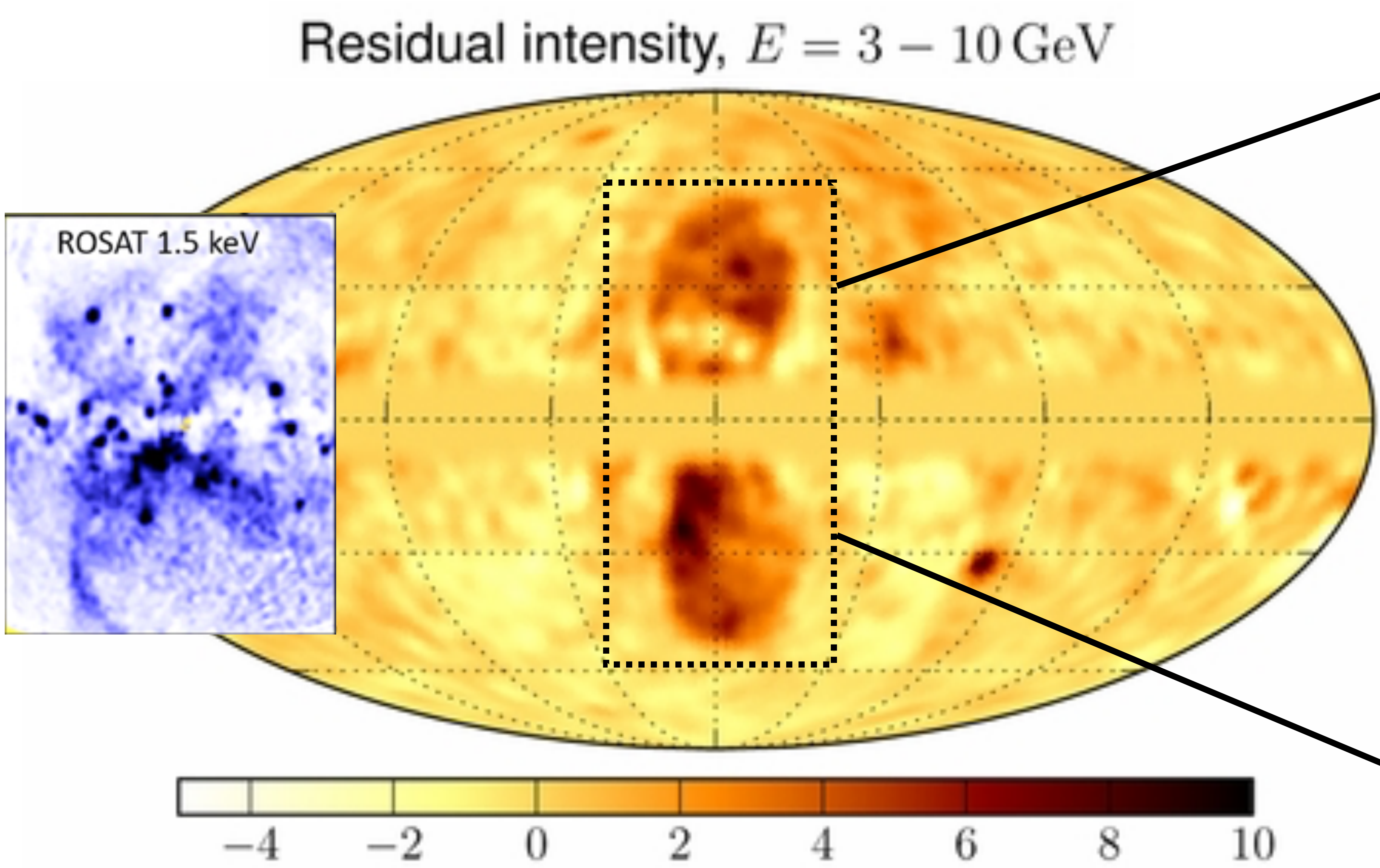




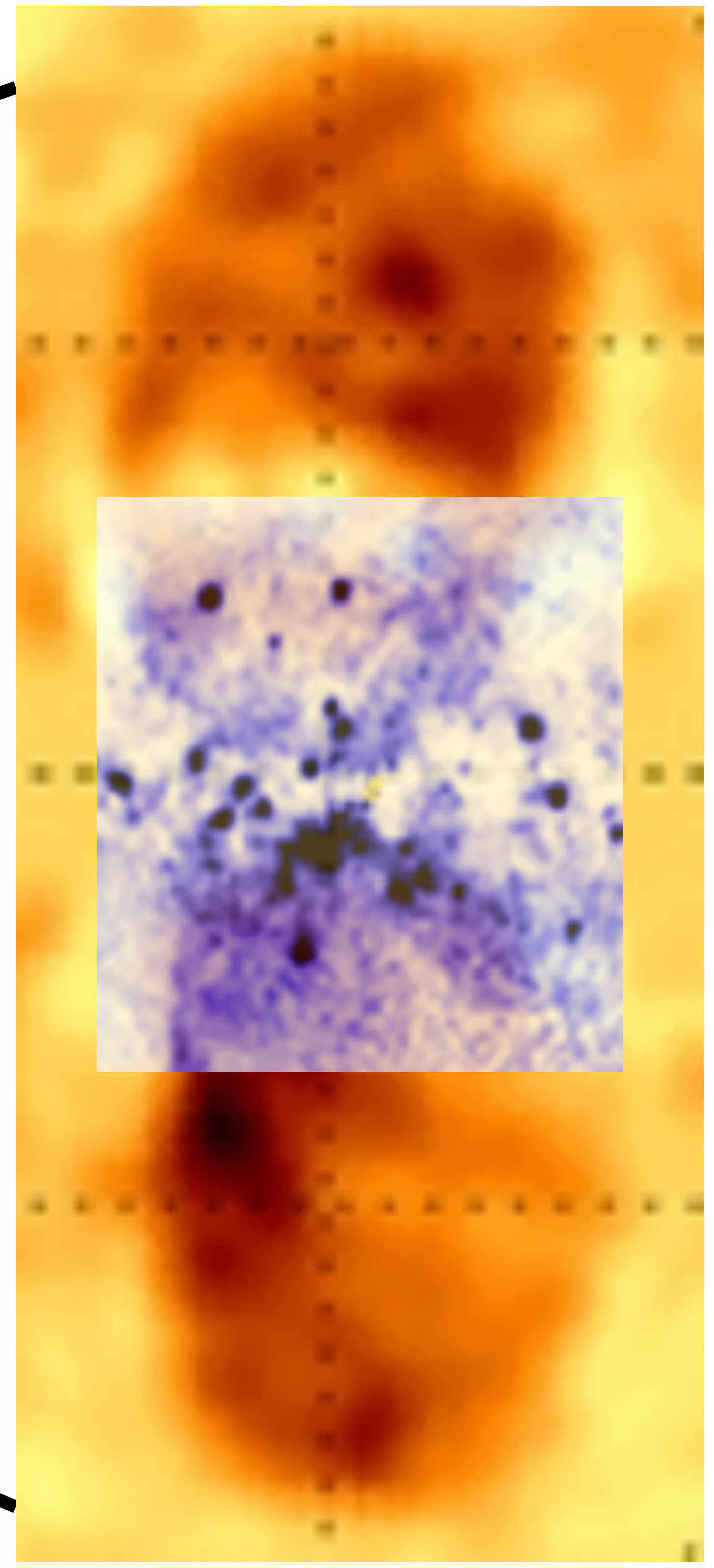
Fermi bubbles (red) and eROSITA Bubbles (cyan)

Problem: bipolar X-ray outflows in ROSAT map



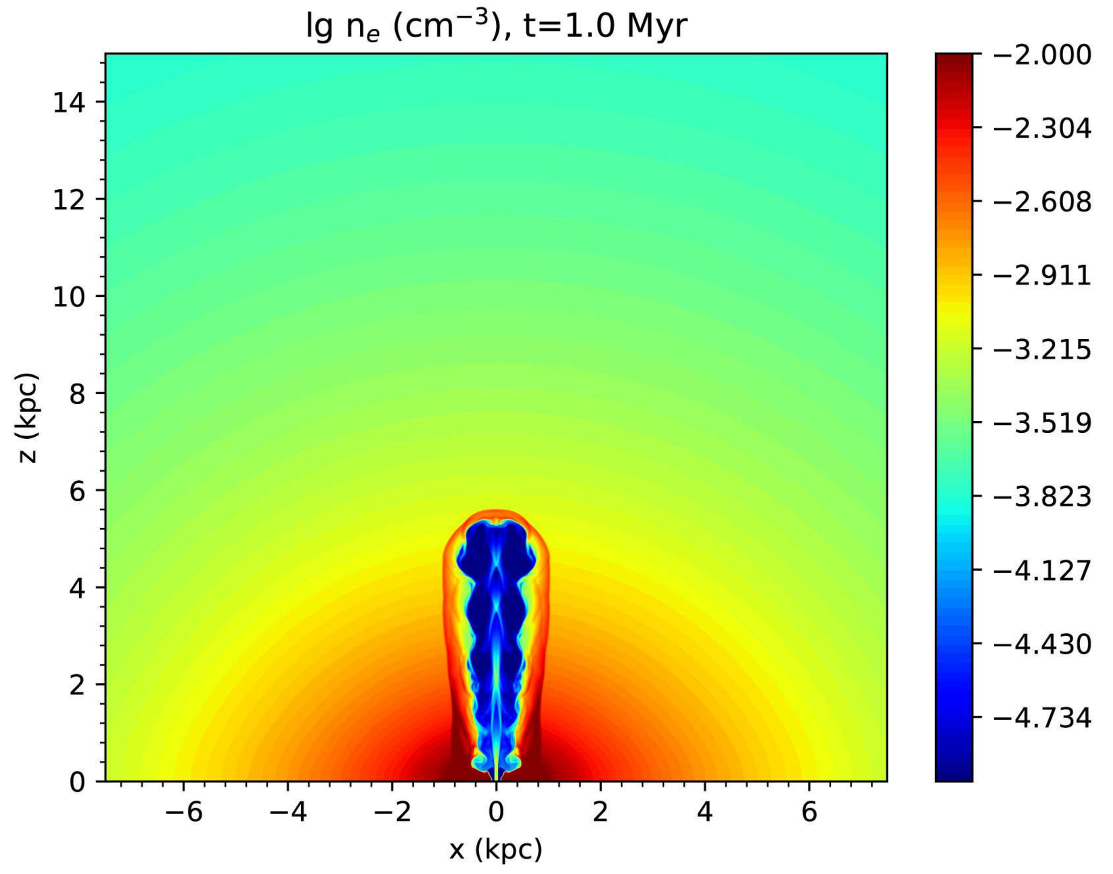


Composite

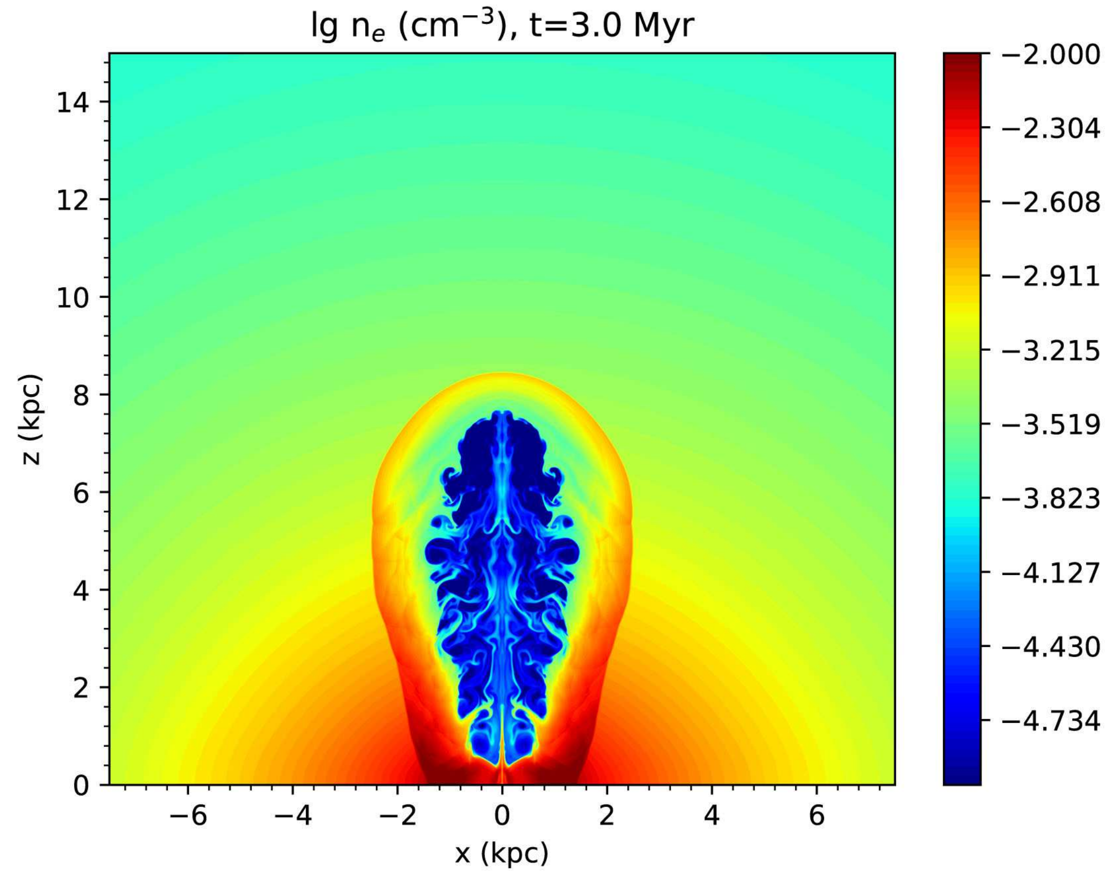


Scenario two: separate models for Fermi and eROSITA bubbles

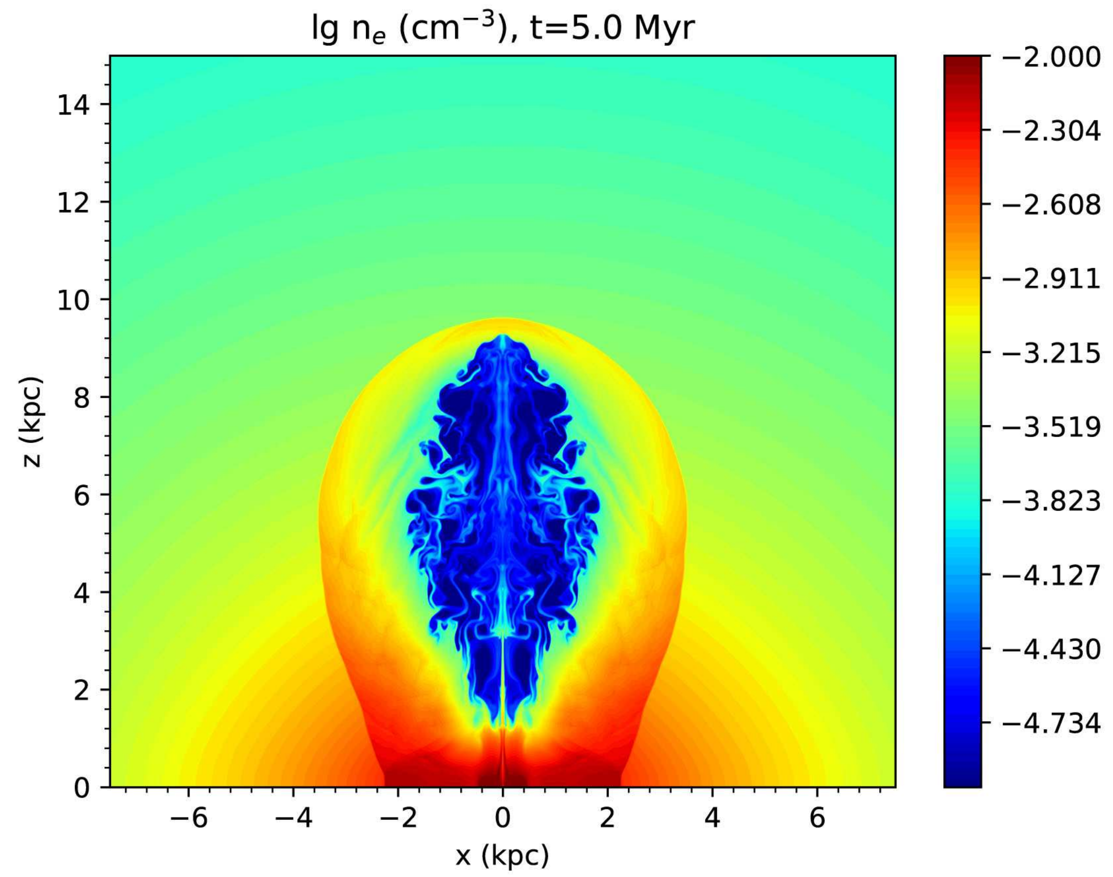
The Jet-Shock Model of Fermi bubbles



(a)



(b)



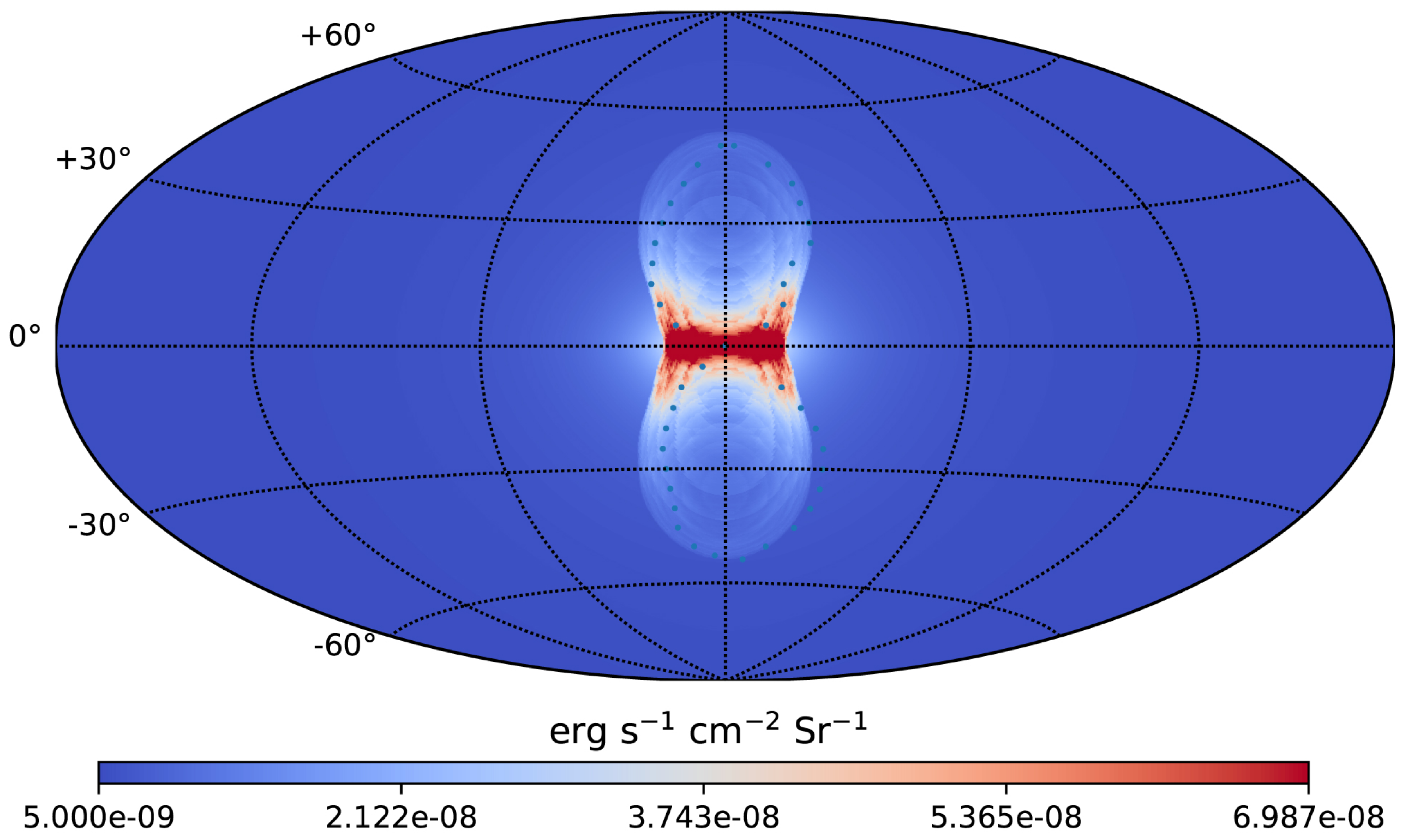
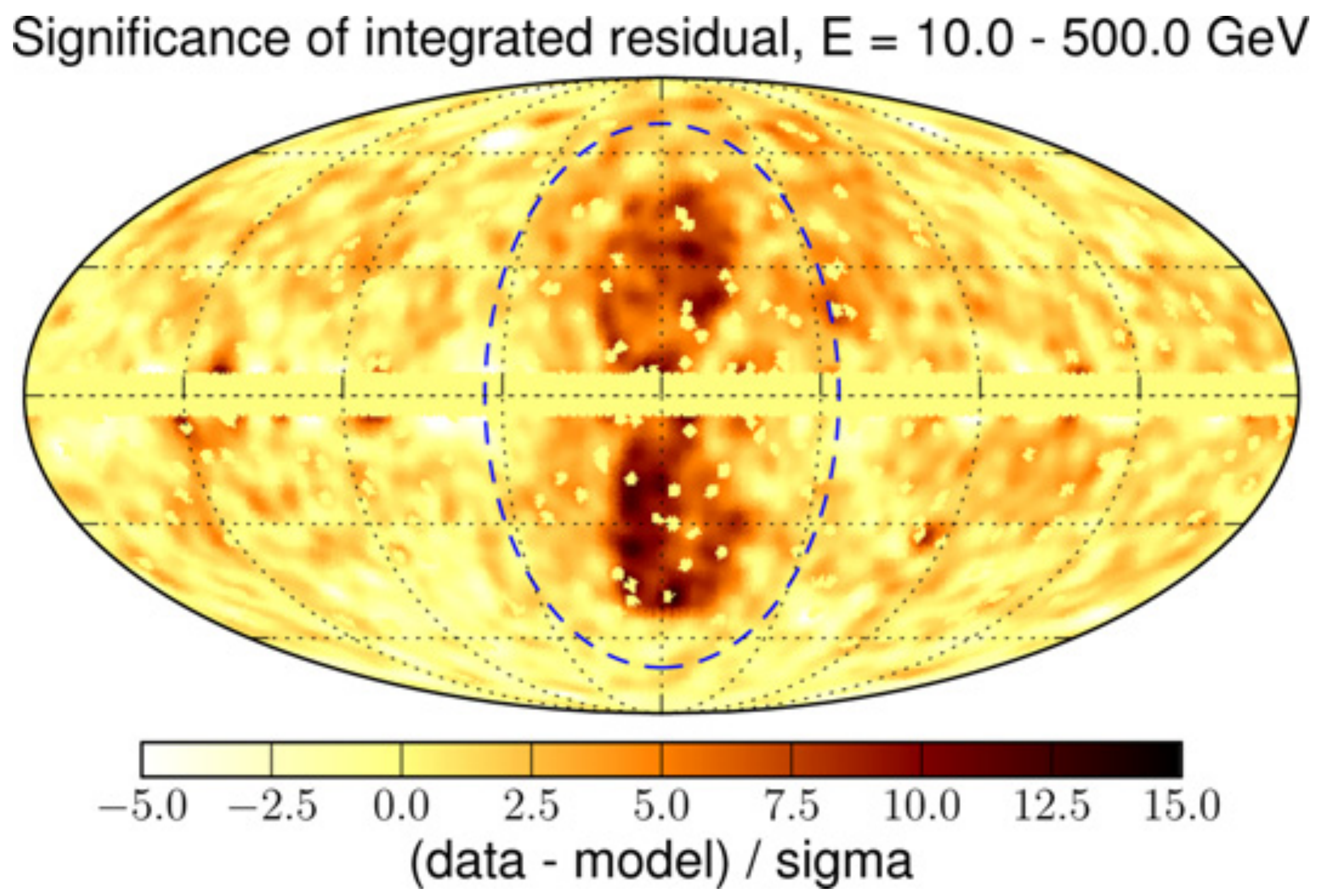


Figure 9. Synthetic X-ray (0.7–2 keV) surface brightness map in Galactic coordinates with a Hammer-Aitoff projection for run A at t = 5 Myr. The dots represent the edge of the observed Fermi bubbles.



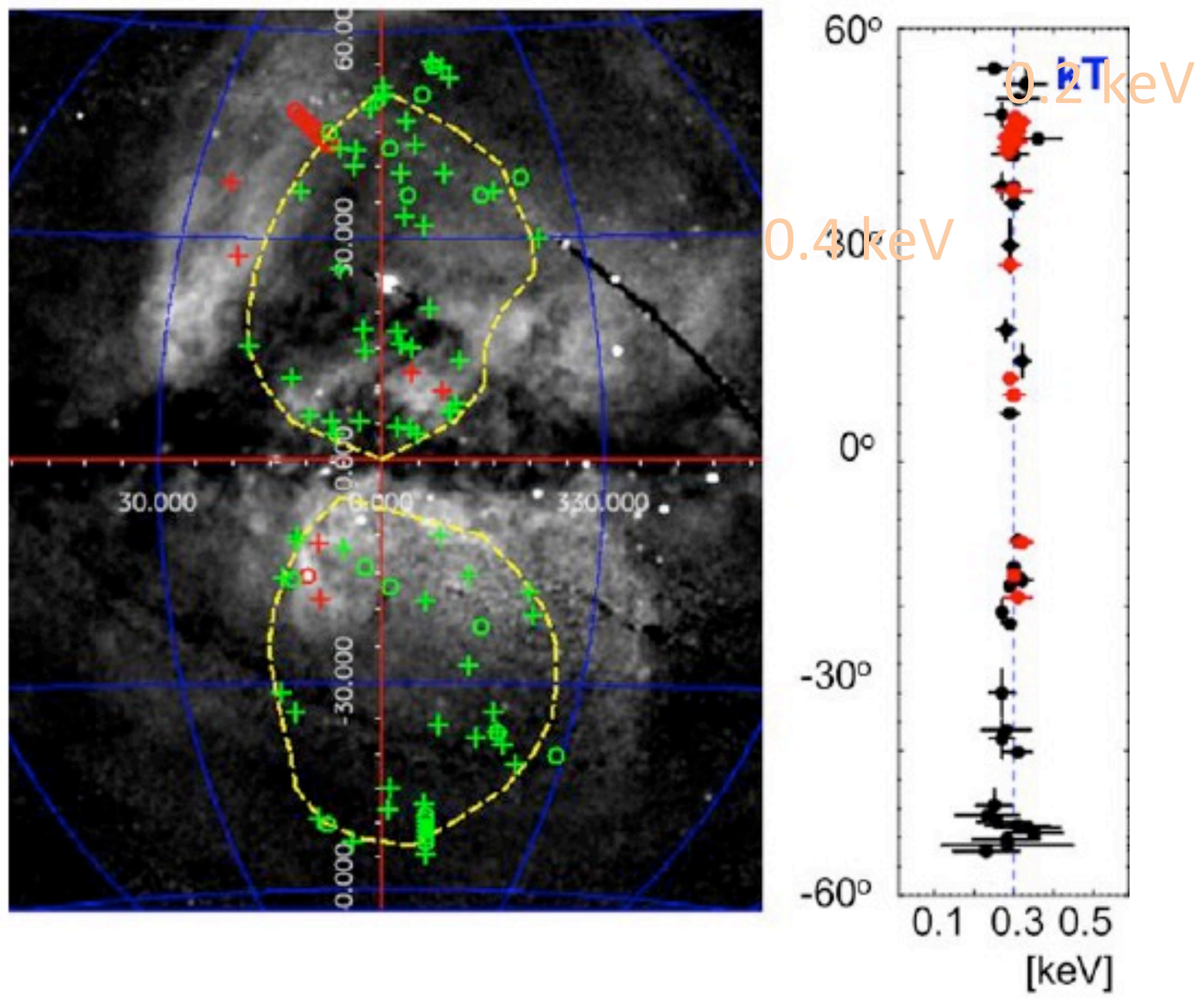
Zhang & Guo, 2020, 2021

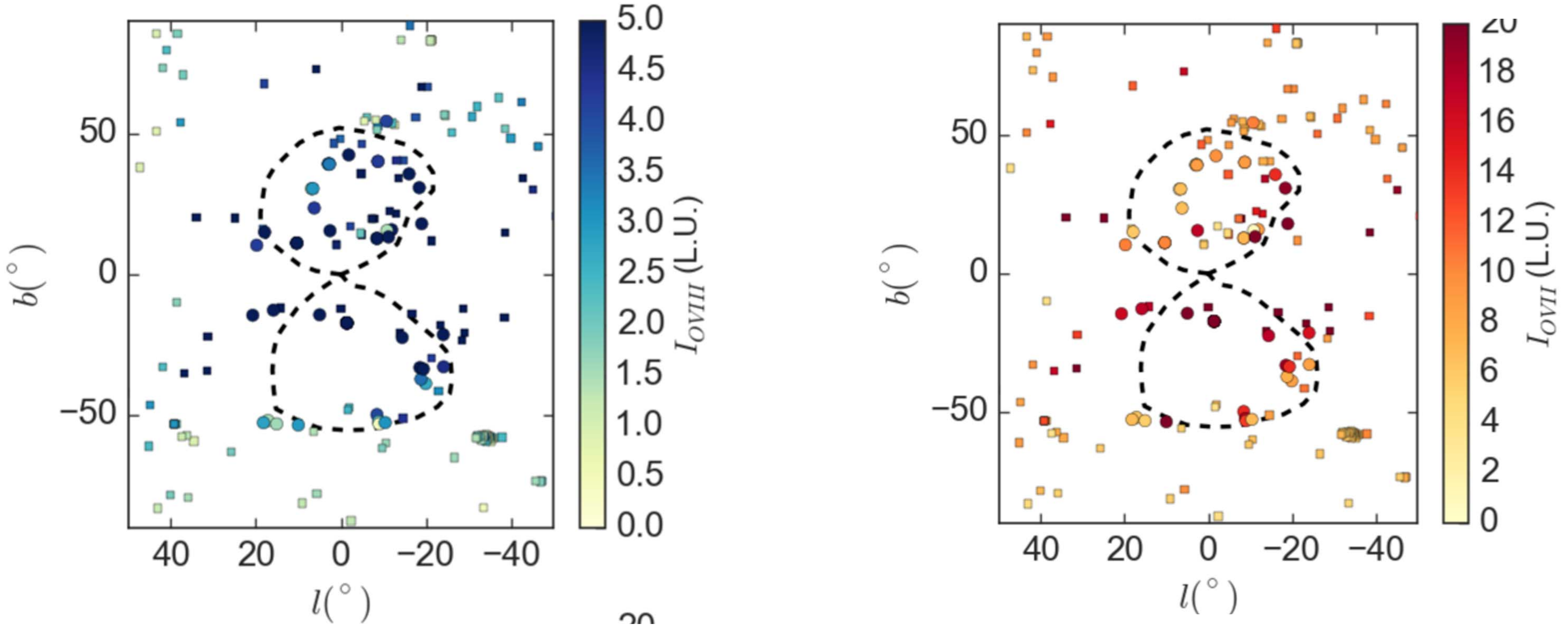
Consistent with Other Potentially Relevant Observations

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 $\sim$ 6±2 Myr





Miller et al.(2016)

Particle Acceleration at the Shock Front

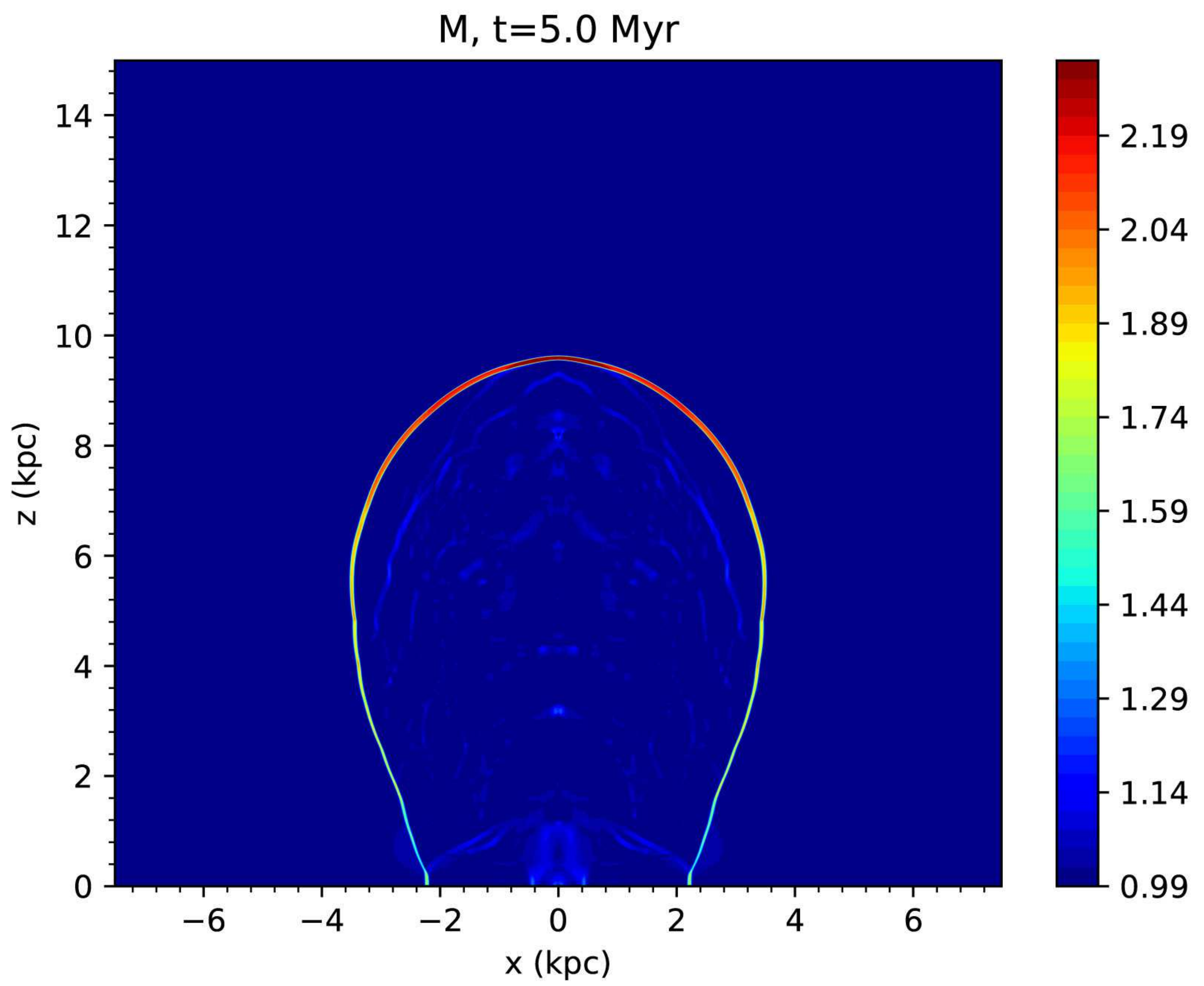


Figure 11. Mach number of the forward shock in Run A at t = 5 Myr. The Mach number increases from low to high latitudes, with an approximate value of about $M \sim 2$.

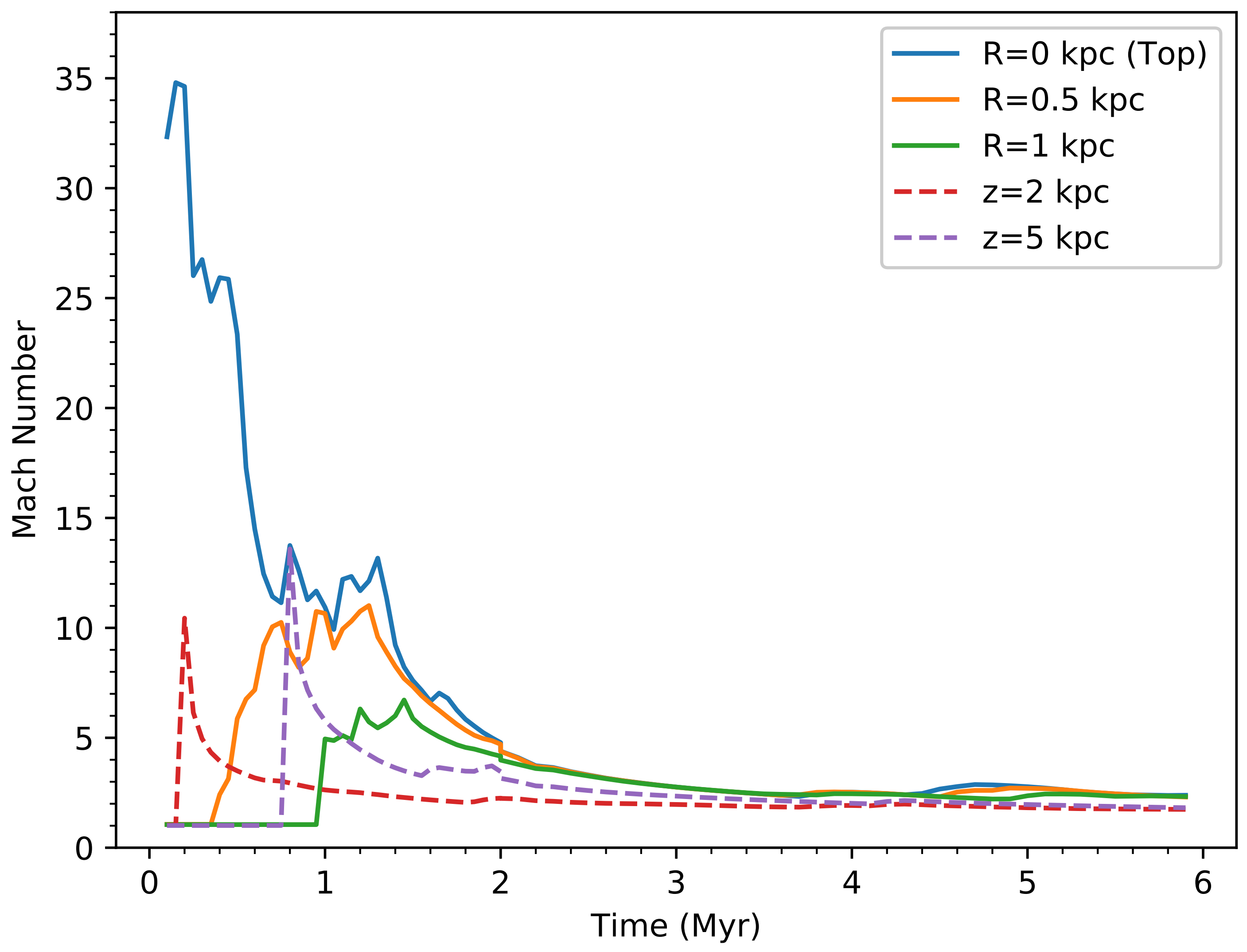
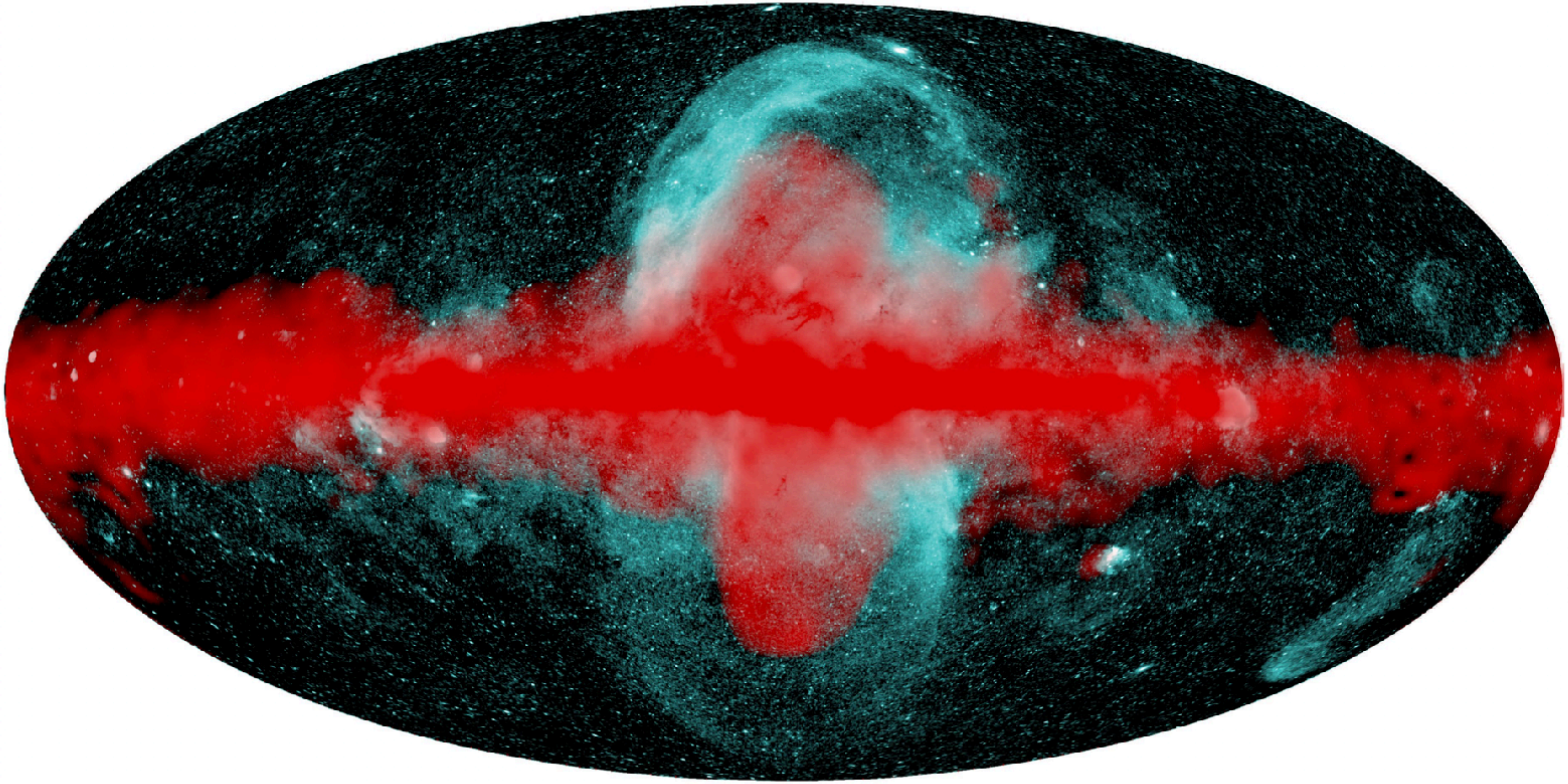


Figure 12. Temporal evolution of the Mach number of the forward shock in Run A. From top to bottom, the solid lines refer to the Mach number evolution at $R = 0$ (the bubble top), 0.5 kpc, and 1 kpc respectively, in the bubble surface. The dashed lines refer to the Mach number evolution at $z = 2$ kpc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

Scenario II needs a separate model for eROSITA Bubbles



See Zhang & Guo, 2021

Summary

Scenario I:

Fermi Bubbles： jet ejecta bubbles in the Milky Way

eROSITA bubbles: shocked CGM bubbles of the Fermi bubble event in the halo

Guo & Mathews, 2012a, 2012b

Scenario II:

Fermi Bubbles： shocked CGM bubbles in the halo

eROSITA bubbles: an older event before the Fermi bubbles

Jet ejecta bubbles: not prominent today

Zhang & Guo, 2020, 2021

LHAASO is also collecting data from this region