

Fermi & eROSITA bubbles: Relics of twin jetted bursts from Sgr A*

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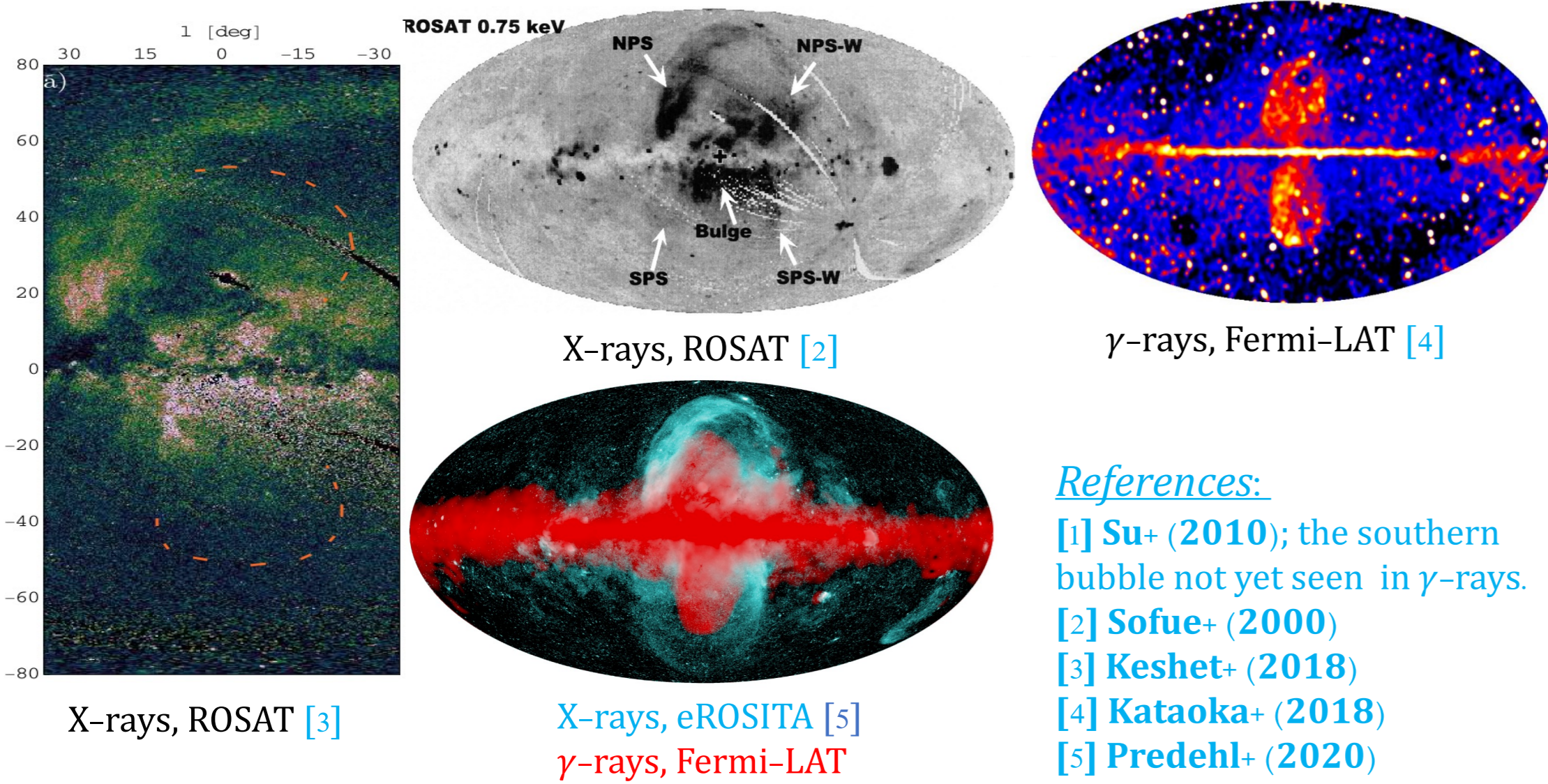
Bubbles in the X-ray and γ -ray sky

Two pairs of bipolar bubbles emanate from our Galactic center (GC):

1. $|b| \approx 50^\circ$ Fermi bubbles (FBs);
2. $|b| \approx 80^\circ$ ROSAT/e-ROSITA bubbles (RBs).

Both are γ -ray bright [1], bounded by an X-ray shell [2,3].

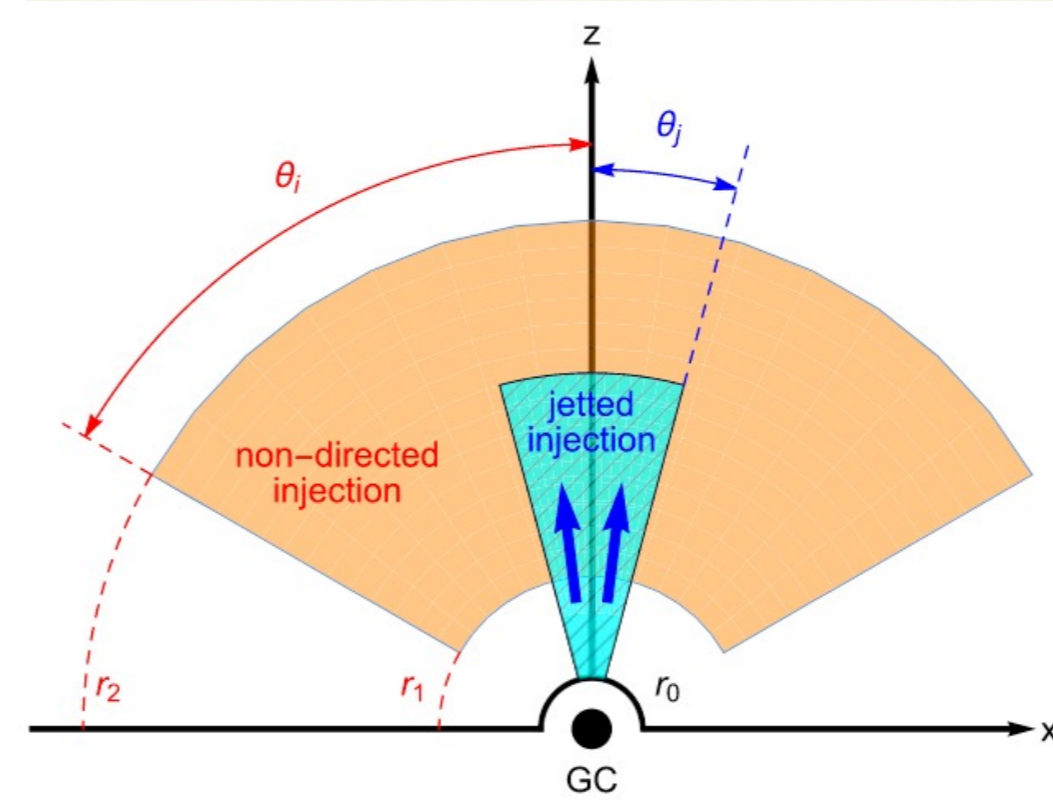
Bubble edges are forward shocks.



References:

- [1] Su+ (2010); the southern bubble not yet seen in γ -rays.
- [2] Sofue+ (2000)
- [3] Keshet+ (2018)
- [4] Kataoka+ (2018)
- [5] Predehl+ (2020)

Simulations of jetted and non-jetted injections

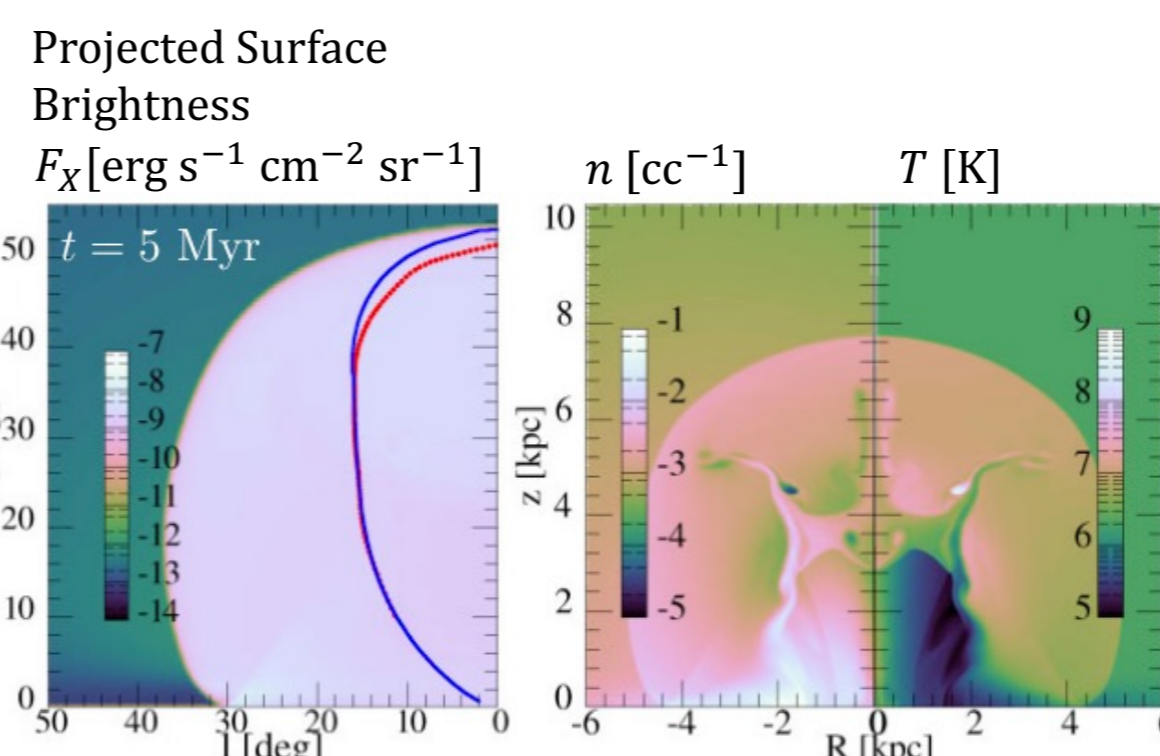


GC jets can be characterized by:

1. energy $E_j = E_{56} 10^{56}$ erg,
2. duration $\Delta t_j = \Delta t_{-2} 0.01$ Myr.

Injection at 0.1 kpc with:

1. velocity $v_j = \beta_{-2} 0.01c$,
2. half-opening angle $\theta_j = \theta_5 5^\circ$.



Non-directed explosions: ruled out (too spherical).

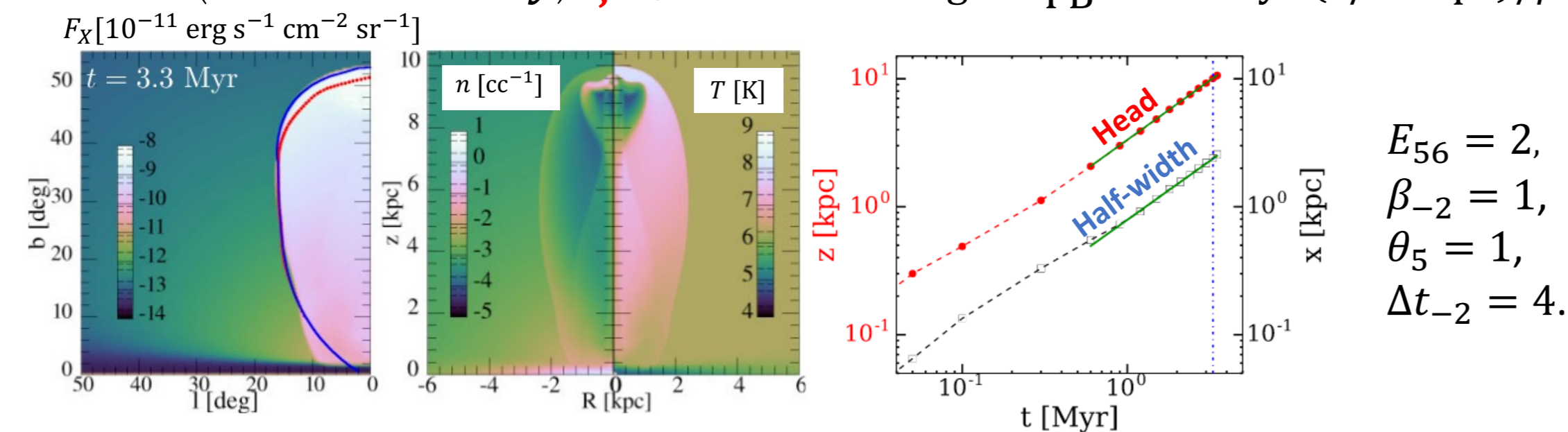
Mondal+ (2021)

Two modes of FB propagation in the CGM

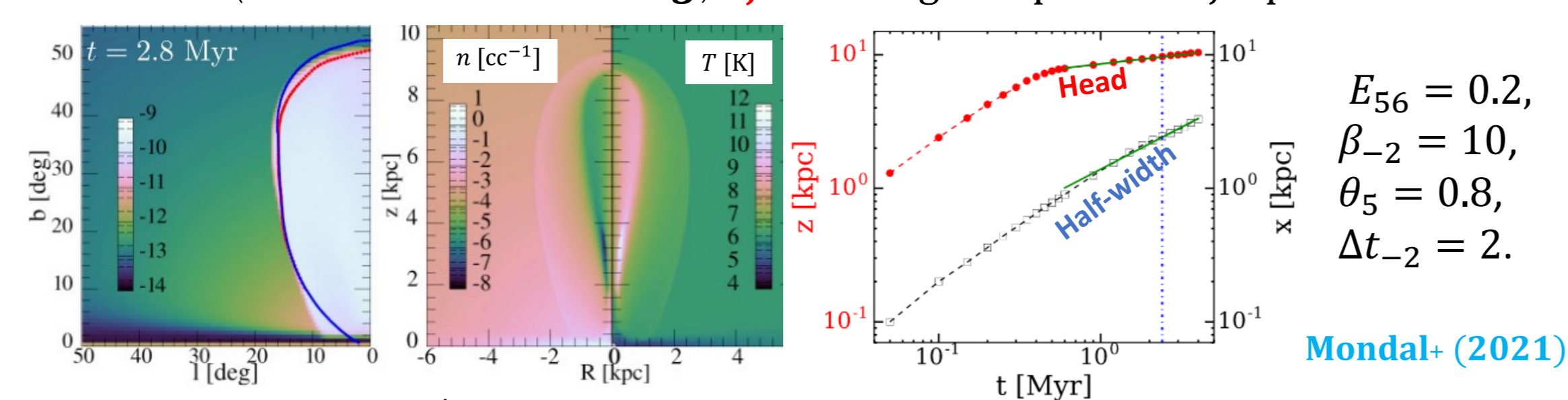
FBs **either** energetic (ballistic) or low-energy (slowing-down) depending on $\xi \equiv \frac{E_{56}}{3(\beta_{-2}\theta_5)^2}$.

Ballistic (constant-velocity): $\xi \gtrsim 1$

Age: $T_{FB} = 3.3$ Myr $(z/10 \text{ kpc})/\beta_{-2}$



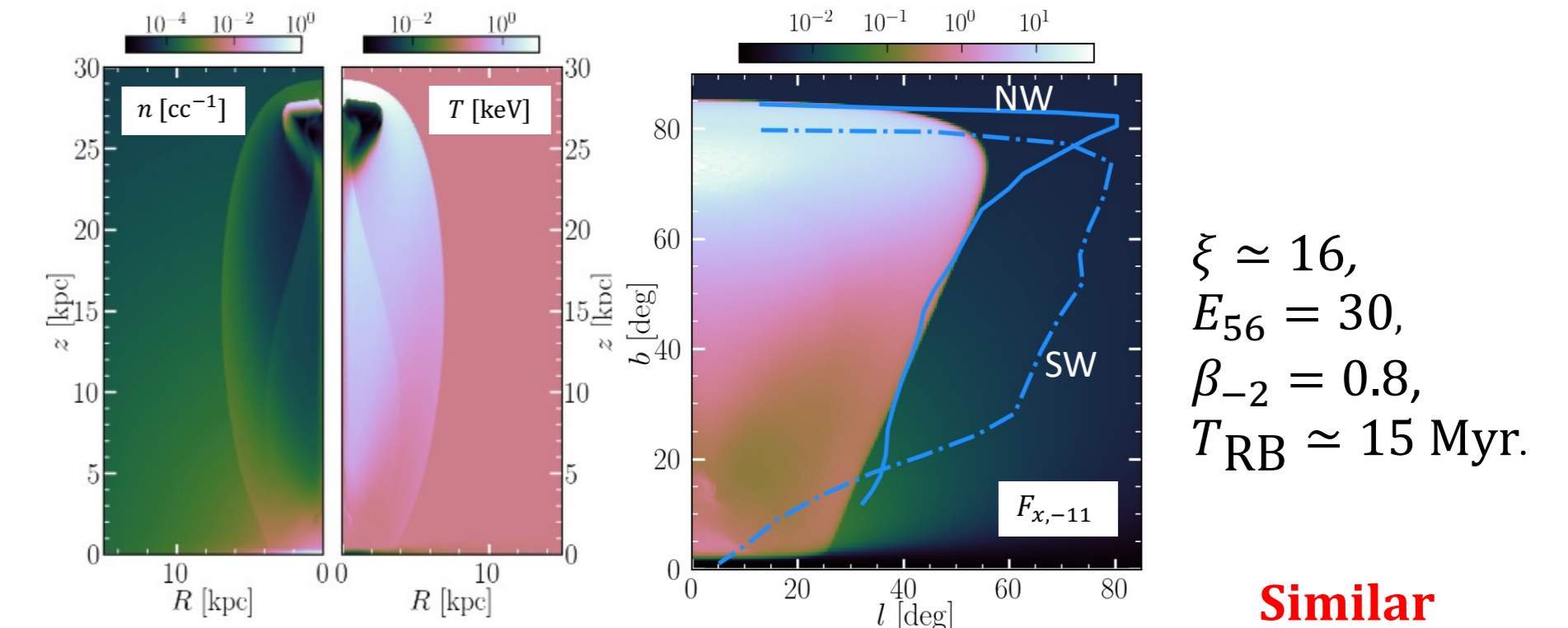
Slowing-down (momentum-conserving): $\xi \ll 1$ Age: depends on jet parameters



Assuming $\rho_{CGM} \propto z^{-3/2}$, bubbles can remain ballistic up to a height of $z \approx 35$ kpc $\xi^{2/3}$.

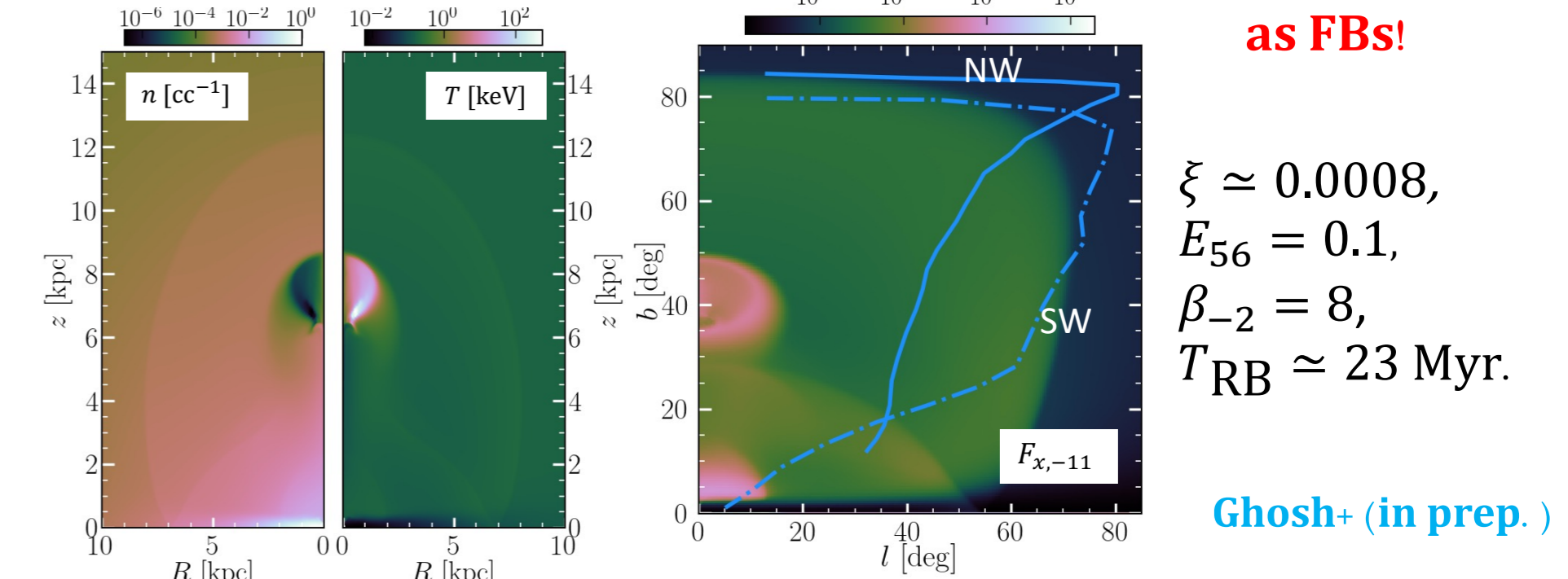
RBs are an older pair of jets!

Ballistic:



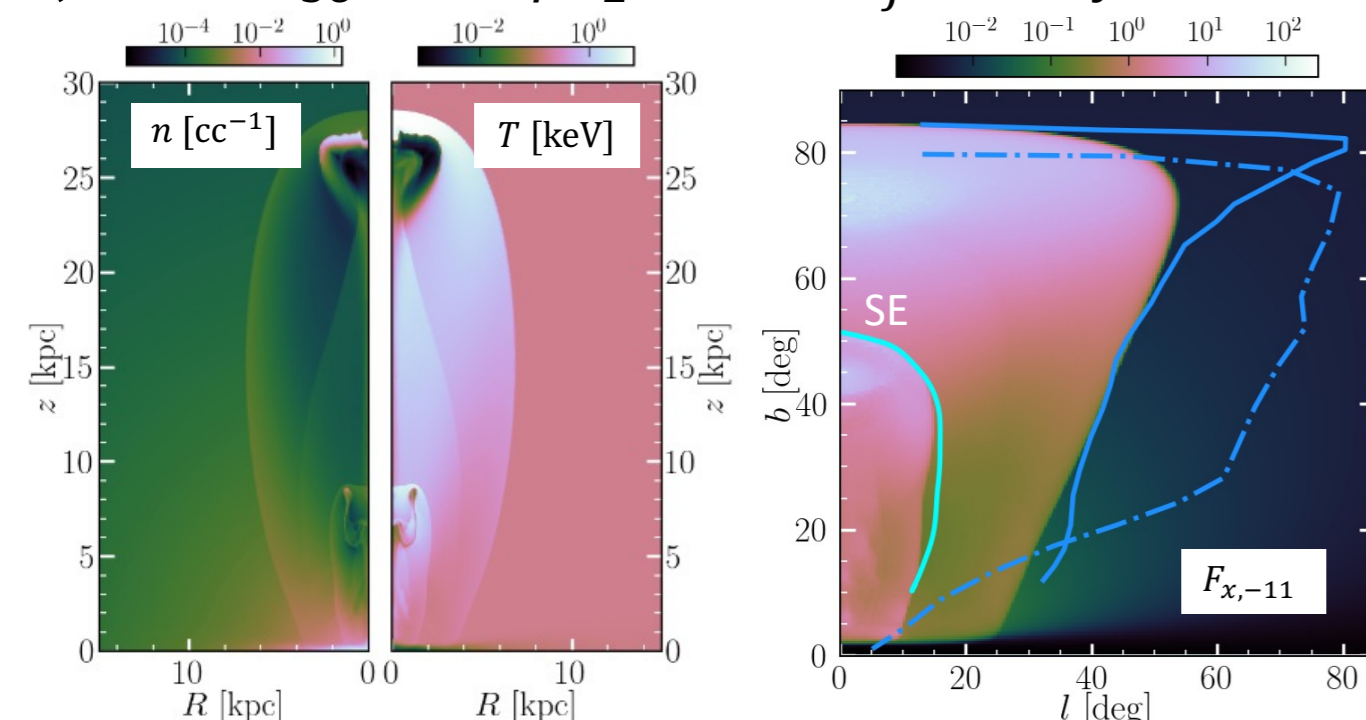
Similar dynamics as FBs!

Slowing-down:



Separate injection events can produce both RBs and FBs - even with the same jet parameters!

$\xi \approx 16, E_{56} = 30, \beta_{-2} = 0.8, \tau_j \approx 7$ Myr.



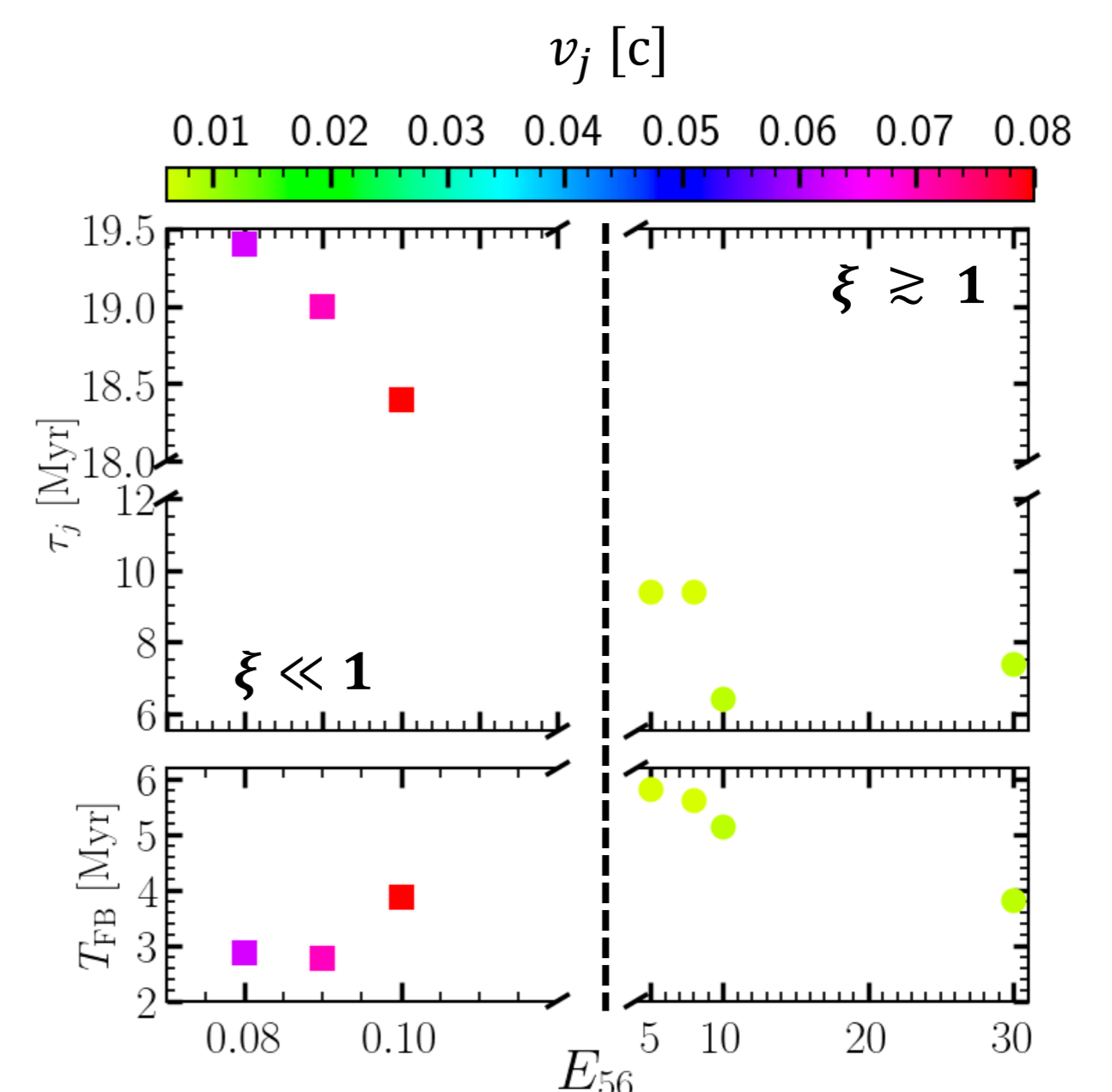
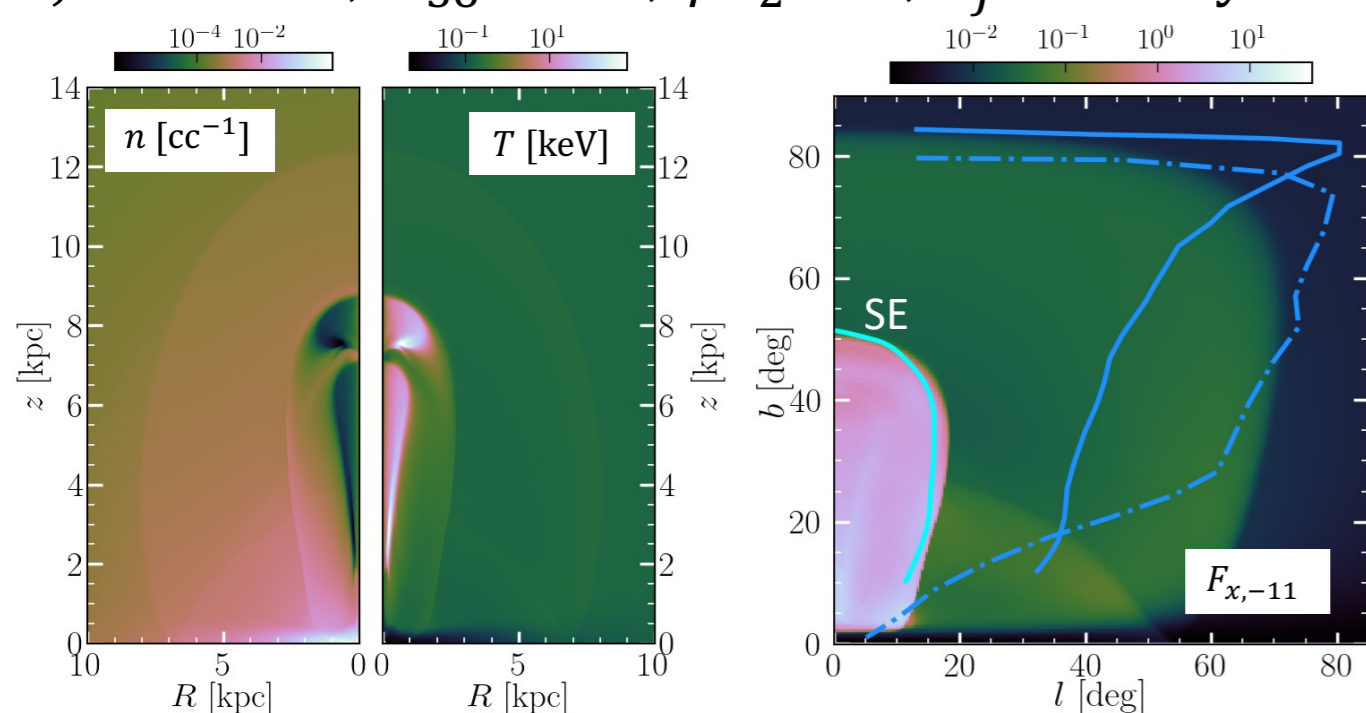
Delay between the jets, τ_j , is related to the bubble ages: $\tau_j = T_{RB} - T_{FB}$.

Irrespective of ξ , the FBs are always ballistic since they propagate in a largely under-dense region, evacuated by the older RBs.

Note: indications that ions (simulated) are hotter than electrons (observed).

Ghosh+ (in prep.)

$\xi \approx 0.0008, E_{56} = 0.1, \beta_{-2} = 8, \tau_j \approx 18$ Myr.



An excursion of the parameter space shows that $T_{FB} \lesssim 6$ Myr.