Bubbles in the X-ray and γ-ray sky

Two pairs of bipolar bubbles emanate from our Galactic center (GC):
1. 15° ≳ θ ≳ 50° Fermi bubbles (FBs);  
2. θ ≳ 80° ROSAT/e-ROSITA bubbles (RBs).

Both are γ-ray bright [3], 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  

Simulations of jetted and non-jetted injections

GC jets can be characterized by:
1. energy $E_j = E_{56} 10^{56}$ erg,  
2. duration $\Delta t = \Delta t_{56}$ 0.1 Myr.

Injection at 0.1 kpc with:
1. velocity $v_j = \beta_2 0.01 c$,  
2. half-opening angle $\theta_j = 5^\circ$.

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 $\xi \equiv E_{56}/\beta_2^2$

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

Age: $t_{FB} = 3.3$ Myr ($z/10$ kpc)/$\beta_2$

Slowdown (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!

$\xi \approx 16$, $E_{56} = 30$, $\beta_2 = 0.8$, $T_{RB} \approx 15$ Myr.

Slowdown: $\xi \ll 1$

Similar dynamics as FBs!

$\xi \approx 0.0008$, $E_{56} = 0.1$, $\beta_2 = 0.1$, $T_{RB} \approx 23$ Myr.

Ghosh (in prep.)

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

Delay between the jets, $t_j$, is related to the bubble ages: $t_j = T_{RB} - T_{FB}$

Irrespective of $\xi$, the FBs are always ballistic since they propagate in a largely underdense region, evacuated by the older RBs.

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

Ghosh (in prep.)

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