Draft version October 21, 2021
Typeset using LaTeX **twocolumn** style in AASTeX631

Fermi and eROSITA bubbles

Po-Hsun Tseng ,[1] H.-Y. Karen Yang ,[2] Hsi-Yu Schive ,[1,3,4,5] and Tzihong Chiueh [1,3,4]

[1] Institute of Astrophysics, National Taiwan University, Taipei 10617, Taiwan
[2] Institute of Astronomy and Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan
[3] Department of Physics, National Taiwan University, Taipei 10617, Taiwan
[4] Center for Theoretical Physics, National Taiwan University, Taipei 10617, Taiwan
[5] Physics Division, National Center for Theoretical Sciences, Taipei 10617, Taiwan

ABSTRACT

Keywords: keywords

1. INTRODUCTION

2. METHODOLOGY

2.1. *Assumptions and Numerical Techniques*

1. Numerical features:
   (a) GPU acceleration with the GAMER-SR code.
   (b)
   (c) special relativistic hydrodynamics.
   (d) Using a new algorithm dedicated to the conversion between primitive and conserved variable, significantly reducing numerical error caused by the non-relativistic cold disk.
2. Assumptions on cosmic-ray:
   (a) We treat CRs as a second fluid and solve directly for the evolution of CR pressure $p_{\rm cr}$ as a function of $\mathbf{r}$ and t.
   (b) We did not model the CR energy spectrum.
   (c) We neglected the cooling and heating processes of CRs, such as energy losses due to synchrotron and inverse Compton emission, and reacceleration in shocks.
   (d) We have assumed cosmic-ray is passive. (i.e. $p_{\rm cr} \ll p_{\rm gas}$)
   (e) We have assumed $\mathbf{B}$ is zero within the simulation box as the field inside the bubbles should be weak due to adiabatic expansion, and thus the magnetic fields has little effect on the overall dynamics. It might somewhat affect the instabilities near the bubble's surface, but that's a secondary effect.
   (f) Since $\mathbf{B}$ is zero, we can also ignore the effect of cosmic-ray diffusion.
3. Assumptions on Gravity:
   (a) Since , we have assumed the

We simulate 3D special relativistic hydrodynamics with passive CR injections from the GC using the special hydrodynamics GPU code GAMER-SR (Tseng et al. 2021).

GAMER-SR solves mass and energy-momentum conservation laws of a special relativistic ideal fluid with CR.

The CRs are advected with the thermal gas, but the gas cannot react to the CR pressure. In this approach, the CRs are treated as a single species without distinction between electrons and protons. We did not model the CR energy spectrum, and we neglected the cooling and heating processes of CRs, such as energy losses due to synchrotron and inverse Compton emission, and reacceleration in shocks.

$$\partial_t D + \partial_j \left(D U^j / \gamma \right) = 0, \tag{1a}$$

$$\partial_t M^i + \partial_j \left(M^i U^j / \gamma + p_{\rm gas} \delta^{ij} \right) = -\rho \partial_i \Phi, \tag{1b}$$

$$\partial_t \tilde{E} + \partial_j \left[\left(\tilde{E} + p_{\rm gas} \right) U^j / \gamma \right] = 0, \tag{1c}$$

$$\partial_t \left(\gamma e_{\rm cr} \right) + \partial_j \left(e_{\rm cr} U^j \right) = -p_{\rm cr} \partial_j U^j, \tag{1d}$$

where the five conserved quantities of gas D, M^i, and $\tilde{E}$ are the mass density, the momentum densities, and the

Corresponding author: Po-Hsun Tseng
zengbs@gmail.com

reduced energy density, respectively. The reduced energy density is defined by subtracting the rest mass energy density of gas from the total energy density of gas. γ and U^j are the temporal and spatial component of four-velocity of gas. ρ is the gas density in the local rest frame defined by D/γ. $p_{\rm gas}$ is the gas pressure. $p_{\rm cr}$ and $e_{\rm cr}$ are the CR pressure and CR energy density measured in the local rest frame. Φ is the gravitation potential. c is the speed of light, and δ^{ij} is the Kronecker delta notation. Throughout this paper, Latin indices run from 1 to 3, except when stated otherwise.

2.2. *The Galactic Model*

1. Gravitational potential

    (a) Isothermal slab

    (b) NFW potential

2. Cold disk

    (a) The fractal density is created using the publicly available pyFC code[1].

    (b)

2.3. *Jet injection*

2.4. *X-ray and Gamma-ray emission*

1. X-ray

    (a)

2. Gamma-ray

    (a)

3. CONCLUSIONS

DATA AVAILABILITY

The data underlying this article are available in the article and in its online supplementary material.

REFERENCES

Tseng P.-H., Schive H.-Y., Chiueh T., 2021, Monthly Notices of the Royal Astronomical Society, 504, 3298

[1] https://pypi.python.org/pypi/pyFC

APPENDIX