

Halo scenario or Local scenario?

Give suggestion to North Polar Spur debate by cosmic-ray and magnetic field

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Based on paper: Cosmic-ray electrons and the magnetic field of the North Polar Spur

<https://arxiv.org/abs/2212.04306>, Published on Astronomy & Astrophysics, 676:L3, August 2023

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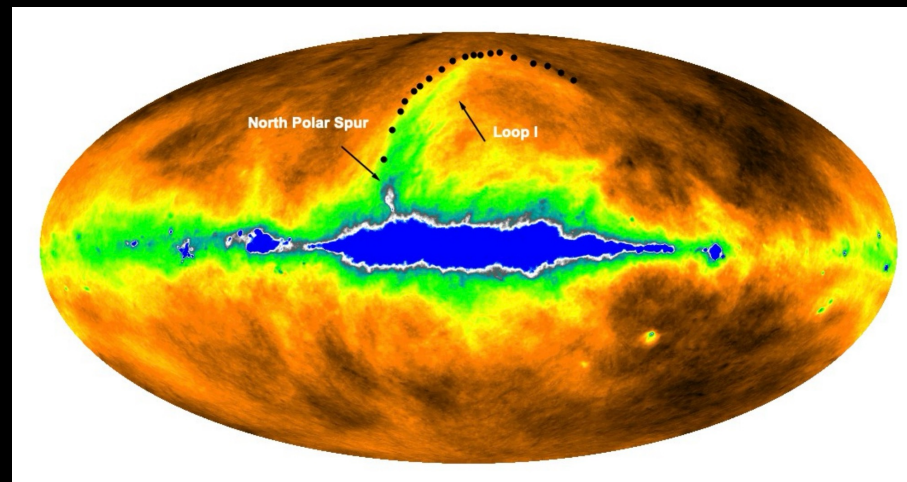


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What did we study?

- **Loop I:** giant loop structure in northern hemisphere, firstly observed in radio band during 1960s
- **North Polar Spur (NPS):** the eastern part of the interior of Loop I, brighter than the western part



Lallement 2022, Comptes Rendus
Physique 23 (2022) S2, 1-24

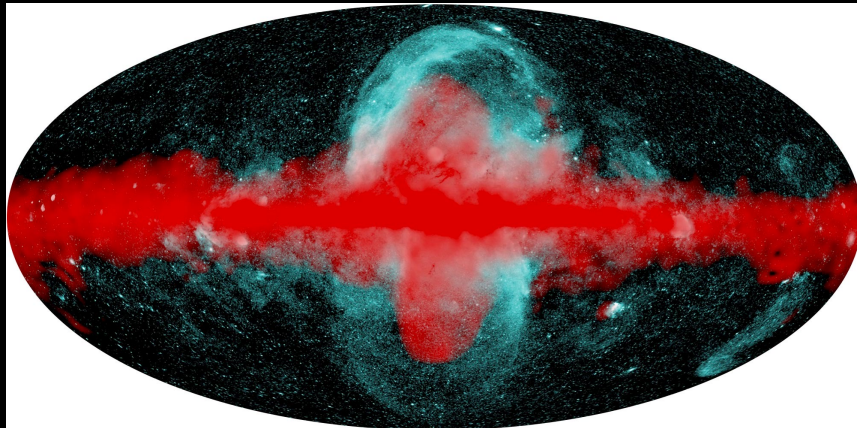
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Preprint: <https://arxiv.org/abs/2212.04306>

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What did we study?

- The most important debate on NPS: the origin of this **post-shock medium**, which has two scenarios
 - Halo Structure scenario (HS):
NPS-a gigantic volume of expanding hot gas, originated from a past outburst of GC
Loop I-marks the shock front



This scenario is consistent with multi wavelength observations
eROSITA bubbles: x-ray (cyan)
Fermi bubbles: gamma-ray (red)

P. Predehl, et al. 2020, Nature

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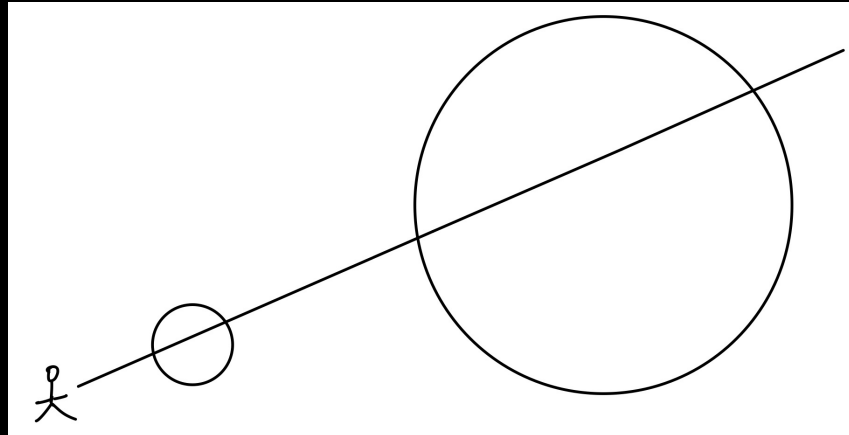
What did we study?

- The most important debate on NPS: the origin of this **post-shock medium**, which has two scenarios

- Local Structure scenario (LS):

NPS-a nearby, ordinary cavity of hot gas blown by supernovae, thus a part of supernova remnant Loop I-is its shock front

This scenario overlaps with the foreground local dust and neutral hydrogen column density map



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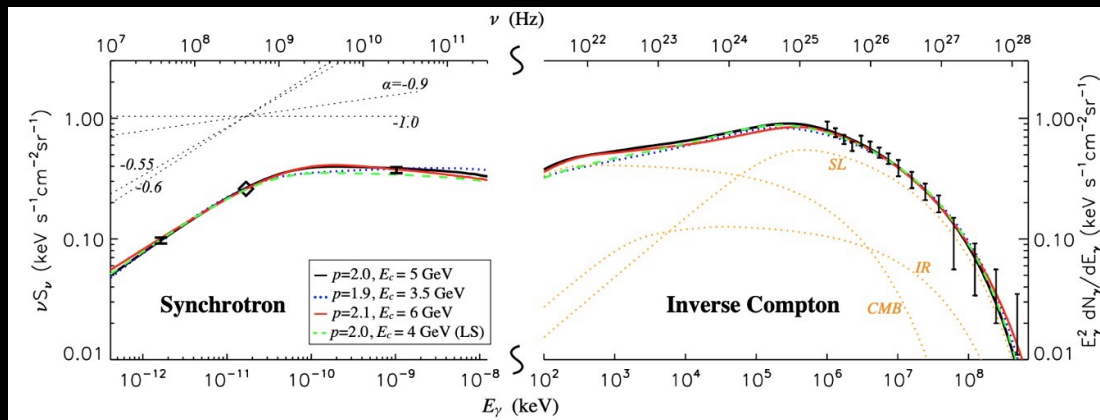
What did we study?

If Halo Structure scenario holds, then the study on NPS:

1. could help studying the past activity of galactic center, its feedback to the CGM, and the evolution of the Milky Way
2. would be the premise of the study on formation of some inner structures of NPS like Fermi Bubbles

How did we study?

- Besides X-ray thermal emission, we have two bands of non-thermal emission to study:
 - radio band: synchrotron
 - gamma band: Inverse Compton Scattering of ISRF by CReS
- We used one-zone assumption to do fitting for the two bands via the all sky survey (45MHz, 408MHz, 23GHz) and Fermi-LAT observational data
- To get the SED of CRe, and Magnetic Field Strength of NPS



$$\frac{dN_{cre}}{d\gamma_e} = \begin{cases} N_0 \gamma_e^{-p} & (\gamma_e < \gamma_{br}) \\ N_1 \gamma_e^{-p-1} \exp(-\gamma_e/\gamma_{ct}) & (\gamma_e \geq \gamma_{br}) \end{cases},$$

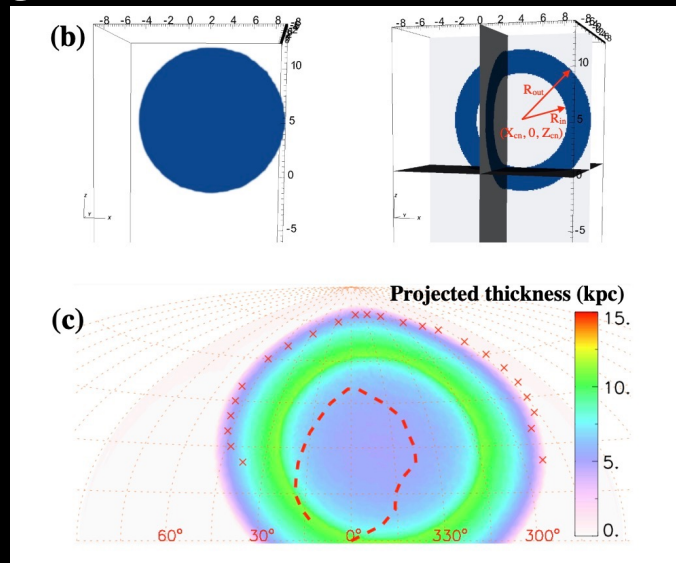
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How did we study?

- We used below geometry structure to do fitting under Halo Structure Scenario and Local Structure Scenario, to get SED of CRe, and the Magnetic Field Strength.



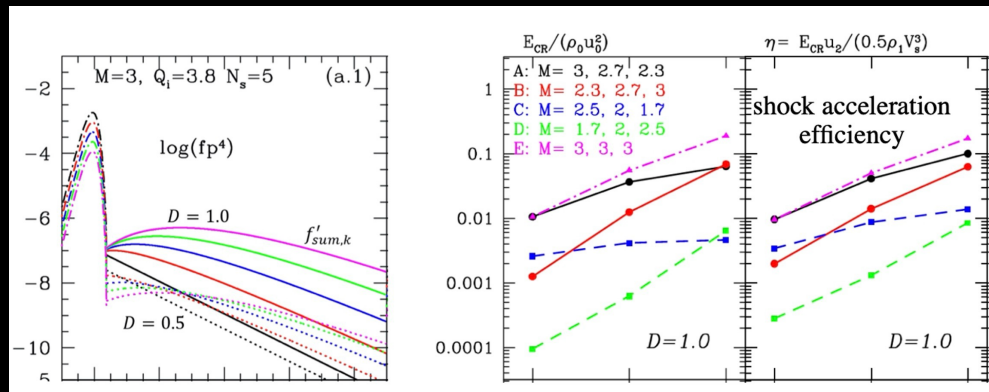
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What did we get?

- For halo structure :
 - The energy density of the CRe is $(3 - 6) \times 10^{-14} \text{ erg cm}^{-3}$, E_{ic} (cooling break energy) is 5 GeV, $p \sim 2.0 \pm 0.1$, The magnetic field strength is $3 \mu\text{G}$
 - the efficiency is 1-2%, quite high for the Mach Number ~ 1.5 (derived from X-ray result)
 - and the spectral index for such a Mach Number should be around 5



Multiple accelerations indeed could flatten SED
&
increase efficiency by orders of magnitude

Kang 2021, arXiv:2106:08521

- from the energy cutoff we could figure out the cooling time scale to be 30-40 million years, which is independently derived from gamma-ray ICS but agrees with the result of eROSITA bubble age ~ 20 million years, derived from x-ray

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What did we get?

- For Local Structure scenario:
 - the efficiency is even higher since the thermal energy is lower, which is unusual
 - Besides, total CRe energy for Local Structure exceeds $1E50$ erg, much higher than the data of Cygnus Loop Supernova Remnant ($<1E49$) and W44 SNR ($\sim 1E48$)
 - Our result gives some suggestions not in favor of Local Structure

Summary

1. We studied the non-thermal emission of NPS: Radio band emission-Synchrotron & Gamma band-Inverse Compton Scattering, from which we derived SED of CRe and Magnetic Field
2. We derived the shock wave acceleration efficiency of NPS: the unusually flat spectral index p and unusually high acceleration efficiency both indicate the multiple accelerations of CRe within NPS, thus GC may experience multiple outbursts in the past tens of Myr; and found the cooling break energy of 5GeV, suggesting CRe has experienced 30-40 Myr of cooling, which agrees with the NPS age derived from X-ray observation: 20 Myr

Thank you for listening!

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