On the origin of the North Polar Spur

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Abstract. Recently, Iwashita, Kataoka and Sofue (2023) reanalyzed the origin of the North Polar Spur (NPS) in order to determine whether it is very old local supernova remnant (SNR) or local superbubble created by a few subsequent supernova explosions from the same stellar association, or a distant object of immense extension, on the Galactic scale, associated with a giant explosion from the Galactic center. After comparative analysis Iwashita et al. concluded that NPS is a rather distant object of Galactic dimensions than an old local old SNR or superbubble. Contrary to conclusion of Iwashita et al, by using method presented in Urošević (2020, 2022), we show that the parameters obtained from radio observations are consistent with SNR (or superbubble) origin of NPS.

Introduction

The North Polar Spur (NPS) forms the north-eastern edge of the giant Galactic bubble, composing the Loop I of radio continuum emission (e.g. Haslam et al. 1982). It is also present in X-ray surveys. Although more than 50 years have passed since its discovery, the origin of NPS emission is still being debated. One idea is that NPS is a local bubble at a distance of ~ 100-200 pc (Berkhujsen et al. 1971). Synchrotron radio-emission, characteristic for SNRs, and spatial non-uniformity goes in favor of this scenario. On the other hand, absence of Hα optical emission (Sofue et al. 2023) is hard to explain for common, older SNRs. Opposite possibility is that NPS is an object related to the Galactic center, representing some remnant of active Galactic nucleus, and/or nuclear starburst (Sofue 1977). Discovery of several similar structures going from the Galactic center, such as Fermi bubbles, and those from ROSAT and eRosita surveys, support the scenario of a distant, 10 Myr old object.

Iwashita et al. (2023) extracted the radio-spectrum of the NPS for each Galactic latitude (with a step of 5°), while Galactic longitude was fixed at l=30°–35°, where the NPS radiation is the brightest. This work generated radio-spectra of NPS for the first time. The NPS emissions were found to decrease as power law with spectral index between -0.4 and -0.7 up to a few GHz, regardless of the Galactic latitude. In addition, break in spectral index were observed around ν_{brk} 1Ghz, especially at high Galactic latitudes. If the spectral turnover ν_{brk} originates from synchrotron cooling, Iwashita et al. (2023) suggested that the magnetic field *B* can be estimated by balancing the advection and cooling timescales of electrons. The magnetic fields of the NPS that they obtained are 8 μGa for the GC model and 114 μGa for the SNR model. Since the NPS radius varies by a few kiloparsecs in the literature for the GC model (see Predehl et al. 2021), when the shell thickness is doubled, *B*=5 μGa and *B*=72 μGa for the GC and SNR models, respectively. Besides this high value of magnetic field, other arguments, such as that the pressure balance would be disturbed in the SNR model, were used in Iwashita et al. (2023) to favor GC object as NPS's origin.

Method for SNR evolution status

Recently, the method for the preliminary determination of evolutionary status of SNRs was presented by Urošević (2020, 2022). This new concept is a combination of three different methods: (1) is based on the location of observationally obtained radio surface brightness and corresponding diameter of an SNR on the Σ-*D* tracks derived by the 3D hydrodynamic simulations, coupled with nonlinear diffusive shock acceleration (DSA) model; (2) is based on the forms of radio spectra; (3) is based on the magnetic field strengths estimated by the equipartition/constant partition calculation. We use this concept to hypothesize the origin of NPS.

To estimate the distance and size of NPS we used data from Das et al. (2020) who found distances (*r*) and extinction to stars towards the NPS using optical and near-infrared photometry and Gaia Data Release 2 astrometry. The results are shown in Fig. 1. From the fit we find distance *d* = 210 pc and radius of 188 pc. This agrees with *R* = 190 pc that we find for angular radius 64.8 degrees (using estimates from Berkhuijsen 1973), for the given distance.

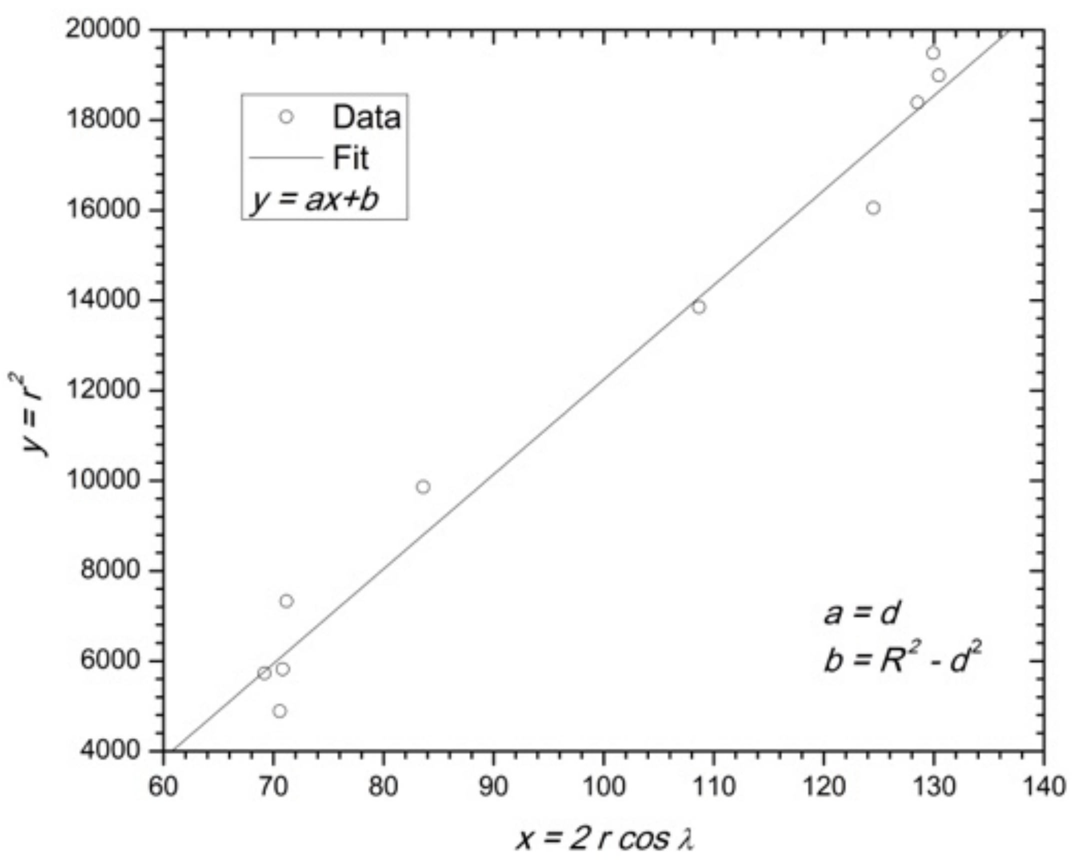

Figure 1. Distance and size estimate of NPS based on Das et al. (2020) data.

We fitted a broken power law to NPS spectrum from Iwashita et. al (2023) and found spectral index ~0.5, typical for SNRs (Fig. 2). From the fit we estimated shell surface brightness at 1 GHz and 5 GHz, 1.3E-21 and 3E-22, respectively. An average surface brightness of the whole source is lower, and is estimated to be 4.6E-22 and 1E-22.

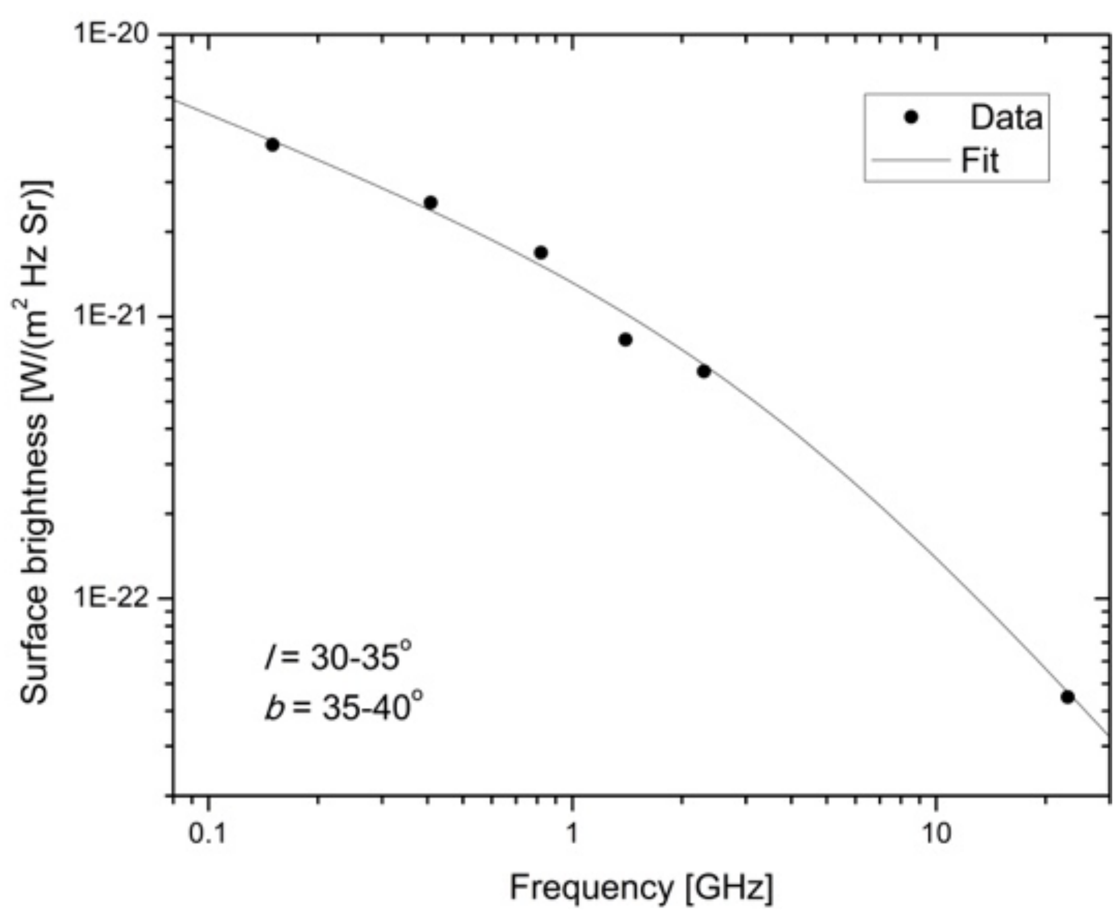

Figure 2. Spectrum of NPS (see Iwashita et al. 2023).

These values are used to estimate magnetic field from equipartition calculation (Arbutina et al. 2012, 2013, Urošević et al. 2018): 86 μGa for proton equipartition and 29 μGa for electron equipartition, consistent with compressed ISM field. In Fig. 3. we give radio Σ-*D* relation i.e. and evolutionary tracks for SNRs sample from Bozzetto et al. (2017), with NPS included.

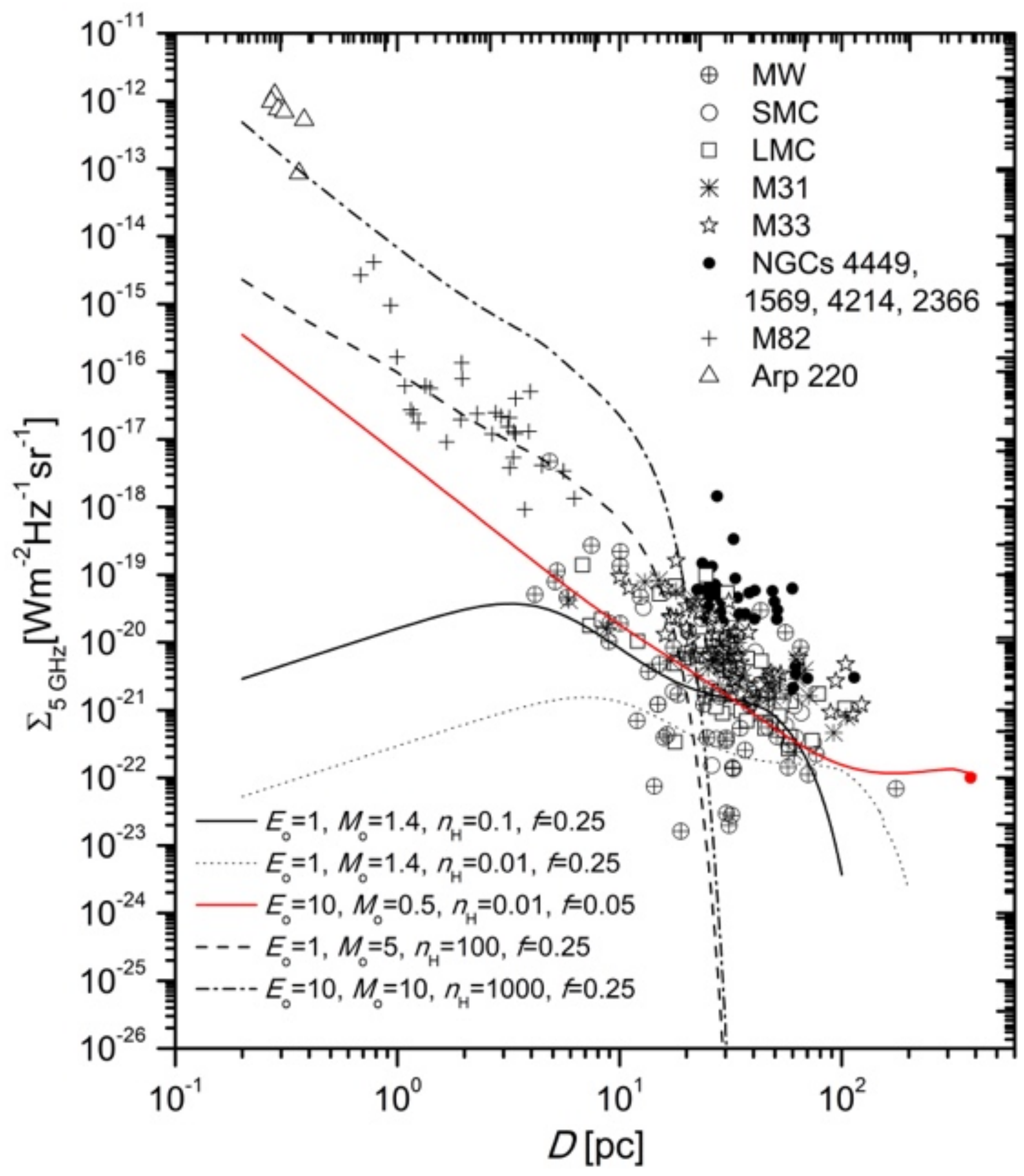

Figure 3. Radio evolutionary tracks for SNRs, with NPS included.

Duscussion

Although, our current estimate gives enormous size of NPS for an SNRs, it can be explained by an hypernova explosion with energy of 10 foe, which after CSM interaction produce a remnant expanding in a low-density bubble or NPS could be a superbubble as a result of multiple explosions. Also, position on Σ-*D* relation suggests 10 foe explosion energy, in very rarefied medium for NPS. In addition, shape of radio-spectra is in the agreement with possible SNR/superbubble scenario, as well as higher value of magnetic field strength from equipartition calculation, typical for old SNRs, where magnetic field is being compressed.

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References:

Arbutina et al.: 2012, ApJ, 746,79;
Arbutina et al.: 2013, ApJ, 777, 31;
Berkhuijsen, E. M., et al.: 1971, A&A, 14, 252;
Berkhuijsen E. M.: 1973, A&A, 24, 143;
Bozzetto et al.: 2017: ApJSS, 230, 2;
Gaia Collaboration: 2018, A&A, 616, A14;
Haslam C. G. T., et al.: 1982, A&AS, 47,
1Iwashita, R., Kataoka, J. & Sofue, Y.: 2023, AJ, 958, 83;
Das, K. et al.: 2020, MNRAS 498, 5863;
Predehl, P., et al.: 2021, A&A, 647, A1;
Sofue, Y. 1977, A&A, 60, 327;
Sofue, Y., Kataoka, J. & Iwashita, R., 2023, MNRAS, 524, 4212;
Urošević et al. 2018: ApJ 855,59;
Urošević, D., 2020, Nature Astronomy, 4, 910;
Urošević, D., 2022, PASP, 134, 061001