The Galactic Neutron Star Population Viewed from Afar
and the implications for fast radio bursts

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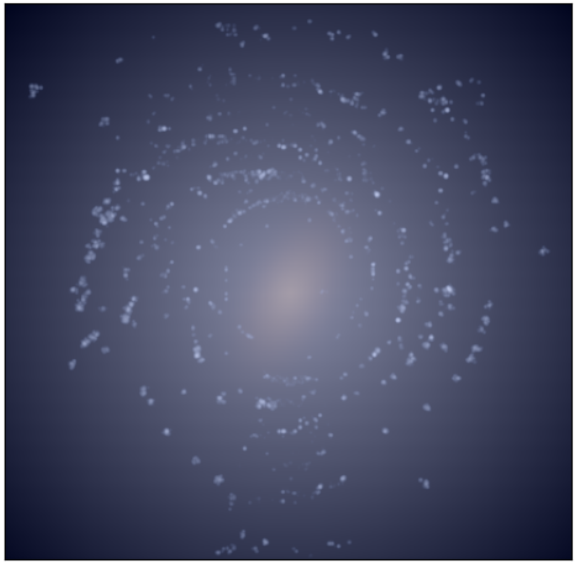


Chrimes et al. 2021

1. Introduction

Deciphering the origin of fast radio bursts (FRBs) has been a key aim in transient and radio astronomy, ever since their discovery [1]. Increasing samples of FRBs have yielded a number of well-localised events [2,3], and host galaxy population studies have consequently begun [4]. There are several ways to compare and contrast FRBs with other extragalactic transients, based on their locations and relationship with light within their hosts, including,

Offsets *Enclosed fluxes* F_{light}

Distributions of transient offsets, host-normalised offsets, enclosed fluxes and fraction of light (F_{light}) provide clues about the stellar populations at transient locations, and therefore the nature of the transients themselves. For example, high offsets indicate kicked progenitors (e.g. short GRBs), while high F_{light} values are suggestive of massive star progenitors (e.g. long GRBs).

2. The Milky Way as an FRB host

The detection of FRB-like bursts from Galactic magnetar SGR1935+2154 [5,6] has furthered interest in magnetar-based FRB progenitor models. If we assume that:

1) SGR1935+2154 is typical of all FRB sources (including the extragalactic population)...
2) ...and that all magnetars are capable of producing FRBs, either periodically or at some point in their life,

we conclude that the distribution of magnetars on their hosts should be similar to the distribution of magnetars on the Milky Way! However, many FRB models invoke neutron star systems, but not magnetars specifically (e.g. binary comb models, X-ray binaries [7]), so we can more generally ask:

How does the distribution of neutron stars (magnetars, pulsars and X-ray binaries) on the Milky Way compare to extragalactic transients – in particular FRBs?

[1] – Lorimer et al. 2007, [2] – The CHIME/FRB Collaboration 2021, [3] – Heintz et al. 2020, [4] – Mannings et al. 2020, [5] – CHIME/FRB Collab 2020, [6] – Bochenek et al. 2020, [7] – Platts et al. 2019

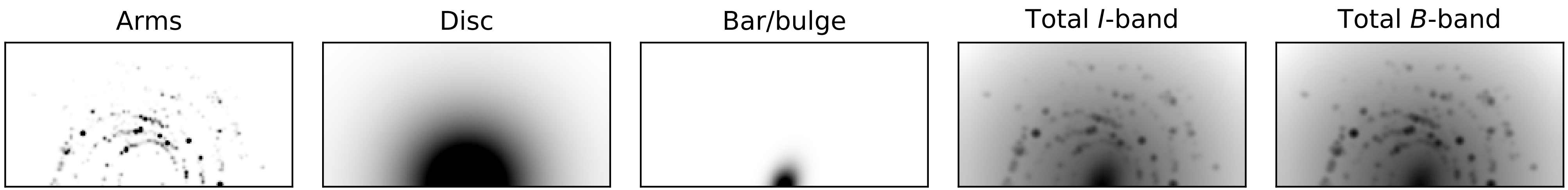
3. Aims

1. Create a synthetic image of the Milky Way, as if viewed from an extragalactic, face-on vantage point.

2. Place Galactic neutron star systems on the map, using best estimates of their heliocentric distance and direction on the sky.

3. Measure the Galactic neutron stars as if they were producing transients – make offset, enclosed flux and F_{light} distributions.

4. Compare Galactic neutron stars on the face-on disc of the Milky Way to extragalactic transients, including FRBs.



4. Milky Way image construction

We split the Galaxy into three components: the spiral arms, the disc and the bulge/bar, as shown above, and restrict all analyses to 'our half' of the Milky Way. This reduces distance uncertainties and incompleteness, and should not bias the results as the Galaxy is expected to be approximately symmetric on a global scale.

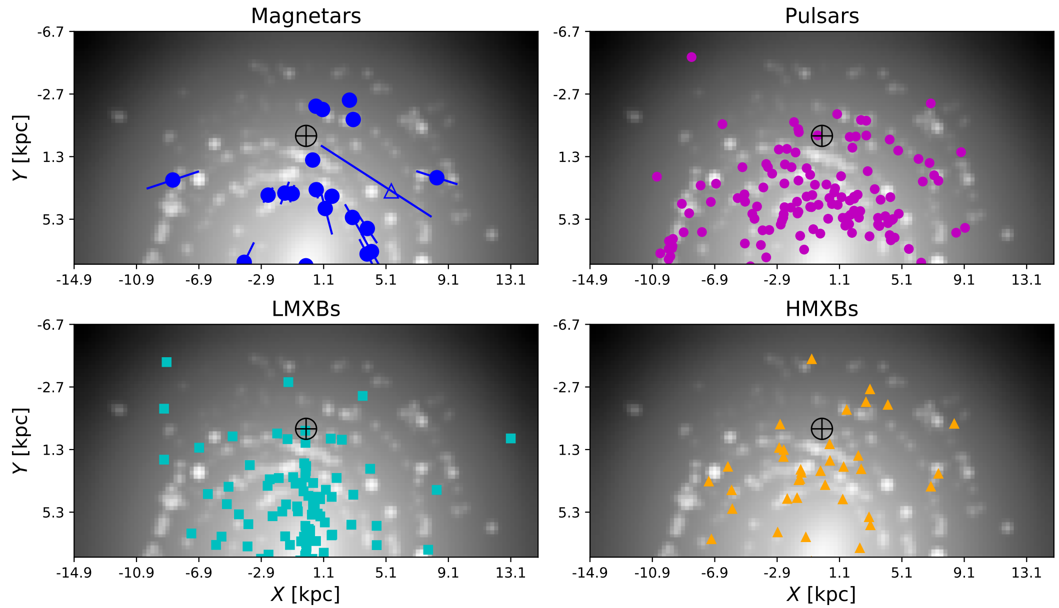
Arms: YSO/HII region masers [8] are assigned a position using the BESSEL distance calculator [9,10]. We assume that the maser bolometric luminosity is proportional to the optical arm luminosity. **Disc:** An exponential disc profile [11]. **Bar/bulge:** A Sérsic profile with n = 1.32 and r_e = 0.64kpc, convolved with a bar profile mapped using *Gaia* [12,13].

The components are weighted using colour estimates for the Milky Way (and analogues) to produced *B* and *I*-band images [14,15].

5. Galactic neutron star populations

We now place Galactic neutron star systems on the Milky Way image, as shown below. Magnetars are drawn from the McGill catalogue [16], pulsars from the ANTF database [17] (restricted to L > 65 mJy kpc^{-2} for high uniformity across the map), and XRBs from INTEGRAL surveys [18,19], which have high completeness out to the maximum heliocentric distances being considered here.

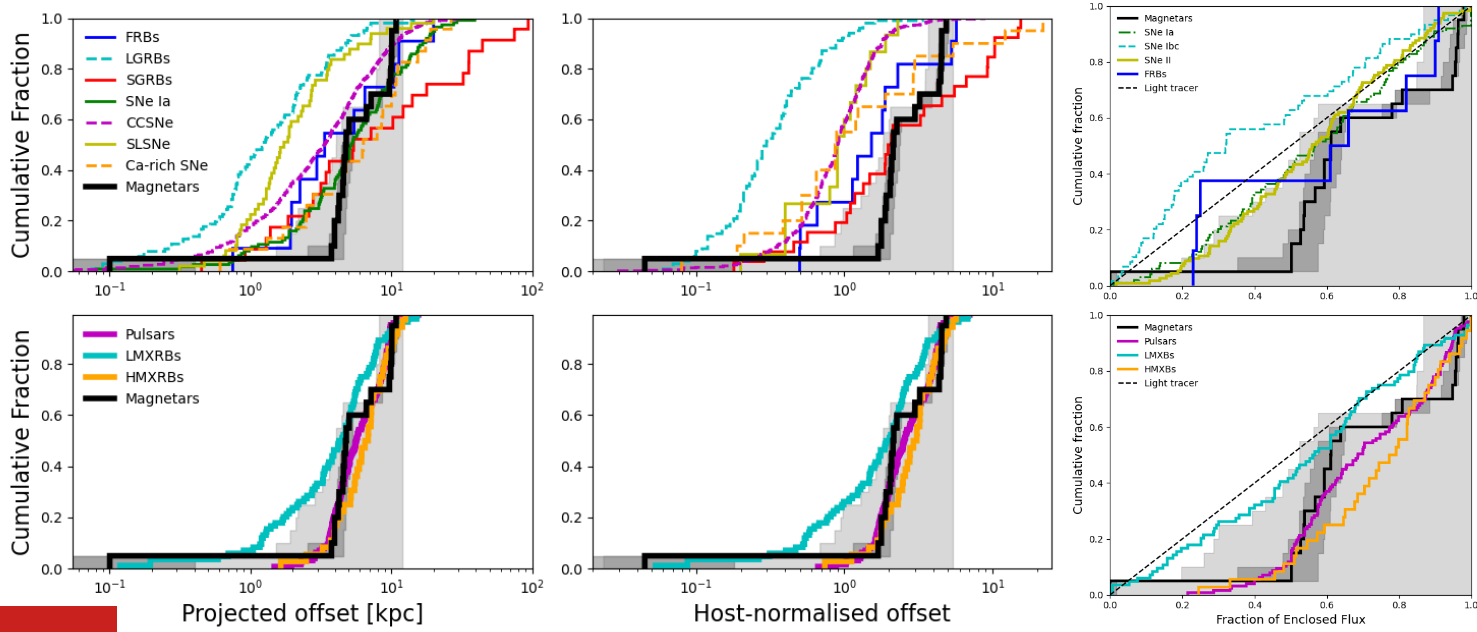
The system locations on the map are 2D projections of their 3D location. The distance estimates are from parallaxes, dispersion measures, HI column densities and other techniques, depending on the population in question.



[8]- Urquhart et al. 2014, [9,10] – Reid et al. 2016,2019, [11] – Bland-Hawthorn & Gerhard 2016, [12] – Widrow et al. 2008, [13] – Grady et al. 2020, [14] – Flynn et al. 2006, [15] – Liquia et al. 2015, [16] – Olausen & Kaspi 2014, [17] – Manchester et al. 2005, [18] – Sazonov et al. 2020, [19] – Kretschmar et al. 2019

6. Offsets & enclosed flux

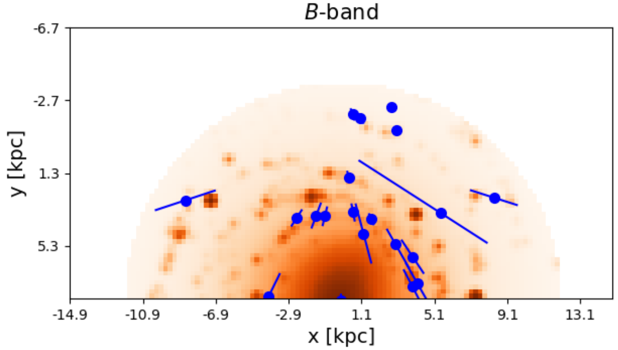
We now measure the neutron stars as if they were transients on other galaxies. *Right*: physical offset, half-light radius normalised offset, and enclosed fluxes for magnetars versus extragalactic transients (top row) and other Galactic systems (bottom). Dark grey shading represents the range of magnetar values that are possible within the estimated heliocentric distance range, light grey is the range possible along the line of sight. A maximum galactocentric offset of 12kpc is assumed.

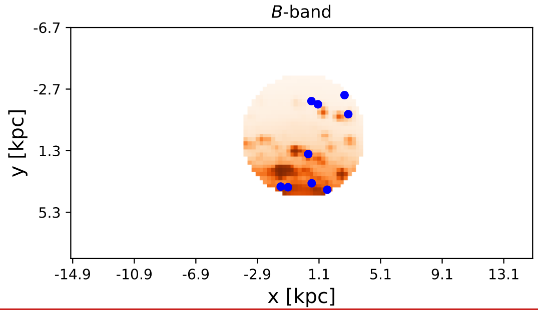


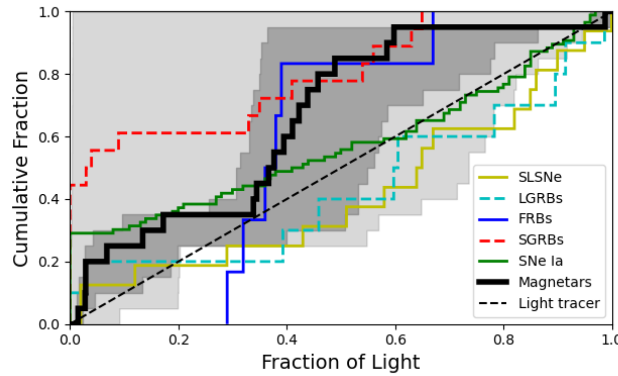
7. Fraction of light

The fraction of light [20] (F_{light}) statistic is another useful tool. To generate an F_{light} value for each pixel, we first decide on which pixels will be 'associated' with the Galaxy (< 12kpc in this case). The associated pixels are ranked by value in a cumulative sum, and normalised by the total cumulative flux such that the brightest pixel takes the value 1. Unassociated pixels are assigned 0.

A cumulative distribution of F_{light} for pixels underlying transients which are uniformly sampled from the light is a 1:1 line. *Right*: the *I*-band F_{light} colour map (top, with magnetars overlaid) and the resultant distribution, compared against extragalactic transients (bottom). The mostly likely Galactic magnetar distribution lies between SNe Ia and short GRBs – in good agreement with FRBs.







8. Summary of comparisons

We perform AD-tests between each Galactic sample - magnetars, pulsars, young pulsars (<10^5yr), LMXBs, HMXBs – and the extragalactic transients, for the following in both bands where possible:

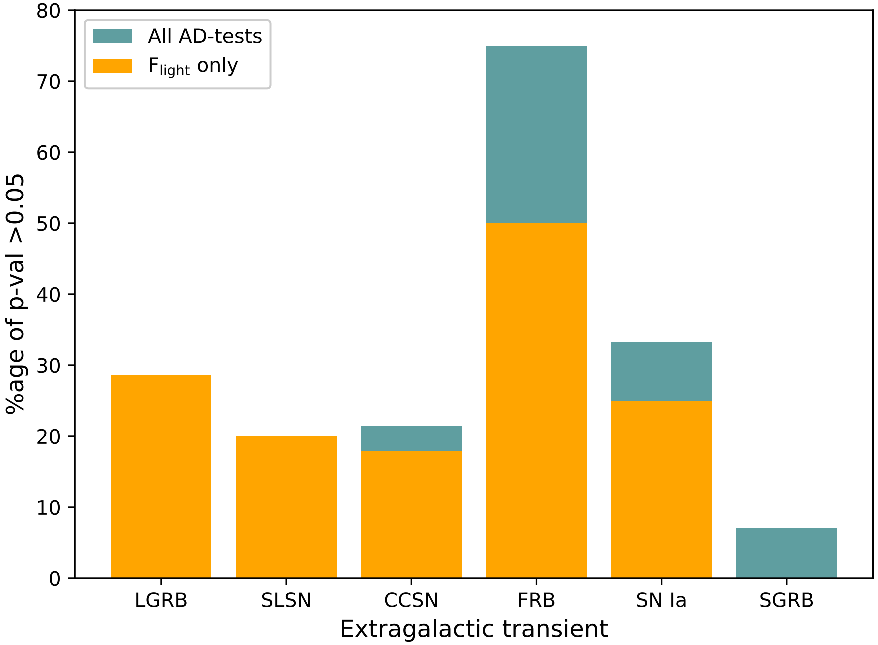
- Offsets
- Host-normalised offsets
- Enclosed fraction of flux
- F_{light} (half-Galaxy)
- F_{light} (local, <4kpc, disc, as shown above)

[20] – Fruchter et al. (2006) & see Chrimes et al. 2021 for a list of transient comparison sample sources

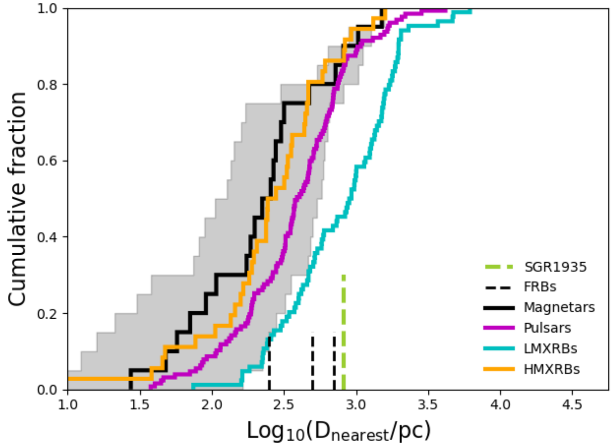
9. Summary of results

The AD-test results for each transients are counted and the percentage of these tests which return p > 0.05 (> 2σ) across every comparison and Galactic neutron star type is plotted below. We add all the neutron star samples together to increase the number of comparisons per transient, individually the number of comparisons is too low to distinguish between them (for example, between magnetars and HMXBs).

These results demonstrate that – of all the extragalactic transients – Galactic neutron stars are the best match for their distribution on their host galaxy. This is further evidence, from an independent method, that FRBs originate from (young) neutron stars.

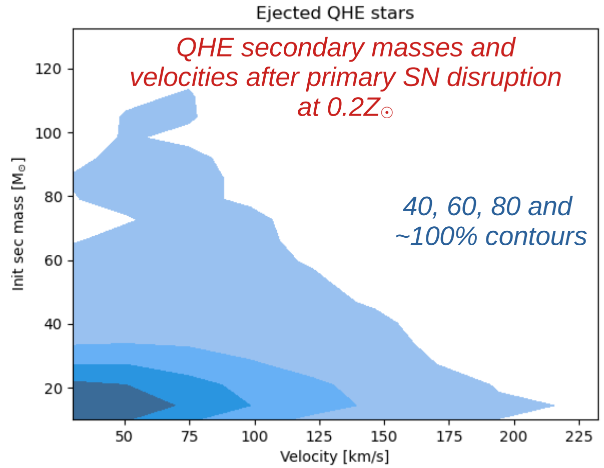


10. Further work – magnetar pop synth



Using the maser map constructed on slide 2, we can also measure the distance of each neutron star system to the nearest maser (approximating the distance to the nearest spiral arm). Those offsets are shown to the left. Also indicated are the offsets of FRBs 20121102 [21], 20190608 [22] and 20180916B [23] from the centres of nearby star-forming regions. Within the heliocentric distance uncertainties, even magnetars (ages 10^3-10^5 yr) are consistent with FRBs.

Another observation is that all Galactic magnetars are (apparently) single. If a significant fraction of all neutron stars are born as magnetars, and most massive stars are in binaries [24], this is surprising.



We are now working on magnetar pop synth with BPASS [25,26]. Plausible channels include spun-up secondaries (which may be ejected upon supernova of their companion, perhaps explaining both the singularity and offsets of magnetars) and the induced collapse of white dwarfs – a long delay time pathway that might be needed to explain FRBs in older stellar populations [27,28].

11. In a nutshell

In this work, we have shown that the Galactic neutron star population is distributed on the Milky Way is a similar way to FRBs on their host galaxies. This implies similar underlying stellar populations and/or kicks, lending further support, from an independent method, to the FRB - neutron star association.

[21] -Bassa et al. 2017 , [22] -Chittidi et al. 2020, [23] -Tendulkar et al. 2021, [24] -Moe & Di Stefano 2017, [25] -Eldridge et al. 2017, [26] -Stanway et al. 2018, [27] -Kirsten et al. 2021, [28] -Fong et al. 2021