Stars and their variability observed from space
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FROM ANCESTORS TO OFFSPRING: TRACING THE CONNECTION BETWEEN MAGNETIC FLUXES OF OB AND NEUTRON STARS

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Abstract.
The origin and evolution of magnetic fields (MFs) of young neutron stars (NSs) is an open question. MFs could be generated through a dynamo during the formation of NSs, or they could be a relic of a pre-supernova magnetic field. We want to test whether MFs of young NSs are the relics of their progenitors, massive OB stars. This could happen through magnetic flux conservation; the MF of massive stars is core confined, so the collapsed core might keep exactly the same magnetic flux as the whole star. Only 5–7% of massive OB stars have well-measured magnetic fields (reaching tens of kG). They can be divided into two groups: highly magnetic stars (B $>$ 20 G) and weakly magnetic stars (B $<$ 20 G). NSs are also divided into normal pulsars (B $\sim 10^{12}$ G) and magnetars (B $> 4 \cdot 10^{13}$ G). We therefore assume that normal pulsars are descendants of weakly magnetic stars, while magnetars originate from highly-magnetic OB stars. To test this hypothesis, our population synthesis code takes into account some severe selection effects in the NS sample, and enables us to compare observed fractions of pulsars and magnetars with the observed fractions of weakly magnetic and highly magnetic OB stars. We also investigated independently the distribution of MFs of massive stars using the maximum likelihood technique.

Keywords: Stars: massive, magnetars, magnetic field, neutron, Methods: statistical

1 Maximum likelihood estimate

We have continued the work of Kholtygin & Makarenko (2019) of testing whether the NS magnetic fields are relics of their progenitor magnetic fields or whether they are generated through a dynamo mechanism during the supernova explosion. To do that, we selected only newer measurements of stellar magnetic fields (MFs), starting from 2006, and mainly from Shultz et al. 2018; Sikora et al. 2019; Chojnowski et al. 2019; Aurière et al. 2007; Freyhammer et al. 2008 as they had relative errors less than 0.5. The corresponding distributions are shown on the left panel of Fig. 1.

We used the maximum likelihood technique to estimate the parameters of the distribution of MFs because it treats properly the observational uncertainties in centring errors in the actual (unknown) values. For the initial distribution of MFs we chose the log-normal distribution having a mean μ_B and standard deviation σ_B. The result of the calculations is presented in Table 1. The log-normal distribution describes very well the values of the measured magnetic fields for B stars; no significant deviations in the cumulative distributions can be seen (right panel of Fig. 1).

We then performed a preliminary optimisation of the pulsar population synthesis model developed by Igoshev & Kholtygin (2011), using parameters mostly similar to those in Faucher-Giguère & Kaspi (2006), and found the initial log-normal distribution for magnetic fields had $\log_{10} B/\mathrm{G} = 13.1$ and $\sigma = 0.7$. In order to trace the magnetic field back to the surface magnetic field of a massive star, we assumed a pure relic origin and occupying a fraction of the core that was 0.2 that of the star.

$$B_{p,\mathrm{B2V}} = B_{\mathrm{NS}} \left(\frac{R_{\mathrm{NS}}}{R_{\mathrm{B2V}}} \right)^2 \frac{R_{\mathrm{core}}}{R_{\mathrm{B2V}}} \approx 18 \text{ G}, \tag{1.1}$$

where B_{NS} is the NS surface dipolar magnetic field, R_{NS} is NS radius, R_{B2V} is a typical radius of a B2 main-sequence star, and R_{core} is the core radius of the massive star. The magnetic field value is given by eq. (1.1) and is similar to ones measured for the weakly magnetic massive stars.

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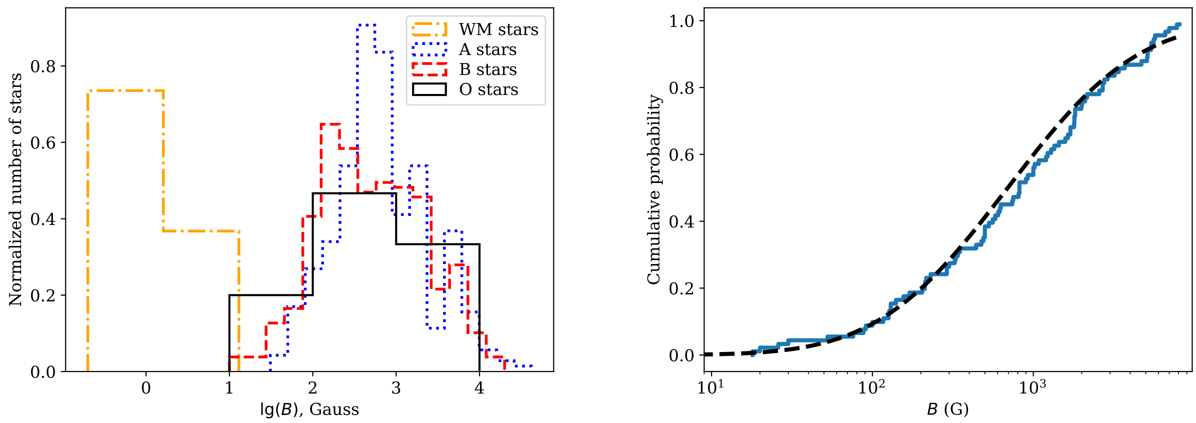

Fig. 1. Left: Histogram of magnetic field strengths for O, B, A and weakly magnetic (WM) stars in our sample. **Right**: Cumulative probability for measured magnetic fields for B stars (blue solid line), and for the best model (dashed black line).

Spectral type	N	μ_B $\log_{10}$ [G]	σ_B
O	11	2.62 ± 0.16	0.25 ± 0.24
B	92	2.84 ± 0.1	0.64 ± 0.08
A	97	3.05 ± 0.11	0.65 ± 0.07
Weakly magnetic	9	0.15 ± 0.47	$0.65^{+0.57}_{-0.26}$

Table 1. Result of the maximum likelihood analysis. N is the number of stars of a particular spectral type.

2 Conclusions

- We performed statistical tests to check which stars are progenitors of different types of neutron stars, using recent observations and considering only stars with confirmed magnetic fields.
- All massive OB stars could be divided into two large groups: weakly magnetic and strongly magnetic.
- The existing code for the pulsar and massive star population synthesis (NINA) has been improved and expanded to include the evolution of magnetars.
- We concluded that it is plausible that normal pulsars are descendants of weakly magnetic OB stars. The precursors of magnetars are magnetic OB stars.

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