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The isolated neutron star in the Carina Nebula revisited

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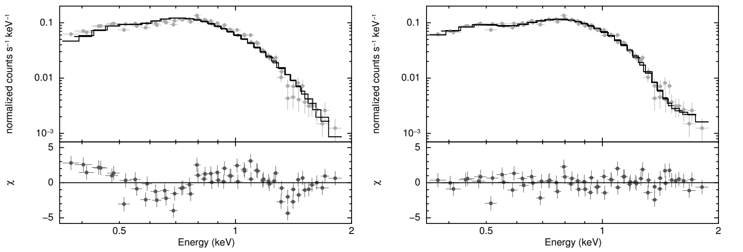
Background and motivation

2XMM J104608.7-594306 (hereafter J1046) is one of only two isolated neutron stars (INSs) to be discovered through their thermal emission since the ROSAT era (the other source being Calvera). Possibly a remnant of a former generation of massive stars in the Carina Nebula, its exact nature is unclear, and it might be unique amongst the several groups of INSs. In a first dedicated XMM-Newton observation of the source, we found intriguing evidence of a very fast spin period of $P \sim 18.6$ ms. Moreover, spectral features in absorption have also been identified. We reobserved 2XMM J104608.7-594306 with XMM-Newton to better characterise the spectral energy distribution of the source, confirm the candidate spin period, and possibly constrain the pulsar spin down.

Spectral energy distribution

Good fits and meaningful physical parameters are only obtained when residuals at 0.55 keV and 1.35 keV are taken into account, (e.g., see below) by adding two Gaussian lines in absorption. In this case, the best-fit neutron star atmosphere models constrain $N_H = (2.5–3) \times 10^{21}\,\mathrm{cm^{-2}}$, $T_{\mathrm{eff}} = (6–10) \times 10^5$ K, and $L_X = (1.1–7) \times 10^{32}\,\mathrm{erg\,s^{-1}}$.



Results of spectral fitting: a simple absorbed blackbody (*left*) and the best-fit neutron star atmosphere with two lines in absorption (*right*).

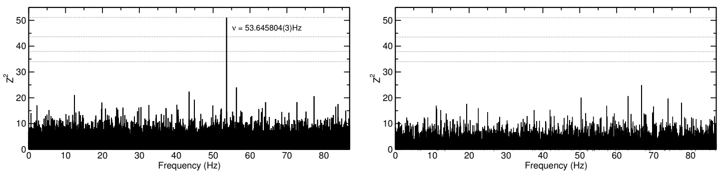
The implied distance is consistent with a location in the Carina Cluster, and radiation radii are compatible with emission originating from most of the surface. Unlike normal (rotation-powered) pulsars, there is no evidence of non-thermal magnetospheric emission (ruled out above 0.5% of the source luminosity).

Origin of the spectral features

While the first feature can be related to a local overabundance of oxygen in the Carina Nebula, or result from the inhomogeneous temperature distribution on the surface, the one at energy 1.35 keV can only be accounted for by invoking a line in absorption. Assuming electron cyclotron absorption (and canonical neutron star mass and radius), we estimate $B_{\mathrm{cyc}} \sim 1.5 \times 10^{11}$ G on the surface.

Timing analysis

The timing analysis of the new XMM-Newton observation provides only an upper limit on the pulsed fraction of the source, $p_f < 14\%$ (4σ), which is very close to the limiting sensitivity to detect the modulation found previously. Nonetheless, the coherent combination of the two EPIC-pn datasets in a two-dimensional periodicity search provides a solution for the pulsar spin and spin-down rate, with a probability of 99.99%. The implied dipolar field is $B_{\mathrm{dip}} = (3–8) \times 10^{11}$ G.



Results of the timing analysis in the first (*left*) and second (*right*) XMM-Newton observations of the neutron star.

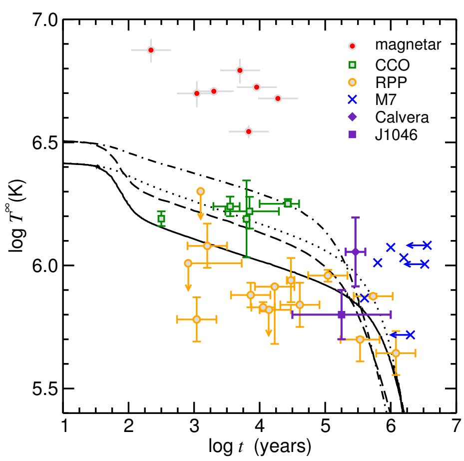
We are currently assessing the statistical significance of the $\dot{P}$ solution.

Association with a runaway star in Carina

J1046 was proposed to have been associated in a binary system with the runaway star MJ 218 (Ngoumou et al. 2013, ApJ, 769, 139). At 2.3 kpc, the known proper motion of the star implies a kinematic age of $t_{\mathrm{kin}} \sim (1.1–3) \times 10^4$ yr (assuming typical masses) – consistent with the absence of a supernova remnant.

Thermal state of the neutron star

We adopt the flight time as a lower limit on the INS age (a conservative value of 1 Myr is taken as an upper limit, based on an association with the Carina Nebula).



Cooling-age diagram for INSs (see legend).

The strong thermal emission in magnetars and the "Magnificent Seven" cannot be explained without taking into account the additional heating of the INS crust by *B*-field decay. CCOs ("anti-magnetars") are young neutron stars showing the slow cooling typical of sources with light-element envelopes. Calvera, a thermal INS with a low B_{dip}, might be evolving from a CCO. The cooling status of J1046 appears consistent with standard theory.

Summary and conclusions. The exact nature of the source remains open for different interpretations. If the short spin and low magnetic field are confirmed, J1046 (similarly to Calvera) may be a candidate for the elusive class of evolved anti-magnetars. Alternatively, if the true period were of the order of seconds and its pulsed fraction remains as yet below the sensitivity of available data, a link with the Magnificent Seven may be put forward.