On the debated nature of Rotating RAdio Transients

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Abstract. Rotating RAdio Transients (RRATs) are a newly discovered astronomical phenomenon, characterised by occasional radio bursts occurring at average intervals ranging from minutes to hours. Analysis of the burst arrival times allowed the identification of periodicities, which fall in the range 0.4 to 7 seconds. For three of them also a secular variation in the periodicity has been measured. In view of these rotational parameters the RRATs seem to be rotating neutron stars, albeit with properties very different from the rest of the population. The characteristics of these sources in the radio band and the X-ray properties of the first detected counterpart to a RRAT are compared with the multiwavelength properties of other classes of neutron stars trying to explain the nature of RRATs and their connections with known types of objects.

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THE DISCOVERY OF RRATS

A recent reanalysis of the data of the Parkes Multibeam Pulsar Survey (e.g. [1]) including a code for the detection of single pulses [2], resulted in the discovery of 11 objects, named Rotating RAdio Transeints (RRATs; [3]), characterised by the emission of single dedispersed bursts. The bursts have a duration between 2 and 30 ms and the average time interval between two consecutive events range from 4 minutes to 3 hours. An example of a discovery plot of a RRAT and of a single dedispersed pulse from the same source are shown in Figure 1. Even though standard periodicity searches failed in detecting these sources, the study of the arrival times of the single bursts allowed to determine for 10 of them a periodicity. The 0.4 - 7 s range interval of the periods of these sources and the measurement, from three of them, of a steady spin down, indicate that these sources are very likely rotating neutron stars.

The properties of the RRATs bursts are very different from those of the normal giant pulses of young pulsars (see e.g. [4] for a review); RRATs seems hence to be a completely new class of object in the zoo of neutron stars (NSs). The discovery of the first X-ray counterpart to a RRAT ([5]; §2) shades new light on these sources and is of key importance in order to compare their characteristics with the multiwavelenght properties of other classes of NSs in the aim of establishing a possible link between RRATs and other kind of NSs (§3).

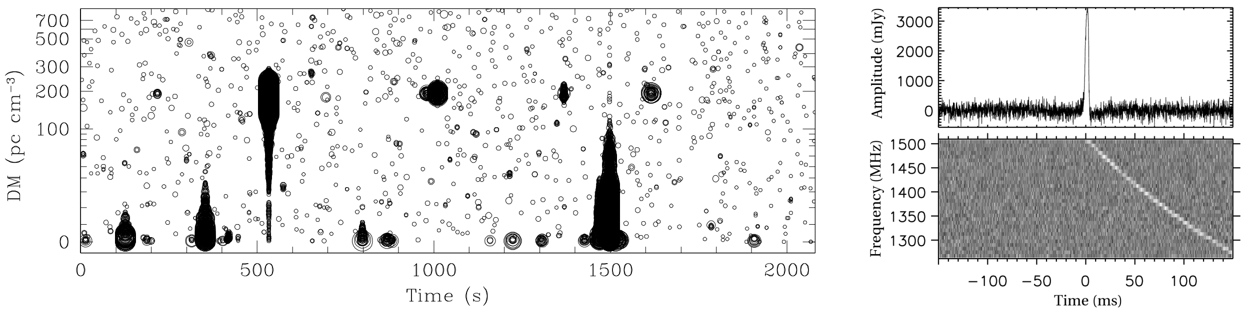

FIGURE 1. Left: discovery plot of RRAT J1819–1458 in the Parkes Survey data showing time series dedispesed at different trial values of the disperion measure (DM). Five strong bursts, occurring at the same DM ~ 200, are clearly visible; bursts at DM ~ 0 are due to terrestrial RFI. Right: an example of a single dedispersed burst from the same RRAT. Top panel shows the pulse profile integrated over the entire 288 MHz band; in the bottom panel the dispersion of the signal across the observing band is visible. From [3].

THE X-RAY COUNTERPART OF RRAT J1819–1458

Analysis of a 30-ks Chandra observation pointed to the SNR G15.9+0.2 [6], revealed an X-ray point source, named CXOU J181934.1-145804, whose error circle is compatible with the position of RRAT J1819–1458 (Fig. 2). This RRAT has a 4.26 s period, a relatively high inferred characteristic surface dipole magnetic field strength of 5×10^{13} G, a characteristic age $P/2\dot{P} = 117$ kyr, and a spin-down luminosity of 3×10^{32} ergs s^{-1}. Its distance, inferred from its DM using the electron-density model of Cordes & Lazio [7], is 3.6 kpc, with considerable uncertainty. RRAT J1819–1458 is characterized by radio bursts of an average duration of 3 ms, with one burst detected every 3 minutes.

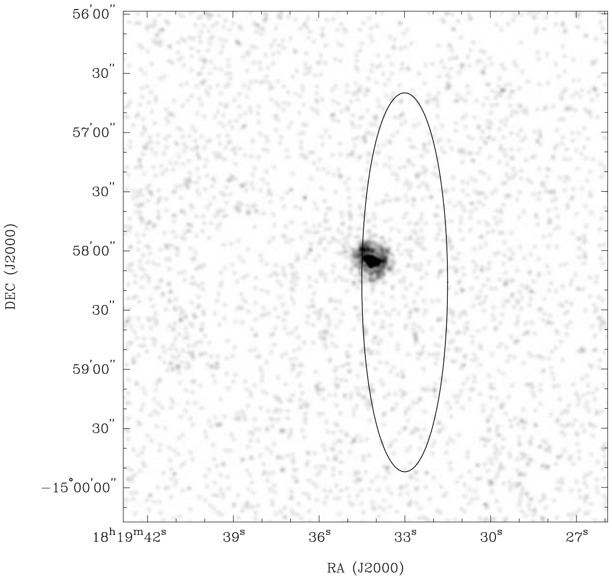

FIGURE 2. A Chandra ACIS image of RRAT J1819–1458. The ellipse shows the 3-σ error for the position of the RRAT, as derived in [3] from radio timing. From [5]

Fitting the X-ray data with a simple power-law or with a blackbody model (the low count-rate not allowing a more detailed modelling), we found that the the spectrum is a poor fit to the former but a good fit to the latter [5]. At a distance of 3.6 kpc the inferred blackbody radius (as viewed at infinity) is $20d_{3.6}$ km (where $d_{3.6}$ is 1 for distance d=3.6 kpc), consistent with standard neutron star equations of state, given the uncertainty in the distance estimate. The absorbing column for this fit is $N_H = 7^{+7}_{-4} \times 10^{21}$ cm^{-2} and the surface temperature (at infinity) is $kT_\infty = 120 \pm 40$ eV. In the energy range 0.5 - 8 KeV the unabsorbed flux is 2×10^{-12} erg cm^{-2} s^{-1} and the isotropic luminosity is $3.6d_{3.6} \times 10^{33}$ erg s^{-1}.

No optical nor infrared counterparts were detected in various catalogues within 1' of our best-fit position. The expected surface density of Galactic plane X-ray sources of at least the flux of CXOU J181934.1–145804 is about 2 deg^{-2}, based on the ASCA Galactic Plane survey [8]. Within the radio error ellipse of RRAT J1819–1458, the likelihood of finding such a source by chance is 10^{-4}, supporting its identification with RRAT J1819-1458.

In summary, the spatial coincidence of RRAT J1819–1458 and CXOU J181934.1–145804 and the lack of any obvious optical or infrared counterpart make it extremely likely that these sources are associated and that the emitting source is a neutron star.

Examination of single CCD frames do not show evidence of any individual burst that might be the counterpart to the RRAT phenomenon. The data also show no evidence of variability on any time-scale ranging from 3.2 s to 5 days. Note however that the time resolution is only slightly shorter than the RRAT spin period.

WHAT'S A RRAT THEN?

The peculiar characteristics of RRATs emission in the radio band suggests that these sources may be a completely new group of neutron stars, or a new manifestation of one of the previously known classes of object. Since all known classes of young neutron star are X-ray emitters, the detection of RRAT J1819–1458 in the X-rays provides new information which allows us to begin to discriminate between various interpretations for the RRATs.

In the following we briefly revise the main characteristics of other classes of isolated neutron stars comparing them to those of RRATs trying to point out possible common features:

Magnetars: although some of the RRATs occupy the same portion of the $P - \dot{P}$ diagram (Fig. 3) as the magnetars, the latter are much more hot and luminous than RRATs and present an hard X-ray tail not detected so far in RRATs. Furthermore magnetars and RRATs birthrate are estimated to be very different [9]. The only possible link between these two classes of objects is represented by the transient magnetar XTE J1810–197 which, while in quiescence, had a surface temperature $kT_\infty \sim 150 - 180$ eV [10, 11], comparable with that of RRAT J1819–1458, and recently showed variable pulsating radio emission [12].

Central Compact Objects: as the name states, these sources are isolated neutron stars located at the center of supernova remnants. This class of objects do not share any clear property with RRATs, the latter not being associated to SNRs and being much more colder than CCOs.

X-ray Dim Isolated NSs: it has been proposed by Popov et al. [9] that RRATs might be far away XDINSs: the birth rates of these two populations is very similar and the period, period derivative and age ranges are comparable. On the other hand RRAT J1819–1458 is overluminous with respect to XDINSs.

Middle-aged radio pulsars: radio pulsars with ages around 100 kyr show X-ray spectra very similar to that of RRAT J1819–1458. For instance PSR J0538+2817 is 30 kyr old and has $kT_\infty = 160$ eV, while PSR B0656+14 is 110 kyr old and has $kT_\infty = 70$ eV. Moreover, recently, Weltevrede at al. [13] discovered RRAT-like bursts in PSR B0656+14: if this pulsar were placed at the distance of RRAT J1819–1458, its occasional bright radio bursts would still be seen, but not the underlying regular train of pulsations. The only difficulty with this model is the fact that RRATs periods seems to cluster at quite high values, which is not the case for middle-aged radio pulsars.

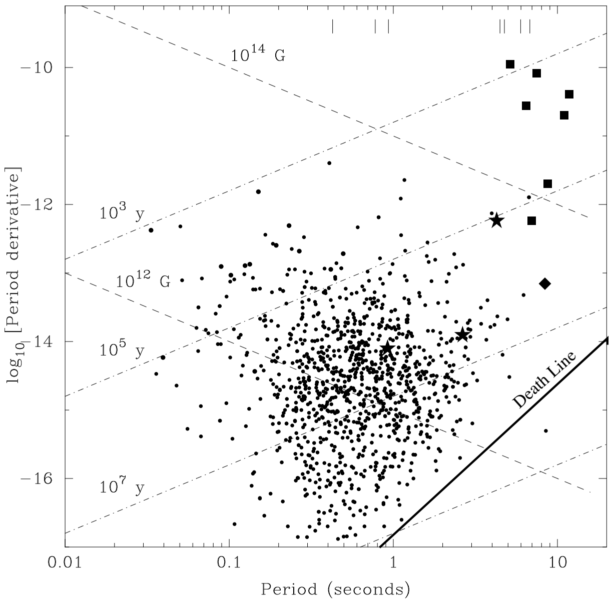

FIGURE 3. The rotational period derivative is plotted against period for pulsars (dots), magnetars (squares), the one radio-quiet isolated neutron star with a measured period and period derivative (diamond), and the three RRATs having measured periods and period derivatives (stars). The vertical lines at the top of the plot mark the periods of the other seven RRATs. Dashed lines indicate the loci of constant values of characteristic age and inferred surface dipole magnetic field strength. The solid line is the so-called death-line, below which the pulsar emission switches off. From [3]

If RRATs are indeed normal radio pulsars, as the above analysis may suggest, it is necessary to explain their unusual bursting behaviour. We here briefly review the principal models proposed so far to explain the lack of persistent radio emission from RRATs.

Zhang et al. [14] propose that RRATs are dead pulsars for which a temporary "star spot" with multipole field components emerges above the surface reactivating the radio emission mechanism and producing the observed bursts. The difficulty with this model is that none of the RRATs with known values of $\dot{P}$ appear to be near the "death line" in the $P-\dot{P}$ diagram, beyond which the pulsar mechanism is expected to switch off.

The same authors [14] also present a model according to which RRATs burst are the signature of brief reversal of the direction of the radio beam. They draw upon the previous work of [15], who showed that whenever PSR B1822–09 produces "nulls" in its main pulse, it produces a much weaker interpulse, which has been interpreted by [16] to correspond to radiation temporarily emitted in the opposite direction. RRATs, in this context, would present the same type of reversal mode but with an emitting geometry in which the main pulse is never seen. The difficulty with this interpretation is that in nullers the reversal lasts for several pulses in succession, while up to now RRATs never showed more that one pulse at a time.

Finally, two other interpretations invoke the presence of material surrounding the neutron star: Cordes & Shannon [17] propose that RRAT emission is produced by the presence of a debris disk or an asteroid belt, whose material would sporadicaly activate a quiescent region of the NS magnetosphese inducing a RRAT burst, while Li [18] suggests that the bursts are produced when a drop of the accretion rate from a fallback disk occurs allowing the radio emission, normally quenched by the accreting material, to temporarily switch on.

CONCLUSIONS

The nature of Rotating RAdio Transients is still a subject of ample debate. Several models have been proposed but none has so far been able to completely account for all the radio and X-ray properties of these sources. Multiwavelength observations of other RRATs and searches for RRAT-like emission from other classes of neutron stars will be invaluable instruments to clarify the nature of these new objects.

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