A Model for RRATs and PSR B1931+21

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Background

A small group of rotating radio transients (RRATs) were recently reported by McLaughlin et al. (2006, Nat, 439, 817). These objects are characterized by single, dispersed bursts of radio emission with durations between 2 and 30 ms. The average time intervals between bursts range from 4 minutes to 3 hr, with radio emission typically detectable for !1 s per day. Periodicities in the range 0.4–7 s for 10 of the 11 sources have been measured, suggesting that they are rotating neutron stars. Three of the sources have measured period derivatives, with one (RRAT J1819-1458) having a very high inferred magnetic field of 5×10^{13} G, if spin-down by magnetic dipole radiation is assumed.

A similar bursting radio source GCRT J1745-3009 was detected previously (Hyman et al. 2005, Nat, 434, 50), whose notable properties include “flares” approximately 1 Jy in magnitude lasting approximately 10 minutes each and occurring at apparently regular 77 minute intervals.

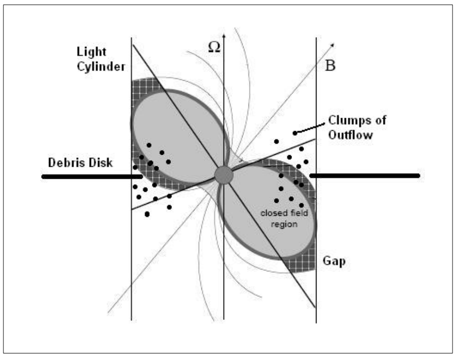
More recently, Kramer et al. (2006, Sci, 312, 549) reported the quasi-periodical pattern in the radio pulsar PSR B1931+24: the radio emission switches off in less than 10 s after the active phases of 5–10 days and remains undetectable for the next 25–35 days, when it switches on again. More remarkably, the pulsar rotation slows down 50% faster when it is on than when it is off, indicating an increase in magnetospheric currents when the pulsar switches on.

No available model can provide a unified interpretation for the above phenomena.

A debris disk model

We propose that these objects are isolated neutron stars surrounded by a debris disk that originates either from the supernovae that produced the neutron stars or from the captured interstellar medium. The neutron stars act as a propeller when the disk penetrates inside the light cylinder, and the outflow or wind from the disk may quench the pair production processes in the pulsar magnetosphere, with only transient radio emission allowed.

Magnetocentrifugally driven outflows from the disks during the propeller phase have been discussed extensively in the literature. One can show that the 10^{12} V potential difference across the magnetospheric gap and the outward-directed electric field required by the Ruderman-Sutherland model for the generation of radio waves will be negated if the number density of matter at the Alfven surface is greater than the Goldreich-Julian density, a condition satisfied by most neutron stars with a debris disk for which there is significant wind or outflow from the disk.



The flow in the inner part of the accretion disk is expected to have density fluctuations (“clumps”) produced by a variety of mechanisms, such as thermal instability, the Kelvin-Helmholtz instability, and magnetoturbulence. The clumpy wind density would be much higher than the averaged value estimated above. They may also leave short, sporadic, “transparent” time for the development of particle acceleration in the gap and generation of pulsar emission. If we assume that the typical clump separation is less than the disk height H at the inner edge R of the disk, the duration of successful pulsar emission should be less than t~H/R, or roughly $11P$ ms < t <$1.7P^{3/2}$ s.

The quasi-periodicity in PSR B1931+24 may be explained in the same picture but with an inclined, precessing disk. We assume that the inner edge of the debris disk is close to the pulsar’s light cylinder. It is known that the inner disk radius always changes during the precession. As soon as the disk penetrates inside the light cylinder, the propeller process commences along with outflows from the disk; particle acceleration processes in the magnetospheric gap are then quenched, and the coherent radio emission cuts off. The neutron star slows down only by magnetic dipole radiation. The pulsar radiation switches on when the disk moves outside the light cylinder. In this case both magnetic dipole radiation and pulsar wind brake the neutron star, so that the pulsar slows down faster than during the off phase. This scenario also suggests that PSR B1931+24 may appear as a RRAT during the off phase.

A more detail discussion can be found in Li (2006, ApJ, 646, L139).