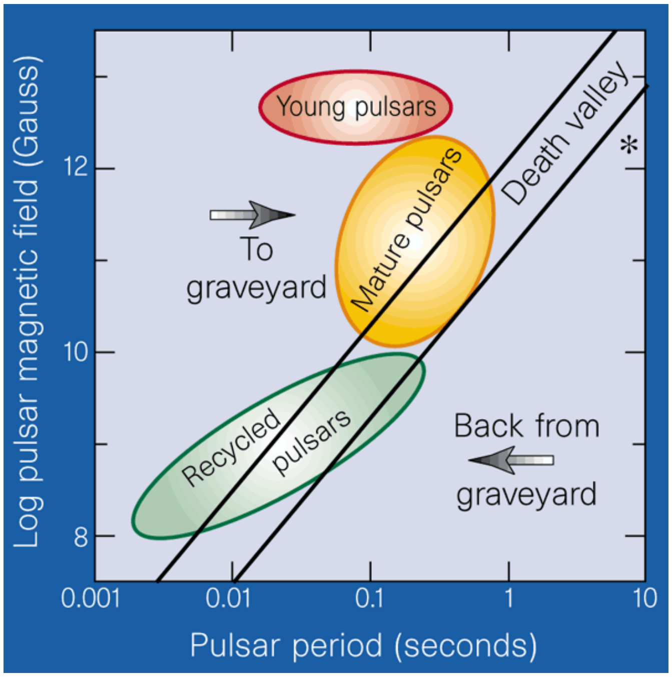
Lecture 25 : Recycled Pulsars



Although the Hulse-Taylor binary discussed in the previous lecture has two neutron stars, only one of them was detectable through its pulsed radio emission. This pulsar was not only the first pulsar to be discovered in a binary, it was also the most peculiar. Its very rapid spin rate suggested that it might be a “very young pulsar”. And yet, its anomalously low magnetic field suggested that it must be a very old pulsar. This intriguing puzzle was solved by the novel idea of “reincarnation of a dead pulsar”. Neutron stars eventually stop functioning as ‘pulsars’ when their period of rotation lengthens and their dynamo weakens. If the ‘dead pulsar’ is in a binary system, then it can be spun back up to short periods by accreting angular momentum from the binary companion. This lecture is devoted to this “Recycling scenario”.

[Image : Wolszczan A., 1999, Nature, 400, 812]

The Astrophysics group of Raman Research Institute (Bangalore) played an important role in Neutron Star research in the 1980 - ’90s under the leadership of Prof. G. Srinivasan. In particular his pioneering ideas (published in the articles listed below) about ‘pulsar recycling’ have been (and remain) some of the truly major milestones in the area of *Neutron Star Astrophysics*.

1. Srinivasan G. & van den Heuvel E. P. J., 1982, A&A,108, 143
   Some constraints on the evolutionary history of the binary pulsar PSR1913+16
2. Radhakrishnan V. & Srinivasan G., 1982, Curr.Sci, 51, 1096
   On the origin of the recently discovered ultra-rapid pulsar
3. Bhattacharya D. & Srinivasan G., 1986, Curr.Sci, 55, 327
   On the implication of the recently discovered 5 millisecond binary pulsar PSR 1855+09
4. Srinivasan G., 1989, A&ARv, 1, 209
   Pulsars: their origin and evolution
5. Srinivasan G., Bhattacharya D., Muslimov A. G. & Tsygan A. J., 1990, Curr.Sci, 59, 31
   A novel mechanism for the decay of neutron star magnetic fields
6. Bhattacharya D. & Srinivasan G., 1991, JApA, 12, 17
   Gamma rays from millisecond pulsars
7. Bhattacharya D. & van den Heuvel E. P. J., 1991, Phys.Rep., 203, 1
   Formation and evolution of binary and millisecond radio pulsars

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Astronomy & Astrophysics : An Introductory Survey

A lecture series by Prof. G. Srinivasan

A 'Golden Jubilee Celebration' Event of the Astronomical Society of India

Lecture 25 : Recycled Pulsars

[Supplementary Material : Dr. Sushan Konar]

Suggested Problems

1. **Accretion & Spin-up**

   Accretion of charged plasma from a companion star (or the interstellar medium) onto a strongly magnetised neutron star is channelised through the magnetic field lines from the Alfven radius onward. Derive an expression for the Alfven radius (R_A) for a star of mass M, radius R, dipolar magnetic field M which is accreting at a rate of $\dot{\mathrm{M}}$. Clearly note the simplifying assumptions you need to make to arrive at this result.

   Convince yourself that for material accretion to take place onto a neutron star the Alfven radius must be smaller than the light-cylinder radius R_{LC} $(= c/\omega_s$, ω_s being the spin frequency of the star).

   Further show that, a neutron star can be spun up via accretion only if the Keplerian radius R_K at which the Keplerian frequency equals the stellar spin frequency is smaller than the Alfven radius.

   From the results above, derive an expression for the equilibrium spin-period of a recycled pulsar of $1.4\mathrm{M}_\odot$. The most massive neutron star detected so far, PSR J0952-0607, is estimated to be of $2.35\pm0.17\mathrm{M}_\odot$. Does P_{eq} change with the mass of a pulsar? If yes, by how much does it change for a recycled pulsar of mass $2.4\mathrm{M}_\odot$compared to that of mass $1.4\mathrm{M}_\odot$?

2. **Magnetic Field - Spin Period Diagram**

   Using the data available at ATNF Pulsar Catalog generate the $B_s - P_s$ plot for the entire radio pulsar population (P_s - measured spin-period, B_s - dipole surface magnetic field derived from measured values of P_s and $\dot{\mathrm{P}}$). [You should check the pulsar 'type' and exclude the Magnetars (labeled as AXP).]

   [Note that a significant fraction of the pulsars (in particular, the millisecond pulsars) do not have any estimate. This is owing to the difficulty of accurately measuring $\dot{\mathrm{P}}$which is extremely small for pulsars (and several order of magnitude smaller for the millisecond pulsars). Moreover, many pulsars have significant space motion (orbital velocity or otherwise) which sometimes contaminate the $\dot{\mathrm{P}}$measurement resulting in unphysical values. In all such cases, an estimation for the dipolar magnetic field becomes impossible.]

   Draw the spin-up line in this plot. Use different symbols / colours for - a) isolated and binary pulsars, b) galactic disc and globular cluster pulsars. Comment on the nature of different populations.

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