## Lecture 19 : Pulsars


Twinkle twinkle little star. In August 1967, Jocelyn Bell, a young student in Cambridge University discovered something that twinkled at radio wavelength. It turned out to be a really 'little star'! It soon emerged that she had made one of the greatest discoveries in astronomy; she had discovered a neutron star. Since then, nearly three thousand neutron stars have been discovered. This lecture explains how a neutron star produces electromagnetic radiation and why it 'pulses'.

The picture on the left is the label of a 1976 music album called 'Unknown Pleasures' by the rock band Joy Division. This artwork was designed by artist Peter Saville, using a data plot of signals from the pulsar CP 1919 (the very object discovered by Jocelyn Bell), by simply reversing the image from black-on-white to white-on-black.

Now, the 'twinkling' in radio wavelength, as detected by astronomers from the Earth, appear like a train of regular pulses. The above image is nothing but a 'stacked plot' of a large number of successive radio pulses. The image was originally created by radio astronomer Harold Craft at the Arecibo Observatory for his 1970 doctoral dissertation as a way to visualize smaller pulses within larger ones with an aim to explain the underlying mechanism of pulsar emission.

**The Pulsar Model..**

- *Energy Emission from a Neutron Star*
  Pacini F., 1967, Nature, 216, 5115
- *Rotating Neutron Stars as the Origin of the Pulsating Radio Sources*
  Radhakrishnan V. & Cooke D. J., 1969, ApL, 3, 225
- *A Model of Pulsars*
  Sturrock P. A., 1971, ApJ, 164, 529
- *The Nature of Pulsar Radiation*
  Pacini F. & Rees M. J., 1970, Nature, 226, 622

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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 19 : Pulsars**

**[Supplementary Material : Dr. Sushan Konar]**

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**Basic Textbooks**

- *Handbook of Pulsar Astronomy*
  Lorimer D. R. & Kramer M., 2005, Cambridge University Press

- *Pulsar Astronomy*
  Lyne A. & Graham-Smith F., 2012, Cambrige University Press

**Suggested Problems**

1. Suppose a spherical body spinning originally at a rate $\omega_1$ with a radius $R_1$ collapses gravitationally to a radius $R_2$, conserving its mass M and angular momentum J. Express the ratios of the new and old spin rates $\omega_2/\omega_1$ and the new and old rotational energies $E_2/E_1$ in terms of the ratio $R_1/R_2$ (assume the moment of inertia for a homogeneous sphere). By what factor would the core of a star spin faster if it were to collapse from a radius typical of a white dwarf to the dimensions typical of a neutron star? By what factor would the rotational energy increase in such a collapse? Where ultimately does this energy come from?

2. A neutron star cannot spin with less than a certain critical period or it will start to shed mass from its equator due to centrifugal force. Consider a neutron star of mass M and radius R. Find the minimum value of the spin-period at the mass-shedding limit.

3. Consider a neutron star (a rotating, magnetised conducting sphere of radius 10km and mass $1.4\mathrm{M}_\odot$). Find the minimum strength of the magnetic field of this neutron star so that the induced electric field in the magnetosphere is able to pull out electrons from the surface.

4. Show that the dipolar model of a pulsar can be expressed as follows -

$$I\Omega\dot{\Omega} = -\beta\Omega^4 \,, \qquad (1)$$

   where, $I$ and $\Omega$ are the moment of inertia and the angular frequency of the star. Obtain the exact form of $\beta$ from what has been discussed in the lecture. Can you define a characteristic time of slow-down for a pulsar in terms of $\Omega$ and $\dot{\Omega}$? Do you see the connection of this timescale with the characteristic age?

5. Find the brightness temperature for X-rays from the Crab pulsar (luminosity $10^{35}$ erg.s$-1$), and argue that the particles energies obtained for such temperatures would not be commensurate with X-ray emission.

6. A pulsar is observed to have a gamma-ray luminosity of $L$ watts and spin-period of $P$ seconds. Estimate a lower limit of $\dot{P}$ assuming dipolar model of radiation.

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