Today in Astronomy 241: degenerate stars IV

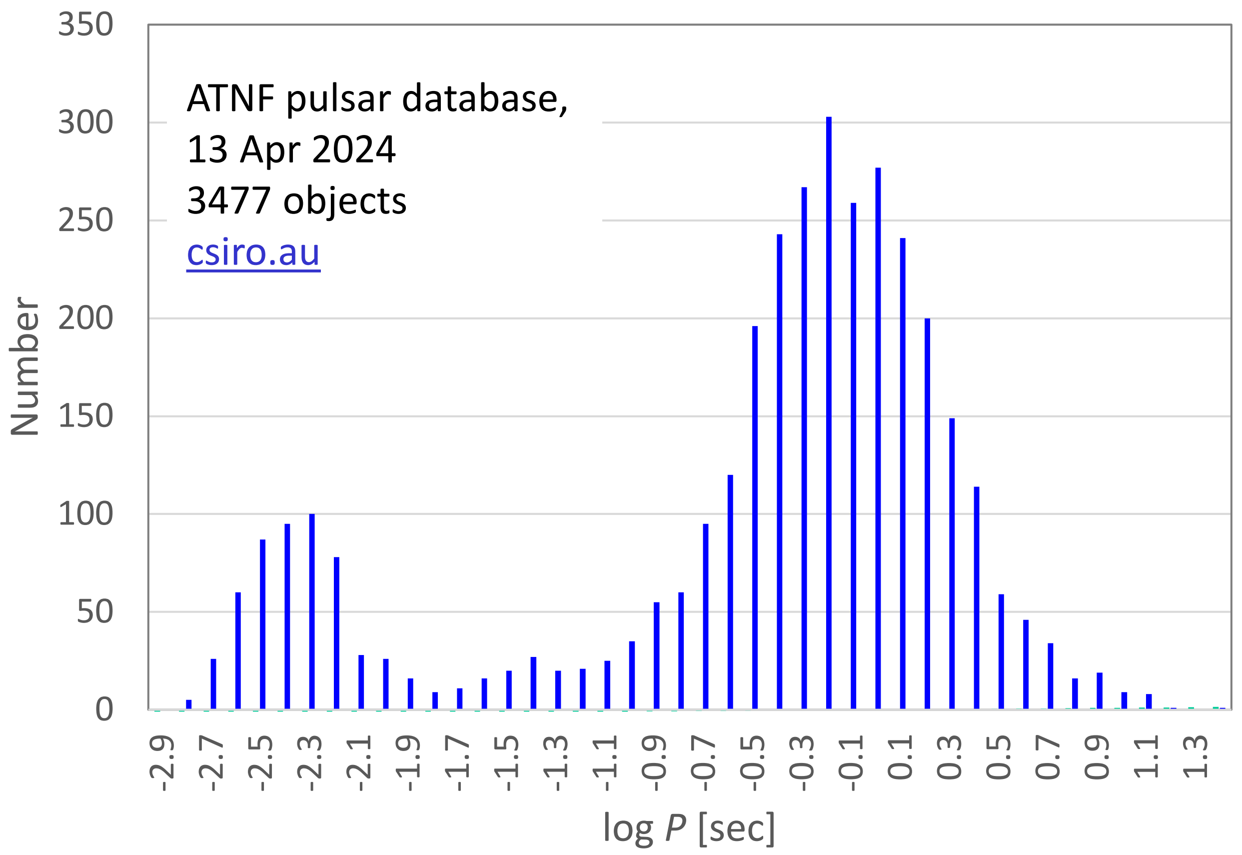
- Pulsars are rotating neutron stars
- Pulsar magnetic fields
- Pulsars and the energetics of supernova remnants
- **Reading**: C&O chapter 16, pp 586-603

Adam Block's 2019 slo-mo movie of the pulsar in the Crab Nebula (M 1). The actual pulse period is 33 ms.

Pulsars

[Discovered](#) serendipitously by Jocelyn Bell and Antony Hewish in 1967.

- High point of Bell's PhD dissertation at Cambridge, and of her thesis adviser Hewish's citation for the Nobel Prize in Physics.
- Compact, **pulsed** sources, with pulses **precisely periodic**, commonly first detected at radio frequencies.
- Very soon after they were discovered, they were identified, not as pulsators, but as **rotating**, **magnetized** neutron stars.
  - Periods consistent with stellar spin and conservation of angular momentum.



Pulsars (continued)

- The periods of most pulsars increase extremely gradually: typically *dP/dt* ~ 10^{-15}; though many have occasional glitches.

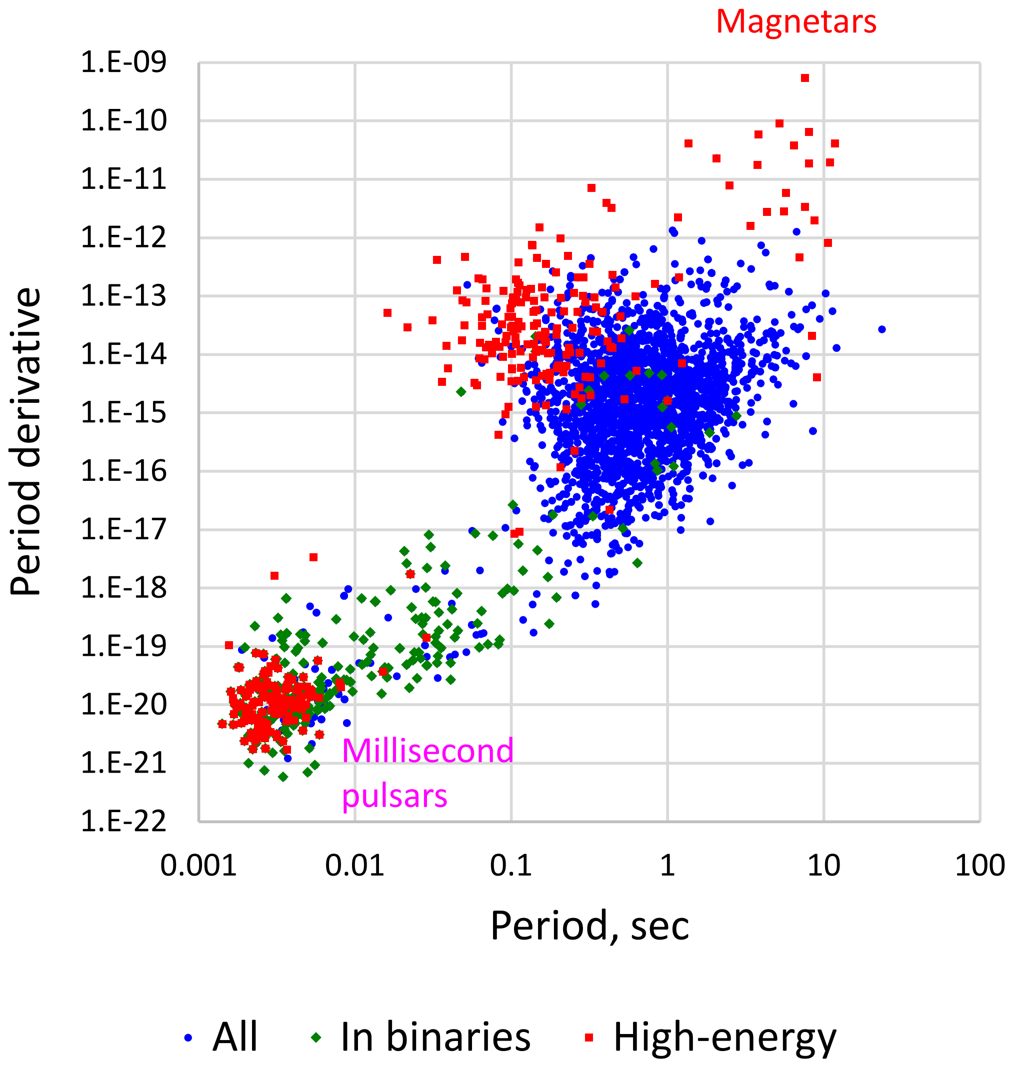
- Thus they are exceptionally good and stable clocks.

  - Especially the **millisecond pulsars**, with *dP/dt* five orders of magnitude smaller than the pack.

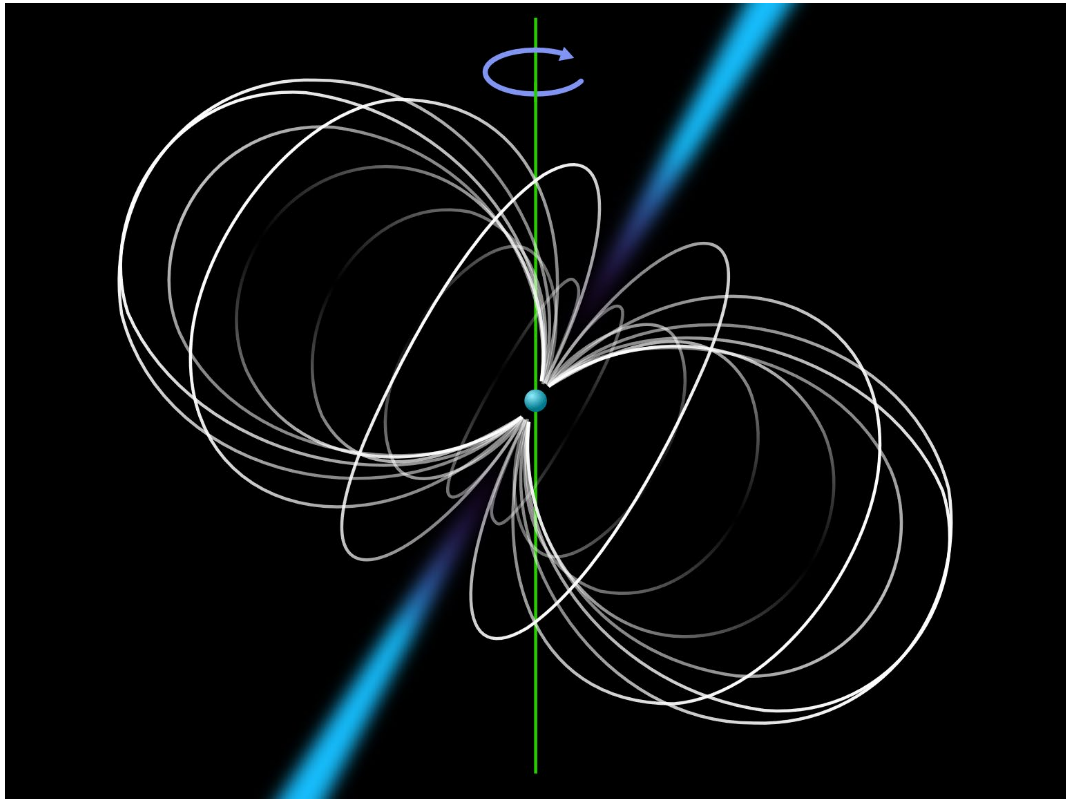
  - Not quite as precise as a redundant array of Rb atomic clocks (e.g. Hobbs+2020); limited by accuracy of solar-system-kinematic knowledge.

  - Networks in use for low-frequency gravitational-wave searches.

ATNF pulsar catalogue



Pulsars (continued)

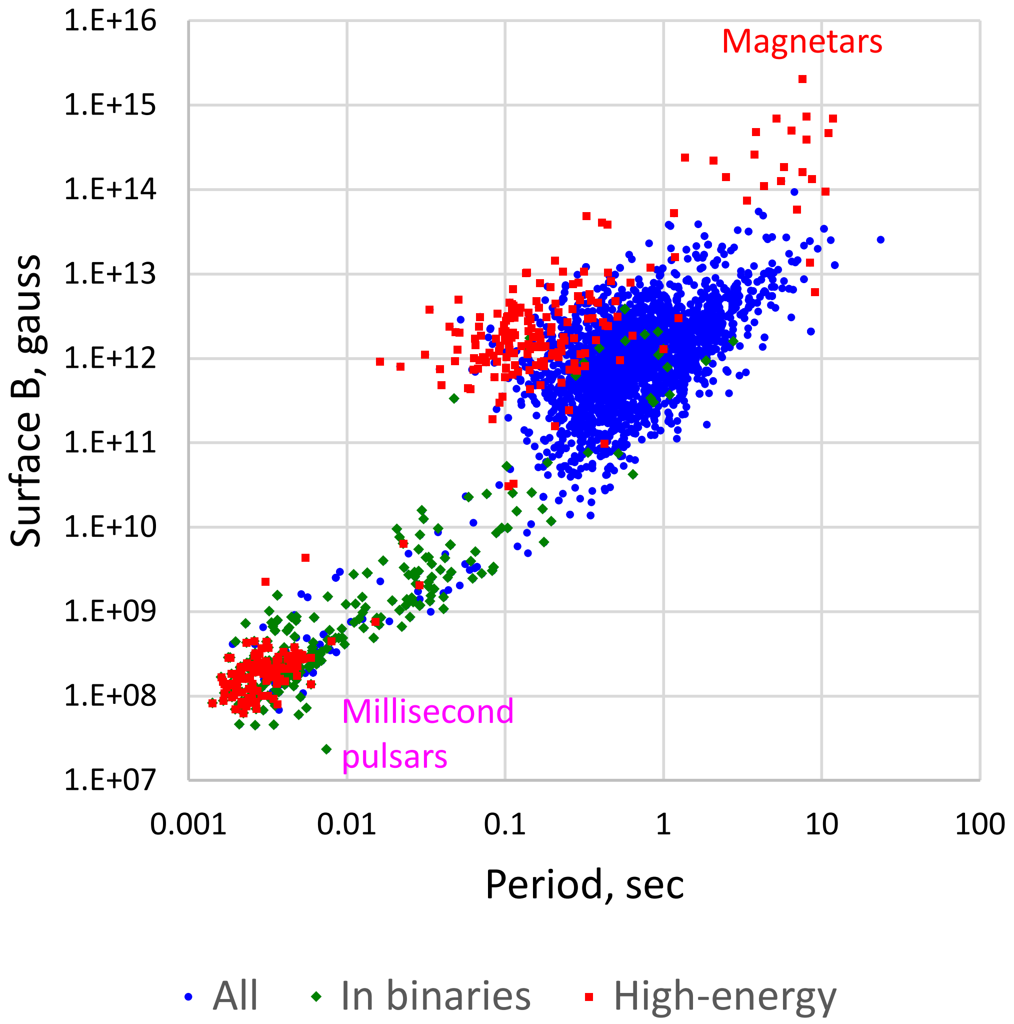


Roy Smits, Wikimedia Commons

- By all accounts, pulsars emit by acceleration of relativistic electrons in magnetic fields, in neutron stars with magnetic axis tilted from rotation axis.
  - Charges are tied by Lorentz forces to magnetic field lines.
  - They accelerate magnetocentrifugally along ***B*** (curvature radiation), and axially about ***B*** (synchrotron radiation).
  - Accelerating relativistic ions beam their radiation strongly in the direction of their velocity (cf. PHYS 218).
  - Thus there is a searchlight-like beam along the magnetic axis, rotating with the neutron star, and appearing as a pulse when the beam crosses the observer's view.
- Nevertheless, the precise acceleration and radiation mechanism is still debated, even after all these decades.

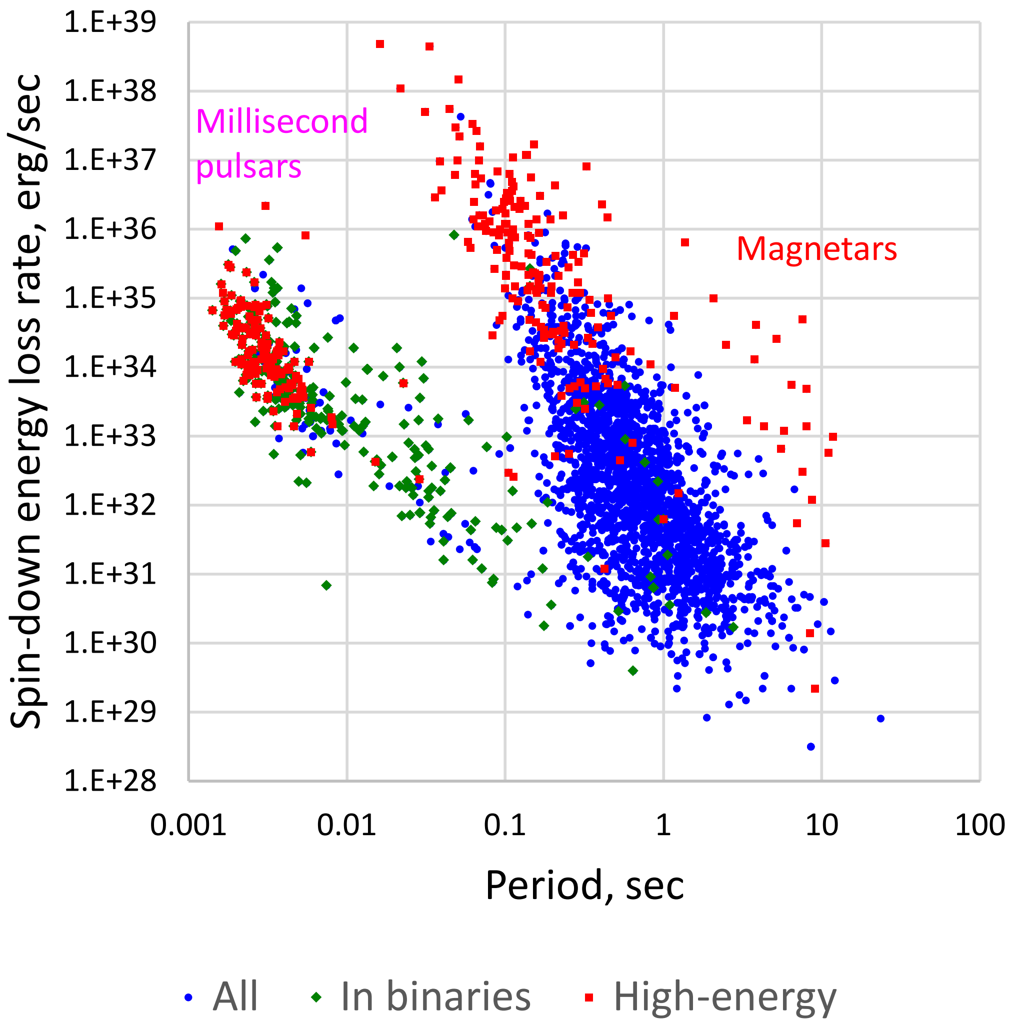
Pulsars (continued)

- Also by any token, the emitted flux can be used to derive the surface magnetic field at the magnetic polar caps.
- Result: pulsars have extremely strong surface magnetic fields – typically $B = 10^{12}$ gauss at their surfaces.
- This is consistent with the magnitude of the dipole magnetic fields of progenitor stars, and magnetic flux conservation during the collapse and neutron-star formation.



Pulsars (continued)

- Emission of this radiation results in a torque on the neutron star, which is why they are generally observed to be spinning down.
- The total energy radiated by a magnetized neutron star is also consistent with that reprocessed and radiated by the supernova-remnant surroundings, as was pointed out before pulsars were discovered ([Pacini 1968]).
- The millisecond pulsars, many of which live in binary systems, are thought to have increased their spins by accretion from their companions.
- The magnetars, which are slowly spinning, must derive their energy from the pulsar's magnetic energy, rather than rotation like most pulsars.



Minimum rotation period

If a $M = 1.4M_{\odot}$, $R = C/2\pi = 11.9$ km neutron star is spun faster than

$$P_{\min} = 2\pi\sqrt{\frac{R^3}{GM}} = 0.6 \text{ ms} \quad ,$$

it will break up: that is, gravity would not be enough to supply centripetal acceleration. See C&O problem 16.16, which you'll work out today.

- That this is close to 1 ms is why it caused such a stir when Don Backer, in the 1980s, discovered millisecond pulsars.

Today's in-class problems

1. C&O 16.14.

2. C&O 16.15.

3. C&O 16.16.

Note:

- The Sun's sidereal rotational period at its equator is 25.38 days, and its average surface magnetic field is about 2 gauss.

- The average density of a 1 $M_\odot$ white dwarf and a 1.4 $M_\odot$ neutron star are

$$\rho_{WD} = 3.0\times10^{6}\ \text{gm cm}^{-3}$$
$$\rho_{NS} = 6.7\times10^{14}\ \text{gm cm}^{-3}$$