Pulsars and Supernovae II

5. DISTRIBUTIONS AND POPULATIONS

P-PDOT plane
characteristic age
death line
galactic distribution
parallax
Crab and Vela pulsars
millisecond pulsars
binary pulsars

The P-Pdot diagram

- By timing pulsars individually, one can measure the variation in period with time. This is usually expressed as a Taylor series:

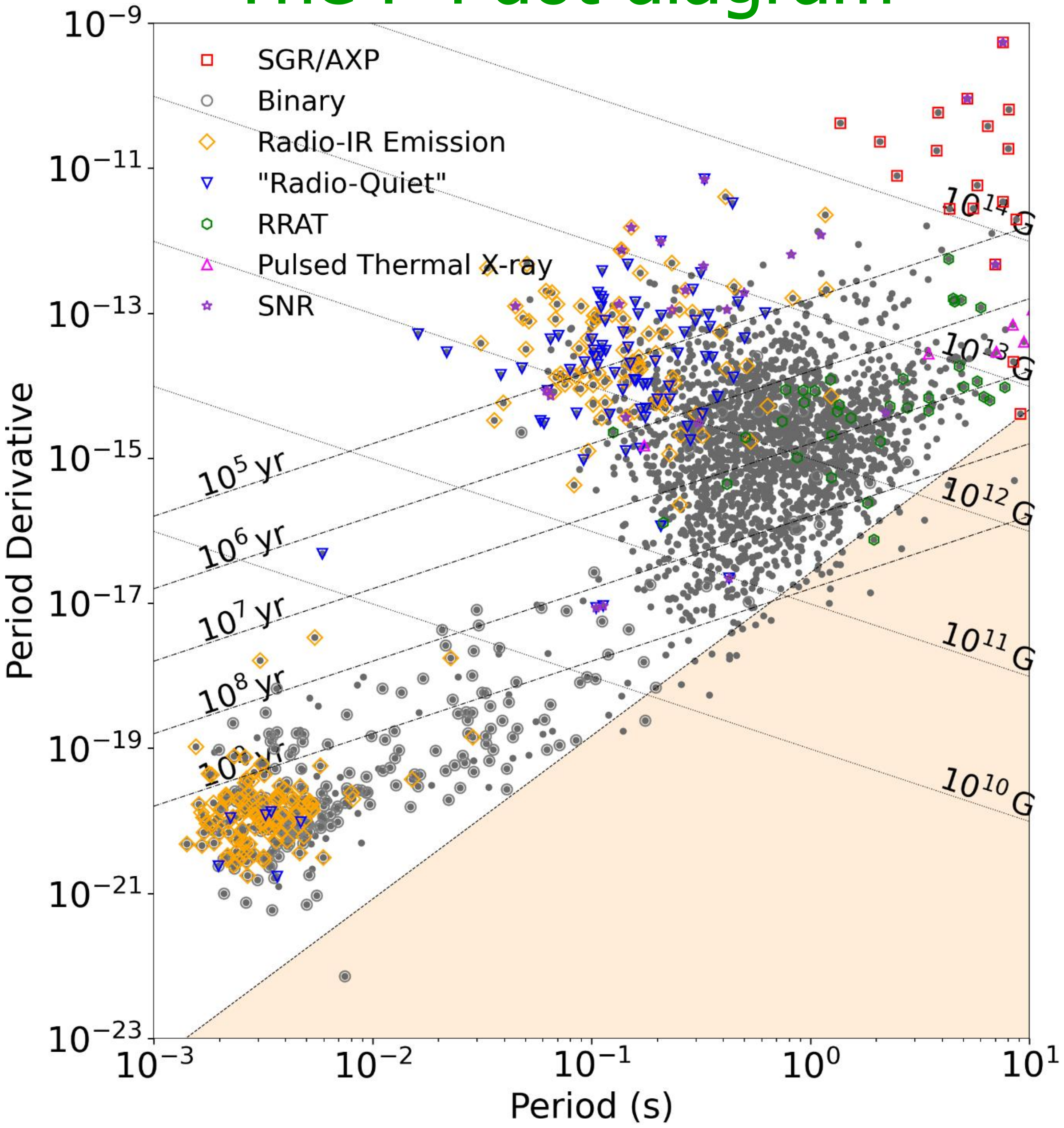
$$P(t) = P(t_0) + \left.\frac{\mathrm{d}P}{\mathrm{d}t}\right|_{t_0} (t - t_0) + \left.\frac{\mathrm{d}^2 P}{\mathrm{d}t^2}\right|_{t_0} \frac{(t - t_0)^2}{2!} + \ldots$$

- The first two coefficients are known as P and Pdot ($\dot{P}$) – the fitted period and period derivative of the pulsar.

- Higher coefficients are always much smaller and are often dominated by the pulsar's timing noise.

- P and Pdot together give a good indication of the age, magnetic field and luminosity of the pulsar, and a scatter diagram of all known pulsars in the P-Pdot plane is useful in identifying types of pulsars, and constraining radiation mechanisms.

The P-Pdot diagram



The P-Pdot diagram

- Age:

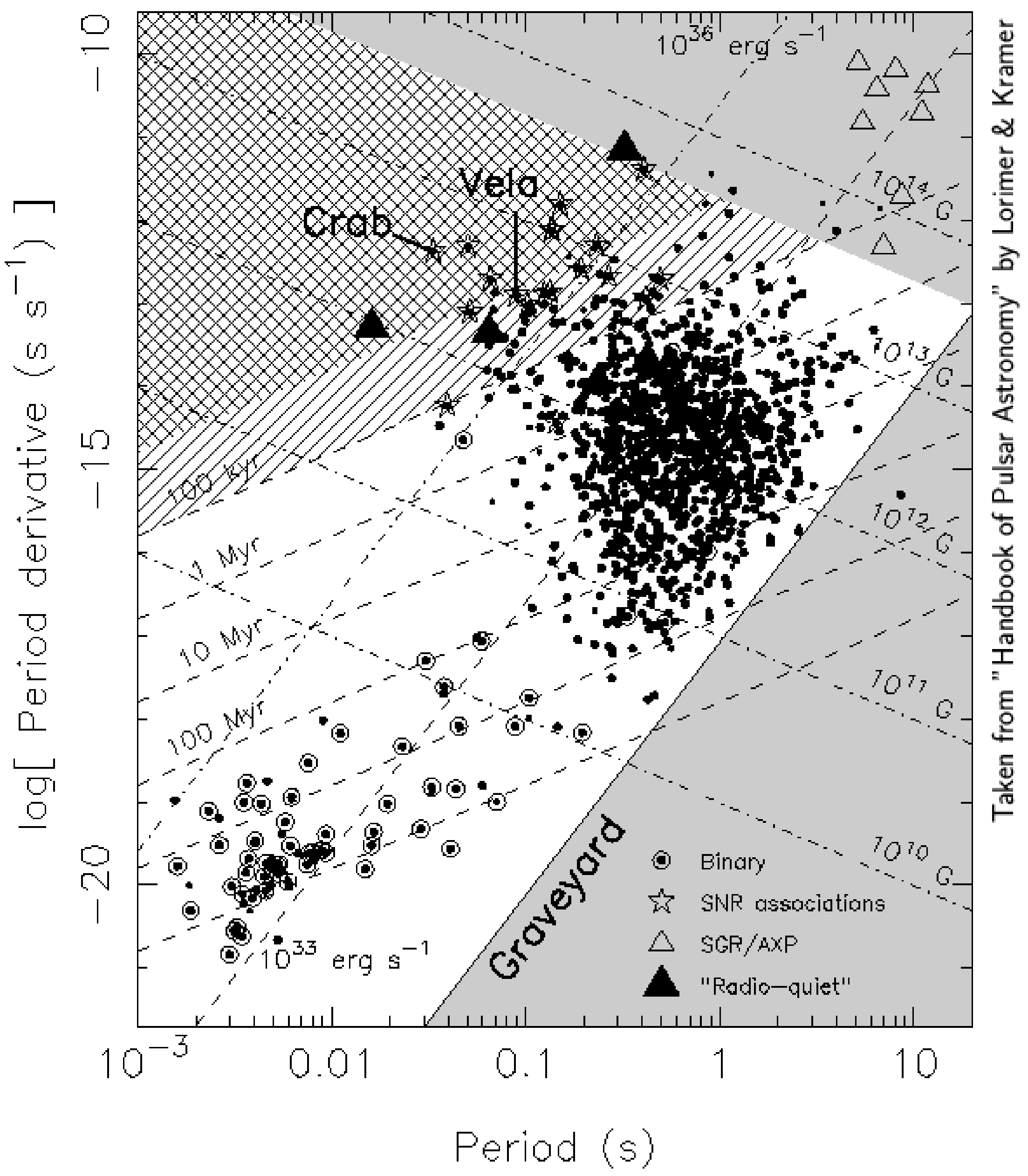
$$\tau \propto P/\dot{P}$$

- Magnetic field:

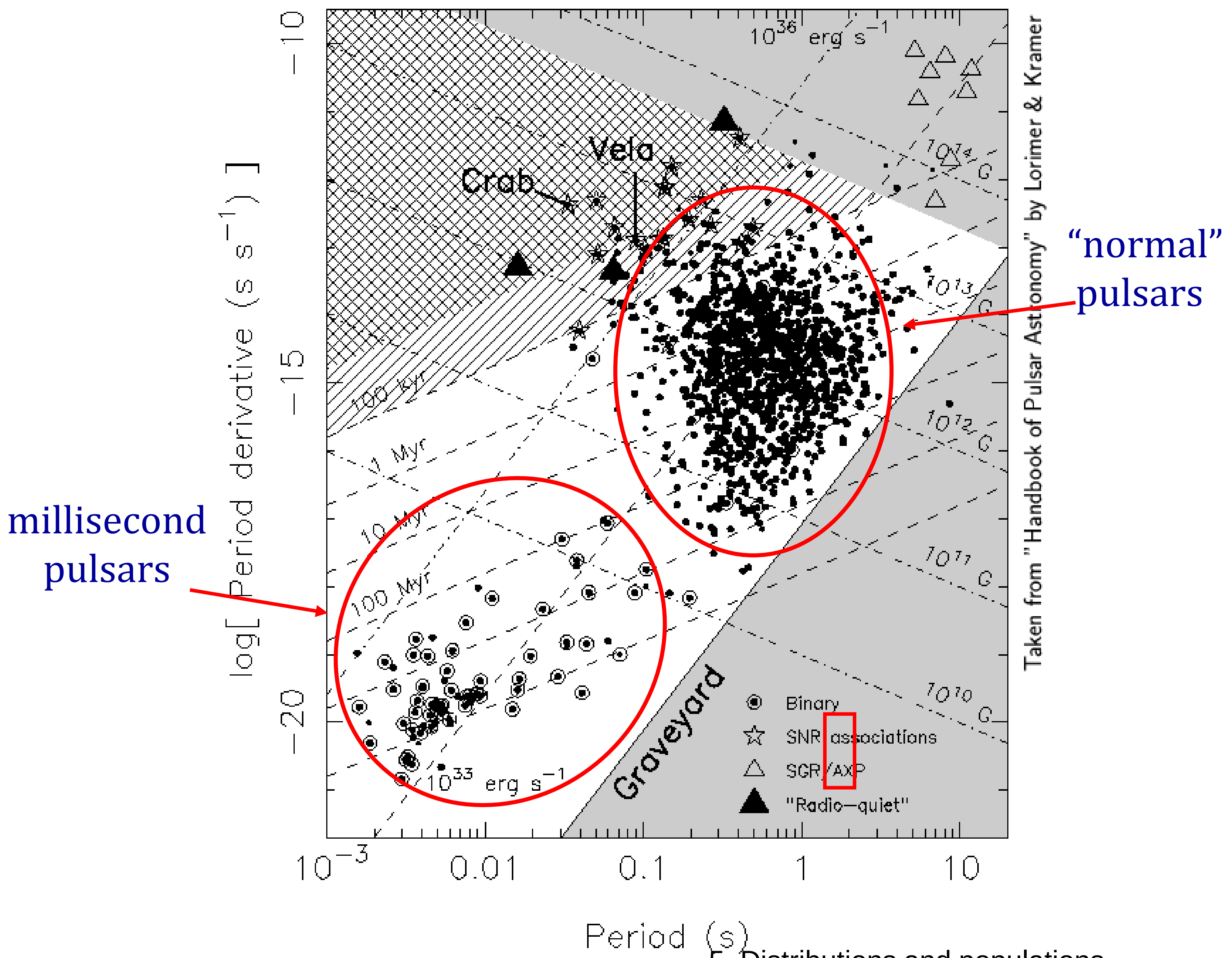
$$B \propto (\dot{P}P)^{1/2}$$

- Spin-down luminosity:

$$L \propto \dot{P}/P^3$$



The P-Pdot diagram



Characteristic age

- We characterise the spin-down of a pulsar in terms of its braking index (see first lecture)

$$\frac{\mathrm{d}\nu}{\mathrm{d}t} (= \dot{\nu}) \propto -\nu^n$$

with $n = 3$ for magnetic dipole braking. Expressing this in terms of pulsar period, and integrating from some initial period P_0 to its present value after time T gives

$$T = \frac{P}{(n-1)\dot{P}} \left[1 - \left(\frac{P_0}{P} \right)^{n-1} \right].$$

- If $P_0 \ll P$ and $n = 3$ we get the characteristic age of the pulsar to be

$$\tau_c = \frac{P}{2\dot{P}}$$

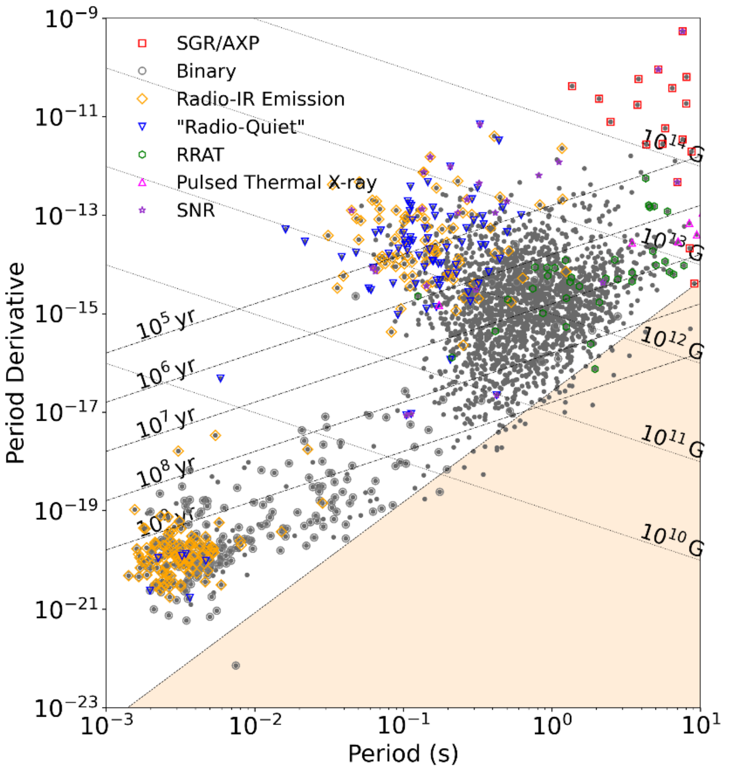
Death line

- There is a clear absence of pulsars in the lower right of the P-Pdot diagram, to the left of the Death line.

- This may be indicating that the pulsar mechanism can't fire-up if the field strengths are too low.

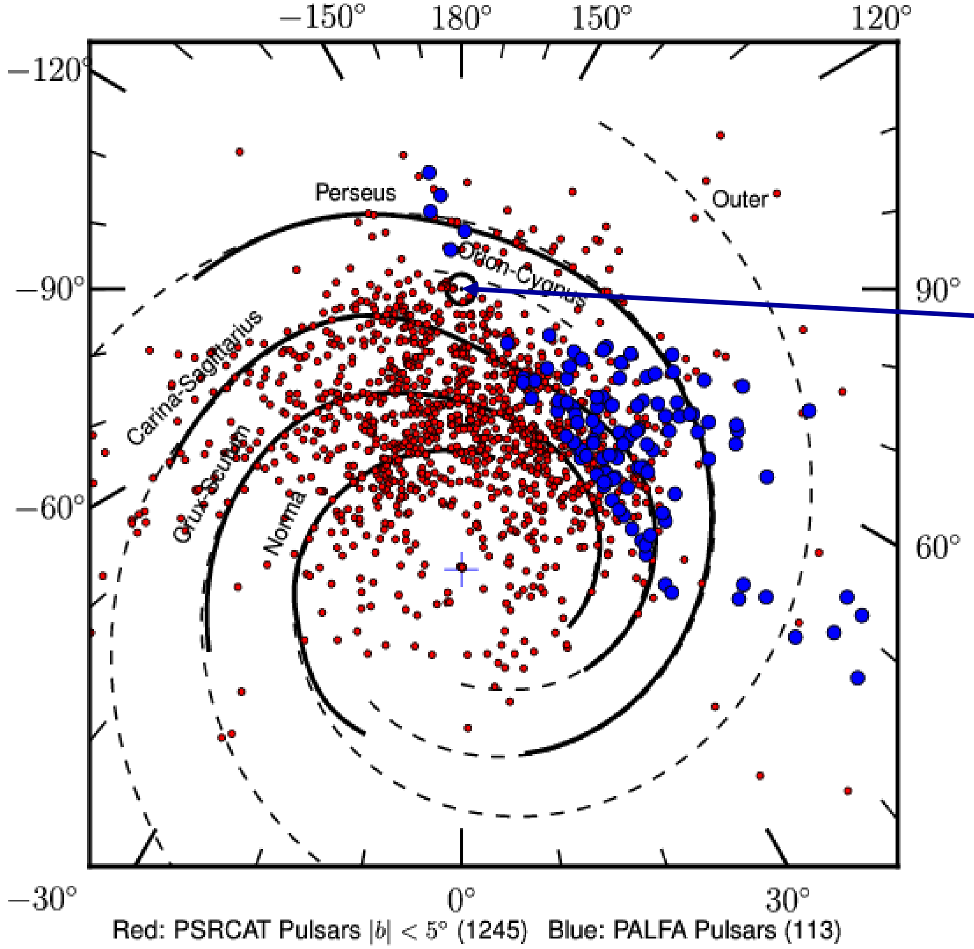
- The rotating magnetised neutron star is expected to generate a strong electric field that accelerates particles and generates more particles by a cascade mechanism (see later lectures).

- Neutron stars below the death line may have too little rotation and/or magnetic field to kick this cascade mechanism off, but it is not a precise boundary.



Galactic distribution

- Our current sample of pulsars shows strong selection effects, reflecting the difficulty of detecting pulsars at great distances:

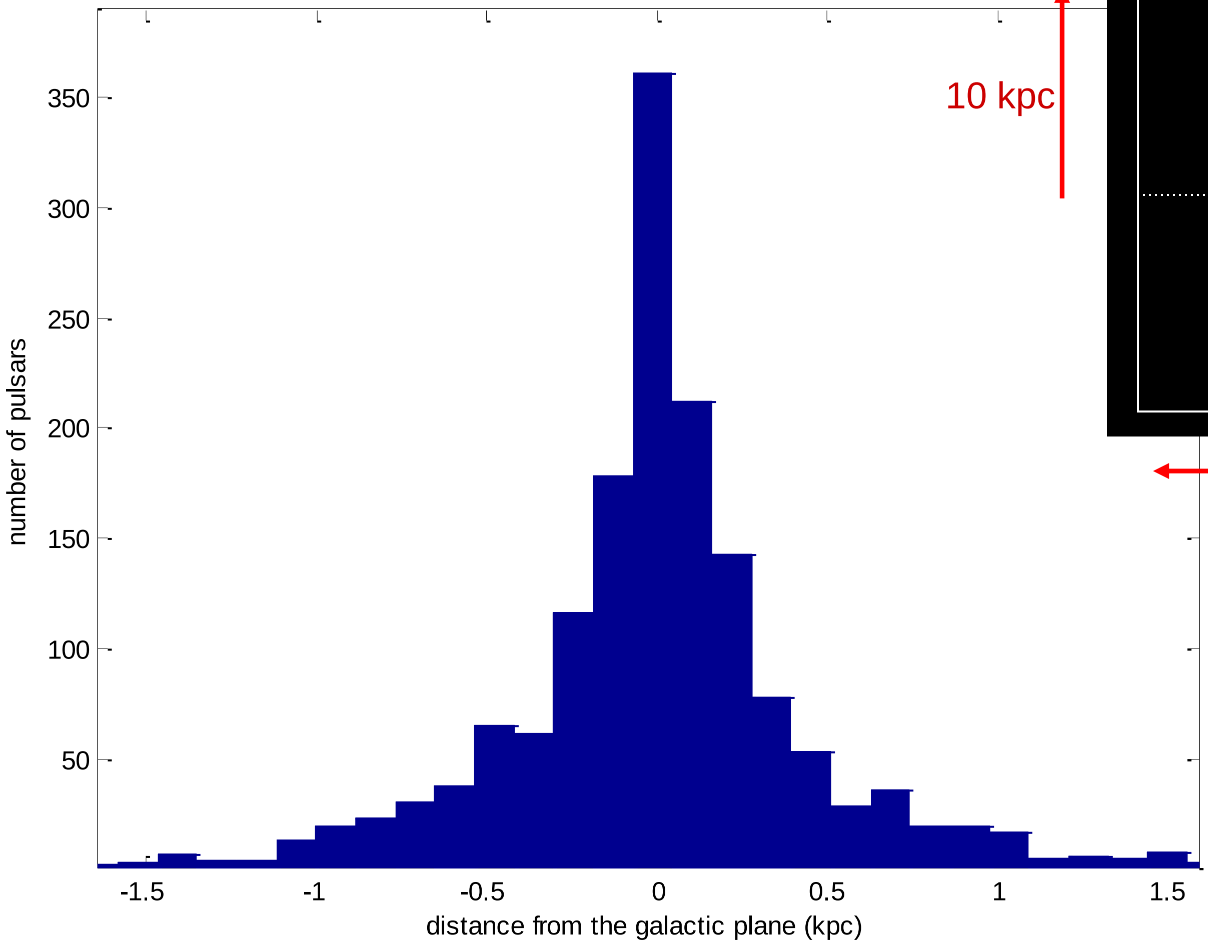


We are here

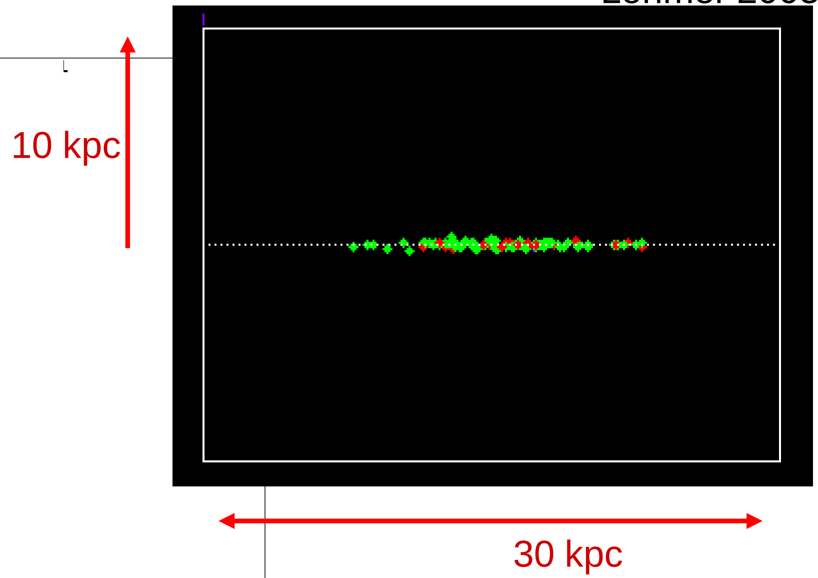
Note the weak
spiral-arm structures.

Galactic distribution

- Most pulsars, like most stars, are in the galactic plane, but with a high velocity dispersion (up to 1000 km/s). Perhaps half have galactic escape velocities

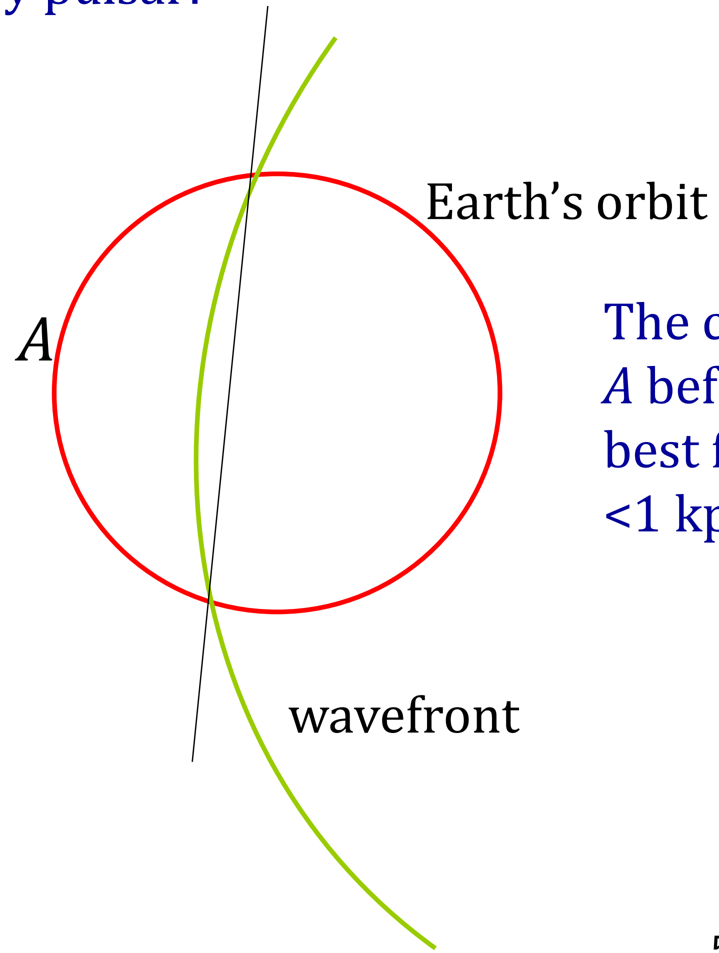


Lorimer 2005



Annual parallax

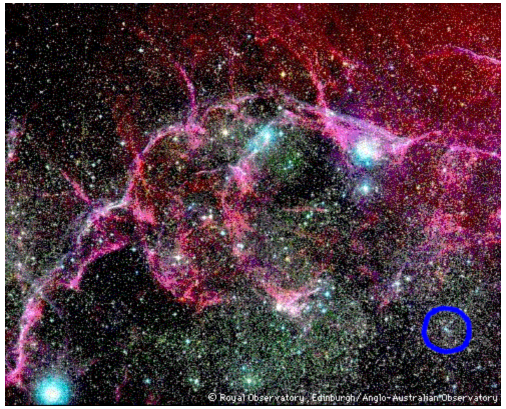
- How distant are pulsars?
  - DM is only a useful indicator once you know the electron density structure in the galaxy!
- Accurate pulsar timing can reveal the curvature of the wavefronts from a nearby pulsar:



The curved wavefront will arrive at *A* before the plane wavefront – best for pulsars in the ecliptic (and <1 kpc).

The Crab pulsar and the Vela pulsars

- Two pulsars deserve particular attention -- the Crab and Vela pulsars are young, with high spindown rates, associated supernova remnants and optical, X and gamma ray pulses:

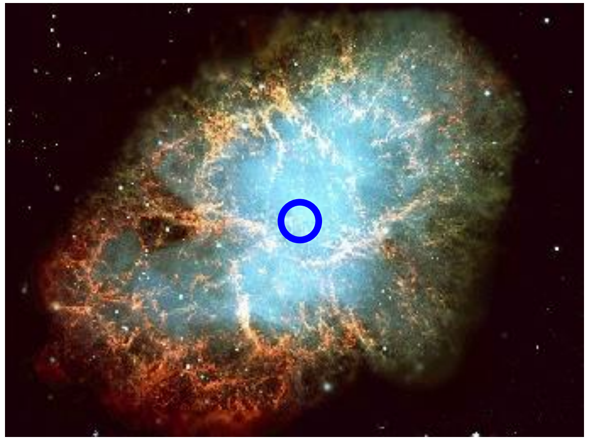


Vela pulsar (PSR B0833-45)

P: 89 ms

Pdot: 10 ns/day

Characteristic age: 12180 y



Crab pulsar

P: 33 ms

Pdot: 36 ns/day

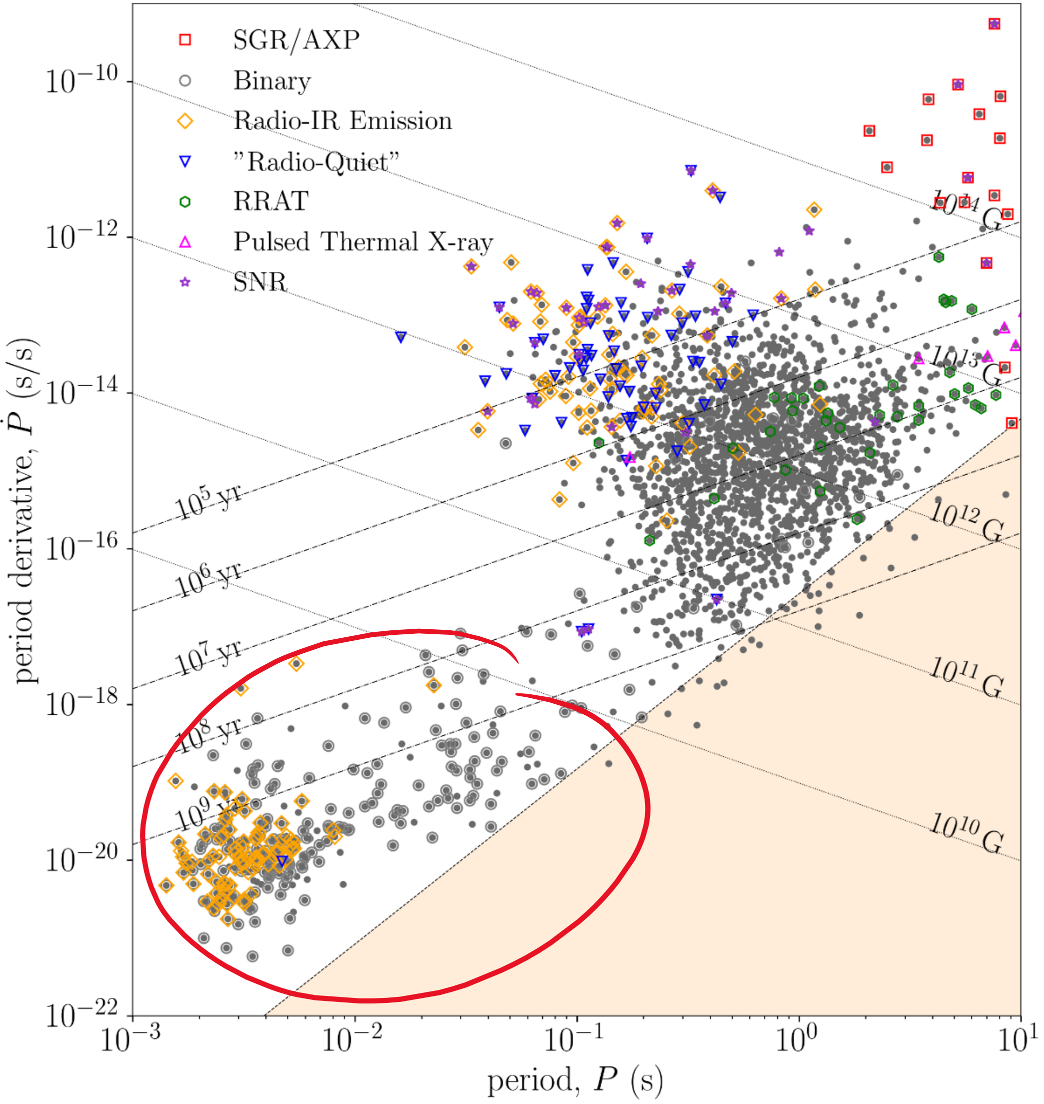
Characteristic age: 1250 y

Sounds!

Millisecond pulsars

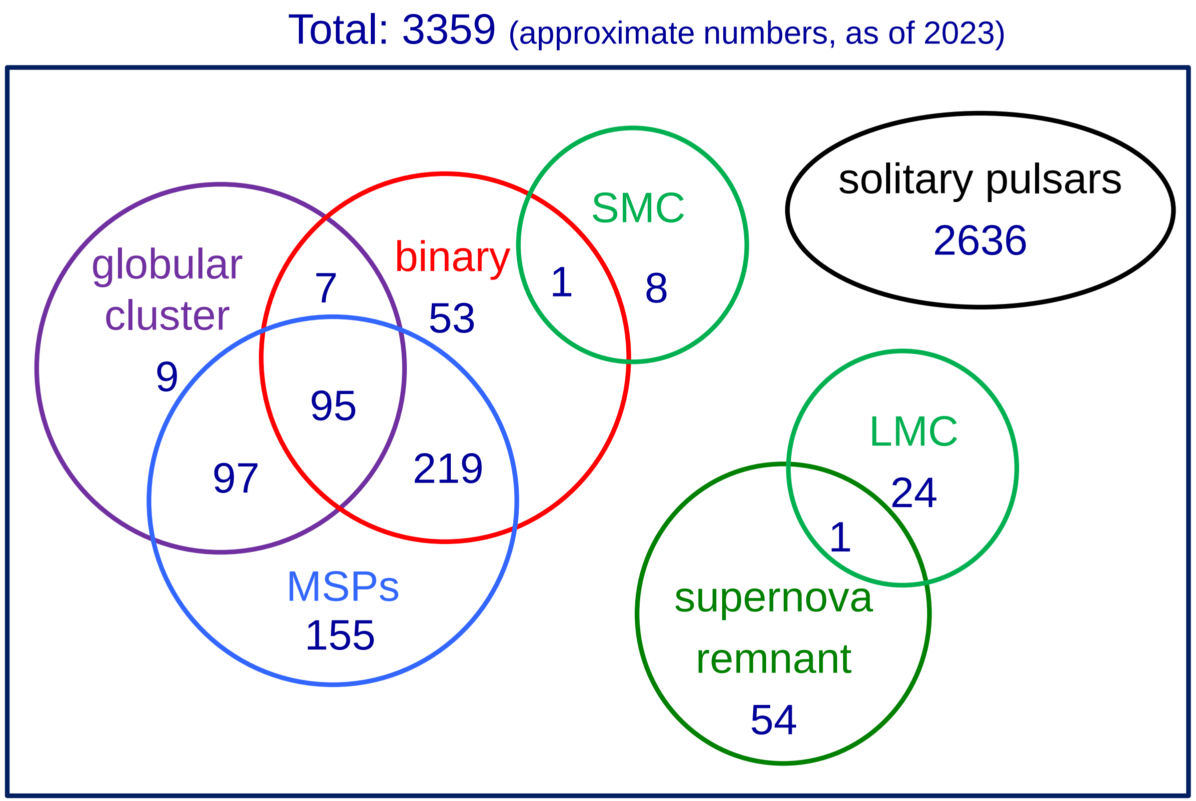
- A clear separate population in the P-Pdot diagram.
- These are old pulsars with short rotational periods and relatively eventful life-histories – they have all been spun-up by accretion from a binary companion.
- Usually very stable clocks.

See lecture 8!



Binary pulsars

- Only about 17% of known pulsars are millisecond pulsars ($P < 30$ ms), but about 55% of these are in binary systems.



Binary pulsars

- There are several evolutionary scenarios for binary systems that involve pulsars.

- Lectures 8 & 9 will cover these.