ASTR 5590 - Neutron Stars: Pulsars

<u>Crab Nebula</u>

- recorded as a "guest star" by the Chinese; July 4th 1054 appearance
  - ↳ potential recordings here, petroglyphs showing correct moon phase & approx. location
- nebula 1st recorded by John Bevis in 1731, included in Messier's catalog of not-comets: M1
- IDed as 1054 SN in 1939
- Two stars near center, couldn't rule out southern one

↳ emission line filaments & continuum
Baade in 1942
optical cont. → synchrotron, predicted polarization confirmed in 53

- $L \sim 10^{38}$ erg/s

lifetime $t_{loss} \approx \frac{E}{(dE/dt)_{syn}} \approx \frac{\gamma m_e c^2}{\frac{4}{3}\sigma_T c \mathcal{E}_B \gamma^2}$

(single e⁻)

$$\nu_s \cong \gamma^2 \nu_g = \frac{\gamma^2 e B}{2\pi m_e c} \quad (\text{cgs})$$

$$t_{loss} \sim 1.5 \times 10^{12}\,\text{s} \left(\frac{B}{1\,G}\right)^{-3/2} \left(\frac{\nu}{Hz}\right)^{-1/2}$$

$t_{loss} <$ age ($\sim 10^3$ yr $\sim 3 \times 10^{10}$ s)

for $\nu \gtrsim 2 \times 10^{13}$ Hz (IR)

seen in optical, so if SN-powered, wouldn't be visible anymore

- 1968, Staelin & Reifenstein III found 2 pulsating sources in vicinity
  ↳ later follow-up confirmed: PSR B0531+21

Pulsars had just been discovered the year before; Bell recounted a story of a woman in the '50s seeing the 30 Hz "flashing" in a telescope in Chicago!

* Show J. Bell BBC clip

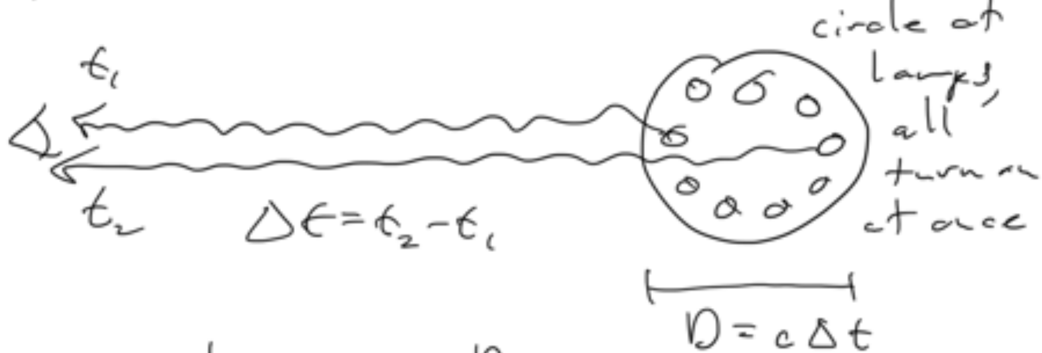
Population had periods $P \sim 0.2-2$ s (original pop.)

$\left|\frac{dP}{dt}\right| < 10^{-13}$ sec/sec (excellent clocks!)

↳ sign neg.: slowing down

radio pulse duration $\gtrsim 20$ ms

→ limits size of emission region



in general, $\Delta t \gtrsim \frac{D}{c}$
(don't have to turn on at once)

Given ~20ms, $D_{pulsar} \lesssim c\Delta t = 10^3$ km

Also, assume spinning obj., size limited by rotating faster than speed of light

$P \sim 0.2s$, $v = \frac{2\pi R}{P} \leq c \rightarrow R < \frac{Pc}{2\pi}$

$$R < \frac{3\times10^5 \text{ km/s} \cdot 0.2s}{2\pi} \sim 10^4 \text{ km}$$

Only candidates are WDs, NSs, or BHs
- BHs have no surface (how to get pulses?)
- WDs too big ($P \sim 1$ms discovered)

Where does the power (luminosity) come from?

→ rotation!

$$E_{rot} = \frac{1}{2} I \dot{\theta}^2 = \frac{1}{2} I \Omega^2$$

$$\Omega \equiv \frac{2\pi}{P}$$

$\Omega - P_{rot}$

Moment of Inertia for a solid sphere is $I = MR^2 \simeq 10^{45}\,g\,cm^2$

$(1\,M_\odot,\ R \sim 15\,km)$

E loss then $\boxed{\dot{E}_{rot} = I\,\Omega\,\dot{\Omega}}$

- can allow I to be const b/c radius doesn't really change (rotation pressure support minimal)

$\dot{E}_{rot} \gtrsim 10^{38}\,erg/s \sim L_{Crab\ Nebula}$

What causes $\dot{\Omega}$ (then to slow down)?

$$\left(\frac{dE}{dt}\right)_{rad} = \frac{2}{3}\frac{|\ddot{\vec{x}}|^2}{c^3}$$

↳ accel. of charge

$$\left(\frac{dB}{dt}\right) = \frac{2}{3}\frac{|\ddot{\vec{\mu}}|^2}{c^3}$$

Mag. moment $\mu = (|\vec{\mu}|\sin\alpha)\sin\Omega t$

$|\ddot{\vec{\mu}}| = \mu\sin\alpha\,\Omega^2$

$$\boxed{I\,\Omega\,\dot{\Omega} = \frac{2}{3}\frac{\mu^2\sin^2\alpha\,\Omega^4}{c^3} = \left(\frac{dE}{dt}\right)_{rot}}$$

$B_{pole} = \frac{2\mu}{R^3}$