Introductory Astronomy

Week 5: Stellar Evolution

Clip 15: Neutron Stars

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What is Left of Core?

- Electron degeneracy cannot stop collapse – few electrons
- Neutron degeneracy pressure at density

$$6 - 7 \times 10^{17} \mathrm{kg/m^3}$$

- $1.4 M_\odot$ in $R \sim 10\,\mathrm{km}$
- Surface gravity $1.9 \times 10^{11} g$

- Physics is relativistic
- Chandrasekhar Limit

$$M R^3 = \mathrm{const}$$

$M_{Ch} = 2.2 - 2.9 M_\odot$ depends on rotation

- Rapid Rotation expected
- High magnetic field frozen in

$$B_{\mathrm{ns}} \sim B\mathrm{wd} \left(\frac{R_{\mathrm{ns}}}{R_{\mathrm{wd}}} \right)^2$$

Discovery

- Physics Predictions:
  - Rapid Rotation

$$MvR \sim MR^2/P$$

$$P_{\rm ns} = P_{\rm c}\left(\frac{R_{\rm ns}}{R_{\rm c}}\right)^2 \sim 0.005\,{\rm s}$$

  - Intense magnetic field

$$B_{\rm ns} \sim B{\rm c}\left(\frac{R_{\rm ns}}{R_{\rm c}}\right)^2 \sim 10^{12} B_\odot$$

  - High Temperature

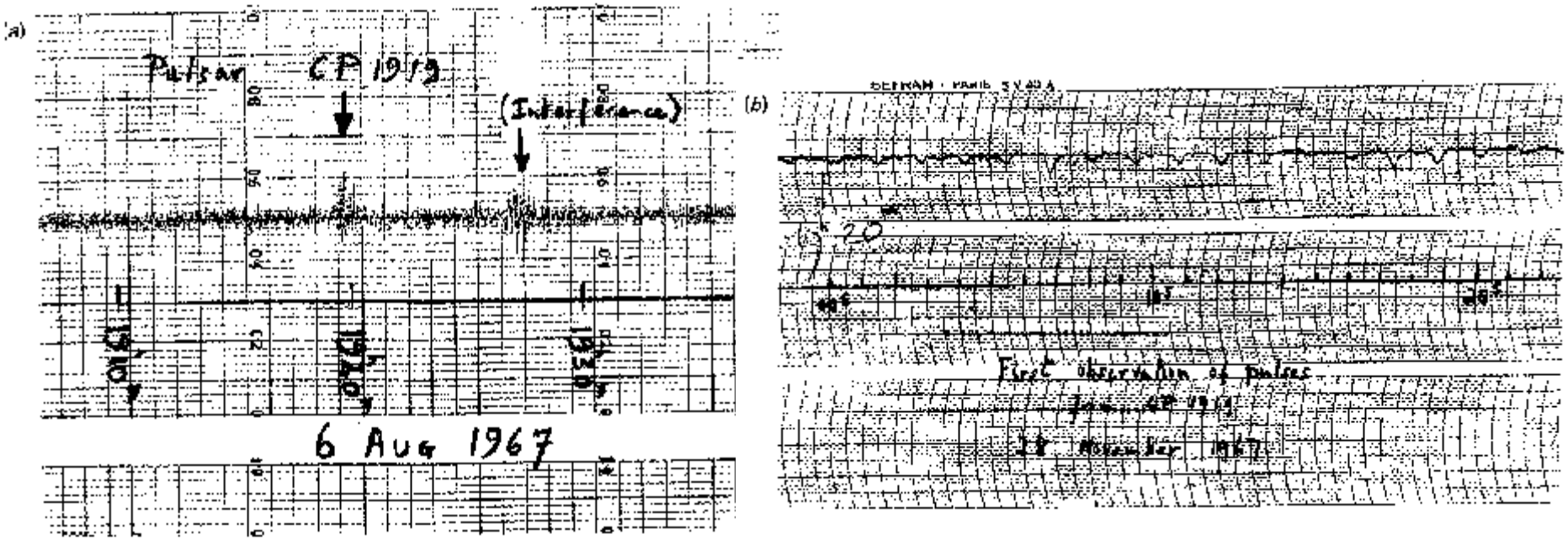
$$T \sim 10^6\,{\rm K}\ \lambda_{\rm max} = 2.9\,{\rm nm}\ L \sim 0.25 L_\odot$$

- Bell 1967: Periodic 1.337s Radio pulses: LGM?
- Quickly found other sources: natural
- Soon find many pulsars

$$0.2\,{\rm s} \leq P \leq 2\,{\rm s}$$

Slow down in $10^7\,{\rm yr}$

LGM Data



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What are Pulsars?

- Rotating star breaks up

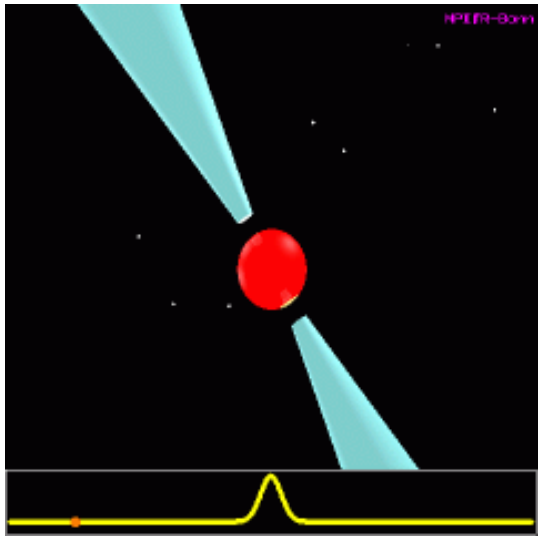
$$v^2/R = 4\pi^2 R/P^2 \sim GM/R^2$$

$$P = 2\pi\sqrt{\frac{R^3}{GM}}$$

- Only NS dense enough to survive $P \sim 1\mathrm{s}$
- Emission aligned to magnetic axis - tilted

- Crab pulsar $P = 0.0333\,\mathrm{s}$:

  Neutron star SN remnant



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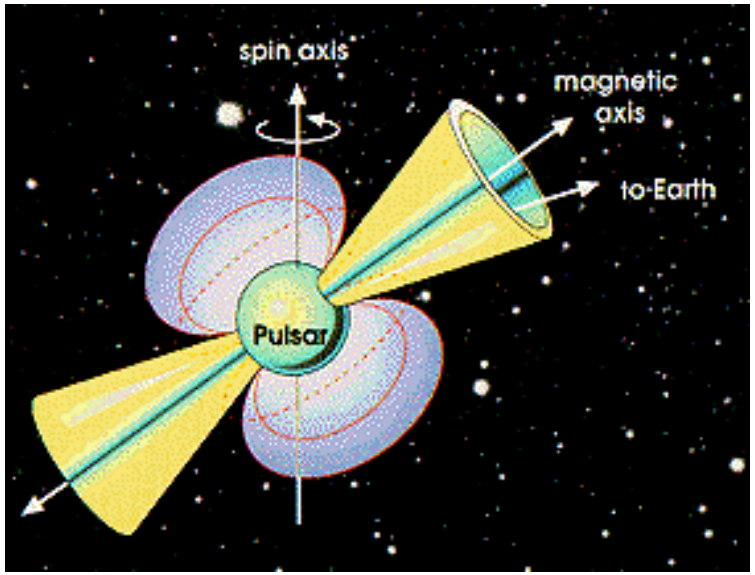
How They Work

- General Idea: Rapidly changing intense magnetic field creates intense electric field
- Lifts charged particles from polar regions into magnetosphere dragged around by rotation
- Accelerated to relativistic speeds – emit synchrotron radiation at all wavelengths in direction of magnetic axis
- Emitted energy slows rotation
- Luminosity of Crab nebula agrees with observed rate of slowing of pulsar

- Pulsars observed in all bands



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Credits

- CP1919 Data, Animation: http://pulsar.ca.astro.it/pulsar/PSR.html
- Pulsar Model: NASA/GFC http://imagine.gsfc.nasa.gov/docs/science/know_l1/pulsars.html