Pulsars

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Outline

The discovery of pulsars

Fig. 1: J. Bell-Burnell at IAU 2006 Assembly

- 1967: discovery by S. Jocelyn Bell-Burnell and Antony Hewish
- results published in Nature, 217, February 24, 1968
- Nobel Prize for Physics in 1974 awarded to A. Hewish and M. Ryle for *"their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars"*

The Nature article

Observation of a Rapidly Pulsating Radio Source

by

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Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.

In July 1967, a large radio telescope operating at a frequency of 81·5 MHz was brought into use at the Mullard Radio Astronomy Observatory. This instrument was designed to investigate the angular structure of compact radio sources by observing the scintillation caused by the irregular structure of the interplanetary medium[1]. The initial survey includes the whole sky in the declination range $-08° < \delta < 44°$ and this area is scanned once a week. A large fraction of the sky is thus under regular surveillance. Soon after the instrument was brought into operation it was noticed that signals which appeared at first to be weak sporadic interference were repeatedly

of three others having remarkably similar properties which suggests that this type of source may be relatively common at a low flux density. A tentative explanation of these unusual sources in terms of the stable oscillations of white dwarf or neutron stars is proposed.

Position and Flux Density

The aerial consists of a rectangular array containing 2,048 full-wave dipoles arranged in sixteen rows of 128 elements. Each row is 470 m long in an E.–W. direction and the N.–S. extent of the array is 45 m. Phase-scanning is employed to direct the reception pattern in declination

Repetition I - Properties

- formation via SNe Type II
- mass: $1.44\,M_\odot < M \lesssim 3\,M_\odot$
- density: $10^{14}\,\mathrm{g\,cm^{-3}}$
- size: $10 - 15\,\mathrm{km}$
- very strong B-fields from $10^{8}\,\mathrm{G}$ up to $10^{12}\,\mathrm{G}$
- conservation of angular momentum leads to fast rotation

Repetition II - Build-up

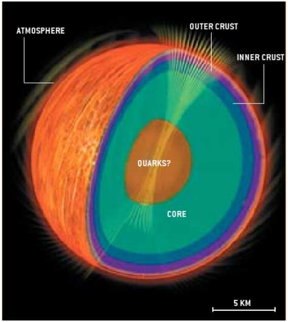

Fig. 2: Neutron Star Structure

- outer crust: solid crust of heavy nuclei + relativistic degenerate electrons
- inner crust: nuclei + relativistic degenerate electrons + superfluid neutrons
- core: superfluid neutrons + a few superfluid, superconducting protons + relativistic degenerate electrons (perhaps solid core consisting of sub-nuclear particles)

What's it that makes a pulsar out of a NS?

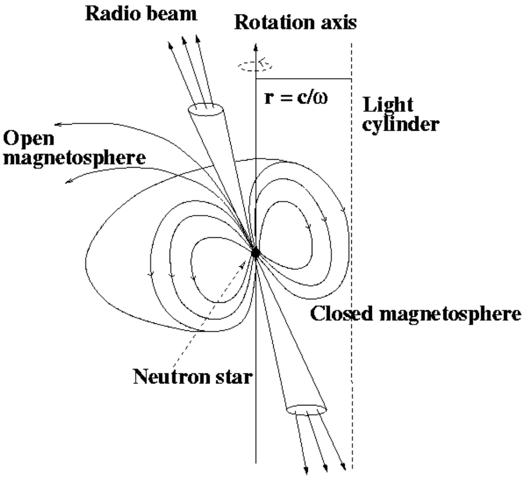

Fig. 3: Lighthouse Model

The Pulsar Zoo

2 types:

- **accretion powered pulsars:**
  - energy supply via accretion
  - millisecond pulsars
  - spin behavior not always the same
- **rotation powered pulsars (radio pulsars):**
  - rotational energy is used
  - slow down
  - magnetars

Advanced Basics I

- total available energy for a rotation-powered pulsar = loss of rotational energy

$$\dot{E} = I\,\omega\,\dot{\omega} = 4\pi^2\,I(\dot{P}/P^3) \tag{1}$$

with $I \approx 10^{45}\,\mathrm{g\,cm^2}$

- di-polar magnetic fields:

$$B = 3.2 \times 10^{19}\,(P\,\dot{P})^{0.5}\,\mathrm{G} \tag{2}$$

(on the equator)

Advanced Basics II

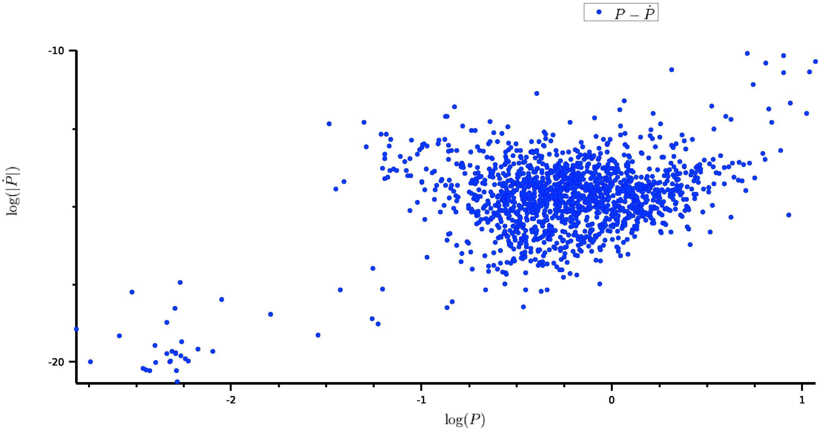

Fig. 4: $P - \dot{P}$-diagram for non-binary pulsars with radio emission

Advanced Basics III

Although generally slowing down pulsars sometimes spin up!
$\Rightarrow$ can be used to probe the interior of neutron stars

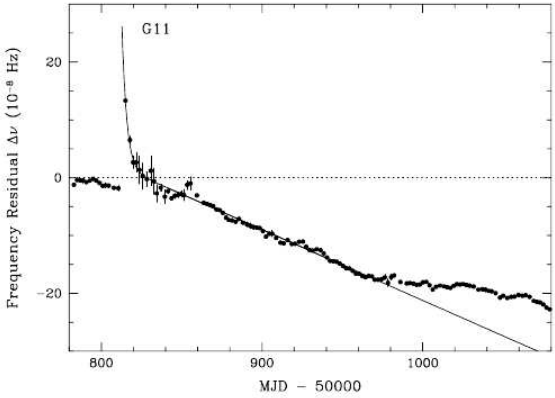

Fig. 5: a small glitch of the Crab pulsar

Vela Pulsar

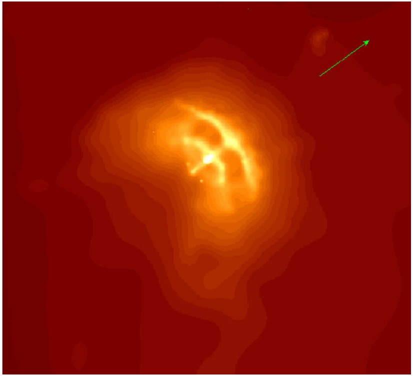

Fig. 6: Vela Pulsar in X-rays (Chandra)

- distance: 0.5 kpc
- $P = 0.0893\,\mathrm{s}$
- $\dot{P} = 1.25 \cdot 10^{-13}$
- $B = 3 \cdot 10^{12}\,\mathrm{G}$
- $\dot{E} = 7 \cdot 10^{36}\,\mathrm{erg\,s^{-1}}$
- age: 11000 yrs

$\Longrightarrow$ middle-aged pulsar

Crab Pulsar

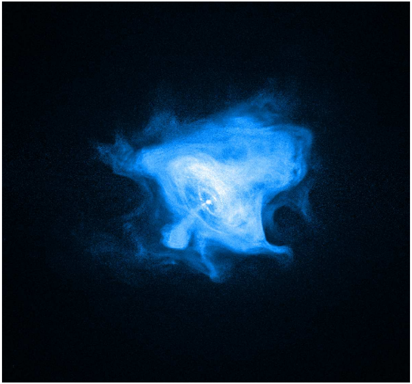

Fig. 7: Crab Pulsar in X-rays (Chandra)

- distance: 2.0 kpc
- $P = 0.0334\,\mathrm{s}$
- $\dot{P} = 4.21 \cdot 10^{-13}$
- $B = 4 \cdot 10^{12}\,\mathrm{G}$
- $\dot{E} = 4 \cdot 10^{38}\,\mathrm{erg\,s^{-1}}$
- age: 1260 yrs

$\Longrightarrow$ young pulsar

Pulse Profiles

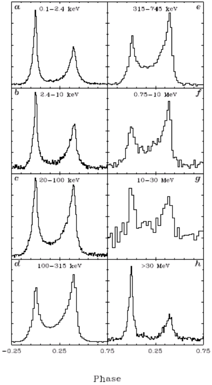

Fig. 8: pulse profiles of the Crab pulsar

⇒ no phase shift

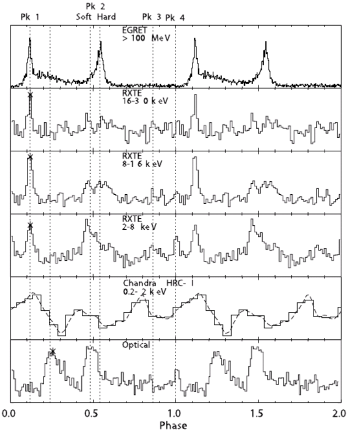

Fig. 9: pulse profiles of the Vela pulsar

⇒ phase shift

Pulsar Spectra I

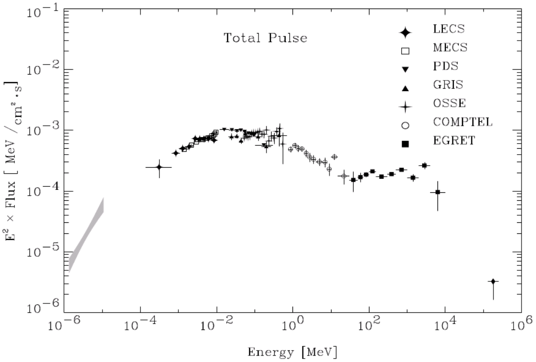

Fig. 10: spectrum of the Crab pulsar

spectrum is made up from different parts:

total = nebula + pulsed (+ thermal)

Pulsar Spectra II

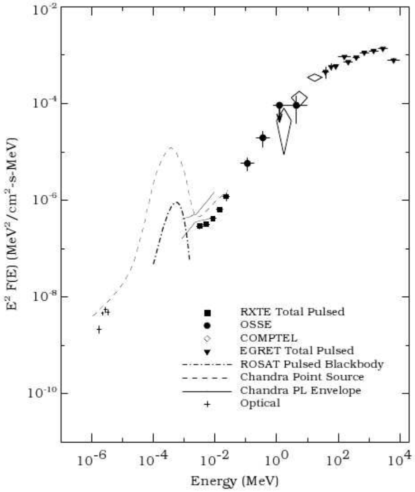

Fig. 11: spectrum of the Vela pulsar

Emission models

Requirements

- must explain phase relation
- must explain pulse profiles
- produce light at all wavelengths
- must explain polarization
- ...

$\Longrightarrow$ several models that differ in the geometry of the emitting regions

Goldreich-Julian I

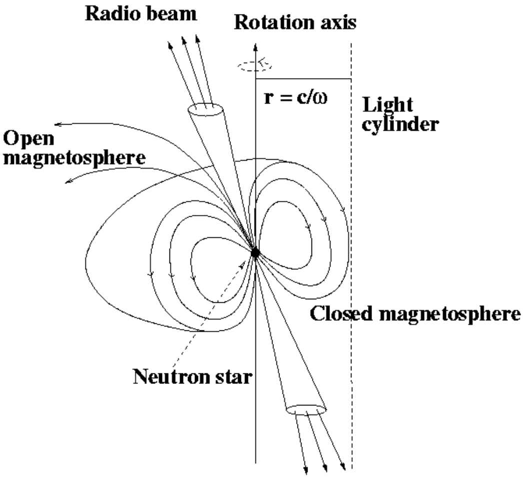

Fig. 3: Lighthouse Model

Goldreich-Julian II

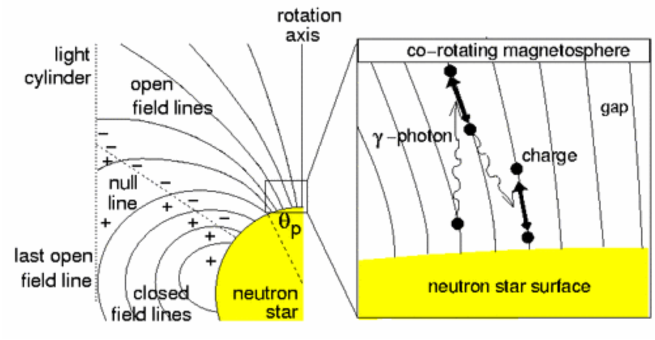

Fig. 12: neutron star magnetosphere

Polar Cap Model

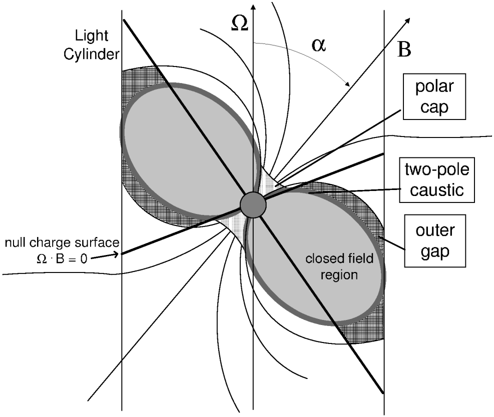

Fig. 13: emission models

- explains high-energy spectrum quite well
- cannot explain double-peaked pulses

Outer Gap Model

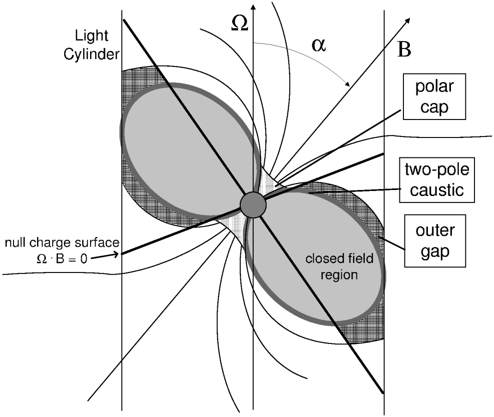

Fig. 13: emission models

- can explain double-peaked pulses but causes problems with some other parts of the pulse profile
- some problems with very high energy radiation

Two-pole caustic model

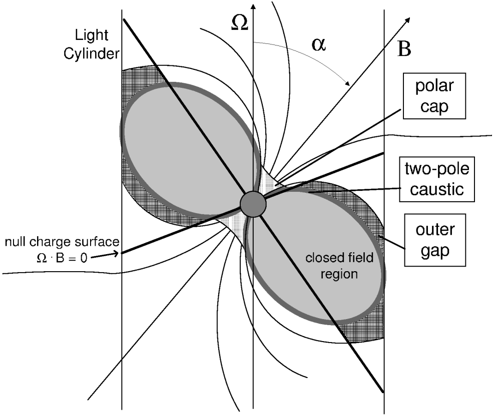

Fig. 13: emission models

- purely geometric idea: particles radiate along the last open field lines
- fundamentally new: outward emission below the null surface $\Rightarrow$ emission from both poles can be observed
- physical explanation by the slot gap

Comparison between models and measurements

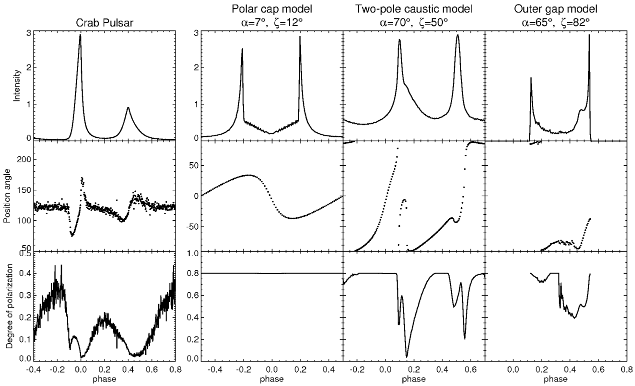

Fig. 14: predicted profiles for different models

$\Longrightarrow$ all models have strengths and weaknesses

Pulsars with Fermi

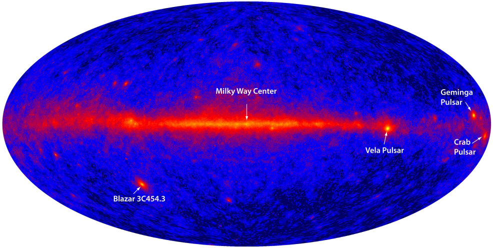

Fig. 15: Fermi's first light

- emitting regions will be mapped
- better spectra + shape of cutoffs
- better pulse profiles
- ...

$\Longrightarrow$ It will be much easier to determine the correct emission model!

References I

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Figures

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Figure 3: http://arecibo.tc.cornell.edu/PALFA/images/pulsarmodel.jpg
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Figure 14: Kaspi, V. M., Roberts, M. S. E. &, Harding, A. K., 2004, astro-ph/0402136v2
Figure 15: http://science.nasa.gov/headlines/y2008/26augfirstlight.htm

Audio

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Thank you for your attention!
Questions???