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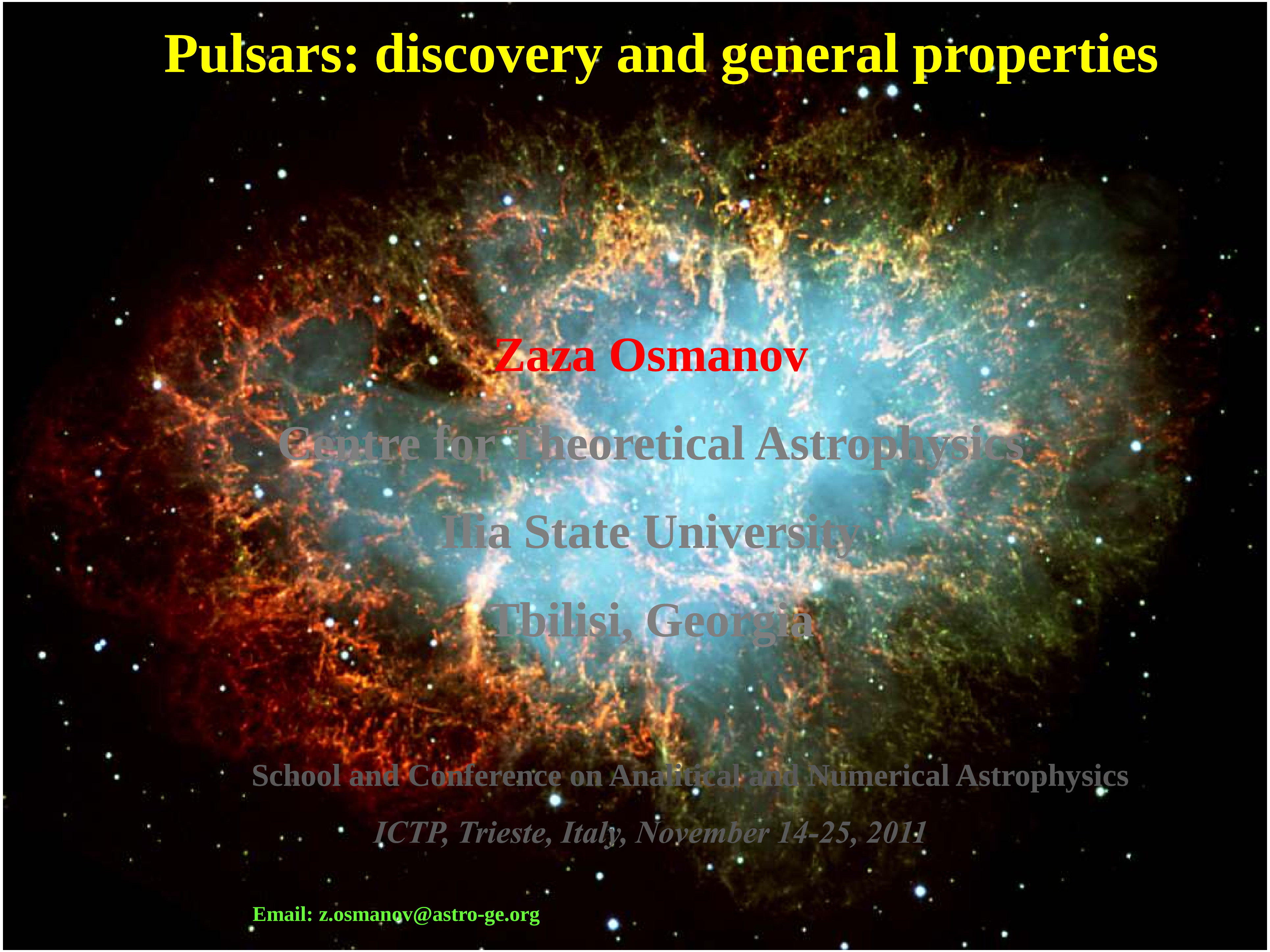
14 - 25 November, 2011

Pulsars - Discovery and General Properties

Zaza Osmanov

Georgian National Astrophysical Observatory, Tbilisi
Georgia



Pulsars: discovery and general properties

Zaza Osmanov

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ICTP, Trieste, Italy, November 14-25, 2011

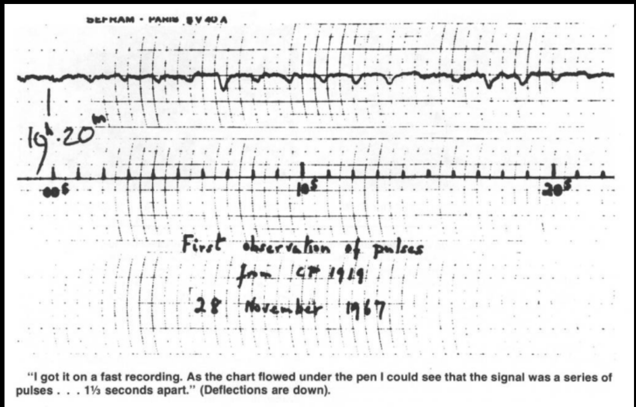
Email: z.osmanov@astro-ge.org

Why are pulsars important?

Fundamental physics...

Astrophysics...

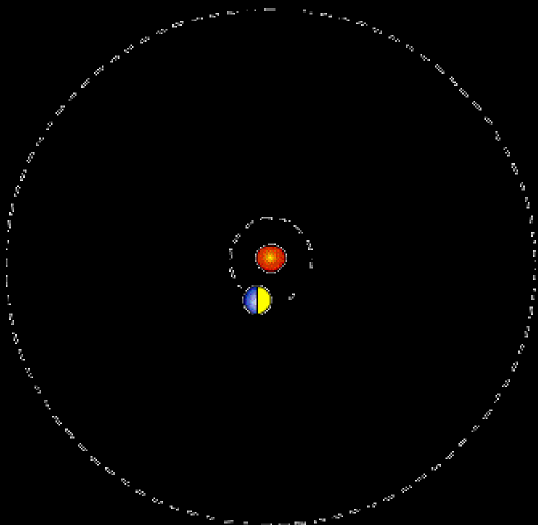
Two Nobel Prizes



"I got it on a fast recording. As the chart flowed under the pen I could see that the signal was a series of pulses . . . 1⅓ seconds apart." (Deflections are down).

The discovery of pulsars

Antony Hewish



The discovery of the binary pulsar

Joseph H. Taylor Jr.

Russell A. Hulse

Interesting fact: *Voyager interstellar mission*

The Voyager (1977) Golden Records

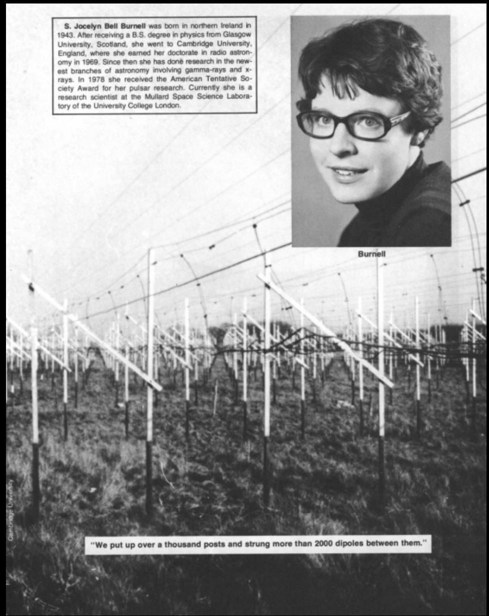
They contain sounds, images selected to portray the diversity of life and culture on Earth

&

Our location in the Solar System

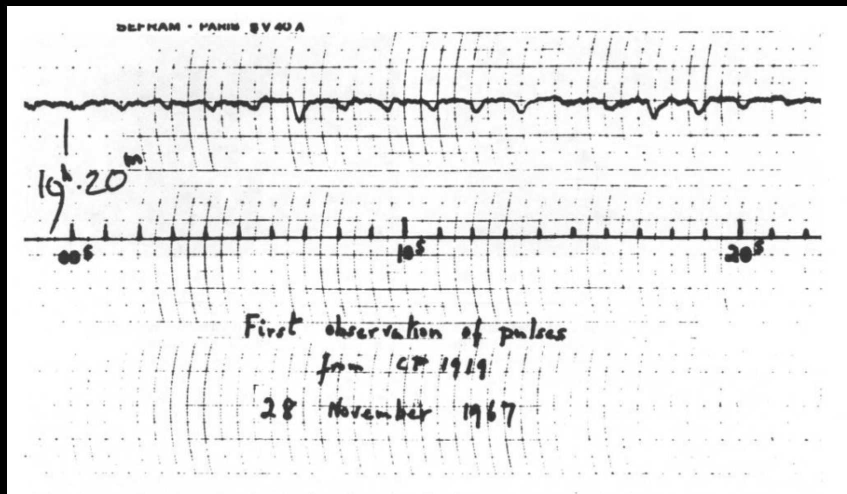
History...

Everything started at Cambridge, where a young PhD student Jocelin Bell worked on constructing a radio telescope



Jocelyn Bell

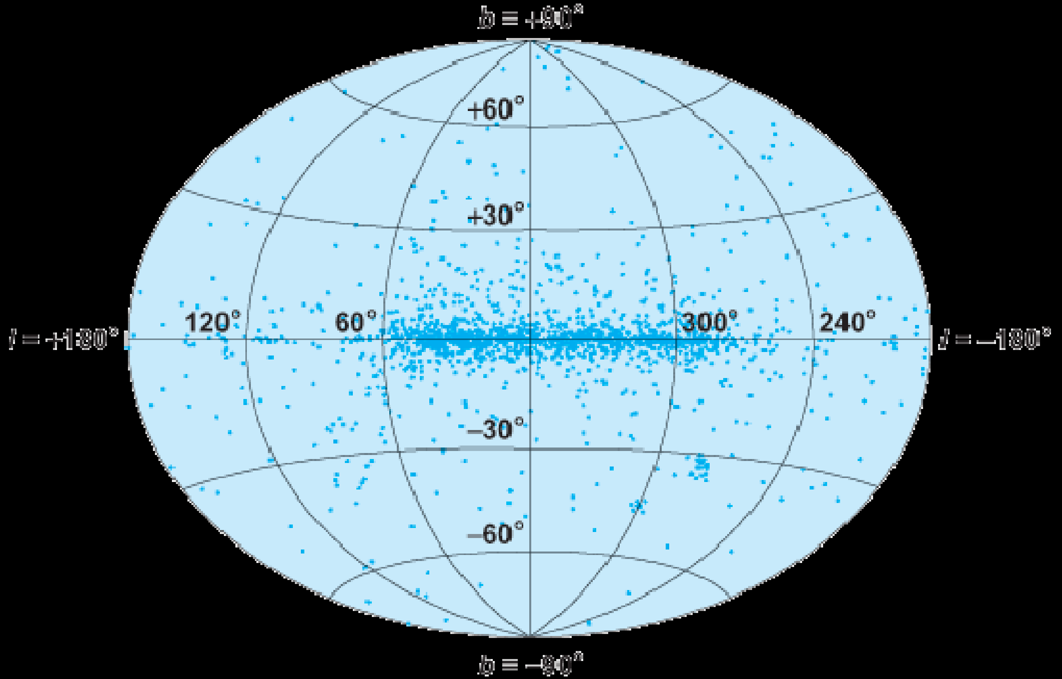
In November 28, 1967 she discovered the first radio pulses from: PSR B1919+21



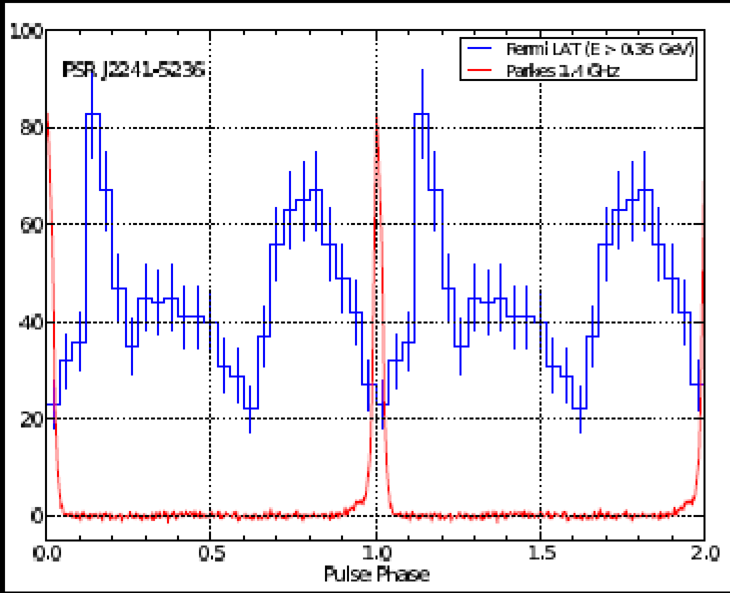
"I got it on a fast recording. As the chart flowed under the pen I could see that the signal was a series of pulses . . . 1⅓ seconds apart." (Deflections are down).

Hewish et al. 1968, Nature, 217, 709

Distribution



Why rotating neutron stars?



Observational facts:

Pulsar periods: $1.4ms - 8.3s$

Pulsar periods always increase

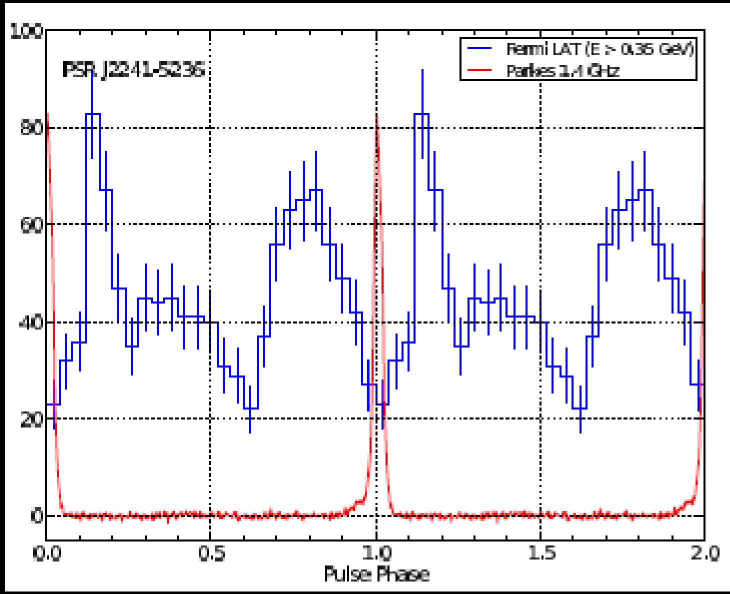
Pulsars are very good clocks

In a time 1.4ms light travels ~400km

Therefore, this is the maximum size of the source

Rotation, pulsation or a binary system?

Why rotating neutron stars?



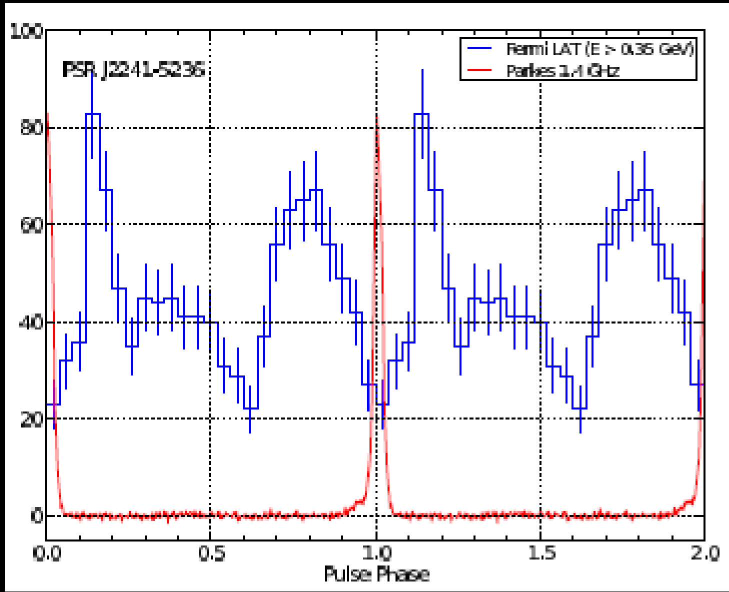
Let us consider the following condition for rotation: $F_g \geq F_{cf}$

$$F_g = \frac{GMm}{R^2}; \; F_{cf} = m\Omega^2 R$$

$$M = \frac{4}{3}\pi R^3 \rho; \quad \Omega = \frac{2\pi}{P} \qquad P \geq \sqrt{\frac{3\pi}{G\rho}}$$

Maximum mean density $\rho \approx 10^8 g/cm^3 \Rightarrow P > 1.2s$

Why rotating neutron stars?

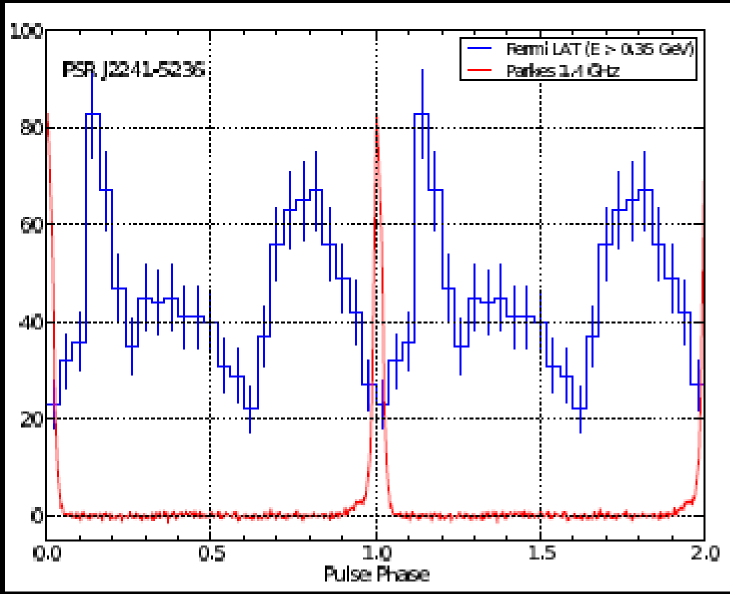


For the binary system:

$$\frac{GM}{r^2} \approx \Omega^2 r$$

But in this case $r \geq 400km$ and we recover the same result: P>1s

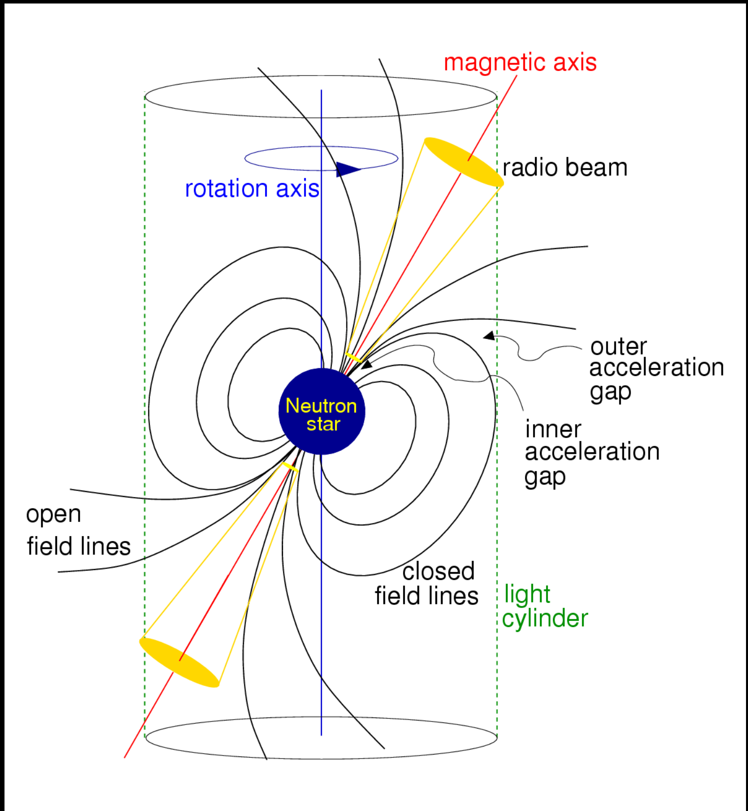
Why rotating neutron stars?



Pulsating neutron stars have densities exceeding the white dwarf density by 6 orders of magnitude, leading to the fundamental period of the order of

$$\sim 10^{-3} << 1.4ms$$

Pulsar model



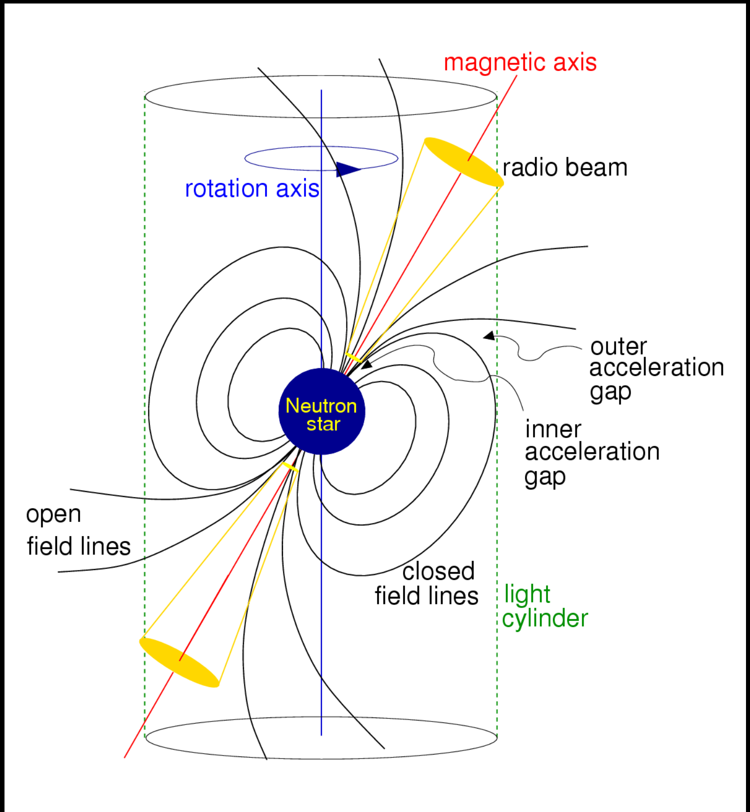
The radiation is observed when the beam of emission is pointing towards the Earth

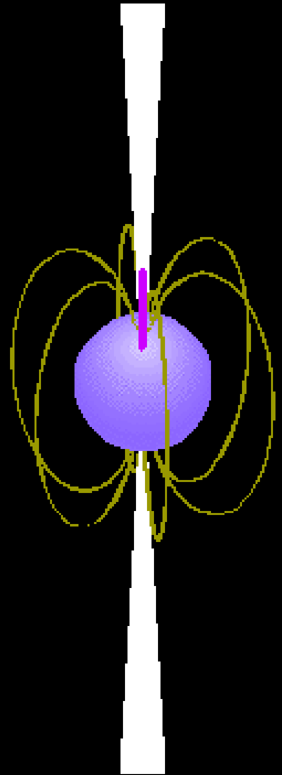
The first argument that pulsars are neutron stars with surface magnetic fields of around

10^{12} G was put forward by Gold

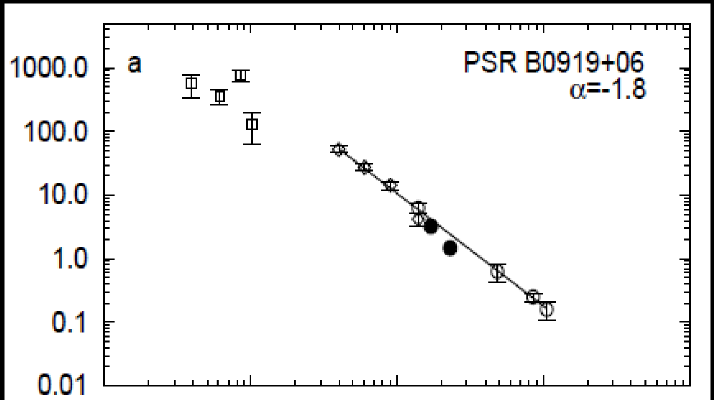
(1968, Nature, 218, 731)

Pulsar model



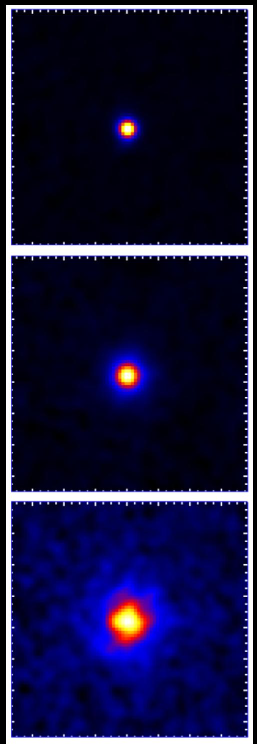


Some properties: spectra

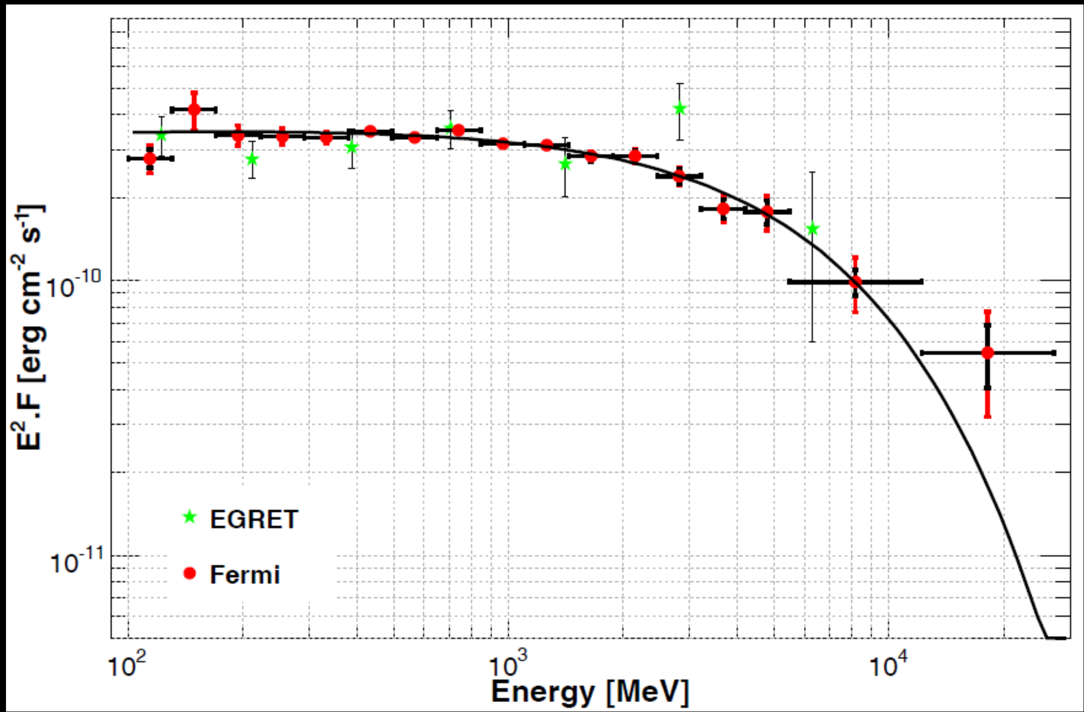


The radio intensity is a steep power law $I_\nu \propto \nu^{-\alpha}, \alpha \sim -1.5$

for $\nu < 1GHz$

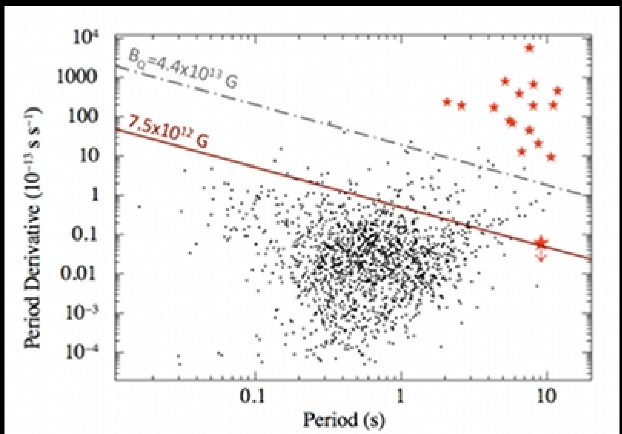


VHE radiation



Some properties: period

Up to now there are more than 1500 pulsars discovered and the period is in the range: ~1.4ms-8.3s

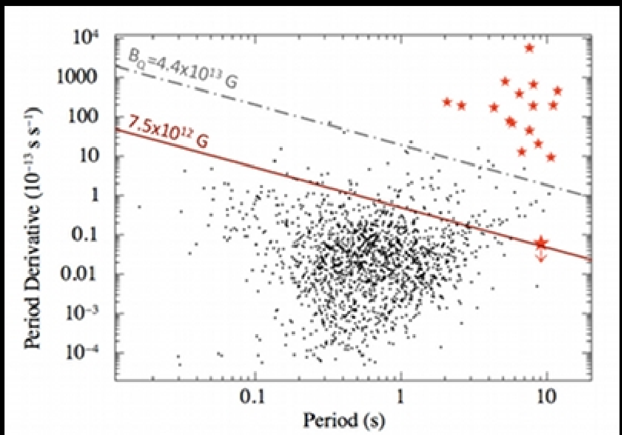


According to observations, all pulsars are found to increase in periods.

The typical value of the period derivative is of the order of $\dot{P} \sim 10^{-15}\, s\, s^{-1}$

Some properties: period – slowdown luminosity

For the Crab pulsar the period derivative is by two orders of magnitude higher than for typical pulsars $\dot{P} \approx 4.21\times10^{-13} s\, s^{-1}$



Energy budget

$$\dot{W} = \frac{d}{dt}\frac{I\Omega^2}{2}$$

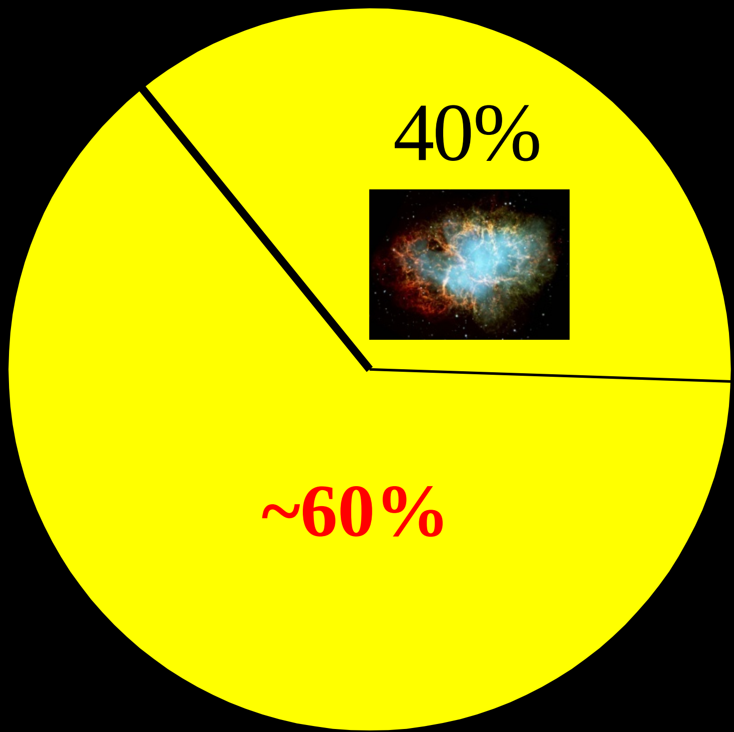
$$I = \frac{2}{5}MR^2;\ M \approx 1.5M_S;\ R \approx 10km$$

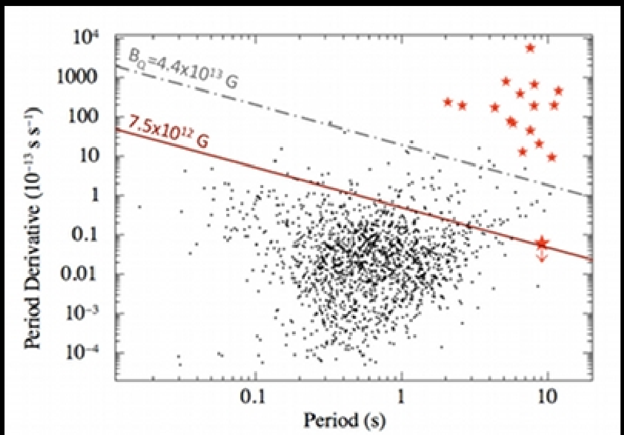
$$P \approx 0.0332s \Rightarrow \dot{W} \approx 5\times10^{38} erg/s$$

Some properties: period – slowdown luminosity

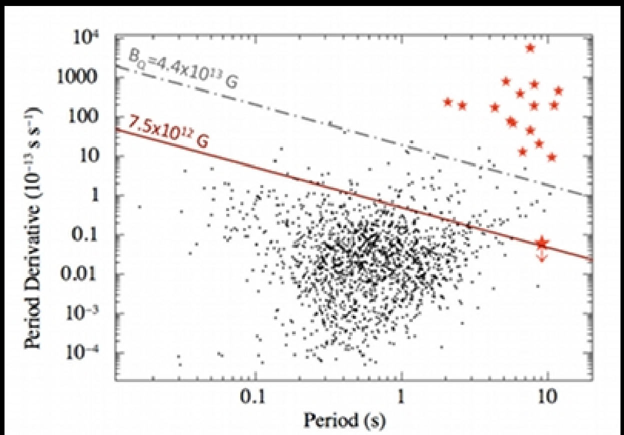
$$\dot{W} \approx 5\times10^{38} erg/s$$

0.2% 

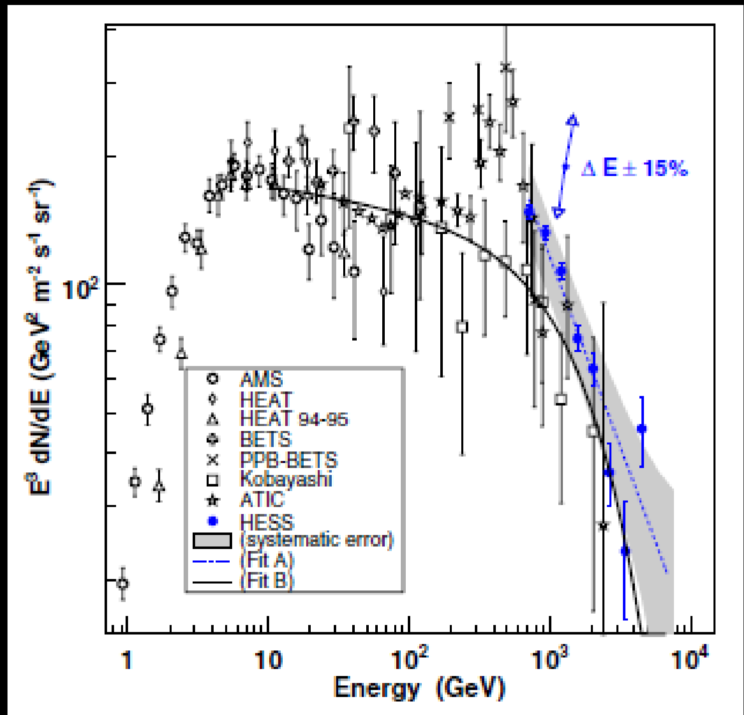




Some properties: period – slowdown luminosity



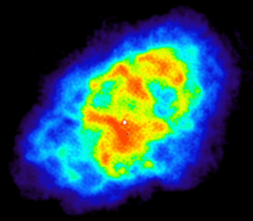
Cosmic ray electrons: HESS collaboration



Aharonian et al. 2008, PRL 101, 261104

Some properties: multiwavelength consideration

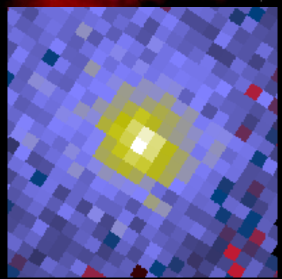
Rad

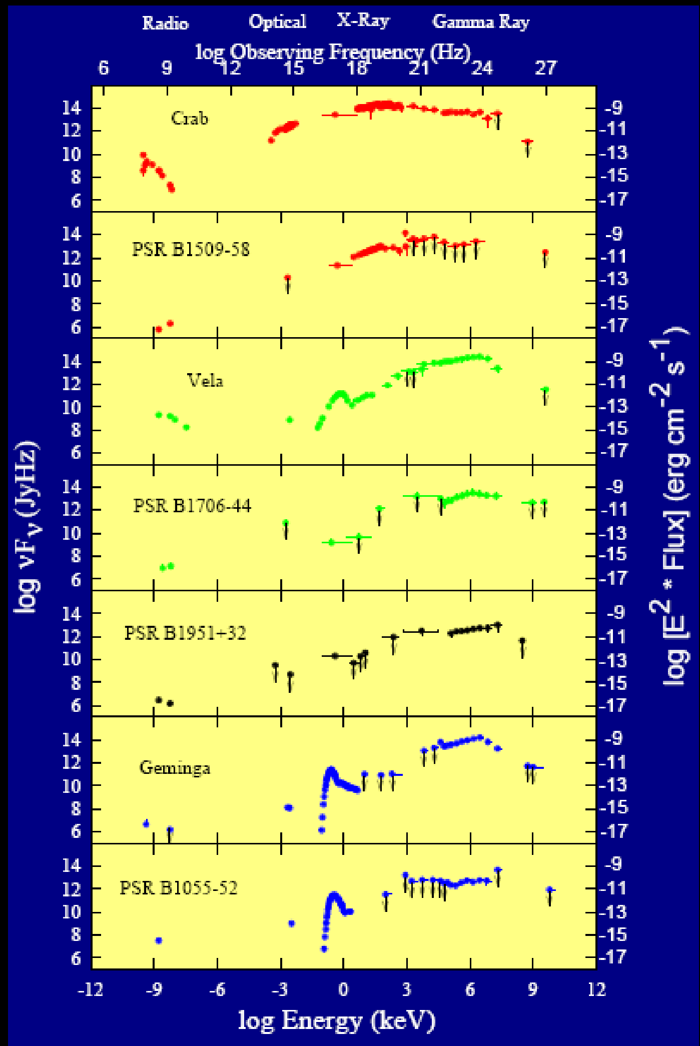


Opt

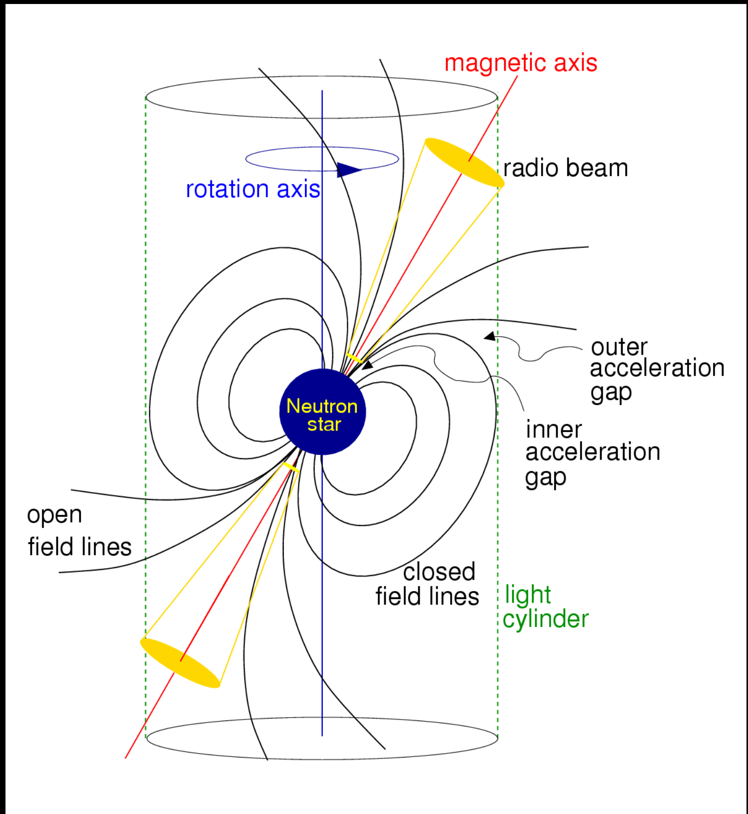
X

g





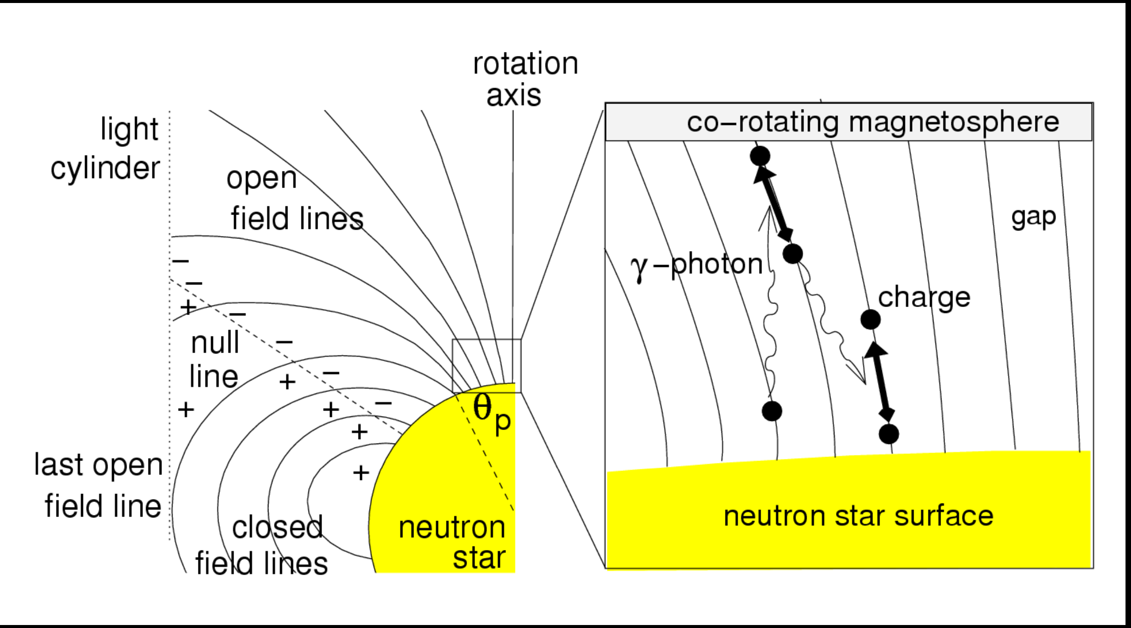
Emission: vacuum dipole approximation



Even for the simplest model of the pulsar, one can consider the pulsar magnetic field as the magnetic dipole. Then it is clear that due to rotation, the altering electric field is created, which in turn created the altering magnetic field…

Emission: nonvacuum approach

Aligned rotator



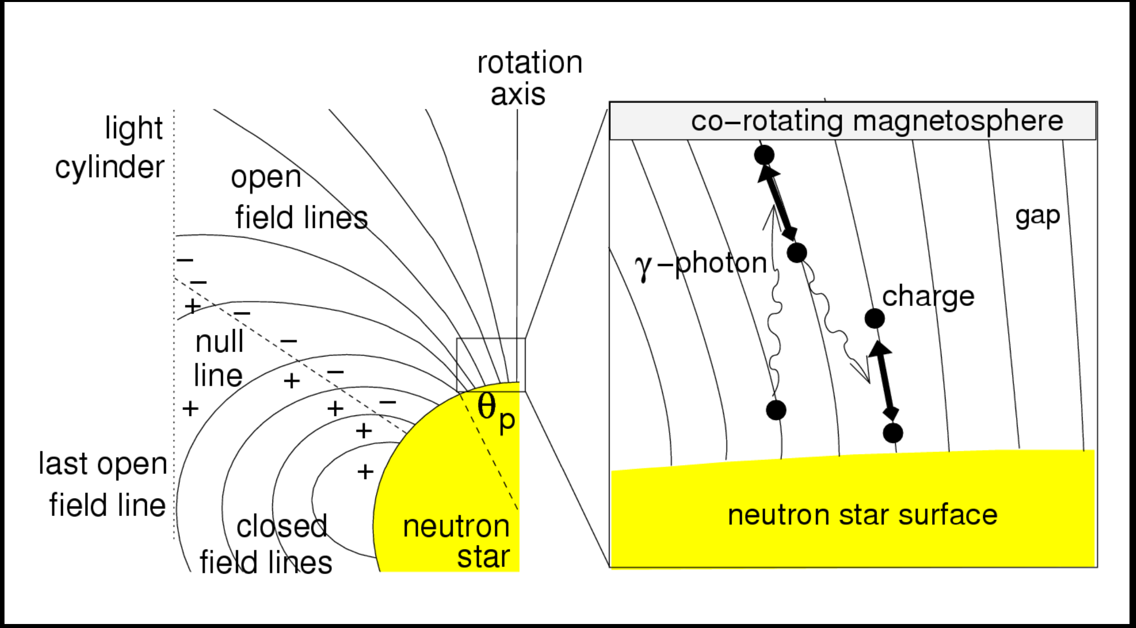
Goldreich & Julian, 1969, ApJ, 157, 869

Goldreich and Julian argued that the particles moving along the closed magnetic field lines must corotate.

The corresponding lengthscale is the light cylinder radius – a hypothetical zone, where the linear velocity of rotation equals the speed of light

Emission: nonvacuum approach

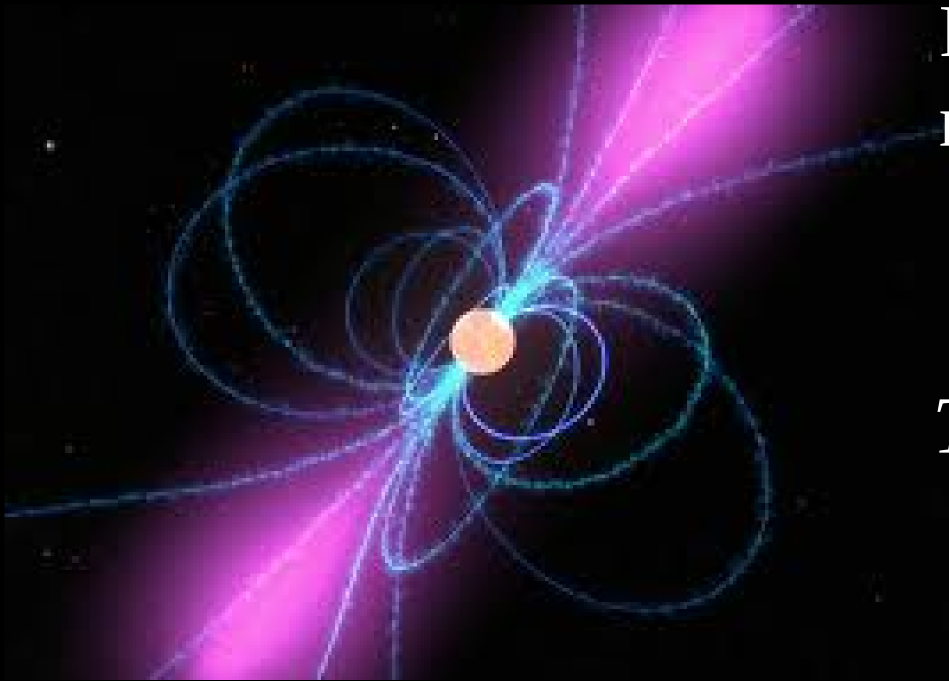
Aligned rotator



Goldreich & Julian, 1969, ApJ, 157, 869

These particles are accelerated in the electric field and radiate photons because of the curvature radiation in the dipolar field. For photon energies greater than $2mc^2$ pair production $B_0 + \gamma \rightarrow e^+ + e^- + \gamma'$ in the ambience of the magnetic field becomes possible.

Emission: nonthermal mechanisms (why?)

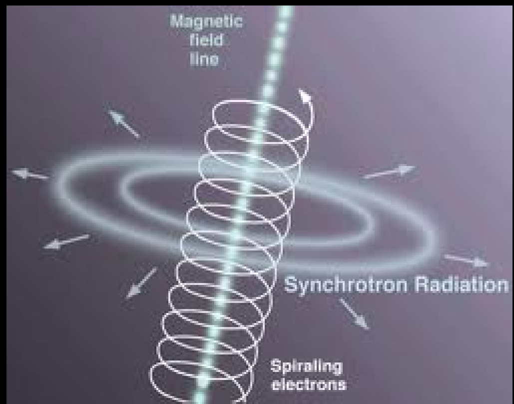


Radio luminosities lie in the range $\left(10^{25} - 10^{28}\right) erg/s$

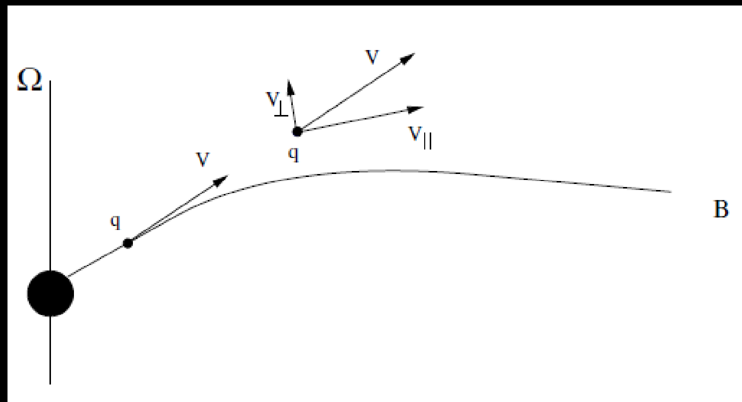
$$T \sim \left(10^{23} - 10^{26}\right) K$$

Emission: nonthermal mechanisms

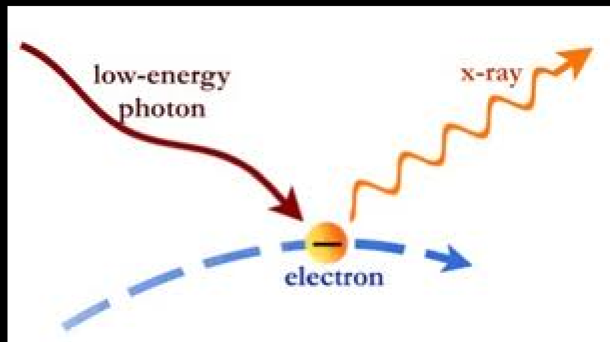
Synchrotron r.



Curvature r.

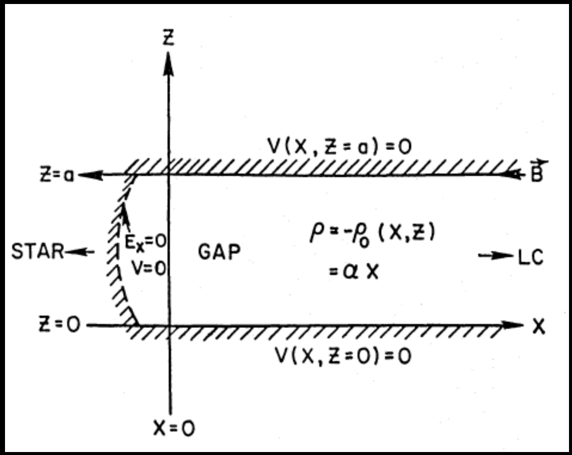


Inverse Compton



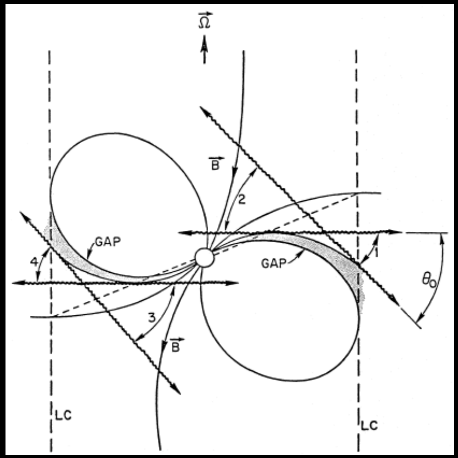
Emission: acceleration problem

Gap model



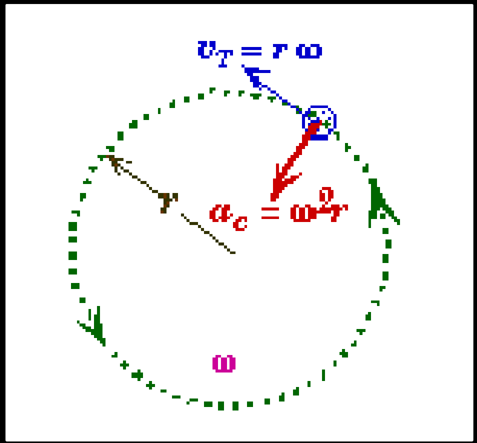
Goldreich & Julian, 1969

Outer gap model



Cheng et al. 1986

Centrifugal acceleration



Gold, 1968; …Machabeli & Rogava, 1994

Thank you