



Pulsars

How Electricity Lets the Stellar Undead Live Again!

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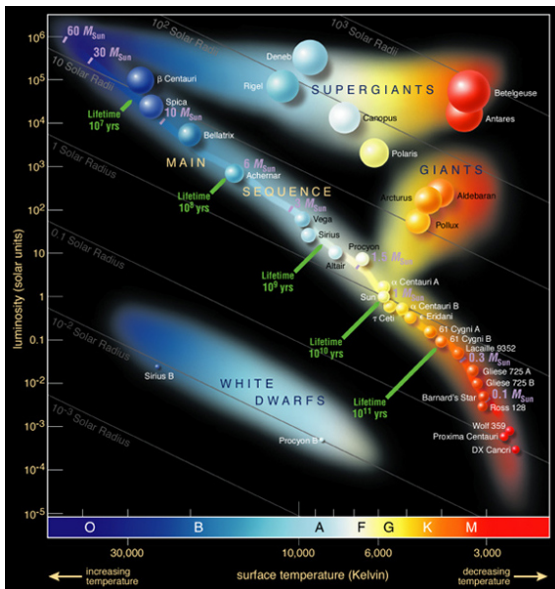
TriState Astronomers General Club Meeting, Dec 17, 2014

Stars are different

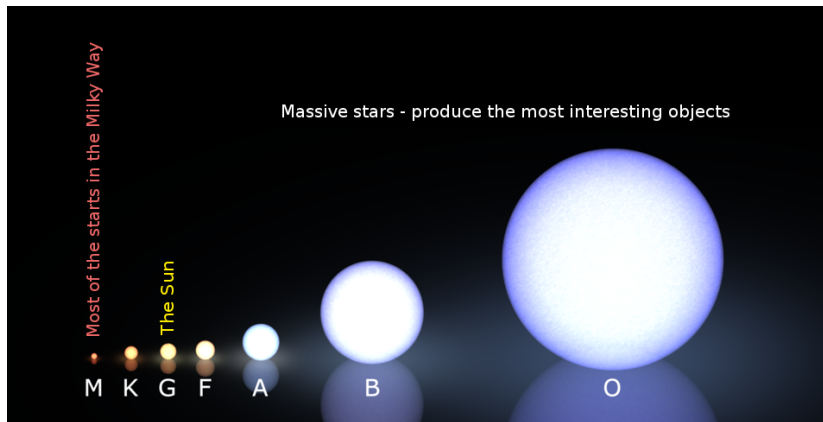
Our Galaxy - the Milky Way



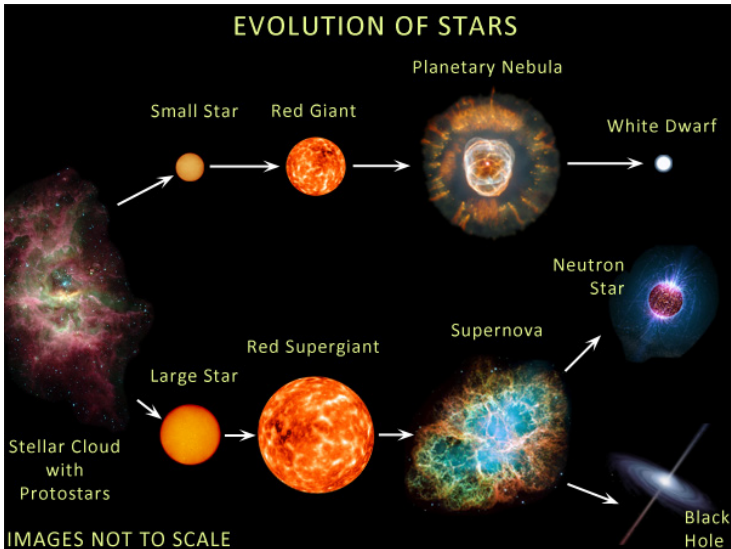
Hertzprung-Russell diagram



Main sequence stars



Stellar evolution

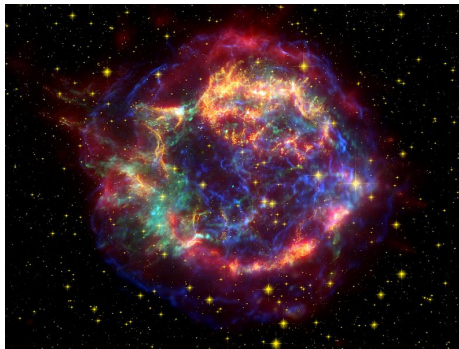


Supernova: violent death of a massive star



Supernova Remnant: Cas A

Short-living remnant of supernova explosion



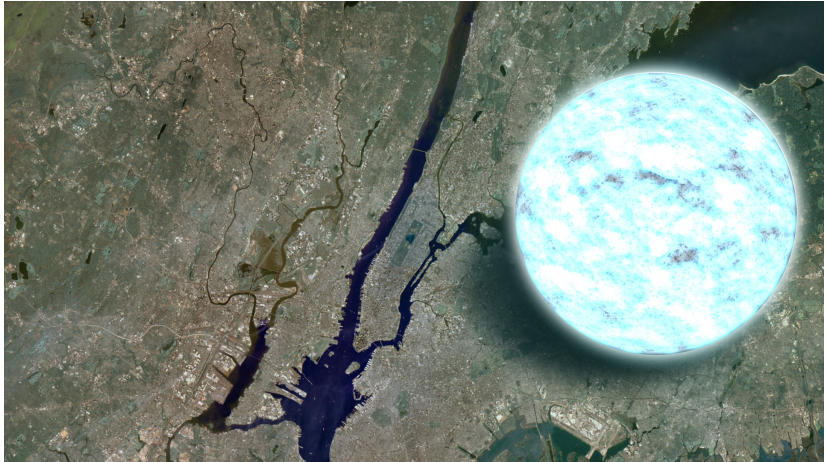
multiwavelength image



optical image

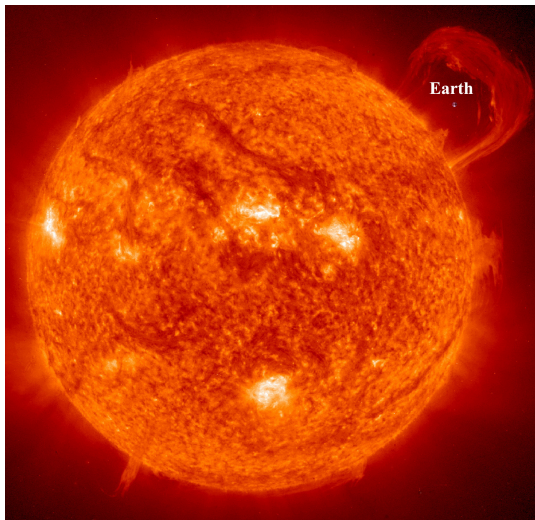
Neutron Star to scale

Neutron Star over Manhattan

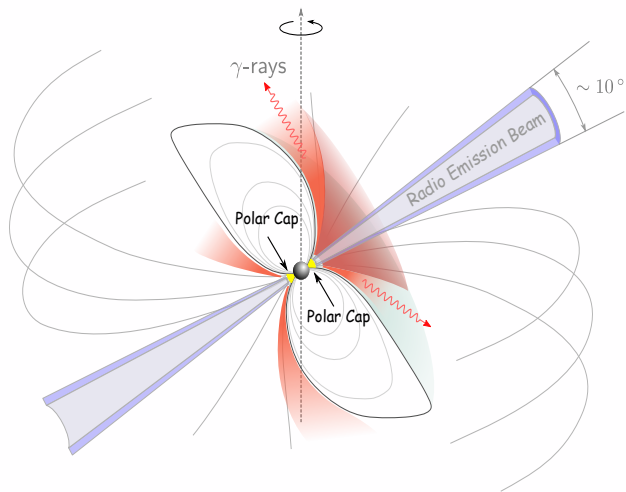


Sun and Earth to scale

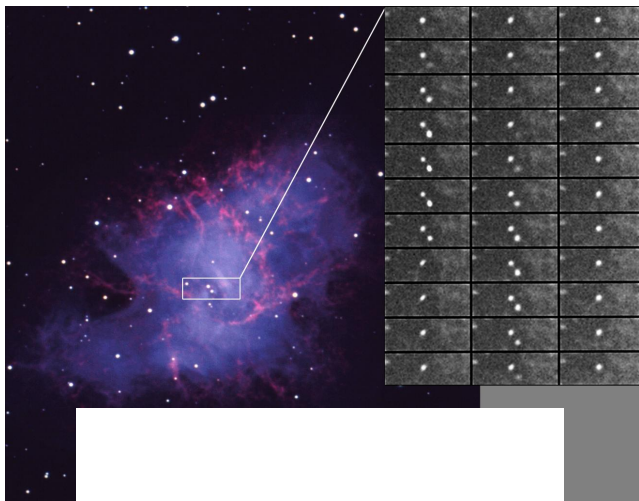
NS is ~ 50% more massive than the Sun!



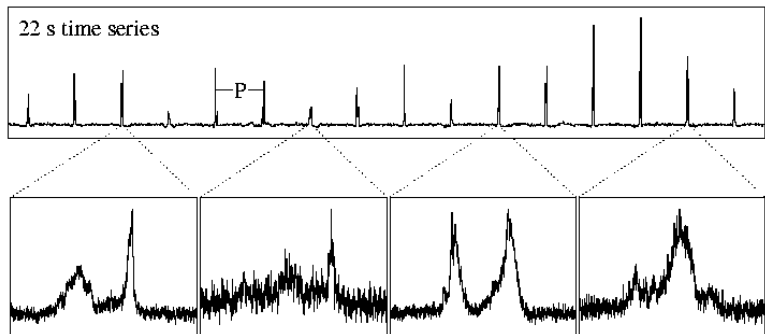
Birth of a zombie star



Pulsating optical source: “Crab pulsar”



Pulsars in radio

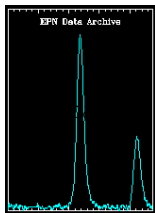


140 ms zoom in on individual pulses

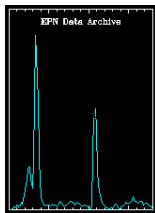
Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer

Sounds of pulsars

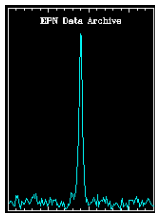
PSR B1937+21
 $P \approx 0.0015$ s



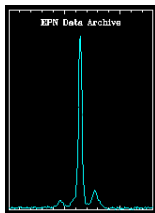
Crab
 $P \approx 0.033$ s



Vela
 $P \approx 0.089$ s

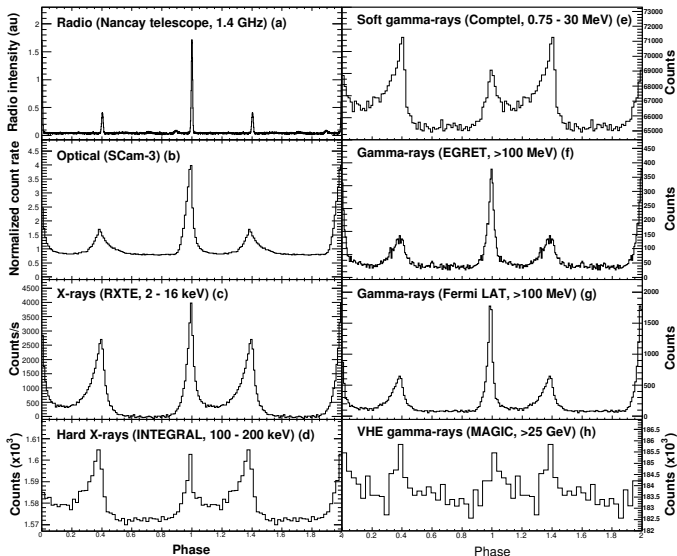


PSR B0329+54
 $P \approx 0.71$ s



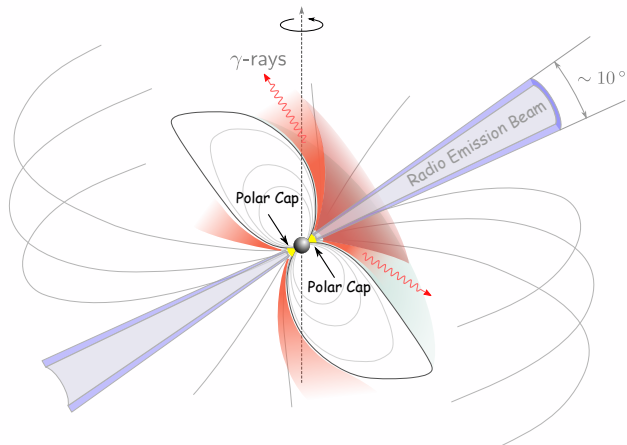
(Credit: Jodrell Bank Centre for Astrophysics)

Crab pulsar: from radio to gamma-rays



Pulsar is a cosmic electric lighthouse

rapidly rotating magnetized object



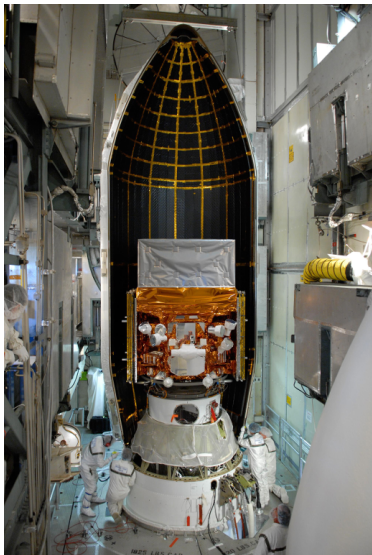
Radio telescopes are huge

Arecibo Observatory – the largest radio telescope



Gamma-ray telescopes are small

Fermi Space Observatory – the largest gamma-ray telescope



Pulsar fact sheet

- Population: > 2000
- Energy source: star's rotation
stored energy $\sim 10^{51}$ ergs
- Emissivity: up to 10^{38} erg/sec
 $\sim 10^5$ of Sun's emissivity
- Periods: ~ 1 msec -10 sec
Linear velocity of rotation at the surface: up to $\sim 15\%c!$
- Extremely stable clocks:
stability $\delta P/P$ up to about one part in $10^{15}!$

NSs are **the** most extreme objects in the Universe

- Mass: $\sim 1.4M_{\text{Sun}} \simeq 3 \times 10^{33} \text{ g}$
- Radius: $10 \text{ km} \simeq 3r_g$
only ~ 3 times larger than a black hole!
- Mean Density: $\sim 10^{15} \text{ g/cm}^3$
Gigantic “atomic nucleus”!
- Magnetic field: $\sim 10^{12} \text{ G}$ (up to $\sim 10^{15} \text{ G}$)
“Density” of the magnetic field: $\gtrsim 40 \text{ g/cm}^3! [(B^2/8\pi)/c^2]$
- Voltage: $\sim 10^{16} \text{ V}$

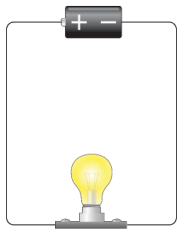
Density: Osmium 22.59 g/cm^3 , Plutonium 19.82 g/cm^3 ,
Iron 7.87 g/cm^3 , Water 1 g/cm^3 , Air 0.00126 g/cm^3

Pulsar on a tabletop



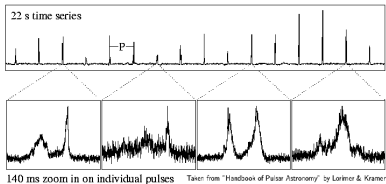
Pulsars are shining **not** because they are hot

Pulsars are a non-thermal emitter

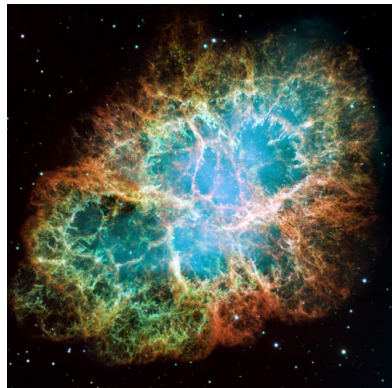
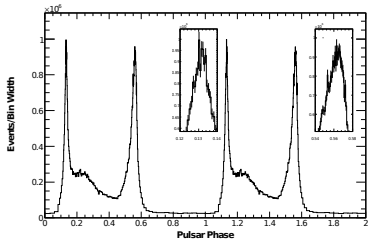


Pulsar emission is like as a whistle of a locomotive

radio:



gamma:

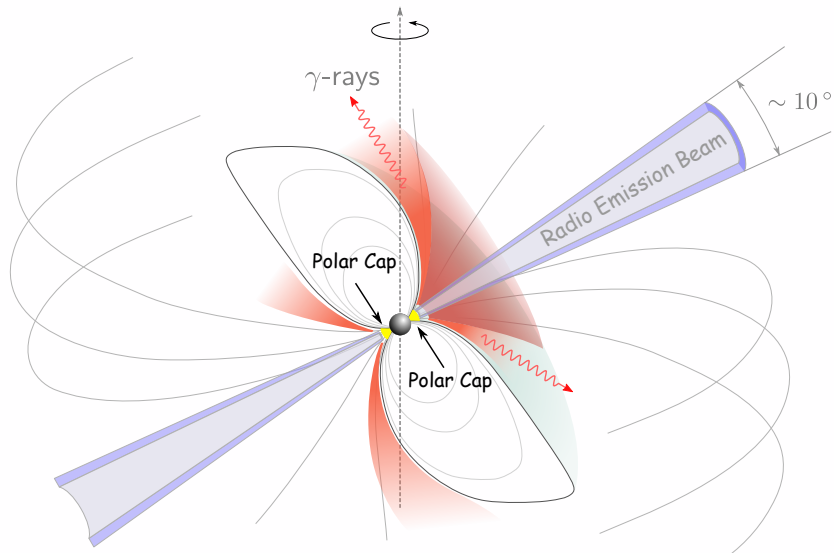


- Very little energy goes into emission

- Energy goes into plasma

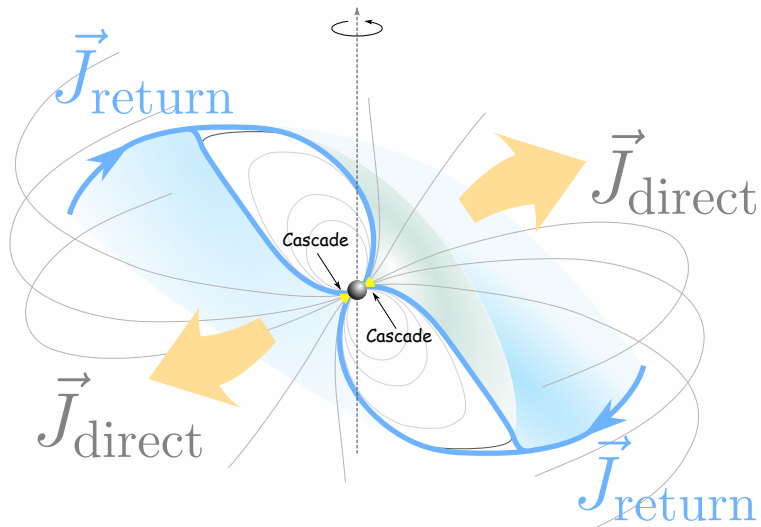
Observer's view of pulsar

Empirical picture of pulsar



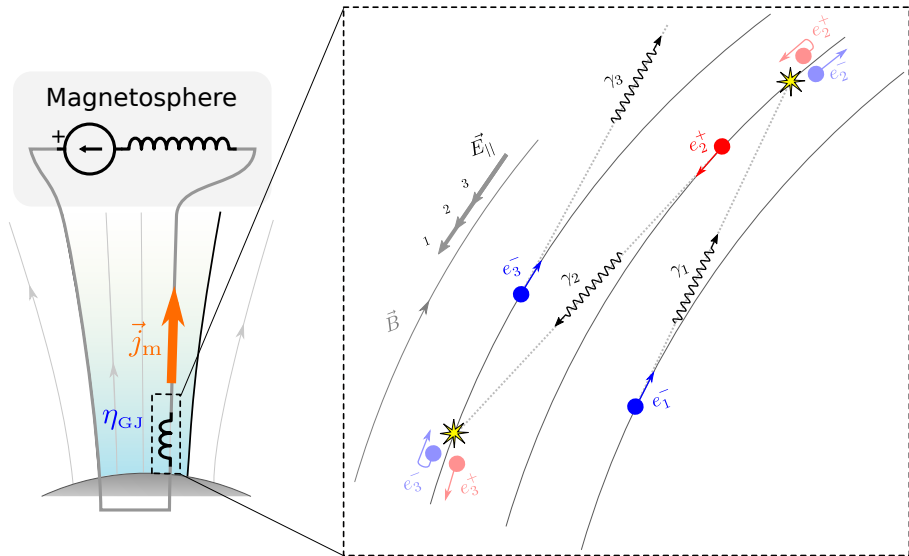
Global electric circuit in the magnetosphere

Theorist's view of pulsar magnetosphere



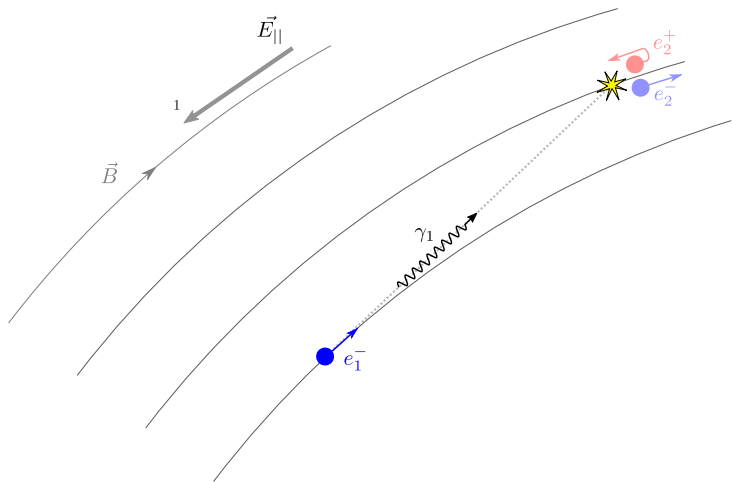
Pulsars must create their own wires

Physical model: plasma creation in the magnetosphere



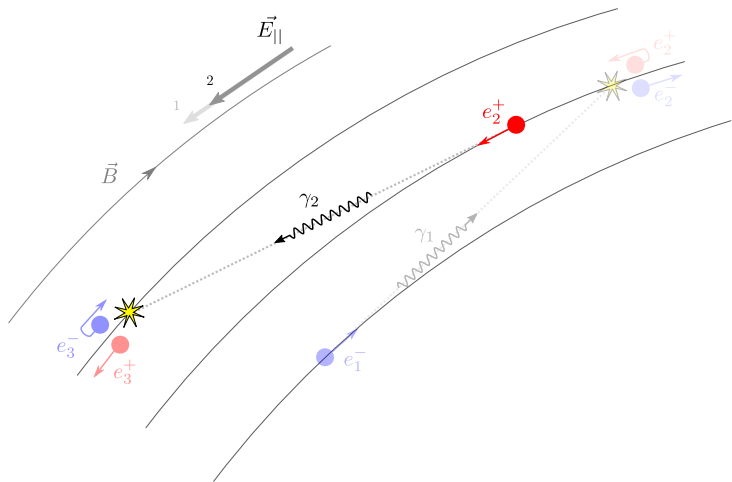
How electron-positron cascades work

Magnetic field is opaque and is helping to “boil the vacuum”



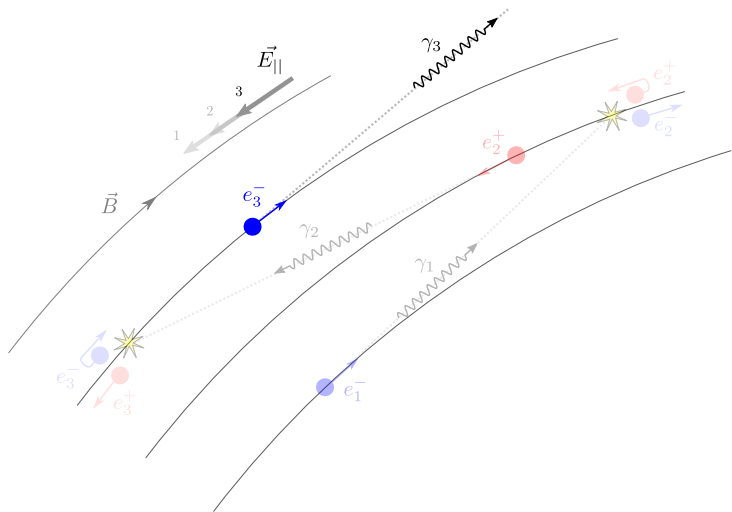
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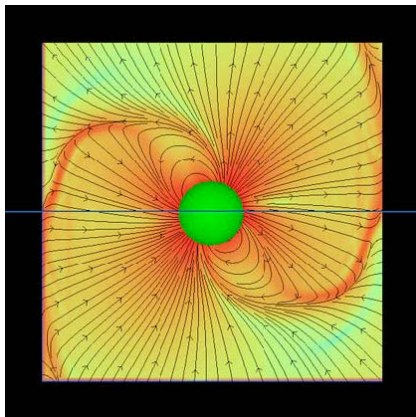
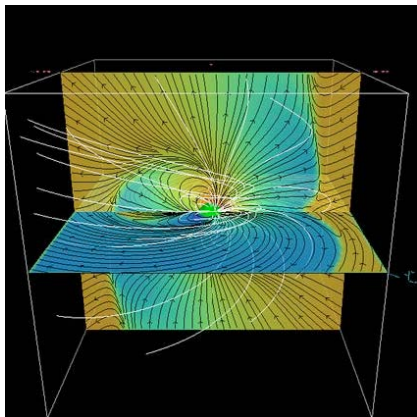
How electron-positron cascades work

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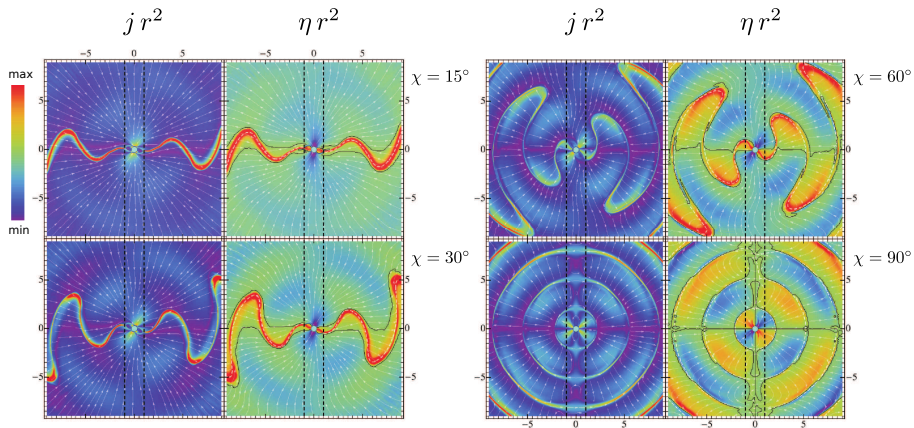
Numerical models of pulsar magnetosphere

Inner parts



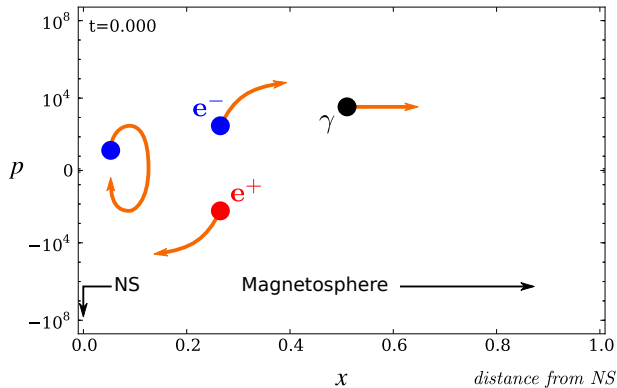
Numerical models of pulsar magnetosphere

Outer parts



Numerical models of electron-positron cascades

particles' momenta $p \equiv \frac{v}{c}\gamma$

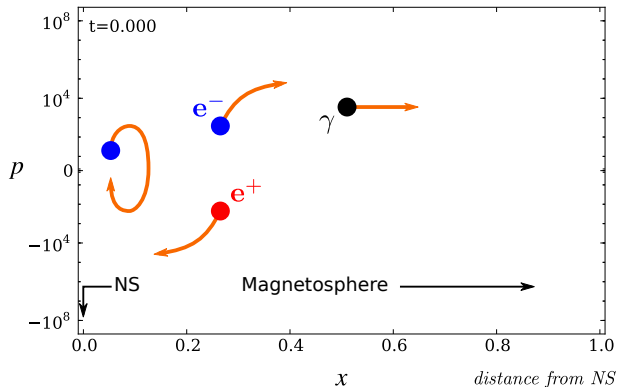


• electrons • positrons • γ -rays

What happens with the electric field during discharge

Possible mechanism for radio emission (?)

particles' momenta $p \equiv \frac{v}{c}\gamma$



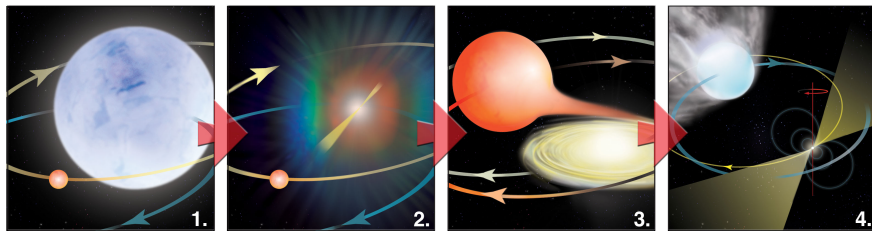
Pulsars Only Live Twice

What happens when pulsar dies?

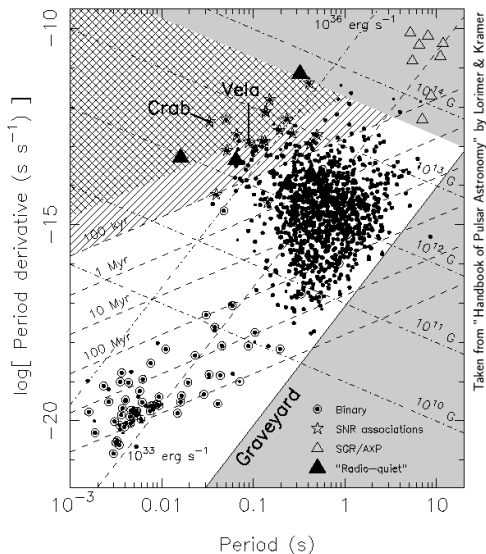


Resurrecting dead undead

Making millisecond pulsar



P-Pdot diagram: Hertzprung-Russell diagram for pulsars



Neutron Star Zoo: there are many types of NSs

