Calculating the Magnetic Field Around a Neutron Star

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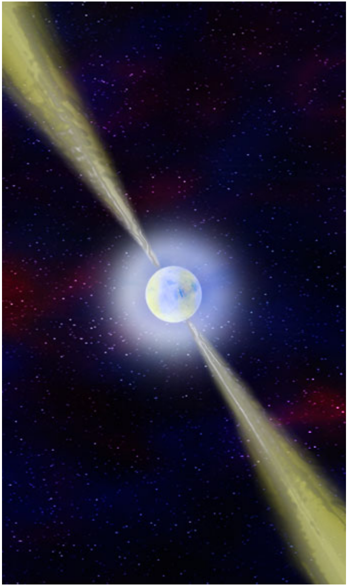
Outline



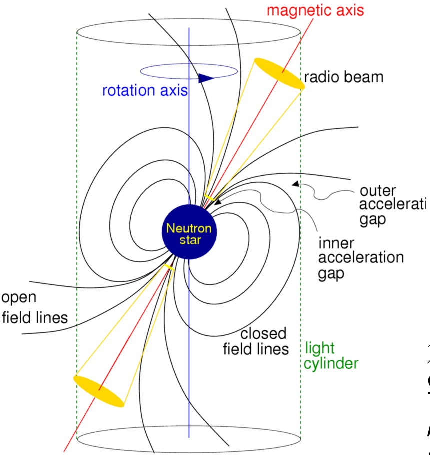
Background

What are Neutron Stars?

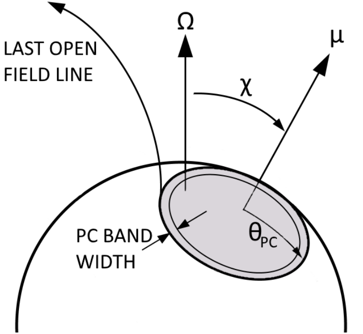
- Extremely compact stars ($\sim$twice the mass of the Sun, with a radius of only $\sim$10km) supported by neutron degeneracy pressure
- Formed from supernovae of stars (10-30 solar masses)
- Rapidly rotating (fastest at 716 Hz) [HRS+06]
- Strong magnetic fields ($10^8 - 10^{15}$ Gauss)
- Strong surface gravity (10^5 times that of the Sun, 10^{-1} that of a black hole)

Neutron stars demonstrate extreme physics. They operate at the limits of current theories.

Geometry of Magnetic Field and Polar Cap



source: [Mor14]



χ - Magnetic Inclination Angle
Ω - Rotation Axis
μ - Magnetic Axis
θ_{PC} - Polar Cap Angle

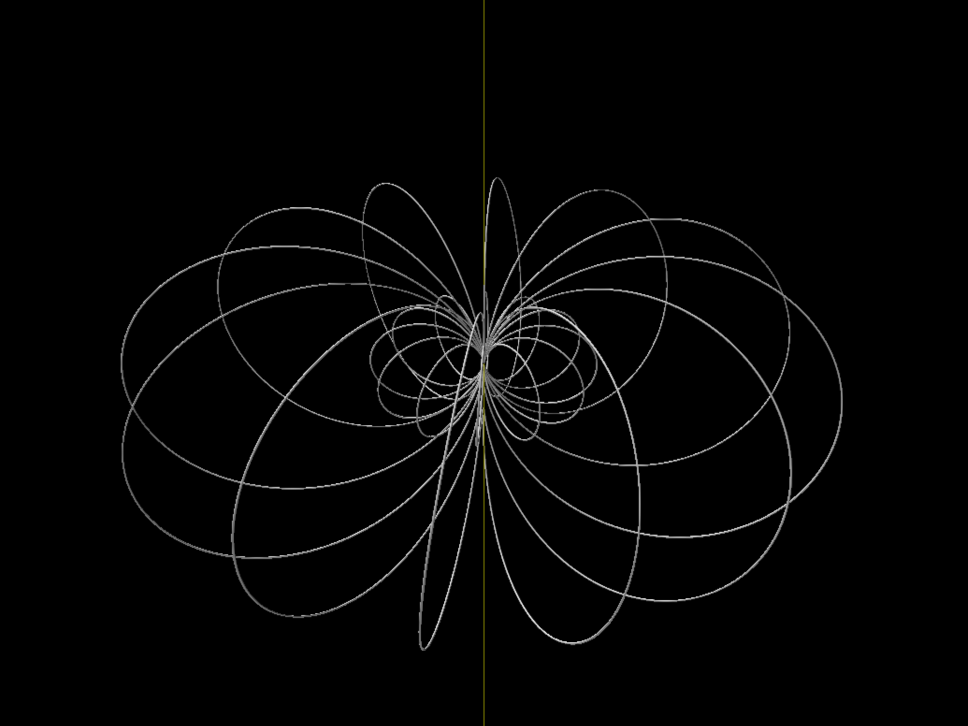
Magnetic Field Models

Deutsch Model (1955)

- Analytic model based on standard dipole magnetic field
- Assumes star is perfectly conducting sphere in a perfect vacuum
- Most commonly used model in research

Muslimov and Harding Model (2005) [MH05]
Accounts for:

- charge flow along open field lines
- distortions due to rapid rotation
- $E \times B$ drift of outflowing charges



Design of Program

Made use of Python's Object Oriented Programming features by creating two classes.

Star Class:

```
myStar = Star(radius, period, chi)
myStar.draw(theta1, theta2, ...)
myStar.animate()
```

Fieldline Class:

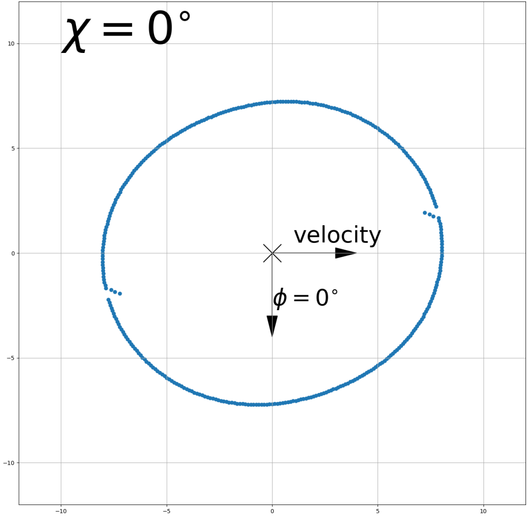
```
myFieldline = Fieldline(star, phi, theta, emissionRad=[0.5])
myFieldline.isOpen
myFieldline.emissionDirections
myFieldline.draw()
```

Algorithm Example

To find polar cap shape:

```
myStar = Star(10, 0.3, 30)
polarCapAngles = [ ]
for phi in range(0, 360):
    theta = 0
    myFieldline = Fieldline(myStar, phi, theta)
    while myFieldline.isOpen:
        theta += 0.1
        myFieldline = Fieldline(myStar, phi, theta)
    polarCapAngles += [theta]
print(polarCapAngles)
```

Polar Cap Shape



Neutron Star Properties Affecting Emissions

Property	Possible Values	Values Used
Observer Viewing Angle	$0^\circ - 180^\circ$	$0^\circ - 180^\circ$
Magnetic Inclination Angle, χ	$0^\circ - 180^\circ$	$0^\circ - 90^\circ$
Emission Distance	$0.1 - 0.9 R_{LC}$	$0.1 - 0.9 R_{LC}$
Polar Cap Band Width	$0^\circ - \theta_{PC}$	0.2°
Emissions Spread	$0^\circ - \sim 5^\circ$	Gaussian, $\sigma = 3^\circ$

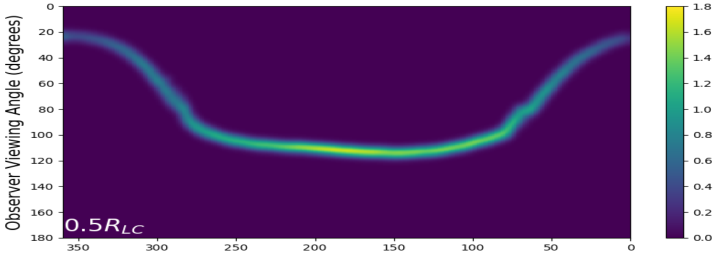
Table 1: Neutron Star Properties Affecting Emissions

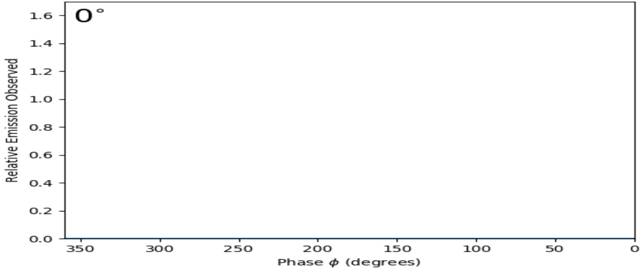
But not even that simple! Also do not know:

- distribution of field lines over polar cap
- distribution of emission spread from each field line
- if emission occurs at spherical distance from star (vs cylindrical, conic)

Plotting Emissions

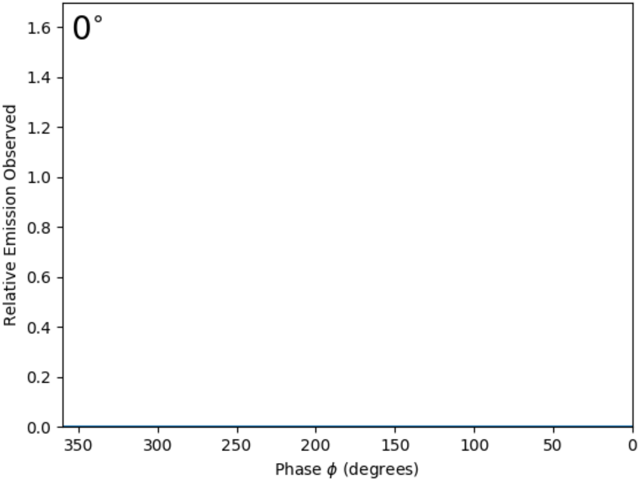
$\chi = 45°$, Emission distance $= 0.5R_{LC}$



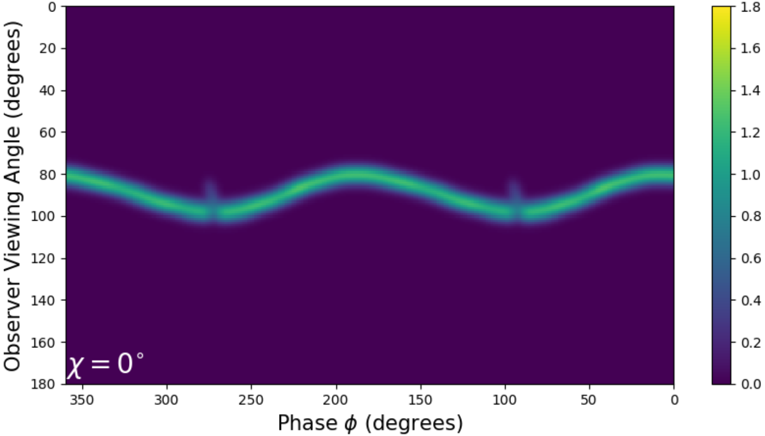


Observed Emissions

$\chi = 45^\circ$, Emission distance $= 0.5R_{LC}$

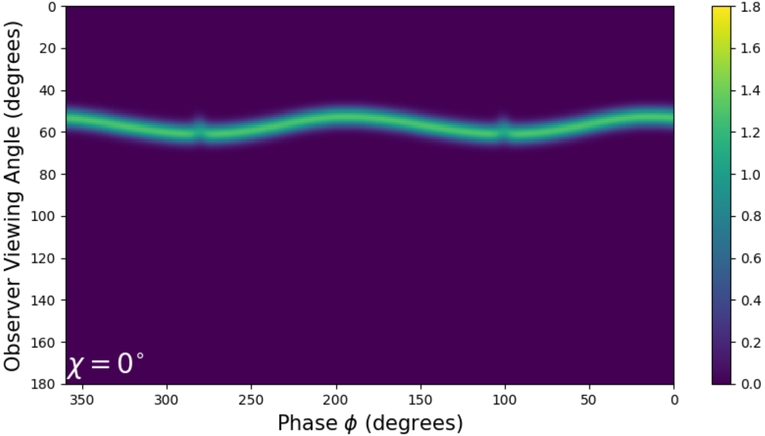


Varying Magnetic Inclination Angle, χ



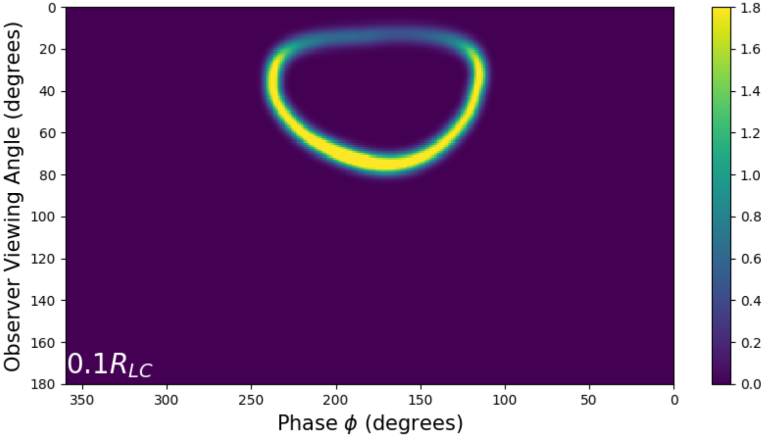
Emission distance $= 0.5R_{LC}$, Band width $= 0.2^\circ$

Varying Magnetic Inclination Angle, χ



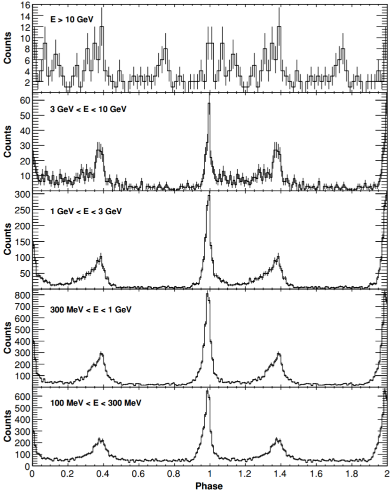
Emission distance $= 0.25 R_{LC}$, Band width $= 0.2^\circ$

Varying Emission Distance



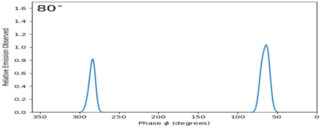
$\chi = 45^\circ$, PC Band Width $= 0.2^\circ$

Comparison to Observed Emissions of Crab Pulsar

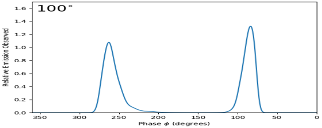


Fermi Large Area Telescope Observations of Crab Pulsar, 2009 [AAA+09]

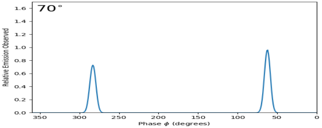
$\chi = 45^\circ$, Observer Angle $= 80^\circ$



$\chi = 45^\circ$, Observer Angle $= 100^\circ$



$\chi = 60^\circ$, Observer Angle $= 70^\circ$



guesses: [NR04, HSDF08]

Future Work

Physical model:

- Including emission from south pole
- Emission in reverse direction
- More equal spread of field lines over polar cap
- Emission from longer region
- Consider different energy emissions differently

Computer program:

- Calculate for several band widths at a time
- Store emissions for entire polar cap
- Introduce multithreading

Conclusion

This program:

- allows for visualisation of the magnetic field of a neutron star with any specified parameters
- shows clearly how observed emissions are affected by changing certain properties of the star
- can be quickly adapted for different purposes
- can be easily built upon in the future

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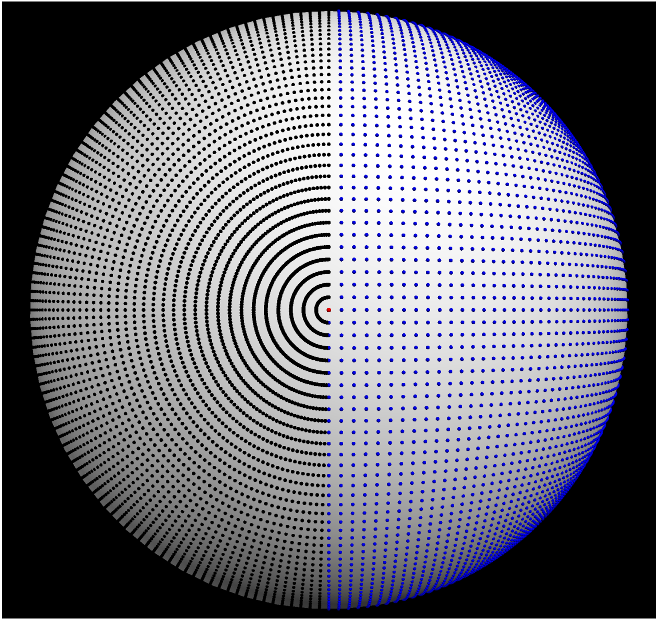
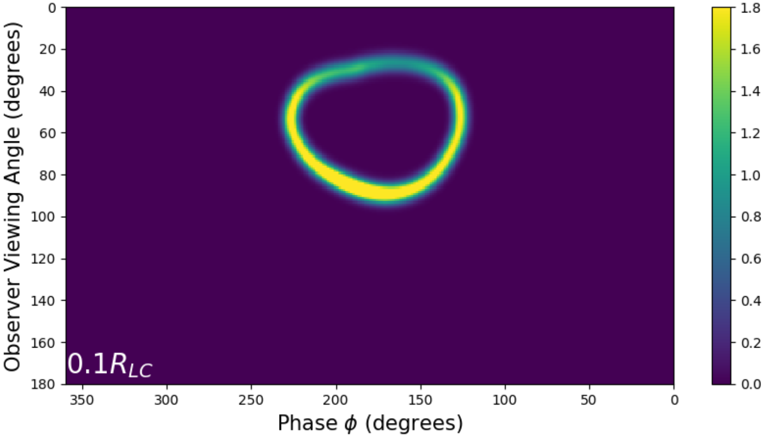
Change of Coordinates (to evenly distribute field lines over polar cap)



Varying Emission Distance



$\chi = 60^\circ$, PC Band Width $= 0.2^\circ$