Magnetospheric structure in the double pulsar

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in collaboration with

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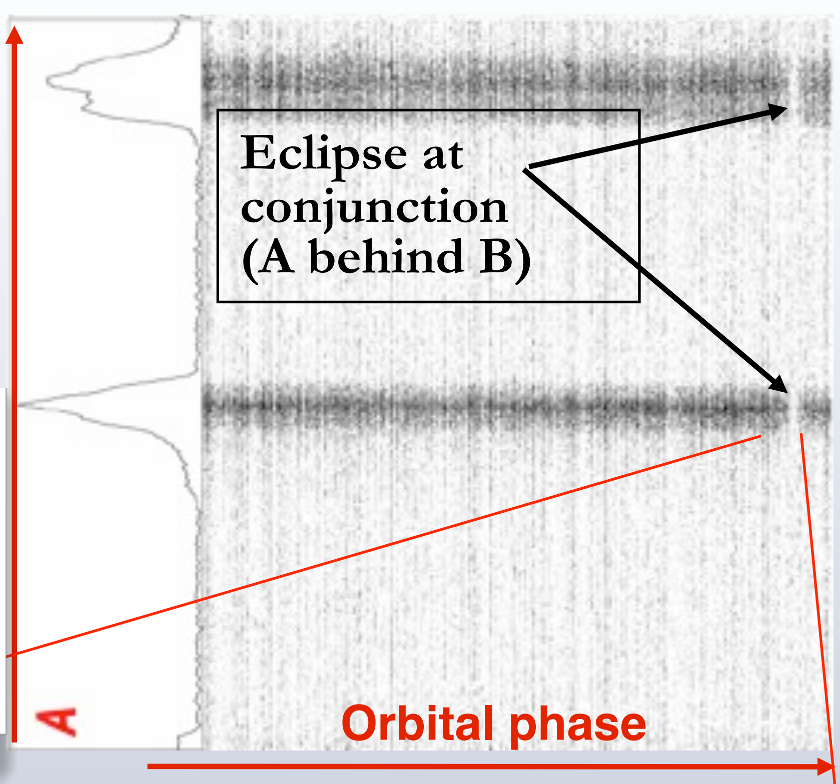
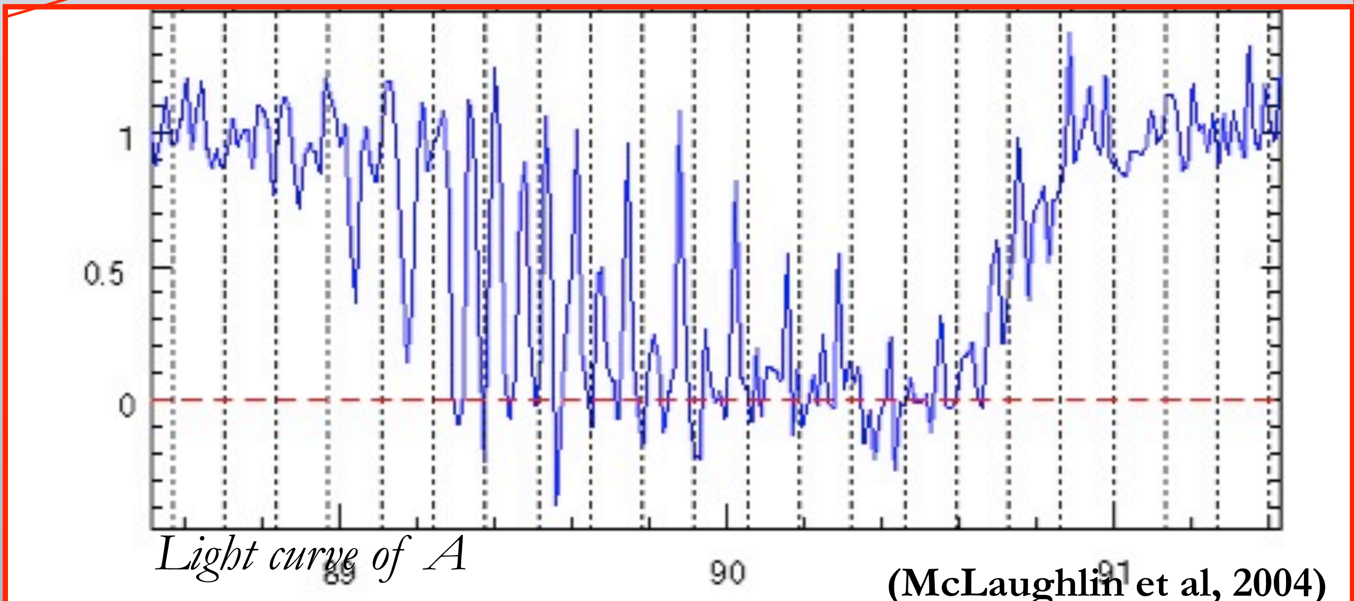
“A” eclipse: modulated at B rotation

- Modulation is at $0.5P_B$, P_B and full eclipse after the conjunction
- Absorption when magnetic axis of B is pointing towards us



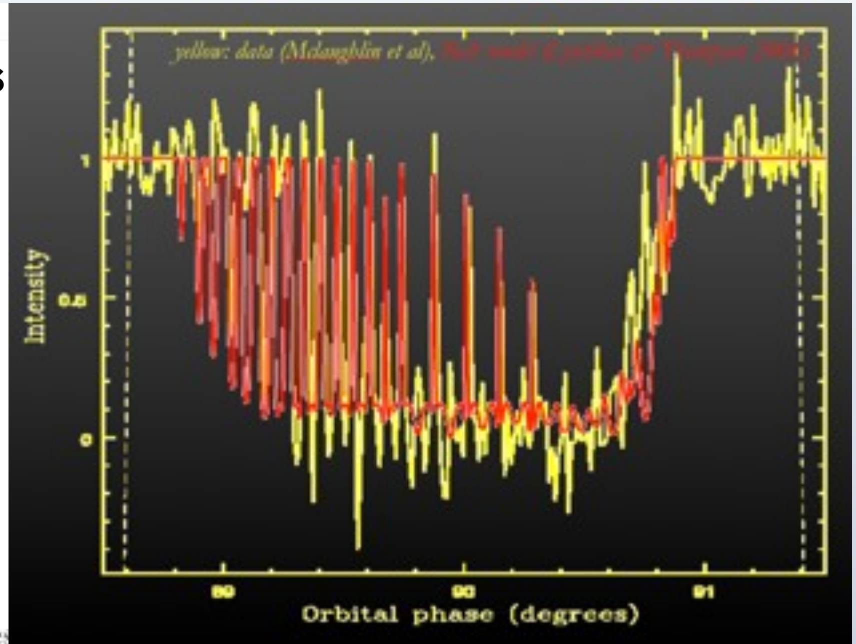


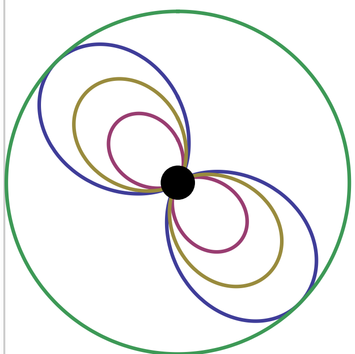
Light curve of A

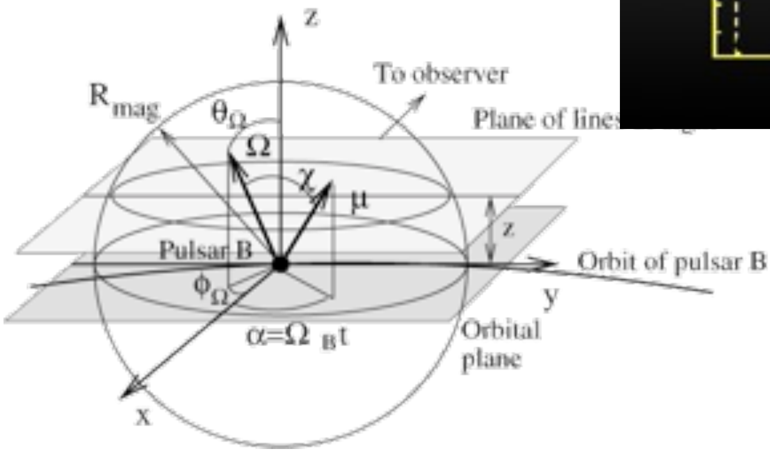
(McLaughlin et al, 2004)

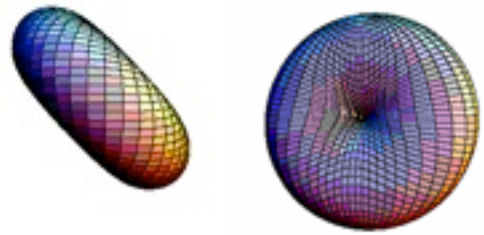
Model of eclipses

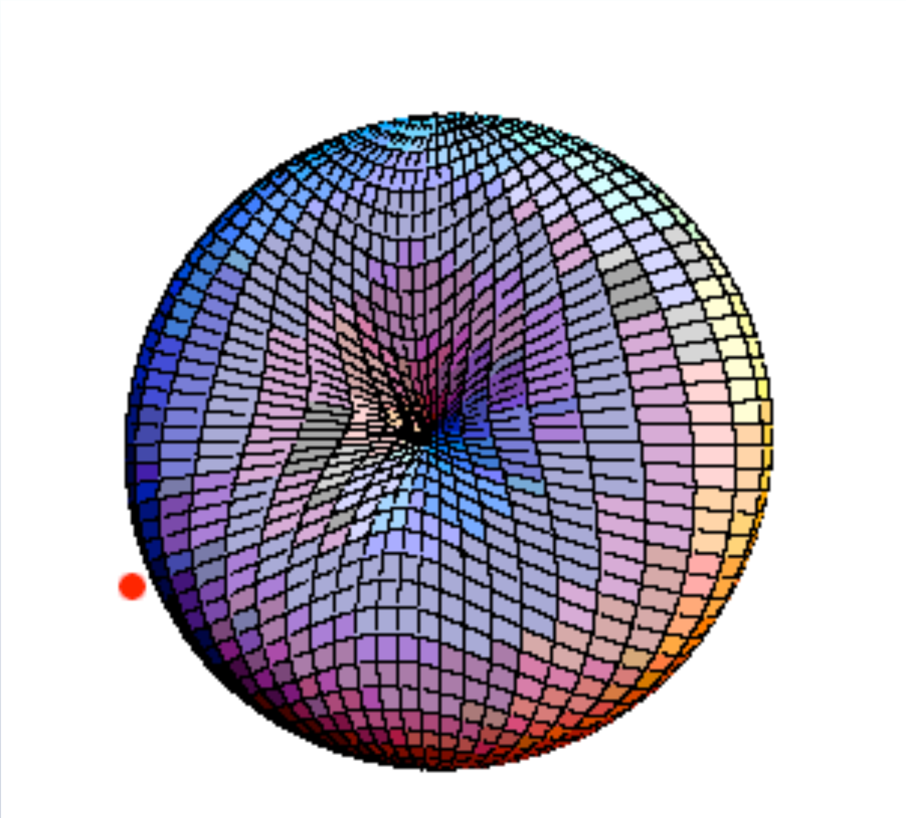
- **Synchrotron absorption on closed field lines**
- Parameters to be fitted :
  - θ_Ω, φ_Ω– orientation of Ω
  - impact parameter z
  - χ angle between Ω and μ
  - Plasma density, normalized to $n_{GJ,mag}$



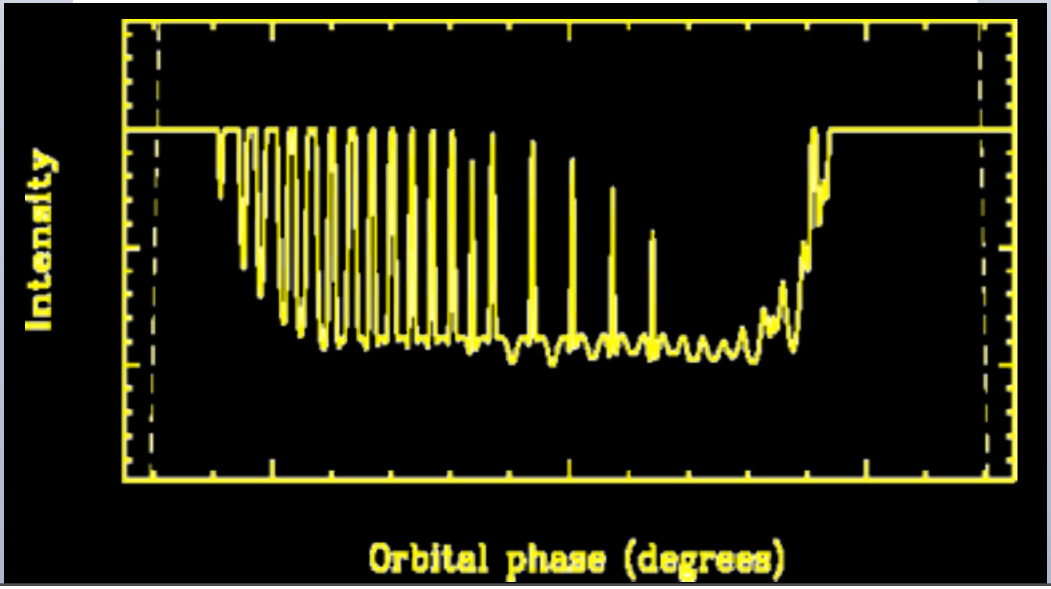








- Red dot: line of sight to pulsar A.
- “Donut”: last closed surface of B magnetosphere



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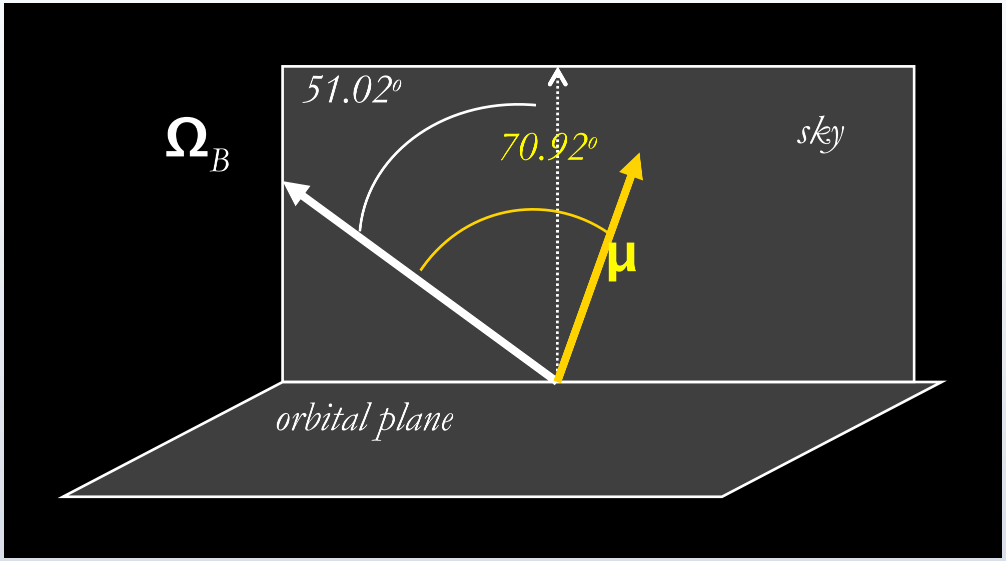
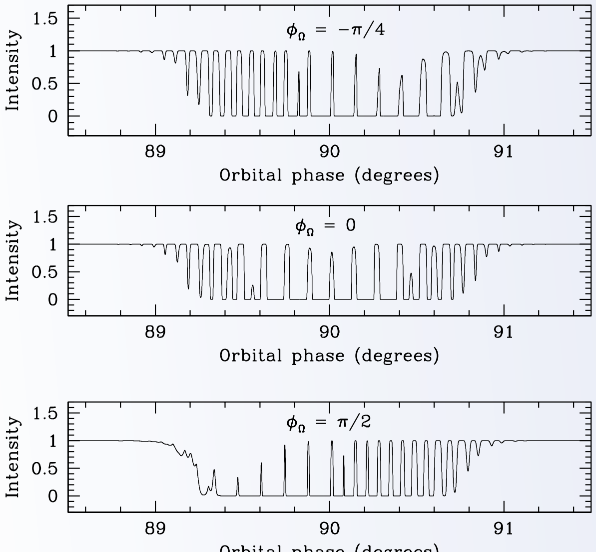
Geometrical parameters determined to < 0.1 degree

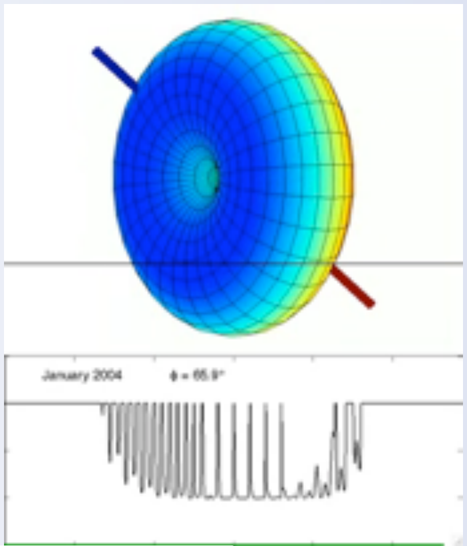
Breton et al, Science 2009

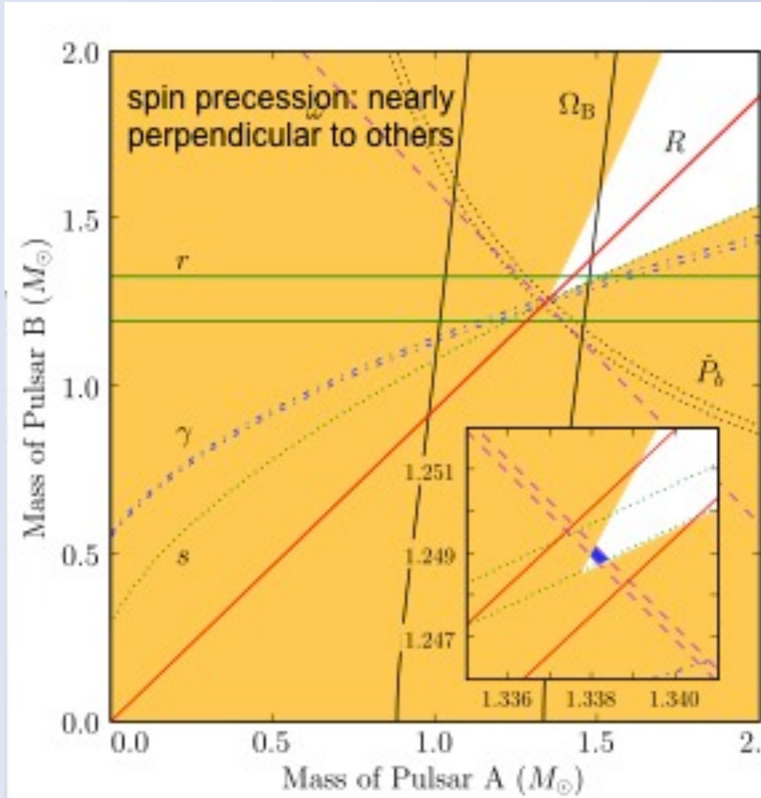


- θ_Ω ~ 51.02° (angle between orbital plane normal and Ω) – expected due to kick at birth of B
- φ_Ω (angle between plane of sky and Ω)- changes, see later
- χ~70.92° degrees (angle between μ and Ω) – close to orthogonal rotator
- High density of plasma on closed field lines, ~ 10^5 higher than expected
- Eclipsing plasma ~ 3 times smaller that the magnetopause

Change of eclipse profile due to geodetic precession: new GR test







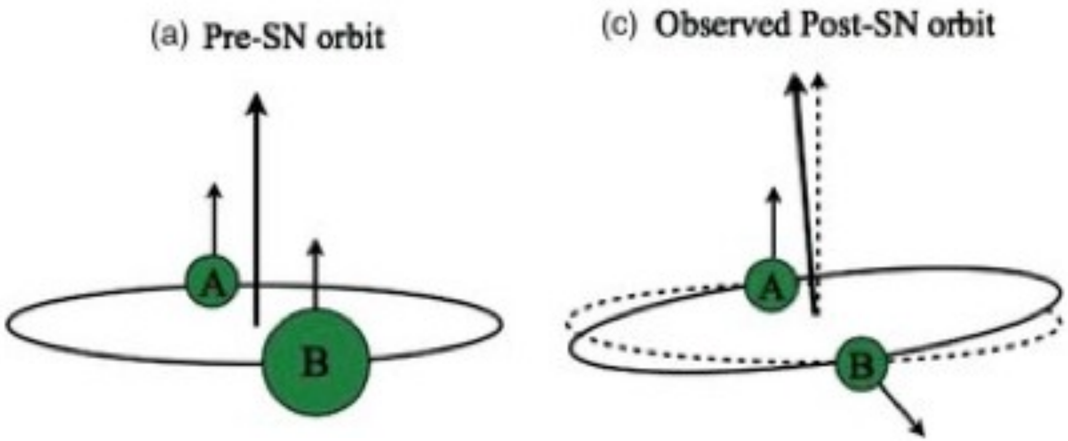
- Observed: $\Omega = 4.98_{+0.43\ -0.23}$ °/yr
- GR-predicted: $\Omega_B = 5.07° / yr$

- **Strong gravity at the source, 5 independent tests**
- GR **in strong regime** is satisfied in the most complete test, in some parameters to 10^{-4}
- Any competing theory of gravity should reproduce first PPN corrections (at least on ~ au scales)

Testing SN explosions mechanisms

Farr+, 2011

- SN explosion can “kick” and “tumble” pulsar B.
- No precession of A: spin still aligned with orbital
- The kick was in the orbital plane



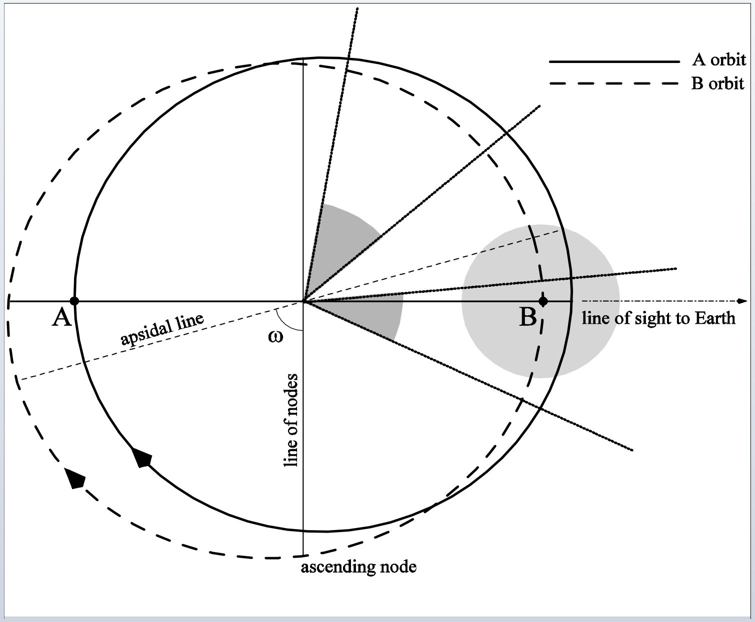
- Highly tumbled post-kick pulsar B: effective kick was highly off-centered

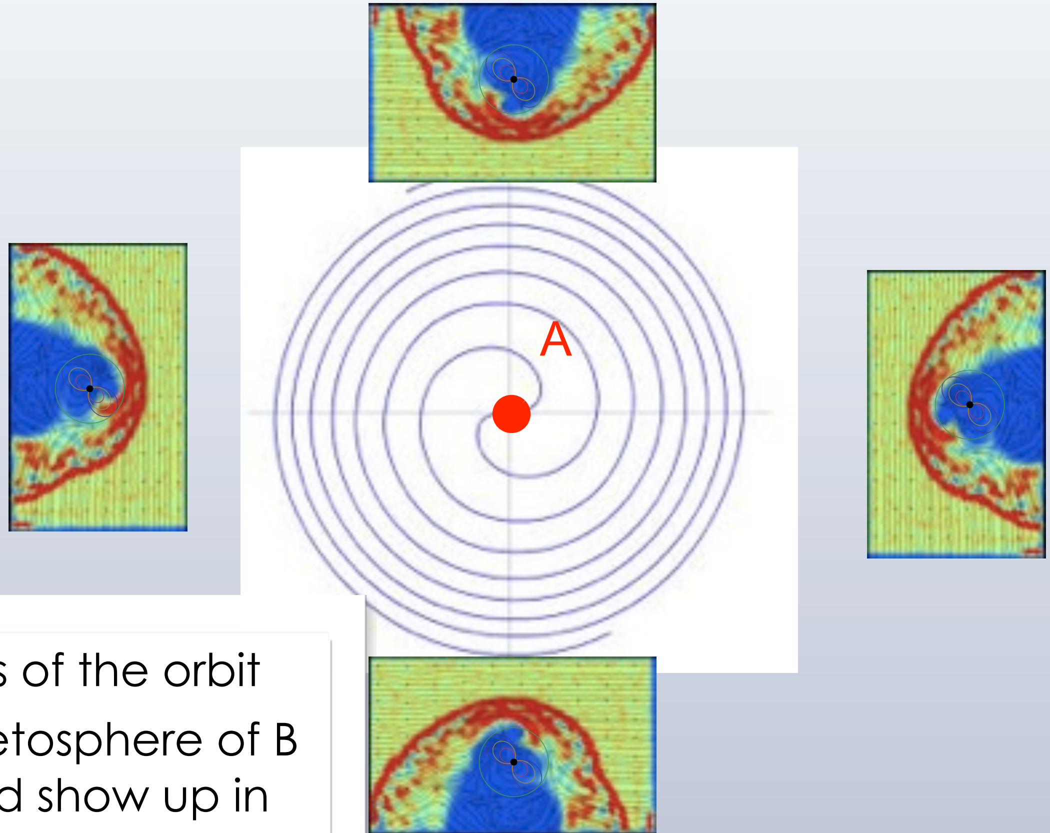
Determining emission hight and shape

- Combine
  - orbital variations
  - changing profiles
  - sub-pulse drift

  to determine shape and location of the emission region

Orbital variations

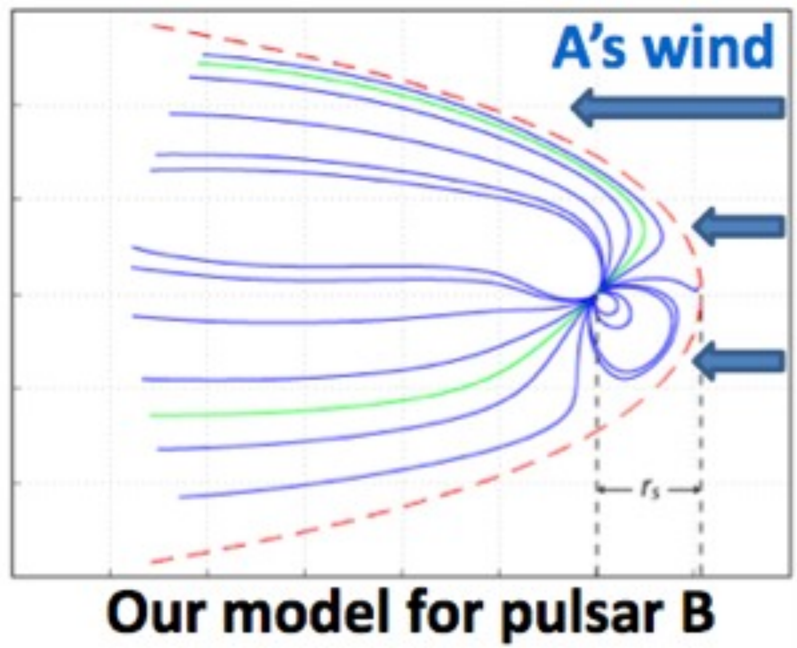




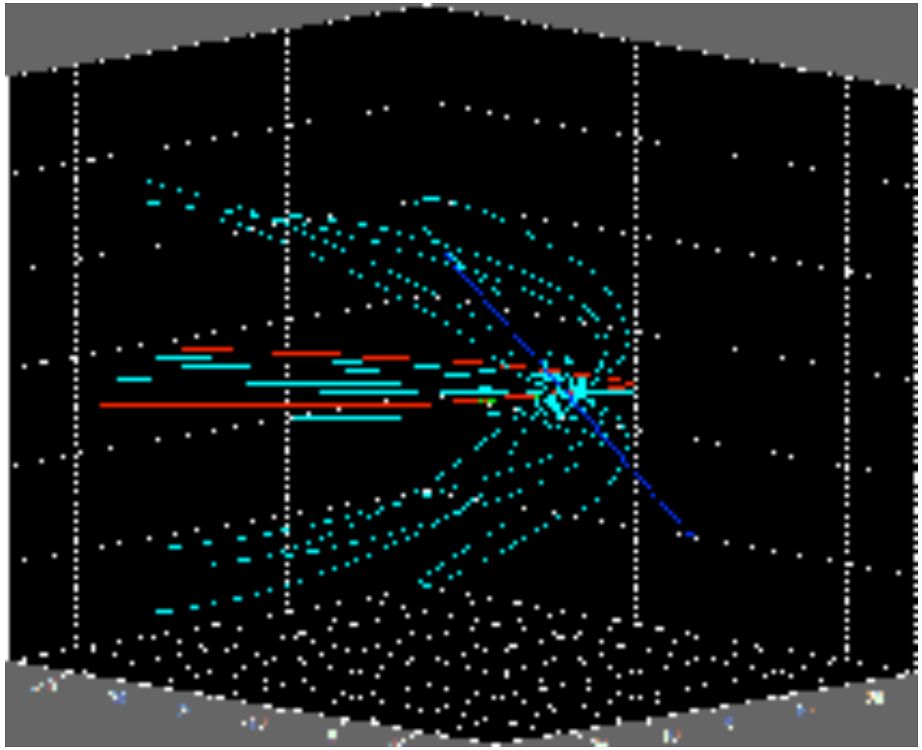
- Pulsar B is seen only at some parts of the orbit
- At different orbital phases magnetosphere of B has different distortions: this should show up in emission properties of B.
- By studying these variation we can infer the structure of the magnetosphere and location of emission region

3D view of distorted magnetosphere

Use Solar physics models of wind-Earth magnetosphere interaction (Tsyganenko)



3D view of the distorted magnetosphere. **Lomiashvili, in prep**



Inverse problem: find location and shape of the emission region to match orbital variations

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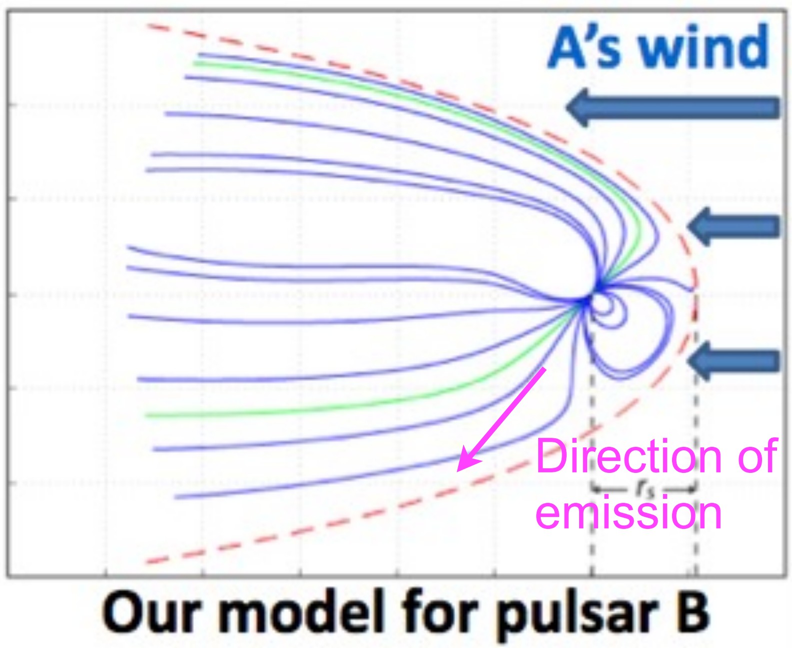

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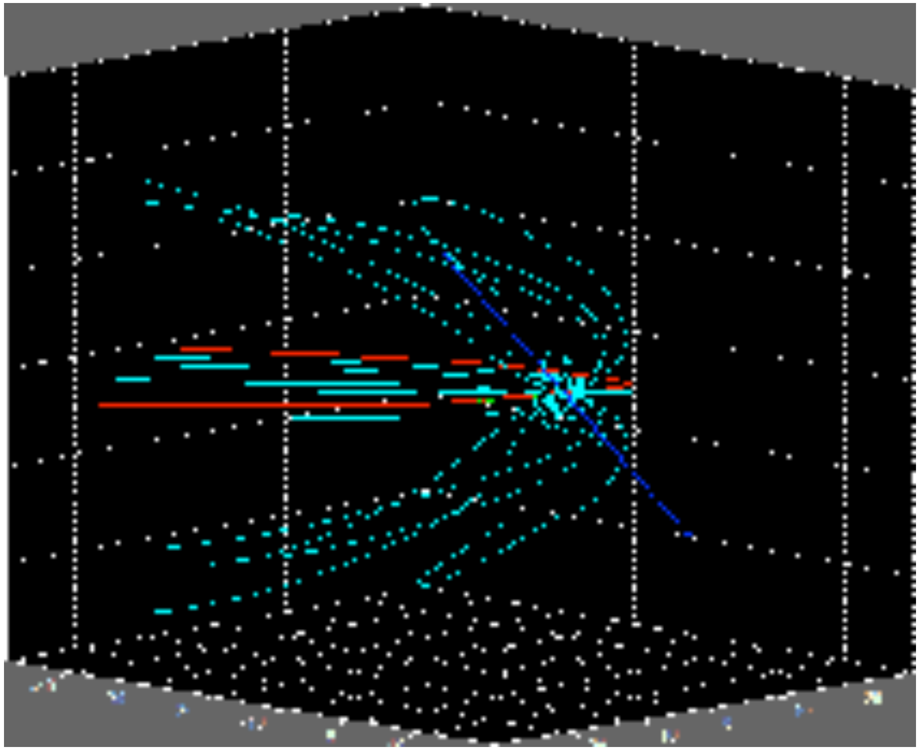

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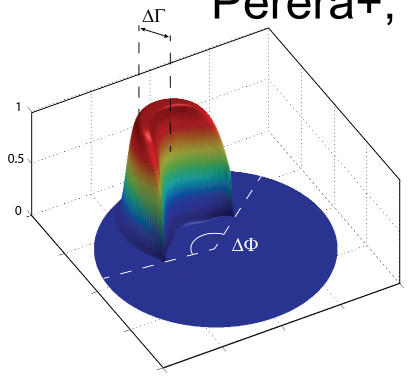
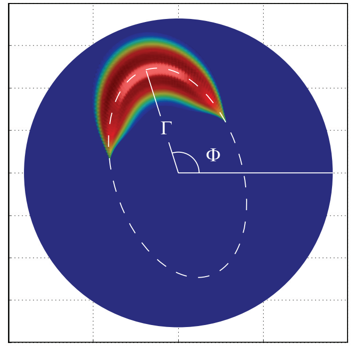
Orbital variations in B emission

Perera+, 2010

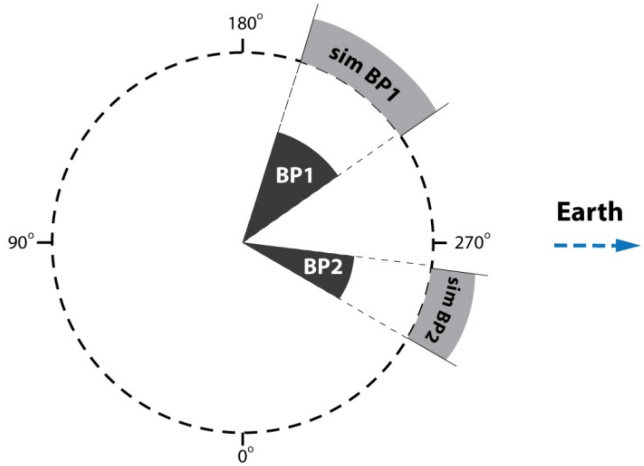


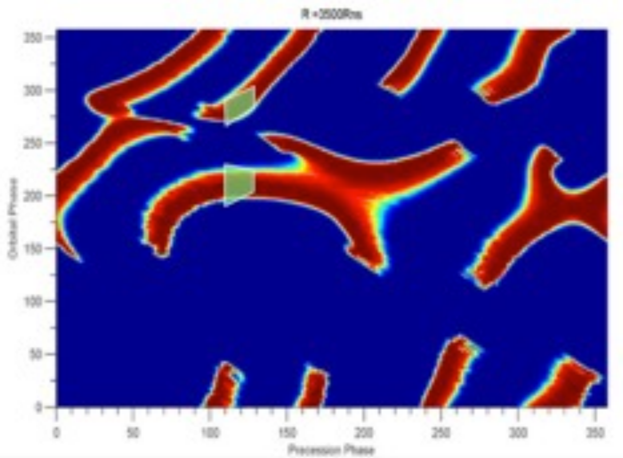


a)

Radius ≡ **ρ** = 16°
Thickness ≡ **d** = 7°
Angle of an arc ≡ **Δϕ** ~ 120°
Flatness ≡ **f** = 0.6

Lomiashvili et al., in prep.

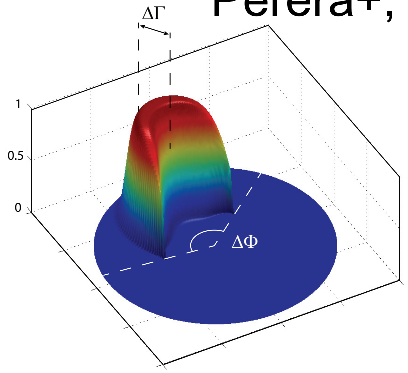


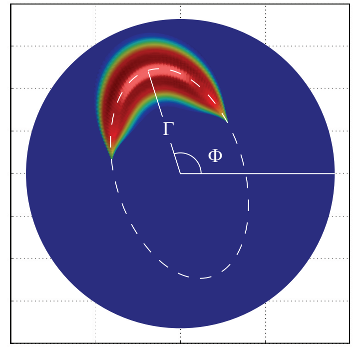


Simulated	*Observed*
BP1 = [199° - 227°]	BP1 = [199° - 226°]
BP2 = [279° - 298°]	BP2 = [277° - 298°]

Orbital variations in B emission

Perera+, 2010





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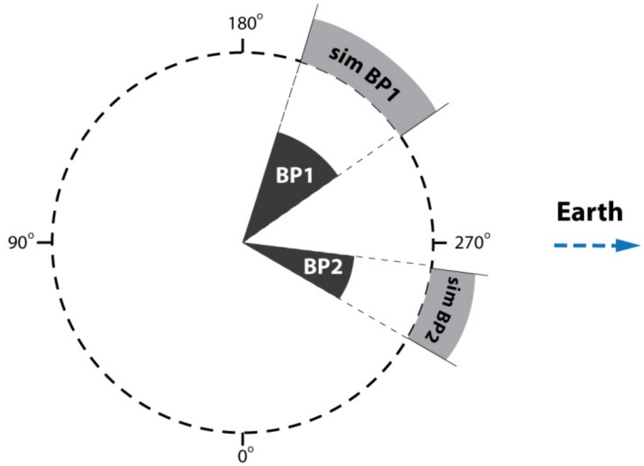

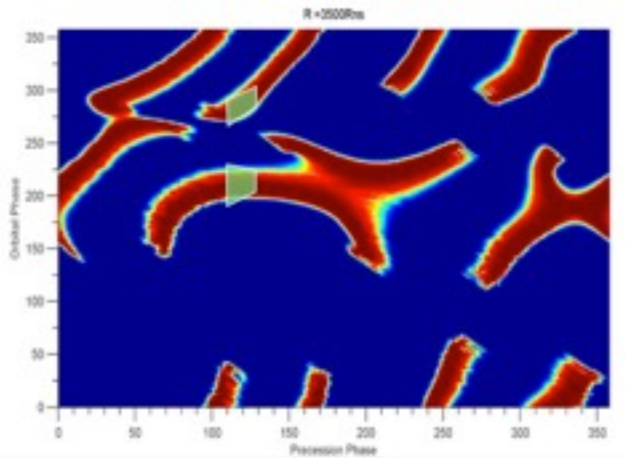

(discrepancy less than one degree !!!)

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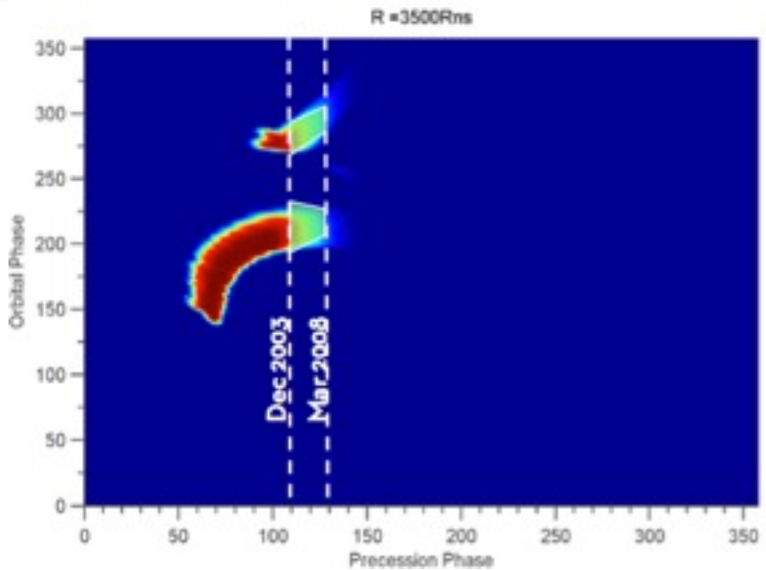
Orbital variations in B emission



in order to simulate the disappearance of pulsar B an additional "cutoff" is required

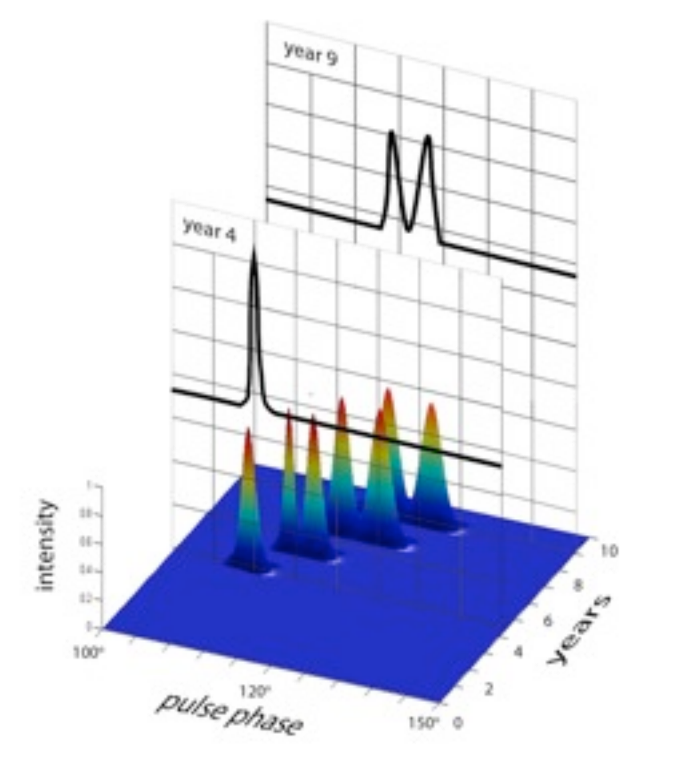
Cutoff: If $\Omega \cdot B < 0$ then $Flux \rightarrow 0$

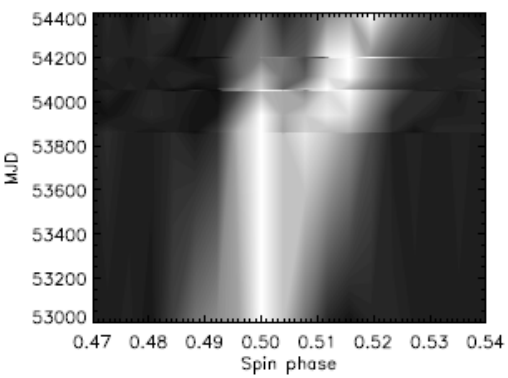
Induced charge changes the sign across the null surface.
Change in the acceleration regime?

Geodetic precession: stereoscopic view of the emission region

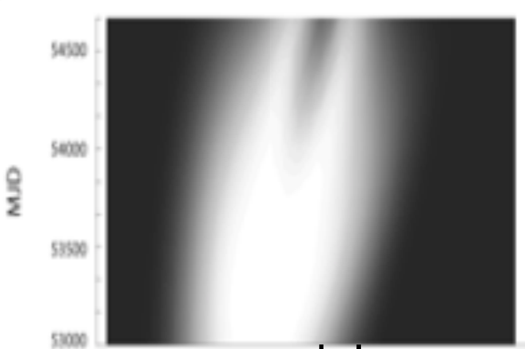
Due to geodetic precession, we get a stereoscopic view of pulsar B magnetosphere - exceptional possibility to study details of pulsar radio emission.

Horse-shoe emission region - different cuts through emission zone





Observed

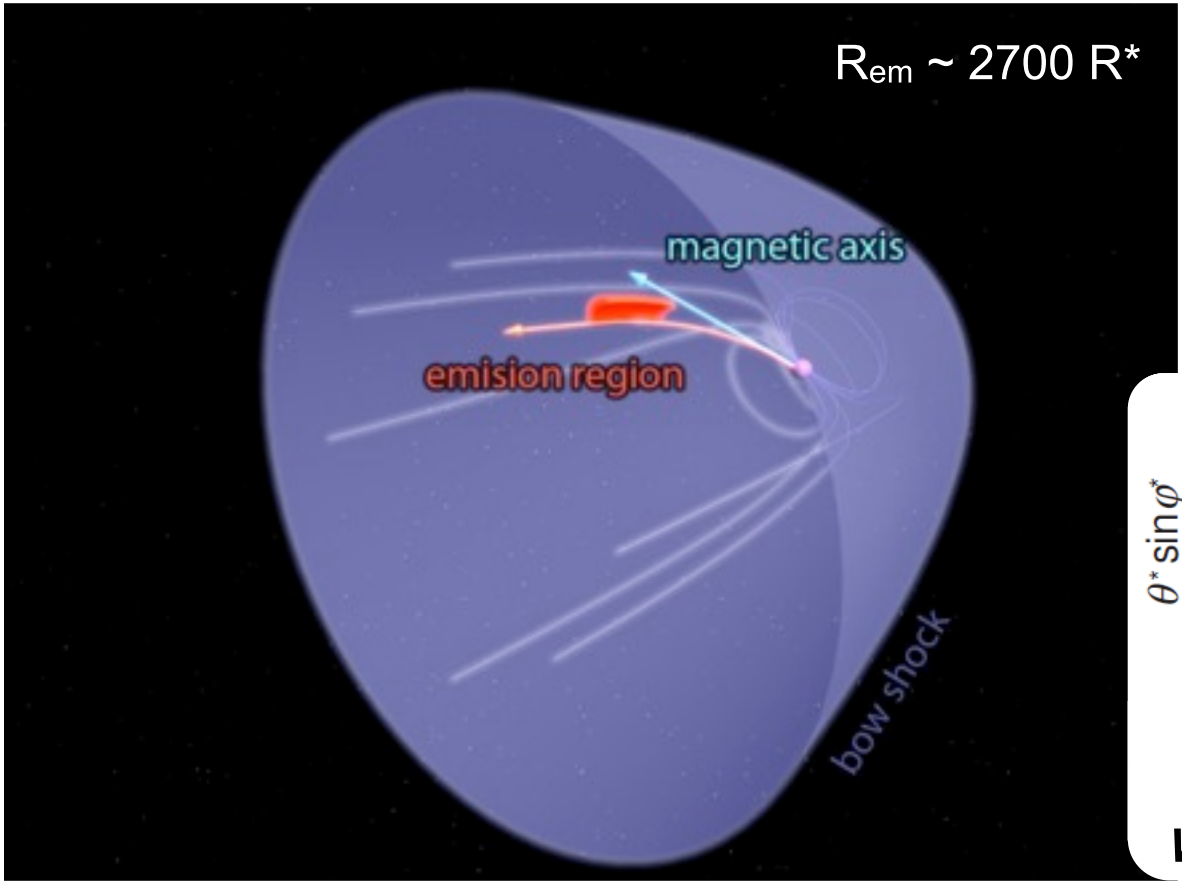


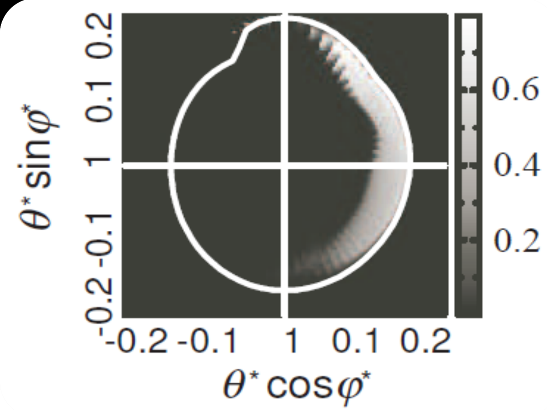
model

Location of radio emission generation

Lomiashvili, in prep

- Combine the two models (orbital and secular variation)

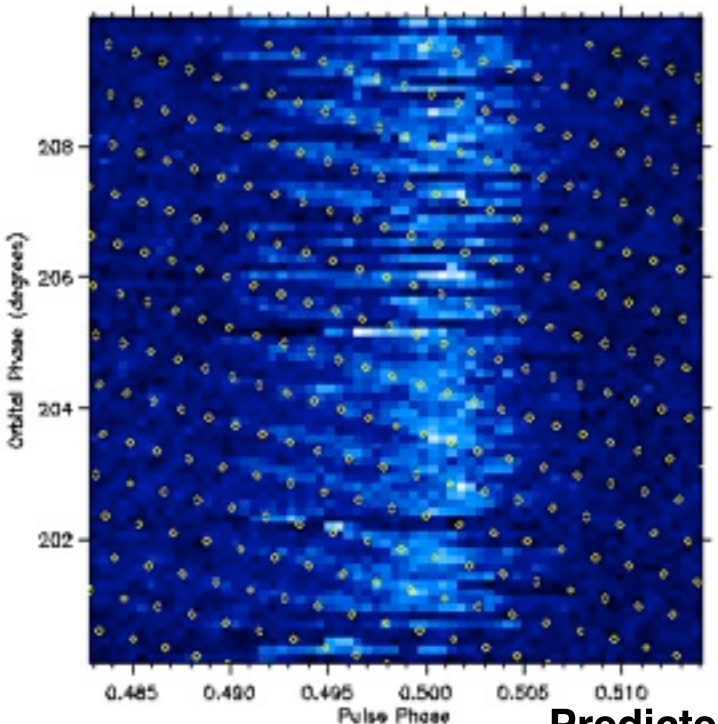




Wang & Hirotani 2011

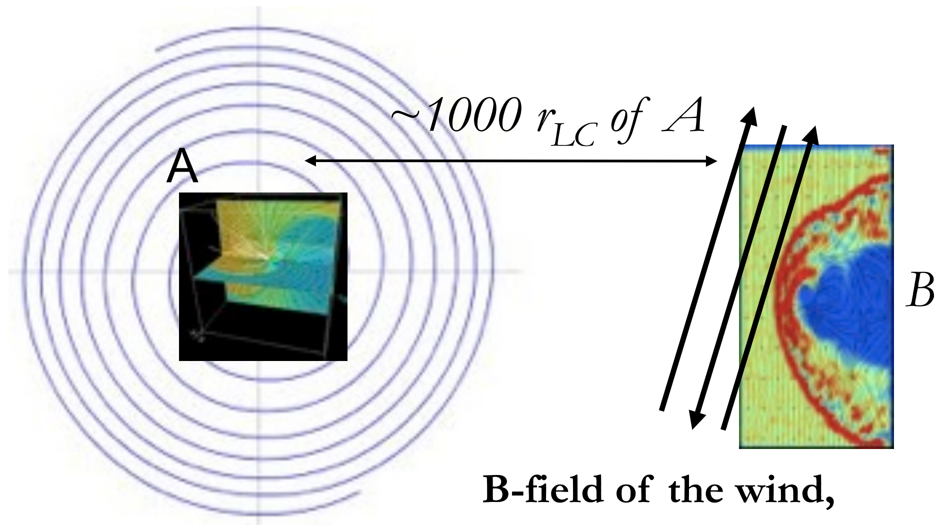
Relativistic reconnection, probes of pulsar winds

- Magnetosphere of B is “shaking” with the period of A: reconnection between B-field in the wind and the magnetosphere: a probe of the NS wind very close in: striped wind



(McLaughin et al., 04)

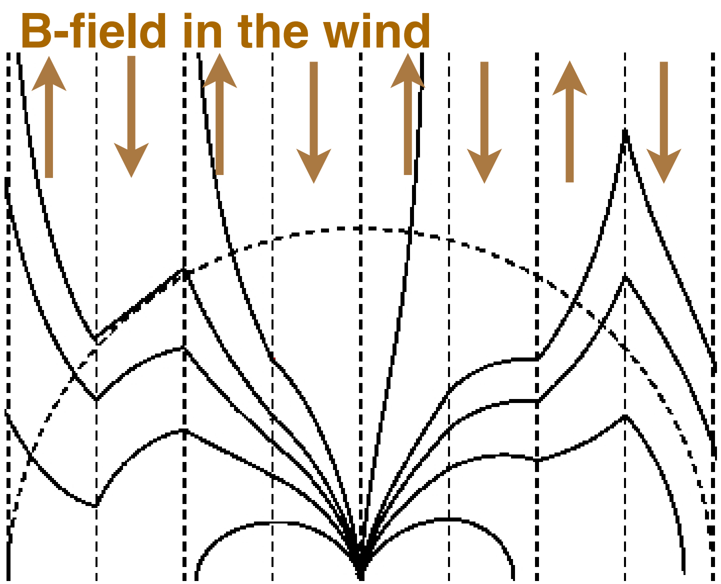
Predicted arrival times of A pulses at B



B-field of the wind, alternating polarity

Relativistic reconnection, probes of pulsar winds

Earth-like models of magnetosphere-wind interaction (Dungey)



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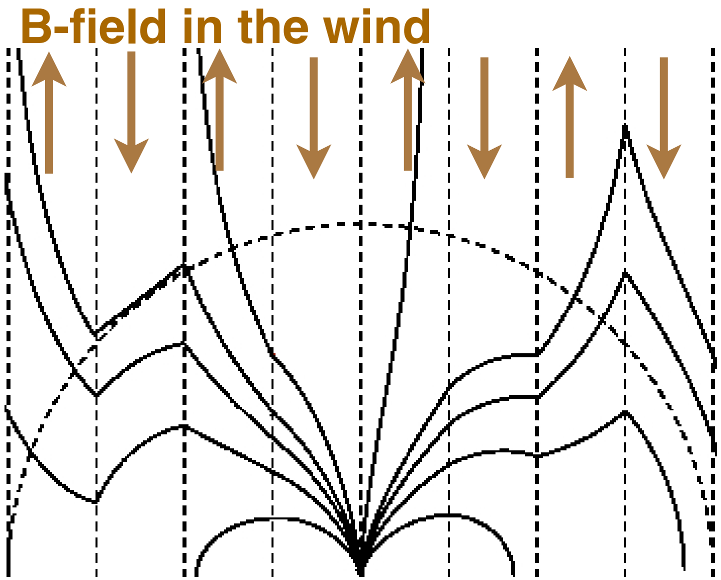

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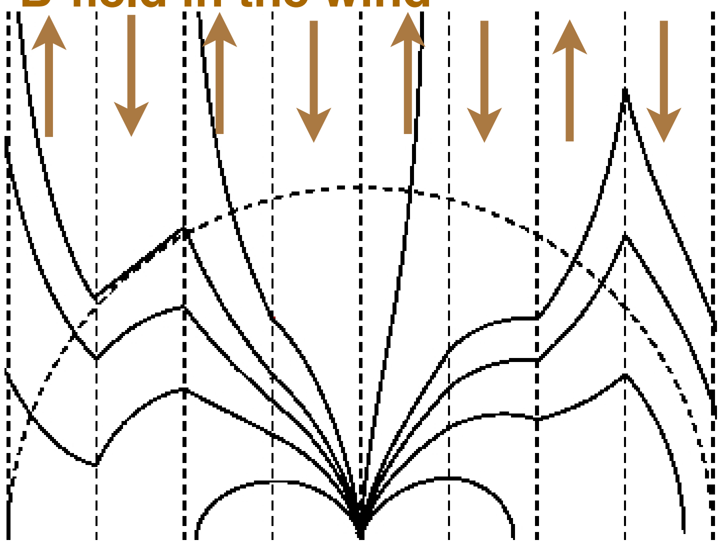
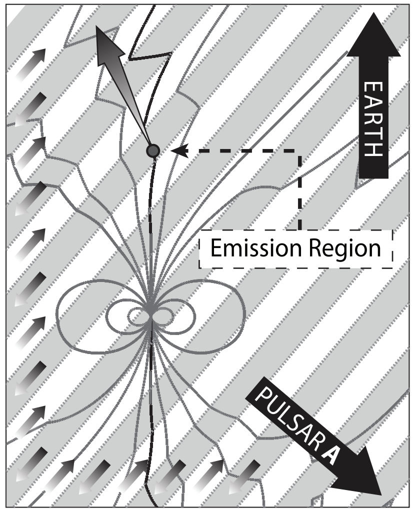
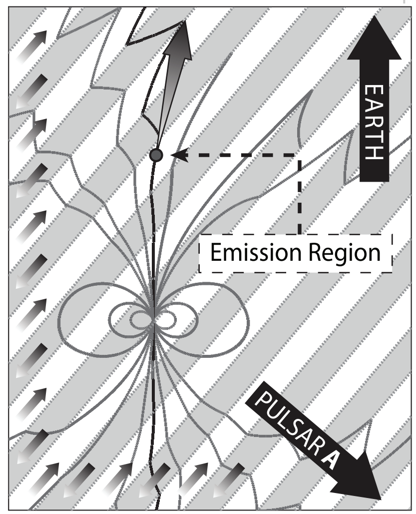




a)



b)

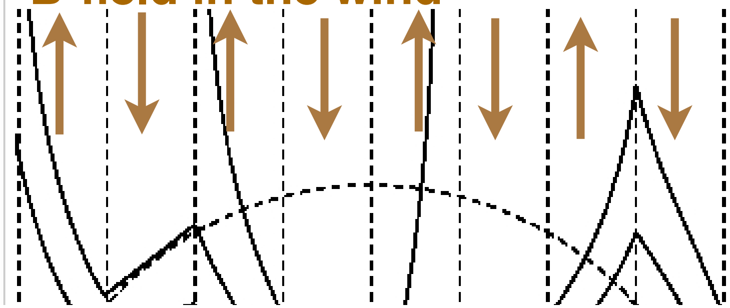
Dungy-type model of magnetosphere ,

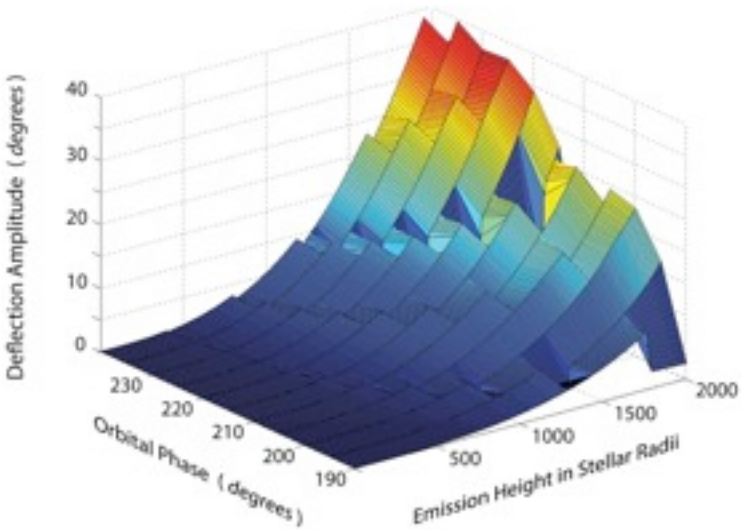
Lomiashvili, in prep

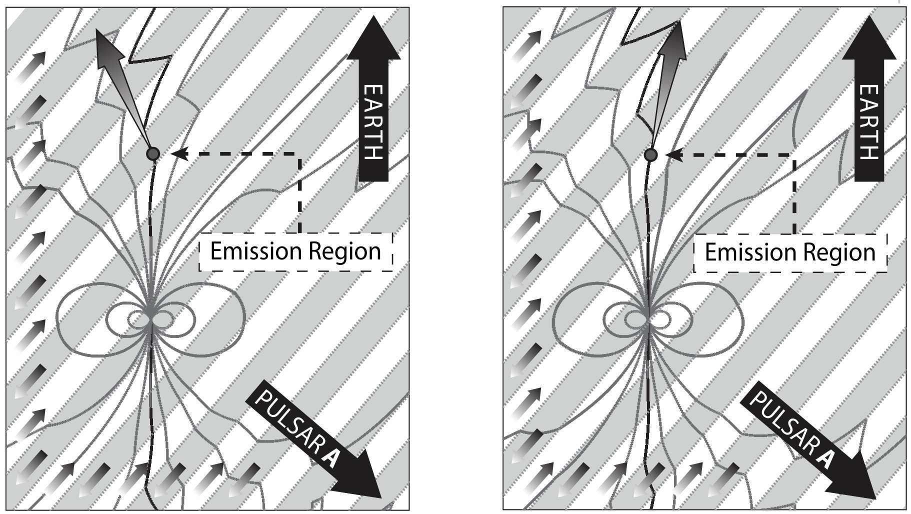
Relativistic reconnection, probes of pulsar winds

Earth-like models of magnetosphere-wind interaction (Dungey)

B-field in the wind







a) b)

Dungy-type model of magnetosphere ,

Lomiashvili, in prep

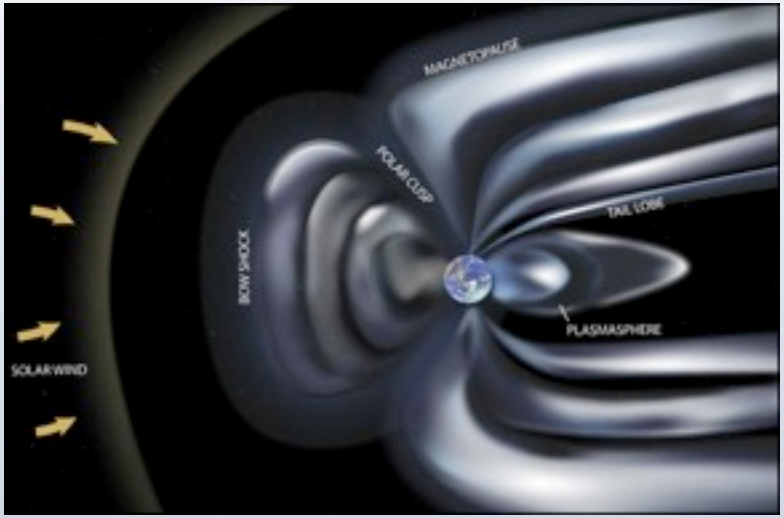
And back to General Relativity

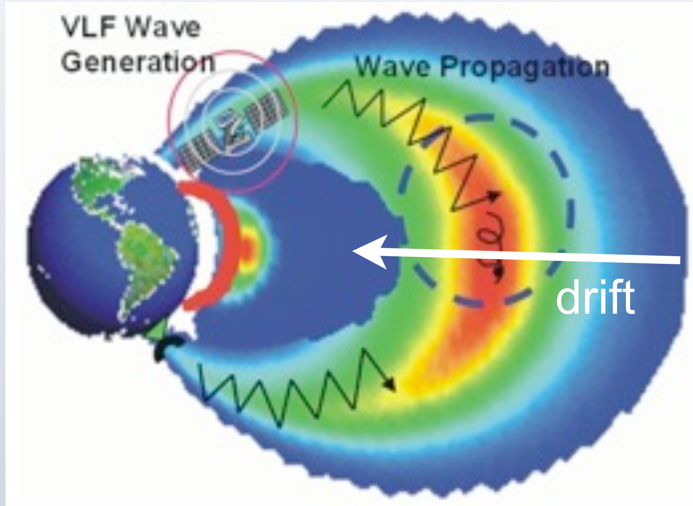
- Rotation of pulsar B is very noisy - the main error in the GR tests.
- Understanding the plasma dynamics will lead to improvements of the GR tests

Conclusion

- We can reproduce:
  - *Bright Phases,*
  - *Pulse profile evolution*
  - *Drifting subpulses*
- Location and shape of the radio emission region:
  ~ 2700 R_{NS} , horse-shoe
- Horse-shoe, radio follows the current?
- Large smission hights: anamalous cyclotron model (Kazbegi + 91, Lyutikov+1999) predict high emission radii

Origin of particles in pulsar B magnetosphere: van Allen radiation belts





- Radial diffusion in co-rotating magnetosphere - testing density distribution
- Testing scaling relations (geometry) over a much wider parameter range than that provided by Solar planets alone. (~ Jupiter turns into Neptune every half period).