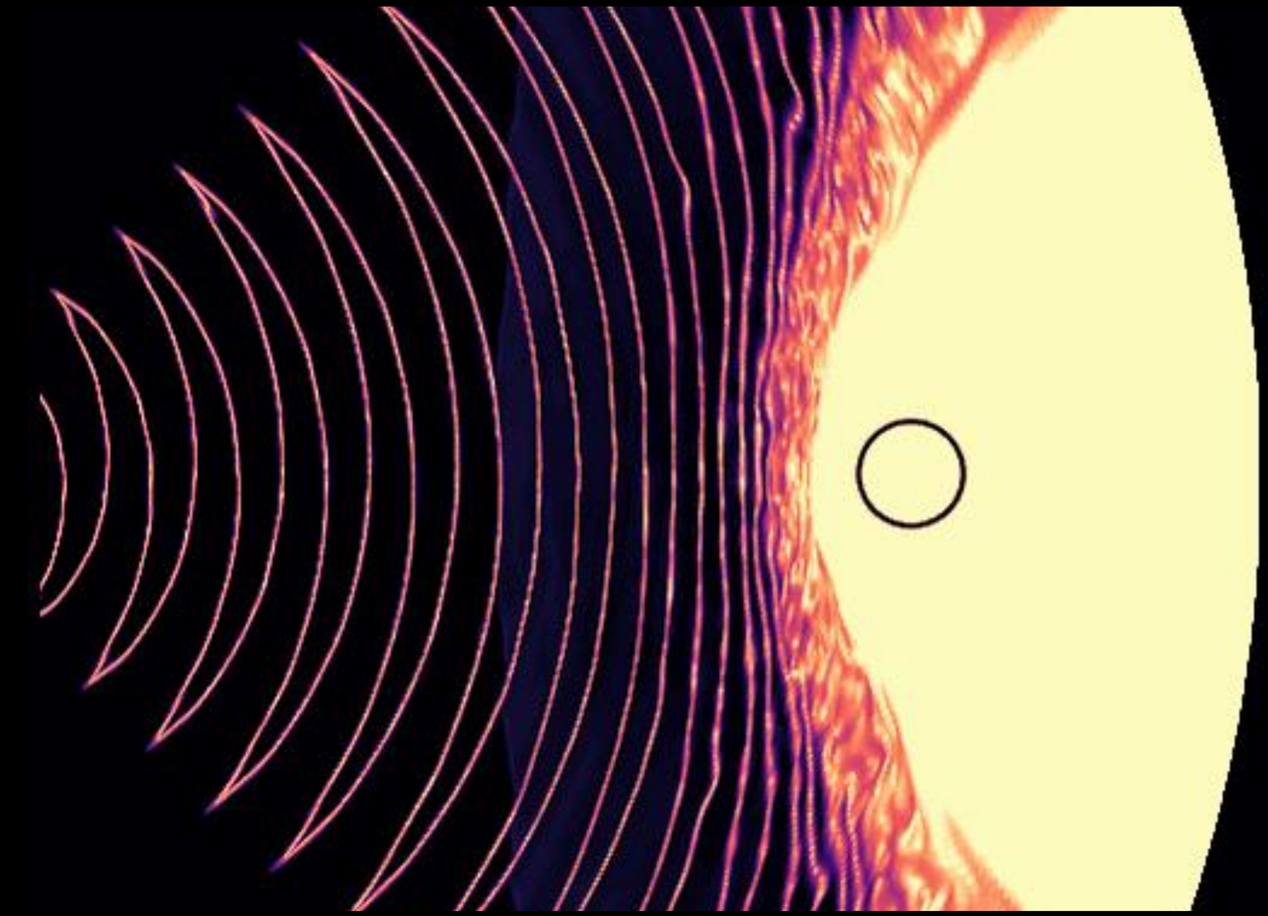
Intrabinary Shocks in Spider Pulsars



Stanford University

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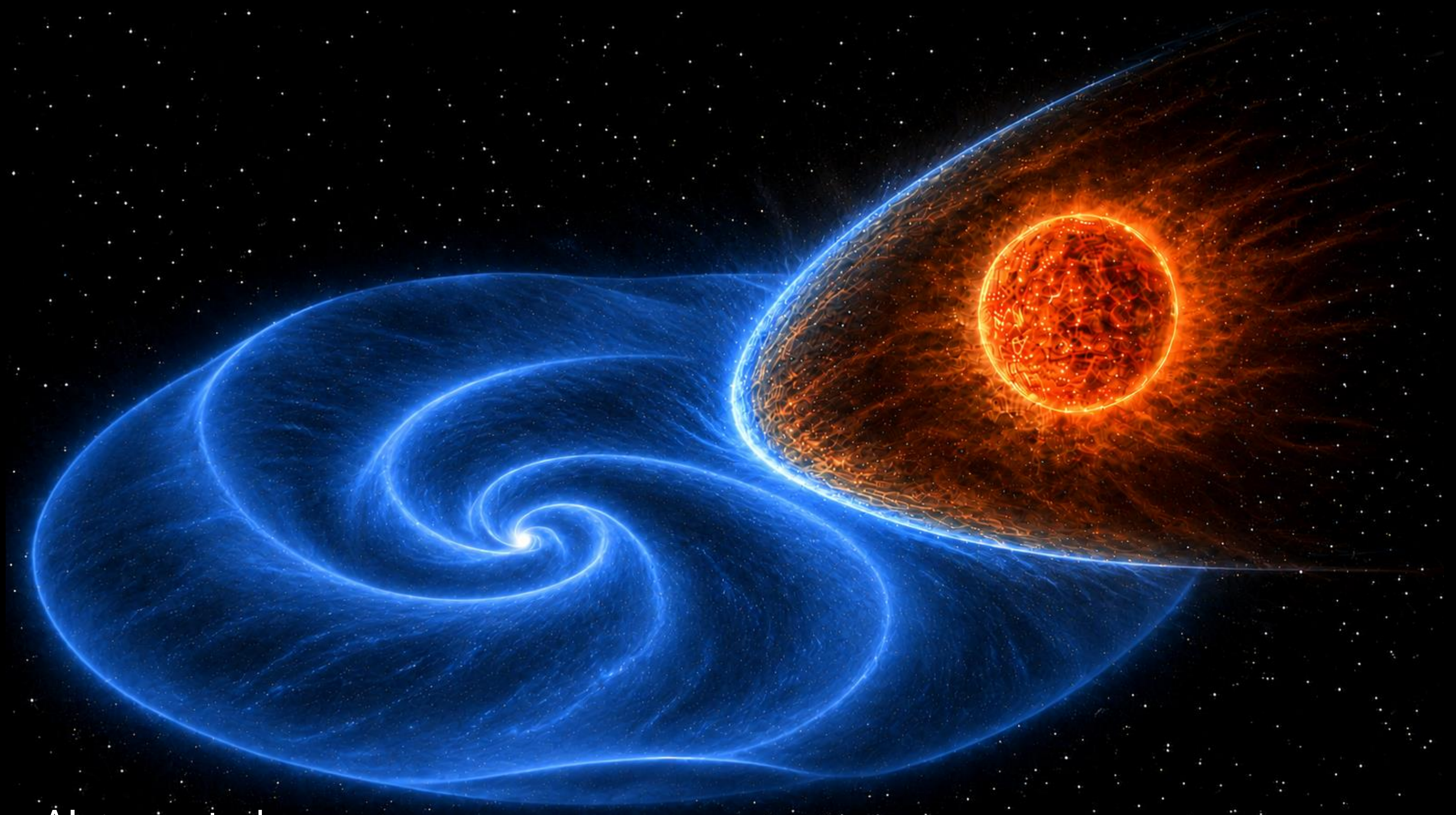
Collaborators: Koushik Chatterjee, Lorenzo Sironi, Alexander Philippov

TeV Particle Astrophysics 2026

Tendo, Japan

August 31, 2026

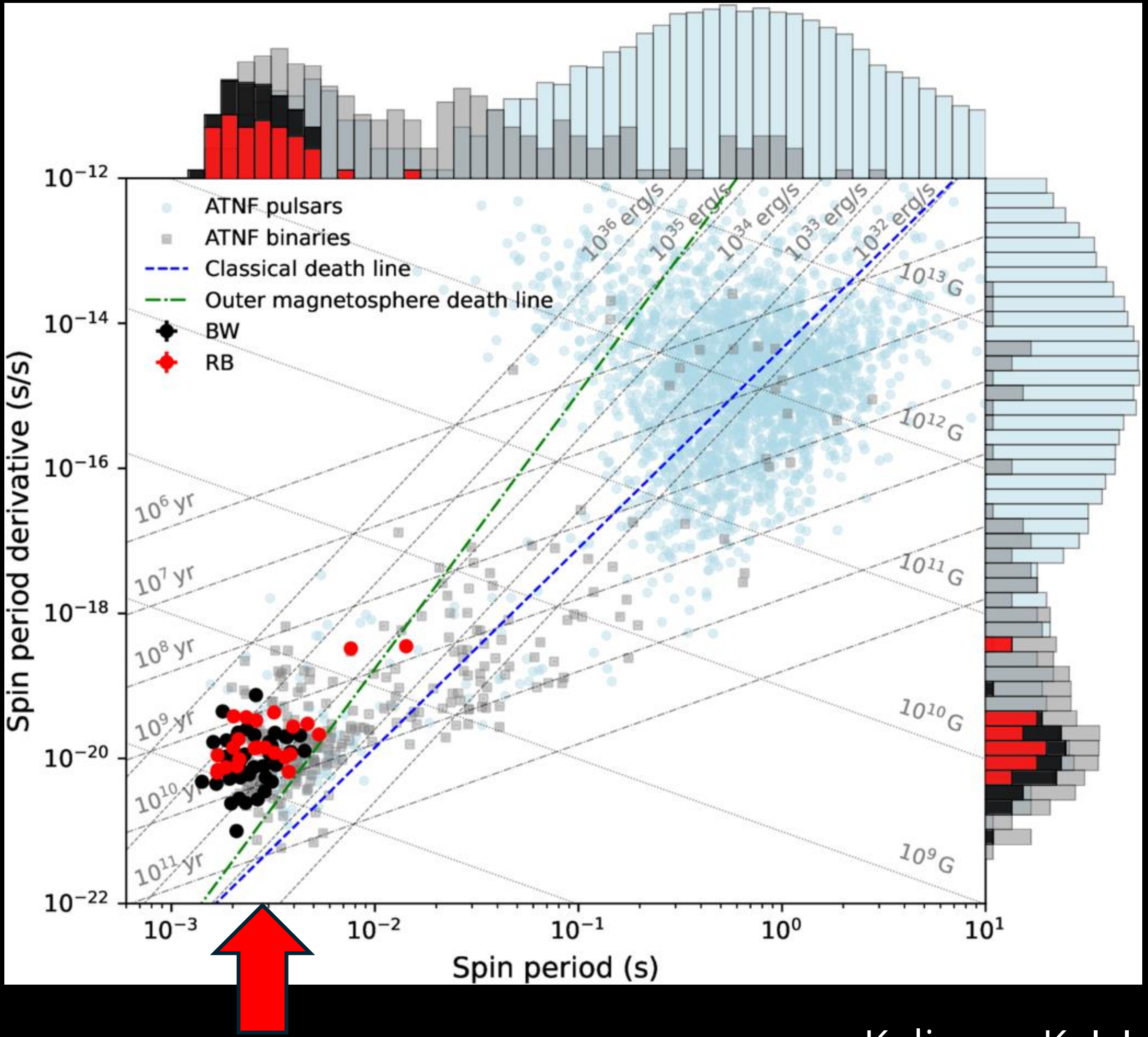
What are Spider Pulsars ?



AI generated

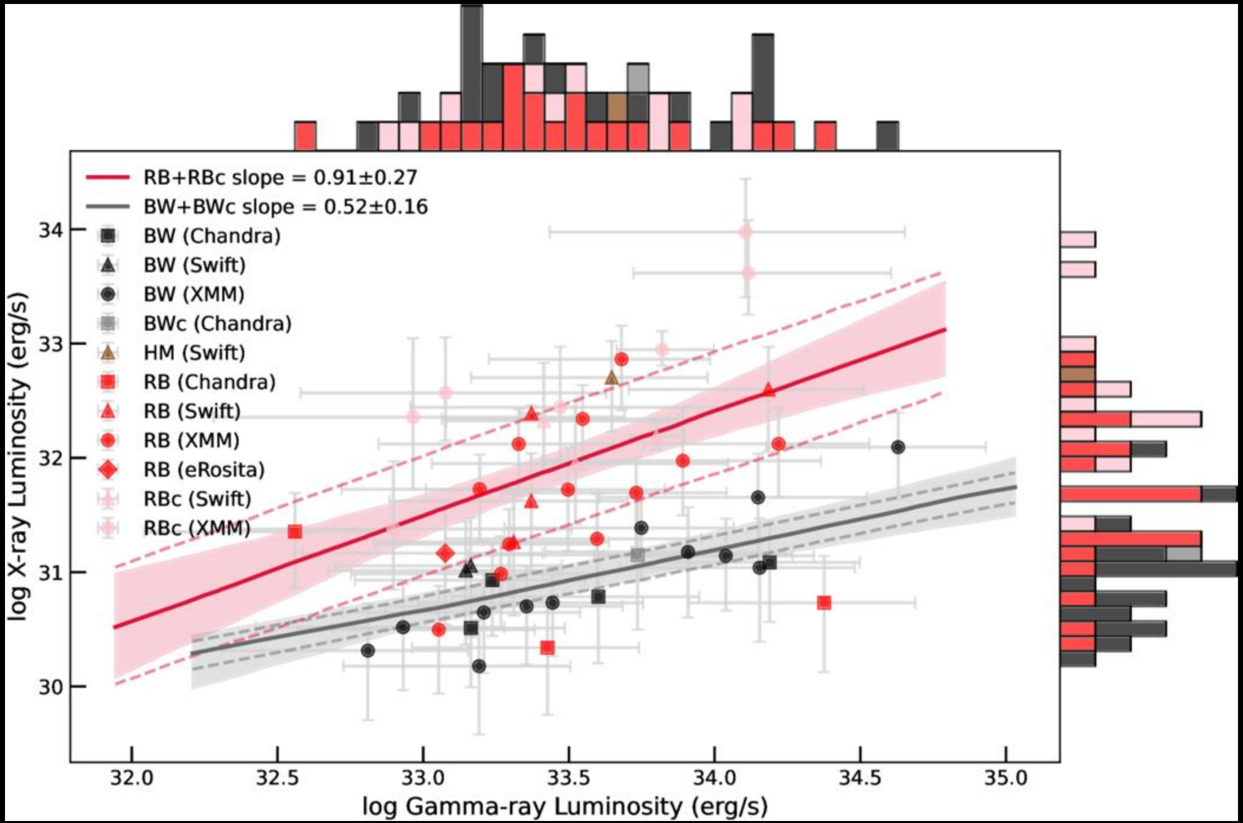
- ms-Pulsar & low-mass companion
- Orbital period $\lesssim$1 day
- Relativistic Pulsar striped wind, corrugated geometry, Parker spiral
- Pulsar wind irradiates companion inducing a companion outflow
- Colliding winds form intrabinary shock region (IBS)
- Orbitally modulated nonthermal X-rays

What do we observe from Spider Pulsars ?



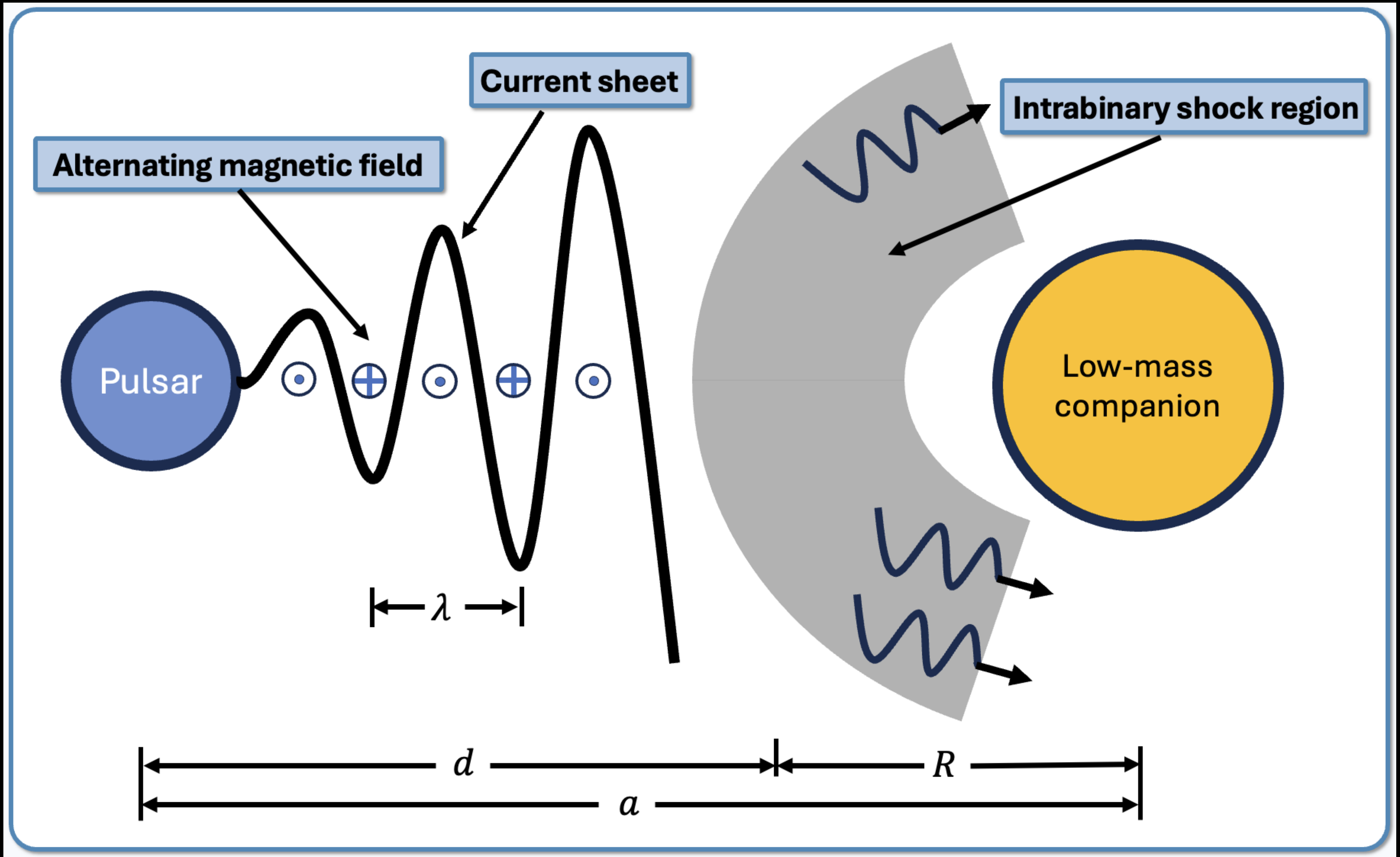
Fastest MSPs

- Multiwavelength (gamma-ray, optical, IR, **X-ray**)
- ~ 100 observed spider systems
- Correlation of spin down power to X-ray luminosity



Koljonen K. I. I. & Linares M. 2025 *ApJ* **994** 8

Why are Spider Pulsars special? *Lengthscales !*



- $\lambda \sim 10^8\,\mathrm{cm}$
- $a \sim 10^3\lambda$
- $R \sim 10^2\lambda$
- $d \sim 10^3\lambda$

$a \geq d \geq R \gg \lambda$

10^6*x closer than in the Crab Nebula !*

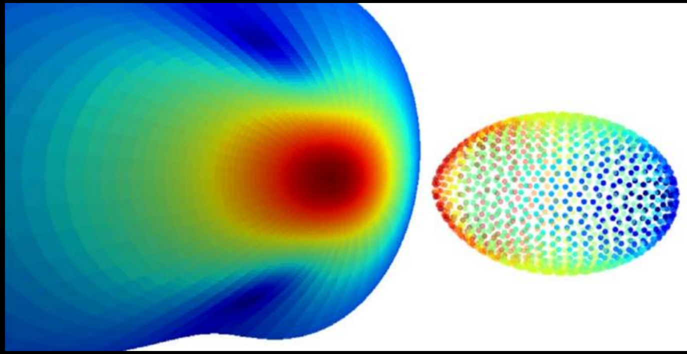
$d_{diss} \sim 10^3\lambda \sim d$

→ still magnetized !

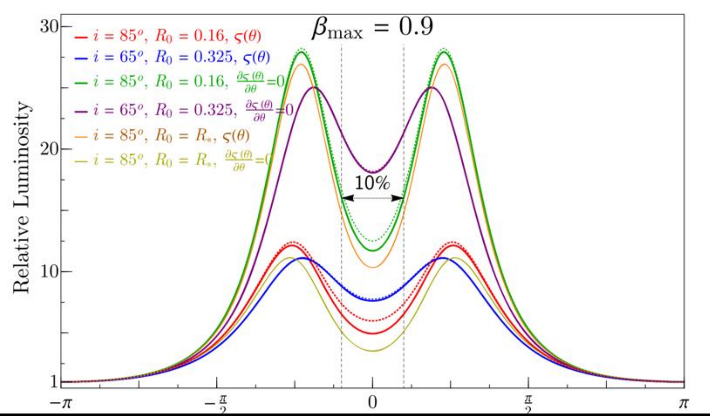
(e.g., Cerutti+2020)

Existing approaches capture parts of the problem

Geometric / emission



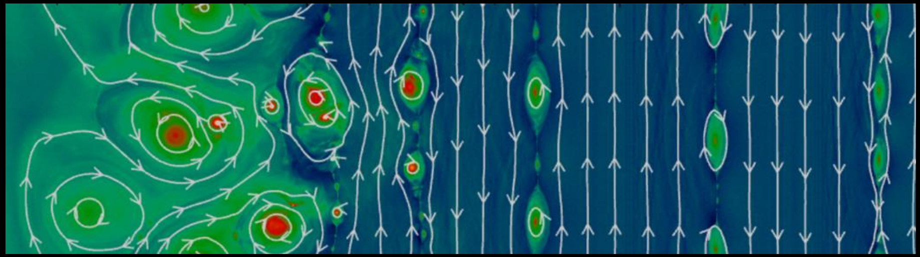
Kandel+2019



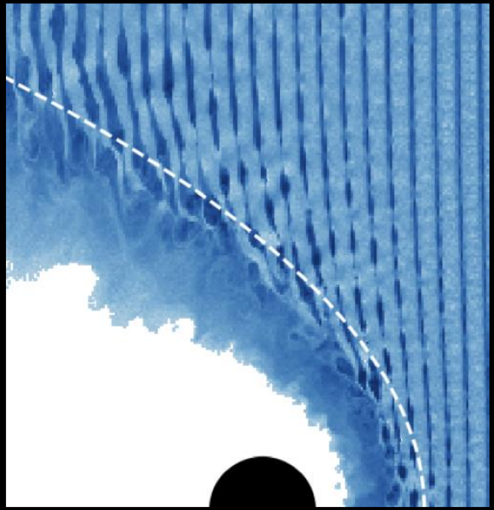
Wadiasingh+2017

✅ shock shape ↔ observations
❌ imposed shock shape

Pulsar wind dissipation



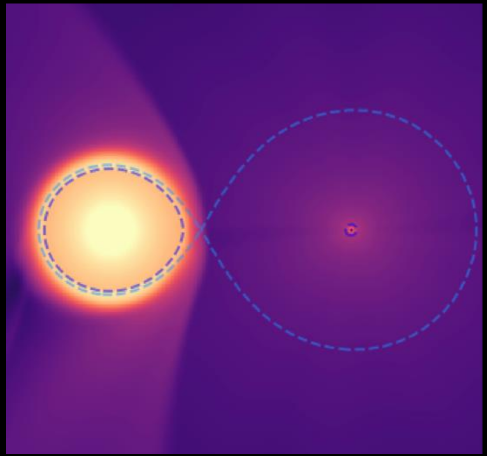
Sironi+2012



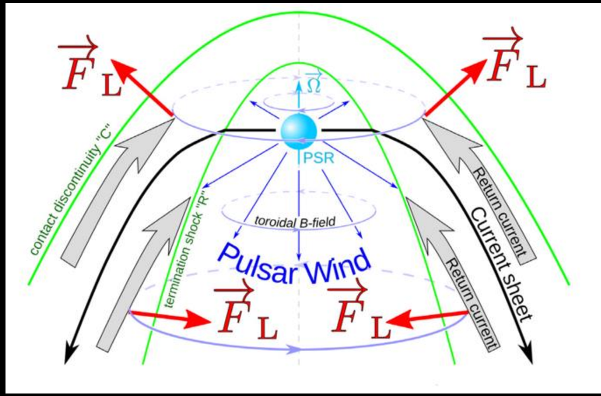
Sullivan+2025

✅ dissipation + nonthermal acceleration
❌ local box + plane parallel waves + no

Wind-wind interaction



Guerra+2024

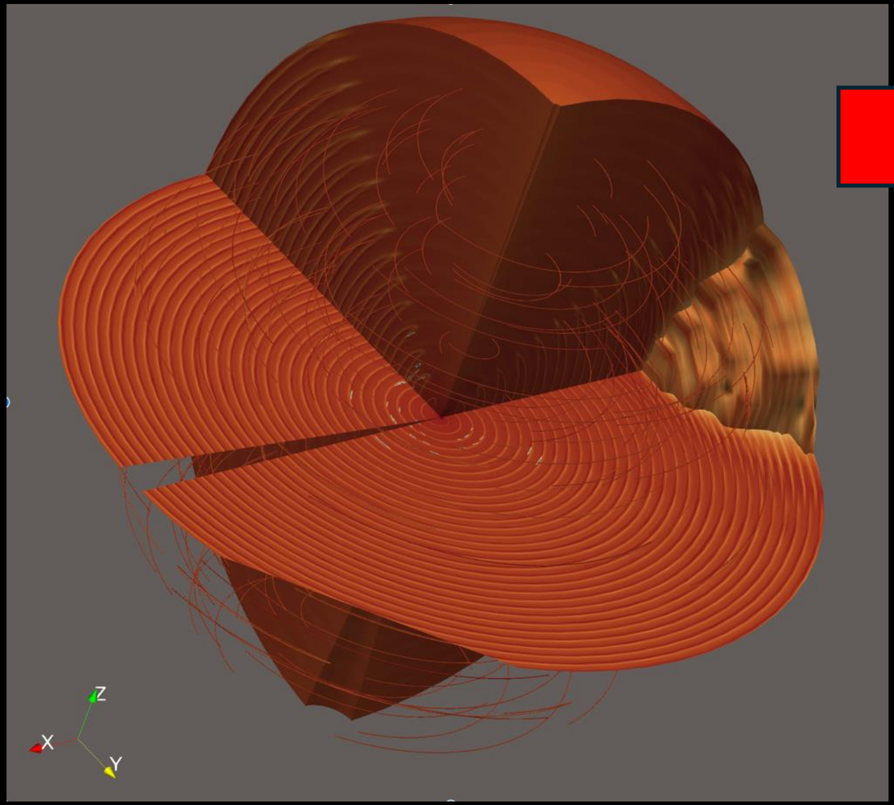


Bogovalov+2019

✅ Global structures
❌ Axisymetric + Hydro + no stripes + not spider regime

Our work: 3D General relativistic magnetohydrodynamics simulations

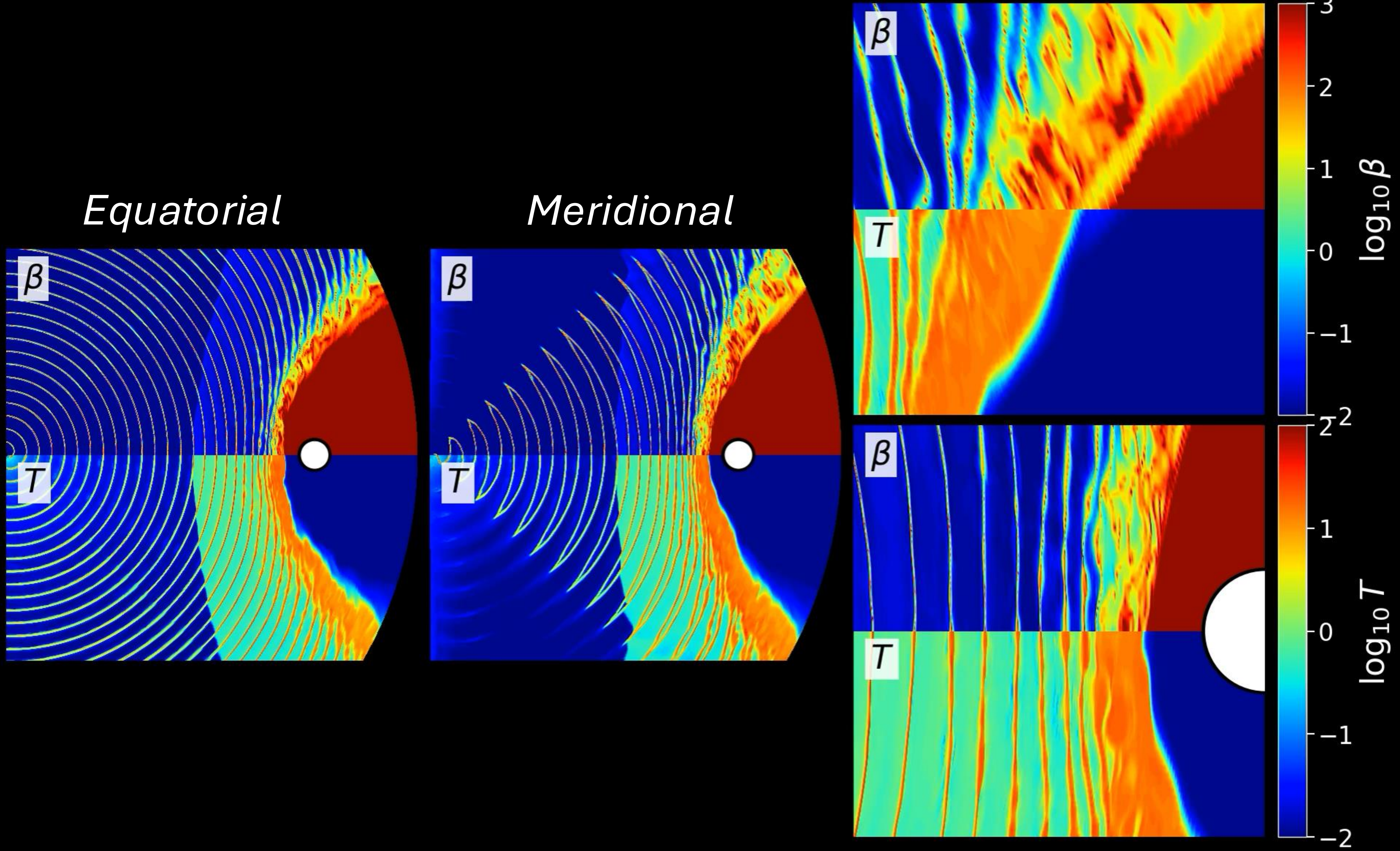
Oblique spinning magnetic dipole



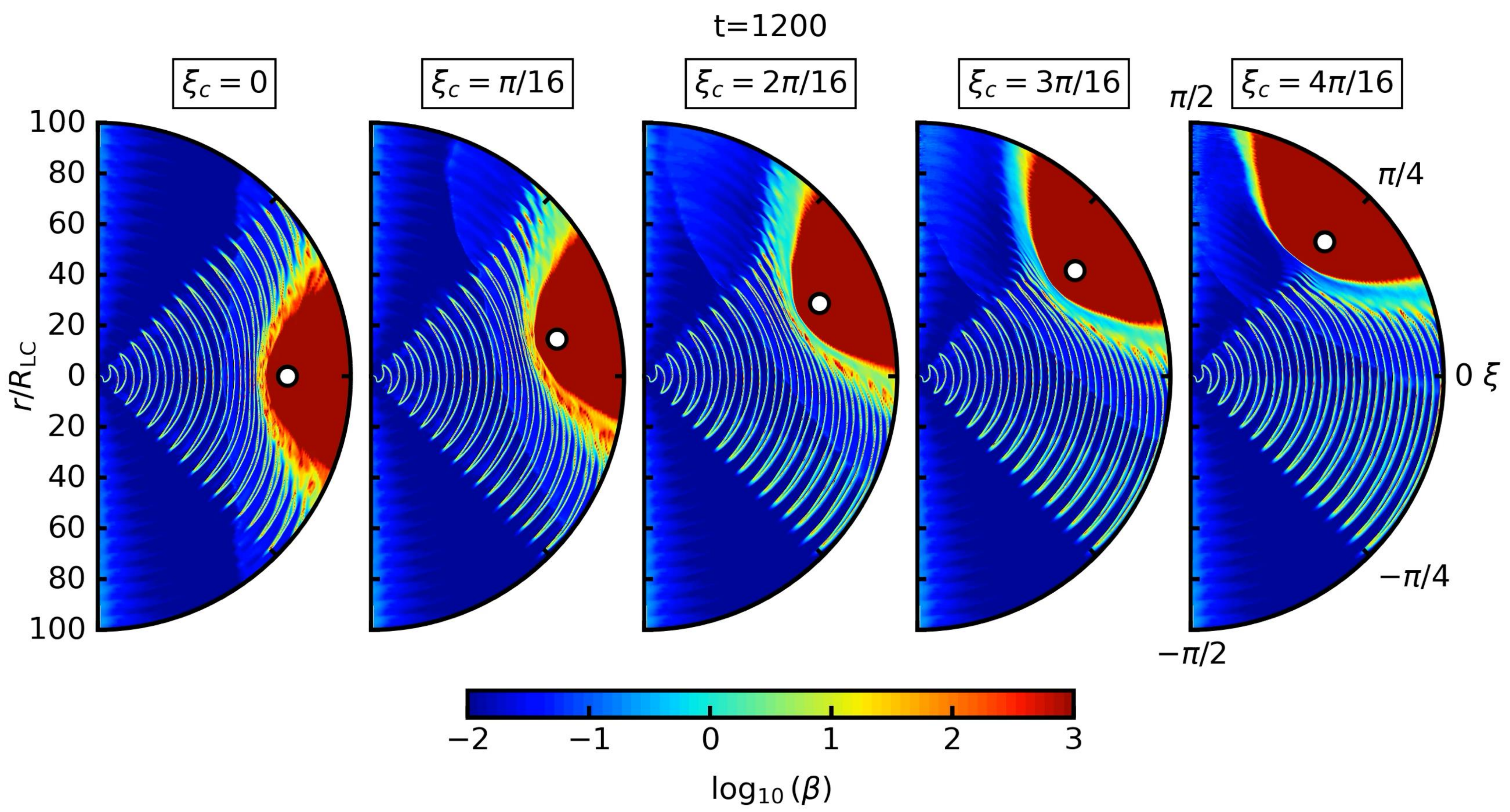
- *Relativistic magnetized striped wind*
- *Latitude dependent wind momentum flux*
- *Magnetic polarity imbalance*
- *Radial incidence angles*
- *IBS formation through interaction with companion outflow*

✅ *IBS geometry*
✅ *Pulsar wind energy conversion*
✅ *Properties of outflows*
✅ *Synthetic emission*

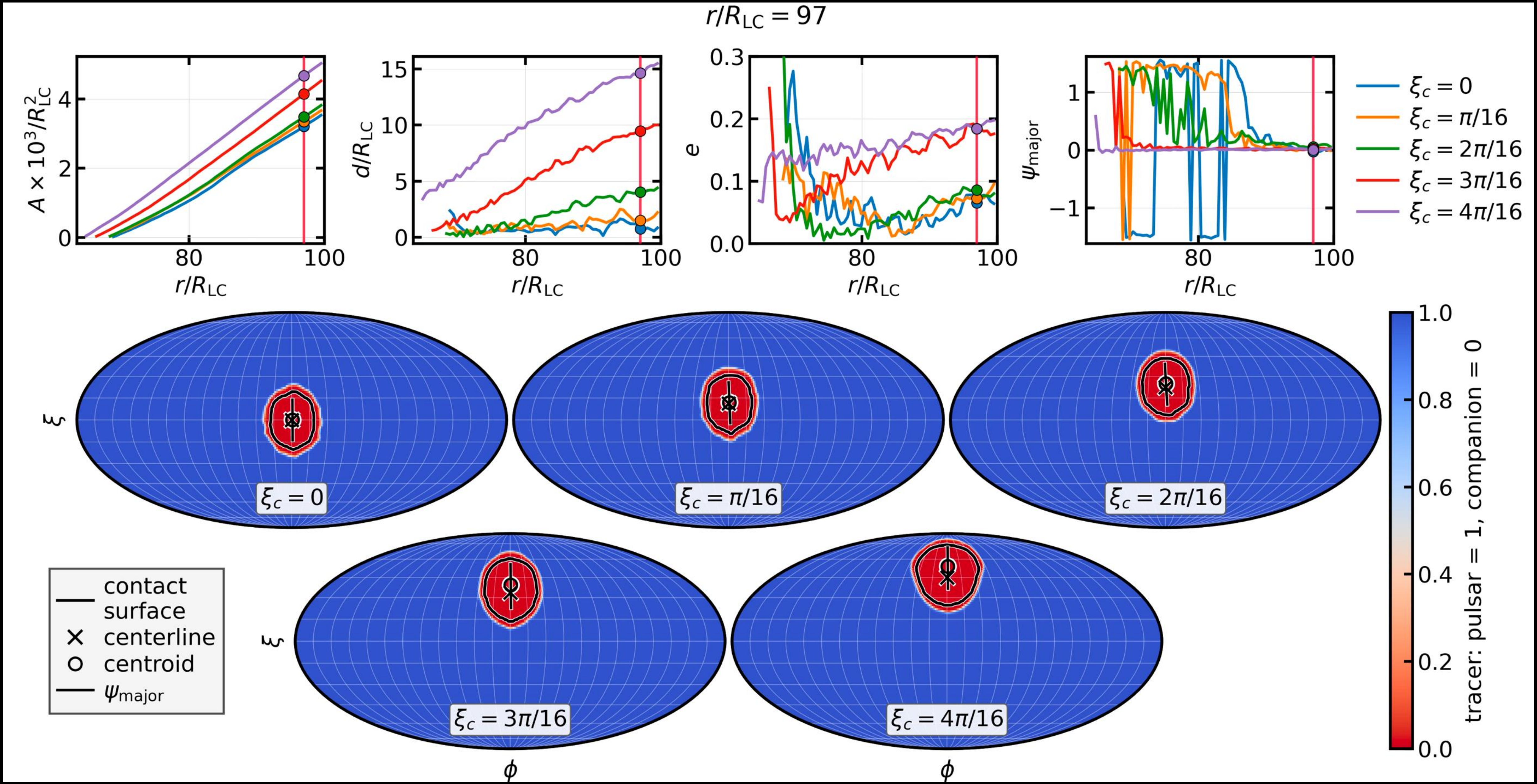
3D pulsar wind forming IBS with companion



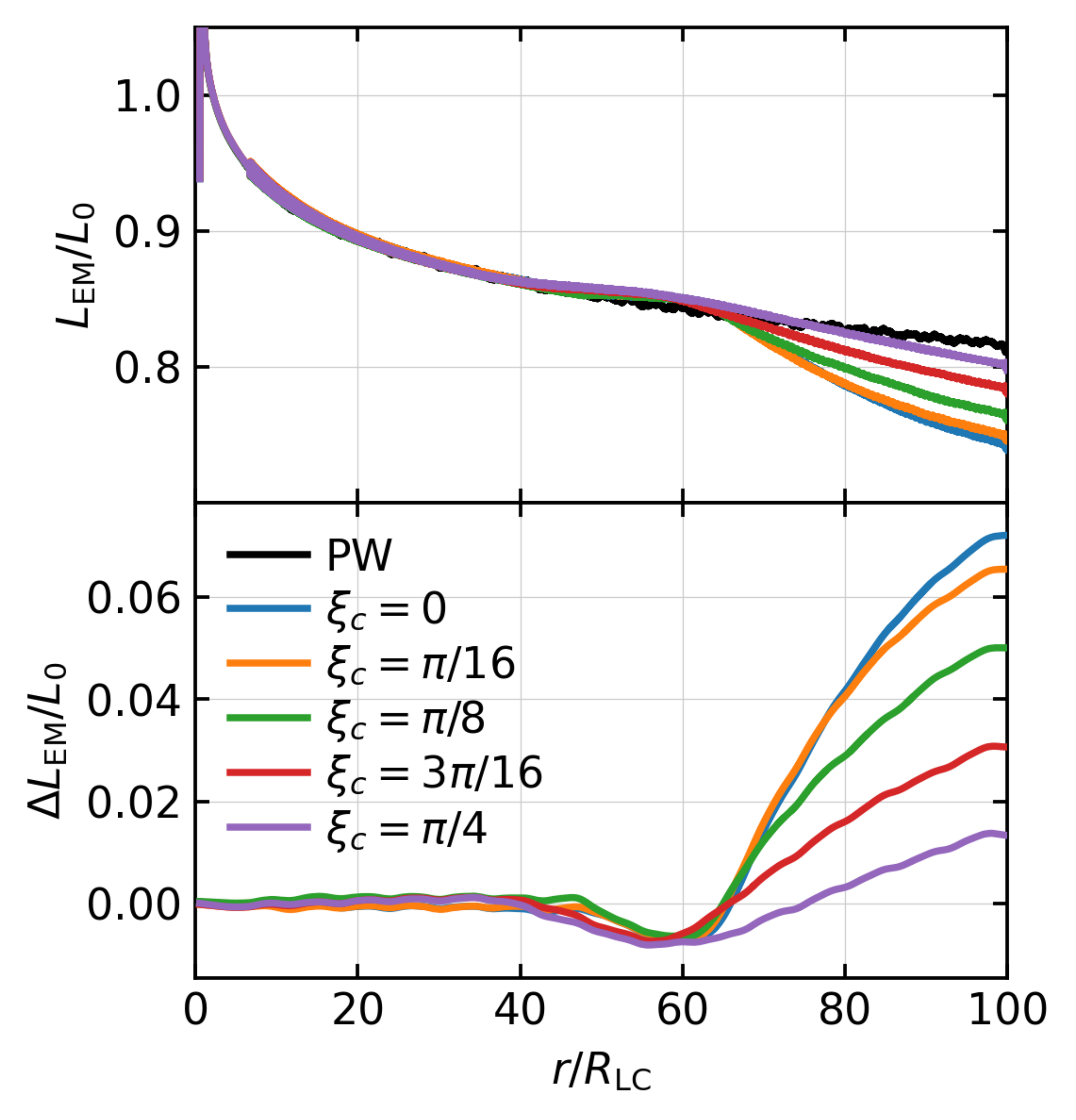
Varying companion latitudes

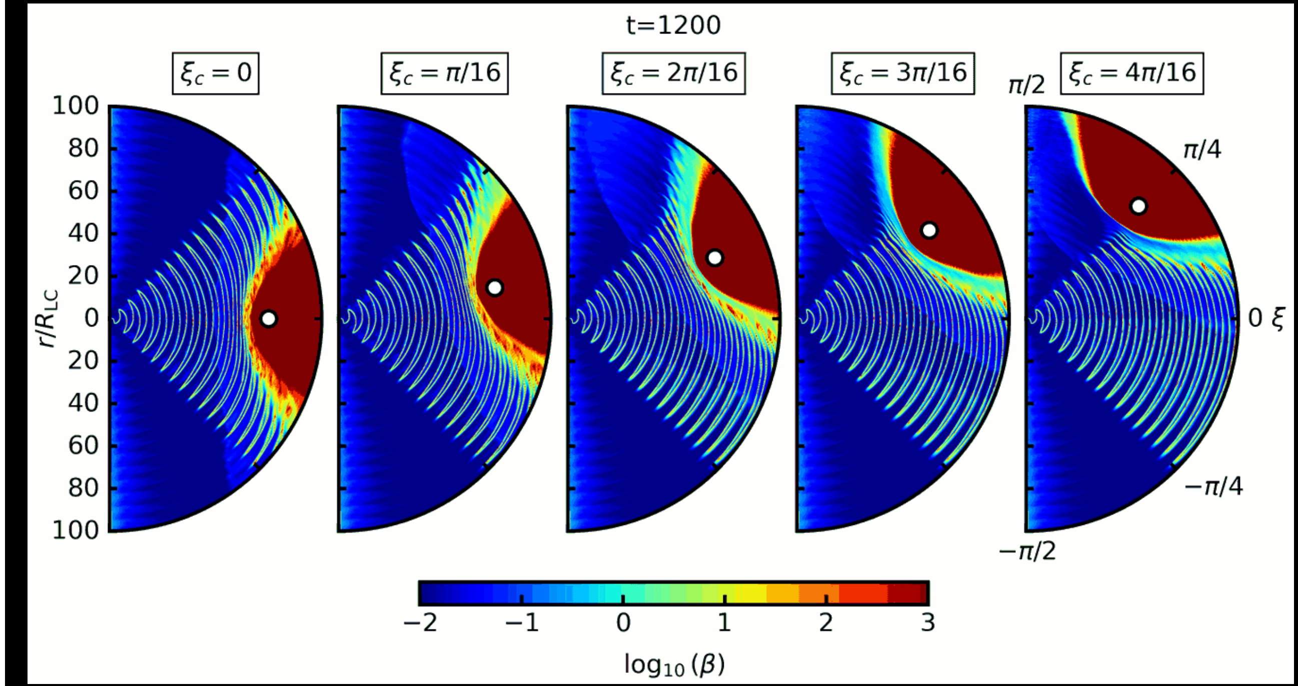


Contact surface geometry through spherical shells



Pulsar wind dissipation





- L_{EM} : EM luminosity though pulsar-centered spherical shells
- $\Delta L_{EM} = L^{PW} - L_{EM}$: EM luminosity deficit relative to isolated pulsar wind (PW)
- ~ 0 – 40R_{LC} : Unshocked PW
- ~ 40 – 60R_{LC} : Post MHD shock pre-apex compression
- ~ 60 – 100 R_{LC} : Post apex bowshock interaction
- Strongest conversion rate near apex
- **Local balance of stagnation and advection of incident annihilable flux governs local reconnection efficiency**

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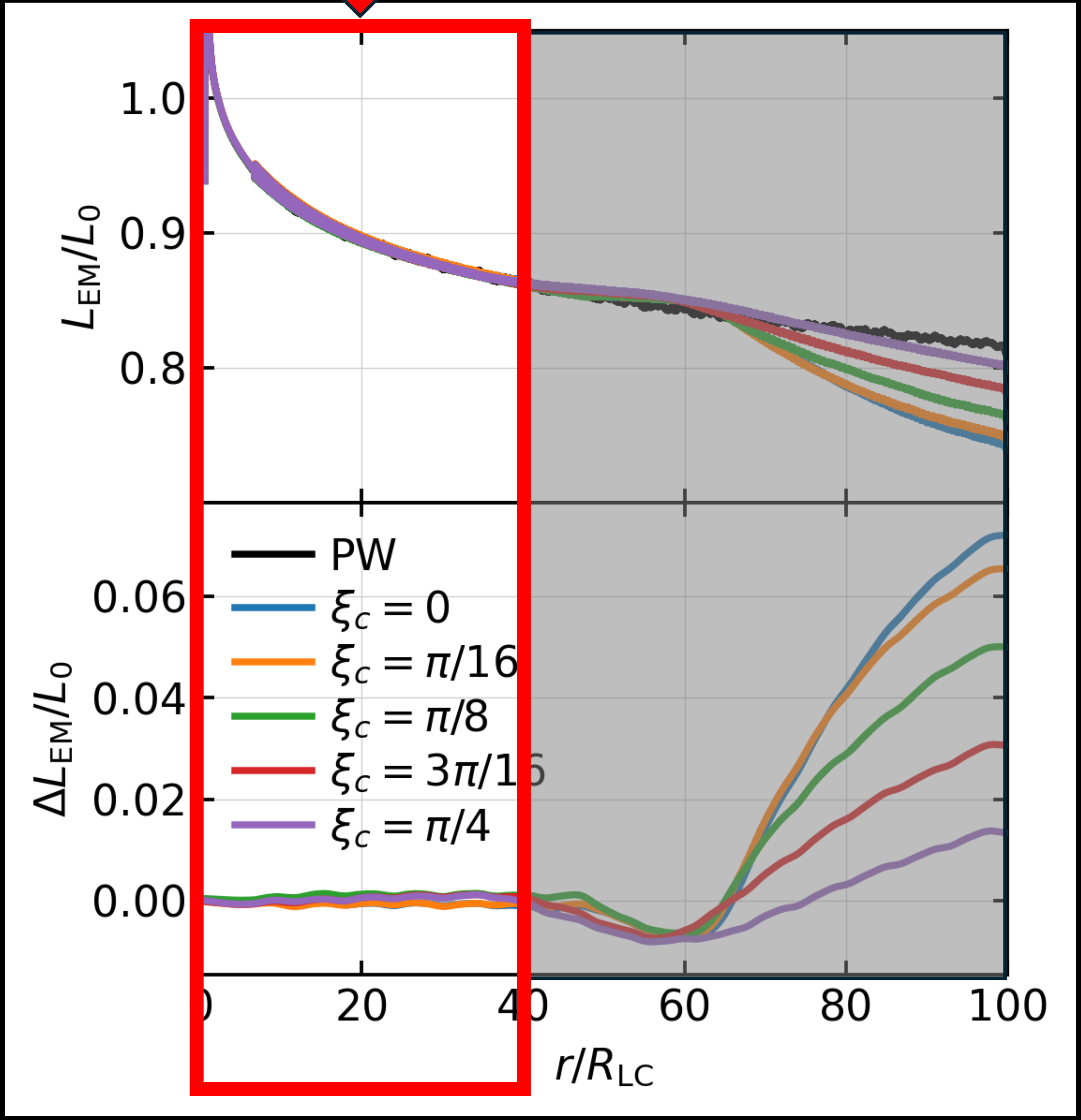

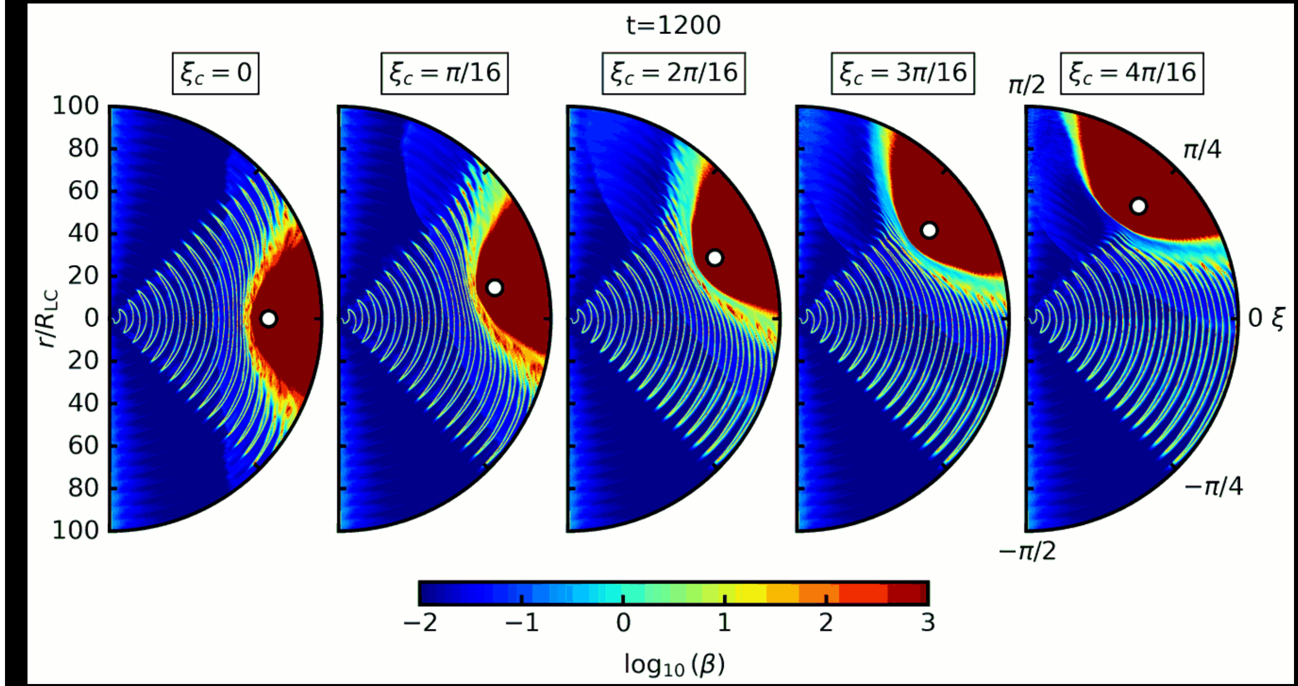

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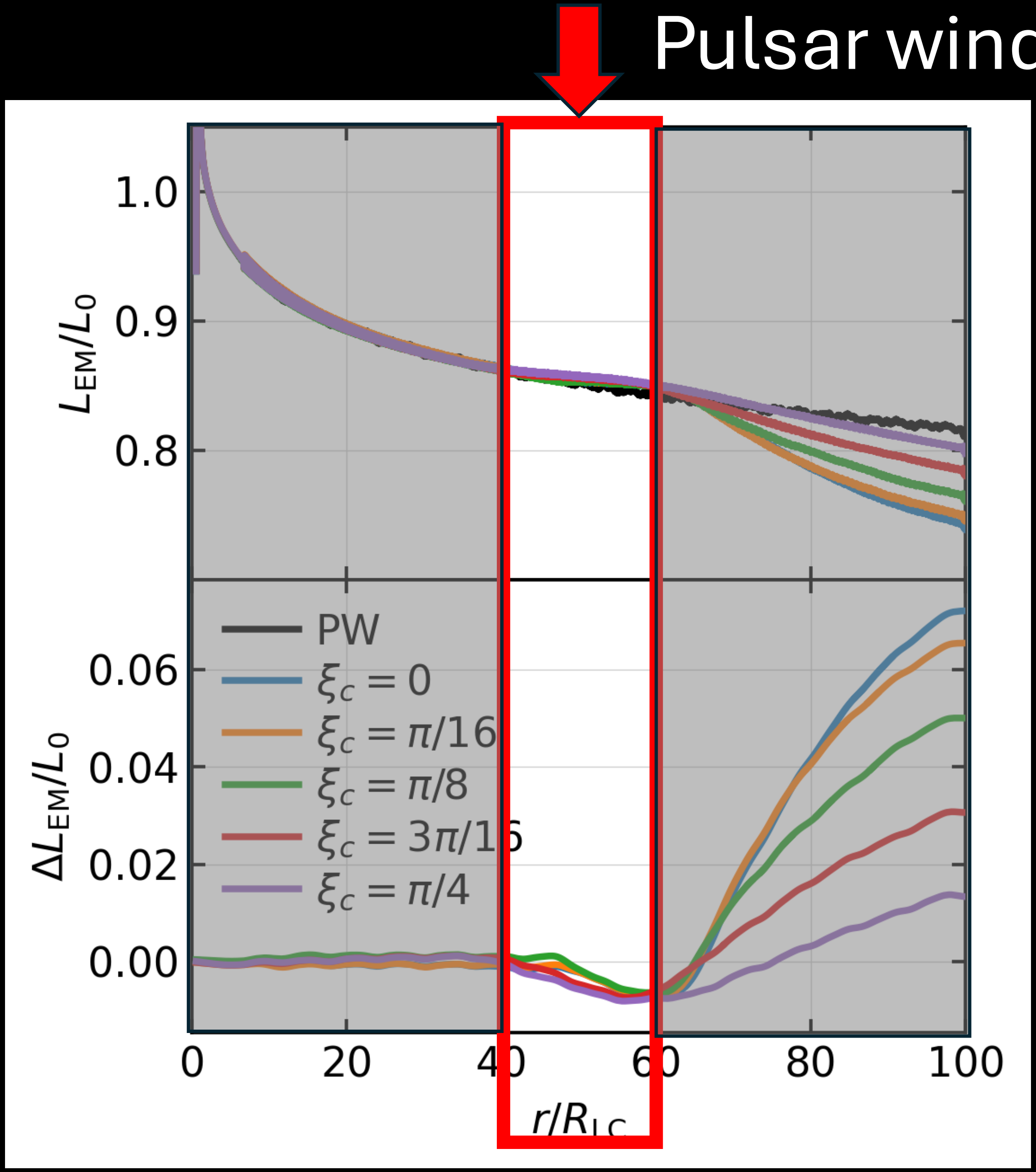

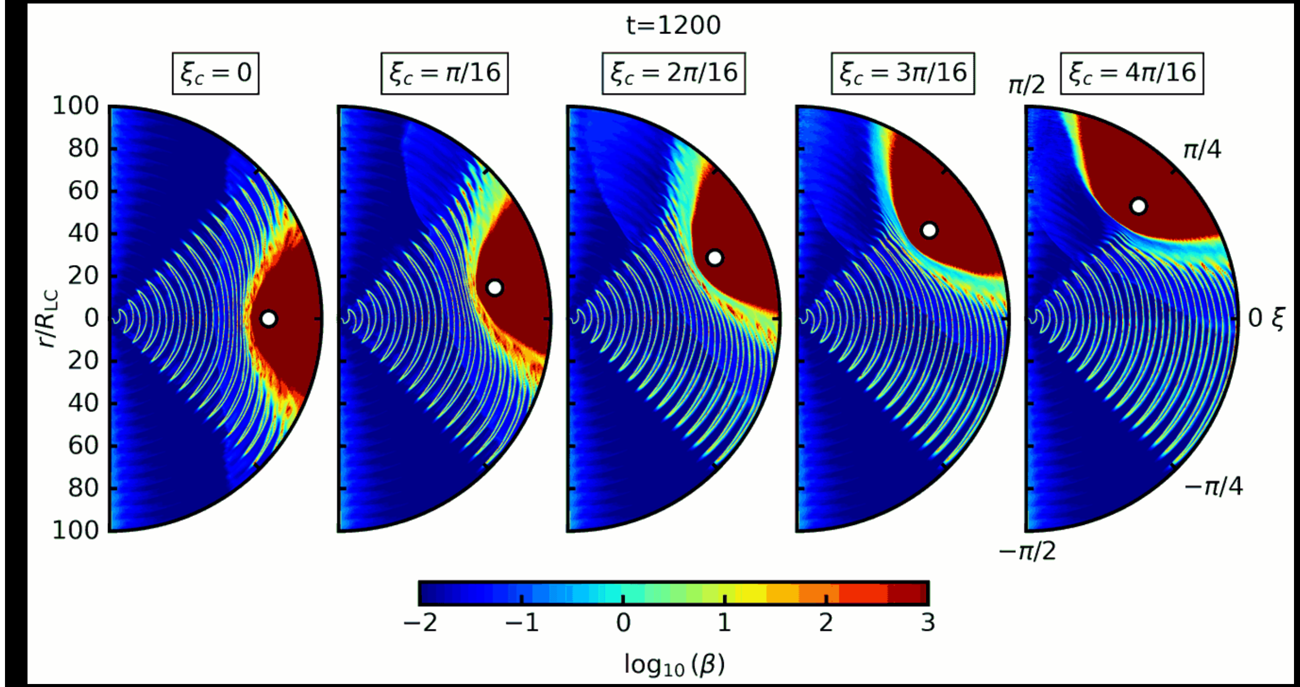

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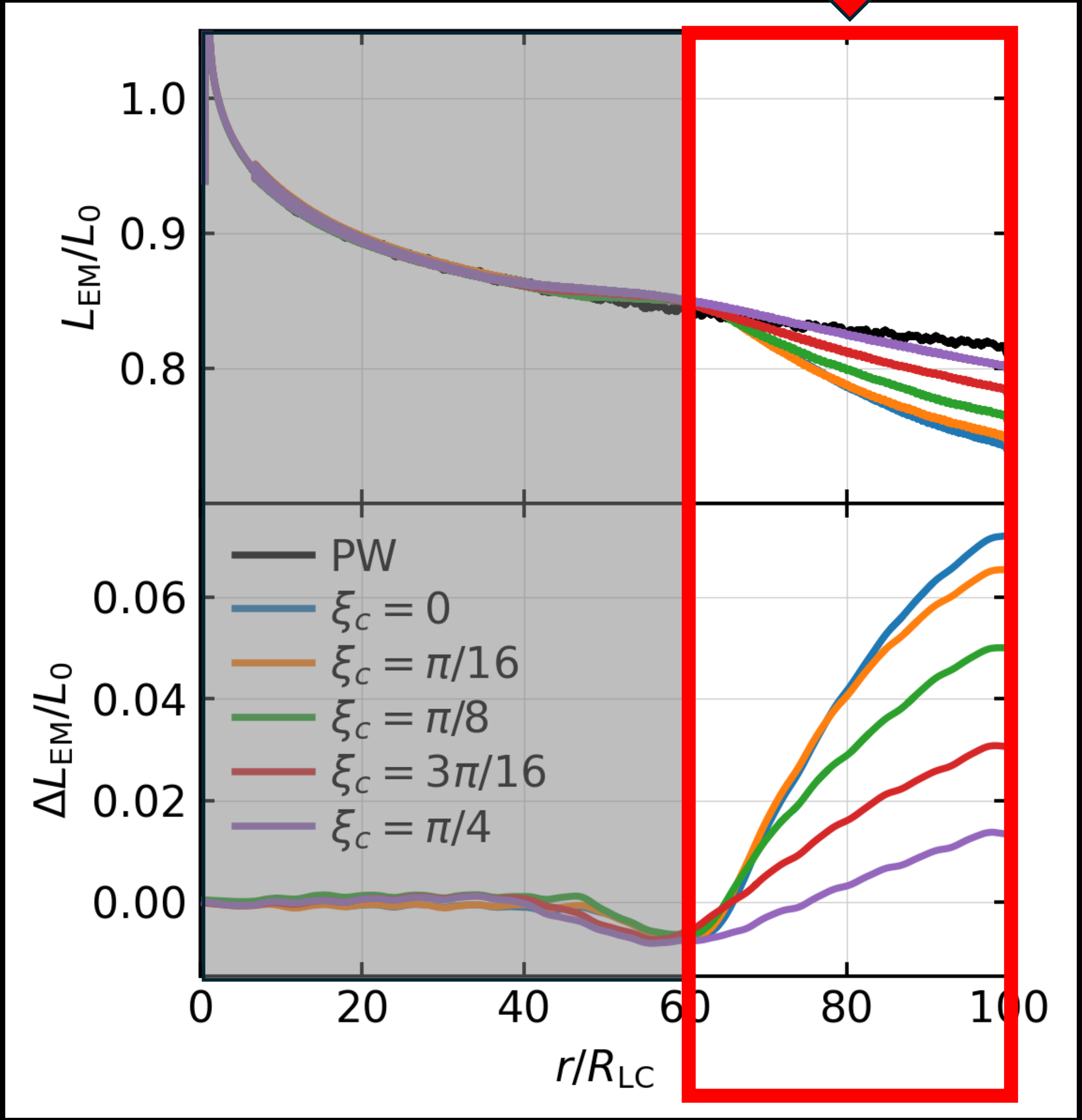

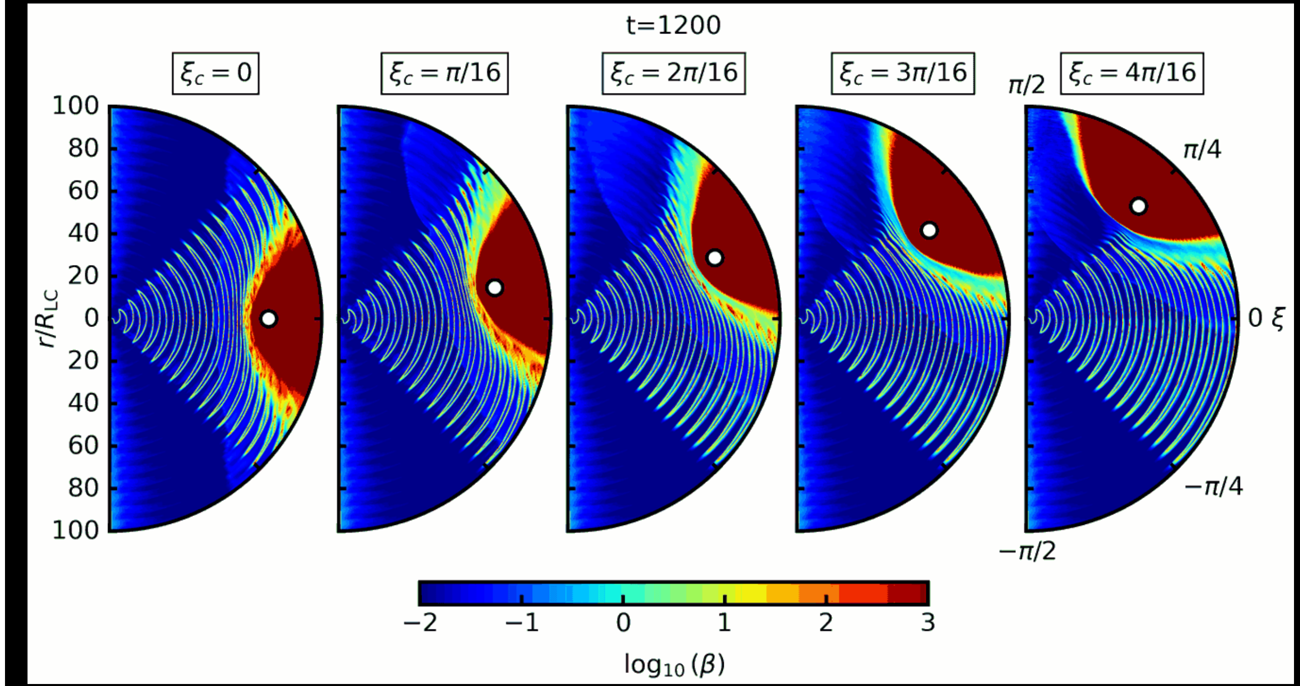

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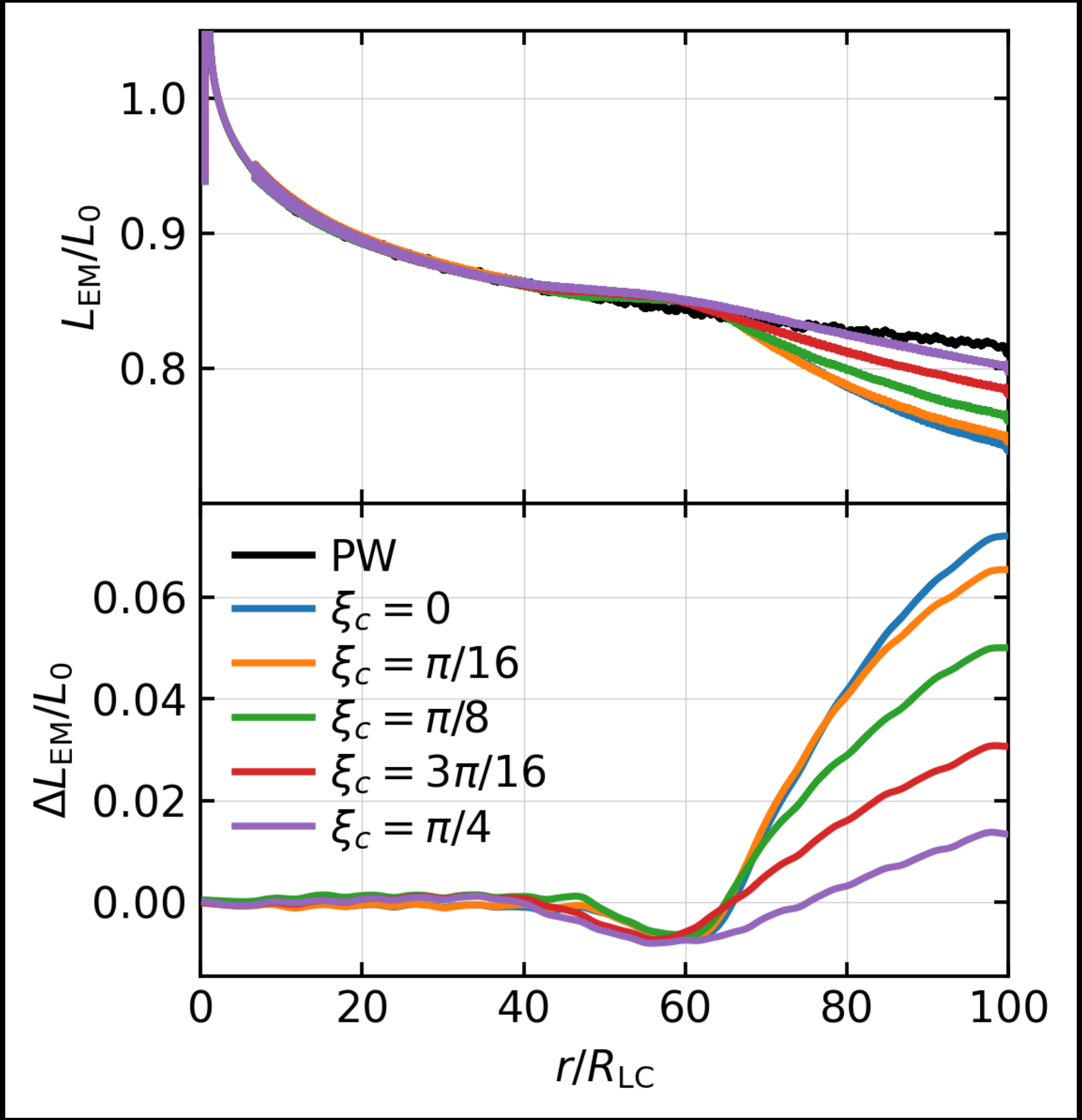

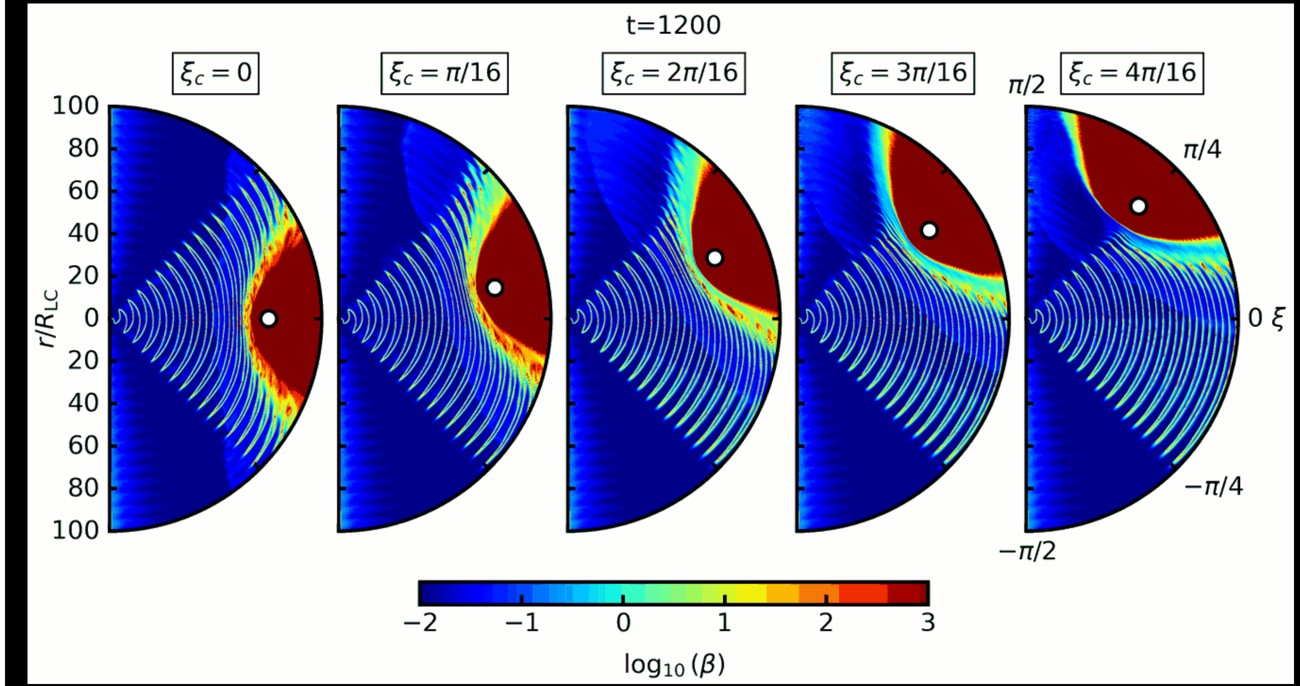

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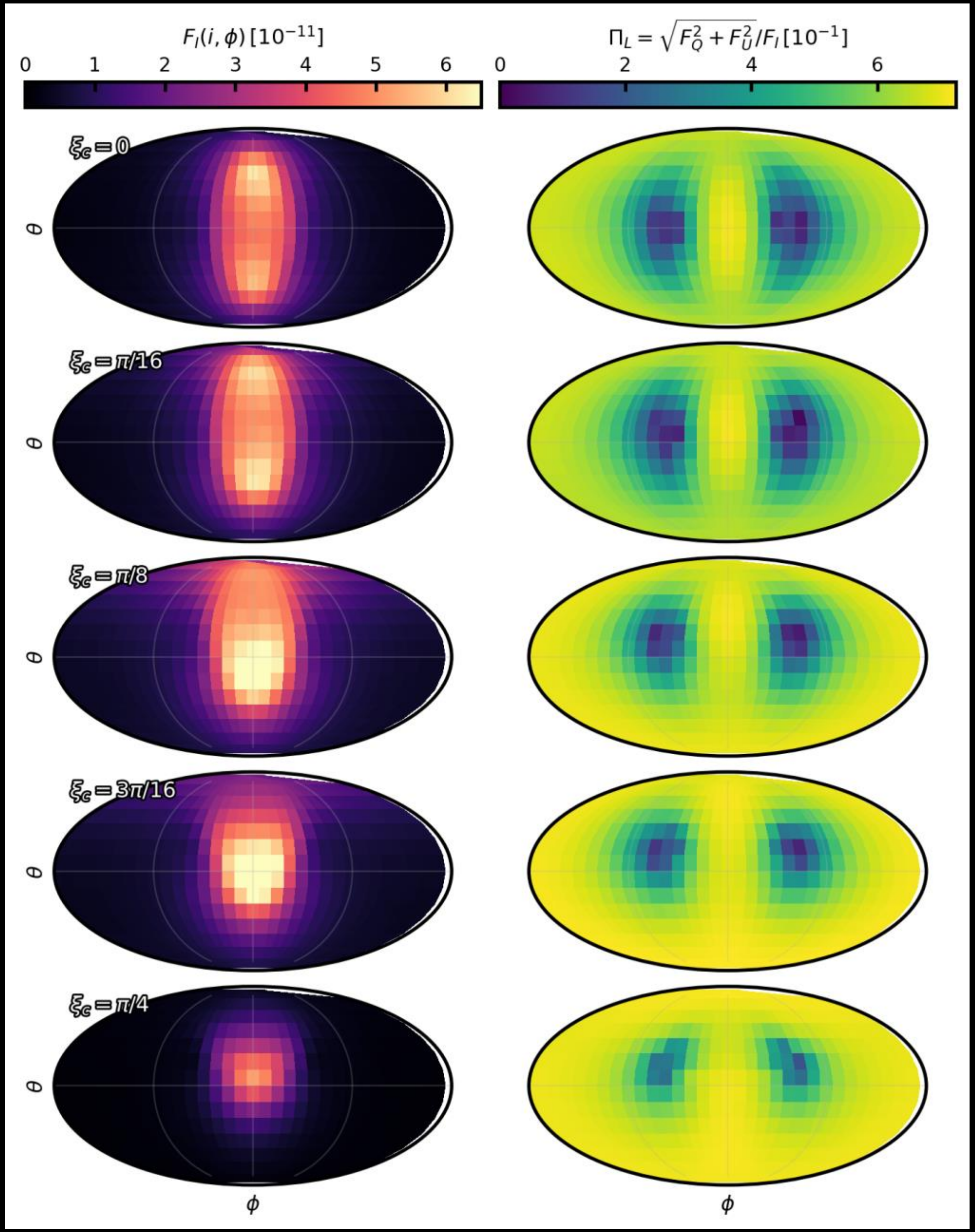
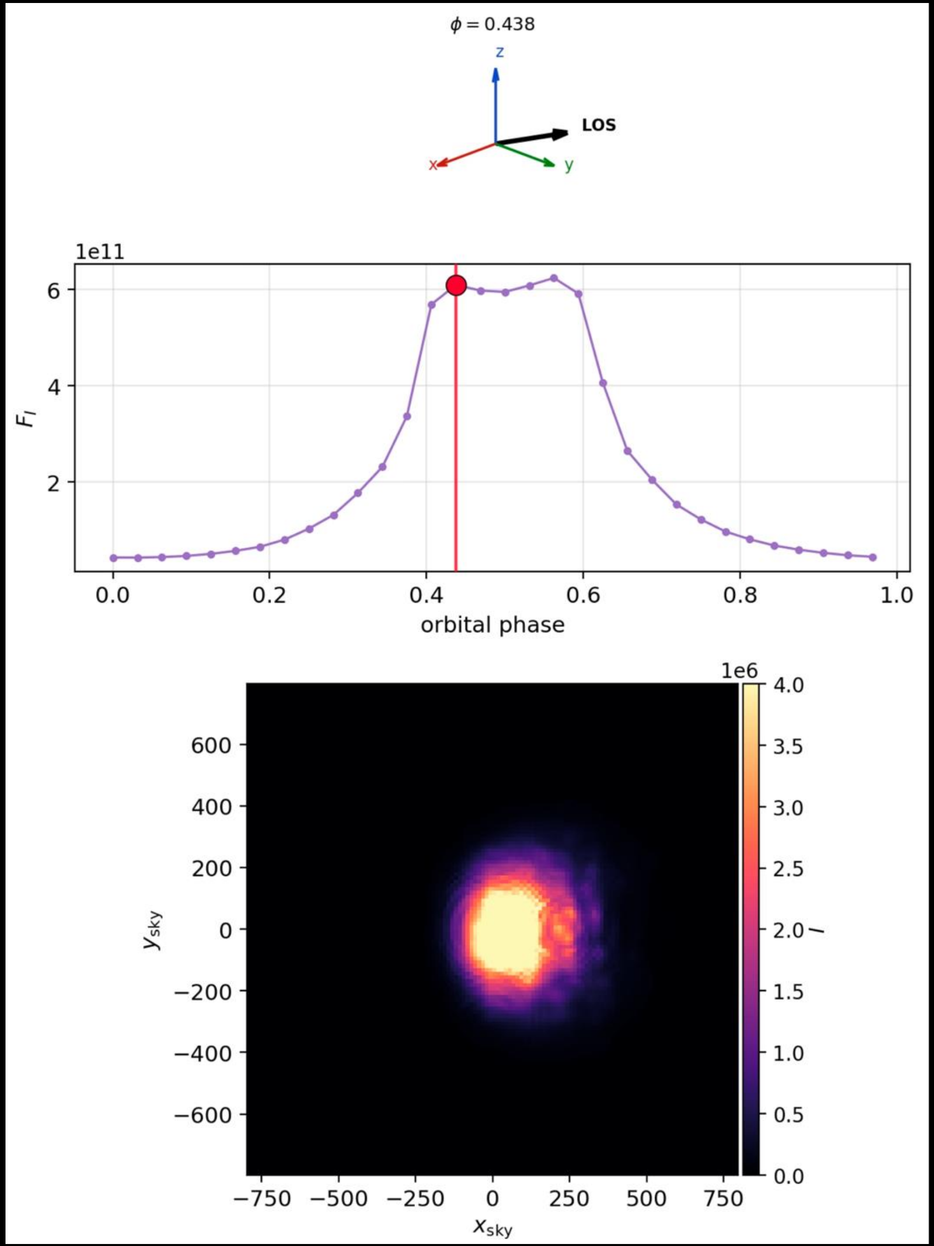
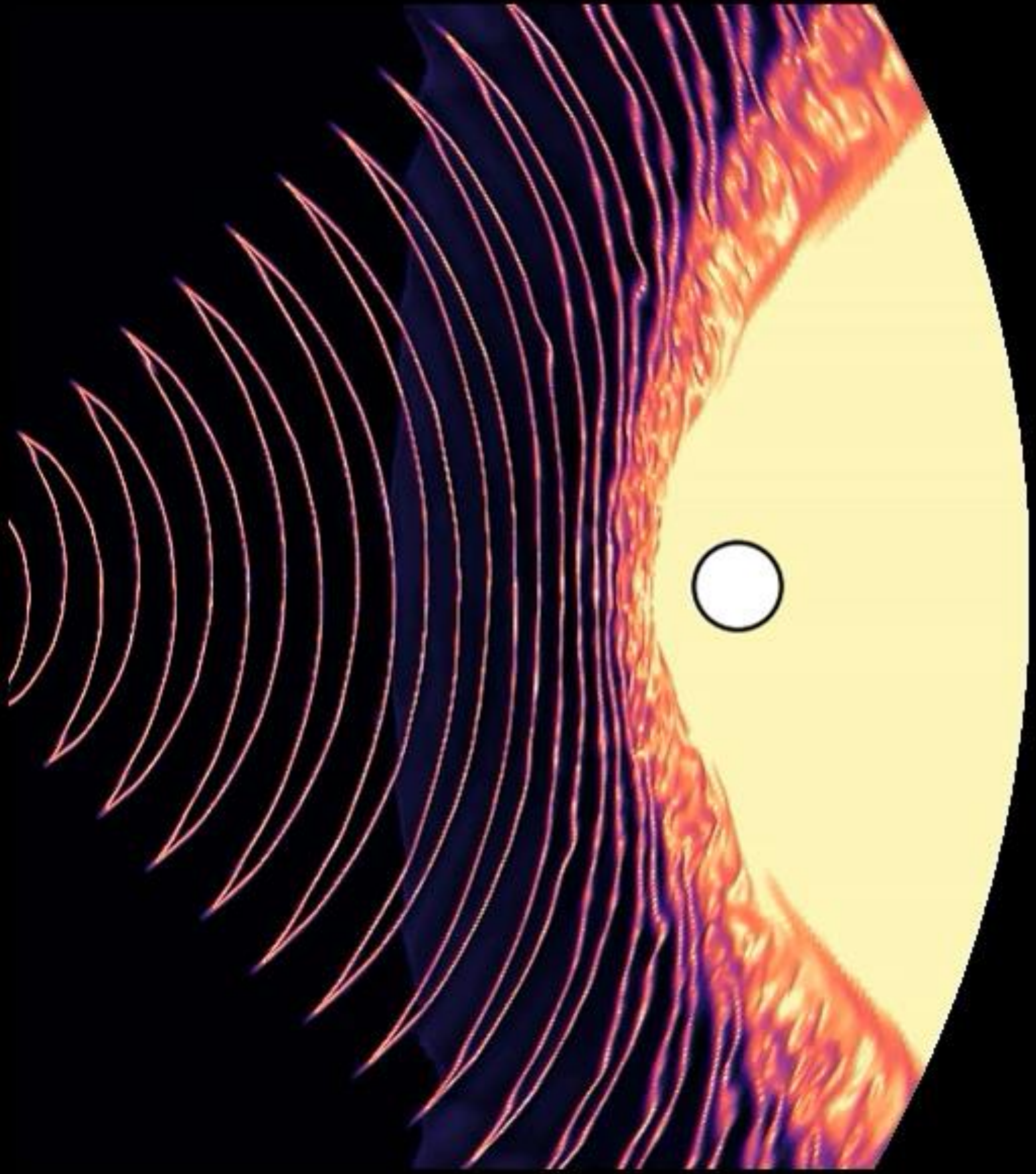
Synthetic emission (preliminary)







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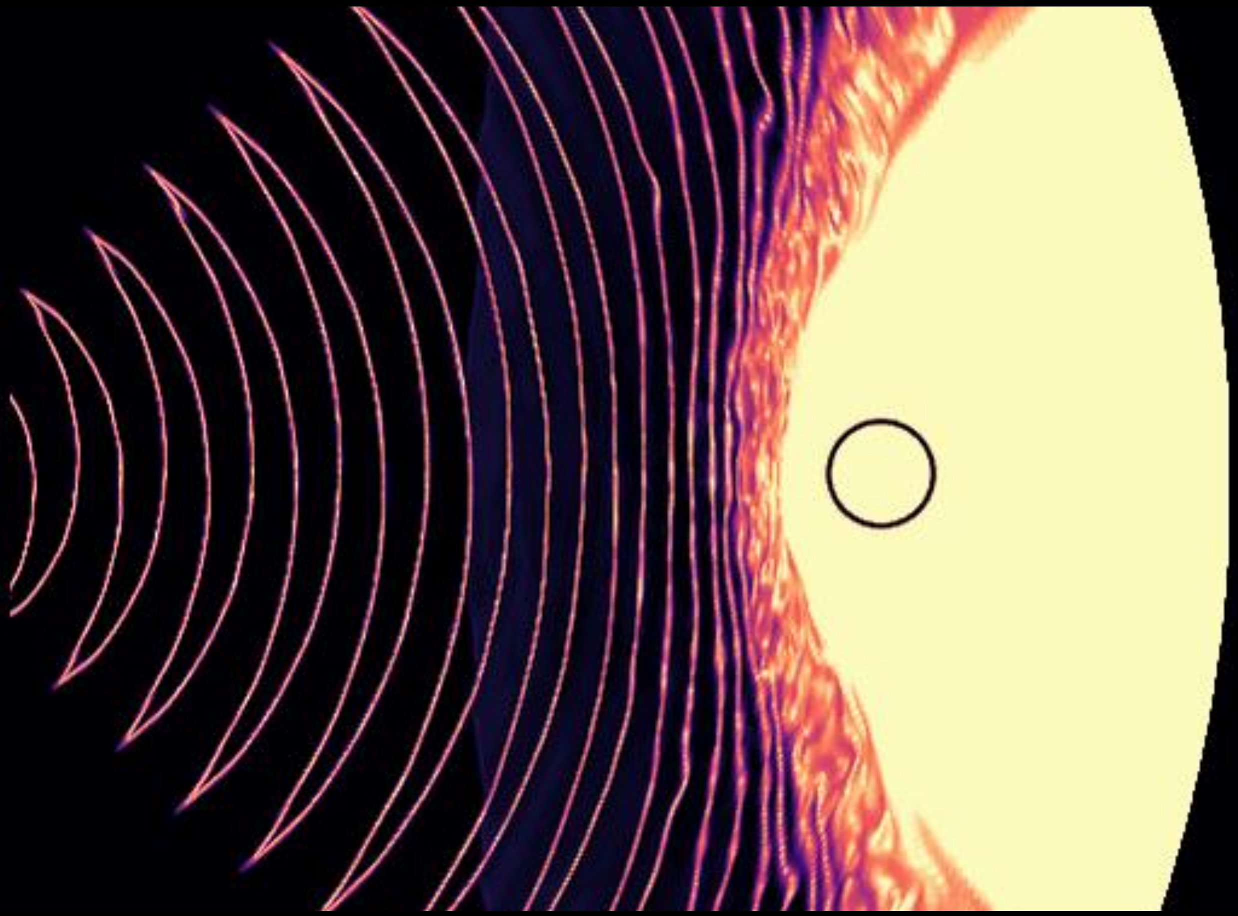

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