The physics behind the non-thermal emission in γ-ray emitting binaries*

*High-mass, relativistic

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Variable Galactic Gamma-Ray Sources VI

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Outline

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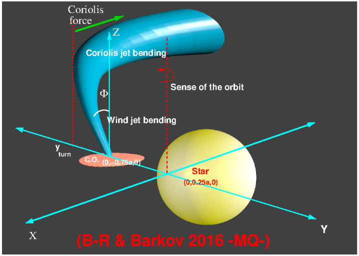
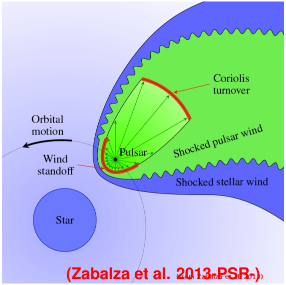
High-mass, relativistic, γ-ray emitting binaries

- **High-mass, relativistic γ-ray emitting binaries are efficient, complex accelerators and powerful high-energy sources.**
- **Important elements common to all these sources:**
  - **Relativistic outflows: winds and jets.** **(BINARY SCALES)**
  - **Dense radiation field.**
  - **Substantial and structured stellar wind.**
  - **Relativistic effects.**
  - **Shocks, instabilities and mixing.**
  - **Magnetic fields.**
  - **Orbital motion and eccentricity.** **(BEYOND BINARY SCALES)**
  - **Interactions on large scales.**



(B-R & Barkov 2016 -MQ-)



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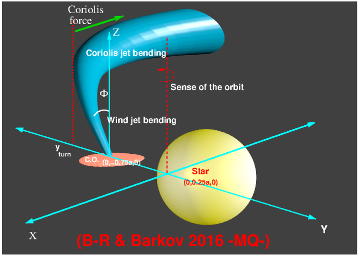

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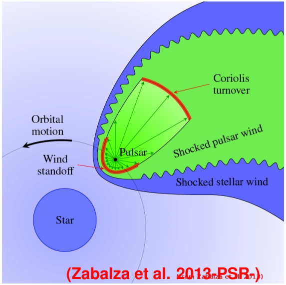

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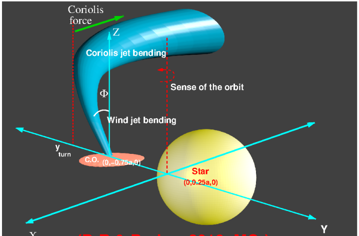

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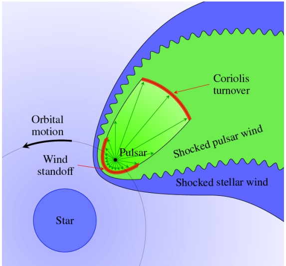

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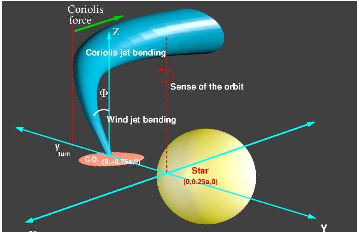

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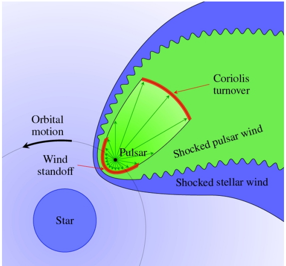

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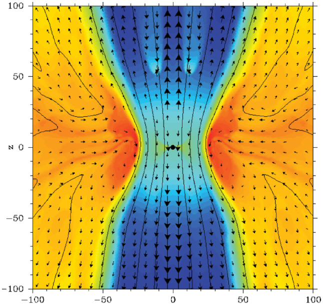
- **In a HMMQ:**
  - A jet can form, protected from the stellar wind by accretion flows.
  - Magnetization, content and velocity are unclear, possibly structured.
  - The jet can already suffer internal or recollimation shocks, and mass-load.
- In a non-accreting pulsar:
  - The unshocked pulsar wind is expected to be magnetized, anisotropic and ultrarelativistic.
  - The pulsar wind is accelerated by a mechanism (B) of unclear efficiency.
- Relativistic outflow and dense local field: the converter mechanism can operate.
- Unshocked outflows can already emit.



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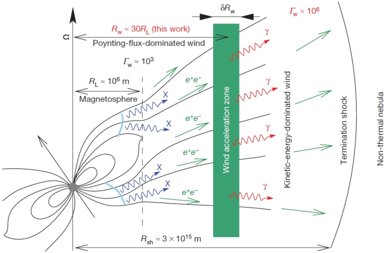

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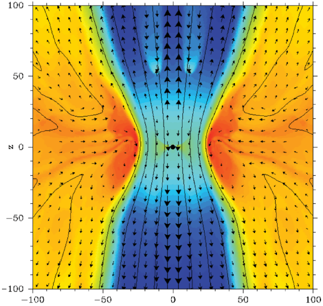

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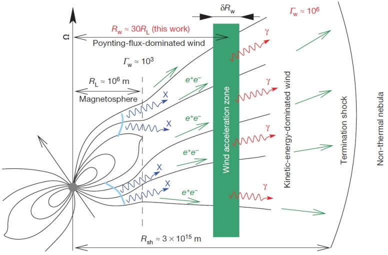

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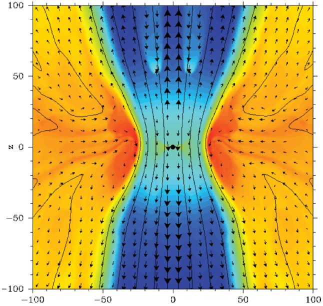

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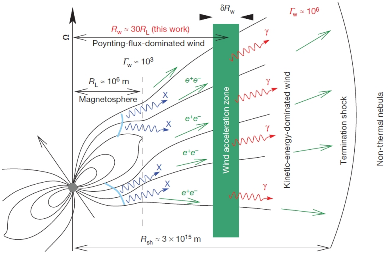

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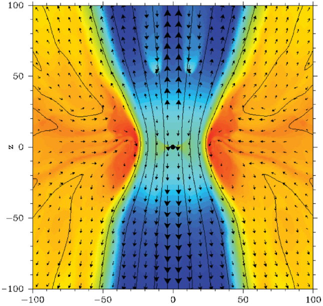

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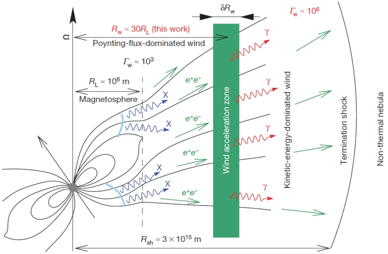

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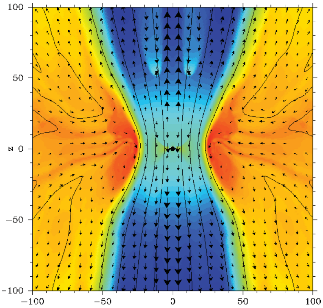

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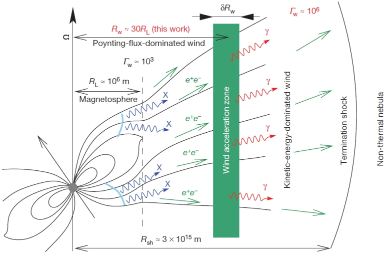

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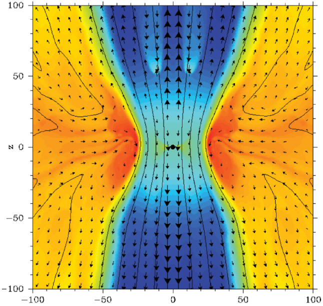

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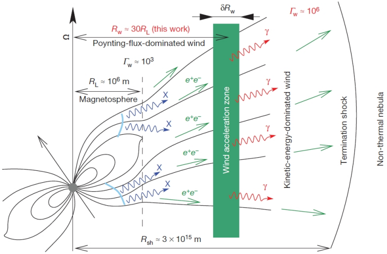

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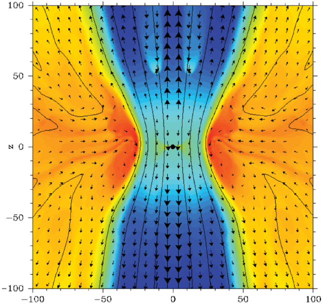

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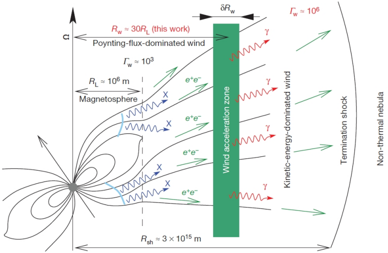

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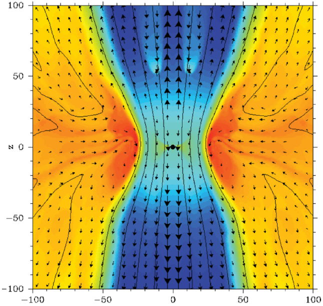

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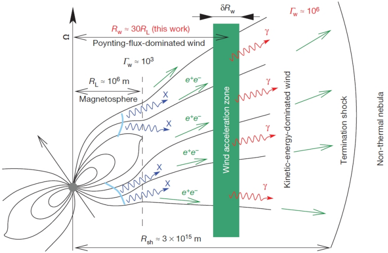

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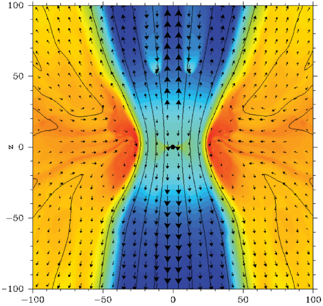

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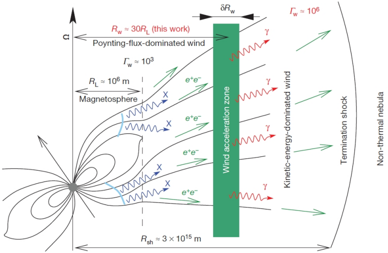

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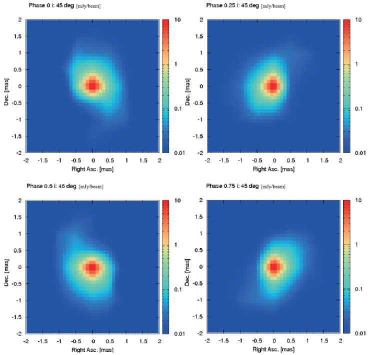
Radiation fields

- **Strong IC:** $u_\star \sim 1 - 100\, u_{\rm B}(L_{\star,38}/L_{\rm o,36})$
- Radiation efficient even outside binary.
- Hadronic processes relevant only in very dense winds, at a jet base, or near the star.
- $\tau_{\gamma\gamma} \gtrsim 0.1 - 1$ for $d_{\rm orb} \lesssim 10^{13}$ cm s^{-1}.
- So far, no clear evidence of radiation reprocessing in radio, X-rays, gamma-rays.



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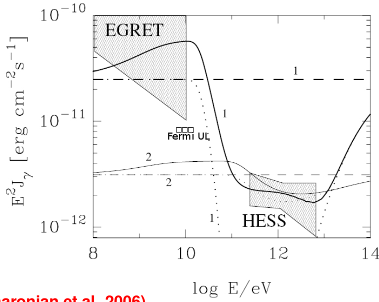

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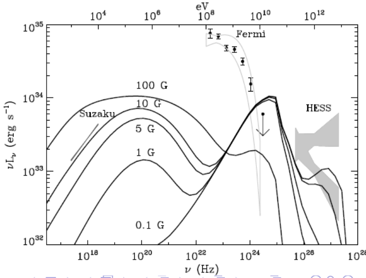

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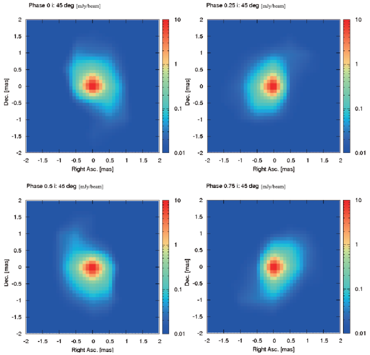

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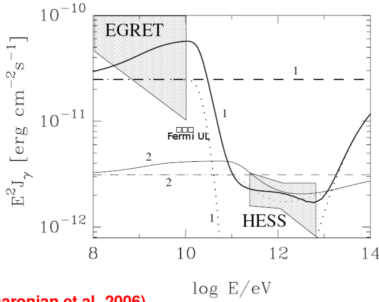

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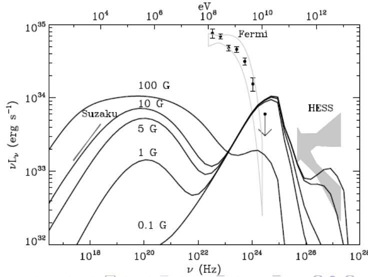

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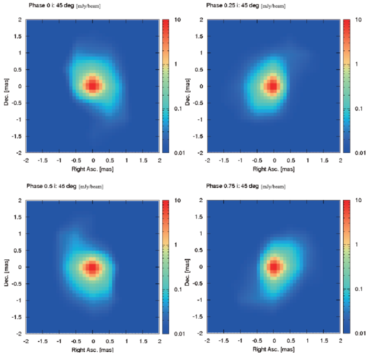

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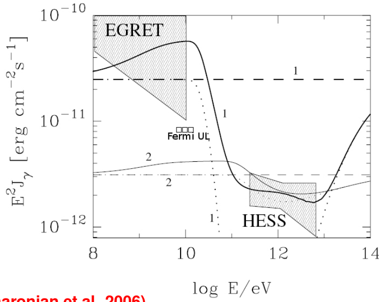

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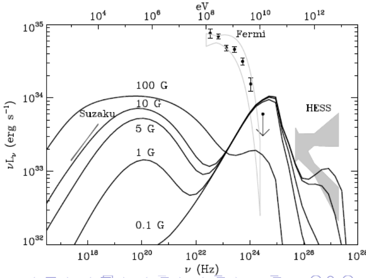

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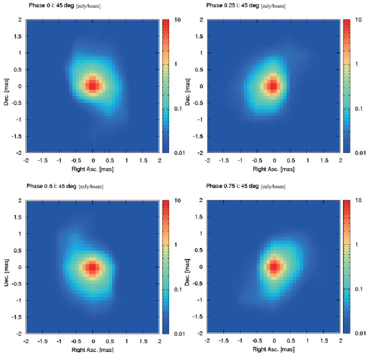

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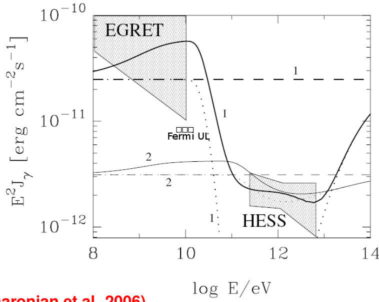

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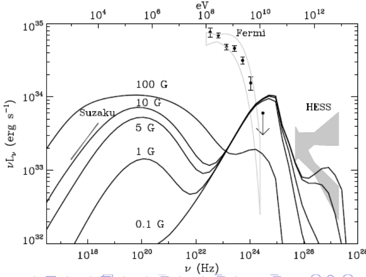

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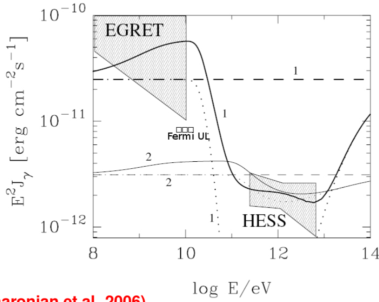

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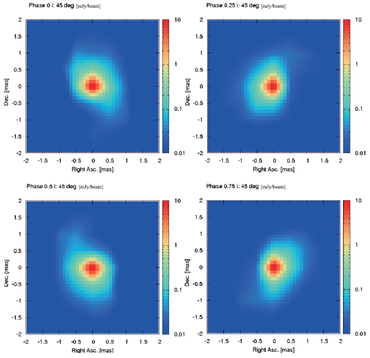

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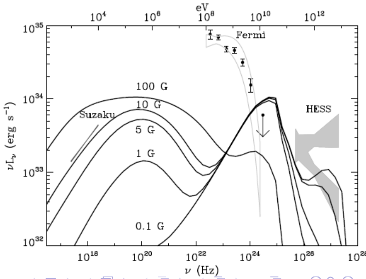

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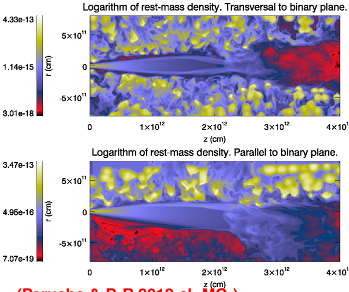
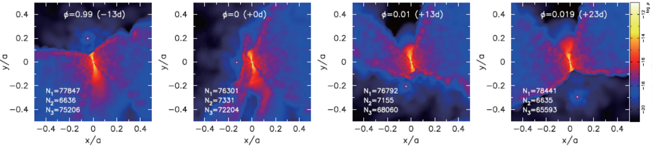
Substantial and structured stellar wind

- **Massive stars have strong winds:**
  - $L_{\rm o}/\dot{M}c \approx 5\times10^{7}\,(L_{\rm o,36}/\dot{M}_{-7})$ **cm s^{-1},**
  - $\sqrt{2L_{\rm o}/\dot{M}} \approx 5\times10^{8}\,\sqrt{L_{\rm o,36}/\dot{M}_{-7}}$ **cm s^{-1}.**
- **However,** $L_{\rm o}/L_{\rm sw}\sim 10\,(L_{\rm o,36}/\dot{M}_{-7}v_{\rm w,8.3}^{2})$**, which is relevant at large scales.**
- **The winds are complex:**
  - **There is a fast, clumpy polar wind.**
  - **Be star has dense slow disk but** $\rho\propto r^{-3}$**.**
- **Wind structures should affect the relativistic outflow and its emission.**



(Perucho & B-R 2012-cl. MQ-)



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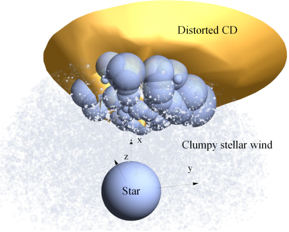

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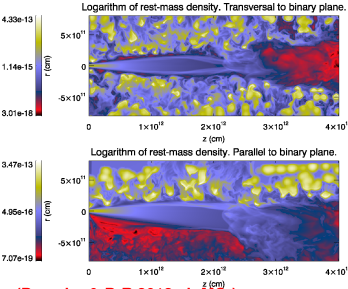

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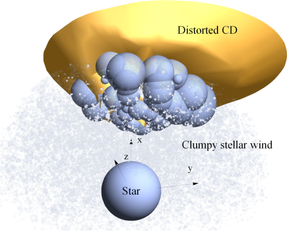

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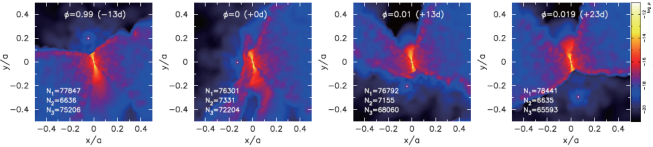

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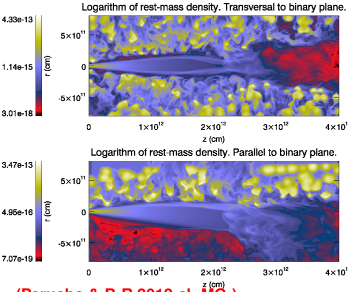

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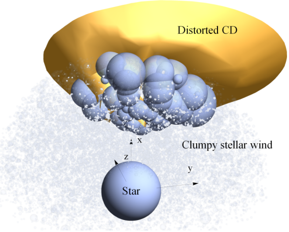

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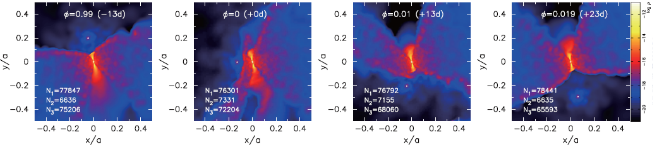

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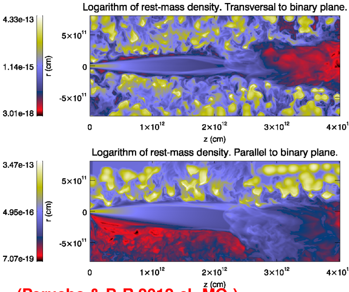

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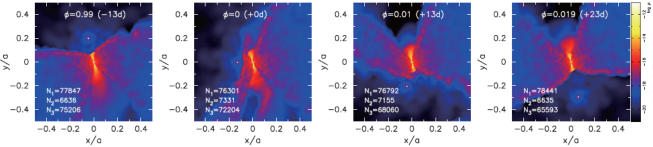

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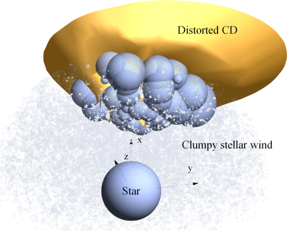

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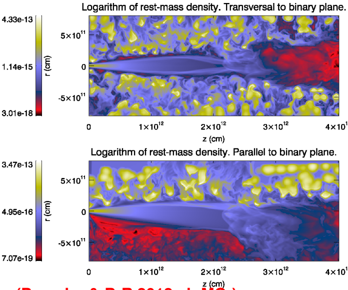

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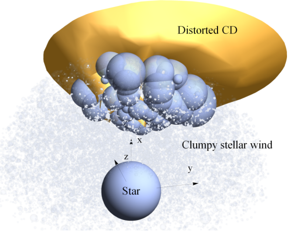

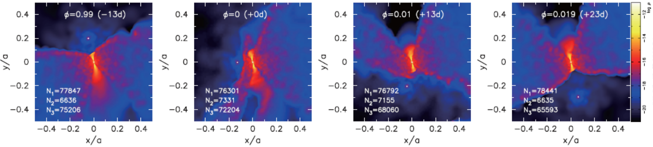

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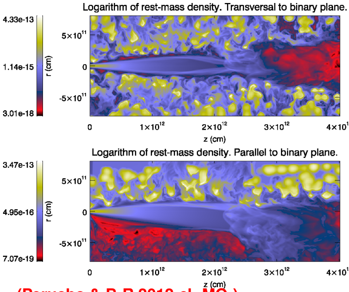

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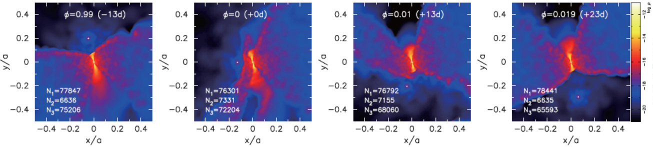

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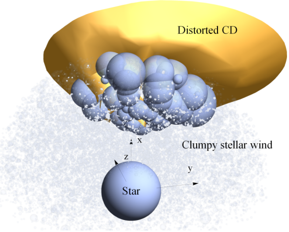

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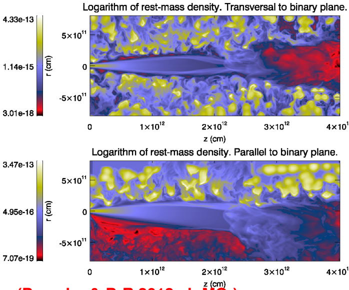

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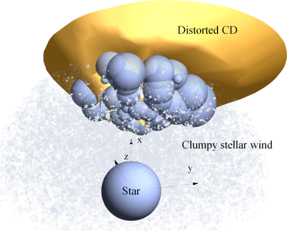

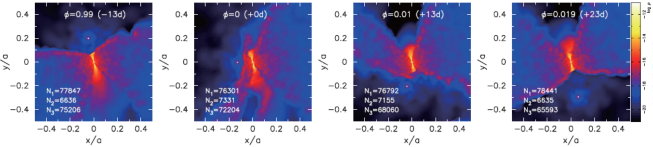

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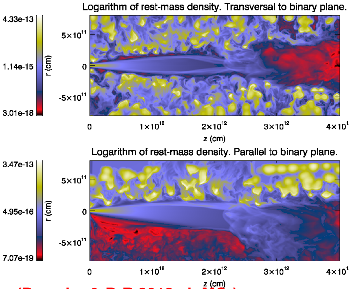

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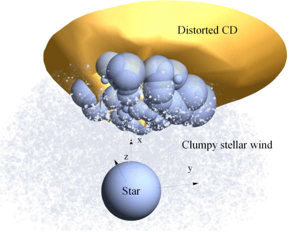

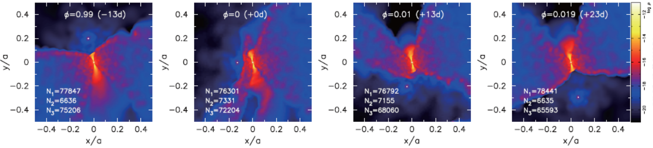

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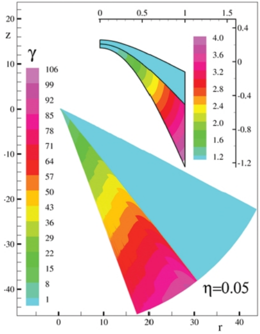

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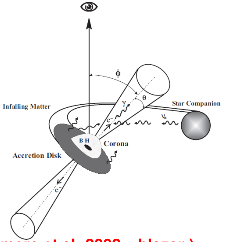

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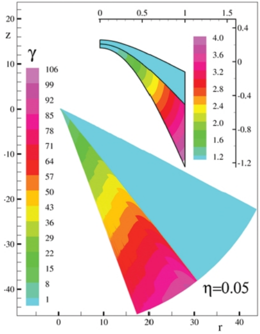

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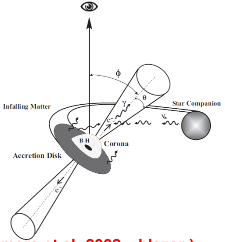

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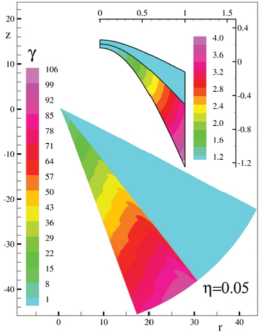

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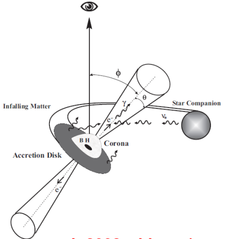

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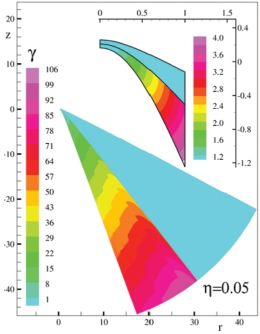

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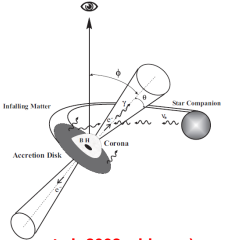

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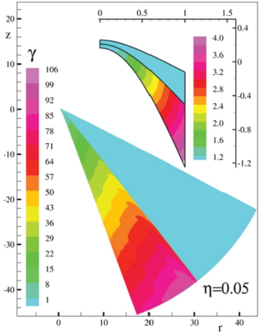

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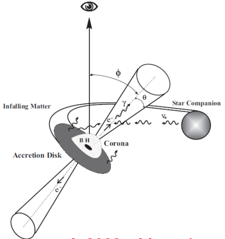

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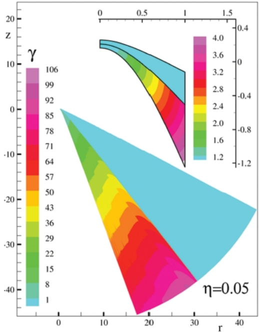

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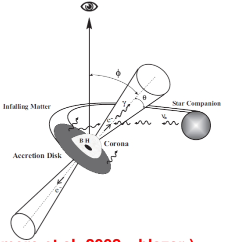

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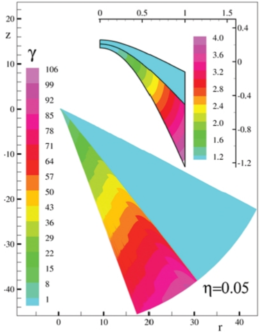

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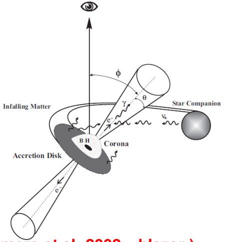

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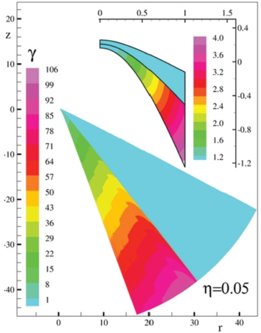

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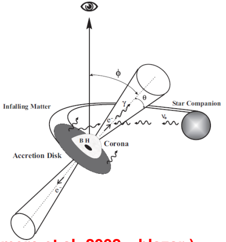

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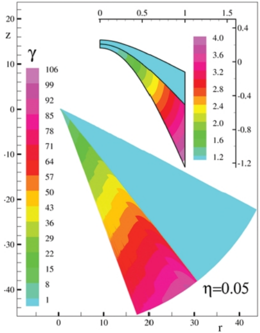
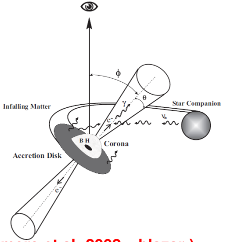


(Bogovalov et al. 2008-wind reacc. PSR-)



(Romero et al. 2002-μblazar-)

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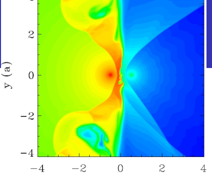
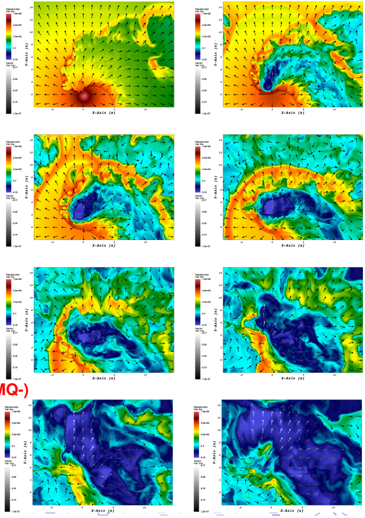
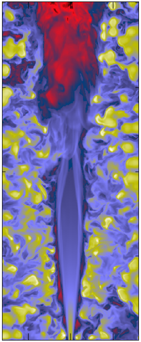
(Lamberts et al. 2013-PSR-→)

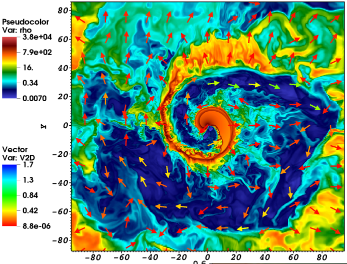


(Barkov & B-R 2022-MQ-↓)



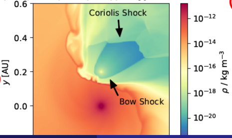


(Perucho&B-R+12-MQ-)



(B-R et al. 2015-PSR-↑)

(Huber et al.2021-PSR-→)



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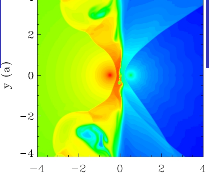

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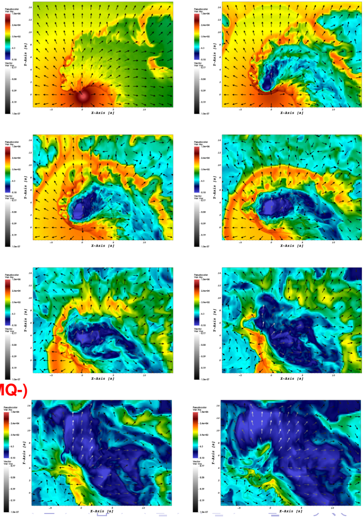

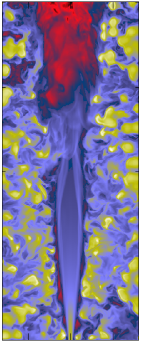

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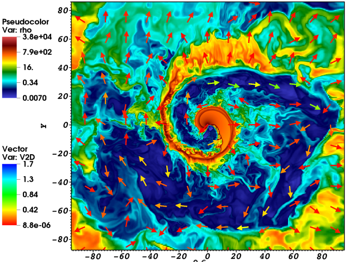

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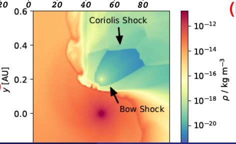

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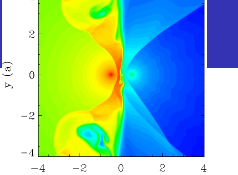

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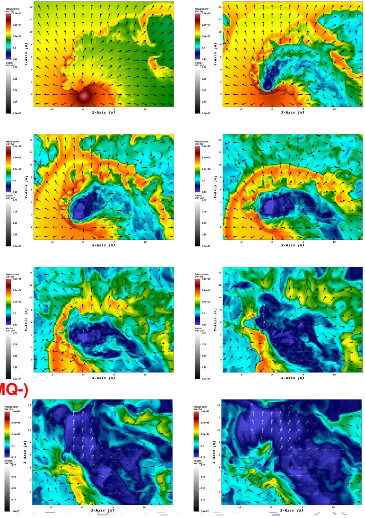

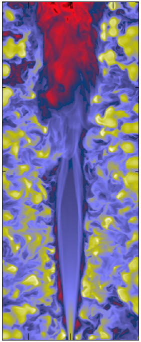

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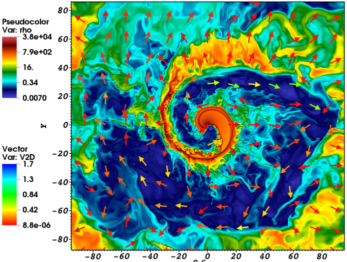

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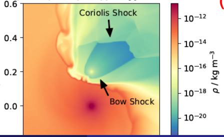

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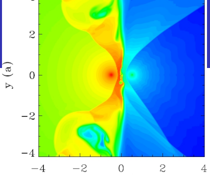

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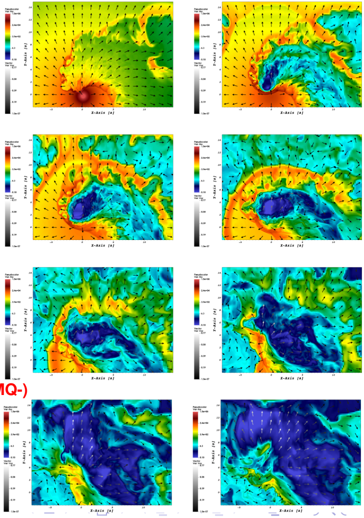

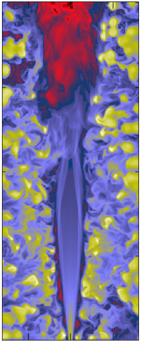

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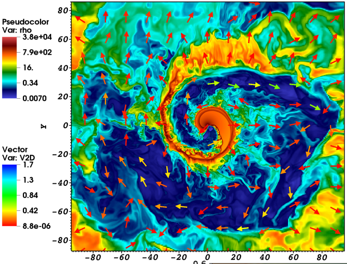

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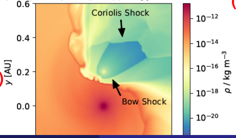

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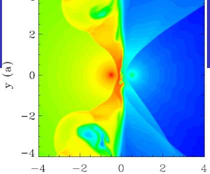
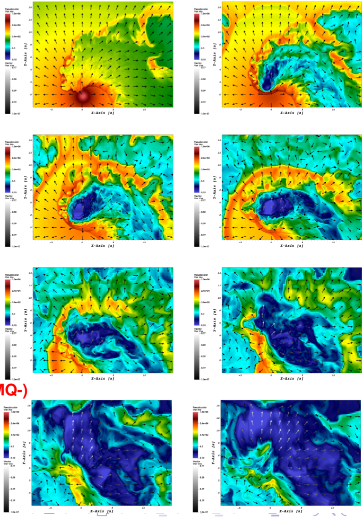
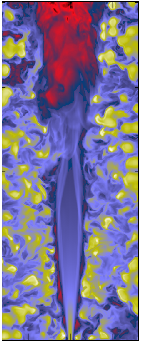


(Barkov & B-R 2022-MQ-↓)





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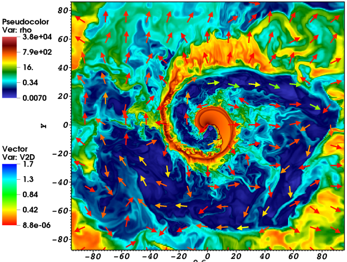

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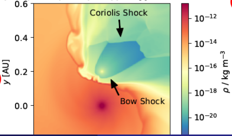

Magnetic fields

- **In winds, as $\sigma \sim 1$, postshock physics is affected:**
  - The anisotropic P_B modifies size and geometry.
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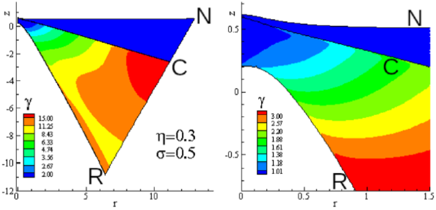

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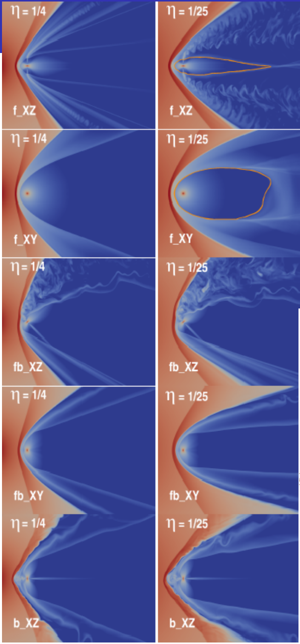

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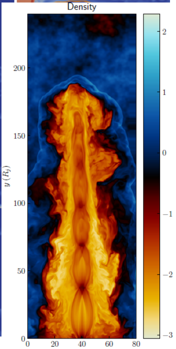

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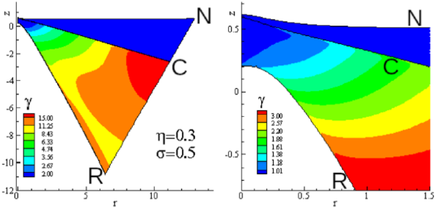

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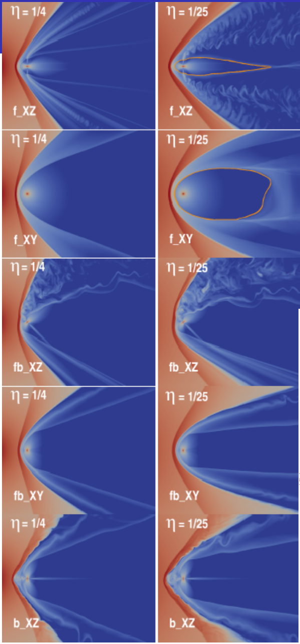

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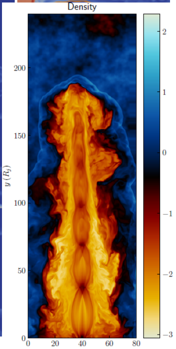

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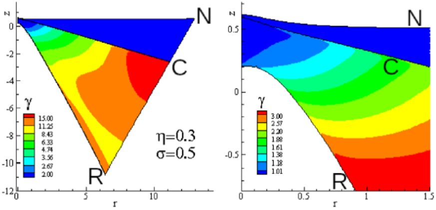

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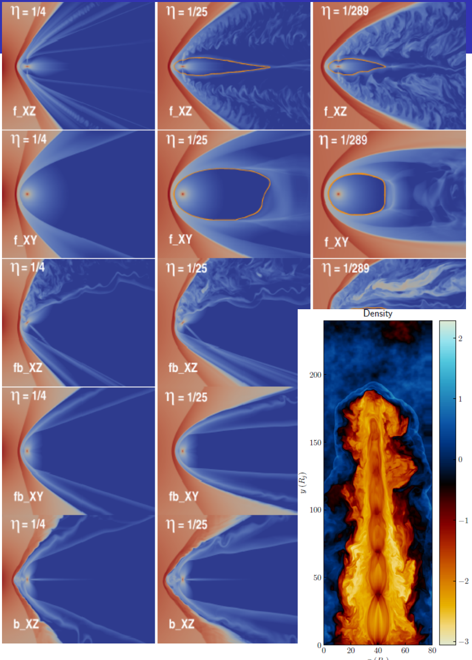

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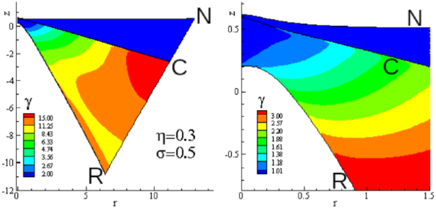

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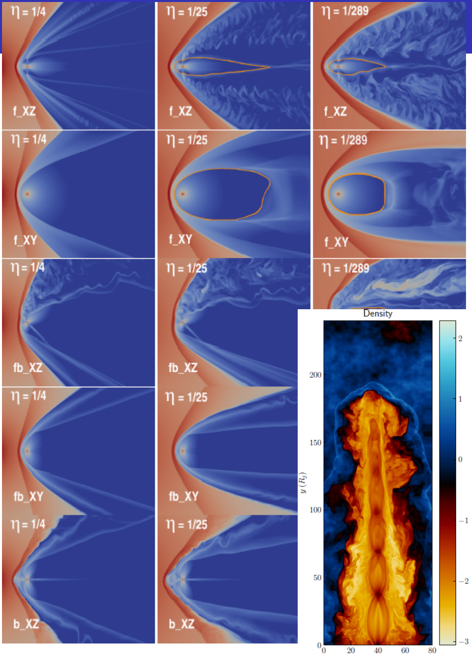

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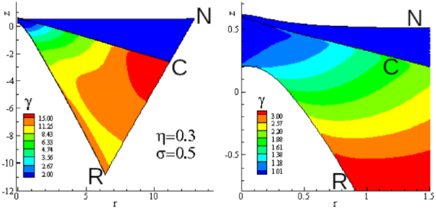

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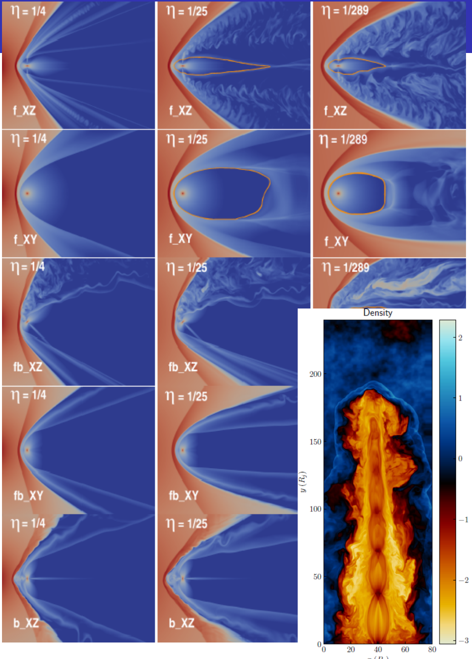

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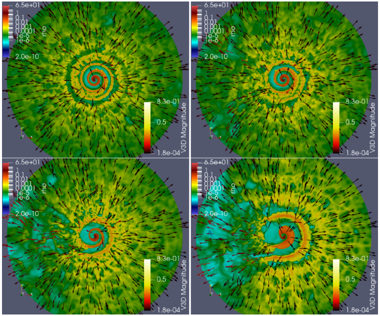
Outline

Orbital motion and eccentricity

- **Orbital motion triggers a strong Coriolis shock, which closes the relativistic outflow *behind* the pulsar.**
- As seen, this means more instability.
- A spiral structure forms on orbit plane, underpressured perpendicularly.
- High eccentricity → one-sided mixed flow in apastron-periastron dir.



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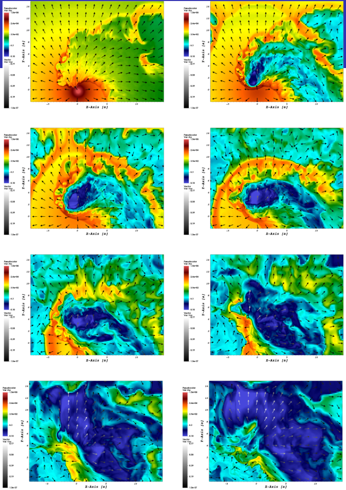

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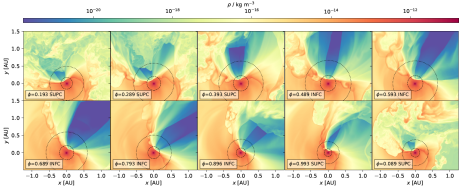

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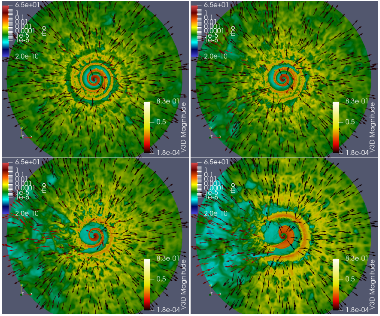

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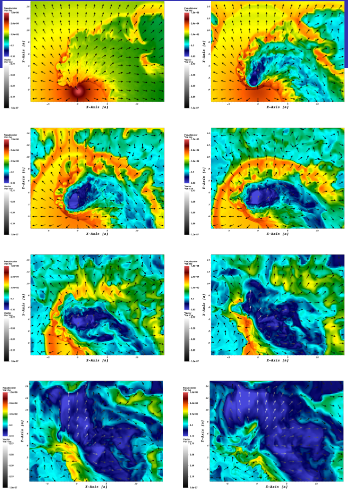

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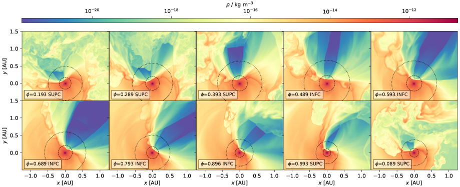

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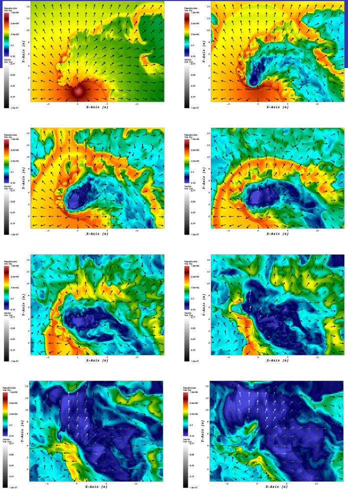

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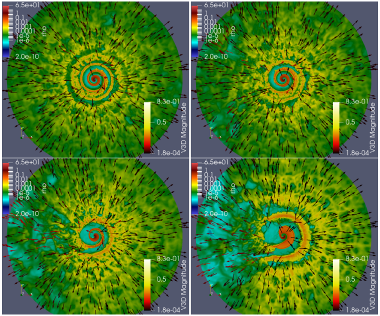

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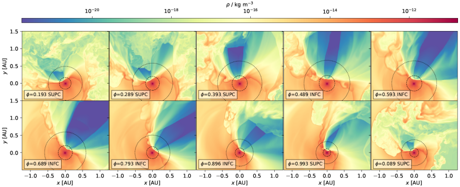

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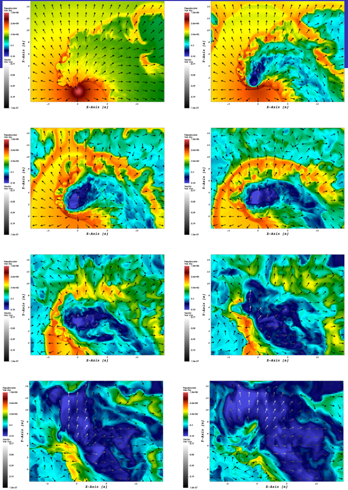

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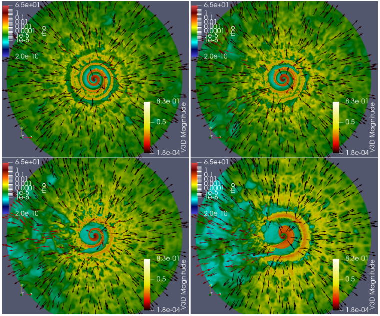

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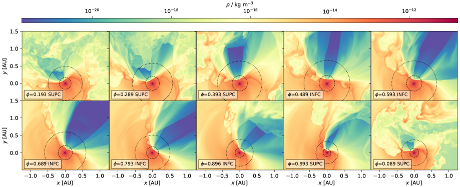
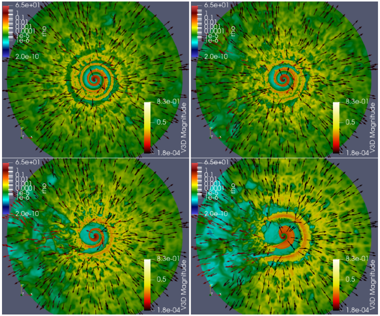


Interactions on large scales.

- **Mass-loaded fast outflow interacts with medium (radio gal., PWN?).**
- **Proper motion? (moving jets, sPWN?)**



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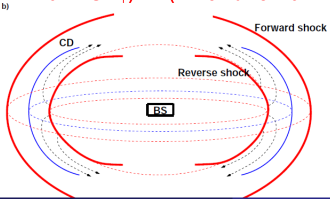

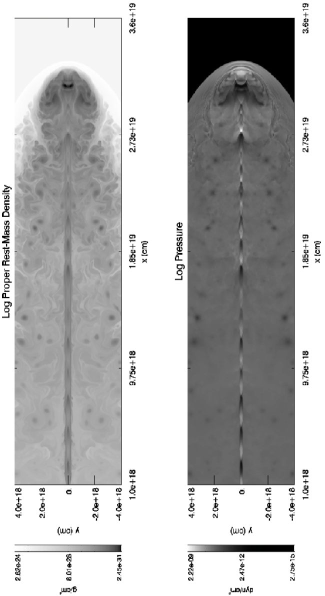

(Bordas et al. 2009-MQ-)

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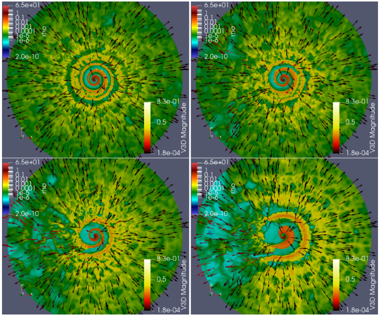

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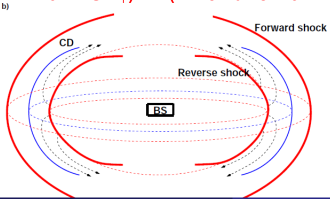

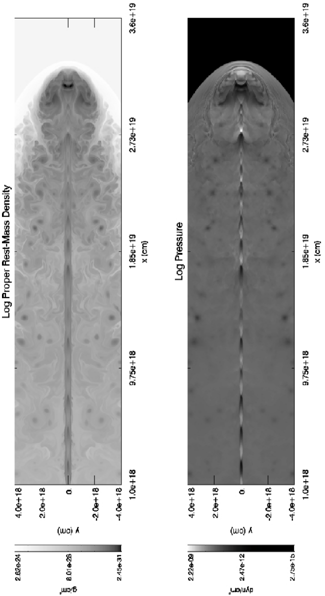

(Bordas et al. 2009-MQ-)

Outline

1. Introduction
2. Binary scales
3. Beyond binary scales
4. Concluding

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