Hydrodynamics and radiation from colliding pulsar and stellar winds in a high-mass binary system

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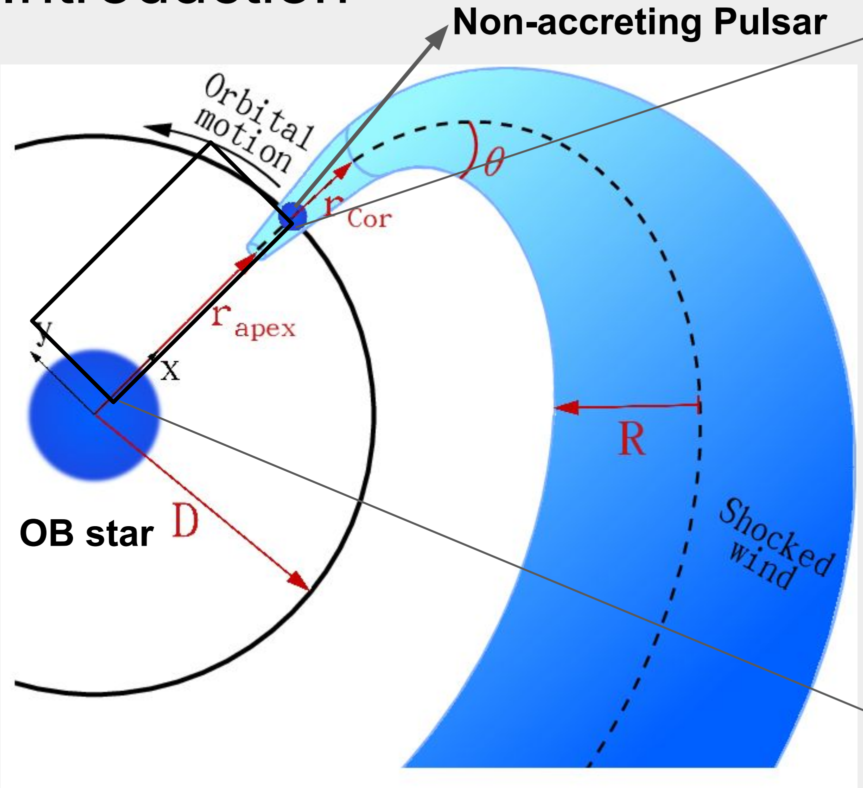
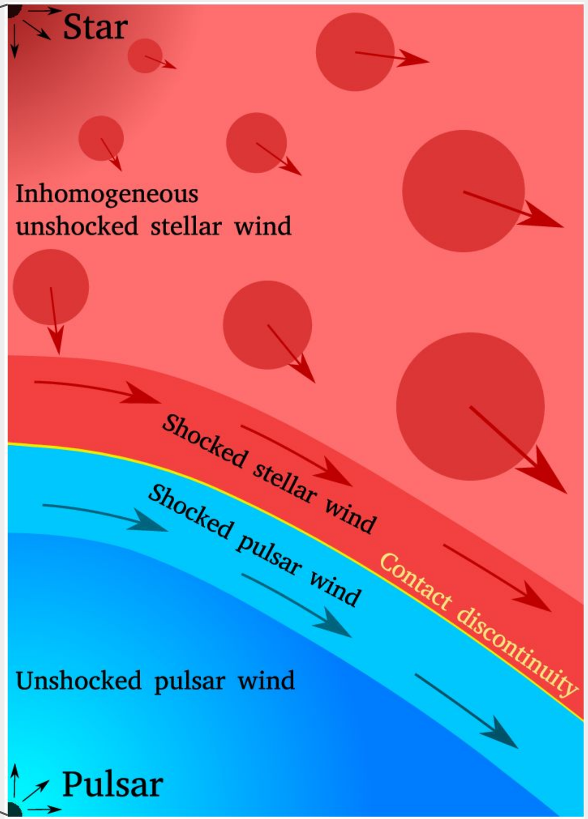
Introduction



Schematic view of the proposed scenario. Reprinted from Molina and Bosch-Ramon 2020, with permission.



Cartoon of the contact discontinuity at the apex of the shocked wind. Reprinted from Paredes-Fortuny et al. 2014

Dynamics of the Shocked Wind

$$r_{\mathrm{apex}} = D/\left(1+\sqrt{\eta}\right)$$

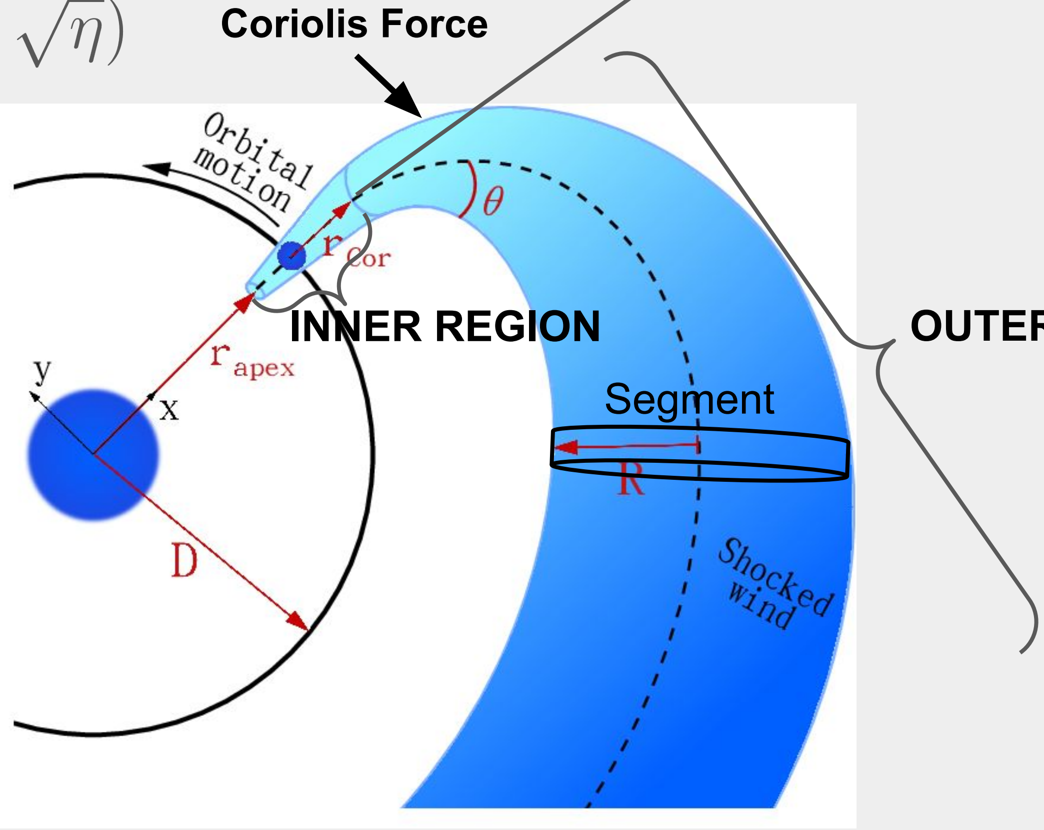
$$\eta = \frac{L_{\mathrm{P}}}{\dot{M}_{\mathrm{w}} v_{\mathrm{w,r}} c}$$

Star-Pulsar Momentum Rate Ratio

Eichler & Usov, 1993

Pulsar Wind Pressure = Stellar Wind Ram Pressure

Bosch-Ramon & Barkov, 2011



Hydrodynamics of the plasma

Assumptions:

- No radiative cooling. **Adiabatic** process.
- The fluid is only ruled by **conservation laws**.
- **Inner region:**
  - Lorentz factor increases approximately with distance (Bogovalov et al. 2008)
  - Initial supersonic fluid ($v_0 = c/\sqrt{3}$)
- **Outer region:**
  - $\beta \approx 1, \quad h \gg 1$
  - Diffused walls. **Mixing**. Mass load is parameterised as a **power law**:

$$\dot{M} = \dot{M}_0 \left(\frac{|r|}{d_{\text{Cor}}} \right)^{\varepsilon}, \quad h\gamma = h_0 \gamma_P \left(\frac{|r|}{d_{\text{Cor}}} \right)^{-\varepsilon} \qquad \varepsilon = 1$$

Mass Load Rate — Energy per Particle

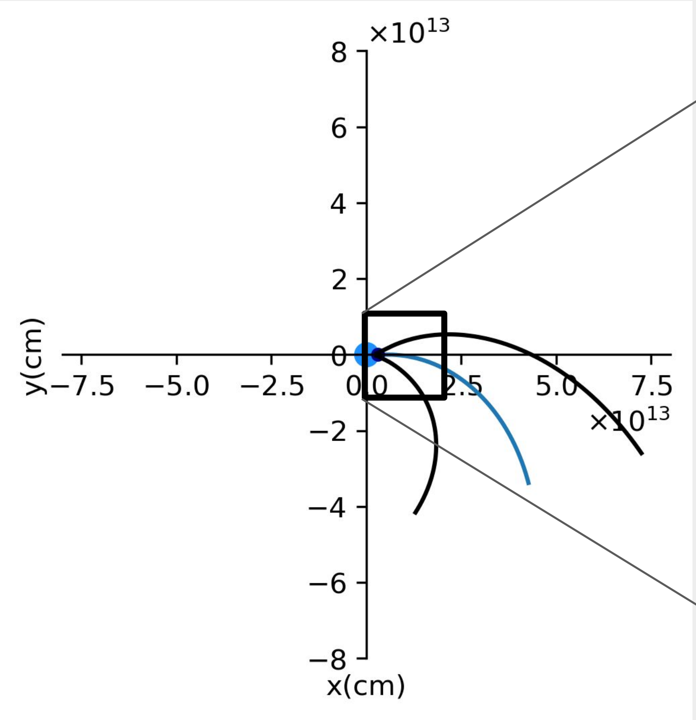
Radiation Mechanism

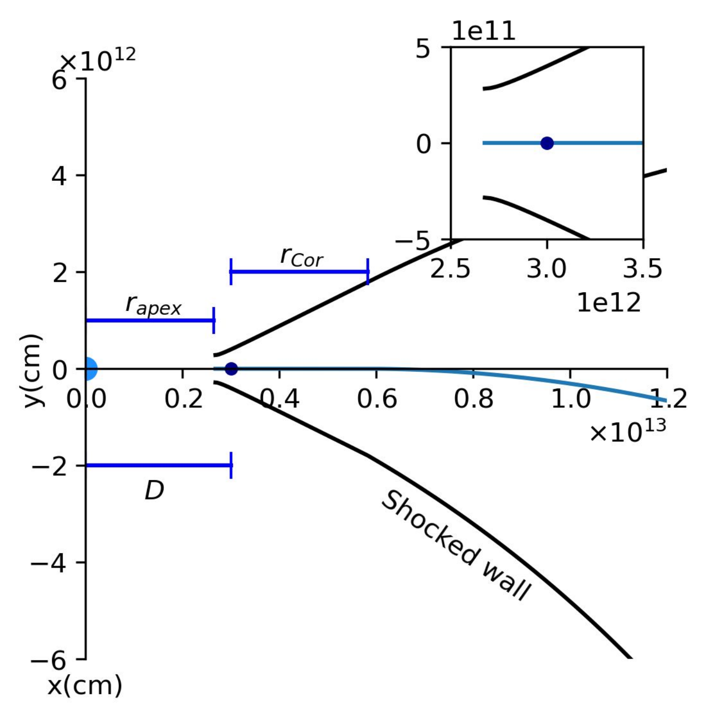
- We only consider **inverse Compton**. Synchrotron may be considered, too, but at long distances it can be neglected.
- **Observer luminosity** of a single segment (Sikora et al. 1997):

$$\mathrm{d}L = \frac{\delta^3}{\gamma}\mathrm{d}L', \quad \delta = \left[\gamma\left(1 - \beta\cos\varphi\right)\right]^{-1}$$

- **Monoenergetic electron**: E_e = 0.01 erg.
- **Observed photon**: E_{IC} = 1 GeV.

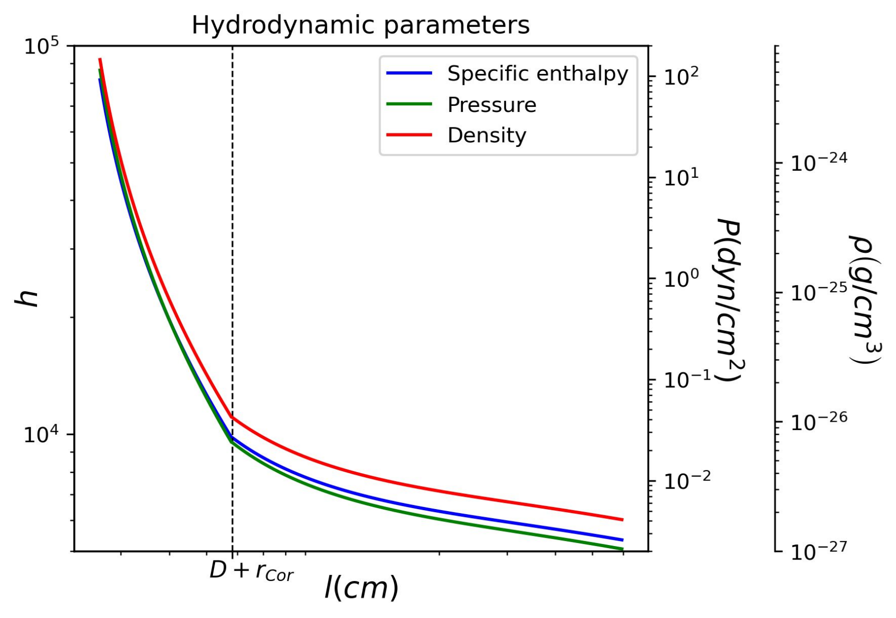
Results: 2D Dynamics $\varepsilon = 1$

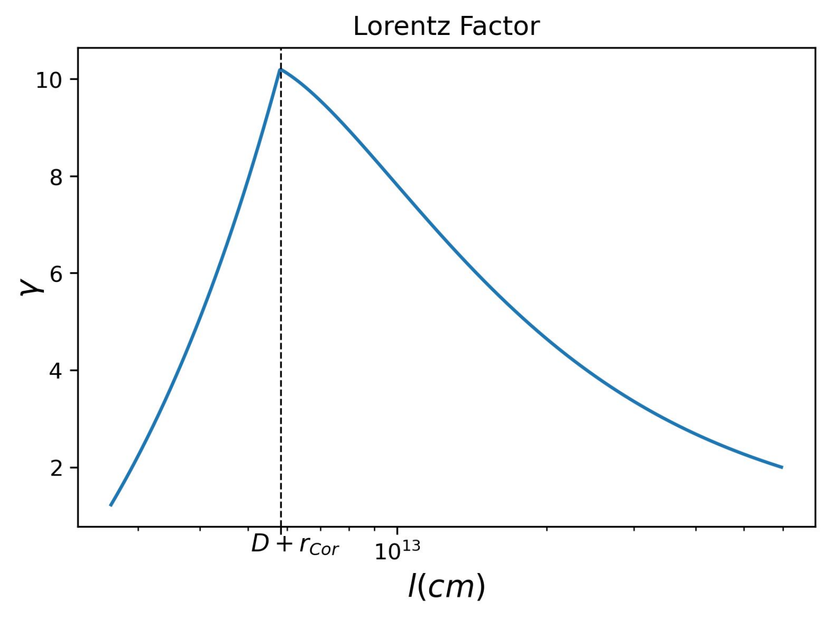




Trajectory of the shocked pulsar wind (left) and a close-up of the trajectory (right).

Results: Hydrodynamics





Parameters of the hydrodynamic evolution along the trajectory.

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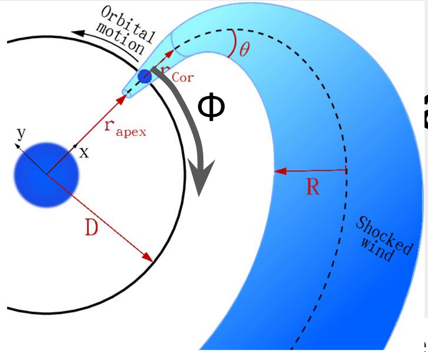
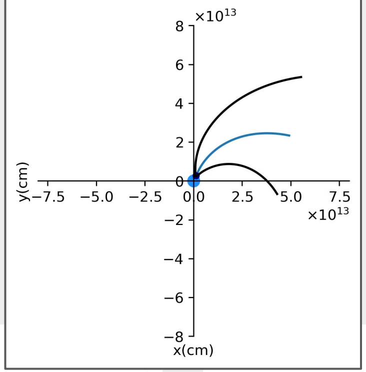
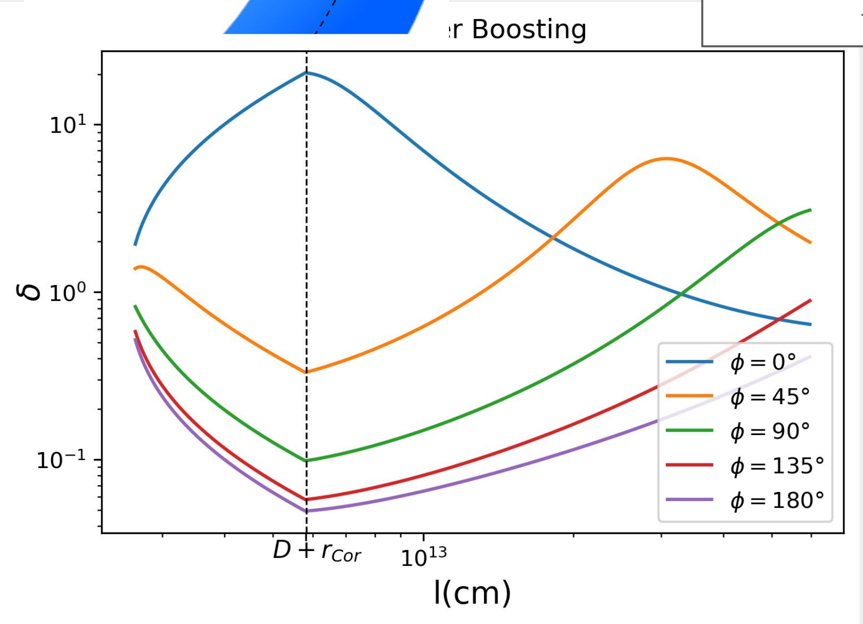


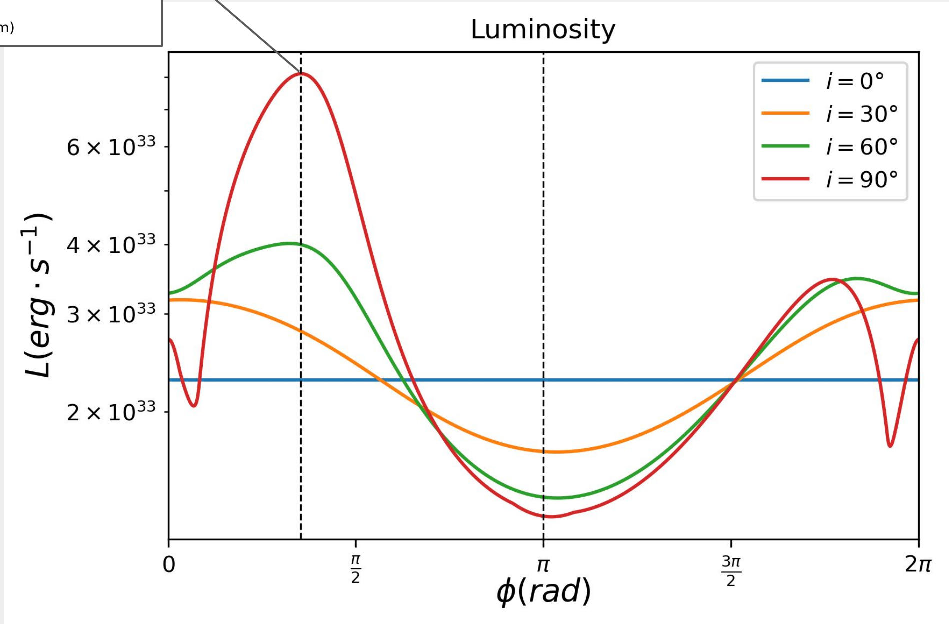


Observer

ΔL_{MAX} = ~630%

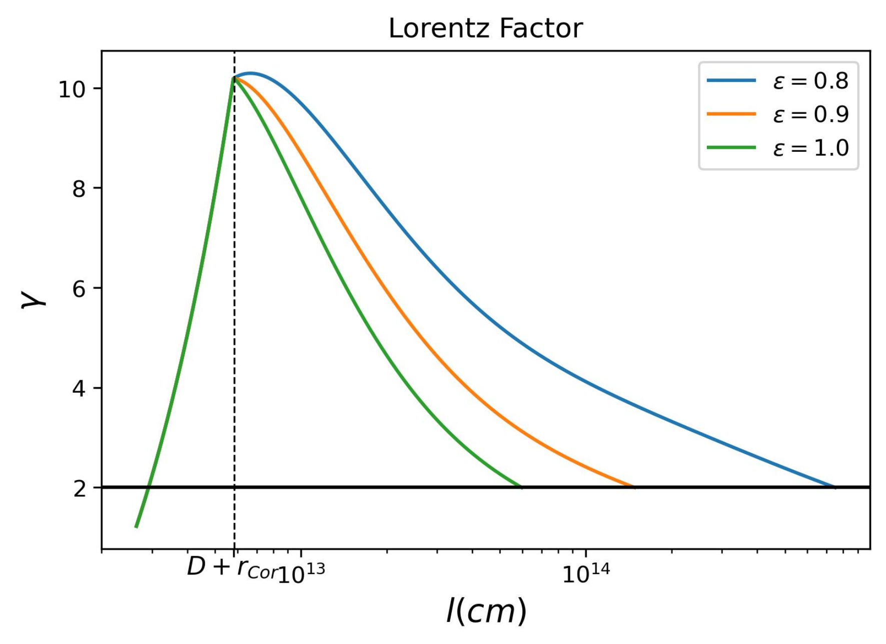


Doppler boosting factor of the shocked wind for different orbital phases and i=90º.

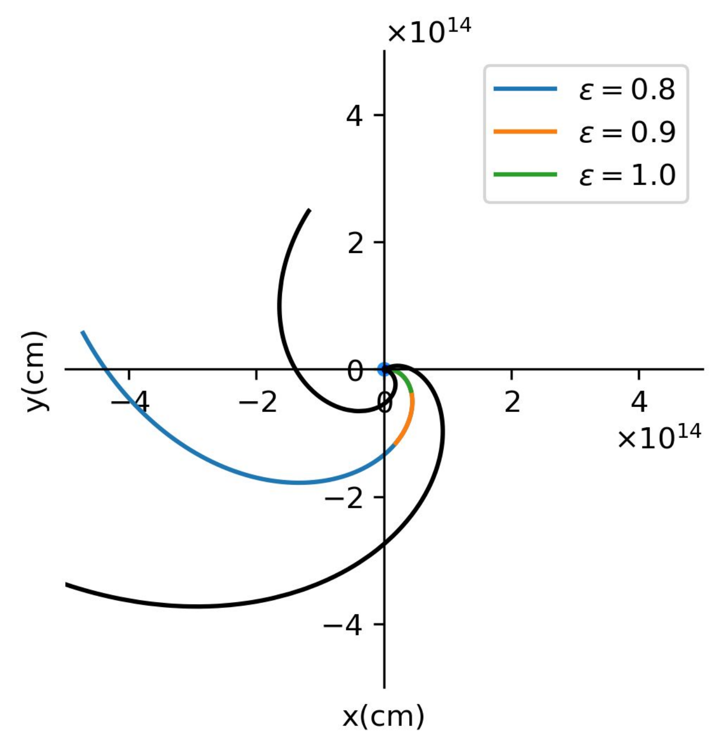


Variation of the luminosity for a full orbital phase.

Results: The ε parameter

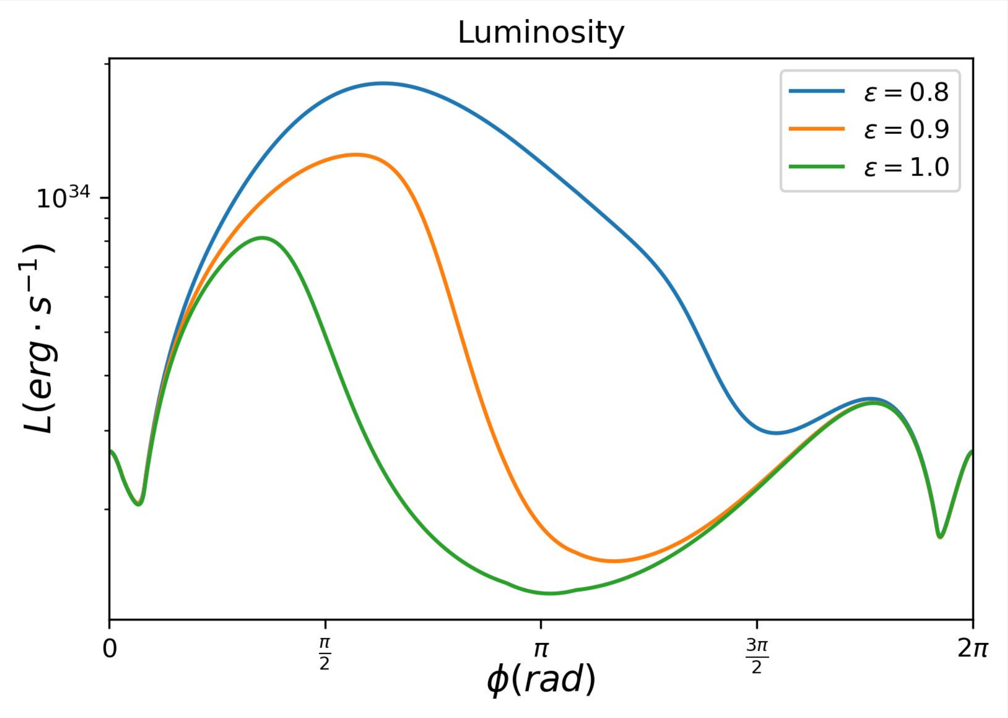


Lorentz factor along the trajectory for different values of ε.



Trajectory of the shocked pulsar wind as seen from the zenith for different values of ε.

Results: The ε parameter



Variation of the luminosity for a full orbital phase and different values of ε and i = 90º.

$$\Delta L_{MAX} = \begin{cases} \sim 630\%, & \varepsilon = 1 \\ \sim 820\%, & \varepsilon = 0.9 \\ \sim 1400\%, & \varepsilon = 0.8 \end{cases}$$

Conclusions

- Model for the shocked pulsar wind of a binary system under some simplifying assumptions.
- Luminosity curves could be observed in binary systems such as PSR B1259-63 and PSR J2032+4127 amongst others.
- Depending on the mixing in the walls the luminosity can vary considerably.
- At longer distances the stellar wind may completely break the structure of the shocked pulsar wind.