The hydrodynamics behind the high-energy emission of high-mass binaries with pulsar

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Variable Galactic Gamma-Ray Sources IV

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Outline

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Gamma-ray High-Mass Pulsar Binaries (HMPB)

- **The colliding wind region is typically considered the high-energy emitter: the shocked and the unshocked pulsar wind, the shocked stellar wind, and electromagnetic cascades.**

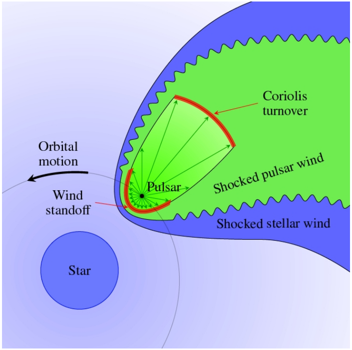
  (e.g. Maraschi & Treves 1981; Tavani & Arons 1997; Kirk et al. 1999; Sierpowska & Bednarek 2005; Dubus 2006; Khangulyan et al. 2007; Neronov and Chernyakova 2007; Derishev & Aharonian 2012)

- **In this talk we assess the potentiality of middle scales as the high-energy emitter.**

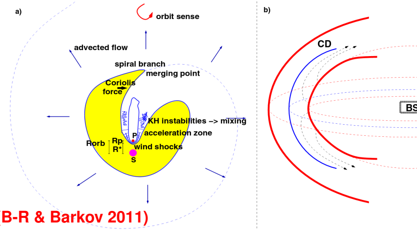
  (see B-R & Barkov 2011; Bednarek & Sitarek 2013)

- **The flow on middle scales is considered here to be well described by relavistic hydrodynamics (i.e. ideal RMHD; $\lambda << R_{\rm orb}$; low-B).**

  (see Bogovalov et al. 2012; see discussion in B-R et al. 2015)



(Zabalza et al. 2013)



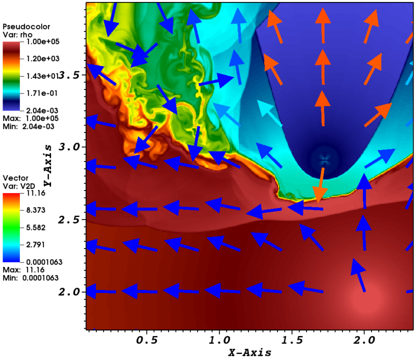
(B-R & Barkov 2011)

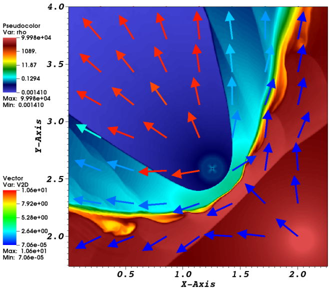
Outline

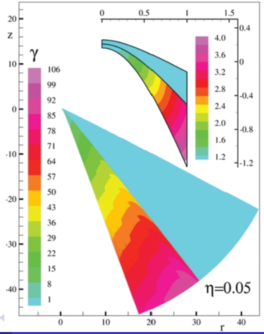
The colliding wind region

- **In HMPB, the massive star and the non-accreting pulsar winds collide.**
- **After being shocked, the pulsar wind quickly reaccelerates while instabilities develop in the CD.**

(B-R, Barkov, Khangulyan & Perucho 2012)↓ ↑

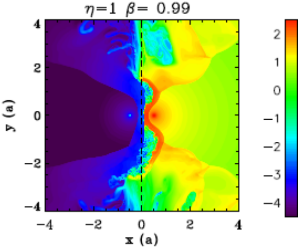


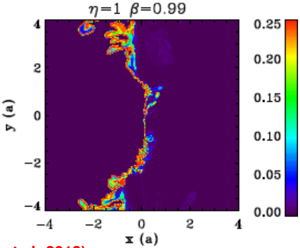




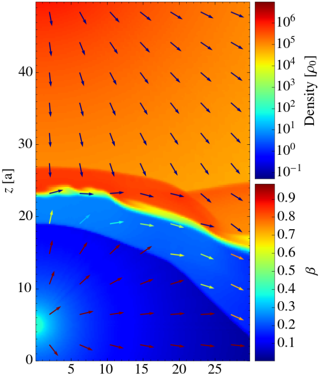
(Bogovalov et al. 2008)→

Instabilities within the colliding wind region

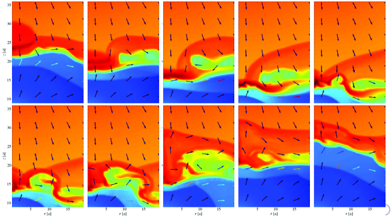




(Lamberts et al. 2013)



(Paredes-Fortuny et al. 2015)

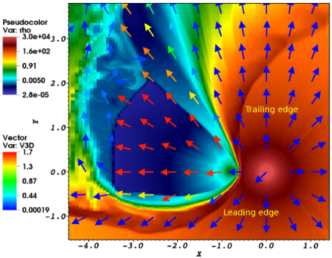


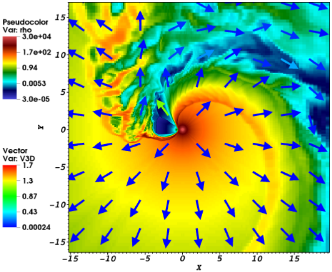
Analytic works on the shocked flow unstable nature:

e.g. B-R & Barkov (2011); Bednarek & Sitarek (2013)

- The stellar wind exerts a strong Coriolis force on the pulsar wind due to orbital motion.
- The reaccelerated and the unperturbed pulsar winds are terminated away from the star.
- Orbital motion deflects the shocked winds; instabilities from the CD:
  *Rayleigh-Taylor (RT)
  *Richtmyer-Meshkov (impulsive RT)
  *Kelvin-Helmholtz
- The shocked pulsar wind suffers reacceleration, turbulence, further shocks, and stellar wind entrainment.

(B-R, Barkov & Perucho 2015)

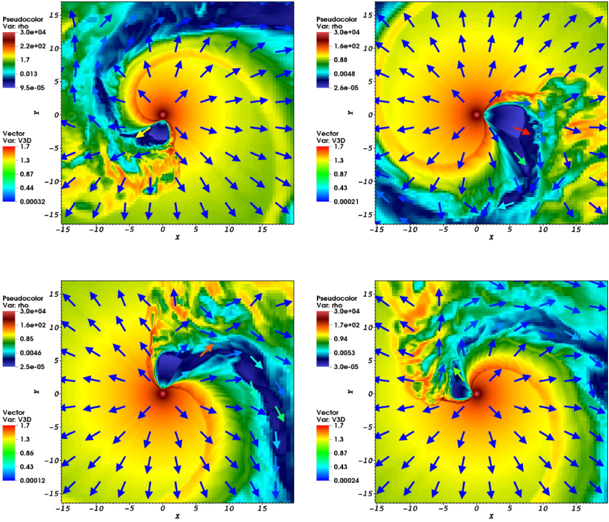




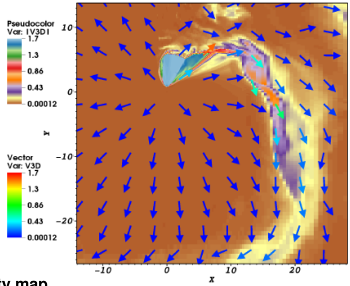
Outline

Middle scales: low eccentricity case (I)

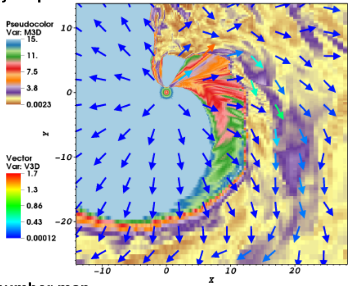
- **A one-arm spiral forms made of shocked stellar wind channelling shocked pulsar wind.**
- **Strong turbulence and mass entrainment from the CD occur.**
- **The shocked pulsar wind is slowed down by mass-load, shocks and turbulence.**
- **Pulsar wind energy is accumulated and smoothly evolves along the orbit.**



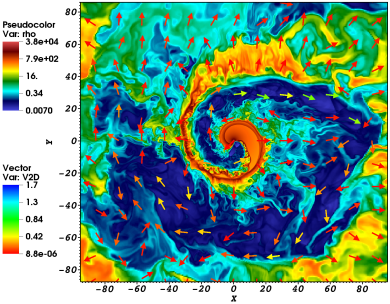
(B-R, Barkov & Perucho 2015)



Velocity map



Mach number map

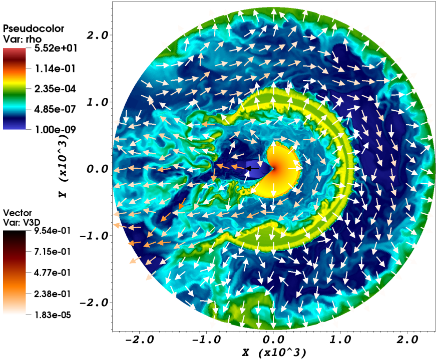


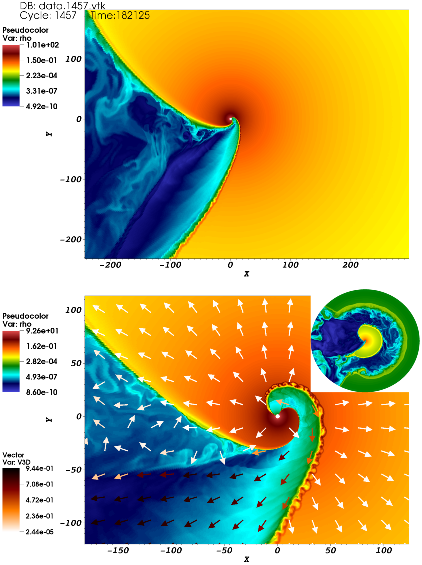
Larger scale density map

- **The shocked pulsar wind is slow and sub- or trans- sonic.**
- **Shocked pulsar wind expansion and instability growth lead to spiral merging and disruption after one turn.**

(B-R, Barkov, Khangulyan & Perucho 2012, B-R, Barkov & Perucho 2015 for LS 5039; $e \approx 0.24$)

- **If eccentricity is high, the pulsar wind is mostly directed apastron-wards.**
- **The flow accumulates from periastron to apastron, and then is released due to spiral disruption at the apastron side.**

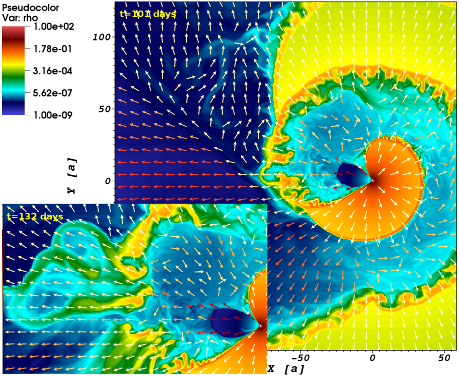


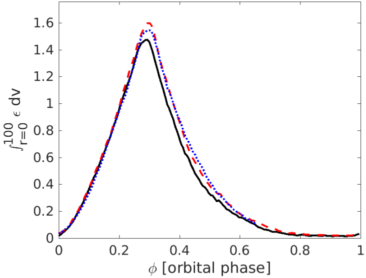


(Barkov & B-R 2016 for PSR B1259-63; $e = 0.87$)

Middle scales: high eccentricity case (II)

- The impact of the pulsar wind blows away the shocked stellar wind close to apastron.
- The material blown away may be detectable on large scales.





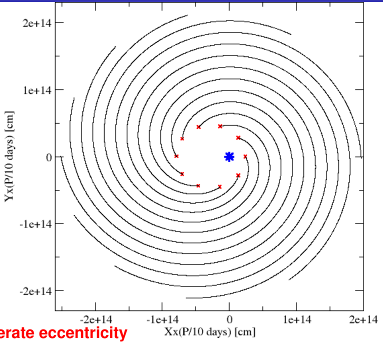
- The pulsar wind energy accumulates in the first spiral turn and peaks around apastron,
- Then, the energy is quickly advected away.

(B-R, Barkov, Mignone & Bordas 2017 for HESS J0632+057; $e = 0.83$)

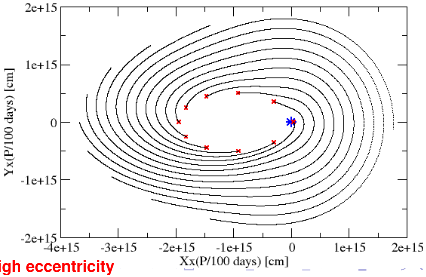
Outline

Shocked wind spiral

- **Initially, the bent shocked flow follows a quasi-ballisitic trajectory dominated by the large stellar wind mass.**
- **The shocked pulsar wind path is determined by the quasi-ballistic trajectory of the stellar wind.**
- **The spiral shape is characterized by starting at $r \sim 3\, v_{\rm w}/\Omega_{\rm orb}$ and ϕ from periastron, and the previously injected matter is radially displaced by $v_{\rm w}$.**
- **As pulsar wind energy accumulates in the region, and instabilities develop, the ballistic trajectory is lost, and the spiral tends to disrupt.**



Moderate eccentricity



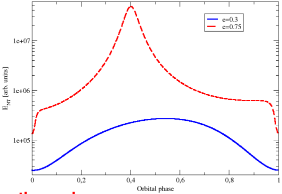
High eccentricity

(B-R & Barkov, in prep.)

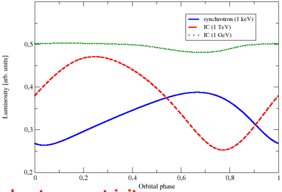
Non-thermal emission

- **Assuming particle injection at the spiral onset, and the flow velocity, the accumulated energy can be computed.**
- **Radiation efficiencies are high $\lesssim 100\%$.**
- **Approximate synchrotron and IC lightcurves can be derived.**

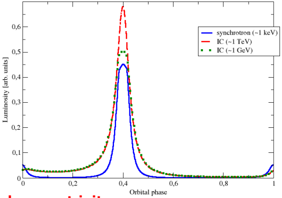
(B-R & Barkov, in prep.)



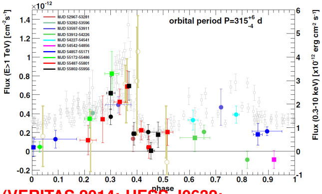
Non-thermal energy



Moderate eccentricity

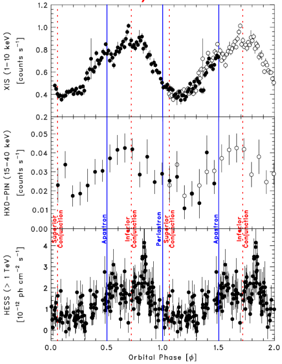


High eccentricity



(VERITAS 2014: HESS J0632;

see also LS I +61 303)



(Takahashi et al. 2009: LS 5039)