# Pulsar/Stellar wind collision in 3D and The origin of the X-ray-emitting object moving away from PSR B1259-63

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**Theoretical slides**

**Numerical slides**

**Observational slides**

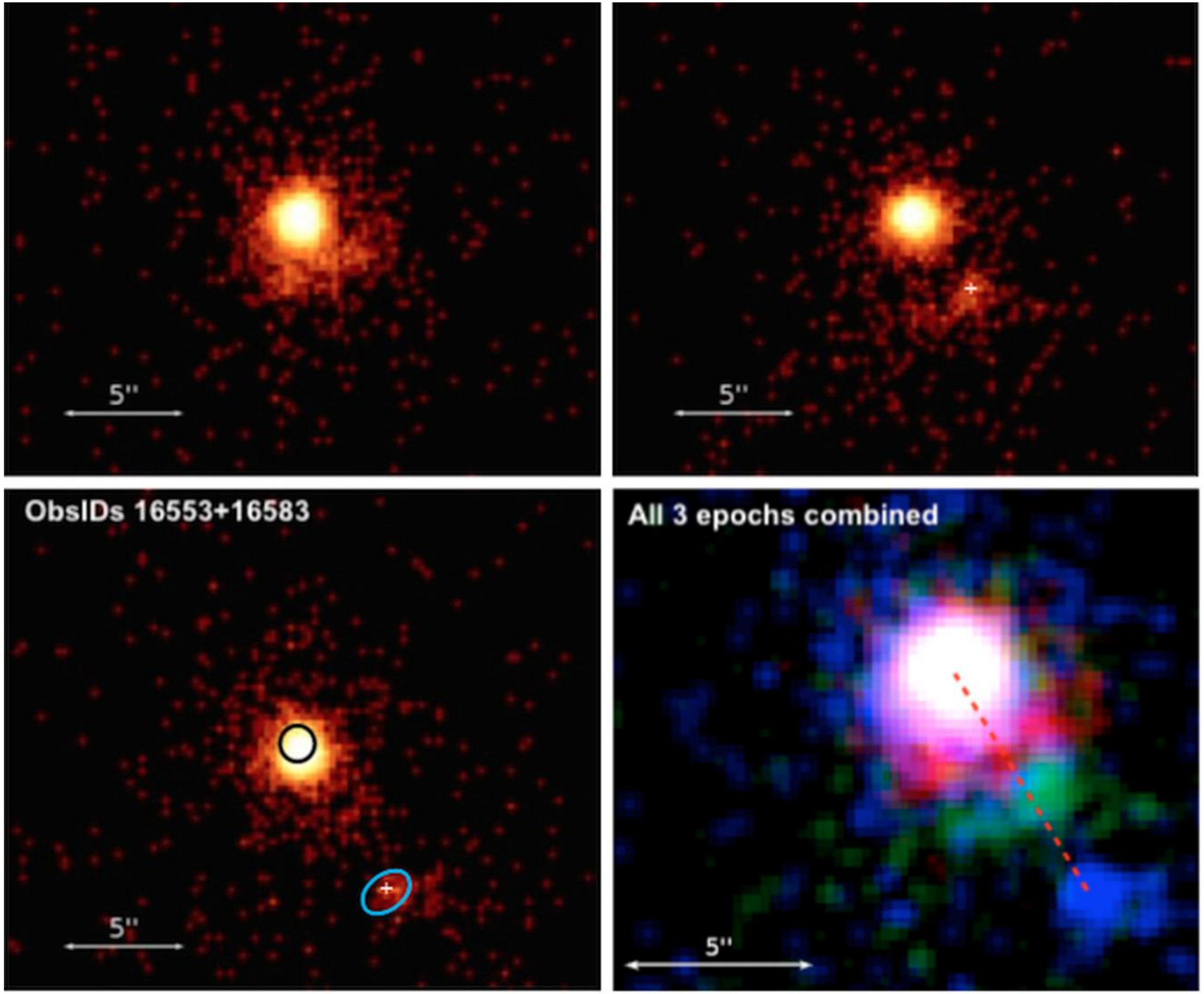
# The origin of the X-ray-emitting object moving away from PSR B1259-63

(Pavlov et al 2015)

$L_{sd}=8\times10^{35}$ erg/s

$L_x=10^{31}$ erg/s

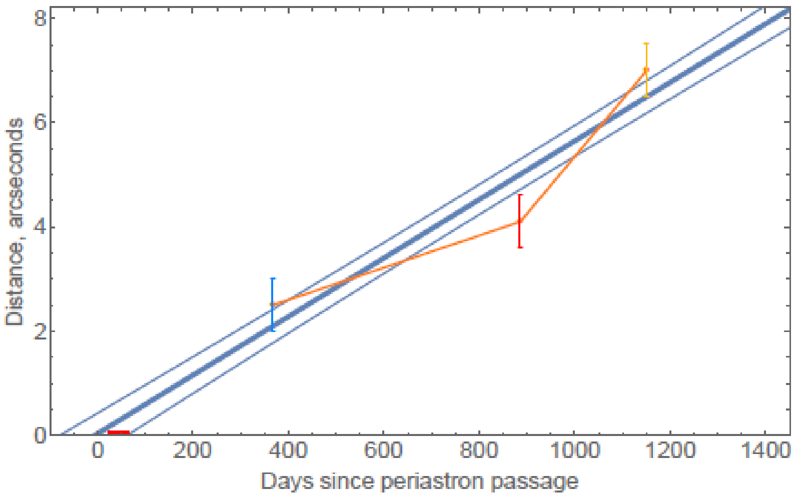
If it is thermal X-ray:
$M_c=10^{29}$ g
$T_{orb}\, dM_{wind}/dt < 10^{26}$ g



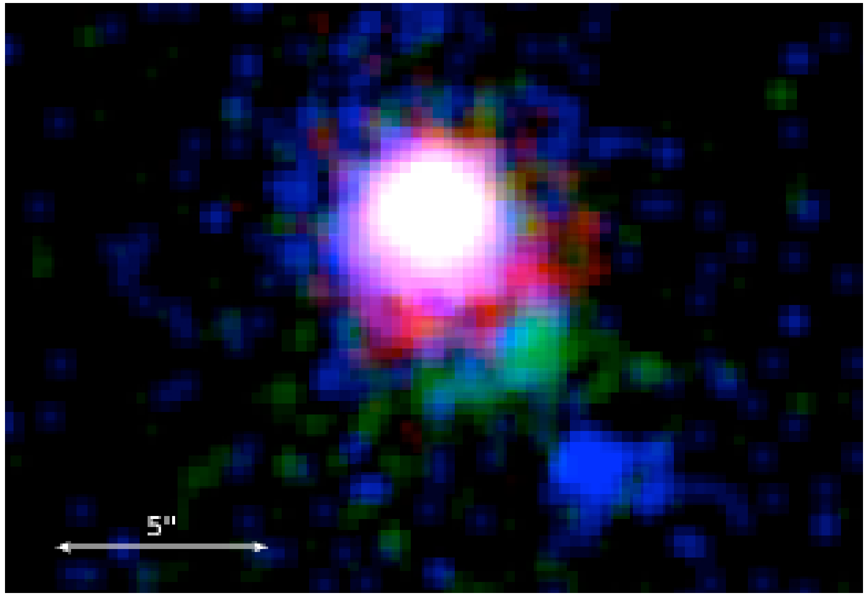
# The origin of the X-ray-emitting object moving away from PSR B1259-63

(Pavlov et al 2015)

If it is thermal X-ray:
$M_c = 10^{29}$ g
$L_k = 10^{40}$ erg/s
$T_{orb}\ dM_{wind}/dt < 10^{26}$ g
$L_{star} = 3\times10^{37}$ erg/s




**Linear fit: V = (0.07+/-0.01)c**




Between 3rd and 4th observations the extended structure moved by 2.5'' ±0.5''.

This corresponds to the apparent proper motion

**V=(0.13±0.03)c**
at d = 2.3 kpc

Apparent acceleration (?)
$90\pm40$ cm $s^{-2}$

# Binary Systems in VHE Regime

| Object | PSR B1259 | LS 5039 | J0632 | J1086 | LS I +61 303 | Cyg X-1 |
|---|---|---|---|---|---|---|
| Type | O8.5e+Pulsar | O6.5+? | Be+? | O6+? | Be+? | O9+BH |
| $L_s$, erg/s | $3 \times 10^{37}$ | $7 \times 10^{38}$ | $10^{38}$ | $7 \times 10^{38}$ | $10^{38}$ | $1.3 \times 10^{39}$ |
| Orbit Size, cm | $10^{13} - 10^{14}$ | $10^{12} - 3 \times 10^{12}$ | $10^{13} - 7 \times 10^{13}$ | $\sim 10^{13}$ | $2 \times 10^{12} - 10^{13}$ | $3 \times 10^{12}$ |
| Eccentricity | 0.87 | 0.24 | 0.83 | 0.25? | 0.72 | 0 |
| Inclination | 35 | 10-75 | 10? | ??? | ~30 | ~30 |
| HE Instrument | EGRET<br>Fermi | EGRET<br>Fermi | - | Fermi | EGRET<br>Fermi | AGILE |
| GeV detection | LC+Spctr | LC+Spctr | - | LC+Spctr | LC+Spctr | Point |
| VHE Instrument | HESS | HESS | HESS, MAGIC<br>VERITAS | HESS | MAGIC<br>VERITAS | MAGIC |
| TeV detection | 13σ | ~100σ | ~10σ | ~10σ | ~10σ | 4σ |
| signal | periodic | Periodic, variable | periodic | periodic | Periodic, variable | flare |

# Stellar wind collision

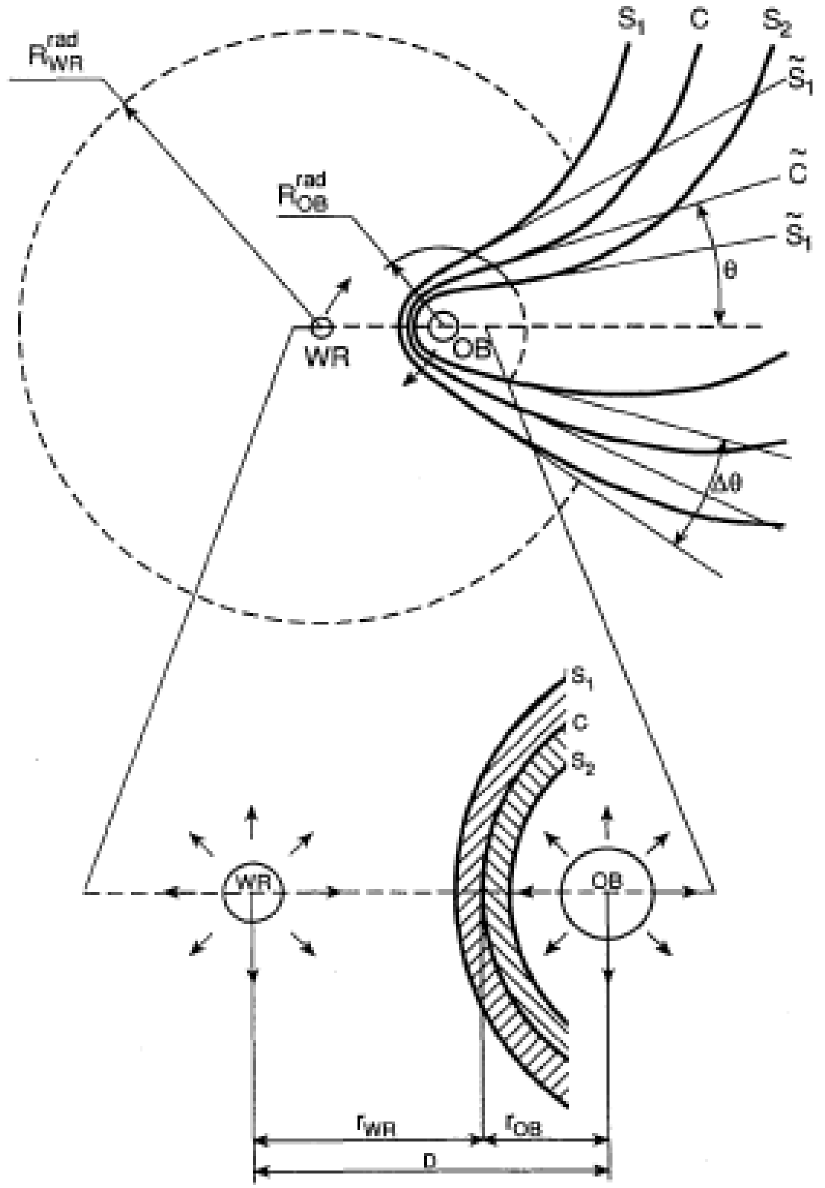
$$r_{\mathrm{WR}} = \frac{1}{1+\eta^{1/2}} D, \quad r_{\mathrm{OB}} = \frac{\eta^{1/2}}{1+\eta^{1/2}} D$$

$$\eta = \frac{\dot{M}_{\mathrm{OB}} V_{\mathrm{OB}}^{\infty}}{\dot{M}_{\mathrm{WR}} V_{\mathrm{WR}}^{\infty}}$$ (non-relativistic)

cally by Girard & Willson (1987). The results of the calculations may be approximated by the following analytic equation (L. M. Ozernoy 1991, private communication)

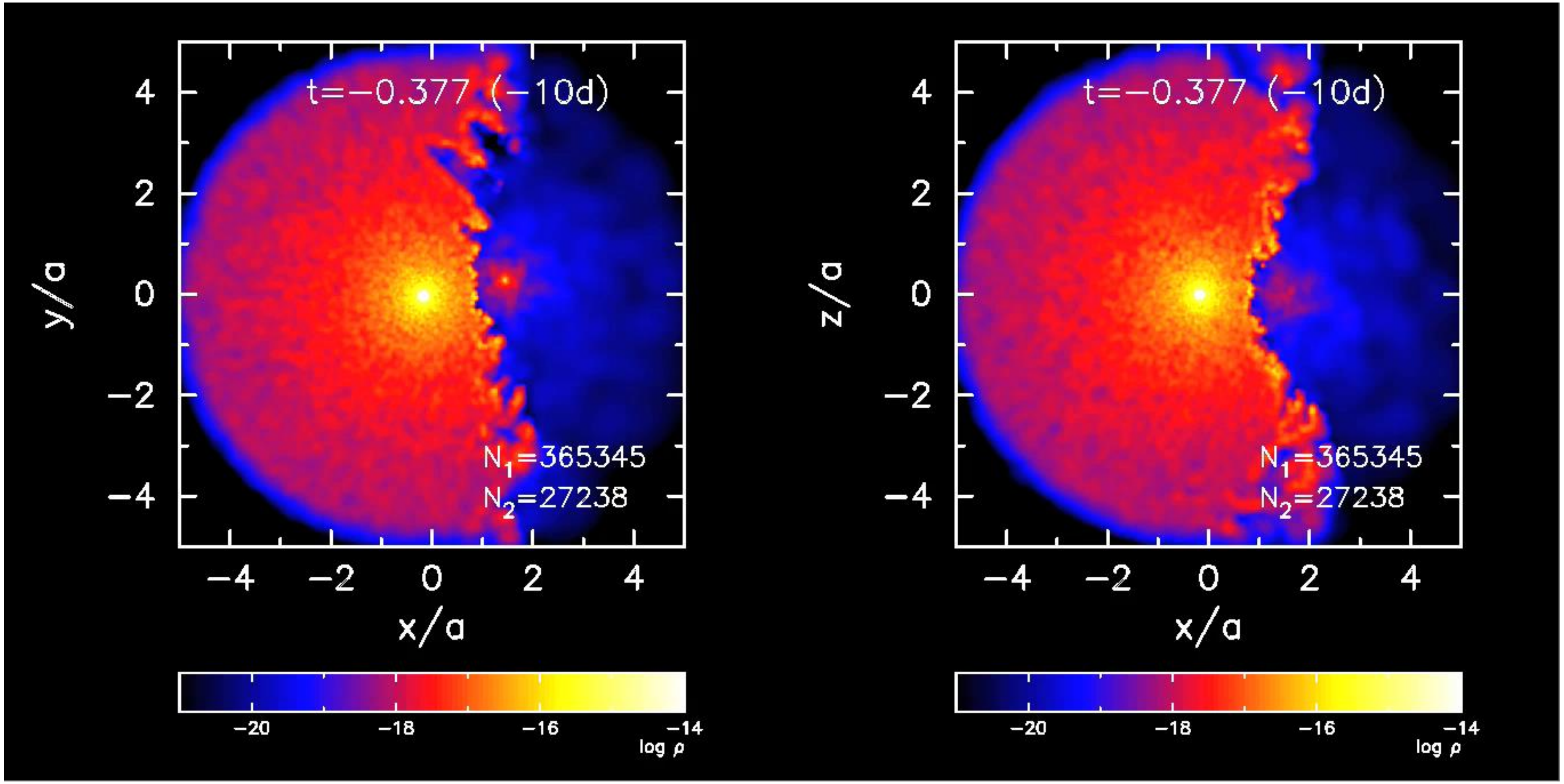
$$\theta \simeq 2.1\left(1 - \frac{\eta^{2/5}}{4}\right)\eta^{1/3} \quad \text{for } 10^{-4} \le \eta \le 1 \qquad (3)$$

Eichler & Usov 1993



# Stellar wind collision

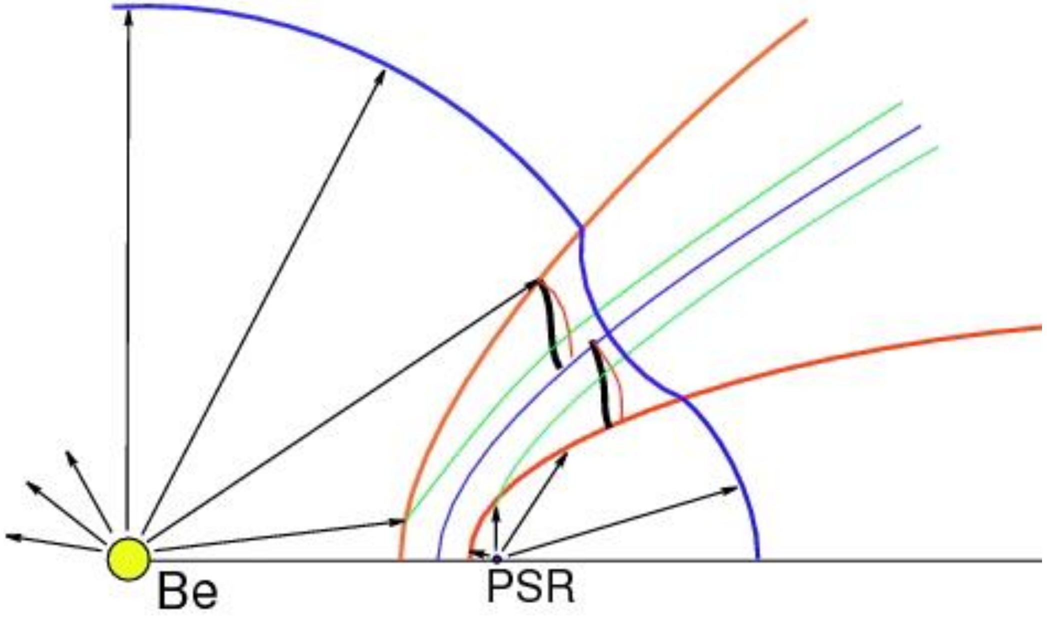
(Romero et al. 2007) SPH Newton, LS I+61 303

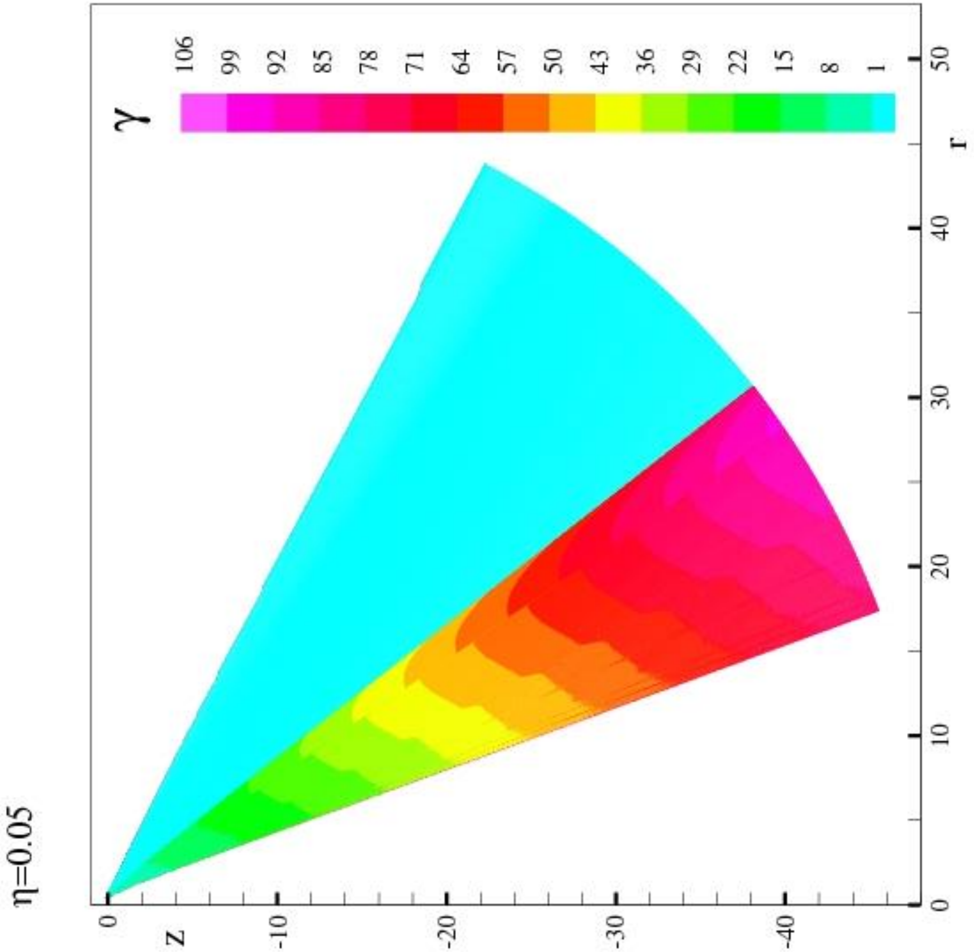


$$\eta = \frac{L_{sd}}{\dot{M} v_w c}$$

# Stellar wind collision

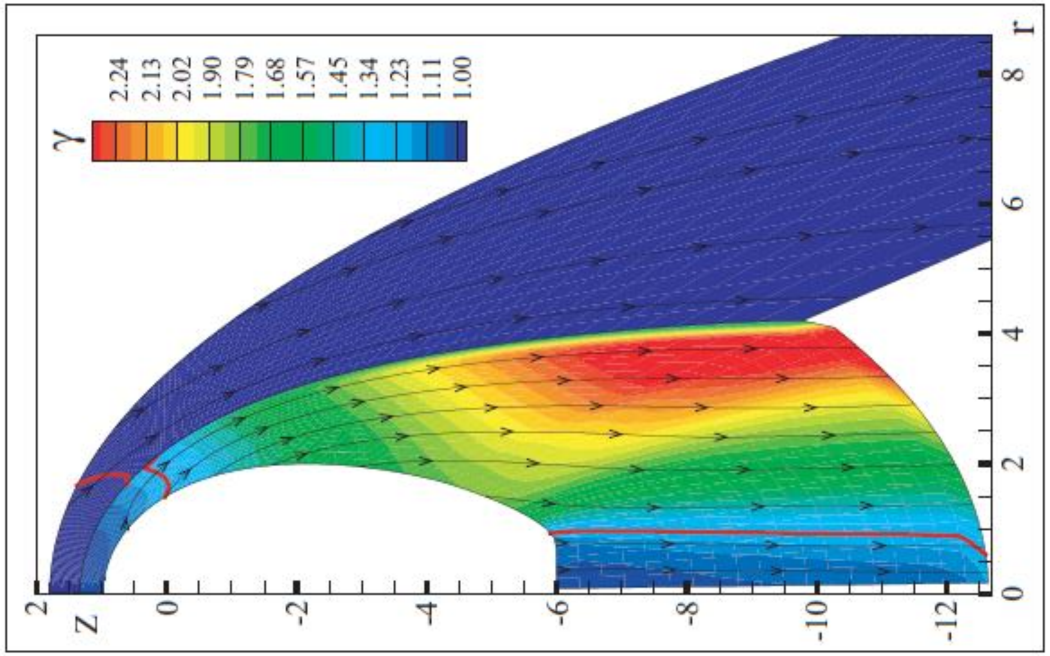
(Bogovalov et al. 2008,2012) 2D RHD, RMHD

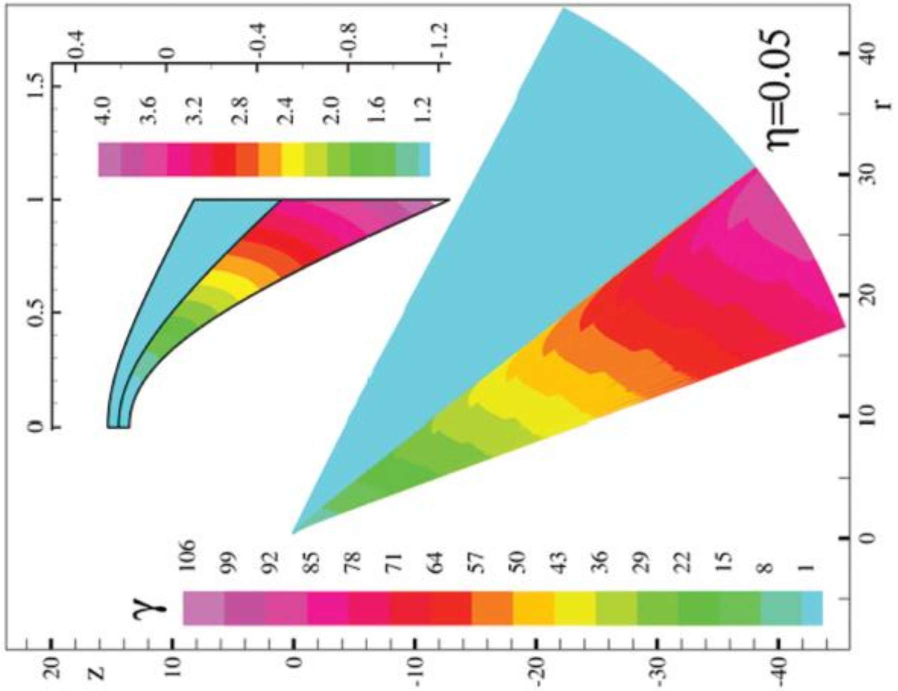


# How to form back shock without orbital motion?

- $\eta = 0.001$ $\eta = 0.05$



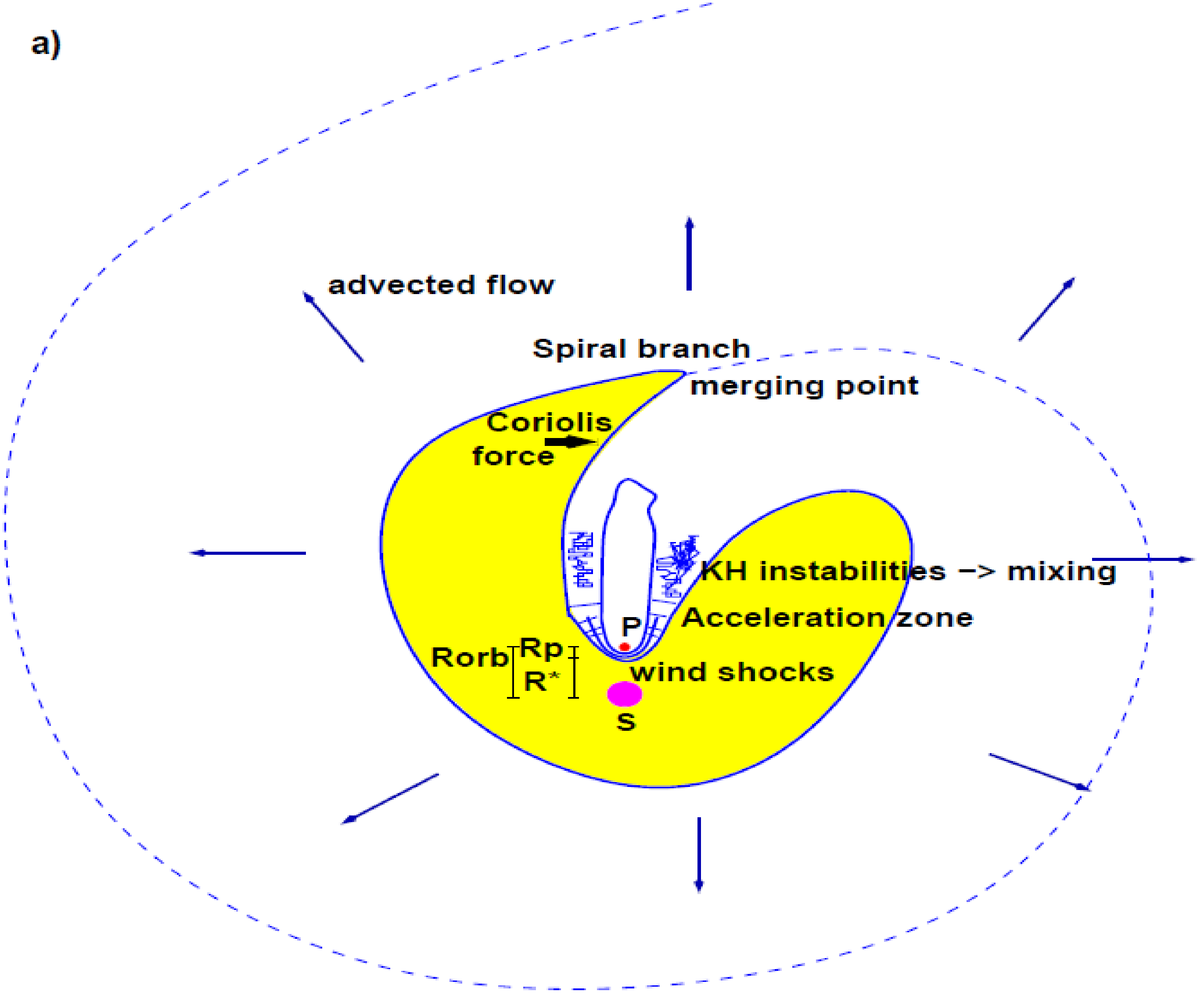


# Stellar wind collision + orbital motion

(Bosch-Ramon & MVB 2011)

$$x \sim 3\eta^{1/2} v_w / 2\Omega$$

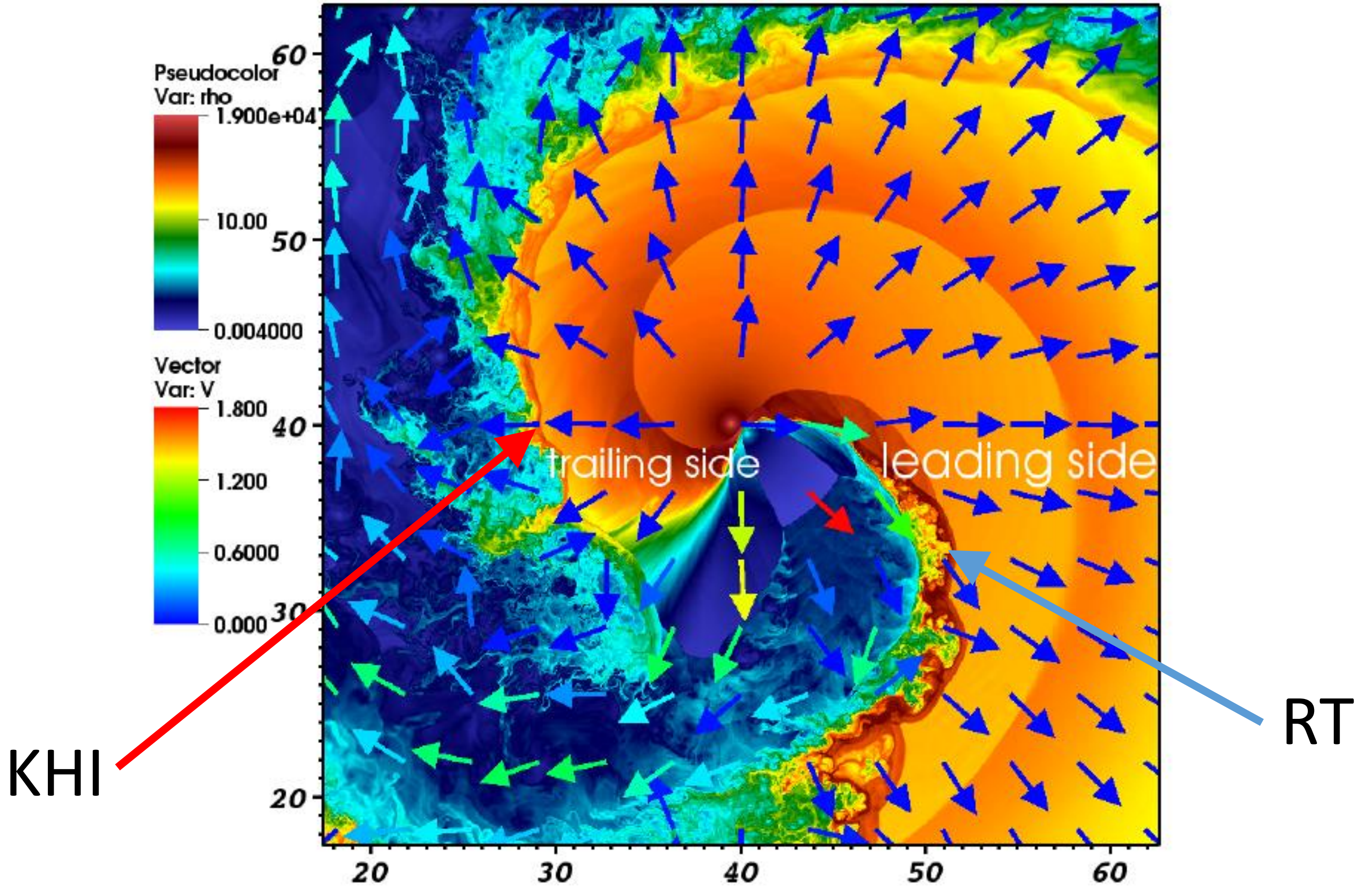
$$v_{exp} \sim 10^9 L_{sd37}^{1/2} \dot{M}_{-6.5}^{-1/2} cm/s$$



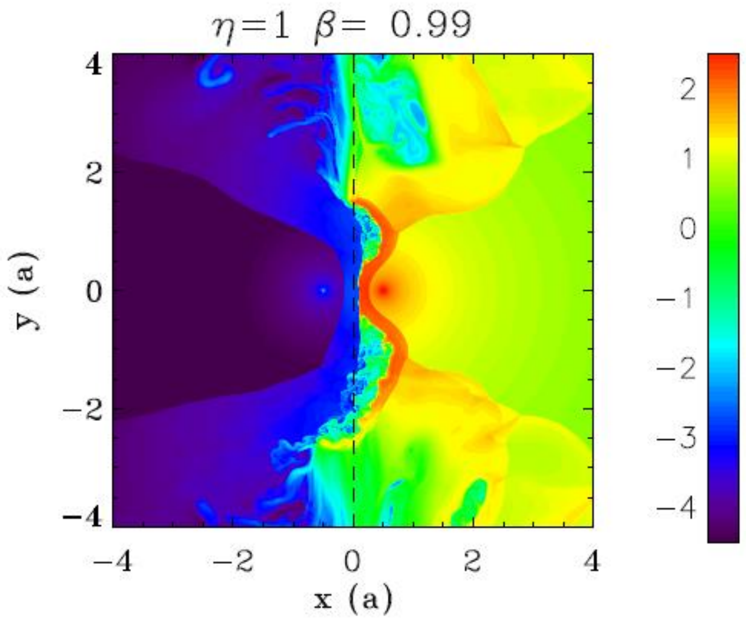
# Density $\Gamma = 2$; $\eta = 0.6$

$$\eta = \frac{L_{sd}}{\dot{M} v_w c}$$

(Bosch-Ramon, MVB, Khangulyan and Perucho 2012)
2D RHD, PLUTO with AMR Chombo



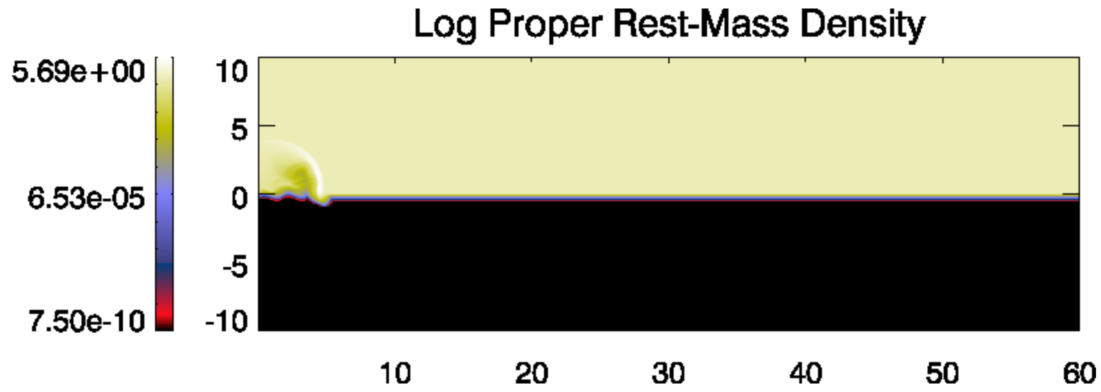

(Lamberts et al. 2013) RHD
Outflow is unstable.



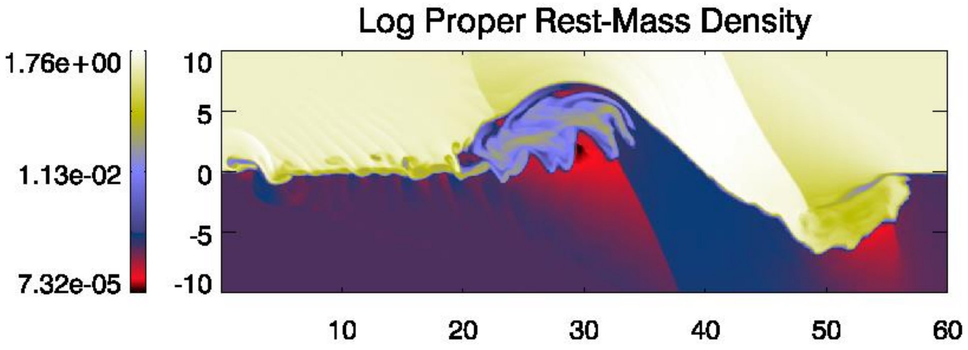
# KHI in pulsar stellar wind collision region:

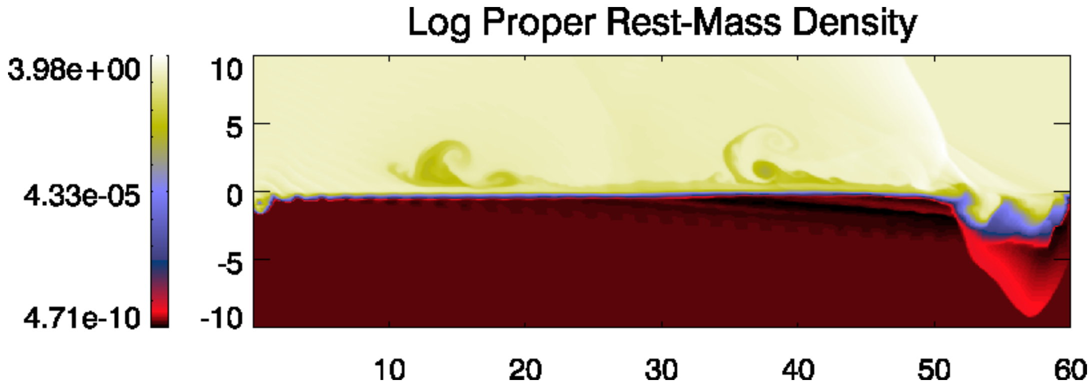
Density $\Gamma = 2$; $\eta = 0.3$

Density $\Gamma = 10$; $\eta = 0.3$


t = 2.8 s

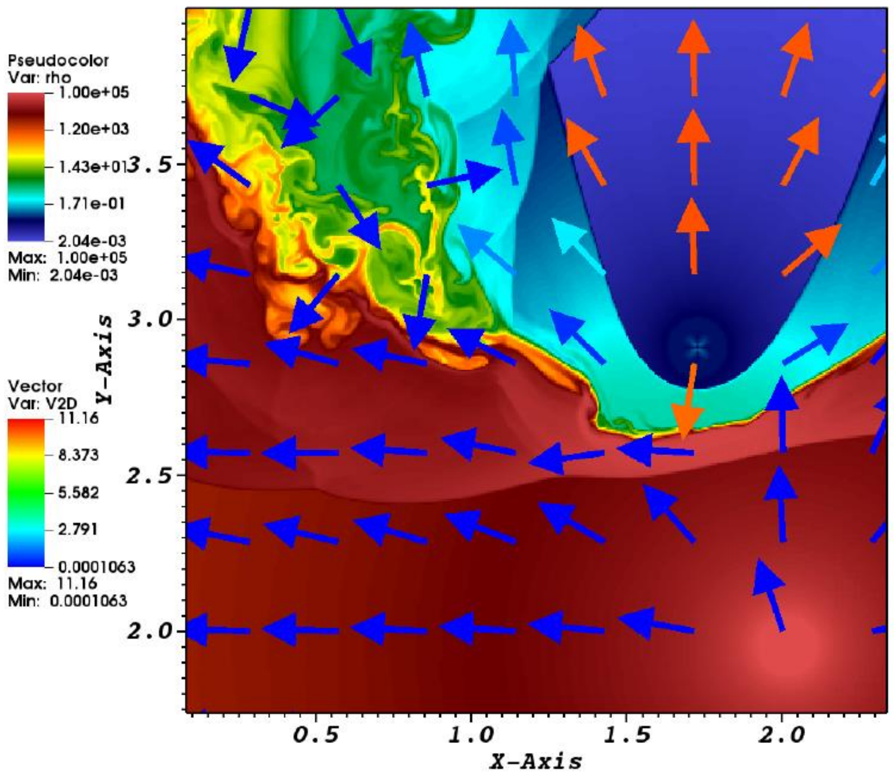


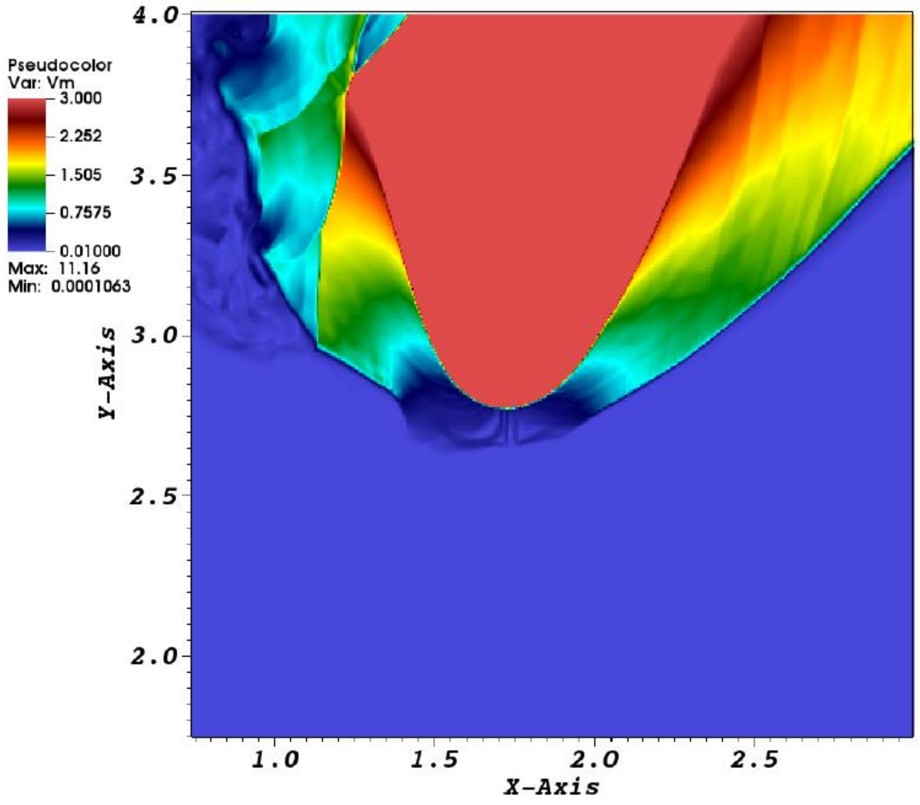




t = 34 s

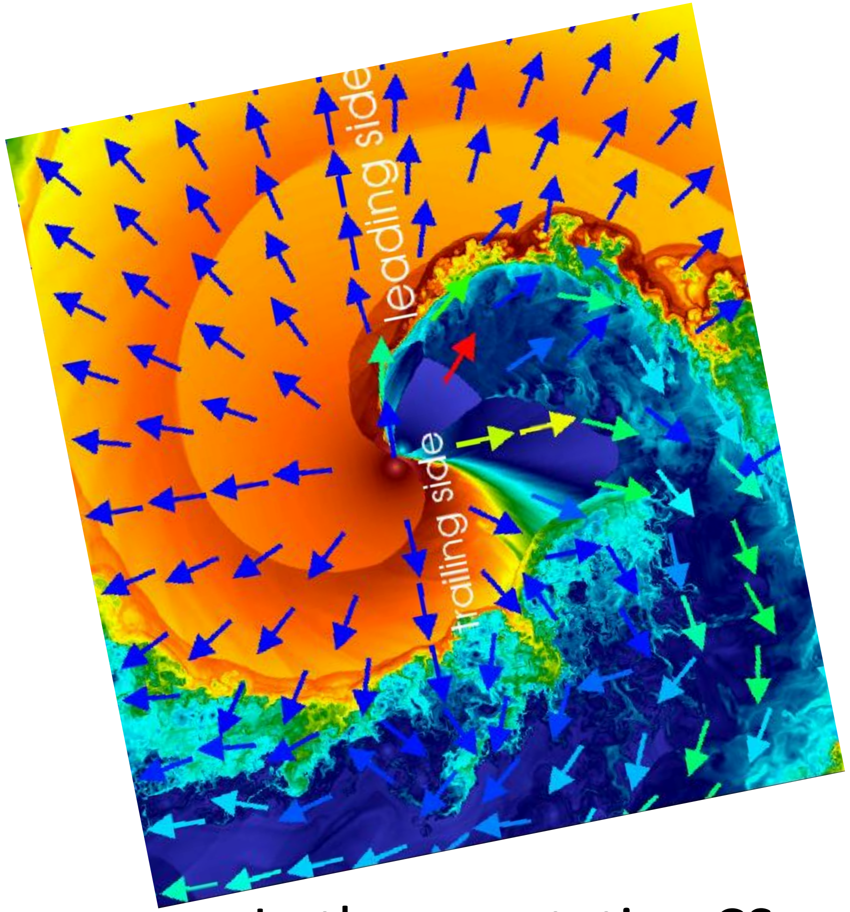
# Density and velosity $\Gamma = 10; \eta = 0.3$

(Bosch-Ramon, MVB, Khangulyan and Perucho 2012) RHD



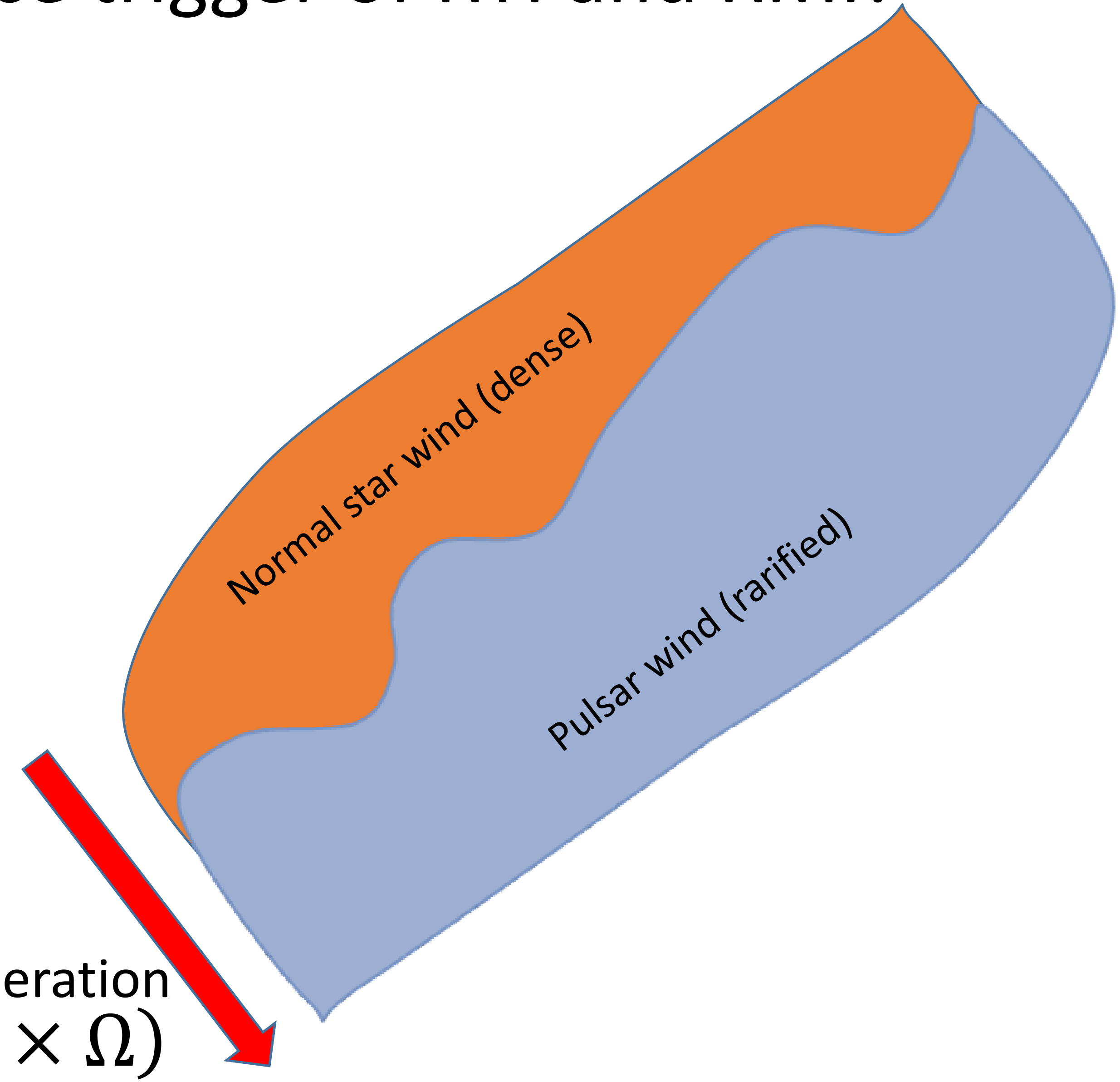
# The Coriolis force trigger of RTI and RMI!




In the co rotating CS

Coriolis force produce acceleration

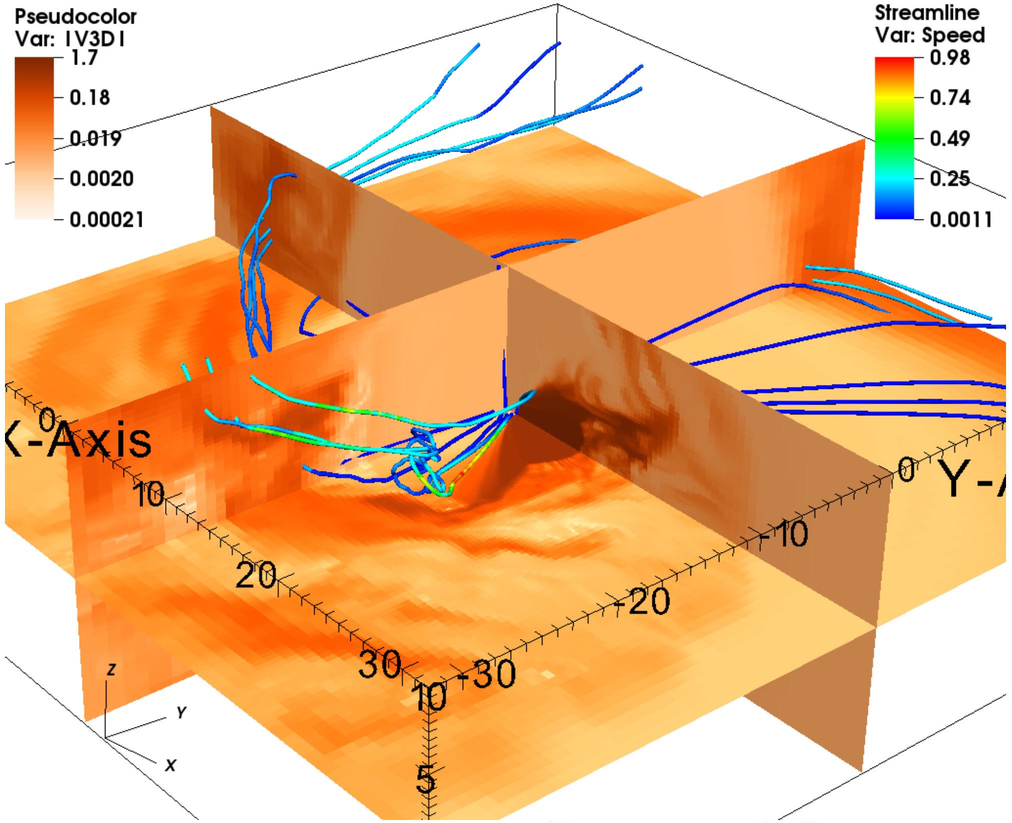
$$a=2(v_w \times \Omega)$$



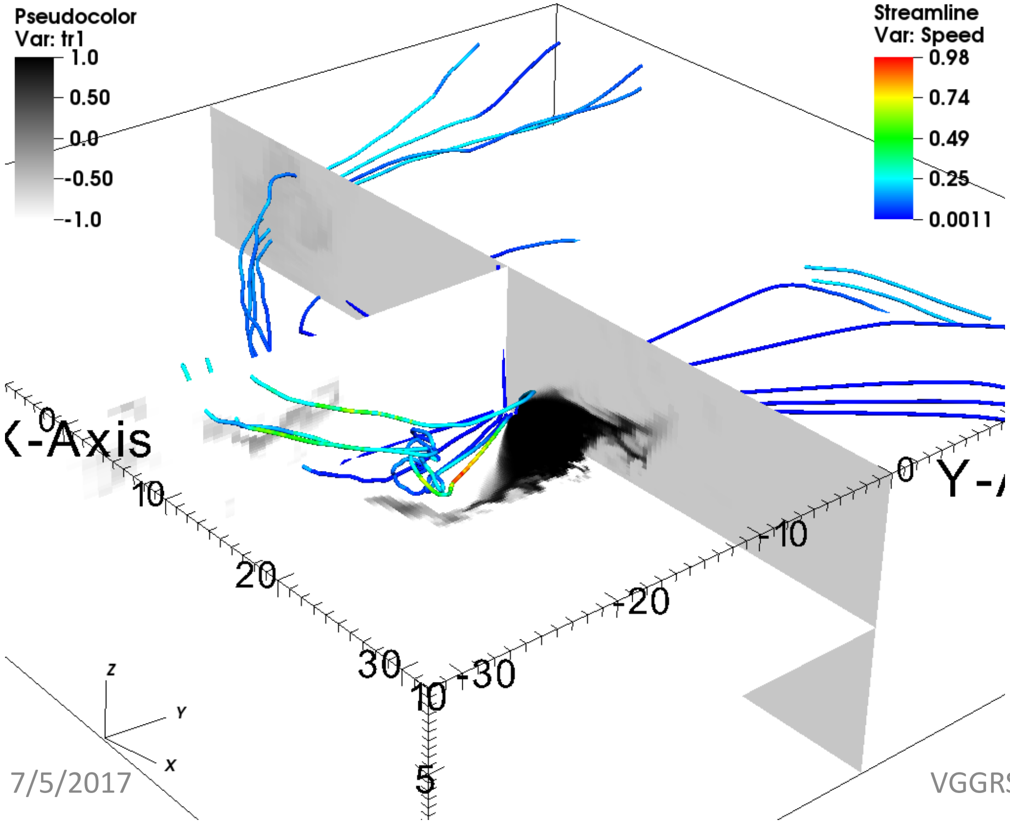
# 3D run with $\Gamma = 2; \eta = 0.1$

## PLUTO non uniform grid

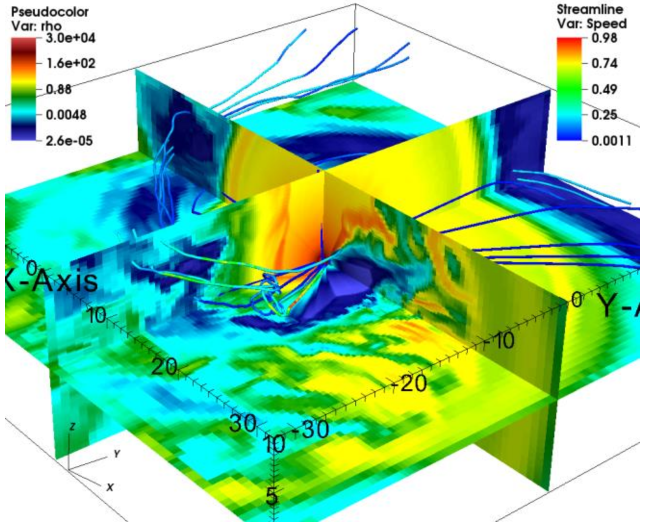
Four velocity.




Tracer.

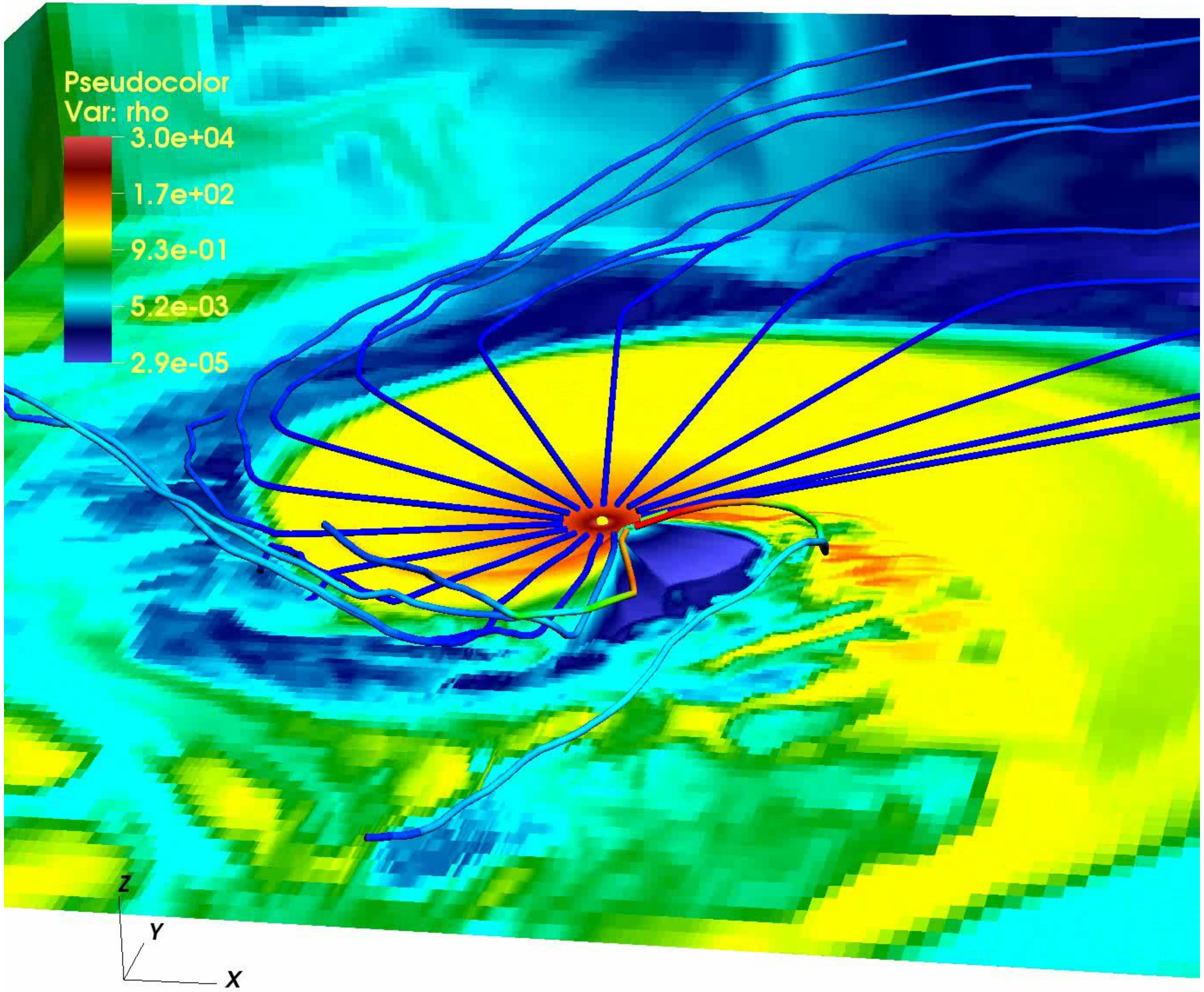



Density



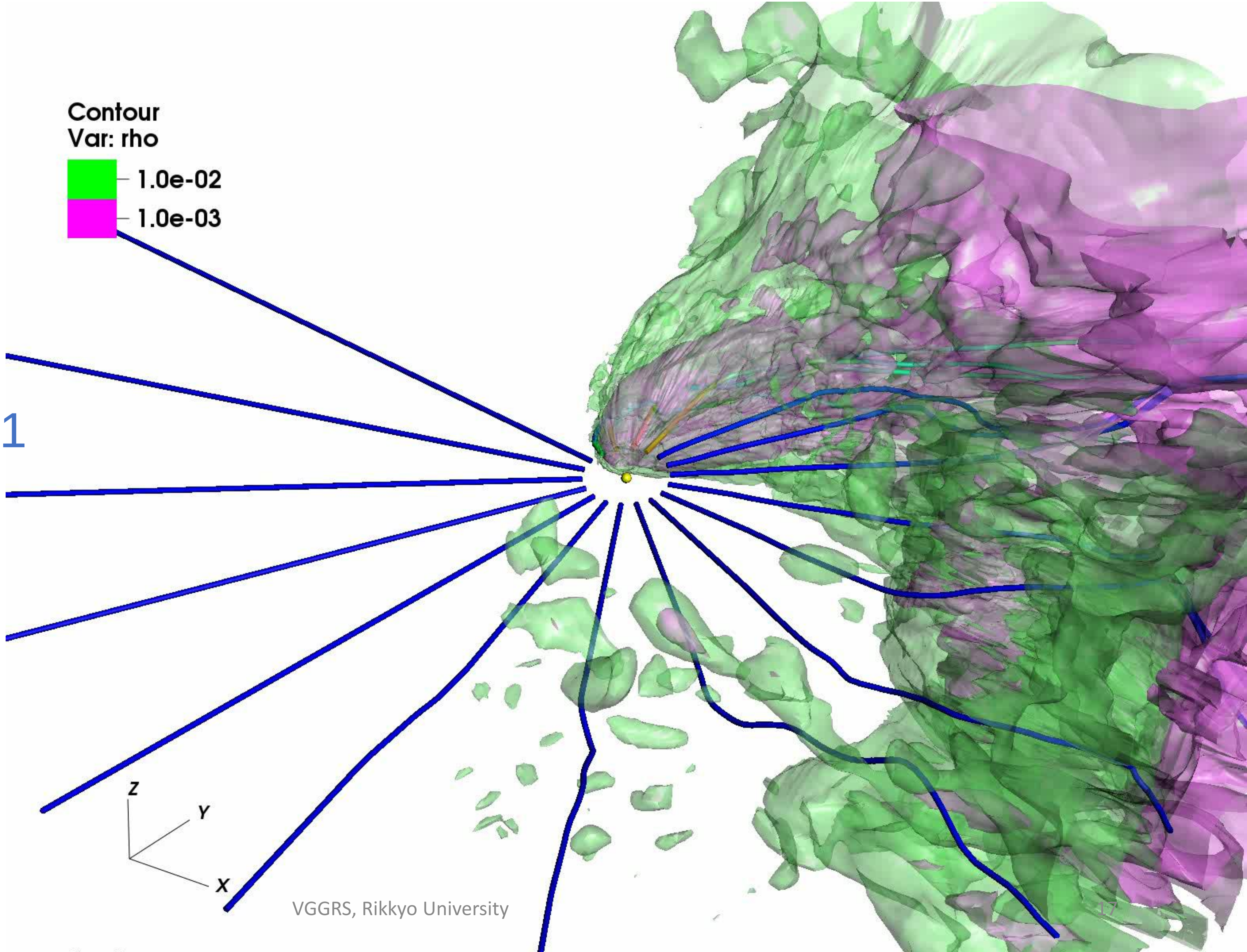
# 3D run $\Gamma = 2$; $\eta = 0.1$

density and stream lines.



3D run $\Gamma = 2$; $\eta = 0.1$

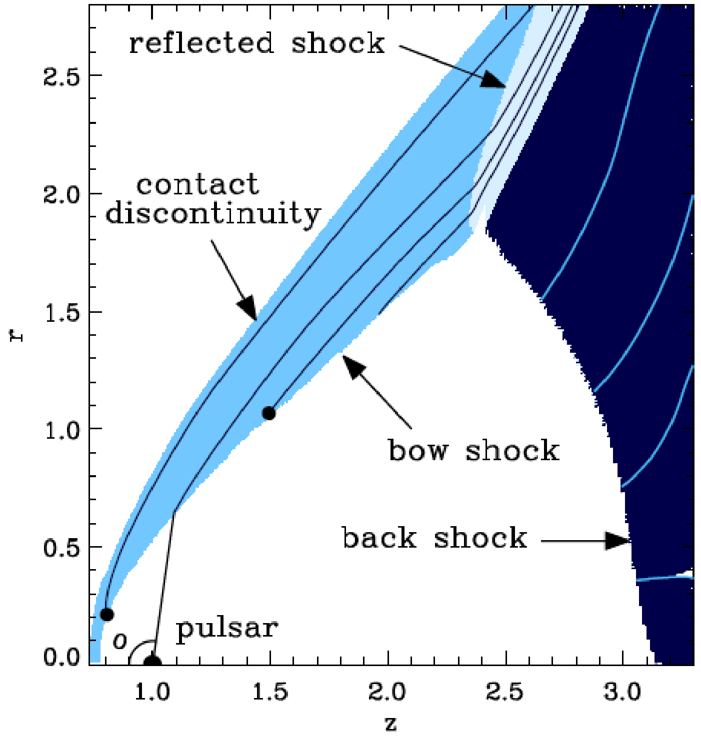
density contours and stream lines.

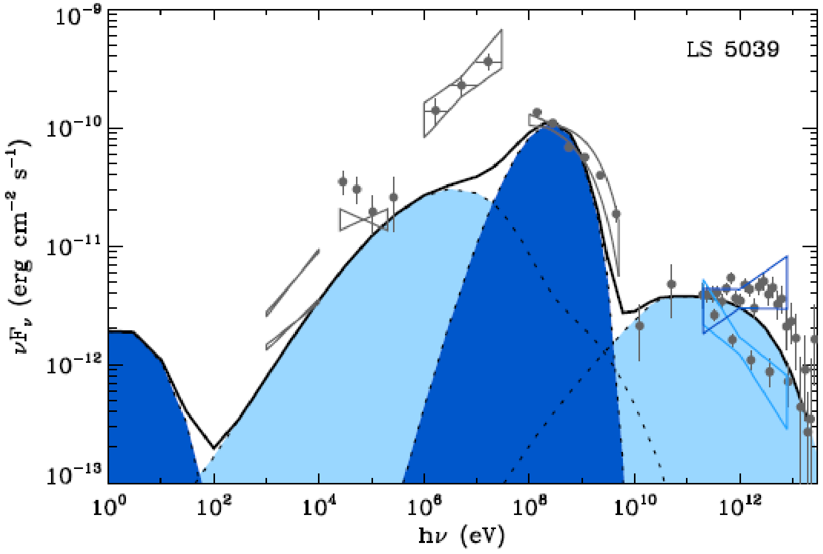


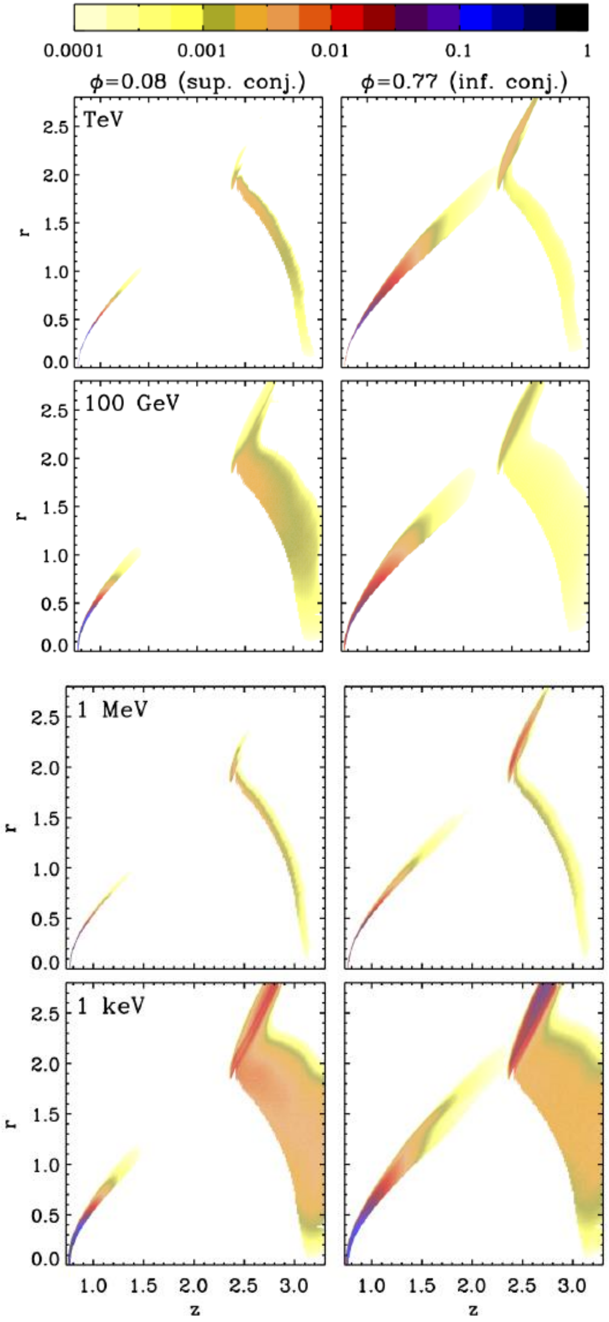
# The first hydro and radiation simulations:

Dubus et al 2015

1) Artificial back shock with $\eta$=0.1.
2) Energy budget is 0.1 of observed one.



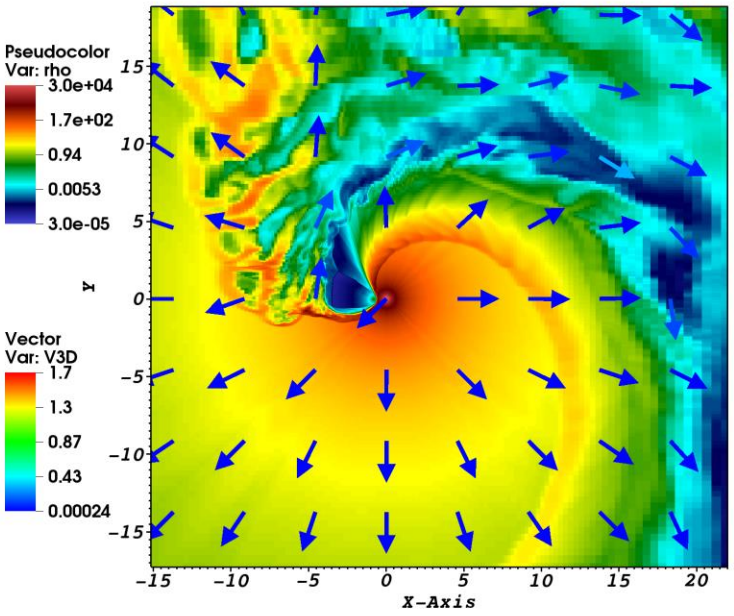



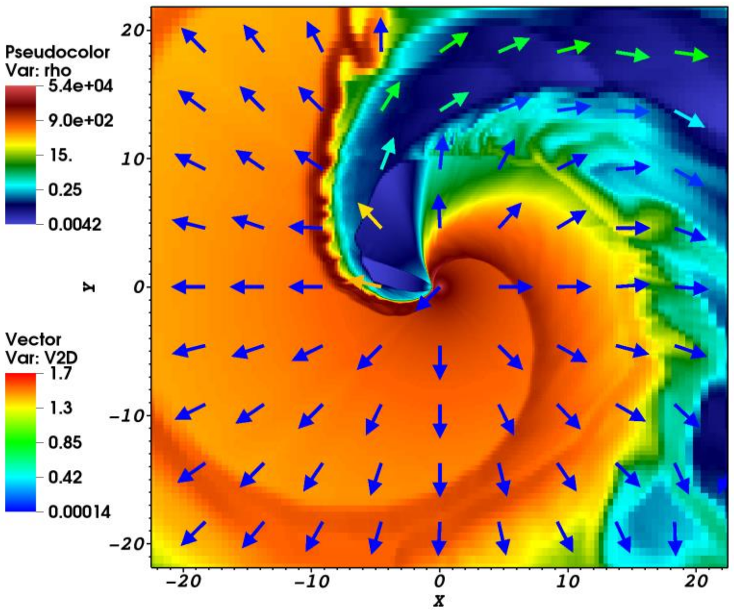
# Comparison of the 3D case and 2D cases with different resolution.

Density presented in the XY plane.

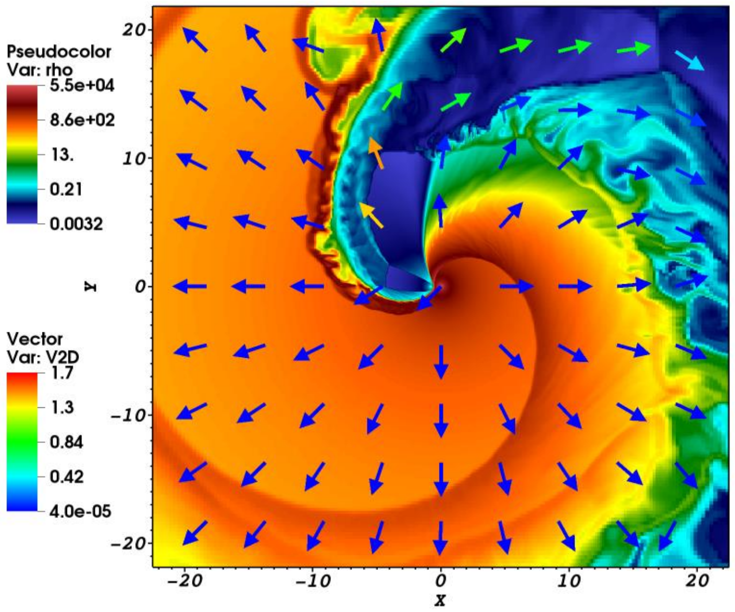
3D



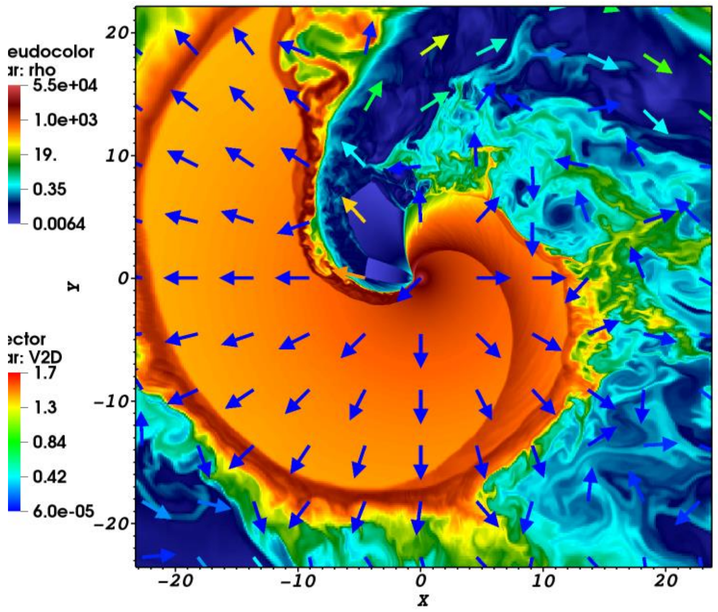

2D



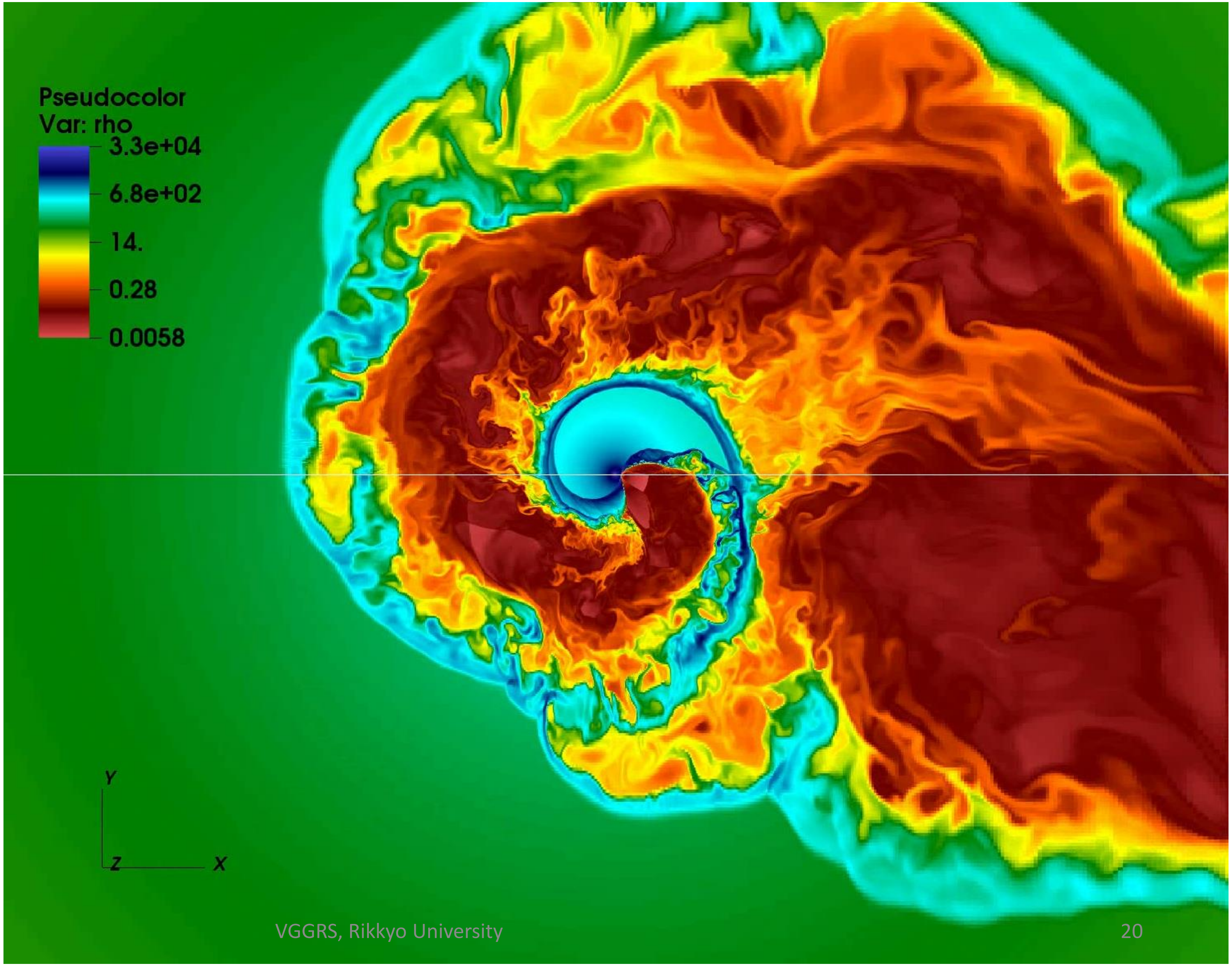

2Dx2




2Dx4

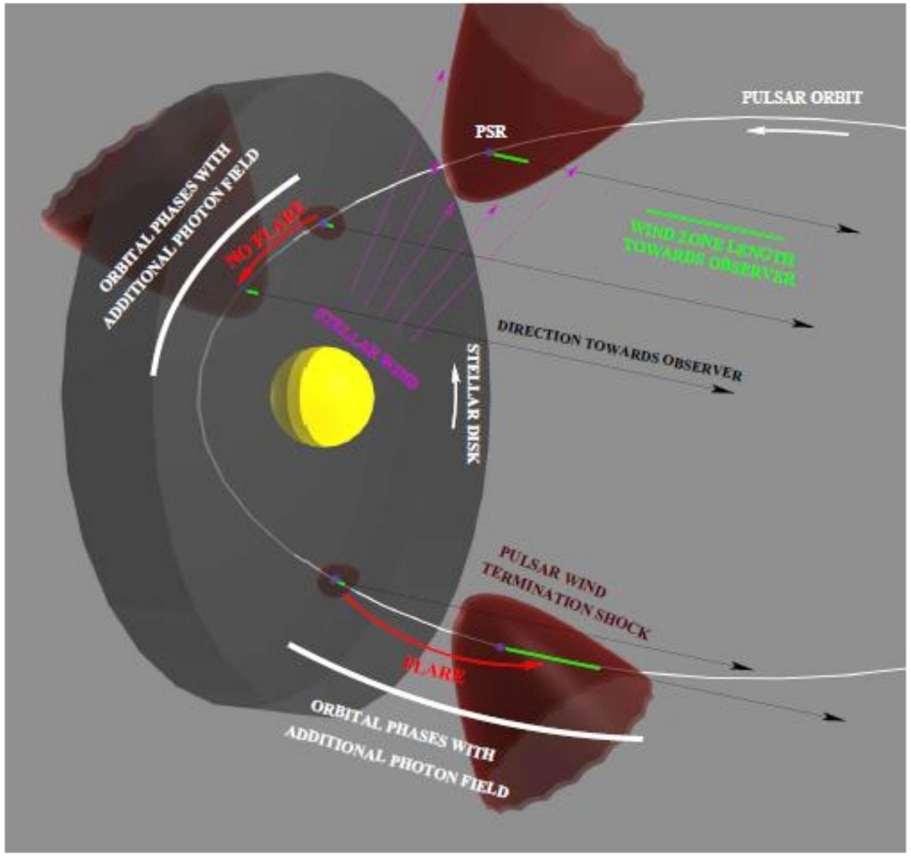


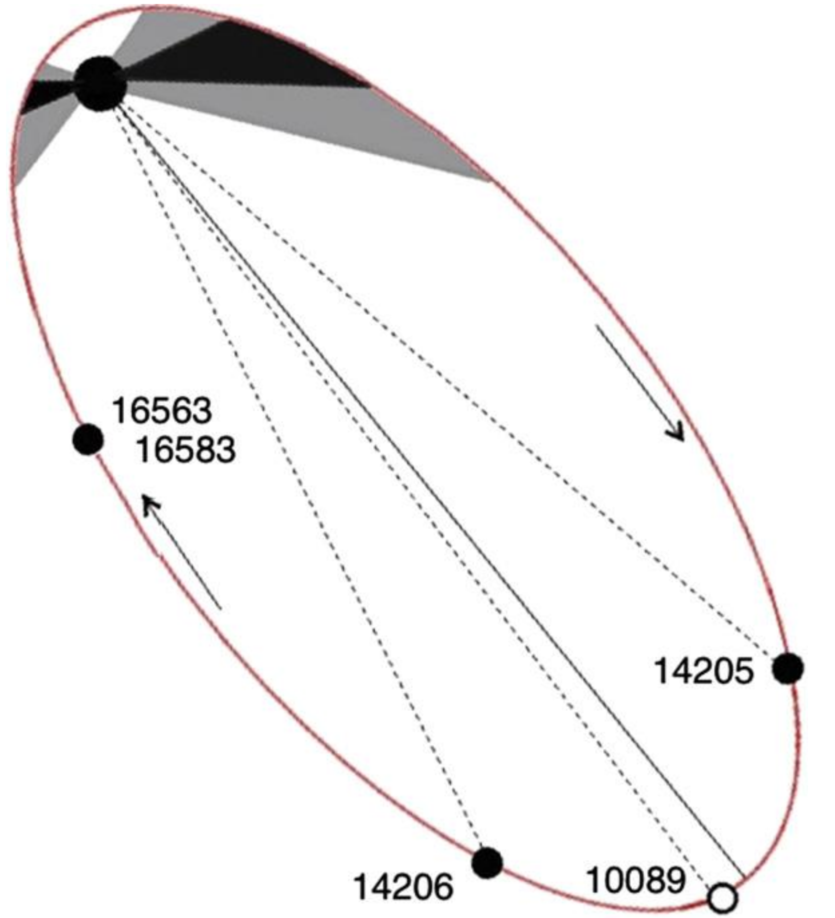
2D $\Gamma = 2$; $\eta = 0.3$ with high resolution in a large domain, density in XY plane.



# The origin of the X-ray-emitting object moving away from PSR B1259-63 in (3-1)D and more

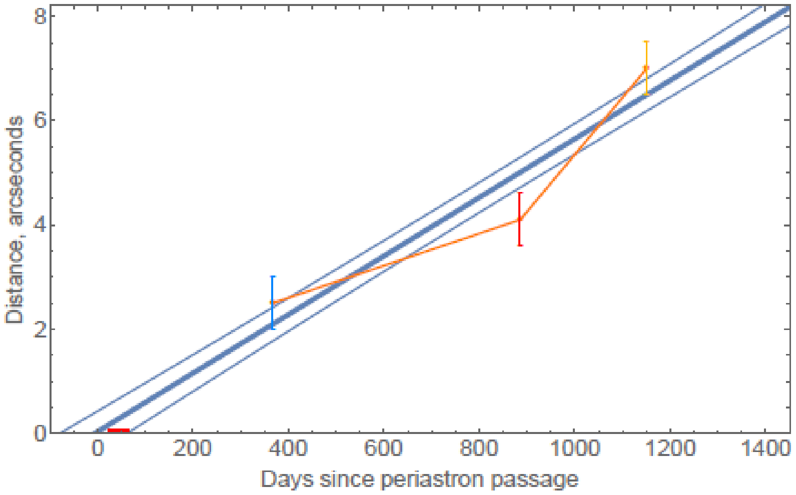
# PSR B1259-63


PULSAR ORBIT
PSR
ORBITAL PHASES WITH
ADDITIONAL PHOTON FIELD
NO FLARE
WIND ZONE LENGTH
TOWARDS OBSERVER
STELLAR WIND
DIRECTION TOWARDS OBSERVER
STELLAR DISK
PULSAR WIND
TERMINATION SHOCK
FLARE
ORBITAL PHASES WITH
ADDITIONAL PHOTON FIELD

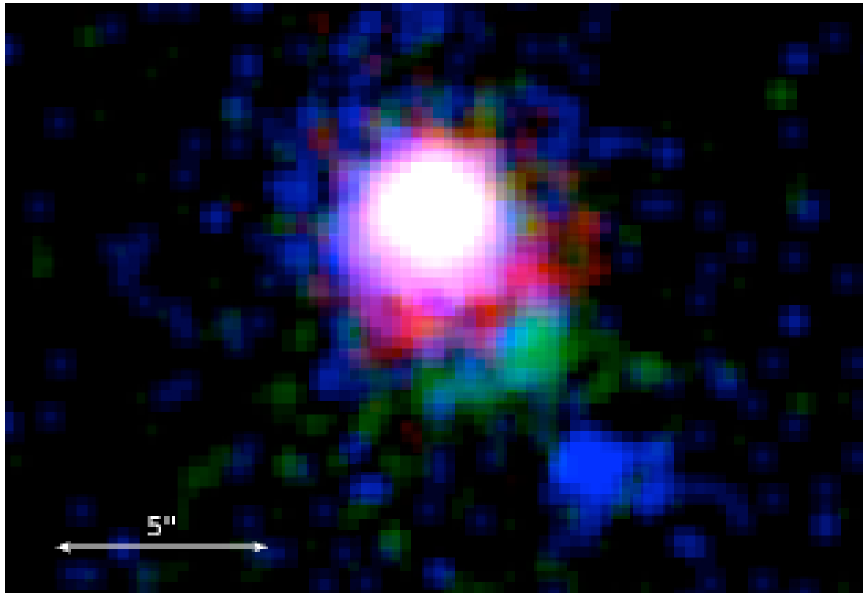

16563
16583
14205
14206
10089

# The origin of the X-ray-emitting object moving away from PSR B1259-63

(Pavlov et al 2015)




**Linear fit: V = (0.07+/-0.01)c**




Between 3rd and 4th observations the extended structure moved by 2.5'' ±0.5''.

This corresponds to the apparent proper motion

**V=(0.13±0.03)c**

at d = 2.3 kpc

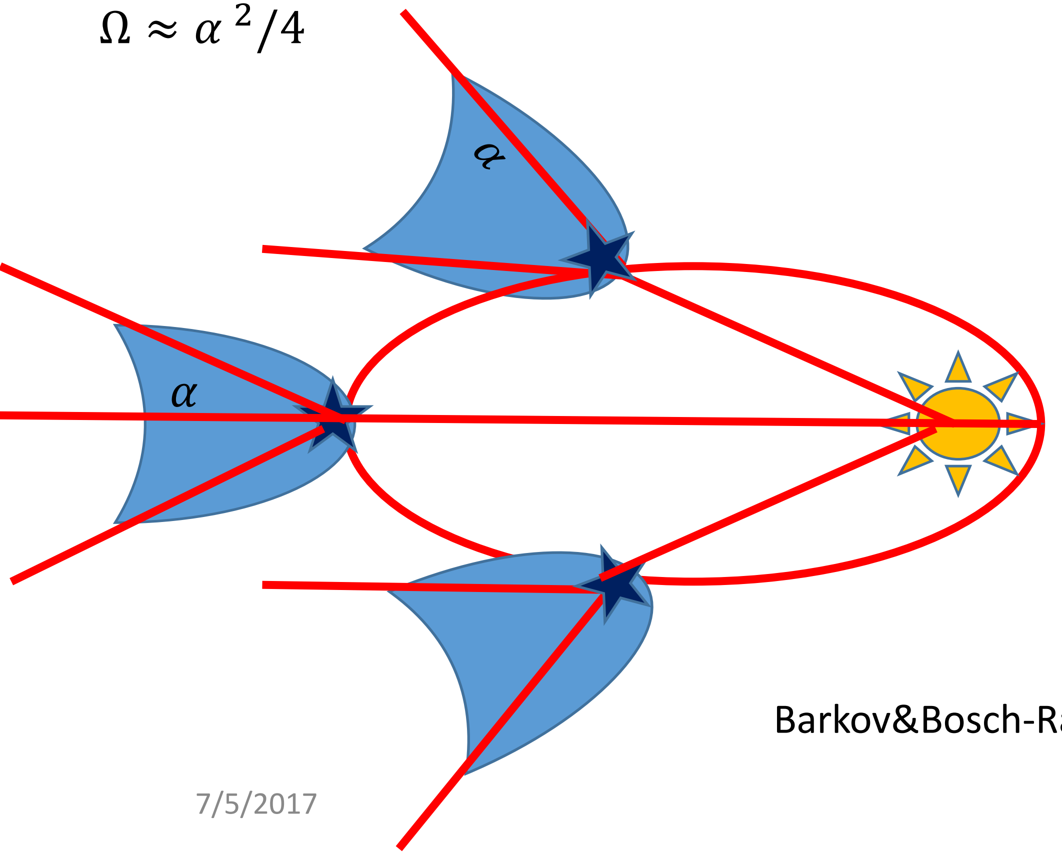
Apparent acceleration (?)

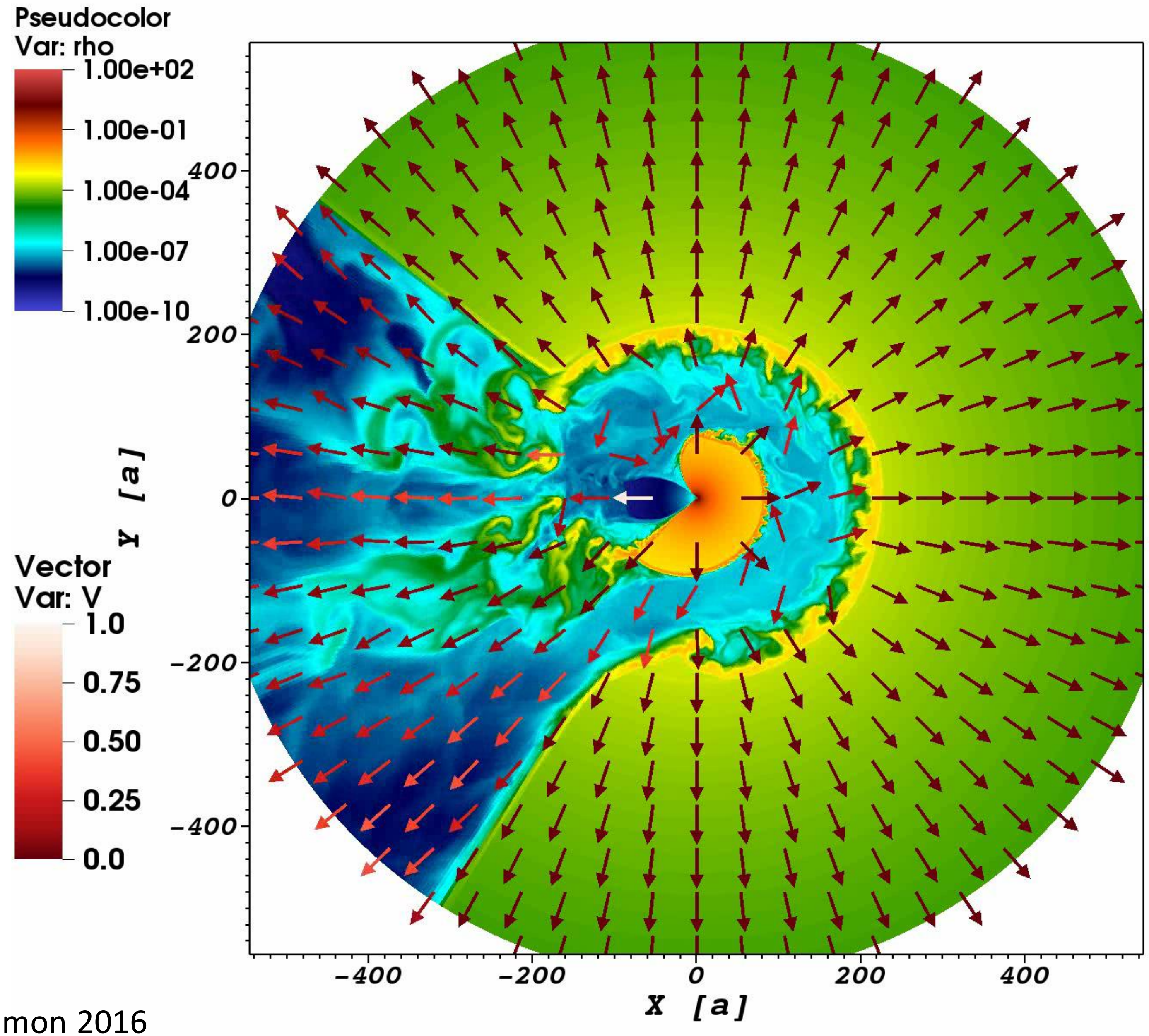
90±40 cm s$^{-2}$

# Model:

$$v_{\rm t} = \sqrt{\frac{2L_{sd}(t_{\rm orb} - t_{\rm pe})}{\dot{M}\Omega t_{\rm pe}}} = \sqrt{\frac{\eta v_{\rm w} c}{\Omega}\frac{\pi - M_{\rm a}}{M_{\rm a}}}$$

$\Omega \approx \alpha^2/4$



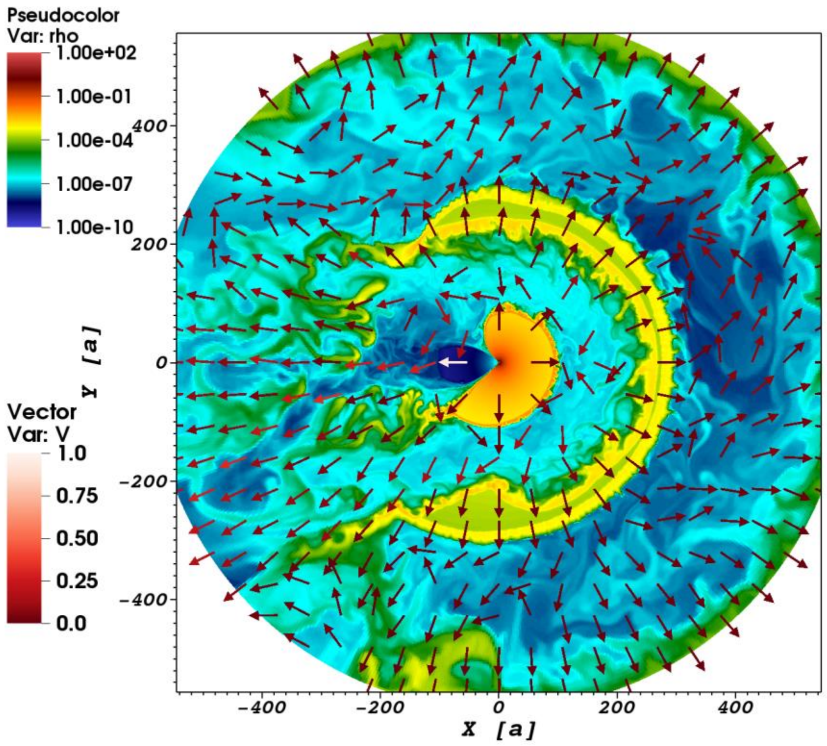

Barkov&Bosch-Ramon 2016

# Results:

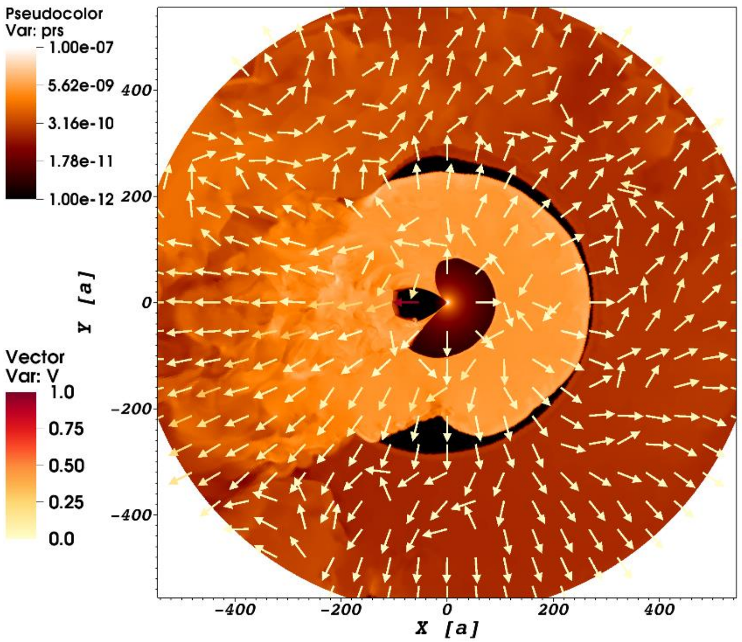
Barkov&Bosch-Ramon 2016

T=3.4 year
e=0.87

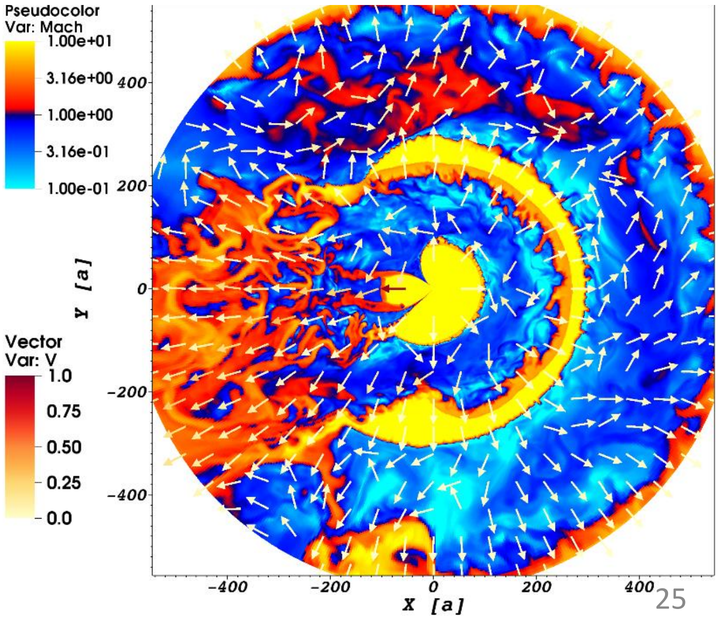
Density

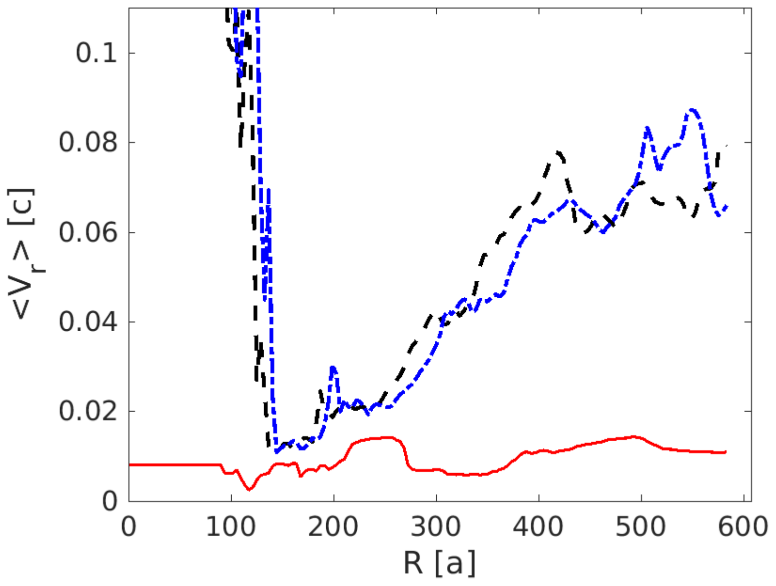


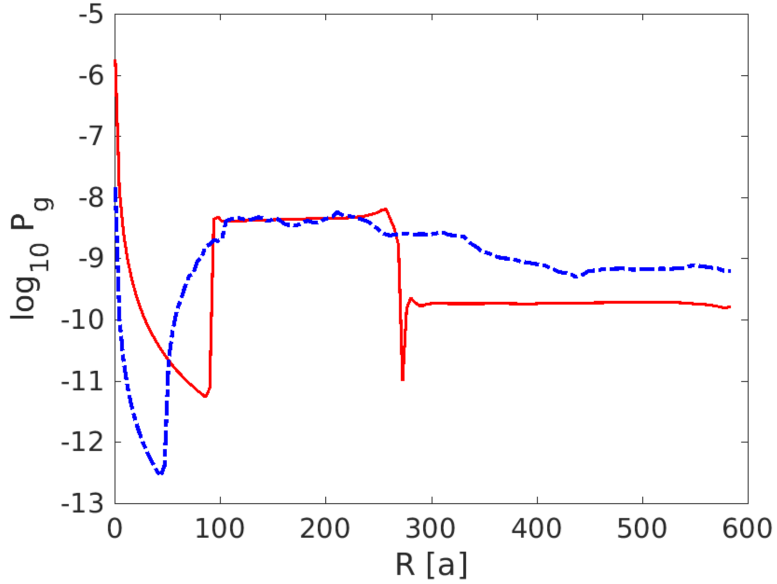

Pressure



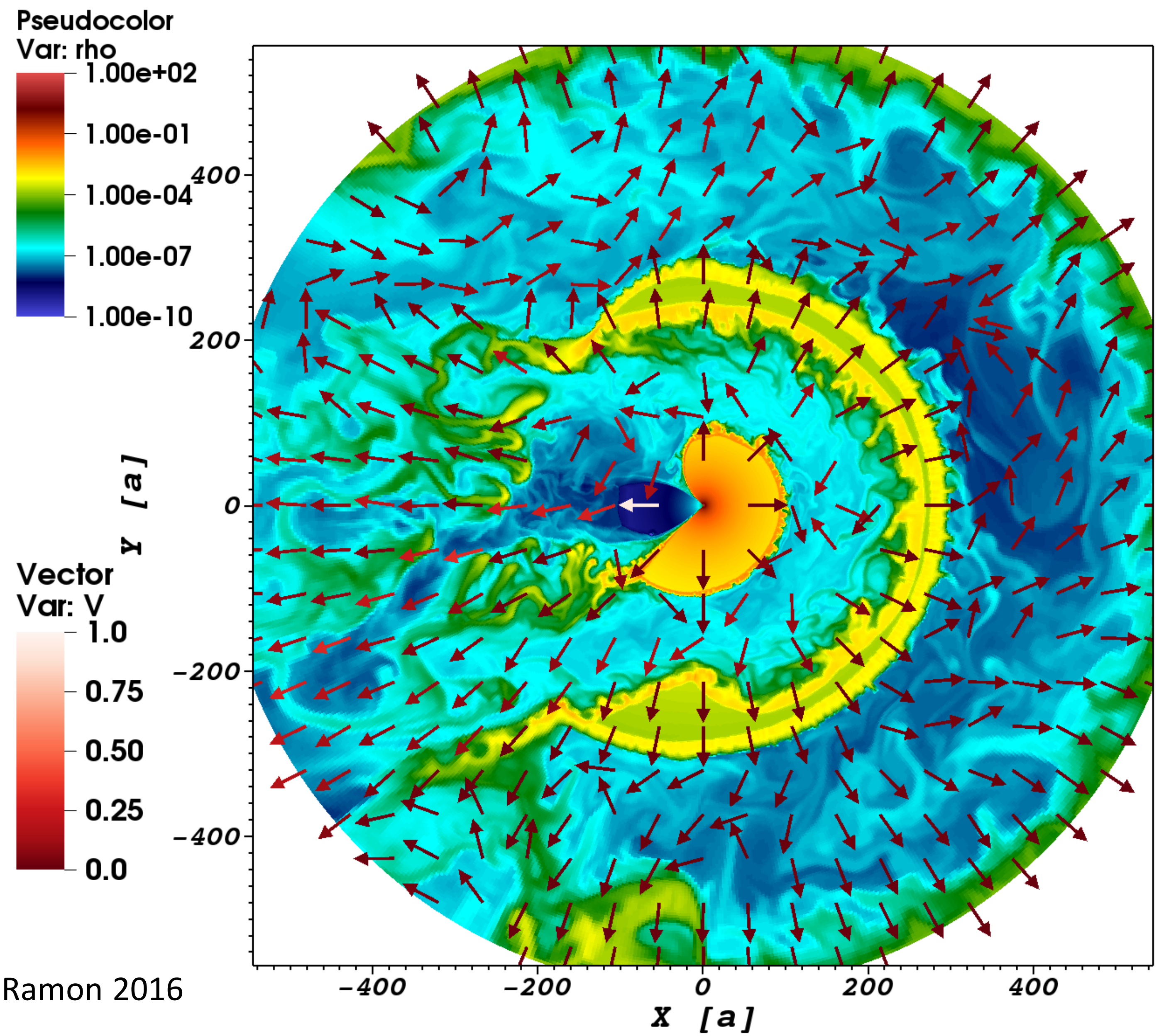

Mach number






Density

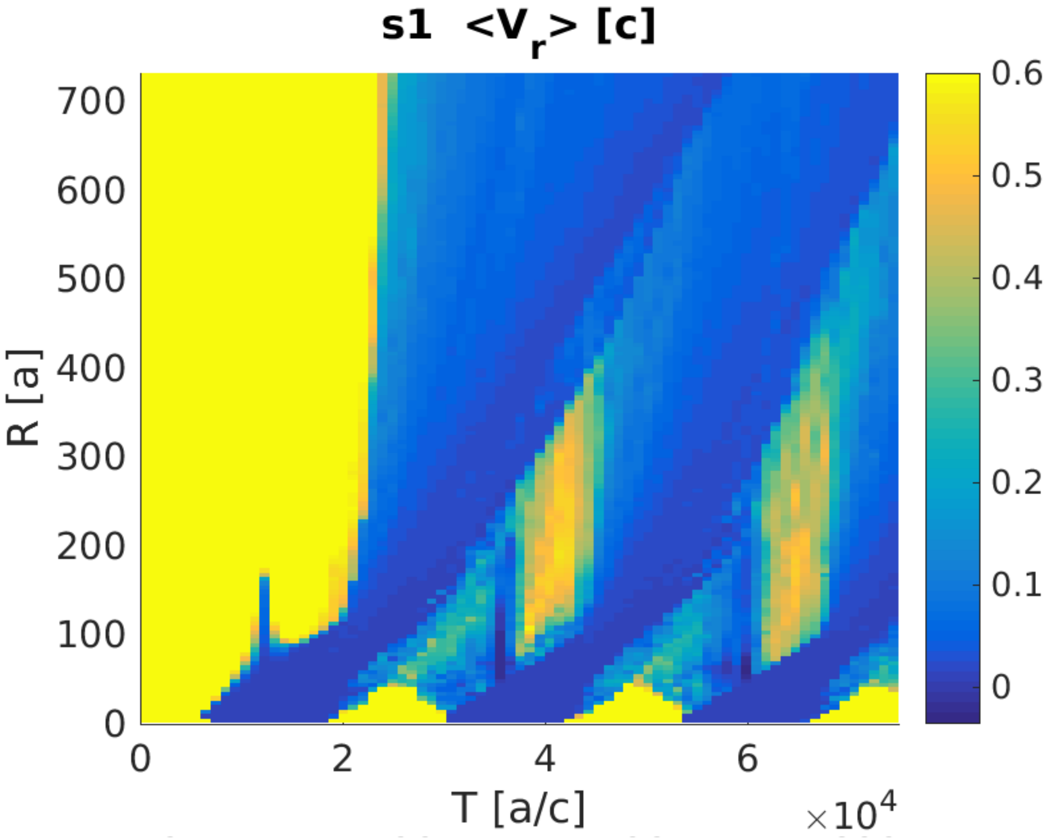



Barkov&Bosch-Ramon 2016

# HESS J0632+57

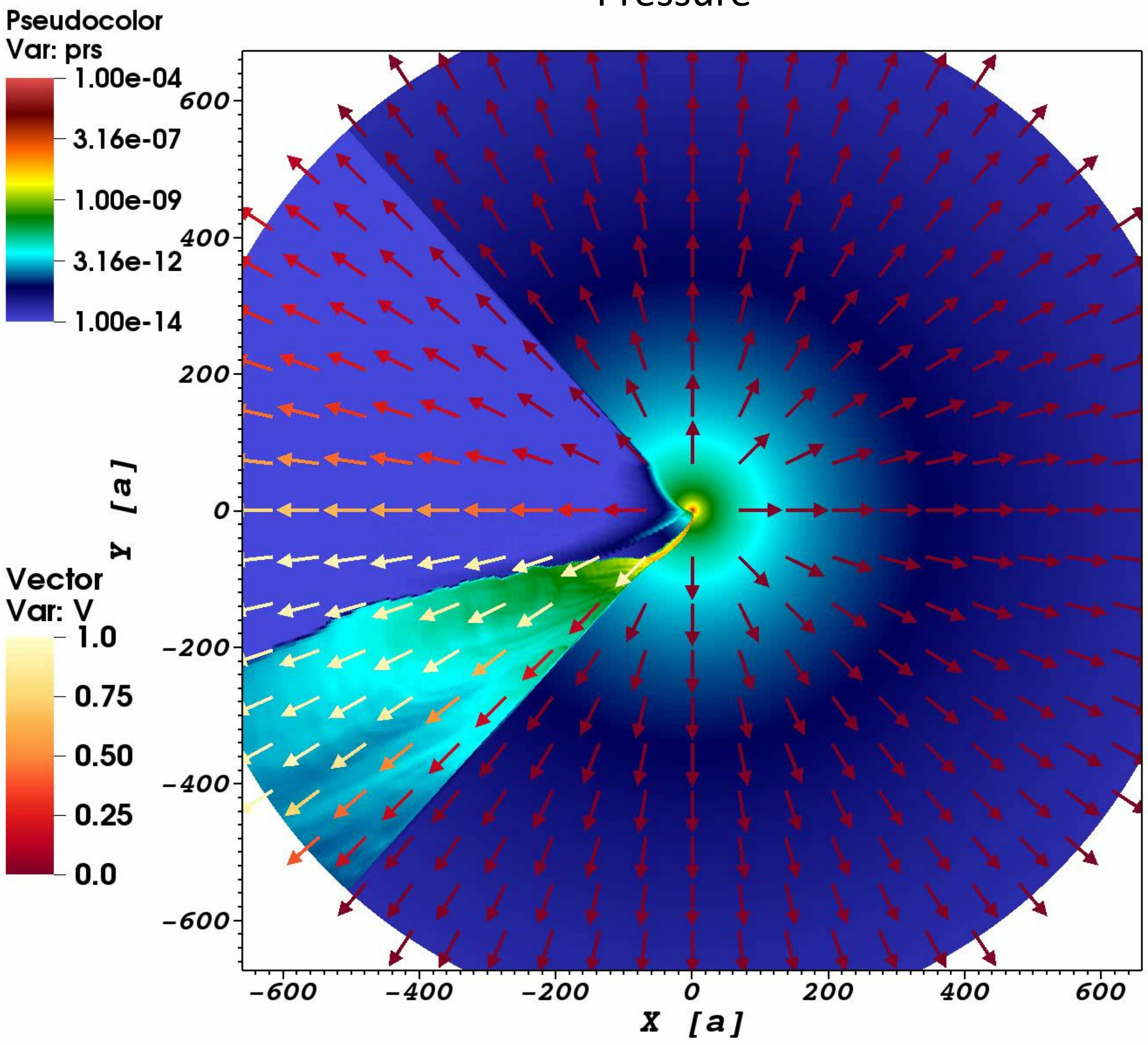
Bosch-Ramon, Barkov, Mignne and Bordas (submitted to MNRAS)

- T=321 day
- e=0.83



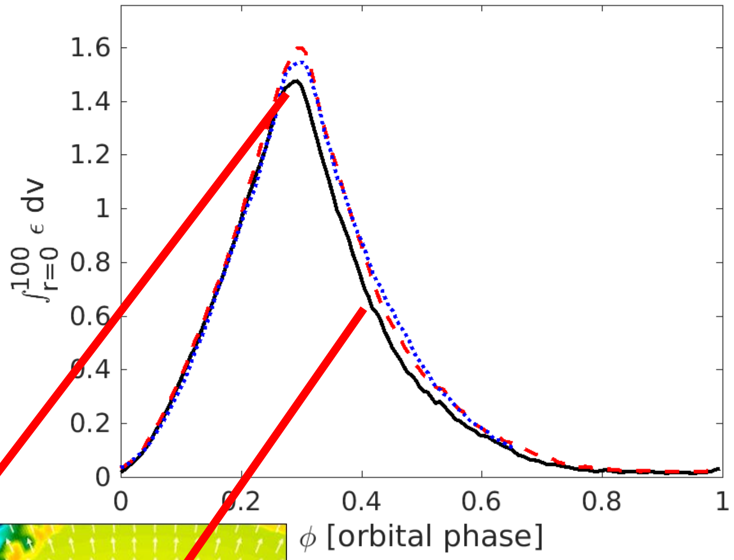

R [a]

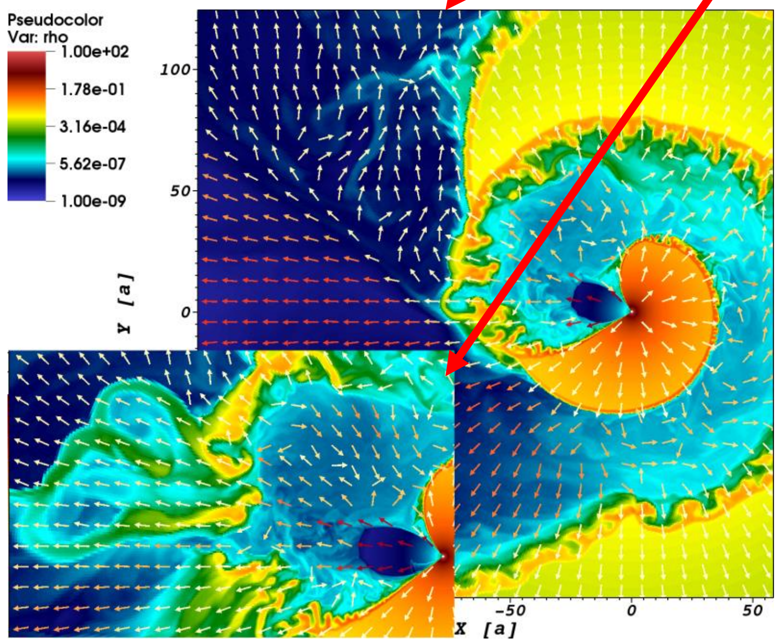
Pressure



# HESS J0632

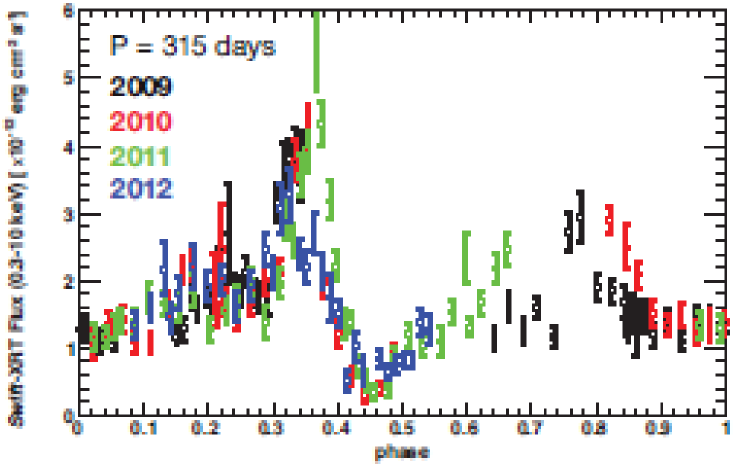
Bosch-Ramon, Barkov, Mignone and Bordas (submitted to MNRAS)



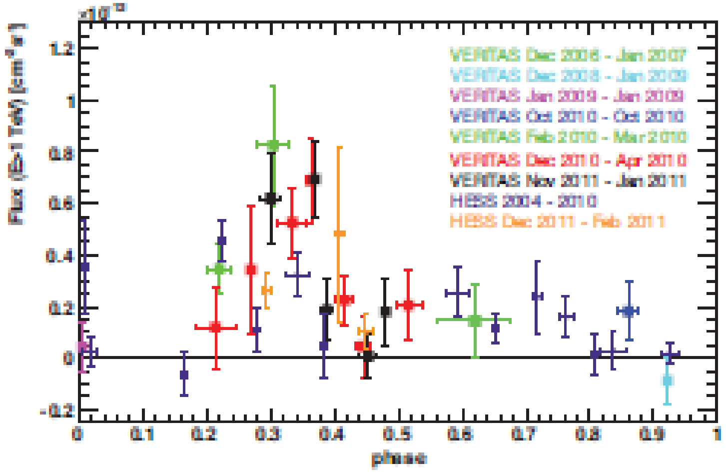




## HESS J0632

X-ray



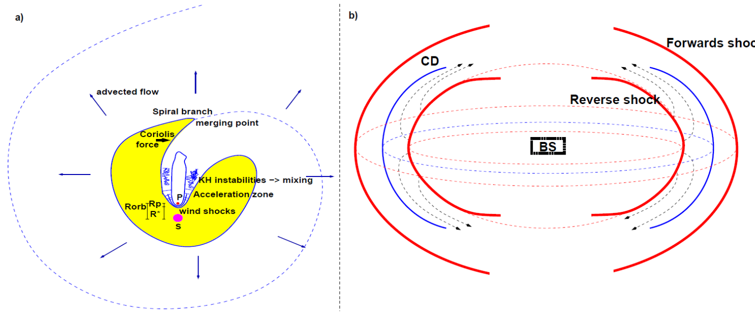

TeV



# Binary Systems in VHE Regime

| Object | PSR B1259 | LS 5039 | J0632 | J1086 | LS I +61 303 | Cyg X-1 |
|---|---|---|---|---|---|---|
| Type | O8.5e+Pulsar | O6.5+? | Be+Pulsar? | O6+? | Be+? | O9+BH |
| $L_s$, erg/s | $3 \times 10^{37}$ | $7 \times 10^{38}$ | $10^{38}$ | $7 \times 10^{38}$ | $10^{38}$ | $1.3 \times 10^{39}$ |
| Orbit Size, cm | $10^{13} - 10^{14}$ | $10^{12} - 3 \times 10^{12}$ | $10^{13} - 7 \times 10^{13}$ | $\sim 10^{13}$ | $2 \times 10^{12} - 10^{13}$ | $3 \times 10^{12}$ |
| Eccentricity | 0.87 | 0.24 | 0.83 | 0.25? | 0.72 | 0 |
| Inclination | 35 | 10-75 | 10? | ??? | ~30 | ~30 |
| HE Instrument | EGRET<br>Fermi | EGRET<br>Fermi | - | Fermi | EGRET<br>Fermi | AGILE |
| GeV detection | LC+Spctr | LC+Spctr | - | LC+Spctr | LC+Spctr | Point |
| VHE Instrument | HESS | HESS | HESS, MAGIC<br>VERITAS | HESS | MAGIC<br>VERITAS | MAGIC |
| TeV detection | $13\sigma$ | $\sim 100\sigma$ | $\sim 10\sigma$ | $\sim 10\sigma$ | $\sim 10\sigma$ | $4\sigma$ |
| signal | periodic | Periodic, variable | periodic | periodic | Periodic, variable | flare |

# Conclusions:



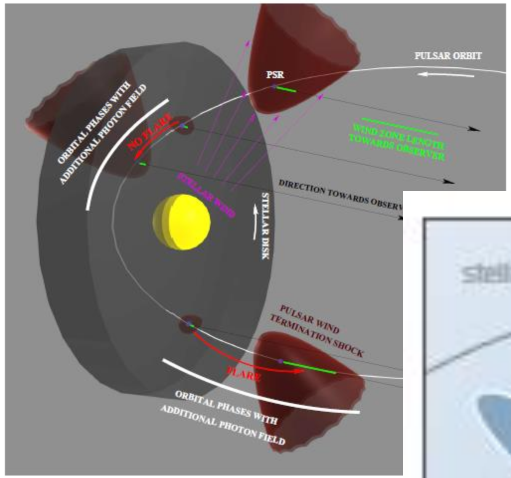

- First 3D RHD simulations of stellar and pulsar wind collision confirm that the interaction of stellar and pulsar winds yields structures that evolve non-linearly and get strongly entangled.
- Large scale simulations show that spiral arms loose their integrity on scales about 300a.
- Orbital eccentricity leads to variation of the Coriolis turnover tail size.
- $x \sim \frac{3\eta^{1/2} v_w}{2\Omega}$
- The X-ray transient observed in PSR 1259 can be explained as result of pulsar and stellar winds interaction on the eccentric binary system.
- the non-thermal activity before and around apastron can be linked to the accumulation of non-thermal particles in the vicinity of the binary, and the sudden drop of the emission before apastron is produced by the disruption of the two-wind interaction structure.

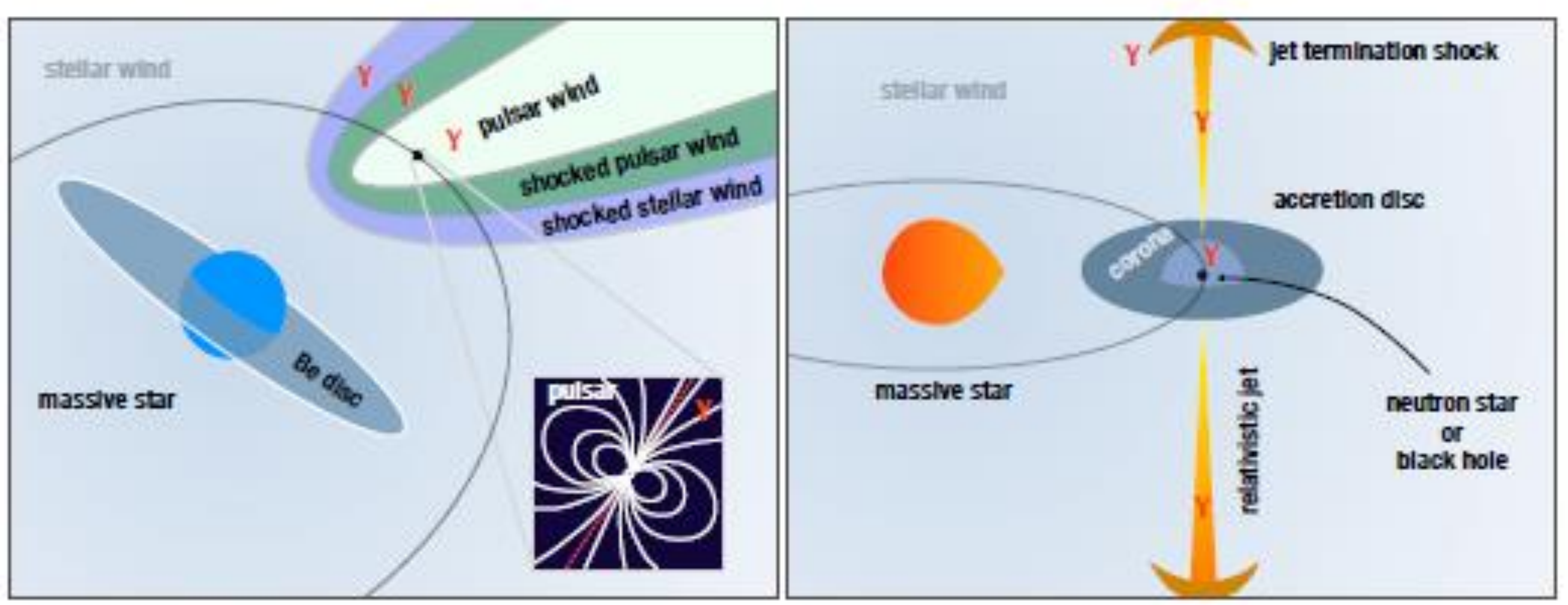
# Thank you for attention!

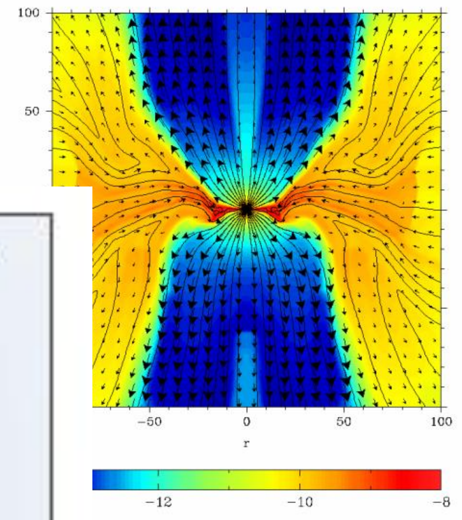
# What are the Scenarios?

## Binary Pulsar

## Jet from spherical accretion to BH




(Khangulyan et al 2012)

(MVB & Khangulyan 2012)

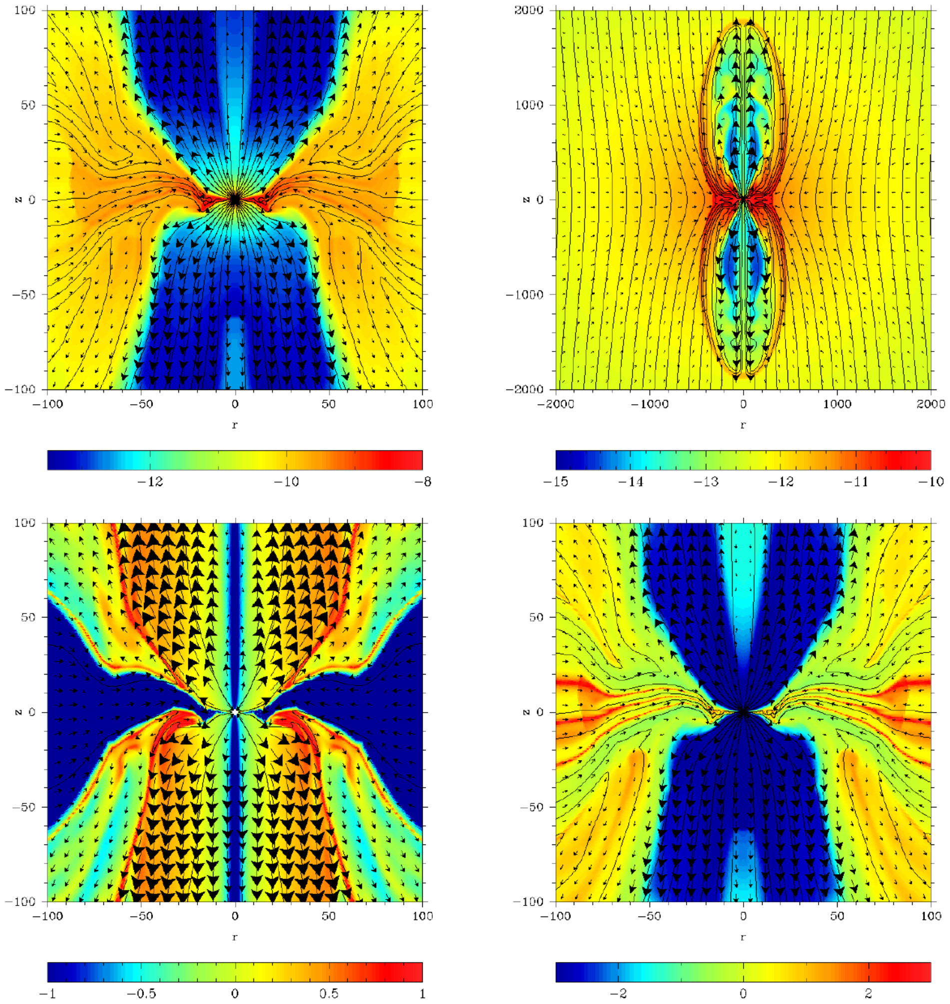
# Jet lunched by spherical accretion of magnetized wind to rotating BH

$\rho$

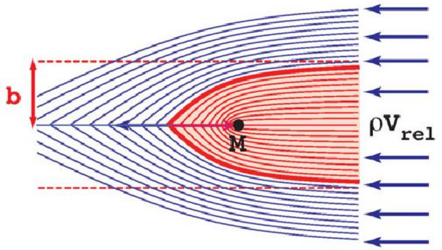
$\rho$

$\frac{B_\varphi}{B_p}$

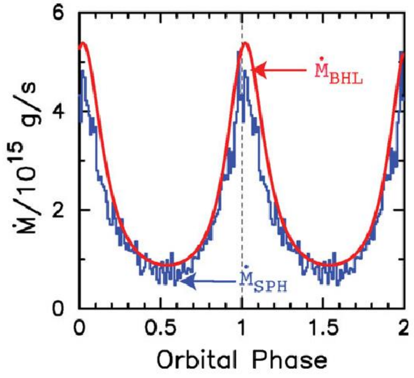
$\frac{P_g}{P_m}$

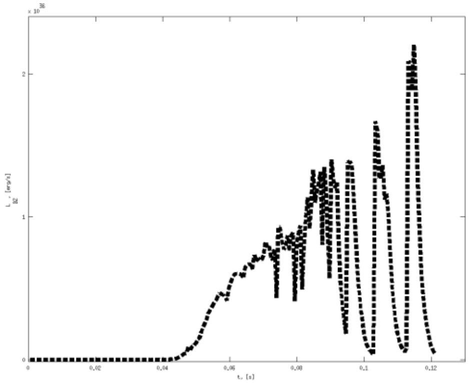


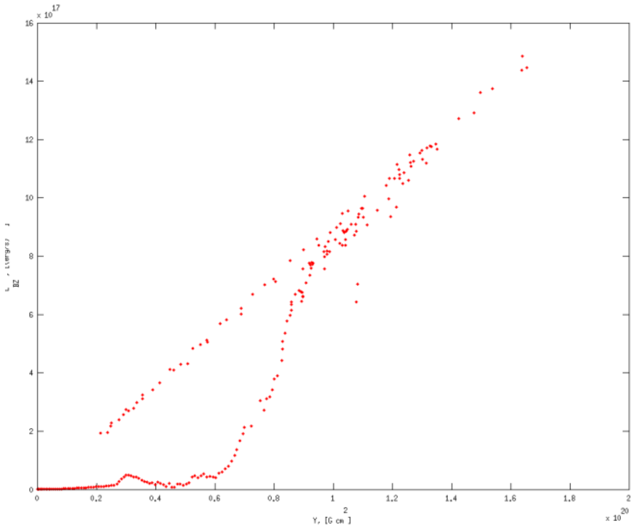
(MVB & Khangulyan 2012)



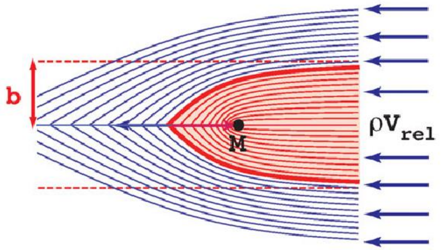

Owocki et al 2011



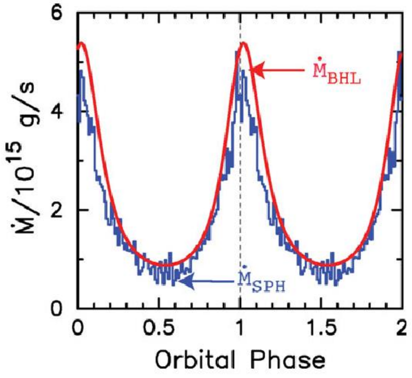



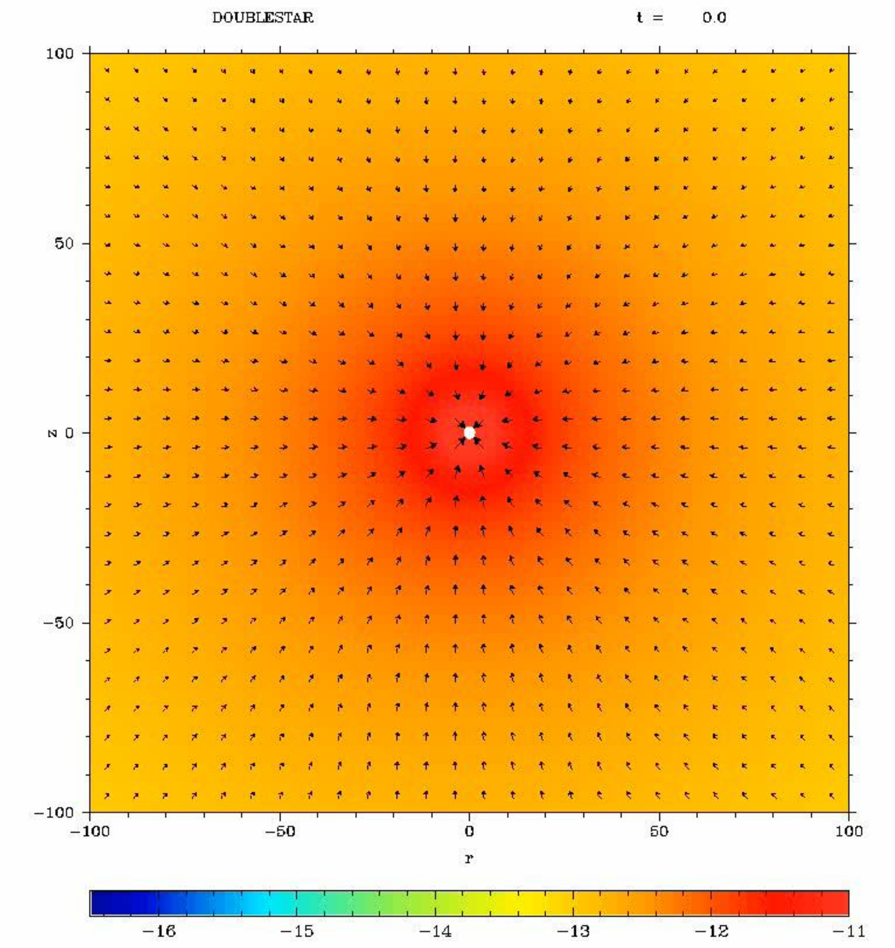


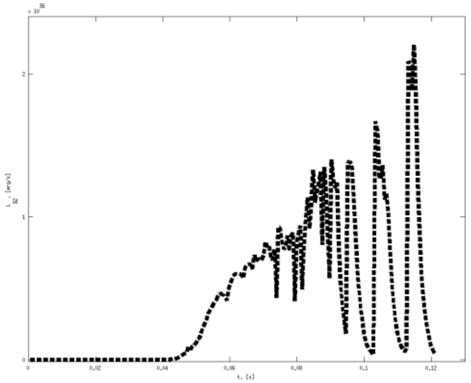
# Jet formation from spherical accretion of magnetized wind to rotating BH

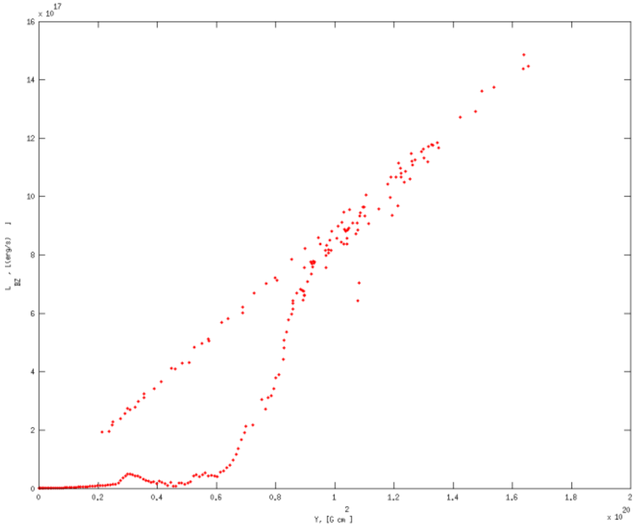



Owocki et al 2011



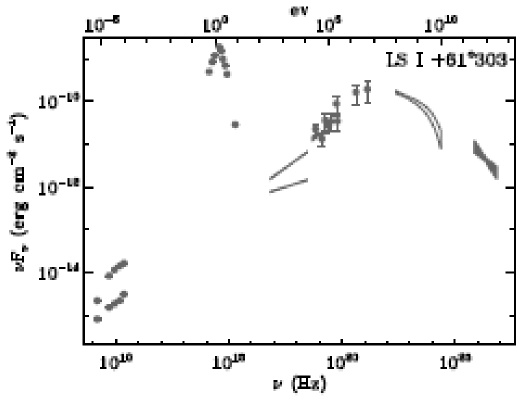



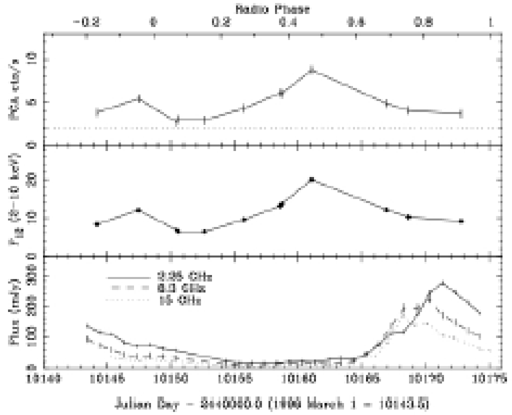



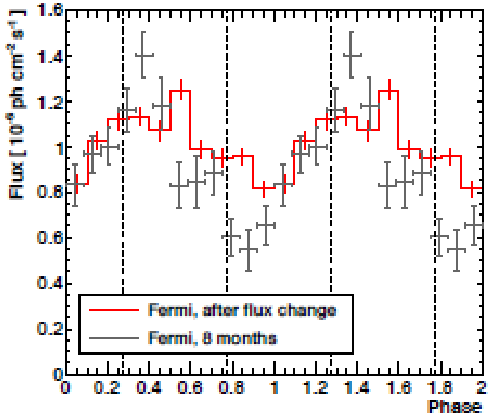


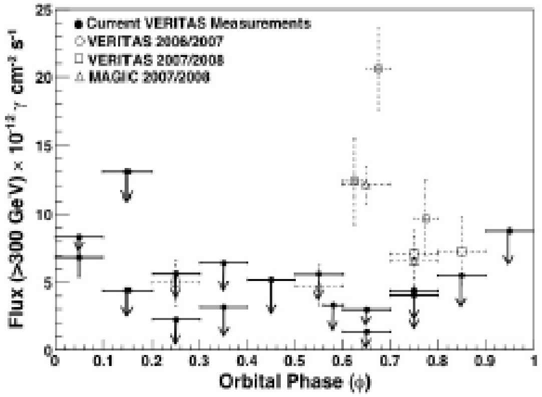
(MVB & Khangulyan 2012)

# LS I +61 303

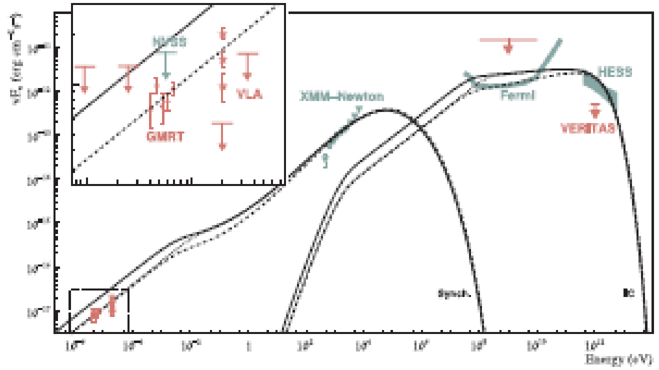


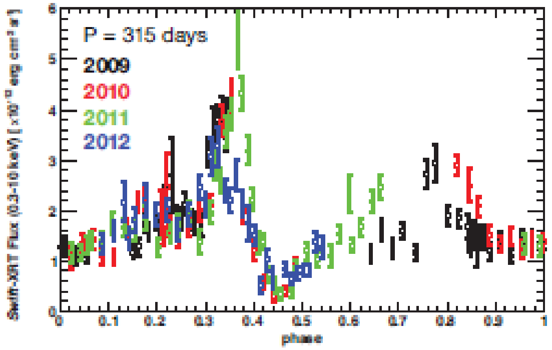



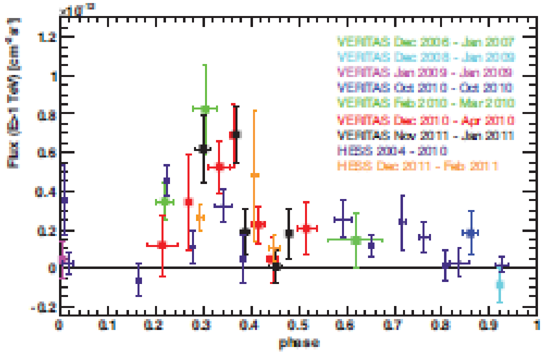




# HESS J0632

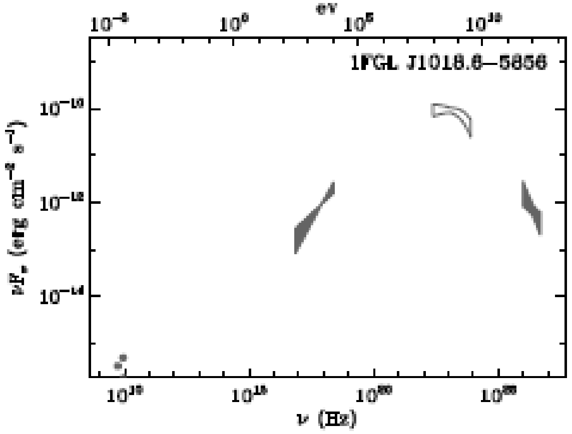


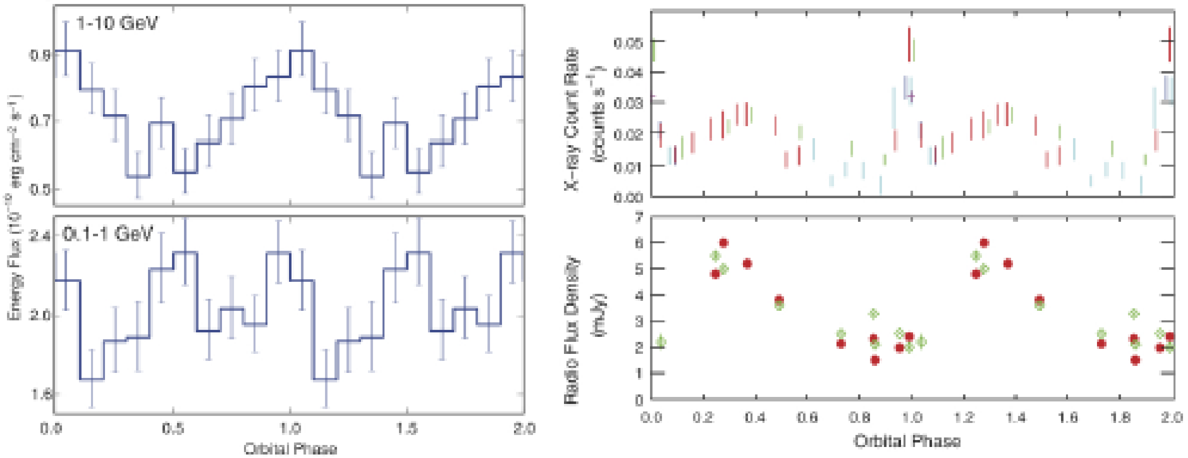



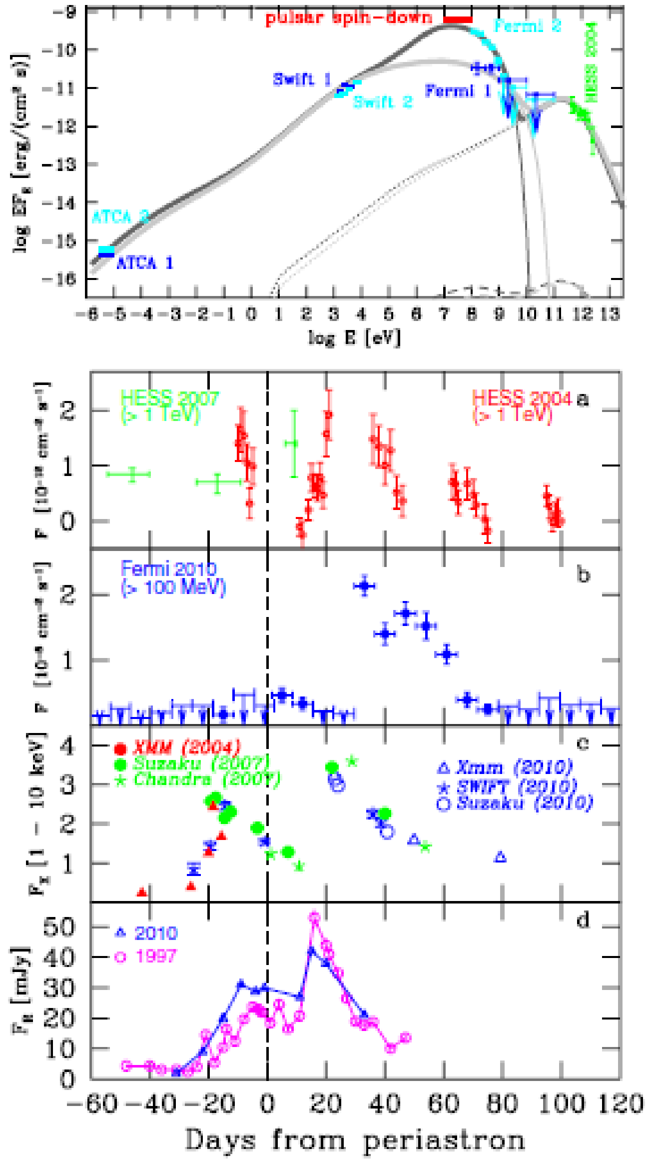



# 1FGL J1018

# PSR 1259

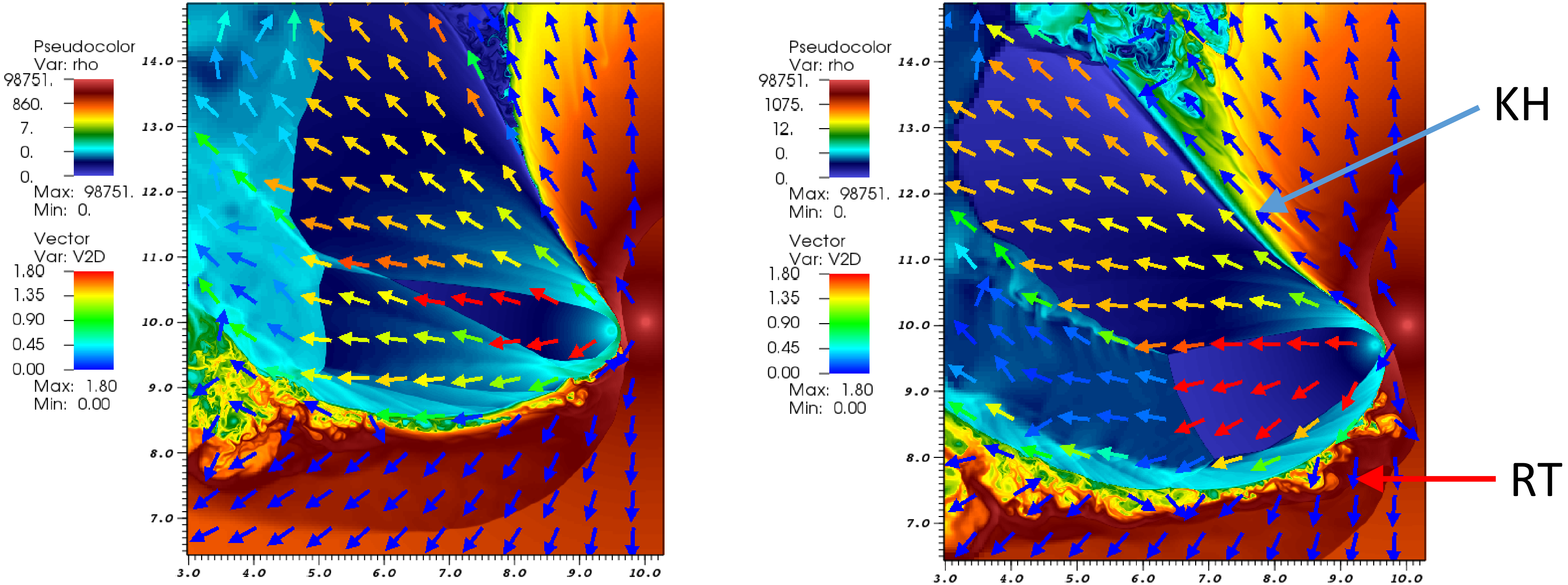


# Effect of eccentric orbit

$$x \sim \frac{3\eta^{1/2} v_w}{2\Omega}$$

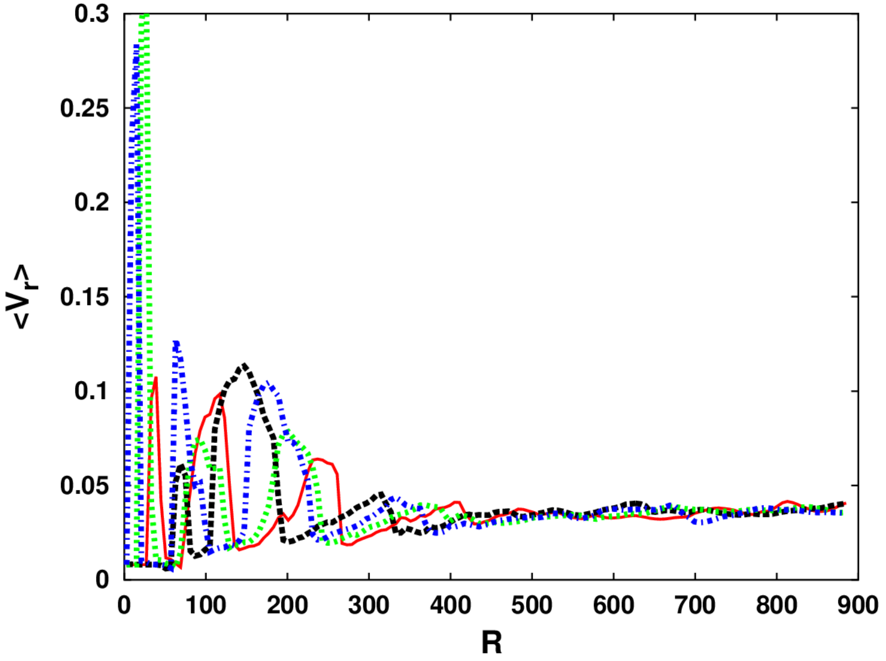


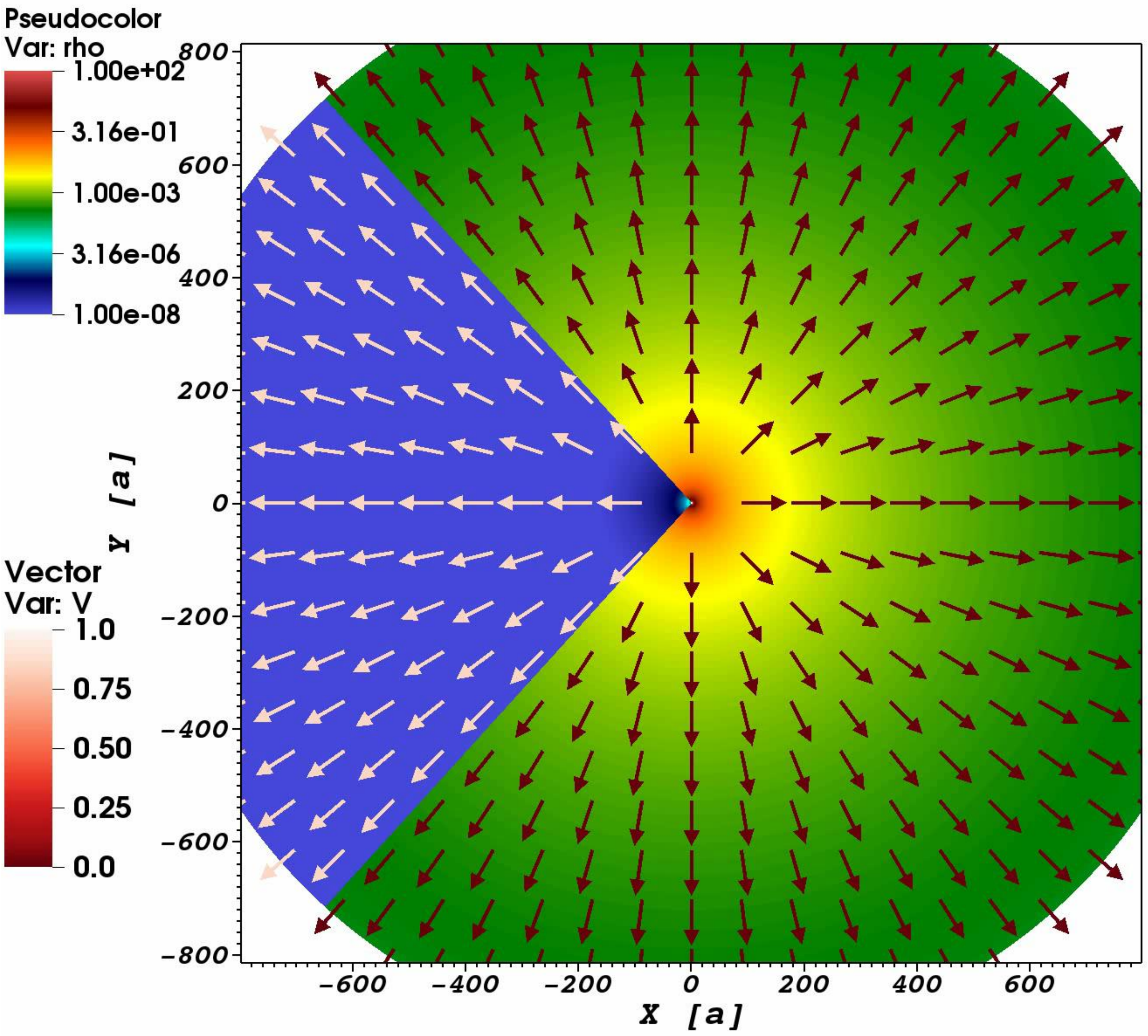
# 3D show time!...

Preliminary

# FGL J1086 & LSI +61  303

- T=16 day
- e=0.0

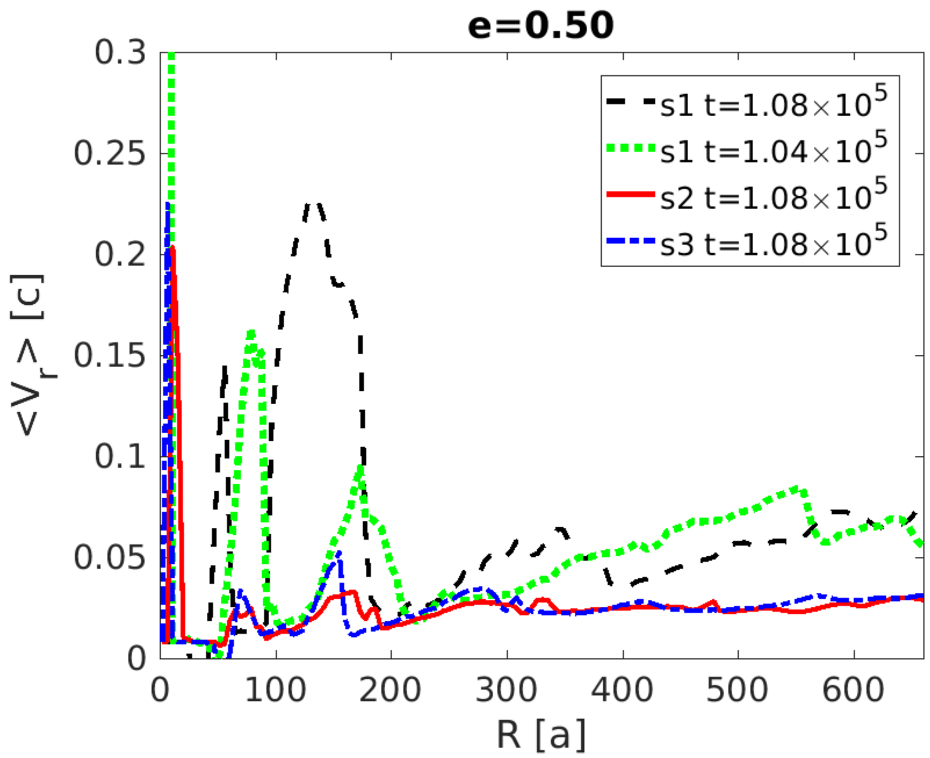


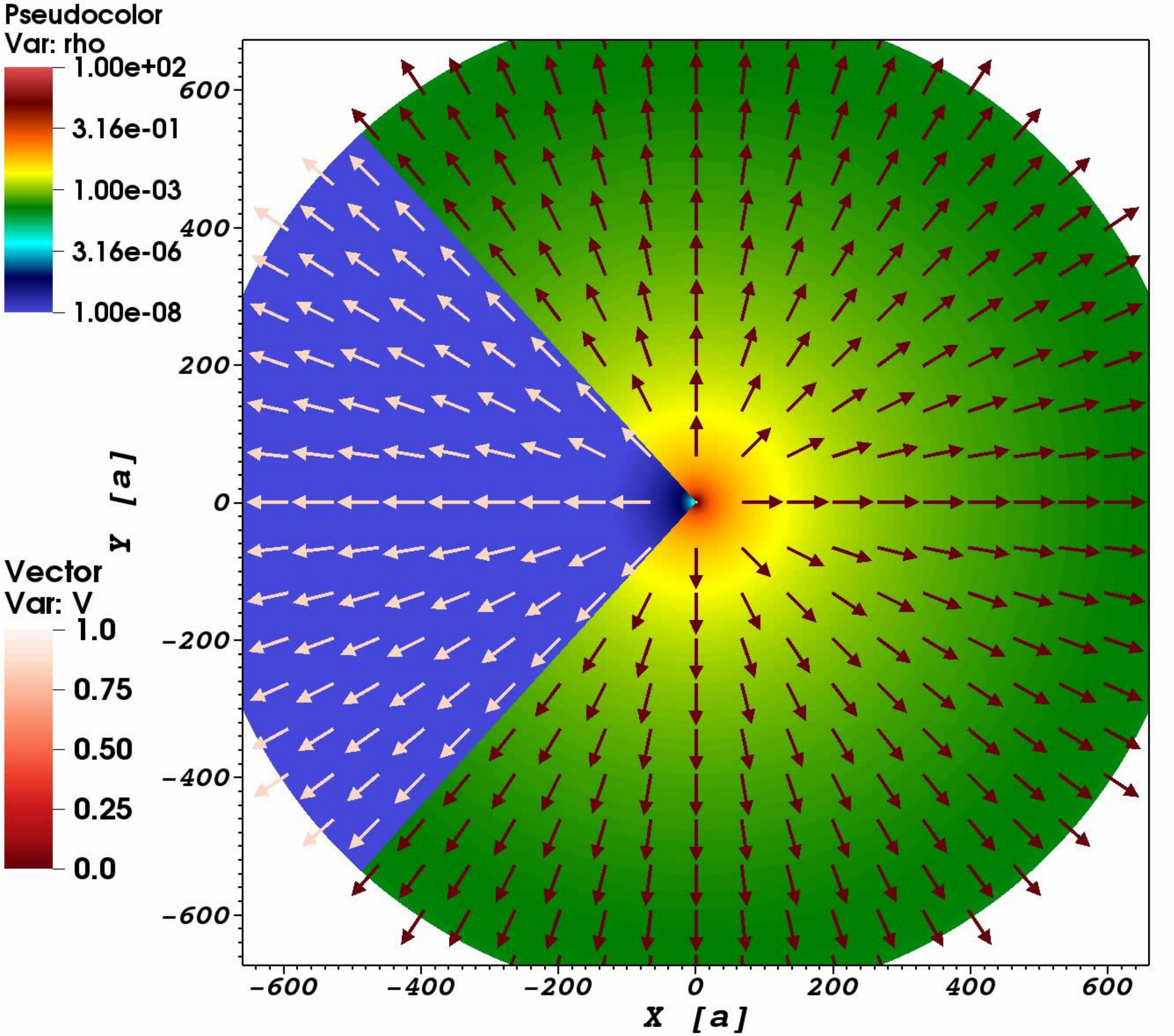



Preliminary

# FGL J1086 & LSI +61  303

- T=16 day
- e=0.5

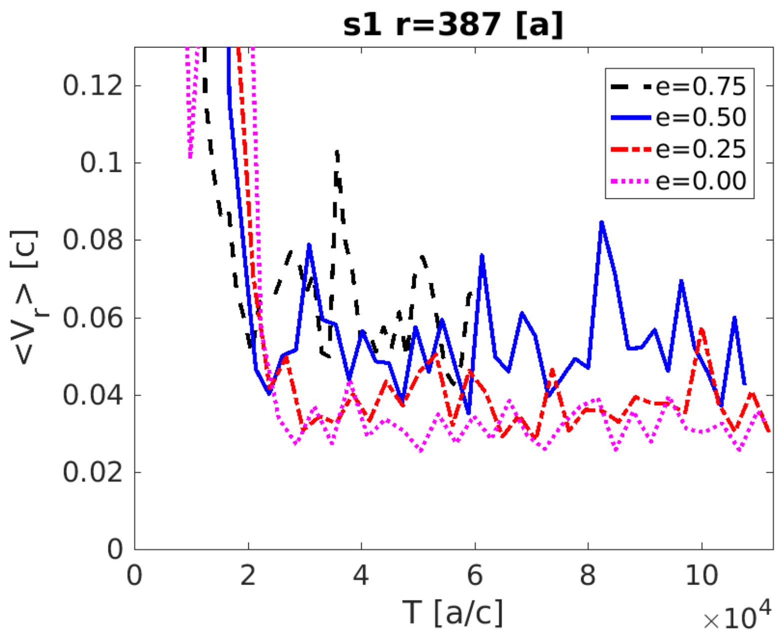


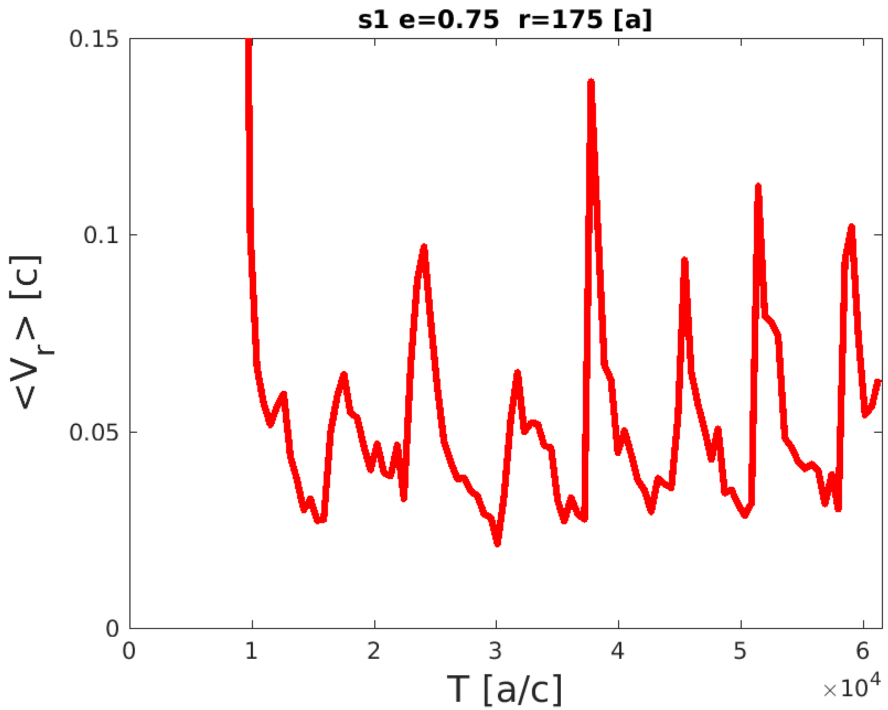



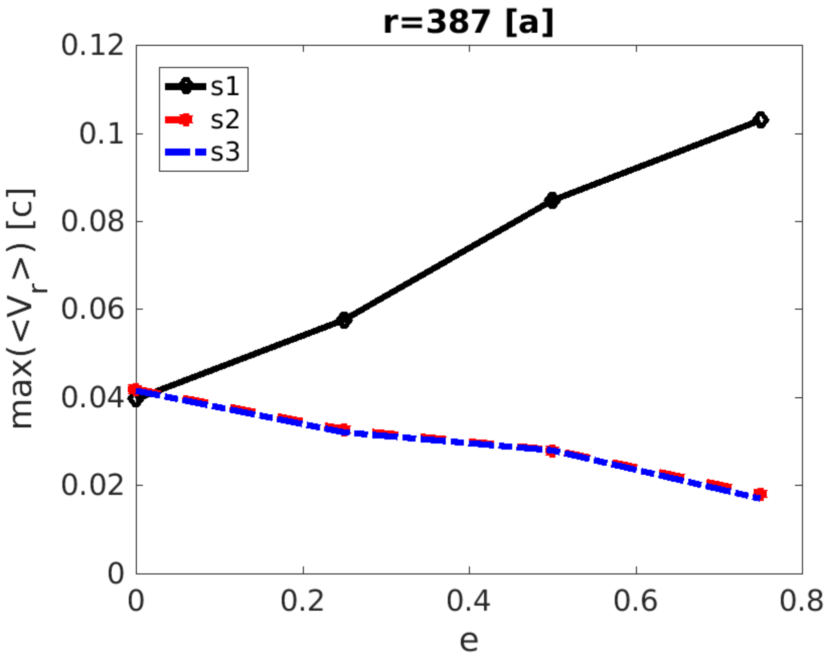

7/5/2017

# FGL J1086 & LSI +61 303

- T=16 day
- e=0.0-0.75



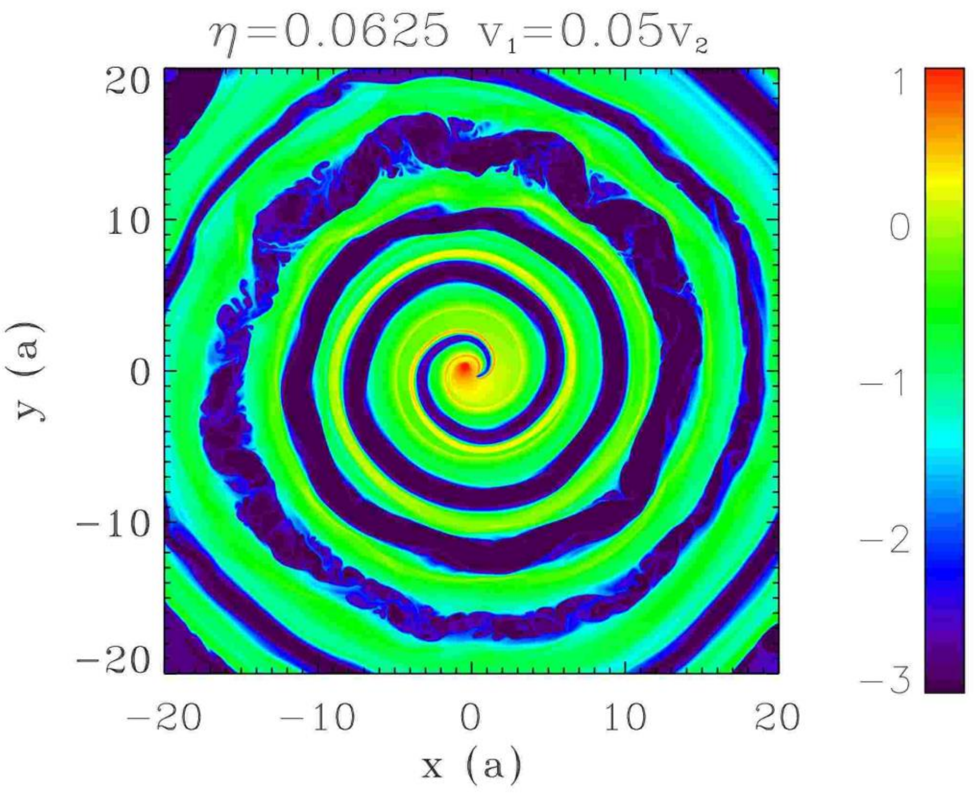



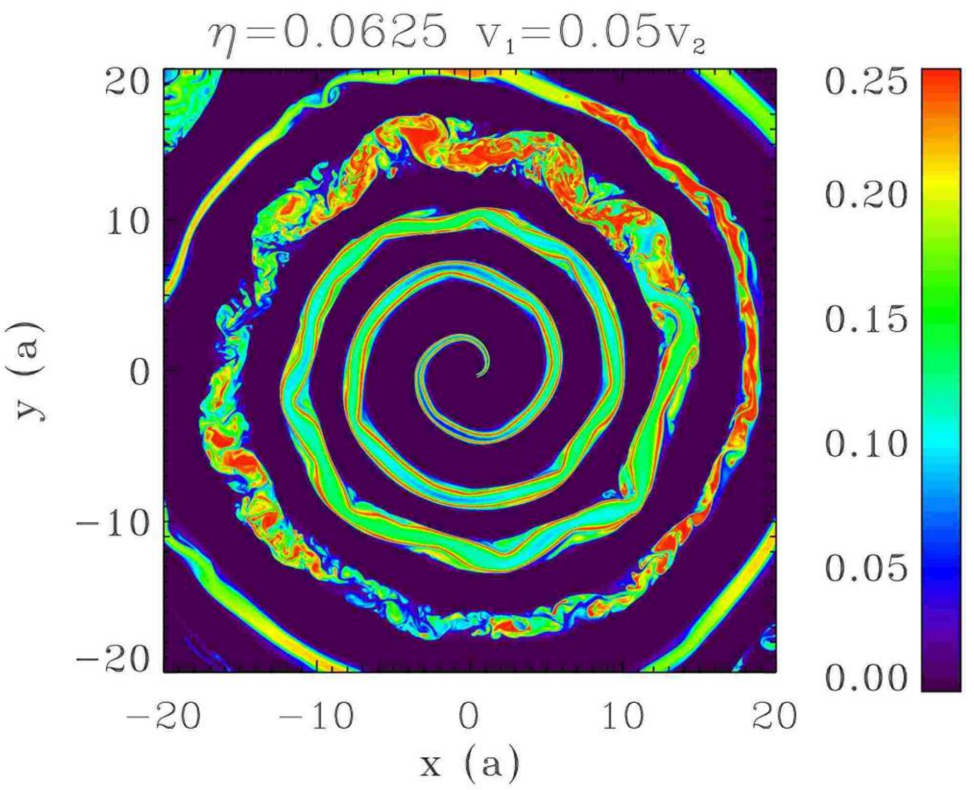



# Density and tracer (Newton HD)

$$\eta = \frac{L_{sd}}{\dot{M} v_w c}$$

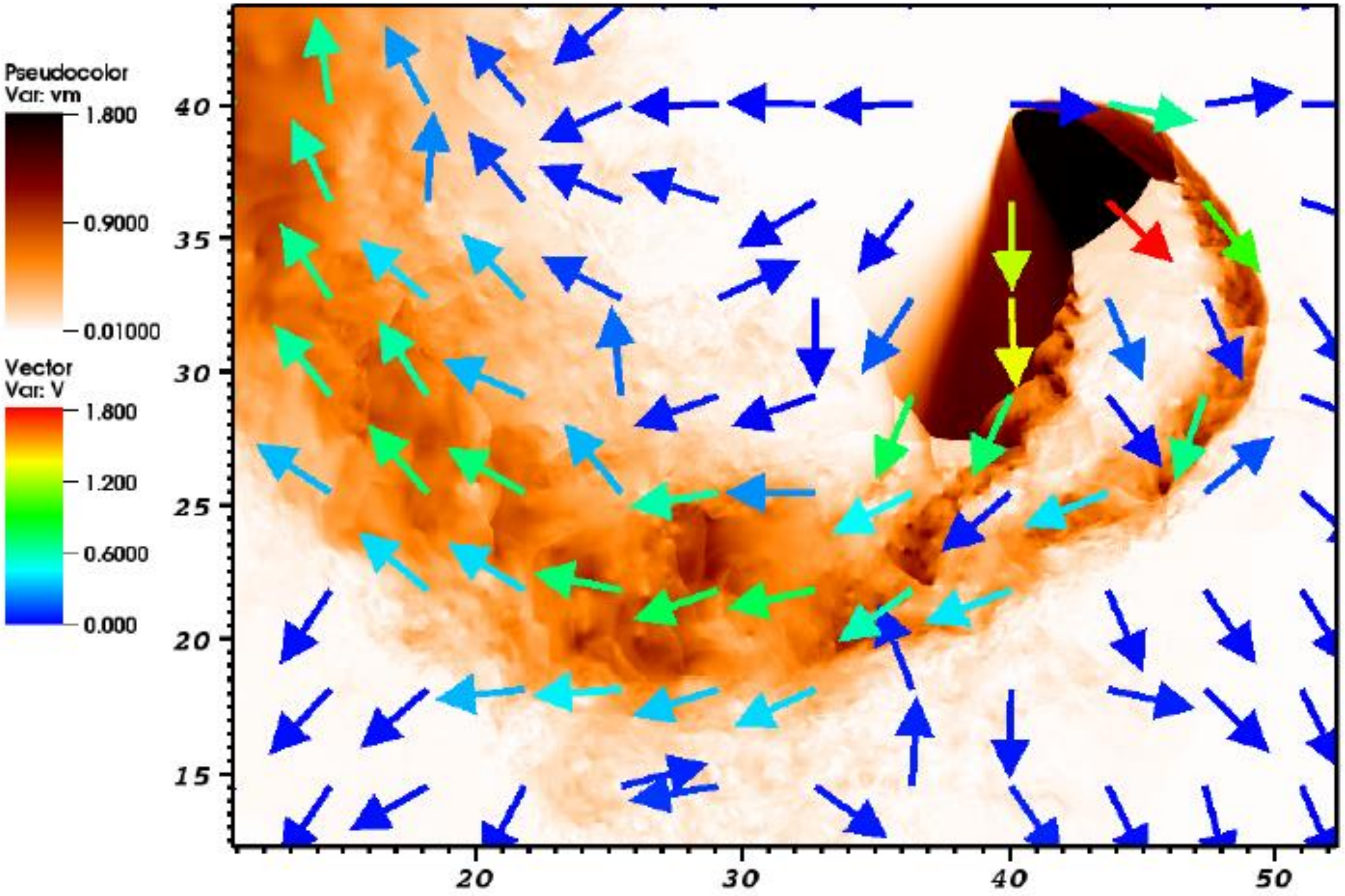
(Lamberts et al. 2012)
Outflow is stable.



# Density $\Gamma = 2$; $\eta = 0.6$

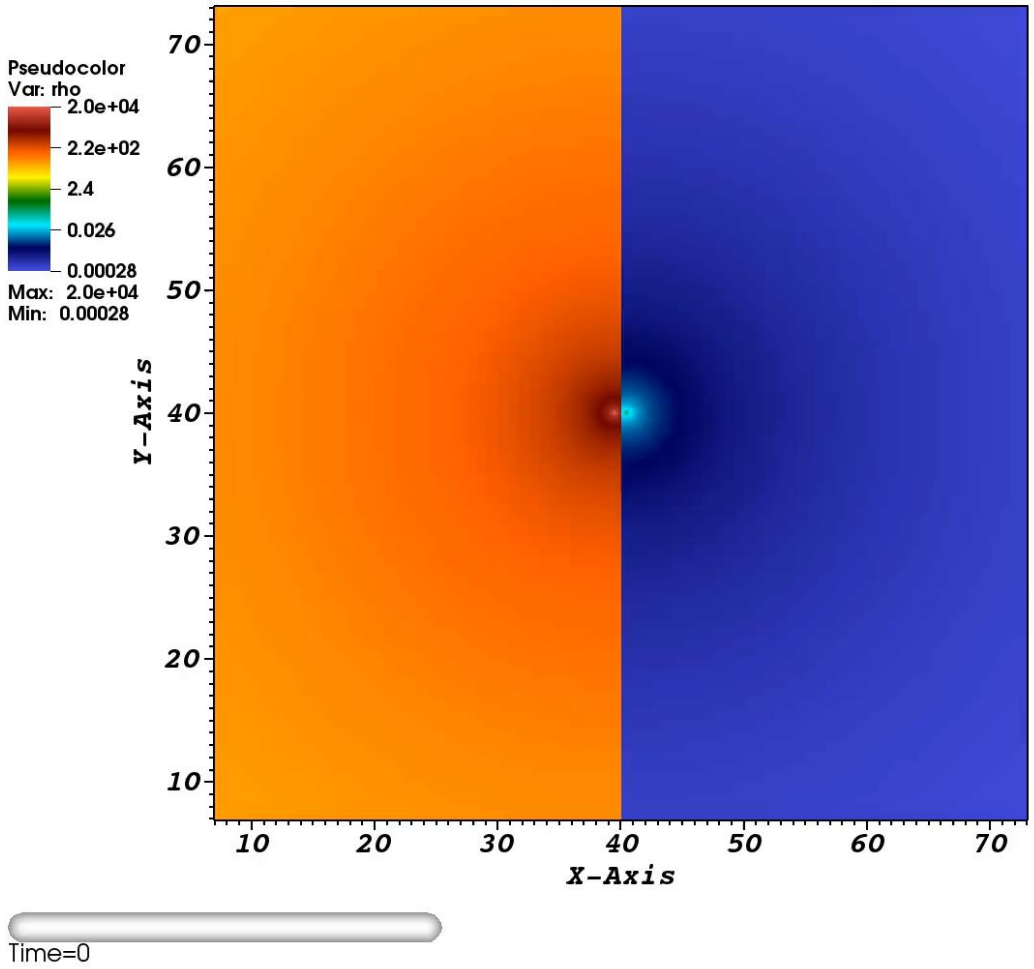
(Bosch-Ramon, MVB, Khangulyan and Perucho 2012) RHD



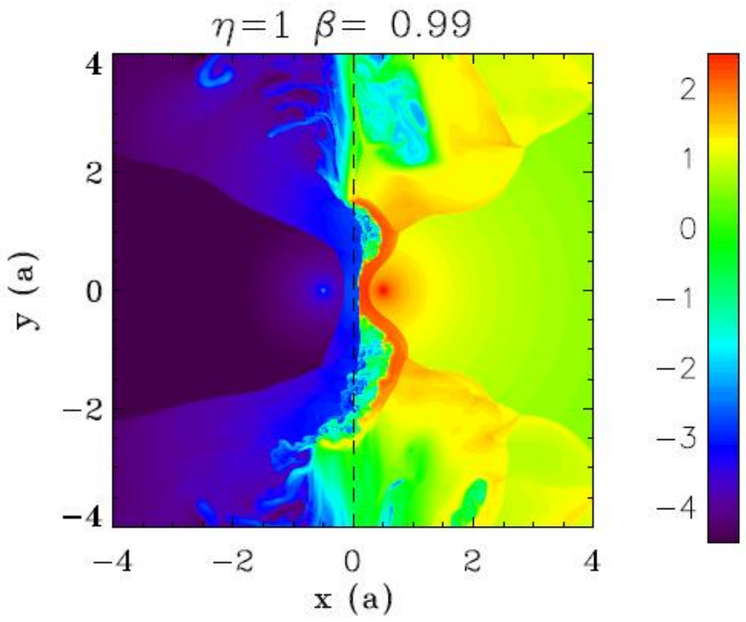
# Density $\Gamma$= 2; $\eta$ = 0.3

$$\eta = \frac{L_{sd}}{\dot{M} v_w c}$$

(Bosch-Ramon, MVB, Khangulyan and Perucho 2012)
2D RHD, PLUTO with AMR Chombo

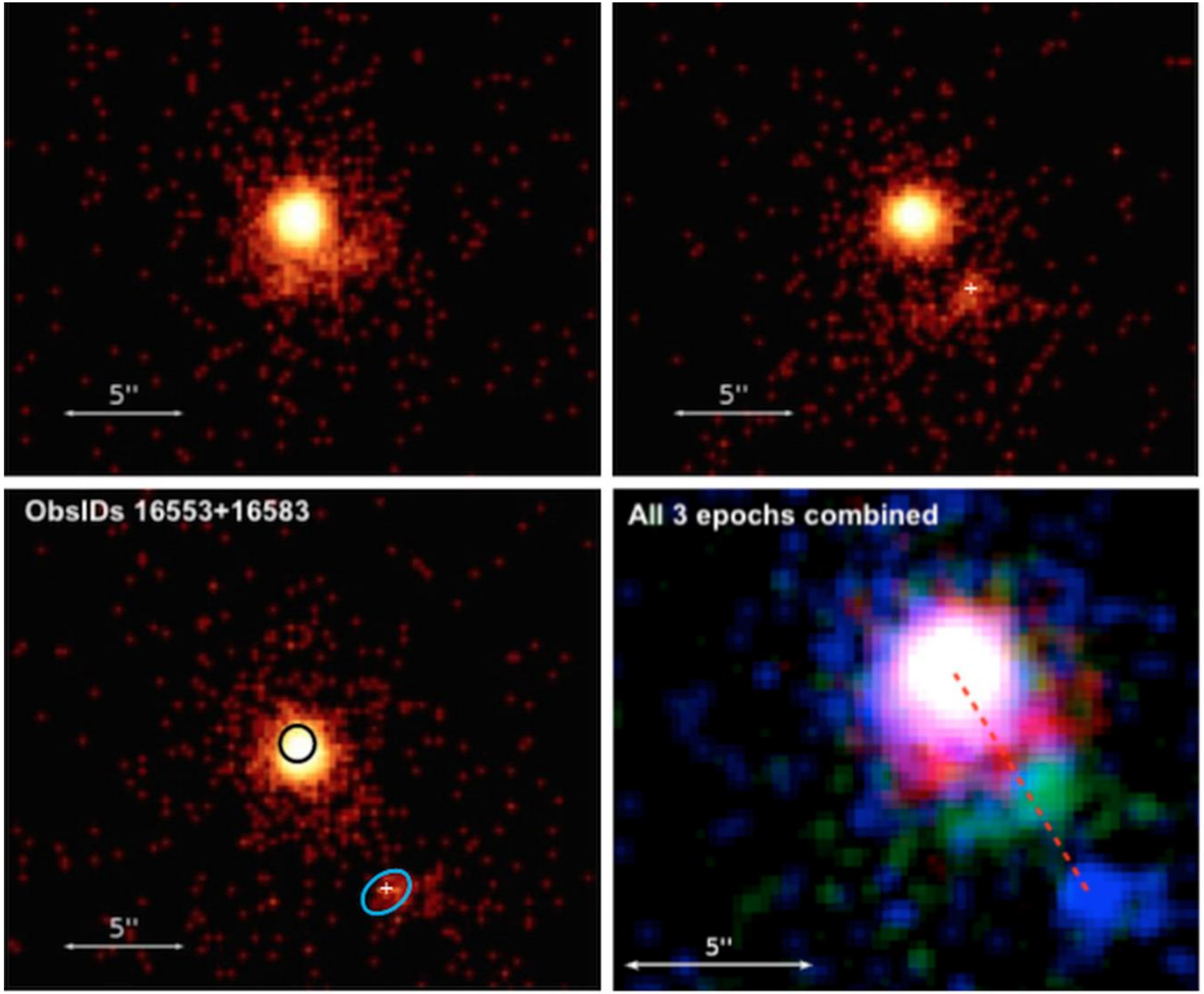



(Lamberts et al. 2013) RHD
Outflow is unstable.

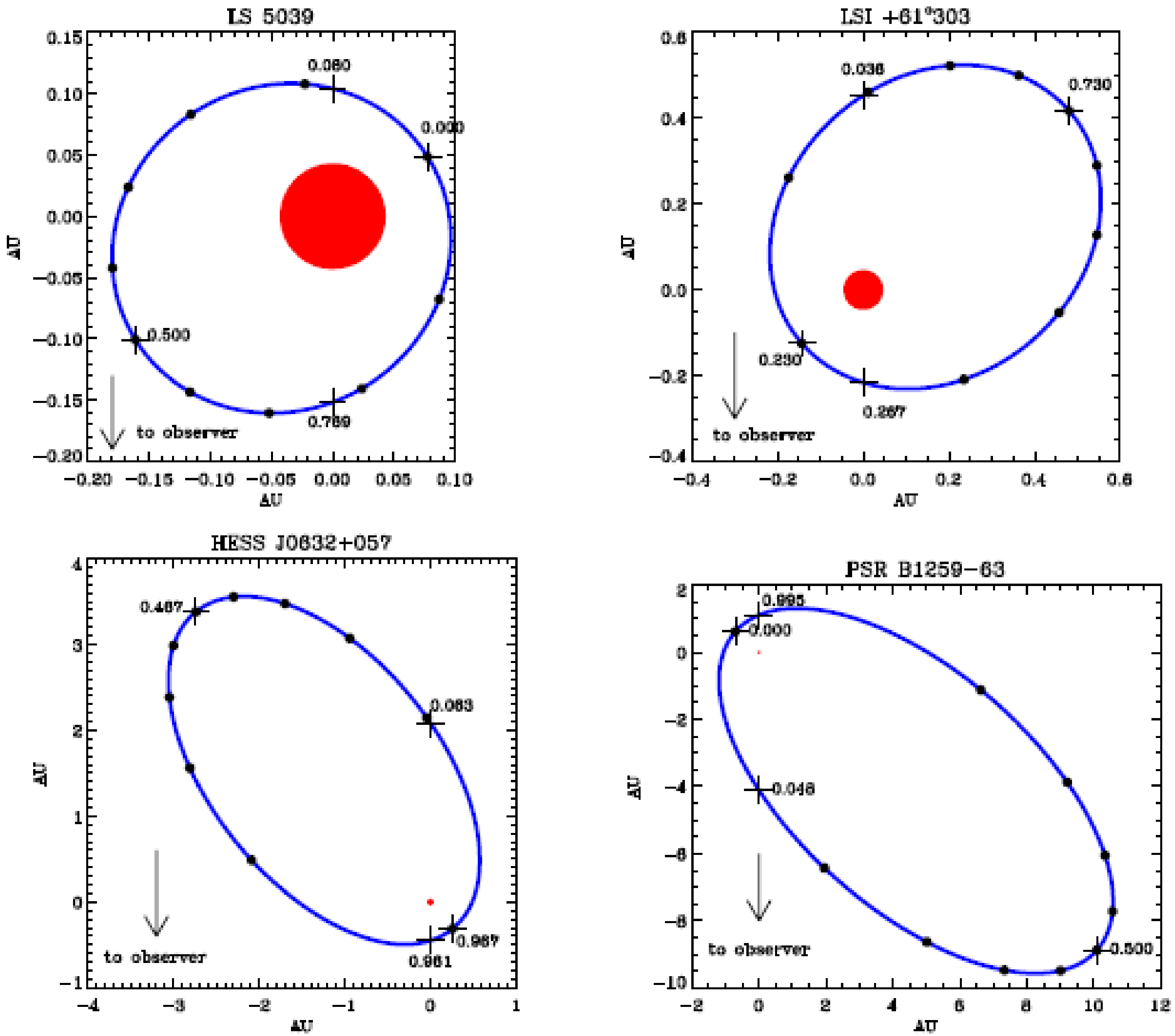


# The origin of the X-ray-emitting object moving away from PSR B1259-63

(Pavlov et al 2015)



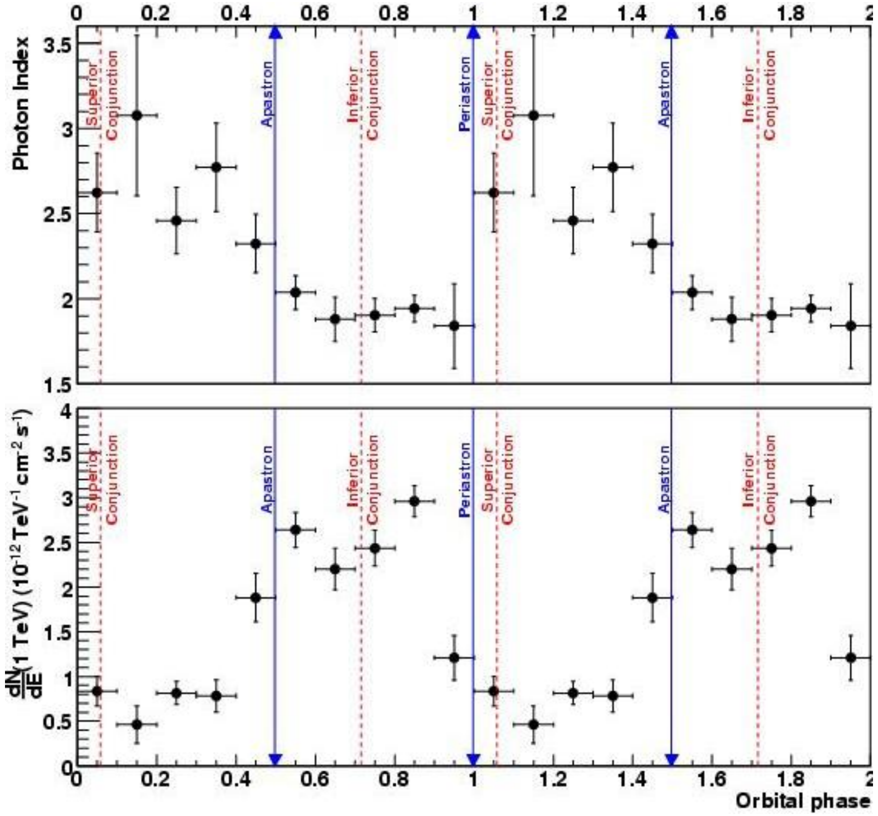
# Binary Systems orbits

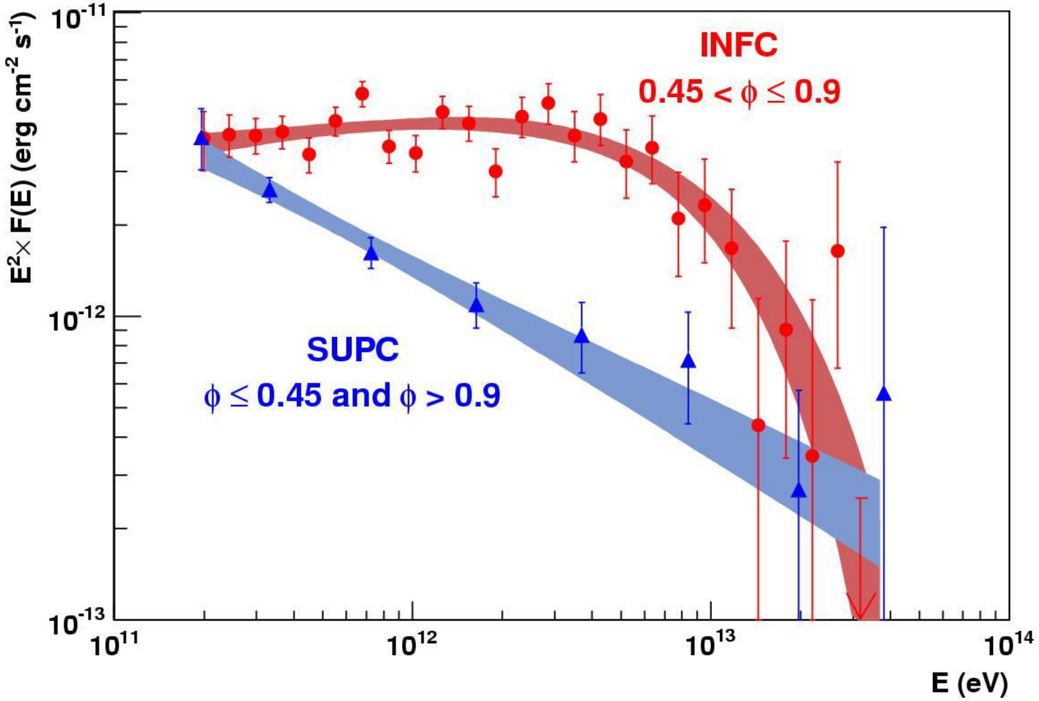


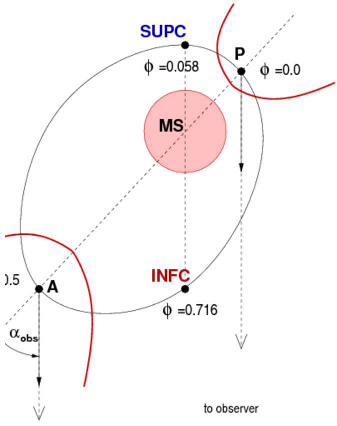

Dubus et al 2013

# H.E.S.S.

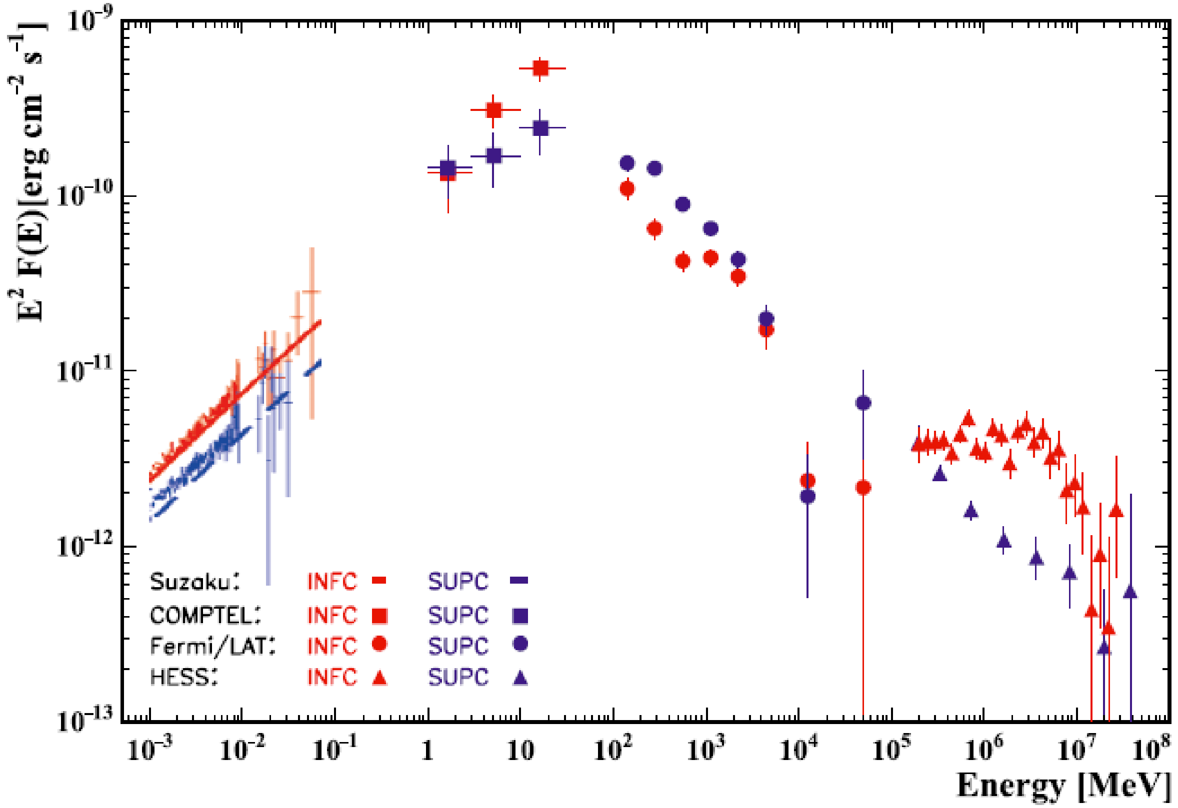
## The best studied system in VHE is LS5039



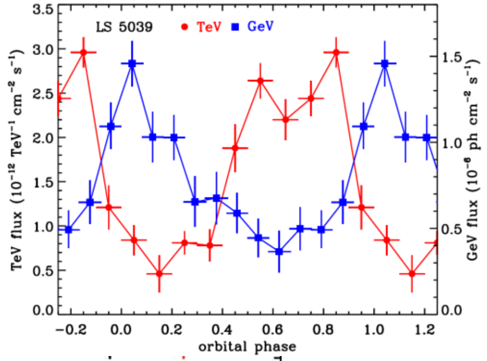



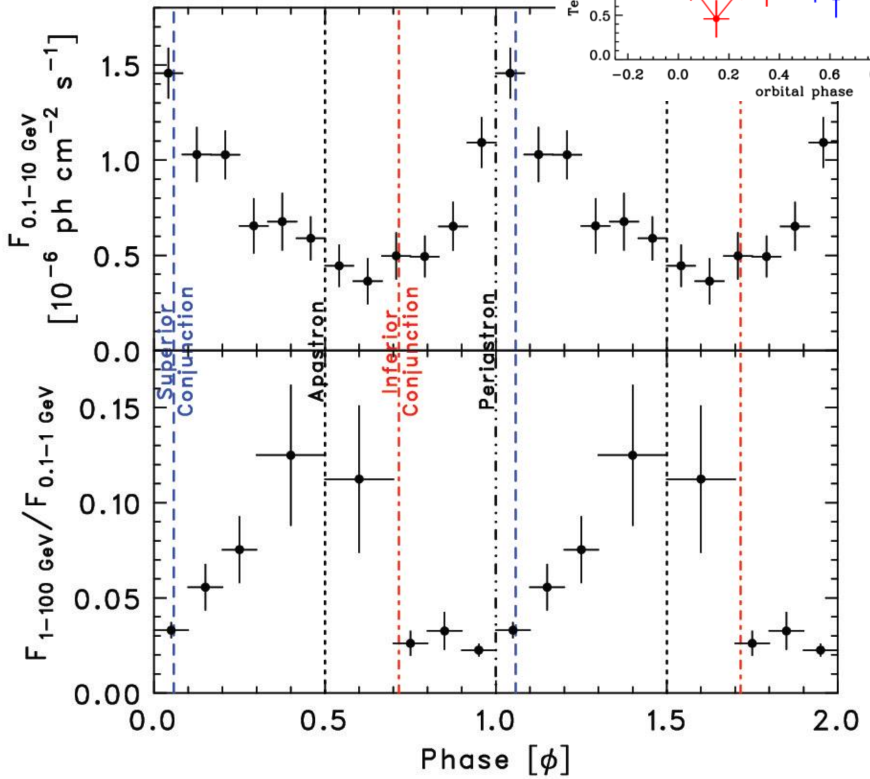
# Fermi Observations of LS 5039




Spectrum with a HE cutoff @ a few GeV

$L_{GeV}=2\times10^{35}\ erg/s$




Lightcurve in GeV has a maximum close to the periastron

# Light curve formation

(Zabalza et al 2013)