

MICROQUASAR JET MODELS

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High Energy Phenomena
in Relativistic Outflows II

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October 26-30, 2009
Buenos Aires, Argentina

What is This Talk About:

- High Energy Phenomena (HEPROII)
- Binary Systems (Microquasar Jet Models)
- Relativistic Outflows (Microquasar Jet Models @ HEPROII)
- Theoretical Modelling and Observation Results interpretation (Microquasar Jet Models)

Modeling of HE Processes in Binary Systems

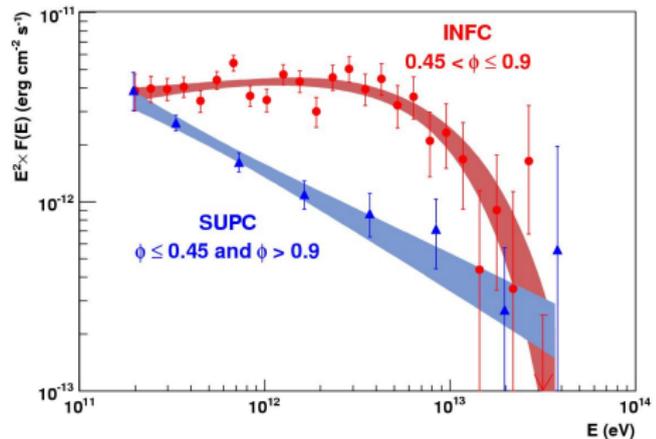
Binary Systems in (V)HE Regime

Gamma-Ray Binary Systems

Object	PSR B1259	LS 5039	LSI+61 303	Cyg X-1
Type	B+Pulsar	O+?	B+?	O+BH
L_* , erg/s	$3 \cdot 10^{37}$	$7 \cdot 10^{38}$	10^{38}	$1.3 \cdot 10^{39}$
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HE Instrument	EGRET	EGRET FERMI	EGRET FERMI	–
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TeV detection	13σ	$\sim 100\sigma$	$> 10\sigma$	4σ
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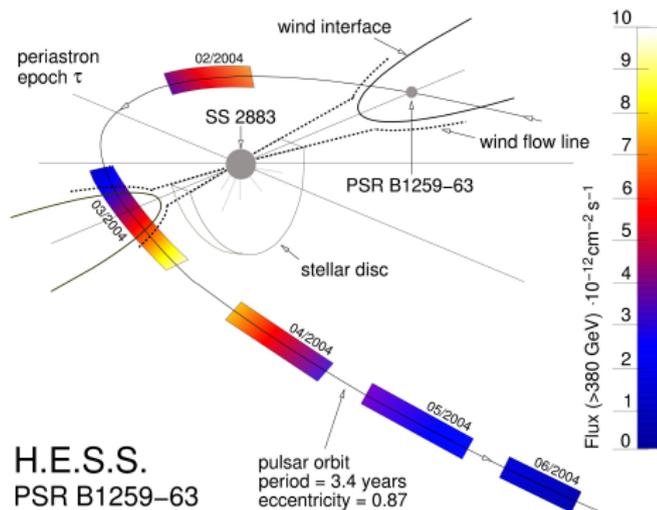
Why are the Binary Systems Important @ VHE Regime?

- Extreme Objects
- Astrophysical Labs
- May allow a deep insight into fundamental physical processes, e.g. PW probing (Ball&Kirk, 2000)



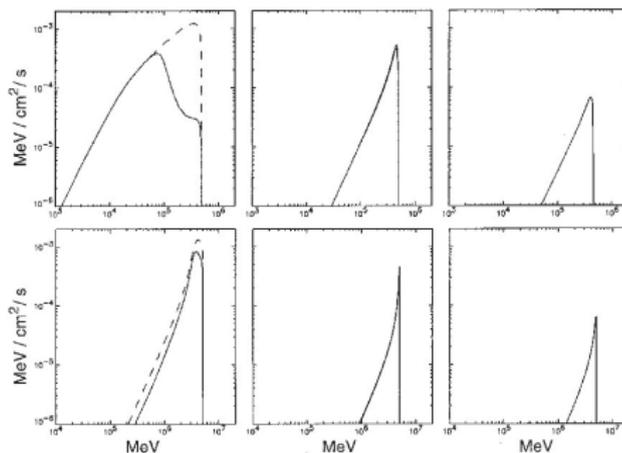
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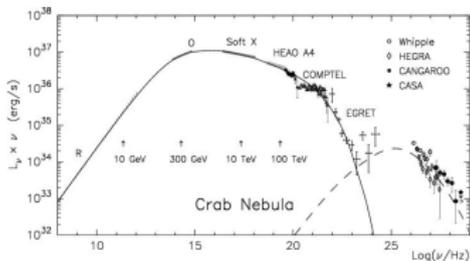


Pulsar Wind Probing

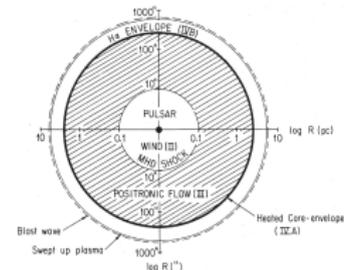
Crab Pulsar



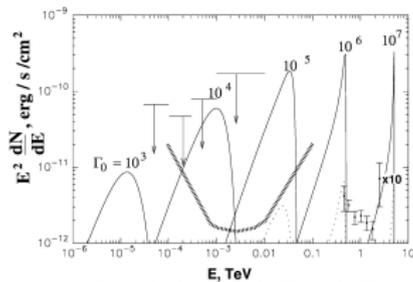
Atoyan&Aharonian, 1998



Kennel&Coronity, 1984



PW should be visible (Ball&Kirk, 2000; Khangulyan et al, 2007)



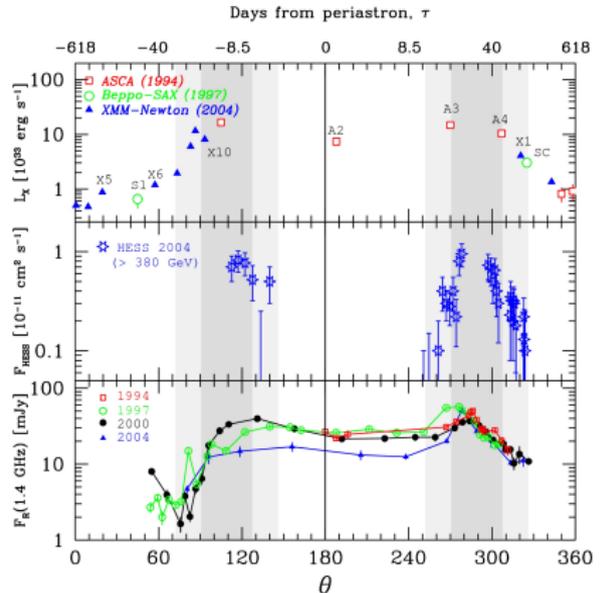
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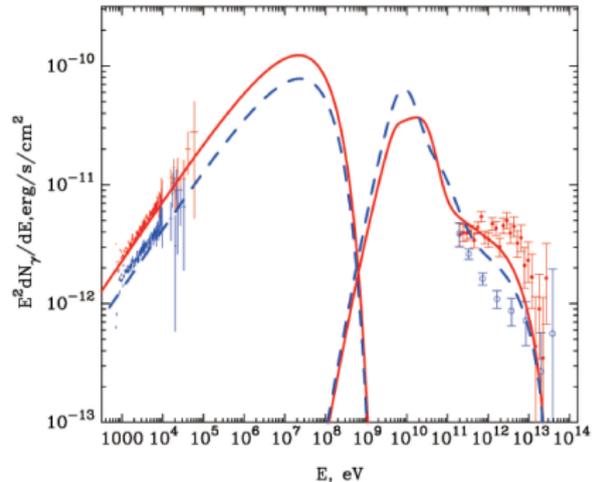
Possible Scenarios

- Hadronic (e.g. Neronov&Chernyakova)
- Leptonic (e.g. Takahashi et al)
- Binary Pulsar (e.g. Dubus et al)
- Microquasars (e.g. Vila&Romero)



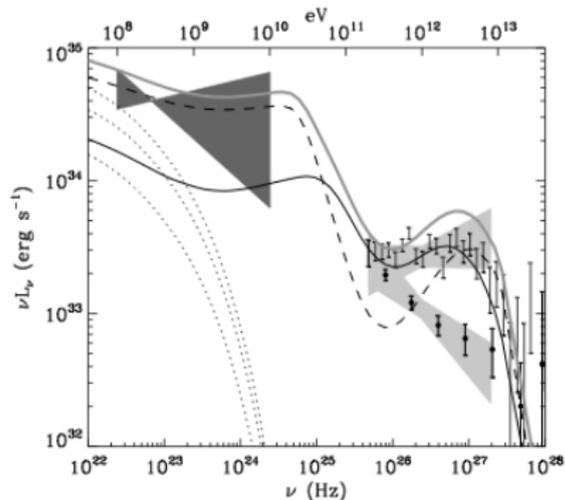
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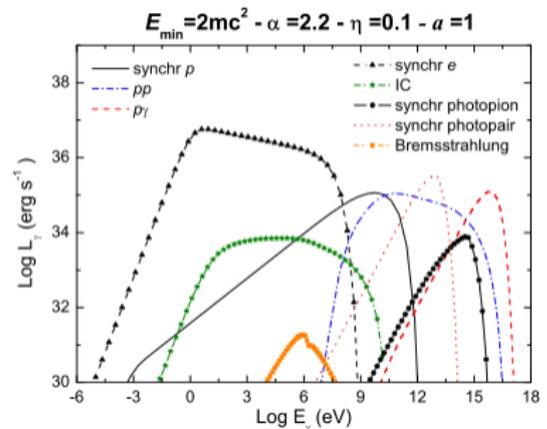
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Radiation Efficiency

- Escape Time: $t_{\text{esc}} = \min(t_{\text{diff}}, t_{\text{ad}})$

$$t_{\text{diff}} = \frac{R^2}{2D} \sim 2 \cdot 10^4 \zeta^{-1} R_{12}^2 B_1 E_1^{-1} \text{ s}, \quad \zeta = \frac{D}{D_{\text{Bohm}}}$$

$$t_{\text{ad}} = \frac{R}{V_{\text{bulk}}} \sim 10^2 R_{12} V_{10}^{-1} \text{ s}$$

- Energy Transfer: $\mu = \frac{E_\gamma}{E_0}$
- Radiation Efficiency: $\kappa = \mu \min(1, t_{\text{esc}}/t_{\text{int}})$

Inverse Compton Scattering

- Cooling Time:

$$t_{\text{ic}} = 40 \left(\frac{L}{10^{38} \text{erg/s}} \right)^{-1} \left(\frac{R}{10^{12} \text{cm}} \right)^2 \left(\frac{T}{3 \cdot 10^4 \text{K}} \right)^{1.7} E_{\text{TeV}}^{0.7} \text{ s}$$

- Energy Transfer:

$$E_{\gamma} = \begin{cases} E_e, & \epsilon E \gg m^2 c^4 \\ \frac{\epsilon E_e^2}{m^2 c^4}, & \epsilon E \ll m^2 c^4 \end{cases}$$

- Radiation Efficiency

$$\kappa \sim 1$$

Proton-proton interaction

- Cooling Time:

$$t_{pp} = 10^6 \left(\frac{n_p}{10^9 \text{cm}^{-3}} \right)^{-1} \text{ s}$$

- Energy Transfer:

$$E_\gamma \sim 0.1 E_p$$

- Radiation Efficiency

$$\kappa = 10^{-3} \frac{t_{esc}}{10^4 \text{s}} \frac{n_p}{10^9 \text{cm}^{-3}}$$

Photo-meson production

- Cooling Time:

$$t_{p\gamma} = 3 \cdot 10^4 \left(\frac{L}{10^{38} \text{erg/s}} \right)^{-1} \left(\frac{R}{10^{12} \text{cm}} \right)^2 \left(\frac{T}{3 \cdot 10^4 \text{K}} \right) \text{s}$$

- Energy Transfer:

$$E_\gamma \sim 0.1 E_p$$

- Radiation Efficiency

$$\kappa = 0.03 \frac{t_{\text{esc}}}{10^4 \text{s}} \frac{L}{10^{38} \text{erg/s}} \left(\frac{R}{10^{12} \text{cm}} \right)^{-2} \left(\frac{T}{3 \cdot 10^4 \text{K}} \right)^{-1}$$

Photo-disintegration (see Bosch-Ramon&Khangulyan, 2008)

- Cooling Time:

$$t_{\text{pd}} \sim 3 \cdot 10^3 \left(\frac{L}{10^{38} \text{erg/s}} \right)^{-1} \left(\frac{T}{3 \cdot 10^4 \text{K}} \right) \left(\frac{R}{10^{12} \text{cm}} \right)^2 \text{ s}$$

- Energy Transfer:

$$E_{\gamma} \sim 0.01 E_{\text{N}}$$

- Radiation Efficiency

$$\kappa = 0.03 \frac{t_{\text{esc}}}{10^4 \text{s}} \frac{L}{10^{38} \text{erg/s}} \left(\frac{R}{10^{12} \text{cm}} \right)^{-2} \left(\frac{T}{3 \cdot 10^4 \text{K}} \right)^{-1}$$

The most Favorable Emission Process in BS

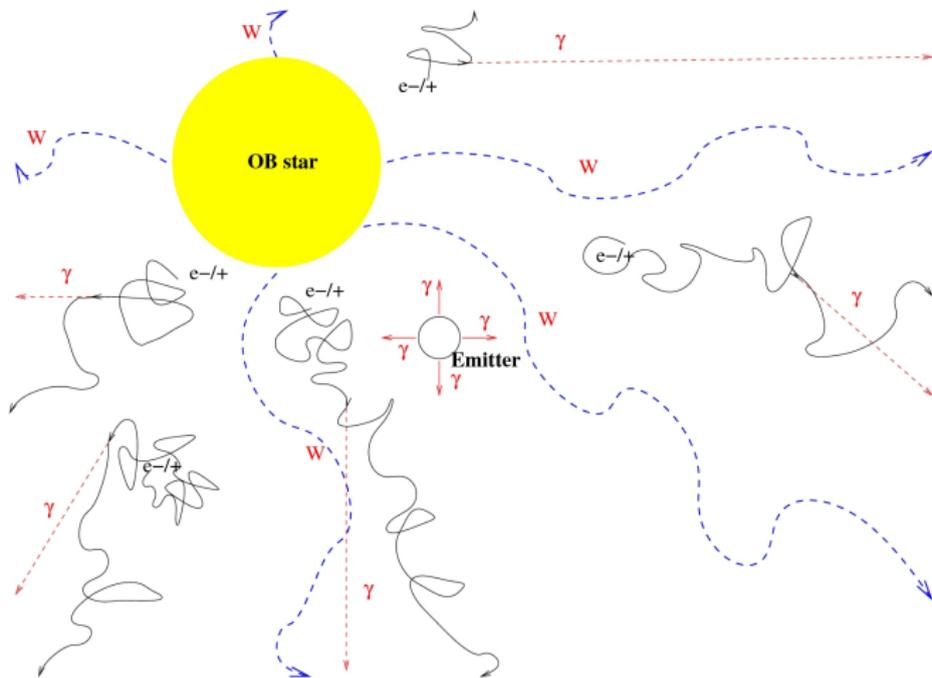
Radiation Processes

Proc.	E_γ/E_0	κ
IC	1	1
pp	0.1	$10^{-3} \frac{t_{\text{esc}}}{10^4 \text{s}} \frac{n_p}{10^9 \text{cm}^{-3}}$
p γ	0.1	$0.03 \frac{t_{\text{esc}}}{10^4 \text{s}} \frac{L}{10^{38} \text{erg/s}} \left(\frac{R}{10^{12} \text{cm}}\right)^{-2} \left(\frac{T}{3 \cdot 10^4 \text{K}}\right)^{-1}$
Photo-des.	0.01	$0.03 \frac{t_{\text{esc}}}{10^4 \text{s}} \frac{L}{10^{38} \text{erg/s}} \left(\frac{R}{10^{12} \text{cm}}\right)^{-2} \left(\frac{T}{3 \cdot 10^4 \text{K}}\right)^{-1}$

IC as a Primary Emission Mechanism

- Optical Star Photon Field is perfect Target
 - All over the System
 - Fast cooling
- “Small” energy of parent Leptons $E_\gamma \sim E_e$
 - Easier to accelerate
 - Easier to confine

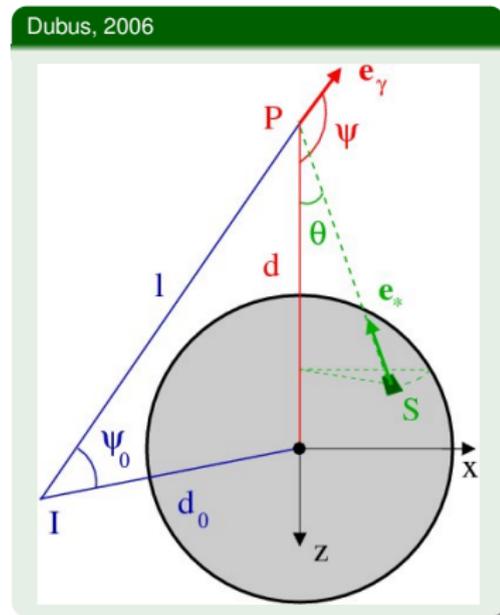
Absorption in BS



from Bosch-Ramon et al, 2008

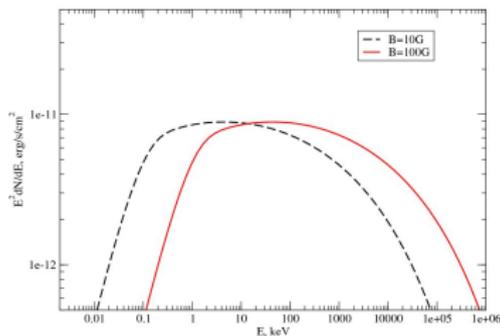
Absorption in BS

- Moskalenko&Karakula, 1994
 - Emitter located in the orbital plane
- Böttcher&Dermer, 2005
 - Emitter located in the jet
- Dubus, 2006
 - Emitter located in the orbital plane
 - Finite Size of the star

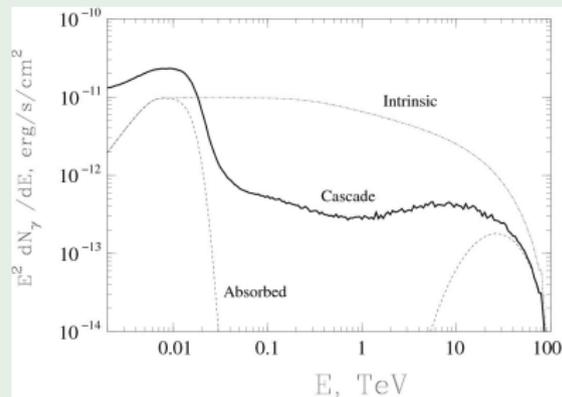


Radiation of Secondary

Strong Magnetic Field



Weak Magnetic Field



Calculations for LS 5039 from Khangulyan et al, 2008

Cascading (Khangulyan et al, 2008)

- K-N regime $E_e \gg \frac{m^2 c^4}{\epsilon_{\text{ph}}} = 30 \left(\frac{\epsilon_{\text{ph}}}{10 \text{eV}} \right)^{-1} \text{ GeV}$
- $t_{\text{IC}} < t_{\text{syn}}$

$$E_e < 60 \left(\frac{W_{\text{pf}}}{10 W_{\text{mf}}} \right)^{0.6} \text{ GeV} = 60 \left(\frac{B_{\text{wind}} R}{100 \text{G} R_{\text{surf}}} \right)^{-1.2} \text{ GeV}$$

- $B_{\text{surf}} = 200 \text{ G} - 1 \text{ kG}$ (Usov & Melrose (1992), Donati et al. (2002))
- For $B_{\text{wind}} \sim 10 \left(\frac{R}{R_{\text{surf}}} \right)^{-1} \text{ G} \rightarrow$ **NO CASCADING** in TeV band
- For $B_{\text{wind}} \sim 100 \left(\frac{R}{R_{\text{surf}}} \right)^{-3} \text{ G} \rightarrow$ **NO CASCADING** in TeV band

see the talk by Valentí Bosch-Ramon

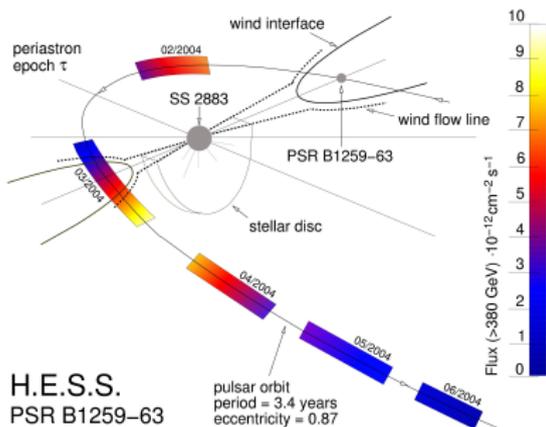
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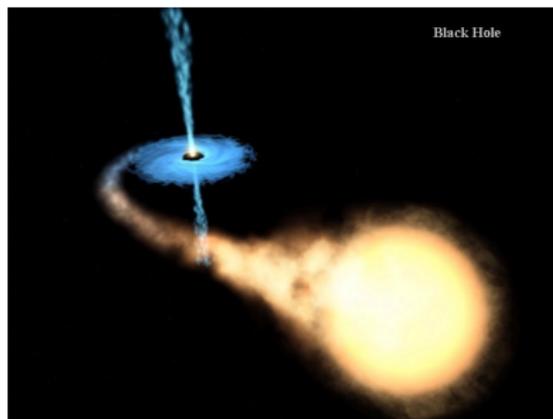
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Binary Pulsar



Microquasar



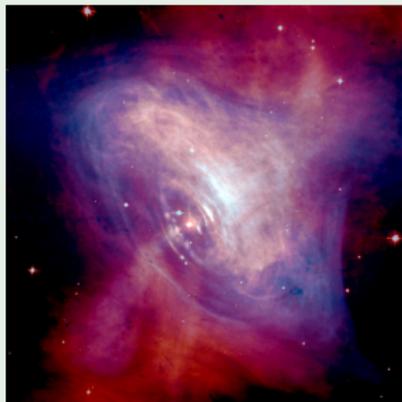
Relativistic Pulsar/Non-relativistic Stellar Wind Colliding System

It means

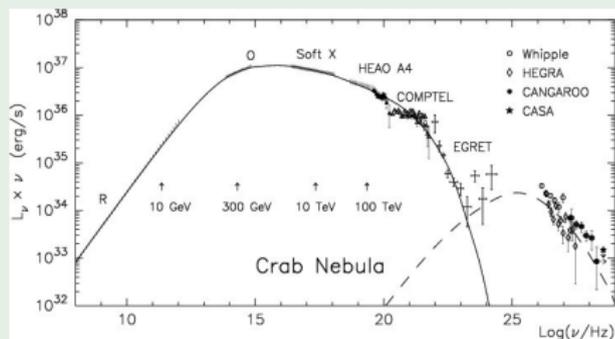
- **NOT** like PSR J0737-3039
 - Double Pulsar: two pulsar system
- **NOT** like IGR J17252-3616
 - Pulsar+Optical star system with accretion on the pulsar
- **BUT** PSR 1259 or PSR J0045
 - $P \sim 4$ yr; $a \sim 10^{13}$ cm

Compactified PWN

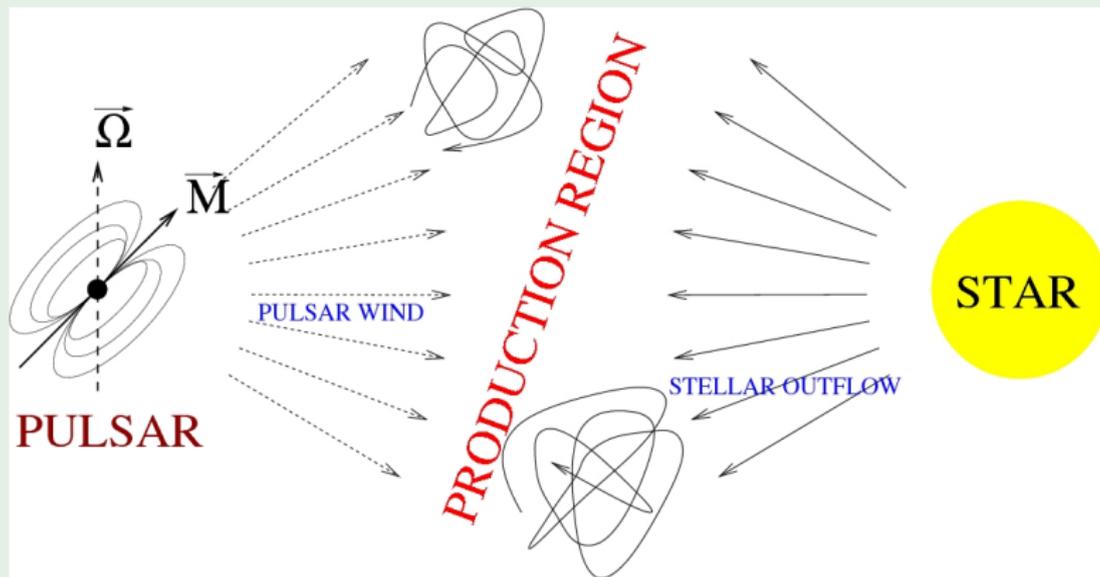
Crab Nebula



Aharonian & Atoyan, 1998



Physical scenario for Binary Pulsars



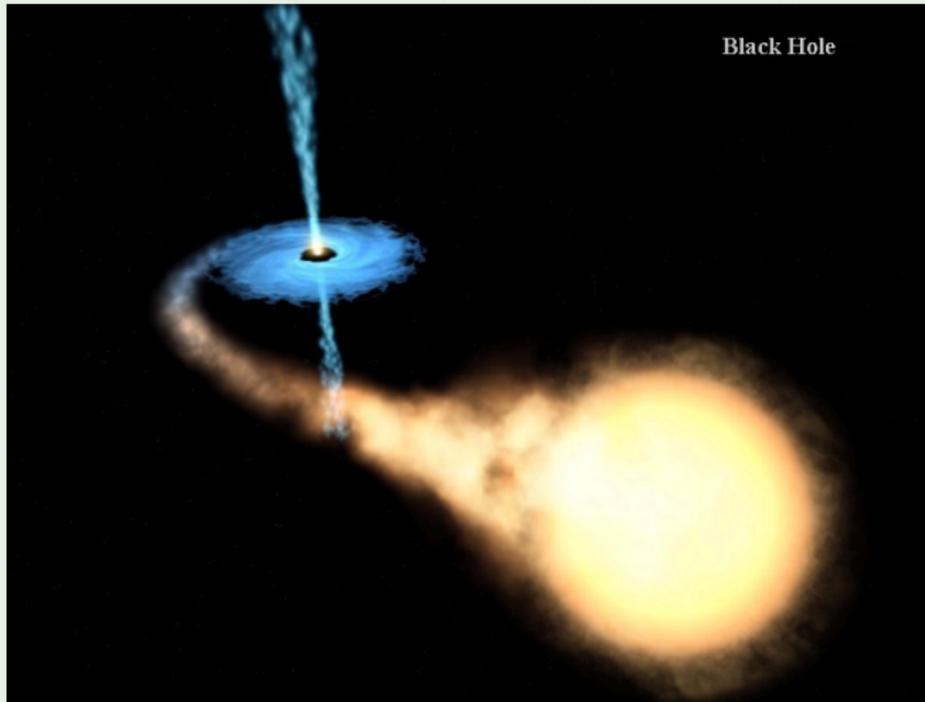
Microquasar

A microquasar is simply a Radio Emitting X-ray Binary displaying relativistic radio jets that can be imaged at a variety of angular scales using different interferometers
(M. Ribó, astro-ph/0402134)

It means

- **X-ray Binary:** Powered by accretion
- **Radio Emitting:** Non-thermal population of particles
- **Radio Jets:** Jets are sites of particle acceleration

Physical scenario for Microquasars



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What is the compact object?

Conclusive tests:

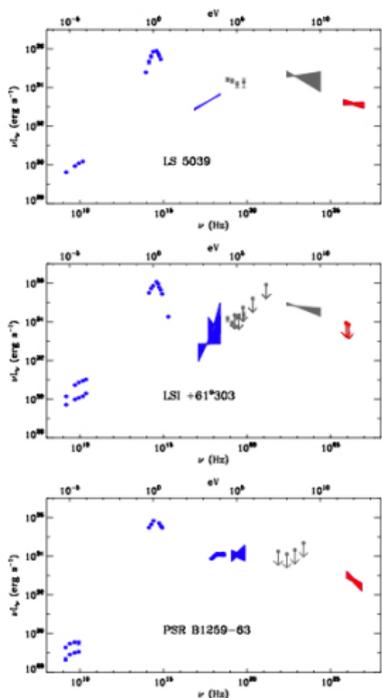
- Mass of the CO
- Pulsed emission
- Thermal emission of the accretion disk
- Non-thermal radiation (?)

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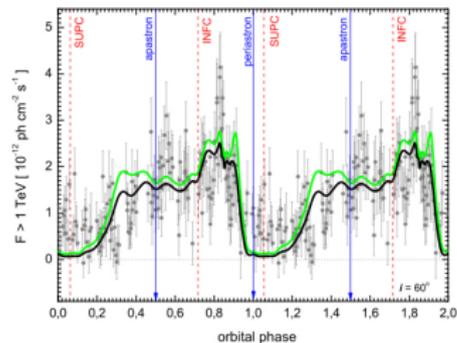
Are they conclusive?

- Mass of the CO
 - Require precise spectrometrical observations...
- Pulsed emission
 - May be absorbed in the dense stellar wind
- Thermal emission of the accreting disk
 - At which level?
- Non-thermal radiation (?)
 - Many impacting factors...

Are non-thermal properties conclusive?



from Dubus, 2006

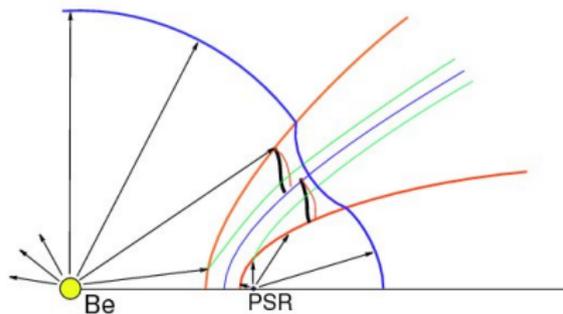


from Sierpowska-Bartosik & Torres, 2008

Binary Pulsar: HD model (Bogovalov et al, 2008)

Basic Assumptions

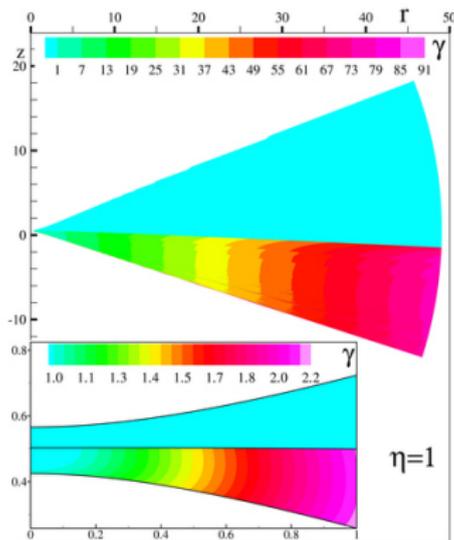
- HD
- Two radial winds
- Pulsar wind is ultrarelativistic
- Stellar wind is nonrelativistic
- Steady state
- Two dimensional



Binary Pulsars: HD results (Bogovalov et al, 2008)

Main Results

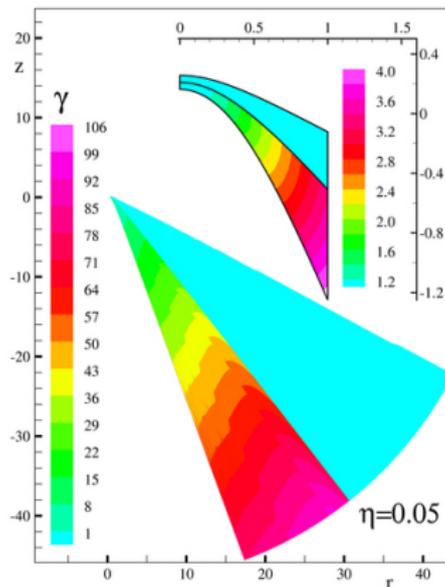
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- Unclosed structure of shock waves ($\eta > 10^{-2}$)
- Significant acceleration even if η is very small



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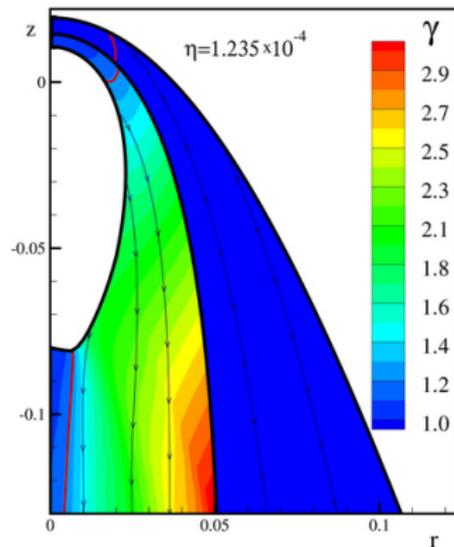
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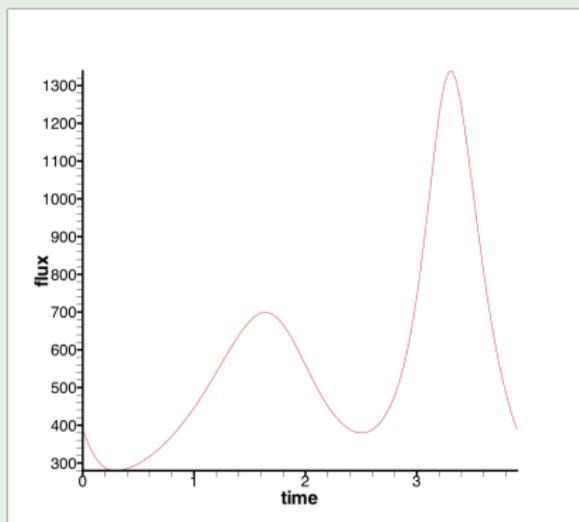
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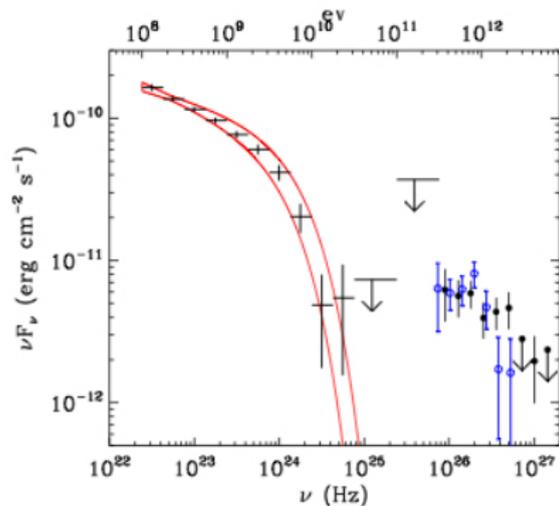


X-Ray Flux Orbital Modulation due to HD

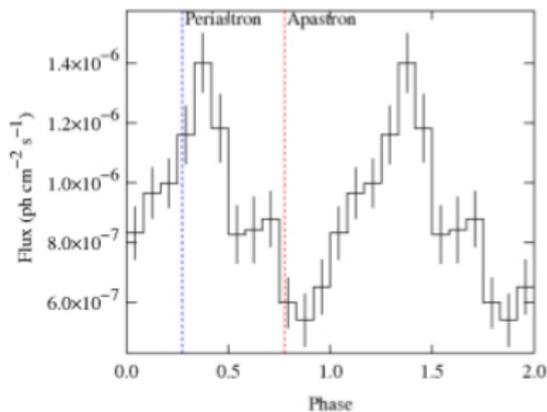


Bogovalov et al (in preparation)

Fermi Observations of LS I +61 303



Spectrum with a HE cutoff @
6GeV



Lightcurve with a maximum
close to the periastron

Summary

- Leptons are more favorable emission process in binary systems
- Absorption leads not only to the attenuation of primary gamma-rays, but also create an addition emission component (see the talk by Valentí Bosch-Ramon)
- HD modeling of binary systems is very important (see as well the talk by Manel Perucho)
- Binary pulsar and microquasar scenarios may share much more in common, e.g. relativistic outflows
- Fermi has already provided puzzling results from binary systems