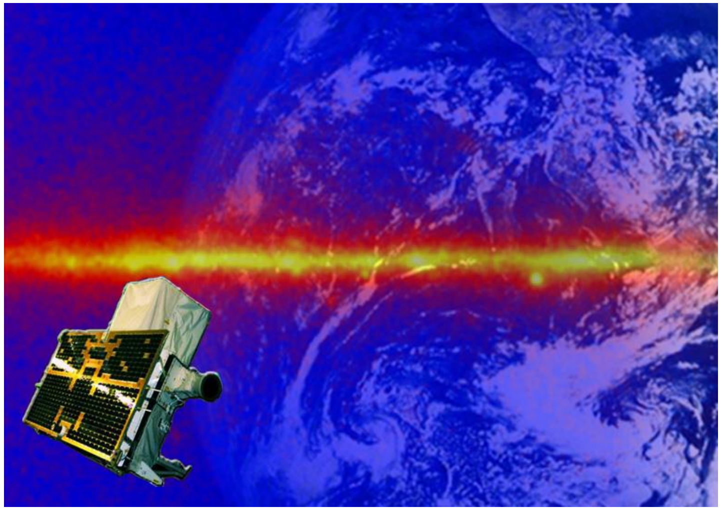
GAMMA-RAY EMISSION FROM BINARY SYSTEMS

13th AGILE Science Workshop

"AGILE: 8 and counting"

May 25-26, 2015

ASI, Rome



Josep M. Paredes

UNIVERSITAT DE BARCELONA

Institut de Ciències del Cosmos

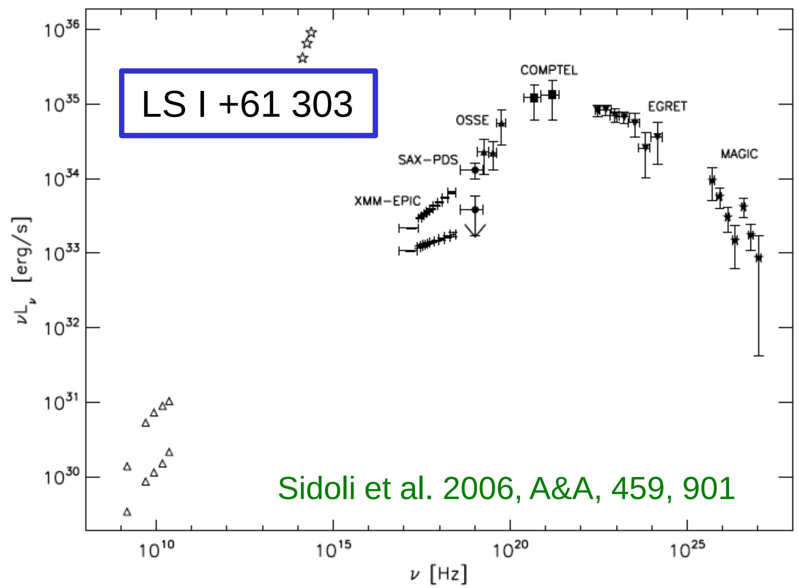
EXCELENCIA MARÍA DE MAEZTU

Binary systems with HE and/or VHE gamma-ray emission

- **Gamma-ray binaries:** Young non-accreting pulsars + massive star

  - SED peak at MeV-GeV
  - PSR B1259-63, detected at HE by *Fermi*-LAT and at VHE by H.E.S.S.

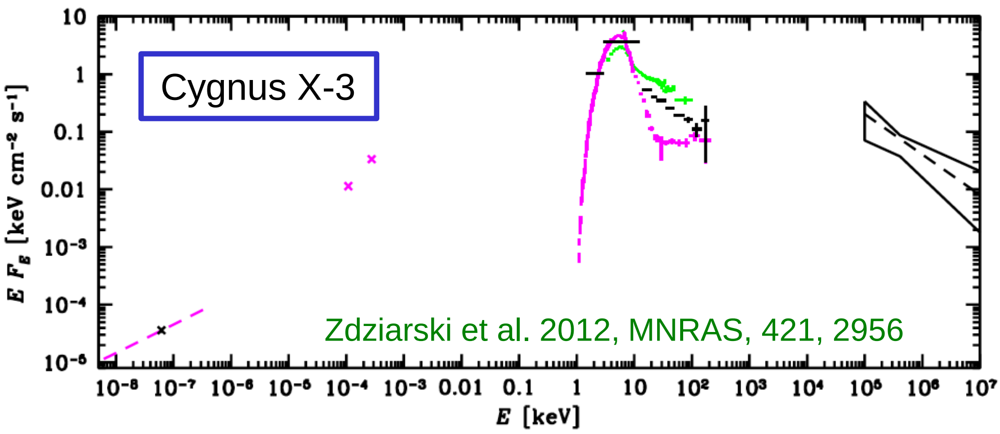
  (Abdo et al. 2011, Aharonian et al. 2005)



- **Microquasars:** Accreting XRBs with relativistic jets

  - SED peak at keV
  - Cygnus X-3, detected at HE by *AGILE* and *Fermi*-LAT

  (Tavani et al. 2009, Abdo et al. 2009)



- **Colliding wind binaries:** two stars belonging to the category of OB- or WR-type stars (No compact companion). Wind-wind interaction region

  - Eta Carinae, detected at HE (*AGILE* and *Fermi*-LAT)
    (Tavani et al. 2009, Abdo et al 2010)

- **Recycled non-accreting MS PSRs in binary systems:** Millisecond pulsar + very low mass companion

  - Black Widow Pulsar PSR B1957+20, detected at HE by *Fermi*-LAT
    (Wu et al. 2012)

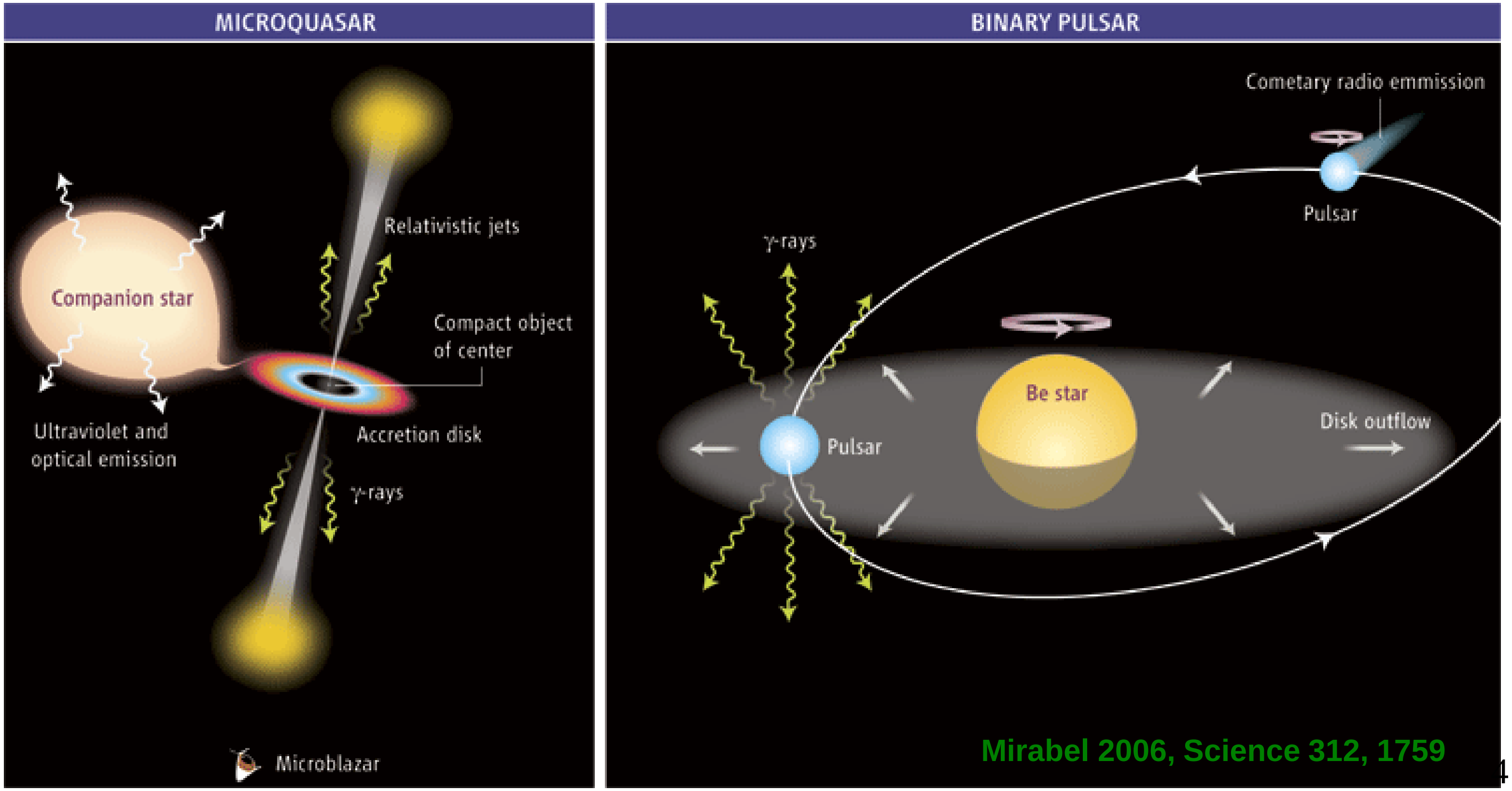
- **Symbiotic novae:** WD is deep immersed in the wind of a late-type companion star. Thermonuclear explosion on the surface of the WD

  - V407 Cygni, detected at HE by *Fermi*-LAT
    (Abdo et al. 2010)

Microquasars and Gamma-ray binaries

Two scenarios to describe the particle acceleration

1. Jets of a microquasar powered by accretion
2. Shocks between the relativistic wind of a young non-accreting pulsar and the wind of the stellar companion



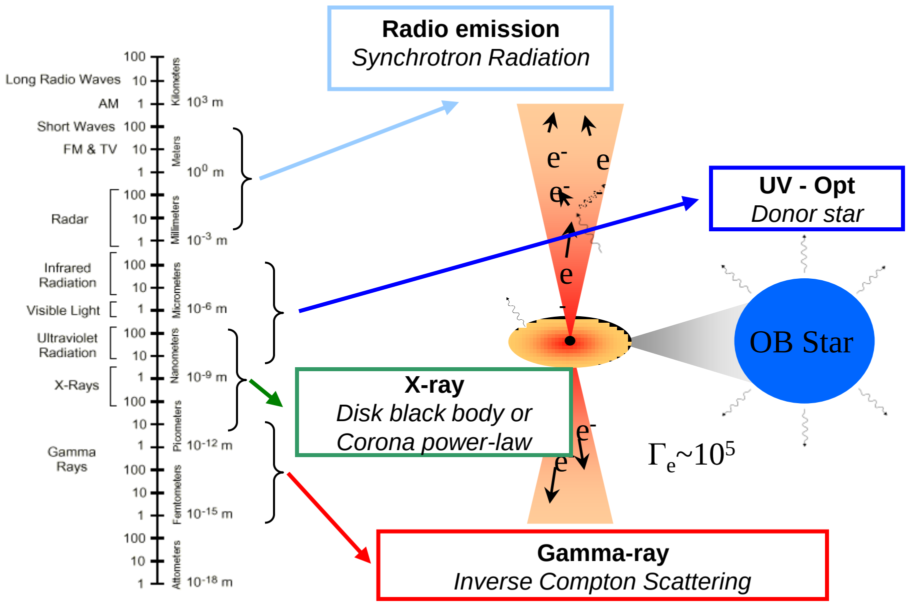
Mirabel 2006, Science 312, 1759

Possible scenarios

Microquasar

- An accretion disk is formed by mass transfer.
- Display bipolar jets of relativistic plasma.
- The jet electrons produce radiation by synchrotron emission when interacting with magnetic fields.
- VHE emission is produced by inverse Compton scattering when the jet particles collide with stellar UV photons, or by hadronic processes when accelerated protons collide with stellar wind ions.

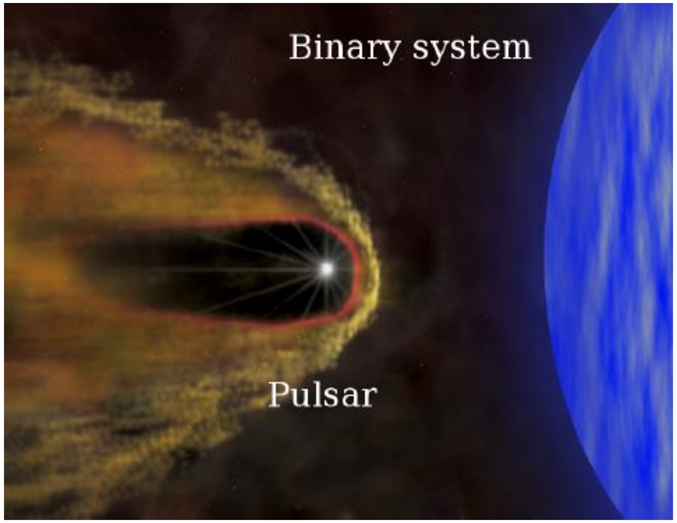
[Bosch-Ramon et al. 2006, A&A, 447, 263; Paredes et al. 2006, A&A, 451, 259; Romero et al. 2003, A&A, 410, L1]



Non-accreting pulsar

- The relativistic wind of a young (ms) pulsar is contained by the stellar wind.
- Particle acceleration at the termination shock leads to synchrotron and inverse Compton emission.
- After the termination shock, a nebula of accelerated particles forms behind the pulsar.
- The cometary nebula is similar to the case of isolated pulsars moving through the ISM.

[Maraschi & Treves 1981, MNRAS, 194, P1; Dubus 2006, A&A, 456, 801; Sierpowska-Bartosik & Torres 2007, ApJ, 671, L145]

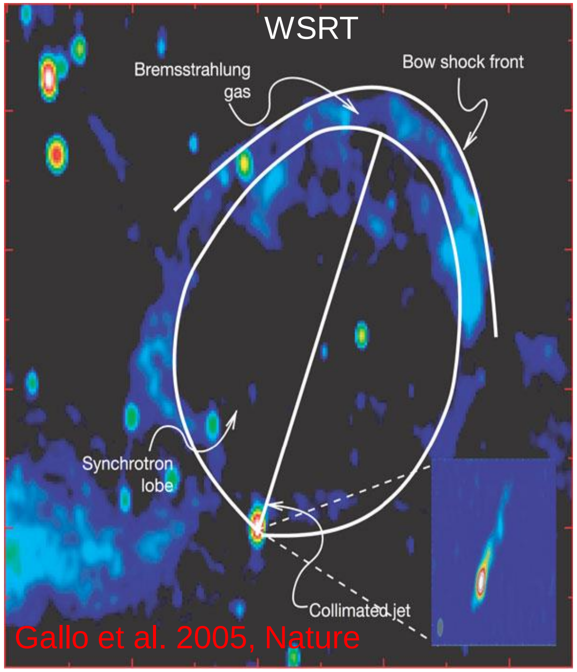


Adapted from NASA/CXC/SAO

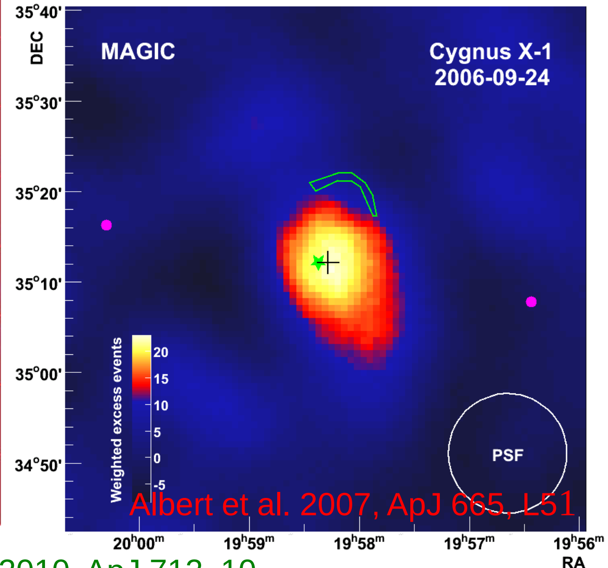
	Source	System Type	Orbital Period (d)	Radio Structure (AU)	Radio	X-ray	GeV	TeV
Non-accreting pulsar	**PSR B1259-63**	O9.5Ve + NS	1237	Cometary tail ~ 120	P	P	P?	P
Non-accreting pulsar	**LS I +61 303**	B0Ve + ?	26.5	Cometary tail? 10 – 700	P	P	P	P
Non-accreting pulsar	**LS 5039**	O6.5V((f)) +?	3.9	Cometary tail? 10 – 1000	persistent	P	P	P
Non-accreting pulsar	**HESS J0632+057**	B0Vpe + ?	321	Elongated (few data) ~ 60	V	P	?	P ?
	1FGL J1018.6-5856	O6.5V((f)) +?	16.6	?	P	P	P	P
Microquasar	**Cygnus X-1**	O9.7I + BH	5.6	Jet 40 + ring	persistent	P	T ?	T?
Microquasar	**Cygnus X-3**	WR + BH?	4.8h	Jet	Persistent & burst	P	P	?
Microquasar	**SS 433**	A3-7 I + BH?	13.1	Jet	V	V	Persistent	?
Microquasar	**AGL J2241+4454 MWC 656 ???**	B2IIIe + BH	60	–		T?	T?	?

Cygnus X-1

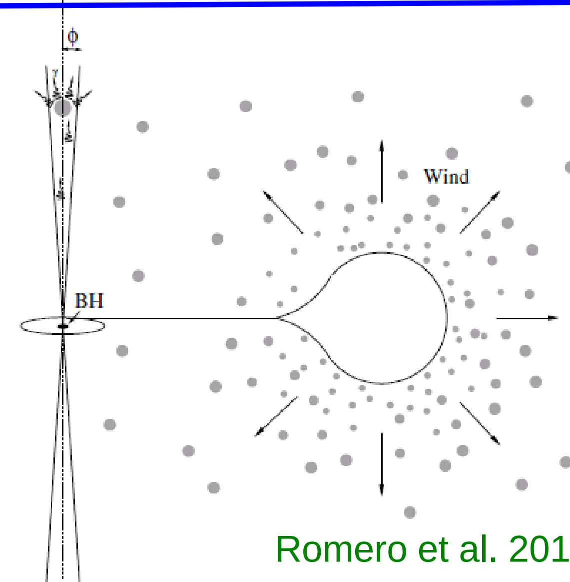
Microquasars



Gallo et al. 2005, Nature



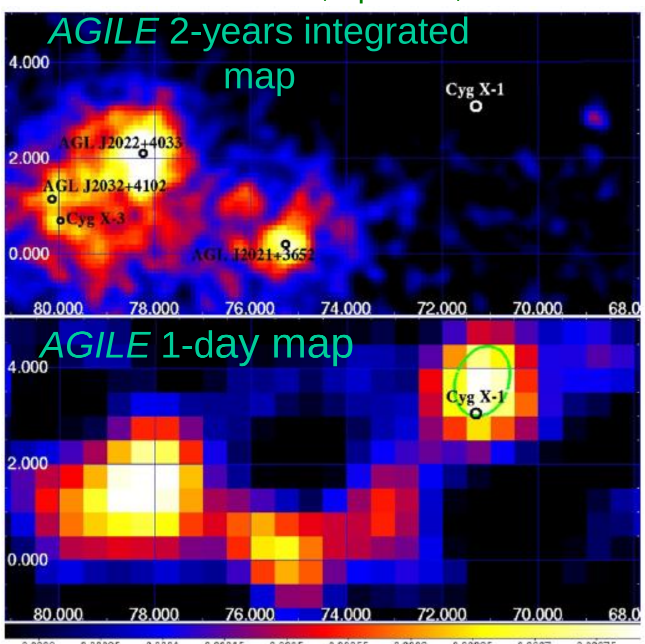
Albert et al. 2007, ApJ 665, L51

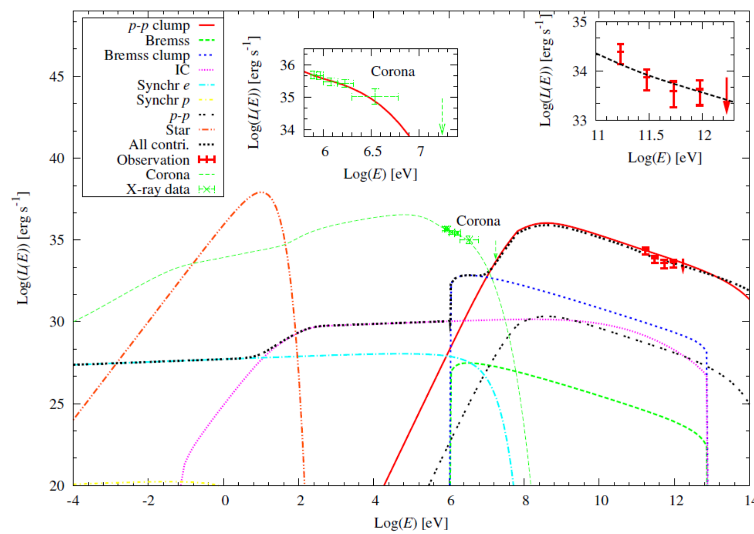


Romero et al. 2010

Cumply wind – jet interaction

Sabatini et al. 2010, ApJ 712, 10



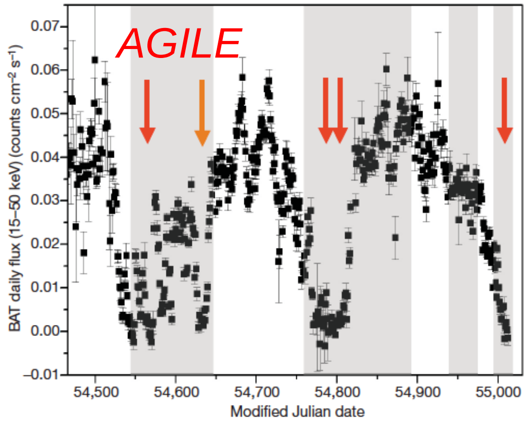


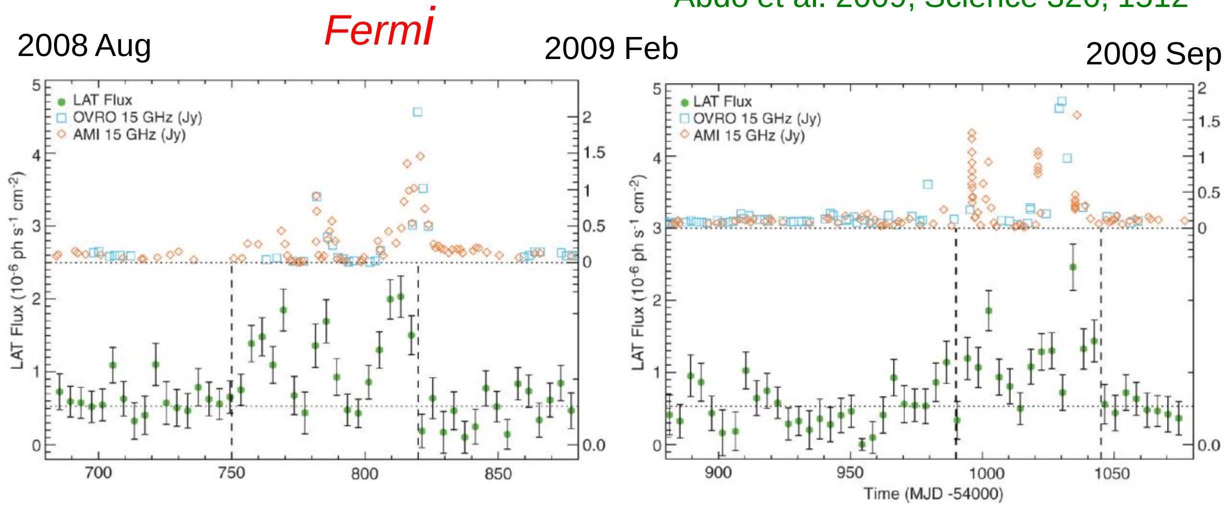
Fermi-LAT Detection of Cygnus X-1

Bodaghee et al. 2013, ApJ 775, 98

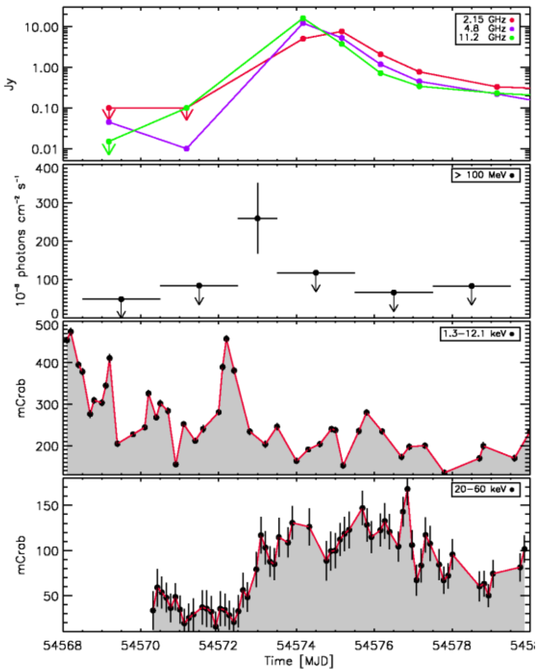
Cygnus X-3

Abdo et al. 2009, Science 326, 1512

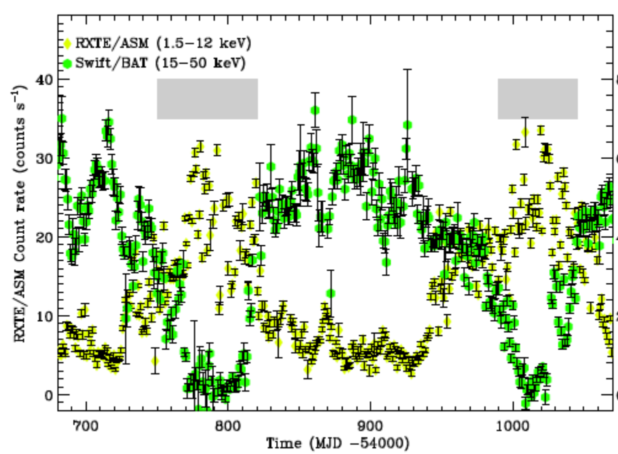




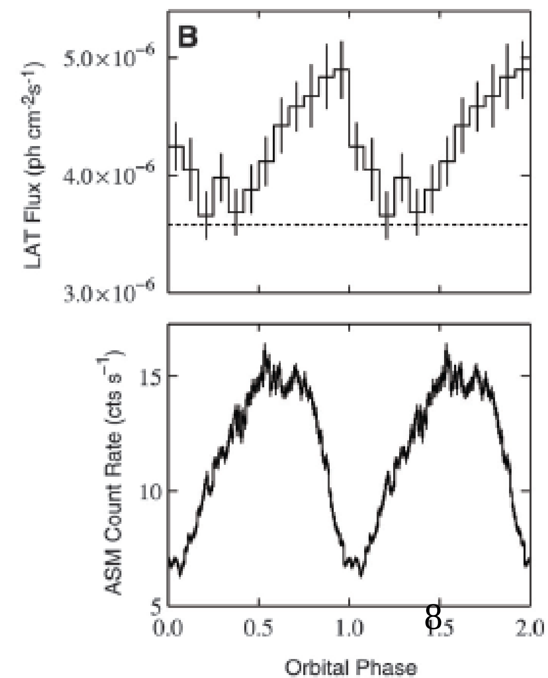
Gamma-ray flares occur only during soft X-ray states or their transitions to or from quenched hard X-ray states



Tavani et al. 2009, Nature 462, 620



Active gamma periods in the soft X-ray states

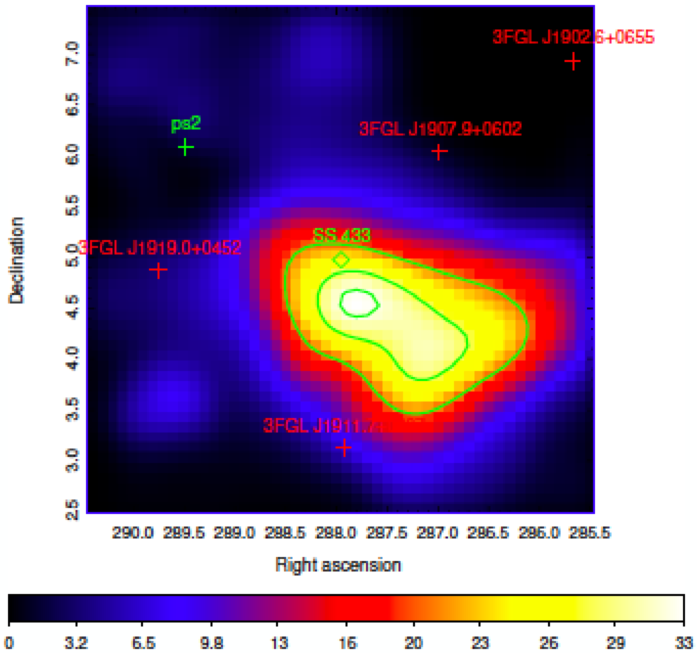


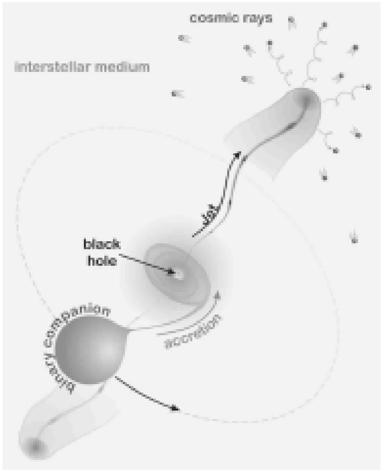
SS433/W50

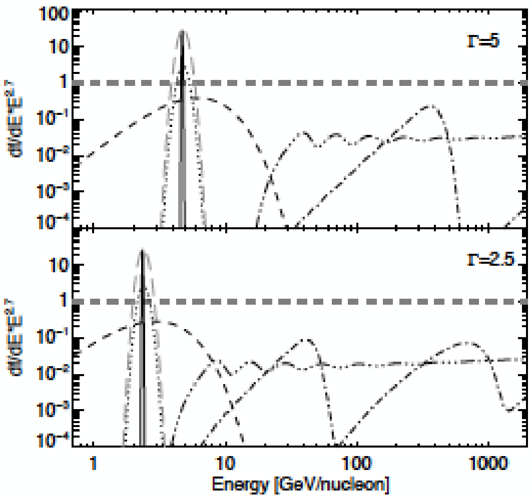
Microquasars

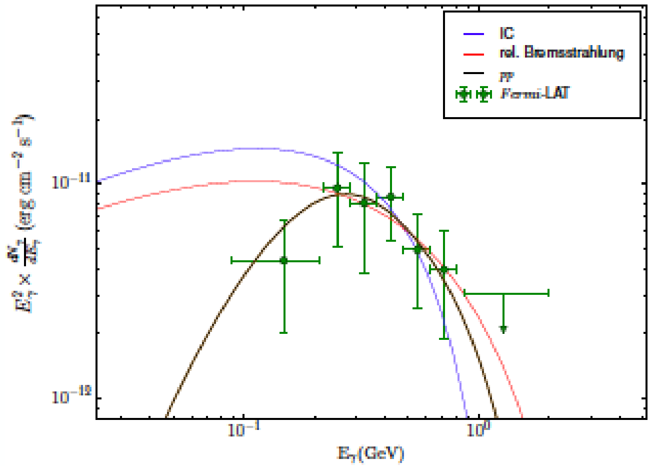
"**Detection of persistent gamma-ray emission towards SS433/W50**" (Bordas+ 2014 arXiv1411.7413B)

- 5-years LAT data, 3FGL: "ps1" with TS = 57
- 3-sigma position contours enclosing SS433/W50
- spectrum: sharp peak at ~250 MeV, up to ~800 MeV only
- no significant variability (phase-folded orbital/precession)
- pp-interactions favored, IC/rel.-Bremss not discarded
- jet/medium interaction regions as possible scenario









Heinz & Sunyaev (2002)

Bordas, + (arXiv1411.7413B)

(from Bordas, **Variable Galactic Gamma-ray Sources Meeting, Heidelberg** 4-6 May 2015)

AGL J2241+4454

- Short γ-ray flare: Integrating from 2010-07-25 01:00 UT to 2010-07-26 23:30 UT,

  → detection at a significance level larger than 5σ, and a flux above 1.5×10^{-6} ph/cm^2/s (E > 100 MeV)

  Lucarelli et al. 2010, Atel 2761

- (l, b) = (100.0°, -12.2°) ± 0.6°

Be star **HD 215227 (= MWC 656)**

- P= 60.37 ± 0.04 d, optical photometry Williams et al. 2010, ApJ 723, L93

MWC 656, the first Be/BH binary

Casares et al. 2014, Nature 505, 378

(see Munar-Adrover talk)

Gamma-ray binaries

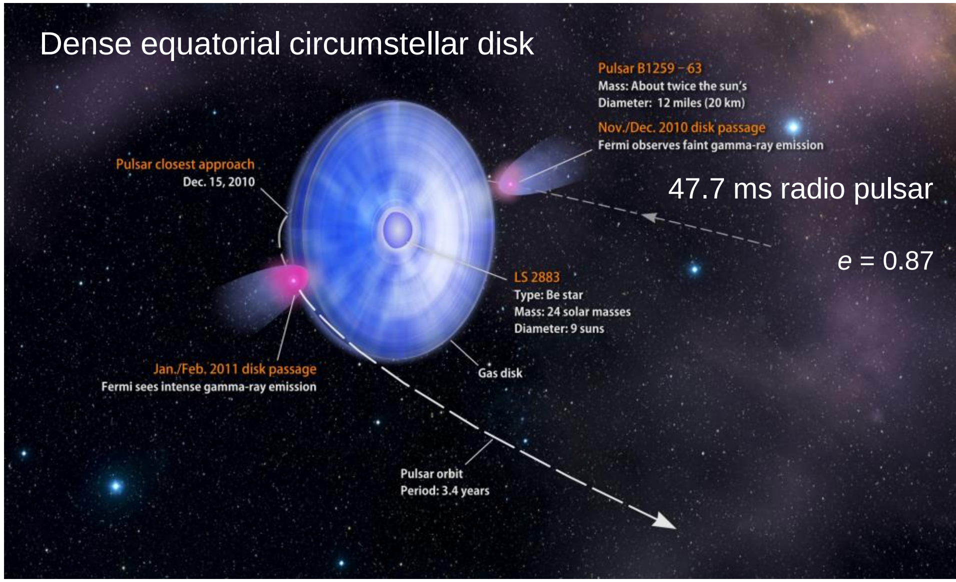
PSR B1259-63

Young pulsar wind interacting with the companion star

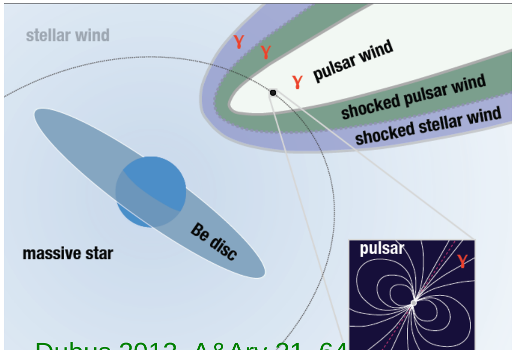
- O8.5-9 Ve +NS (Negueruela et al. 2011, ApJL, 732, L11)

✧ The first variable galactic source of VHE

✧ Orbital plane of the pulsar inclined with respect to the disk (Melatos et al. 1995, MNRAS 275, 381; Chernyakova et al. 2006, MNRAS 367, 12



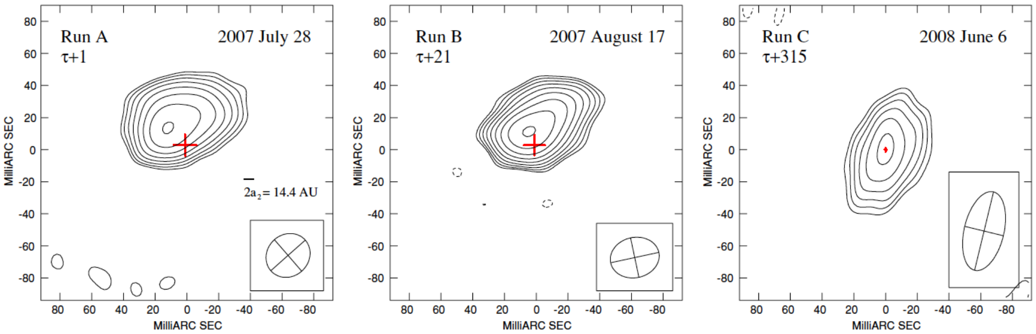
✧ A shock forms between the pulsar wind and the circumstellar material. The non-thermal emission is due to high energy particles that are scattered and accelerated at the shock (Tavani & Arons 1997, ApJ 477, 439)



Dubus 2013, A&Arv 21, 64

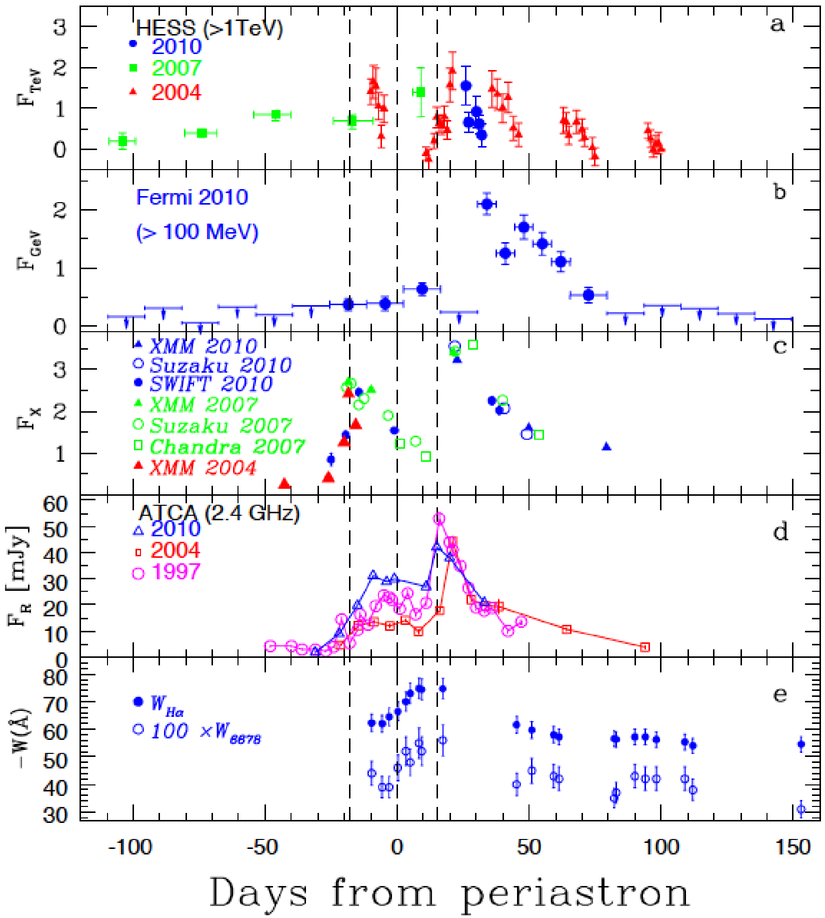
✧ Radio emission is produced by the HE outflow reaching distances 10–100 times larger than the binary system size

✧ (Moldón et al. 2011, ApJ 732, L10)

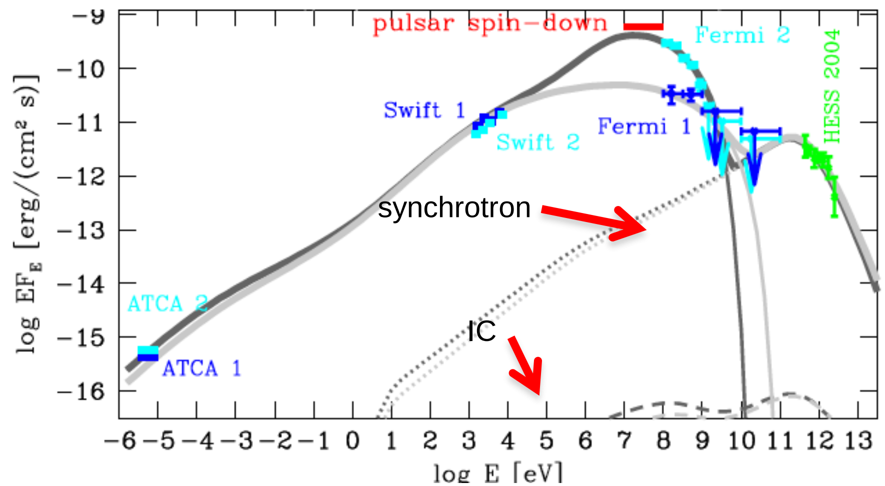


PSR B1259−63 / LS 2883

✧ The TeV light curve, and radio/X-ray light curves, can be explained if the interaction with the circumstellar disk is considered (Chernyakova et al. 2006)



Chernyakova et al. 2014, MNRAS 439, 432



HE flare

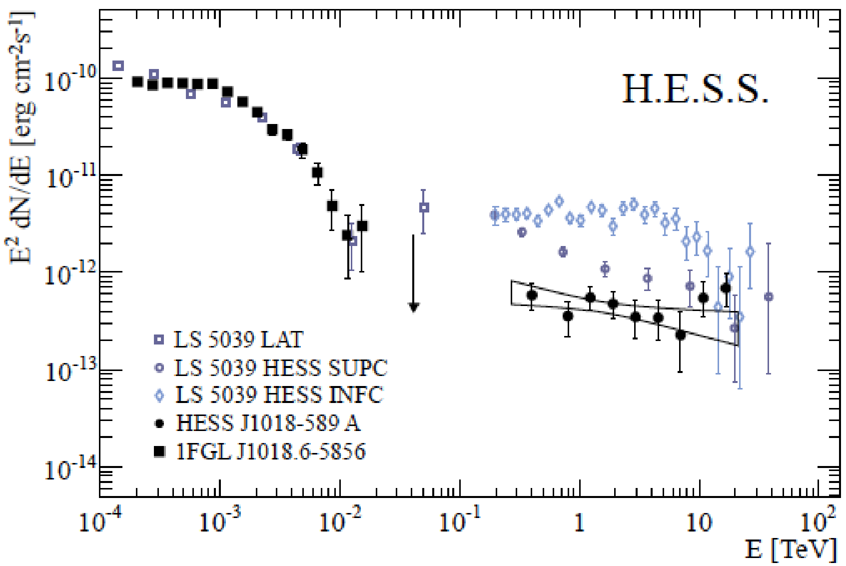
✧ Nearly all the spin-down power is released in HE gamma rays (Abdo et al. 2011)

✧ Doppler boosting suggested (Tam et al. 2011), but very fine tuning is needed and lack of concurrent variability (see also Khangulyan et al. 2012)

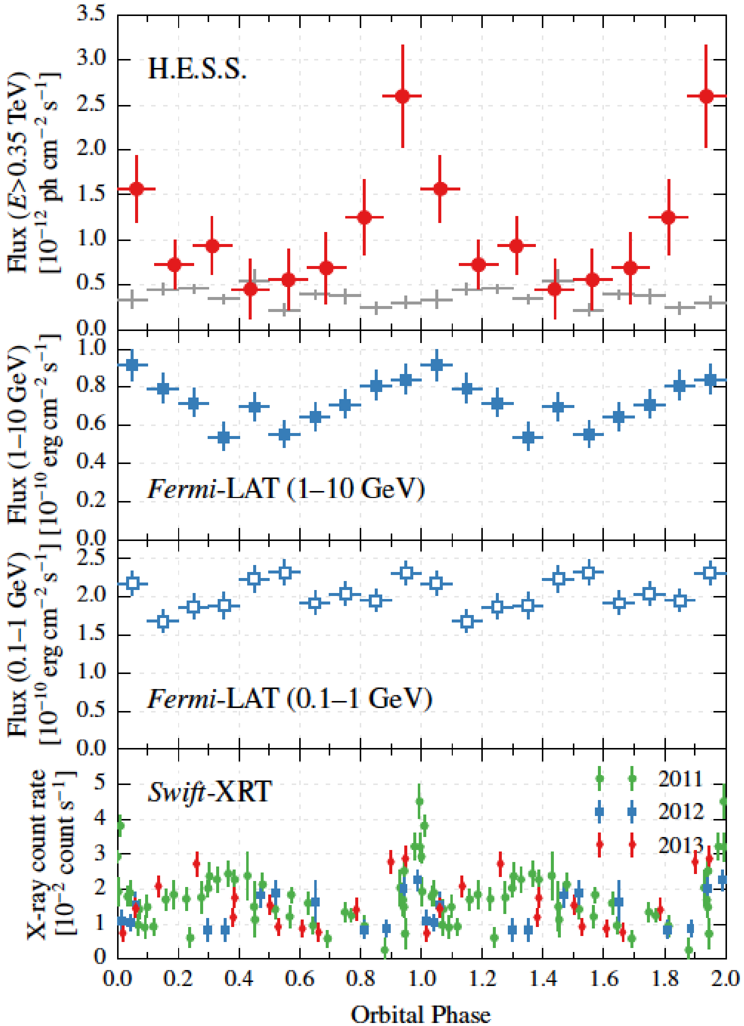
1FGL J1018.6-5856

- 1FGL J1018.6-5856 is one of the brighter Fermi sources (Ackermann et al. 2012, Fermi Col., Science 335, 189)
- X-ray flare-like behaviour near phase 0, coinciding with gamma-ray maximum
- Optical counterpart ~O6V((f)), just like LS 5039. Orbital parameters unknown
- An spatially coincident variable radio source
- Radio structure ?

LAT spectrum similar to a pulsar - but no pulsations seen



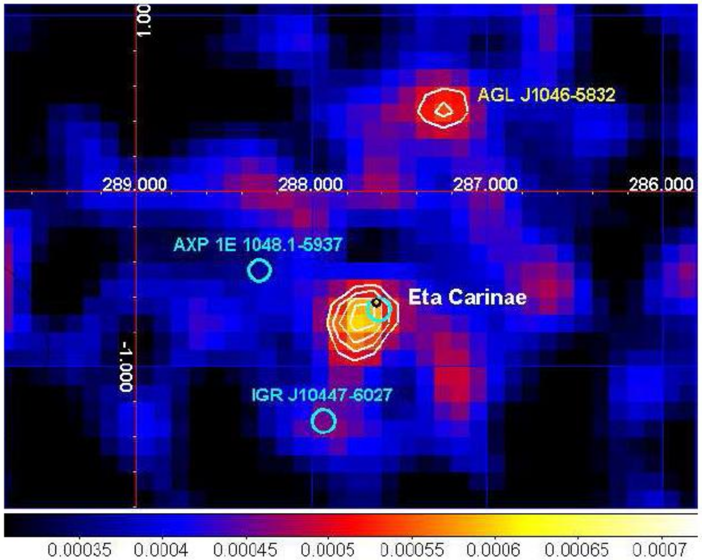
Flux modulated with a 16.6 d period



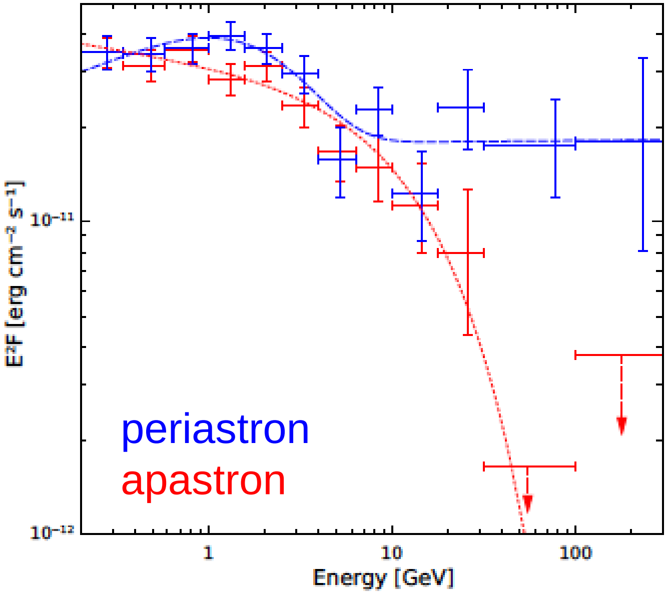
H.E.S.S. Coll. 2015, arXiv 1503.02711

Eta Carinae

Tavani et al. 2009, ApJ 698, L142

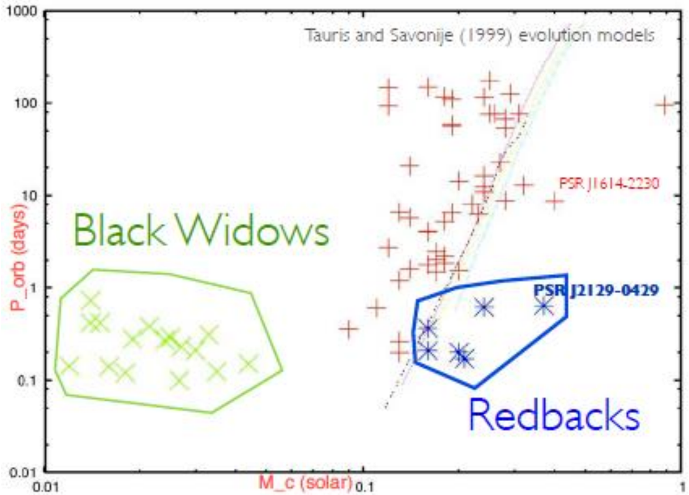


Reitberger et al. 2015, A&A 577, A100



- ✧ Eta Car is the only colliding-wind binary for which high-energy gamma rays are detected
- ✧ Significant variability on a few day time-scale
- ✧ The gamma-ray spectrum exhibits two features that can be interpreted as emission from the shocks on either side of the contact discontinuity.
- ✧ A time dependent particle acceleration, evolution and radiation model of η Car (Ohm et al. 2015, MNRAS, 449, L132)

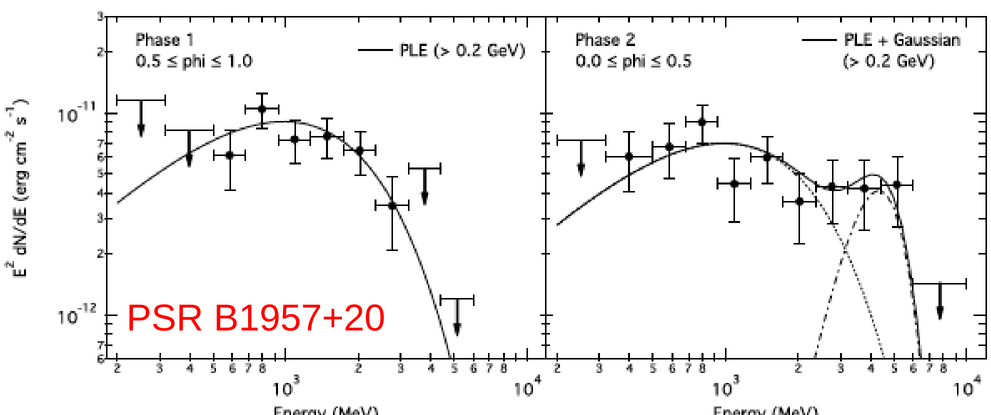
Recycled non-accreting MS PSRs in binary systems



Black widows and **Redbacks:** Eclipsing millisecond pulsars in close (P_b < 1 day) binary systems
✧Companion: Nearly Roche-lobe filling
Heated by the pulsar which drives mass loss from the companion
✧The pulsar wind shocks with this material just above the surface of the companion

Fermi/LAT has detected γ-rays from more than a dozen black widows and redbacks (Roberts 2012, IAU Symp 291)

Non-thermal emission from the intra-binary shock, detected in X-rays in these systems, could contribute to unpulsed gamma-ray emission (Bogdanov et al. 2005, ApJ 630, 1029)



Wu et al. 2012, ApJ 761, 181

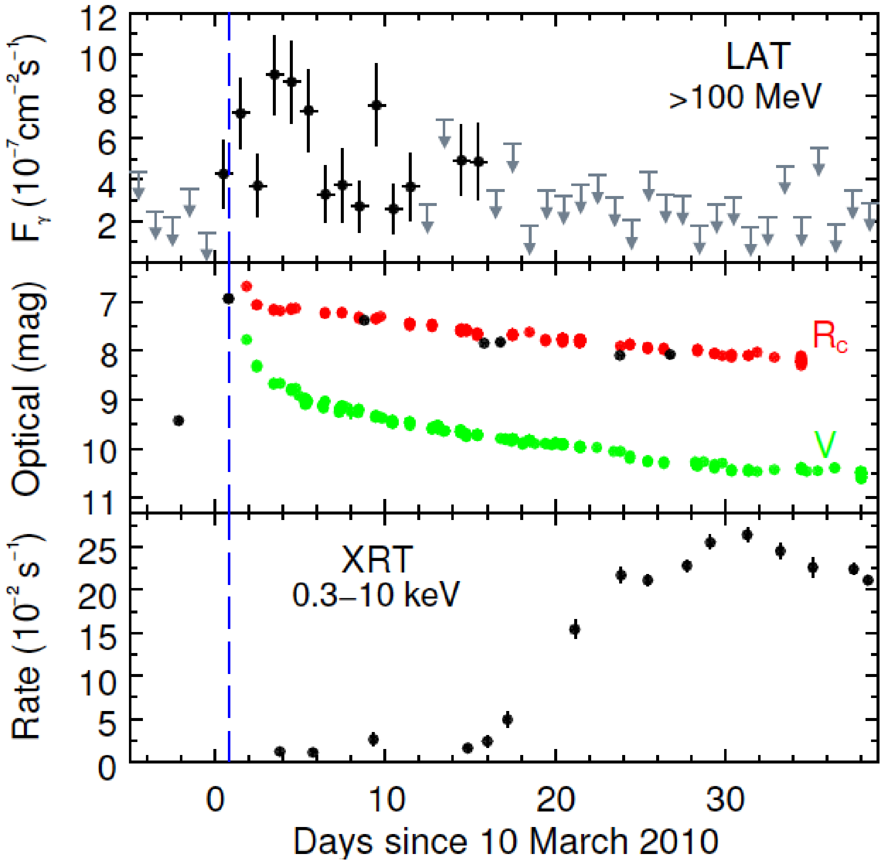
Orbital modulation of the HE emission in the black widow pulsar PSR B1957+20

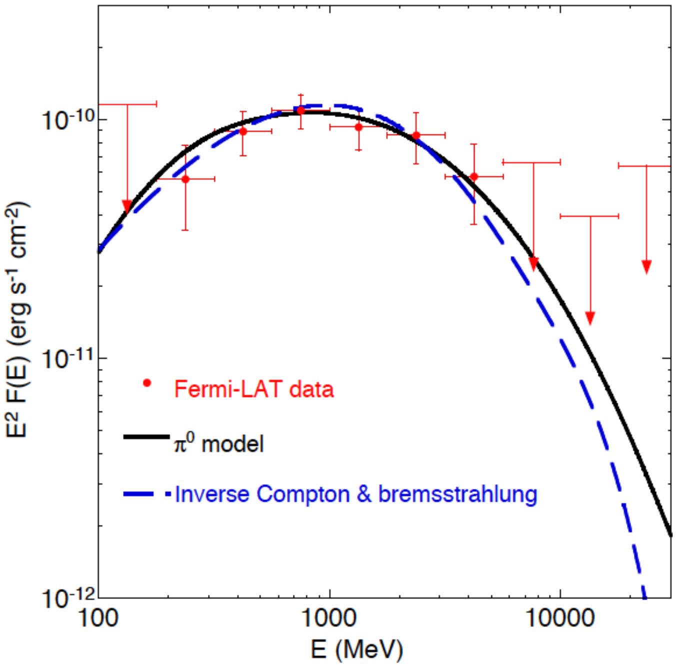
The pulsar spectrum with a cutoff at $E_c \approx$ 1GeV is not variable (pulsar magnetosphere)

Modulation restricted to the component above 2.7 GeV, attributed to pulsar wind emission (IC of the thermal radiation of the companion star off a "cold" ultrarelativistic pulsar wind)

The system behaves like a "low-mass" gamma-ray binary

V407 Cygni





Abdo et al. 2010 Sci 329, 817A

In the last few years the Fermi-LAT has discovered GeV gamma-ray emission from a few more novae: V1324 Sco, V959 Mon, V339 Del, and V1369 Cen

Summary

- Five gamma-ray binaries (SED peak at MeV-GeV). VLBI observations support the presence of young non-accreting pulsars. Correlated X-ray/TeV emission suggest a leptonic origin (synchrotron+IC). Unclear location of the GeV and TeV emissions

- Microquasars: 3 detected at HE + 1 new candidate. *AGILE* high contribution

- Colliding wind binaries. Only one source detected but other candidates are available

- Black widow and Redback binaries might show modulated GeV/TeV γ-ray emission

- Novae. Several have been detected at HE. Transient emission.