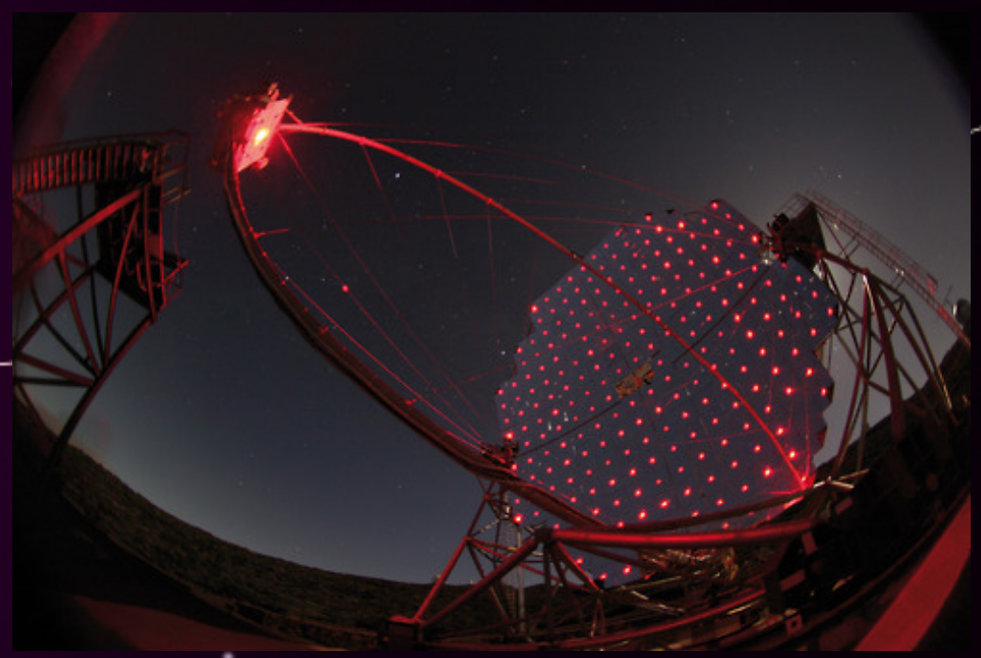
Gamma-ray binaries: years of MAGIC

Guillaume Dubus

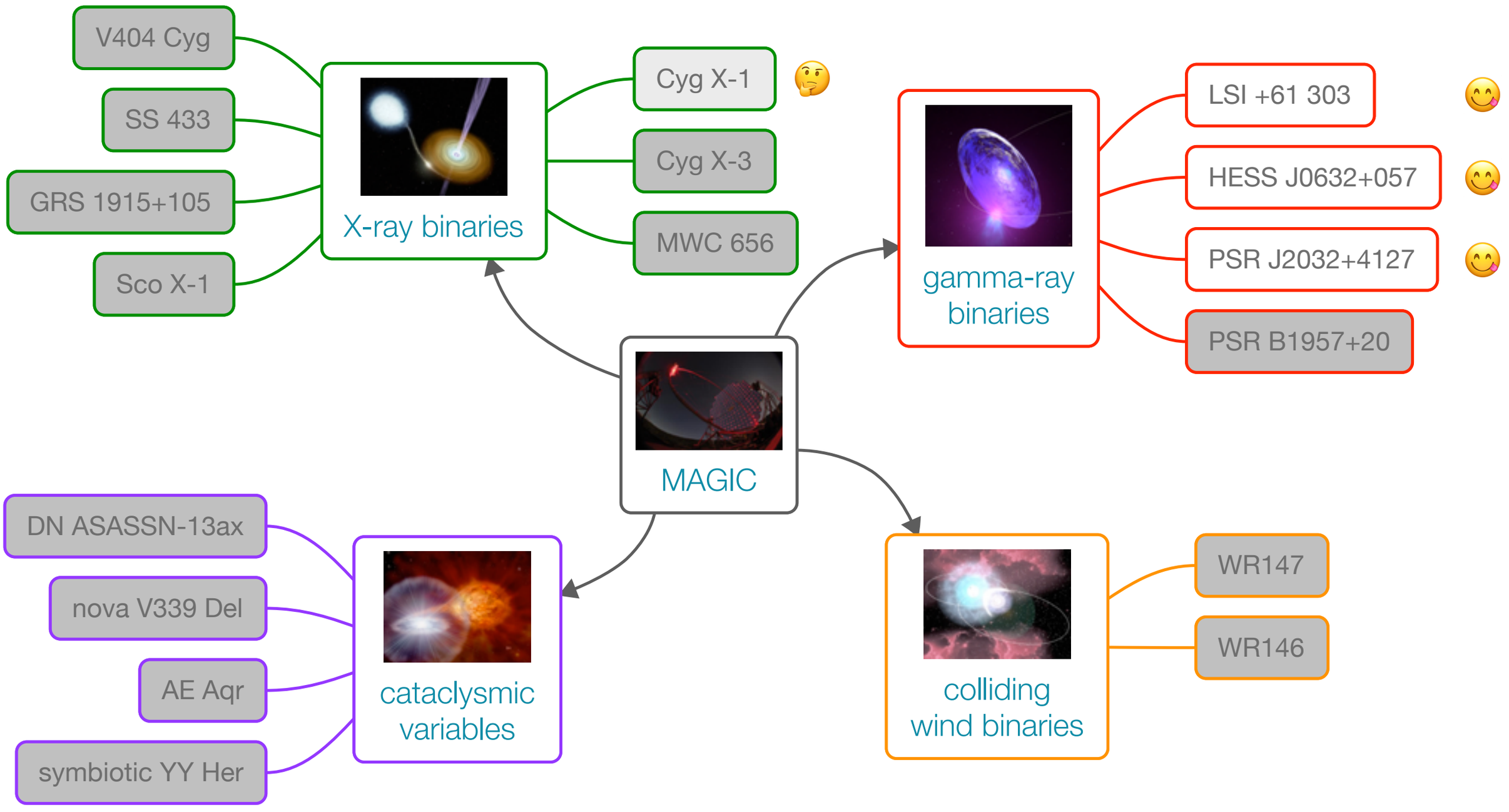
image credit
NASA / GSFC/F. Reddy



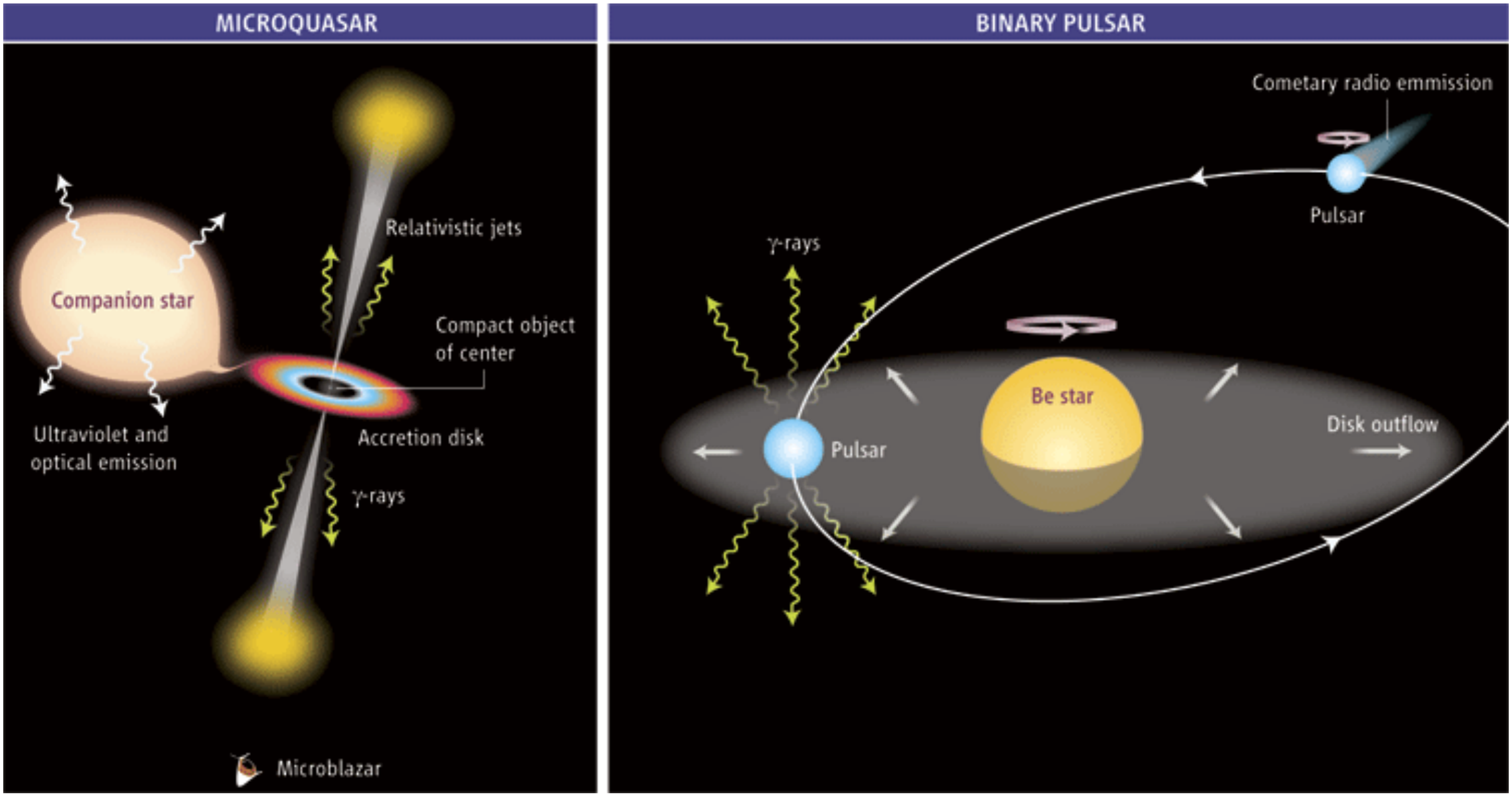
IPAG Institut de Planétologie et d'Astrophysique de Grenoble
cnrs
UNIVERSITÉ GRENOBLE ALPES

15 years of MAGIC, La Palma, June 29, 2018

binaries with MAGIC



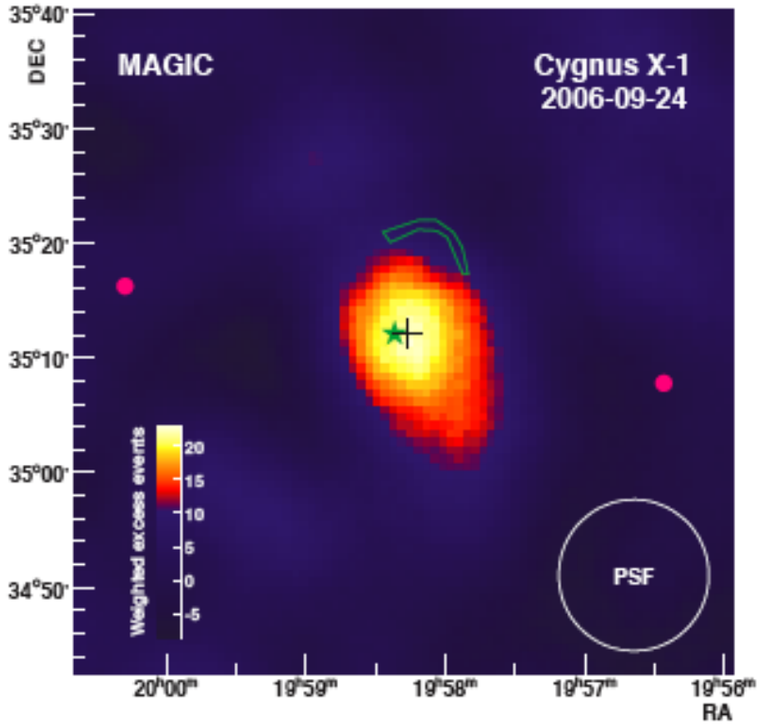
Basic framework for VHE emission



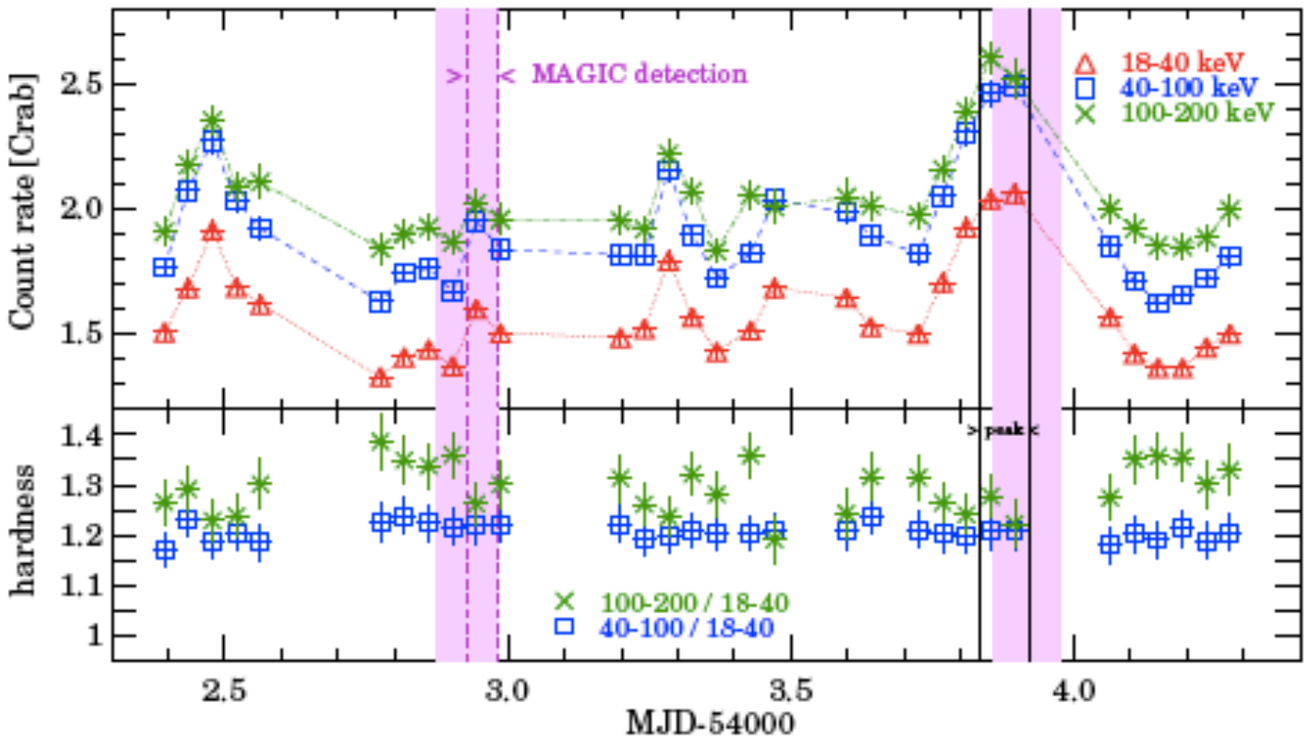
Mirabel 2006

VHE emission from a microquasar ?

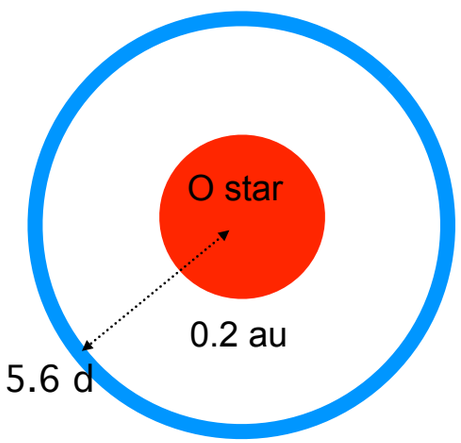
MAGIC 4.1σ detection of emission at location of Cyg X-1 on sep. 24, 2006



MAGIC coll. (2007)



INTEGRAL (Malzac+ 2008)



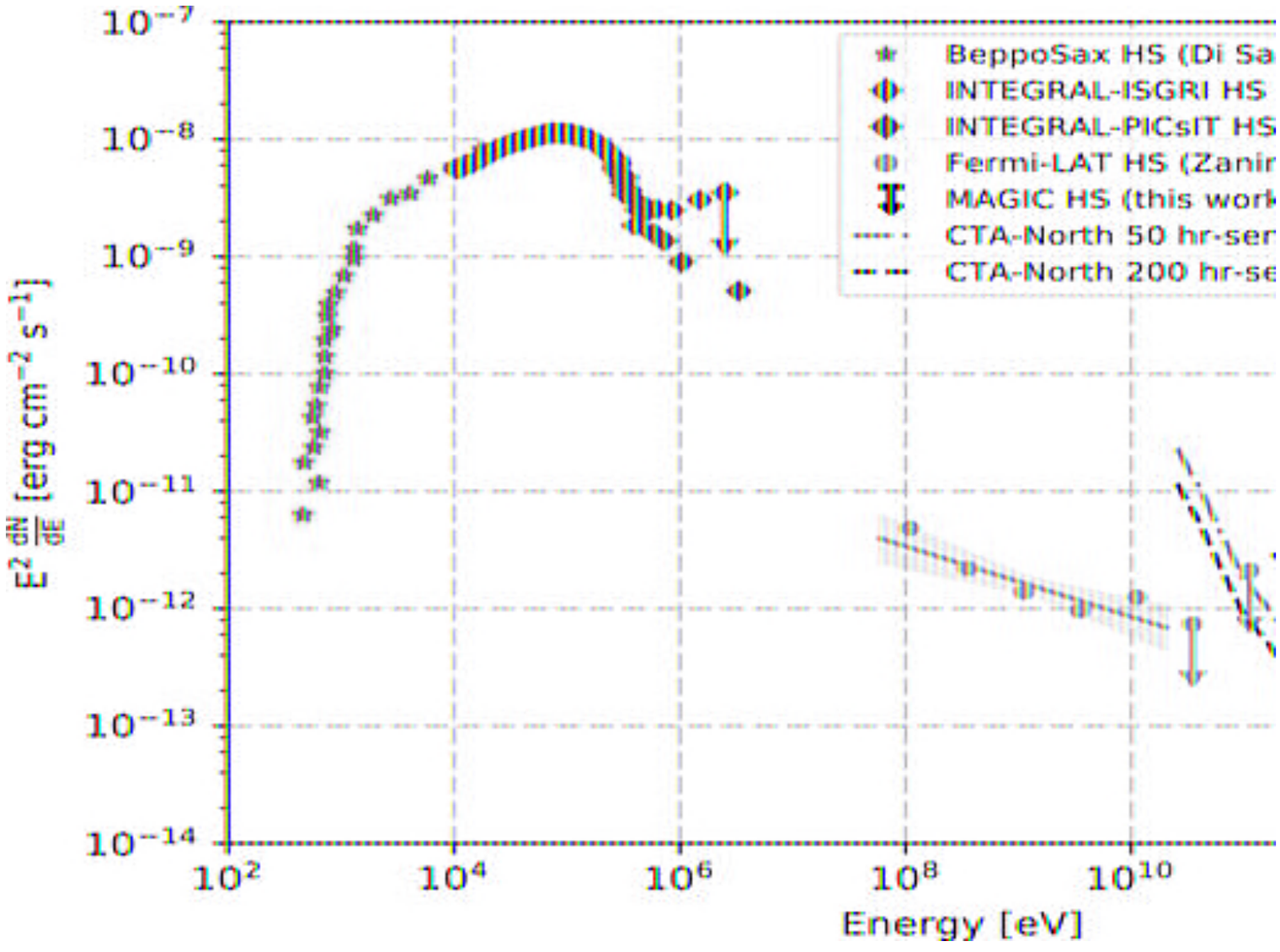
Source was bright in X-rays, $L_{vhe} \sim 10^{-4} L_X$,

BH behind star at time of detection

Microquasars are sources of HE gamma rays

VHE has yet to be confirmed: no other detection by MAGIC or VERITAS

HE emission confirmed with *Fermi*-LAT, ass. with hard X-ray state Zanin+2016, Zdziarski+2016

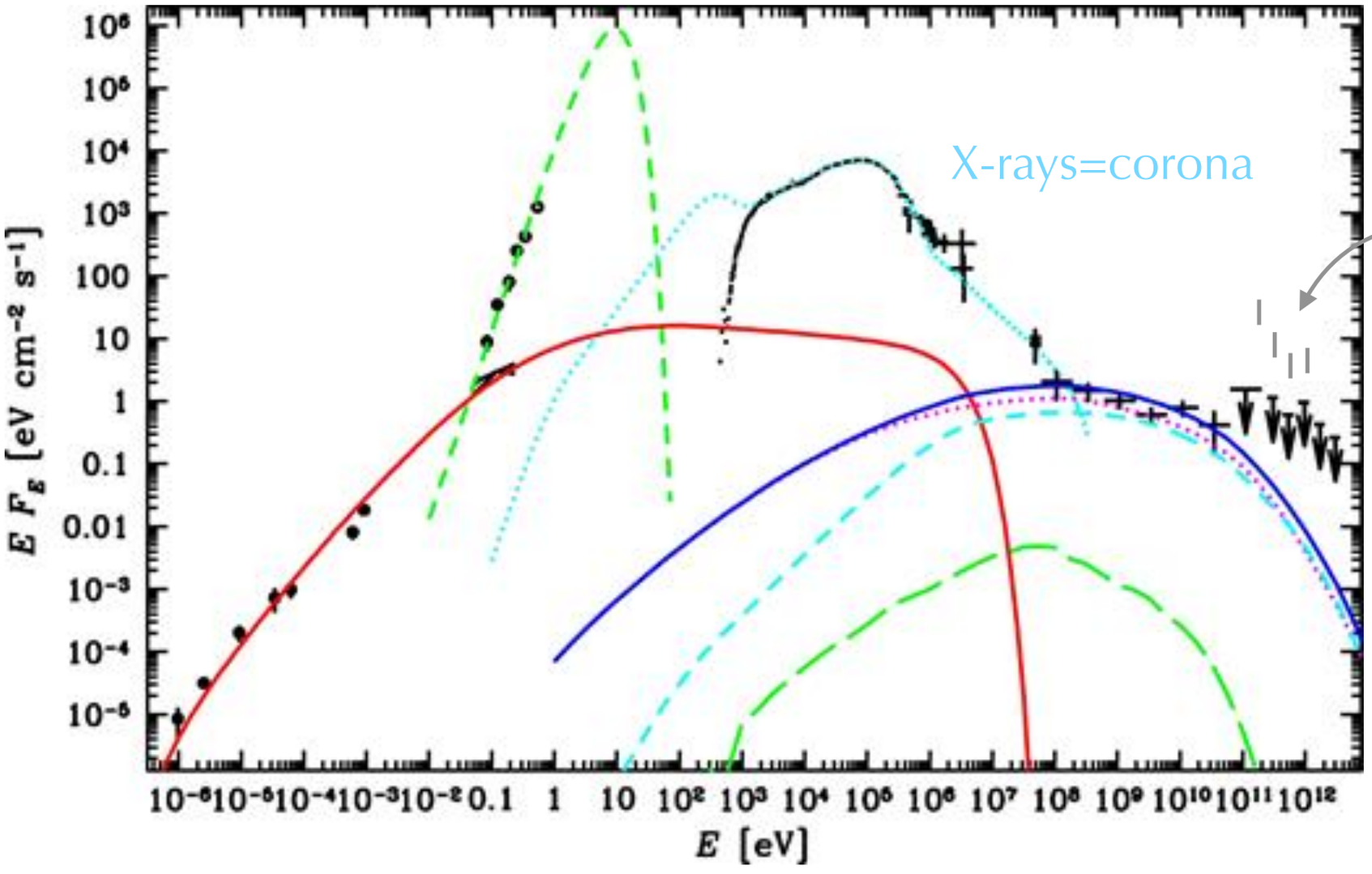


MAGIC coll. 2017

Constraining jet physics with Cyg X-1

HE gamma-ray emission in hard state, when radio compact jet is present.

detection from 40 MeV to 60 GeV, *weak* orbital modulation.

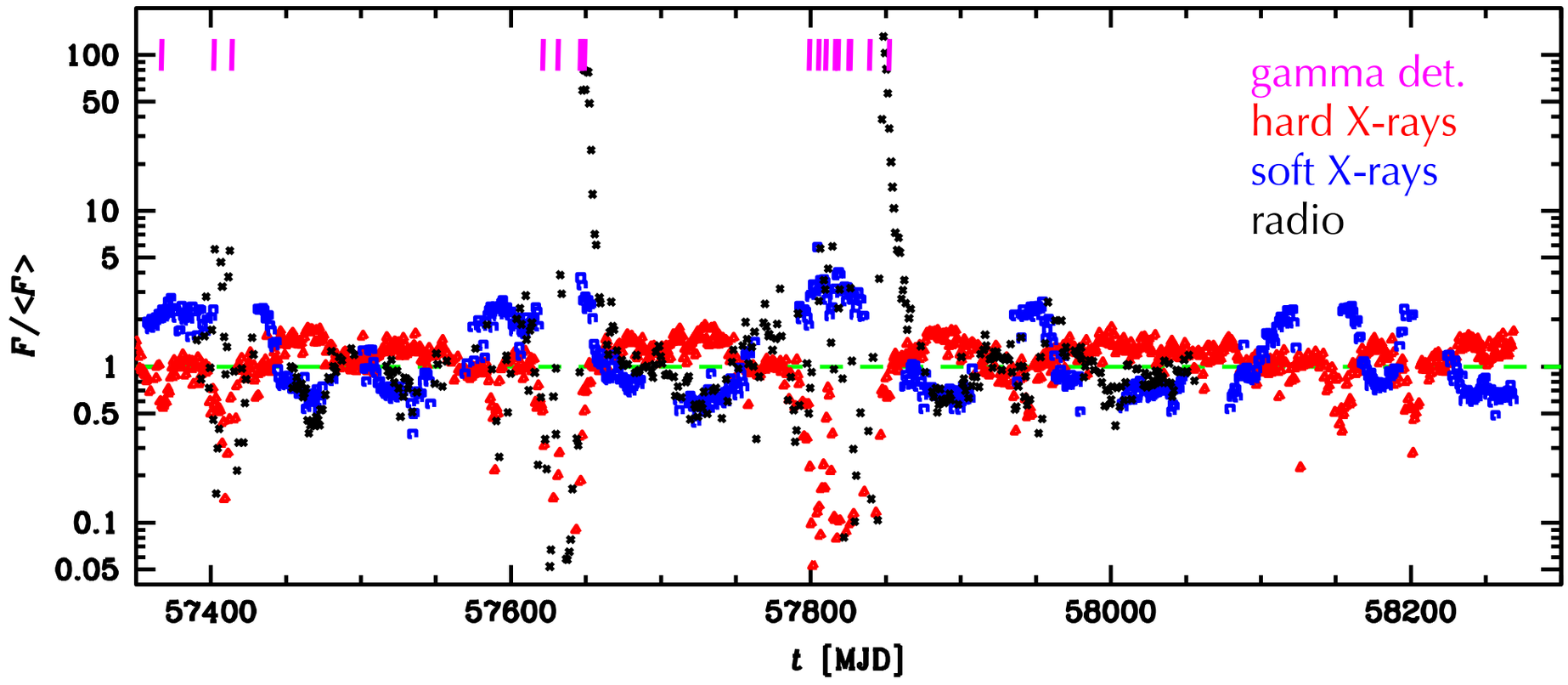


Zdziarski+ 2016

Non-thermal « clumps » ?

Gamma-ray emission clearly related to jet

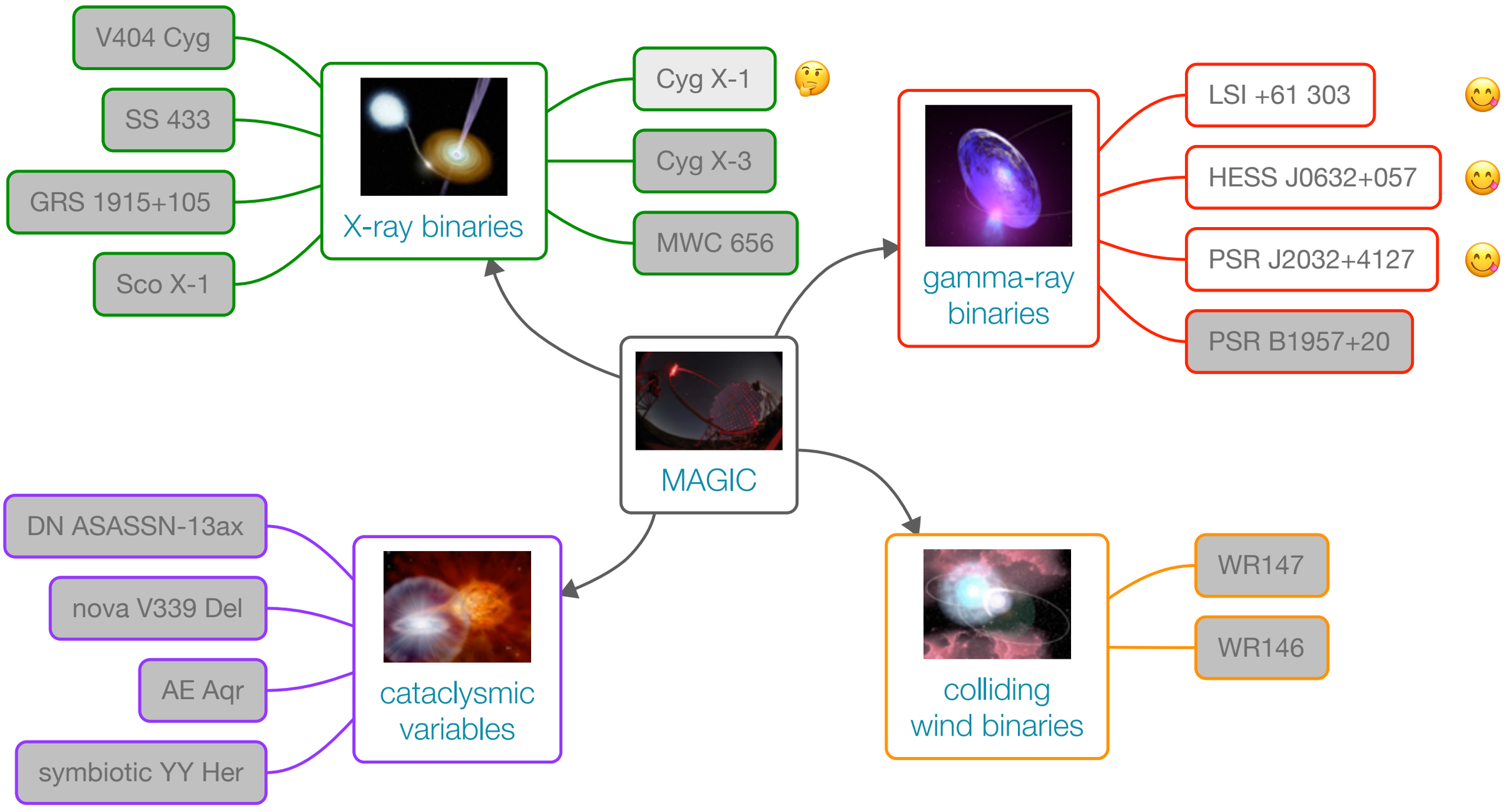
Cyg X-3: a window into the accretion-ejection-acceleration relationship ?



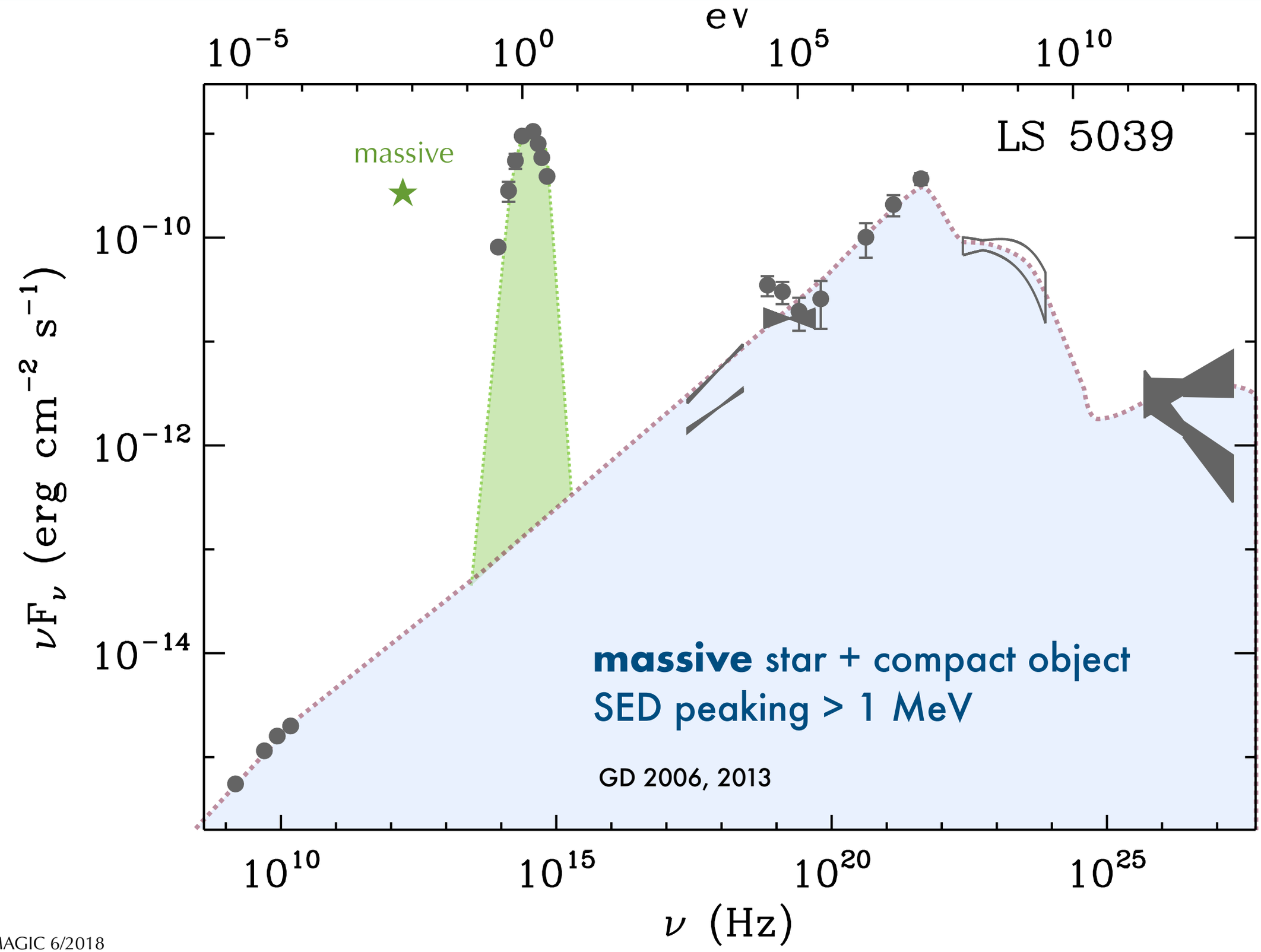
Zdziarski+2018

Also hint of HE emission from V404 Cyg at time of major ejection Loh+ 2016, MAGIC coll. 2017

binaries with MAGIC



« Gamma-ray » binary



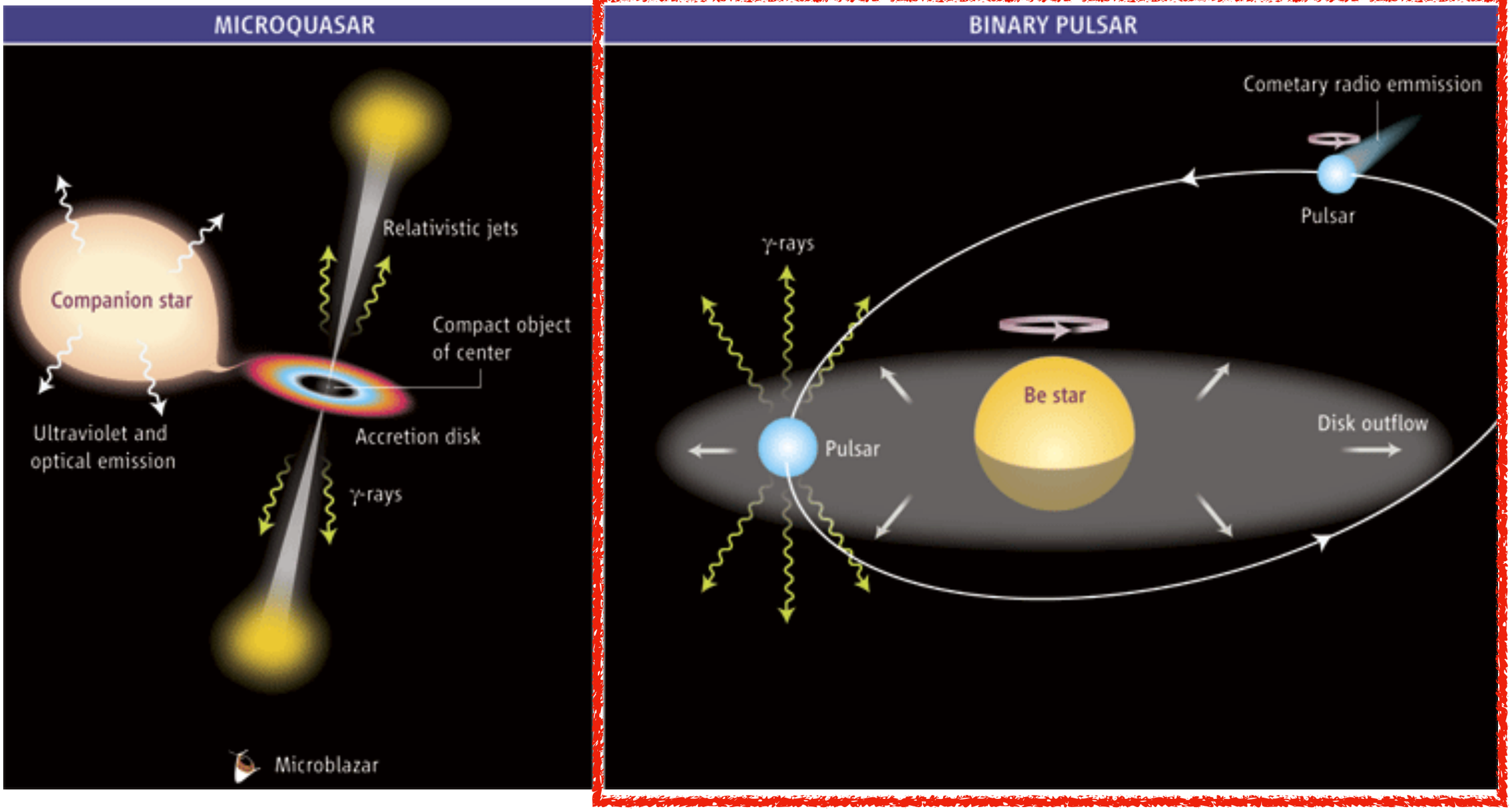
Dubus, MAGIC 6/2018

Gamma-ray binaries

by time of discovery

system	star	radio pulsar	P_{orb} (days)	VHE gamma-rays
PSR B1259-63	Be	yes	1237	yes
LS 5039	O	?	3.9	yes
LS I +61 303	Be	(?)	26.5	yes
HESS J0632+057	Be	?	320	yes
1FGL J1018.6-5856	O	?	16.6	yes
LMC P-3	O	?	10.3	yes
PSR J2032+4127	Be	yes	9000?	yes
PSR J1740-3052	>11 Msun	yes	231	too far
PSR J1638-4725	>6 Msun	yes	1941	low spindown
PSR J0045-7319	>4 Msun	yes	51	low spindown

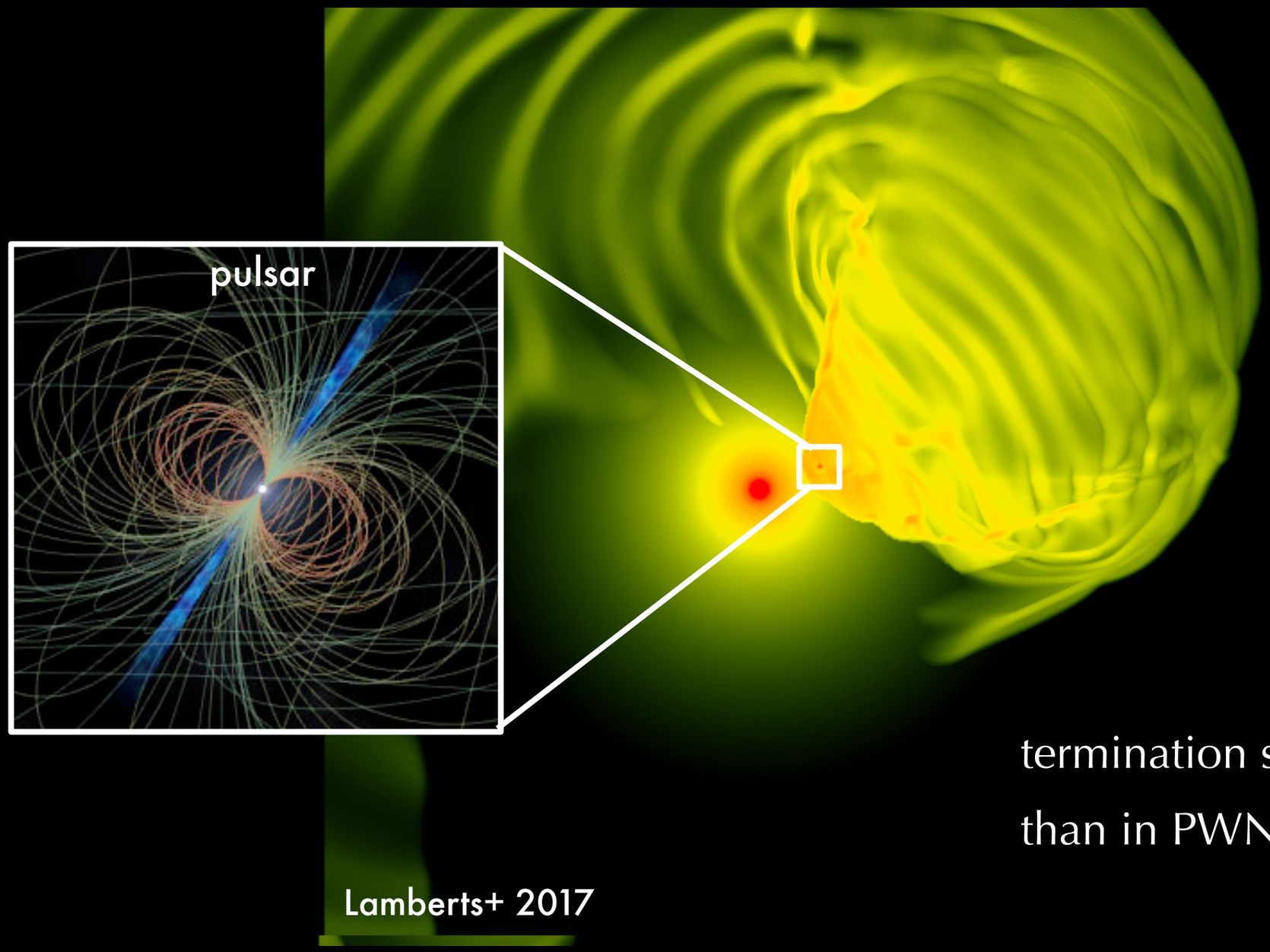
Basic framework for VHE emission



Mirabel 2006

Binary pulsar wind nebulae

bow shock as pulsar wind interacts with massive star wind

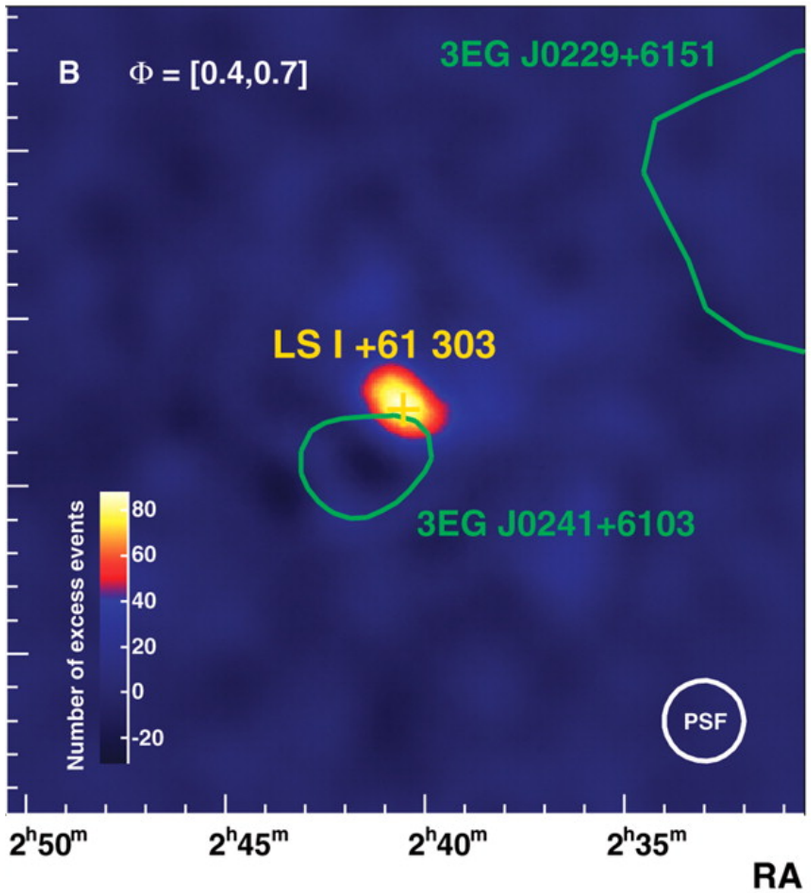


termination shock closer to pulsar than in PWNe: $R_s \sim (10^4 \text{ to } 10^6) R_{lc}$

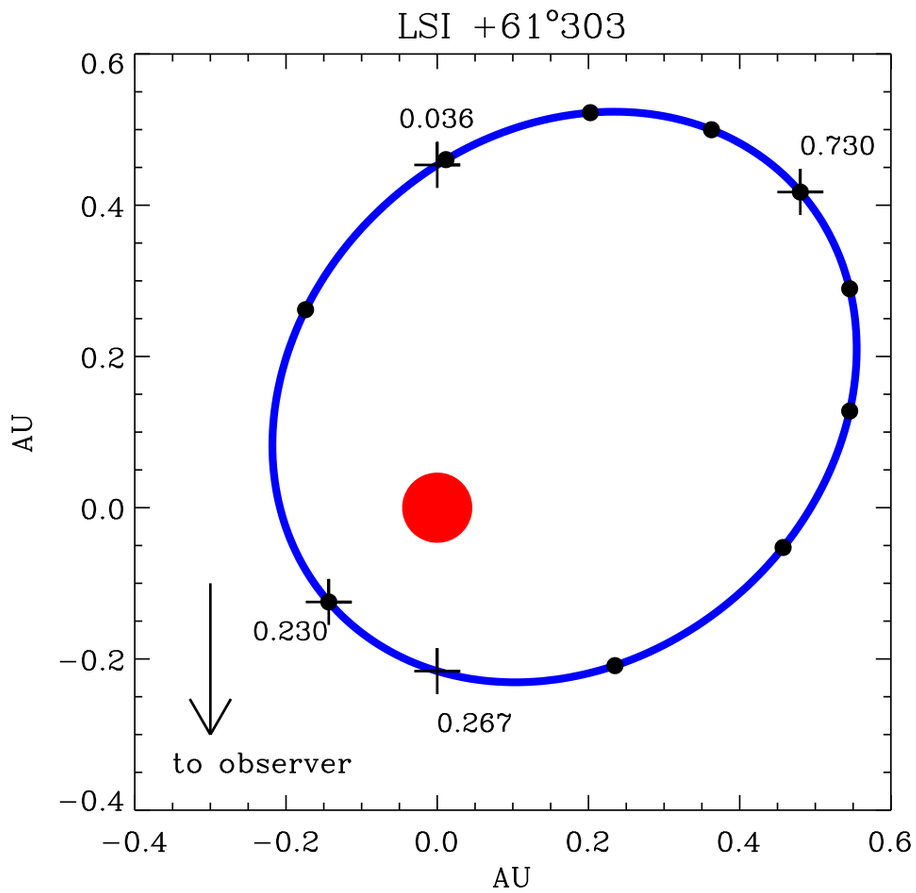
LS I+61 303

MAGIC detection, confirming suspicions since Cos B that binary emits HE gamma rays

Massive star with an **unknown** compact object in 26 day orbit



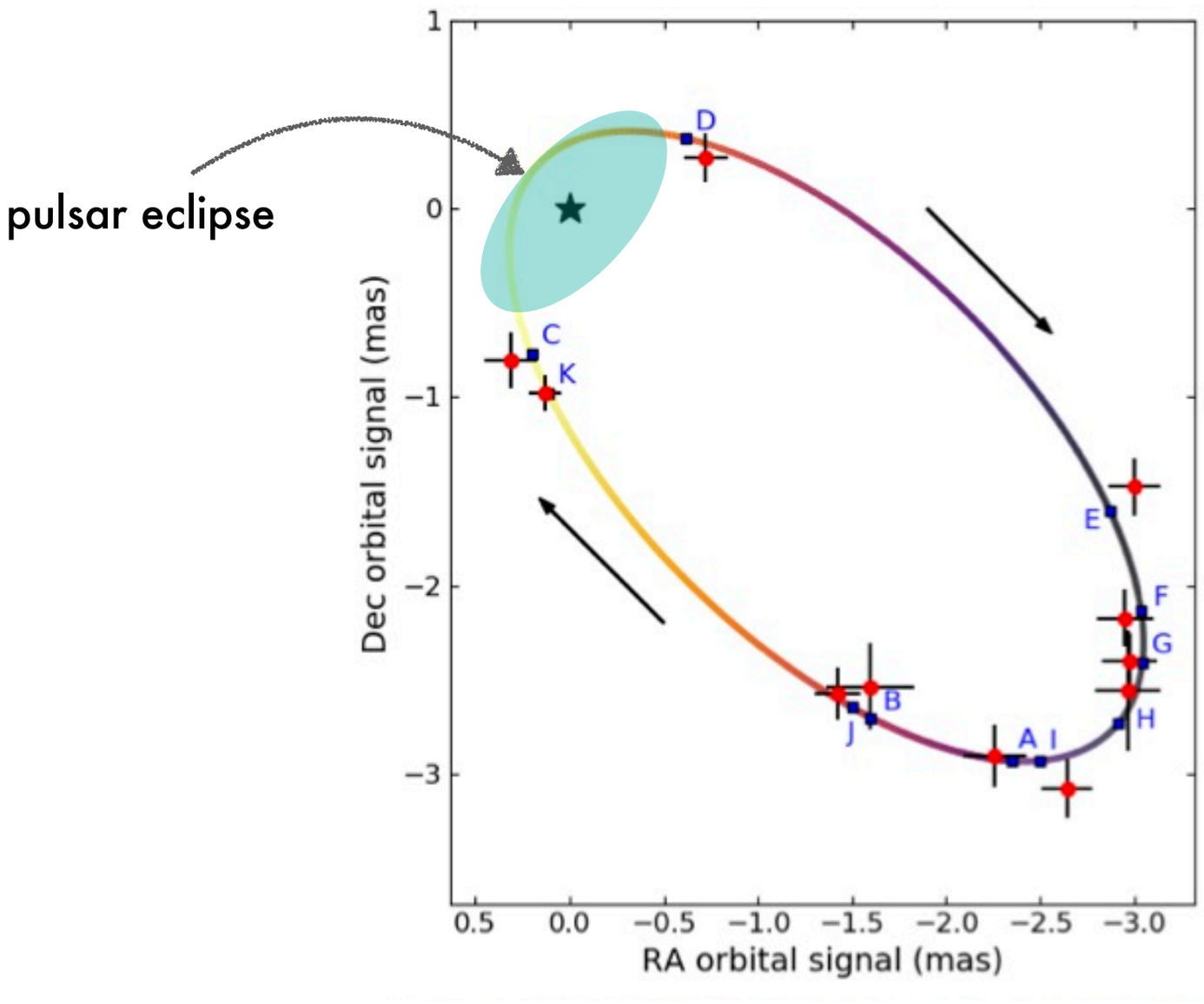
MAGIC coll. 2006



Stellar wind hides radio pulsar

PSR B1259-63 orbits around massive star with a **circumstellar disc**

radio flaring at periastron from interaction but pulsations eclipsed by dense material

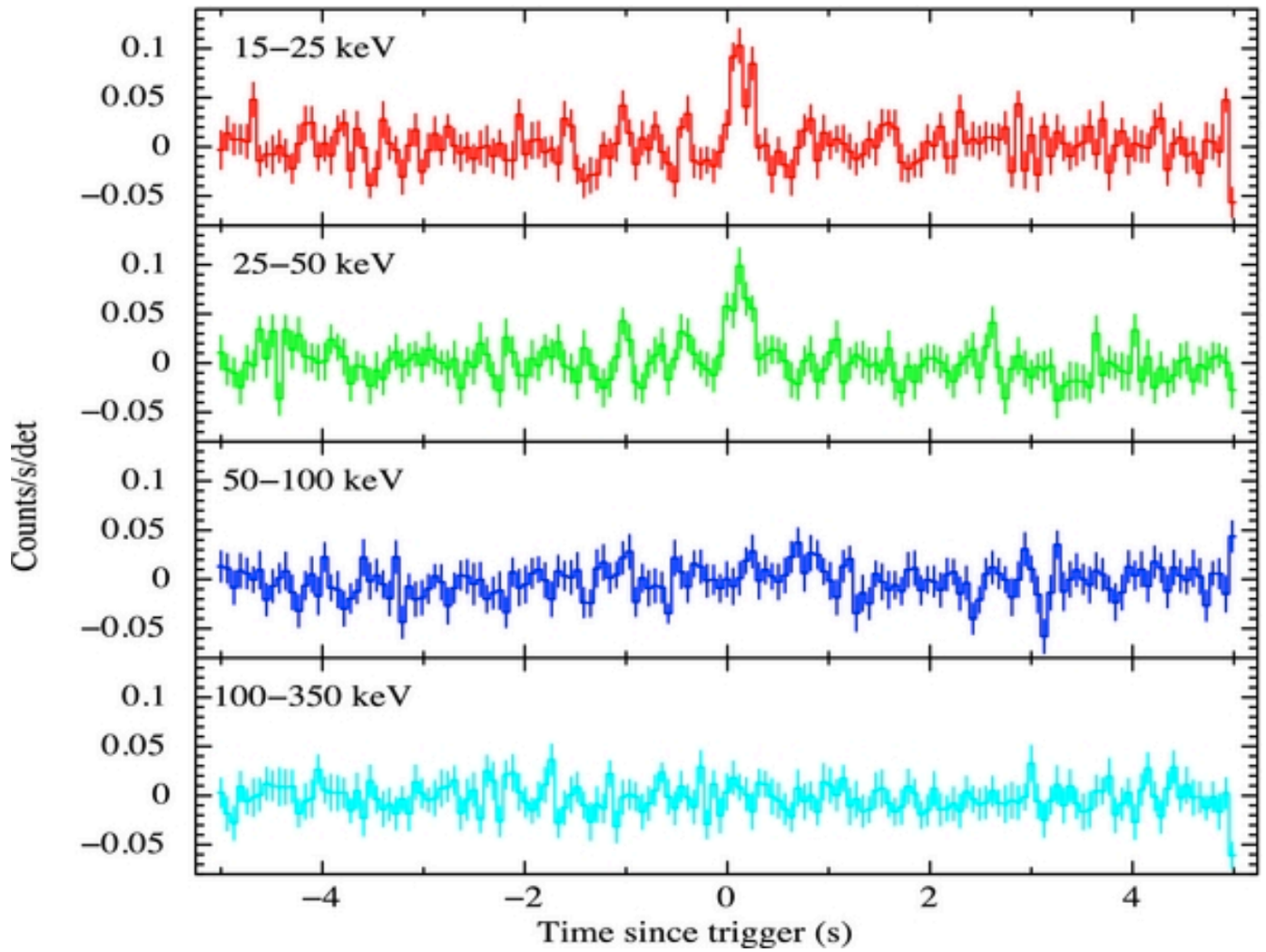


Miller-Jones+ 2018

Magnetar-like bursts from LS I+61 303

Swift BAT burst alerts consistent with gamma-ray binary position

Barthelmy+ 2008, GCN 8215, Burrows+ 2012, GCN 12914, see also GD 2010



Torres+2012

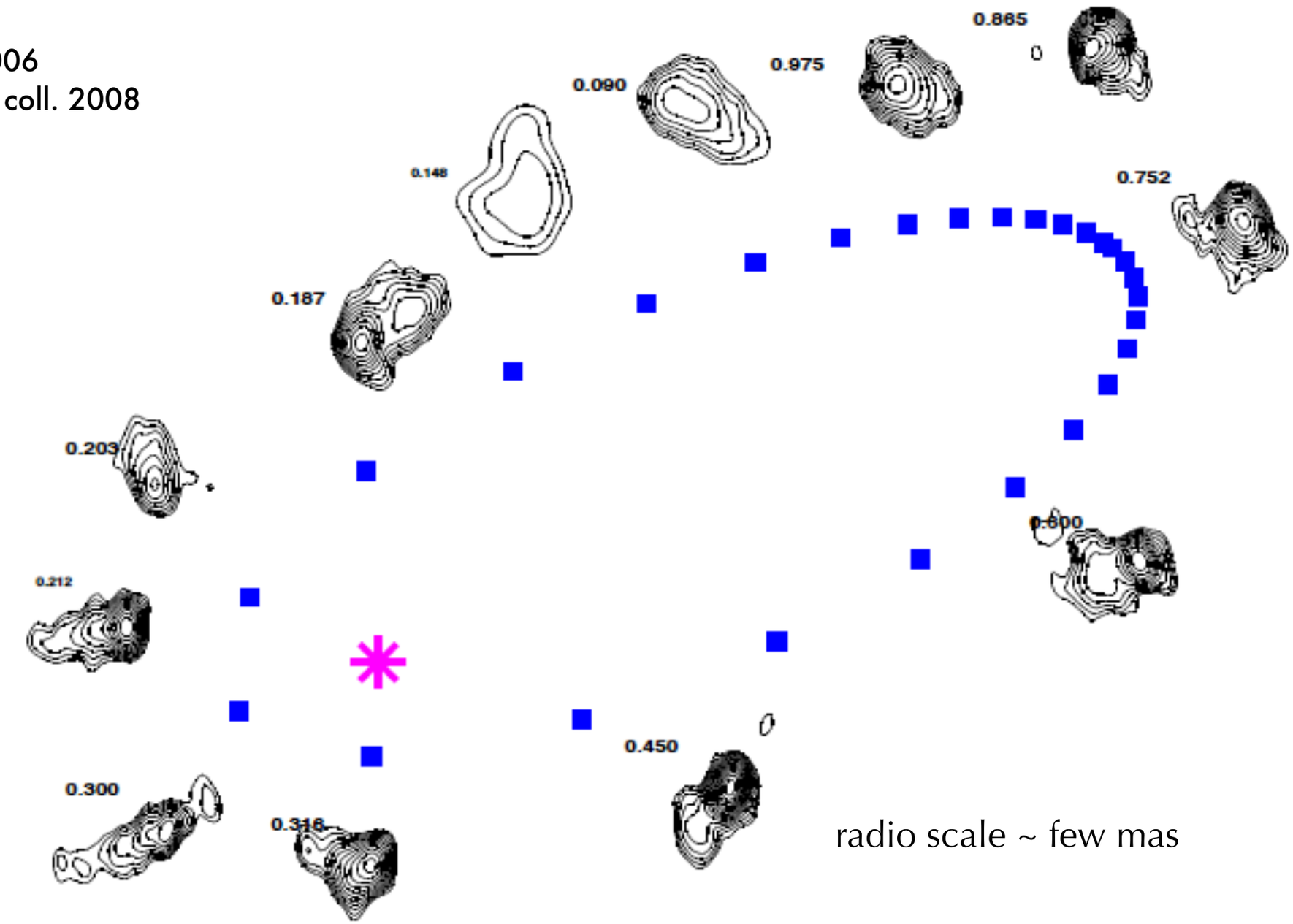
duration < 0.3 s ; L ~ (3-10) x 10^{37} erg/s
7.5 keV blackbody R ~ 200 m (at 2.6 kpc)

LS I+61 303 radio maps

Orbital modulation in “tail” direction not expected from a relativistic jet

natural in binary pulsar wind nebula

Dhawan+ 2006
also MAGIC coll. 2008

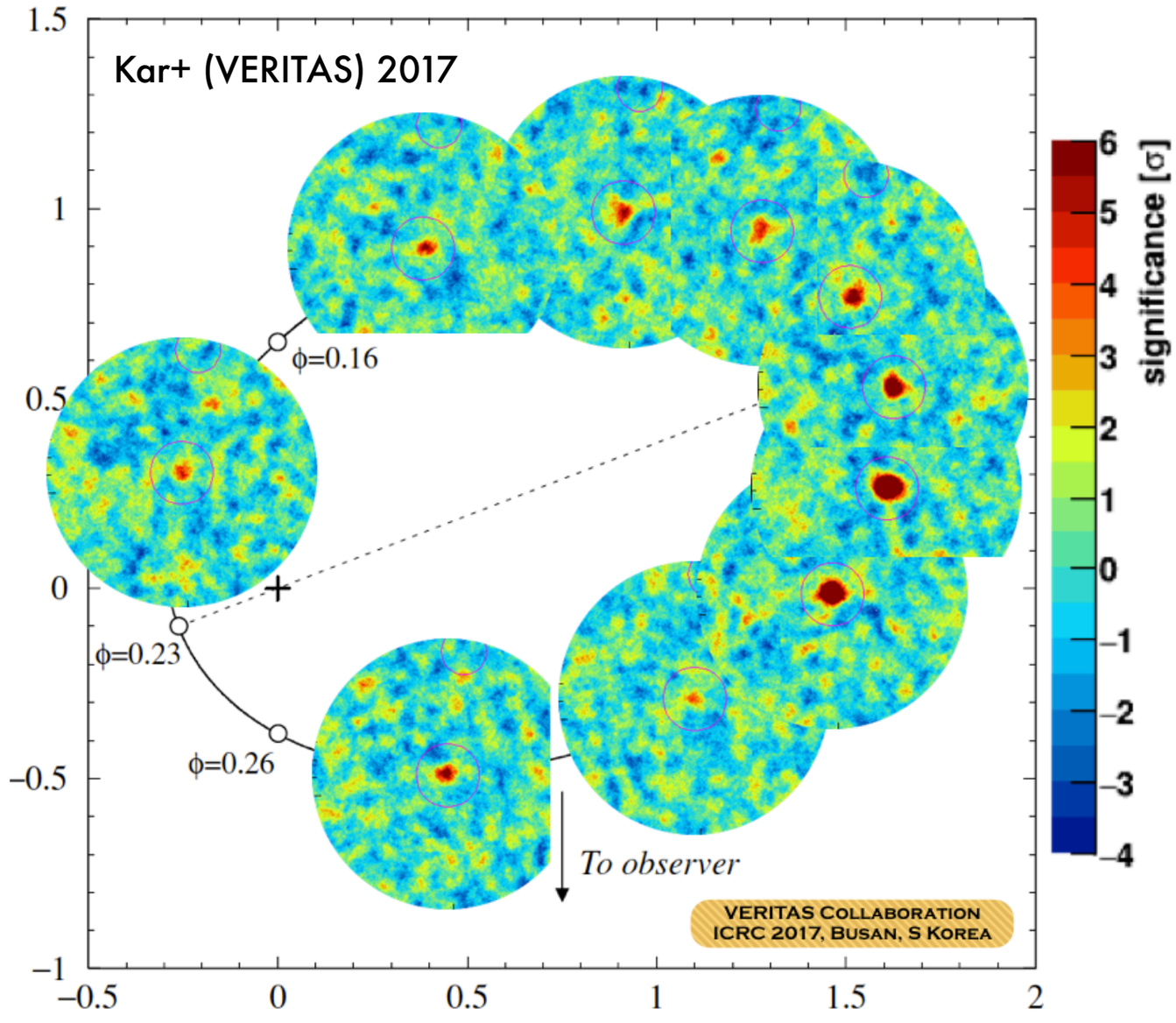


radio scale ~ few mas

LSI orbital modulation of the VHE flux MAGIC coll. 2009

Orbital modulation probably not a purely geometrical effect (anisotropic IC, pair prod.)

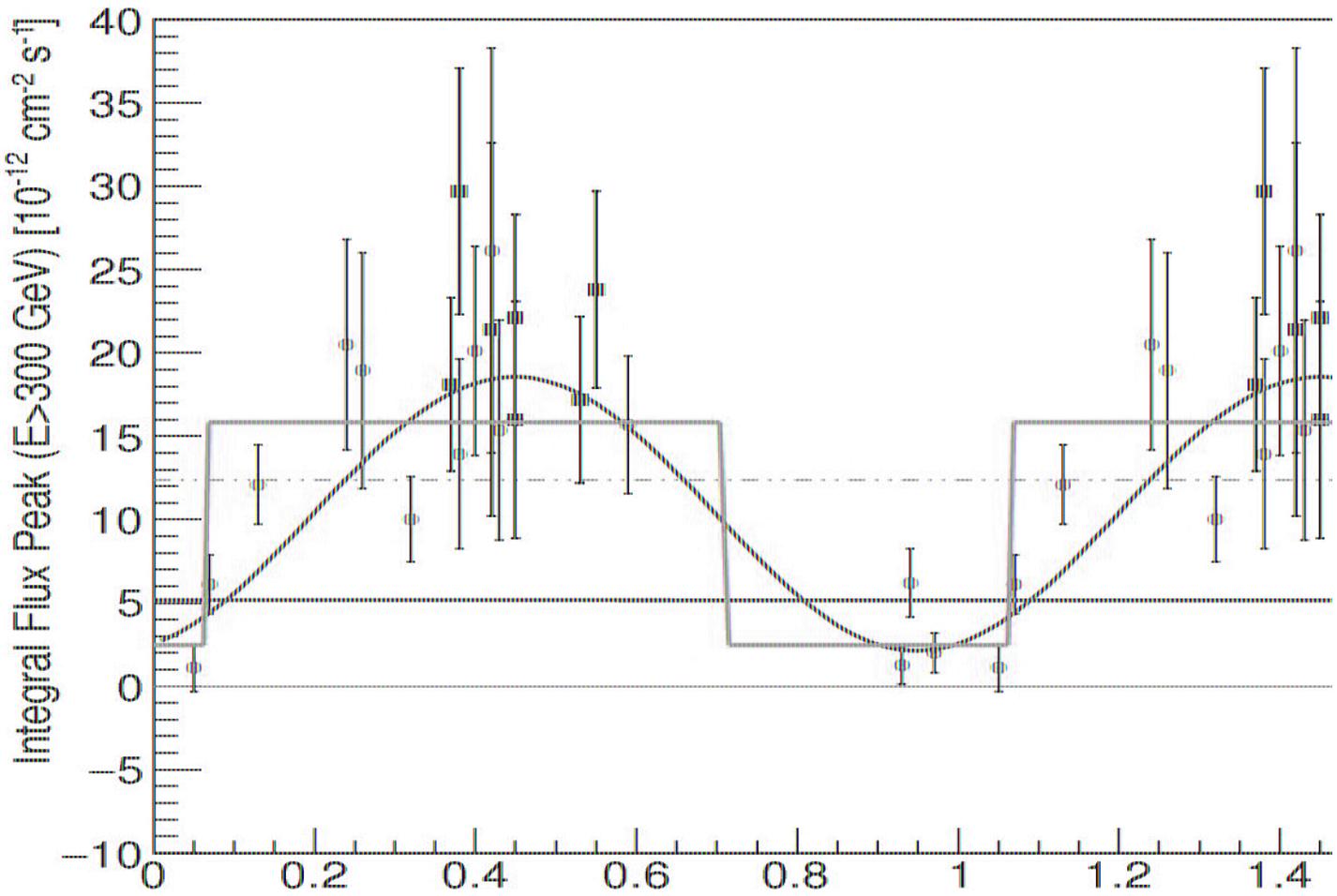
Neutron star "flip-flopping" between propeller and ejector ? Zamanov 1995, Torres+ 2012



Superorbital modulation of the flux

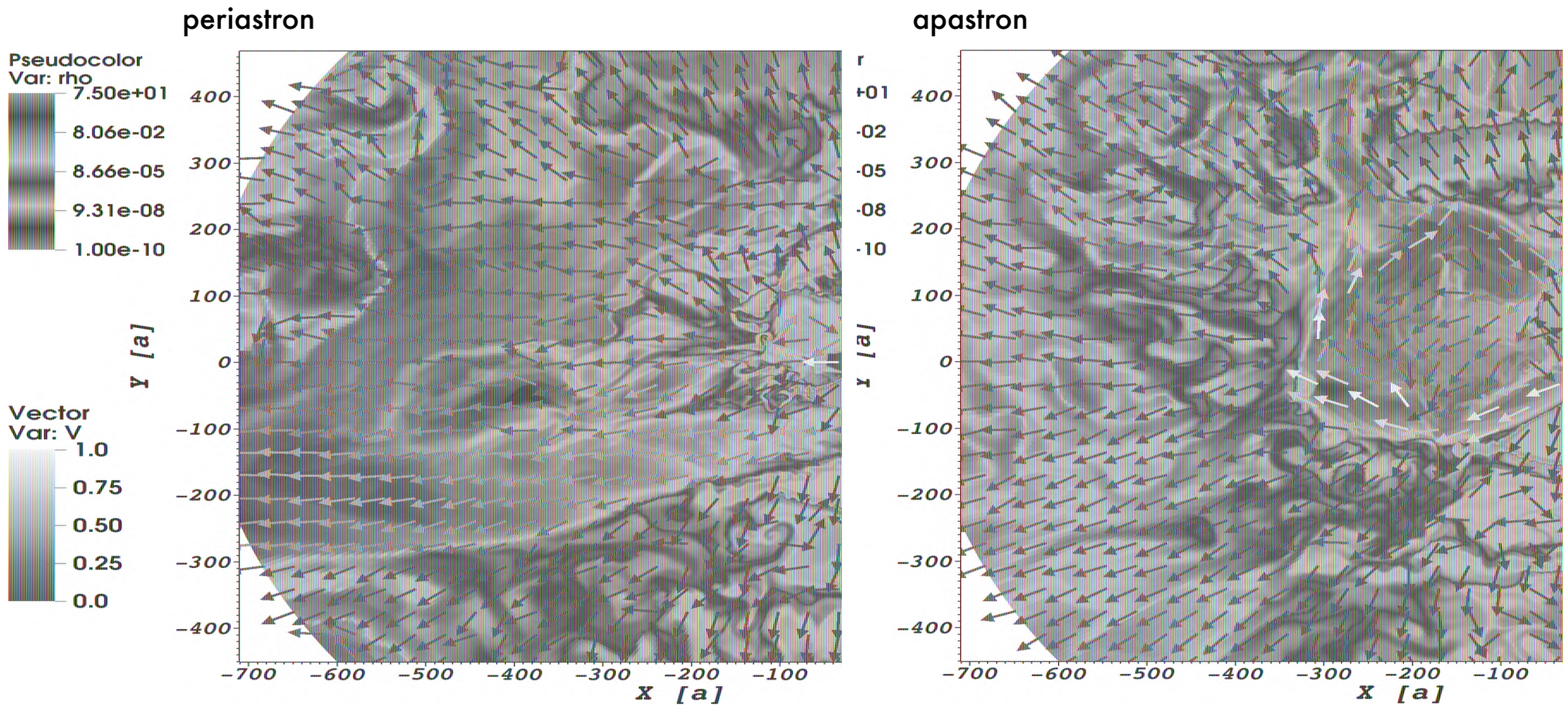
Maximum VHE flux changes with 4.5 yr superorbital cycle (linked to Be disc cycle ?)

MAGIC coll. (2016)



Complex large scale wind interaction

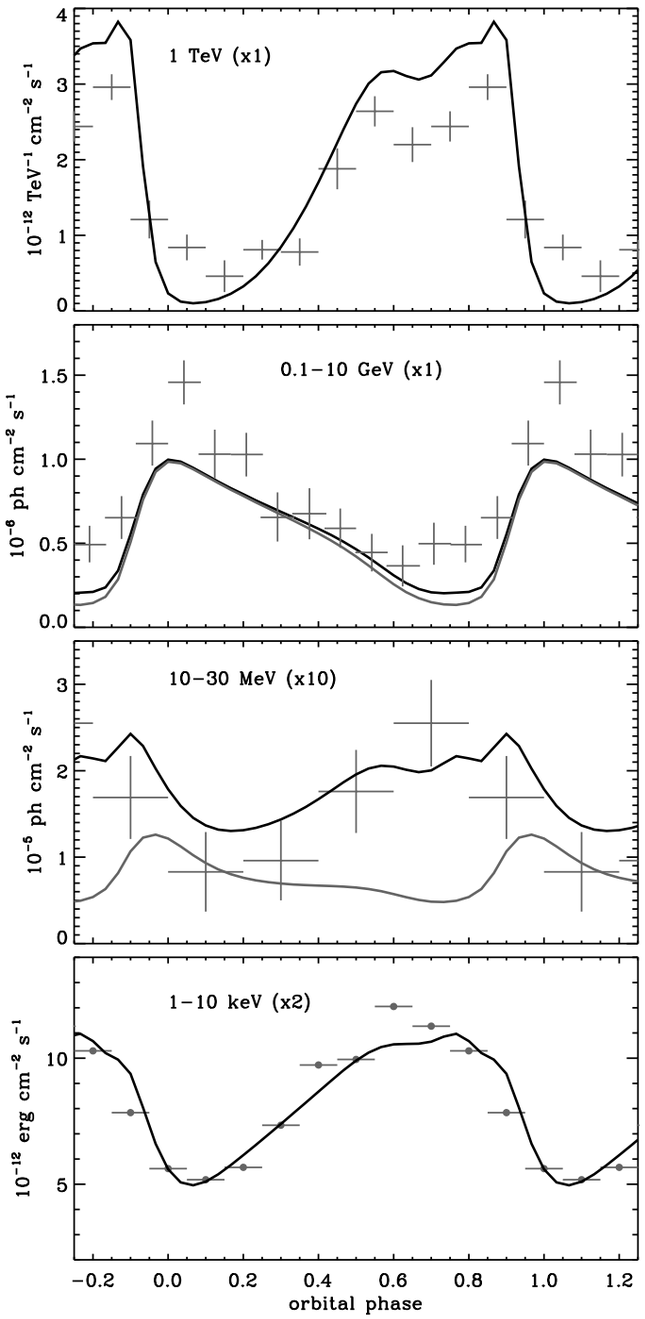
Numerical simulations required but very costly (3D, instabilities, relativistic, radiation…)

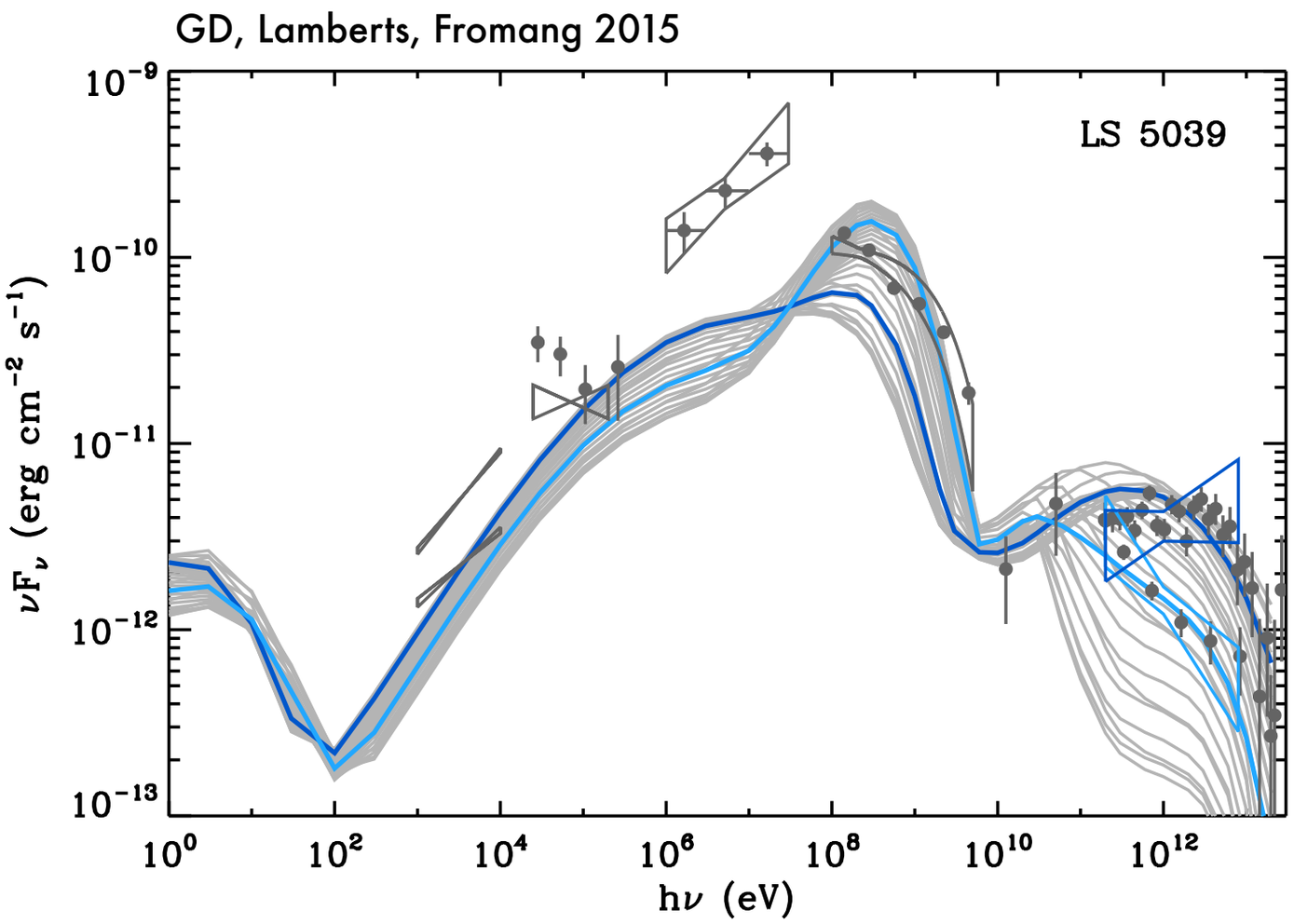


Barkov & Bosch-Ramon 2018

Modelling VHE spectra & orbital variability

Relativistic hydro simulation of LS 5039 (easier: no Be disc!) + emission in post-processing



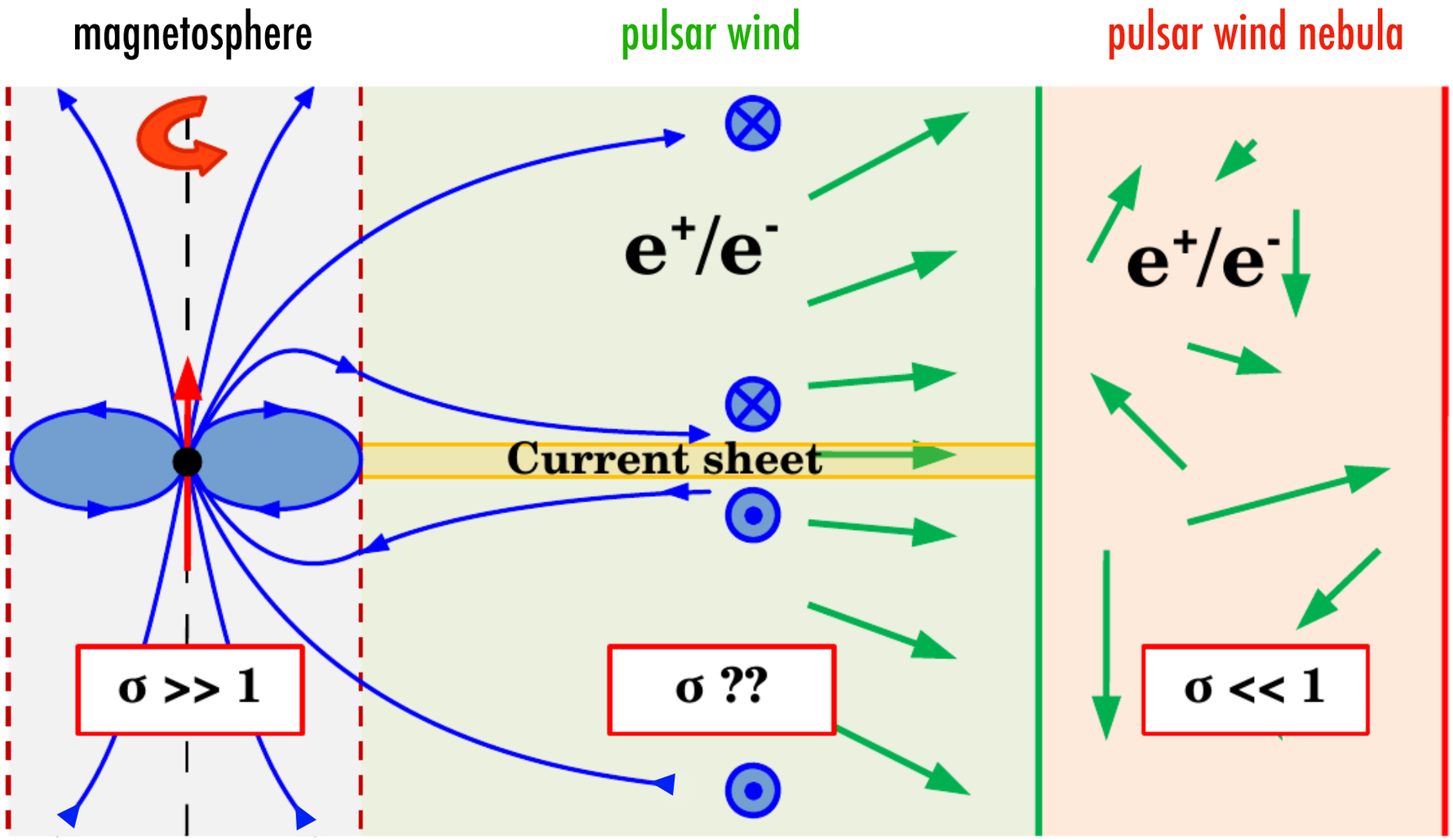


need injection of multiple populations of high-energy e-

high B, hard power-law suggest magnetic reconnection

Probe of pulsar wind region

Binaries provide new probe of particle acceleration in pulsar wind and its nebula



Cerruti & Philippov 2017

$$\sigma = \frac{B^2}{4\pi\Gamma n m_e c^2}$$

Population of gamma-ray binaries

LMC P-3

PSR B1259-63

LS 5039

LSI+61 303

HESS J0632+057

1FGL J1018.6-5856

PSR J2032+4127

How many are there?

How many can we expect to see?

Population of gamma-ray binaries

How many are there?

How many can we expect to see?

Population statistical study to evaluate detection rate based on flux variability & survey characteristics

GD+ 2017

Population of gamma-ray binaries

LMC P-3

PSR B1259-63

LS 5039

LSI+61 303

HESS J0632+057

1FGL J1018.6-5856

PSR J2032+4127

How many are there? 101^{+89}_{-52} systems

How many can we expect to see?

Fermi (2025): up to 8 new detections

CTA : up to 14 new detections

combine with eROSITA, SKA

GD+ 2017

15 years of MAGIC for binaries

- **VHE emission from binaries clearly established**
  - new window into jet physics and pulsar physics
- **MAGIC highlights: Cyg X-1 and LS I+61 303**
  - VHE is not an extrapolation of the HE domain
  - orbital modulations are key but dynamics complex
  - very much look forward to results on PSR J2032 !
- **A great legacy of binary observations**
  - novae ? colliding wind binaries ? transitional millisecond pulsars ?