Unveiling the nature of compact binary systems

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SAp – AIM, Postdoc Seminar, 29th September 2015


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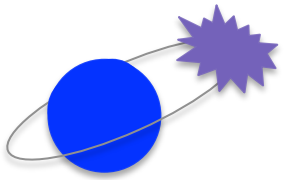
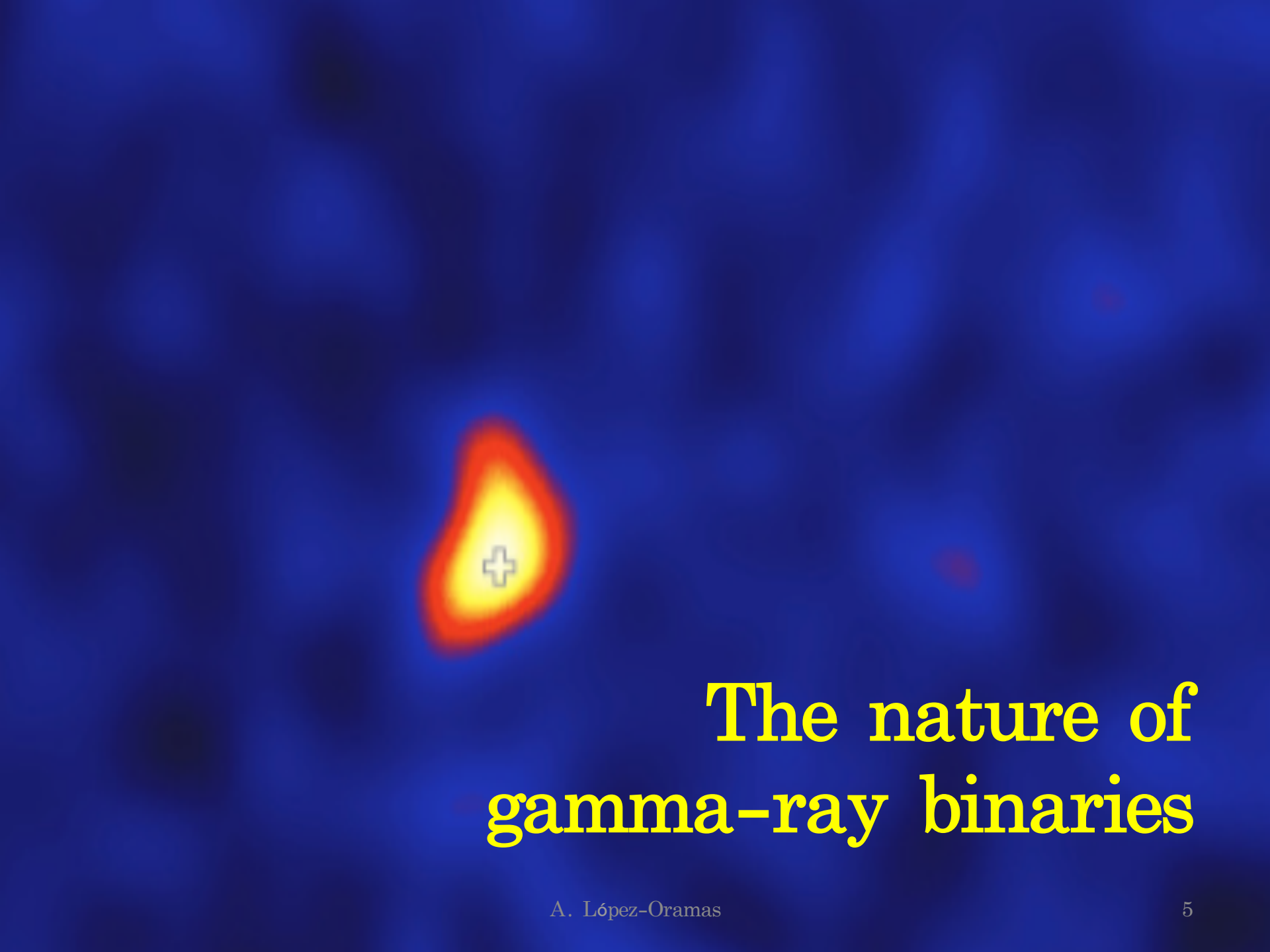
Observatorio del Roque de Los Muchachos (La Palma)

OUTLINE

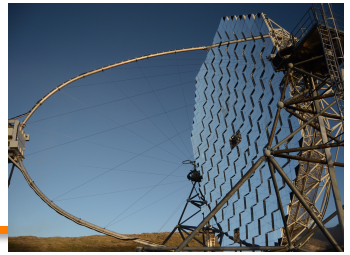


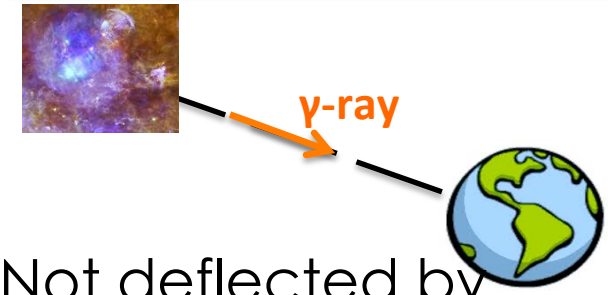
- **The nature of gamma-ray binaries**
  - VHE gamma-rays and IACT technique
  - Gamma-ray binaries
    - Multi-year Campaign of LS I +61° 303
    - Search for VHE Emission from Gamma-ray candidates:
      - MWC 656
      - SS 433
- **The nature of Swift J1745-26**
- **Future work**



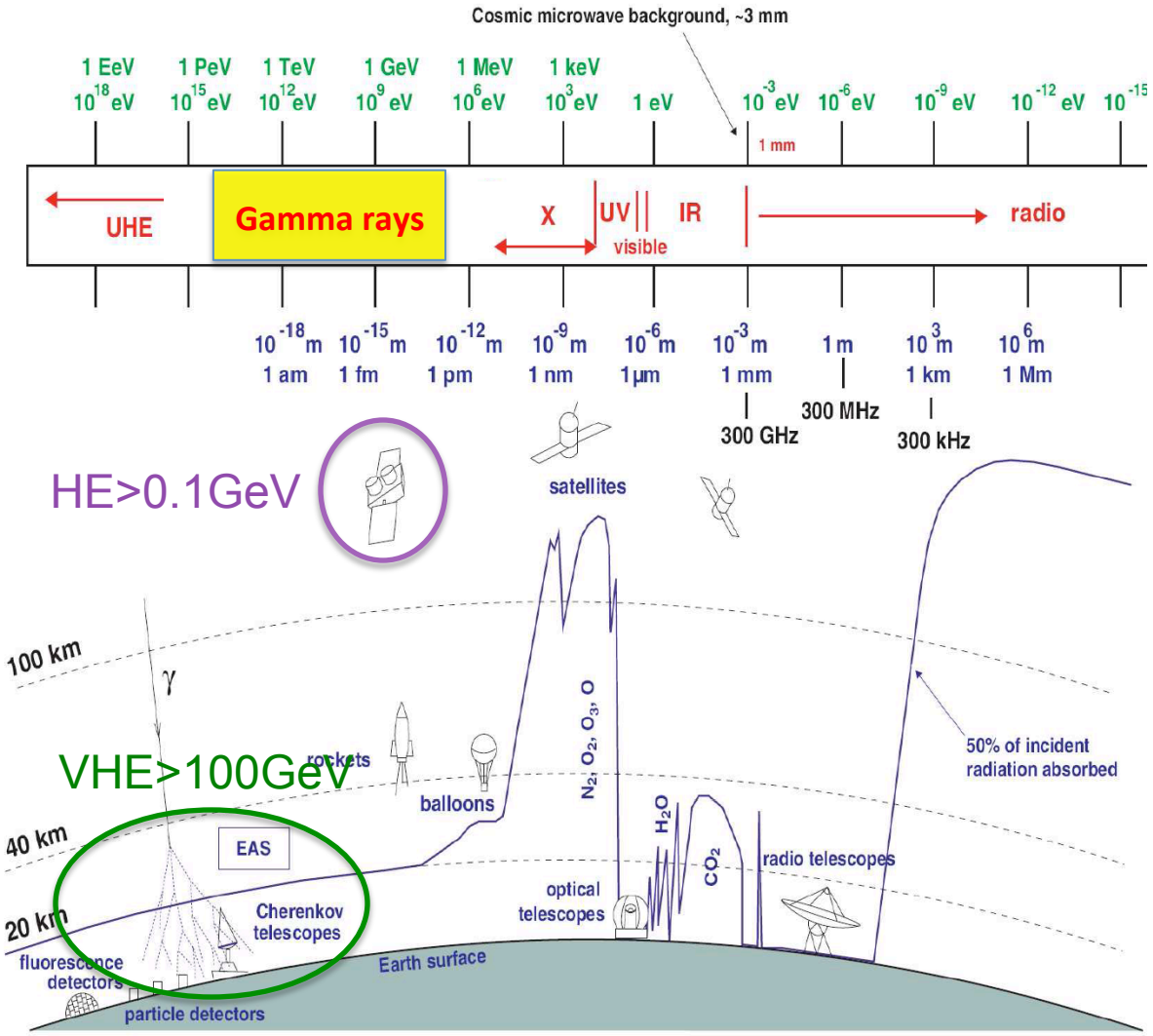
The nature of gamma-ray binaries

Gamma Rays



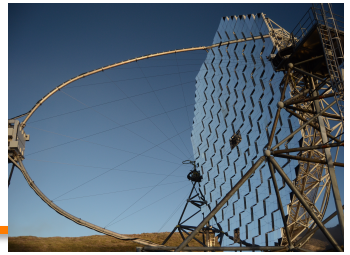


- Not deflected by magnetic fields
- Non-thermal processes
- Provide information:
  - Sources of origin (SNRs, AGNs, GRBs…)
  - Production mechanisms
  - Characteristics of the intergalactic/stellar medium
  - Studies of fundamental physics

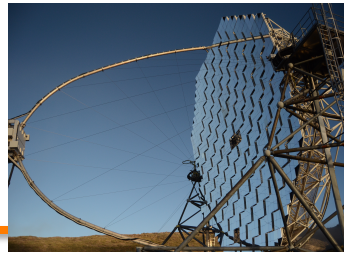


Longair, 1992

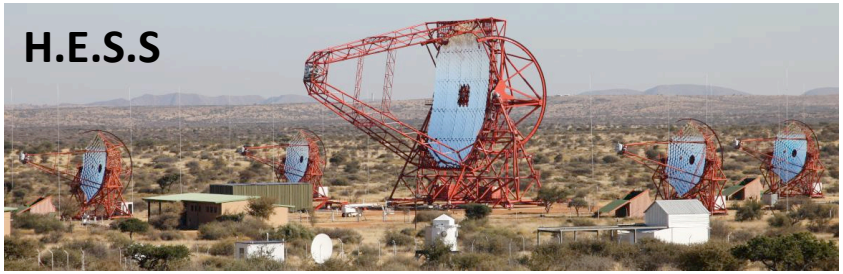
VHE γ -ray detection: Extensive Air Showers (EAS)

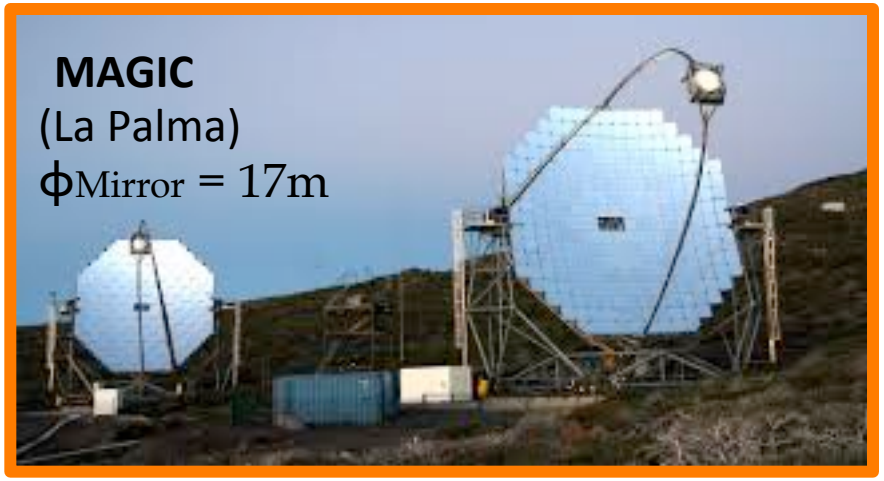


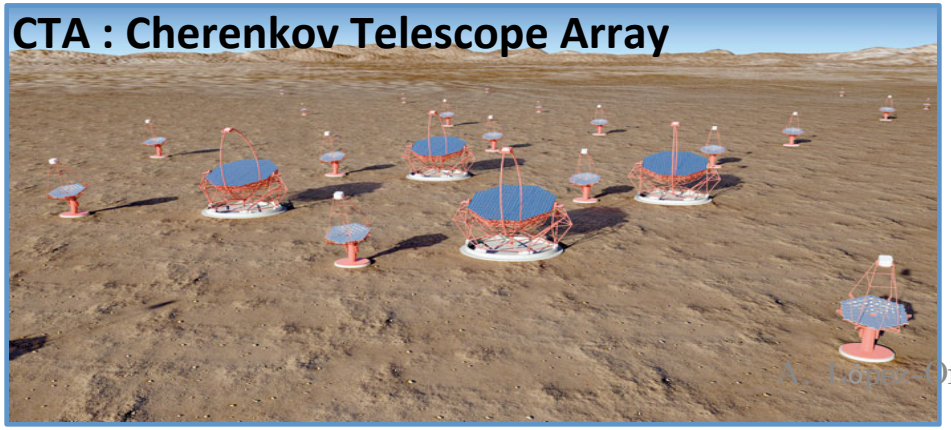
VHE γ -ray detection: The IACT Technique



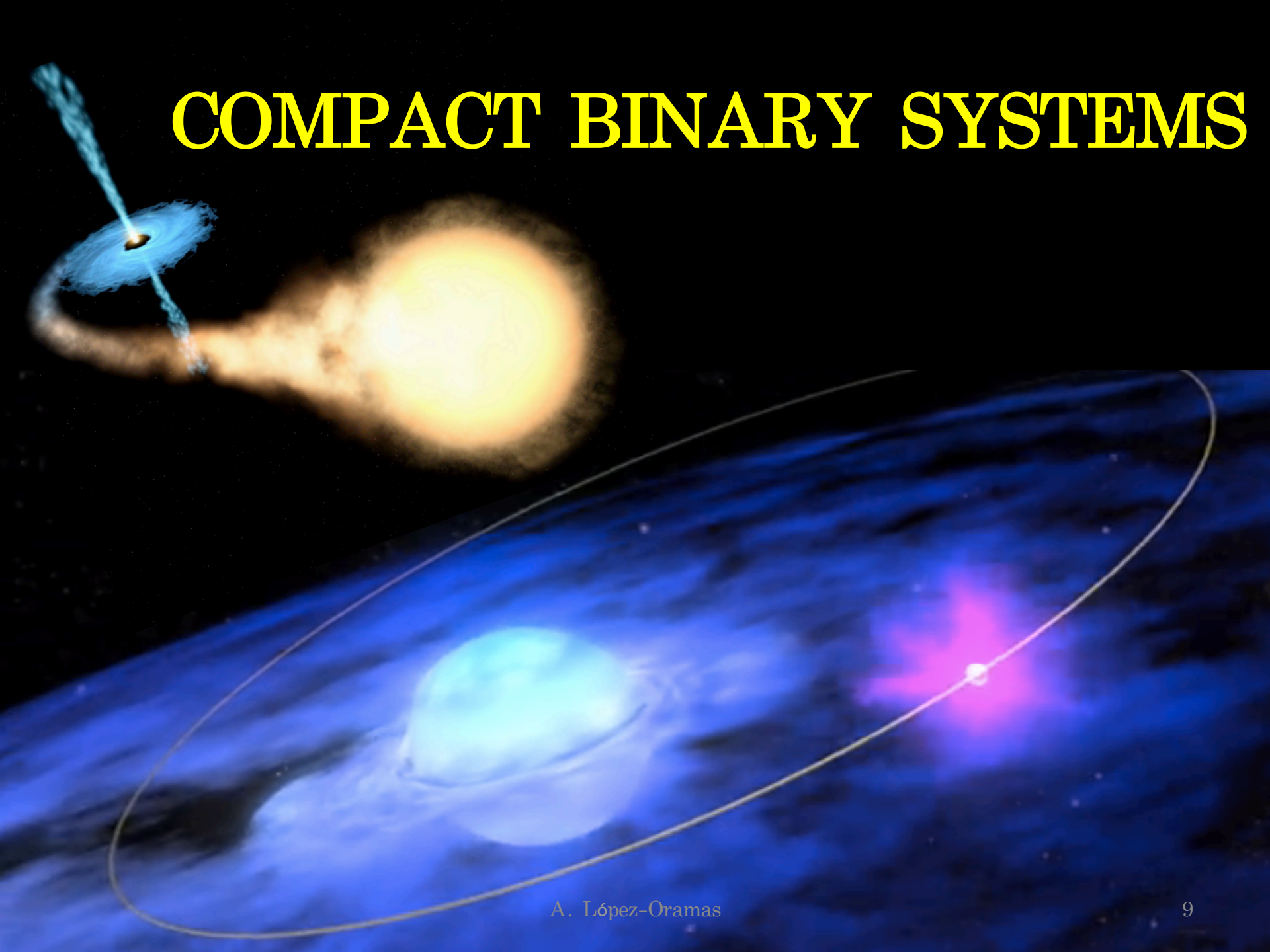
- Indirect detection: Imaging Air Cherenkov Telescopes (IACT)
- Cherenkov flashes emitted in EAS
- Characteristics:
  - Large collection areas
  - Highly sensitive pixelized camera (PMTs)
  - Fast trigger system and readout electronics







COMPACT BINARY SYSTEMS



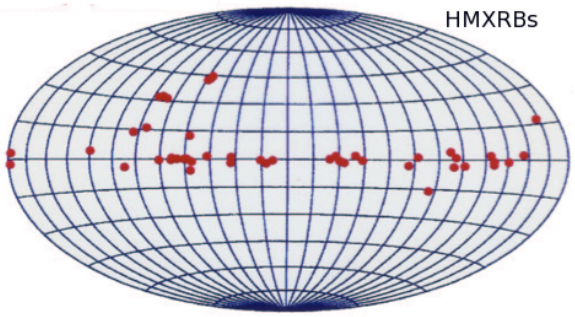
Compact Binaries

Star + compact object : neutron star (NS) or black hole (BH)

- Most of these systems are X-ray emitters: X-ray binaries (XRB)

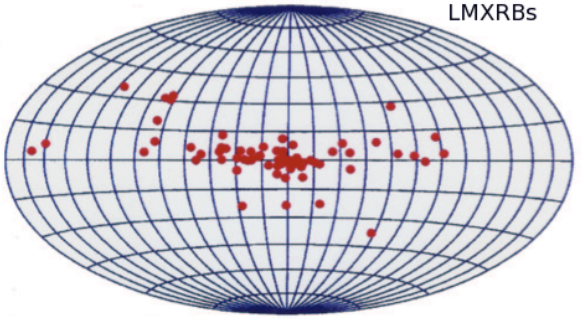
HMXRB ($M>10M_{\odot}$)

- Early spectral type : O, B, A…
- Hard X-ray spectra
- Majority: NS (~4% BH candidates)
  - Supergiant (OB)
  - Be (B star + circumstellar disk)



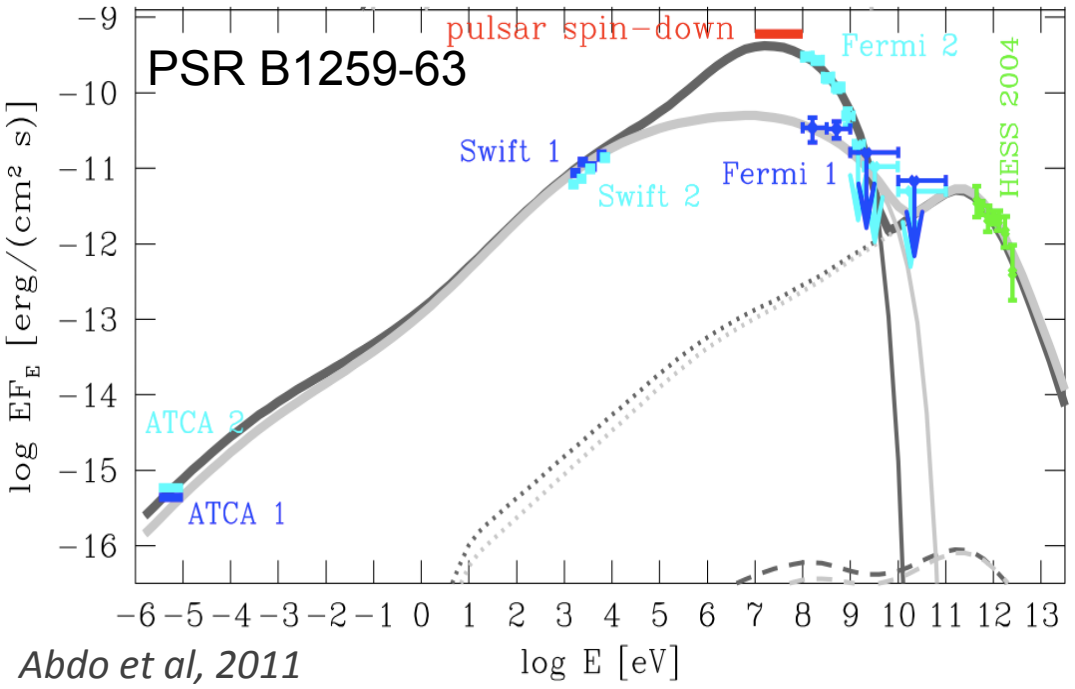
LMXRB ($M<1M_{\odot}$)

- Late spectral type: K, M…
- Soft X-ray spectra
- Majority: BH
- Transient emission:
  x-ray nova/x-ray transients



http://www.physics.utah.edu/~whanlon/spectrum.html

Gamma-ray Binaries



Abdo et al, 2011

- Compact binary: Star + compact object (NS/BH)
- Emit HE and/or VHE γ-rays
- Bulk of the non-thermal emission in the γ-ray domain (E>1MeV)
- **Only 5 systems known up to date!**

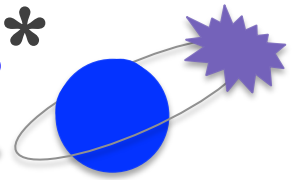
- ✦ Massive companion star
- ✦ Similar spectra & γ-ray emission variability
- ✦ Non-thermal radio emission
- ✦ Moderate X-ray emission

Gamma-ray Binaries

Parameter	PSR B1259-63	LS 5039	LS I +61 303	HESS J0632+057	FGL J1018.6-5856
Star Spectral Type	Be	O	Be	Be	O
Compact Object	48 ms pulsar	-	-	-	-
Star mass $[M_\odot]$	31	23	12	16	31
Distance [kpc]	2.3	2.5	2.0	1.5	5.4
$P_{orb}[days]$	1236.72	3.91	26.49	315.50	16.58
$\phi_{periastron}$	0	0	0.23	0.967	-
$\phi_{sup.conj}$	0.995	0.080	0.036	0.063	-
$\phi_{inf.conj}$	0.048	0.769	0.267	0.961	-
eccentricity	0.87	0.35	0.54	0.83	-
inclination	19–31	13–64	10–60	47–80	-
HE emission	∼P	P	P	-	yes
VHE emission	P	INFC	A	∼A	yes

- Cyg X-3 : WR+BH(?), HE emission, but HMXRB
- Cyg X-1 : O+BH, 4σ at VHE
- MWC 656 : AGILE > 100 MeV

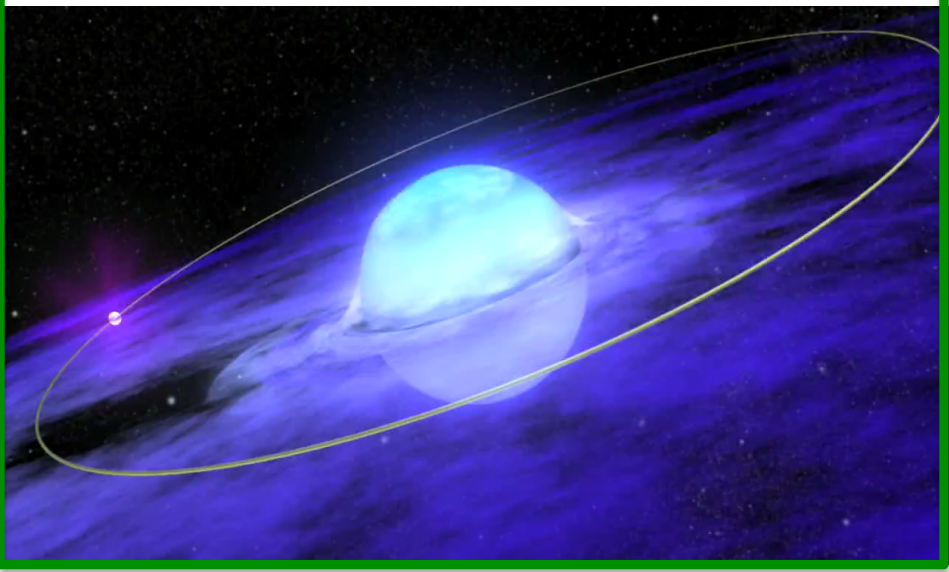
Gamma-ray Binaries : Scenarios*



Pulsar-wind

- Rotation-powered highly magnetized pulsar
- Pulsar wind+stellar wind
- IC: UV photons to gamma

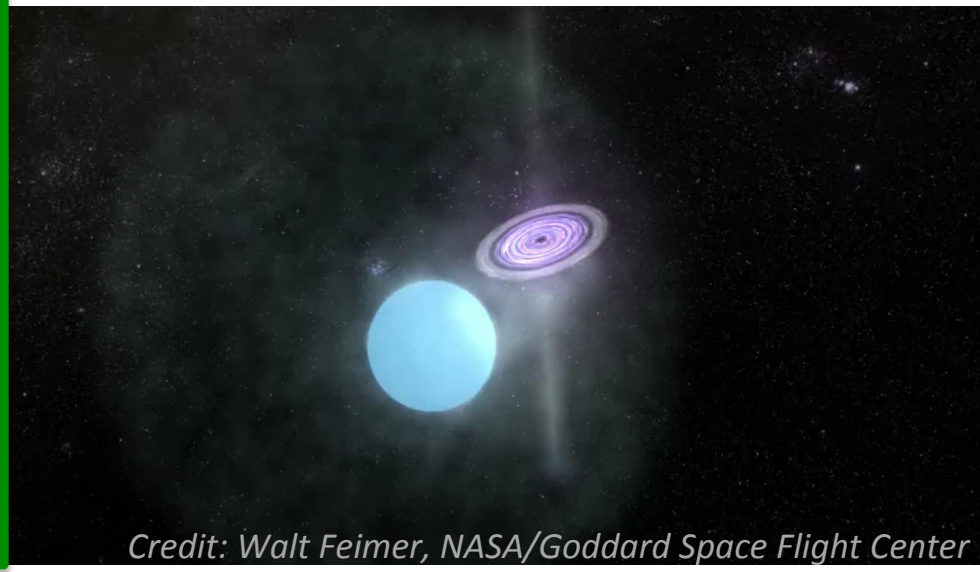
Lack of pulsations



Microquasar

- Accretion onto compact object (NS/BH)
- Ejection of plasma in jets
- Synchroton emission

Lack of jets



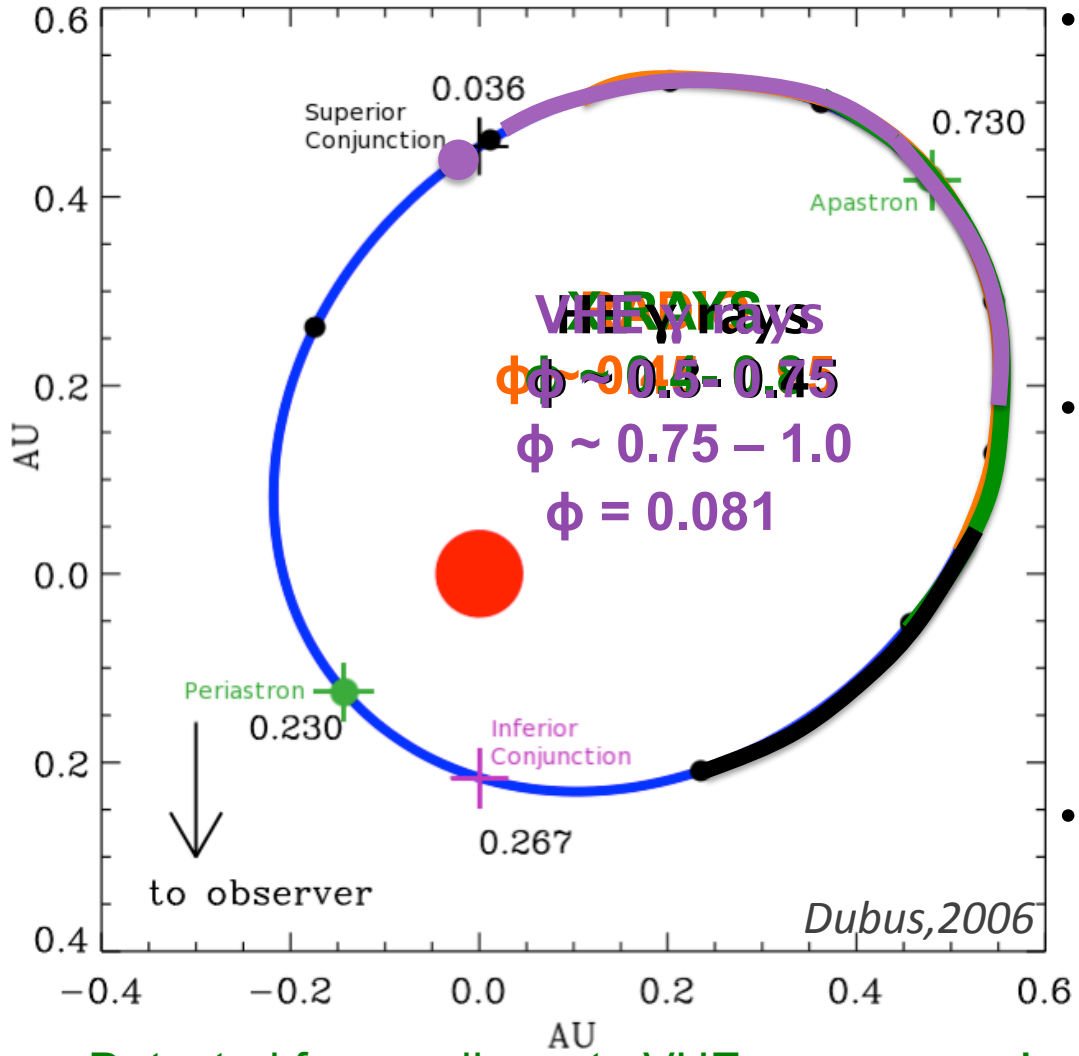
*Mirabel (2006)

Gamma-ray Binary:

LS I +61° 303

MAGIC Collaboration (submitted)
López-Oramas as corresponding author

LS I +61° 303 : The system

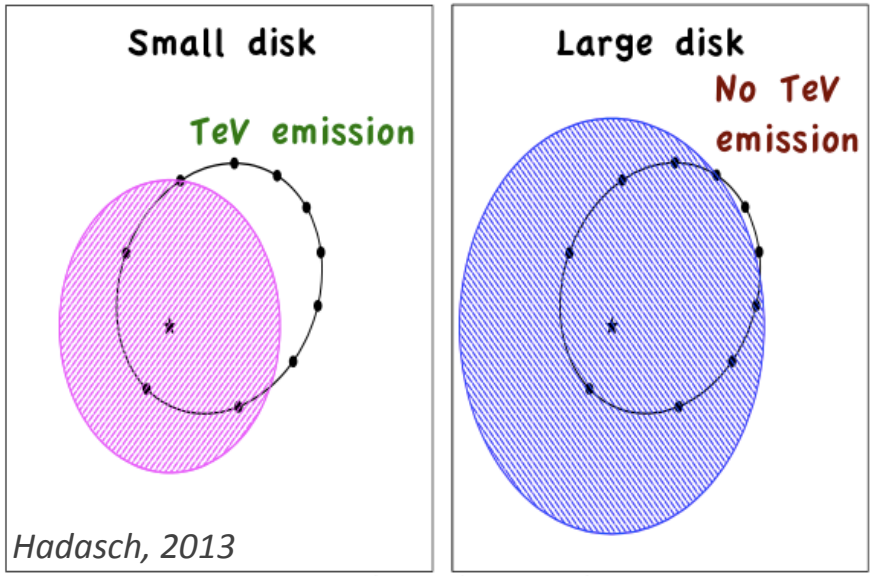


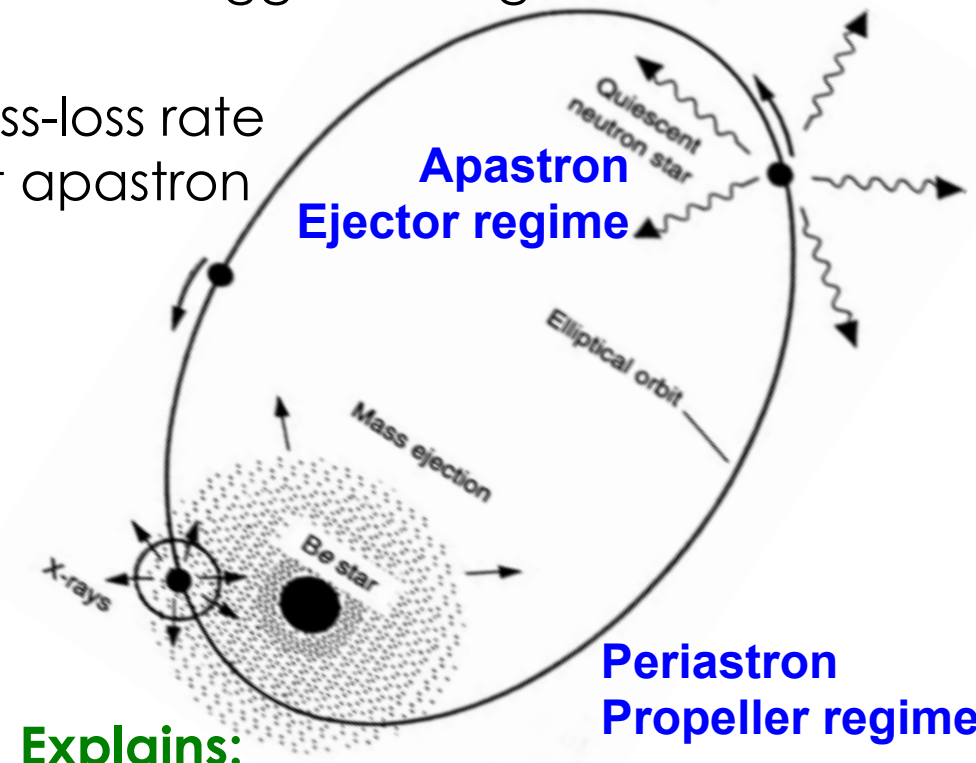
- Be star + unknown compact object (NS/BH)
  - Star type: B0Ve (circumstellar disk)
  - Star mass: ~ 10$M_{\odot}$
  - Compact object mass: 1 -5 $M_{\odot}$
- Orbital parameters:
  - Period: 26.496 ± 0.0028 days *(Gregory et al. 2002)*
  - Super-orbital period: 1667 ± 8 days *(Gregory et al. 2002)*
  - i = 10 – 60°
  - e = 0.537 ± 0.034 *(Aragona et al. 2009)*
- Gamma-ray emission
  - VHE discovered by MAGIC *(MAGIC Coll. 2006)* subsequent observations by MAGIC and VERITAS
  - HE discovered by Fermi *(Fermi Coll., 2009)*

Detected from radio up to VHE gamma rays!

Interpretation

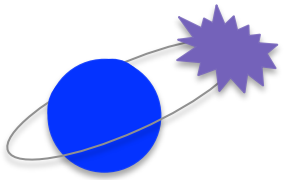
- Flip-flop magnetar model *(Torres al. 2012)*
- Inter-wind shock: pulsar wind + star wind= acceleration up to TeV
- Orbital : changes in the accreted mass trigger change from rotational-powered to accretor
- Super-orbital: changes in the mass-loss rate can set propeller regime even at apastron
- The larger the mass-loss rate, the lower VHE emission





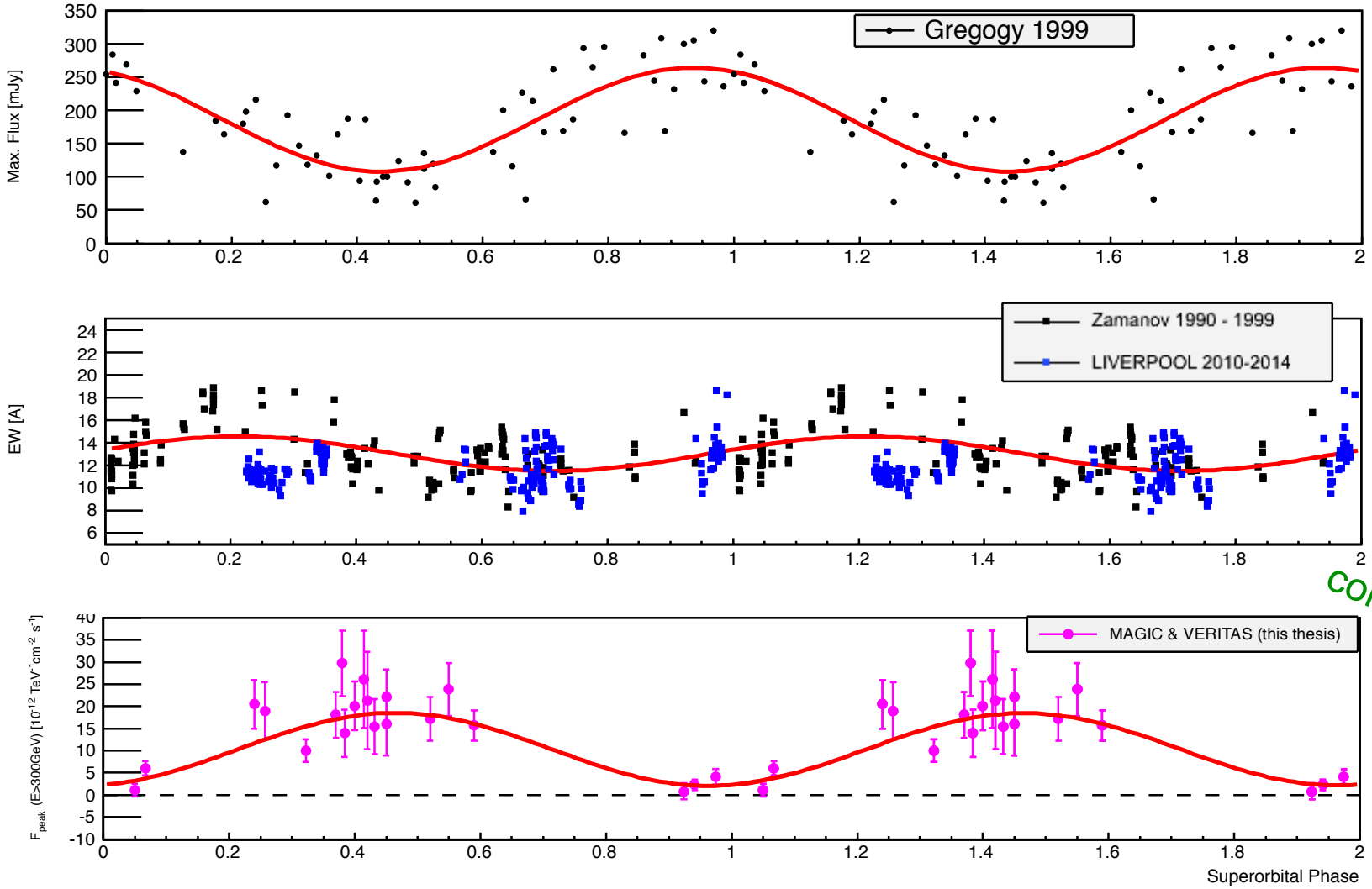
Explains:
- Orbital variability
- Super-orbital variability
- GeV-TeV anticorrelation

Questions to be answered



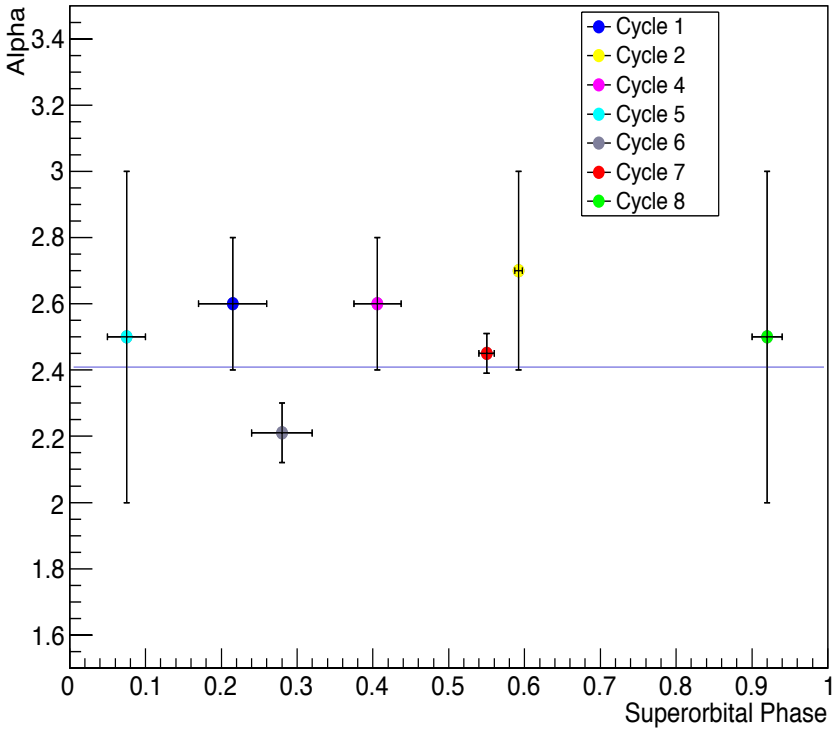
- What is it the origin of the outburst peak?
  - Is there a super-orbital modulation of the flux at VHE? Is it the same as found in another wavelengths?
- Is the same mechanism always in progress?
  - Is there spectral hardening/softening of the peak of the outburst?
- Does the VHE emission at all orbital phases have the same origin?
  - Is there a correlation between the mass-loss rate (measured through Hα) and the VHE emission?

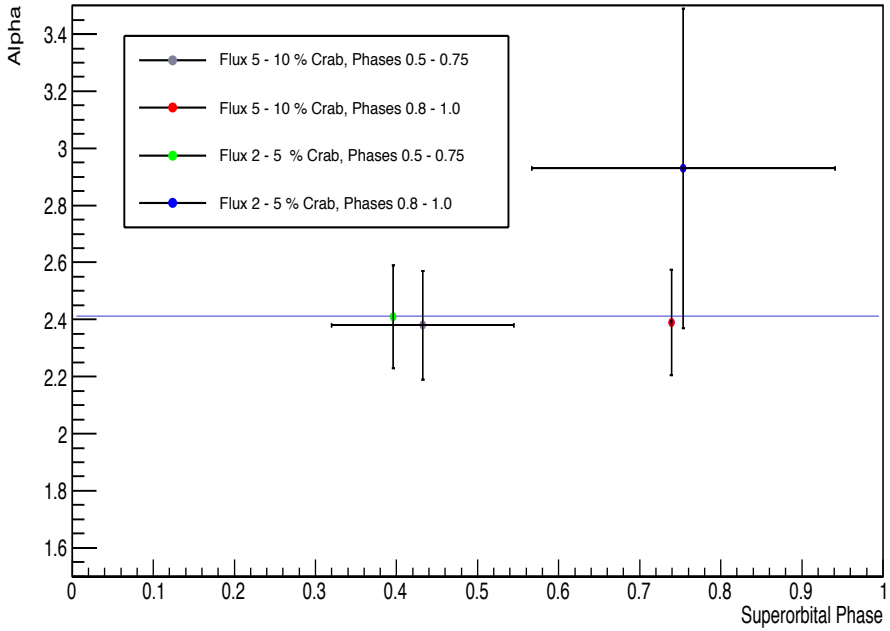
Super-orbital Modulation

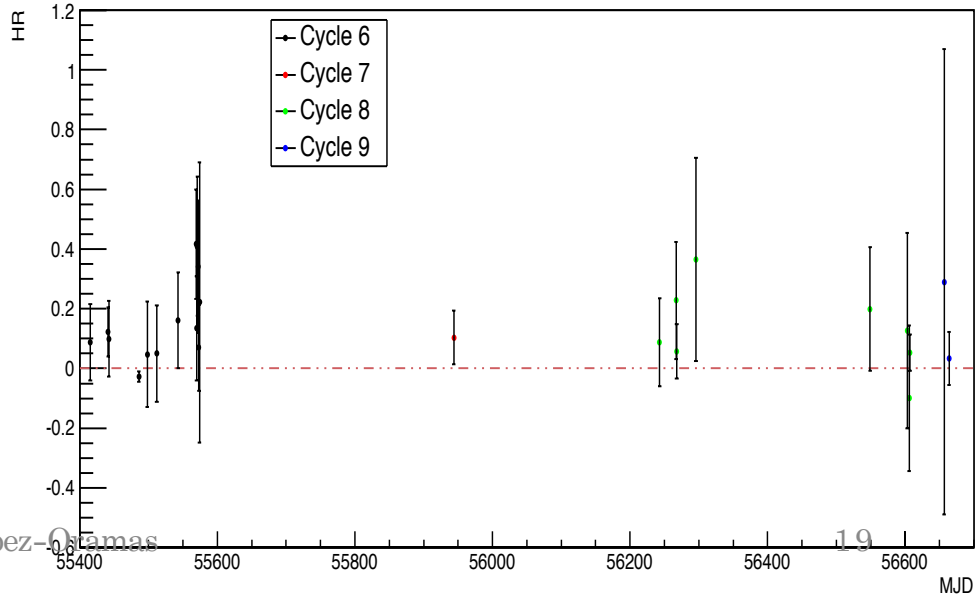


compatible

Spectral Variability

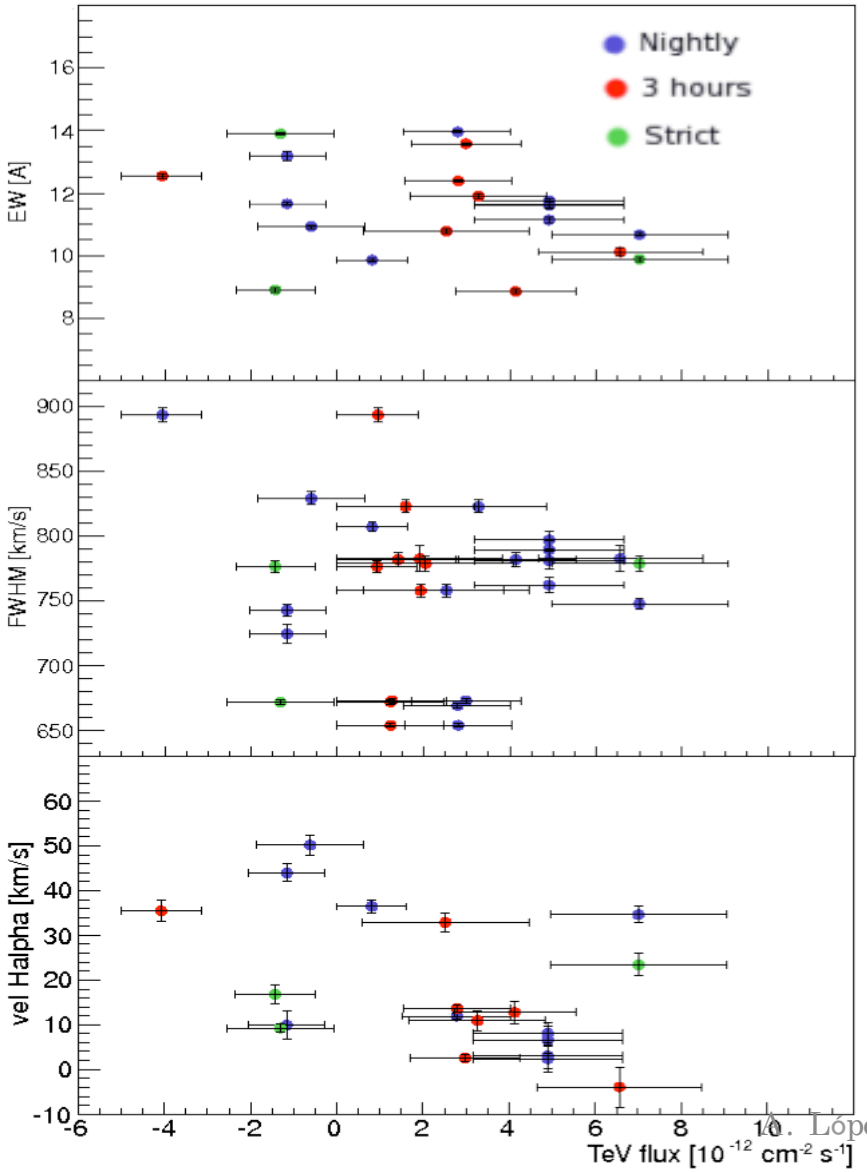






- Not possible to claim spectral variability
- Spectral index : 2.4 ± 0.1 (prob: 0.83)

Optical/TeV Correlation



Simultaneity	Parameters	r	Prob
Nightly	TeV - EW	-0.19	0.78
Nightly	TeV - FWHM	-0.15	0.70
Nightly	TeV - vel	-0.41	0.96
3 hours	TeV - EW	-0.28	0.77
3 hours	TeV - FWHM	-0.22	0.70
3 hours	TeV - vel	-0.41	0.87
Strict	TeV - EW	-0.27	0.58
Strict	TeV - FWHM	0.47	0.45
Strict	TeV - vel	0.79	0.30

- No significant correlation found
- Fast variability of the optical parameters
- Blurred correlation?
- Not possible to test the model

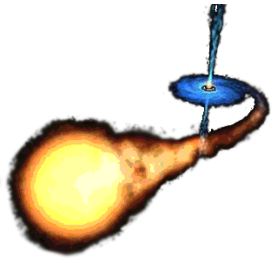
Gamma-ray Binary Candidates:

MWC 656 & SS 433

MAGIC Collaboration, A&A, 576, A36
López-Oramas, A. as corresponding author

H.E.S.S & MAGIC Collaborations, in preparation
López-Oramas as corresponding author

Gamma-ray Candidates

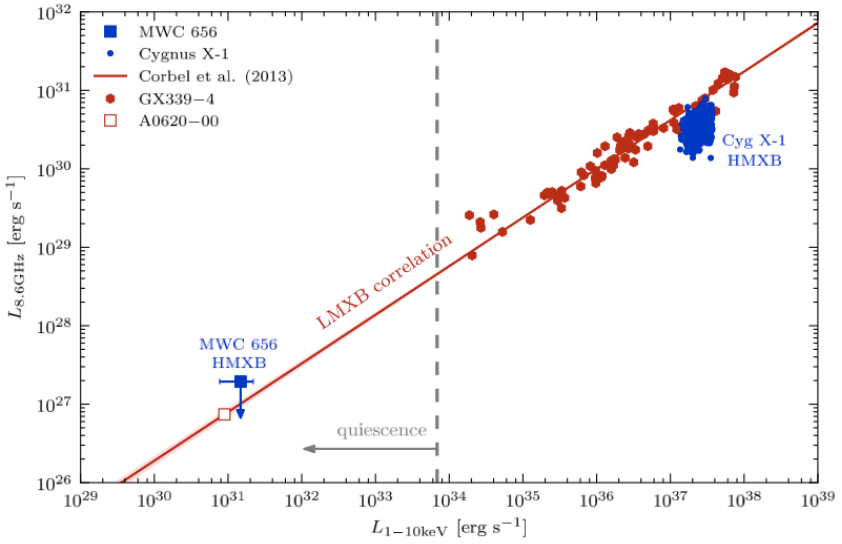


MWC 656

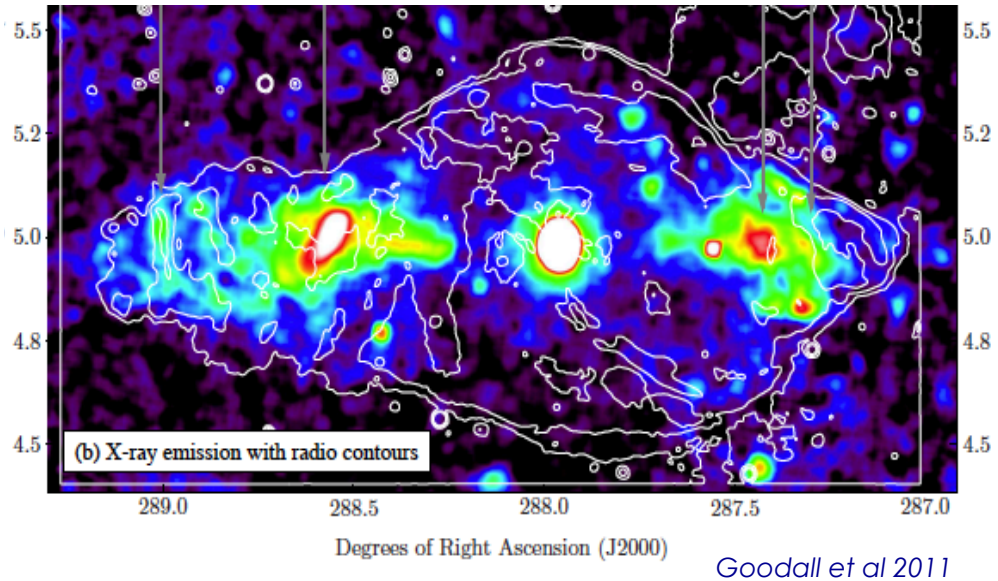
- Only Be/BH system yet known
- Emission detected by AGILE: gamma-ray triggered observations
- Low X-ray luminosity
- 23 h obs. time with MAGIC

SS 433

- Super-critical accretion
- Strongly-collimated hadronic persistent relativistic jets
- Embedded in W50
- 20 h obs. time with MAGIC

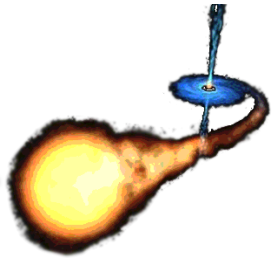


Munar-Adrover et al, 2014

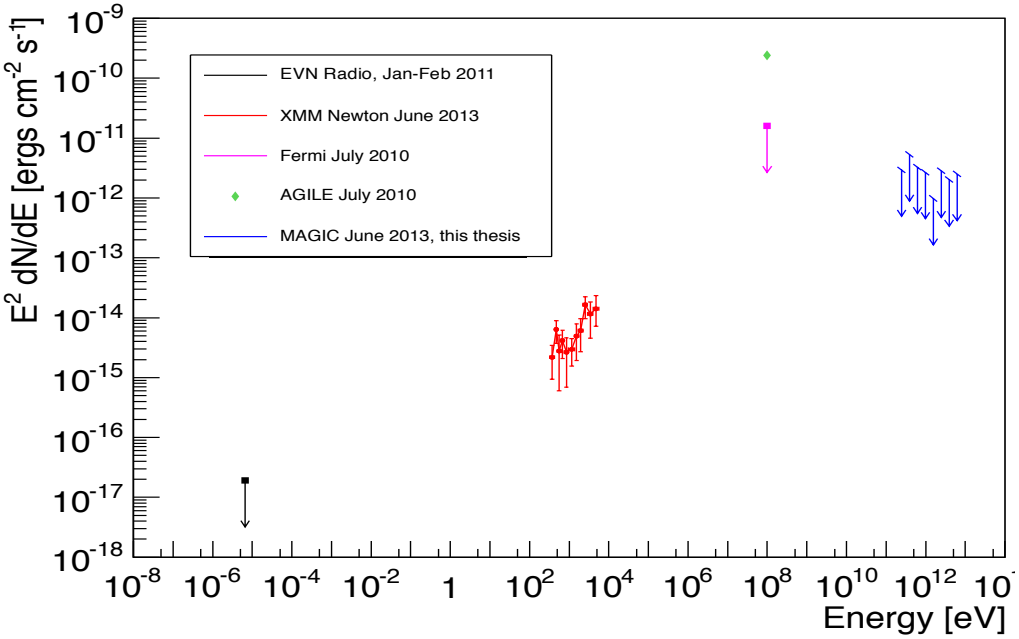


Goodall et al 2011

Gamma-ray Candidates



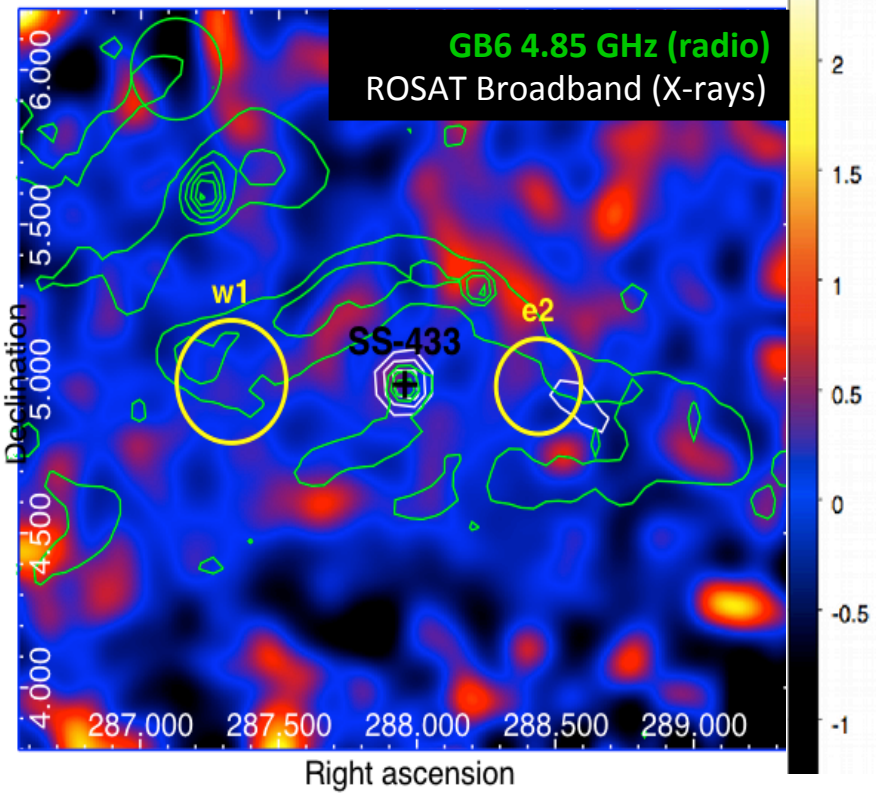
MWC 656



System in quiescence
Challenging to detect (CTA) by still a possible VHE gamma-ray emitter

SS 433

No significant VHE emission detected



Not possible to confirme/rule out models
Still VHE gamma-ray candidate

Conclusions: gamma-ray binaries

Gamma-ray binaries are complex systems

Only 5 (+ 3) up to date and not easy to detect gamma-ray emission from new compact binary systems

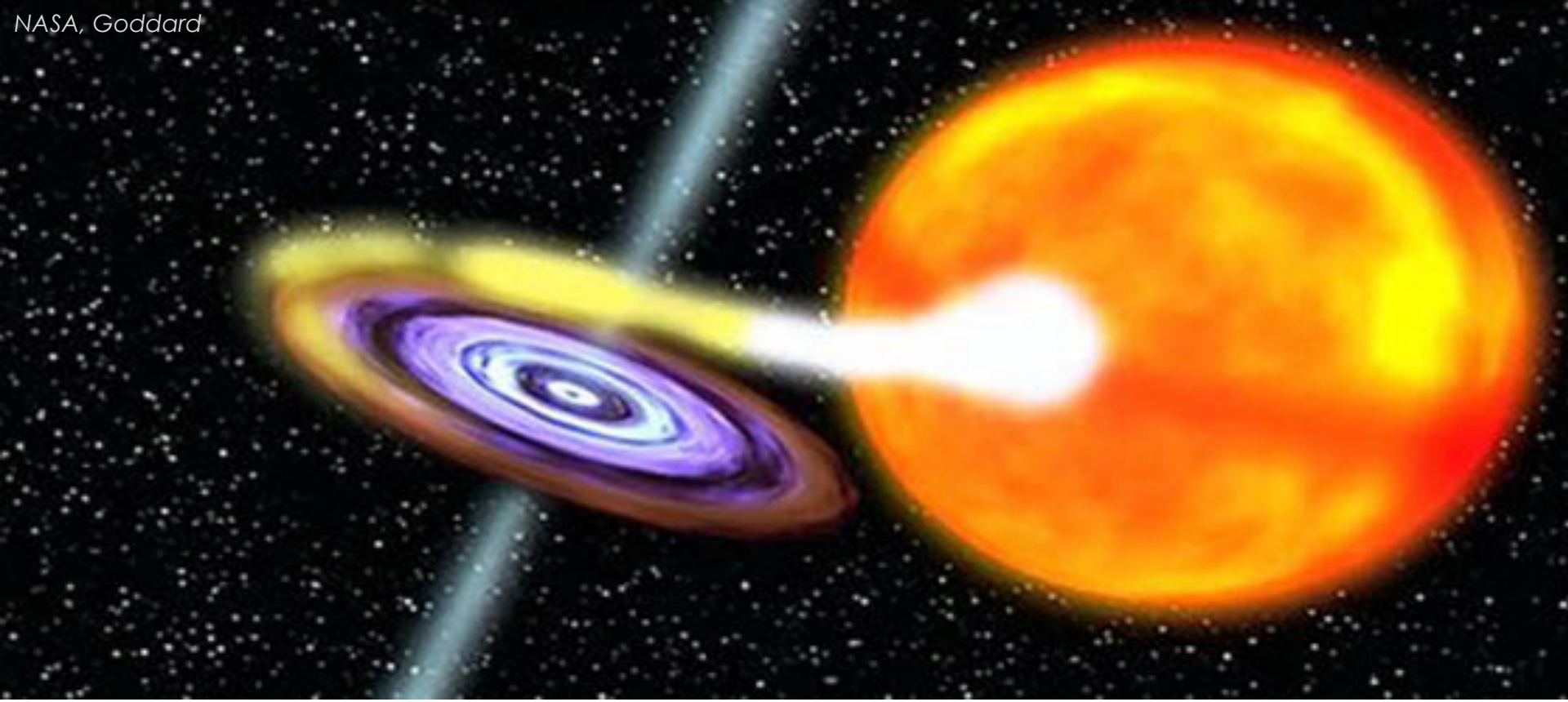
- Understading the behavior of **LS I +61° 303**:
  - Super-orbital modulation of the flux at VHE compatible with the period found at another wavelenghts: same origin?
  - No spectral variability: same mechanism in process
  - No correlation with mass-loss rate at sporadical emission phases: different mechanism?

Conclusions: gamma-ray binaries

Gamma-ray binaries are complex systems

Only 5 (+ 3) up to date and not easy to detect gamma-ray emission from new compact binary systems

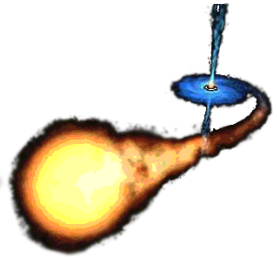
- Non-detection of microquasars :
  - **MWC 656**:
    - Steady emission too low at VHE
    - Flaring emission possibly detectable but challenging
    - SED
  - **SS 433**:
    - Constrains of physical values: q_{acc}, L_{kint}
    - Still a suitable gamma-ray candidate

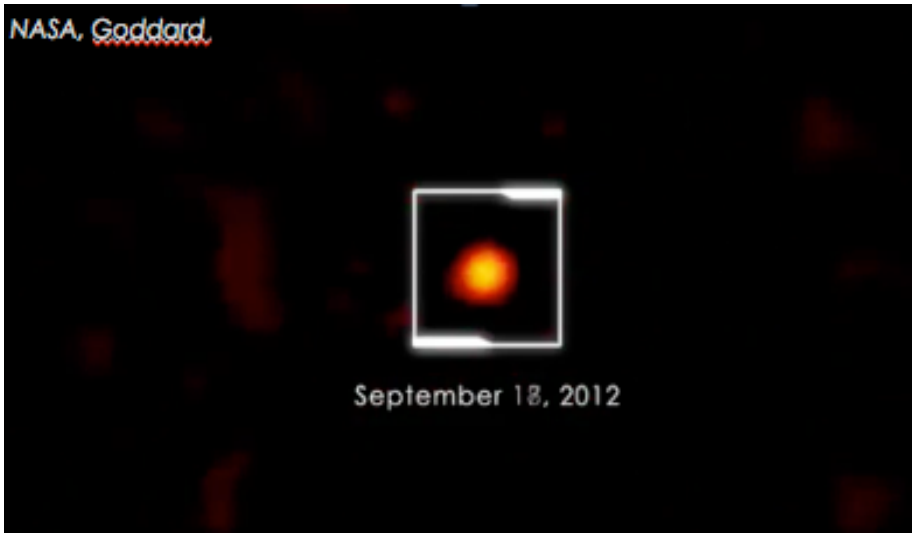


The nature of Swift J1745-26

Swift J1745-26

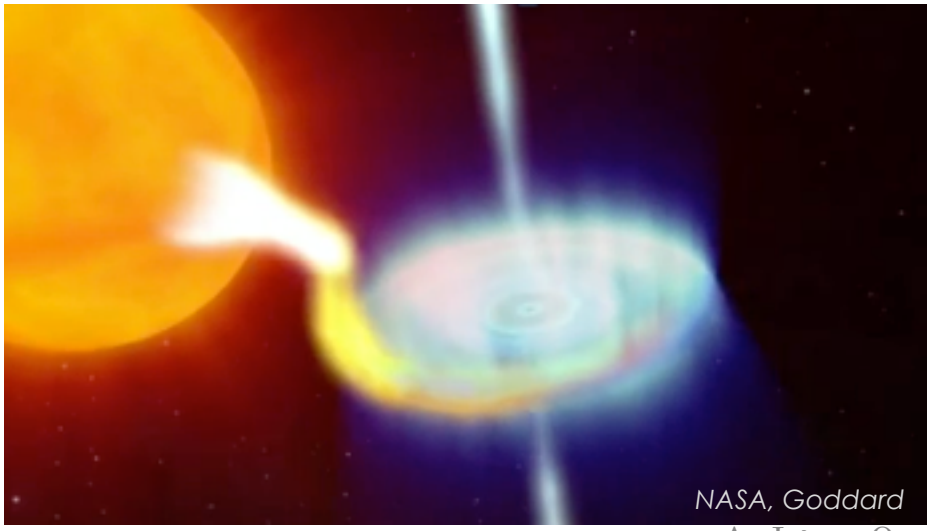
NASA, Goddard





Swift J1745-26

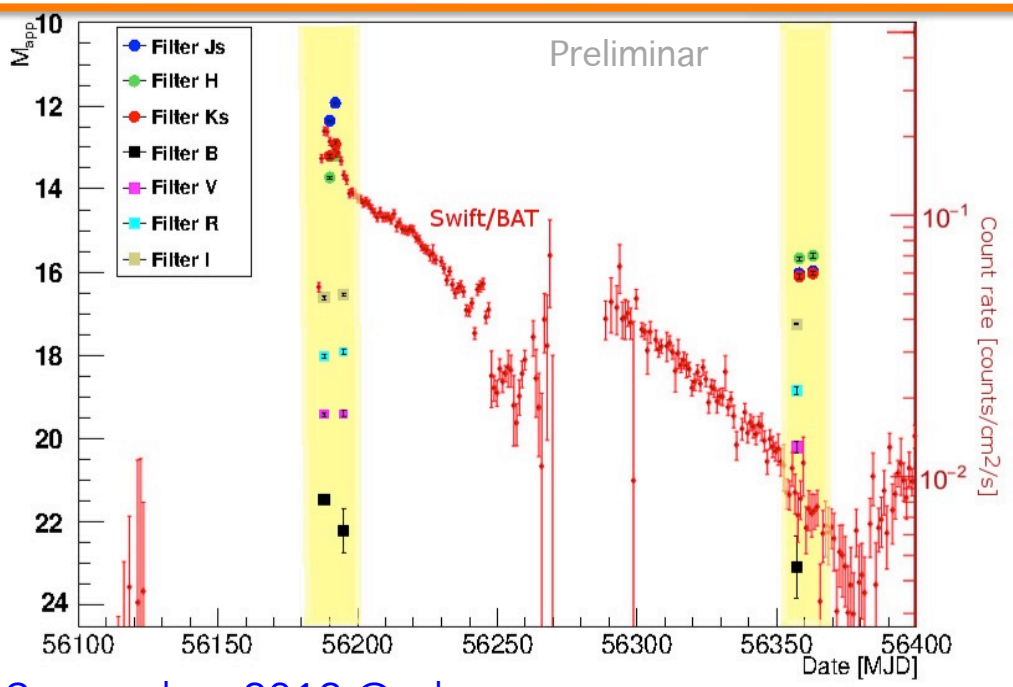
- Discoverd by Swift/BAT in September 2012
- It displayed X-ray properties resembling those of BH-SXTs
- Outburst decay visible during several months.
- Secondary outburst detected in March 2013

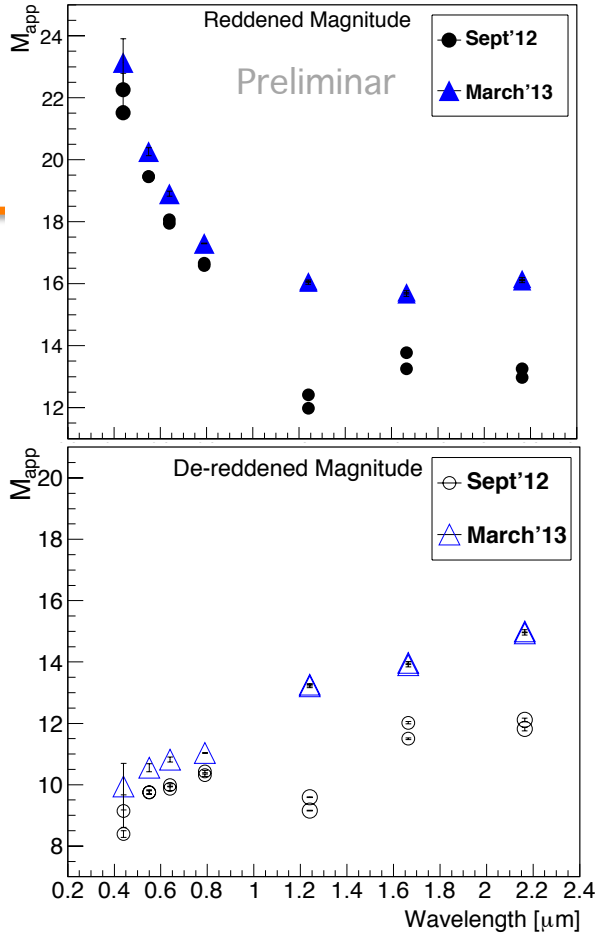


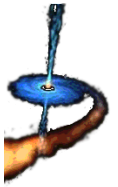
X-ray transients

- LMXBs which spend most of their lifes in quiescence and that show punctual strong X-ray (and radio) outbursts
- Accretion via Roche-Lobe overflow through an accretion disc
- Typically, the outburst shows soft X-ray emission, dominated by the accretion disc

Swift J1745-26

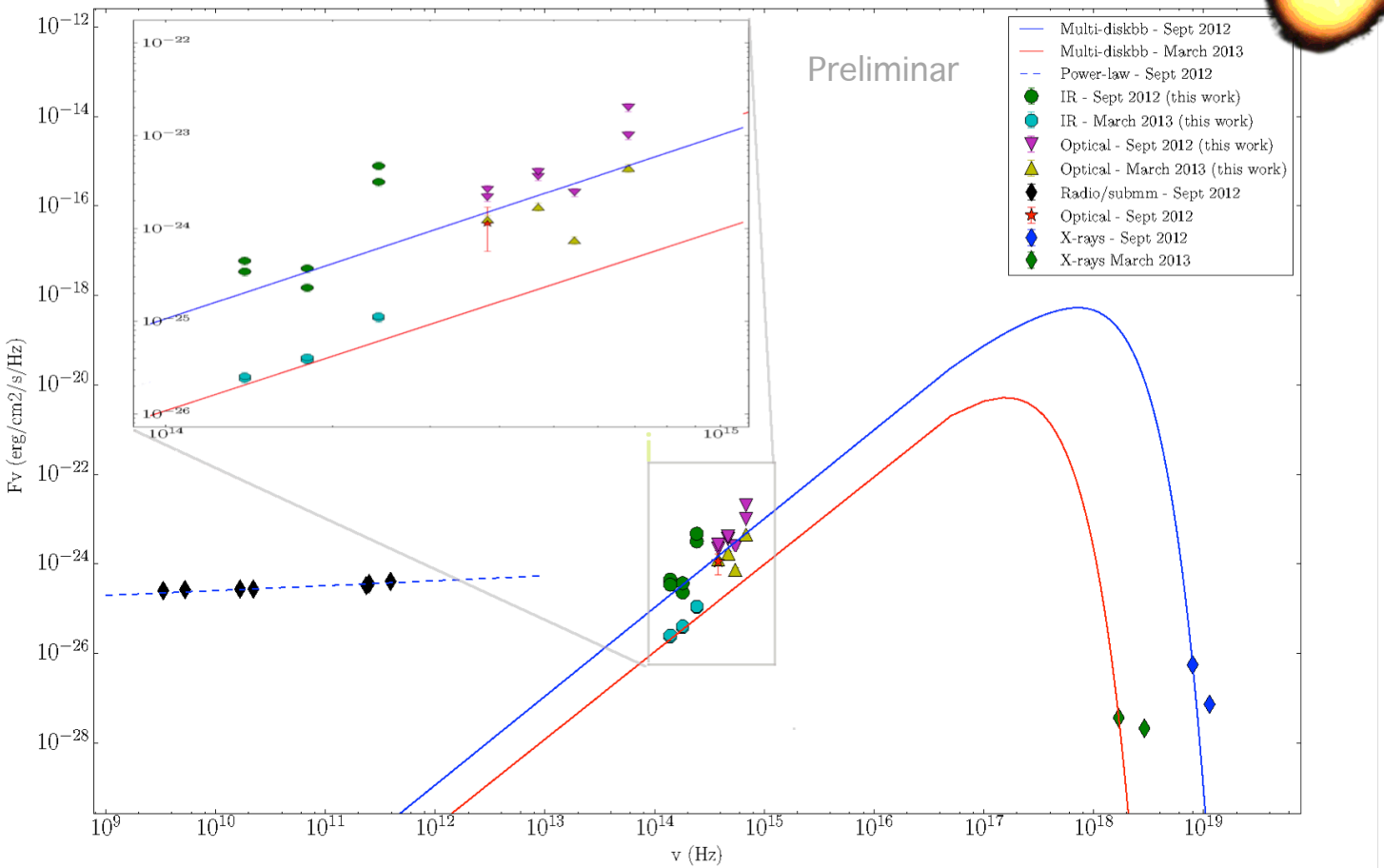






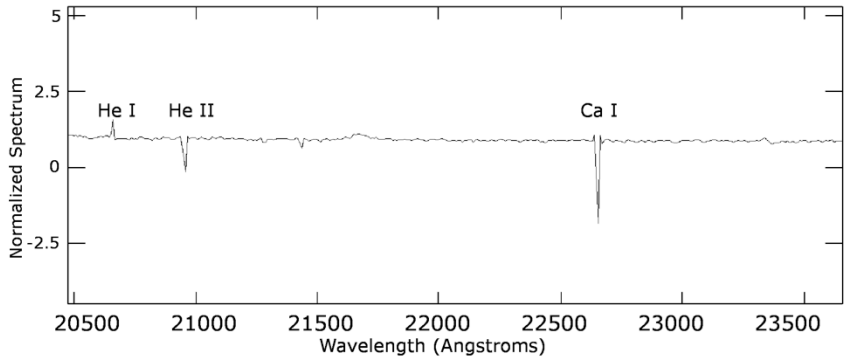
- September 2012 Outburst
- Sub-mm-radio observations : jet spectrum: power-law with(most likely) spectral break at $\nu \geq$ 1x1014 Hz [4]
- Optical30-day monitoring: companion star of spectral type later than A0 and orbital period ≤ 21 days. [5]
- March 2013 Outburst
- X-ray, optical and radio: likely failed outburst:did not undergo a soft state. High-energy cut-off at 112 keV
- VLT optical/NIR observations in September 2012 and March 2013 (phot/spect)

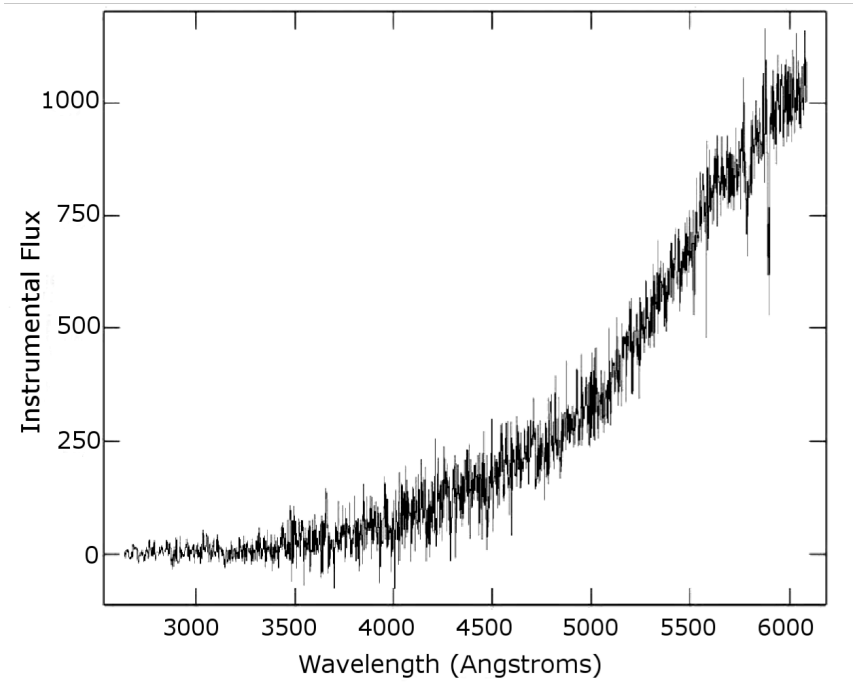
Swift J1745-26



- Multi-color blackbody with T~1.2x106K
- Column density: NH=8.7x1021cm-2
- Orbital period: 16.7±7 h
- Density of the companion star: ρ >0.4 g/cm3
- Spectral type A0V-A5V

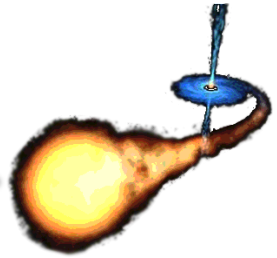
Swift J1745-26



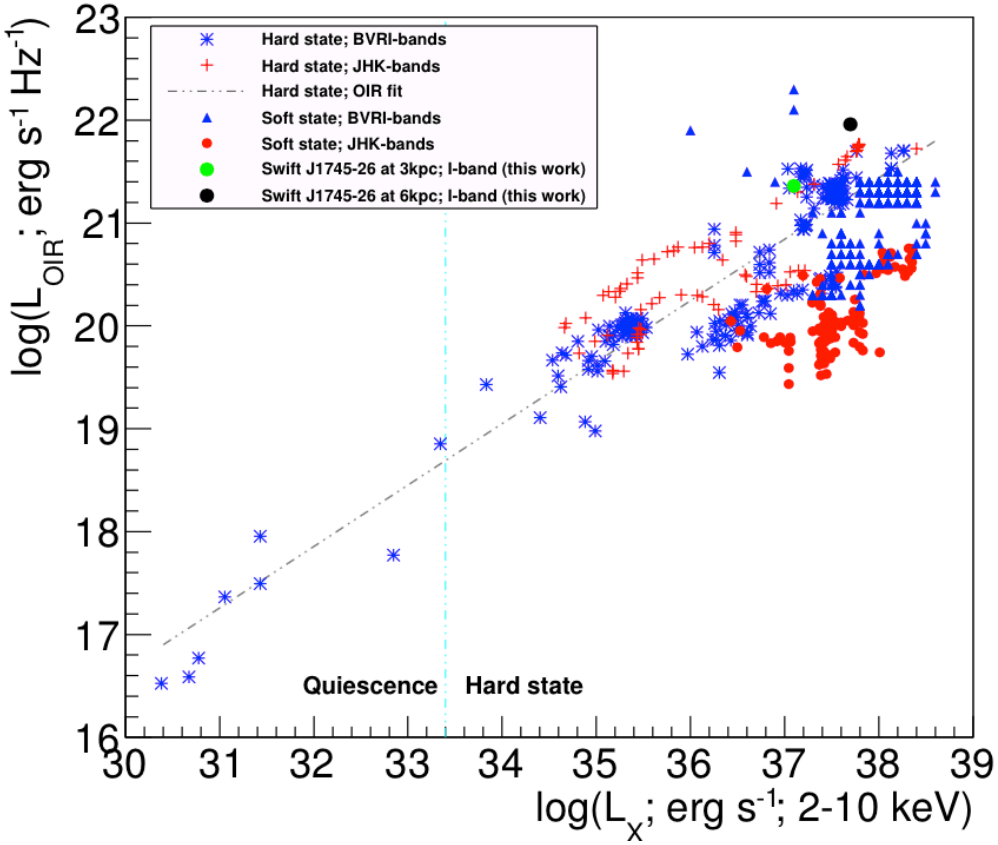


- IR spectra:
  - Ks-band: HeI and HeII from the accretion disk.
  - Ks-band: CaI absorption line: companion star
    -> late spectral type star, later than A (or even F)
  - No lines are detected in the Js and H bands
- Optical spectra (b-band) does not show any line due to the low signal-to-noise ratio

Swift J1745-26: Summary

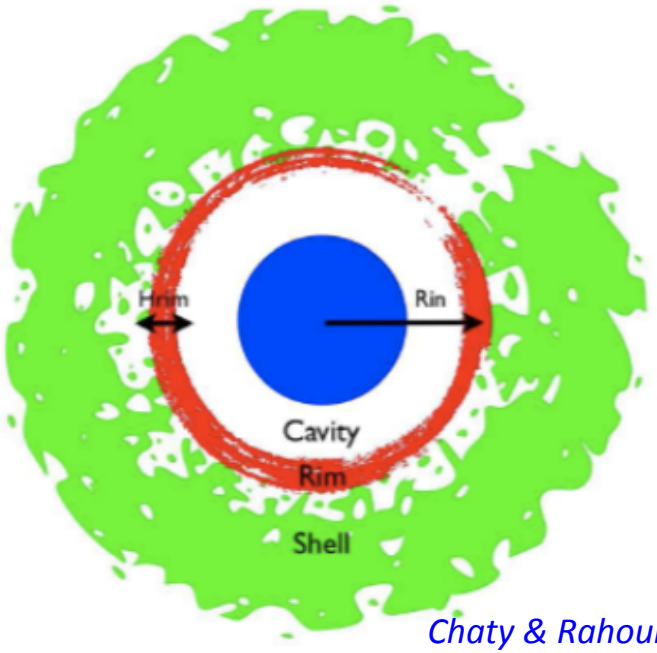


- Optical and IR counterparts arise mainly from the accretion disk
  - Accretion disk visible in the IR spectra
  - Star contributes at large wavelengths
- Late spectral type star: A0V-A5V (A or F according to spectroscopic results)
- Confirm its BH-LMXB nature
- Transient in low/hard state, never entered the soft state (failed outburst)

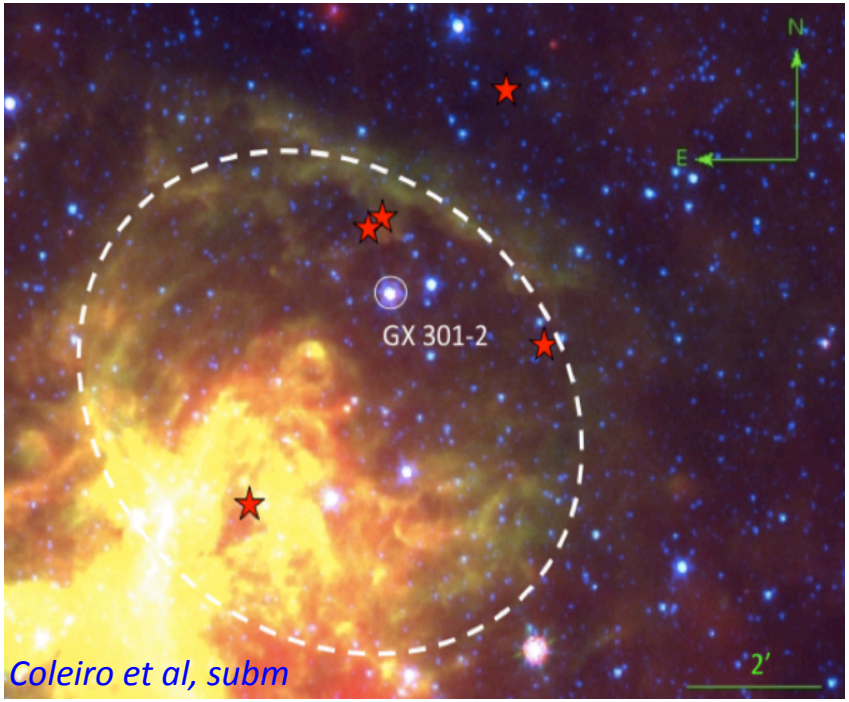


Future work

- Objects with accretion processes and/or outflows of matter: HMXBs and YSOs
- Evolution & link: Connection between these objects
- Impact and feedback in the ISM:
  - Star formation might be triggered by HMXBs
- Study of HMXBs and YSOs in a multi-wavelength context
- *Herschel* data



Chaty & Rahoui 2012



Coleiro et al, subm

Merci de votre attention!