Courtesy of D. Lopez

MAGIC VHE γ-ray observations of (some)binary systems

D. Hadasch on behalf of the MAGIC collaboration

Overview

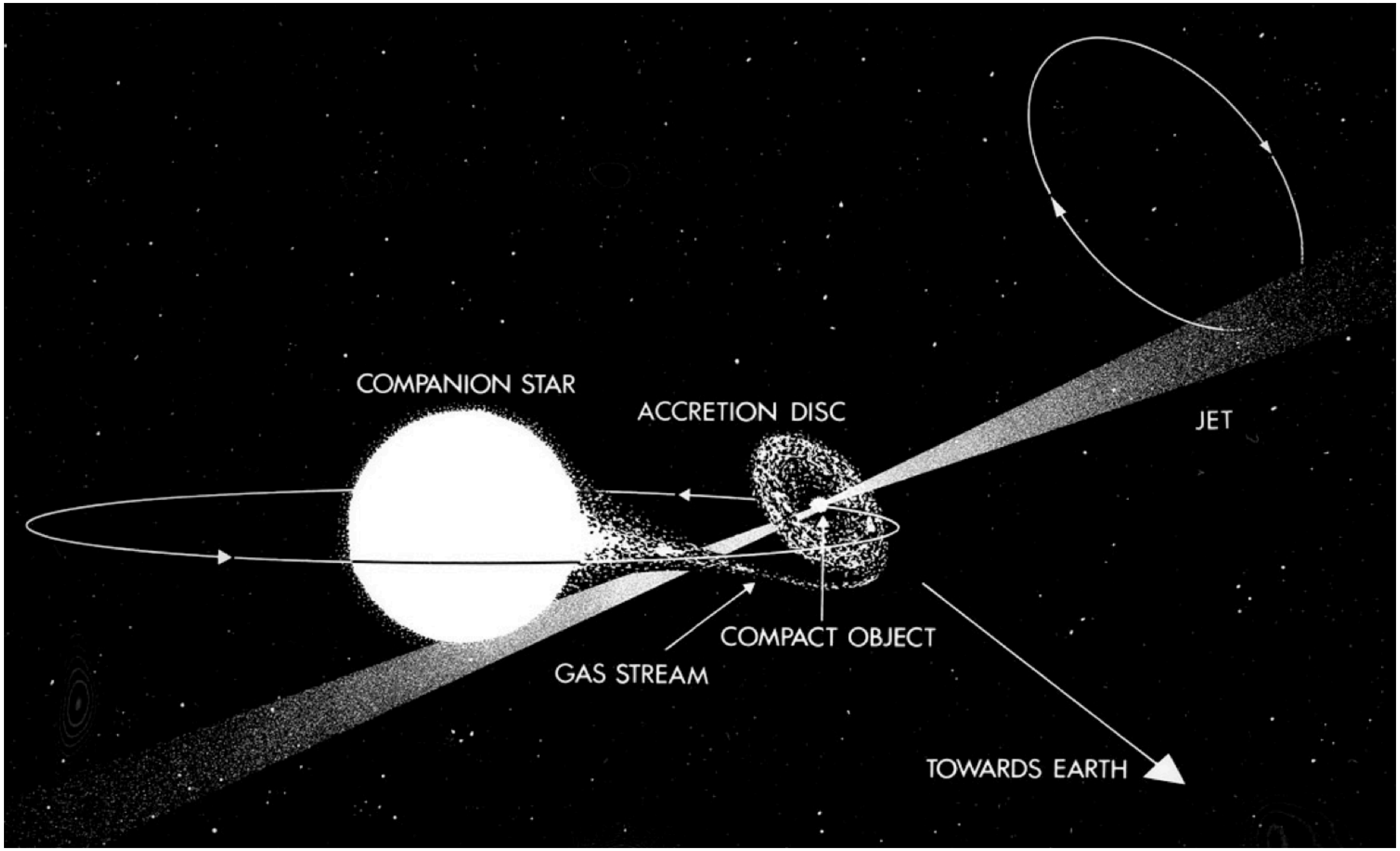
- **Looking for new Gamma-ray binaries**

  ➔ Coordinated campaign (with H.E.S.S.) to observe the super-critical accretion system SS433

- **Using Gamma-Ray Burst alerts to follow up rapidly flaring systems**
  - LMXB V404 Cygni

- **Deep studies on microquasars**
  - Cyg X-1
  - Cyg X-3

See talk by R. Zanin



SS433

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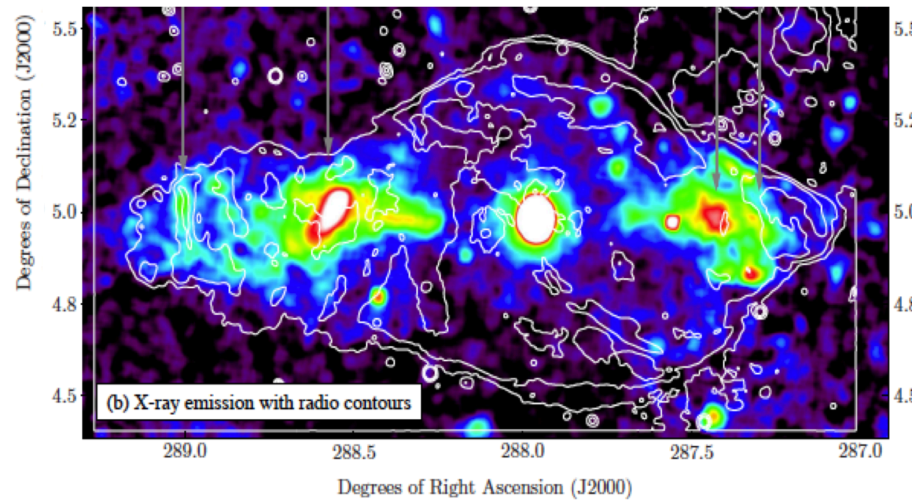
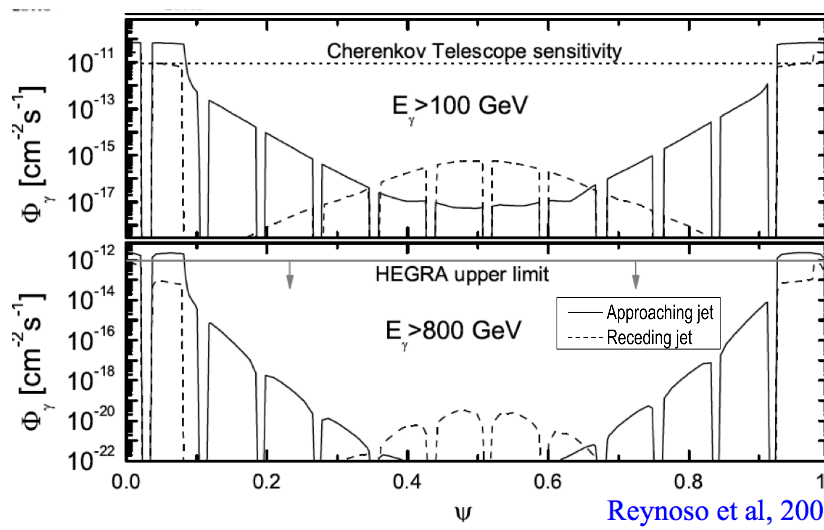
SS433 - the system

- Precessional and orbital periods constant over decades
  - P_{or} ~13 days, P_{pre} ~162 days
- Only galactic super-critical accretor
- Strongly-collimated persistent hadronic relativistic jets
- Embeded in W50 nebula
  - Interaction between jets and nebula: east & western blobs
  - X-ray emission & radio non-thermal emission
- Absorption of putative emission in ~80% of the orbit
  - **Best opportunity for observations: Φpre=0.91-0.09**



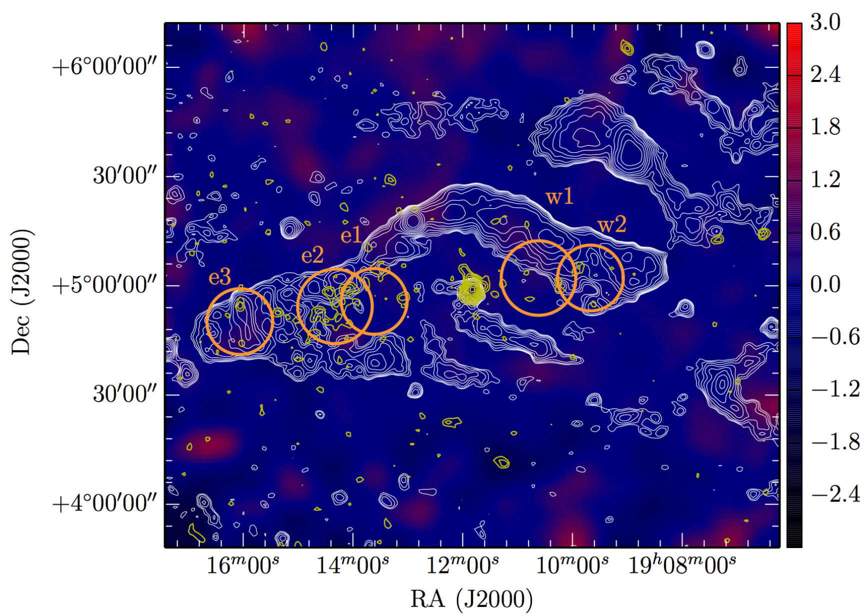


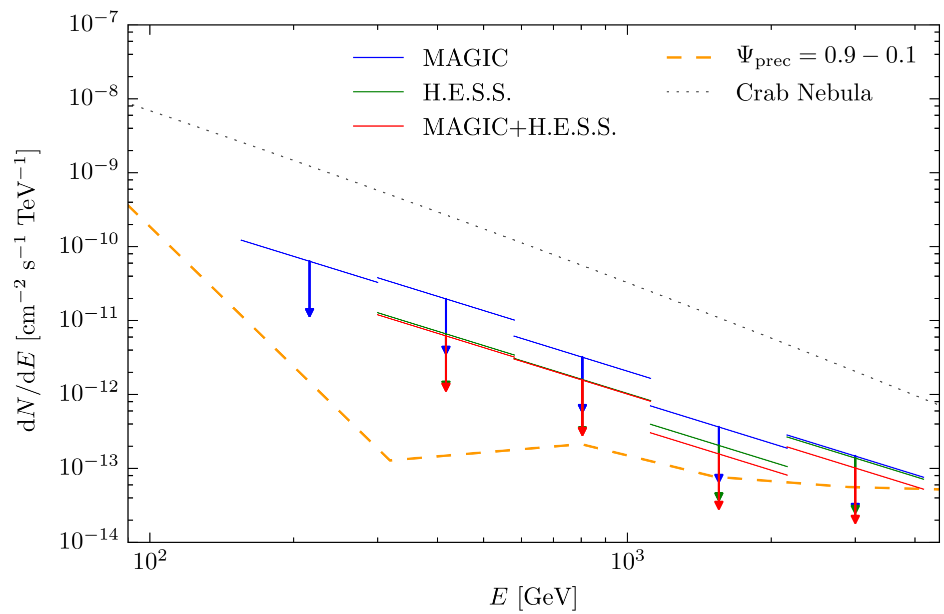
Reynoso et al, 2008

SS433 campaign

H.E.S.S. & MAGIC Coll., accepted for A&A

- Observation campaign performed in collaboration with H.E.S.S.
  - No excess detected → **in contrast with non-thermal emission** observed in radio, X-rays and possibly high-energy gamma rays
  - Upper limits (CL=95%) **compatible with predictions** by Reynoso et al., 2008
- Efficient proton acceleration constrained by lack of TeV emission





Discussion: hadronic scenario

- MAGIC and H.E.S.S. observations: **wide coverage** of relevant precession phases from 2006 to 2011
  - If long-term super-orbital variability exists due to **varying jet injection power** or to **changing conditions of the absorber** in the surroundings of the central compact object → not detected: **no enhancement of TeV flux detectable**
- γ-ray flux predicted by Reynoso et al. (2008) depends on **efficiency** in transferring **jet kinetic energy** to **relativistic proton population**: q_p
  - We can **constrain** fraction of power carried by relativistic protons in SS 433 jets: $\mathbf{q_p \leq 2.5 \times 10^{-5}}$
- Hadronic scenario: expect neutrinos from decay of charged pions.
  - **No detection in IceCube :** limit on q_p ~3.3×10^{-5} marginally less restrictive
- Note: **Different values** for the magnetic field, target proton densities and/or adiabatic expansion velocities in acceleration region imply **variations in predicted γ-ray and neutrino fluxes**.

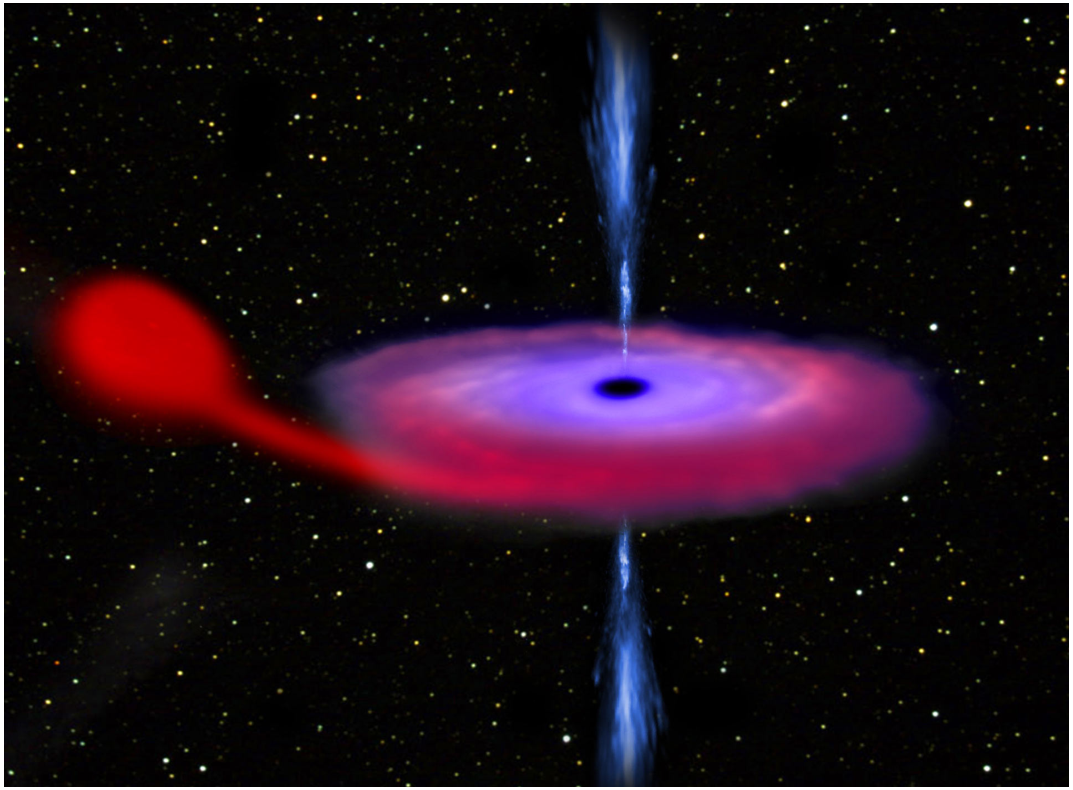
Discussion: leptonic scenario

- At interaction regions of the jets with the surrounding W50 nebula: X-ray spectra from the extended lobes represented by power-law model → **synchrotron origin** → presence of electrons up to ~50 TeV

- Bordas et al. (2009) considered **non-thermal emission** produced in microquasar jets/ISM **interaction regions.**
  - Providing **γ-ray flux estimates** as a function of the kinetic power of the jets, the age of the system, and particle density of the environment.
  - Application of this model → fluxes at level of ~10^{-13} erg cm^{-2} s^{-1} for $E > 250$ GeV: **roughly at level of the upper limits reported here.**

- However: **e^{-}s** accelerated at interaction region shock interface could **loose most of energy** through synchrotron emission for ambient magnetic fields ≥~10 μG → **preventing effective channeling** through IC scattering that is relevant for the production of γ rays at HE and VHE.

- **Our new ULs**: We constrain the magnetic fields in shocked jets/ISM interaction regions → **lower limit on the magnetic field** of 20–25 μG.



V404 Cygni

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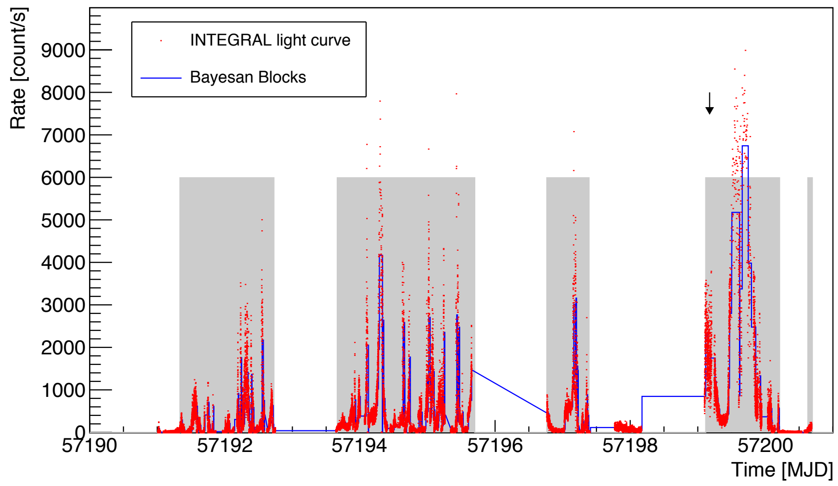
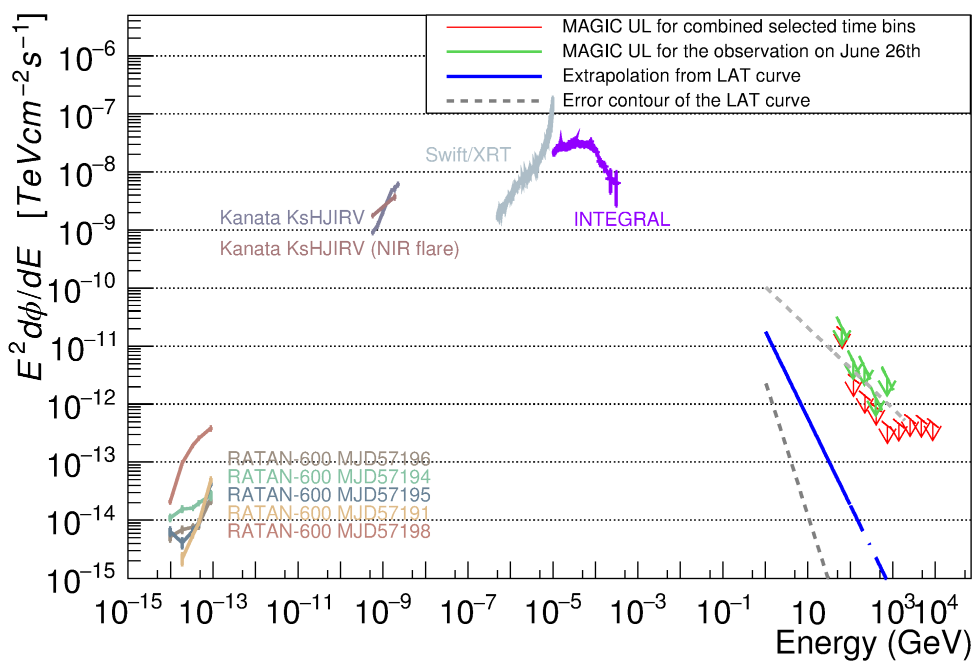
Low mass X-ray binary: V404 Cygni

- Nearby system (2.39 ± 0.14 kpc) (Miller-Jones et al. 2009)
  - ~9-15 $M_\odot$ black hole + ~1 $M_\odot$ companion star (Khargharia et al. 2010)
  - Orbital period: 6.5 days (Casares et al. 1992)
- **Major outburst** in June 2015 after 26 years in quiescent state
- MAGIC was triggered by INTEGRAL
  - MAGIC observed the source in Gamma-ray burst mode
  - Observations for several nights between June 18 - 27 → **about 11h**
- Time intervals with highest INTEGRAL flaring activity (gray bands) used in MAGIC analysis are defined following the Bayesian Block method.



V404 Cygni MAGIC results

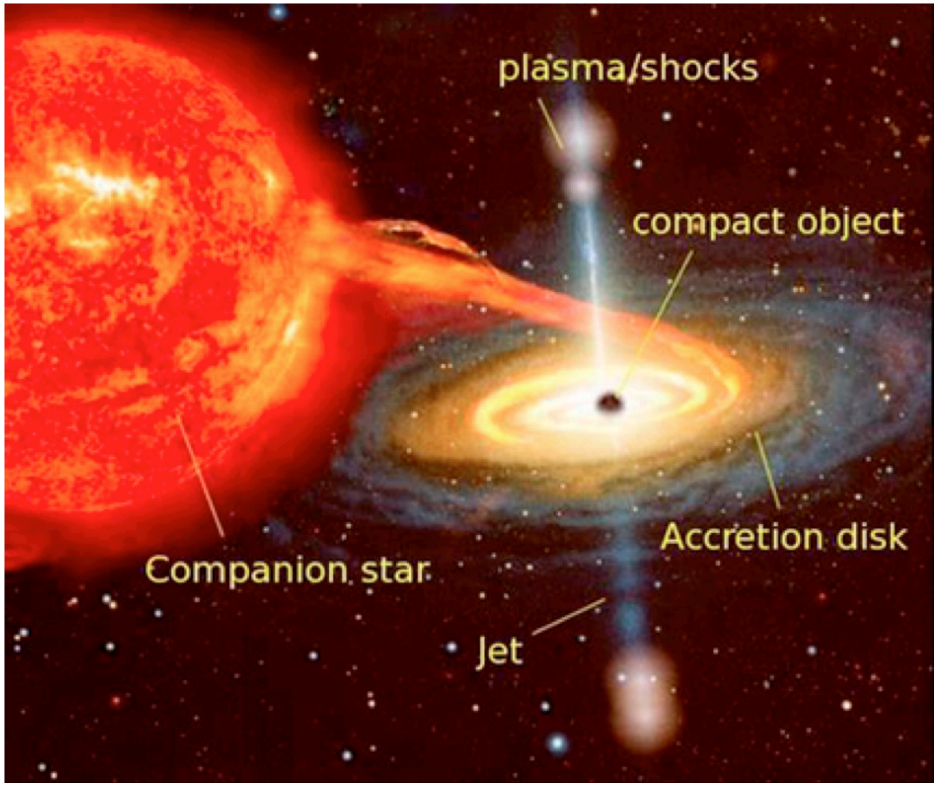
- Selection of the flaring times done from the INTEGRAL light curve to avoid increasing trials
  - 7h of observation distributed in different nights → No signal found (0.08σ)
  - UL of 4.8×10^{-12} ph $cm^{-2}s^{-1}$ (E= 200-1250 GeV) was computed (few percent of Crab flux)



MAGIC Coll., accepted in MNRAS

Discussion

- Evidences of jet emission given by the optical observations
  - Hint of detection in Fermi-LAT data (~4 σ) + giant radio flare + increase of hardness ratio in X-ray band + optical fast variability
  - → jet environment dramatically changed on that day
  - Temporally coincident: **No detection in MAGIC data.**
- Luminosity MAGIC upper limits ~2×10^{33} erg s^{-1} , **in contrast** with extreme luminosity emitted in X-ray band ~2×10^{38} erg s^{-1}
- Estimated **γ-ray opacity** during flaring period & **non-detection** → **inefficient acceleration** in V404 Cyg jets if VHE emitter is located >1×10^{10} cm from the compact object.



Microquasars

Cygnus X-1 & Cygnus X-3

General information

Cygnus X-1

25-35 $M_\odot$ O9.7 Iab supergiant + 15 $M_\odot$ BH

Distance ~ 1.86 kpc

Orbital period = 5.6 days

SUPC @ phase=0

X-ray and radio orbital modulation

5 pc ring-like radio structure (@ 10^{19} cm)

Cygnus X-3

Wolf Rayet + 1.4 $M_\odot$ NS or <10 $M_\odot$ BH

Distance ~ 7 kpc

Orbital period = 4.8 hr

SUPC @ phase=0

X-ray and HE gamma-ray orbital modulation

Unusual high absorption

Detected @ HE by AGILE and *Fermi*-LAT

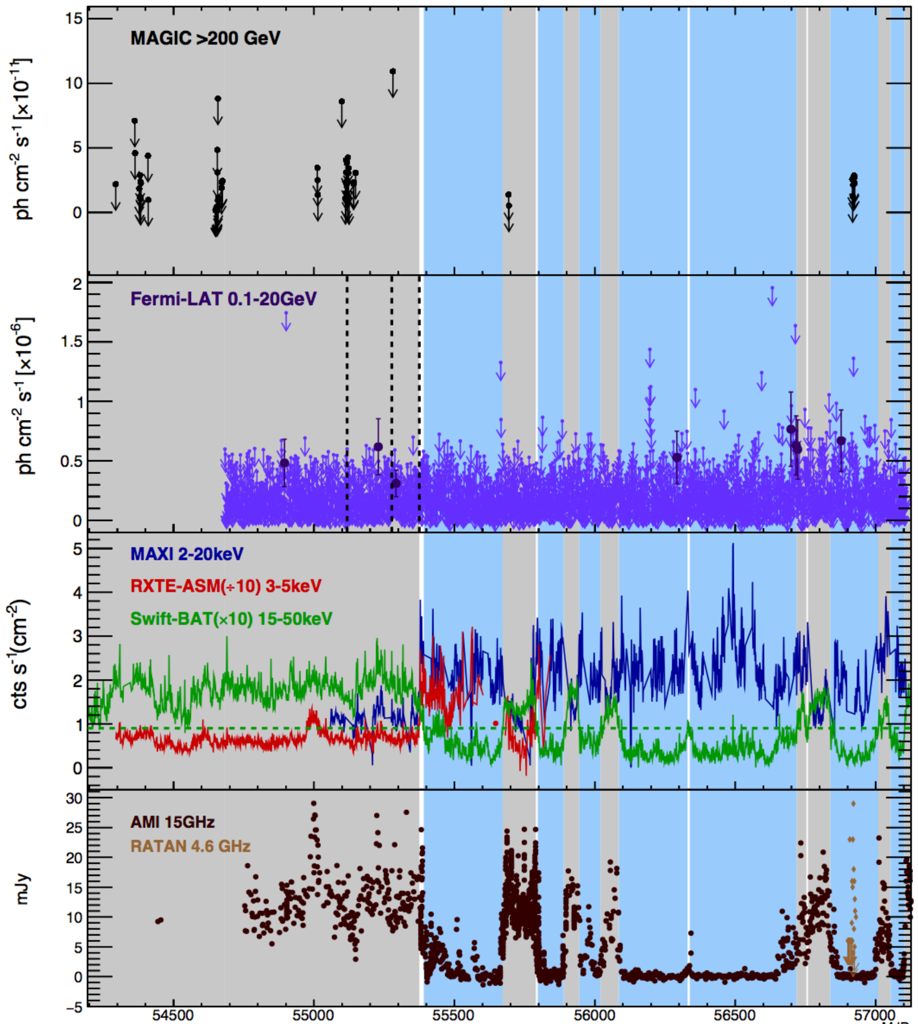
Cygnus X-1: HE & VHE emission

- **Three transient episodes** (~1-2 d) detected by AGILE (>100 MeV): two during hard state (HS) , one during intermediate state (IS) (Bulgarelli+2008;Sabatini+2010, 2013)
- Hint @ TS=16 with 3.8 yr *Fermi*-LAT data during HS (Malyshev+2013)
- Detection during HS: 7.5 yr PASS8 *Fermi*-LAT data → detection TS=53 (Zanin+2016)
- Evidence of emission @ VHE with MAGIC (mono): Sept 2006, ~4σ in 80 min (Albert+2007)
  - Simultaneously with hard X-ray flare (INTEGRAL, *Swift*-BAT and *RXTE*-ASM)
  - During HS and SUPC

See talk by R. Zanin

Cygnus X-1: lightcurve

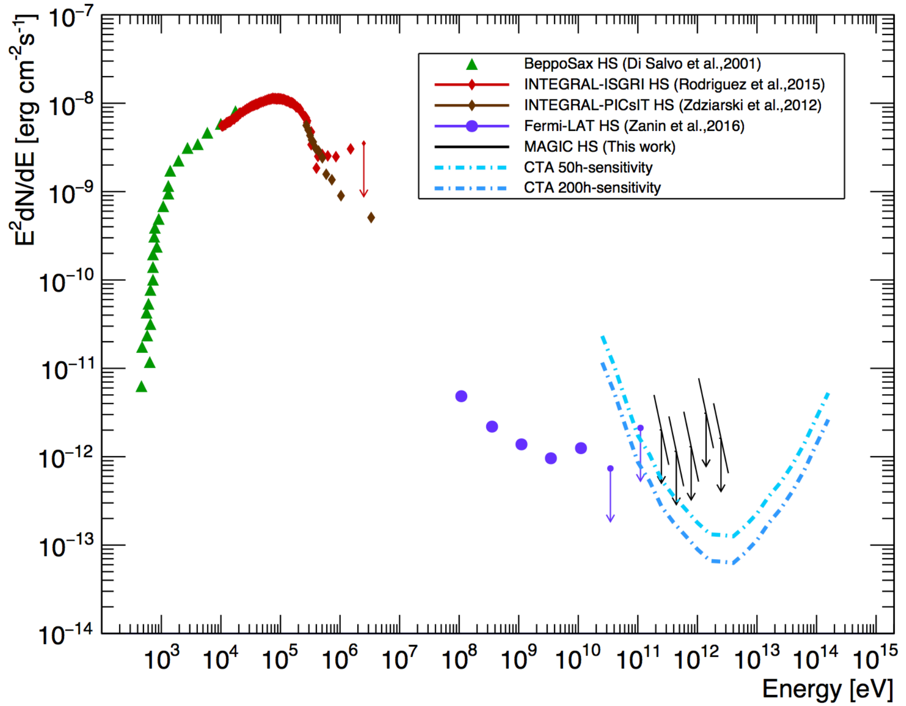
- MAGIC observations between 2007-2014, for ~100 hr (focused on HS)
- Search for steady and variable emission >200 GeV, at each X-ray state (~83 hr HS, ~14 hr SS)
- **No significant excess** was found for steady, orbital modulated or daily basis emission
- Grey: hard state; blue: soft state



MAGIC Coll., submitted to MNRAS

Cygnus X-1: Implication of VHE results

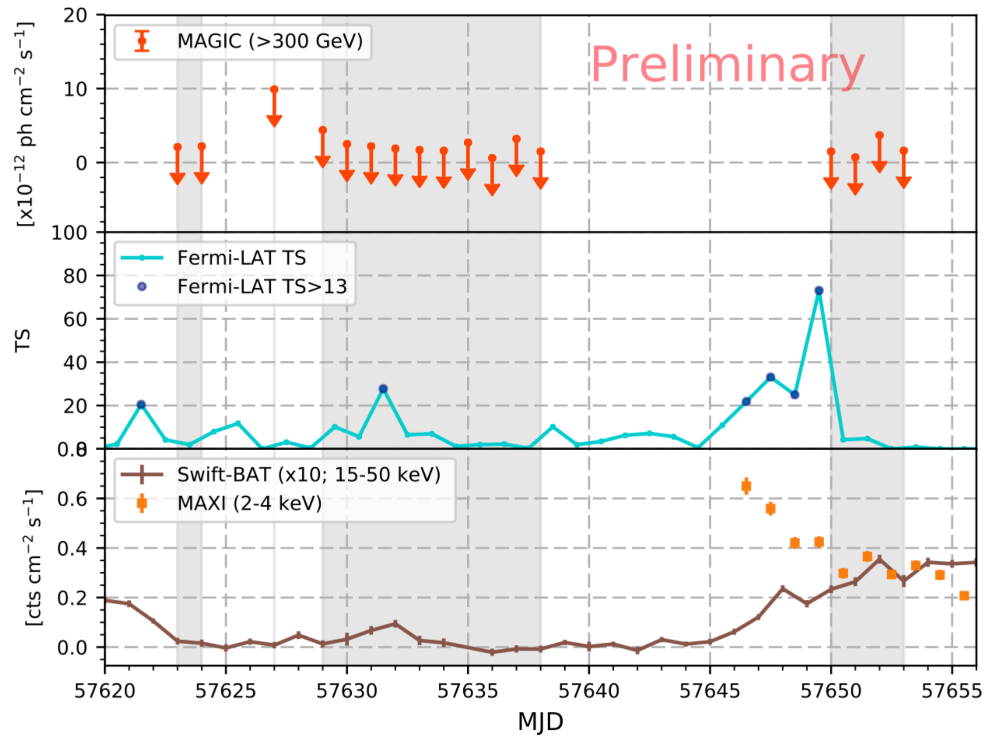
- **Jet-medium interaction discarded** as possible region for VHE emission above MAGIC sensitivity level: not affected by γ–γ absorption
- @ **binary scale** (~R_{orb} = size of the system) less conclusive: **Transient event**, as reported previously, cannot be ruled out (no observations simultaneously with hard X- ray flare)
  - Radio-emitting-blobs during IS (like in Cygnus X-3)



MAGIC Coll., submitted to MNRAS

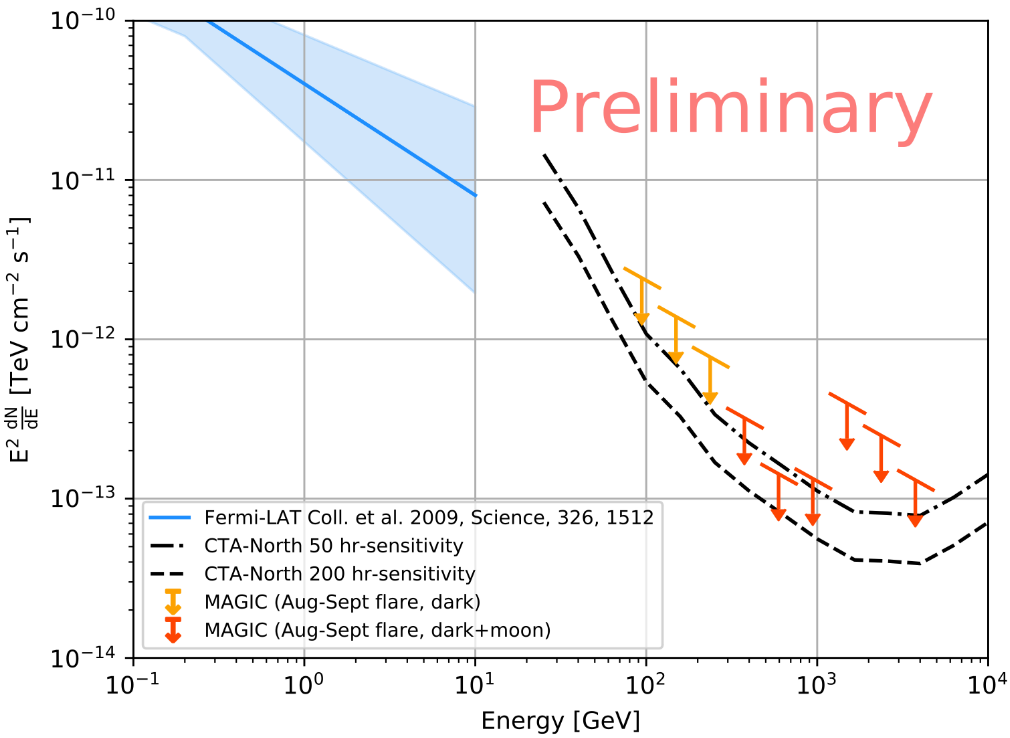
Cygnus X-3: new results

- Radio and HE **gamma-ray flare** in Aug-Sept 2016
- MAGIC observations between Aug 23rd and Sept 22nd: ~70 hr during SS
- Searches for steady, orbital modulated and daily basis analysis: **no significant excess**



Cygnus X-3: new results

- **Non-negligible absorption,** $\tau \sim \sigma_{\gamma\gamma} \cdot n_{NIR} \cdot R$, **up to R~$10^{13}$ cm**
  - assuming $\sigma_{\gamma\gamma} \sim 10^{-25}$ cm, $L_{NIR} = 10^{38}$ erg/s
  - Possible VHE emission could be related with HE production site (@ binary scales, R>10^{11} cm)
  - Observation with **radio flare**, but **no MAGIC detection** --> VHE emission originated inside binary scale and not at radio-emitting regions of the jets far from compact object
- Already very constraining ULs: further investigation with *Fermi*-LAT data



Cygnus X-1 & Cygnus X-3

Cygnus X-1

- Cygnus X-1 emits up to ~20 GeV, most likely related to relativistic jets
- Probable mechanism anisotropic IC on stellar photons
- HE Emission site constrained at **10^{11} cm < R < 10^{13} cm from the BH**
- No cutoff detected => TeV component not excluded, but expected @ binary scales

See talk by R. Zanin

Cygnus X-3

- MAGIC observed Cygnus X-3 for an entire radio and HE flare
- Given the high γ-γ absorption, MAGIC non-detection could point to VHE emission inside the system

Open questions

- Are we at the limit with our VHE instrument sensitivity?
  - Next generation of telescopes (CTA) needed for detection?
- Or do these systems simply not emit at VHE?
  - No emission detected due to absorption effects/ high magnetic fields, …?
- If VHE γ-rays are produced…
  - Where? Close to compact object? Outside of binary scale?
  - Hadronic or leptonic?

MAGIC

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THANK YOU