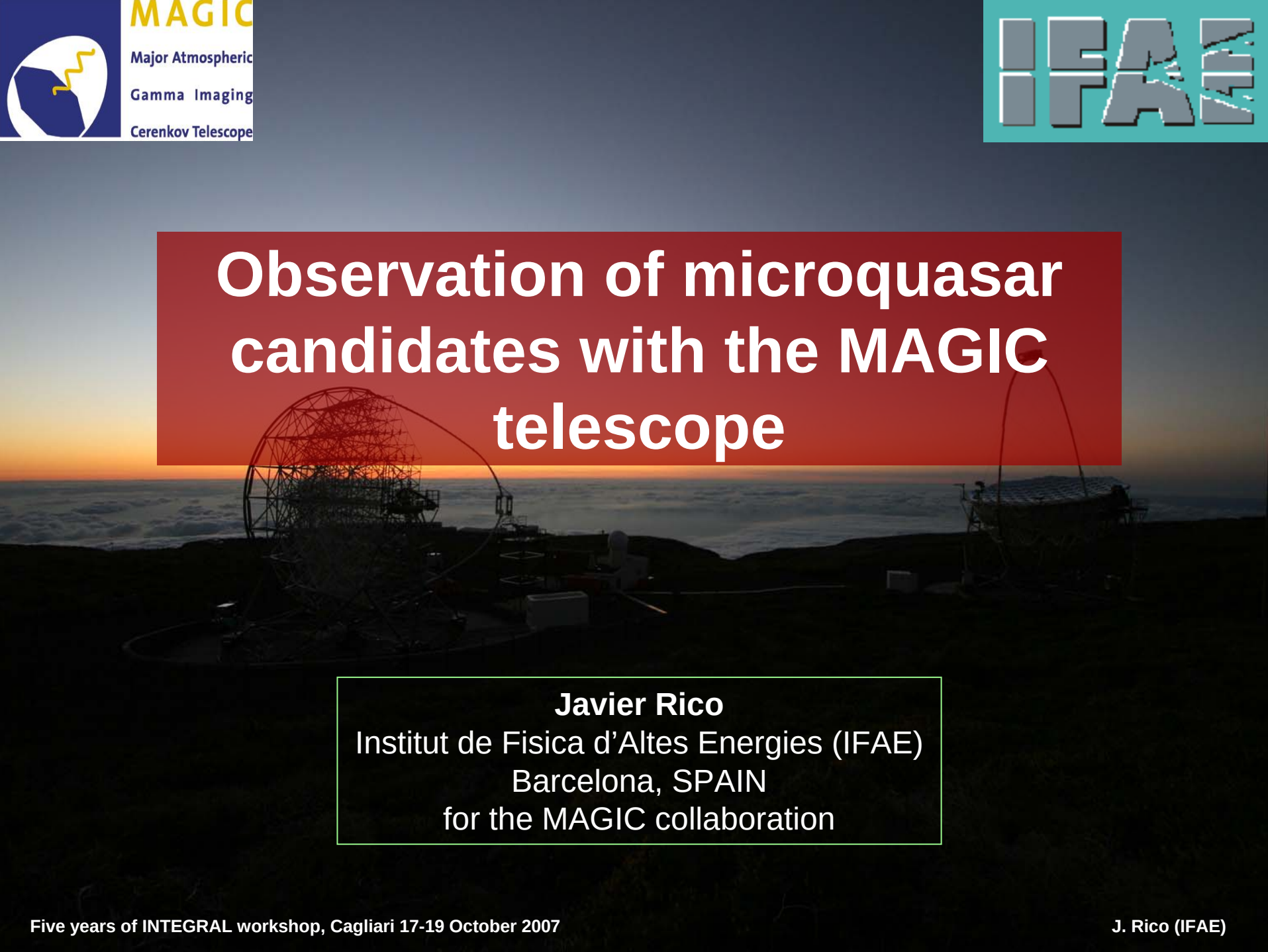

Observation of microquasar candidates with the MAGIC telescope

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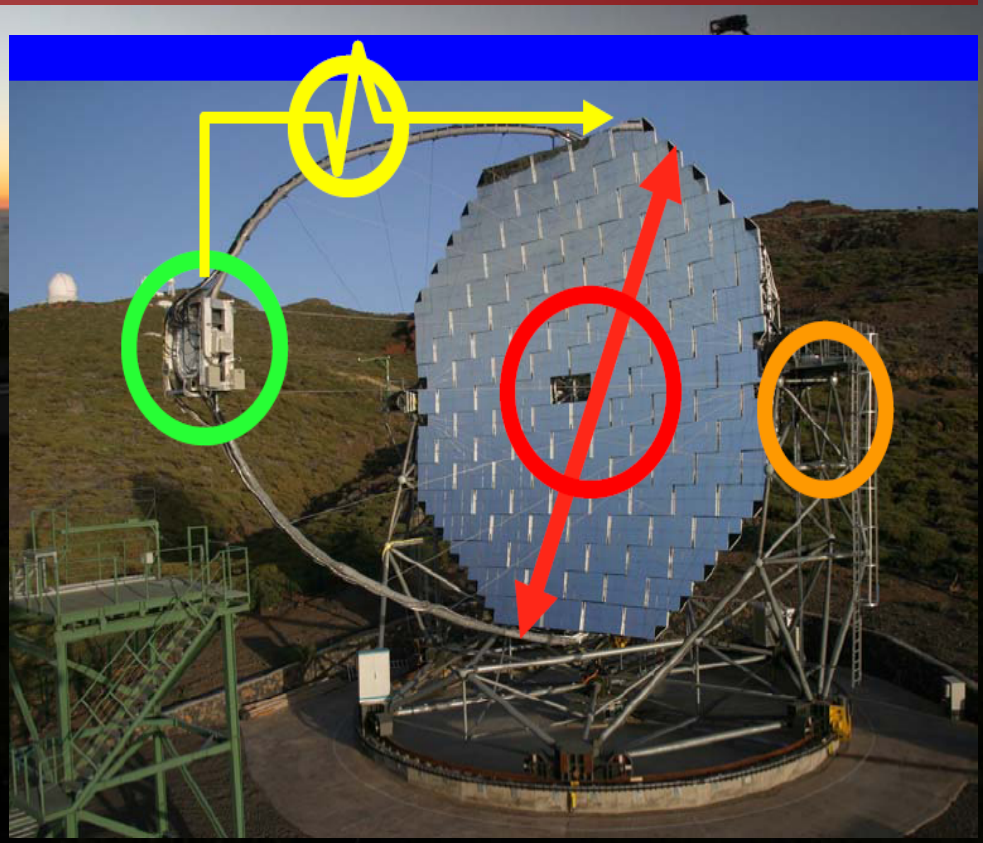
for the MAGIC collaboration

The MAGIC telescope

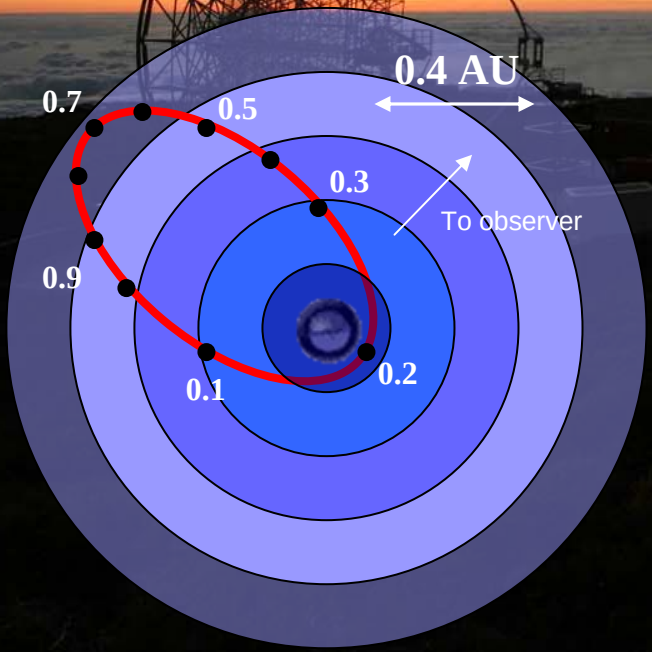
- MAGIC is a **Imaging Air Cherenkov telescope** operating in the energy range 50 GeV – 50 TeV
- Located in the **Roque de los Muchachos** observatory, La Palma, Canary Island (Spain) at **28.8° N**
- **Largest** single-dish (17 m Ø) ⇒ **lowest** energy threshold
- 576 **high QE PMT** camera with 3.5° Ø FOV
- Good **angular resolution** ~ 0.1°
- Determination of point-like sources **position** within 2'
- **Energy resolution** 20-30%
- **Flux sensitivity**: 2% Crab Nebula flux with 5σ in 50h
- **Fast repositioning** (<40s average) for GRB observation
- **Observations under moonlight** possible ⇒ 50% extra observation time

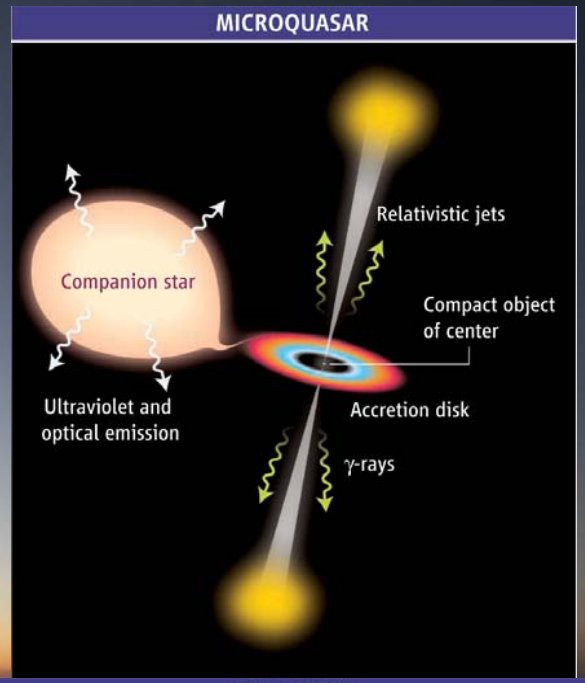


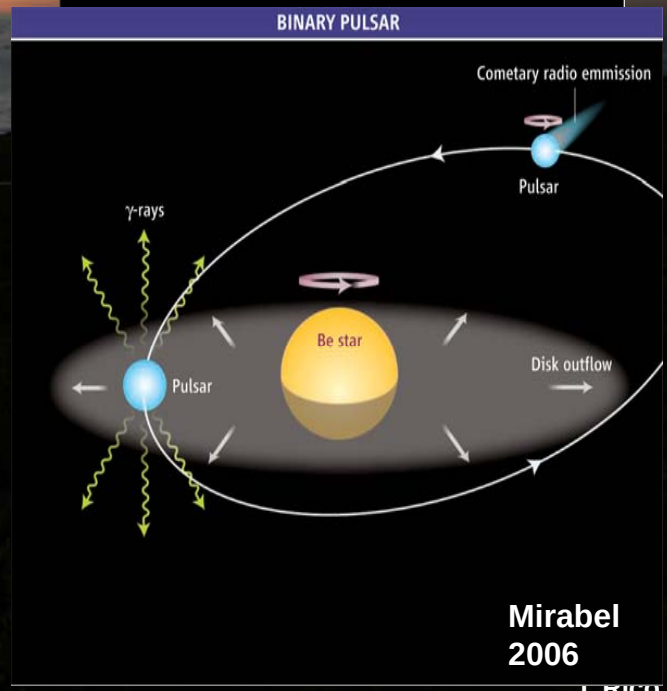
LS I +61 303

LS I +61 303
- B0 V star with disc (Be)
- Compact object unknown
- Orbital period 26.496 days
- Distance ~ 2 kpc
- Periastron at $\phi = 0.23$
- Eccentricity $\varepsilon = 0.73$

Microblazar? Binary pulsar?





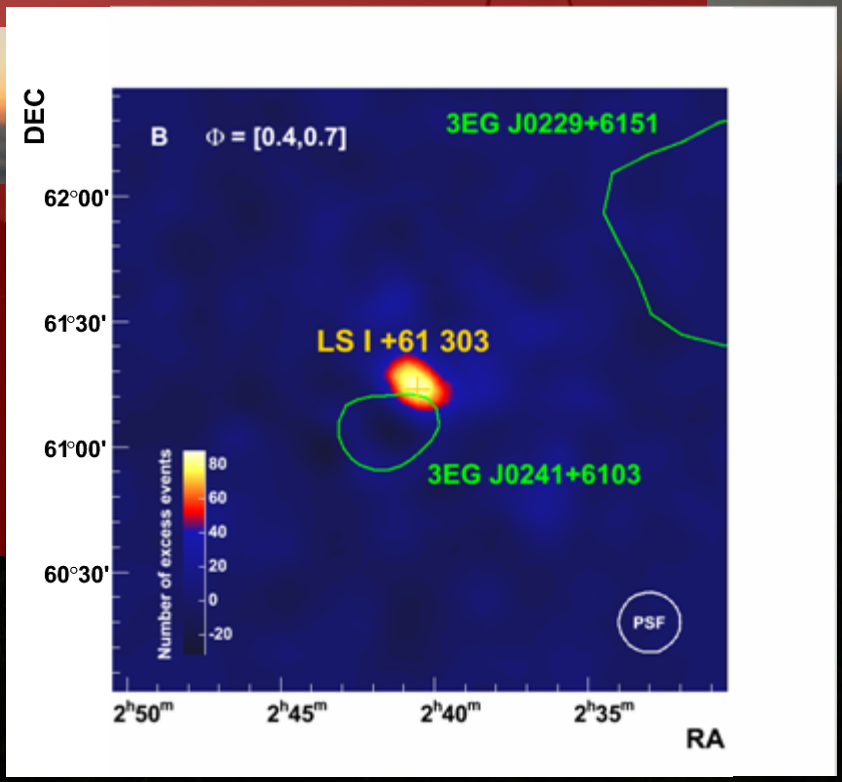


Mirabel 2006

Discovery of LS I +61 303 at TeV

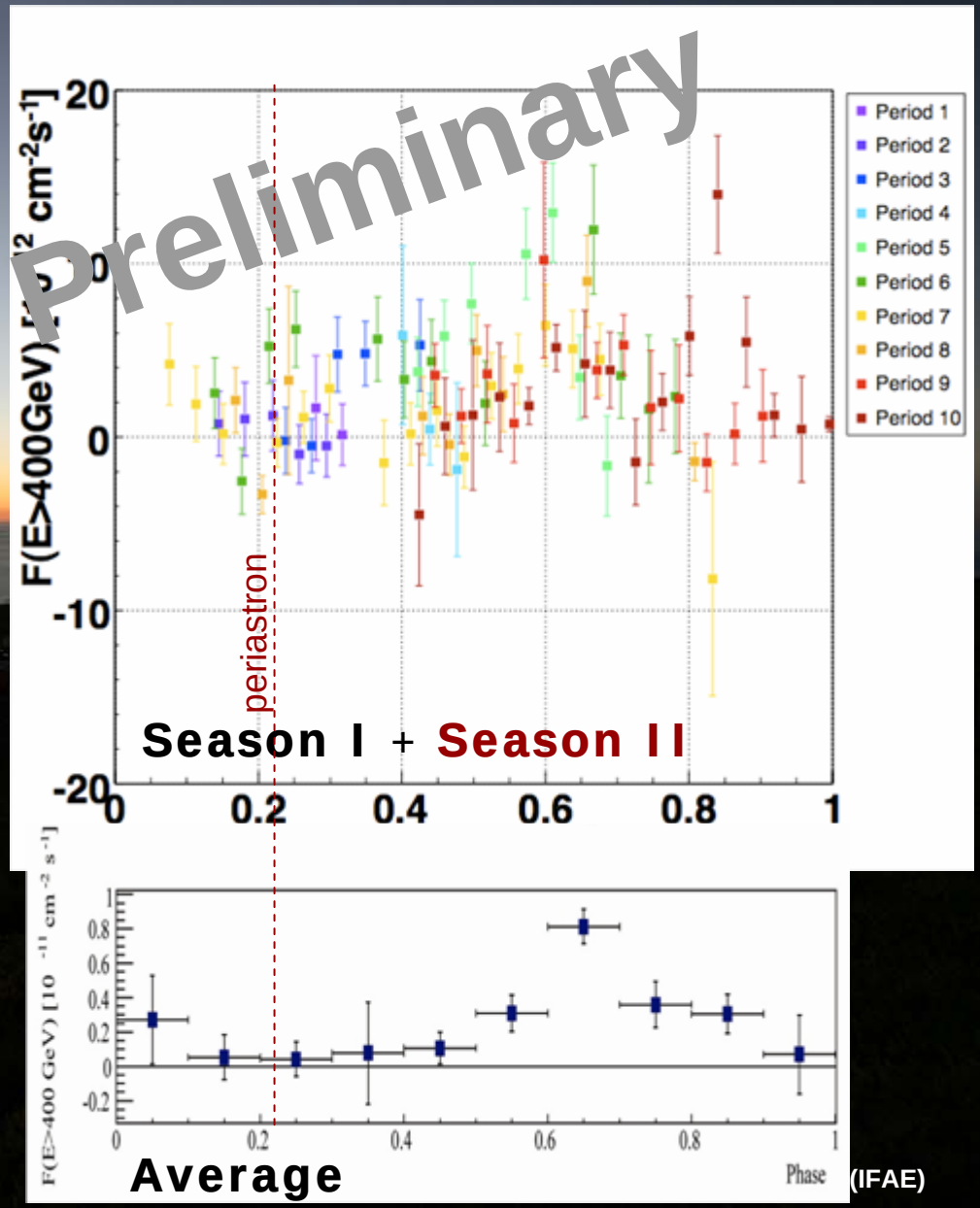
- LS I was observed for 6 orbits between Oct 05 and March 06
  54 hours of data, 22% of data taken during moon
- 2nd observation campaign in Sep to Dec 2006,
  112 hours of data
- In total ~ 166 hours of data !!!

- Clear detection in 1st campaign
  with 8.7 sigma
- Excess position:
  RA=2h 40m 34s DEC= + 61°15' 25"
  In agreement with LS I position



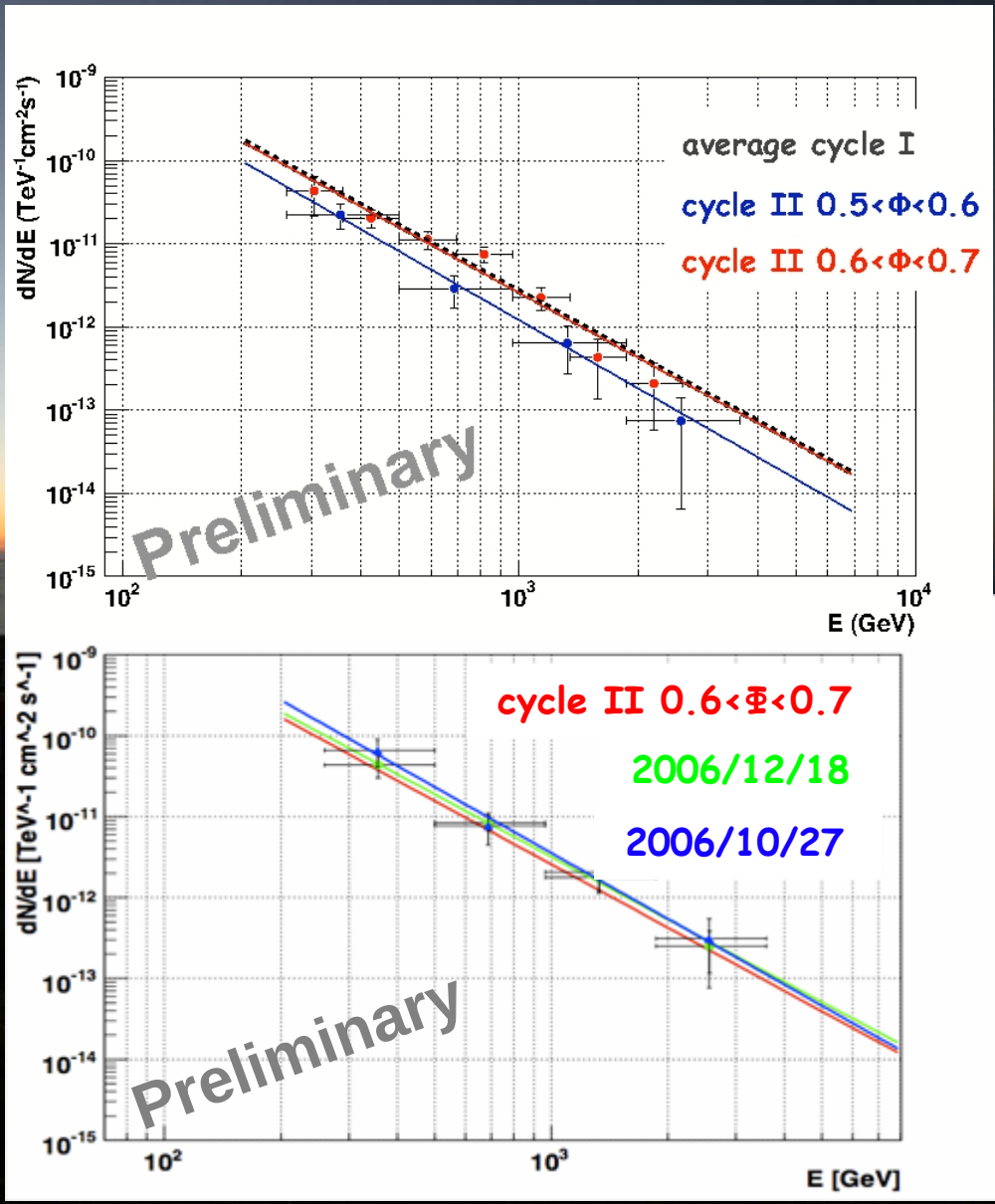
Lightcurve and phaseogram

- The source is clearly variable at TeV energies (prob of being constant $<10^{-11}$)
- Intra-night flux stable
- Periodicity studies in progress
- Flux maximum at phases 0.6-0.7 with 10-20% Crab nebula flux
- Quiet at periastron
- Intense, isolated peak detected at phase 0.85



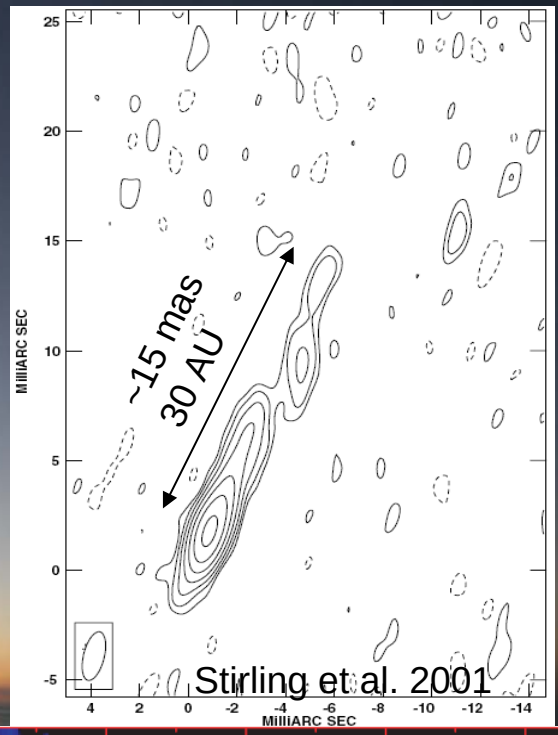
Spectral properties

- Spectrum between 300 GeV and 2 TeV
- No variability on the spectral shape with day, phase, cycle or season observed
- Well fitted by power-law with spectral index 2.6 ± 0.2 stat ± 0.2 sys
- The absolute flux changes by a factor 3

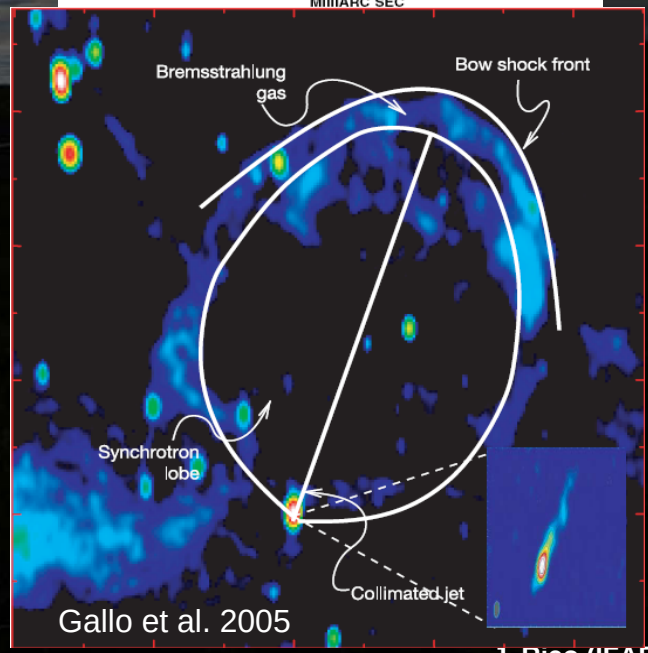


Cygnus X-1

- Cygnus X-1 is binary system. Compact object is a black hole of $M>13M_{\odot}$
- The optical companion is an O9.7 super-giant with $M=30M_{\odot}$ and a strong stellar wind
- The orbit is low-eccentric or circular with radius 0.2 AU and 5.6 days period. Modulation detected in radio and X-rays
- Inclination between 25 and 67 deg, 35 deg normally assumed
- Single-sided jet resolved in radio (microblazar?) Opening angle <2°, bulk velocity is $\beta>0.6c$
- Ring (∅=5 pc) of bremsstrahlung emitting ionized gas at the shock between jet and ISM



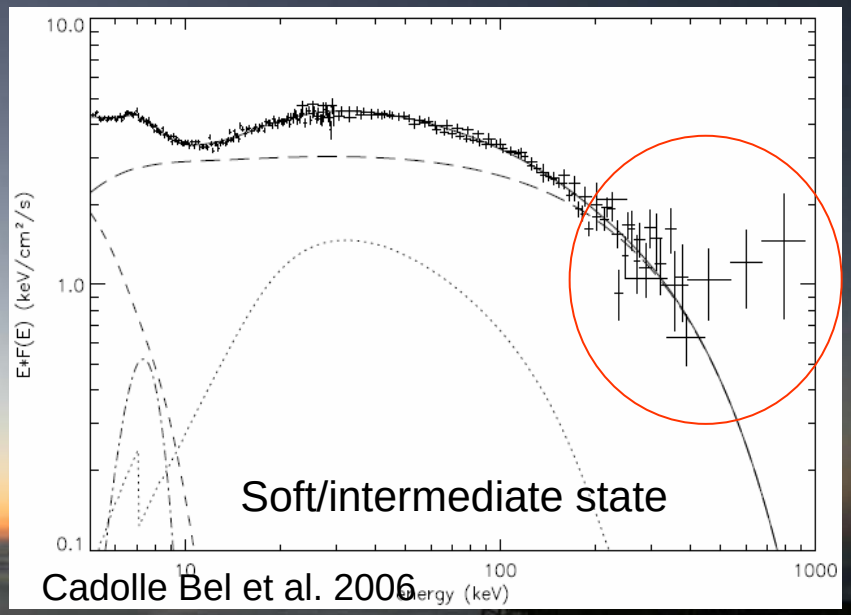
Stirling et al. 2001



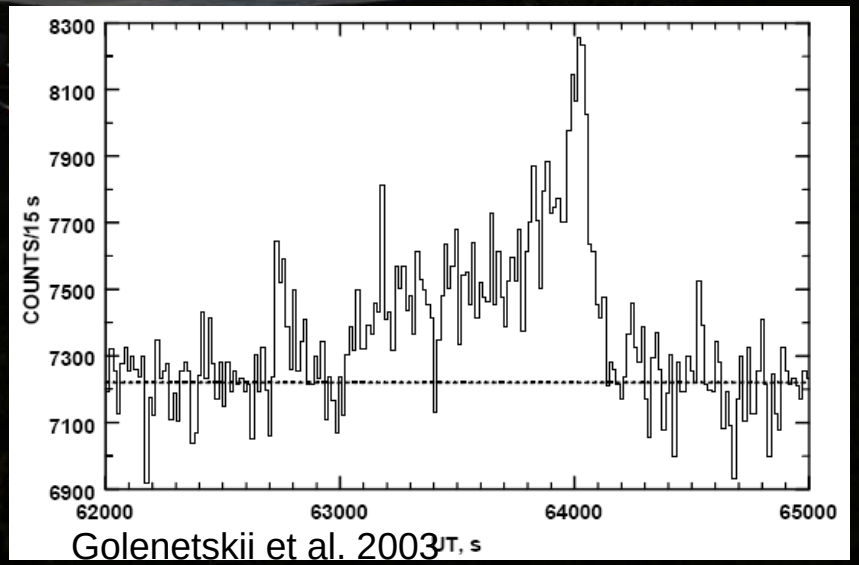
Gallo et al. 2005

X-ray phenomenology

- **X-ray spectrum** well described by a model including:
  - Thermal disk + Fe line
  - Thermal comptonization at corona + reflection on disk
- **Non-thermal component** at 400 keV during the intermediate state (seen by INTEGRAL & COMPTEL)
- 15 min – 8 hrs **outbursts** seen by Ulysses, Konus-Wind, BATSE
  - **Fluxes enhanced** by factor 3 to 10 up to ~10^{38} erg/s (2 kpc)
  - during **hard and soft states**
  - No change in the **spectral shape**
  - Seems **unrelated from accretion rate** changes as hard/soft transitions (jet?)



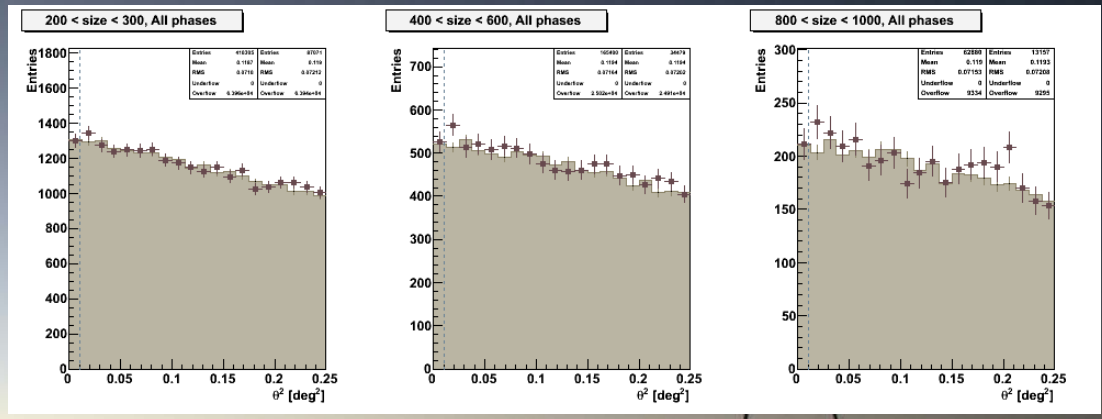
Cadolle Bel et al. 2006

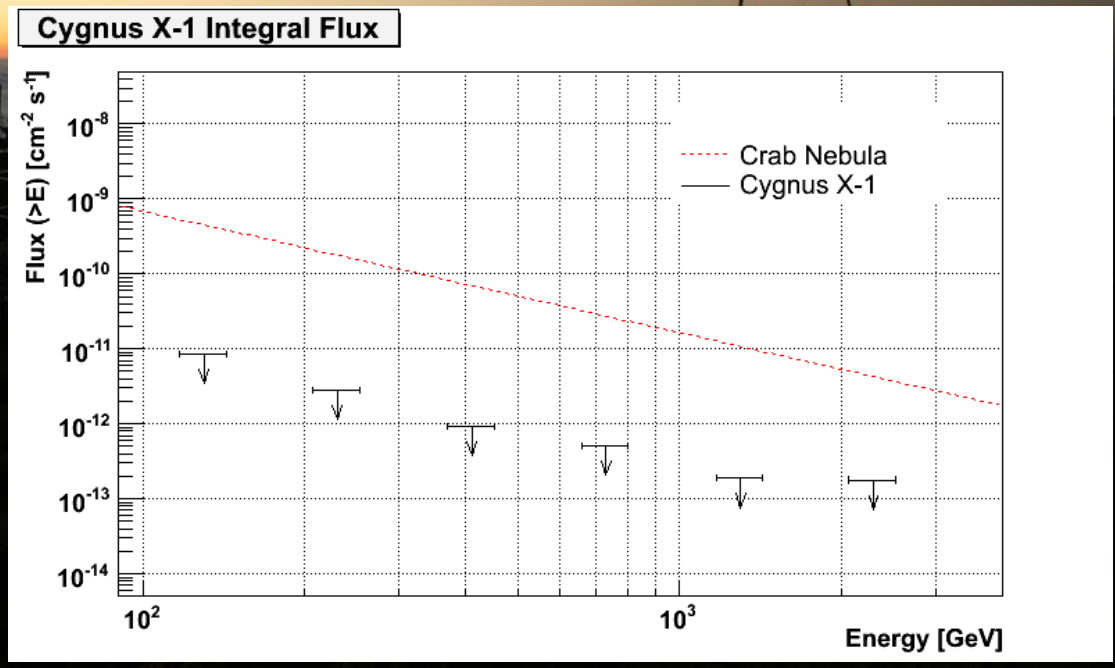


Golenetskii et al. 2003

MAGIC observations

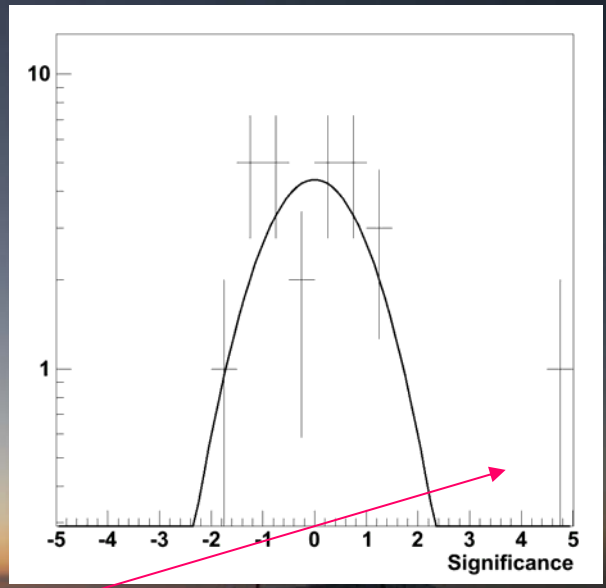
- Cygnus X-1 observed from June to November 2006
- 40 hours in 26 nights
- No significant signal is observed at any energy cut for the entire data sample
- Upper limits to steady flux at the order of 1% Crab
- First limits at these energies





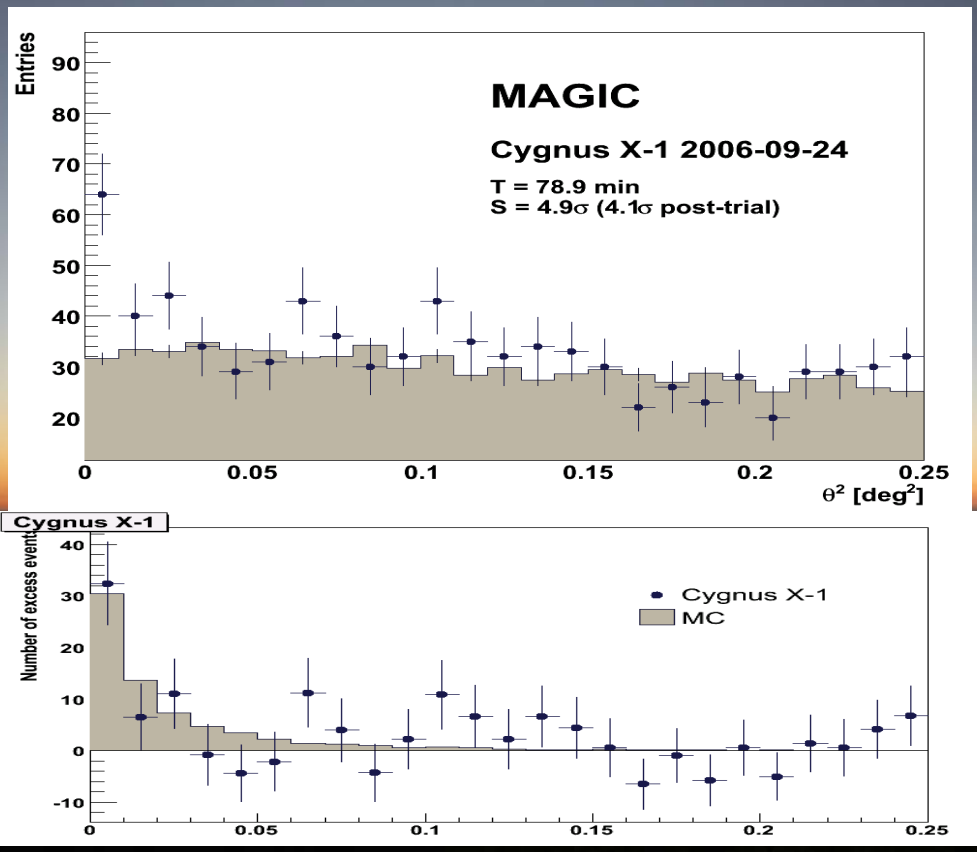
Daily searches

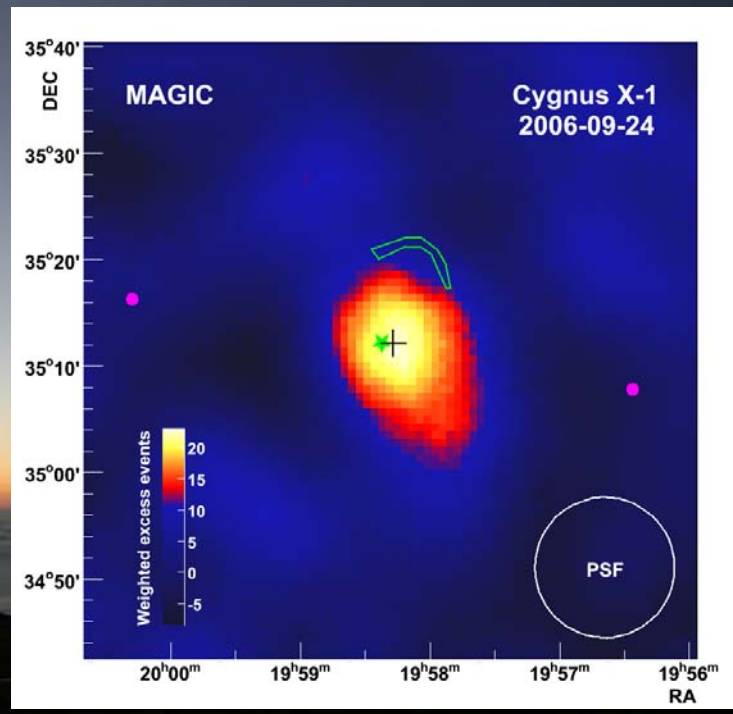
MJD [days]	T [min]	N_{excess} [evts]	S [σ]	Post [σ]	U.L. [evts (% CU)]
53942.051	61.1	3.6± 4.8	0.8	< 0.1	15.02(11.1)
53964.887	105.6	4.8± 6.9	0.7	< 0.1	21.49(9.2)
53965.895	195.3	−13.2± 10.1	−1.3	< 0.1	8.74(2.0)
53966.934	124.8	9.4± 9.5	1.0	< 0.1	33.07(11.9)
53967.992	48.5	−9.0± 4.7	−1.7	< 0.1	1.57(1.5)
53968.883	237.5	−4.4± 11.6	−0.4	< 0.1	22.76(4.3)
53994.953	53.6	−4.0± 4.9	−0.8	< 0.1	6.84(5.8)
53995.961	58.1	−2.8± 4.6	−0.6	< 0.1	7.76(6.0)
53996.855	176.2	1.6± 9.1	0.2	< 0.1	22.15(5.7)
53997.883	132.7	5.2± 7.6	0.7	< 0.1	22.95(7.8)
54000.852	165.2	11.4± 9.7	1.2	< 0.1	35.41(9.7)
54002.875	154.4	36.8± 10.4	4.0	3.2	...
54003.859	166.9	−7.0± 9.1	−0.8	< 0.1	13.35(3.6)
54004.891	123.3	−6.0± 7.9	−0.7	< 0.1	11.33(4.1)
54005.914	87.9	−2.2± 6.3	−0.3	< 0.1	11.88(6.1)
54006.938	28.0	5.4± 4.1	1.4	< 0.1	15.26(24.6)
54020.891	65.5	−8.6± 5.9	−1.4	< 0.1	4.27(2.9)
54021.887	68.6	−6.2± 5.7	−1.0	< 0.1	6.30(4.1)
54022.887	58.1	1.6± 5.9	0.3	< 0.1	14.55(11.3)
54028.863	68.6	3.4± 5.9	0.6	< 0.1	18.28(12.0)
54029.895	33.5	3.4± 5.1	0.7	< 0.1	15.93(21.5)
54030.863	19.6	−1.8± 3.0	−0.6	< 0.1	5.41(12.5)
54048.824	47.2	1.6± 5.7	0.3	< 0.1	14.99(14.3)
54049.824	47.9	−6.0± 5.4	−1.1	< 0.1	6.09(5.7)
54056.820	27.1	−5.2± 3.8	−1.3	< 0.1	3.55(5.9)
54057.820	21.5	1.2± 2.6	0.5	< 0.1	7.96(16.7)



- 4.0σ on 2006-09-25 between 20h58 and 23h41 UTC
- Sample splitted until maximum significance is reached
- Correct probability by number of trials
- 4.9σ (4.1σ after 52 trials) from 79 minutes between 22h17 23h41

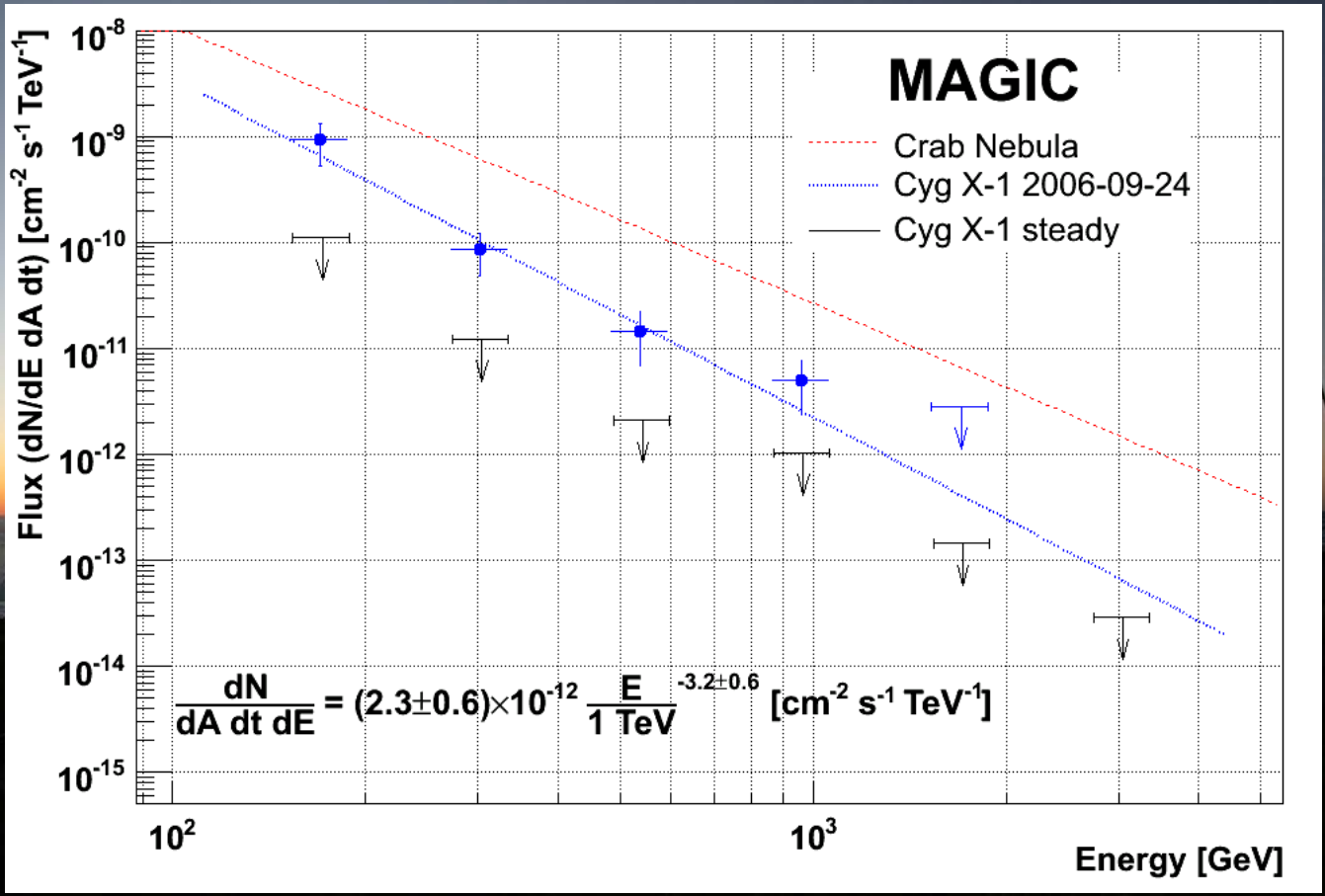
Signal significance and extension





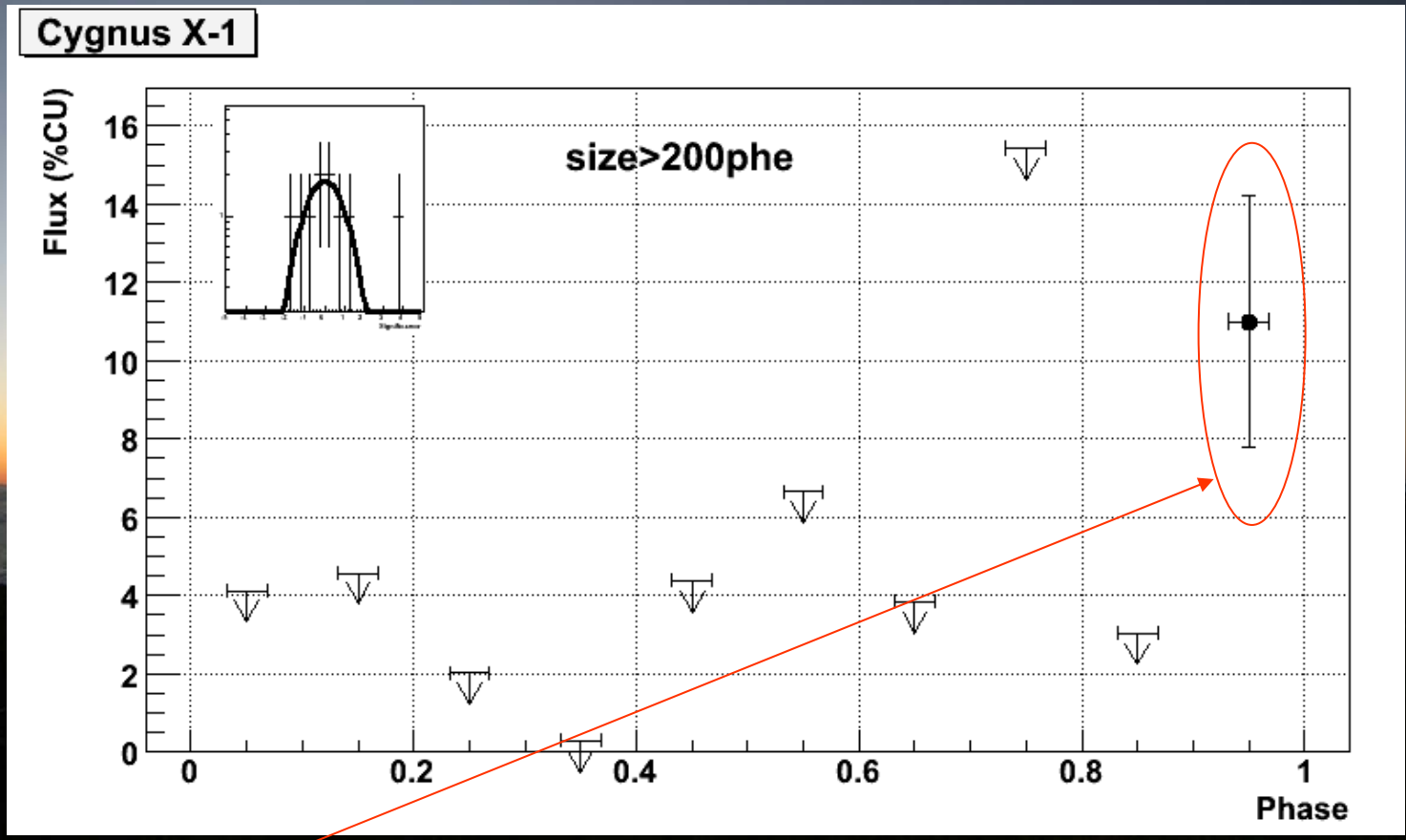
- Excess compatible with point-like source at location $\alpha = 19^h58^m17^s$, $\delta = 35°12'8"$ ±1.5' (stat) ± 2' (syst)
- Compatible with the position of Cygnus X-1 and exclude radio ring

Spectrum



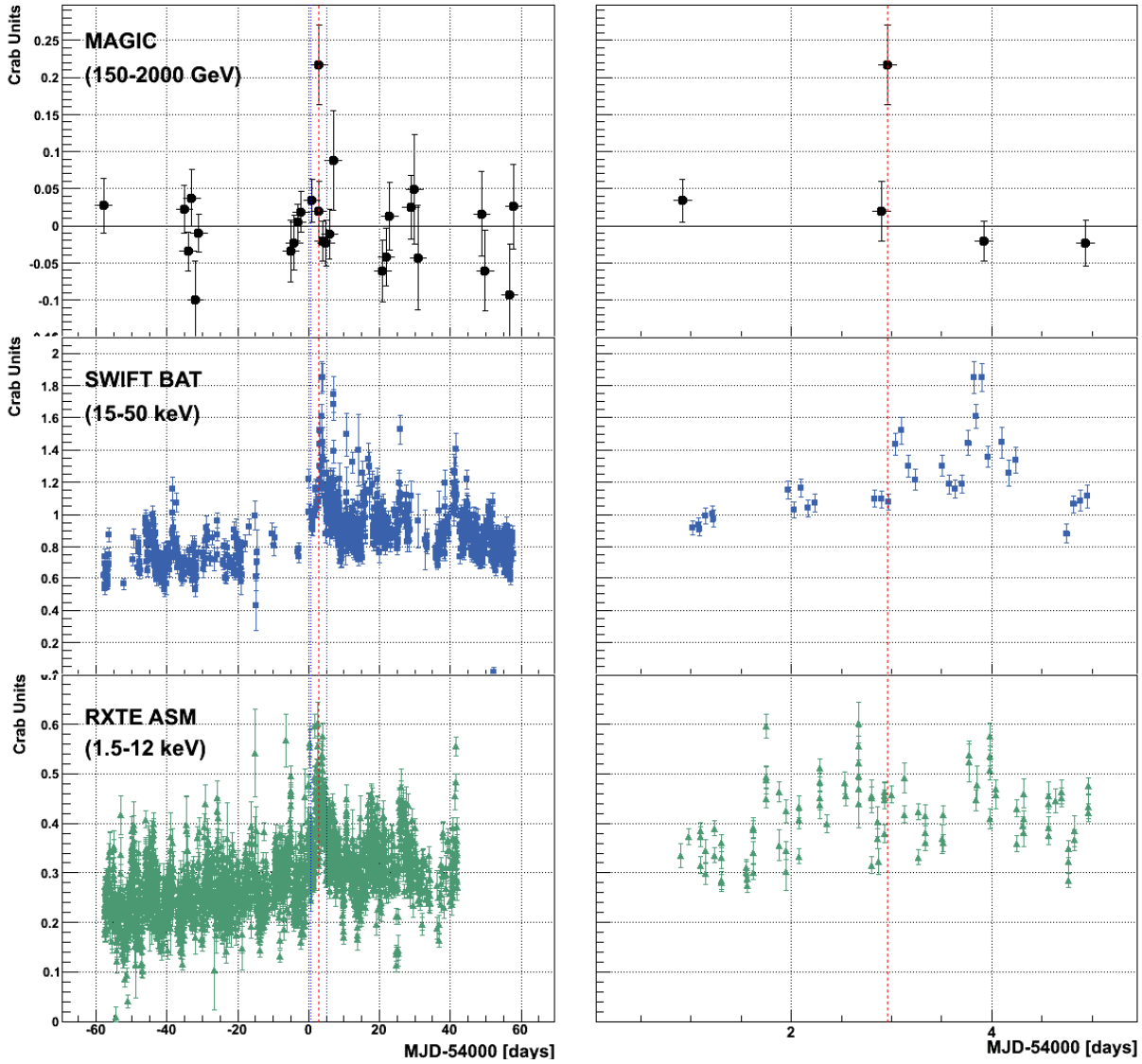
- Spectrum unfolded of detector effects
- Well fitted by power law with index -3.2±0.6 and ~10% Crab at 1 TeV

Search for orbital emission



- 3.8σ at phase 0.9-1.0 (BH superior conjunction)
- All (97%) data correspond to the same observation night

Correlation with X-rays



- **Correlation** MAGIC- X-rays (also INTEGRAL)
- MAGIC sees an excess **right before the first Swift peak** rise and zero flux in the decaying edge of second Swift peak
- Hard x-rays could be produced at the **base of the jet** and γ-rays further away by interaction with stellar wind
- BUT… **opacities** are expected to be huge (10 at 1 TeV)

Conclusions

- **LS I +61 303 has been deeply study at TeV energies with MAGIC over 2 years**
- **With Cygnus X-1, the number of known γ-ray binaries are 4, together with LS I +61 303 (MAGIC), LS 5039 and PSR B1959-63 (HESS), but:**
  - **this is the first experimental evidence of VHE γ-ray emission from a system powered by accretion**
  - **this is the first experimental evidence of VHE γ-ray emission from a system containing a stellar mass black hole**
  - **the phenomenology is completely new:**
    - **short time (<1day), intense flares**
    - **probably not related to the orbital motion**
    - **hints that the emission is produced far from the compact object**