Overview of Galactic results obtained by MAGIC

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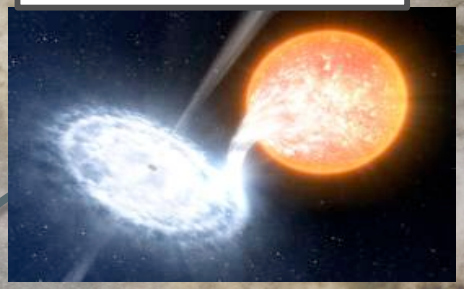
for the MAGIC collaboration
(Universitat de Barcelona, Spain)

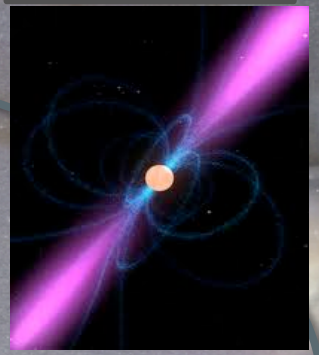
SciNeGhe
Lecce, 20 June 2012

Outline

Binary systems:
- HESS J0632+057
- LS I +61° 303

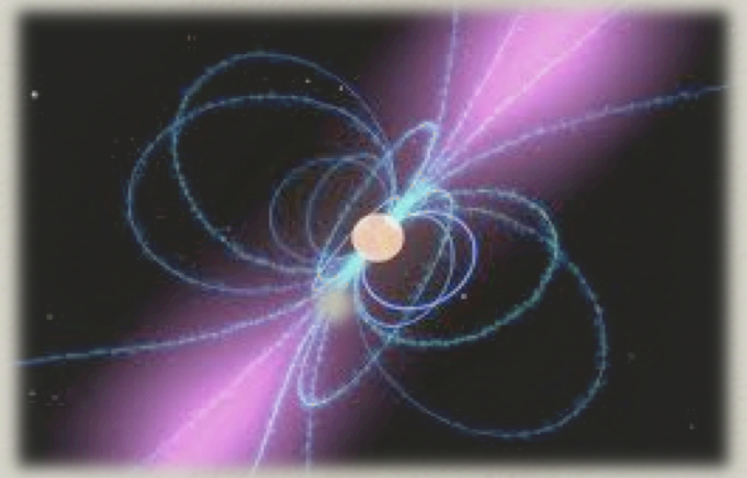


Pulsars:
- Crab pulsar



SNRs:
- W51C

PWNe:
- Crab Nebula
- HESS 1857

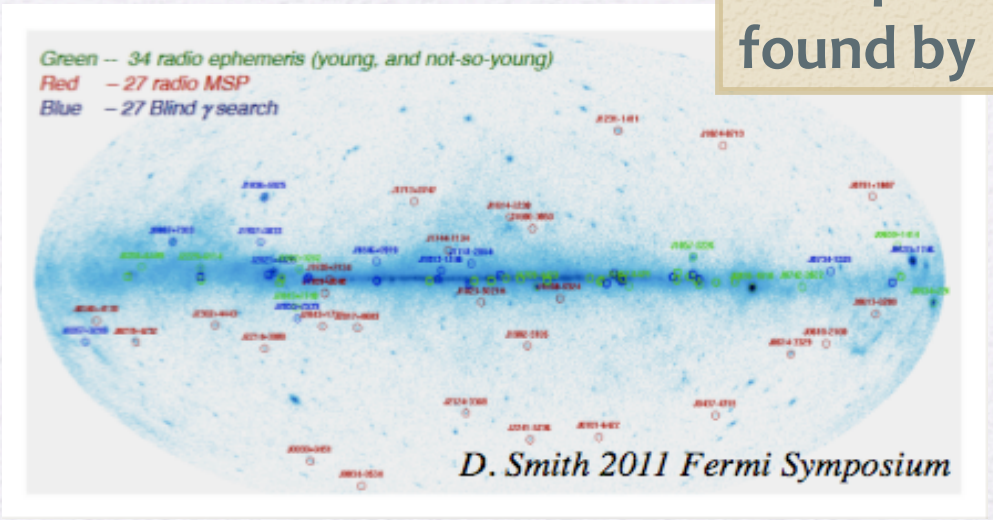


PULSARS

Pulsars: standard view

- curvature radiation: main process at high energies
- high-altitude emission zones (outer gap & slot gap models)
- exponential cutoffs between some hundred MeV and few GeV

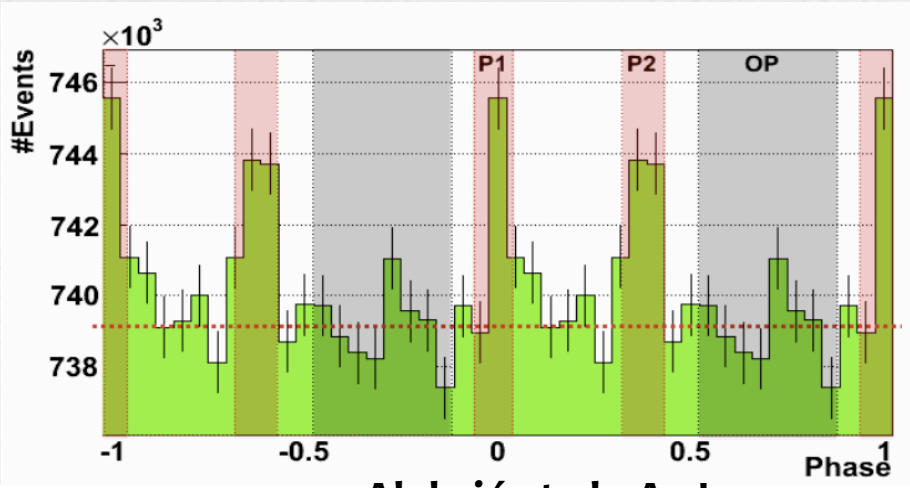
~100 pulsars found by Fermi/LAT



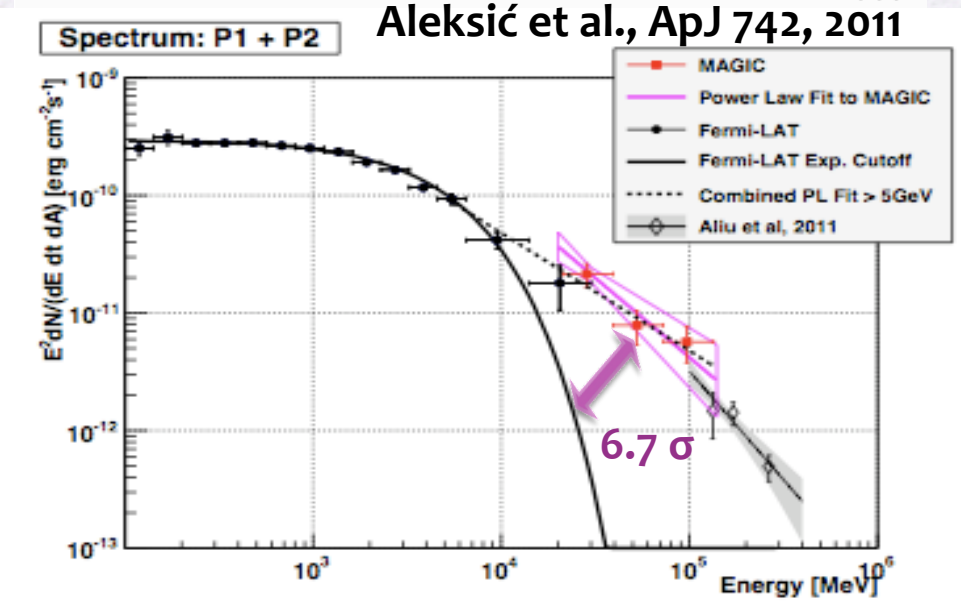
Crab pulsar: a counterexample

HISTORY:

- **[2008] MAGIC: > 25 GeV**
  - first time a pulsar detected at VHEs !
  - sum trigger
- **[2010] Fermi-LAT: < 20 GeV**
  - exp. cutoff at 6 GeV
- **[2011] VERITAS: 100 - 400 GeV**
- **[2011] MAGIC-I: 25 – 100 GeV**
  - sum trigger
  - Oct. 2007 – Feb. 2009: 59 hrs
  - P1: 4.3σ; P2: 7.4σ
  - power-law: Γ = 3.4± 0.5 ± 0.3
  - EGRET phase definition (Fierro et al. 1998)



Aleksić et al., ApJ 742, 2011



Crab pulsar: a counterexample

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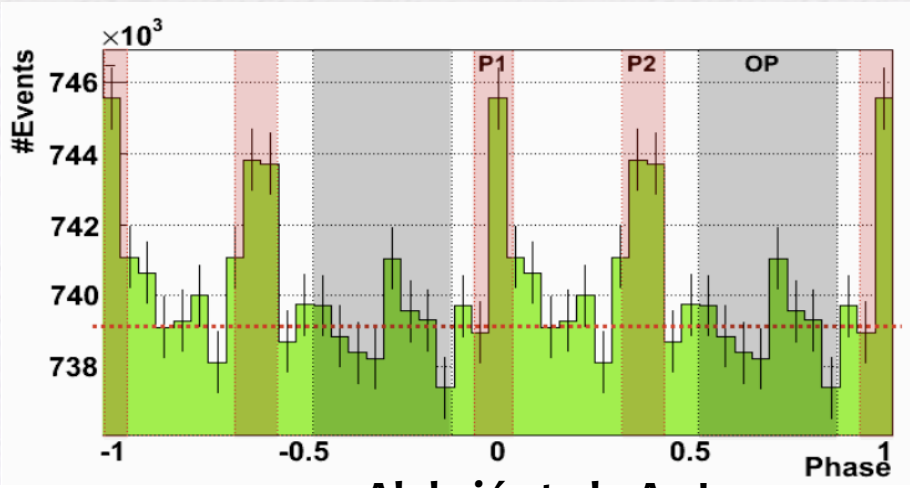

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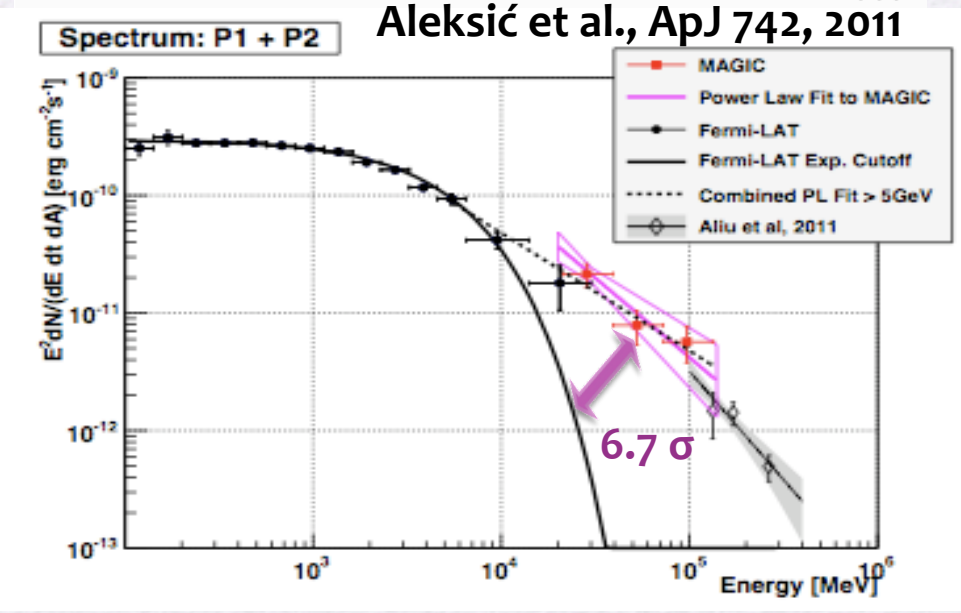
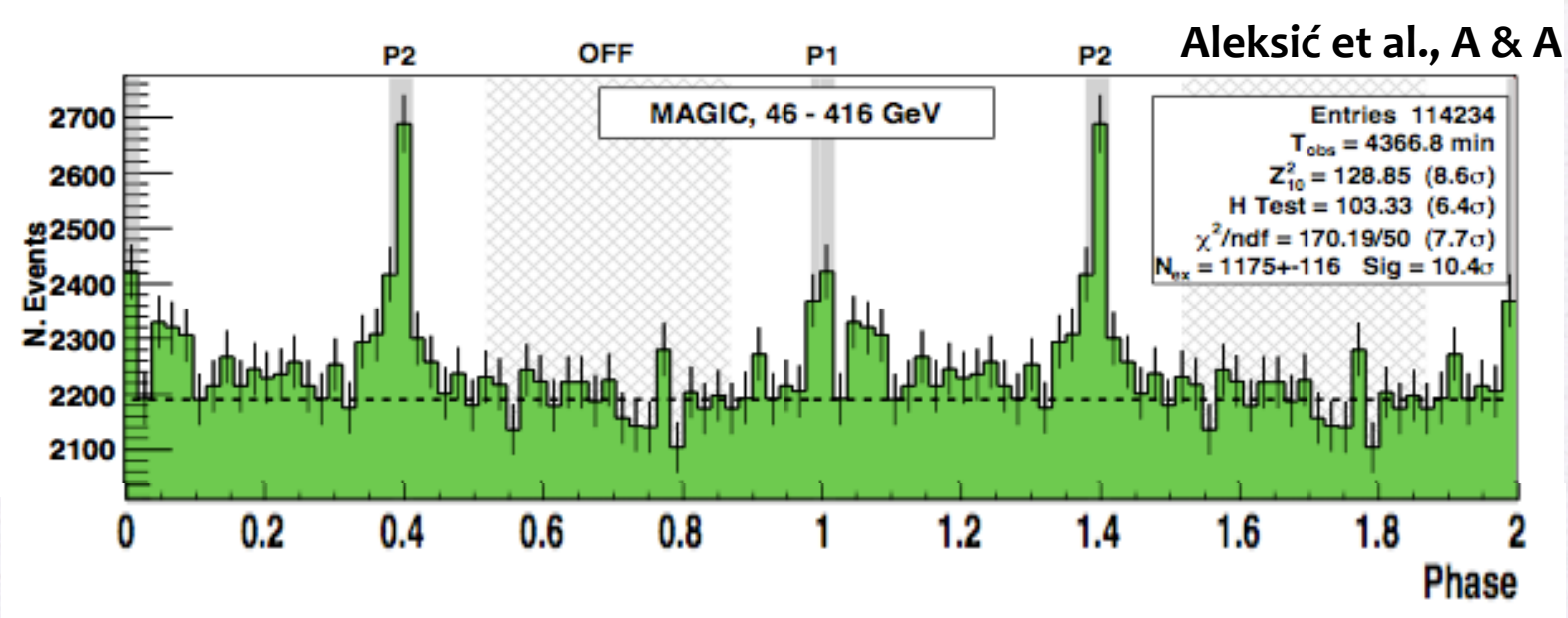


- **inconsistent with exponential cutoff**
- **excluded std outer gap and slot gap models**

MAGIC stereoscopic: 50-400 GeV



Aleksić et al., A & A 540A, 2012

- Oct. 2009 – Feb. 2011 (73h)
- Z, H-, χ^2: 8.6, 6.4, 7.7 σ
- P1: ~5σ P2: ~10σ
- pulse shape: Gaussian
- pulses aligned and narrower a posteriori defined intervals: P1[0.983-0.026] P2[0.377-0.422]

Stereoscopic spectra

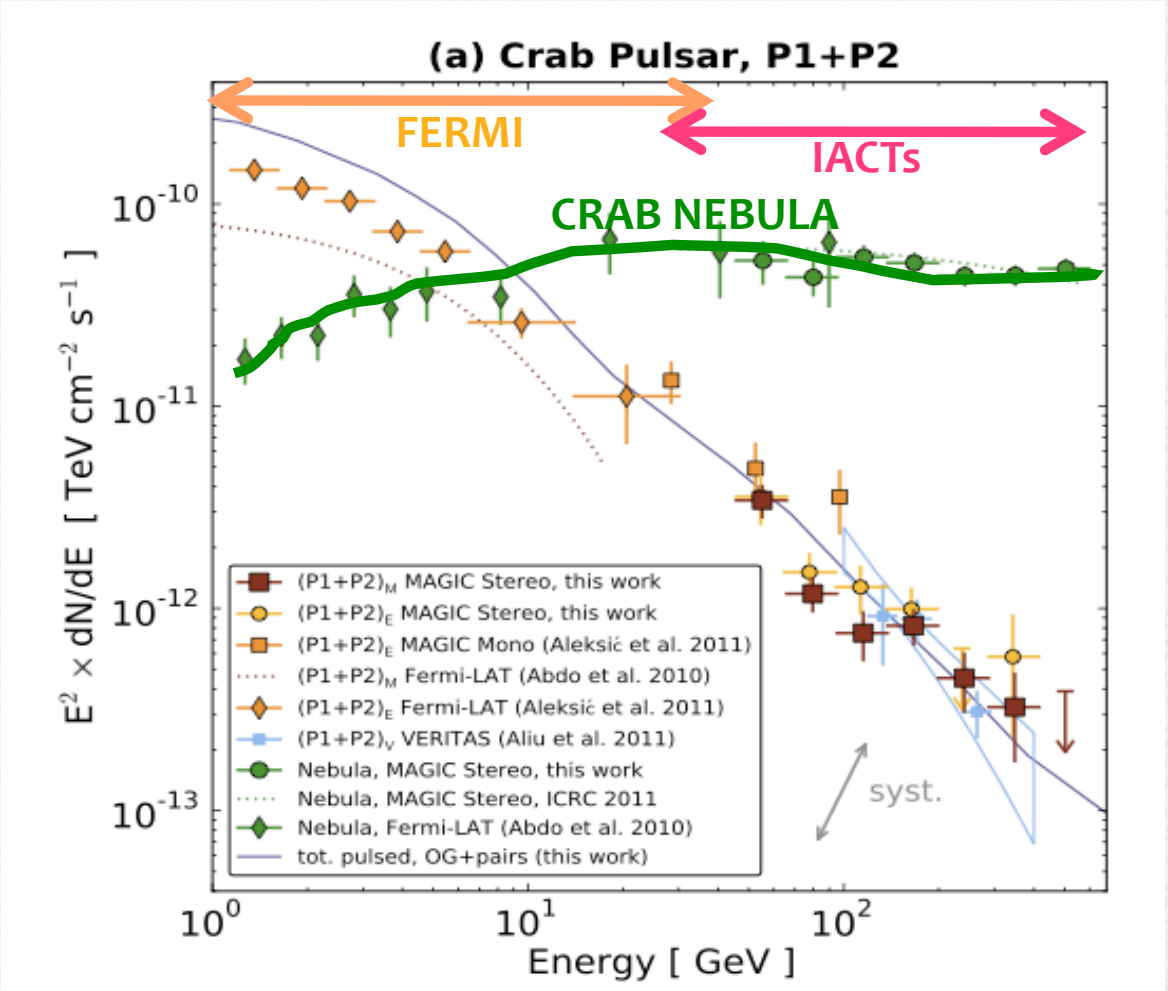
GREEN: Nebula
(good agreement GeV-TeV)

YELLOW DIAMOND: FERMI
(EGRET time intervals)

YELLOW SQUARE: MAGIC-I
(EGRET time intervals → 21%)

RED: MAGIC STEREO
(MAGIC time intervals → 8.8%)

BLUE: VERITAS
(VERITAS time intervals → 6.8%)



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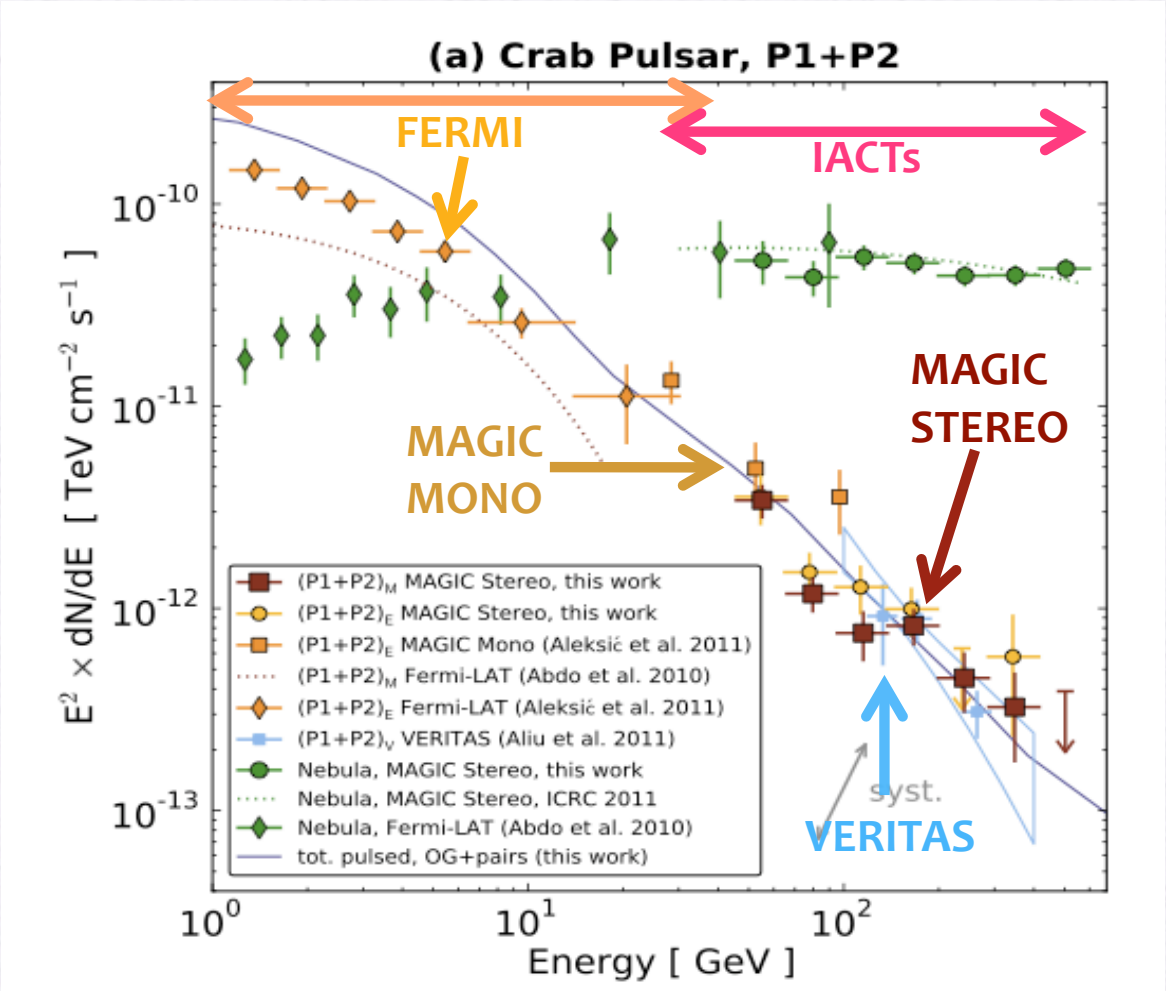

Aleksić et al., A & A 540A, 2012

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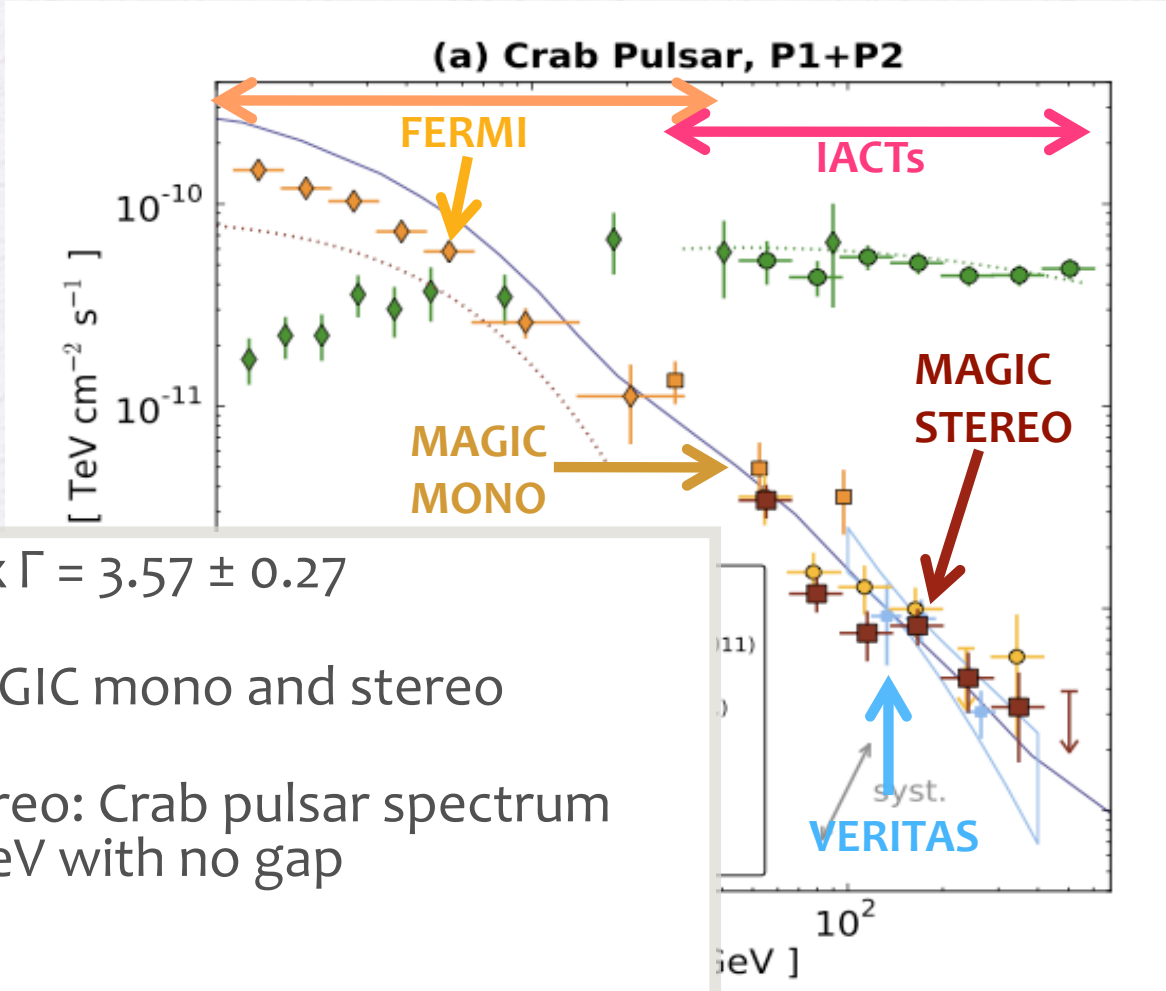
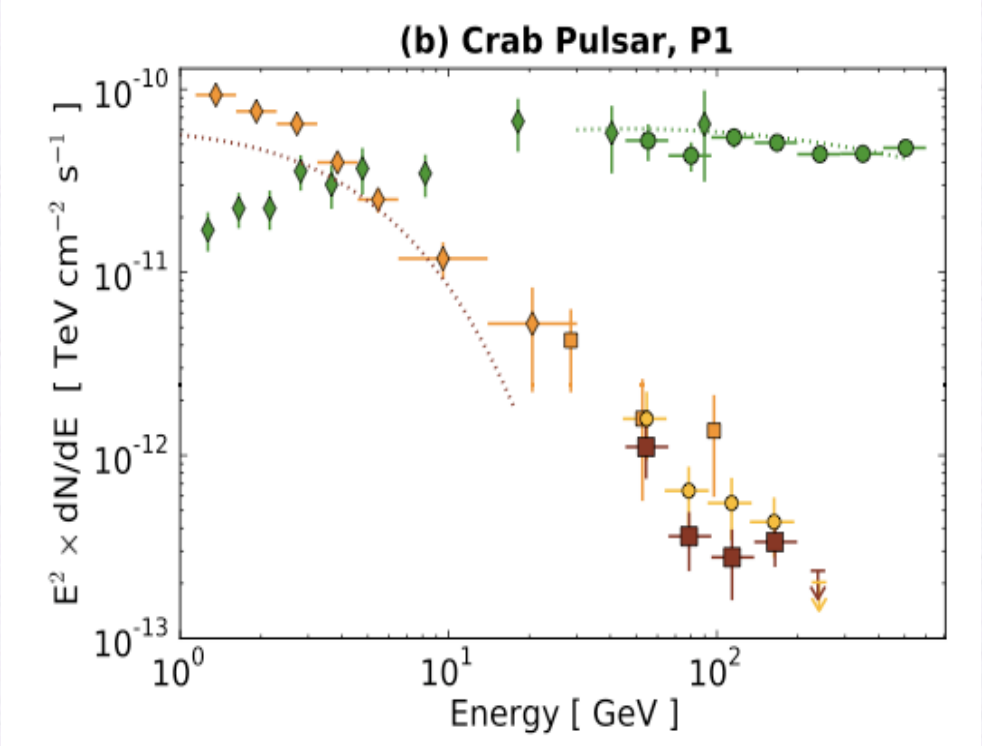
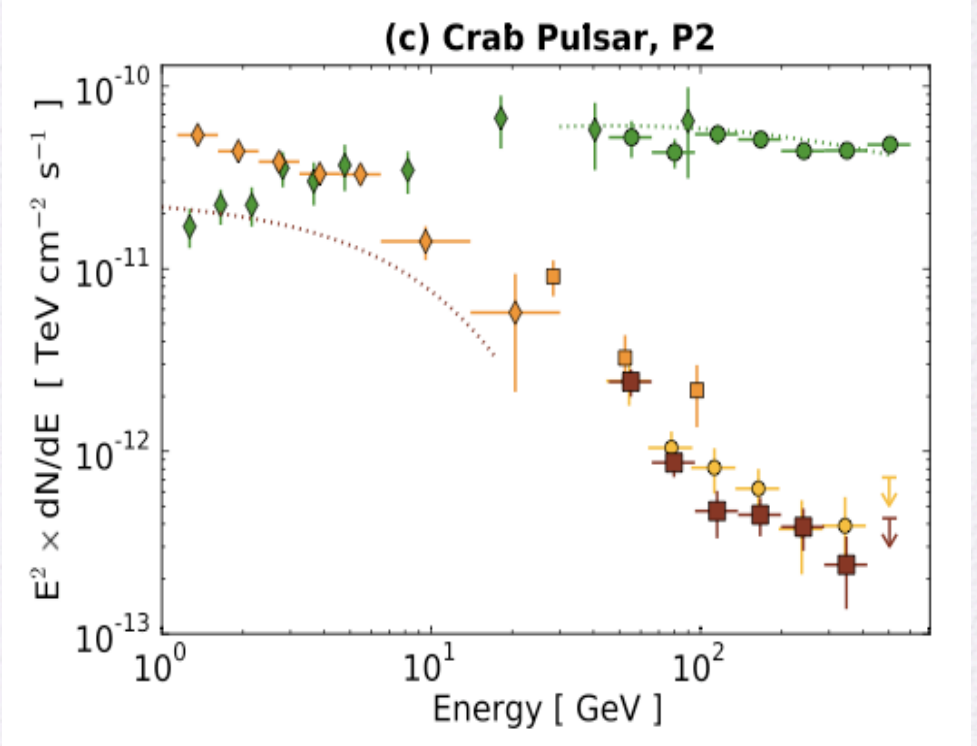


- power-law with photon index Γ = 3.57 ± 0.27
- agreement (2σ) between MAGIC mono and stereo
- Fermi + MAGIC-I + MAGIC stereo: Crab pulsar spectrum between 100 MeV and 400 GeV with no gap
  → broken power-law
- agreement with VERITAS also in peak position and width

Phase resolved stereoscopic spectra

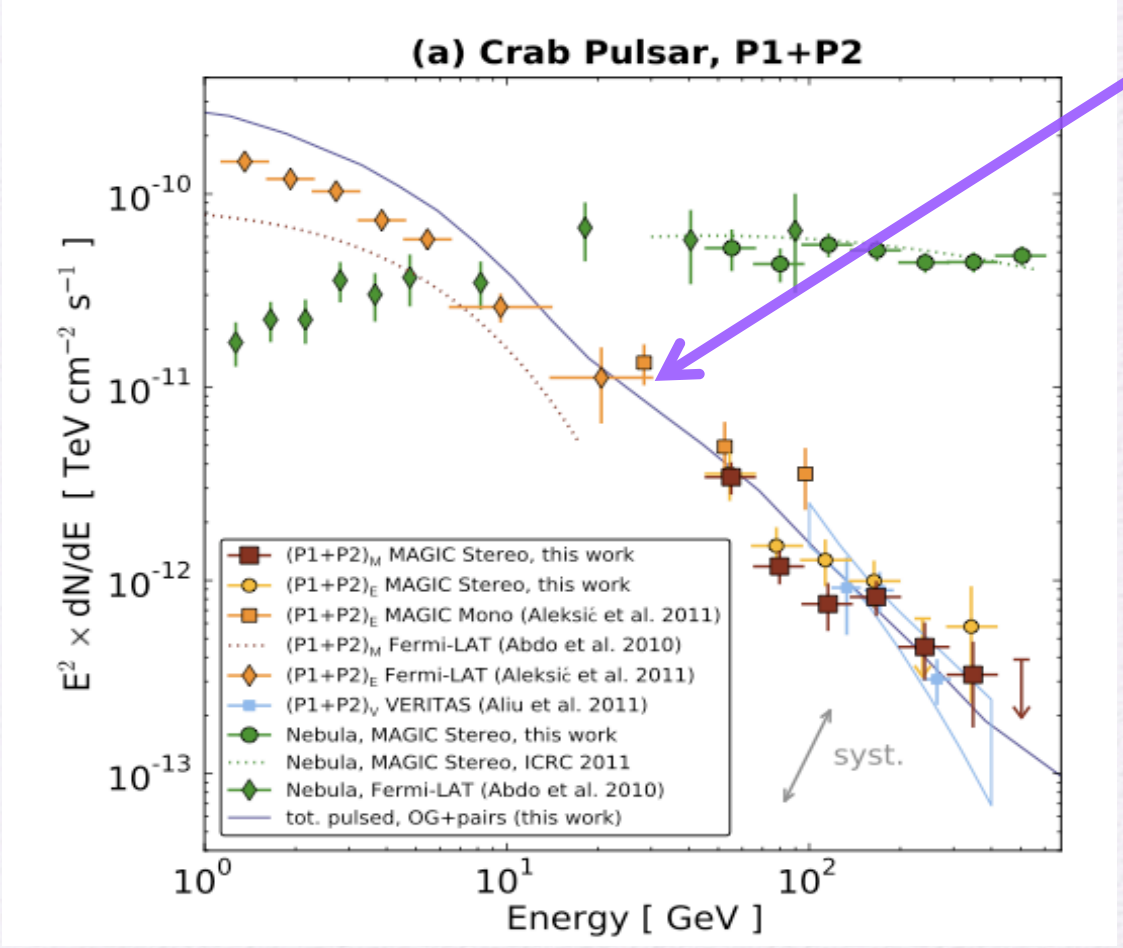




Aleksić et al., A & A 540A, 2012

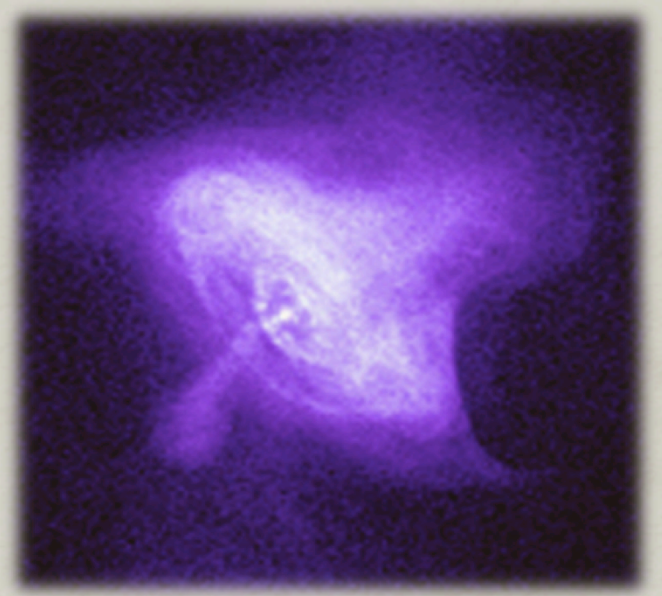
single power-law with $\Gamma = 4.0 \pm 0.8$ (P1) and 3.4 ± 0.3 (P2)

A possible explanation?



- curvature radiation: unlikely
- emission region > 10 r_*
- 2 scenarios at work:
  1. extension outer gap scenario by Hirotani *(Aleksić et al., ApJ 742, 2011)*
     - SSC of secondary and tertiary $e^{\pm}$-pairs on IR-UV photons
     - power-law component up to 1 TeV
  2. IC of cold relativistic wind with pulsed X-rays outside the light cylinder *(Aharonian et al., Nature, 2012)*
     - sharp cutoff at ~ 500 Gev

Aleksić et al., A & A 540A, 2012



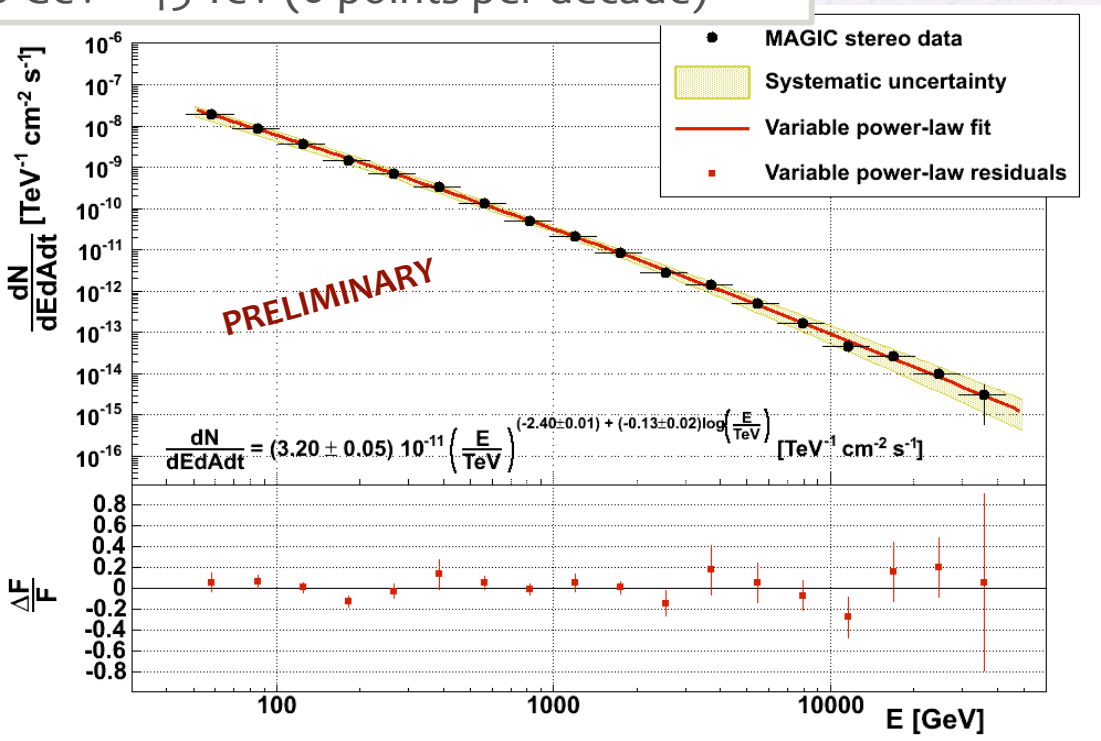
Pulsar Wind Nebulae

Crab Nebula:

unprecedented spectral measurement

- standard candle of astronomy & archetypal PWN
- Oct. 2009–Mar. 2011 (49 h)
- new analysis technique to lower the energy threshold

50 GeV – 45 TeV (6 points per decade)

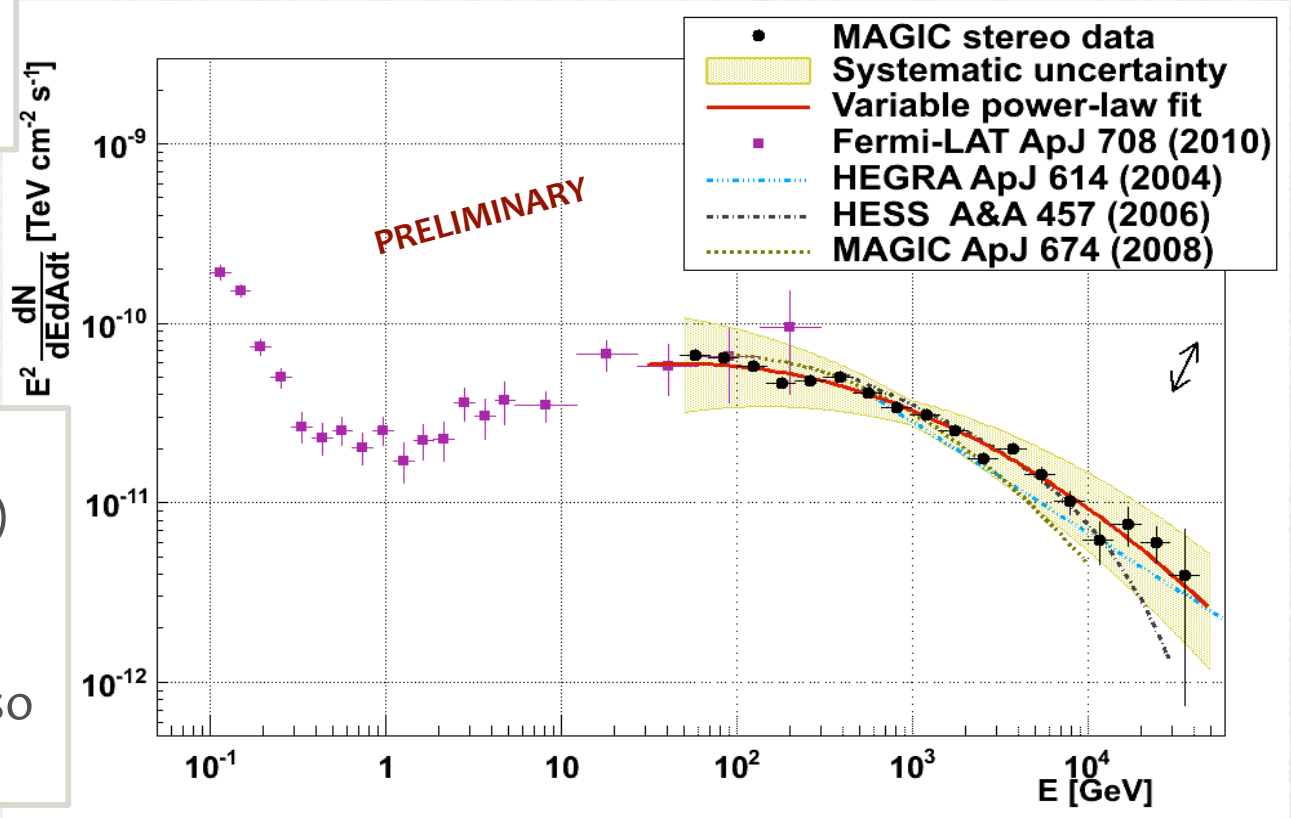


statistical errors as low as 5% below 100 GeV

Crab Nebula:

unprecented spectral measurement

dominated by systematic uncertainties
→ impossible to exclude cutoff at 10 TeV

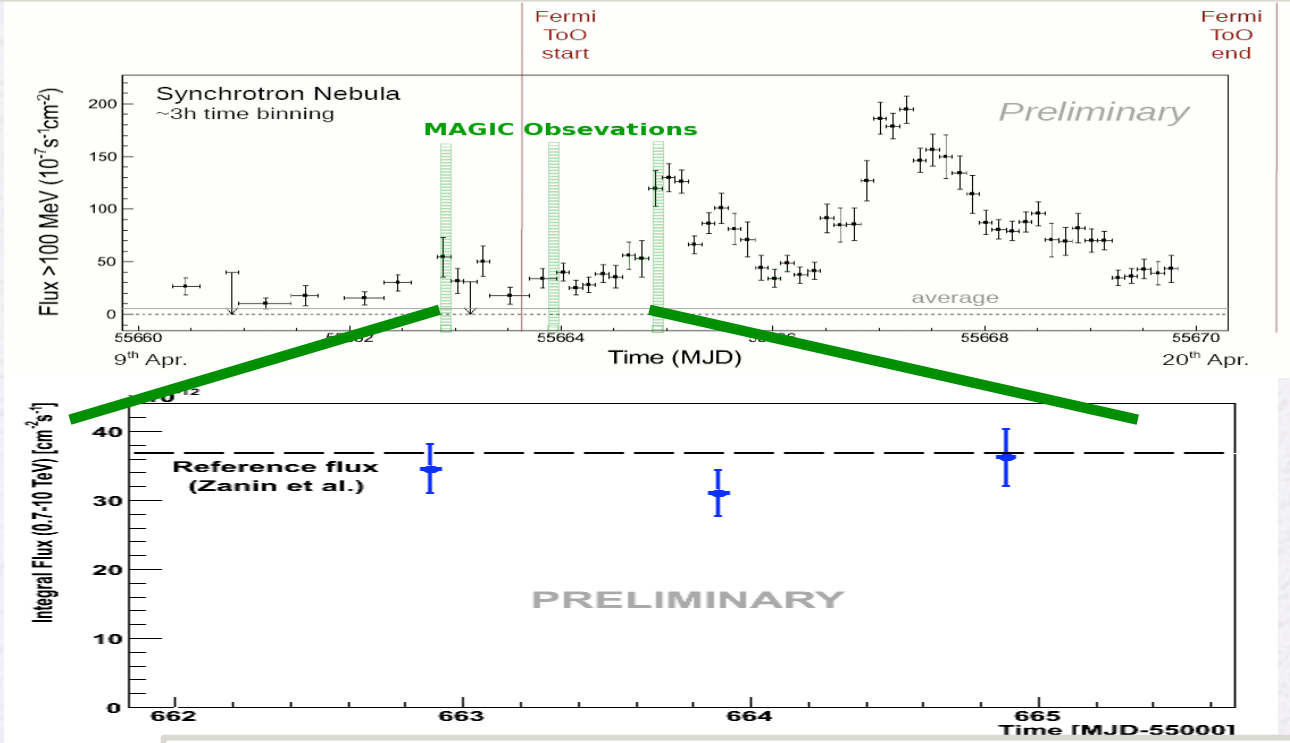


Inverse Compton peak estimation (MAGIC + Fermi)
59 ± 6 GeV (stat. only):

most precise measurement so far

Crab Nebula flux variability

flux constant within systematic error (13%) at 95% probability,
but what during GeV superflares?

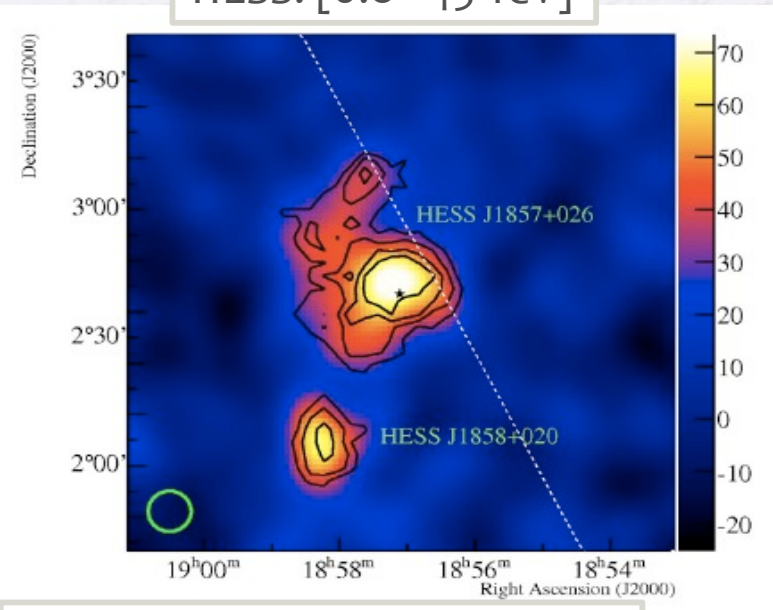


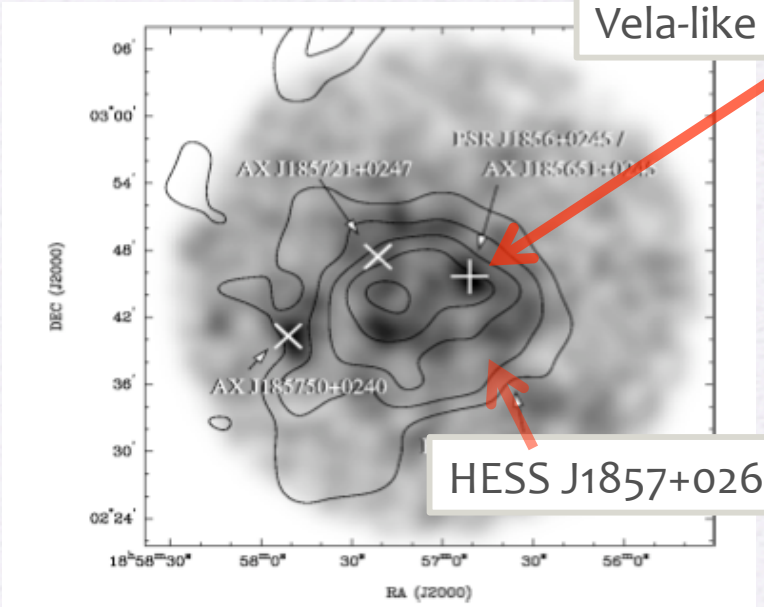
no variability observed between 0.7 and 10 TeV

three nights in April 2011 on top of a 3 hrs Fermi-bin
when flux > 100 MeV was 15 times higher than steady flux

HESS J1857+026: PWN?

HESS: [0.8 - 45 TeV]





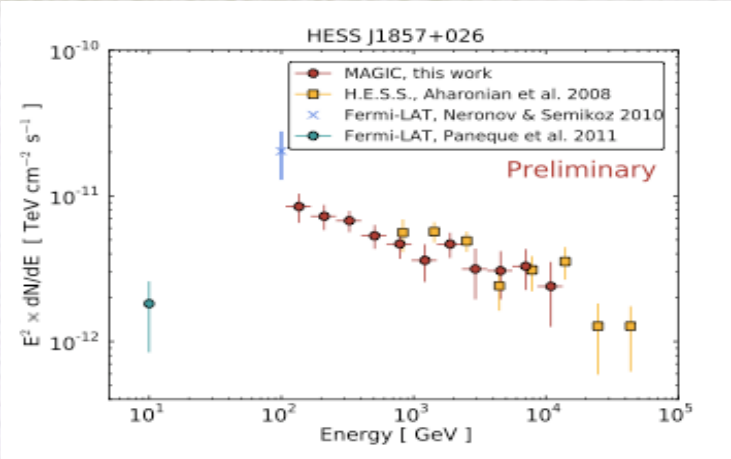
- power-law with Γ=2.39 ± 0.08
- extension σ=0.11° ± 0.08°
- Northern tail?

Is the pulsar powering the PWN seen as TeV source?

HESS J1857+026: PWN?

- Jul.-Oct. 2010: ~30hrs
- E > 100 GeV detection at 12σ

power-law spectrum with Γ = 2.27 ± 0.08
→ turnover between 10 and 100 GeV



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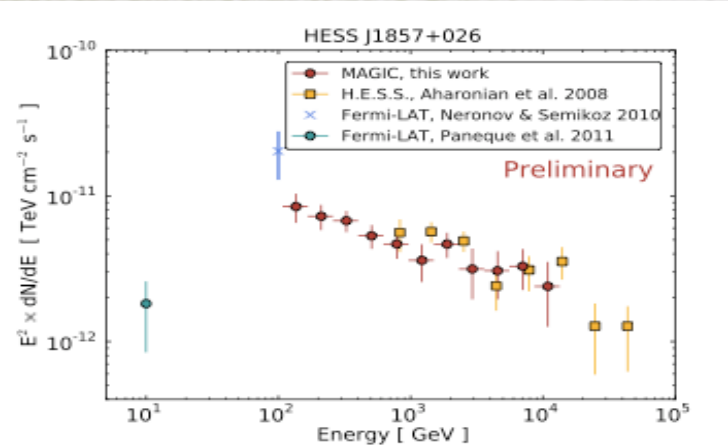
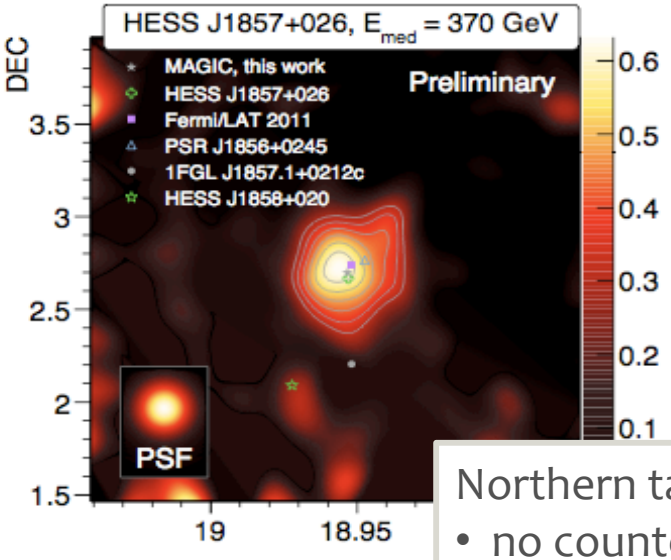
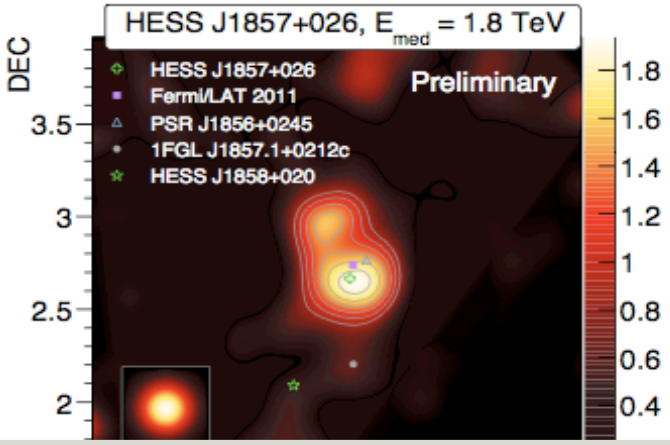


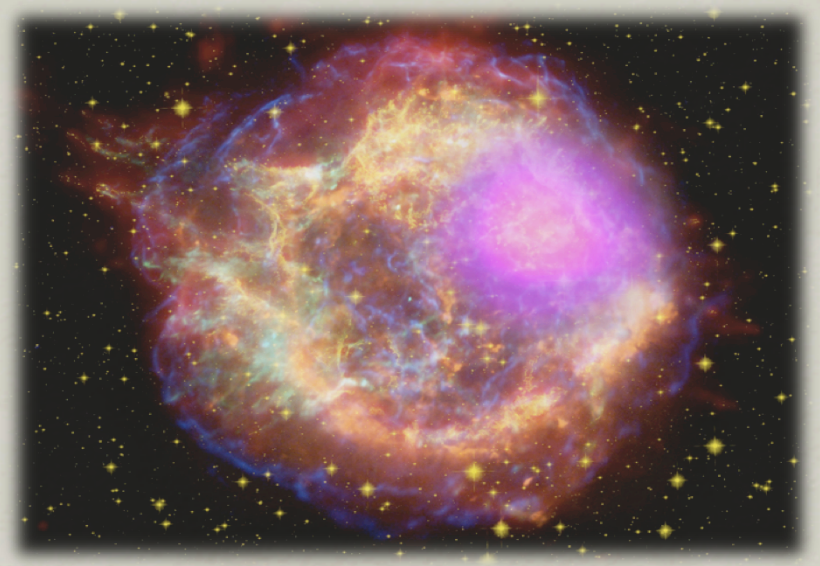
peak position compatible with HESS





extension
σ=0.22° ± 0.02°
larger than HESS
→ support to the PWN scenario

Northern tail:
- no counterpart at low energies
- a different object or different mechanism at work?

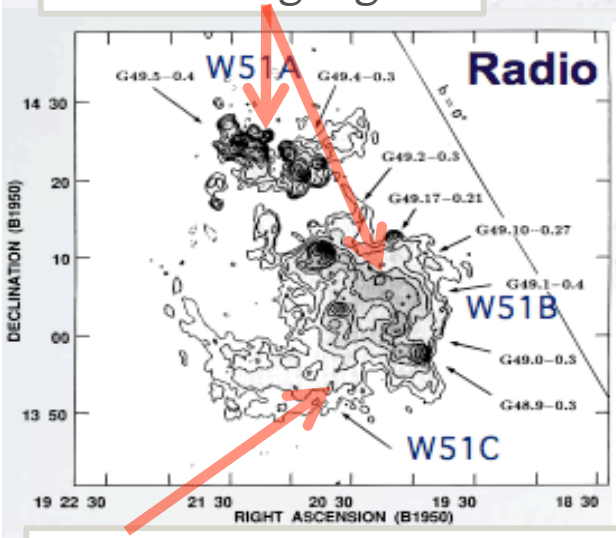


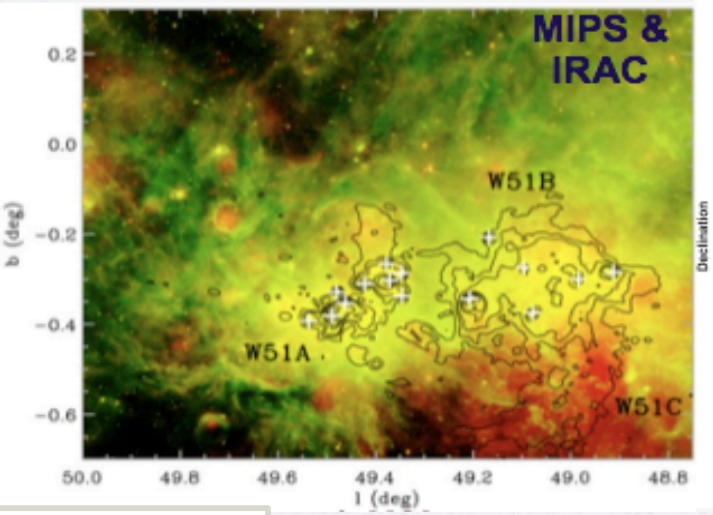
Supernova Remnants

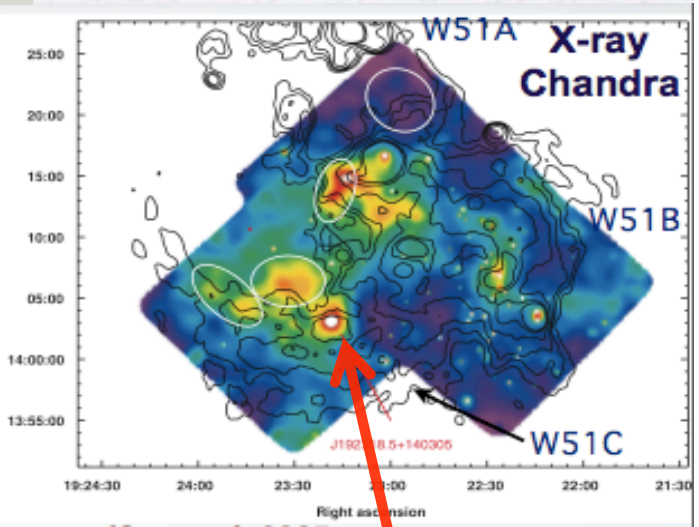
W51 complex

W51A & W51B
star forming regions

3 components





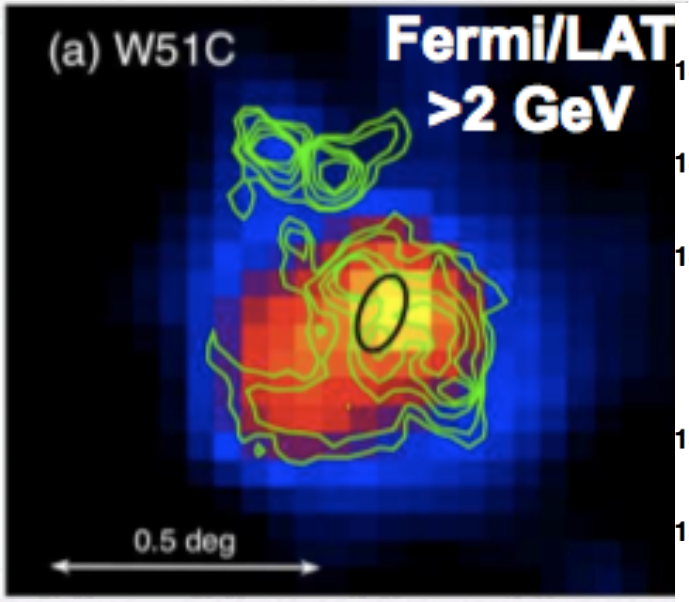


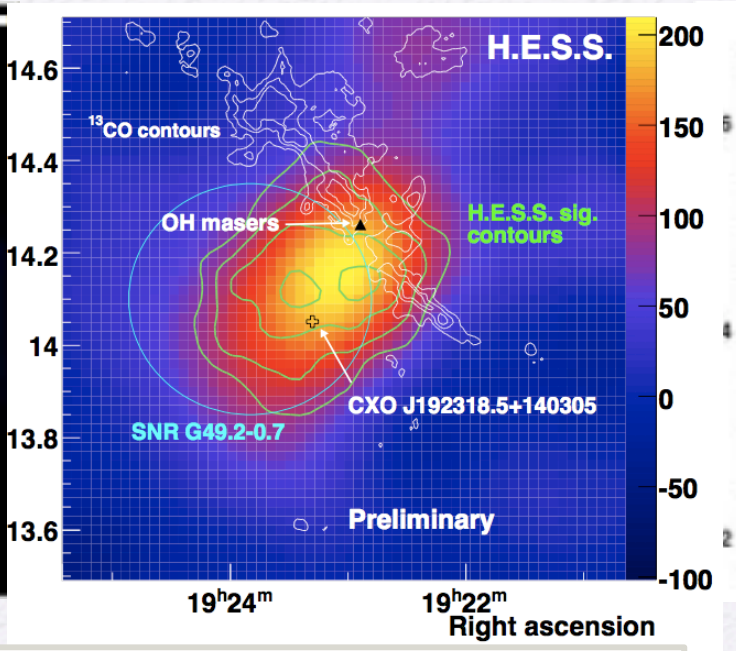
W51C: medium age (~30kyr) SNR at 6 kpc

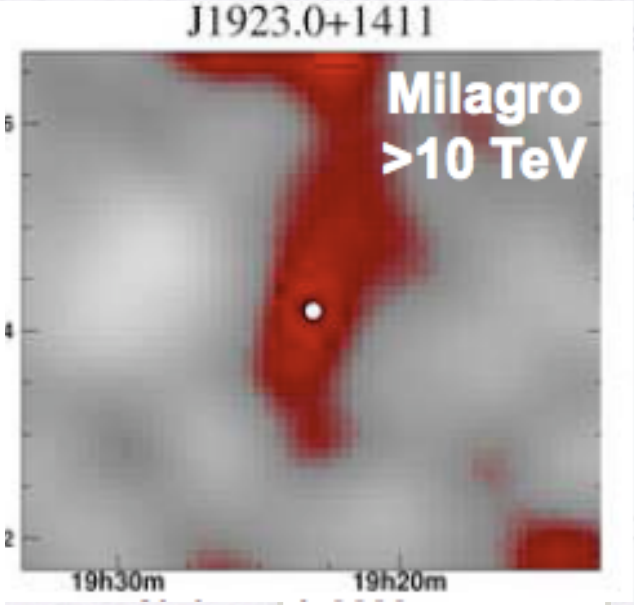
CXO J192318 hard X-ray source:
possible PWN associated to SNR

The shell of the remnant interacts with
the surrounding molecular clouds

W51 C





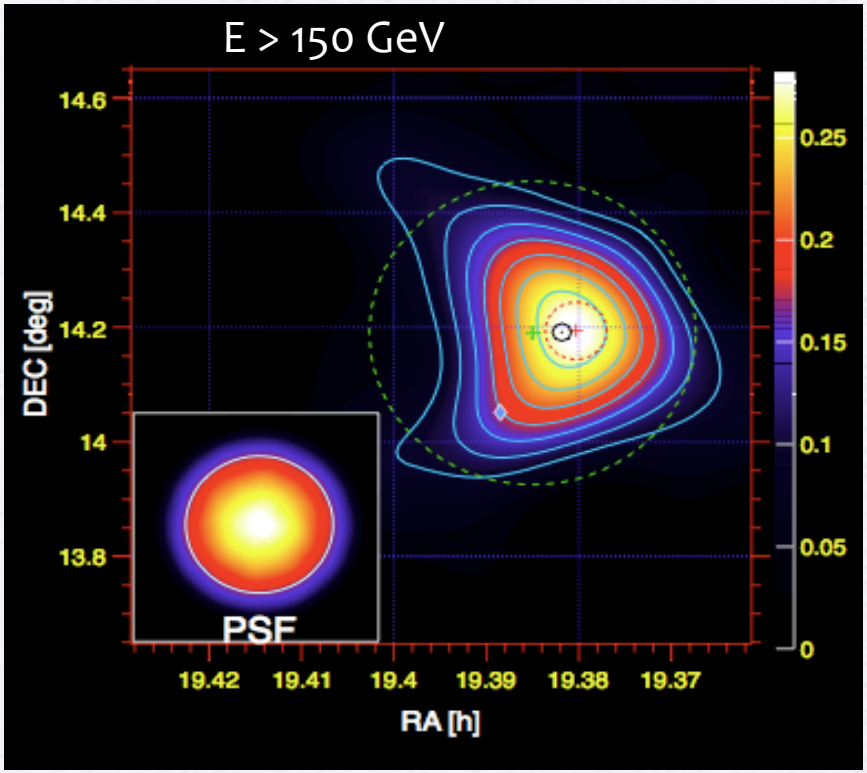


Evidence at 3σ

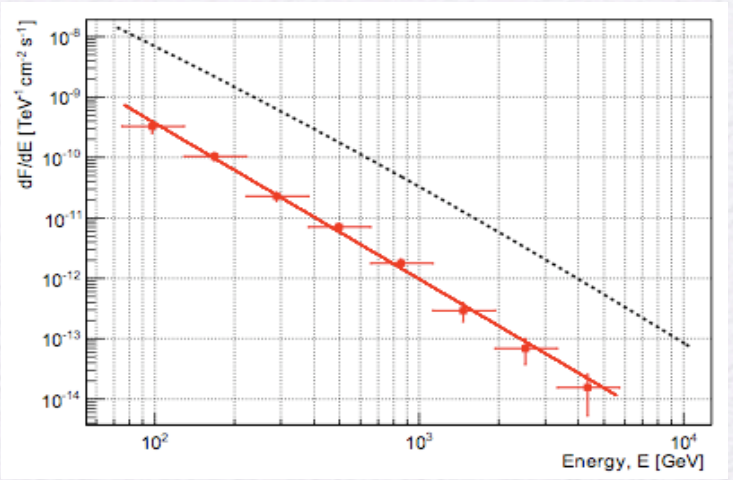
Detected by Fermi/LAT above 2 GeV and by HESS above 1 TeV

interesting candidate to test and study cosmic ray acceleration in SNRs

W51: MAGIC detection



- May 2010- June 2011: 53 h →11.4 σ
- flux level: ~4% of the Crab Nebula flux
- source centered 0.4° away from Fermi/LAT position
- extension: 0.12 ° ± 0.02° ± 0.02°



Aleksić et al., A & A 541, 2012

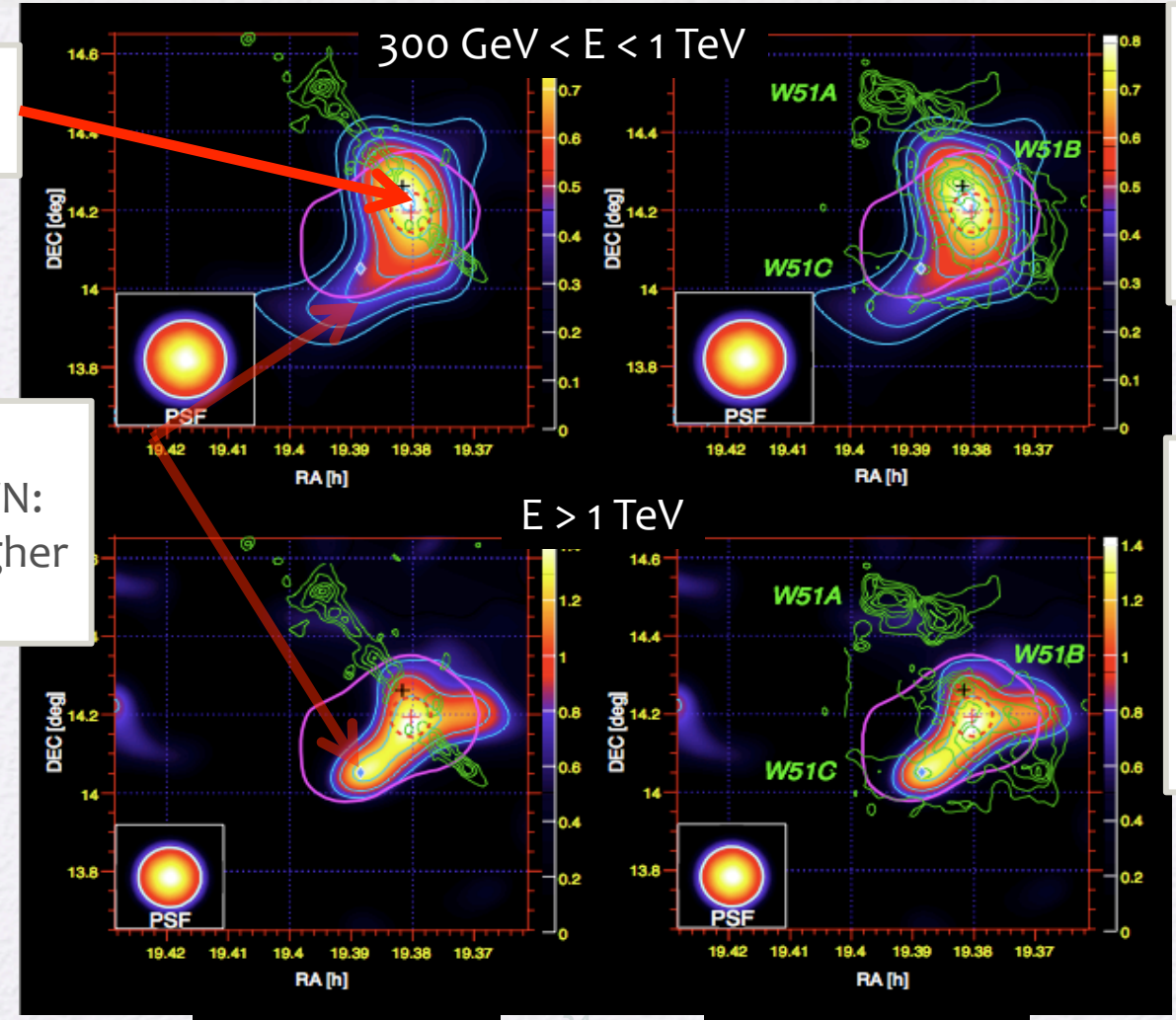
- power-law spectrum: Γ = 2.58 ± 0.07 ± 0.22 in agreement with Fermi one (Γ = 2.5)

single power-law from 10 GeV to 5 TeV

Any substructure in the emission?

maximum at the shocked-gas region

South-Eastern tail coincident with PWN: more evident at higher energies



centroid and extension in agreement with those for E > 150 GeV

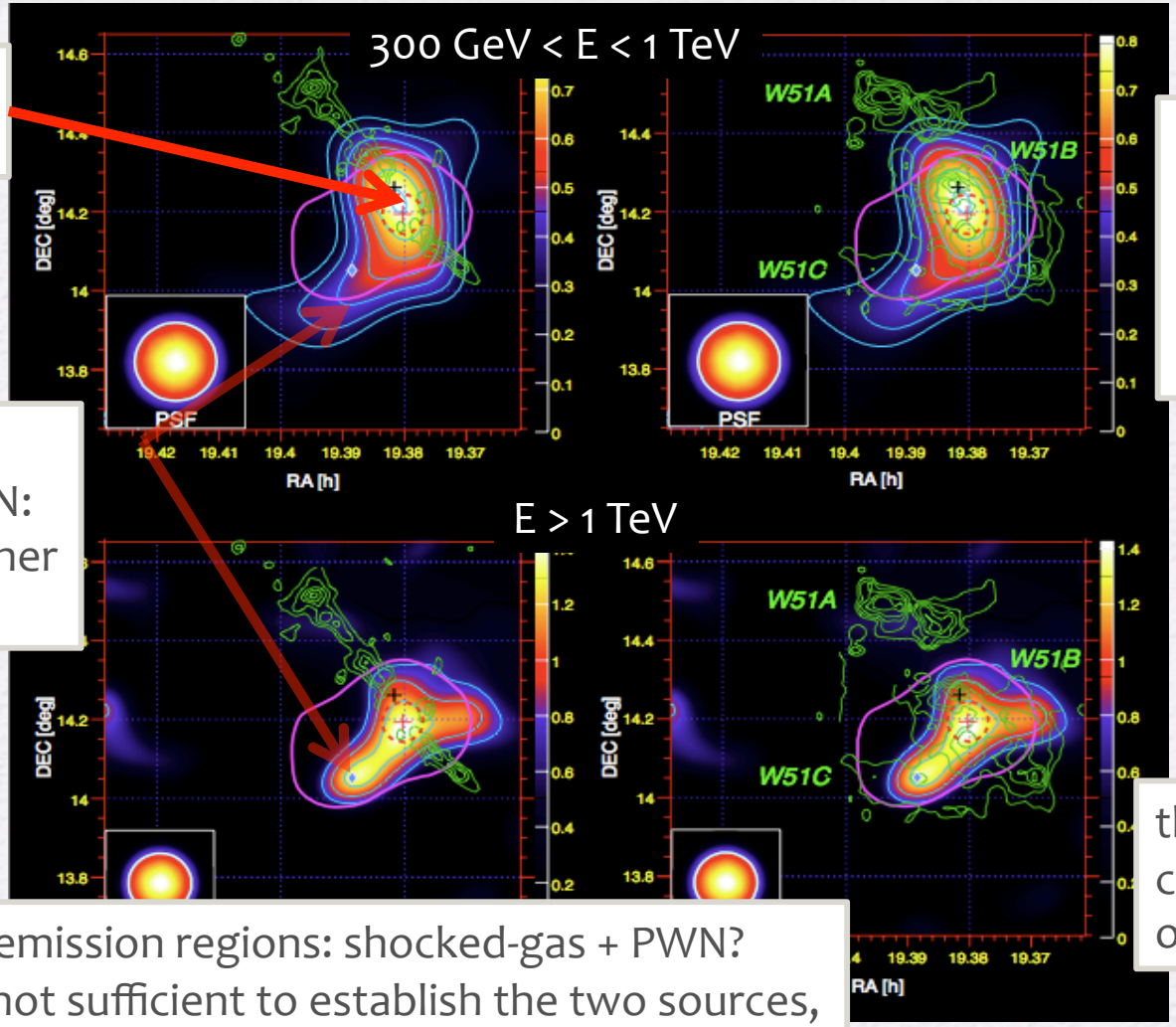
no VHE emission coinciding with W51B
→ CRs escaping the SNR scenario is disfavored

^{13}CO contours

radio contours

Any substructure in the emission?

maximum at the shocked-gas region



centroid and extension in agreement with those for E > 150 GeV

South-Eastern tail coincident with PWN: more evident at higher energies

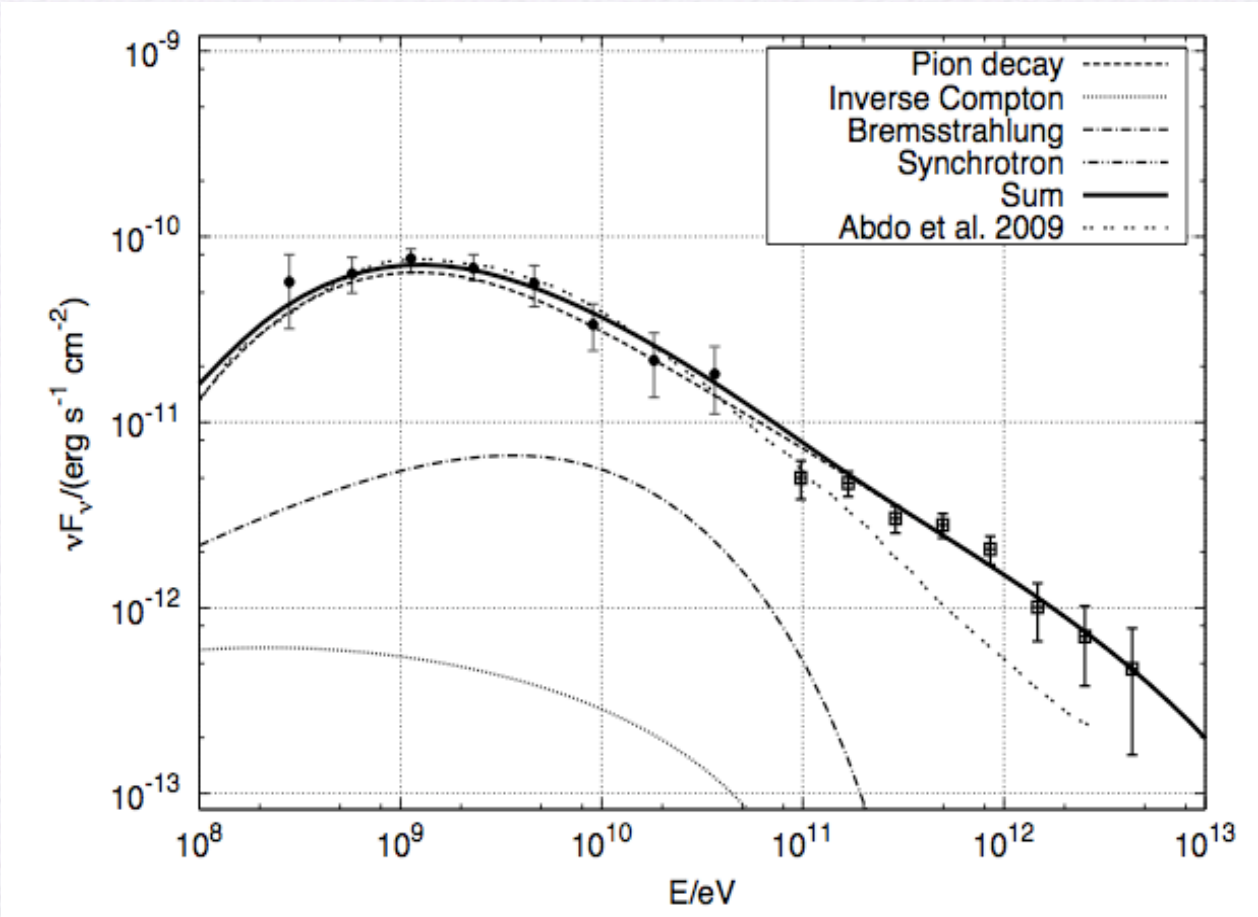
the PWN region contributes 20% of overall emission

2 TeV emission regions: shocked-gas + PWN?
statistics not sufficient to establish the two sources, but physically plausible (no dense gas close to PWN)

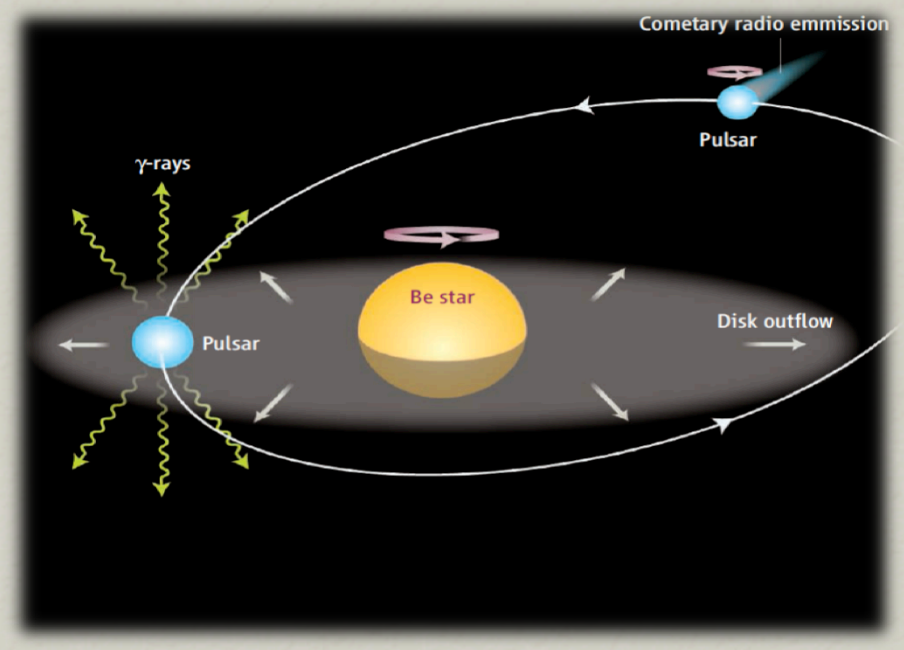
W51: a probable site of CR acceleration!

- favored: γ rays from neutral pion decay
  - SED best described by hadronic model
  - morphology: maximum emission in shocked region (SNR shell- cloud) close to the acceleration site of parents particles

→ proton acceleration up to 100 TeV?
(waiting for news from ν telescopes..)



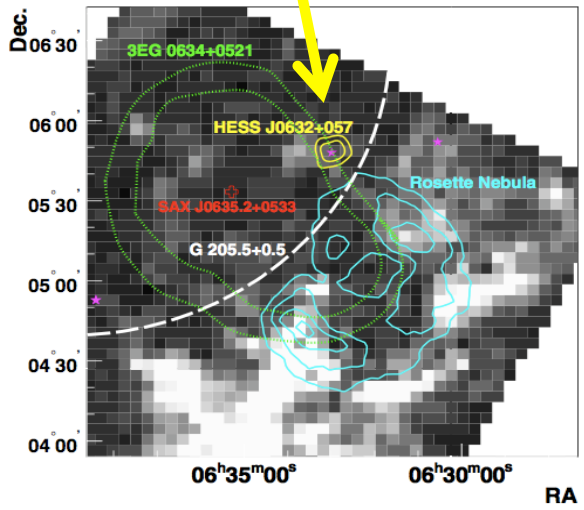
Aleksić et al., A & A 541, 2012



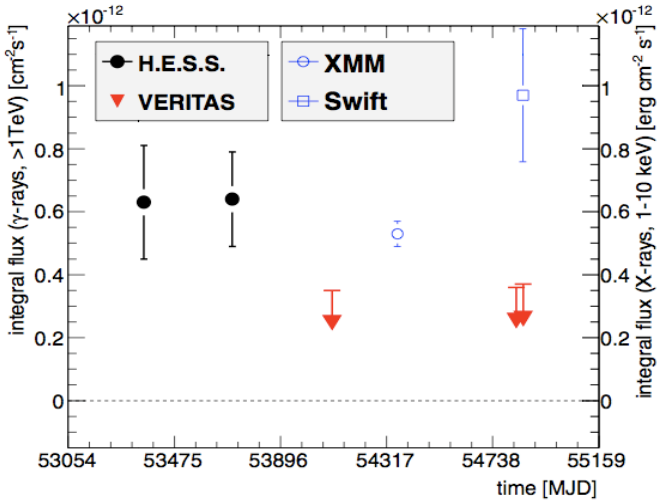
BINARY SYSTEMS

HESS J0632+057: a new binary

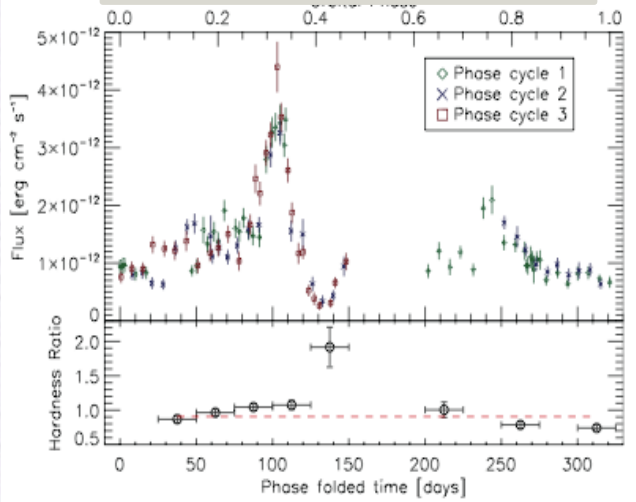
HESS point-like source



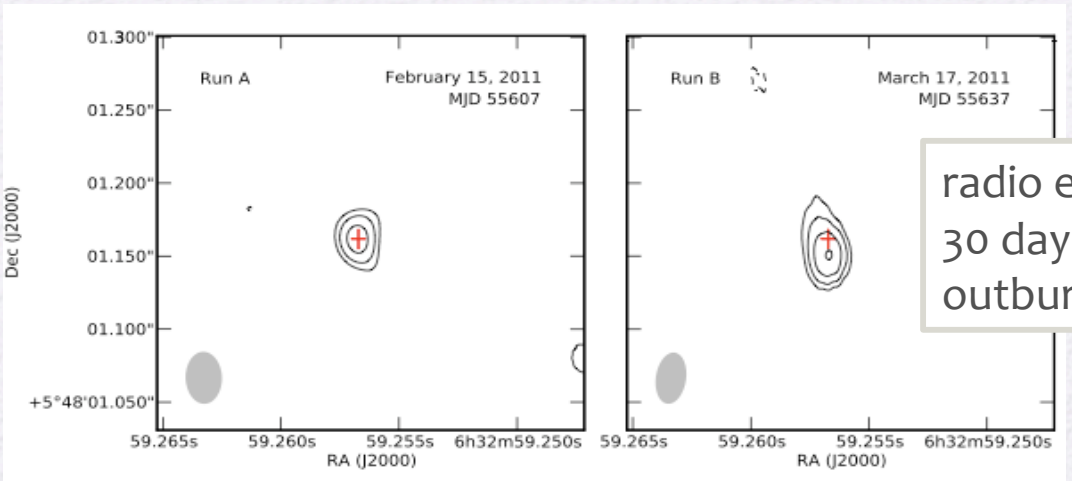
variable at TeV



X-ray variability and periodicity P = 321 days



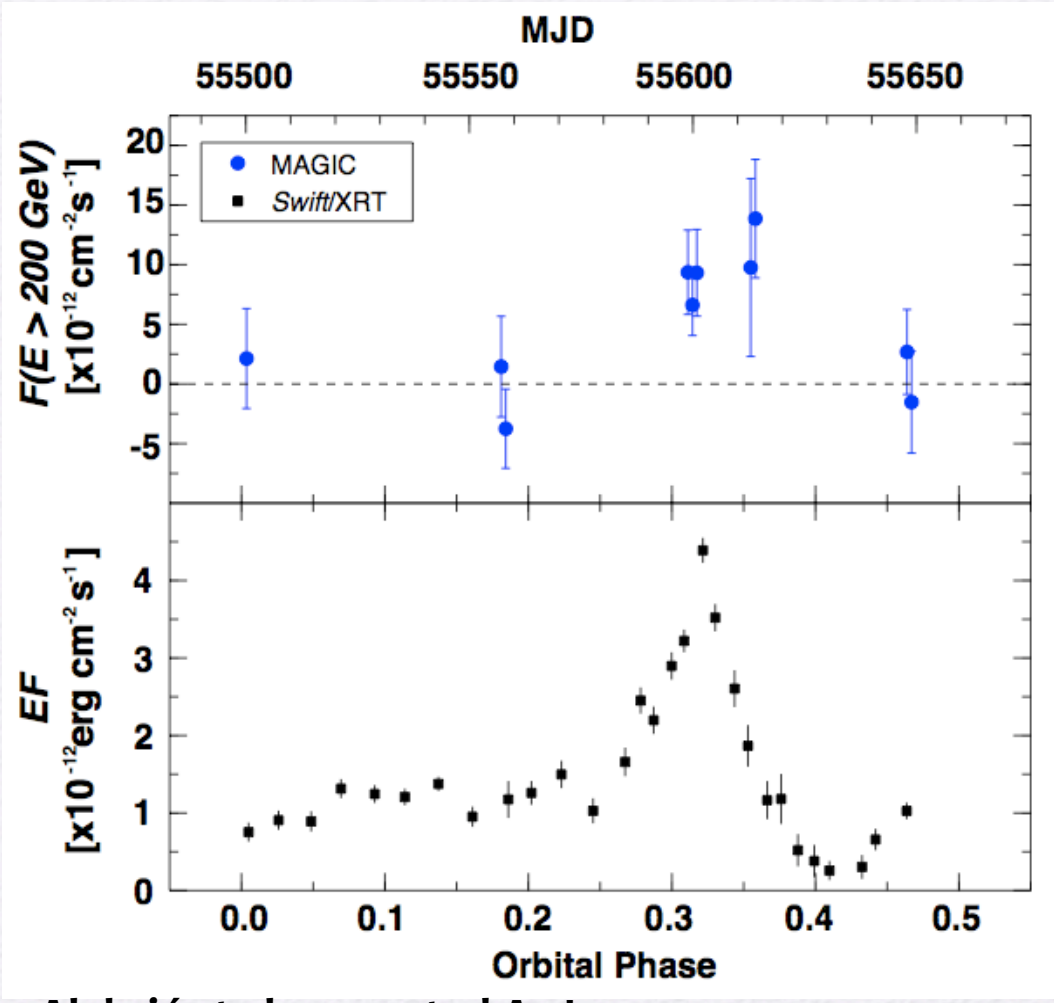
coincident with Be star MWC 148



radio extension 30 days after X-ray outburst

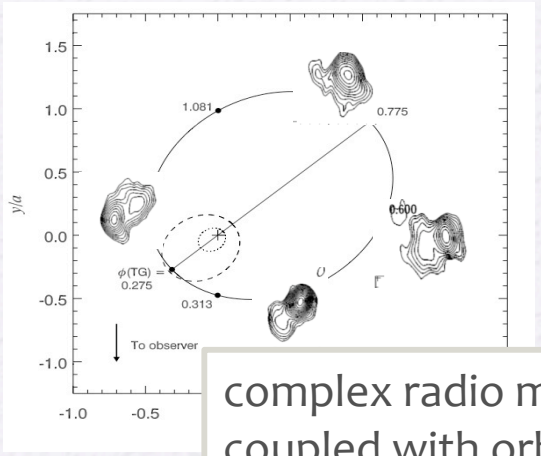
HESS J0632+057: MAGIC detection

- Oct. 2010–Mar. 2011: 10.6 h
- detected only in Feb. 2011:
  ~6σ in 5.6 h
  at $\Delta\phi$=0.3 after periastron
- at 4% Crab flux level
  (as for previous observations)
- power-law spectrum:
  $\Gamma = 2.6 \pm 0.3 \pm 0.32$
- correlation with X-rays?
  cannot be proven statistically



Aleksić et al., accepted ApJ, 2012

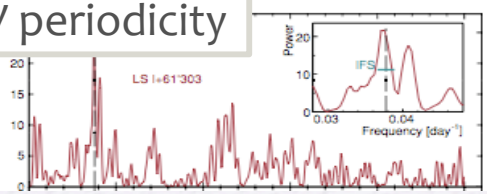
LS I +61° 303



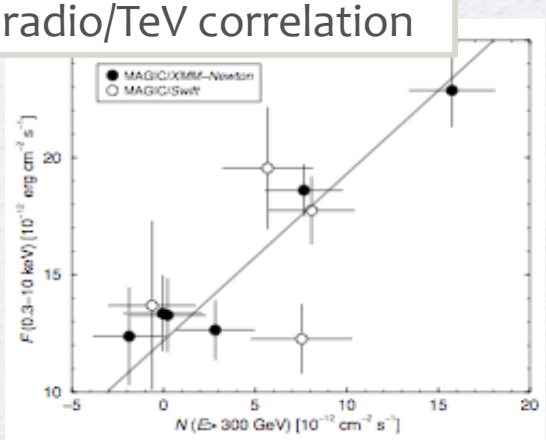
- Be star + unknown compact object
- distance 2 kpc
- periodic P = 26.5 days
- X-ray variability in orbital profiles

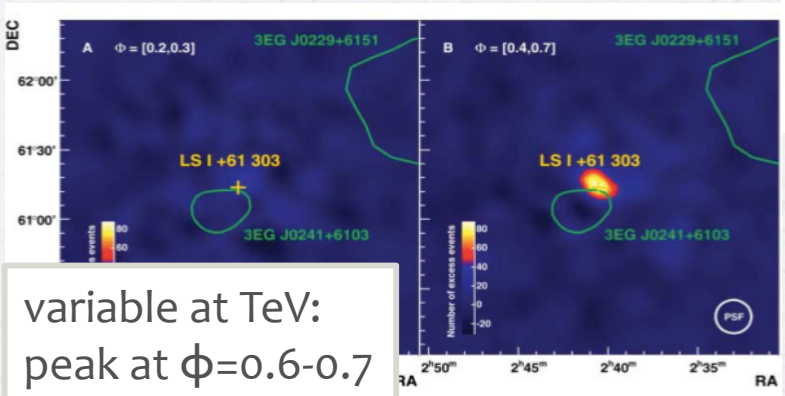
complex radio morphology coupled with orbital period

TeV periodicity



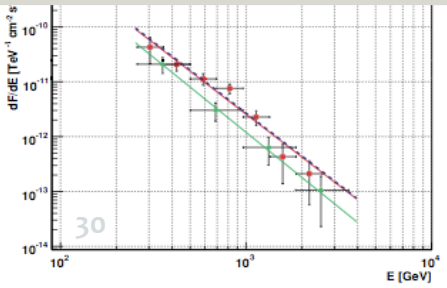
X-ray/TeV correlation (r≈0.8), but no radio/TeV correlation





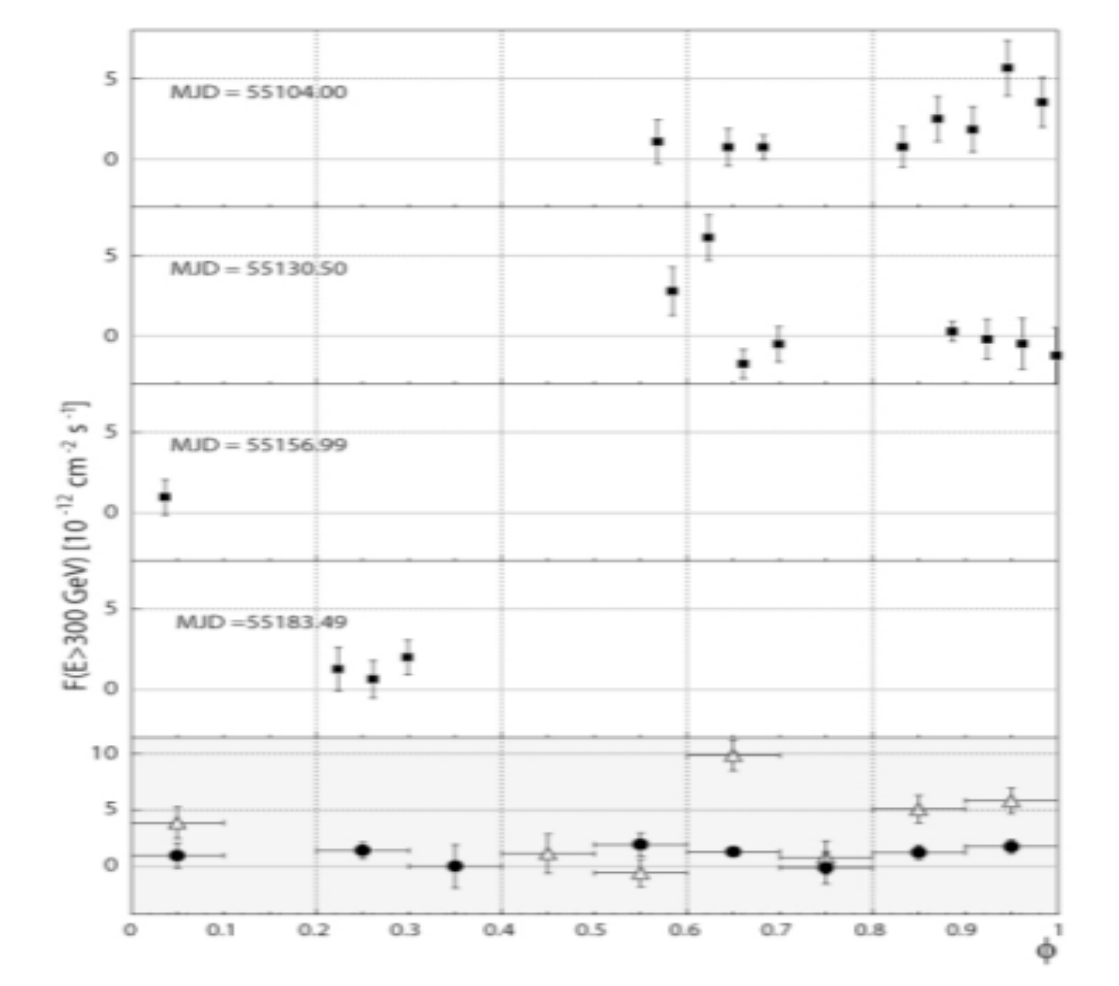
variable at TeV:
peak at ϕ=0.6-0.7
@ 15% Crab flux

Crab-like spectrum Γ=2.6



LSI +61° 303: detection of low emission level

- Oct. 2009–Jan. 2010: 48h
- overall 6σ
- flux level lower than previous campaigns
- variable emission peaking at ϕ=0.6-0.7 and ϕ=0.9-1
- periodicity gone? not possible to tell



Aleksić et al., ApJ 746, 2012

Conclusions

- **PULSARS:**
  - spectrum of the **Crab pulsar** from 25-400 GeV
    → well beyond the expected cutoff: new OG scenarios at work
- **PWNe:**
  - **Crab Nebula:** unprecedented differential energy spectrum over three orders of decades in energy and most precise IC peak measurement.
    No flux variability detected simultaneously to the Fermi flares
  - **HESS J1857+026:** single power-law spectrum in 0.1-45 TeV (turnover between 10 and 100 GeV), but energy dependent extension may support a PWN scenario
- **SNRs:**
  - **W51C:** the maximum of the emission coincides with shocked-gas region, a second source (PWN?) may appear at E > 1 TeV. Hadronic model favored → proton acceleration up to 100 TeV
- **BINARY SYSTEMS:**
  - detection of the new binary **HESS J0632+057** during an X-ray outburst in Feb. 2011
  - detection of **LS I +61° 303** in a low emission period in 2009

The end