Recent MAGIC results on Galactic sources of VHE gamma-rays

Victor Stamatescu (IFAE) for the MAGIC collaboration

Rencontres de Moriond
La Thuile, 14 March 2013
The MAGIC telescopes

Two 17 m diameter telescopes located on La Palma, Spain

Trigger threshold: 50 GeV, under standard operating conditions
Sensitivity: 0.8% C.U. above 290 GeV in 50 hours

Aleksic et al. 2012, Astropart. Phys. 35:435A
Outline

The Crab Pulsar
The Crab Nebula
PWN candidate HESS J1857+026
Magnetars 4U 0142+61
Magnetar 1E 2259+586
Binary LSI +61 303
Binary HESS J0632
The W51 complex
The Crab Pulsar and Nebula

- The Crab Pulsar and Nebula are well studied from Radio to TeV
- Standard candle in gamma-ray astronomy

Surprising Recent Results:

- **Nebula**
  - Discovery of Flares (>100 MeV)
  - **AGILE** (Tavani et al. 2011 Science 331:736)
  - **Fermi-LAT** (Abdo et al. 2011, Science 331:739)

- **Pulsar**
  - Detection of VHE emission (>100 GeV)
  - **VERITAS** (Aliu et al. 2011, Science 334:69)
  - **MAGIC**
    - (Aleksic et al. 2012 A&A 540:A69)

April 2011 Flare seen by Fermi-LAT
Credit: NASA/DOE/Fermi LAT/R. Buehler
The Crab Pulsar: recent VHE results

2008
- MAGIC mono
  Discovery $E > 25$ GeV
  Ruled out Polar Cap model
  (emission must come from outer regions)
  Exponential cutoff at $\sim 17$ GeV

2011-2012
- VERITAS
  pulsed emission & spectrum at $E > 100$ GeV
  (Aliu et al. 2011, Science 334:69)

  phase-dep. spectrum $25 < E < 100$ GeV

  phase-dep. Spectrum $50 < E < 400$ GeV

Important VHE measurements
- exclude exponential cutoff
- challenge all existing models
The Crab Pulsar: stereo observations


At low energies possible 3.4σ hint of emission from the “bridge” [0.04-0.14]

46 < \( E_{\text{true}} \) < 138 GeV
\( \langle E_{\text{true}} \rangle \sim 80 \text{ GeV} \)

138 < \( E_{\text{true}} \) < 416 GeV
\( \langle E_{\text{true}} \rangle \sim 180 \text{ GeV} \)

46 < \( E_{\text{true}} \) < 416 GeV
\( \langle E_{\text{true}} \rangle > 100 \text{ GeV} \)

Collection of Half-Widths v.s. Energy

Peak shape shows narrowing trend from few GeV to energies > 100 GeV
The Crab Pulsar: spectra

- MAGIC mono and stereo data establish a gap-free phase-resolved (P1 and P2) spectrum from 25 GeV to 400 GeV

- Agreement with VERITAS in overlap regime

Yellow diamonds: Fermi-LAT EGRET time intervals

Yellow squares: MAGIC mono EGRET time intervals – 21% of phase

Red squares: MAGIC stereo MAGIC time intervals – 8.8% of phase

Blue squares: VERITAS VERITAS time intervals – 6.8% of phase
The Crab Pulsar: spectra

- **MAGIC mono**: 25-100 GeV (‘sum trigger’)

- Inconsistent with exponential cutoff
- Excluded standard outer gap and slot gap models


Systematic Errors
Flux = ~20%
Energy = ~16%
Index = ± 0.3
The Crab Pulsar: spectra


• Phase-averaged spectrum has power law shape with index 3.6

• Compatible with individual peak spectra

• Spectra connect with mono measurements within stat. & sys. errors

Systematic Errors
Flux = ~17%
Energy = ~19%
Index = ± 0.2

MAGIC STEREO
\( \Gamma_{P1+P2} = 3.6 \pm 0.3 \) stat
The Crab Pulsar: models

- Curvature radiation unlikely
- Emission region > 10 stellar radii
- Extension of OG model
  - Magnetospheric cascade:
    pulsed VHE gamma-rays
    produced via SSC
    by secondary & tertiary $e^\pm$-pairs
  - Power law component up to 1 TeV
- IC of pulsed X-ray photons
  in cold relativistic wind outside the LC
- Synchrotron or Curvature emission
  by ultra-relativistic particles at LC
- IC of secondary pairs in annular gap
The Crab Nebula: unprecedented spectral measurement

Stereo mode
2009-2011
48.7 hours
Zenith 5°-50°

8 decades in flux
3 decades in E
50 GeV 45 TeV
The Crab Nebula: unprecedented spectral measurement

Log-parabola fit of only MAGIC data from 50 GeV to 45 TeV

\[
\frac{dN}{dE d\Omega d t} = (3.20 \pm 0.05) \times 10^{-11} \left( \frac{E}{\text{TeV}} \right)^{(-2.40 \pm 0.01) + (-0.13 \pm 0.02) \log \left( \frac{E}{\text{TeV}} \right)} [\text{TeV}^{-1} \text{cm}^{-2} \text{s}^{-1}]
\]

Stat. Errors < 5% below 100 GeV

Sys. Errors
Flux = ~15%
Energy = ~15%
Index = ± 0.15
The Crab Nebula: unprecedented spectral measurement

IC peak = $59 \pm 6_{\text{stat}}$ GeV
(Fermi-LAT+MAGIC data)

Most precise measurement to date

Where is the cutoff?

Dominated by sys. uncertainties
--- can not exclude cutoff at 10 TeV
The Crab Nebula: flux variability

**Fermi-LAT**

Daily lightcurve at E>300GeV is constant within systematic uncertainty.

**MAGIC**

What about during the April 2011 Fermi-LAT GeV super-flare?

No variability observed (0.7-10 TeV) (observation under strong moonlight)

Also no significant flux variability detected during the Sept. 2010 HE flare
PWN candidate HESS J1857+026

- MAGIC observed the source during 2010, taking 29 hours of data, and mapped the source down to Fermi-LAT energies.
- A point-like source was detected from 3 years of Fermi-LAT data (Rousseau et al. 2012, A&A 544:A3)
- Combined SED shows a strong turnover around 100 GeV, which may be attributed to the IC peak.
- MAGIC skymaps show that the source is less compact above 1 TeV, which disfavors a PWN scenario. The Northern tail-like feature may be a separate source or component.
Binary Systems


LSI +61° 303

- Be star & unknown compact object
- d ~ 2 kpc and P = 26.5 days
- X-ray/TeV correlation in orbital profile variability
- Monitored with MAGIC since 2005
- In 2005-2007 the flux was clearly modulated with orbital period
- Changed from high to low state in 2007/2008
- In 2009 flux of ~ 1.3% C.U. was measured
- No spectral variability detected
- In 2010-2011 changed back to high state

\[ \Gamma = 2.6 \]

HESS J0632+057: a new binary

- Coincident with Be star MCW 148
- X-ray periodicity P = 321 days
- Detected in Feb. 2011, with ~6σ in 5.6 hours at Δφ = 0.3 after periastron
- Flux level was 4% Crab
- No significant gamma-ray variability detected during the X-ray outburst

\[ E_{\gamma} > 200 \text{ GeV} \]

V. Stamatescu, MAGIC Galactic results, Rencontres de Moriond, La Thuile 14 March 2013
Magnetars


**4U 0142+61**

- X-ray luminosity: $L_X \sim 1.0 \times 10^{35}$ erg s$^{-1}$ (among the brightest)
- $B_{\text{surf}}$: $1.3 \times 10^{14}$ G
- Distance: $3.6 \pm 0.4$ kpc
- MAGIC mono: 17 hours in 2008
- No emission detected, integral upper limit at $E > 200$ GeV: 0.5% C.U.

**1E 2259+586**

- X-ray luminosity: $L_X \sim 0.3 \times 10^{35}$ erg s$^{-1}$
- $B_{\text{surf}}$: $0.59 \times 10^{14}$ G
- Distance: $4.0 \pm 0.8$ kpc
- Embedded in SNR CTB109
- MAGIC stereo: 8 hours in 2010
- No emission detected, integral upper limit at $E > 200$ GeV: 0.6% C.U.
The W51 Complex

- **W51A** & **W51B** are star forming regions, **W51C** is a medium-age (~30 kyr) SNR at d ~5.5 kpc
- PWN candidate **CXO J192318.5+1403035** may be associated with **W51C** (Koo et al. 2005)
- The SNR interacts with **W51B** (Koo et al. 1997 a&b, Green et al. 1997)
- Cosmic Ray ionization rate is high ~ 100 x ISM value (Ceccarelli et al. 2011)

**W51 looks to be a promising laboratory for understanding CR acceleration in a SNR**
Detection of W51 by MAGIC

- MAGIC stereo data taken in 2010 and 2011
- 11.4\(\sigma\) detection from 53 hours of data
- source is clearly extended w.r.t. our PSF
- measured source extension 0.12\(^{\circ}\)\(\pm\)0.02\(^{\circ}\) \text{stat} \pm 0.02\(^{\circ}\) \text{sys}

Flux level ~ 4% of the Crab Nebula flux

power law spectrum with \(\Gamma = 2.58\pm0.07\) \text{stat} \pm 0.22 \text{sys}

in agreement with that of Fermi-LAT: \(\Gamma = 2.5\)


Single power law from 10 GeV to 5 TeV
The W51 Complex

- OH Maser emission
- Region of shocked atomic & molecular gas
- Fermi-LAT 3 counts above 1 GeV contour
- CXO J192318.5+1403035

300 GeV - 1 TeV

- 13CO(J=1-0) 63-72 km/s
- 21 cm continuum

Fermi-LAT
3 counts above 1 GeV contour
The W51 Complex

South-Eastern tail toward PWN candidate

Appears more prominent at higher energies

Possibility of two distinct sources exists (lack of molecular gas around PWN), but insufficient event stats to prove this

PWN region accounts for 20% of VHE emission

max VHE emission at shocked gas region
W51: a probable site of CR acceleration

- Simple hadronic 1-zone model describes the data well.
- Predicts ~16% of the explosion energy is converted into CR kinetic energy
- Simple 1-zone Leptonic models fails, in agreement with Abdo et al. 2009
- The bulk of VHE gamma-ray emission originates at the interaction zone between W51C and the molecular cloud

interpret this as strong evidence of gamma-ray production via neutral pion decay
The breakthrough measurements of the pulsed VHE gamma-ray emission from the Crab Pulsar have challenged existing models, and excluded curvature radiation as the main radiation mechanism. The dominant emission mechanism remains an open question.

The Crab Nebula differential spectrum has been measured by MAGIC over 3 decades in energy, ranging from 50 GeV to 45 TeV, making it possible to localize the IC peak with unprecedented precision.

HESS J1857+026 exhibits a turnover near 100 GeV, which supports a PWN scenario. However the morphology above 1 TeV leaves open the possibility of source confusion or additional component.

The binary system HESS J0632+057 was detected by MAGIC during an X-ray outburst in Feb. 2011.

The binary system LSI +61 303 was seen to change from a high to a low state during 2007/2008 and changed back to a high state in 2010/2011.

The Magnetars 4U 0142+61 and 1E 2259+586 have been observed by MAGIC and no emission was detected. Upper limits of 0.5% and 0.6% Crab above 200 GeV were set, respectively.

MAGIC has explored for the first time the VHE spectral and morphological properties of the SNR W51C and its surroundings. Based on these findings we argue that the W51 region exhibits strong evidence of cosmic ray acceleration.