Highlights of the MAGIC telescopes

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Outline

• MAGIC, performance of stereo system.

• Highlights of:
  – Galactic observations.
  – Extragalactic observations.
  – Cosmic rays and dark matter searches.

• Outlook, the MAGIC upgrade.
The MAGIC collaboration

- **Bulgaria** Sofia
- **Croatia** Consortium
- **Finland** Tuorla Observatory
- **Germany** DESY Zeuthen, Dortmund, MPI Munich, U Wuerzburg
- **Italy** INFN Padova, INFN Siena/Pisa, U Siena, INFN Udine, INAF consortium, U Insubria
- **Poland** U Lodz
- **Spain** U Barcelona, UAB Barcelona, IEEC-CSIC Barcelona, IFAE Barcelona, IAA Granada, IAC Tenerife, U Complutense Madrid
- **Switzerland** ETH Zurich
MAGIC: from mono to stereo

Single telescope (MAGIC-I): largest IACT yet constructed (17m Ø), i.e. lowest energy threshold. Fastest sampling (2GSPs), ultralight CF frame and mirrors, fast repositioning (<20 secs/180º), active mirror control…

MAGIC system: stereo observations down to 50 GeV regularly from Fall 2009. M-II is an improved copy of M-I.
Performance of stereo system

- Based on a selected sample of Crab data (see poster Carmona et al, id500; arXiv:1108.1477 & submitted to ApP).
- **Energy threshold** (peak of the energy distribution of stereo recorded events) has been estimated to be 50 GeV for $\Gamma = -2.6$.

Flux sensitivity = 0.76% crab >300 GeV

- Angular resolution: 0.1° at 100 GeV, down to 0.04° at >1 TeV.
- Energy resolution: 20% at 100 GeV, down to 15% around 1 TeV.
 Galactic observations
Crab Nebula

- Standard candle of VHE astronomy and archetypal PWN.
- 49 hrs (ZA: 0° -50°) in the last two winters. New analysis techniques to lower further the energy threshold (see Lombardi et al, poster id1150).
- For detailed results see talk by Zanin et al (id195)

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

- 6 spectral points in every decade of energy
- First spectral point at 58 GeV

preliminary
Crab Spectral Energy Distribution

- Dominated by systematic uncertainties
- Given the systematic impossible to exclude the cutoff at $E > 10$ TeV
- Inverse Compton peak estimation (MAGIC + Fermi): $59 \pm 6$ GeV stat. err. only

MOST PRECISE IC PEAK MEASUREMENT SO FAR

Preliminary graph showing $E^2 \frac{dN}{dE d\Omega}$ with various data points and fits.
Crab variability $>300$ GeV

- After reports of flares of hours/days in AGILE & Fermi and ARGO-YBJ and of year-long variability in X-rays… is Crab stable at TeV?

$$F(E > 300 \text{ GeV}) = (1.29 \pm 0.03_{\text{stat}} \pm 0.23_{\text{sys}}) \times 10^{-10} \text{ photons cm}^{-2} \text{ s}^{-1}$$

- No indication for variability $> 300$ GeV (probability of 95% constant flux considering the systematic error)… any shorter term variability…?
Crab April 2011 GeV flare

- 3 nights of data in April 12—14, 2011 just on top of a 3 hrs Fermi bin when flux >100 MeV was 15 times higher than the steady flux.
- No variability observed in flux between 700 GeV and 10 TeV.
Crab: the Pulsar

- Models for high energy emission (polar cap, outer or slot gap) predict exponential or superexponential cutoffs in pulsar spectra at a few GeV.
- In fact that’s what Fermi has been observing for all pulsars at 100 MeV - 10 GeV.
- Question is: can we see pulsed gammas from the Crab beyond the expected cutoffs?
Crab pulsar: previous results


Science 322, 2008
Inconsistent with the extrapolation of the exponential cutoff (>5 $\sigma$).
Spectra between 25 GeV and 100 GeV show a power law.
All details: talk today at 17:00 in OG session, id1289, Lopez
HOT NEWS: after 73 more hours of stereo data

- Stereo data provides precise spectra up to 400 GeV.
- No gap between Fermi and MAGIC.
- We can even produce spectra for both peaks separately.
- Mono/stereo spectra agree… and go well beyond a cutoff at few GeV!
This is how the sky around Crab looks like with millisecond $\gamma$-ray eyes.

Don’t miss TODAY’S talk at 17:00 in Meeting Hall 2!
PWN? SNR? HESS J1857 & W51

- Both J1857+026 and W51 discovered by HESS.
- Stereo allows high resolution maps. MAGIC adds: lower energy threshold.
- Morphological evolution with energy? Different source?
- Talks by Klepser (id891) and Carmona (id399).
γ-ray Binaries: LS I+61 303

- Recently submitted to A&A and talk by Jogler: id1215.
- The source “faded away” in 2008, but we managed to detect it during this low VHE state in 2009.
- And even more news: in Fall 2010 to Spring 2011 source was back to normal!
- Superorbital periodicity (P=1667 days, as observed in radio, Gregory 2002)??
Where are the microquasars??

- LSI+61, together with PSR1259, LS5039 and HESS J0632 (also detected by MAGIC, see Jogler, poster id888), are probably powered by pulsar wind/stellar wind interaction.

- **But where are the binaries powered by jets, the µqsrs??**

- MAGIC has spent hundreds of hours in the last years searching:
  - Hint of Cyg X-1 could not be confirmed after 100h observation.

  - During or shortly after radio flares
  - During low-hard or high-soft X-ray states
  - With 4.8 hour period.
  - Recently also during Fermi/AGILE flare.

NO DETECTION!
Extragalactic observations
Beyond blazars….

- New generation IACTs have established new classes of VHE active galaxies different than blazars…

**Blazars (BL Lacs):**
- still the vast majority:
  - ~40 — 15 discovered by MAGIC
  - Extensive studies

**Radiogalaxies**
- 4 — 2 discovered by MAGIC
  - Study emission in jet: they are nearby (can be resolved in other wavelengths) and jets not aligned with line of sight.
  - May be sources of UHECRs?

**Quasars**
- 3 — 2 discovered by MAGIC
  - Different physics: intense radiation fields.
  - Very far: useful to study EBL

**Starbursts**
- 2 — none discovered by MAGIC
  - No central source, probably global emission of all CR in galaxy
Radiogalaxies: M87

• Very nearby (17 Mpc) and very well characterized in other frequencies.
• M87 was the first radiogalaxy discovered at VHE (HEGRA) and has been extensively studied by HESS, VERITAS & MAGIC.
• In 2008, using all 3 experiments and simultaneous radio VLBI: VHE emission came from very close to the central BH (a few Schwarzschild radii, $R_s \sim 100$ A.U.).
Radiogalaxies: M87

Further cooperation of the 3 experiments and multiwavelength add essential information... but may be complicating the picture! Results about to be submitted to ApJ:

• In total, 3 flares at VHE: 2005, 2008 and 2010.
• Flare in 2010 showed exponential rise and decay. Not so clear for the others.
• 2nd flare was followed by a radio brightening of the core. The others not.
• In 2008 and 2010, VHE simultaneous to increase in X-rays. Unclear in 2005.
• Do all flares come from the same emission site? How are they produced?

Recently, MAGIC studied only low state (see poster Berger, id1093): spectral index consistent with high state emission, pointing to the same emission mechanism.
MAGIC has discovered 2 radiogalaxies: IC-310 and NGC-1275, both in the Perseus cluster (see talk by Hildebrand et al, id1221).

Detected during Fermi enhanced activity. Very steep spectrum $\Gamma = -4.0 \pm 0.4$. Detection only possible thanks to stereo threshold and sensitivity.

“Head-tail” radiogalaxy. Very hard spectrum: $\Gamma = 2.00 \pm 0.14$
Quasars: 3C 279 & PKS 1222+21

• 3C 279 (z=0.536) is the farthest VHE source, discovered by MAGIC in 2006.

• **Spectrum for such a far source allowed to place strong constraints on Extragalactic Background Light.**

• PKS 1222+21 (z=0.432) discovered by MAGIC in 2010. Spectrum confirms past claims on EBL!

• Results of PKS 1222 and recent observations of 3C279 show the same problem (A&A 530 (2011) A4 and **MAGIC extragalactic review talk: Berger ic1178**):
  – Emission up to hundreds of GeV
  – Fast variability (9 min doubling time in PKS 1222)

• Why is this a problem?
Quasars: canonical scenario

If $\gamma$-rays produced outside BLR by IC scattering of dusty torus photons: less absorption but hard to explain fast variability!

If $\gamma$-rays produced inside BLR by IC scattering of BLR photons: strong absorption and Klein-Nishina suppression (cutoff \(<100\) GeV)
Possible solutions?

• Strong recollimation of the jet.
• Blobs or minijets inside the jet.
• Two-zone model: large emission zone inside the BLR + small blob outside.

More details on detection of PKS 1222 and models in talk by Becerra et al, id67.
Blazars

Many contributions to this conference reporting on discoveries or new observations of blazars with MAGIC:

- Blazar 3C 66A, poster Klepser, id884.
- MWL Observations of HBL 1ES 1011+496, poster Reinthal, id1273
- 1ES1215 (discovered last January) and 1ES1218 (discovered 2005), talk by Colin, id1092
- Monitoring of bright nearby AGNs: Mrk 501, Mrk 421, 1ES1959, talk by Wagner, id1030.
- MAGIC & MWL of Mrk 180 and 1ES 2344+514 in 2008, talk by Rügamer, id832.
- MWL observations Mrk 421 and Mrk 501 in 2009, talk by Barres, id829.
- Extragalactic overview talk (Berger id1178): discovery of a new BL Lac: 1ES 1741+196
Blazars: optical triggers

Successful strategy to discover VHE blazars:

- Monitor candidates with the KVA telescope in La Palma
- Observe with MAGIC during high optical state (ToO)

**MAGIC phase-I:**
- Mrk180: HBL ($z = 0.045$)
- 1ES1011+496: HBL ($z = 0.212$)
- S5 0716+714: LBL ($z = \sim 0.31$)

**MAGIC phase-II:**
- B3 2247+381: HBL ($z = 0.119$)
- 1ES1215+303: HBL ($z=0.130$ or $z=0.237$)
Blazars: MWL and modeling

- MWL observations involving many instruments, lately also Fermi, allow to generate more detailed SEDs of sources.


- Unprecedented SED sampling demands modeling with a double broken power law electron distribution and allows to put tight constraints on the model parameter space.
Gamma Ray Bursts

- MAGIC was especially designed to search for the prompt emission of GRBs: the telescope can move 180 deg in 20 seconds and does so in a totally automatic manner after an alert from GCN.

- We are observing ~1 GRB/month. No detection so far. Lately:
  
  - Observation of GRB110328, later disregarded as GRB due to long-lasting activity. Nature still unknown. MAGIC observed starting 2.5 days after onset. No detection (see Berger id1178).
Cosmic Ray measurements, galaxy clusters and dark matter searches
CR $e^- + e^+$ spectrum

• See talk by Borla-Tridon, id680.
• First result based on only 14h of observations: measured $e^\pm$ spectrum in the energy range between 100 GeV and 3 TeV.
• Preliminary results fitted by a power-law with index $\Gamma = -3.16 \pm 0.06_{\text{stat}} \pm 0.15_{\text{sys}}$.
• Spectrum in good agreement with previous measurements (bump observed by ATIC cannot be excluded or confirmed).

Related initiative: determine $e^+ / e^-$ ratio by measuring the moon shadow. Observations ongoing, see talk by Colin, id1114.
Clusters of galaxies may emit VHE $\gamma$-rays:

- Actively evolving objects
- Cosmic Energy reservoirs: expected to contain substantial populations of Cosmic Rays
- 80% of the mass in Dark Matter
Perseus: latest stereo results

• See talk by Lombardi et al, id1220, 85h of observations in 2009-2011.

• **MAGIC flux ULs (95%CL) below some theoretical expectations.**

• Constraints on maximum CR acceleration efficiency in simulation.

• Tighten the constraints on the CR-to-thermal pressure to < 2% (center) - 4% (whole cluster).

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DM searches: neutralino annihilation $\gamma$-rays

- **Perseus cluster**: challenging due to presence of NGC 1275, because expected flux much smaller than that coming from CR interactions, and due to possibly very extended DM profile.

- **UFO (“Unassociated Fermi Objects”)** = Fermi unid objects far from galactic plane and with especially hard spectrum. Could correspond to mini-halos of DM in our galaxy. Relatively short exposures (~10h) of 1FGL J0338.8+1313 and 1FGL J2347.3+0710: no detections, see ULs in talk by Nieto, ic696.

Dwarf Sph Segue-1

- Ultra faint dSph, the most DM dominated object known so far (M/L > 1000), d=23 kpc.
- Observation of 29h with MAGIC-I in 2008/09 (Longest published survey of a dSph by IACT). No significant excess.
- See talk by Aleksić, ic331.

Still a factor 600 above the most optimistic expectations of mSUGRA (supersymmetry) models

- More stereo observations of dSph ongoing.
Outlook: MAGIC upgrade

• The MAGIC telescopes were shut down on June 15th to perform a major upgrade of the hardware:
  1. Both telescopes will be equipped with a new 2 GSamples/s readout based on DRS4 chip (linear, low dead time, low noise).
  2. The camera of MAGIC-I be upgraded from 577 to 1039 pixels to match the camera geometry and the trigger area of MAGIC-II.
  3. Both telescopes will be equipped with sumtrigger covering the total conventional trigger area (see talk ic1326).

• We expect slightly better sensitivity for point sources and significantly better performance for extended sources.
Conclusions

- The MAGIC two 17m telescopes have now operated for two years in stereoscopic mode.
- Performance has been evaluated: 0.76% Crab integral sensitivity for E>300 GeV (10% differential below 100 GeV) and analysis threshold energy 50 GeV.
- Crab Nebula spectrum measured from ~50 GeV to ~50 TeV.
- Crab pulsar detected up 400 GeV, spectra measured for both P1 and P2.
- Two new radiogalaxies discovered (NGC 1275 and IC-310).
- No energy cutoff and fast variability of quasars 3C 279 and PKS 1222+21.
- Discovery and characterization of numerous blazars: multiwavelength studies, optical triggers.
- Upper limits to emission of Perseus cluster of galaxies, DM annihilation in dwarf Spheroidals.
- Measurement of electron+positron spectrum between 100 GeV and 3 TeV.
- Telescope system being upgraded with new readout, camera and trigger.
Sensitivity of all experiments

- HESS and VERITAS points from Becherini, Moriond 2009.
- Experiments use different methods to estimate sensitivity: \( \text{Li&Ma vs } N_\gamma/\sqrt{N_{bg}} \), condition on \( N_\gamma/N_{bg} \)
Performance of stereo system

- **Angular resolution**: 0.1° at 100 GeV, down to 0.04° at >1 TeV.
- **Energy resolution**: 20% at 100 GeV, down to 15% around 1 TeV.
Differential energy spectrum

- 6 spectral points in every decade of energy
- First spectral point at 58 GeV

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\]
Where are the microquasars??

- **Cygnus X-3**: observed by MAGIC
  - During or short after radio flares
  - During low-hard or high-soft X-ray states
  - Recently also during Fermi/AGILE flare.
  - Searched with 4.8 hour period.
- Still no detection.
New, just submitted for publication:
Mono observations 2007-09

P1 (-0.06-0.04): 6200 ± 1400 events (4.3 $\sigma$)
P2 (0.32-0.43): 11300 ± 1500 events (7.4 $\sigma$)
P1+P2: 17500 ± 2300 (7.5 $\sigma$)

- 59 hours
- Sum Trigger
- >25 GeV

- All details: talk today at 17:00 in OG session, ic1289, Lopez
Crab mono+stereo: closer look

Crab Pulsar, P1+P2

$E^2 \times dN/dE$ [TeV cm$^{-2}$ s$^{-1}$]

Preliminary

Spectrum: P1 + P2

$E^2 dN/dE dA$ [erg cm$^{-2}$ s$^{-1}$]

Preliminary
PWN: HESS J1857?

- Stereo allows high resolution maps. New with MAGIC: lower energy threshold.
- J1857+026: discovered by HESS in galactic survey.
- Uncertain counterpart: pulsar in the FOV?

- Talk by Klepser et al: ic891, OG2.2.
W51: low energy map and spectrum

- W51 is a good candidate for hadron-originated $\gamma$-ray emission.
- Detected by HESS and Fermi.
- Same MAGIC map compared to info from other wavelengths: tracers for molecular mass or shock activity.
- We have extracted a spectrum linking Fermi and HESS flux point.
- Talk by Carmona et al: ic399, OG2.2