The MAGIC highlights

Konstancja Satalecka for the MAGIC Collaboration

TeVPA 2017, August 7th 2017, Columbus Ohio
★ MAGIC-I in operation since 2004, MAGIC-II (stereo mode) since 2009
★ 170 scientists from 10 countries across Europe & Asia
★ Camera FoV: 3.5° (LV PMT)
★ Energy range: \( \sim 50 \) GeV (30 GeV with \( \Sigma \) -Trigger) - 50 TeV \( \Rightarrow \) low E threshold perfect for distant sources
★ Mirrors: 2 \times 240m^2 (d = 17m)
★ Light-weight: \( \sim 70 \) T
★ Re-positioning speed: 7 deg/s \( \Rightarrow \) prompt response to transients
★ Energy resolution: 15% (@1 TeV) – 23% (@100 GeV)
★ Angular resolution: 0.06 deg @ 1 TeV - 0.1 @100 GeV
★ Integrated sensitivity: \( \sim 0.66\% \) Crab (5\( \sigma \) in 50h above 220 GeV)
MAGIC - performance under moonlight

★ Camera: FoV: 3.5°, adapted to operations with moonlight (LV PMTs):
★ Nominal settings: 1-8xNSB_{dark}
★ Reduced HV: 5-18xNSB_{dark}
★ UV-pass filters: 8-30xNSB_{dark}
★ Duty cycle could be extended by 40% (more time for monitoring, opportunities to catch flares, ToOs, etc.)
★ Special analysis including higher cleaning level, dedicated MC production for reduced HV & UV-pas filters
★ can recover Crab Nebula spectrum as for dark nights
★ Energy threshold ~ (NSB/NSB_{dark})^{0.4}
★ Sensitivity degradation < 10% for nominal HV settings and up to 8xNSB_{dark}
★ No significant worsening of the angular resolution was observed > 300 GeV

Science scopes

Galactic sources
Pulsars, SNR, binaries, novae, Emission mechanisms, LIV...

AGN
BL Lacs, FSRQs, radio galaxies
Emission mechanisms, propagation: EBL, IGM...

Fundamental Physics
DM, LIV, tau neutrinos...

Transients & MM
follow-up of GRBs, FRBs, GWs, neutrino events...
Galactic sources - teaser :)  

**SNR: Cas A**, Emma de Oña Wilhelmi  
*Mon @14:45 Gamma-ray session*  
160 h of data + 8 yrs Fermi/LAT  
Final answer to the PeVatron question!

**Galactic Center**, Ievgen Vovk  
*Mon @16:45 Galactic session*  
LC, Sgr A* spectrum, diffuse emission  
cosmic rays + new source!

**Pulsars**, Jezabel R. Garcia  
*Tue @17:00 Galactic session*  
320 h of data  
Crab pulses from 20 GeV to 2 TeV!
Lorentz Invariance Violation

Postulated in many QG theories:

⇒ modified dispersion relation
\[ E^2 = p^2 + m^2 + f\left(\frac{p}{M_{Pl}}, \xi\right) \]

⇒ energy-dependent shift in pulsar phase
\[ \Delta \phi = \frac{d_{Crab}}{c \cdot P_{Crab}} \cdot \xi \cdot \frac{n+1}{2} \left( \frac{E_{h}^n - E_{l}^n}{E_{QG}^n} \right) \]

\[ n=1: \text{linear case } \xi=1: \text{subluminal (slower than } c) \]
\[ n=2: \text{quadratic case } \xi=-1: \text{superluminal (faster than } c) \rightarrow \text{more interesting for pulsars } > 100 \text{ GeV} \]

MAGIC analysis:
★ data from Crab Pulsar, 320 h from 2007-2014, pulses detected up to 1.2 TeV
★ additional Fermi data to constrain flux & spectral index at lower energies
★ LLH analysis (full profile likelihood)
★ linear & quadratic cases tested (E_{QG1} & E_{QG2})
★ nuisance parameters: flux, spectral index, mean pulse position, mean pulse width
Lorentz Invariance Violation

Crab pulsar is in the game again for LIV!
Pulsars case more interesting for quadratic term $E_{QG2}$ limits
With current data, MAGIC set almost world-best limits on $E_{QG2}$ (including systematics $\sim 30\%$)
Future analyses (combinations of likelihood + new data) will reveal nature of the Crab pulses and possibly better limits than GRBs!

$M. Gaug et al., ICRC 2017$
The 2nd HAWC catalogue (2017) contains 39 detected TeV sources
19 of them have no association with any known VHE source
Some of these 19 unid. sources were in the FoV (<1.5°) of former MAGIC observations (MAGIC archival data)
Re-analysis of these MAGIC data looking for point-like (0.10°) or slightly extended (0.16°) emission
No signal found
Gamma-Cygni SNR

- SNR: Gamma Cygni (G78.2+2.1) ~7000yrs (middle-aged) → unique laboratory to study early Sedov phase SNR
- hosts the pulsar PSR J2021+4026 (the only known variable γ-ray pulsar)
- VERITAS and Fermi-LAT: complex, energy-dependent morphology in GeV-TeV, different from X-rays
- MAGIC collected 45h of good quality data in May-Nov 2015
- new spacial LLH analysis (à la ftools)
- Fermi/LAT data from 8.7 yrs pass8

MAGIC & Fermi/LAT clearly resolve energy dependent morphology:

- <200 GeV emission contained in SNR shell, > 450 GeV extends beyond the radio shell by 0.2 deg → cosmic rays start to escape the shock above several TeVs, expected for an early Sedov phase SNR [Caprioli et al., 2009]
- Brightest VHE γ-ray emission (NW) specially coincident with X-ray bright thermal emission → SNR expands inside the progenitor star bubble and starts to interact with a putative cavity wall [Ladouceur & Pineault, 2008]
- Alternative: no known AGNs or PWN within 0.2 deg from the position → NW source a “dark accelerator”? 
PKS 1510-089 flares

- One of only a few FSRQs detected in VHE gamma rays (H.E.S.S. Collab., 2009)
- Moderately distant (z=0.36)
- Highly variable in optical and GeV gamma rays
- One of the highest apparent speeds of superluminal motion, up to 46c
- Large swings (up to 720°) of optical polarisation vector
- MAGIC performs monitoring of PKS1510-089 since its first detection in 2012
- Two flares were observed so far: May 2015 and May 2016

See talk by Matteo Cerruti
Tue @16:45
Gamma-ray session

J. Sitarek et al., ICRC 2017
PKS 1510-089 2015 flare

Radio: new jet component, moving in unusual direction.
Zero separation epoch ~ May 2015 high state.

smooth rotation of EVPA by ~100°

★ VHE g-ray flux ~4 x brighter than in 2009 & 2012
★ Similar spectral shape (intrinsic slope: 3.2±0.8)
★ Similar situation to that of 2012 (MAGIC discovery): VHE g-rays + EVPA rotation + new radio component

★ EC scenario on BLR and dust torus photons
★ Emission region placed just outside BLR
★ Variability due to changes in B field and electron distribution flowing through the emission region
BL Lac 2015 flare

Prototype of the BL Lac objects class (z = 0.069)
Discovered by MAGIC in 2005
Fast variability observed by VERITAS in 2011, flux up to 1.25 x Crab Nebula
June 2015 flare: MAGIC collected 8.5 h of good data over 10 days

No simultaneous increase measured in other wavelengths → “TeV orphan flare”?
Simultaneous increase of HE g-rays (Fermi) and optical flux → correlation? same emitting region?

Fast variability in VHE g-rays, with halving time ~33+/−9 min → small emission region ~10^{13} d cm

SED with broad IC peak, but w/o large Compton dominance → additional VHE component, intermediate state between BL Lac and FSRQ?
Best studied radio galaxy in VHE $\gamma$-rays

- Monitored by MAGIC: over 150h gathered between 2012 and 2015 (also in Moon-time!)
- No flares observed in that time
- VHE $\gamma$-ray spectrum extending up to 20 TeV connects smoothly to the GeV spectrum
- SSC model describe the data well, alternative hadronic model by Spanier&Finke under investigation
Monitoring of radio galaxies - NGC1725

- Mean flux 7-9 times higher than in 2009-2011 of 3% C.U. [Aleksić et al., 2014]
- Oct./Nov. 2016 16% C.U. (ATel #9689) and Jan. 2017 150% C.U. (ATel #9929)
- Rise in January 2017 within a few days → doubling time scale of 611 ± 101 min from exponential fit
- Harder spectrum w.r.t. Aleksić et al. 2014 and curved
- Significant signal found above 1 TeV
- Power-law fits plus exponential cutoff at ~500 GeV? (EBL cutoff at 10 TeV Ahnen et al. 2016)

- Spine-Sheet model [Tavecchio&Ghisellini, 2016]: excluded due to too high absorption > 1 TeV
- Shock-in-jet model: new estimates on the viewing angle θ< 9-16, in tension with previous measurements
Galaxy clusters best targets for indirect searches for decay DM

Perseus: 80% DM content, close-by (z = 0.0183), brighter in X-ray

MAGIC observations: 2009-2017, more than 270 h of good quality data collected!

We find no evidence of dark matter decay

Reach sensitivities on decay lifetimes of $8 \times 10^{25}$ seconds for both channels (~10 times better sensitivity than previous MAGIC results (Segue))

Best limits on decay lifetimes for $\chi \rightarrow \tau \tau$ for DM masses above 2 TeV

First ever results for DM masses above 20 TeV
Perseus Cluster - DM search

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Look for universal effects for which results from different instruments can be easily combined following JCAP 1210 (2012) 032:

→ We invite YOU to this cooperative effort!
★ 32 highly significant spectra from 12 blazars in $z = 0.030$ to 0.944
★ 316 h of stereoscopic observations over 7 years (2010 – 2016)
★ contemporaneous Fermi-LAT data
★ overall calling and wavelength-resolved scaling tested

→ learn more from Gaia Vanzo's talk, Wed @ 14:00, Gamma-ray session
MAGIC as neutrino detector

★ Neutrinos start to be absorbed by Earth ~50 TeV
→ look for Earth skimming tau neutrinos ~PeV energies
★ tau neutrinos HAVE TO be astrophysical (only mu & e produced in source + oscillations)
★ CR background shielded by the Earth/rock (background-free search!)
★ Feasibility studies with MAGIC on-going (40h collected)
★ For most optimistic fluxes (GRB & AGN flares) ULs ~ AUGER could be set
★ Cheap observation time - can be done with clouds/low atmospheric transmission
★ broad transient & MM program: GRBs, FRBs, GW & neutrino follow-up
★ observation strategies, upper limits and… hint of the (un?)expected! :)

⇒ learn more from KS talk, Fri @ 15:00, Multi-messenger session
Starting from this year external scientists can apply for observation time with MAGIC.

Deadline for the call is tentatively set on 2017/11/03, but if you would like to apply please contact us not later than mid September!

https://magic.mpp.mpg.de/outsiders/magicop/