

### Status of TeV gamma-ray astronomy

### Daniel MAZIN

# Personal overview on the recent highlights, clearly biased ...

using slides from recent conferences and publications

CTA-Japan meeting, Kashiwa-no-ha, 2017 Dec 18

### **TeV source catalog**





- Nominally 207 sources as of Dec 15, 2017
- Dominated by HESS, MAGIC and VERITAS
  - Contains already 20 HAWC sources

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### **Golden Era for TeV astronomy**





### **MAGIC**, 2 x 17m

### H.E.S.S., 4 x 12m + 1 x 28m

### VERITAS, 4 x 12m

# HAWC, 300 water tanks at 4100m asl





### Due to the boost in flux sensitivity







### **Galactic Sources**

- SN 1006
- Galactic Plan scan: H.E.S.S. legacy
- Galactic center region

Crab

SNR

**PWN** 



### Binaries

Eta Car

Pulsars: big surprise!

# H.E.S.S. Survey HEGRA Survey VERITAS Cygnus Survey

Φ

-45

### H.E.S.S. Galactic Plane Survey

- ~ 3000 hours of observations on the Galactic plane conducted
- Used to compile a survey in gamma-rays
- 78 sources included in the upcoming paper



#### 13 articles in special A&A issue Planck CO map



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### **Galactic Pevatron?**







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Diffuse emission shows a power-law spectrum up to 50 TeV with no sign of a cut-off

Injection model fit to spectrum, solving transport equation of protons injected at the Galactic Centre

Quasi continuous injection lasting ~10<sup>4</sup> years

Total CR power injected at GC ~10<sup>38</sup> erg/s

#### Parent proton spectrum extends to PeV energies

First detection of a galactic **PeVatron**!

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### **Galactic Pevatron?**







t<sub>pp</sub> ~ 10<sup>8</sup> yr (1/n cm<sup>-3</sup>) — Other sources of cooling? Non-symmetric diffusion?

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# HAWC survey vs IACTs



### 507 Days of observation with HAWC found 39 Gammaray sources





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# **CasA is not a PeVatron**

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![](_page_12_Picture_1.jpeg)

![](_page_12_Figure_2.jpeg)

### **CasA is not a PeVatron**

![](_page_13_Picture_1.jpeg)

Rav Research

![](_page_14_Figure_0.jpeg)

# Crab: where is the cutoff?

![](_page_15_Picture_1.jpeg)

![](_page_15_Figure_2.jpeg)

Stay tuned for more data!

### Crab is extended in TeV

![](_page_16_Picture_1.jpeg)

![](_page_16_Figure_2.jpeg)

### **Binaries: first extragalactic**

![](_page_17_Picture_1.jpeg)

![](_page_17_Figure_2.jpeg)

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### **Binaries: Eta Car**

![](_page_18_Picture_1.jpeg)

![](_page_18_Figure_2.jpeg)

### **PSR J2032 +4107 Binaries: Once in a life time**

#### The system

- Extremely eccentric binary:
  - Be star (MT91 213) + pulsar
  - Orbital period: 45-50 years (Ho et al. 2017)
  - Associated TeV J2032+4130 (HEGRA 2002, Aharonian et al. 2005)
- Periastron: 13 November 2017
- Monitoring of the source: MAGIC+VERITAS joined campaign

#### Latest results

- September 2017 (ATel #10810):
  - DEC DEC TeV gamma-ray flux increased a factor 2 wrt June-August 2017 average
- November 2017 (ATel #10971) Periastron passage (MJD 58069.8):
  - Flux increased almost a factor 10 wrt the average flux in June-August

![](_page_19_Figure_13.jpeg)

ATel #10810, ATel # 10971

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[deg]

10

![](_page_19_Picture_17.jpeg)

### **Pulsars: Crab**

![](_page_20_Figure_1.jpeg)

![](_page_20_Picture_2.jpeg)

- Discovered pulsed emission from Crab spectrum extending up to 1.5 TeV
- Spectra of both peaks extending as power-laws far beyond the expected cutoffs:
  - P1 detected up to 0.6 TeV  $(\Gamma = 3.5 \pm 0.1)$
  - P2 detected up to 1.5 TeV  $(\Gamma = 3.0 \pm 0.1)$
- Model implications of detection of TeV photons:
  - Emission from outer magnetosphere via IC
  - Synchrotron-curvature ruled out (It would require unrealistic curvature radii)
  - However no model can fully explain presence of TeV pulsations 15

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#### H.E.S.S.-I result

Data from 2004 - 2016

**Pulsars: Vela** 

- 60 hrs in stereoscopic mode
- >3 TeV: 5.3σ
- >7 TeV: 5.6σ
- H-test (>7TeV): 4.5σ

![](_page_21_Figure_8.jpeg)

![](_page_21_Figure_9.jpeg)

![](_page_21_Picture_10.jpeg)

### **Extragalactic Sources**

![](_page_22_Picture_1.jpeg)

![](_page_22_Figure_2.jpeg)

# Extragalactic results dominated by MAGIC

![](_page_23_Figure_1.jpeg)

![](_page_23_Figure_2.jpeg)

# PG 1553+113: from radio to VHE

2007 2008 2009 2010 2011 2012 2013 2014 2015

![](_page_24_Figure_2.jpeg)

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**BL** Lac

#### BL Lac

### Mrk 421 changing peak frequency by 1 order of magnitude in 2013

![](_page_25_Picture_2.jpeg)

![](_page_25_Figure_3.jpeg)

![](_page_26_Picture_0.jpeg)

### BL Lacertae: flares in 2015 and 2016

![](_page_26_Picture_2.jpeg)

![](_page_26_Figure_3.jpeg)

# OJ 287: finally detected

- Optically bright blazar @ z = 0.306
  - Classification uncertain

**FSRQ** 

- TeV candidate: Costamante & Ghisellini 2002
- "Periodic" optical behavior: T ~ 12 yr
  - Binary black hole system? Helical jet?
  - Next optical outburst in 2019
- VERITAS limit in '07: 10 h, <2.6% Crab
- Swift XRT flaring => 2016-17 ToO
- VHE discovery in Feb. '17: ATel #10051
- 2016-17: ~50 h, 9.7 $\sigma$ ,  $\Gamma$  = 3.49 ± 0.28
  - F(>150 GeV) = (4.61±0.61) x 10<sup>-12</sup> cm<sup>-2</sup> s<sup>-1</sup>; 1.3% Crab
  - O'Brien Talk: GA080, July 13, ~16:30
- Copious MWL data: SED shifts

![](_page_27_Figure_16.jpeg)

![](_page_27_Picture_17.jpeg)

VHE Discovery

![](_page_28_Picture_0.jpeg)

### PKS1510-089 flare in 2016

![](_page_28_Picture_2.jpeg)

![](_page_28_Figure_3.jpeg)

![](_page_29_Picture_0.jpeg)

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![](_page_30_Picture_0.jpeg)

Two zone model

**FSRQ** 

- "Jet in" zone: larger region within BLR, mostly responsible for low energy emission
- "Jet out" zone: smaller region outside BLR, mostly responsible for gamma rays (SSC + EC)

![](_page_31_Picture_0.jpeg)

### 3C 279: 2015 flare

![](_page_31_Figure_2.jpeg)

 $\times 10^{-10}$ 

6

H.E.S.S. II MONO: E > 66 GeV

### NGC 1275 flare: New Year 2017

![](_page_32_Picture_2.jpeg)

- Harder spectrum w.r.t. Aleksić et al. 2014 and curved
- Significant signal found above 1 TeV
- Power-law fits plus exponential cutoff indicate cutoff at ~500 GeV

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### M87: quiescent state 2012-2015

![](_page_33_Picture_2.jpeg)

![](_page_33_Figure_3.jpeg)

#### MAGIC in cooperation with K. Asano (ICRR)

explained by: Constant injection of particles at ~200 R<sub>a</sub> (~0.13pc) • The model can describe the observations well assuming ~15° viewing angle and  $\Gamma=3$ • The model requires energy density in the jet strongly dominated by particles

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![](_page_34_Picture_0.jpeg)

# Gamma ray bursts (MAGIC)

![](_page_34_Picture_2.jpeg)

18.8

18.7

18.6

![](_page_34_Figure_3.jpeg)

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![](_page_35_Figure_0.jpeg)

# **EBL limits (MAGIC)**

 $F_{observed} = F_{intrinsic} \times exp(-\alpha \tau)$ 

![](_page_36_Figure_2.jpeg)

![](_page_36_Picture_3.jpeg)

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λ

# **EBL limits (MAGIC)**

![](_page_37_Picture_1.jpeg)

![](_page_37_Figure_2.jpeg)

![](_page_38_Figure_0.jpeg)

### **Electron spectrum**

![](_page_39_Picture_1.jpeg)

![](_page_39_Figure_2.jpeg)

### Iron spectrum

![](_page_40_Picture_1.jpeg)

![](_page_40_Figure_2.jpeg)

### **Fundamental Physics**

![](_page_41_Picture_1.jpeg)

![](_page_41_Figure_2.jpeg)

### LIV: likelihood analysis using Crab Pulsar data

![](_page_42_Picture_1.jpeg)

![](_page_42_Figure_2.jpeg)

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### **Dark matter searches**

![](_page_43_Picture_1.jpeg)

![](_page_43_Figure_2.jpeg)

The search goes on. No positive hints so far

### Multimessenger

Neutrino

Photon

Search for gamma-ray emission associated with astrophysical neutrinos

# Multimessenger

![](_page_45_Picture_1.jpeg)

September 2017: TXS0506+056 (unknown redshift) in flaring state coinciding with Extremely High Energy (EHE, through-going track) v event
Chance coincidence or prove of hadronic emission?

![](_page_45_Figure_3.jpeg)

## Conclusion

![](_page_46_Picture_1.jpeg)

![](_page_46_Picture_2.jpeg)

- Publication rate is stable, limited by the man power, can publish for the next 3-4 years in the same rate
- Saturation effects not seen yet, thanks to upgrades of the major instruments

![](_page_46_Picture_5.jpeg)

Looking forward to the CTA observatory!

### BACKUP

![](_page_47_Picture_1.jpeg)

# **EBL limits (MAGIC)**

![](_page_48_Picture_1.jpeg)

![](_page_48_Figure_2.jpeg)

Free parameters:  $\theta$  (intrinsic spectra) + one or more EBL parameters

Poisson parameters of the background in each E<sub>est</sub> bin are treated as nuisance