MAGIC status report & highlights

- The MAGIC telescopes: status & performance
- Selected recent scientific highlights
- What's next ?

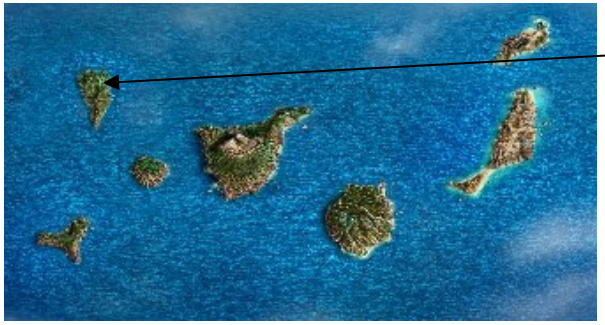
Cosmic Ray International Seminar CRIS2015 – 15 September 2015, Gallipoli, Italy

Barbara De Lotto, INFN sez. Trieste - gr. coll. & University of Udine
on behalf of the MAGIC Collaboration

Two 17m Ø Atmospheric Gamma-ray Imaging Cherenkov Telescopes

~160 physicists from 10 countries:
Bulgaria, Croatia, Finland, Germany, India, Italy, Japan, Poland, Spain, Switzerland

Canary island of La Palma



at ~ 2300 m a.s.l.

Detection technique in a nutshell

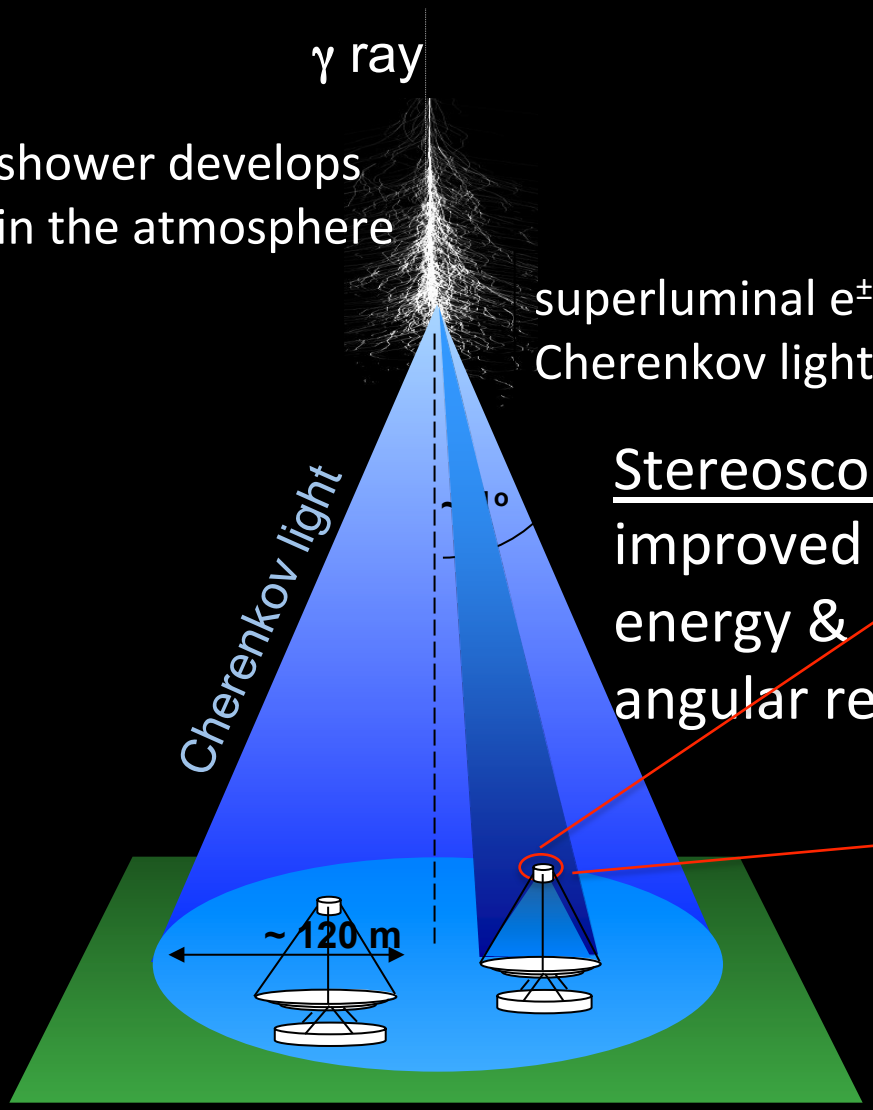
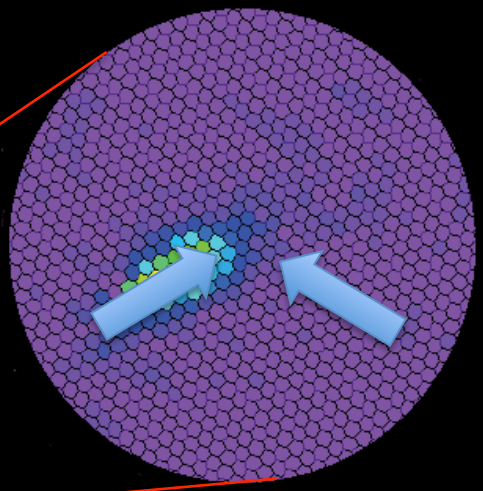


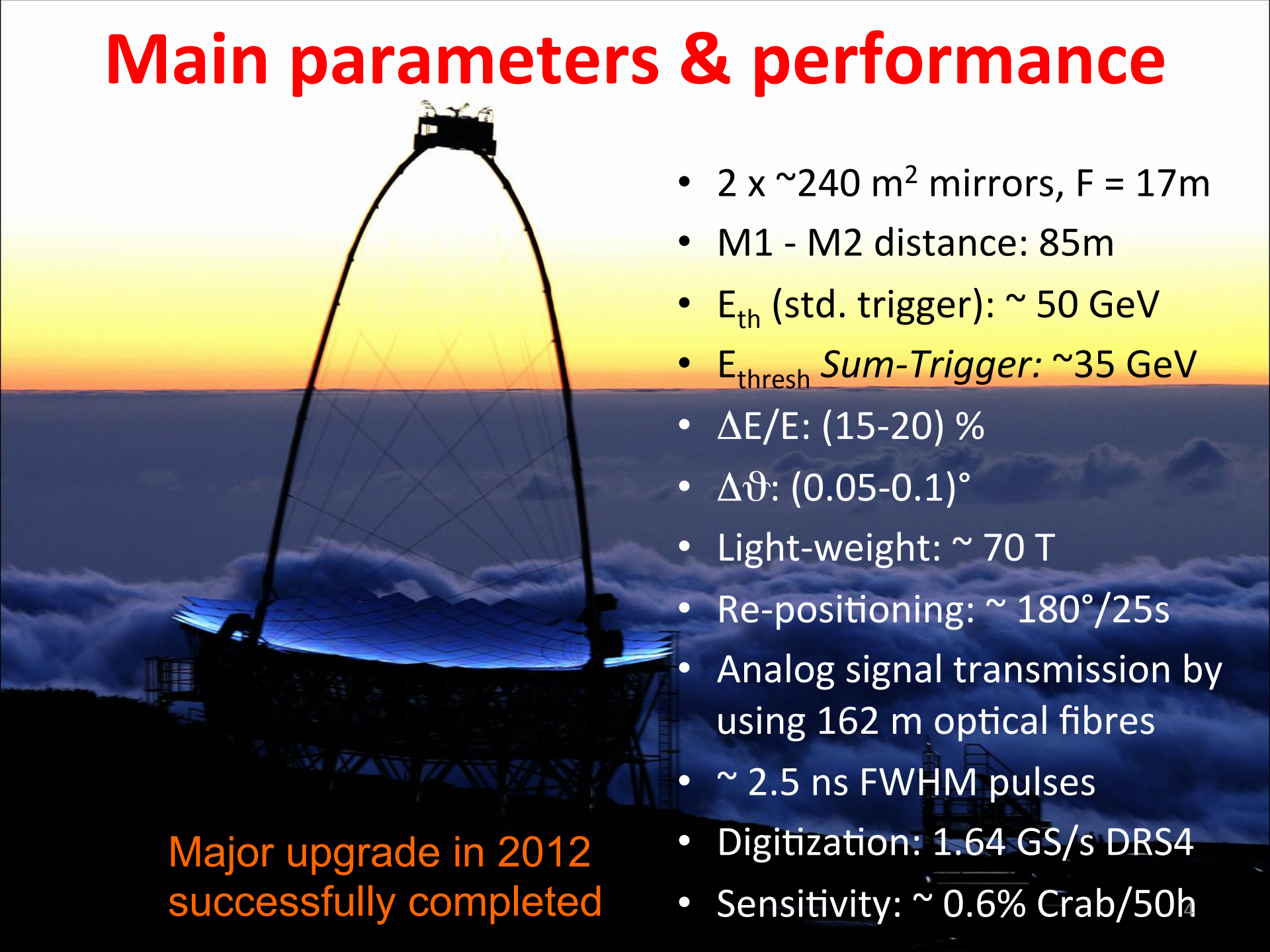
image of an air shower
detected by the camera



Stereoscopy :
improved sensitivity
energy &
angular resolutions

- reconstruct: arrival direction, energy of primary γ
- reject hadron background

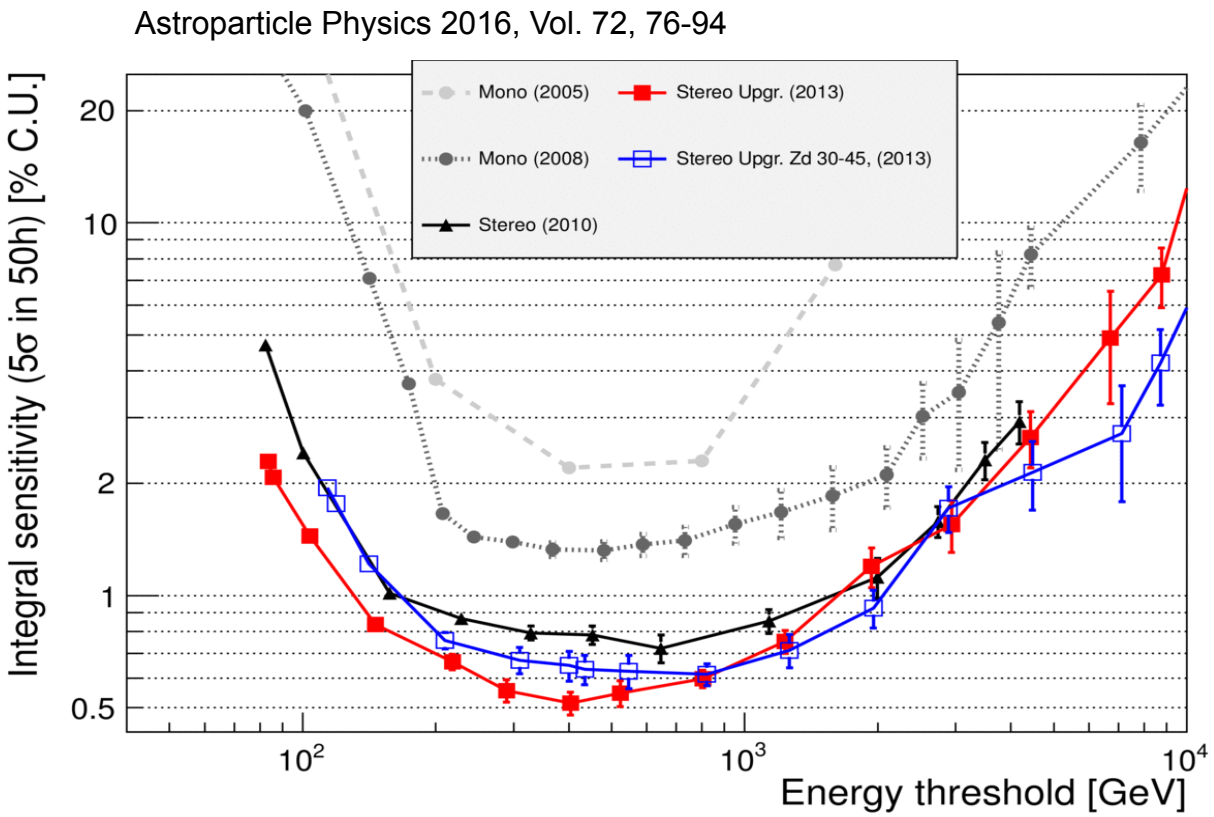
Main parameters & performance



- 2 x ~240 m^2 mirrors, F = 17m
- M1 - M2 distance: 85m
- E_{th} (std. trigger): ~ 50 GeV
- E_{thresh} *Sum-Trigger:* ~35 GeV
- $\Delta E/E$: (15-20) %
- $\Delta\vartheta$: (0.05-0.1)°
- Light-weight: ~ 70 T
- Re-positioning: ~ 180°/25s
- Analog signal transmission by using 162 m optical fibres
- ~ 2.5 ns FWHM pulses
- Digitization: 1.64 GS/s DRS4
- Sensitivity: ~ 0.6% Crab/50h

Major upgrade in 2012 successfully completed

Evolution of MAGIC sensitivity with time

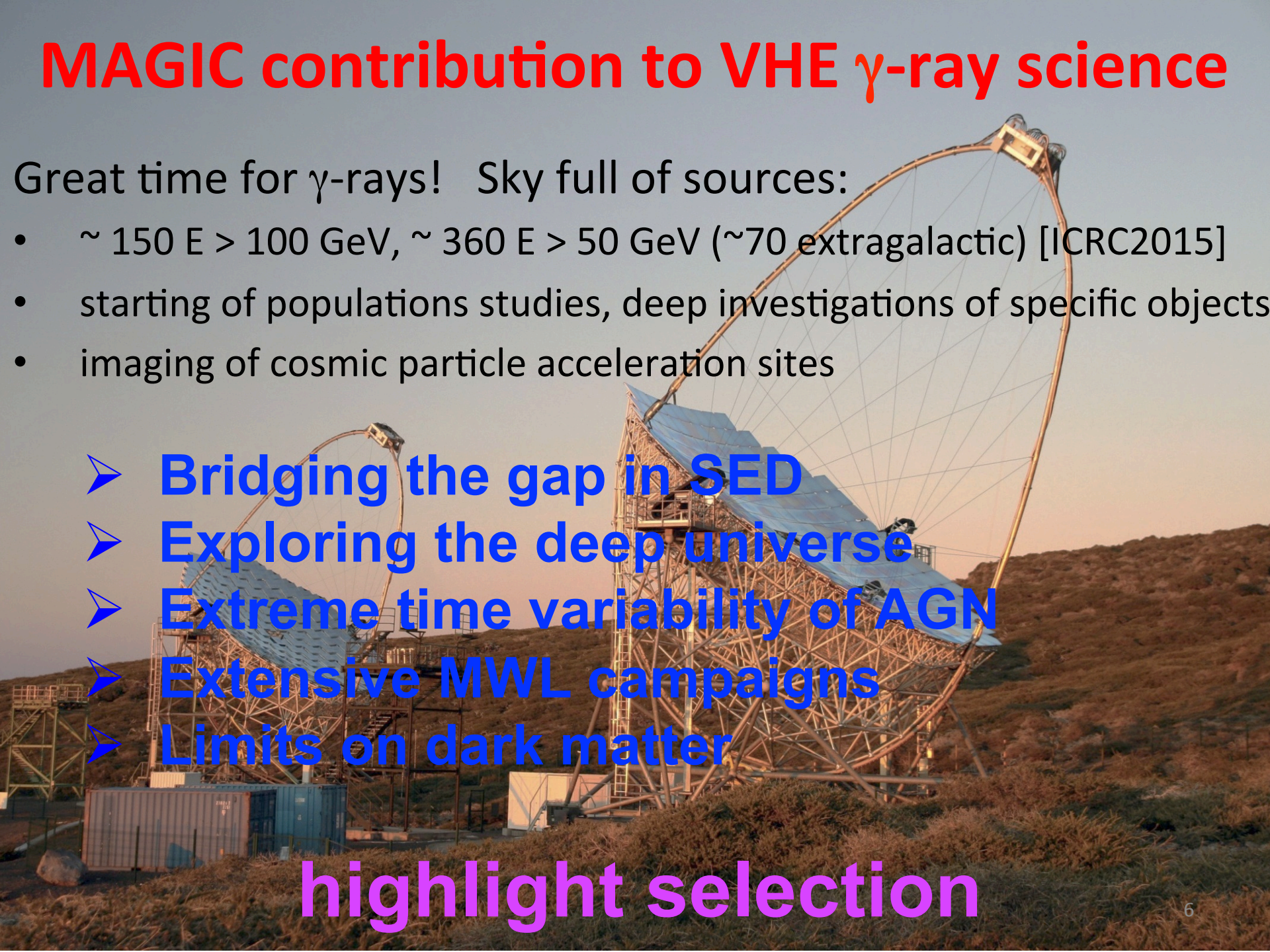


~ 4-fold improvement over the last decade (~ 10-fold @ lowest energies)

MAGIC contribution to VHE γ-ray science

Great time for γ-rays! Sky full of sources:

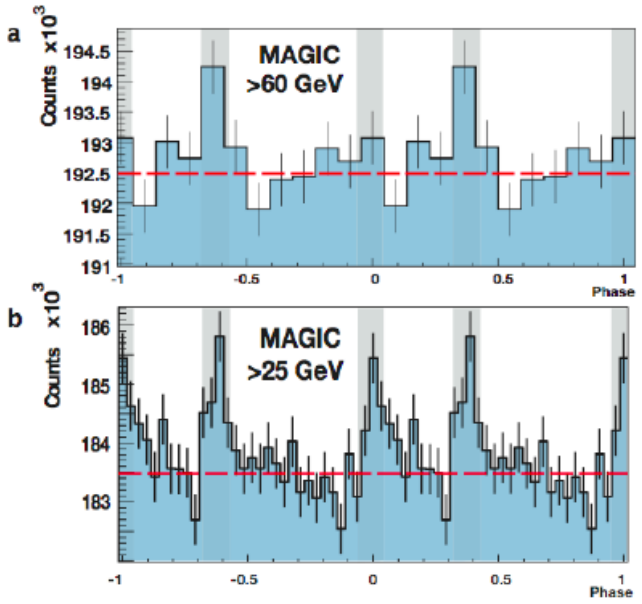
- ~ 150 E > 100 GeV, ~ 360 E > 50 GeV (~70 extragalactic) [ICRC2015]
- starting of populations studies, deep investigations of specific objects
- imaging of cosmic particle acceleration sites

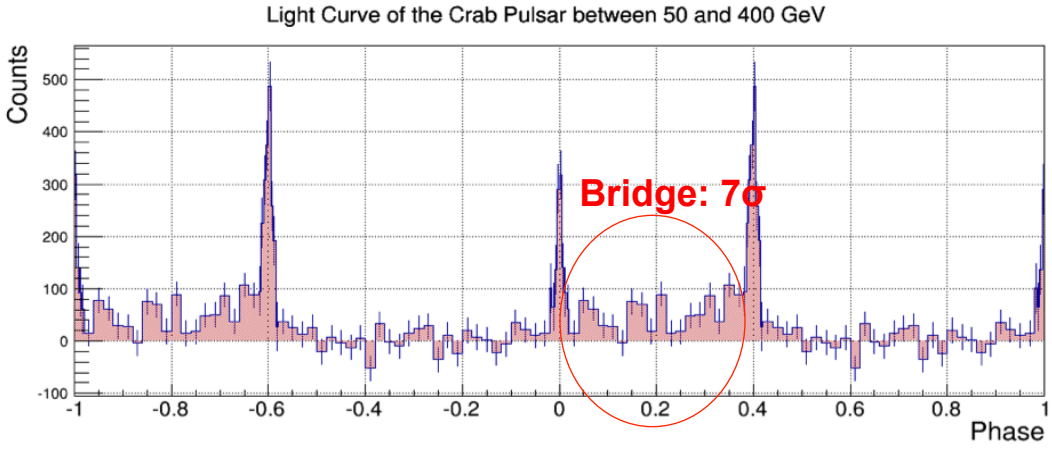


- **Bridging the gap in SED**
- **Exploring the deep universe**
- **Extreme time variability of AGN**
- **Extensive MWL campaigns**
- **Limits on dark matter**

highlight selection

Crab pulsar: recent history





Long scientific record:

MAGIC Science 322 (2008)
First detection of emission above 25 GeV from a pulsar

VERITAS: Science 334 (2011)
First detection of emission above 100 GeV

MAGIC ApJ 742 (2011)
First spectrum 25-100 GeV

MAGIC A&A 540 (2012)
First spectrum 50-400 GeV

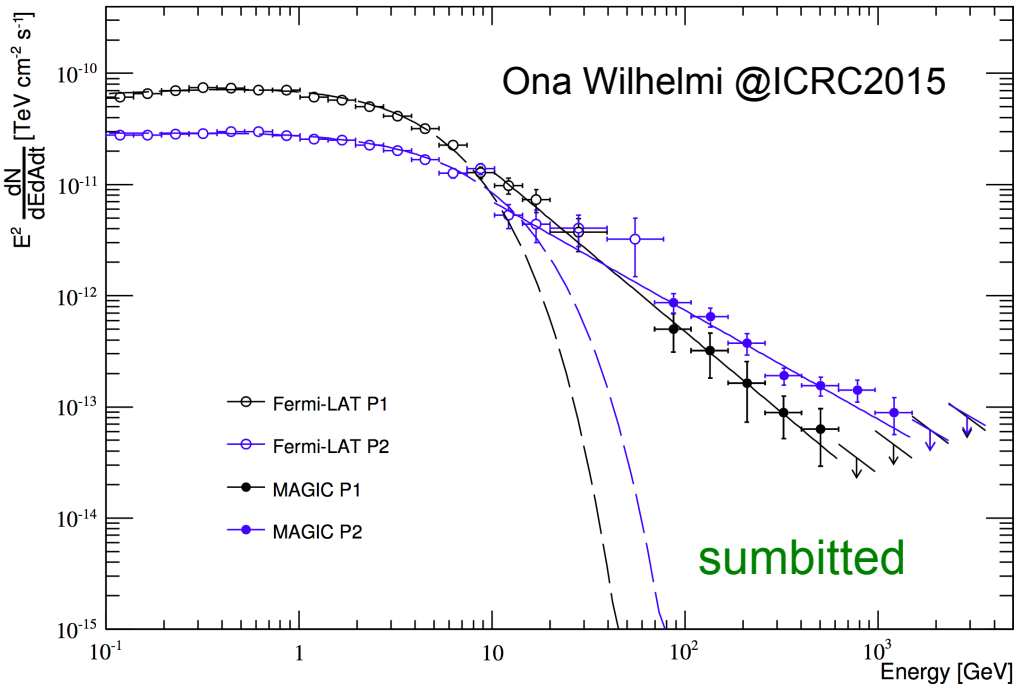
MAGIC A&A 565, L12 (2014)
Bridge Emission ≥ 50 GeV

Crab pulsar established by MAGIC as the most compact accelerator of TeV γ-rays

- 320 hours of mono & stereo observations (2007 – 2014)
- spectrum extending ≥ 1TeV

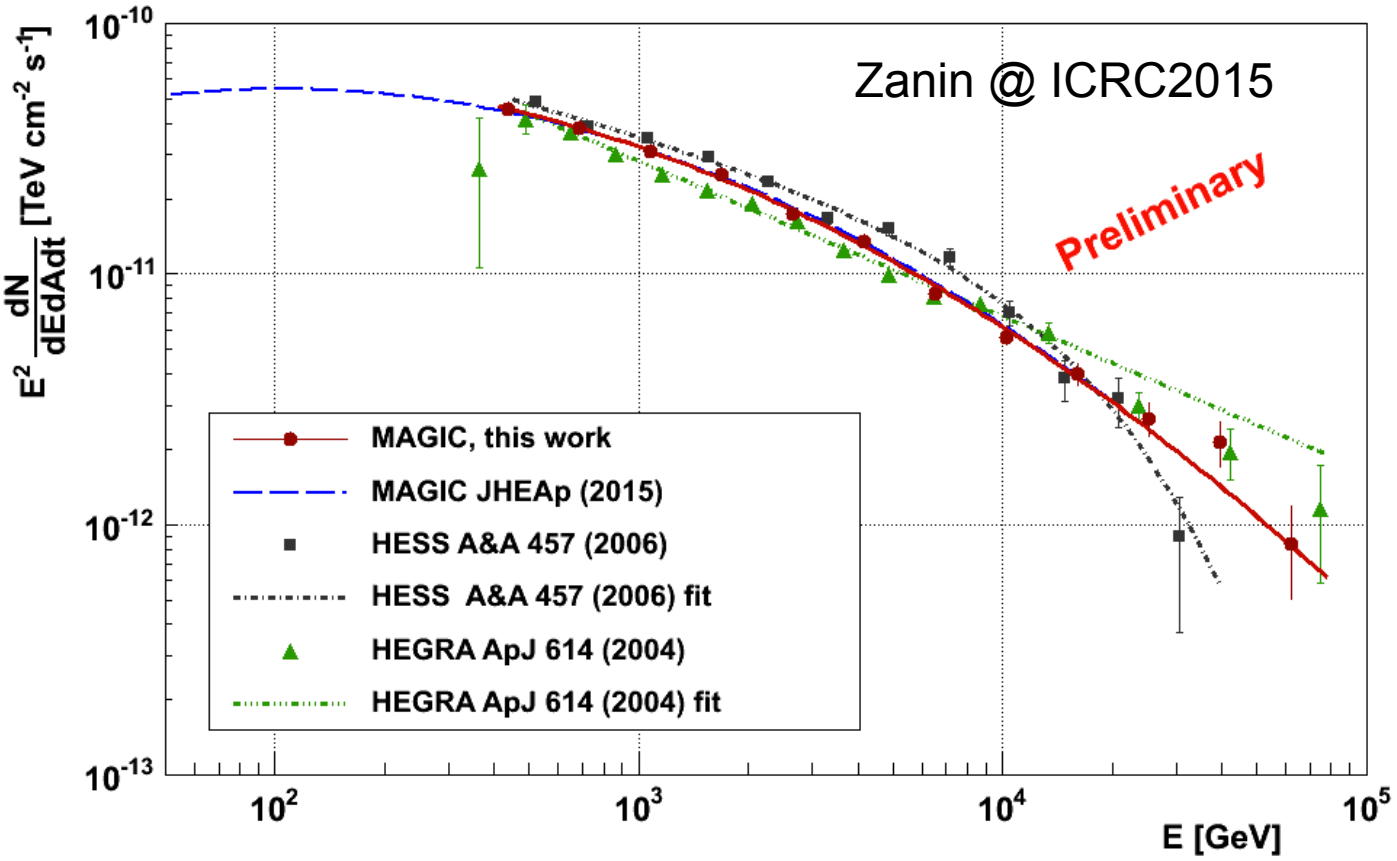
- MAGIC-Fermi fit shows IC emission component from ~10 GeV to above 1 TeV

- challenging the emission models



Crab Nebula spectrum up to ~ 80 TeV

Submitted for publication



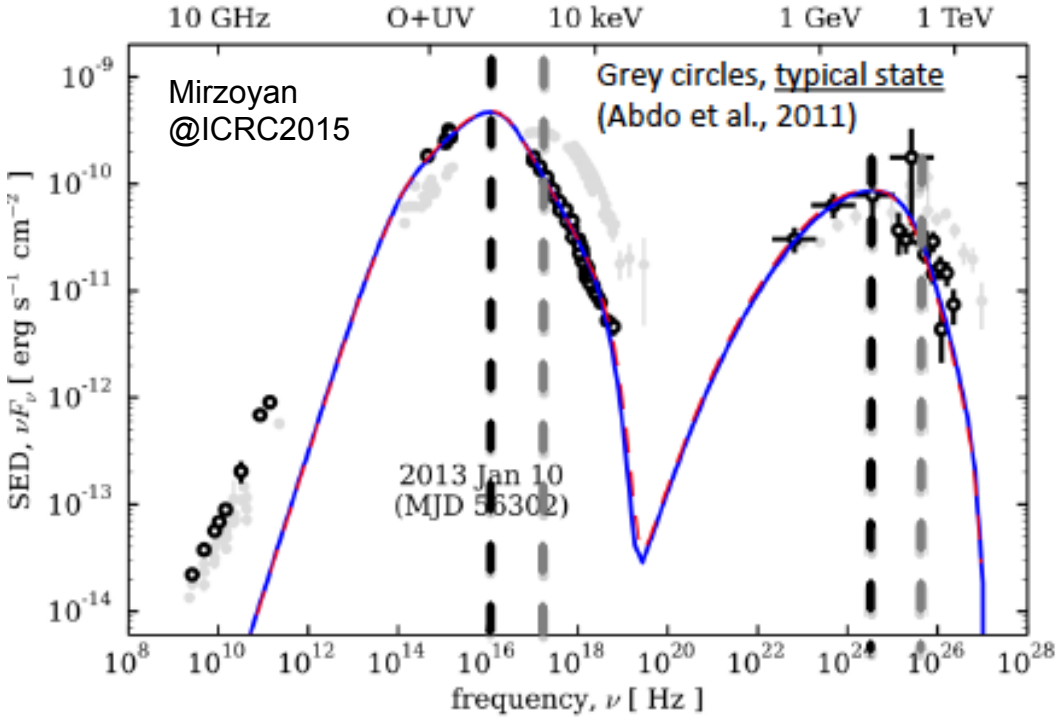
Extensive MWL campaigns on Mrk421 and Mrk501

- Blazars emit over a very wide energy range (from radio to VHE γ-rays)
- Mrk421 and Mrk501 "easiest": nearby, bright at all energy bands
- More than 25 instruments participate,
  - Regular observations by MAGIC and VERITAS
  - Monitoring regardless of activity, also in "low states"

Peculiar flare (January 2013):

- Synchrotron and IC peak shifted to ~ 10 times lower energies
- Never seen before for any blazar
- "HBL moving towards IBL"
- Low activity softened the X-ray and VHE spectra, but did not show spectral cutoffs

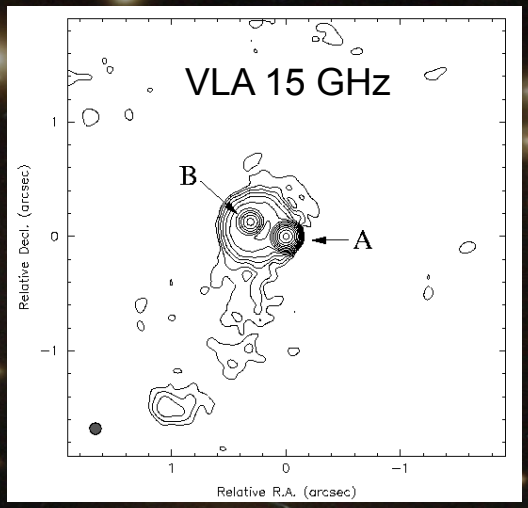
SED of Mrk421 in January 10, 2013

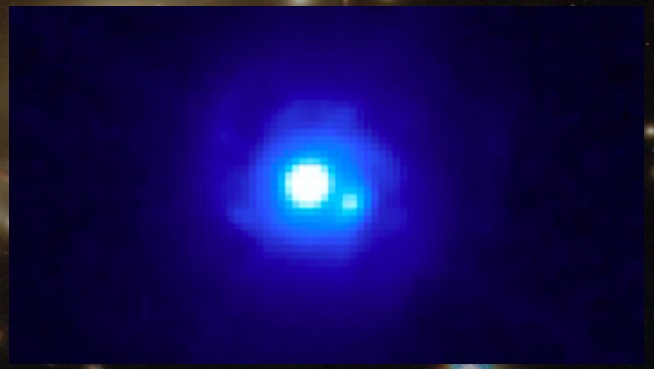


MAGIC breaking the red shift barrier: QSO B0218+357

First gravitationally lensed TeV blazar @ z = 0.944 ± 0.002 discovered thanks to its delayed emission

- Gravitationally lensed double image visible in radio and optical



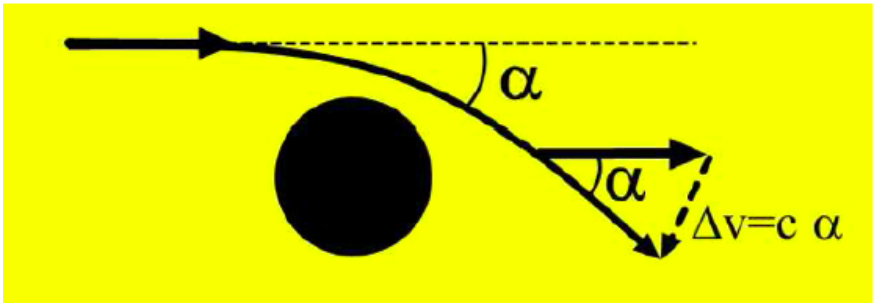


HST - Image credit NASA/ESA

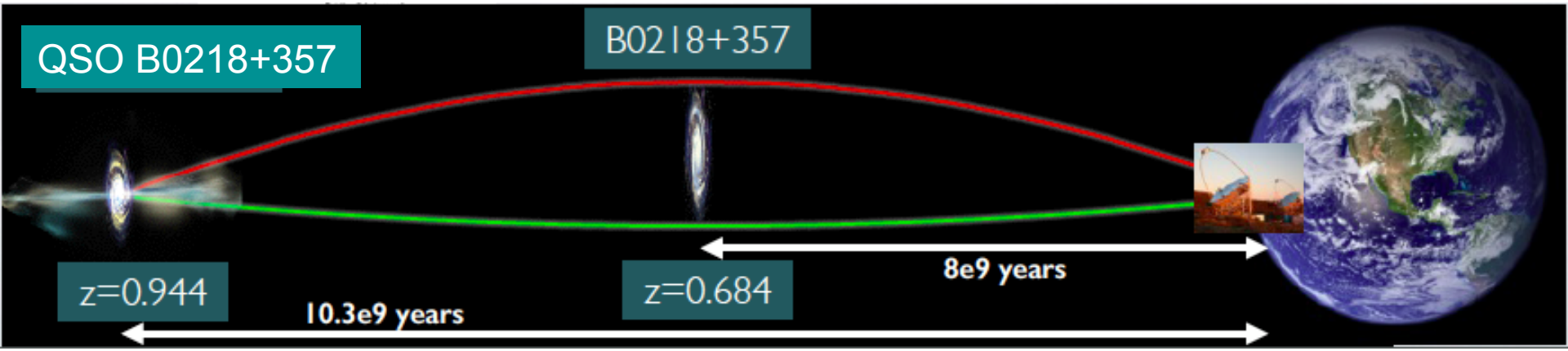
- A delay of 10.5 ± 0.2 days between the two components observed in a 3 months long campaign by VLA
  [A. D . Biggs et al. (1999), MNRAS, 304-349]

Gravitational lensing

Radiation is deflected in gravitational field: multiple images, time delays



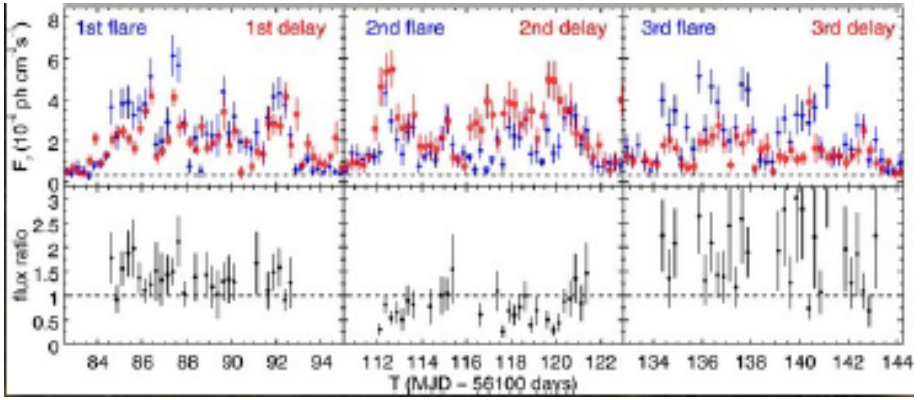
$$\alpha = \frac{4GM}{Rc^2}$$



Previous Fermi-LAT results on QSO 0218+357

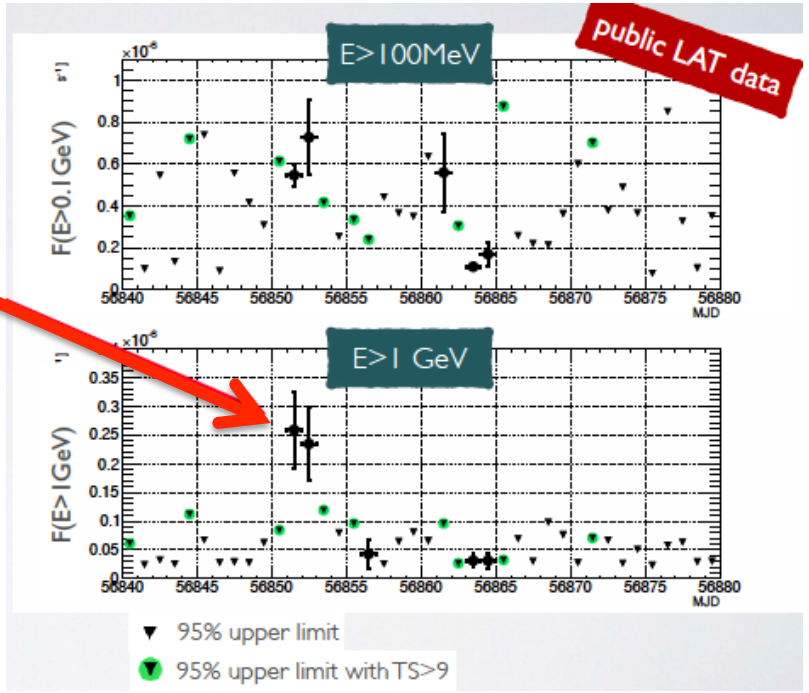
ApJ 782, L14 (2014)

- Fermi-LAT 2012 data: multiple flares, from autocorrelation analysis, fitted delay 11.5 ± 0.4 days, roughly similar flux



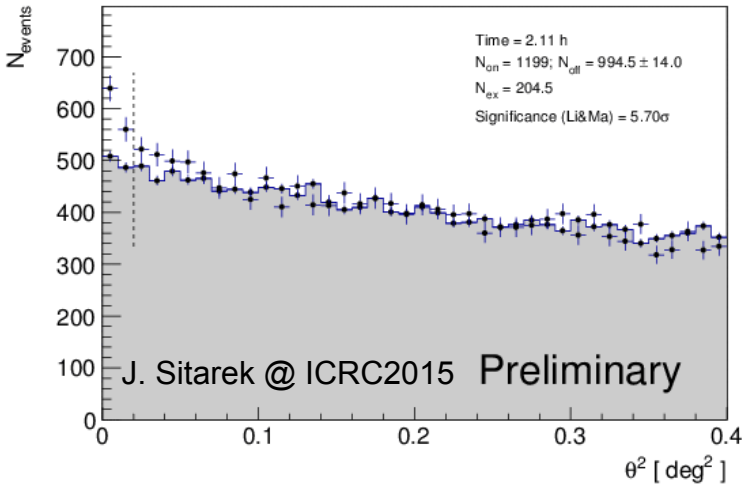
- On July 2014 Fermi again detects a high state, not as strong as in 2012 but with a much harder spectrum

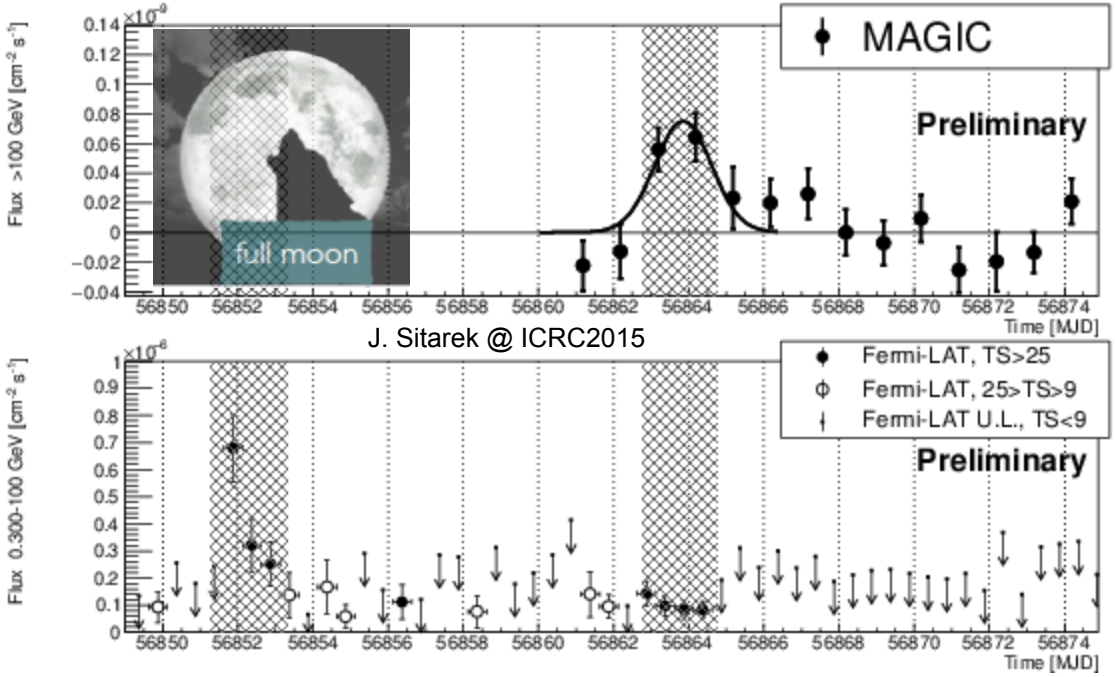
- Magic cannot observe (full moon period ☹)
  ➔observations are scheduled for the delayed flare !



QSO 0218+357 first lensed TeV blazar

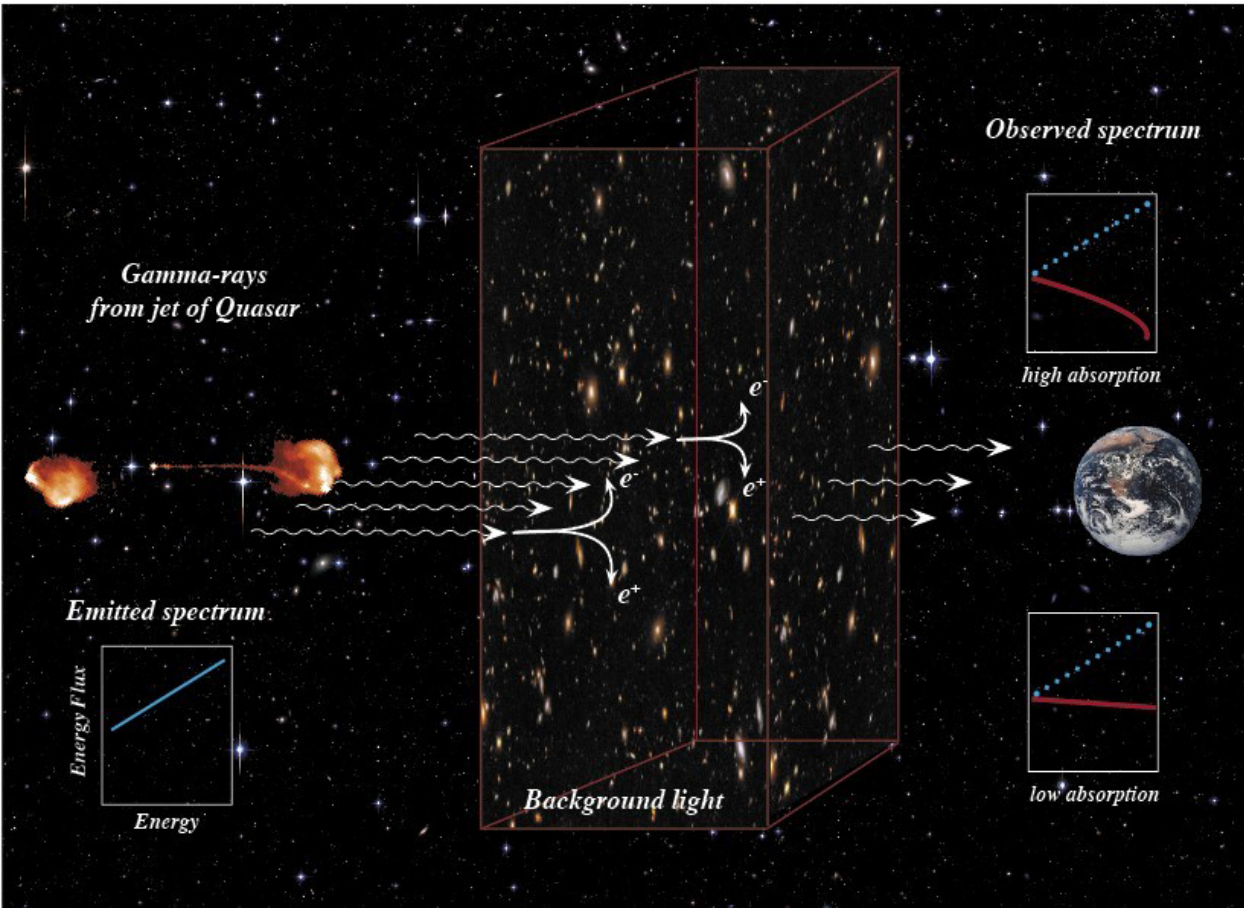
- The two nights around the time of the expected delayed emission lead to a detection with 5.7σ significance



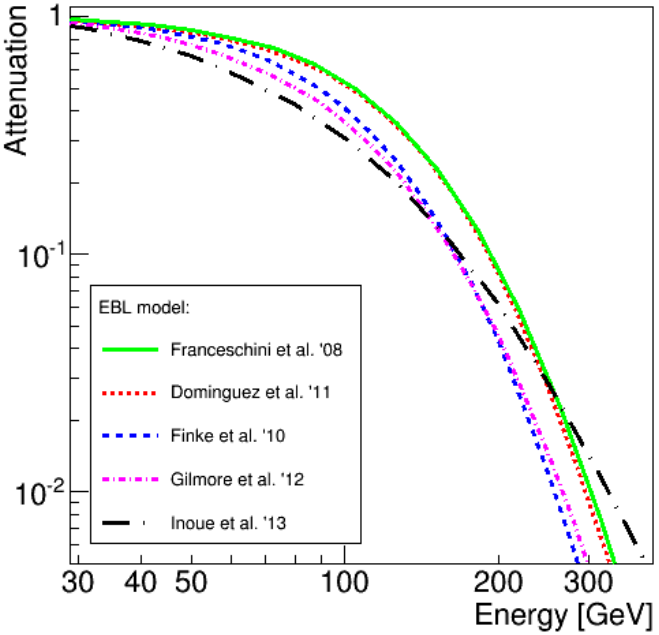


- No increase during the second component of the flare in x-rays and optical range

Why no sources with higher *z* detected?



- For z ~ 1 strong absorption above 100 GeV

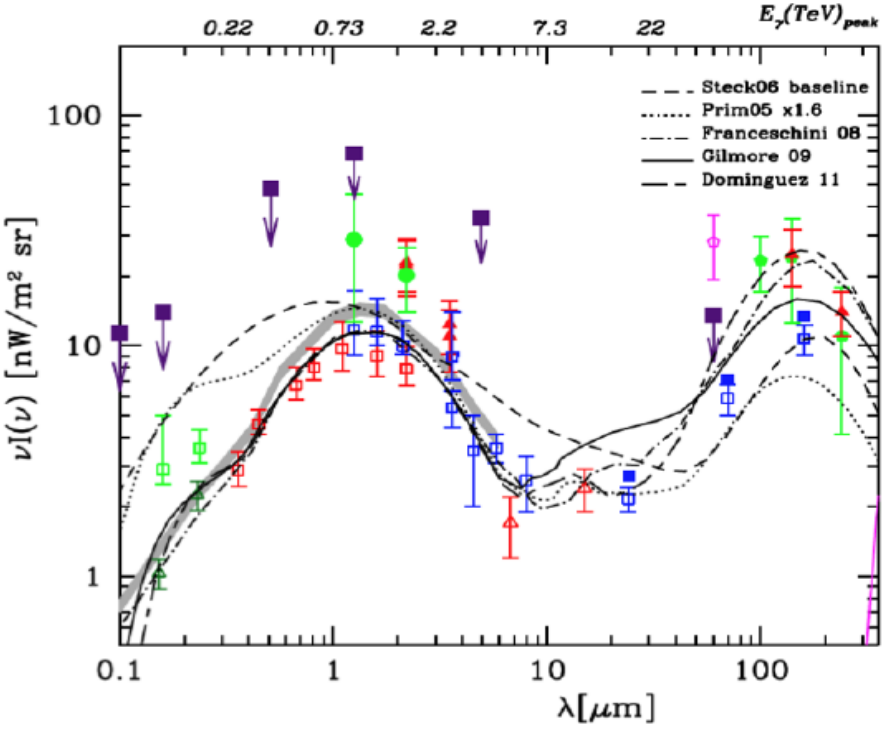


$$\Phi_{\rm obs}(E,z) \equiv \Phi_{\rm em}(E) \times e^{-\tau(E,z)}$$

$$\tau(E,z) = \int_0^z dl(z) \int_{-1}^{1} d\cos\theta \frac{1-\cos\theta}{2} \int_{E_{thr}(E,\theta)}^{\infty} d\epsilon(z)\, n_\epsilon(\epsilon(z),z)\, \sigma(E(z),\epsilon(z),\theta)$$

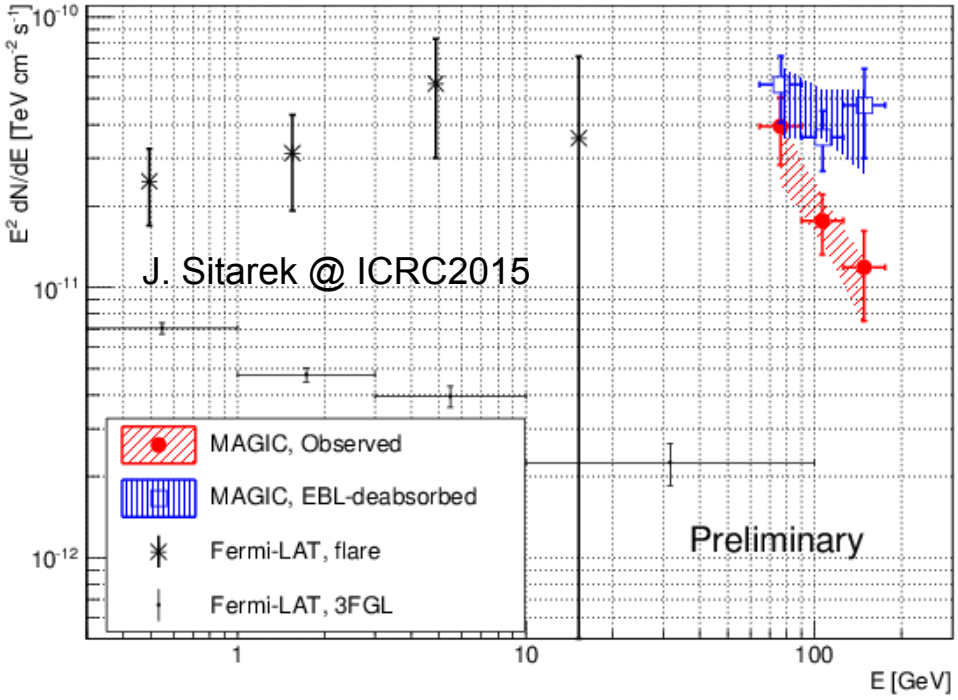
Measurement of background photons (EBL) in the Universe

- The low energy near-optical photons are abundant in the Universe, they stem from star and galaxy formation
- Measurement of VHE spectra of distant galaxies @ different red shifts can constrain the density of extragalactic background light →strong input for cosmology



VHE sky expanded from *z* 0.6 to 0.94

- Magic measured spectrum is very soft
- Deabsorbing it with state-of-the-art EBL models (Dominguez et al. 2011) : intrinsic spectral index ~ 2

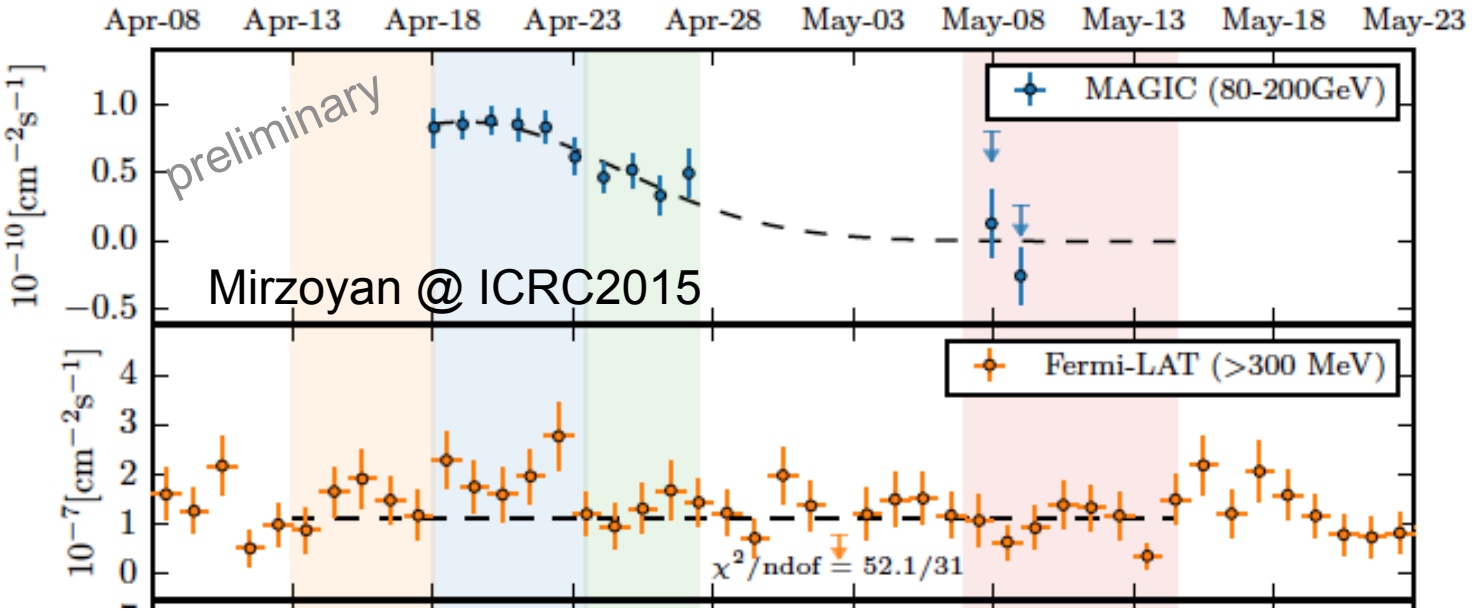


- First estimates of the EBL absorption in the **previously unexplored redshift range**: **VHE spectrum consistent with the current EBL models**

MAGIC breaking the red shift barrier: PKS 1441+25

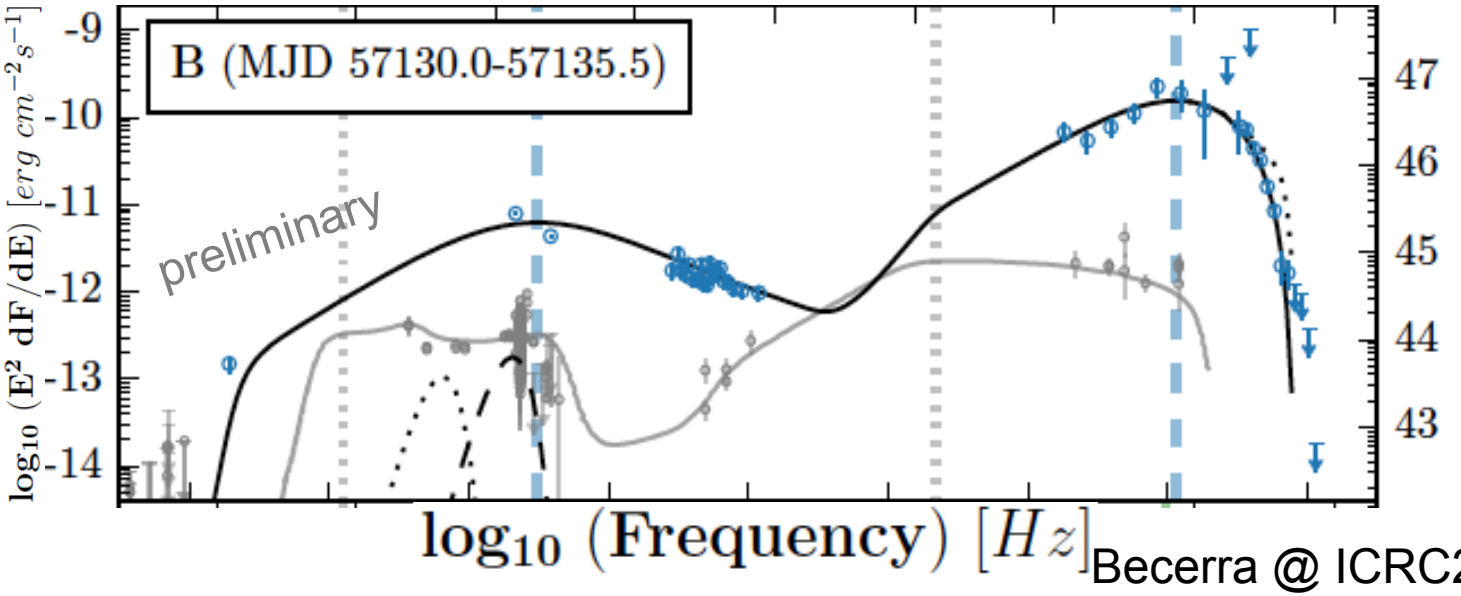
FSRQuasar half a universe away @ z = 0.939

Atel #7416 20 Apr 2015



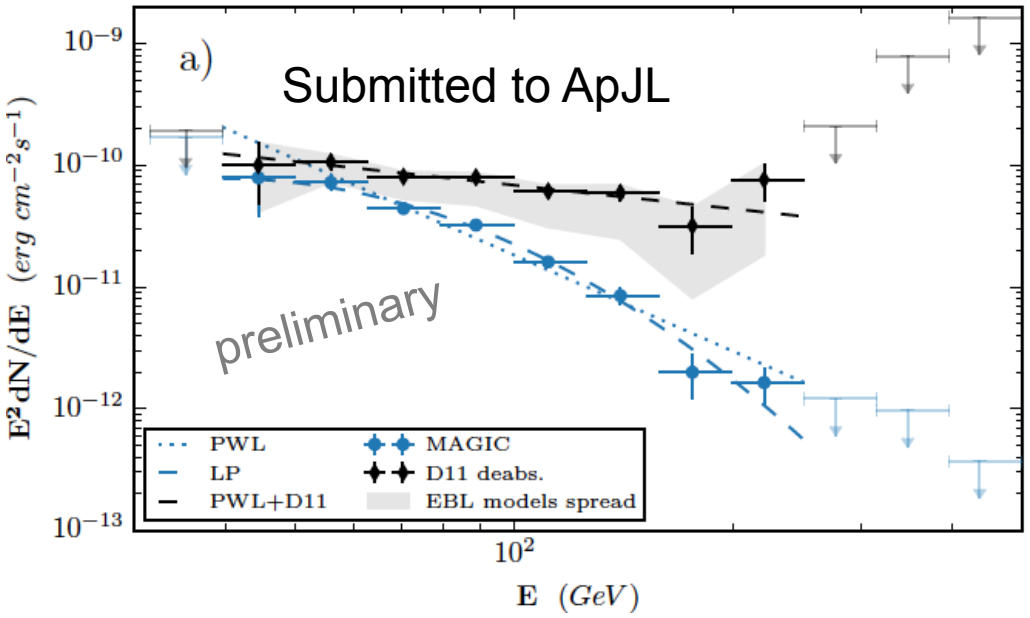
- **detection @ 25 σ**
- VERITAS confirmation

PKS 1441+25 MWL SED



Becerra @ ICRC2015

- Spectrum from 40 to 250 GeV
- for the first time EBL probe @ z ~ 1 : stringent upper limits on EBL density (between 0.20 and 0.30 μm)



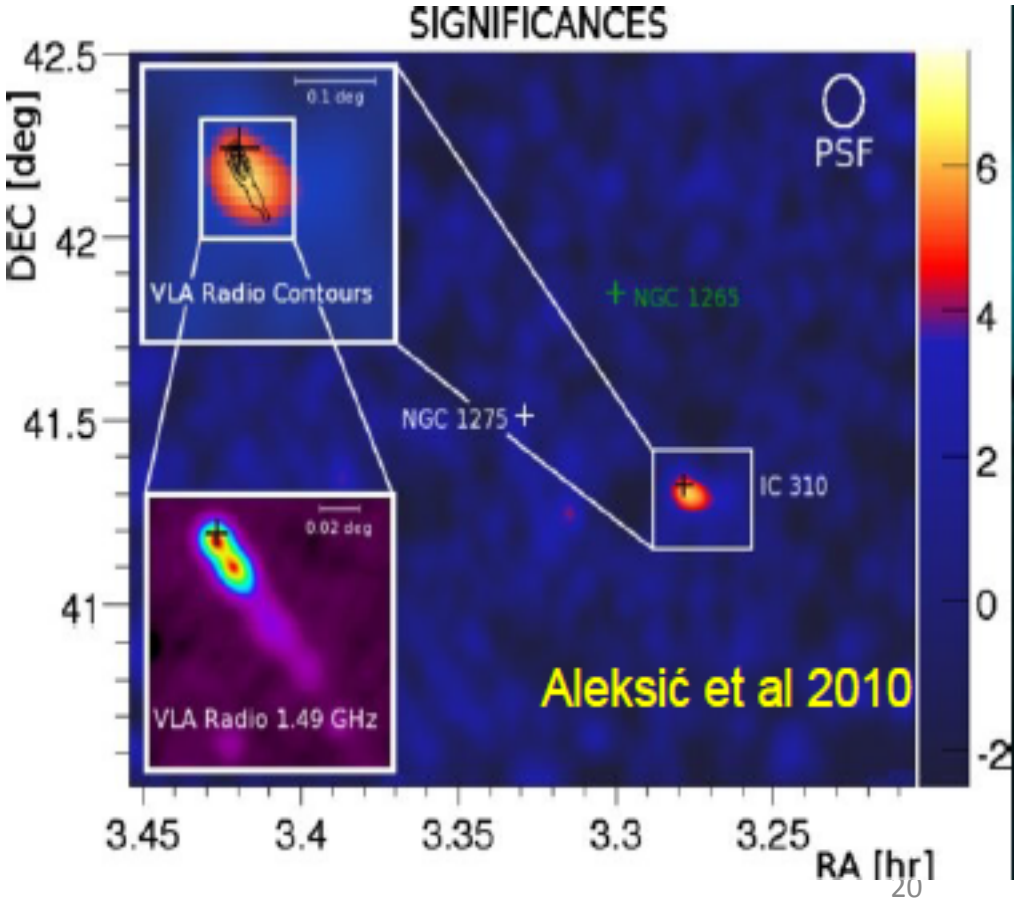
Sciencexpress Research Articles

Science, **346**, 1080, November 2014

Black hole lightning due to particle acceleration at sub horizon scales

Brief source history:

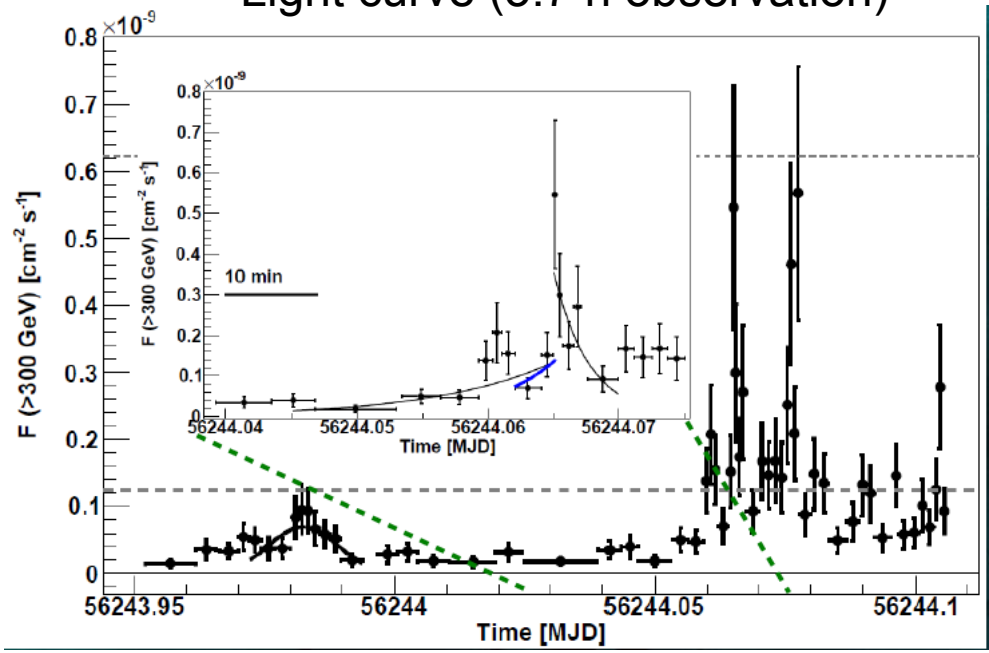
- Active galaxy **IC 310** already known in radio, optical, X-rays
- Detected above 30 GeV in Fermi data (Neronov et al. 2010)
- Serendipitously discovered in VHE in the outskirts of the Perseus cluster [MAGIC, Aph.J. 2010]
- Night to night variability [MAGIC, Aph.J. 2014]



Close-up view of the flaring night

- during MWL campaign in Nov. 2012 MAGIC detected an extreme flare
- Flux doubling time < 4.8 min at 95% CL
- Previously unobserved for a radio galaxy
- Corresponds to 20% of the light crossing time of the BH gravitational radius

Light curve (3.7 h observation)

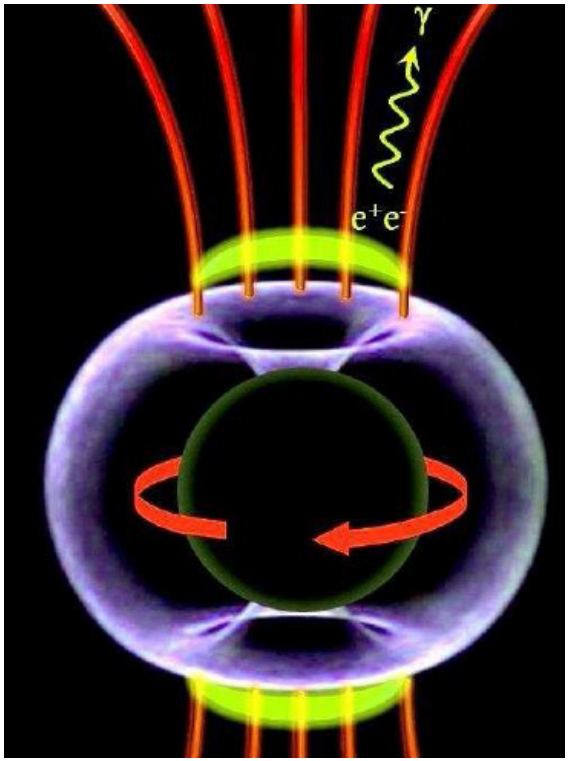


- Spectral shape constant and without curvature from 60 GeV to 10 TeV: difficult to explain with current standard theoretical scenarios !

Challenging emission models

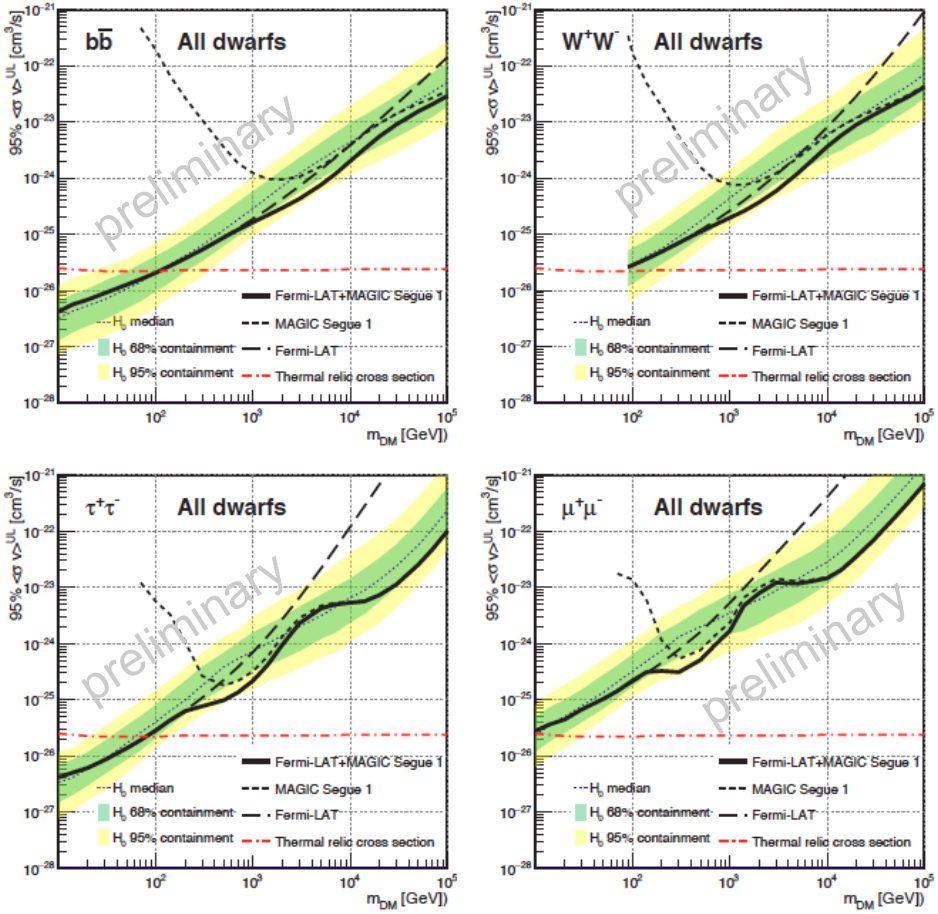
- Could not be explained by the shock acceleration in the jet
- Among alternative possibilities

a pulsar-like scenario with e^+e^- accelerated in an electric field in vacuum gap close to black hole: "magnetospheric emission model"



Dark Matter searches

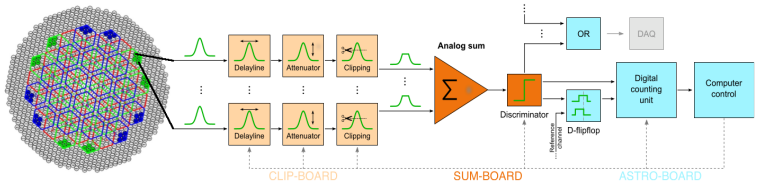
- Deepest observation (158 h) of Dwarf Spheroidal galaxy Segue 1 [JCAP 02 (2014) 008]



- **Combined** MAGIC-Fermi-LAT
- **Coherent** analysis
  (statistical method, J factor)
- **Most constraining limits** on
  DM annihilation cross section
  in the mass range 10 GeV – 100TeV
  [Wood @ ICRC2015, arXiv:1508.05827]
- Next step: combine results from
  H.E.S.S., HAWC, MAGIC, VERITAS & Fermi-LAT + ν detectors

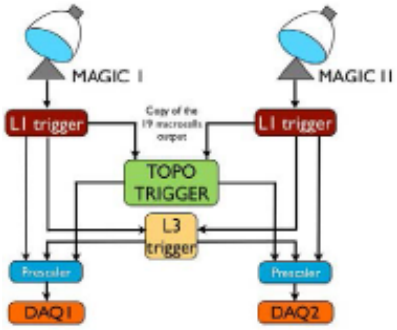
What's next: always improving our tools!

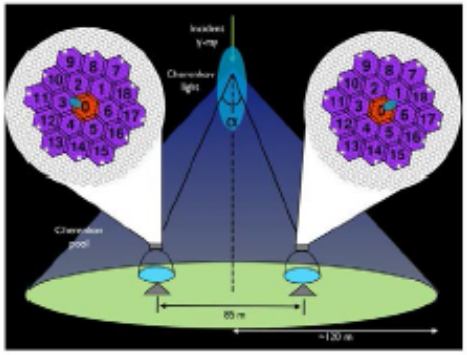
- **Sum trigger** tuning:



Main concept: to add up signals from a group of neighboring pixels (macrocell) and apply a threshold to the summed signal
➔improve signal/noise ratio, sensitivity, E_{th}

- **Topological trigger** under testing:





making use of the L1 trigger information allows to reduce NSB while decreasing the thresholds ➔ improvements in E_{th} (>10%) and collection area

…

What's next

- MAGIC sensitivity further improving: we are very competitive for energies ≥ 30 GeV, at least for the next ~ 5 years
- Memorandum of Understanding with HAWC and Ligo-Virgo collaborations signed (aLIGO O1 science run is just starting)
- The CTA prototype 23m Ø LST will be hosted by the MAGIC site: first stone on Oct 10th !

Conclusions

- The upgraded MAGIC telescopes system has proven to be a powerful instrument: never has been any better than now !
- We are planning to have smooth operation for the next 5 years
- Software and HW improvements are boosting its performance in successful Physics outcome
- Seed test site for the future Cherenkov Telescopes Array

Thank you

backup

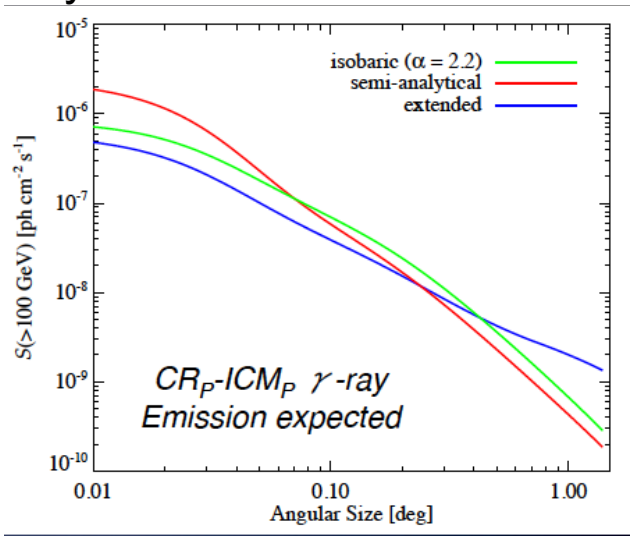
Furthest VHE sources

source	redshift	discovered by	year
3C 279	0.536	MAGIC	2006
PKS 1510 - 089	0.361	H. E. S. S.	2009
PKS 1222 + 216	0.432	MAGIC	2010
S4 0954 + 65 *	0.368	MAGIC	2015
QSO B0218 + 357	0.944	MAGIC	2014
PKS 1441 + 25	0.939	MAGIC	2015

Deep observation of the Perseus cluster

Search for diffuse γ-ray emission induced by the CR population

- Cluster of galaxies are the largest gravitationally bound systems in the universe
- Actively evolving and dissipating energy
- Non-thermal emissions observed in radio
- Expected in γ-rays: $CR_P + ICM_P \rightarrow \pi^o \rightarrow \gamma + \gamma$



◆ **Perseus**: nearby (z~0.018) brightest x-ray cluster best target to search for CR-ICM emission

◆ 253 h of stereo observations with MAGIC:

- ➢ two γ-ray bright AGNs discovered
- ➢ no sign of any diffuse/CR- induced signal
- ➢ constraining flux upper limits at TeV energies:

- CR-to-thermal pressure < 1-2 %
- on-going constraints on cluster magnetic field assuming the hadronic model of radio mini-halo

Colin @ ICRC2015