



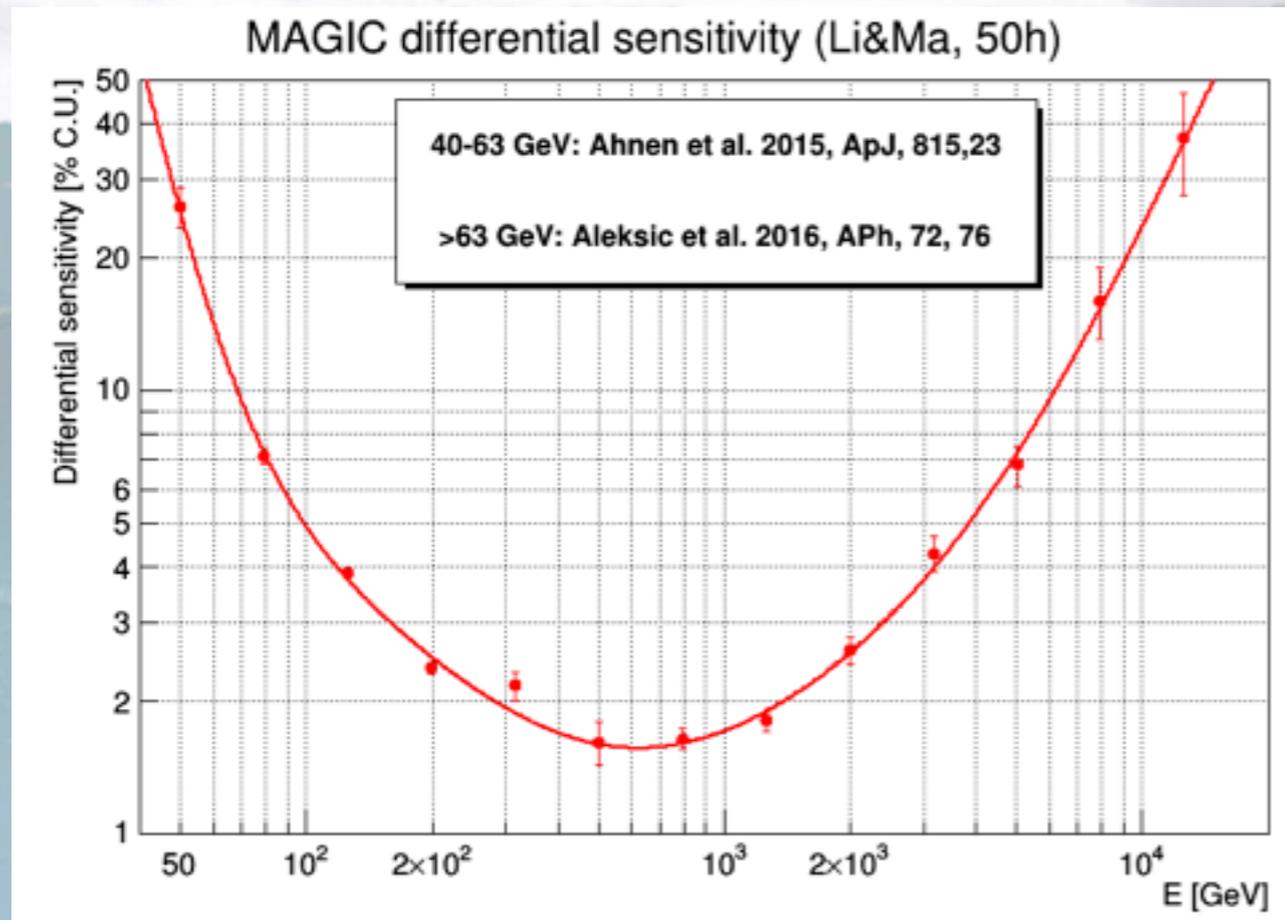
# The MAGIC highlights

Konstancja Satalecka for the MAGIC Collaboration

TeVPA 2017, August 7th 2017, Columbus Ohio



# MAGIC - short info

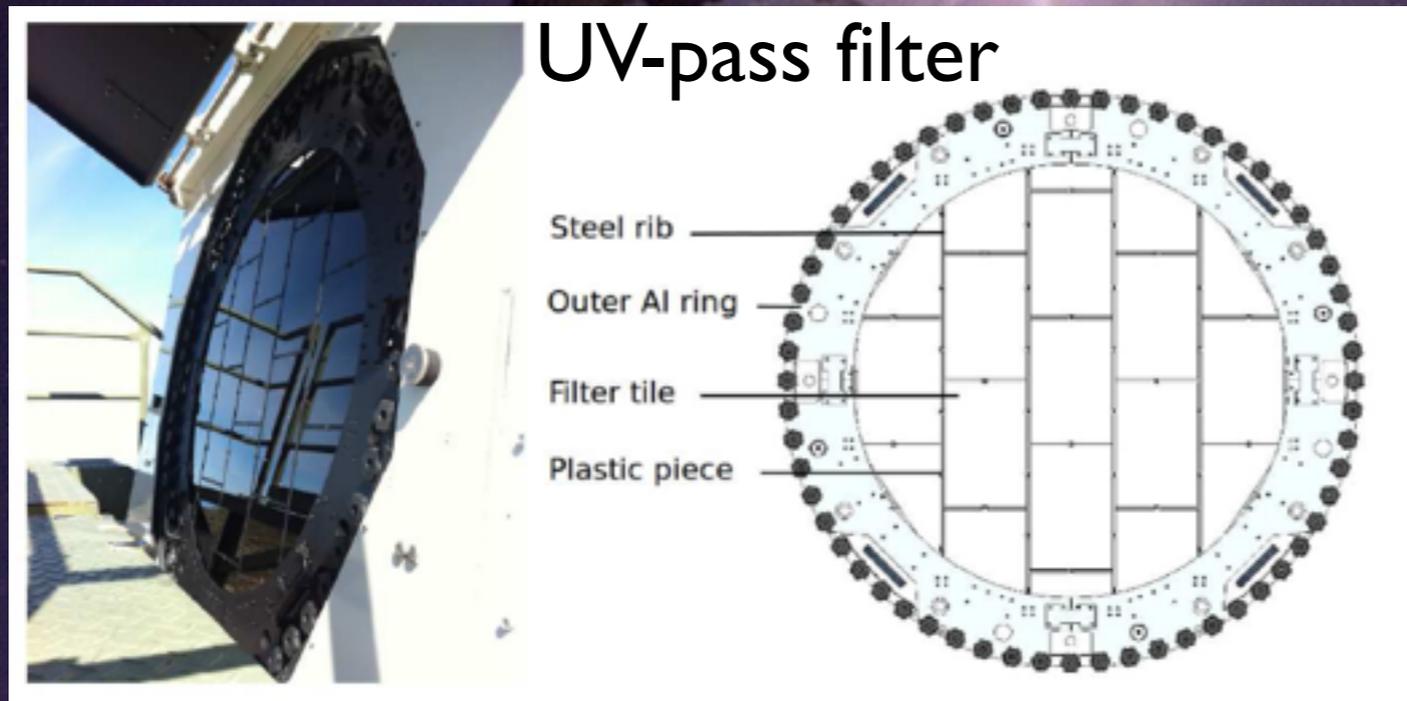


- ★ MAGIC-I in operation since 2004, MAGIC-II (stereo mode) since 2009
- ★ 170 scientists from 10 countries across Europe & Asia
- ★ Camera FoV:  $3.5^\circ$  (LV PMT)
- ★ Energy range:  $\sim 50$  GeV (30 GeV with  $\Sigma$  -Trigger) - 50 TeV  $\Rightarrow$  low E threshold perfect for distant sources
- ★ Mirrors:  $2 \times 240\text{m}^2$  ( $d = 17\text{m}$ )
- ★ 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

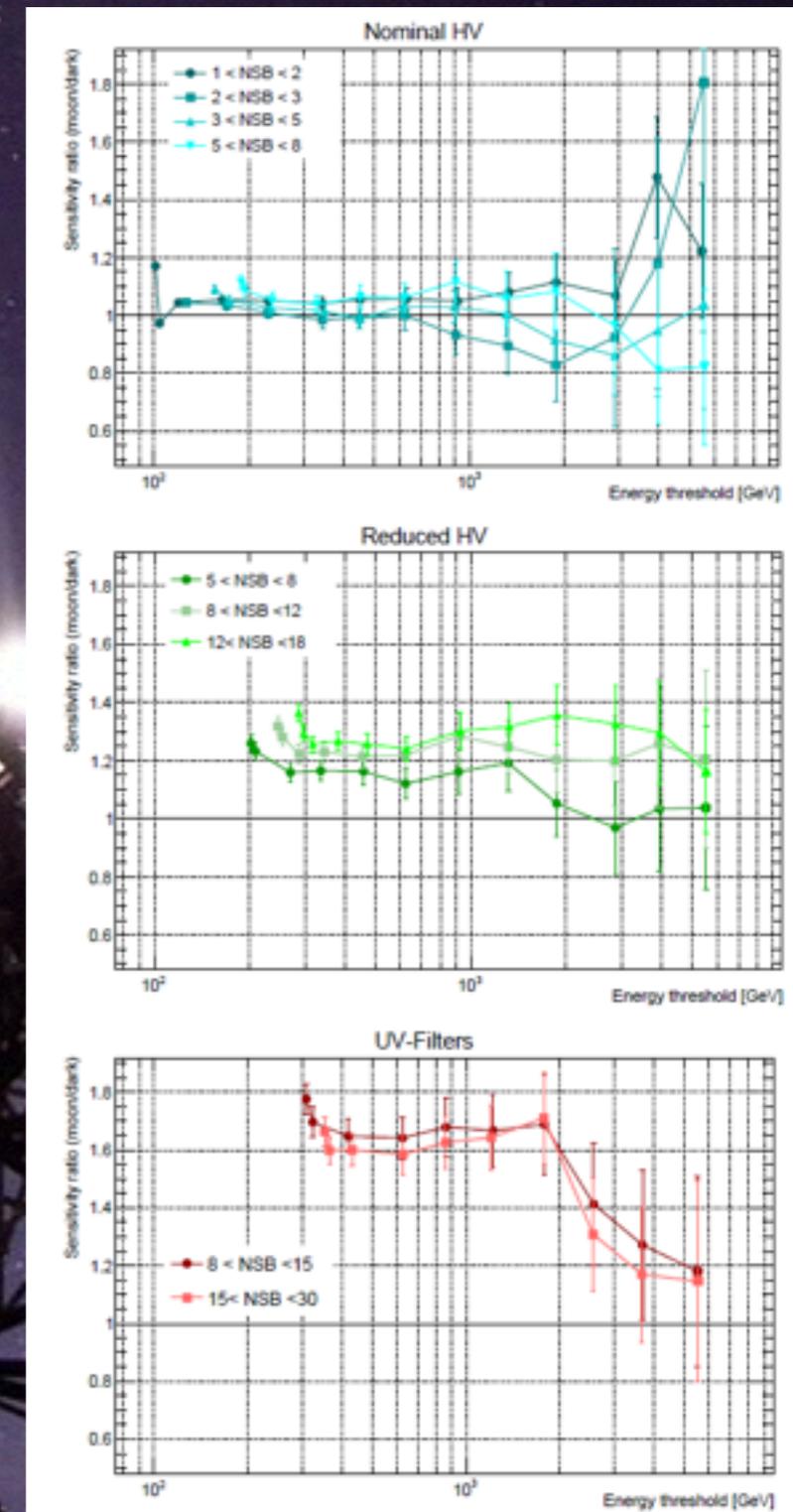


MAGIC Coll., submitted to Astropart. Phys. 2017, arXiv: 1704.00906



UV-pass filter

- ★ Camera: FoV:  $3.5^\circ$ , adapted to operations with moonlight (LV PMTs):
  - ★ Nominal settings:  $1-8 \times \text{NSB}_{\text{dark}}$
  - ★ Reduced HV:  $5-18 \times \text{NSB}_{\text{dark}}$
  - ★ UV-pass filters:  $8-30 \times \text{NSB}_{\text{dark}}$
- ★ 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-pass filters
- can recover Crab Nebula spectrum as for dark nights
- ★ Energy threshold  $\sim (\text{NSB}/\text{NSB}_{\text{dark}})^{0.4}$
- ★ Sensitivity degradation  $< 10\%$  for nominal HV settings and up to  $8 \times \text{NSB}_{\text{dark}}$
- ★ No significant worsening of the angular resolution was observed  $> 300 \text{ GeV}$



# 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...*

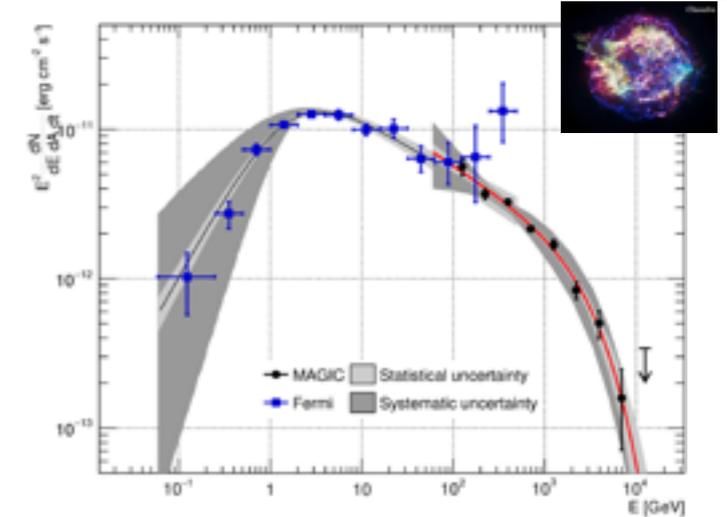
## Transients & MM

*follow-up of GRBs, FRBs,*  
*GWs, neutrino events...*

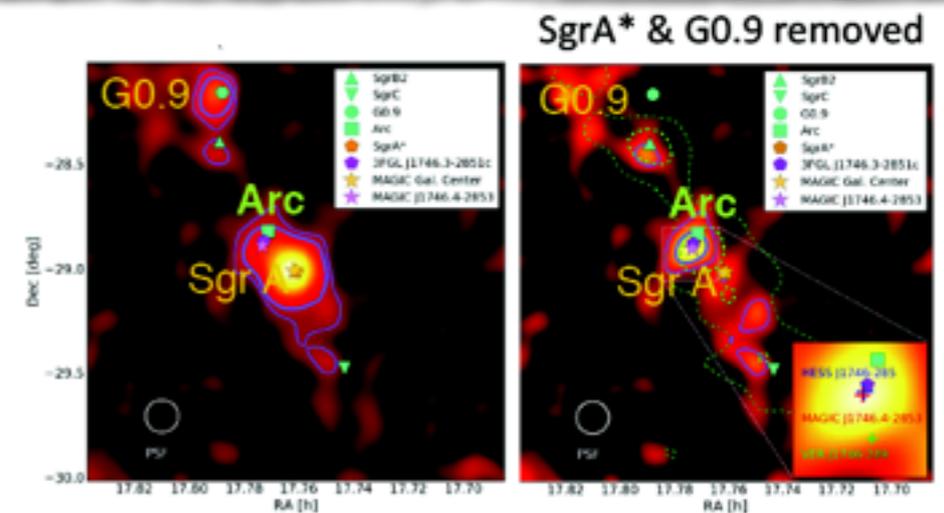
# Galactic sources - teaser :)



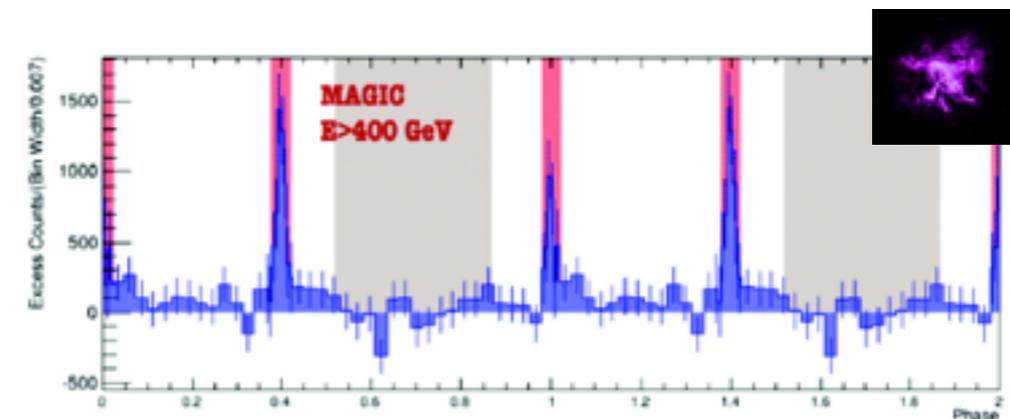
**SNR: Cas A**, Emma de Oña Wilhelmi  
Mon @ 14:45 Gamma-ray session  
160 h of data + 8 yrs Fermi/LAT  
Final answer to the PeVatron question!



**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  $E^2 = p^2 + m^2 + f(p; \xi / M_{Pl})$

➔ energy-dependent shift in pulsar phase 
$$\Delta\phi = \frac{d_{Crab}}{c P_{Crab}} \cdot \xi_n \frac{n+1}{2} \frac{E_h^n - E_l^n}{E_{QG_n}^n}$$

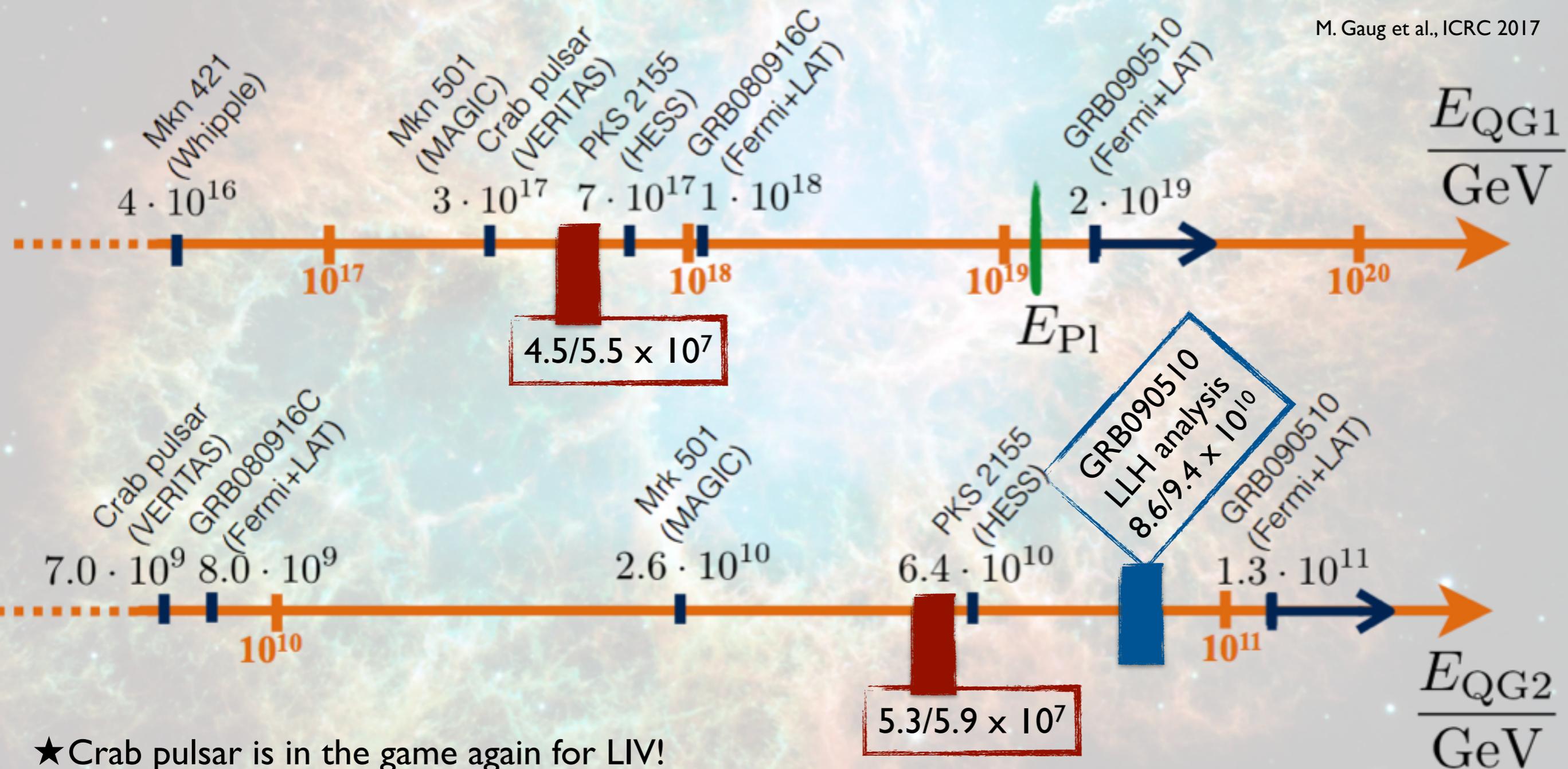
n=1: linear case  $\xi=1$ : subluminal (slower than c)

n=2: quadratic case  $\xi=-1$ : superluminal (faster than c) → more interesting for pulsars > 100 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

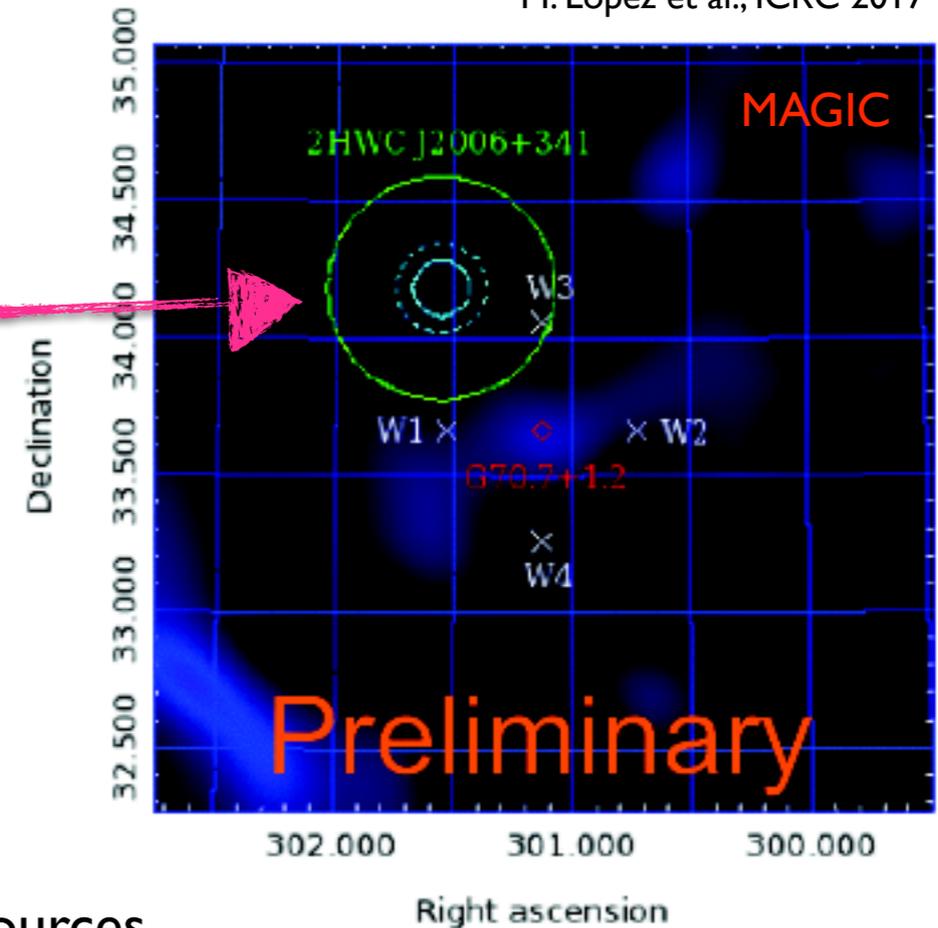
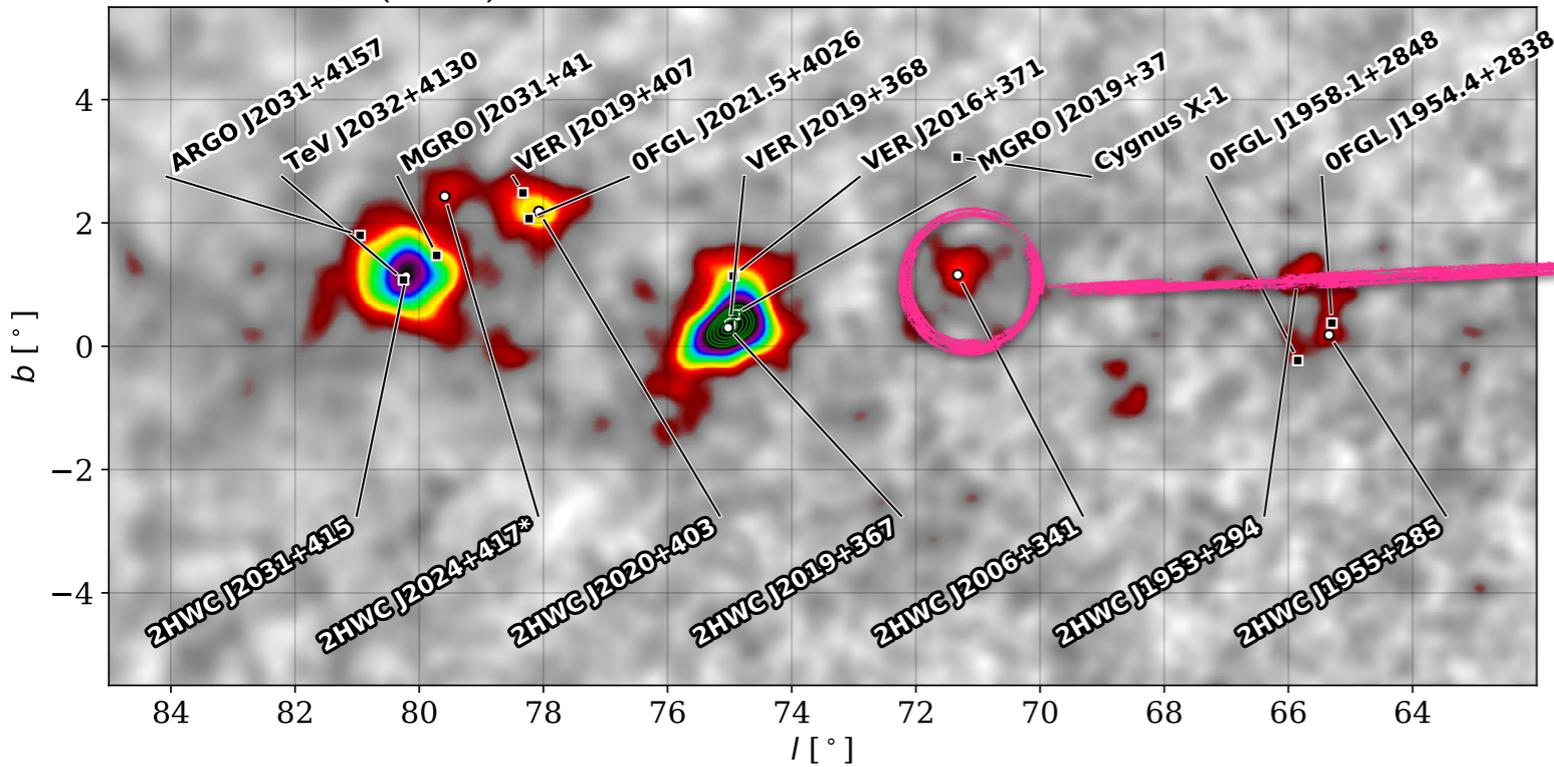


- ★ Crab pulsar is in the game again for LIV!
- ★ Pulsars case more interesting for quadratic term  $E_{QG2}$  limits
- ★ With current data, MAGIC set almost world-best limits on  $E_{QG2}$  (including systematics  $\sim 30\%$ )
- ★ Future analyses (combinations of likelihood + new data) will reveal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

# HAWC follow-up

M. Lopez et al., ICRC 2017

HAWC Coll. (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 ( $< 1.5^\circ$ ) of former MAGIC observations (MAGIC archival data)
- ★ Re-analysis of these MAGIC data looking for point-like ( $0.10^\circ$ ) or slightly extended ( $0.16^\circ$ ) emission

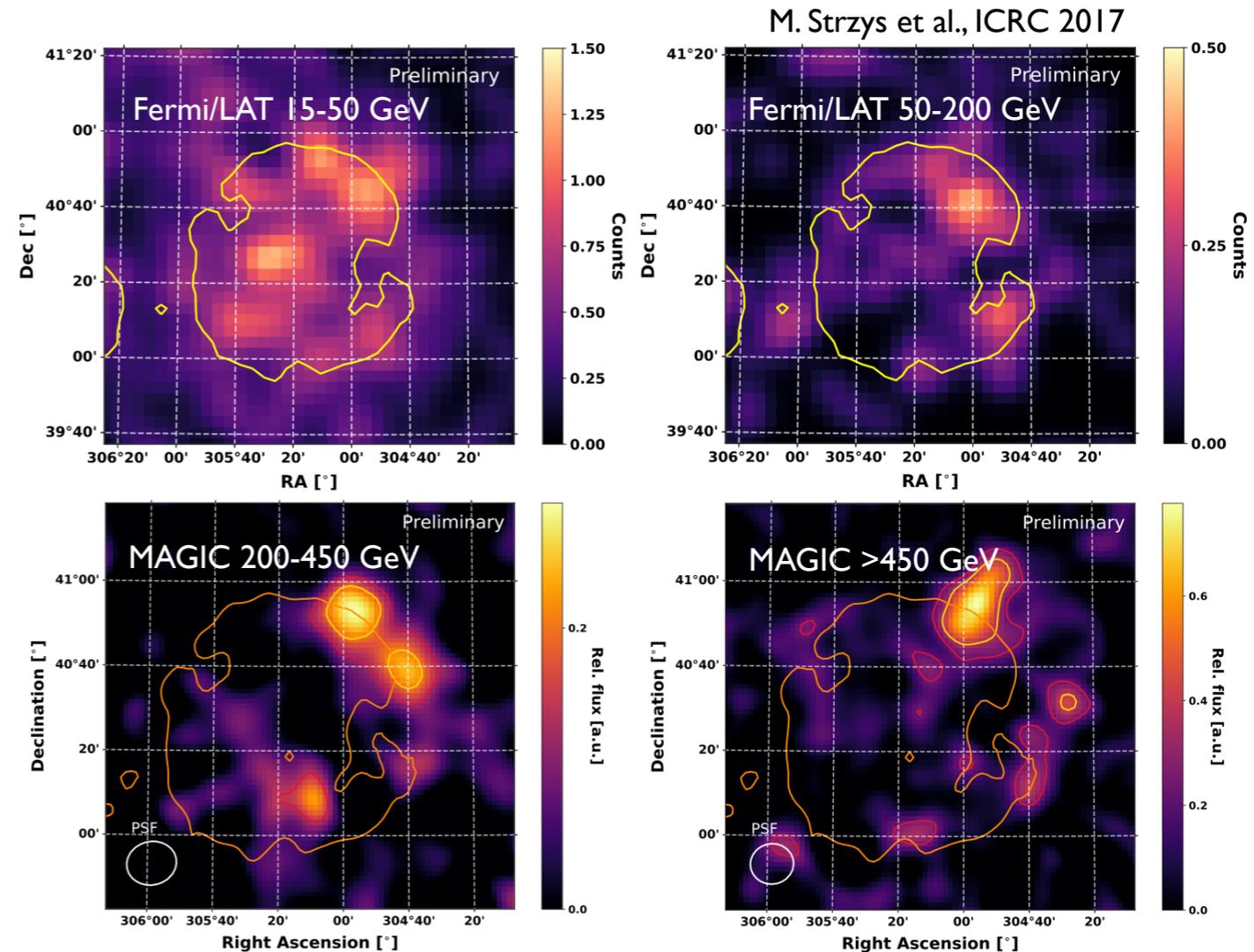
→ No signal found

HAWC source	Tobs [h]
2HWC J2006+341	61
2HWC J1907+084	4
2HWC J1852+013	120

# Gamma-Cygni SNR



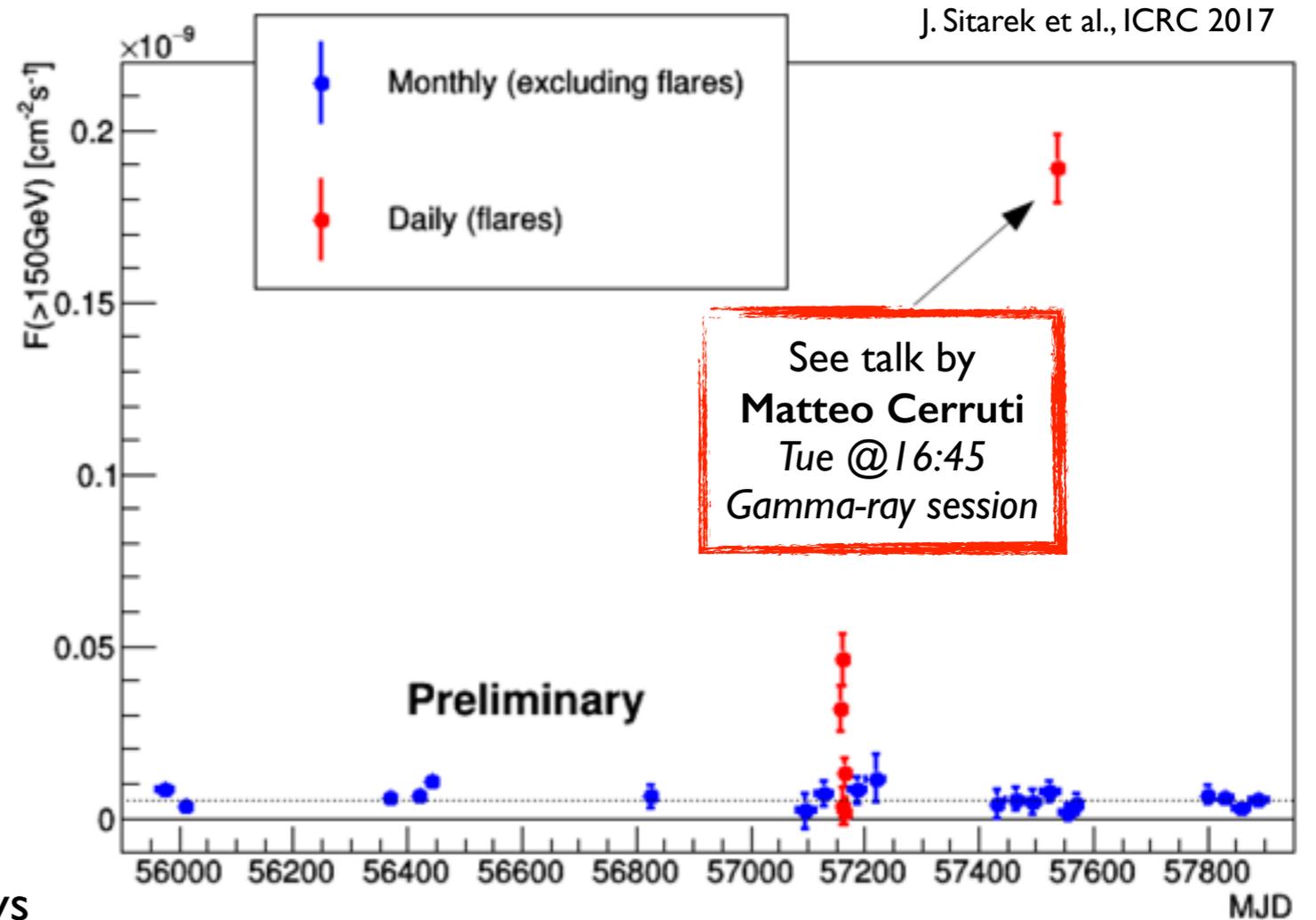
- ★ SNR: Gamma Cygni (G78.2+2.1) ~7000yrs (middle-aged) → unique laboratory to study early Sedov phase SNR
- ★ hosts the pulsar PSR J2021+4026 (the only known variable  $\gamma$ -ray pulsar)
- ★ VERITAS and Fermi-LAT: complex, energy-dependent morphology in GeV-TeV, different from X-rays
- ★ MAGIC collected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

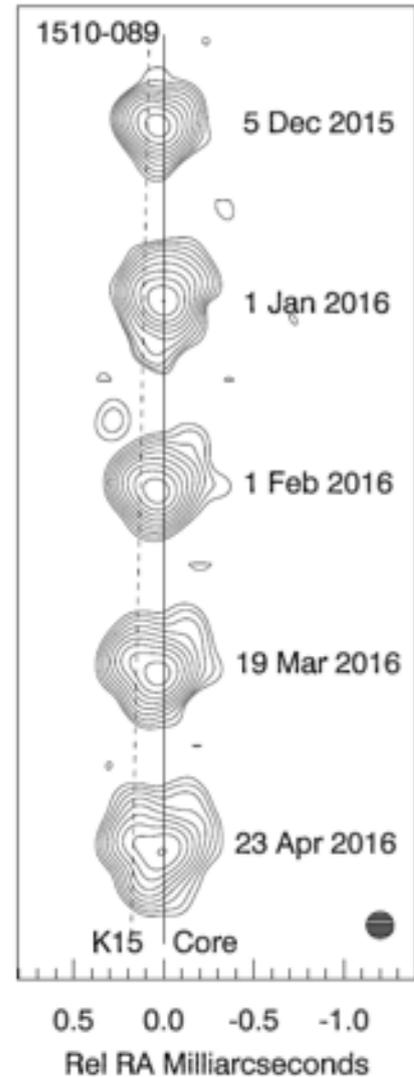
# PKS 1510-089 flares



- ★ 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  $720^\circ$ ) 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

# PKS 1510-089 2015 flare

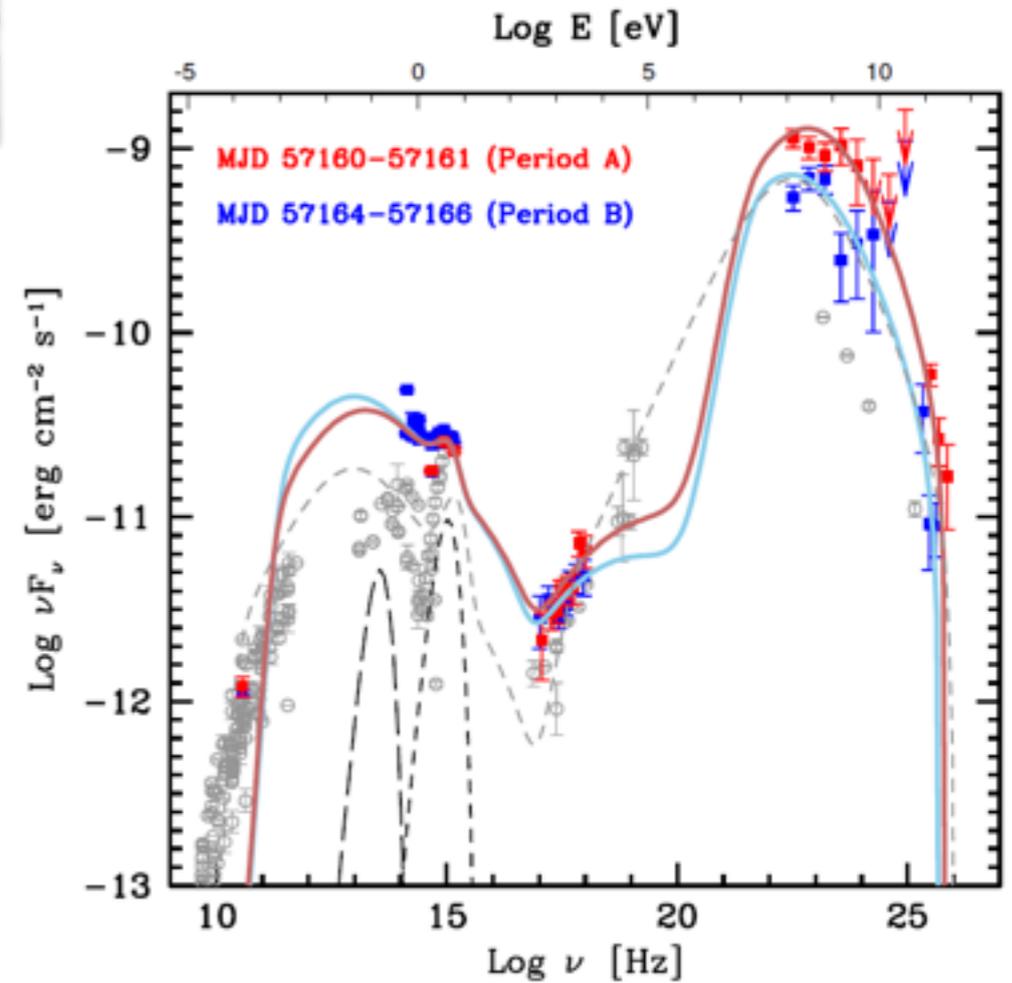
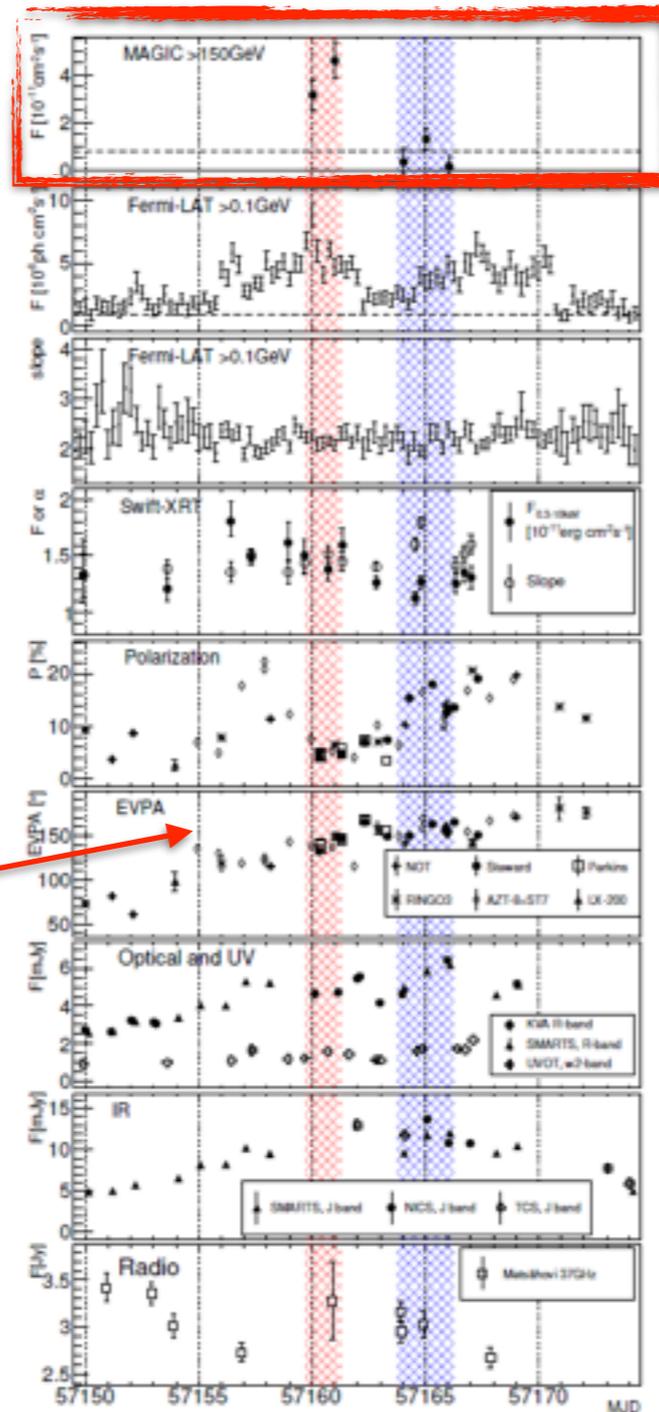
J. Sitarek et al., ICRC 2017



Radio: new jet component, moving in unusual direction.

Zero separation epoch  $\sim$  May 2015 high state.

smooth rotation of EVPA by  $\sim 100^\circ$



- ★ 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

★ VHE g-ray flux  $\sim 4$  x brighter than in 2009 & 2012

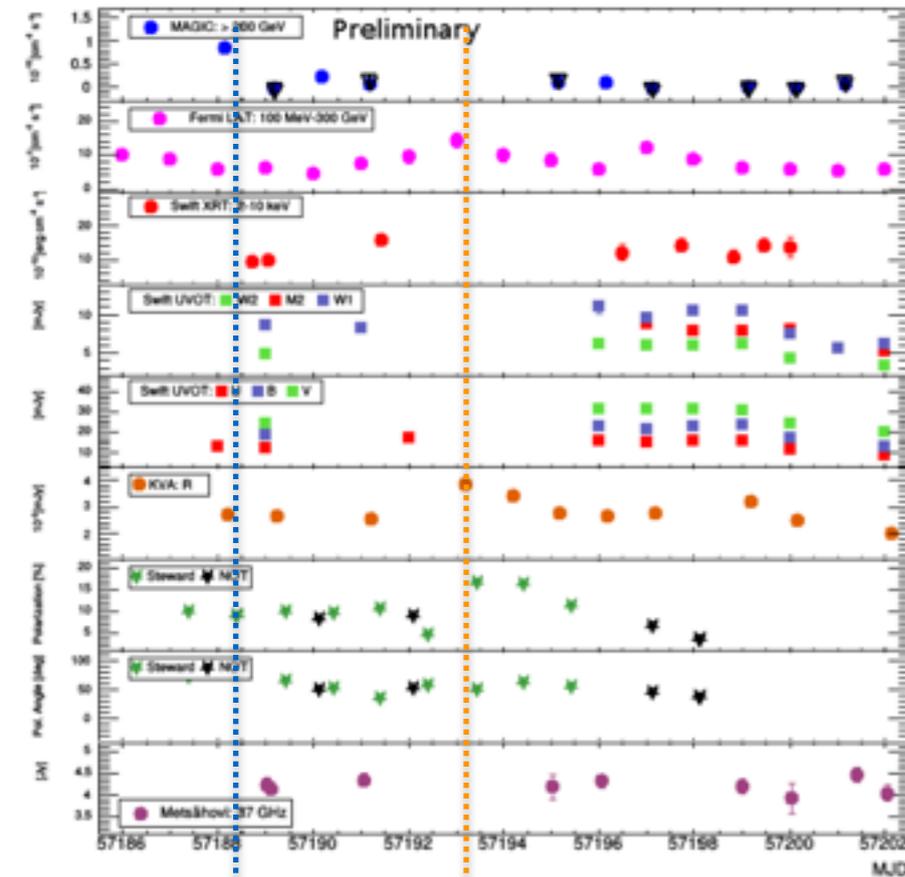
★ Similar spectral shape (intrinsic slope:  $3.2 \pm 0.8$ )

★ Similar situation to that of 2012 (MAGIC discovery): VHE g-rays + EVPA rotation + new radio component

# BL Lac 2015 flare

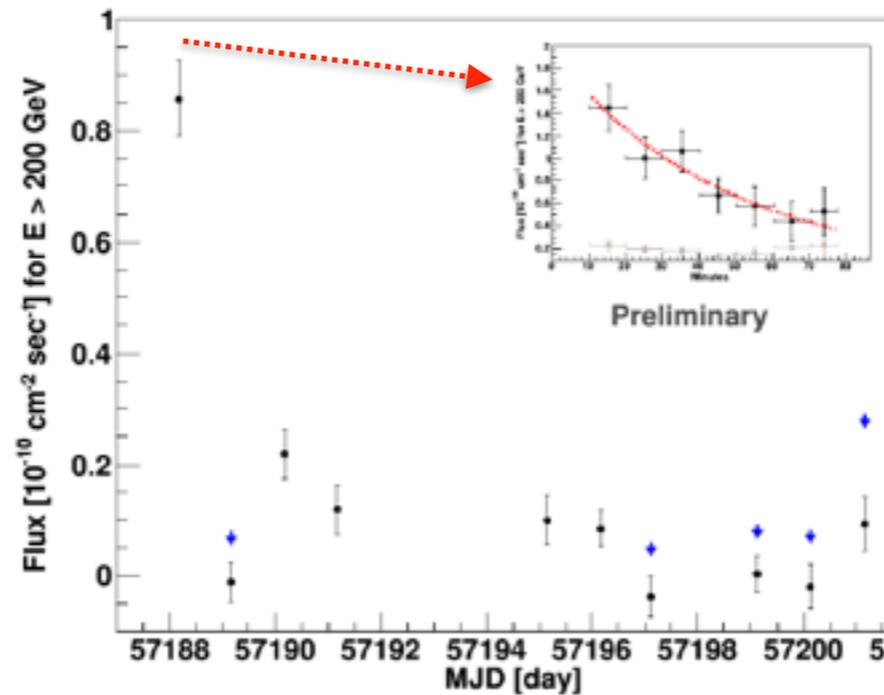
S. Tsujimoto et al., ICRC 2017

- ★ 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

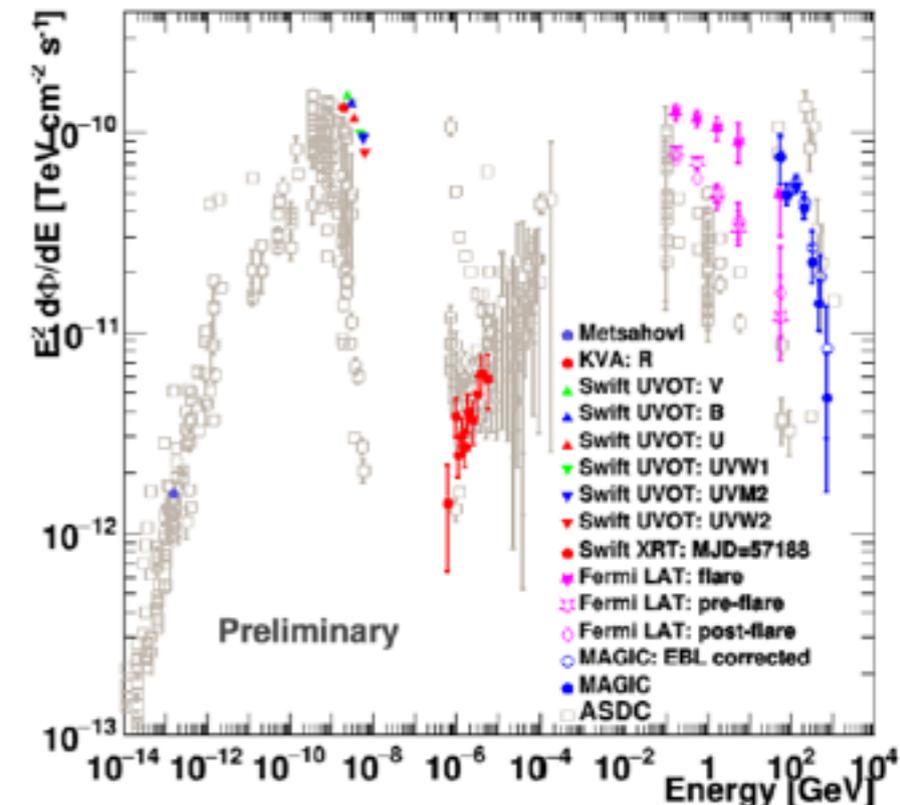


No simultaneous increase measured in other wavelengths  
 → “TeV orphan flare”?

Simultaneous increase of HE g-rays (Fermi) and optical flux → correlation? same emitting region?



Fast variability in VHE g-rays, with halving time  $\sim 33 \pm 9$  min → small emission region  $\sim 10^{13}$  d cm

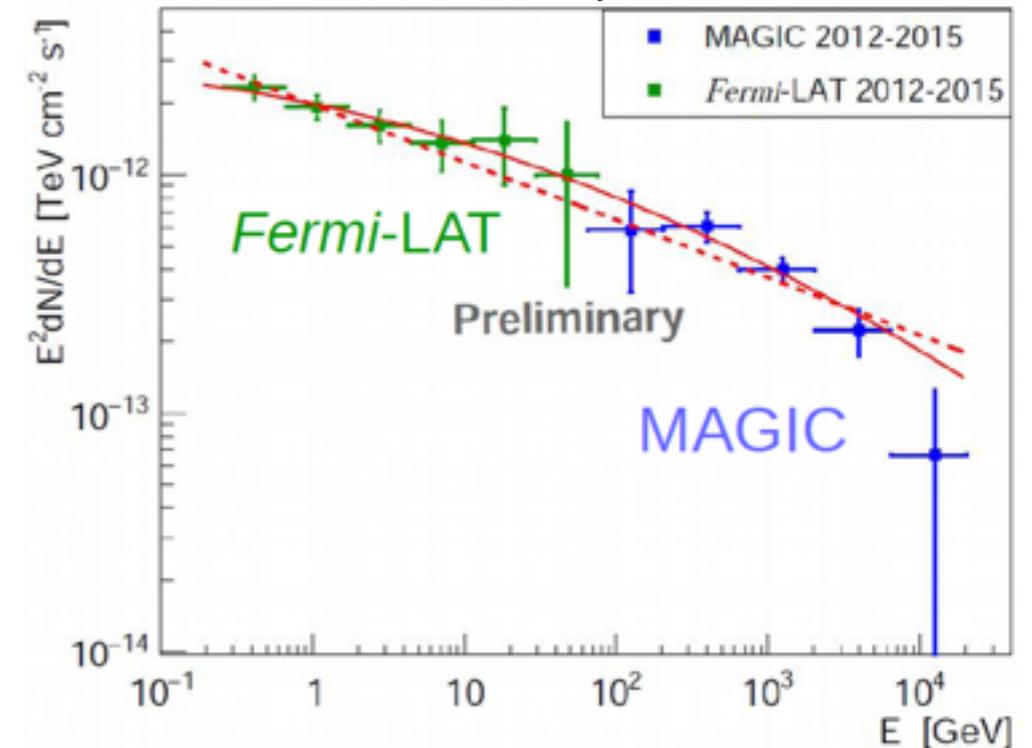
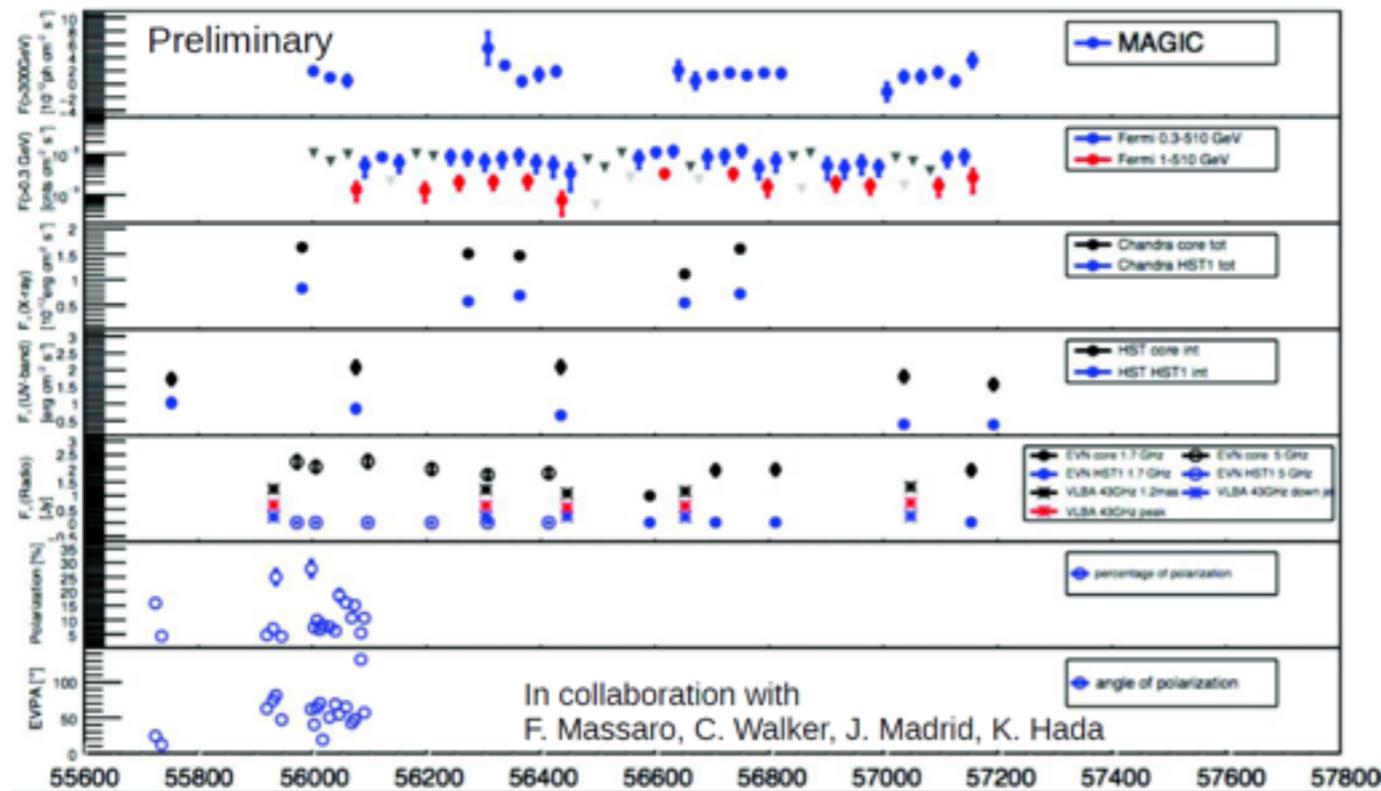


SED with broad IC peak, but w/o large Compton dominance  
 → additional VHE component, intermediate state between BL Lac and FSRQ?

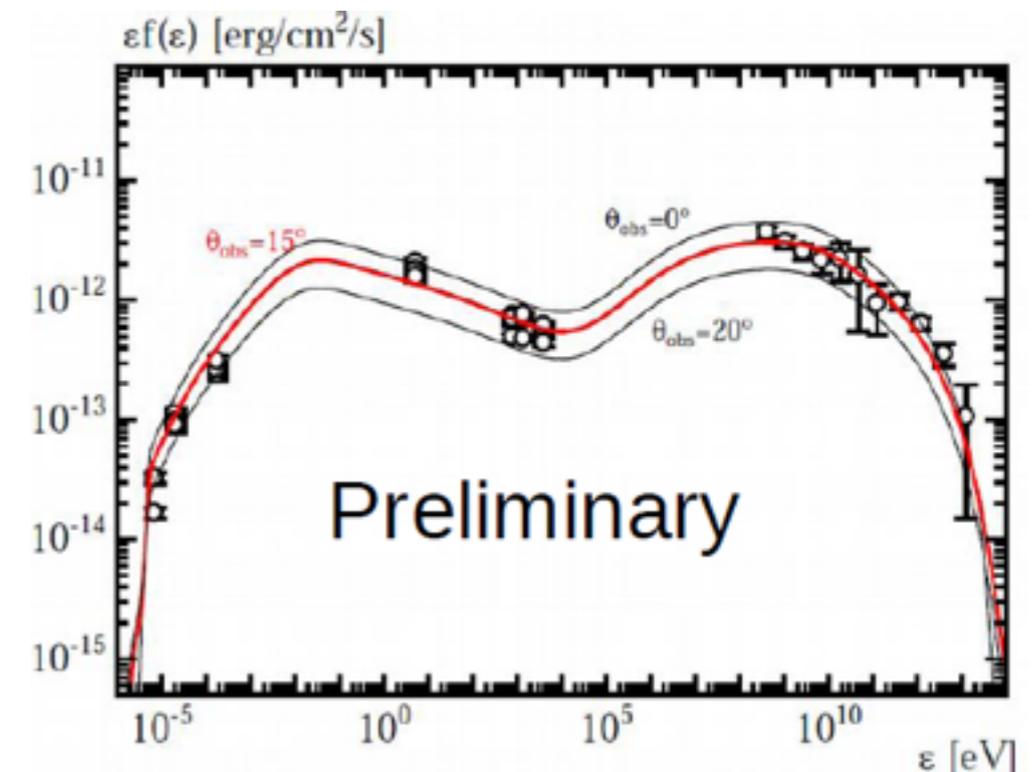
# Monitoring of radio galaxies - M87



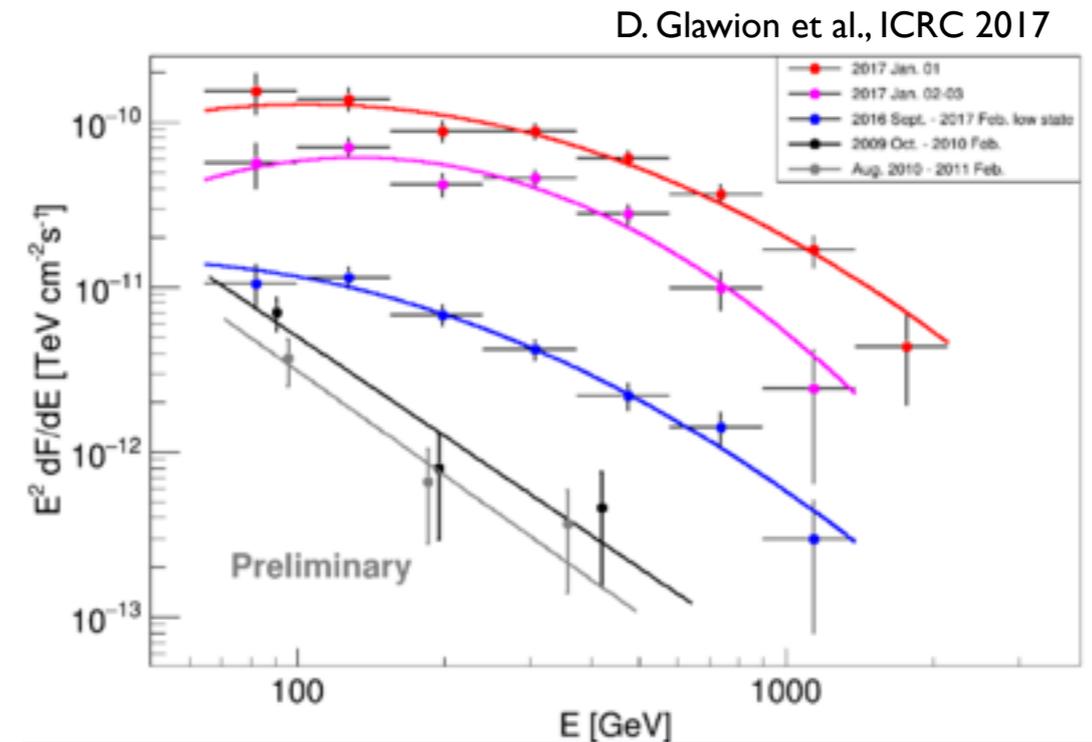
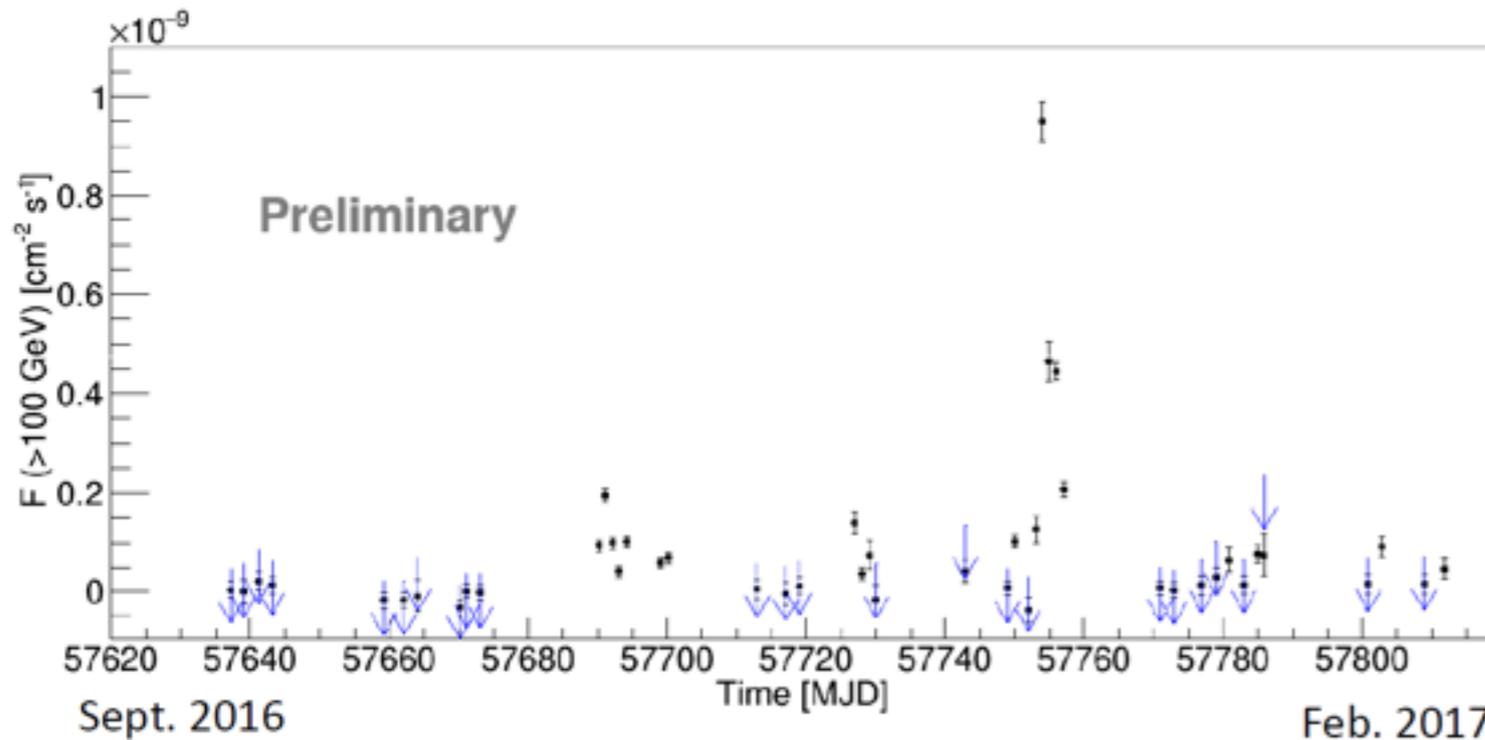
J. Sitarek et al., ICRC 2017



- ★ 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 - NGC 1725



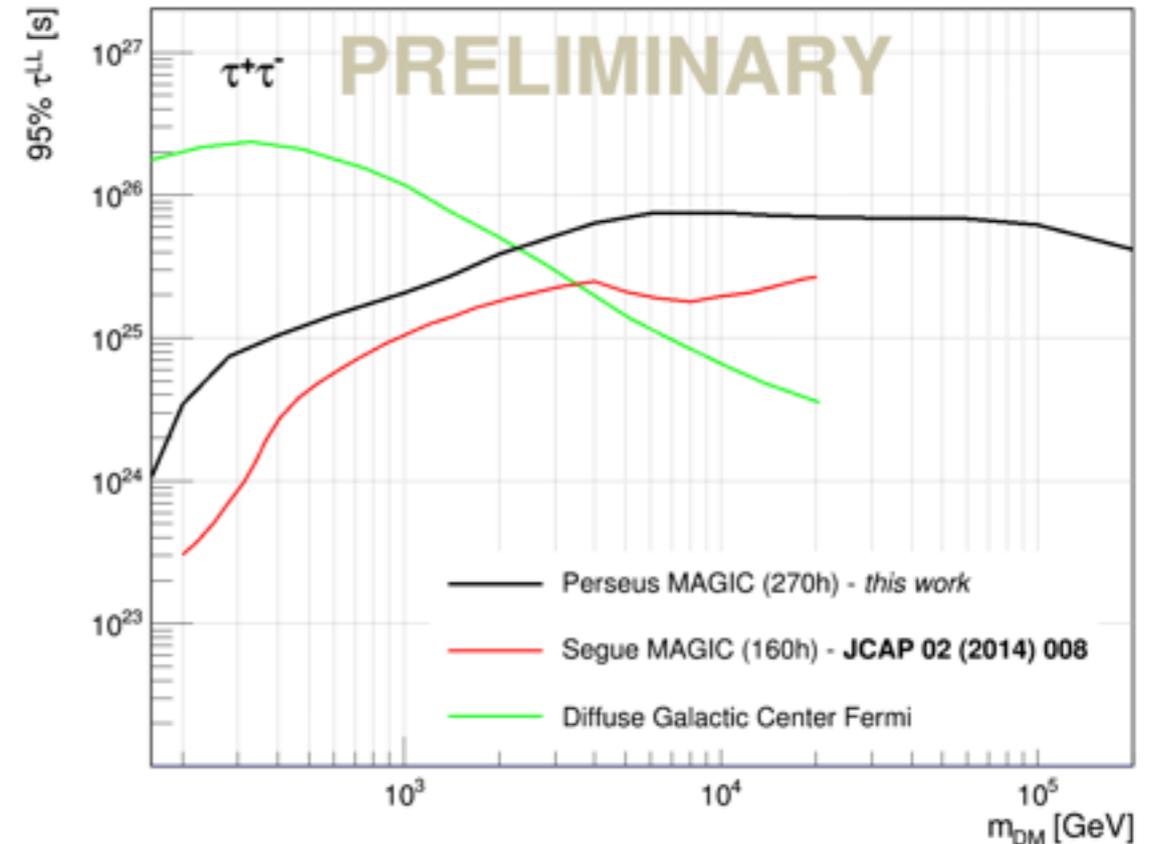
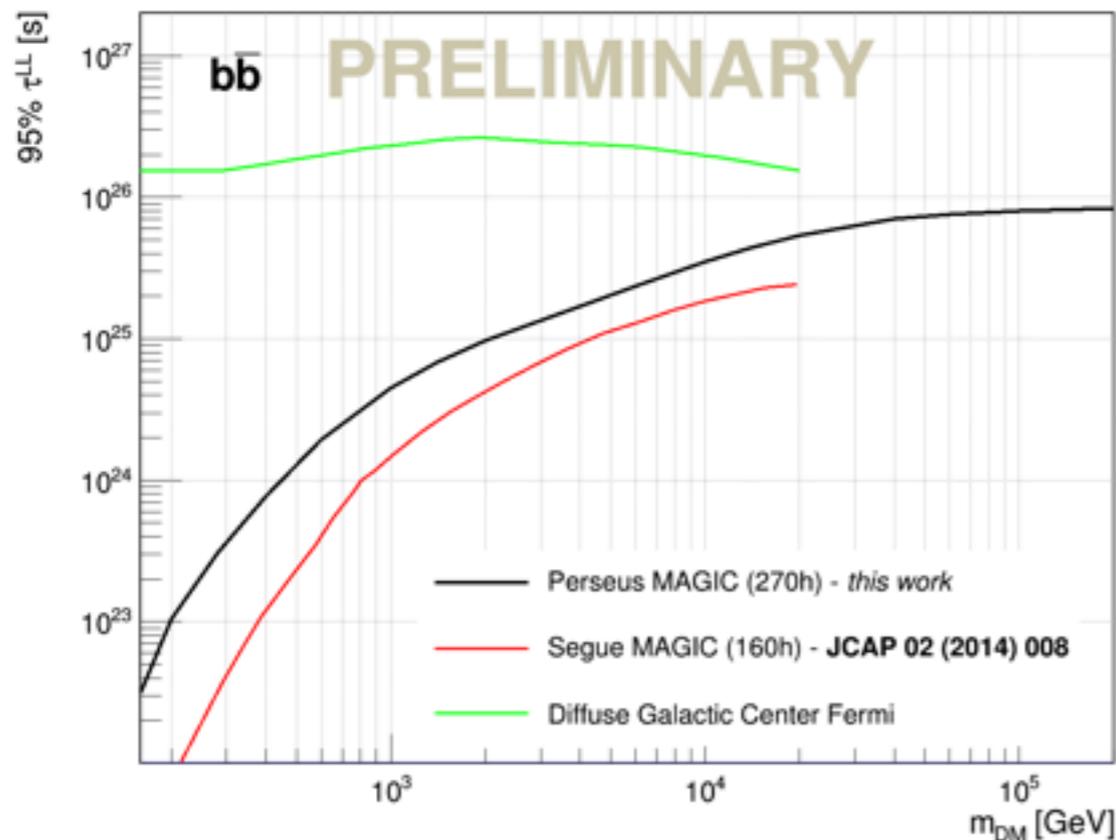
D. Glawion et al., ICRC 2017

- ★ 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  $611 \pm 101$  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  $\sim 500$  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  $\theta < 9-16$ , in tension with previous measurements

# Perseus Cluster - DM search

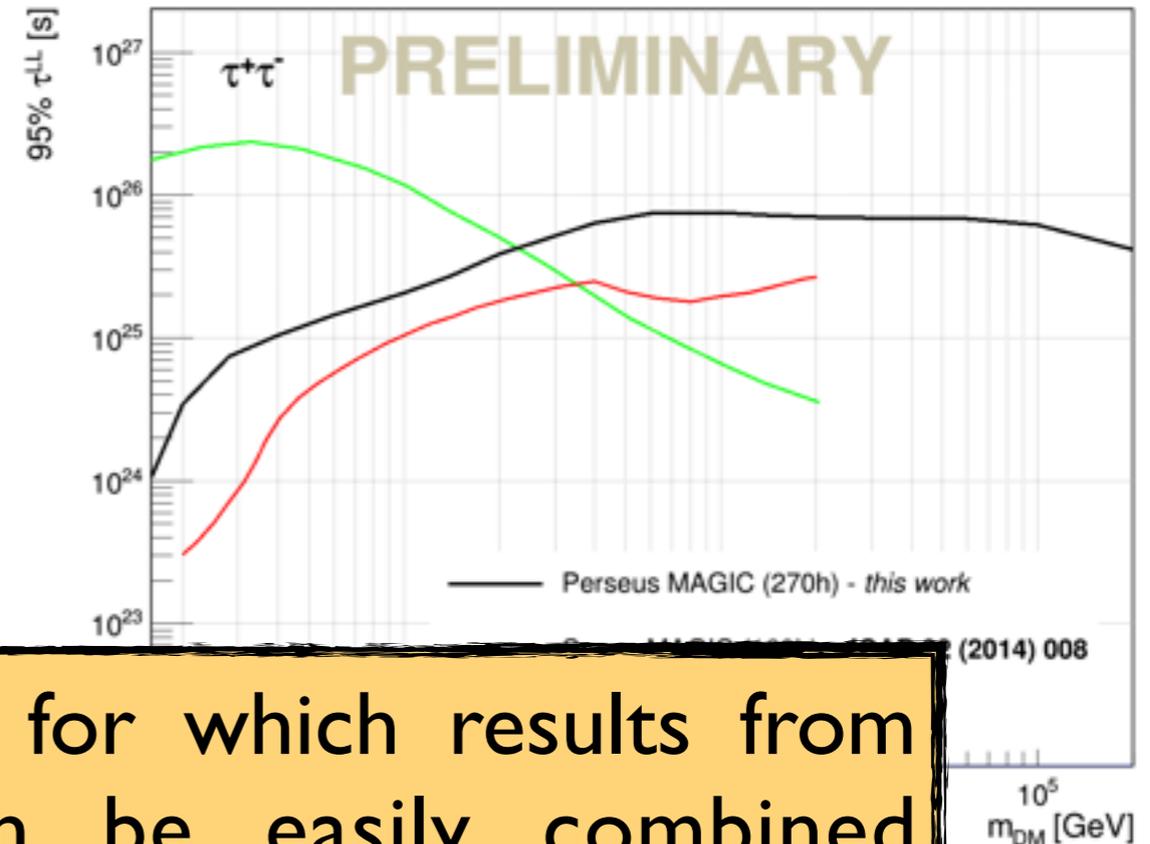
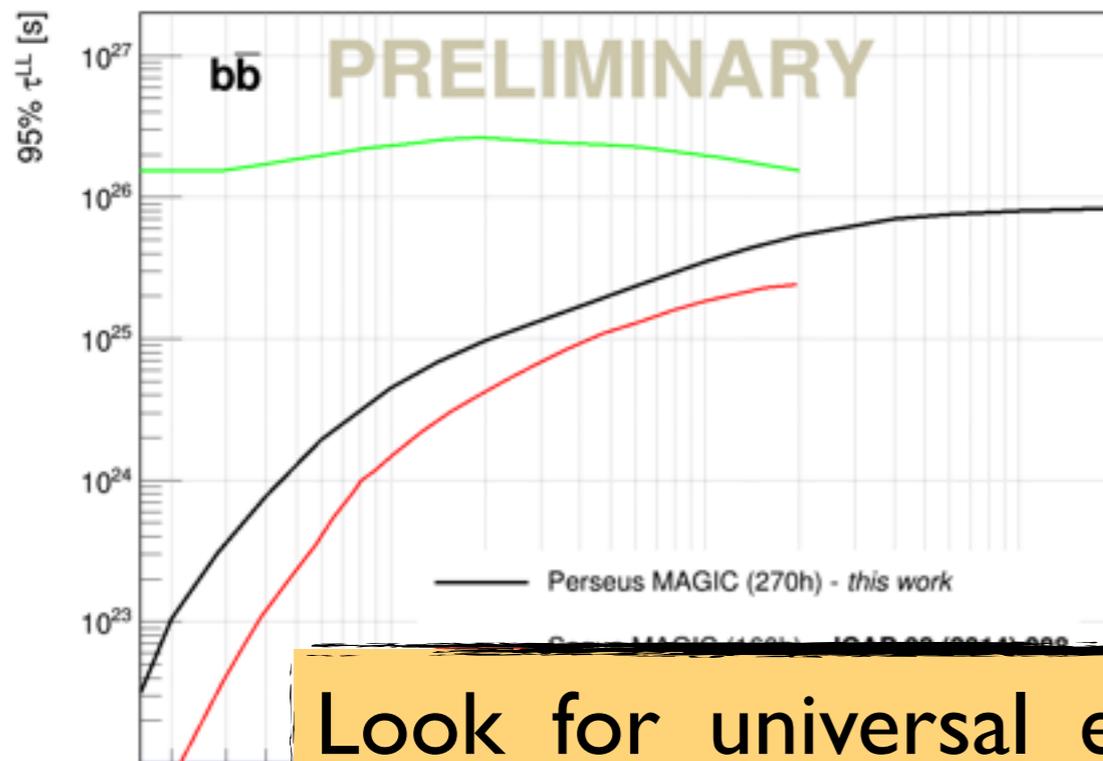


Q. Palacio et al., ICRC 2017



- ★ 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 life times of  $8 \times 10^{25}$  seconds for both channels ( $\sim 10$  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



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!

- ★ Galaxy cluster
- ★ Perseus: 8
- ★ MAGIC d

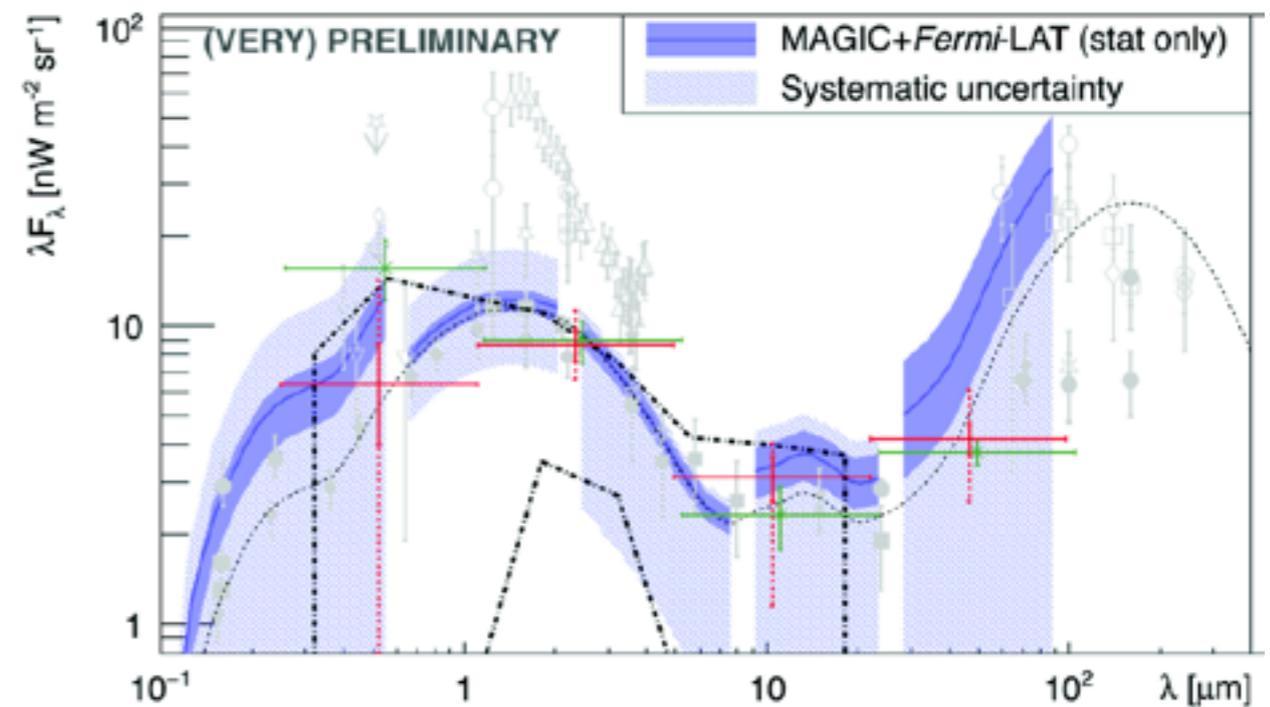
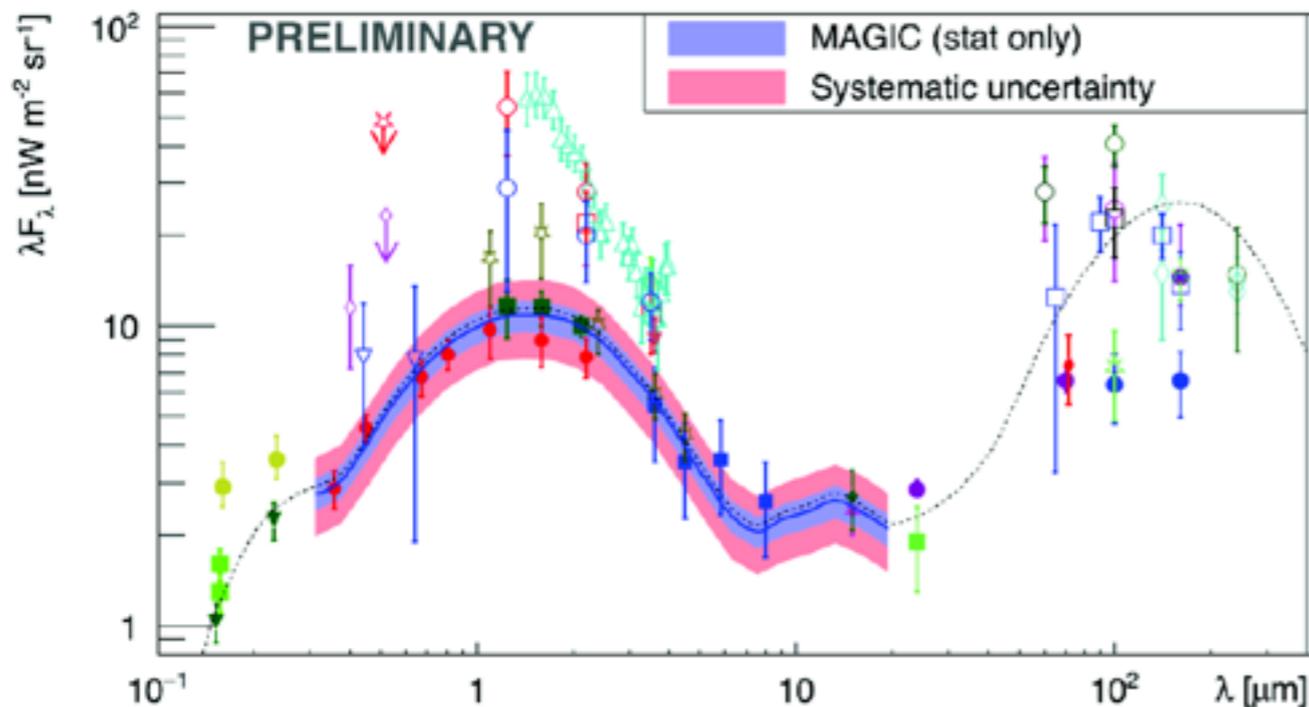
★ We find no evidence of dark matter decay

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★ 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

# EBL studies - teaser :)

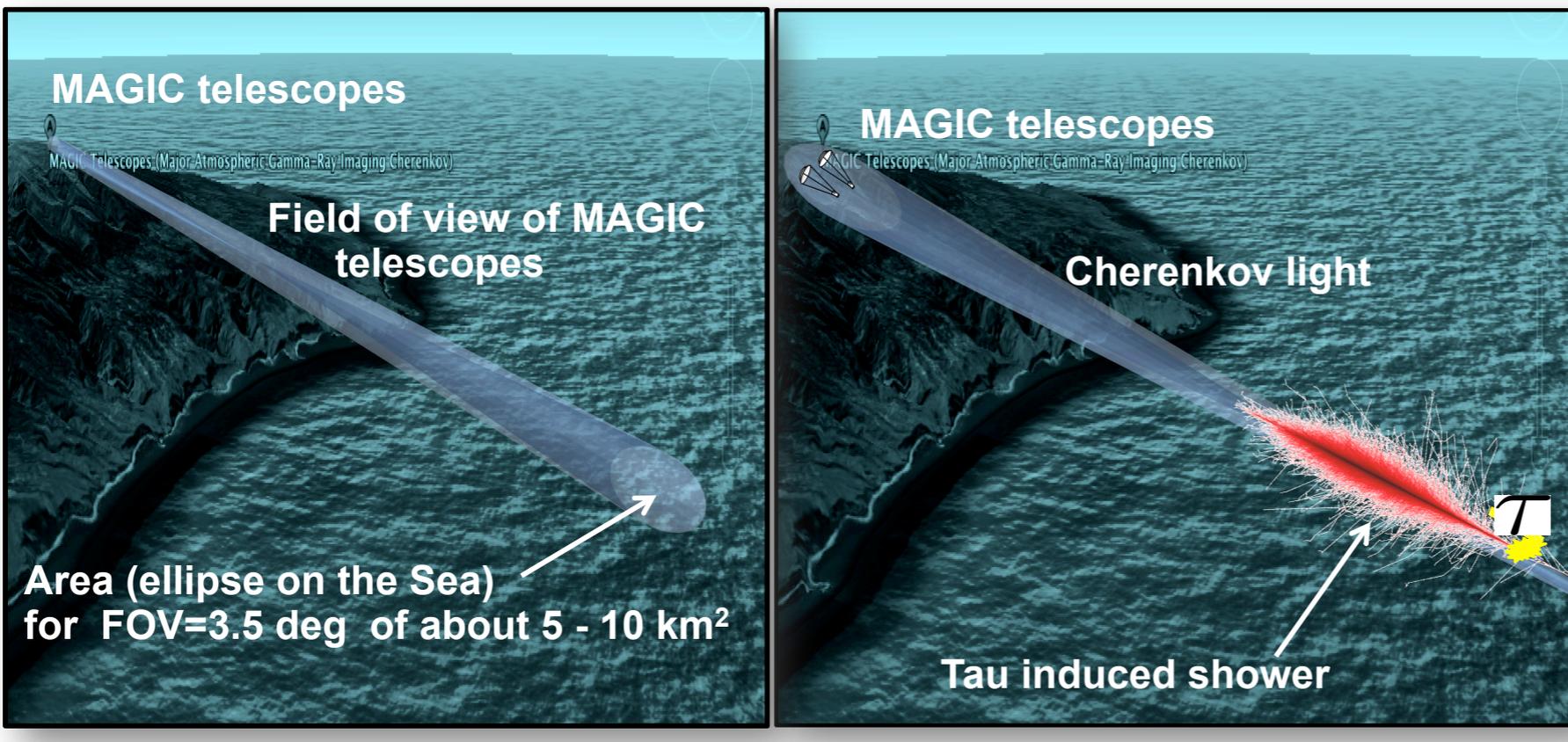


- ★ 32 highly significant spectra from 12 blazars in  $z = 0.030$  to  $0.944$
- ★ 316 h of stereoscopic observations over 7 years (2010 – 2016)
- ★ contemporaneous Fermi-LAT data
- ★ overall calling and wavelength-resolved scaling tested

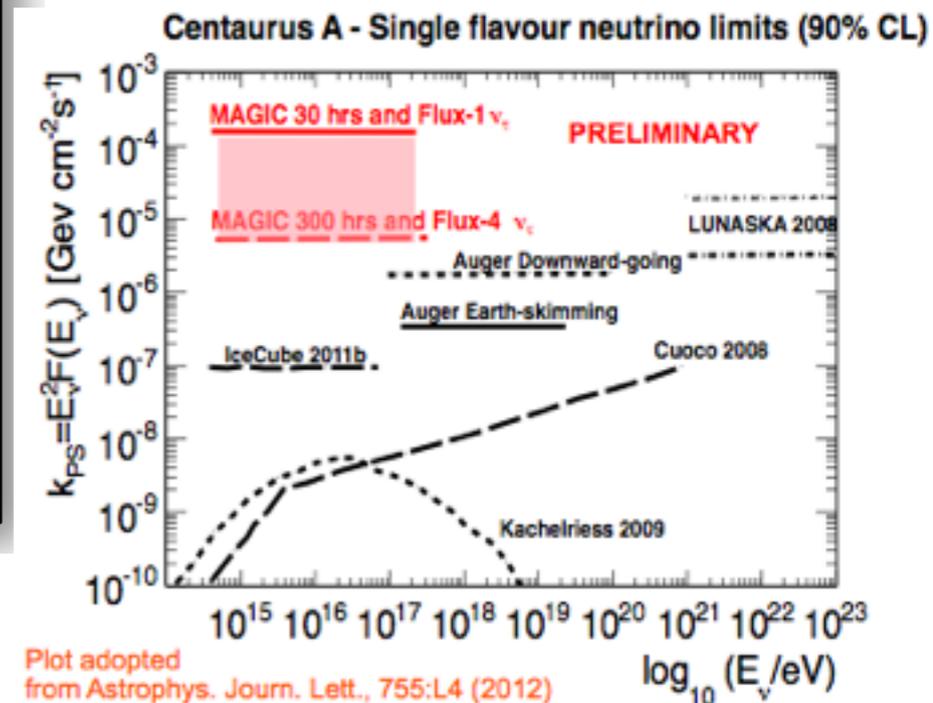
→ learn more from **Gaia Vanzo's talk, Wed @ 14:00, Gamma-ray session**



# MAGIC as neutrino detector

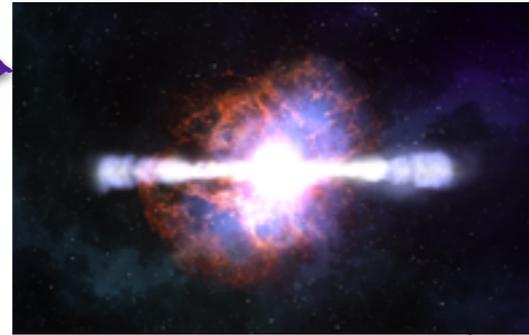
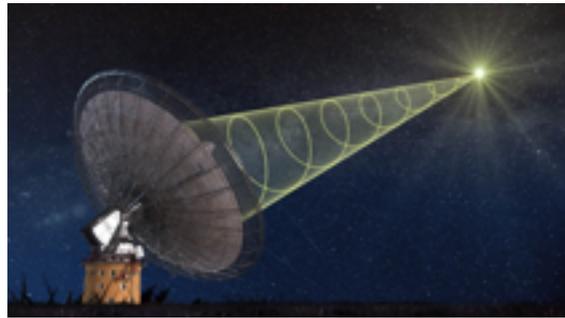


D.Gòra et al., EPS-HEP 2017

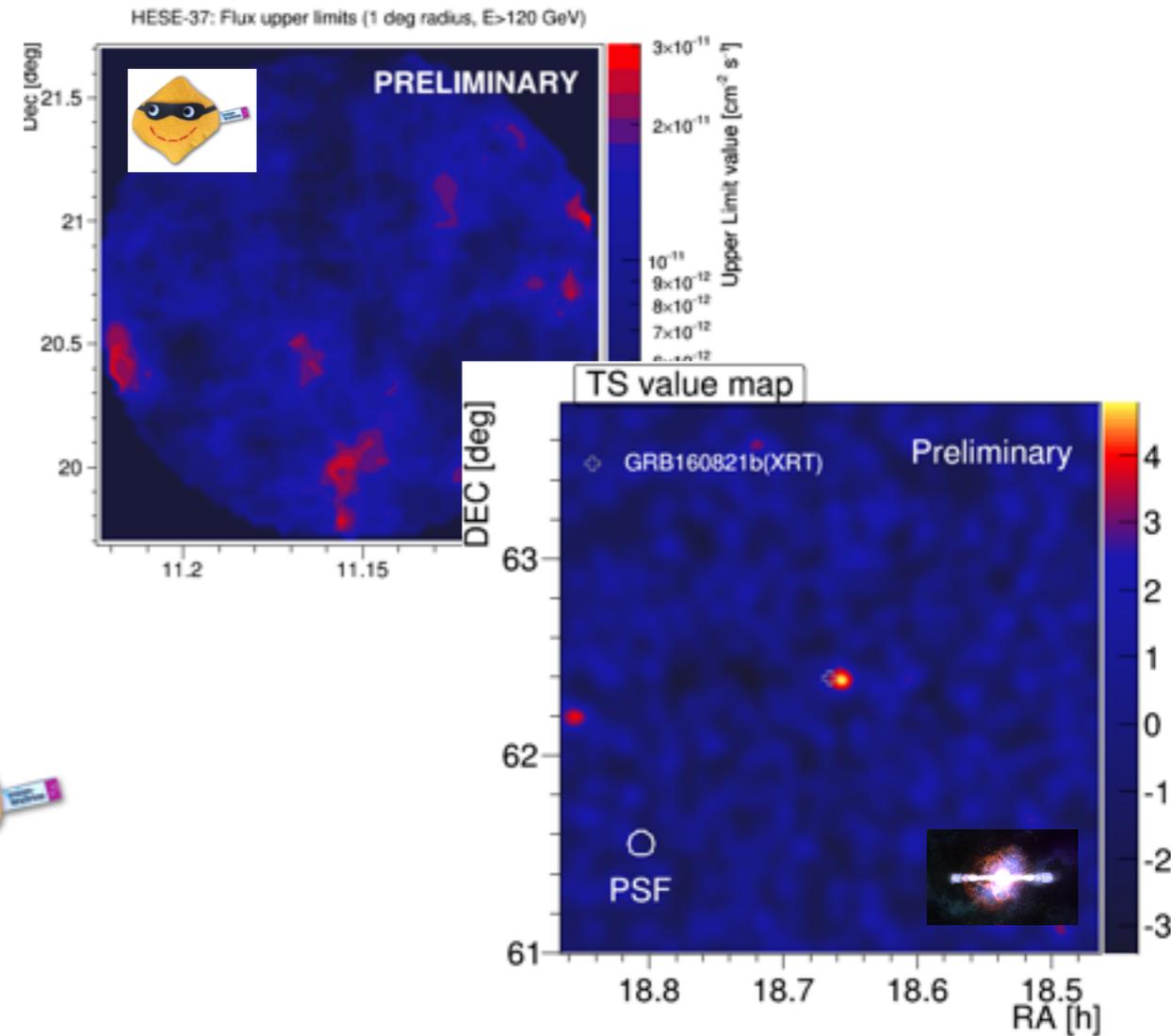


- ★ Neutrinos start to be absorbed by Earth  $\sim 50$  TeV
  - look for Earth skimming tau neutrinos  $\sim$ PeV energies
- ★ tau neutrinos **HAVE TO** be astrophysical (only mu & e produced in source + oscillations)
- ★ CR background shielded by the Earth/rock (background-free search!)
- ★ Feasibility studies with MAGIC on-going (40h collected)
- ★ For most optimistic fluxes (GRB & AGN flares) ULs  $\sim$  AUGER could be set
- ★ Cheap observation time - can be done with clouds/low atmospheric transmission

# Transients & MM - teaser :)



??????



- ★ 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

# Your science with MAGIC!



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/outsidere/magicop/>

Back-up

