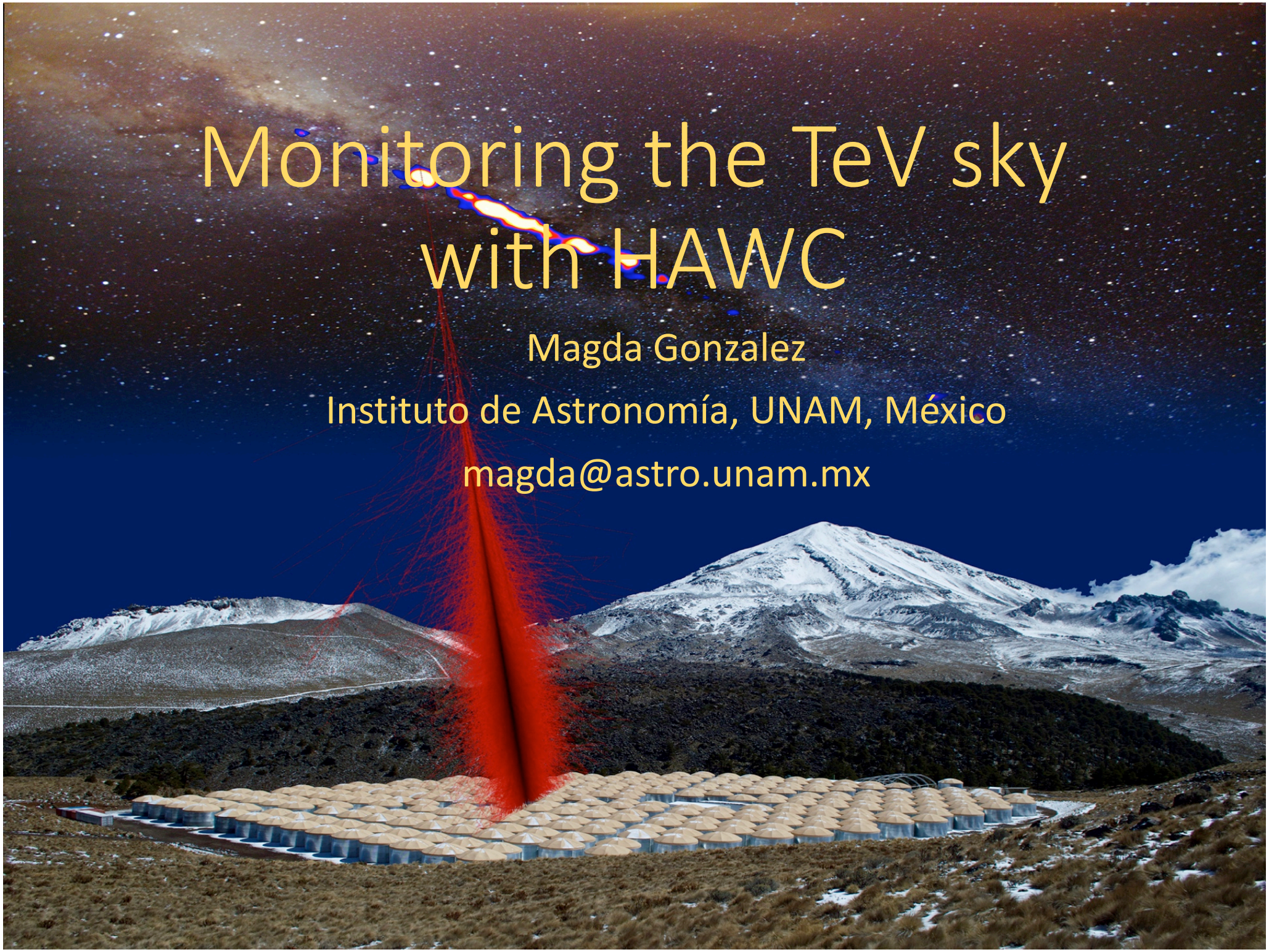
Monitoring the TeV sky with HAWC

Magda Gonzalez

Instituto de Astronomía, UNAM, México

magda@astro.unam.mx



A collaboration between Mexico, USA, Germany, Poland, Italy and Costa Rica

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Mapping the Northern Sky in High-Energy Gamma Rays

HAWC Observatory

HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.

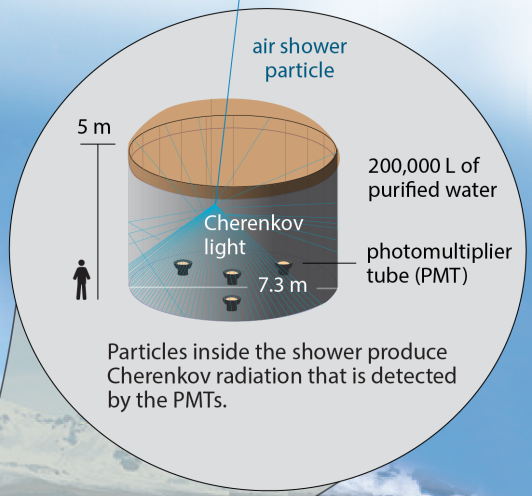
Pico de Orizaba
(5,626 m)

HAWC is located at 4,100 m above sea level, covering an area of 20,000 m^2.

150 m

Water Cherenkov tank

HAWC comprises an array of 300 tanks that record the particles created in gamma-ray and cosmic-ray showers.

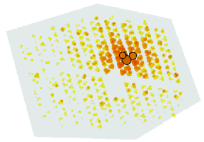


Particles inside the shower produce Cherenkov radiation that is detected by the PMTs.

Gamma rays vs cosmic rays

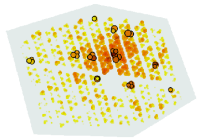
HAWC selects gamma rays from among a much more abundant background of cosmic rays.

gamma-ray shower



"hot" spots concentrate around the core

cosmic-ray shower



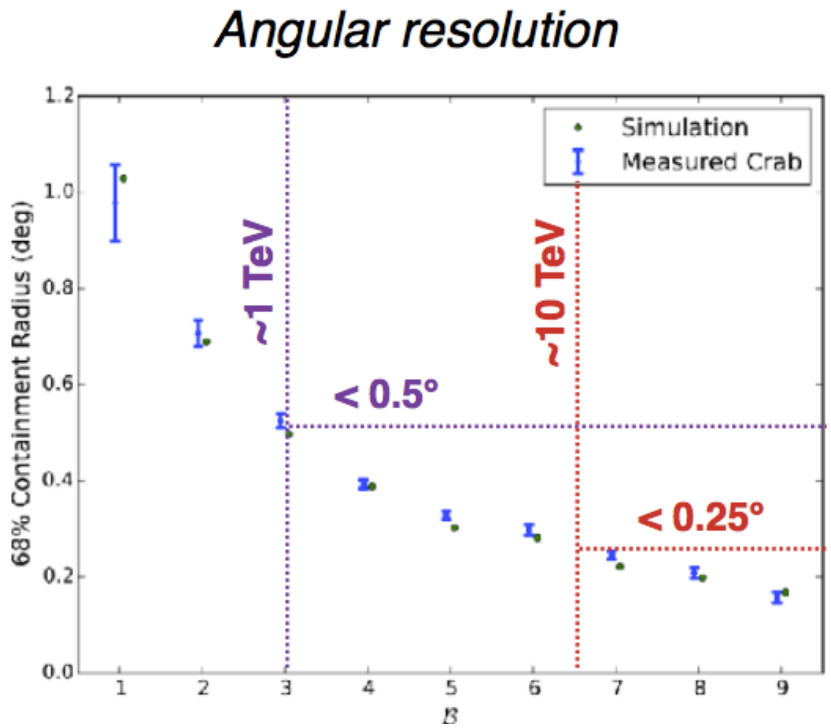
"hot" spots are more dispersed

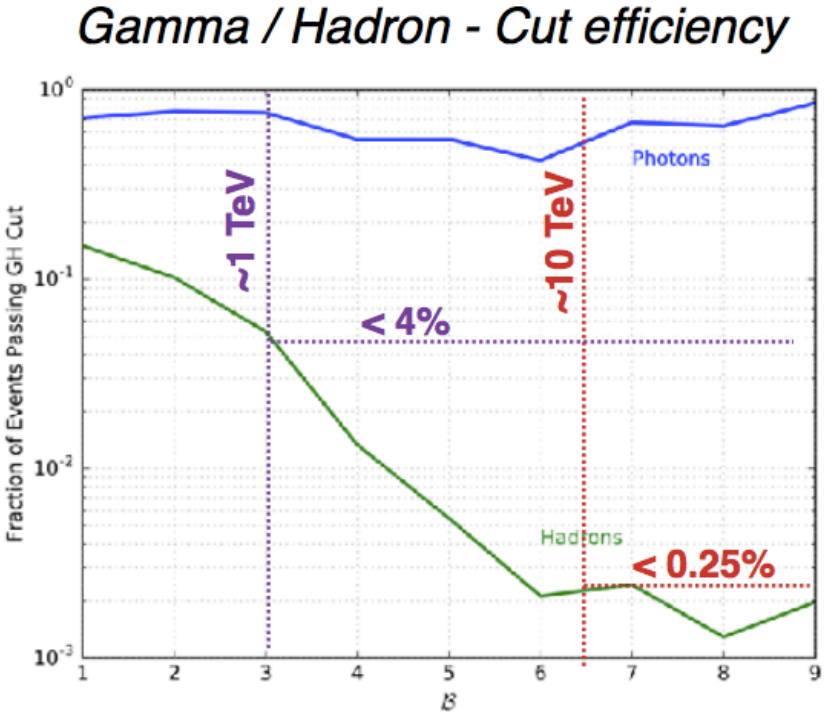
HAWC

- 0.1 – 100 TeV sensitive energy range
- Angular resolution of 1.3˚ (1 TeV) – 0.2˚ (>10 TeV)
- 2 sr of f.o.v., observes 2/3 of the sky daily
- Continuous operation > 95% of the time

➔ Much higher exposure than IACTs

For a source with Crab declination: 1 yr of HAWC data ~ 2190 hr of observation





A. U. Abeysekara, et al. ApJ, 843, 2017

HAWC strengths for:

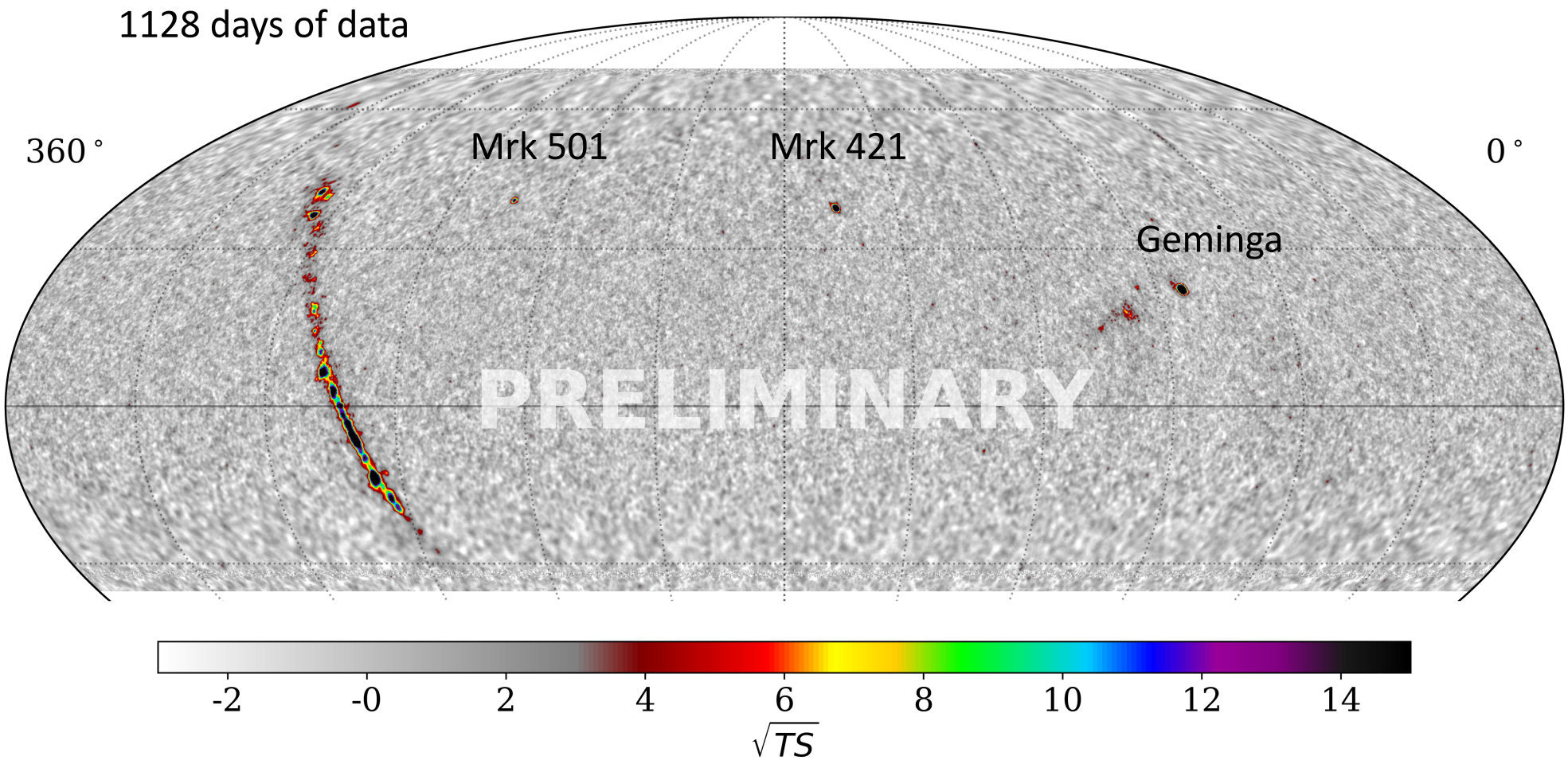
- Sky Survey
- Extended sources (>1-2˚)
- Sources of the highest energies (>10 TeV)
- Transient/variable sources

- HAWC operating since March 2015
- Standard analysis excludes the smallest showers (< 10.5% of detector) ➔ energy range (~1-100 TeV for ≥1 day integration time)

2HWC Catalog

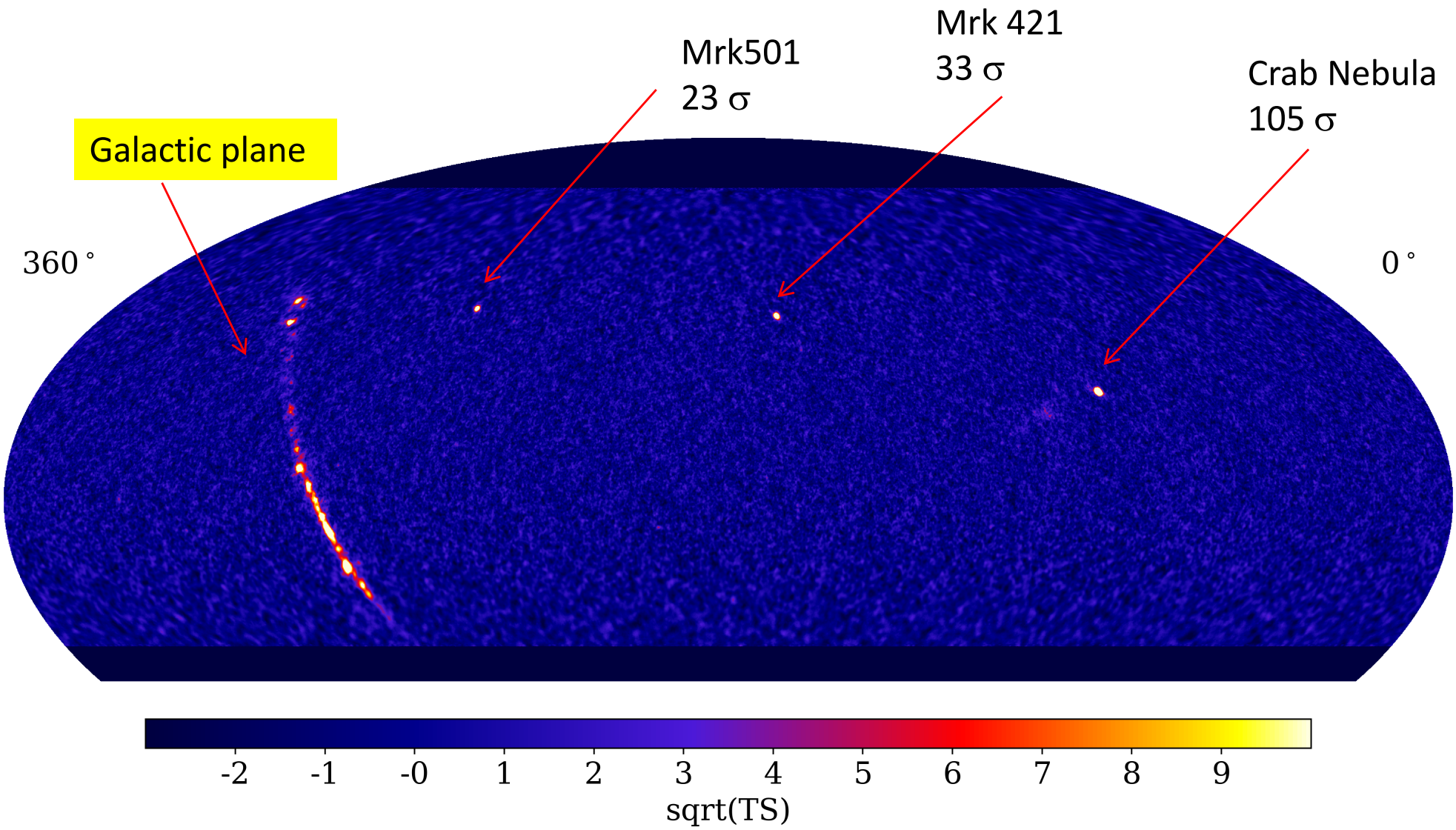
Abeysekara, et al, ApJ 843 (2017) 40.

- 17 months of data
- 39 sources, ¼ not detected previously in TeV



2HWC Catalog Abeysekara, et al, ApJ 843 (2017) 40.

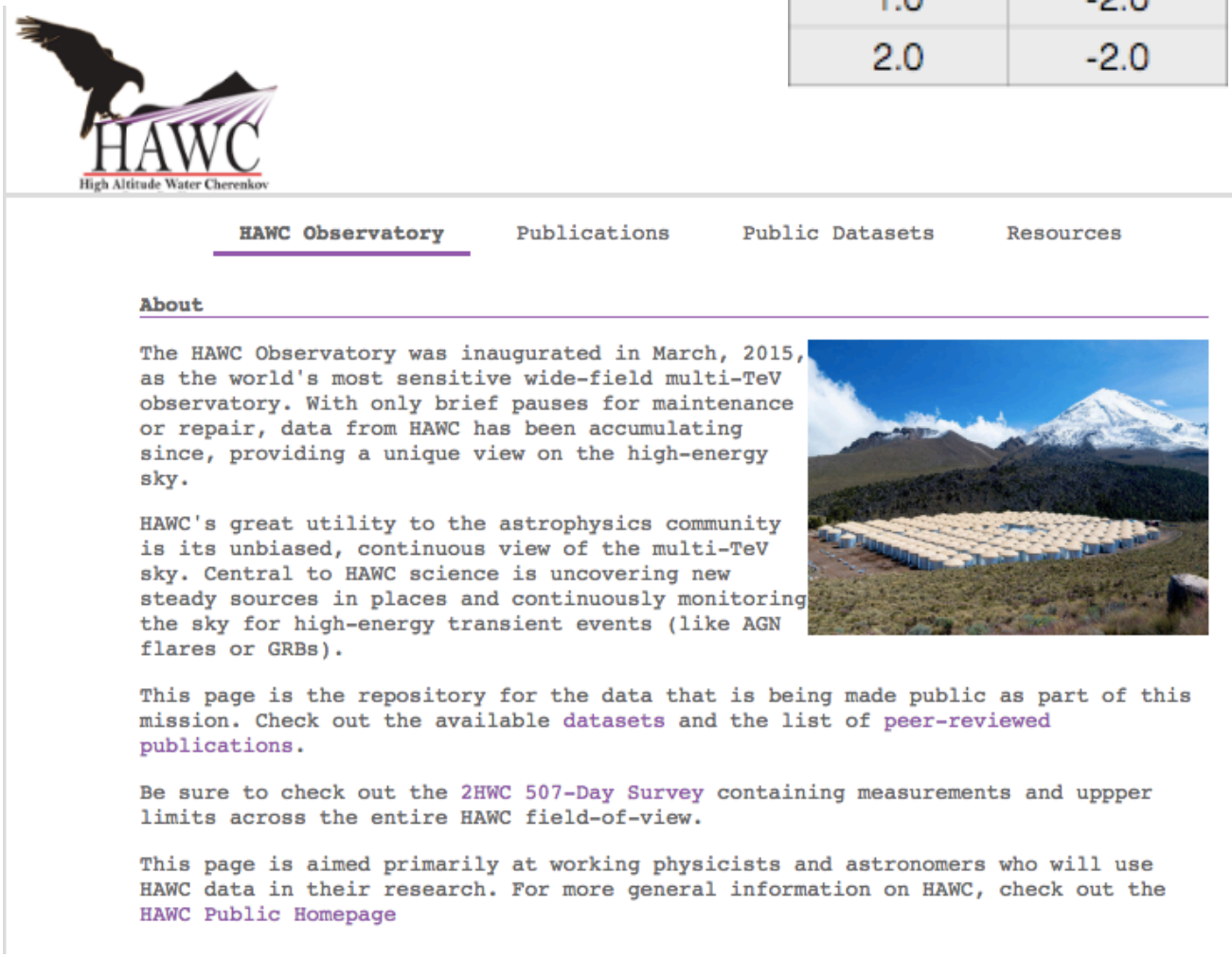
- 17 months of data
- 39 sources, ¼ not detected previously in TeV



Public HAWC data in https://data.hawc-observatory.org/

Published maps (UL) for four hypothesis and light curves for Crab, Mrk 421 and Mrk 501

Size	PL Index
Point Src	-2.7
0.5	-2.0
1.0	-2.0
2.0	-2.0



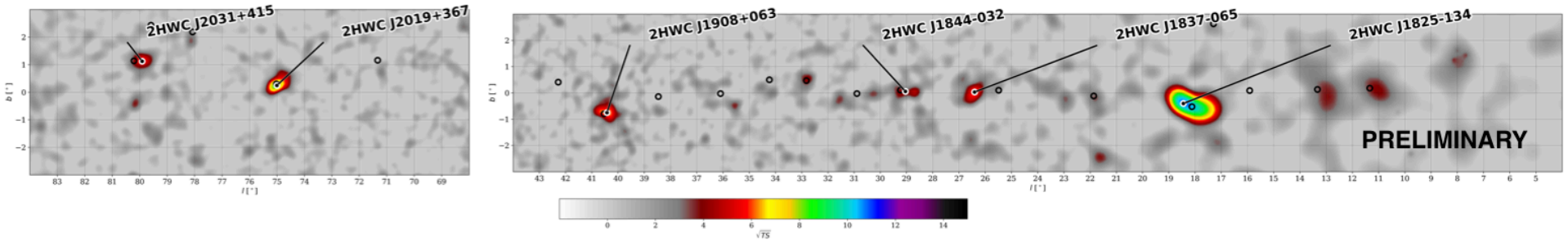
Highest-energy sources

Map E > 50 TeV

Candidates coincident with Pulsar Wind Nebulae, Super Nova Remnants or Pulsars

Production mechanism: most likely hadronic interactions

ν? E_ν > 25 TeV

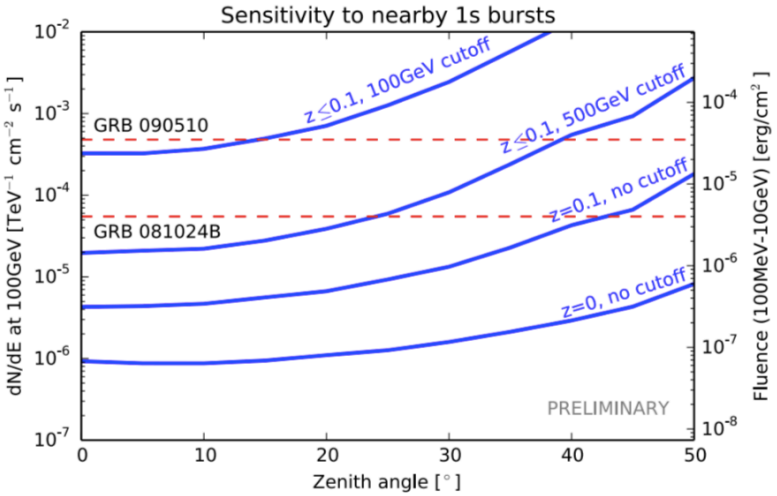


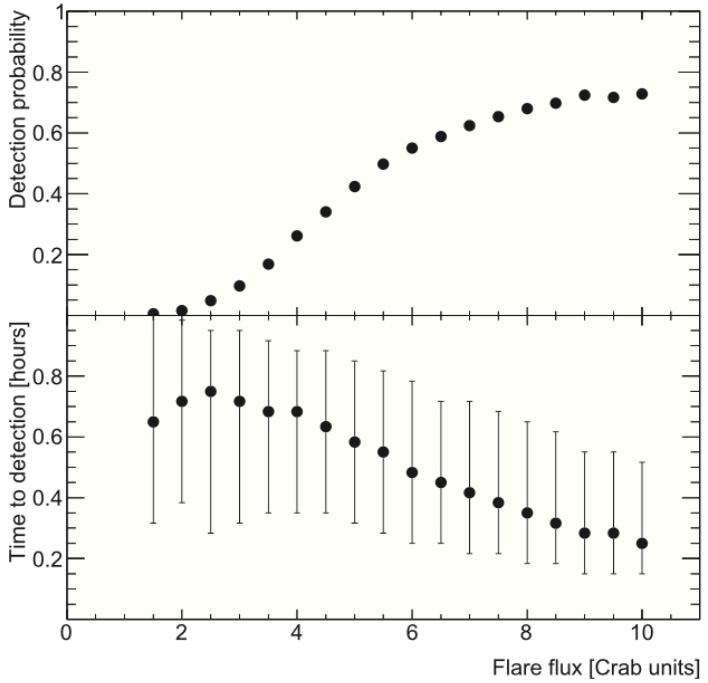
HAWC monitoring programs

ONLINE Searches

- All sky monitoring (A. U. Abeysekara, et al., ApJ 843 (2017))
  - Self-triggered
  - 2.1 x 2.1 square degree space bin
  - Time windows 0.2, 1 and 10 seconds and 0.5, 1, 2 and 3 transits.
  - Sliding time windows by 10% its width
  - "TeV GRBs", GW follow ups (Israel talk, wed) and any other unknown transient source
- Monitoring known 187 TeV sources (MoU)
  - Sensitive to time scales of minutes to hours
  - "bright flares, mostly Mrk 421 & Mrk 501"
- Alerts follow up (MoU)
  - Fixed sky positions
  - Time windows 1s, 20s, 300s
  - "GRB"

MoU partners: Veritas, MAGIC, HESS, FACT, Fermi, IceCube, LIGO/VIRGO, AMON, Swift, NuStar, ANTAREs





OFFLINE analysis

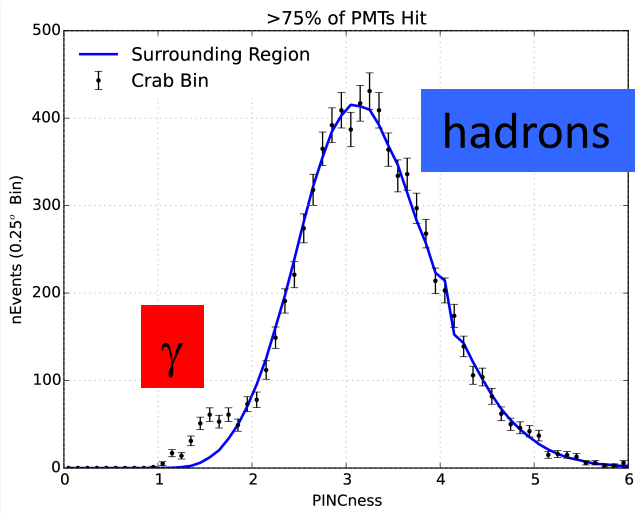
- Bayesian blocks analysis of light curves
  - Crab, Mrk 421, Mrk 501

- Search for VHE emission from GRBs
  - Prompt & long lasting emission
    - T90, 3*T90, 10*T90
  - Long lasting & delayed emission
    - 10 time windows of T90 (long GRBs), 2s (short GRBs)
  - Very long TeV counterpart

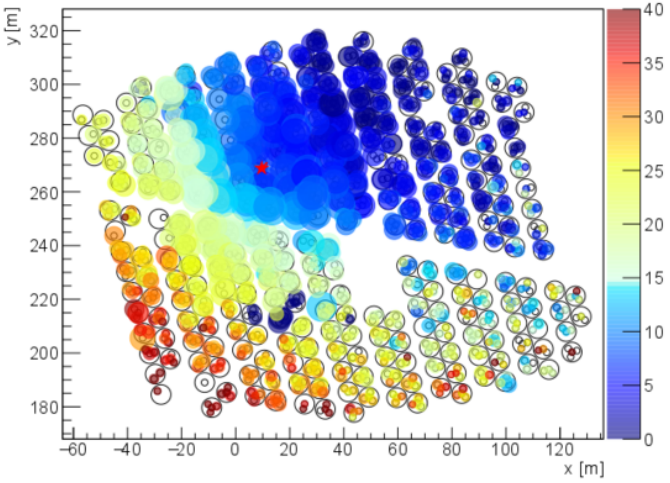
Crab

- Brightest gamma source detected by HAWC (>145σ)
- Used to refine analysis, validate simulations and probe the highest emission

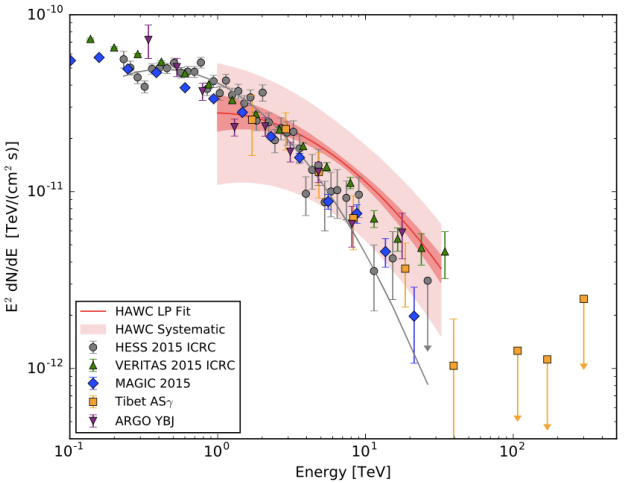
γ/hadron discrimination



~60 TeV event near Crab



Crab spectrum



Abeysekara, et al, ApJ 843 (2017) 39.

CRAB FLARING

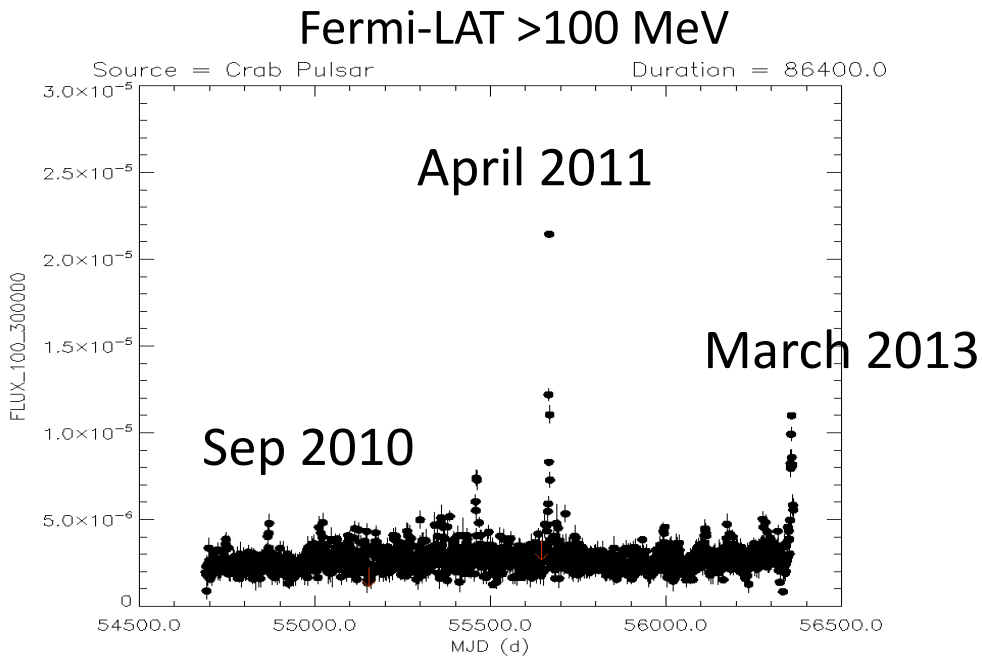
Sep. 2010: Fermi and AGILE observe a 3x flare at > 100 MeV

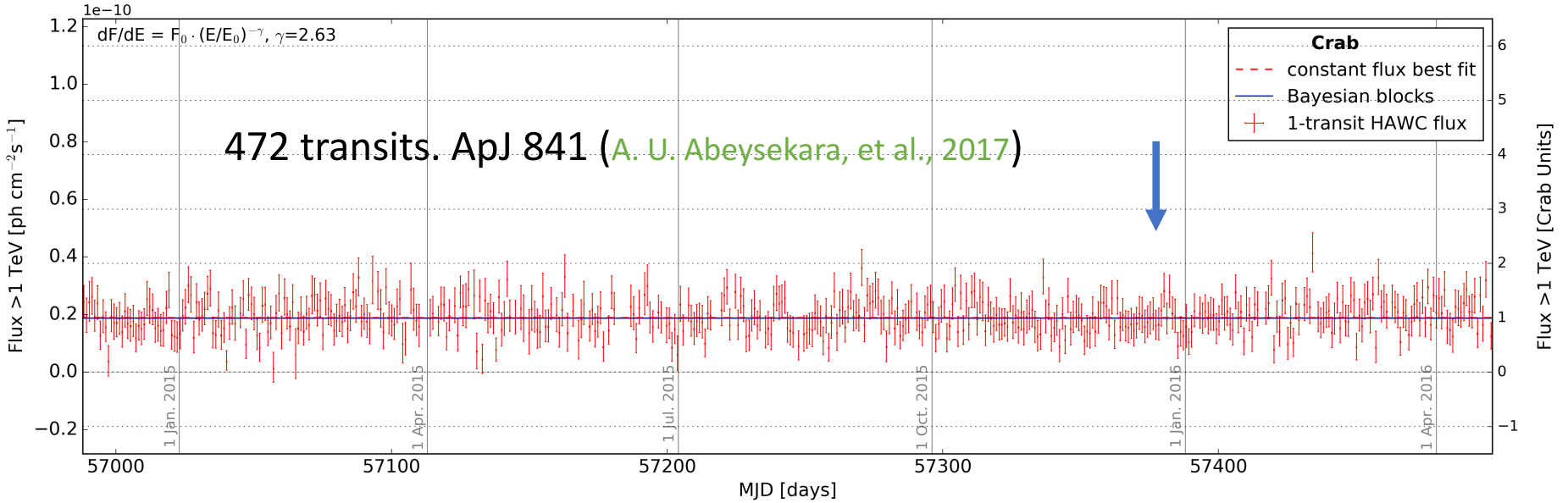
April 2011: Fermi and AGILE observe a 30x flare!

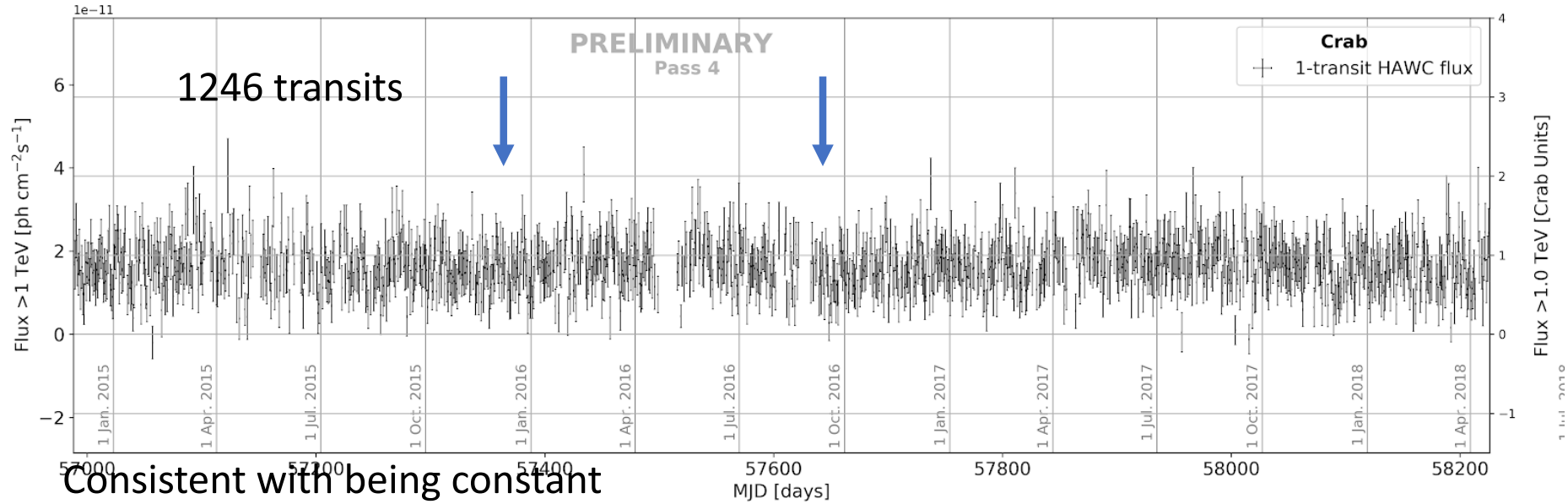
Mar. 2013: Fermi and AGILE observe a 4-5x flare

Dec 2015 – Jan 2016: Fermi observe a 5x flare

Sep 2016 – Oct 2016: Fermi and Agile observe a 1.8x flare





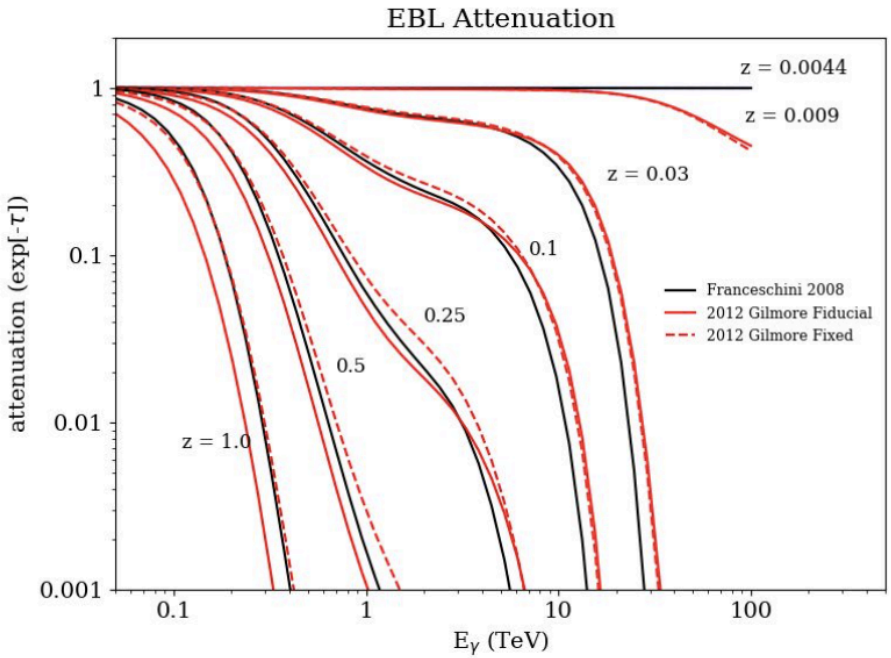


Consistent with being constant

Extragalactic sources

➔EBL absorption (z=0.1 – 1 TeV, z=0.03 – 5 TeV)

➔ need better gamma-hadron separation and PSF at lower energies.



So far, Mrk 421 and Mrk 501 are the only extragalactic sources detected by HAWC. Closest and brightest.

No positive detection of TeV counterpart from GRBs or neutrinos or GW. But, interesting upper limits.

Blazars

Duty cycle in TeV?
Flux distribution shape – what triggers flares
highest flaring state achievable and duration– maximum available power
Variability on various time scales? Why?
Spectra evolution with flux intensity? If yes, why?
Periodicity?
Radiation mechanism and emission zones– MW & MM observations & simultaneous
Sample of observations triggered by TeV alerts/flares – orphan TeV flares?

Radio galaxies

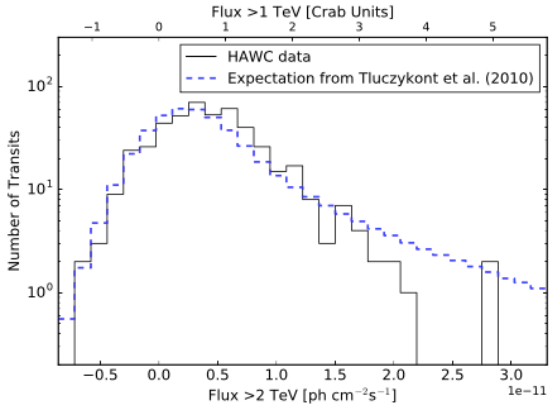
Are all TeV emitters? Only 4 or 6 in TeVCaT (3C 264, PKS 0625-354?, NGC 1275, IC310?)

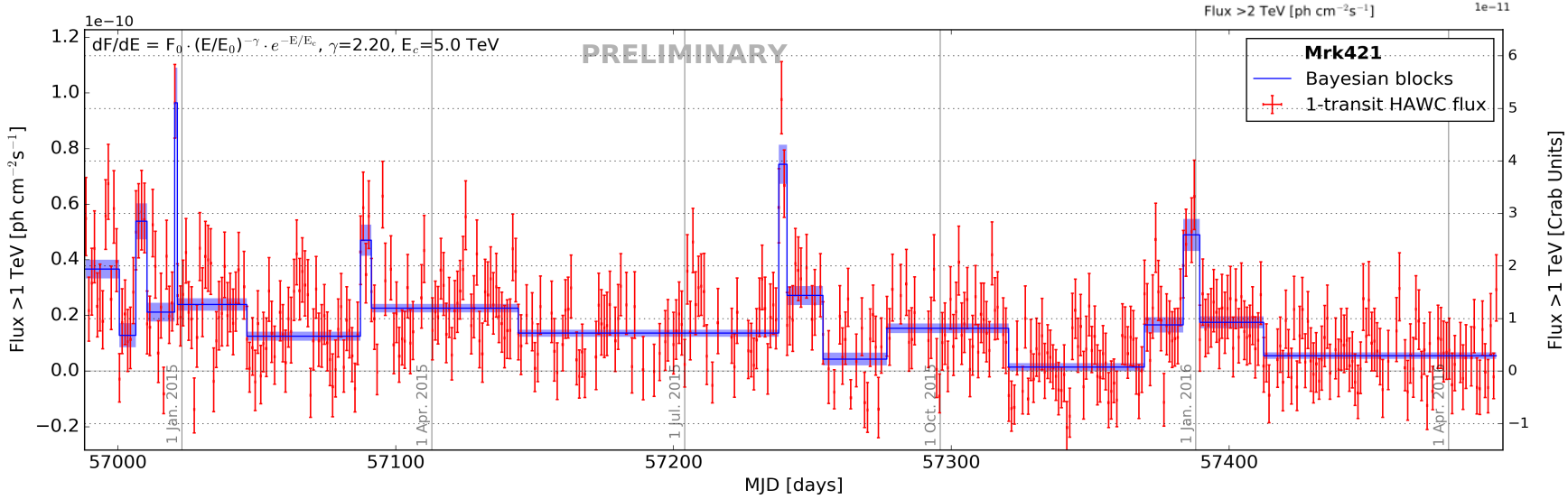
Cen A – TeV emission aligned with jets
M87 – days scale variability : close to core

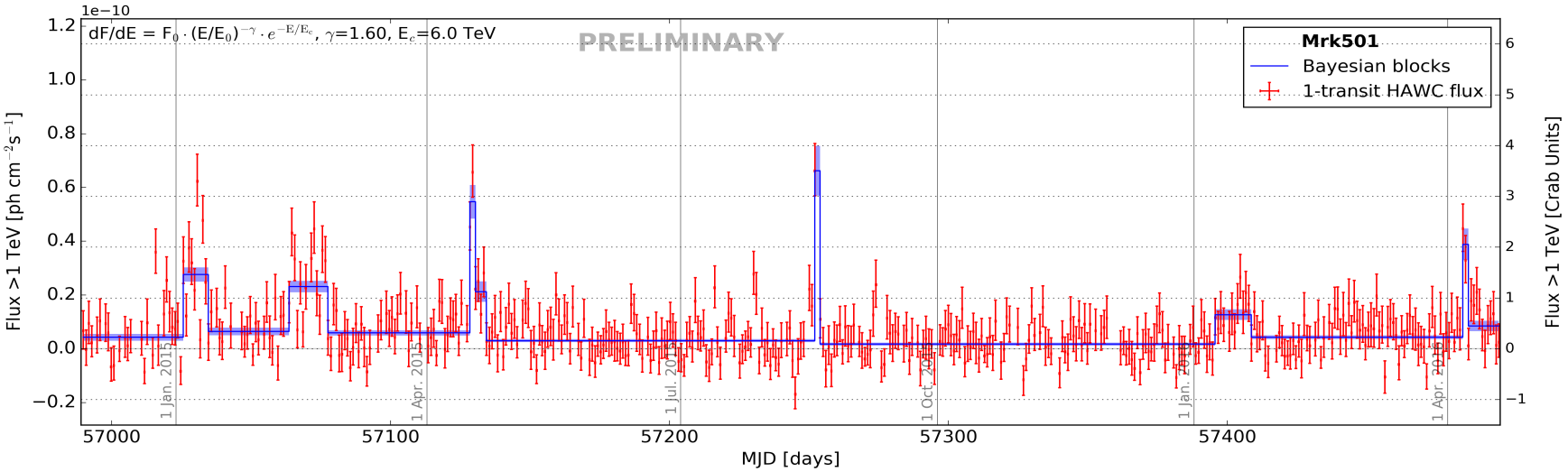
Variable sources?
Where is the emission zone?

Mrk 421 and Mrk 501

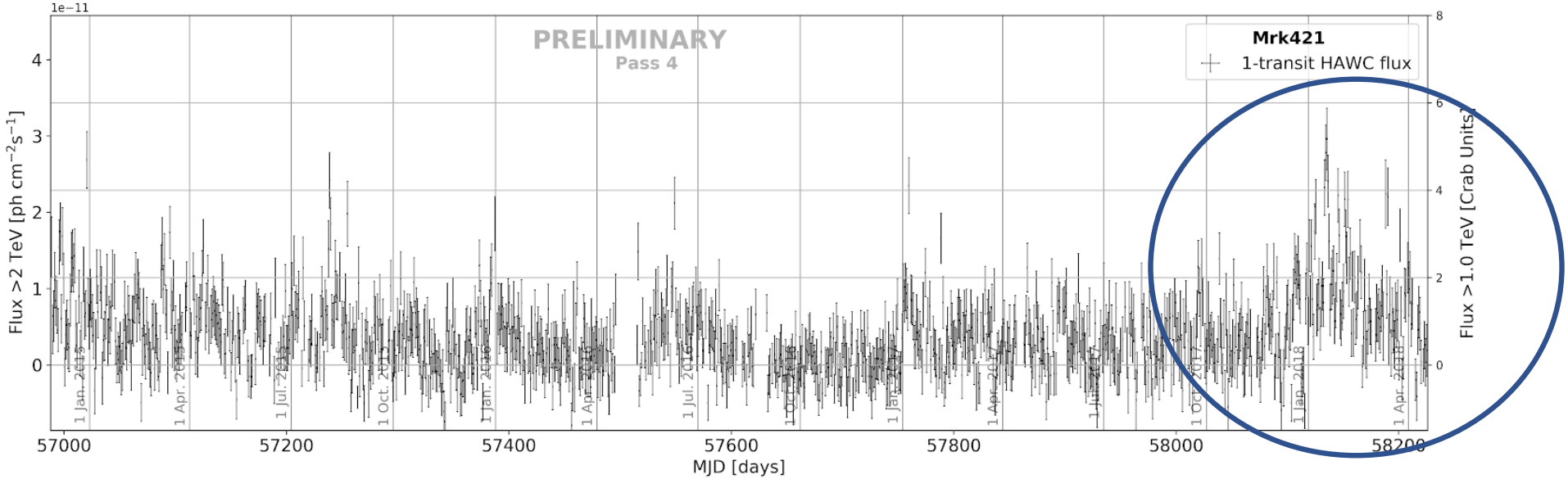
A. Albert, et al., ApJ 841 (2017)

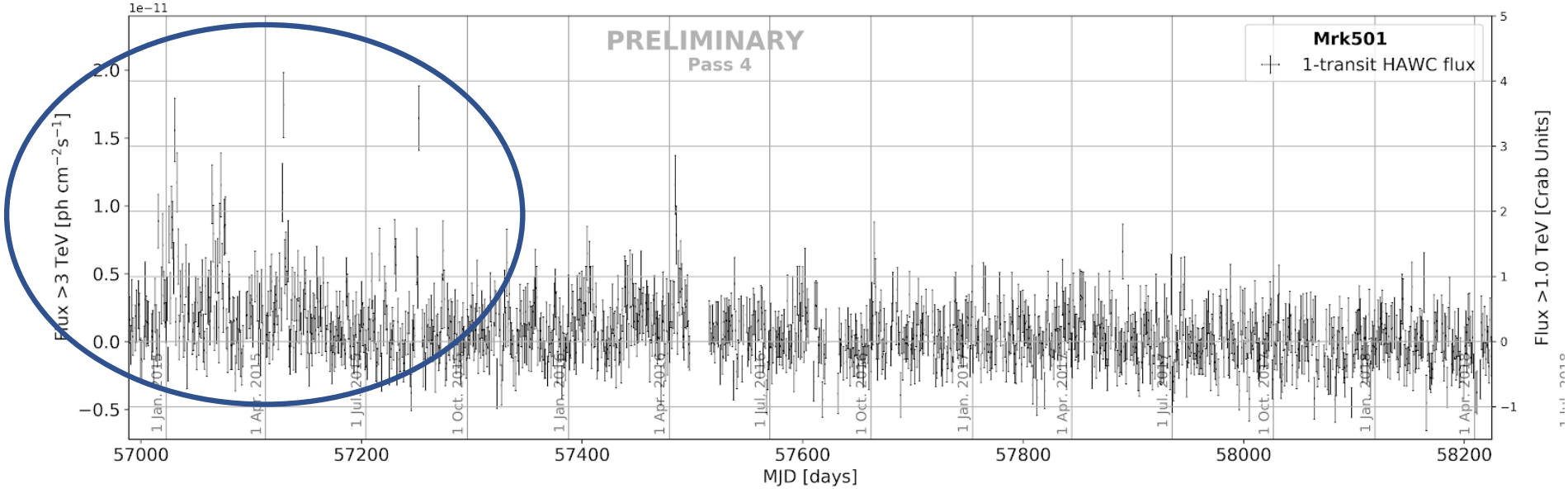


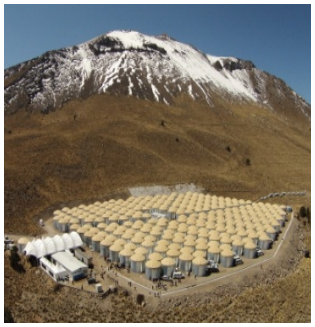


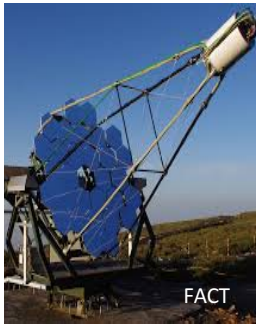


3 years of data









Daily Monitoring of Markarian 421

HAWC, TeV gamma rays

FACT, TeV gamma rays

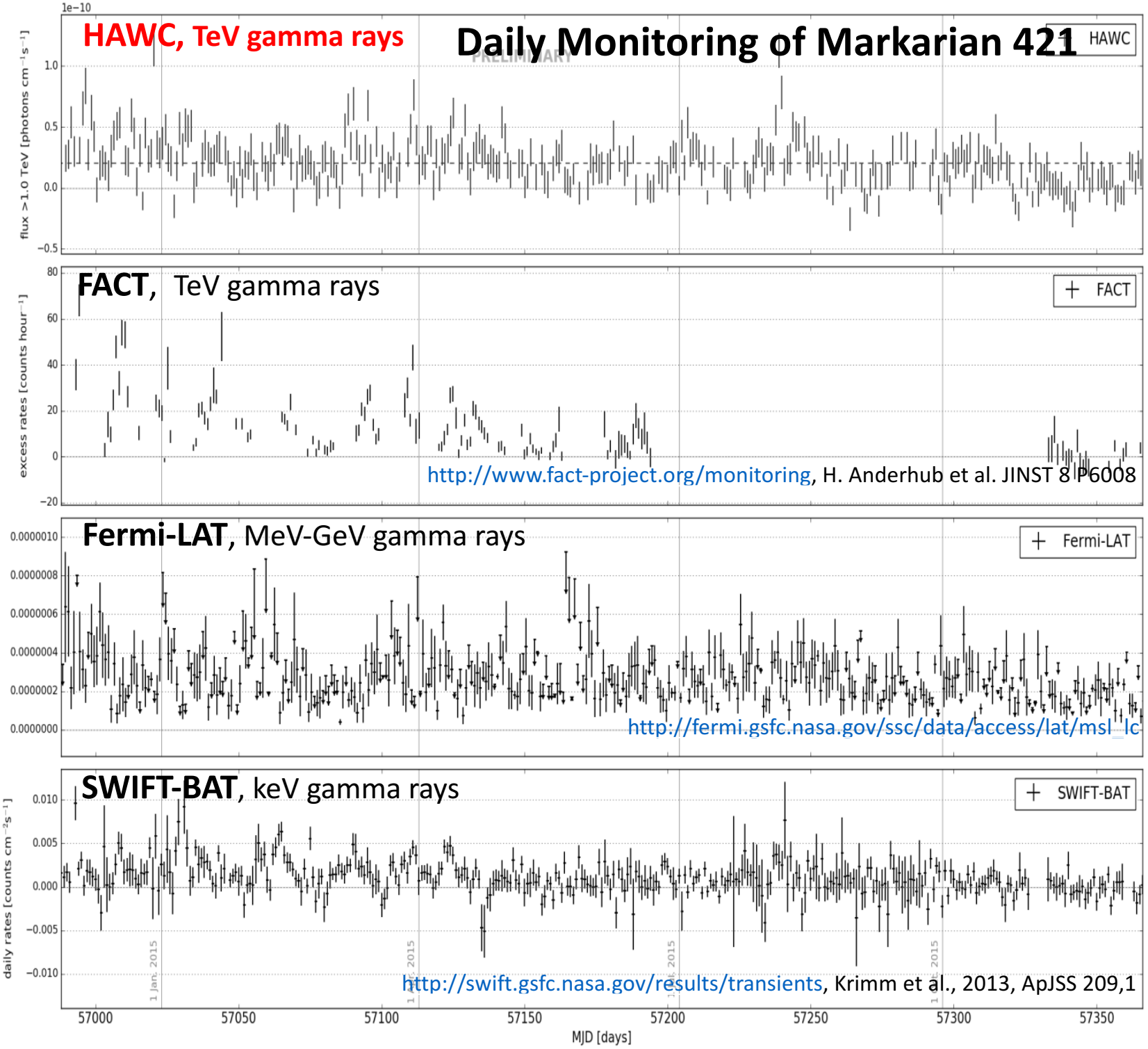
http://www.fact-project.org/monitoring, H. Anderhub et al. JINST 8 P6008

Fermi-LAT, MeV-GeV gamma rays

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc

SWIFT-BAT, keV gamma rays

http://swift.gsfc.nasa.gov/results/transients, Krimm et al., 2013, ApJSS 209,1

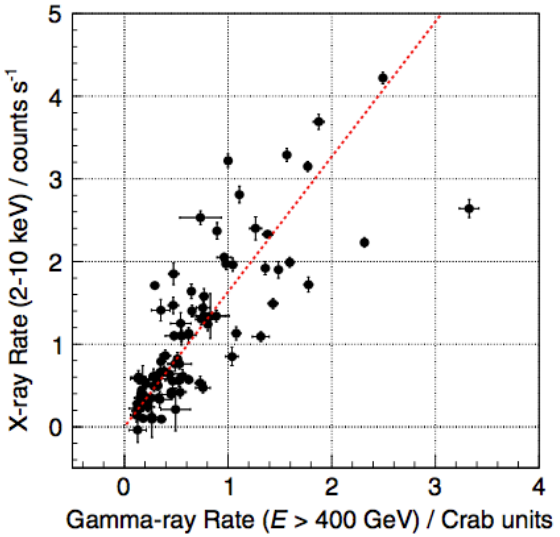


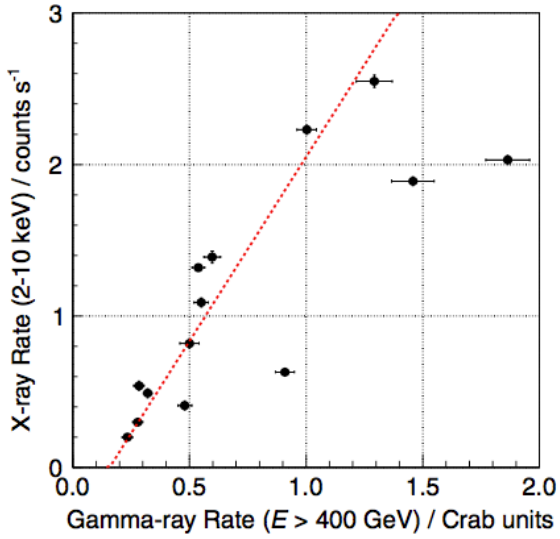
Gamma – X ray correlation Mrk 421

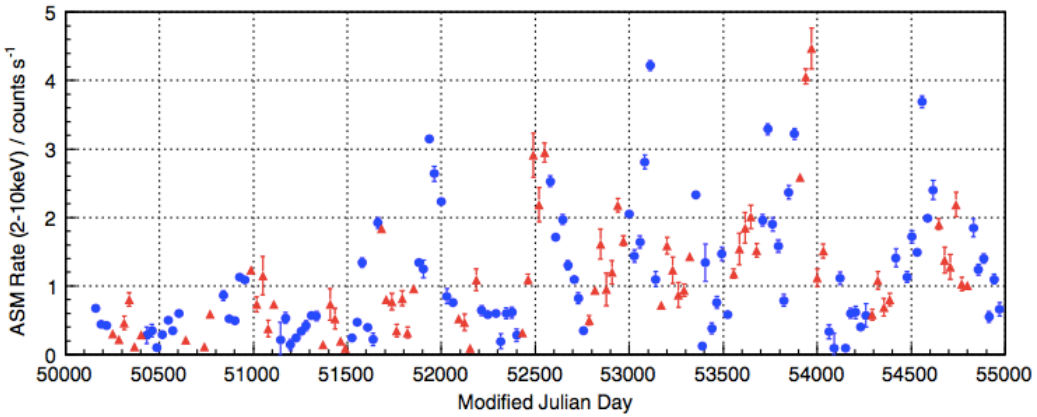
Whipple

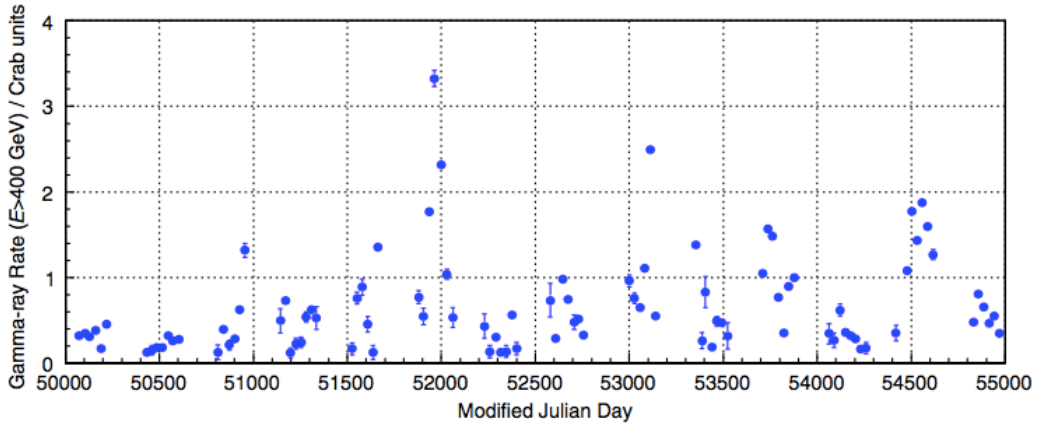
- 14 years of DATA
- correlation on monthly, yearly time scales

Acciari et al, Astro. Part. Phys., 54 (2014)



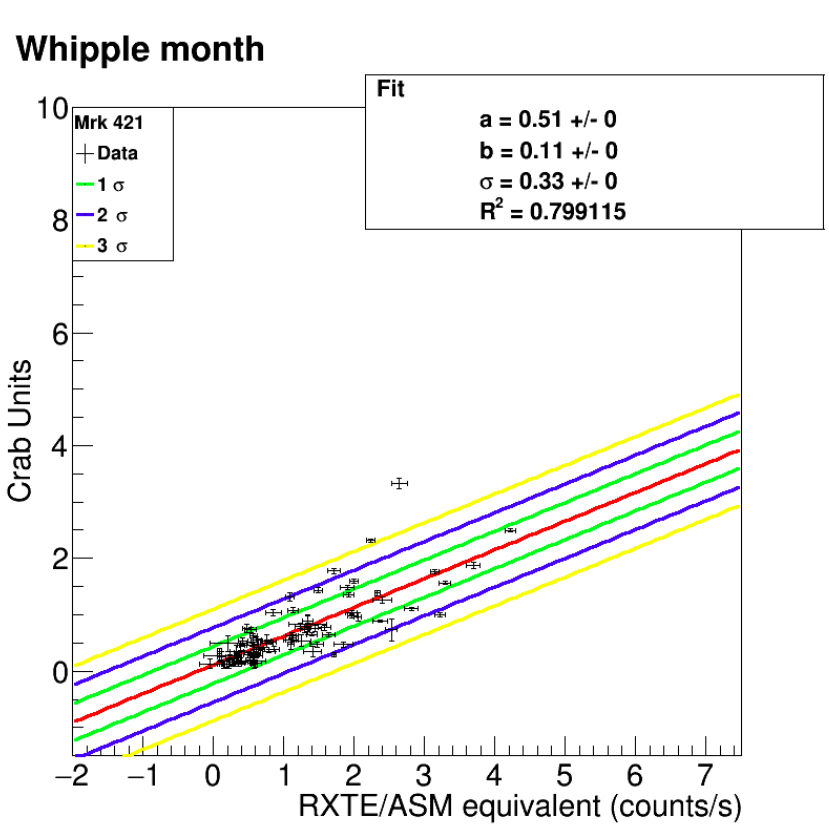


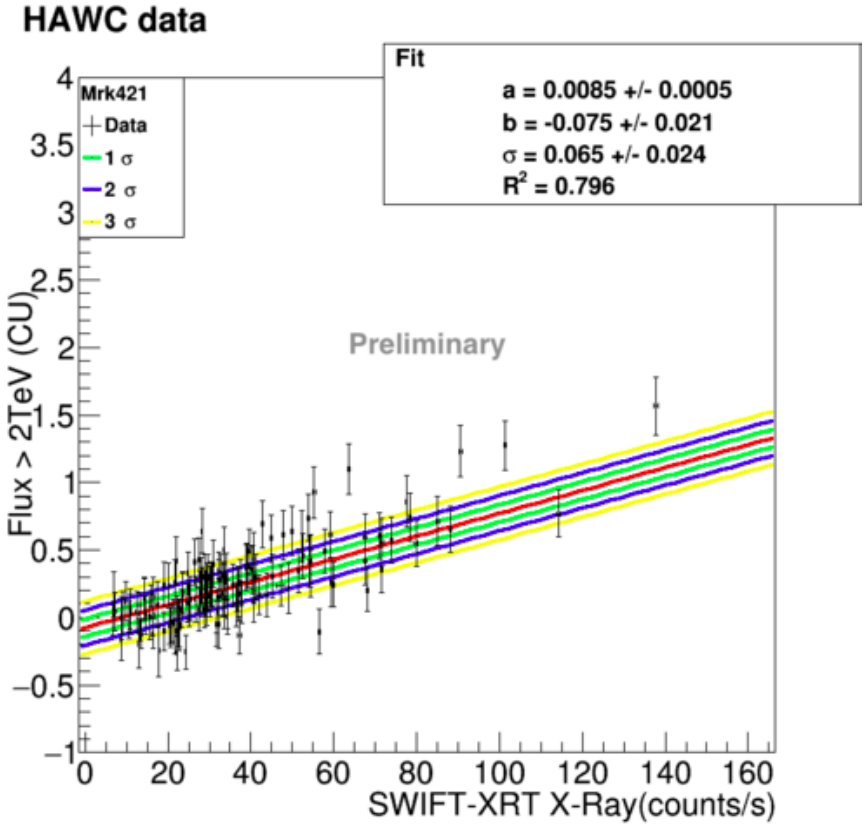




- Monthly/yearly averaged fluxes
- Variability in ONE wavelength will worsen correlation
- How non/quasi-simultaneity worsens the correlation?
- What is the origin of the dispersion in the data? Is it significant?
- More than one emission zone or electron population might not result in a linear correlation.

- maximum likelihood method, D'Agostini (2005).





What do we learn from it? Nissim´s talk, wed

GRBs

Do they emit in TeV energies?

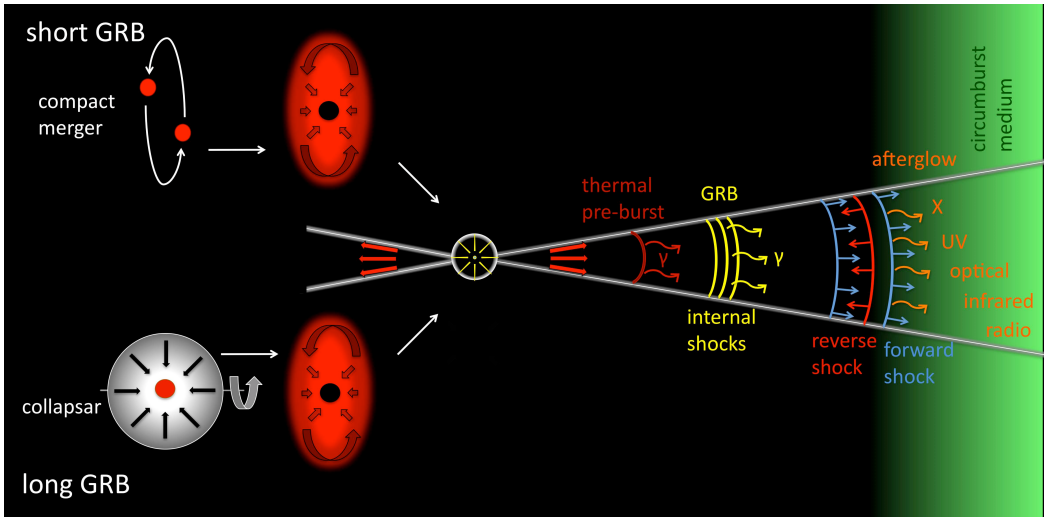
If yes, they have to be close to be detected => short ones

If yes, most likely scenario SSC from external shocks

If so, most likely to be long lasting emission

If yes, are our instruments sensitive enough?

But …. Who knows!



GRBs

- Self-triggered all-sky search in time sliding windows from 0.1, 2, 10 sec.
- Search for prompt EM counterpart for
  - 64 GRBs Alfaro, et al, ApJ 843 (2017).
  - T90, 3xT90 and 10xT90 for long GRBs, 6 and 20s for short GRBs. 1 and 20s when T90 is not available.
  - Now >146 GRBs (29 short GRBs), Dec 2014 - Feb 2018.
- Delayed and extended emission
  - T90 sliding window
  - 10 time windows of duration T90 (long) and 2s (short)

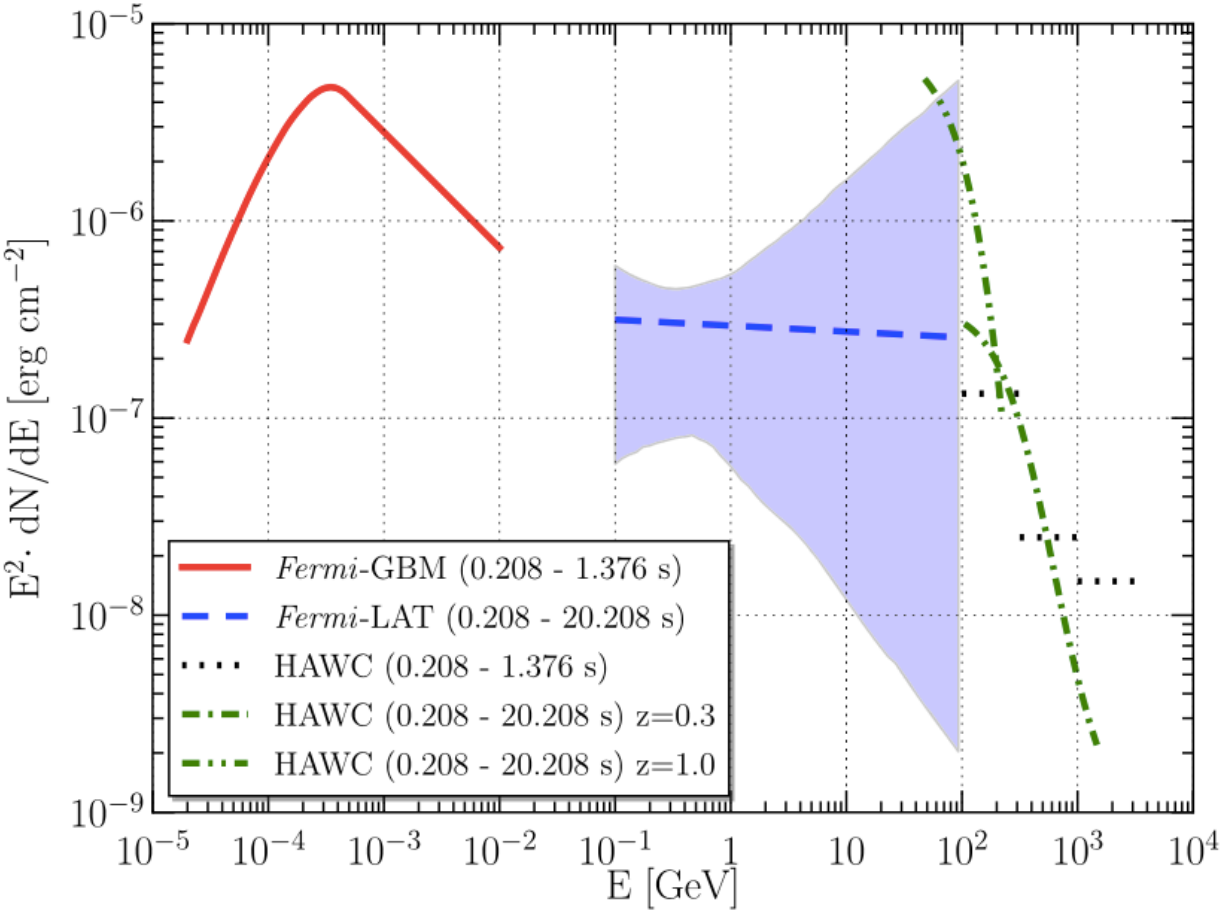
GRB 170206

One of the brightest short burst.

Detected by GBM and LAT

index of -2

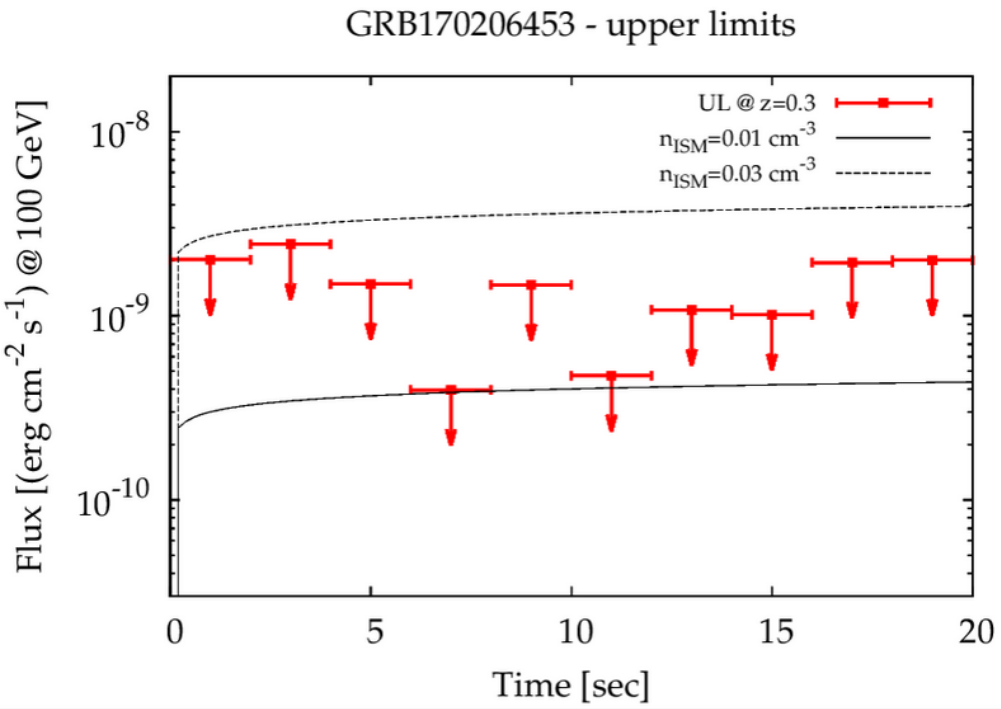
Energy cutoff < 100 GeV

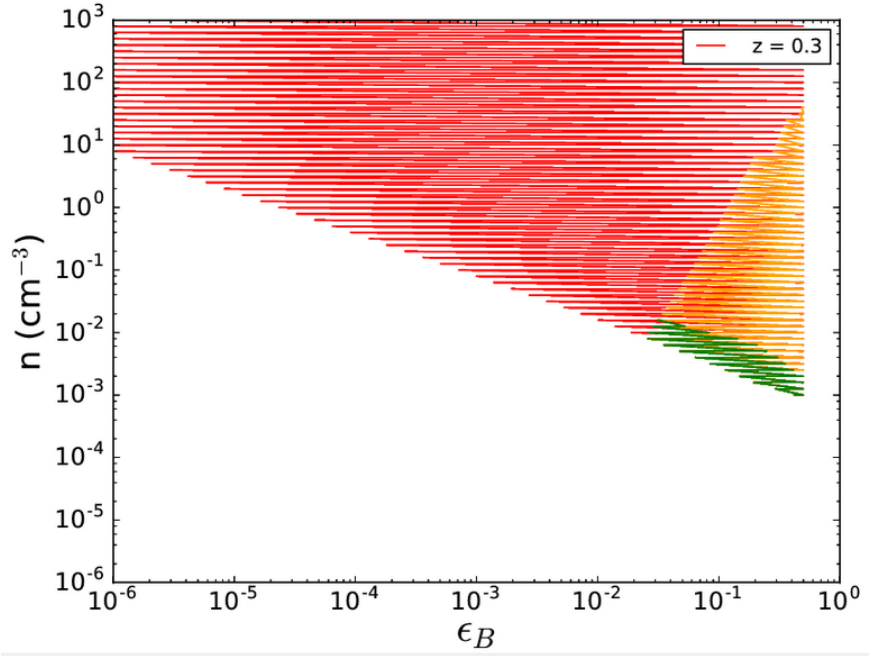


Assume SSC emission, obtain LC and compare with flux limits considering all regimes (fast and slow cooling)

z is assumed 0.3

Our most restrictive UL



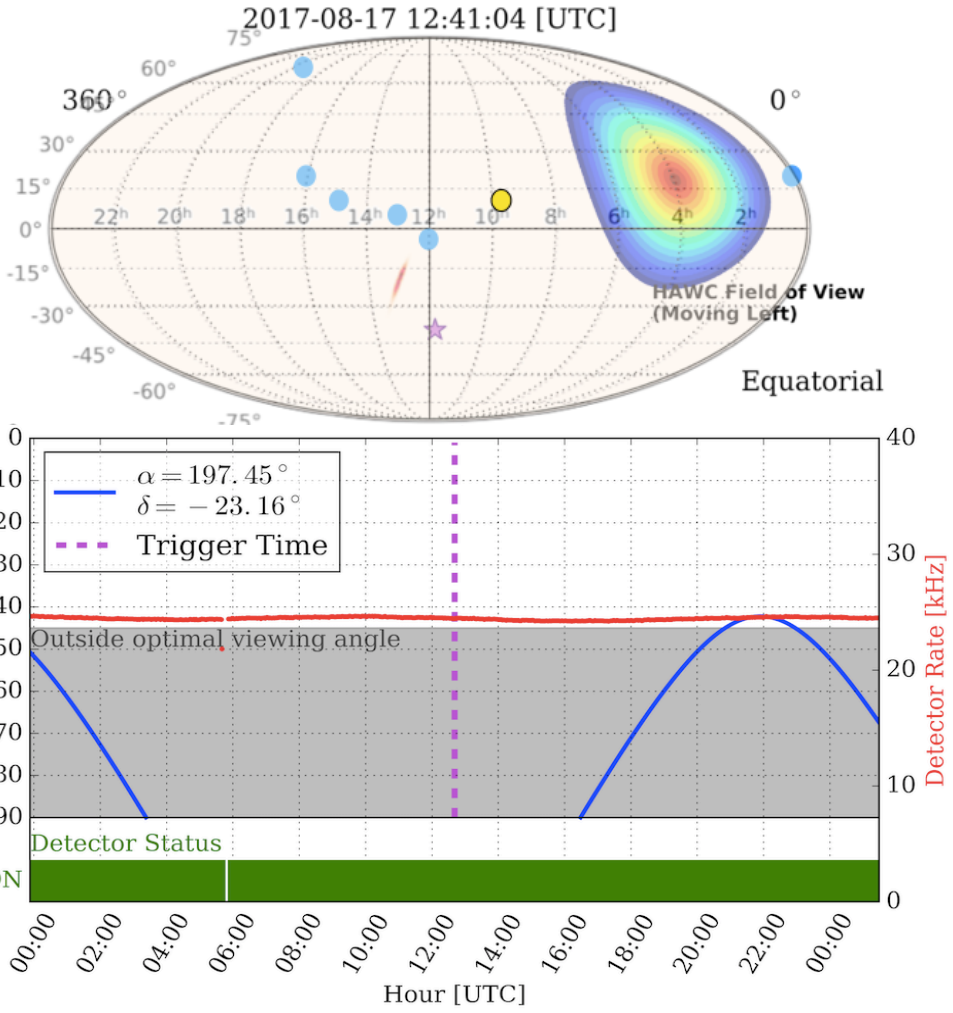


GW follow-ups Israel talk, wed

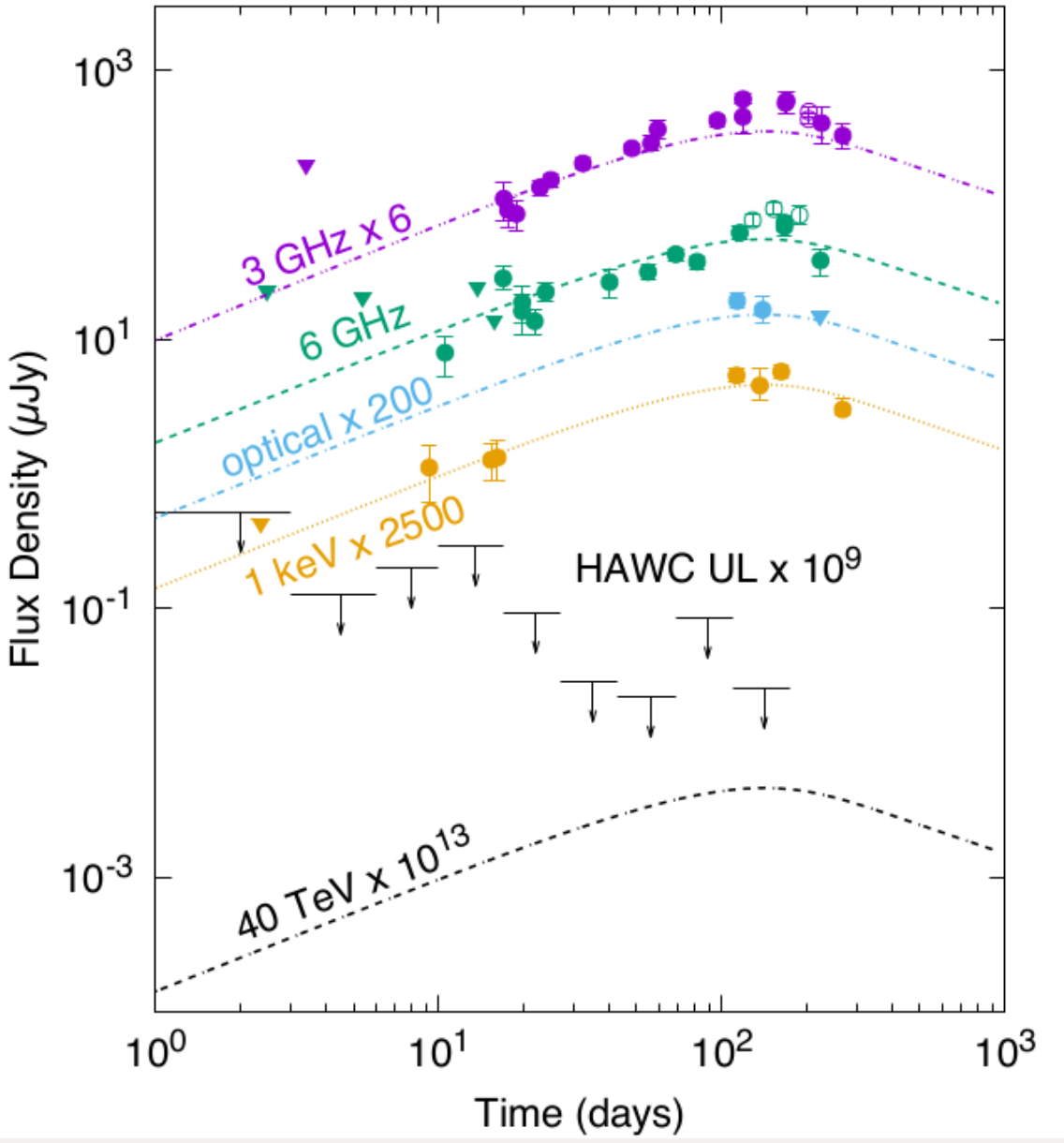
- it has followed up more than a dozen alerts from LIGO/VIRGO, only a quarter of them within our field of view at the time of the alert.

GW170817

- Outside of HAWC´s field of view at the time of the alert.
- We observed 9 hours later with a zenith angle larger than 45 degrees and only 6% of the region.
- Set upper limit to the TeV emission between 4-100 TeV.



short GRB, z ≈ 0.01, T90 = 2 s, E_{iso}= 5 10^{46} erg



Not too good !!

But could be detectable if:

- On axis
- Close to HAWC zenith?

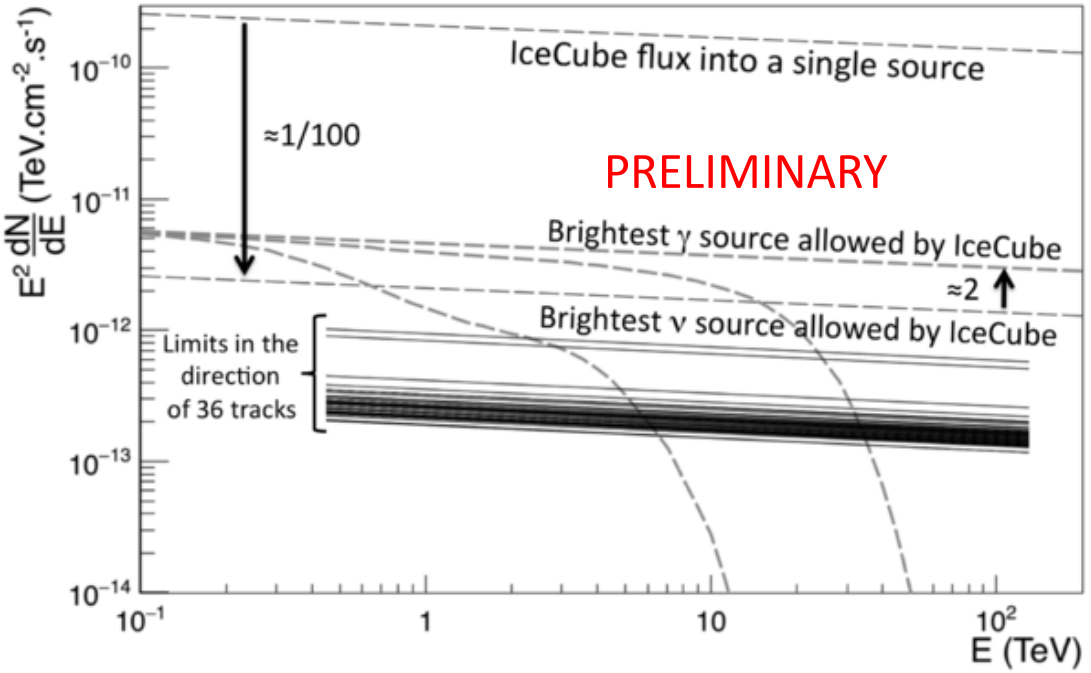
- How many short GRBs are like GRB170817A ?

- Searching on past short GRBs (>40)
- Calculation of GeV-TeV emission expectation from SSC

Follow up Neutrino alerts

- IceCube neutrino triplet on February 17, 2016, within 100 s of each other, within HAWC f.o.v., U.L. for 1, 11, 508 transits, Aartsen, et al., A&A, A115 (607).

- Search for EM counter part of 41 astrophysical ν.
  - No positive observation
  - If local, then weaker
  - High z
  - Opaque to gammas
  - transients

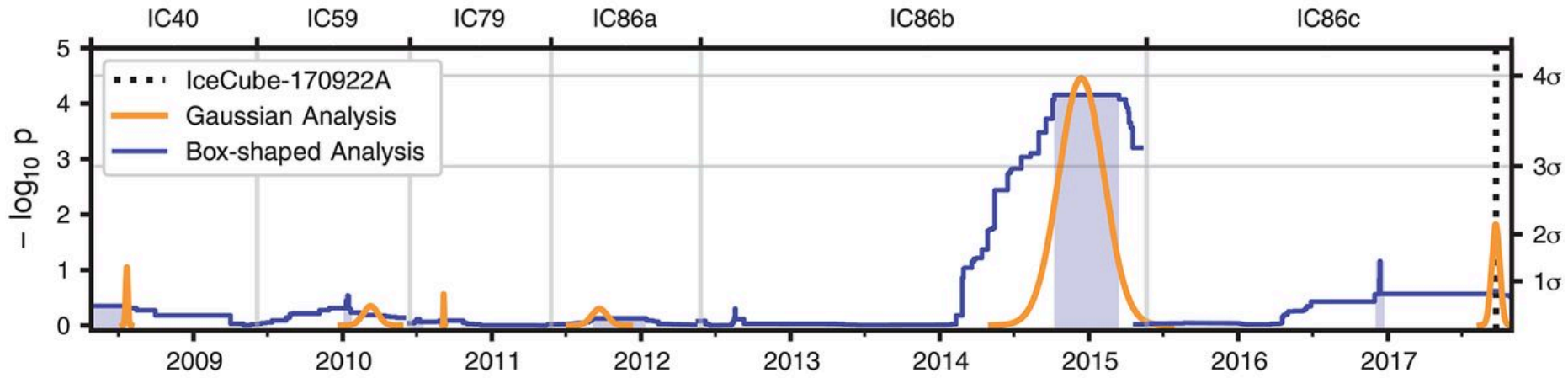


Neutrino alerts

- Follow up of a high-energy ν observed by IceCube on Sep 22, 2017.
- Fermi-LAT 3FGL showed blazar TXS 0506+056 within 0.1 degree
- TXS 0506+056 was showing brightening in the GeV band, hard spectrum and MAGIC detected TXS 0506+056 flaring

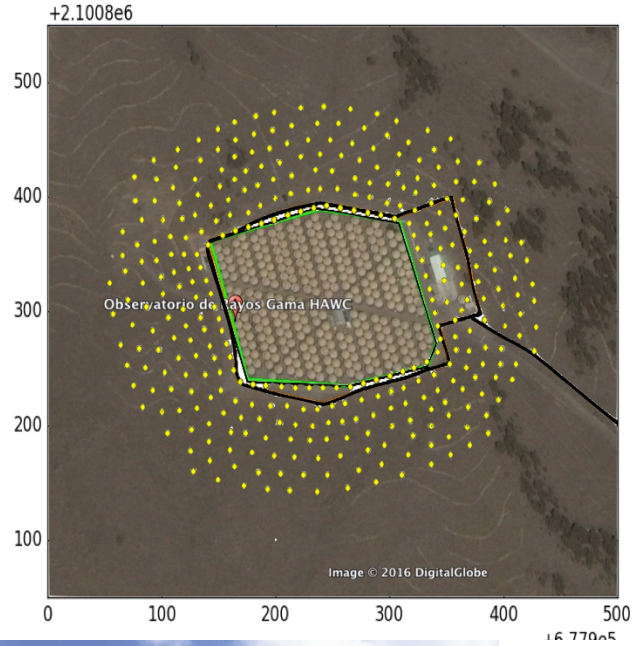
- IceCube – neutrino emission from blazar prior to the alert.

We have interesting limits coming soon. Abeysekara, A. U., (2018)



HAWC is larger!!

350 smaller detectors
4x HAWC area
Increased sensitivity to > 10 TeV
Finished



Conclusions

- HAWC is daily monitoring 2/3 of the sky. More flare alerts to come
- Light curves variability studies will be applied to known sources.
- More and detailed multi-wavelength and multi-messenger correlation studies
- New search strategies for searching TeV emission from GRBs.
- Extreme flares detection + ν in blazars will play an important role
- Need to improve low energy sensitivity