



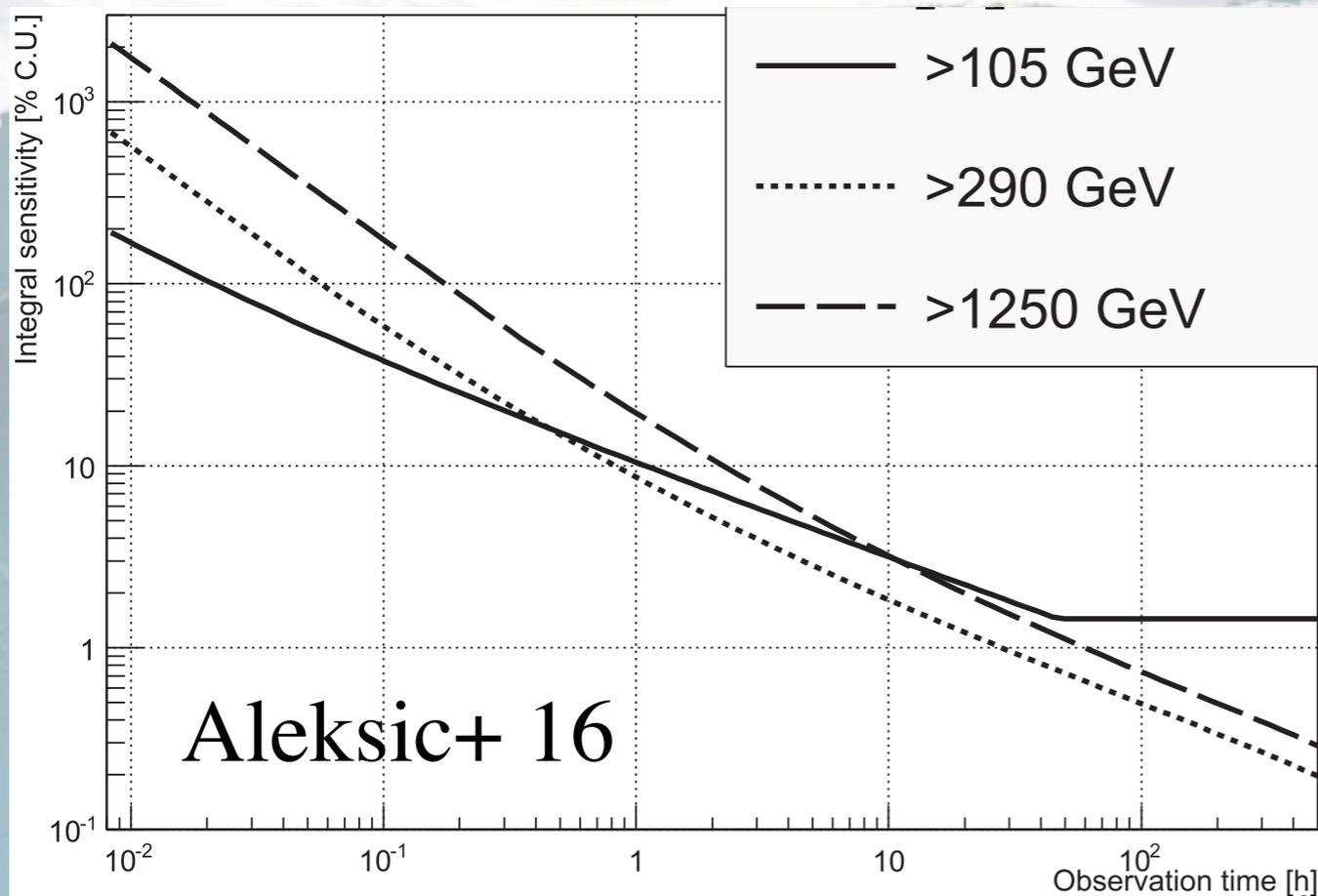
The MAGIC Transient & MM Program

Konstancja Satalecka for the MAGIC Collaboration

TeVPA 2017, Aug 11th 2017, Columbus



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° (LV PMT)
- ★ Energy range: ~ 50 GeV (30 GeV with Sum-Trigger) - 50 TeV \Rightarrow low E threshold suitable for distant sources & pulsars
- ★ Mirrors: $2 \times 240\text{m}^2$ ($d = 17\text{m}$)
- ★ Light-weight: ~ 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
- ★ Sensitivity: 10% Crab in 1h > 100 GeV

MAGIC transient searches

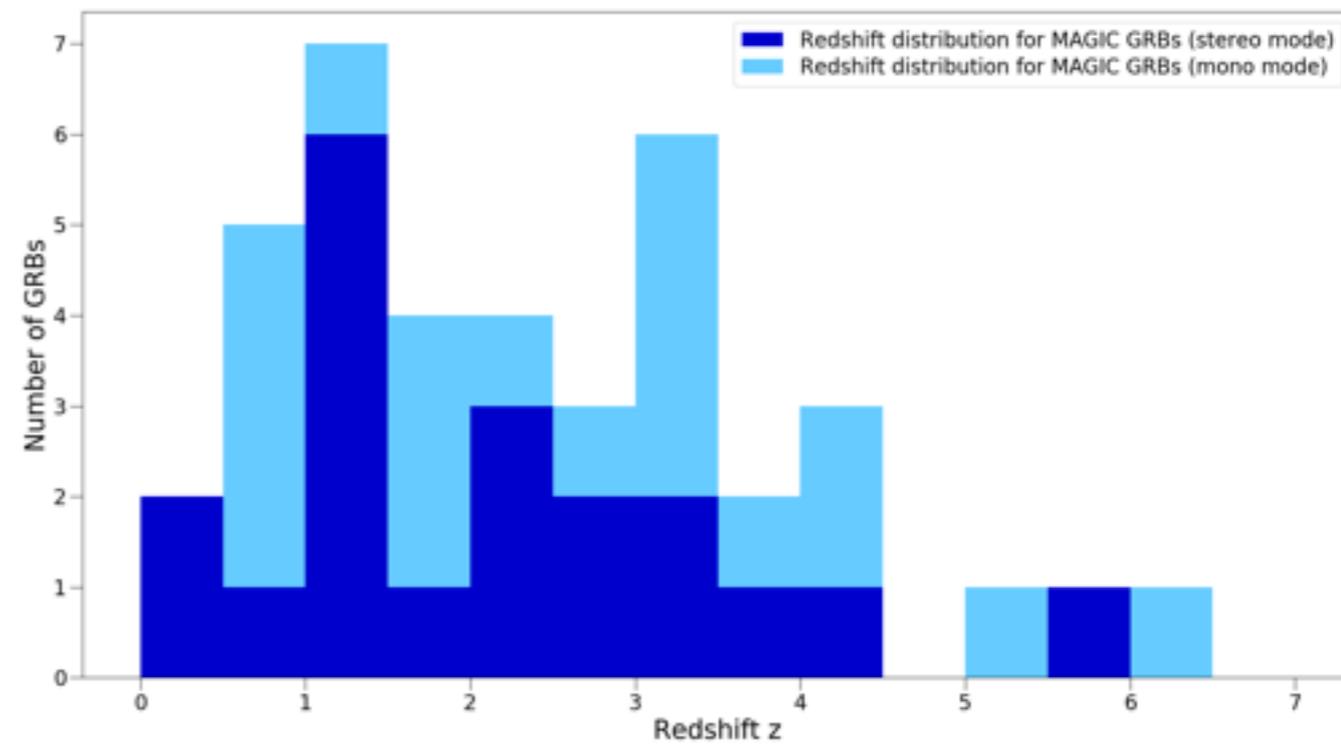
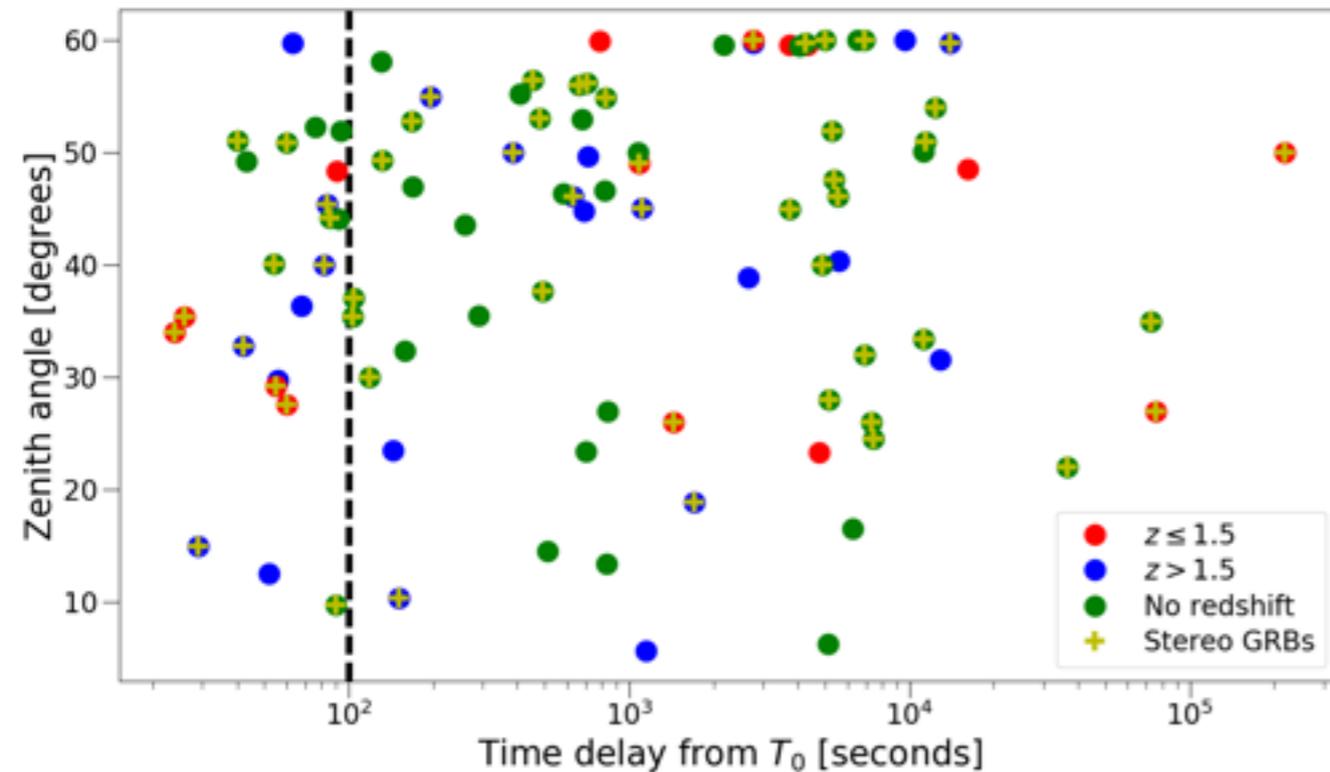


MAGIC, Canary Islands

**Rich MM & Transient follow-up program:
GRBs, GWs, FRBs, neutrino events, ...
Each year ~15 % of obs. time invested!**

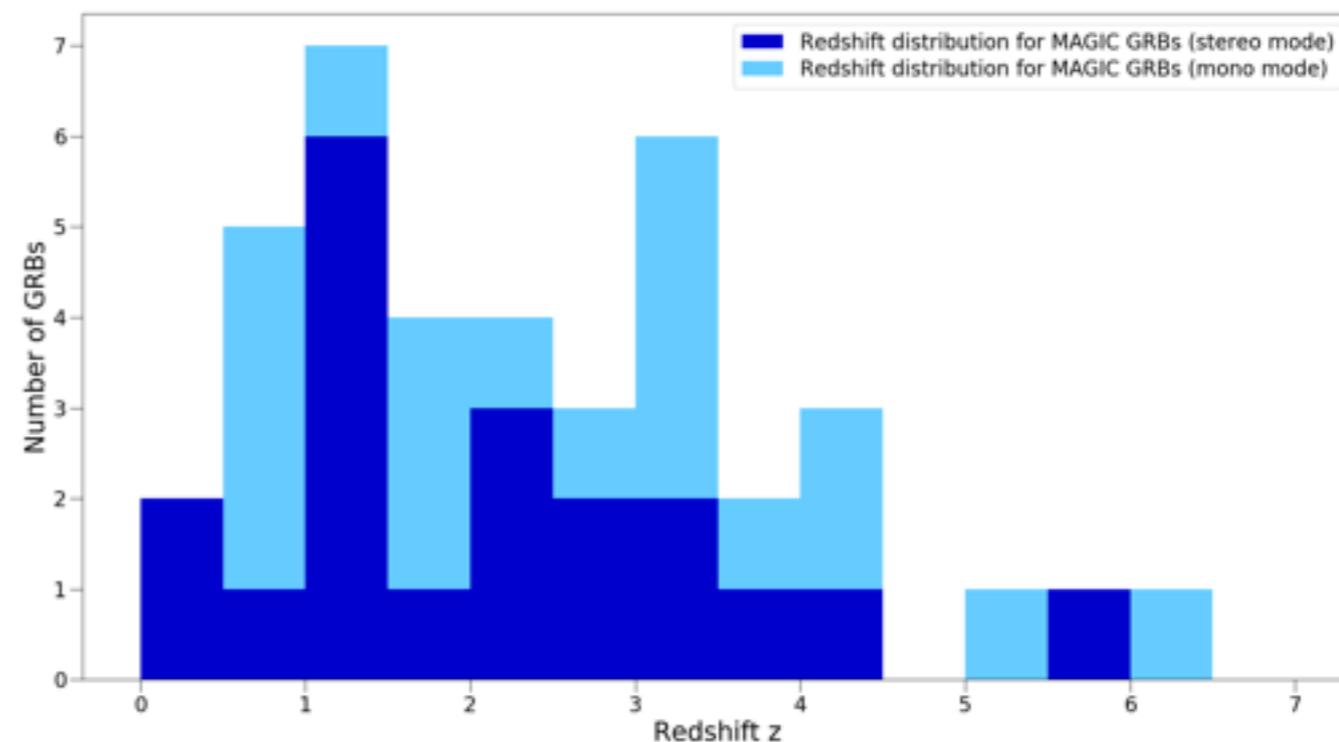
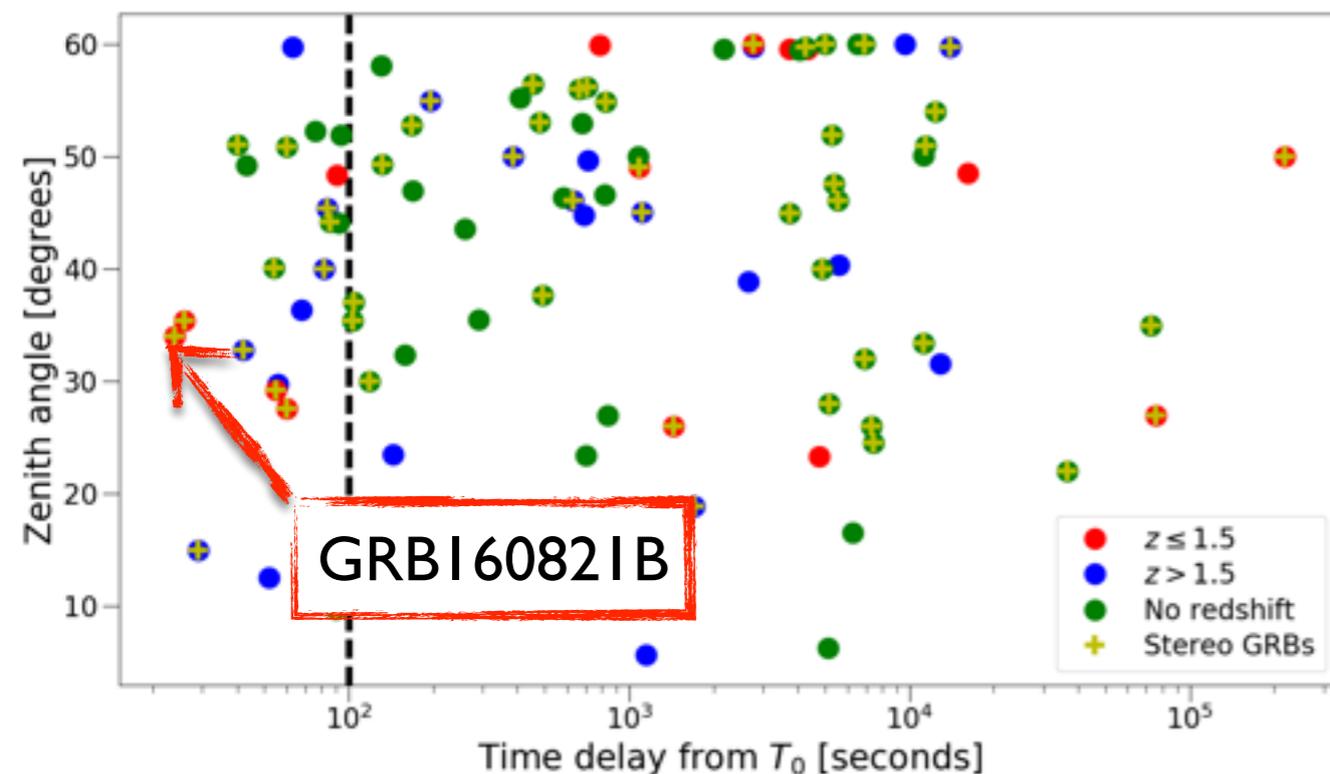
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MAGIC GRB follow-up



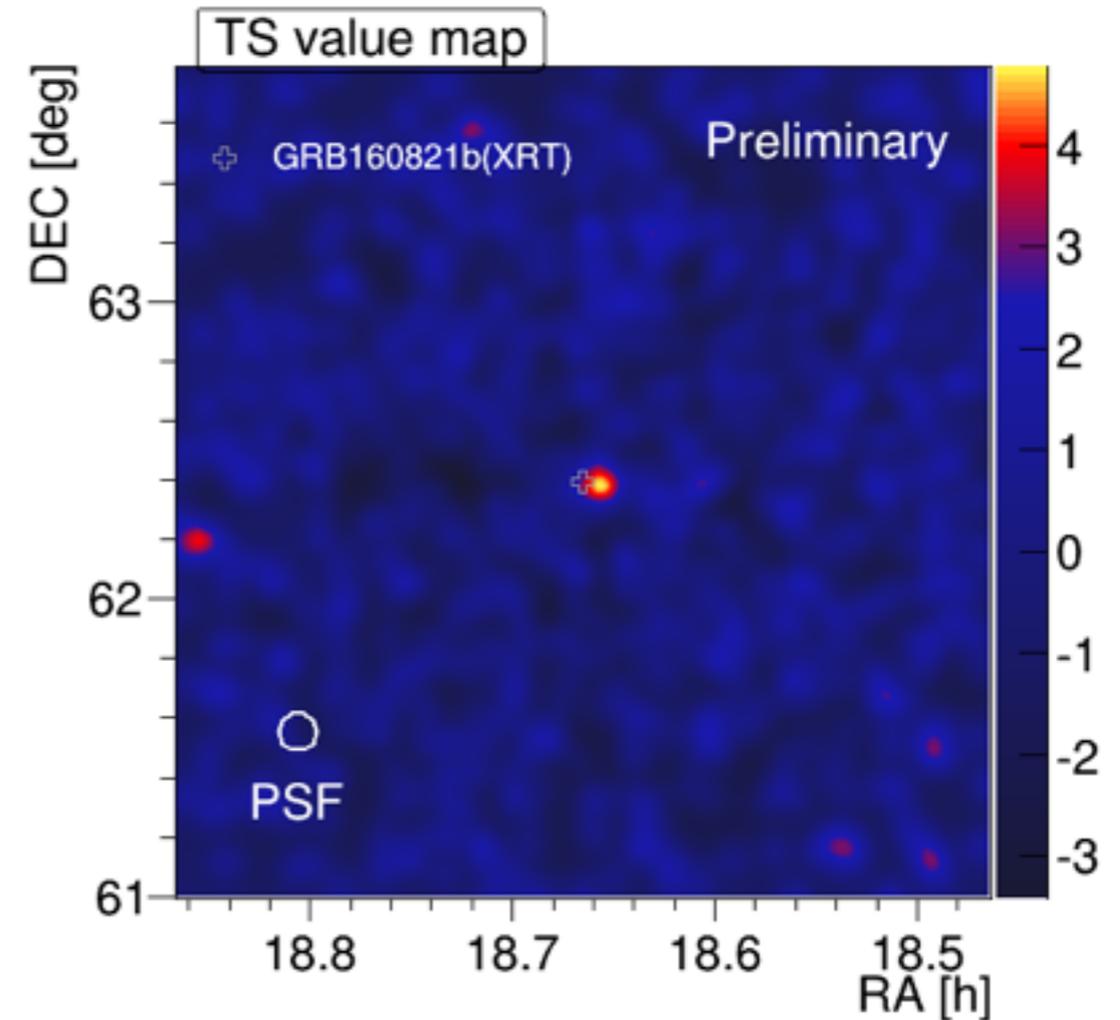
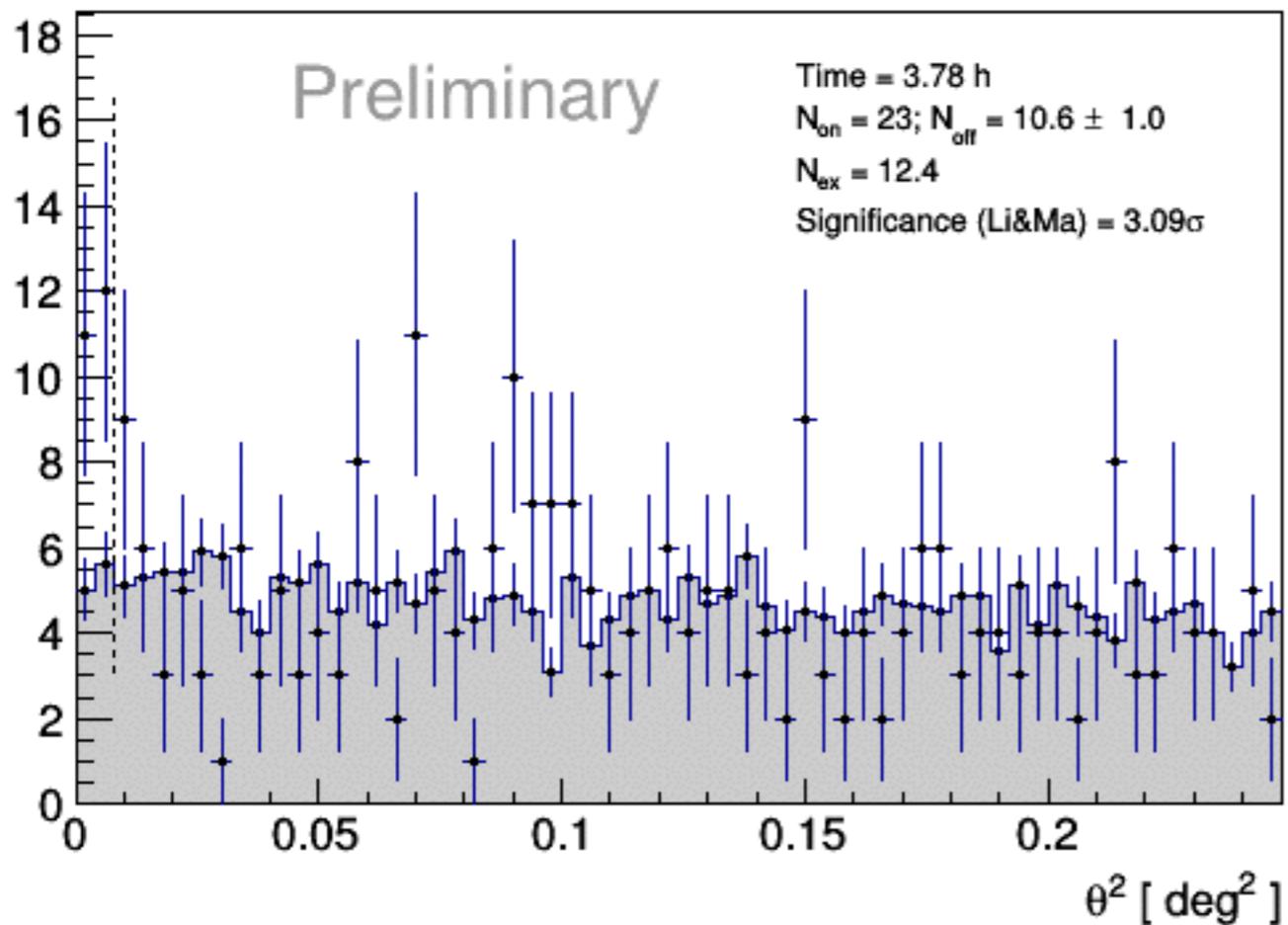
- ★ Key Observational Program - each year > 50 h invested
- ★ 96 GRBs observed so far, mono + stereo (includes bad weather, moon-time and high- z GRBs)
- ★ 39 with known redshift, 15 with $z < 1.5$
- ★ Fast repositioning: 22 with delay < 100 s!
- ★ New follow-up procedure, including late-time follow-up, since 2013 \Rightarrow **2013-2016 summary paper coming soon: > 20 GRBs, ULs with lowest threshold possible - stay tuned!!**

MAGIC GRB follow-up



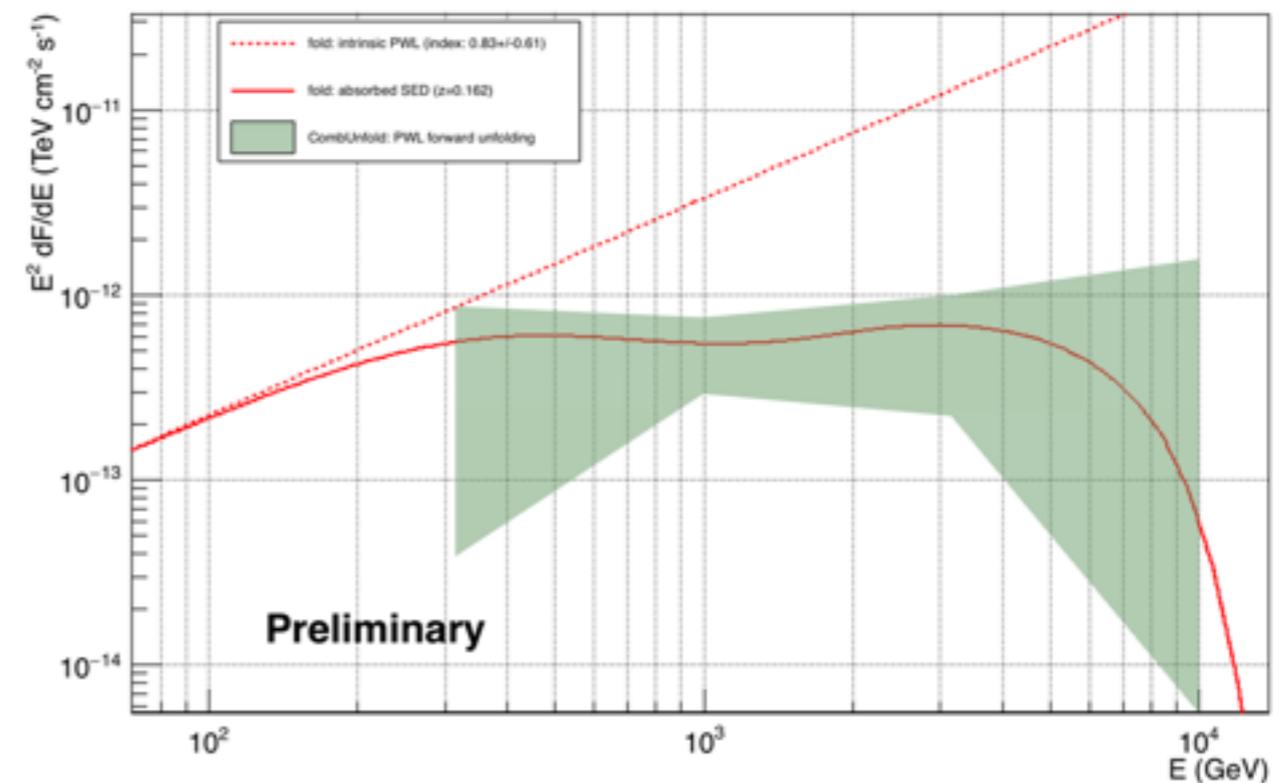
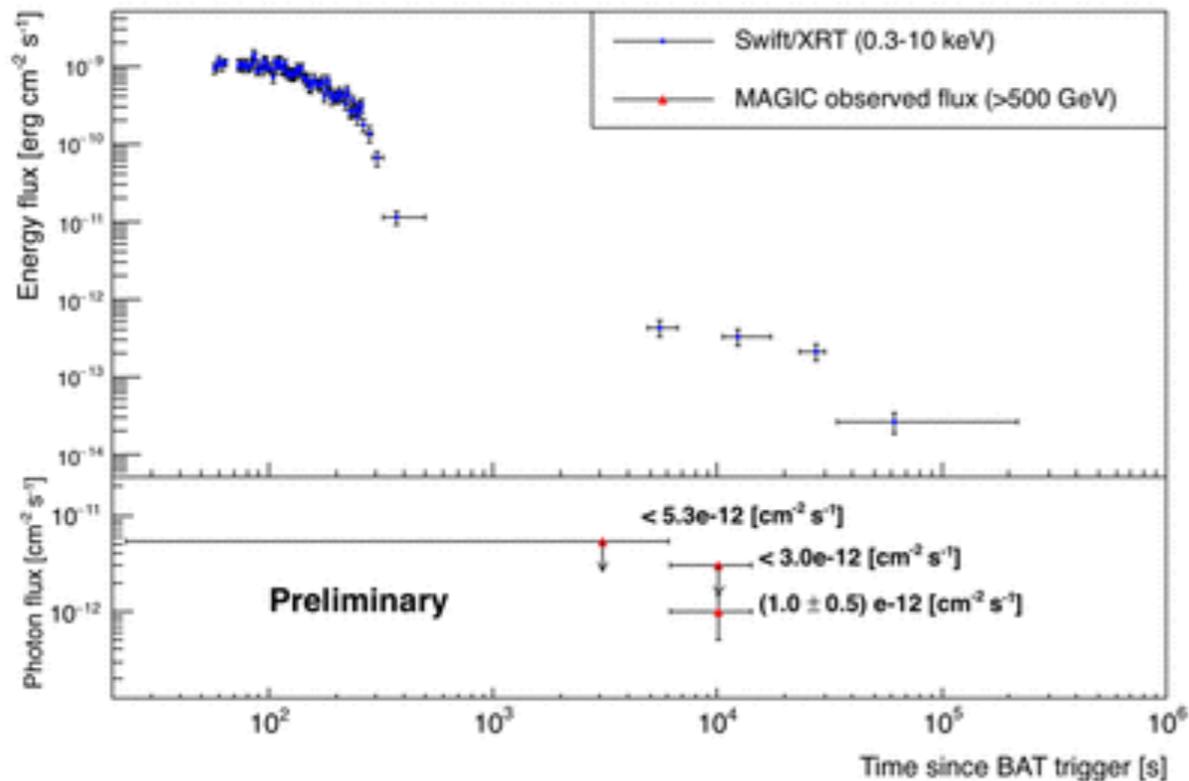
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GRB 160821B



- ★ Short GRB, very close by ($z = 0.16$)
- ★ t_0+24 s automatic follow-up → fastest follow-up from MAGIC!
- ★ $t_0+(24$ s - 1.5 h): $Z_d \sim 34-40^\circ$ poor weather NSB $\sim 3-5 \times$ dark
- ★ $t_0+(1.5 - 4$ h): $Z_d \sim 40-55^\circ$ good weather NSB $\sim 5-9 \times$ dark (higher Moon)
- ★ Three independent cross-check analyses: excess at GRB position ~ 3.0 sigma for $E > 500$ GeV (hot-spot significance ~ 4.0 sigma, off-set 0.05-0.09 deg - compatible with statistical uncertainty)

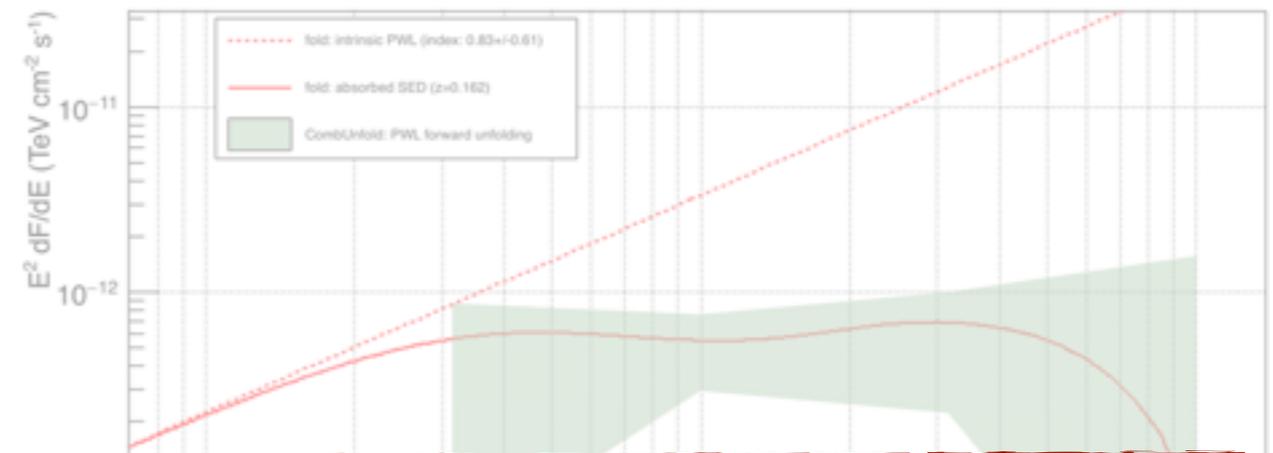
GRB 160821B



IF SIGNAL IS REAL:

- ★ energy flux > 500 GeV ~ 2 x energy flux in X-rays ~ 10⁴s after the trigger
→ suggest relatively shallow decay → analogous to X-ray plateau?
- ★ suggests a relatively hard spectrum → new spectral component beyond the synchrotron?

GRB 160821B



IF SIGNAL REAL:

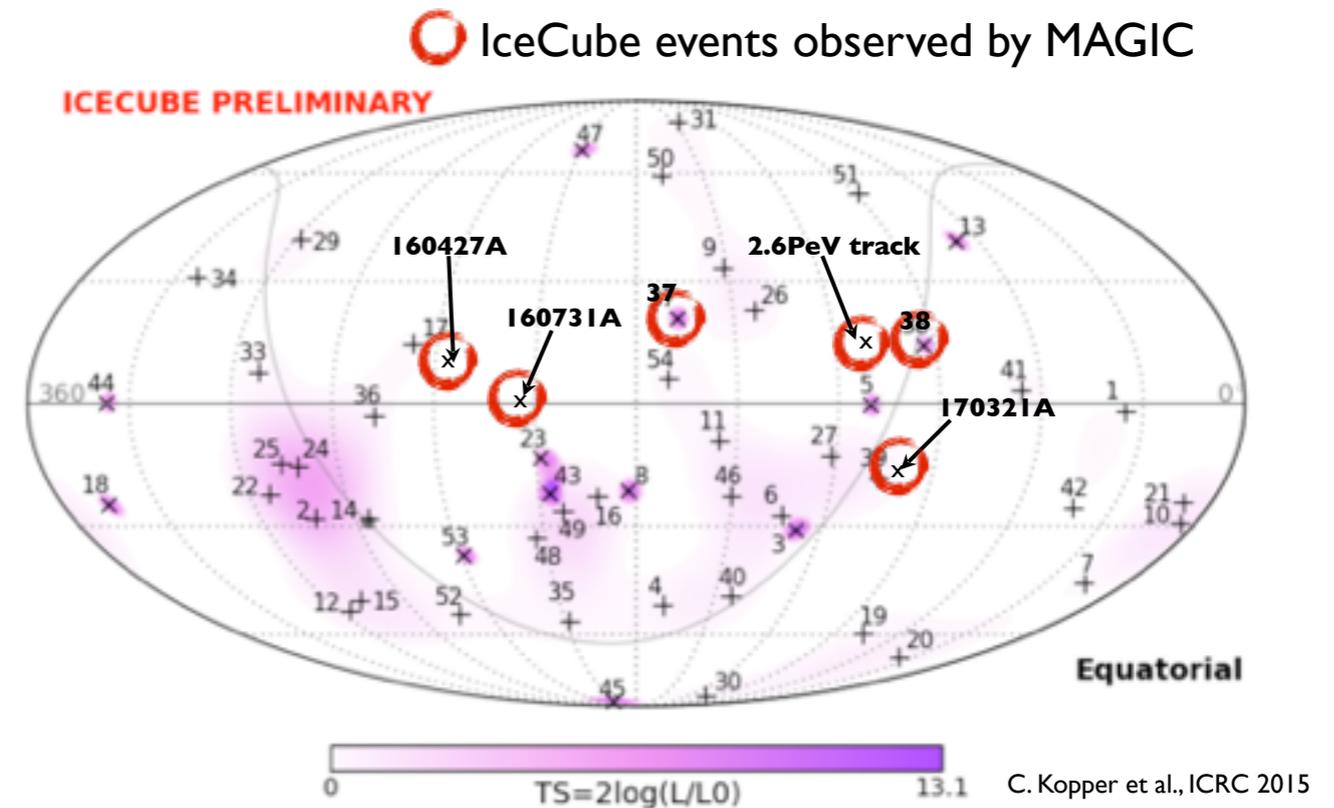
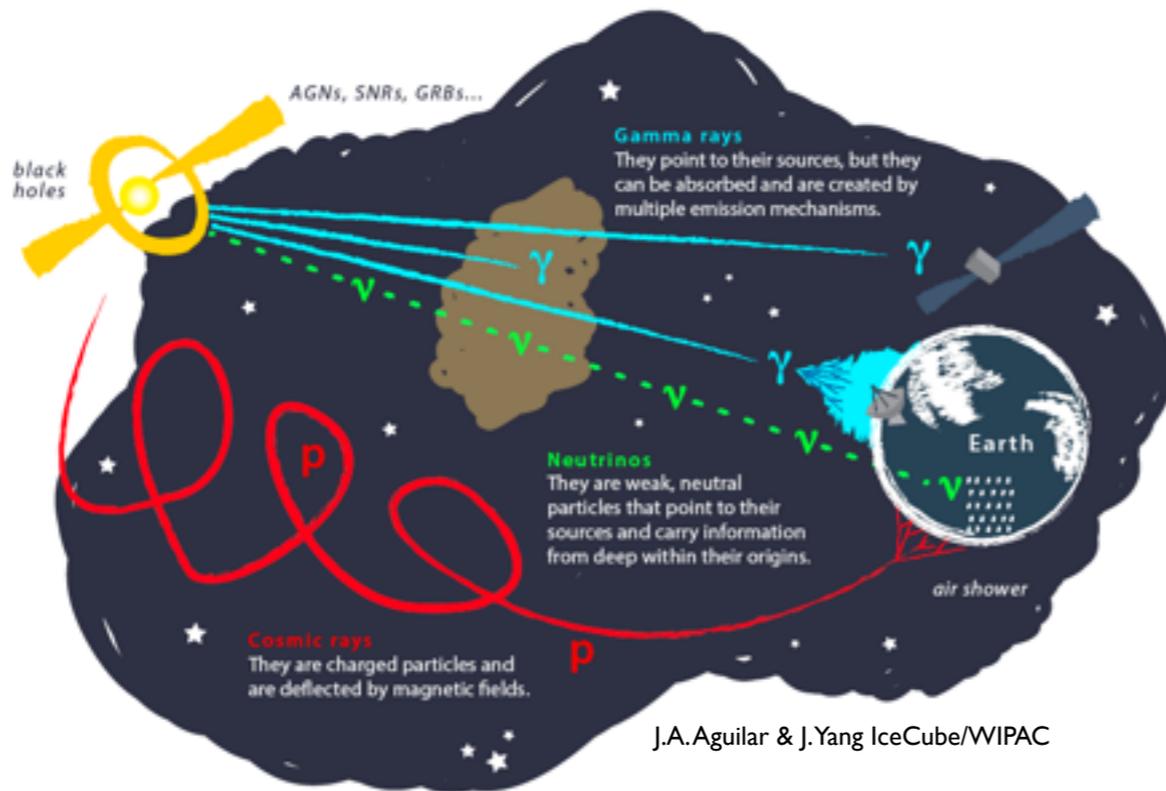
First GRB seen by an IACT!

First short GRB seen up to t₀ + 10⁴s > GeV

Second short GRB with known redshift seen > GeV

- ★ energy flux > 500 GeV ~ 2 x energy flux in X-rays at t₀ + 10⁴s → suggest relatively shallow decay → analogous to X-ray plateau?
- ★ suggests a relatively hard spectrum → new spectral component beyond the synchrotron?

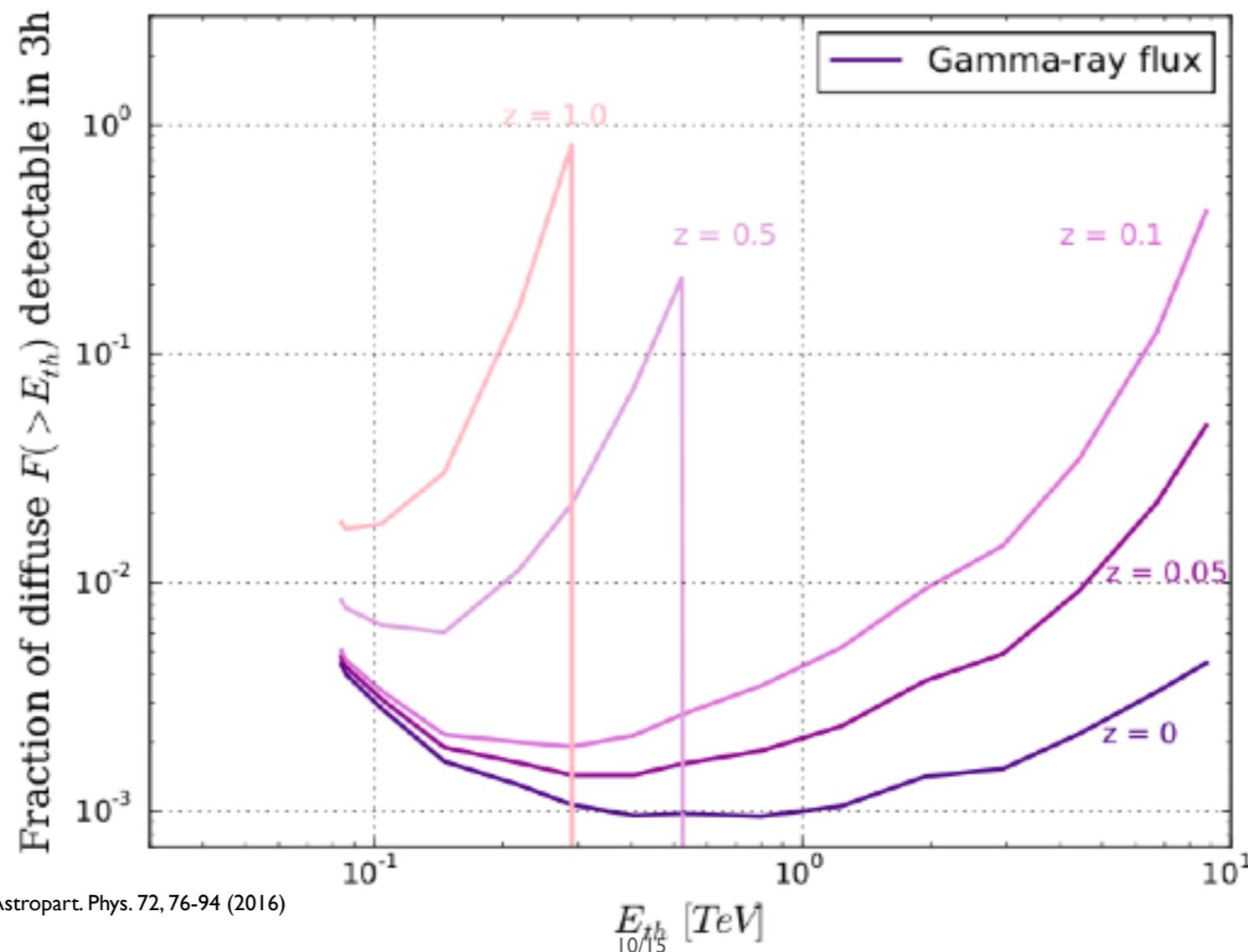
Neutrino follow-up



- ★ MAGIC participates in Gamma-ray Follow-Up (GFU) since 2012: 1 alert observed [JINST, 11, P11009 (2016)]
- ★ 3 archival nu-mu tracks: 2 HESE + multi-PeV track (“Kloppo”, ATel#7856)
- ★ 3 HESE/EHE real-time alerts: I60427A, I60731A, I70321A (AMON GCN Notices)
- ★ In total > 30 h observational time invested
- ★ New analysis procedure: off-axis flux UL calculation (“UL sky map”, also for GW)

Neutrino follow-up

- ★ Assumptions: p-p interactions and 1:1 neutrino: γ -ray flux ratio
- ★ Diffuse neutrino flux from: Phys. Rev. Lett 113, 101101 (2014)
- ★ Assumed spectral index 2.3 (still allowed by Fermi IGRB measurement [ApJ, 799, 1 (2015)])
- ★ All sources of equal strength and located at a redshift z , EBL absorption by Dominguez et al. 2011
- ★ MAGIC can limit the astrophysical flux at the level of \sim few \times 0.1% diffuse flux: \sim 1000 near-by, stable sources
- ★ Recent limits from IC: $>$ few \times 100 sources in the Northern Sky [arXiv:1609.04981]

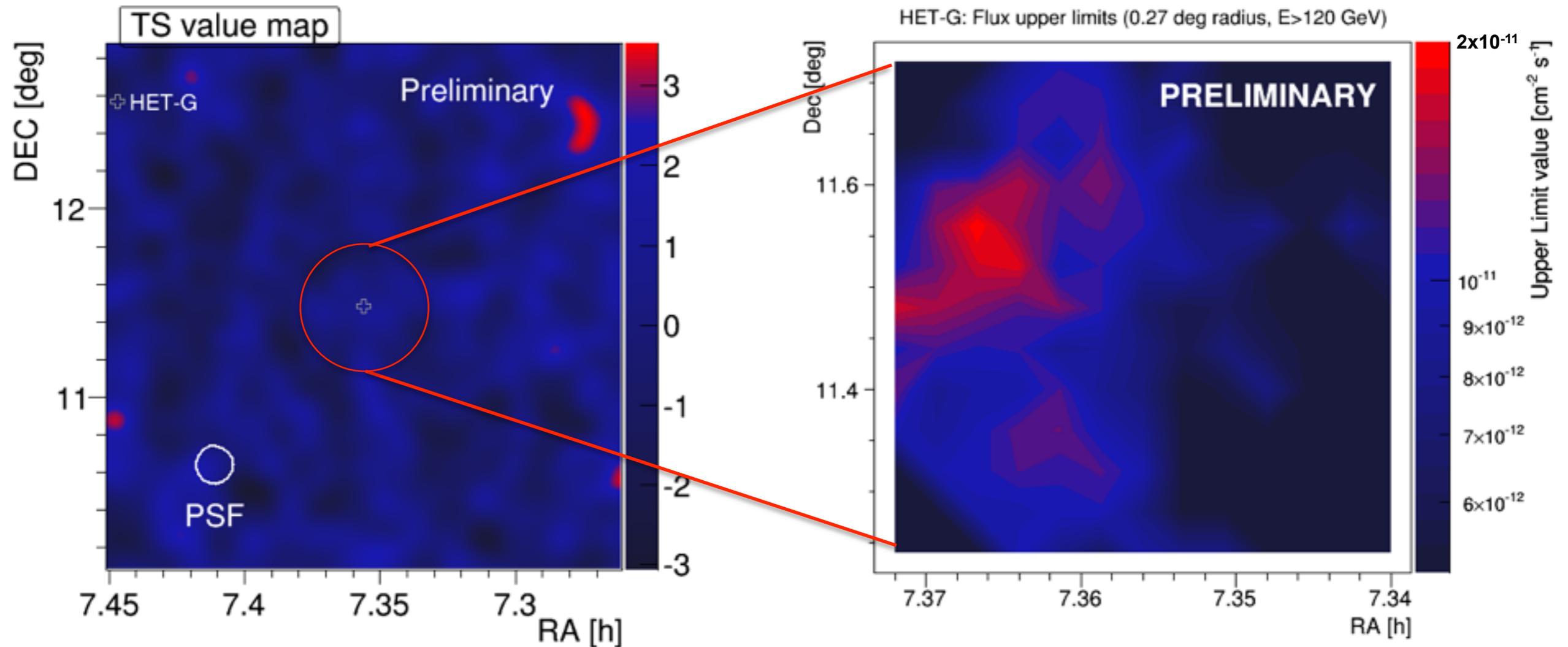


Example: 2-PeV track (ATel#7856)



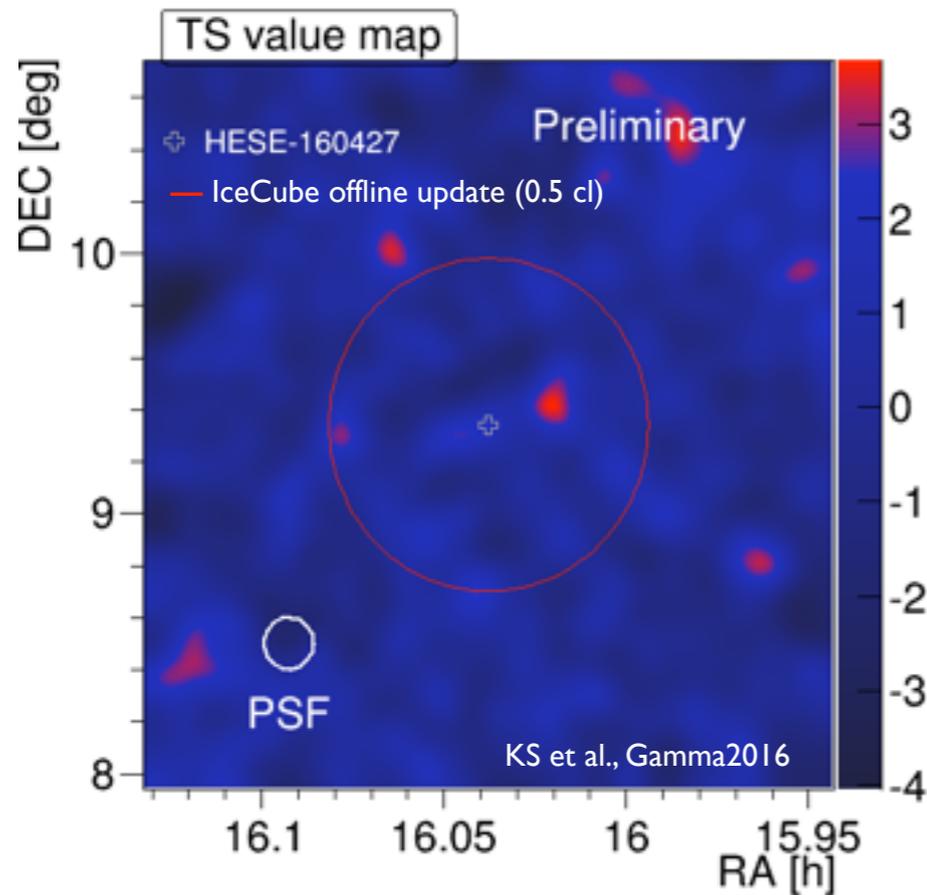
M. Santander et al., ICRC 2017

- ★ 11.5 h observations in March & December 2016
- ★ zenith 16 -38 deg
- ★ $E > 120$ GeV
- ★ Flux UL (95% C.L., $a=2.0$): $(0.6-2) \times 10^{-11} \text{ cm}^{-2}\text{s}^{-1}$ ($\sim 2-7\%$ C.U.)



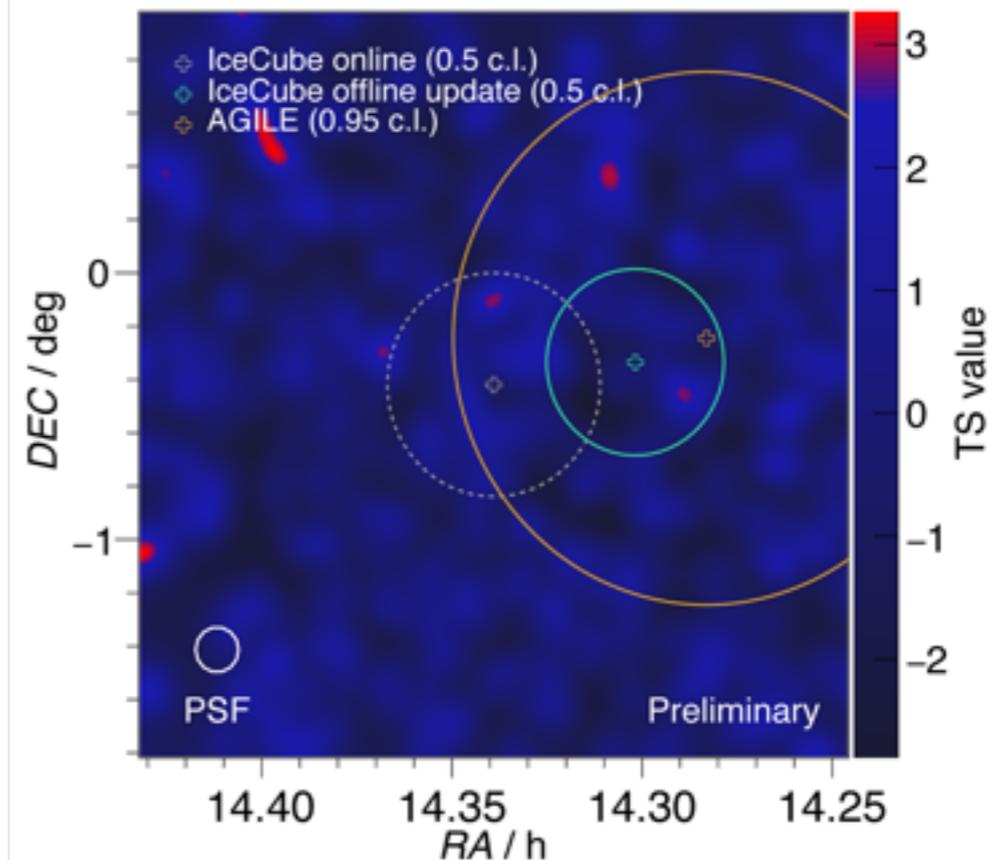
➔ All-IACTs nu-track observation paper in preparation!

Example: HESE/EHE alerts



HESE-160427A

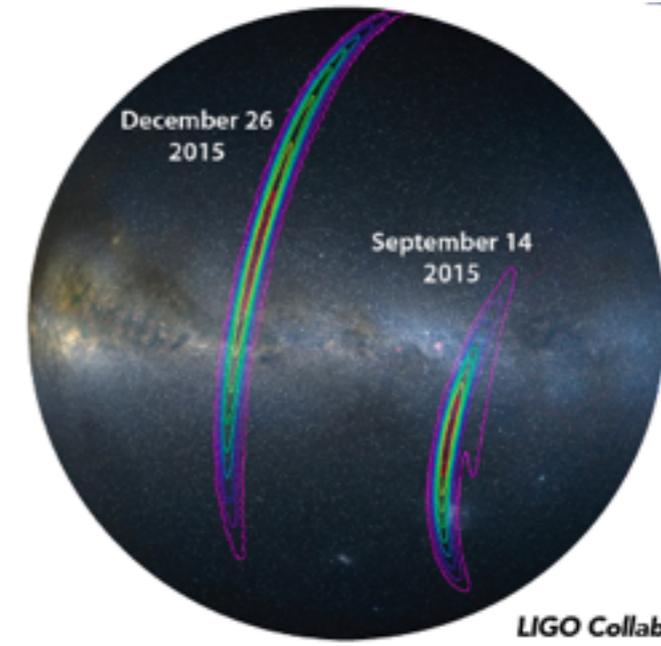
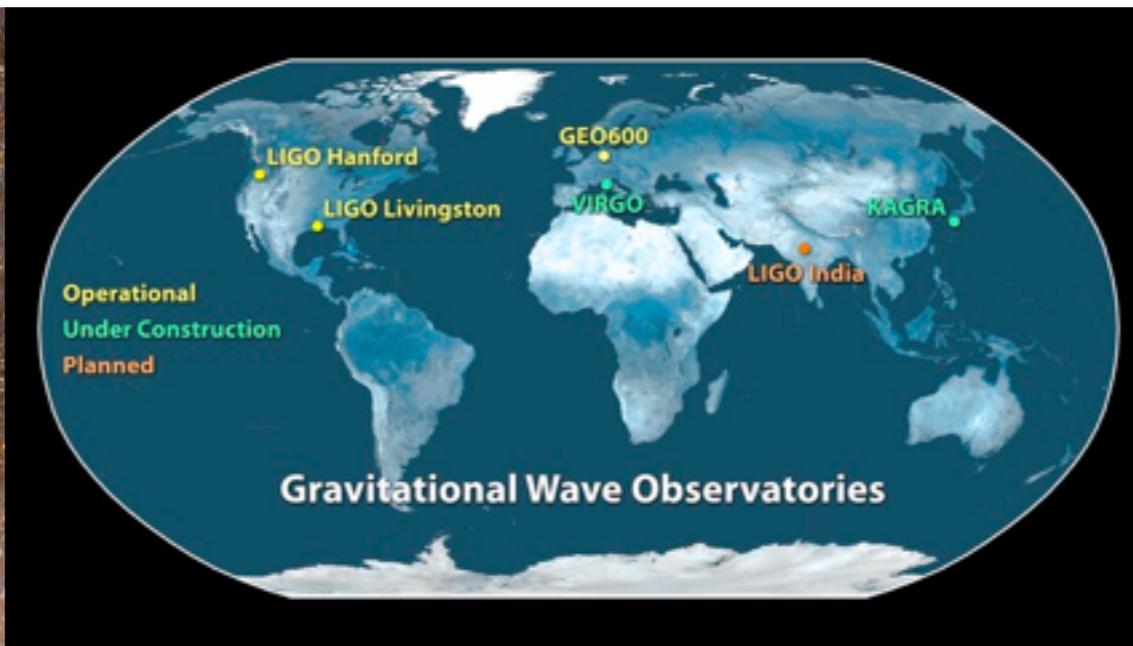
- ★ 2h data taken on 29/04/2016 (delay ~ 42h) with moderate moon (updated position)
- ★ night 27/28 Apr not possible - Moon too bright
- ★ zenith range: 18-26 deg
- ★ E threshold ~120 GeV
- ★ hot spot 0.3 deg away, significance: ~ 3.6 sigma (2.1 sigma after trials)
- ★ UL - analysis ongoing...



HESE/EHE-160731A

- ★ 1.3h taken on 2016-07-31 21:31 UTC (delay ~16 h)
- ★ Calima = sand from Sahara, low atmospheric transmission :(
- ★ Zenith range: 45-65 deg
- ★ E threshold ~800 GeV
- ★ no signal found
- ★ no significant excess at the AGL J1418+0008 position
- ★ 2016-08-04: ATel #9315

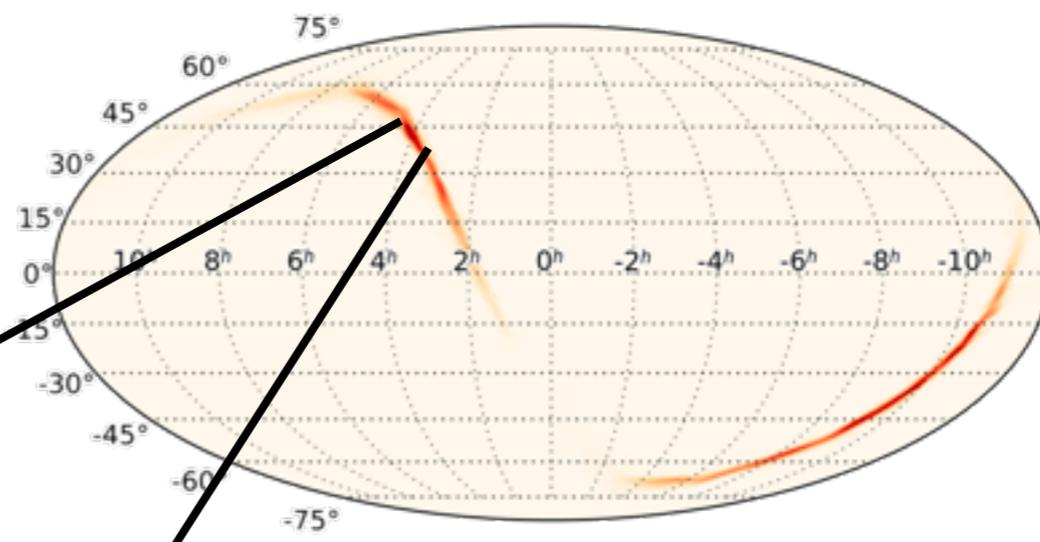
Gravitational Waves follow-up



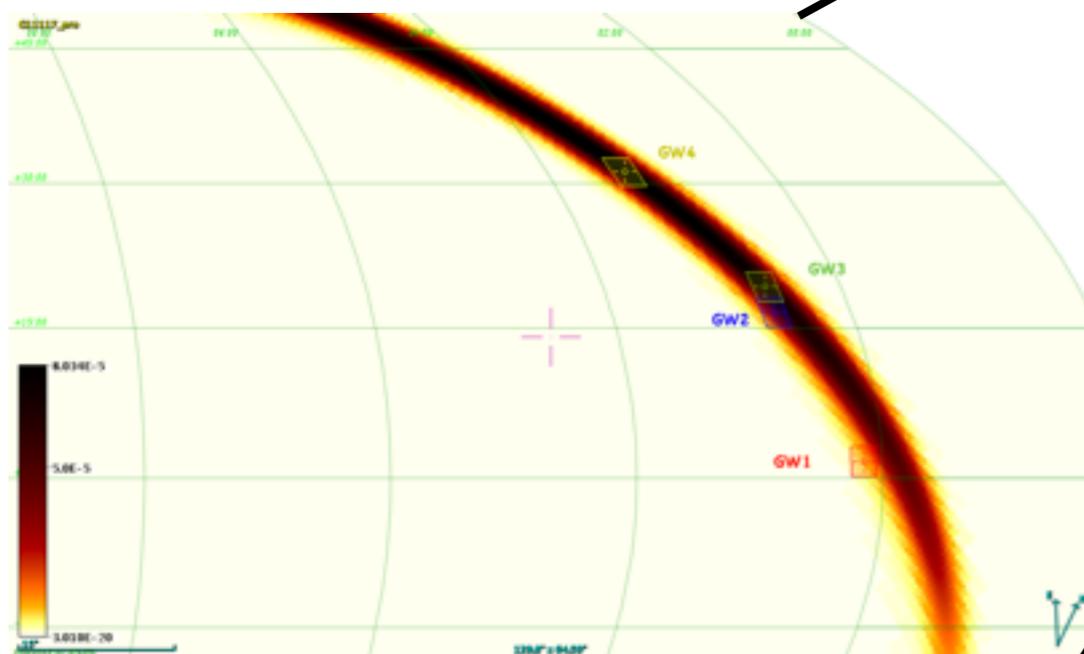
- ★ EM counterpart observations hold a key role in: localizing the GW source and constraining the physical nature of these transient events
- ★ LV still looking for first NS–NS detection: an EM counterpart could test neutron star – neutron star merger as the progenitor of a short GRB [e.g. Bartos et al., 2014]
- ★ MAGIC advantages: fast slewing, the best sensitivity at ≤ 100 GeV in γ -ray; caveat: small FoV
 - ➔ could provide important information on the GW counterpart in an energy range not affected by selective absorption processes typical of other wavelengths
- ★ MAGIC joined the LIGO/Virgo call for identification and follow-up of electromagnetic counterparts of gravitational wave candidate events in 2014
- ★ First direct observation, merger of two stellar–mass BH (GW150914) MAGIC could not observe it (out of visible region)
- ★ Second GW alert (GW151226) - observed! [B. de Lotto, Black Holes 2016]

GW151226

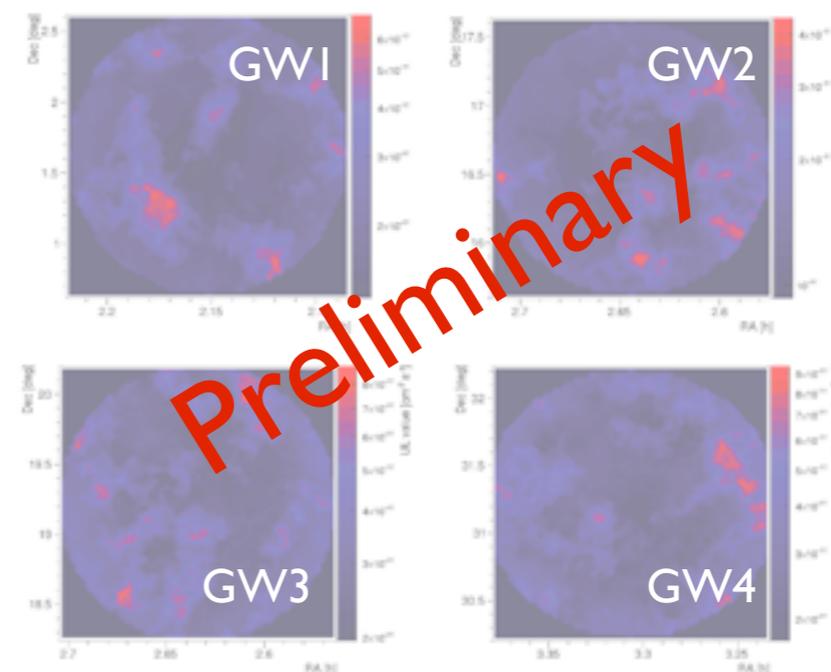
- ★ T_0 : 2015-12-26 03:38:53.648 UT internal GCN circular
- ★ T_{Notice} : 2015-12-27 17:40:00 UT
- ★ T_{Start} : 2015-12-28 21:00:00 UT
- ★ Probability sky-map: 50% (90%) $\sim 430 \text{ deg}^2$ (2200 deg^2)
- ★ False Alarm Rate passing threshold $\sim 1/\text{month}$
(later refined to $< 1/100$ years)



Four sky pointed positions selected by hand in the region showing maximum probability according to the visibility, observations of EM-partners and overlap with existing catalogs (GCN #18776, Stamerra et al.)



No significant emission detected



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



GW151226: first MAGIC follow-up

- Four sky pointed positions selected by hand in the region showing maximum probability according to the visibility, observations of EM-partners and overlap with existing catalogs
(GCN #18776, Stamerra et al.)

GW 1: PGC1200980 (OT MASTER GCN#18729)

RA,Dec (J2000): 02:09:05.8, +01:38:03.0

Duration: 42 min

GW 2: strip from GW map

RA,Dec (J2000): 02:38:38.93, +16:36:59.27

Duration: 56 min (moonlight conditions)

GW 3: Field VST (GCN#18734)

RA,Dec (J2000): 02:38:02.208, +19:13:12.00

Duration: 28 min (moonlight conditions)

GW 4: Field VST (GCN#18734)

RA,Dec (J2000): 03:18:23.712, +31:13:12.00

Duration: 30 min (moonlight conditions)

