



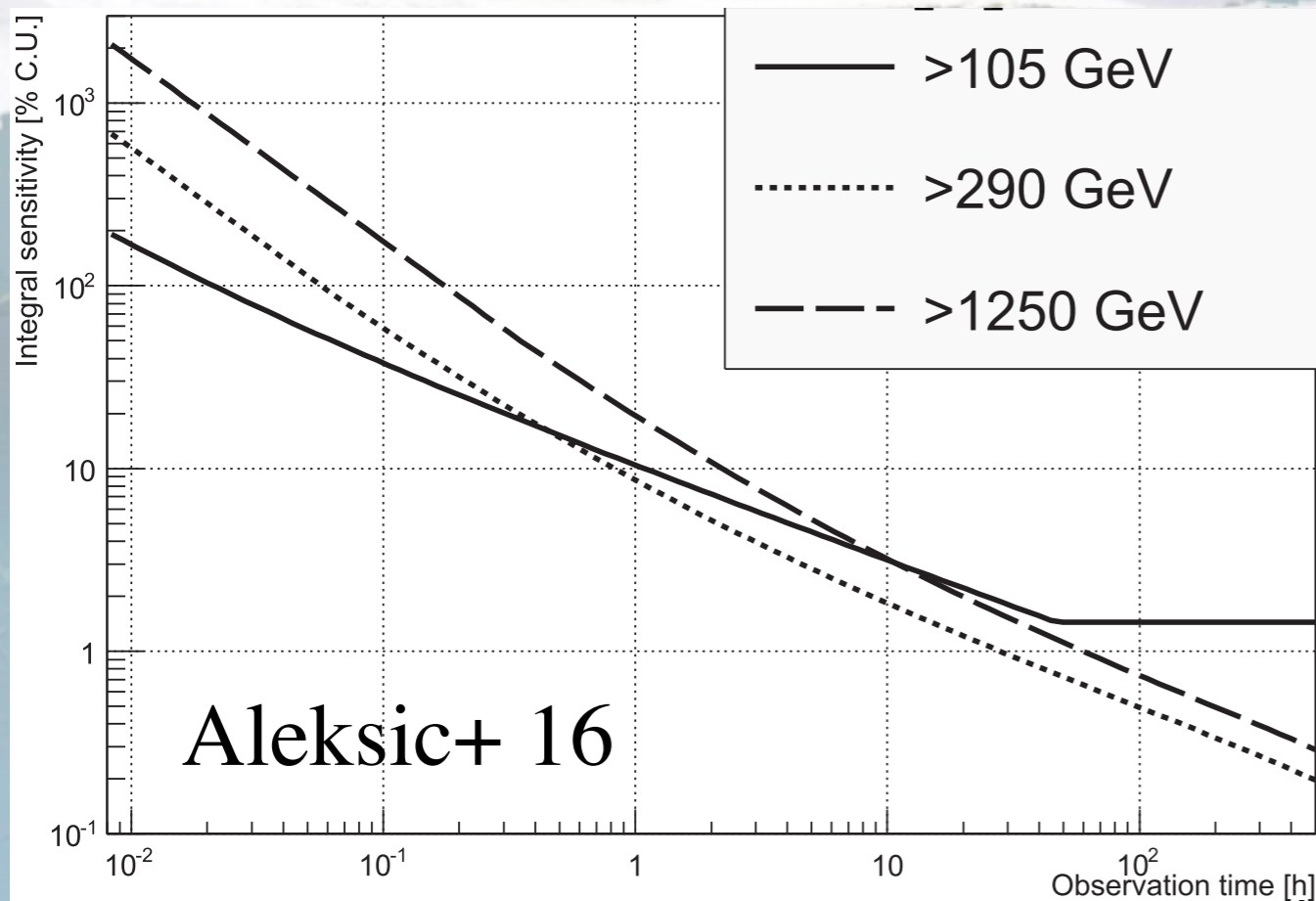
# The MAGIC Transient & MM Program

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:  $3.5^\circ$  (LV PMT)
- ★ Energy range:  $\sim 50$  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:  $\sim 70$  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
- ★ Sensitivity: 10% Crab in 1h > 100 GeV



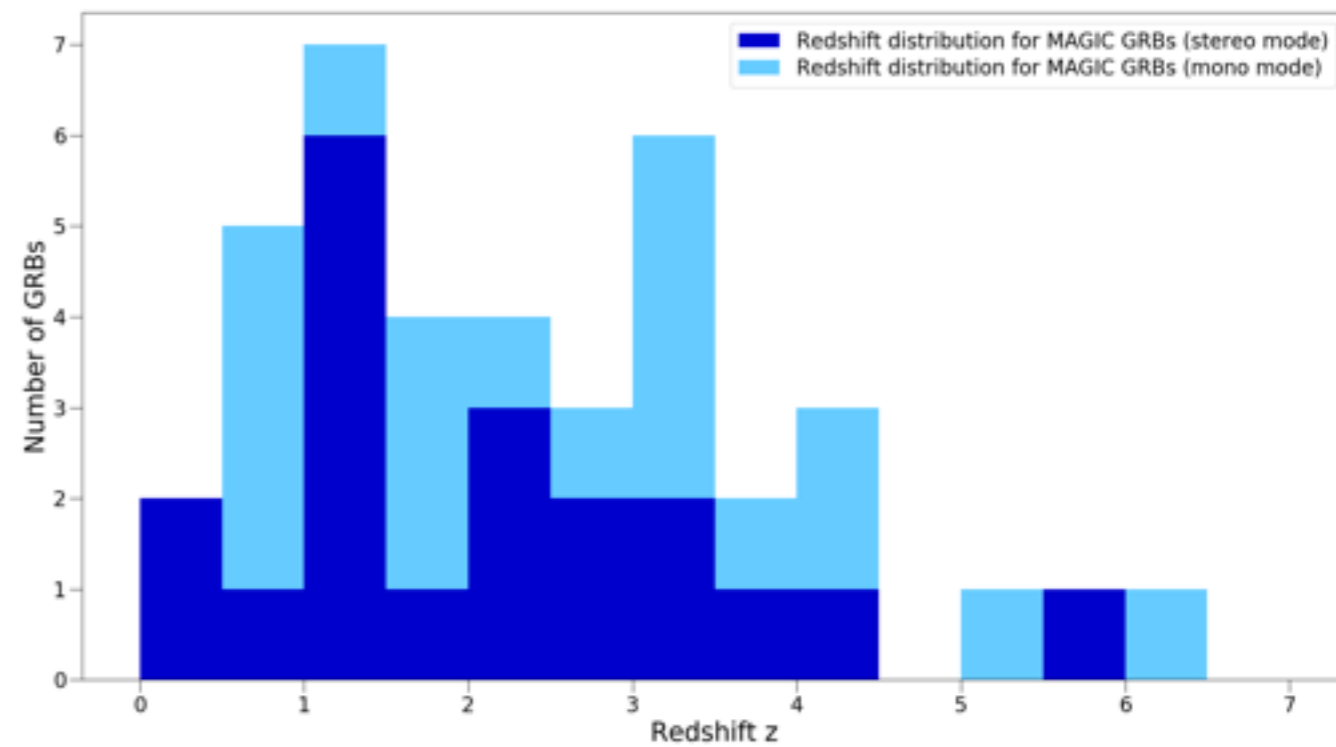
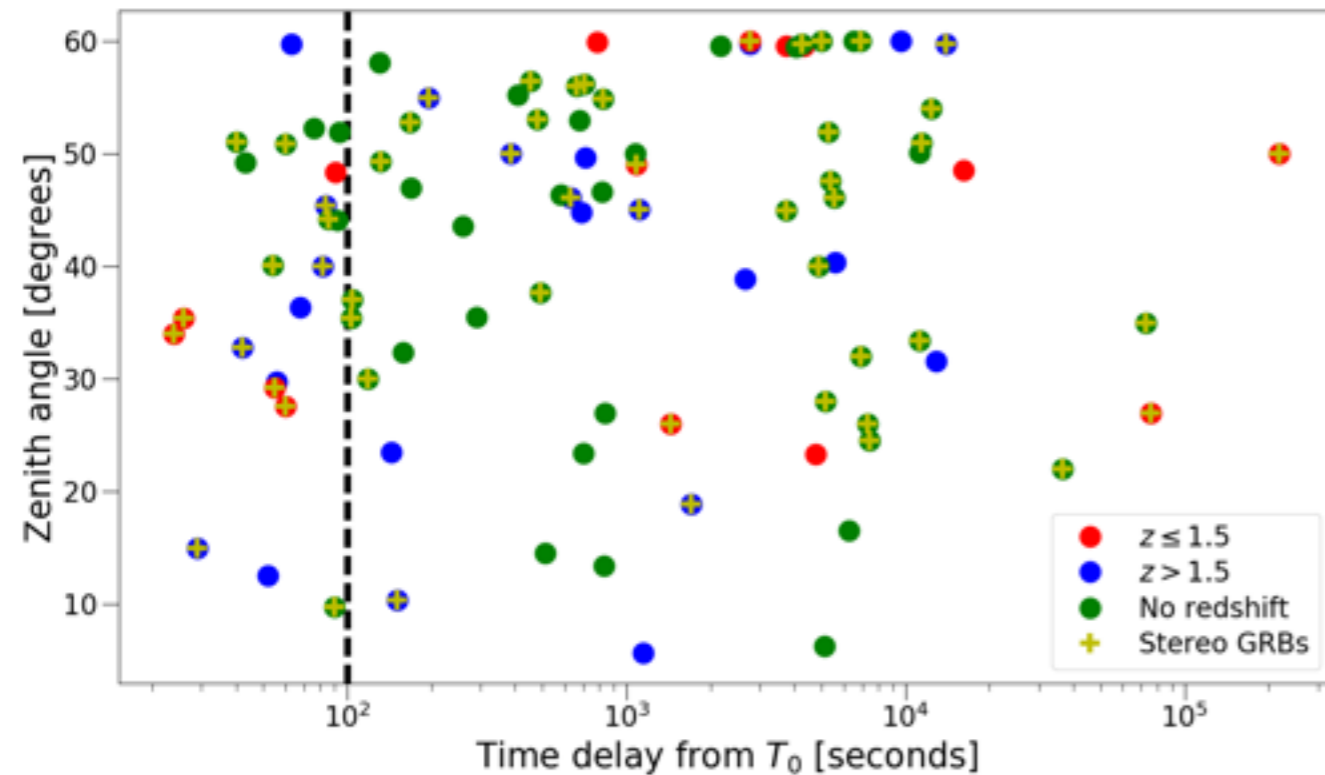
# MAGIC transient searches



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

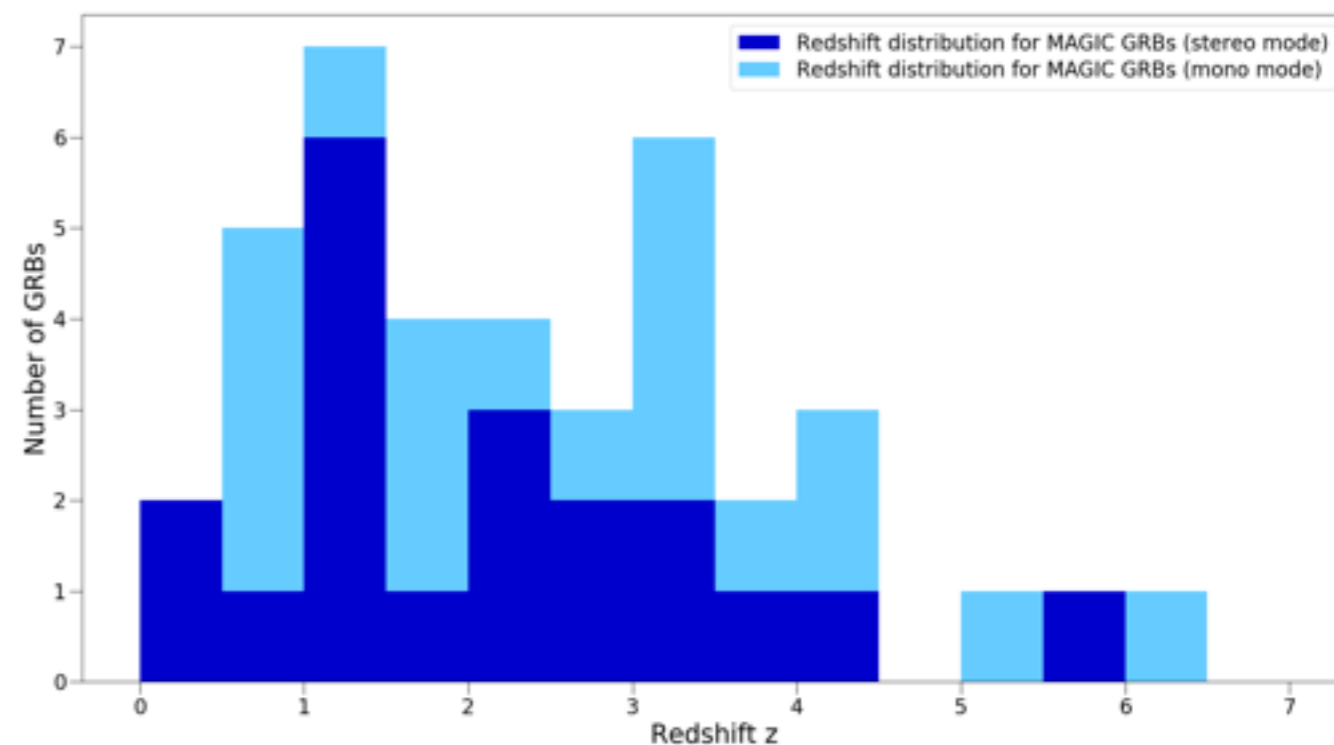
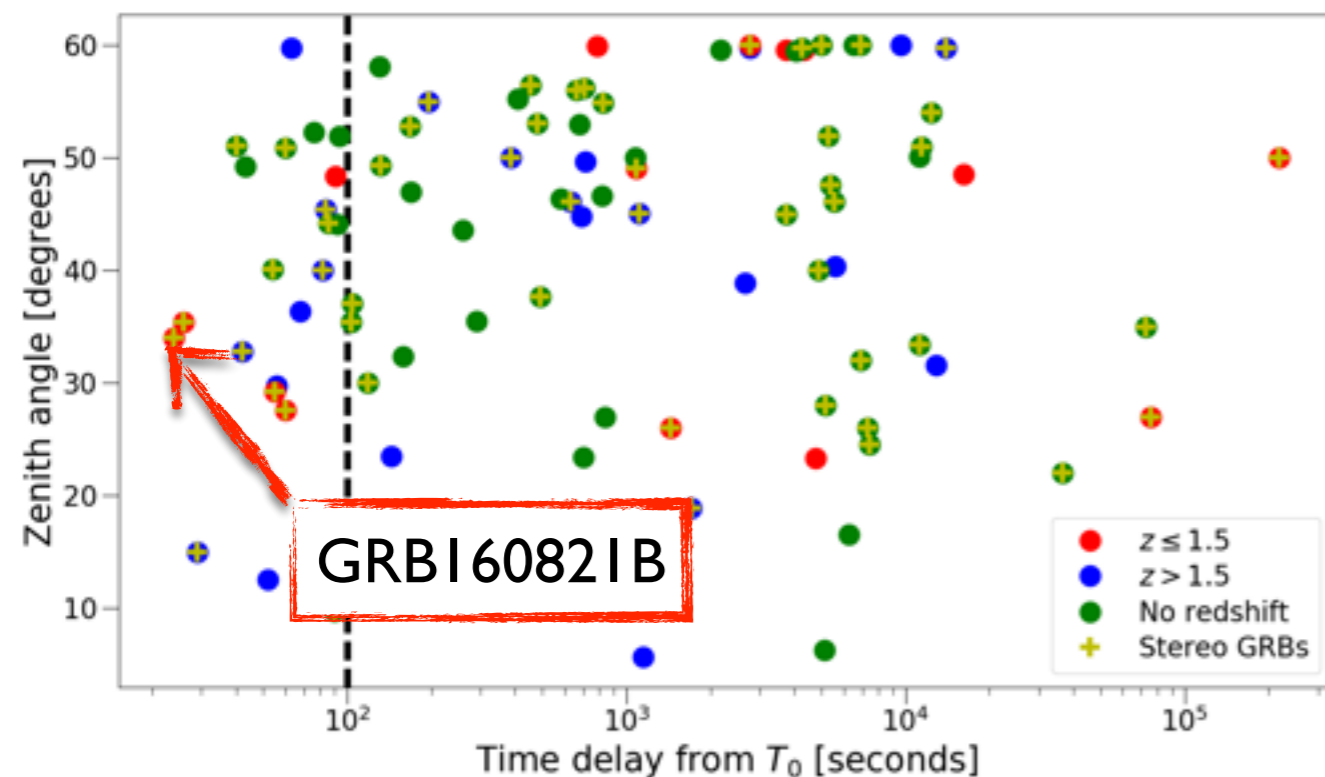
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# MAGIC GRB follow-up



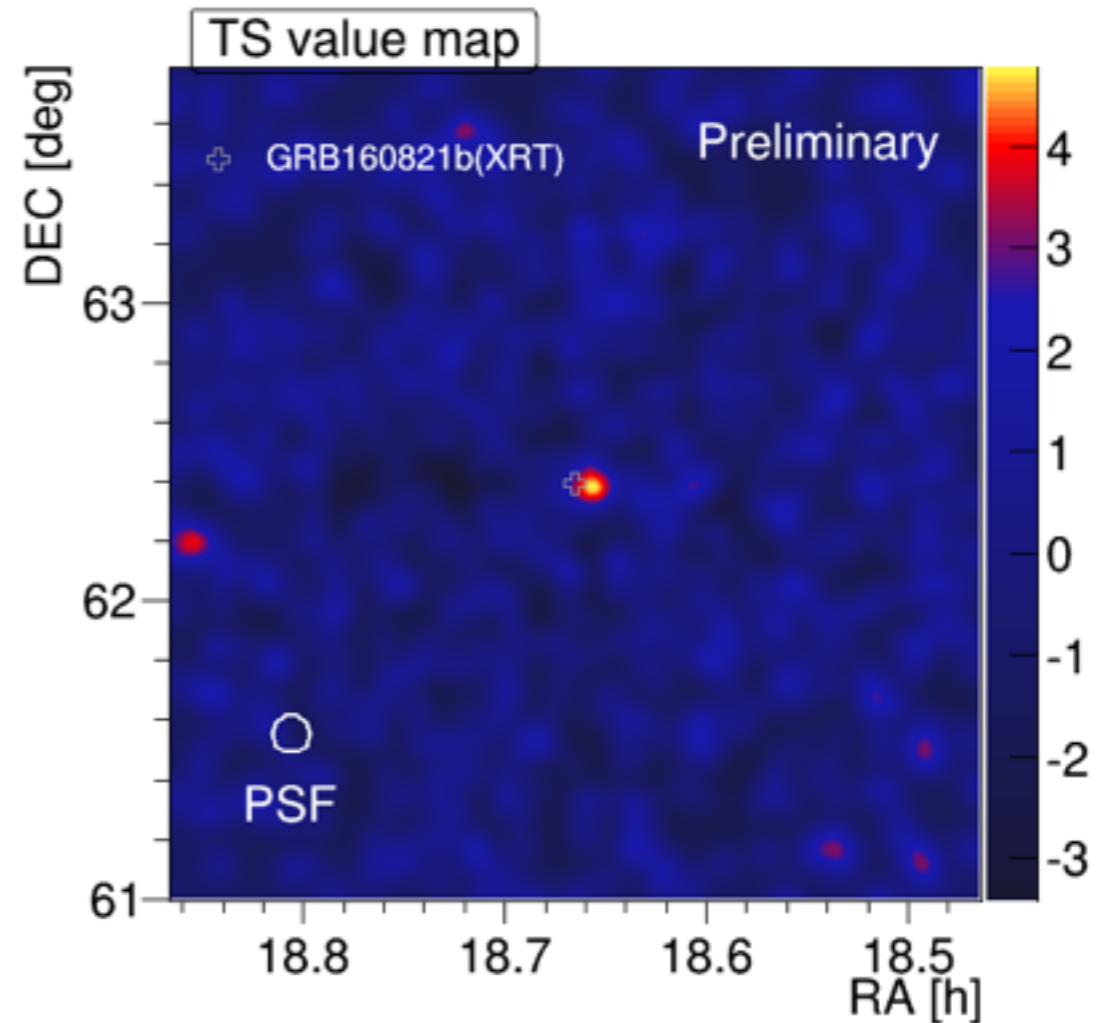
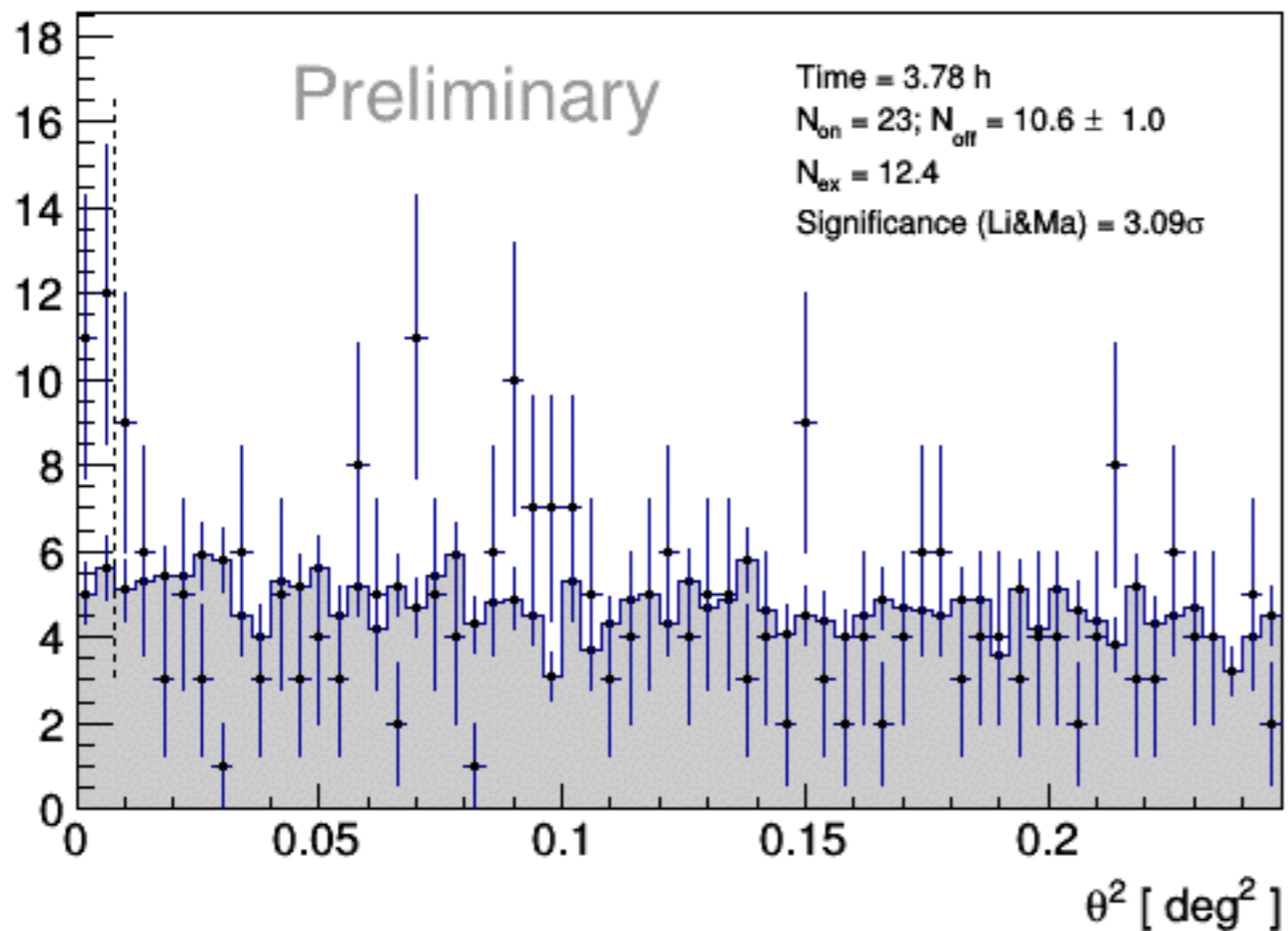
- ★ Key Observational Program - each year  $> 50$ h invested
- ★ 96 GRBs observed so far, mono + stereo (includes bad weather, moon-time and high- $z$  GRBs)
- ★ 39 with known redshift, 15 with  $z < 1.5$
- ★ Fast repositioning: 22 with delay  $< 100$  s!
- ★ New follow-up procedure, including late-time 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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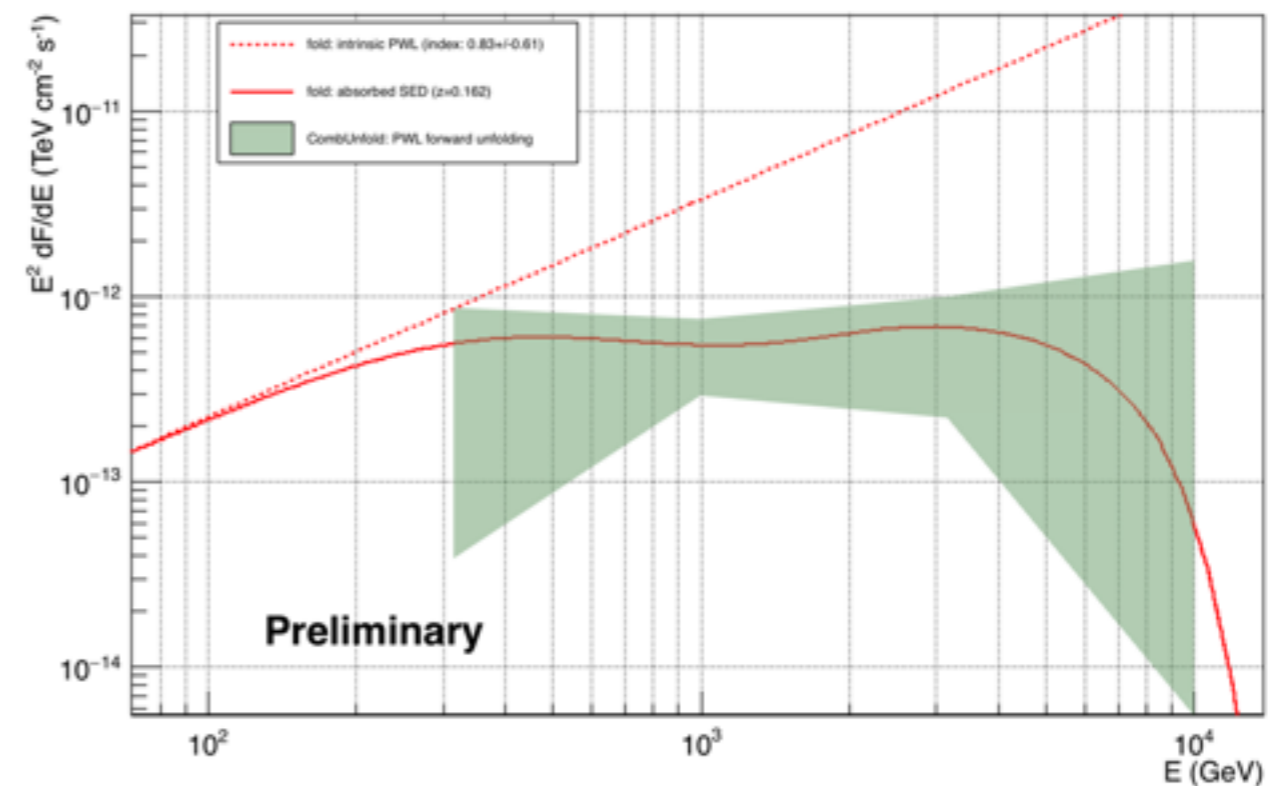
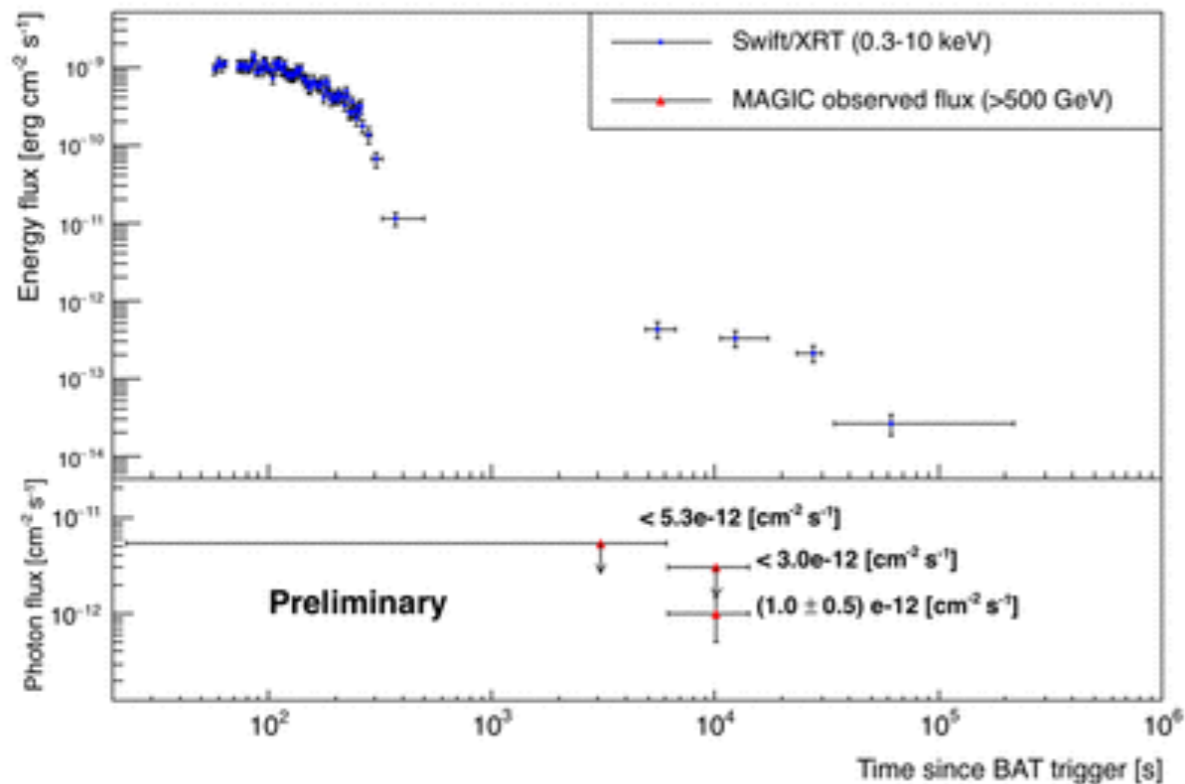
# GRB 160821B



- ★ 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  $\sim 3.0$  sigma for  $E > 500$  GeV (hot-spot significance  $\sim 4.0$  sigma, off-set 0.05-0.09 deg - compatible with statistical uncertainty)



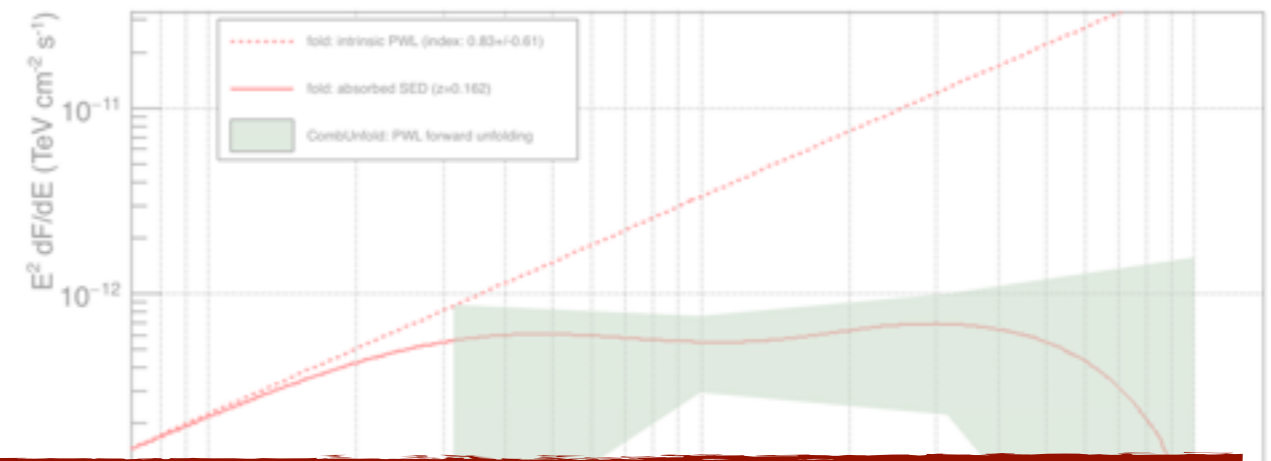
# GRB 160821B



## IF SIGNAL IS REAL:

- ★ energy flux  $> 500$  GeV  $\sim 2 \times$  energy flux in X-rays  $\sim 10^4$ s 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!**

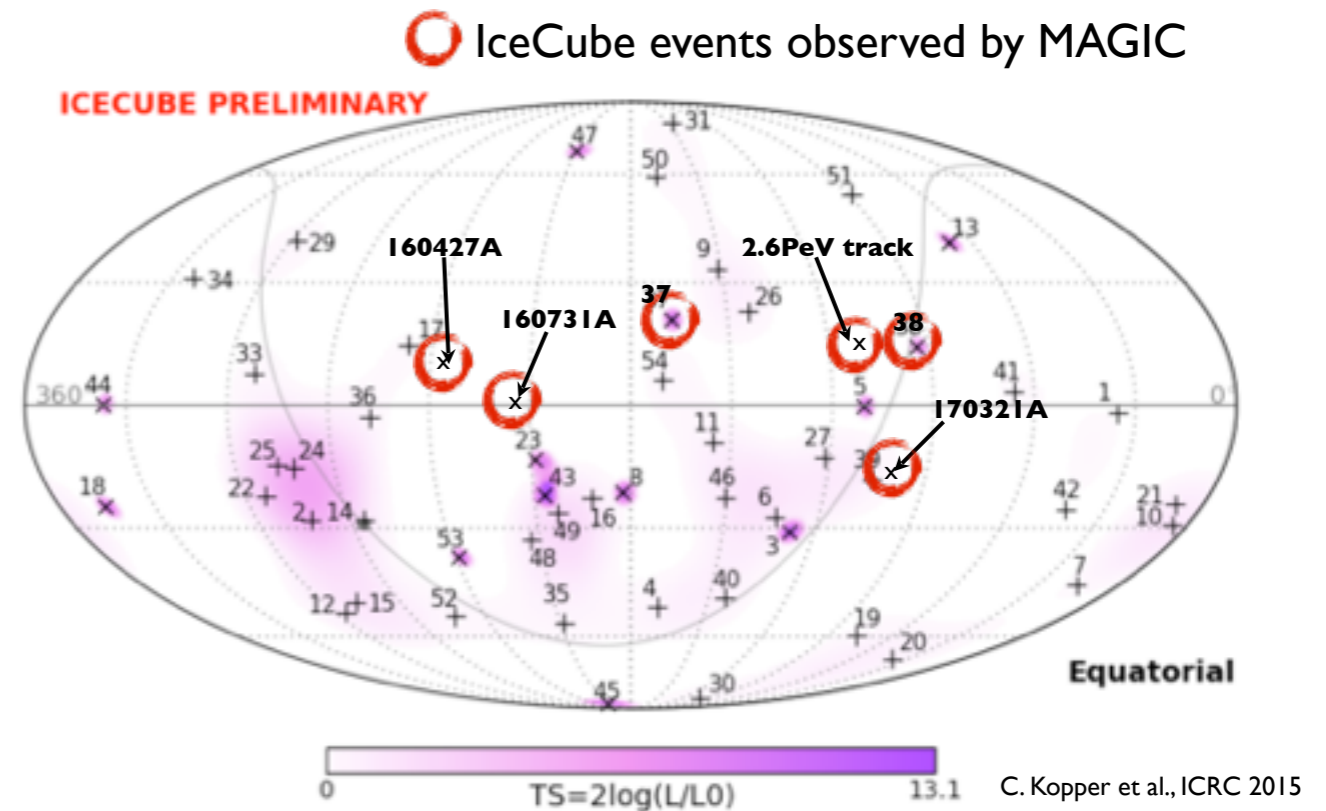
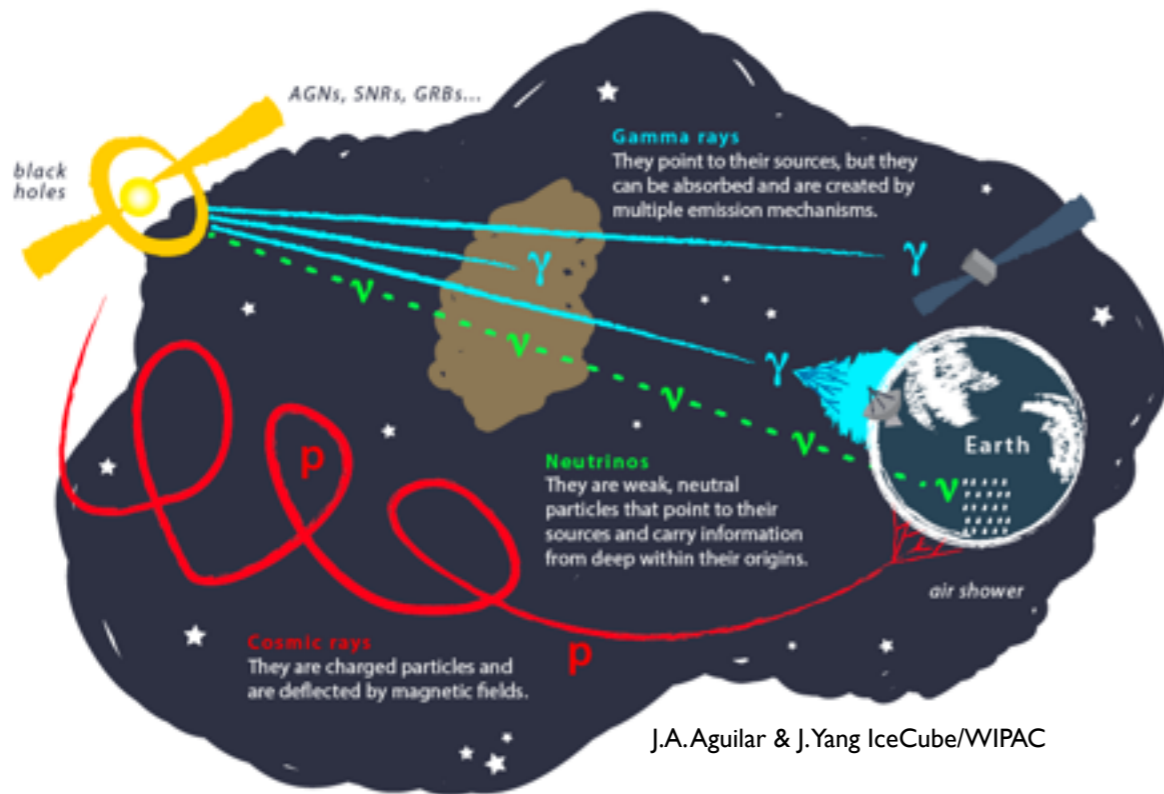
**First short GRB seen up to t<sub>0</sub>+10<sup>4</sup>s > GeV**

**Second short GRB with known redshift seen > GeV**

- ★ energy flux > 500 GeV ~ 2 x energy flux in X-rays at t<sub>0</sub> + 10<sup>4</sup>s → suggest relatively shallow decay → analogous to X-ray plateau?
- ★ suggests a relatively hard spectrum → new spectral component beyond the synchrotron?



# Neutrino follow-up

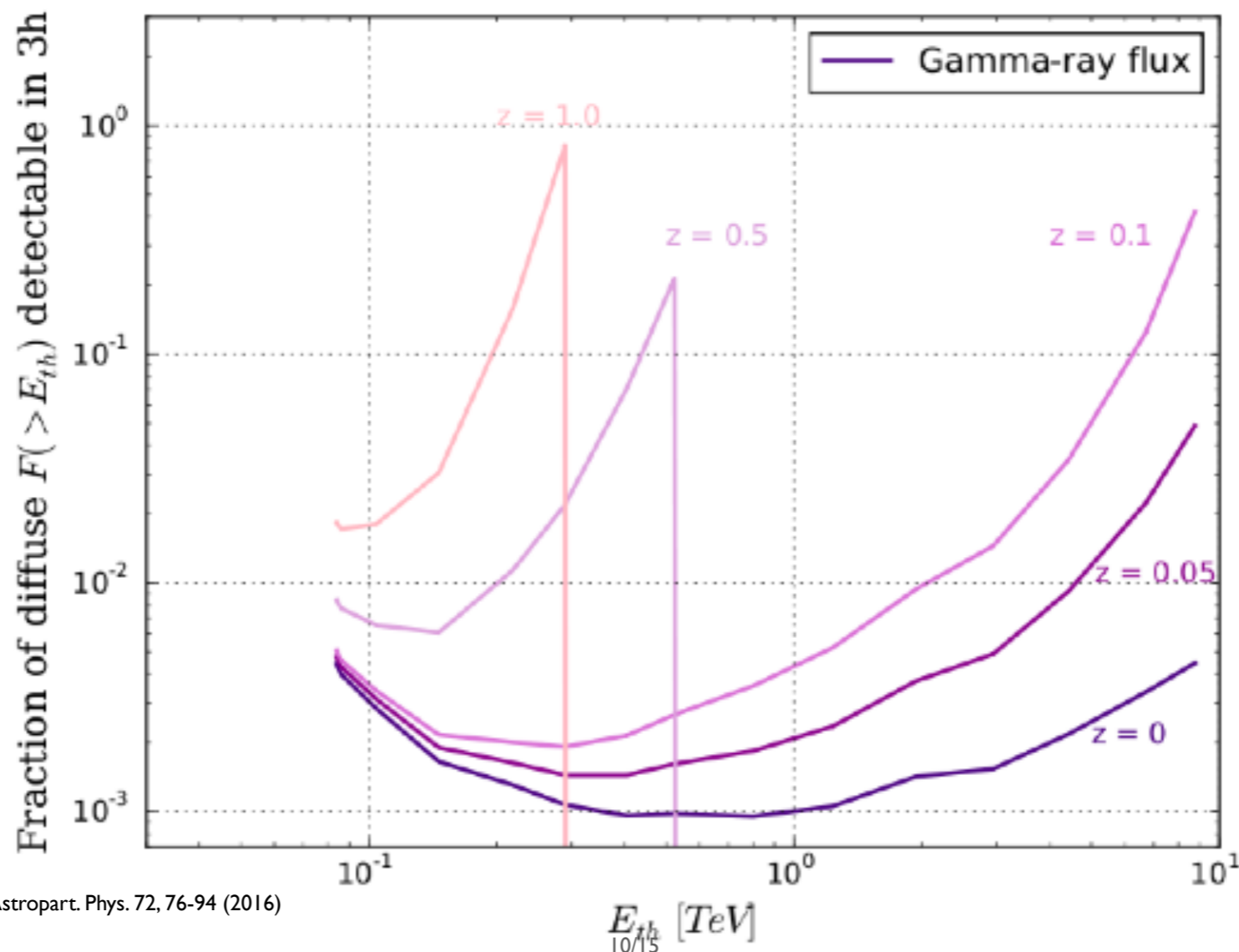


- ★ MAGIC participates in Gamma-ray Follow-Up (GFU) since 2012: 1 alert observed [JINST, 11, P11009 (2016)]
- ★ 3 archival nu-mu tracks: 2 HESE + multi-PeV track (“Kloppo”, ATel#7856)
- ★ 3 HESE/EHE real-time alerts: 160427A, 160731A, 170321A (AMON GCN Notices)
- ★ In total > 30 h observational time 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:  $\gamma$ -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]

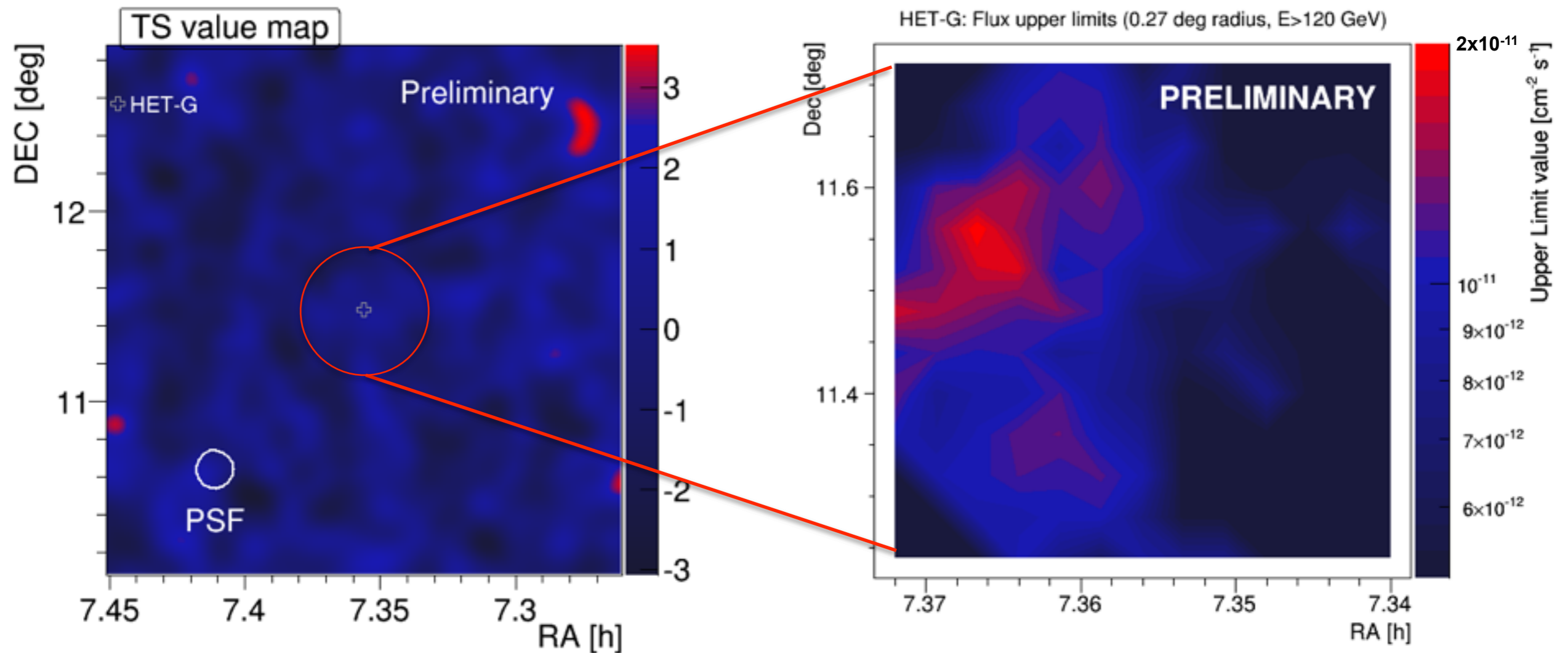


# Example: 2-PeV track (ATel#7856)



M. Santander et al., ICRC 2017

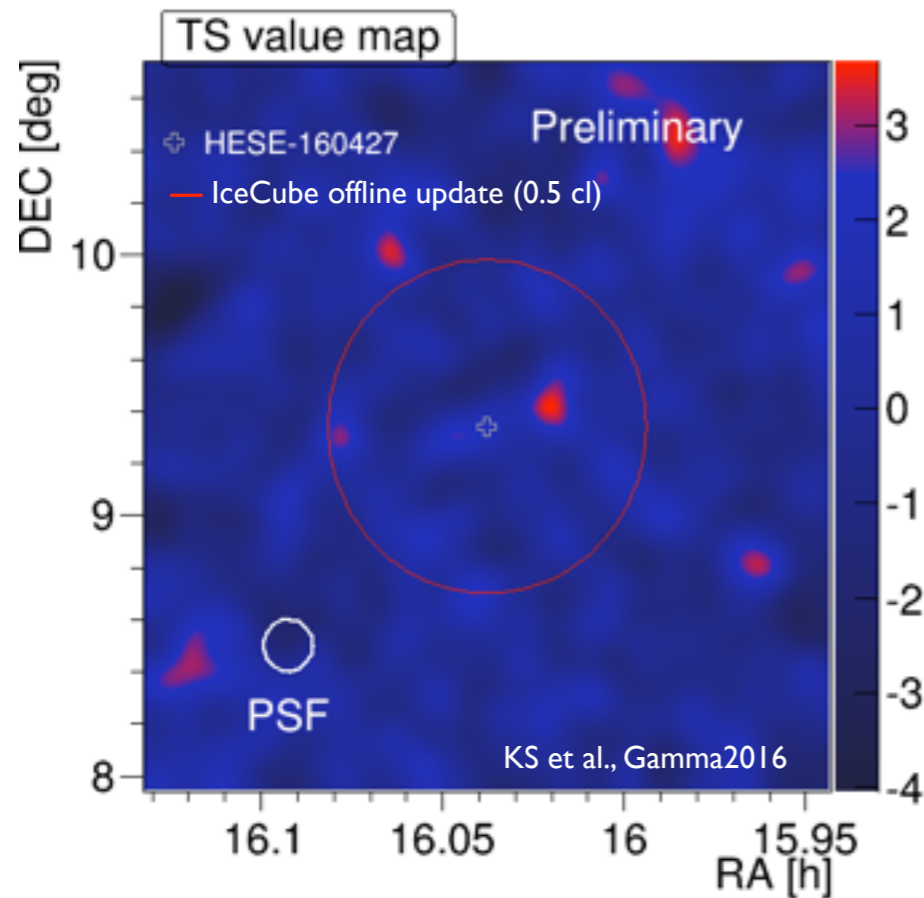
- ★ 11.5 h observations in March & December 2016
- ★ zenith 16 -38 deg
- ★  $E > 120$  GeV
- ★ Flux UL (95% C.L.,  $a=2.0$ ):  $(0.6-2) \times 10^{-11} \text{ cm}^{-2}\text{s}^{-1}$  ( $\sim 2-7\%$  C.U.)



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

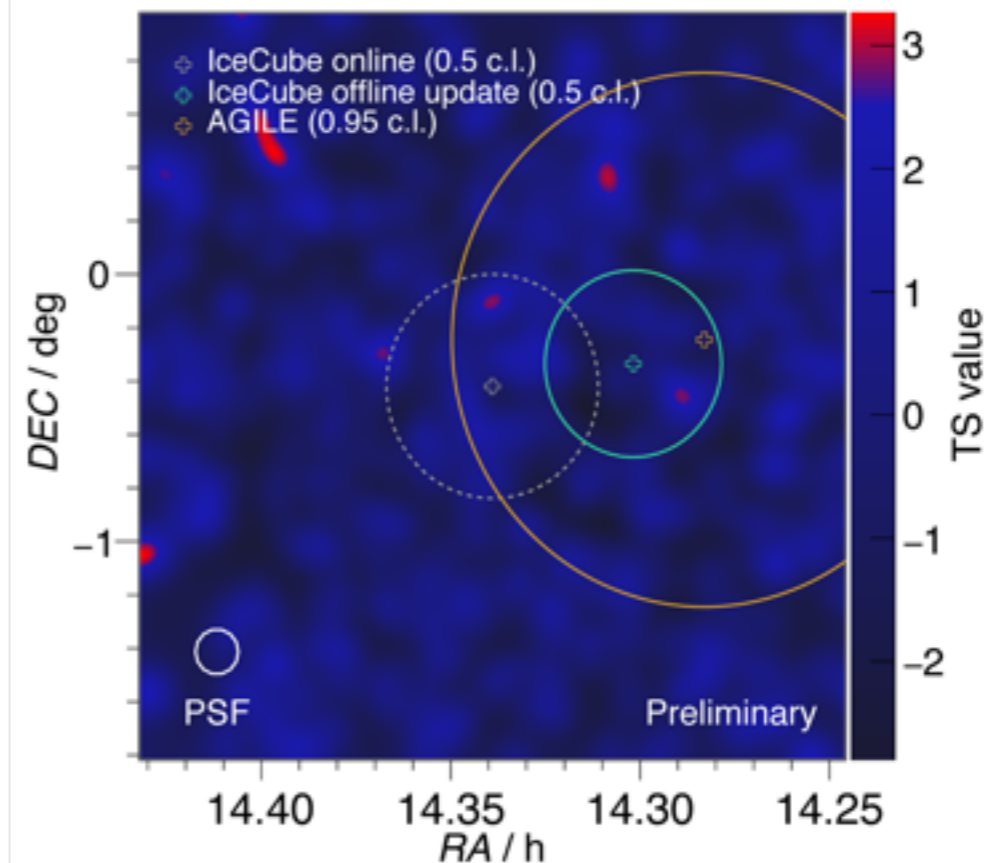


# Example: HESE/EHE alerts



## HESE-160427A

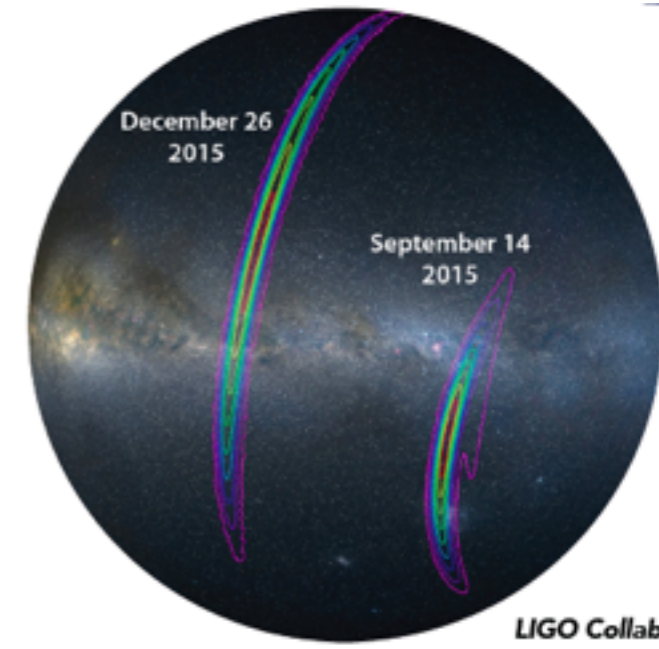
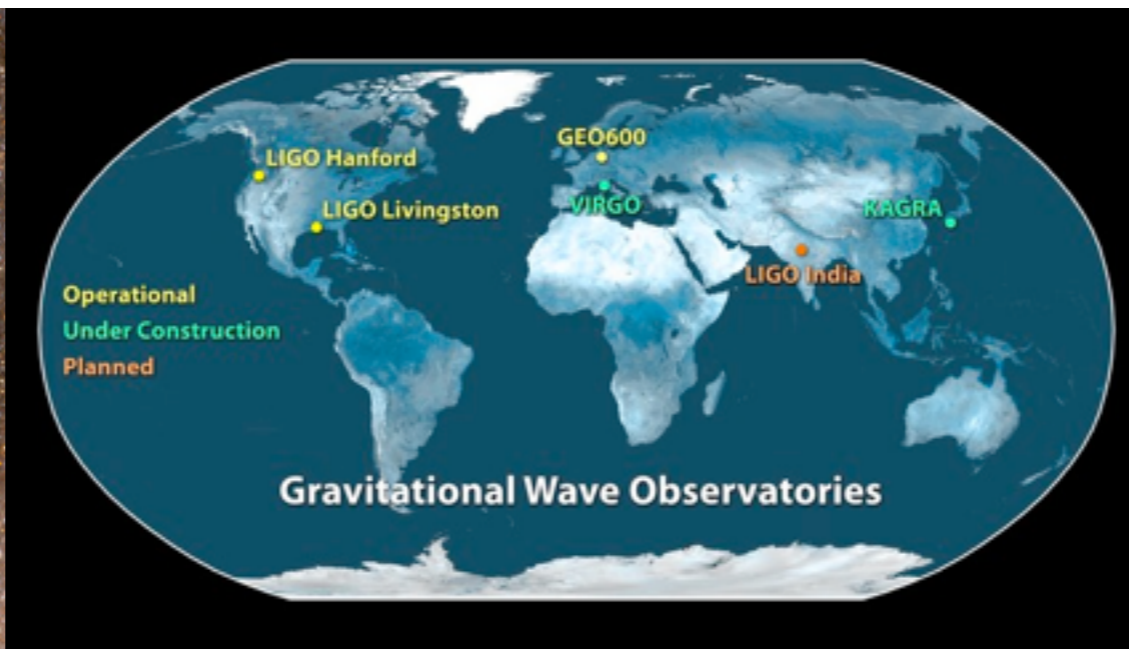
- ★ 2h data taken on 29/04/2016 (delay ~ 42h) with moderate moon (updated position)
- ★ night 27/28 Apr not possible - Moon too bright
- ★ zenith range: 18-26 deg
- ★ E threshold ~120 GeV
- ★ hot spot 0.3 deg away, significance: ~ 3.6 sigma (2.1 sigma after trials)
- ★ UL - analysis ongoing...



## 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

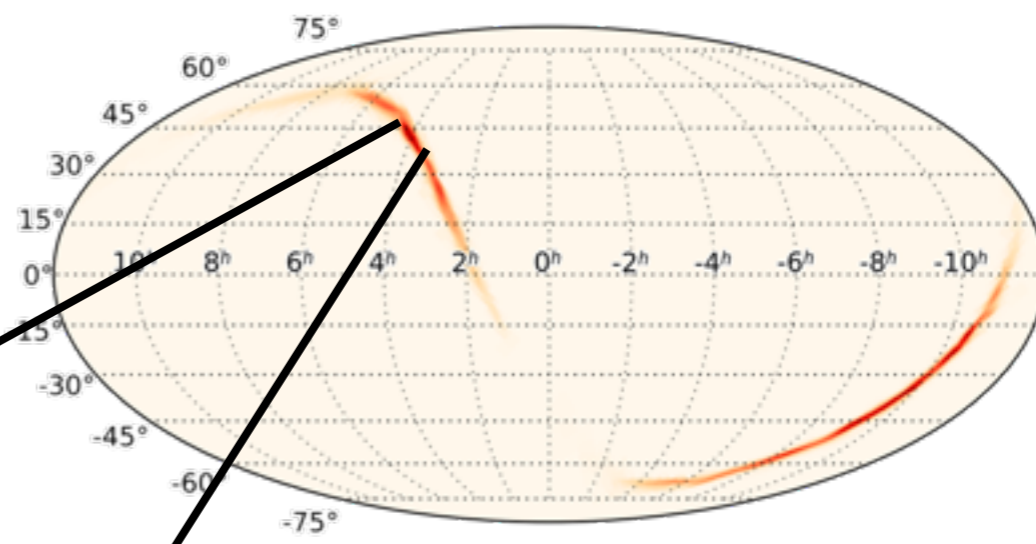
# Gravitational Waves follow-up



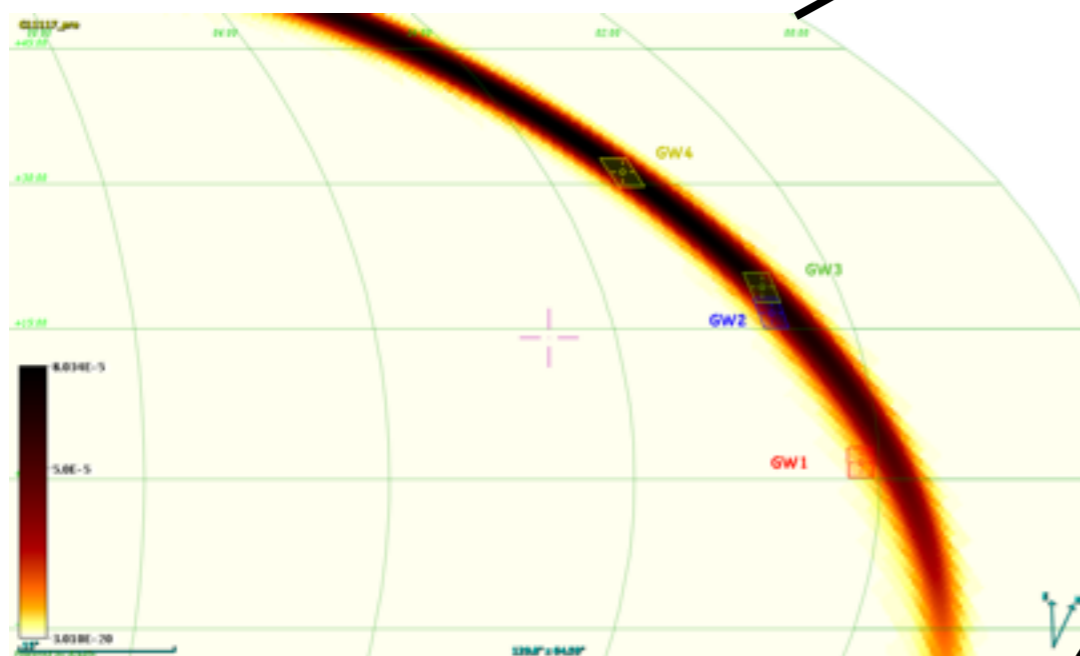
- ★ EM counterpart observations hold a key role in: localizing the GW source and constraining the physical nature of these transient events
- ★ LV still looking for first NS–NS detection: an EM counterpart could test neutron star – neutron star merger as the progenitor of a short GRB [e.g. Bartos et al., 2014]
- ★ MAGIC advantages: fast slewing, the best sensitivity at  $\leq 100$  GeV in  $\gamma$ -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

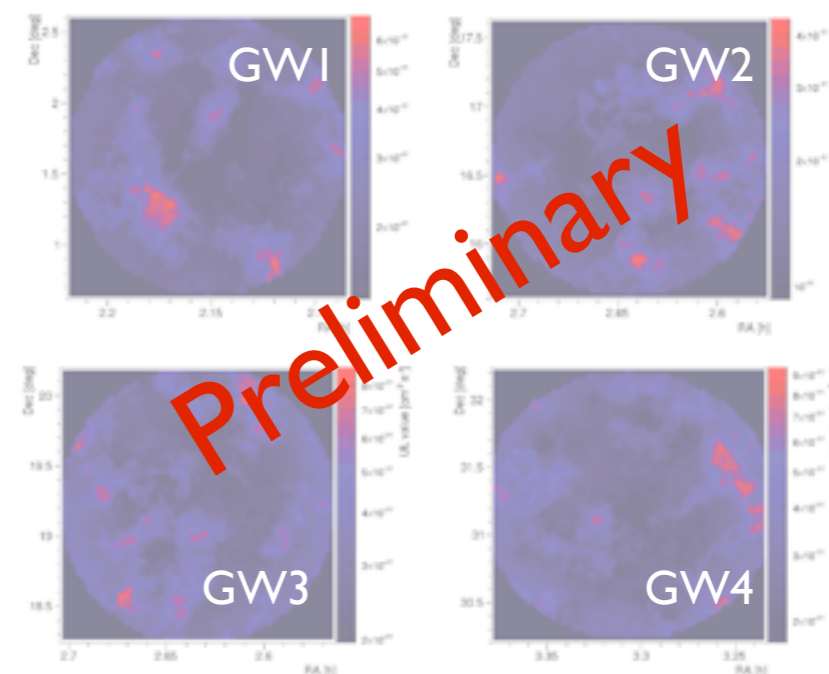
- ★  $T_0$ : 2015-12-26 03:38:53.648 UT internal GCN circular
- ★  $T_{\text{Notice}}$ : 2015-12-27 17:40:00 UT
- ★  $T_{\text{Start}}$ : 2015-12-28 21:00:00 UT
- ★ Probability sky-map: 50% (90%)  $\sim 430 \text{ deg}^2$  (2200  $\text{deg}^2$ )
- ★ False Alarm Rate passing threshold  $\sim 1/\text{month}$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

