



The MAGIC MultiMessenger Program

Konstancja Satalecka for the MAGIC Collaboration

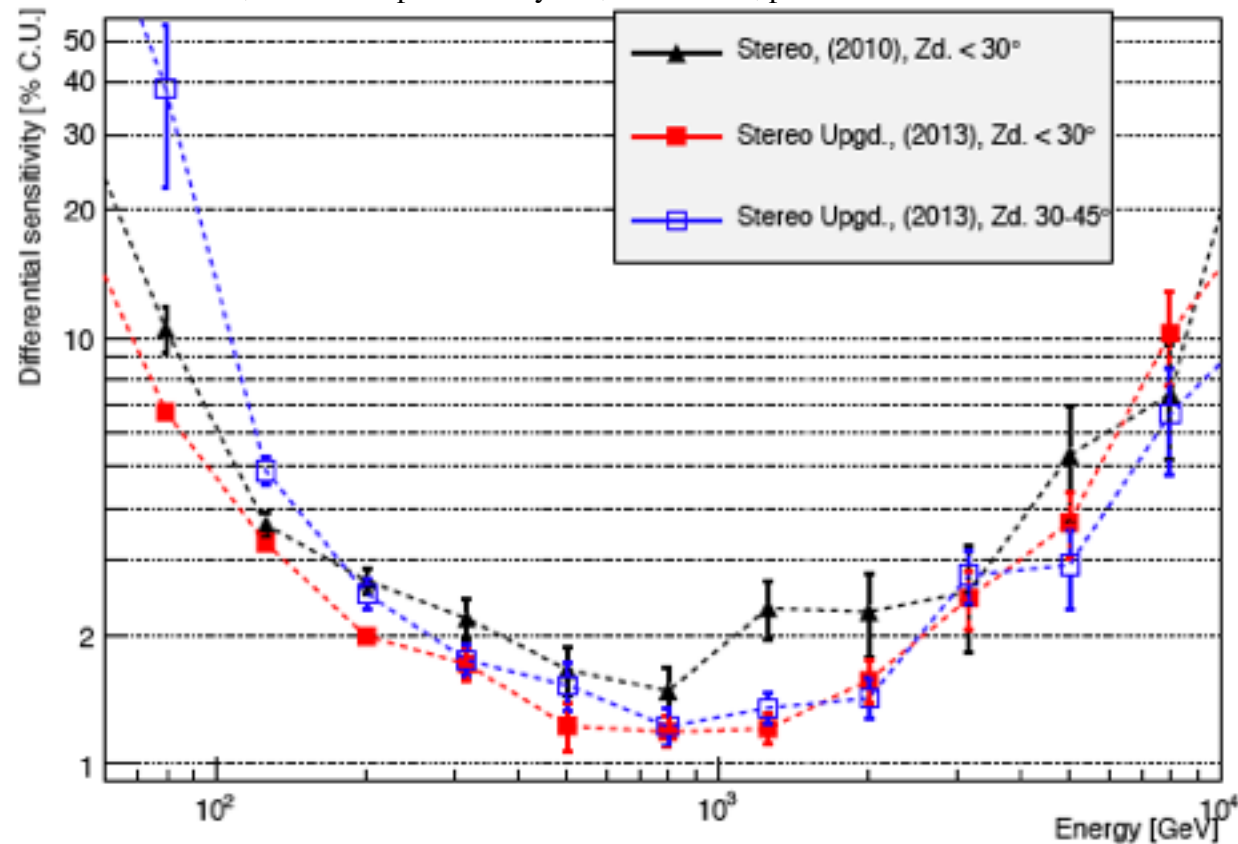
AMON Workshop, Dec 10th 2016, Cochem



MAGIC – short info



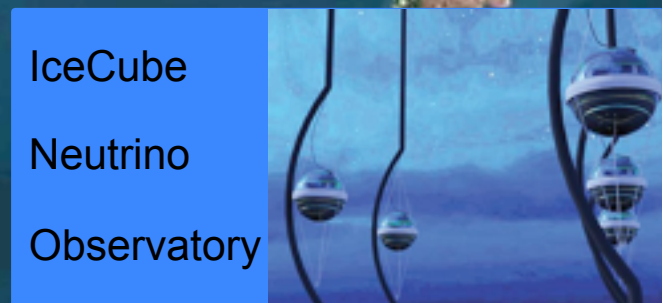
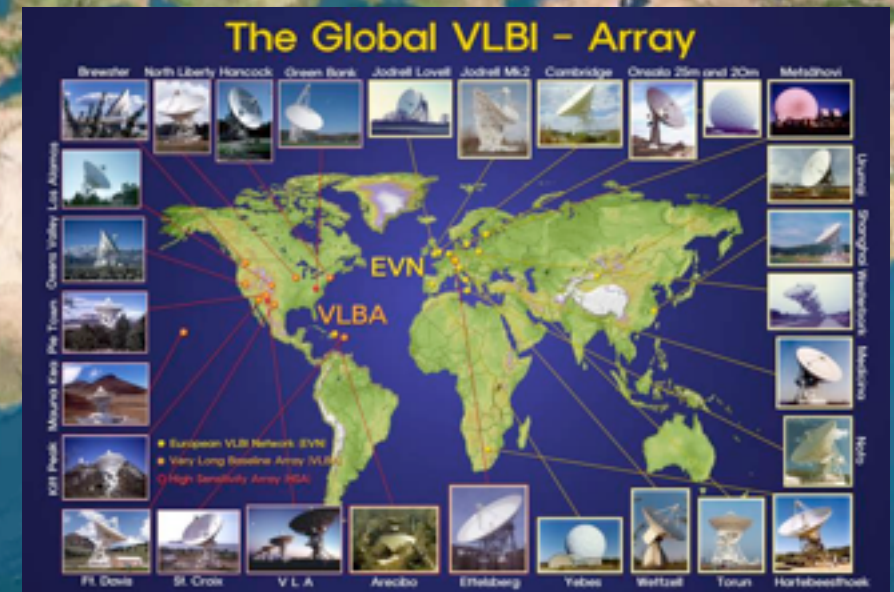
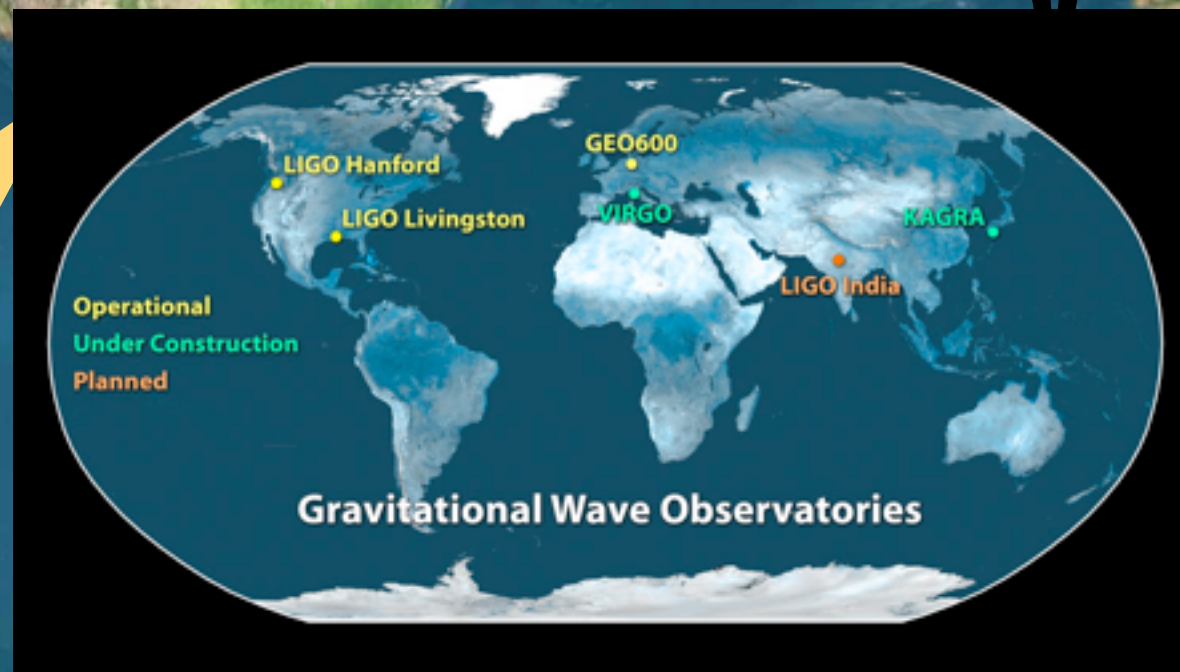
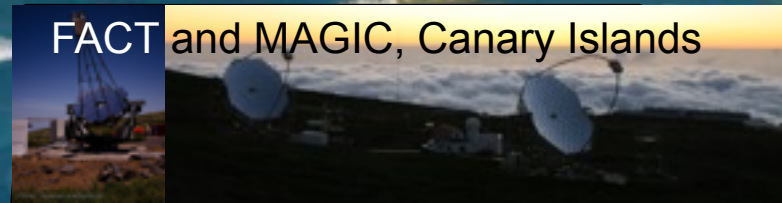
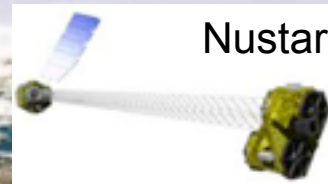
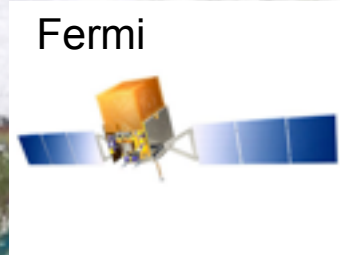
Aleksic J., et al. Astroparticle Physics, Volume 72, p. 76-94



MAGIC, Canary Islands

- ★ 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 Σ -Trigger) - 50 TeV $\Rightarrow$ low E threshold perfect for distant sources
- ★ Mirrors: 2 x 240m² (d = 17m)
- ★ Light-weight: ~ 70 T
- ★ Re-positioning speed: 7 deg/s $\Rightarrow$ prompt response to transients
- ★ Energy resolution: 15% (@1TeV) – 23% (@100 GeV)
- ★ Angular resolution: 0.06 deg @ 1TeV - 0.1 @100 GeV
- ★ Sensitivity: ~ 0.66% Crab (5 σ in 50h above 220 GeV)

Multimessenger partners



MAGIC MWL highlights

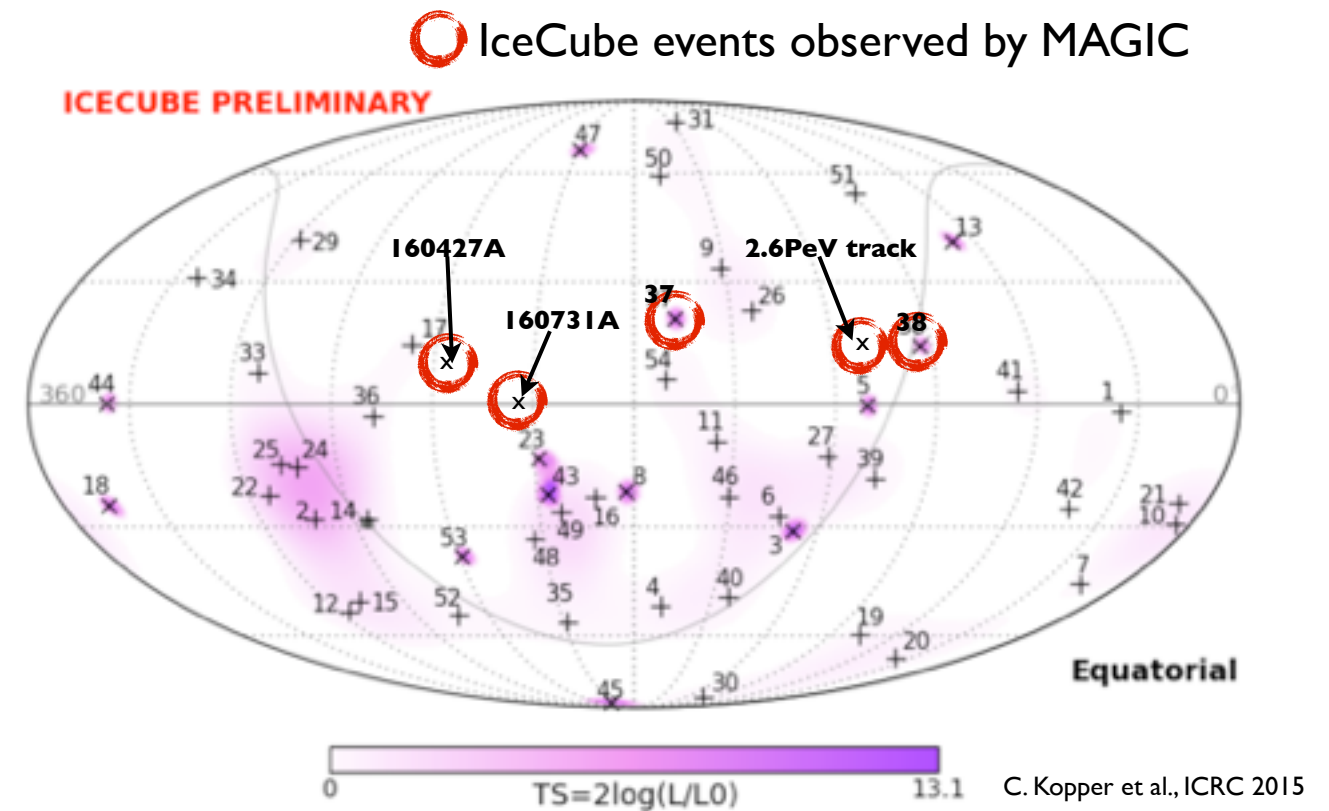
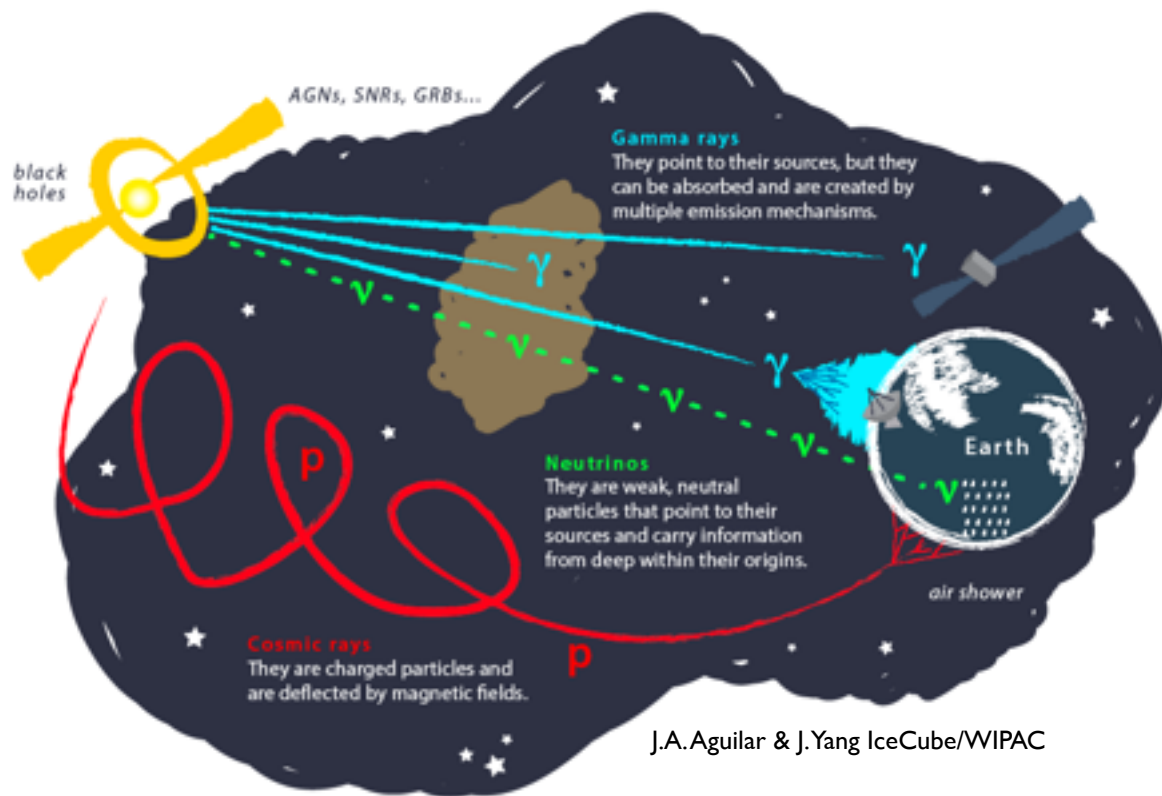


MWL campaigns, pre-planned and ToO - standard in our field :)

A few examples:

- ★ IACTs + HAWC agreement on real-time alerts from known sources
 - ★ *Fermi*/LAT, Swift/XRT, Tuorla/KVA alerts, etc...
 - ★ Long-term MWL monitoring of “classical blazars” Mrk 421 and Mrk 501, and M87 radio galaxy
 - ★ Binary system LSI+61 303 MWL monitoring
 - ★ GRB alerts from *Swift* and *Fermi*/GBM
 - ★ Farthest VHE gamma-ray source detected thanks to gravitational lensing + alert from *Fermi*
 - ★ etc, etc....
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- ★ Every year > 50% of observation time invested in MWL/MM related projects
-
- ★ Great scientific output:
 - ★ 15 papers on “classical blazars” so far (!!!),
 - ★ most stringent M87 emission region location constraints [Science, 325, 5939 (2009)] ,
 - ★ LSI+61 303 [A&A 591 76 (2016)]
 - ★ QSO B0218+357 at $z = 0.944$ detected [A&A 595 (2016)],
 - ★ 8 -10 GRBs/yr $\Rightarrow$ 90 GRBs observed so far (paper coming soon!),
 - ★ etc...

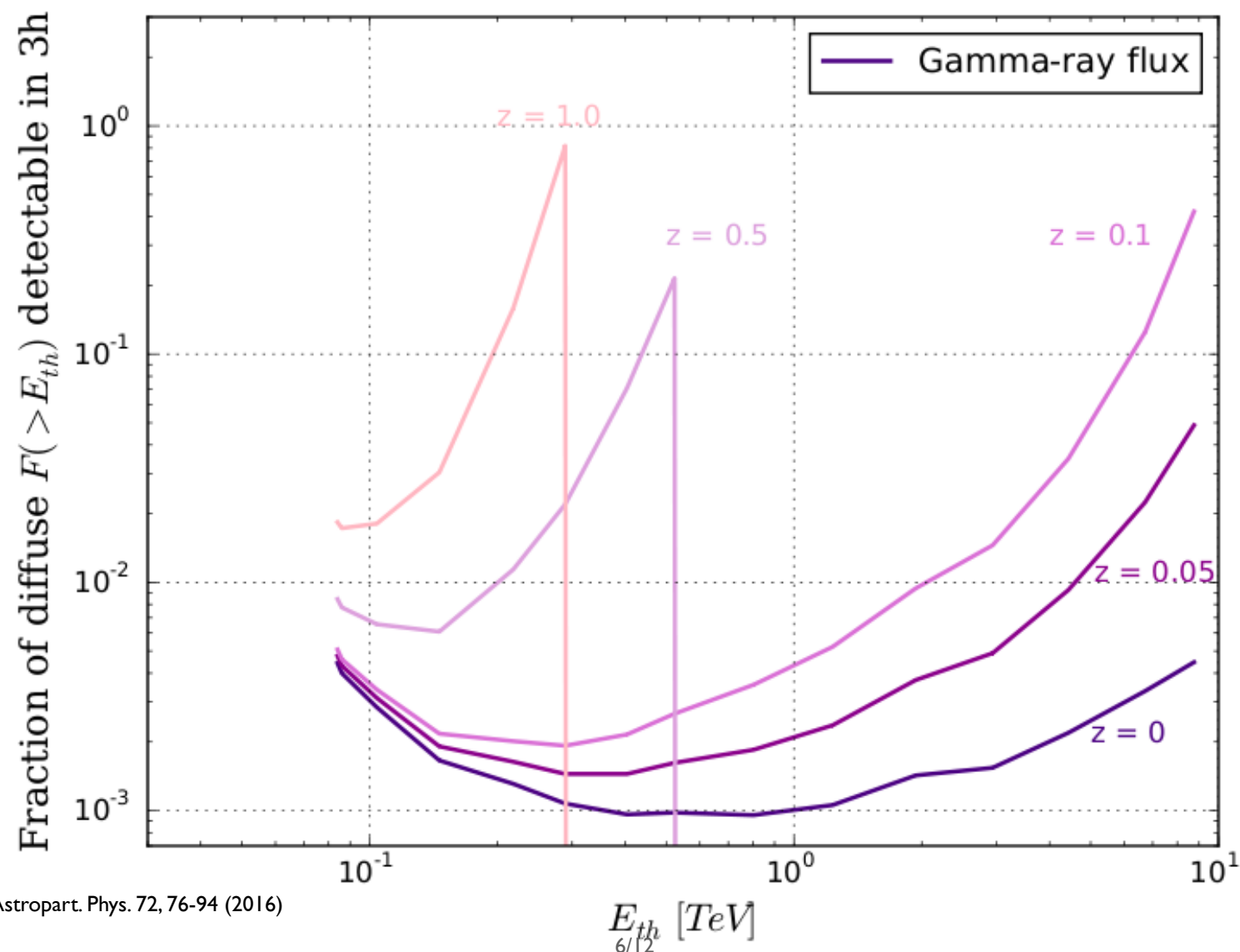
Neutrino follow-up



- ★ MAGIC participates in Gamma-ray Follow-Up (GFU) since 2012: 1 alert observed (see talk by Thomas Kintscher earlier today :) and [JINST, 11, P11009 (2016)]
- ★ 3 archival nu-mu tracks: 2 HESE + multi-PeV track (“Kloppo”, ATel#7856)
- ★ 2 HESE/EHE real-time alerts: 160427A, 160731A (alert received via AMON GCN Notice, alerts from August and September not visible)
- ★ In total > 20 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 $\sim \text{few} \times 0.1\%$ diffuse flux: ~ 1000 near-by, stable sources
- ★ Recent limits from IC: $> \text{few} \times 100$ sources in the Northern Sky [arXiv:1609.04981]



MAGIC sensitivity from Aleksic et al., Astropart. Phys. 72, 76-94 (2016)

K. Satalecka for MAGIC, 10.12.2016, AMON

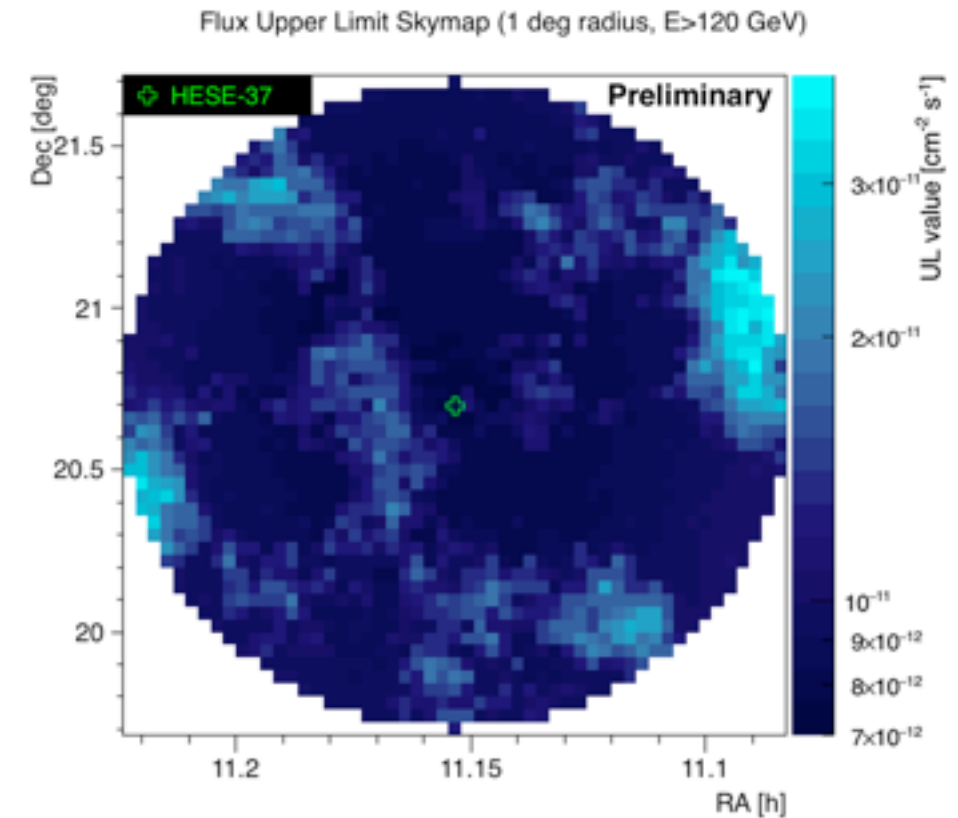
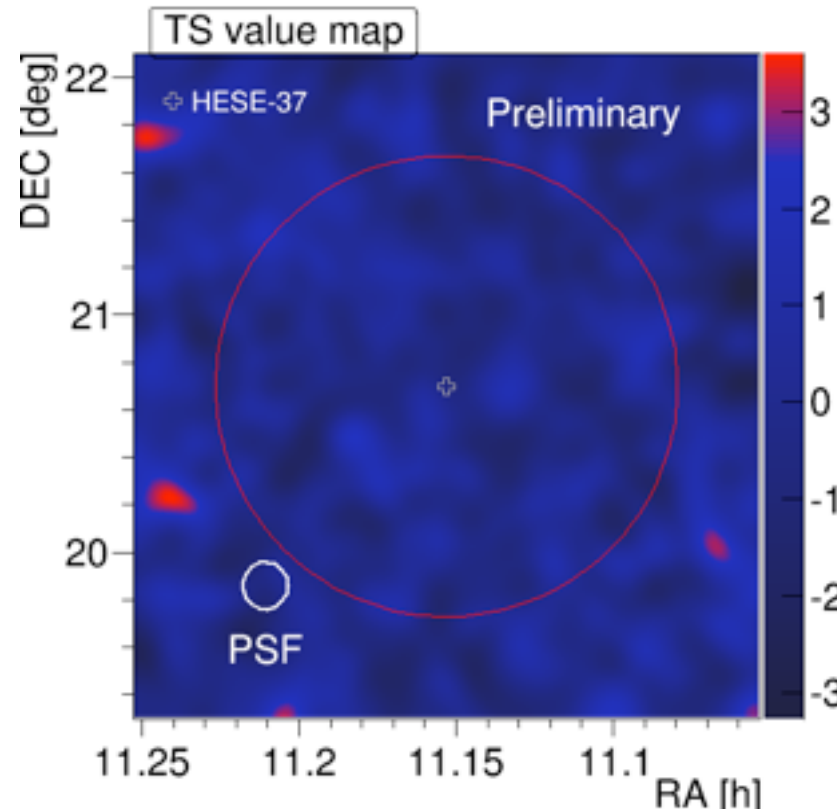
Archival HESE directions

D. Gora et al., Neutrino2016
KS et al., Gamma 2016
K. Noda et al., TeVPA 2016



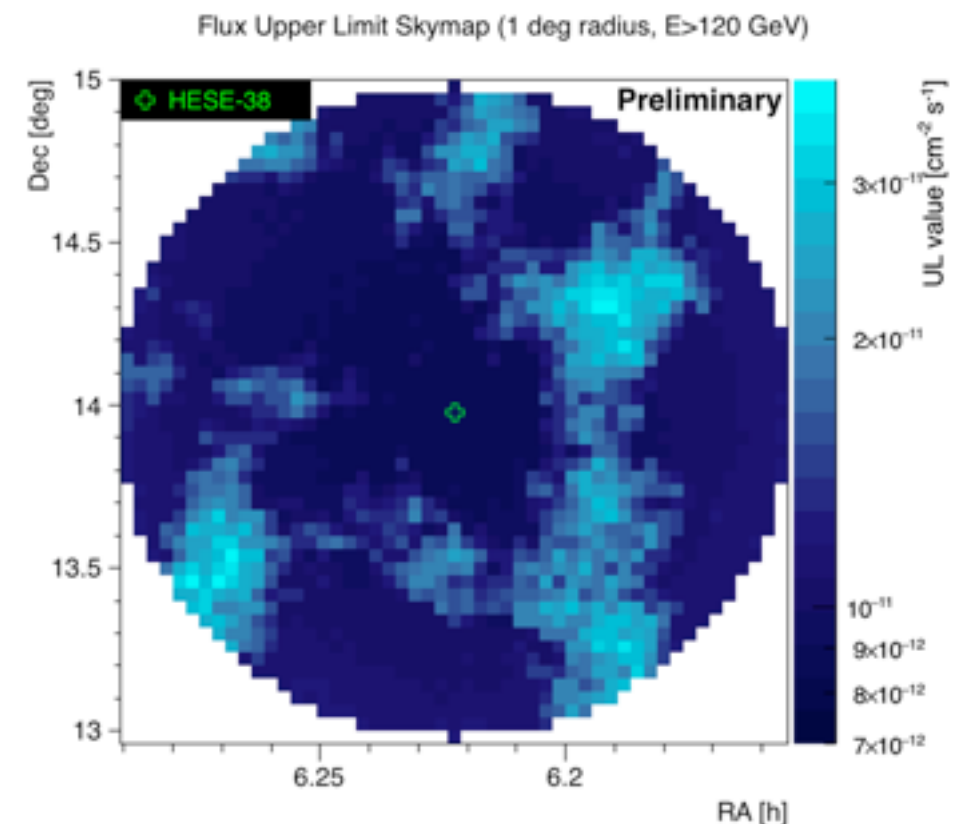
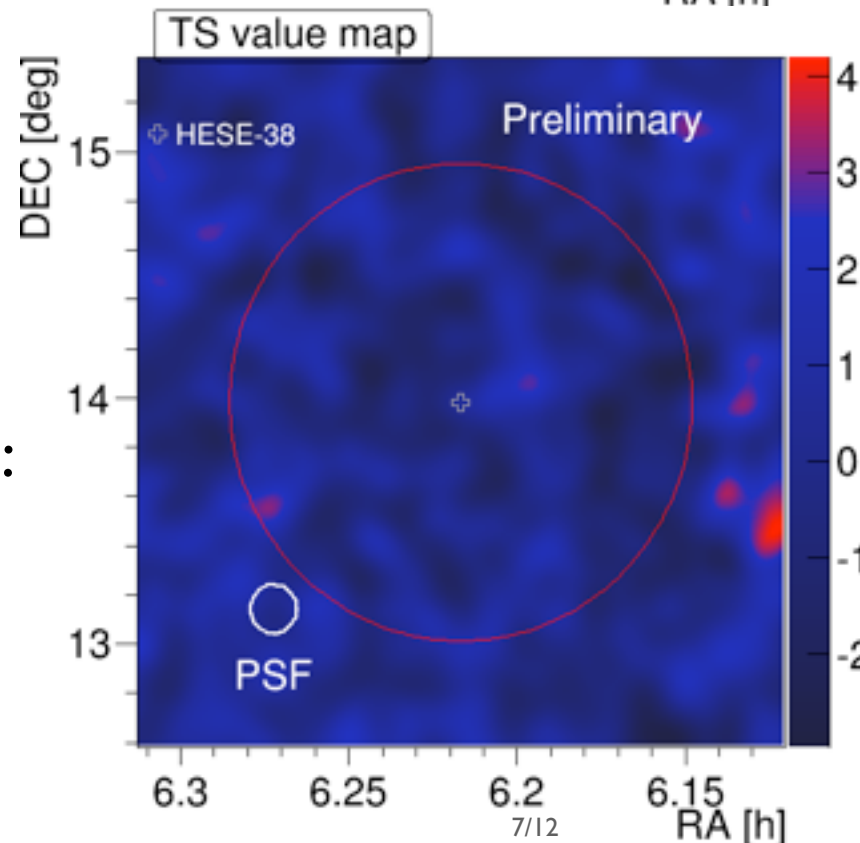
HESE-37

- ★ 7.5 h in Jan/Feb 2016
- ★ zenith 8 -30 deg
- ★ $E > 120$ GeV
- ★ Flux UL (95% C.L., $a=2.3$):
 $(0.7 - 4.0) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$
(~1-10% C.U.)



HESE-38

- ★ 5.7 h in Feb/Mar 2016
- ★ zenith 15 -50 deg
- ★ $E > 120$ GeV
- ★ Flux UL (95% C.L., $a=2.3$):
 $(0.9 - 3.9) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$
(~2-10% C.U.)



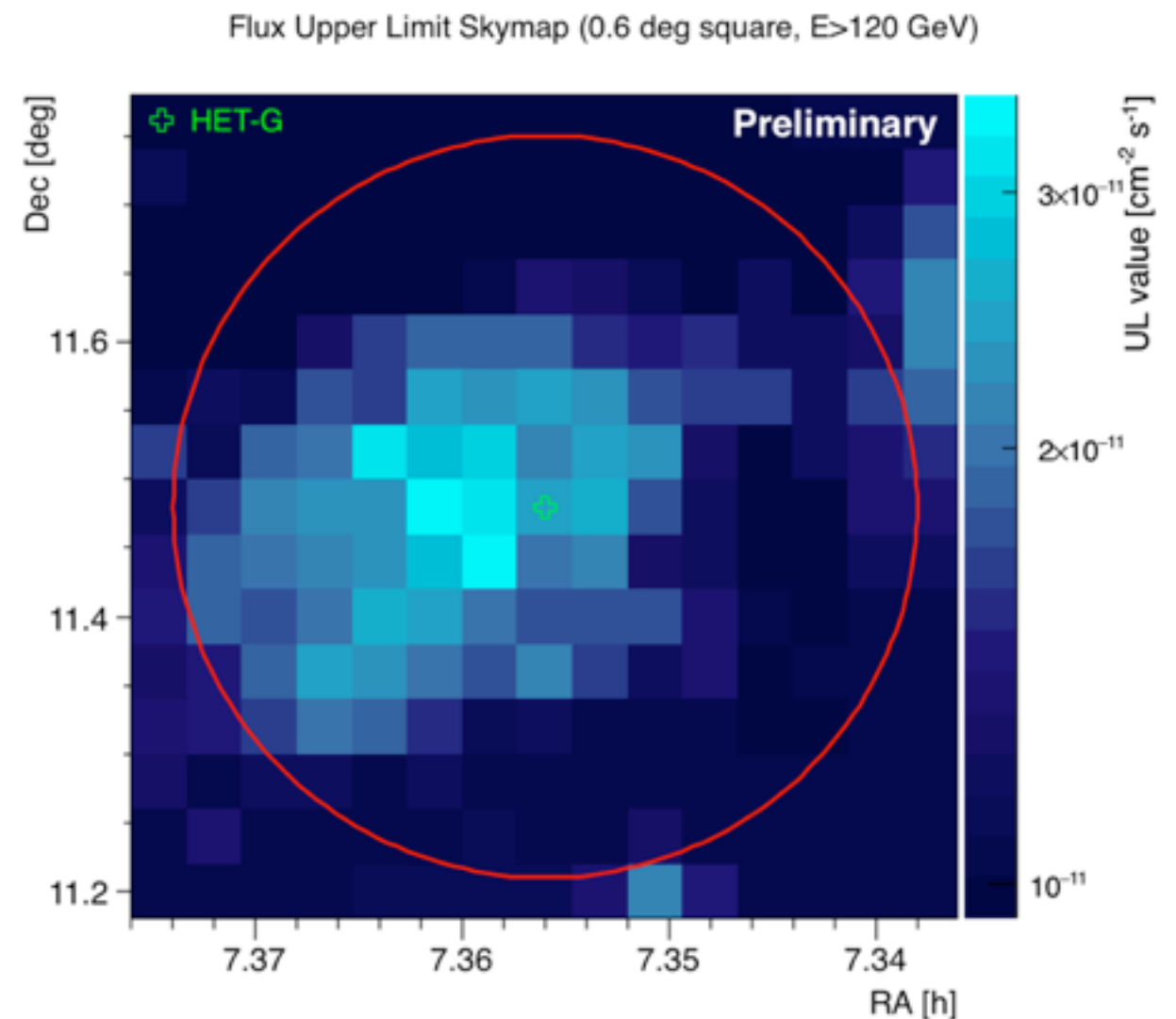
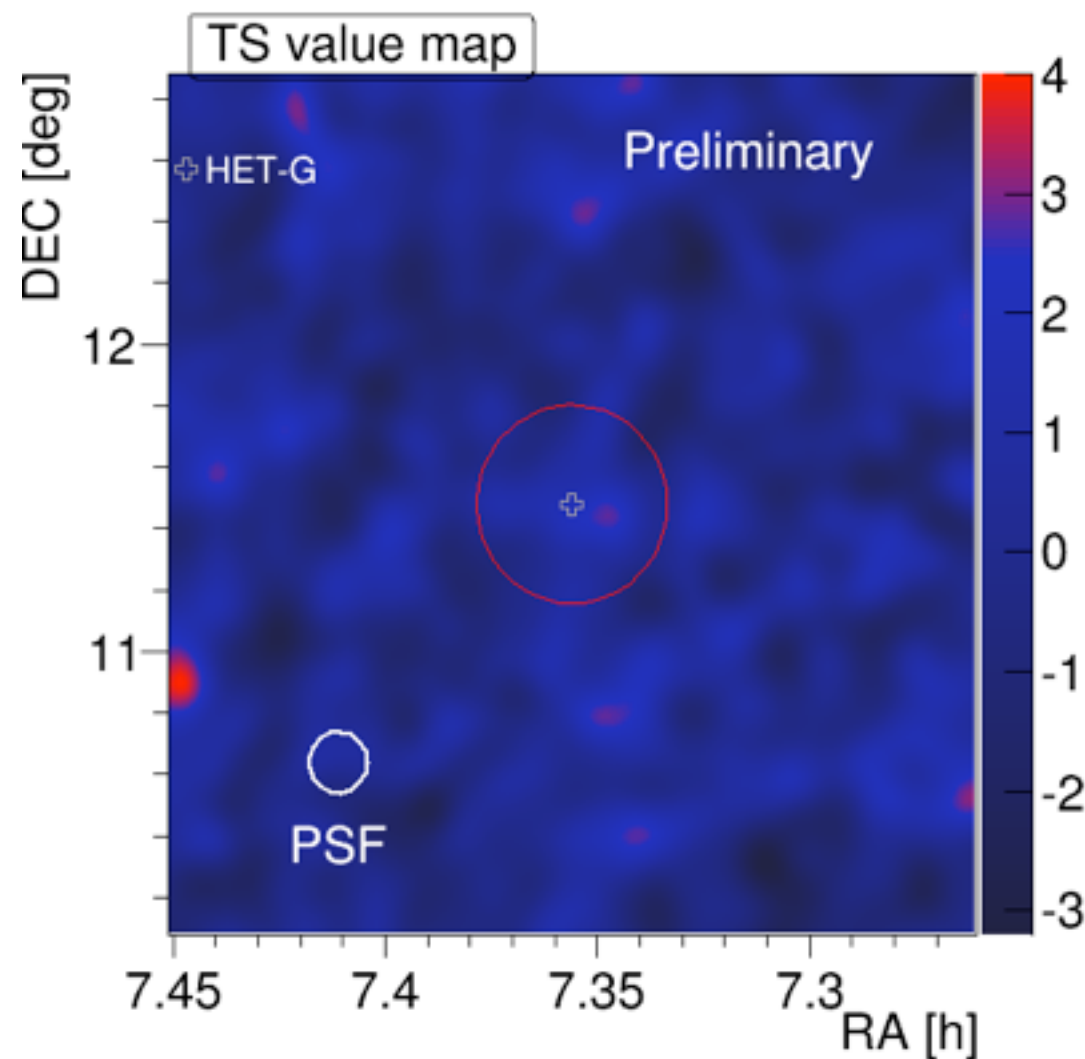
Multi-PeV track (ATel#7856)

- ★ 5 h observations in March 2016
- ★ zenith 21 -38 deg
- ★ $E > 120$ GeV
- ★ Flux UL (95% C.L., $a=2.3$): $(0.9- 3.5) \times 10^{-11} \text{ cm}^{-2}\text{s}^{-1}$ ($\sim 2-10\%$ C.U.)

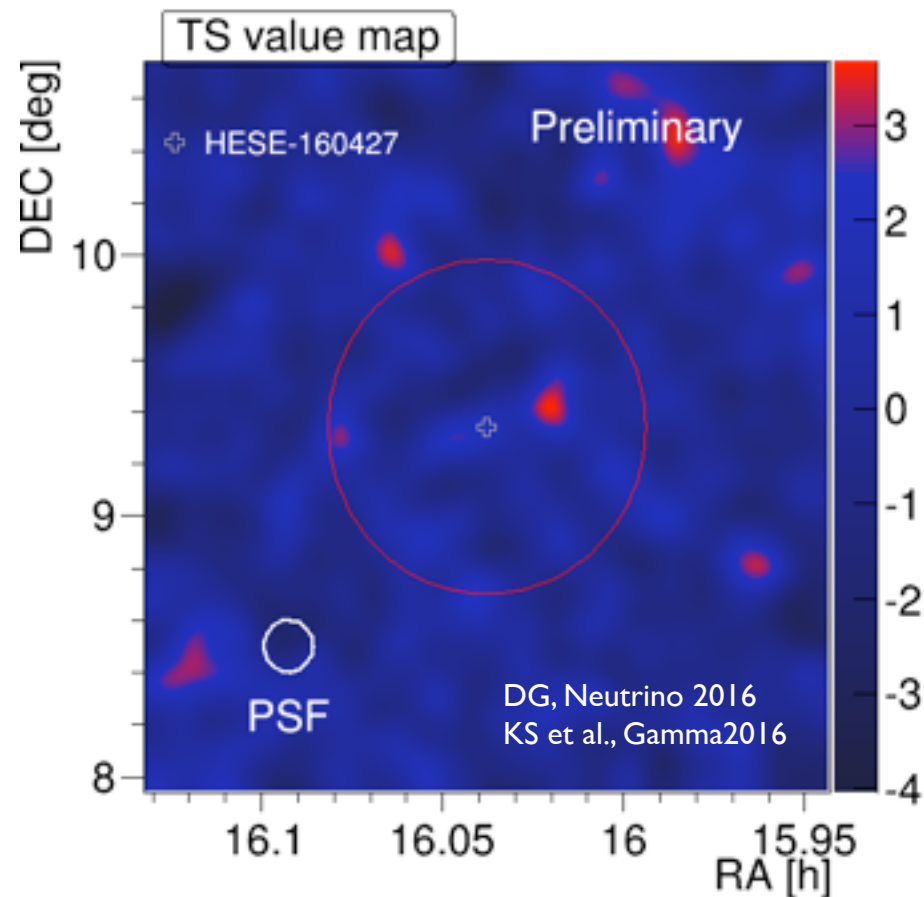
DG et al., Neutrino2016

KS et al., Gamma2016

KN et al., TeVPA 2016

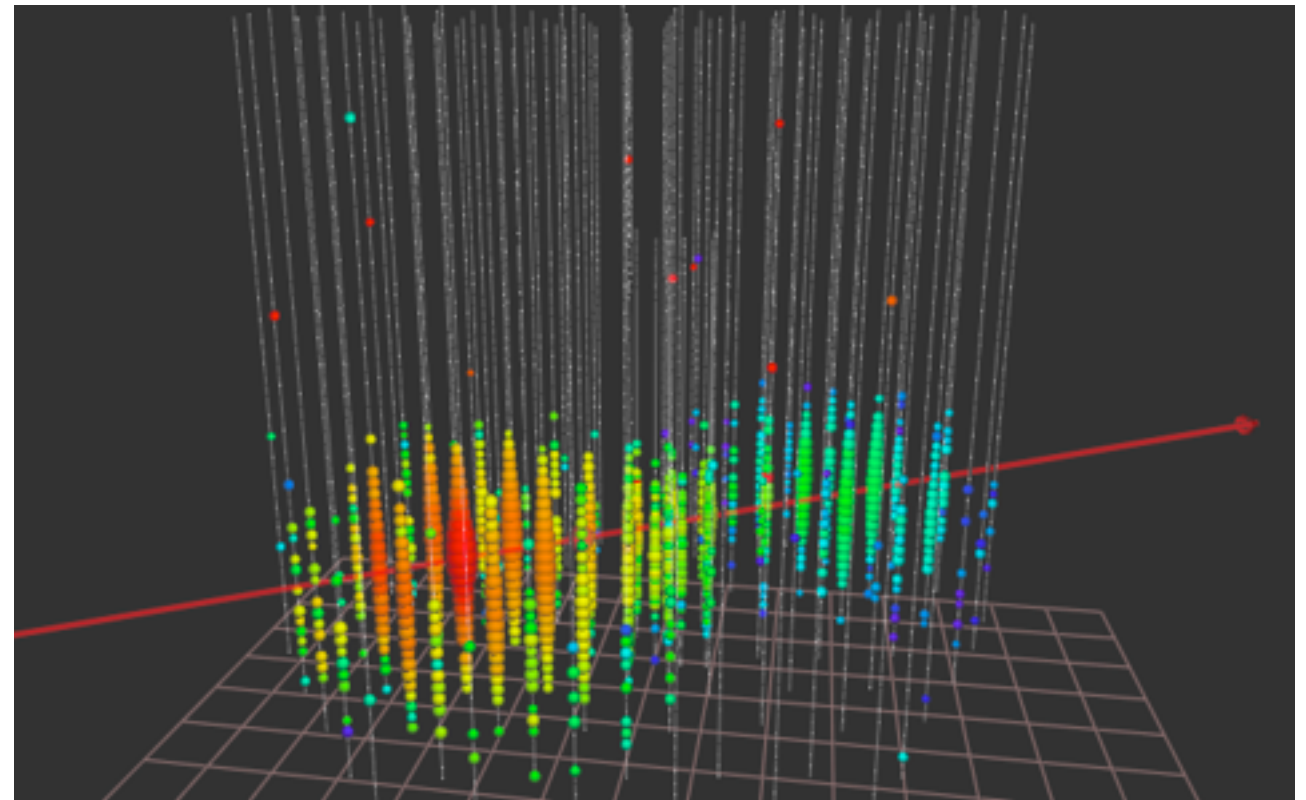


HESE/EHE alerts



HESE-160427A

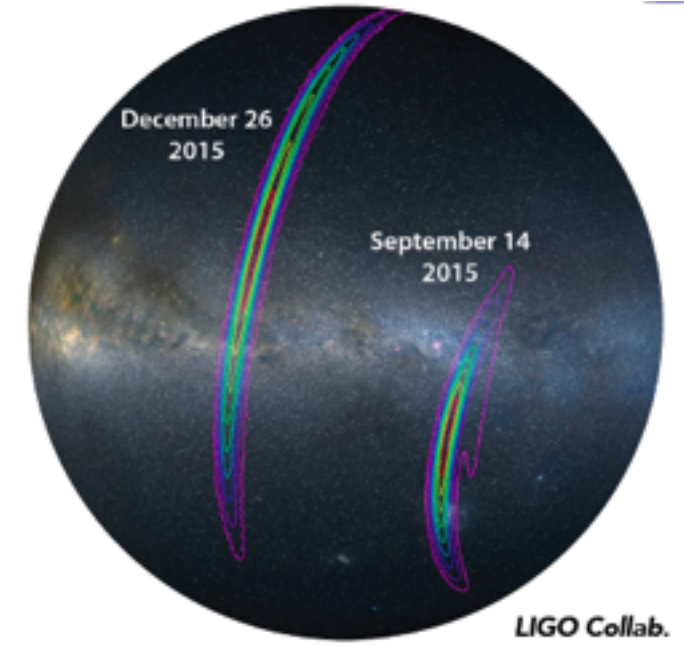
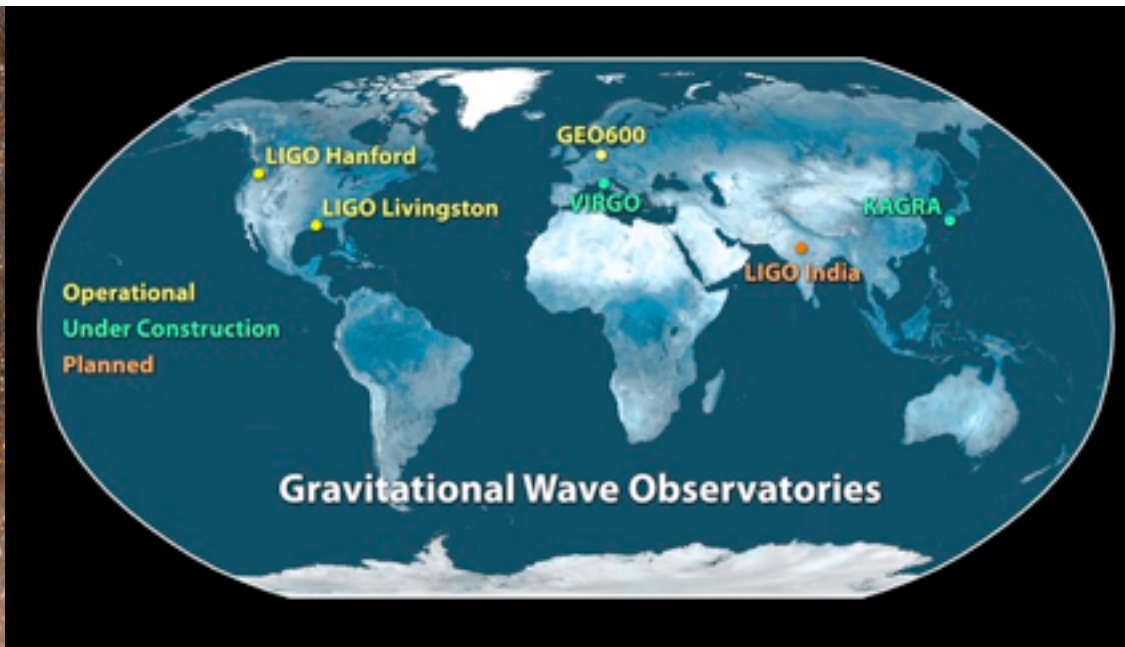
- ★ 2h data taken on 29/04/2016 (delay ~ 42h) with moderate moon (updated position)
- ★ night 27/28 Apr not possible - Moon too bright
- ★ zenith range: 18-26 deg
- ★ E threshold ~120 GeV
- ★ hot spot 0.3 deg away, significance: ~ 3.6 sigma (2.1 sigma after trials)
- ★ UL - analysis ongoing...



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 ~600 GeV
- ★ no signal found
- ★ 2016-08-04: ATel #9315

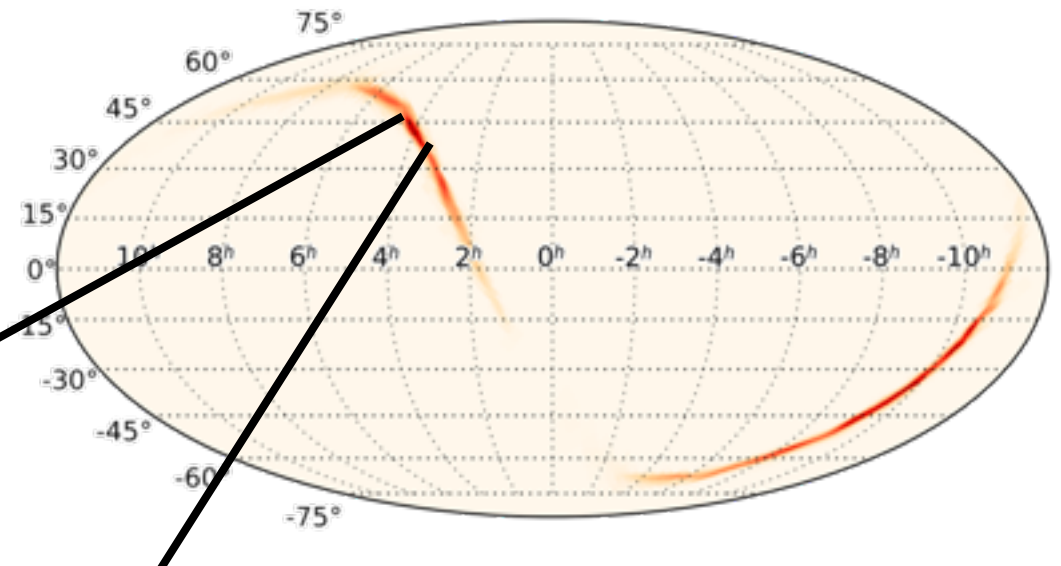
Gravitational Waves follow-up



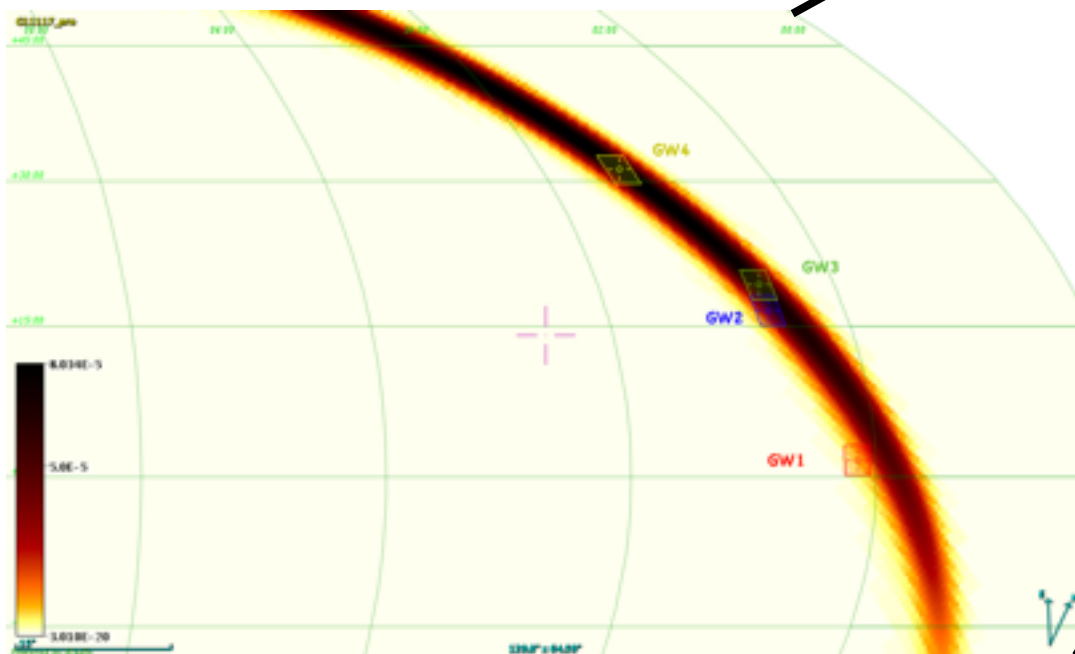
- ★ EM counterpart observations hold a key role in: localizing the GW source and constraining the physical nature of these transient events
- ★ LV still looking for first NS–NS detection: an EM counterpart could confirm neutron star – neutron star merger as the progenitor of a short GRB [e.g. Bartos 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

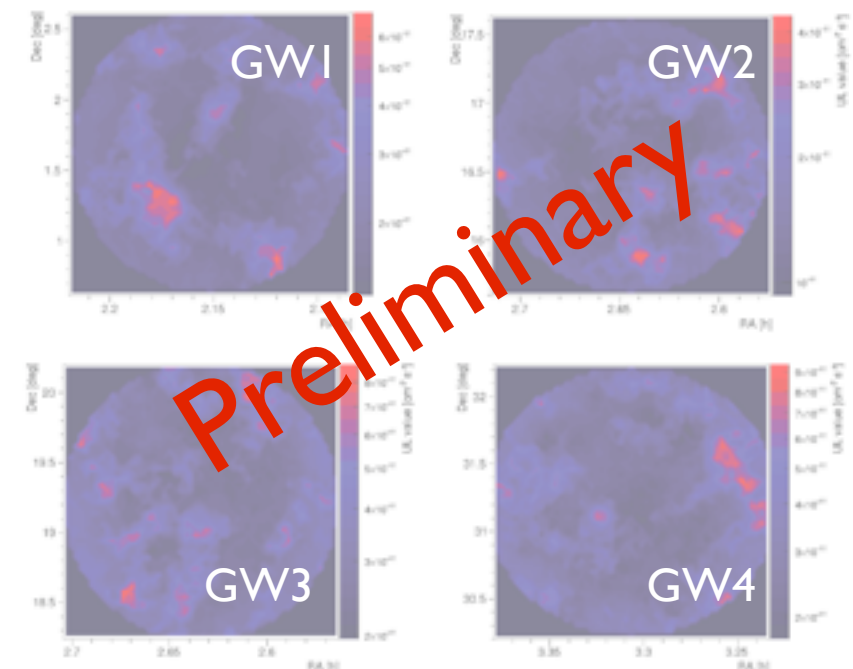
- ★ T_0 : 2015-12-26 03:38:53.648 UT internal GCN circular
- ★ T_{Notice} : 2015-12-27 17:40:00 UT
- ★ T_{Start} : 2015-12-28 21:00:00 UT
- ★ Probability sky-map: 50% (90%) $\sim 430 \text{ deg}^2$ (2200 deg^2)
- ★ False Alarm Rate passing threshold $\sim 1/\text{month}$
(later refined to $< 1/100$ years)



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



Summary & Outlook



- ★ MAGIC actively involved in many MWL and MM programs (pre-scheduled and ToO)
- ★ Important scientific output from MWL observations
- ★ Neutrino and GW alerts: we are just starting!
- ★ Next cycle: observation time granted for follow-up of neutrino and GW alerts and follow-up of interesting candidates from other EM partners
- ★ More accurate pointing/observation strategies are under development
- ★ More sophisticated data analysis & interpretation is in progress (expect papers soon!)
- ★ Have a good MWL/MM proposal? - Contact us!



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)

