MAGIC electromagnetic follow-up of Gravitational Wave alerts

IAU-BlackHoles2016, Ljubljana, Slovenia, September 15th 2016

- **The MAGIC telescopes system**
- **GW follow-up ToO proposal & observations**
- **Strategy for the forthcoming LVC O2 run**

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

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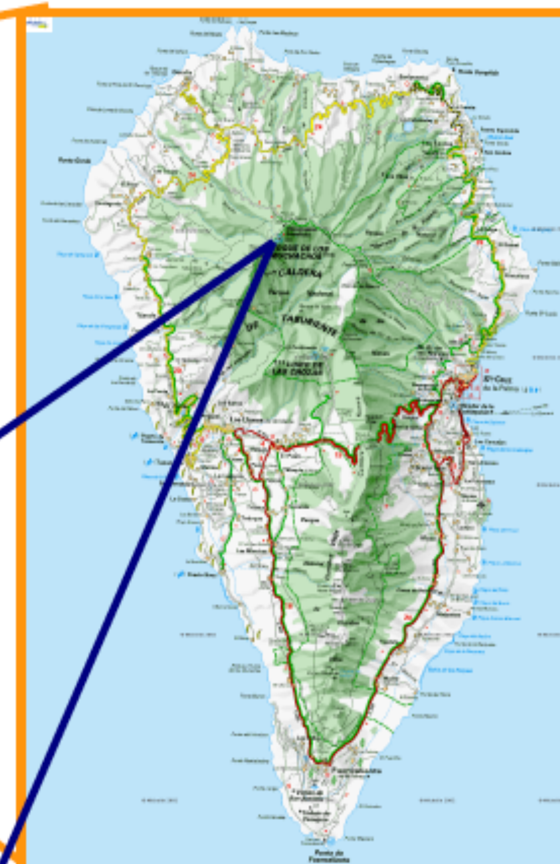
INFN

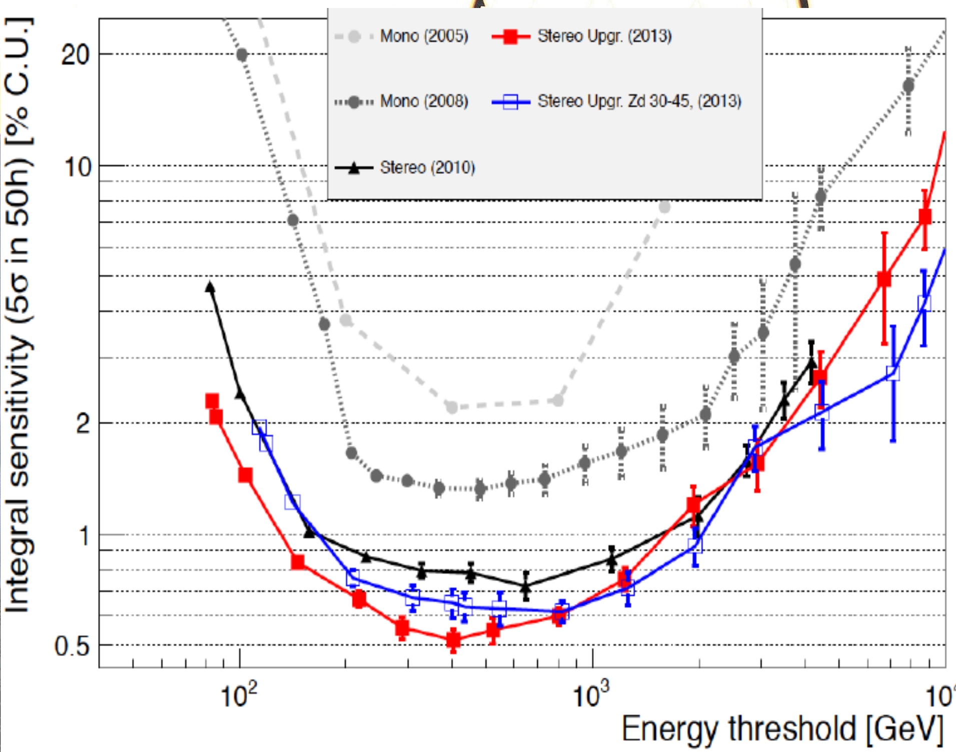
Major Atmospheric Gamma-ray Imaging Cherenkov telescopes

two 17m diameter telescopes, located on Canary island La Palma



~ 170 scientists from 10 countries across Europe & Asia

Main parameters & performance



MAGIC Coll. 2016, Astropart. Phys, 72, 76

- 2 x ~240 m^2 mirrors, F = 17 m
- Light-weight: ~ 70 T
- Re-positioning speed: 7° / s

  ➡ **prompt response to transients**
- Analog signal transmission using 162 m optical fibers
- ~ 2.5 ns FWHM pulses
- Digitization: 1.64 GS/s DRS4

  (1TB per telescope per night)

- **Energy range:**

  50 GeV (30 GeV Σ-Trigger) - 50 TeV

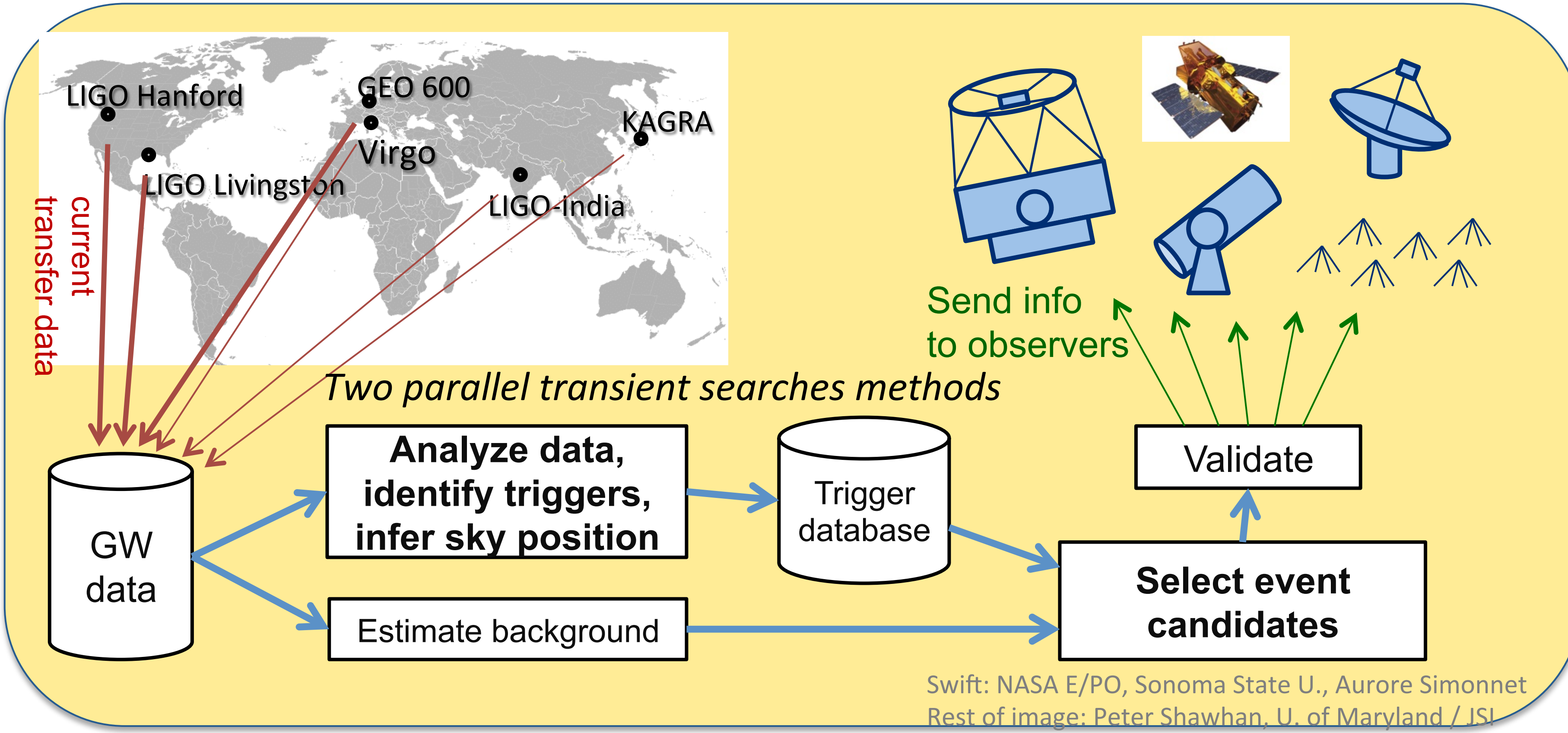
  lowest IACT threshold (looking far away)
- **Energy resolution:**

  15% (@ 1 TeV) – 23% (@100 GeV)
- **Angular resolution:**

  0.06° @ 1 TeV , 0.1° @ 100 GeV
- **Sensitivity**:

  ~ 0.66% Crab (5σ in 50h above 220 GeV)
- Pointed observations: FOV 3.5°

Part of a vast collaboration of em facilities (MoU) for GW follow-up



Alert content:

Time of GW candidate
Significance
False Alarm Rate (FAR)
Probability Sky Map

T0+3m: event uploaded to DB
T0+17m: First Sky Map
T0+1 day: Alert sent
T0+1 month: refined Sky Map

Observing motivations

- Electromagnetic (EM) counterpart observations will play a key role in localizing the GW source (large FoV and duty cycle instruments such as Fermi, HAWC ...) and constraining the physical nature of these transient events
- MAGIC needs to know where to look: **fast slewing**, **large effective area**, the **best sensitivity at ≤ 100 GeV** ➔could provide important information on the GW counterpart in an energy range not affected by selective absorption processes typical of other wavelengths
- LVC still looking for first NS-NS detection: an EM counterpart could confirm neutron star – neutron star merger as the progenitor of a short GRB

Can we have γ-rays from BHBH merger?

A merger of two BHs in vacuum is expected to have no EM counterpart.

- Fermi/GBM: a weak γ-ray burst 0.4 seconds after the 1st GW detection
- INTEGRAL – an upper limit, lower than the Fermi detection flux

Savchenko et al., 2016, ApJ820L36.

A hint, but not significant enough to claim detection.

Greiner et al., 2016, ApJ.827L38

A lot of ideas:

- Two BHs merging inside a star: Loeb A., *Electromagnetic counterparts to black hole mergers detected by LIGO*, 2016, ApJL, 819L21.
- Perna R. et al., *Short γ-ray bursts from the mergers of two black holes*, 2016, ApJL, 821L18.
- Binary system massive star – BH, 2nd BH formation triggered: Janiuk A. et al., *On the γ-ray burst-gravitational wave association in GW150914,* NewAstr.51(Feb 2017).
- Two charged BH: Fraschetti F., *Possible role of magnetic reconnection in the electromagnetic counterpart of binary black hole merger*, arXiv:1603.01950.
- More exotic objects (gravastars): Chirenti C. et al., *Did GW150914 produce a rotating gravastar*?, arXiv:1602.08759.

Merging neutron stars binaries

Besides BH binary systems, the most promising candidates for GW detection with the LIGO and Virgo interferometers.

Thought to be connected with short GRB.

- Veres P., & Meszaros P., Prospects for Gev–Tev detection of short γ-ray bursts with extended emission, 2014, ApJ, 787, 168: "current GeV-TeV instruments such as HAWC, VERITAS, MAGIC and HESS have a good chance of detecting afterglows of short bursts with extended emission, assuming a reasonable response time":

  (timescale 10^2 -10^3 s after the burst trigger)
- G. Ghirlanda et al., "pretty low probability to detect gravitationally a NS-NS event", arXiv160707875
- B. Patricelli et al., Prospects for joint observations of gravitational waves and γ-rays from merging neutron star binaries, arXiv:1606.06124
- Takami K. et al., High-energy radiation from remnants of neutron star binary mergers, 2014, Phys. Rev. D, 89, 063006

not an exaustive bibliography …

- MAGIC joined the LIGO/Virgo call for Identification and follow-up of electromagnetic counterparts of gravitational wave candidate events since 2014

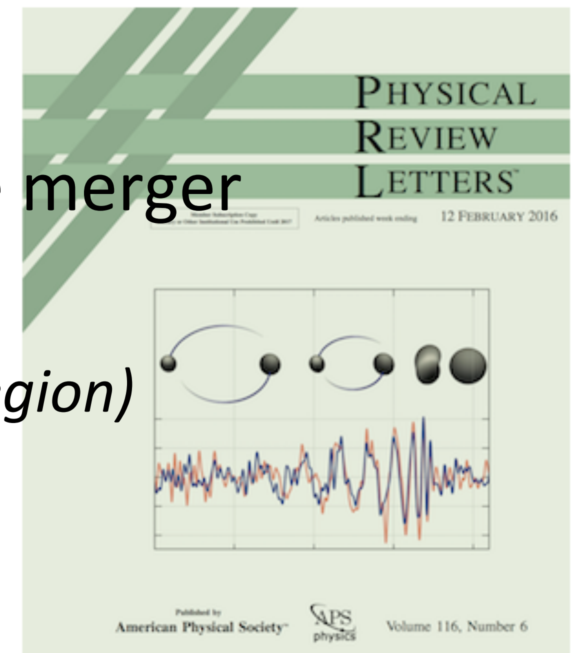
  [*ToO proposals for years 2014 and 2015 (PI: B. De Lotto)*]

- Since then it's history:

  - First direct observation from the merger of two stellar-mass BH (GW150914)

  MAGIC could not observe it (out of visible region)

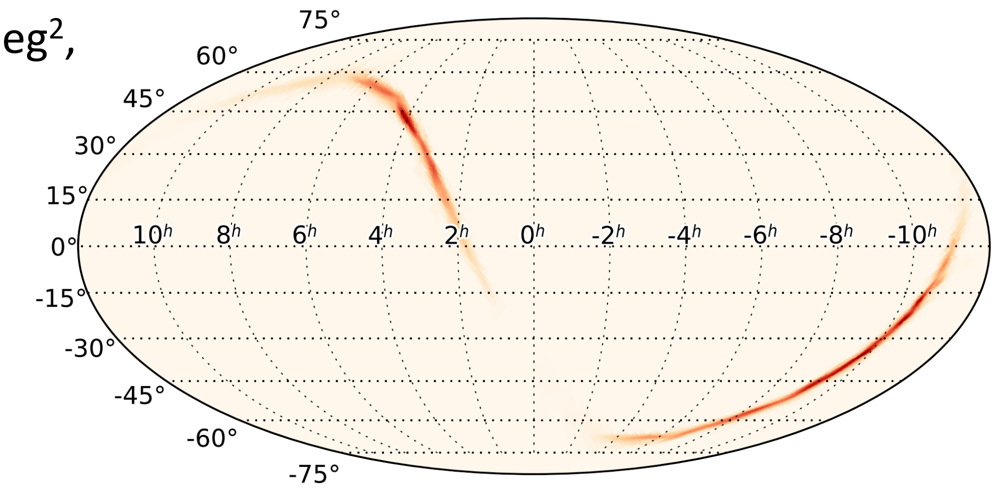
  - Second one (GW151226) published in June 2016



MAGIC ToO follow-up observations: GW151226

- T_o: 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:
    median 50% credible region ~ 430 deg^2,
    90% credible area ~ 2200 deg^2.
  - False Alarm Rate (FAR)
    passing threshold ~ 1/month
    later refined to < 1/100 years

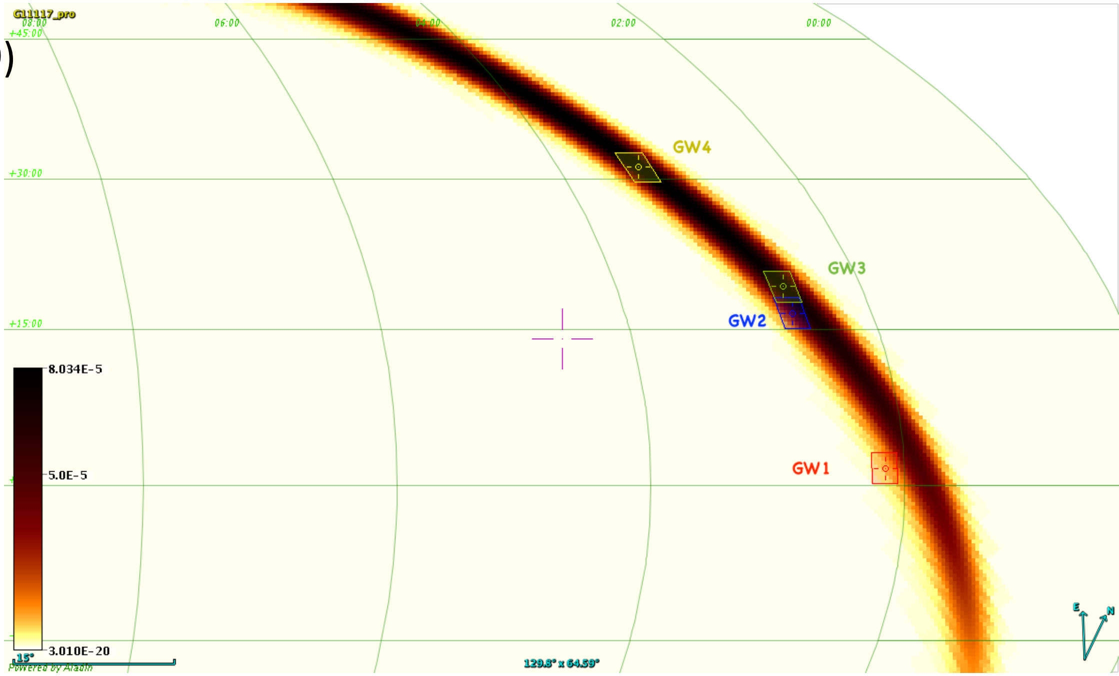


GW151226: first MAGIC follow-up

- 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)



No significant emission detected

GW151226: upper limits evaluation

- Non standard procedure for MAGIC: off-axis flux upper limits calculation (we do not know where the source is)
- Integral flux UL skymaps

for the four sky GW pointed positions under production (*A. Berti et al.*)

- Tools in preparation for

the forthcoming LVC science run

O2 science run

- September: engineering run , Sept.?: start, Summer 2017: end

- Same communication tools (internal GCN circulars, notices) and info (time, pipeline, significance, neighbors, sky maps through GraceDB) as in O1

- New for O2: - 3D sky map with *a posteriori* mean luminosity distance

  L. Singer et al., arXiv:1603.07333

  - Probability that the less massive companion has a source-frame mass < 3 $M_\odot$
  - Probability that the system ejected a significant amount of NS material

- Region of Interest: **hundreds deg^2** ➔ **~ 10 deg^2** when Virgo joins
- Release significant triggers to the entire scientific community ?

  (MoU: after 4th GW detection published)

MAGIC to do list

- Refine observation criteria (possibly in coordination with other EM observers with large FoV)
- Implement a semi-automatic GW follow-up procedure when Virgo joins
- As usual, it always helps:

Conclusions

- The aLIGO-aVirgo interferometers joint effort will improve in O2 the sky-localization accuracy (currently hundreds of square degrees)
- Electromagnetic follow-up of GW candidates extremely challenging, but not impossible

  → rich scientific rewards.
- MAGIC will enter the game provided an efficient coordination with other EM observers is set up

  (we need to know where to look!): ToO proposal in preparation

Thank you !