

The MAGIC Transient Program

Alessio Berti on behalf of the MAGIC Collaboration

University of Torino and INFN Torino

6th June 2018

30th Rencontres de Blois



The MAGIC Telescopes

The MAGIC Transient Program

Transient Sources with MAGIC

- Gamma-Ray Bursts

- Gravitational-Waves Counterparts

- Neutrinos

- Fast Radio Bursts

The MAGIC Telescopes



El Roque de los Muchachos
Observatory
(La Palma, Spain)

The MAGIC Collaboration is composed of ~150 members (~230 in total, including engineers, technicians and other staff) from 12 countries





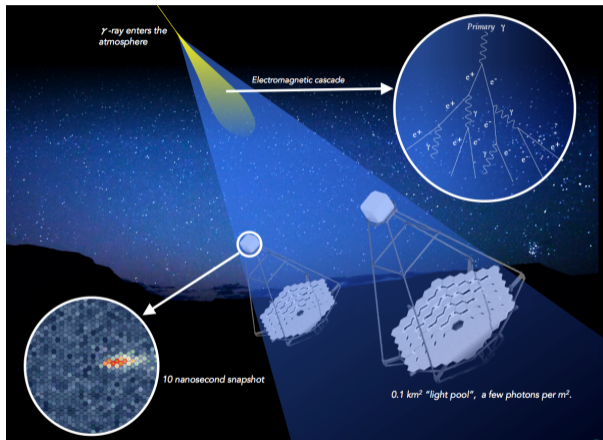









Credit: MAGIC Outreach Team



Credit: <https://www.cta-observatory.org/about/how-cta-works/>

- Primary particle (γ or cosmic ray) interacts with atmosphere molecules
- ↓
- creation of Extensive Air Shower (electromagnetic or hadronic)
- ↓
- secondary particles move with $v > c_{\text{air}}$
- ↓
- production of Cherenkov light and collection by large mirrors
- ↓
- focus on pixelized (PMTs) camera
- ↓
- creation of image of the Cherenkov flash on camera
- ↓
- reconstruction of primary particle properties (nature, energy, direction)

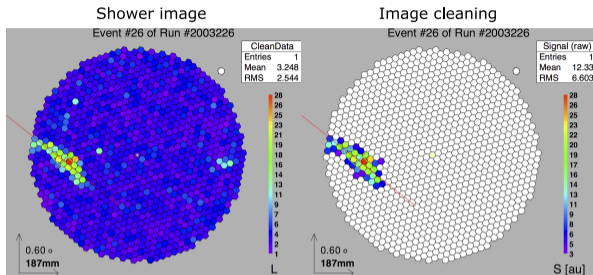
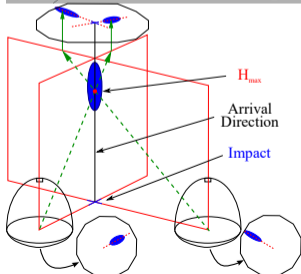
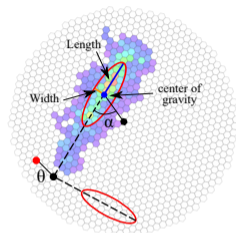
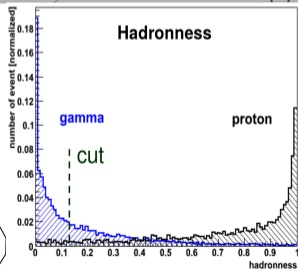


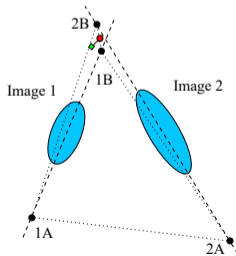
Image parametrization



Stereo reconstruction

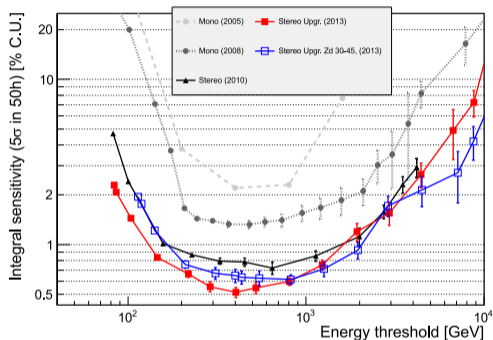


Event classification



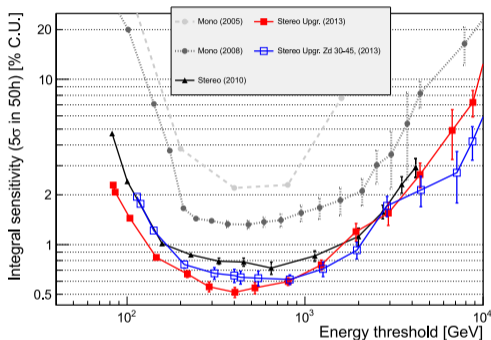
Direction and energy

- Mono up to 2009, then stereo system
- Energy range: ~ 50 GeV-50 TeV (with Sum-Trigger, $E_{\text{thr}} \sim 30$ GeV)
- Field of view: 3.5°
- Sensitivity: $\lesssim 0.7\%$ Crab flux above 220 GeV in 50 h (10% Crab in 1 h above 100 GeV)
- Energy resolution: 15% (@1 TeV) \div 24% (@100 GeV)
- Angular resolution: 0.06° (@1 TeV) \div 0.1° (@100 GeV)
- Light-weight telescopes: ~ 70 t
- Fast repositioning: $7^\circ/\text{s}$ ($4^\circ/\text{s}$ in std mode)



Aleksić et al., *Astropart. Phys.* 72 (2016)

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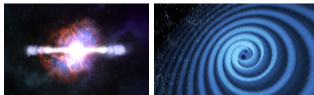


Aleksić et al., *Astropart. Phys.* 72 (2016)

MAGIC is well suited to observe transient sources!

Gamma-Ray Bursts

- 50 h reserved per year
- Automatic (prompt) follow-up
- Late-time observations

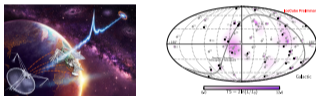


Gravitational Waves Counterparts

- Signed MoU with LIGO/Virgo in 2014
- Follow-up of several alerts
- New strategy implementation

Neutrinos

- Follow-up of alerts from IceCube
- Real-time and archival events
- 60 h per year allocated

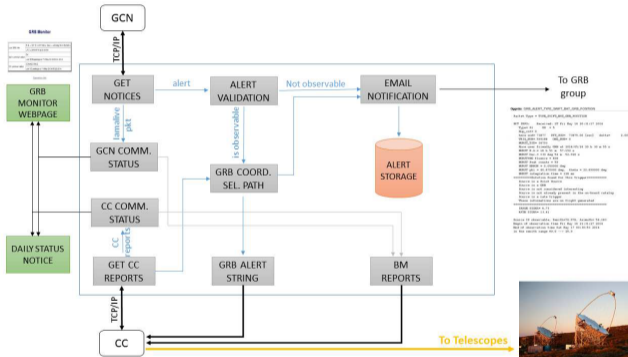


Fast Radio Bursts

- Observations of FRB 121102 in VHE and optical
- Coordination with radio observatories
- Multiwavelength campaign in September 2017

15% of total observation time per year

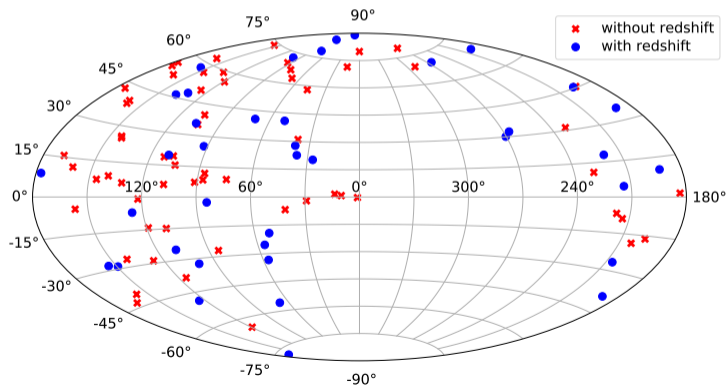
The MAGIC Automatic Alert System

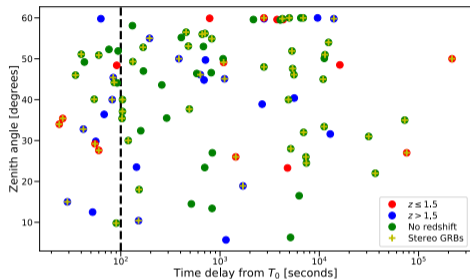


Credit: A. Carosi

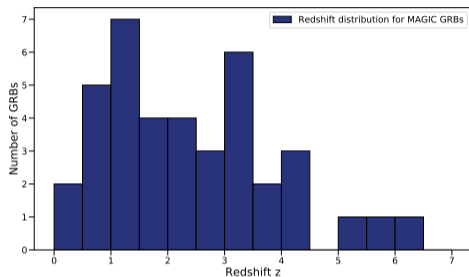
- Active since 2003
- Listens to GCN Alerts
- Automatic repointing for GRBs
- Adapted to neutrino and GW alerts
- New protocol VEvent is being implemented
- A multimessenger system!

- Since 2013, new follow-up procedure + late-time observations
- 101 GRBs observed so far (mono && stereo)
- Different observational conditions
- Filters for GCN alerts
- 8-10 GRBs/year
- 39 GRBs with known redshift
- 50 h allocated per year





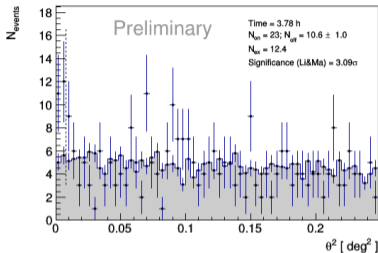
- 23 GRBs observed with delay < 100 s
- Minimum delay: 24 s (GRB 160821B)
- Late-time observations included (delay > 1 d)



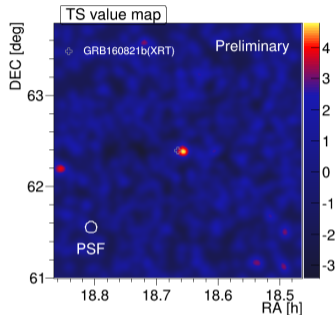
- 15 GRBs with $z < 1.5$
- Closest GRB: GRB 160821B ($z = 0.16$)
- Mostly long GRBs

2013-2015 GRBs paper coming soon: ULs on > 20 GRBs

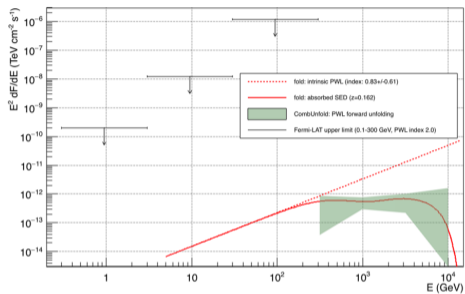
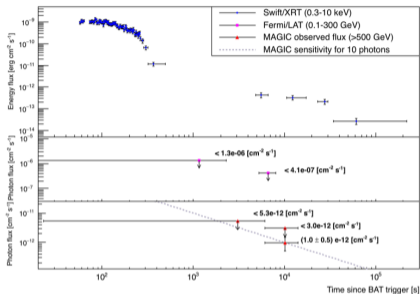
GRB 160821B standalone paper coming soon as well (see next slides)



Inoue et al., Proc. 35th ICRC 2017



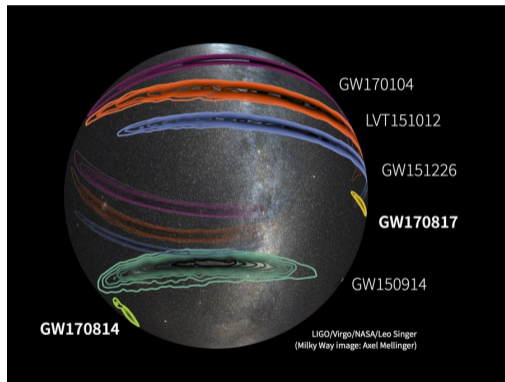
- Short GRB ($t_{90} = 0.5$) detected by Swift-BAT
- Close GRB: $z = 0.16$ (William Herschel Telescope)
- Possible macronova association
- Fast automatic follow-up: MAGIC on target after 24 s
- Bright moon conditions: dedicated analysis
- [$t_0 + 24$ s; $t_0 + 1.5$ h]: zd $34^\circ \div 40^\circ$, poor weather, NSB $\sim 3 \div 5 \times$ dark
- [$t_0 + 1.5$ h; $t_0 + 4$ h]: zd $40^\circ \div 55^\circ$, good weather, NSB $\sim 5 \div 9 \times$ dark
- 4 h data, $> 4\sigma$ pre-trial, 3.1σ post-trial above 600-800 GeV: **detection hint** (3 independent analyzers)

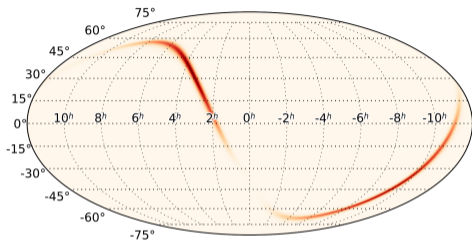


IF signal is real:

- relatively shallow decay: is it analogous to plateau seen in X-rays?
- hard spectrum (after EBL absorption): new spectral component beyond synchrotron?
- interpretation: “refreshed shock” scenario (Sari & Meszaros 01, Veres & Meszaros 14) or impulsive blastwave with single Γ
- first GRB detected by a IACT and second SGRB with z at GeV energies

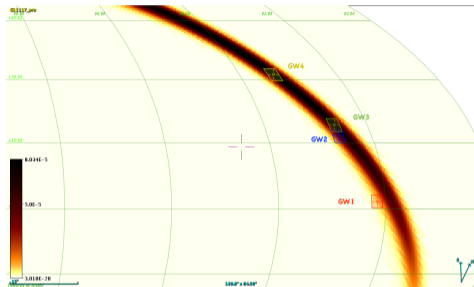
- Crucial role of EM follow-up of GW sources to detect counterparts and infer physical properties (see GW170817/GRB170817A case)
- MAGIC has fast repositioning, very good sensitivity below 100 GeV but a small FoV
- MAGIC inside the EM follow-up community since 2014 signing a MoU
- LIGO+Virgo: small localization regions, good news for small FoV instruments like IACTs



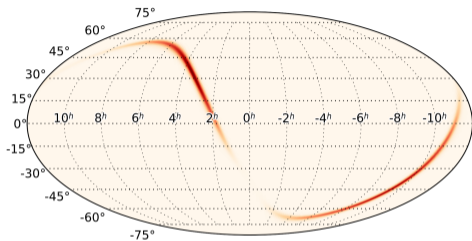


De Lotto et al., Proc. New Frontiers in Black Hole Astrophysics, IAU Symposium 324 (2016)

- t_0 : 2015-12-26 03:38:53.648 UT (internal GCN Circular)
- t_{notice} : 2015-12-27 17:40:00 UT
- 90% (50%) credible region: 1337 deg² (430 deg²)
- False Alarm Rate: 1/100 year

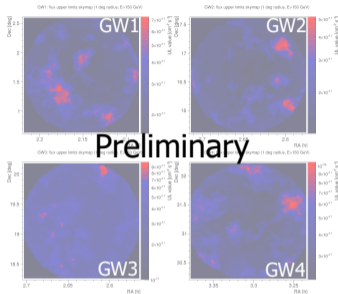


- Observation by MAGIC started on 2015-12-28 21:00:00 UT
- Four targets pointed
- Selection by hand according to visibility, probability, EM partners observations and catalogs
- No signal found



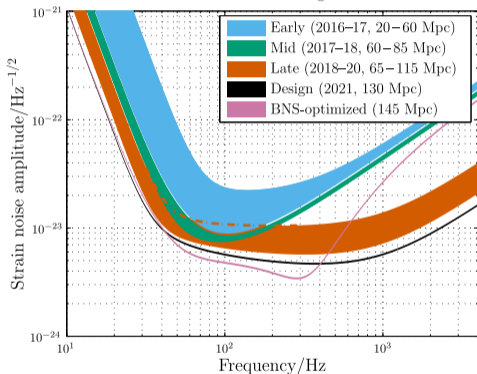
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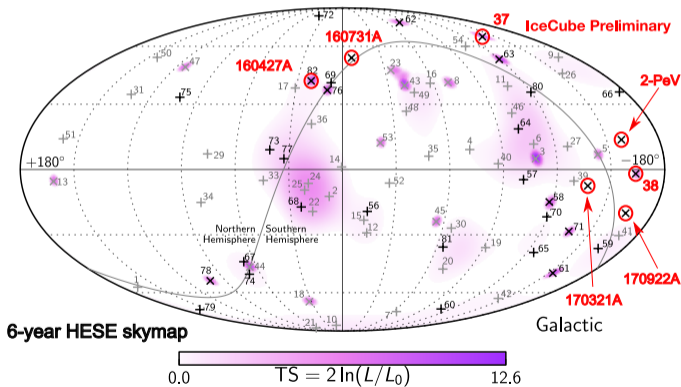
Advanced Virgo



Abbott et al., LRR 19 (2016)

- O1: follow-up of GW151226 (first and only IACT)
- O2: follow-up of two events (analysis ongoing)
- O3: planned to start 1st February 2019
 - Improved sensitivity of LIGO and Virgo
 - Larger event horizon
 - More events (~ 1 BNS alert/month)
- MAGIC plans: improve follow-up strategy
 - Select suitable targets looking at catalogs
 - Scan a sky region according to the expected signal, given an emission model
 - Update the MAGIC Automatic Alert system to automatize the response

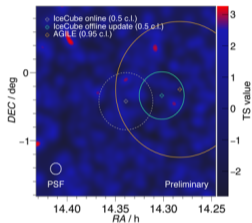
- Since 2012 MAGIC is inside the *Gamma-ray Follow-Up* (GFU) (see JINST, 11, P11009 (2016))
- HESE+EHE: 4 real-time alerts observed after delivery of AMON GCN Notices
- Archival tracks: 2 HESE (37 and 38) and 2 PeV track (Highest Energy Track, HET)
- More than 30 h of observations



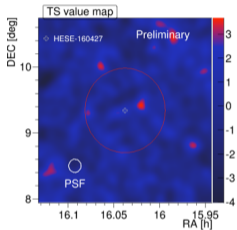
Adapted from Kopper et al., Proc. 35th ICRC 2017

Gora et al. Neutrino 2016; Satalecka et al. Gamma 2016; Noda et al. TeVPA 2016; Santander et al. ICRC 2017

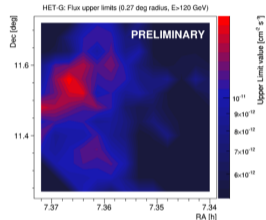
⇒ all-IACT nu-track observation paper in preparation



HESE/EHE-160731A (ATel #9315)



HESE-160427A



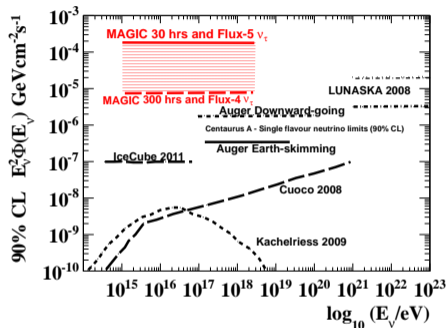
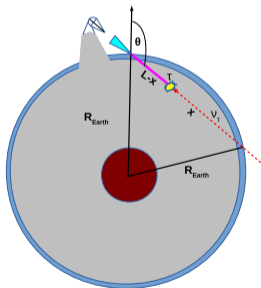
2 PeV track (ATel #7856)

- 1.3 h data starting at $\sim t_0 + 16$ h
- $z_d 45^\circ \div 65^\circ$
- $E_{\text{thr}} \sim 800$ GeV (due to calima)
- No signal found (no excess at AGL J1418+0008 position)

- 2 h data starting at $\sim t_0 + 42$ h
- $z_d 18^\circ \div 26^\circ$
- $E_{\text{thr}} \sim 120$ GeV (due to moon)
- Hotspot (3.6σ , 2.1σ after trials) 0.3° away from center

- 11.6 h in March/December 2016
- $z_d 16^\circ \div 38^\circ$
- $E_{\text{thr}} \sim 120$ GeV
- Flux UL at 95% C.L.: $(0.6 \div 2) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-2}$ ($\sim 2 \div 7\%$ C.U.)

- MAGIC can observe towards the horizon
- τ neutrinos can interact with Earth's crust or with ocean
- τ leptons produced can induce an air shower
- Feasibility study presented in Ahnen et al. *Astroparticle Physics* (accepted for publication, arXiv 1805.02750)



- Such technique can probe ν_τ from 1 PeV to 3 EeV
- 30 h of “Sea data” obtained
- $UL = 2 \times 10^{-4} \text{ GeV cm}^{-1} \text{ s}^{-2}$ (90% C.L., $\gamma = 2$)
- If 300 h and strong flare, the upper limit can be improved of almost 2 orders of magnitude

- Neutrino on 22nd September 2017, 20:54:30.43 UT
- EHE Notice: $t_0 + 43$ s
- GCN Circular 21916 by IceCube on 23rd September 01:09:26 GMT
- Immediate follow-up of other instruments (INTEGRAL, Swift, HAWC, Konus-Wind)
- At MAGIC site, bad weather prevented prompt observation, but...

```
TITLE:          GCN/AMON NOTICE
NOTICE_DATE:    Fri 22 Sep 17 20:55:13 UT
NOTICE_TYPE:    AMON ICECUBE EHE
RUN_NUM:        130033
SRC_RA:         77.2853d {+05h 09m 08s} (J2000),
SRC_DEC:        +5.7517d {+05d 45' 06"} (J2000),
SRC_ERROR:      14.99 [arcmin radius, stat+sys,
                  50% containment]
DISCOVERY_DATE: 18018 TJD; 265 DOY;
                17/09/22 (yy/mm/dd)
DISCOVERY_TIME: 75270 SOD {20:54:30.43} UT
ENERGY :        1.1998e+02 [TeV]
SIGNALNESS:     5.6507e-01 [dn]
CHARGE:         5784.9552 [pe]
```

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791: *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Koccevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration on 28 Sep 2017; 10:10 UT*
Credentia Certification: *David J. Thompson (David.J.Thompson@nasa.gov)*

- ... within IceCube-170922A error circle, the blazar TXS 0506+056 was found to be flaring
- Brightening of in GeV band detected by Fermi-LAT (ATel#10791)
- Between September 15th to 27th, increase of factor ~ 6 wrt 3FGL flux
- Also flare in optical/IR, radio
- MAGIC started the follow-up on 24th September 2017, then on 28th September

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration on 4 Oct 2017; 17:17 UT*

Credencial Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: [10830](#), [10833](#), [10838](#), [10840](#), [10844](#), [10845](#), [10942](#)

 Tweet  Recommend 20

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10787, #10791, #10792, #10794, #10799, #10801, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstancja.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatorio Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

- 12 h data between September 28th and October 3rd: 5σ detection
- Redshift estimated (GTC): 0.3365 (Paiano et al. ApJL 854 2018)
- First time VHE γ -rays detected from a direction consistent with a neutrino event



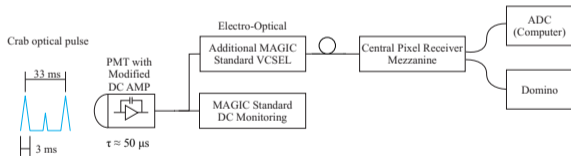
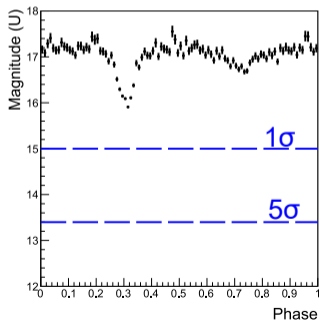
Work is being done on this interesting event, so stay tuned!

FRBs in short

- GHz-band emission
- Duration of the order of ms
- Peak fluxes of the order of Jy levels
- DMs exceeding the ones from the Galaxy
- Galactic/Extragalactic? EGAL favored
- Still not clear progenitor

MAGIC and FRBs

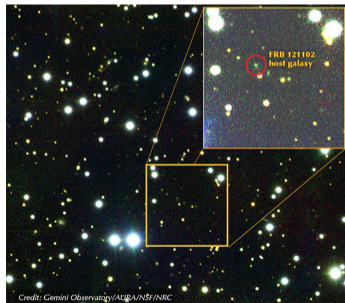
- MWL observations needed
- MAGIC can contribute in VHE and optical
- MAGIC-II central pixel: sensitive to 1 ms-1 s pulses
- Sensitivity: $m_U \sim 13.4$ (U band)
- Crab pulsation detectable in 10 s



Hassan et al., Proc. 35th ICRC

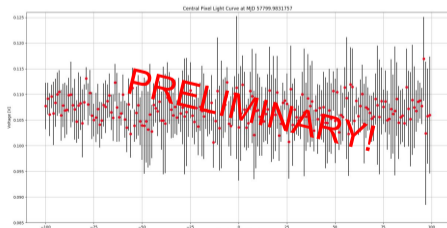
FRB 121102

- Only known repeating FRB
- Associated sources in optical and radio
- Located at $z = 0.193$ in a dwarf galaxy
- Search of counterparts at other wavelengths



MAGIC observations

- From September 2016, simultaneous observations with Arecibo and Effelsberg
- MWL campaign with INTEGRAL, Effelsberg,GBT and Nancy in September 2017
- 20 h of data analyzed
- Constraints on VHE (burst and persistent) and optical burst emission:
[paper on FRB 121102 in review process](#)
- For 2018, additional 20 h allocated



Transient sources are a key topic for MAGIC

- MAGIC Automatic Alert System for prompt reaction
- GRBs, GWs, neutrinos, FRBs, flaring AGNs
- Multimessenger science

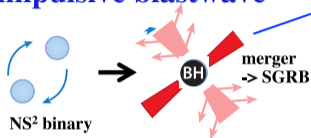
Prospects for the future

- Many results to be published
- Tuning/updating of MAGIC Automatic Alert system
- Commissioning of Sum Trigger to lower energy threshold
- Coordination with other instruments
- Impact on transient searches with CTA

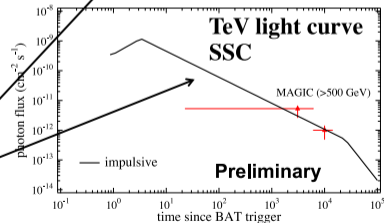
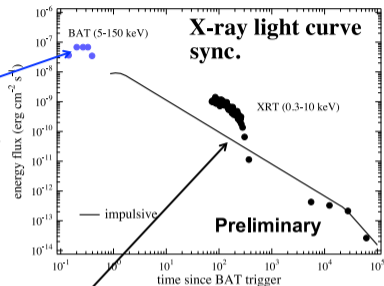
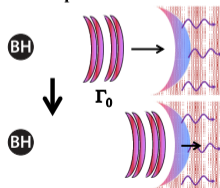
Stay tuned!

BACKUP

short GRB 160821B impulsive blastwave

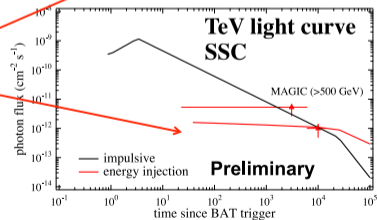
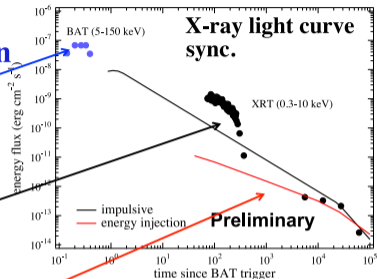
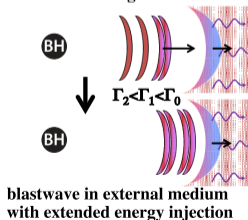
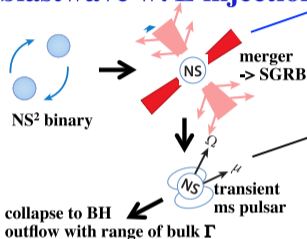


impulsive explosion with bulk Γ



Credit: Susumu Inoue @ICRC2017

short GRB 160821B blastwave w. E injection



Credit: Susumu Inoue @ICRC2017