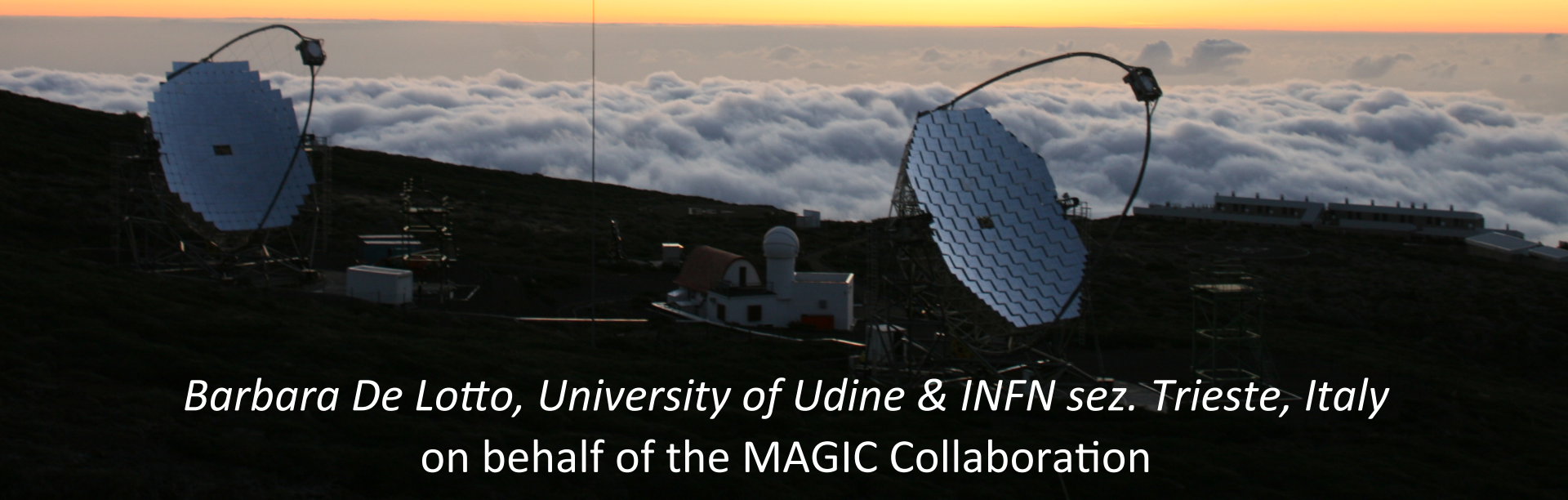
MAGIC multi messenger results and perspectives

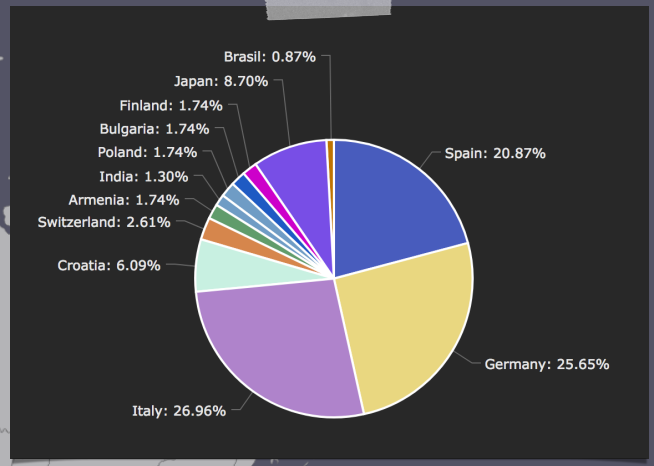
- The MAGIC telescopes
- The multi messenger program:

  follow-up of HE neutrinos and gravitational wave events
- Plans and perspectives



Barbara De Lotto, University of Udine & INFN sez. Trieste, Italy
on behalf of the MAGIC Collaboration

The MAGIC collaboration



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

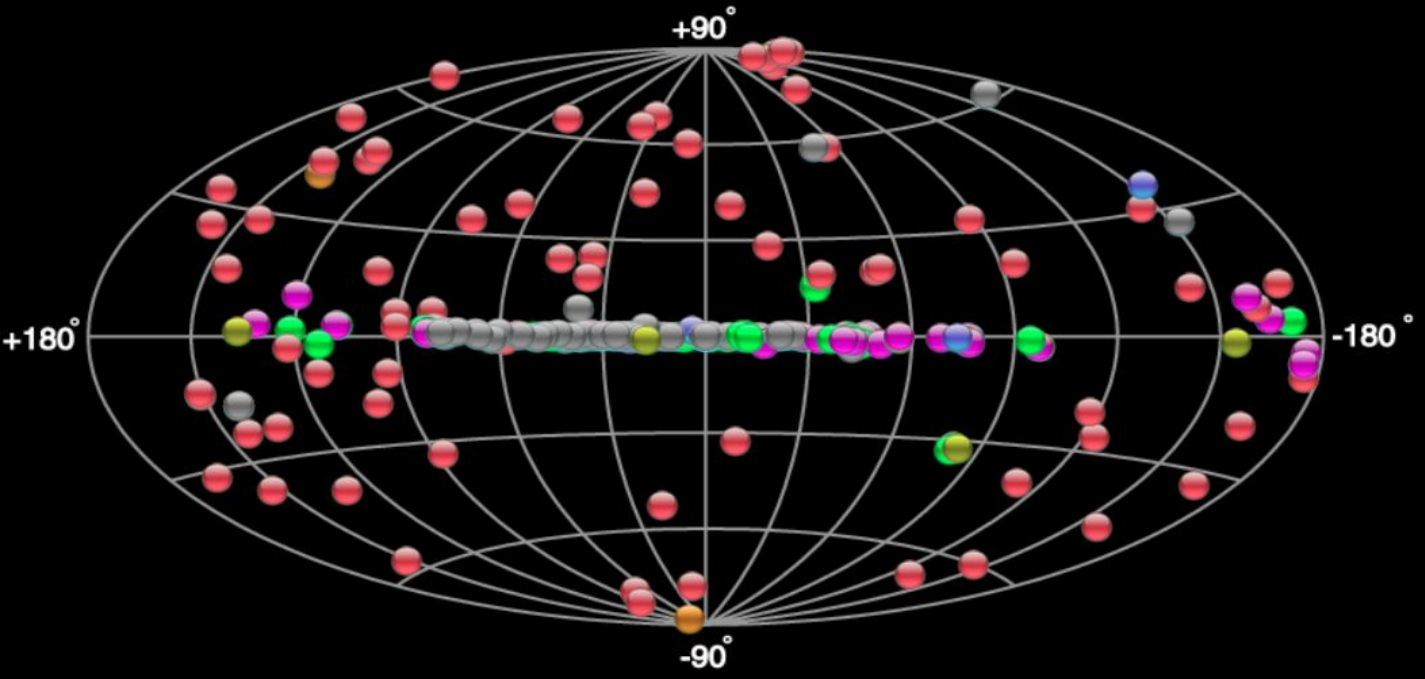
The MAGIC Collaboration is composed by 230 members from 12 countries

Credits: MAGIC outreach group

One of the three main actors shaping the VHE γ-astrophysics

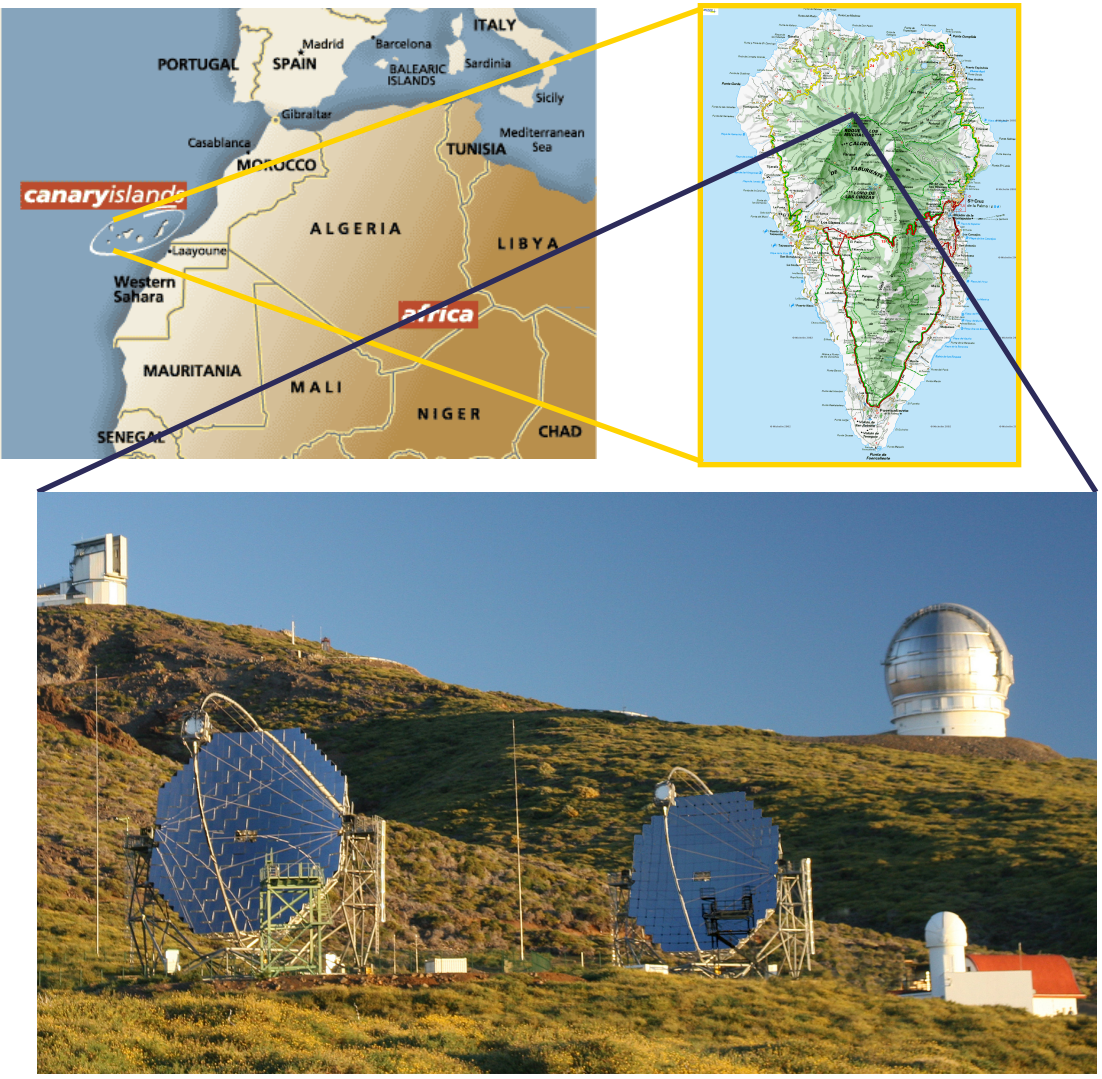
with some special characteristics

> 200 established VHE γ-ray sources



A new tool for cosmic-ray physics and fundamental physics

The MAGIC Telescopes



Roque de los Muchachos Observatory @ La Palma, ~ 2300 m a.s.l.

2 x 17 m telescopes

Active since 2003
In stereo configuration since 2009
At least 5 more years foreseen

Distinctive Technologies

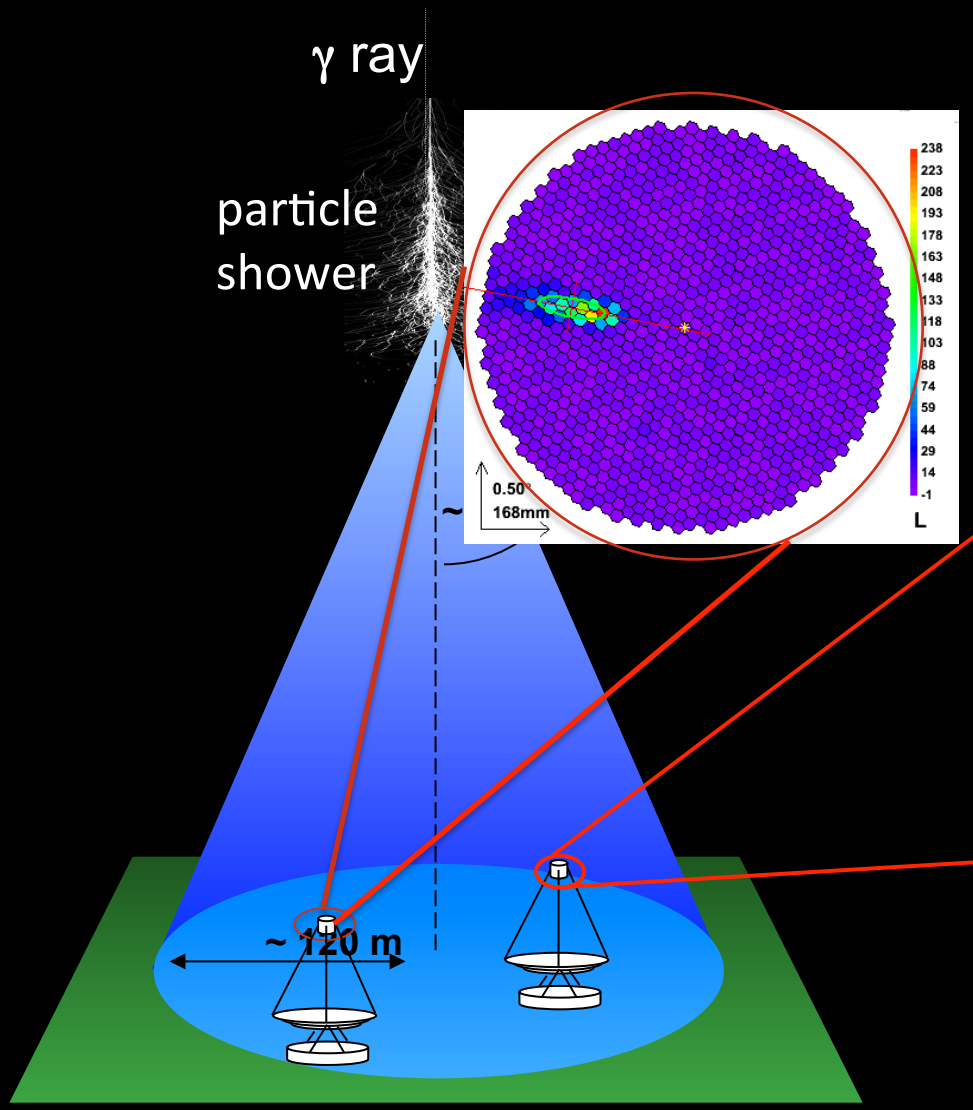
Lowest energy threshold: 30 GeV
➔ **farthest horizon**
Fast rotation < 30 s for 180°
➔ **look for transients**

1.64/2 GHz Ultra Fast ADCs
Operation in moderate moonlight

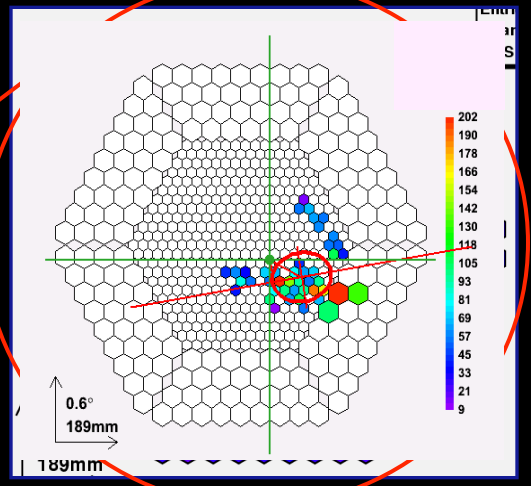
Current Performance

Sensitivity ~0.5% of Crab in 50 h
Energy Resolution ~ 15%
Angular resolution ~ 0.06 degrees
Field of View ~ 3.5 degrees

Imaging Air Cherenkov Technique

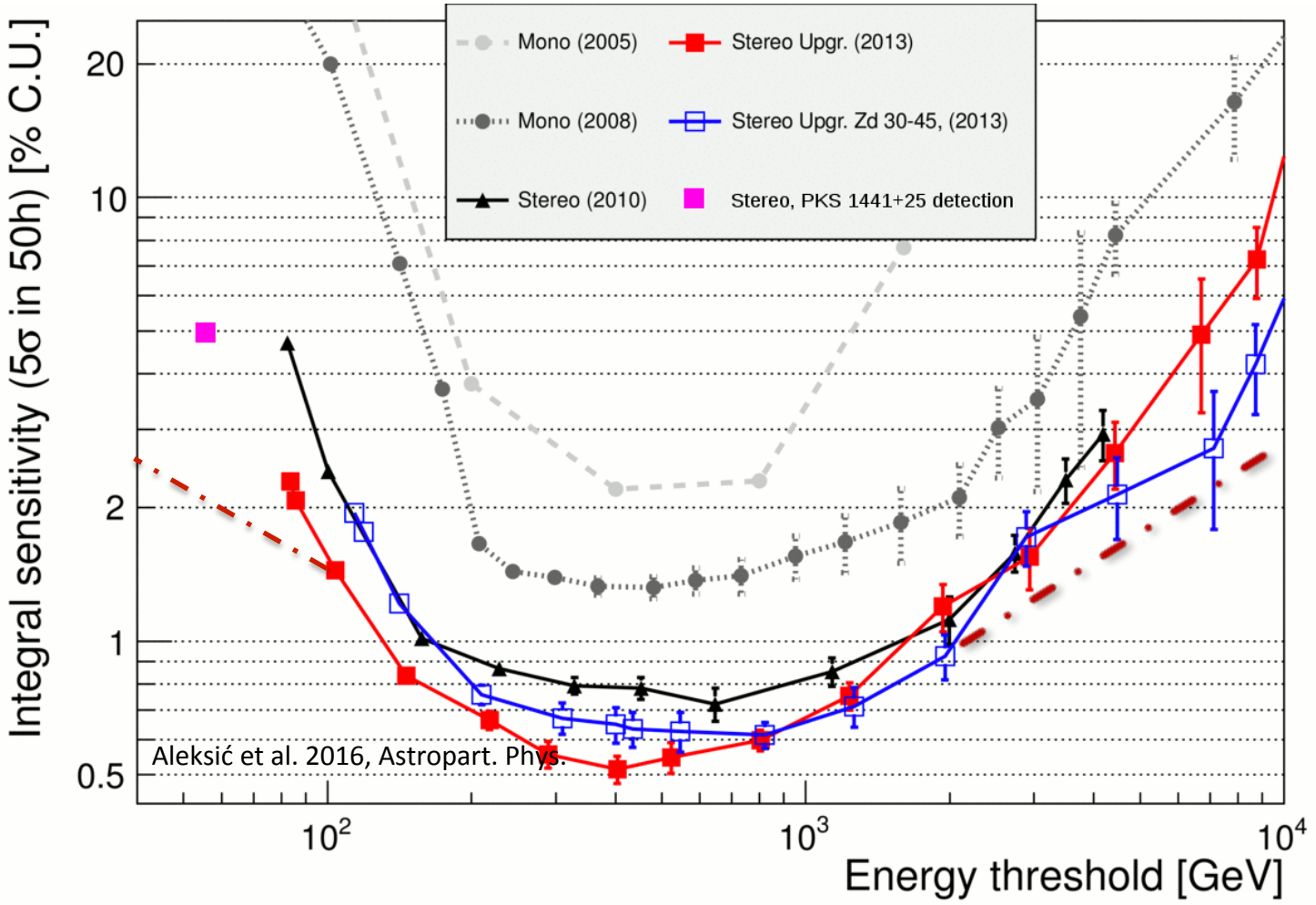


Cherenkov light image of shower in telescope camera



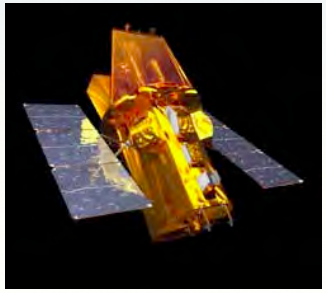
- reconstruct:
  arrival direction, energy
- reject hadron background
  statistically in the analysis

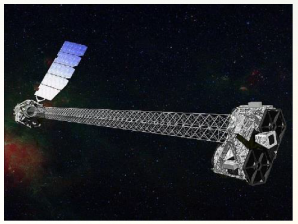
Significant improvements in sensitivity during the recent years

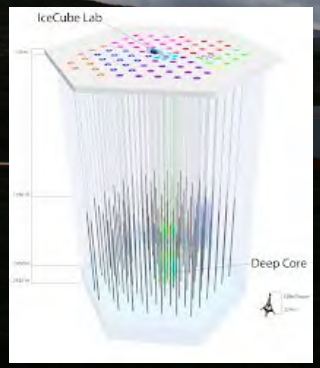


Further improvements foreseen at lowest and highest energies due to new techniques of Sum-Trigger & very large zenith angle observations

We entered a new era:
MULTI-MESSENGER ASTROPHYSICS







MAGIC active in various multi-messenger and multi-wavelength (MWL) campaigns

- Pre-planned observations: monitoring of known sources
- Target of Opportunity observations: AGN flares, Gamma Ray Bursts, Fast Radio Bursts:

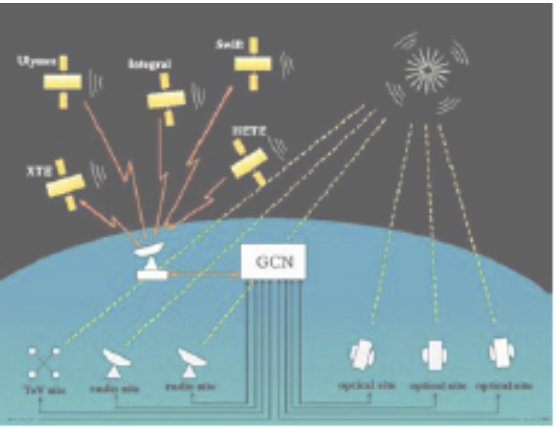
~ 15% of total observation time per year allocated to transients

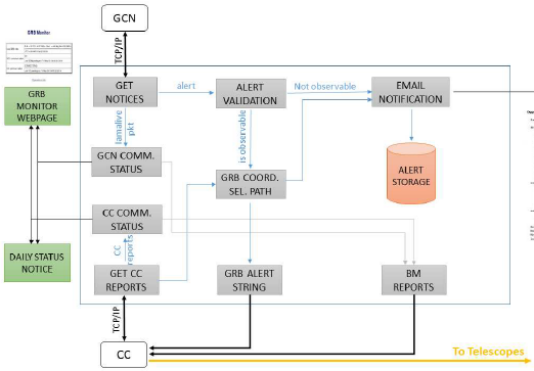
key topic for MAGIC

Automatic Alerts System for prompt reaction already tuned for GRBs

recently adapted for

multi-messenger approach

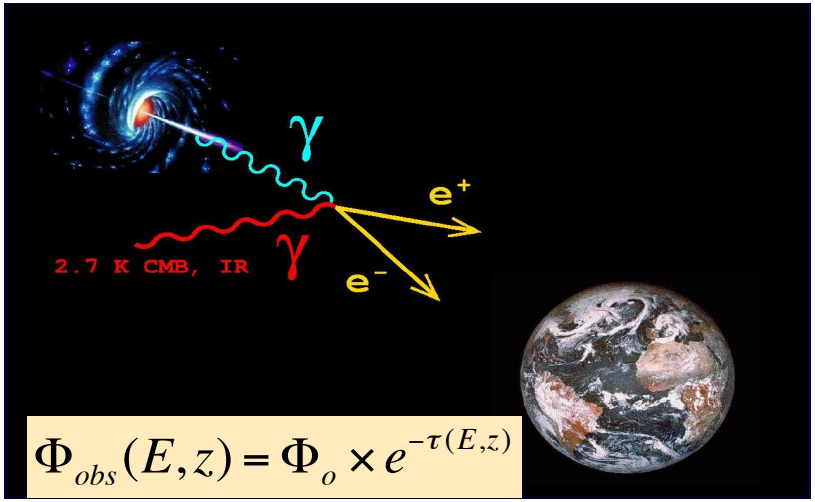


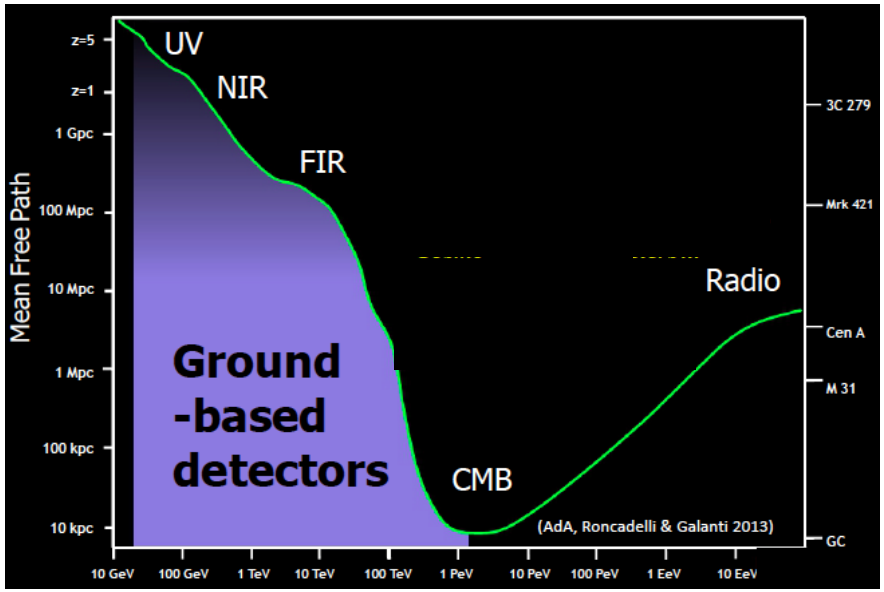


Transients astrophysics with Cherenkov telescope wrt satellites

☺ : - large effective area (~ 10^4 - 10^5 m^2)
- relatively large field of view (>~3.5-5 deg)
- fast repointing (< 30 s)

😐 : - limited duty cycle (~15%)
- limited zenith angle range (~<70 deg)
- EBL attenuation for high-z extragalactic sources:

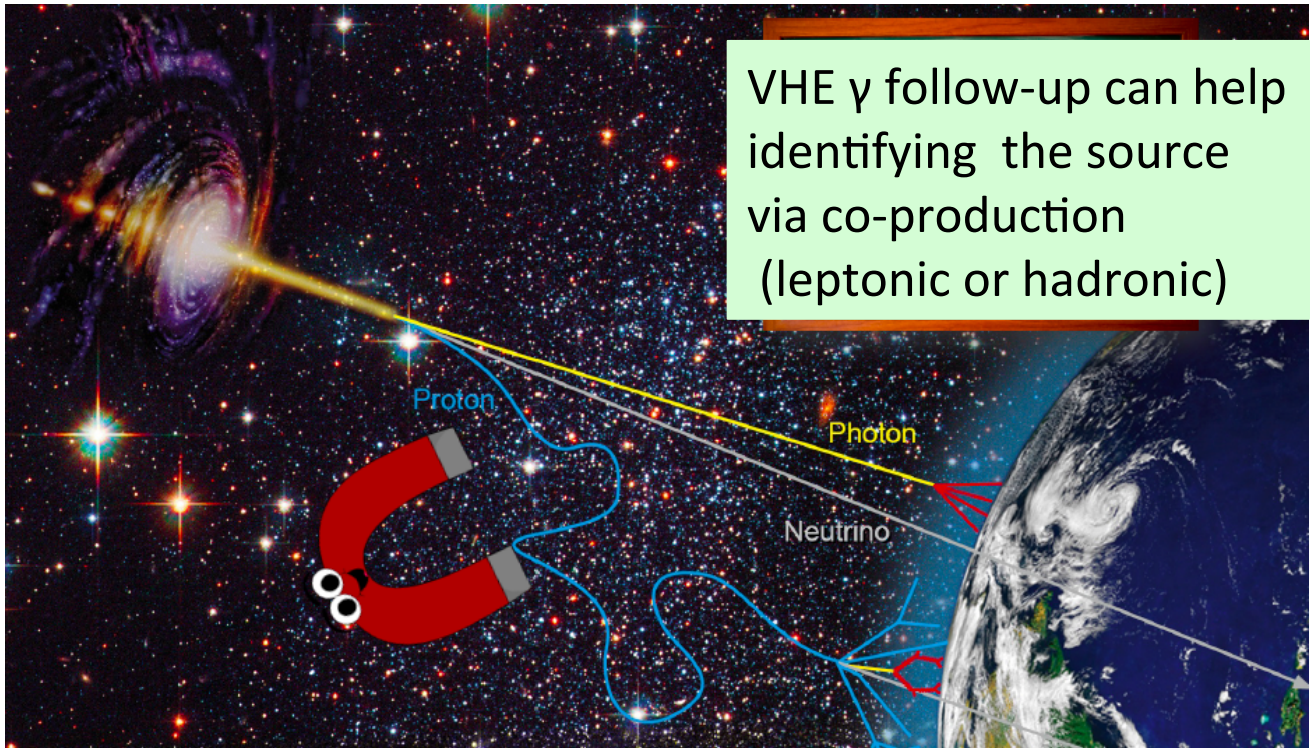




Follow-up of VHE neutrinos

[IceCube+MAGIC+VERITAS coll., 2016 JINST 11 P11009]

- ν new window onto the Universe
- not deflected by magnetic fields (like γ)
- clear indicators of VHE/UHE cosmic ray production
- detected by IceCube, only diffuse flux, no correlation with promising sources (bright GRBs, bright blazars) until recently



5 MAGIC prompt follow-up observations (AMON GCN notices)

Astronomical Telegram #10817 (28 September 2017):

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

22nd Sept 2017

IceCube-170922A: IceCube observation of an extremely-high-energy neutrino candidate event

Direction consistent with the location of the γ-ray blazar TXS 0506+056 observed to be in a flaring state

An extensive multi-wavelength campaign followed

27th Sept

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

Further Swift-XRT observations of IceCube 170922A

AGILE confirmation of gamma-ray activity from the IceCube-170922A error region

Related

10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056

10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056

10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)

10838 MAXI/GSC observations of IceCube-170922A and TXS 0506+056

10833 VERITAS follow-up observations of IceCube neutrino event 170922A

10831 Optical photometry of TX0506+056

10830 SALT-HRS observation of the blazar TXS 0506+056 associated with IceCube-170922A

10817 First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

10802 HAWC gamma ray data prior to IceCube-170922A

10801 AGILE confirmation of gamma-ray activity from the IceCube-170922A error region

10799 Optical Spectrum of TXS 0506+056 (possible counterpart to IceCube-170922A)

10794 ASAS-SN optical light-curve of blazar TXS 0506+056, located inside the IceCube-170922A error region, shows increased optical activity

10792 Further Swift-XRT observations of IceCube 170922A

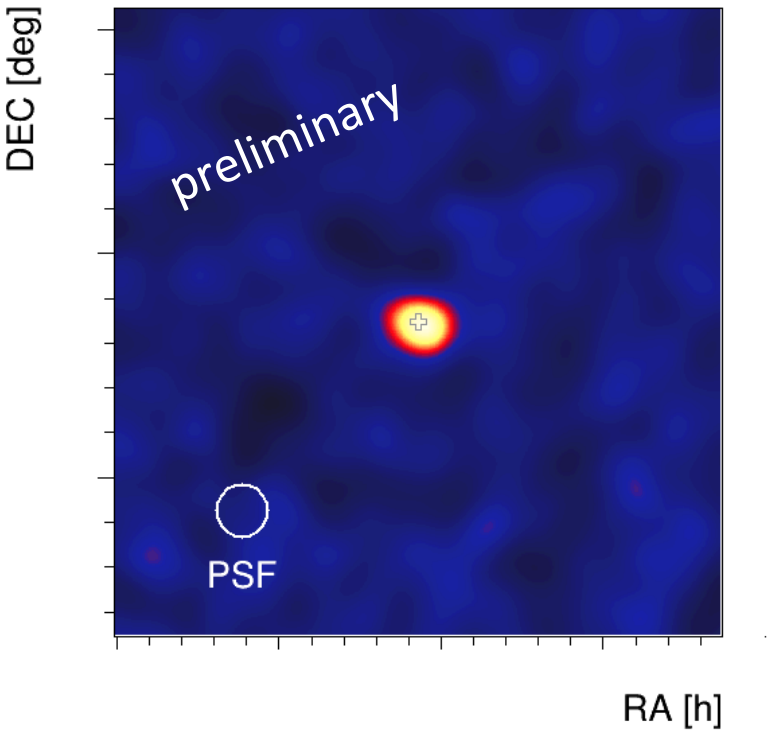
10791 Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

10787 H.E.S.S. follow-up of IceCube-170922A

10773 Search for counterpart to IceCube-170922A with ANTARES

The MAGIC detection of TXS 0506+056

TXS 0506+056 is a BL Lac, z = 0.3365 ± 0.0010 (Paiano+ 2018)



ATel #10817

- > 5 σ detection
- 12 hours of good quality data observation
  2017 Sep 28th – Oct 3th
- E > 100 GeV

Hadronic acceleration in a blazar

Blazar: active galaxy with the jet pointing at the observer

- The accelerated protons interact with the surrounding matter and radiation. Main production processes:

- **Proton-hadron**

$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

- **Photoproduction**

$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+ \nu_\mu \rightarrow n\,e^+ \nu_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

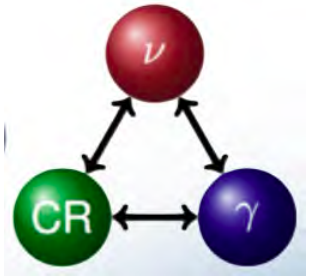
$$\sigma_{p\gamma} \approx 0.3 \text{ mb} \approx \frac{\sigma_{pp}}{100}$$

favored in jets because the photon density is expected to be larger

- threshold (Δ^+) at $E_p \sim 350$ PeV/E_γ (eV): the creation of a ν from a photon gas at 10 eV requires protons at $E_p > 35$ PeV
- average momentum fraction carried by the neutrino $\langle x_F \rangle_\nu \sim 0.05$ ➔ $E_\nu \approx \frac{E_P}{20}$

➡ **if E_ν can be estimated => E_p**

The multi-messenger connection

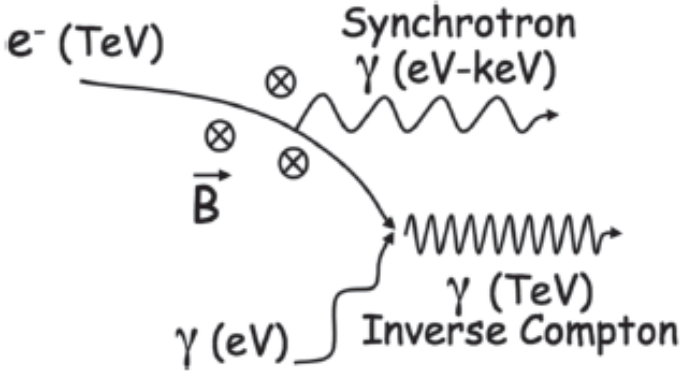


- In cosmic-ray accelerators, ~ equal energies are injected in secondary γ and ν:

  F. Halzen, Nature Physics 2017

$$E_\nu^2 \frac{dN_\nu}{dE_\nu dt}\left(E_\nu\right) \sim E_\gamma^2 \frac{dN_\gamma}{dE_\gamma dt}\left(E_\gamma\right)$$

- HE gamma rays can also come from purely leptonic mechanisms (Synchrotron Self Compton model)



Reprocessing

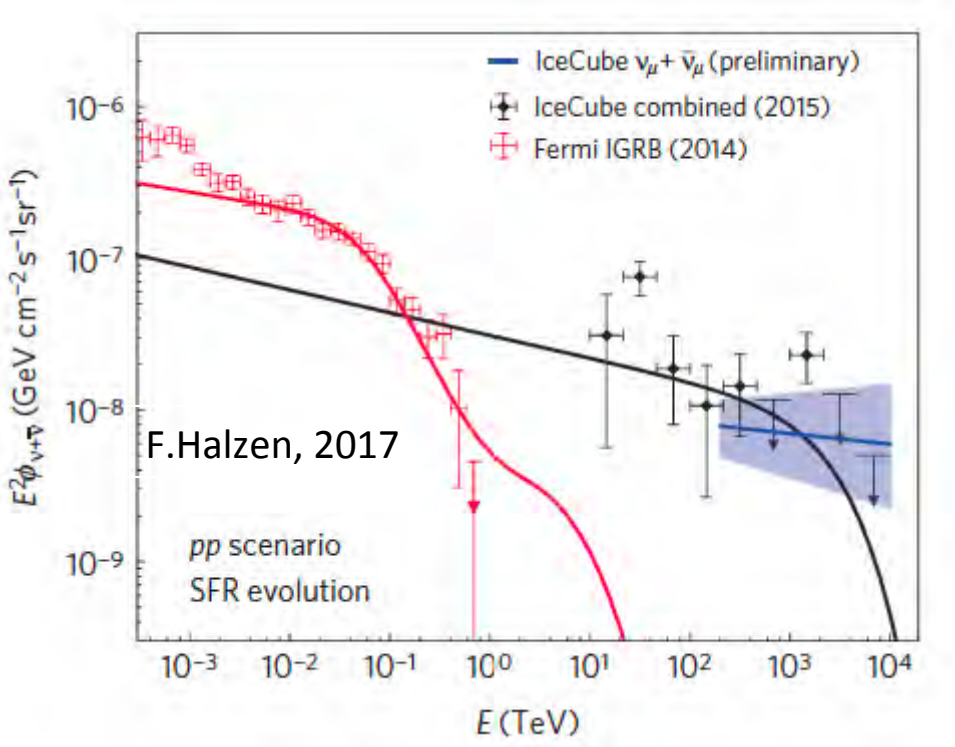
- Gamma rays are likely to be reprocessed in the photon gas, to shower and degrade their energy

IceCube cosmic ν flux

Corresponding cascaded γ-ray flux (after interaction with the cosmic radiation background)

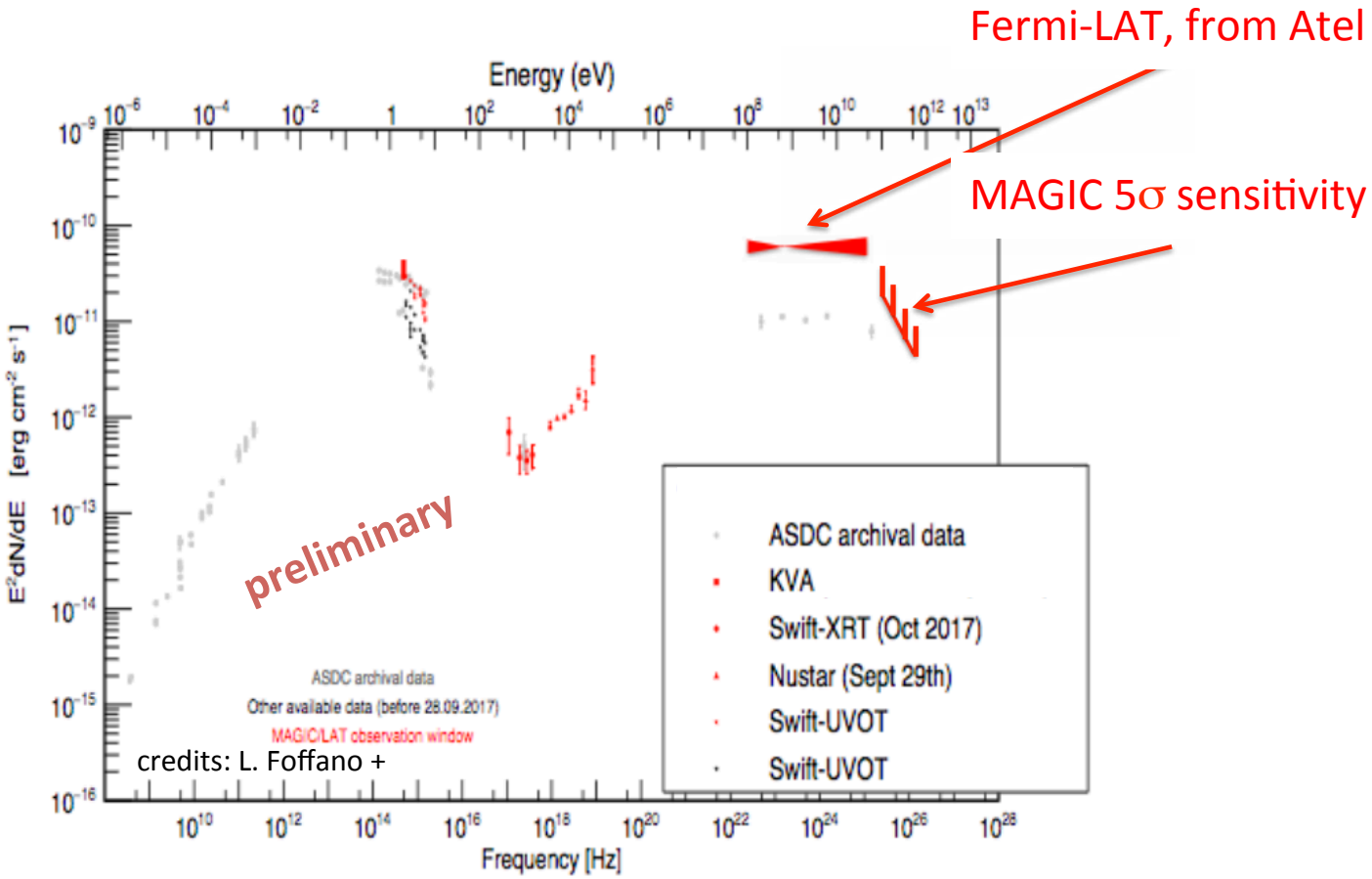
Matches the extragalactic isotropic diffuse gamma-ray background measured by Fermi

suggesting a common origin



Broadband spectral energy distribution

- Archival SED data of TXS0506+056 show the usual Synchrotron/Inverse Compton double peak

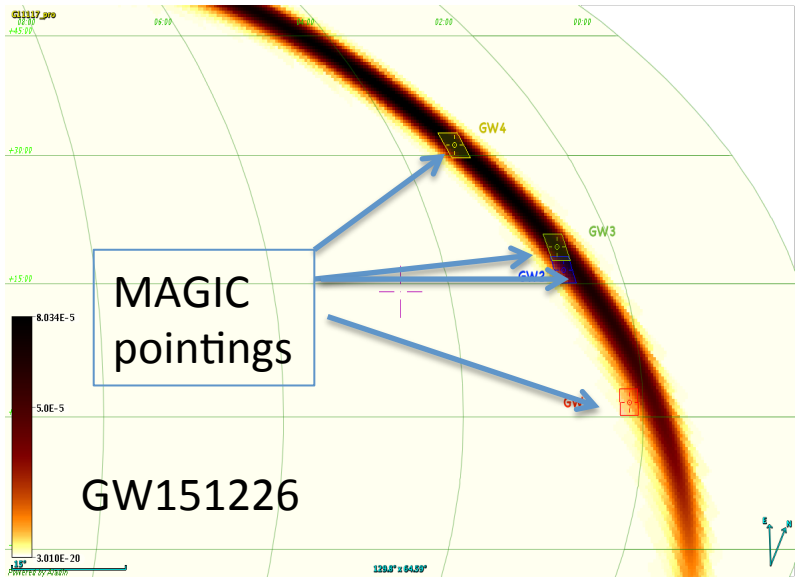


Crucial information can be extracted from the spectra study:
possible constraints on the theoretical modeling of the electromagnetic and neutrino observations of TXS0506+056 are under study

Gravitational Waves follow-up

- MAGIC in the business since 2014 (signed MoU with LVC)

O1: first and only IACT ToO observation (*B. De Lotto, Black Holes 2016*):
BH-BH, UL for 4 small regions
O2: follow-up of 2 events (UL analysis ongoing)
GW170817 NS-NS event unobservable ☹
due to high ZA (~ 88°)



- Difficult task: energetics, timing, small MAGIC FoV vs LIGO/Virgo localization precision

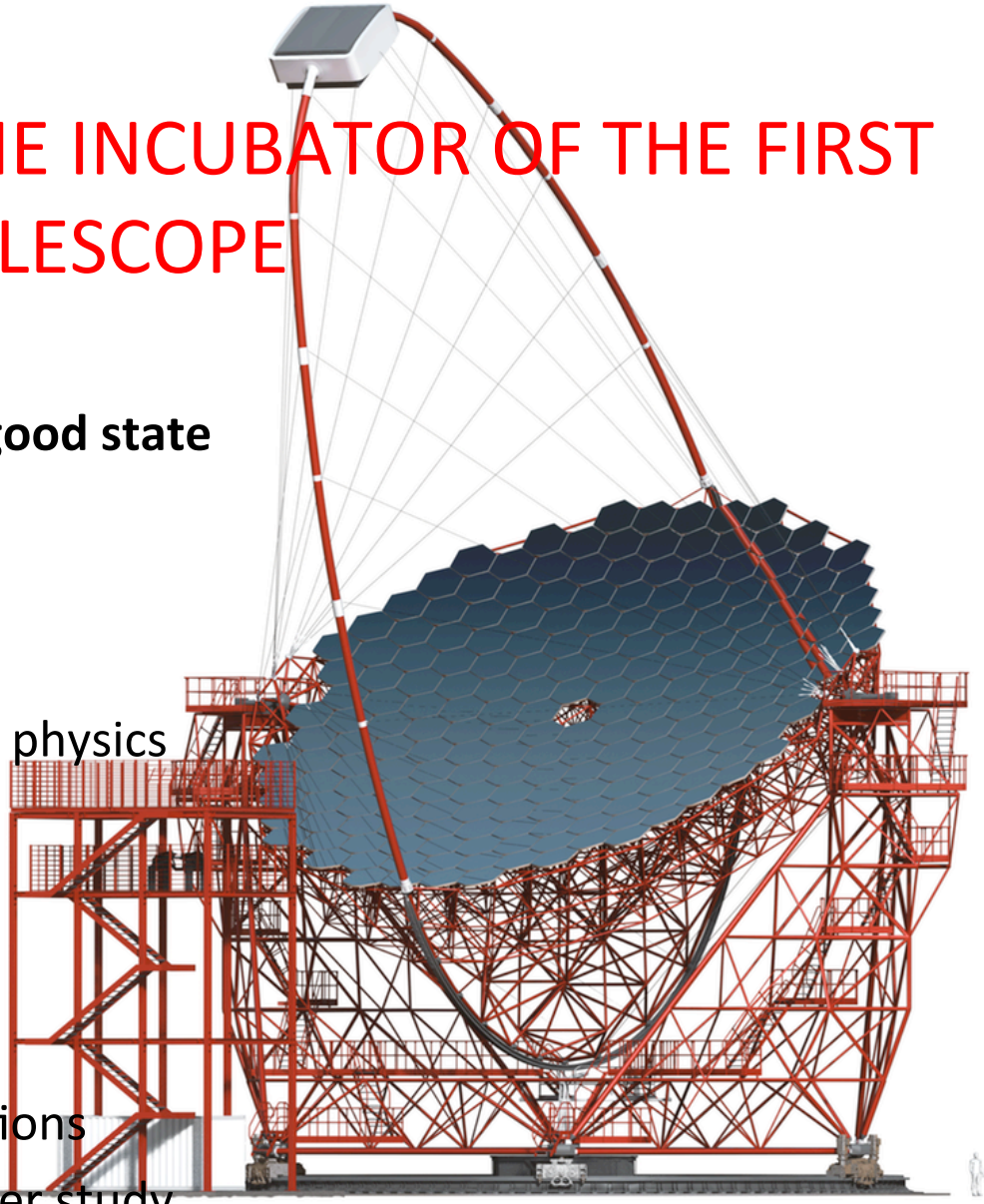
- Optimizing the follow-up strategy in view of the forthcoming LIGO-Virgo **O3** observing run:
  - Select suitable targets looking at source catalogs
  - Scan a selected sky region according to the expected signal, given an emission model
  - Update the MAGIC Automatic Alert system to automatize the response

MAGIC IS GOING TO BE THE INCUBATOR OF THE FIRST CTA TELESCOPE

- **MAGIC has never been in such a good state**
- smooth operation
- top performance
- cycle 13 of data taking on going,

with ambitious plans for fundamental physics and astrophysics

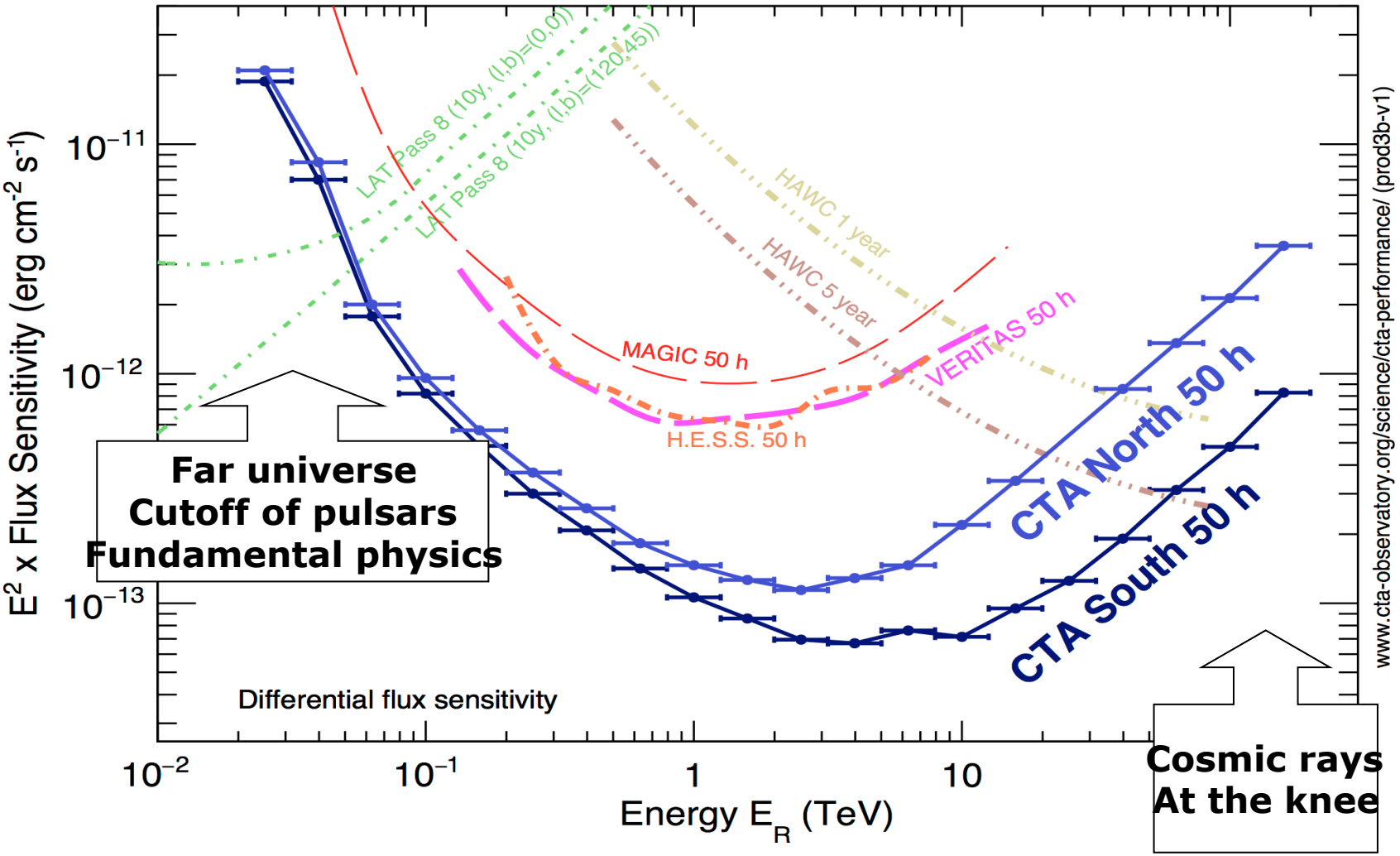
- **LST is growing at ~ 80 m from us** (within the Cherenkov light pool of a gamma ray shower)
- Performance of common observations with prototype LST + MAGICs under study



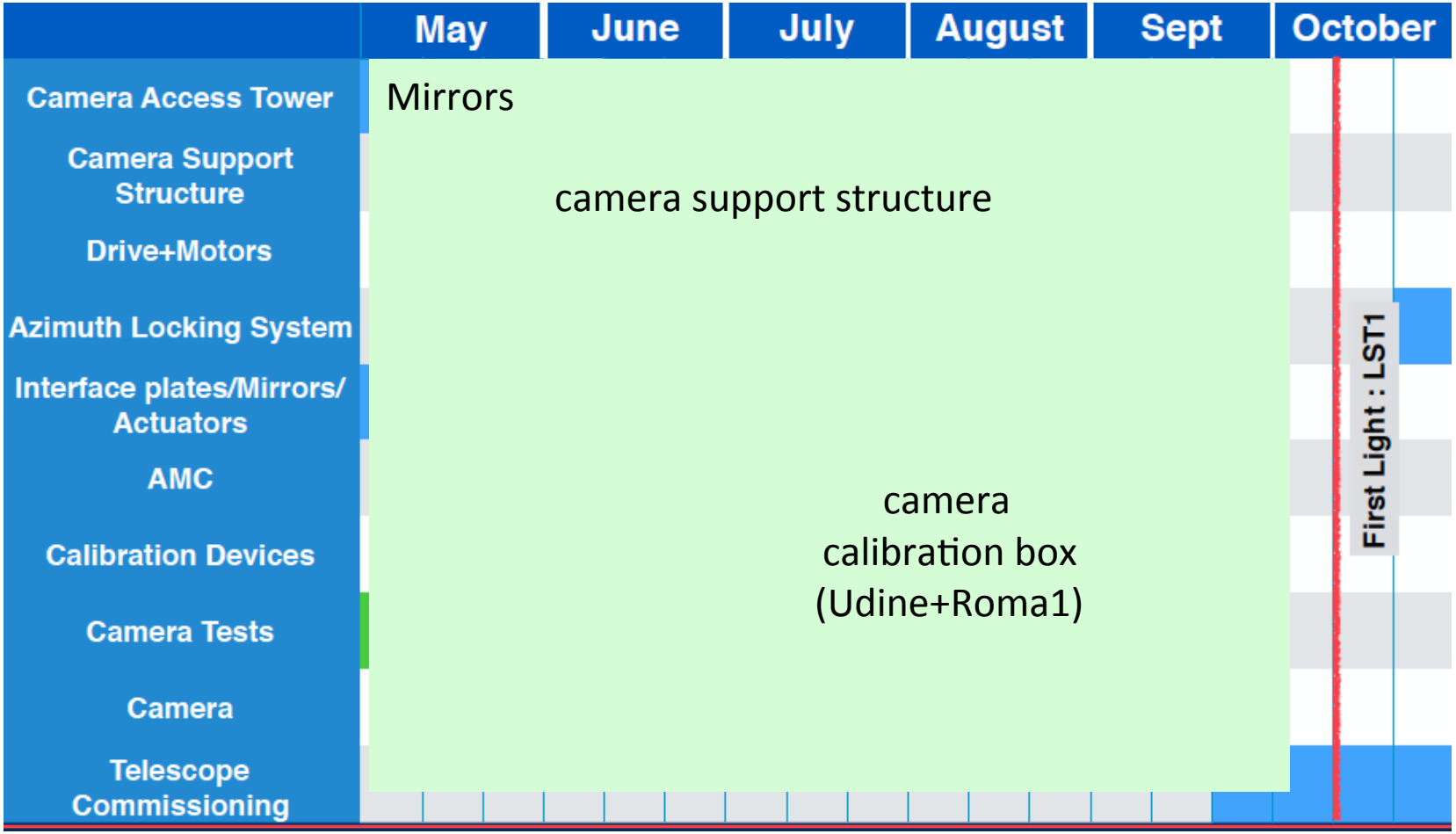

CTA Large Size Telescope, May 2018
Credits: T. Dettlaff

Ideal geometry for common observations

CTA expected performance: a factor 5 to 20 improvement in sensitivity



1st LST schedule

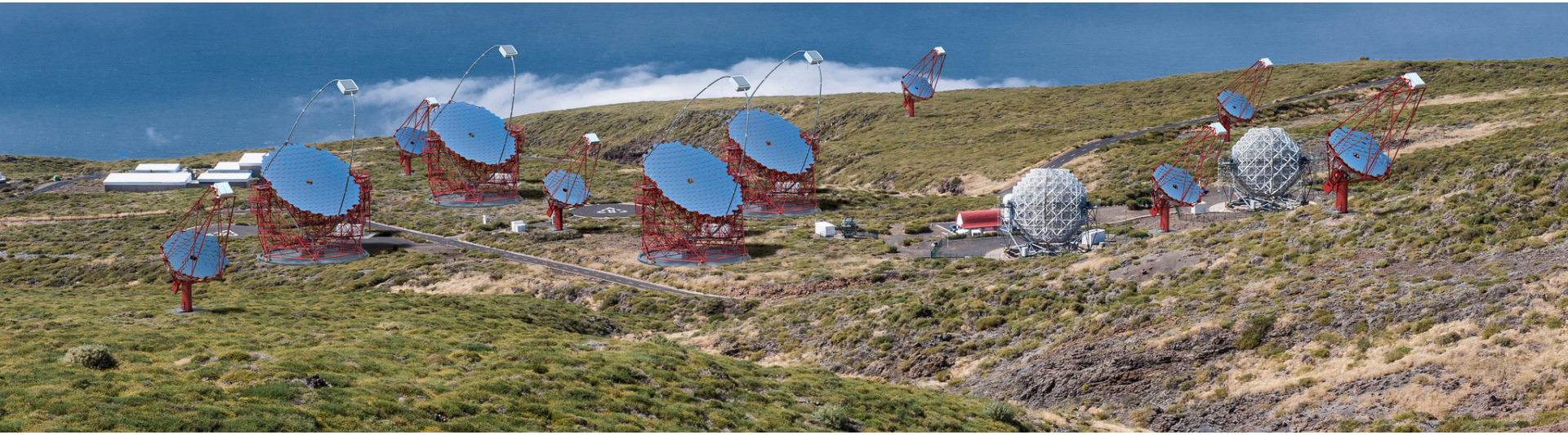


D. Mazin @ CTA general meeting, May 2018

October 2018 10th: inauguration

first light during O3 LIGO-Virgo observing run!

Future vision



- At least 5 more years of MAGIC data taking with minimal maintenance
- If supported, they will continue producing 1st quality science and contribute to the development and commissioning of LSTs

Conclusions

- MAGIC is at its most productive time in terms of physics:
  extremely interesting results are coming out
- First CTA Large Size Telescope is in construction phase and will be in commissioning phase in collaboration with MAGIC
- Multi-messenger astrophysics will play a key role in astroparticle and fundamental physics in the next years
- Great opportunity for young students to train in VHE γ-astrophysics

Thank you !