Risultati recenti e prospettive dell'astrofisica delle alte energie e particellare

Antonio Stamerra
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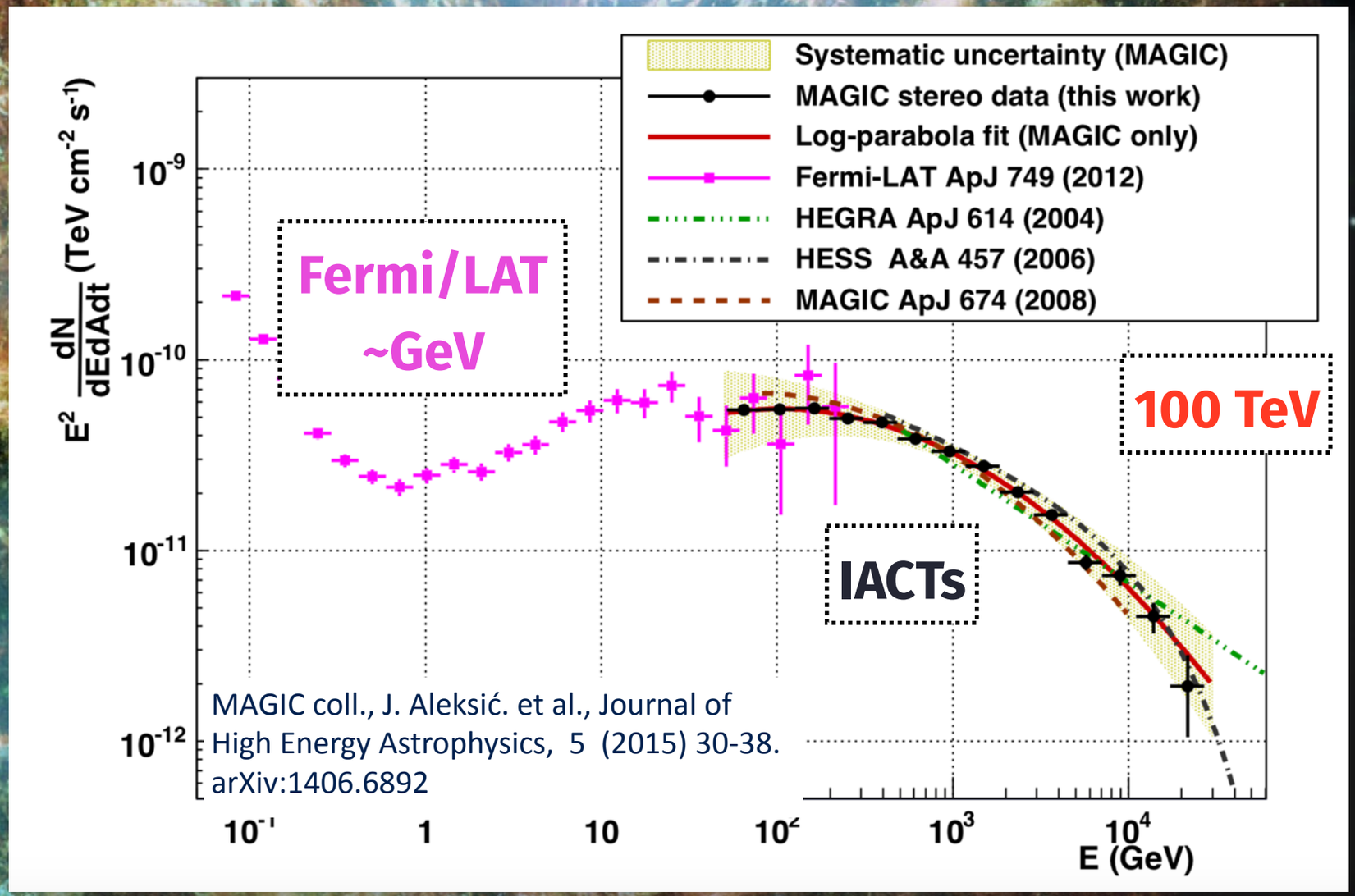
VERY-HIGH ENERGY GAMMA-RAY ASTRONOMY, TODAY

ANTONIO STAMERRA - OAR

Extreme energies

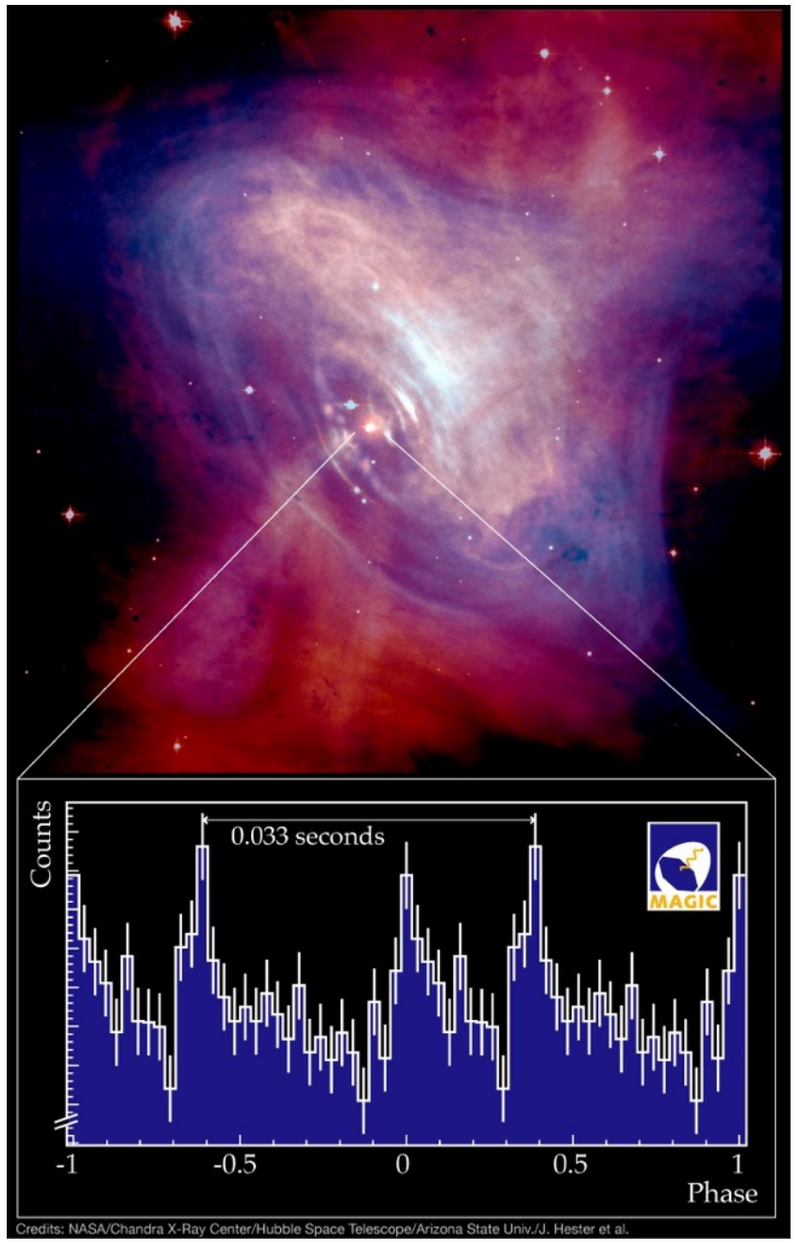
- **Crab Nebula**
- **VHE covers three orders of magnitude in energy**



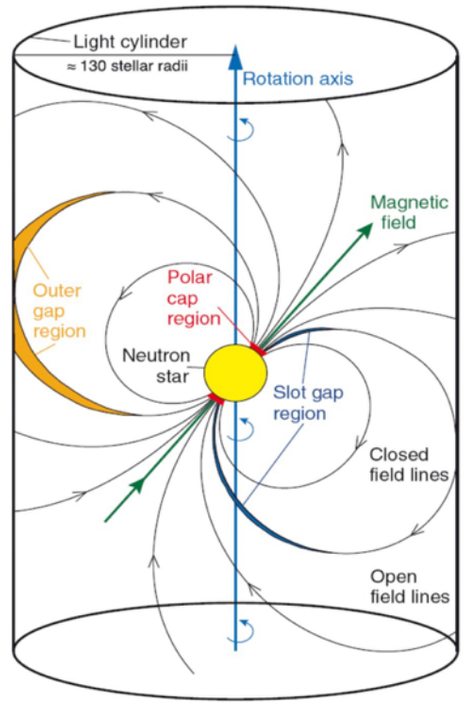
MAGIC coll., J. Aleksić. et al., Journal of High Energy Astrophysics, 5 (2015) 30-38. arXiv:1406.6892

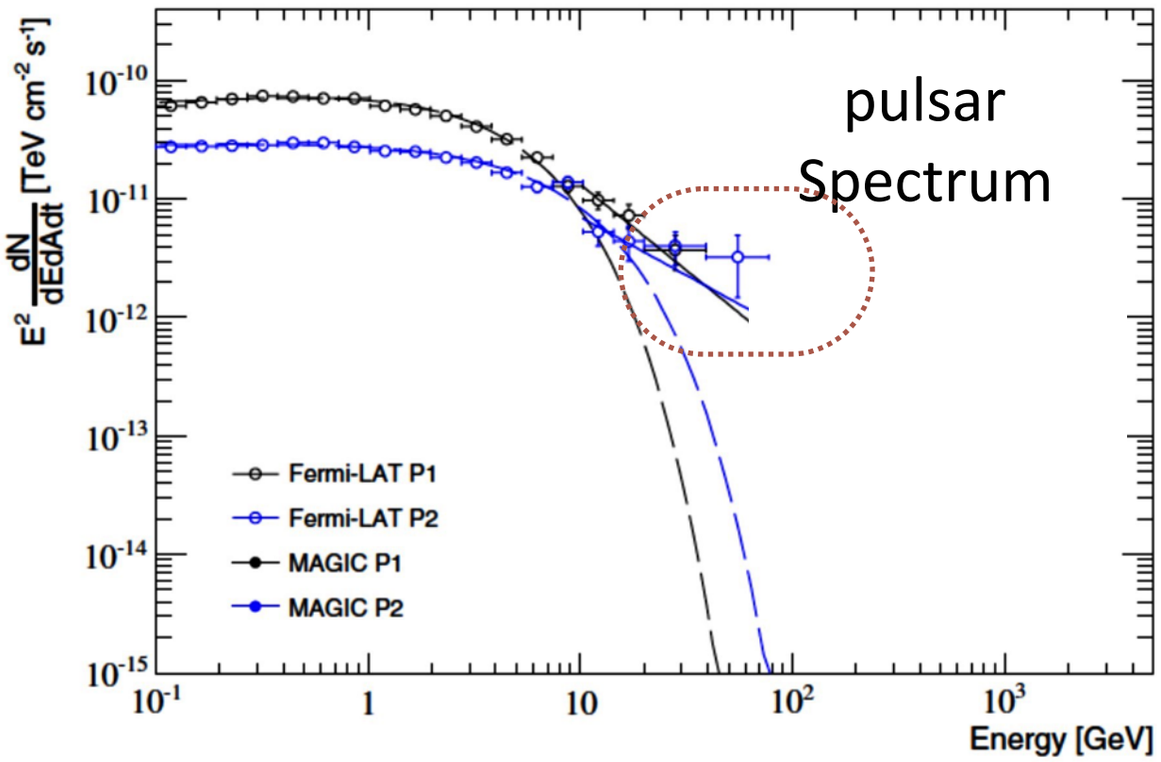
Extreme energies

- Crab pulsar



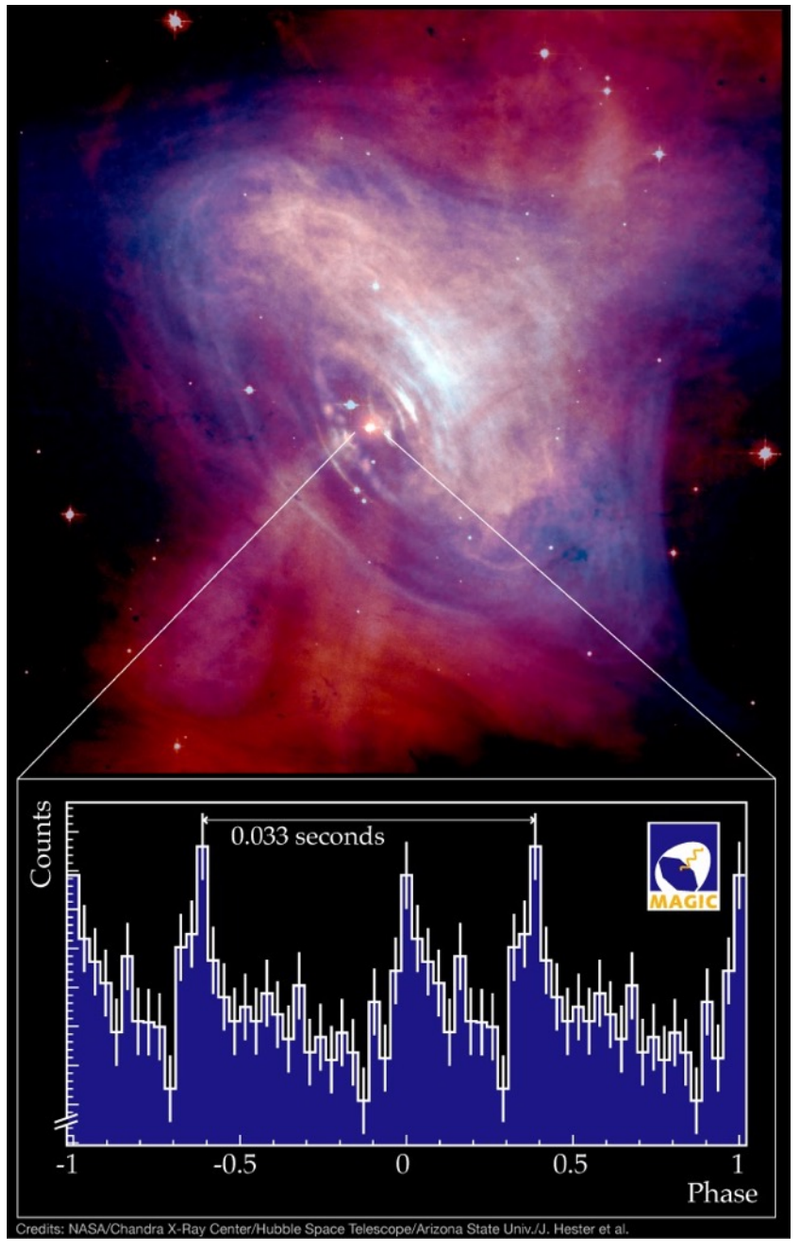
MAGIC Coll. 2008, Science 322





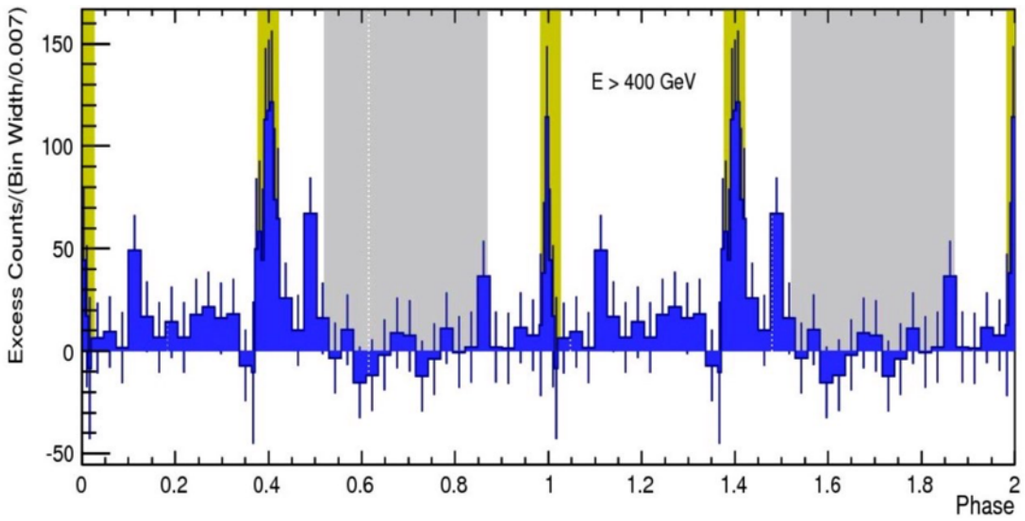
Extreme energies

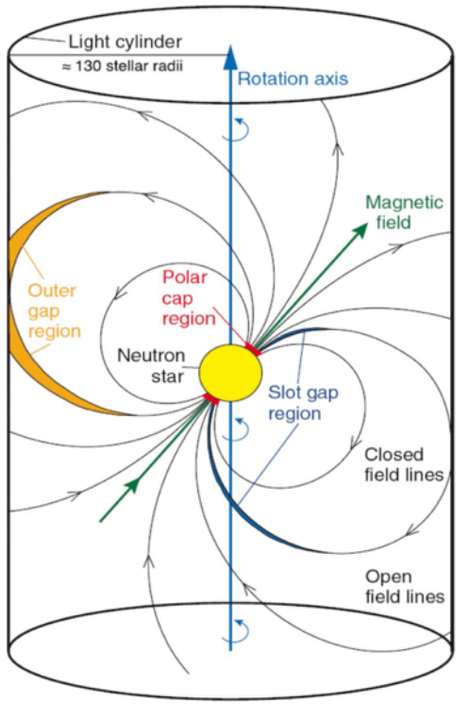
- Crab pulsar

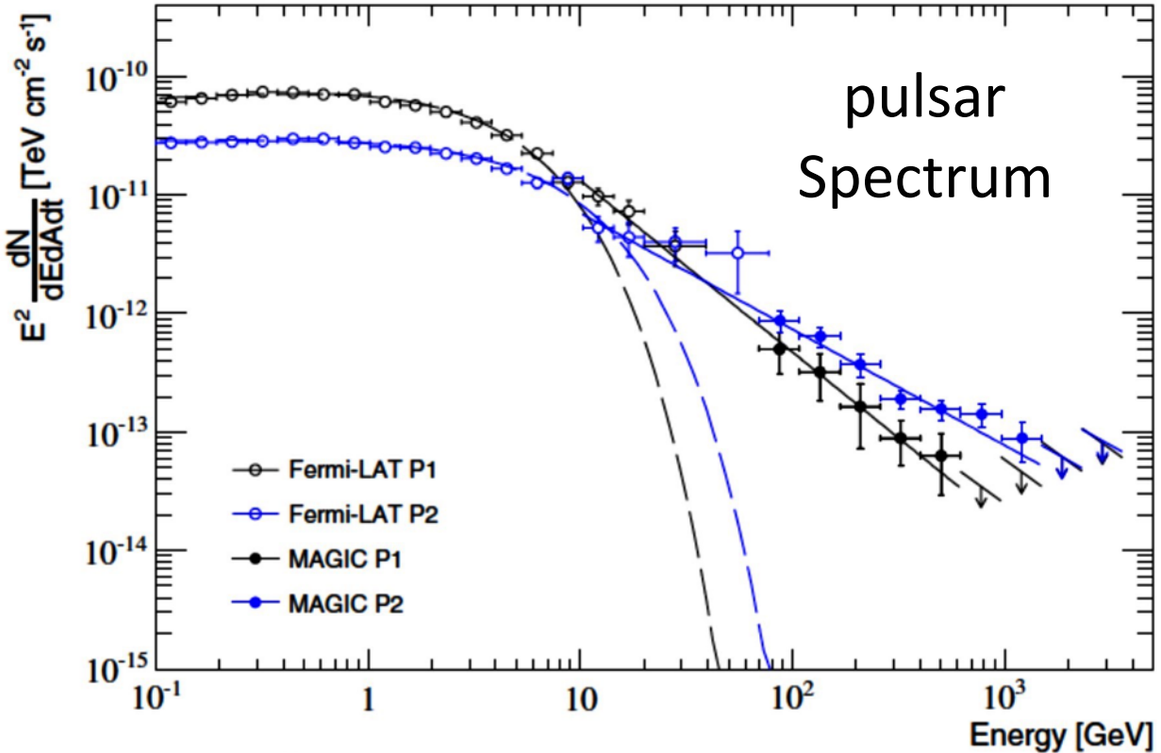


MAGIC Coll. 2008, Science 322

Phaseogram E>400 GeV



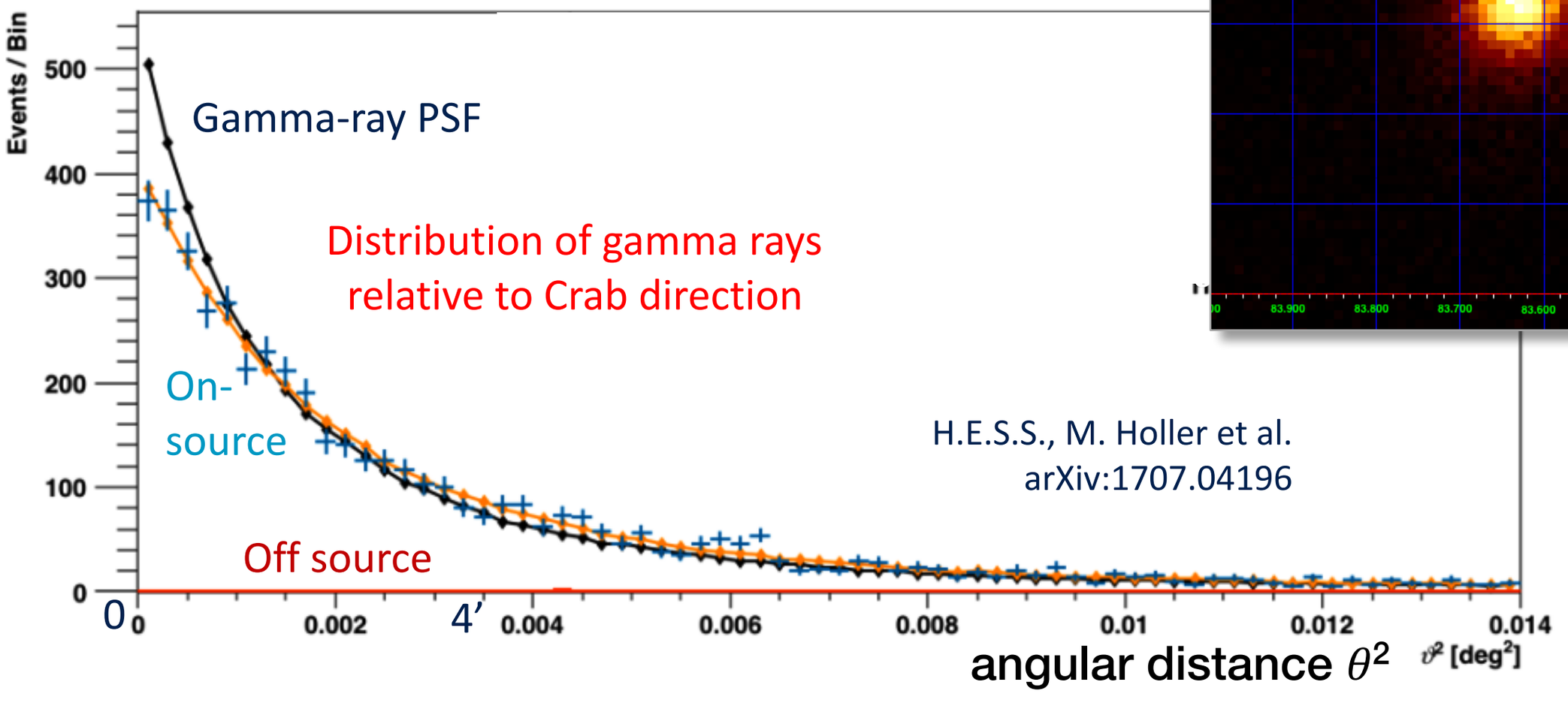


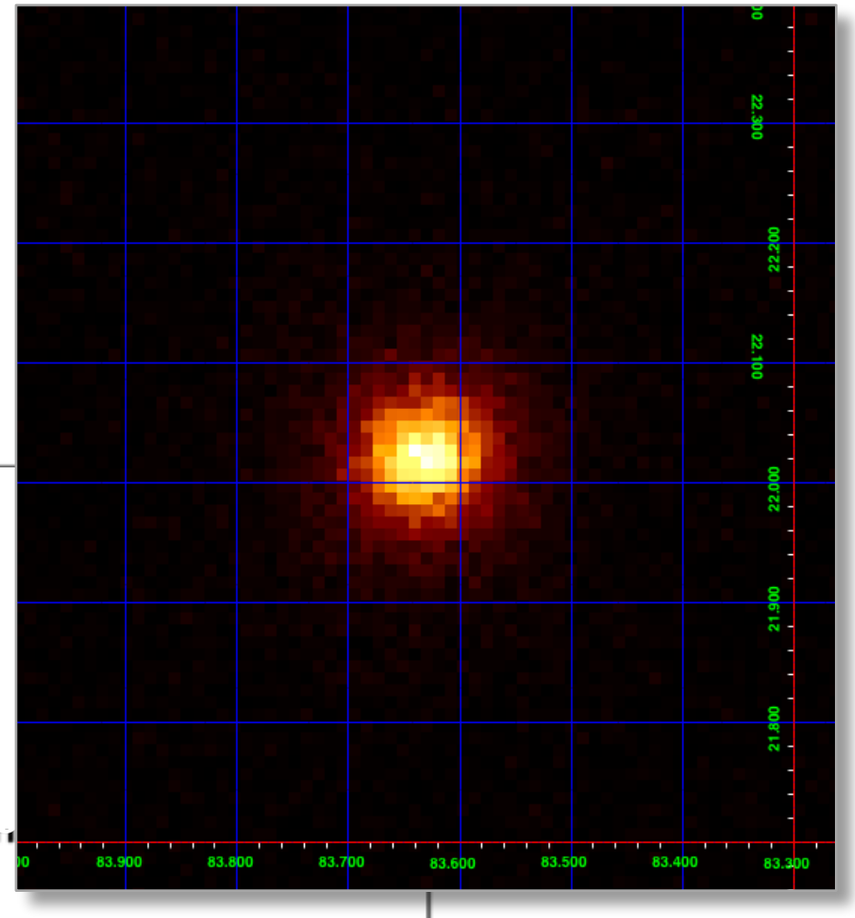


MAGIC Coll. 2014 A&A 565
MAGIC Coll. Ansoldi+2016

Precision VHE astronomy: angular resolution

- Measurement of Crab extension of gamma-ray emission





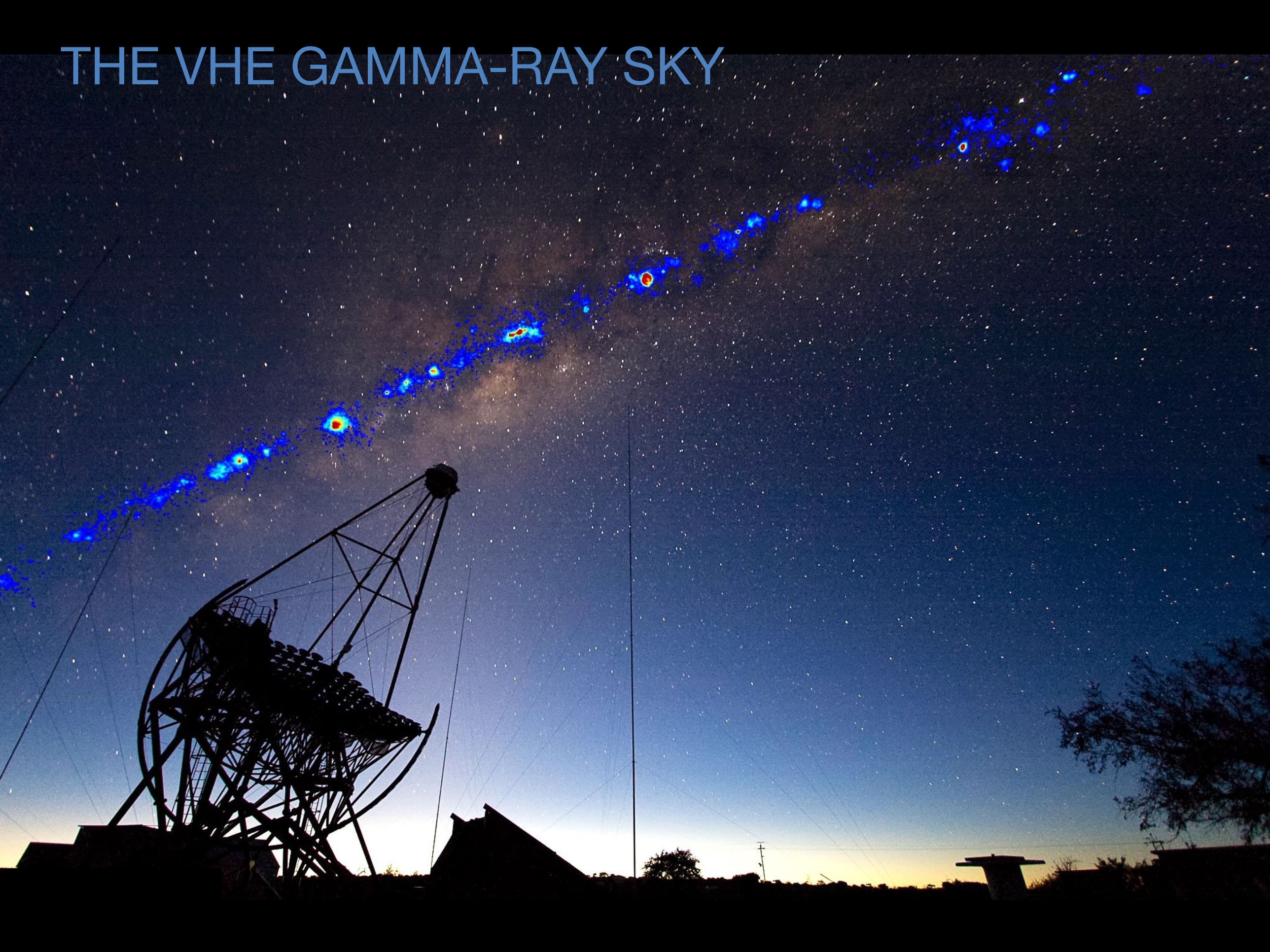
H.E.S.S., M. Holler et al.
arXiv:1707.04196

H.E.S.S.

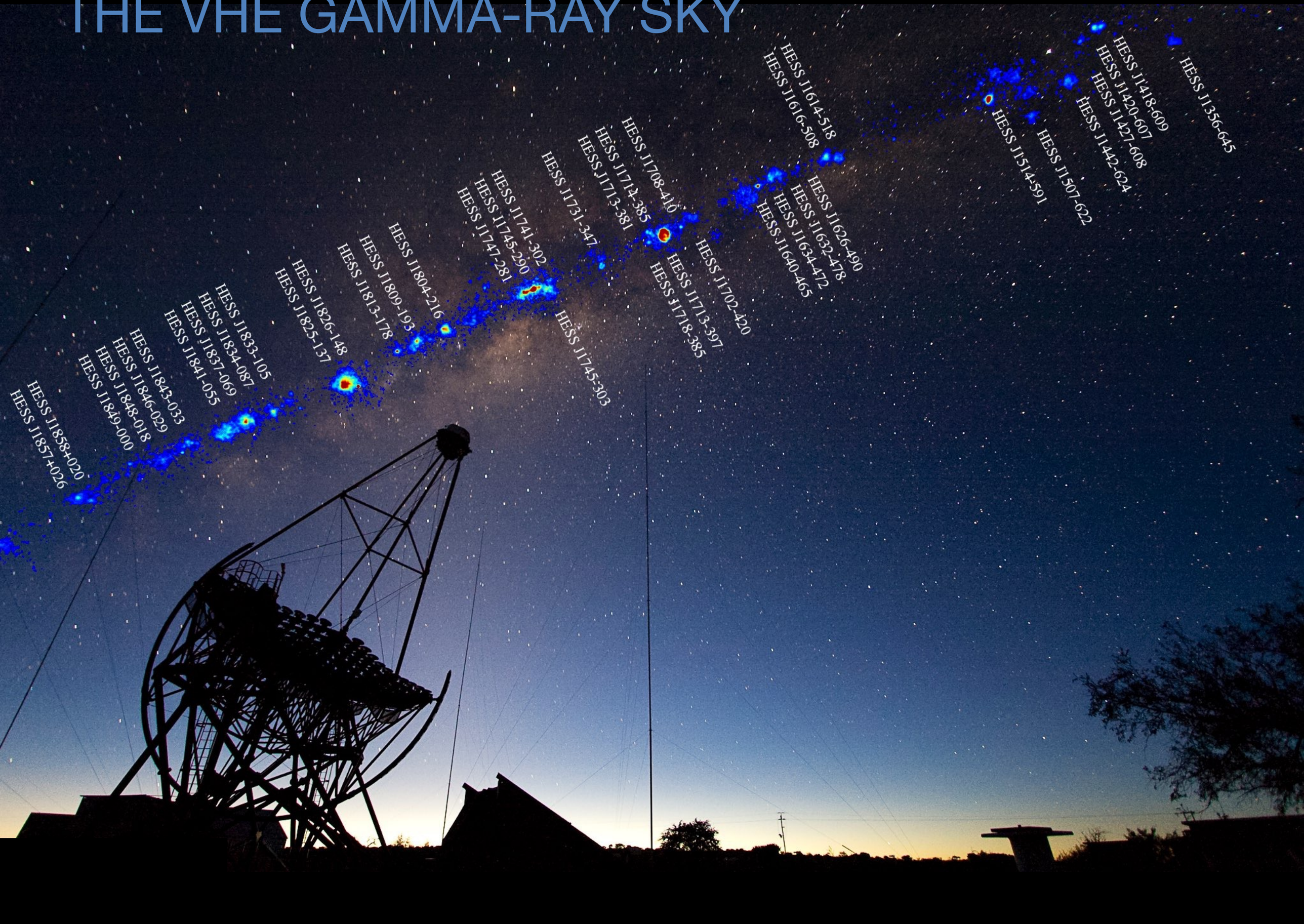
Gamma-ray size of Crab Nebula: 52”±3”±8”

Credits: W. Hoffmann (CTA-Symposium)

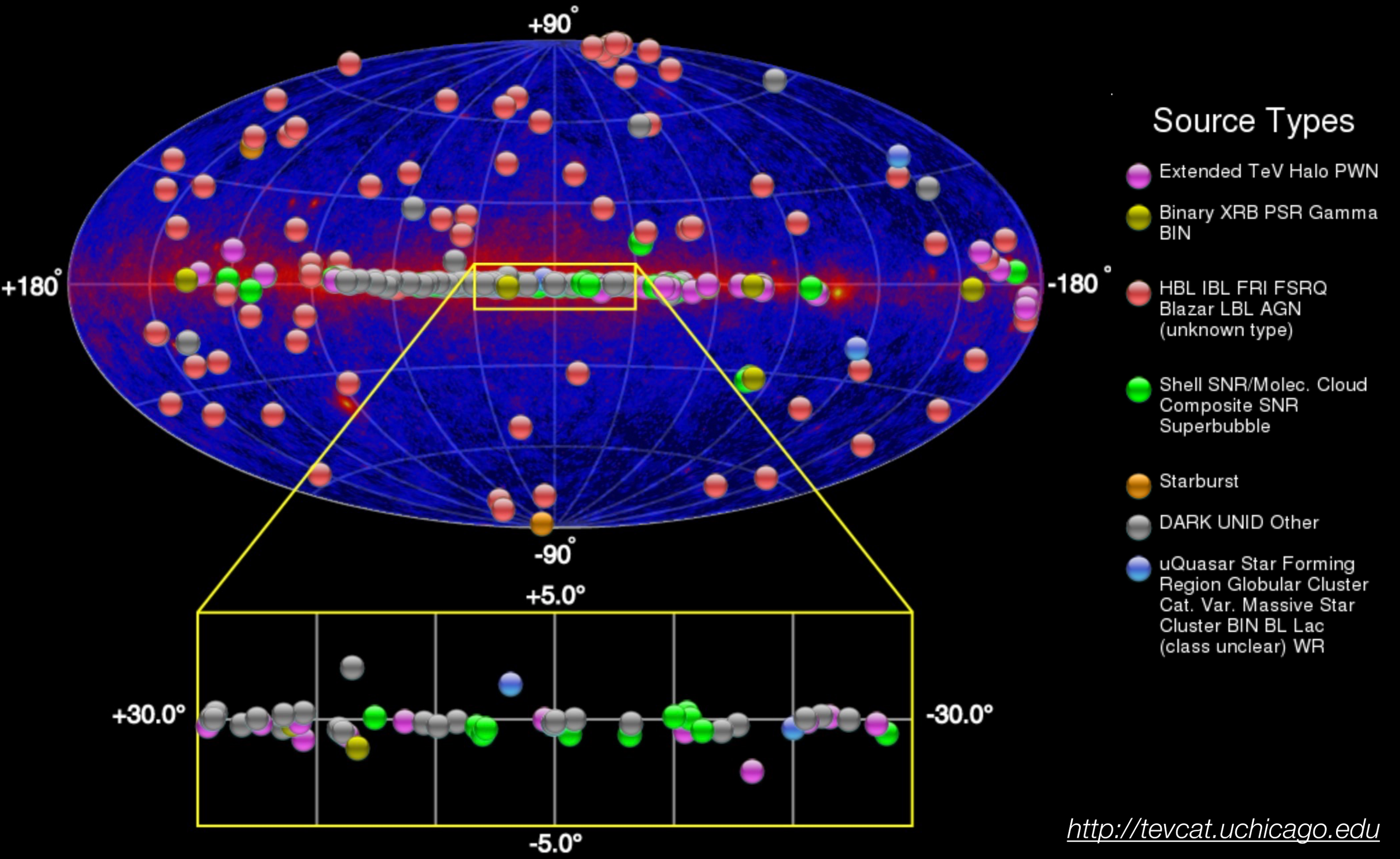
THE VHE GAMMA-RAY SKY



THE VHE GAMMA-RAY SKY

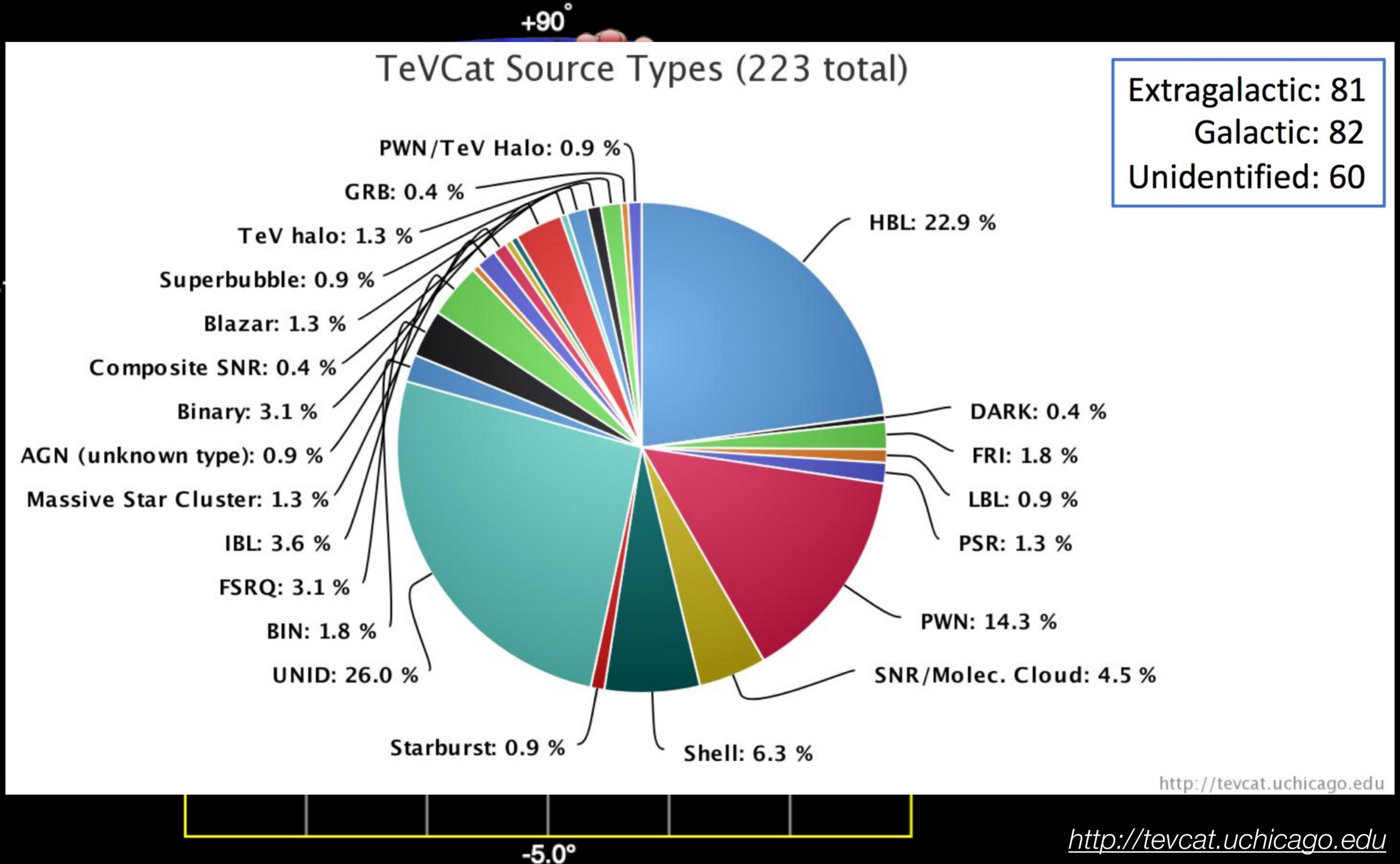


The VHE gamma-ray sky



http://tevcat.uchicago.edu

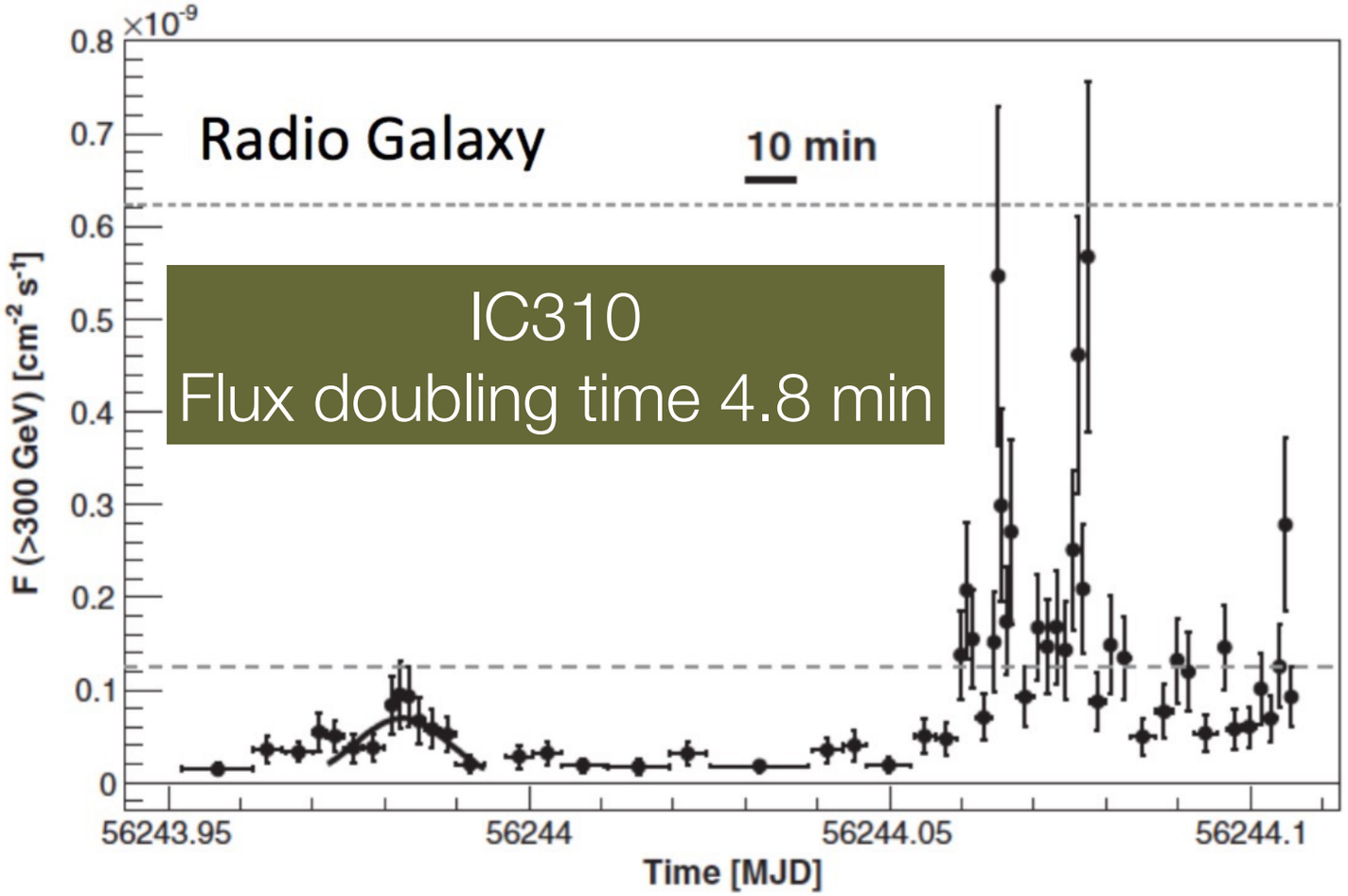
The VHE gamma-ray sky

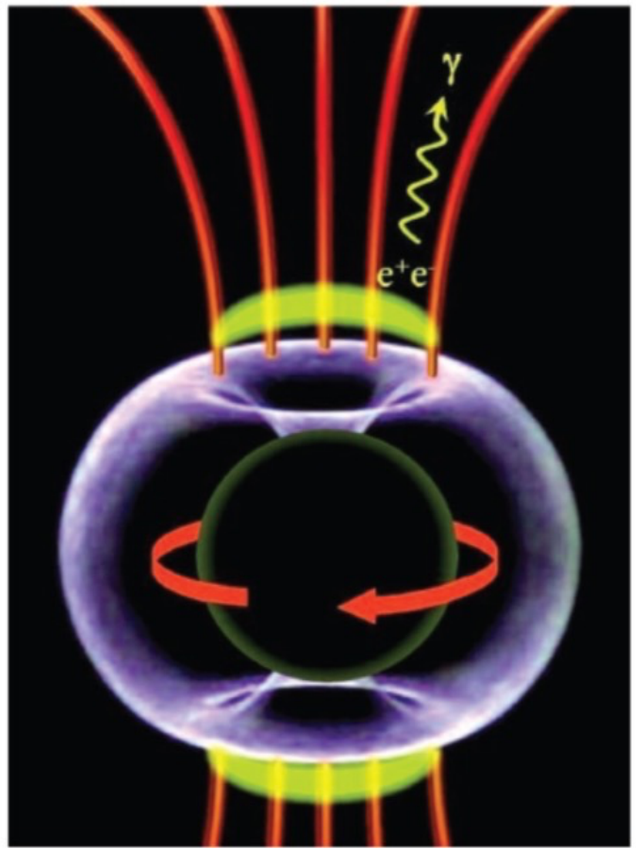


http://tevcat.uchicago.edu

Variability

- VHE emission in gamma-ray blazars **varies FAST**!
- Which emission process?
- Where is the emission region?

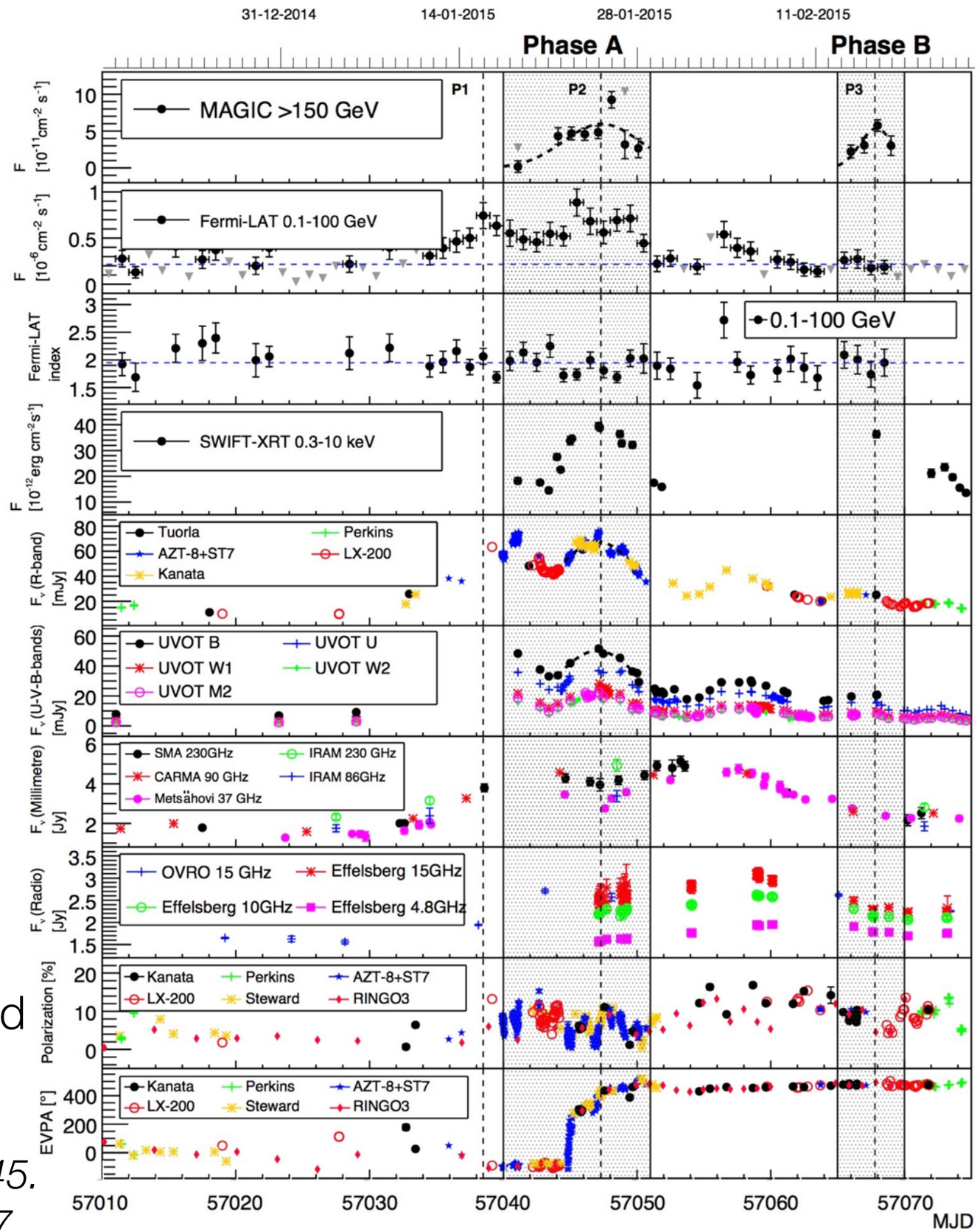




Aleksić et al, 2014, Science, 346, 1080

Variability and MWL coverage

- VHE emission in gamma-ray blazars varies FAST!
- Which emission process?
- Where is the emission region?
- **Multifrequency coverage is needed**
  - Coordination



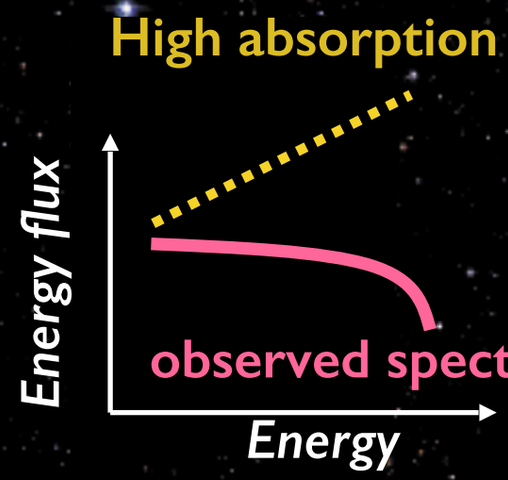
"Multi-wavelength characterization of the blazar S5 0716+714 during an unprecedented outburst phase."

MAGIC Collaboration. et al., A&A, 619 (2018) A45.
https://doi.org/10.1051/0004-6361/201832677

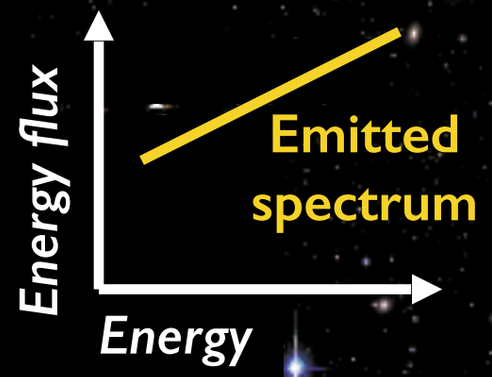
EBL MEASUREMENT WITH TEV BLAZARS

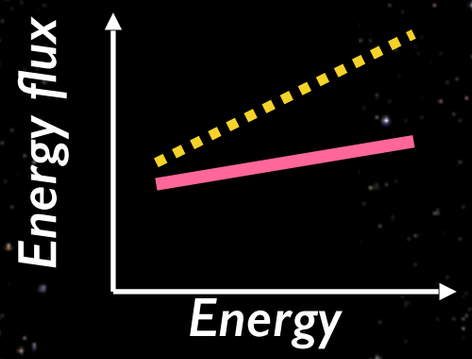
Background radiation fields

Gamma-rays from jet of Quasar



$$\Phi_\gamma^{obs}(E) = \Phi_\gamma^{source}(E) \times \mathrm{e}^{-\tau(E_\gamma, z)}$$





EBL: extragalactic Background Light

Precision and statistics: EBL measurement

- Sum contribution of 32 spectra of blazars
- Combined spectrum of Fermi/LAT and MAGIC
- Different intrinsic spectral shapes/models

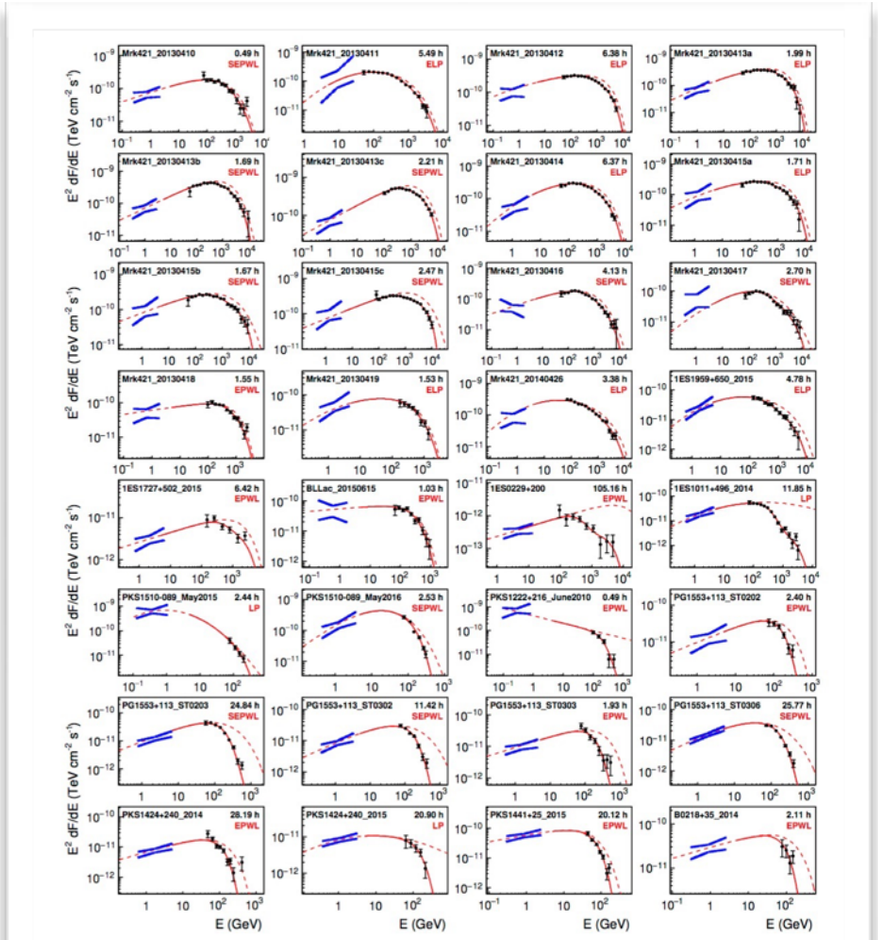


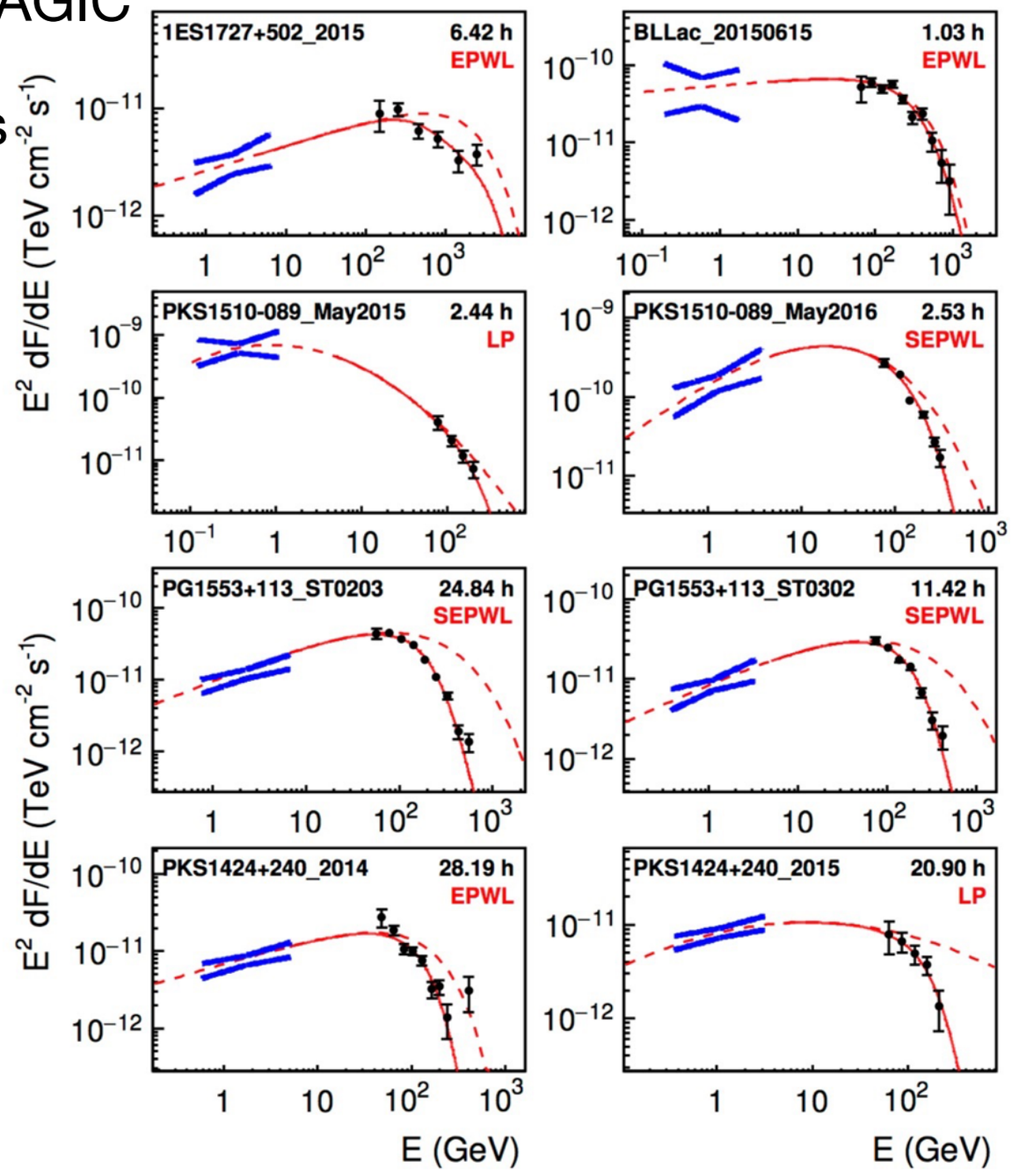
Figure 5. Spectral energy distributions of the 32 spectra measured by MAGIC (black points) and *Fermi*-LAT (blue bow-ties). The fits correspond to the analysis which uses the D11 EBL template and a single free EBL parameter (overall scale factor) - see Table 3. The dashed red curves are the best-fit intrinsic spectra, the functional form of which is shown in red (as an acronym) below the observation time. The solid curves are the corresponding absorbed spectra. Each of the individual spectral points (black dots) is obtained from the excess of gamma-like events in a given bin of *estimated* energy E_{est}; the corresponding flux is evaluated at the median *true* energy of the events (as estimated from the Monte Carlo simulation).

PWL: $F_0\,(E/E_0)^{-\Gamma}$ EPWL: $F_0\,(E/E_0)^{-\Gamma}\,e^{-E/E_c}$

LP: $F_0\,(E/E_0)^{-\Gamma-b\log(E/E_0)}$

ELP: $F_0\,(E/E_0)^{-\Gamma-b\log(E/E_0)}\,e^{-E/E_c}$

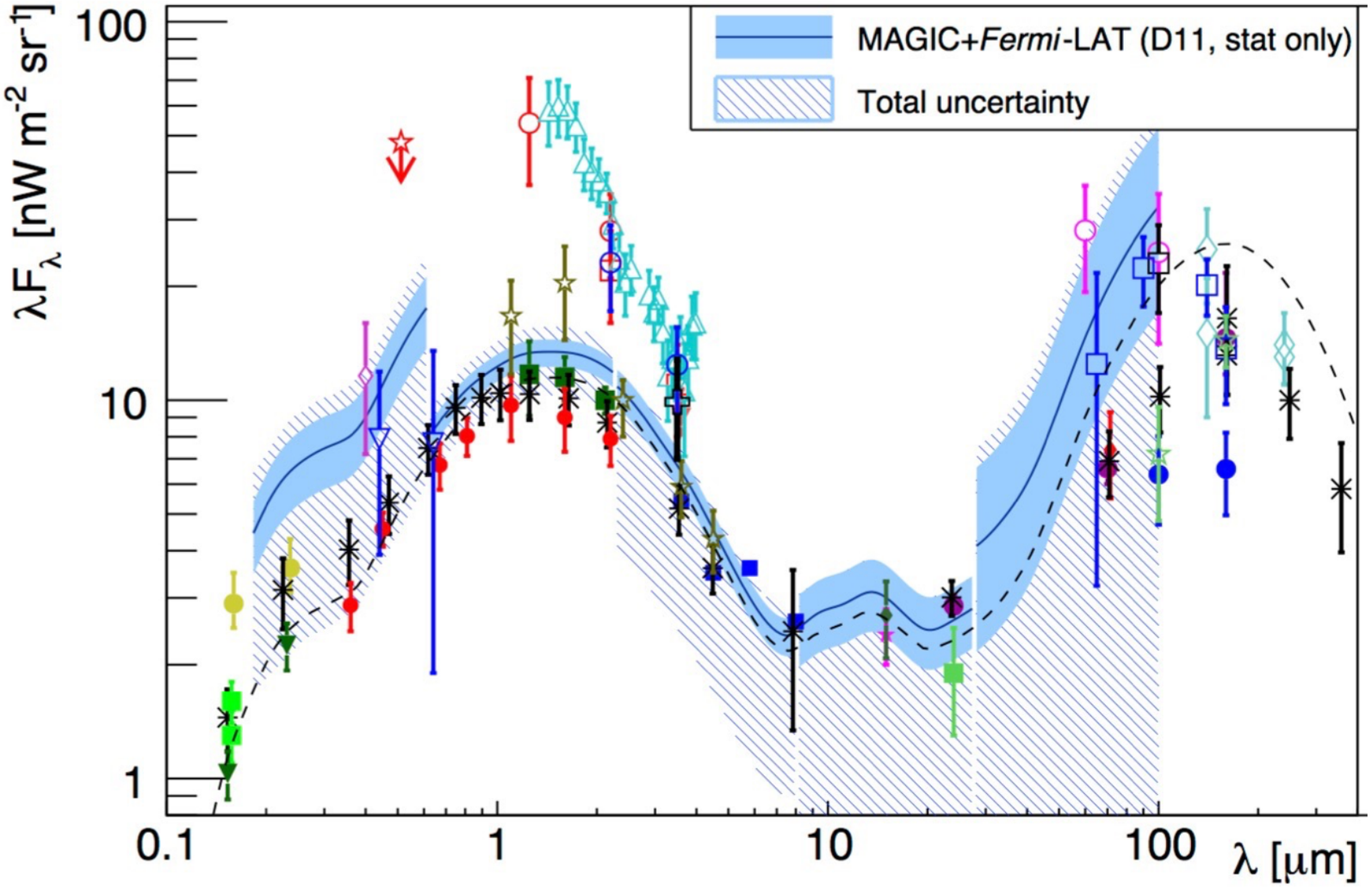
SEPWL: $F_0\,(E/E_0)^{-\Gamma}\,e^{-(E/E_c)^d}$

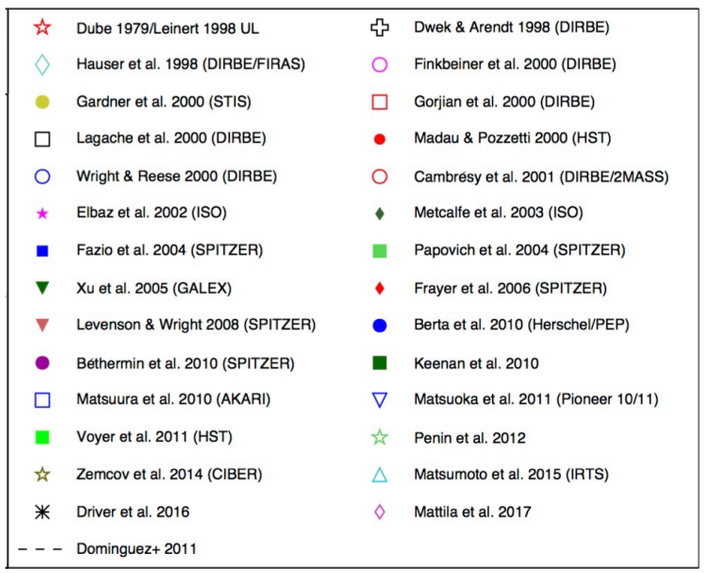


MAGIC coll., MNRAS acc., Measurement of the Extragalactic Background Light using MAGIC and Fermi-LAT gamma-ray observations of blazars up to z = 1 https://arxiv.org/abs/1904.00134

Precision and statistics: EBL measurement

- Sum contribution of 32 spectra of blazars
- Combined spectrum of Fermi/LAT and MAGIC
- Different intrinsic spectral models
- **Studies on systematics**
  - intrinsic models
  - instrument response

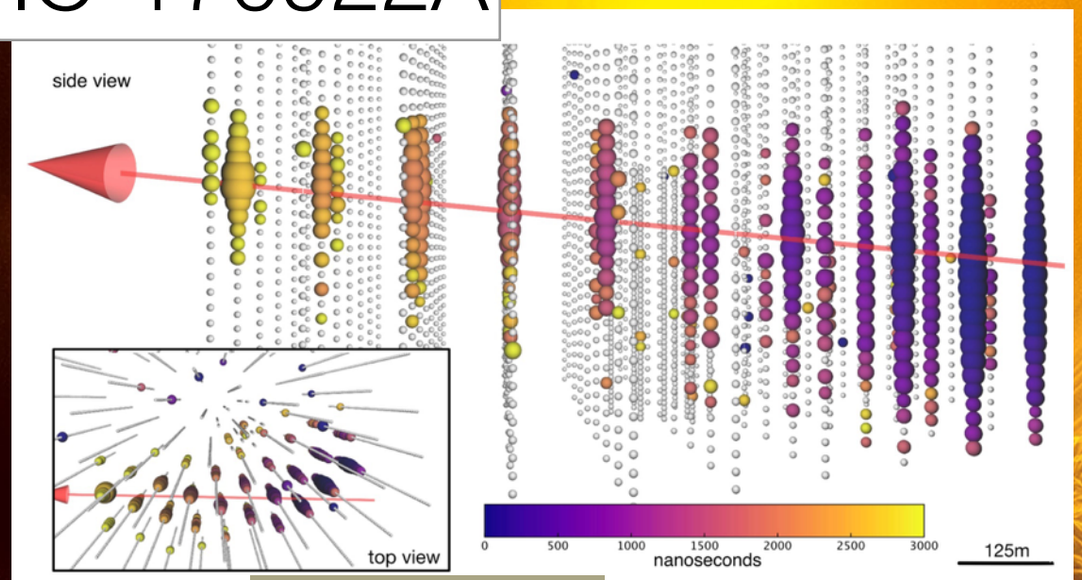




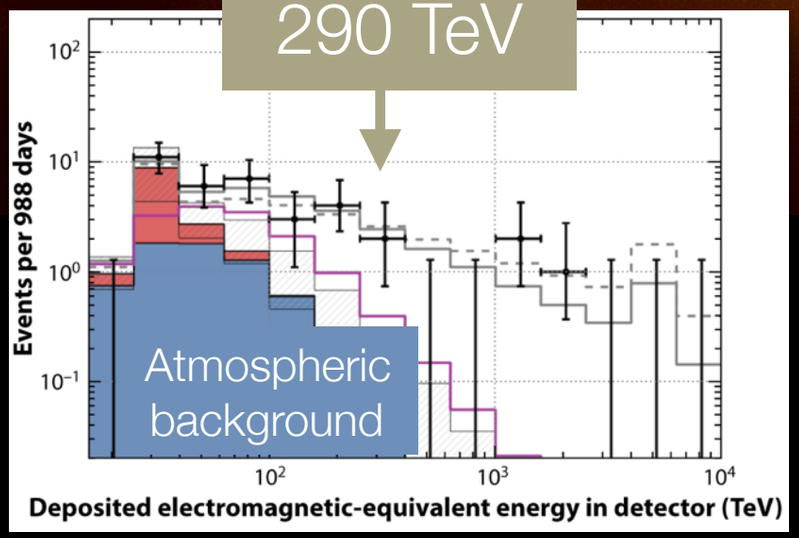
MAGIC coll., MNRAS acc., Measurement of the Extragalactic Background Light using MAGIC and Fermi-LAT gamma-ray observations of blazars up to z = 1 https://arxiv.org/abs/1904.00134

VHE astronomy in the multi-messenger domain: The blazar-neutrino connection

IC-170922A



290 TeV



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 Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT

Further Swift-XRT observations of IceCube 170922A

ATel #10792; *P. A. Evans (U. Leicester) A. Keivani (PSU), J. A. Kennea (PSU), D. B. Fox (PSU), D. F. Cowen (PSU), J. P. Osborne (U. Leicester), and F. E. Marshall (GSFC) report on behalf of the Swift-IceCube collaboration:*
on 28 Sep 2017; 11:57 UT
Credential Certification: Phil Evans (pae9@star.le.ac.uk)

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

ATel #10794; *A. Franckowiak (DESY), K. Z. Stanek, C. S. Kochanek, T. A. Thompson (OSU), T. W.-S. Holoien, B. J. Shappee (Carnegie Observatories), J. L. Prieto (Diego Portales; MAS), Subo Dong (KIAA-PKU)*

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

ATel #10801; *F. Lucarelli (SSDC/ASI and INAF/OAR), G. Piano (INAF/IAPS), C.*

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

Joint Swift XRT and NuSTAR Observations of TXS 0506+056

B. Fox (PSU), J. J. DeLaunay (PSU), A. Keivani (PSU), P. A. Evans , C. F. Turley (PSU), J. A. Kennea (PSU), D. F. Cowen (PSU), J. P. (U. Leicester), M. Santander (UA) & F. E. Marshall (GSFC)

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

H. Negoro (Nihon U.), S. Ueno, H. Tomida, M. Ishikawa, Y. Sugawara, R. Shimomukai (JAXA), T. Mihara, M. Sugizaki, S. Nakahira, W. Iwakiri, tsu, F. Yatabe, Y. Takao, M. Matsuoka (RIKEN), N. Kawai, S. Sugita, T. Tachibana, S. Harita, K. Morita (Tokyo Tech), A. Yoshida, T. Sakamoto, Y. Kawakubo, Y. Kitaoka, T. Hashimoto (AGU), H. Tsunemi, T. Yoneyama , M. Nakajima, T. Kawase, A. Sakamaki (Nihon U.), Y. Ueda, T. Hori, A.

A Radio Observations of the blazar TXS 0506+056 sociated with the IceCube-170922A neutrino event

10861; A. J. Tetarenko, G. R. Sivakoff (UAlberta), A. E. Kimball (NRAO), and J. C.A. Miller-Jones (Curtin-ICRAR)
on 17 Oct 2017; 14:08 UT

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
Credential 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, 12260

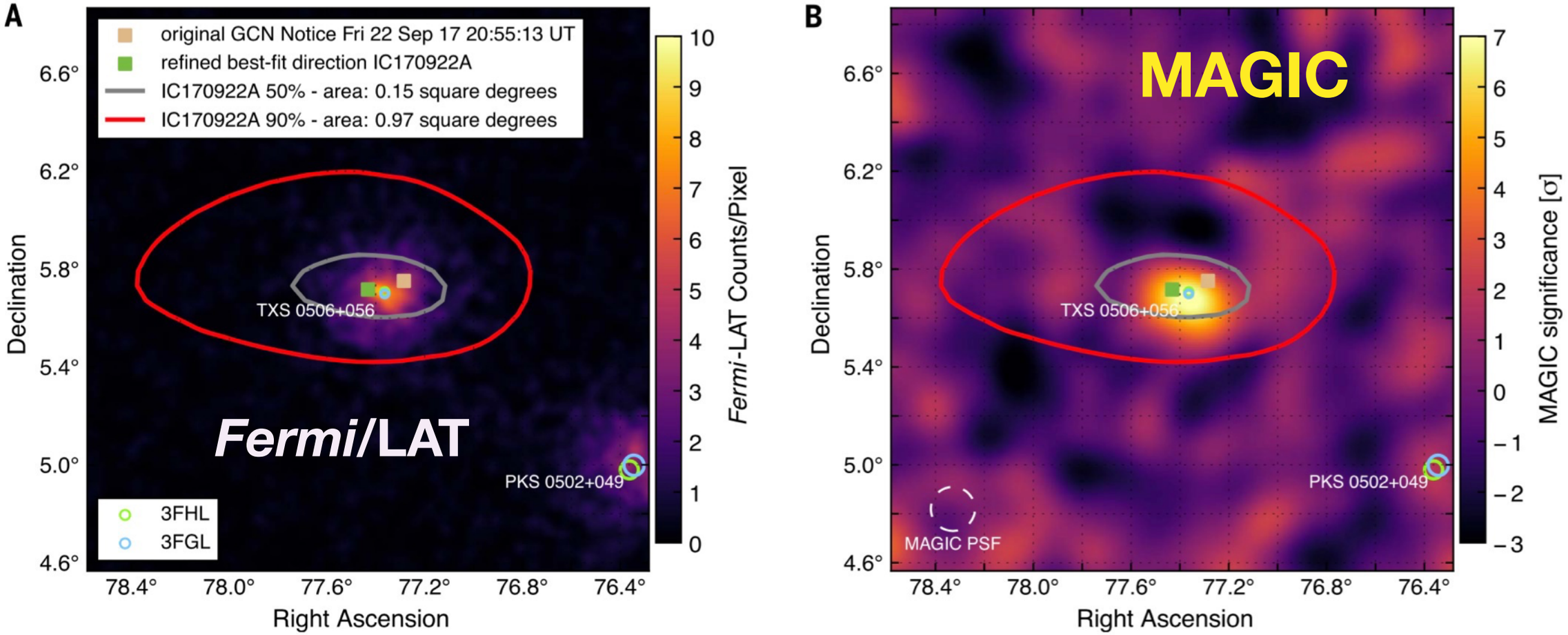
Tweet

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 Observatory 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.

The γ-ν connection in TXS 0506+056

- ✦ Relatively small angular uncertainty of the HESE ν event
- ✦ The blazar TXS 0506+056 only plausible candidate
- ✦ Time correlation: TXS 0506+065 in γ high-state

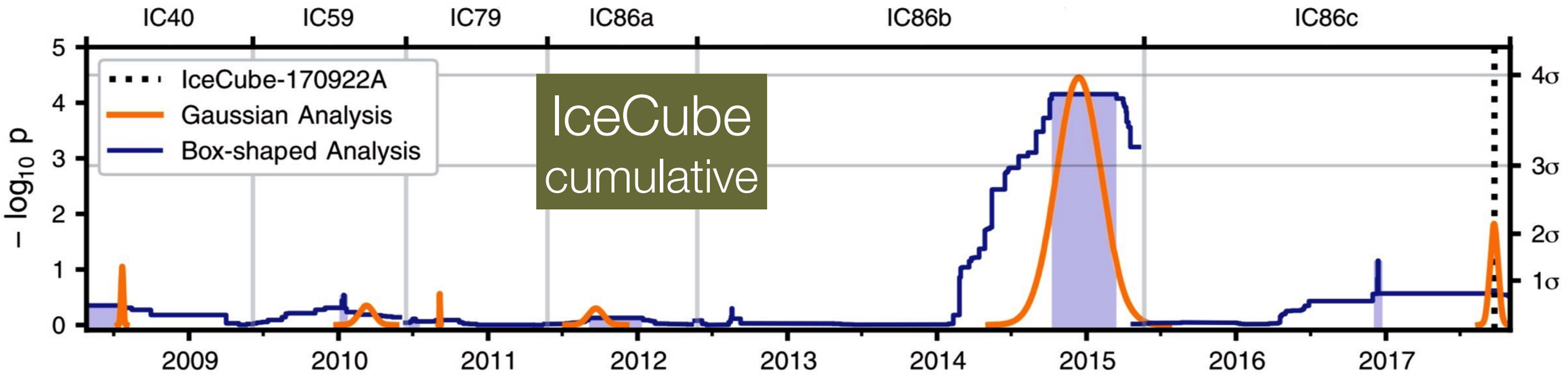
Science 361, eaat1378 (2018)



Chance coincidence rejected at 3σ level

The γ-ν connection in TXS 0506+056

- ✦ Relatively small angular uncertainty of the HESE ν event
- ✦ The blazar TXS 0506+056 only plausible candidate
- ✦ Time correlation: TXS 0506+065 in γ high-state
- ✦ Archival analysis in IceCube reveals an excess in 2015!



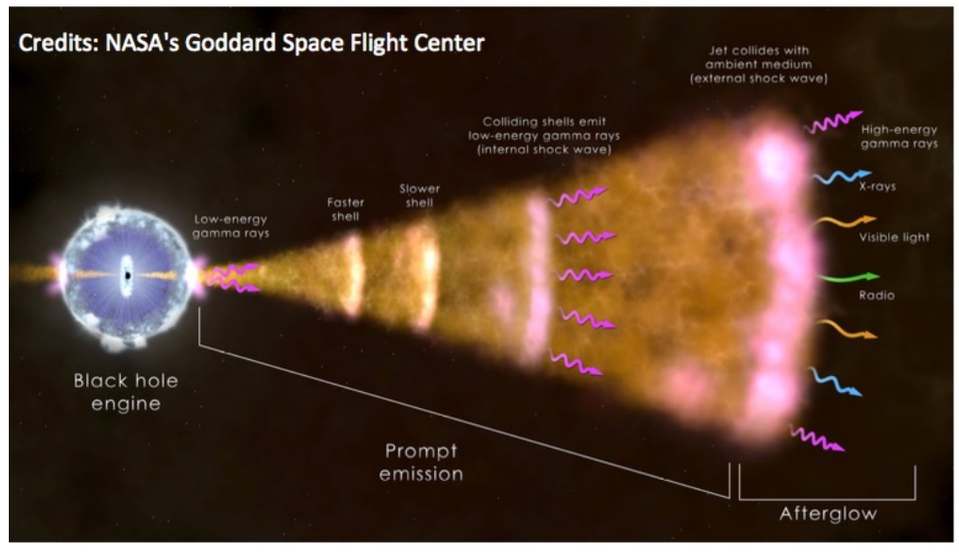
Science 13 Jul. 2018: Vol. 361, Issue 6398

Transients at VHE

- GRB hunt at VHE: are IACTs good transient factories?
- The MAGIC program

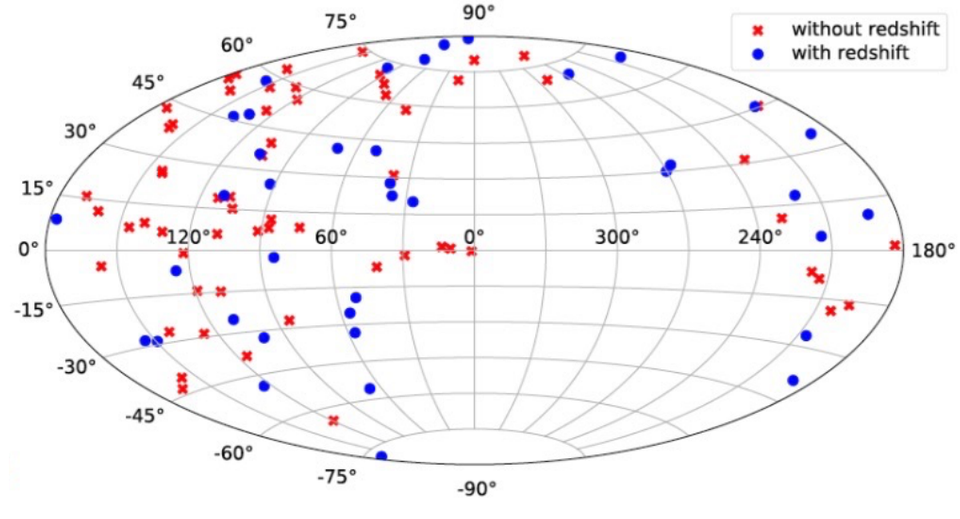
MAGIC has the required performance to study GRBs:

- low-energy sensitivity
- pointing speed



- Key observational program: more tan 50 h/yr
- Alerts received through the Gamma-ray Coordinates Network (GCN)

101 GRBs observed since 2005 → 8-10 GRBs / yr
39 with redshift → 14 with z < 1.5
22 observed with delay < 100 s → Thanks to MAGIC speed



Transients at VHE

- GRB190114C
  - Long GRB - redshift ~ 0.4
  - Observed in moon conditions, at large zenith angles
  - Strongest VHE source ever!

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory 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.

Transients at VHE

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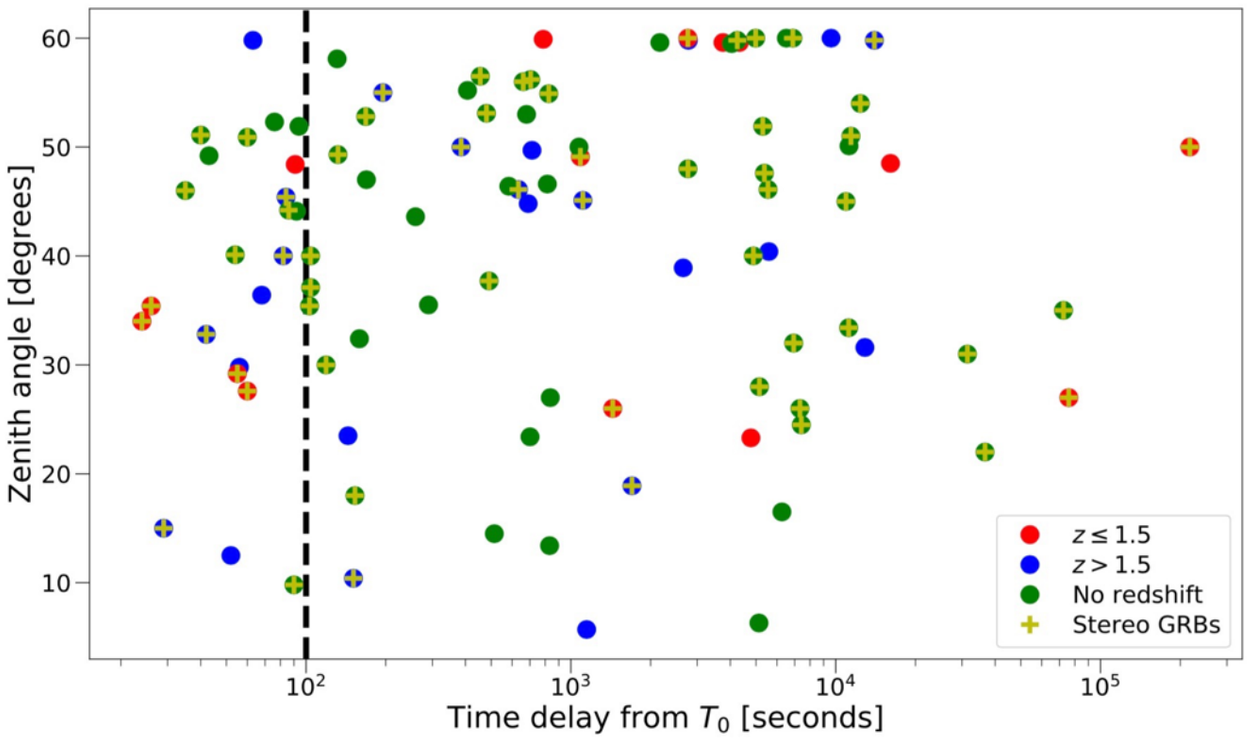
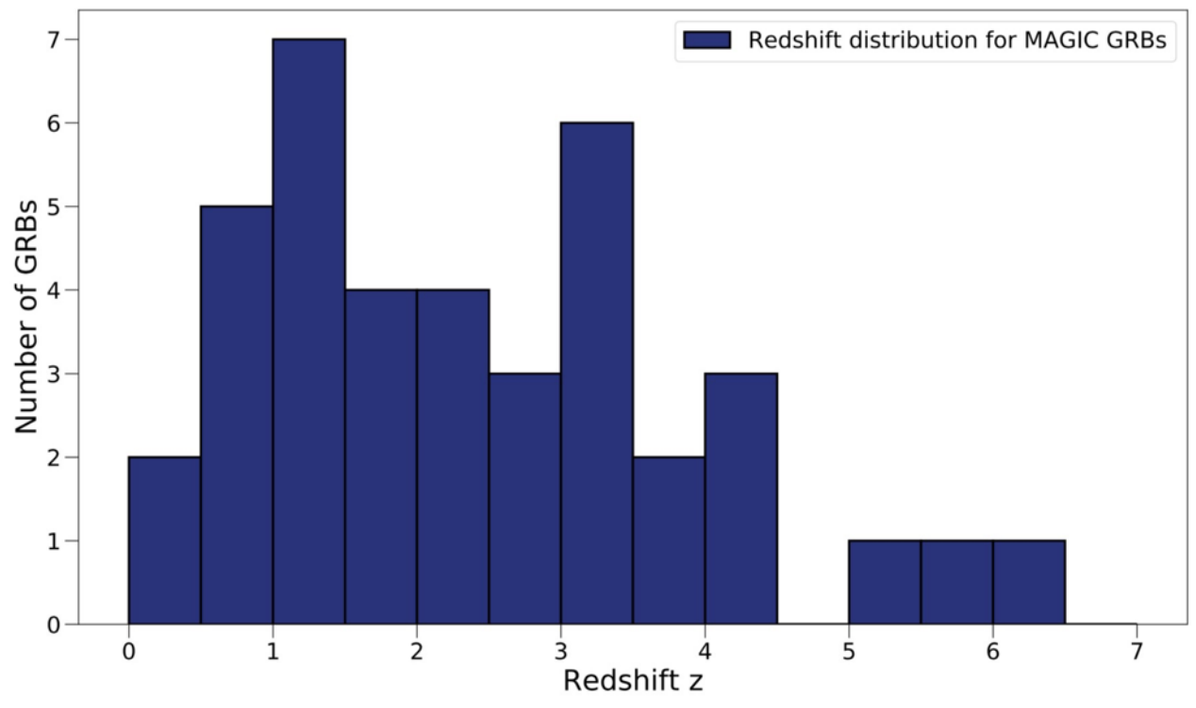
  - Long GRB - redshift ~ 0.4
  - Observed in moon conditions, at large zenith angles
  - Strongest VHE source ever!

How did we catch it?

Fast Repointing



Redshift



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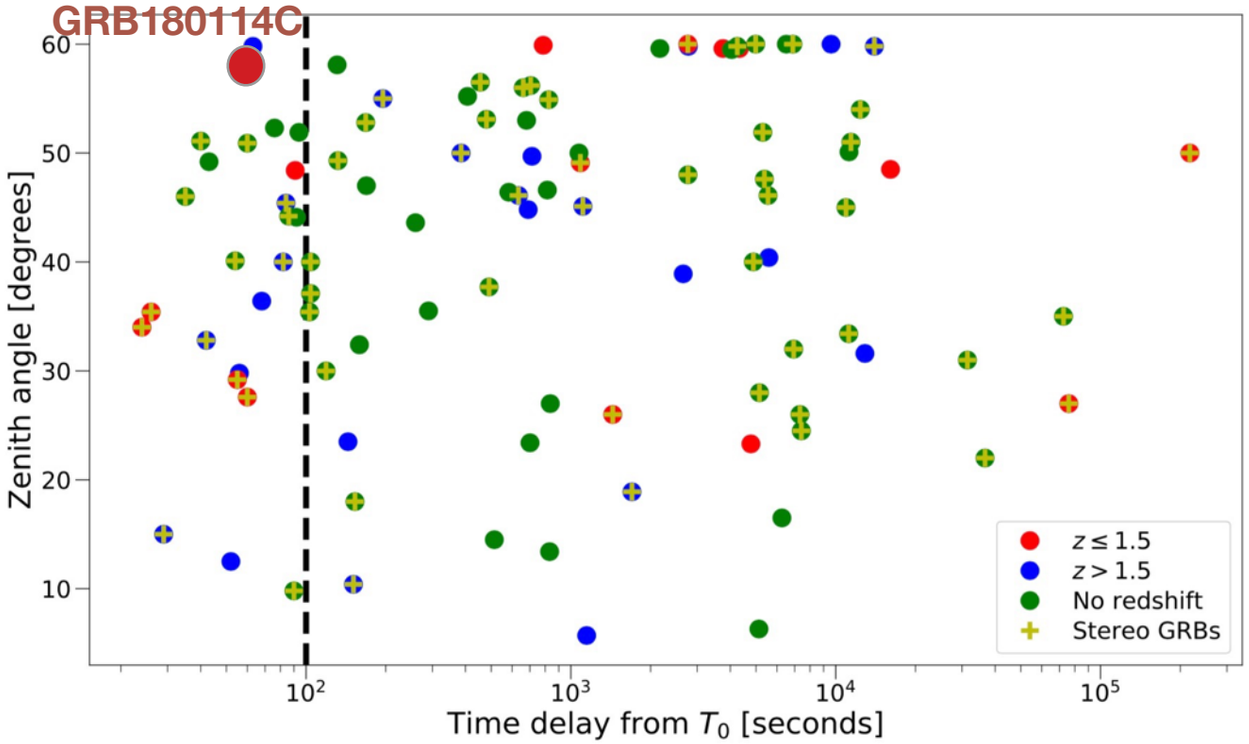
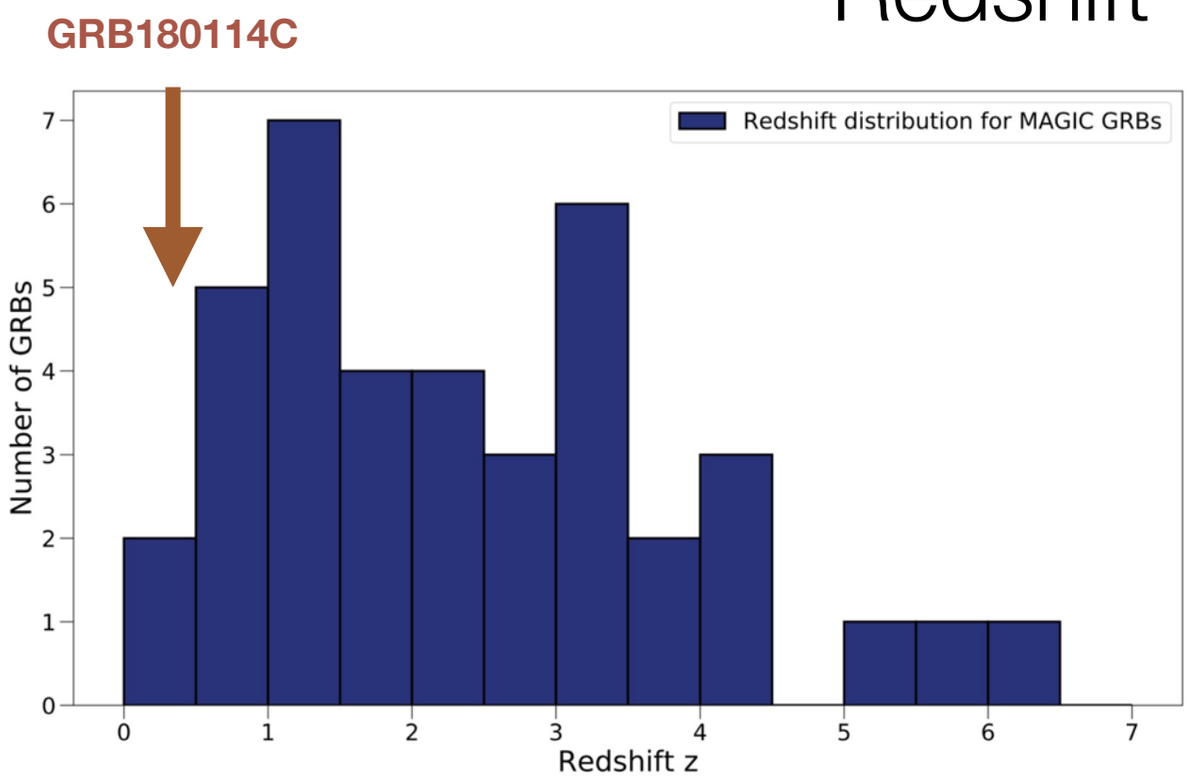


Redshift

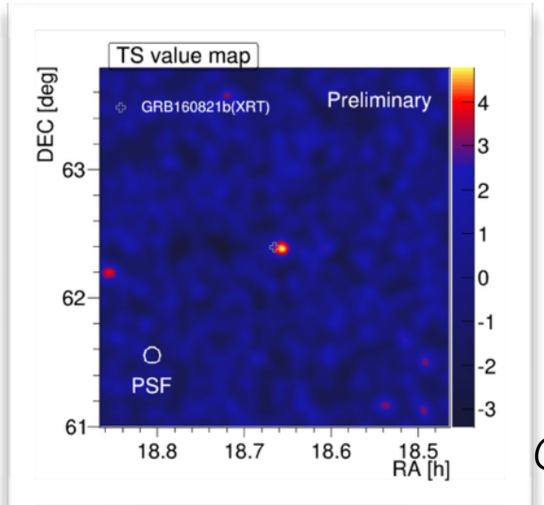


Transients at VHE

- **First clear and strong detection of a GRB!**
- Report of 5σ of late -afterglow emission from GRB180720B by H.E.S.S. (announced at CTA-symposium)
  - bright GRB; detection 10 hours after T0
- Hint of detection on the **short** GRB160721B by MAGIC (Berti et al., 2019, Proc. MG15)
- z=0.16; recently associated at a kilonova Lamb et al. 2019 arXiV:1905.02159

GRB160721B

4 h data, $> 4\sigma$ pre-trial, 3.1σ post-trial above 600-800 GeV: **detection hint** (3 independent analyzers)

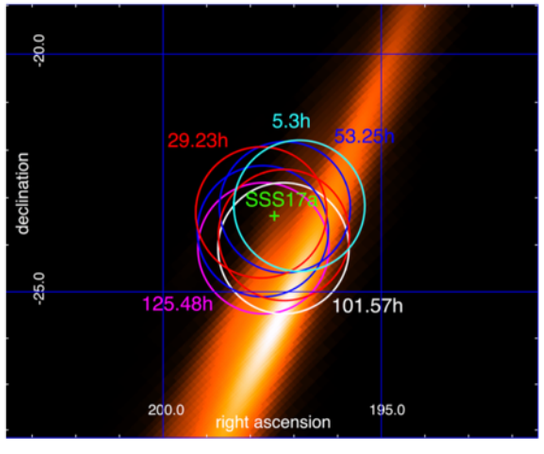


Credits: A. Berti

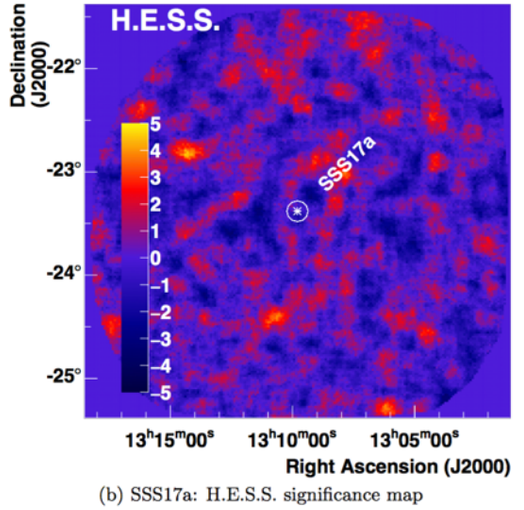
Compelling for future TeV-detection of GW counterparts!

IACTs chasing GW counterparts

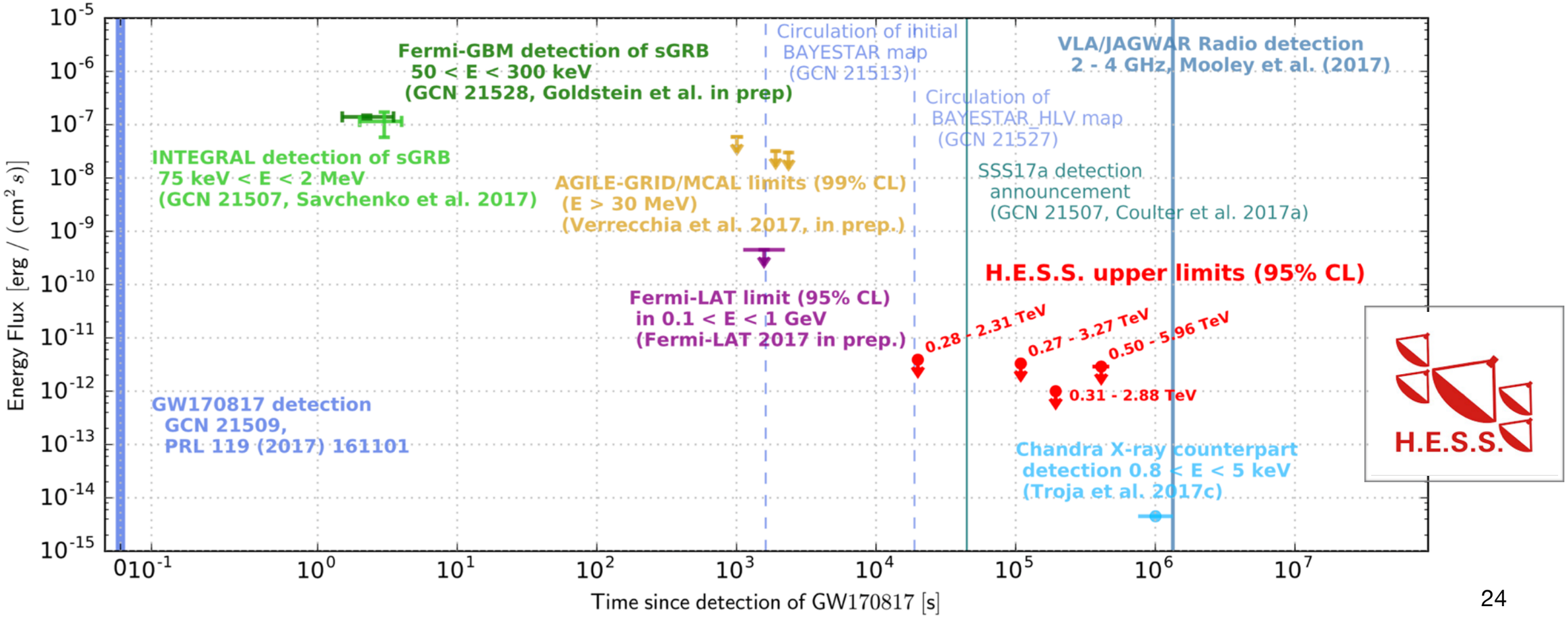
- H.E.S.S. observations
  - GW170817
- First ground telescope to point the region

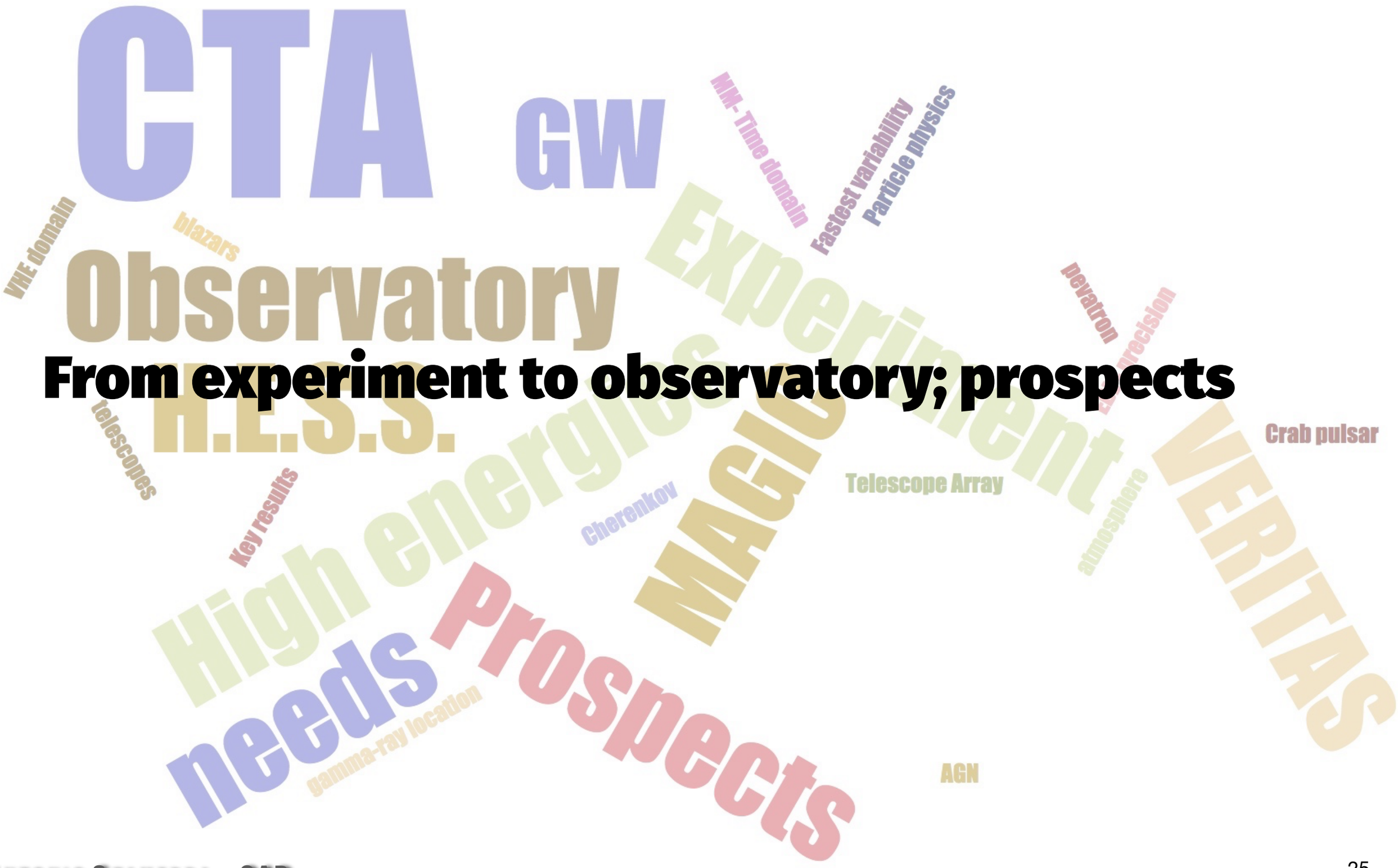


(a) SSS17a: H.E.S.S. pointings



(b) SSS17a: H.E.S.S. significance map

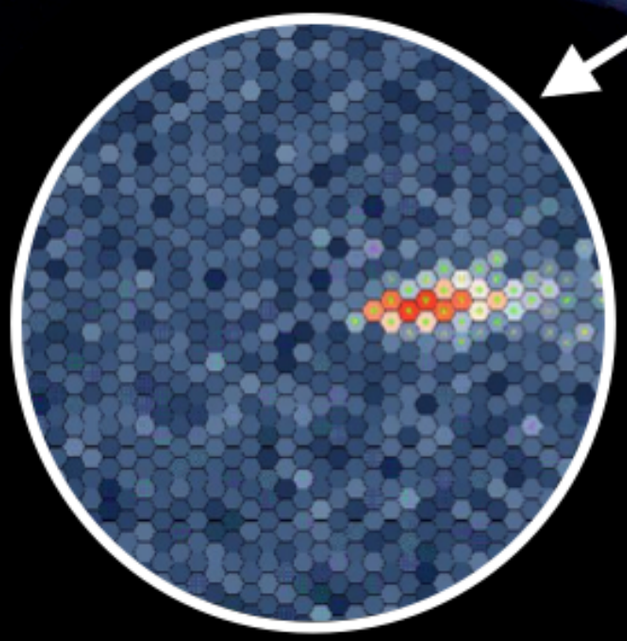




From experiment to observatory; prospects

γ-ray enters the atmosphere

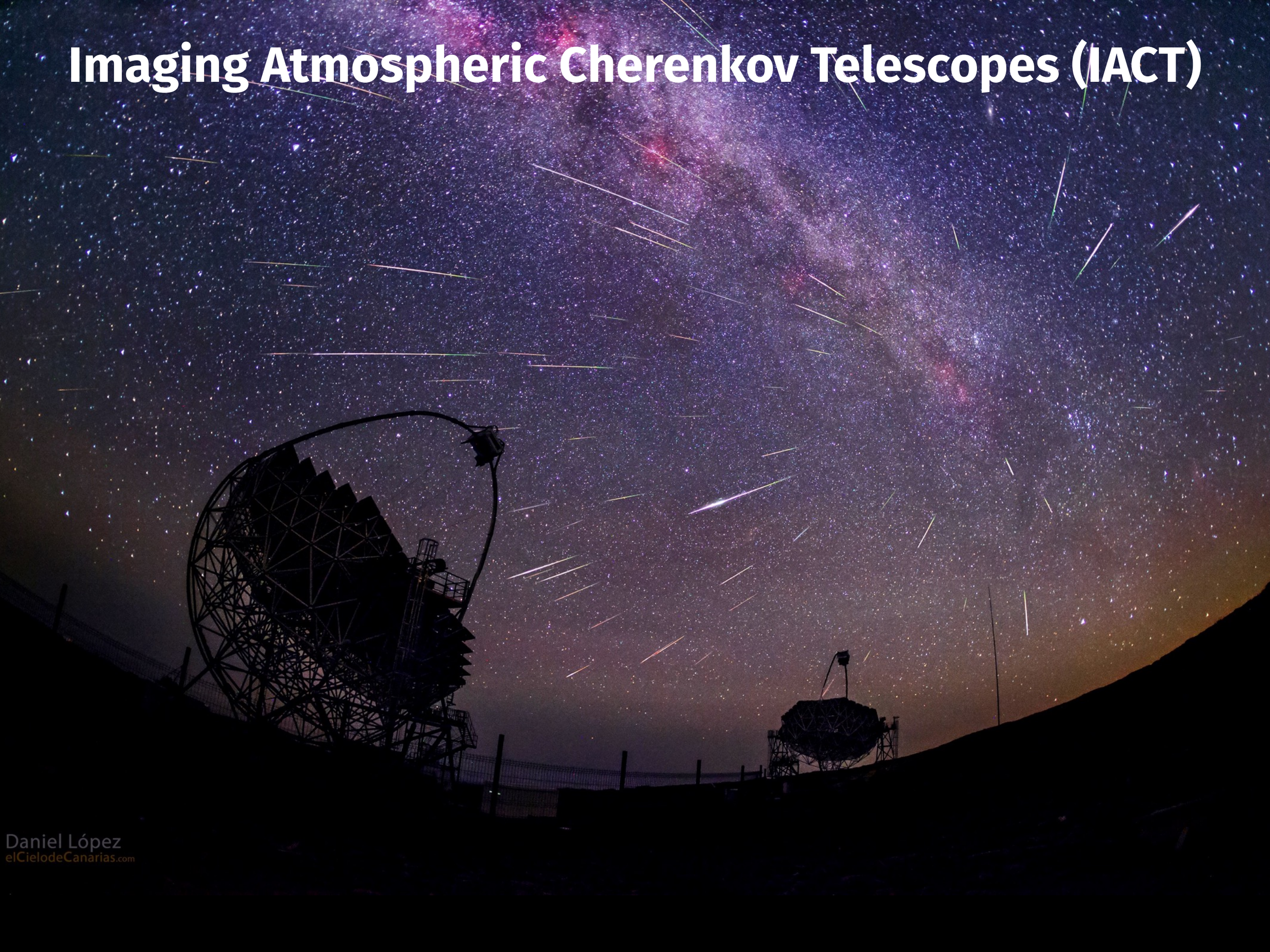
Electromagnetic cascade



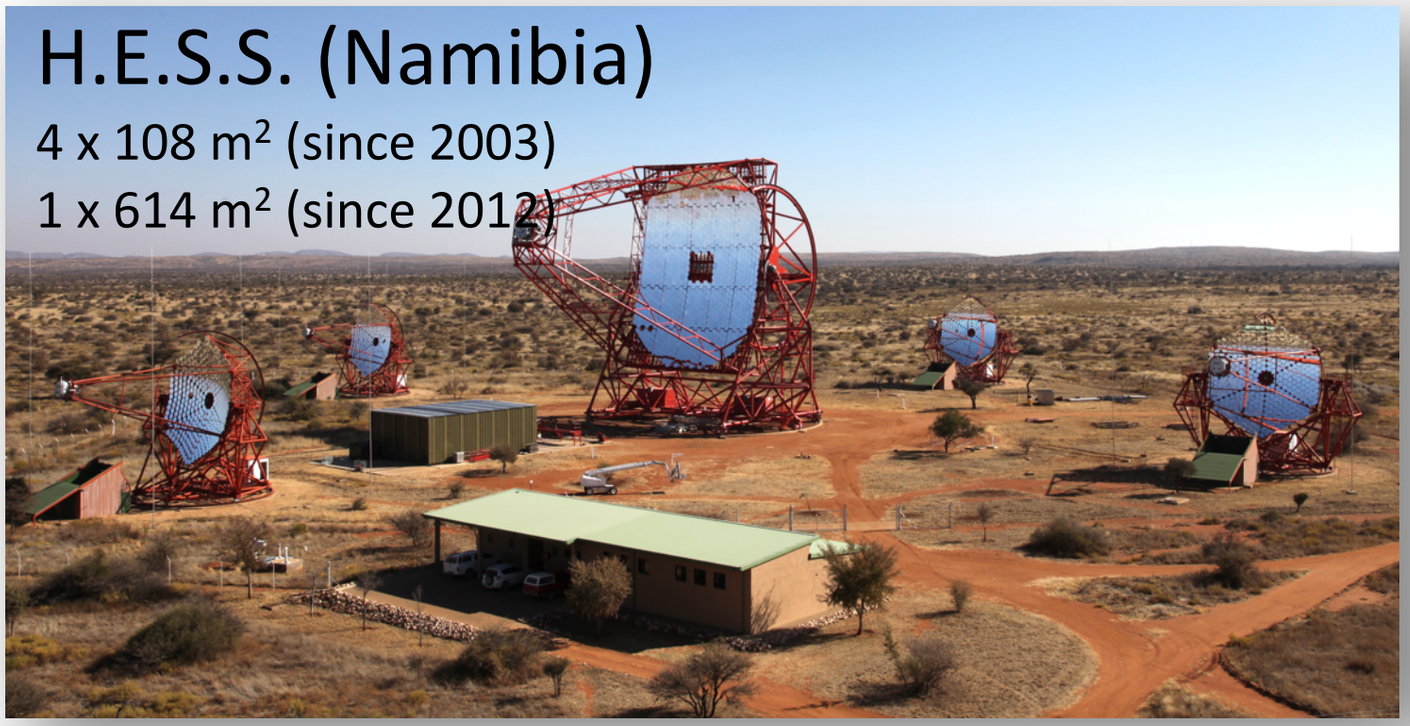
10 nanosecond snapshot

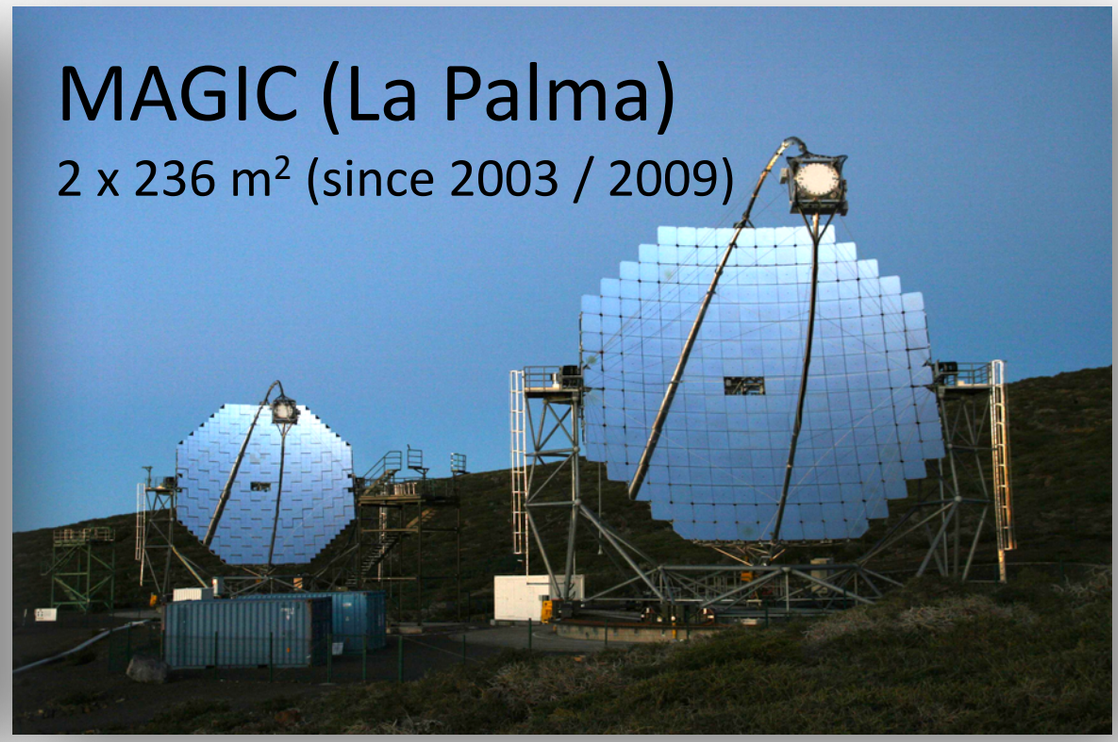
0.1 km² "light pool", a few photons per m².

Imaging Atmospheric Cherenkov Telescopes (IACT)



Present generation of IACTs





From experiment to observatory

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

Evolution of MAGIC sensitivity

2005 → 2008 → 2010 → 2013

HW and SW upgrades

Mono (2005)
Mono (2008)
Stereo (2010)
Stereo Upgr. (2013)
Stereo Upgr. Zd 30-45, (2013)

Integral sensitivity (5σ in 50h) [% C.U.]

20
10
2
1
0.5

10^2
10^3
10^4

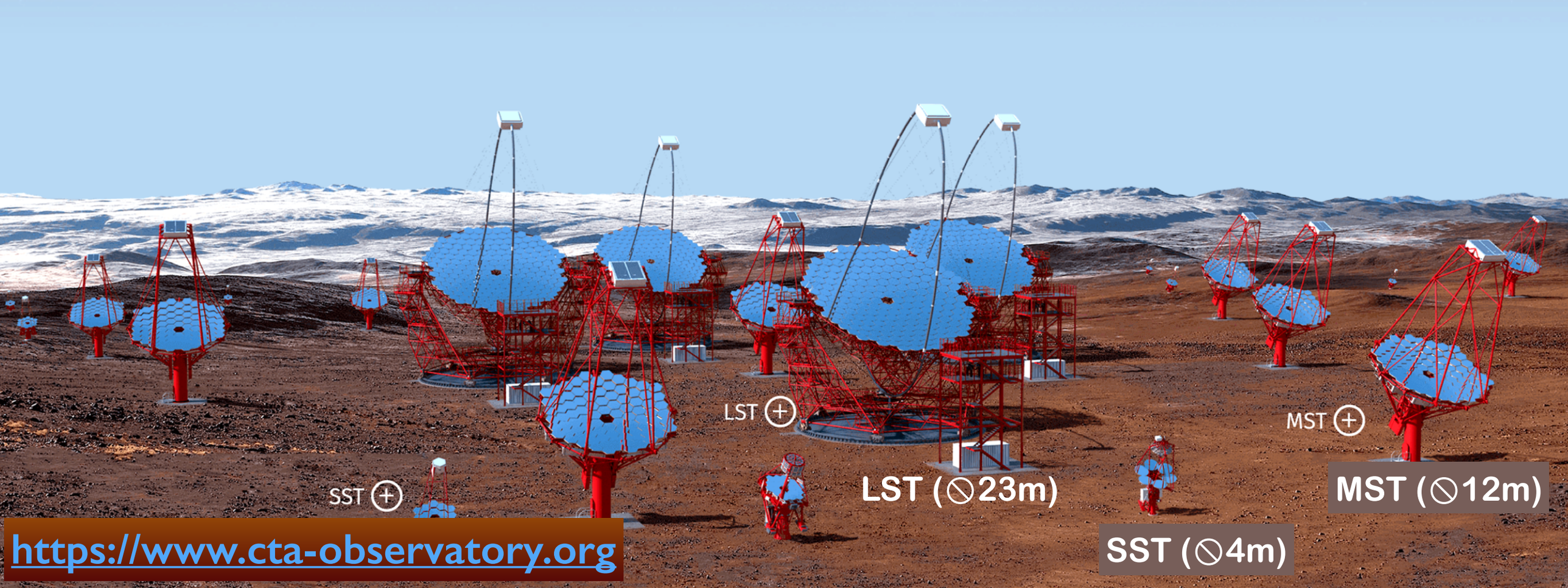
~10^{-12} *erg/cm²/s* ***(50 hr)***

Energy threshold [GeV]

100 GeV

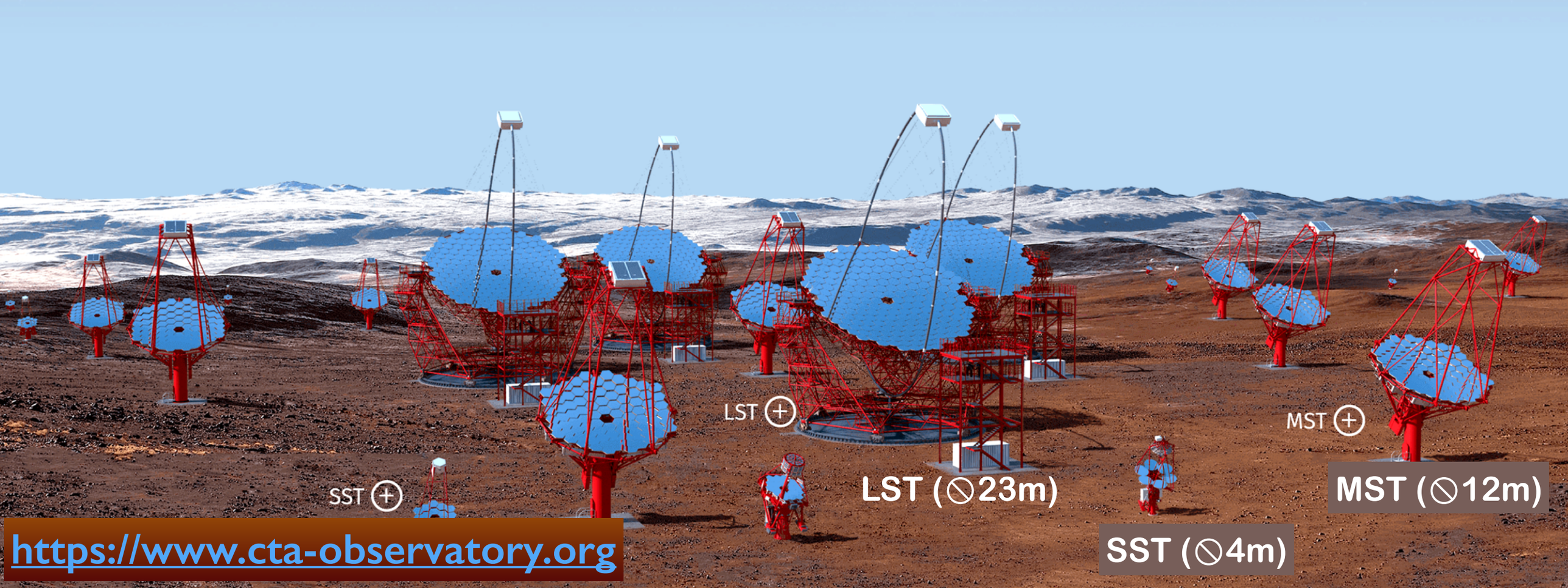
10 TeV

The Cherenkov telescope array



The Cherenkov telescope array

Presentazione dedicata
F. Ferrini



CTA concept

10 GeV **100 GeV** **1 TeV** **10 TeV** **100 TeV**

1000 γ / h km^2

10 γ / h km^2

0.1 γ / h km^2

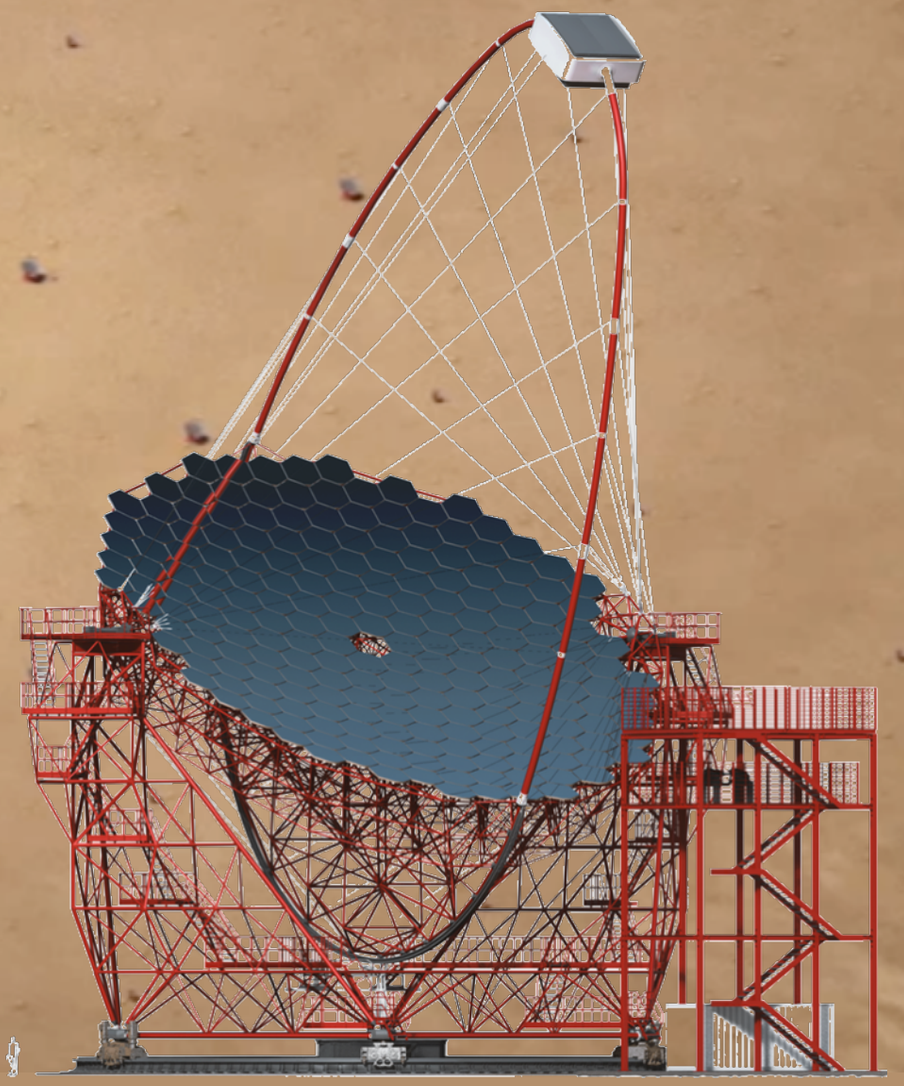
Needs:
precision
extreme energies
fast variability

Southern array
of Cherenkov telescopes
- about 3 km across

10 GeV 100 GeV 1 TeV 10 TeV

100 TeV

4 x 23 m ∅ Large Size Telescopes (LST)

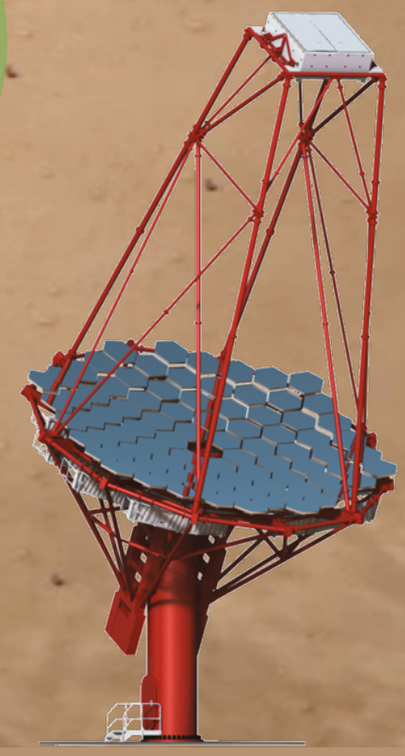


10 GeV 100 GeV 1 TeV 10 TeV

100 TeV

25 x 12 m ∅ Medium Size Telescopes (MST)

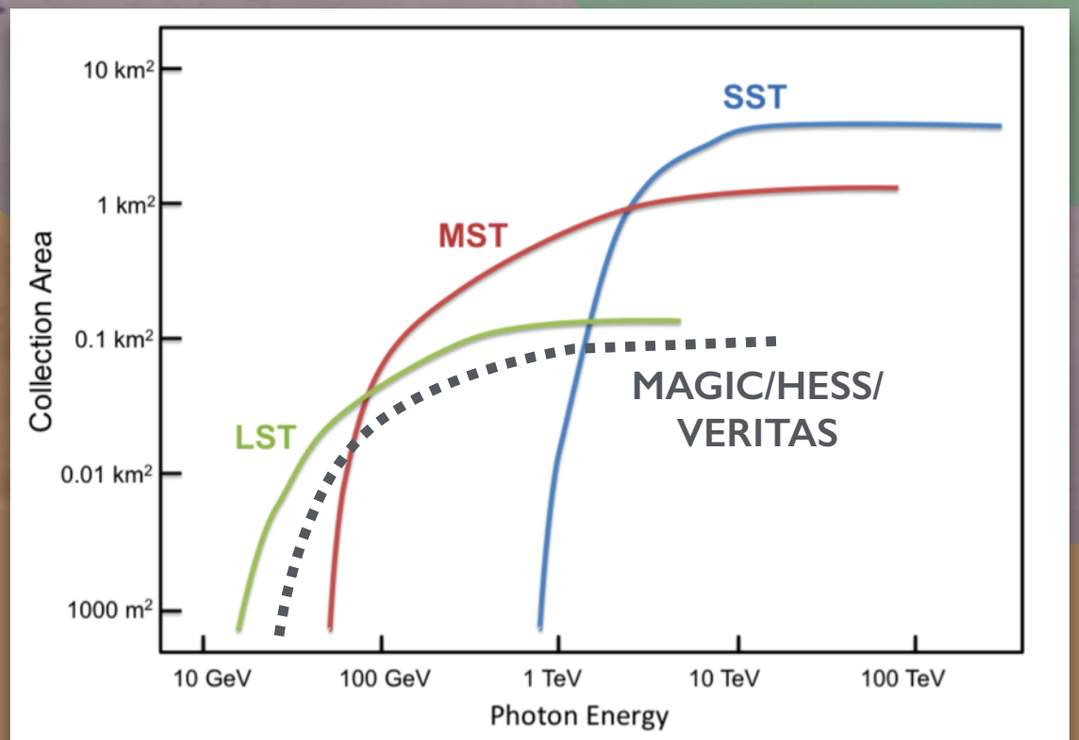
(North: 15)

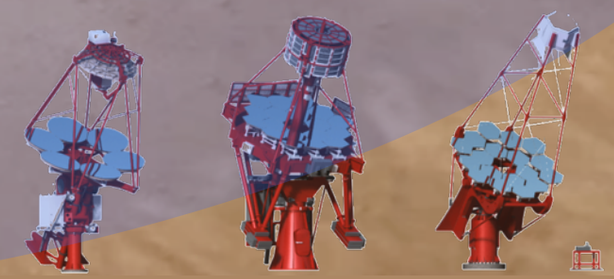


10 GeV 100 GeV 1 TeV 10 TeV

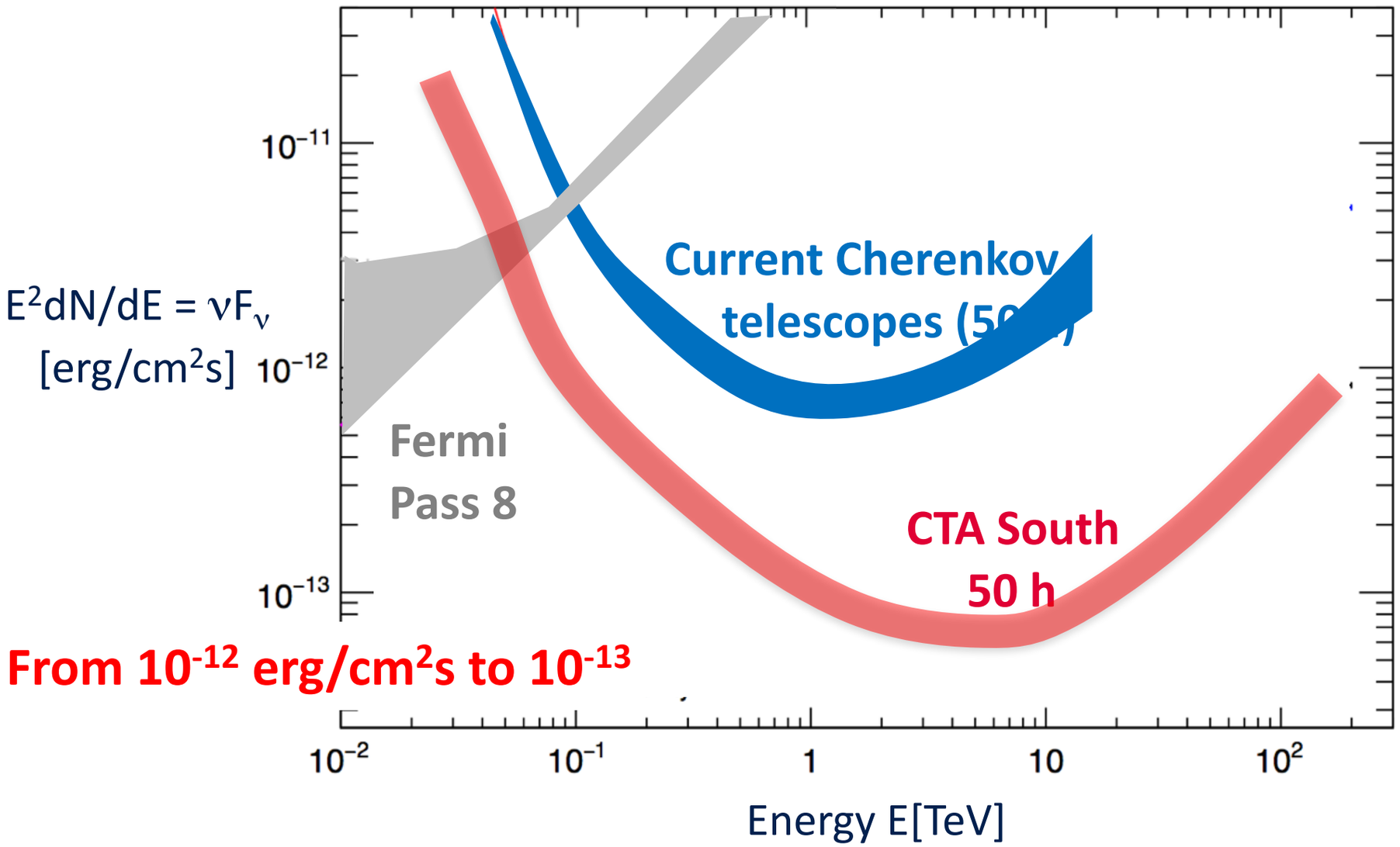
100 TeV

70 x 4 m ∅ Small Size Telescopes (SST
(South)



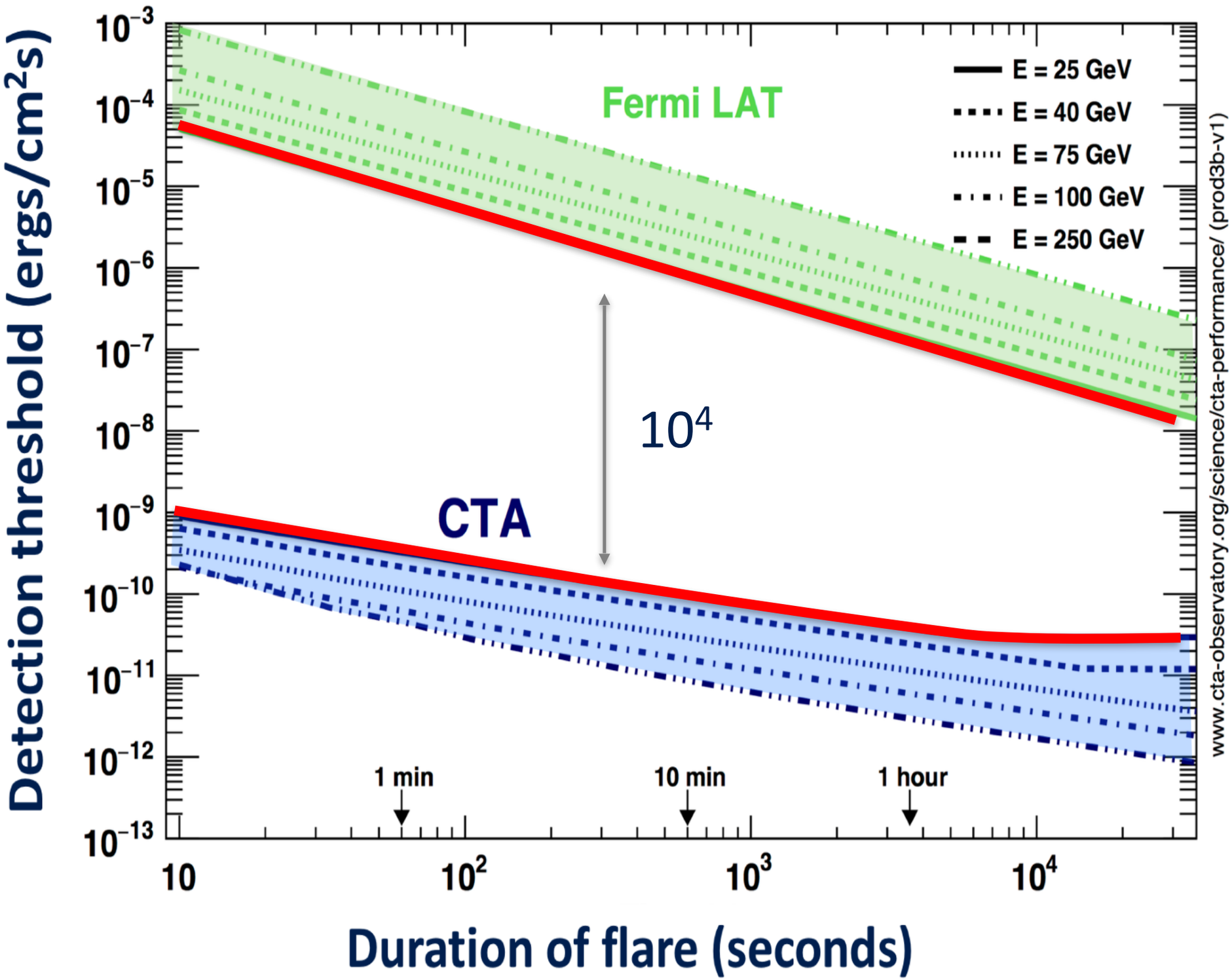


Sensitivity (Steady sources)

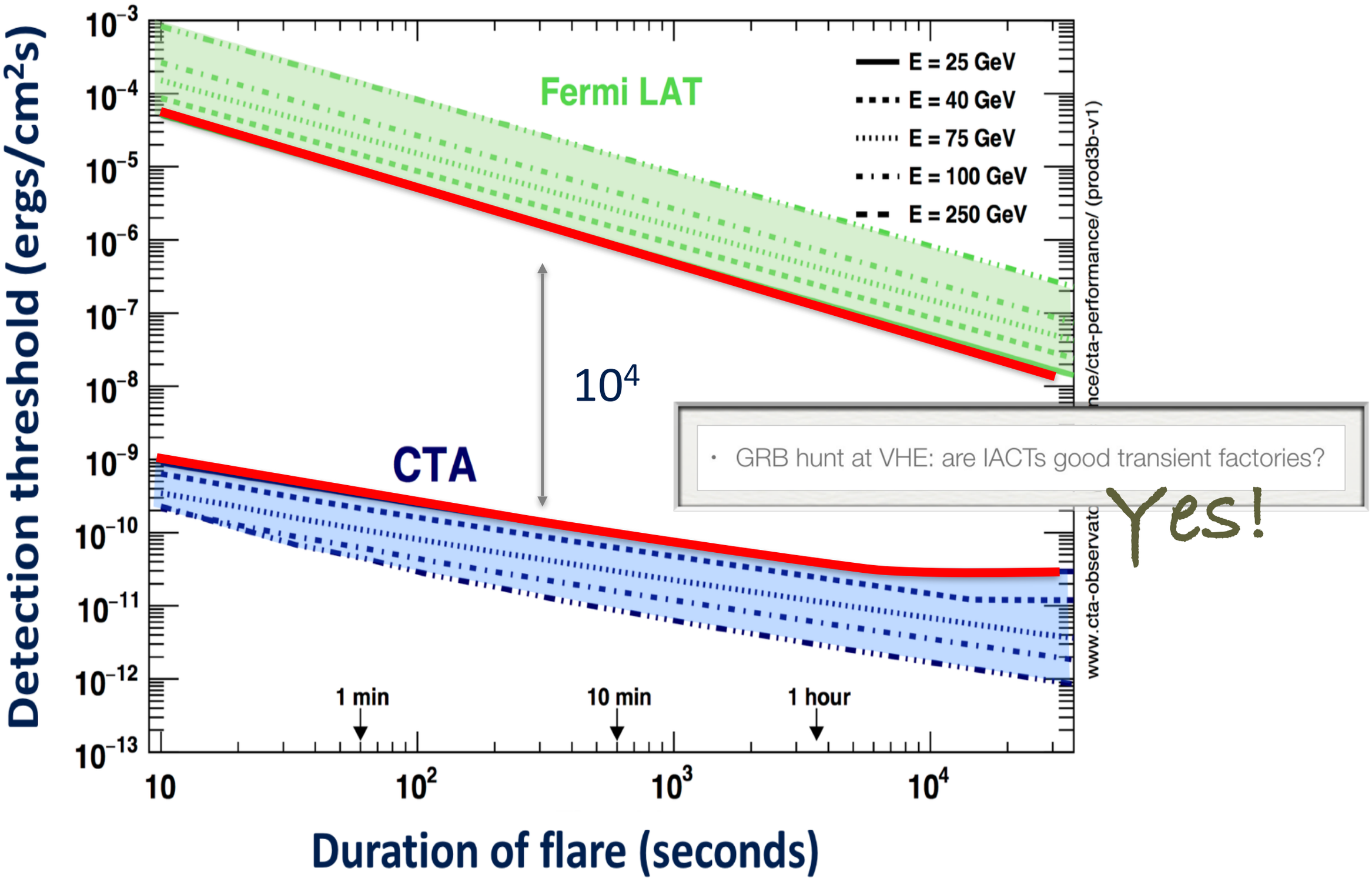


Credits: W. Hoffmann

CTA sensitivity (transient sources)

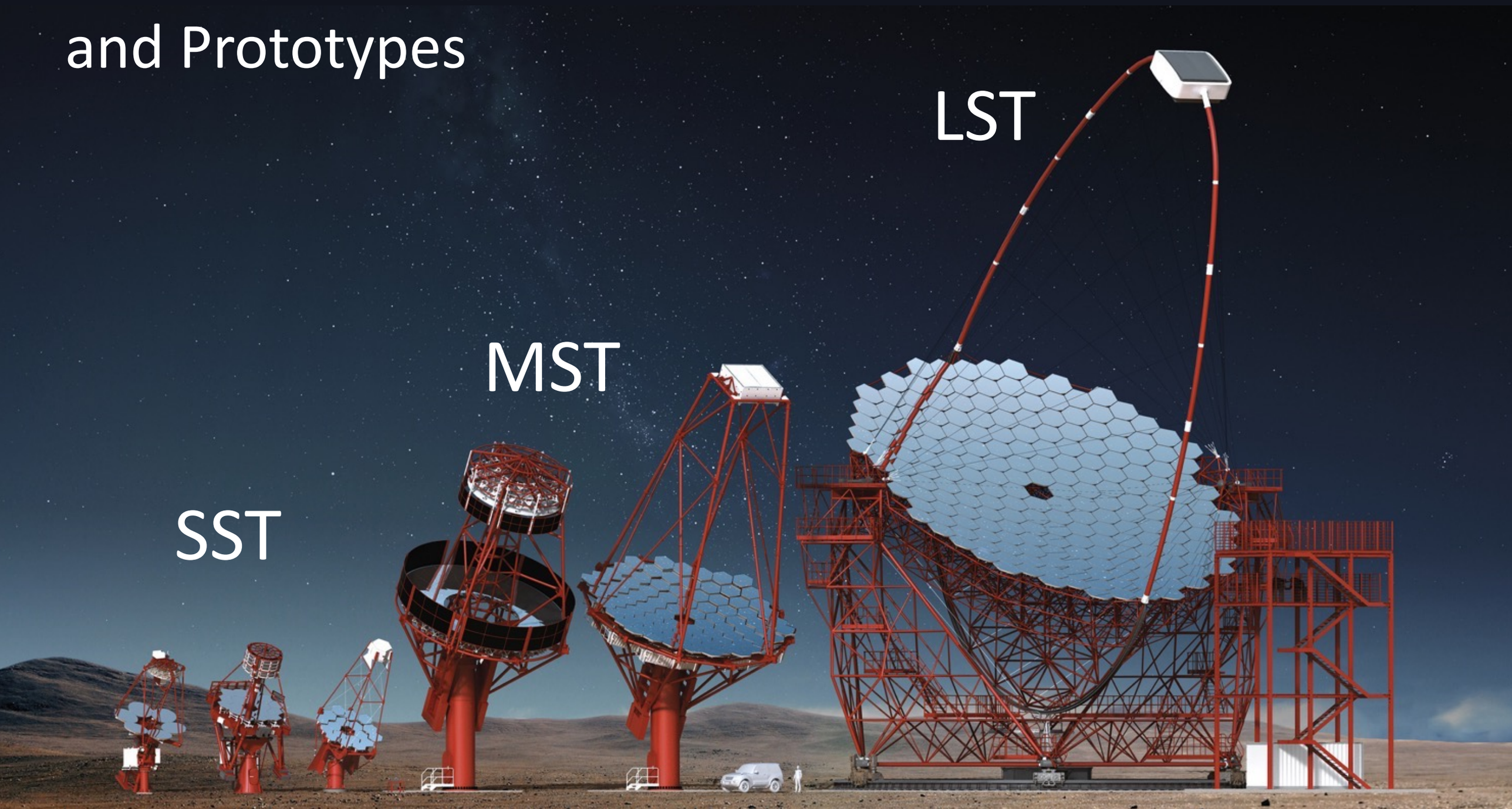


CTA sensitivity (transient sources)



CTA telescopes

Telescope Designs and Prototypes




LST
prototype
M2
M1
Live webcam
http://www.lst1.iac.es/webcams.html

The INAF project for the SST

Presentazione dedicata S. Scuderi

- ASTRI prototype for CTA-SST

THE ASTRI-HORN TELESCOPE

Telescope characteristics [4,5]:

- **Optical design = Schwarzschild-Couder**
- Primary mirrors = 4.3 m (18 panels)
- Secondary mirror = 1.8 m (monolithic)
- F/D_1 = 0.5; F = 2.15 m
- M1-M2 distance = 3.0 m
- Effective Area = 6.5 m^2

Camera properties [6]:

- **Sensor type = SiPMs**
- 21 Photo-Detection-Modules (PDMs)
- 1344 logical pixels (64 per PDM)
- Pixel size = 0.19° (plate scale = 37.5 mm/°)
- Field of View = 7.6°

Expected performance [7]:

- Energy threshold: ≈1 TeV
- Energy/Angular resolution ≤ 25% / ≤ 0.15°
- Sensitivity ≈ 1 Crab @ 5σ in a few hours

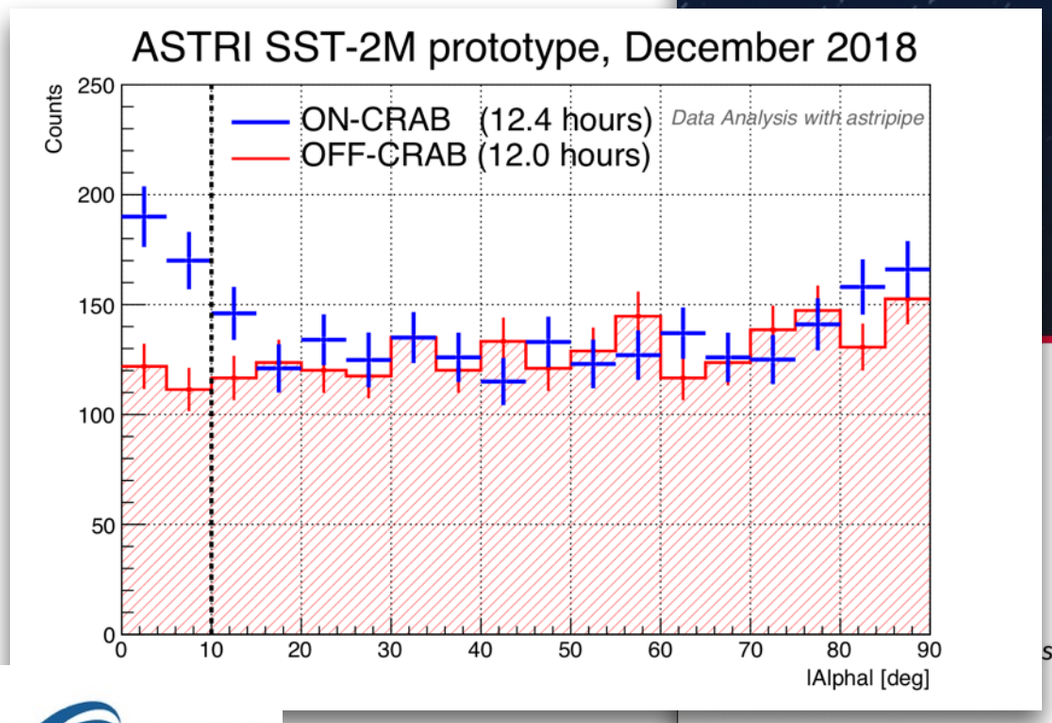
Fig.1: The ASTRI-Horn dual-mirror Cherenkov telescope located on Mt. Etna (Italy) at the INAF "M.C. Fracastoro" observing station.

Credits: S. Lombardi (CTA-Symposium)

The first source detected by CTA!

- ***Proudly made in Italy!***

8.May 2019



OSSERVATORIO ASTRONOMICO DI ROMA

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Home About Science Project News Outreach & Education 2019 Symposium

cta cherenkov telescope array

Press Release

ASTRI-Horn is first Cherenkov telescope in dual-mirror configuration to detect the Crab Nebula at TeV energies

The ASTRI-Horn prototype telescope is located at the observing station of the INAF Astrophysical Observatory of Catania, in Serra La Nave, on Etna, where it was installed in 2014. The primary tassellated mirror has a diameter of 4 meters and the secondary monolithic mirror is 1.8 meters in diameter.

Exactly 30 years after the first historical observation of Crab nebula at TeV energies, which opened the era of TeV astronomy with the Imaging Atmospheric Cherenkov Technique (IACT), another advancement in IACT technology has been achieved. The ASTRI-Horn Cherenkov Telescope, based on the innovative Schwarzschild-Couder dual-mirror configuration and equipped with an innovative camera, has detected the Crab Nebula at TeV energies for the first time, proving the viability of this technology.

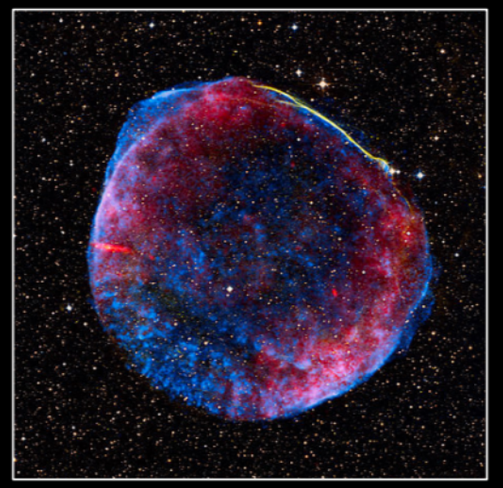
In 1989, the very first detection of the Crab Nebula at TeV energies (about a trillion times the energy of visible light) was obtained with the Whipple Telescope. This discovery was the initiation of *TeV astronomy*, which, with its rapid growth, has led to the detection of about 200 gamma-ray sources from other ground-based detectors like H.E.S.S.,

https://www.cta-observatory.org/astri-detects-crab-at-tev-energies/

CTA themes

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

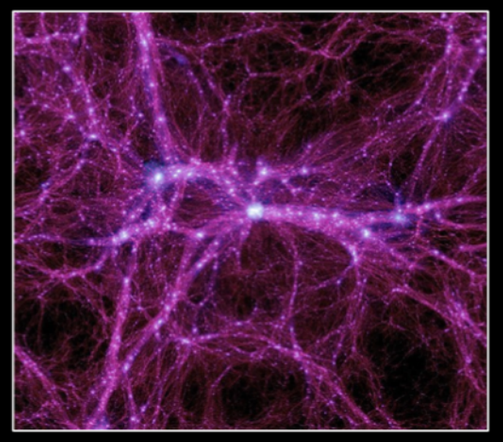


Theme 2: Probing Extreme Environment

- Close to neutron stars and black holes?
- Relativistic jets, winds and explosions?
- Cosmic voids

Theme 3: Physics Frontiers

- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?



The CTA key-science projects

provide legacy data sets and data products

1. Dark Matter Programme
2. Galactic Centre
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma Rays

Surveys

Key objects

Credits: R. Ong (CTA-Symposium)

www.worldscientific.com/worldscibooks/10.1142/10986

The CTA key-science projects

provide legacy data sets and data products

1. Dark Matter Programme
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9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma

Surveys

Key objects

Presentazione su osservazioni sul "prototipo"du Seyfert 2 NGC1068

A. Lamastra

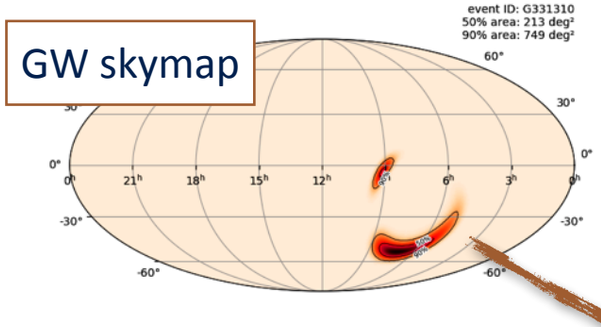
Credits: R. Ong (CTA-Symposium)

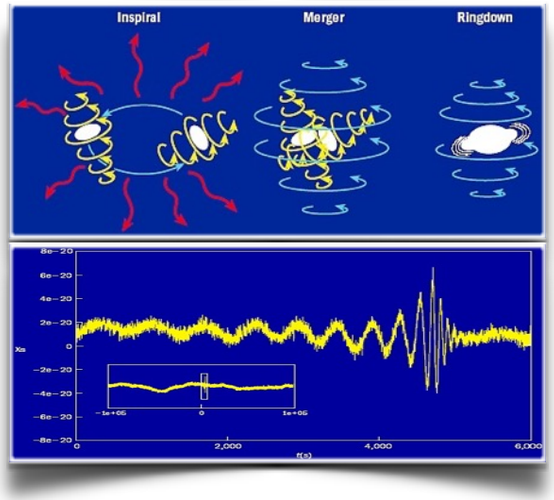
www.worldscientific.com/worldscibooks/10.1142/10986

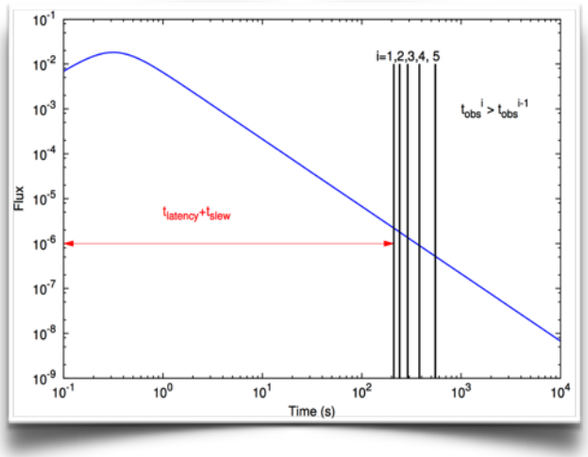
Follow-up of gravitational waves with CTA

Example on BNS mergers *from Patricelli+2018*

- **Simulation of mergers** and GW signal in local universe

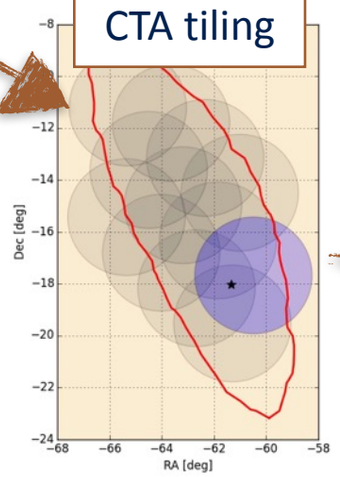


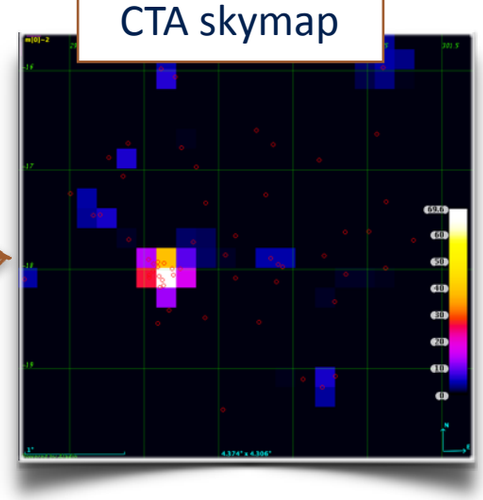




- **Phenomenological model** of VHE emission, from short-GRB templates
- Off-axis emission

- **CTA observing strategy**

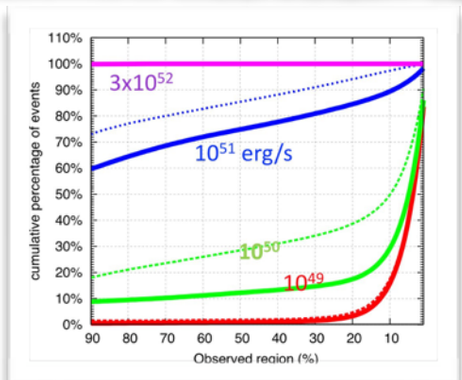




- **Simulation of CTA** response (IRFs, EBL)

Results

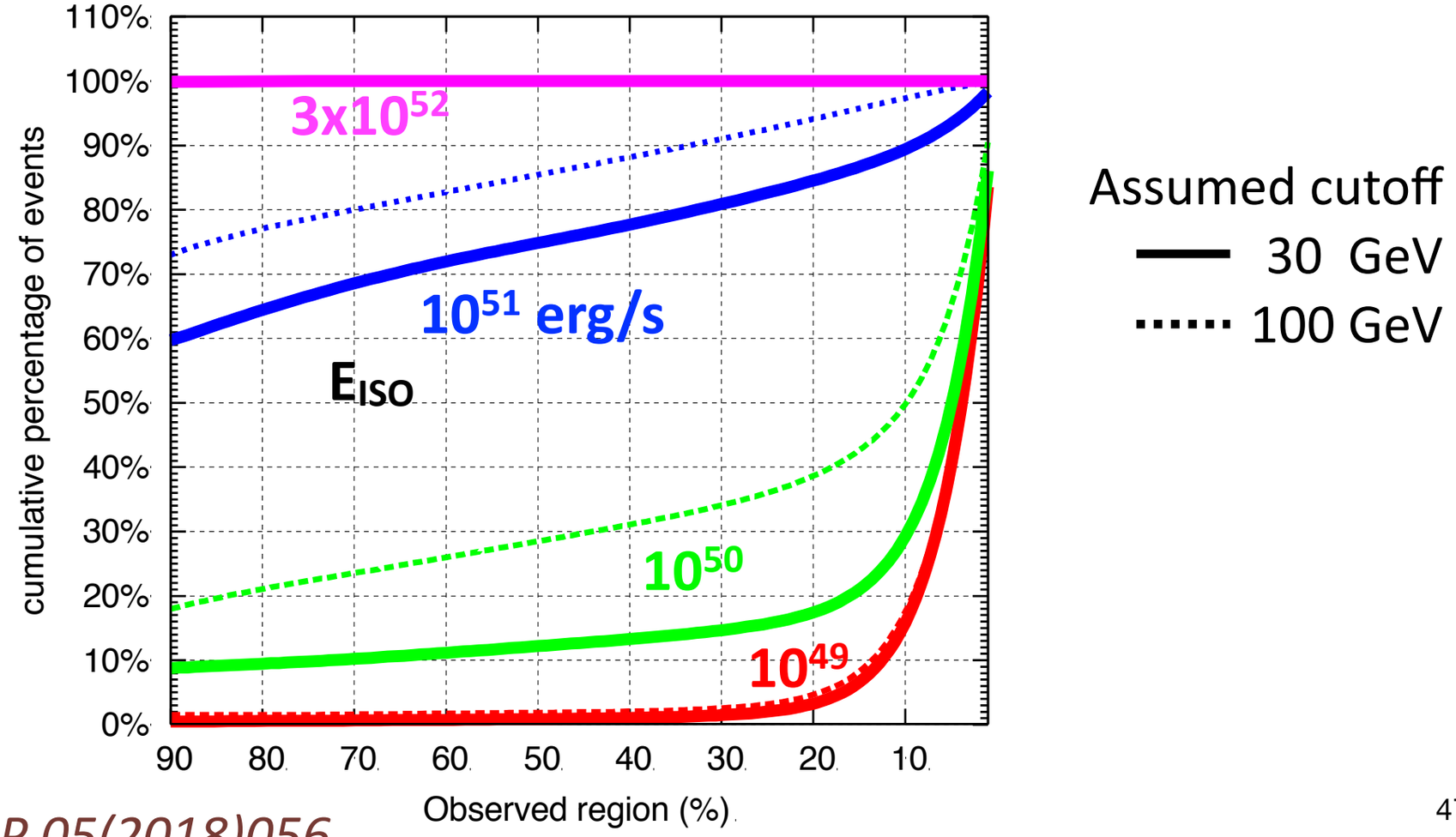
- ✓ Joint GW-CTA detection rates and coverage
- ✓ Optimal observation strategies



GW-CTA BNS joint rates

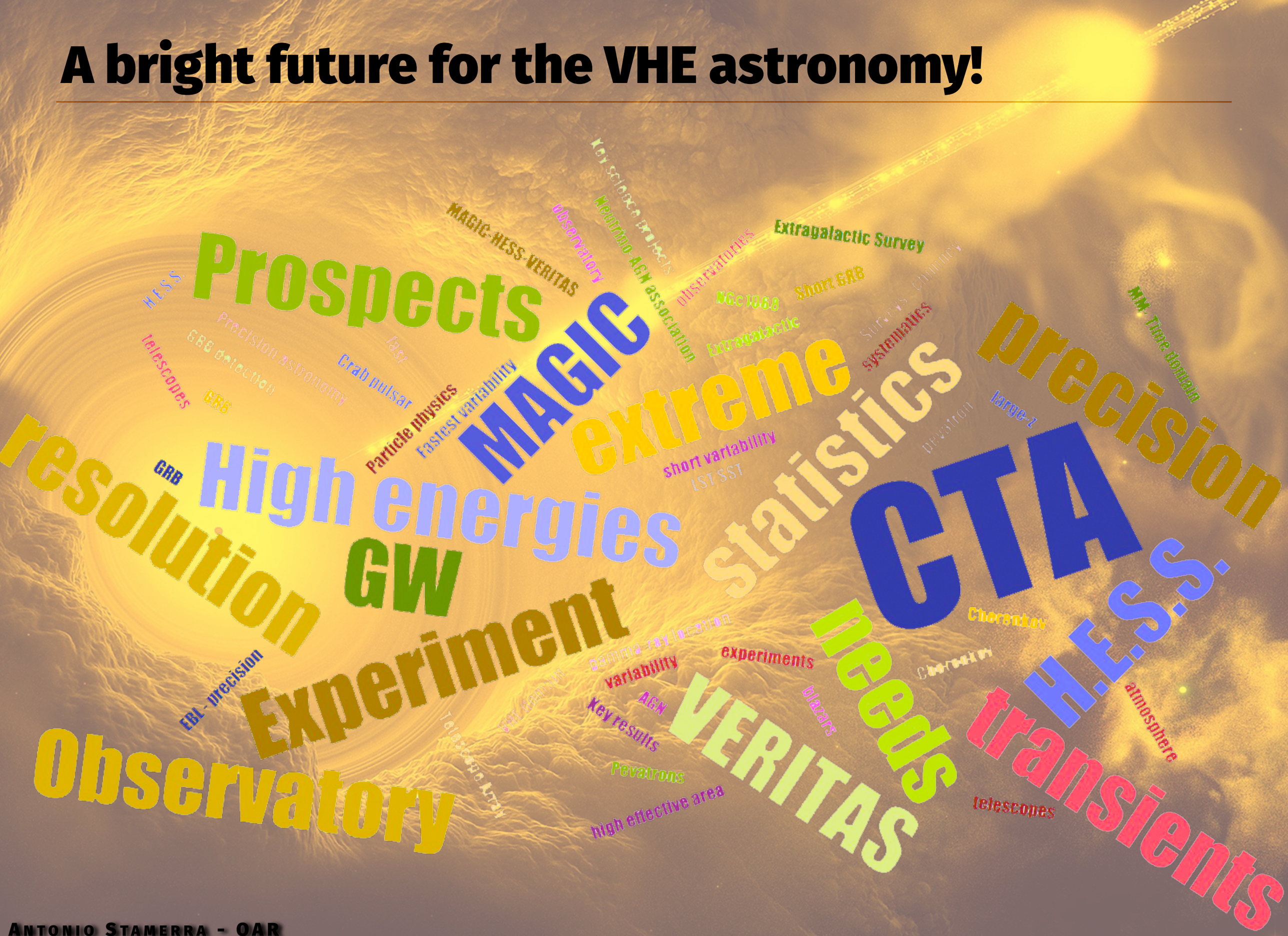
- **Coverage** of detectable BNS mergers
- Expected rate of detection with CTA: up to **0.08 yr^{-1}** for most luminous GRB, ***assuming a GeV energy cutoff***
- Recent VHE detection of the (long) GRB190114C and the hint on the short-GRB160720A may point to a hard TeV component, thus making the detection of GW counterpart more compelling!

coverage



Patricelli, AS et al. 2018 JCAP 05(2018)056.

A bright future for the VHE astronomy!



Antonio Stamerra - OAR

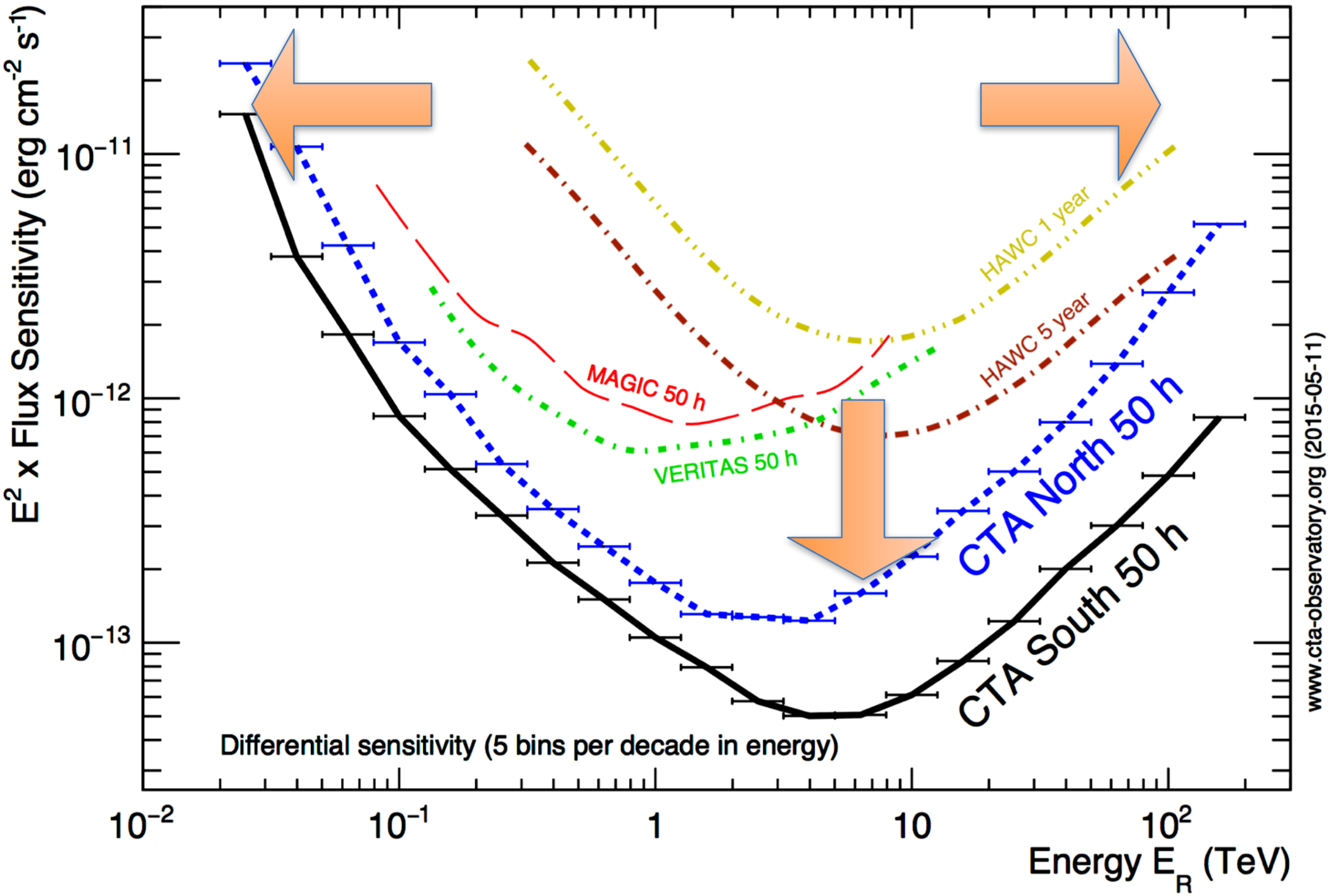
LXIII Congresso della Società Astronomica Italiana - Accademia dei Licei, Roma, 15 maggio 2019

CTA OBSERVATORY

During the first decade:
~40% Key Science Projects
(CTA Consortium)
~50% User time
~10% Host country time

www.worldscientific.com/worldscibooks/10.1142/1

CTA sensitivity (steady sources)

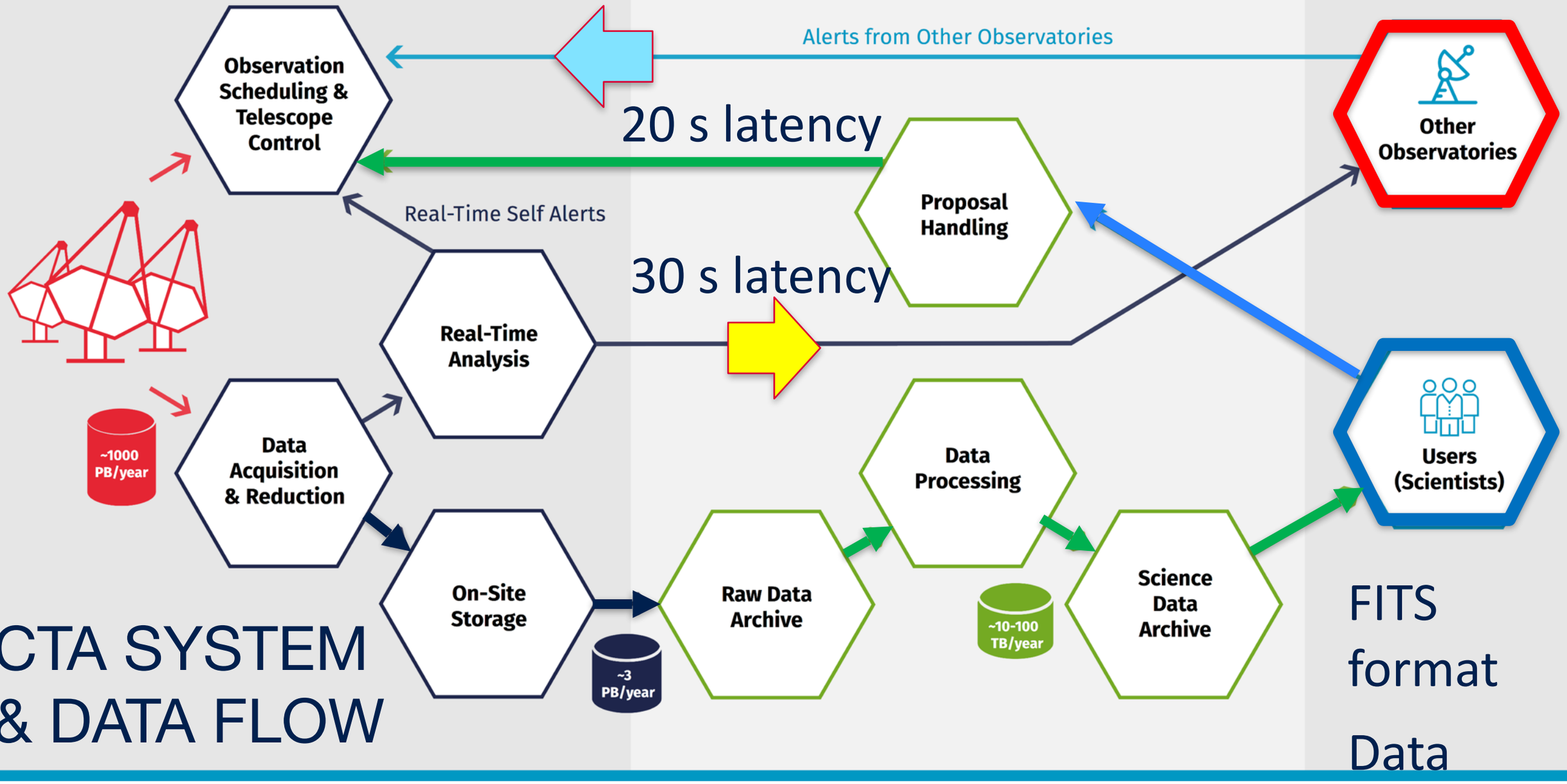


On Site

Off Site

Outside World

Alerts & ToOs



CTA SYSTEM & DATA FLOW

FITS format

Data open after 1

Outline

- The VHE domain
  - Key results
    - Crab pulsar - large energies - pevatron
    - AGN gamma-ray location
    - EBL - precision
    - Fastest variability
    - MM- Time domain
      - Neutrino-AGN association
        - NGc1068
      - GRB detection
        - MAGIC - HESS - Short
        - GW
  - --> the process to get there (continous improvement)
  - Cherenkov telescopes - description
    - from experiments to observatories
- The needs
    - Precision astronomy
    - high effective area (short variability)
    - High energies
- Prospects: needs + observatory -> CTA
  - Surveys - chimney
  - NGC1068
  - GRB (large-z) - GWs

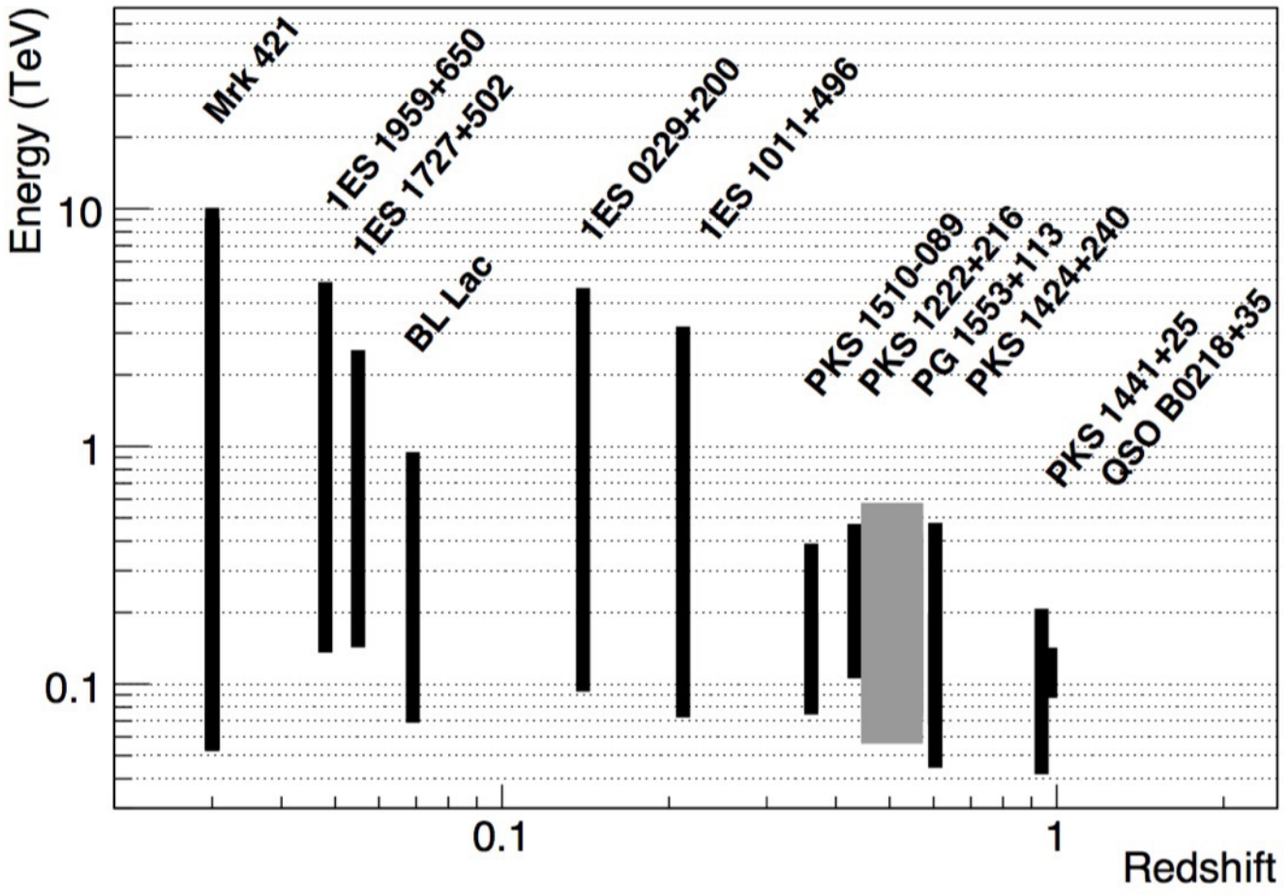
- The VHE domain Key results AGN gamma-ray location EBL - precision Fast variability Crab pulsar - large energies - pevatron multi messenger "Time domain" Neutrino-AGN association GRB MAGIC H.E.S.S. Short-GRB GW improvement "Cherenkov telescopes" experiment observatory needs Precision astronomy effective area (short variability) High-energies Prospects needs observatory CTA Surveys NGC1068 GRB (large-z) GW "angular resolution" PSF "Energy resolution"

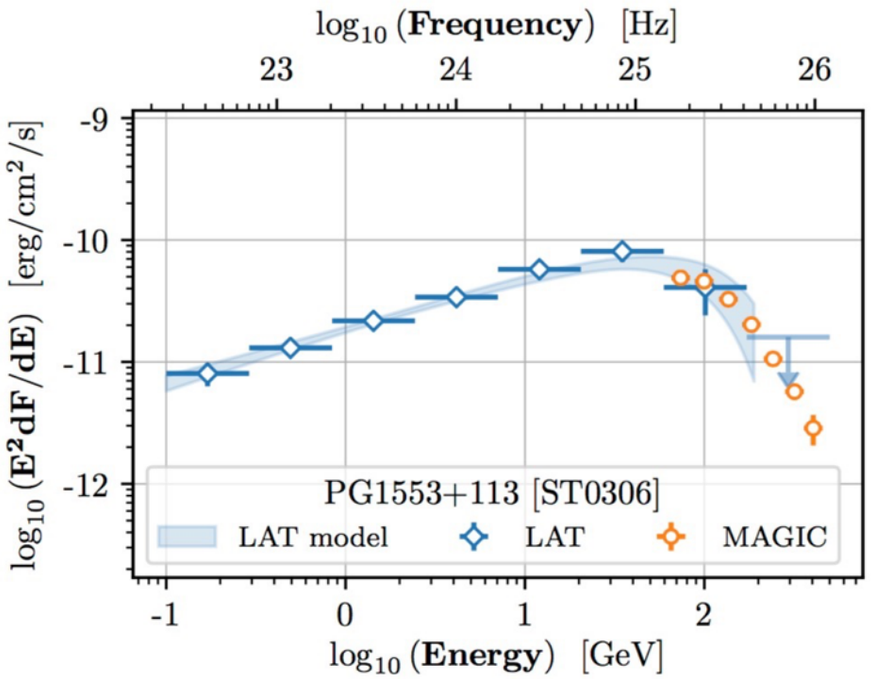
Ground-based gamma ray astronomy TODAY

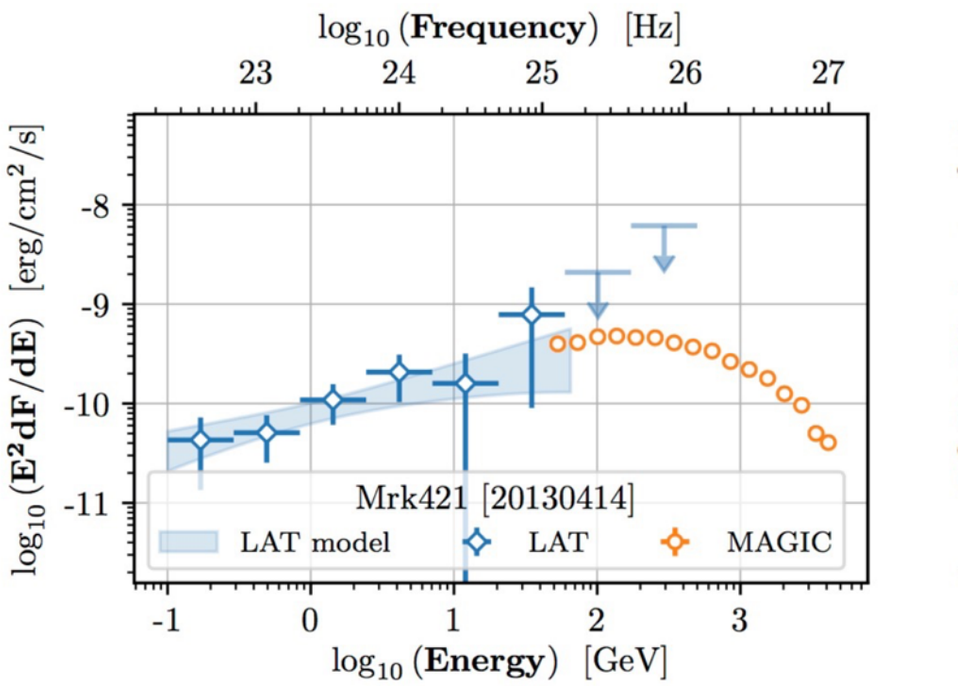
- 200+ sources of TeV gamma rays
- Sky images and sky maps
- Resolution approaches that of the human eye
- Sources like the Crab Nebula are virtually free of cosmic-ray background
- Dynamic range in gamma-ray flux: 3+ orders of magnitude
- Dynamic range in energy: 3+ decades
- Light curves on all scales from minutes to years

Precision and statistics: EBL measurement

- Sum contribution of 32 spectra of blazars
- Combined spectrum of Fermi/LAT and MAGIC







MAGIC coll., MNRAS acc., Measurement of the Extragalactic Background Light using MAGIC and Fermi-LAT gamma-ray observations of blazars up to z = 1 https://arxiv.org/abs/1904.00134