UNIVERSITÉ DE GENÈVE

Gamma-rays and their future

CRIS 2018 11th Cosmic Ray International Seminar

Gamma-ray fluxes & current reach on sources

Instruments

- Focus on indirect gamma-ray detection from ground
- Imaging Atmospheric Cherenkov Telescopes (IACTs)
- Extensive air shower telescopes (EAST)
- Current & Future instruments
  - SiPM/PMTs
  - Duty cycle

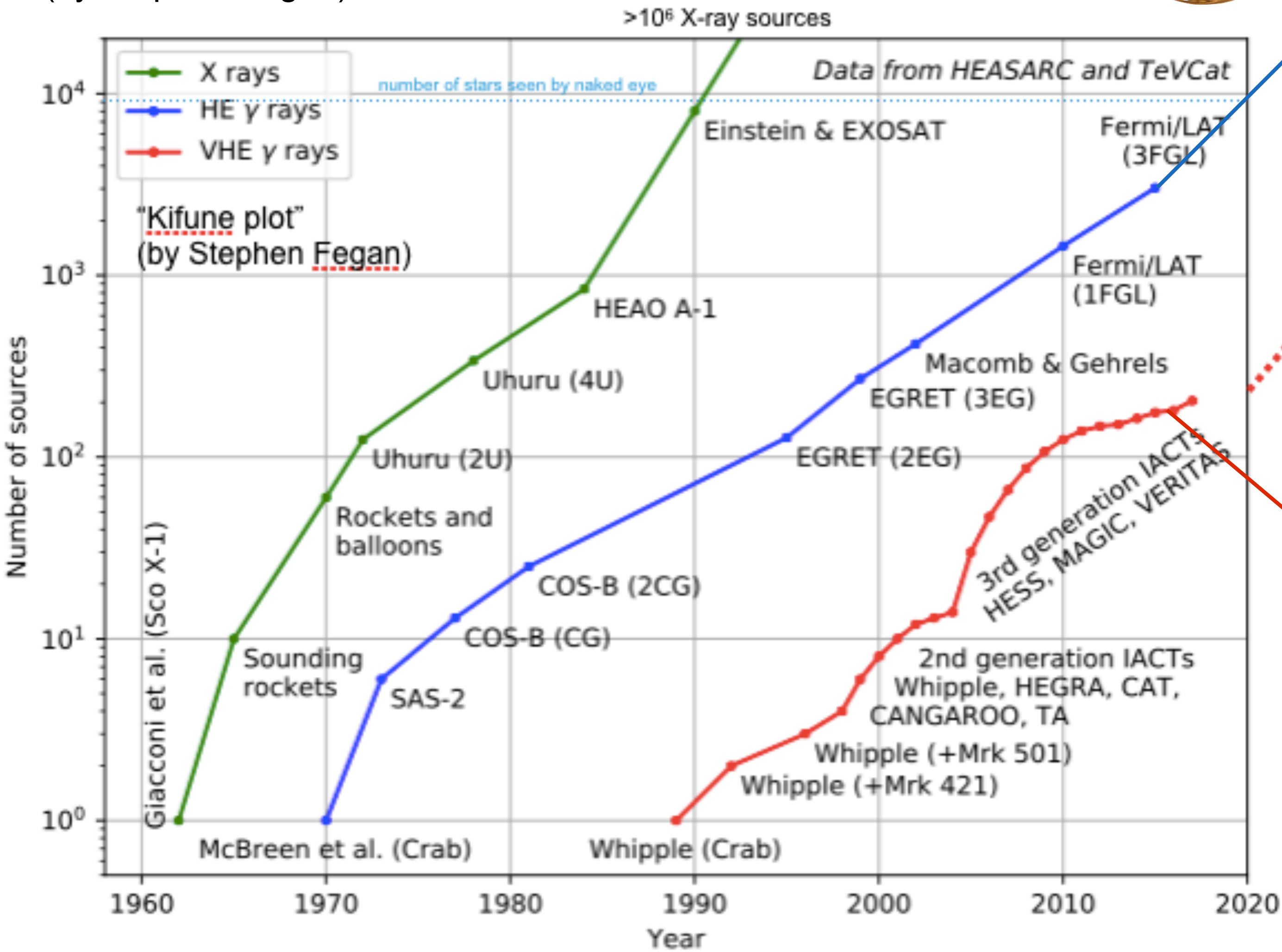
Some highlight results (in my view**…)

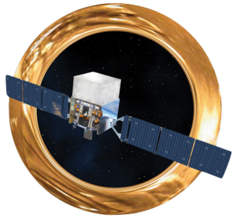
- Surveys
- Diffuse flux
- Sources: pulsars, SNR, blazars, GRBs in a MWL approach

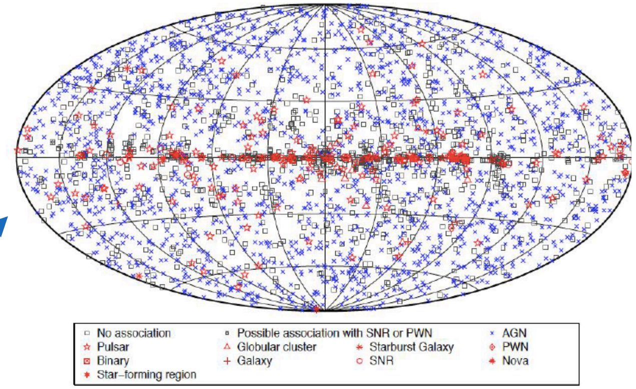
** My view is biased by work on instrumentation for CTA and in IceCube and on a work mostly in the >100 GeV region (not much DM…).For more results see other review talks on Fermi, MAGIC, HAWC,…at this conference and other talks listed at the end

Gamma-ray Sources & Detection Technique Advancement

"Kifune plot"
(by Stephen Fegan)





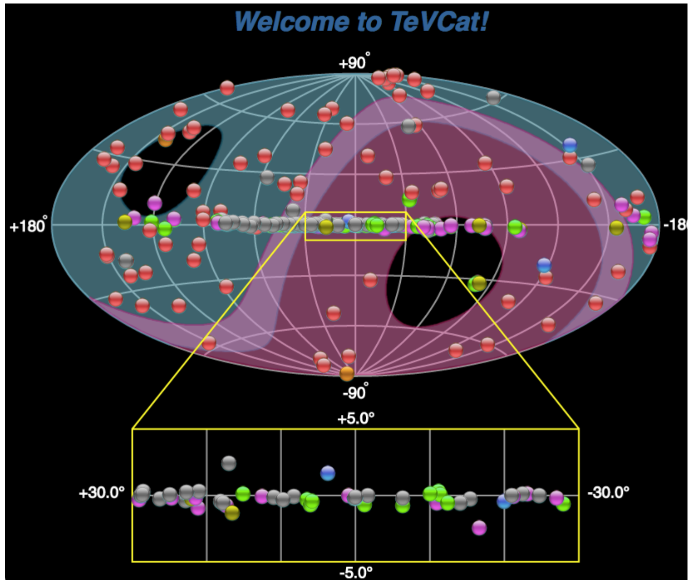


Acero, F. et al. 2015

F.Longo et al. – 30

CTA

3FGL 3034 sources > 100 MeV
95% extragalactic!
21% BL Lacs
16% FSRQ
19% unclassified blazars +
22% unassociated high lat
Still lots of classification work to come! (CTA, HAWC, LHAASO, SPACE??…)



About 210 TeV sources > 100 GeV
~37% discovered day H.E.S.S.
(exposure to the Galaxy matters!)

tevcat.uchicago.edu

What gamma-rays we aim to measure?

Not only sources…but also cosmic ray interactions in Galactic and extragalactic environment

Components of the Gamma Ray flux (0.1 – 1000 GeV)

E & ang. res, E range and threshold, n. of telescopes, waveform

$+$

Stability of PSF over FoV
Large FoV, Duty Cycle

$$\phi_\gamma(E,\Omega) = \sum_{j\in\{\text{Galactic}\}} \phi_j(E,\Omega_j) + \phi^{\text{Galactic}}_{\text{diffuse}}(E,\Omega)$$

+ Fermi bubbles

$$+ \sum_{j\in\{\text{extragal.}\}} \phi_j(E,\Omega_j) + \phi^{\text{extragal.}}_{\text{isotropic}}(E,\Omega)$$

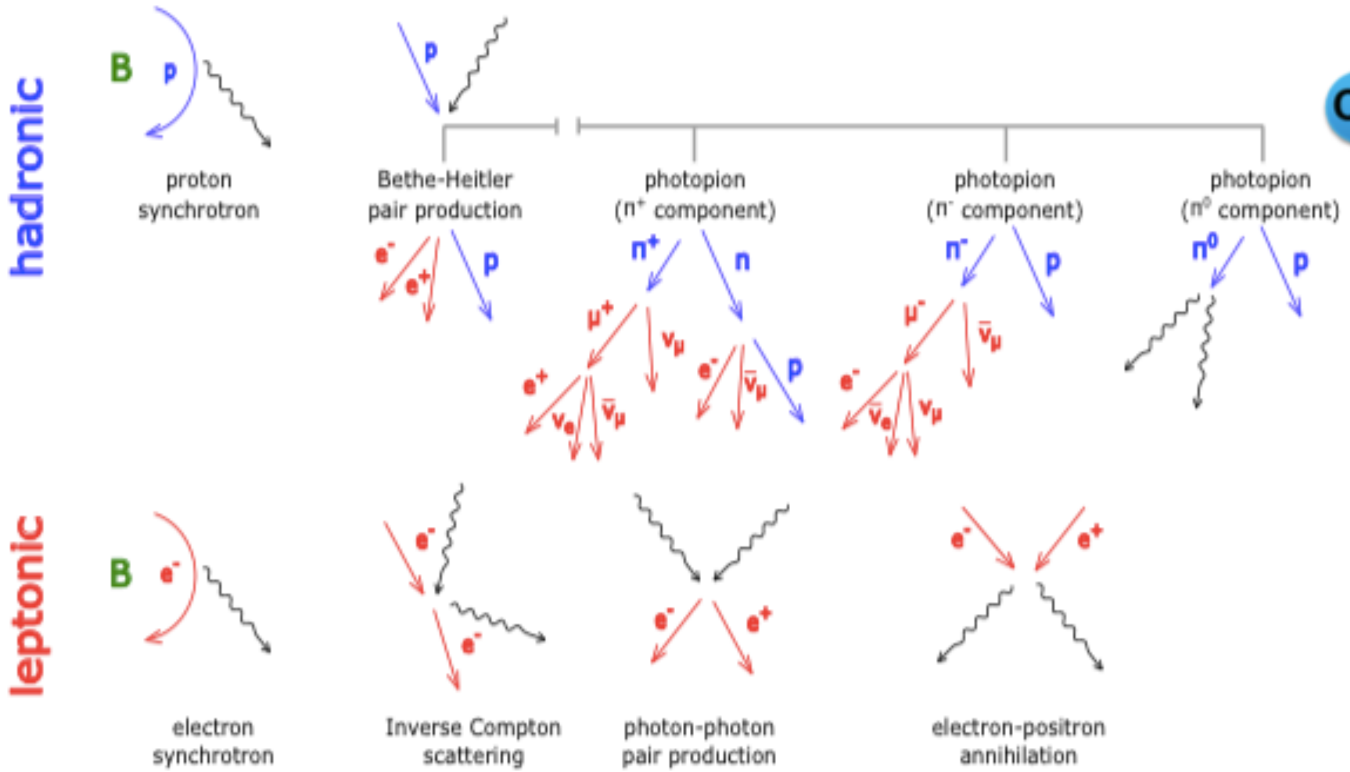
$$\phi^{\text{extragal.}}_{\text{isotropic}}(E,\Omega) = \phi^{\text{extragal.}}_{\text{unresolved sources}}(E) + \phi^{\text{extragal.}}_{\text{diffuse}}(E,\Omega)$$

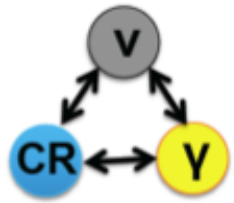
Five components which also compose the neutrino flux

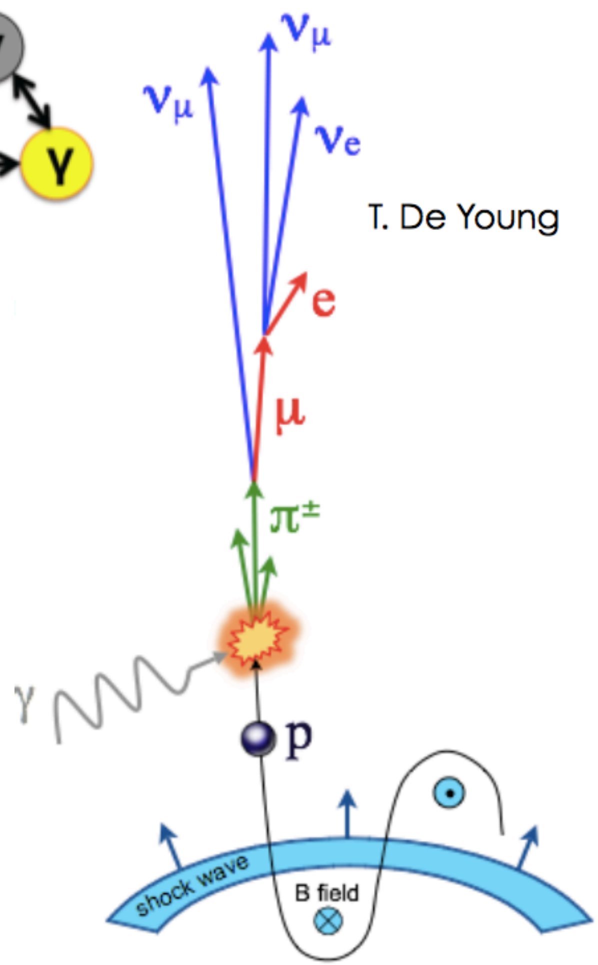
P. Lipari, at MIAPP topical workshop, Feb.-March 2018

Sources

- Astrophysical objects (and transients) accelerating particles to relativistic energies
- contain populations of relativistic protons, nuclei electrons/positrons
- emit cosmic rays, neutrinos, gamma-rays and in the cataclysmic events also GWs







T. De Young

Image from Petropolou et al, 2016

How do we detect gamma rays?

From ground and space

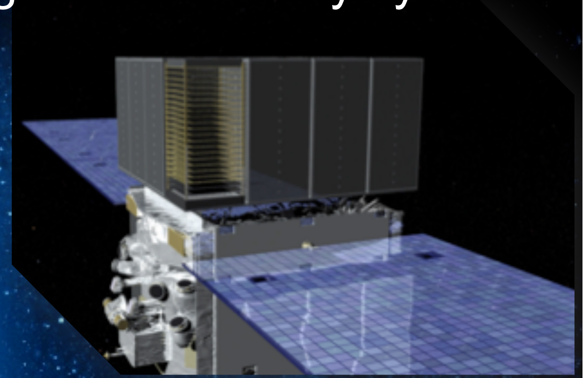
IACTs

- atmosphere is calorimeter
- Sets of mirrors focus Cherenkov pool light into fast camera in focus
- ~10% duty cycle due to Moon and weather and exposed mirrors
- decreasing efficiency by order of 2% due to mirror deterioration

Quantity	*Fermi*	IACTs	EAS
Energy range	20 MeV–200 GeV	100 GeV–50 TeV	400 GeV–100 TeV
Energy res.	5–10 %	15–20 %	$\sim$ 50 %
Duty cycle	80 %	15 %	$>$ 90 %
FoV	$4\pi/5$	5 deg $\times$ 5 deg	$4\pi/6$
PSF (deg)	0.1	0.07	0.5
Sensitivity	1 % Crab (1 GeV)	1 % Crab (0.5 TeV)	0.5 Crab (5 TeV)

Image from S. Ohm, ISVHECRI 2018, Table from De Angelis, Mallamaci, arXiv:0805.05642

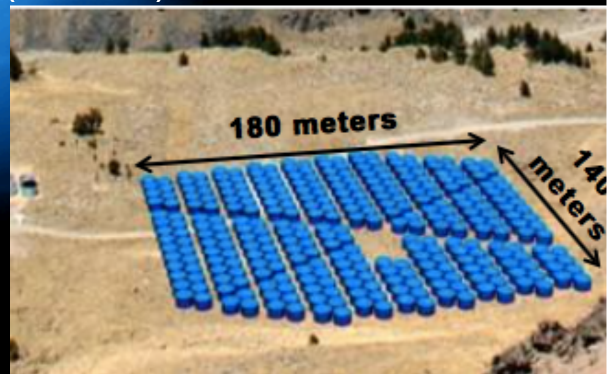
SPACE-based: 0.1 - 100 GeV
Large FoV and duty cycle



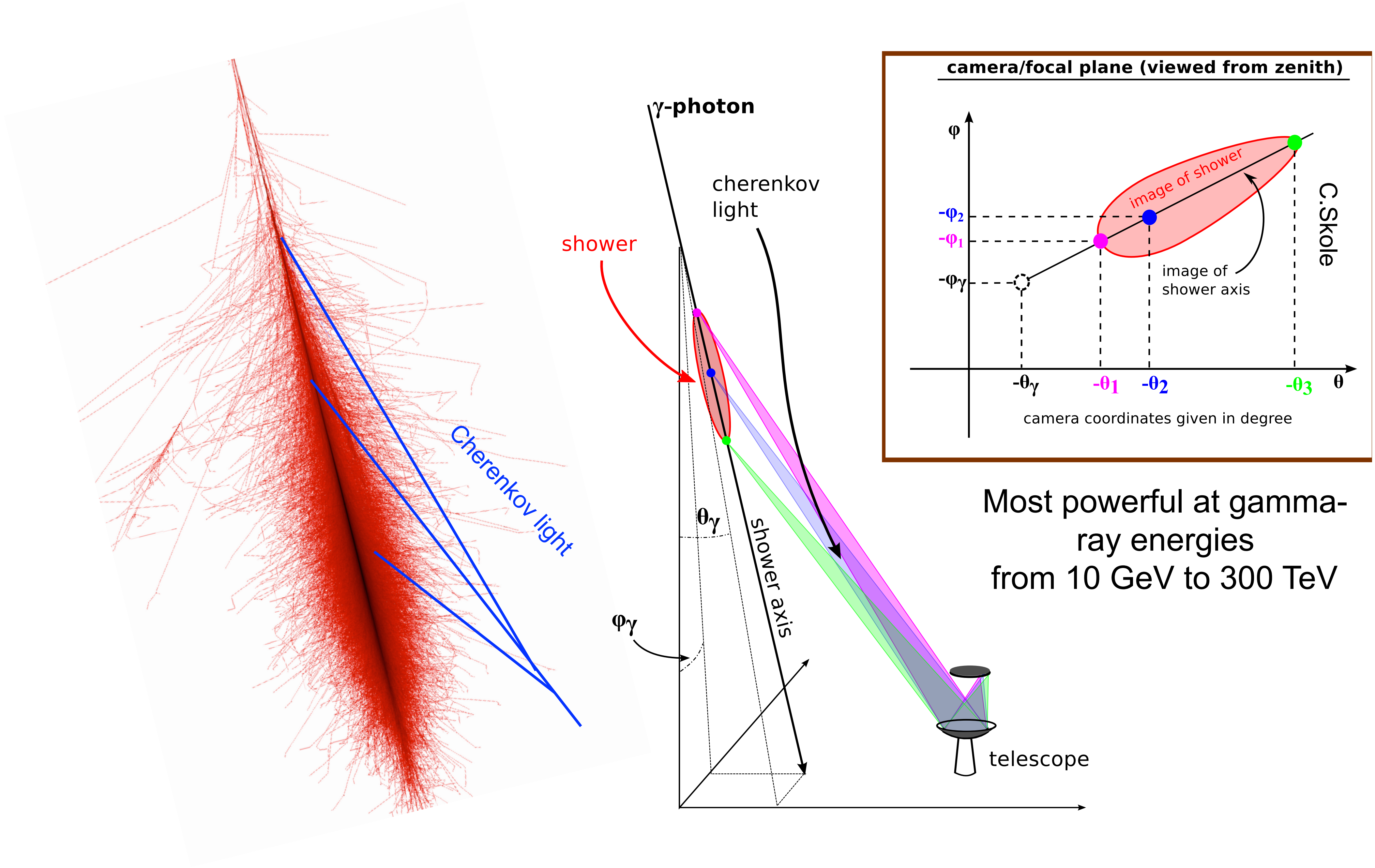
R. Bonino10 years of Fermi (Jun 11 https://fermi.gsfc.nasa.gov/fermi10)
AGILE

EAS:

- collect Cherenkov radiation produced by charged particles in water tanks or ponds equipped with photosensors
- > 90% duty cycle
- degrading quality of water transparency negligible (HAWC)



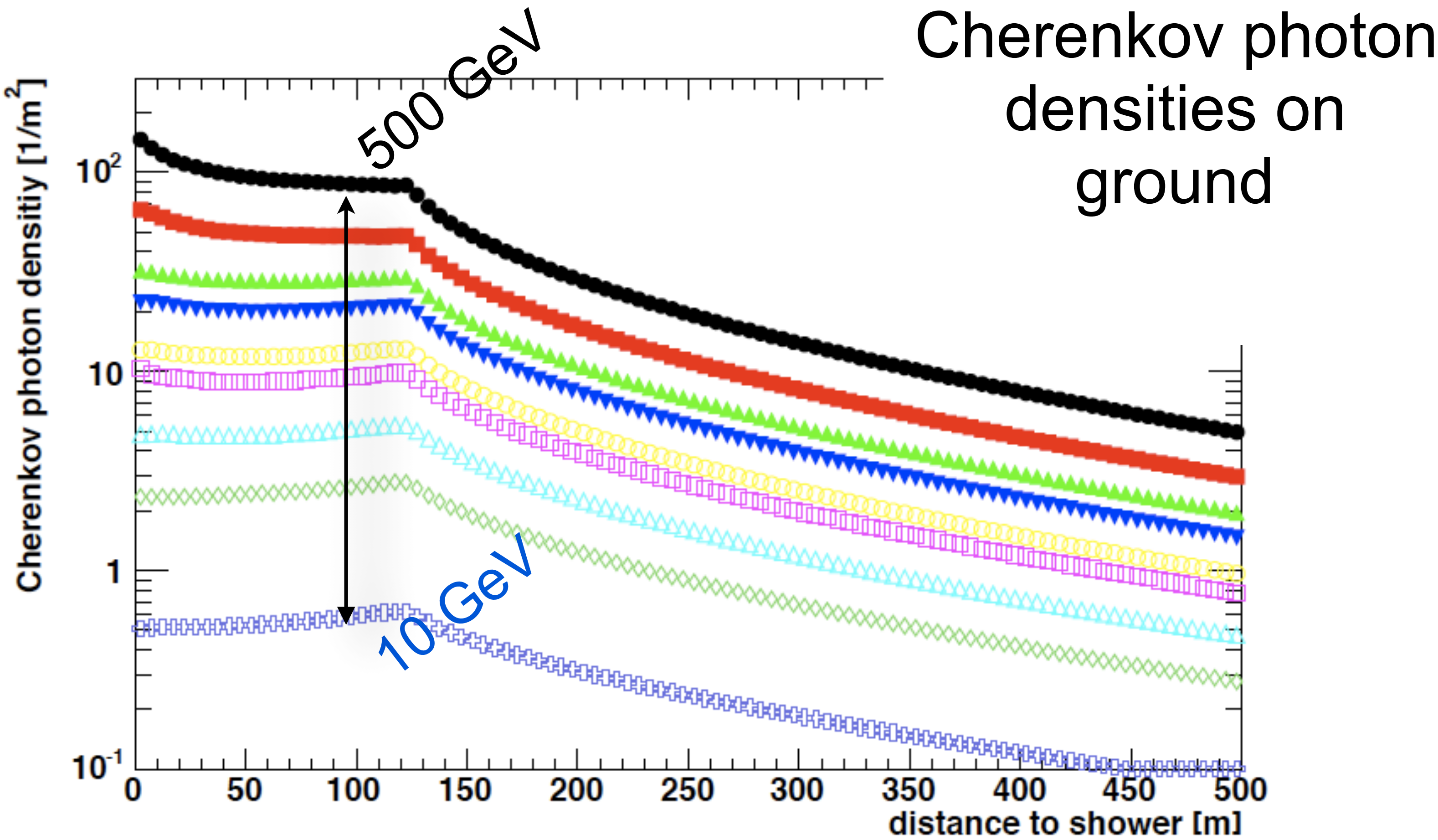
Imaging Technique - Air Showers



Most powerful at gamma-ray energies from 10 GeV to 300 TeV

From G Maier’s talk, ISVHECRI 2018

Light at ground



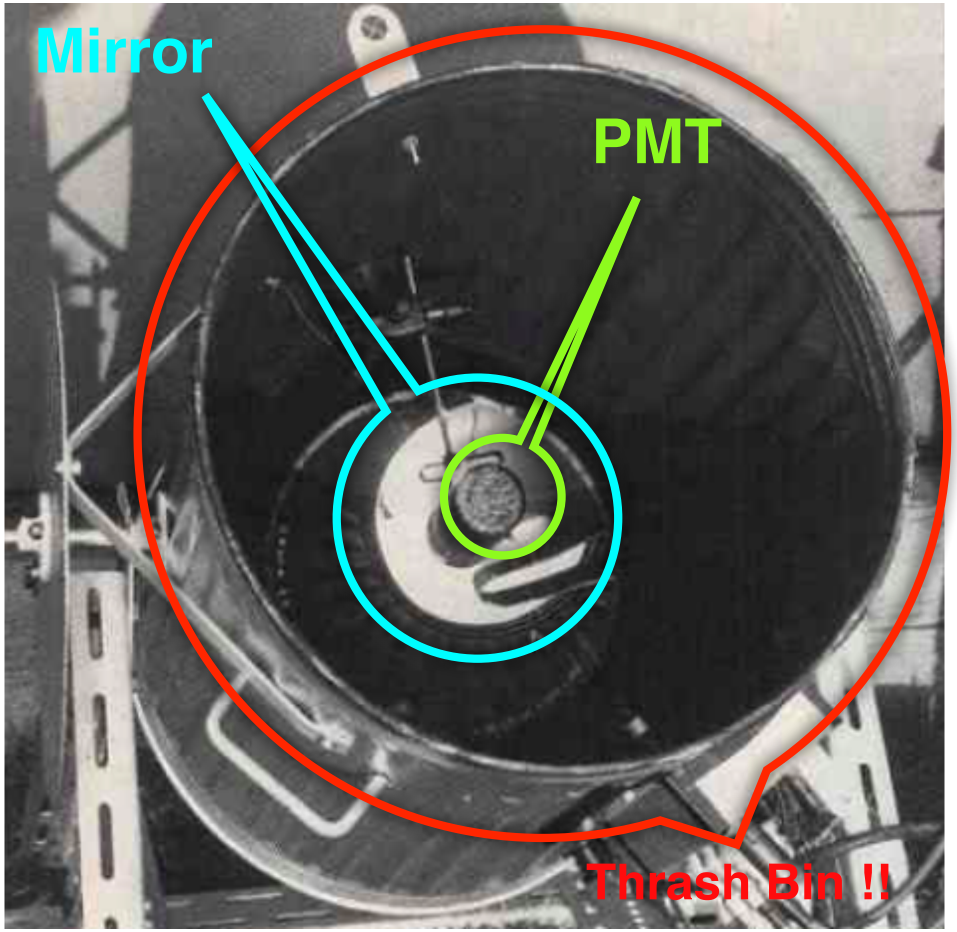
From G Maier's talk, ISVHECRI 2018

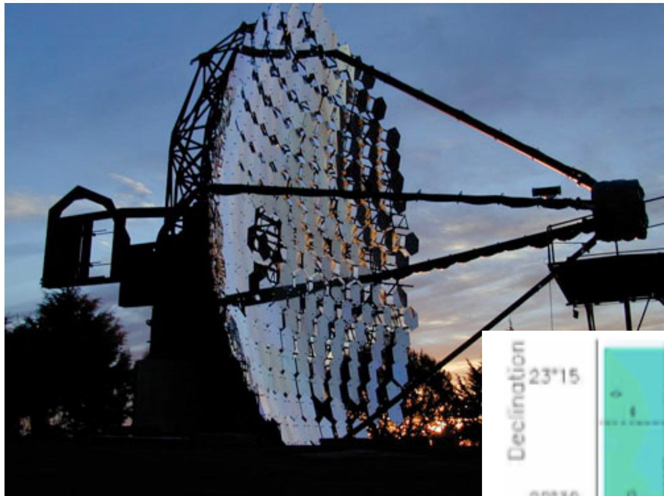
Light at ground preserves information on the gamma ray energy and direction (Cherenkov effect) reconstructable with high precision on a statistical basis

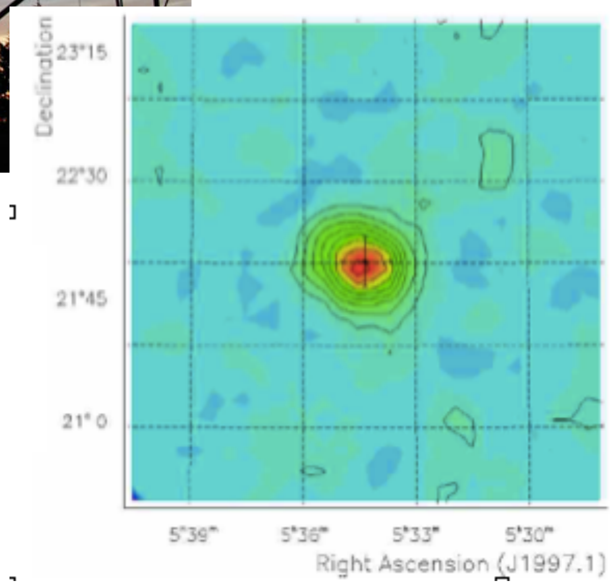
It all started with a trash can…

C. **Galbreith** & J. **Jelley**, when visiting the Harwell Air Shower Array in UK in **1952**, used a a 5 cm PMT mounted on the focal plane of a 25 cm parabolic mirror in a garbage can. They observed oscilloscope triggers from light pulses that exceeded the average night-sky background every 2 min. In **1953**, fro the polarisation and spectral distribution, they confirmed P. Backett's assertion that **Cherenkov light** is produced by charged CRs in the atmosphere on top of the night sky background. In 1959 G. **Cocconi** proposed to measure TeV gamma-rays using air shower detectors.

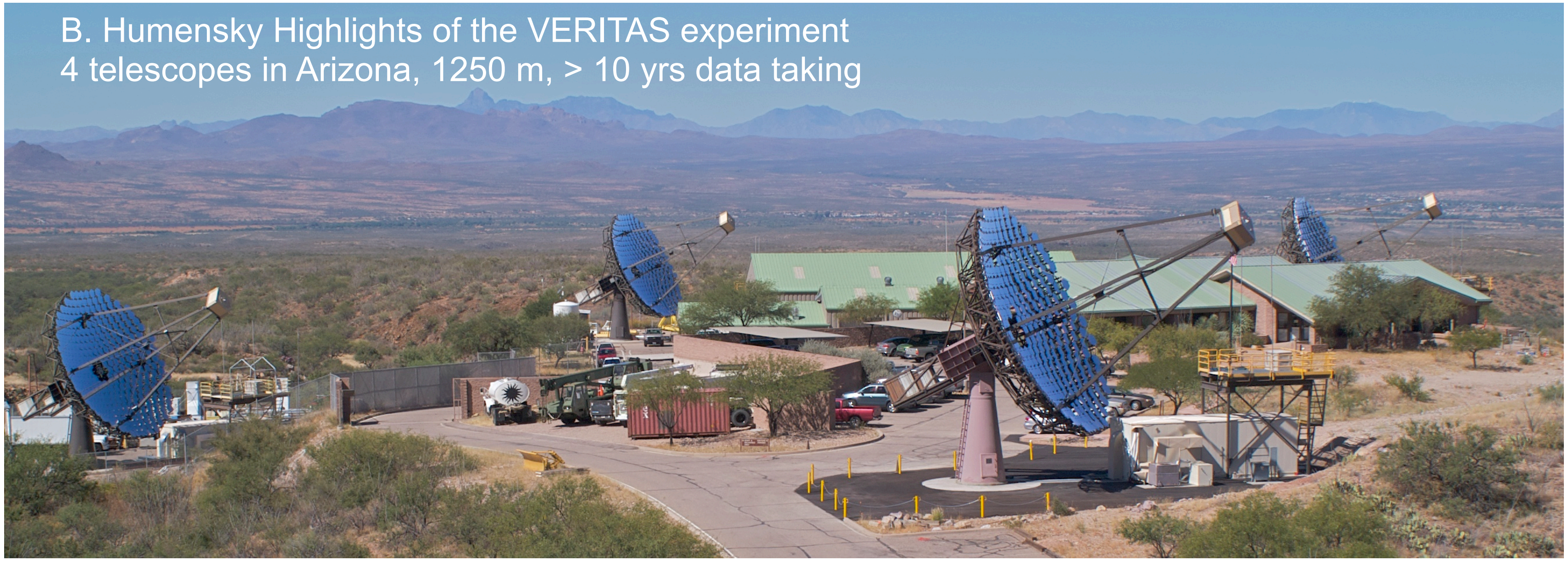
Gamma signals from sources (Crab Nebula) where detected only in **1989** by **Whipple**…





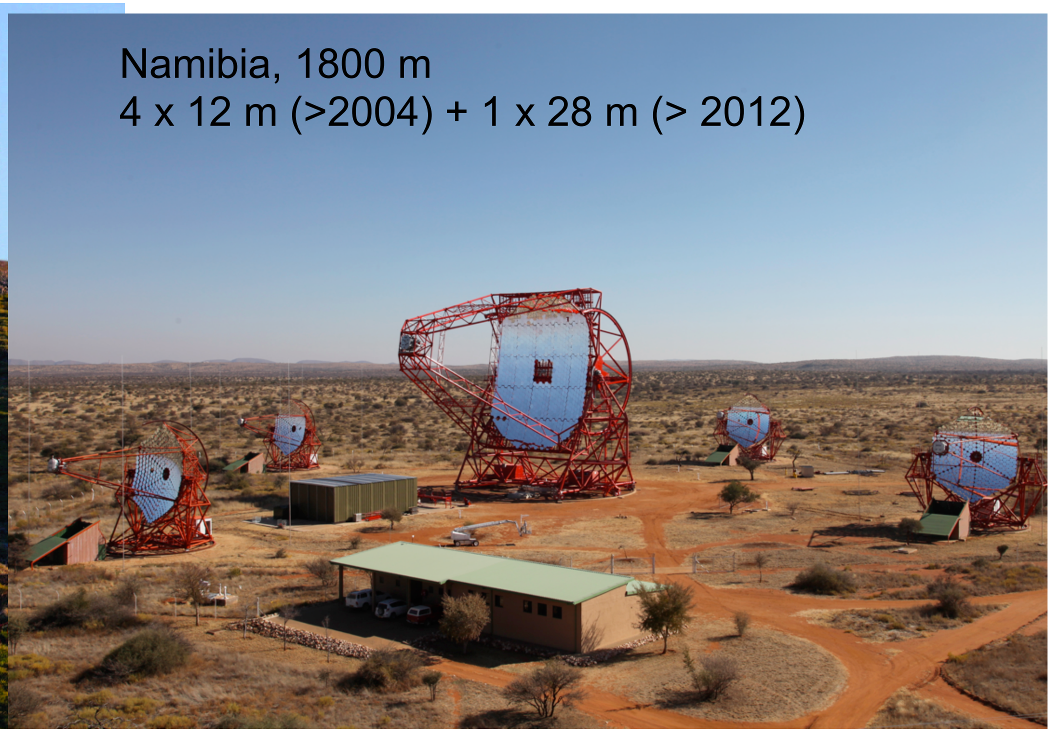


Ground-based IACT arrays



B. Humensky Highlights of the VERITAS experiment
4 telescopes in Arizona, 1250 m, > 10 yrs data taking

M. Doro 15 years of MAGIC observations a crowded TeV sky
2 x 17 m dia. telescopes at La Palma, 2200 m
MAGIC-I in > 14 yrs, MAGIC-II since 10 yrs



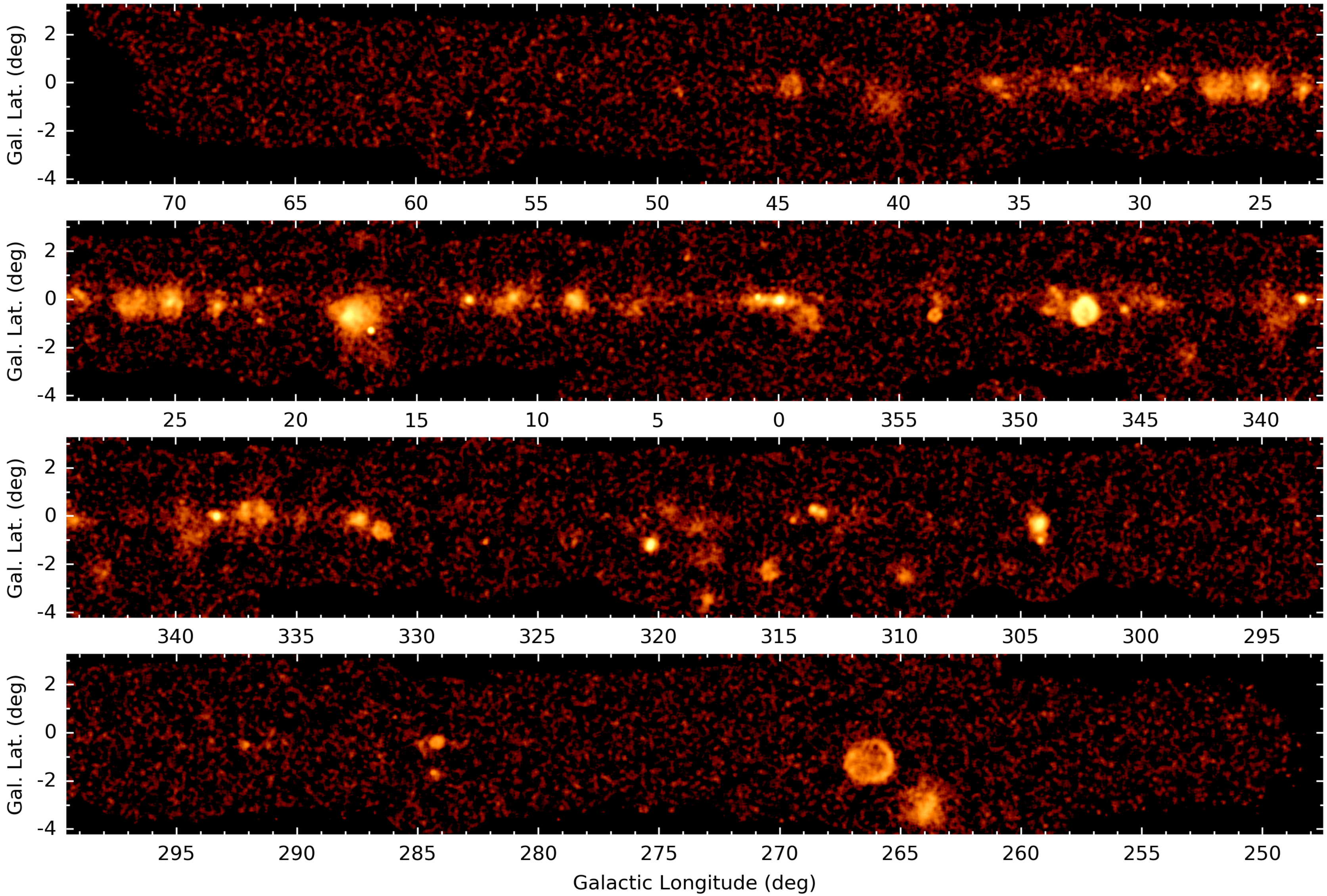
Namibia, 1800 m
4 x 12 m (>2004) + 1 x 28 m (> 2012)

H.E.S.S. first light
https://www.youtube.com/watch?v=OEvgrDgqLDw

H.E.S.S. Galactic plane survey

S. Ohm, ISVHECRI, 2018

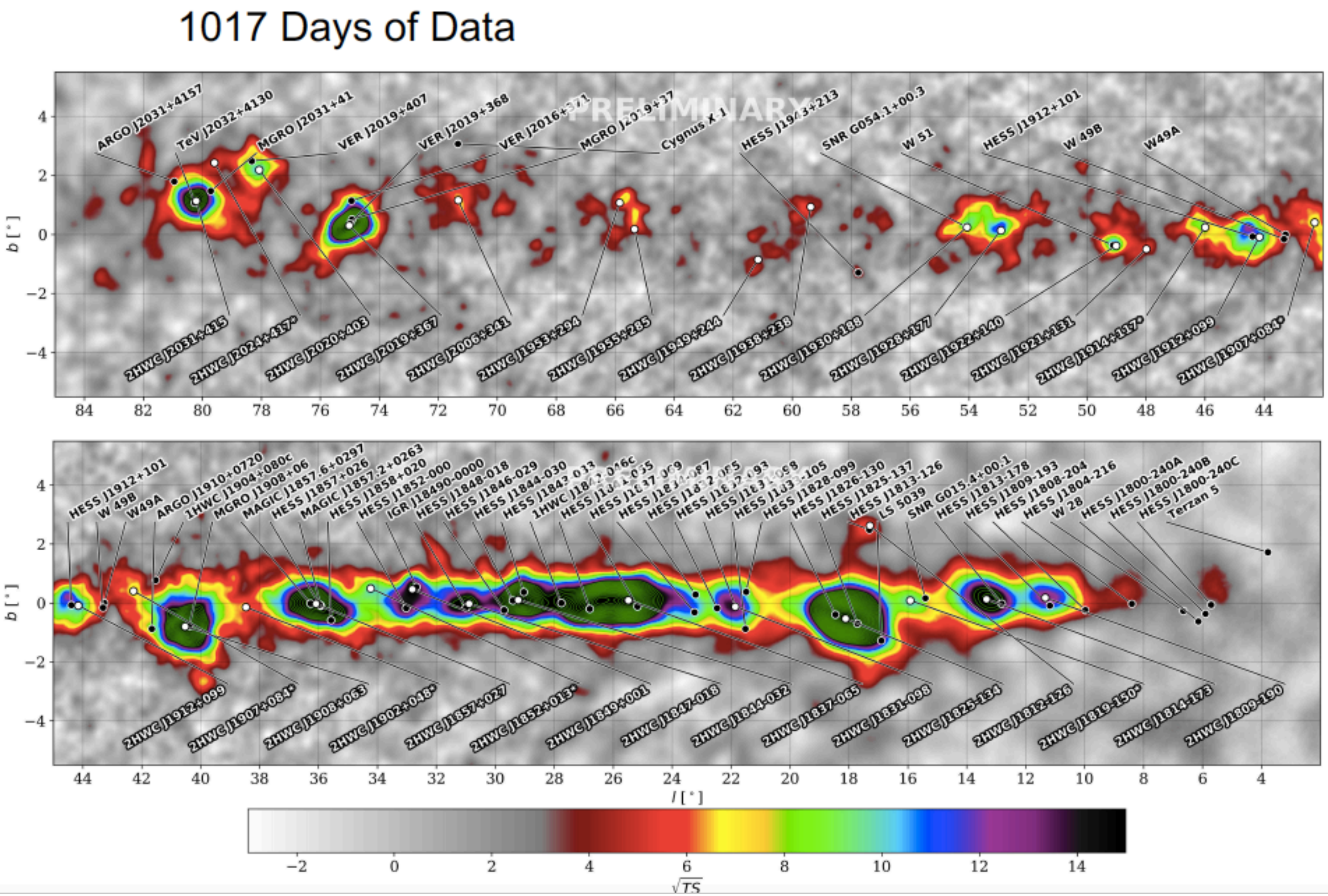
Browse our Galaxy in GeV to TeV gamma rays! Data from 2004-2013 (3000 h - ~3% of total time)
Source catalogue released in FITS format: https://www.mpi-hd.mpg.de/hfm/HESS/hgps/
Sensitivity better than 2% up to 0.5% at the Galactic plane center of Crab**
Sensitivity at ~tens of GeV and > 5° FoV matter.

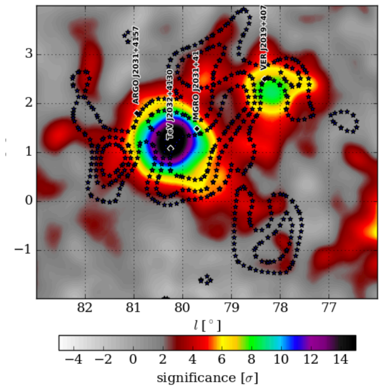


** spectral index 2.57+/-0.05 (stat) and a flux above 1 TeV of (2.1+/-0.1(stat)) 10^{-11}/cm^{2}s

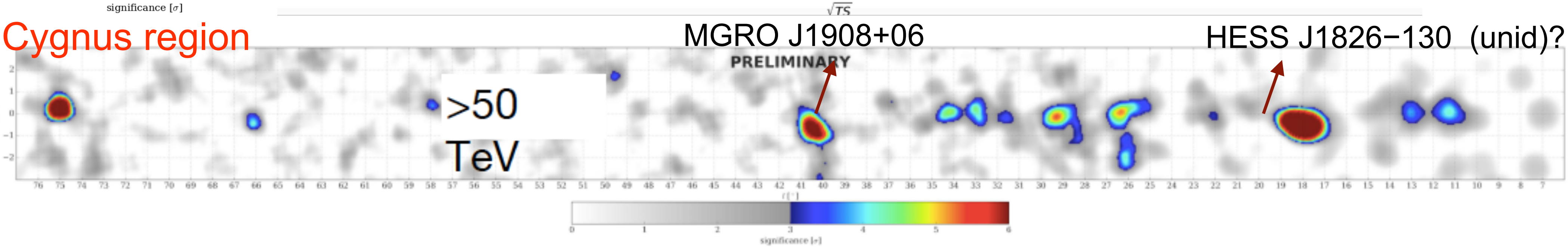
T. Montaruli | CRIS2018 | June 18, 2018

HAWC Survey of the galactic plane





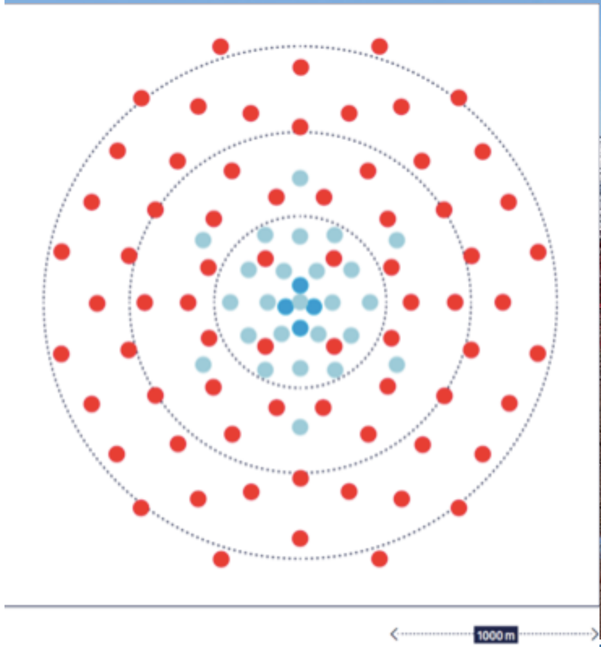
Cygnus region



First map with E>50 TeV! Looking for the PeVatrons producing the galactic CR knee

Southern array site: ESO Chile

4 large (LST), 25 medium(MST), 70 small-size telescopes (SSTs)



R. Zanin at this conference

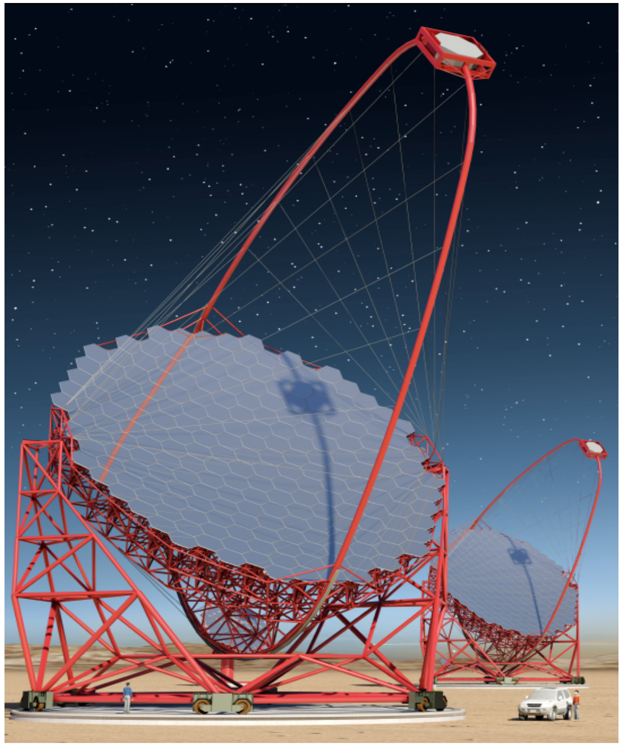
Negotiations with Chile being finalized

Northern array: Roque de los Muchachos Observatory in La Palma

4 Large telescopes (LST), 15 medium-size telescopes (MST)

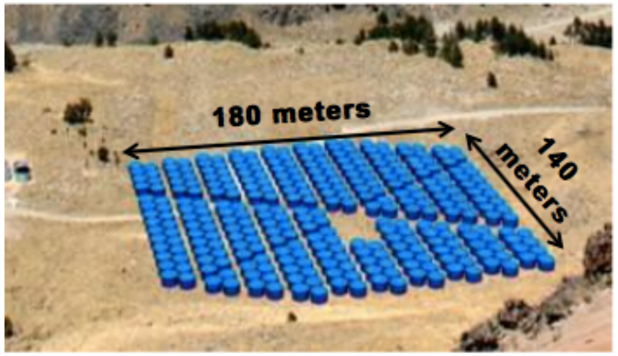
The first large size telescope at La Palma

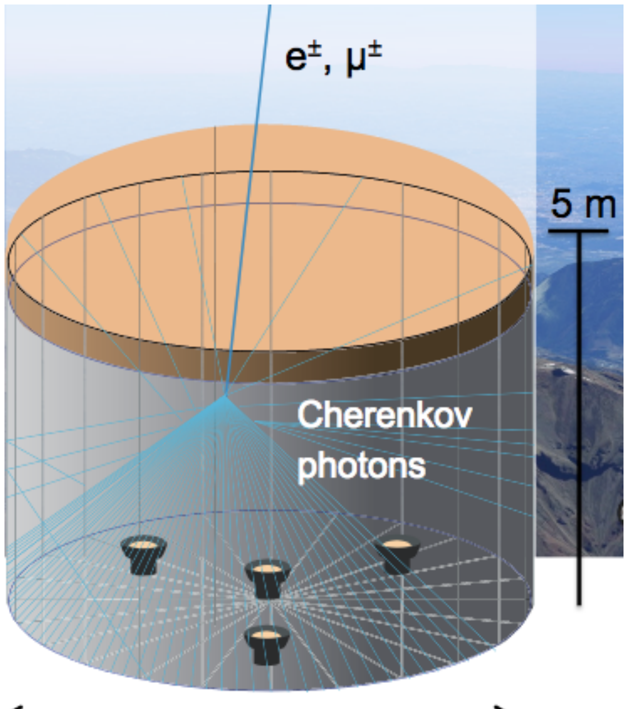
23 m diameter	4.5° field of view
389 m^2 dish area	0.1° pixels
28 m focal length	Camera ∅ over 2 m
1.5 m mirror facets	Carbon-fibre structure
Active mirror control	for 20 s positioning



Extensive air showers: HIGH Altitude Water Cherenkov gamma-ray observatory

300 water tanks (each 7.3m dia x 4.5 m deep of 2×10^5 litres with 4 upward PMTs at the bottom)
Inaugurated on March 2015
Preliminary data release: https://data.hawc-observatory.org/datasets.php
Daily coverage ½ sky : 2 sr ; >90%duty cycle





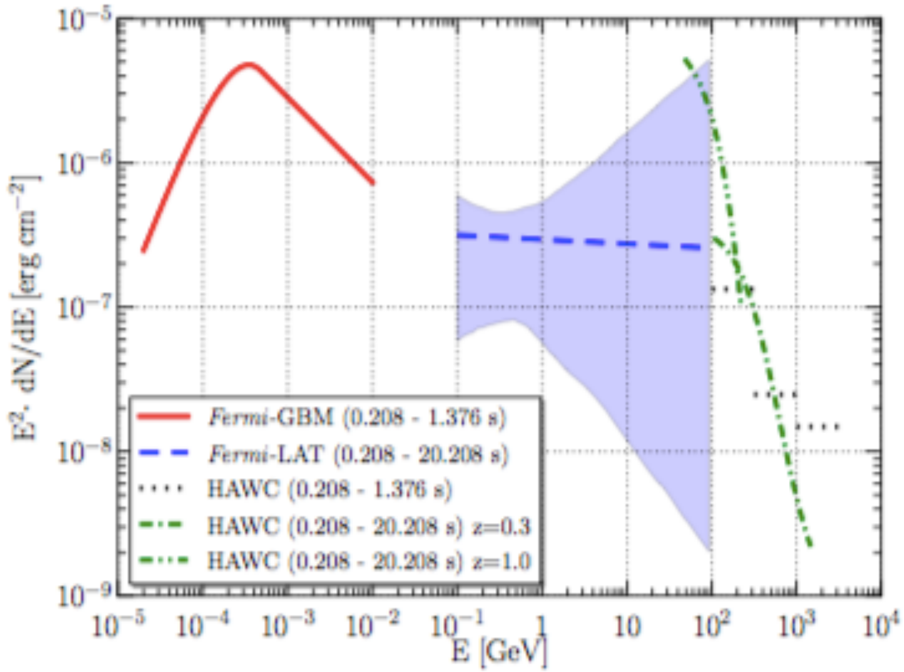
Highlights from the HAWC Observatory

Gamma-ray burst monitoring

HAWC scaler system counts in 10 ms

https://arxiv.org/pdf/1705.01551.pdf

First 18 months monitoring for GRBs. Fluence of GRB 170206A implied by HAWC upper limit is < Fermi-GBM fluence for z = 0.3 -1. Expected cut-off is constrained < 100 GeV

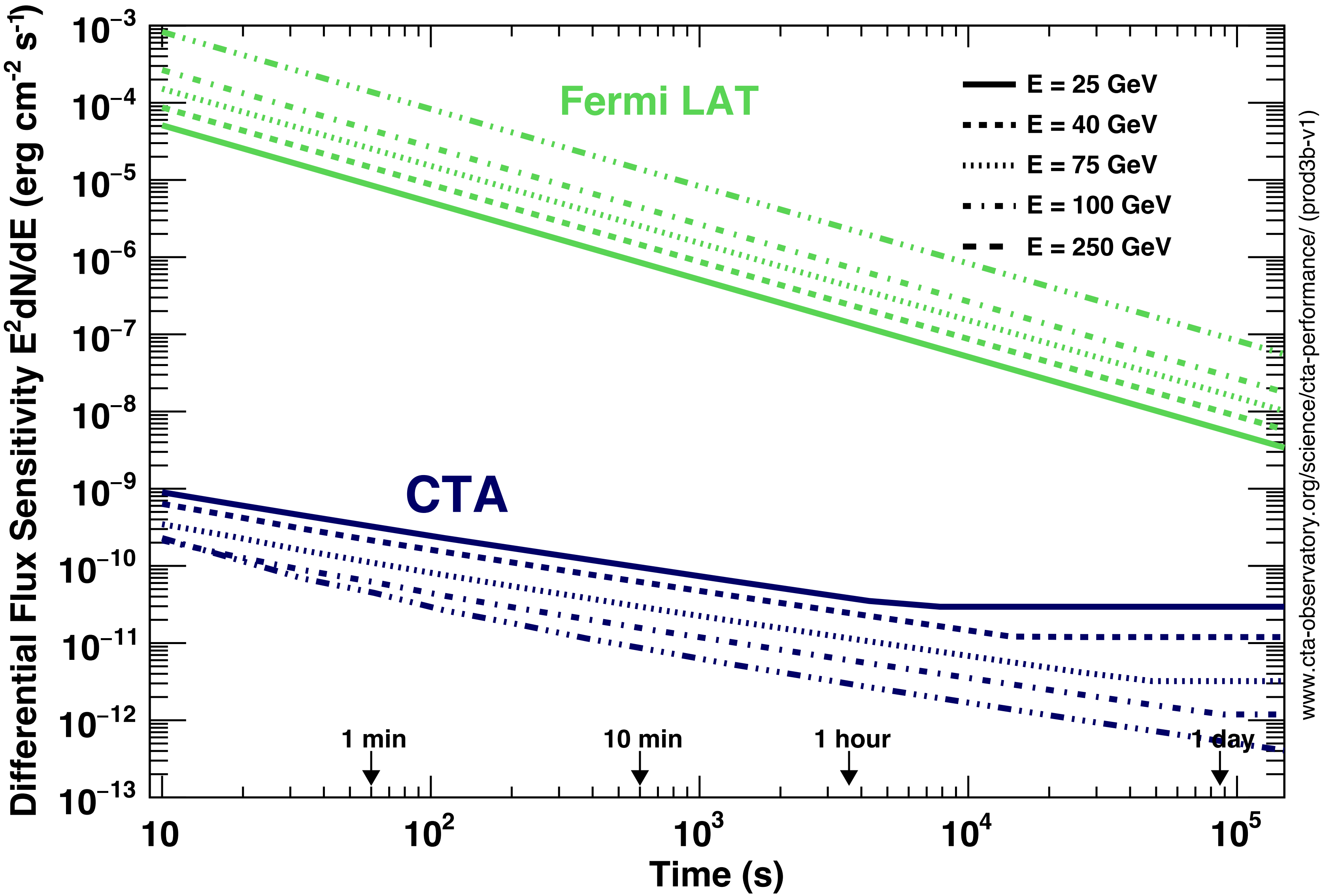


arXiv:1410.1536

For GRB 130427A at z = 0.34 and power law with index -1.66 to 95 GeV (128 GeV if corrected by redshift),HAWC would observe a gamma-ray peak energy at 300 GeV

IceCube constraints the role of GRB to 1% of contribution to its astrophysical flux (arXiv:1702.06868)

Sensitivity to transients from ground and space



The next future Science: surveys and targeted observations

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

CTA will run in the era of the synoptic observations of LSST and GW network.
An enormous amount of transient signals…

The high energy view of the TIME-DOMAIN ASTRONOMY will be very important


Springer Link

Living Reviews in Relativity
December 2016, 19:1 | Cite as

Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo

Authors | Authors and affiliations

B. P. Abbott, The LIGO Scientific Collaboration, Virgo Collaboration, R. Abbott, T. D. Abbott, M. R. Abernathy, F. Acernese, K. Ackley, C. Adams, T. Adams, P. Addesso, R. X. Adhikari, V. B. Adya, C. Affeldt, M. Agathos, show 930 more

Open Access | Review Article
First Online: 08 February 2016

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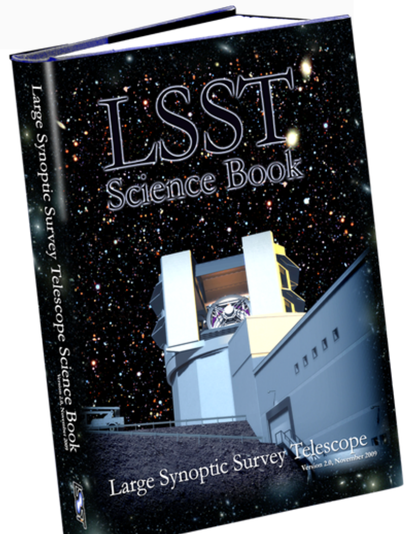
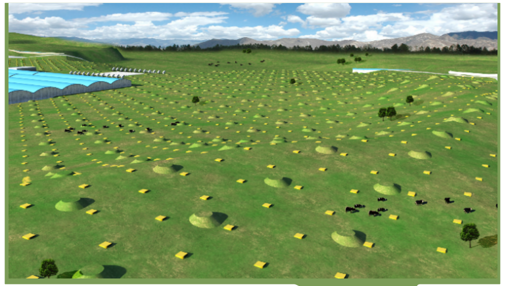
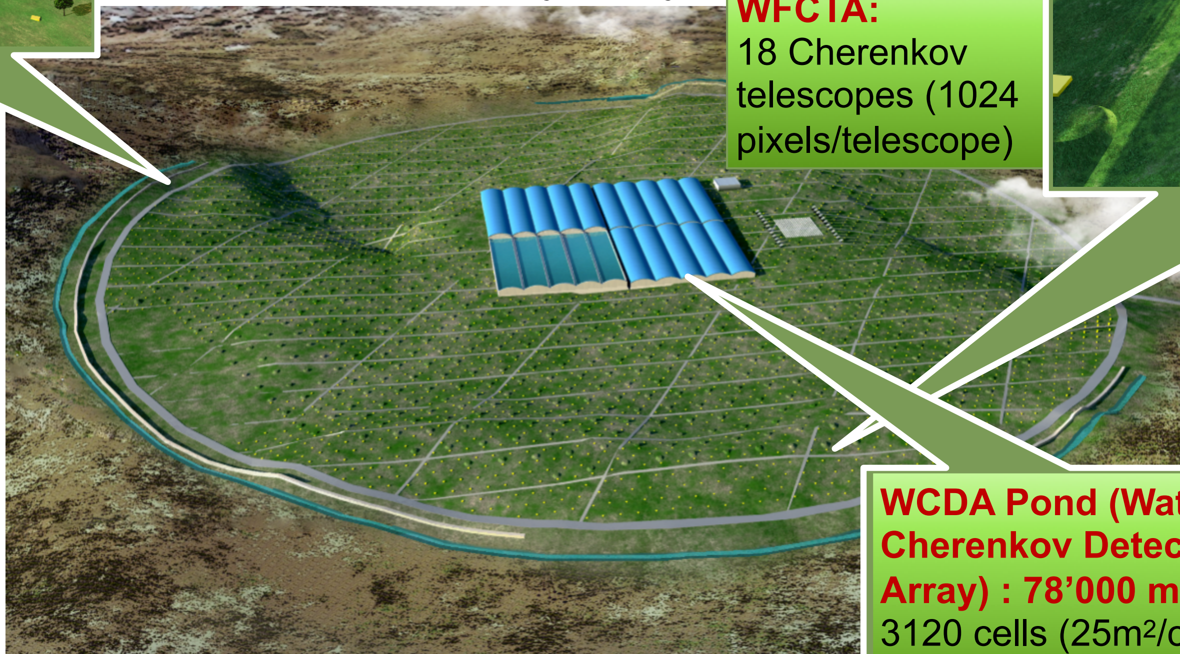
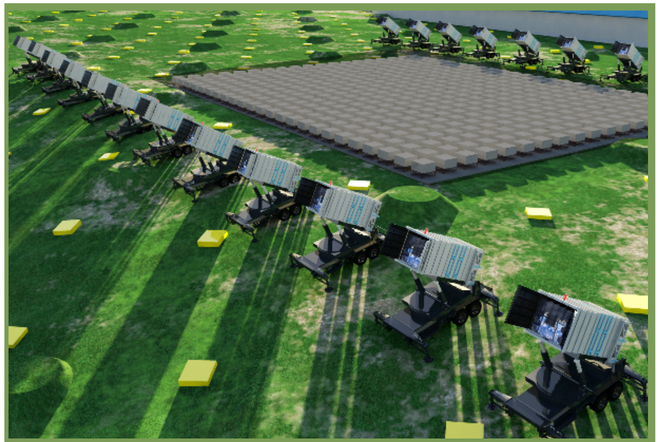


Large High Altitude Air Shower Observatory (LHAASO)

- Duty cycle potentially >90%
- Wide FoV:
  - 1/7 of the sky at any moment
  - 60% of the sky / day



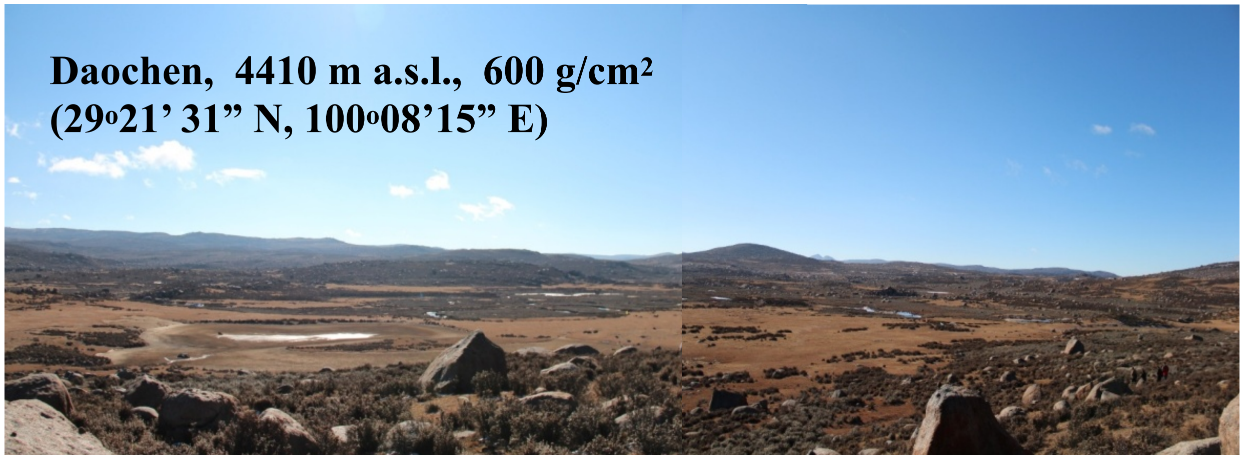




KM2A:
• 5195 Scintillators: 1 m^2, 15m spacing
• 1171 Muon Detectors: 36 m^2 water tanks, 30m spacing
•Completion in 2020

WFCTA:
18 Cherenkov telescopes (1024 pixels/telescope)

WCDA Pond (Water Cherenkov Detector Array) : 78’000 m^2
3120 cells (25m^2/cell)
<0.1° E>20 TeV

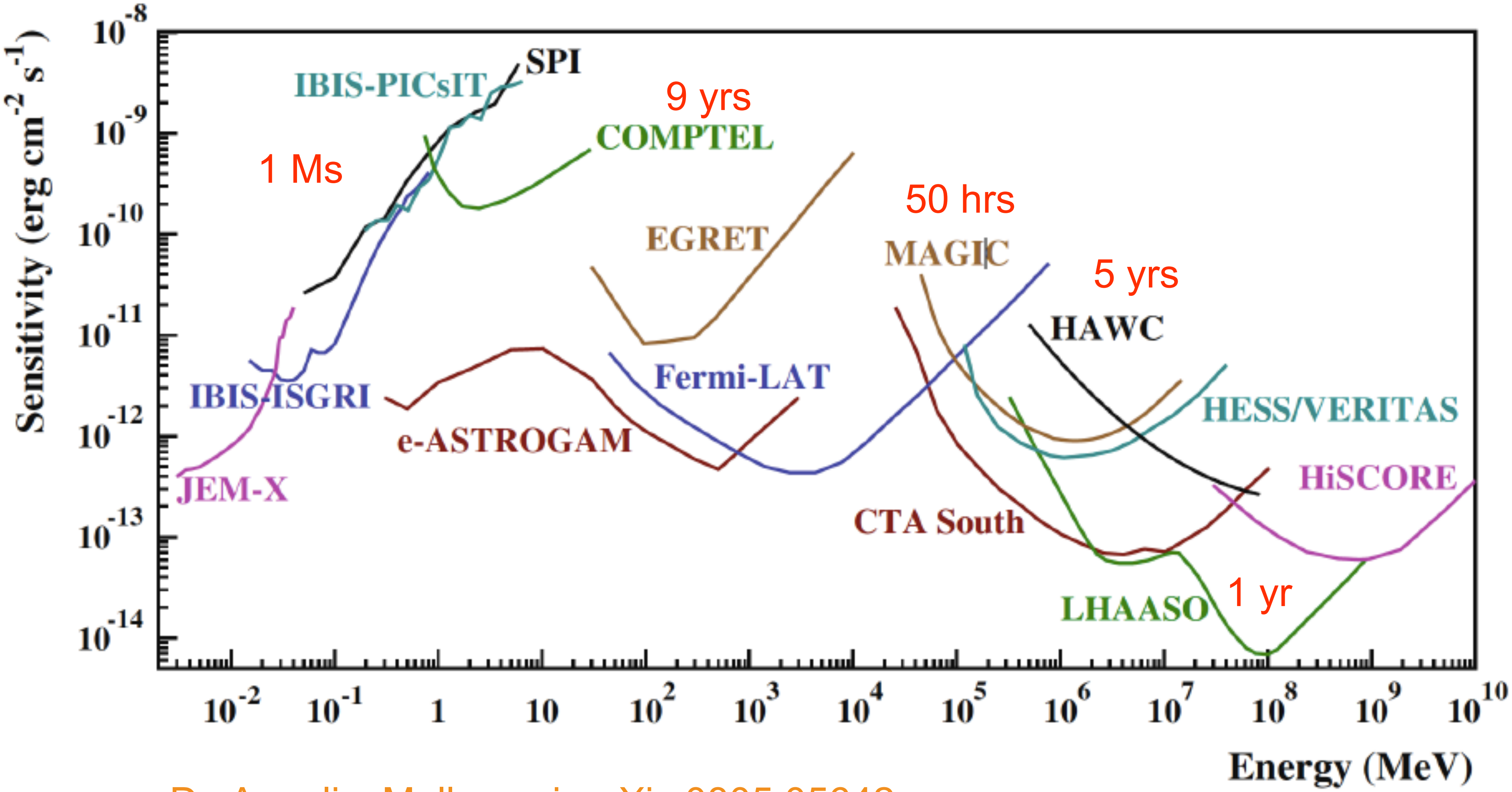


http://ihep.cas.cn/lhaaso/

LHAASO
高海拔宇宙线观测站

Status of construction

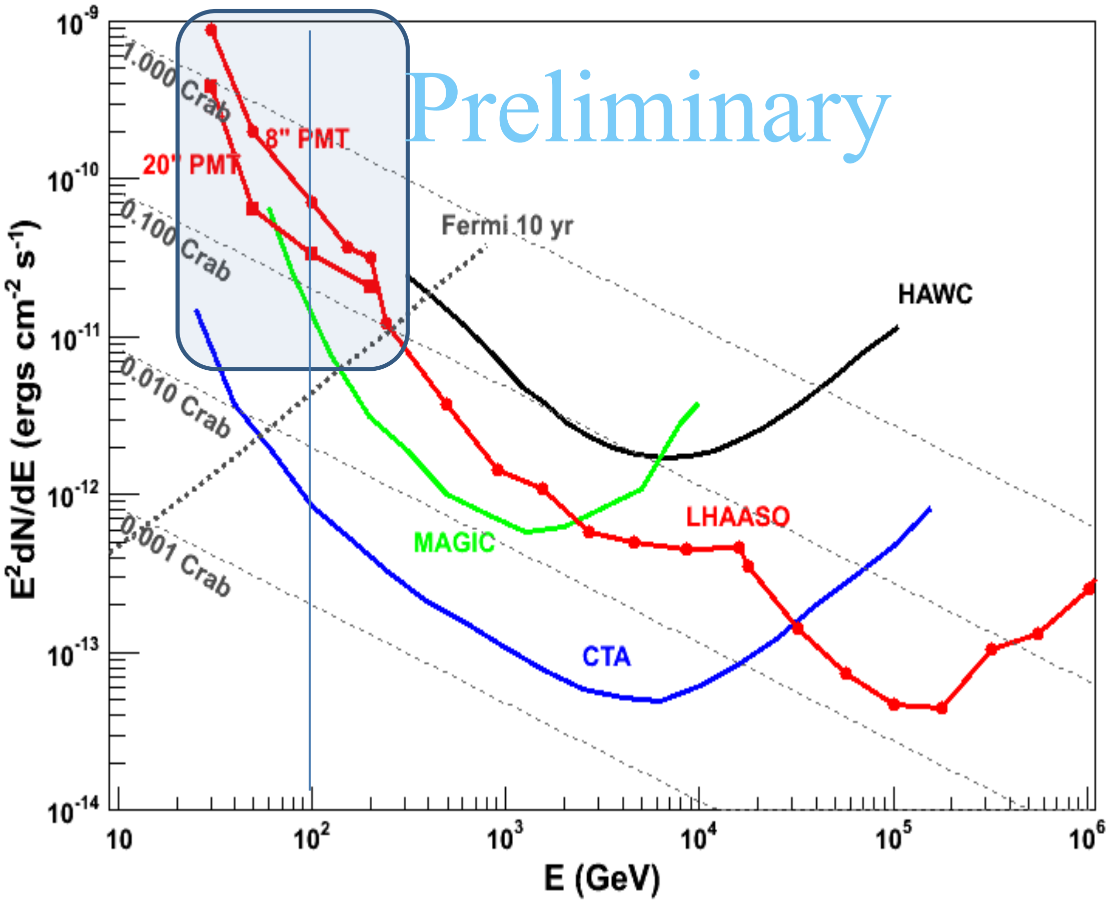
Differential sensitivity to point gamma ray sources

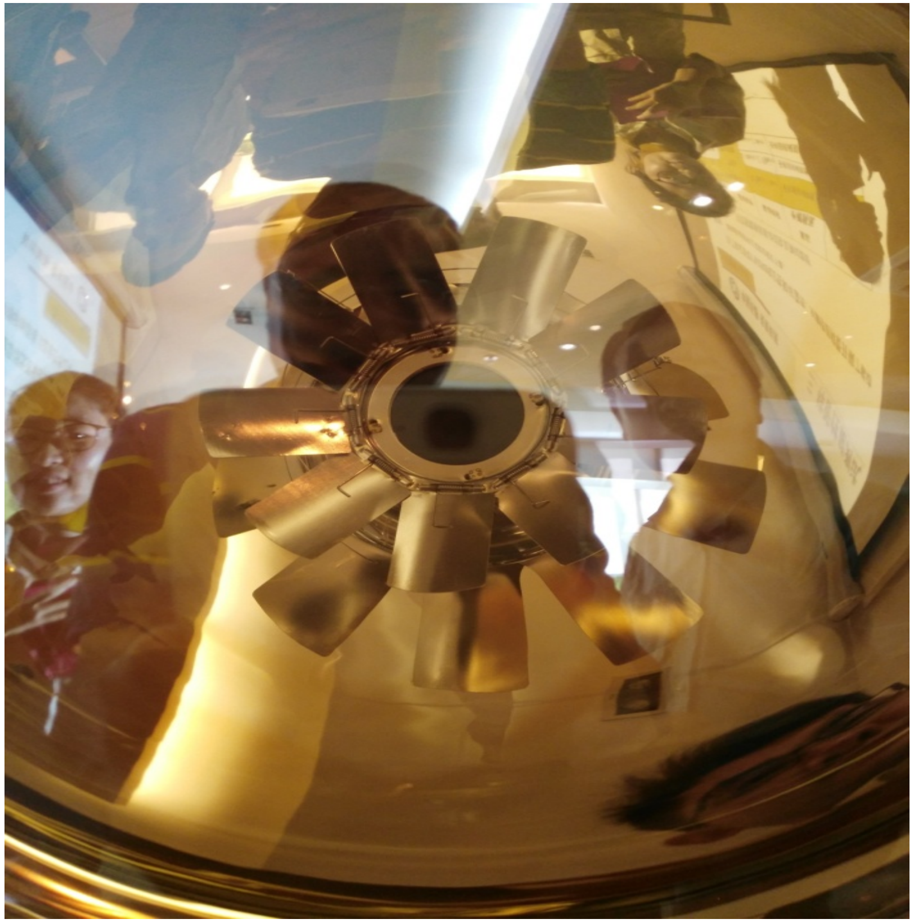


De Angelis, Mallamaci, arXiv:0805.05642

20" PMTs (same as for Juno) in #2 and #3 ponds of WCDA

https://doi.org/10.1016/j.nima.2015.10.106





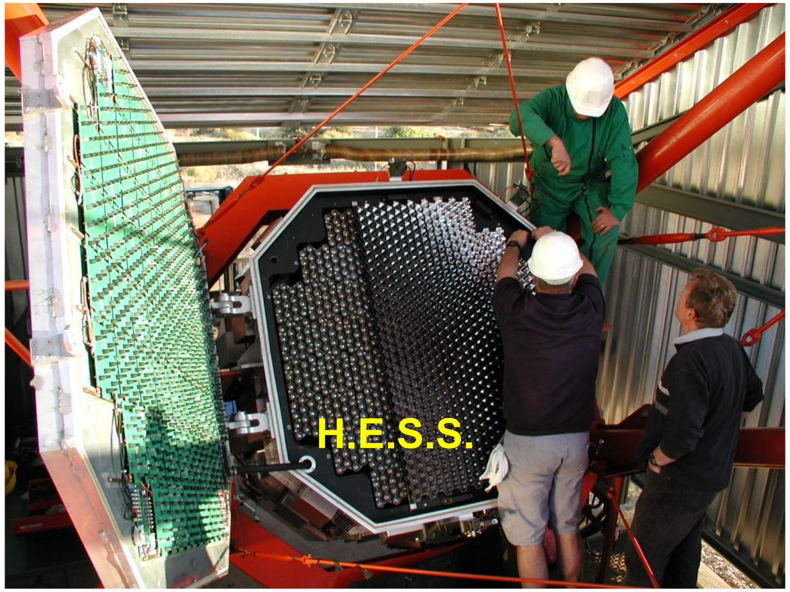
Courtesy of Zhen Can

The eyes on the sky: Current cameras

MAGIC-II

- FoV ~3.5°
- 1039 pixel super-bialkali PMTs, each of 0.1°
- 500 MHz FADC readout

- 3.5° FoV
- 500 pixel PMTs
- 500 MHz FADC readout



12 m telescope camera:

- FoV ~5°
- 960 pixels of PMTs, each of 0.16°

28 m camera

- FoV ~3.2°
- 2048 pixels of PMTs, each of 0.067°
- 8 kW, 2.8 tons

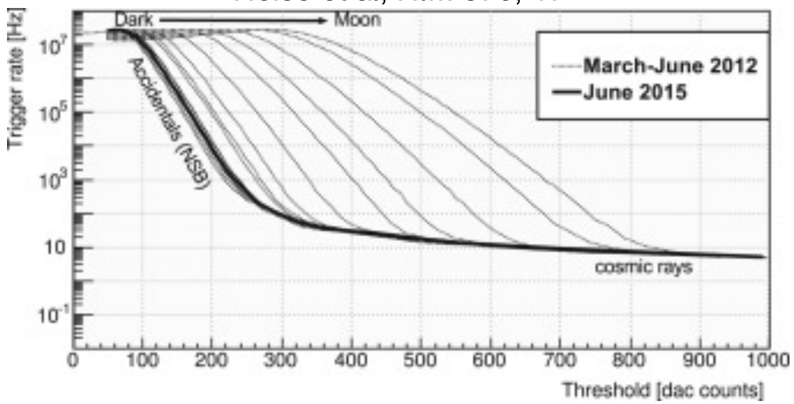
The eyes on the sky: new cameras

The duty cycle is a factor to improve. Filters on PMTs can mitigate the effect of Moonlight.
Eg. VERITAS typical per year: 850 h dark, 200 h moonlight, 250 h very bright moonlight ~14% duty cycle)
As well as the usage of SiPM without filters.

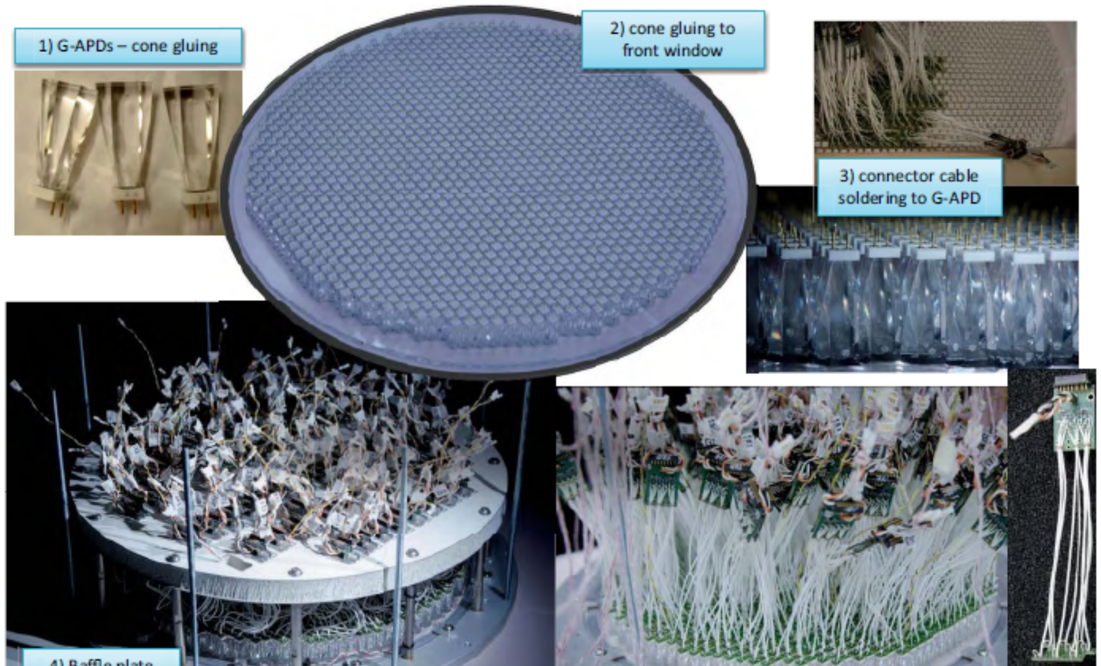
FACT: DC coupled preamplifying electronics:

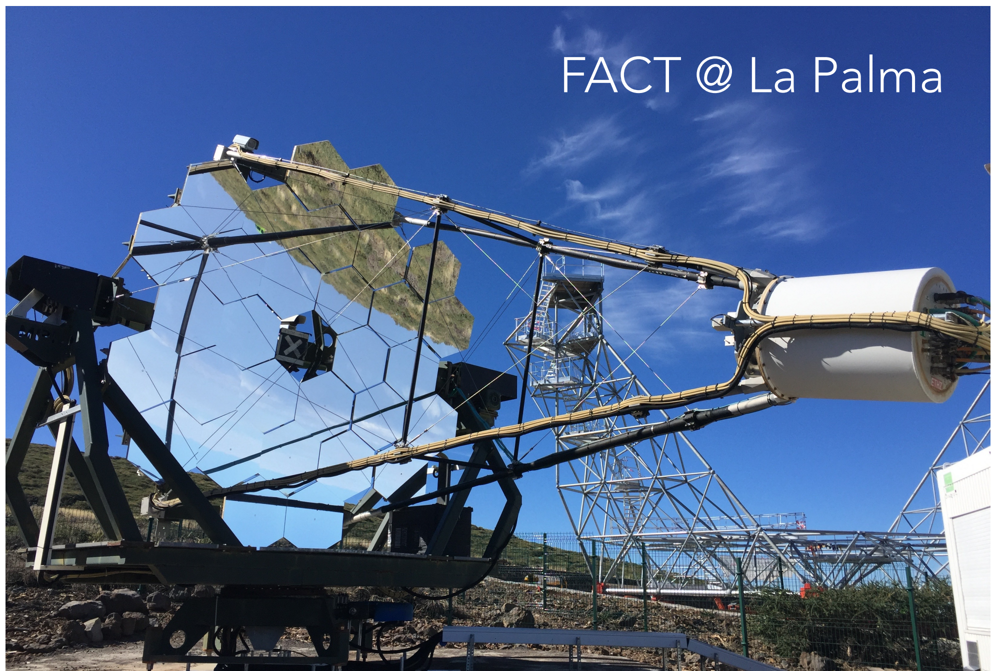
- Dark night current per pixel of ~5uA/pixel (~ 30 MHz); Highest current (Moon): 100 uA/pixel (~ 600 MHz).
- ~6200 h for < 6.5 uA and 4200h for > 6.5 uA = ~30% above MAGIC definition of dark night in 6 years (during which they cannot operate 4 nights/month): ~(12-29.5%/year duty cycle, effects not only related to SiPM)!
- But trigger threshold increases.

Neise et al, NIM 876, 17

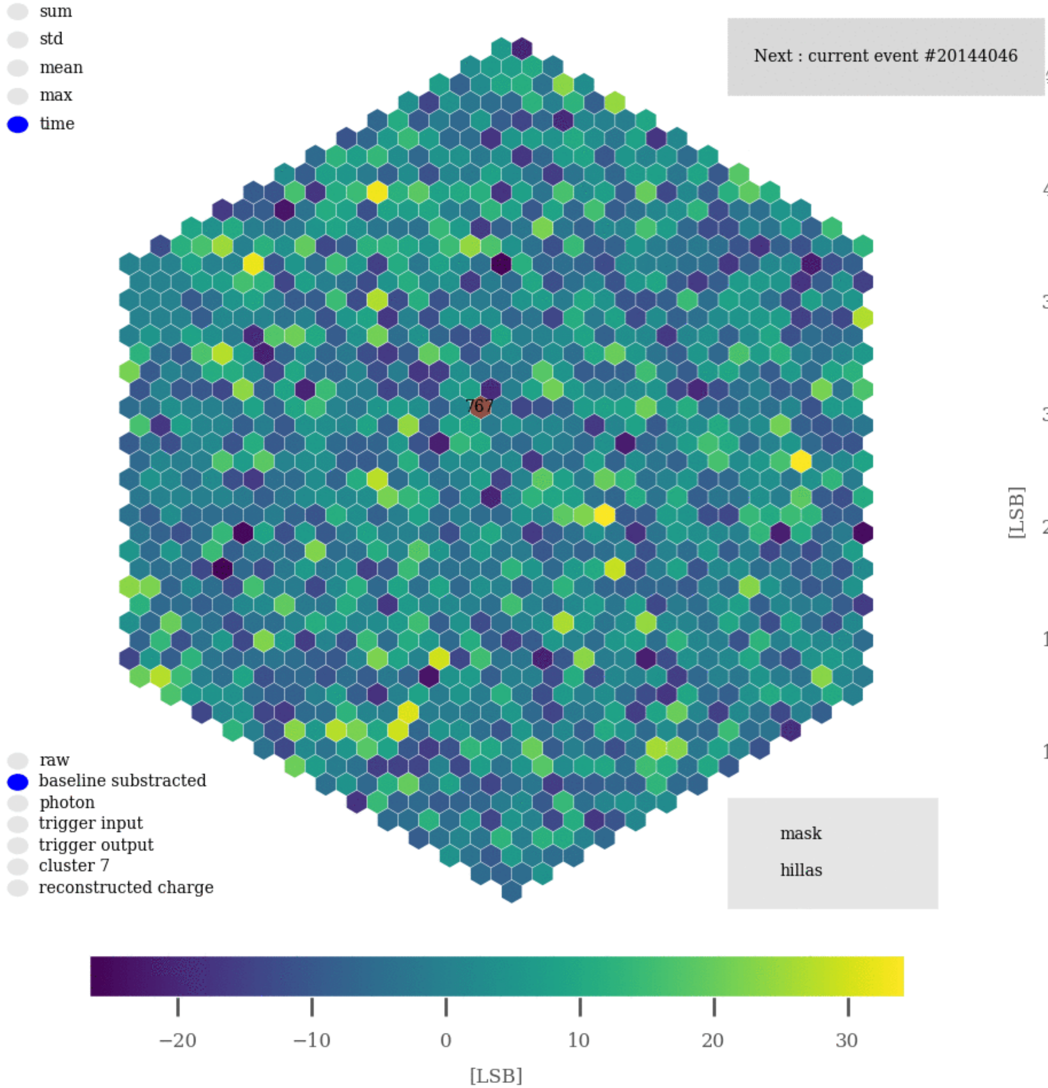


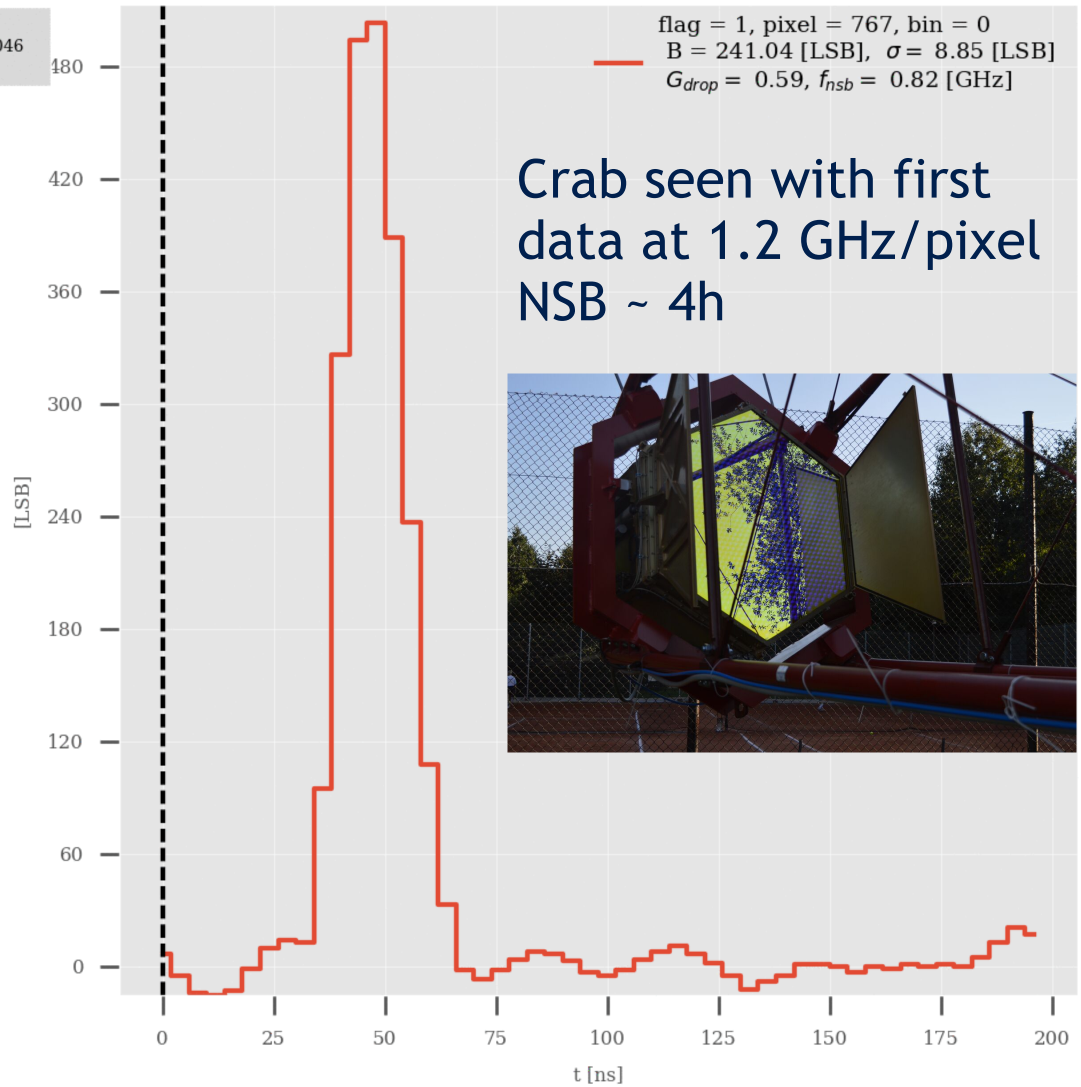
FACT : Great lessons on SIPM operation, dedicated monitoring of blazars, ToO and multi-messenger observations.





The importance of the full waveform



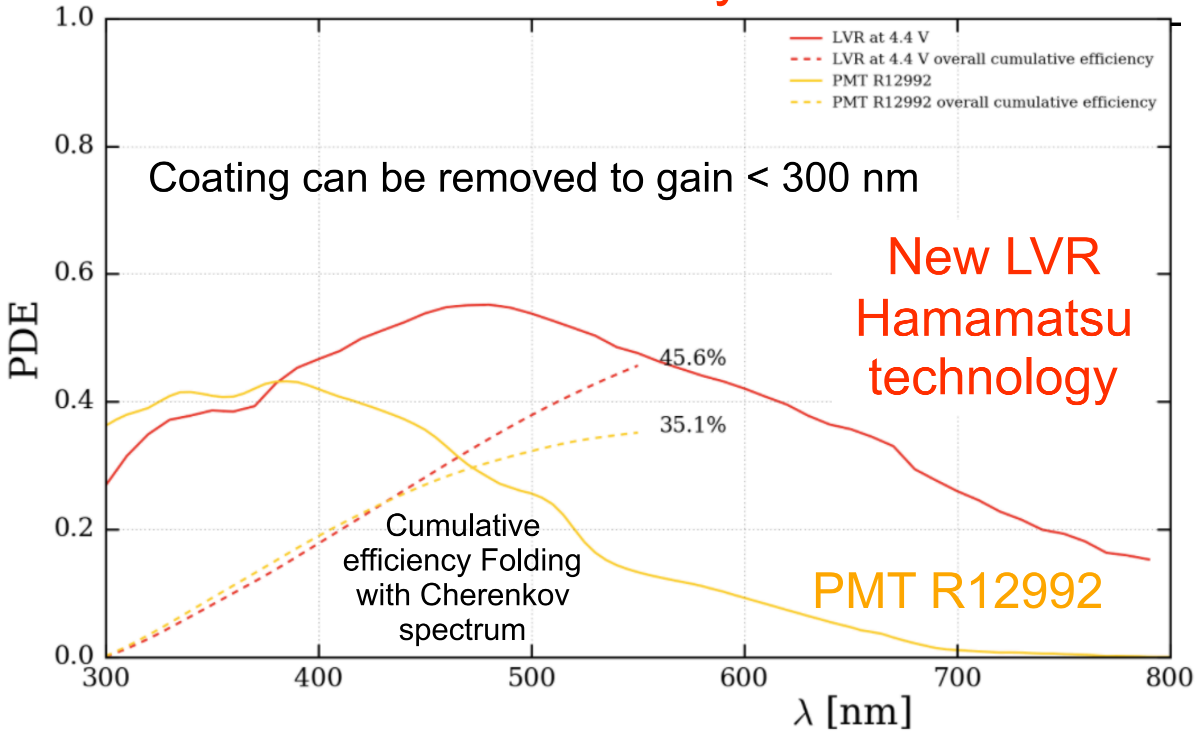


Crab seen with first data at 1.2 GHz/pixel NSB ~ 4h

- Enables more modern reconstructions accounting for time evolution of signal (leading edge of each photon pulse) since the full time development of the shower is measured
- Helps in establishing the noise from NSB, delayed x-talk, afterpulses with wavelet/FFT filtering

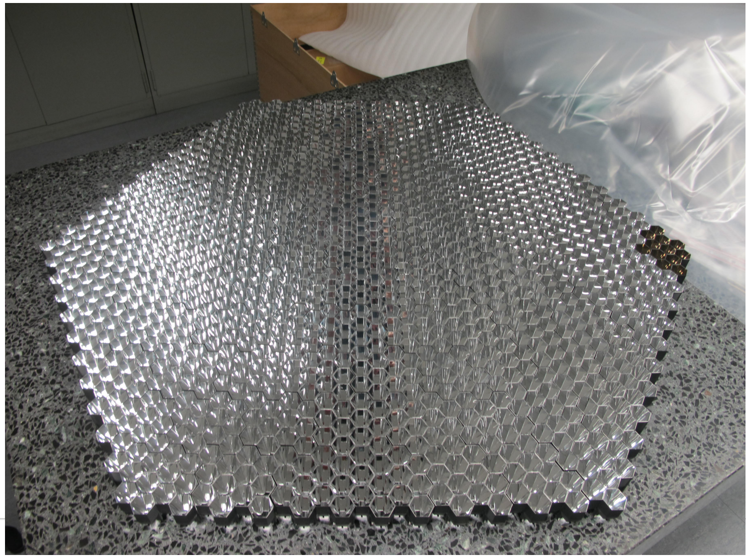
PMTs/SiPMs

Photodection efficiency

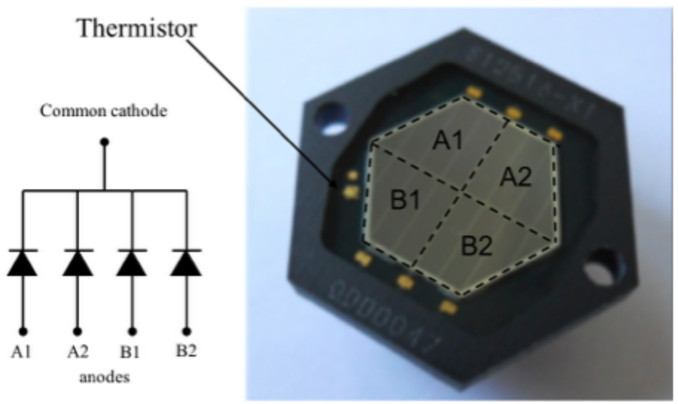


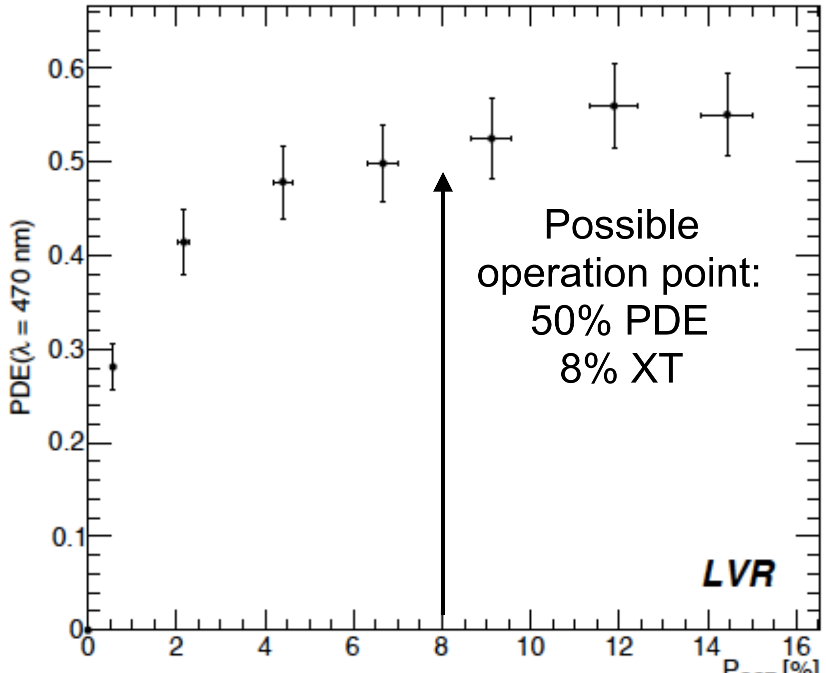
Then we need to convolve

- camera entrance window (now patched fused silica solution with filters cutting > 550 nm
  Lightguides: now fully industrial with injection molding



Monolithic Hexagonal 1 cm² side Hamamatsu S10943-2832(X): 55 € for > 5000 units



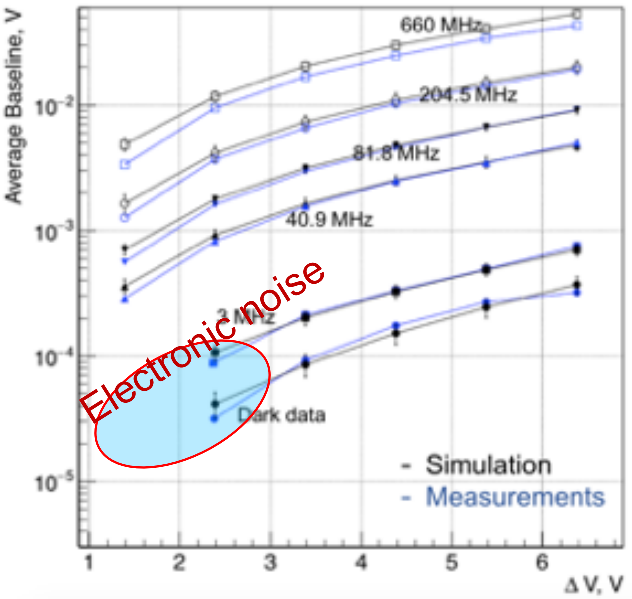


SiPMs under indoor light

A. Nagai

R_{bias} causes a voltage drop in the presence of current in the pixel
Active Loop to correct T-V_{op}-Gain
Cooling of photo sensing plane

The behaviour of PDE, DCR, XT, can be predicted vs NSB reliably



Do we need R_{bias}?

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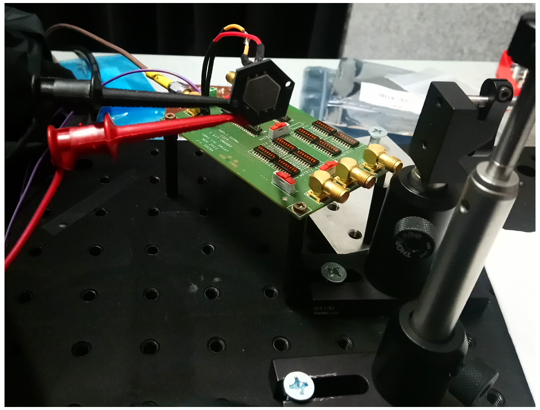
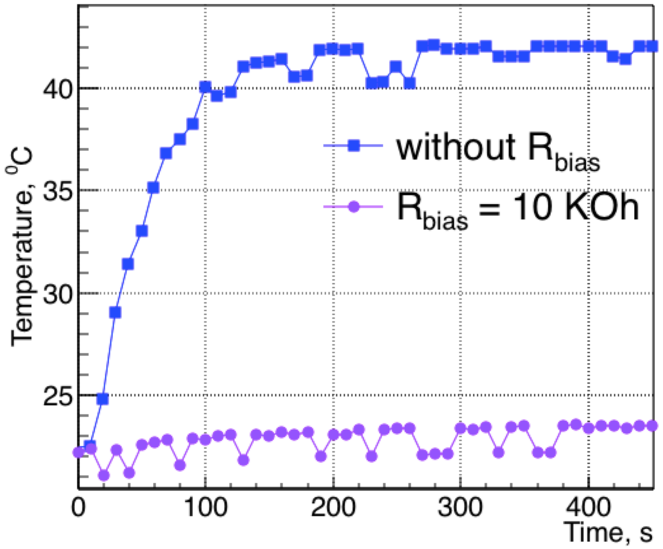
FACULTÉ DES SCIENCES

SiPM under indoor light:





SENSE

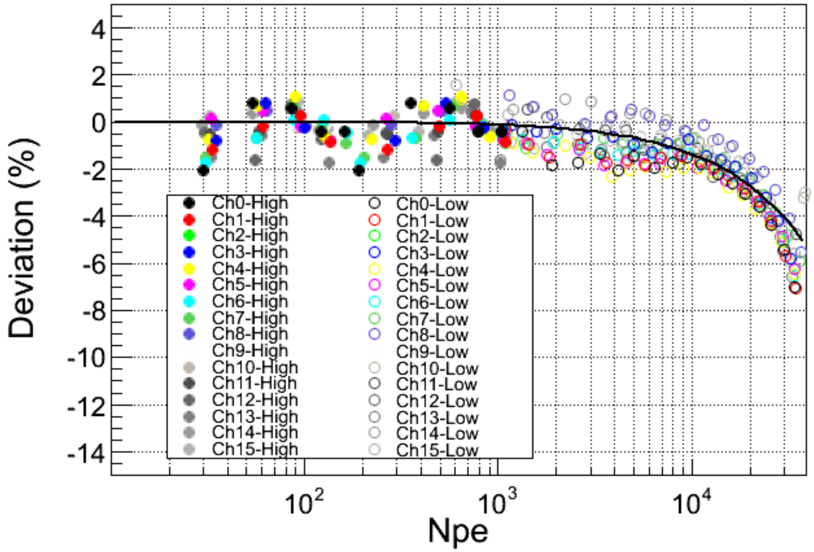
Without R_{bias} => self heating ⇒ T↗ => ΔV↘

To be presented at SENSE TechForum
https://indico.cern.ch/event/688729/timetable/#20180621.detailed

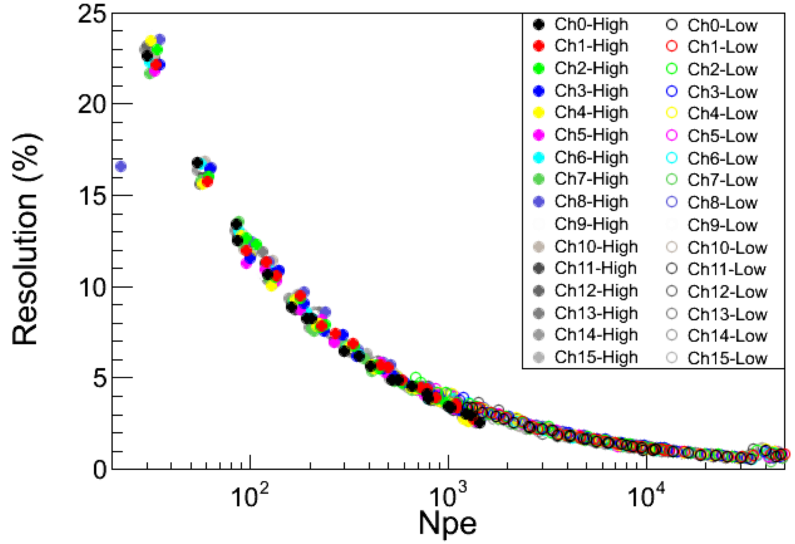
Value of R_{bias} should be chosen from expected light intensity and operational voltage but can be much smaller than what currently recommended in manuals

LHAASO SiPM cameras

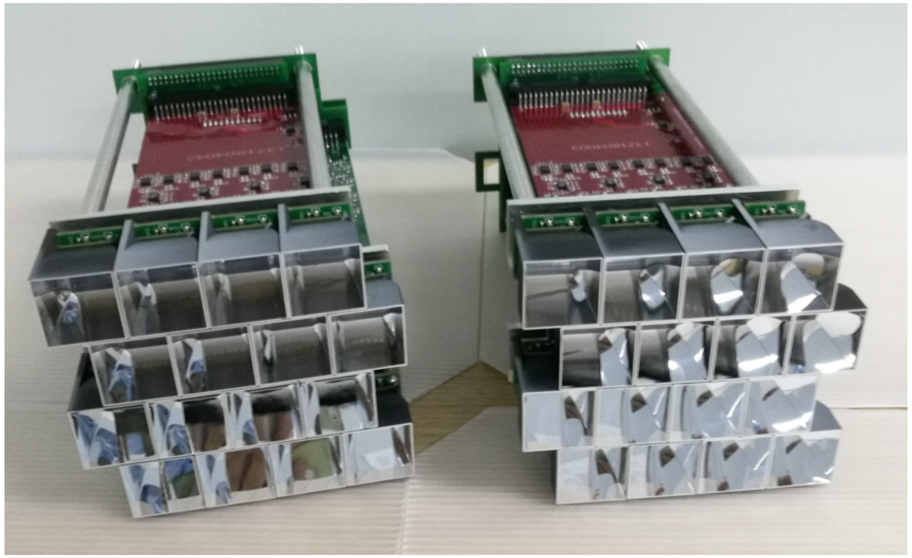
Thanks to Zhen Can and S. Zhang



Linearity correction possible



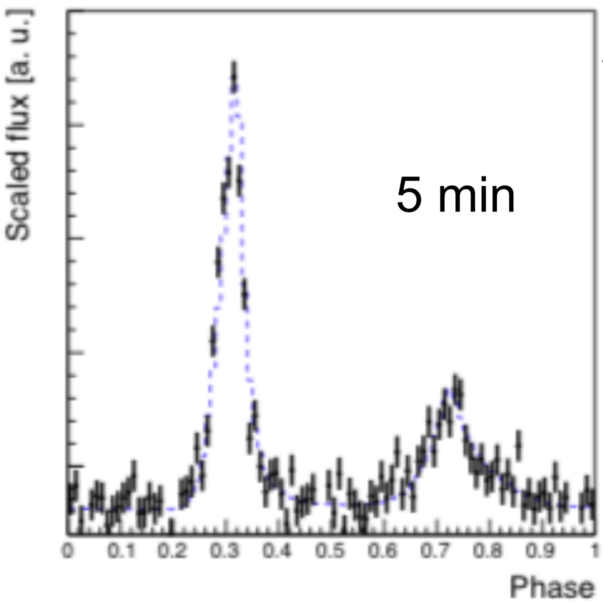
dynamic range suitable for HE CRs



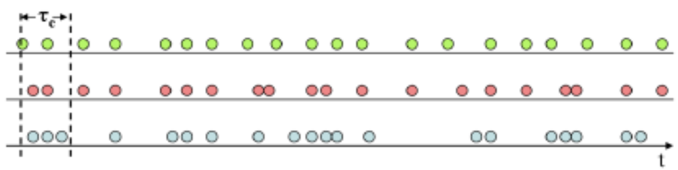
1st camera completed
Hamamatsu/FbK
square sensors
Square coated light
guides
(UniGE)

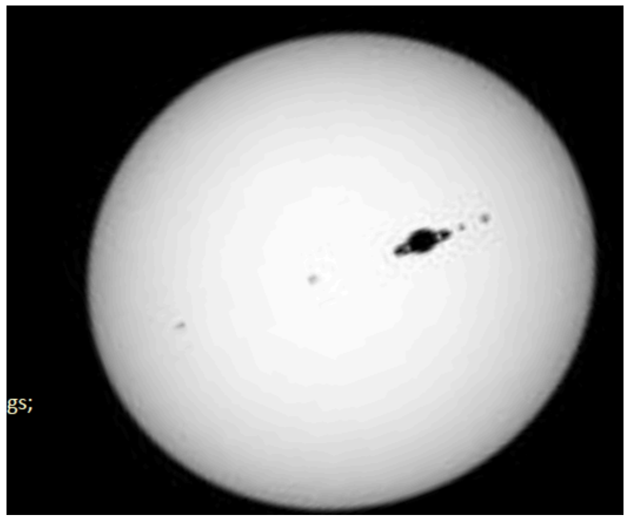
An important potential : fast photometry and intensity interferometry

MAGIC-II used the central pixel of the camera for optical photometry 1-10 ms level (Fast radio bursts, pulsars, blazars).
Crab Pulsar: dispersion measured with off-source data and using the phaseogram of the Crab Pulsar, this pixel is able to detect orphan millisecond optical flashes as faint as $m_U \sim 13.4$.
Important background from meteorites.
Cherenkov cameras can fully digitise at few ns level the full WF per pixel. This can provide the time of each photon to the level of ~500 ps. Beating the noise cal lead to intensity interferometry (Hanbury Brown 1964-1991) with large arrays such as CTA (Dravins et al, 2013) and achieve 10^{-4} arcsec. Tests ongoing at VERITAS (Nolan and Kieda, ICRC 2017)



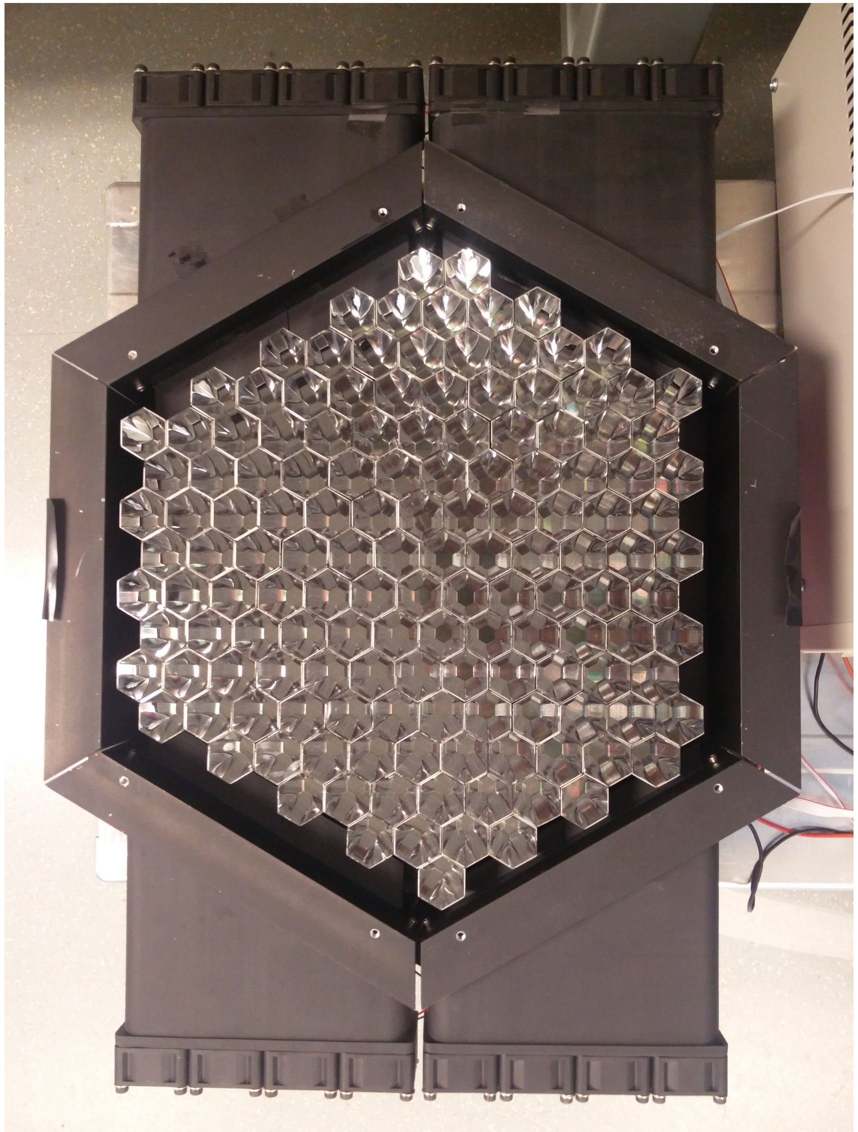
2nd order coherence of light from temporal correlations of arrival times Photon bunching (Glauber, Nobel prize 2005)



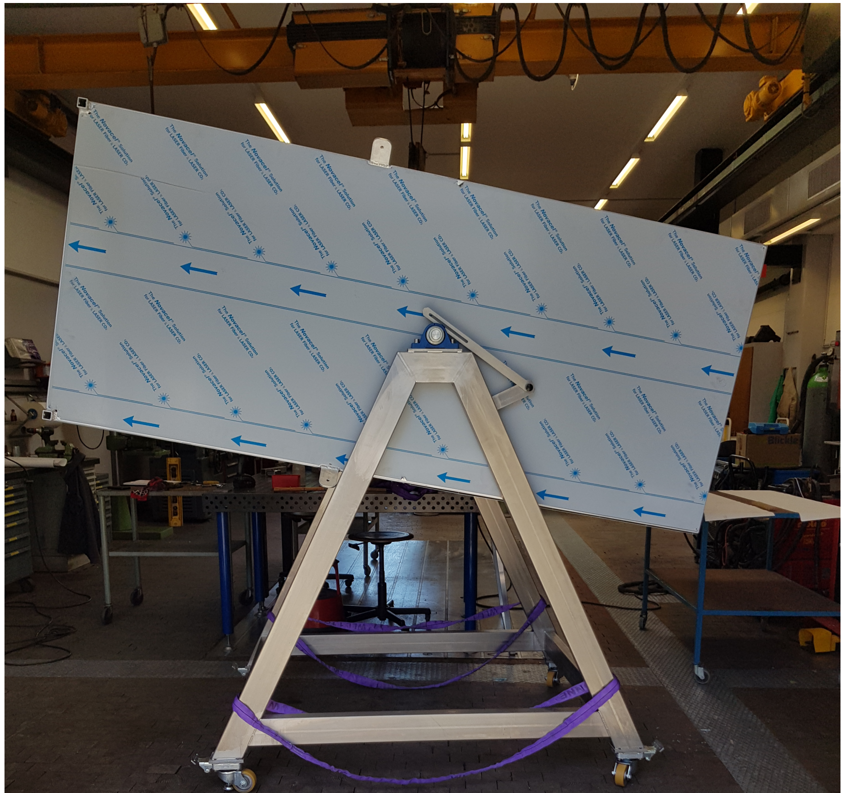


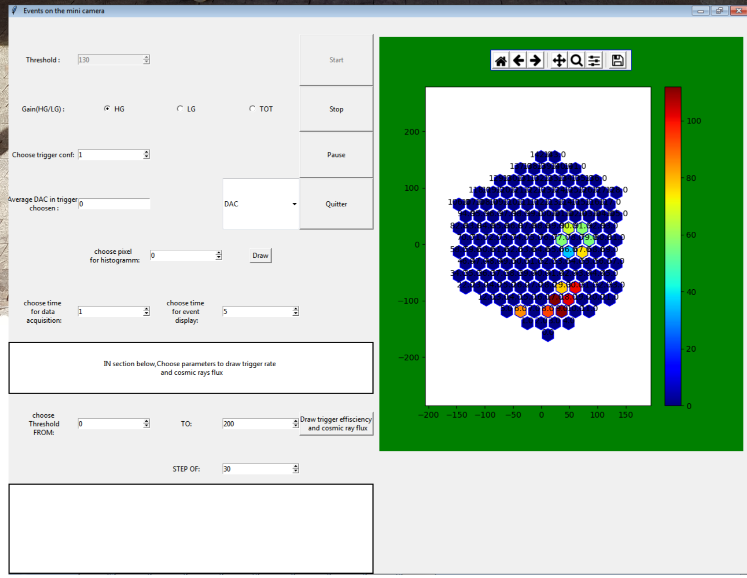
T. Hassan et al. for MAGIC, arxiv:1708.07698
Similar attempts in VERITAS and H.E.S.S. (arXiv:0810.3155)

A portable gamma-astronomy SiPM camera for outreach



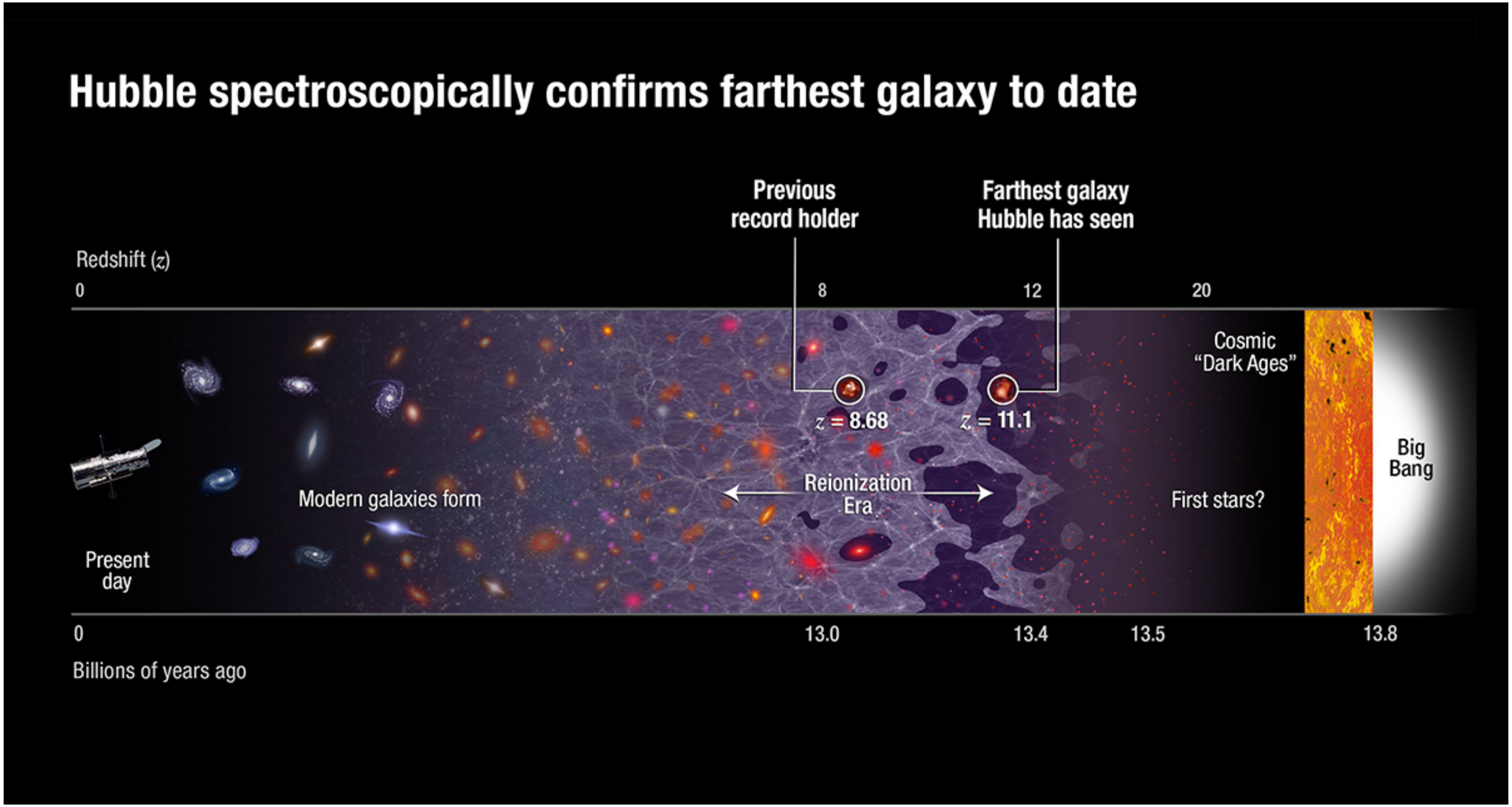
Combined to a UV sensitive lens of 1m dia. And 2m focal length.





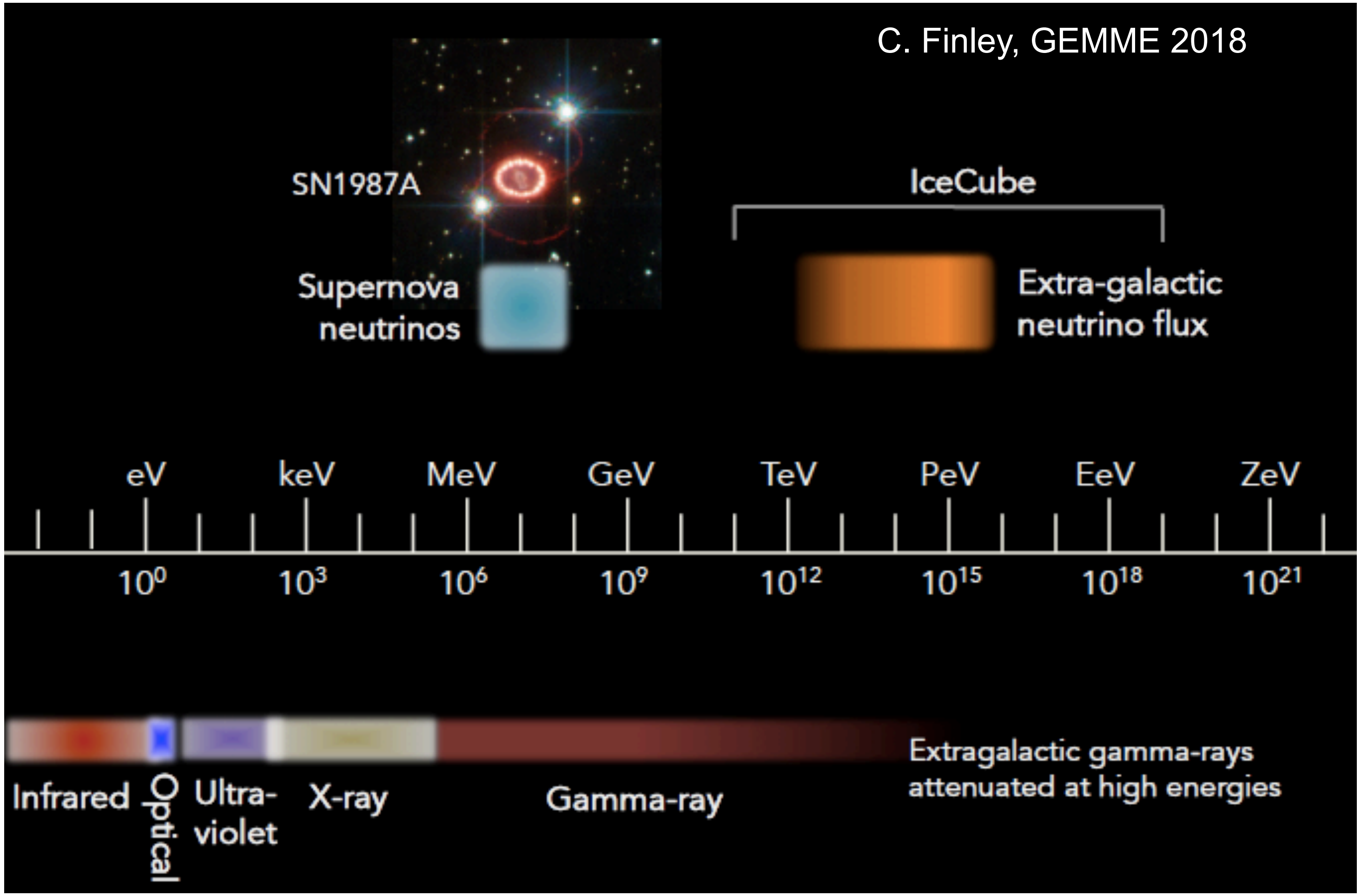
Theodore Ekoume & Matthieu Heller & UniGE Ateliers

The census of galaxies by Hubble



https://www.nasa.gov/feature/goddard/2016/hubble-team-breaks-cosmic-distance-record

The high-energy frontier

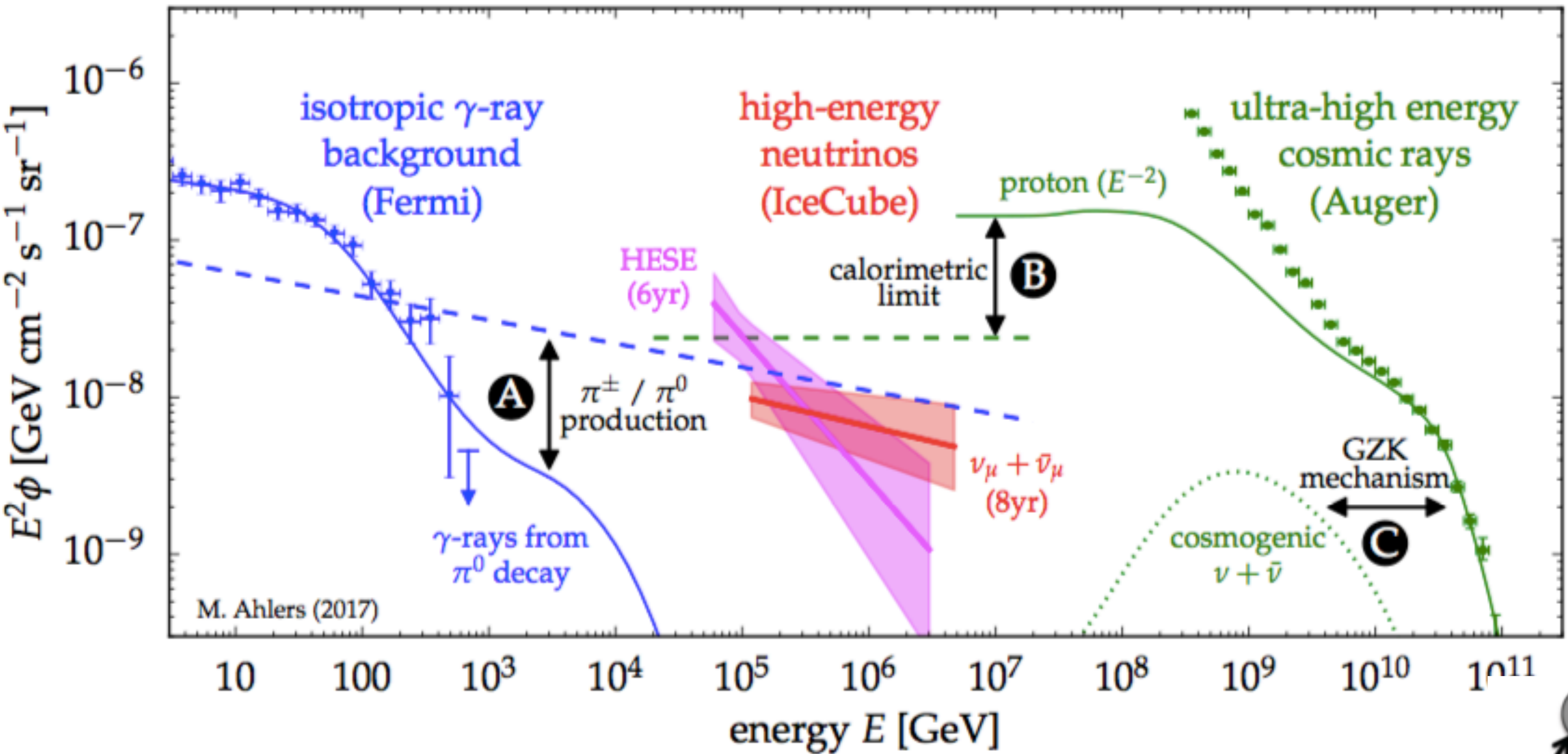


Knapp's talk
Yoshida's talk

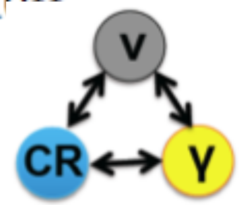
- High-energy Multi-Messenger Astrophysics is one of the MOST FASCINATING fields
- It allows to understand relevant aspects of the universe and to test the Laws of Physics in extreme conditions not reproducible in the lab
- Gamma-rays are currently the messenger providing most precise information on the >100 GeV sky
- Cosmic rays are observed up to energies (>>100 TeV) when gamma-rays begin to be absorbed on the way to us
- neutrinos can be used since they reach us from well beyond z = 2
- The horizon of new messengers, which include gravitational waves, is still limited in the high energy range

Energy balance in diffuse fluxes

Fermi diffuse isotropic gamma background (IGRB) constrains cosmic neutrino diffuse emission (Murase, Ahlers & Lacki'13; Chang & Wang'14)



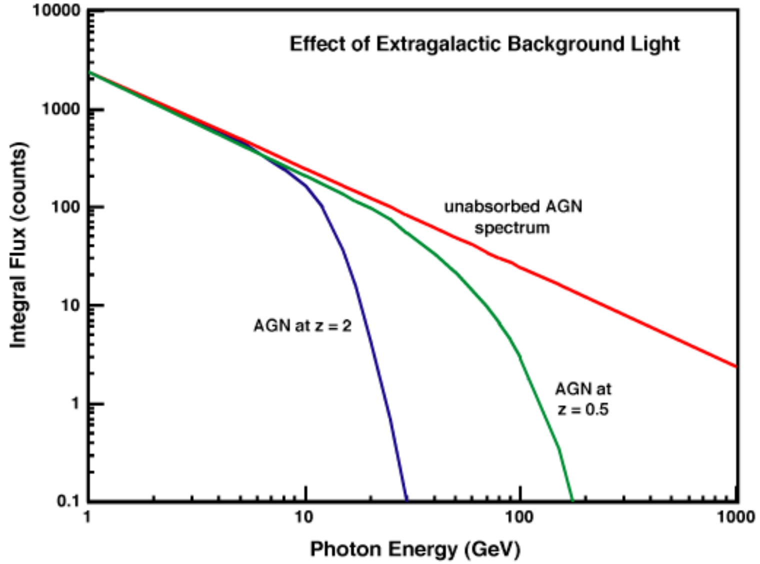
https://arxiv.org/pdf/1805.11112.pdf



Gamma-ray exploration by Fermi: up to z ~ 2.5

$\gamma_{VHE}\,\gamma_{EBL} \rightarrow e^{+} + e^{-}$

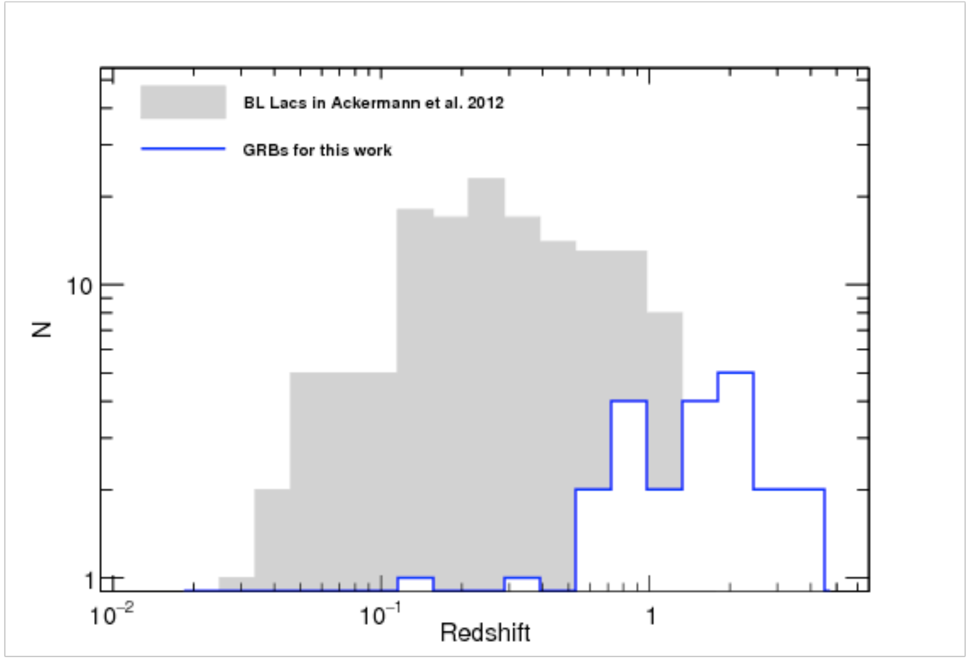
$E\gamma_{VHE} \cdot E\gamma_{EBL} > (m_e c^2)^2$

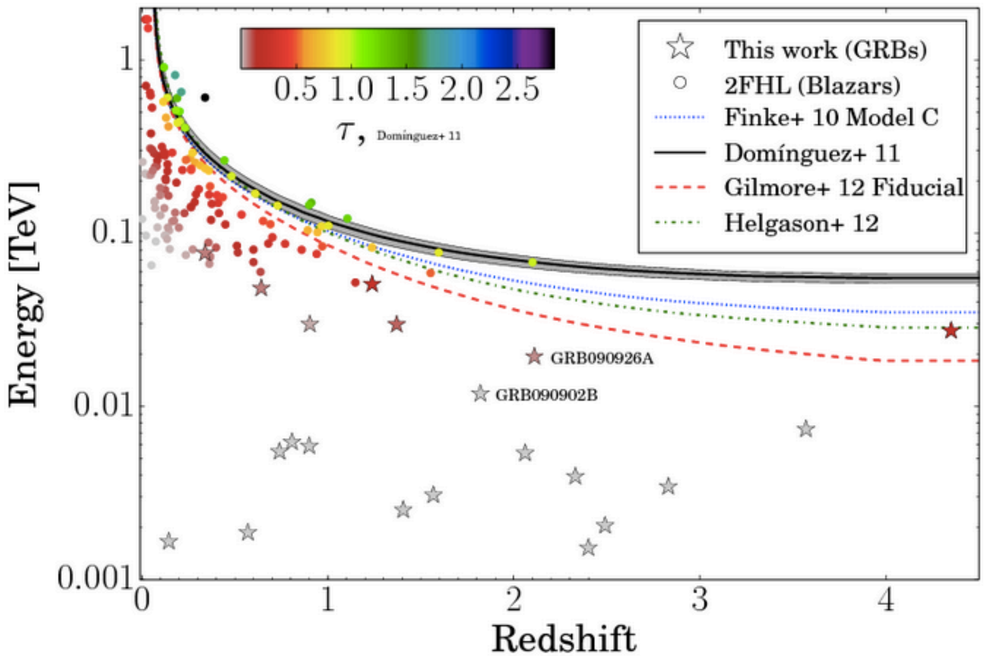


$\Phi_{obs}(E_\gamma, z) = e^{-\tau(E\gamma, z)} \times \Phi_{int}(E_\gamma).$

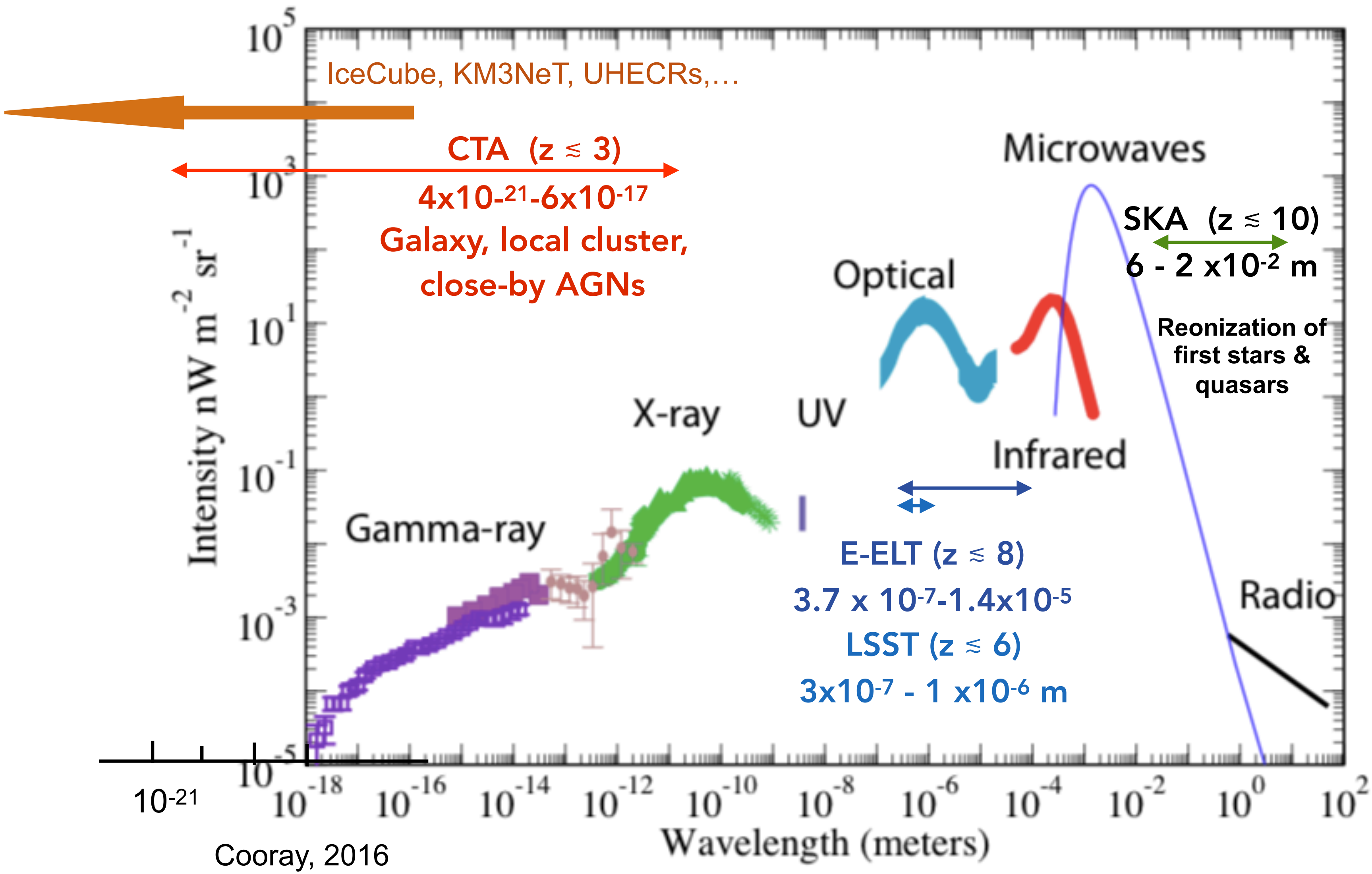
22 Fermi GRBs 65-550 GeV

~80% of the 3rd Fermi-LAT Catalog of Hard Sources are blazars. Highest redshifts z~4.31





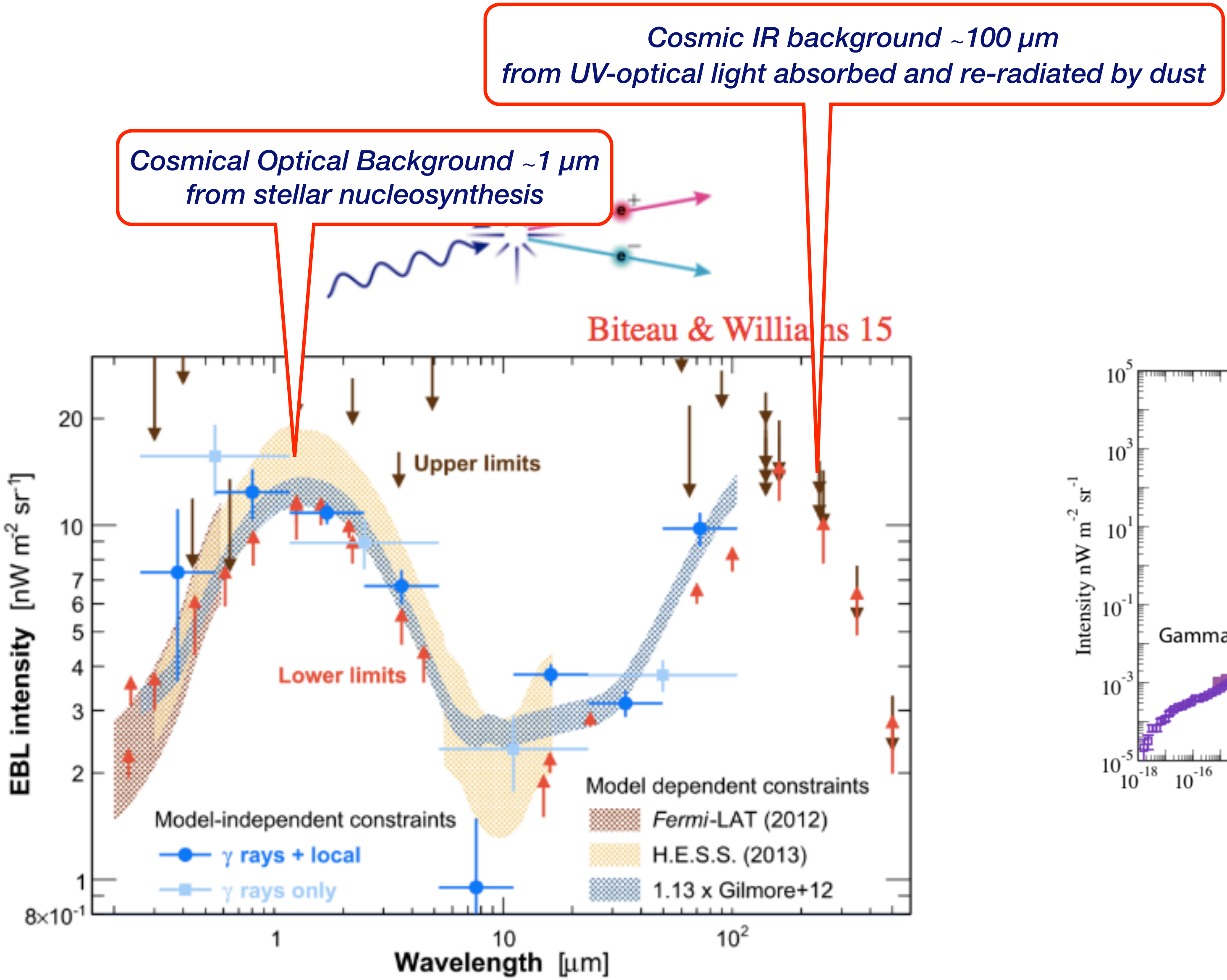
Fluxes from the Heavens (z=0)

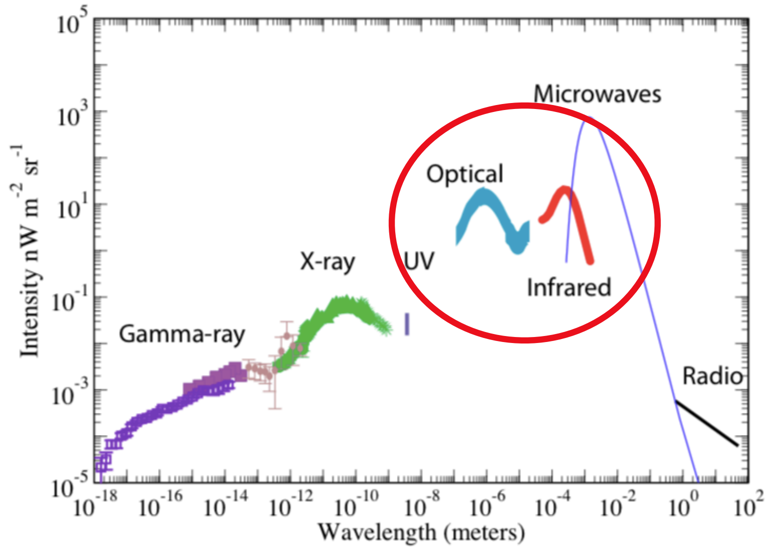


20 decades in the wavelength of the extragalactic diffuse radiation

Extragalactic Background Light

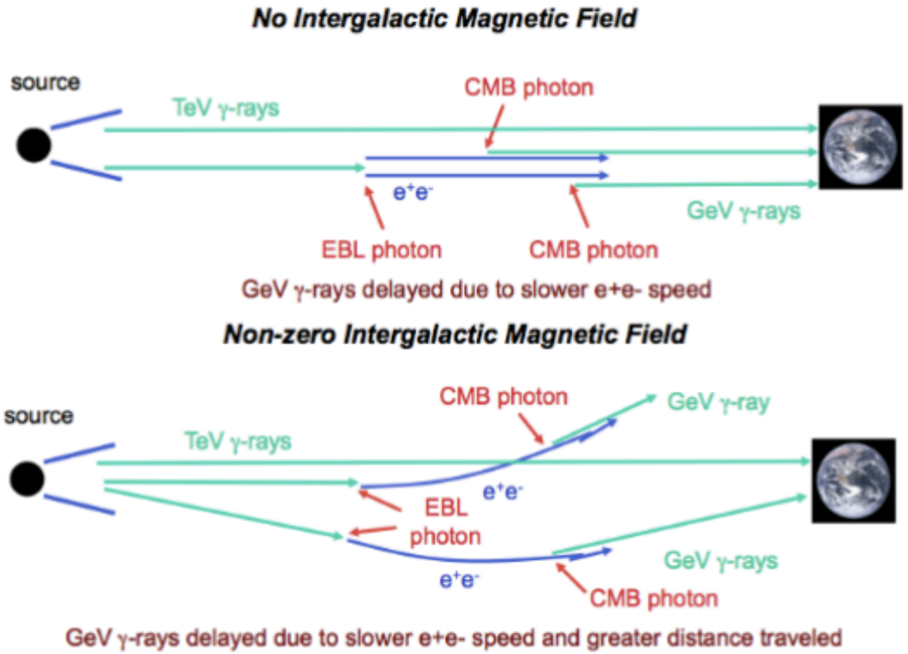
The EBL probes the amount of light emitted by stars throughout the evolution of the Universe, depends on the process of galaxy formation and evolution, and is hence of cosmological interest. CTA and IceCube/KM3NeT have sensitivity to the Optical - IR bumps.





Constraints of Intergalactic magnetic field (IGMF)

The measurement of the TeV spectrum of a blazar by IACTs, together with the upper limit on the GeV emission from the source set by Fermi results in a lower limit on the IGMF which depends on the source activity time scale.



A Neronov & I Vovk 2010 **Science 328** 73.

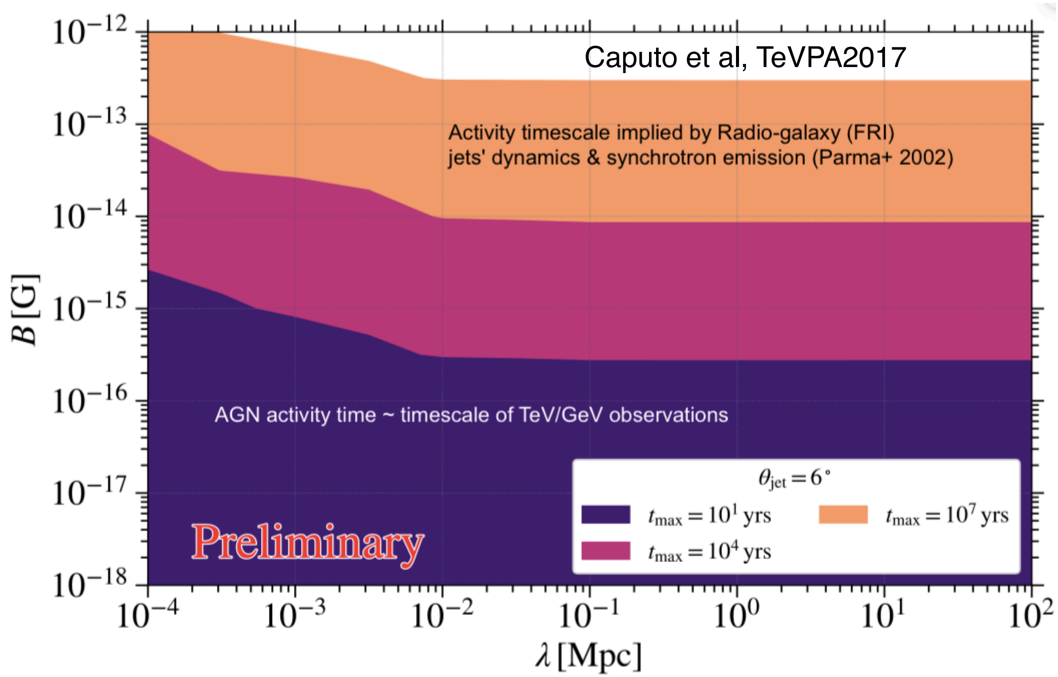
The blazar emits beamed TeV gamma-rays towards the Earth. They will interact with EBL photons and produce e^+e^- that upscatter CMB photons in the GeV.

A weak IGMF will not significantly deflect electrons and positrons => GeV photons will be emitted in the same direction as the primary TeV photons,

A strong IGMF => isotropically distributed GeV emission.

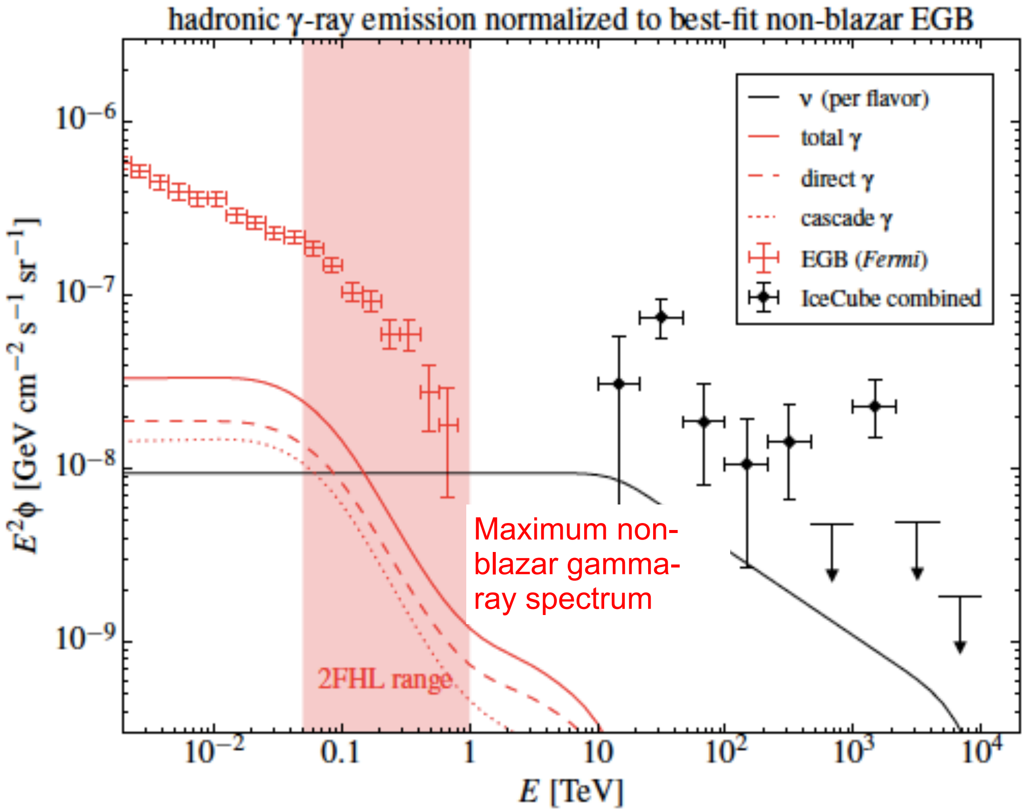
IGMF > 3 x 10^{-13} G (active for 10 Myr)

IGMF > 3 x 10^{-16} G (active for 10 yr)



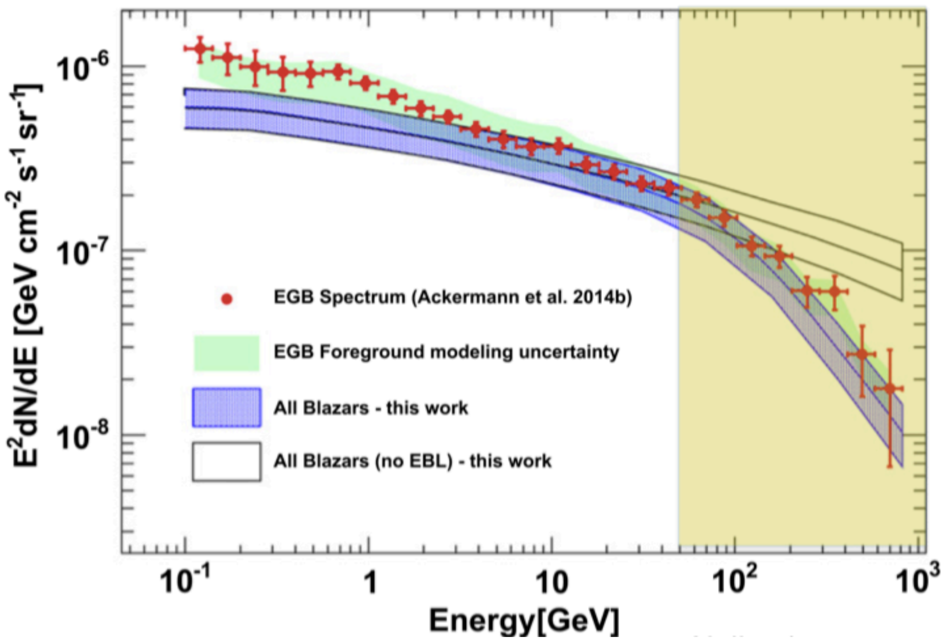
Fermi extragalactic backgound and IceCube neutrinos

Optically thin gamma-ray source



[Bechtol, MA, Ajello, Di Mauro & Vandenbroucke'15]

EGB: Ackermann et al. 2015, Models: Ajello+2015, Di Mauro+2015



Models predict that the >50 GeV EGB is produced by blazars, only

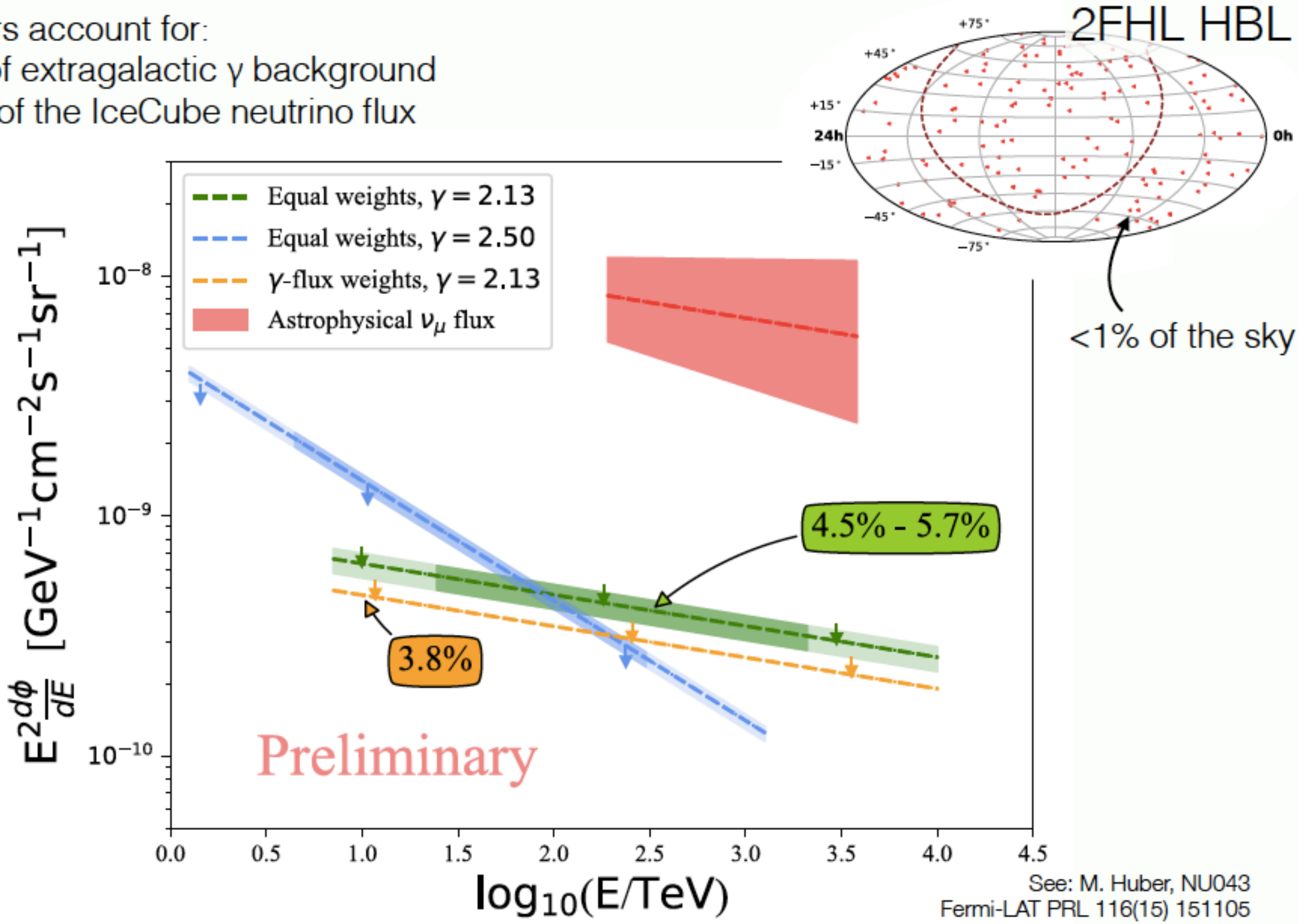
$14^{+14}_{-14}\%$ of EGB

is left to other sources, e.g. starburst galaxies

Fermi blazars and IceCube neutrinos

IceCube disfavour a large population of blazars dominating the 100 MeV-100 GeV region as the sources of neutrinos and CRs

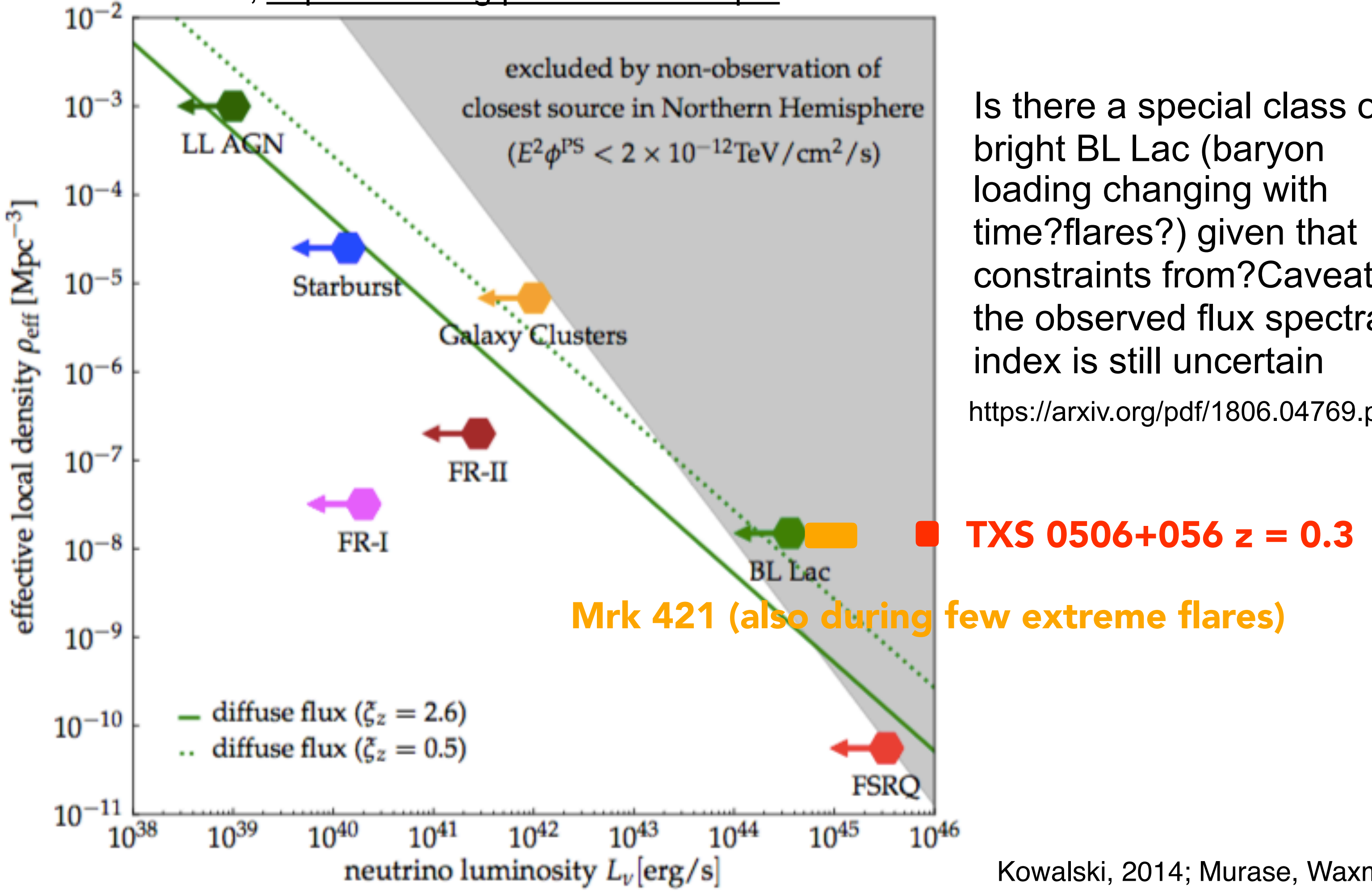
Blazars account for:
85% of extragalactic γ background
< 6% of the IceCube neutrino flux



See: M. Huber, NU043
Fermi-LAT PRL 116(15) 151105
Astrophys.J. 835 (2017) no.1, 45

The updated Kowalski's (after Hillas') plot

Ahlers & Halzen, https://arxiv.org/pdf/1805.11112.pdf & 2014



Is there a special class of bright BL Lac (baryon loading changing with time?flares?) given that constraints from?Caveat: the observed flux spectral index is still uncertain

https://arxiv.org/pdf/1806.04769.pdf

Kowalski, 2014; Murase, Waxman, 2016

Green line: the neutrino emissivity for the sources producing the IceCube neutrino flux (muon up-going tracks) with E^{-2} power law, normalisation ~ 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}, and for no evolution in the local universe (z<2) (dotted green line) and for star formation rate (SFR) ns$\propto$ $(1 + z)^3$ fr z < 1.5 (solid green line). They gray region indicates the region at the level of the discovery potential of IceCube in point source searches with 2032 d (Reimann et al, ICRC 2017).

IceCube-170922A - Fermi-AGILE-GBM - MAGIC

Date: 22 Sept 2017

RA: 77.43° (-0.80°/+1.30° 90% CL)
Dec: 5.72° (-0.40°/+0.70° 90% CL)

Energy (prelim. reported est.): > 120 TeV

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17/09/23 01:09:26 GMT
FROM: Erik Blaufuss at U. Maryland/IceCube <blaufuss@icecube.umd.edu>

Claudio Kopper (University of Alberta) and Erik Blaufuss (University of Maryland) report on behalf of the IceCube Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability of being of astrophysical origin. The event was identified by the Extremely High Energy (EHE) track event selection. The IceCube detector was in a normal operating state. EHE events typically have a neutrino interaction vertex that is outside the detector, produce a muon

Date: 28 Sept 2017

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
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Date: 4 Oct 2017

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

Related

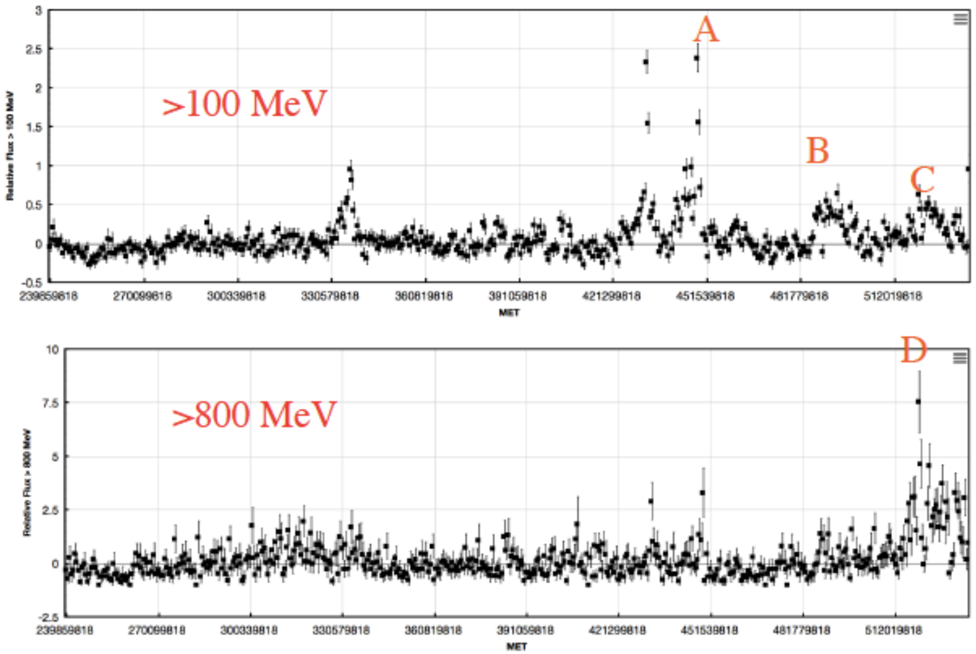
- 10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
- 10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
- 10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)
- 10838 MAXI/GSC observations 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

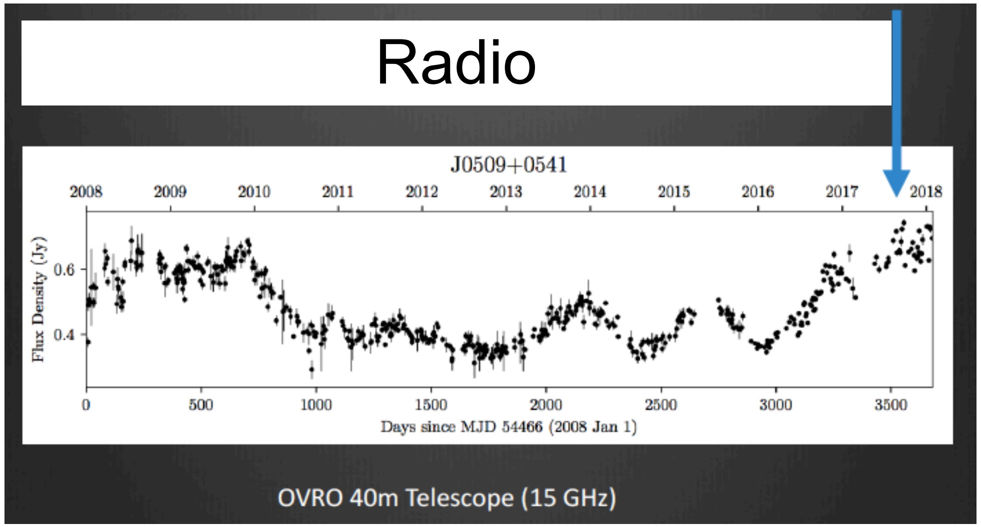
https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon

Lightcurves

FAVA TXS 0506+056

`Fermi All-sky Variability Analysis' (Abdollahi+17)

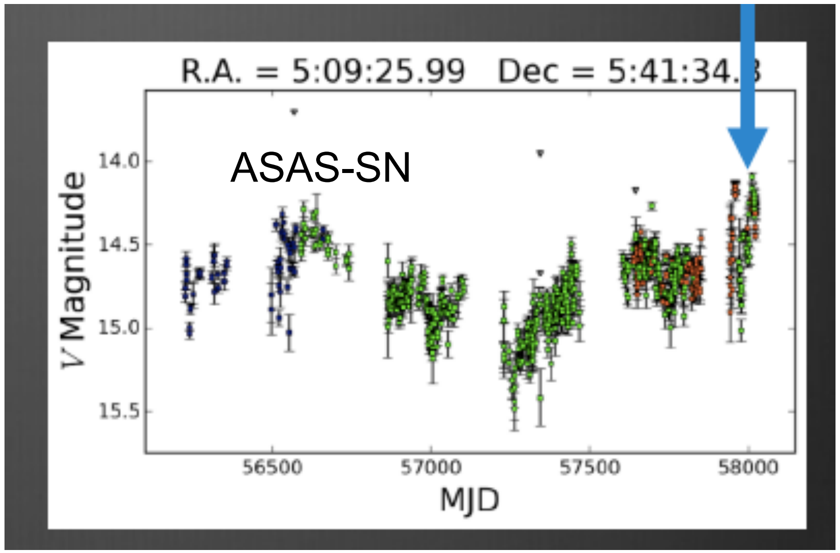




$Z = 0.3365 \pm 0.0010$

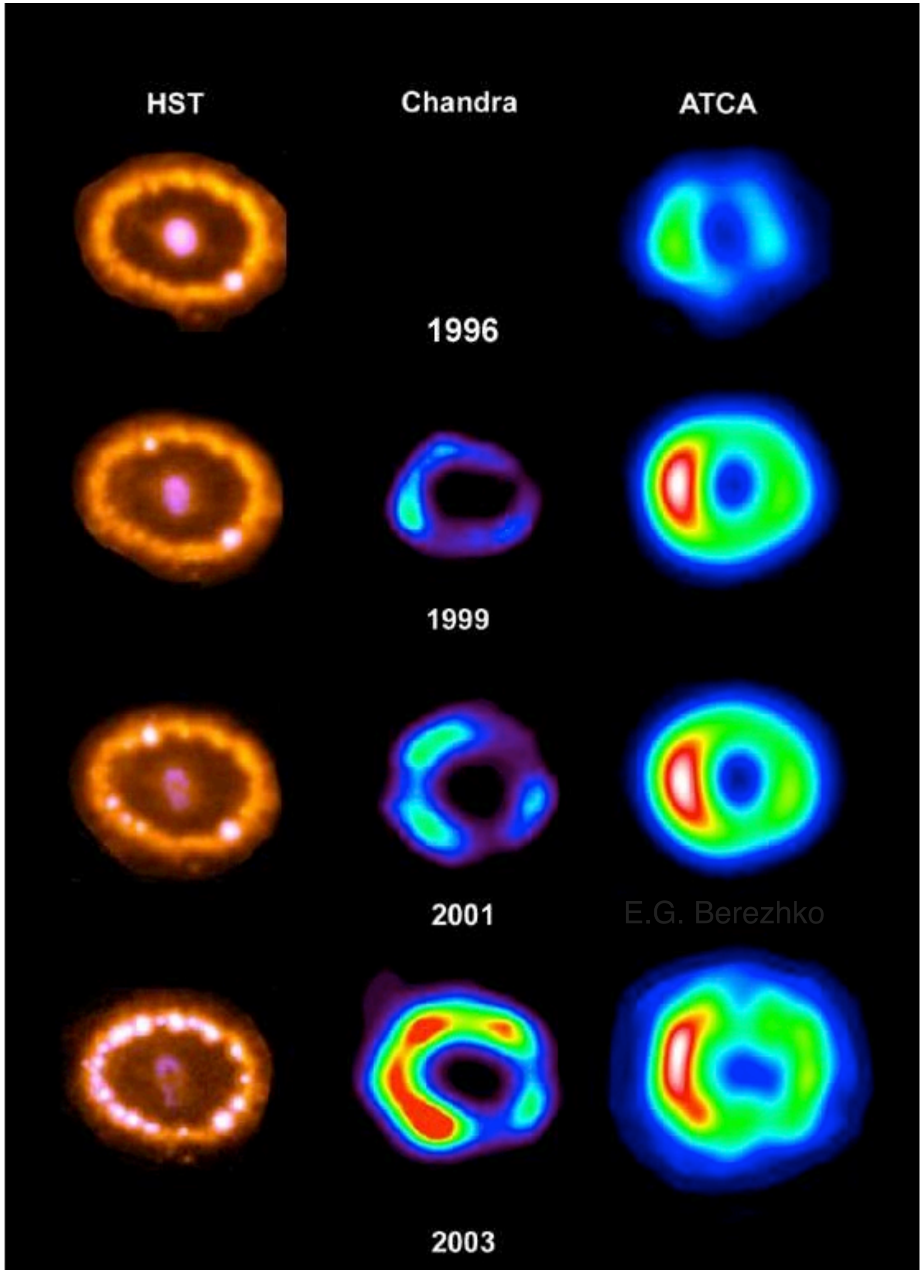
(Paiano+ 2018 ApJ, 854)

Optical



Galactic sources: 1st multi-messenger event SN1987A

- Hystorical SNR since Kepler (1604):
  - photons (over a wide spectrum)
  - neutrinos (Kamiokande, IMB, Baksan)
- Many lessons learned:
  - physics of collapse and signatures of non-spherical collapse
  - formation of heavy elements up to Fe, Ni, C detected in circumstellar material
  - Physics of neutrino oscillations in matter and mass hierarchy
  - Limits on coupling of ALP-gamma-rays (Primakoff process in the hot dense medium of core-collapse SN)
- Future long-term monitoring in X-rays and gamma-rays will complete the picture of SN shock wave and the circumstellar medium and the efficiency versus age.



Multi-wavelength observations: The Crab Nebula

Hystorical Supernova remnant observed in the year 1054 by Chinese Astronomers

X-ray	Optical	Infrared	Radio
~ 10^4 eV	~ few eV	~ 1 eV	~ 10^{-4} eV

Credit: NASA/CXC/SAO (X-ray), Paul Scowen and Jeff Hester (Arizona State University) and the Mt. Palomar Observatories (optical), 2MASS/UMass/IPAC- Caltech/NASA/NSF (infrared), and NRAO/AUI/NSF (radio)

Variability challenges shock acceleration (diffusive and non)

Flare date	Duration	Peak γ-ray flux	Instruments
October 2007	**~ 15 days**	**~ $6\cdot10^{-6}$ ph cm^{-2} s^{-1}**	**AGILE**
February 2009	**~ 15 days**	**~ $4\cdot10^{-6}$ ph cm^{-2} s^{-1}**	***Fermi***
September 2010	**~ 4 days**	**~ $5\cdot10^{-6}$ ph cm^{-2} s^{-1}**	**AGILE, *Fermi***
April 2011	**~ 2 days**	**~ $30\cdot10^{-6}$ ph cm^{-2} s^{-1}**	***Fermi*, AGILE**

Other γ-ray flaring states seen by Fermi and AGILE:

Mar and Oct 2013, Aug 2014, Oct 2016... **Rate: ≈1/year**

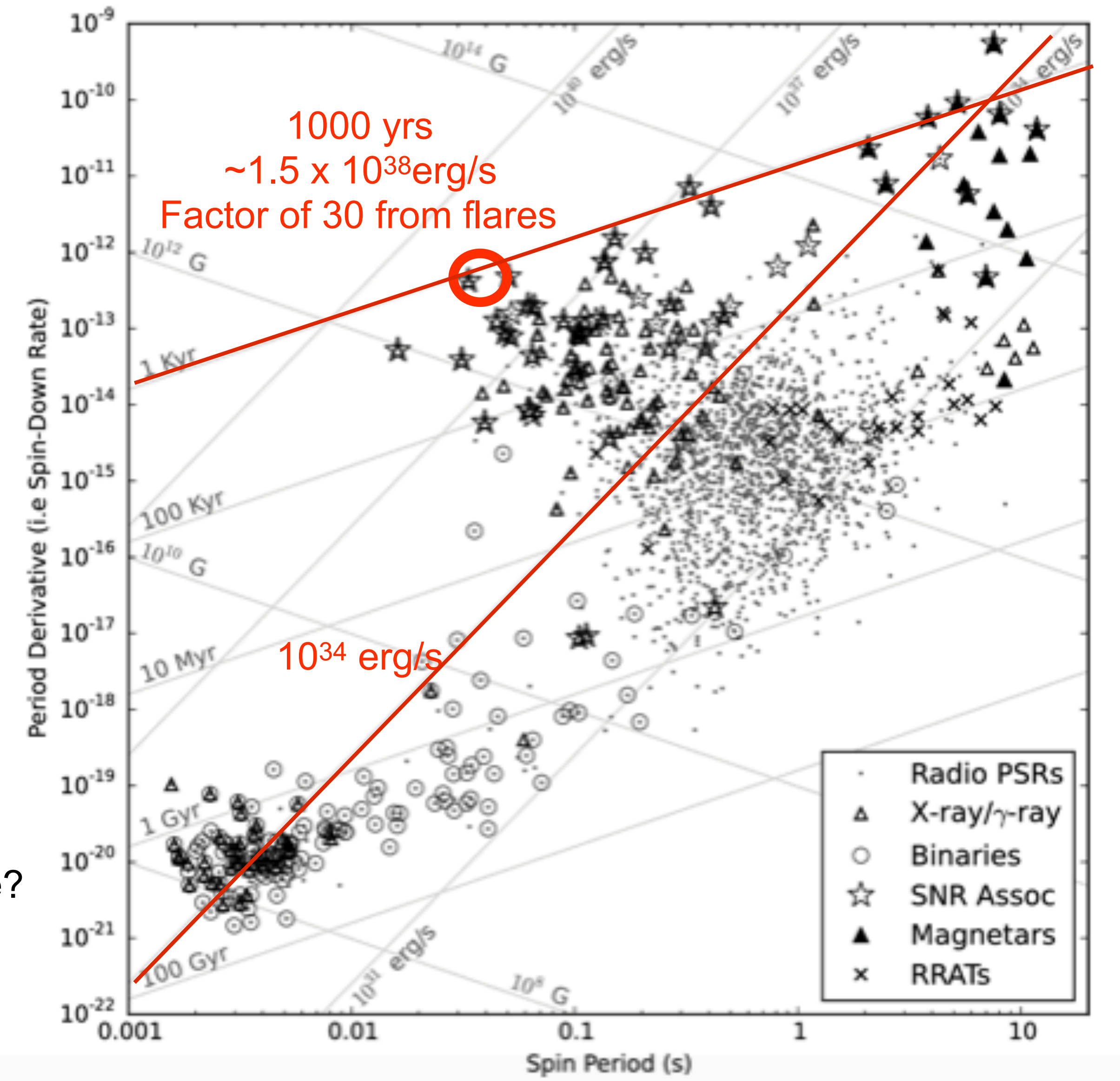
Big theoretical challenge:
the Crab Nebula is not a standard candle in gamma-rays!

Crab Sept. 2010 flare:
- peak luminosity ≈ $5\cdot10^{35}$ erg cm^{-2} s^{-1}
- kin. power fraction of PSR spindown: $\varepsilon \approx 0.001 (\eta\text{-}1/0.1) \approx 0.01$
- B field goes up to 1-3 mG compared to average 200 uG

Crab is surely an electron PeVatron, hadron one?

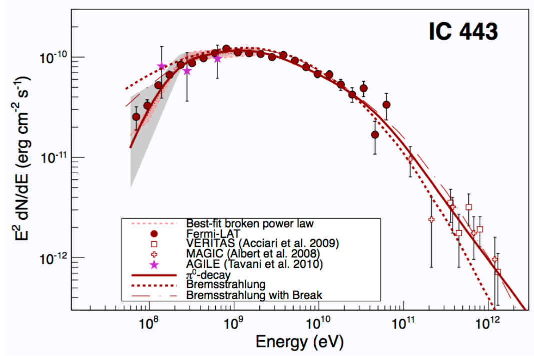
Pittori, Vulcano 2018

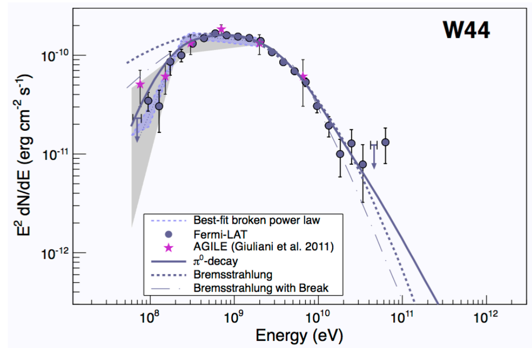
Ajello et al. http://science.sciencemag.org/content/331/6018/739

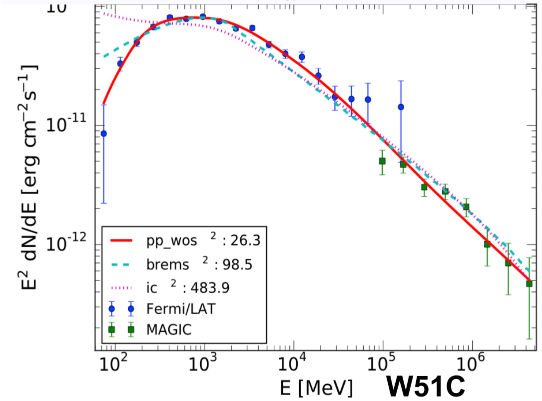


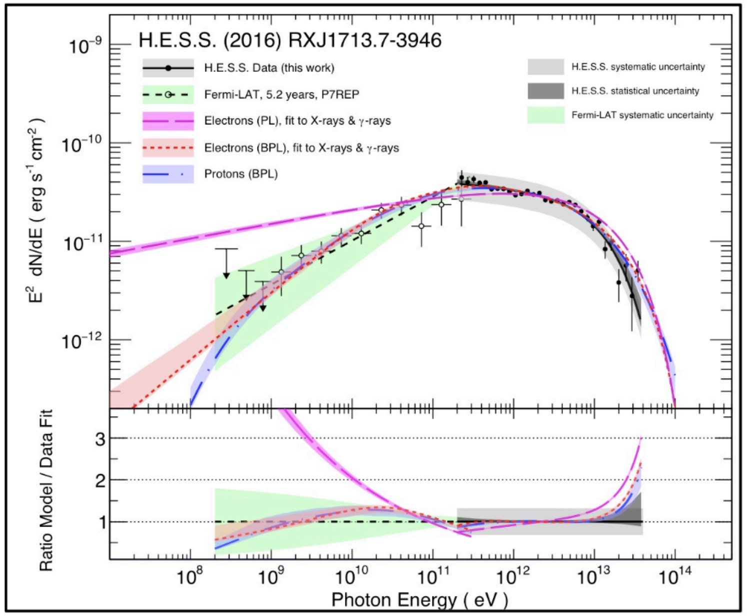
SNRs & origin of Galactic CRs

- Origin of Galactic CRs
  - Characteristic π^0-decay cutoff seen in IC 443, W44, W49B and W51C (p acceleration)
  - SNR are born, live and die in molecular clouds (accelrtion processes may involve colliding wind binary systems CR interaction with molecular clouds)
- RX J1713.7-3946 is still in the hadronic game…
- Cassiopeia (330 yr)
  - MAGIC + Fermi-LAT data exclude single electron population as origin of emission
  - Hadronic model works, E_{cut} = 3.5 TeV → Cas A is presently no CR PeVatron

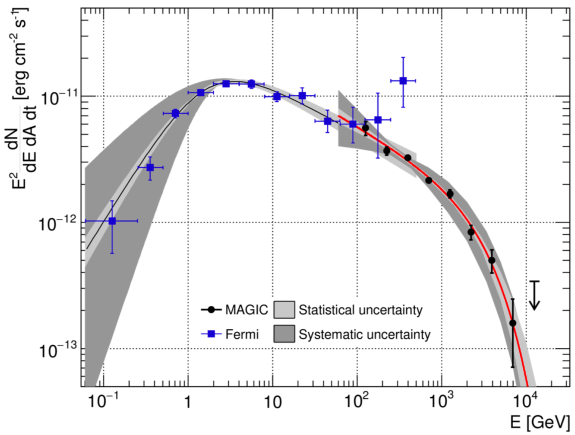


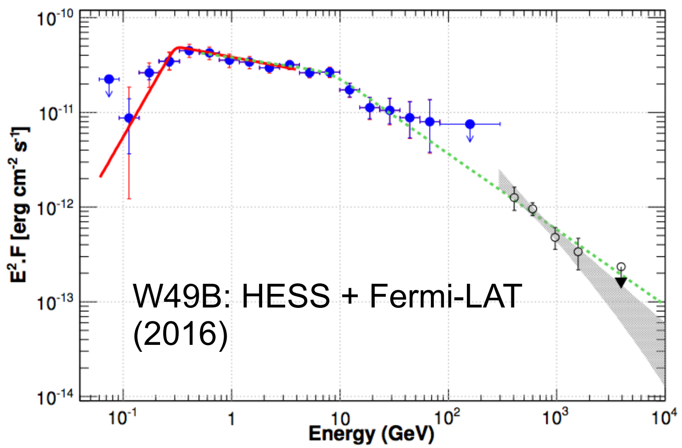






Cas A: MAGIC + Fermi-LAT (2017)





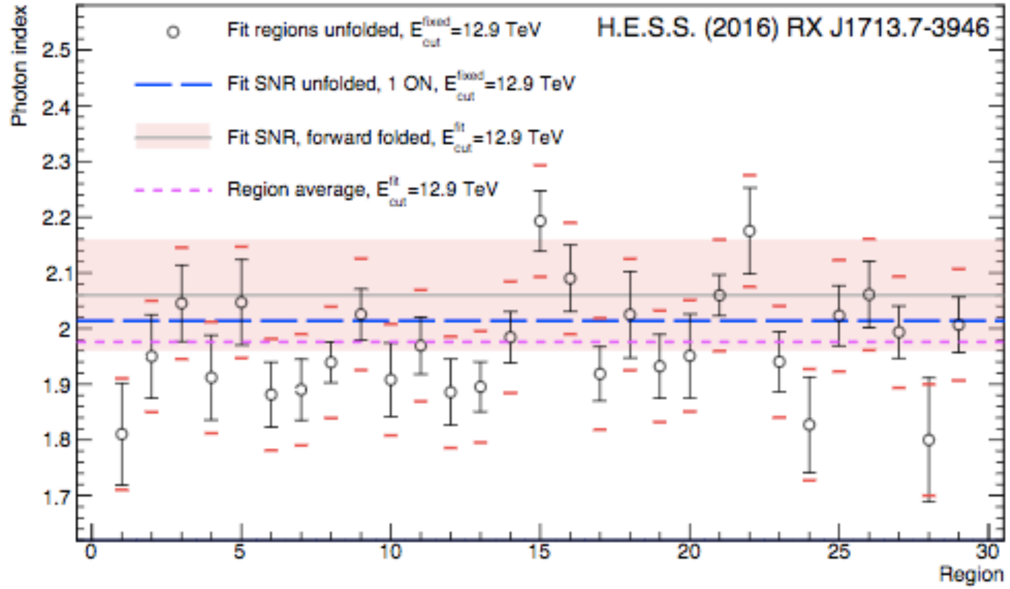
Morphology…

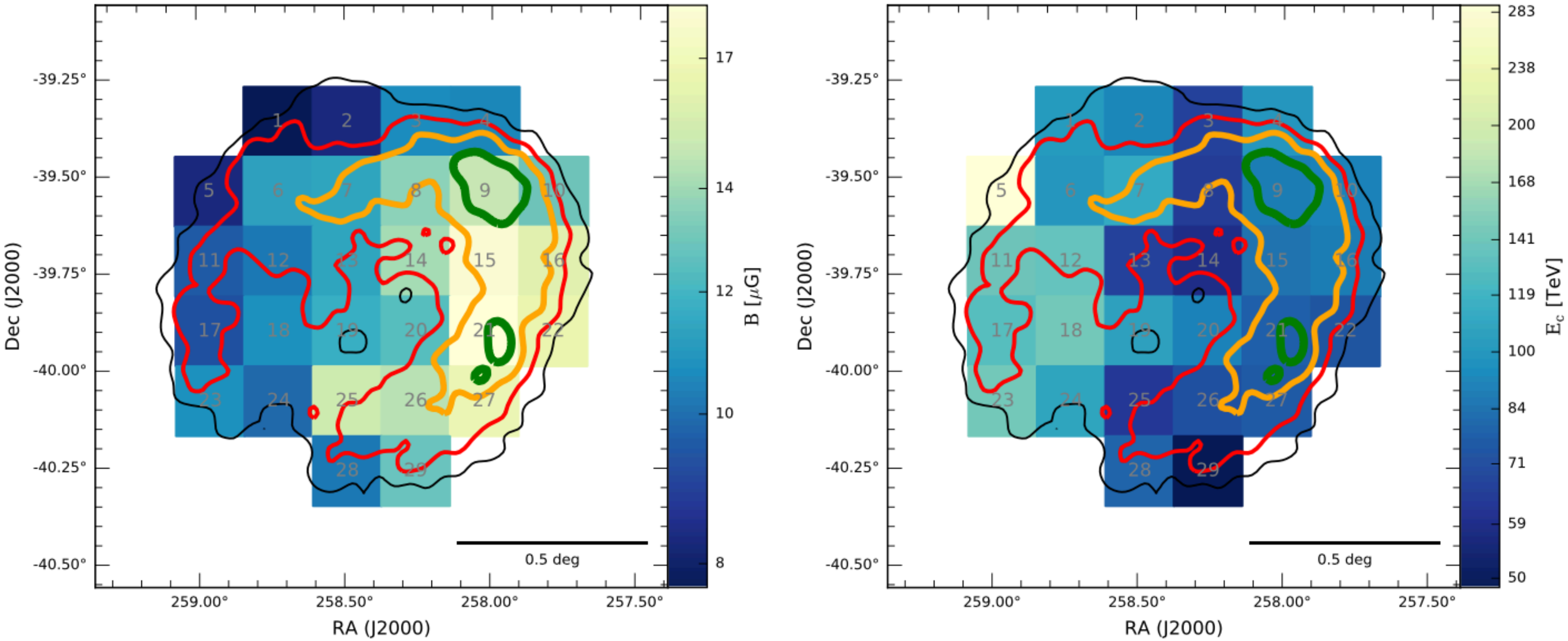
HESS https://arxiv.org/pdf/1609.08671.pdf

S. Ohm, ISVHECRI

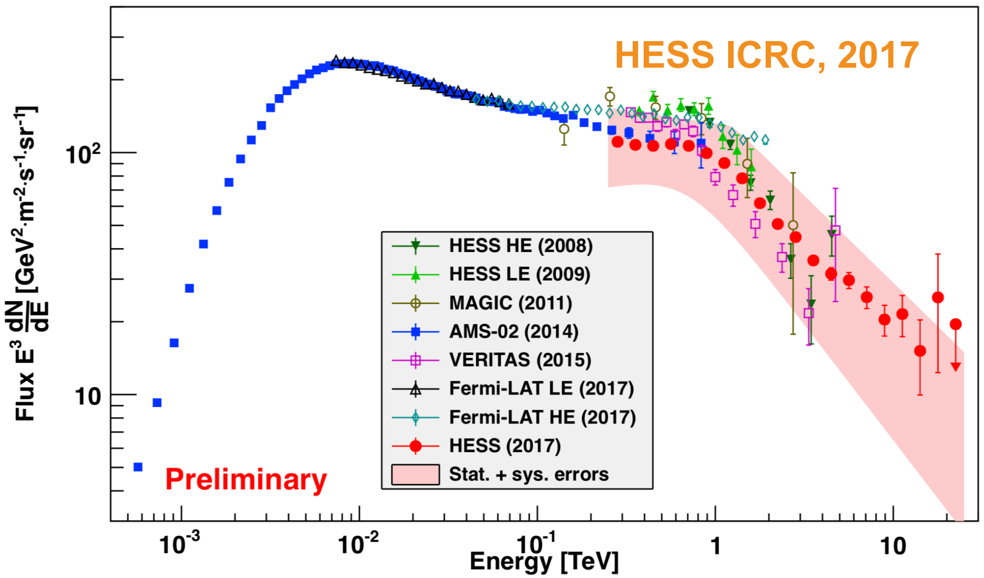
- Spectrum characteristics
  - Best described by broken power-law + exponential cutoff
  - Pure power-laws don't describe data
- Hadronic model
  - Break results from higher energy CRs diffusing faster into cold, dense MC clumps (e.g. Gabici & Aharonian 2014)
  - E_{break} depends on SNR age and density profile; E_c ~100 TeV
- Leptonic model
  - B ~ 10 – 15 μG, E_{break} ~2 TeV
  - Break requires 2nd electron population, or additional seed photon field. Detailed hydro-CR codes can reproduce observed emission

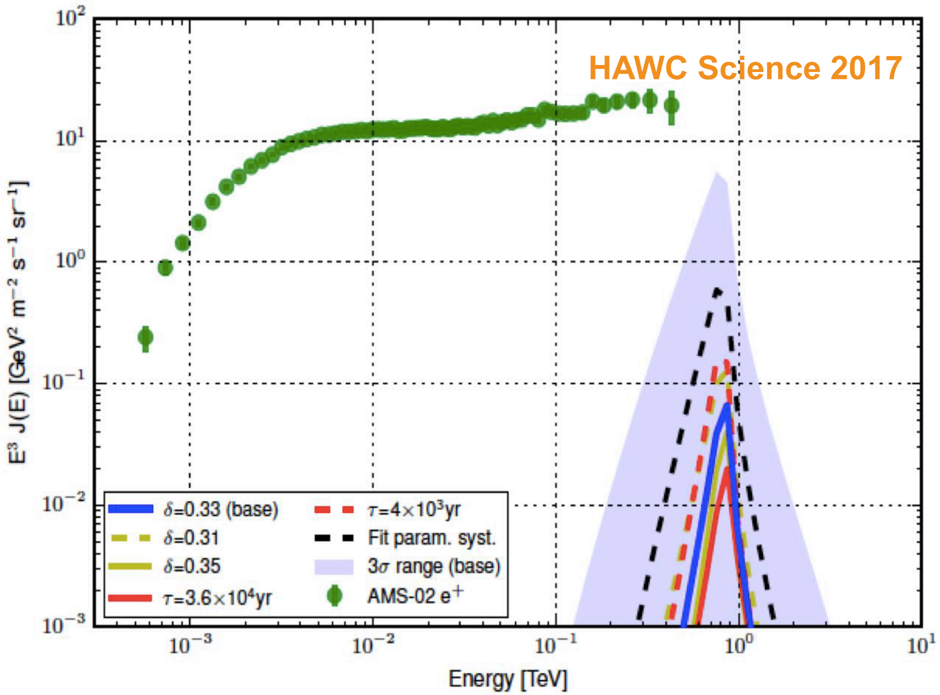
→ No clear case for either leptonic or hadronic accelerator





Not only gammas…

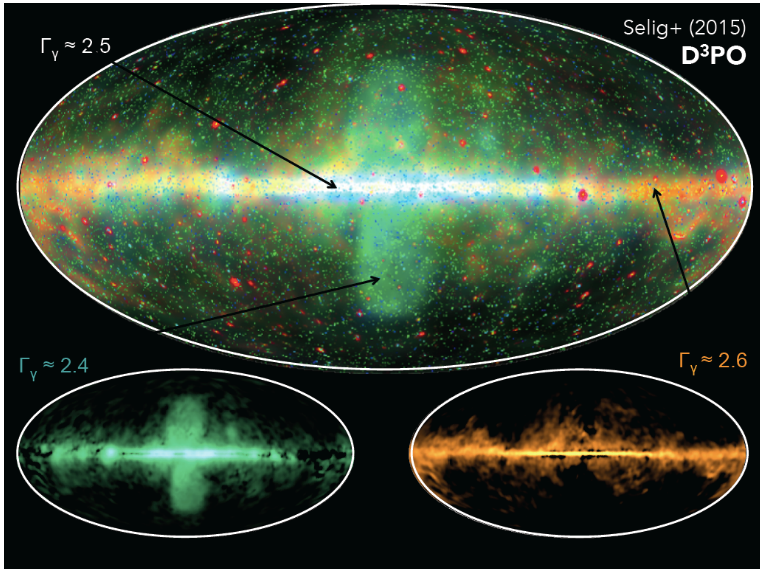




No prominent HE features from local PWN and sources and even from extended gamma-ray sources around pulsars (Geminga, Monogem)
HAWC & AMS prefer a low diffusion coefficient 0.3
Has consequences on DSA

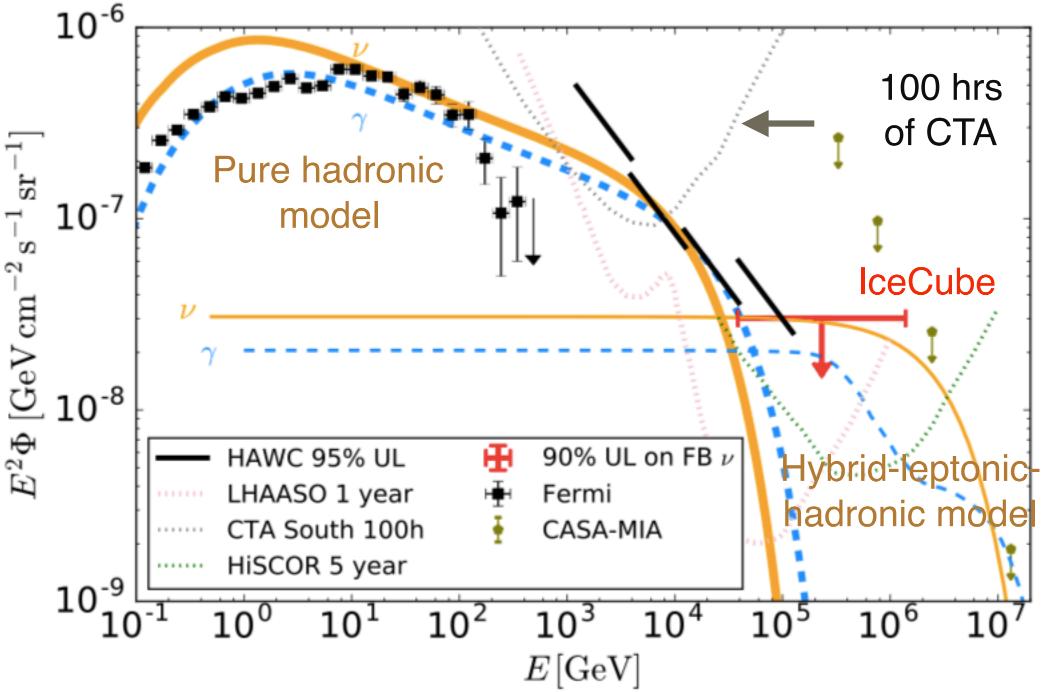
The serendipity of Fermi Bubbles

- 23’000 light-years above the plane of the Milky Way
- Energy ~1-100 GeV;
- Gamma-ray power ~ 4.0×10^{37} erg s^{-1}
- enough cool gas to create 2M x M_{Sun}
- ~$E^{-2.4}$ hard gamma-ray emission ~ latitude independent.
- Counterpart of WMAP haze (Planck) which fades beyond 35°.
- HST (ApJ 2017) : “big meal” by Sgr A* of a gas cloud which fired off jets of matter ~6-9Myrs ago (tidal disruption)
- IC neutrinos > 60 TeV in Fermi bubbles (4 yr-sample): 90%CL prediction = 6 events; 4 atmospheric + cosmic backgrounds

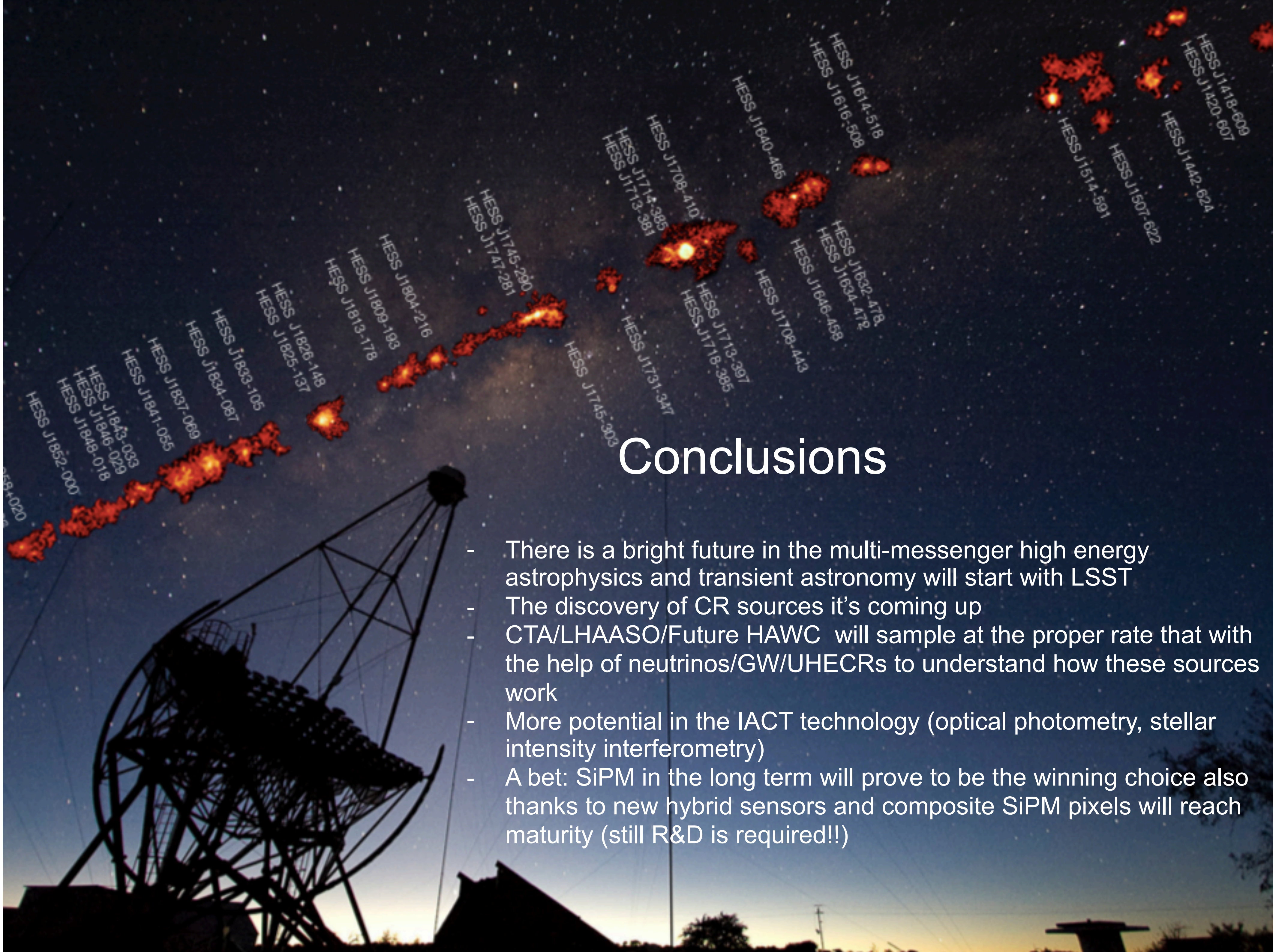


Fang et al, 2017 [arXiv:1704.03869]

Hybrid-leptonic hadronic models imply that Fermi observes the leptonic component and that the subdominant hadronic gamma-rays and neutrino fluxes are very hard.



Finkbeiner et al., 2010; Karen Yang, Ruszkowski, Zweibel et al, 2018

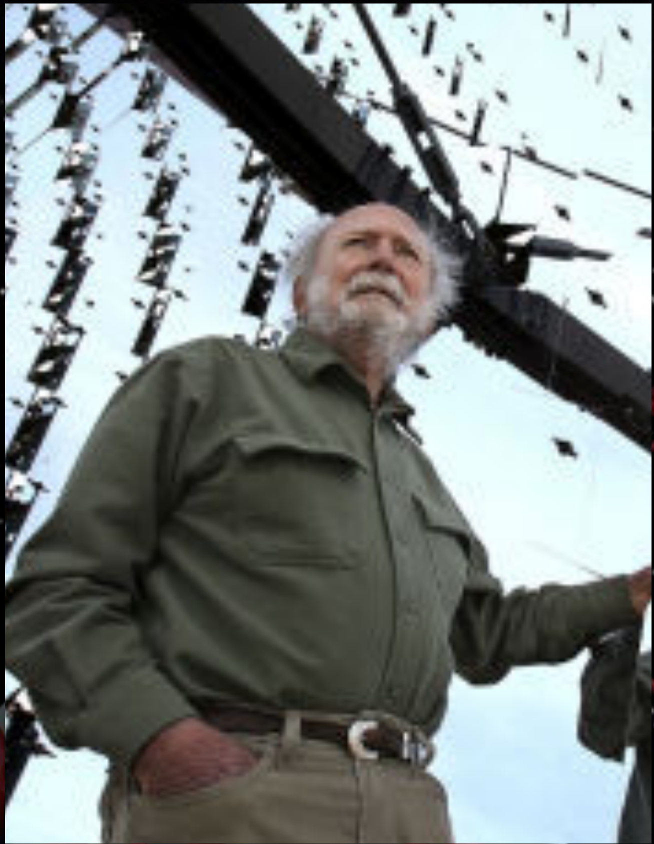


Conclusions

- There is a bright future in the multi-messenger high energy astrophysics and transient astronomy will start with LSST
- The discovery of CR sources it's coming up
- CTA/LHAASO/Future HAWC will sample at the proper rate that with the help of neutrinos/GW/UHECRs to understand how these sources work
- More potential in the IACT technology (optical photometry, stellar intensity interferometry)
- A bet: SiPM in the long term will prove to be the winning choice also thanks to new hybrid sensors and composite SiPM pixels will reach maturity (still R&D is required!!)

Many more presentations…

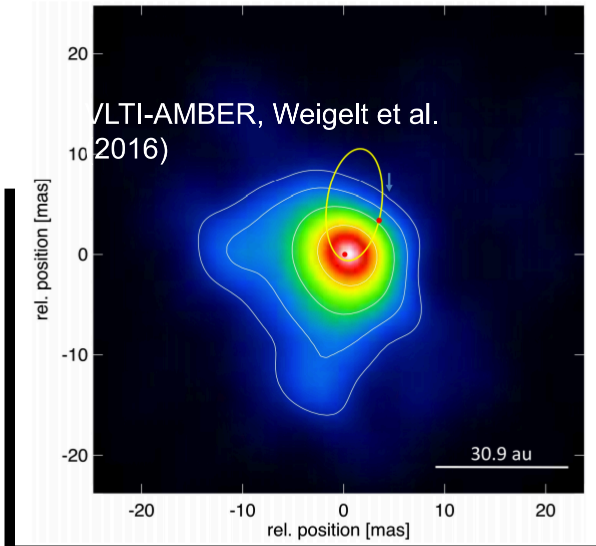
M. Doro 15 years of MAGIC observations a crowded TeV sky
B. Humensky Highlights of the VERITAS experiment
Highlights on Fermi
Highlights from the HAWC Observatory
T. Di Girolamo Strategies for the Follow-up of Gravitational Wave Transients at Very High-Energy Gamma Rays with the Cherenkov Telescope Array
P. Sangiorgi The ASTRI camera control software for CTA
V- Vagelli SiPM for SCT of CTA and FBK NUV HD for CTA camera with SiPM
R. Zanin CTA: overview and galactic science program
J. Knapp The multi-messenger astronomy era: status and potential
PW Cattaneo Multi-messenger astronomy with AGILE
S. Raino' Observations of the Sun and The gamma-ray properties of low-redshift BL Lacs



Trevor Weekes (1940-2014)

Eckart Lorenz (1938-2014)

Thank You for your attention



η Carinae vs. Solar system

Eta Car characteristics

- Two massive stars in 5.5 yr orbit
- Wind speeds of 500 – 3000 km/s
- ~Gauss B-fields
- Densities of ~10^8 – 10^{12} cm^{-3}

Implications

- TeV particles cool on minute (electrons) to days (protons) timescales
- >100 GeV gammas indicative of accelerated protons

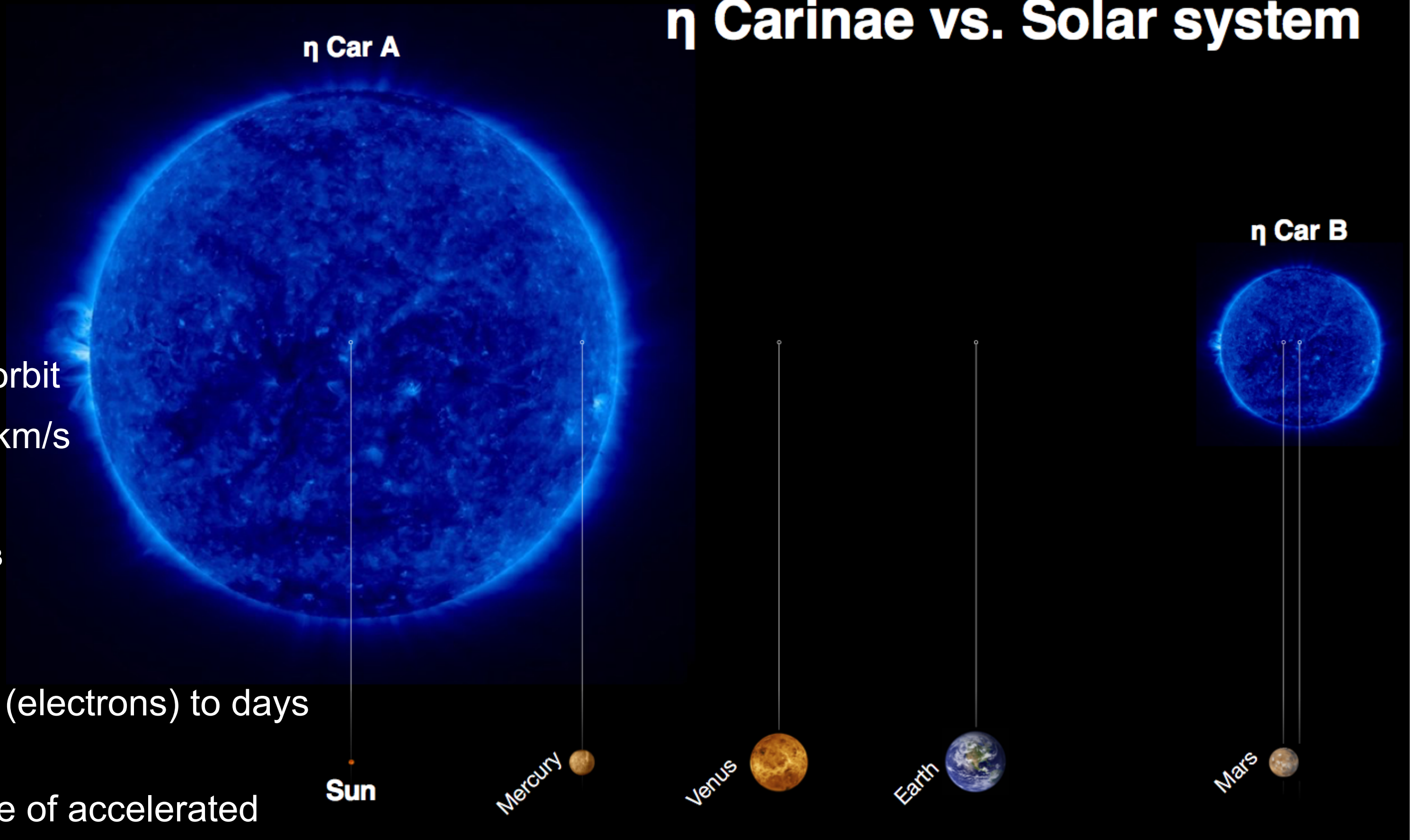
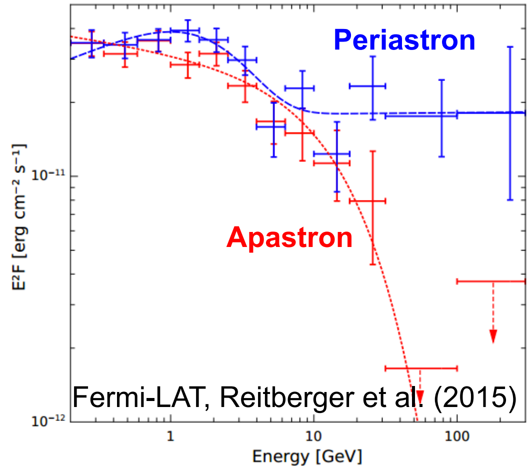
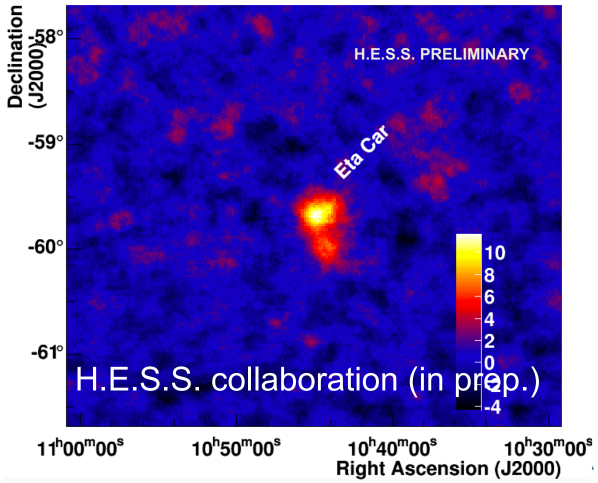


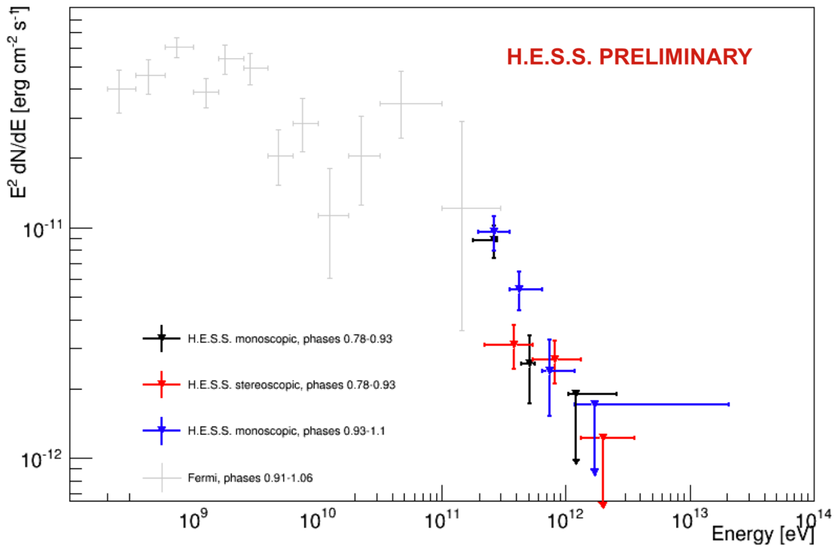
Image Credit:
NASA/JPL/SDO/Earth Observatory
Stefan Ohm

- *All distances, star sizes, and planet sizes to scale*
- *Star-to-planet size **not** to scale*
- *UV image of the Sun as template for η Car stars*

Eta Carinae in gamma rays







Fermi-LAT

- Two components
- Both variable along orbit
- Emission extends to ~100 GeV

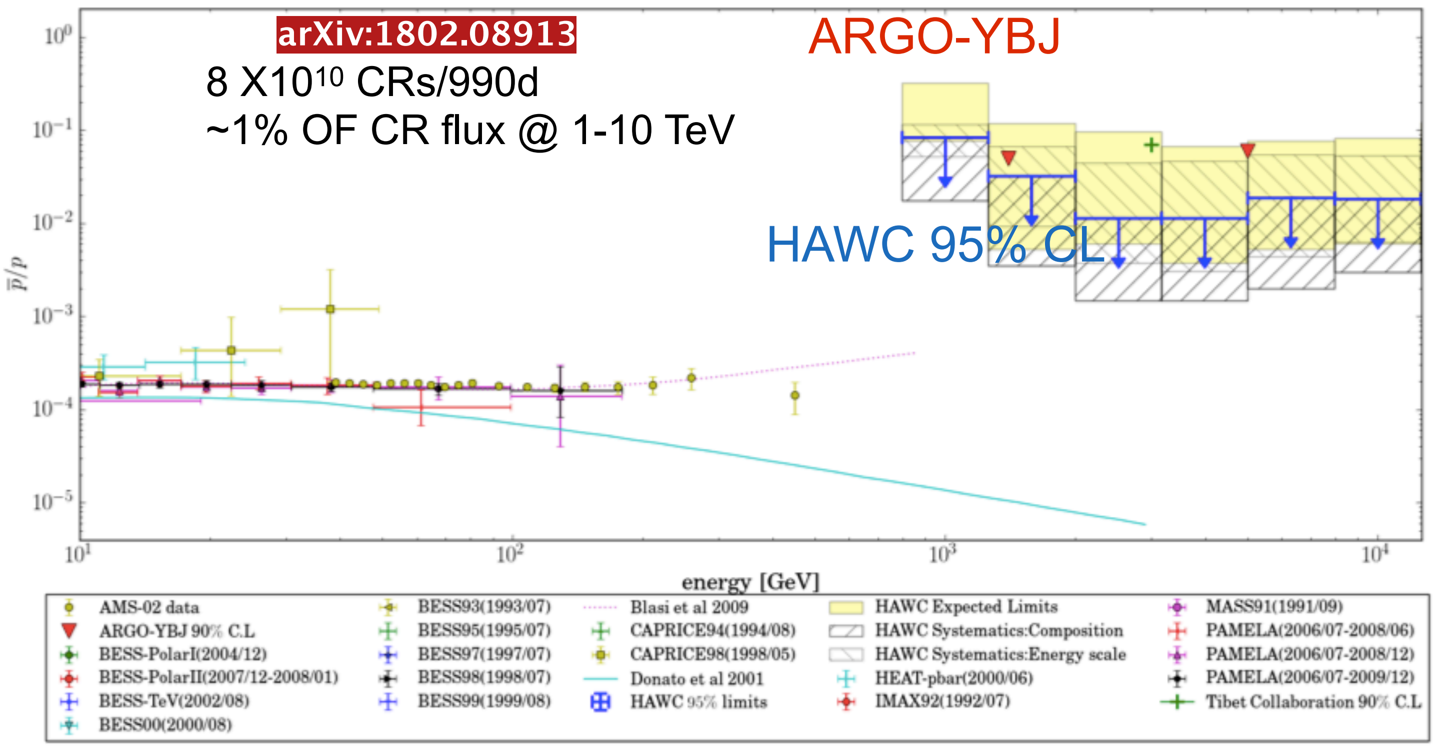
H.E.S.S.

- Challenging measurement due to strong night sky background
- First colliding wind binary seen in VHE gamma rays
- Steep spectrum

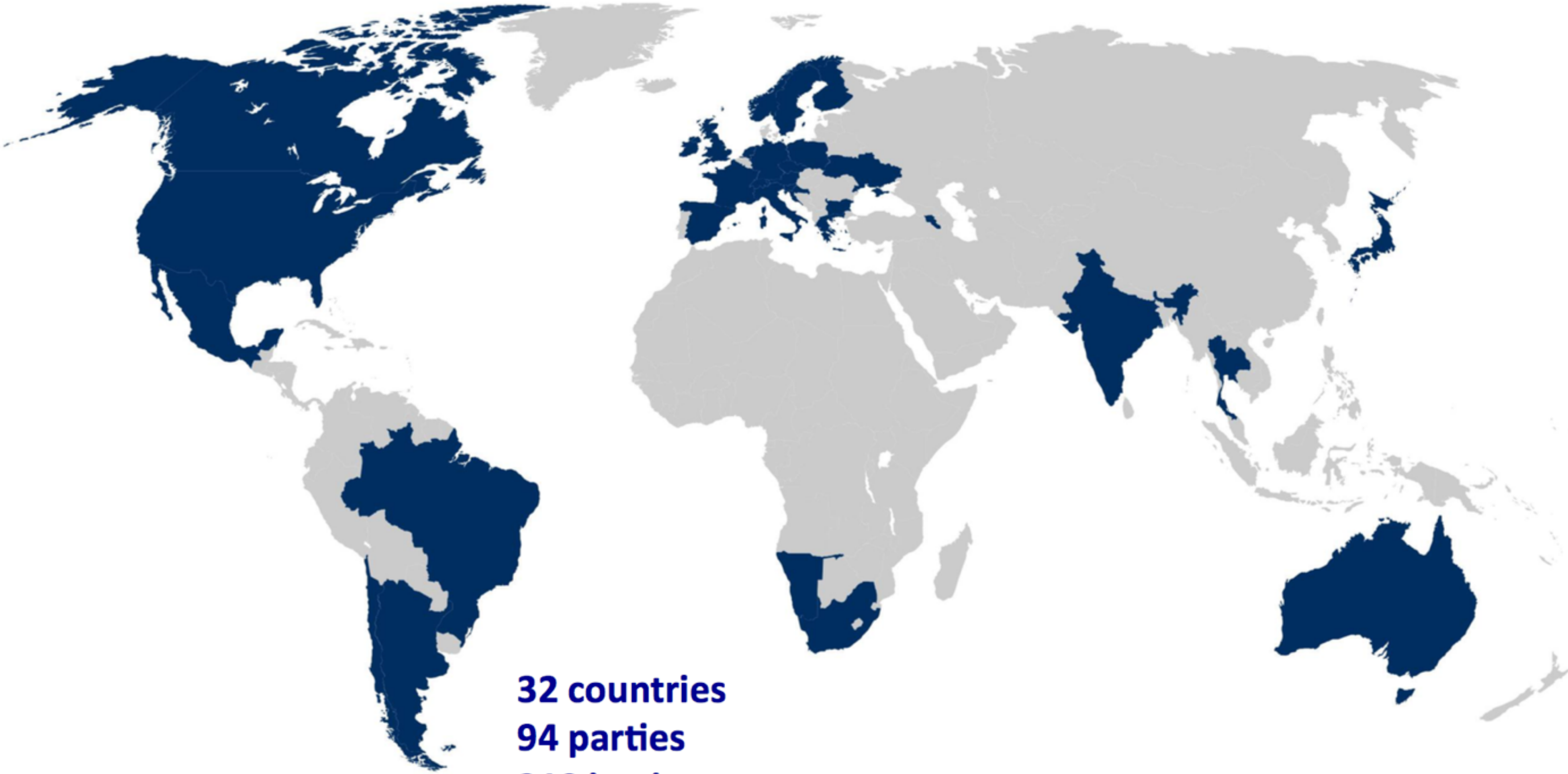
Implications for Eta Car

- Accelerates particles to TeV energies
- May act as a CR calorimeter at low energies
- Significant fraction of accelerated CRs may escape the system

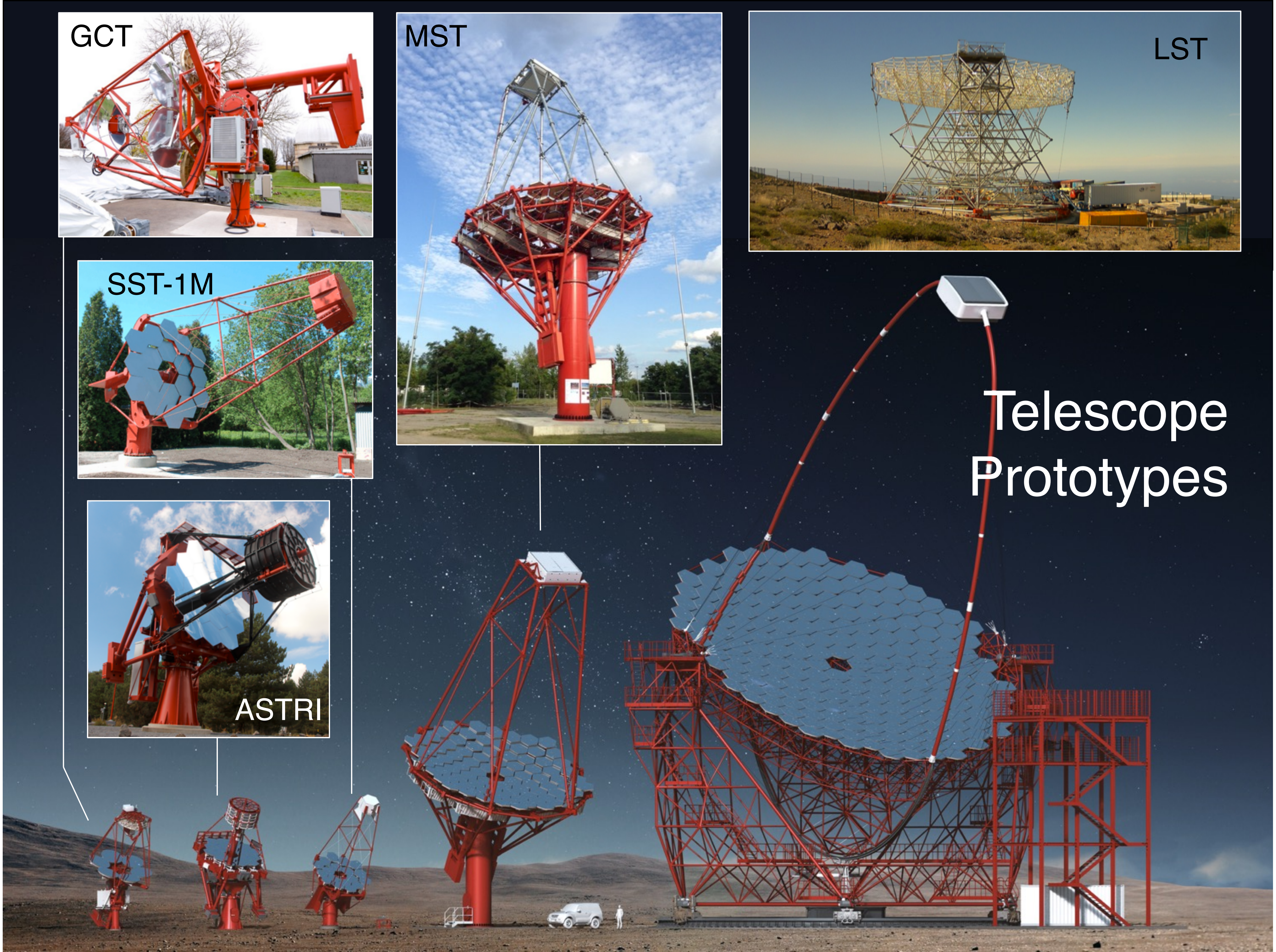
Anti-proton constraints from the the Moon shadow displacement

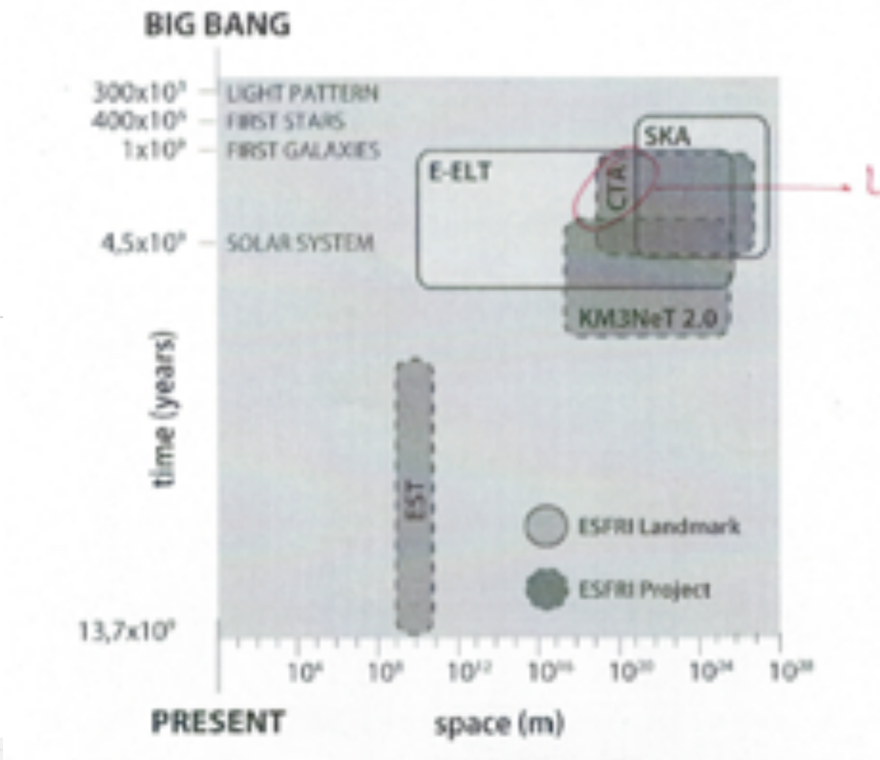


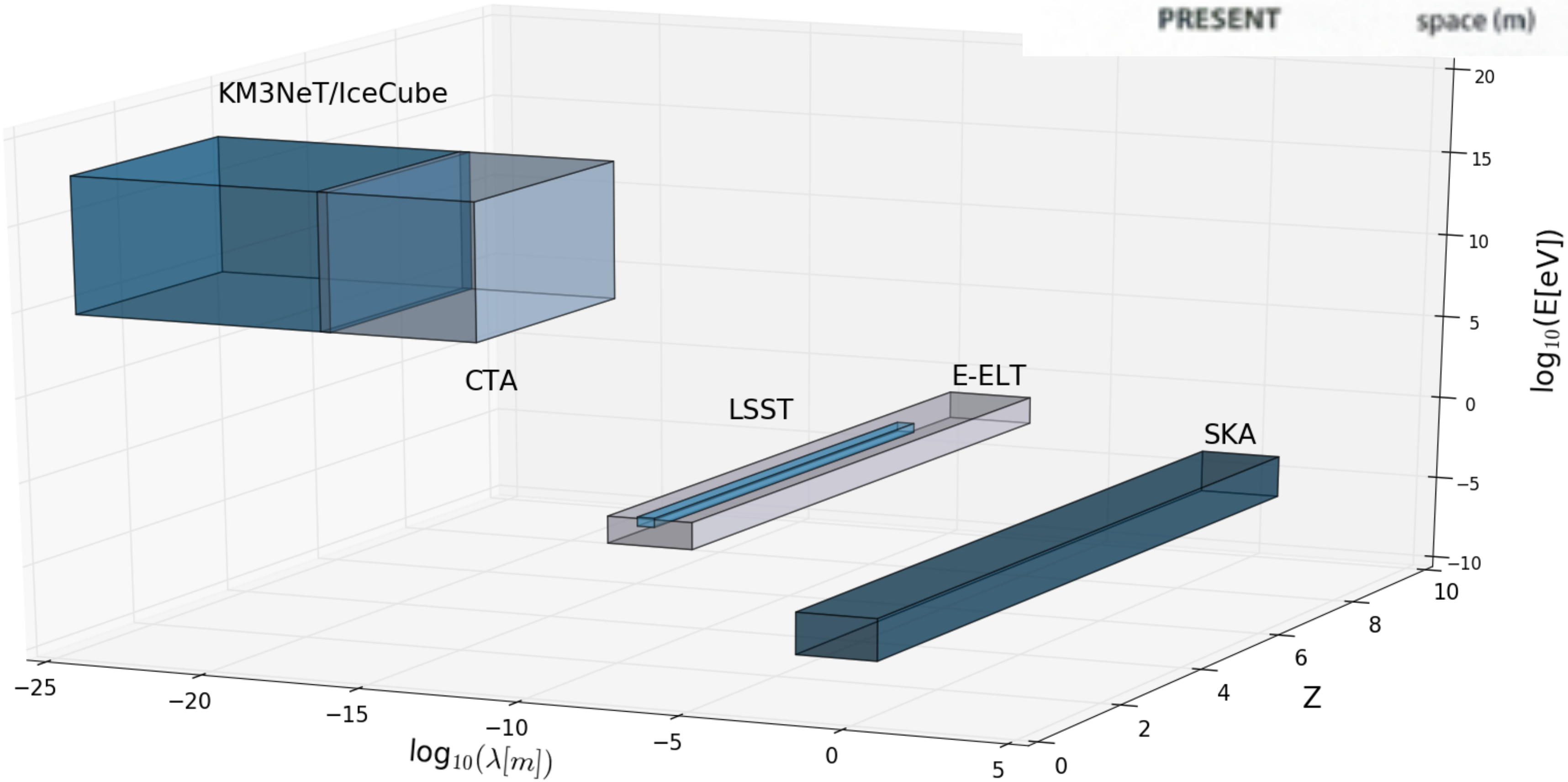
Consortium Membership



32 countries
94 parties
210 institutes
1420 members (484 FTE)


GCT
MST
LST
SST-1M
ASTRI
Telescope
Prototypes


BIG BANG
300x10³ LIGHT PATTERN
400x10⁶ FIRST STARS
1x10⁹ FIRST GALAXIES
4,5x10⁹ SOLAR SYSTEM
13,7x10⁹
SKA
E-ELT
CTA
KM3NeT 2.0
EST
ESFRI Landmark
ESFRI Project
time (years)
space (m)
PRESENT


KM3NeT/IceCube
CTA
LSST
E-ELT
SKA
$\log_{10}(E[eV])$
$\log_{10}(\lambda[m])$
Z