
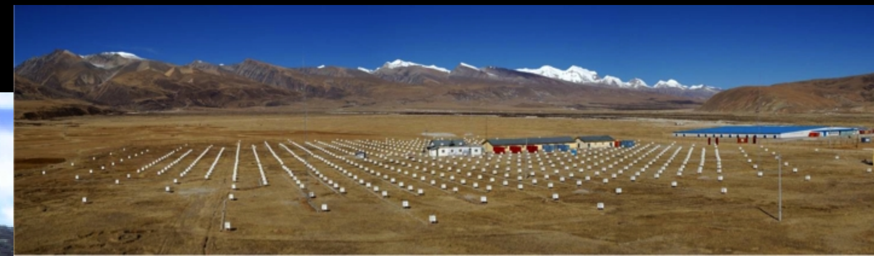
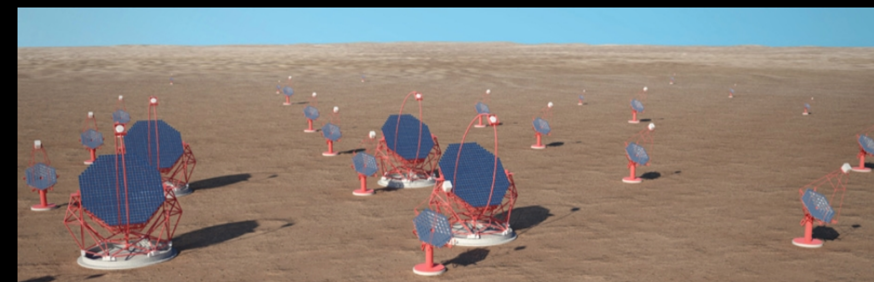

Rapporteur: Ground-based gamma-rays

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CENBG – Université de Bordeaux
CNRS-IN2P3



Disclaimer

Many great results at this conference:

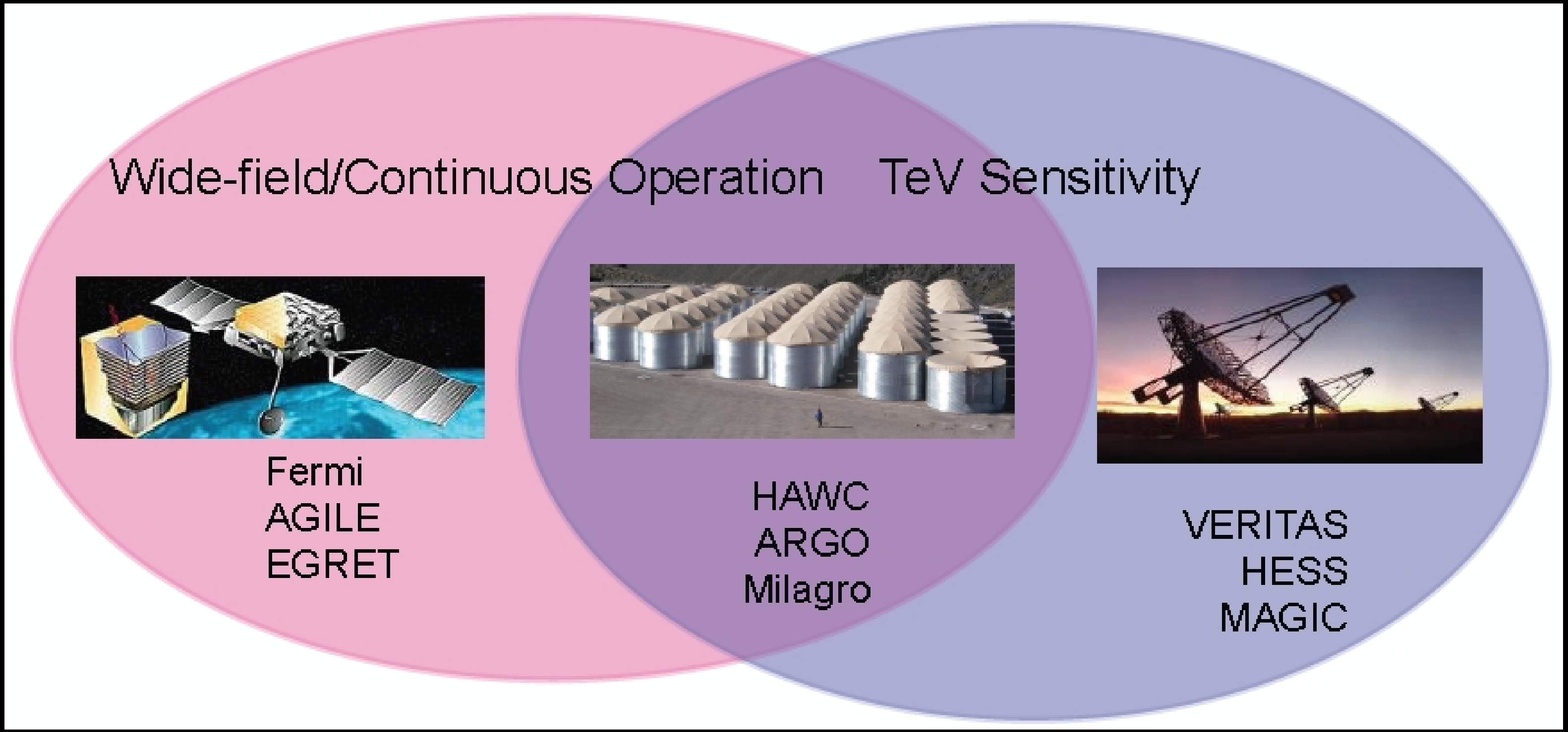
- 19 gamma-ray sessions, 84 talks and 176 posters on this topic
- I won't be able to summarize everything: apologies to everyone
- Already a lot has been presented and summarized in the highlights talks by E. Hays, M. de Naurois and J. Pretz

NB: IDs for the contributions refer to the one listed in INDICO (not the proceedings)

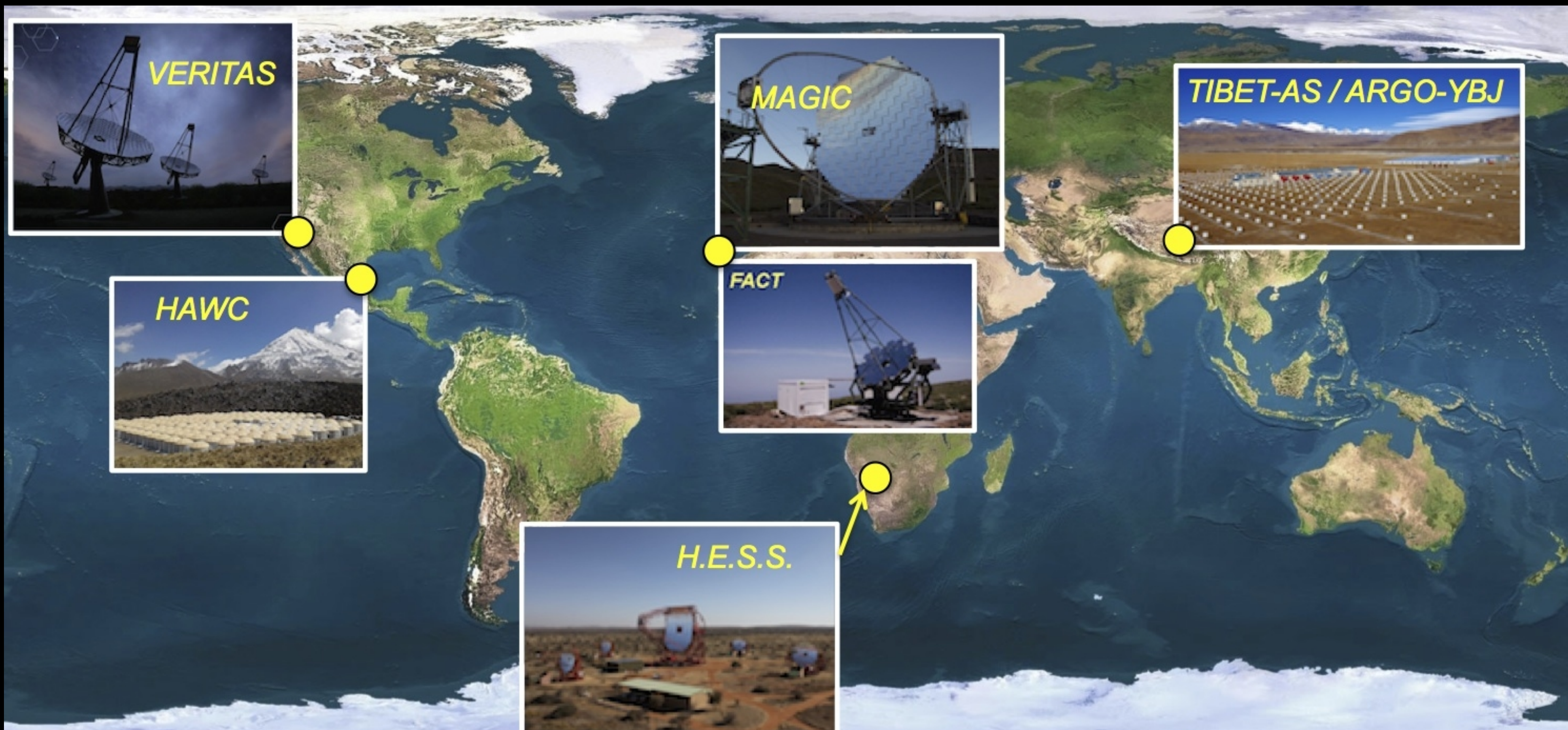
Complementarity of gamma-ray instruments

- Space-based detectors - continuous full-sky coverage in GeV

- Ground-based detectors have TeV sensitivity
    • Current Imaging Atmospheric Cherenkov Telescopes (IACTs) have excellent energy and angle resolution, but FoV of 0.003 sr and duty cycle of 10%
    • Particle detectors have an aperture > 2 sr and duty cycle of 90% but angular resolution of ~0.6° (@ 1 TeV)



INSTRUMENTS



Status of VERITAS

VERITAS has been operating smoothly since 2007 with 4 12m IACTs

Two major upgrades since inauguration:
In 2009, relocation of one of the telescopes
In 2011-2012, replaced the L2 trigger system and new high efficiency PMTs
Since fall 2012, observations carried out under bright moonlight: detection of flaring activity from the BL Lac object 1ES 1727+502

Energy range: 85 GeV to > 30 TeV
Sensitive to 1% Crab in ~25 hours
Angular resolution ~0.1° (68% containment)

VERITAS Highlight, 90, 676, 762

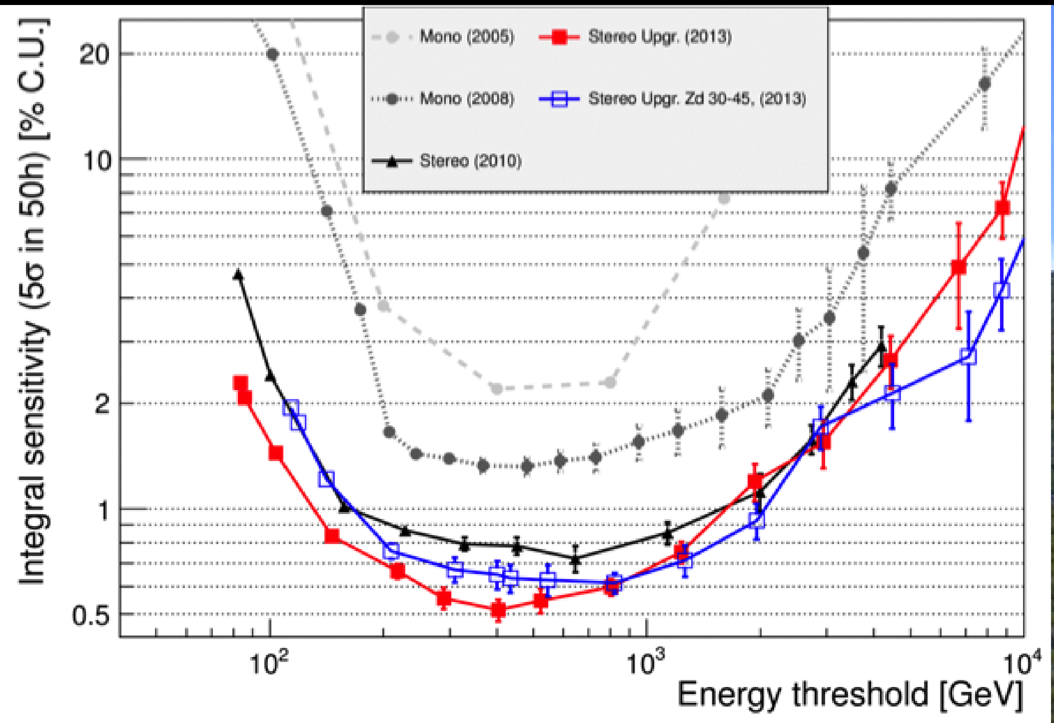
Status of MAGIC II

MAGIC is a system of two 17m diameter IACTs located at 2200m at La Palma
2 major upgrades in 2011-2012 (Camera, Data Acquisition)

During Winter 2013-2014, a new system (sum-trigger) was implemented for stereoscopic observations after several years of development

$E_{threshold}$ (trigger): ~ 50 GeV
$E_{threshold}$ *Sum-Trigger:* ~35 GeV
Energy resolution: (15-20) %
Angular resolution: (0.05-0.1)°
Sensitivity: ~ 0.6% Crab/50h

MAGIC Highlight, 60, 68, 101, 579



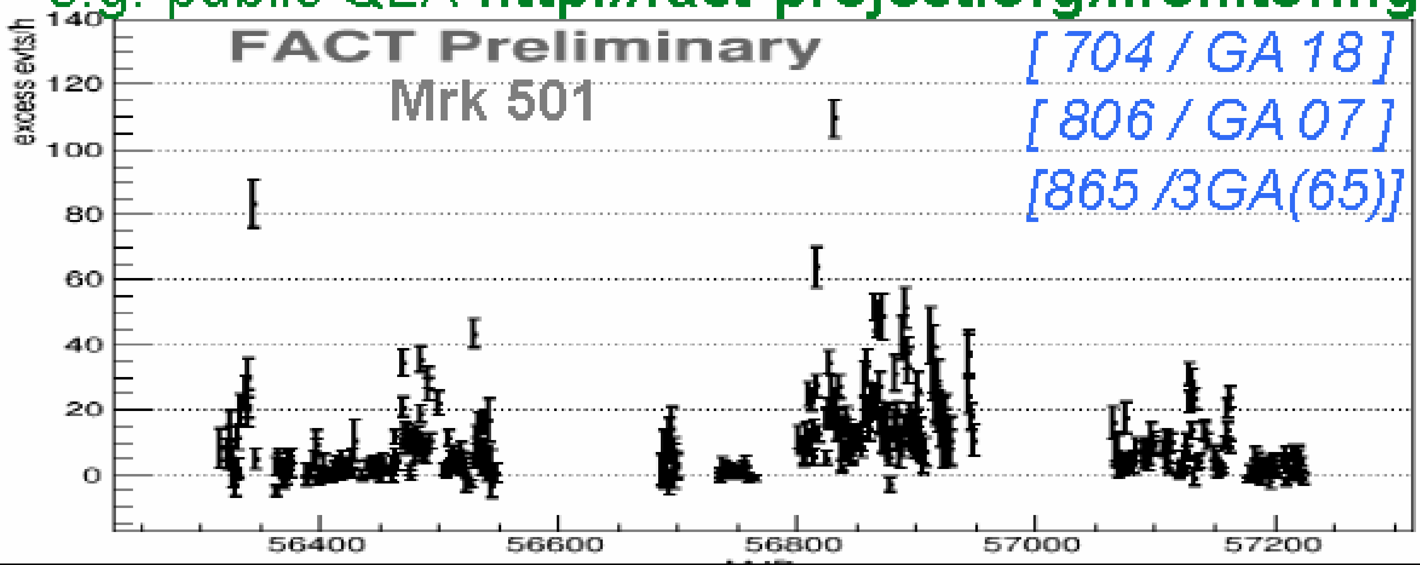
Status of FACT
First G-APD Cherenkov Telescope

October 2011: Mounted in refurbished HEGRA CT3 (9.5m2) @ La Palma
Equipped with a 1440 pixel GAPD camera; total FoV of 4.5°

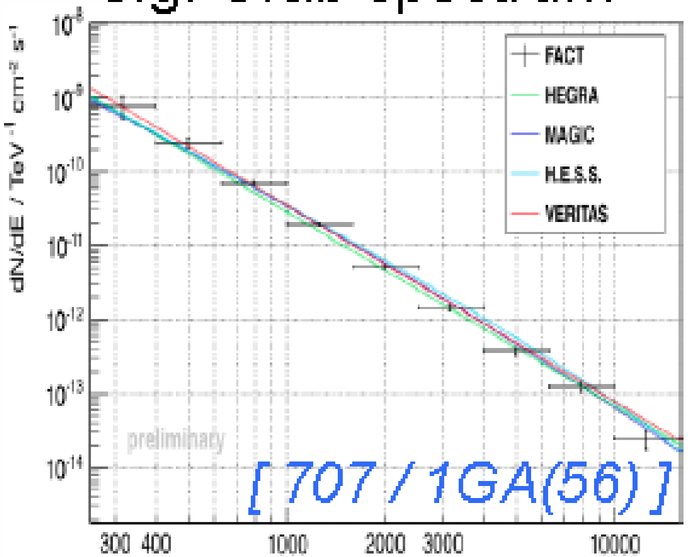
Completely remote operation since autumn 2012 => > 90% data taking efficiency
Safe operation under bright moonlight
< 0.02 failures per year
Stability allows to predict trigger rates and measure the quality of the atmosphere

56, 60, 67, 68, 84, 121, 1177, 704, 707, 806, 865

e.g. public QLA http://fact-project.org/monitoring



e.g. Crab spectrum



Status of H.E.S.S. II

HESS is an array of four 12m IACTs + one 28m telescope (CT5, FoV ~ 3.5°)

CT5 is operationnal since 2012
Energy range from 30 GeV to 100 TeV
Focus system of CT5 under study => Focusing close to the altitude of shower maximum maximizes the γ-ray acceptance close to the energy threshold

Major upgrade of HESS I camera from 2015-2016: reducing the dead time of the cameras, improving the overall performance of the array and reducing the system failure rate related to aging

62, 98, 107, 108, 1011, 1046

Status of HAWC

HAWC Highlight, 96, 112, 418, 529, 692, 716, 739, 829

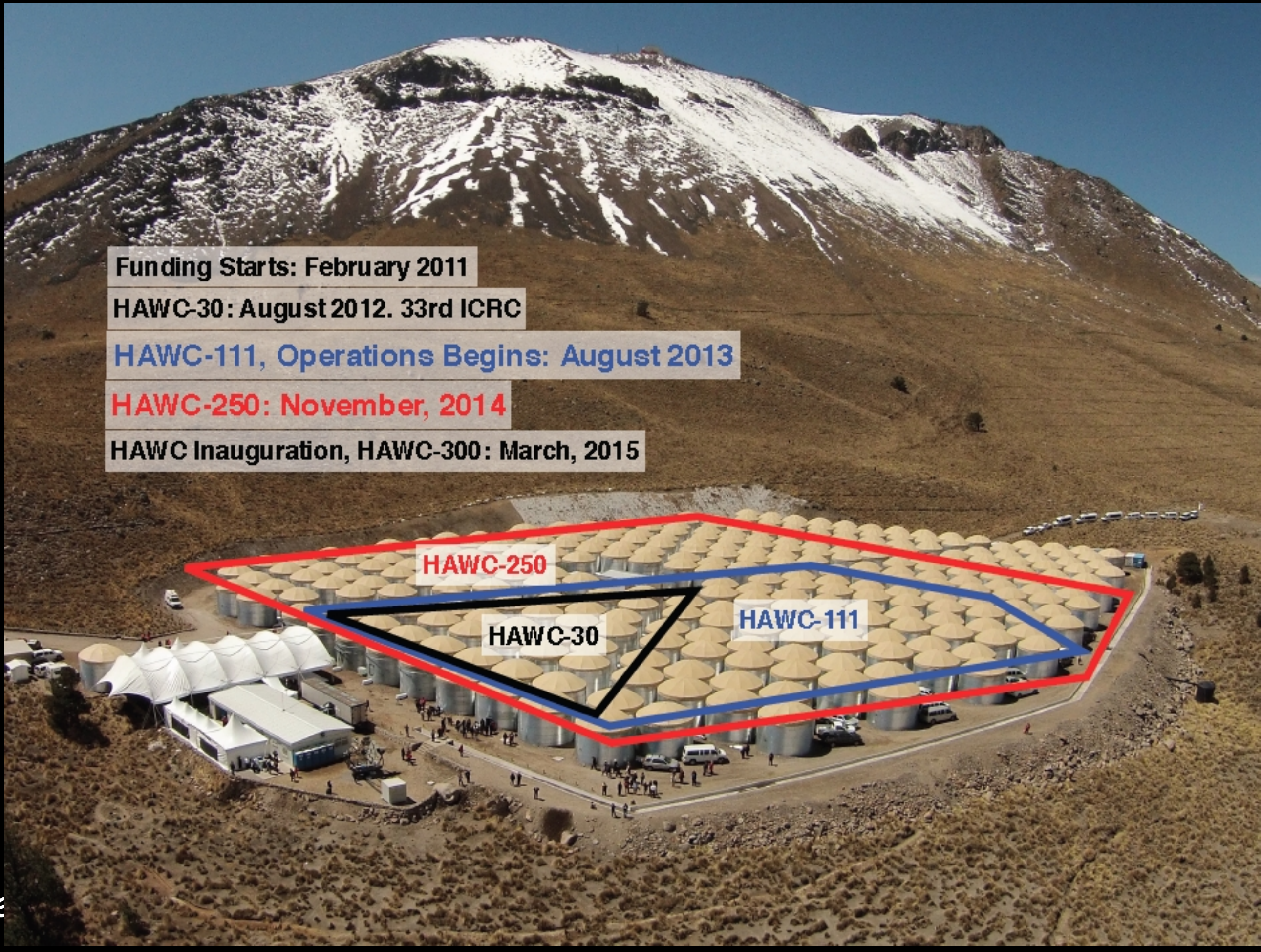
Array of water Cherenkov detectors (WCDs) spread on a 22 000 m2 area
Located on the slope of the Sierra Negra Volcano in Mexico
HAWC construction ended in March 2015 but data collection started already 2 years before, producing the first scientific results

HAWC Inauguration, HAWC-300: March, 2015

100 GeV - 100 TeV Sensitivity

Public data release of all-sky data in 2017

HAWC Sparse Outrigger Array: Enhanced Sensitivity above 10 TeV



Status of ARGO-YBJ

849, 162

Tibet, China, 4300 m above sea level

Full coverage with RPC detectors

Large field of view

Zenith angle < 50°

Survey of the Galactic plane at $25^\circ < l < 100^\circ$ and $130^\circ < l < 200^\circ$

Energy threshold

300 GeV => Overlaps the Fermi-LAT energy range

Angular resolution

0.99° for $N_{pad} > 100$

Five years of stable operation until February 2013

Sky survey of the Northern hemisphere at 24% Crab flux sensitivity

M.

Status of Tibet ASγ + MD

426, 452, 953, 1181

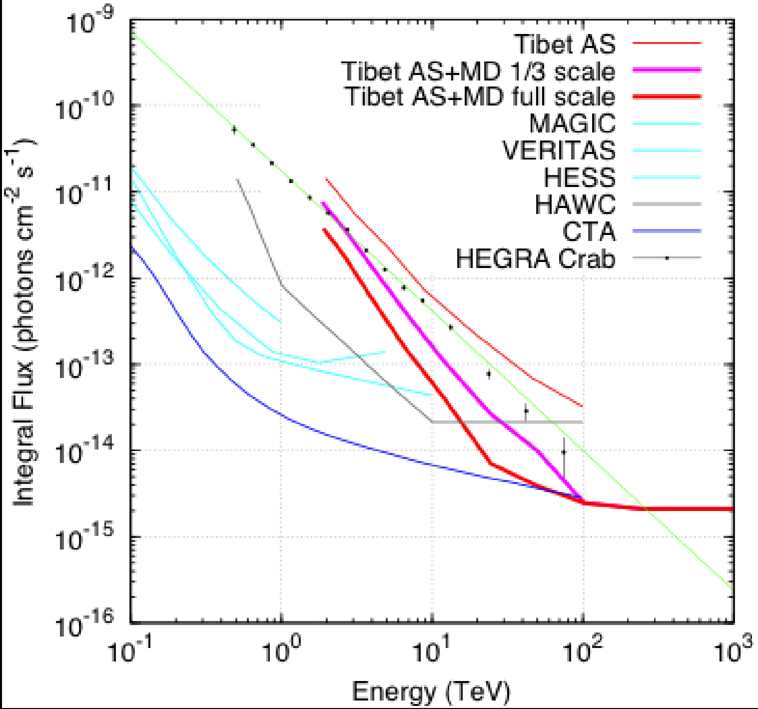
37000m2 air shower particle detector array

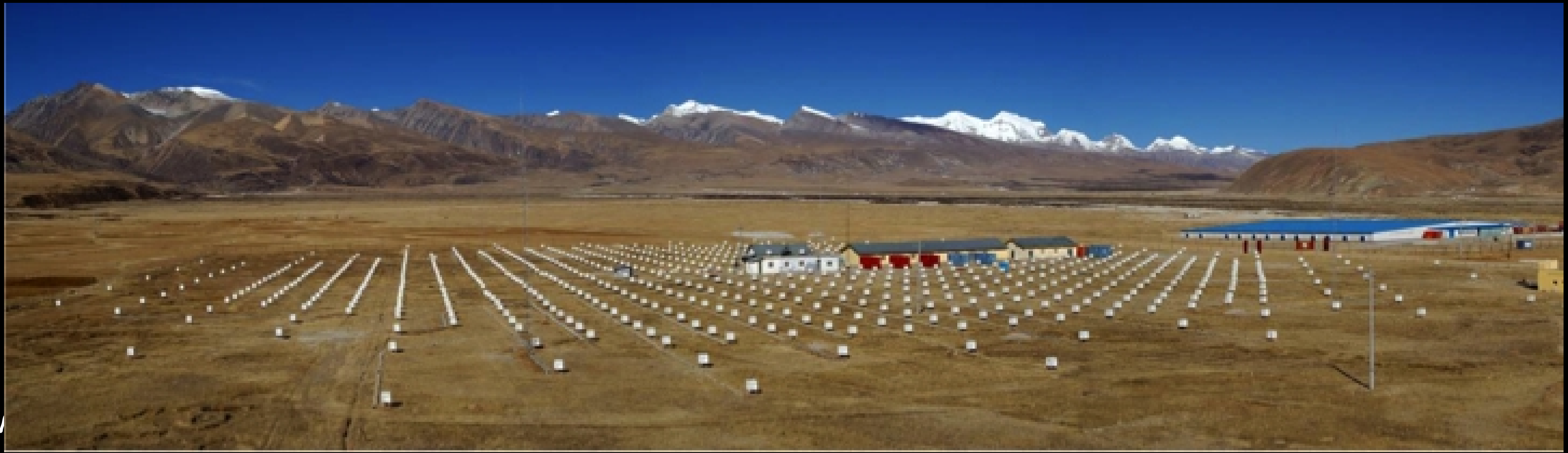
789 scintillator detectors, at 4300m a.s.l.

Tibet III in operation since 1999

Energy interval: ~TeV to 100 PeV
Angular resolution: ~0.2° @ 100 TeV

Muon detector array under construction:
- data taking has started with 5/12 since 2014
- reduce background CRs by selecting γ-like events



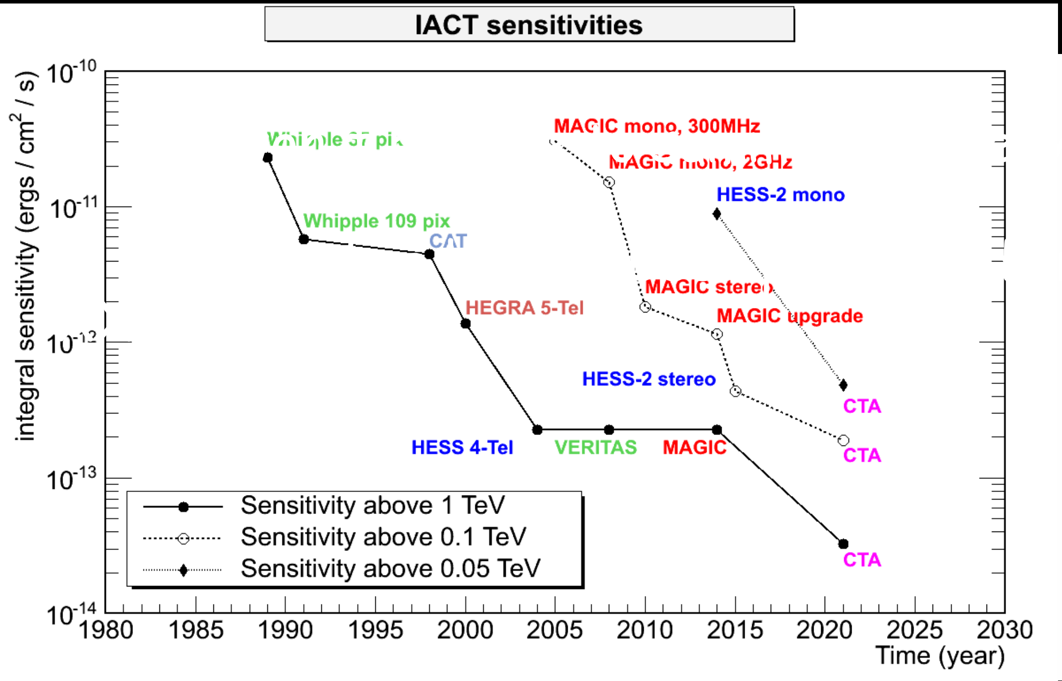


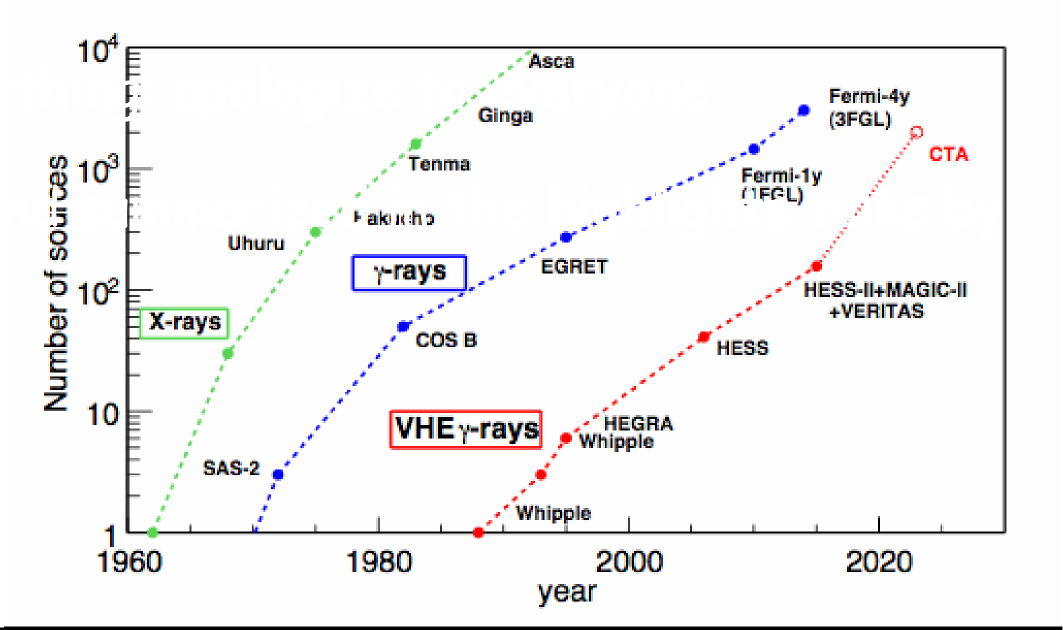
M. Le

Improving sensitivity & Number of sources growing

- Sensitivity of TeV instruments is far from being saturated

- Exponential rise in the number of sources since ~25 years





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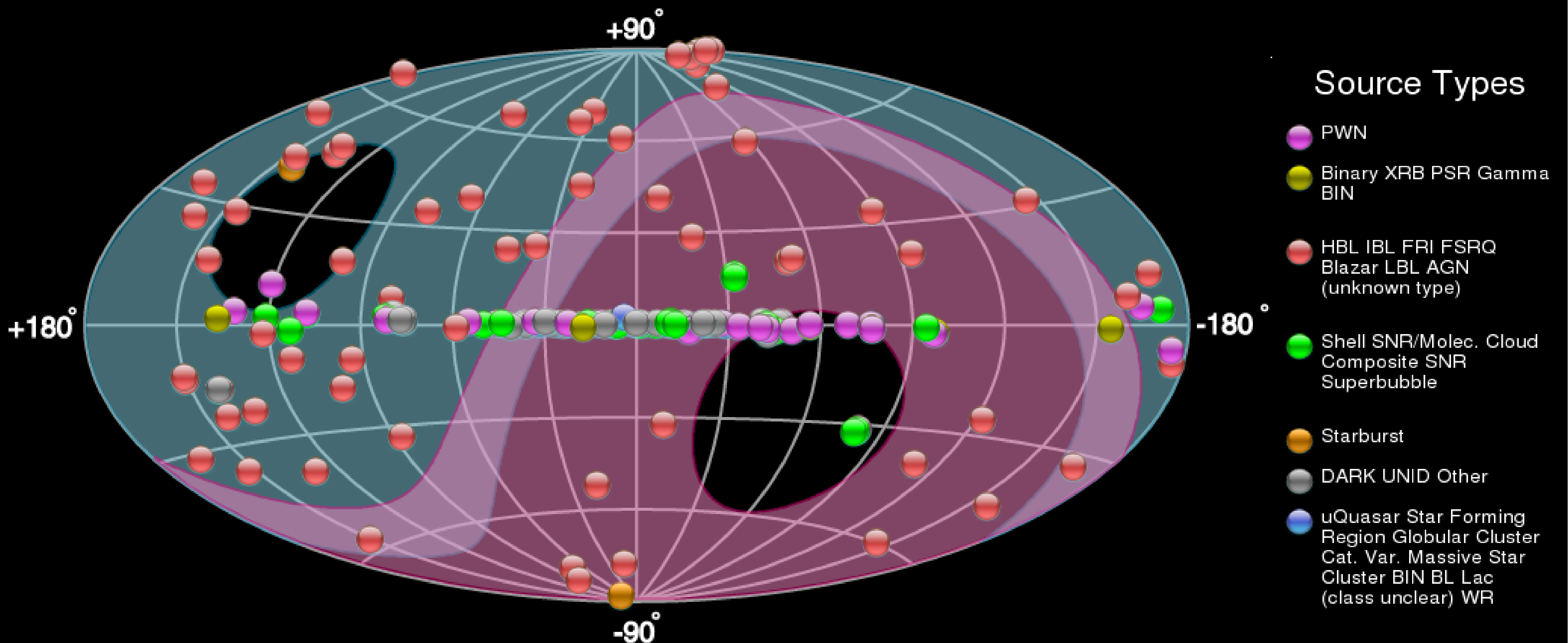
The TeV sky today: a large variety of sources

Already 162 detected sources reported in the TeV Catalog in August 2015 !
65 sources are extragalactic – 70 are Galactic – 27 UNID



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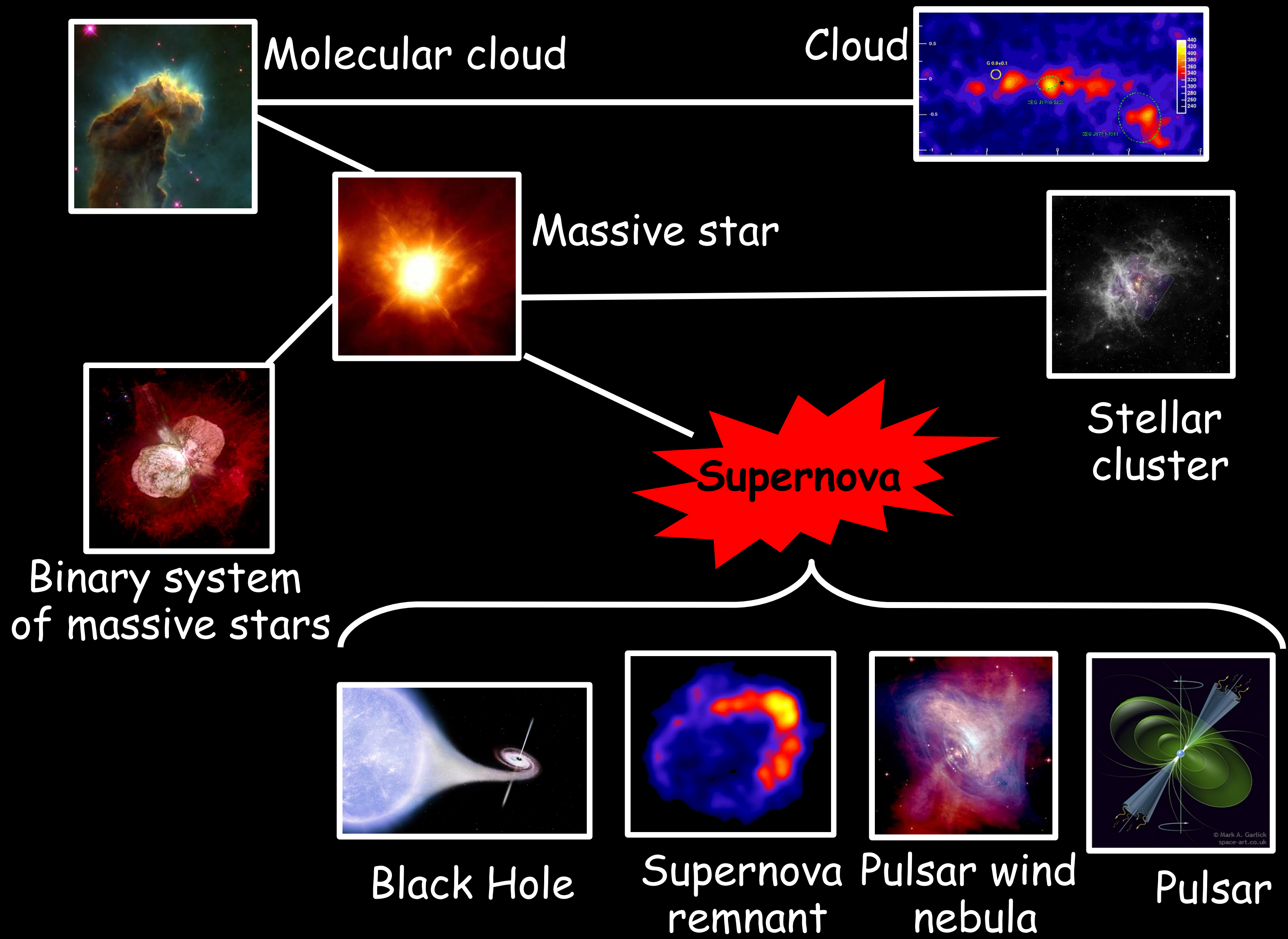
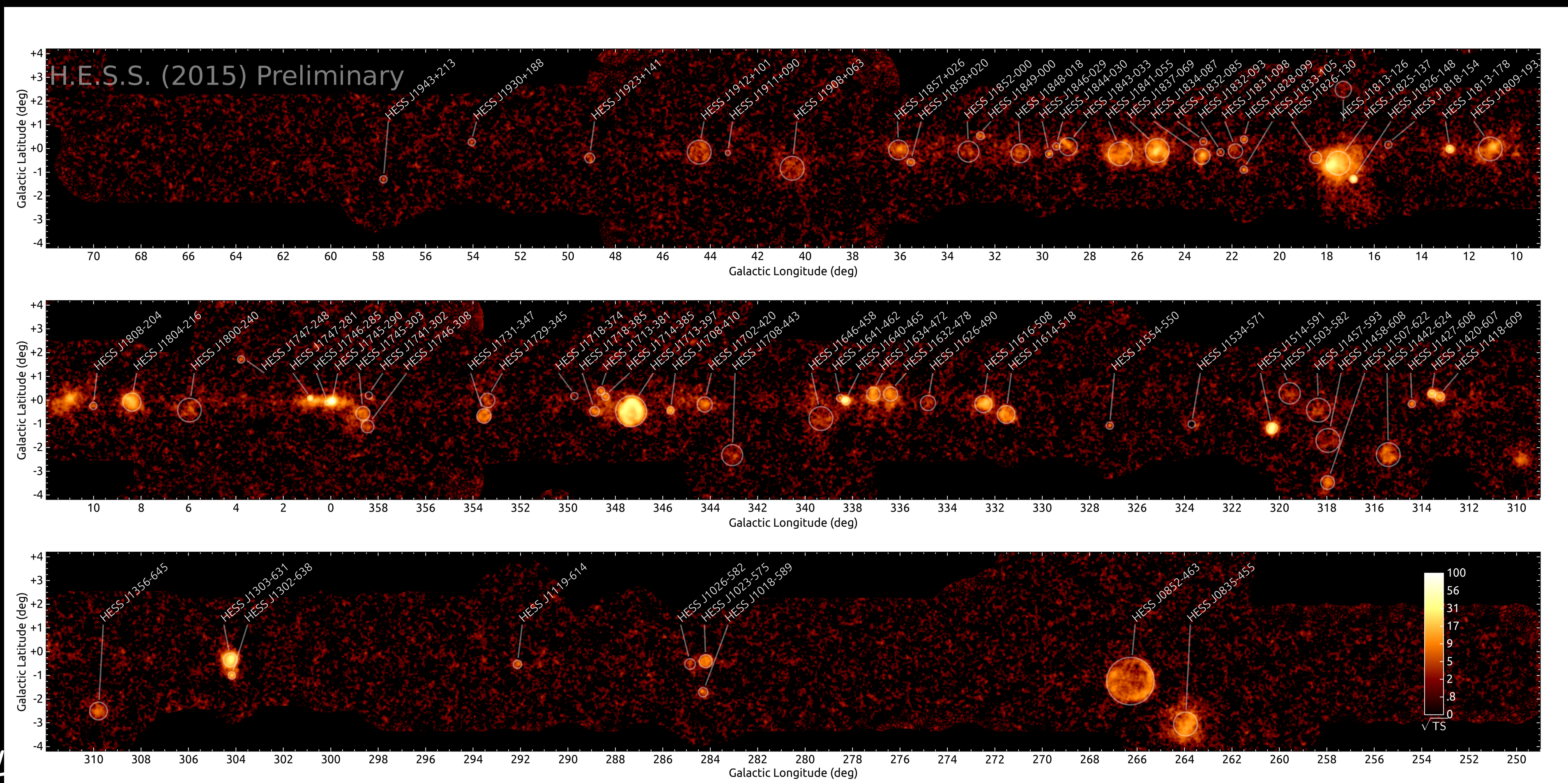
GALACTIC SCIENCE



H.E.S.S. Galactic Plane Survey

54, 627

Final HESS catalog of survey sources
Data collected 2004 – 2013
3000 hours
Significance and flux maps
Automatic pipeline for source extraction
64 VHE sources
+ 13 complex sources (e.g. shell SNR) excluded



M. L

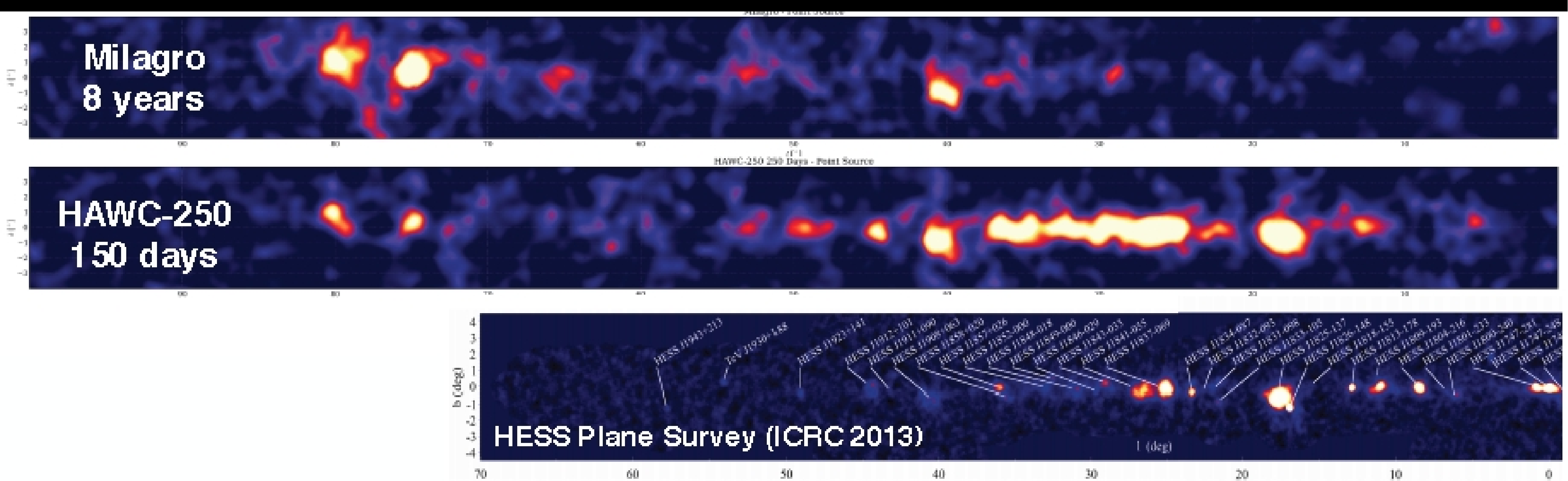
More on surveys with HAWC

First analysis of Galactic Plane with HAWC
Longitude between [+15°, +50°] and latitude between [-4°, +4°]
New likelihood framework allowing to fit jointly flux and position of sources

10 source candidates, 8 of them with possible TeV counterparts

source candidate	α	δ	pre-trial significance	possible association	type
1HWC J1857+023	$284.3° \pm 0.1°$	$2.3° \pm 0.2°$	$7.1\,\sigma$	HESS J1857+026, HESS J1858+020	PWN UID
1HWC J1838-060	$279.6° \pm 0.1°$	$-6.0° \pm 0.1°$	$7.0\,\sigma$	HESS J1841-055	UID
1HWC J1825-133	$276.3° \pm 0.1°$	$-13.3° \pm 0.1°$	$6.4\,\sigma$	HESS J1825-137	PWN
1HWC J1844-031	$281.0° \pm 0.1°$	$-3.1° \pm 0.1°$	$5.8\,\sigma$	HESS J1843-033	UID
1HWC J1907+062	$286.8° \pm 0.2°$	$6.2° \pm 0.2°$	$5.7\,\sigma$	MGRO J1908+06	UID

737, 323

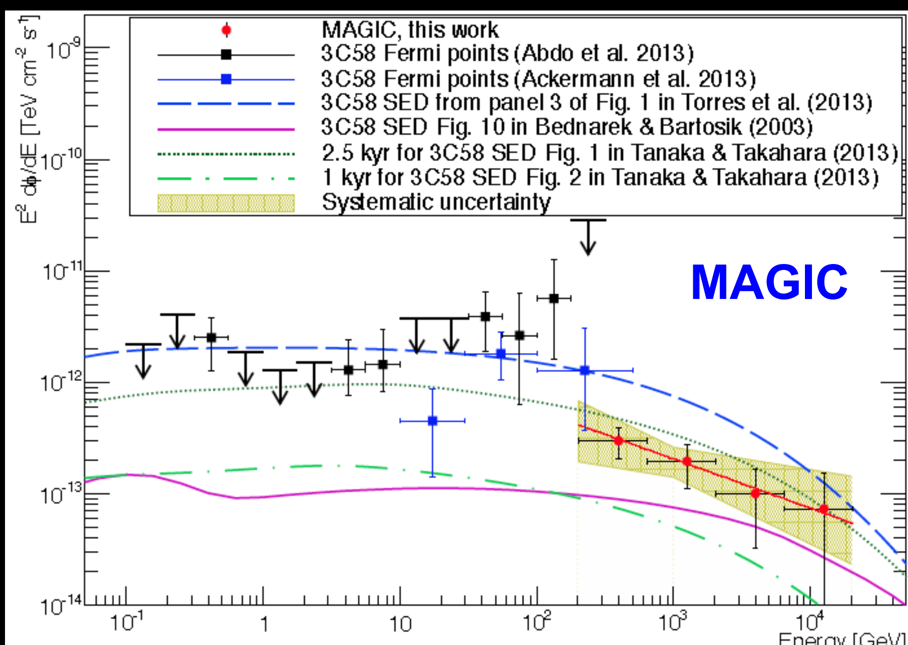


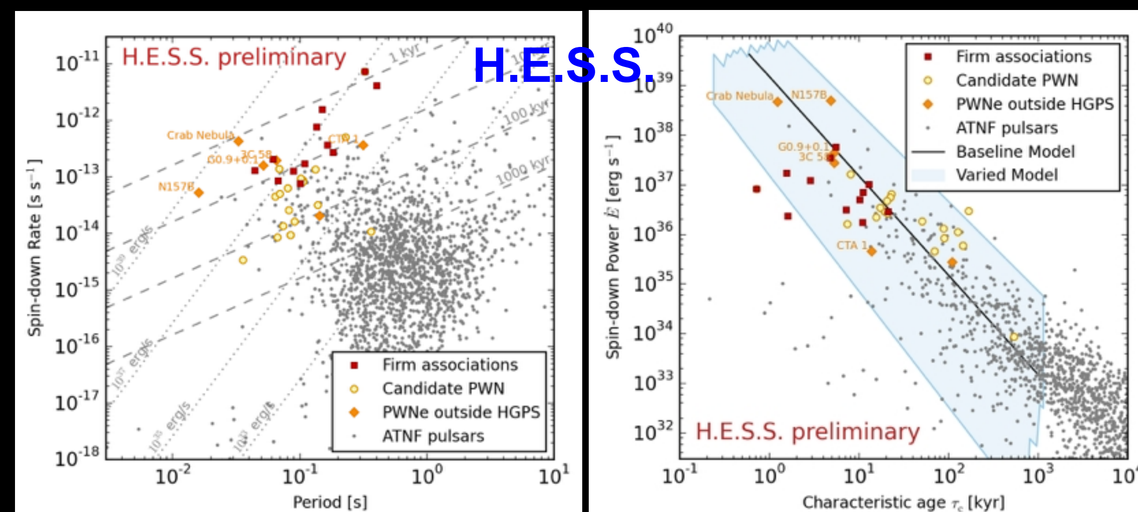
Pulsar Wind Nebulae (PWNe)

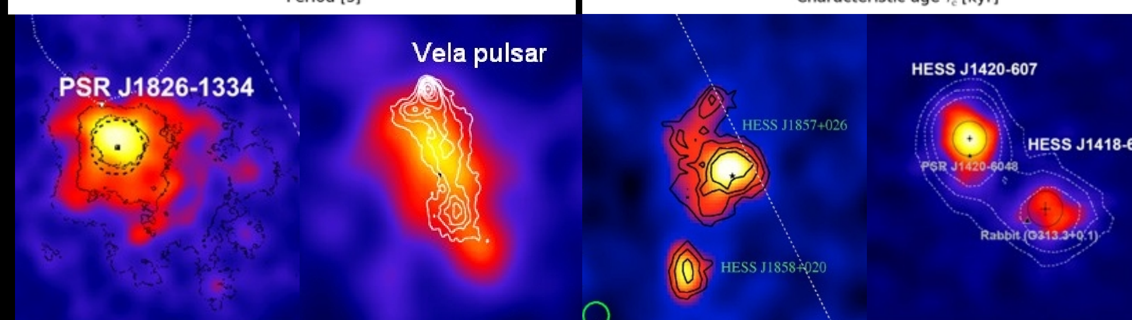
289, 323, 635

Dominant class of objects in the Galactic Plane survey are PWNe
New PWNe are still being detected (eg. 3C58 by MAGIC)
Population studies show trends but also variations in the evolutions of the systems

May be due to differences in surrounding medium and intrinsic starting conditions







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The most famous PWN: the Crab Nebula

VERITAS (115 hours):
No evidence for extension of the nebula;
No variability during the flares

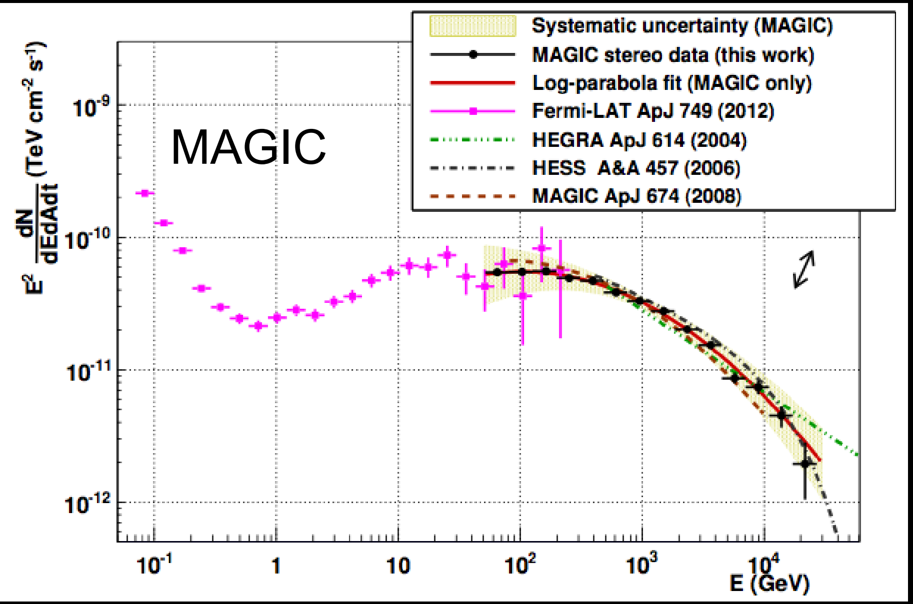
HAWC:
Clear detection at 38σ with HAWC-250;
No variability detected during the flares

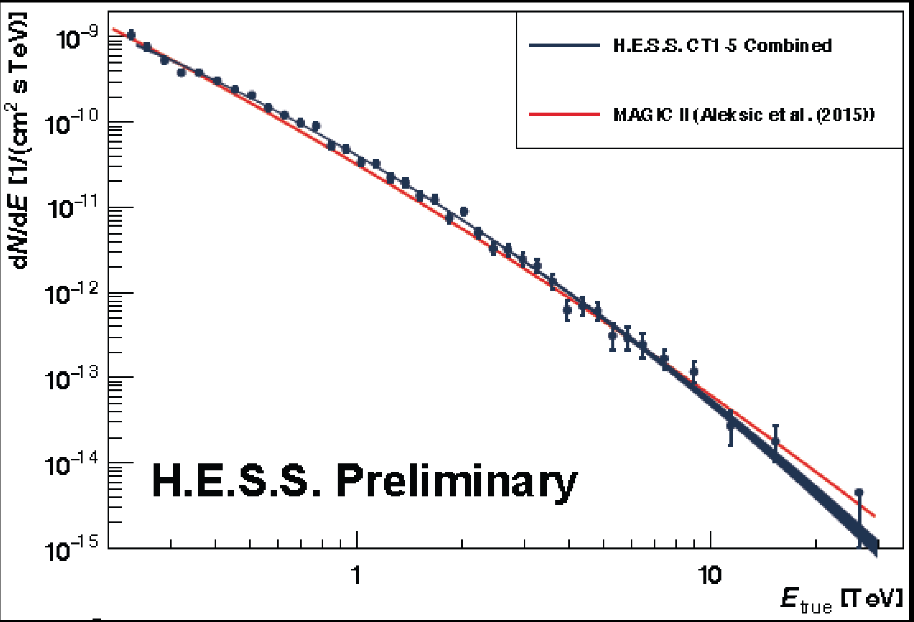
MAGIC:
Spectral measurements cover 3 decades in energy => new challenges to models

HESS II (7.5 hours):
New spectrum with energy threshold of 230 GeV

Tibet AS gamma:
No detection above 140 TeV
Strong Upper Limits

91, 348, 707, 940, 953, 1046





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A detour to the positron excess with Geminga

247, 322, 726, 1157

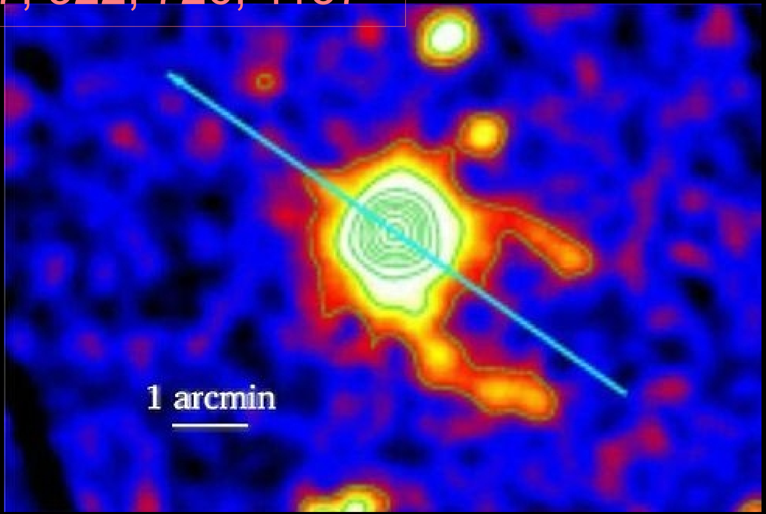
HAWC excess of 6.3σ at the location of the Geminga pulsar with an additional 3° smoothing

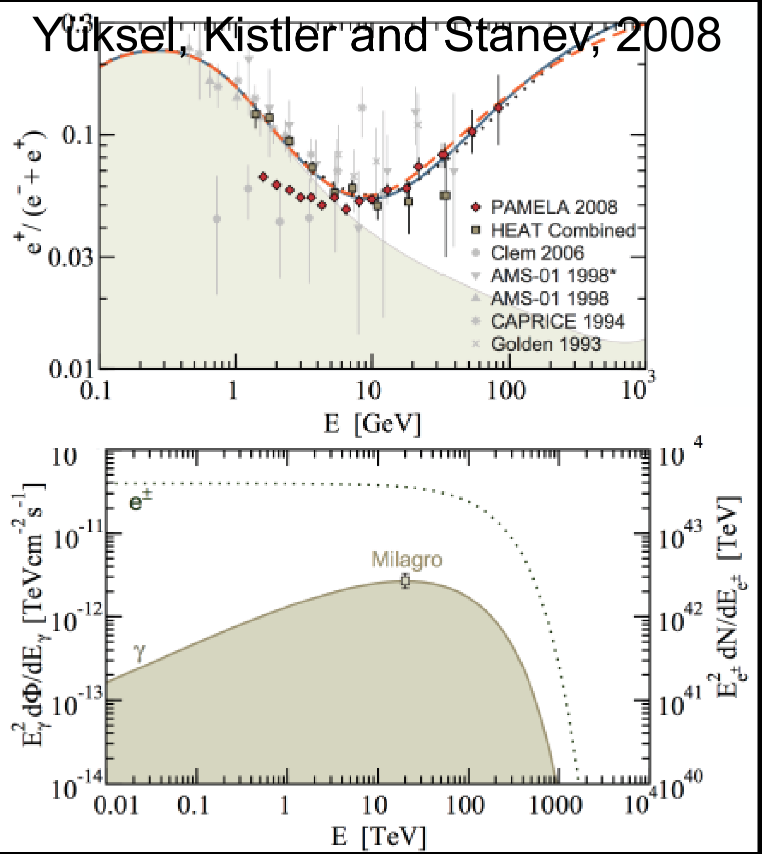
Consistent with Milagro's observation of an extended source around the Geminga pulsar

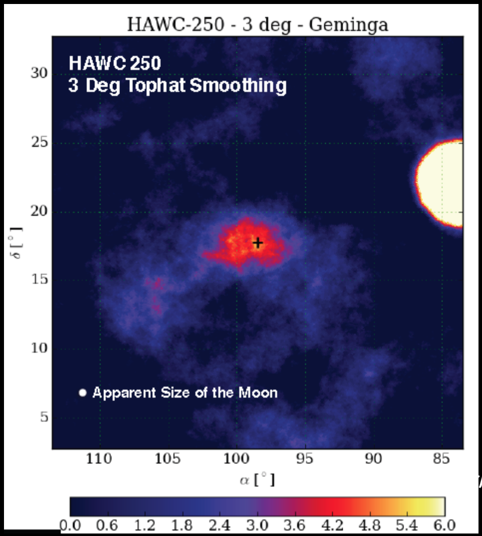
Consistent with a spectrum harder than the Crab but a Crab-like spectrum cannot be ruled out

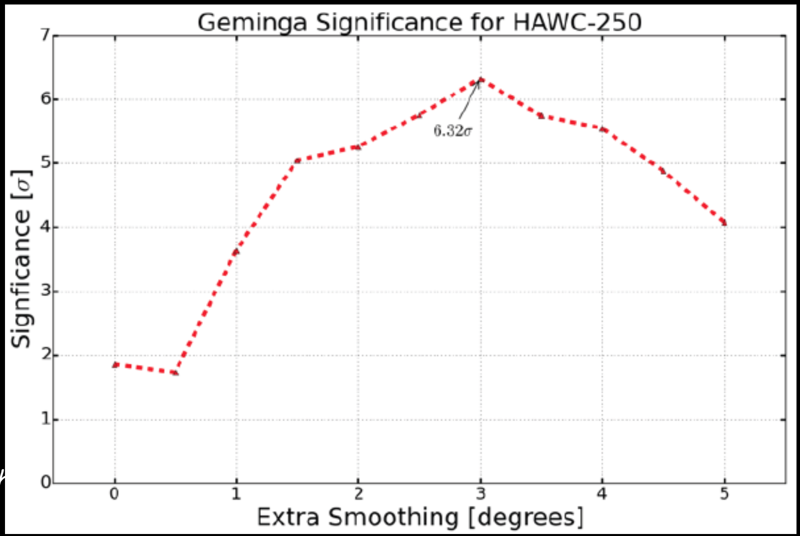
No detection by MAGIC and VERITAS

Could be the source of the positron excess ?







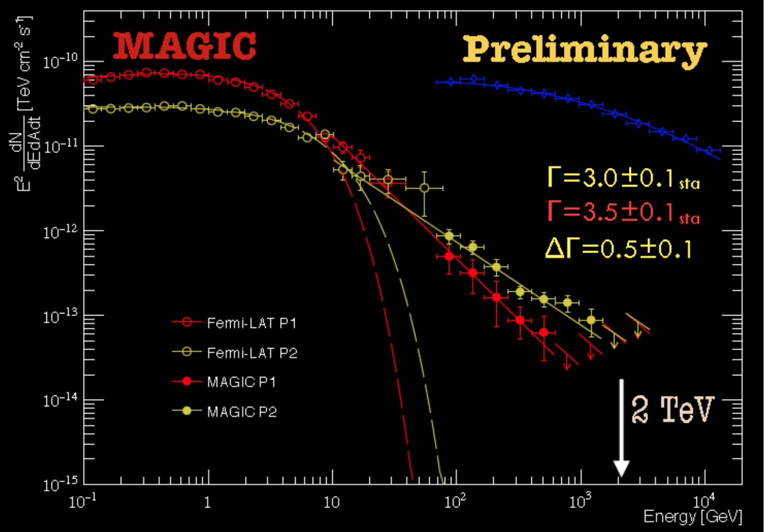


Pulsars

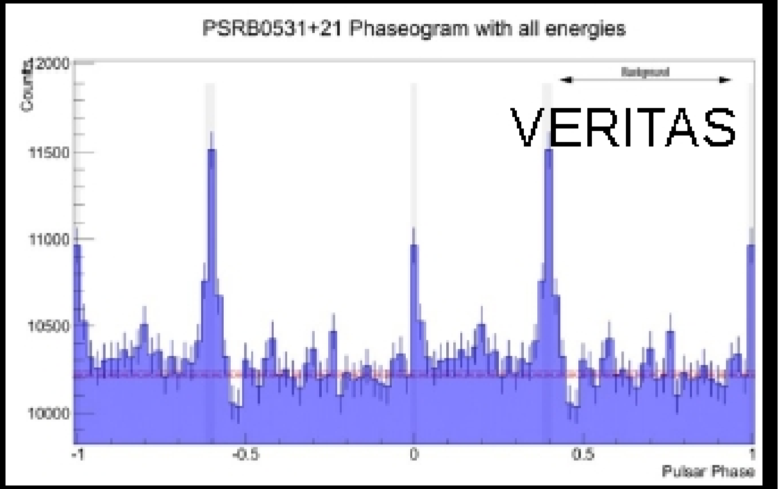
74, 78, 92, 322, 360, 1013

VERITAS observations of the Crab:
 - Pulsed Emission > 400 GeV

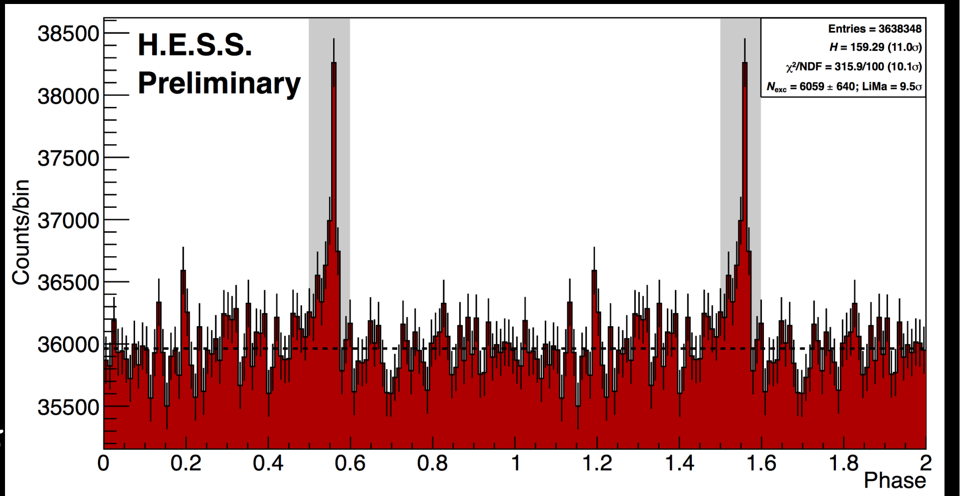
MAGIC observations of the Crab:
 - Pulsed Emission from 10 GeV to > 1 TeV
 - Emission from the bridge (toroidal bending of B lines?)



Challenges for pulsar models:
 - Impossible to reach such energies via synchro-curvature => inverse Compton
 - Emission from the neighbourhood of the Light Cylinder (r ~1600km)
 - Difficult to explain simultaneous lightcurve



HESS observations of Vela:
- Second VHE pulsar detected
- Deep observation campaign needed to investigate maximum energy



Strong Upper limits on pulsed emission from Geminga by MAGIC and VERITAS

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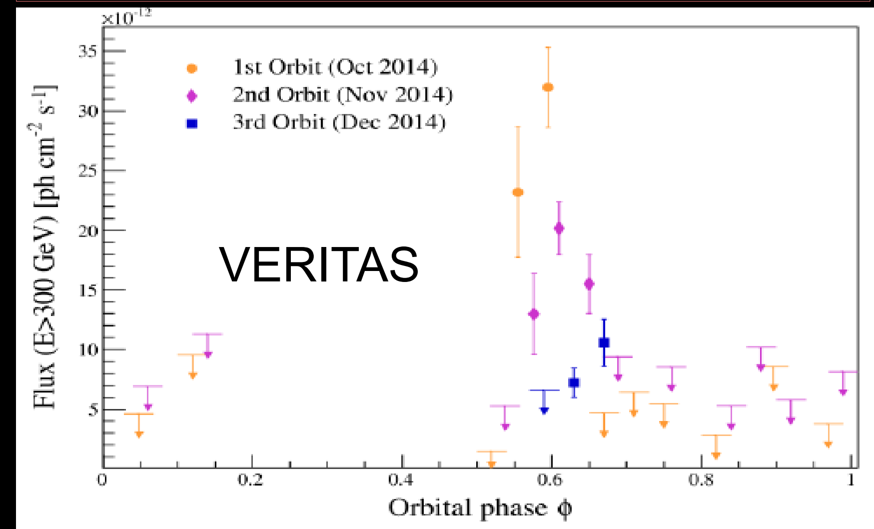
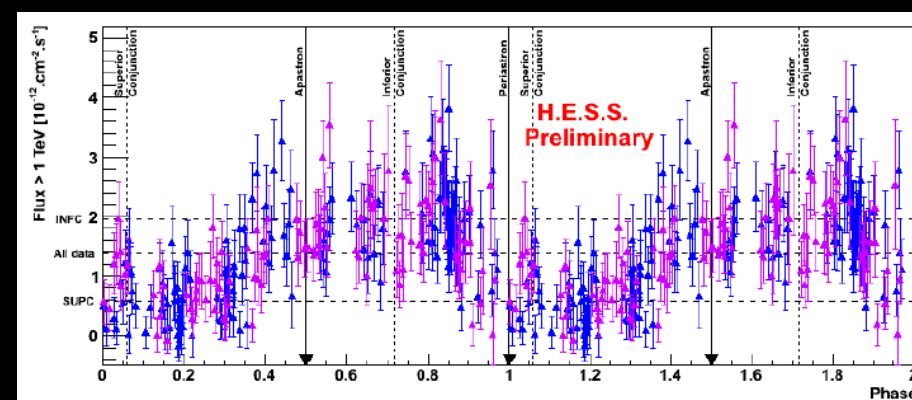
Gamma-ray Binaries

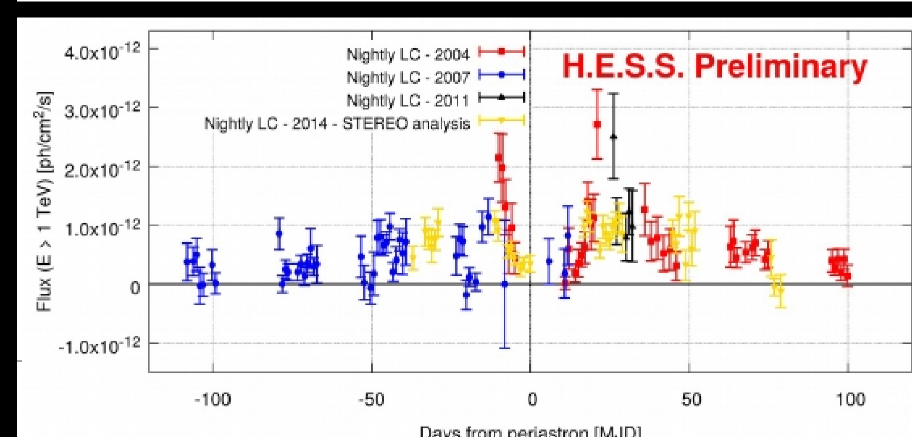
Binaries session, 217, 447, 662, 1000



LSI +61 303:
- Compact object + Be star
- Orbital period: (26.496 +/- 0.0028 days)
- Super-orbital period: (1667 +/- 8) day detected by MAGIC
- Brightest detection of the source by VERITAS during the October flare (30% Crab flux) with a rise and fall < 1 day



LS 5039:
- Compact object + OB star
- New H.E.S.S. II data
- Perfectly periodic over 10 years: swiss clock



PSR B1259-63:
- Only binary system for which the compact object has been confirmed to be a pulsar
- New H.E.S.S. II data
- Smooth flux decline towards a relative minimum of the TeV emission at periastron

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New views on Supernova remnants (SNRs)

323, 400, 612, 596, 726, 973, 1107, 1136, 1268, 1299

New shell-type SNRs by HESS

HESS J1534-471 & HESS J1912+101

Shell identification (RCW 86)

New VERITAS spectrum on Cas A

Covers 400 GeV to 7 TeV

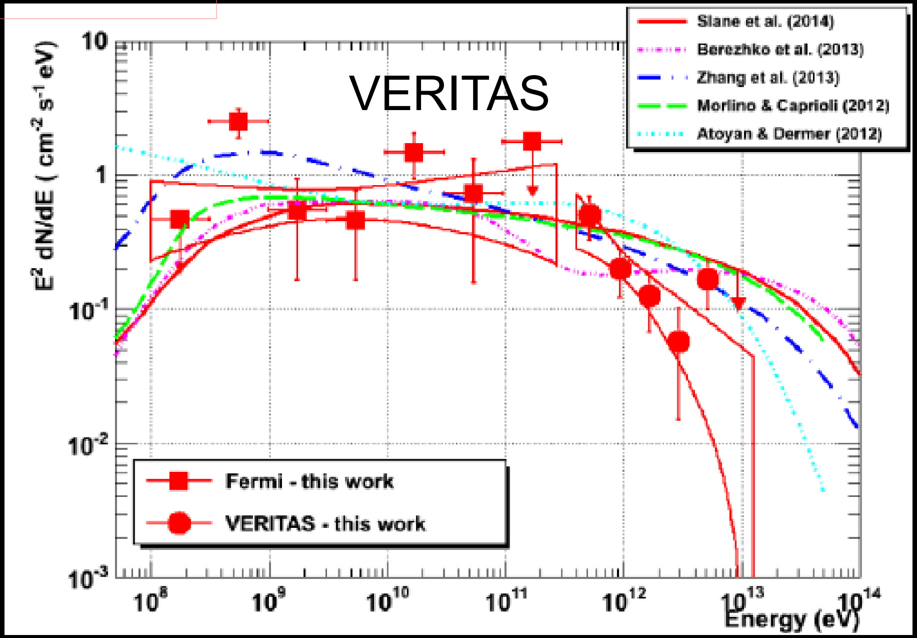
Softer spectrum on Tycho

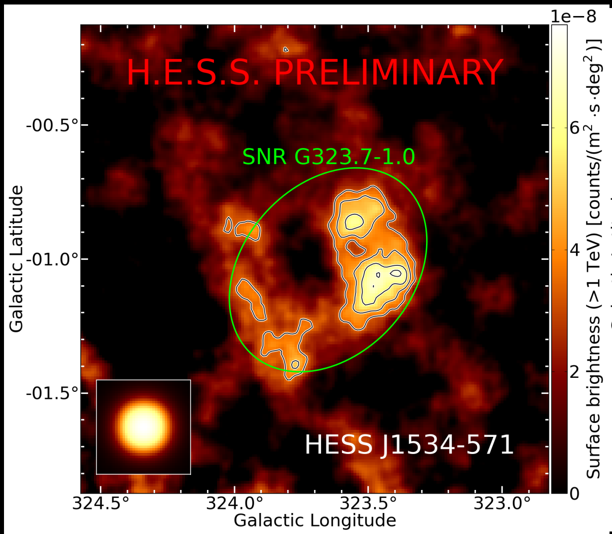
Data are in tension with emission models

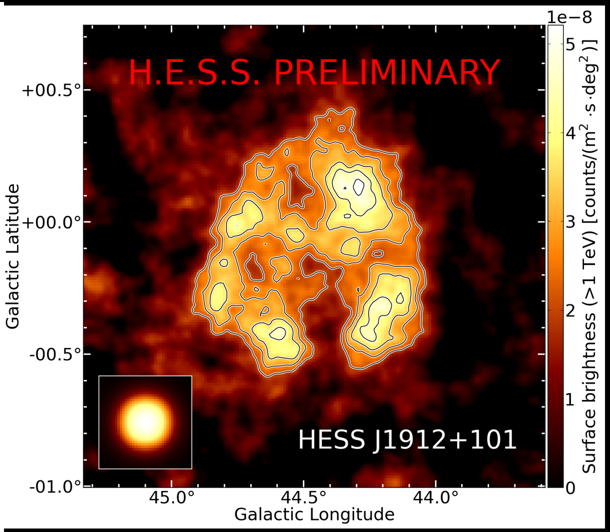
Spectro-imaging of RX J1713.7-3946 by H.E.S.S.

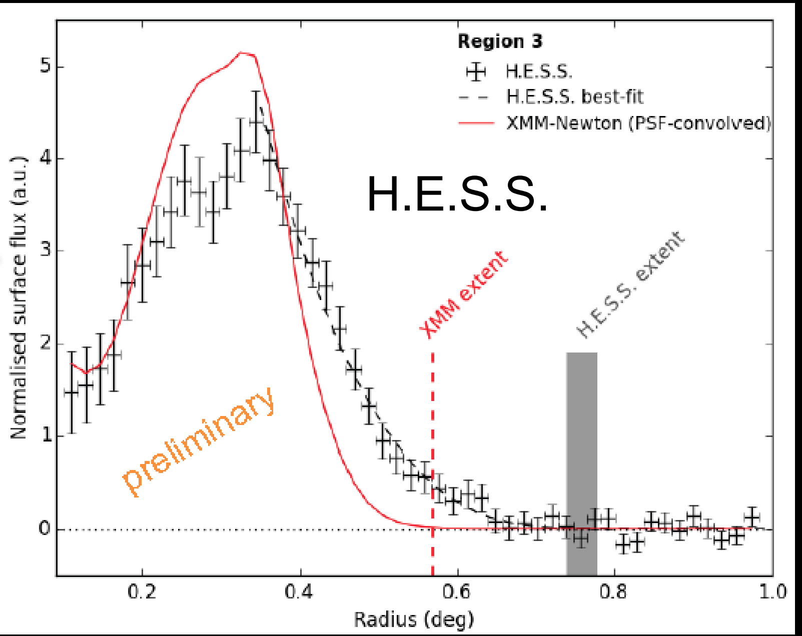
Difference between X-ray and gamma-ray profiles

Particle escape or B field geometry ?



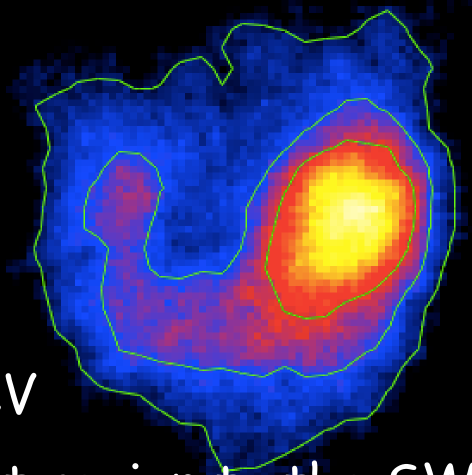






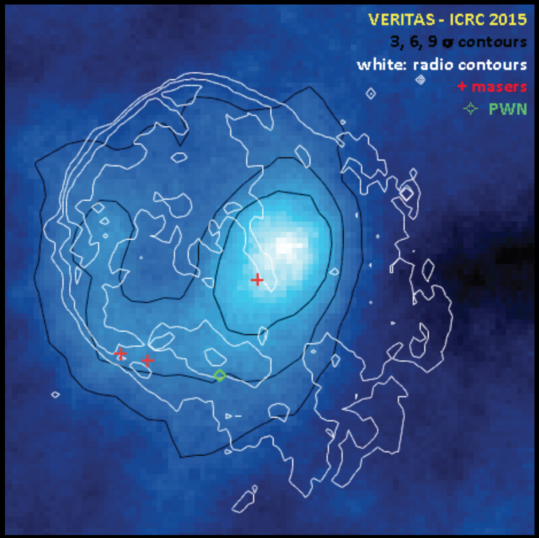
Resolving the Jellyfish Nebula (IC 443) in γ-rays

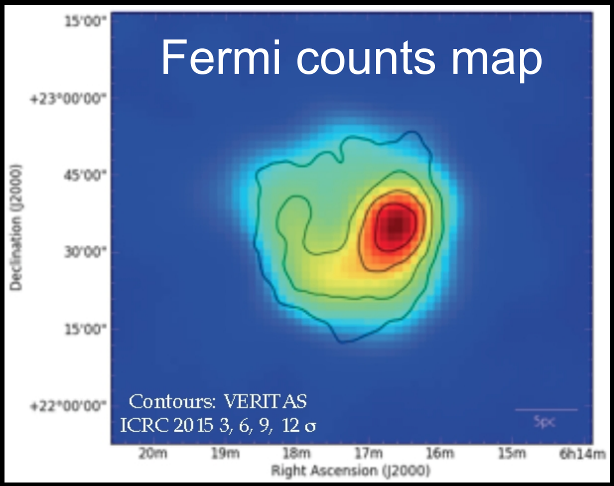
1214

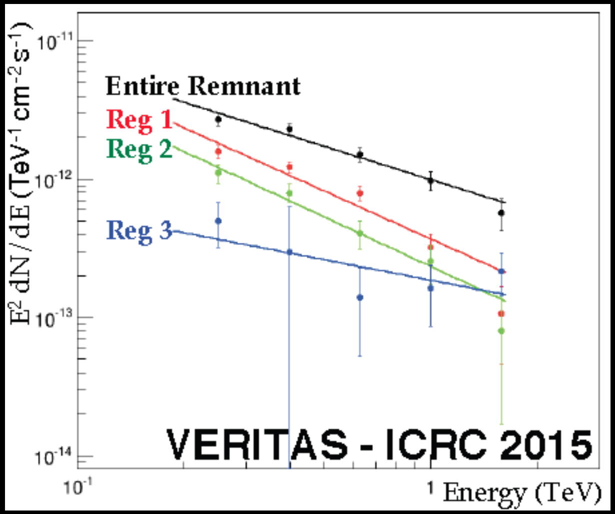


- VERITAS deep observation of IC 443
- Significant VHE emission from the entire northeast lobe
- VHE emission probes very different environmental conditions
- Pass-8 Fermi-LAT data reveals similar morphology above 5 GeV
- No significant emission detected associated with the breakout region to the SW

=> Can extract spectra from different regions to probe the environmental dependence of cosmic-ray diffusion



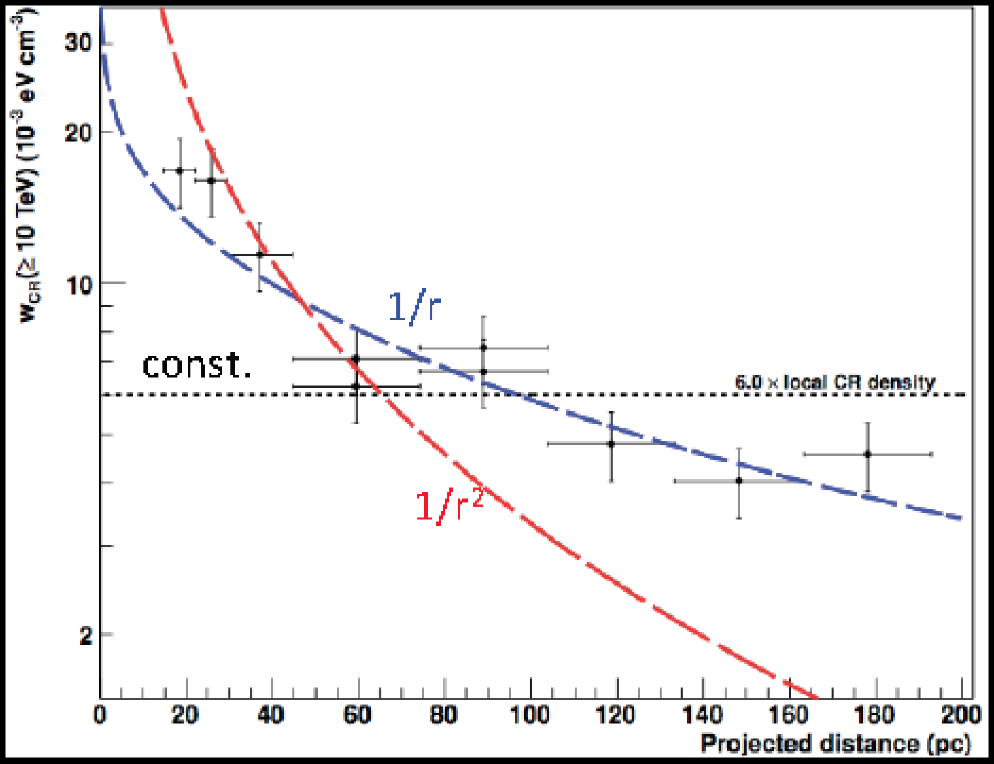


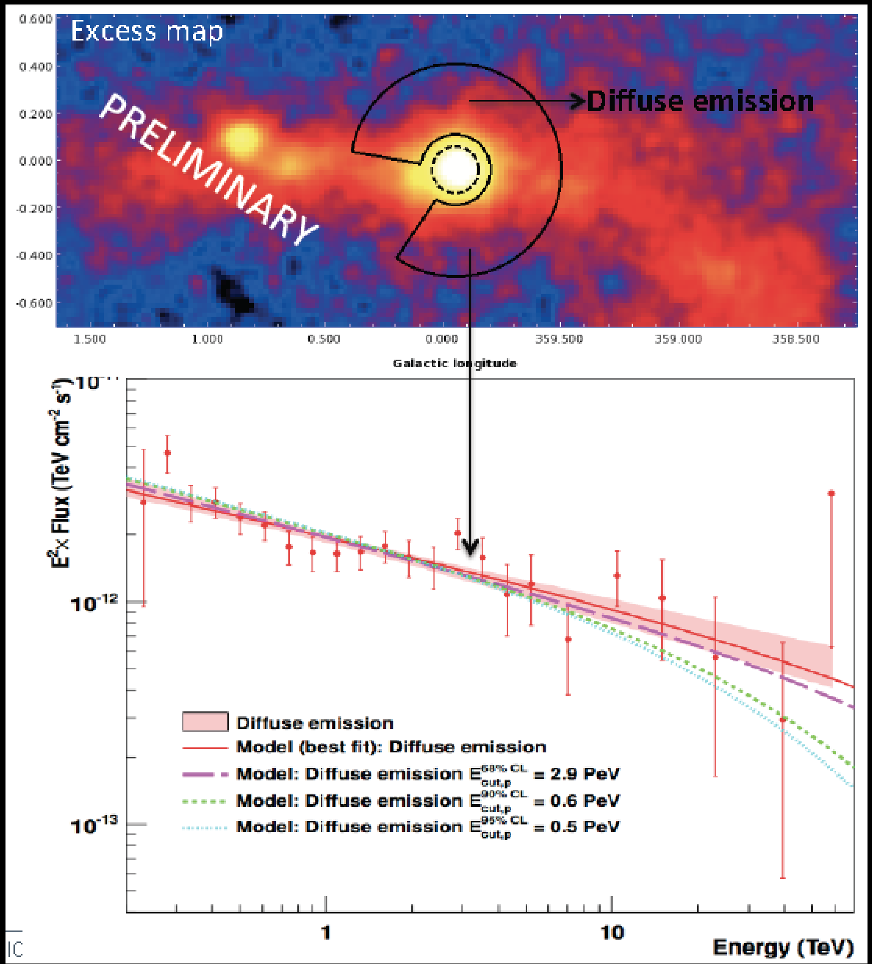


The Galactic Centre

982, 1254

HESS: Deep observation (250h)
Half of GC ridge emission is distributed like dense gas tracers + large scale component + extended component centered on the Galactic center
HESS J1746-285 coincident with the Fermi Arc source and the PWN G0.13-0.13
Diffuse emission shows no cut-off
=> constant injection and diffusion for > 1 kyrs
=> emission likely due to propagation of protons from central black hole
=> parent proton population up to 1 PeV: first detection of a PeVatron





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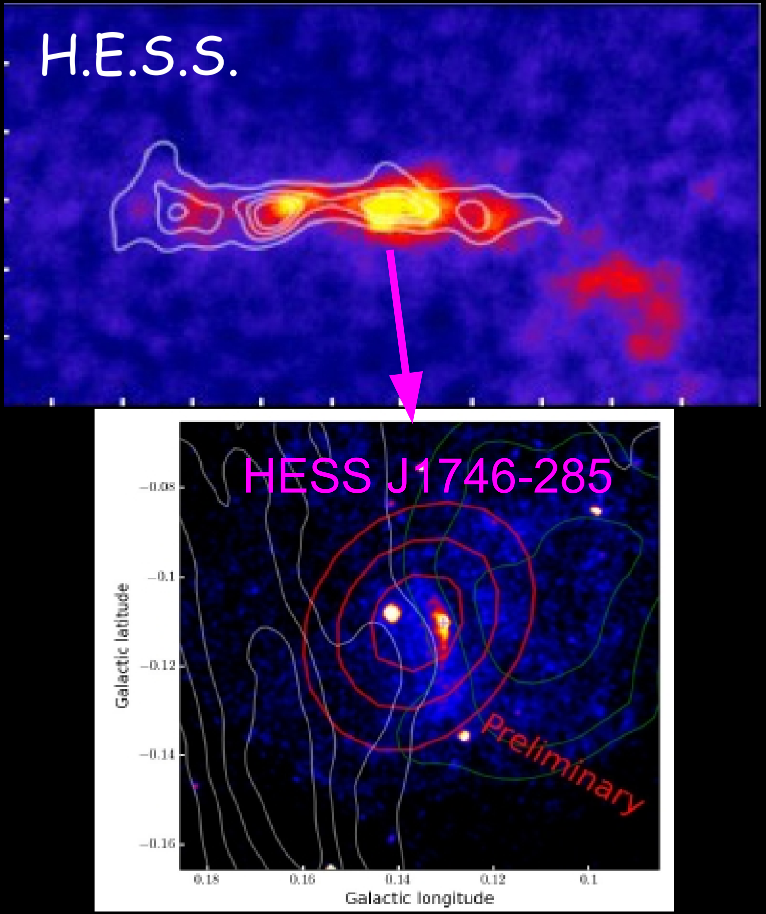
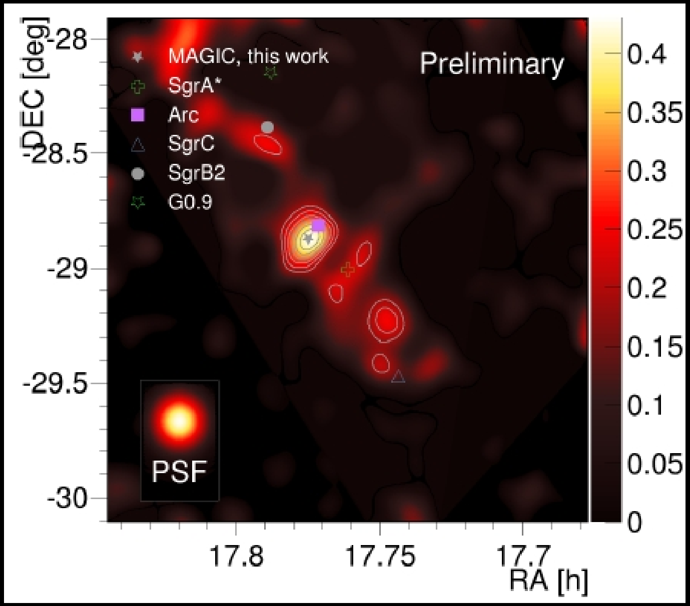
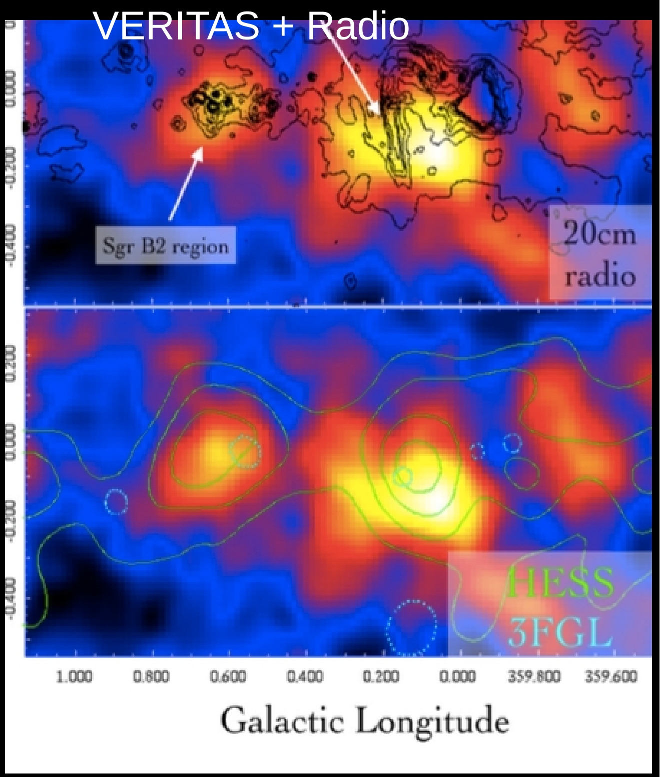
Diffuse emission

431, 686, 1092, 1188, 1254

VERITAS: Diffuse emission at GC correlates with radio, 3FGL & HESS
MAGIC: detailed imaging and spectral studies of the GC region
detection of a new source coincident with the radio Arc (HESS J1746-285 ?)
ARGO-YBJ study of diffuse emission in the Galactic plane from 350 GeV to 2 TeV
- Spatial distributions for 25°<l<100° and 130°<l<200° consistent with Fermi
- Energy spectra obtained in different regions







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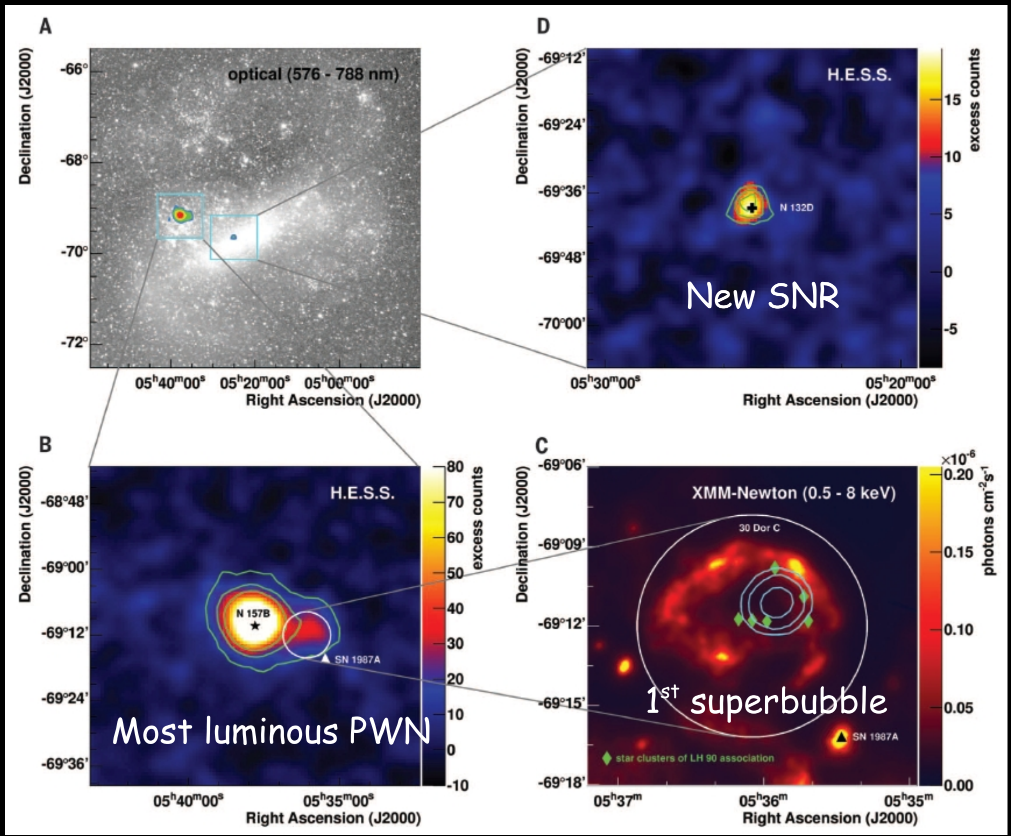
The Large Magellanic Cloud (LMC)

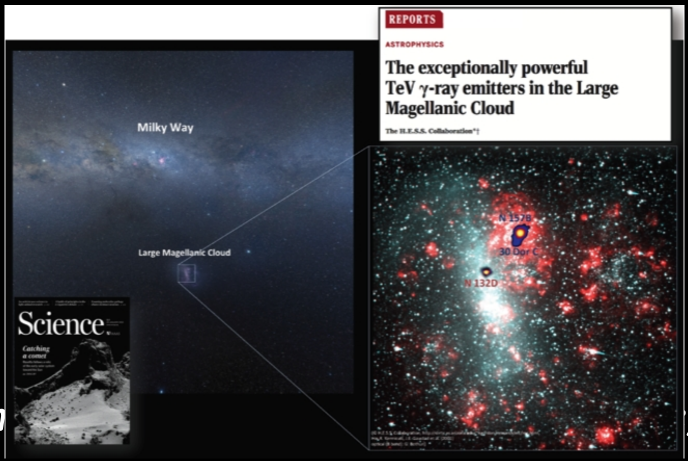
1053

3 TeV sources in LMC:
- PWN N 157B
  Crab counterpart but low B field
- 30 Dor C
  first unambiguous detection of
  a superbubble in gamma rays
- N 132D
  one of the oldest TeV emitting SNRs

First individual cosmic-ray sources in an external galaxy
→ *Science* **347**:6220 (2015)

tip of the iceberg?
  future observations with CTA



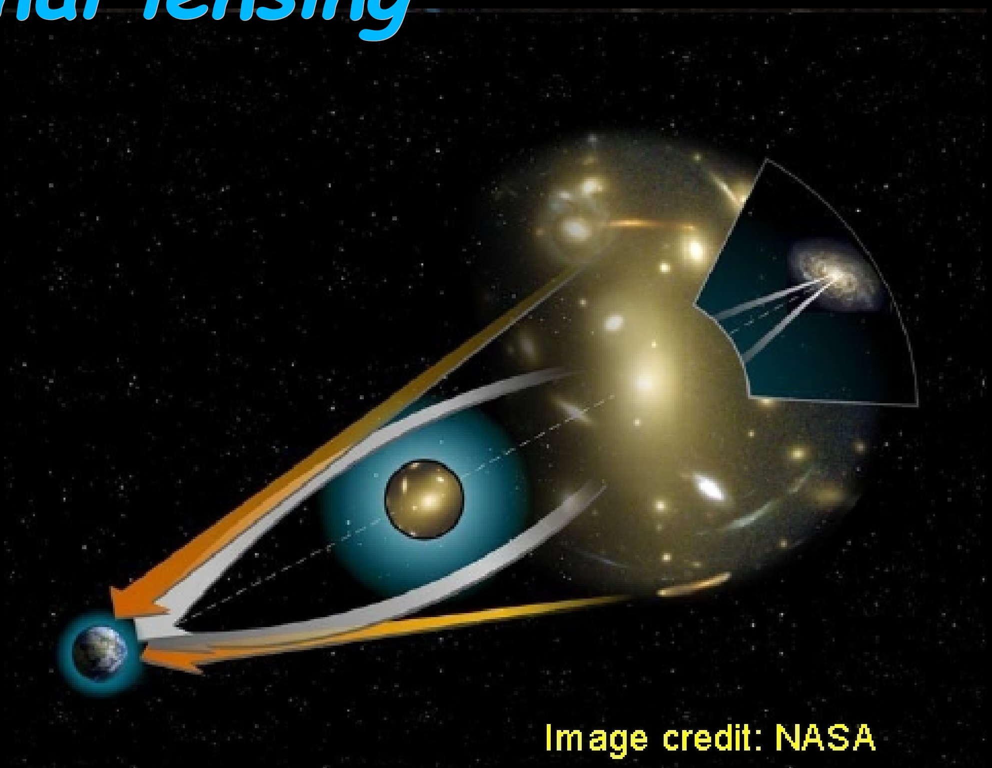


EXTRAGALACTIC SCIENCE

- Physics of AGN jets
- Cosmology: Density of cosmological extragalactic background light (EBL)
- Quantum gravity & exotics

Gravitational lensing

If there is a substantial mass (e.g. a galaxy or a cluster) between the source and the observer the light path will be bent



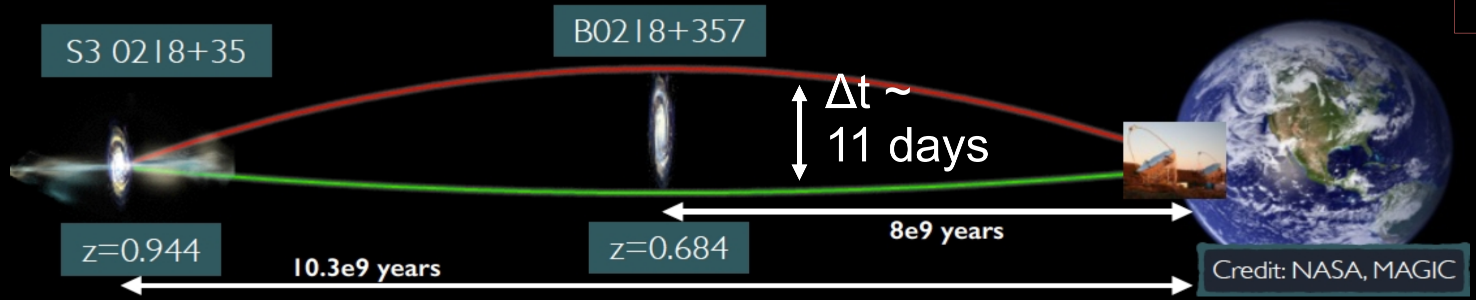
For strong lensing: one can get Einstein's ring (most pronounced for perfect alignment) and/or multiple images with different multiplication and timing

Excellent candidate:

Gravitationnally lensed blazar by a spiral Galaxy @ z = 0.68
Double emission in radio and Einstein' s ring is visible

QSO 0218+357: gravitationnally lensed blazar @ z = 0.944

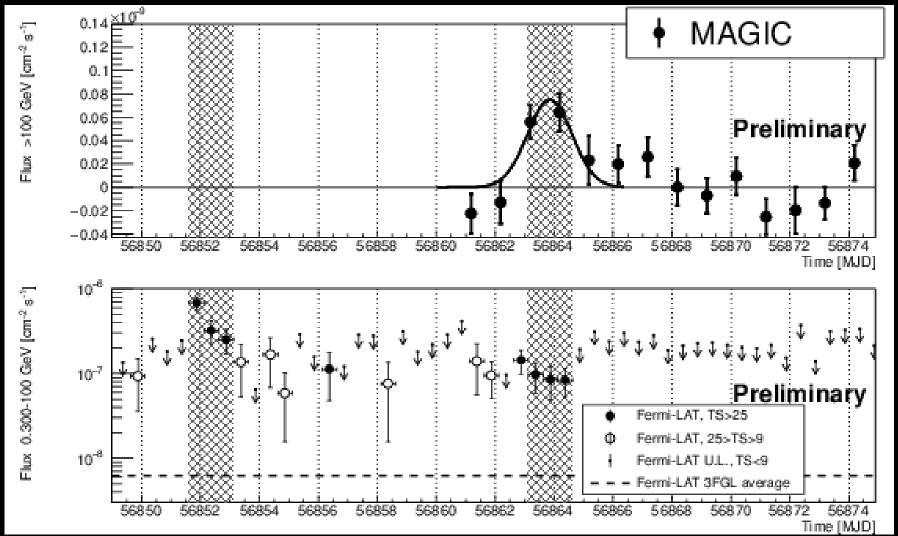
927, 1224

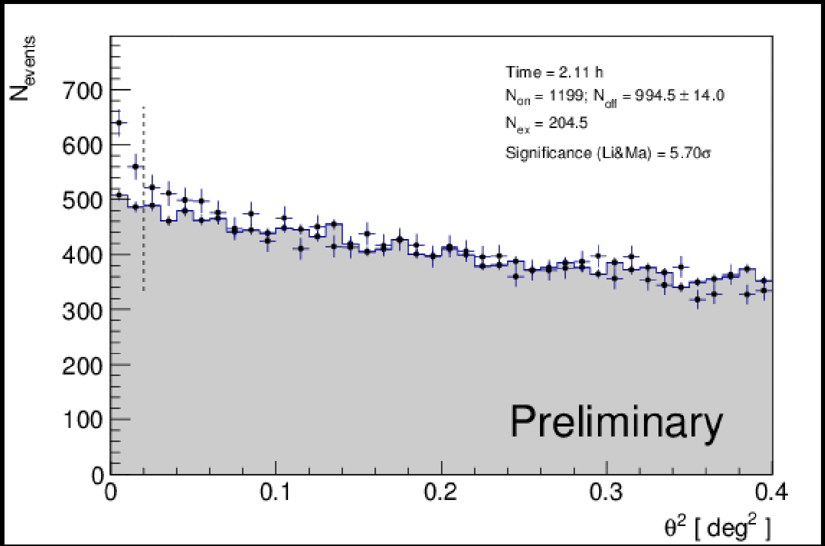


~11.5d delay between the direct & lensed components (Fermi – 2012)

Observations with MAGIC performed during the 2nd flare: detection of sub-TeV lensed emission

- much more prominent emission than by Fermi
- VHE emission from z~1 is strongly attenuated above ~100 GeV





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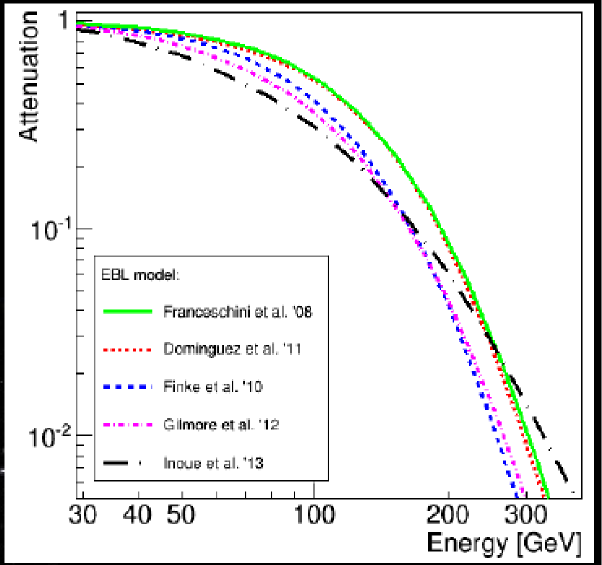
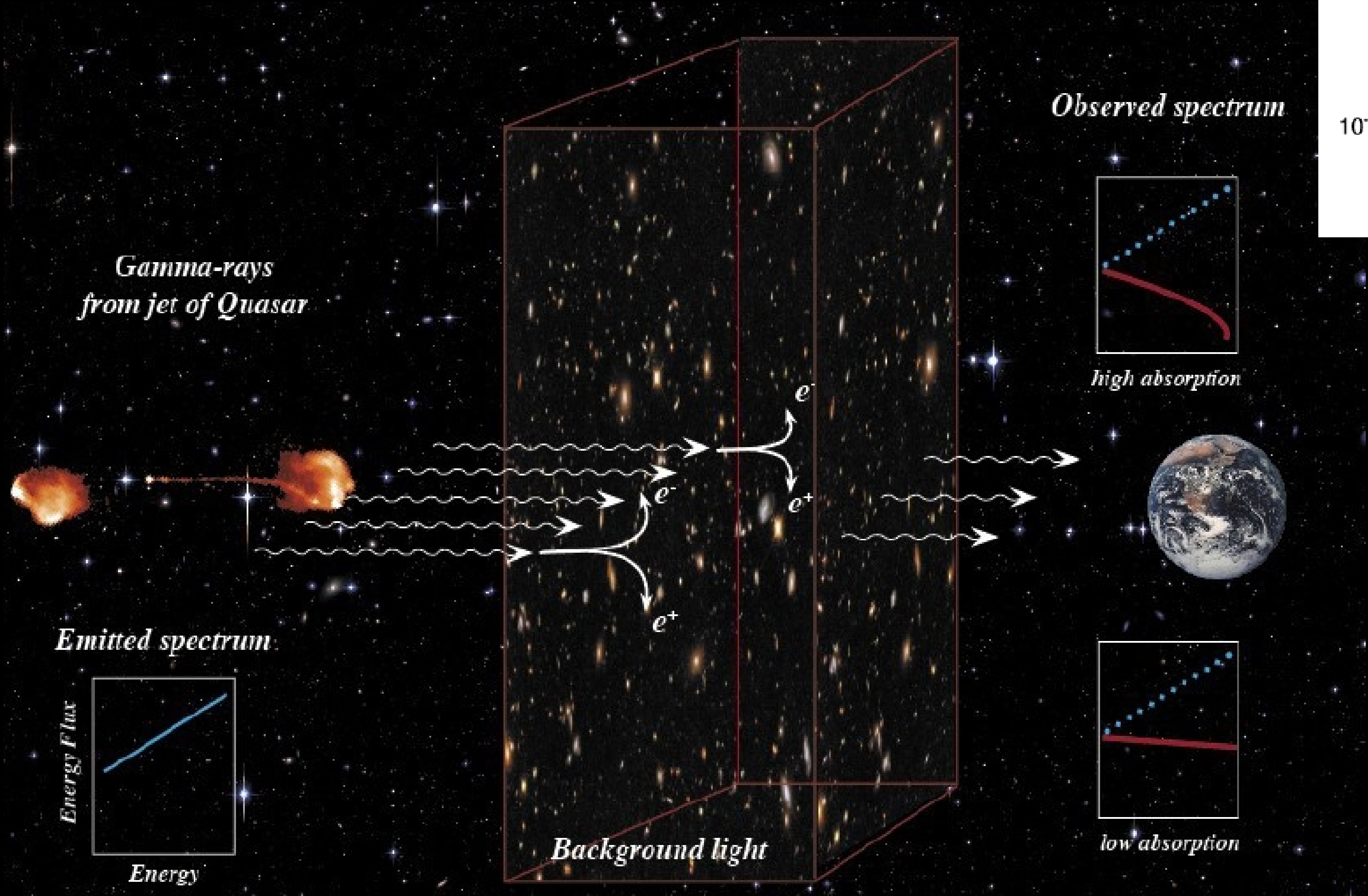
Absorption by the Extragalactic Background Light

Sources with z~1 strong absorption above 100 GeV

GeV+TeV spectrum can be used for testing EBL models





CTA portal

Breaking the redshift barrier with PKS 1441+25 => Constraints on the EBL

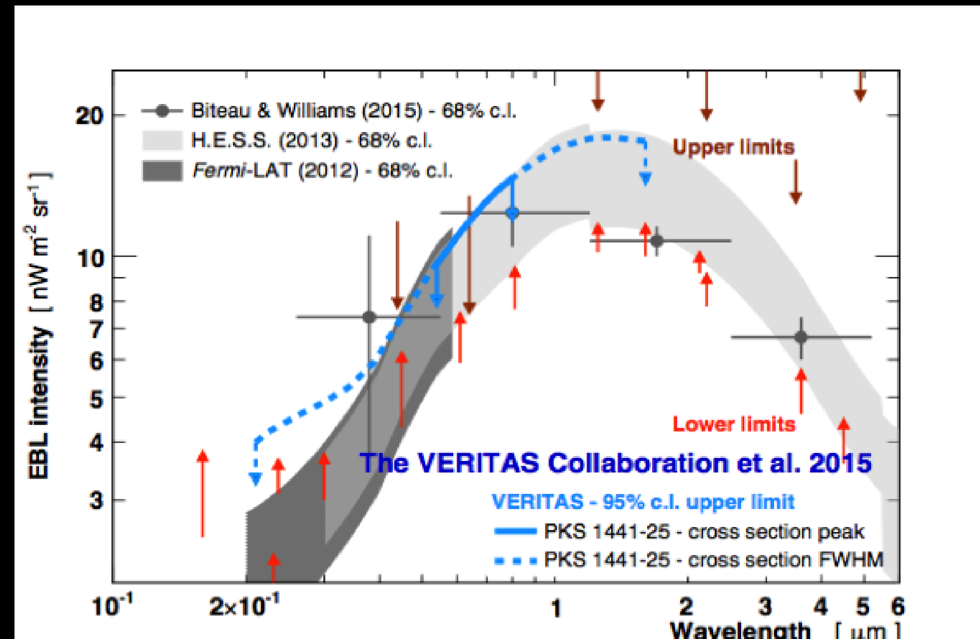
868, 1220, 1336

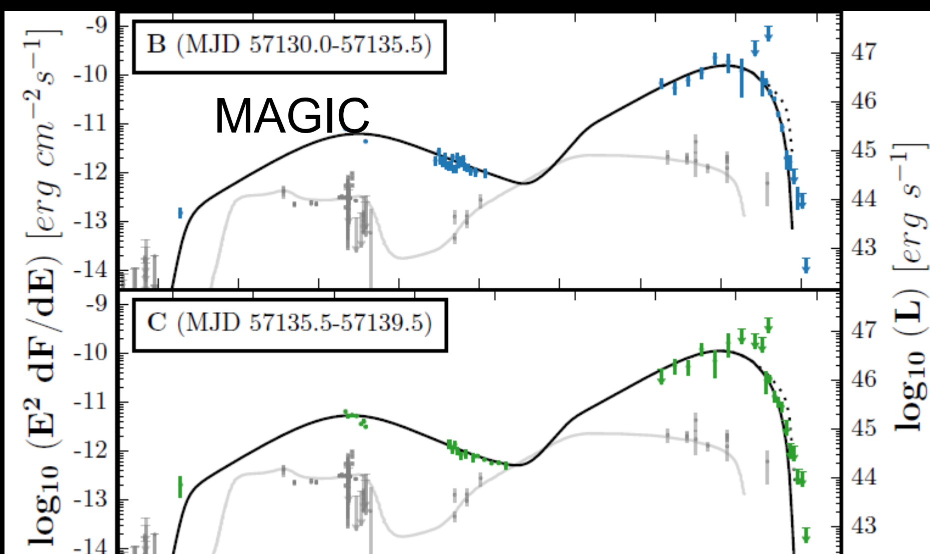
FSRQ @ z = 0.939

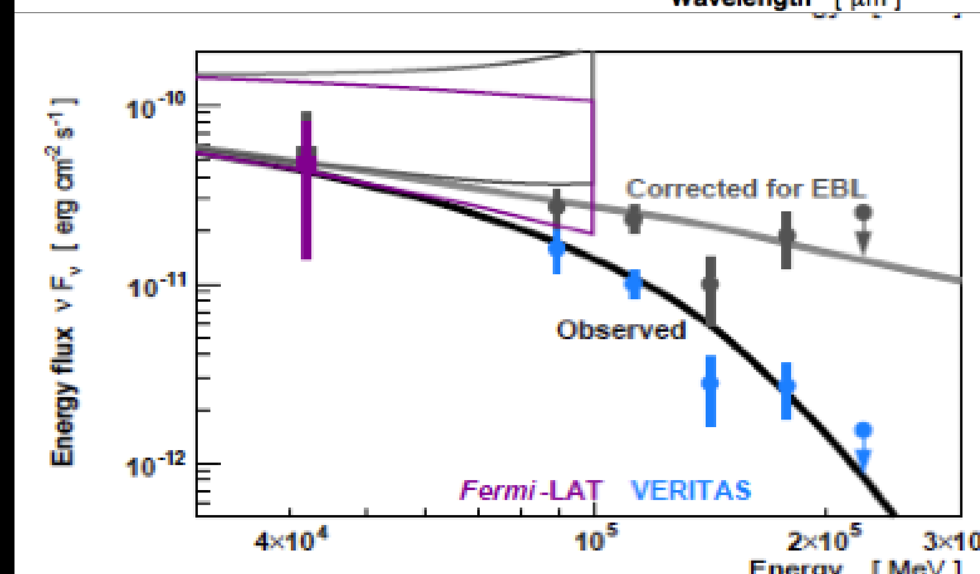
MAGIC detection

VERITAS Confirmation
Up to 200 GeV
~400 GeV accounting for z!

Stringent constraints on the EBL







Multiwavelength campaign of Mkn 421

Another famous, close-by and bright blazar

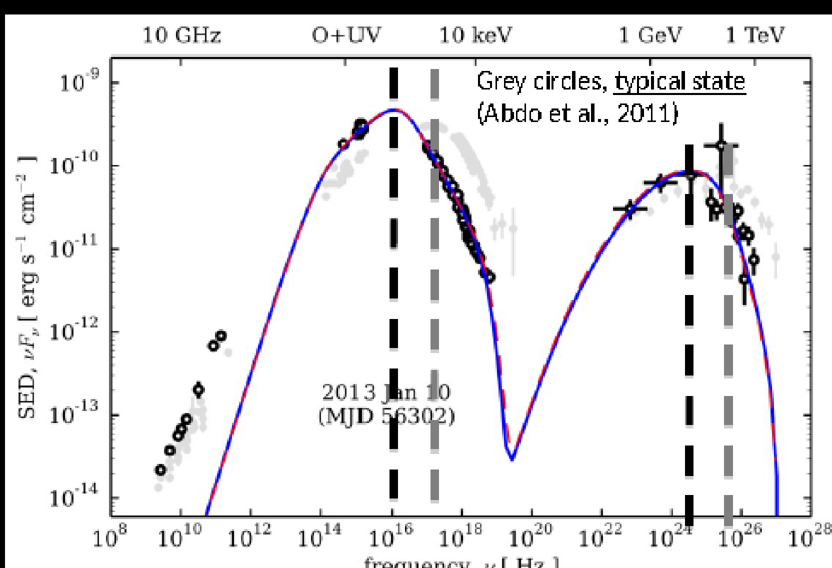
162, 787, 1118

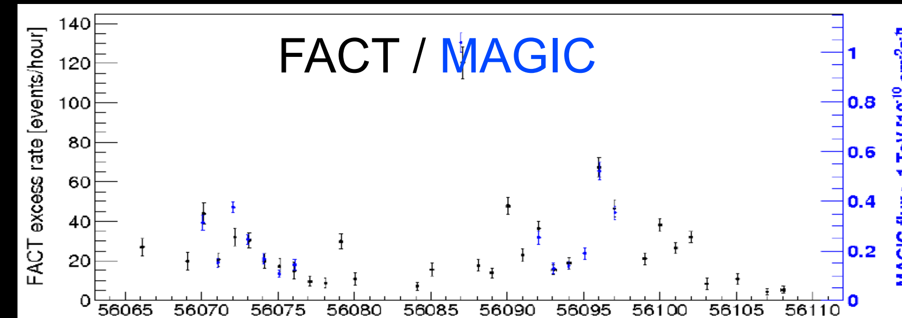
January 2013 flare:
Synchrotron and IC peak shifted to ~ 10 times lower energies
=> Never seen before for any blazar

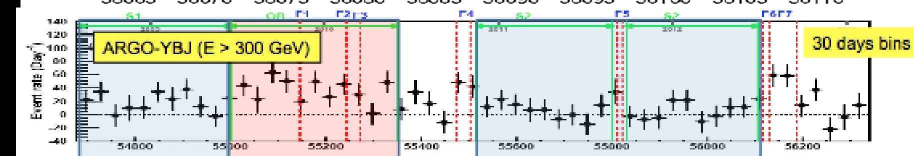
4.5 year campaign also followed by ARGO-YBJ

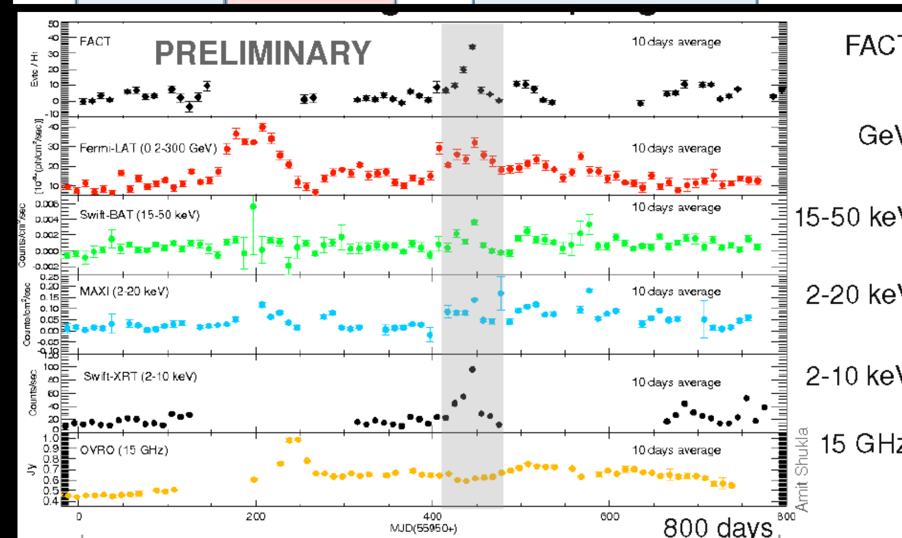
Variability clearly detected by HAWC

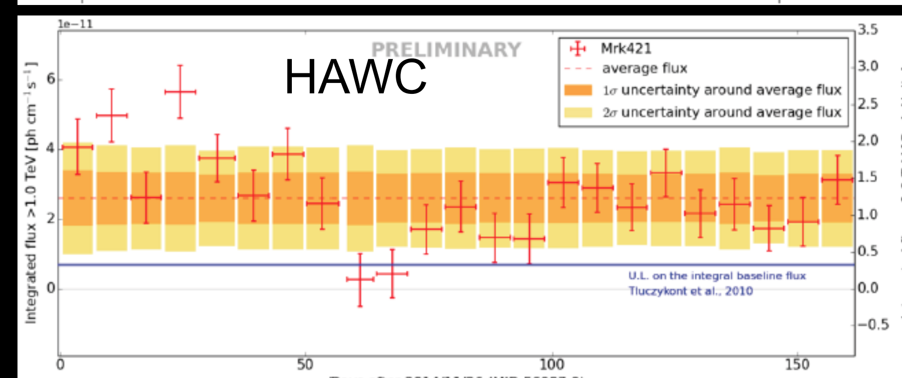
Deep monitoring by FACT











Other AGNs results

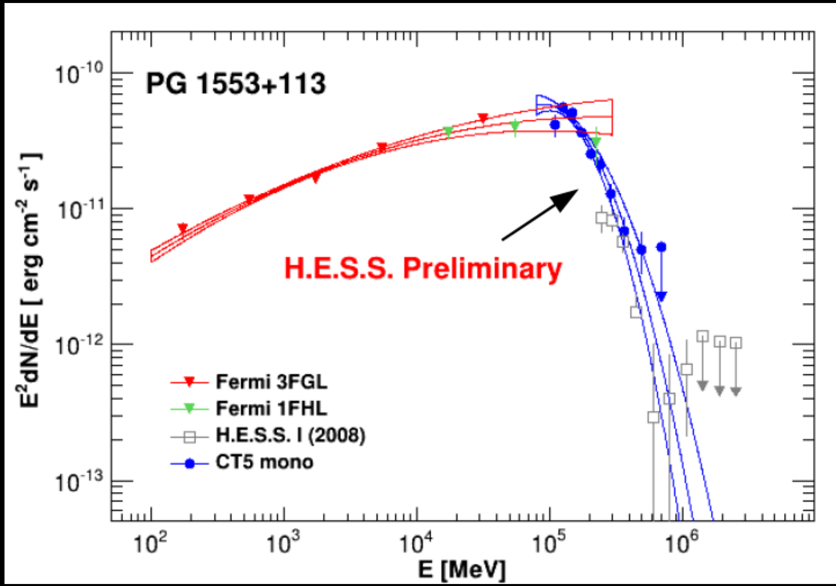
70, 731, 780, 868, 1156,
547, 772, 485, 1187

Other new detections:

- PKS 1440-389 (HESS)
- RGB J2243+203 (VERITAS)
  - z>0.39 (photometric redshift estimate)
- S3 1227+25 (VERITAS)
  - Fermi-detected LSP/ISP, z = 0.135
  - Variable flux peaking at ~ 6-8 % Crab flux

Long term monitoring & variability:

- 1ES 0229+200
  - H.E.S.S. confirmation of variability (previous hints by VERITAS)
- 1ES 1011+496:
  - MAGIC detection of February 2014 flare
  - Constraints on EBL
- PG 1553+13:
  - Periodicity study: yearly periodicity
  - Possible binary SMBH system
- Mkn 501:
  - MWL observations include NuSTAR
  - 1st time TeV observations are corrected to produce a physics result



Lightning of a black hole: IC 310

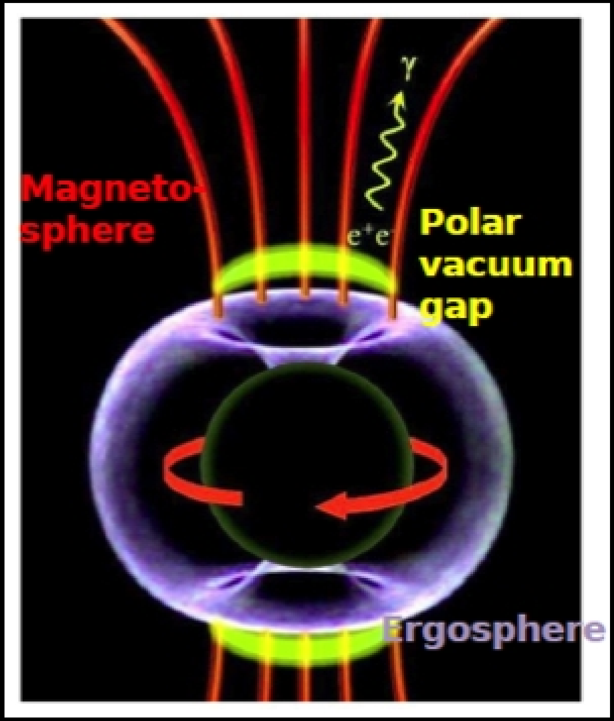
288

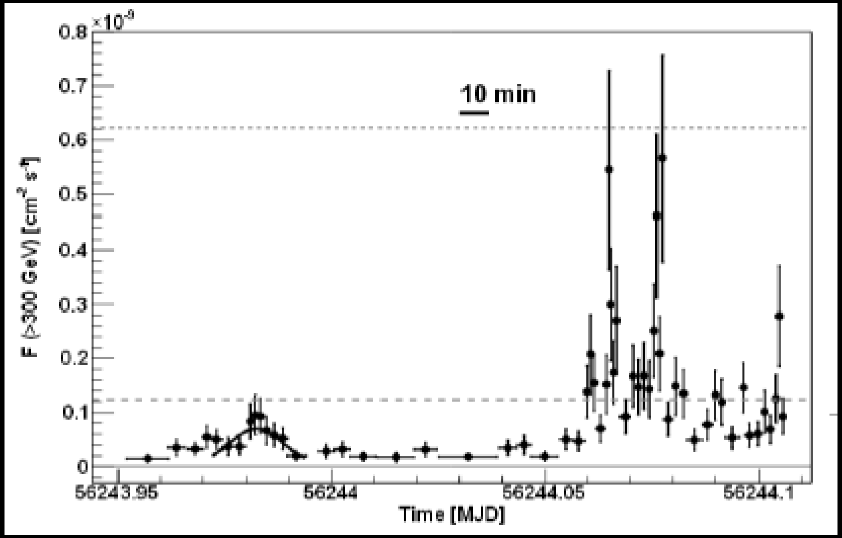
Viewing angle $10° \leq \theta \leq 20°$
=> Not a blazar, no strong Doppler Boost

TeV Variability < 4mn
=> Emission region constrained to < $0.2\delta R_G$

Huge optical depth for γ-γ pair production due to small Doppler boost
=> inconsistent with shock-in-jet model

Likely pulsar-like emission model
Acceleration of particles close to black hole in vacuum gaps
hard γ-ray spectrum due to electromagnetic cascading





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Comparison with other TeV emitting radio galaxies

541, 742

Most of extragalactic objects in TeV are blazars but not only
M87, Cen A, IC 310, NGC 1275, and PKS 0625-354: new class of VHE emitters

Increasing the sample of "γ-**ray loud**" RG important for modeling and understanding the contribution of non-blazar AGN to extragalactic γ-ray background

	PKS 0625-354	NGC 1275	M87	Centaurus A	IC 310
Spectral index	2.8 ± 0.5	4.1 ± 0.7	2.9 ± 0.8 (2003) 2.63 ± 0.35 (2004) 2.22 ± 0.15 (2005) 2.31 ± 0.17 (2008) 2.21 ± 0.21 (2012)	2.7 ± 0.5	~ 2.0
Flux (mean) [ph cm^{-2} s^{-1}]	(8.7±3.2) 10^{-13}	(1.3 ± 0.2) 10^{-11}	(0.95 ± 0.23) 10^{-12} (2003) (2.43 ± 0.75) 10^{-13} (2004) (11.7 ± 1.6) 10^{-13} (2005) (8.5 ± 1.5) 10^{-12} (2008) (5.06 ± 0.77) 10^{-12} (2012)	(1.6 ± 0.7) 10^{-12}	(3.6 ± 0.4) 10^{-12}
Variability	no significant variability detected	no hints of variability on a month time scale (Aleksic et al. 2011)	strong evidence for a year-scale variability (Accari et al. 2008) and on time scales of days (Aharionian et al. 2006)	no significant variability detected with H.E.S.S. (Aharionian et al. 2009)	Rapid variability on daily time scale detected by MAGIC (Aleksic et al. 2013)

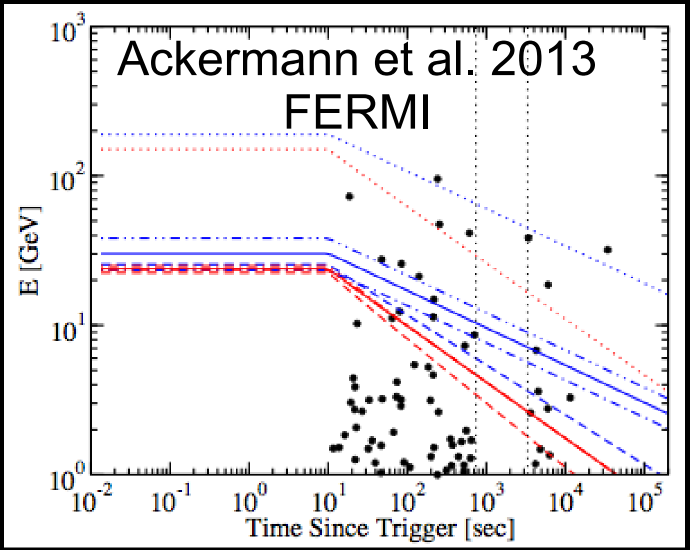
Gamma-ray bursts (GRBs)

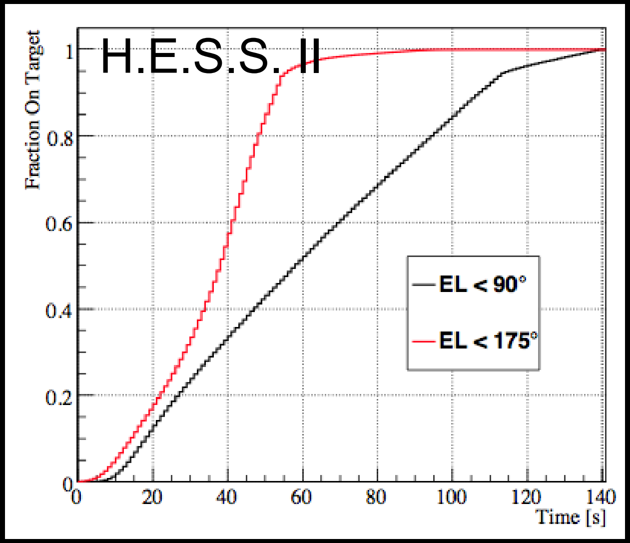
237, 783, 1071

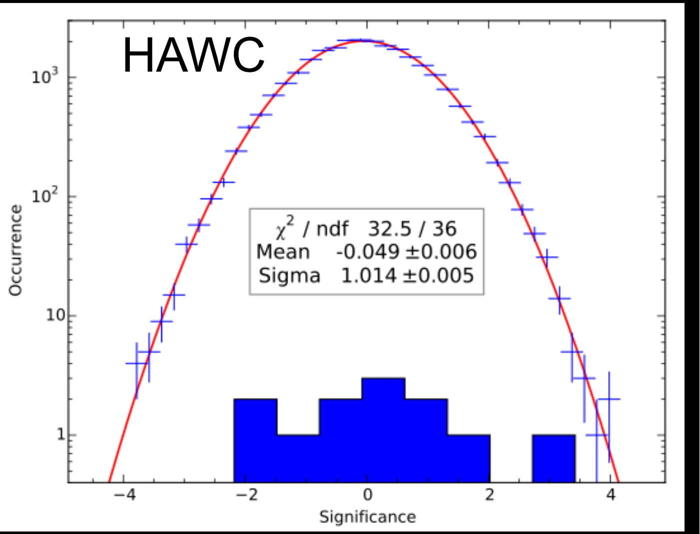
HAWC:
HAWC might detect GRBs with a rate as high as 1–2 GRBs per year
18 Swift detected GRBs analyzed: none of them is significant above 3σ
Triggered GRB analysis + Untriggered GRB analysis

MAGIC:
74 GRBs observed since 2005, 50% being at favorable redshift: No detection
Since 2013: new GRB automatic procedure => 7 GRBs observed with delay < 100s

HESS rapid repointing system: (CT5 180° rotation in 110s)
expect to arrive at the GRB position within 2 minutes
(delay of the GCN system + hardware and software overheads + repointing time)







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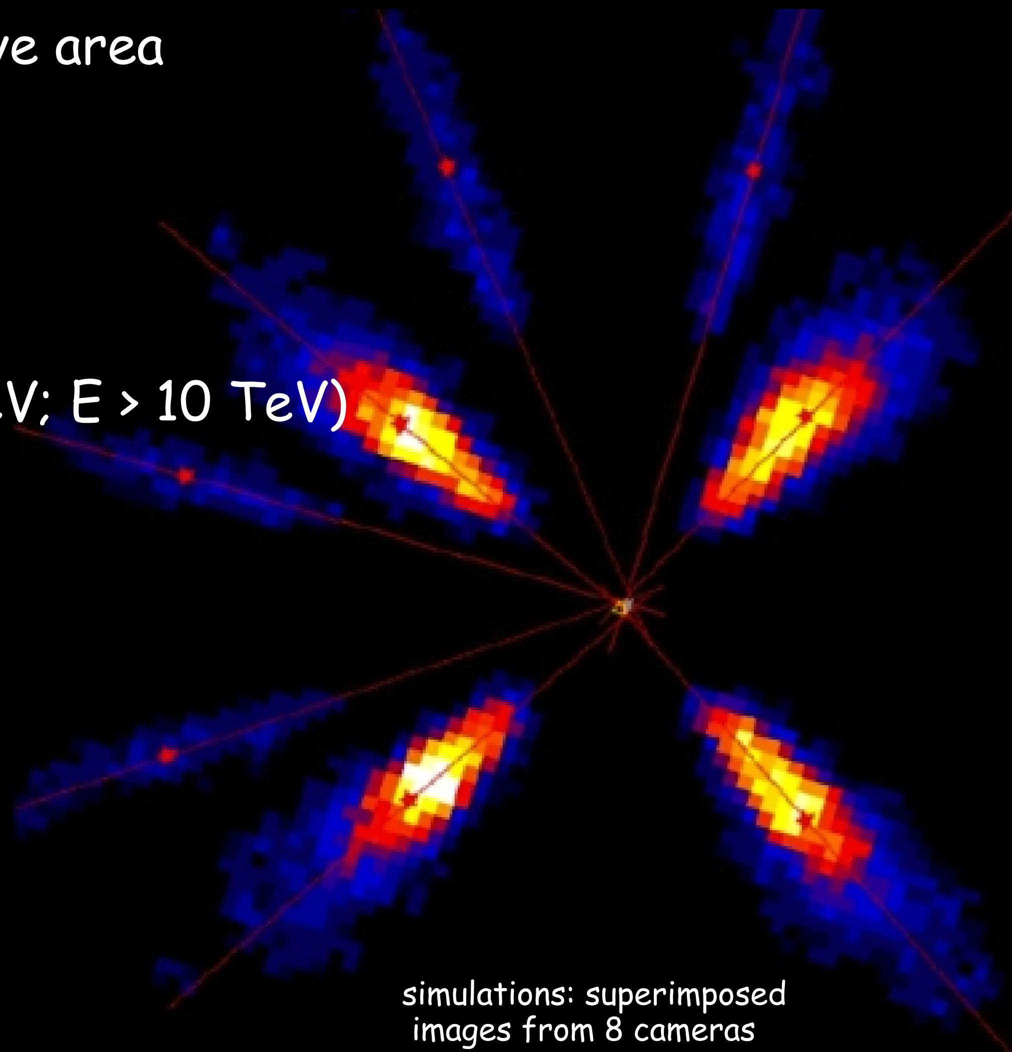
THE FUTURE

- More events
  More photons from larger effective area

- Better events
  Better reconstruction

- New events
  Extended energy range (E < 50 GeV; E > 10 TeV)



simulations: superimposed images from 8 cameras

The Cherenkov Telescope Array (CTA)

46, 47, 58, 61, 62, 63, 65, 78, 83, 202, 204, 209, 210, 236, 249, 252, 264, 265, 274, 276, 294, 305, 318, 329, 370, 372, 395, 424, 465, 469, 506, 556, 603, 605, 610, 629, 665, 673, 674, 684, 699, 723, 736, 773, 824, 862, 882, 900, 954, 965, 1052, 1057, 1058, 1101, 1179, 1319, 1324, 1397

> 1200 members

194 Institutes from 31 countries

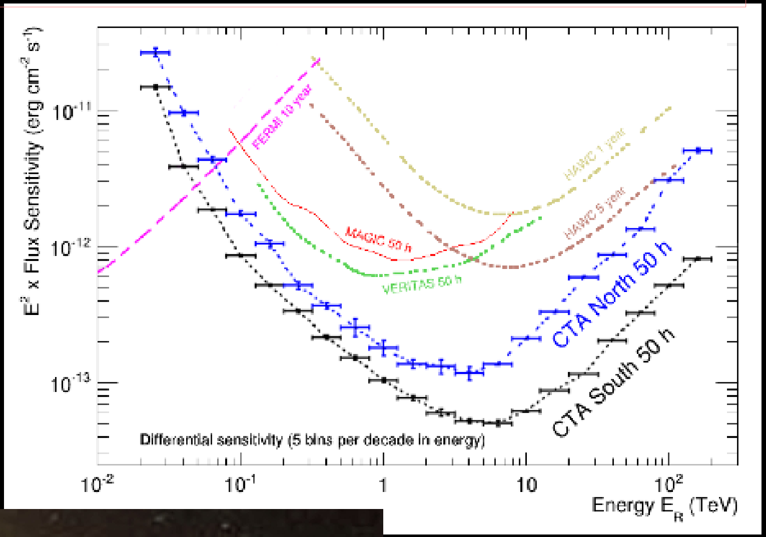
2 sites selected:

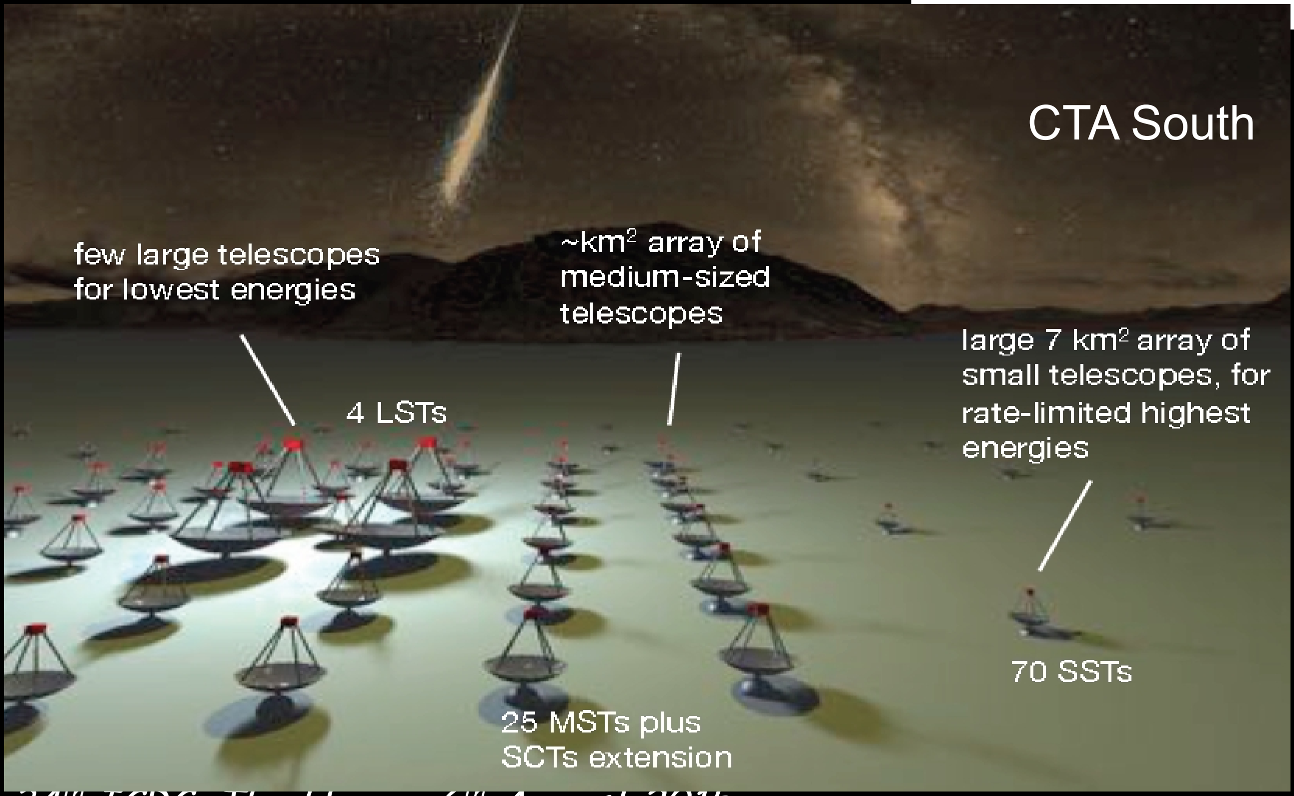
North (La Palma, Spain)

South (Paranal, Chile)

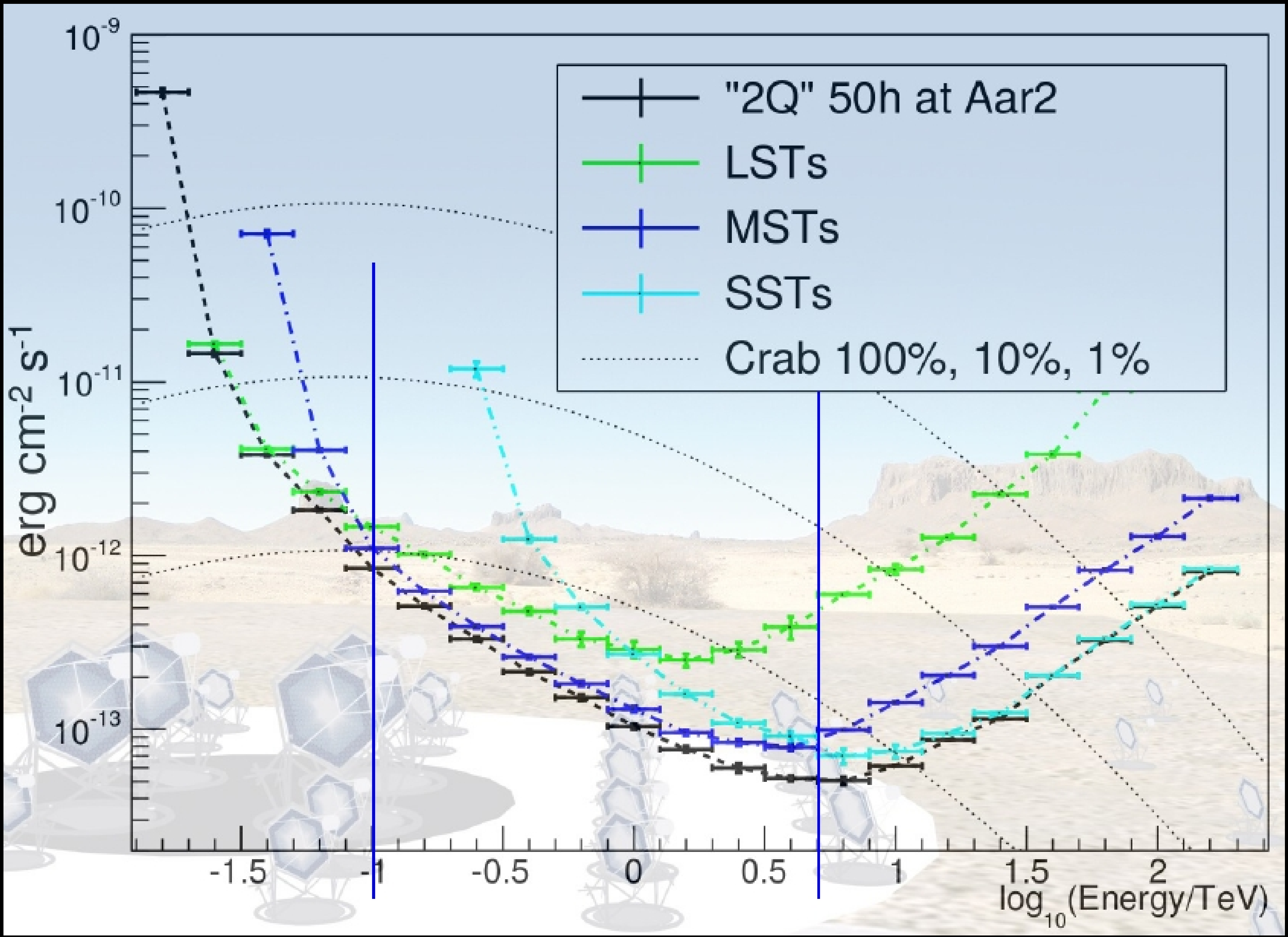
Initial construction could start in 2016

Early science: towards the end of the decade





CTA telescopes contribution



CTA small size telescopes

63, 95, 96, 102, 105, 106, 114, 116, 122, 1397

3 designs with associated prototypes proposed for the CTA array:
- A Davies-Cotton telescope (SST-1M)
- 2 Dual mirror Schwarzschild-Couder telescopes: ASTRI and CGT

All SST variants use silicon sensors

6-8 m2 mirror area; FoV of 9° => very powerful for surveys

70 SSTs on South site (projects will provide > 20 telescopes each to CTA)

SST-1M,
Krakow since Nov. 2013

ASTRI, Serra la Nave, Mt. Etna,
Sicily since Aug. 2014

GCT, Observatoire Paris, Meudon, since
Apr. 2015

CTA medium size 12m telescopes

95, 97, 98, 106, 318, 673, 684, 1101, 1319

Optimized for the 100 GeV to ~10 TeV energy range
25/15 MSTs on South/North sites
+ dual mirror telescopes extending the array

Modified Davies-Cotton layout
Effective mirror area > 88m2
Field of view > 7°

Prototype for the mechanical structure, drive assemblies assembled in 2012

Two camera designs:

- FlashCam
- NectarCam

Test of fully equipped FlashCam prototype during 2016
Start production of NectarCAM qualification camera in 2016

Pre-production MSTs ready in 2017

CTA Large size telescopes

86, 87, 95, 104, 108, 110, 197

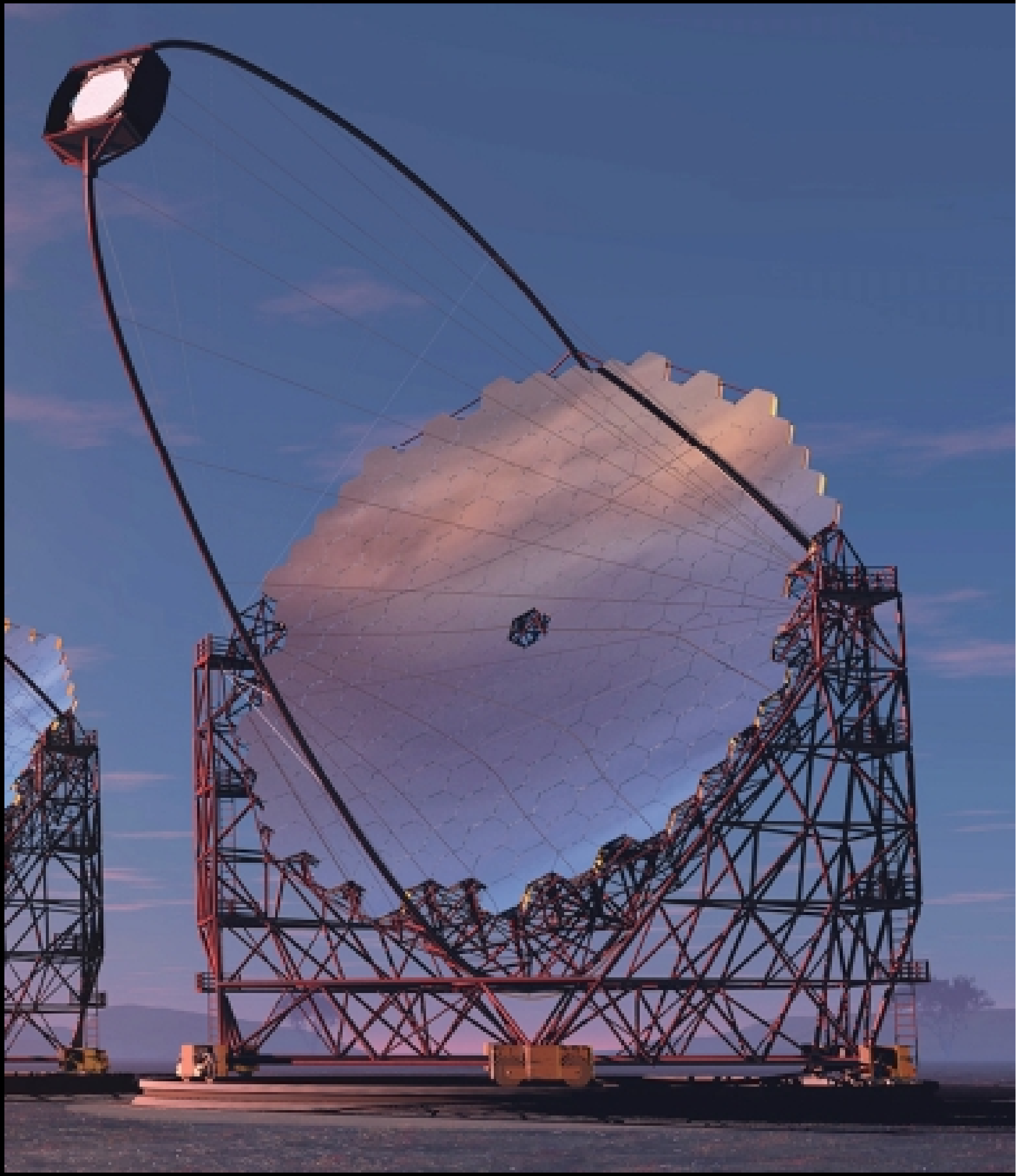
4 LSTs in CTA South and 4 in CTA North
=> Cover the low energy domain from 20 GeV to 200 GeV

Diameter of the telescope: 23 m
Total effective mirror area: 368 m2
Focal Length: 28 m
Total weight of the LST: ~100 tons
Fast rotation: 180° in 20 sec for GRBs
High Resolution Camera with 4.5° FOV

Project has passed the Critical Design Review on June

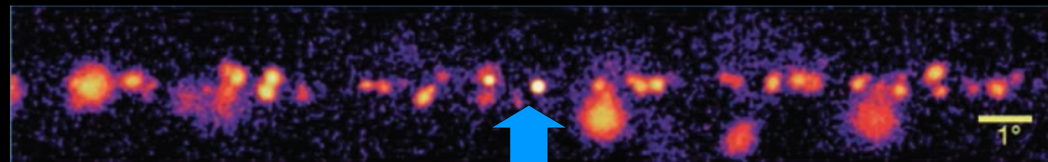
Production of the first LST (LST1) is well underway

LST1 will be installed in La Palma in 2016



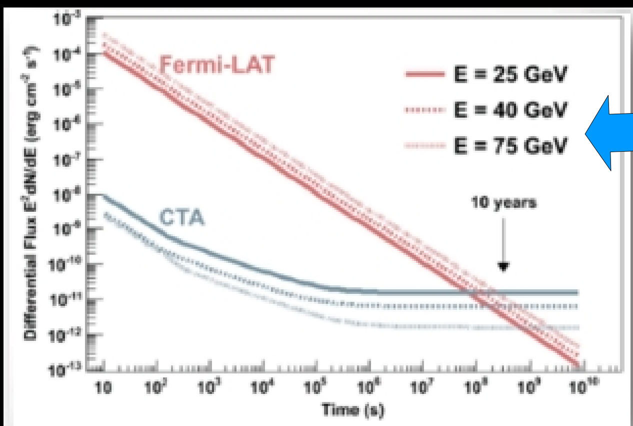
CTA science prospects

197, 629, 1397

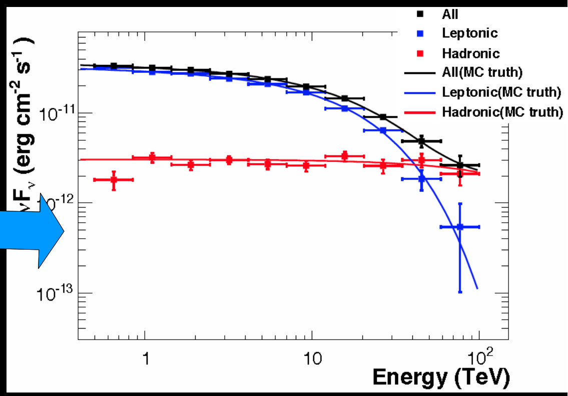


8° FoV => Surveys

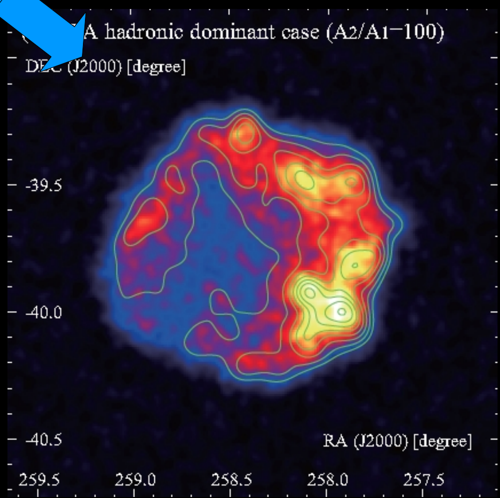
Fast slewing => Transients



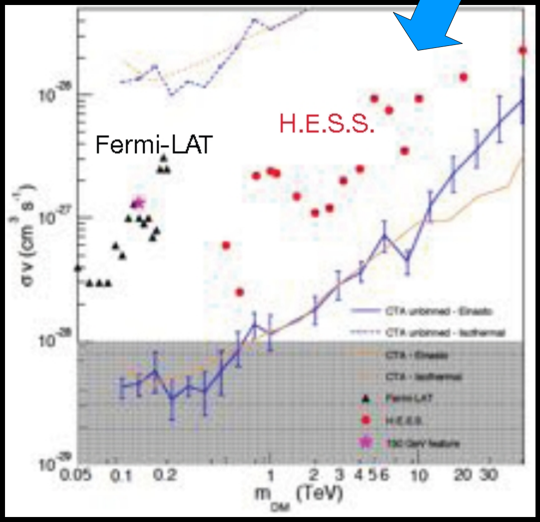
Energies up to 300 TeV
=> PeVatron



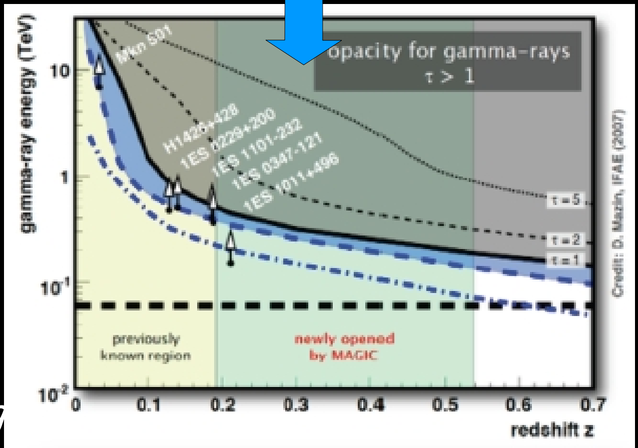
Excellent angular resolution
=> Morphology



Excellent energy resolution => Lines



Energies down to 20 GeV
=> Cosmology



The Large High Altitude Air Shower Array (LHAASO)

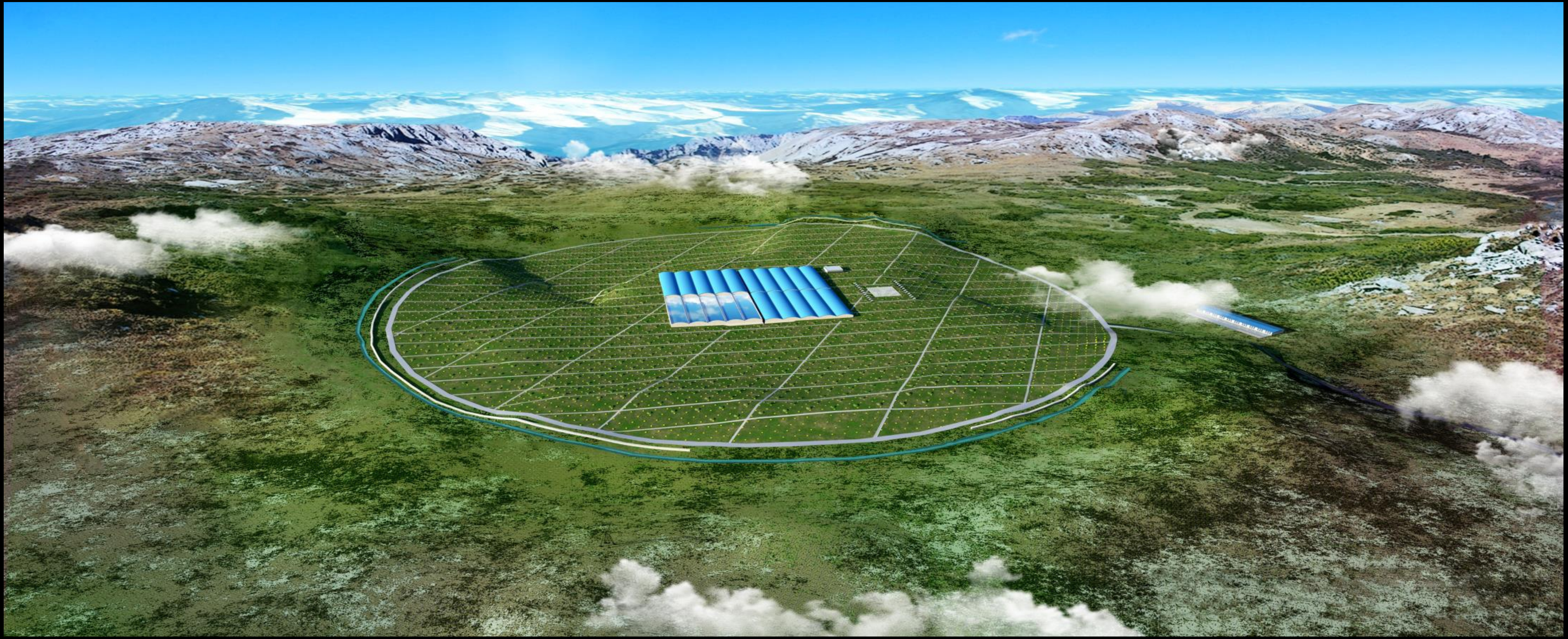
LHAASO detectors: 285, 315, 324, 335, 464, 470, 564, 833, 885, 894, 896, 901, 904, 908, 941, 985, 1042, 1079

- air shower array of 1 km^2

. 75 000 m2 Water Cherenkov Detector Array (WCDA)

- 12 Wide-field Cherenkov telescopes (WFCTA)
- Infilled shower core detectors

Engineering at ARGO site (~1% LHAASO in operation for > 2 years)



Performances and prospects of LHAASO

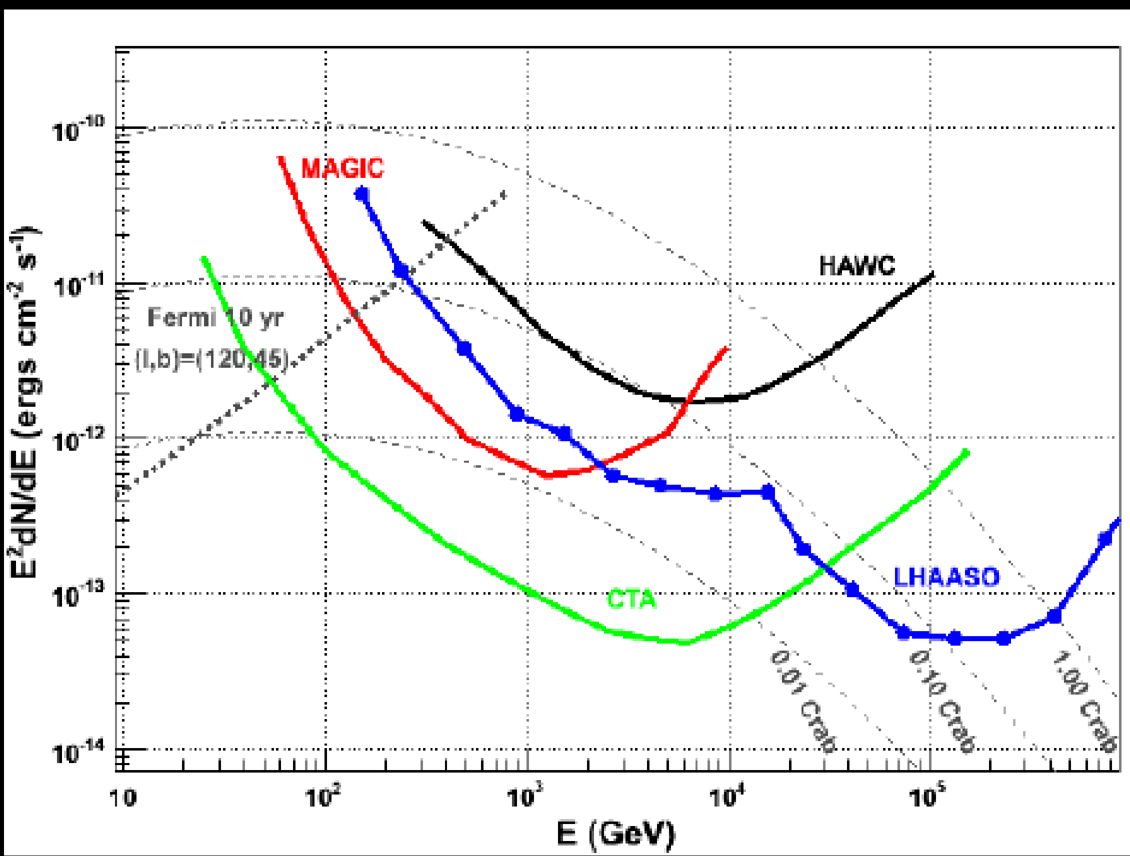
904, 335

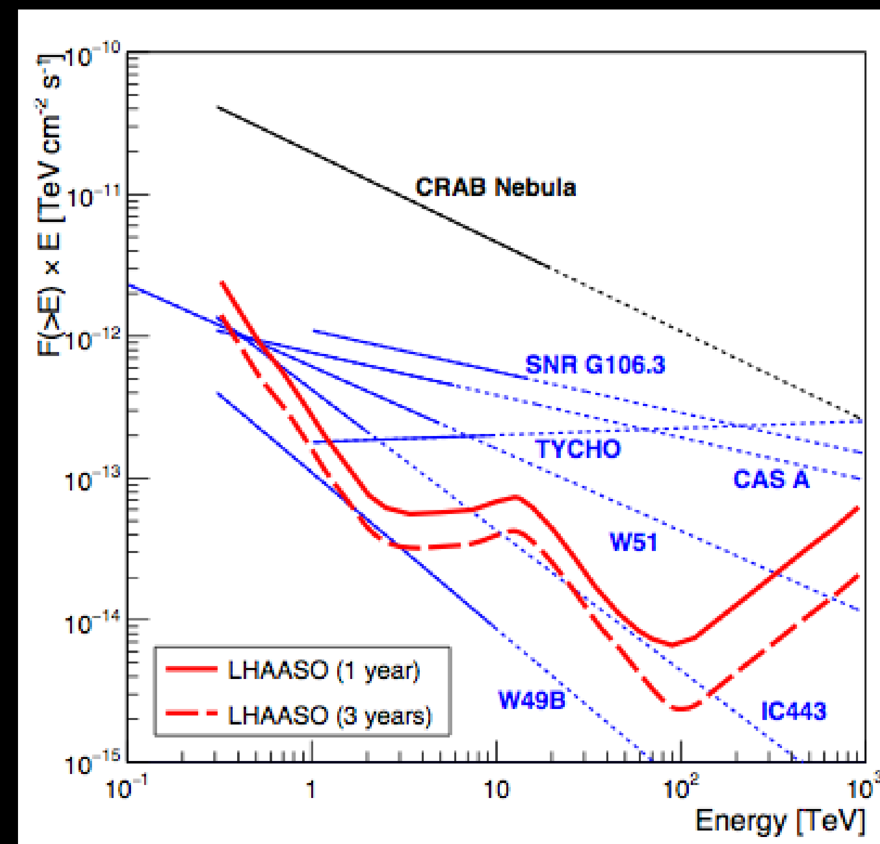
Better sensitivity than CTA for E > 30 TeV

Official approval was drafted, waiting the funding agency to sign it

LHAASO infrastructure construction has started at Mt. Haizi, Sichuan

The detector deployment will start by the end of next year



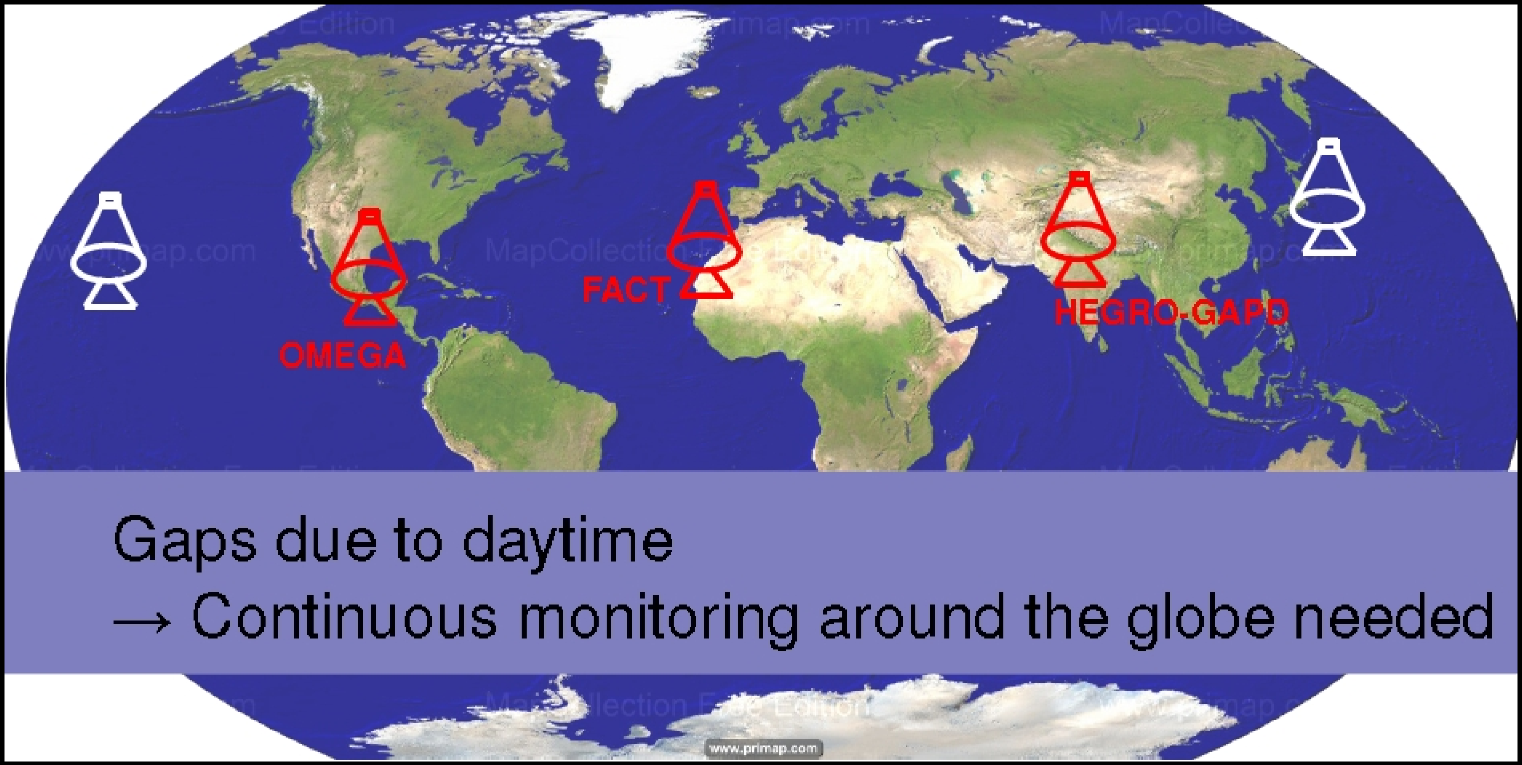


Continuous monitoring of the TeV sky

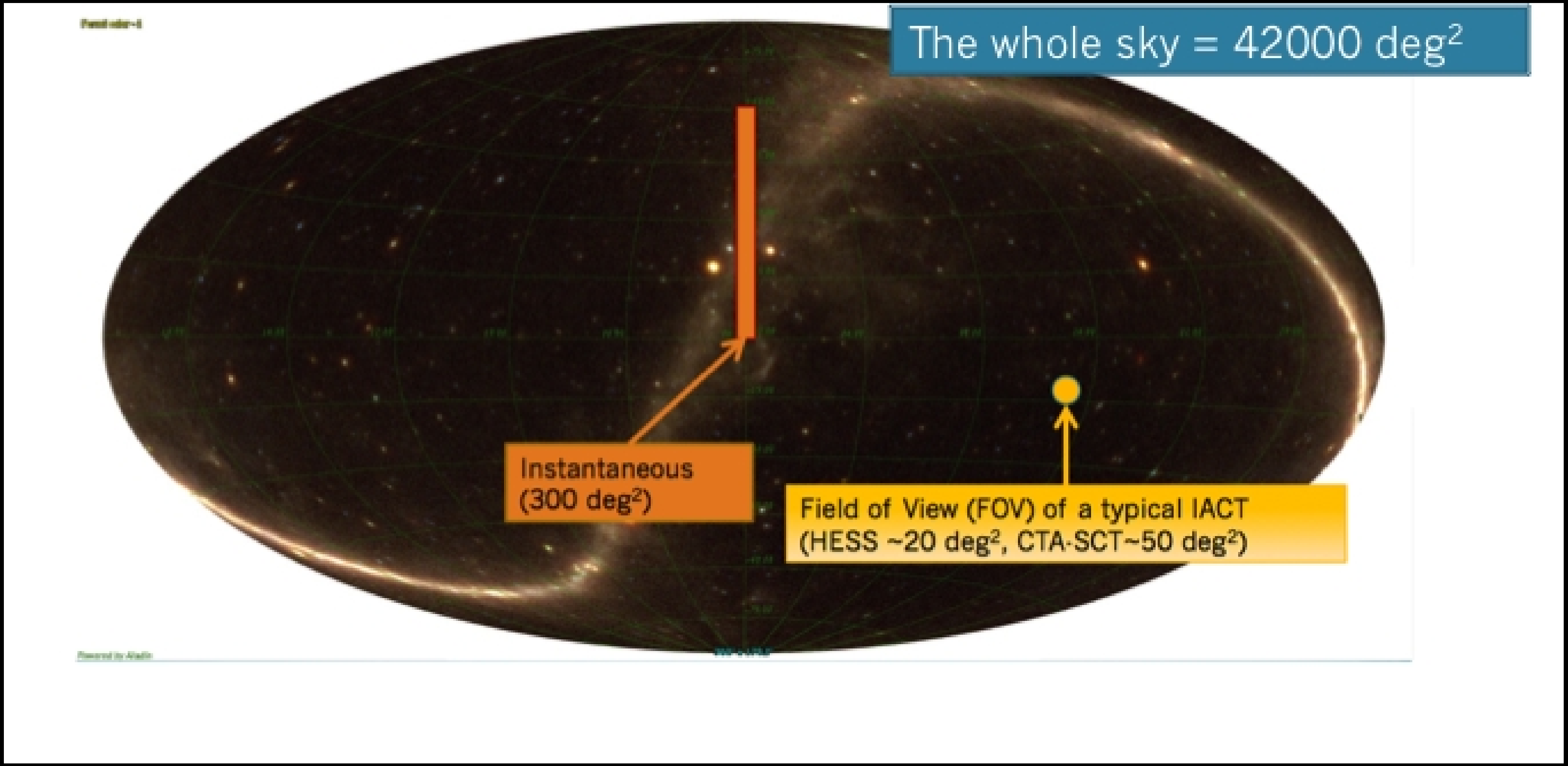
To better catch the rising and falling edge of a flare, more continuous monitoring is necessary, i.e. the gaps due to daytime have to be closed

M@TE: Monitoring at TeV Energies

- 2 mounts from OMEGA project available
- Mexico: two possible sites: 5 or 7 hours from La Palma
- Goal: Equip mount with improved SiPM camera
  → close more gaps in TeV monitoring



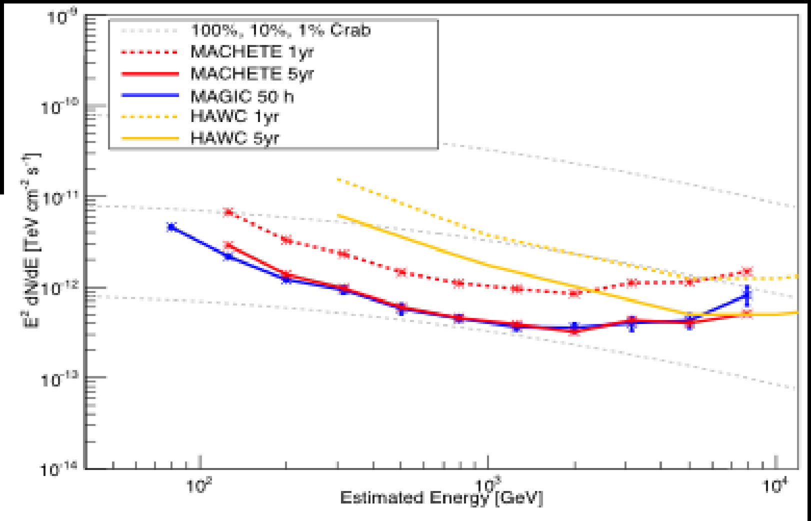
Towards a large field of view IACT

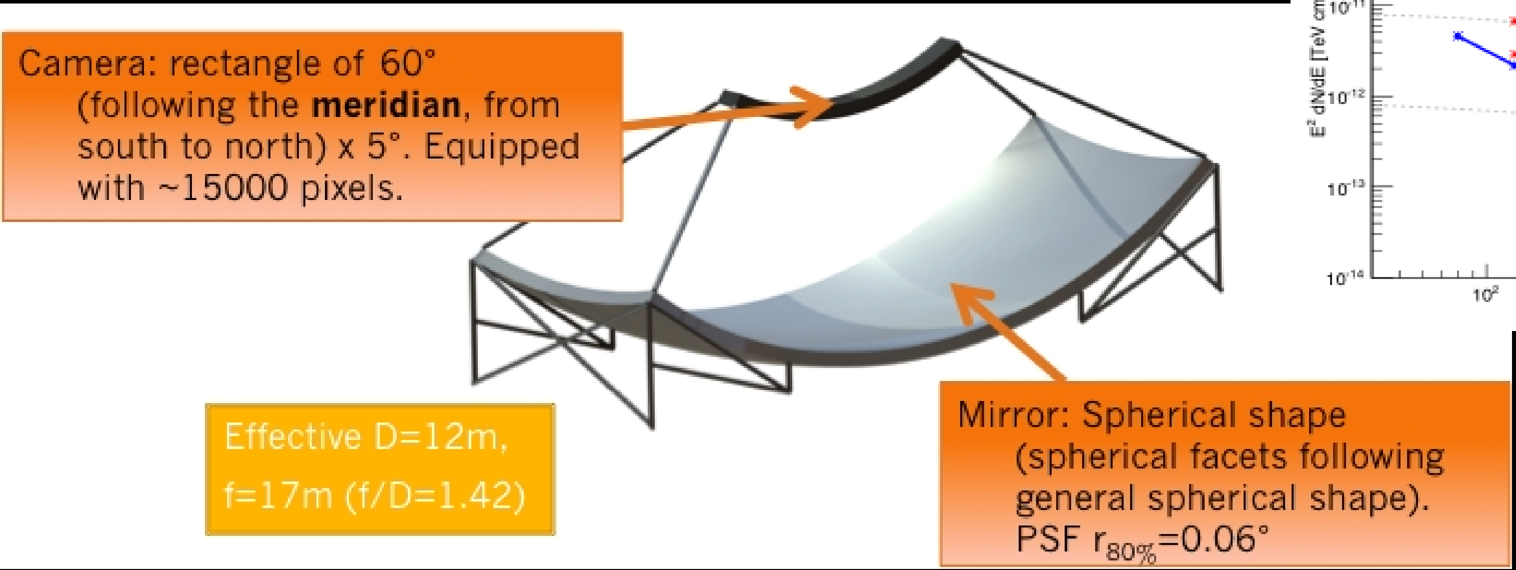


MACHETE
(Meridian Atmospheric CHErenkov Telescope array)

121

Two **fixed** IACTs with a very large FOV of 300 sq.deg aligned with the meridian.
Sky drifts through FOV => surveys 43% of the sky along a year
Reaches 0.55% Crab sensitivity after 5 years operation
For sources observable in a single night it reaches a sensitivity of 8% Crab: perfect to trigger other telescopes





Summary

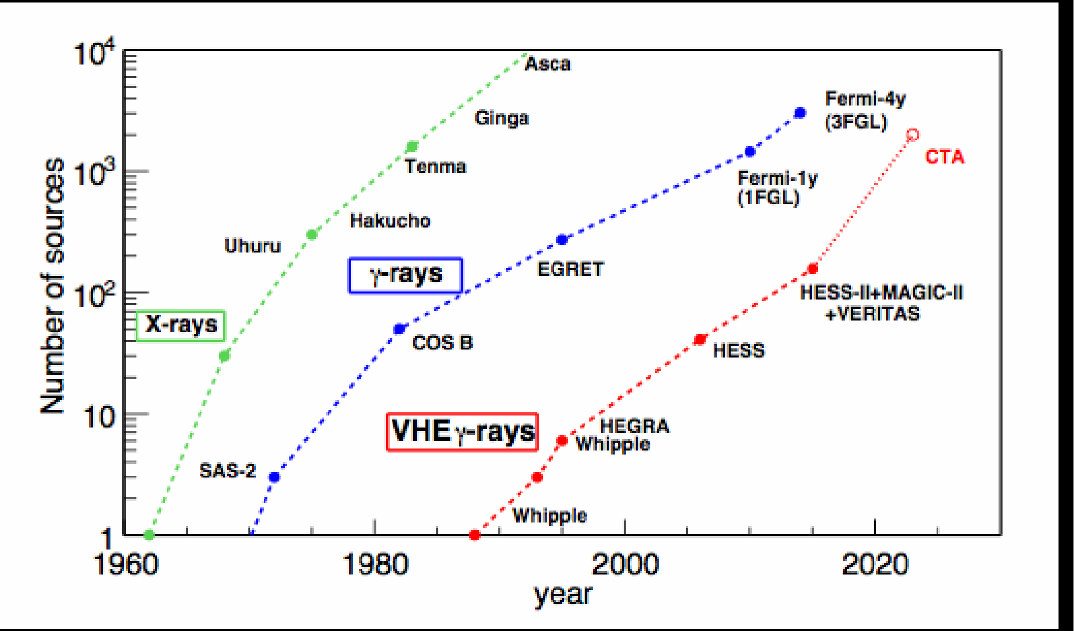
Many great results presented at this conference

Number of sources allows new population studies (eg. SNRs, PWNe....)

Key science projects and MWL collaborations and complementarity with Fermi and AGILE are extremely fruitful

The next few years promise more fruitful science (number of sources is not the limiting factor) while new ground-based observatories are being developed

« It's a great time for gamma-rays. In terms of mapping gamma rays, we have barely opened our eyes. »
E. Hays



BIG THANK YOU TO ALL SPEAKERS AND COLLABORATIONS
from the gamma-ray sessions

Thanks for listening and apologies to everyone I missed