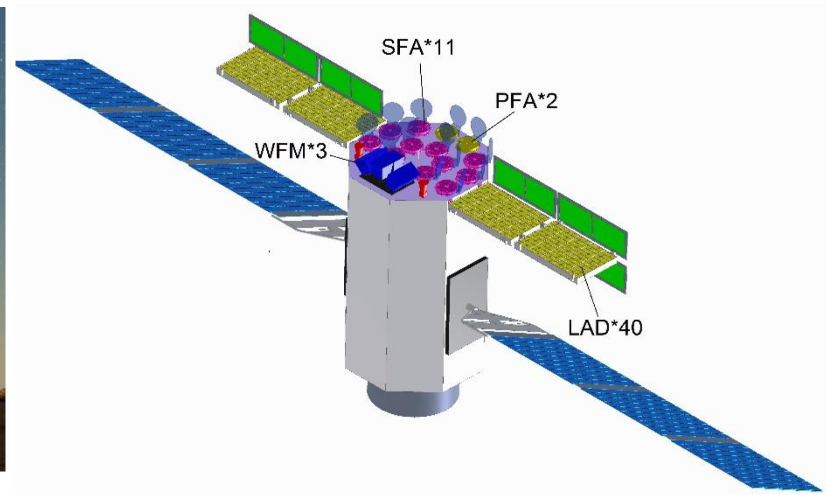
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

MATHEMATISCH-
NATURWISSENSCHAFTLICHE FAKULTÄT

Institute of Astronomy and Astrophysics



TeV Astrophysics in the eXTP era

Andrea Santangelo* IAAT Kepler Center Tübingen

Also at IHEP, CAS, Beijing

High Throughput X-ray Astronomy in the eXTP Era, February 6-8, Roma, Italy

Outline

- The talk is divided in three parts (of 4 minutes each!):

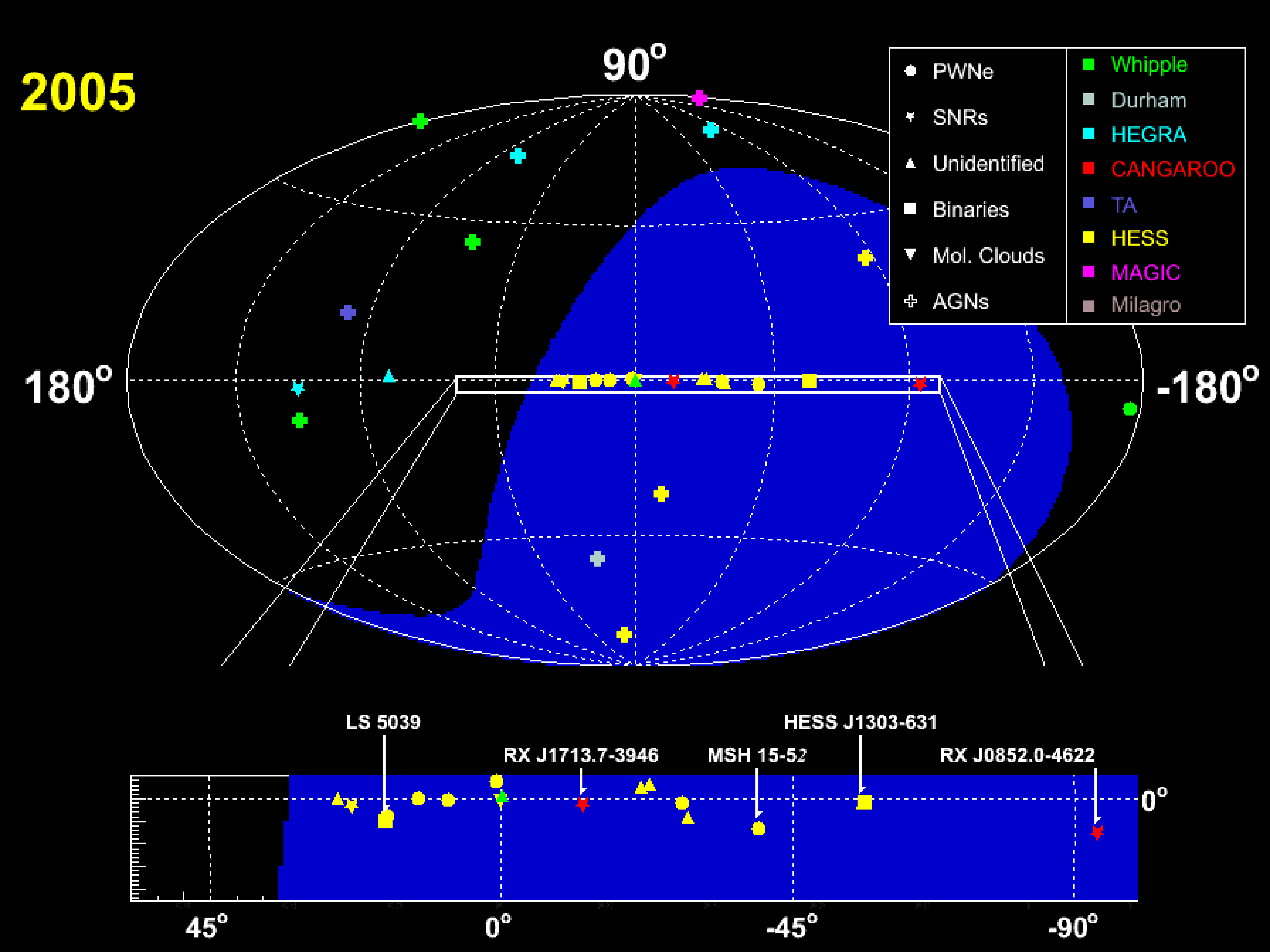
Part I: **The age of TeV astrophysics**
(We mean from 30 GeV to 100 TeV →)

Part II: **The keV-TeV connection**

Part III: **The near term future** (up to when eXTP operates)

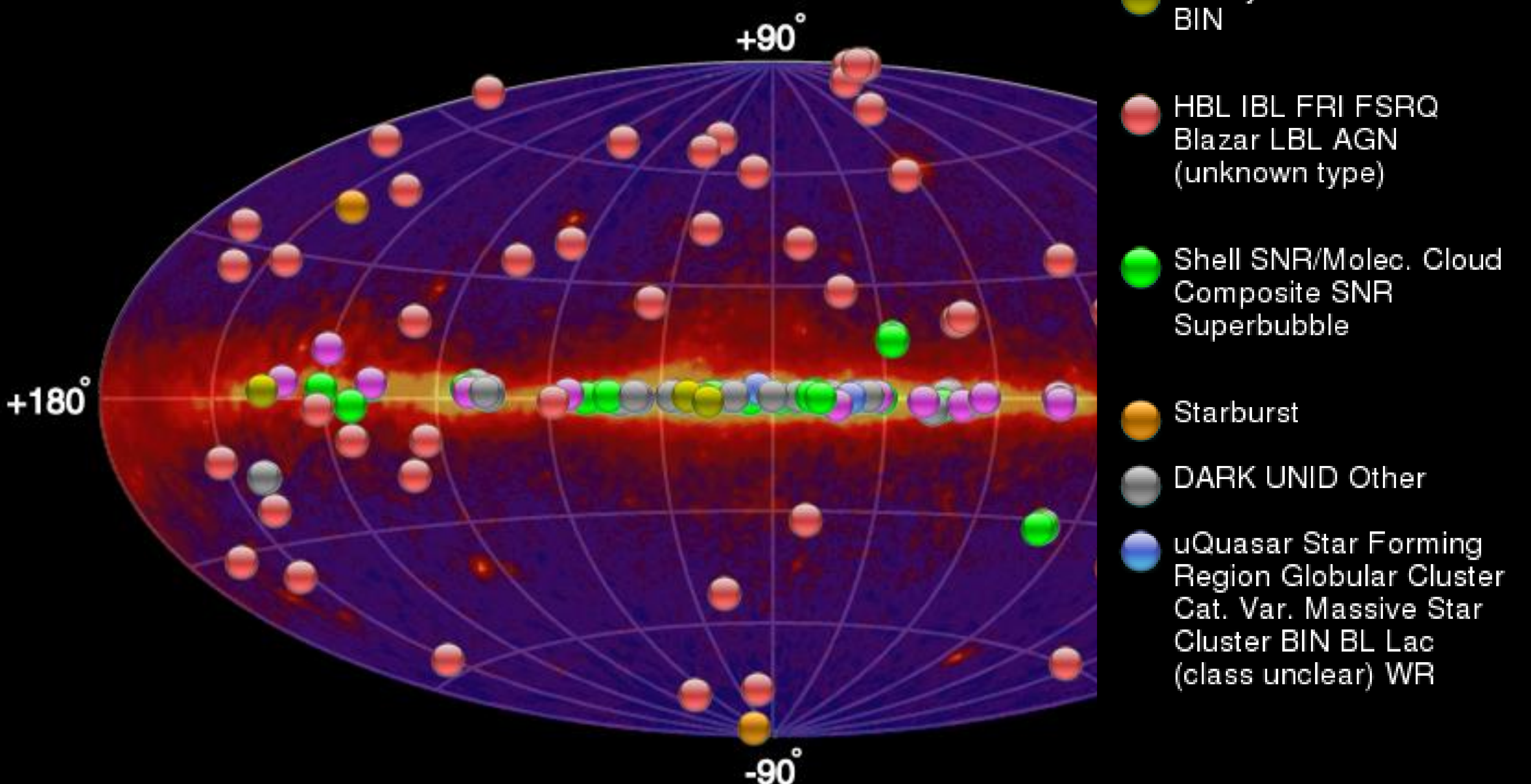
Part I

The age of TeV astrophysics
(We mean: 30 GeV to 100 TeV→)



2005
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
0°
45°
0°
-45°
-90°

The TeV sky

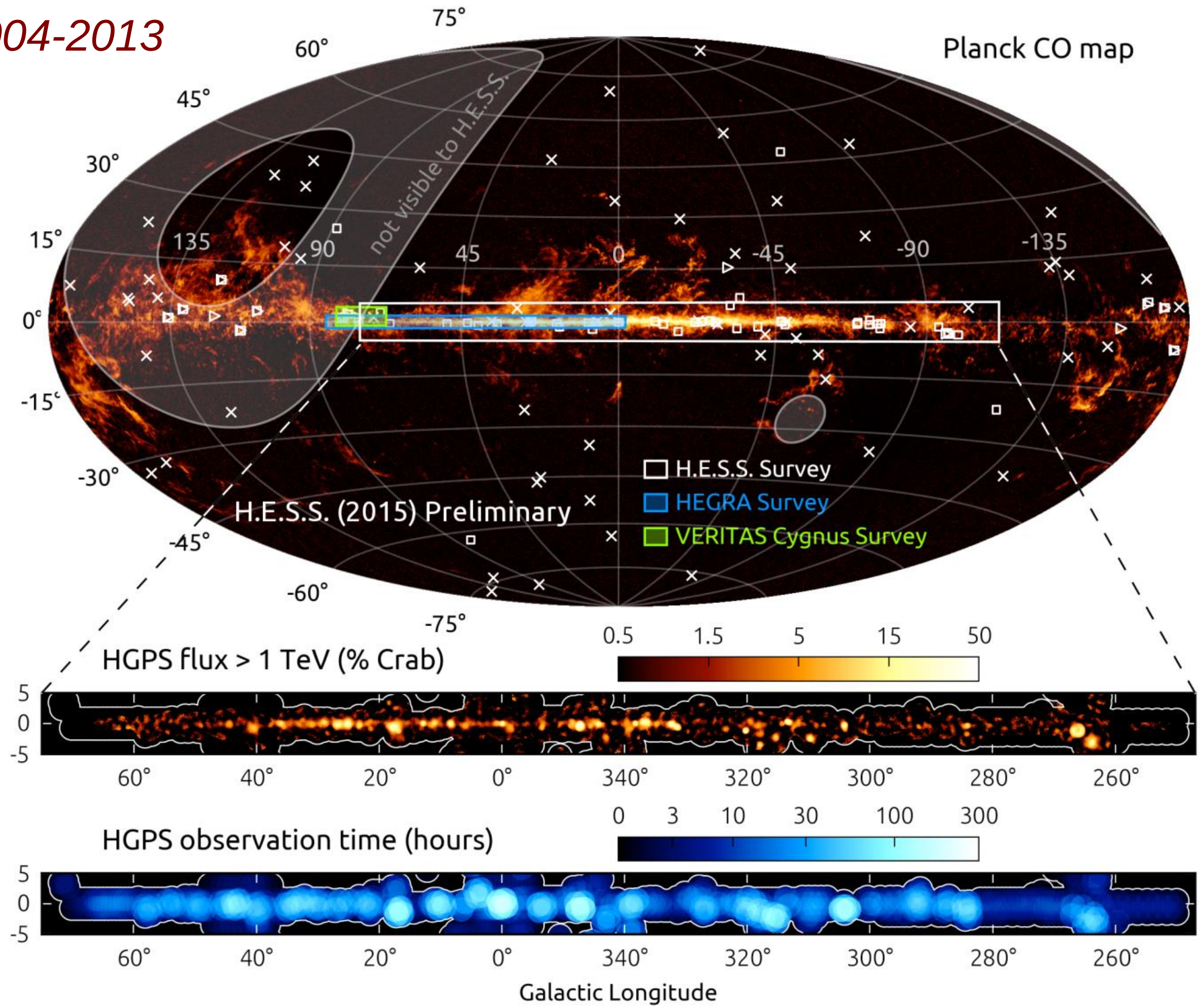


More than 180 sources are now known to emit in the TeVs

Courtesy of the TeVCat online source catalog (http://tevcat.uchicago.edu)

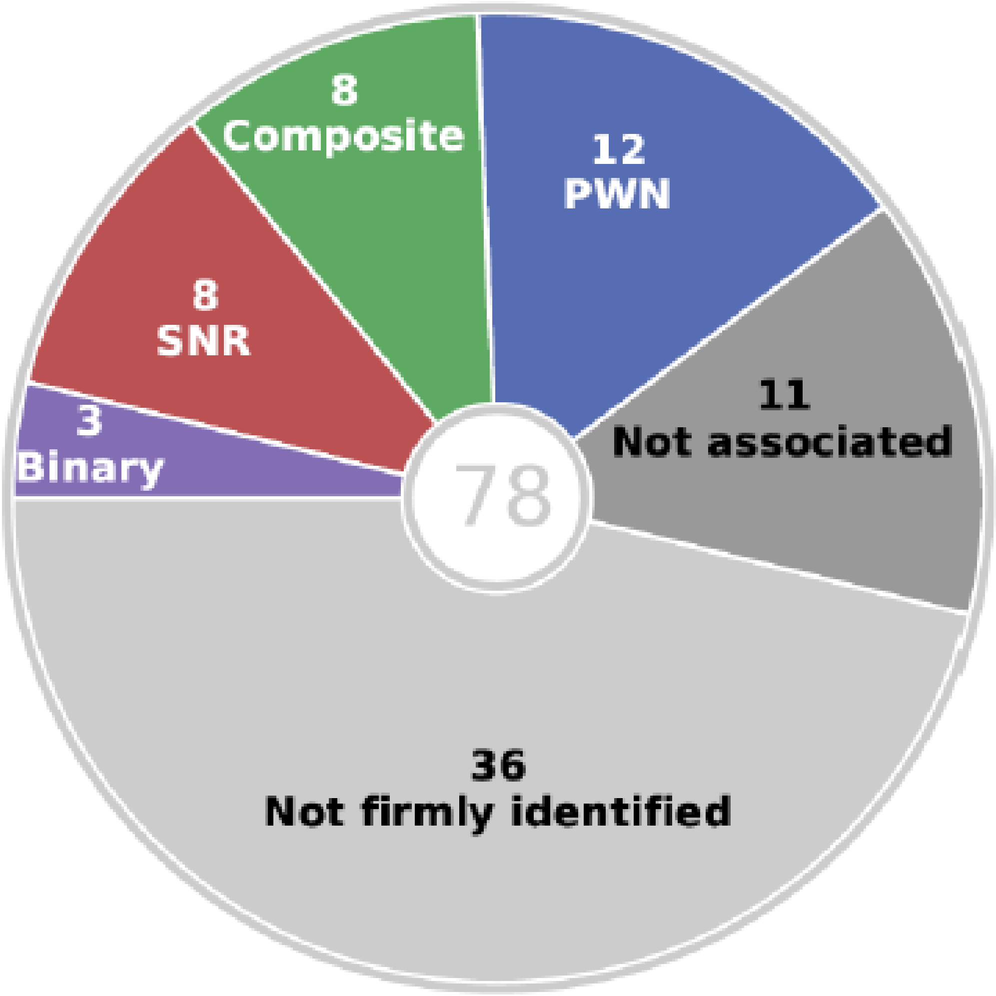
H.E.S.S. galactic plane survey

Data 2004-2013



2673 h of observation after quality selection.

Census of the HGPS catalogue



Preliminary

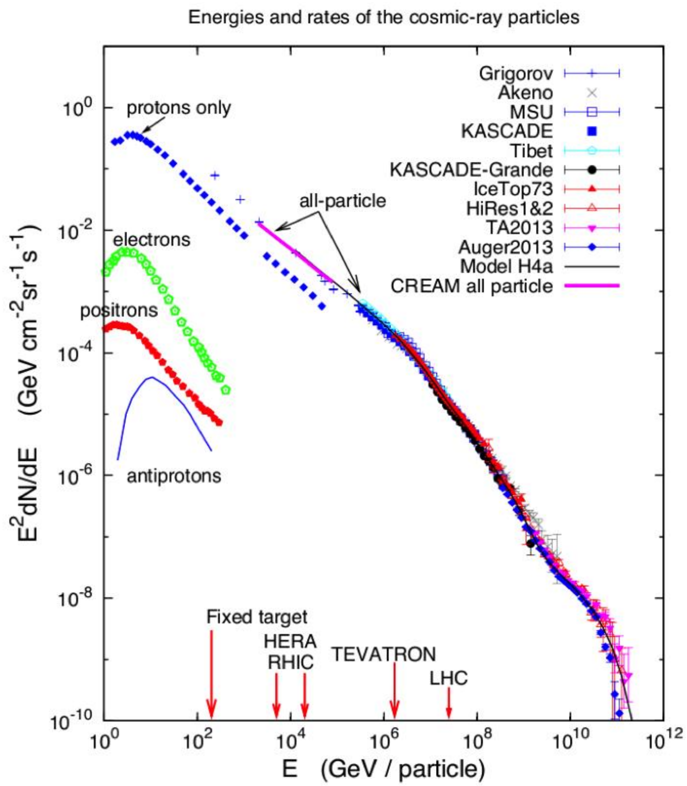
Some of the **10+ classes of objects** found to be galactic or extragalactic accelerators)

→

The "local fog" of Galactic Cosmic rays

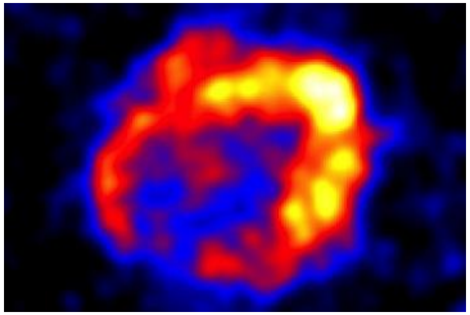
Science challenges of TeV astrophysics

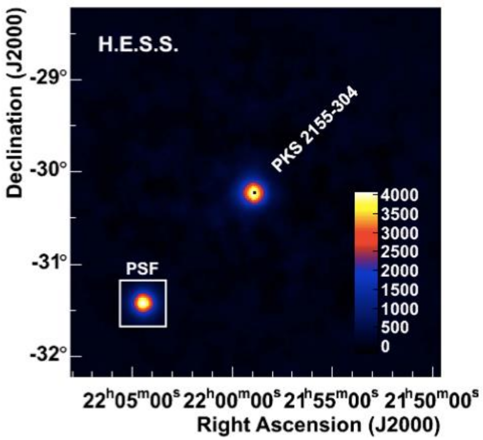
Origin of Cosmic Rays



Where are the Pevatrons?
How do CR propagate?
Impact on the ISM?

Particle Acceleration



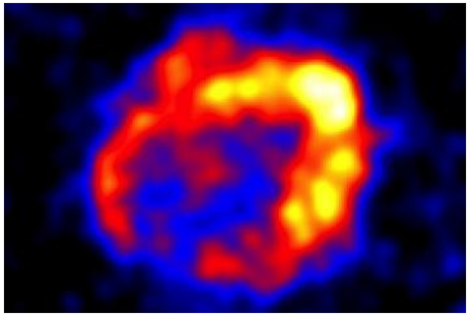


What are the mechanisms?
Size of the regions from variability?

Physics of the non-thermal Universe

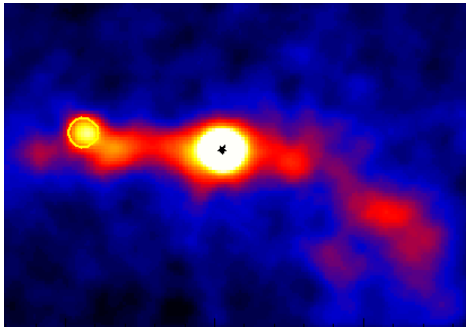
The puzzle of the origin of cosmic rays

Search for Galactic Cosmic Rays **accelerators**



acceleration

Understanding CR **escape into the ISM**

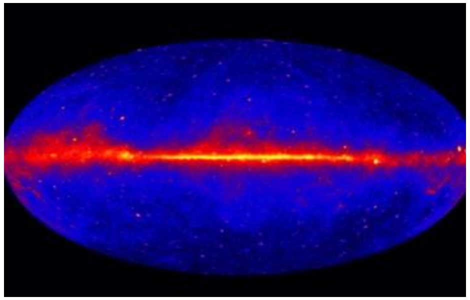


escape = injection into ISM

Big Puzzle:

Factories of 10^{15} eV particles

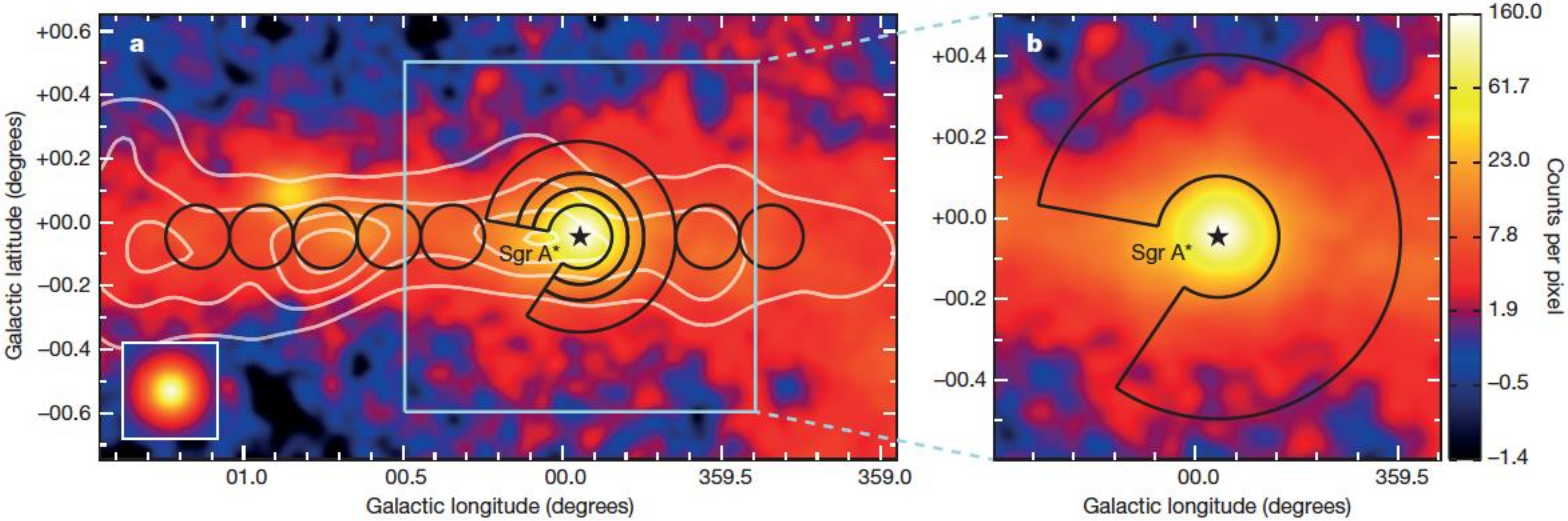
PeVatrons (CR accelerators can accelerate/confine PeV particles for short amounts of time)



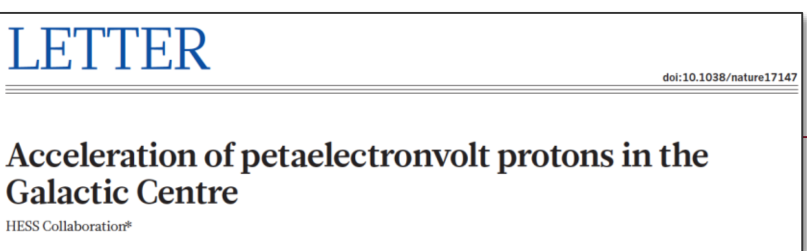
diffusing and filling the Galaxy

Galactic Centre: a pevatron

Point like, central source on top of an extended (ridge emission)



- Central point source: cut-off @ 10 TeV
- Diffuse emission shows no cut-off well > 10 TeV
- Parent **proton population** up to 1 PeV (2.9 PeV @ 68% CL)


LETTER

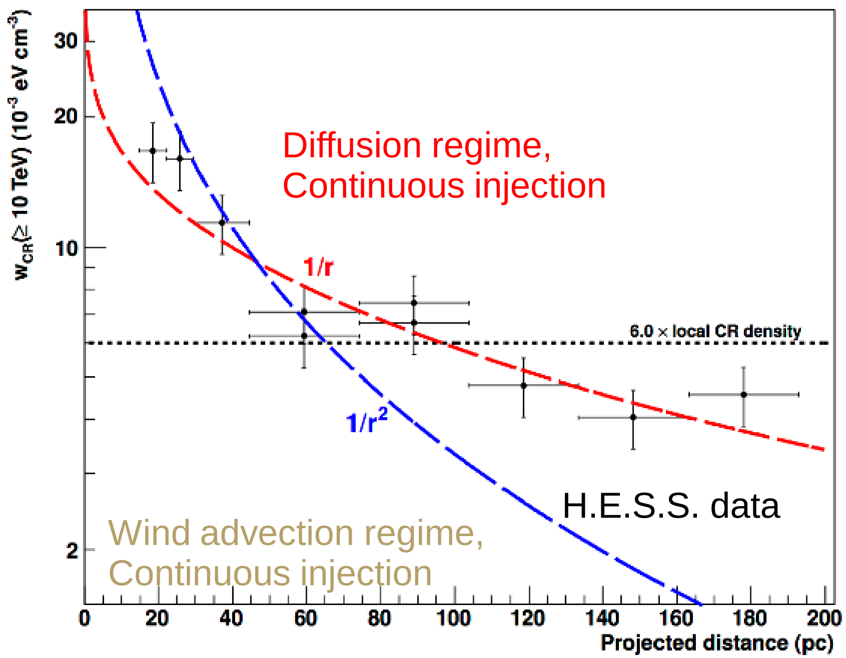
doi:10.1038/nature17147

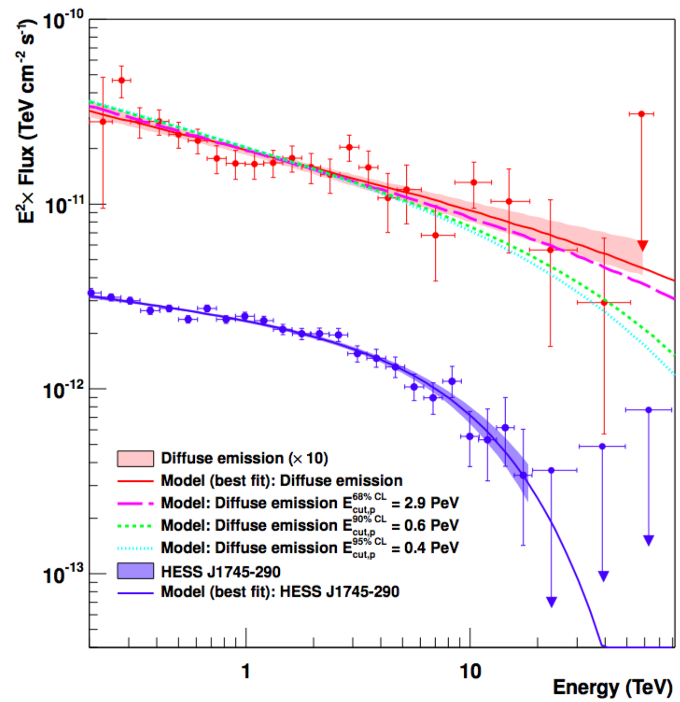
Acceleration of petaelectronvolt protons in the Galactic Centre

HESS Collaboration*

Galactic Centre with H.E.S.S.

- Emission profile consistent with propagation of protons accelerated around central black hole and diffusing away

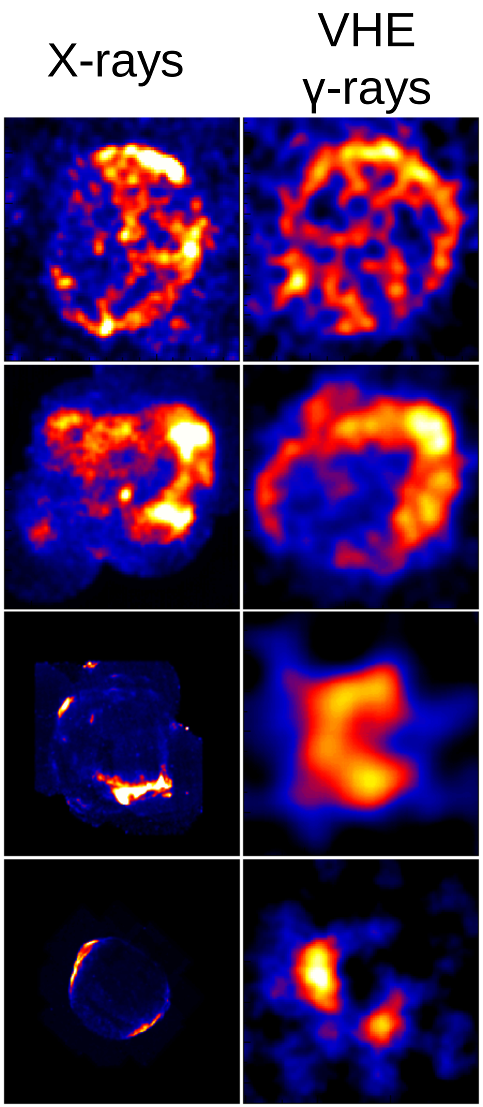




Gamma-ray emitting SNRs

- **Young, historical supernovae, in different evolutionary stages → SNRs can be pevatrons during a (very short time)**
  - **inverse Compton of the population emitting non thermal X-rays**

- **More evolved SNRs proven to accelerate protons**
  - **In interaction with molecular clouds**
  - **π^0 bump in Fermi-LAT**



RX J1713.7-3946: SED modeling

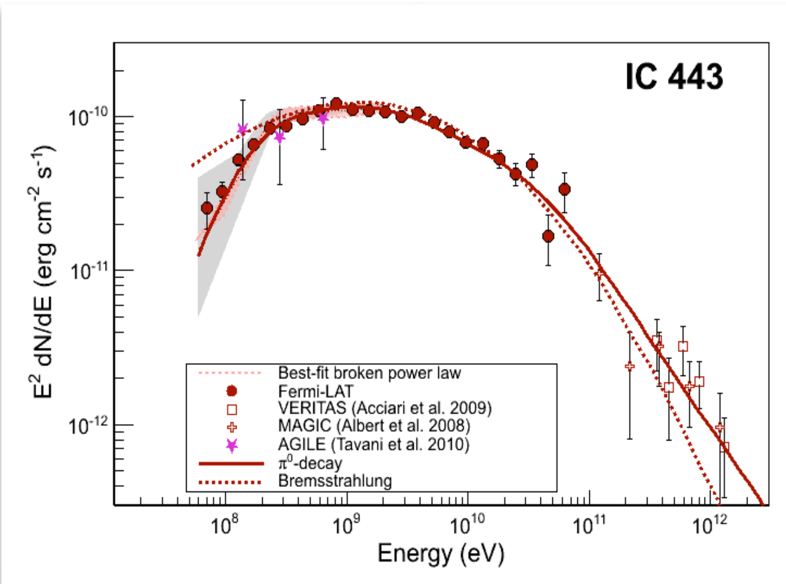
leptonic model

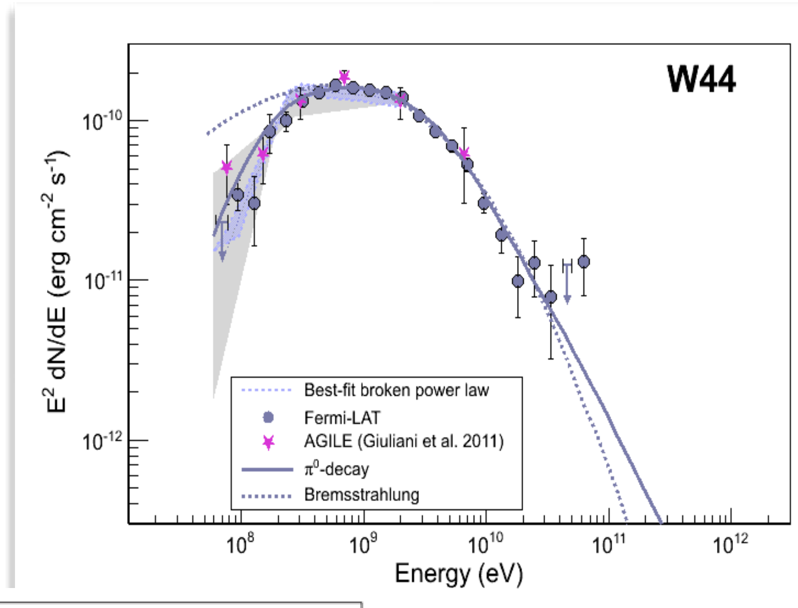
hadronic model

- Leptonic processes would require large B field (~140 μG) or very large target photon field, at odds with other observations

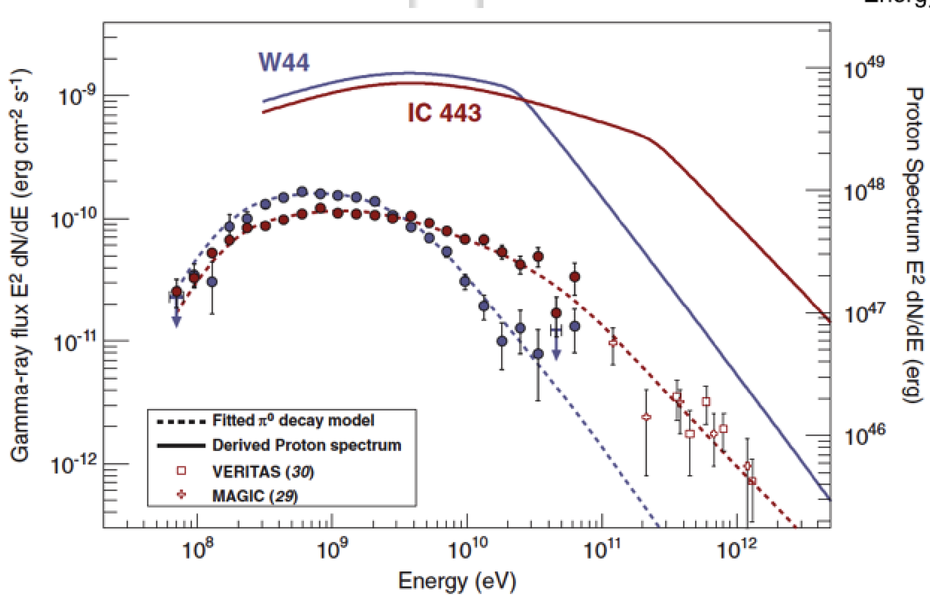
- Hard proton spectrum (break at 0.8 TeV) in hadronic model
- Could be explained e.g. by energy-dependent diffusion of CR protons into a clumpy medium inside the SNR (Aharonian & Gabici 2014)

Clear detection of the pion-bump





IC 443



W 44

- Clear indication of a low-energy turnover

Science 339, 2013

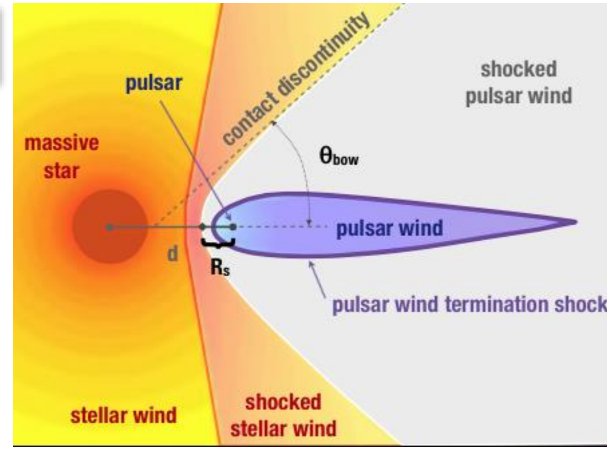
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

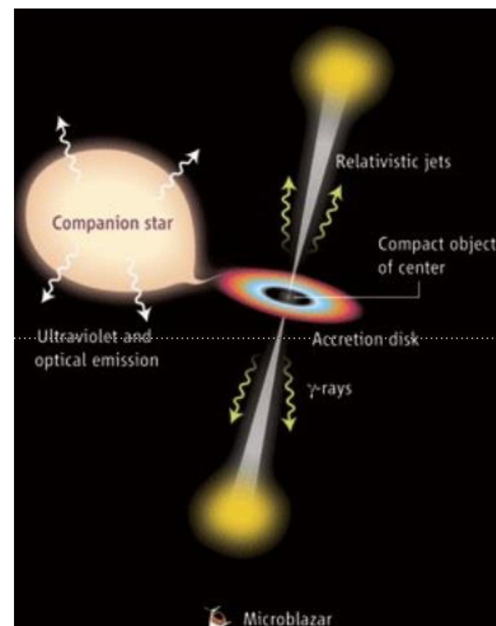
TeV Gamma Ray Binaries

- Gamma-ray binaries: small class of objects

	Period (days)	$M_*(M_\odot)$
PSR B1259-63	1236	31
LS 5039	3.9	23
LS I +61 303	26.4	12
HESS J0632+057	315	16
1FGL J1018.6-5856	16.6	31

- Accretion/ejection in binary systems
- Anisotropic radiation fields (absorption by pair creation)



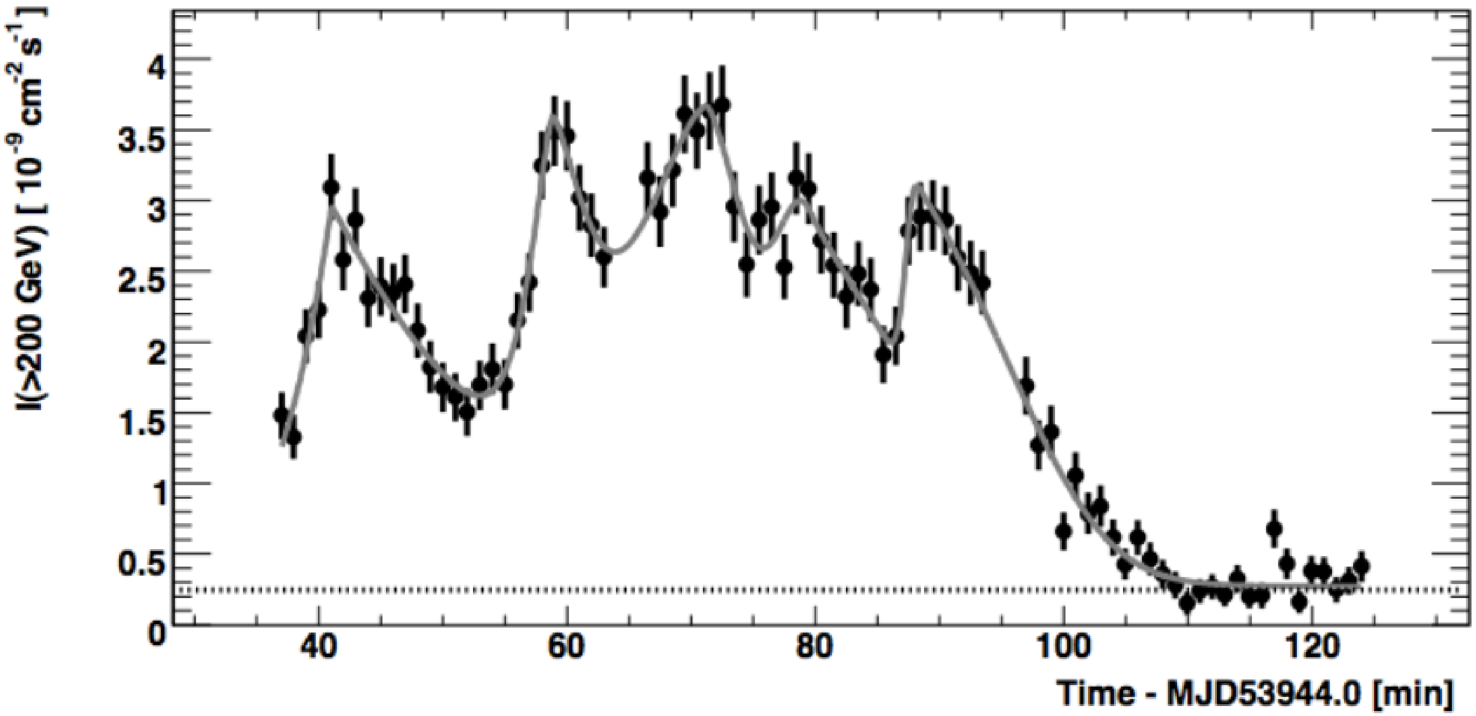


G. Dubus, ArXiv: 1307.7083

A new kid in town: +HESS1832-093?

TeV Blazar: PKS 2155-304

Temporal structure of the flares



temporal structure down to minutes found

$ct_{\mathrm{var}} \ll r_{\mathrm{Schwarzschild}}$

HESS collaboration: Aharonian et al. ApJ 664 (2007)

Part II

The keV-TeV connection: why TeV astrophyscs needs X-rays and viceversa

keV – TeV connection (1)

synchrotron X-rays of directly accelerated electrons –

A tool for probing Cosmic TeVatrons:

SNRs, Pulsar Wind Nebulae, gamma-ray loud binaries, AGN/Blazars

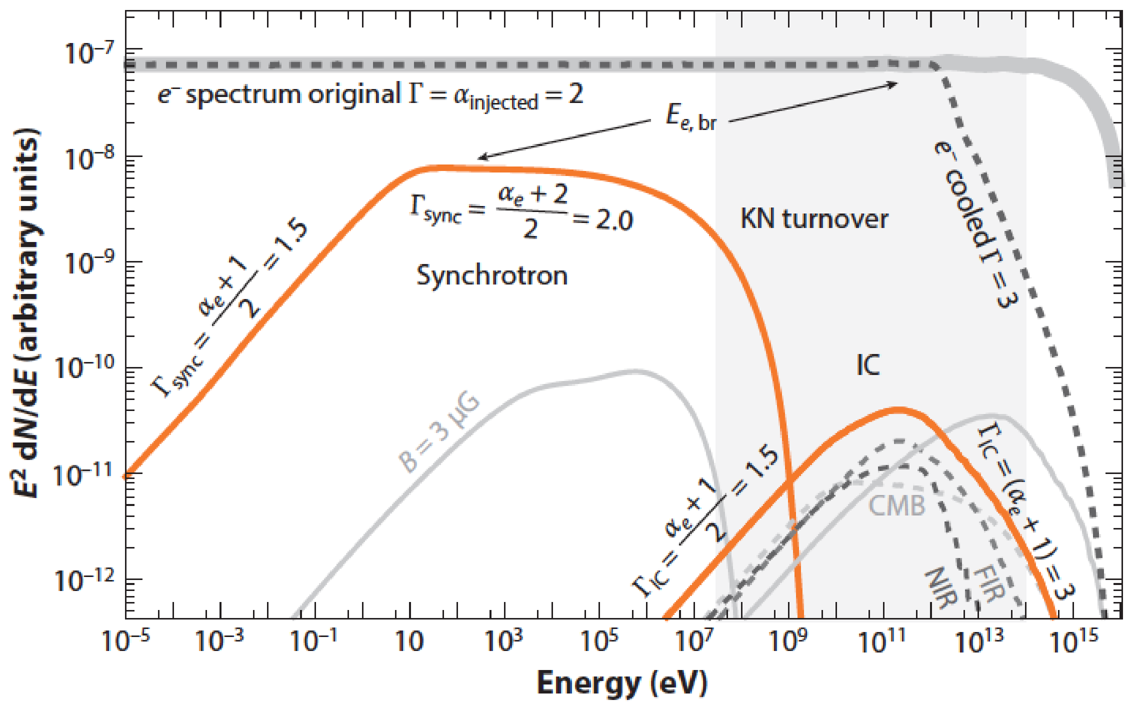


Figure from the review by S. Funk (2015)

keV – TeV connection (2)

synchrotron X-rays of secondary electrons –
A tool, complementary to TeV (and neutrinos…) for not yet discovered PeVatrons and even higher energy-trons…

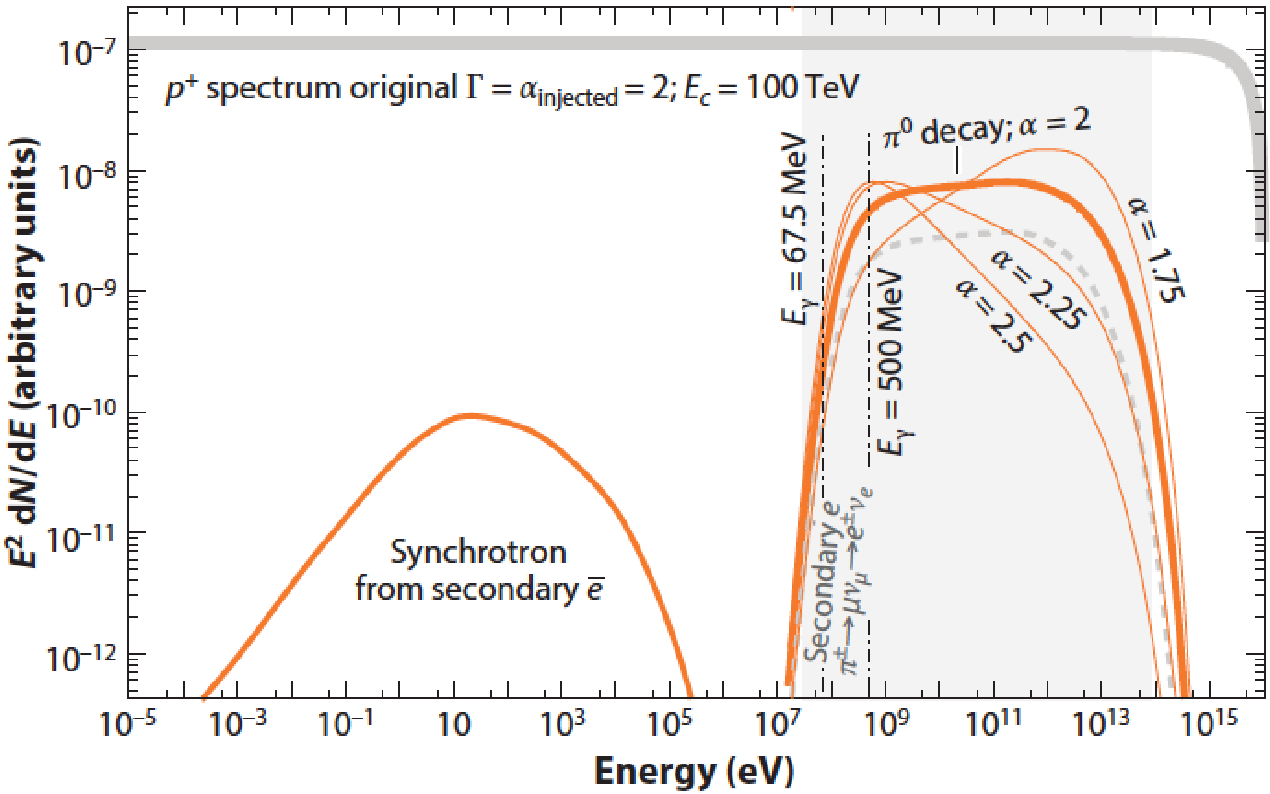


Figure from the review by S. Funk (2015)

Pevatrons and acceleration

It is difficult for theories to model such accelerators:
we have to accept accept that those machines are operating at the highest possible efficiency

Acceleration efficiency: fraction of available energy converted to nonthermal particles in SNRs, in PWNe and AGN) → essential for understanding **Diffusive Shock Acceleration**

Maximum possible energy achieved by individual particles

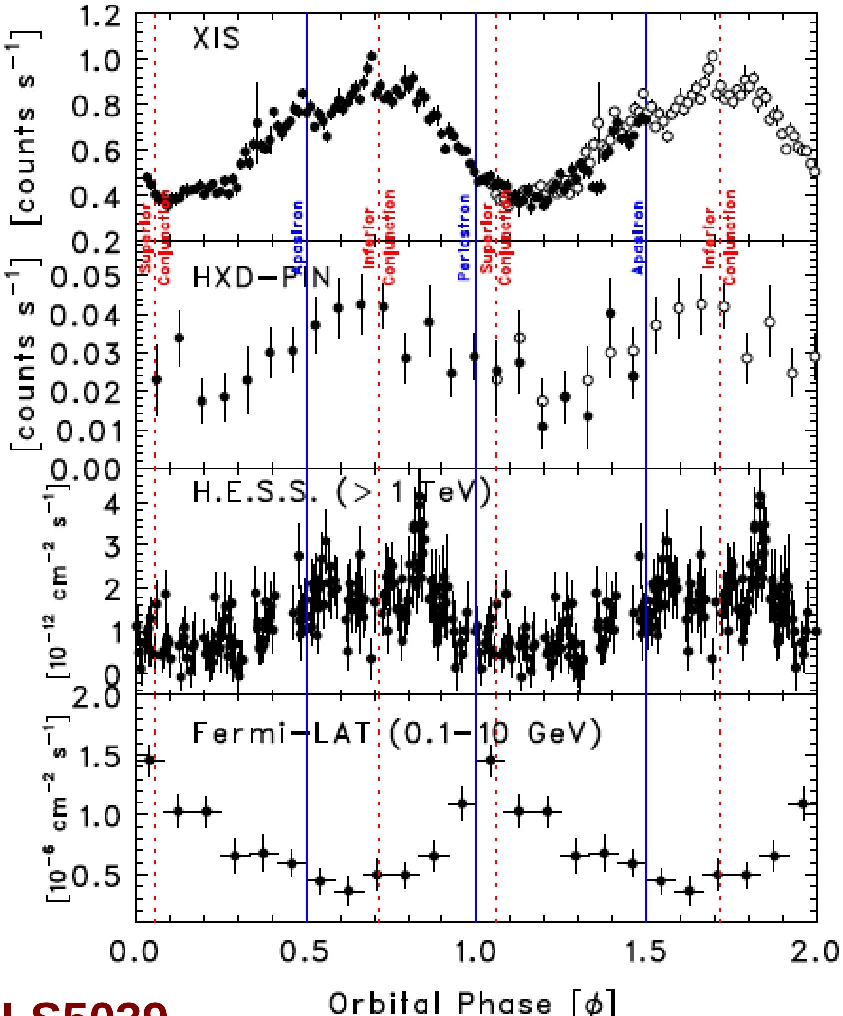
Magnetic Field Amplification due to cosmic ray pressure

Why eXTP in CR studies?

- **LAD:** Hard X-rays, at which the non-thermal emission dominates on the thermal emission
- **SFA:** Characterization of the thermal emission (lines and continuum)
- **PFA:** image in spatial details the turbulences of the magnetic field (test magnetic field amplification)
- (Nice) talks by **Cheng Yang** and **Zhang Shuo**!

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Orbital studies of Gamma Binaries



LS5039

Through combined Gamma and X-ray observations the **complex physics can be understood:**

X-ray→ synchrotron (?)

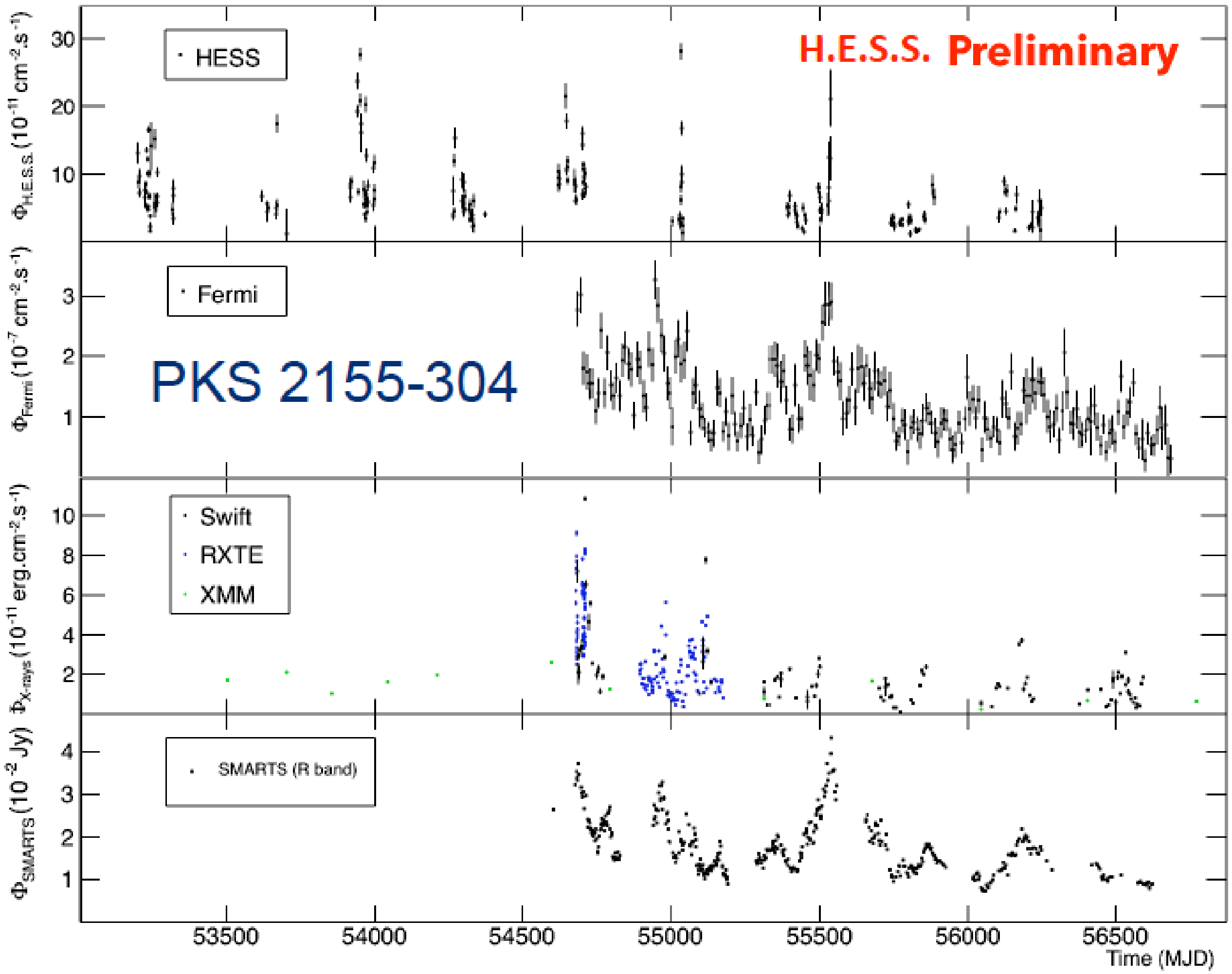
TeV → inverse Compton + pair production absorption in the stellar wind

GeV → unaffected by pair production absorption

In the future: **Orbital Phase resolved spectroscopy at TeV!**

Suzaku + HESS + Fermi (Takahashi et al. 2009)

Long Term monitoring of Blazars



H.E.S.S.
VHE

Fermi-LAT
HE

Swift,
RXTE
XMM

R-band

Part III

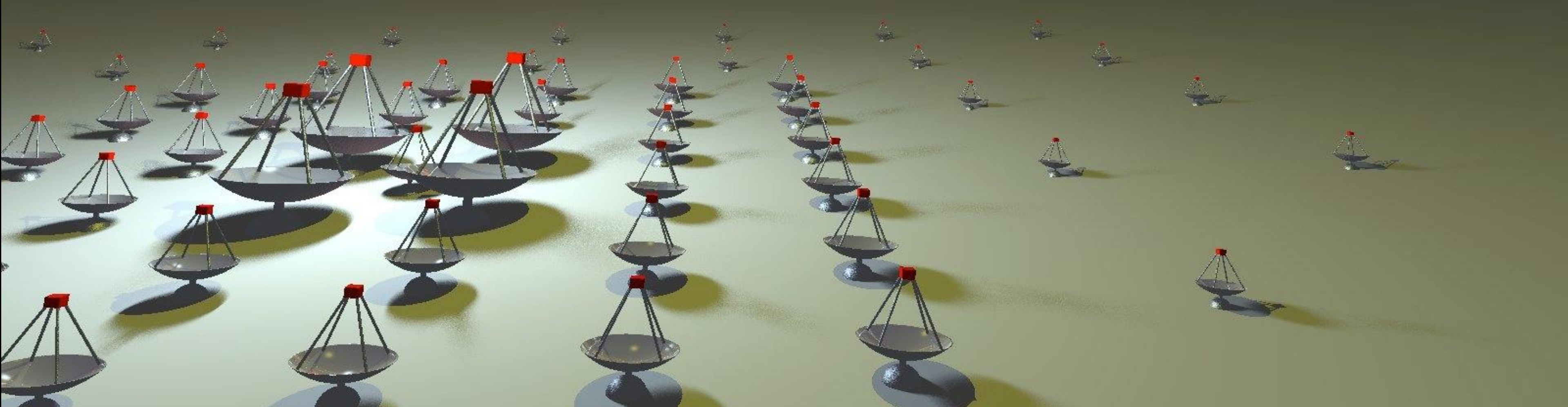
TeV observatories of the eXTP era

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

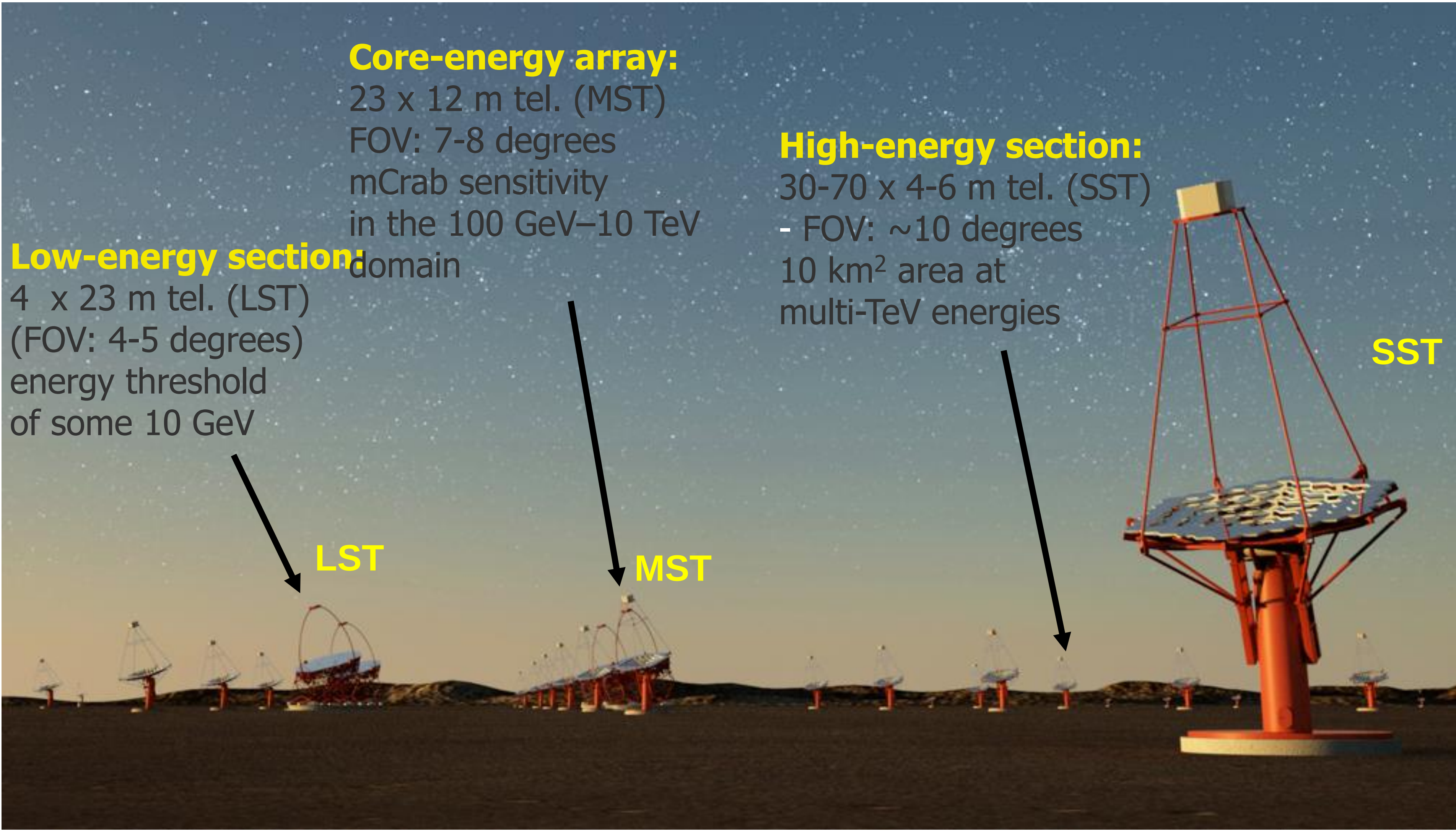
We would like to reach

Key design goals:

- 10-fold increased sensitivity at TeV energies
- 10-fold increased effective energy coverage
- Larger field of view for surveys
- Improved angular resolution
- Full sky coverage: an array in each hemisphere

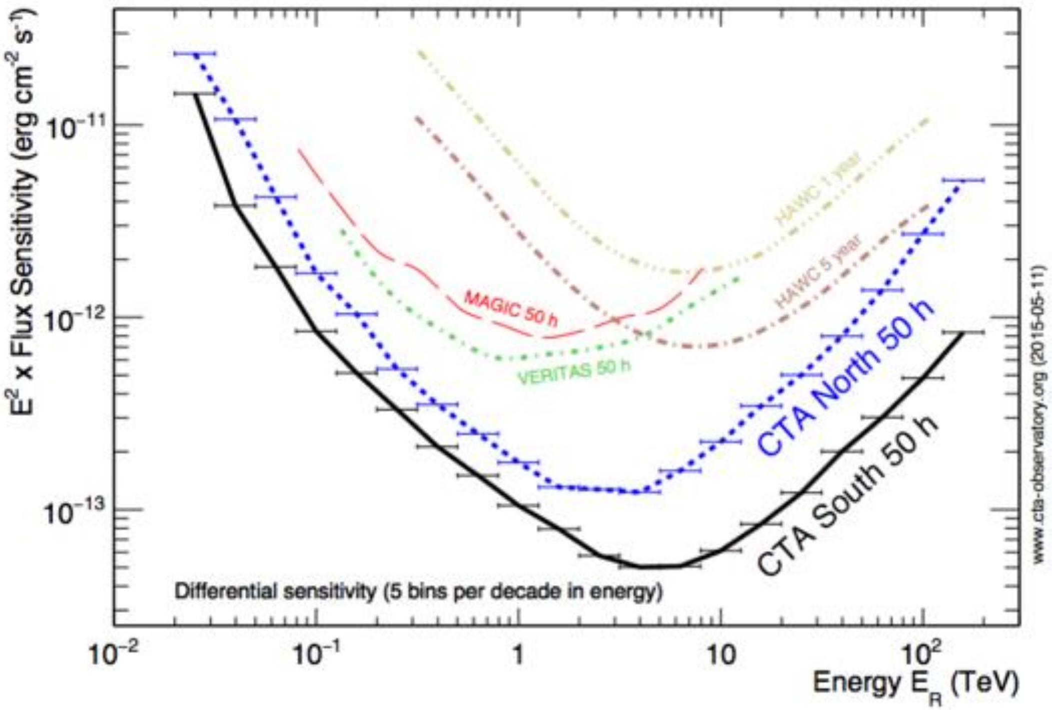


Cherenkov Telescope Array

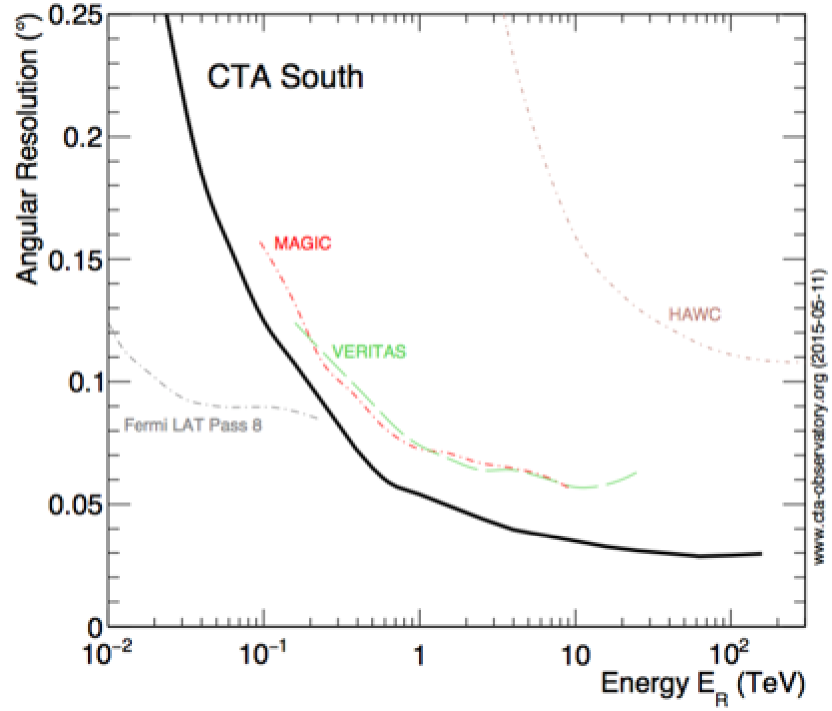


CTA flux sensitivity – steady point sources

Next generation observatory

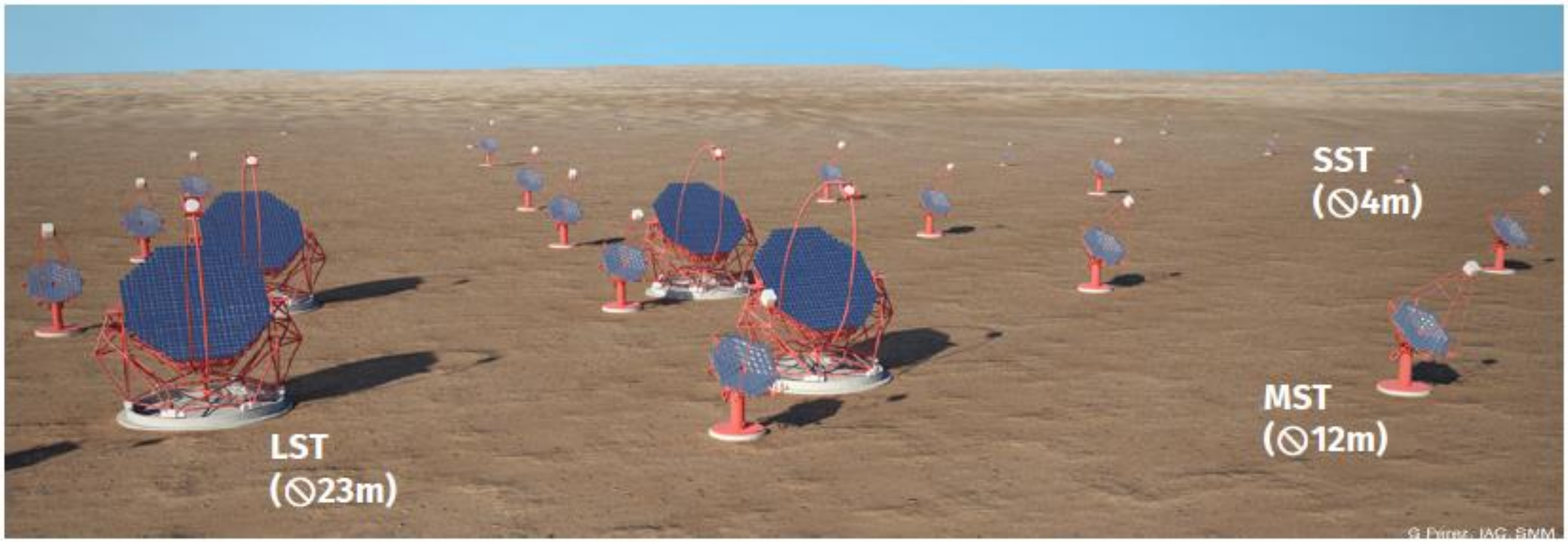


Differential point source sensitivity

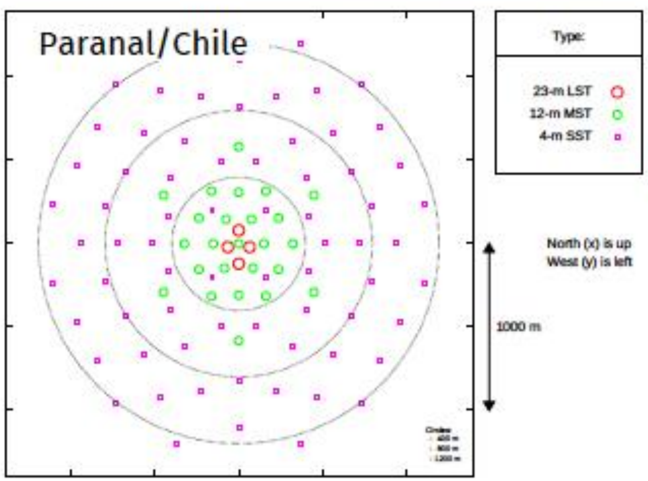


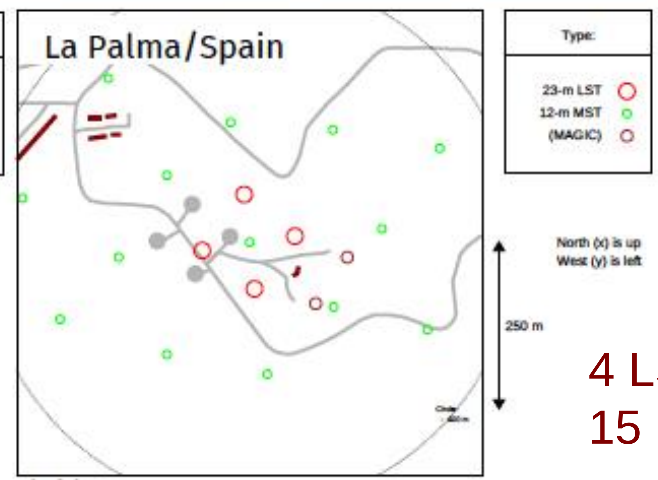
Angular resolution (80% containment radius)

CTA sites



4 LSTs
25 MSTs
70 SSTs



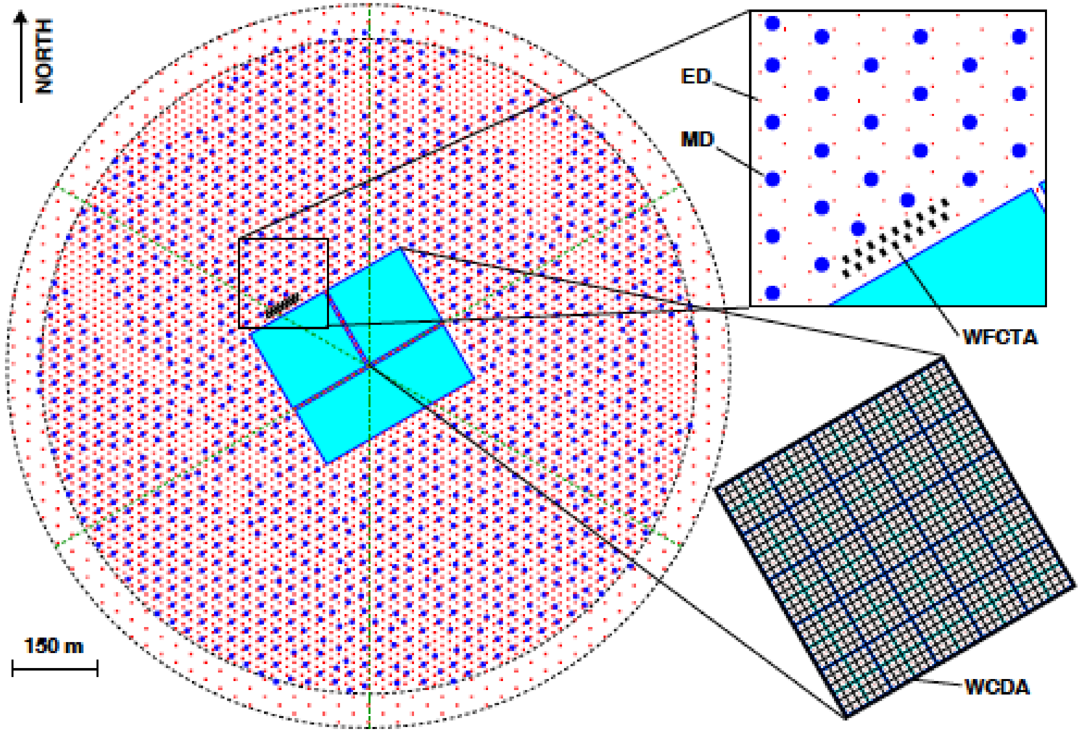


4 LSTs
15 MSTs

The Large High Altitude Air Shower Obs.

1 km² array, with 4941 scintillator detectors 1 m² (spacing 15 m)

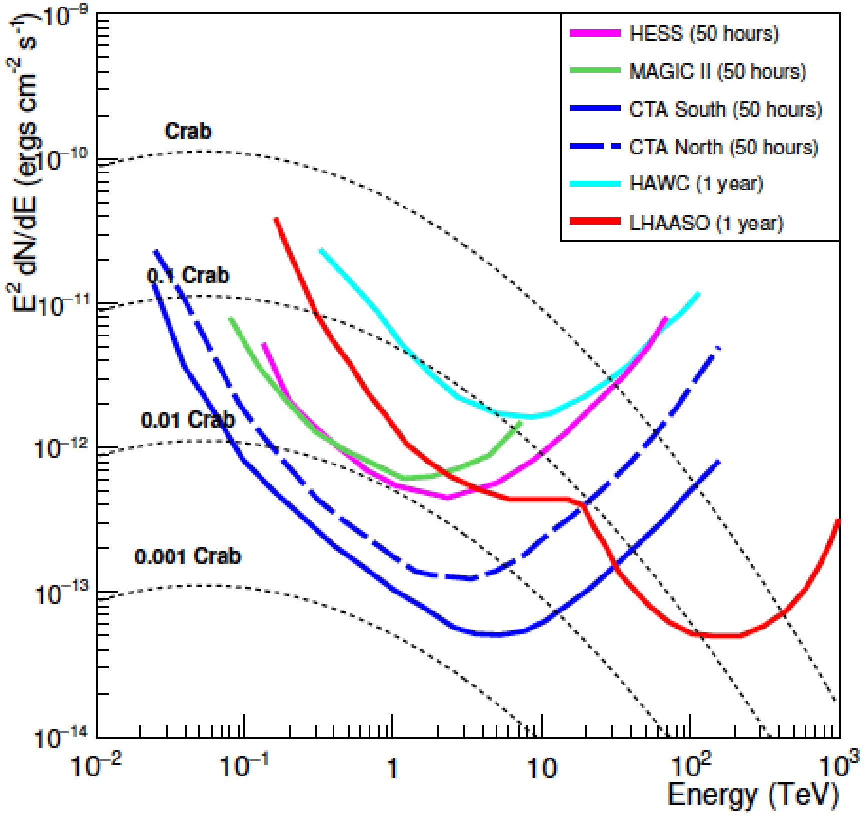
1 km² array of 1146 **underground water Cherenkov tanks** 36 m² each (for muon detection area 42,000 m2)

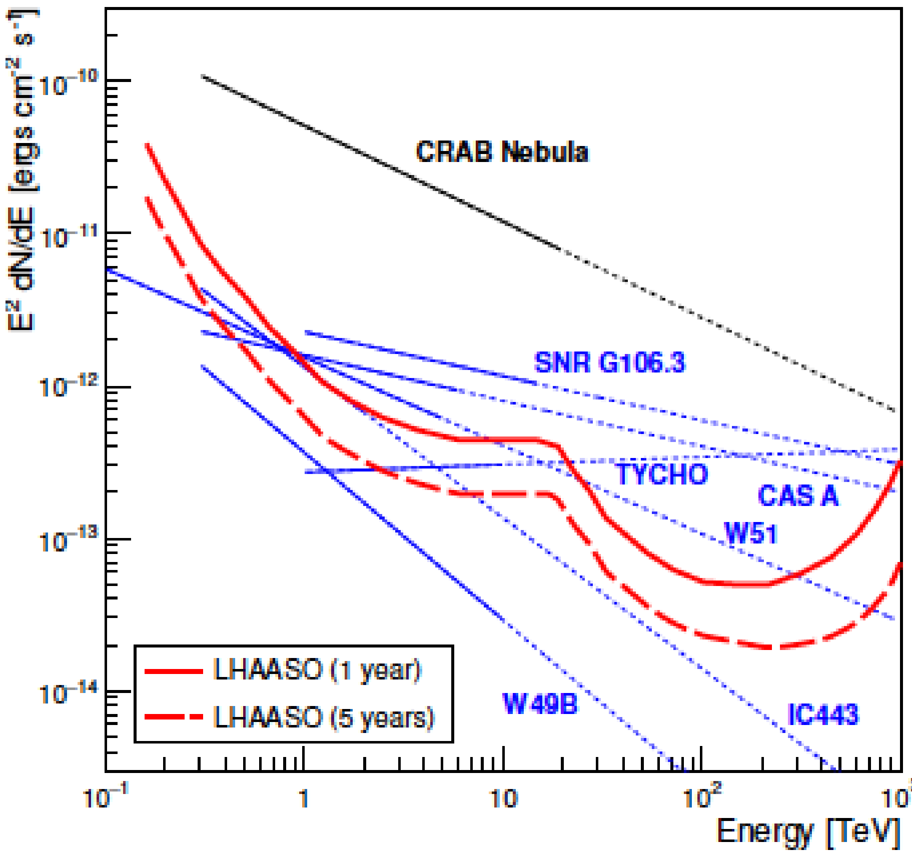


A close-packed, **surface water Cherenkov detector facility** with a total area of 80,000 m²

18 wide field-of-view air Cherenkov and fluorescence telescopes.

Sensitivity of LHAASO





Left Sensitivity of LHAASO to a Crab-like point gamma ray source

Integral Spectra of SNRs in the LHAASO field of view extrapolated to 1 PeV.

Conclusions

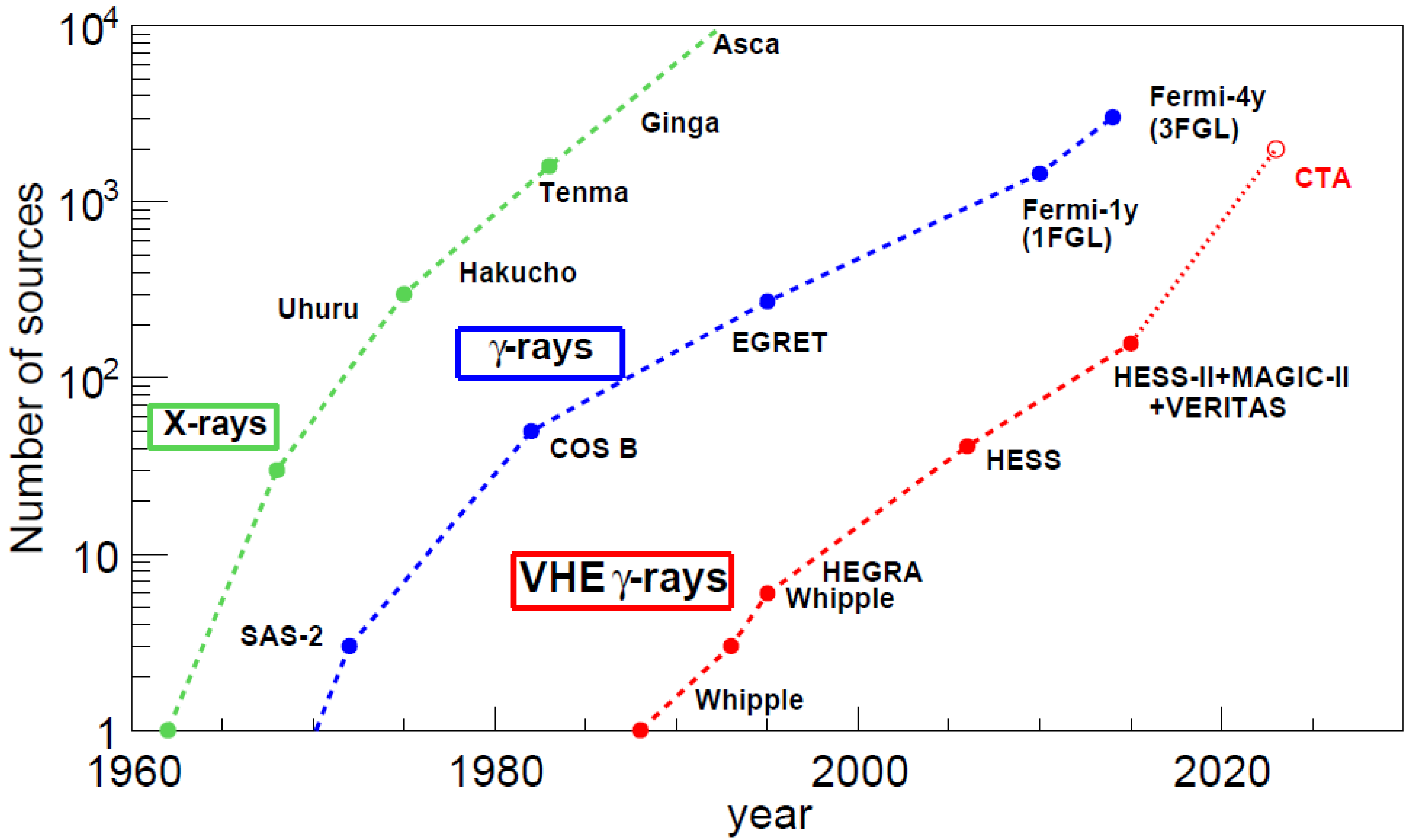
- eXTP will operate in the same time window of CTA and LHAASO.

- X-rays are going to provide key observational information on the physics of the non-thermal Universe and…

- On the identification of the astrophysical nature of the observed TeV-PeV – atrons.

- Most likely some long standing puzzle on the nature of the sources of the Cosmic Rays, on the Acceleration Mechanisms, on the nature of the TeV Gamma Binaries and more will be eventually clarified.

The Future: Kifune plot



Stay tuned for surprises!

Stay Tuned for surprises!

Thank you.

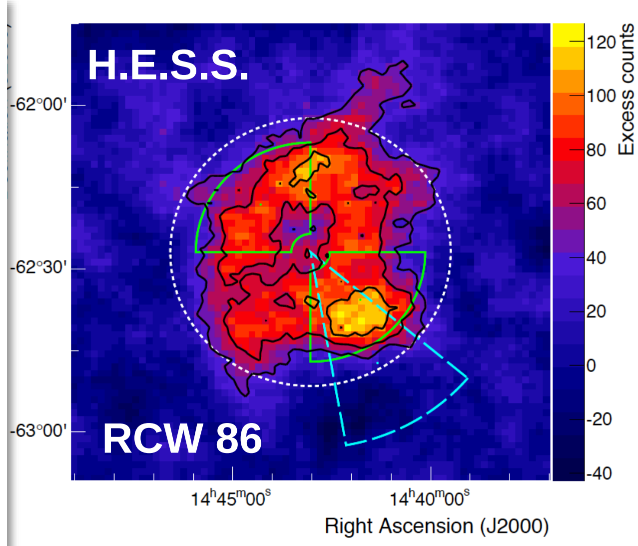
Contact:

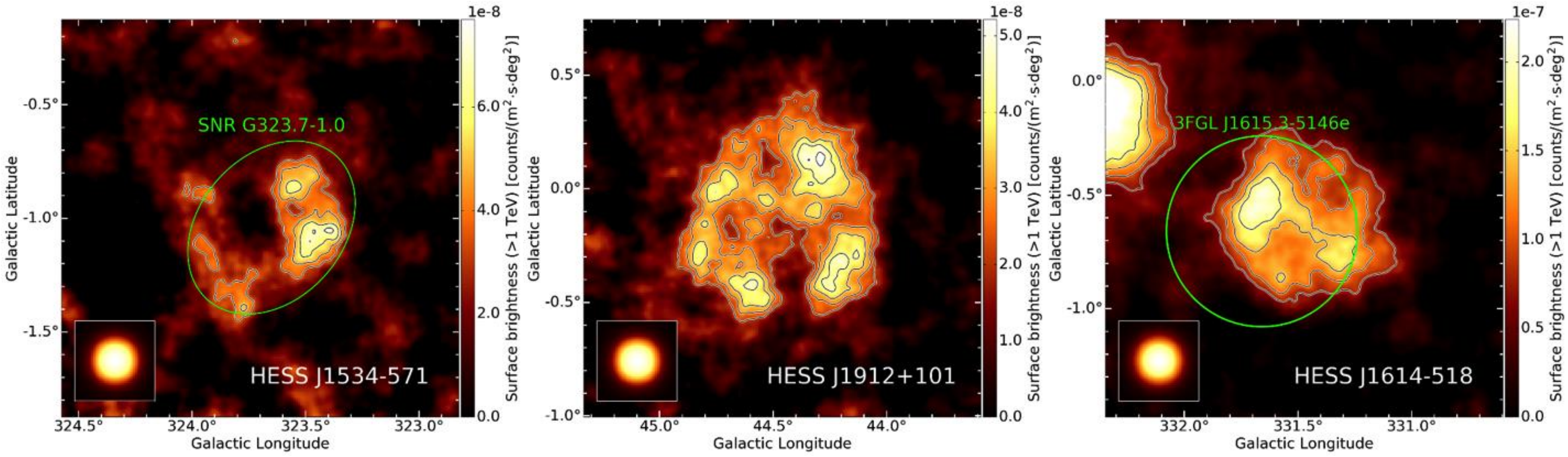
Andrea Santangelo
Abteilung Hochenergieastrophysik
Sand 1, 72076 Tübingen · Germany
Phone: +49 7071 29-76128
Andrea.Santangelo@uni-tuebingen.de

New shell-type SNRs with H.E.S.S.

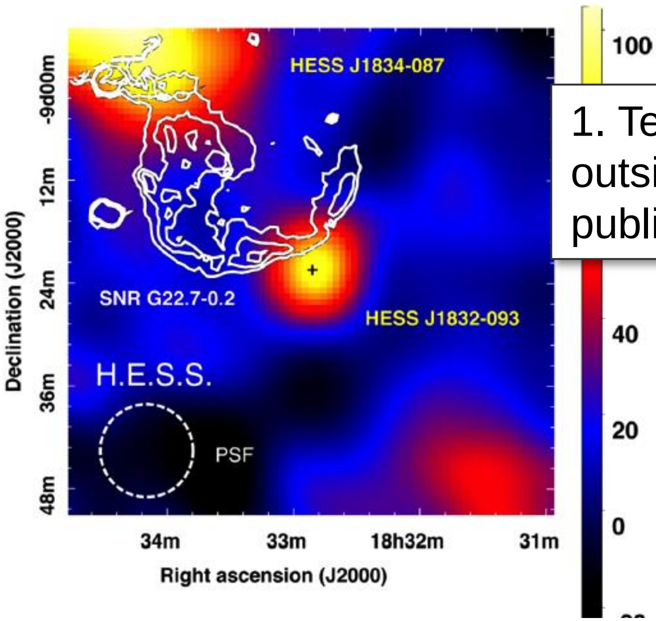
- RCW 86:
  deep exposure confirms TeV shell appearance
  - Good correlation between TeV and hard X-ray (IC vs. synchrotron), likely leptonic dominated, B ~20 μG
  - Maximum energy ~ 3 TeV

- New TeV shells:
  HESS J1534-571, HESS J1614-518, HESS J1912+101
  - Identified in the HESS Galactic Plane Survey (HGPS) data set
  - HESS J1912+101 likely the only TeV SNR w/o counterparts in other wavebands
  - Lack of nonthermal X-ray synchrotron emission (at least for HESS J1534-571): hints at proton emission(?)



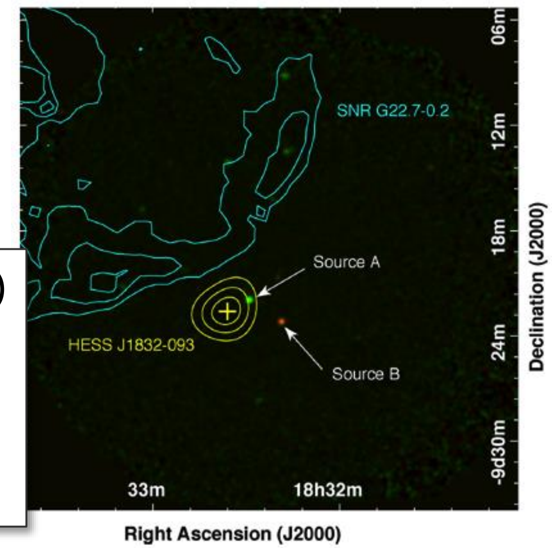


HESS J1832-093: The new kid in town?

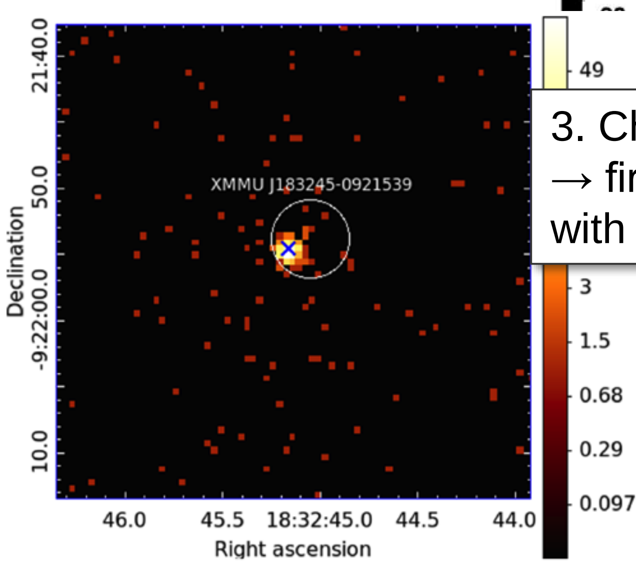


HESS coll. 2015

1. TeV point source just outside SNR G22.7-0.2, published 2015

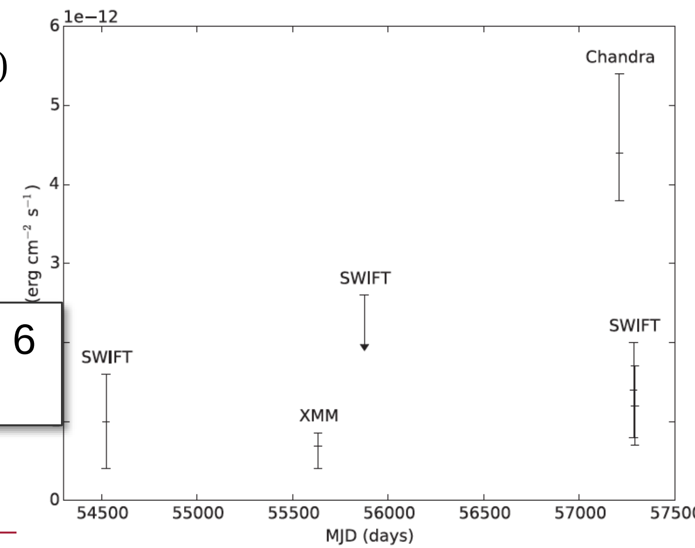


2. XMM-Newton (point-source) localisation
→ likely identification with TeV source + likely identification with optical counterpart



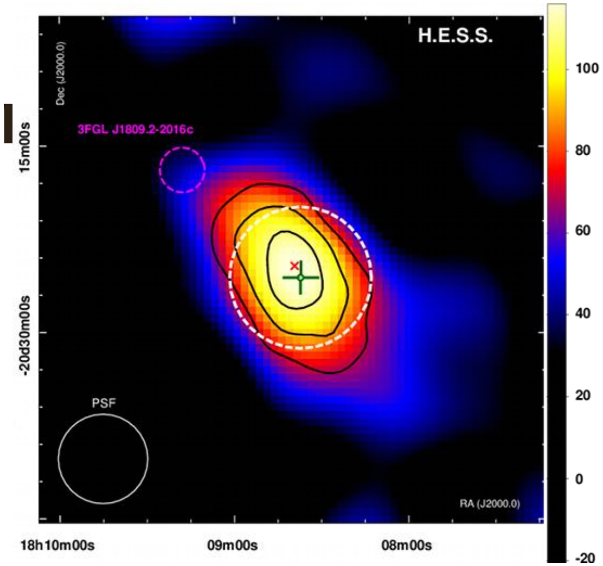
Eger at al., MNRAS 457 (2016)

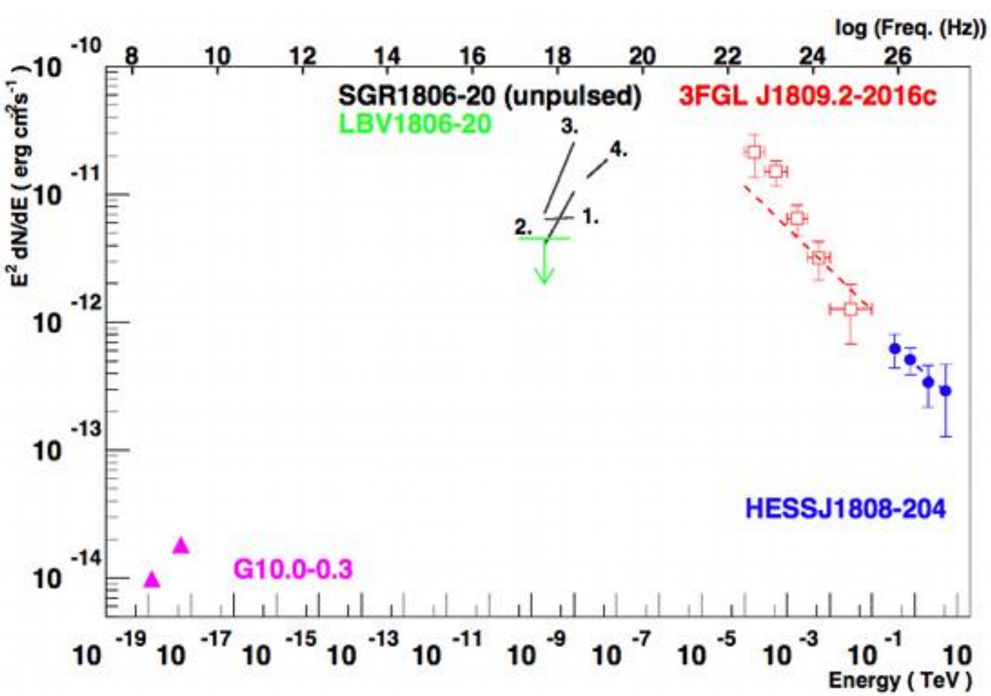
3. Chandra localisation
→ firm identification with optical counterpart

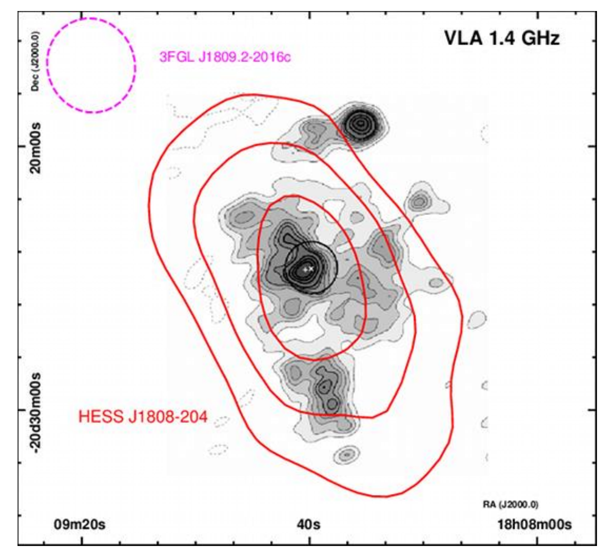


4. X-ray variability by × 6
→ likely a new binary

- HESS J1808-240 might be powered by the magnetar SGR1806-20; in this case, the TeV source is more likely powered by magnetic dissipative effects (rather than rotation-powered)
- Alternative counterparts (LBV1806-20, stellar cluster) also interesting, discrimination not yet possible





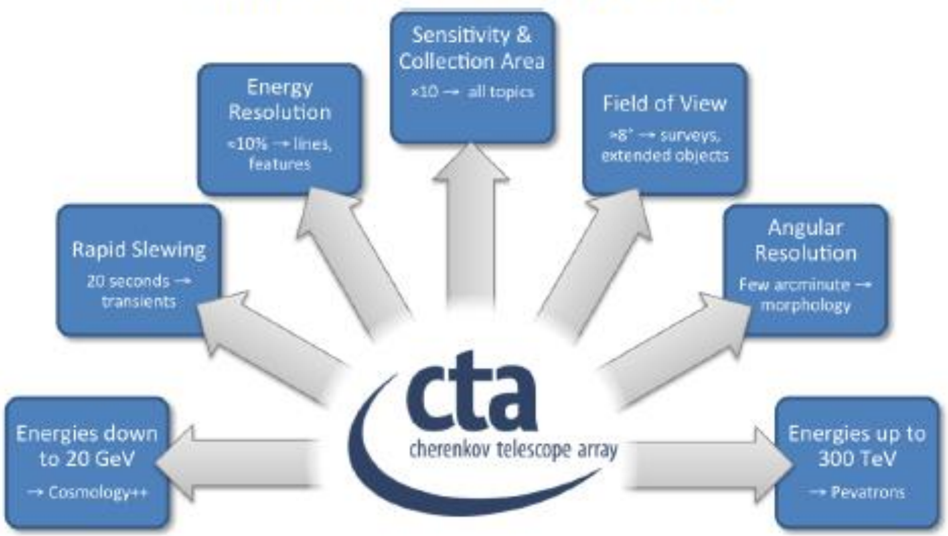


CTA Programmatics

An Open Observatory

A world-wide endeavour

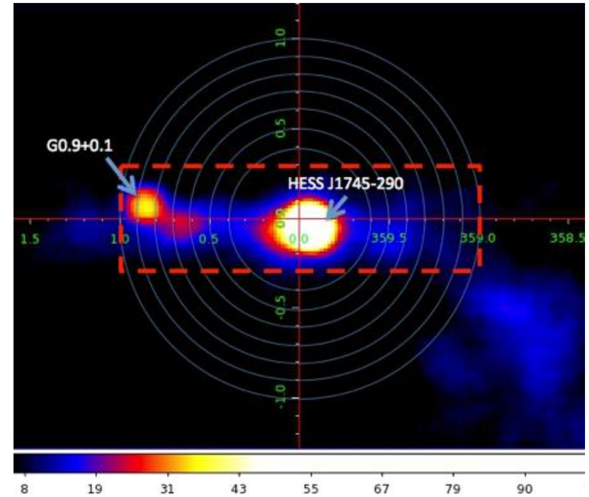
Improvements everywhere

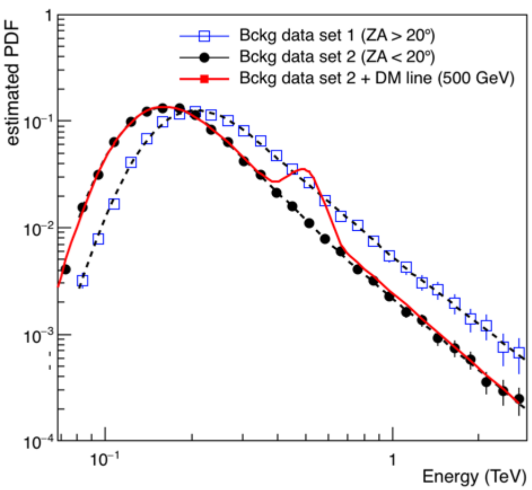


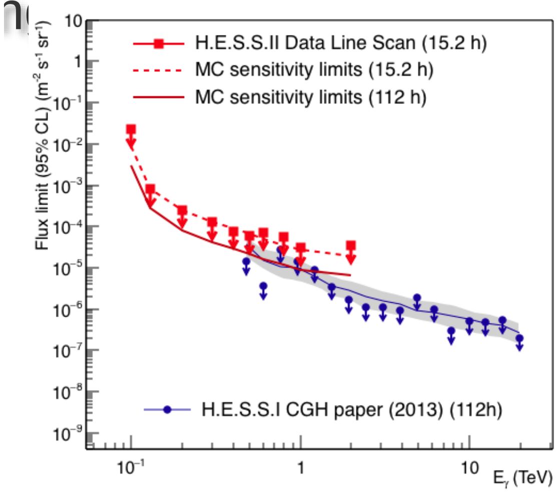
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

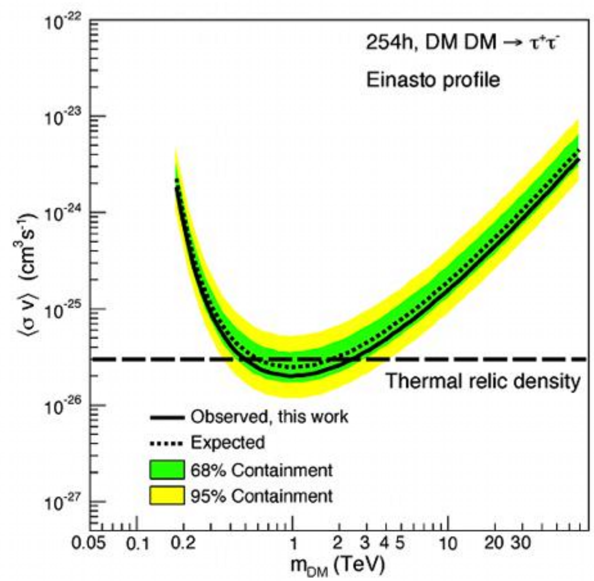
Dark Matter Searches

- Current targets:
  - Galactic Centre Halo
  - Dwarf spheroidals
- Strategies
  - Deep observations (≥200 h)
  - Optimal statistical treatments
  - Search for annihilation lines









EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Large Size Telescopes

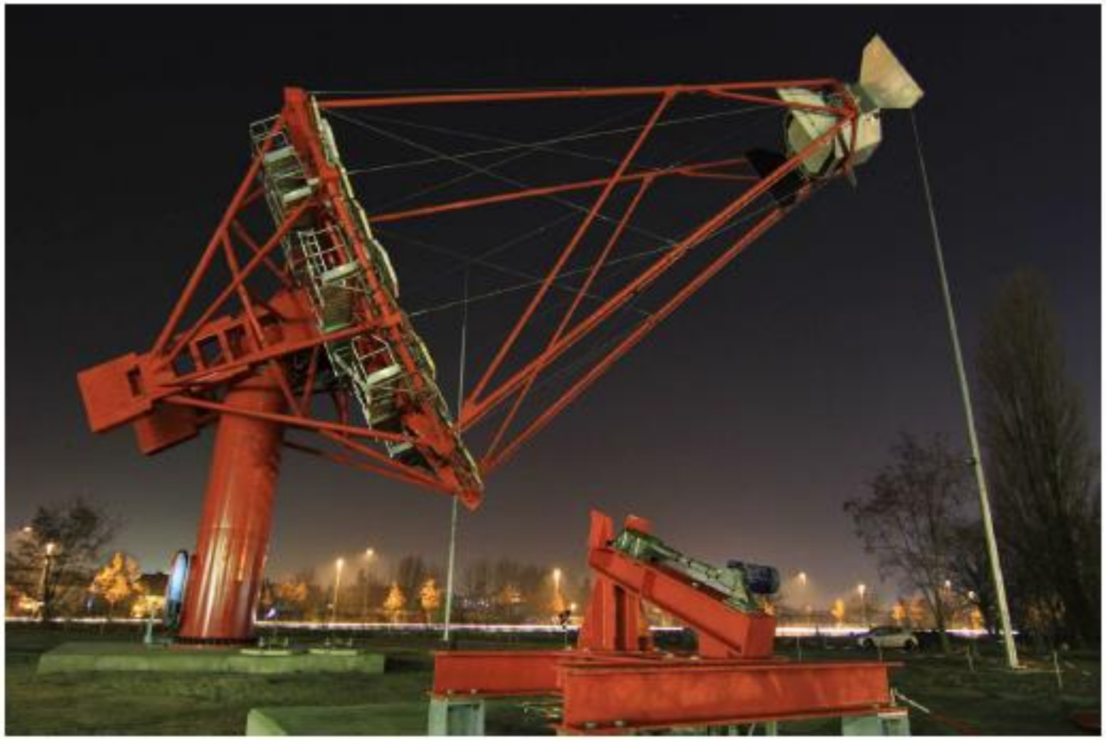
Science drivers
- Lowest energies (< 200 GeV)
- Transient phenomena
- DM, AGN, GRB, pulsars

Characteristics
- Parabolic design
- 23 m diameter
- 370 m^2 effective mirror area
- 28 m focal length
- 1.5 m mirror facets
- 4.5° field of view
- 0.11° PMT pixels
- active mirror control
- Carbon-fibre arch structure (fast repointing)

Array layout
- South site: 4
- North site: 4

Status
- Some elements prototyped
- First full telescope under construction in La Palma (http://www.lst1.iac.es/webcams.html)

Mid Size Telescopes



Science drivers
- Mid energies (100 GeV – 10 TeV)
- DM, AGN, SNR, PWN, binaries, starbursts, EBL, IGM

Characteristics
- Modified Davies-Cotton design
- 12 m diameter
- 90 m^2 effective mirror area
- 1.2 m mirror facets
- 16 m focal length
- 8° field of view
- 0.18° PMT pixels

Array layout
- South site: 25
- North site: 15

Status
- Telescope prototyped (Berlin-Adlershof)
- Prototype cameras under construction (2 types: NectarCAM & FlashCam)

Small Size telescopes

Characteristics
- Davies-Cotton design
- 4 m diameter
- 8.5 m² effective mirror area
- 5.6 m focal length
- 9° field of view
- 0.24° SiPM pixels

Status
- Prototype telescope built
- Camera prototype under construction

Characteristics
- Schwarzschild-Couder design
- 4.3 m primary diameter
- 1.8 m secondary diameter
- 6 m² effective mirror area
- 2.2 m focal length
- 9.6° field of view
- 0.17° SiPM pixels

Status
- Prototype telescope built
- Camera prototype under construction

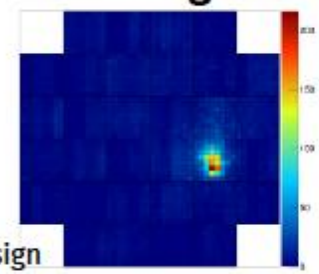
Characteristics
- Schwarzschild-Couder design
- 4 m primary diameter
- 2 m secondary diameter
- 6 m² effective mirror area
- 2.3 m focal length
- 8.6° field of view
- 0.16° SiPM pixels

Status
- Prototype telescope structure built
- Tested with MAPMT-based CHEC camera

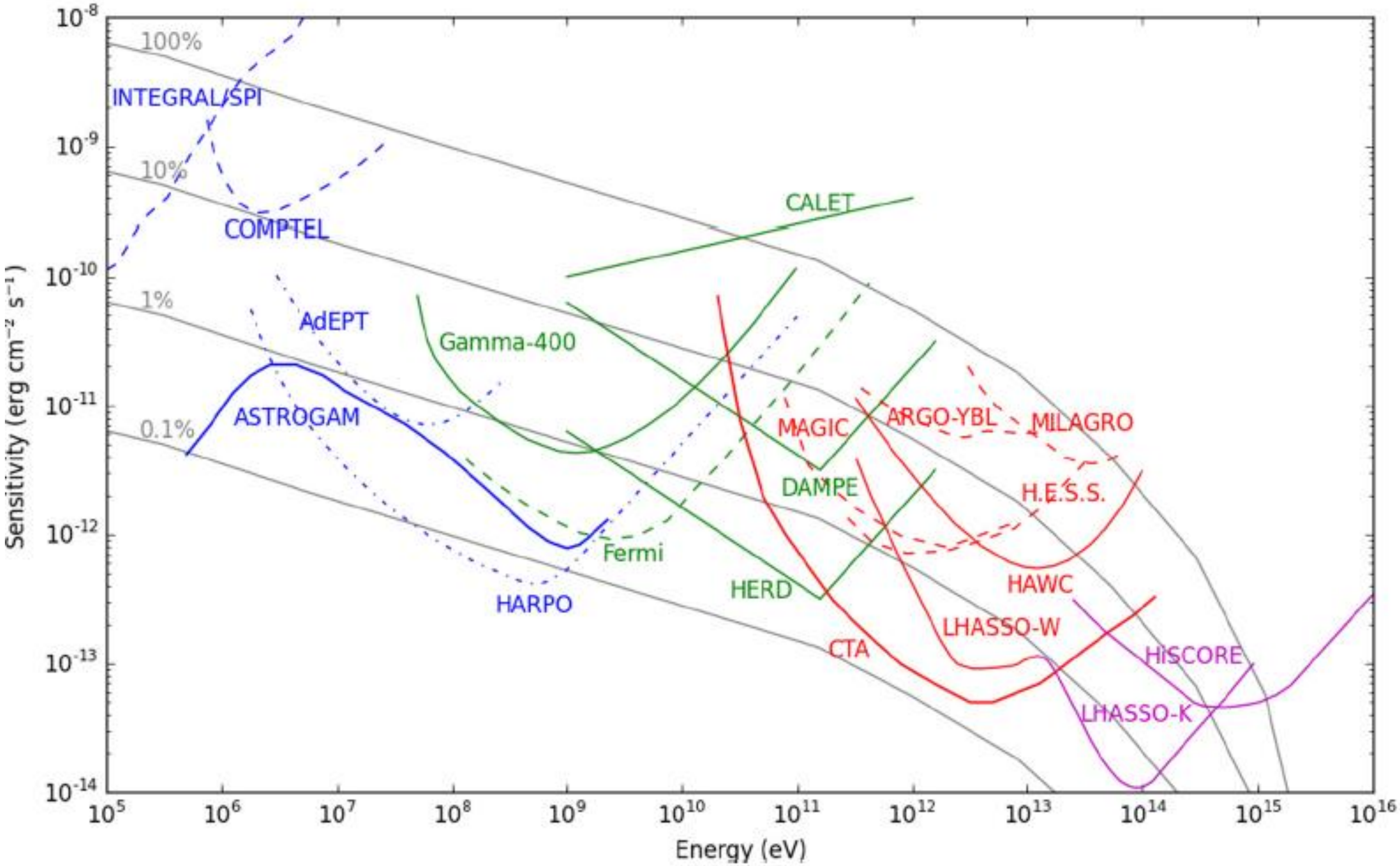
Science drivers
- Highest energies (> 5 TeV)
- Galactic science, PeVatrons

Array layout
- South site: 70
- North site: -

First CTA light



An overview of sensitivity



Courtesy of Jürgen Knödlseder Comptes rendus – Physique, 17, 6 (2016)

Extragalactic source classes for H.E.S.S.

TeV Blazars – today more than 30 objects discovered

quite unexpectedly:

TeV γ-rays from distant blazars;

➜ strong impact on diffuse Extragalactic Background Light (EBL) models

Very fast and intense flares (e.g., PKS 2155–304)

➜ strong impact on AGN/jet physics

most exciting results:

- variability on minute timescales ➜ extremely compact acceleration regions
- unusually hard gamma-ray spectra ➜ (internal) γγ absorption less than thought **particularly relevant in FSRQs that feature strong internal photon fields**

no good spatial information at TeV energies, but:

- structure in time — excellent time resolution
- structure in energy — very good energy resolution

➜ **study flaring episodes, but also ensembles of states**