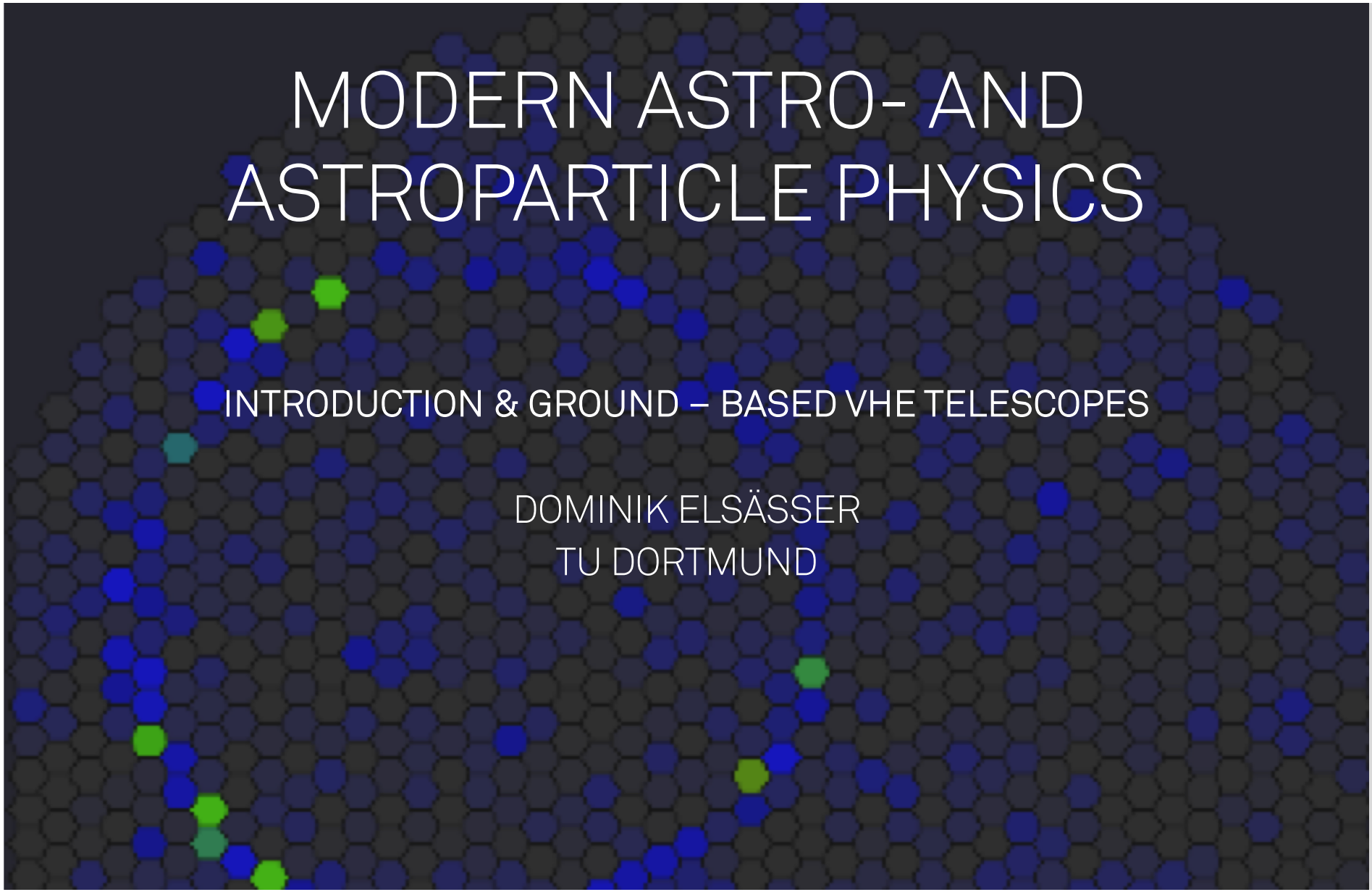


MODERN ASTRO- AND ASTROPARTICLE PHYSICS

INTRODUCTION & GROUND – BASED VHE TELESCOPES

DOMINIK ELSÄSSER
TU DORTMUND

technische universität dortmund

RAPP Center

A CORDIAL WELCOME!

- The focus of this lecture is foundations, modern instruments, methods and scientific results of astro- and astroparticle physics
- This is a wide topic. And the audience is equally diverse. So instead of providing a complete basic curriculum, we chose to invite distinguished scientists to speak on highlight topics
- Universities represented here: Hamburg, Dortmund, Bochum, Wuppertal, Würzburg, Erlangen – Nürnberg
- Let us together make this endeavor a successful one!

06.11.: Dominik Elsässer „Current Generation of ground-based VHE Gamma-Ray Telescopes“

13.11.: Tim Ruhe “The IceCube Neutrino Observatory”

20.11.: Anna Pollmann „Beyond Standard Model Physics with IceCube“

27.11.: Julia Tjus „Understanding Multimessenger Signatures with Cosmic-Ray Propagation and Interaction in Astrophysical Plasmas“

04.12.: Karl-Heinz Kampert „Cosmic Rays at the Highest Energies“

11.12.: Karl Mannheim “Theoretical concepts”

18.12.: Ralf-Jürgen Dettmar “The sky at long wavelengths as seen with LOFAR”

08.01.: Marcus Brüggen “The radio Universe as seen through the Square Kilometre Array and its precursors”

15.01.: Anna Nelles “Radio Detection of Neutrinos and Cosmic Rays”

22.01.: Klaus Helbing „The Mass of the Neutrino and the KATRIN Experiment“

29.01.: Stefan Funk “The Cherenkov Telescope Array”

05.02.: Wolfgang Rhode “Methods and Perspectives for Astroparticle Physics”

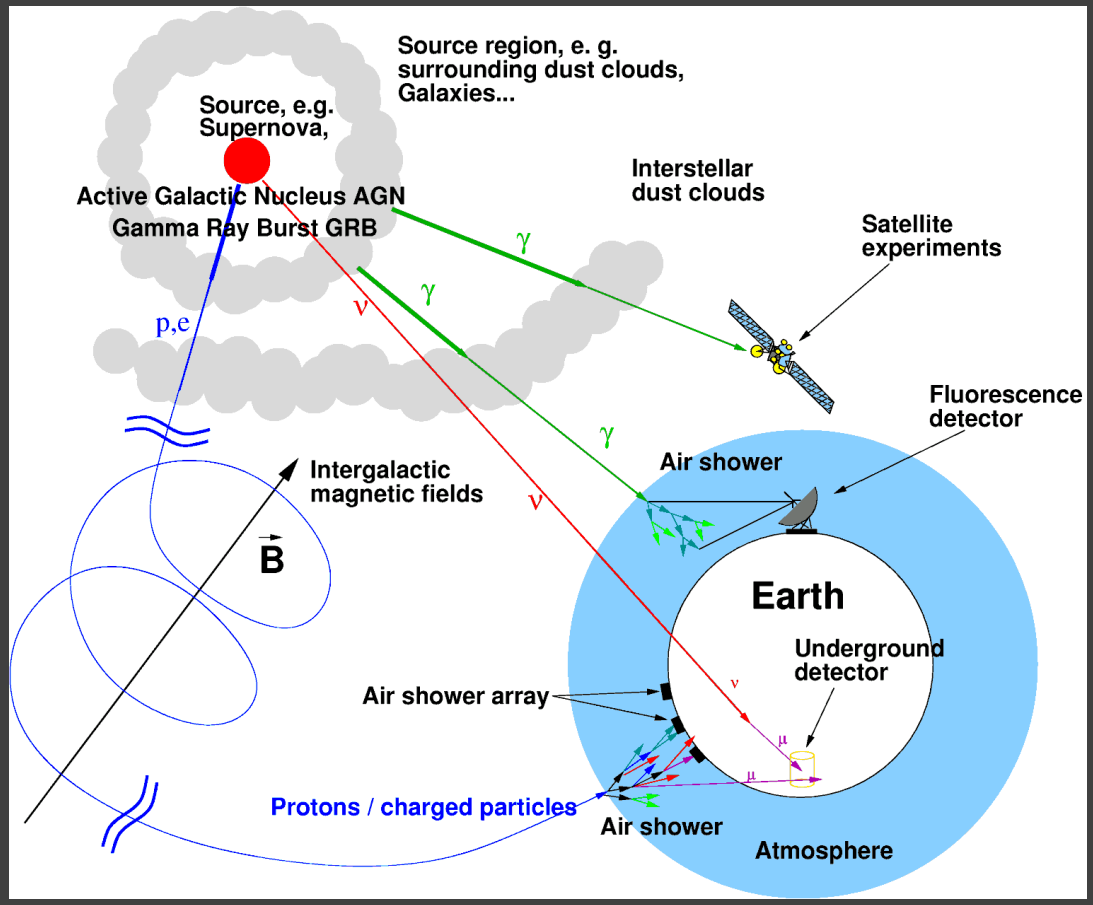
Indico:
https://indico.e5.physik.tu-dortmund.de/event/700/

Contact:
kevin3.schmidt@tu-dortmund.de

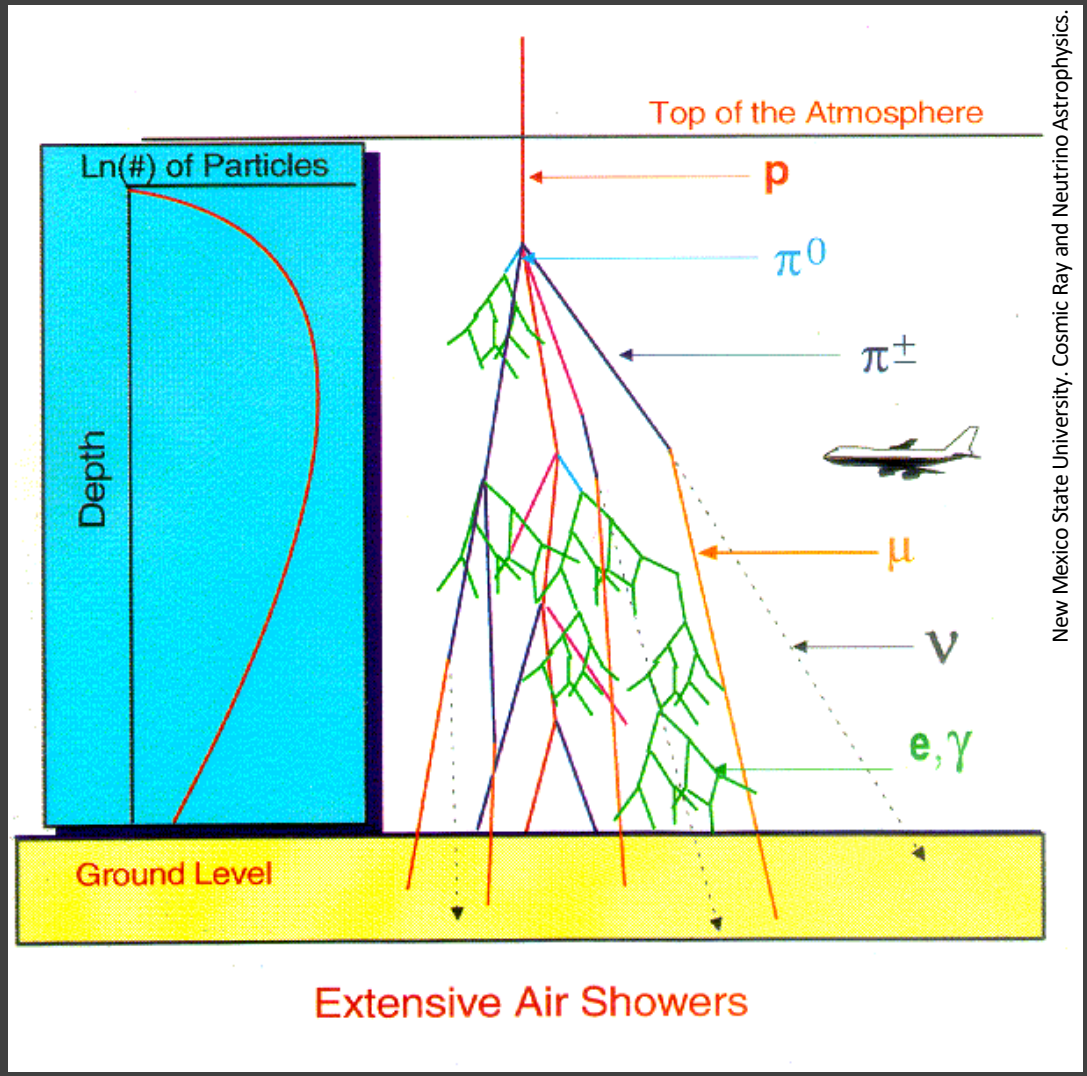
SOME ORGANIZATIONAL POINTS

- Lectures Fridays, starting 14:15, via Zoom
- (45 –)60 minutes lecture + discussion afterwards
- Ring lecture of all lecturers
- Dortmund organizers of course available any time: D. Elsässer, T. Ruhe, W. Rhode
- Recording not allowed (sorry…)
- Will aim to put slides in the Indico
- 3 Credits (and grade): regular participation and a written exam (Covid-19 compatible modus, details to follow in due course) after finishing the lecture series
- Questions?

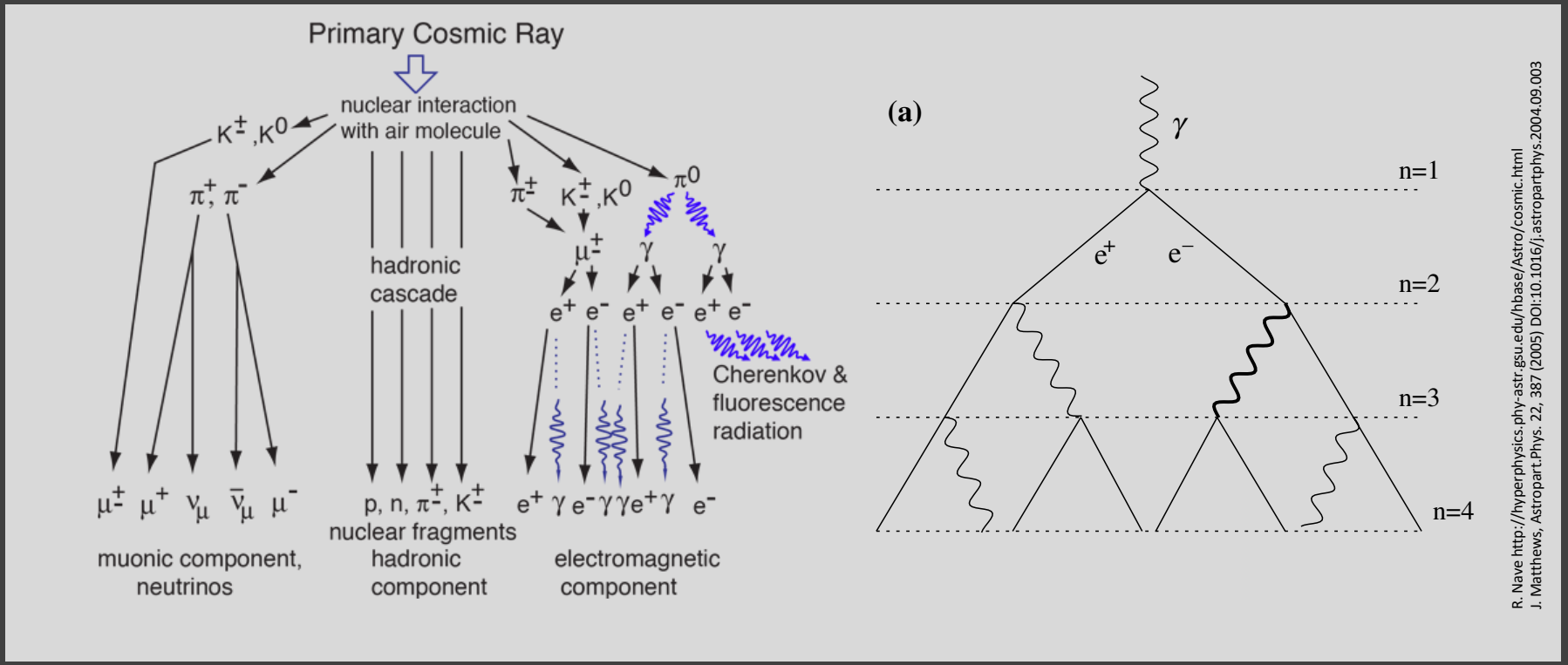
CURRENT GENERATION OF GROUND – BASED VHE GAMMA – RAY TELESCOPES



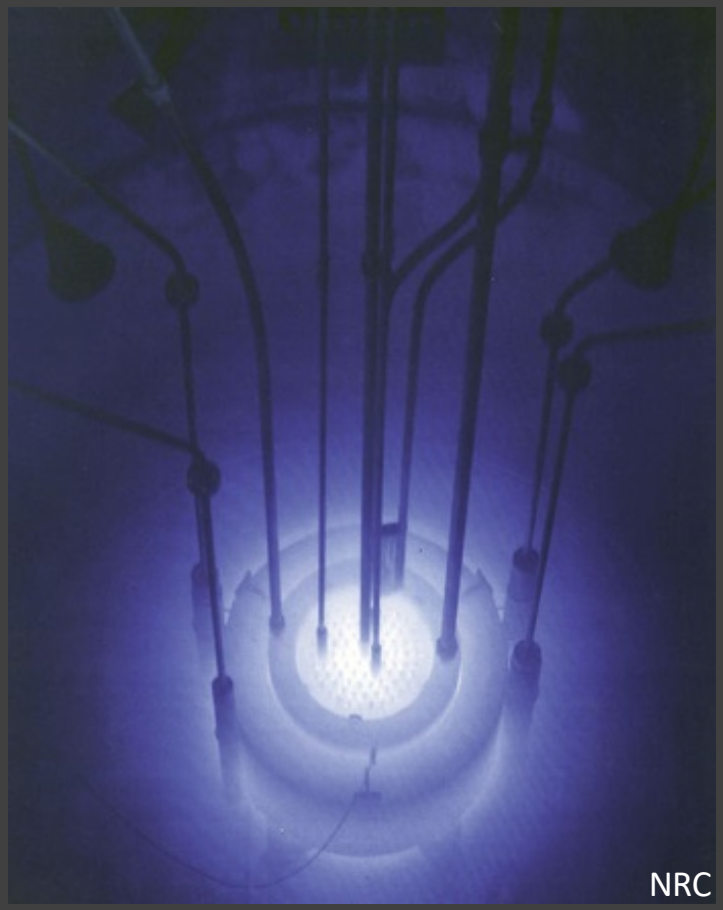
EXTENDED AIR SHOWERS



EXTENDED AIR SHOWERS

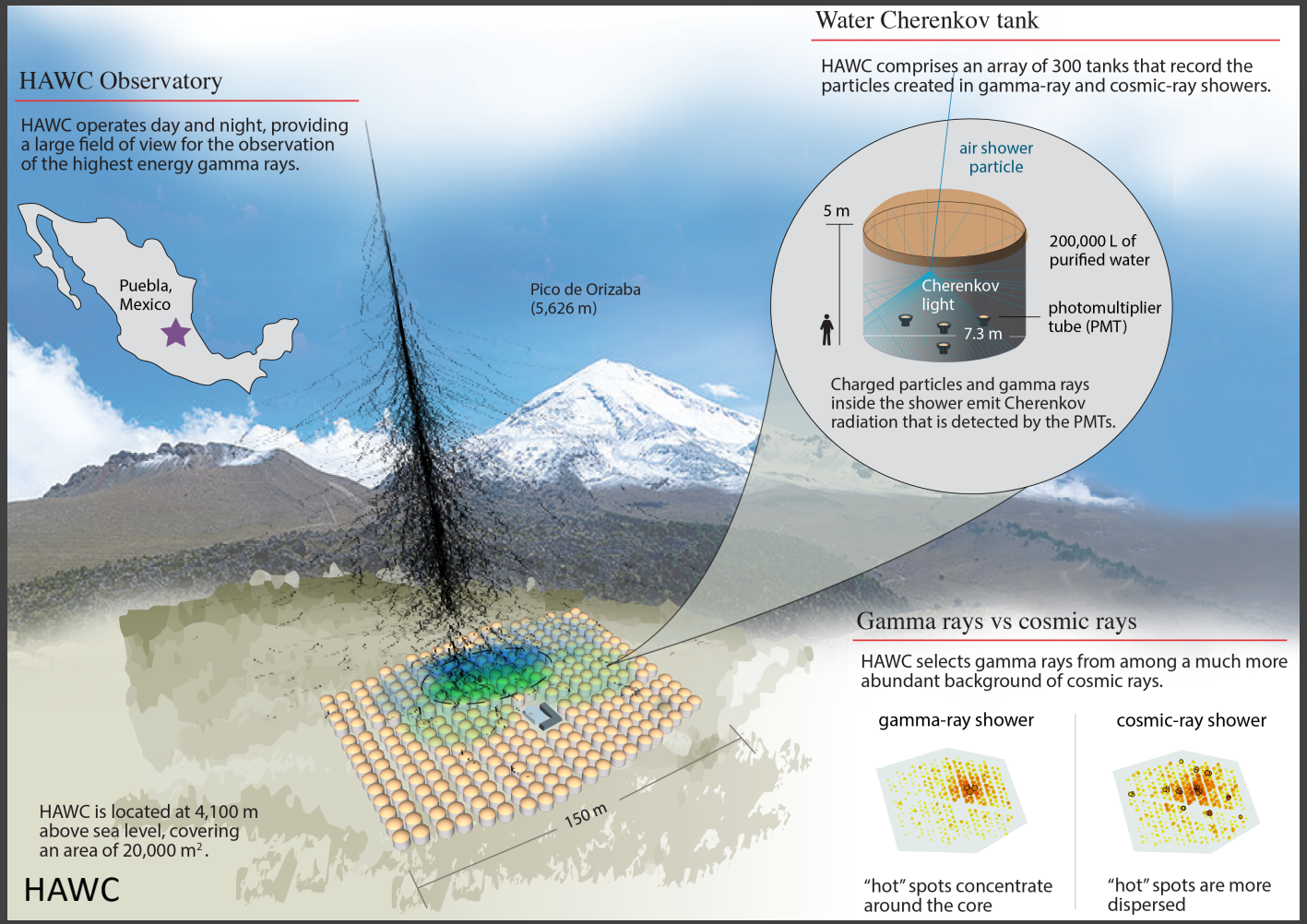


R. Nave http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/cosmic.html
J. Matthews, Astropart.Phys. 22, 387 (2005) DOI:10.1016/j.astropartphys.2004.09.003

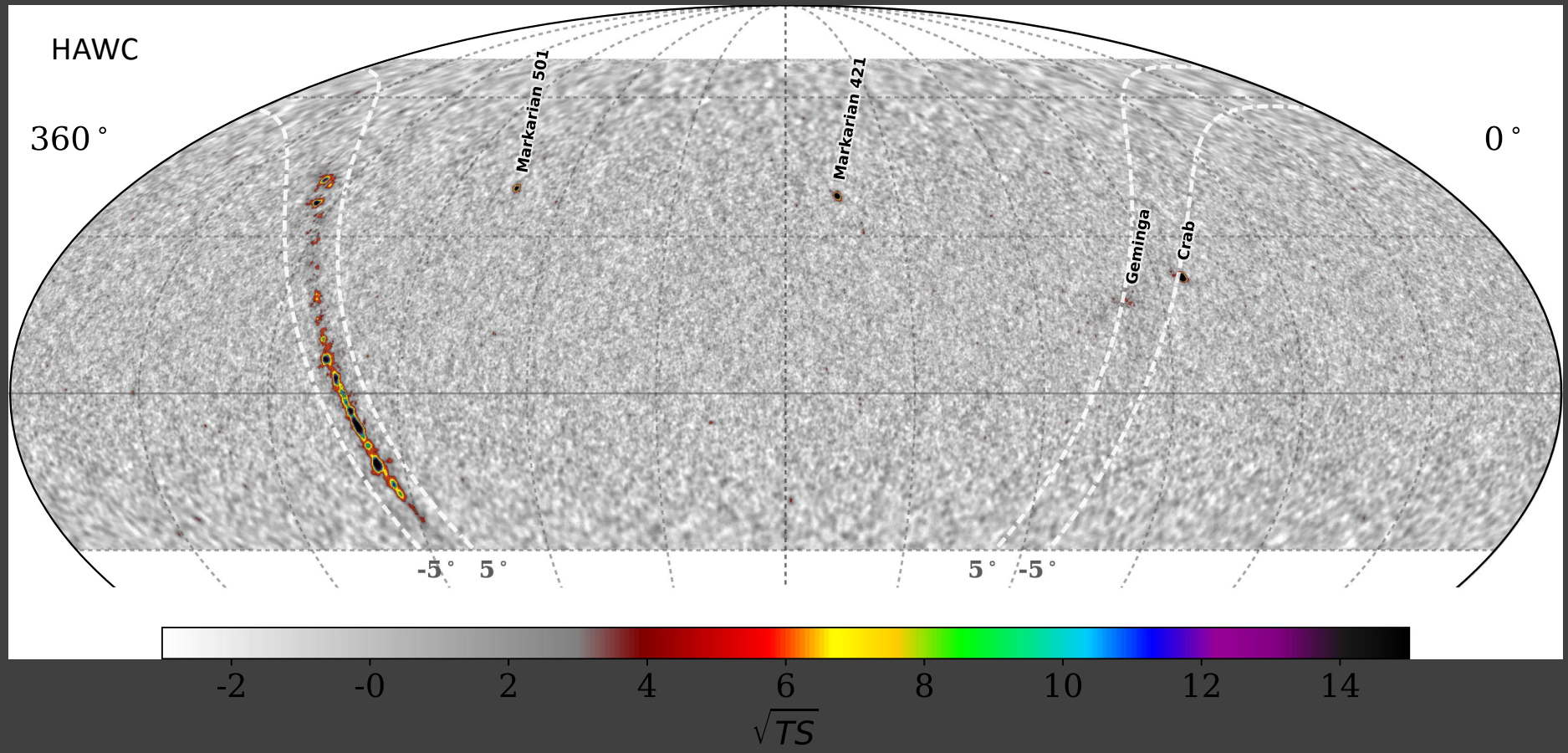

NRC

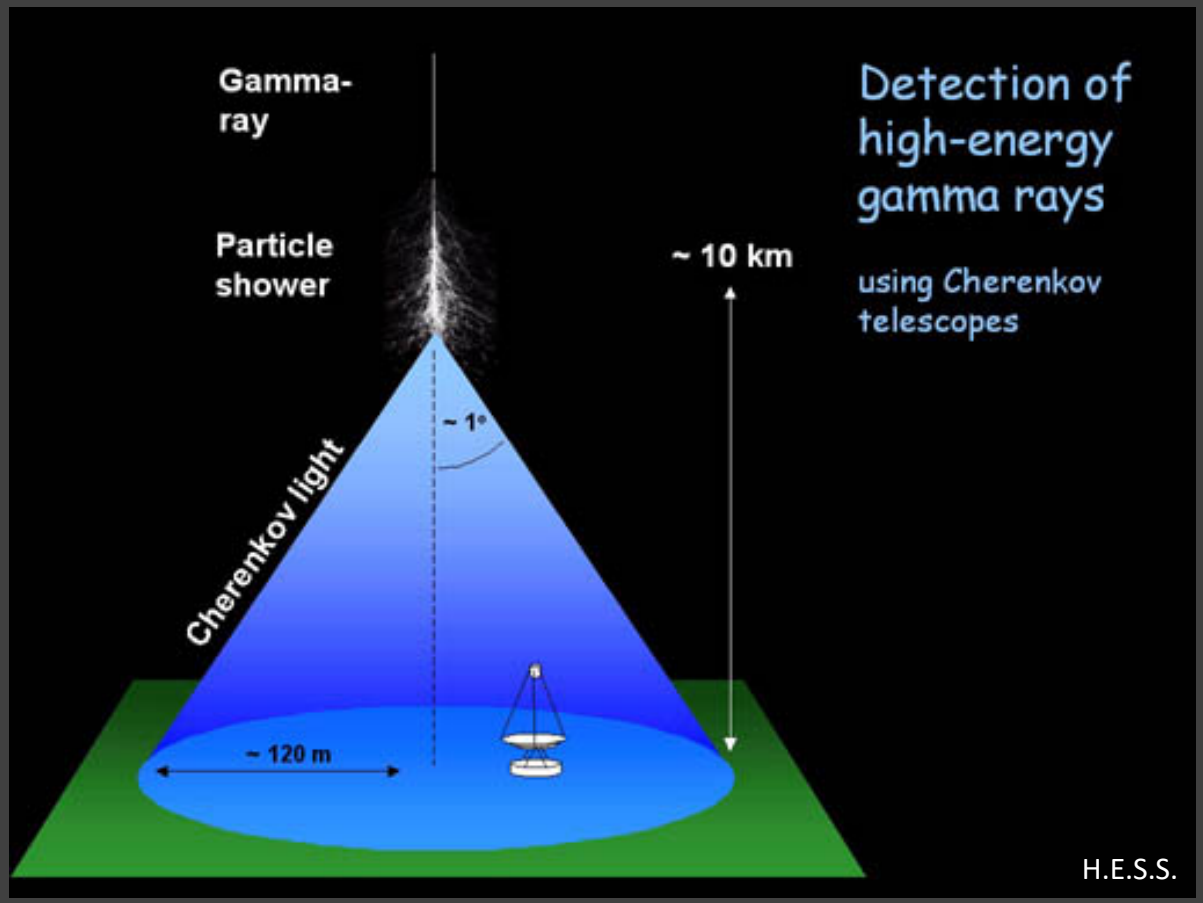

US Air Force

HIGH ALTITUDE WATER CHERENKOV OBSERVATORY



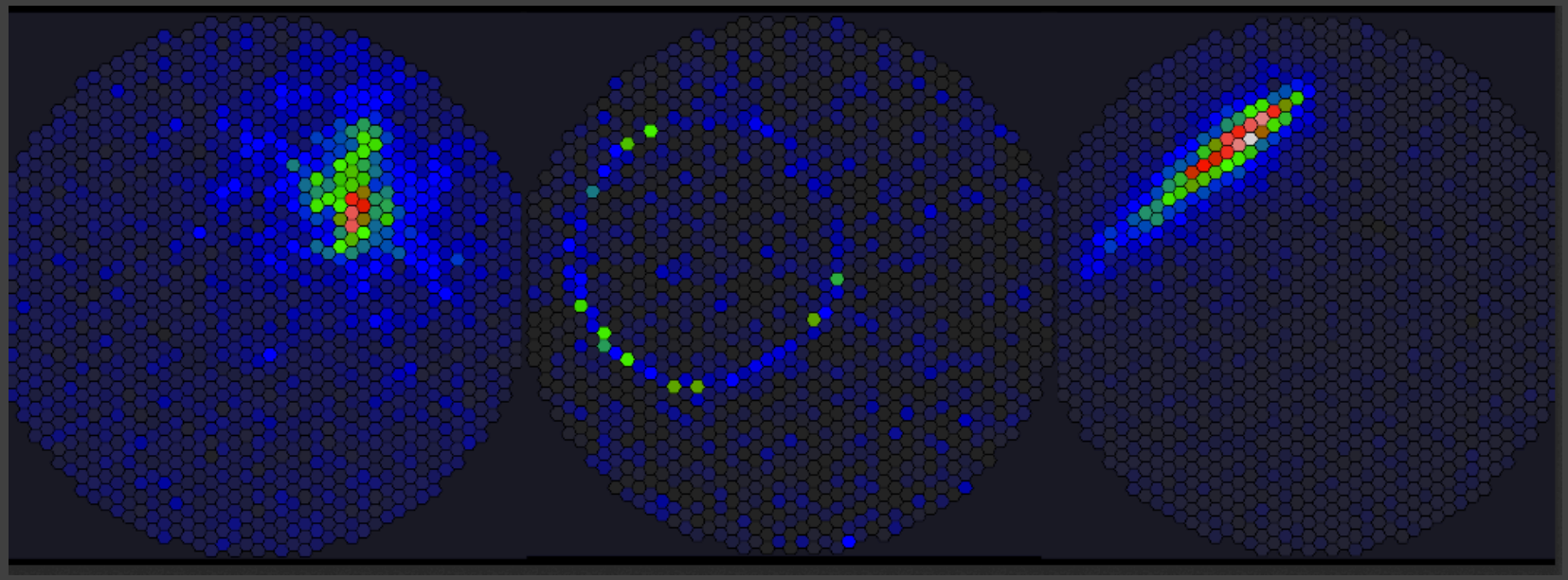
HIGH ALTITUDE WATER CHERENKOV OBSERVATORY




Gamma-ray
Particle shower
~ 10 km
Detection of high-energy gamma rays
using Cherenkov telescopes
~ 1°
Cherenkov light
~ 120 m
H.E.S.S.

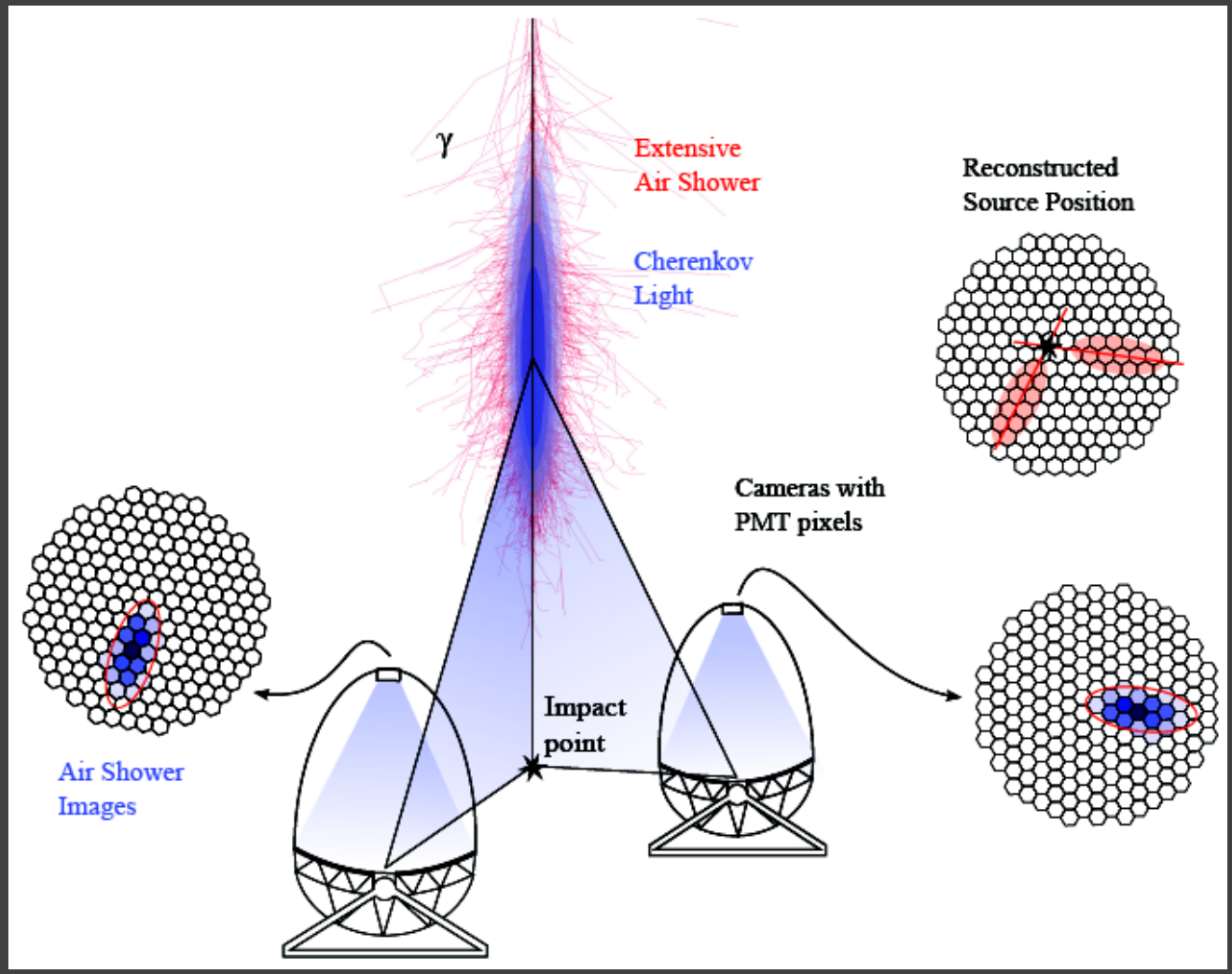
DISCOVERY OF AIR SHOWER CHERENKOV EMISSION

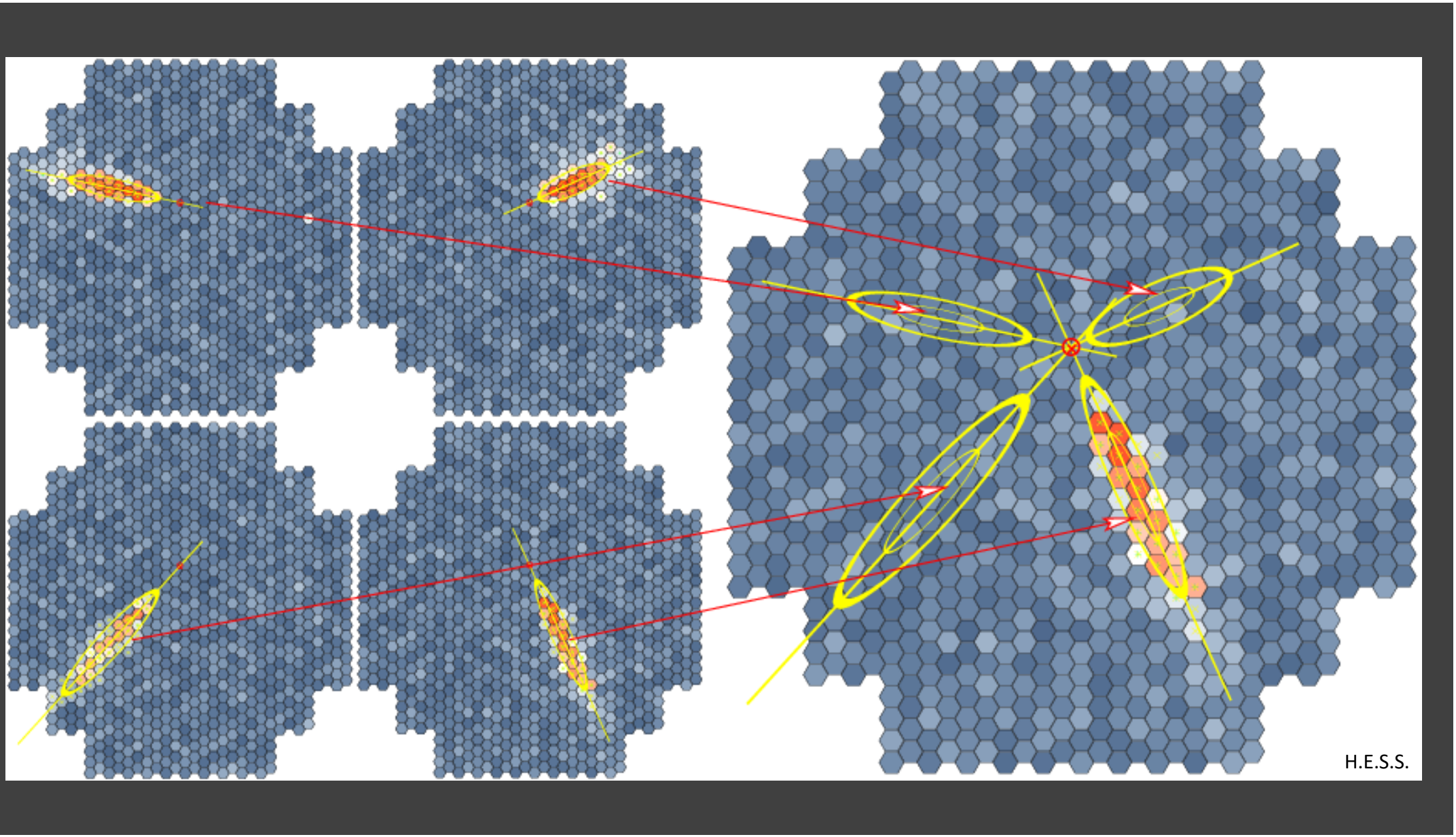
Hadron Muon Gamma



Events seen by the FACT-Telescope

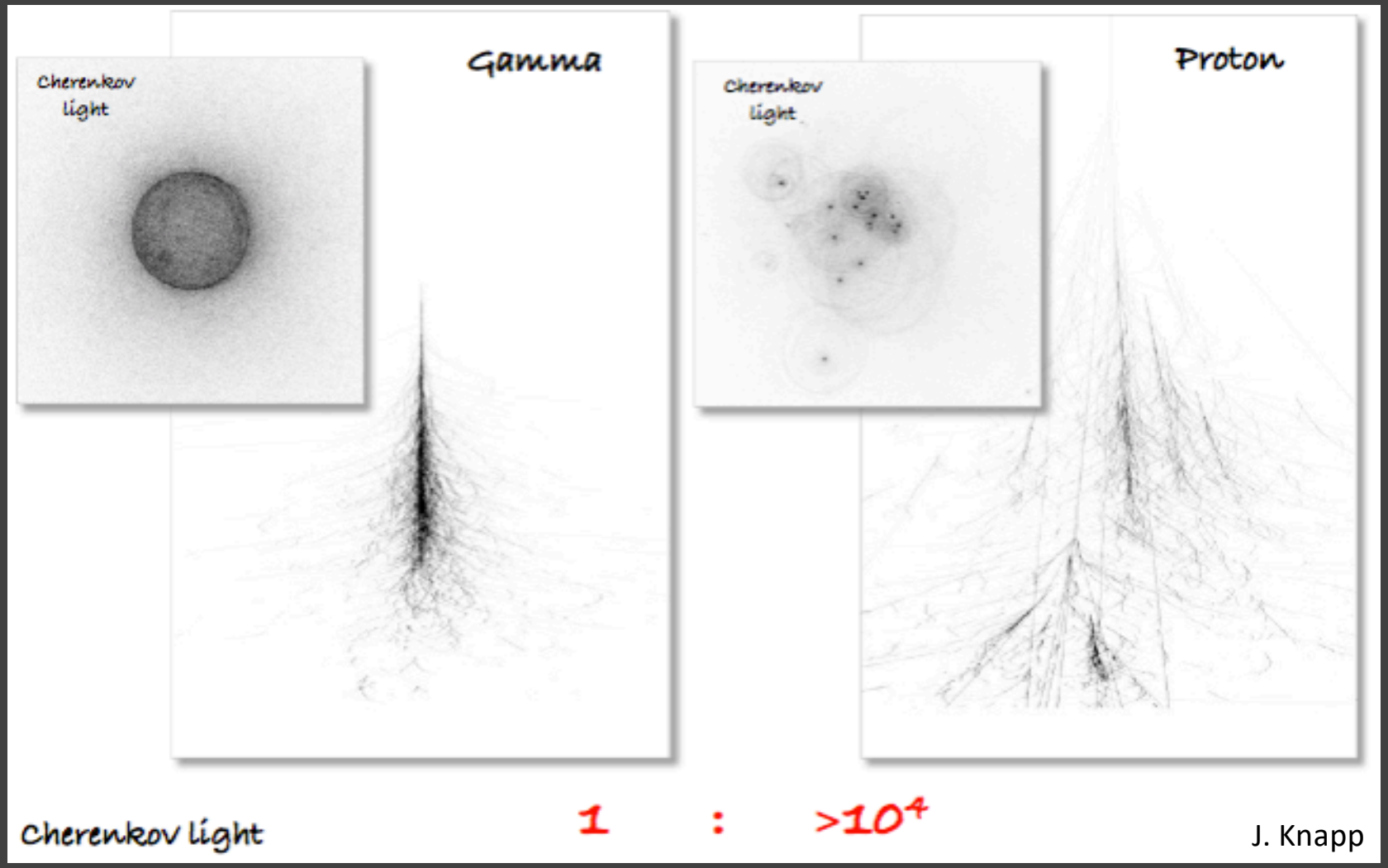
STEREOSCOPIC VIEW




H.E.S.S.

(AT LEAST) THREE FORMIDABLE ANALYSIS TASKS

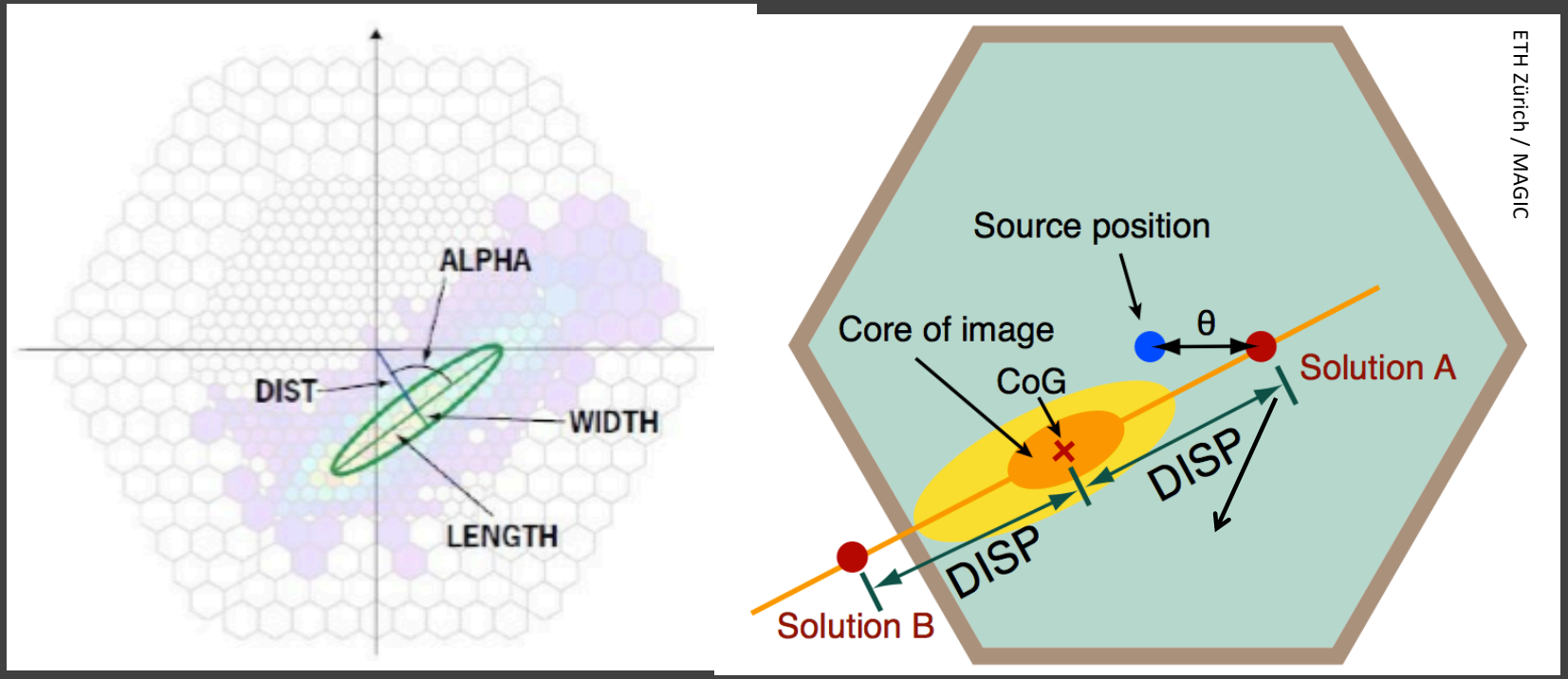
- Gamma / Hadron Separation


Gamma
Cherenkov light
Proton
Cherenkov light
Cherenkov light
1 : >10⁴

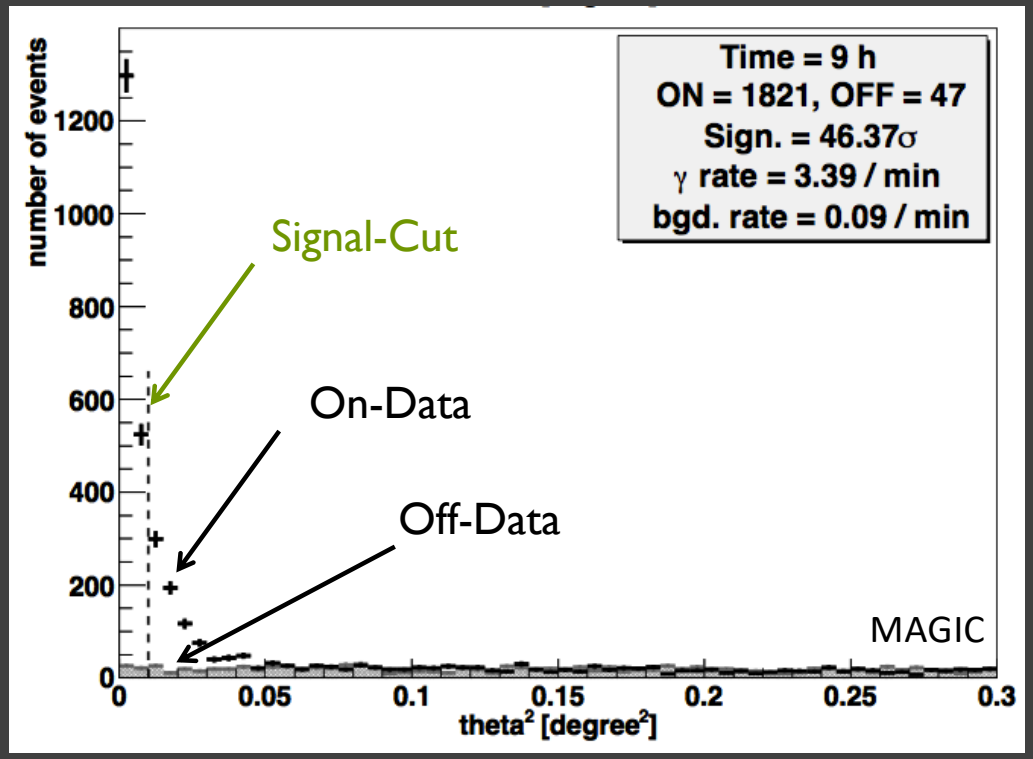
J. Knapp

(AT LEAST) THREE FORMIDABLE ANALYSIS TASKS

- Gamma / hadron separation
- Directional reconstruction

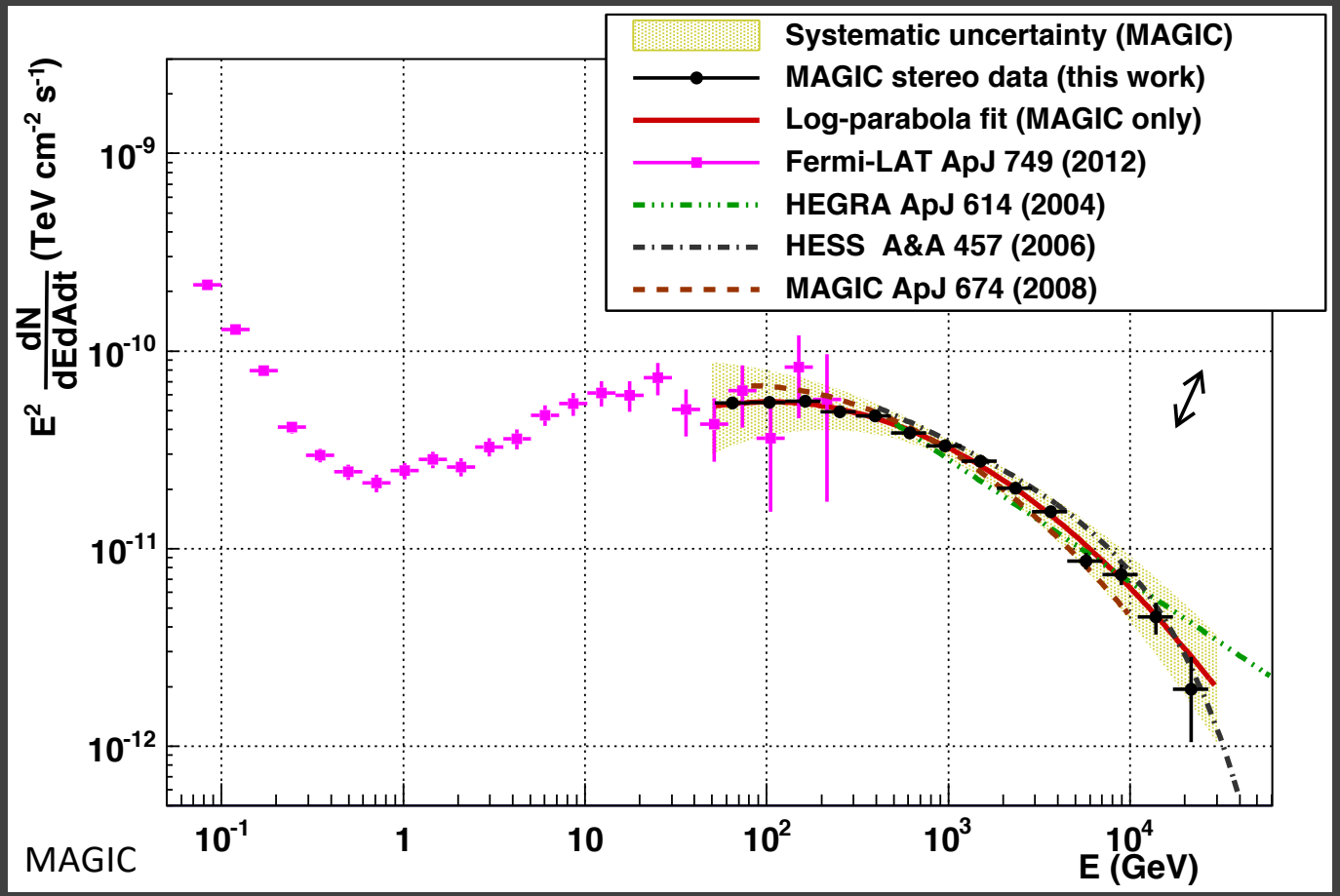

ALPHA
DIST
WIDTH
LENGTH
Source position
θ
Core of image
CoG
Solution A
DISP
DISP
Solution B
ETH Zürich / MAGIC


Rolf Werder


Time = 9 h
ON = 1821, OFF = 47
Sign. = 46.37σ
γ rate = 3.39 / min
bgd. rate = 0.09 / min
Signal-Cut
On-Data
Off-Data
MAGIC
number of events
0
200
400
600
800
1000
1200
0
0.05
0.1
0.15
0.2
0.25
0.3
theta² [degree²]

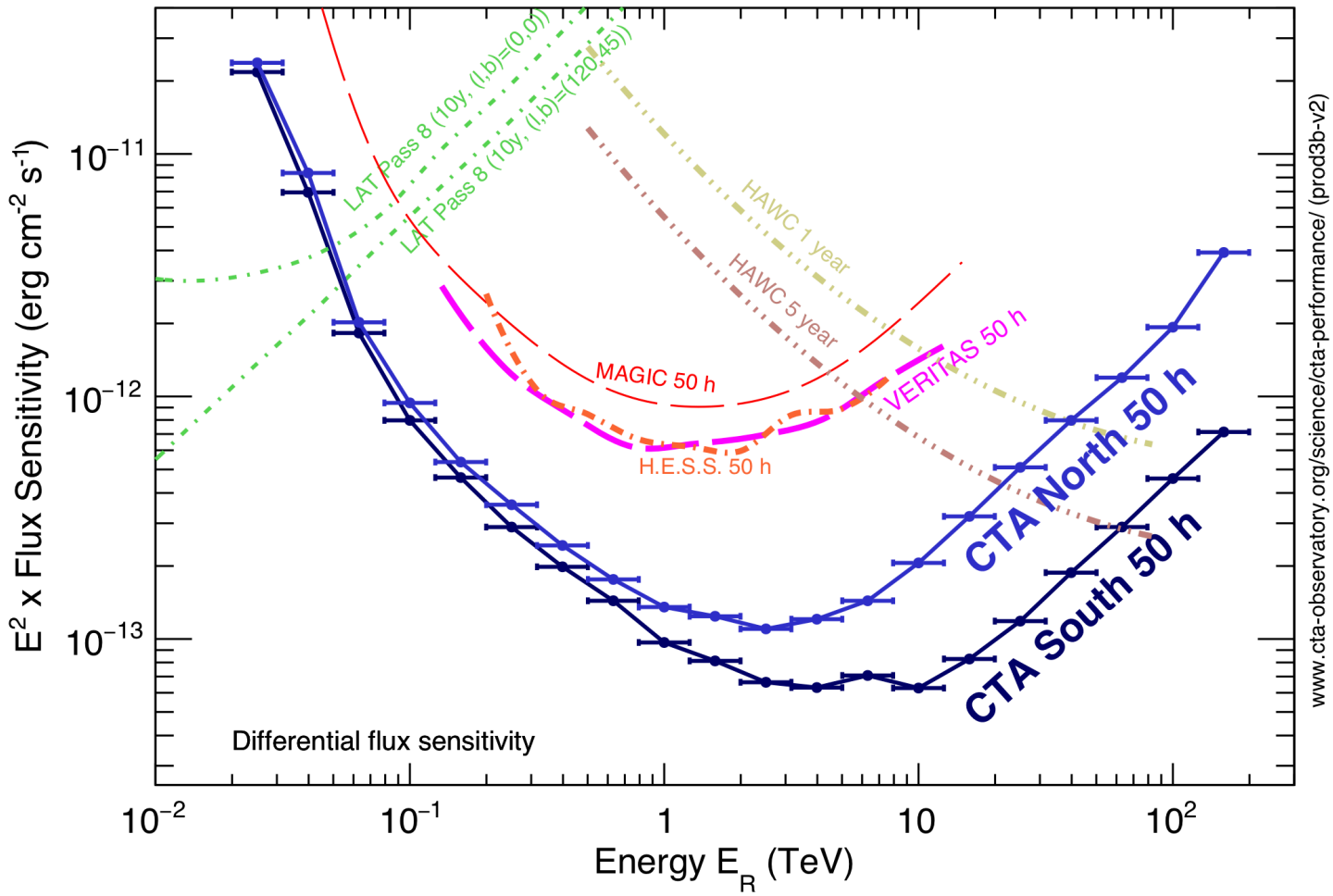
(AT LEAST) THREE FORMIDABLE ANALYSIS TASKS

- Gamma / hadron separation
- Directional reconstruction
- Unfolding the energy spectrum

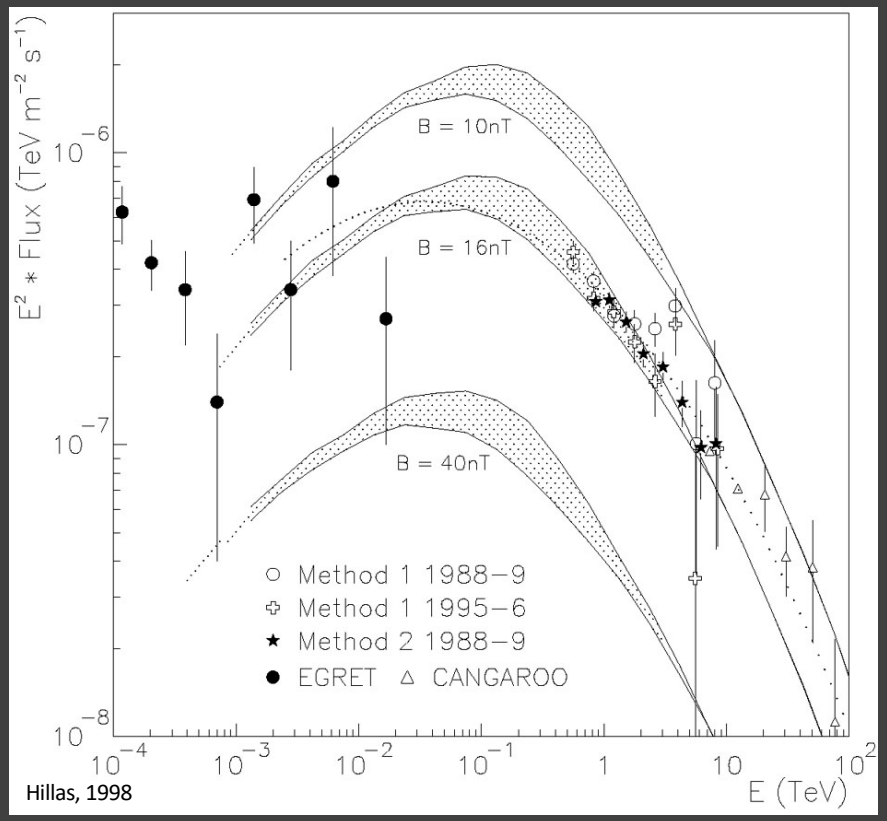

Systematic uncertainty (MAGIC)
MAGIC stereo data (this work)
Log-parabola fit (MAGIC only)
Fermi-LAT ApJ 749 (2012)
HEGRA ApJ 614 (2004)
HESS A&A 457 (2006)
MAGIC ApJ 674 (2008)
$E^2 \frac{dN}{dEdAdt}$ (TeV cm^{-2} s^{-1})
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
E (GeV)
MAGIC

(AT LEAST) THREE FORMIDABLE ANALYSIS TASKS

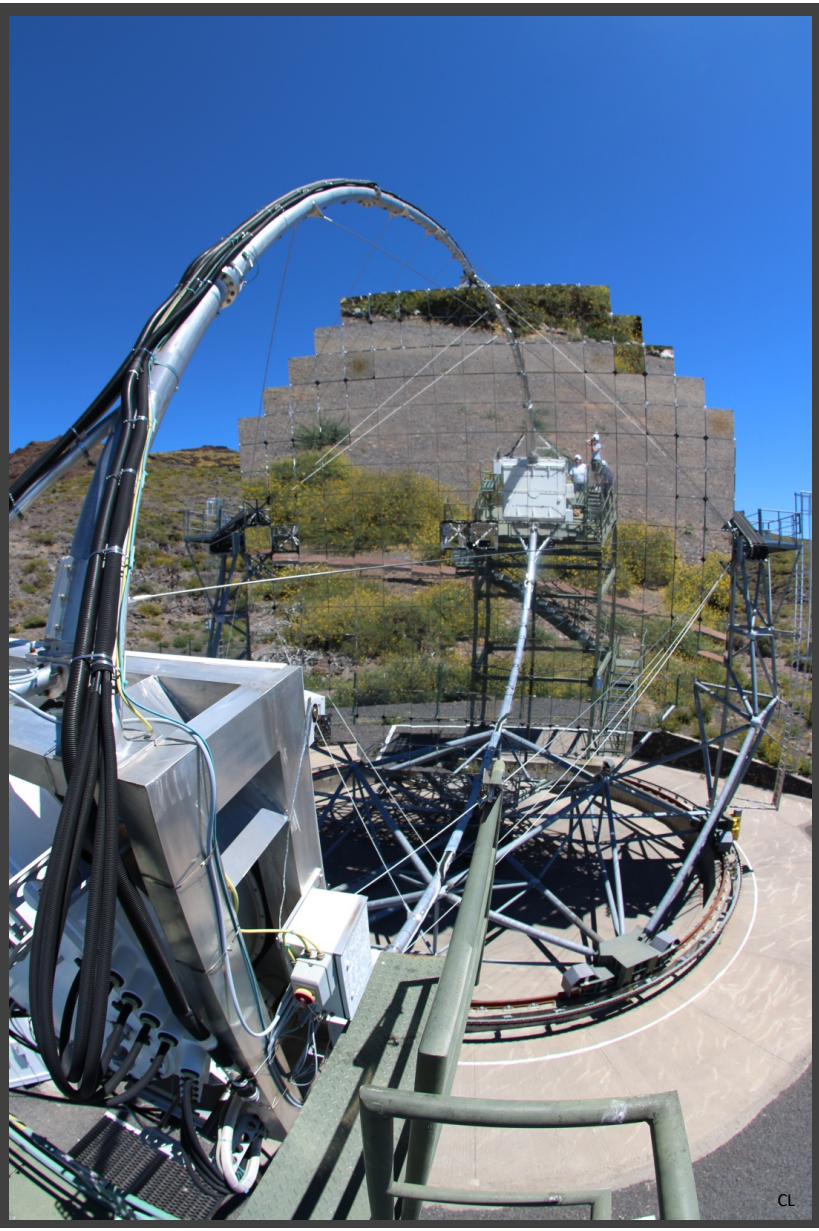
- Gamma / hadron separation
- Directional reconstruction
- Unfolding the energy spectrum
- Heavily Monte Carlo simulation and analysis dependent experiments


LAT Pass 8 (10y, (l,b)=(0,0))
LAT Pass 8 (10y, (l,b)=(120,45))
HAWC 1 year
HAWC 5 year
MAGIC 50 h
VERITAS 50 h
H.E.S.S. 50 h
CTA North 50 h
CTA South 50 h
Differential flux sensitivity
E² x Flux Sensitivity (erg cm⁻² s⁻¹)
Energy E_R (TeV)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻²
10⁻¹
1
10
10²
www.cta-observatory.org/science/cta-performance/ (prod3b-v2)

WHIPPLE --> First detection of the Crab nebula in1989

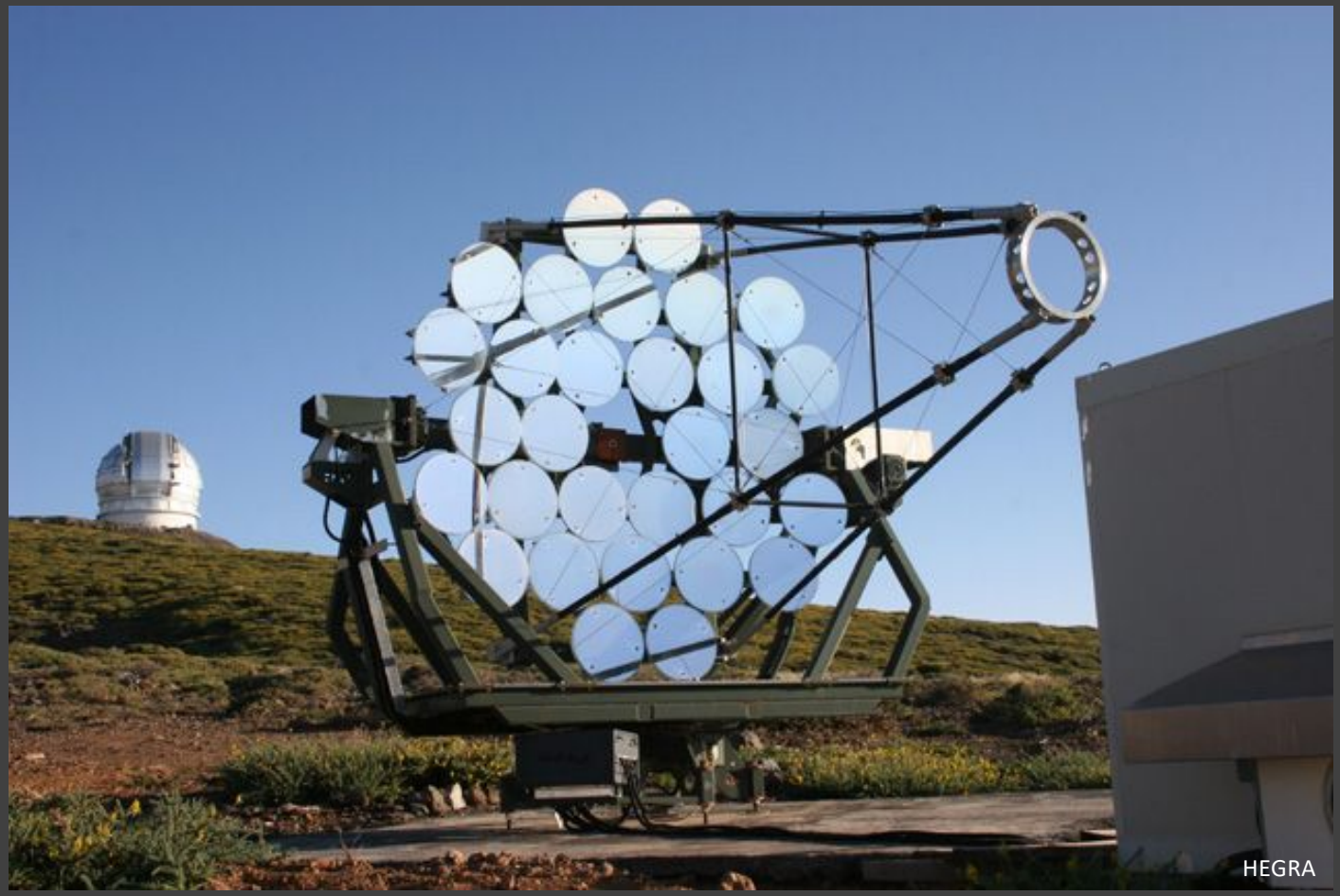


Hillas, 1998


CL


CL/DE

HEGRA (1987 - 2002)

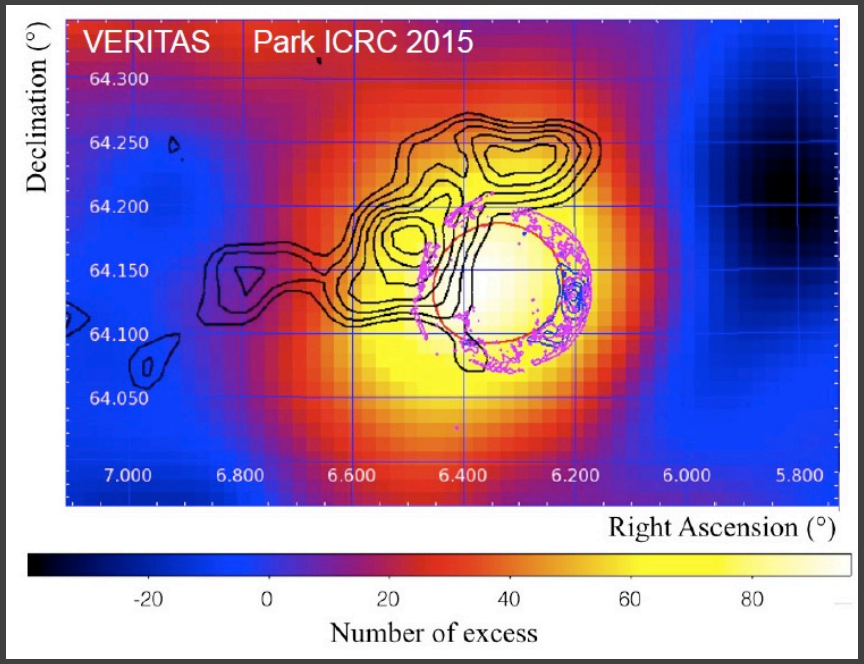


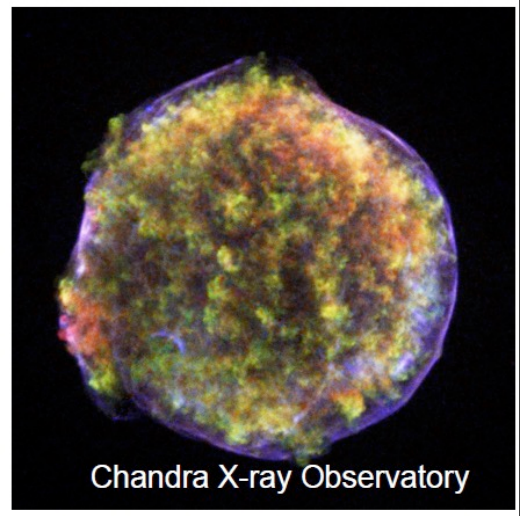
VERITAS (ARIZONA)

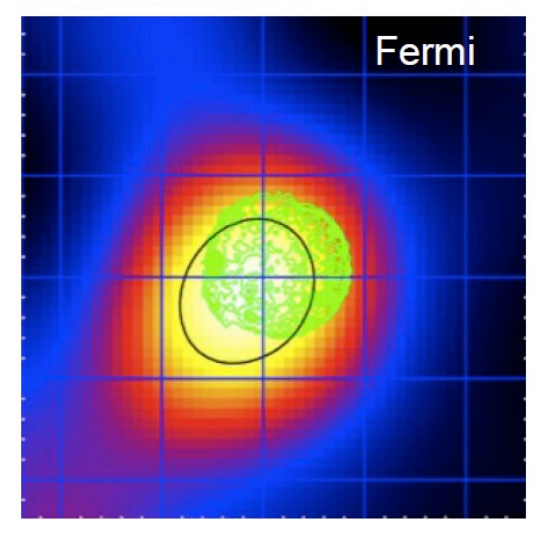
USING DIRECT INPUT FROM: BENJAMIN ZITZER – MCGILL UNIVERSITY

TYCHO'S SNR (SN1572)

- Age: 444 years, distance 2-5 kpc
- Explosion into clean environment - relatively symmetric
- Well-studied at nearly all wavelengths

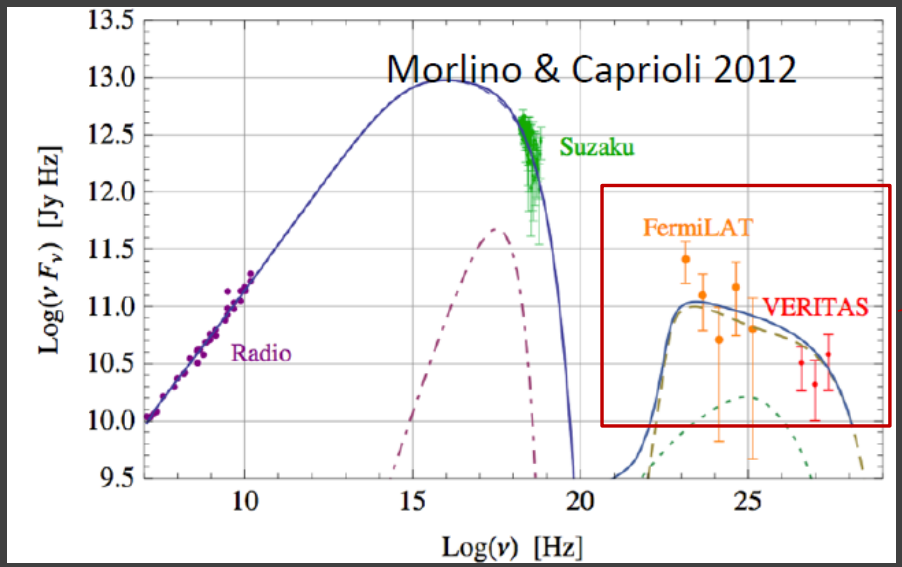


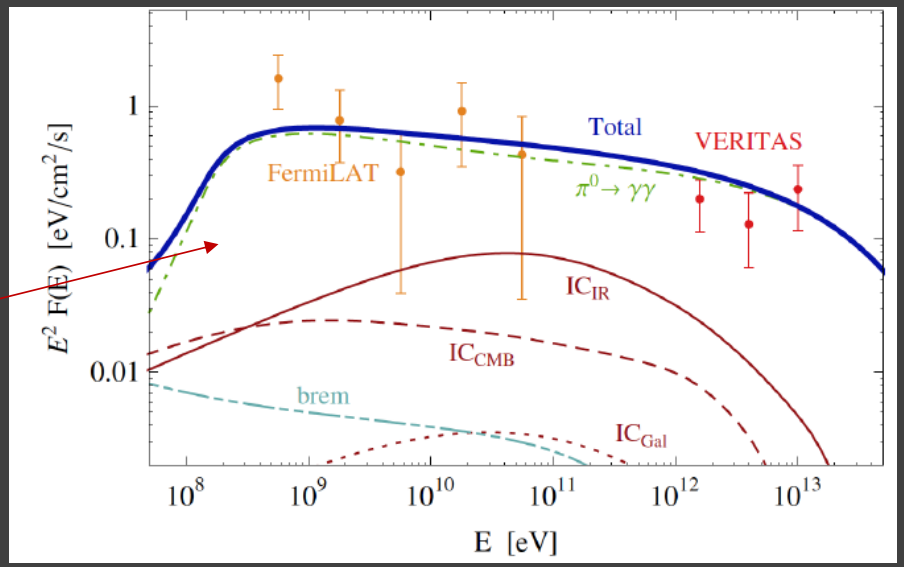




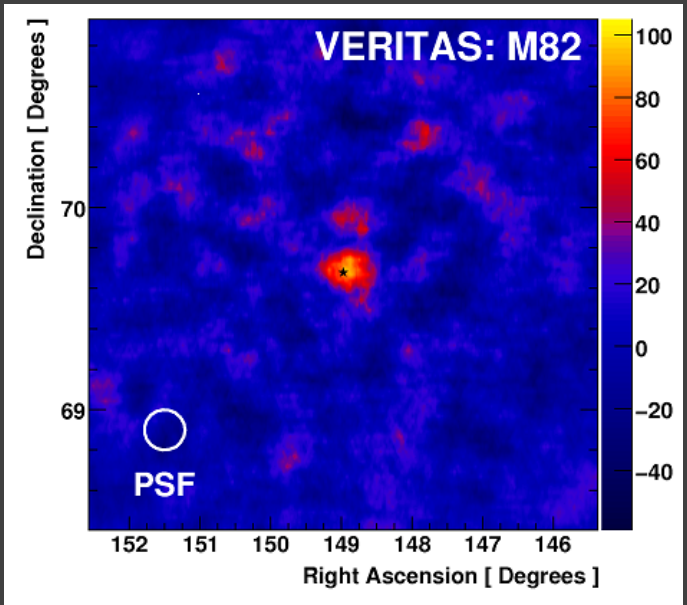
TYCHO'S SNR (SN1572)

- Hadronic acceleration models: proton collisions producing neutral pions -> decay to gamma rays
- This is an important question for SNR as well as AGN observations: origin of the hadronic Cosmic Rays?
- Detection of 10 TeV photons with no sign of cutoff
  - implication of protons accelerated to several hundred TeV





M82: A nearby star forming galaxy

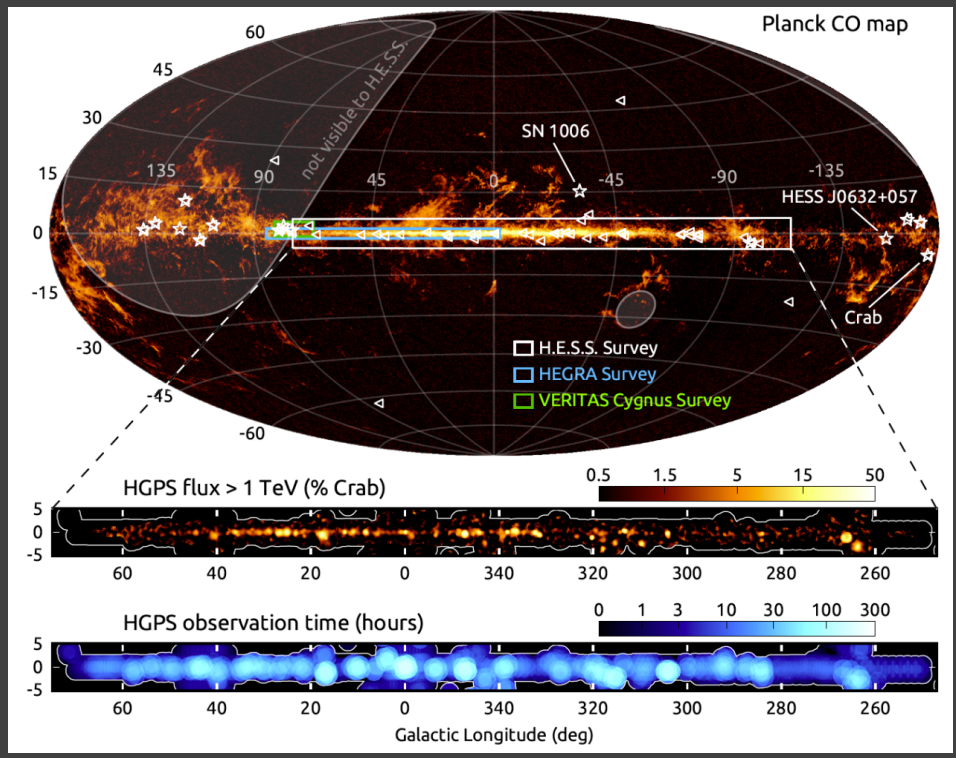


H.E.S.S. (NAMIBIA)

USING DIRECT INPUT FROM: MATHIEU DE NAUROIS – LLR – ECOLE POLYTECHNIQUE – IN2P3/CNRS

H.E.S.S.-I LEGACY SURVEY

- Major H.E.S.S. project
- Data collected 2004 – 2013
  - 2673 h after quality selection
  - l in [-110°, 70°]
  - b in [-5°, 5°]
  - Inhomogeneous exposure (sources of particular interest)
- Maps to be released in FITS format

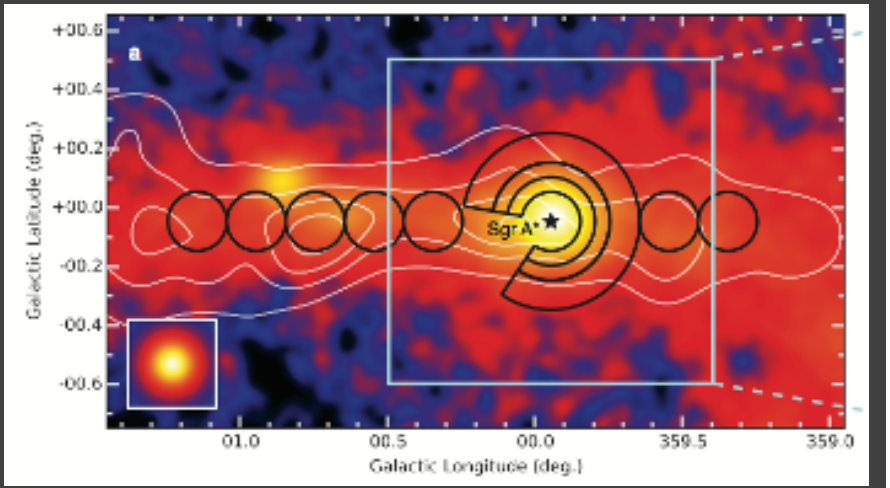


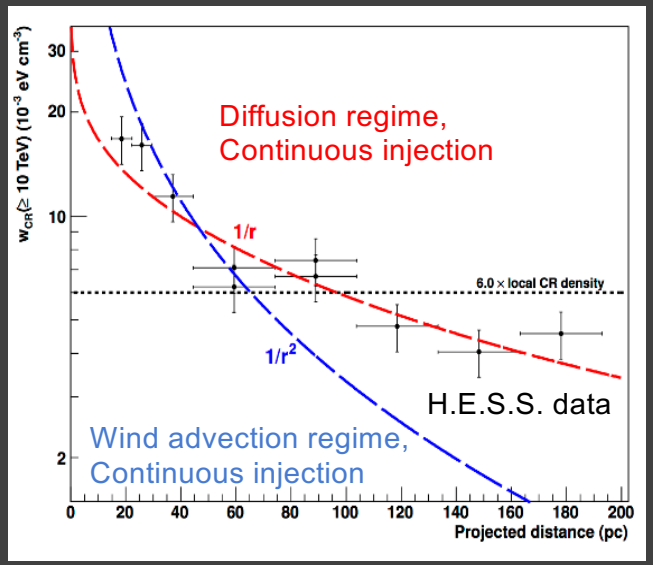
H.E.S.S. Collaboration (**A&A Special Issue**)

THE GALACTIC CENTRE REGION – EVIDENCE FOR PEV – SCALE ACCELERATION

- Full dataset analyzed: 2004-2012 ← 220h obs. time (175h acc. corrected)
- Point like source > 100 σ, central source on top of extended (ridge) emission
- Diffuse emission up to > 50 TeV, attributed to protons accelerated around central black hole and diffusing away (projected radial distribution matches)
- Parent proton population up to 1 PeV (2.9 PeV @ 68% CL)
- Central accelerator located within 10 pc and injecting CRs continuously for > 1 kyrs

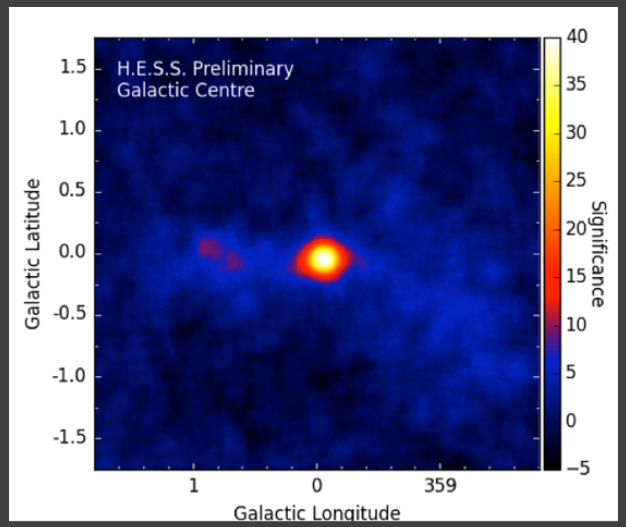
HESS Collaboration, Nature 531 (2016)

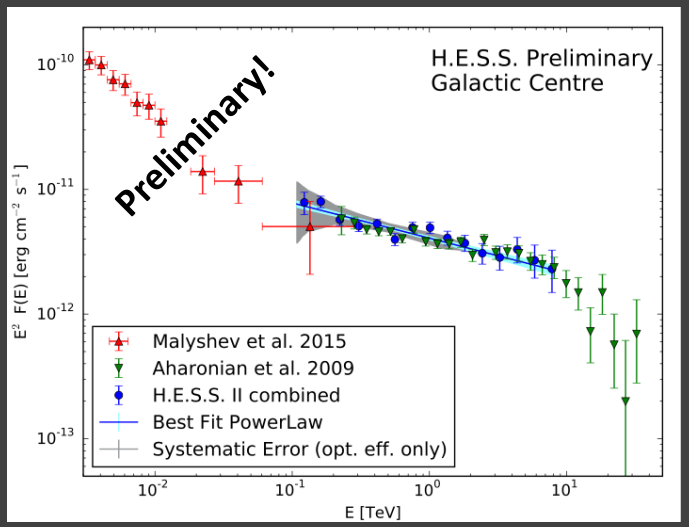




GALACTIC CENTER WITH H.E.S.S.-II

H.E.S.S. collaboration, ICRC 2017



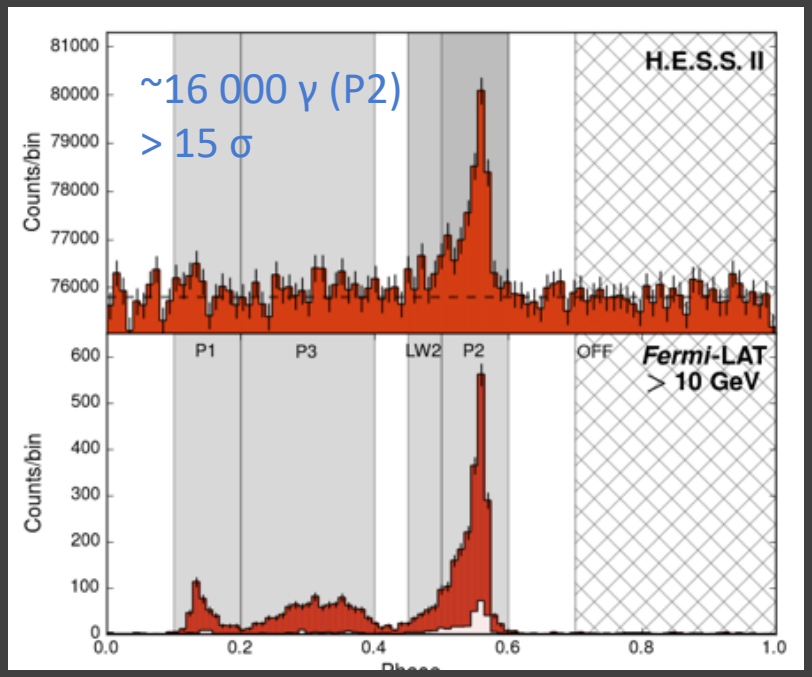


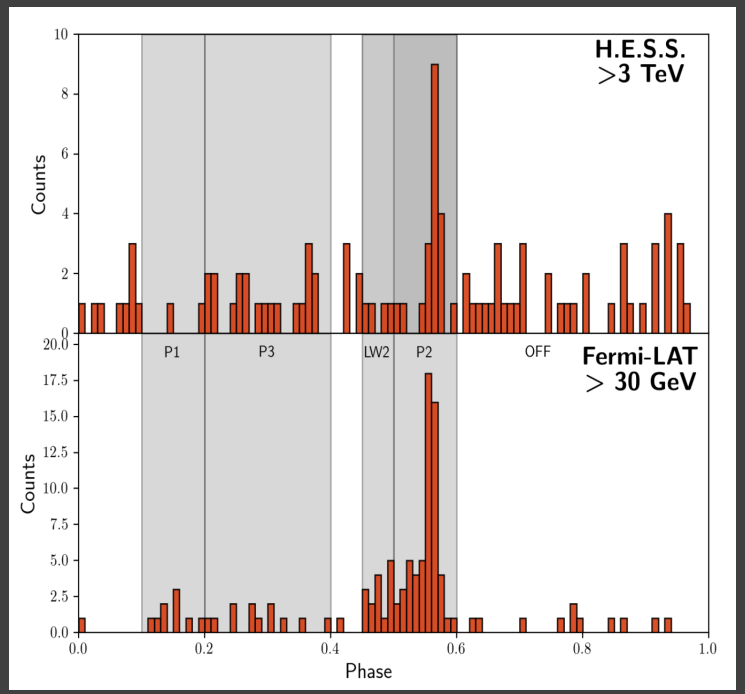
- GC with the H.E.S.S. II array down to ~100 GeV
- Detection of central source (40 σ), PWN G0.9+0.1, HESS J1745-303 + diffuse emission
- Smooth continuation from spectrum seen in H.E.S.S. I
- E-threshold not low-enough to fully describe Fermi-LAT - H.E.S.S. spectral break
- +50h obs. time coming soon (blinded for dark matter searches…) vs 58h so far…

VELA PULSAR – H.E.S.S. II

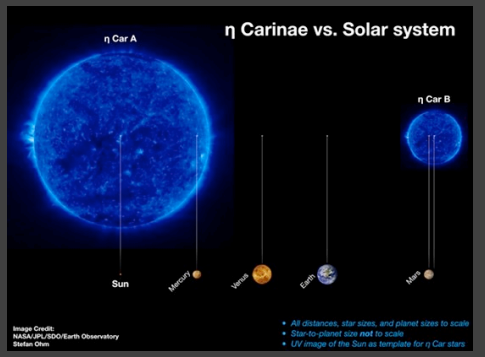
One of only a few VHE pulsars detected as of yet

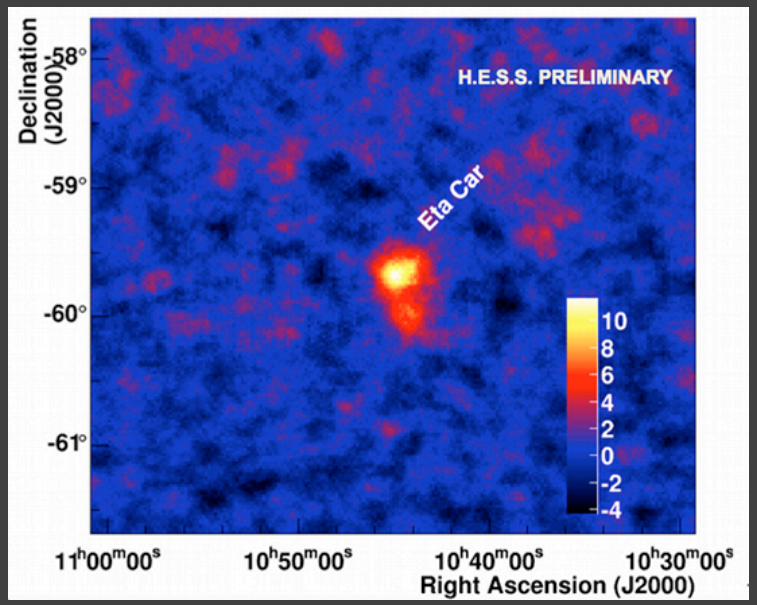
H.E.S.S. Collaboration





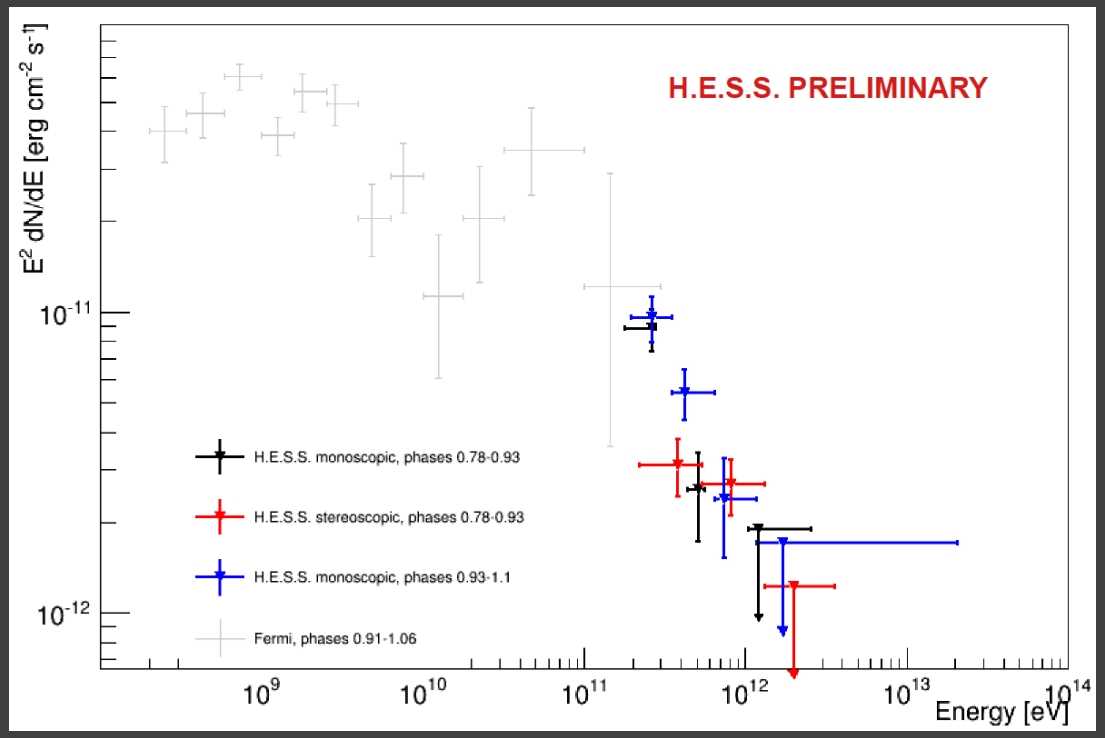
ETA CAR WITH H.E.S.S. II – A NEW TEV BINARY SYSTEM





- A colliding wind binary system now detected in very high energy gamma-rays
- Detected with H.E.S.S. II pre-periastron and around periastron (in total > 13 σ)

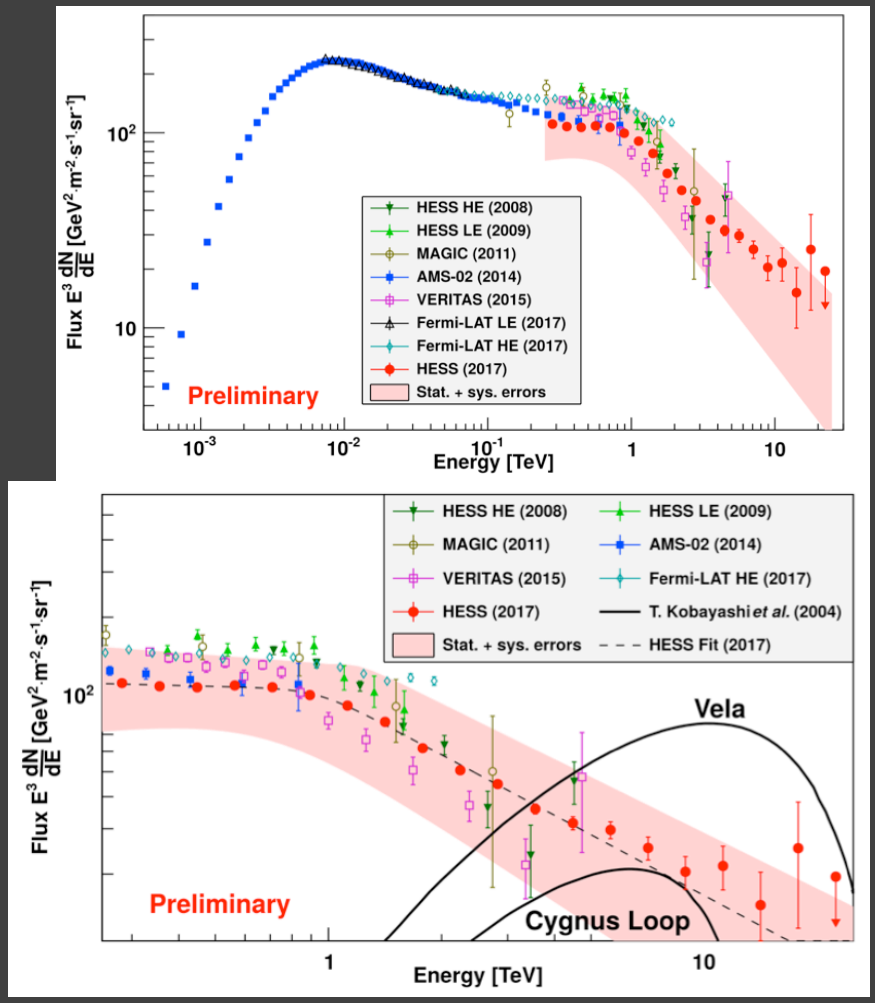
H.E.S.S. collaboration, ICRC 2017



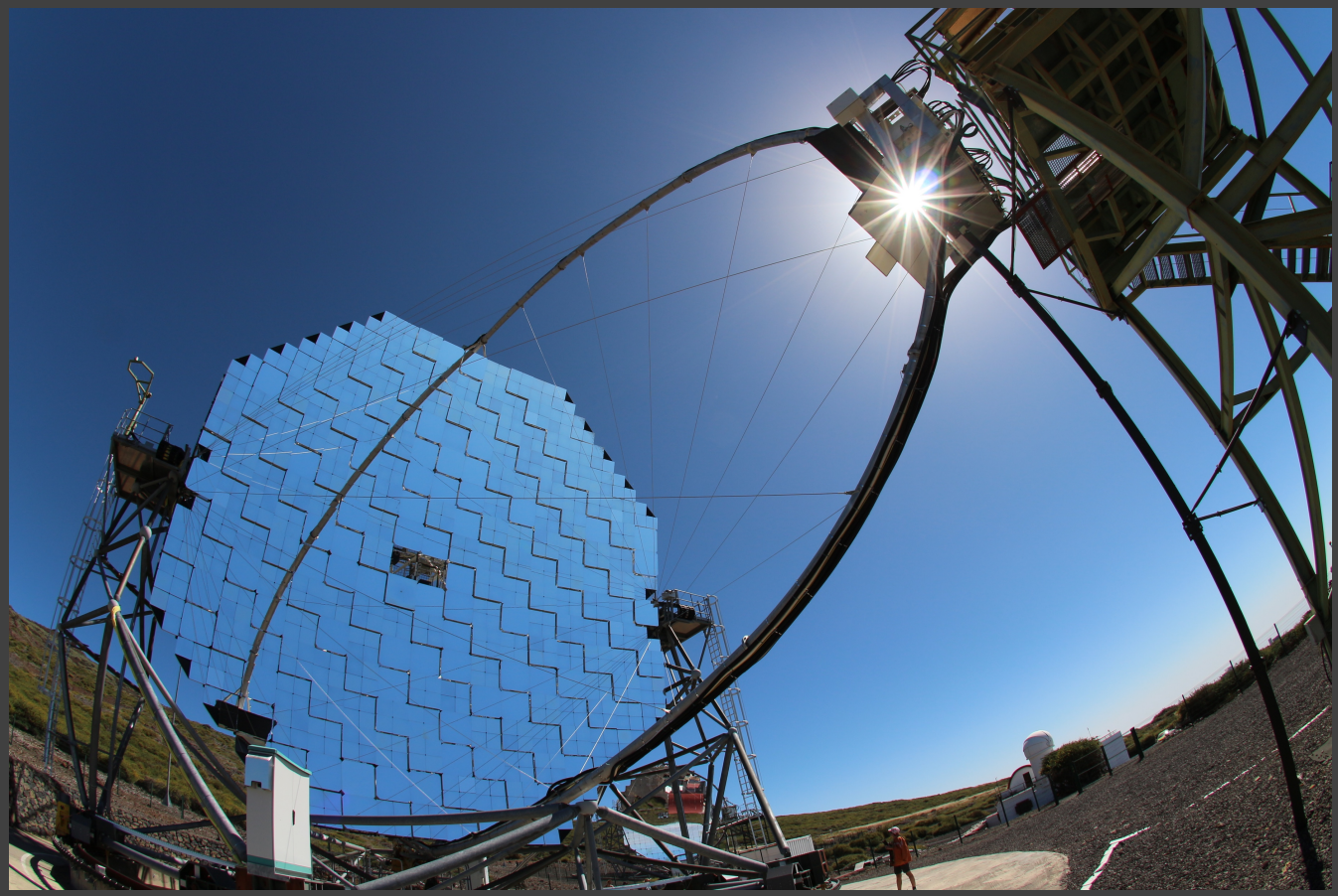
THE LOCAL CR ELECTRON SPECTRUM

- Electron spectrum between 0.25 TeV and 20 TeV:
  - Break at ~1 TeV (change of diffusion regime?)
  - Probing local PWNe and SNRs
- Break @ 1TeV recently confirmed by DAMPE satellite experiment

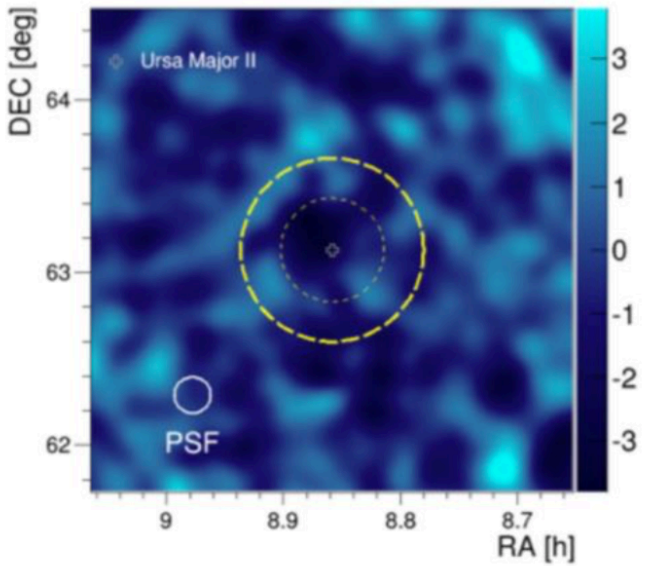
H.E.S.S. collaboration, ICRC 2017

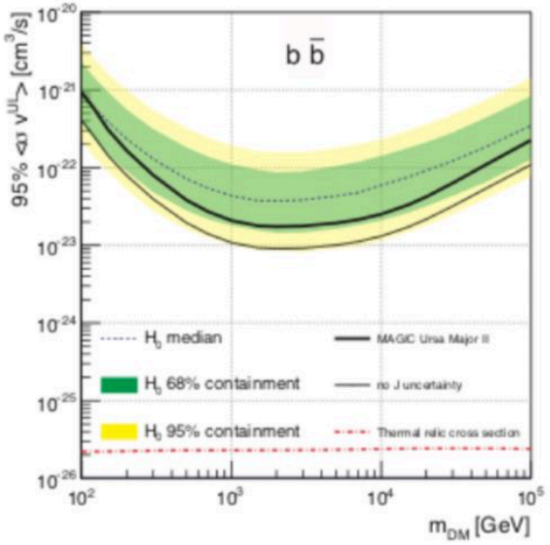


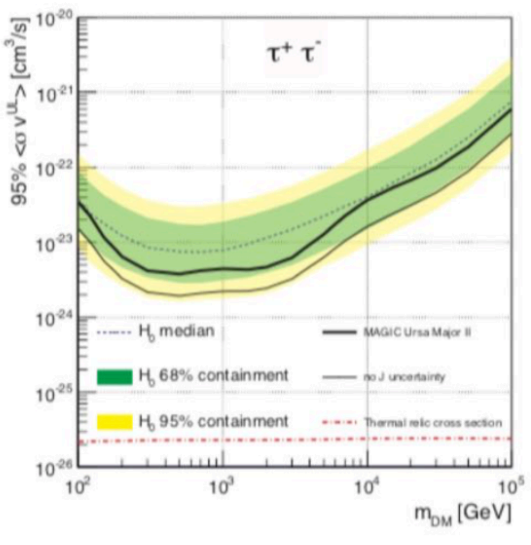
MAGIC (LA PALMA / CANARIES)



URSA MAJOR II DM SEARCH







$$\log_{10}(J(\theta_{\max})\ [\mathrm{GeV}^2\ \mathrm{cm}^{-5}]) = 19.42^{+0.44}_{-0.42}$$

$$\mathrm{M/L} \sim 4000^{+3700}_{-2000}\ M_\odot/L_\odot$$

distance of $\sim$ 30 kpc

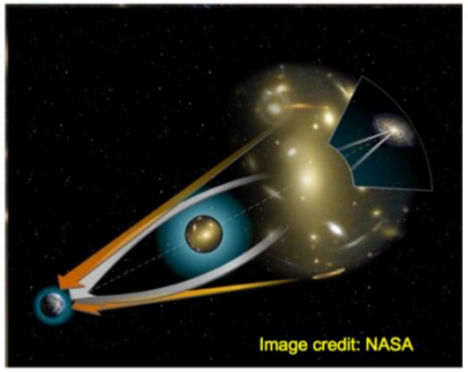
Indirect dark matter searches in the dwarf satellite galaxy Ursa Major II with the MAGIC Telescopes

MAGIC Collaboration (M.L. Ahnen (ETH, Zurich (main)) *et al.*). Dec 7, 2017. 21 pp.

Published in **JCAP 1803 (2018) no.03, 009**

AGN: QSO B0218+357

Gravitational lensed gamma-rays

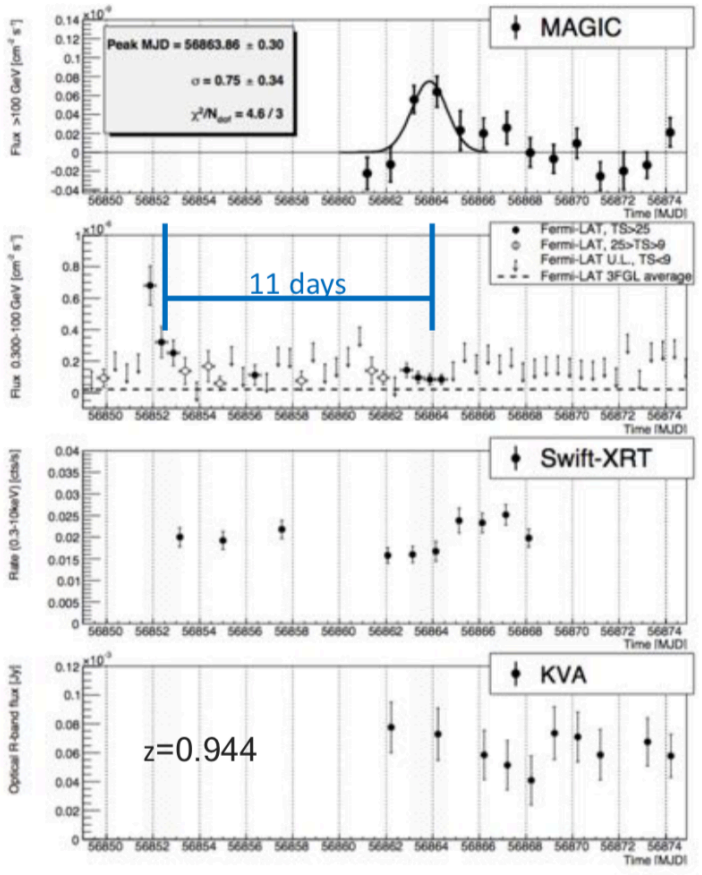


QSO B0218+357 is a gravitationally lensed blazar at redshift: 0.944 where the lens is probably a spiral galaxy B0218+357G at z=0.68

11-days is the time-delay

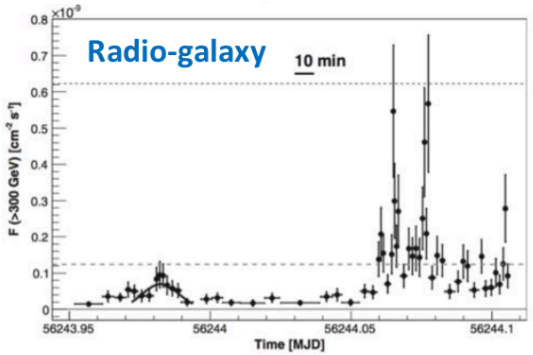
In 2014, Fermi got the first flare, and 11 days after, MAGIC detected the afterlight

- MAGIC could not observe the leading image due to the Full Moon.
- First gravitationally-lensed VHE gamma rays ever observed
- 2hours, 6 sigma significance

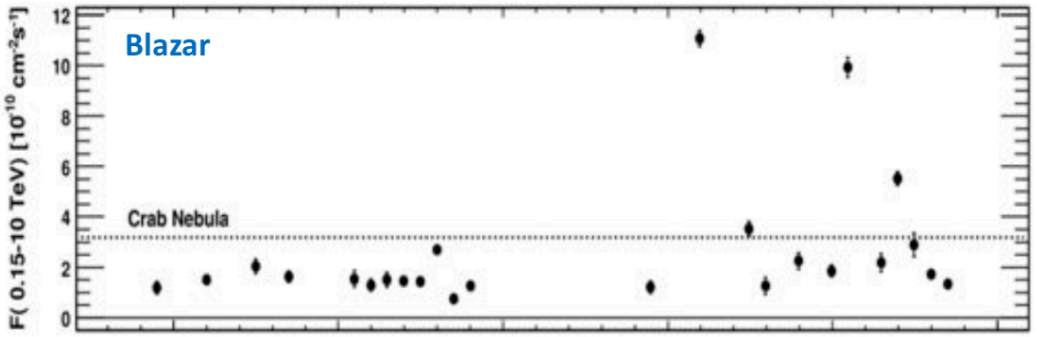


Detection of very high energy gamma-ray emission from the gravitationally-lensed blazar QSO B0218+357 with the MAGIC telescopes
MAGIC Collaboration (M.L. Ahnen *et al.*). Sep 5, 2016. 11 pp.
e-Print: arXiv:1609.01095 [astro-ph.HE] | PDF

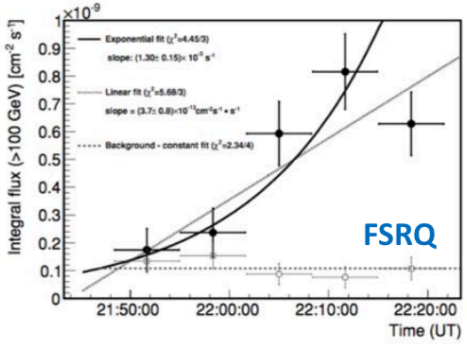
FLARES AS POWERFUL PROBES INTO BH/JET MECHANISMS



IC310. Doubling time 4.8 min



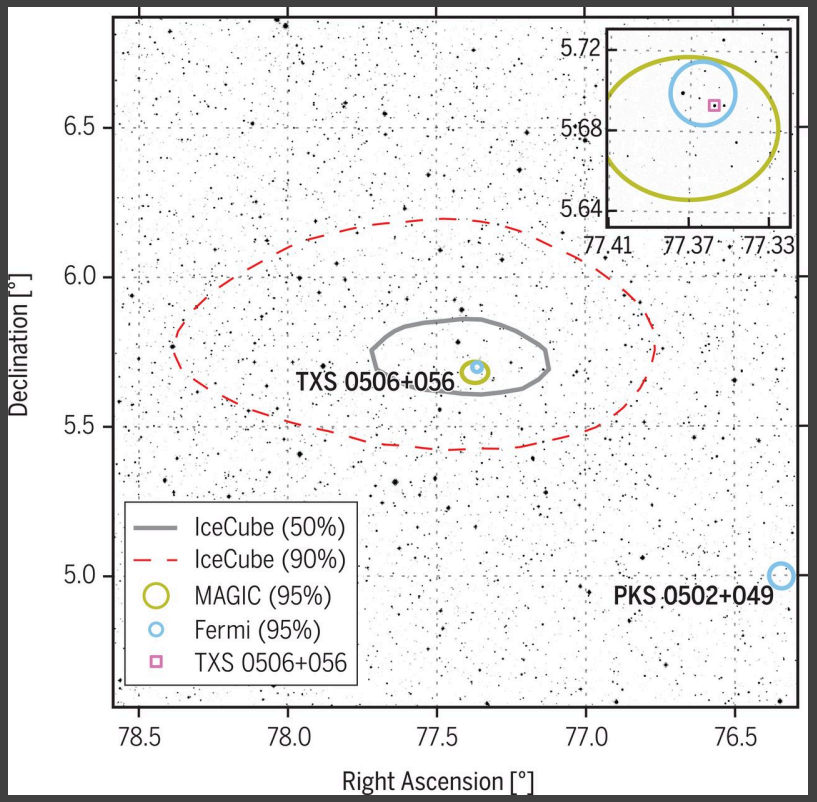
Mrk501 2005. Flux doubling time ~2min

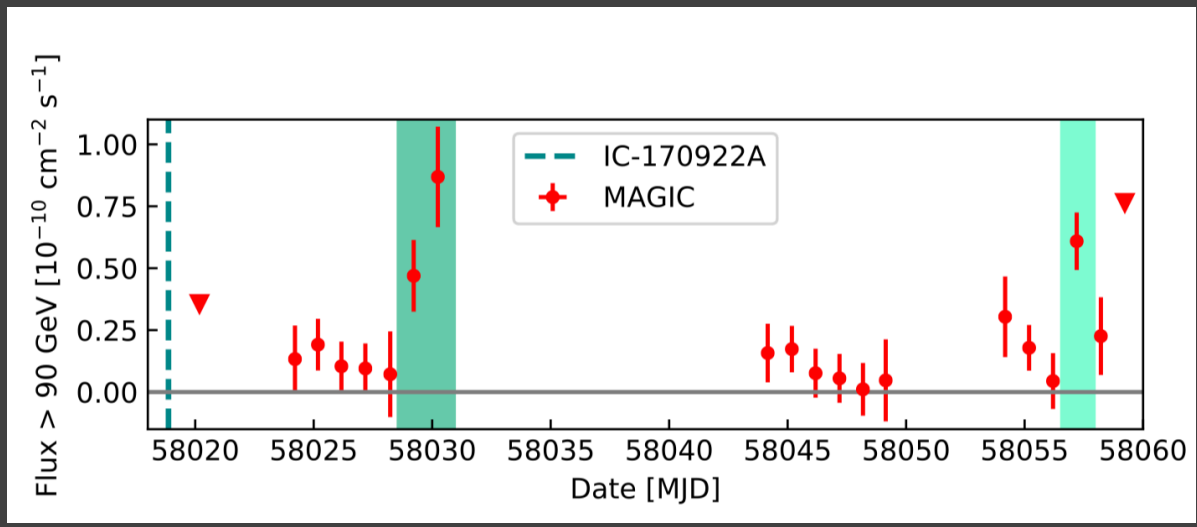


PKS1222. Doubling time 10 min

- MAGIC has detected extremely fast variability in all classes: Radio-galaxy, Blazars and FSRQ.
- Useful probe:
  - One can infer size of emission region with indirect better “angular resolution” than any other instrument
- However, still unclear whether emission scenarios is:
  - Close to the central engine
  - Far out emission region

TXS 0506+056 – HARBINGER OF THE NEUTRINO POINT SOURCE ERA

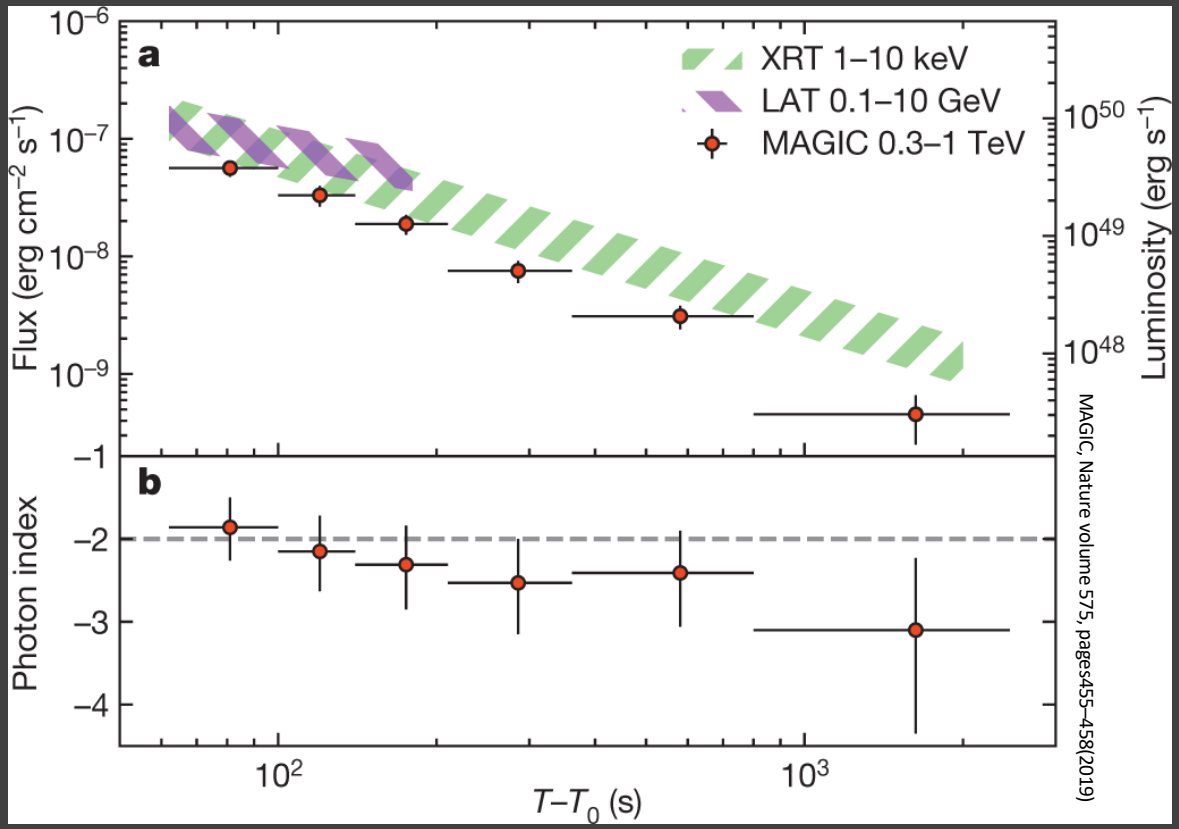




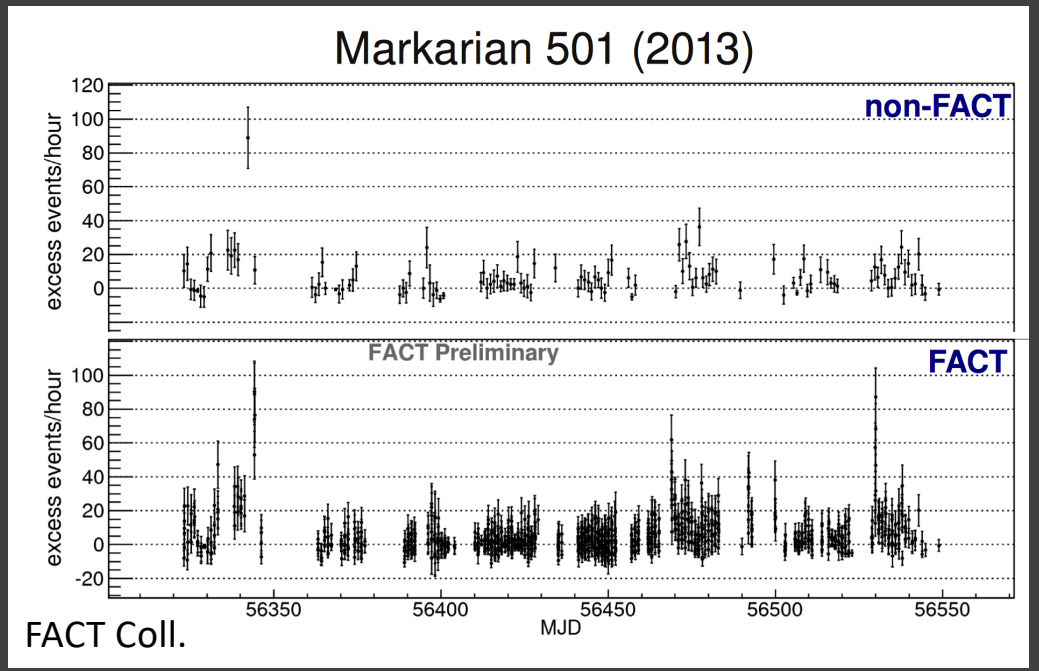
The Astrophysical Journal Letters, 863 (2018) L10

Science 13 Jul 2018:
Vol. 361, Issue 6398

GRB 190114C

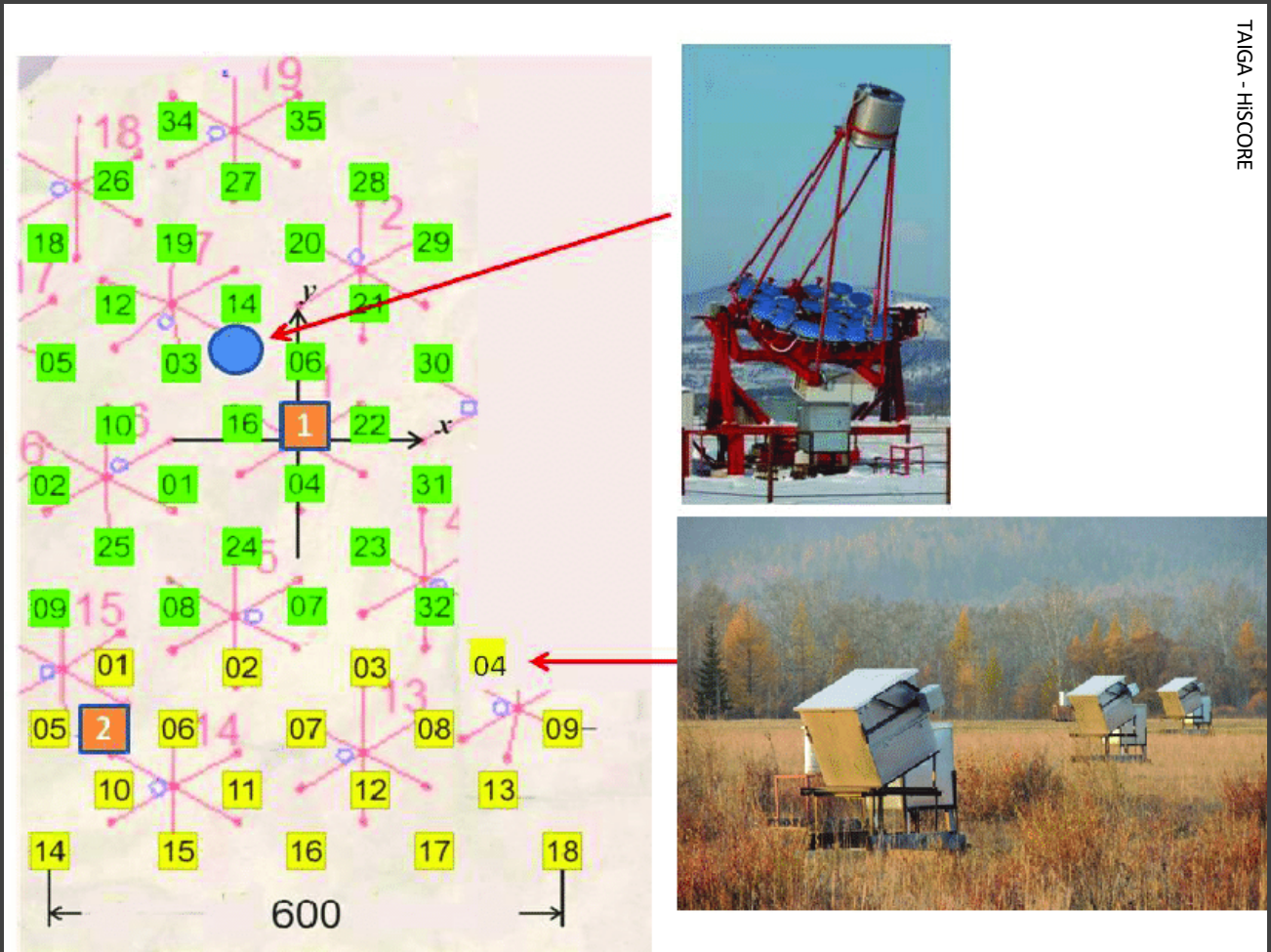

a
XRT 1–10 keV
LAT 0.1–10 GeV
MAGIC 0.3–1 TeV
Flux (erg cm^{-2} s^{-1})
Luminosity (erg s^{-1})
b
Photon index
T–T_0 (s)
MAGIC, Nature volume 575, pages455–458(2019)

FACT: A HIGHLY SUCCESSFUL TECHNOLOGY & METHODS PIONEER



FACT Coll.

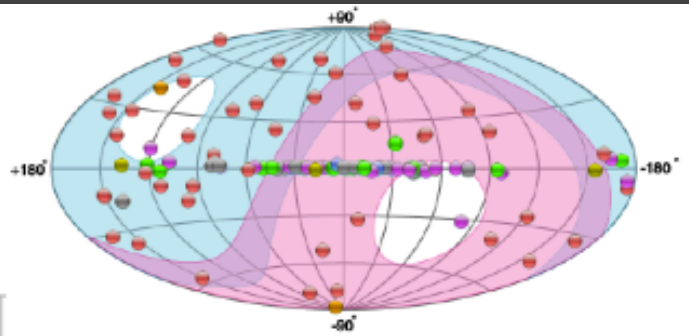
TAIGA - HiSCORE

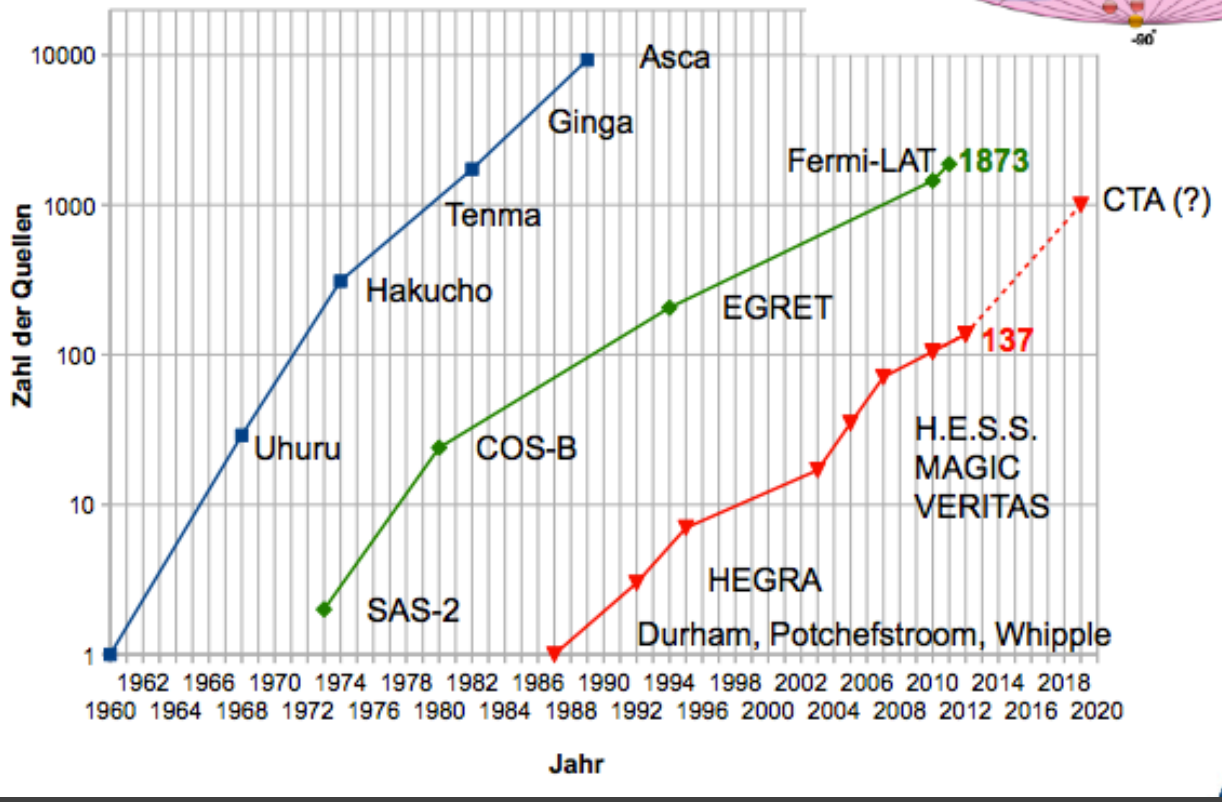


Cherenkov Telescope Ring (CTR)

- Strong physics motivation for expanded world – wide monitoring capability
- Concept idea to re-dedicate or build an all – longitude covering monitoring array of IACTs
- Can be achieved with realistic efforts now by building upon existing facilities & expertise from pioneering instruments (CTA, FACT, et al.)
- Additional motivation: technological and educational continuity for students into the CTA era

Quellen-Statistik






M. Nöthe