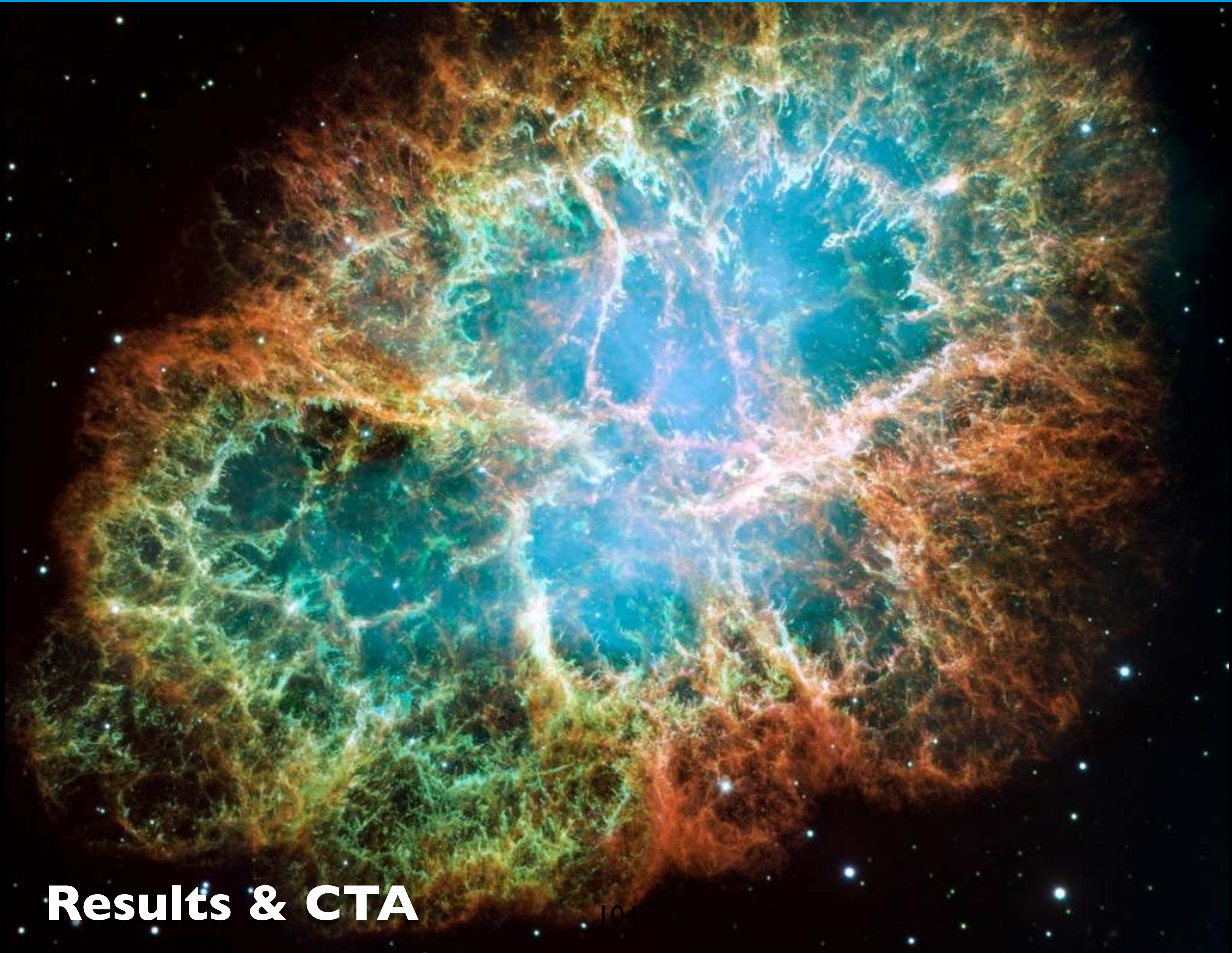
Gamma Rays



Part 2: Results & CTA

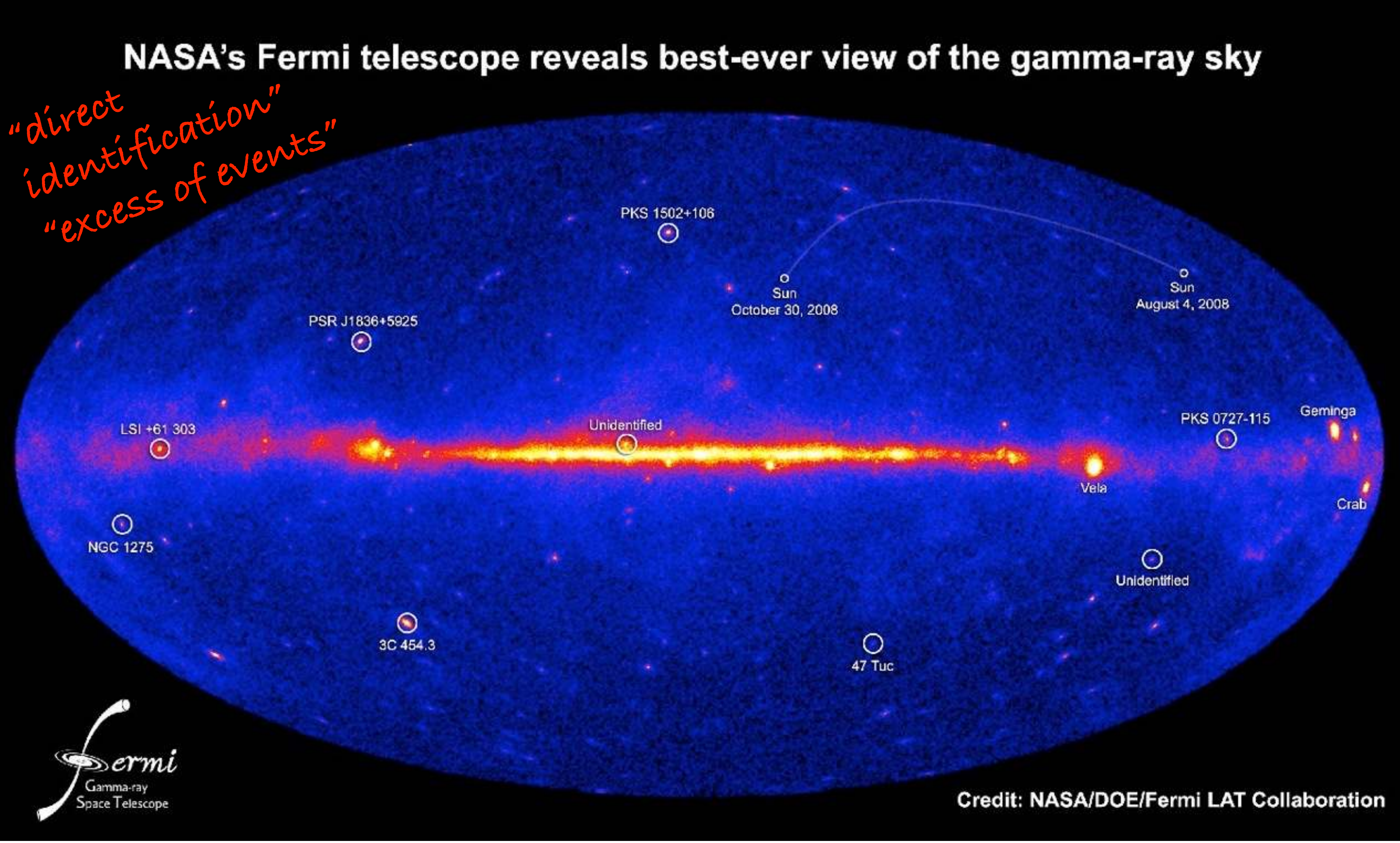
2008 - …

Fermi Satellite

LAT: 10 MeV - 300 GeV
BGO: ….
GBM: 10 keV-1 MeV

> 5000 sources 50 MeV - 1 TeV
> 5000 GRBs

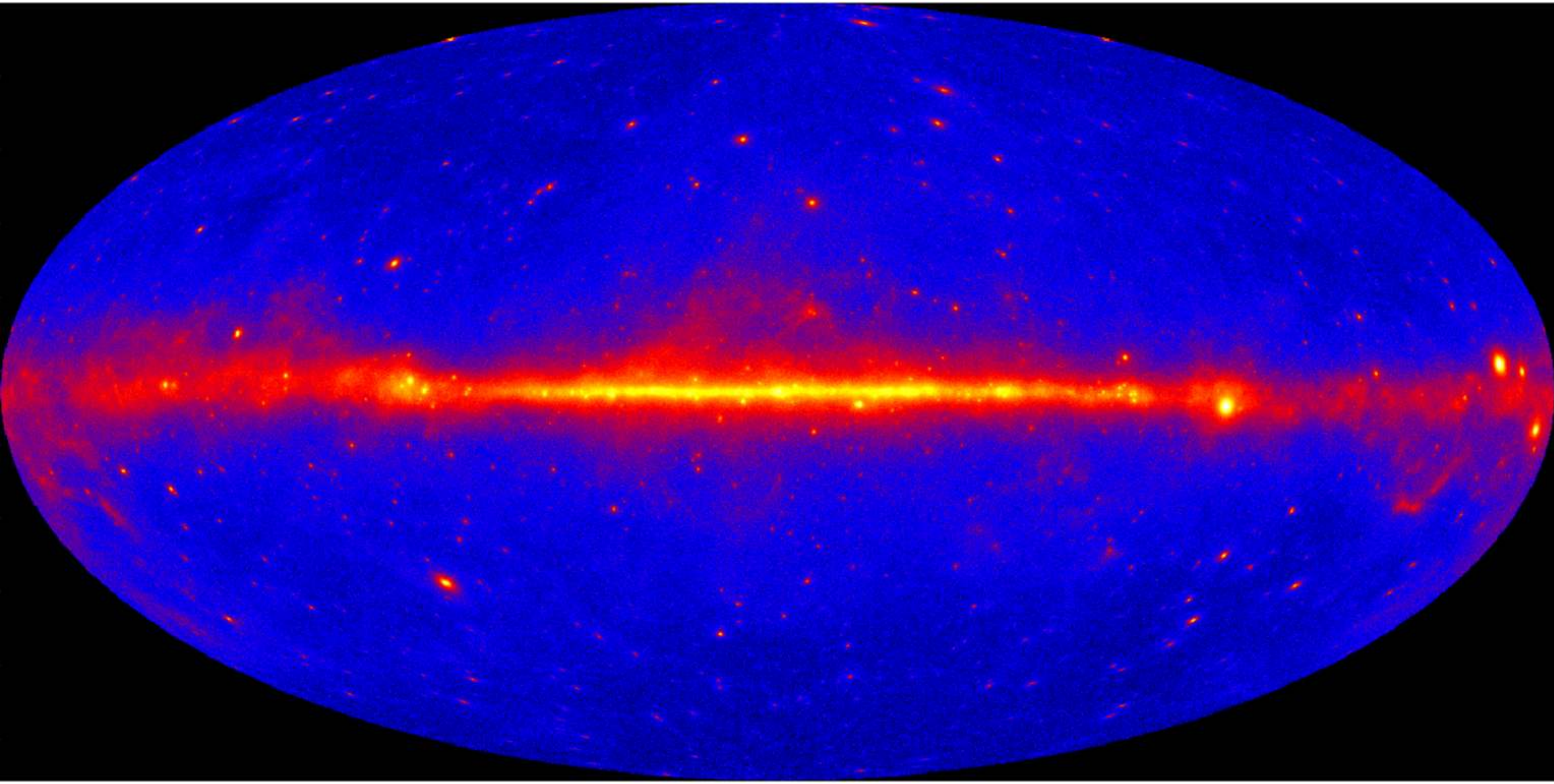
≈ 1 m^2 2.5 sr
LAT: 10 MeV - 300 GeV



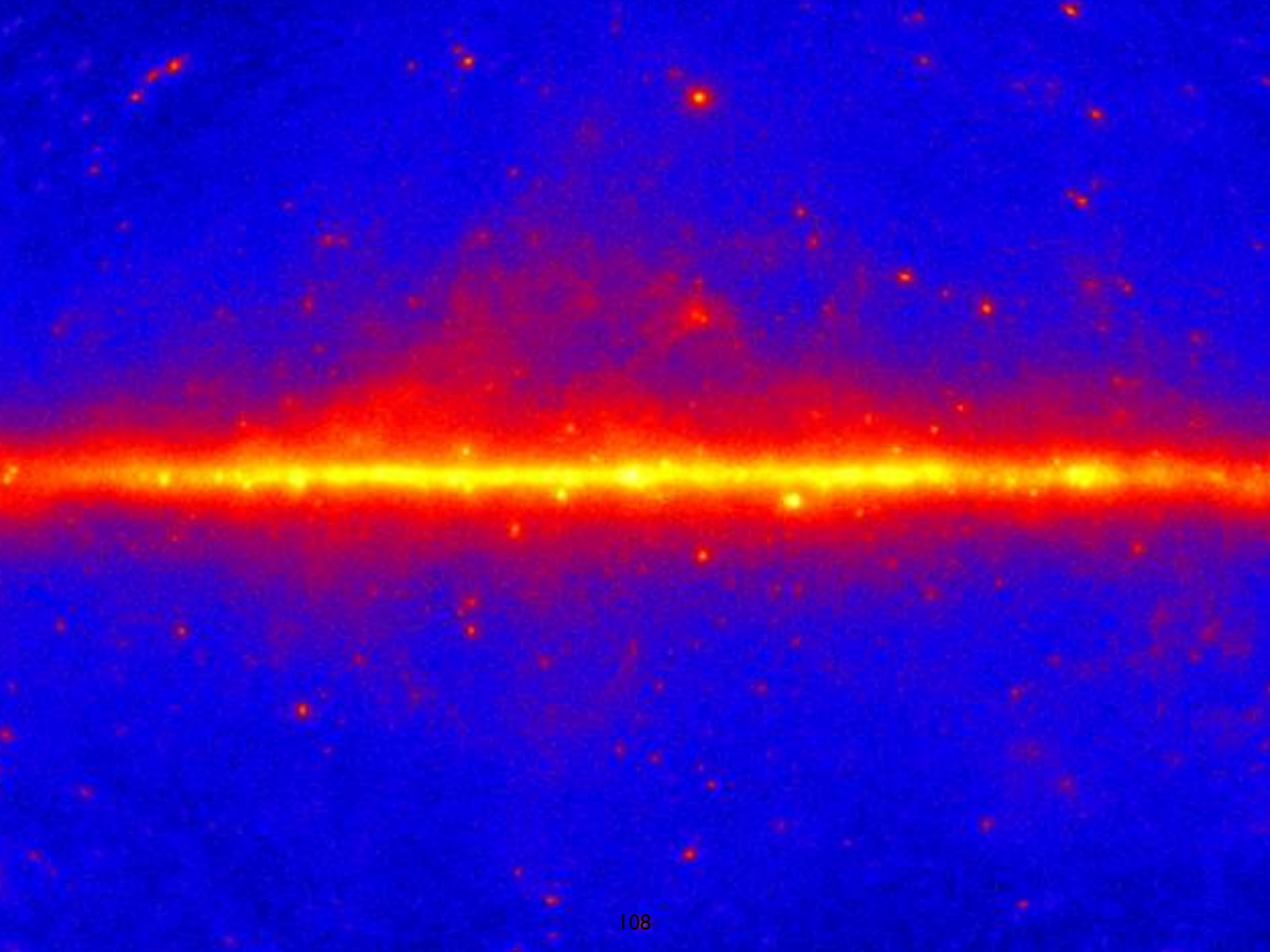
Satellite experiment: 100 MeV - 100 GeV

point sources, extended sources and diffuse emission, ...

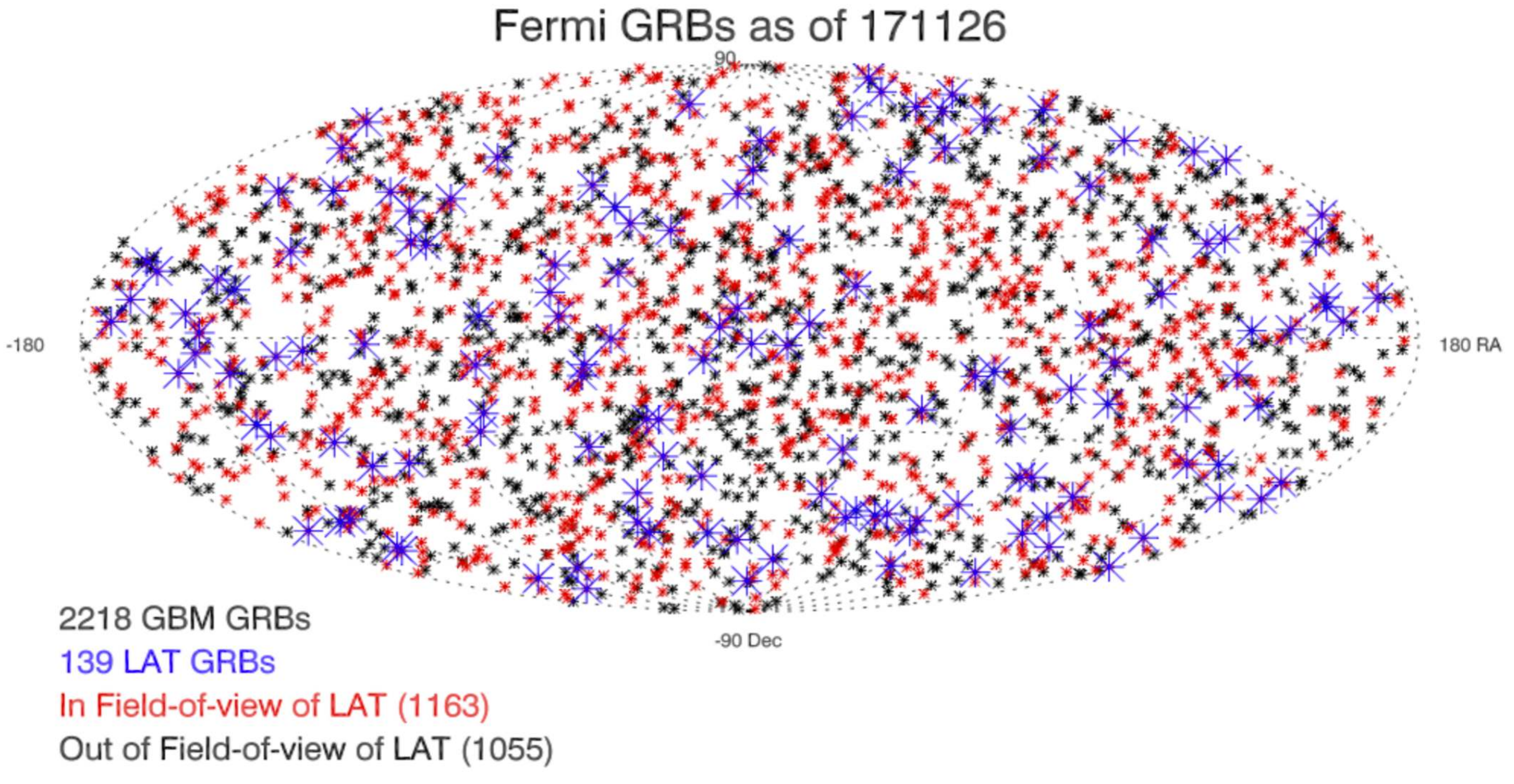
Fermi-LAT: 2-year catalog



Satellite experiment: 100 MeV - 100 GeV
point sources, extended sources and diffuse emission, ...

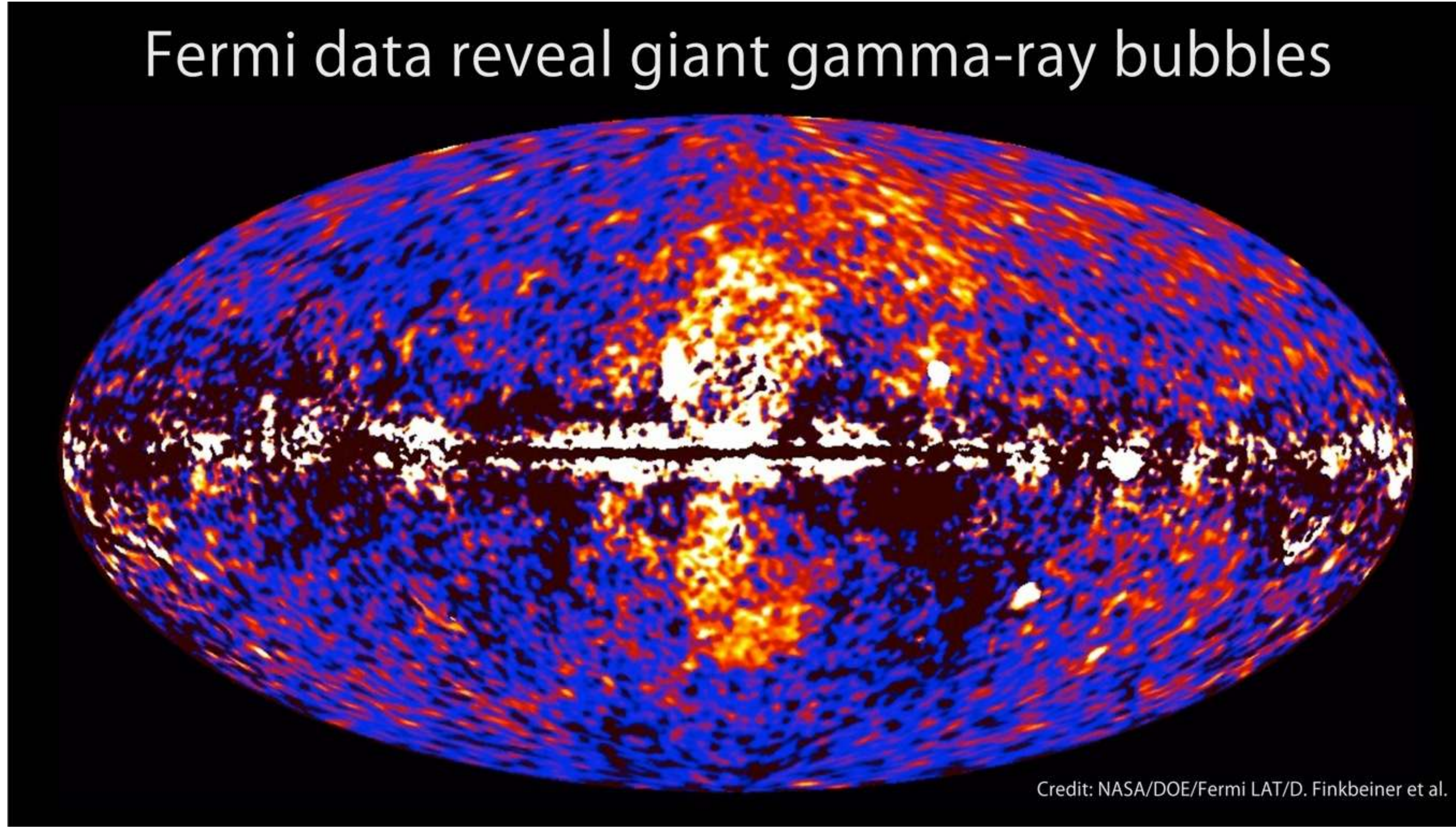


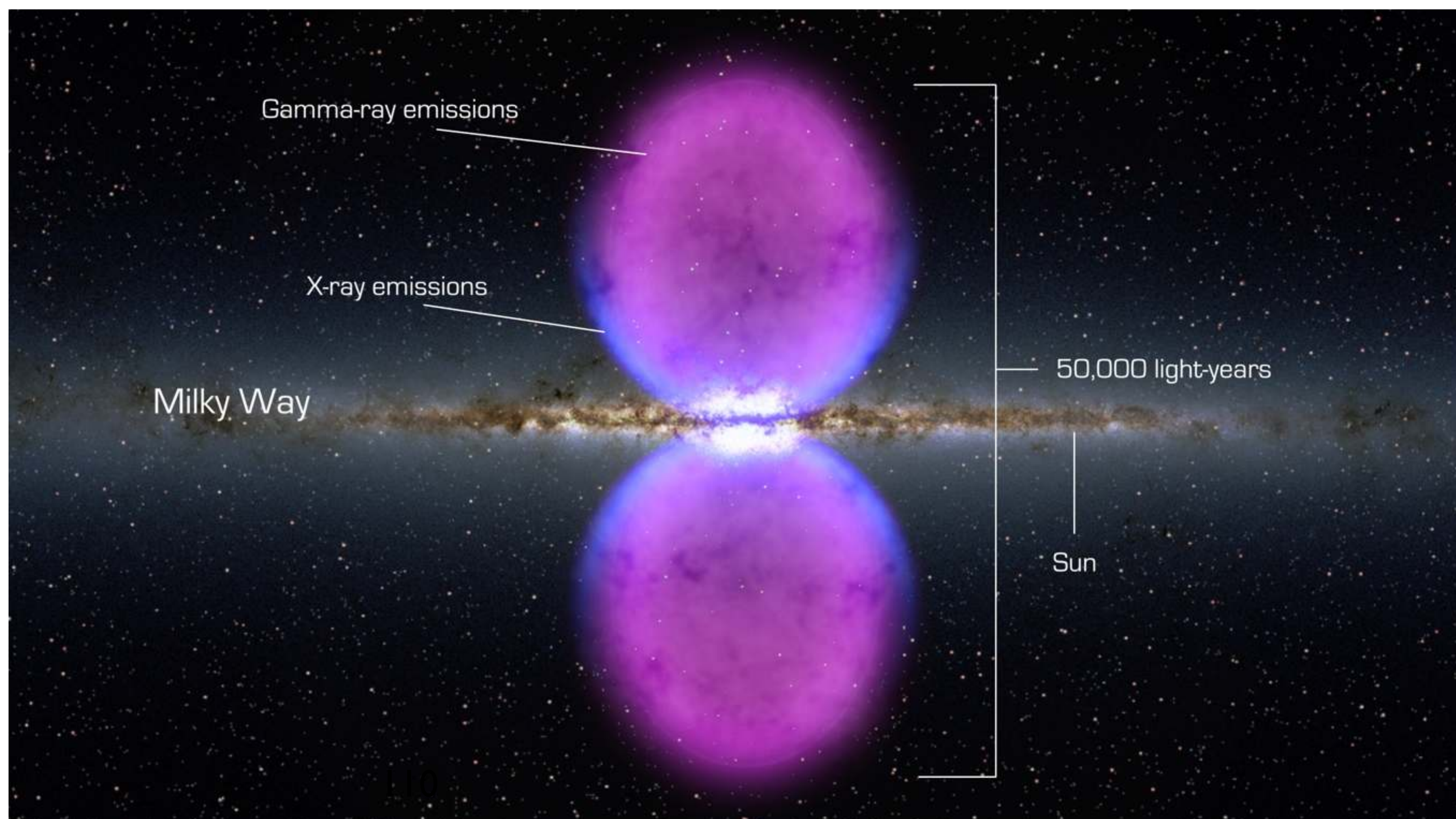
Gamma Ray Bursts

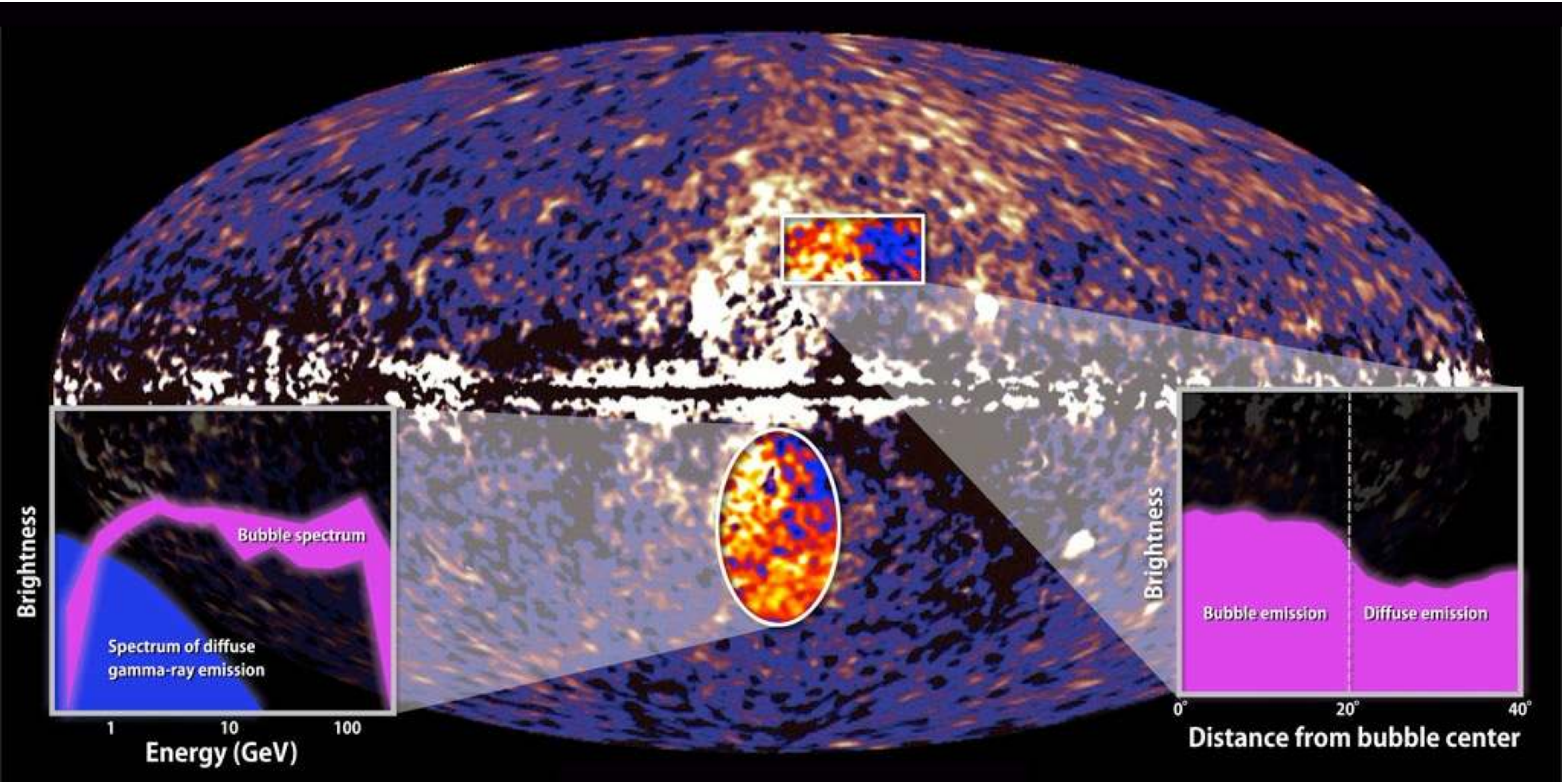


The Fermi Bubble

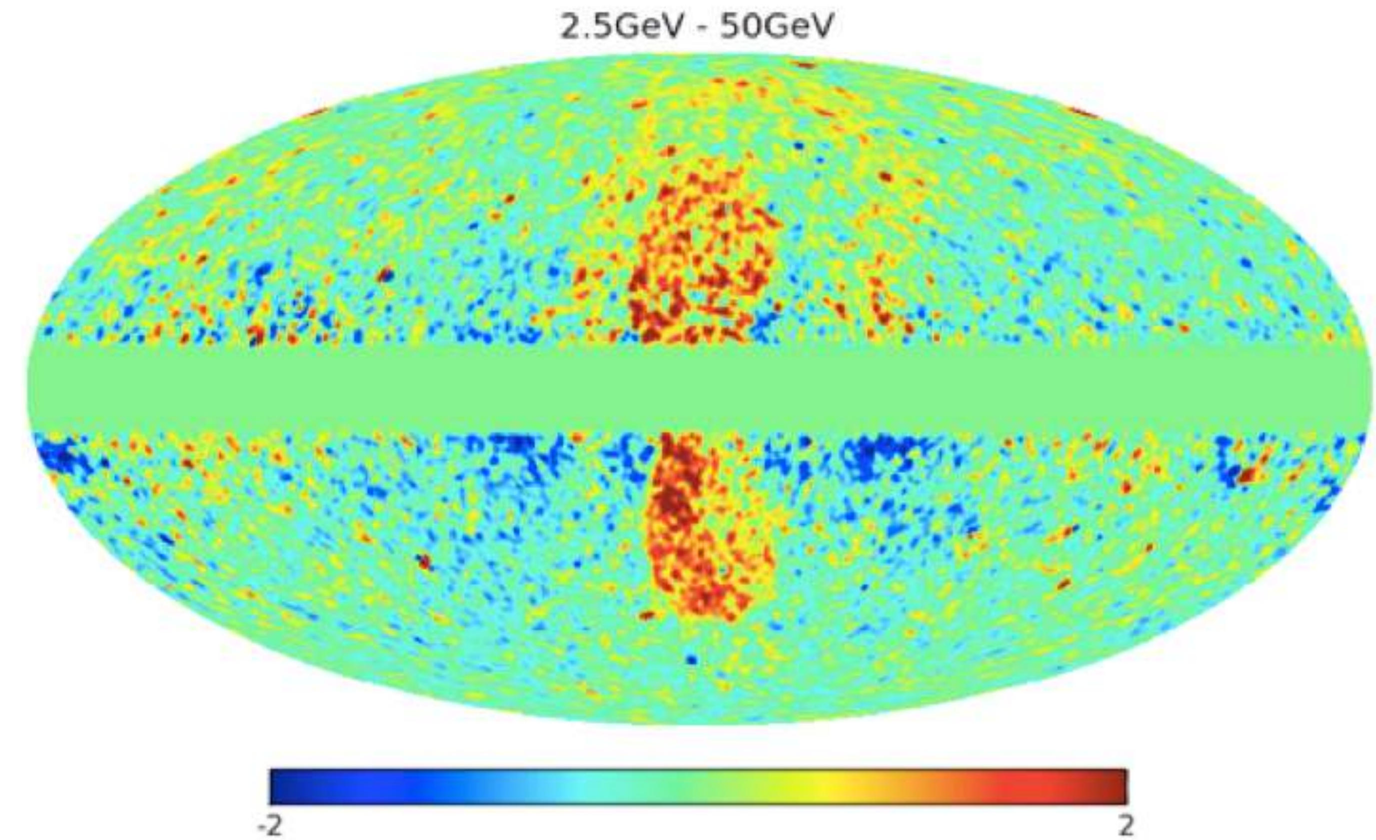
... a remnant of recent activity of our galaxy ?



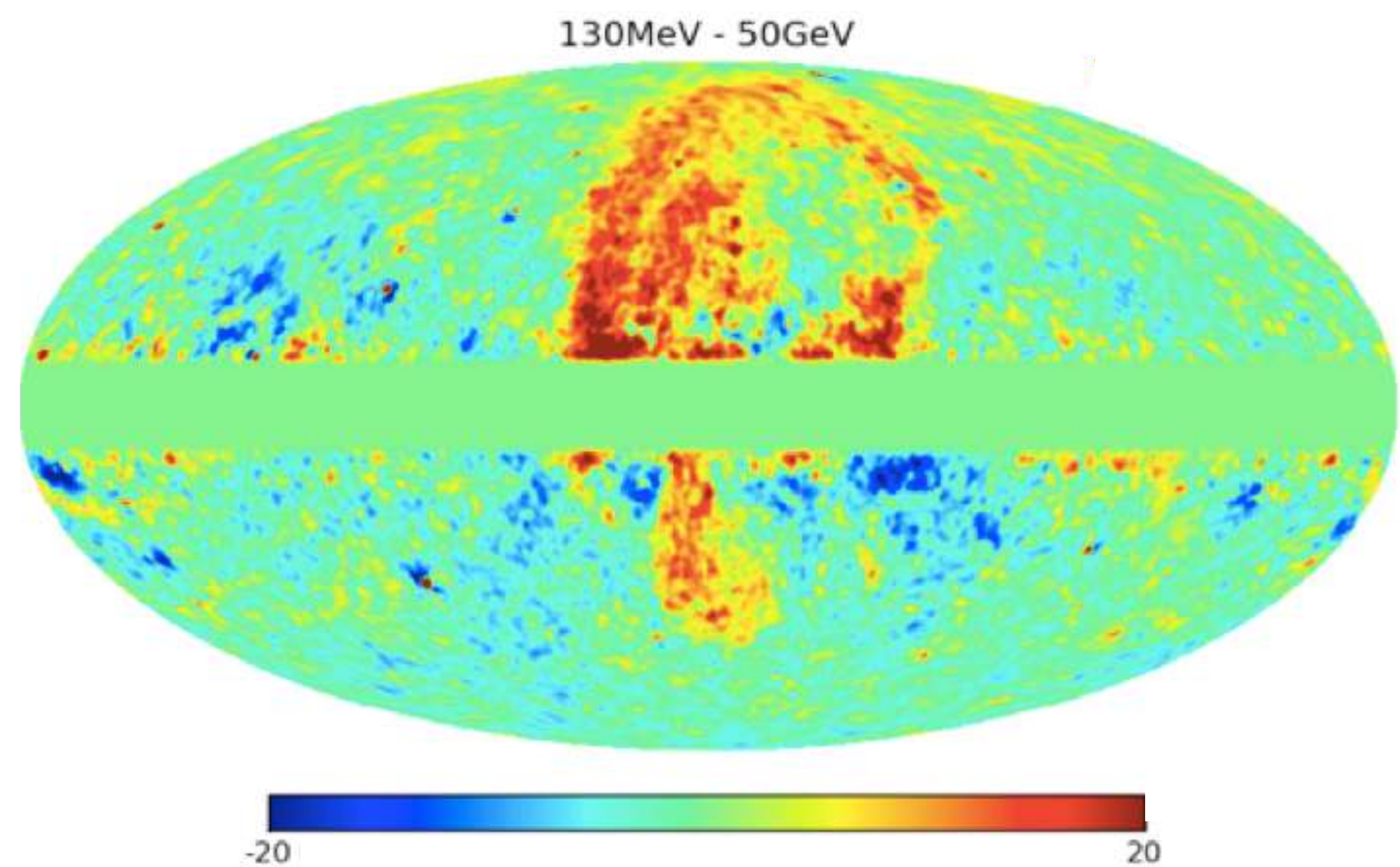



Brightness
Bubble spectrum
Spectrum of diffuse
gamma-ray emission
1
10
100
Energy (GeV)
Brightness
Bubble emission
Diffuse emission
0°
20°
40°
Distance from bubble center

Fermi Bubble

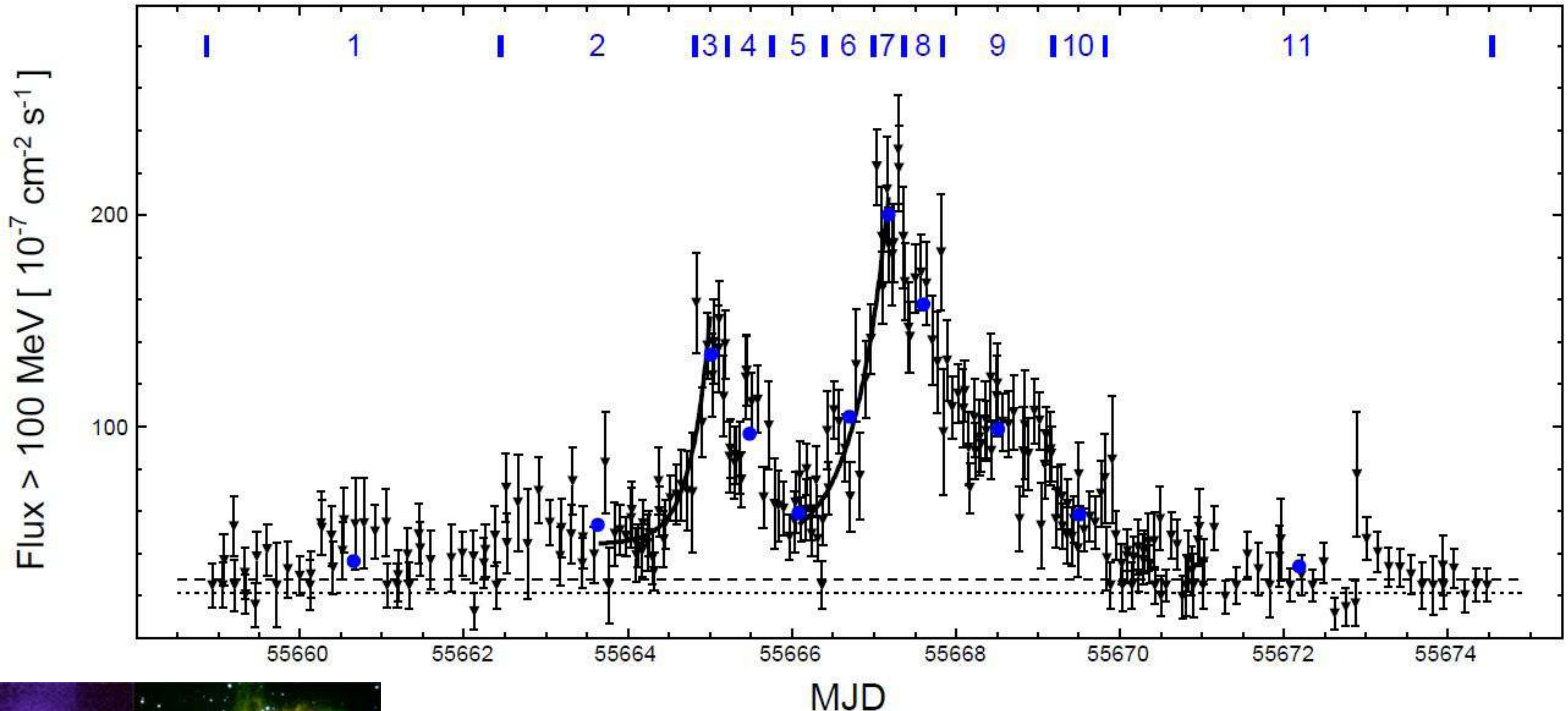


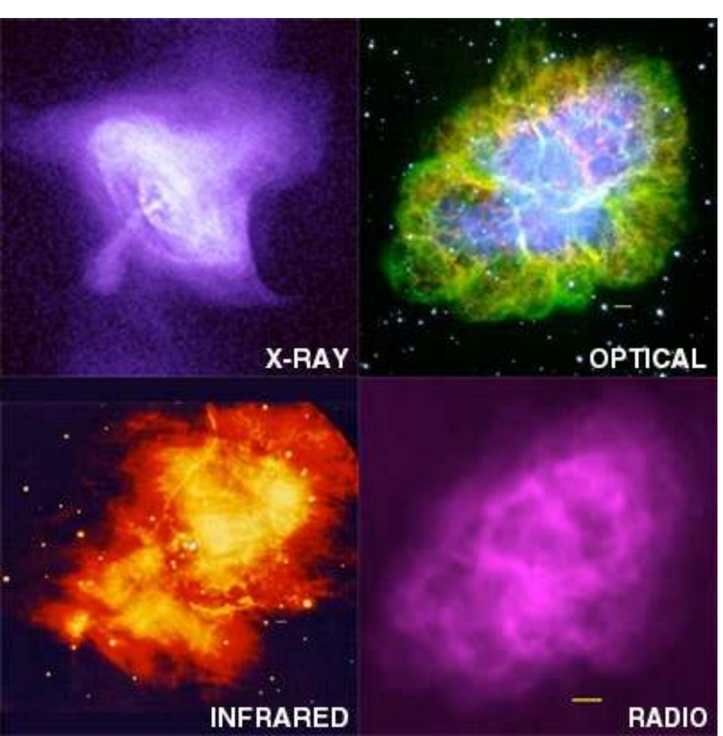
Fermi Loop

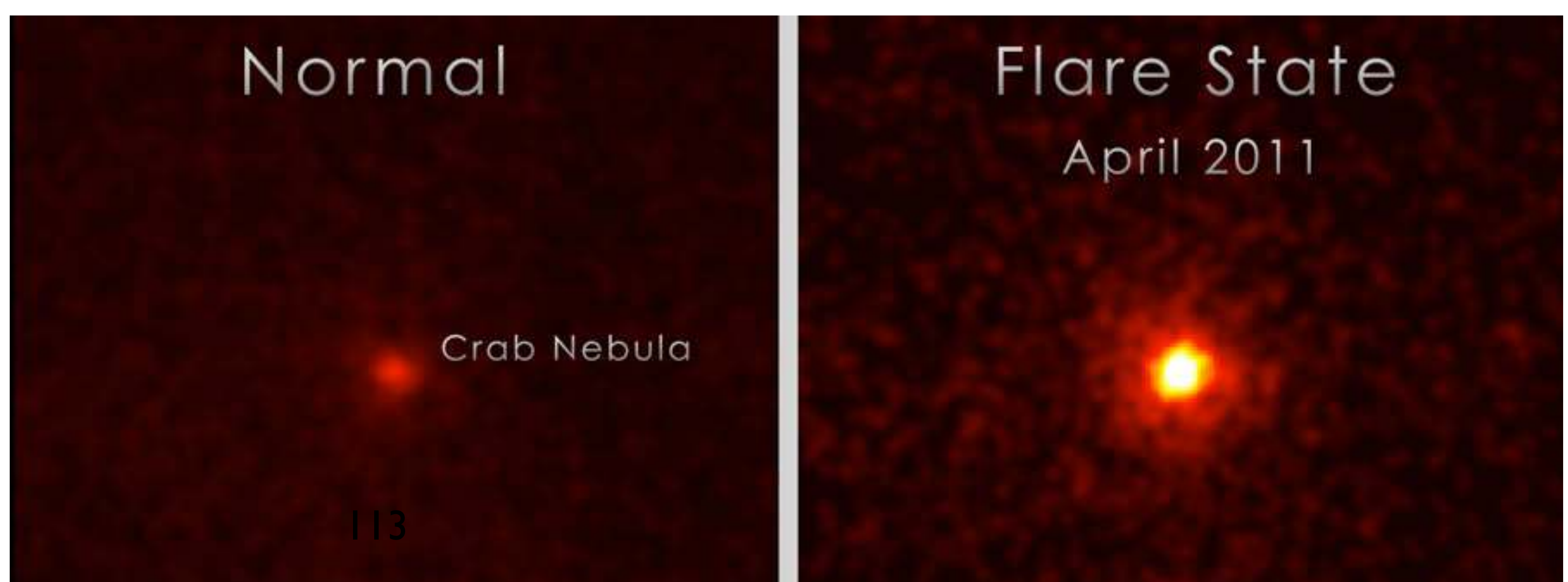


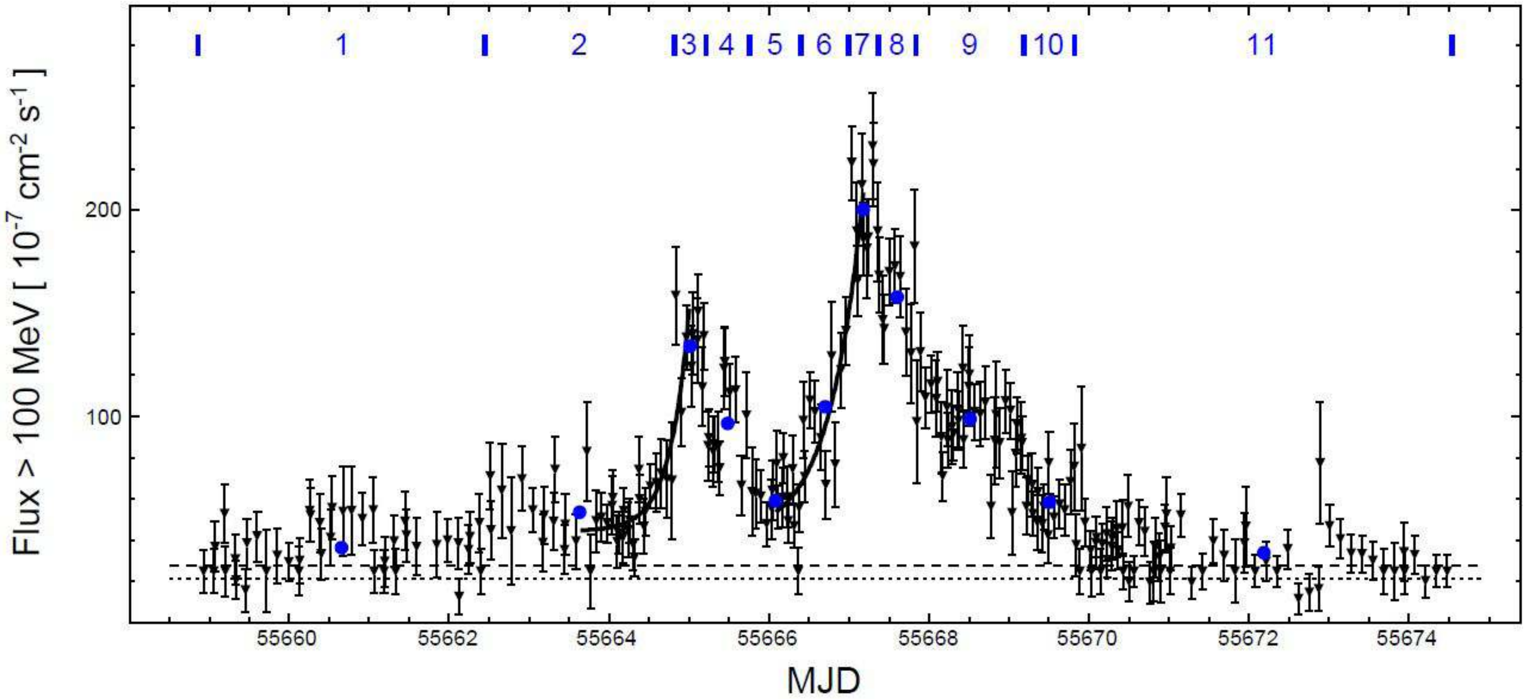
Major gamma-ray flare from Crab Nebula (April 2011)

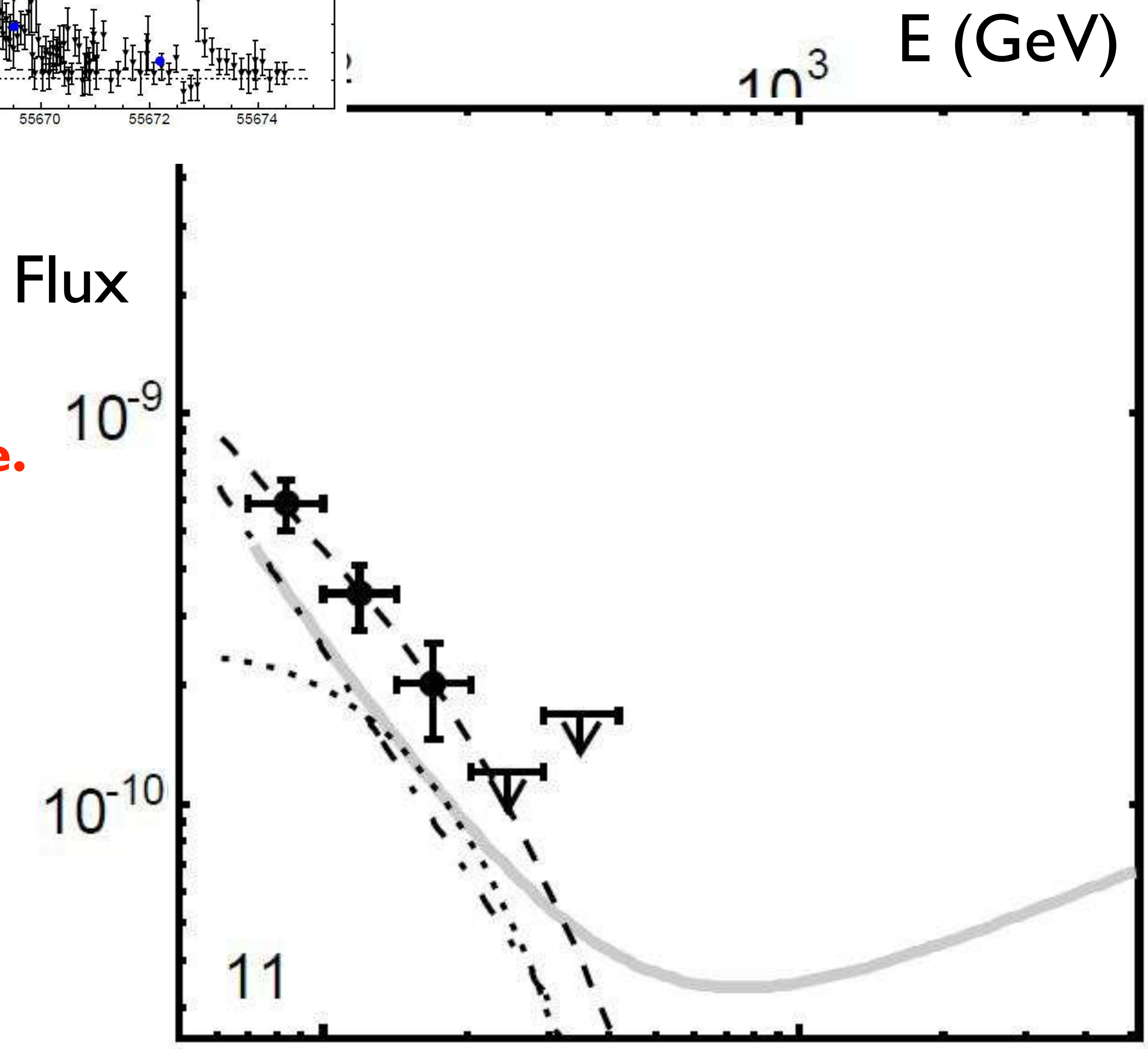
Crab was always seen as the "standard candle"











Spectrum varies with time.
Allows study of the
"dynamic processes"
of particle acceleration.

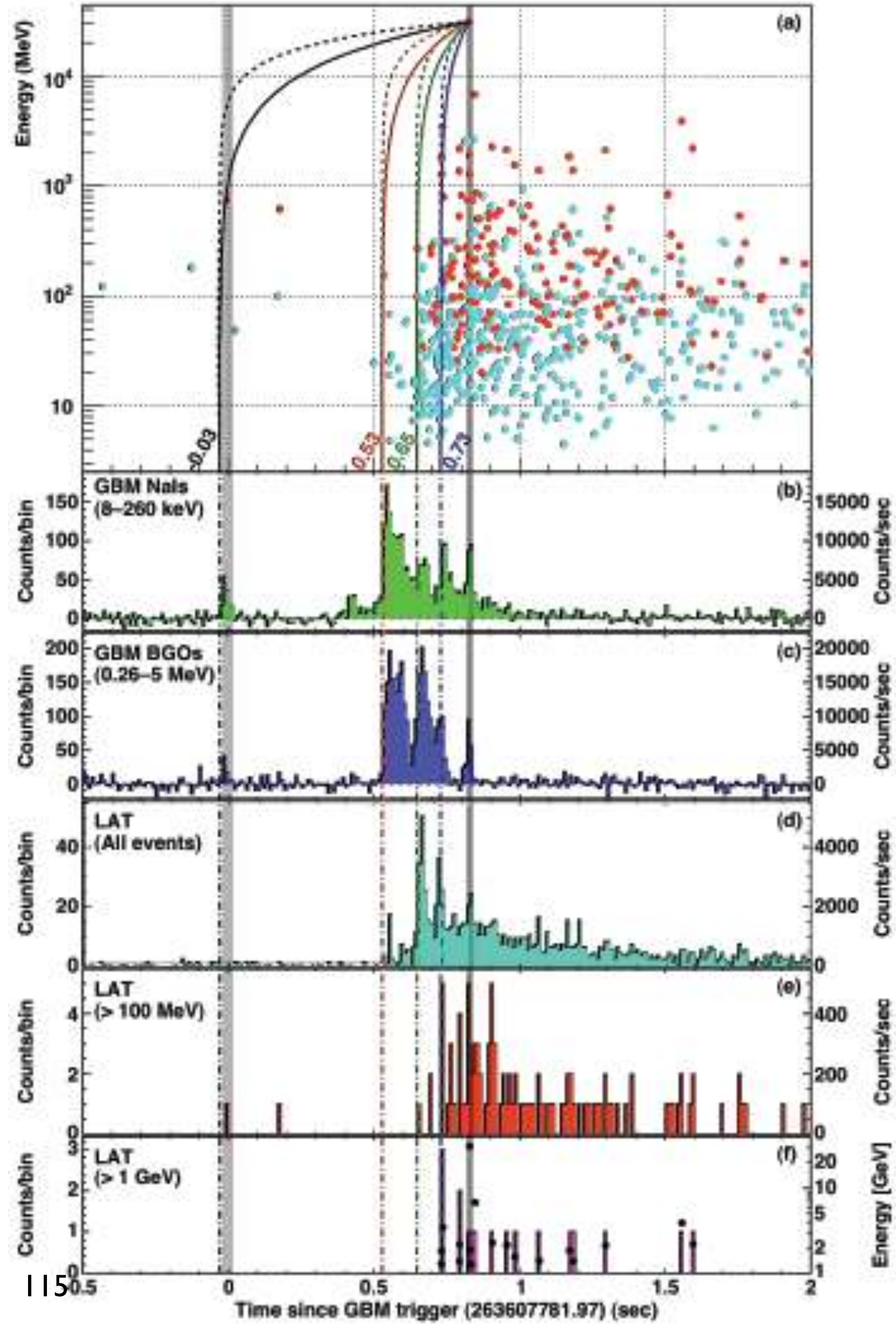
Fermi:
LIV test: GRB

Fermi LAT+GBM:

QG energy scale > 1.2 E_{Planck}

(linear dep. of the speed of light on energy)

... plus many more exciting results. 100s of papers...



Search for "dark matter" with gamma rays.

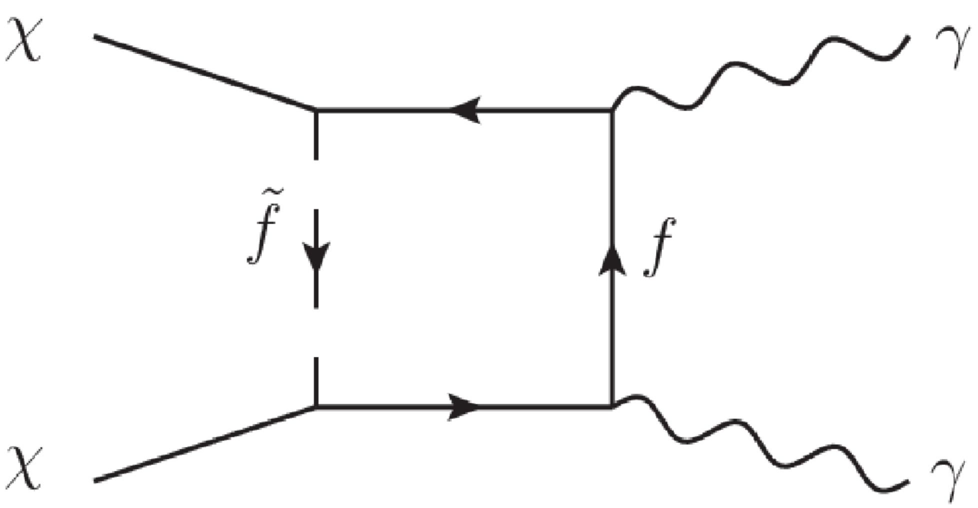
DM particles should cluster in gravitational potentials
e.g. in centre of galaxies

They could annihilate and produce gamma rays
with $E_\gamma \approx m_{DM}$

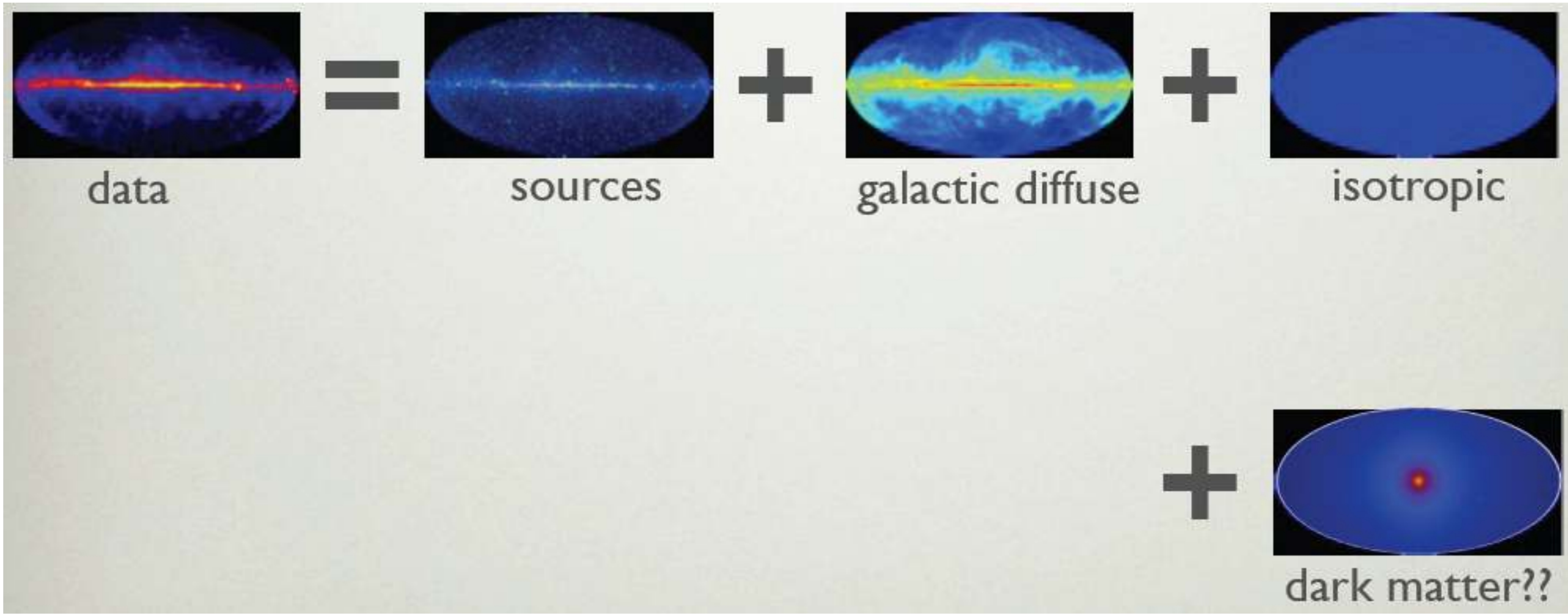
i.e. line emission

$$\chi\chi \to \gamma\gamma,\ \gamma Z,\ \gamma h$$

$$\mathrm{BR}(\chi\chi \to \gamma\gamma) \sim \alpha_{\mathrm{em}}^2 \sim 10^{-4}$$

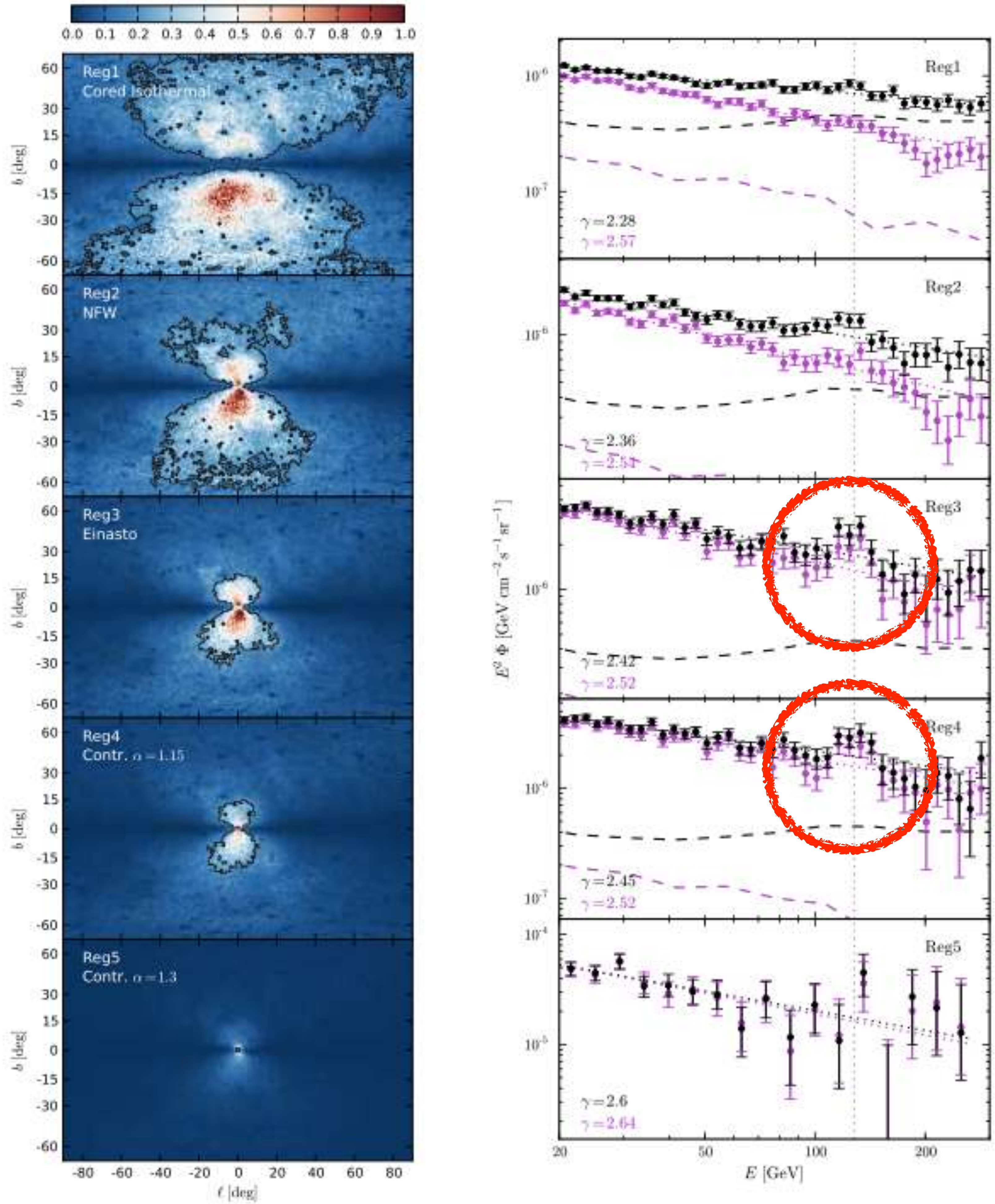


Understand the gamma ray sky ...

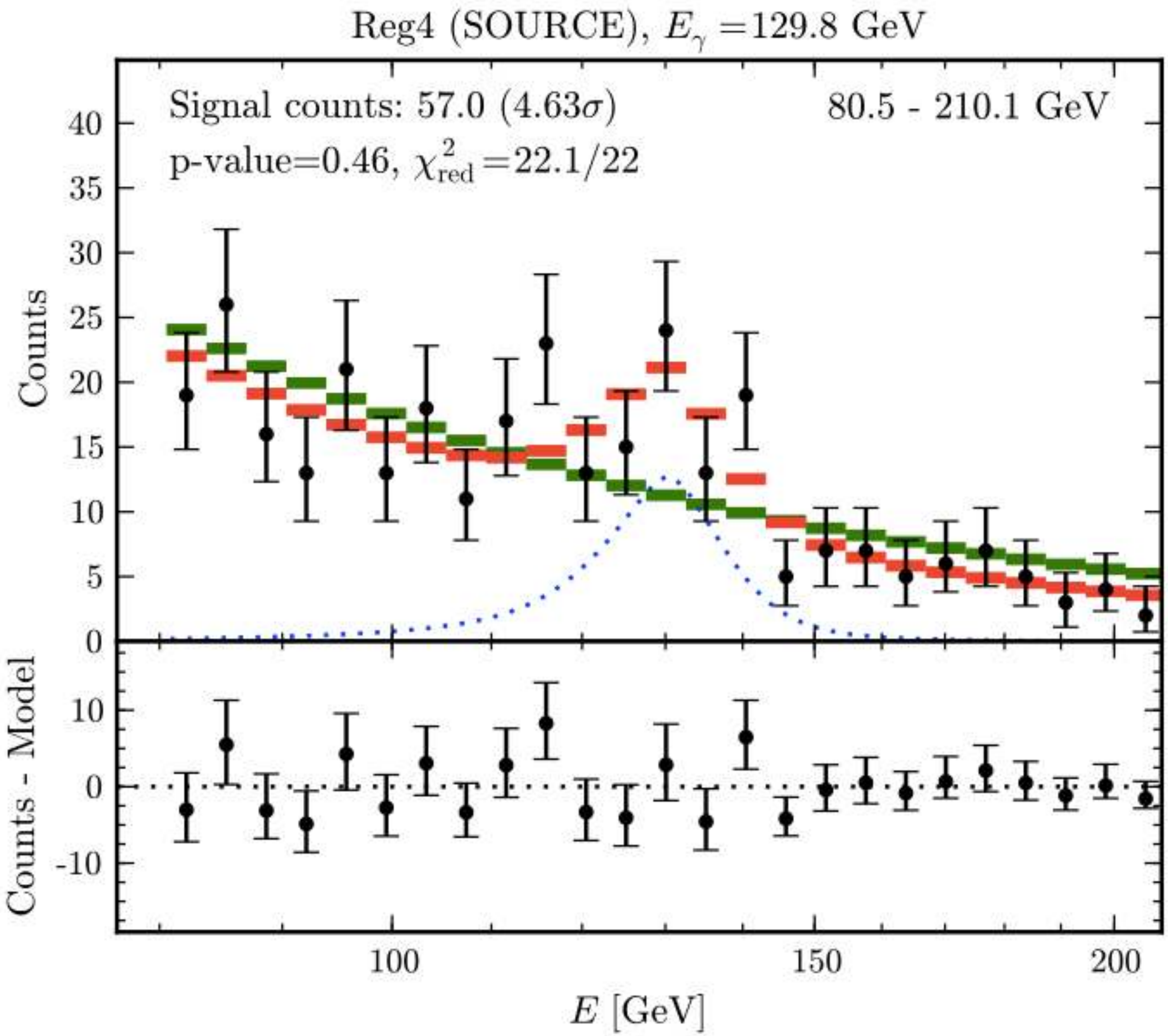


... before claiming Dark Matter

search in several,
theoretically suggested,
regions for
emission from DM



Indication of an emission line from the galactic centre at $E \approx 130$ GeV



4.6 σ (?)

Blob of emission from the galactic centre in the 120-140 GeV range

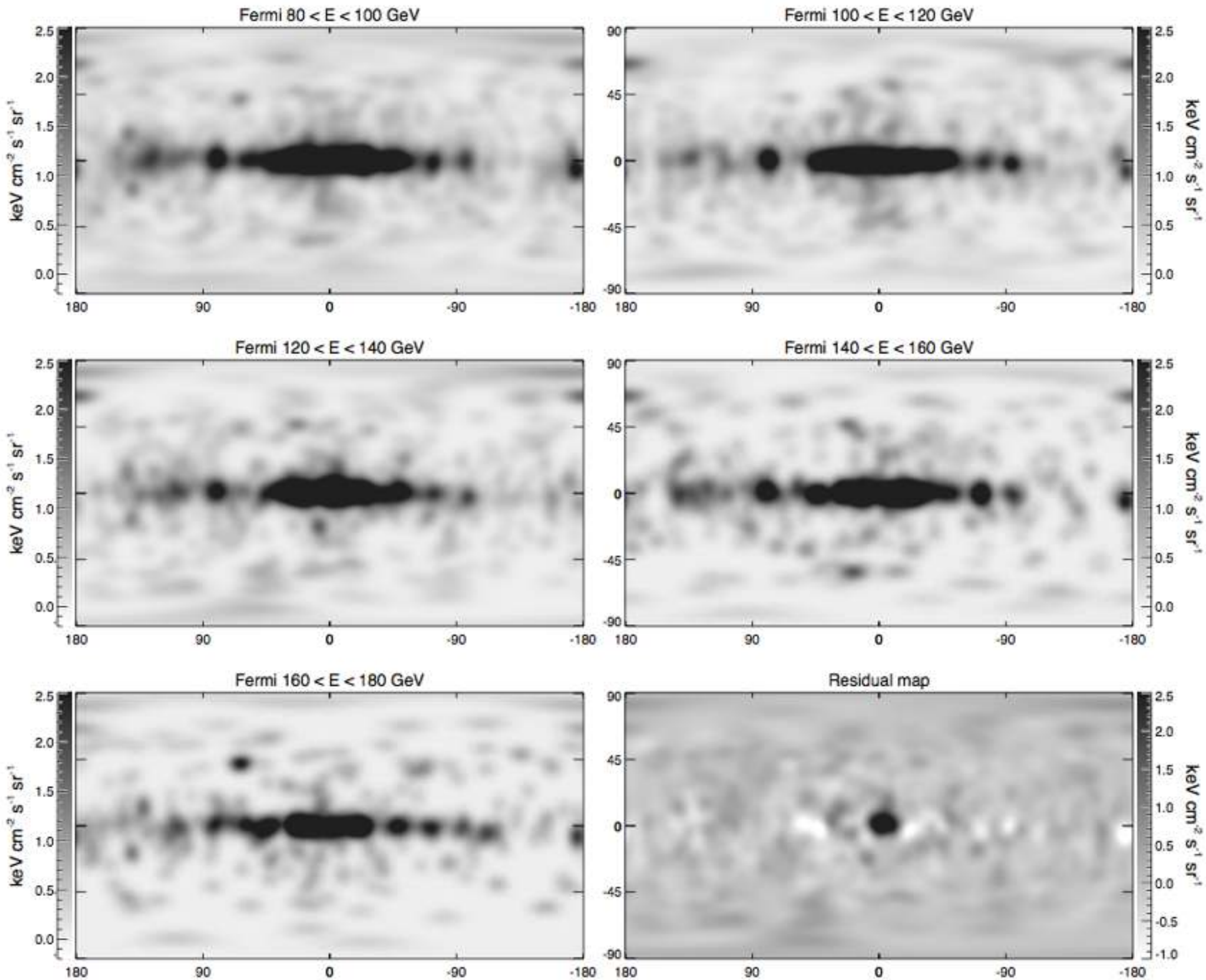
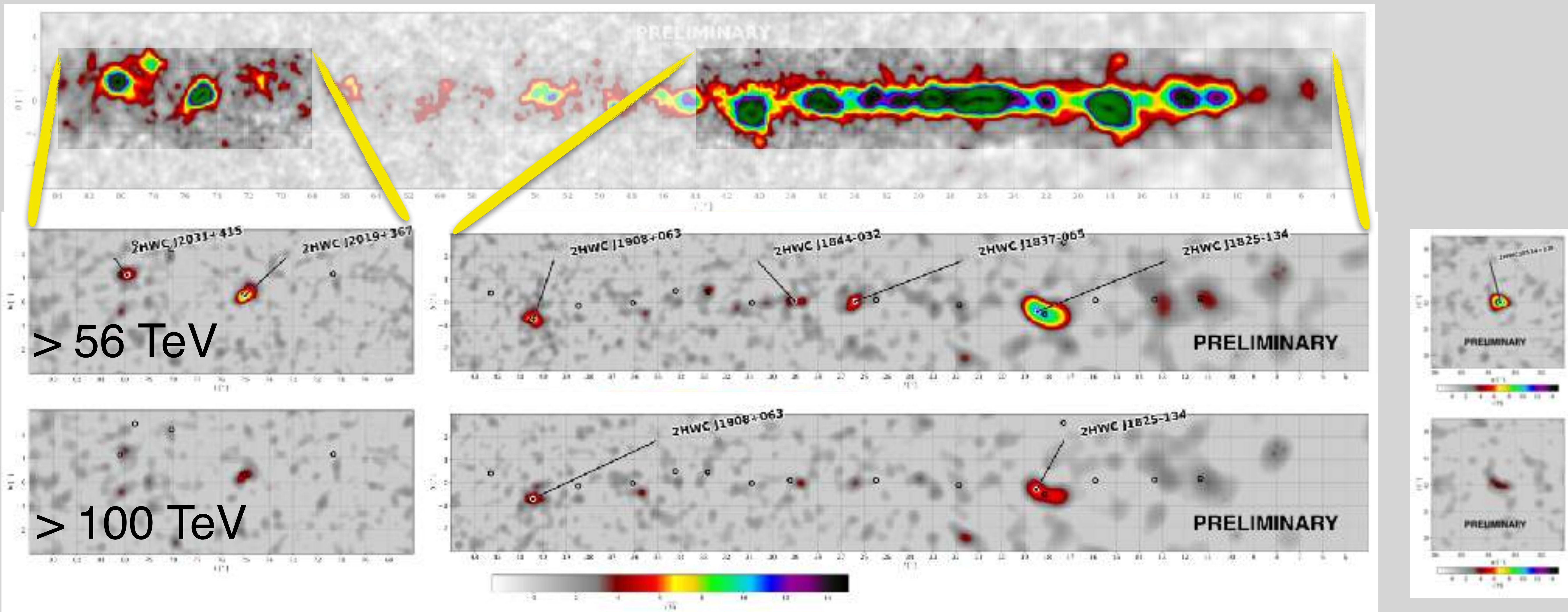


FIG. 3.— All-sky CLEAN 3.7 year maps in 5 energy bins, and a residual map (*lower right*). The residual map is the 120 – 140 GeV map minus a background estimate, taken to be the average of the other 4 maps where the average is computed in $E^2 dN/dE$ units. This simple

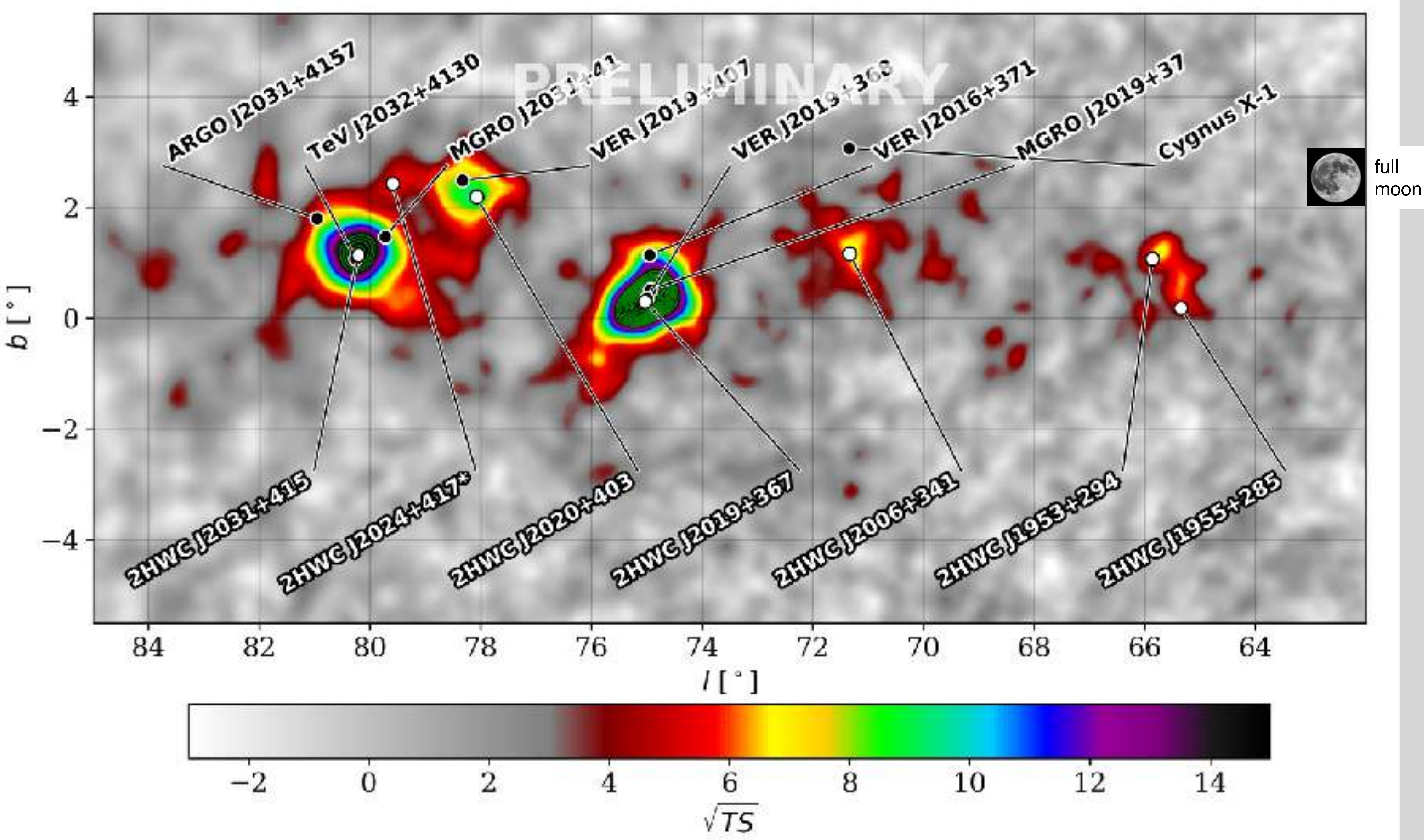
HAWC High Energy Catalog

7 candidate sources, energy > 56 TeV, energy spectra forth coming



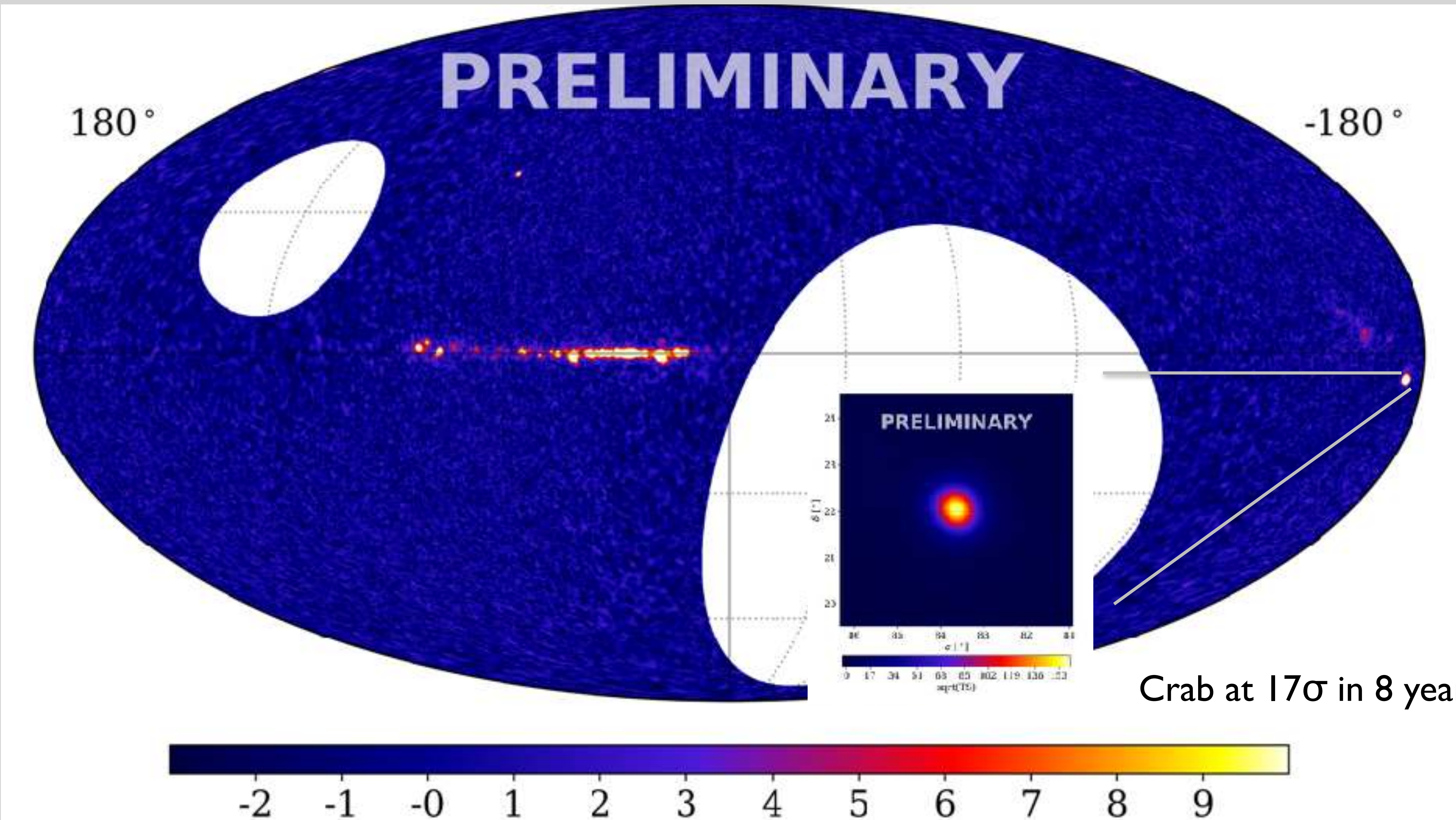
- Acceleration mechanisms: hadronic or leptonic?
- Correlation with neutrinos?
- Prospects for testing Lorentz Invariance Violation.

Multisource Fitting Example: Hunting for CR Acceleration in SFRs with HAWC



Latest Survey: HAWC 11/2014-04/2018

>39 candidate sources, pivot energy ~ 7 TeV

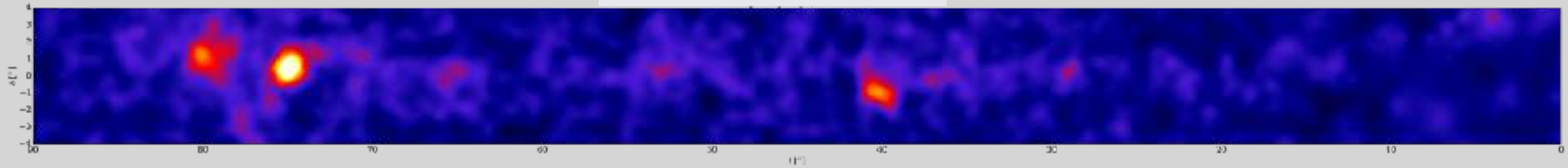


Crab at 17σ in 8 years.

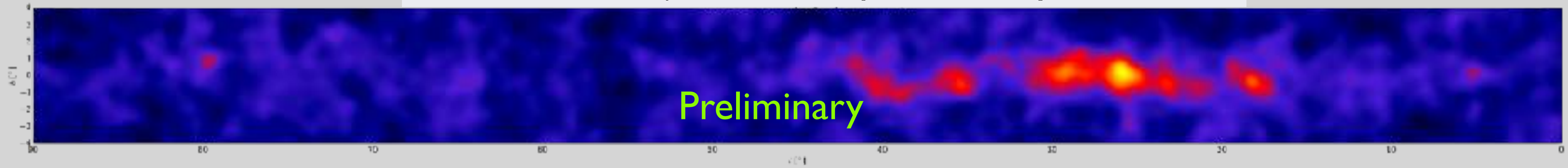
The Astrophysical Journal, Volume 843, Issue 1, article id. 40, 21 pp. (2017)

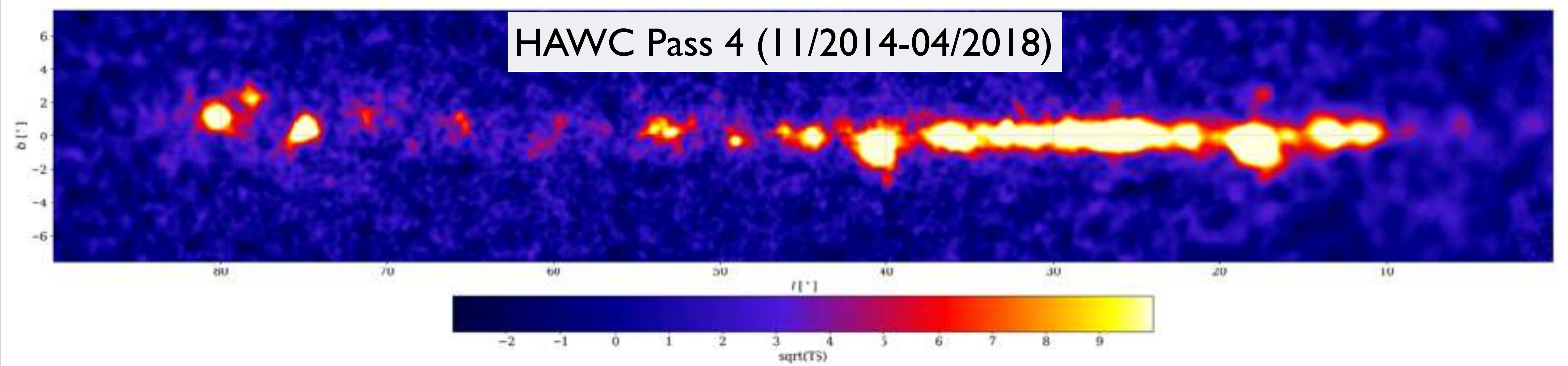
Galactic Plane Observations over the Years

Milagro (2000-2008)

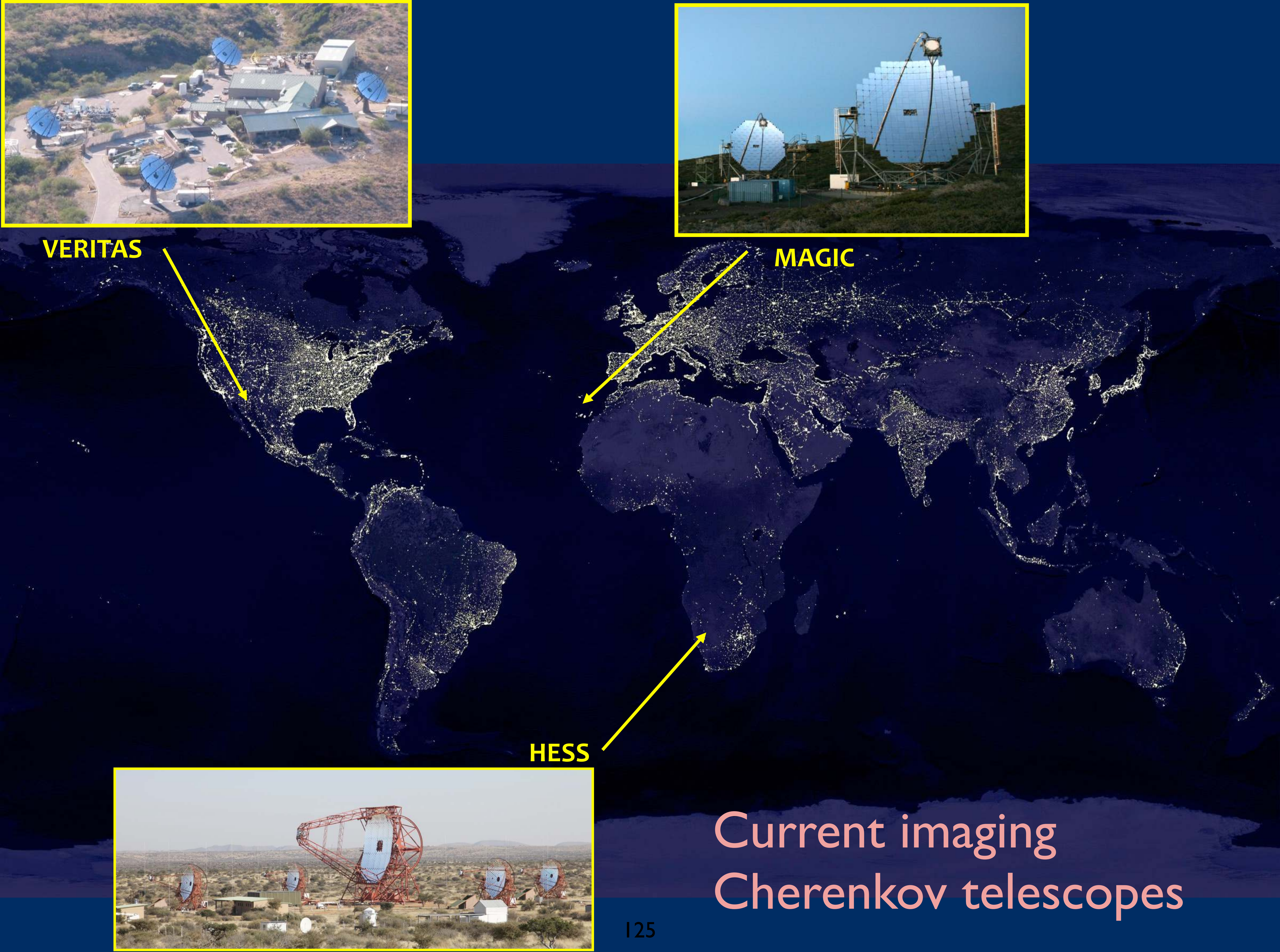


HAWC Pass 1 (2013-2014, partial array, candidates



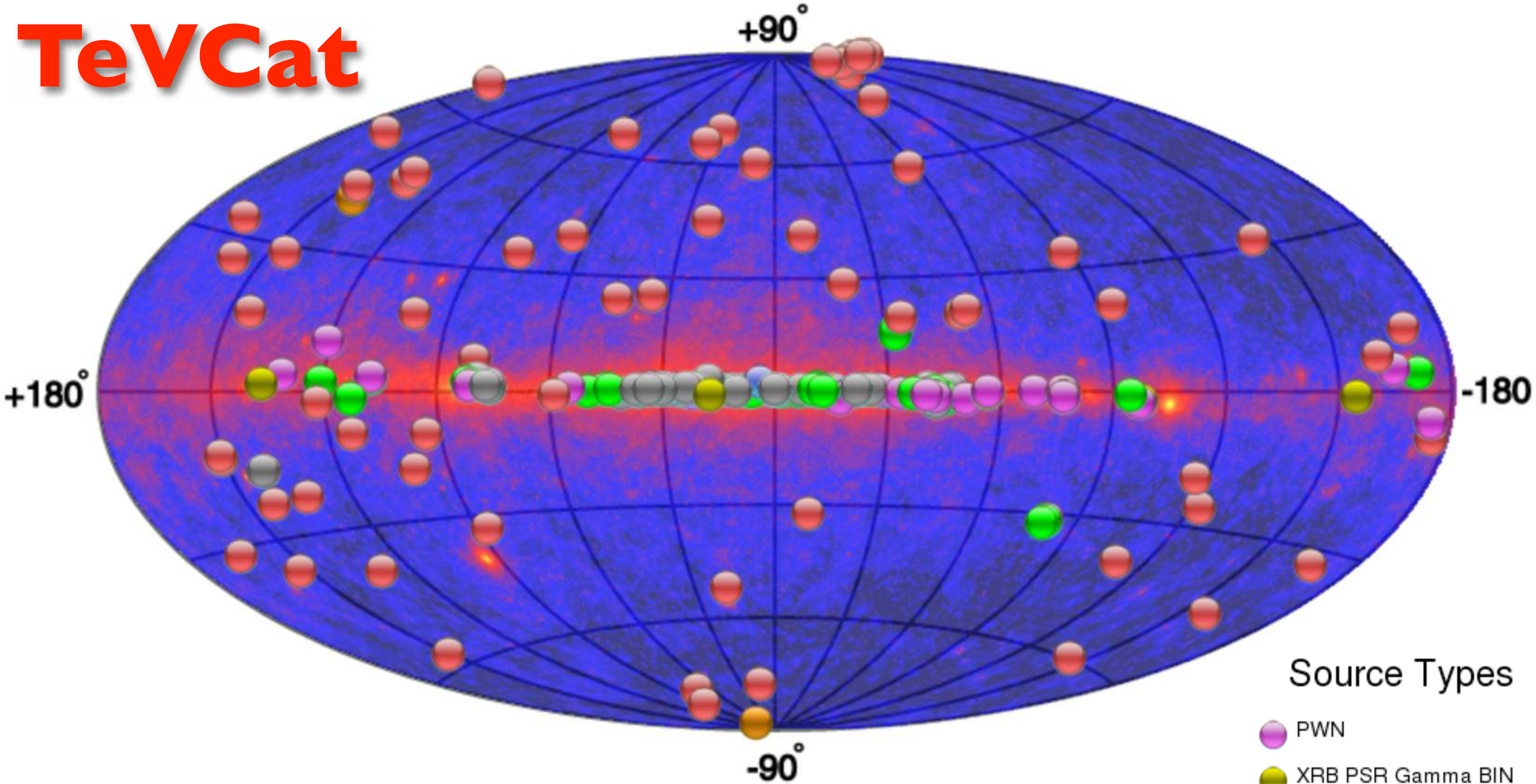


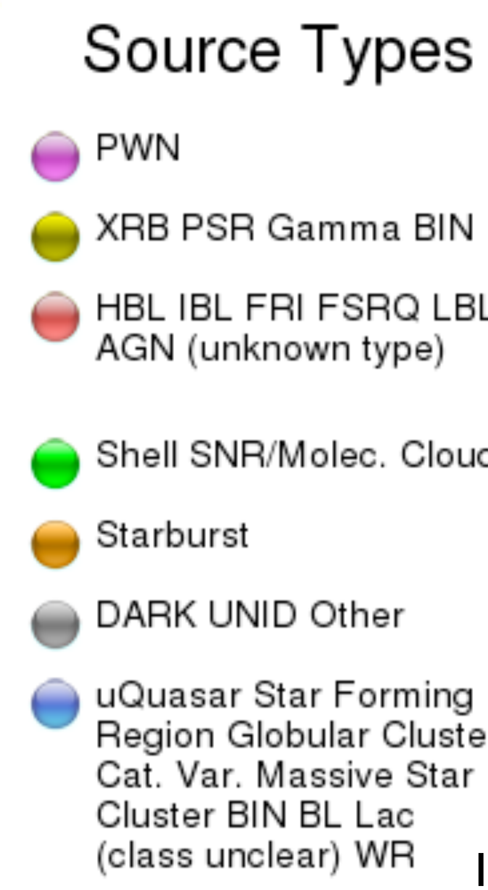
Milagro was located near Los Alamos, New Mexico
- different sensitivity by declination along Galactic plane.



Current imaging Cherenkov telescopes

TeVCat





background image:
Fermi sky map (MeV-GeV)

now: >200 sources (> 100 GeV)
gal. / extragal. / unid.

gamma ray emission is present
wherever there are shocks and relativistic flows

TeV astronomy highlights

from **HESS, MAGIC** and **VERITAS**
Descartes & Rossi Prize for HESS

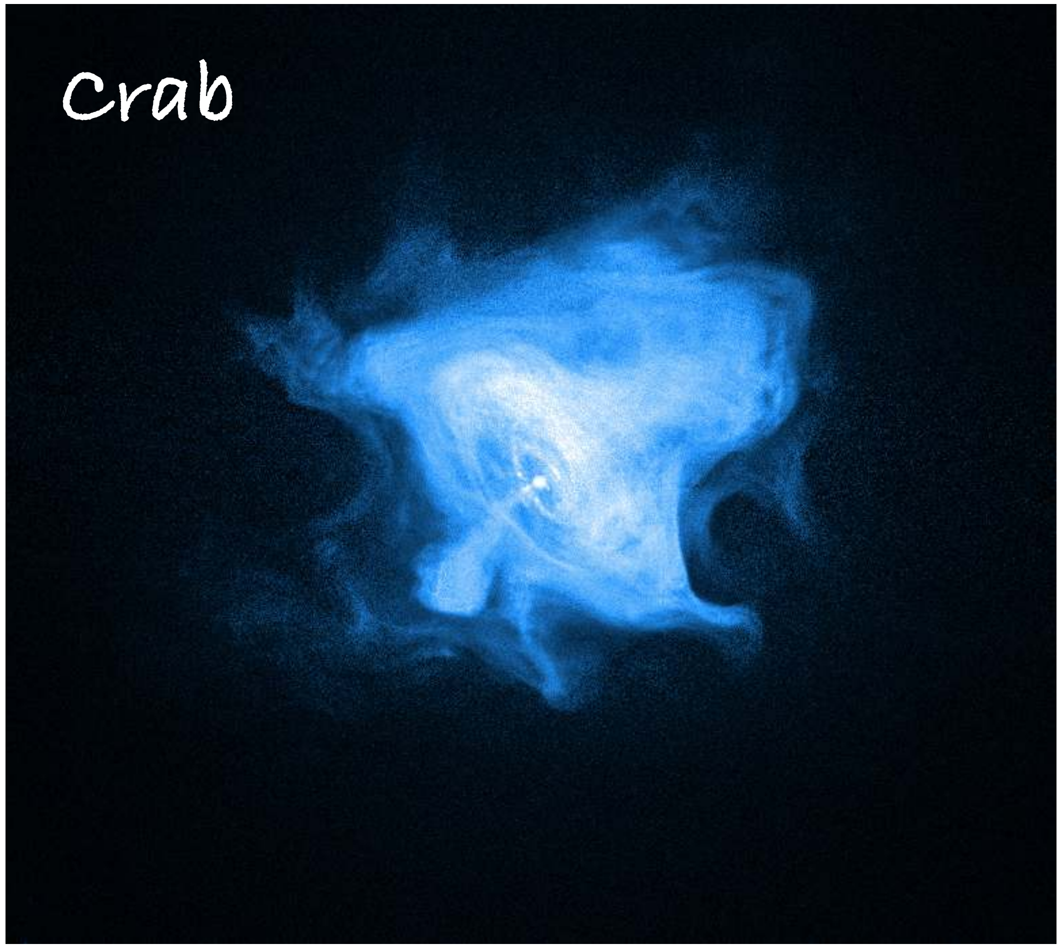
Supernova remnants:	Nature	432 (2004) 75		
Microquasars:	Science	309 (2005) 746	Science	312 (2006) 1771
Pulsars:	Science	322 (2008) 1221	Science	334 (2011) 69
Galactic Centre:	Nature	439 (2006) 695	Nature	531 (2016) 476
Galactic Survey:	Science	307 (2005) 1839		
LMC:	Science	347 (2015) 406		
Black Holes:	Science	346 (2014) 1080		
Starbursts:	Nature	462 (2009) 770	Science	326 (2009) 1080
Active Galactic Nuclei:	Science	314 (2006) 1424	Science	325 (2009) 444
EBL:	Nature	440 (2006) 1018	Science	320 (2008) 752
Dark Matter:	PRL	96 (2006) 221102	PRL	106 (2011) 161301
	PRL	114 (2015) 081301	PRL	110 (2013) 41301
Lorentz Invariance:	PRL	101 (2008) 170402		
Cosmic Ray Electrons:	PRL	101 (2008) 261104		

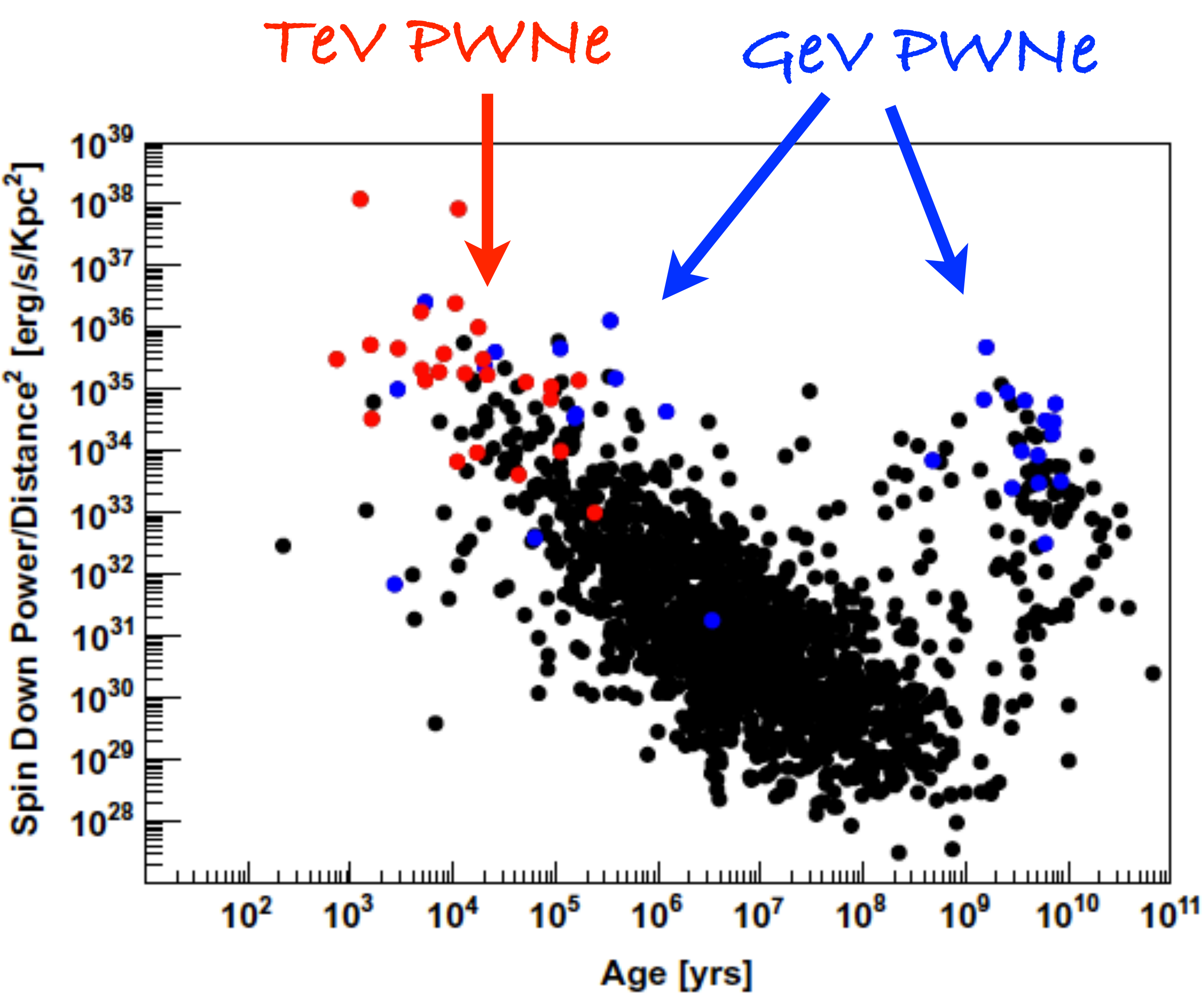
+ many papers in other journals
… a booming field.

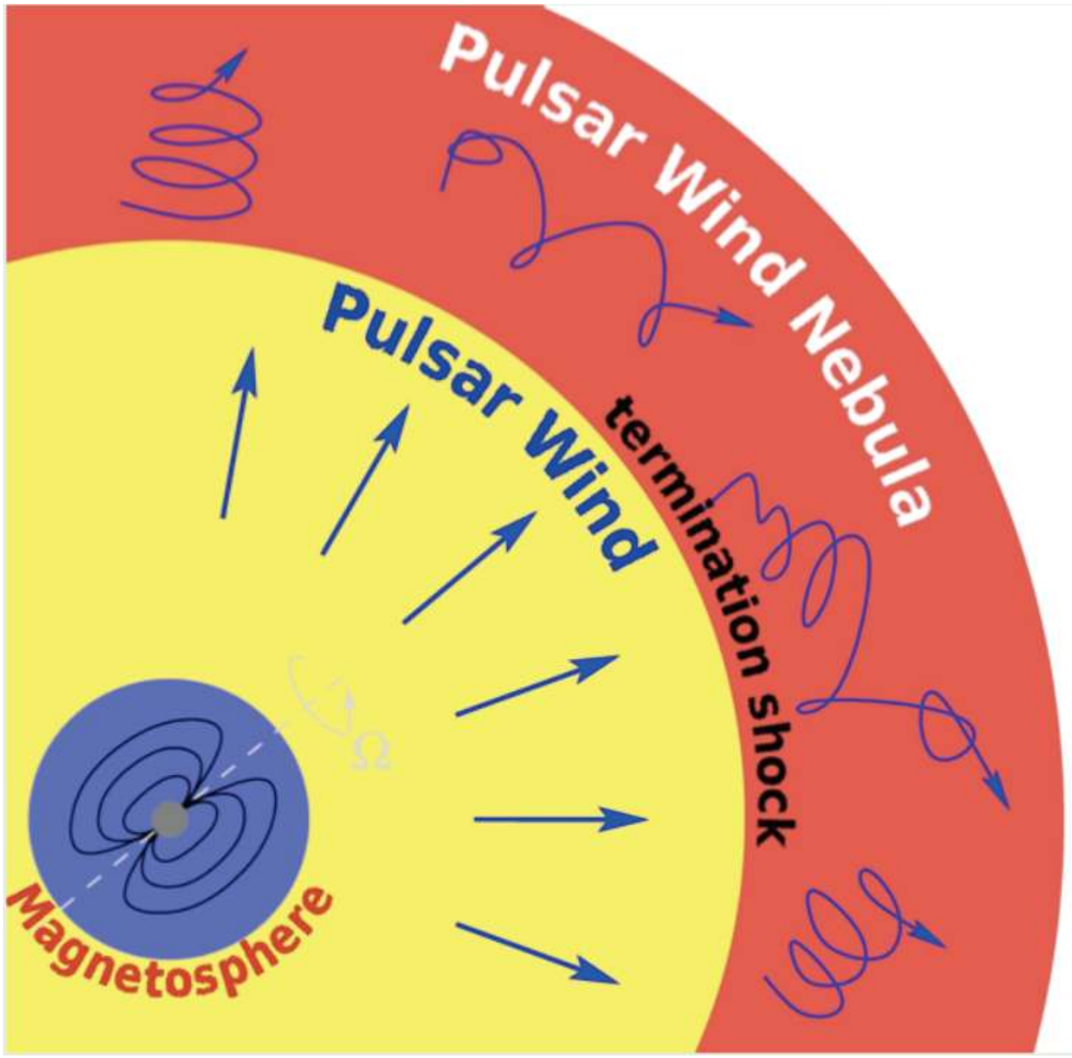
~30 pulsar wind nebulae (PWN)

young (~10 ky) pulsars with large spin-down power
magnetised relativistic winds

morphology
SED: GeV - TeV connection
SNR - PWN connection
electron cooling
population studies

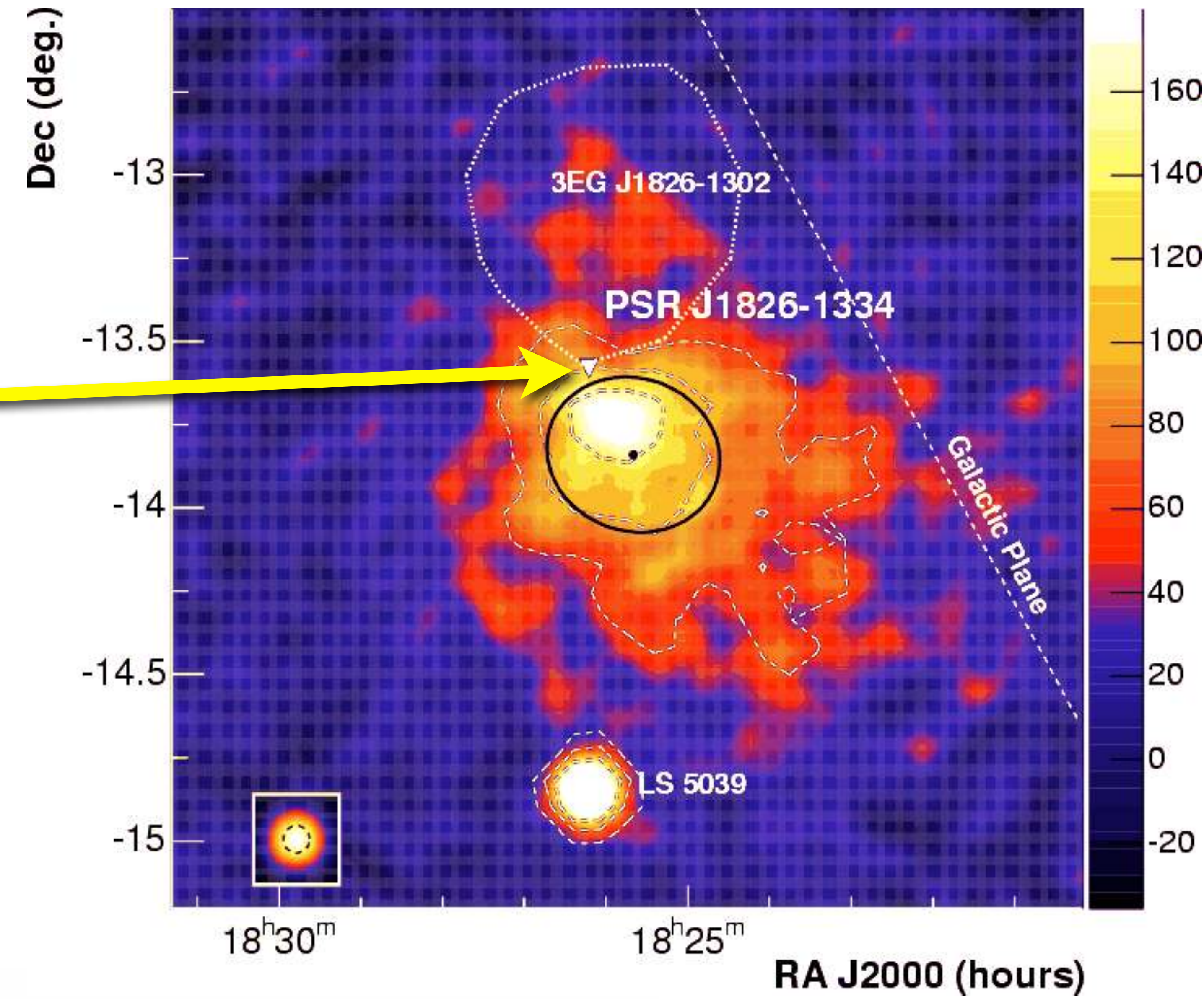




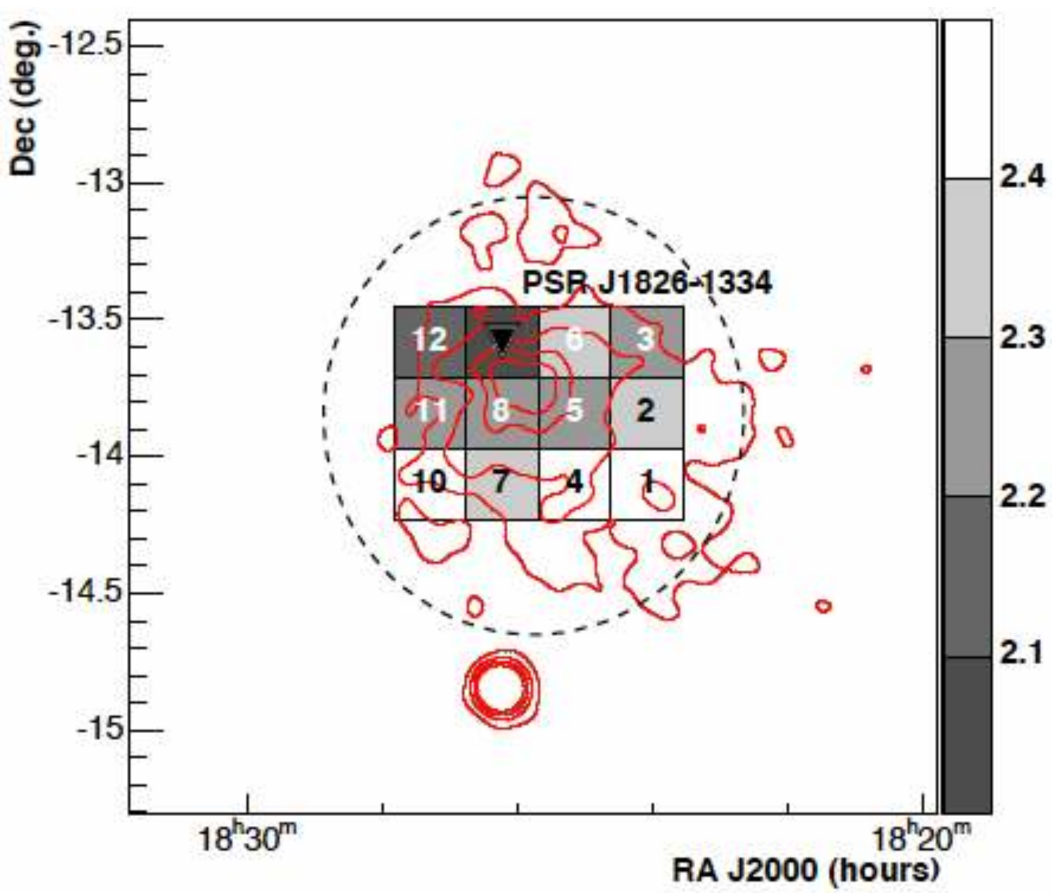


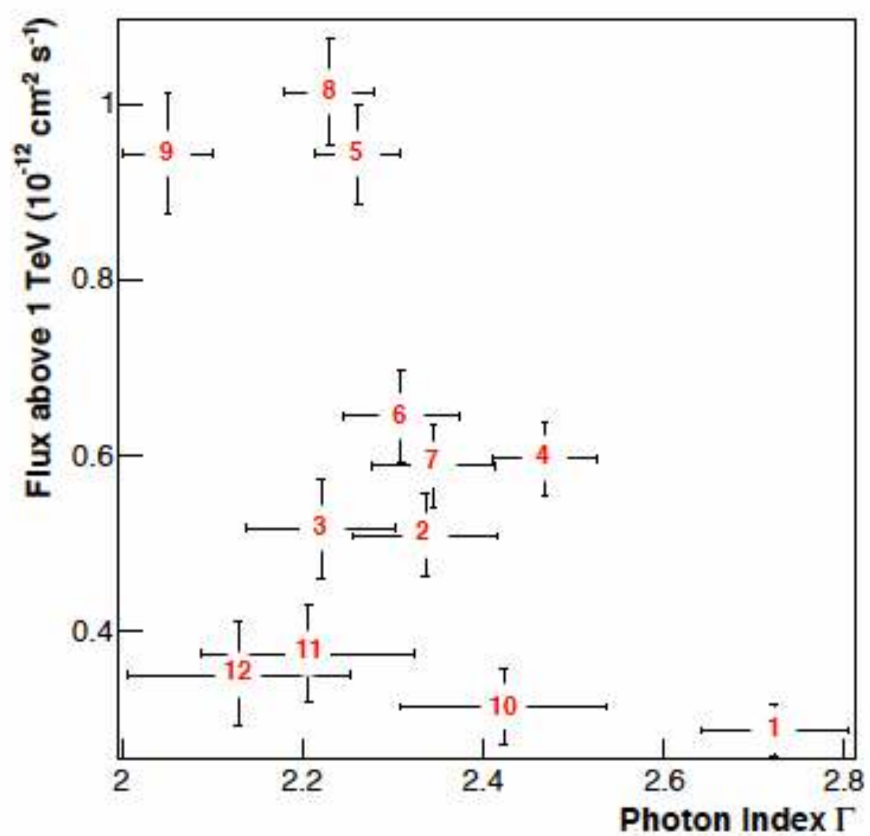
e.g. HESS J1825-137

source of wind

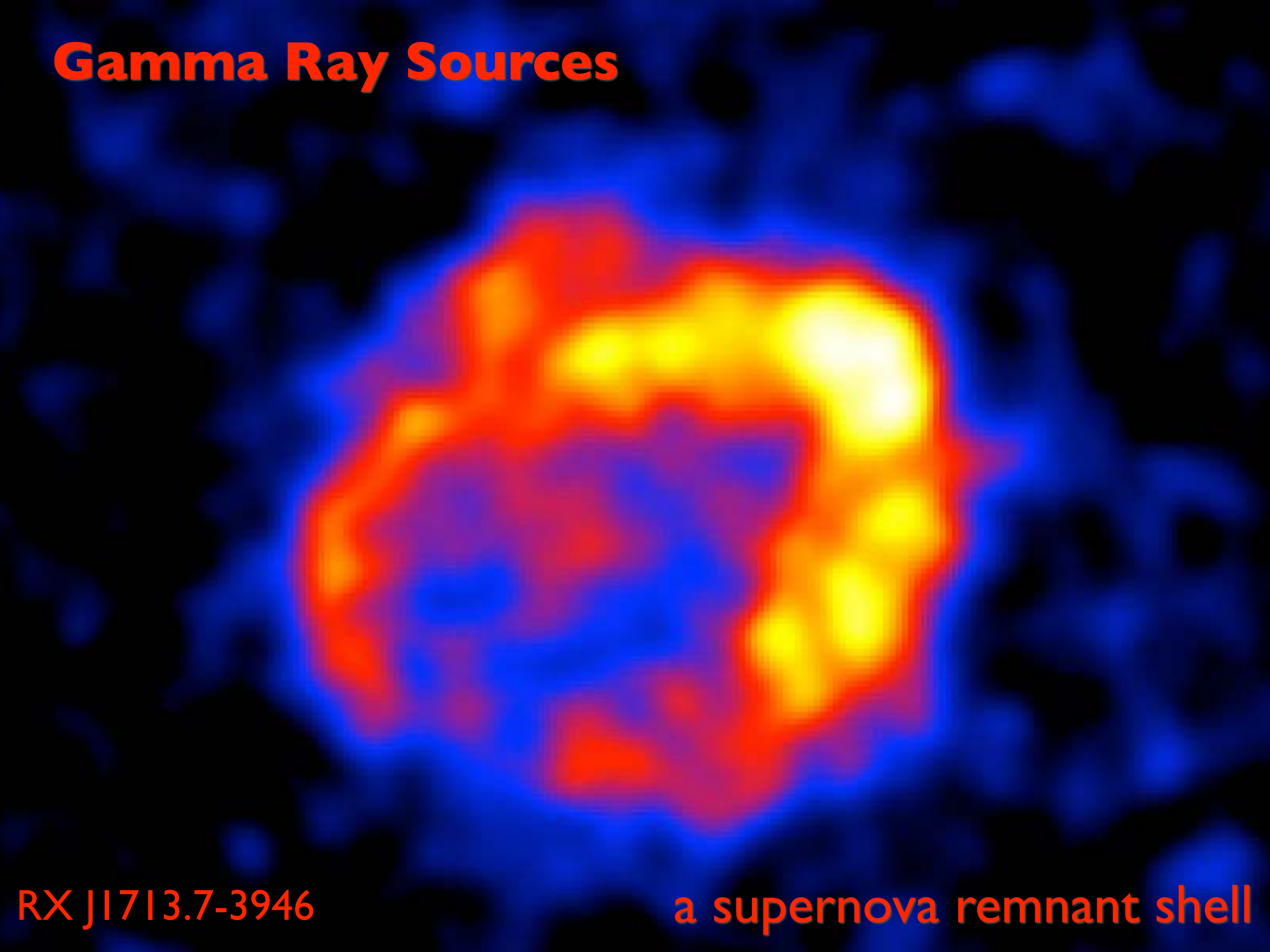


270 GeV to 35 TeV

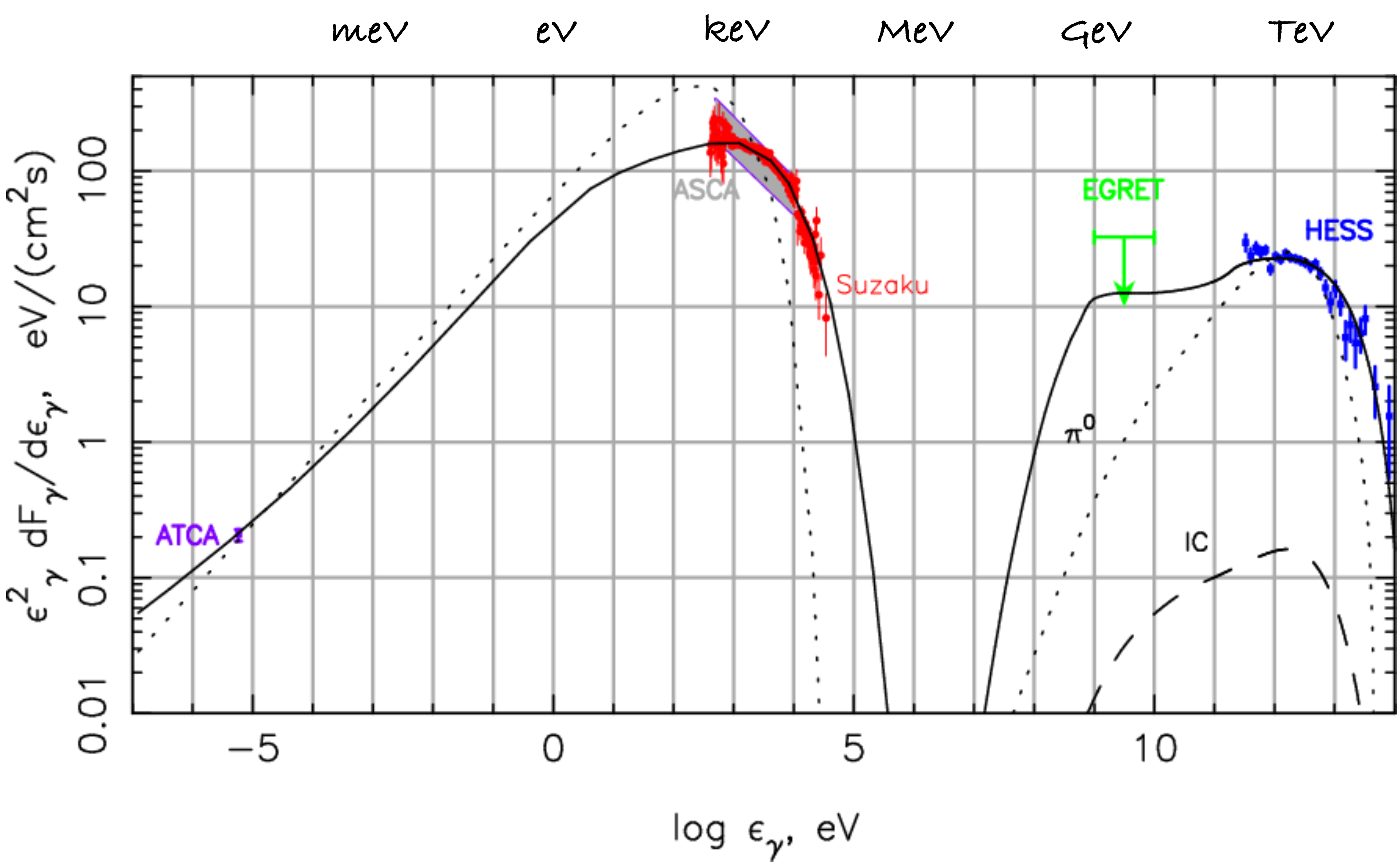




spatially resolved spectra

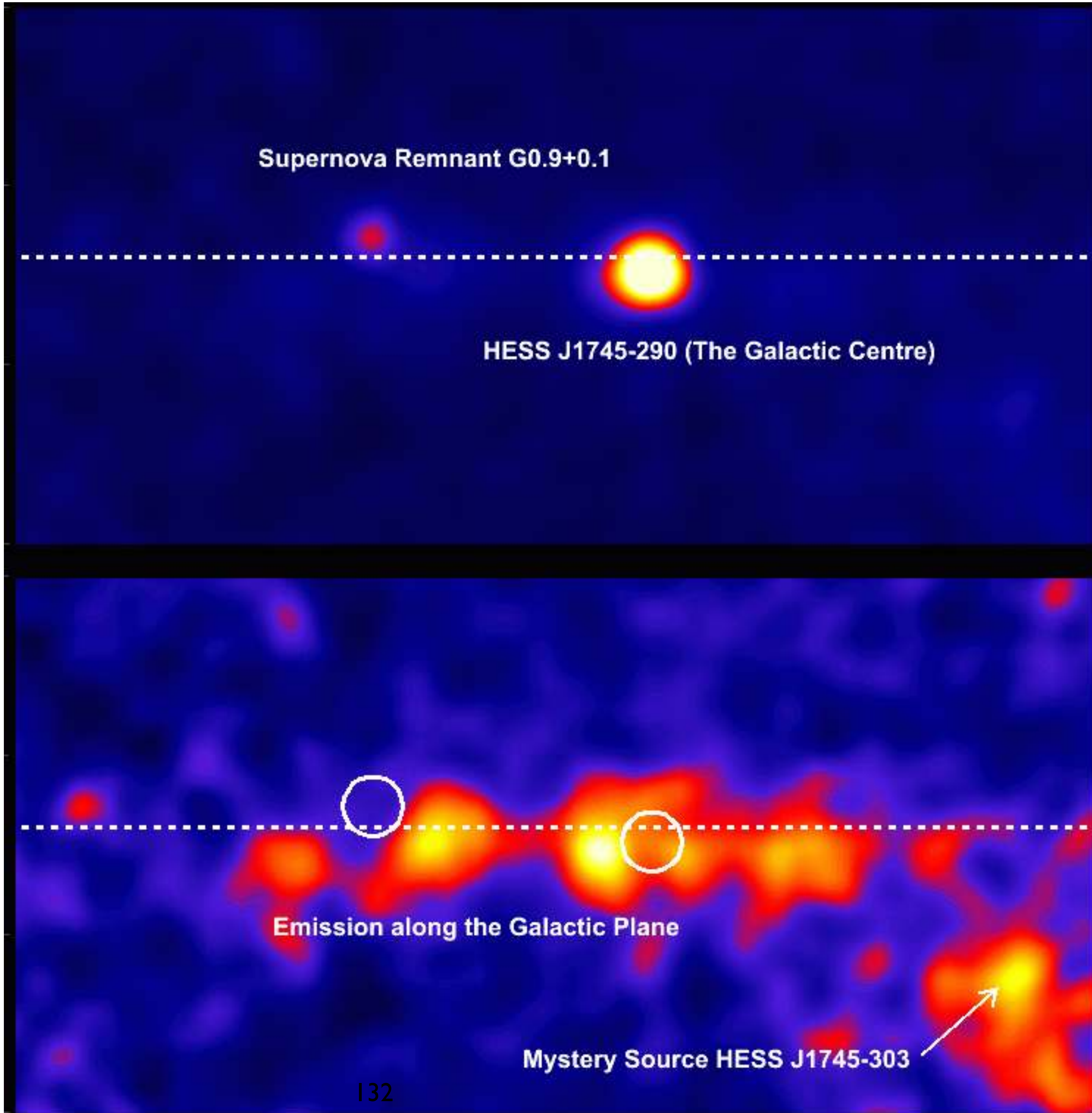

Gamma Ray Sources
RX J1713.7-3946
a supernova remnant shell

Supernova Remnant RX J1713.7-3946



HESS:
gal. centre

CRs with
mol. clouds



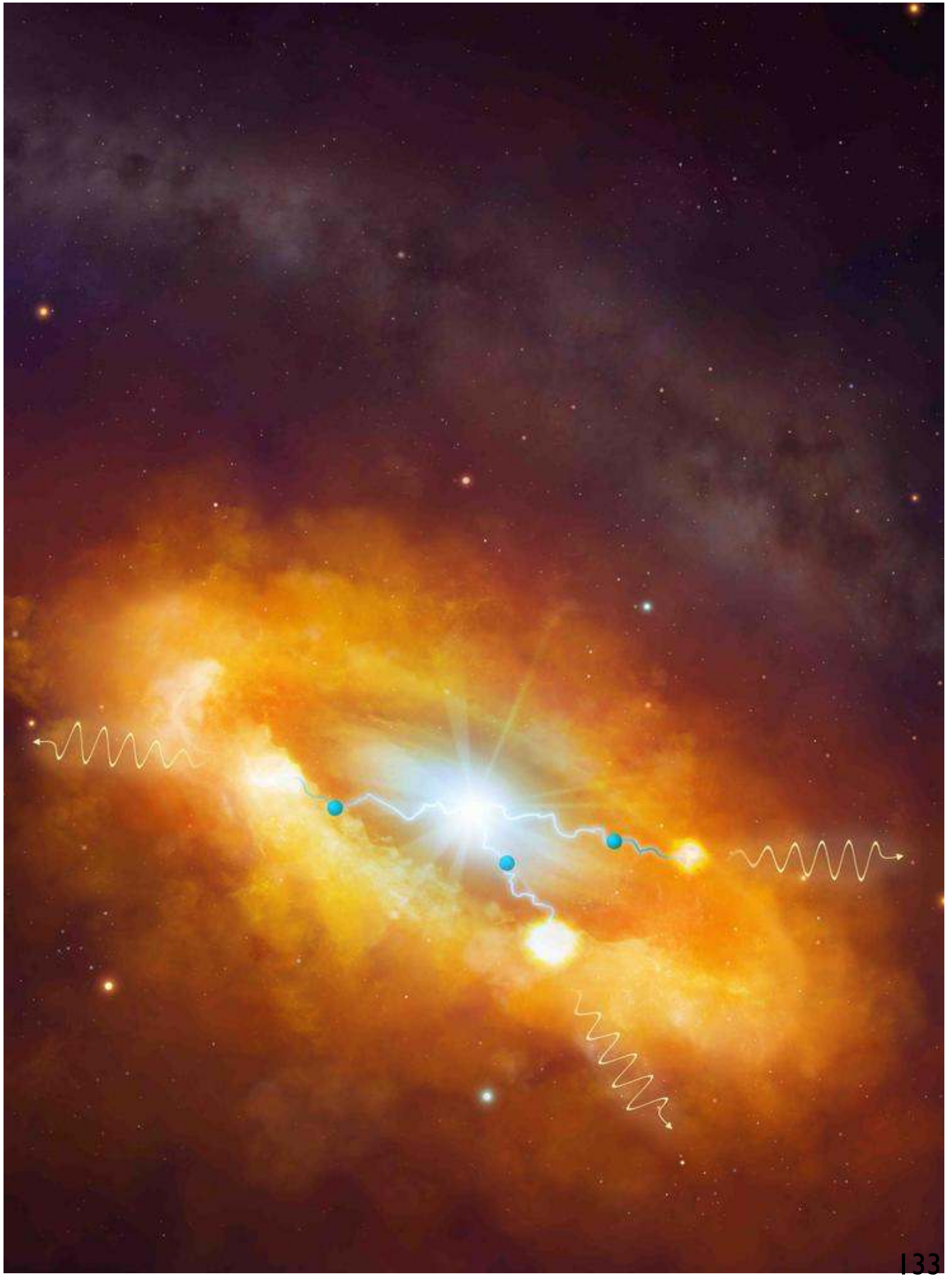
A PeV-atron in the Galactic centre

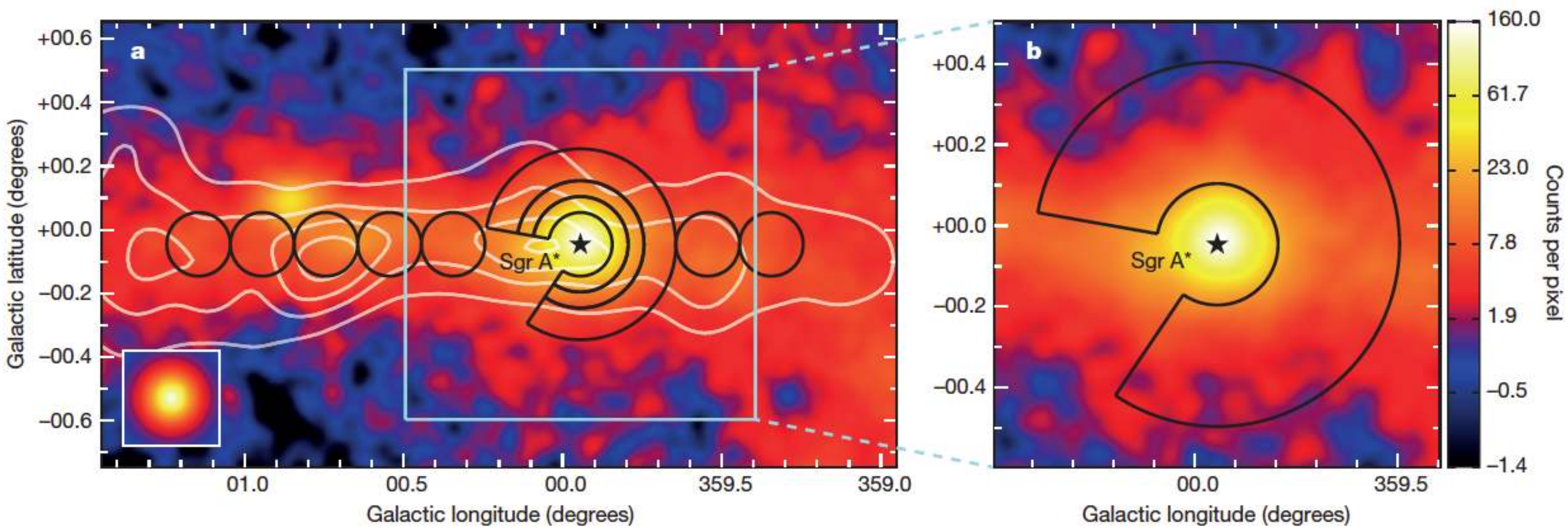
Nature 531, 476-479 (2016

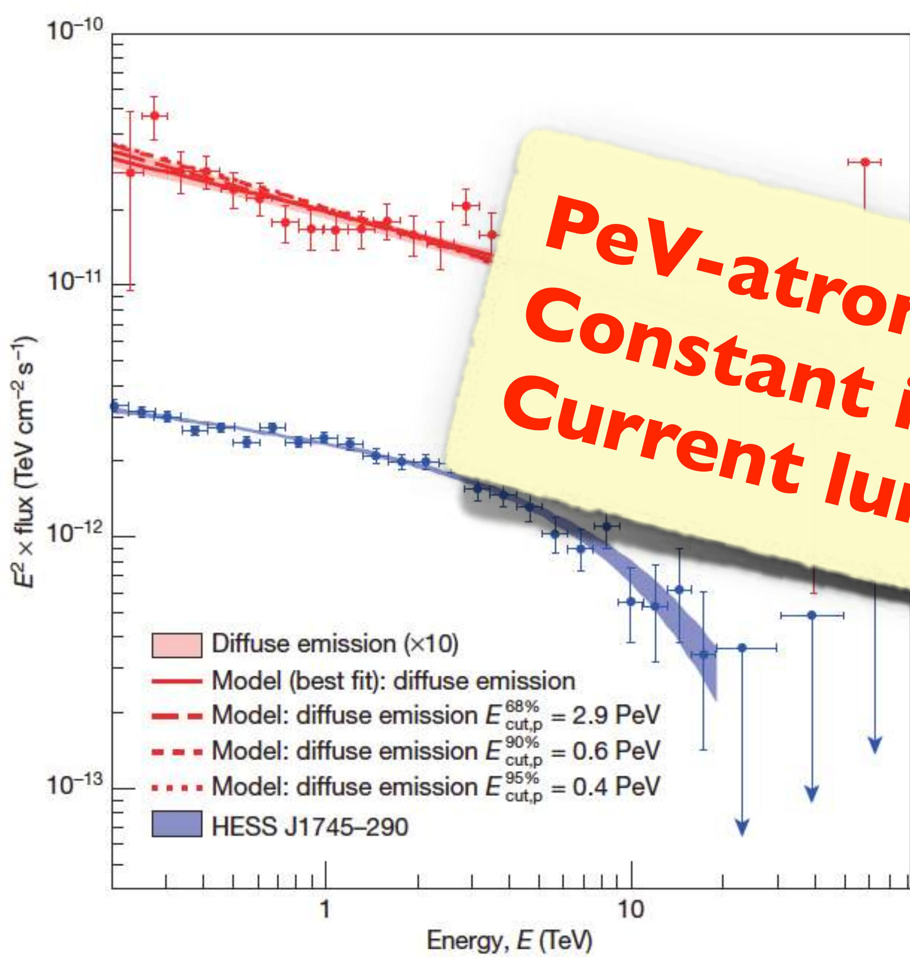
H.E.S.S. 2016:
diffuse emission in
Galactic Centre Ridge region

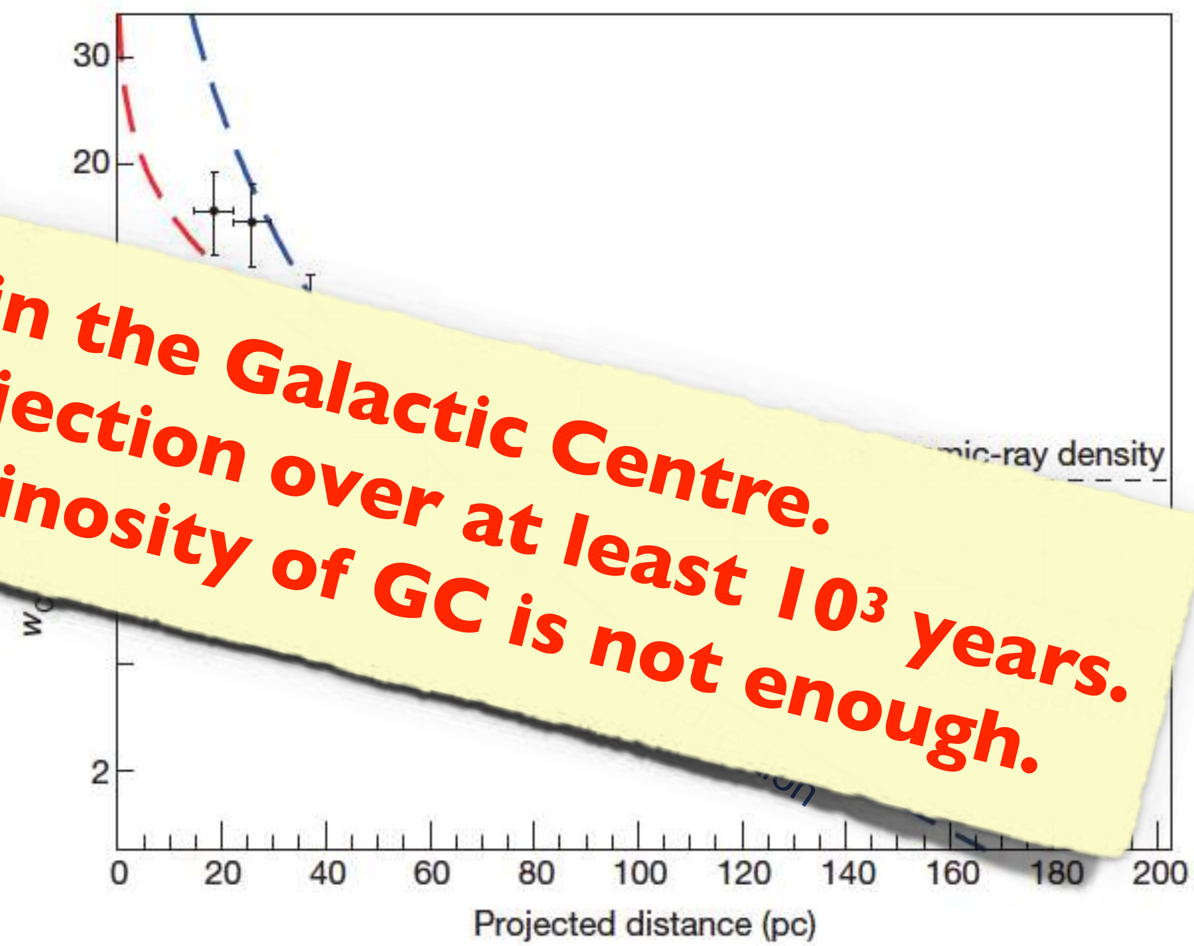
Presence of protons of ≈ 10^{15} eV

Dataset: 2004 - 2015





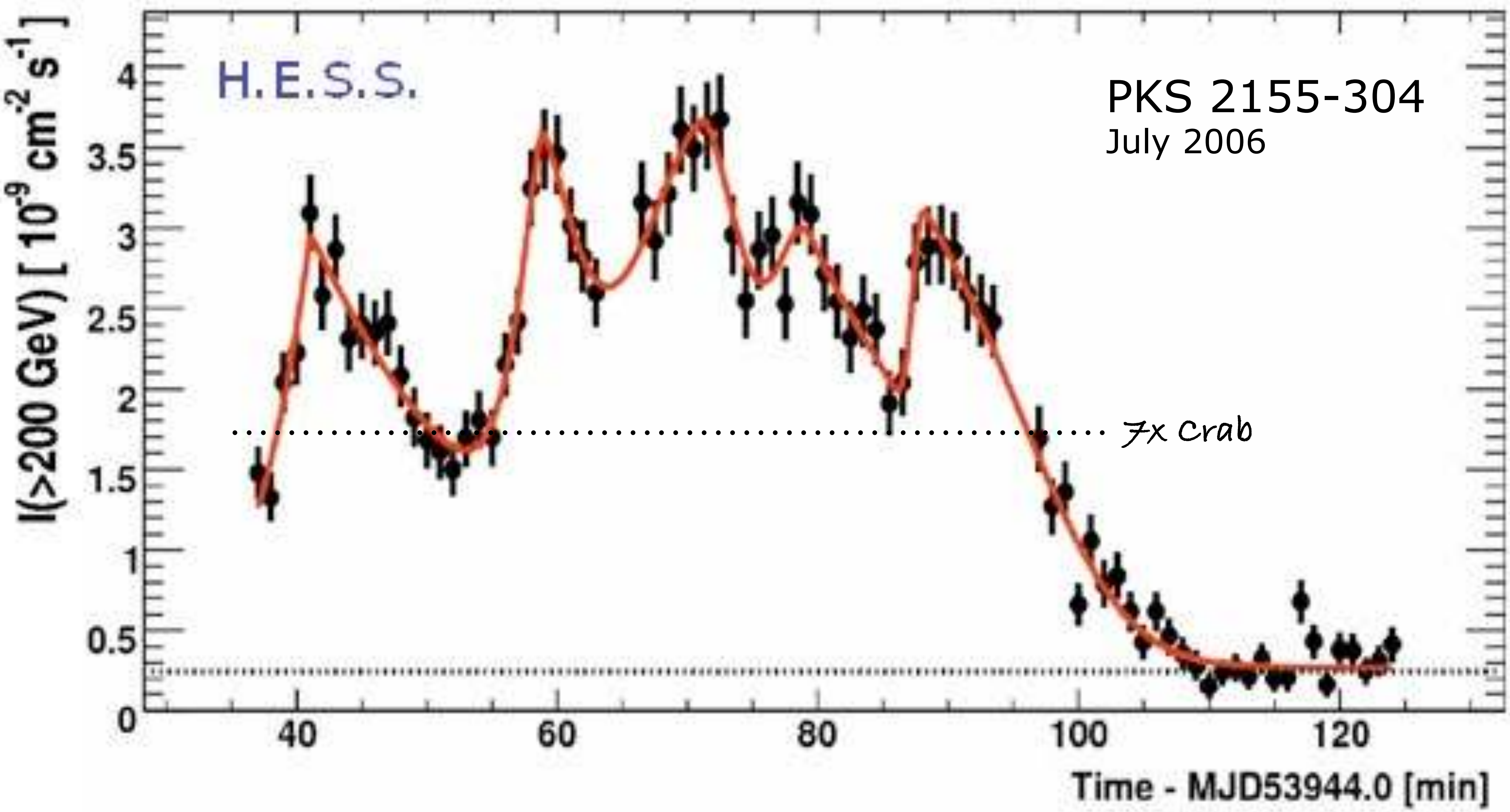




PeV-atron in the Galactic Centre.
Constant injection over at least 10^3 years.
Current luminosity of GC is not enough.

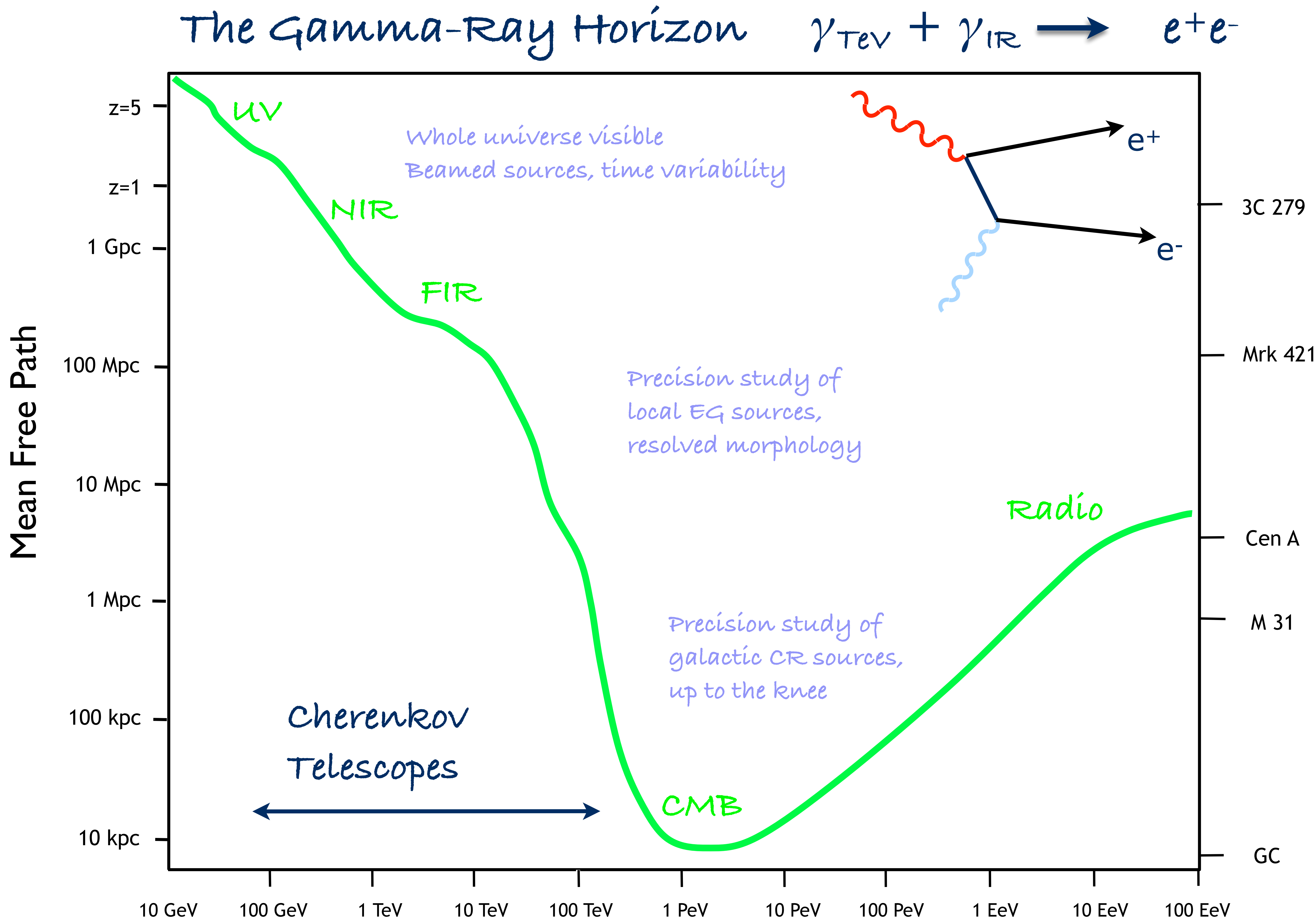
Very hard emission, no cutoff, untypical for extended emission

Cosmic ray density profile using matter densities from molecular line surveys.

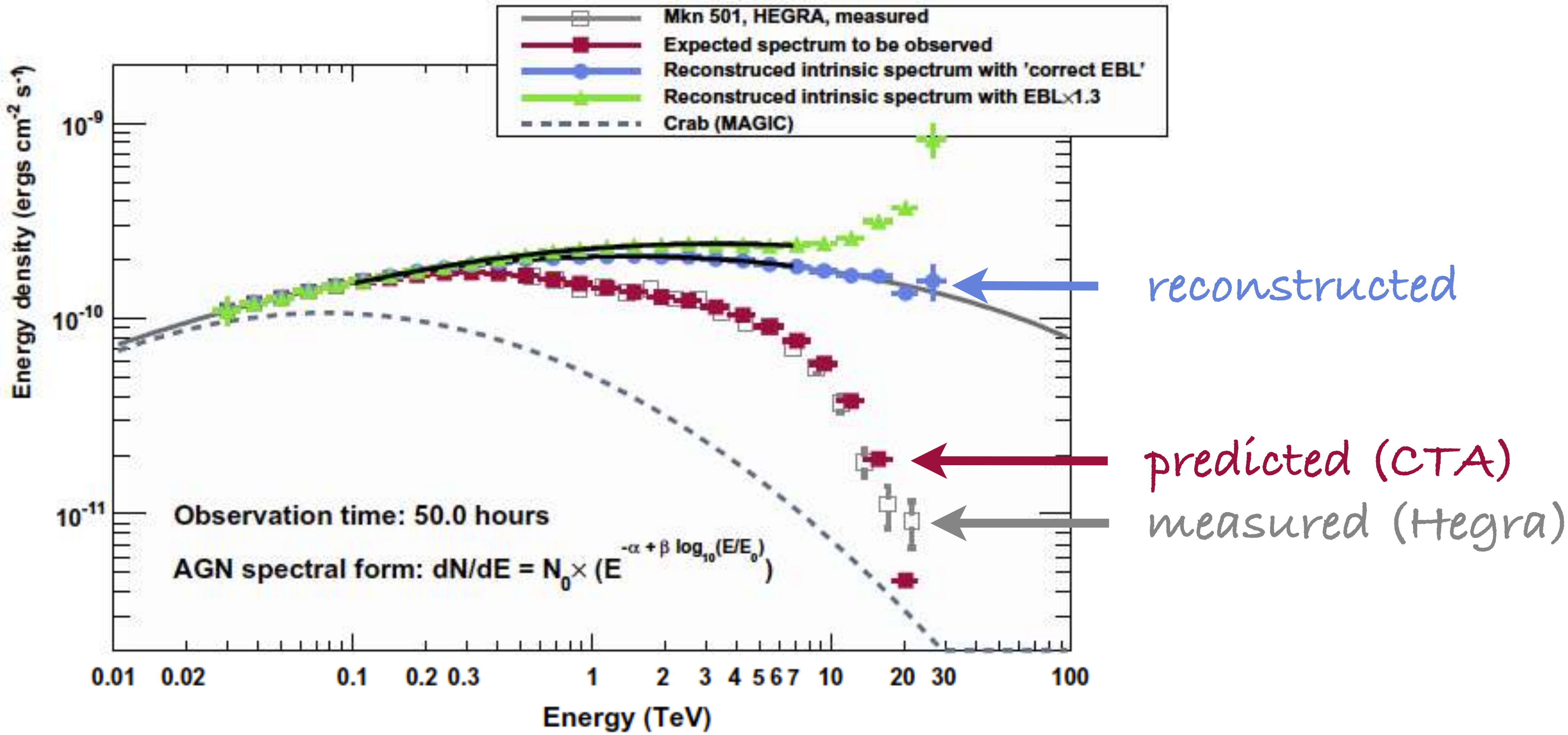


BL Lac object $z = 0.116$
bursts on minute scales
$\Gamma \geq 100$ are required

Extragalactic Background light

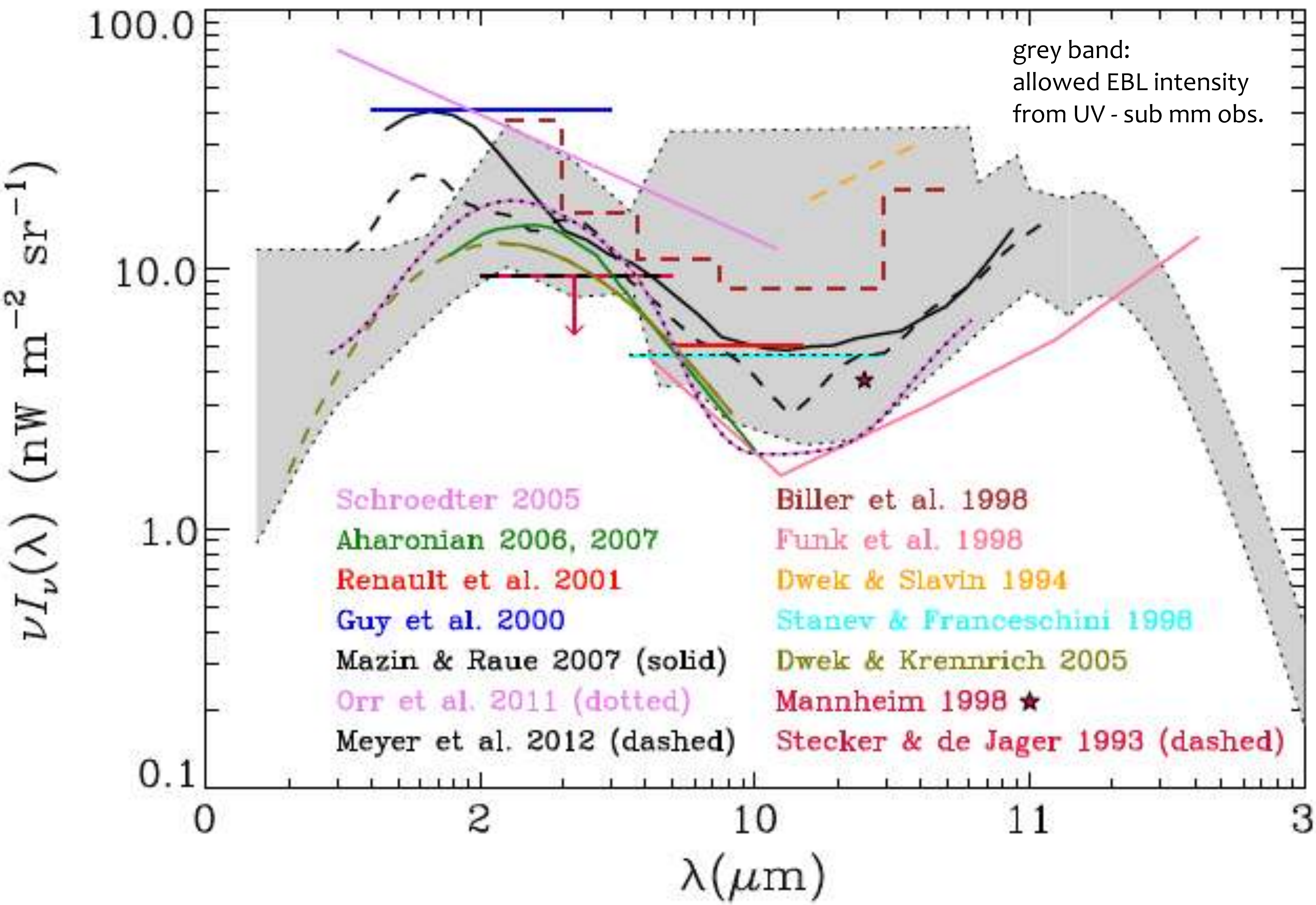


Mazin et al. 2012



analyse absorption features in the spectra of distant sources.

Dwek & Krennrich 2012



universe is surprisingly transparent.

Gamma Rays are ubiquitous:

many sources / source types
complex structures in space, time and energy

test extreme end of high-energy phenomena
complement observations at longer wavelengths
with other particles

The Imaging Atmospheric Cherenkov technique
is not yet at its limit:

Big improvements are possible with existing technology.

Science Scope:

Cosmic energetic particles

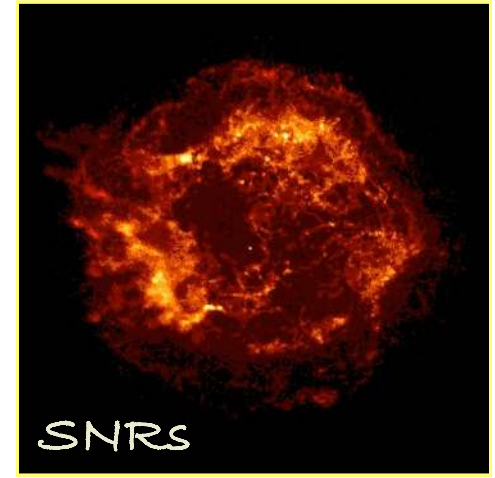
- Origin of the galactic cosmic rays
  - Also UHECR signatures
- Role of ultra-relativistic particles in in clusters of galaxies, AGN, Starbursts…
- The physics of (relativistic) jets and shocks

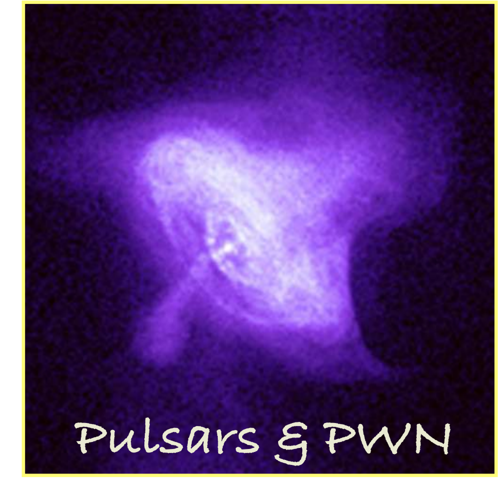
Fundamental Physics

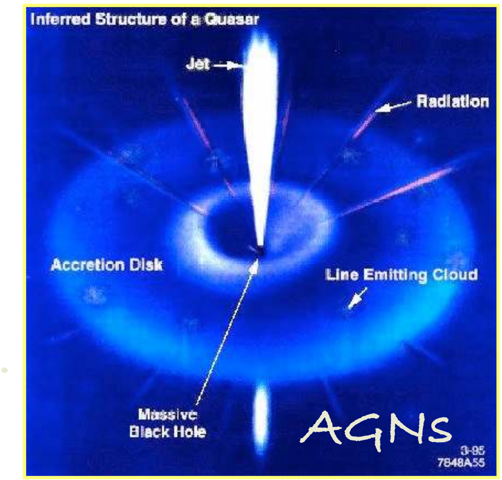
- Dark Matter annihilation / decay
- Lorentz Invariance violation

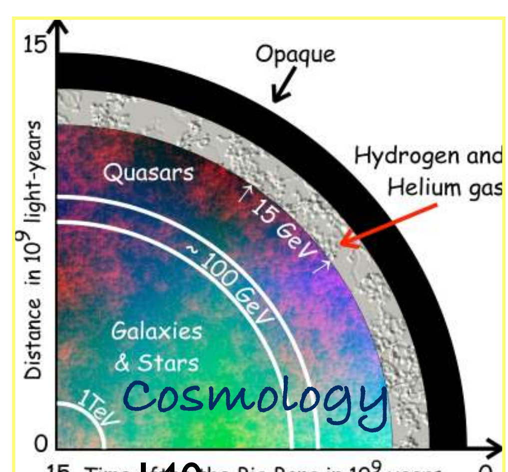
Cosmology

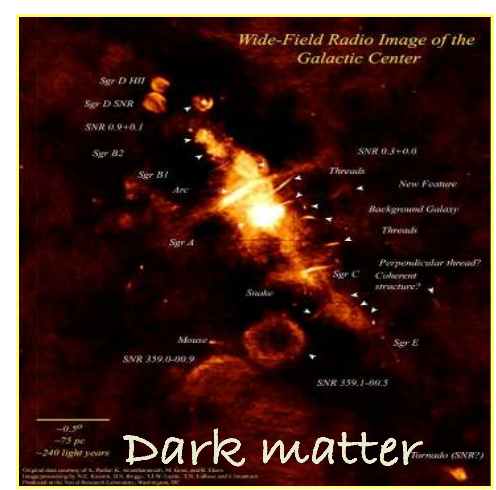
- cosmic FIR-UV radiation,
- cosmic magnetism

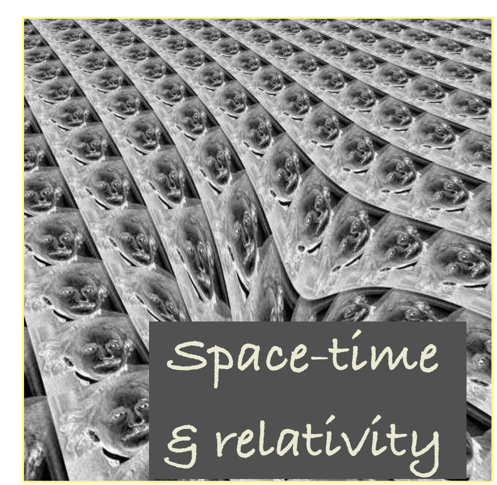












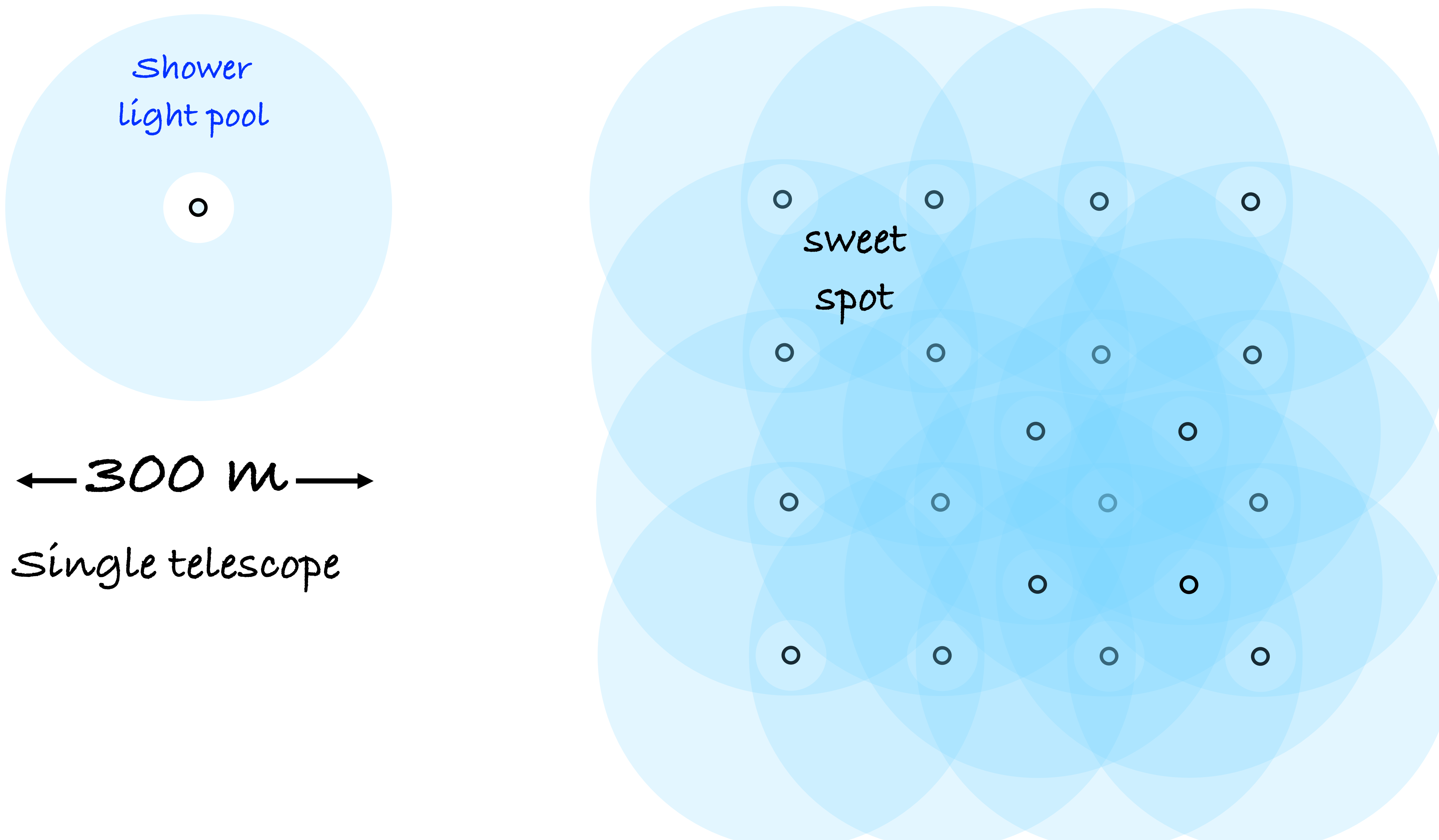
The future with

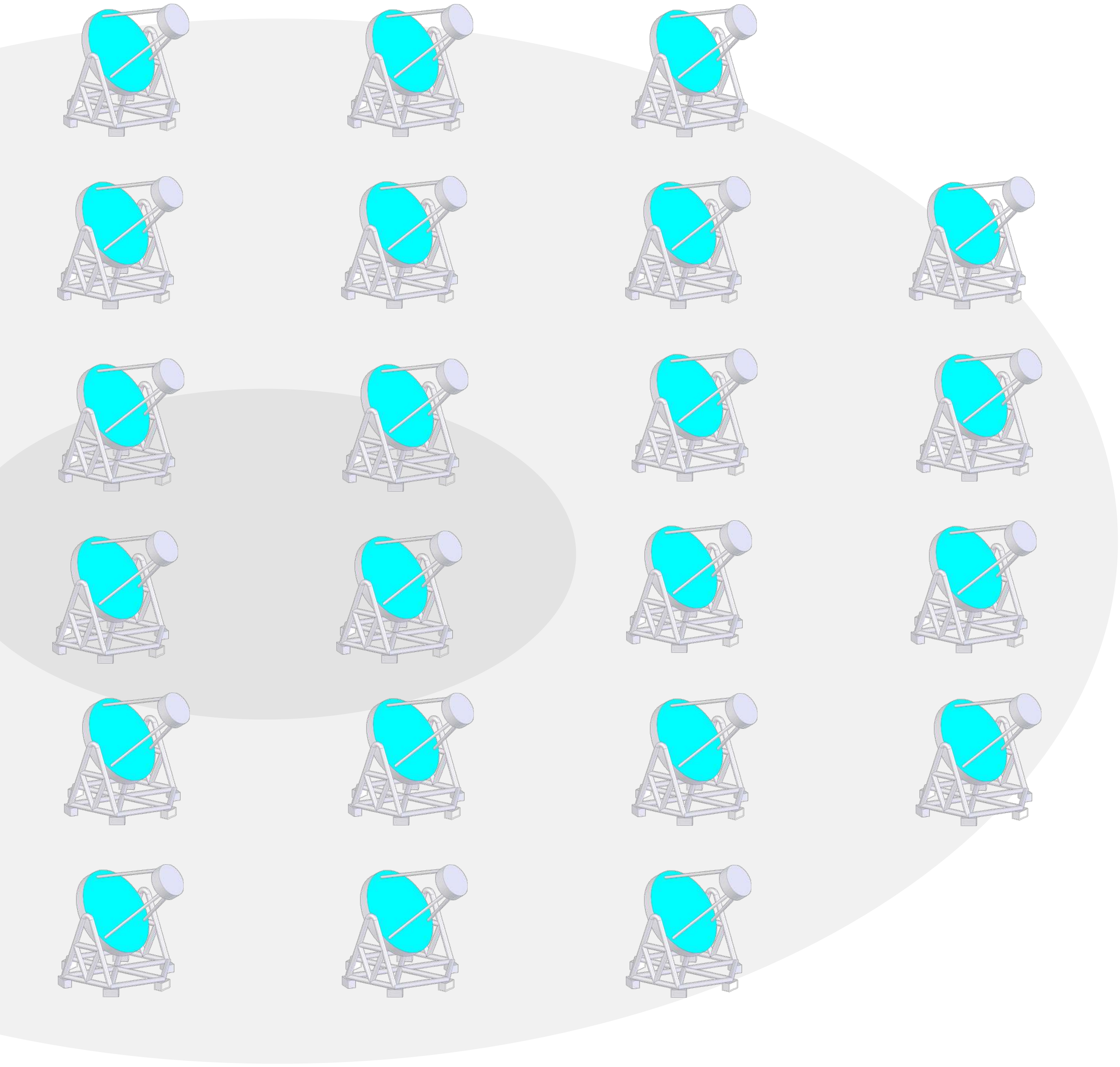
An advanced facility for ground-based gamma-ray astronomy.

CTA is the global, next-generation project
with largely enhanced performance and energy range
two observatories (South and North),

probing the **extreme universe** with huge potential for
high-energy astronomy and fundamental physics.

Boosting sensitivity & resolution: Arrays of Cherenkov telescopes





Core array:
mCrab sensitivity
in 0.1–10 TeV range

Not to scale !

Low-energy section

energy threshold of some 10 GeV

(a) bigger dishes or

Not to scale !

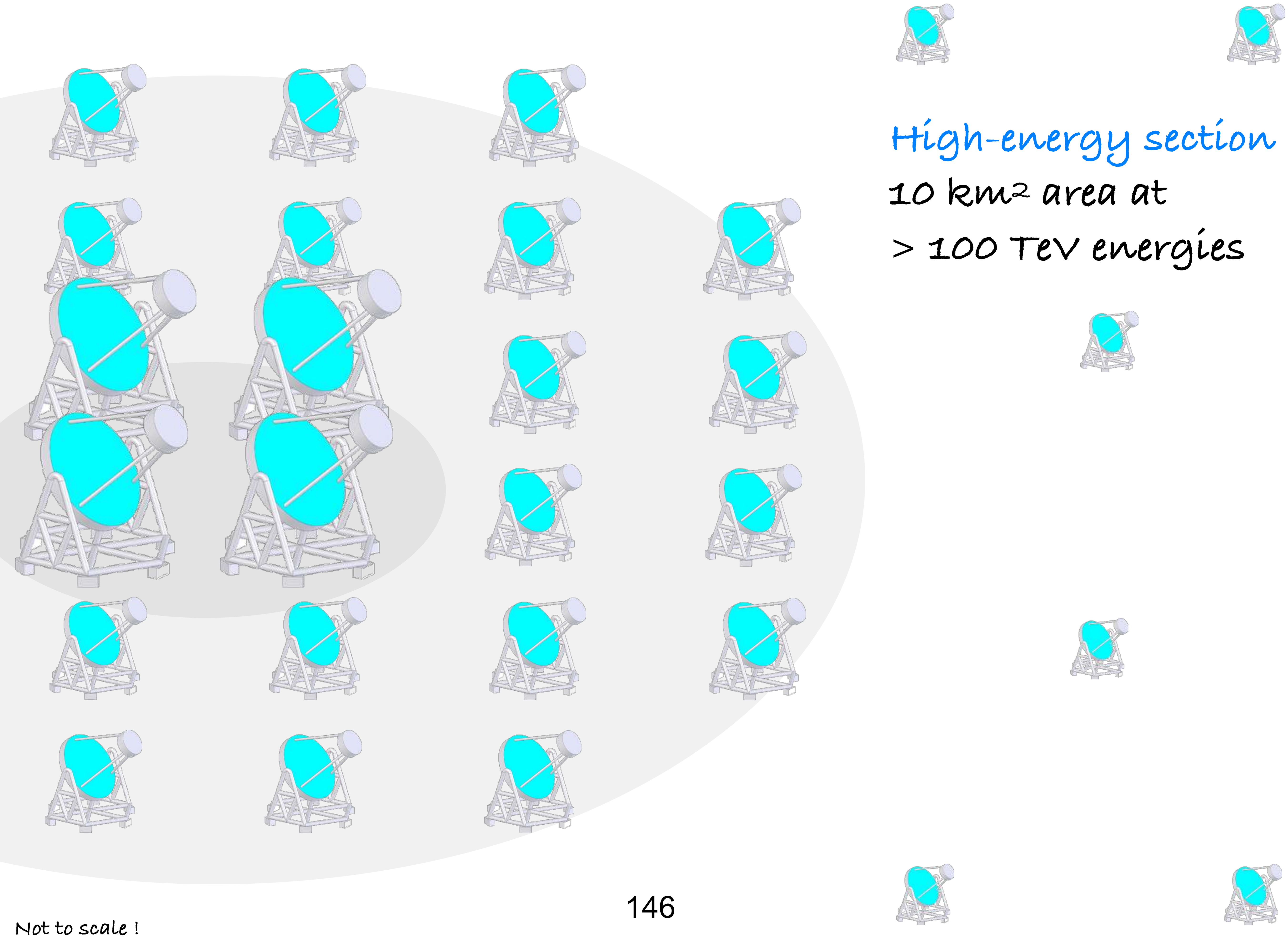
Low-energy section

energy threshold of some 10 GeV

(a) bigger dishes or

(b) dense packing / high-QE sensors

Not to scale !


High-energy section
10 km² area at
> 100 TeV energies
Not to scale !

CTA

10x more sensitive than current instruments

+ much wider energy coverage and field of view

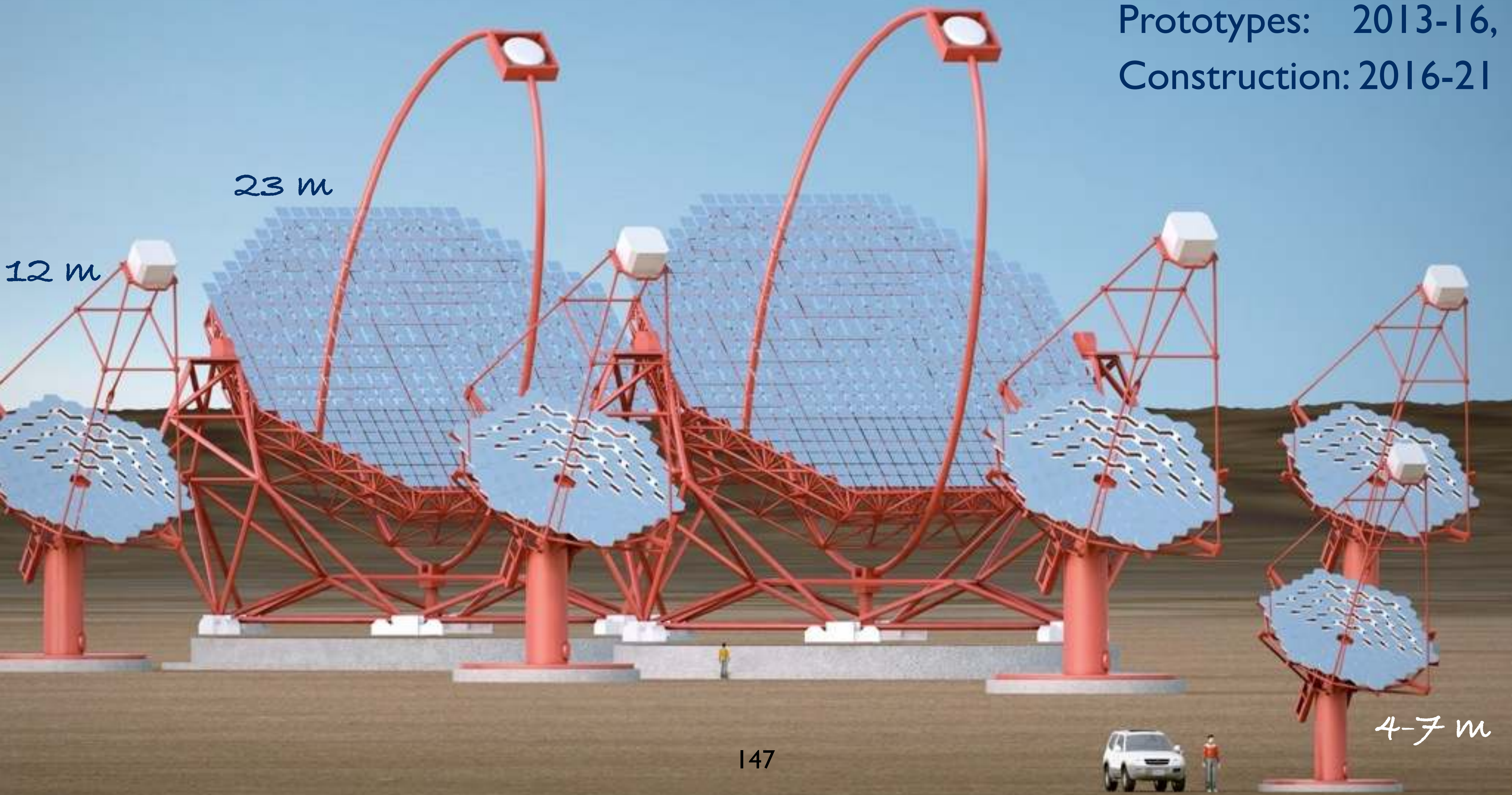
substantially better angular and energy resolution

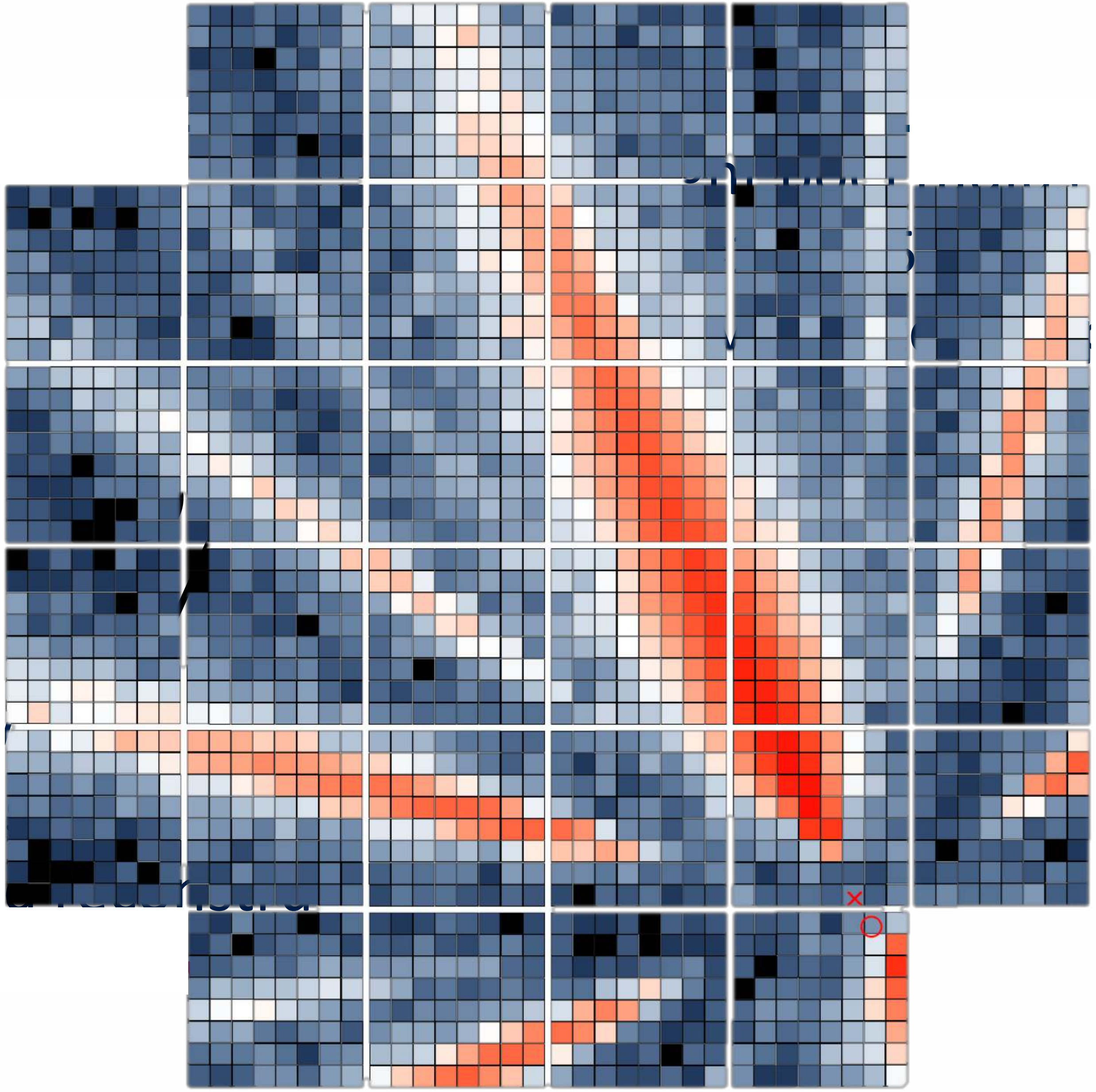
telescopes: ~100 (3 sizes)

Design: 2008-12,

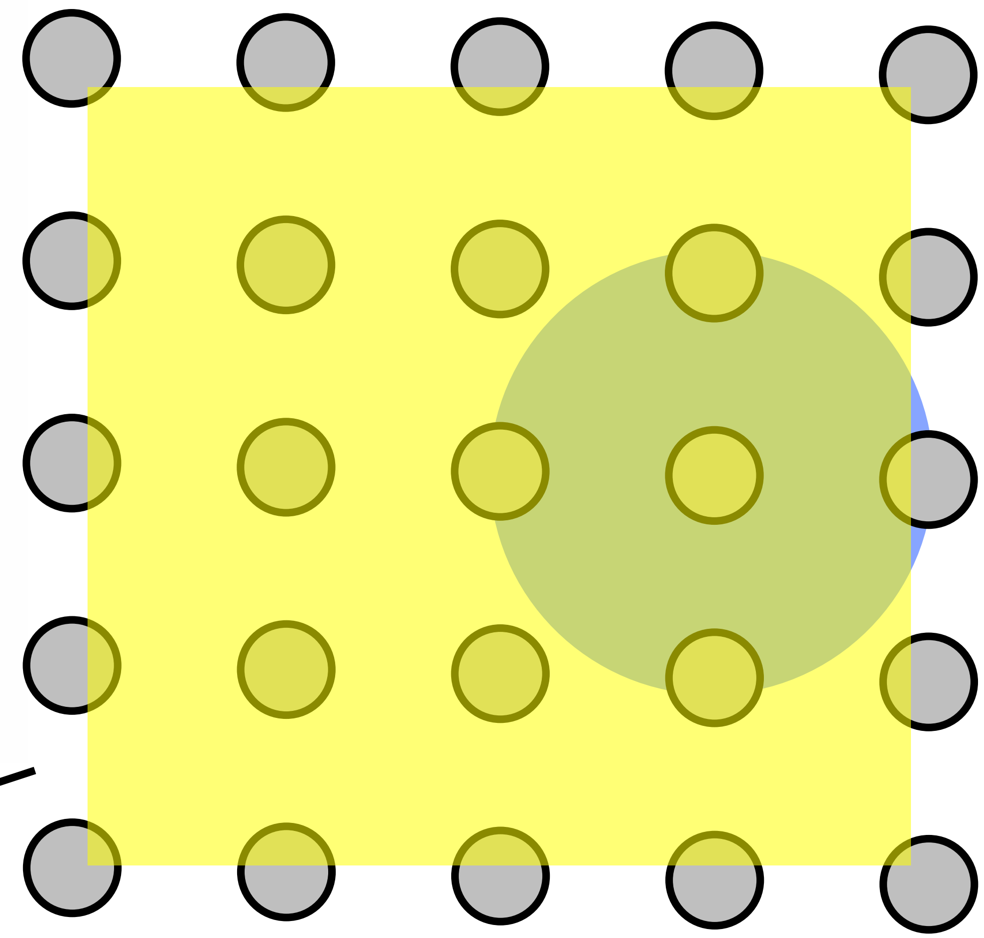
Prototypes: 2013-16,

Construction: 2016-21



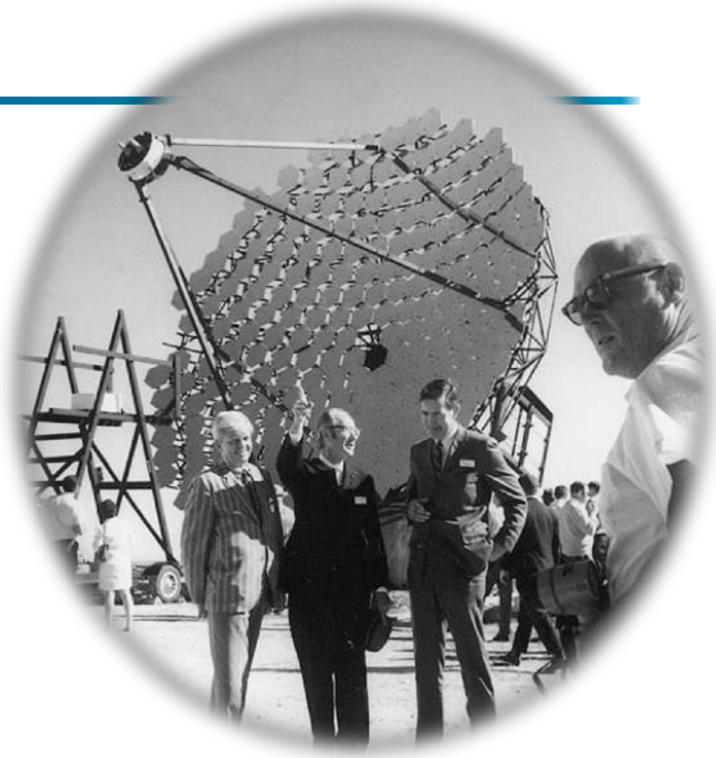


From current arrays to CTA



large detection area
more images per shower
lower trigger threshold

CHERENKOV IMAGING IMPROVEMENTS



Improved imaging: larger fov, finer pixels

Large dish

Stereoscopy

Large arrays

High-QE PMTs, silicon sensors

Novel optics concepts

Extremely detailed simulation models

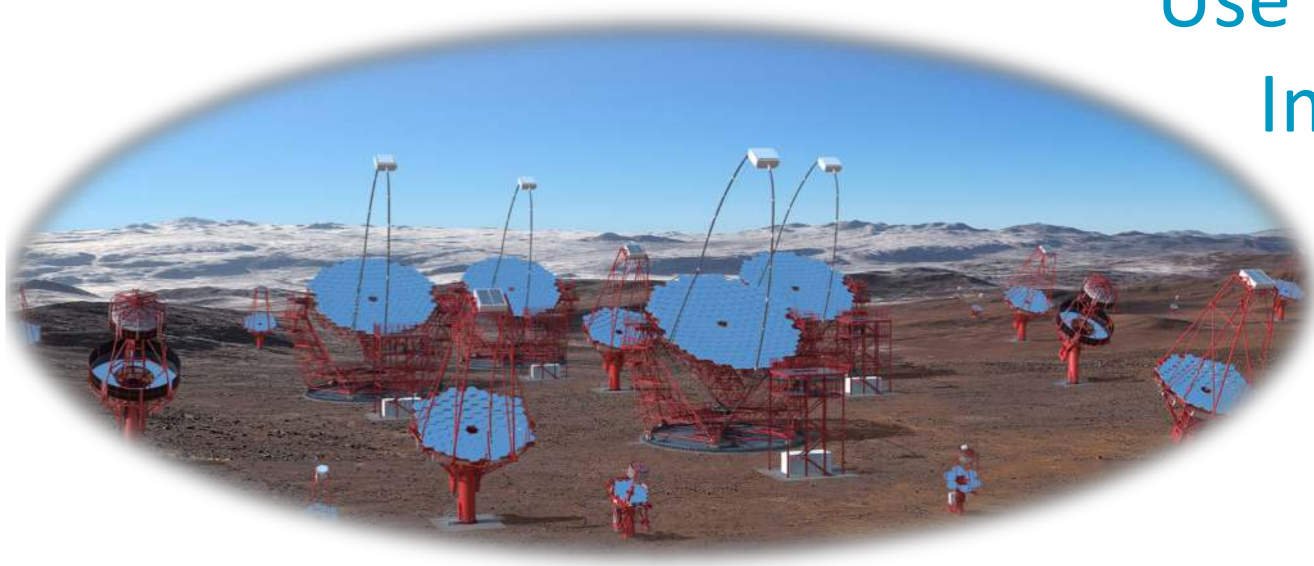
Atmospheric monitoring and modeling

Use of pixel waveforms

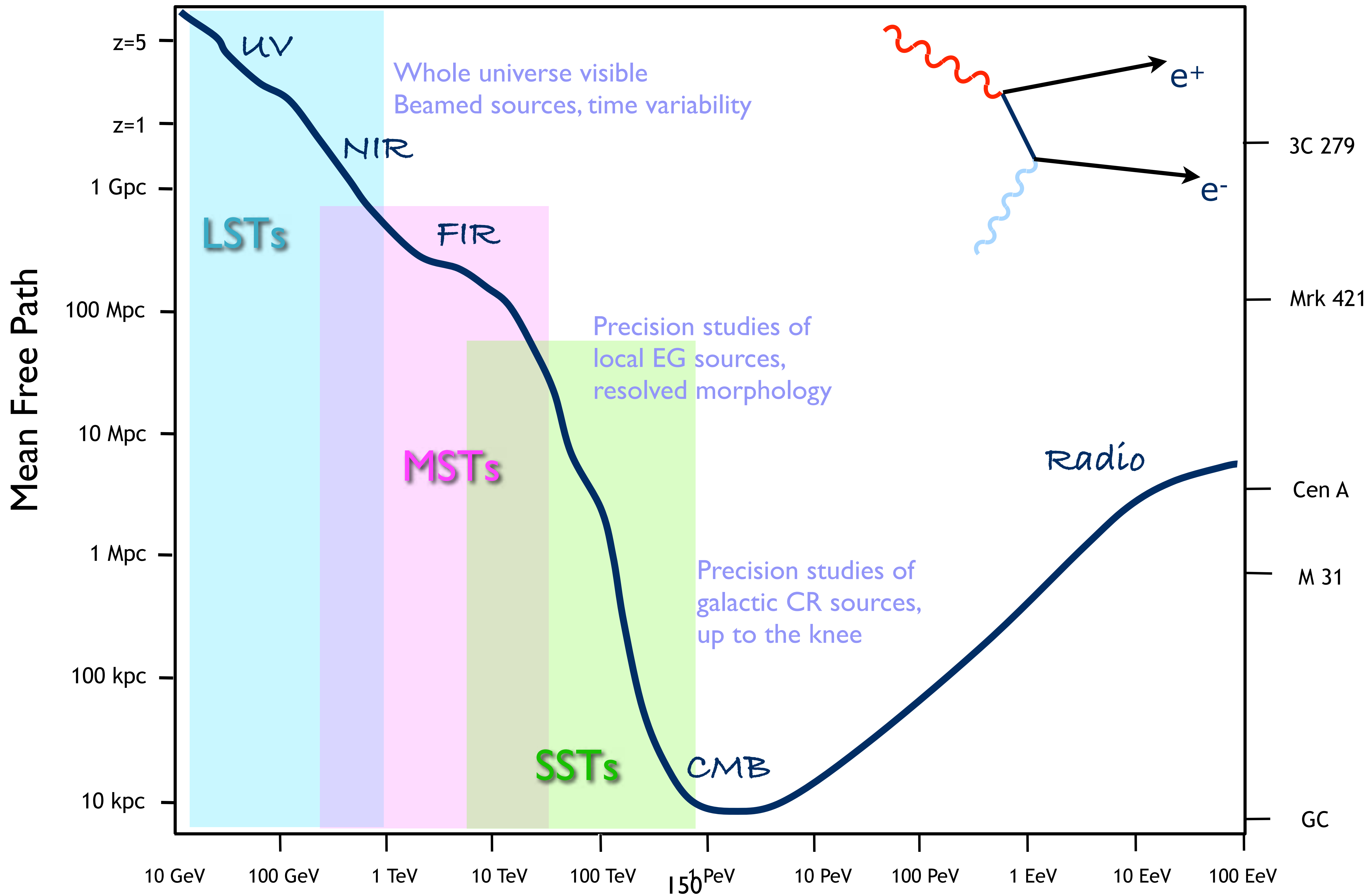
Image fitting

Deep neural networks

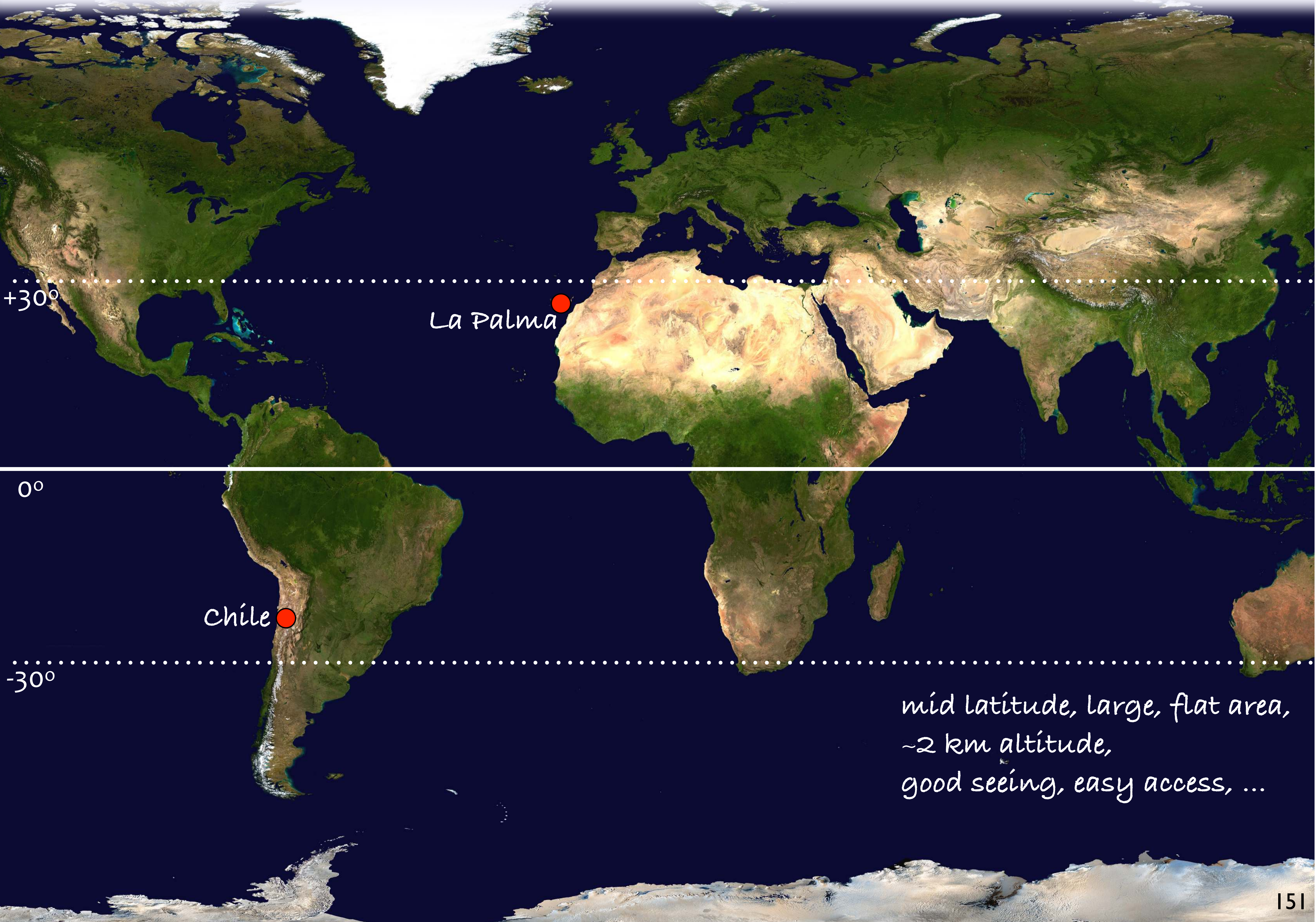
Run-wise simulations



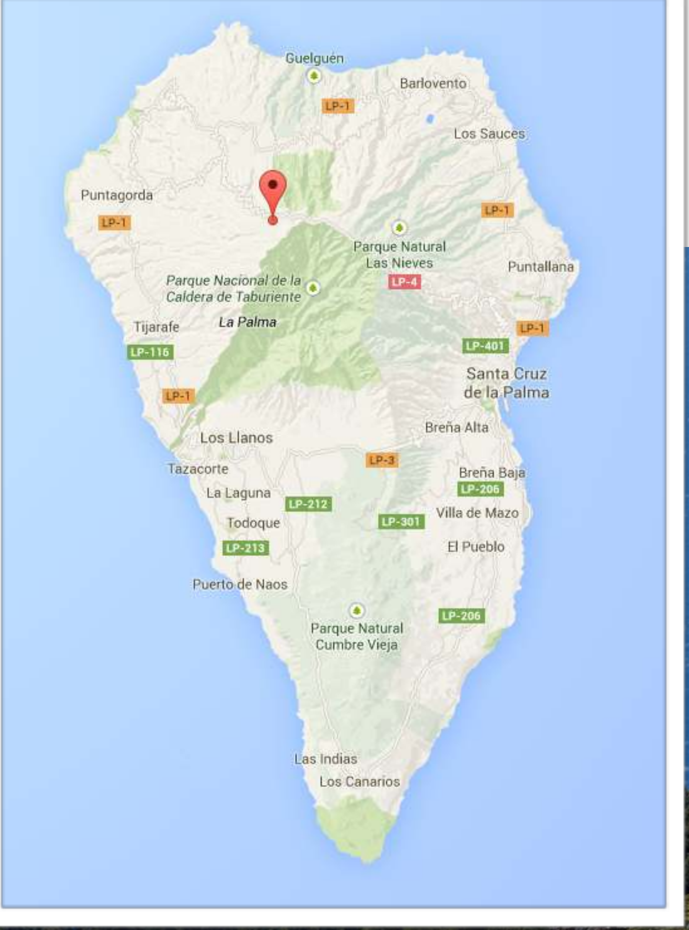
The Gamma-Ray Horizon $\gamma_{VHE} + \gamma \longrightarrow e^+e^-$



One observatory with two sites



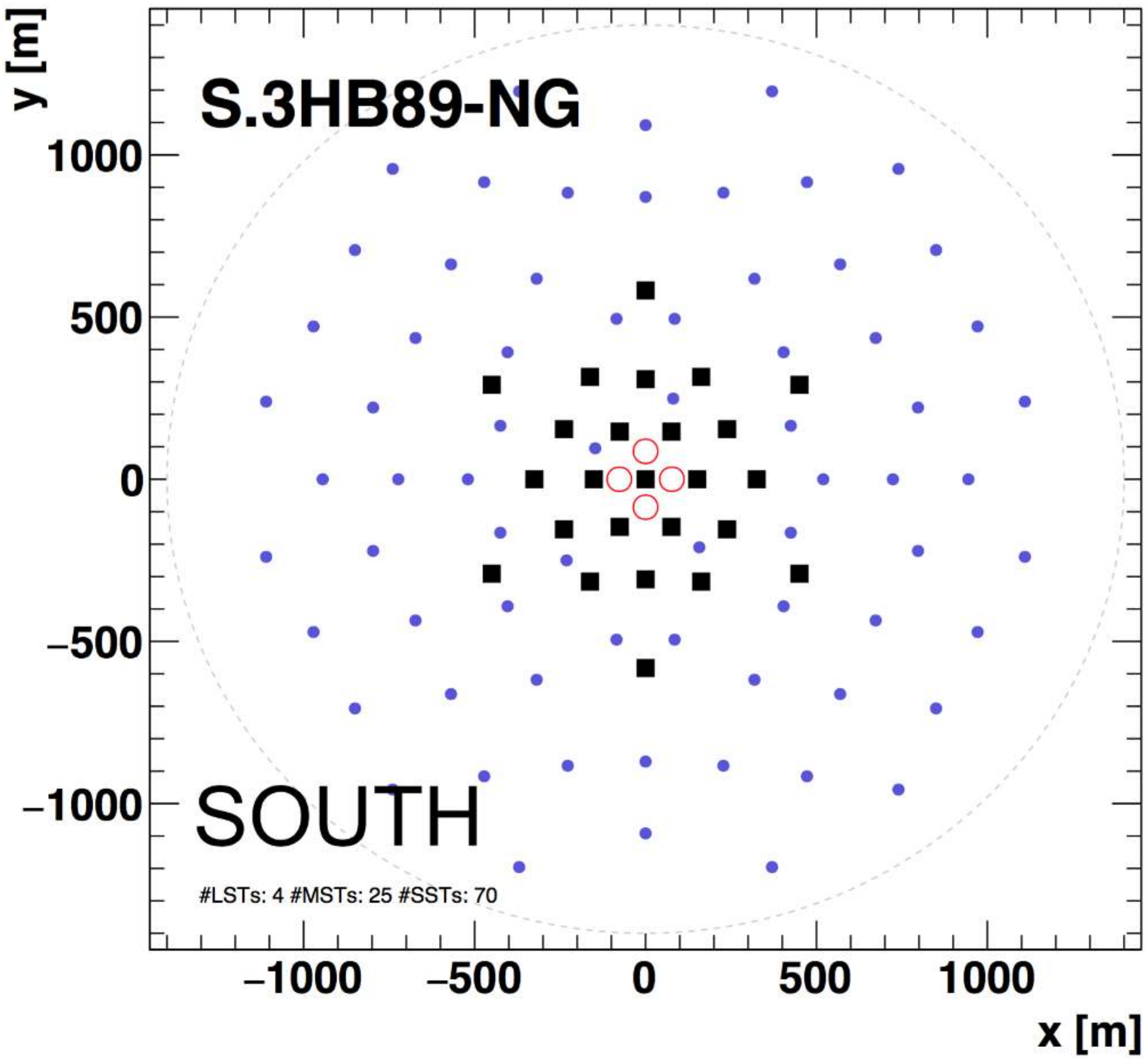
La Palma, Spain (near MAGIC site)

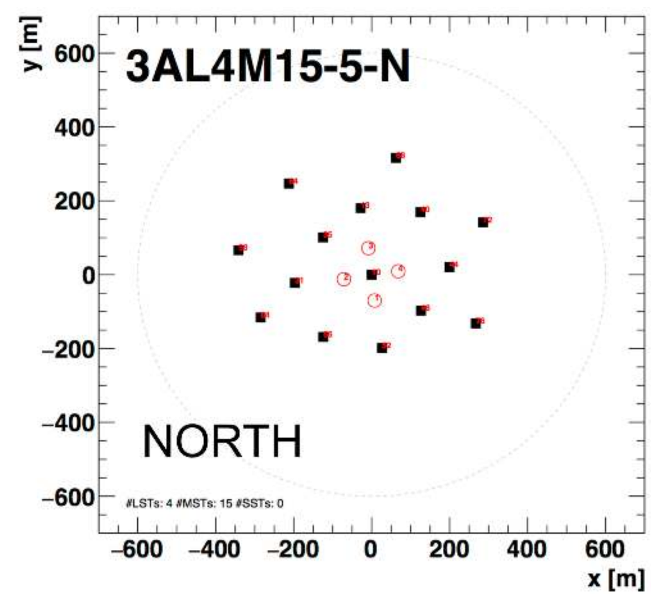


Paranal, Chile (ESO site, Atacama desert)

Baseline Arrays

South: 4 LSTs 25 MSTs 70 SSTs **North: 4 LSTs 15 MSTs**



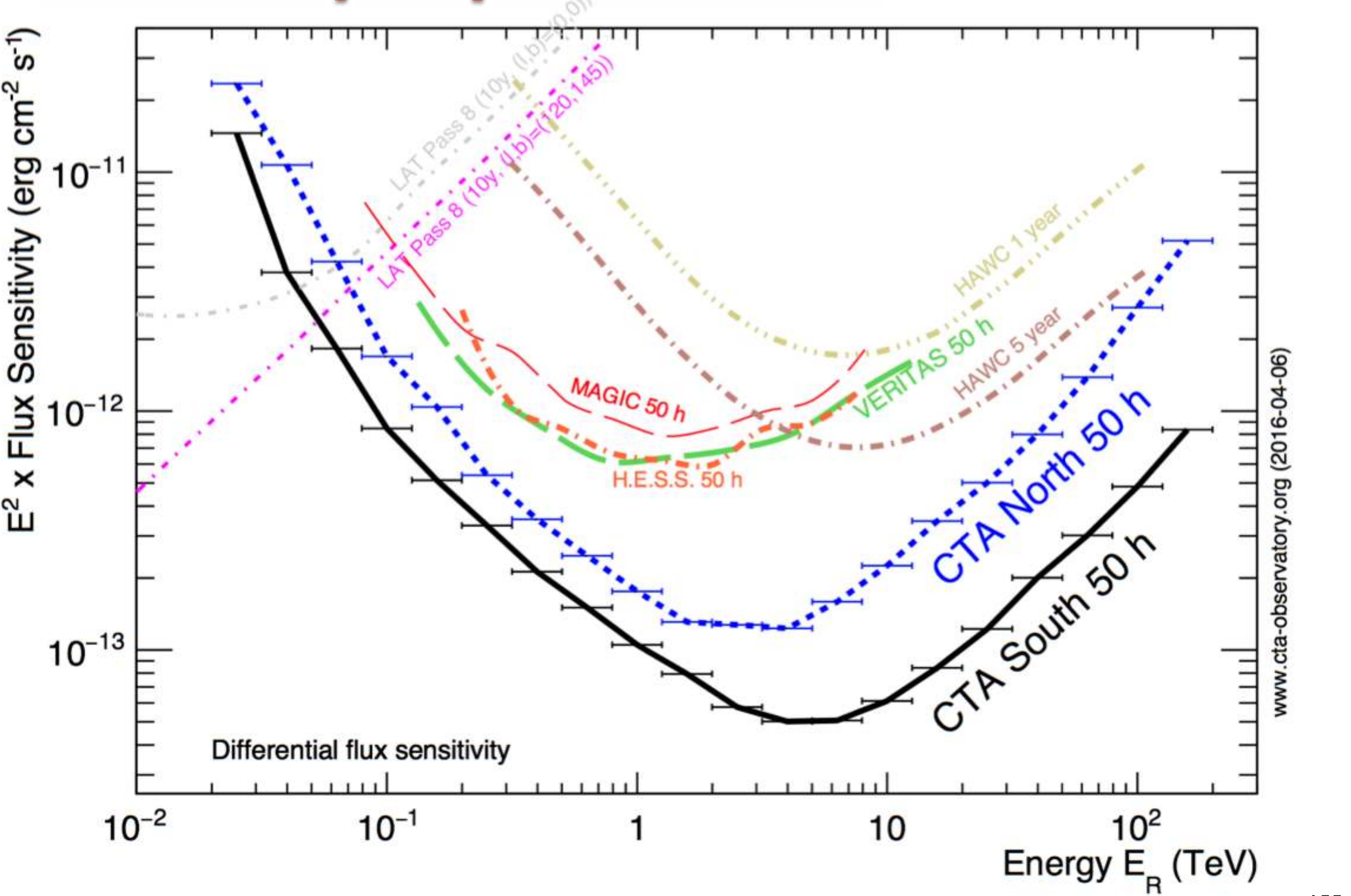


to scale

full energy range

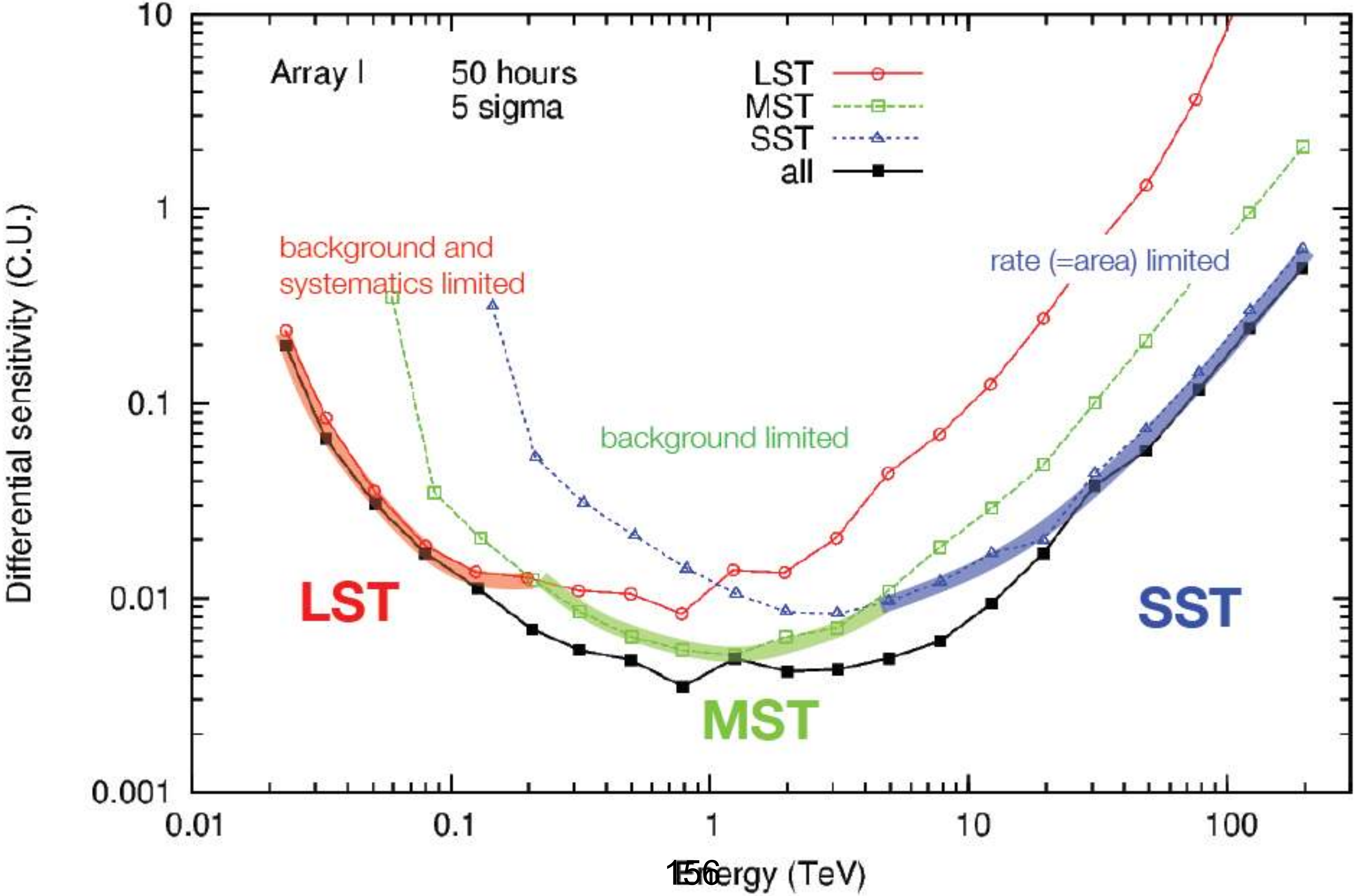
mainly low energies

Sensitivity to point sources



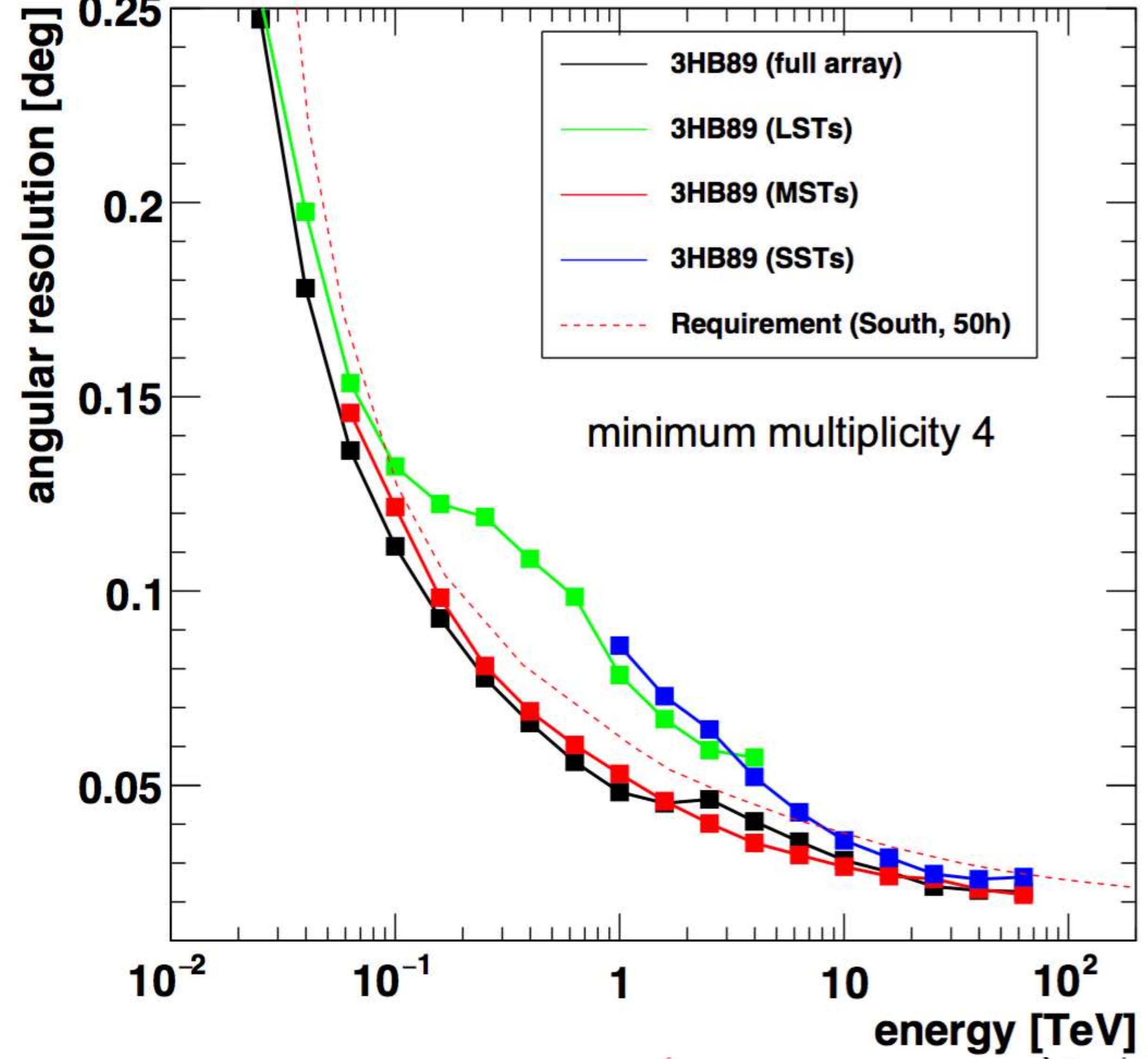
3 telescope sizes for a wide energy coverage

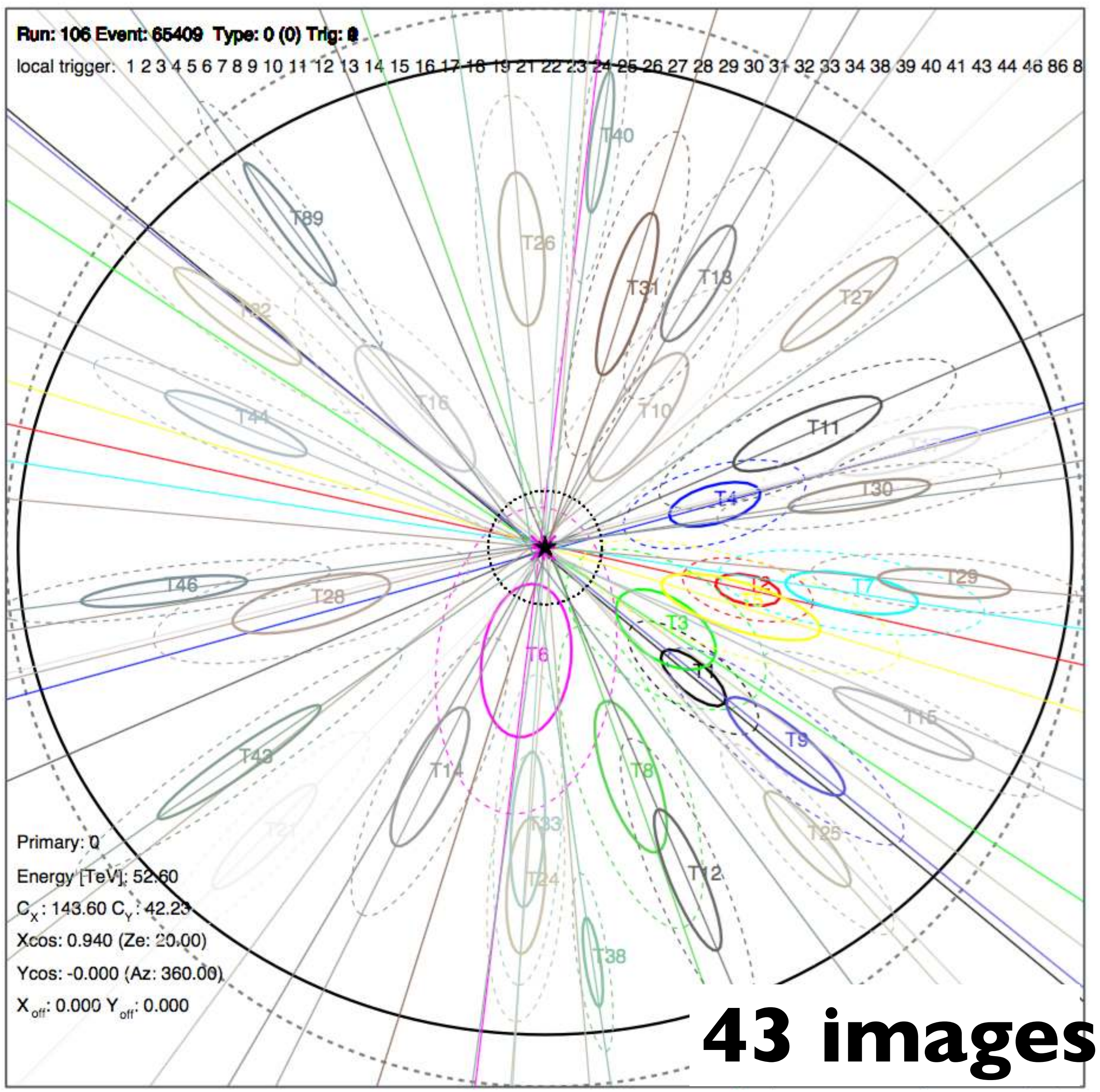
Sensitivity (in units of Crab flux)
for detection in each 0.2-decade energy band



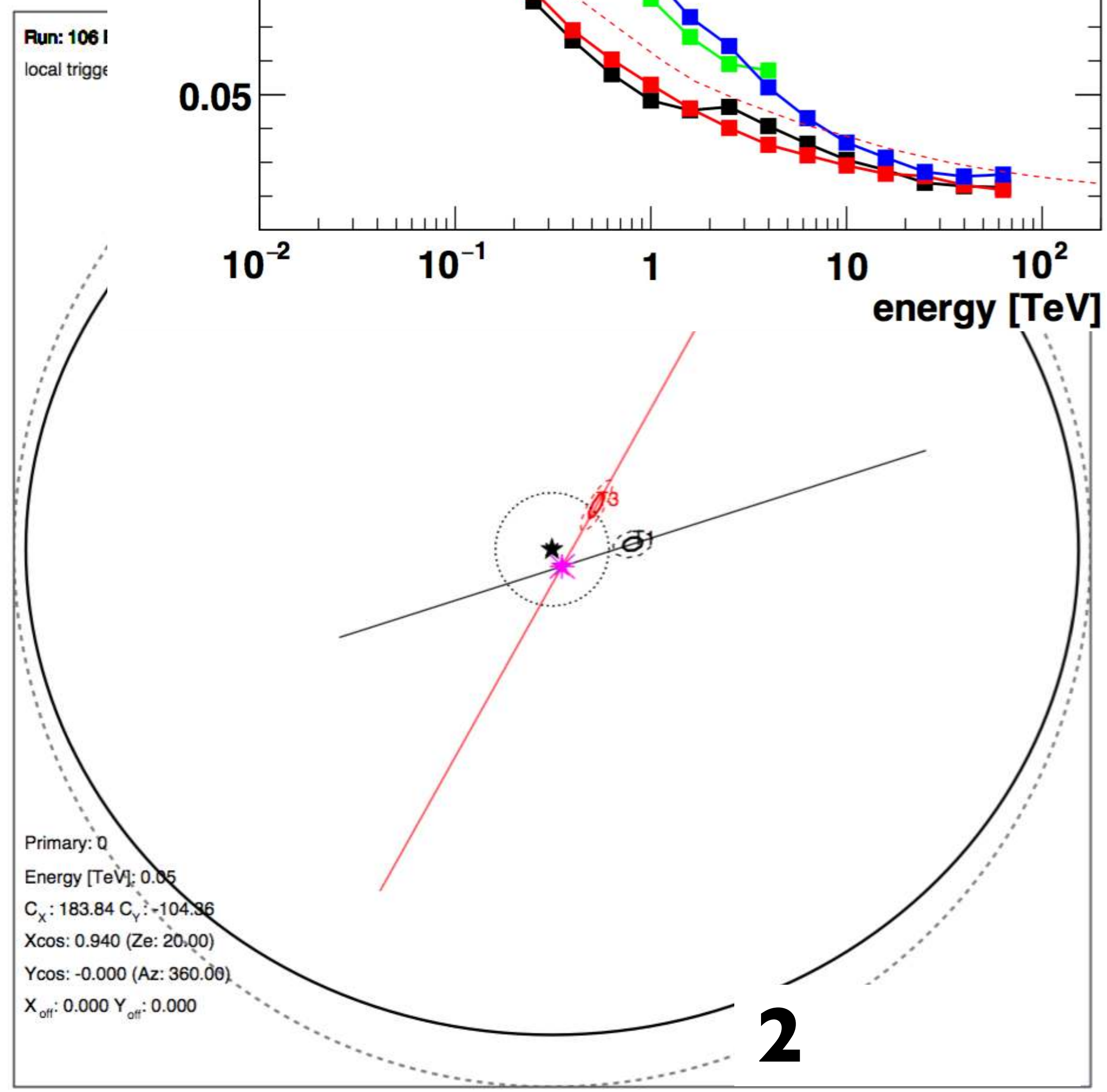
Angular Resolution:

< 0.1° for ≥ 5 images
or for E > 100 GeV (≥ 4 images)





43 images

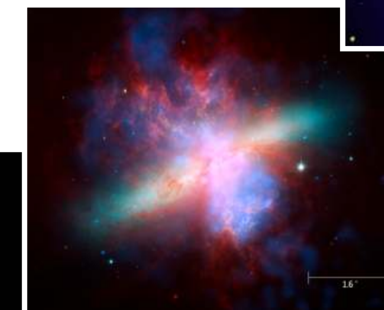


2

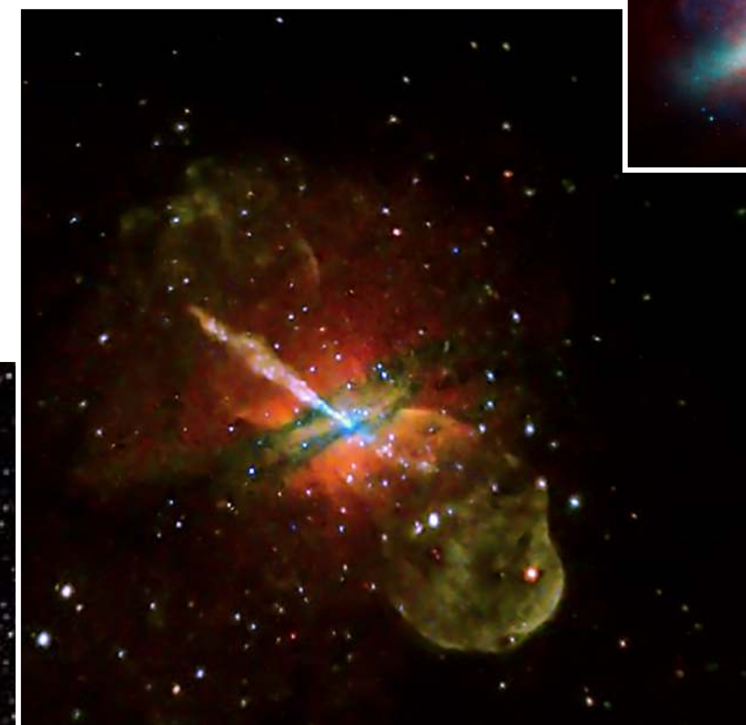
... allows study of morphologies

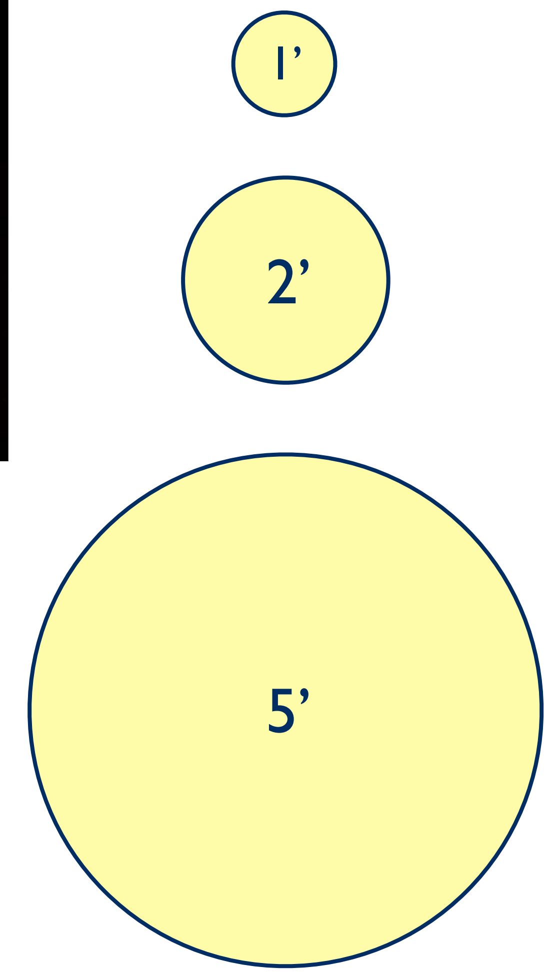
Hydra A

M 82

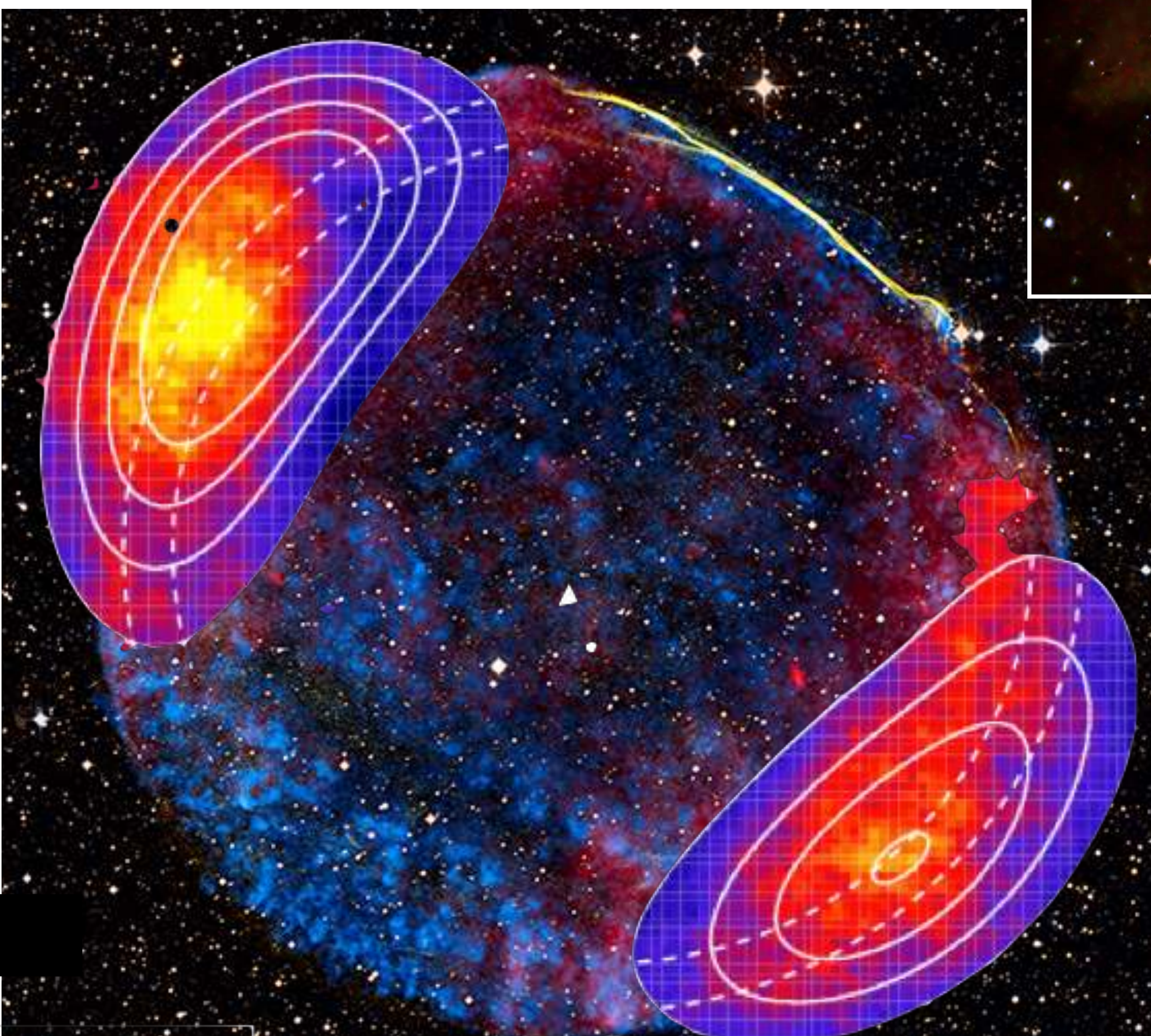


Cen A

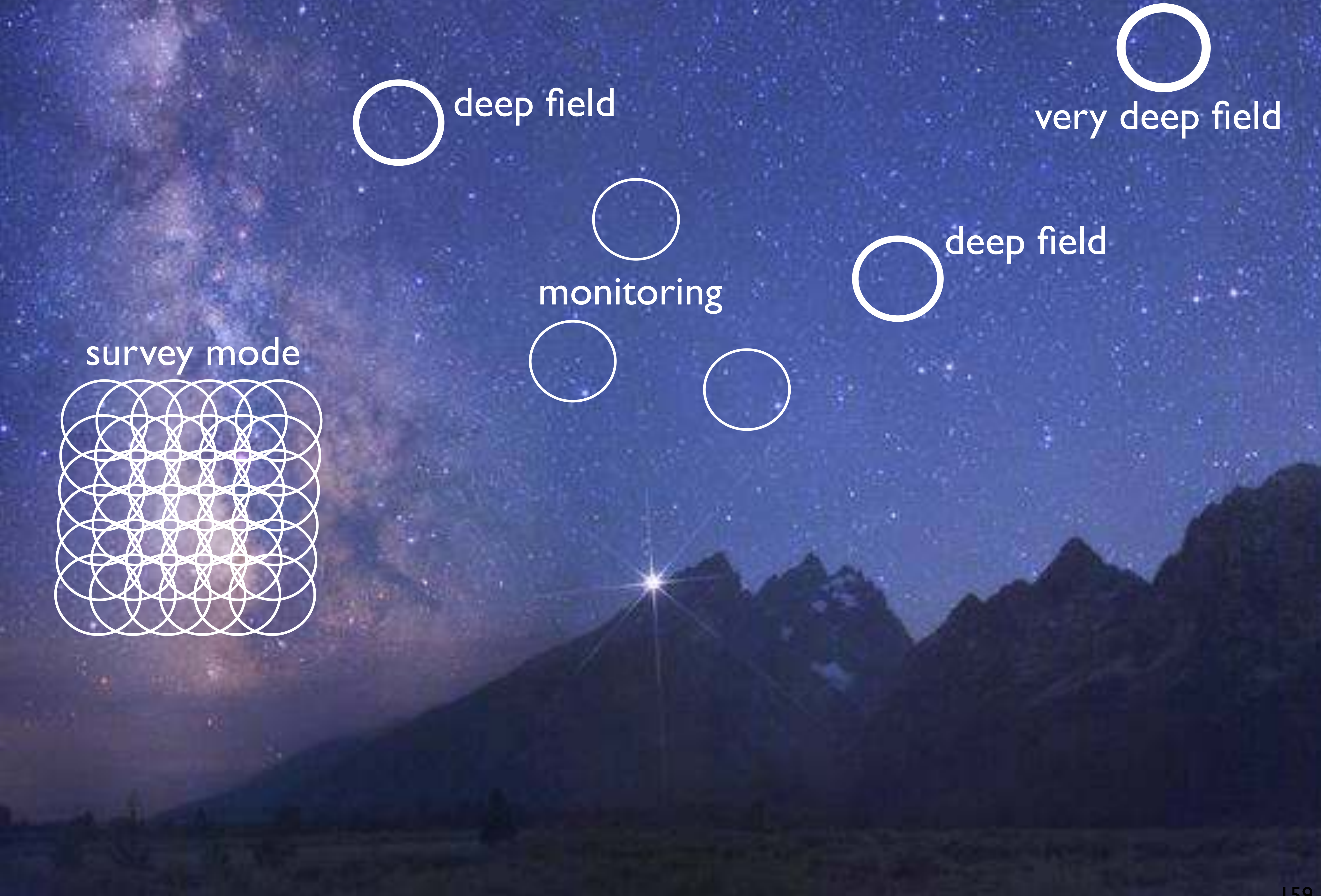




SN 1006

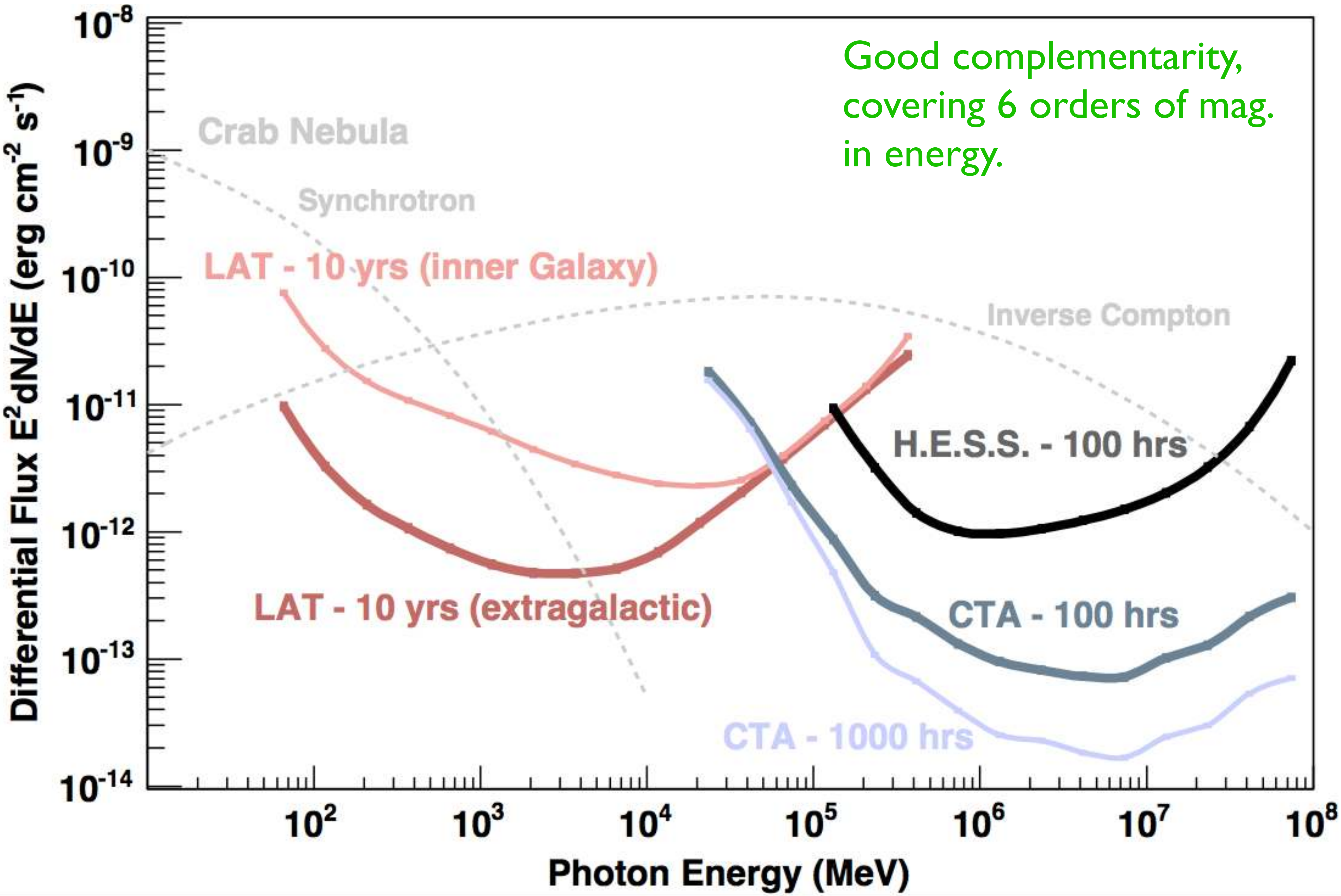


CTA observation modes



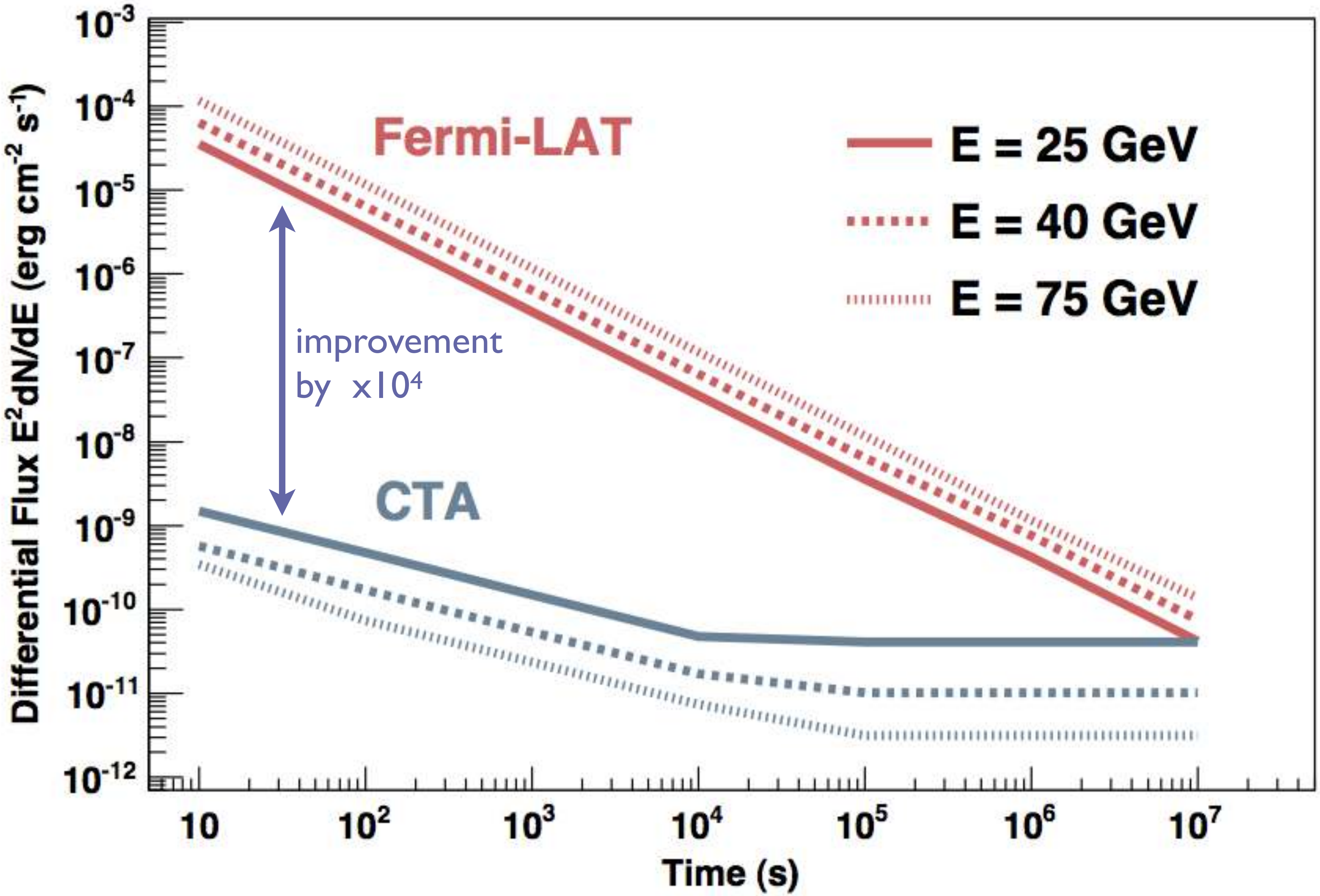
CTA and Fermi

(Steady sources)

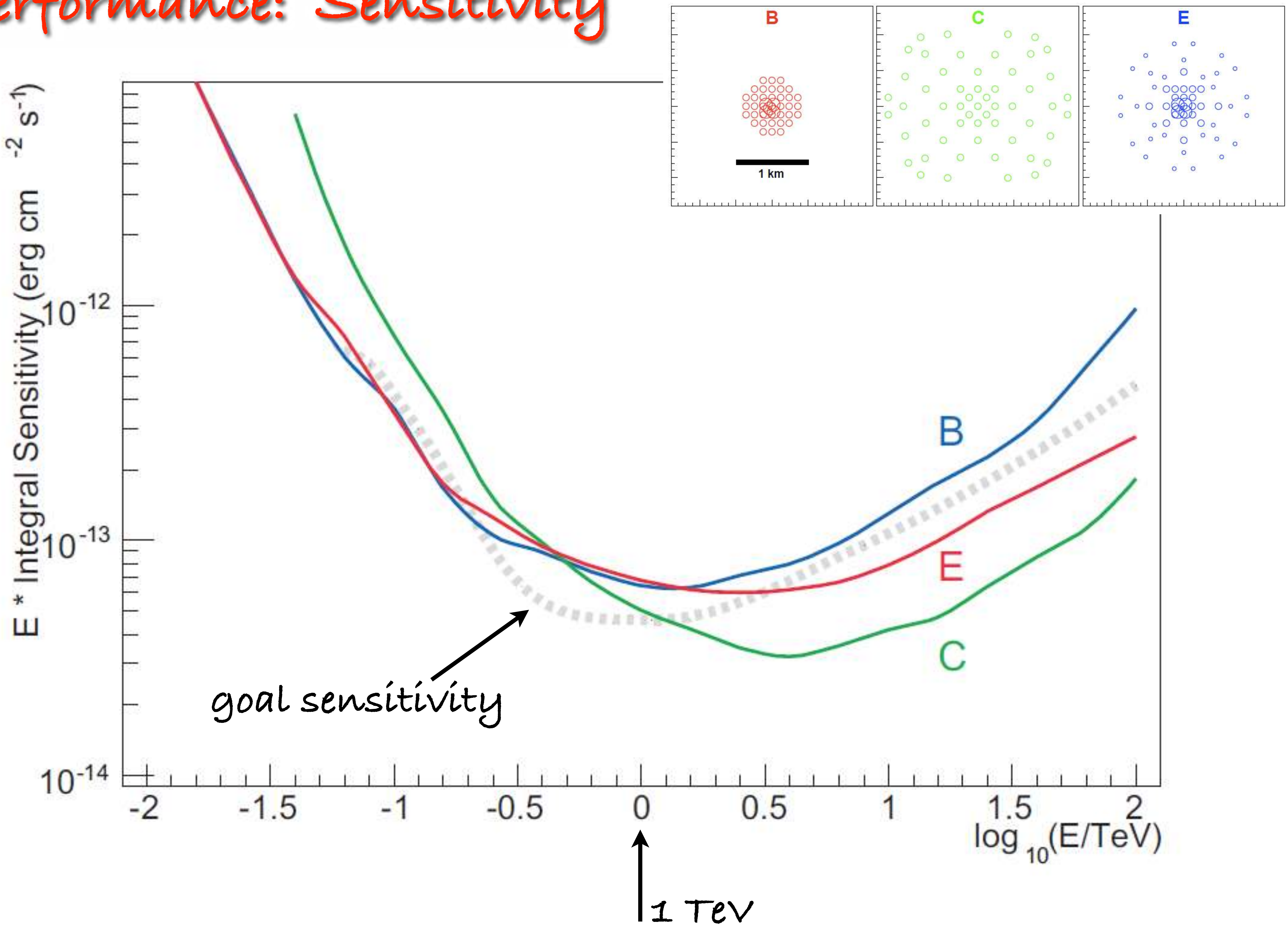


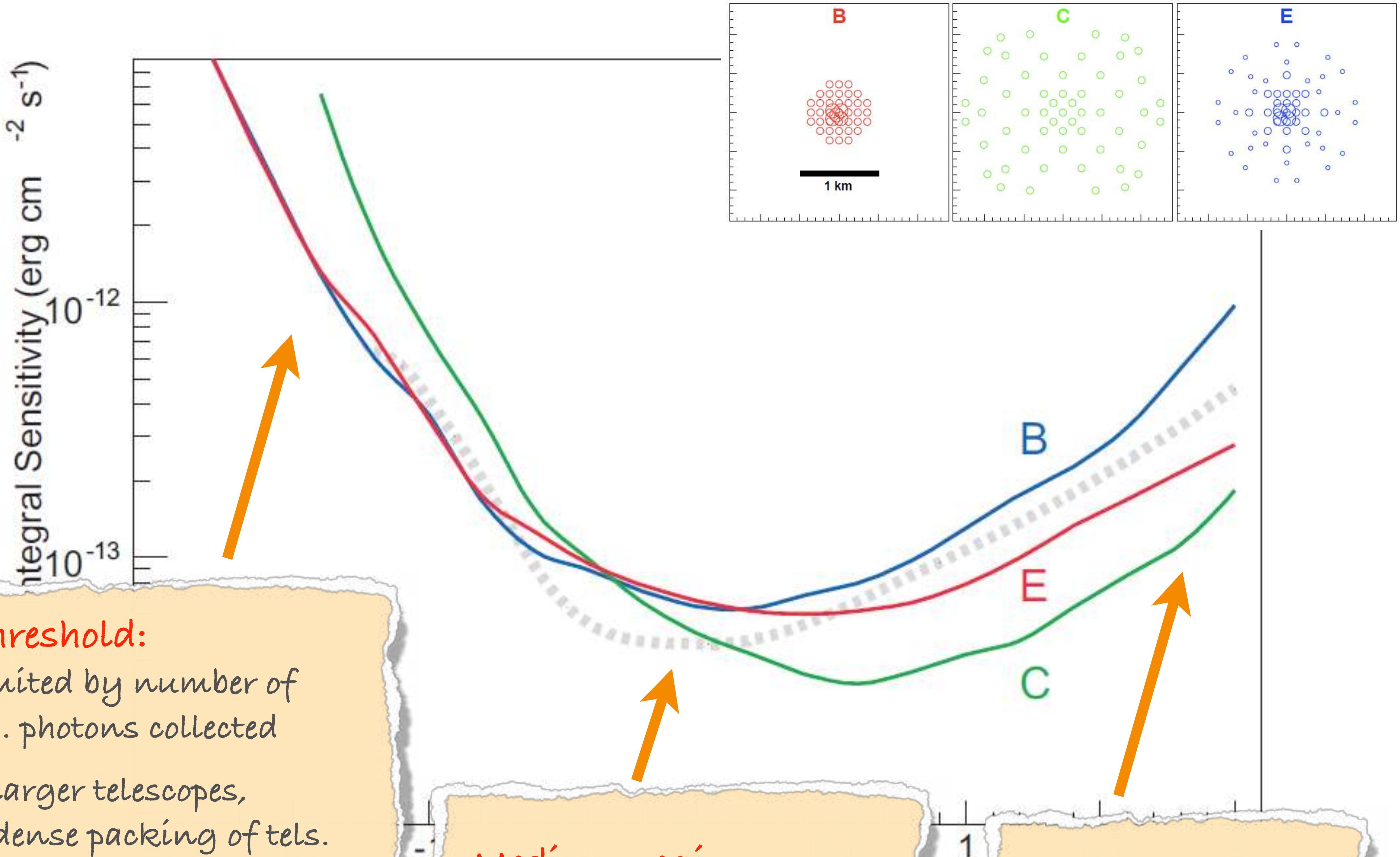
Variability and Short-Timescale Phenomena

(flares, GRBs, ... all sorts of transients)



Performance: Sensitivity





Threshold:
limited by number of Ch. photons collected

- larger telescopes,
- dense packing of tels.
- better photo detectors

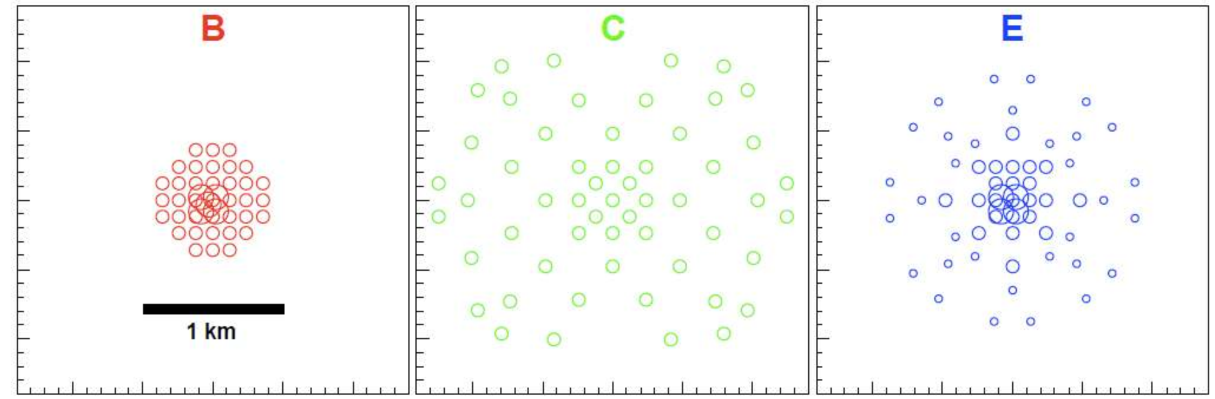
Medium region:
limited by signal / BG

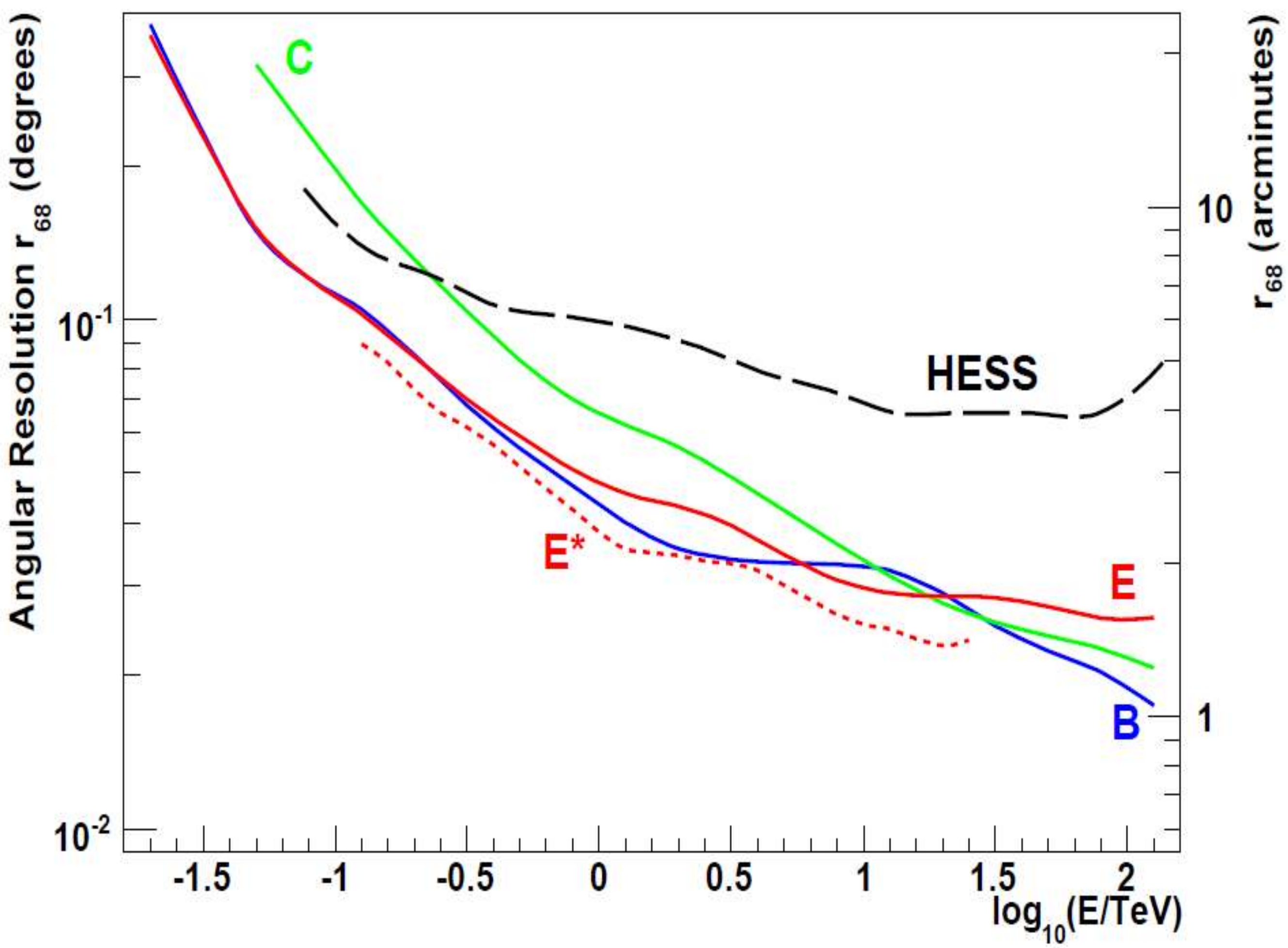
- better BG rejection,
- improved ang. resolution,
- better photon statistics

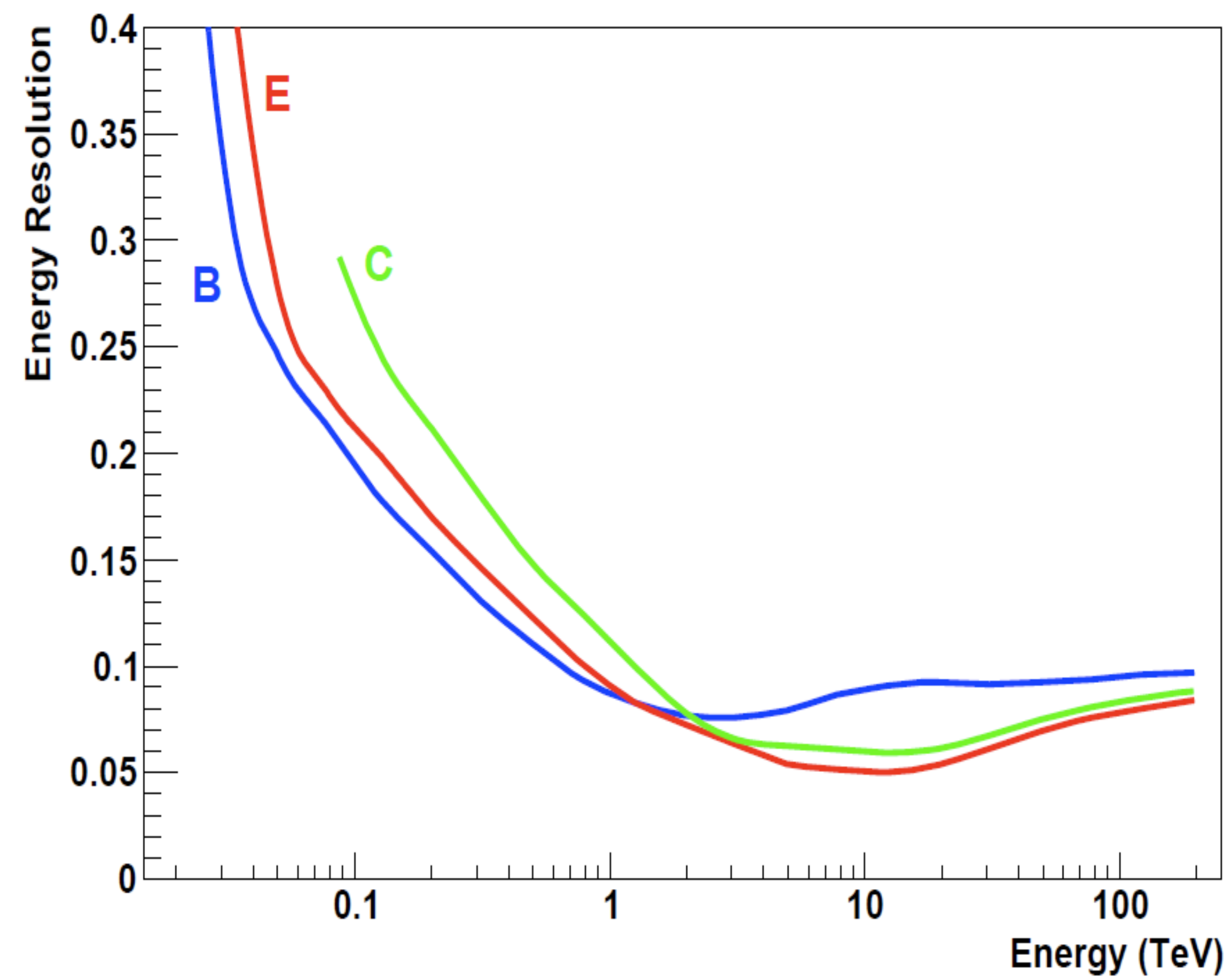
High energies:
limited by statistics

- large array

Performance: angular and energy resolution

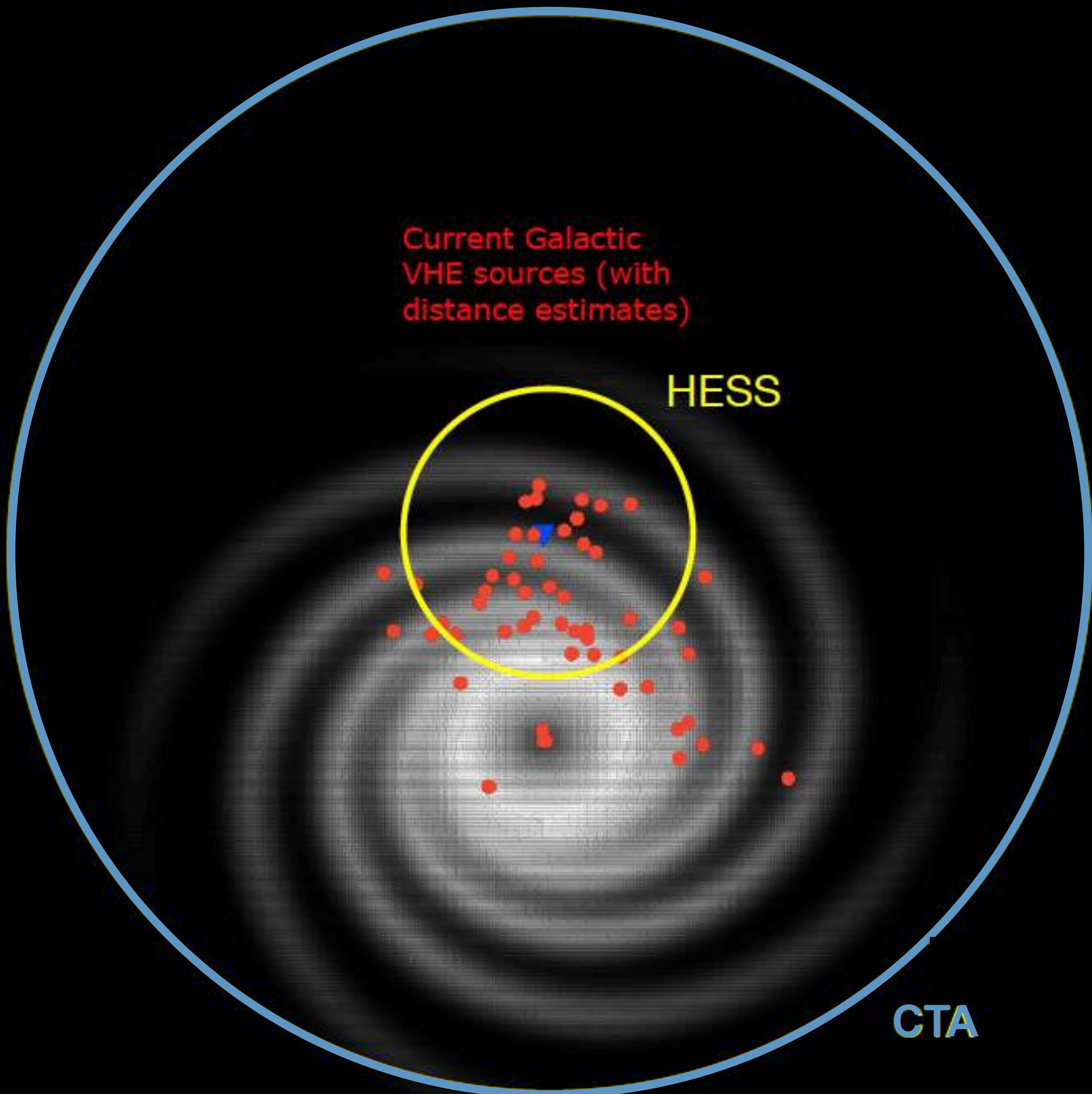






1-2’ for E > 1 TeV
(fundamental limit: ~ 10’’)

<10% for E > 1 TeV



visibility for 1% Crab sources

CTA will be the
ultimate instrument …

… for surveys
~400x faster than H.E.S.S.

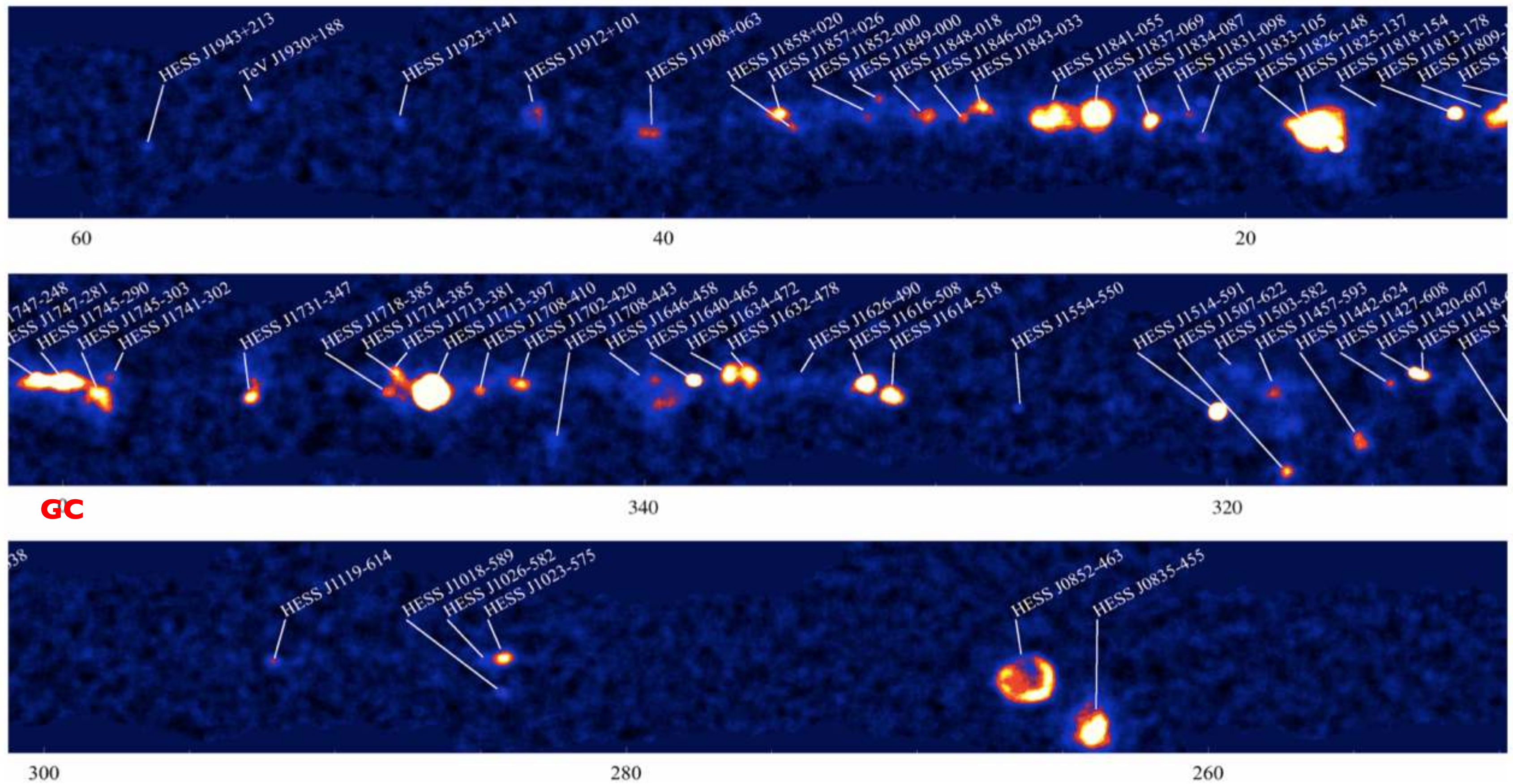
… for transients
at 25 GeV,
10^4x better than Fermi

Two observatories (S+N)
for full-sky coverage.

CTA prognosis: >1000 new sources

galactic disc

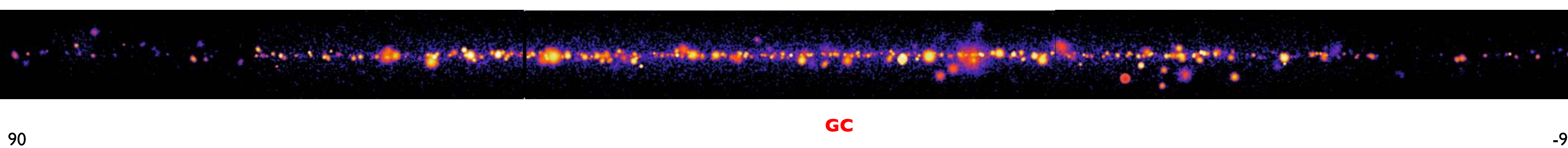
HESS
+60 … -120°



58 sources

CTA prognosis:

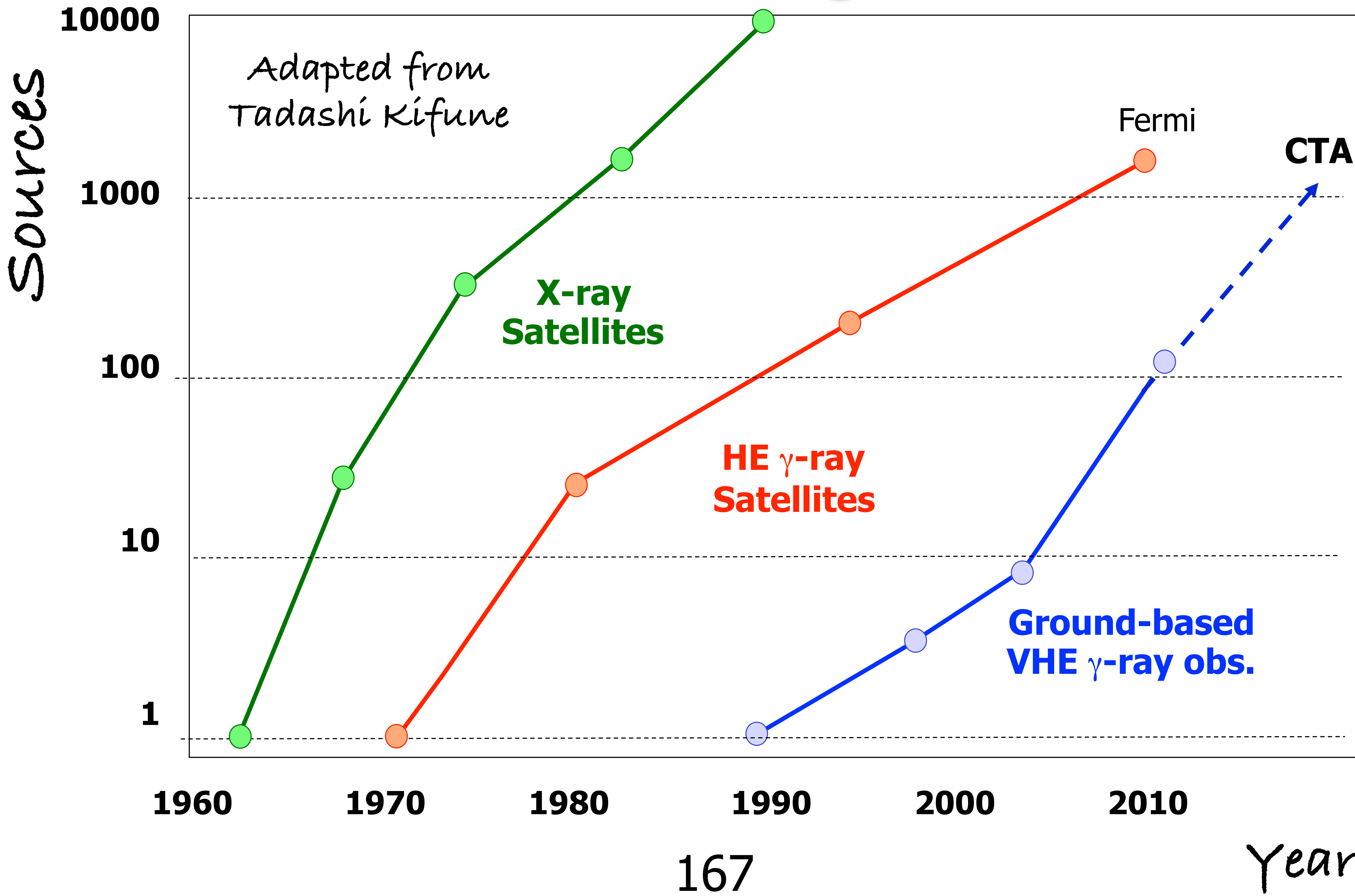
~600 sources



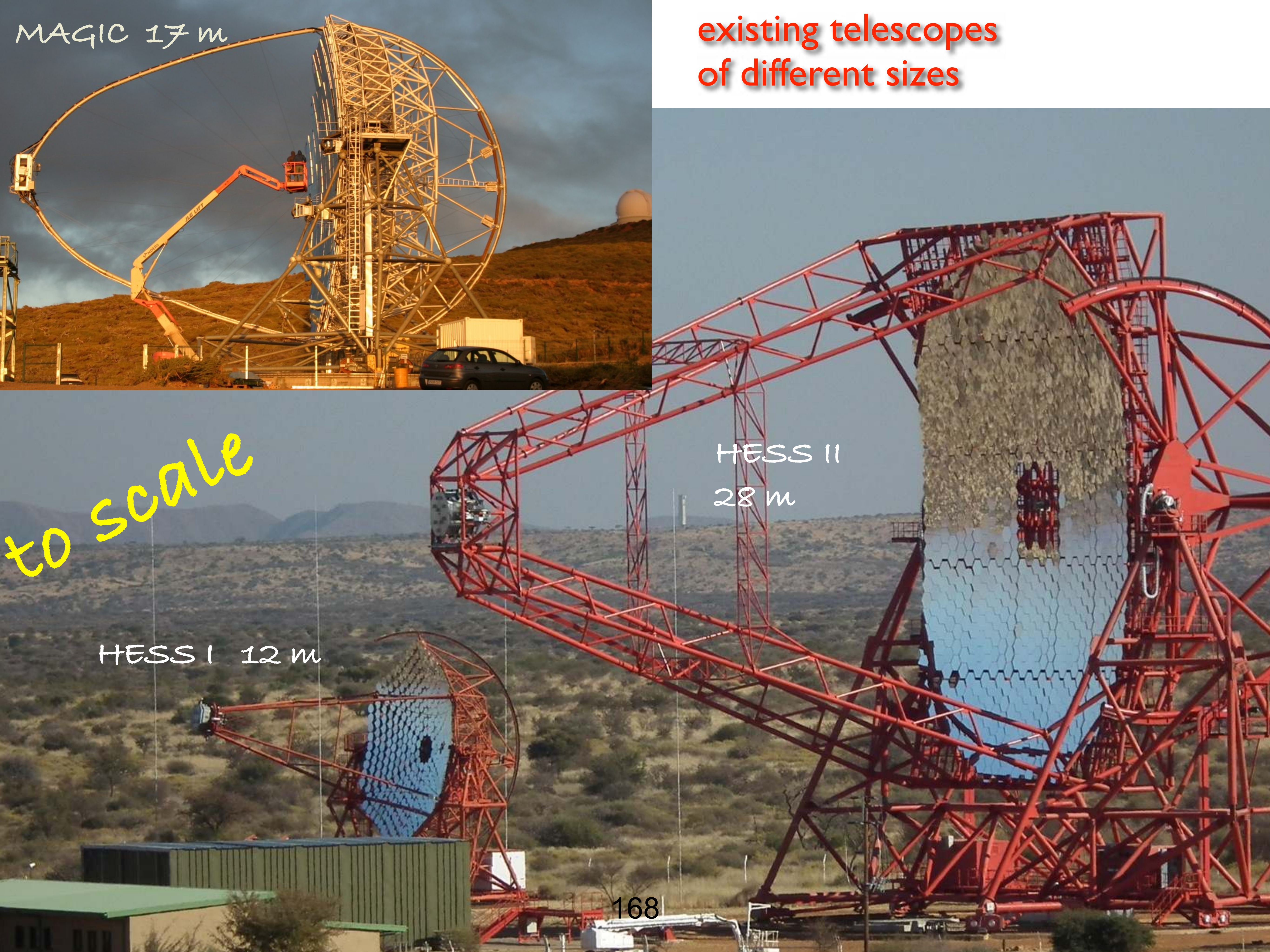
galactic + extragalactic: ≥ 1000 sources

Source Number

Gamma-Ray Astronomy goes "mainstream"



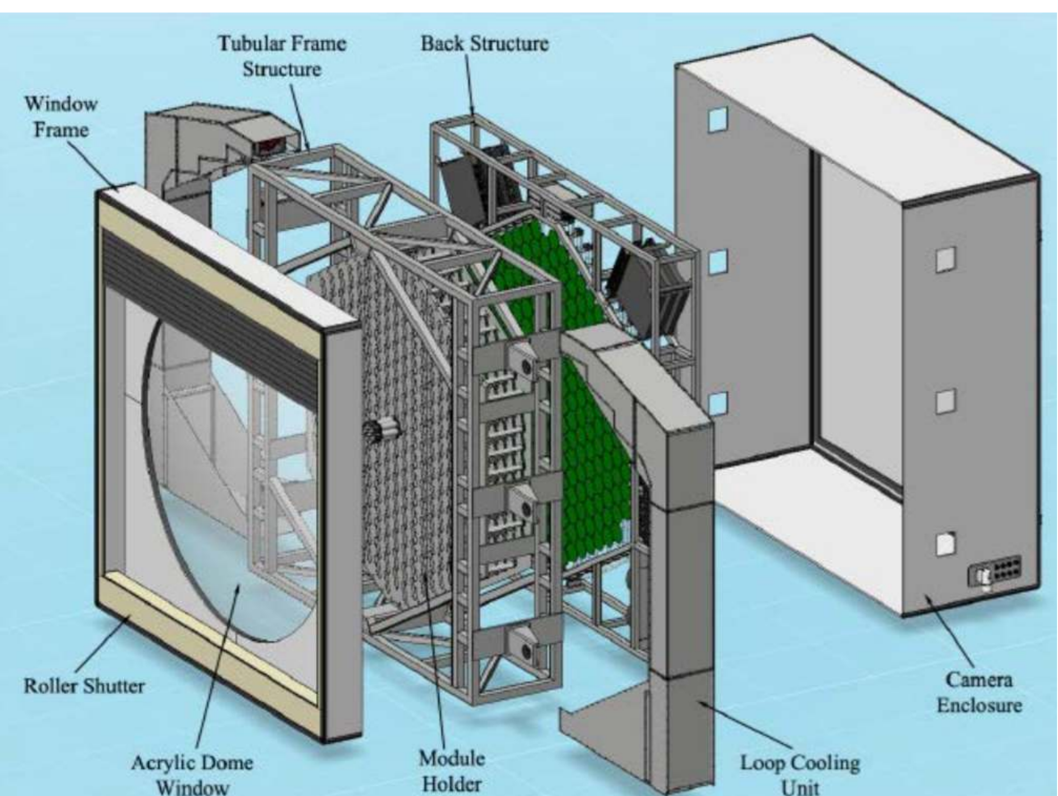
existing telescopes
of different sizes



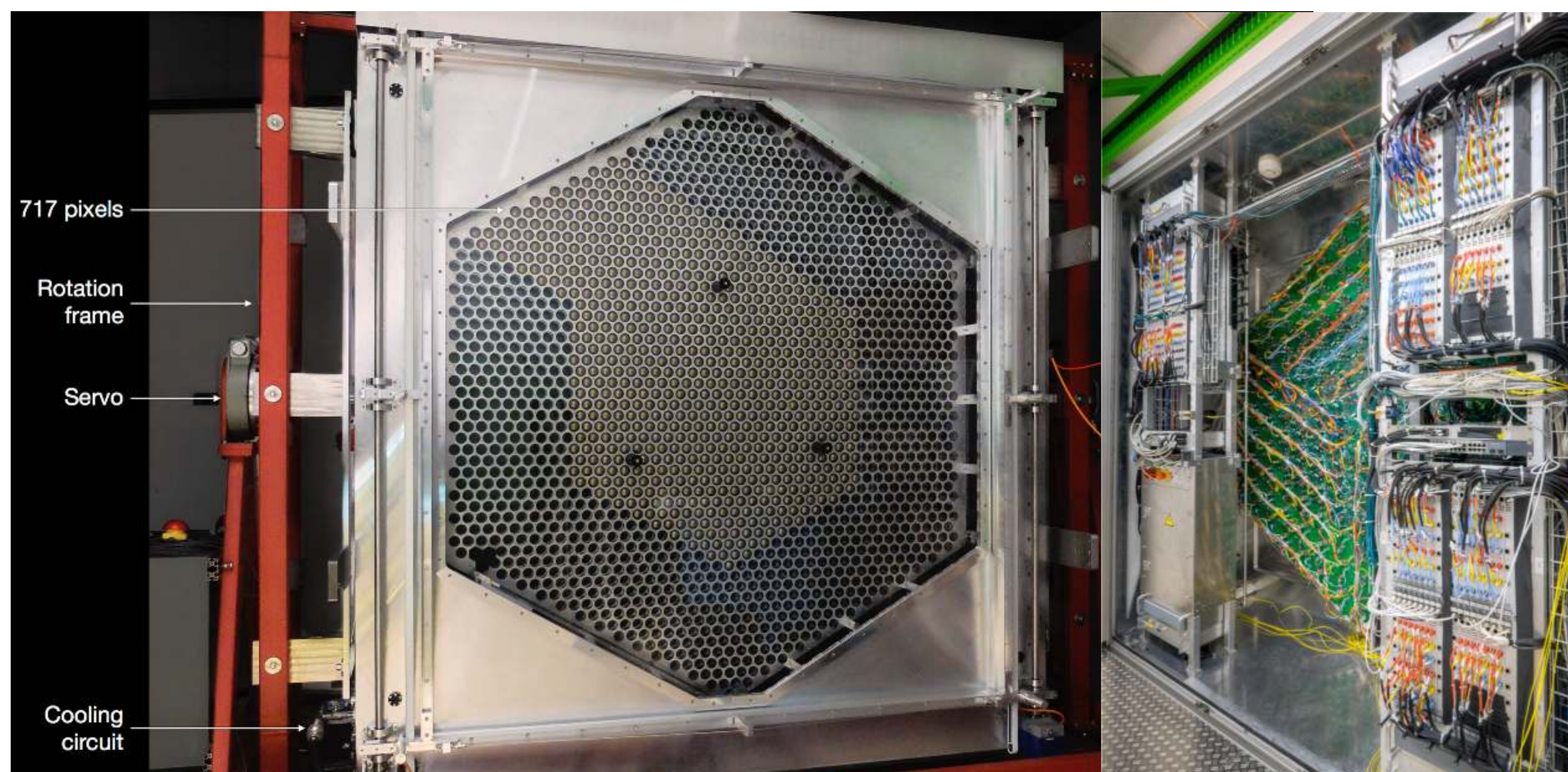
MST Prototype

DESY Zeuthen

France / Spain



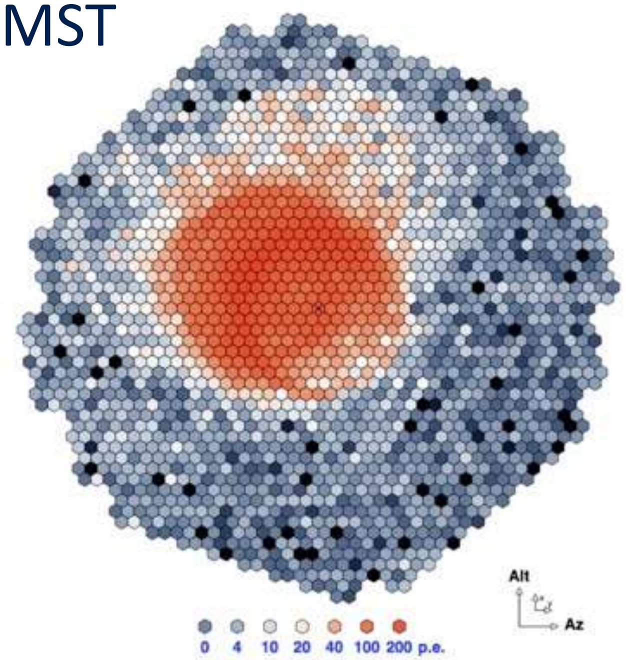
MPIK Heidelberg



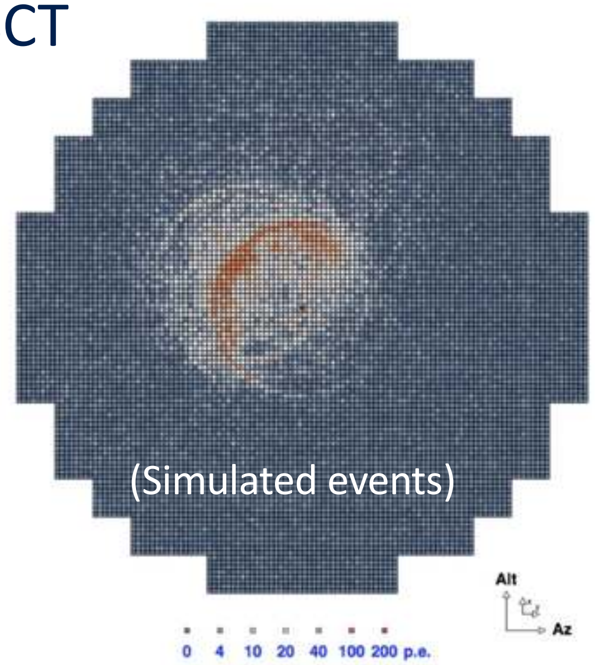
SCHWARZSCHILD COUDER TELESCOPE (SCT)

9.7 m primary
5.4 m secondary
11328 x 0.07° SiPMT pixels

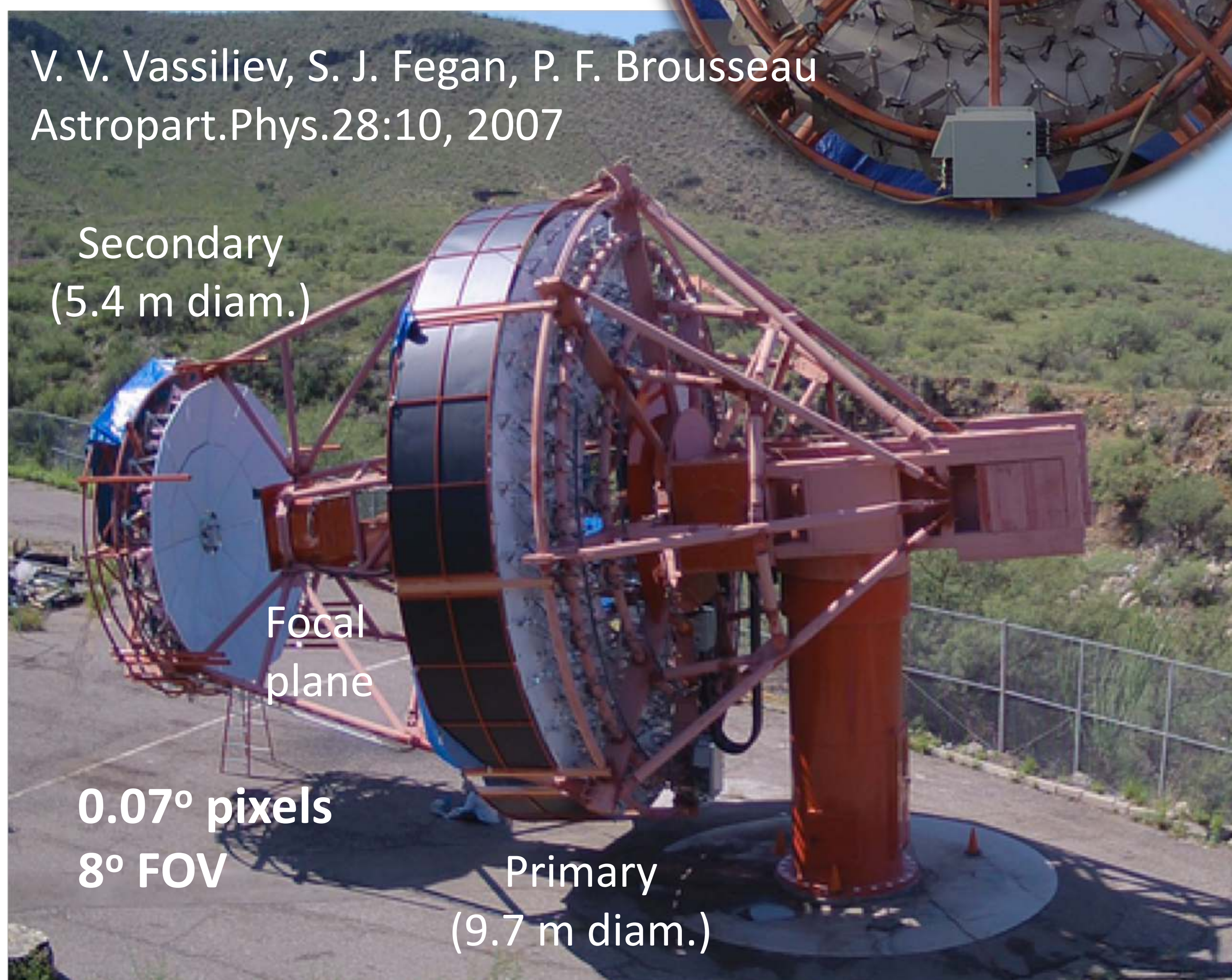
Single-mirror MST



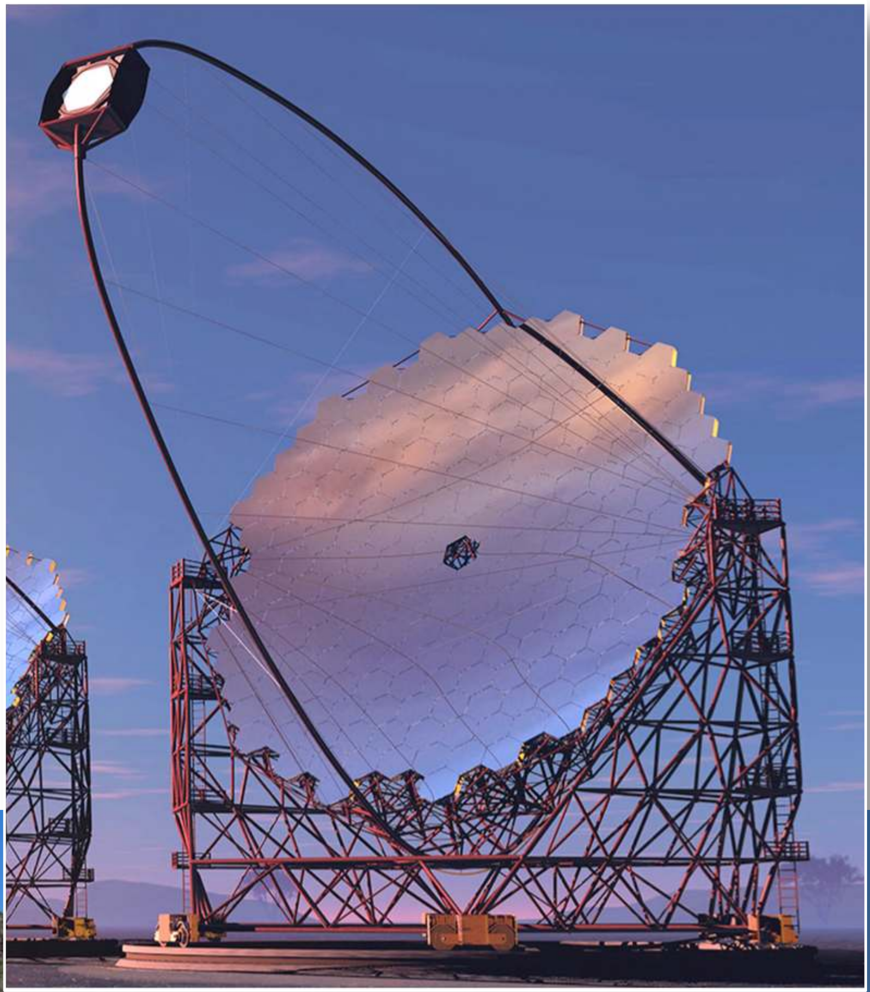
Dual-mirror SCT



Back side of secondary mirror



Large Size Telescope Prototype



Ground breaking on La Palma

SST Prototypes

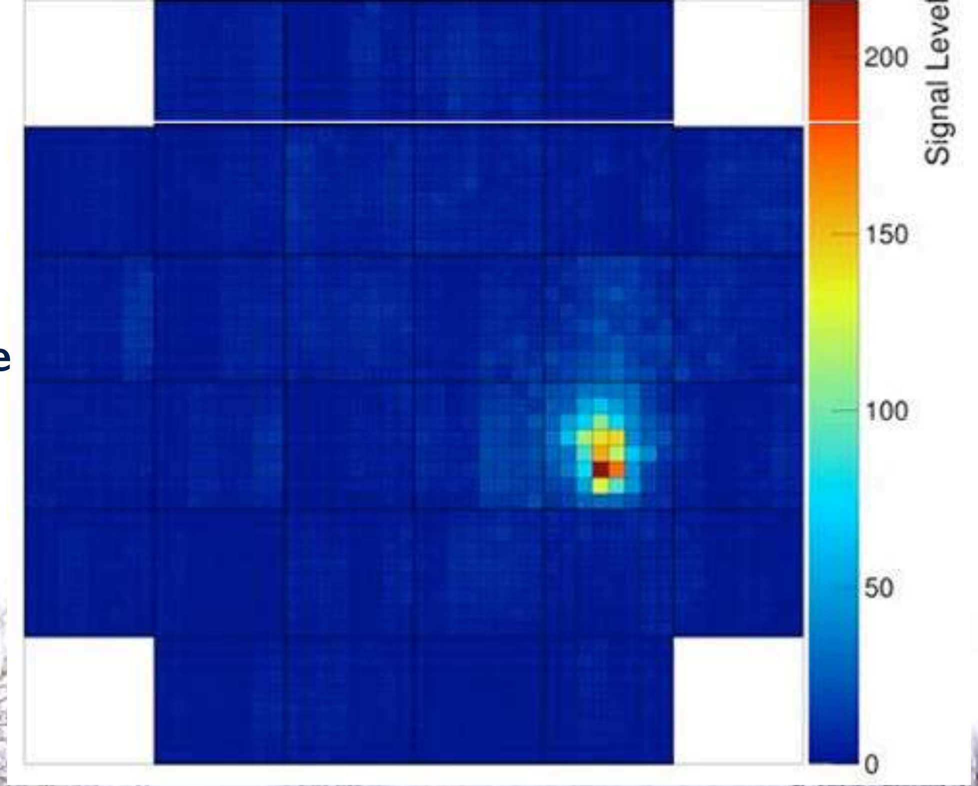
dual mirror telescope

at Cracow

on Sicily

SST Prototype at Meudon

First images from a
dual mirror telescope



Tels. technical data

Telescope	Large	Medium		Small		
	LST	MST	SCT	SST-1M	ASTRI SST-2M	GCT SST-2M
Number North array	4	15	TBD	0		
Number South array	4	25	TBD	70		
Optics						
Optics layout	Parabolic mirror	Davies-Cotton	**Schwarzschild-Couder**	Davies-Cotton	**Schwarzschild-Couder**	**Schwarzschild-Couder**
Primary mirror diameter (m)	23	13.8	9.7	4	4.3	4
Secondary mirror diameter (m)	–	–	5.4	–	1.8	2
Eff. mirror area after shadowing (m^2)	368	88	40	7.4	6	6
Focal length (m)	28	16	5.6	5.6	2.15	2.28
Focal plane instrumentation						
Photo sensor	**PMT**	**PMT**	**silicon**	**silicon**	**silicon**	**silicon**
Pixel size (degr.), shape	0.10, hex.	0.18, hex.	0.07, square	0.24, hex.	0.17, square	0.15-0.2, square
Field of view (degr.)	4.5	7.7/8.0	8.0	9.1	9.6	8.5 - 9.2
Number of pixels	1855	1764/1855	11328	1296	1984	2048
Signal sampling rate	GHz	250 MHz / GHz	GHz	250 MHz	S&H	GHz
Structure						
Mount	alz-az, on circular rail	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner
Structural material	CFRP / steel	steel	steel	steel	steel	steel
Weight (full telescope, tons)	100	85	~85	9	15	8
Max. time for repositioning (s)	20	90	90	60	80	60

Technological challenges:

CTA: – 30 years of operation ***
– in a desert environment, exposed to wind & weather
– earthquake proof

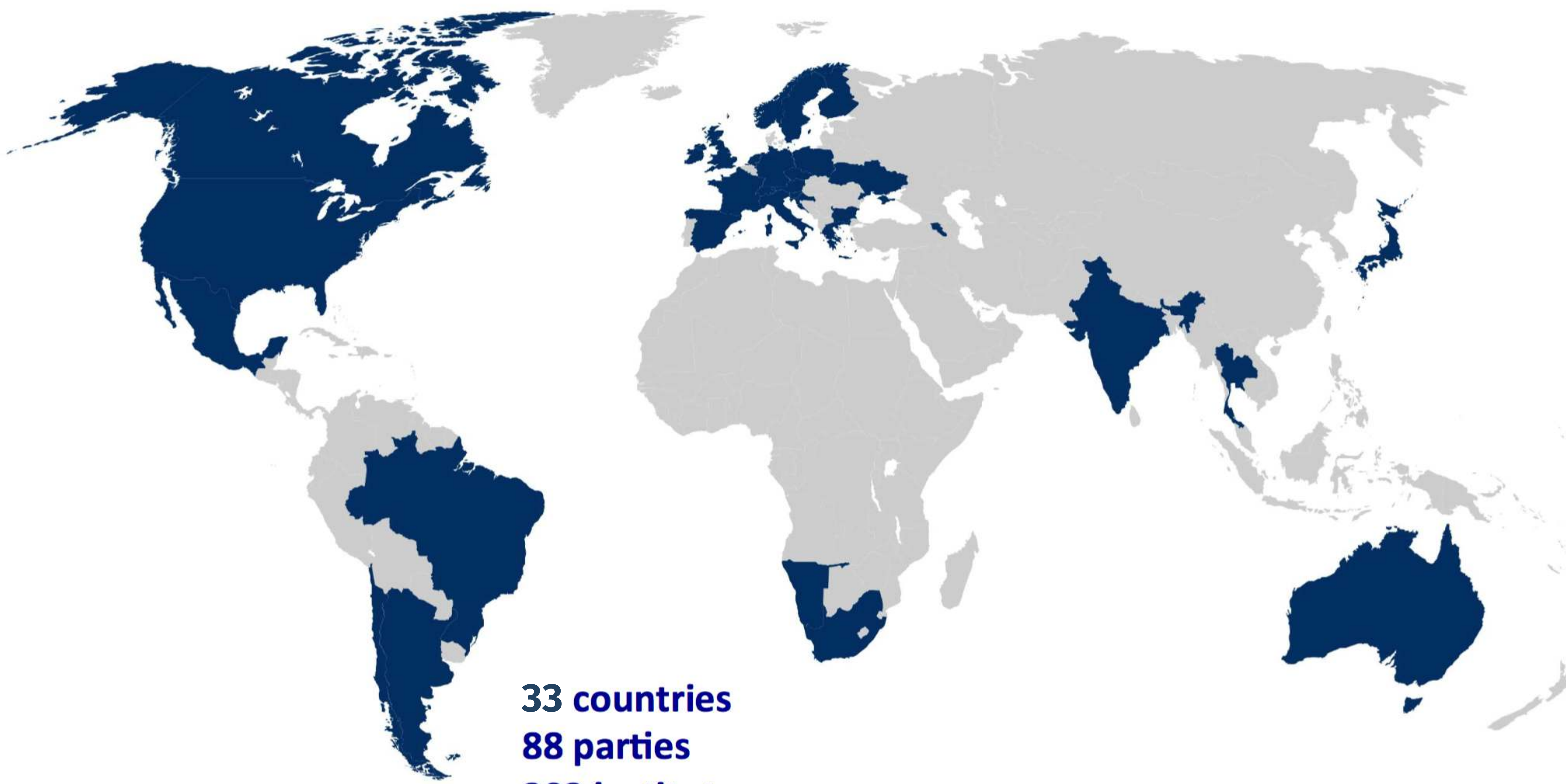
– Opt. & mech. precision (not too good)
– minimal operating costs (≪10% invest/yr) ***

– robust, quick construction,***
error-free operation, easy to maintain ***

– cheap, light-weight, long-lived mirrors
– cheap, efficient photo sensors
– low-power electronics, cooling, computing
....

*** **improved wrt. existing instruments**

CTA Consortium



33 countries
88 parties
202 institutes
1308 members (438 FTE)

Argentina, Armenia, Australia, Austria, Brazil, Bulgaria, Canada, Chile, Czech Republic, Croatia, Finland, France, Germany, Greece, India, Italy, Ireland, Israel, Japan, Mexico, Namibia, Netherlands, Norway, Poland, Slovenia, Spain, South Africa, **Sweden**, Switzerland, Thailand, UK, Ukraine, USA

Main Science Themes:

Cosmic Particle Acceleration

- Particle acceleration
- Particle propagation
- Impact of rel. particles on their environment

Probing Extreme Environments

- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Cosmic voids

Physics frontiers

- Nature & distribution of Dark Matter
- Lorentz-Invariance at high energies
- Axion-like particles
- Exotics

CTA Key Science Projects

Key Science Projects

Theme		Question	Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
	1.2	What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	✔
	1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
	2.2	What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
	2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
	3.2	Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
	3.3	Do Axion-like particles exist?					✔	✔			✔✔	

Surveys **Targets**

CTA is a new, powerful observatory for ground-based gamma-ray astronomy

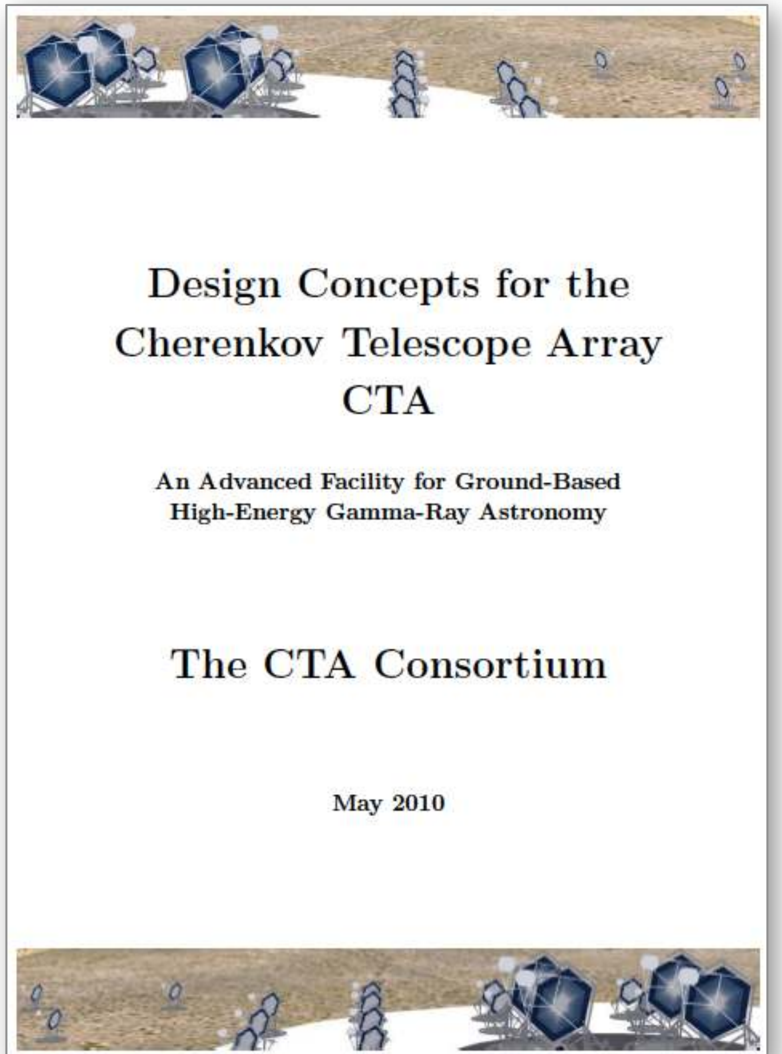
- has a huge science potential (for a moderate price)
- offers an attractive mix of discovery potential and a wealth of "guaranteed" good astrophysics,
- complements data from other wavelengths / messengers
- is almost production ready,
- first funding is in hand / construction start very soon ...

CTA will considerably advance our knowledge on high-energy astrophysics and cosmic accelerators.

https://www.cta-observatory.org

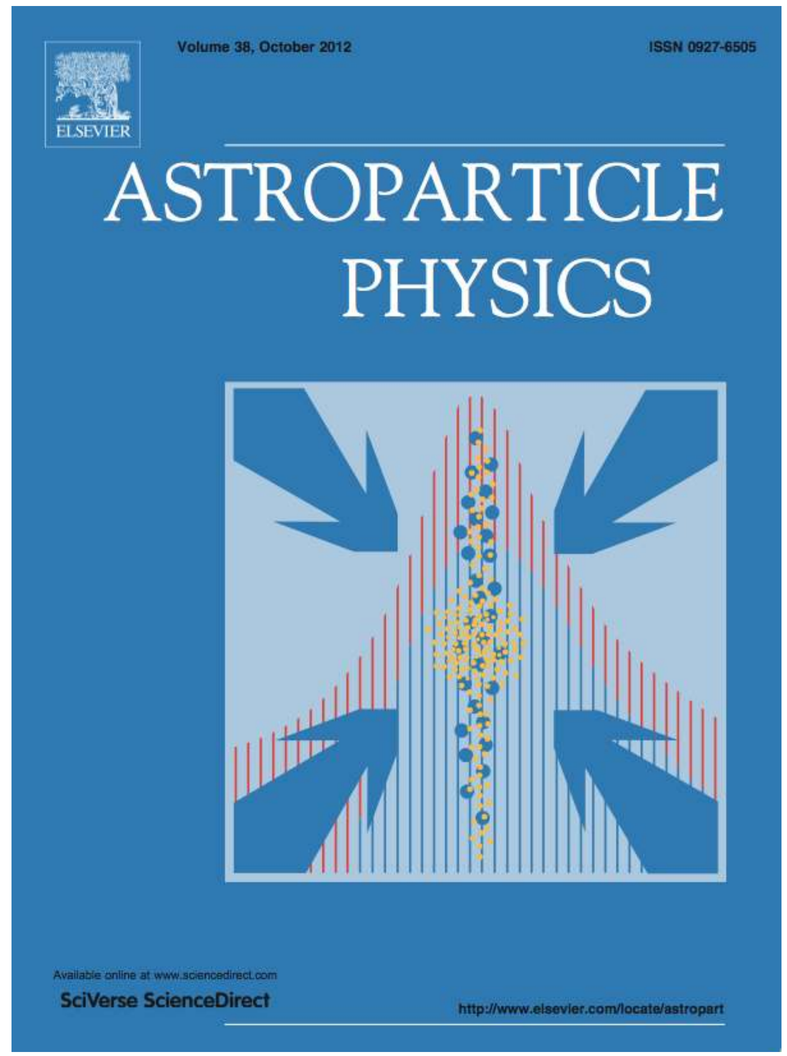
More Details:

general info: www.cta-observatory.org



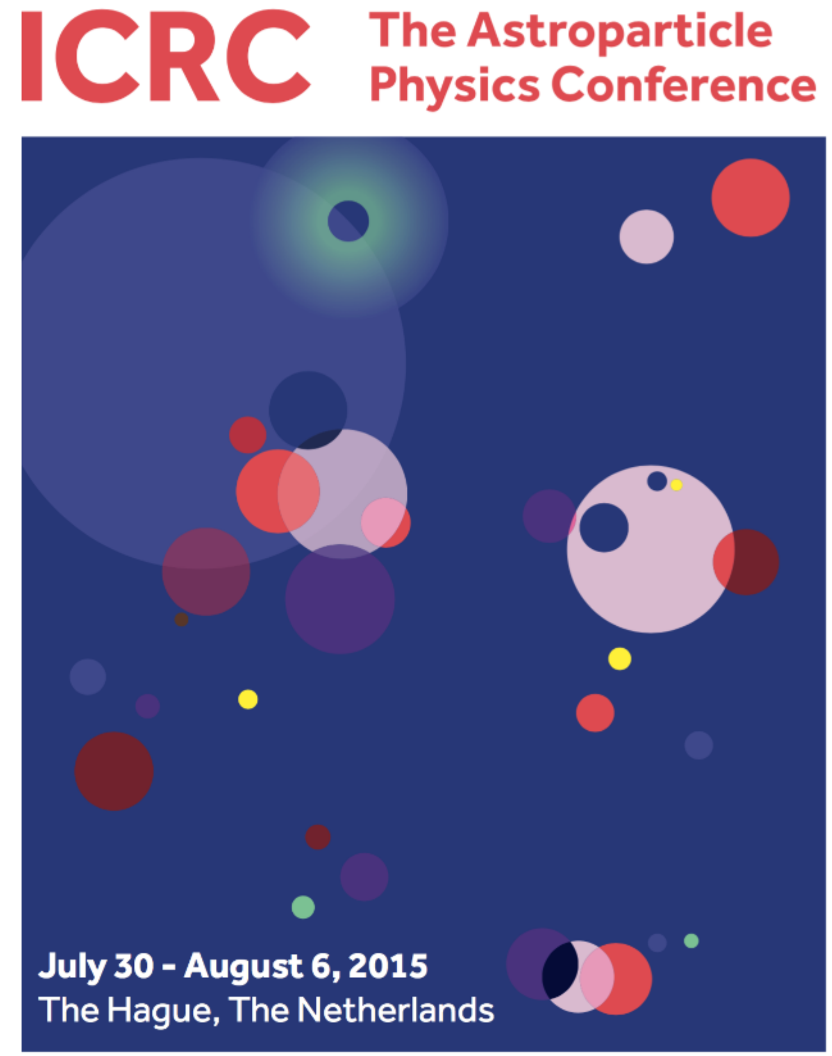
“Design Concepts for the Cherenkov Telescope Array”

120 pages
Exp. Astronomy 32 (2011) 193-316



“Seeing the High-Energy Universe with the Cherenkov Telescope Array”

24 articles, 356 pages
Astroparticle Physics 43 (2013) 1-356



CTA Contributions to the 34th ICRC 2015, Den Haag

60 papers
arXiv:1508.05894

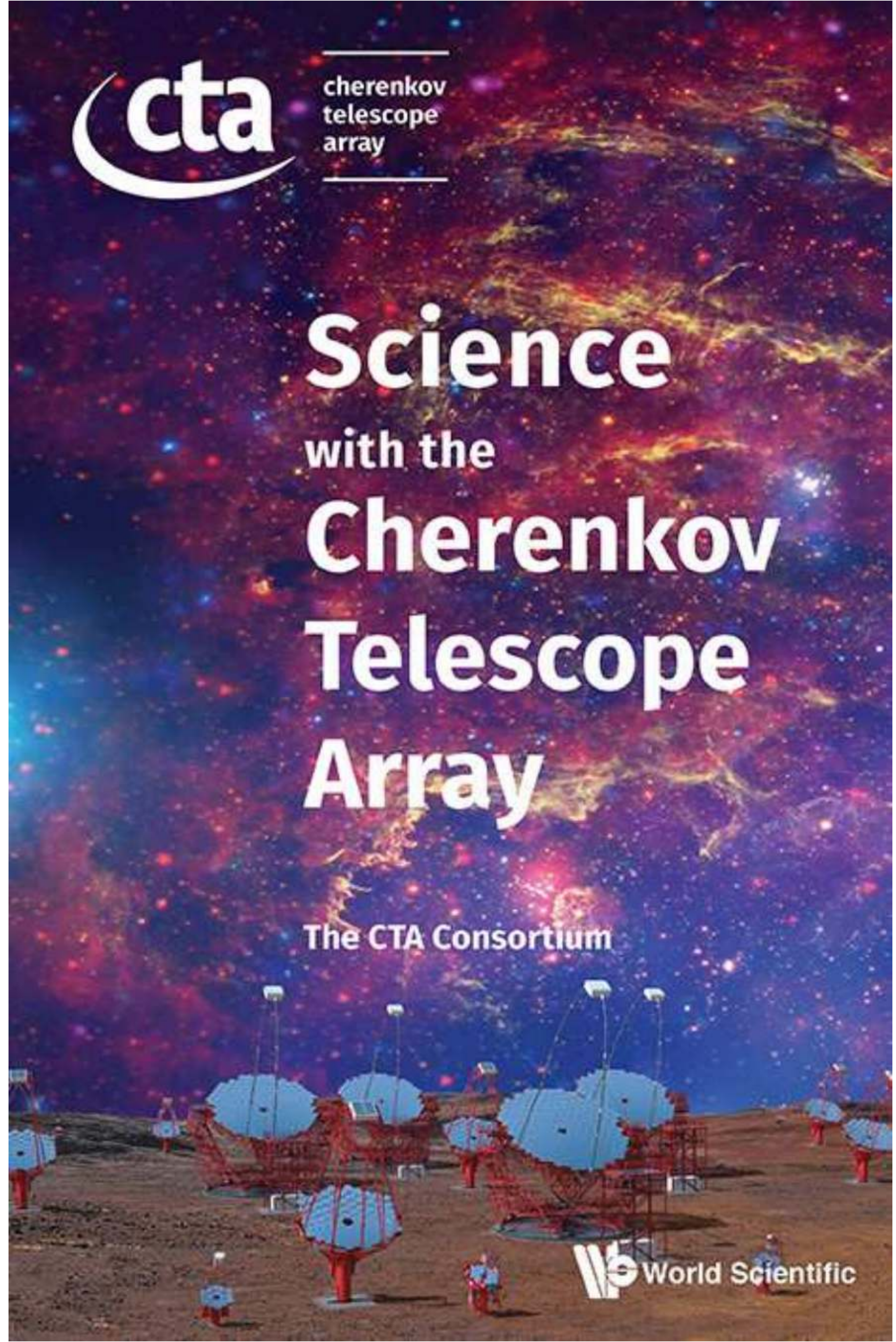
Key Science Projects

arXiv 1709.07997   2017

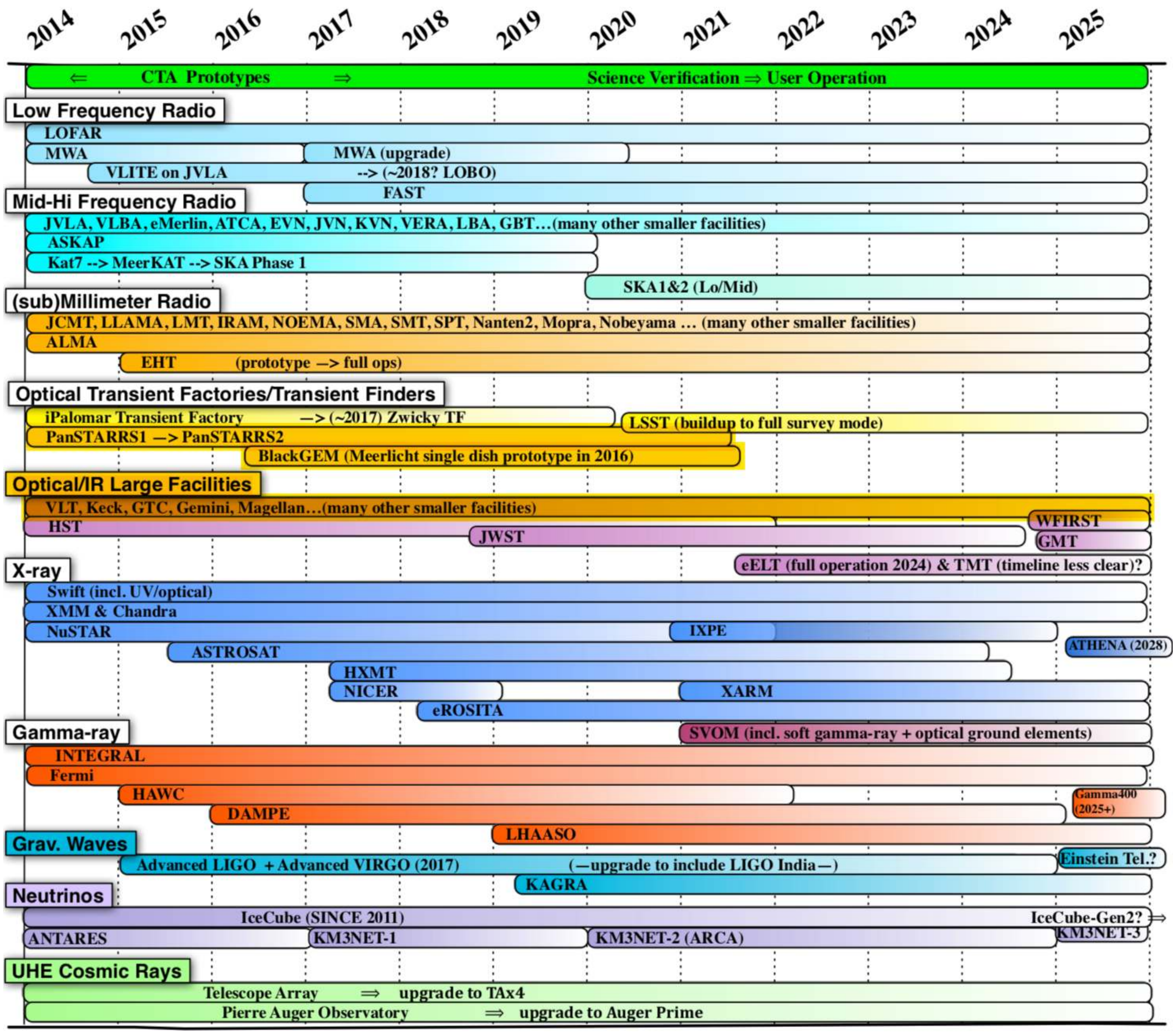
World Scientific 2019
https://doi.org/10.1142/10986

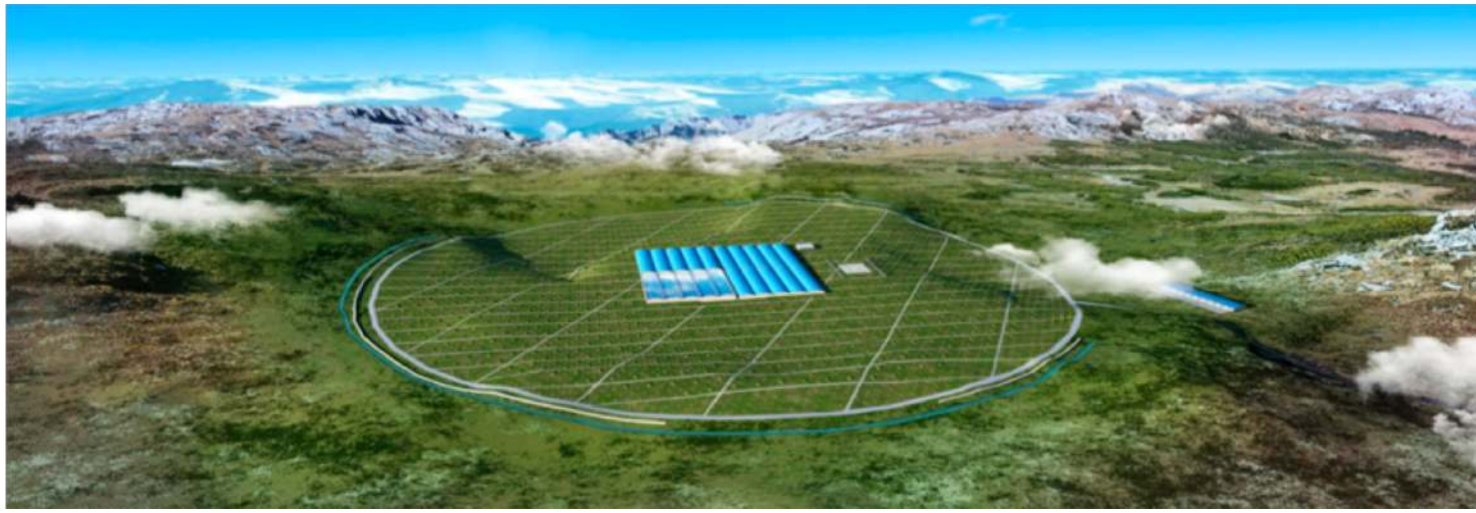
210 pages

Contents



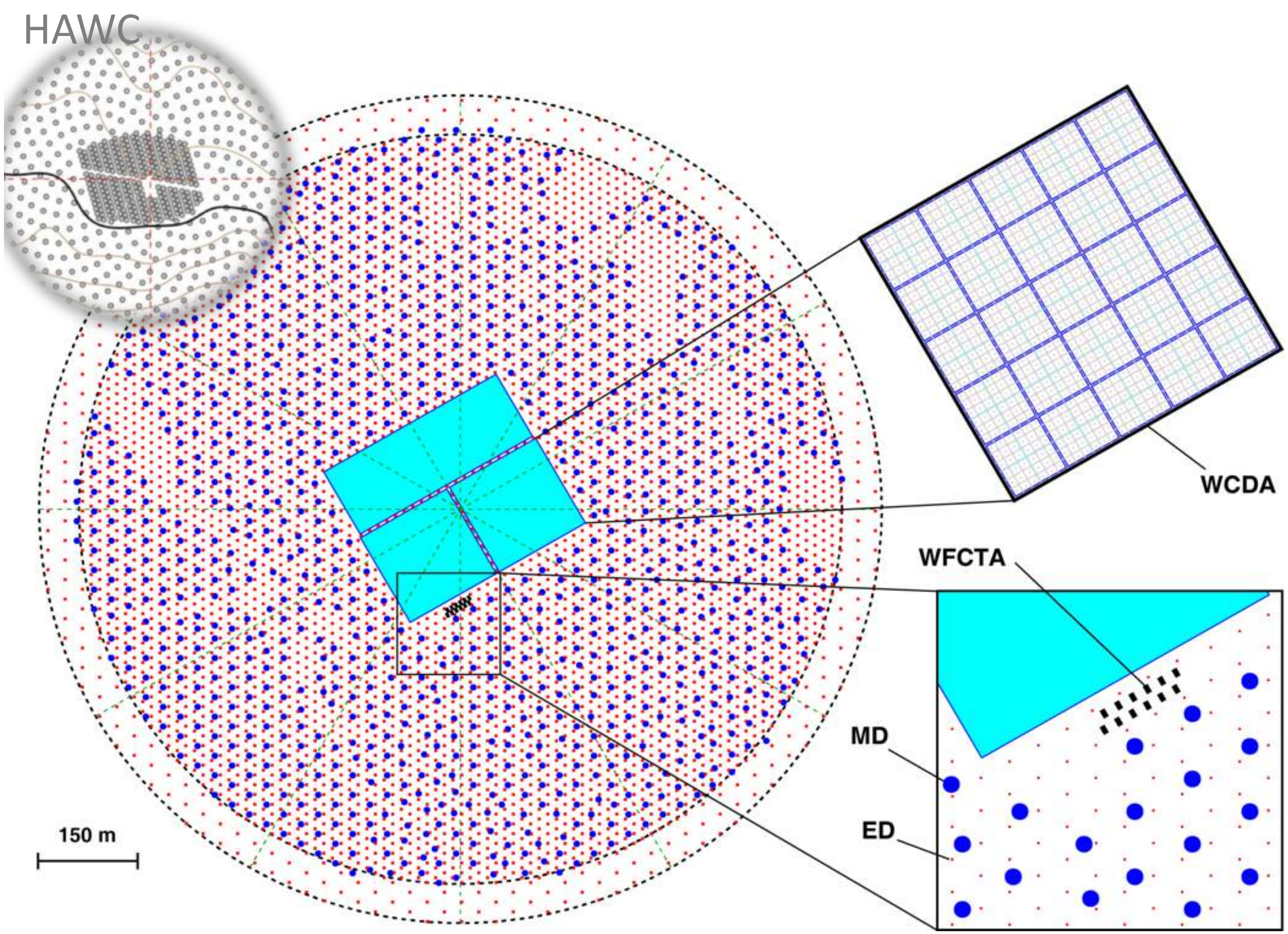
Synergies with other existing and upcoming instruments





LHAASO

Sichuan, China, 4410 m asl



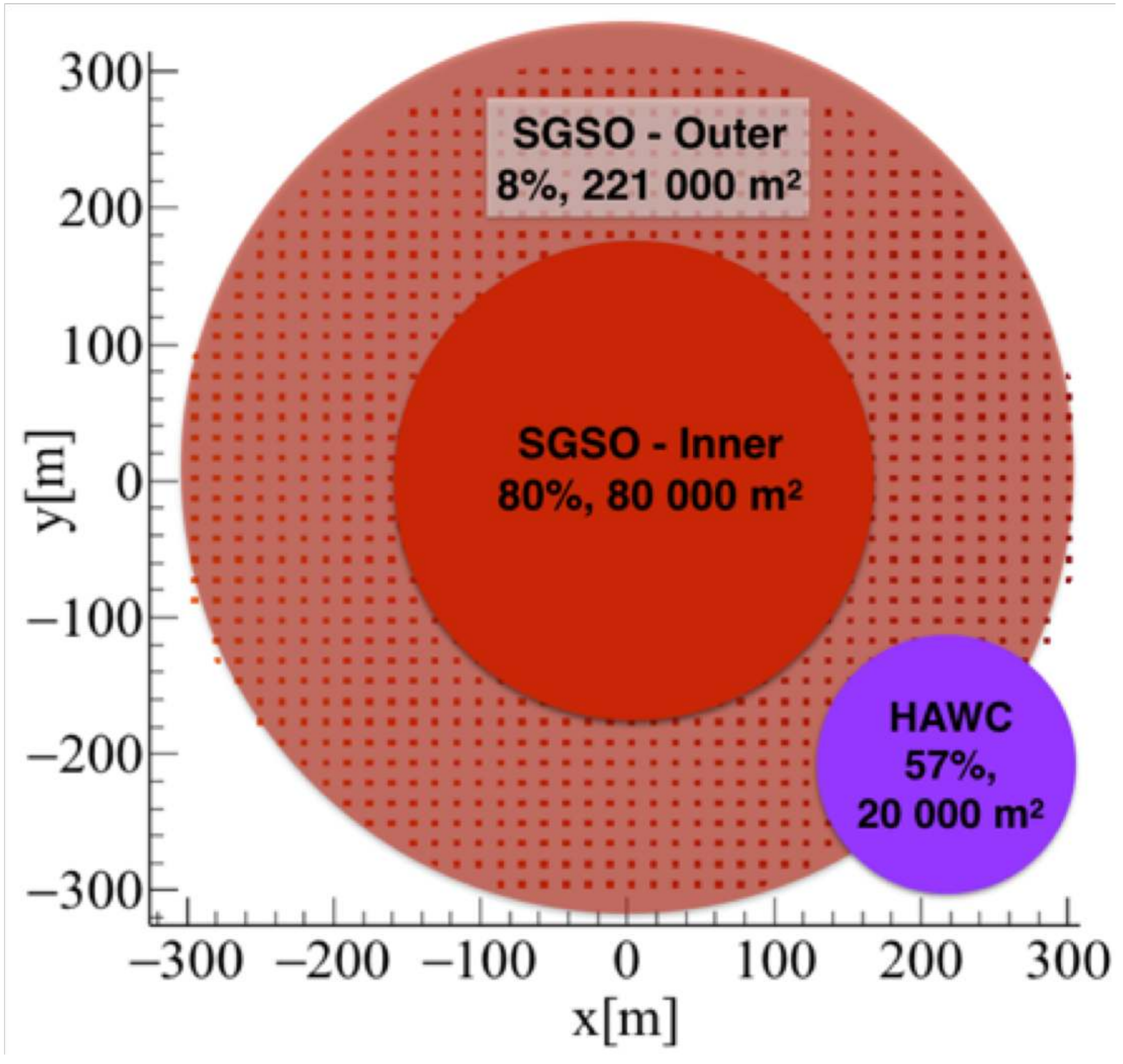
5195 Scintillators
- 1 m^2 each
- 15 m spacing

1171 Muon Detectors
- 36 m^2 each
- 30 m spacing

3000 Water Cherenkov Cells
- 25 m^2 each

12 Wide Field Cherenkov Telescopes

SOUTHERN
GAMMA-RAY
SURVEY
OBSERVATORY

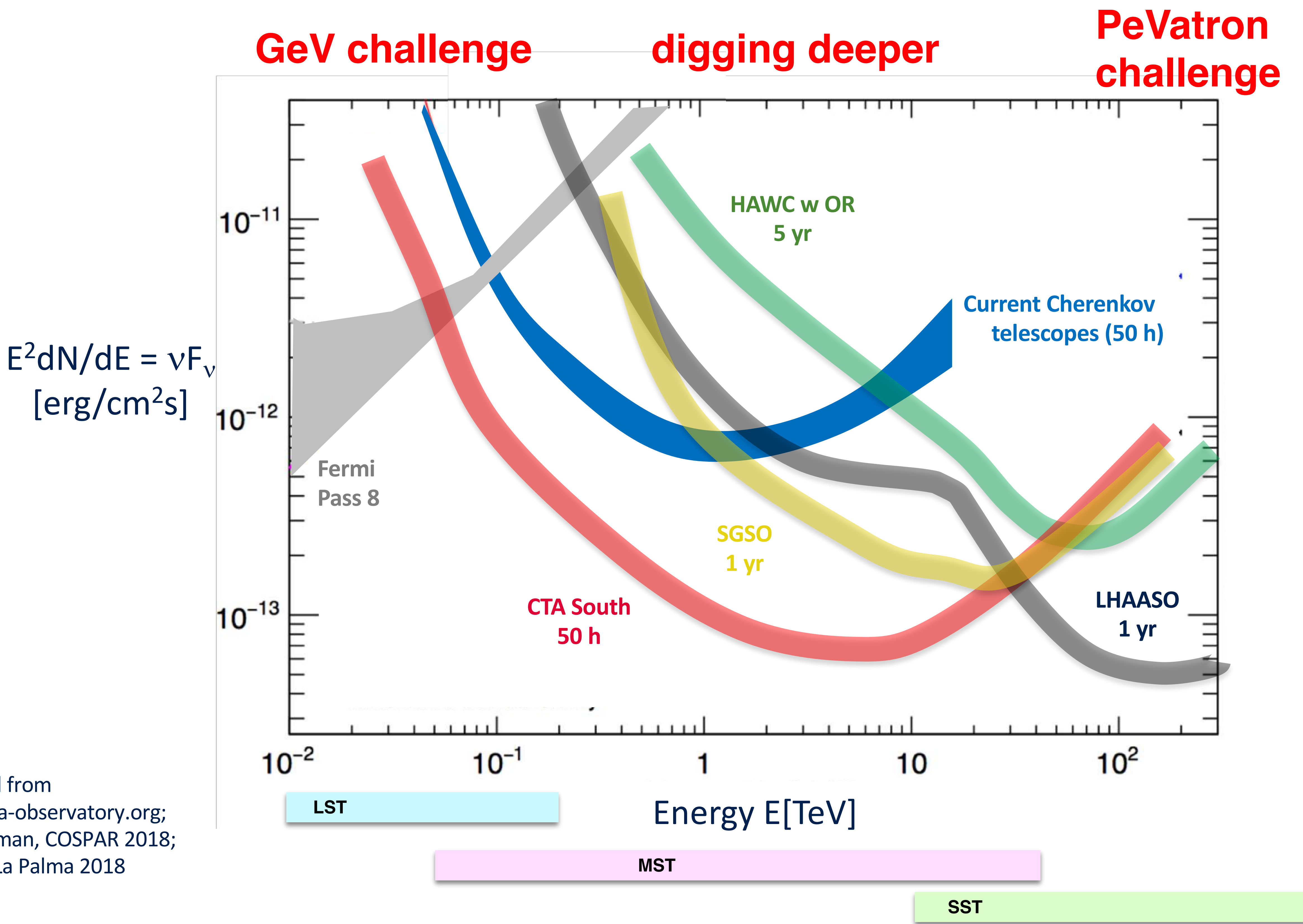


SGSO

an enlarged version
of HAWC in the South

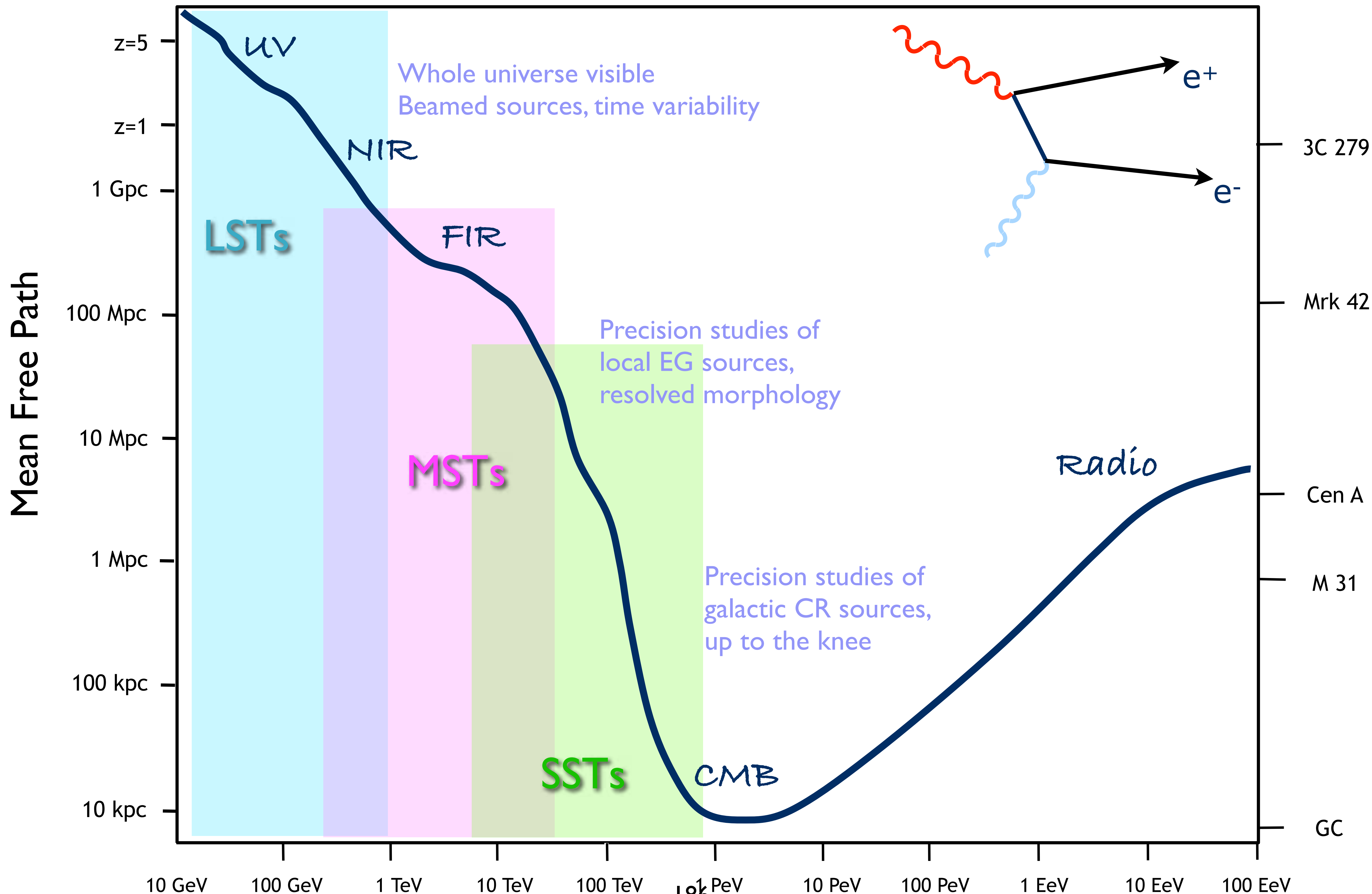
Dense core area ≈ LHAASO

SENSITIVITY (STEADY SOURCES)



adapted from
www.cta-observatory.org;
J. Goodman, COSPAR 2018;
Z. Cao, La Palma 2018

The Gamma-Ray Horizon $\gamma_{VHE} + \gamma \longrightarrow e^+e^-$



Multi-Messenger Physics:

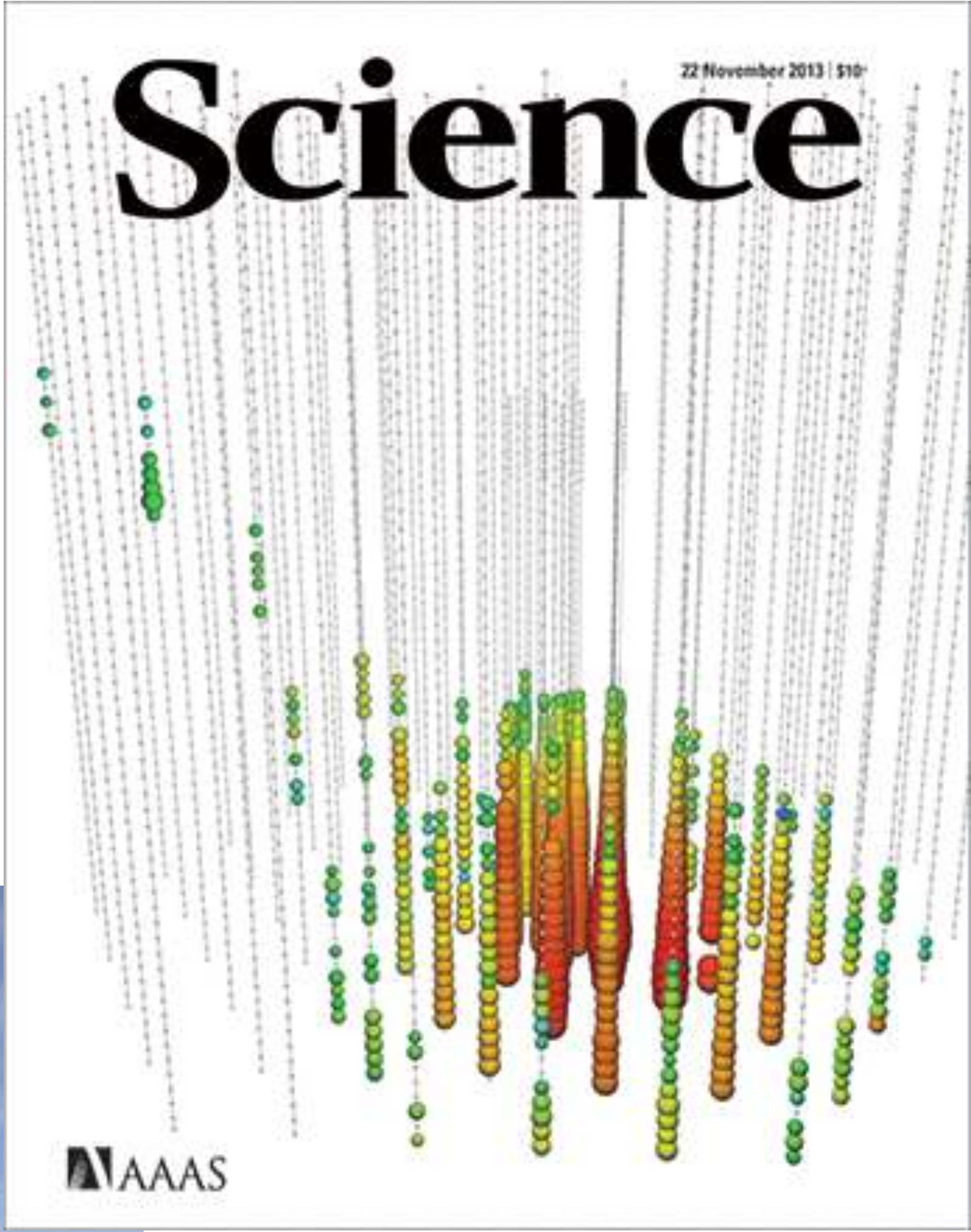
Radio	LOFAR, ALMA, SKA …
optical	VLT, GMT, eELT, LSST, …
X-rays	SWIFT, XMM, SVOM, …
Gamma rays (keV-GeV)	Fermi, DAMPE, …
(TeV)	HAWC, LHAASO, **CTA**
neutrinos	IceCube/Gen2, KM3NeT
gravitational waves	Adv Ligo, KAGRA, Ligo-India

many complementary / contemporary experiments

28 high-energy νs

Clear evidence for astrophysical origin

($>5\sigma$)



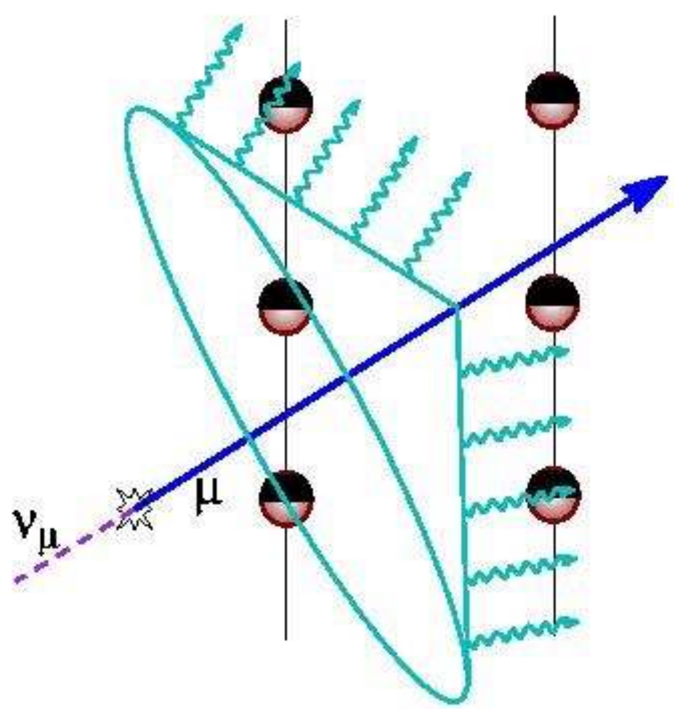
Nov 2013

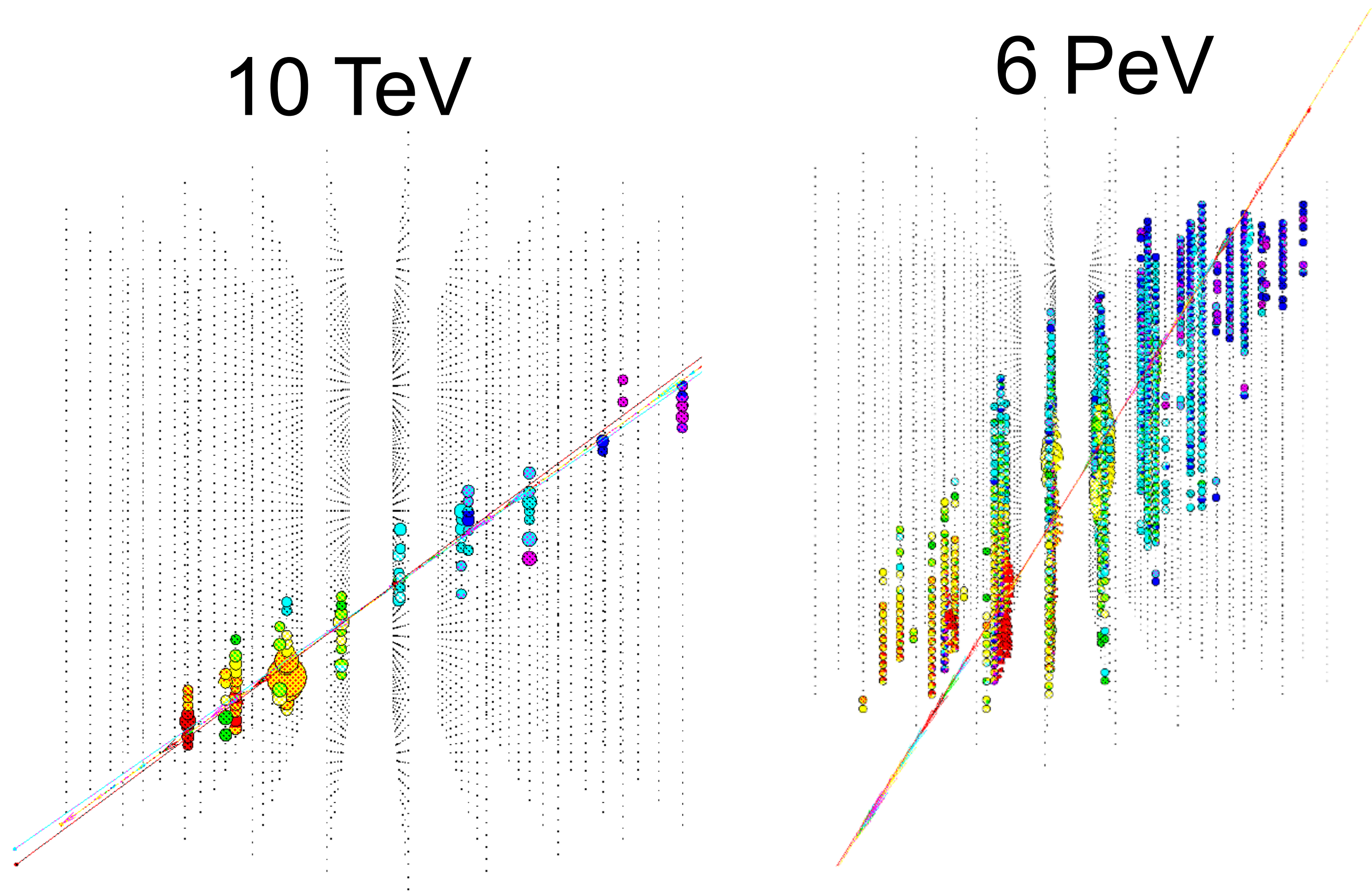
Neutrinos create charged particles
which in turn produce Cherenkov light.

Muon-tracks

good pointing (<1 degree)

large event rates due to long muon tracks



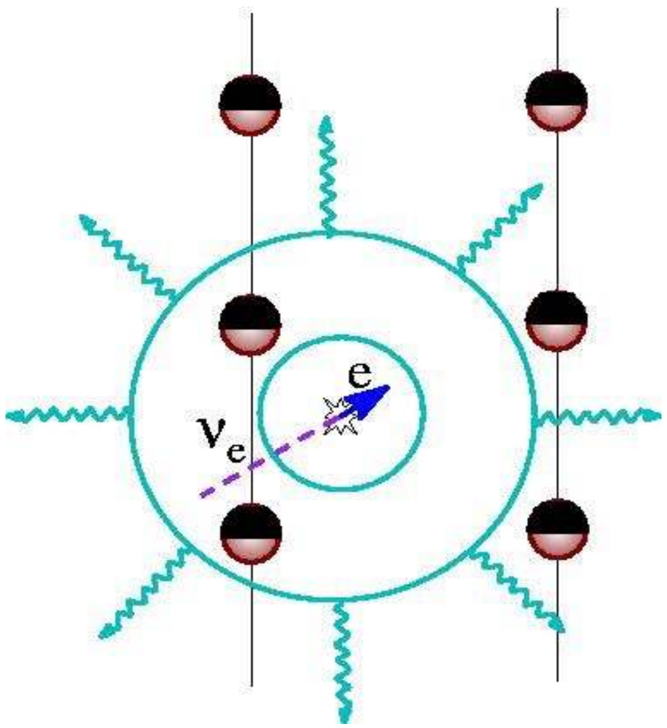


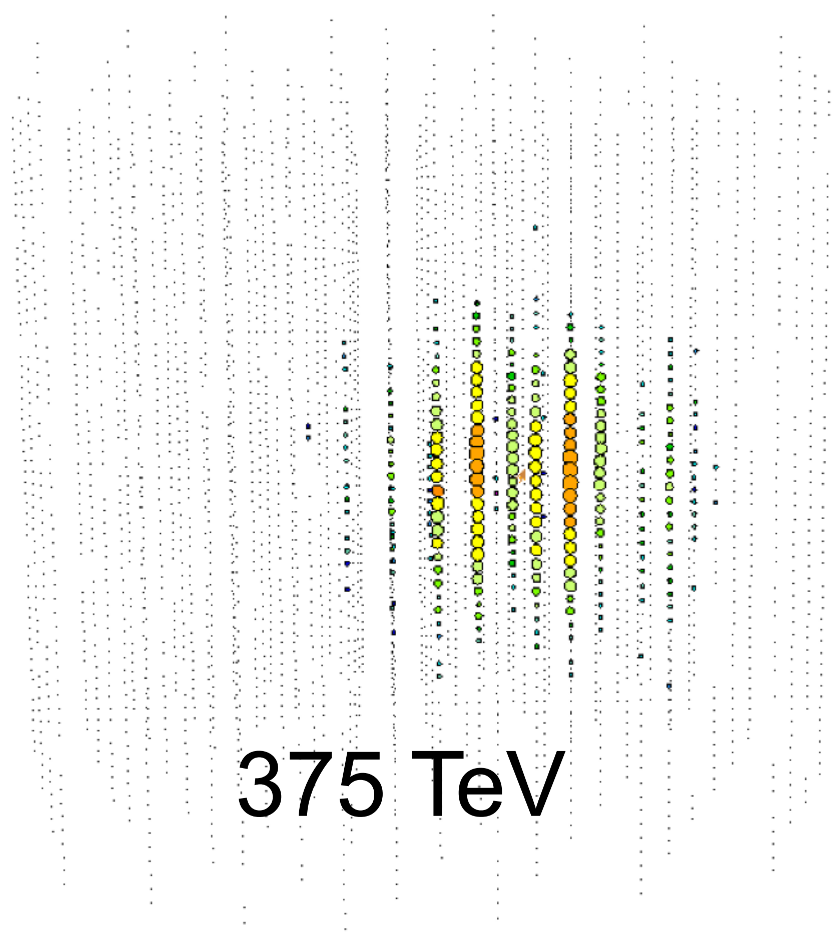
signature of ν_μ

Particle cascades

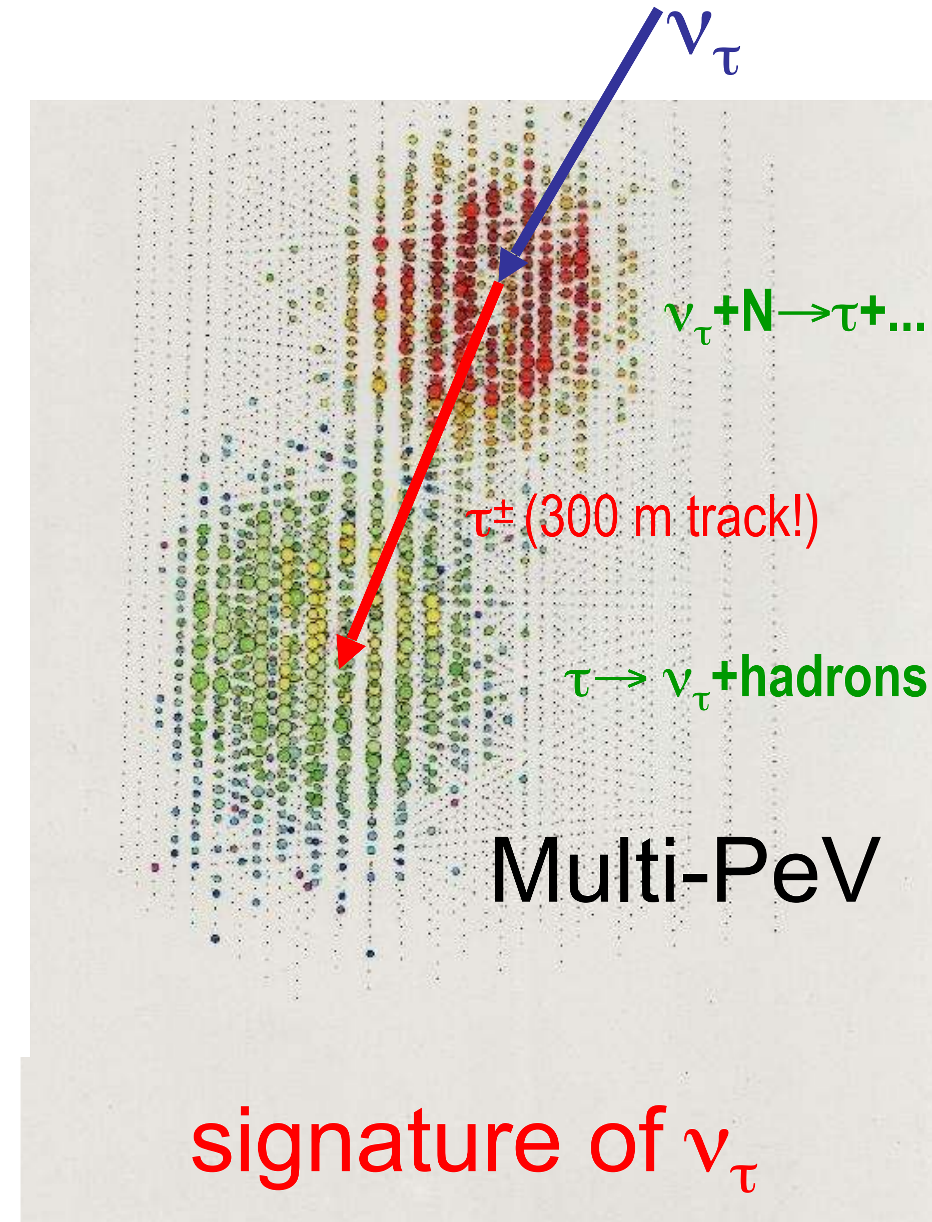
ν_e , ν_τ

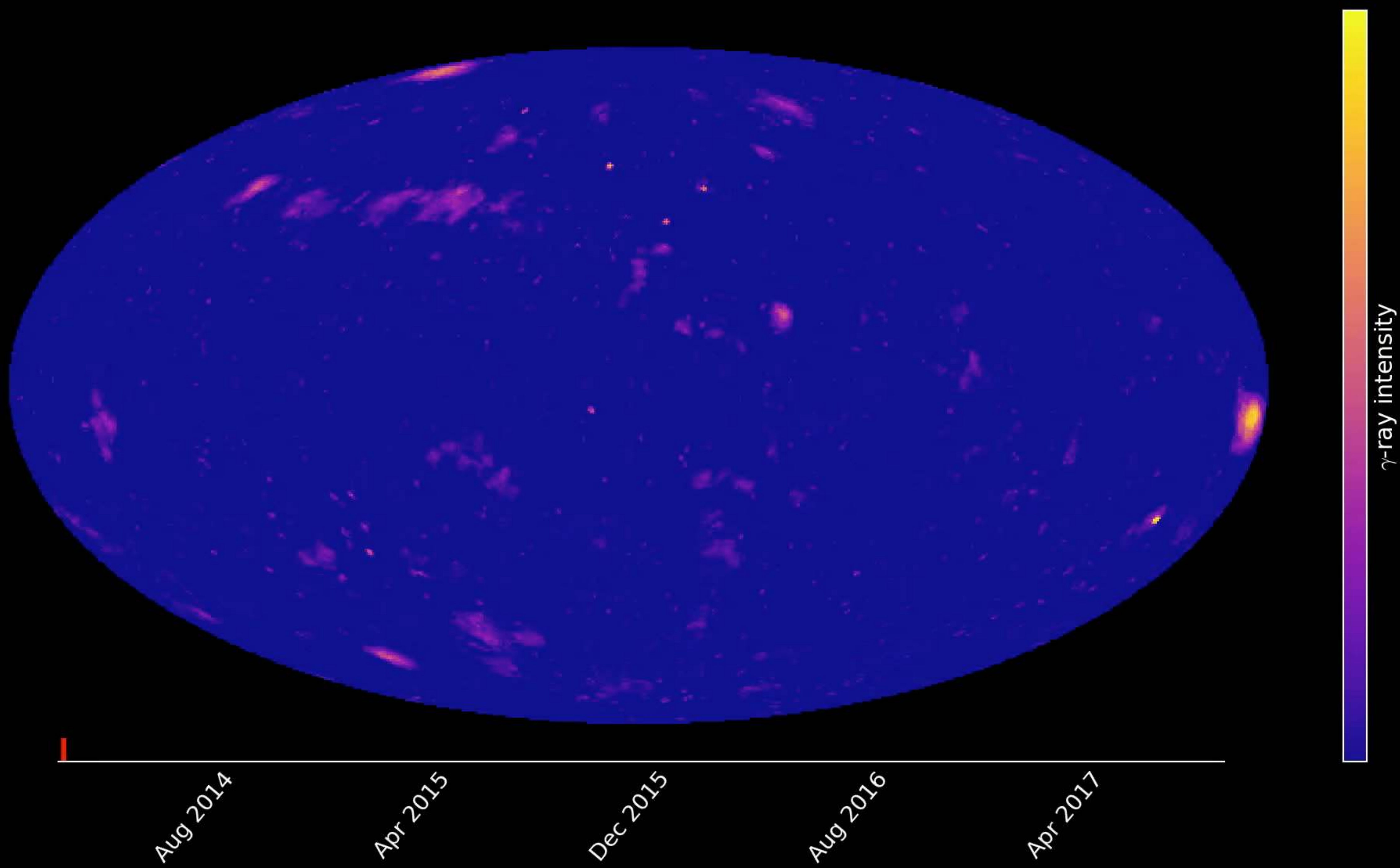
good energy resolution,
little background





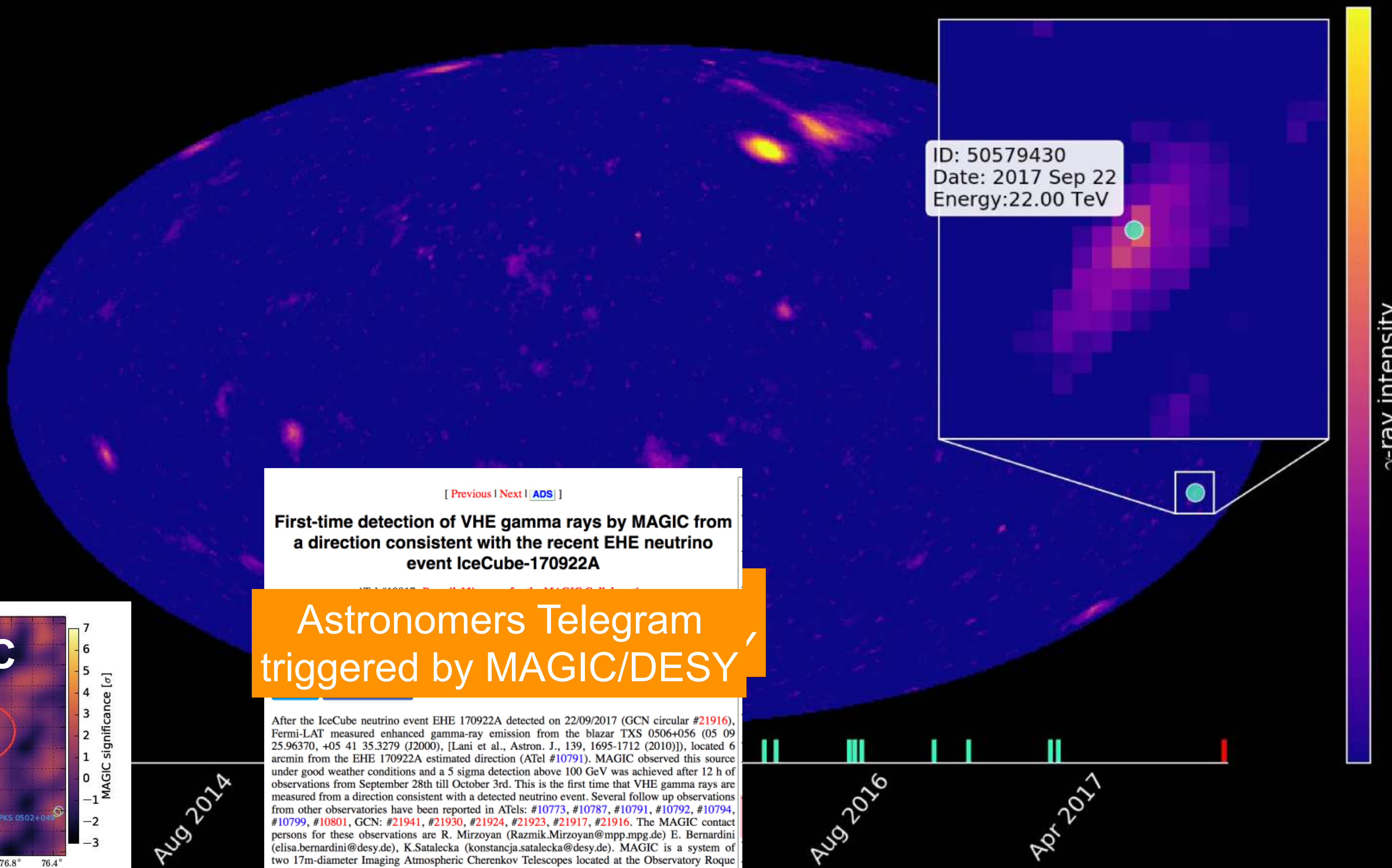
signature of ν_e

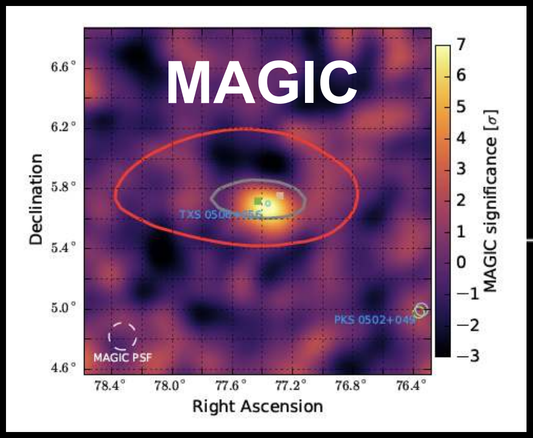




Aug 2014
Apr 2015
Dec 2015
Aug 2016
Apr 2017
γ-ray intensity

Science paper: IceCube + MAGIC + VERITAS + H.E.S.S. + Fermi-LAT





[Previous | Next | ADS]

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

Astronomers Telegram triggered by MAGIC/DESY

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10787, #10791, #10792, #10794, #10799, #10801, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstancja.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

~~A~~ The neutrino event in IceCube

TXS 0506+56

High-energy, through going track

IC170922A
Alert sent
Sep 22, 2017
via *Realtime* stream

Coincident observations by Fermi-LAT and MAGIC

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasyuki T. Tanaka* … *Daniel Kocevski (NASA/MS* …

Further Swift-XRT observations of IceCube 170922A

ATel #10792; *P. A. Evans (U. Leicester) A. Keivani (PSU), J. A. Kennea (PSU), D. B.* … *cester), and F. E. Marshall* … *be collaboration:*

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

ATel #10794; *A. Franckowiak (DE* … *(OSU), T. W.-S. Holoien, B. J* … *(Diego Portale* …

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

ATel #10801; *F. Lucarelli (SSDC/ASI and INAF/OAR), G. Piano (INAF/IAPS), C.* … *AR), M. Tavani (INAF/IAPS, and Univ.* … *-Bo), P. Munar-Adrover, G. Minervini,* … *DA-Brera), I. Donnarumma (ASI), V.* … *(CIFS and INAF/IAPS), M. Cardillo* … *tti, M. Trifoglio (INAF/IASF-Bo), A.* … *otti (INAF/IASF-Mi), A. Chen (Wits* … *onte, Y. Evangelista, M. Feroci, F.* … *Soffitta, S. Sabatini, V. Vittorini* … *ENEA-Frascati), G. Di Cocco, F.* … *(INAF/IASF-Bo), A. Pellizzoni, M.* … *llini, E. Vallazza (INFN Trieste), F.* … *orselli, P. Picozza (INFN and Univ.* … *ia), P. Lipari, D. Zanello (INFN and* …

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT

Joint Swift XRT and NuSTAR Observations of TXS 0506+056

ATel #10845; *D. B. Fox (PSU), J. J* … *(U. Leicester), C. F. Turley (PSU* … *Osborne (U. Leicester), M.* …

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

ATel #10838; *H. Negoro (Nihon U.), S. Ueno, H. Tomida, M. Ishikawa, Y. Sugawara,* … *ki, S. Nakahira, W. Iwakiri,* … *N), N. Kawai, S. Sugita, T.* … *), A. Yoshida, T. Sakamoto,* … *U), H. Tsunemi, T. Yoneyama* … *on U.), Y. Ueda, T. Hori, A.*

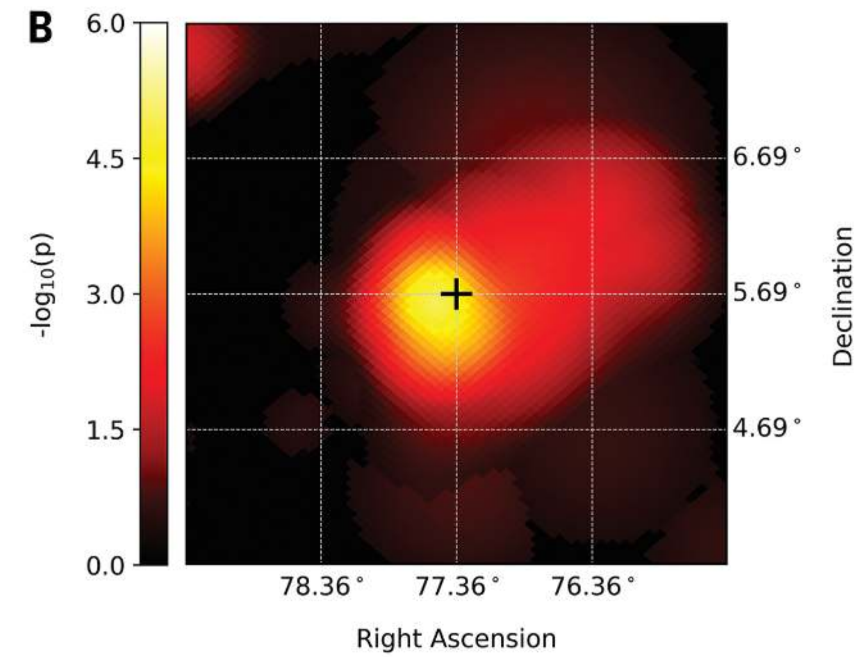
VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event

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

Science 361 (2018) no.6398, eaat1378

IC170922A / TXS 0506+56

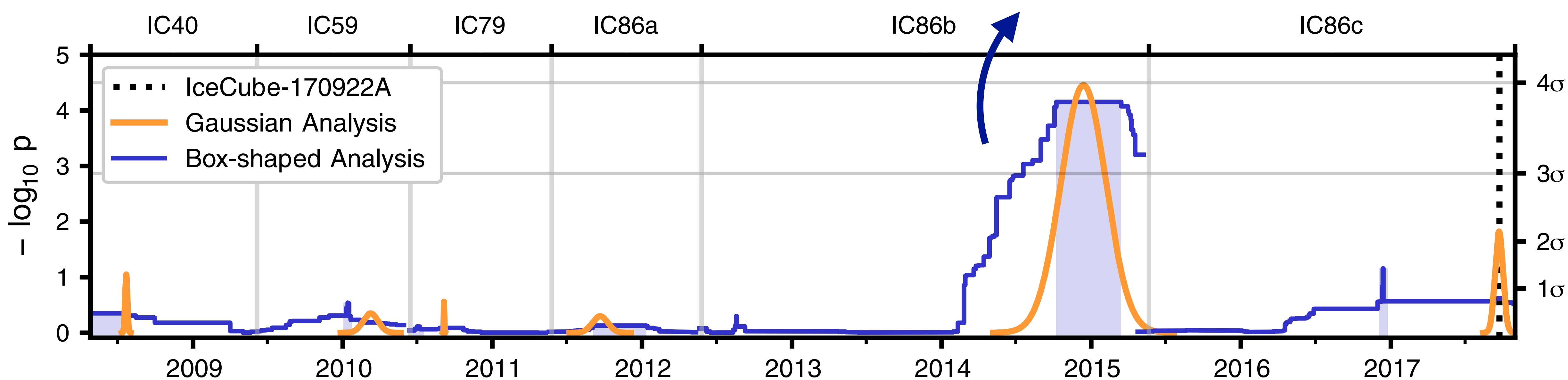
First evidence for a neutrino point source



Archival search

- Check historical IceCube data for pileup of neutrinos from direction of TXS 0506+56
- Look for clustering in time

T. Kintscher



Science 361 (2018) no.6398, 147-151

Inconsistent with background-only hypothesis at the 3.5σ level

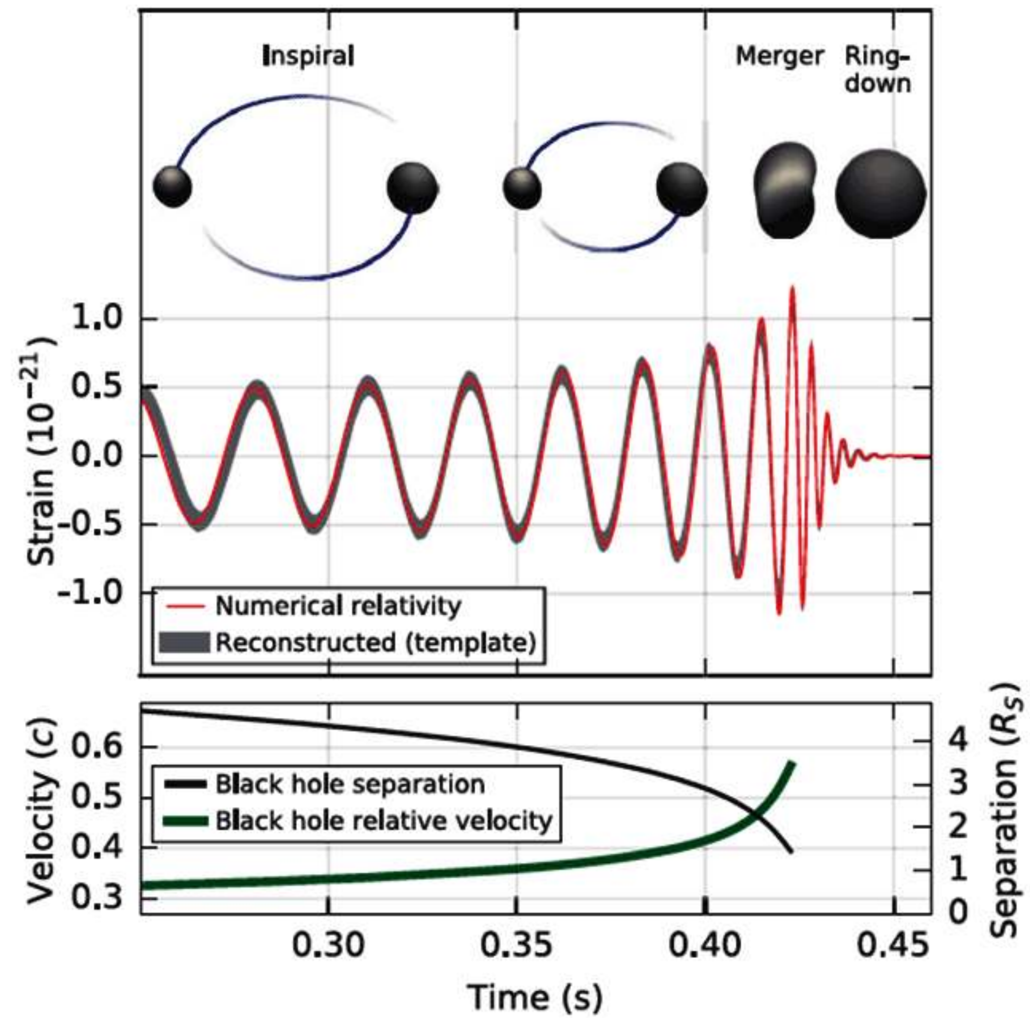
Independent of the 2017 alert when looking in this specific direction!

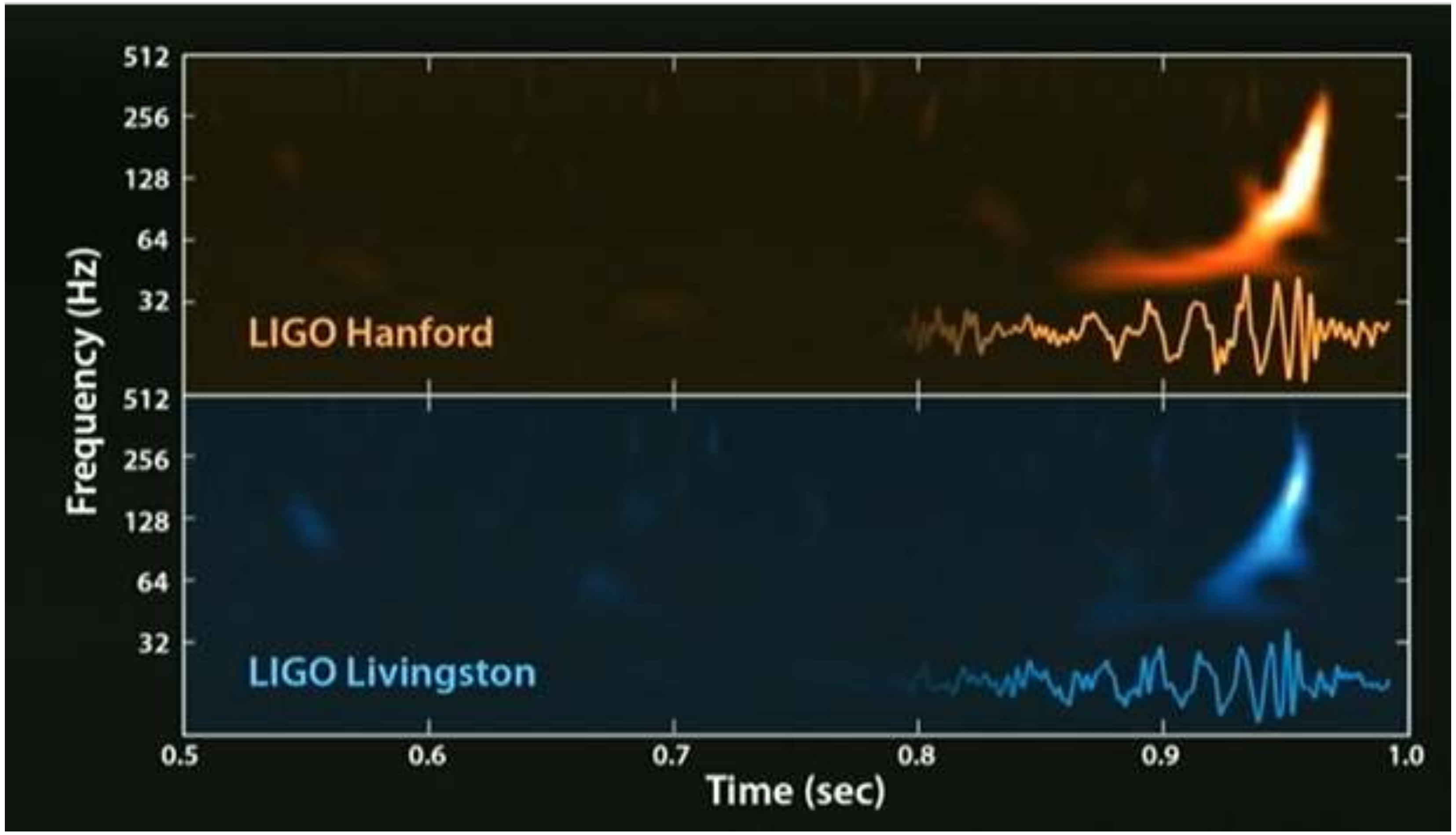
Gravitational Waves:

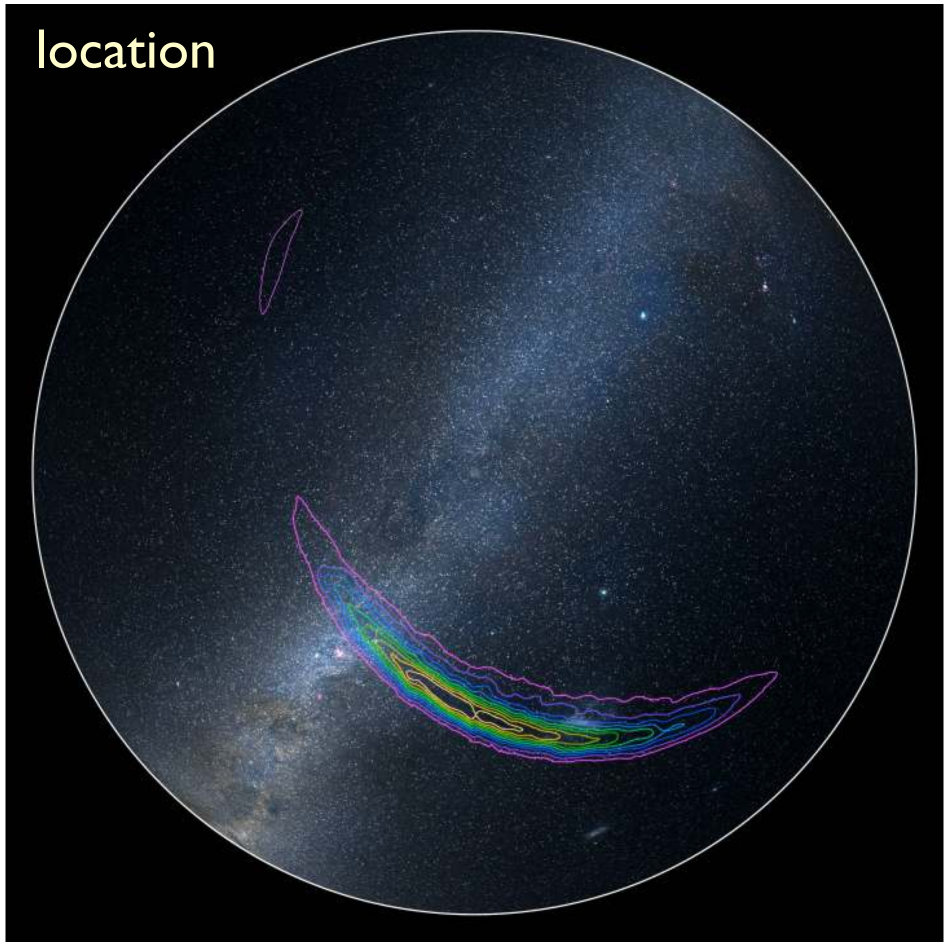
event GW150914 : Merger of two black holes
29 and 36 solar masses
1.3×10^9 light years away

New messenger in the multi-messenger approach to high-energy astrophysics.

Do grav. events produce also other measurable outputs (light, neutrinos, gamma rays)? Some might …

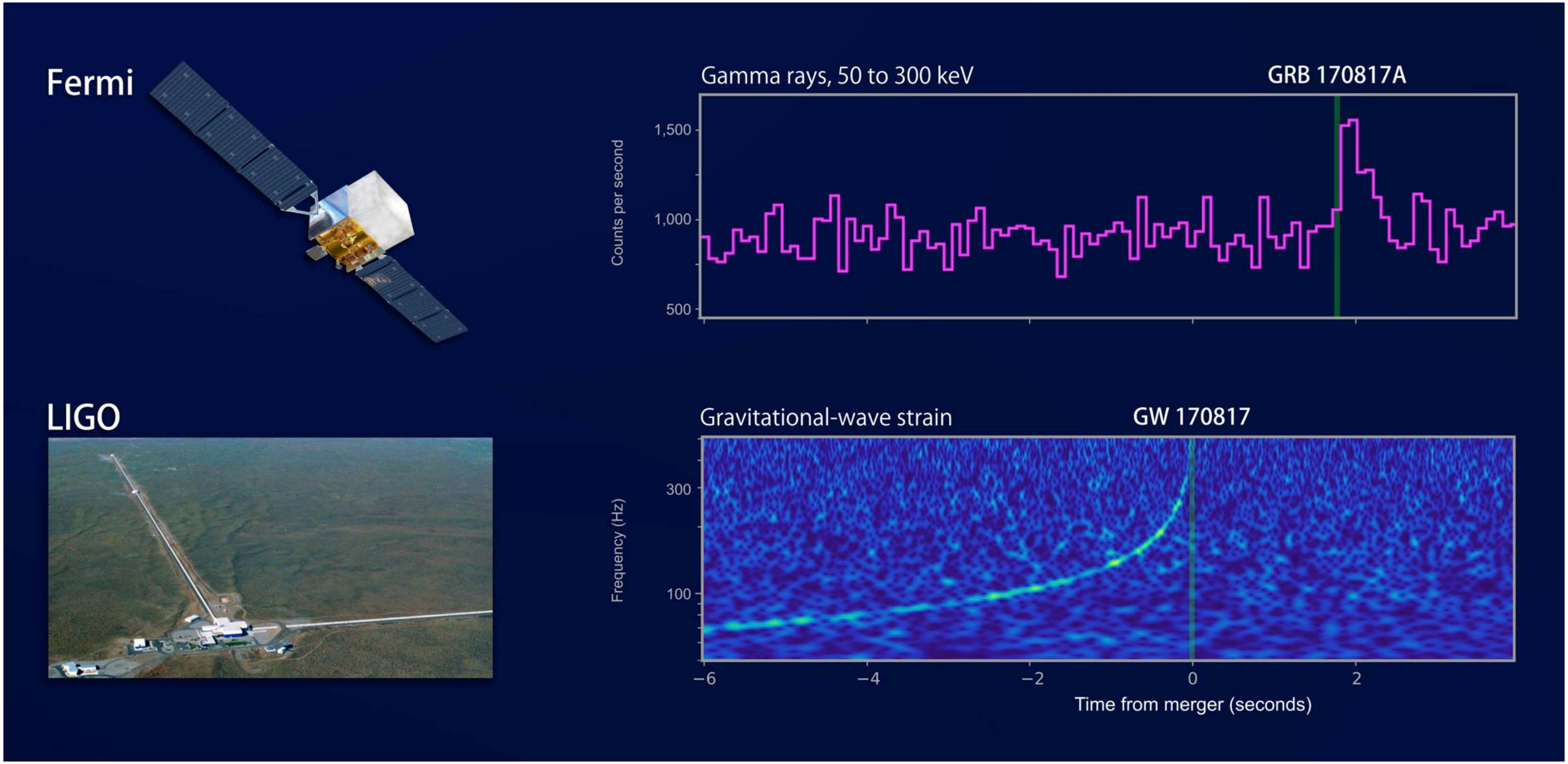




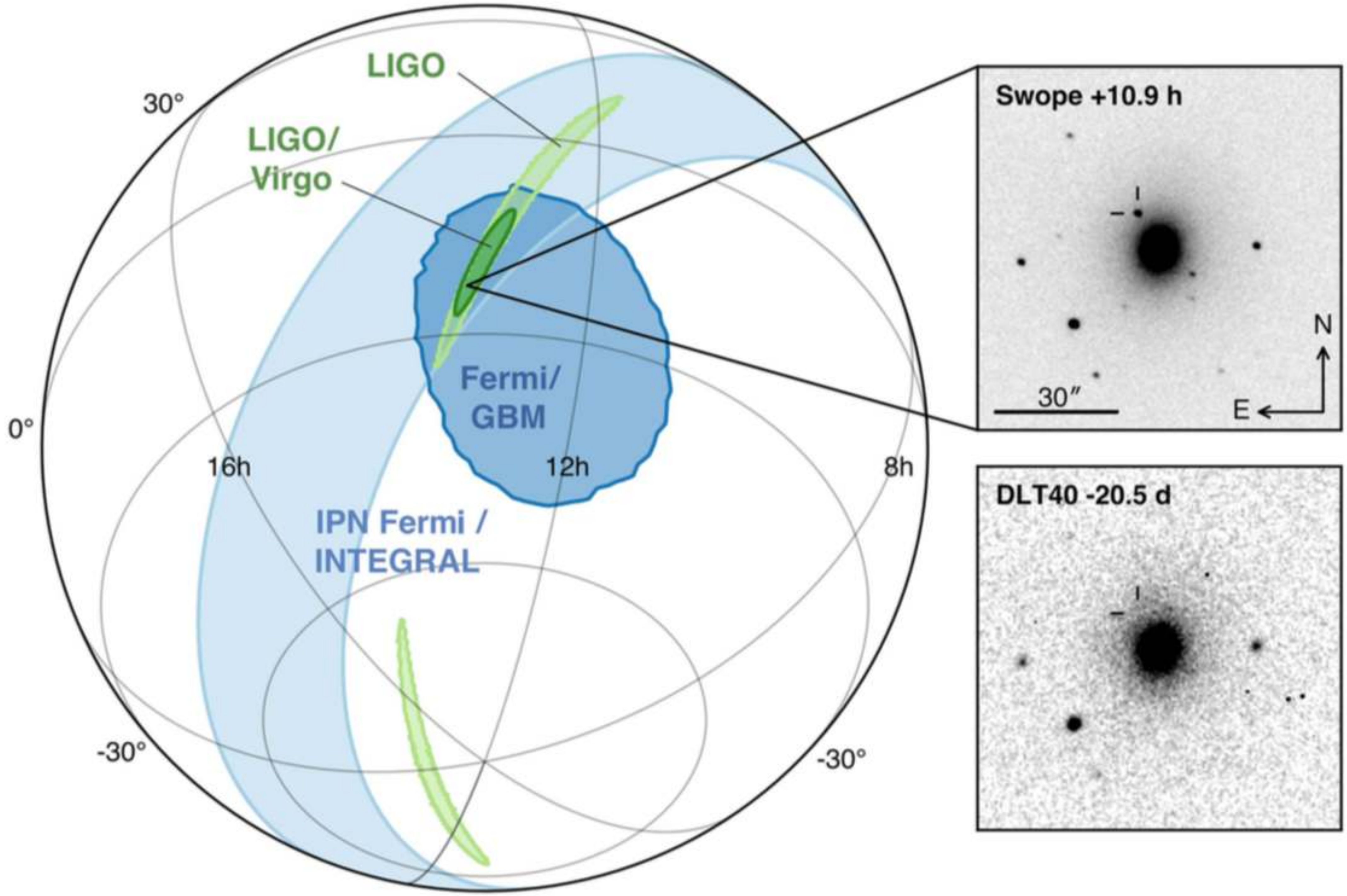


Another first: neutron star merger (NS-NS)

2017: LIGO detected the first binary Neutron-Star merger: GW170817 - this time with an electro magnetic counterpart



The follow-up of GW170817

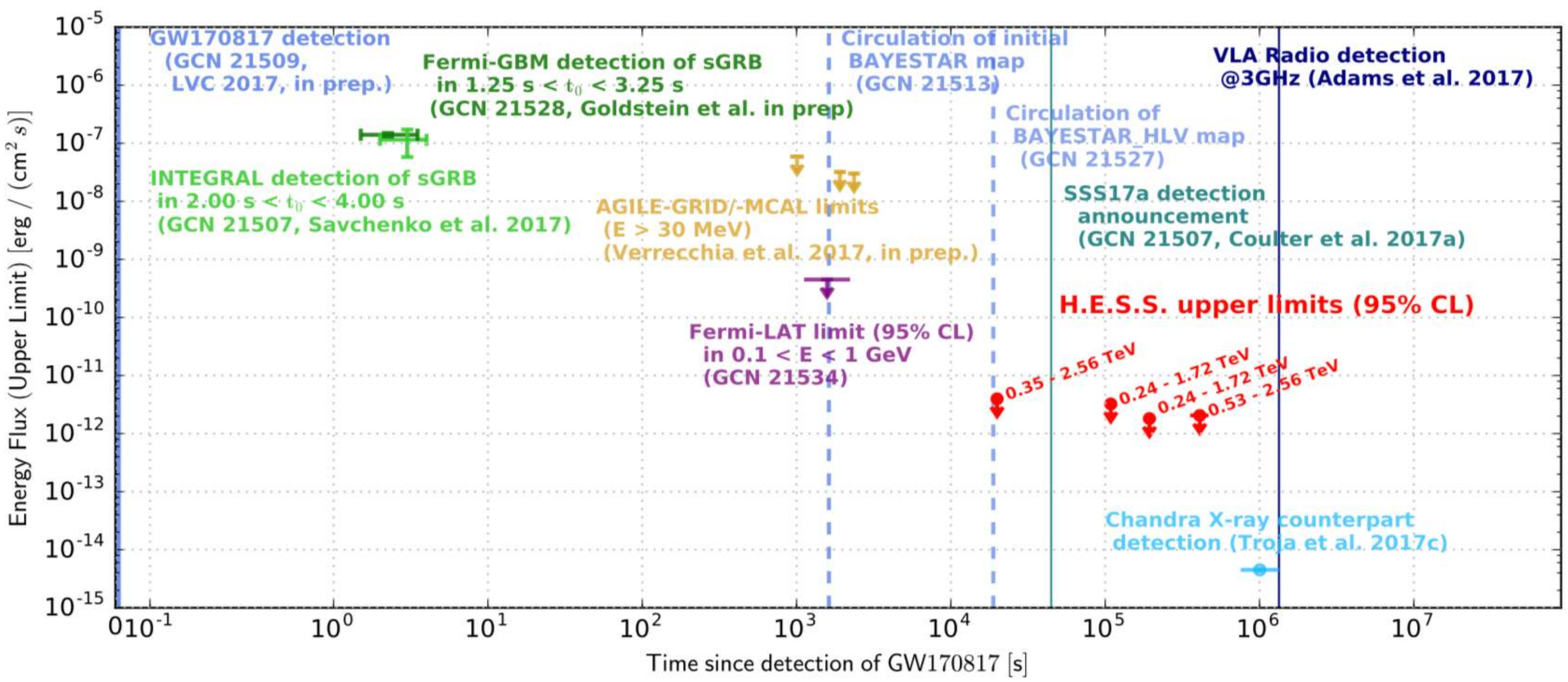


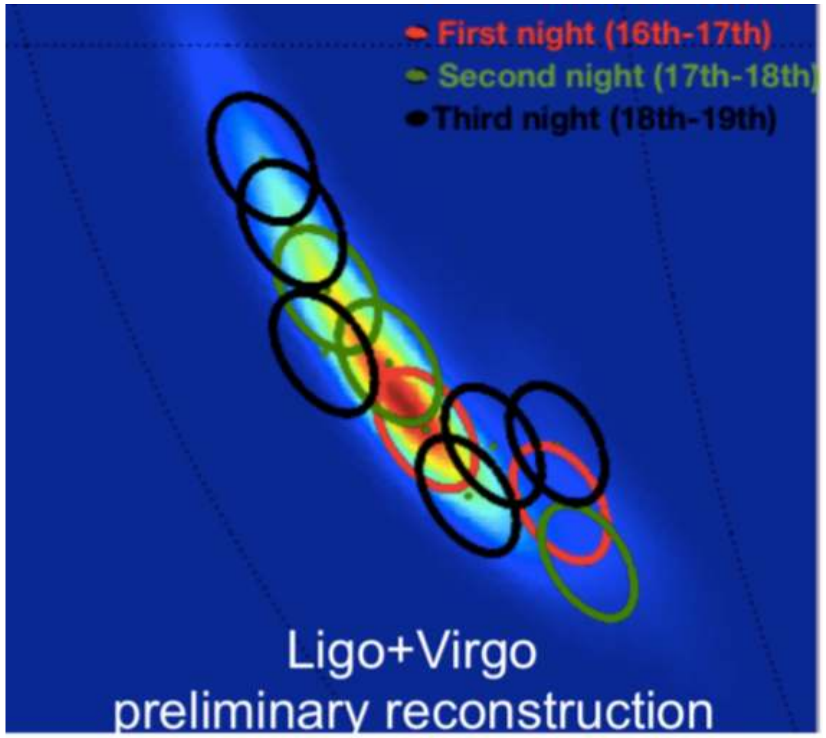
3000 astronomers / 70 observatories - Astrophys.J. 848 (2017) no.2, L12

Real-time Multi-Messenger Astronomy @ DESY

Gamma ray follow-up of NS/NS merger GW170817

- H.E.S.S. first ground-based pointing telescope on target, 5 hours after the event
- DESY PhD students happened to be on shift in Namibia, they scanned the uncertainty region within three nights
- 3 of the lead authors of the H.E.S.S. paper (Abdalla et al 2017) from DESY





Summary:
Gamma Ray Astronomy

– 1948: first ideas
– 1989: first source

41 years!
(thanks to very dedicated physicists)

– 2000: ~10 sources ~10 collaborators
– 2010: ~100 sources ~100 collaborators
– 2030: ~1000 sources ~1000 collaborators

– Cherenkov Telescopes are the best means of studying γ-rays at energies 50 GeV ... 300 TeV

– Astrophysics in the GeV ... >300 TeV range will see major scientific progress with

Fermi, CTA and many other experiments

Astroparticle Physics

- Astroparticle Physics is an exciting field.
- Highest energy particles are rare & difficult to detect
  ... but new experiments (with increased sensitivity) are getting better in detecting these particle and identifying their sources.
- The most-energetic CRs, gamma rays & neutrinos come likely from the same, most violent environments in the universe. (Multi-messenger approach)

- Four new windows in Astronomy:
  TeV gamma rays, Neutrinos, Gravitational waves, Cosmic rays

Bright future with many challenges for bright young scientists.