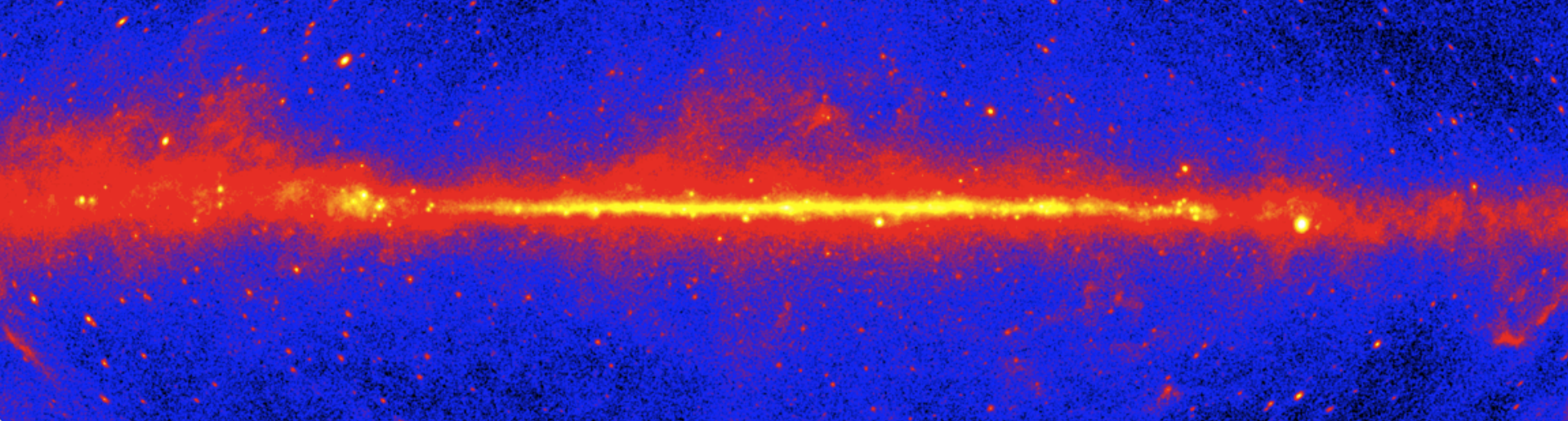


Gamma Ray Astronomy.

The end of the electromagnetic spectrum

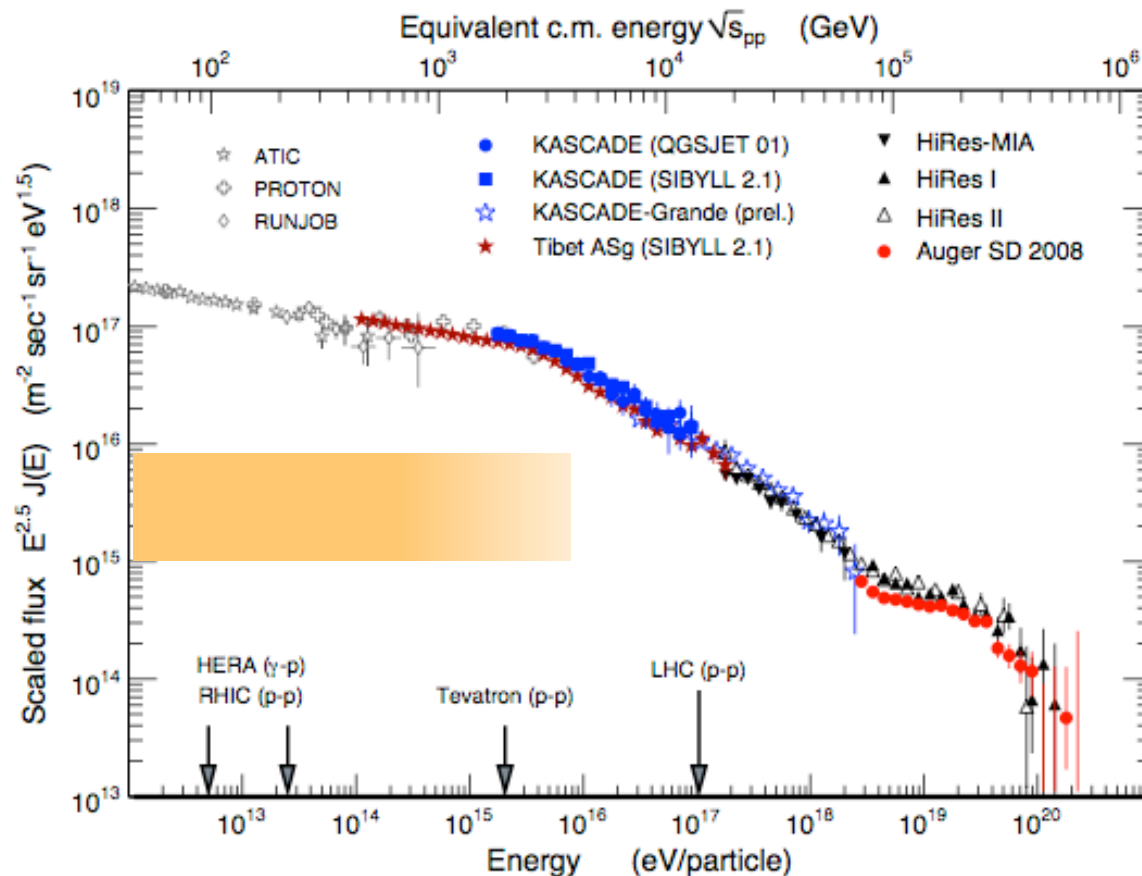


Christian Stegmann

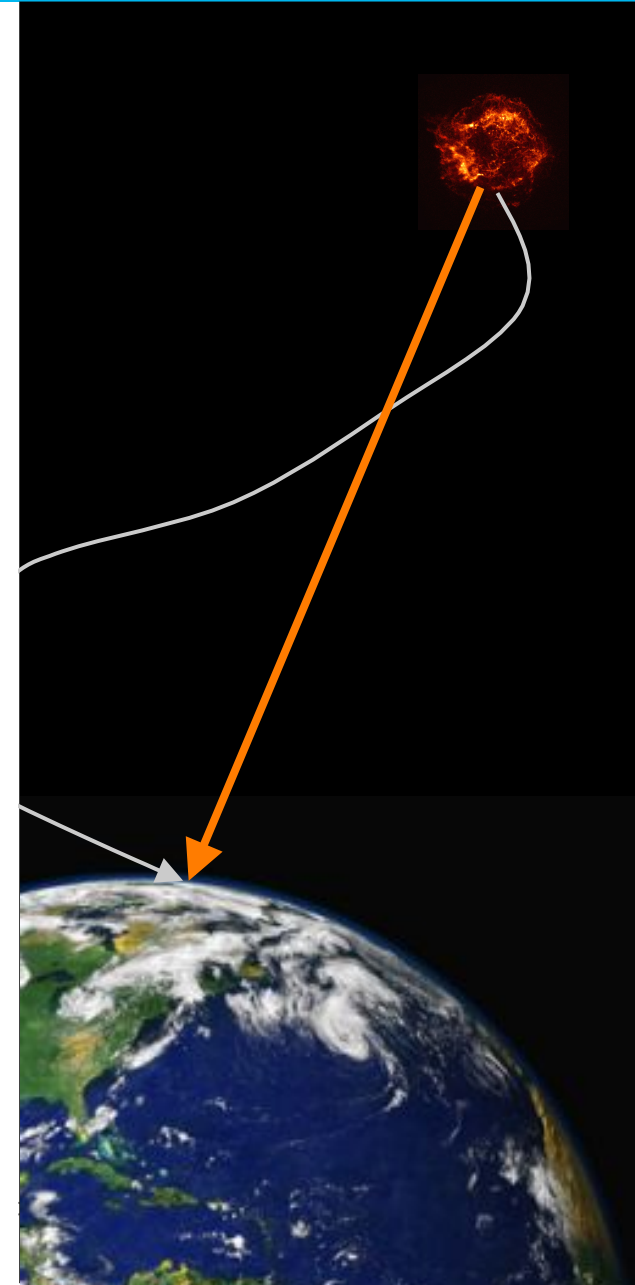
MG14, Rome

July, 18th 2015

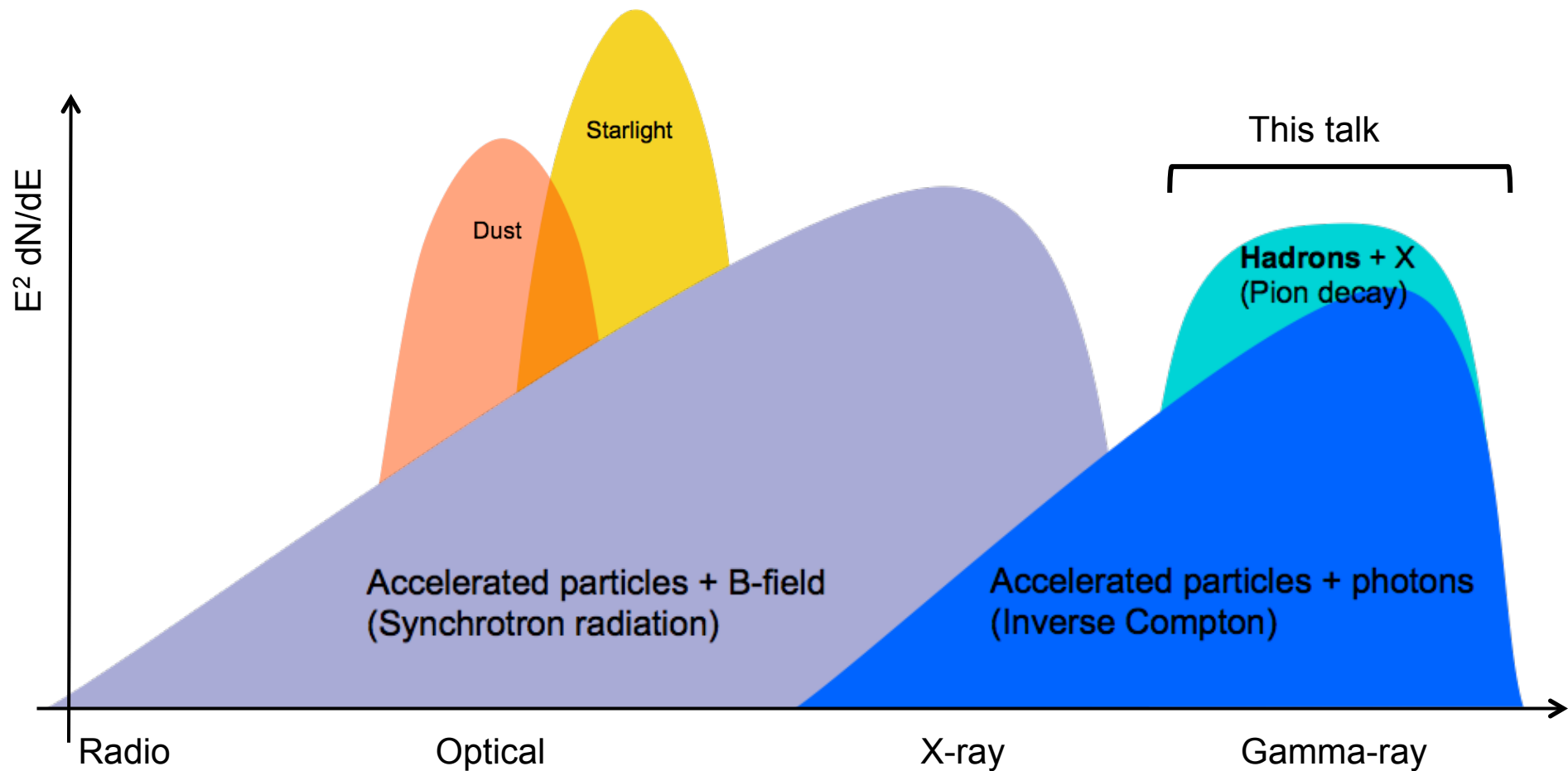
Gamma rays – Messengers from the High Energy Universe



- Gamma rays are excellent tracers of the acceleration sites of ultra-relativistic cosmic rays



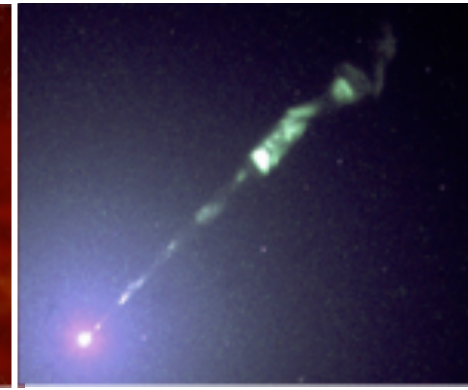
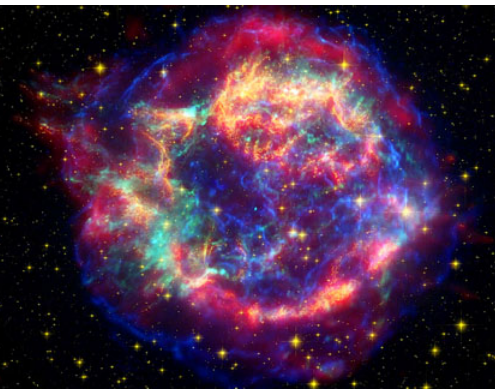
Displaying Cosmic Particle Accelerators



> Production

- protons: pion-decay: $\pi^0 \rightarrow \gamma\gamma$
- electrons: Inverse Compton Scattering: $e^\pm \gamma \rightarrow e^\pm \gamma$

Displaying Cosmic Particle Accelerators



Stellar type	Collective type	Complex type	Black-hole type
Supernova shell	Star forming region	Y-ray binaries	Galactic centre
Pulsars	Starburst galaxies	Microquasars	AGNs (HBL, FSRQ, ...)
Pulsar Wind Nebulae	Diffuse Galactic emission	ms-PSR	
	Isotropic extragalactic emission	GRBs	
		Molecular clouds	

Experimental techniques

MeV

GeV

TeV

PeV

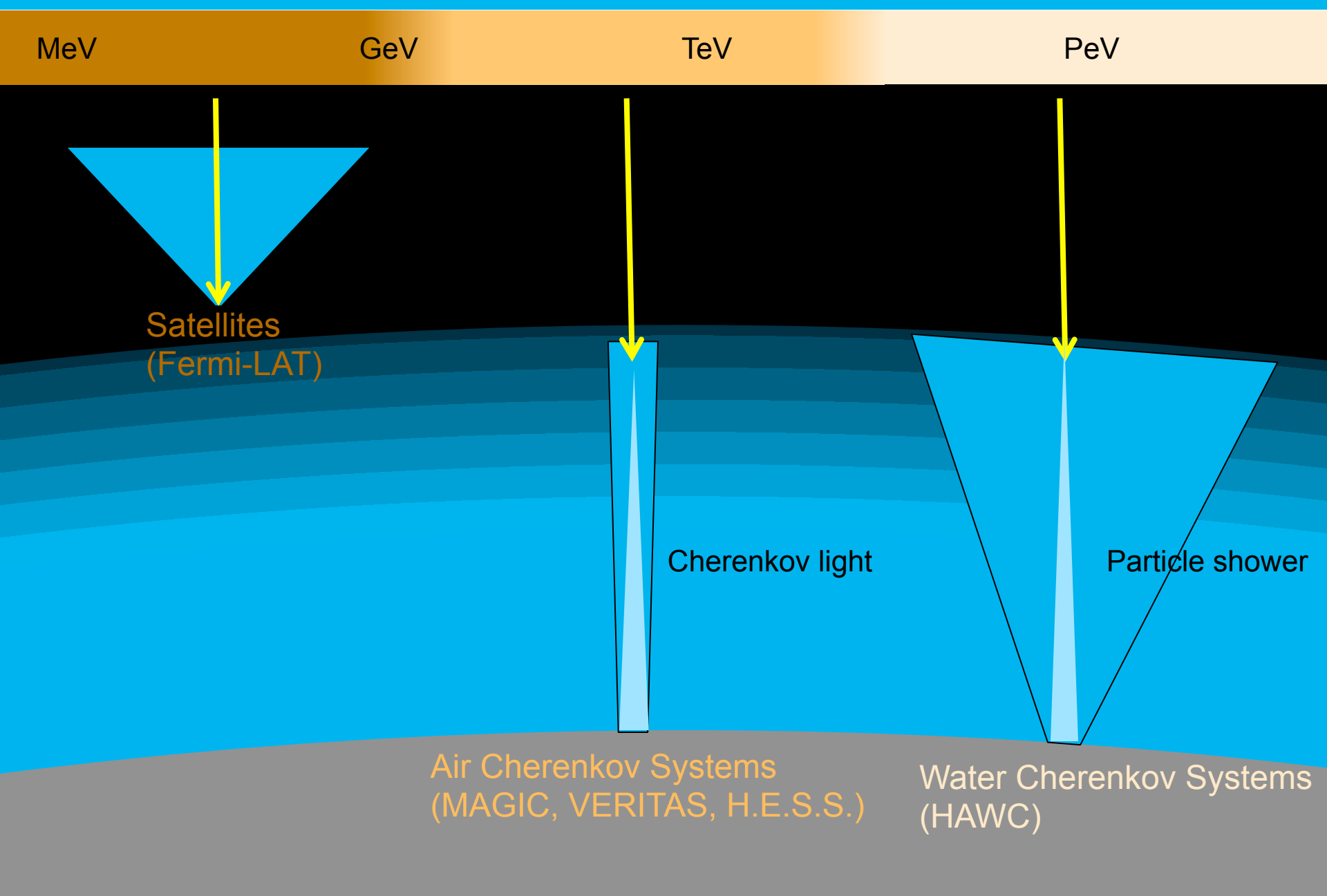
Satellites
(Fermi-LAT)

Cherenkov light

Particle shower

Air Cherenkov Systems
(MAGIC, VERITAS, H.E.S.S.)

Water Cherenkov Systems
(HAWC)



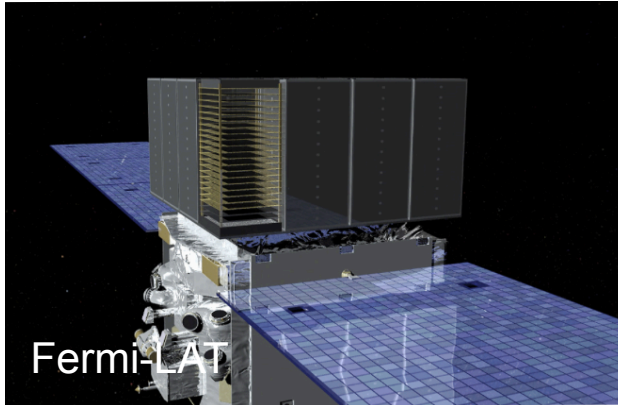
Experimental techniques

MeV

GeV

TeV

PeV



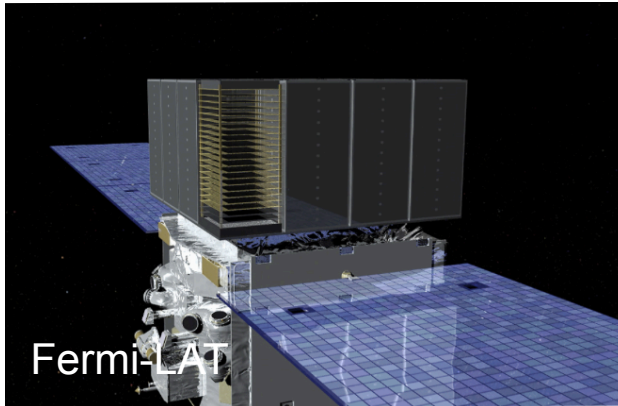
Experimental techniques

MeV

GeV

TeV

PeV

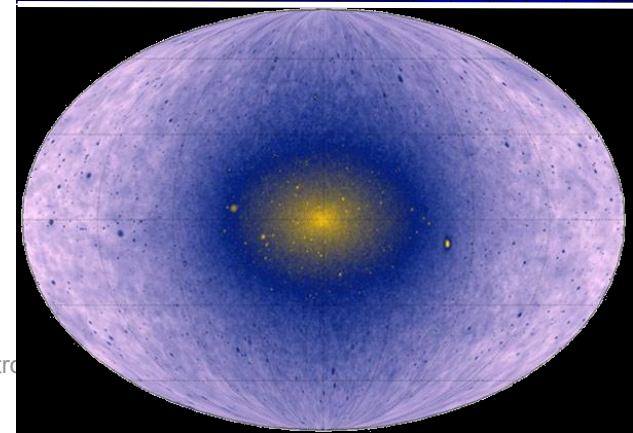
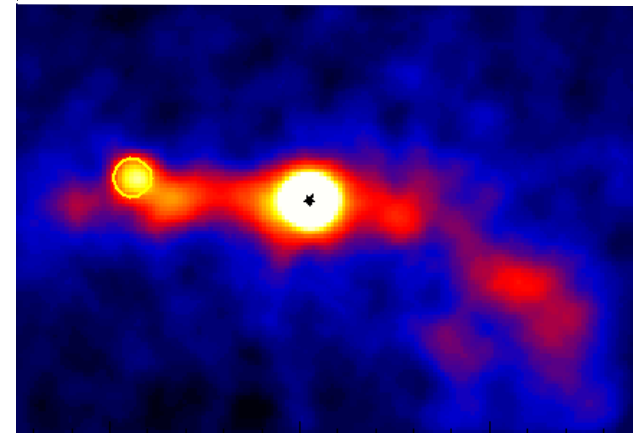
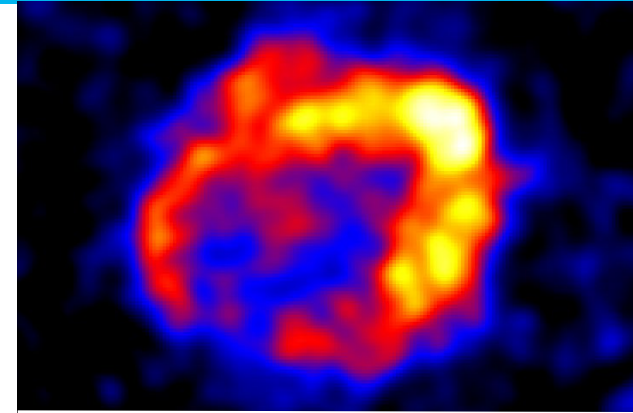


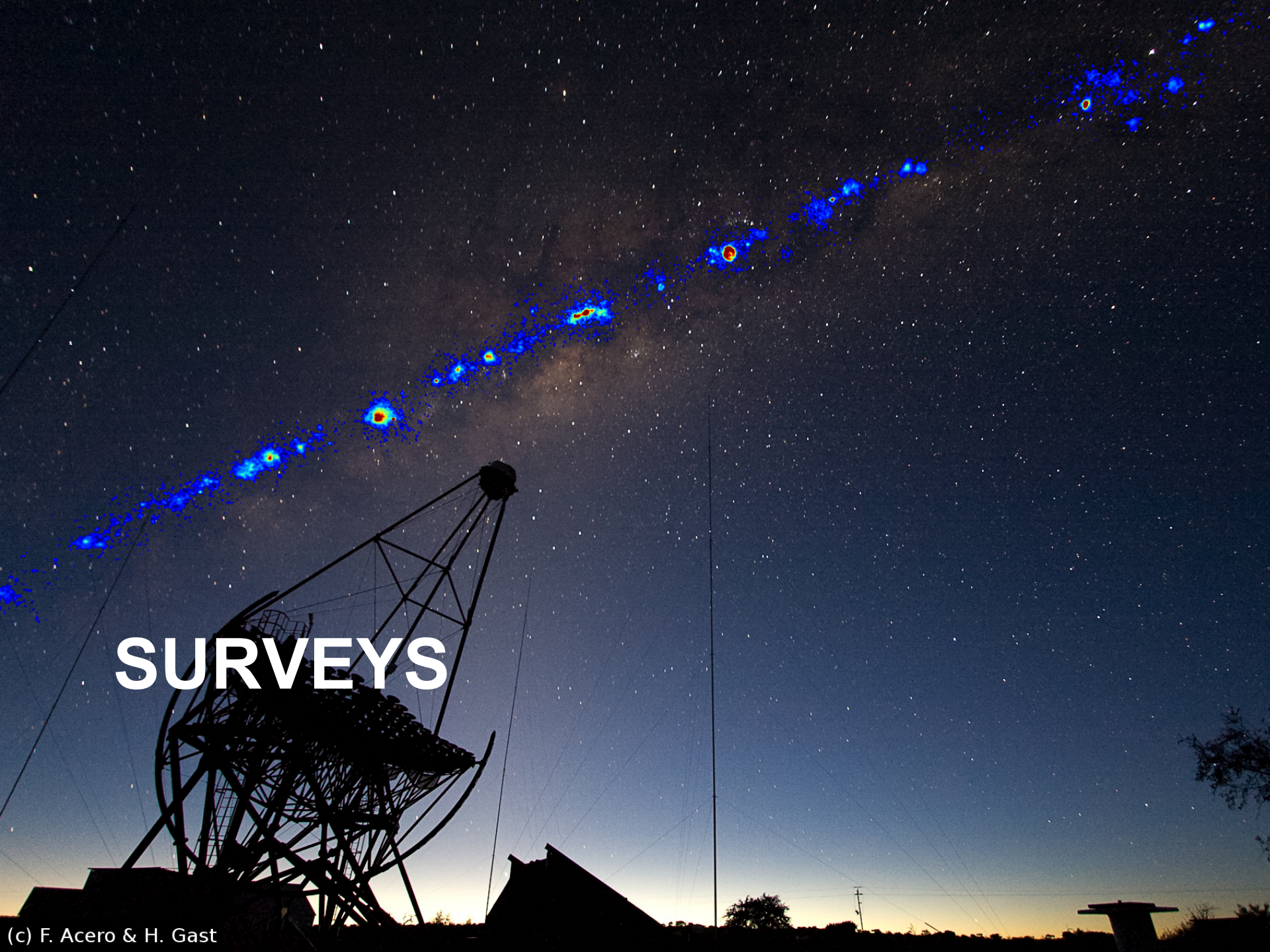
	Fermi LAT	IACTs	HAWC
Effective area	1 m ²	10 ⁵ m ²	10 ⁵ m ²
Field of view	20% of the sky	3° – 5°	15% of the sky
Energy res.	10%	10%	100% – 20%
Angular res.	6° – 0.3°	0.1°	1° – 0.2°
Duty cycle	Full year	1400 h/year	Full year



Scientific Highlights

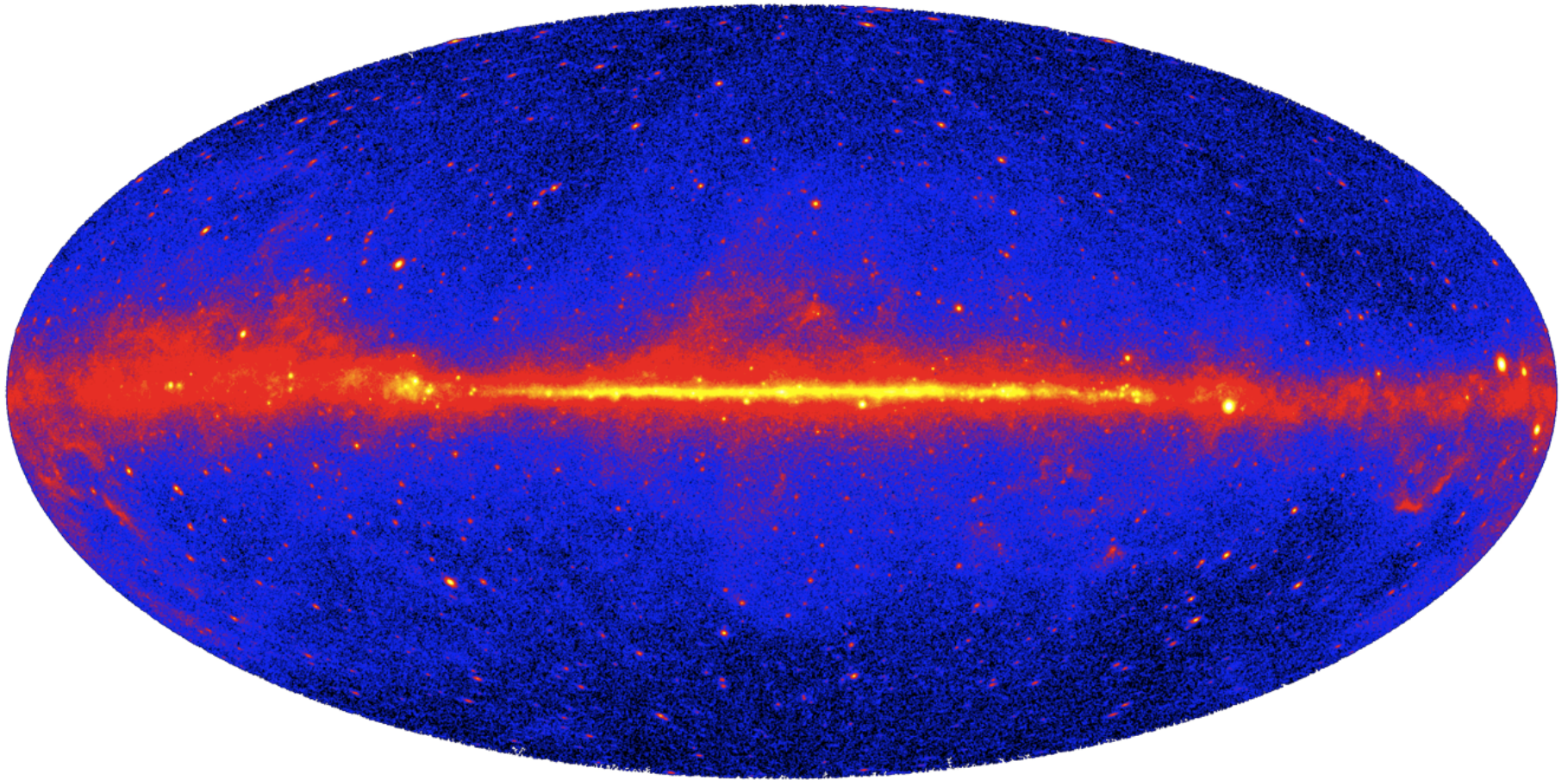
- > Surveys from parts of the Milky Way to the whole sky
 - > Imaging of cosmic particle acceleration sites
 - > Physics of pulsars and pulsar winds
 - > Extreme variability of AGN
-
- > **Major contributions from all current instruments**



The image is a composite. The background is a photograph of a night sky with a dense field of stars. In the lower-left foreground, the silhouette of a large radio telescope dish is visible, pointing towards the upper right. A bright, diagonal band of light, representing the Milky Way, stretches across the sky. Overlaid on this image is a simulated astronomical survey. This simulation consists of numerous small blue dots scattered across the sky, primarily following the path of the Milky Way. Several of these dots are larger and more prominent, with a color gradient from blue to yellow to red at their centers, indicating different levels of brightness or intensity. The word 'SURVEYS' is written in large, white, sans-serif capital letters across the middle of the image, partially overlapping the telescope silhouette and the simulated survey dots.

SURVEYS

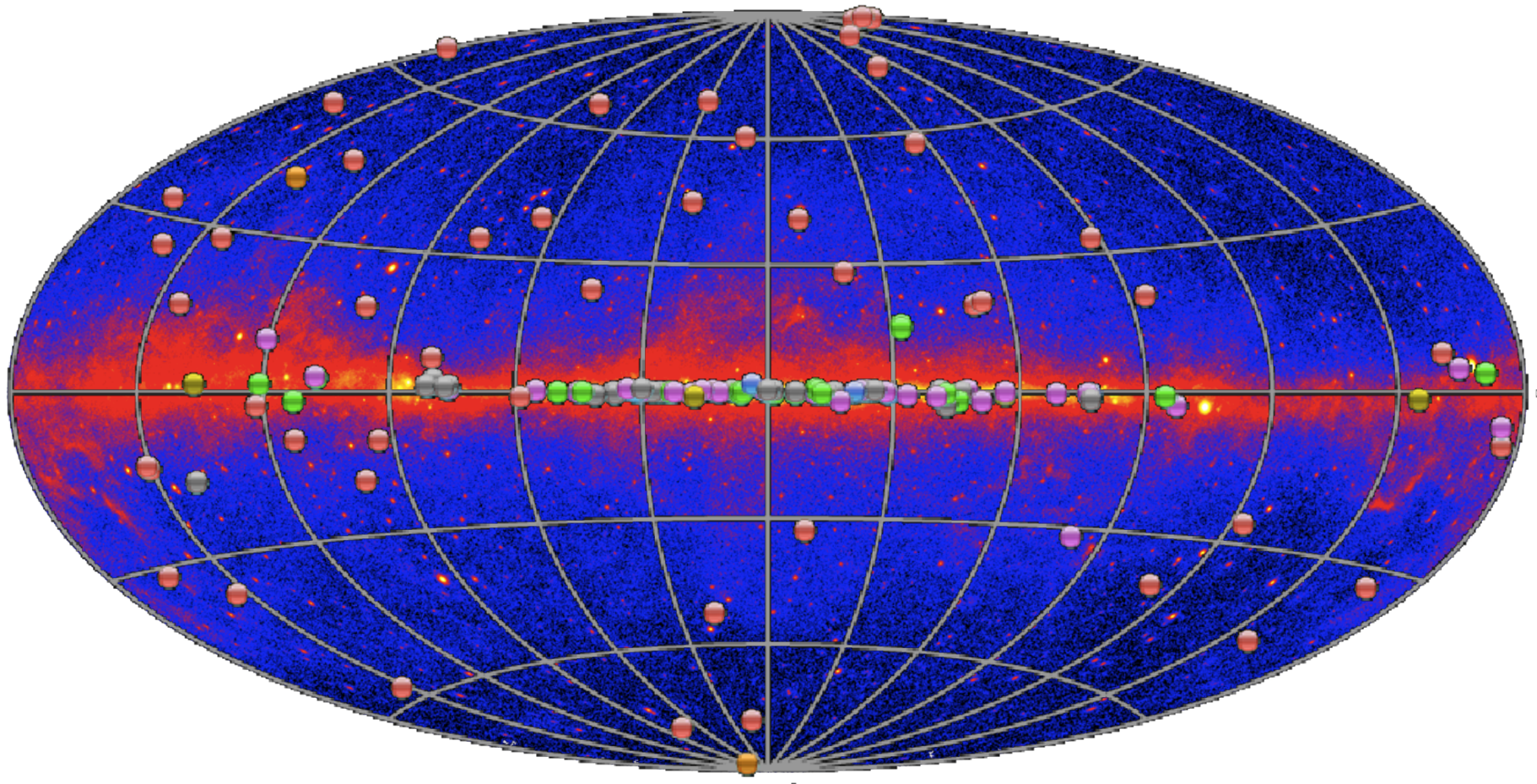
The Gamma-ray Sky at GeV Energies



> Fermi 3FGL catalogue (arXiv:1501.02003v3)

- 3300 sources; significant fraction Extragalactic; many Galactic sources confused with diffuse Emission

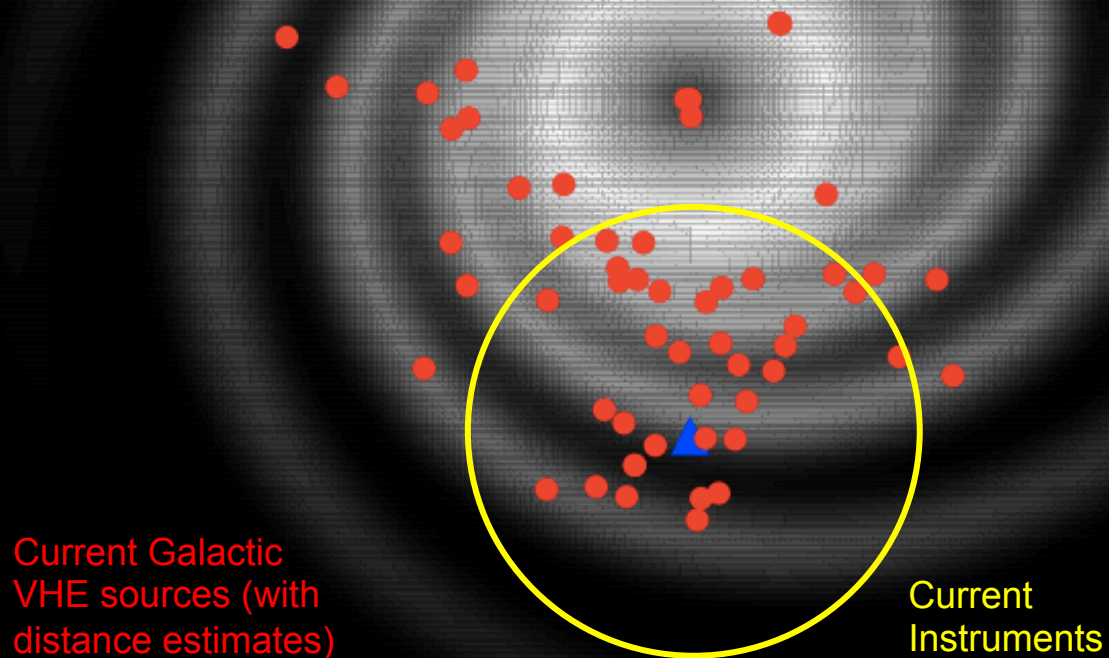
The Gamma-ray Sky at TeV Energies



> TeVCat

- ~50 extragalactic sources; ~100 Galactic sources

The Sky at TeV Energies

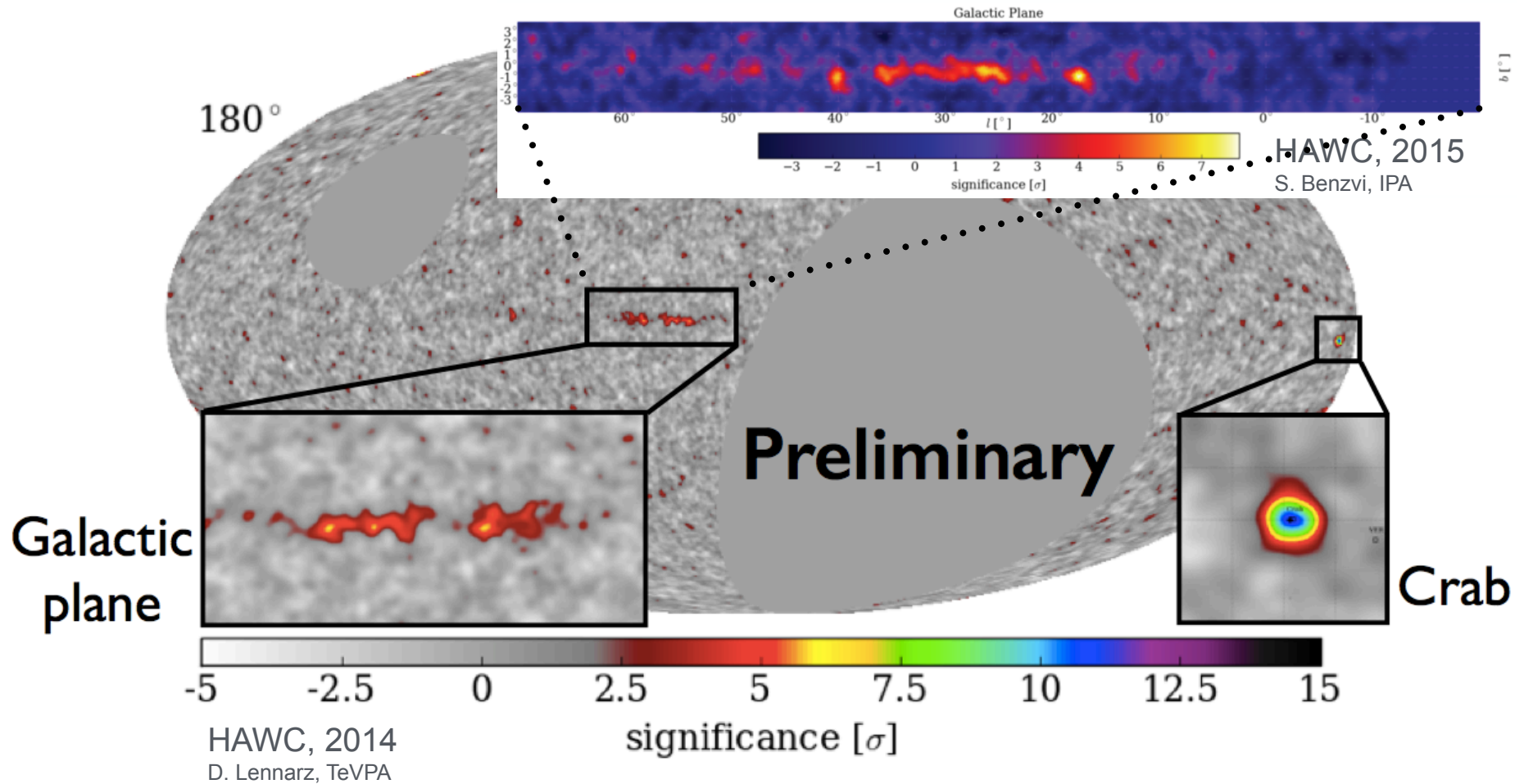


The HAWC Observatory

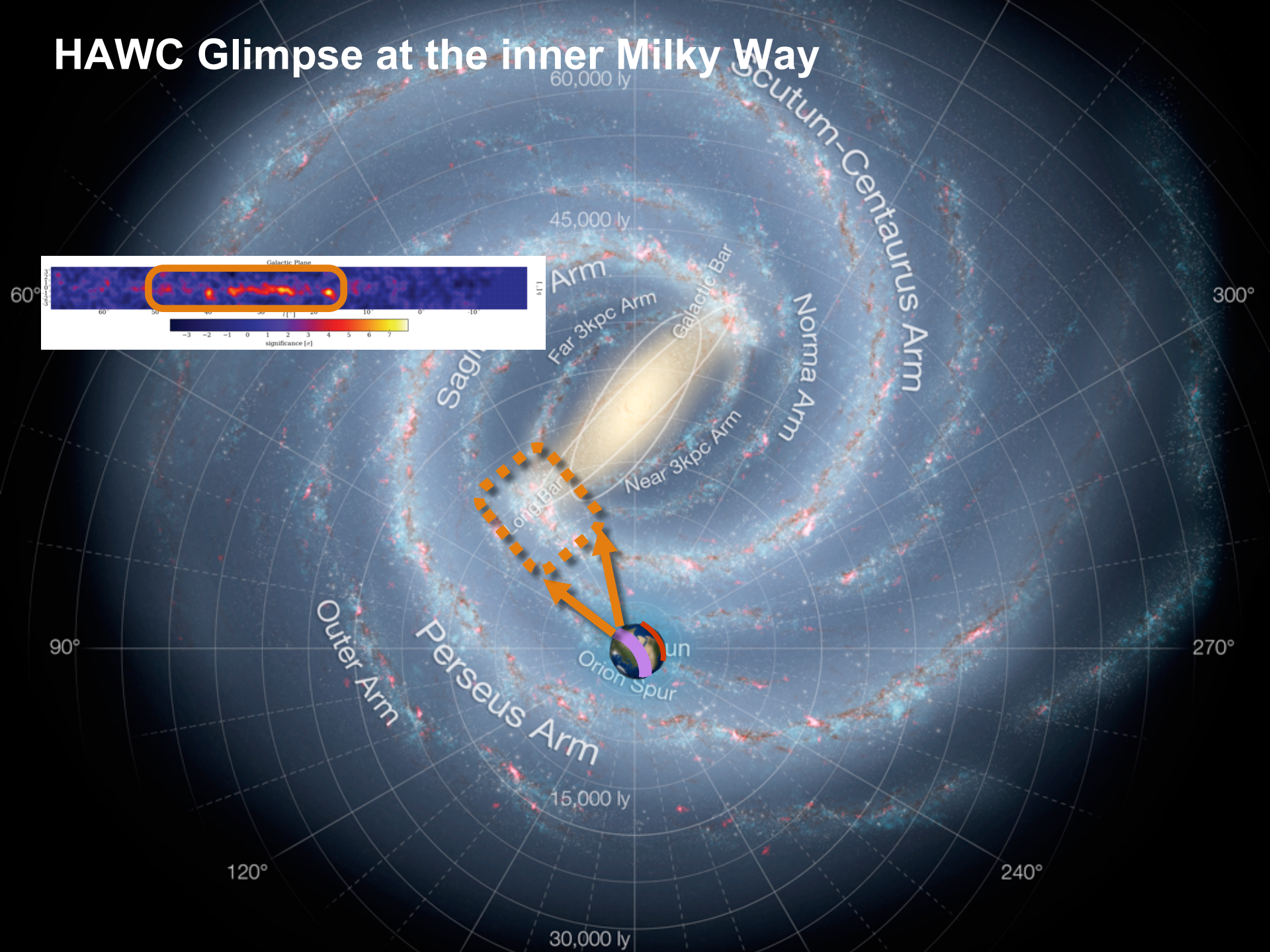
- > Altitude: 4100m
- > 20000 m² covered with 300 water Cherenkov detectors equipped with 1200 PMTs
- > Inaugurated Mar 20, 2015



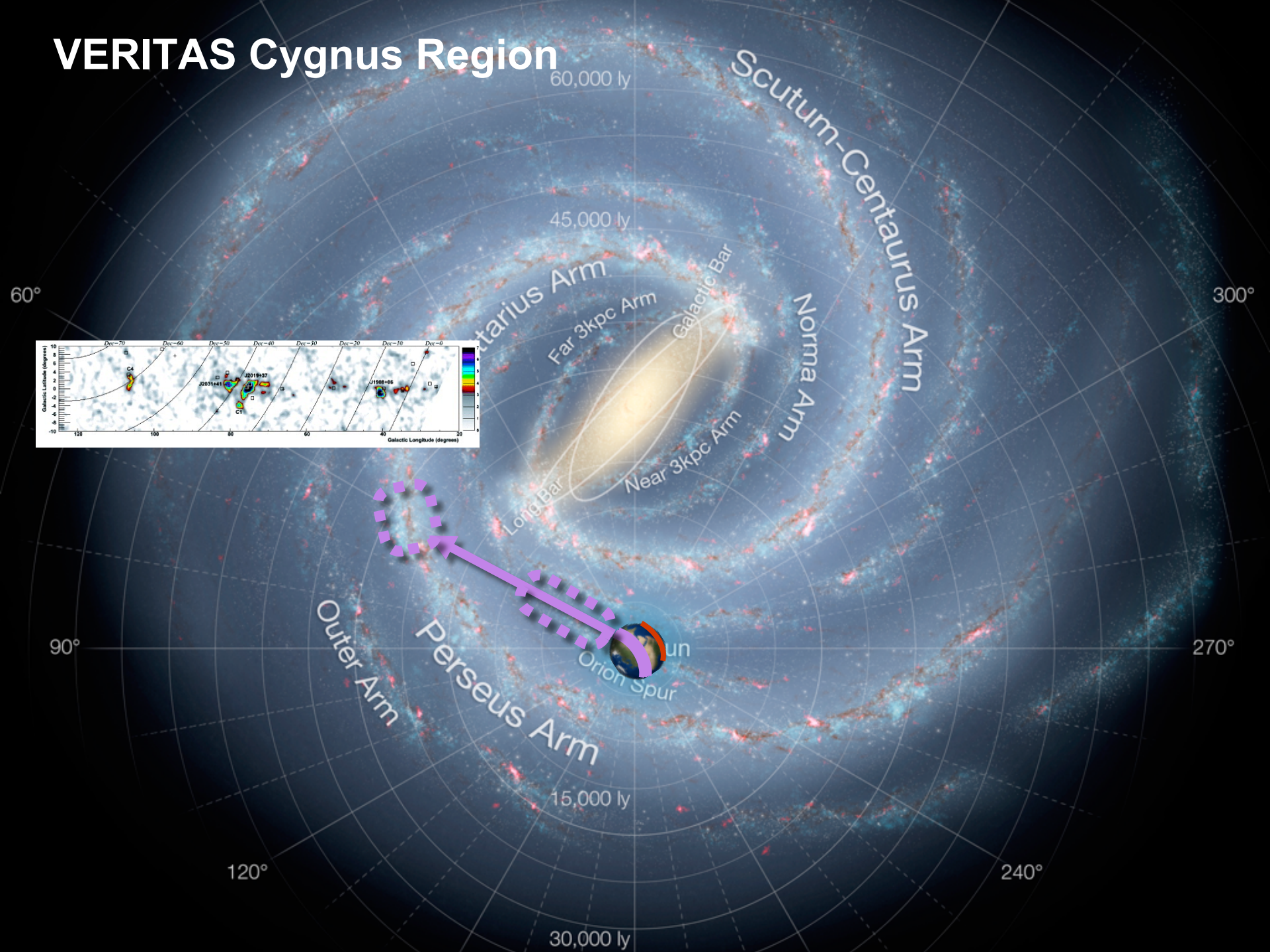
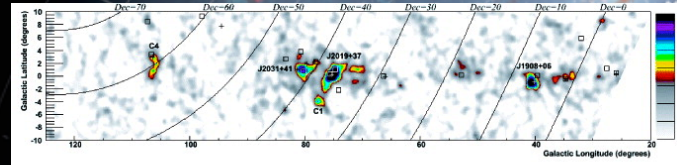
The sky seen with HAWC



HAWC Glimpse at the inner Milky Way



VERITAS Cygnus Region



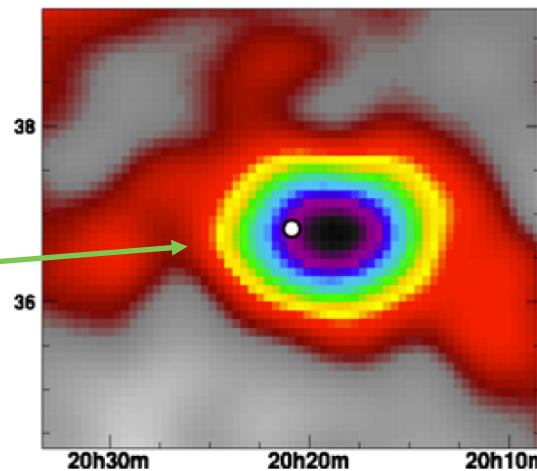
Surveys of IACTs: VERITAS Cygnus Region Scan

- Published in bits
- Some sources newly resolved:

MILAGRO, 2009

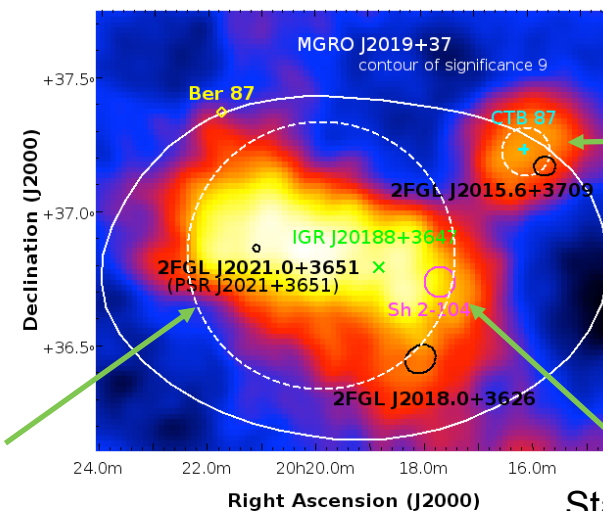
<http://iopscience.iop.org/1538-4357/700/2/L127>

J2020.8+3649



VERITAS, 2014

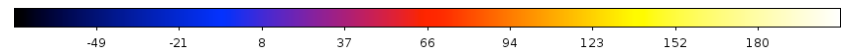
<http://iopscience.iop.org/0004-637X/788/1/78/>



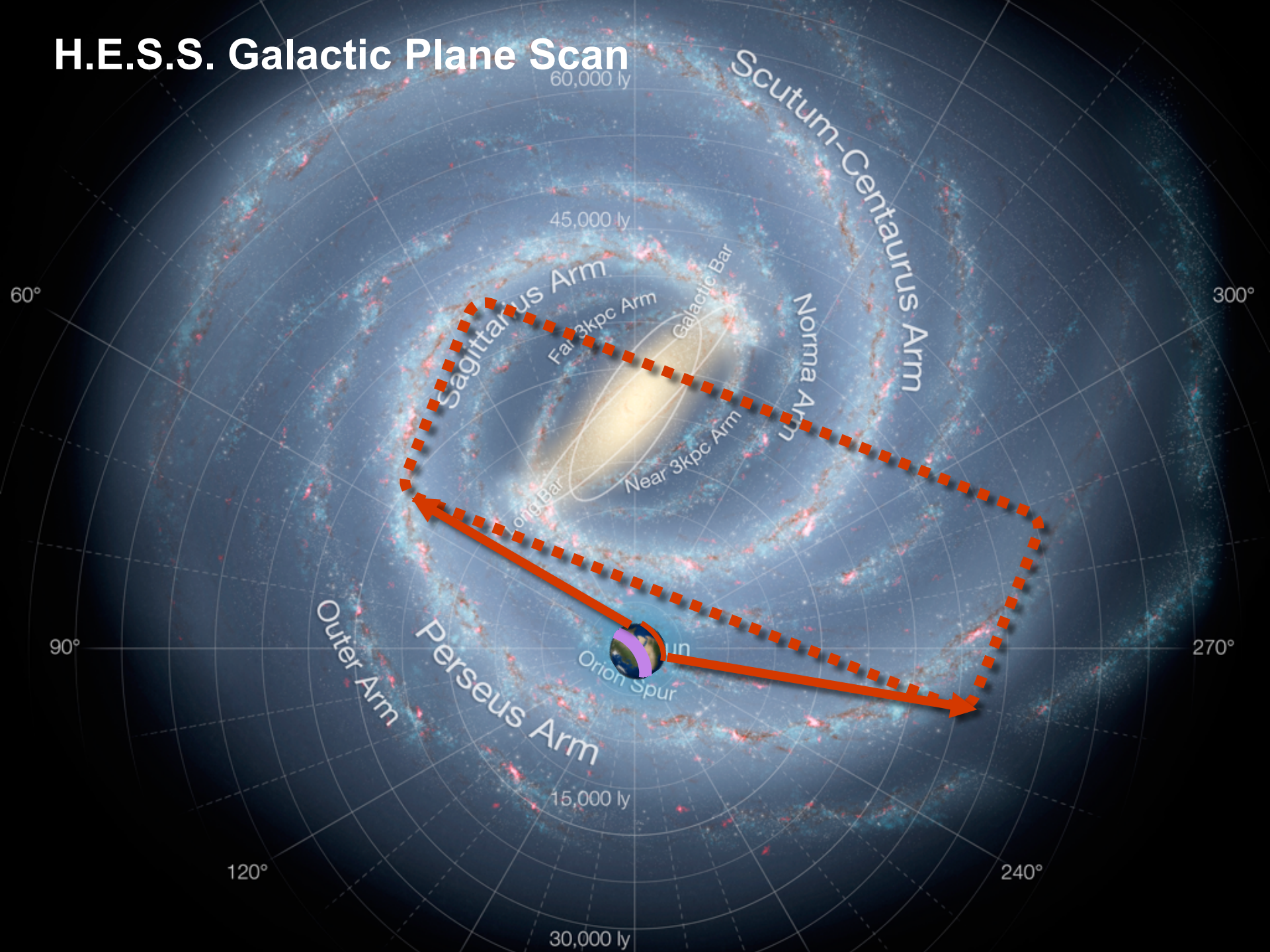
PWN

PWN?

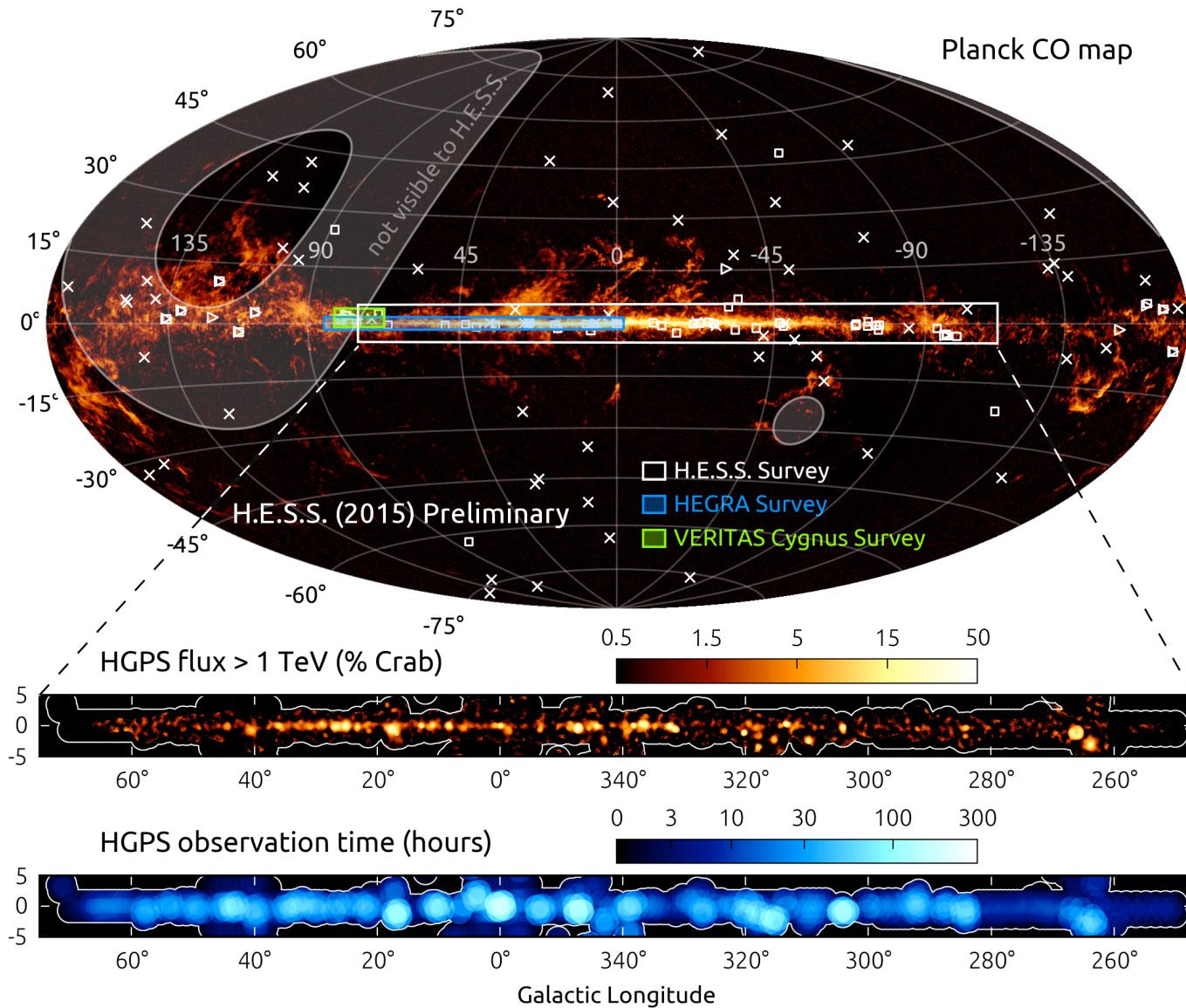
Star forming region?



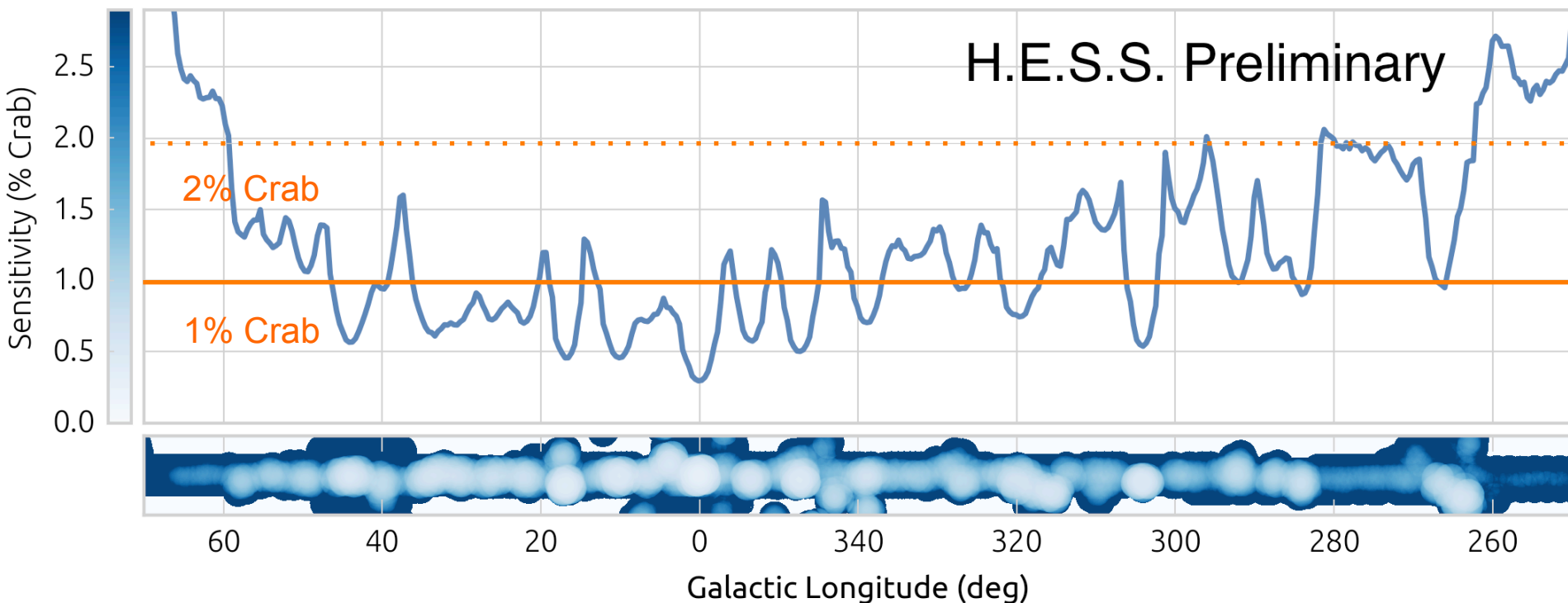
H.E.S.S. Galactic Plane Scan



H.E.S.S. Galactic Plane Scan



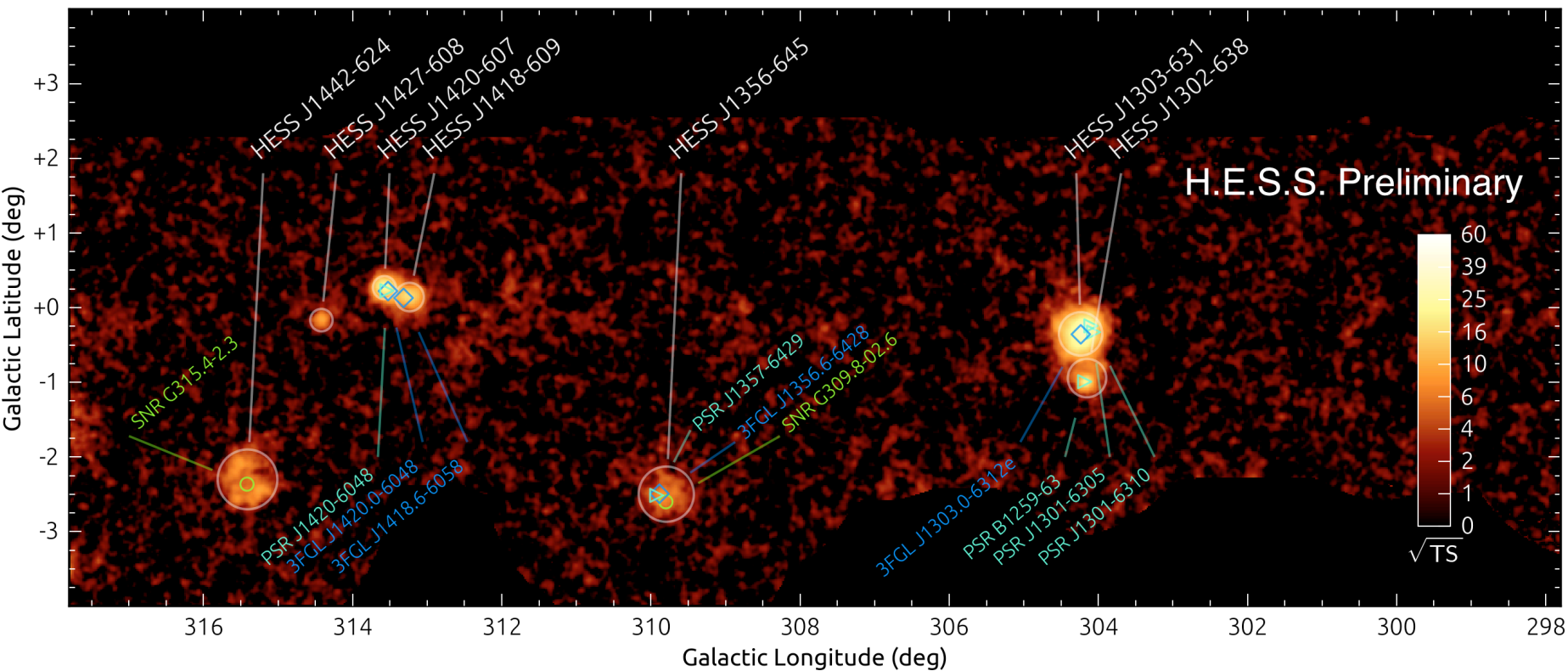
H.E.S.S. Galactic Plane Scan



➤ 2673 hours of high-quality data, taken in the years 2004 to 2013.

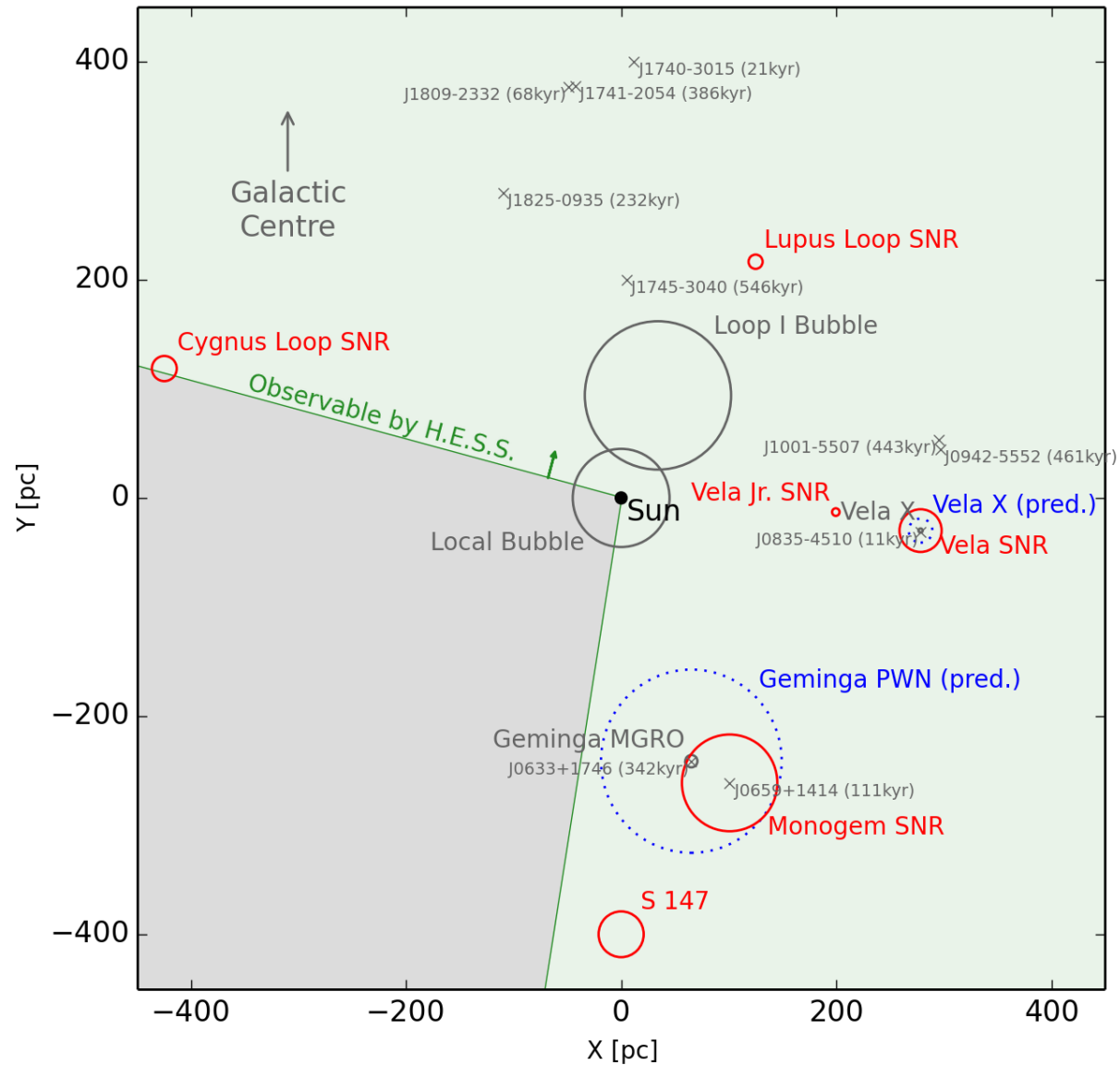
- Longitude $l = 250$ to 65 degrees, latitude $|b| < 3.5$ degrees
- Sensitivity for the detection of point-like sources is at the level of 2% Crab or better

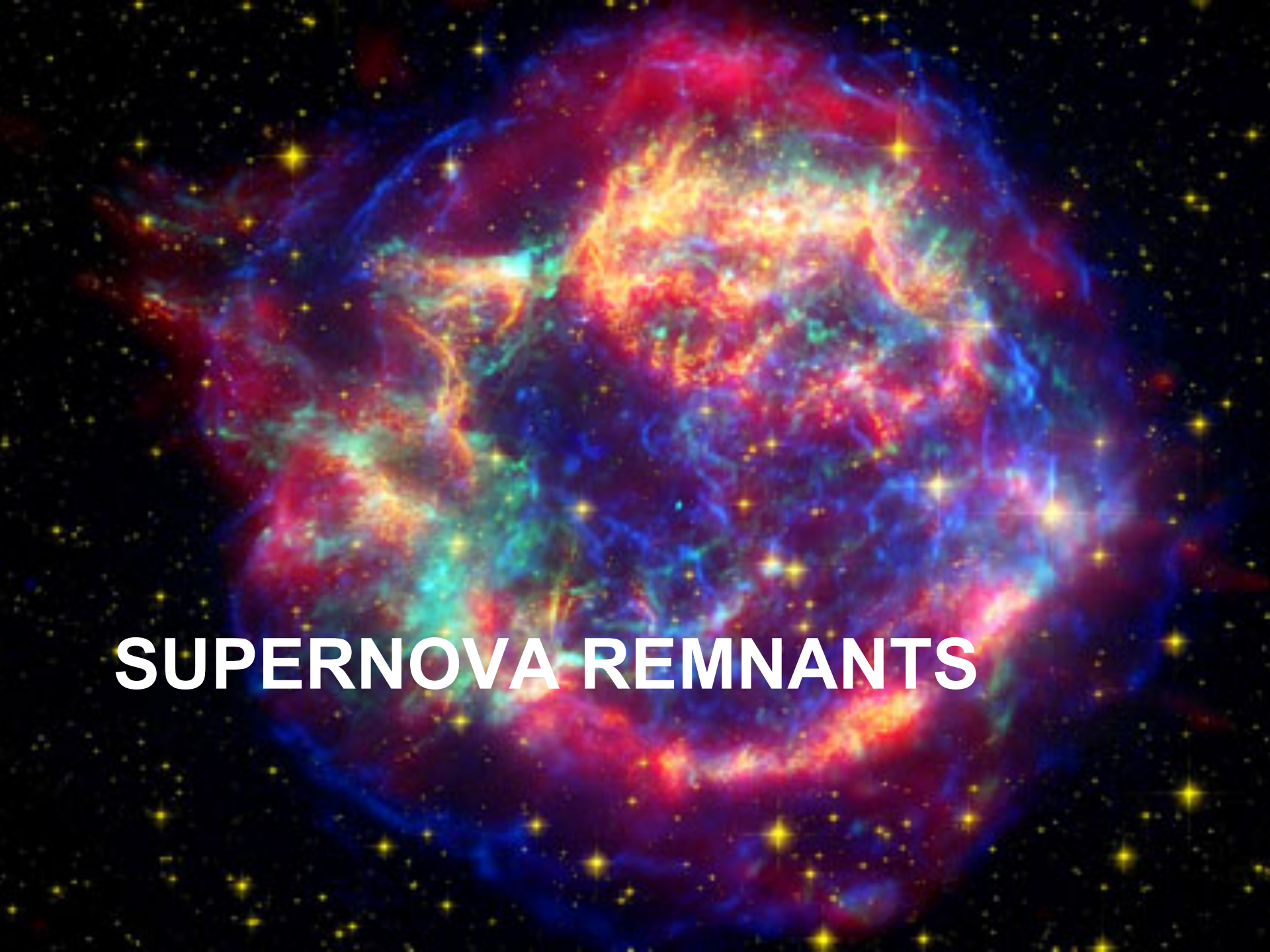
H.E.S.S. Galactic Plane Scan



- 66 VHE sources + 11 complex sources (e.g. shell SNR) excluded from automatic pipeline

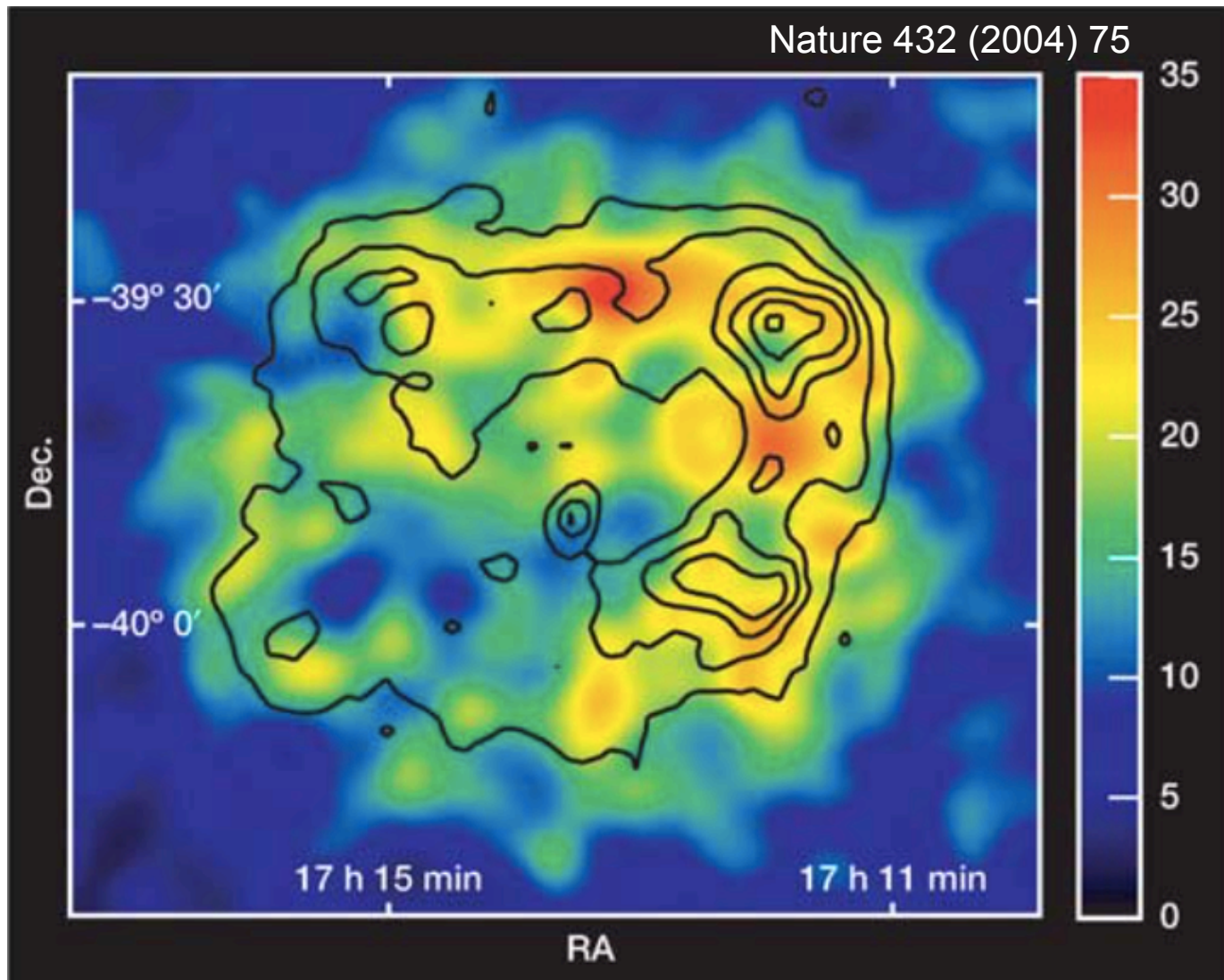
Our local neighbourhood



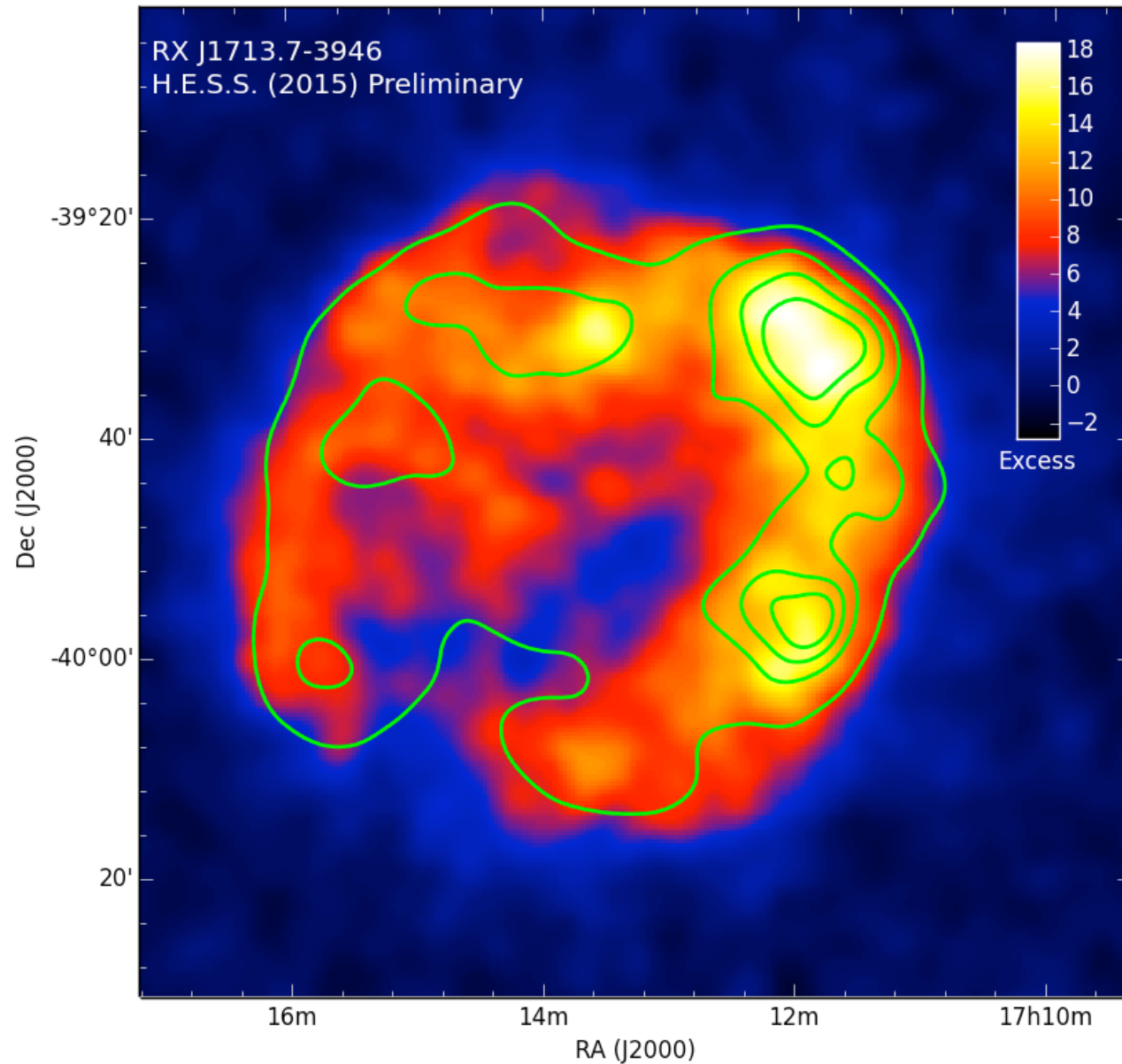
A large, glowing supernova remnant is the central focus of the image. It exhibits a complex, filamentary structure with a rich palette of colors including deep reds, bright oranges, yellows, and cool blues. The remnant is set against a dark, star-filled background, with numerous small, distant stars visible as points of light. The overall composition is centered, with the remnant's energy and light radiating outwards.

SUPERNOVA REMNANTS

The first image of a supernova remnant in TeV

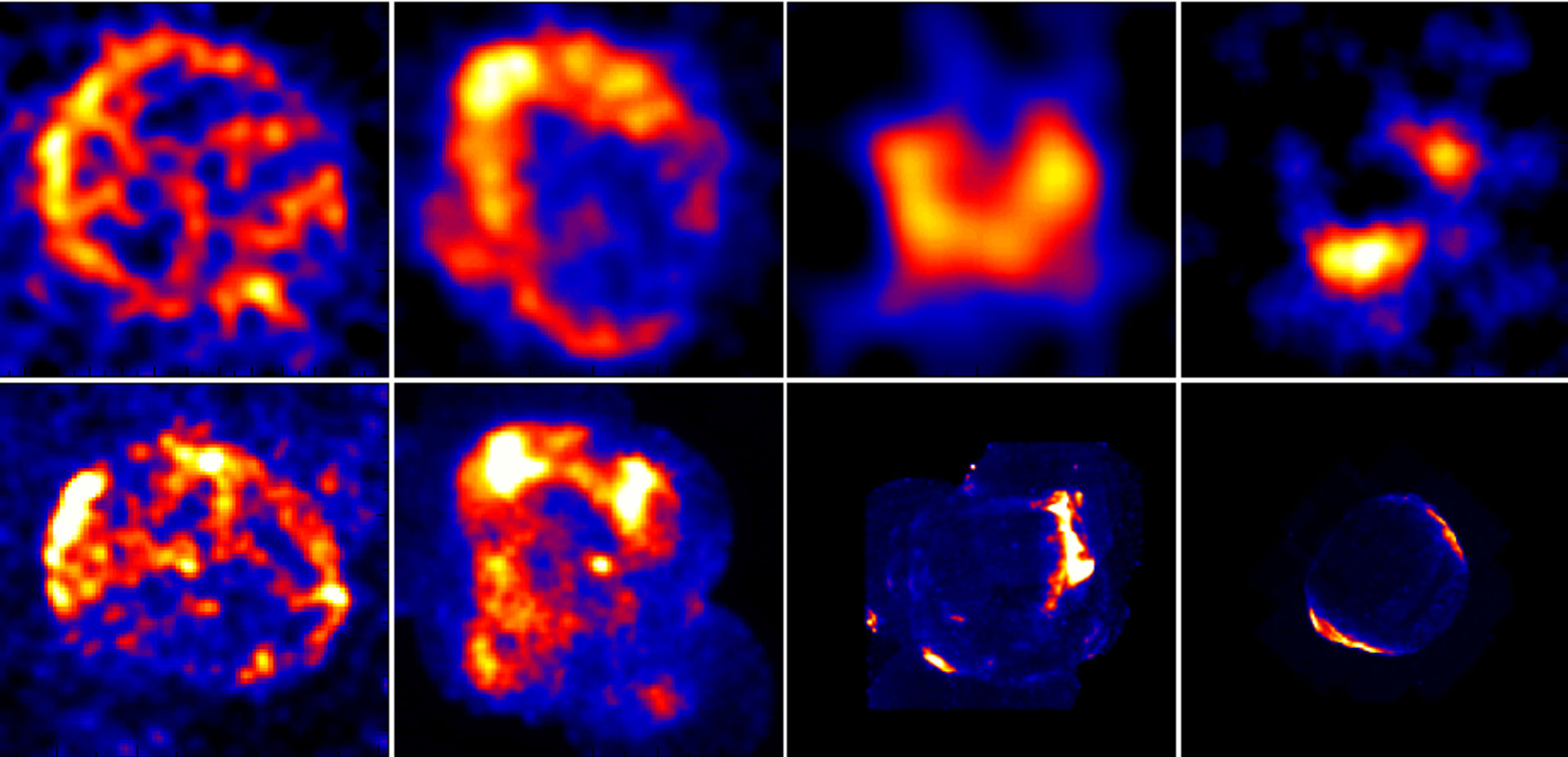


The first image of a supernova remnant in TeV today



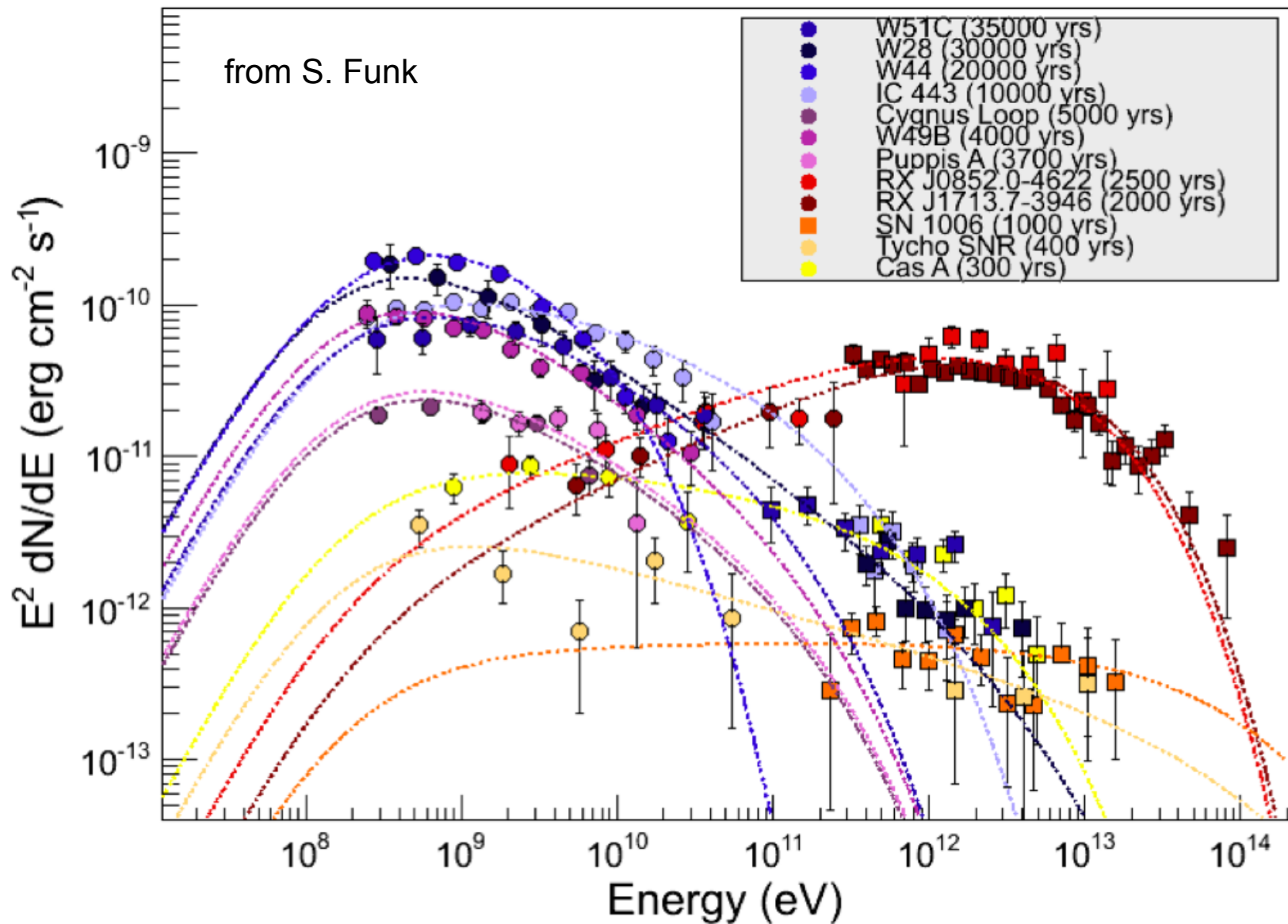
Supernova Remnants

Gamma rays

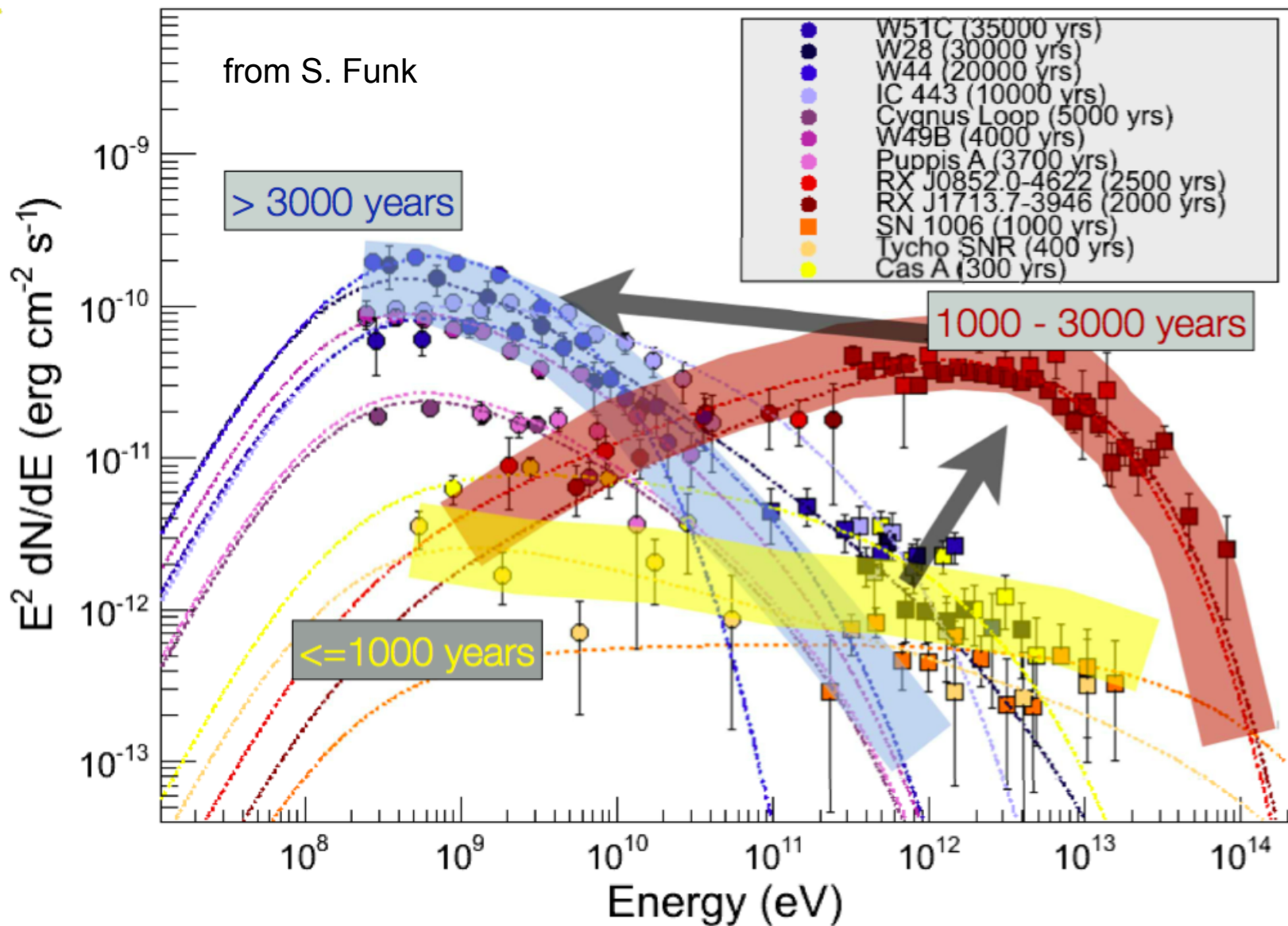


X rays

GeV-TeV spectra of supernova remnants

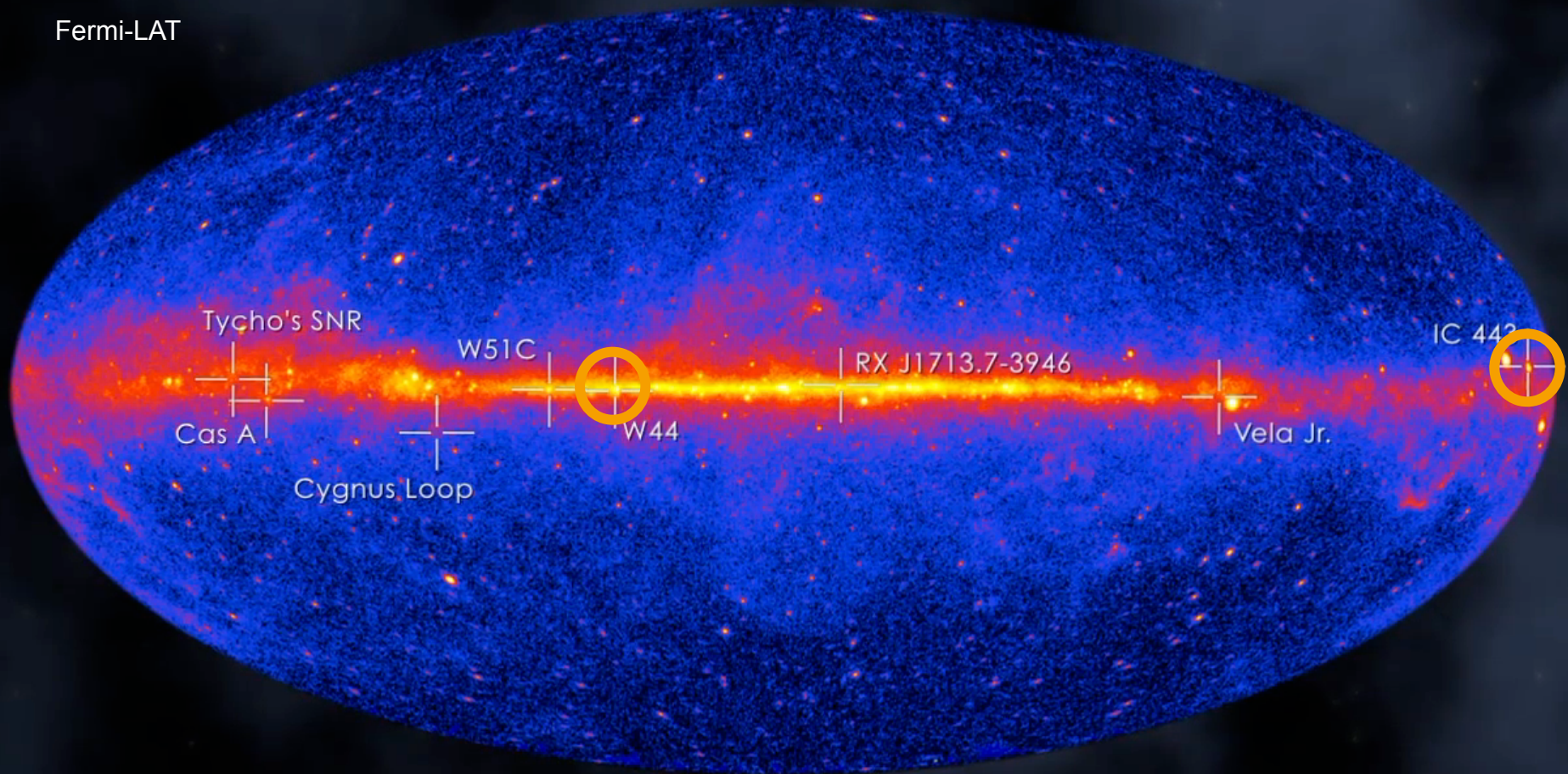


GeV-TeV spectra of supernova remnants



Supernova Remnants

Fermi-LAT

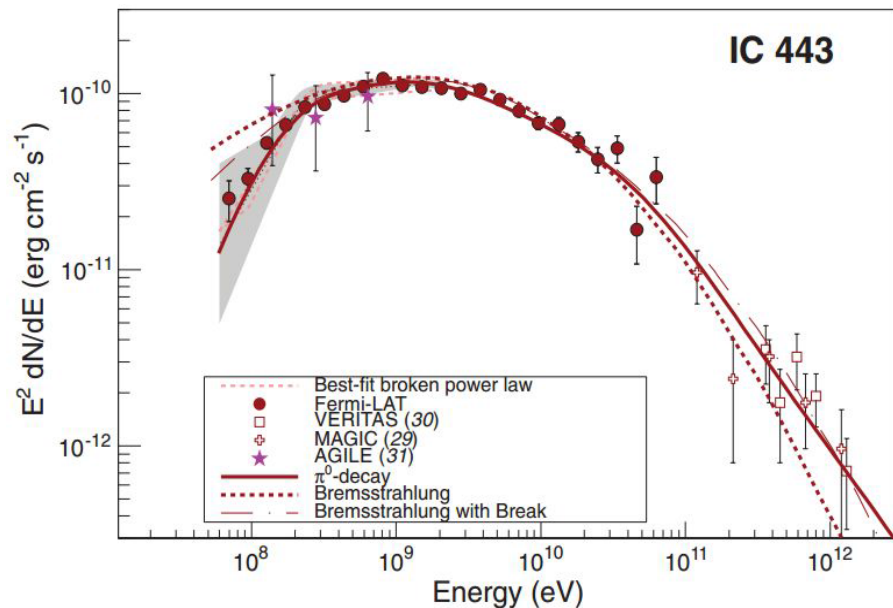


Detection of the “pion cutoff” in supernovae remnants

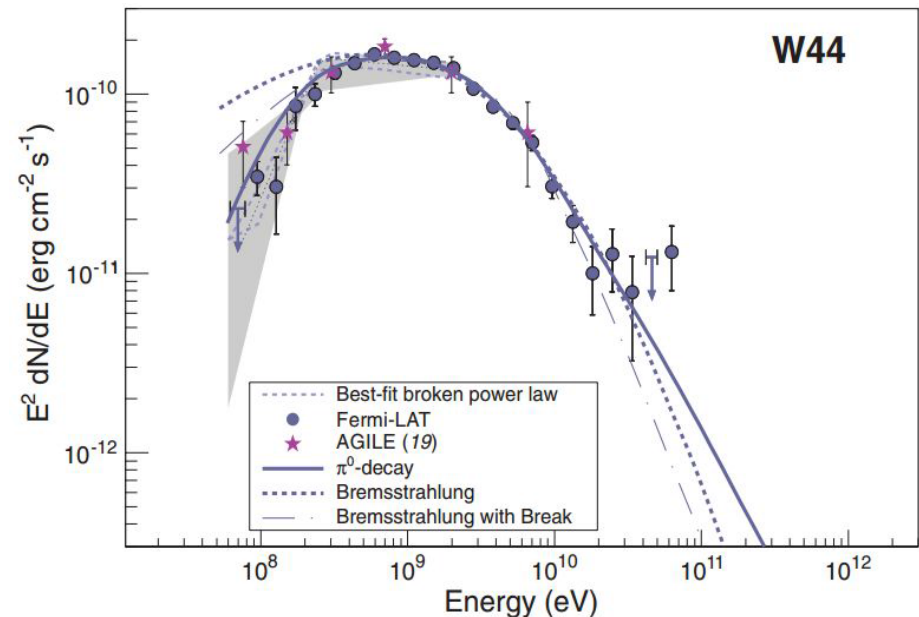
- Supernovae are accelerators of hadronic cosmic rays



Science 339, 2013



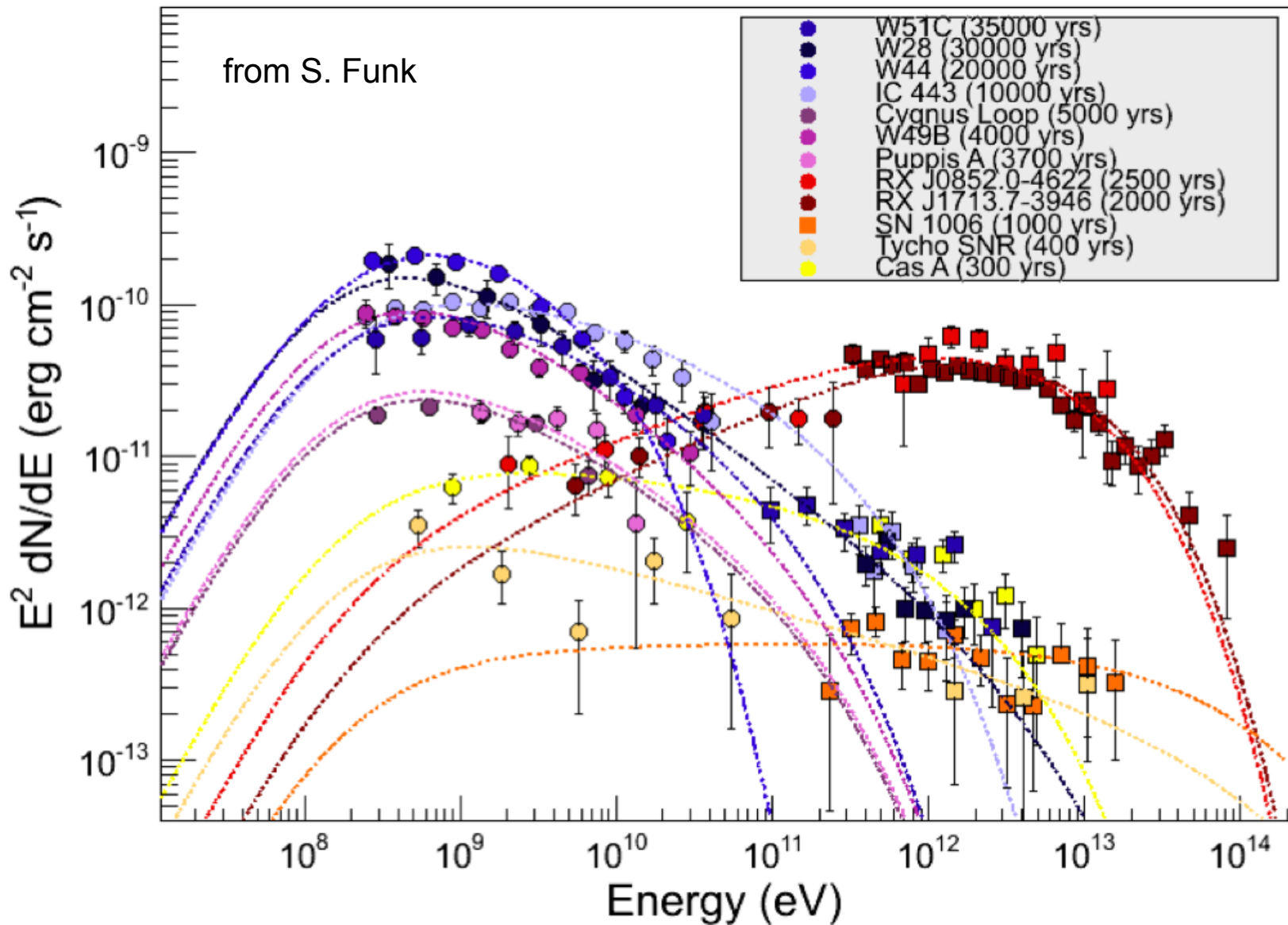
Science 339, 2013

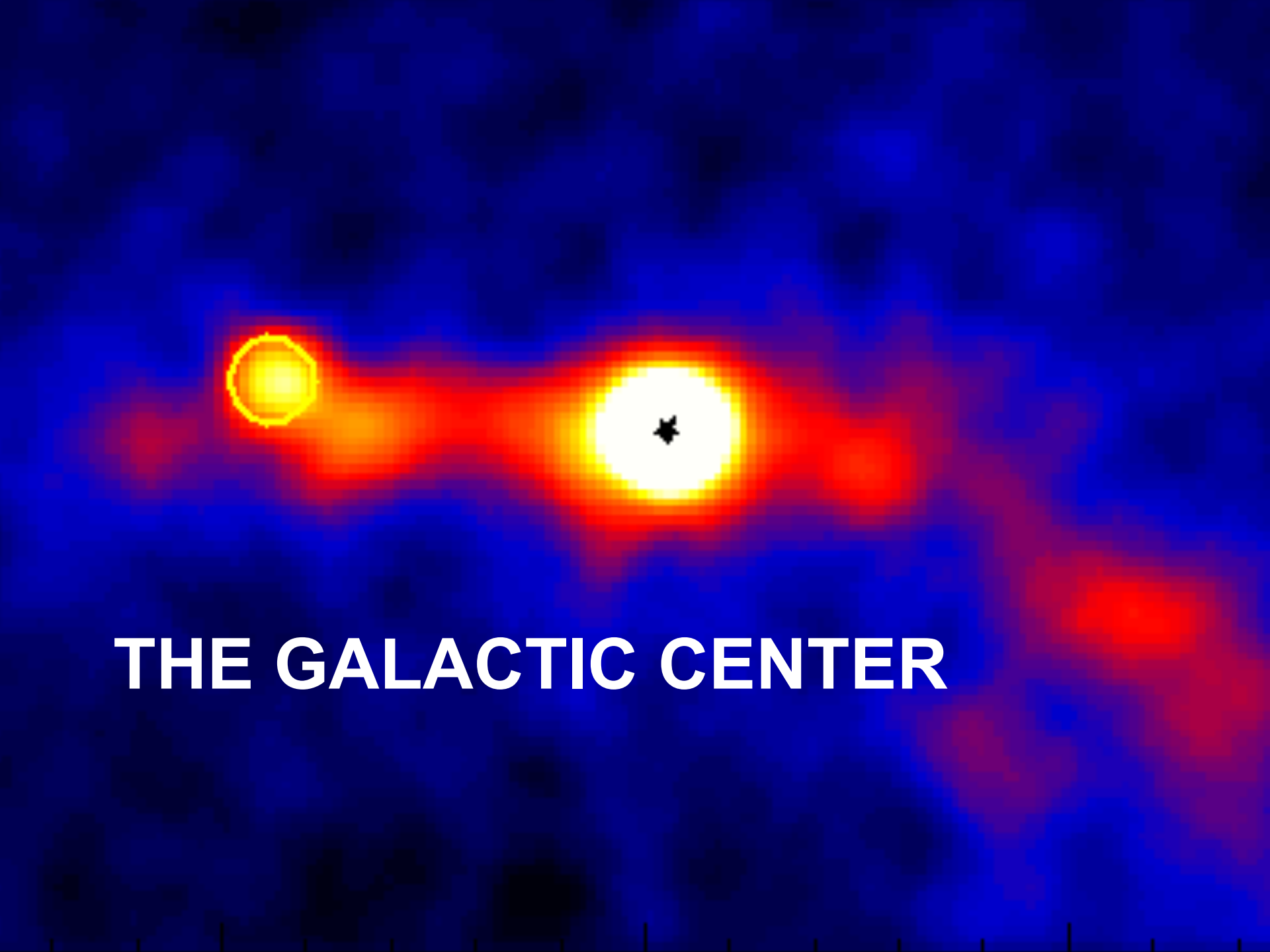


➤ but ...



... no PeVatrons yet

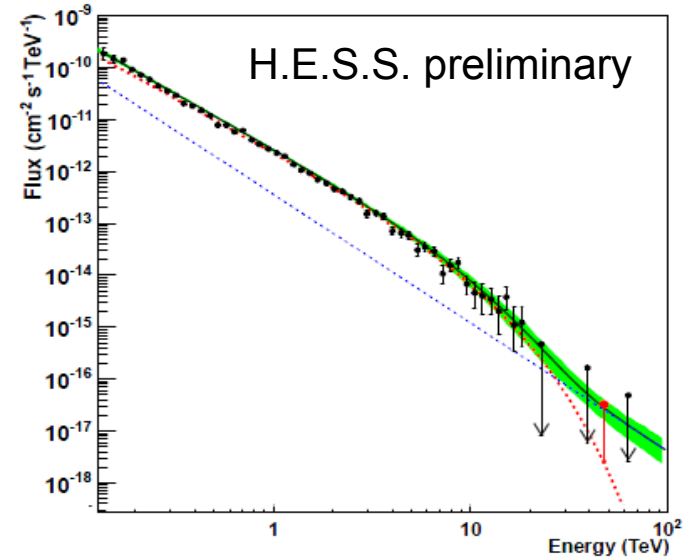
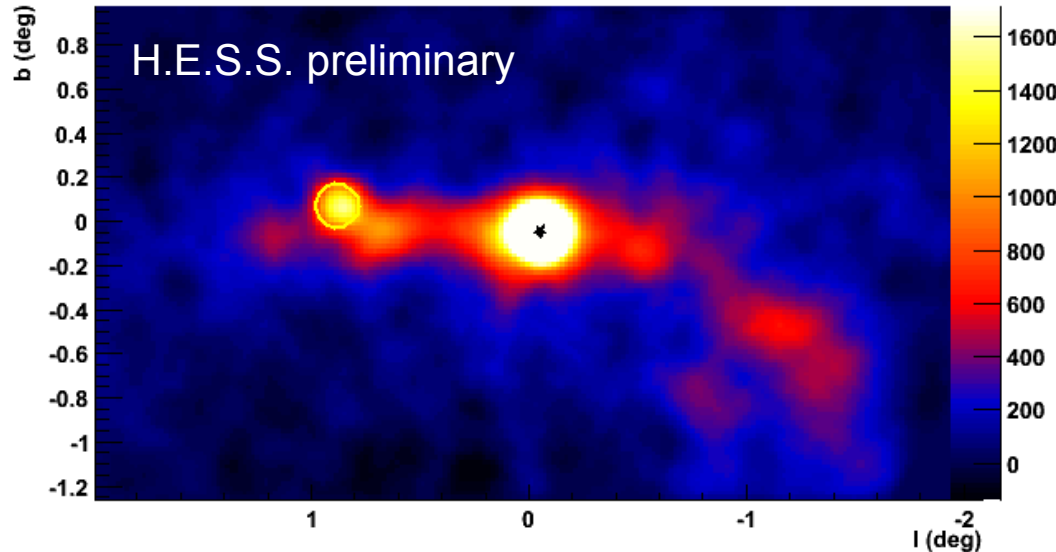




THE GALACTIC CENTER

The Galactic Centre at $E > 200$ GeV

Excess Map



- Intrinsic GC source spectrum has a stronger cut-off ~ 7 TeV
 - Spectrum of diffuse shows no indication of a cut-off below 25 TeV and follows a power-law up to at least 50 TeV
- Indication of a central source accelerating protons to energies > 500 TeV ?



THE EXTRA-GALACTIC SKY

Time Variability: IC 310

> IC 310

- AGN, black hole size ~ 23 min

> Flare in November 2012 (few hrs)

- $\Delta t/(1+z) \sim 4.8$ min
- Cannot be shock acceleration in jet

> Possible explanations?

- Cloud/star falling into jet
- Subjet structure
- Plasma or accretion turbulence of polar vacuum gap

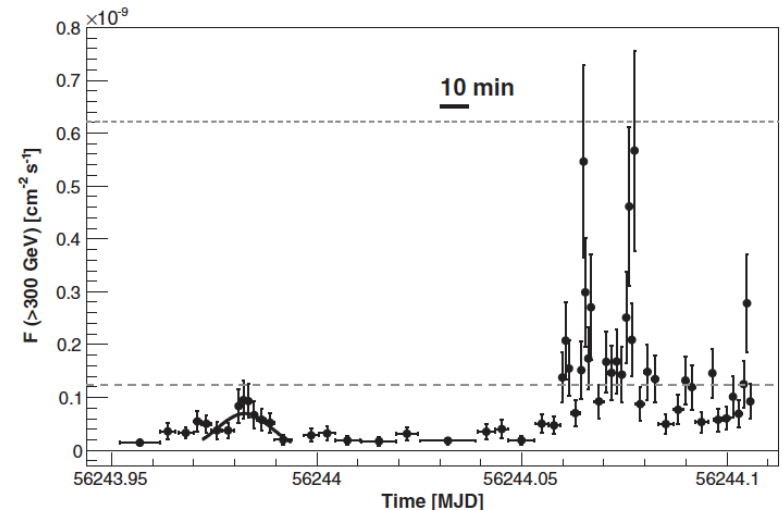
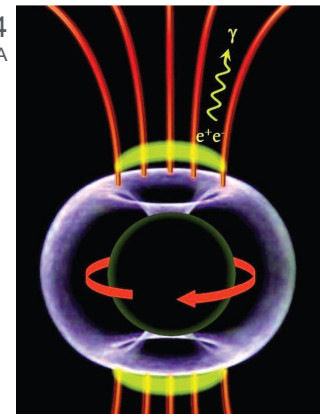


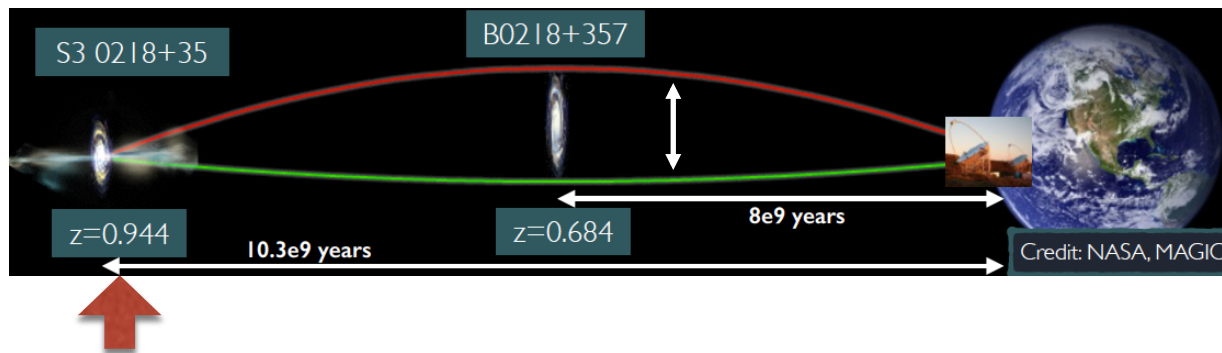
Fig. 4. Light curve of IC 310 observed with the MAGIC telescopes on the night of 12/13 November 2012, above 300 GeV. As a flux reference, the two gray lines indicate levels of 1 and 5 times the flux level of the Crab Nebula, respectively. The precursor flare (MJD 56243.972-56243.994) has been fitted with a Gaussian distribution. Vertical error bars show 1 SD statistical uncertainty. Horizontal error bars show the bin widths.

MAGIC, 2014
<http://adsabs.harvard.edu/abs/2014Sci...346.1080A>

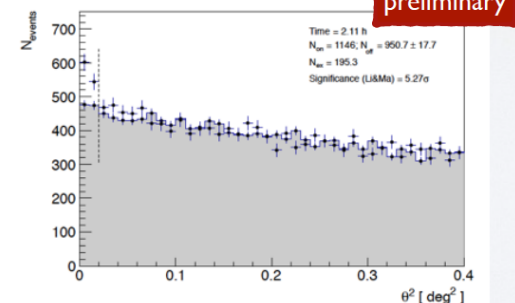


Gravitationally Lensed Blazar S3 0218+357

> ...or tunneling the full moon period using general relativity



MAGIC, in prep.
D. Mazin, Fermi Symposium 2014



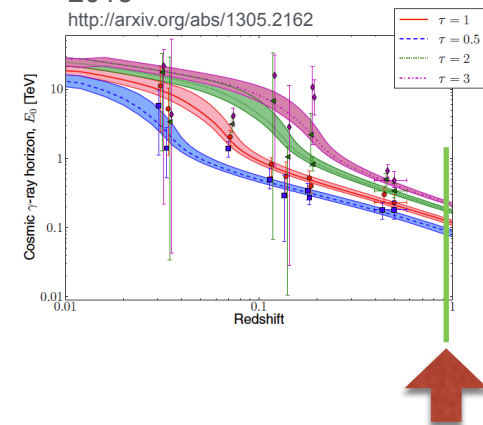
> April 2015: Atels on another very distant AGN

- FSRQ PKS 1441+25, $z = 0.939$
- MAGIC & VERITAS detections (Atels #7416, #7433, #7459)

> New constraints on extragalactic background light?

- I.e. opacity of the Universe!

Dominguez et al., 2013
<http://arxiv.org/abs/1305.2162>



The Large Magellanic Cloud

Milky Way

Large Magellanic Cloud

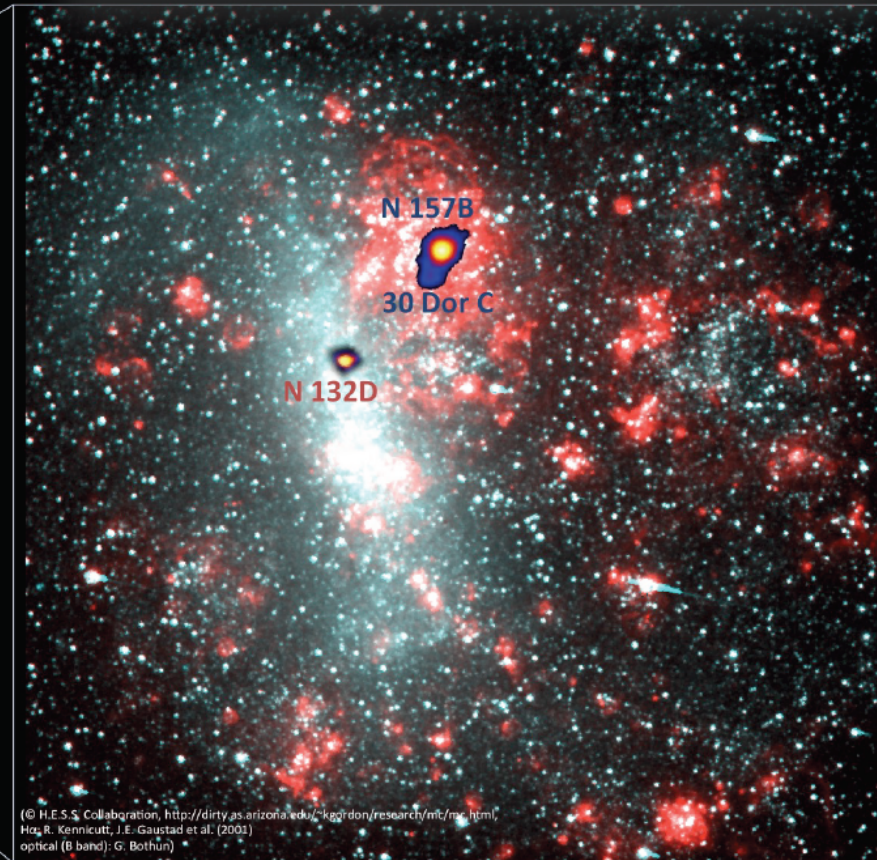


REPORTS

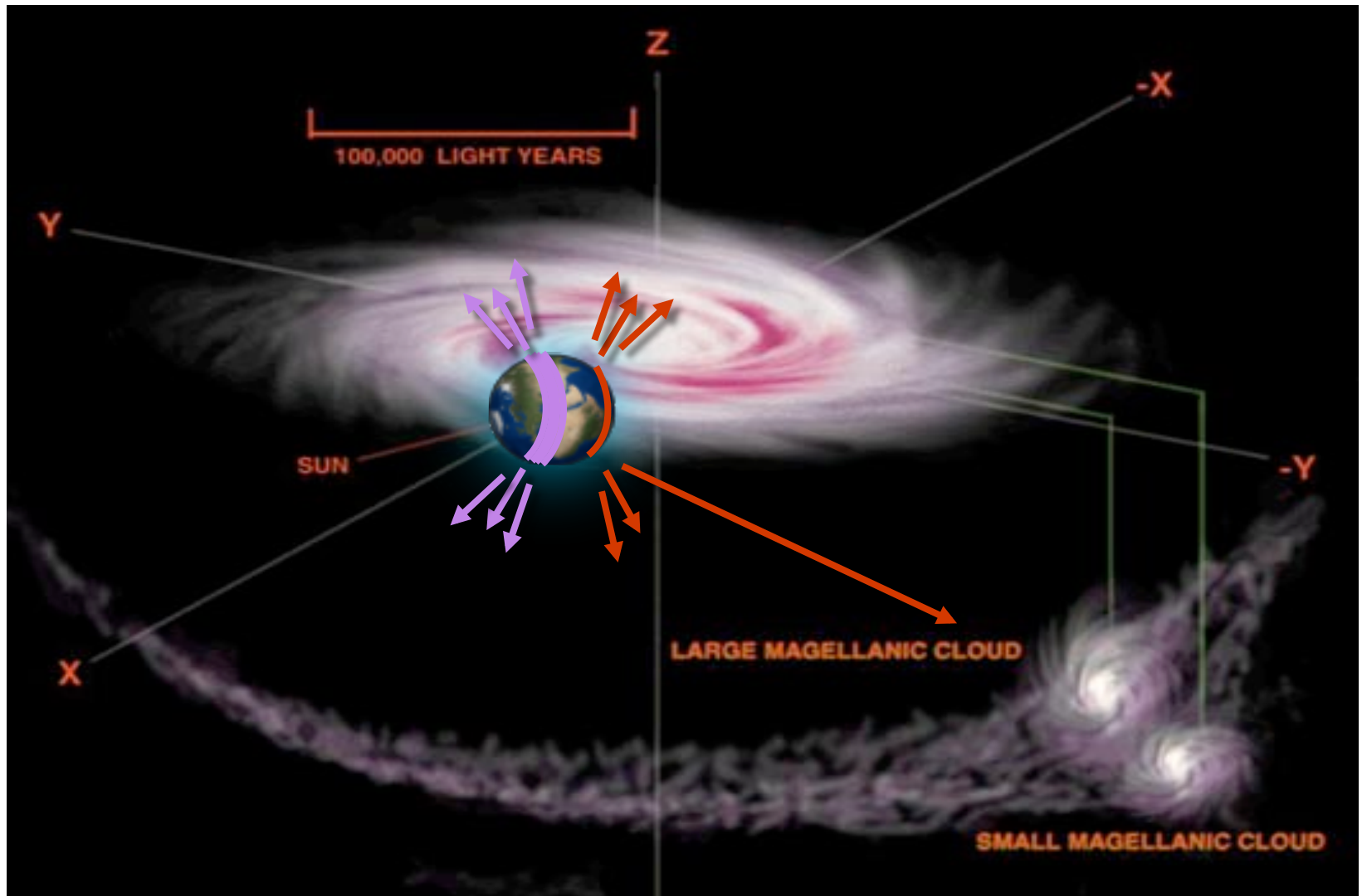
ASTROPHYSICS

The exceptionally powerful TeV γ -ray emitters in the Large Magellanic Cloud

The H.E.S.S. Collaboration*†



...more Southern Territory

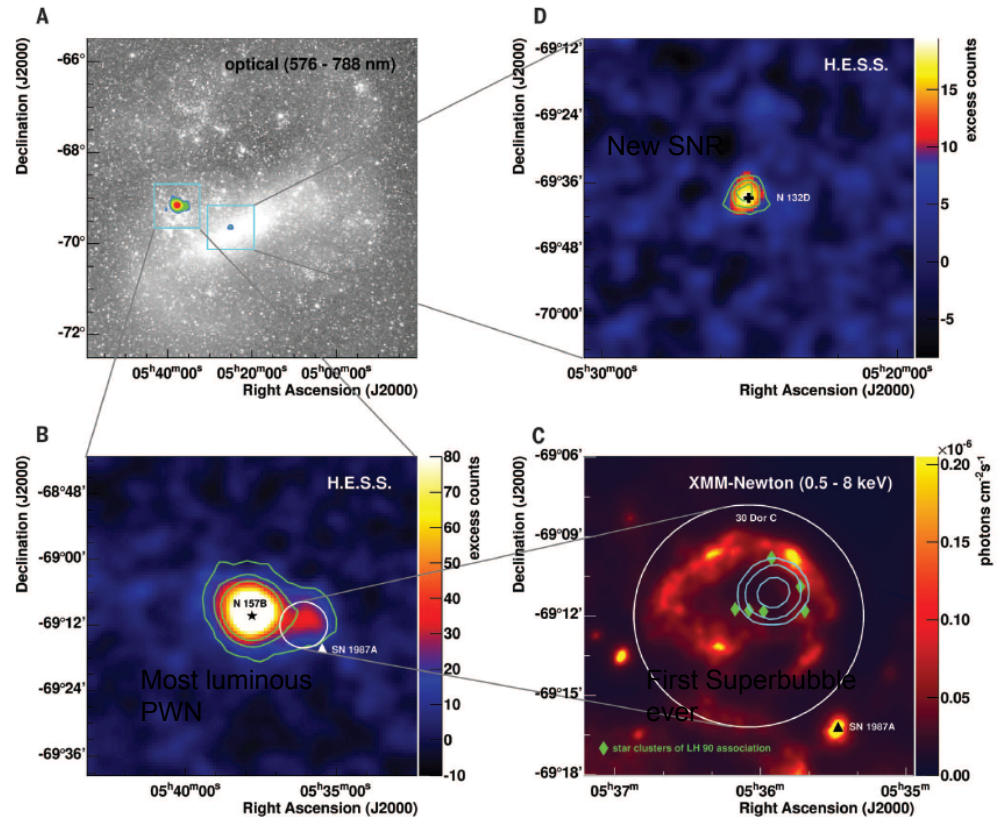
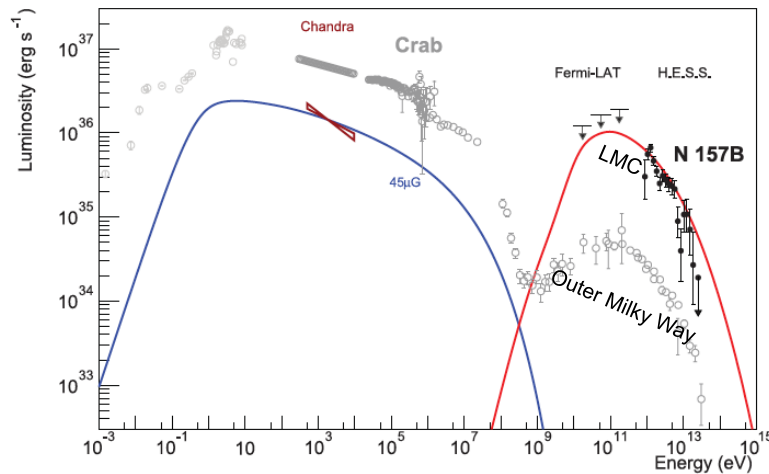


First glimpse of the LMC population

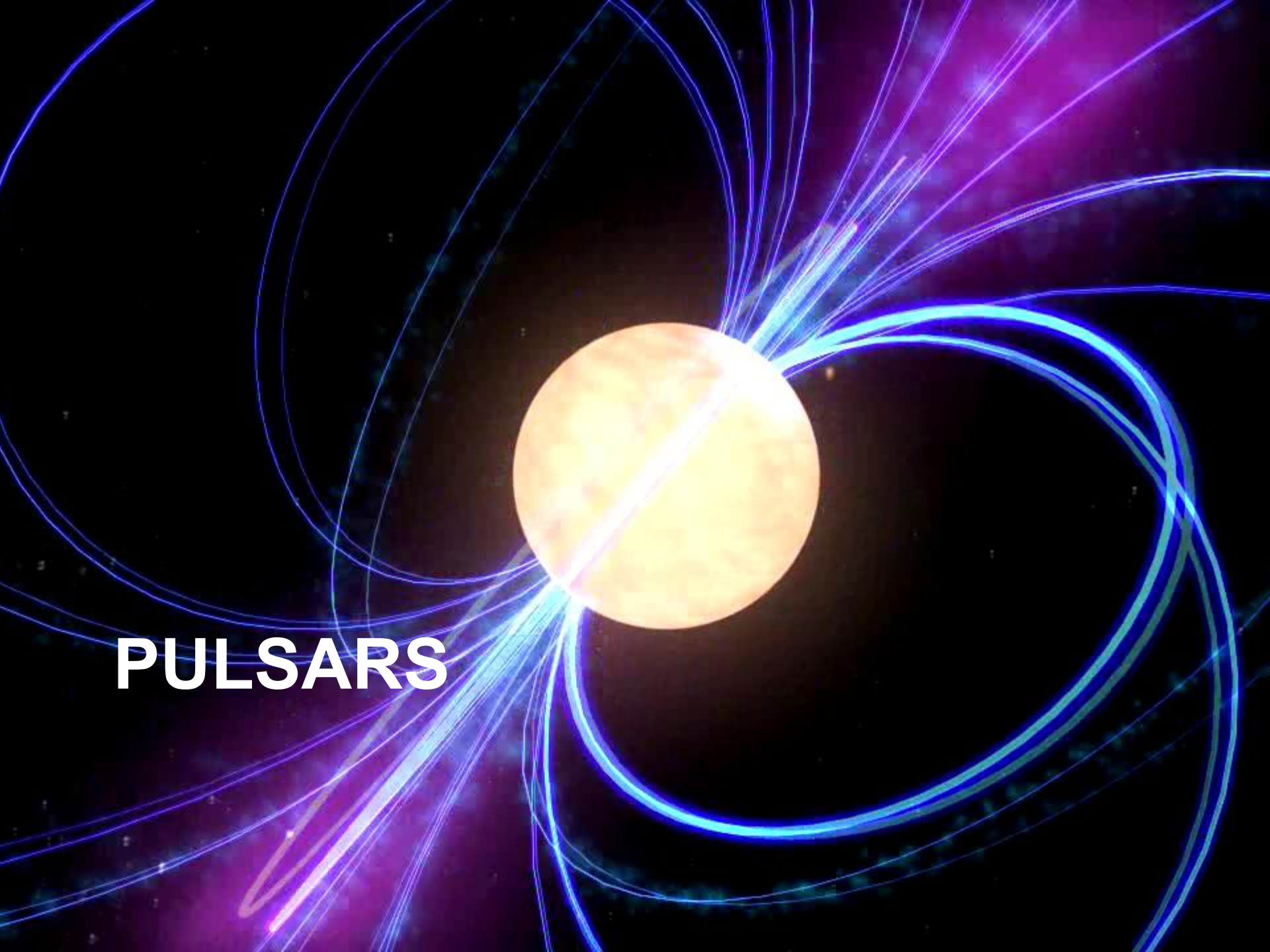
- First glimpse of the LMC population of (stellar-type) particle accelerators

H.E.S.S., 2015

<http://www.sciencemag.org/content/347/6220/406>



PULSARS

A central yellow-orange sphere represents the pulsar. It is surrounded by a complex network of blue and purple magnetic field lines that curve around it. Two bright, narrow beams of light extend from the poles of the sphere, representing the pulsar's emission. The background is a dark space filled with faint, distant stars.

Pulsars in Gamma Rays

> Pulsars

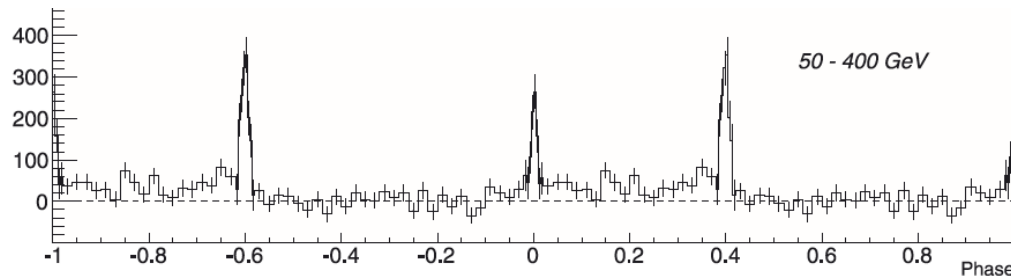
- Hot topic since the Crab PSR detection by MAGIC

> Second IACT pulsar: Vela

> Refined Crab PSR measurements

MAGIC, 2014

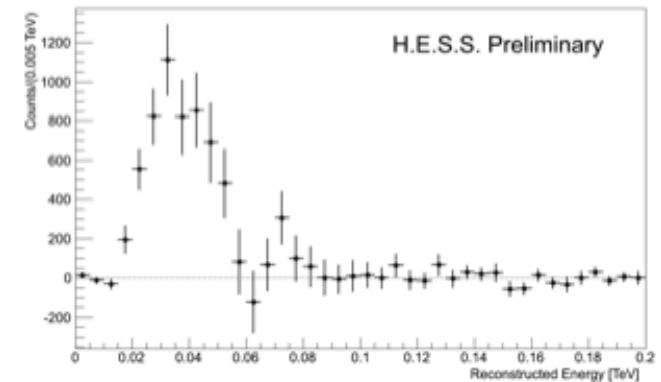
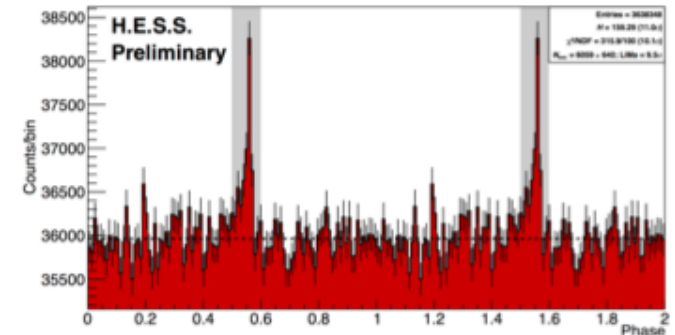
<http://www.aanda.org/articles/aa/abs/2014/05/aa23664-14/aa23664-14.html>



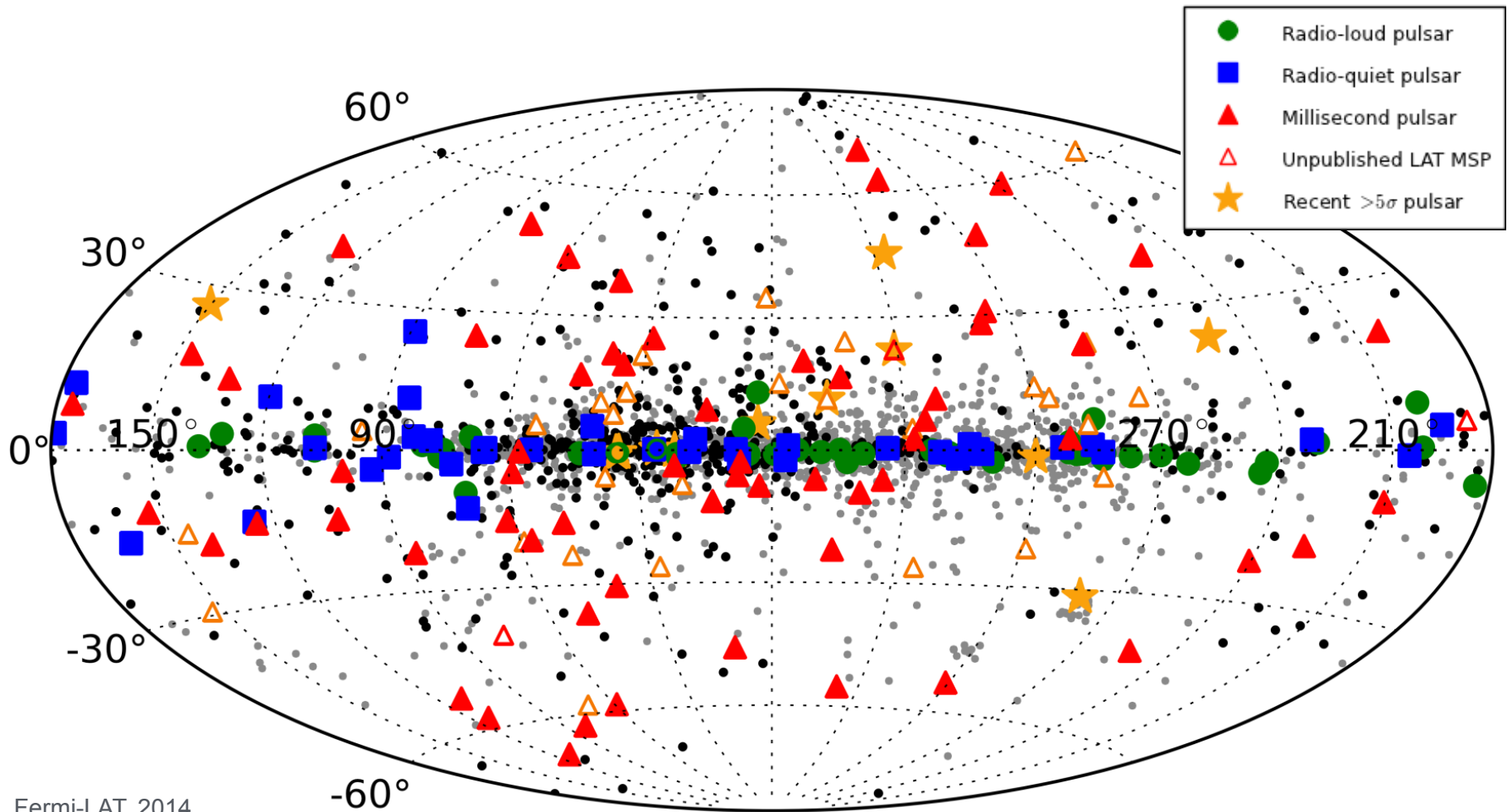
> Upper limit on Geminga from VERITAS

H.E.S.S., 2014

<http://www.desy.de/news/@@news-view?id=8361>



Pulsars are Fermi-LAT territory

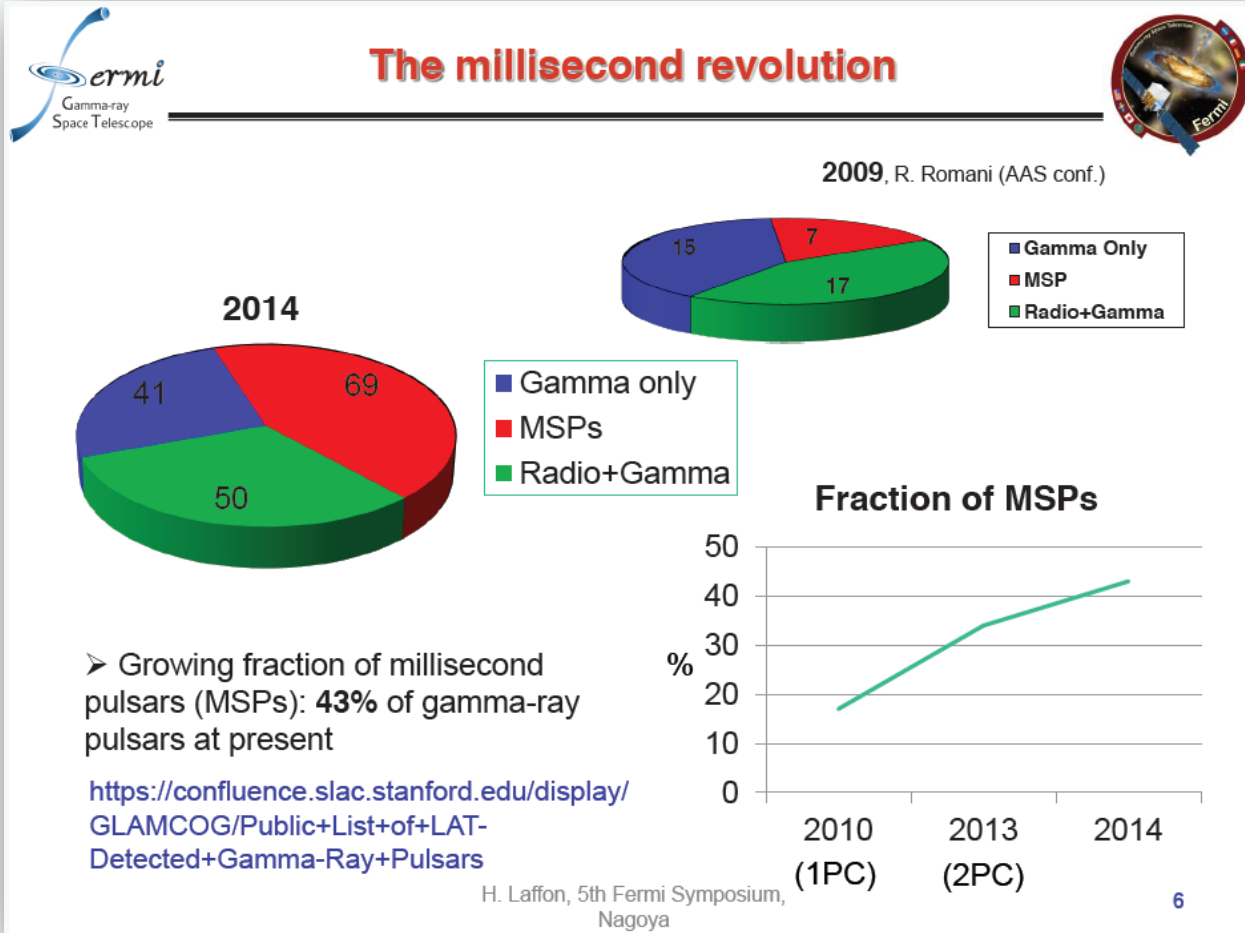


Fermi-LAT, 2014
H. Laffon at the Fermi Symposium 2014

Fermi Millisecond Pulsars

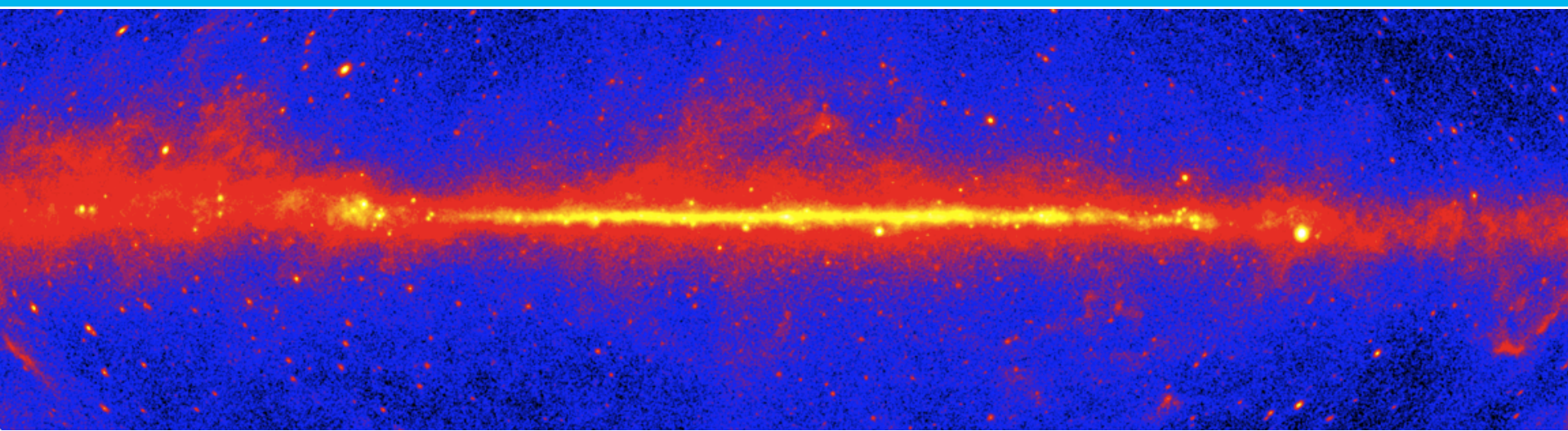
Fermi-LAT, 2014

H. Laffon at the Fermi Symposium 2014



- MSPs = old pulsars, powered by accretion of binary partner
- "Recycled pulsars"

Summary and Conclusion



- > Gamma-ray experiments today offer
 - an unique view into the high-energy Universe,
 - from MeV to PeV energies and
 - deliver unprecedented data of high precision
- > resulting in an increased understanding of the astrophysical foreground
- > **But we just see the tip of the iceberg**