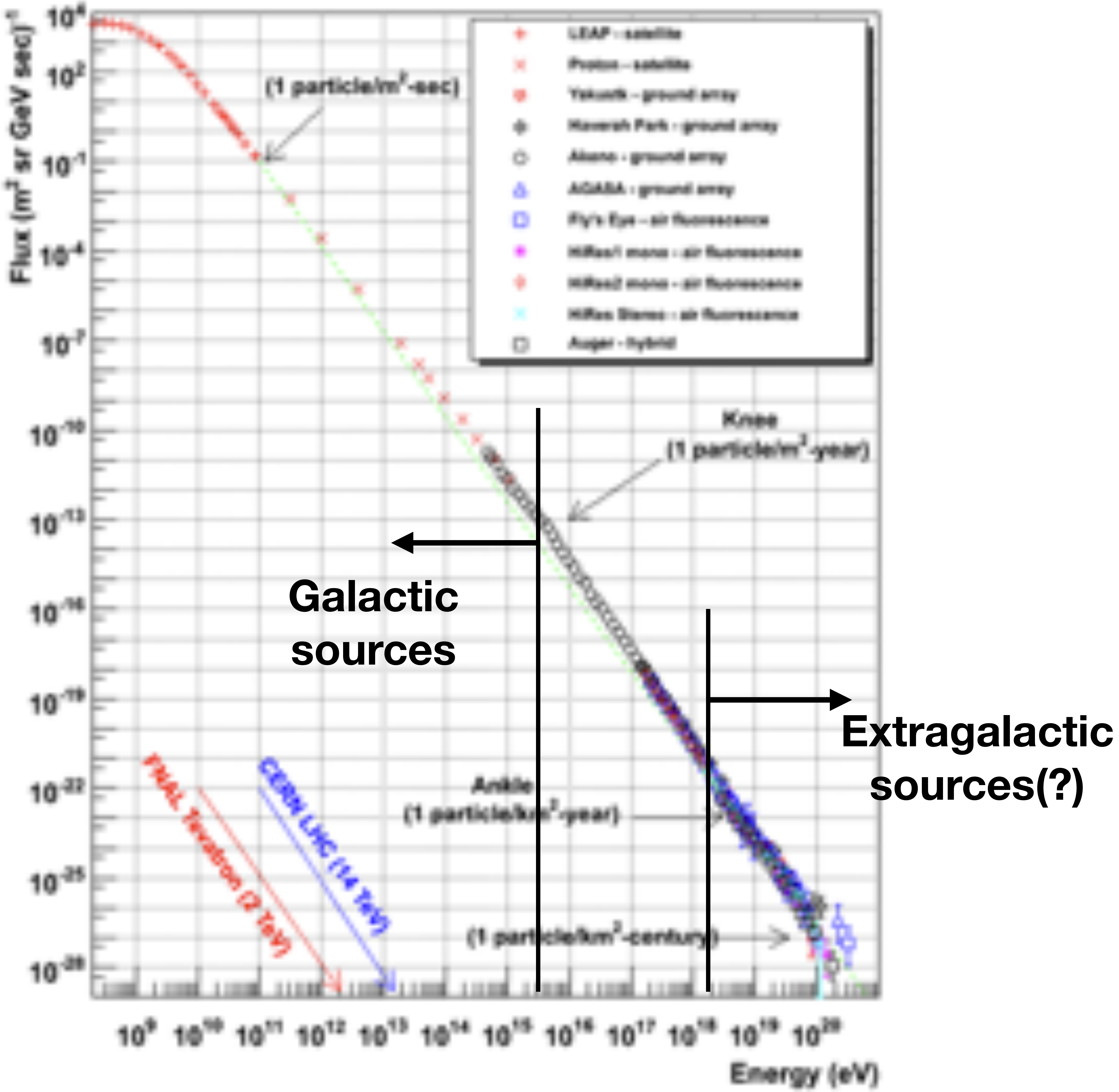
# Recent Highlights from the H.E.S.S. Gamma-ray Observatory

R D Parsons

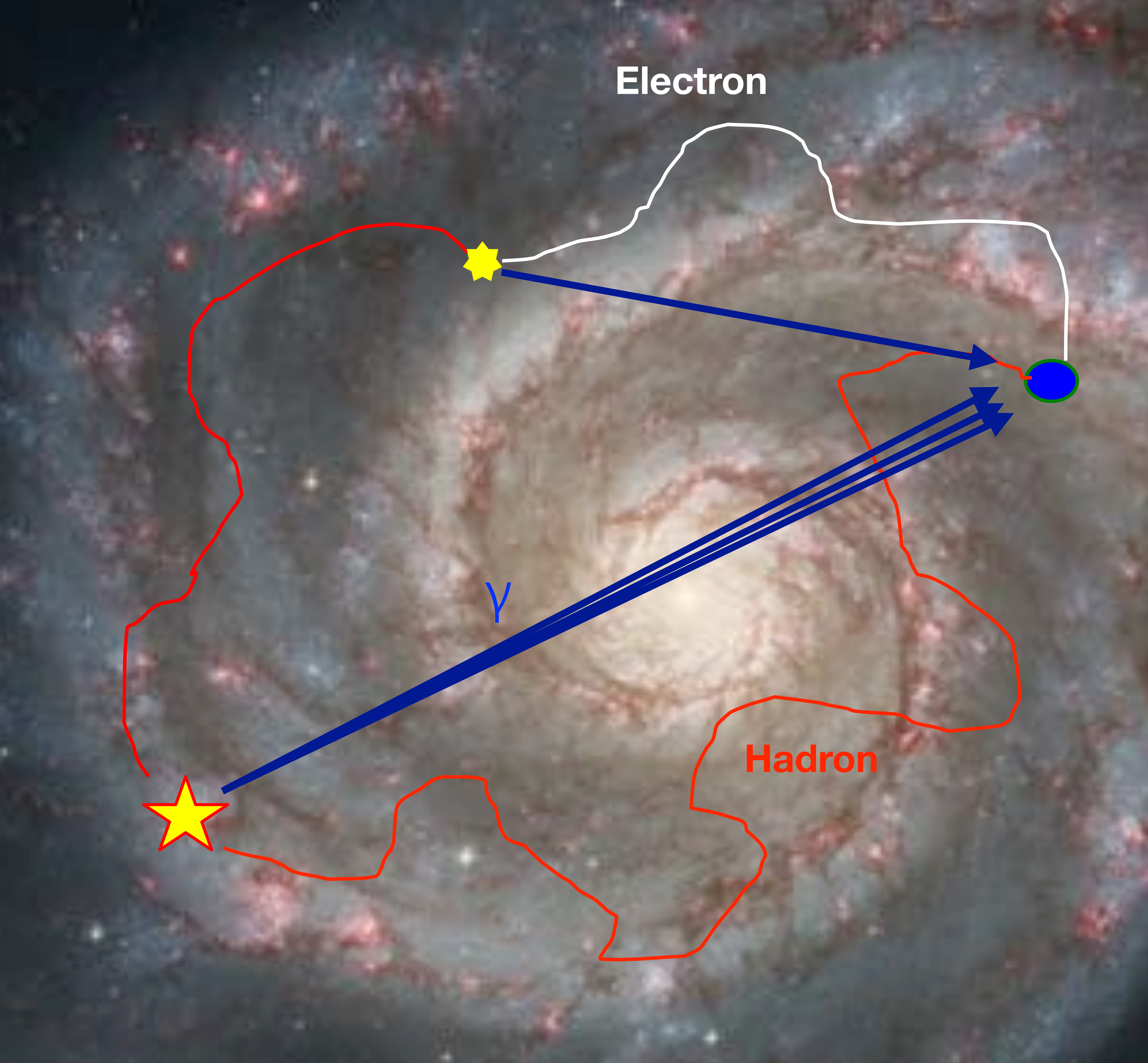



Cosmic-ray energy spectrum shows a remarkable **power-law behaviour** over **ten orders on magnitude in energy**

Breaks at **$10^{15}$** and **$10^{18}$ eV**

Could be the **transition from the galactic to extragalactic source** populations

Sources of energetic cosmic rays still **largely unknown**




Cosmic rays are **scattered** by the magnetic fields inside (or outside) the galaxy

Cosmic rays interact within the source (hadronic interaction or inverse Compton emission)

Gamma-rays travel **without deflection**

# Detecting Gamma-rays (Space based)

The problem for us observers however is that gamma-rays are **blocked by the Earth's atmosphere**

The obvious solution is therefore to **put your detector in space**

Essentially a **tracking detector** to detect and reconstruct gamma-rays showering inside the instrument

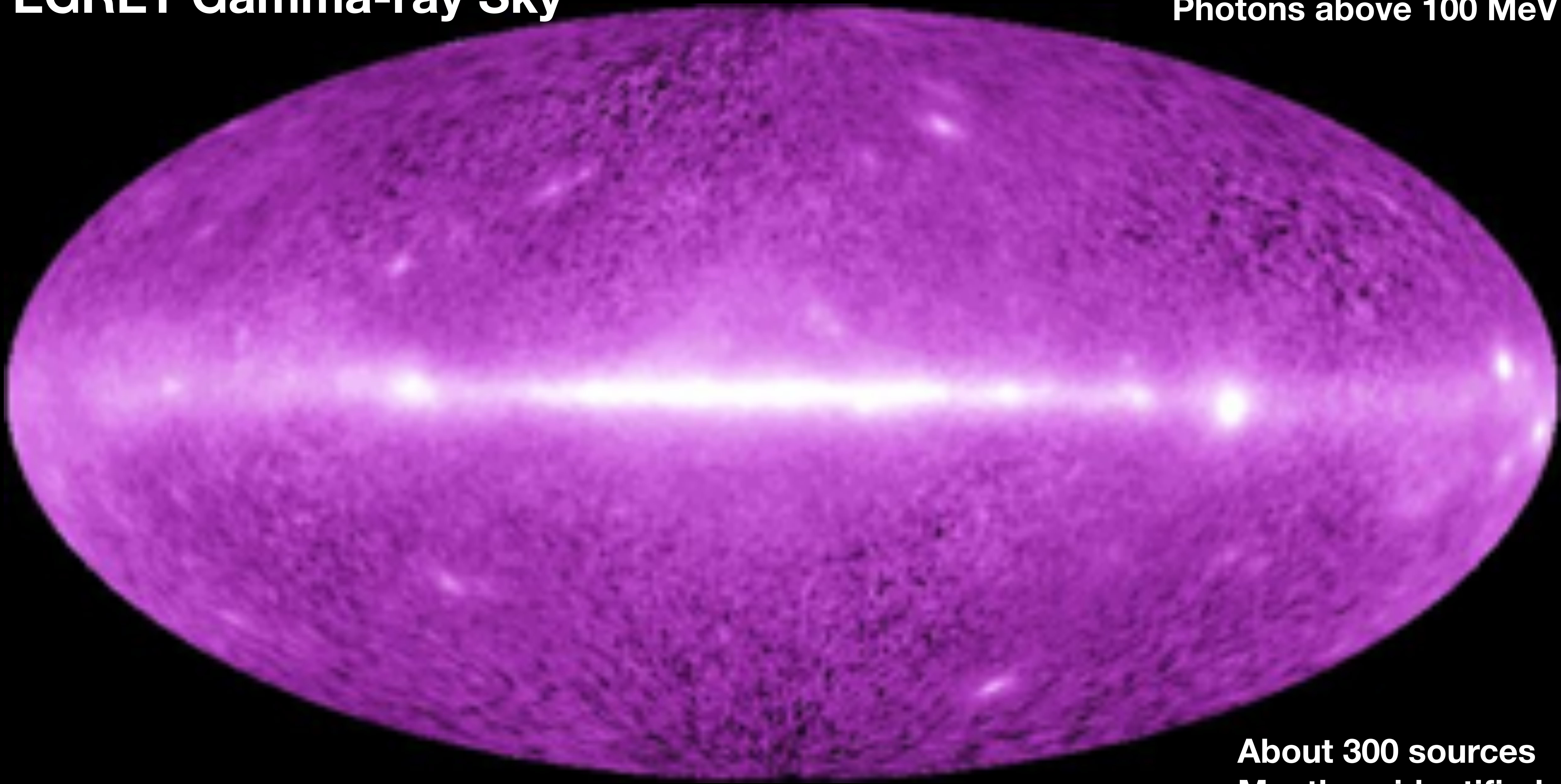
Surrounded by a **scintillator** to reject charged cosmic rays

Pioneered by the **EGRET telescope** and mastered by the **Fermi telescope**

Sensitive in energy range **(100 GeV - 1 TeV)**

# EGRET Gamma-ray Sky

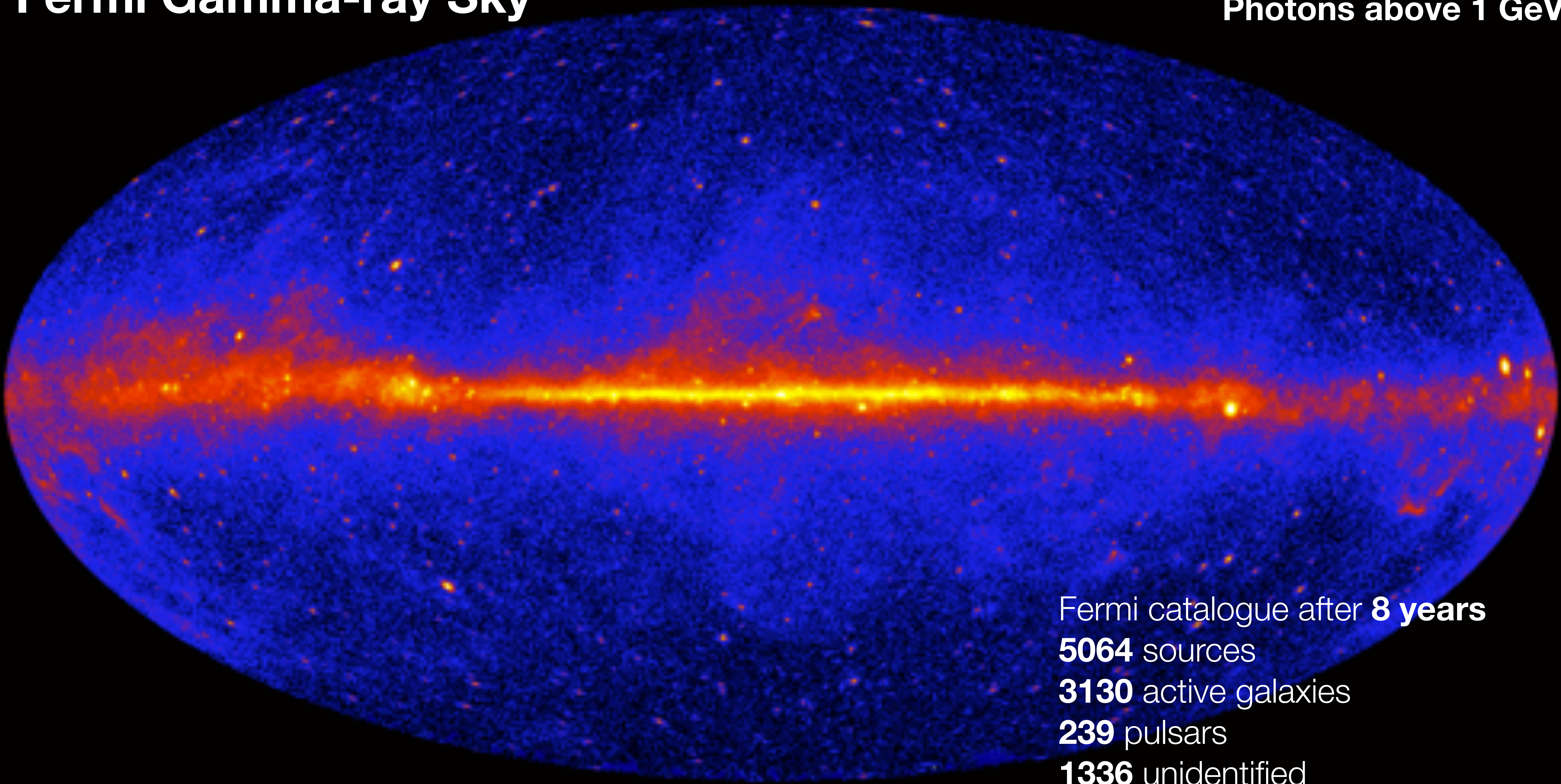
**Photons above 100 MeV**



**About 300 sources**
**Mostly unidentified**

# Fermi Gamma-ray Sky

**Photons above 1 GeV**



Fermi catalogue after **8 years**

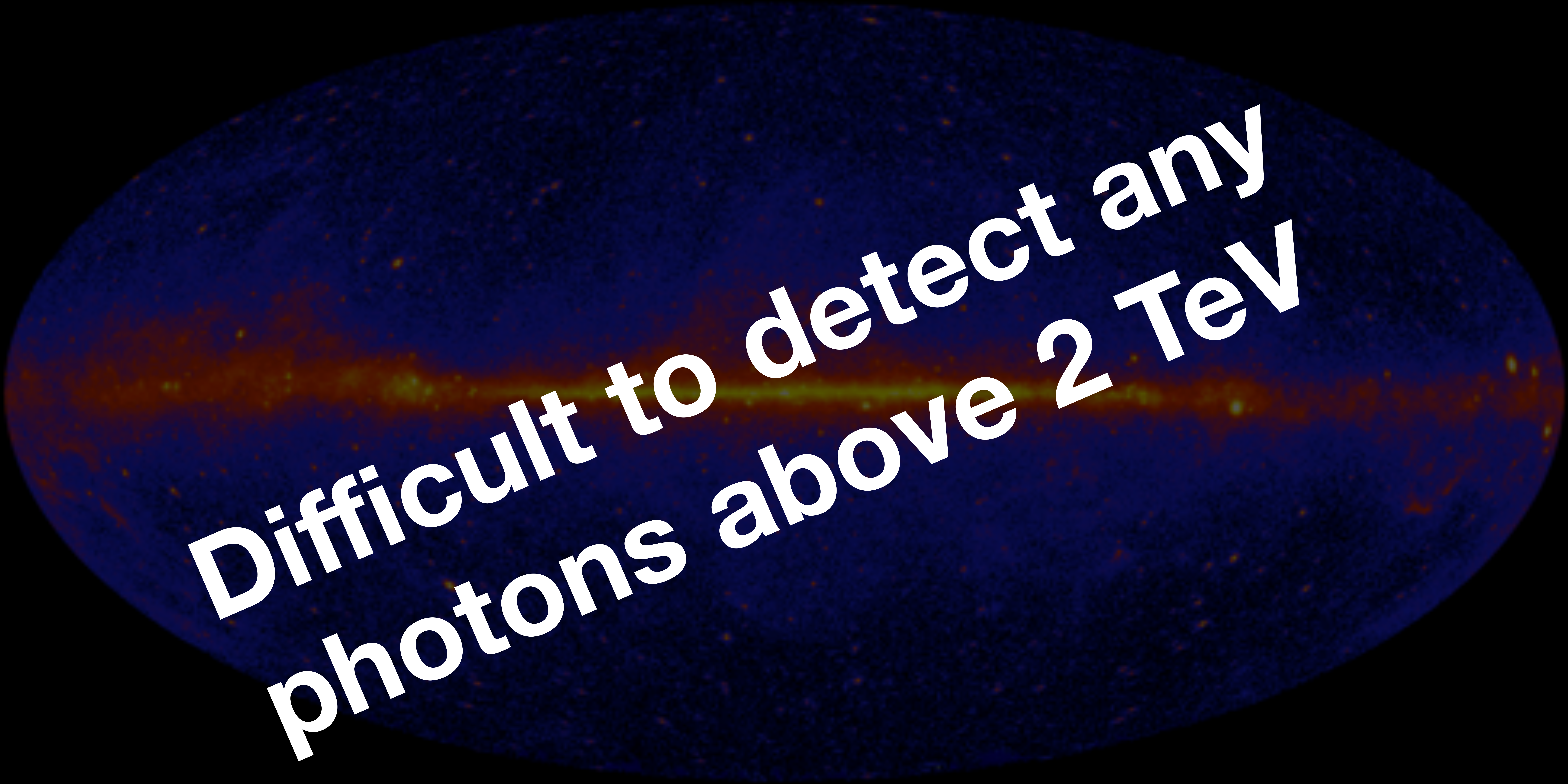
**5064** sources

**3130** active galaxies

**239** pulsars

**1336** unidentified

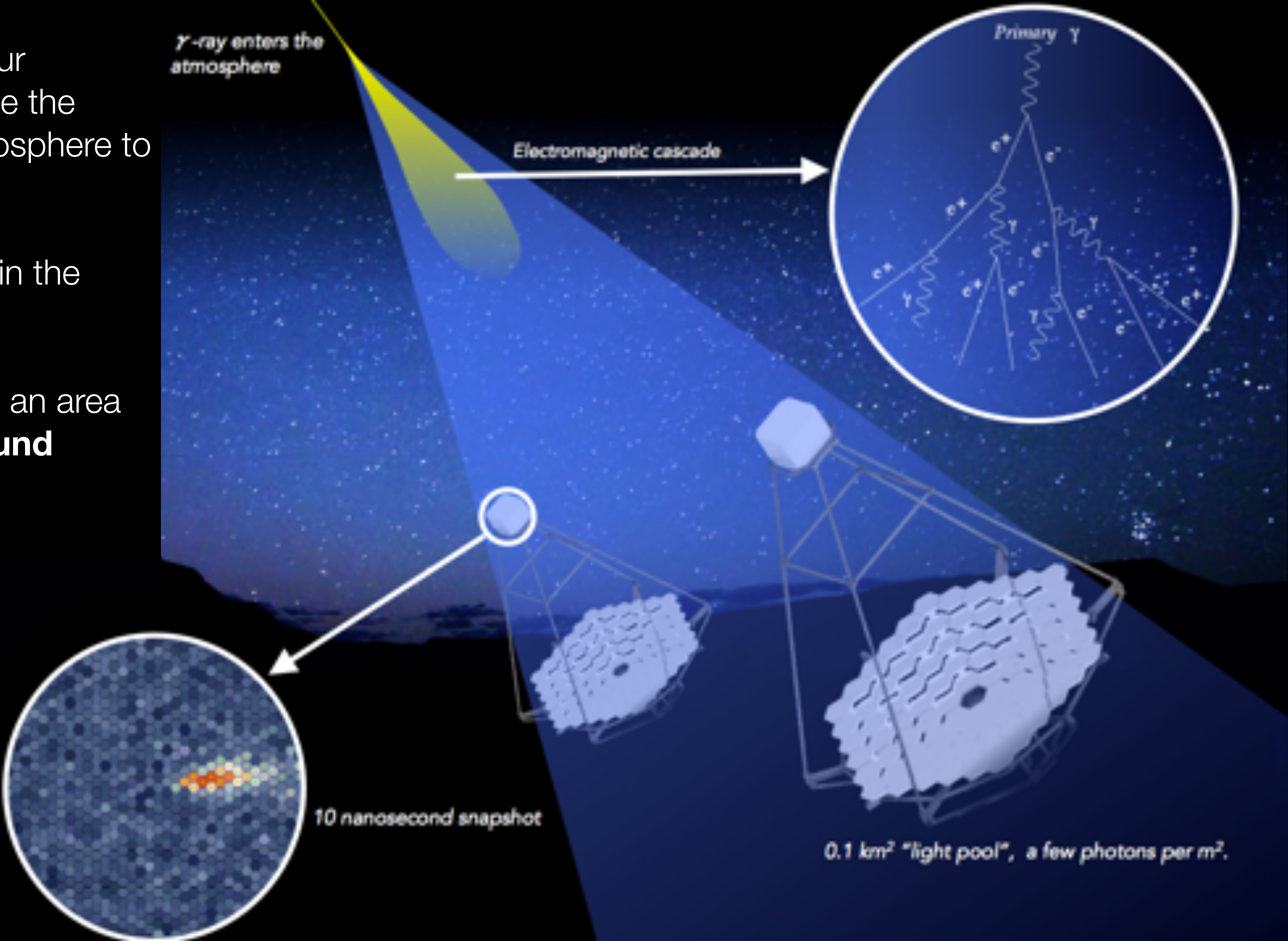
**358** various galactic sources


Difficult to detect any
photons above 2 TeV

If we want to increase our effective area we can use the interaction with the atmosphere to our advantage

**EM cascade** develops in the atmosphere

Emits Cherenkov light in an area of about **120 m on ground**

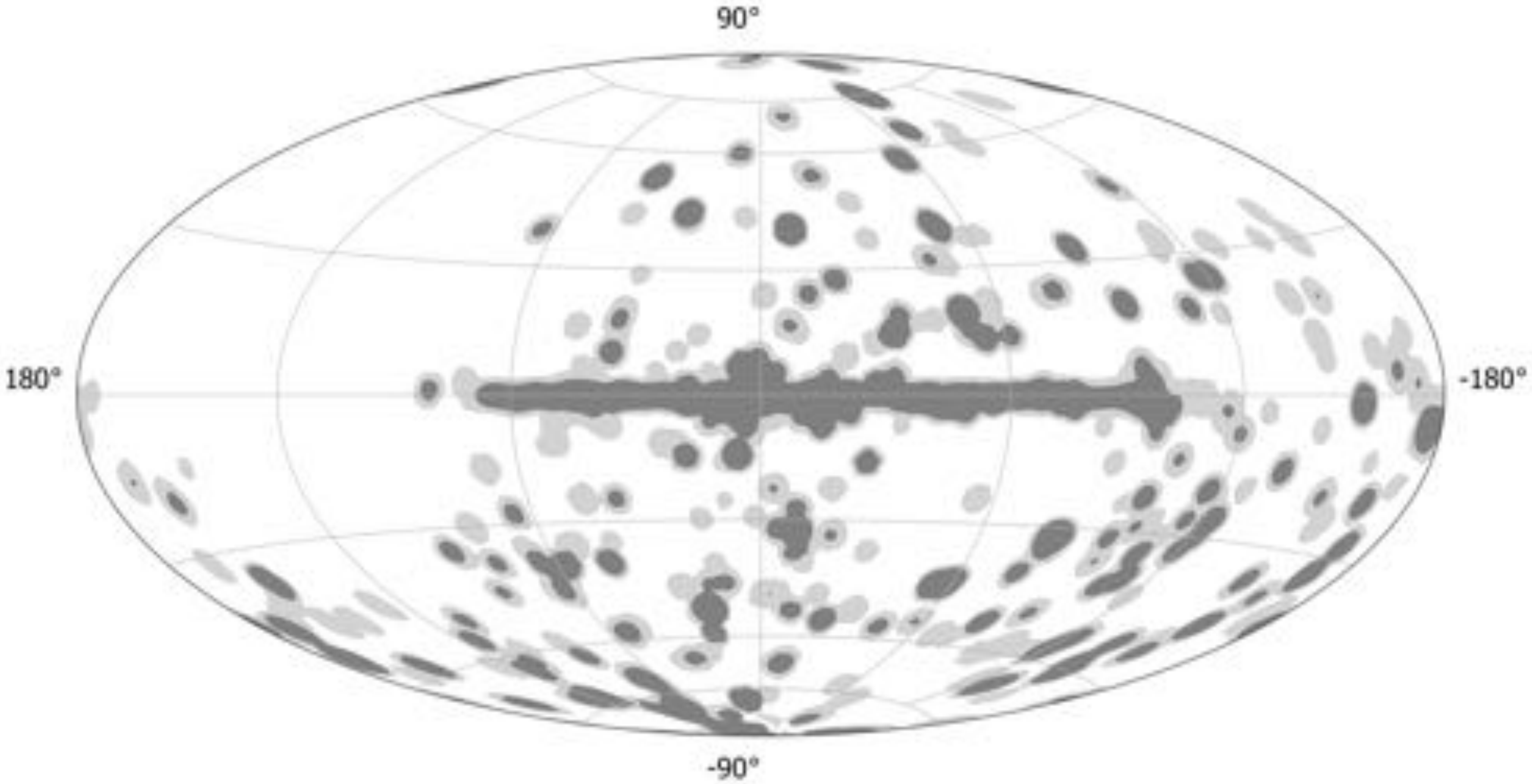



MAGIC
VERITAS
H.E.S.S.

# High Energy Stereoscopic System

**4 x 12m** Telescopes (phase-I)
**1 x 28m** Telescope
**5 degree** FoV
Energy Range: **0.05 - 50 TeV**
Angular Resolution: **<0.1 deg**

Sited in the highlands of Namibia
15 years of operation
Excellent views of the galactic plane
~100 sources discovered (~60% of total)

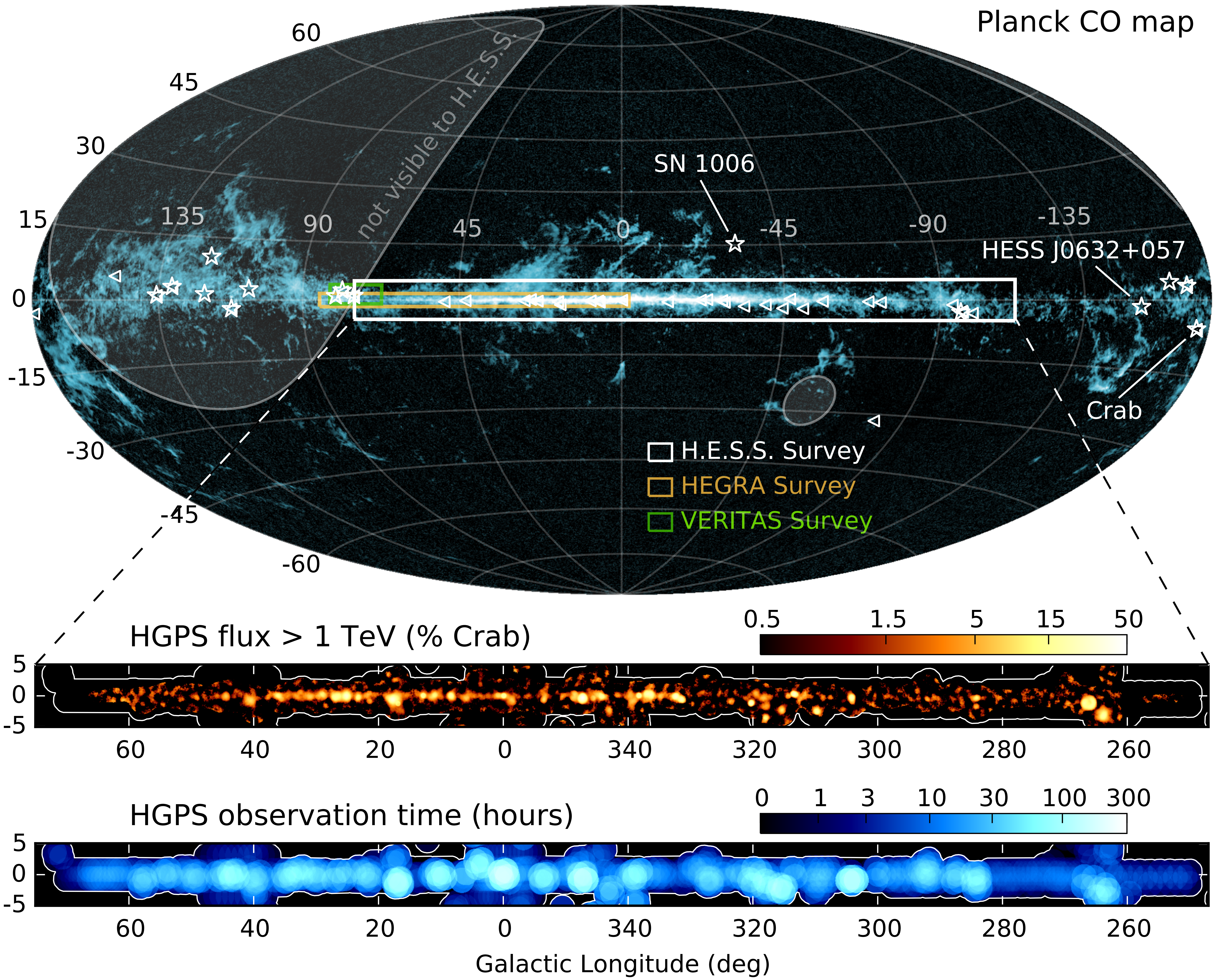

90°
180°
-180°
-90°

# H.E.S.S. Galactic Plane Survey

Almost **2700 hours** of observation taken on the galactic plane by H.E.S.S.

Coverage to at least **10% Crab Flux**

Much better in most places



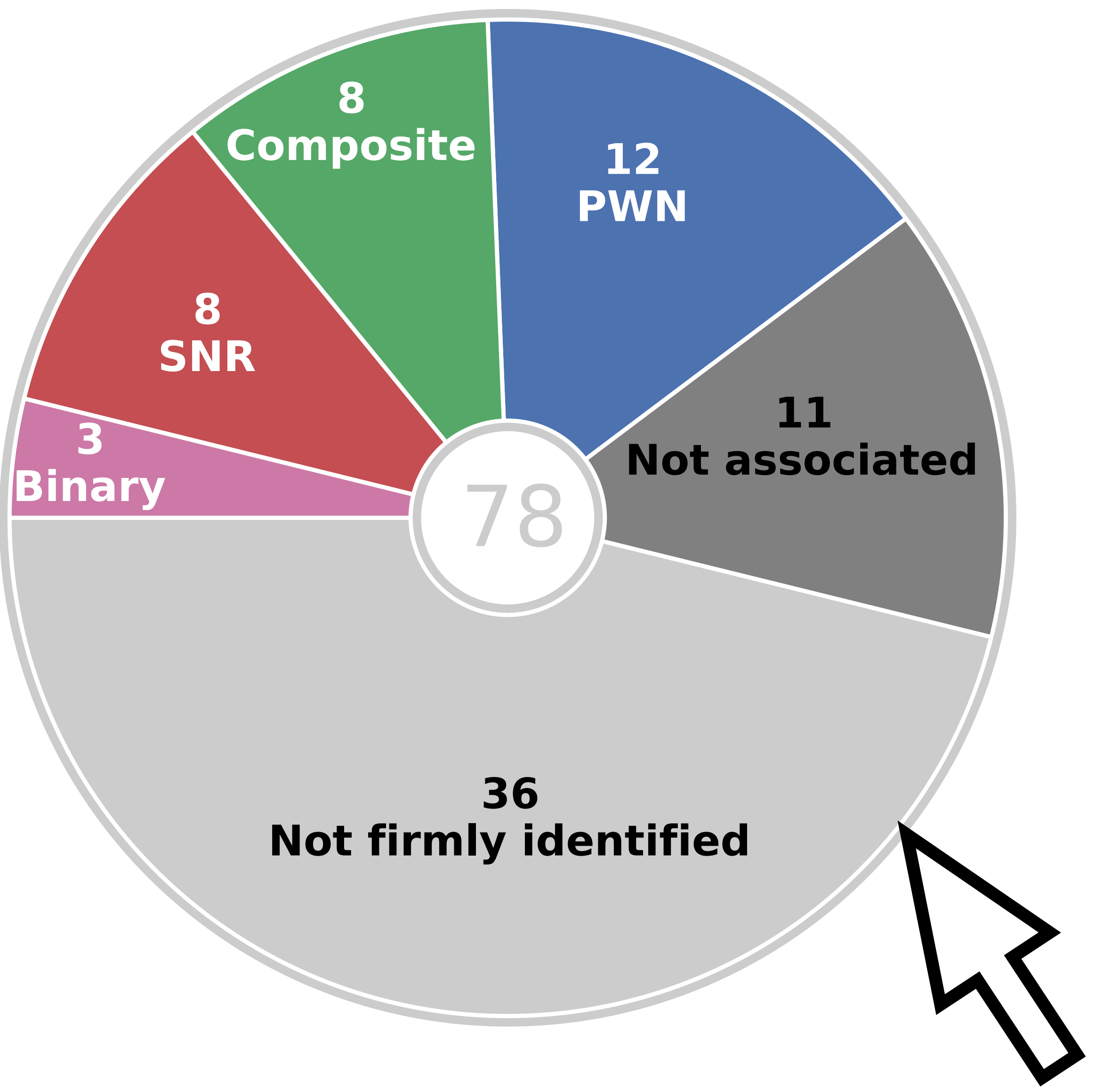

https://www.mpi-hd.mpg.de/hfm/HESS/hgps/

# H.E.S.S. Galactic Plane Survey

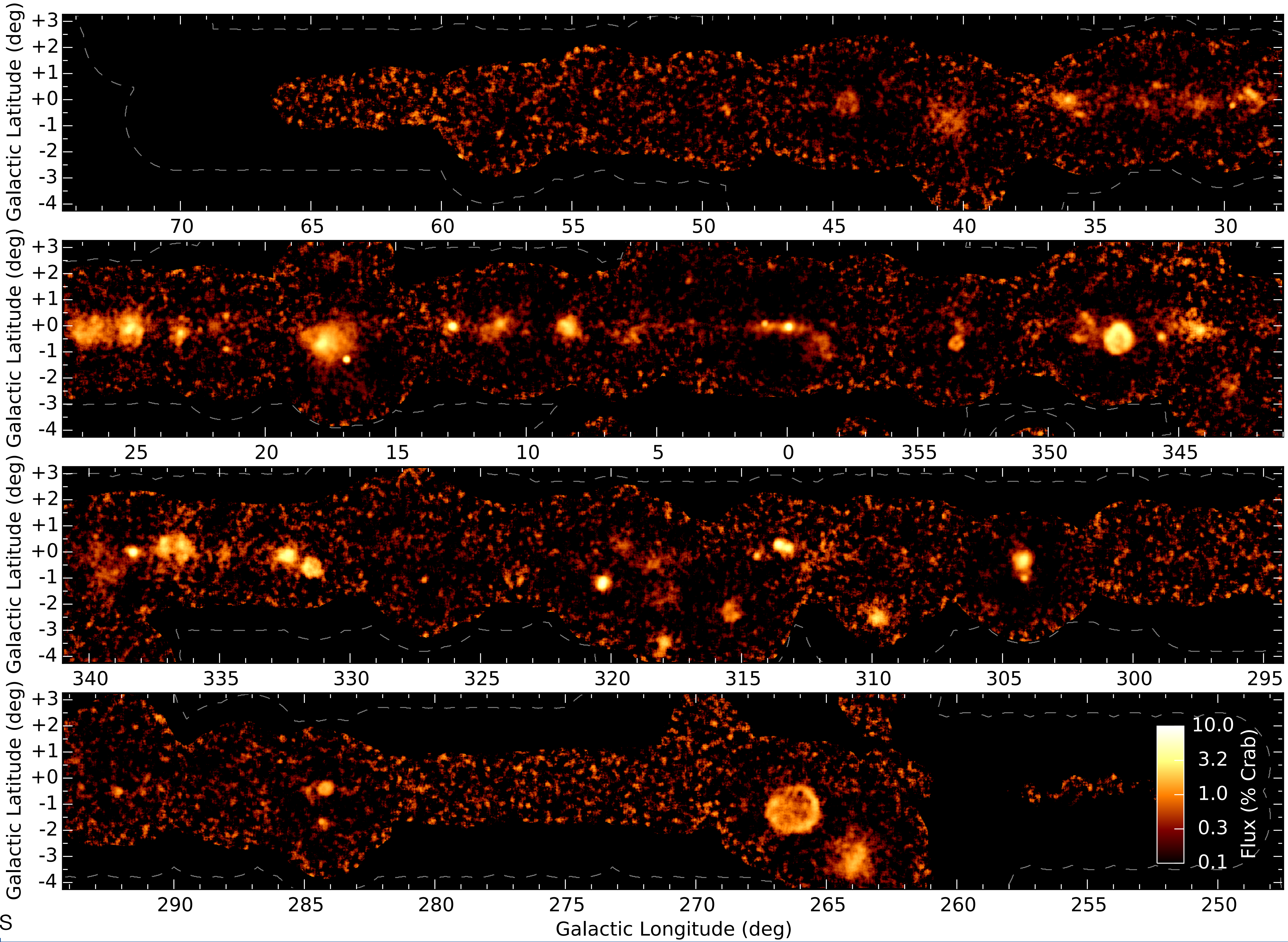
78 sources discovered in total

Most do not have strong strong associations with known MWL sources

Of the known sources PWN are the most numerous class




May have multiple potential counterparts



# Pulsar Wind Nebulae

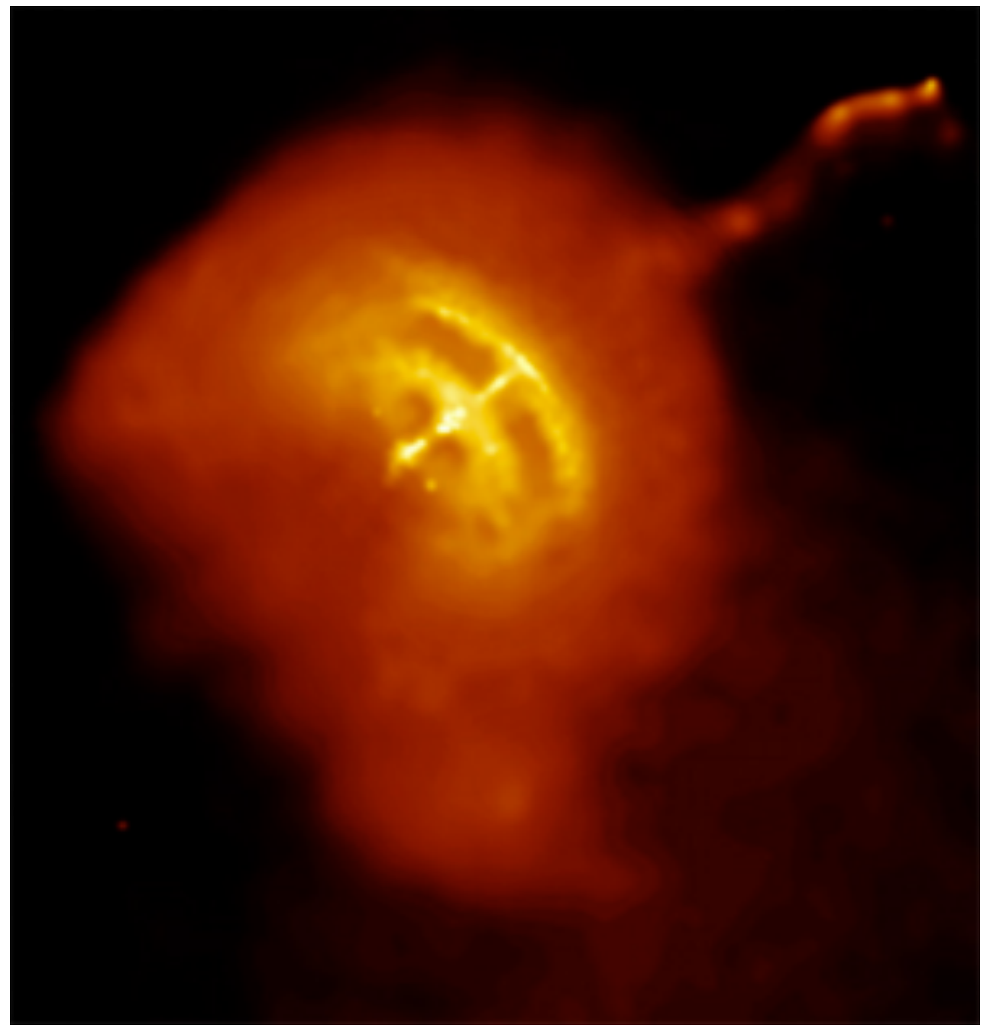
Nebula formed around a **central pulsar engine**

Electrons and positrons stream from the central pulsar and are **shocked at the interaction with interstellar material**

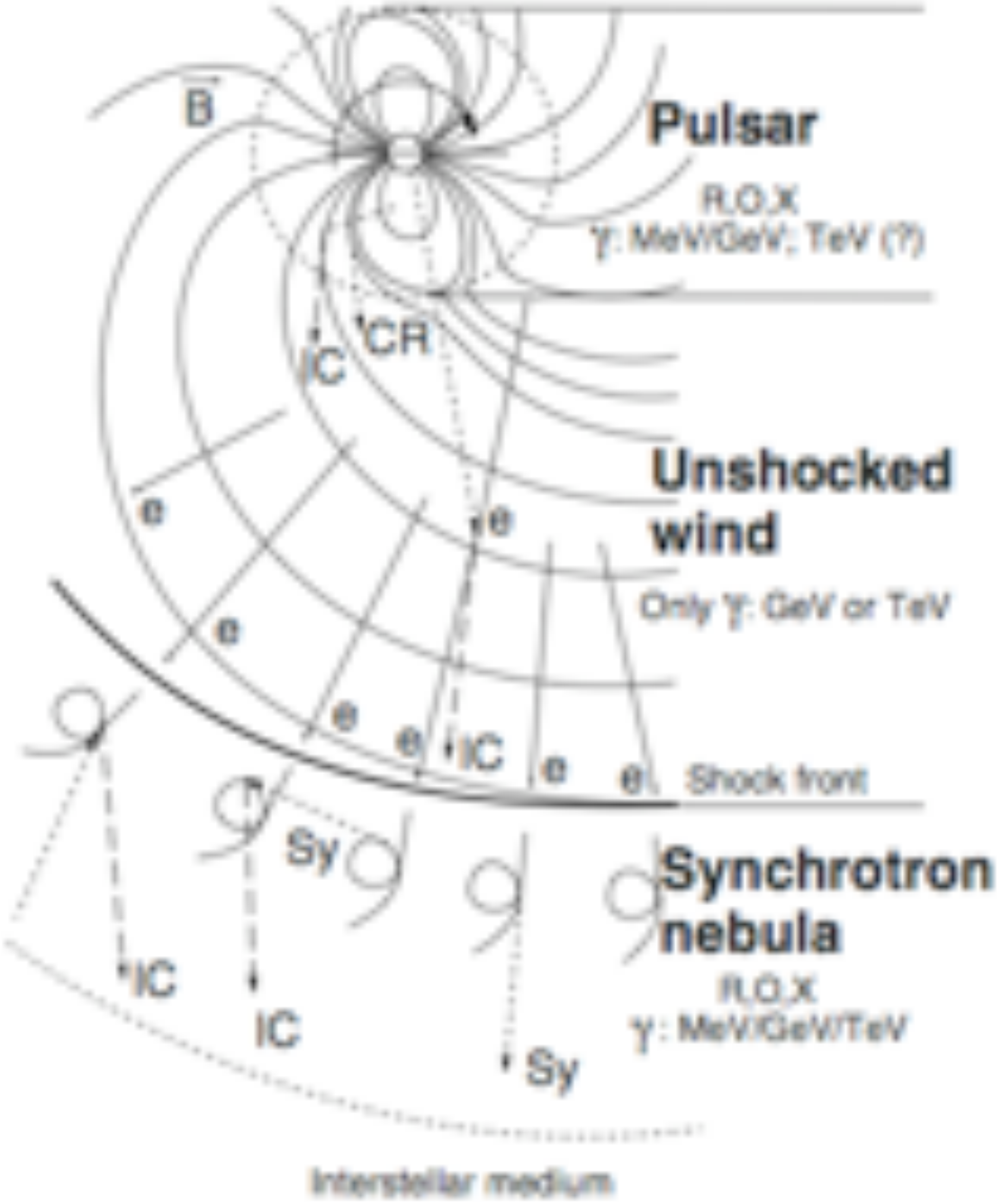
Particles can then be **accelerated at this shock front** (likely the same electrons and positrons)

Accelerated electrons lose their energy rapidly through **synchrotron and inverse Compton emission**

**Crab Nebula**



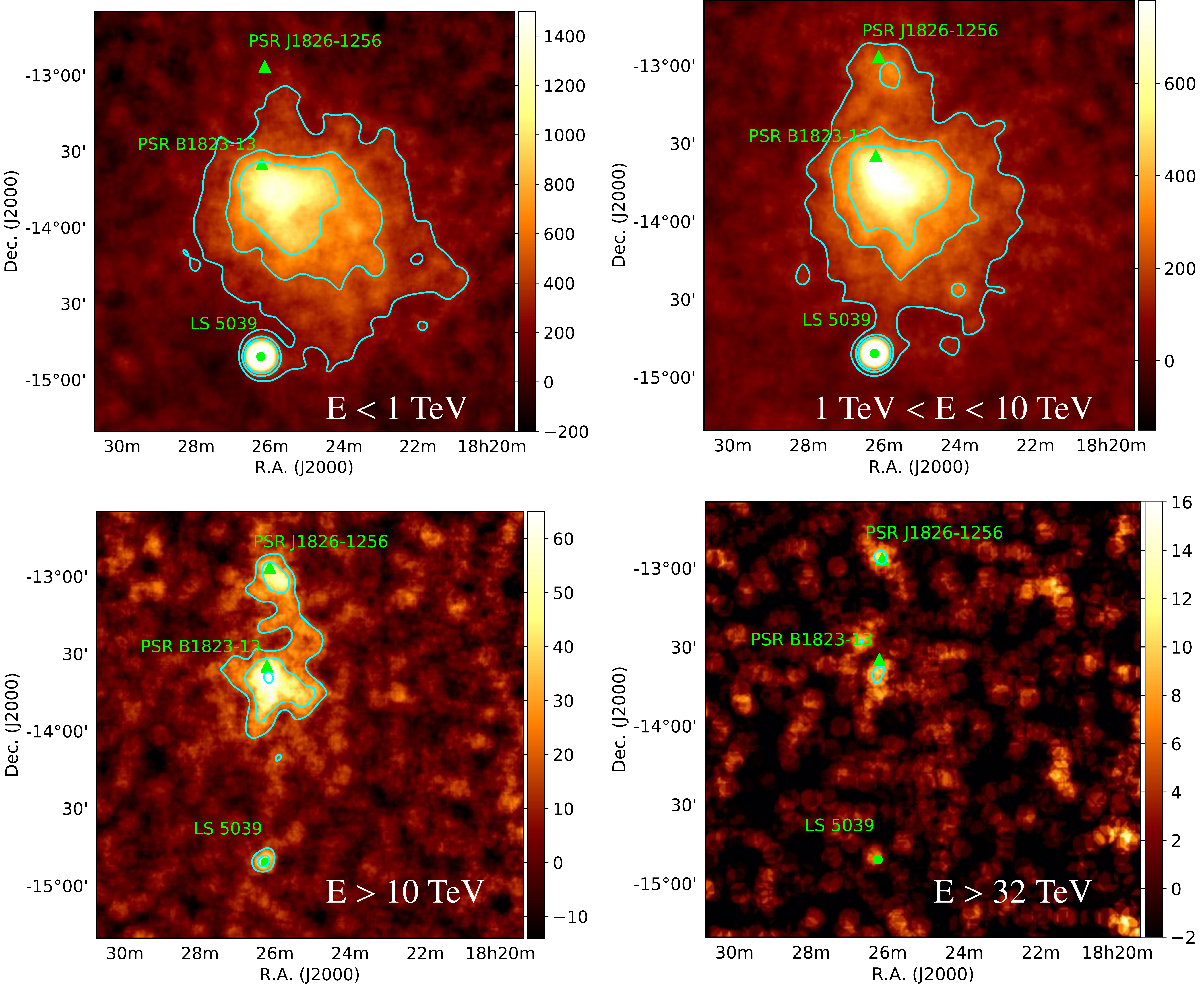
**Vela X**



# HESS J1825-137

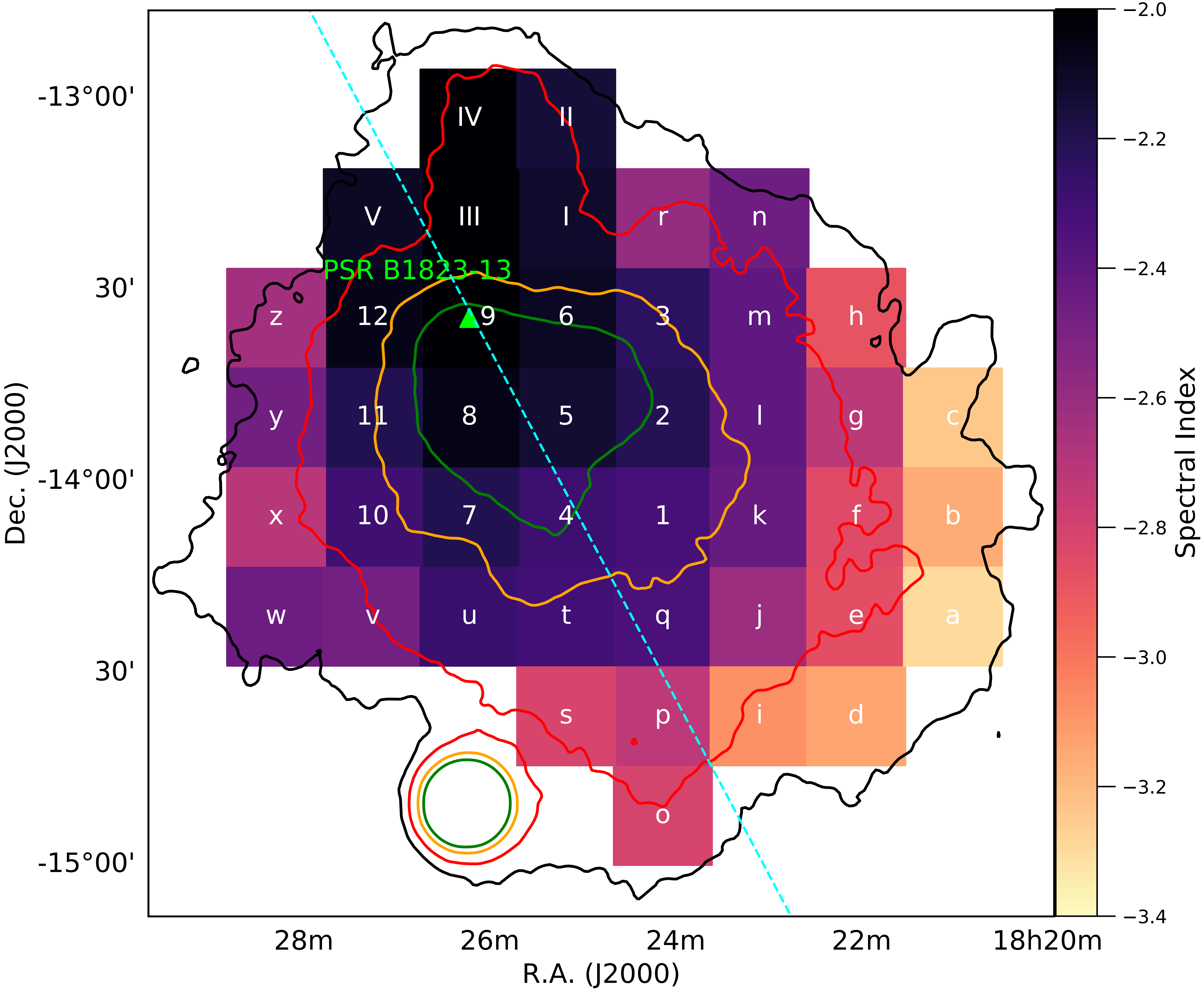
**Bright very extended source**

**Shows strong energy dependent morphology**



# HESS J1825-137

Can be more clearly seen in the spatially resolved spectra of this source

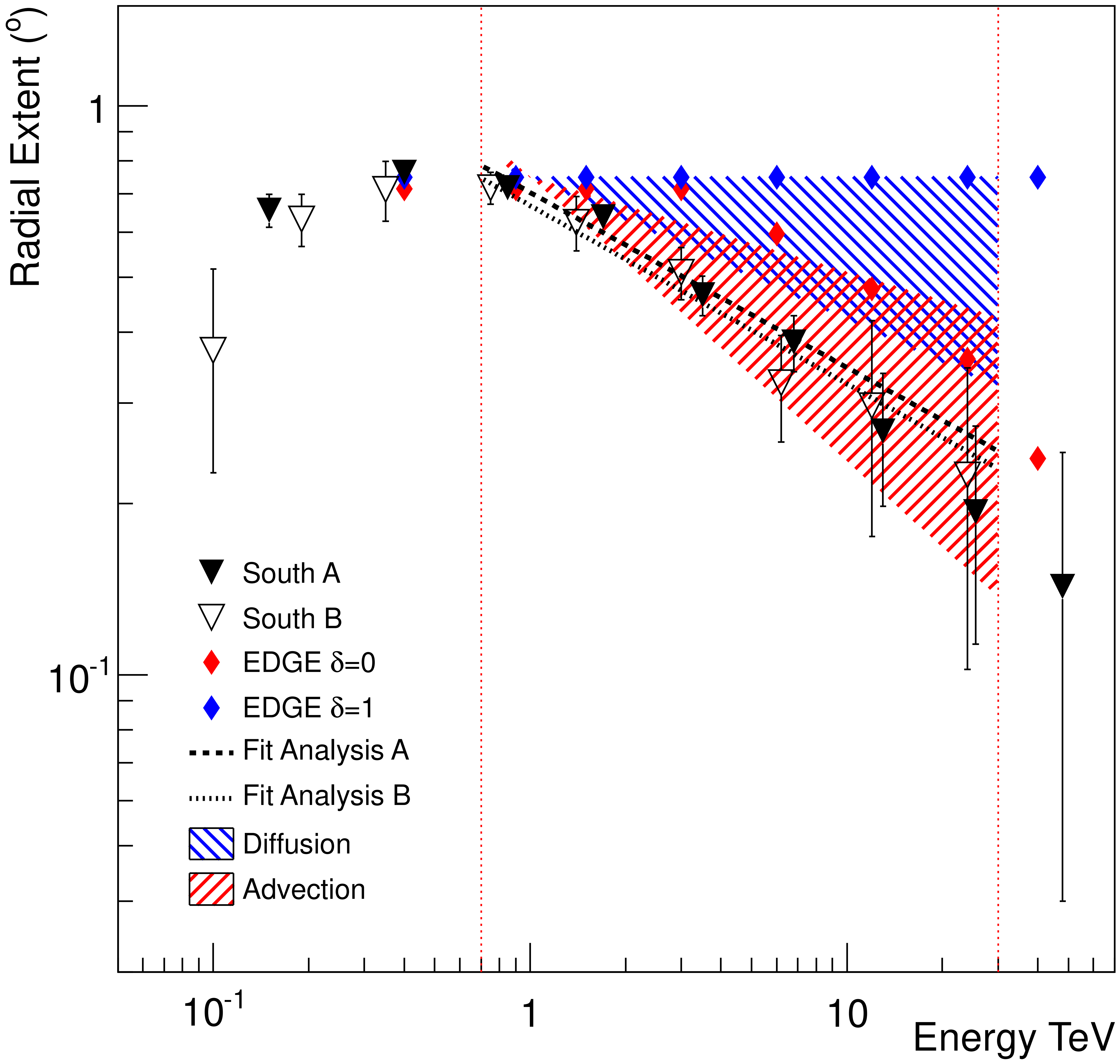


# HESS J1825-137

By measuring the extent of the nebula it allows us (Alison) to explore the **transport of particles** in the source

Consistent with the the advection (streaming) of electrons within the source

However we are in an environment which has been modified by the presence of the pulsar



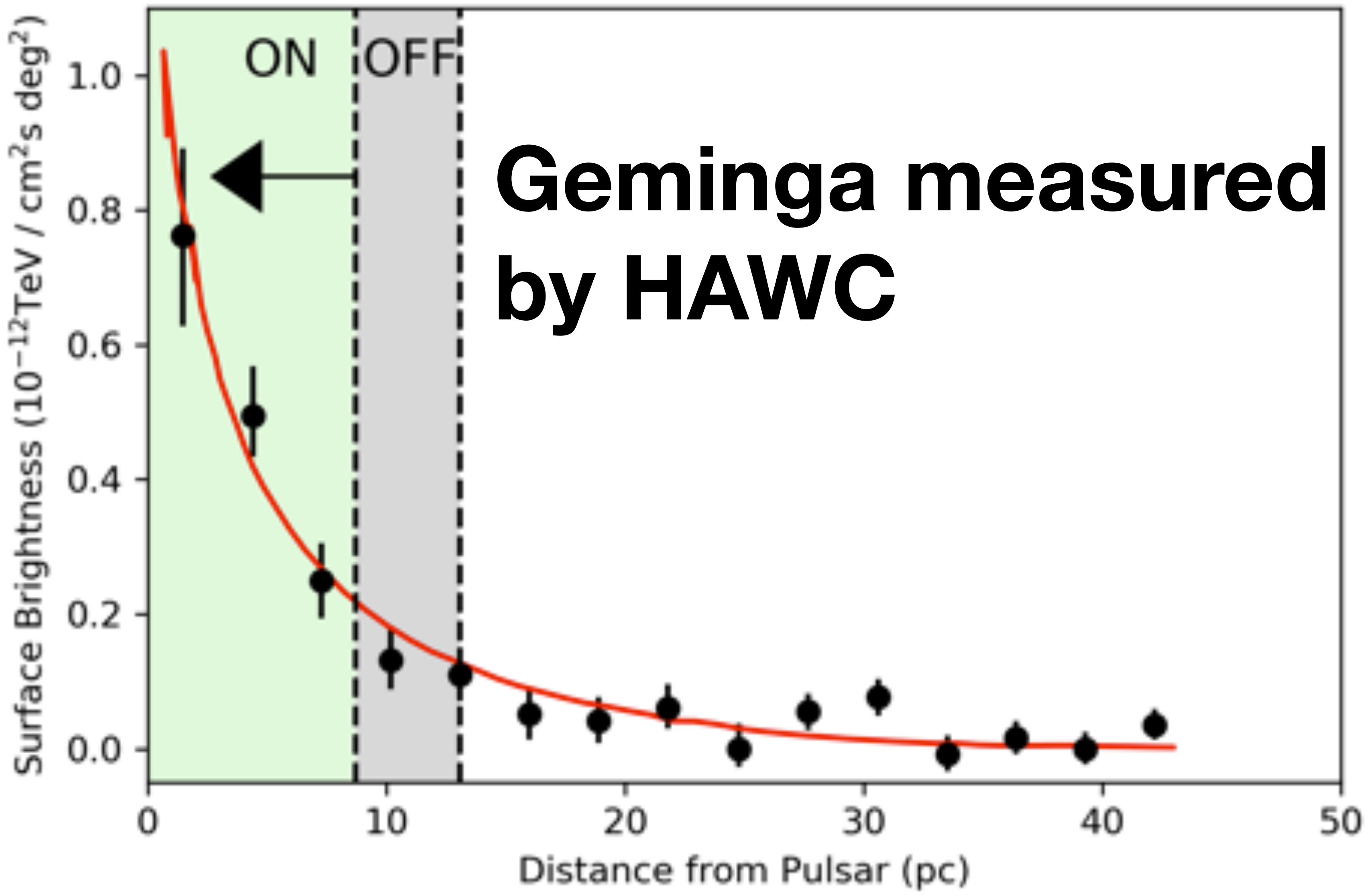
# Geminga

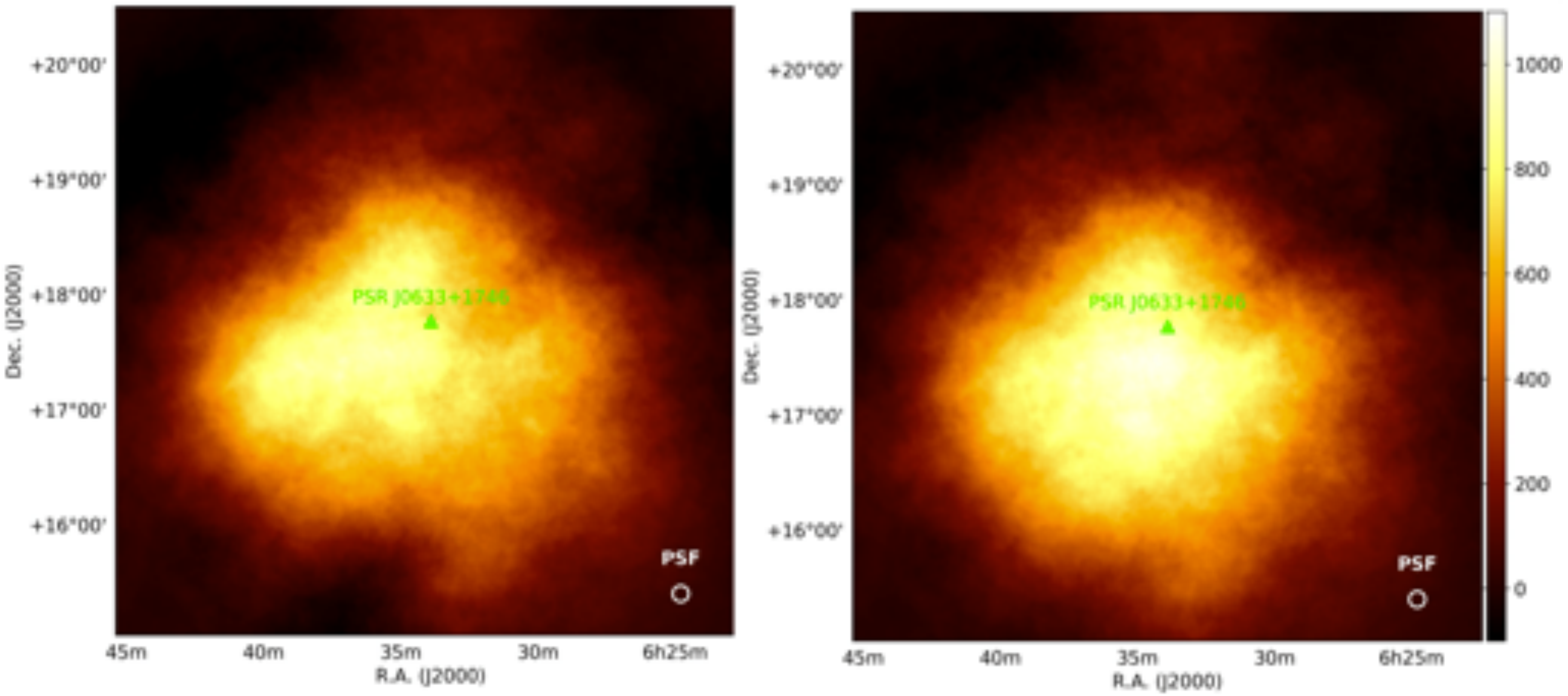
In the case of the **old and very local pulsar** Geminga this is not the case

Much larger than the region modified by the pulsar

Has already been used by the HAWC observatory to derive the **speed of particle diffusion in the local environment**

**Much slower than expected at 10 TeV**




Geminga was recently detected by H.E.S.S. (Alison)

**Will allow measurement of local speed of diffusion** at lower energies and with energy dependence

**Paper in the works…**

# RXJ 1713.7-3946

Young (**10,000 year old**) supernova remnant

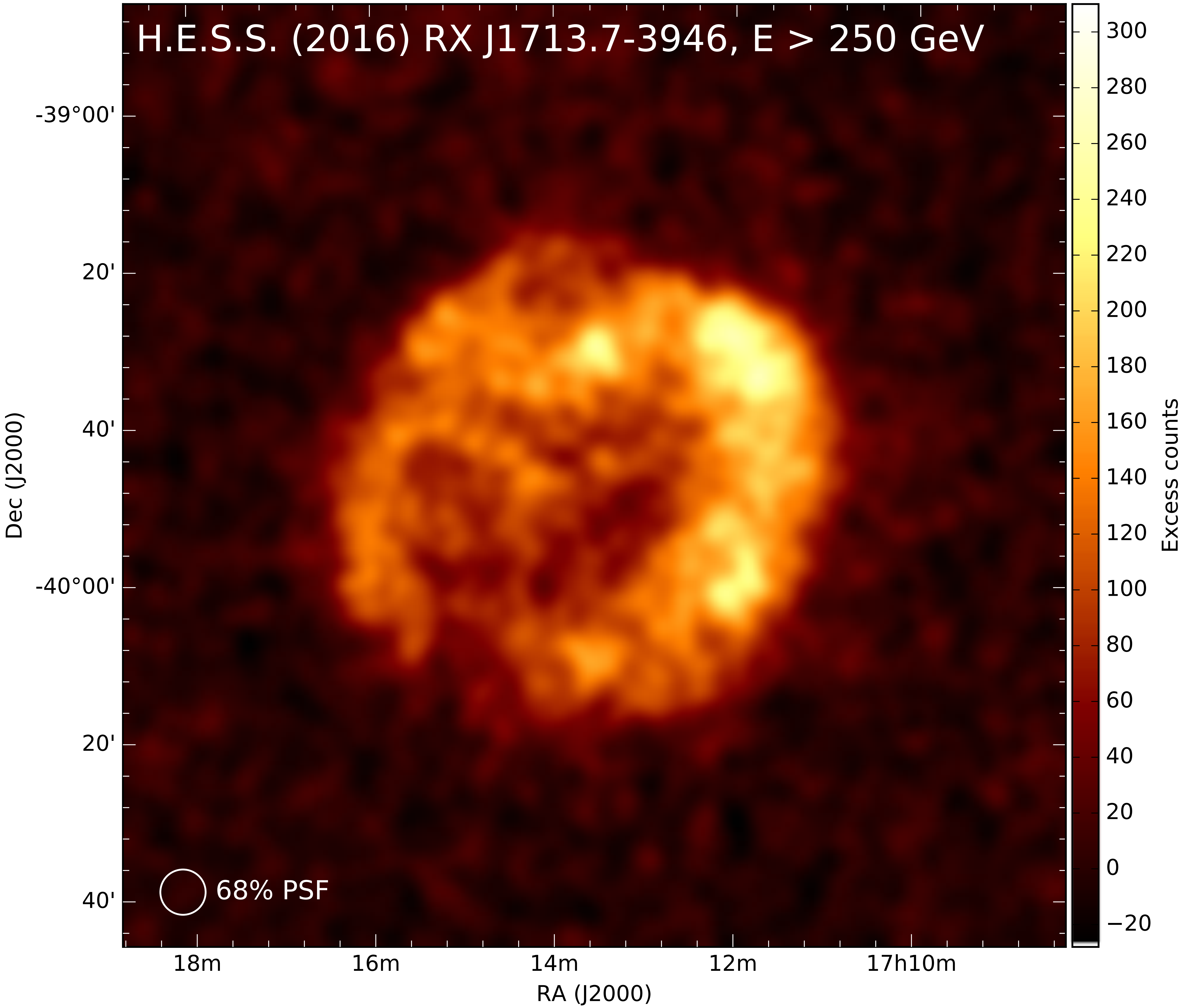
Remnant of the **death of a massive star**

Prime candidate for the acceleration of cosmic rays by the **diffusive shock acceleration mechanism**

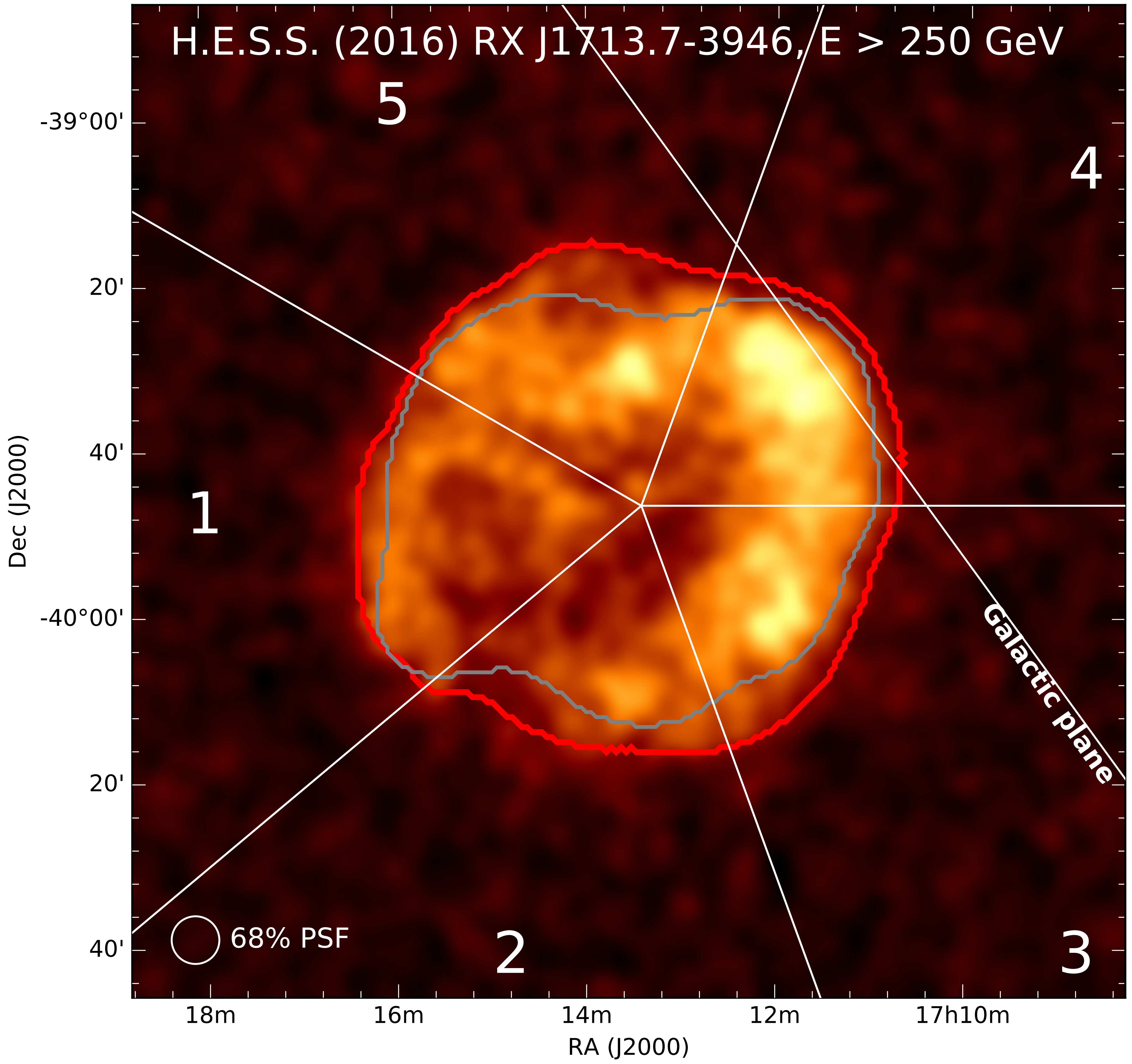
Particles (electrons and protons) accelerated at the shock interaction with interstellar material

RXJ 1713 one of the **brightest persistent gamma-ray sources**

Allows us to perform detailed spectral and morphological analysis

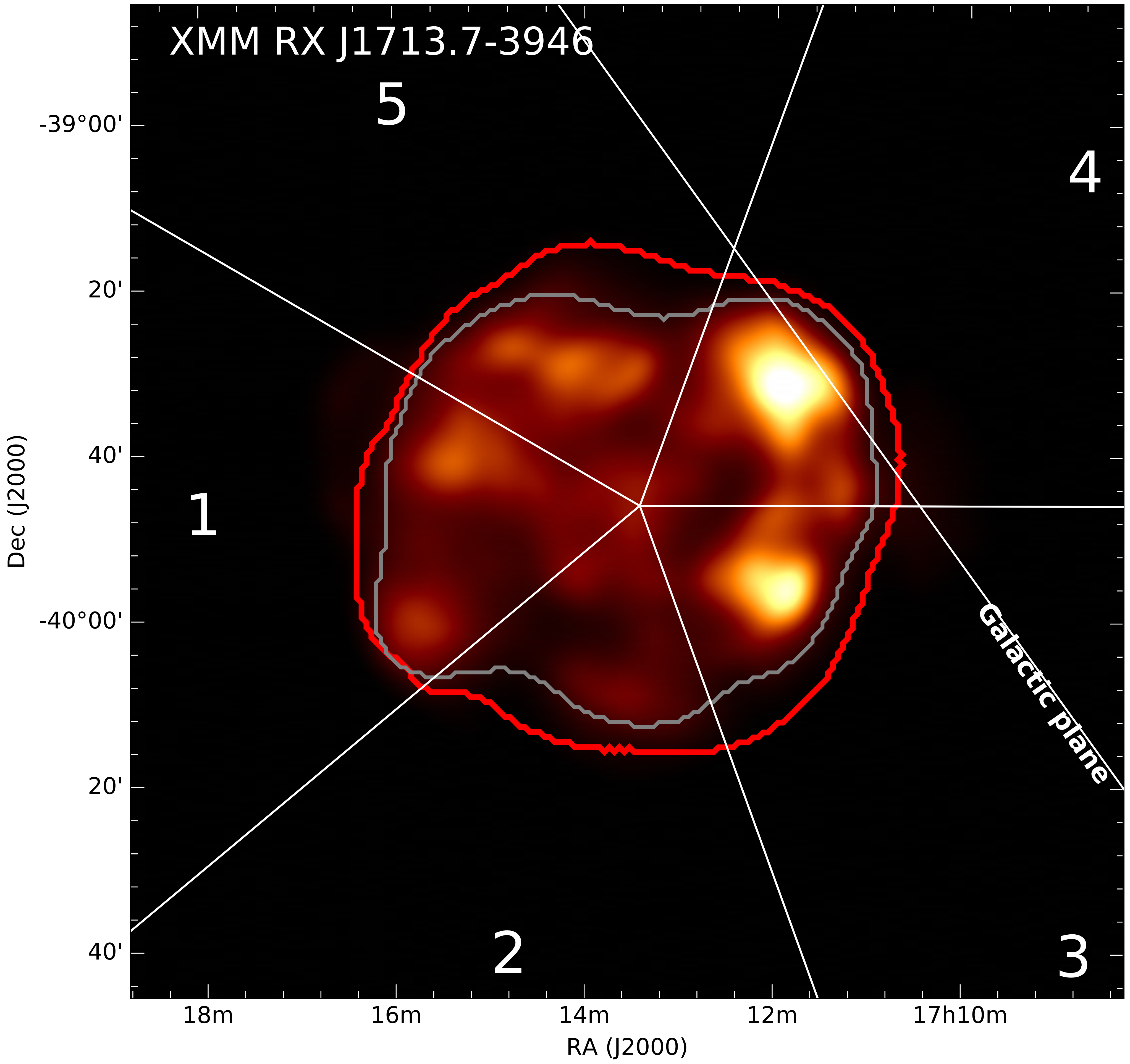


# RXJ 1713.7-3946




VHE gamma-rays could **either hadrons or electrons**

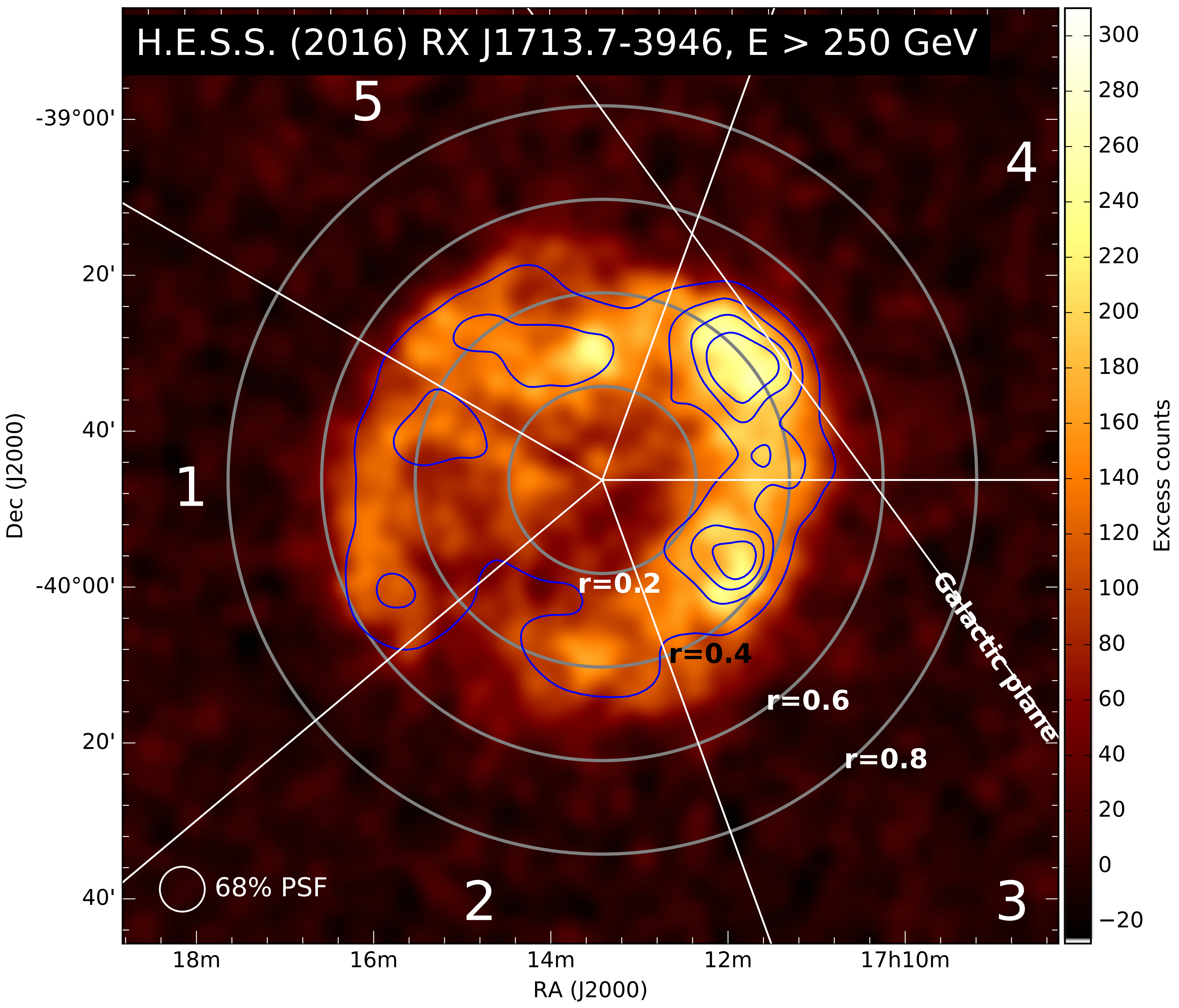
Comparison of morphologies can indicate the **nature of the emission**

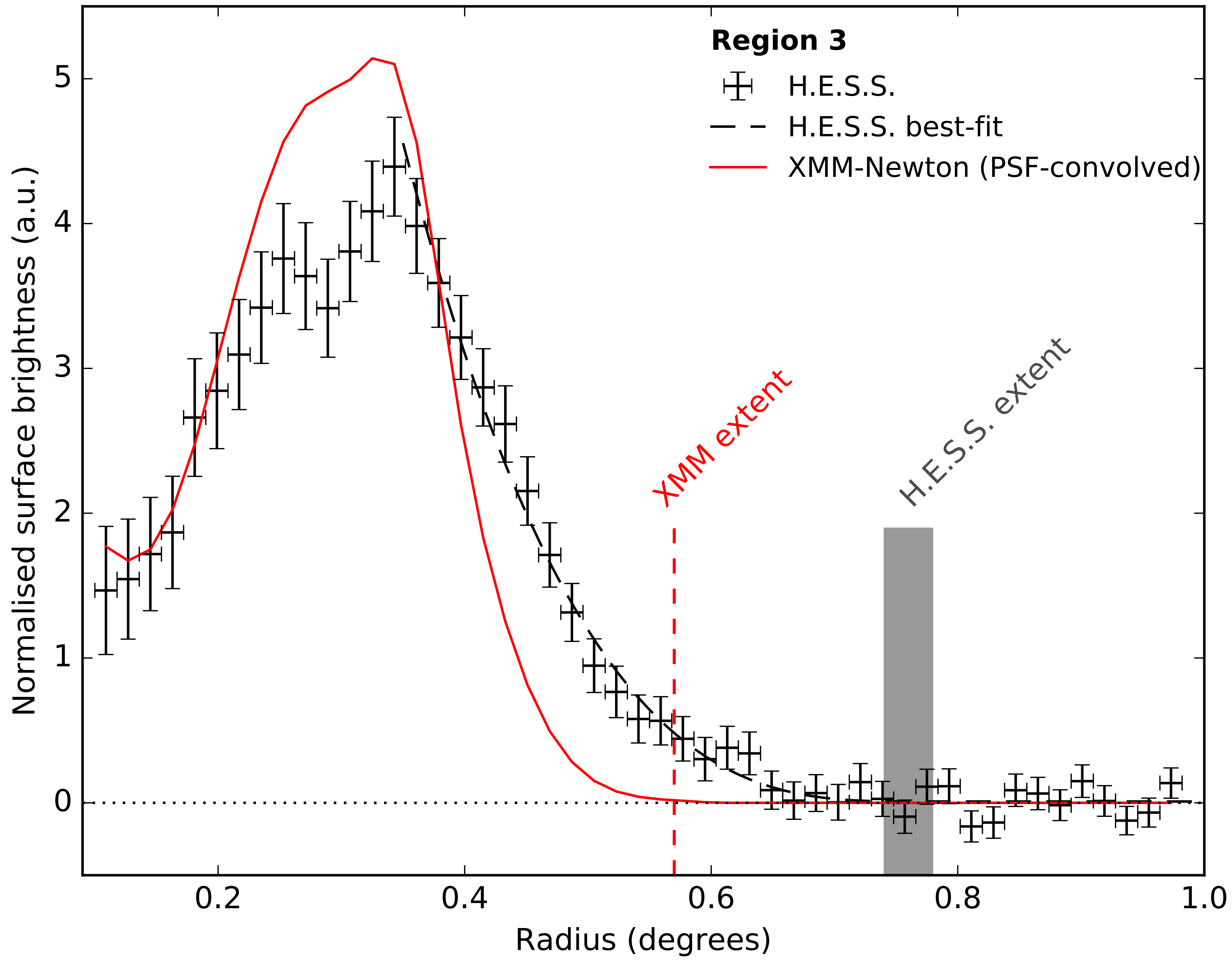



X-rays trace the presence of **energetic electrons**

**Lose their energy very quickly** by synchrotron or inverse Compton losses

# RXJ 1713.7-3946




Clear evidence of the **extension of the TeV emitting shell beyond X-rays**

Could this be evidence of the escape of energetic hadronic cosmic rays?

# RXJ 1713.7-3946

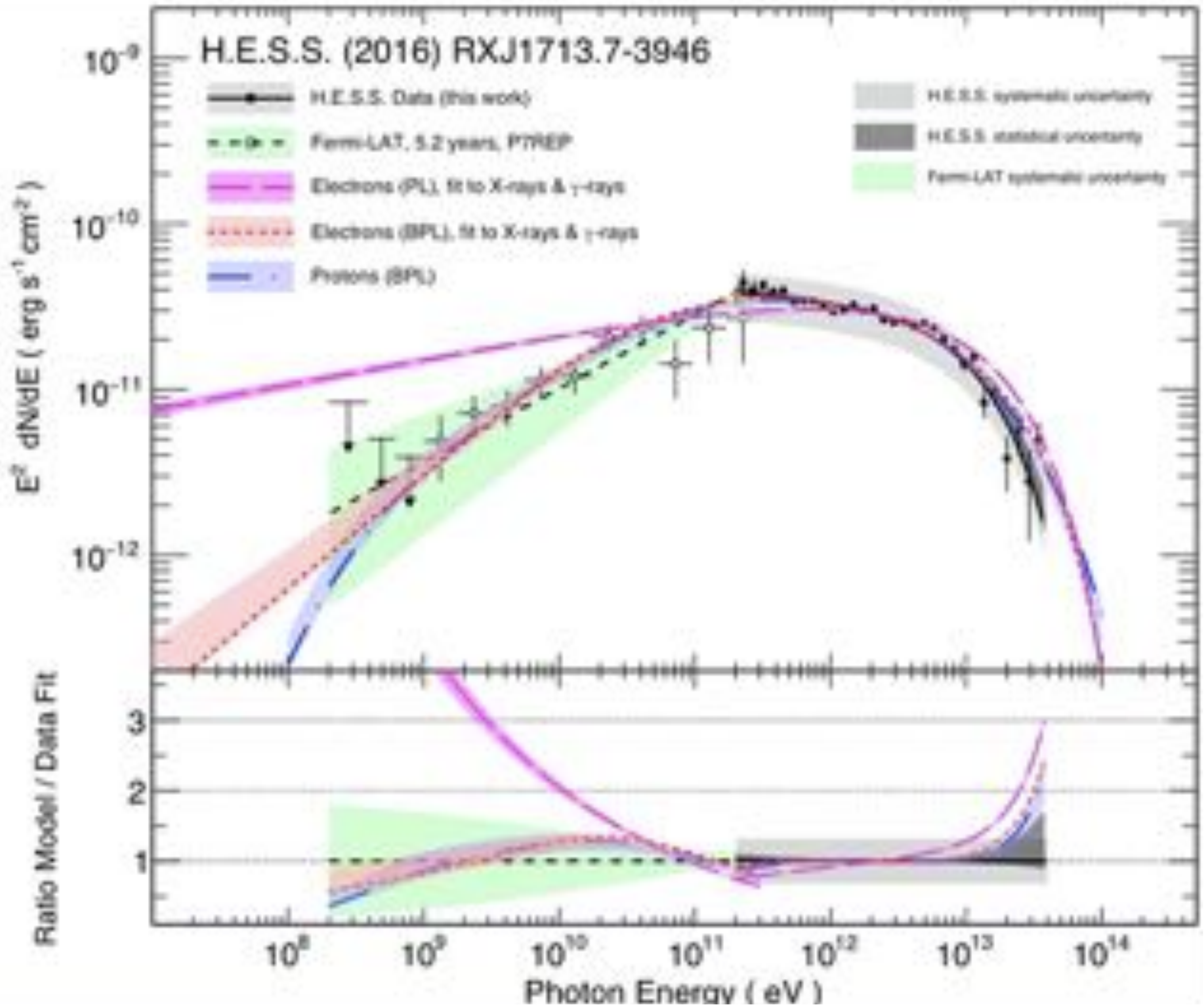
**Perhaps**

The source spectrum seems best fit by **hadronic models**

However, if we look at the energy spectrum we see a cut-off at **10 TeV**

Implies a cut-off in the proton spectrum at **100 TeV**

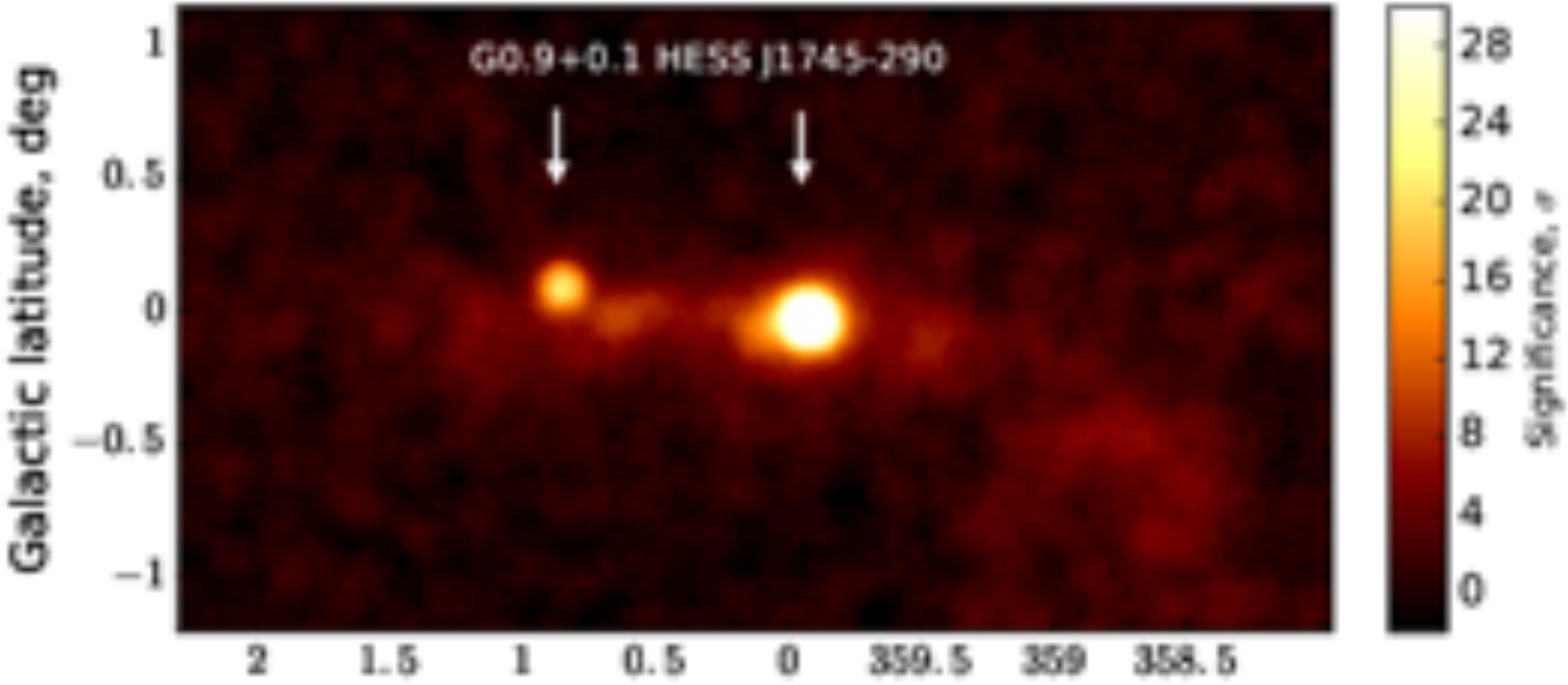
Probably can't explain our $10^{15}$ eV cosmic rays



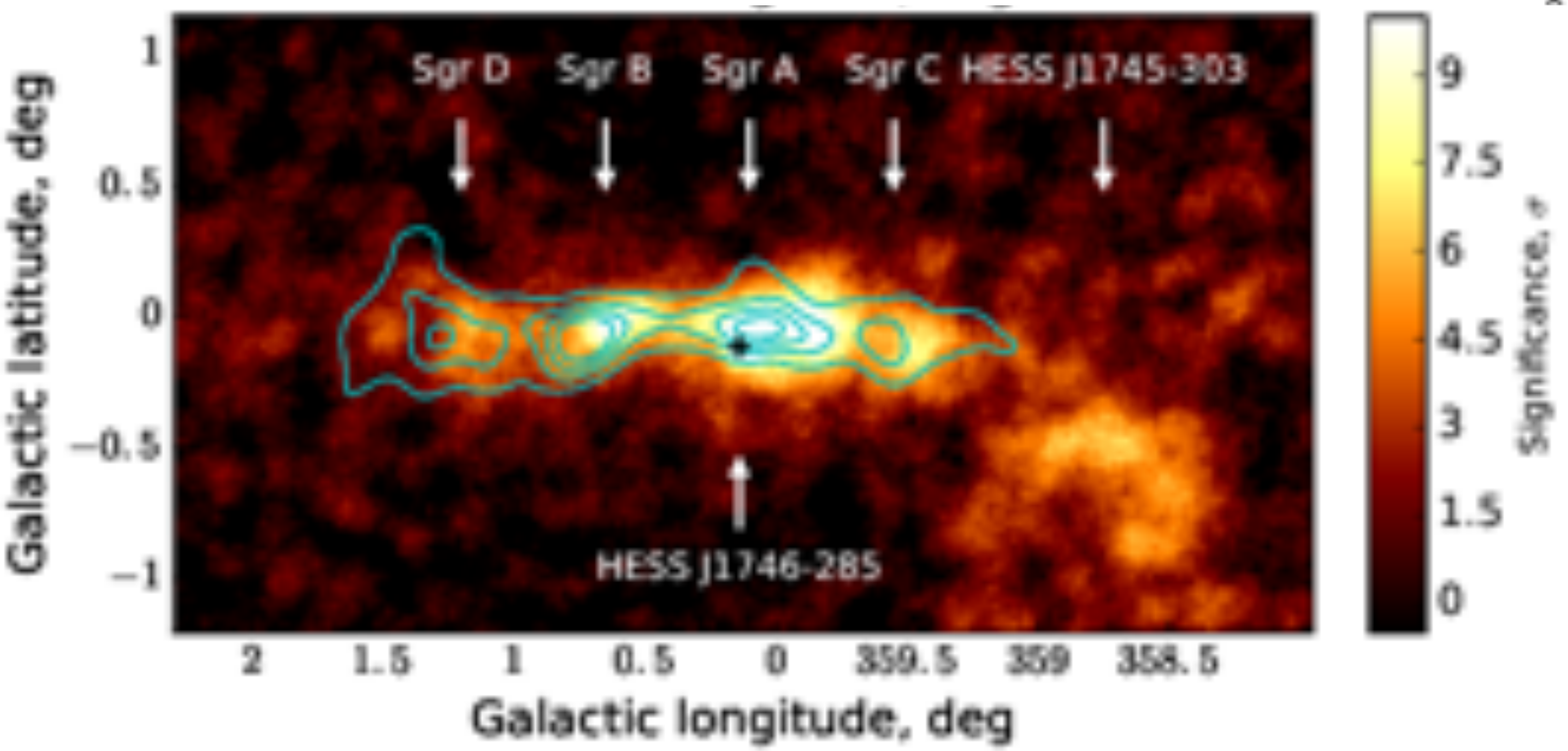
# The Galactic Centre with H.E.S.S.

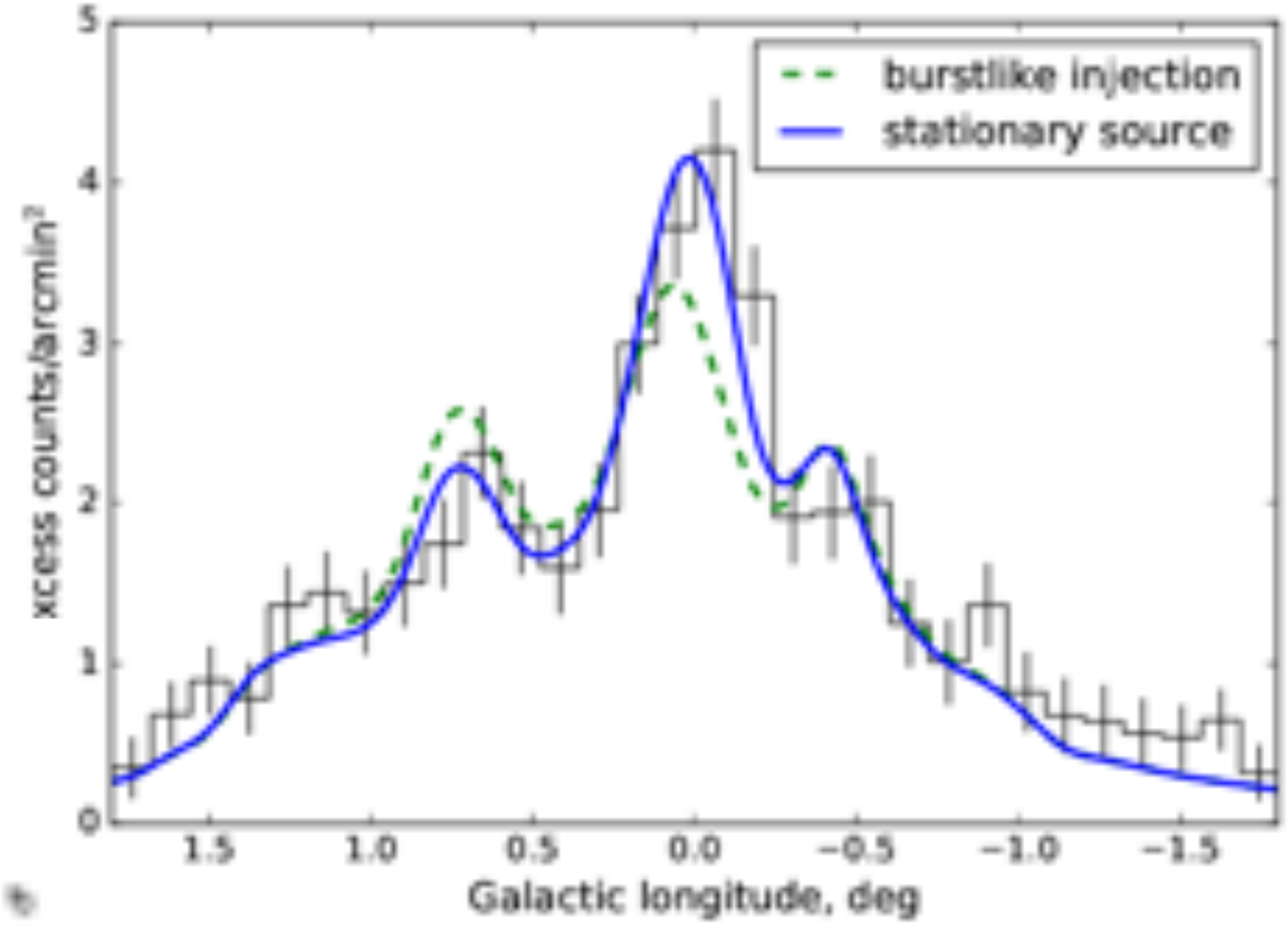
At the centre of our galaxy lies a strong gamma-ray source

Coincident with the position of the **supermassive black hole Sgr A***



# The Galactic Centre with H.E.S.S.




A ridge of diffuse emission is seen when the point sources are subtracted

**Not compatible with the gas profile in the galactic centre**

Central source is a **cosmic ray accelerator**

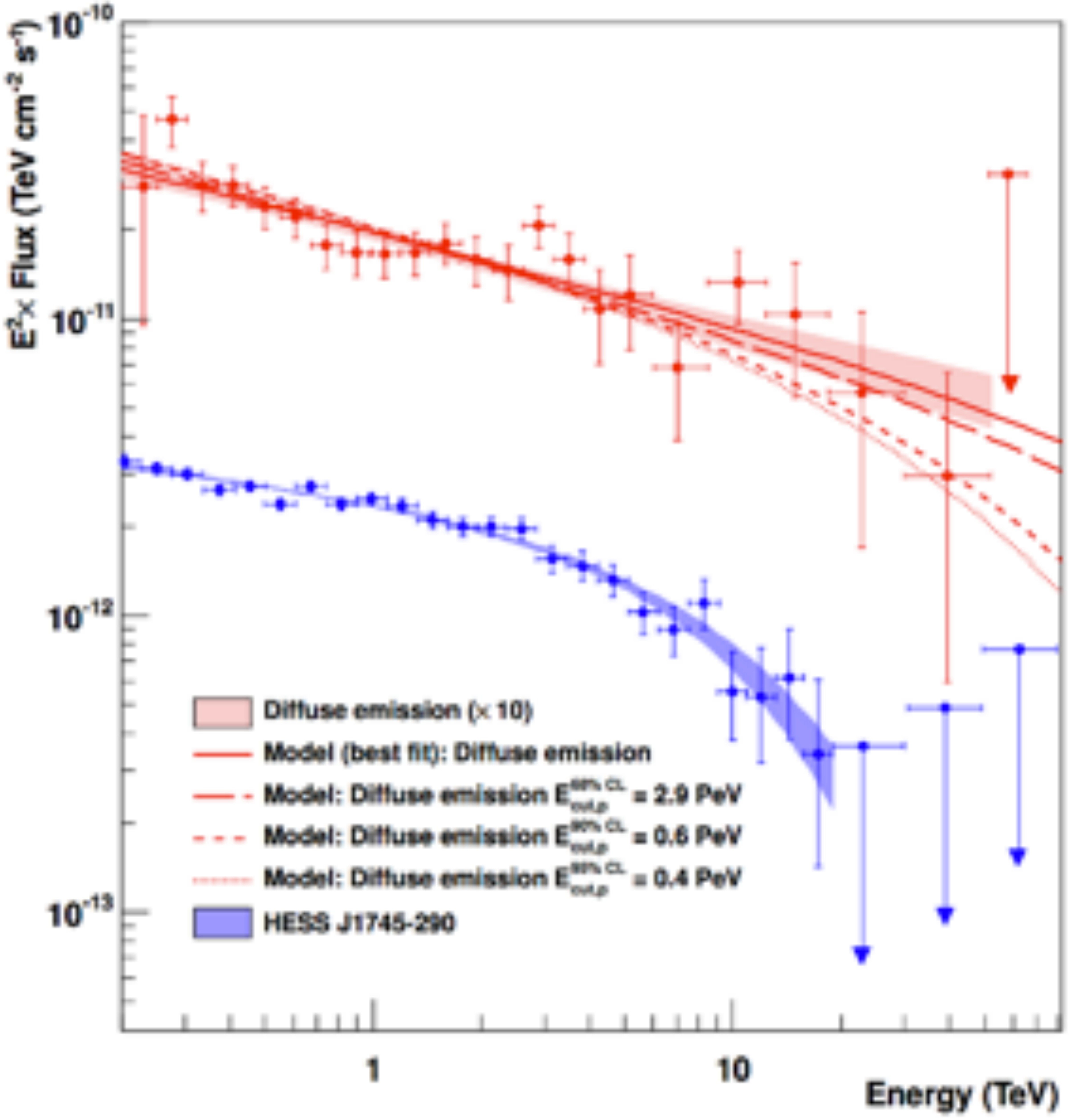
# H.E.S.S. Galactic Plane Survey

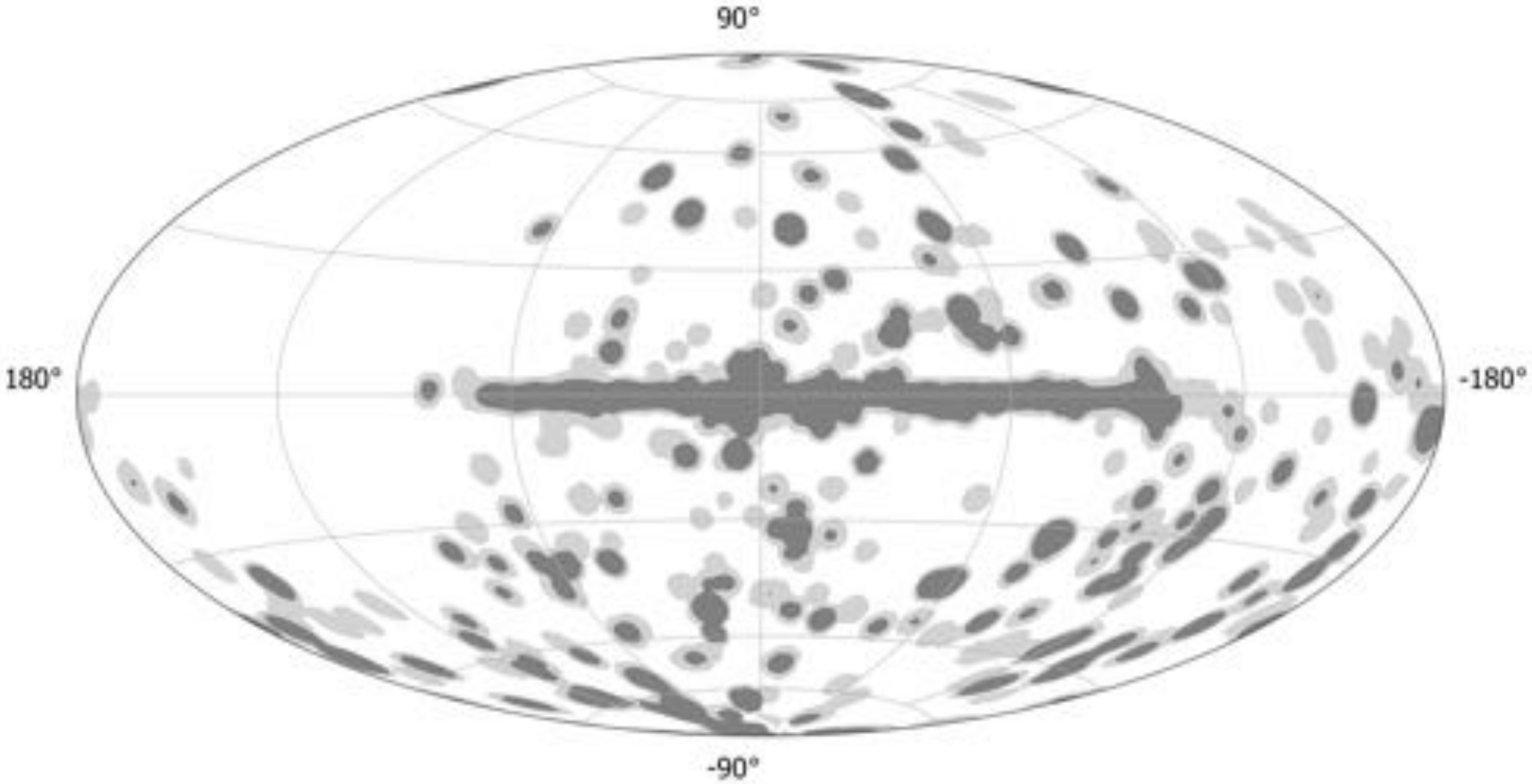
Spectral study of the ridge region close to the central source shows **no evidence of a spectral cut-off**

In contrast to the central source (**10 TeV cut-off**)

Compatible with **PeV hadron acceleration**

Still need to answer why we a cut-off in the central source. **Variability? Absorption?**

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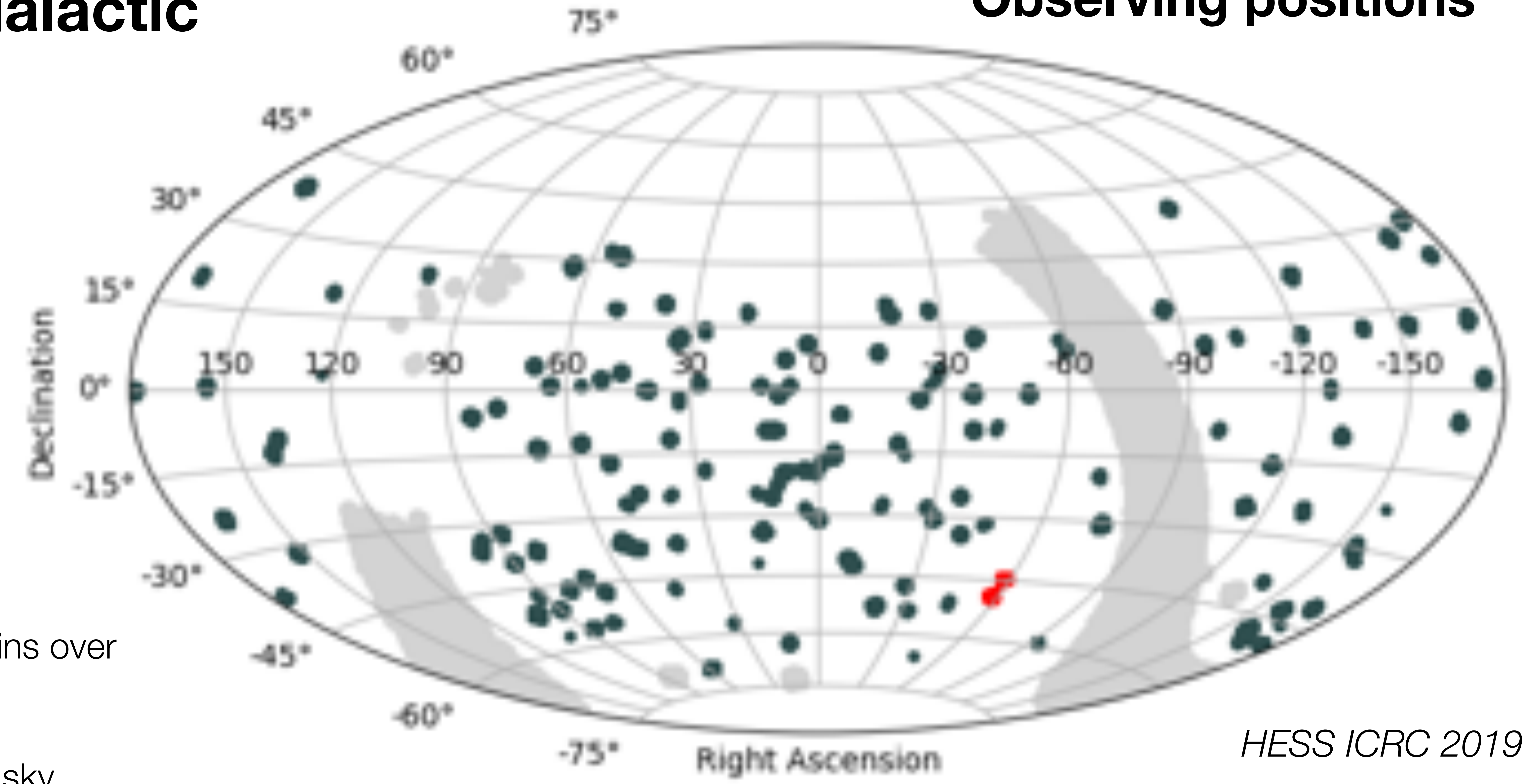
-90°

# H.E.S.S. Extragalactic Survey

## Observing positions




*HESS ICRC 2019*

Extragalactic survey contains over **2500 hours** of data

Covering about **6%** of the sky

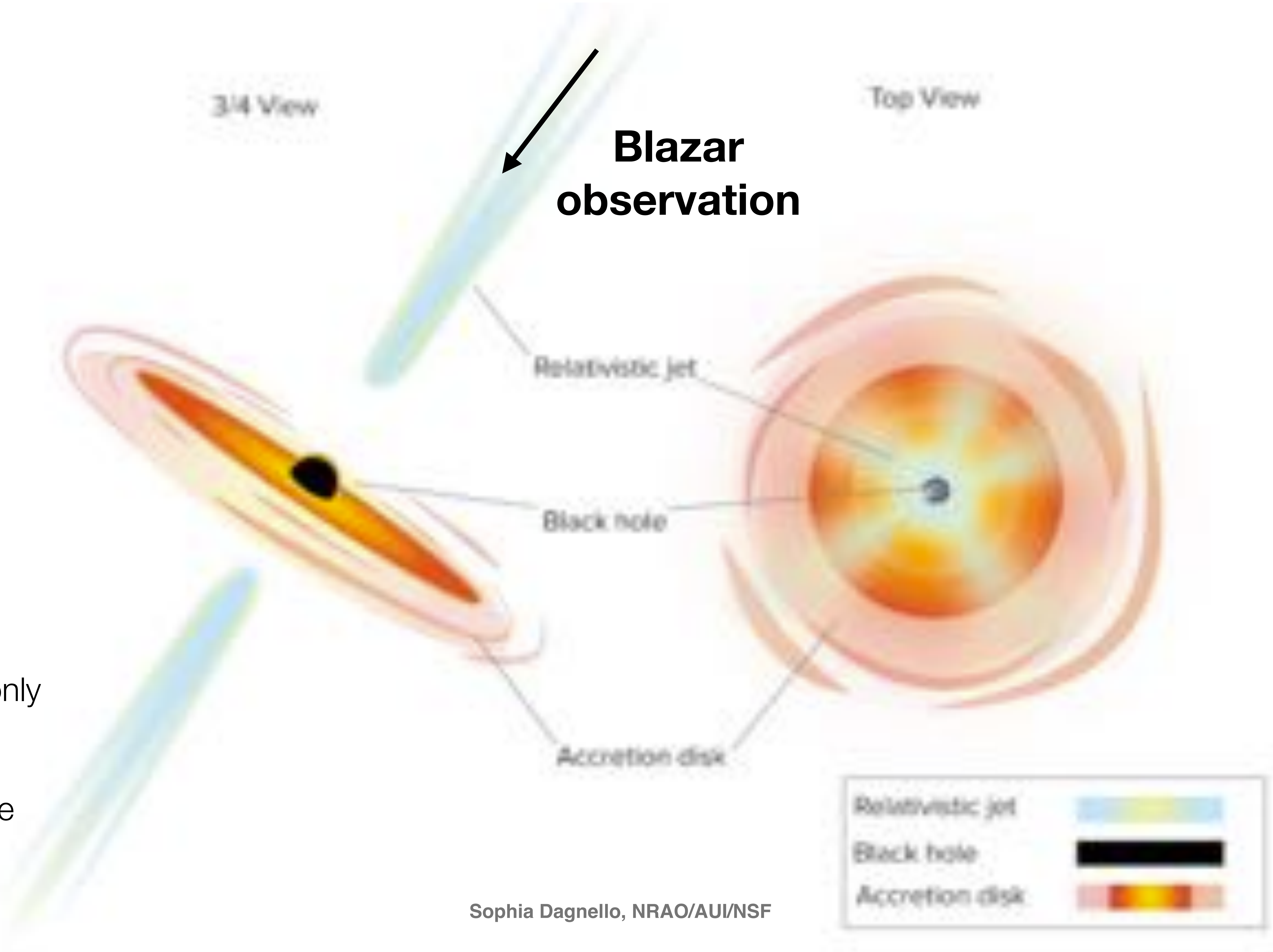
Long term studies of many sources with deep >100 hour datasets

# Extragalactic Observations

**Blazar**

21 HBLs
2 LBLS
3 FSRQs
2 Radio Galaxies
1 Starburst

# Extragalactic Observations



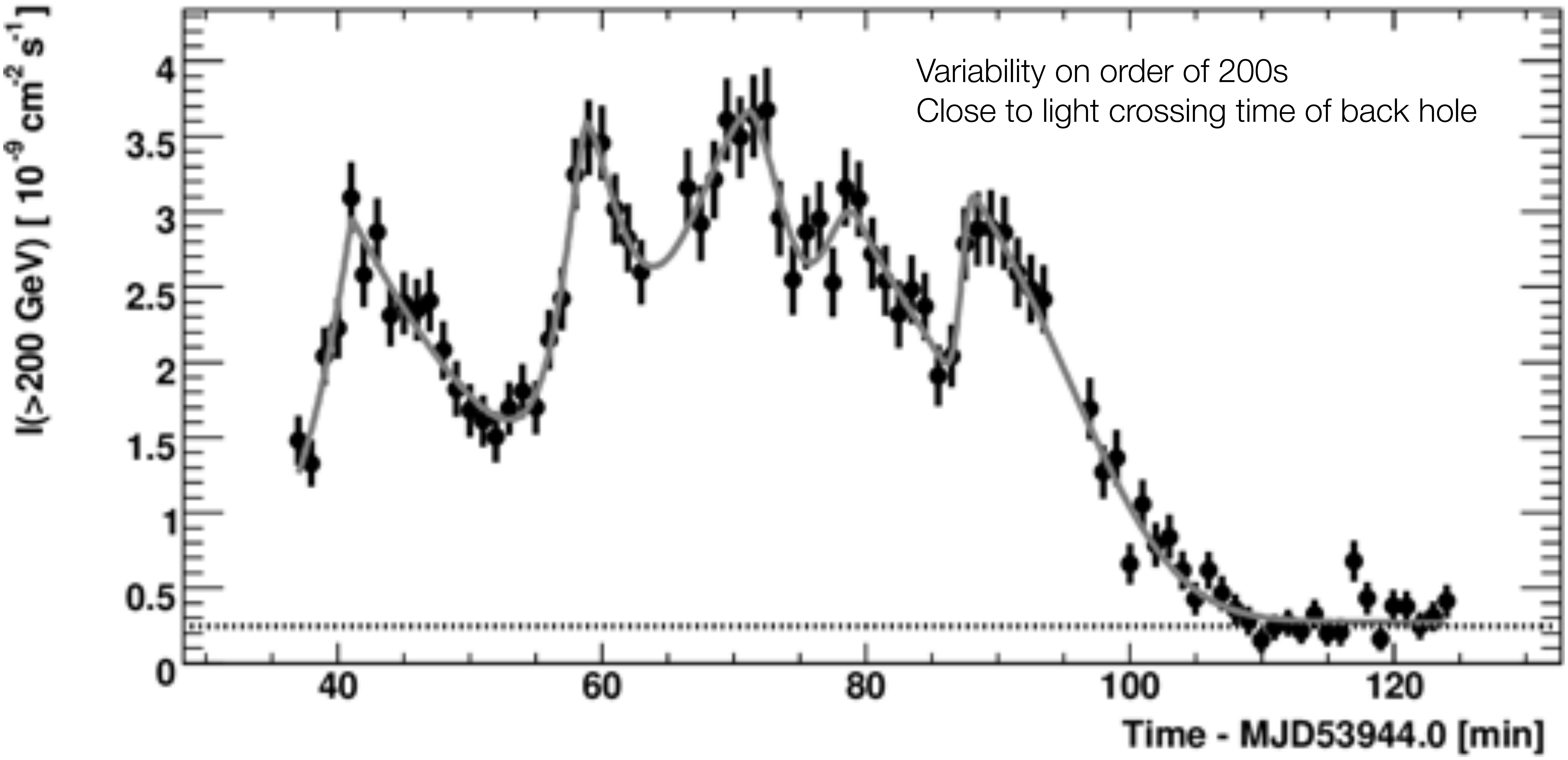
Sophia Dagnello, NRAO/AUI/NSF

These distant blazars appear only as **point sources** in H.E.S.S.

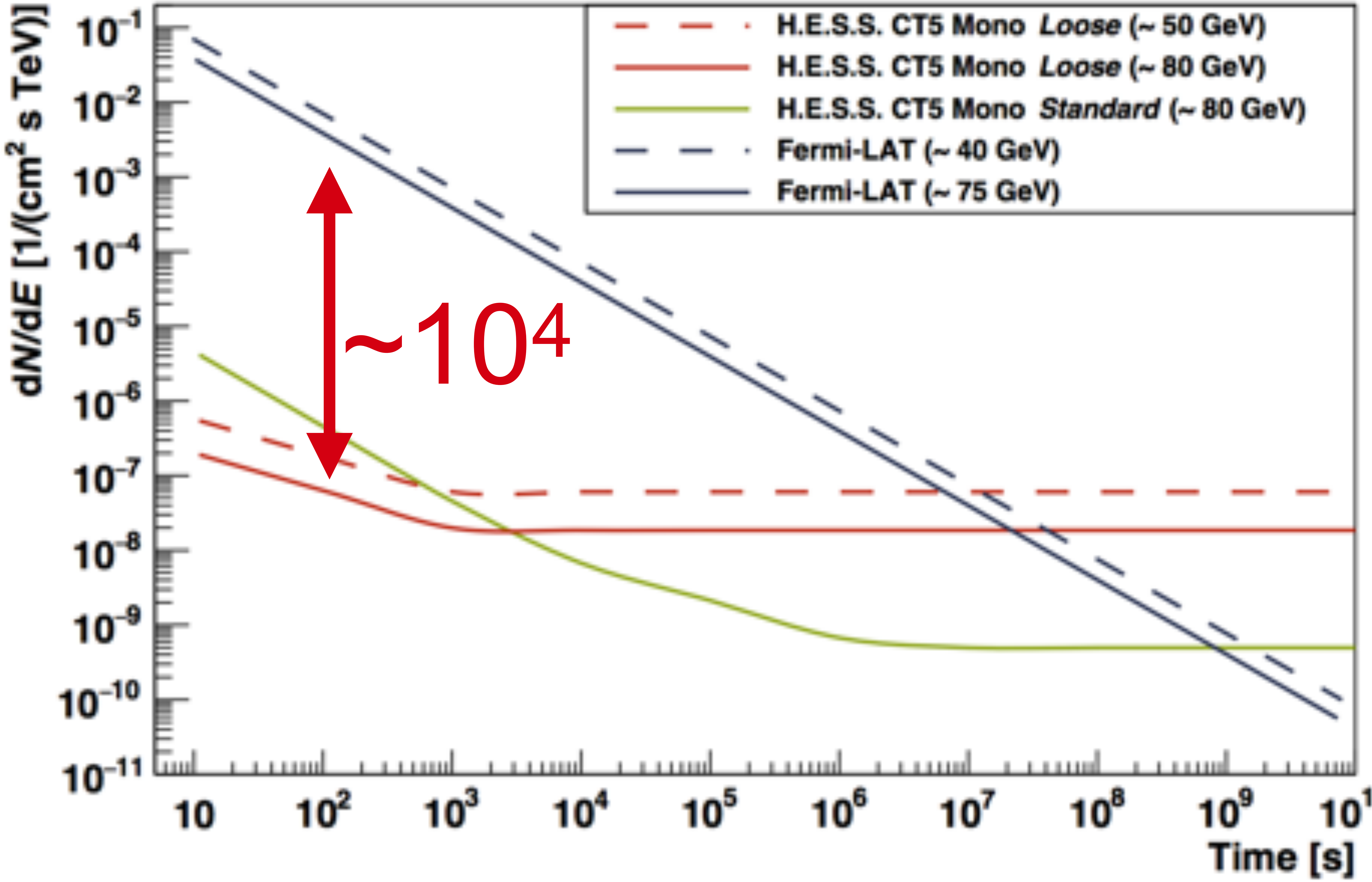
Gamma-ray variability timescale consistent with emission from **close to the black hole**

# PKS 2155-304

Variability on order of 200s
Close to light crossing time of back hole



# Transients with H.E.S.S.

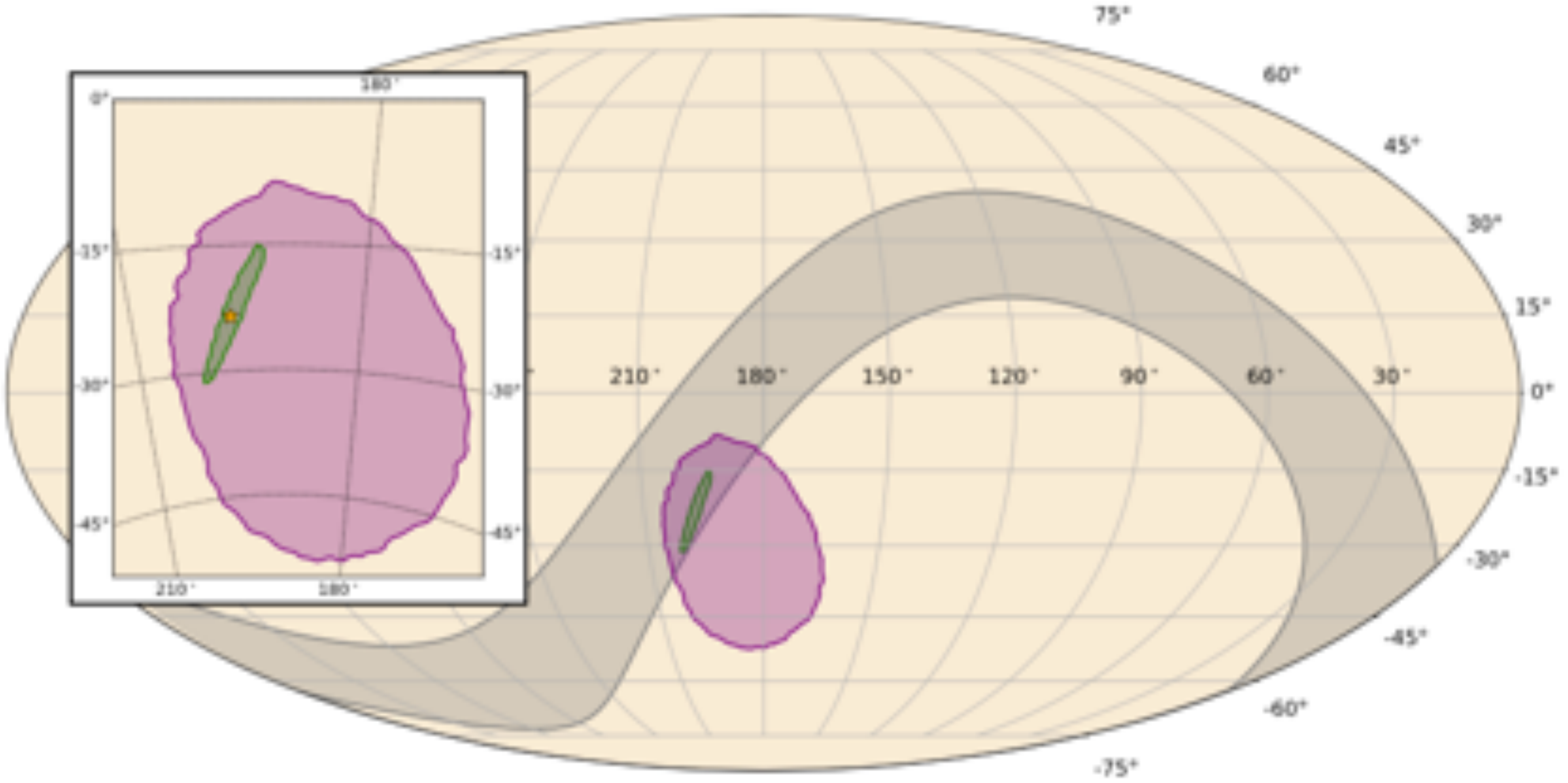


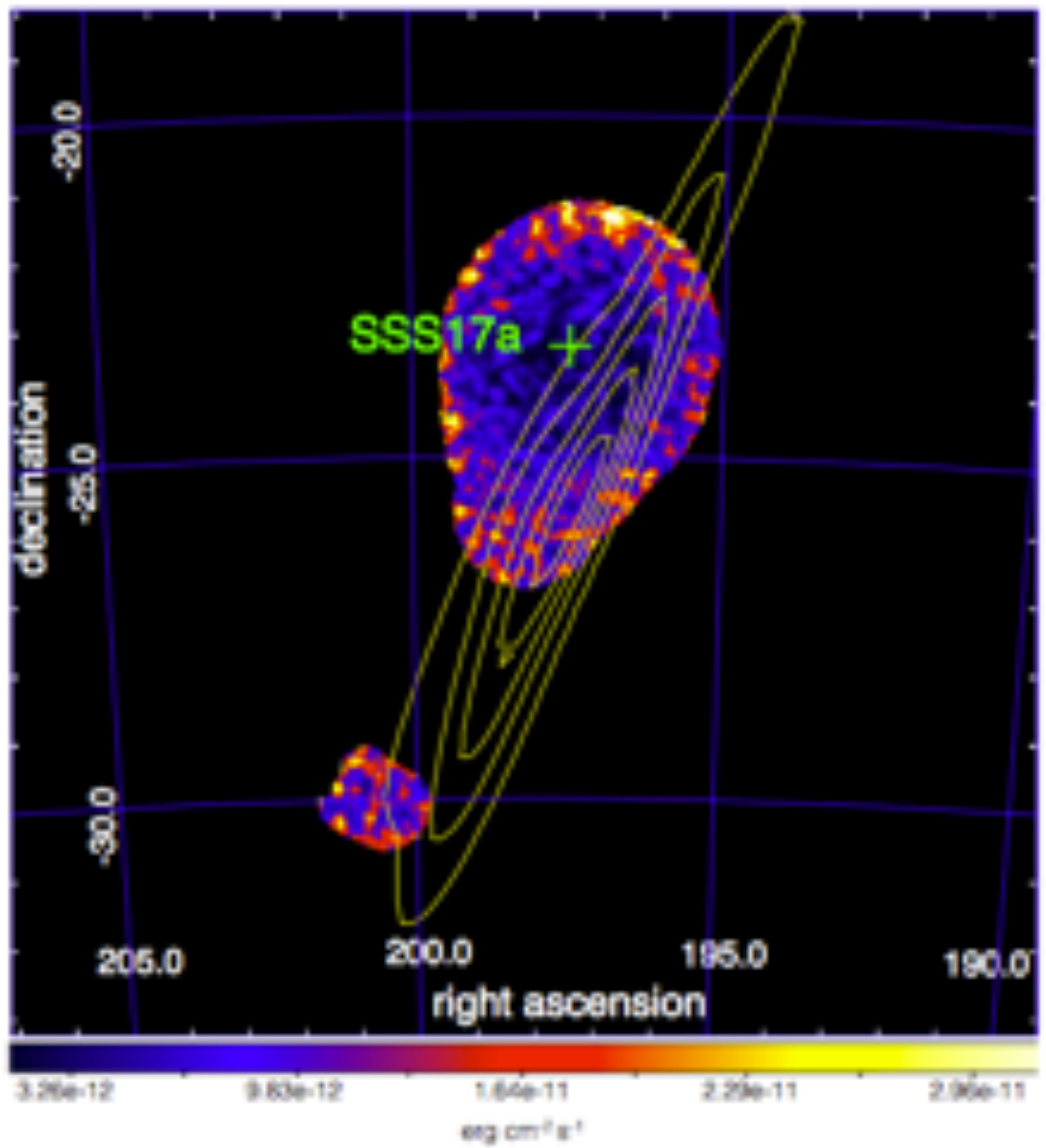

HESS Collaboration(ICRC2015)

Use of IACTs like H.E.S.S provide a **significant sensitivity boost** over satellite instruments like Fermi

# Gravitational Waves

H.E.S.S. now regularly observing and placing upper limits of gravitational wave events



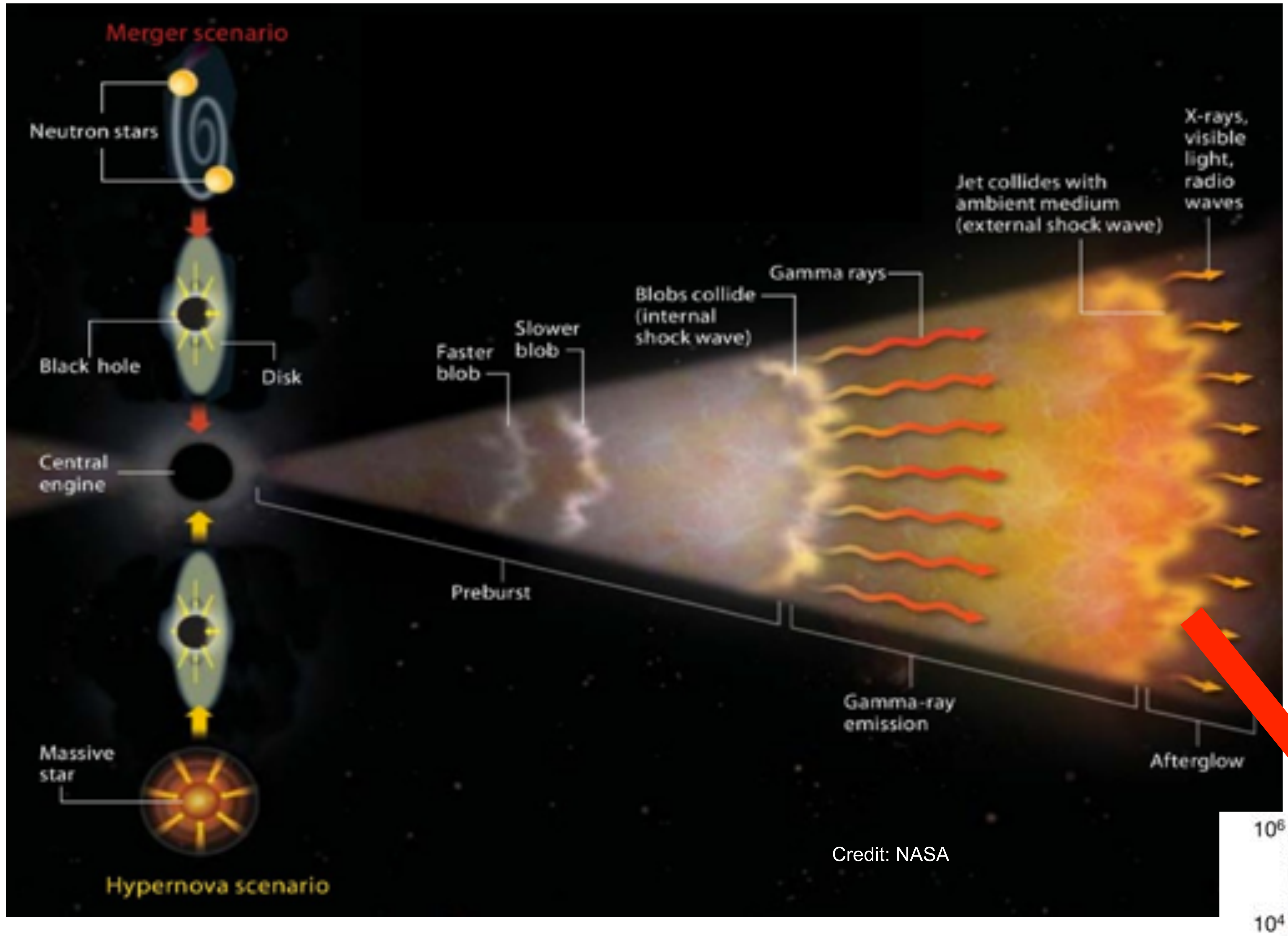



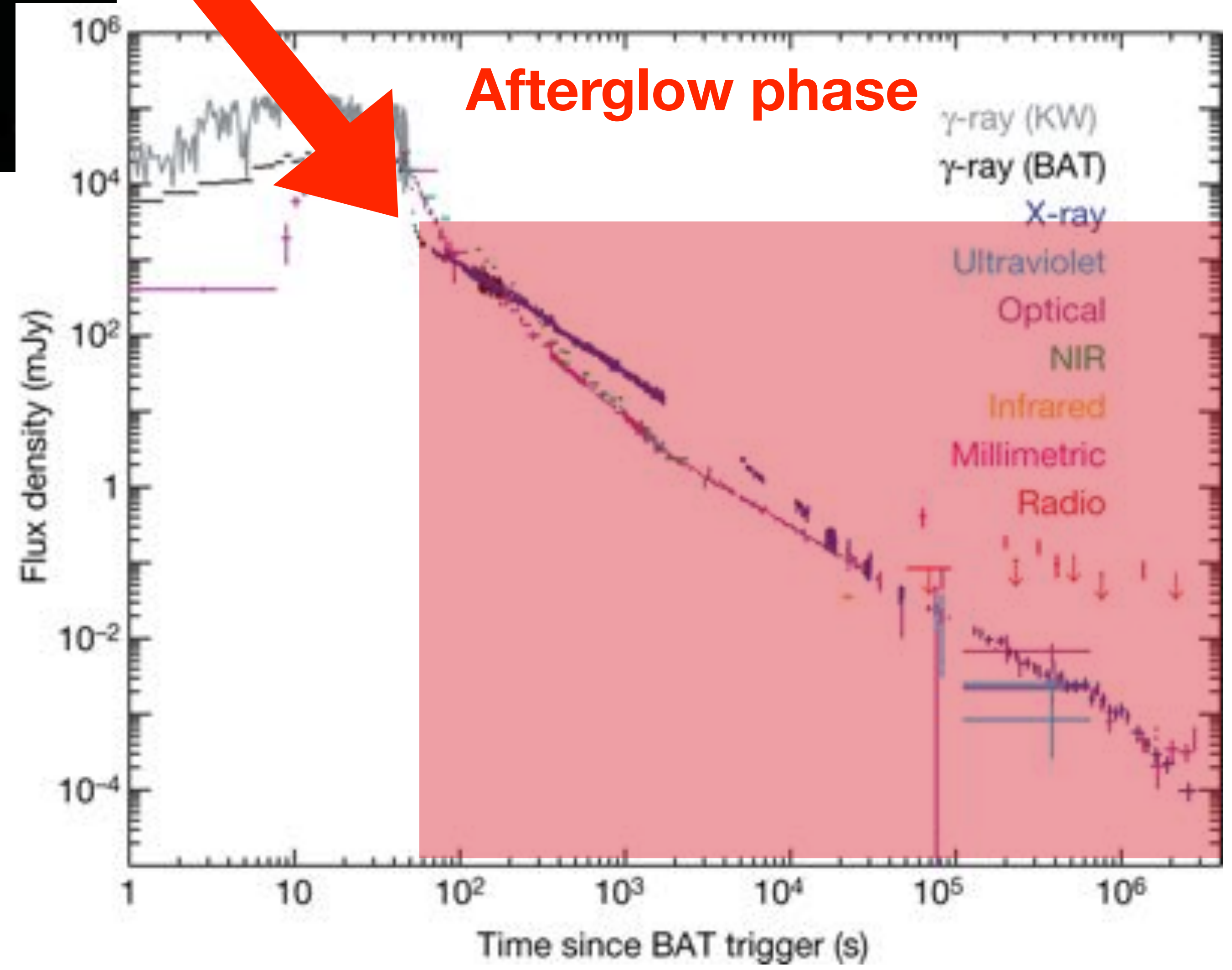

Uncertainty region of GW events can be thousands of square degrees

Requires careful planning of observation scheme

Released very high energy limits of the emission of **GW 170817**

# Gamma ray Bursts



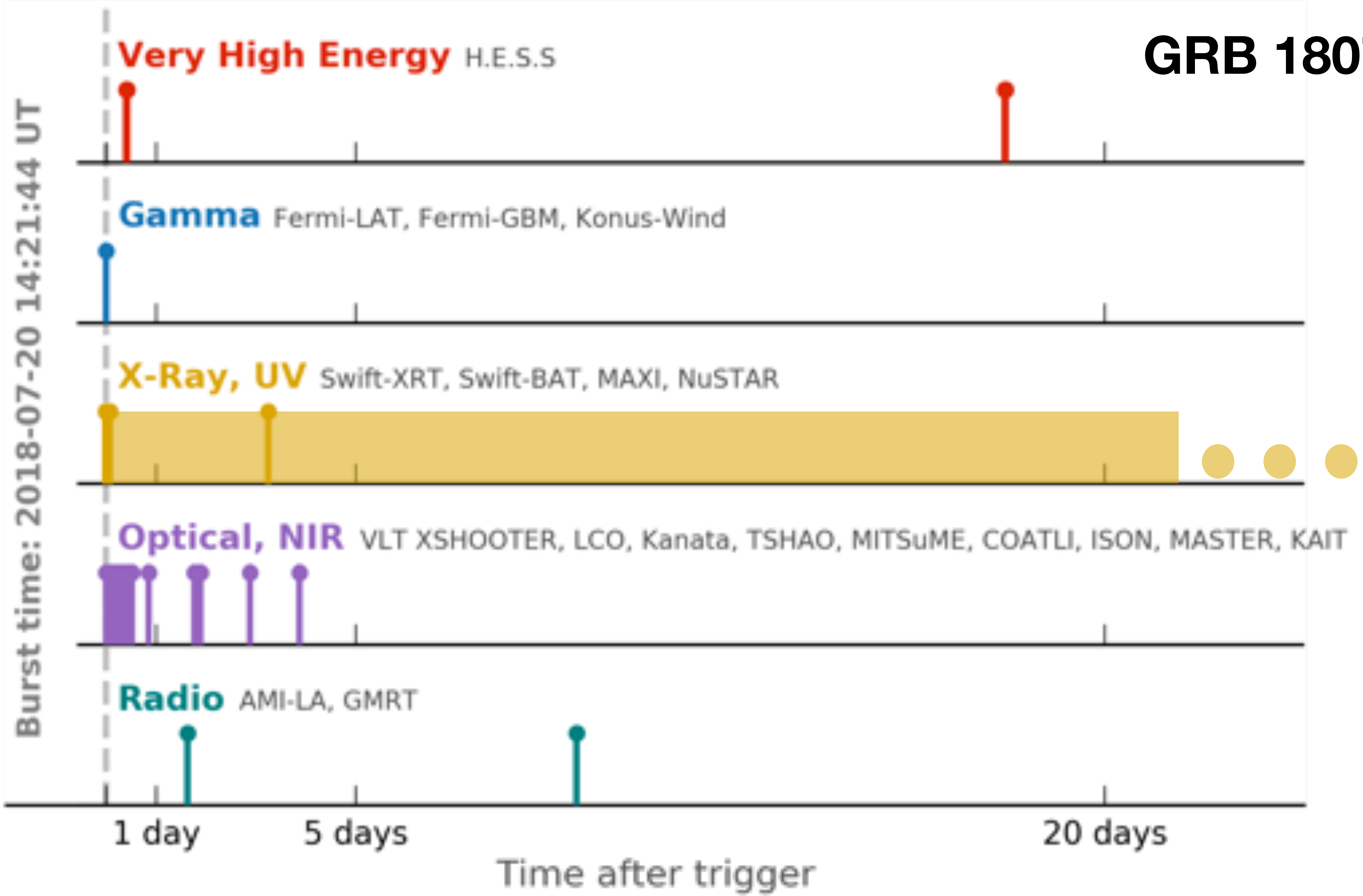

GRBs regularly detected by satellite instruments,
**Fermi-GBM + Swift-BAT (~300/yr)**

Typical detections in **keV-MeV** range but Fermi-LAT showed these powerful accelerators emit at much higher energies

Before last year the most energetic photon was **93 GeV**

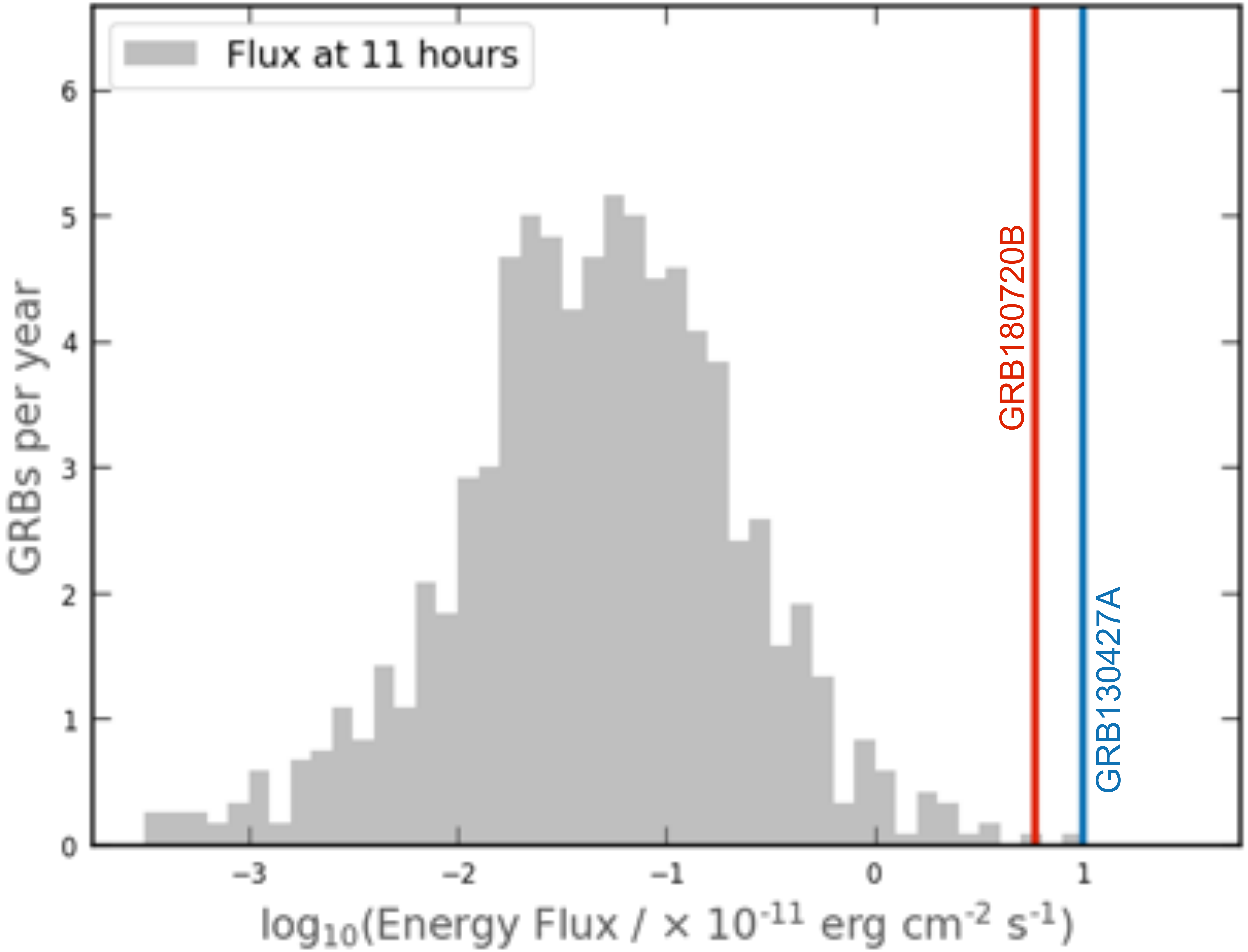
Energies above this limited by **photon statistics**

# GRB 180720B



Very High Energy H.E.S.S
Gamma Fermi-LAT, Fermi-GBM, Konus-Wind
X-Ray, UV Swift-XRT, Swift-BAT, MAXI, NuSTAR
Optical, NIR VLT XSHOOTER, LCO, Kanata, TSHAO, MITSuME, COATLI, ISON, MASTER, KAIT
Radio AMI-LA, GMRT
Burst time: 2018-07-20 14:21:44 UT
1 day
5 days
20 days
Time after trigger

# GRB 180720B



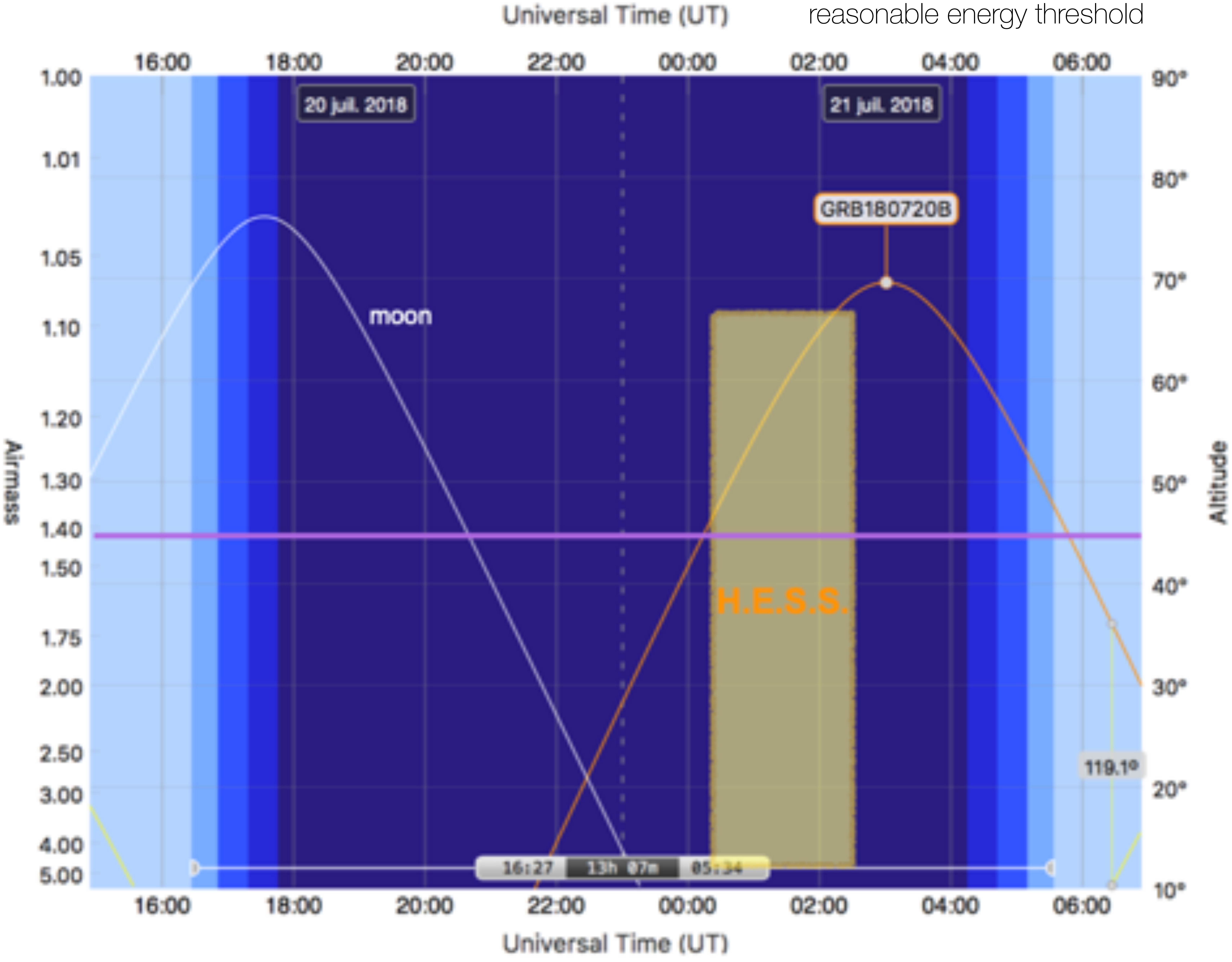

**Swift-XRT GRBs** energy flux distribution at **11 hours**

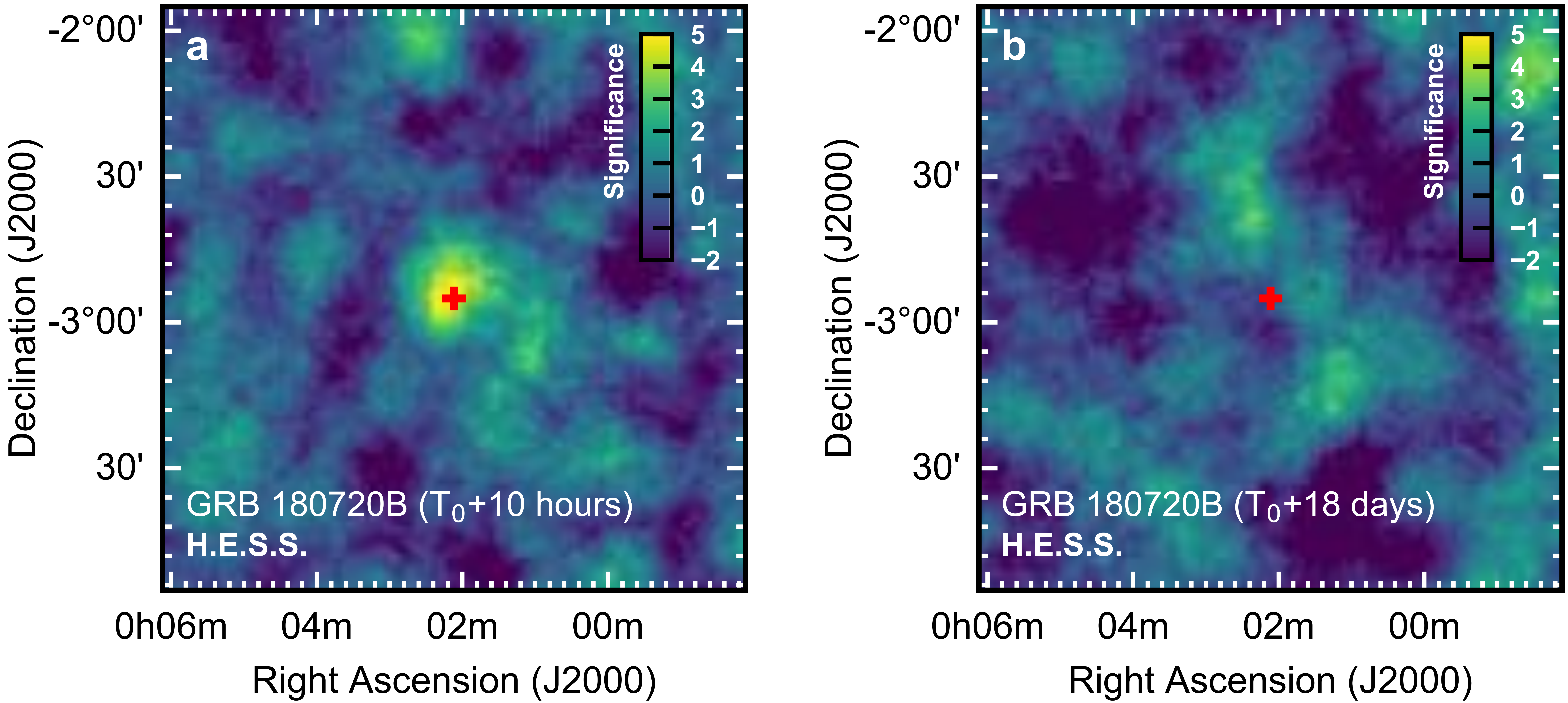
**2nd brightest** afterglow measured by Swift-XRT

VLT/X-Shooter measured

**Z = 0.653**

Took some time to become visible with a reasonable energy threshold






Observation started **~10 hours** after the burst.

Follow-up performed for **~2 consecutive hours** (zenith 40º to 25º)

Moderate presence of clouds at the beginning **not affecting the observations**.

# First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

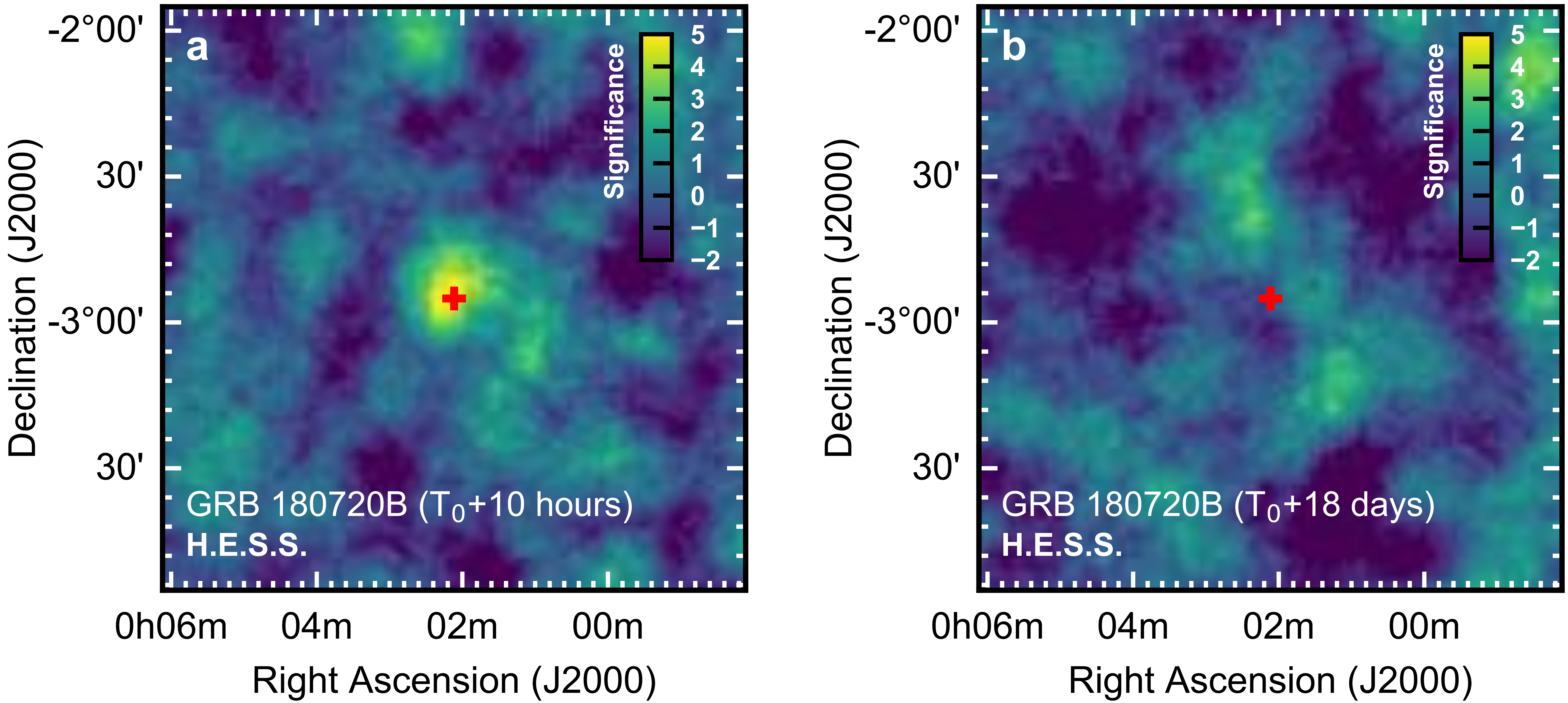
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
on ***15 Jan 2019; 01:03 UT***
*Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)*

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

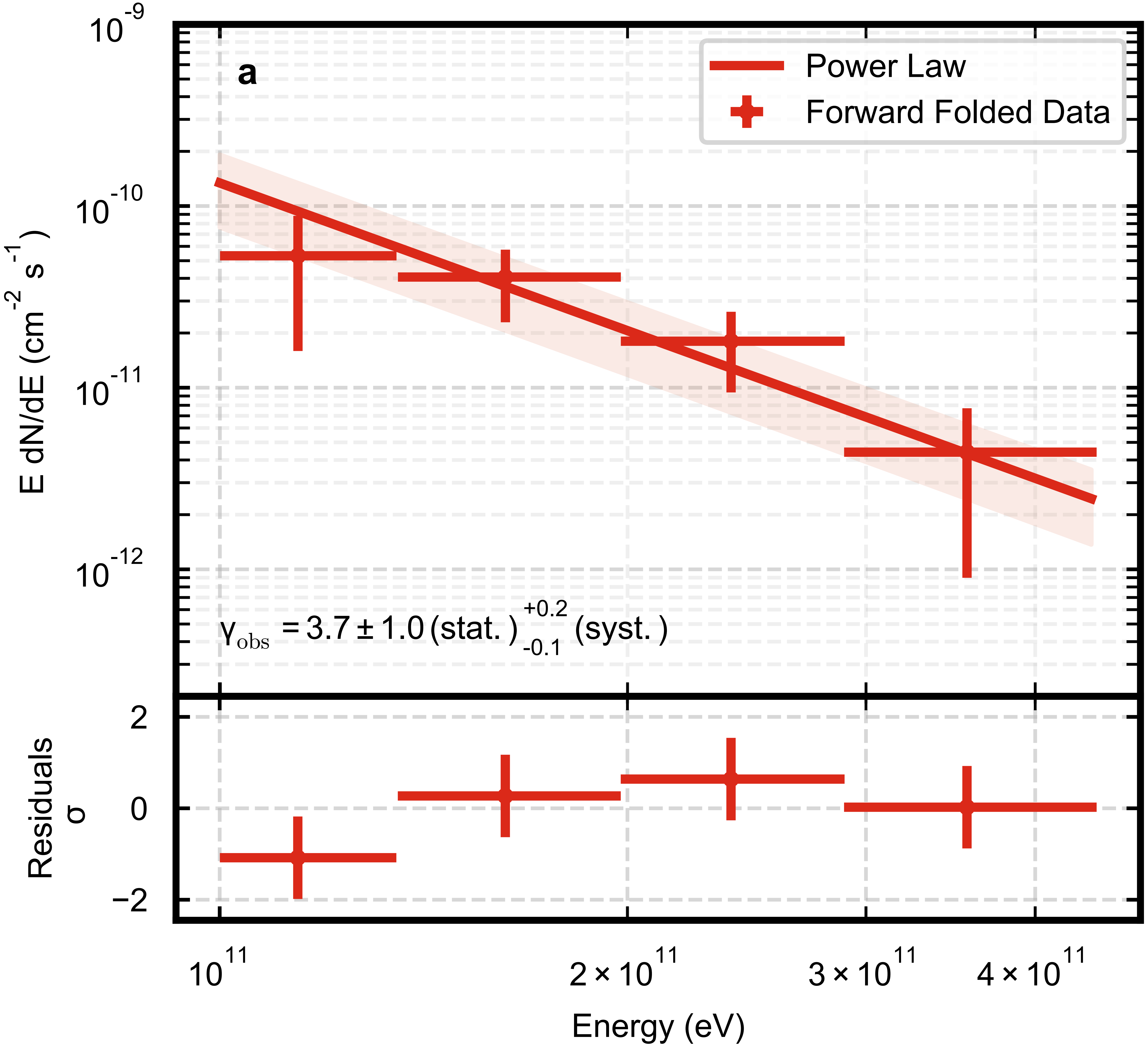
The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). 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.




H.E.S.S. detection: ~5.3σ pre-trial, **5.0σ post-trial**

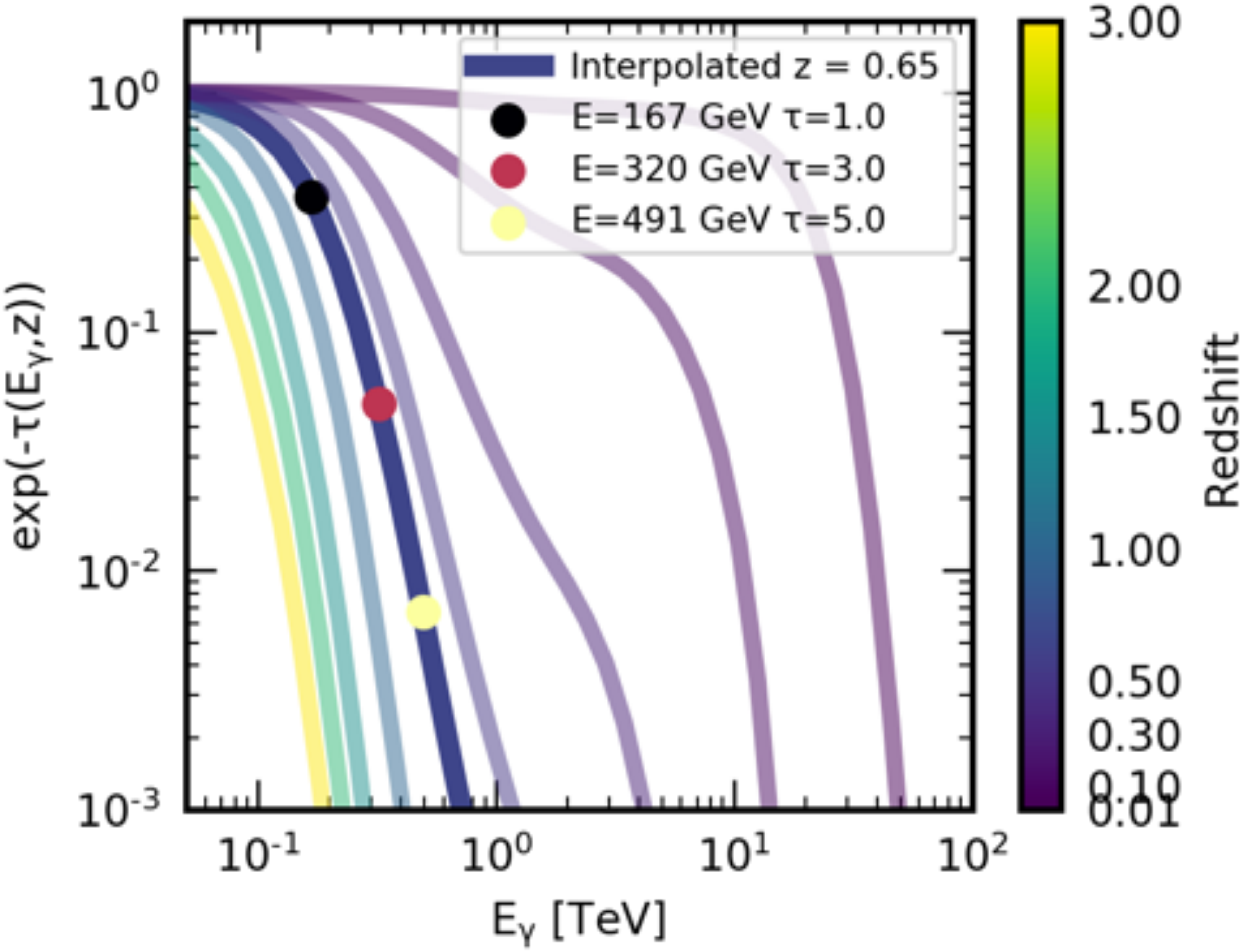
**Gone in re-observation** of this location 18 days after T0.

Announced to public in May 2019




When a power-law fit to the spectrum

Spectral index of **~3.7**




However this source is very distant

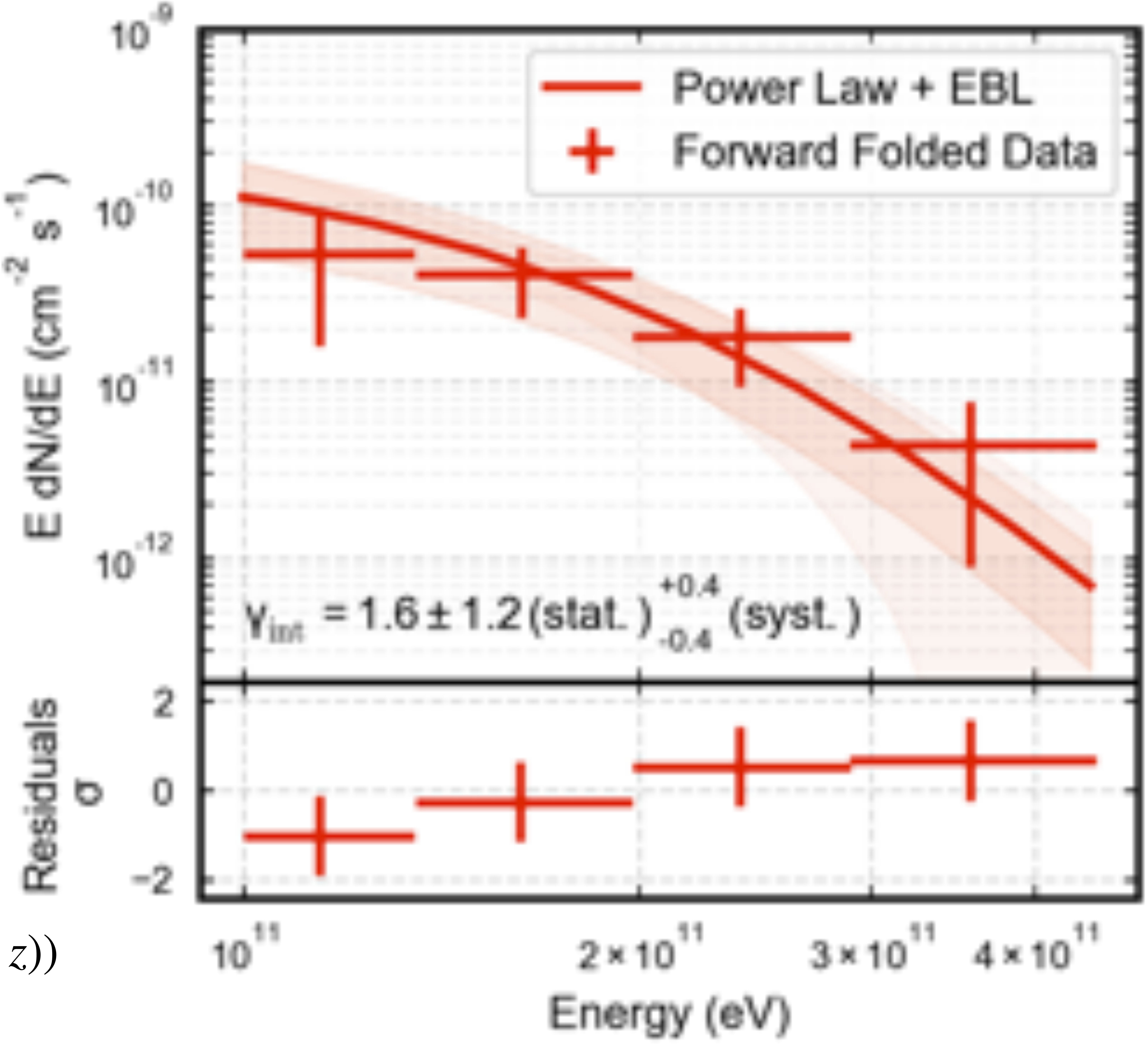
Our gamma ray photons can **pair produce with infra-red photons** over this distance

Produces a distance dependent **cut-off in the spectrum**

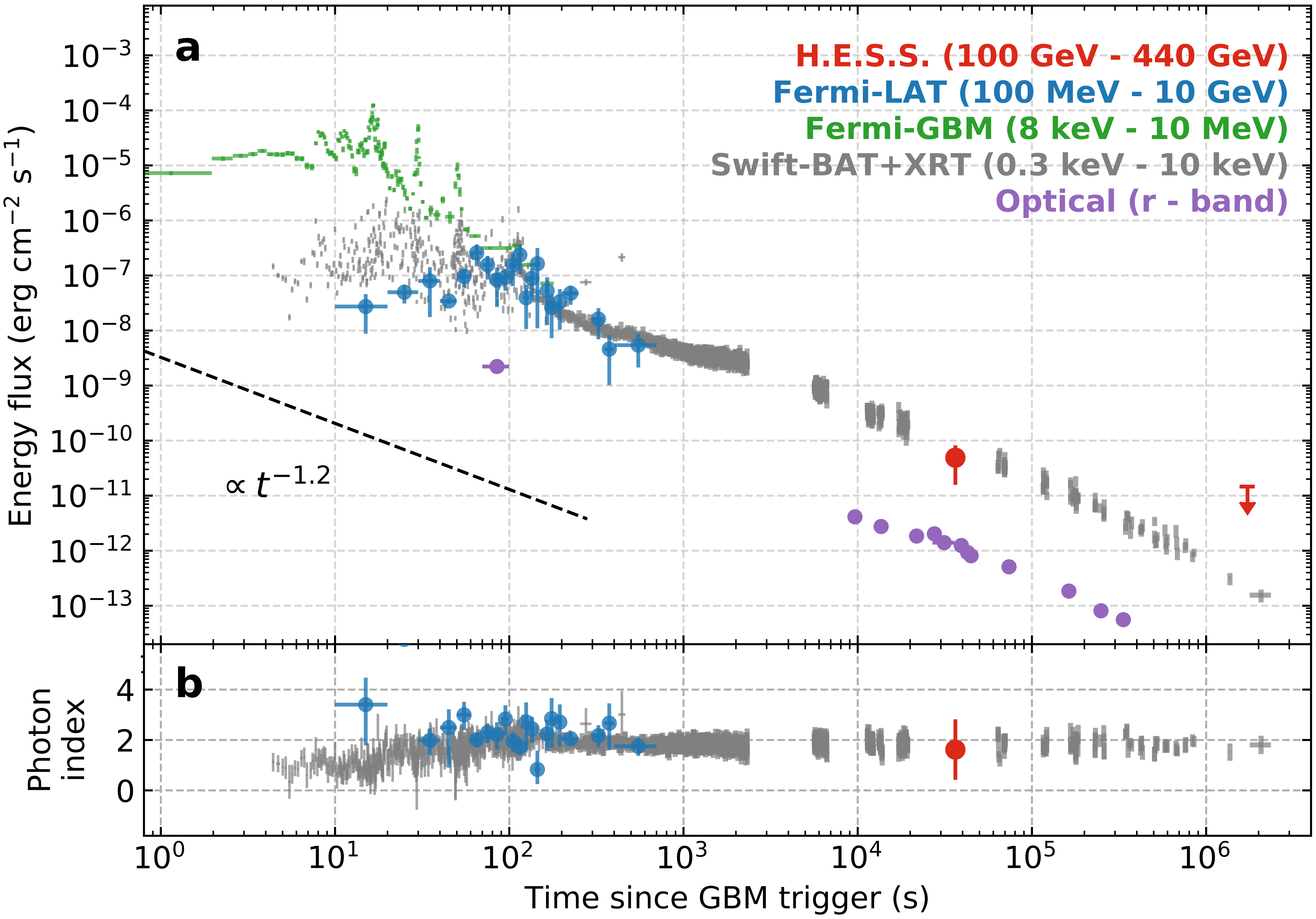
This effect must be corrected for based our knowledge of the **extragalactic background light**

**Very hard** intrinsic spectrum (EBL de-absorbed),

Spectral index of **~1.6**




$$\frac{dN}{dE} = \Phi_0 \left(\frac{E}{E_0}\right)^{-\gamma_{int}} \times exp(-\tau(E,z))$$


a
b
H.E.S.S. (100 GeV - 440 GeV)
Fermi-LAT (100 MeV - 10 GeV)
Fermi-GBM (8 keV - 10 MeV)
Swift-BAT+XRT (0.3 keV - 10 keV)
Optical (r - band)
$\propto t^{-1.2}$
Energy flux (erg cm$^{-2}$ s$^{-1}$)
Photon index
Time since GBM trigger (s)
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
4
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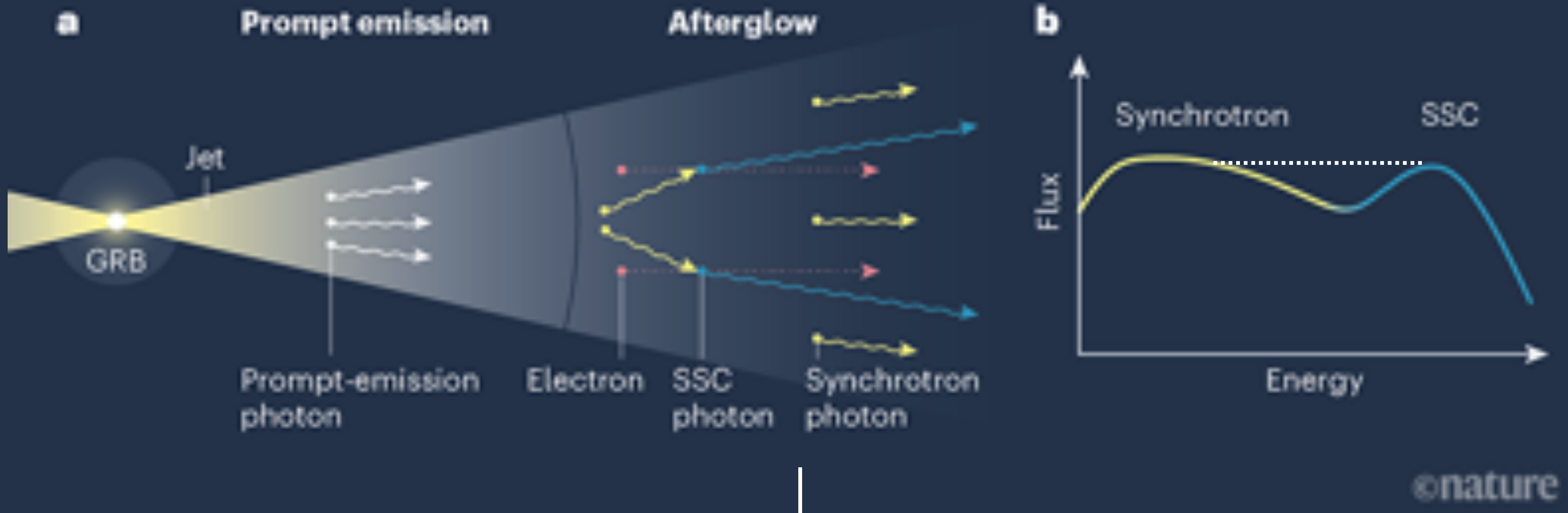
$10^{1}$
$10^{2}$
$10^{3}$
$10^{4}$
$10^{5}$
$10^{6}$




**Synchrotron emission**

$$E_{\mathrm{sync}}^{\max} = 100\Gamma\,\mathrm{MeV}$$

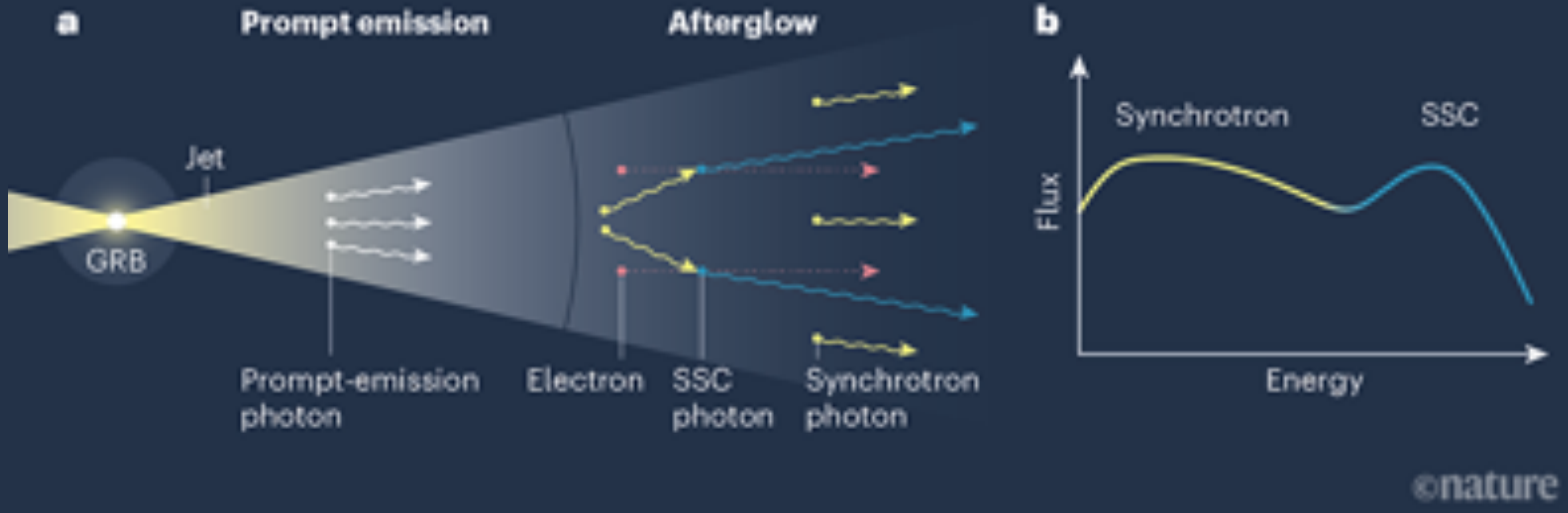
**Γ>1000** at 10hrs!
while **Γ~O(10) expected**

Could be achieved with small scale magnetic turbulence

**Synchrotron self Compton emission**

Electron with $E_e$ **upscatters synchrotron photon** of energy **$E_t$ to $E_{ssc}$**

i.e. Requires **$E_t$~1 keV** for $E_e$~10 GeV boosted with Γ~20




**In principle we cannot distinguish between these two emission mechanisms from the SED (no data in the MeV-GeV range)**

**However, "by default" we prefer the SSC model due to the more sensible gamma factor needed**

Article

# A very-high-energy component deep in the γ-ray burst afterglow

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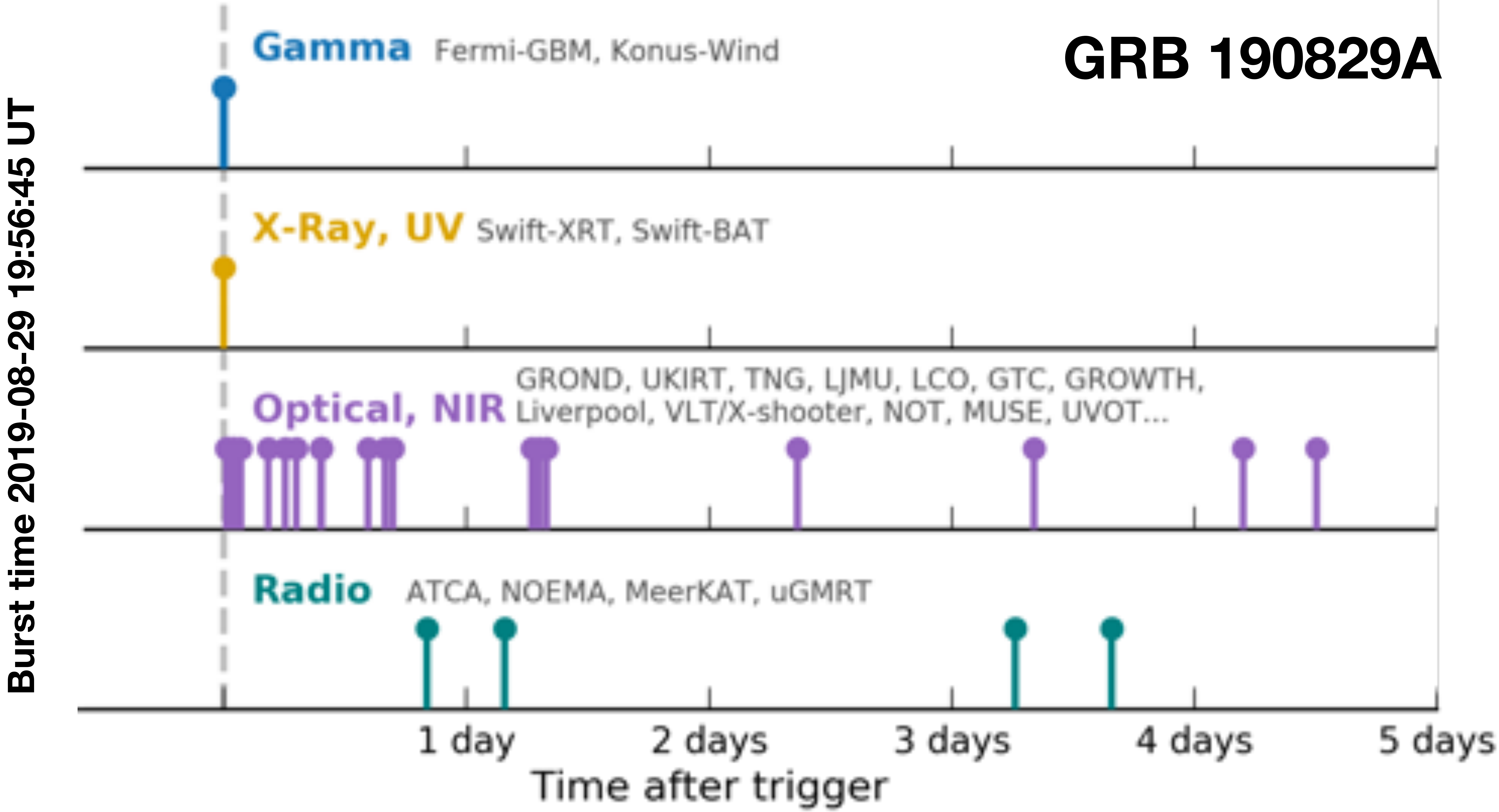
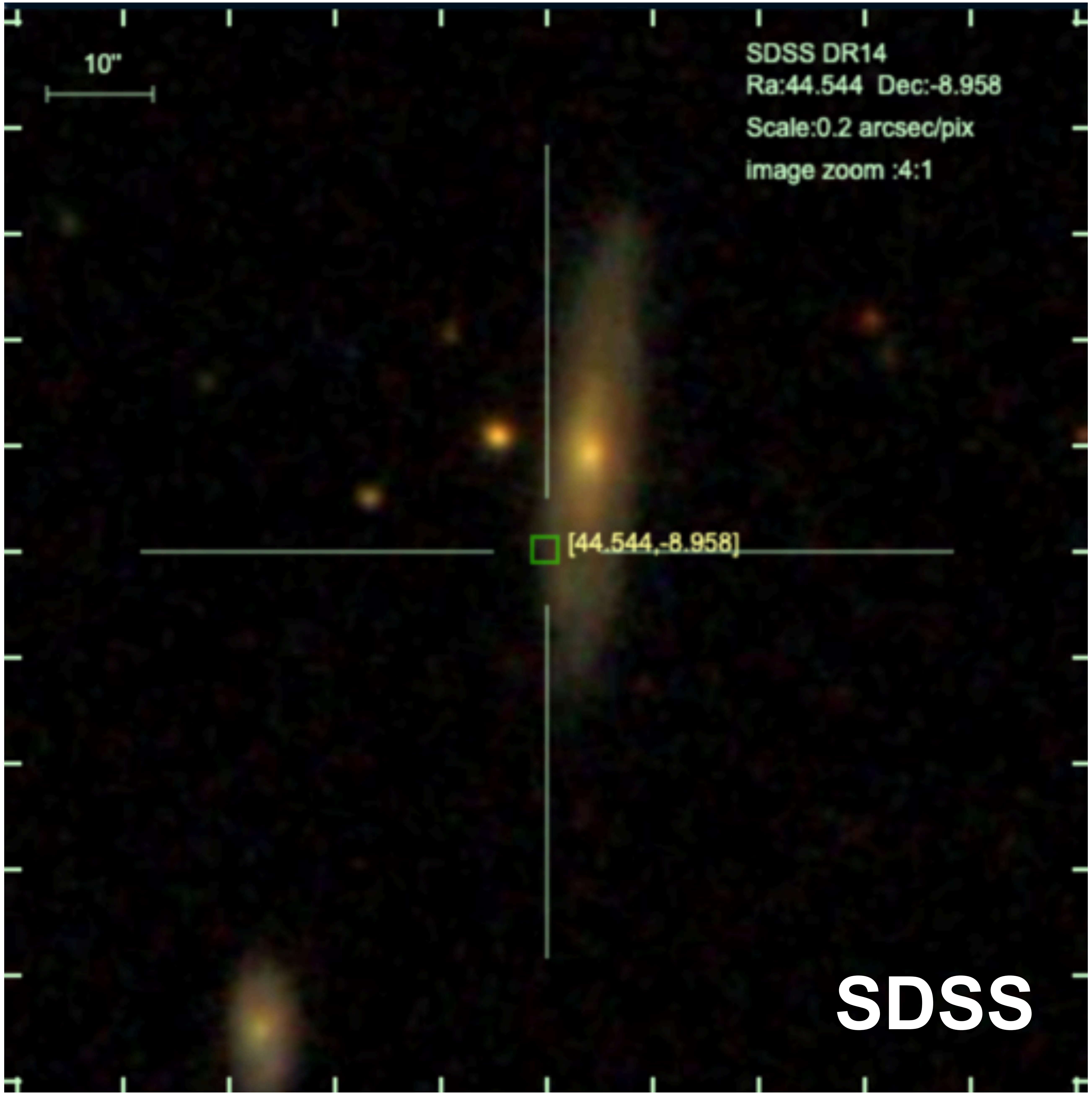
Gamma-ray bursts (GRBs) are brief flashes of γ-rays and are considered to be the most energetic explosive phenomena in the Universe[1]. The emission from GRBs comprises a short (typically tens of seconds) and bright prompt emission, followed by a much longer afterglow phase. During the afterglow phase, the shocked outflow—produced by the interaction between the ejected matter and the circumburst medium—slows down, and a gradual decrease in brightness is observed[2]. GRBs typically emit most of their energy via γ-rays with energies in the kiloelectronvolt-to-megaelectronvolt range, but a few photons with energies of tens of gigaelectronvolts have been detected by space-based instruments[3]. However, the origins of such high-energy (above one gigaelectronvolt) photons and the presence of very-high-energy (more than 100 gigaelectronvolts) emission have remained elusive[4]. Here we report observations of very-high-energy emission in the bright GRB 180720B deep in the GRB afterglow—ten hours after the end of the prompt emission phase, when the X-ray flux had already decayed by four orders of magnitude. Two possible explanations exist for the observed radiation: inverse Compton emission and synchrotron emission of ultrarelativistic electrons. Our observations show that the energy fluxes in the X-ray and γ-ray range and their photon indices remain comparable to each other throughout the afterglow. This discovery places distinct constraints on the GRB environment for both emission mechanisms, with the inverse Compton explanation alleviating the particle energy requirements for the emission observed at late times. The late timing of this detection has consequences for the future observations of GRBs at the highest energies.



GRB 190829A
Burst time 2019-08-29 19:56:45 UT
Gamma Fermi-GBM, Konus-Wind
X-Ray, UV Swift-XRT, Swift-BAT
Optical, NIR GROND, UKIRT, TNG, LJMU, LCO, GTC, GROWTH, Liverpool, VLT/X-shooter, NOT, MUSE, UVOT...
Radio ATCA, NOEMA, MeerKAT, uGMRT
1 day
2 days
3 days
4 days
5 days
Time after trigger




Host galaxy quickly identified

Measured redshift
**Z=0.0785**

**Very nearby**

# GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.

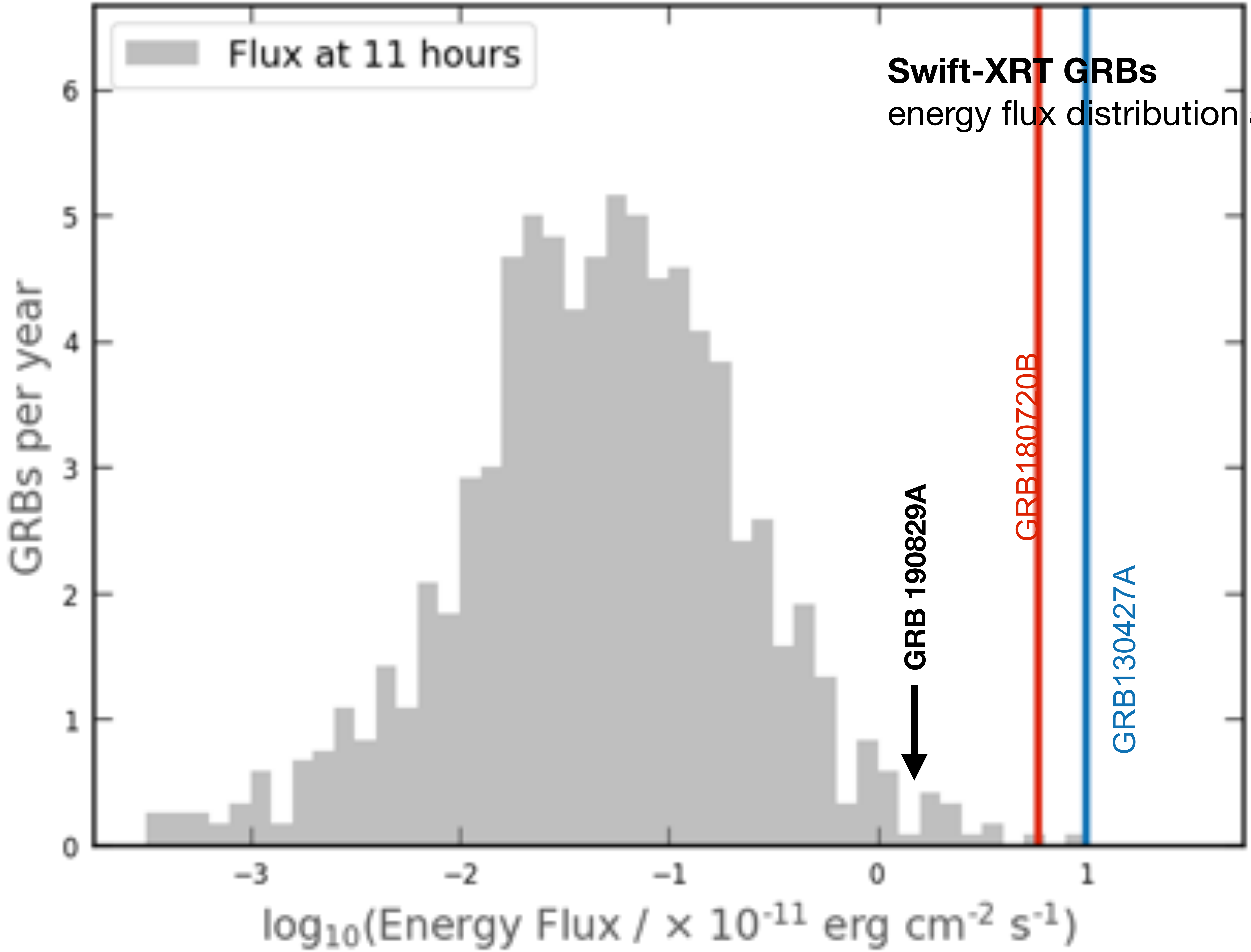
ATel #13052; *M. de Naurois (H. E.S. S. Collaboration)*
*on 30 Aug 2019; 07:12 UT*
*Credential Certification: Fabian SchÃ Â¼ssler (fabian.schussler@cea.fr)*

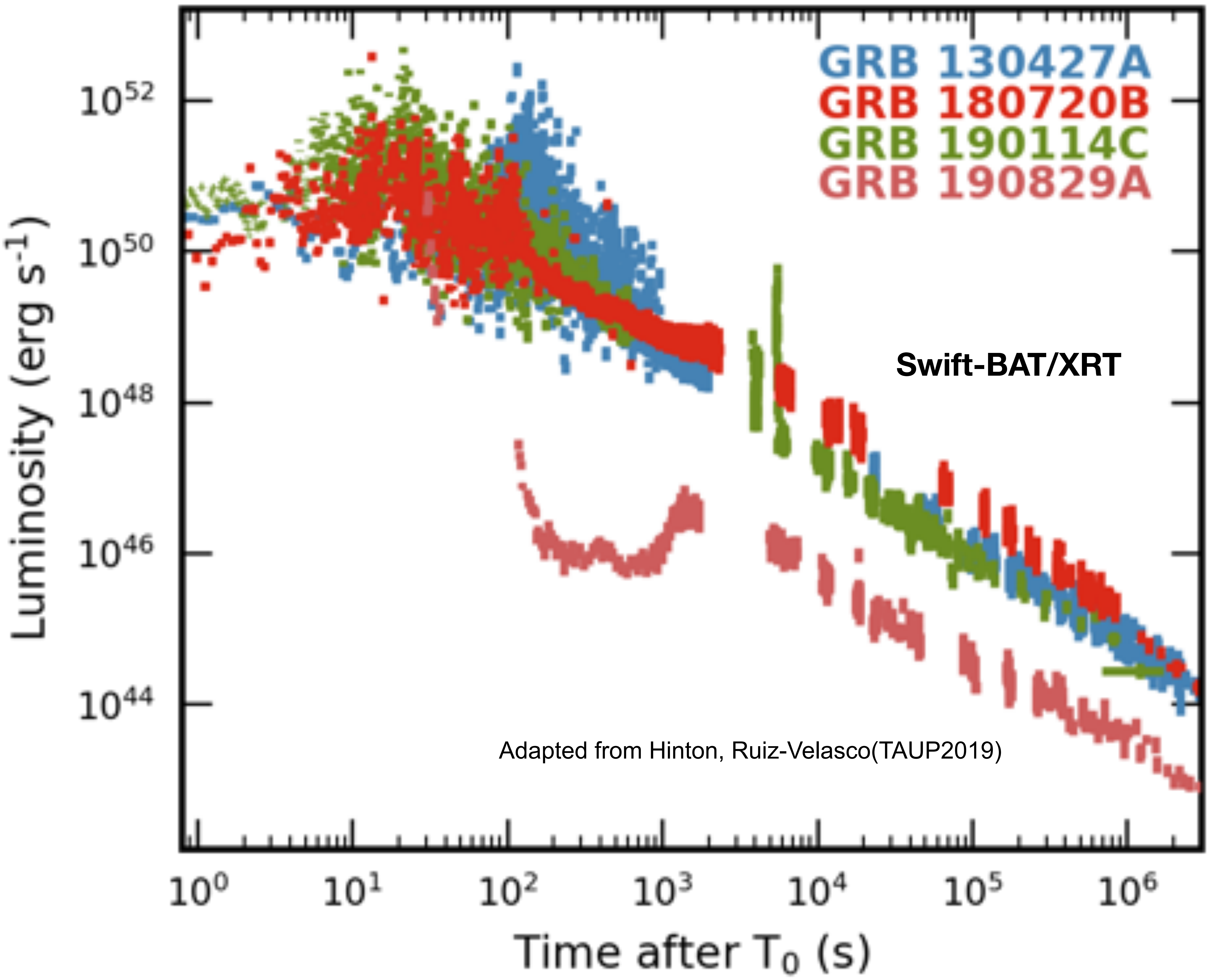
Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Tweet

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552). At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date. H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A. Further analyses of the data are on-going and further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths. H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

**Swift-XRT GRBs**
energy flux distribution at **11 hours**






The energy output of GRB 190829A is **far lower** than the other GRBs

# What did we learn from our GRBs

Getting on target early is clearly very important, but **VHE afterglow emission** seems to stick around for much **longer than we first expected**

**Don't despair/give up** if nothing bright is seen in the online analysis

Detection by **Fermi-LAT** is maybe not as important as we thought…

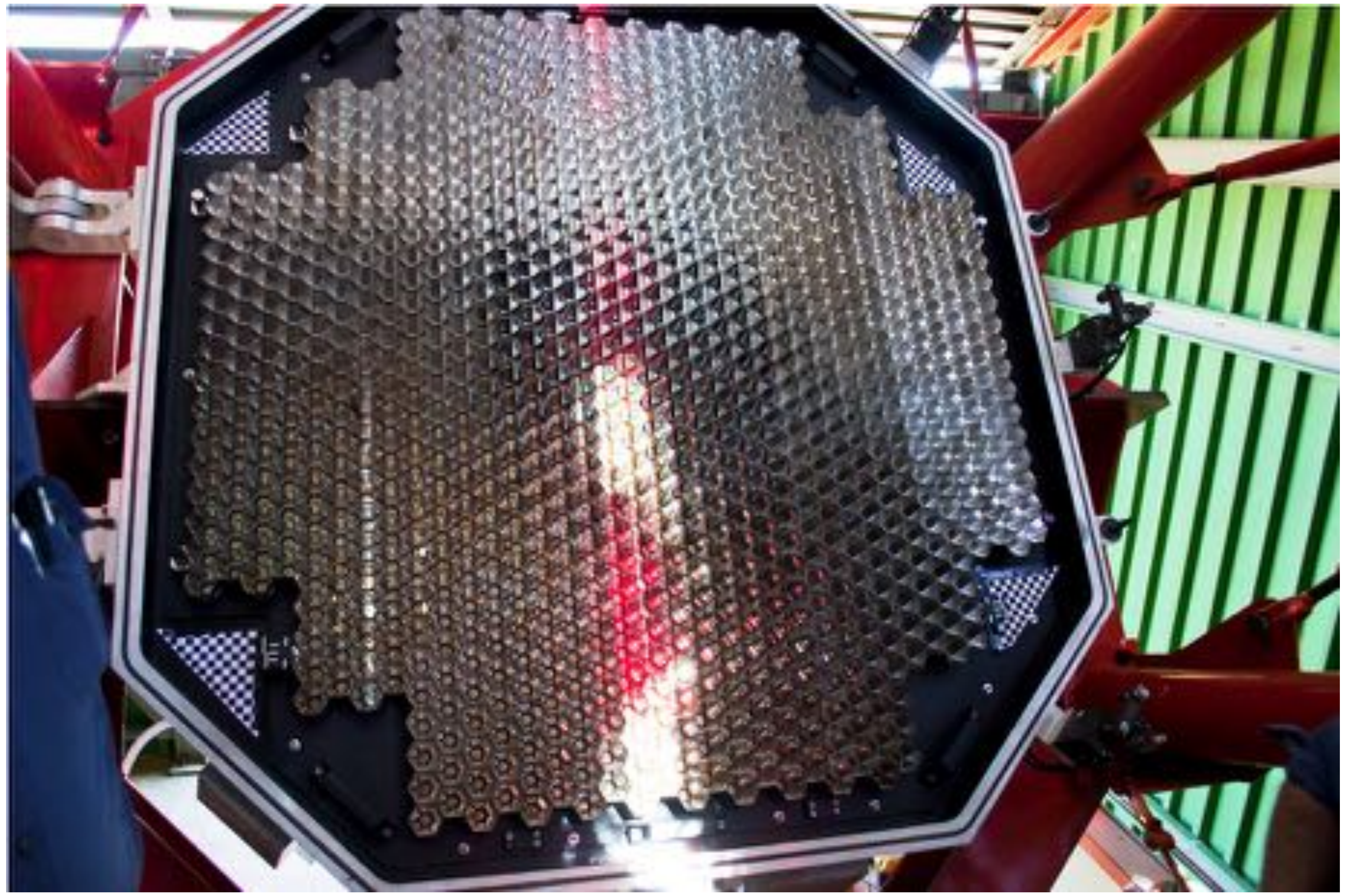
But the flux level measured by **Swift-XRT** seems to be

It seems like the bursts we have seen are **not "special"** in any particular way **($E_{ISO}$ of GRB 190829A is pretty low)**

**Longer timescale** observations and signal integrations seem to be rather useful

# Upgrading the H.E.S.S. I Cameras

*New model, original parts*



HESS-I

HESS-IU

Major upgrade campaign performed on the now 15 year old phase I camera over 2017

# Summary

Over the last 15 years H.E.S.S. has discovered a rich zoo of sources at the highest energies

H.E.S.S. has made a major contributions to the understanding of cosmic rays

Many galactic accelerators have been discovered with some indications of acceleration up to PeV energies

As well as numerous powerful and variable active galactic nuclei

The discovery of VHE emission from gamma-ray bursts has greatly added to the understanding of these phenomena

But clearly there is still some way to go

H.E.S.S. has now been fully upgraded and should be able to maintain stable operation for many years