# HESS Highlights and Status


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SLAC Summer Institute, August 2008

# Overview

## The Instrument

- Technique
- Specifications

## Goals

## Scientific Results

- The Galactic Plane Survey
- Galactic Sources
- Extra-galactic Sources
- Other

## Future and Status

- HESS Phase II

H E S S

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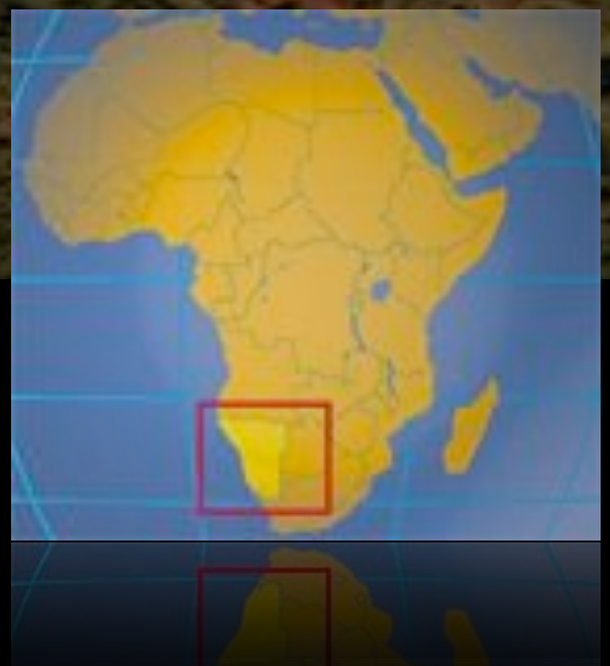
# H.E.S.S.

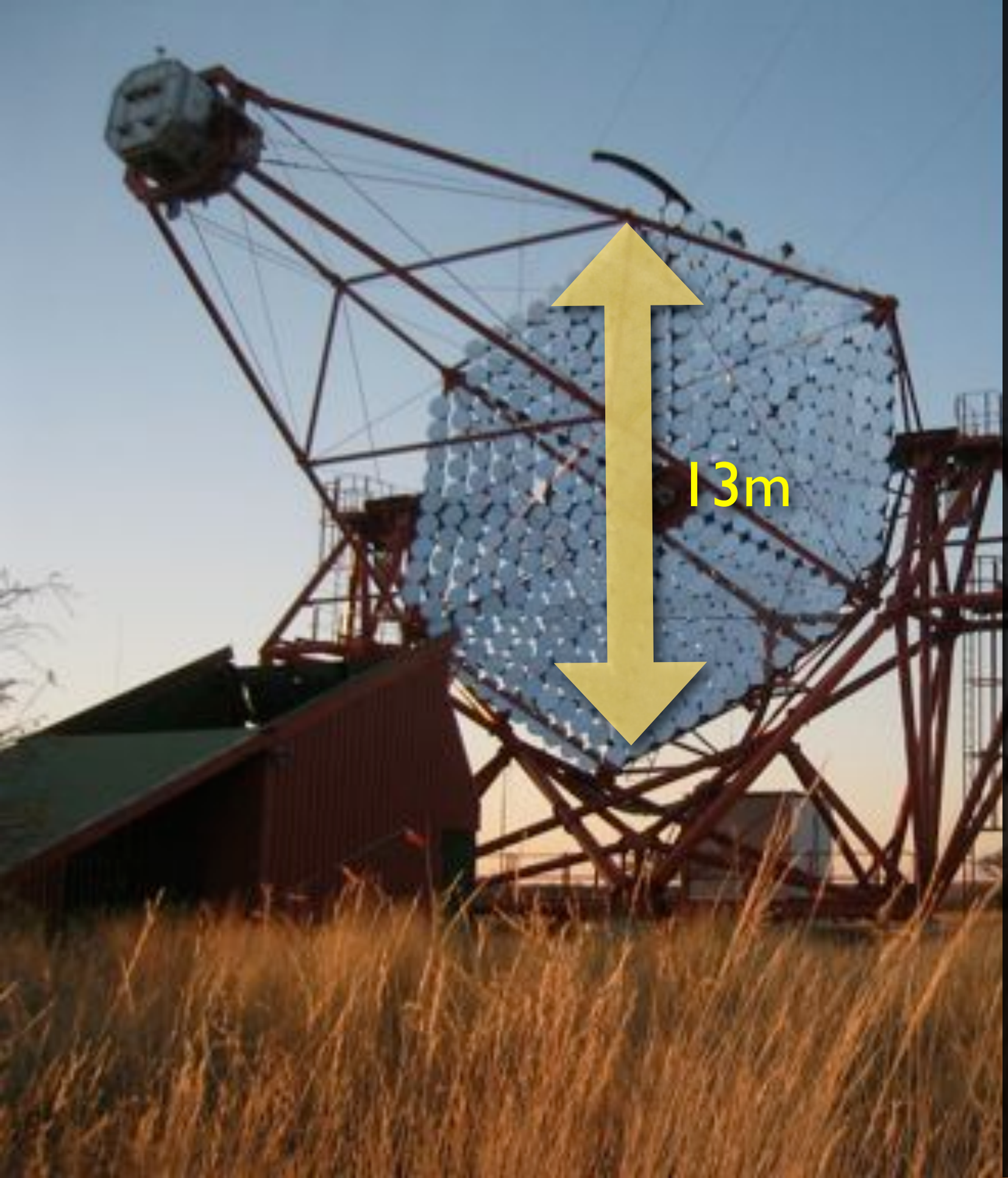
High Energy Stereoscopic System

| | |
|---|---|
| MPI Kernphysik, Heidelberg | Germany |
| Humboldt-Univ. Berlin | |
| Ruhr-Univ. Bochum | |
| Univ. Erlangen-Nürnberg | |
| Univ. Hamburg | |
| Landessternwarte Heidelberg | |
| Univ. Tübingen | |
| Ecole Polytechnique, Palaiseau | France |
| APC Paris | |
| Univ. Paris VI-VII | |
| Paris Observatory, Meudon | |
| LAPP Annecy | |
| LAOG Grenoble | |
| LPTA Montpellier | |
| CEA Saclay | |
| CESR Toulouse | |
| Durham Univ. | United Kingdom |
| Univ. Leeds | |
| Dublin Inst. for Adv. Studies | Ireland |
| Polish Academy of Sciences, Warsaw | Poland |
| Jagiellonian Univ., Cracow | |
| Charles Univ., Prague | Czech Republic |
| Yerewan Physics Inst. | Armenia |
| Univ. Adelaide | Australia |
| North-West Univ., Potchefstroom | South Africa |
| Univ. of Namibia, Windhoek | Namibia |

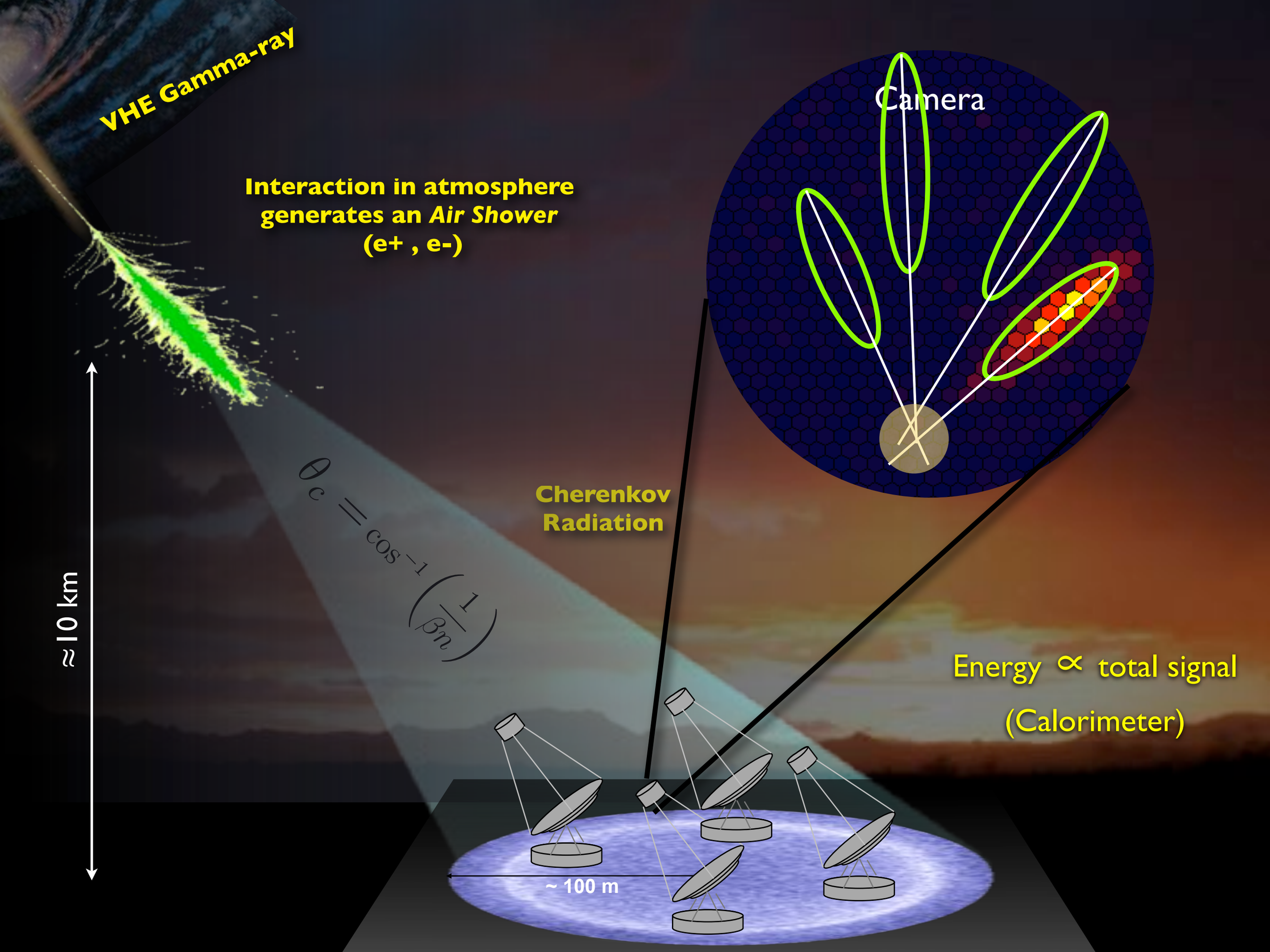


# H.E.S.S. Details

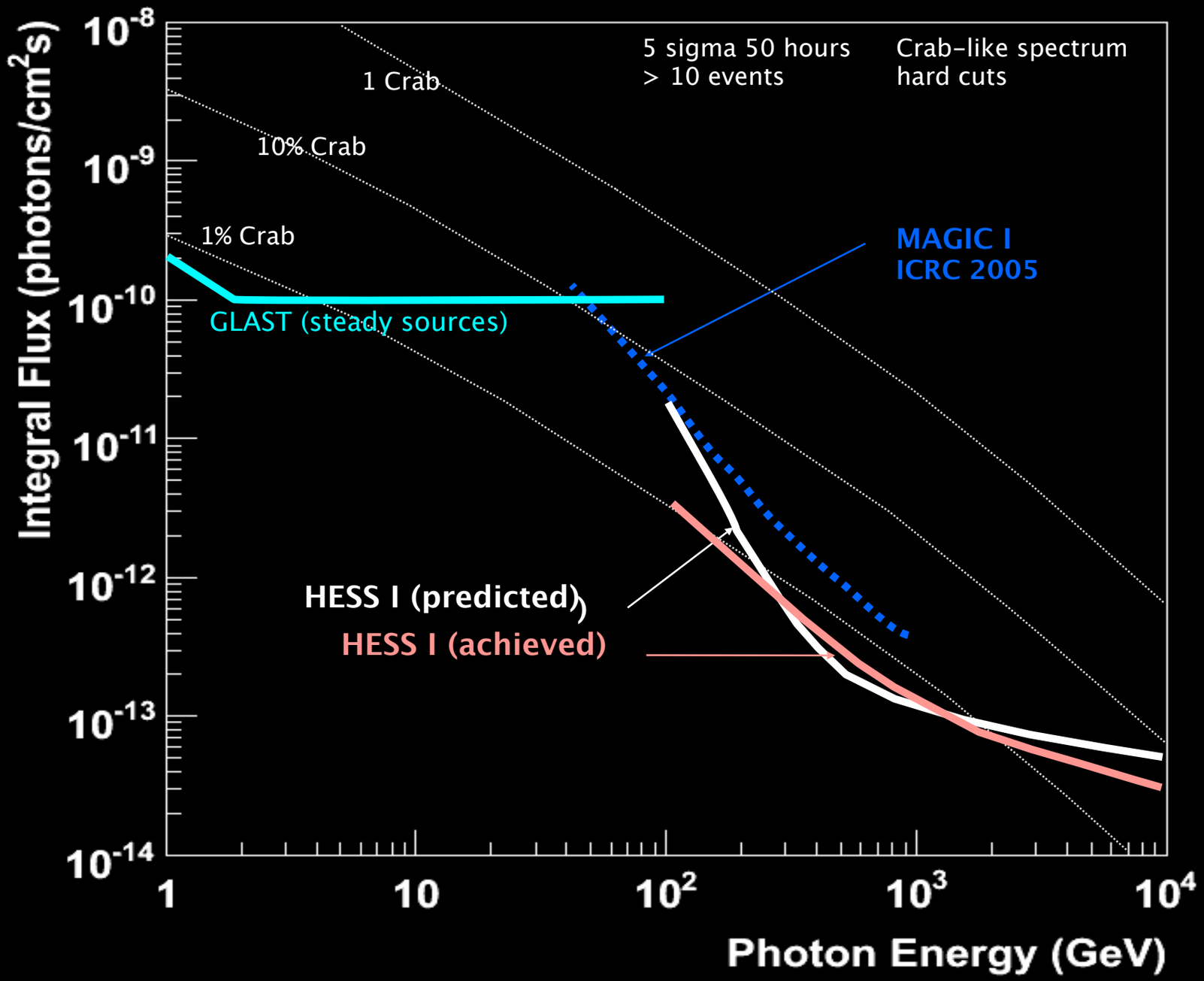
- **Wide energy range**
  - ★ Very High Energy ≈100 GeV - 100 TeV
- **Angular Res:** <0.1° per event
  - improves with telescope multiplicity and shower intensity
- **Effective Area**: > $10^5$ $m^2$
- **Energy Res:** 15 %
- **Pointing** accurate within 10″
- ≈**1000 hrs** observation/year
- Fully operational since **2003**




- **4 Telescopes**
  - 120 m spacing
  - 107 $m^2$ mirror
- **Cherenkov Cameras**
  - 960 pixels, 0.16° / pixel
    - ★ 5° Field of View
- **Central Array Trigger**
  - Requires 2 telescope coincidence
  - Better sensitivity + ang. resolution


VHE Gamma-ray
Interaction in atmosphere generates an *Air Shower* (e+ , e-)
Camera
Cherenkov Radiation
$\theta_c = \cos^{-1}\left(\frac{1}{\beta n}\right)$
≈ 10 km
Energy ∝ total signal
(Calorimeter)
~ 100 m

# Sensitivity




| % Crab | Obs. Time |
|---|---|
| 100% | 30 s |
| 5% | 1 h |
| 1% | 25 h |

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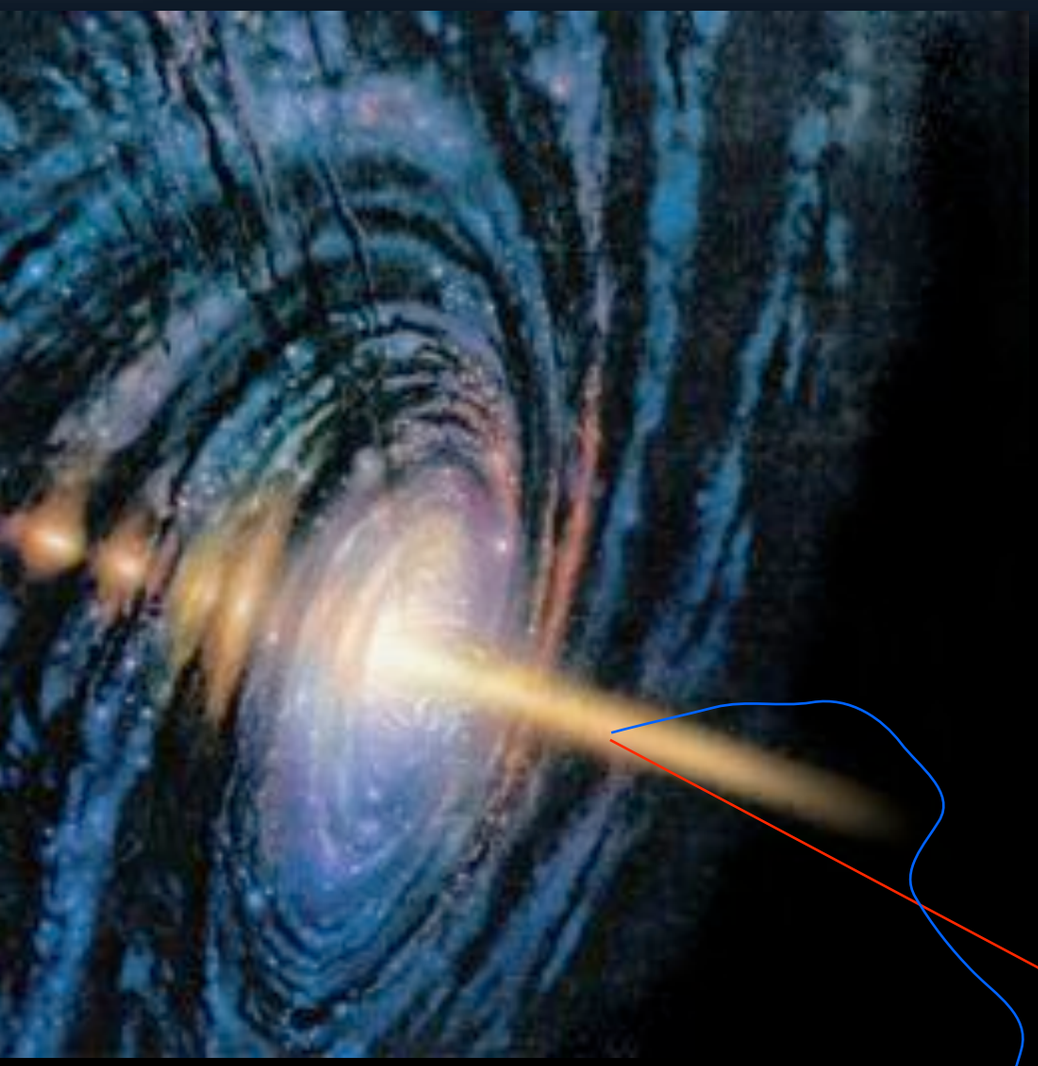
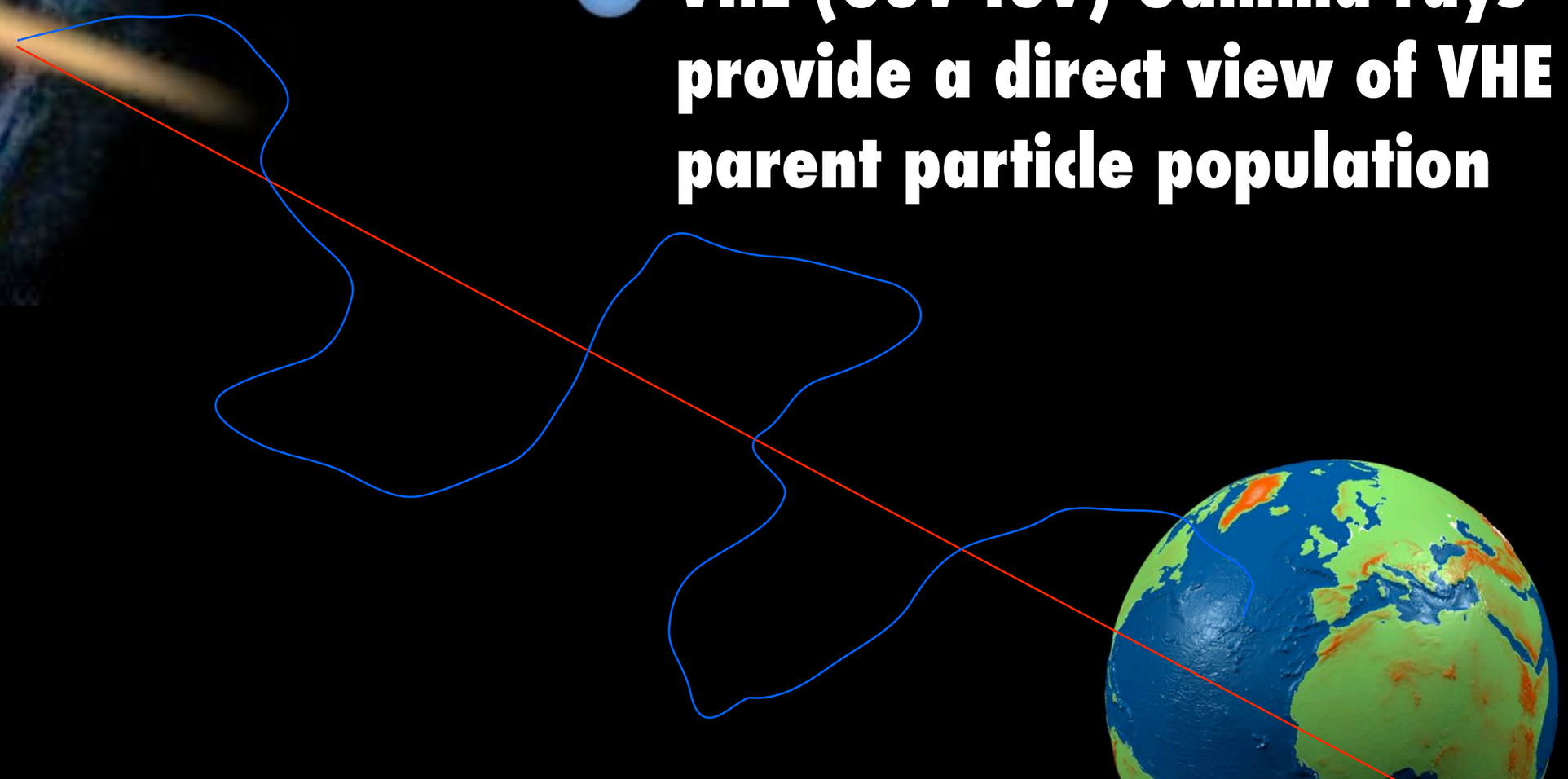
# Goal:



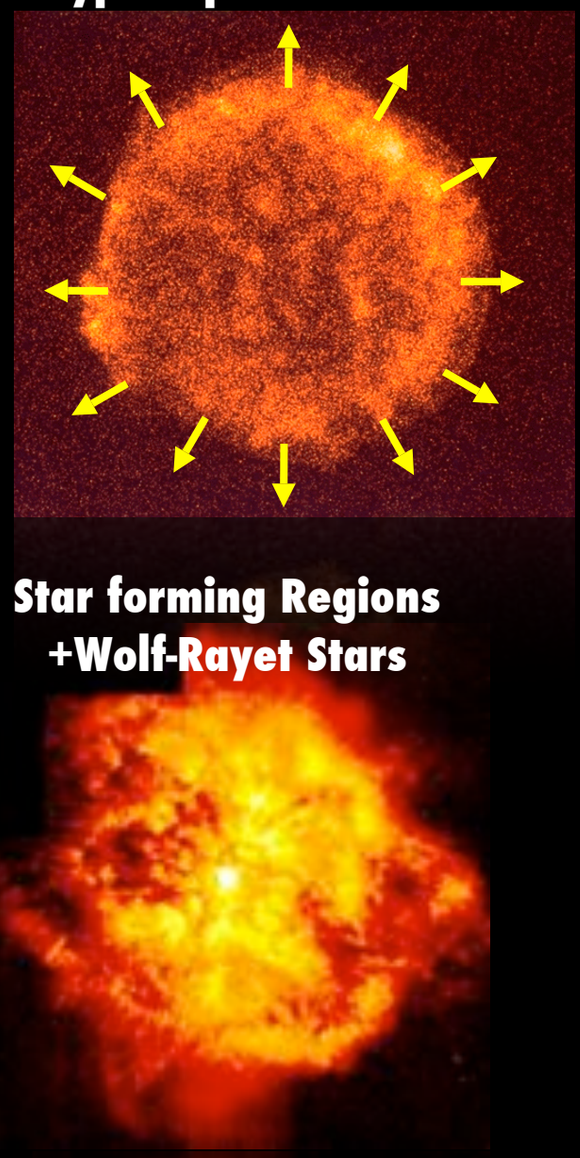
- **Identify and study the sources of cosmic rays**
  - Which processes can accelerate particles up to $10^{20}$ ev?
- **VHE (GeV-TeV) Gamma rays provide a direct view of VHE parent particle population**



# Predicted VHE Sources

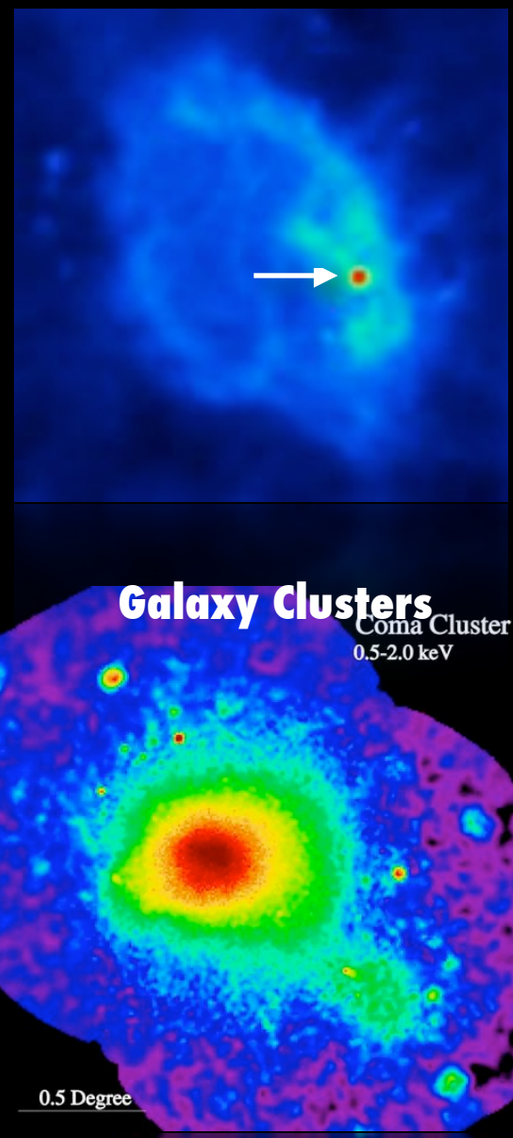
Active Galactic Nuclei

Shell-type Supernova Remnants



Pular Wind Nebulae

Supermassive Black Holes



Microquasars/Binaries



Star forming Regions
+Wolf-Rayet Stars



Gamma-ray Bursts

Galaxy Clusters




, ...

# Acceleration Mechanisms

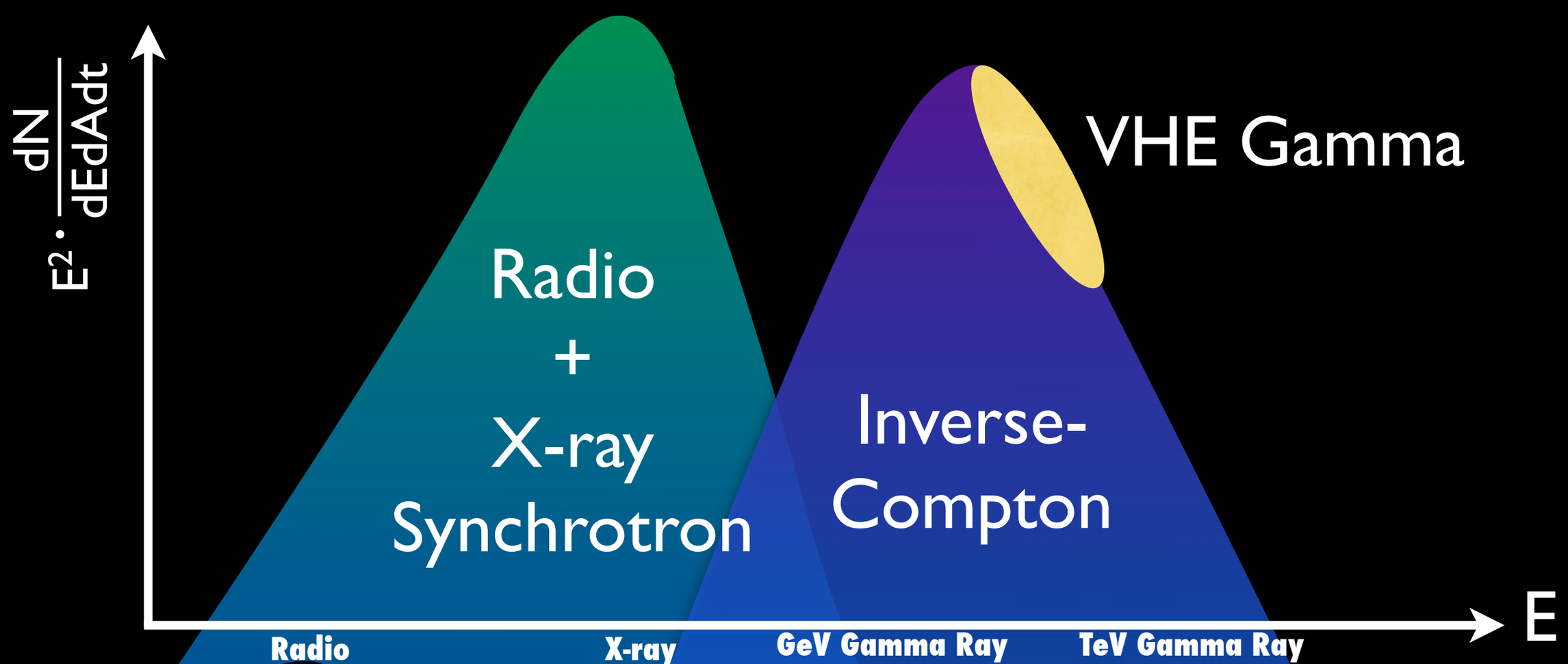
- **Shock acceleration produces relativistic particles**
- **Electron population:**
  - + **B**-field
  - synchrotron emission (Radio–X-ray)
  - Inverse-Compton scattering produces VHE Gamma
- **Proton population:**
  - + target material
  - produces Pions + ...
  - $\pi^0$-decay produces VHE gammas



$$\pi^{\pm} \rightarrow \mu^{\pm} + 2\nu \rightarrow e^{\pm} + \gamma$$

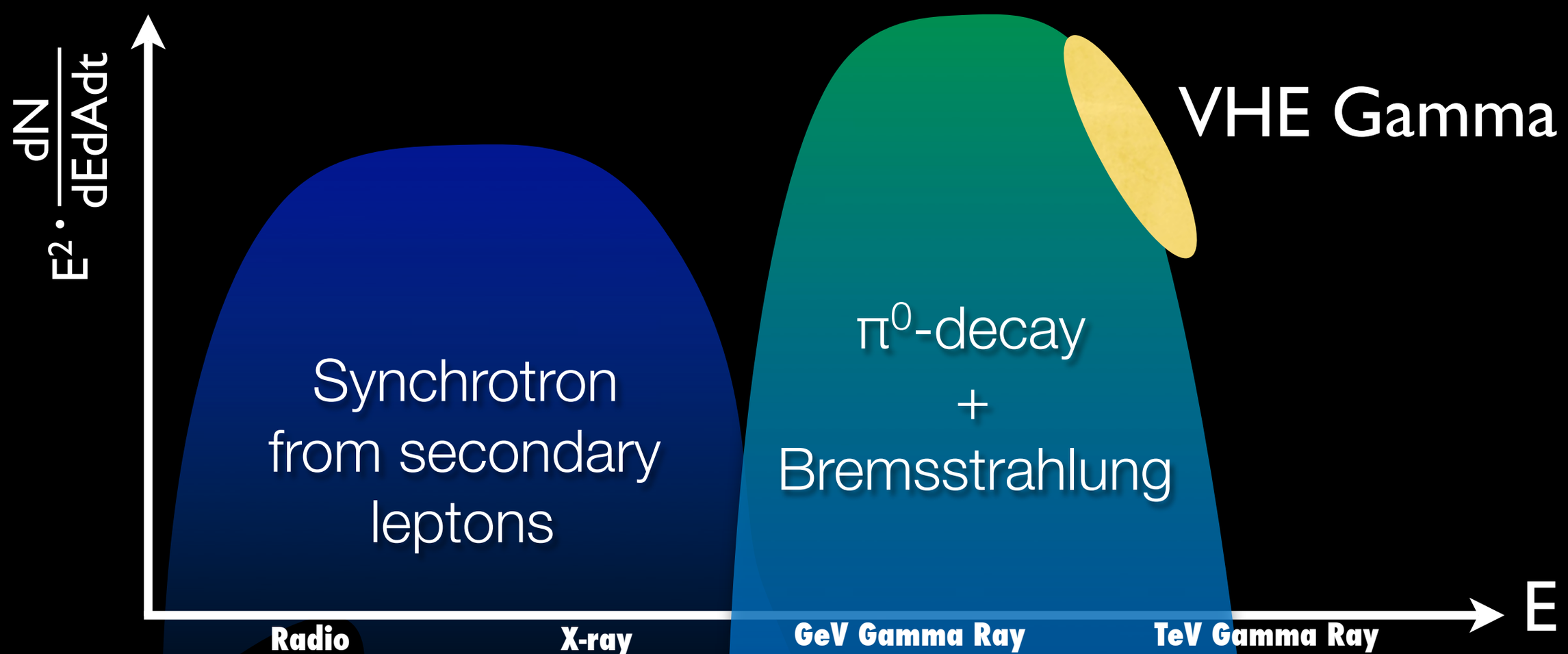
# What do we expect?

- So far nearly all VHE sources can be explained with electrons
- leptonic sources exhibit 2-humped spectrum



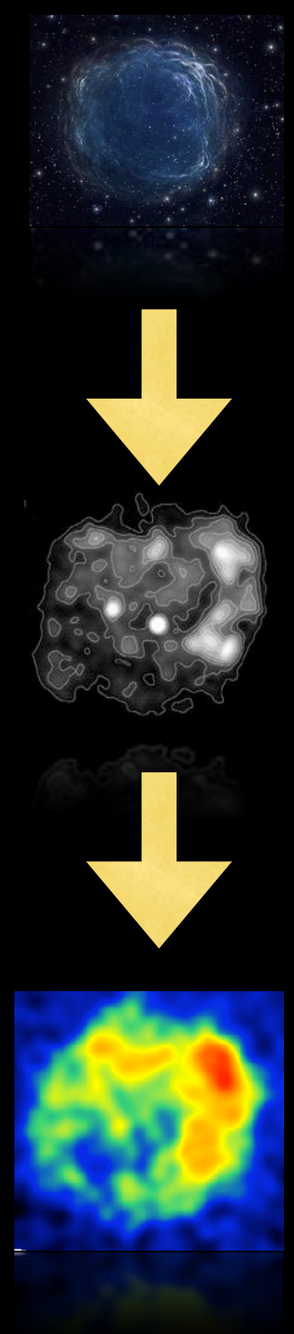
# What do we expect?

- Proton scenario produces the following:
- Relative height depends on target density, distance to source, B-field



# VHE Spectra

- **Spectra we measure in the VHE energy range have very few "features"**
  - **No lines** at these energies*
  - Only get:
    - Flux, Spectral slope
    - Cutoff energy (sometimes)
    - Peak energy (rarely)
- **Multi-wavelength data are crucial for understanding the sources!**



*unless we detect dark matter, e.g. annihilating Neutralinos

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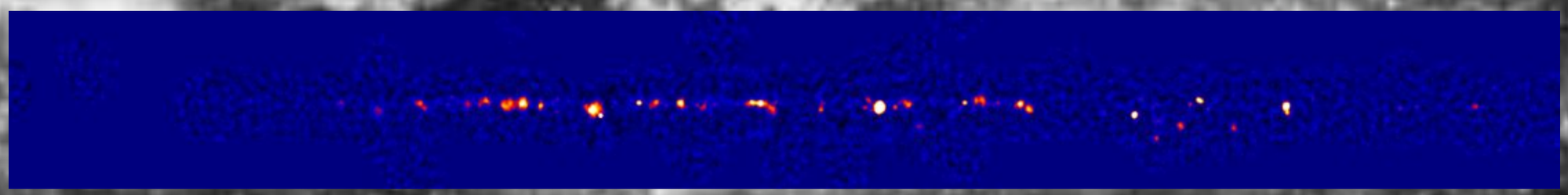
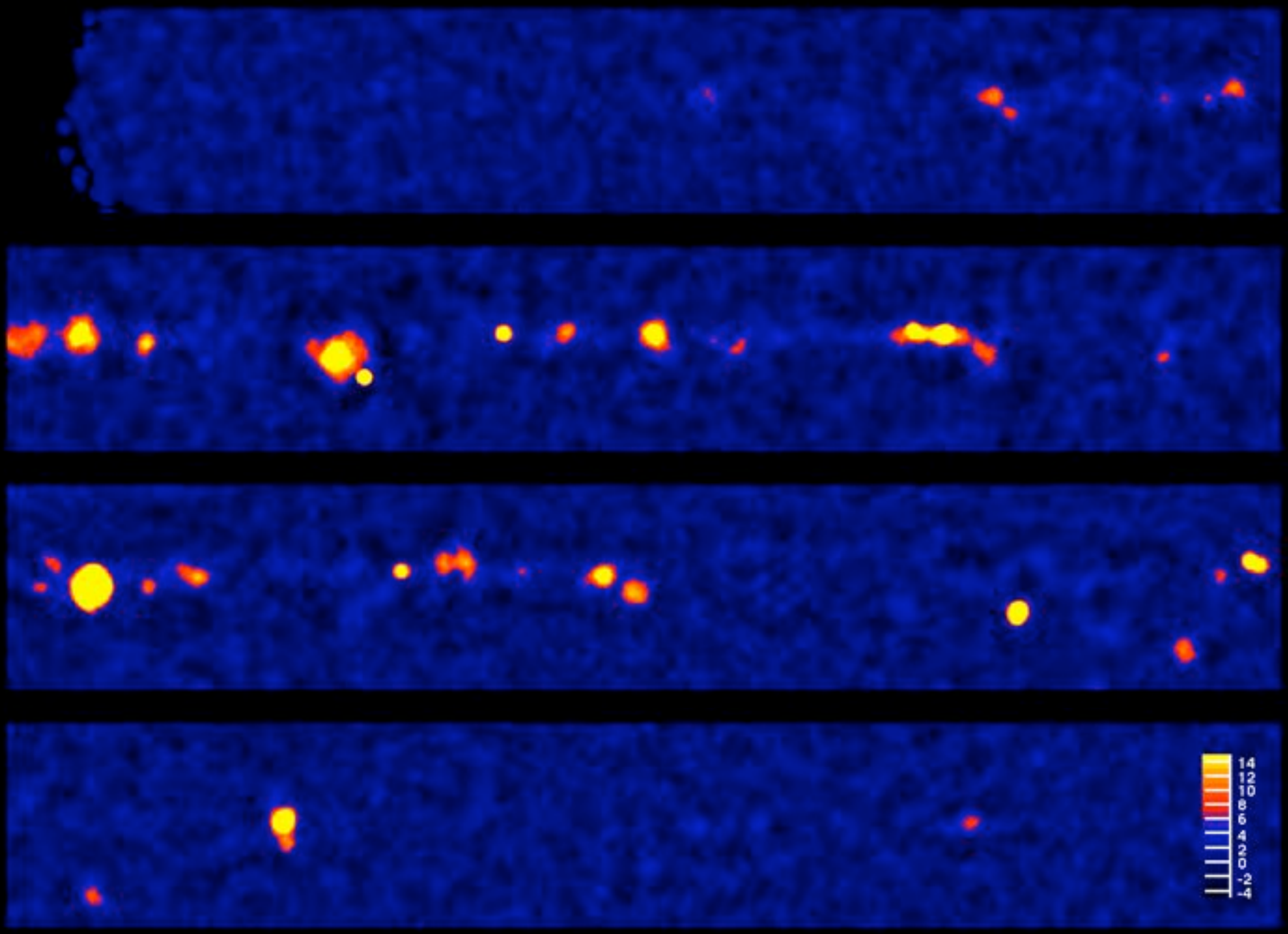
# VHE Astronomy in the recent past...

- Only a handful of sources
- No extended sources, morphological studies
- Focused on AGN Science


optical



The Galaxy is full of VHE Gamma-ray Sources!


14
12
10
8
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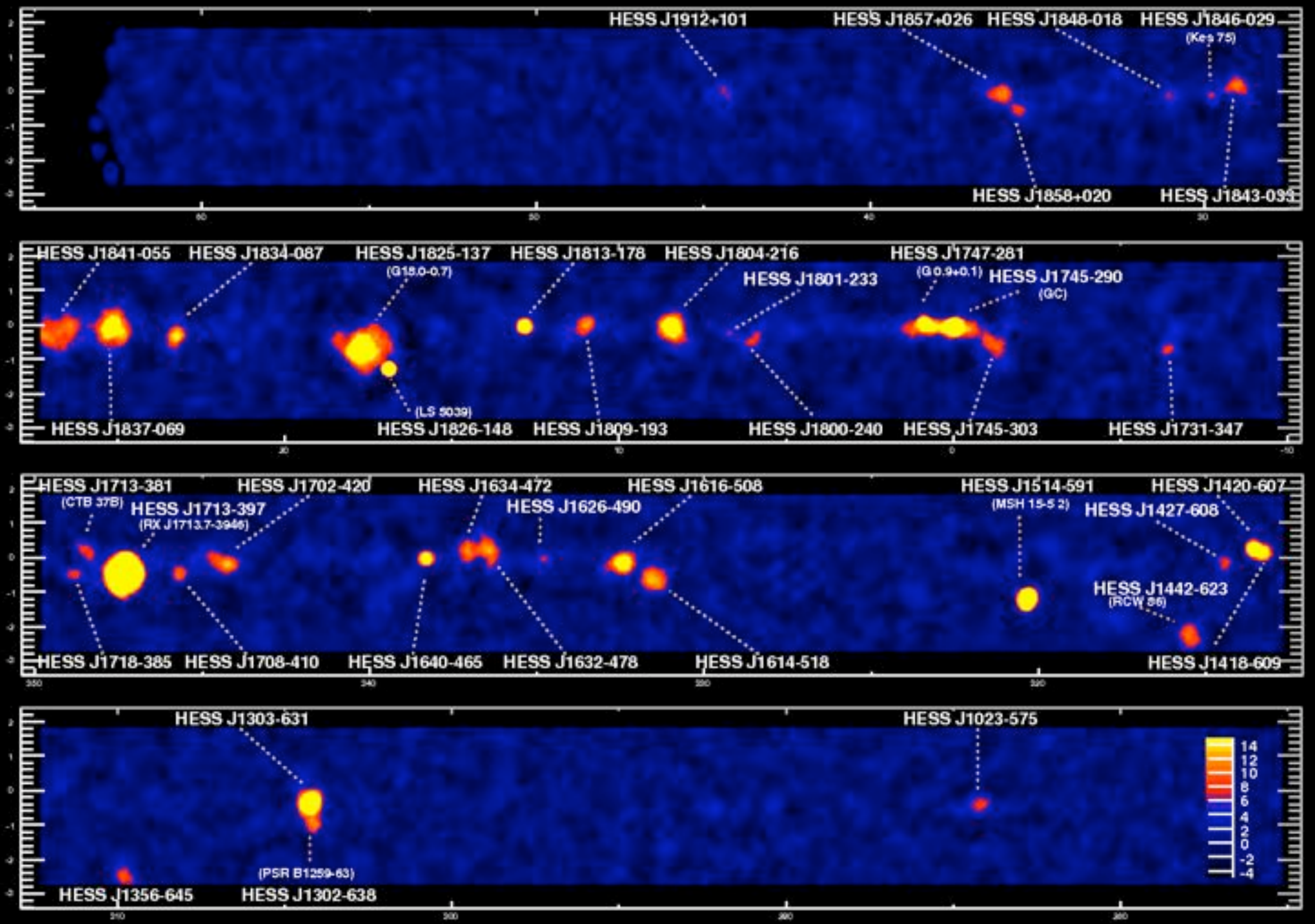
-2
-4


HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G0.9+0.1)
HESS J1745-290
(GC)
(LS 5039)
HESS J1837-069
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-347
HESS J1713-381
(CTB 37B)
HESS J1702-420
HESS J1634-472
HESS J1616-508
HESS J1514-591
(MSH 15-52)
HESS J1420-607
HESS J1713-397
(RX J1713.7-3946)
HESS J1626-490
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1303-631
HESS J1023-575
(PSR B1259-63)
HESS J1356-645
HESS J1302-638
14
12
10
8
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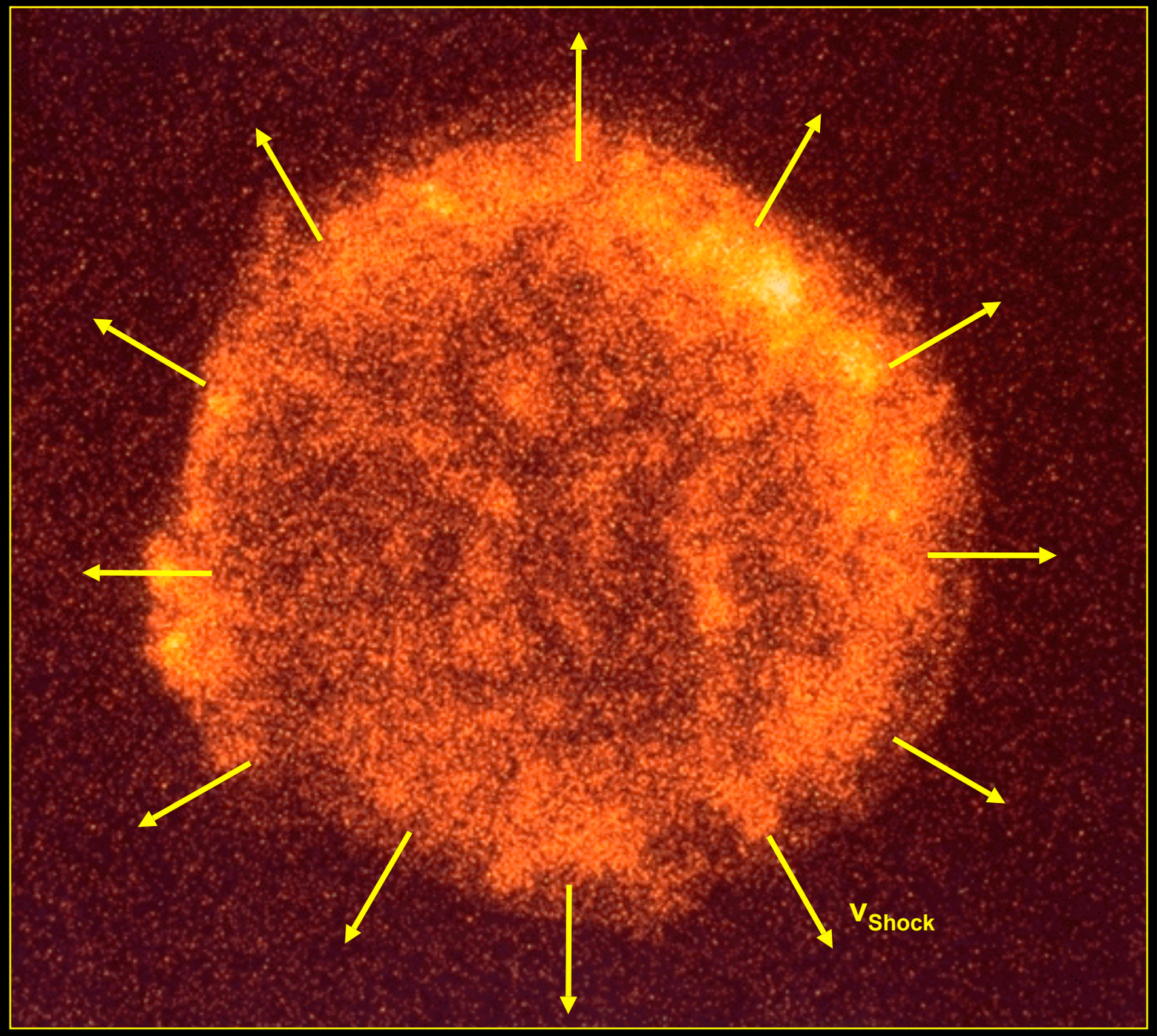
2
0
-2
-4

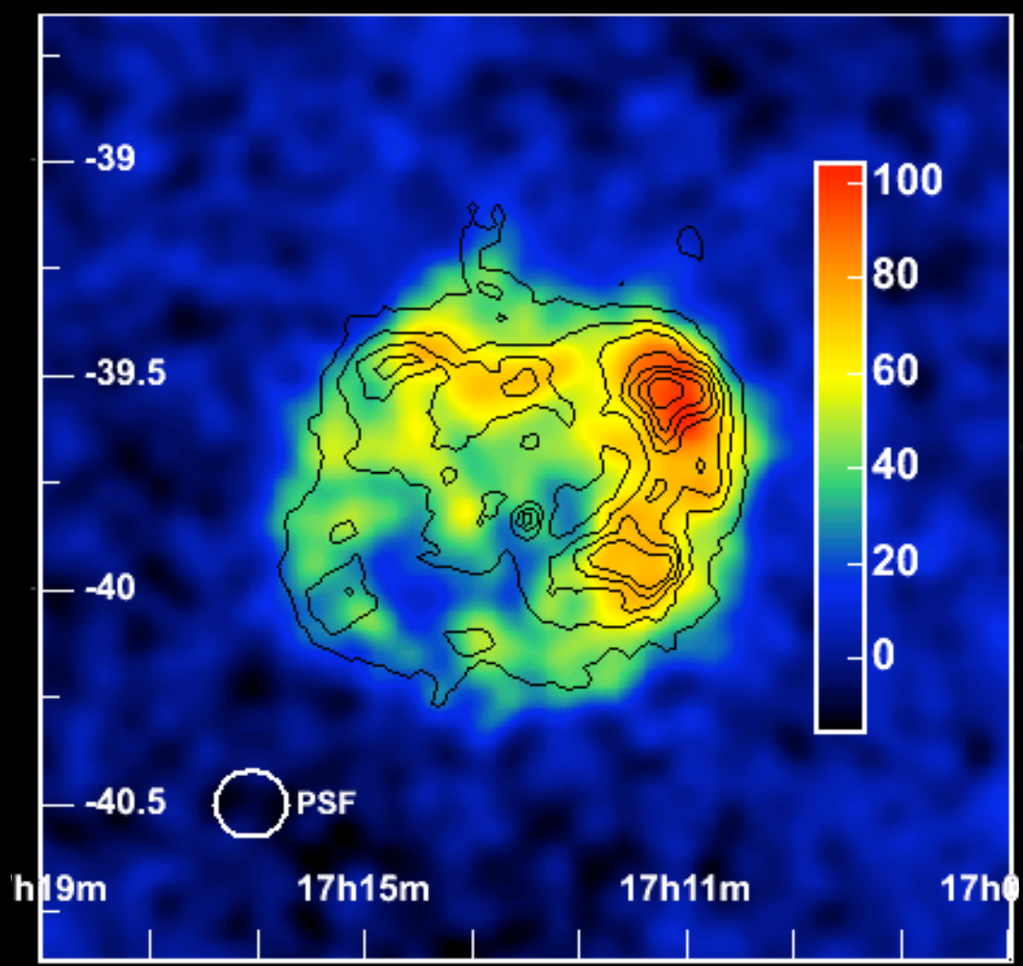
# Galactic Sources

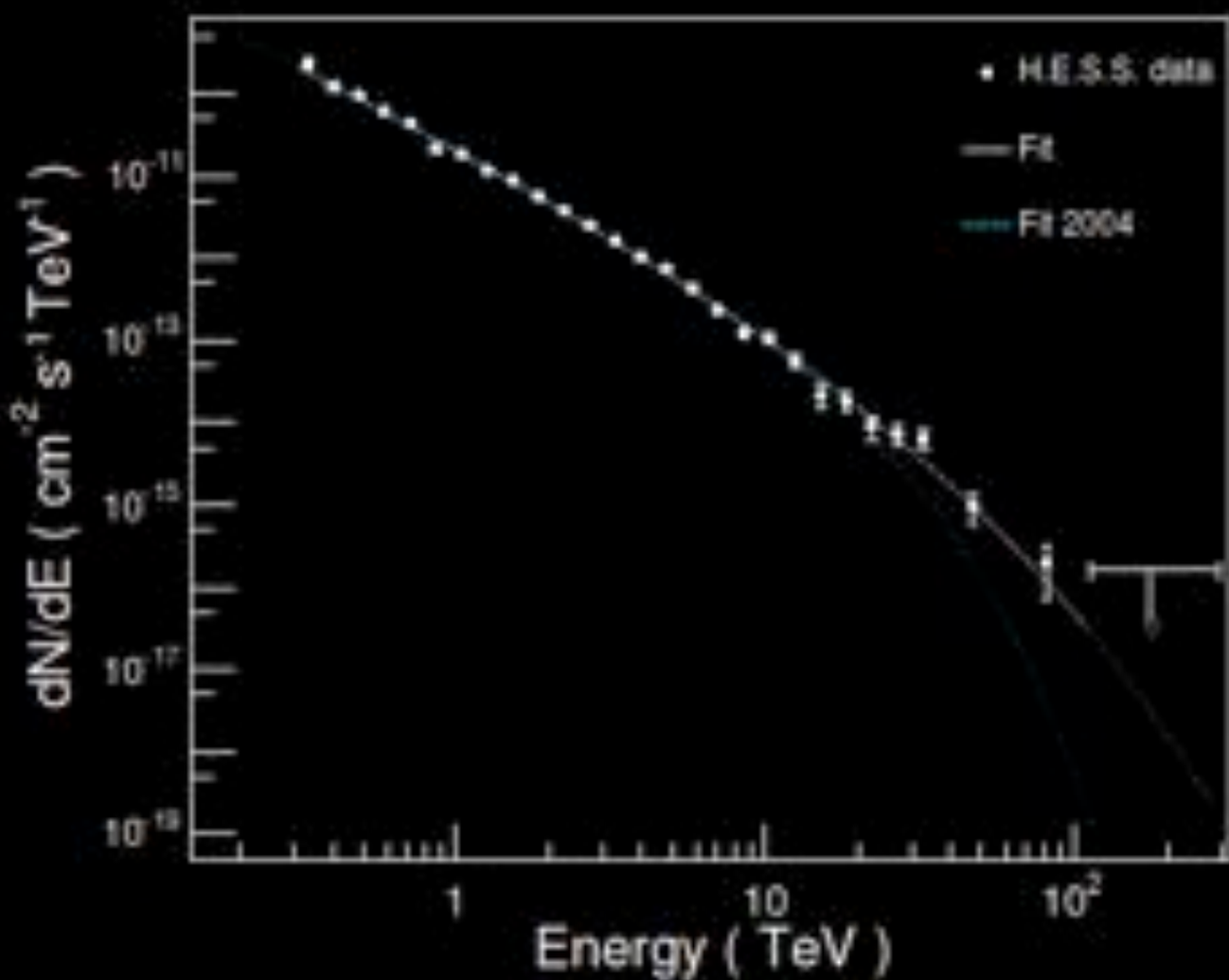
- Shell-type Supernova Remnants
- Pulsar Wind Nebulae
- Microquasars
- The Galactic Center
- Diffuse Emission
- Unidentified sources
- Molecular Cloud associations

# Supernova Remnants



# Supernova Remnants



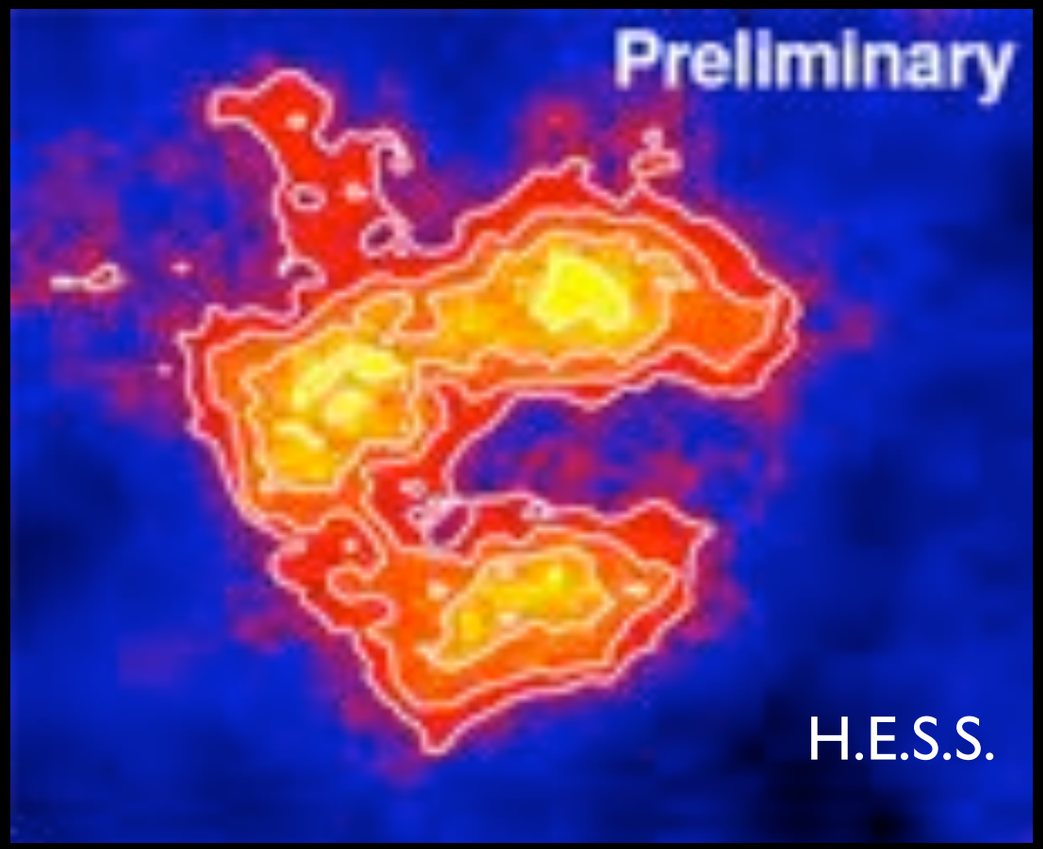



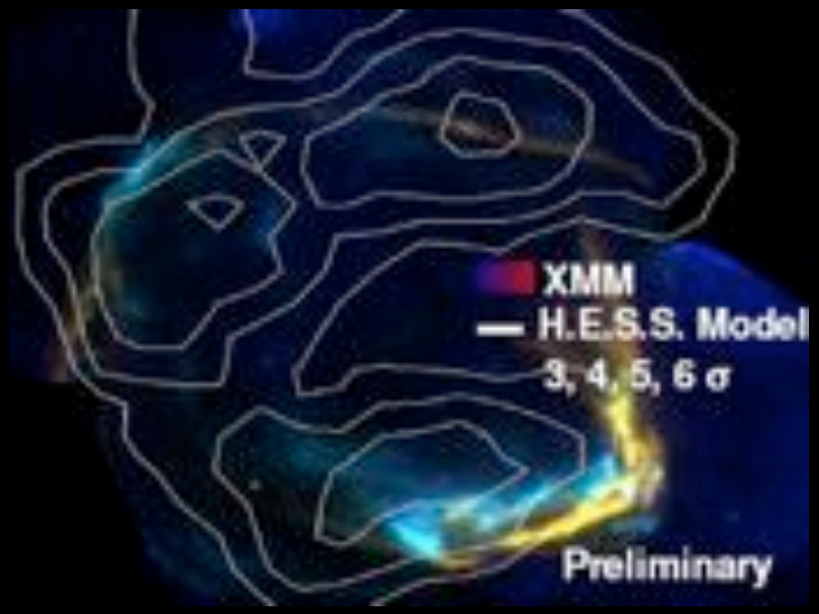

RX J1713

**Aharonian et al., 2004, *Nature*, 432, 75**

First resolved extended TeV source!
Correspondance with X-Ray morphology: implies gamma/X-ray production mechanism linked

# RCW 86: New VHE Shell?

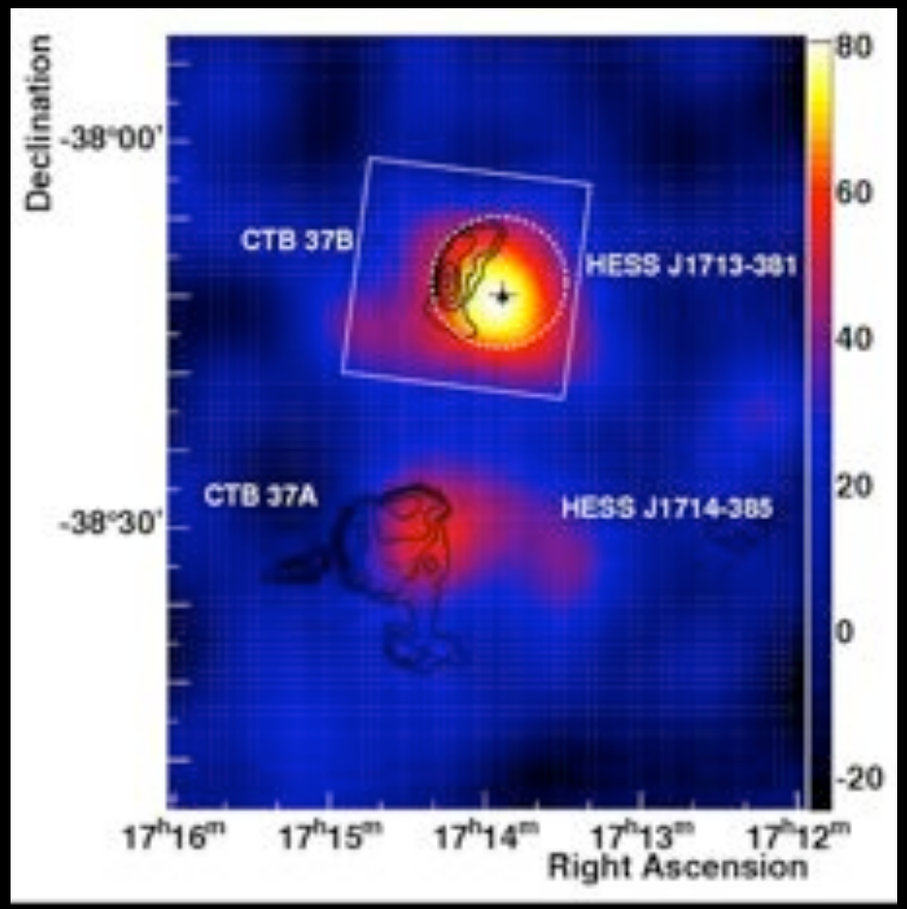



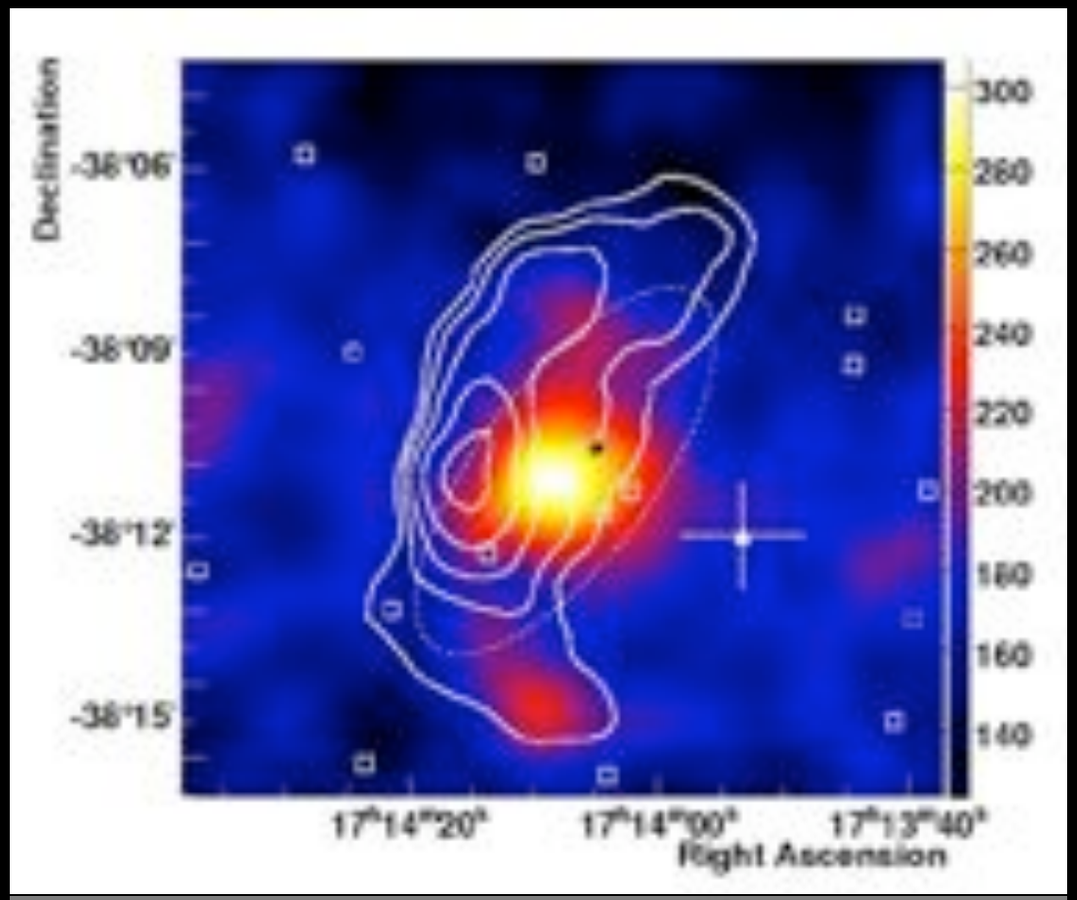




Accepted for publication, A&A

# CTB 37B

- Chandra + HESS
- VHE + Non-thermal X-Ray discovery

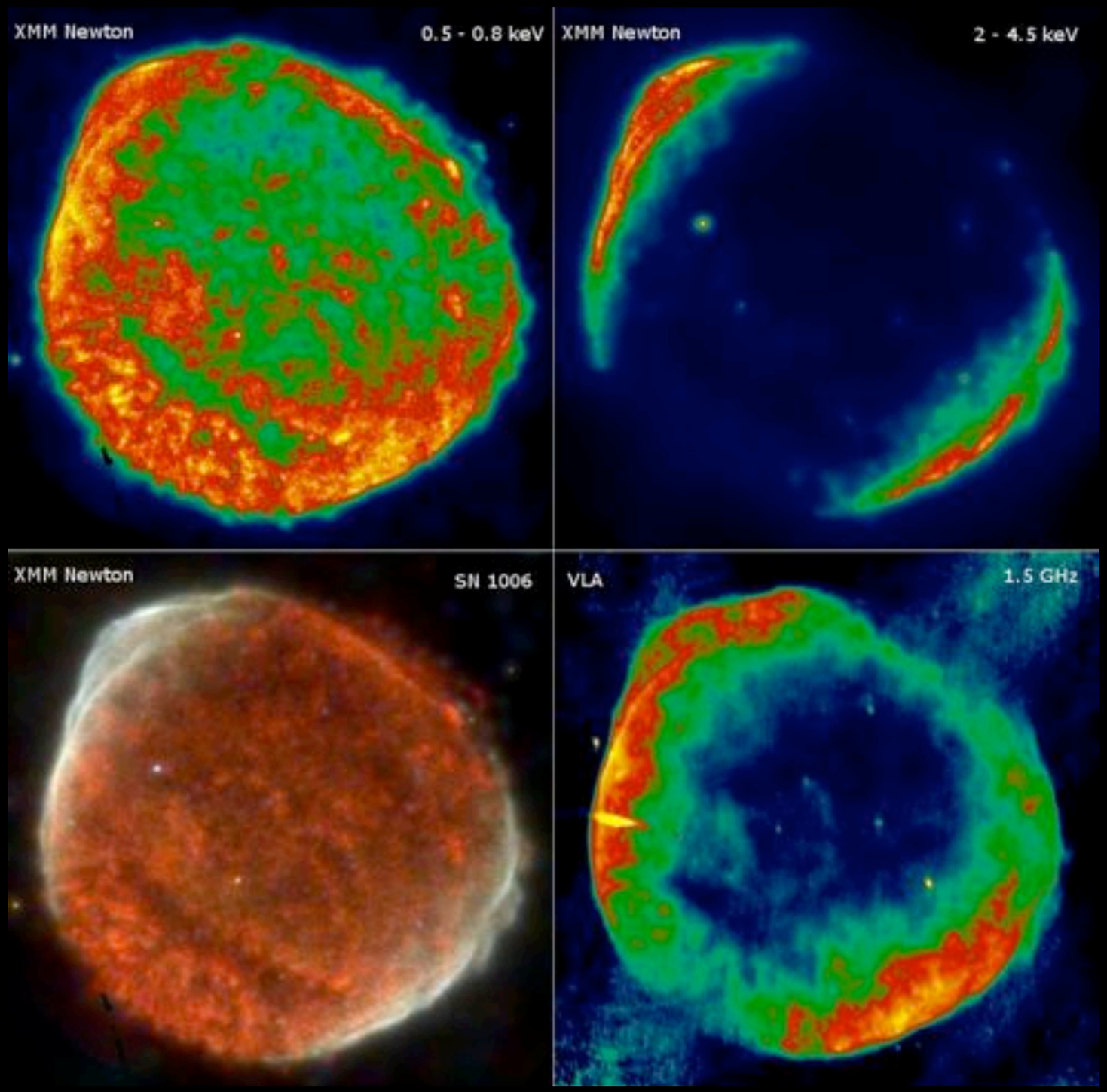



•Accepted A&A (May 2008)

# Breaking News: SN 1006

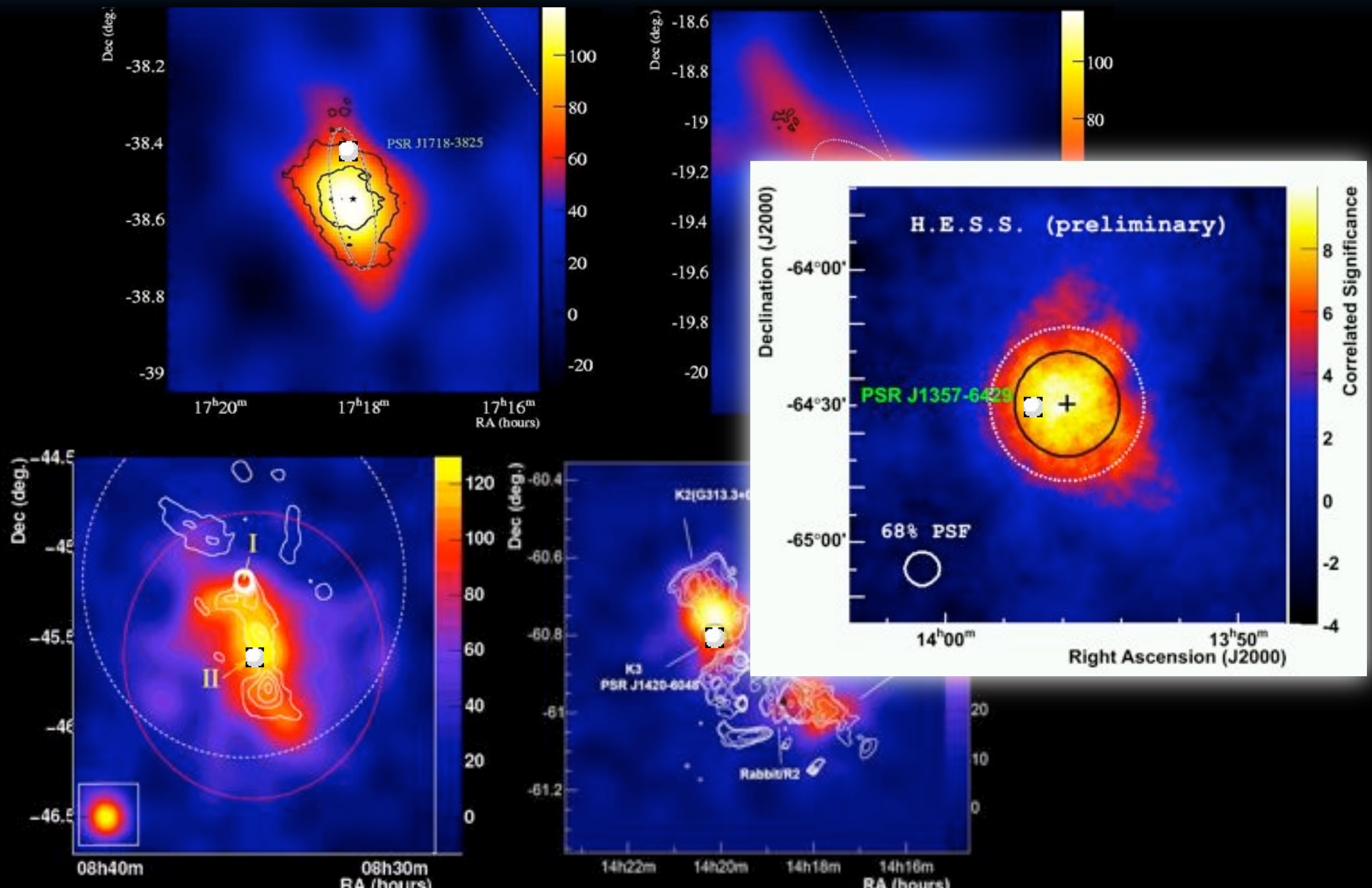
- "New" VHE SNR?



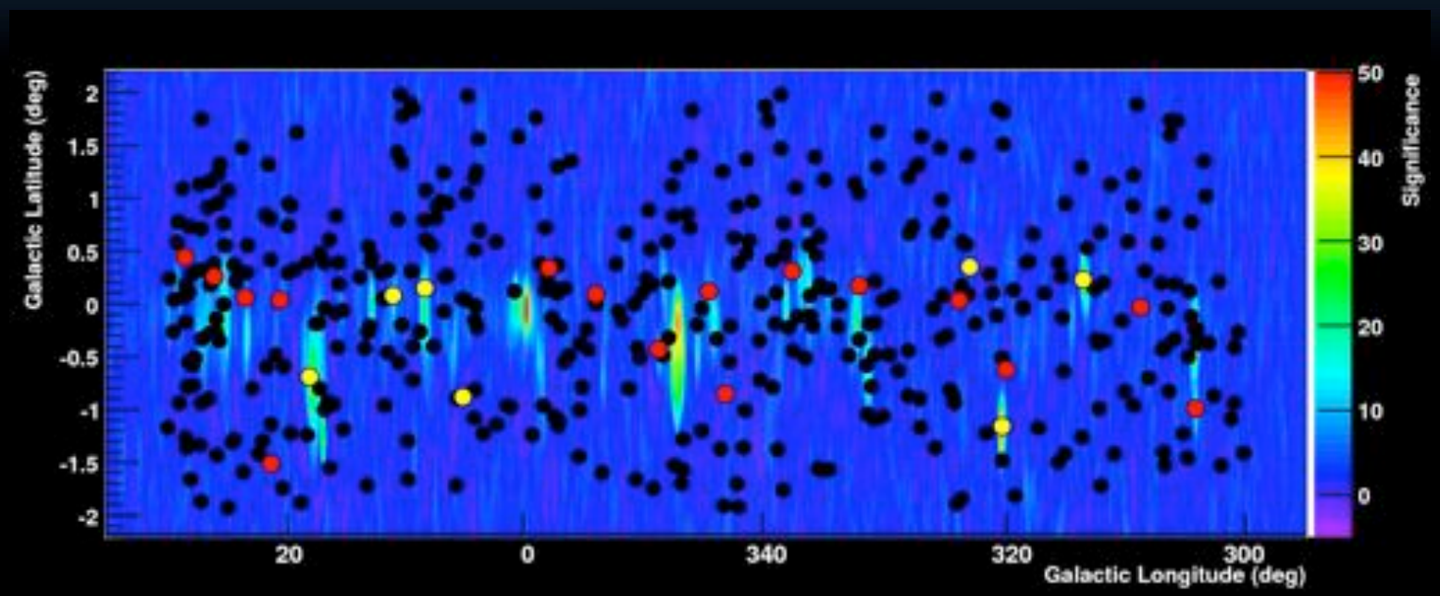
# SN 1006 HESS/Chandra

- Smooth (degrade) Chandra image to the HESS PSF
- Compare with HESS excess map

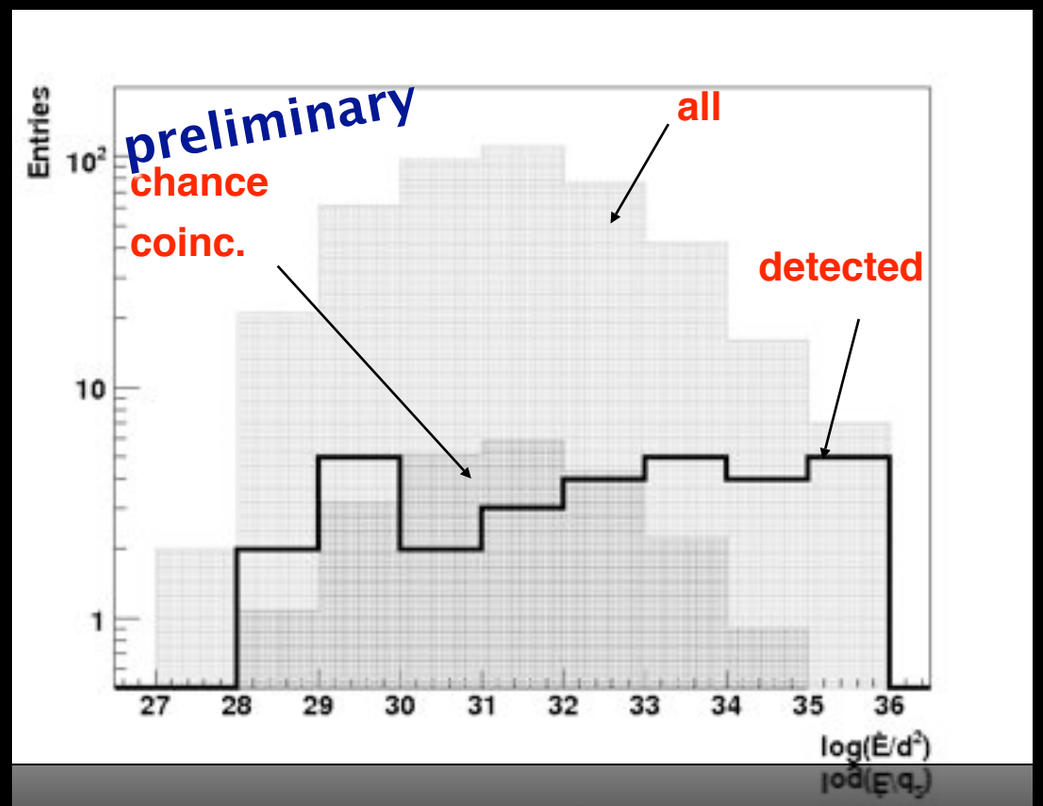
# Pulsar Wind Nebulae

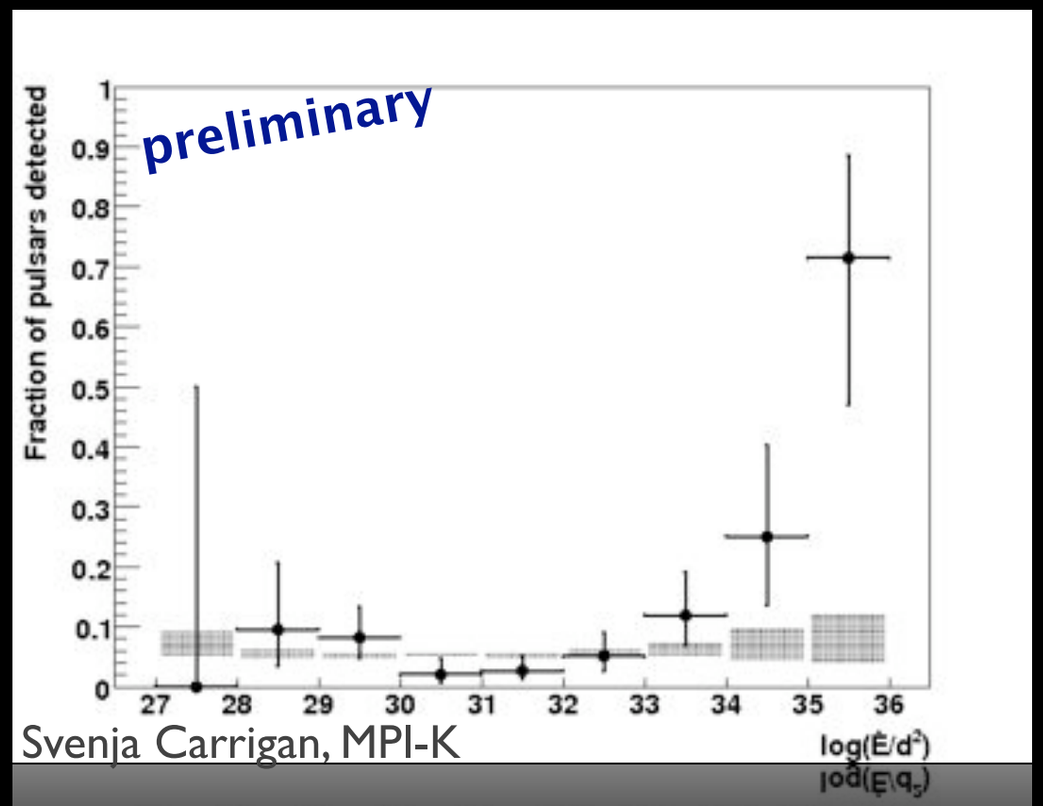


# Population Studies?



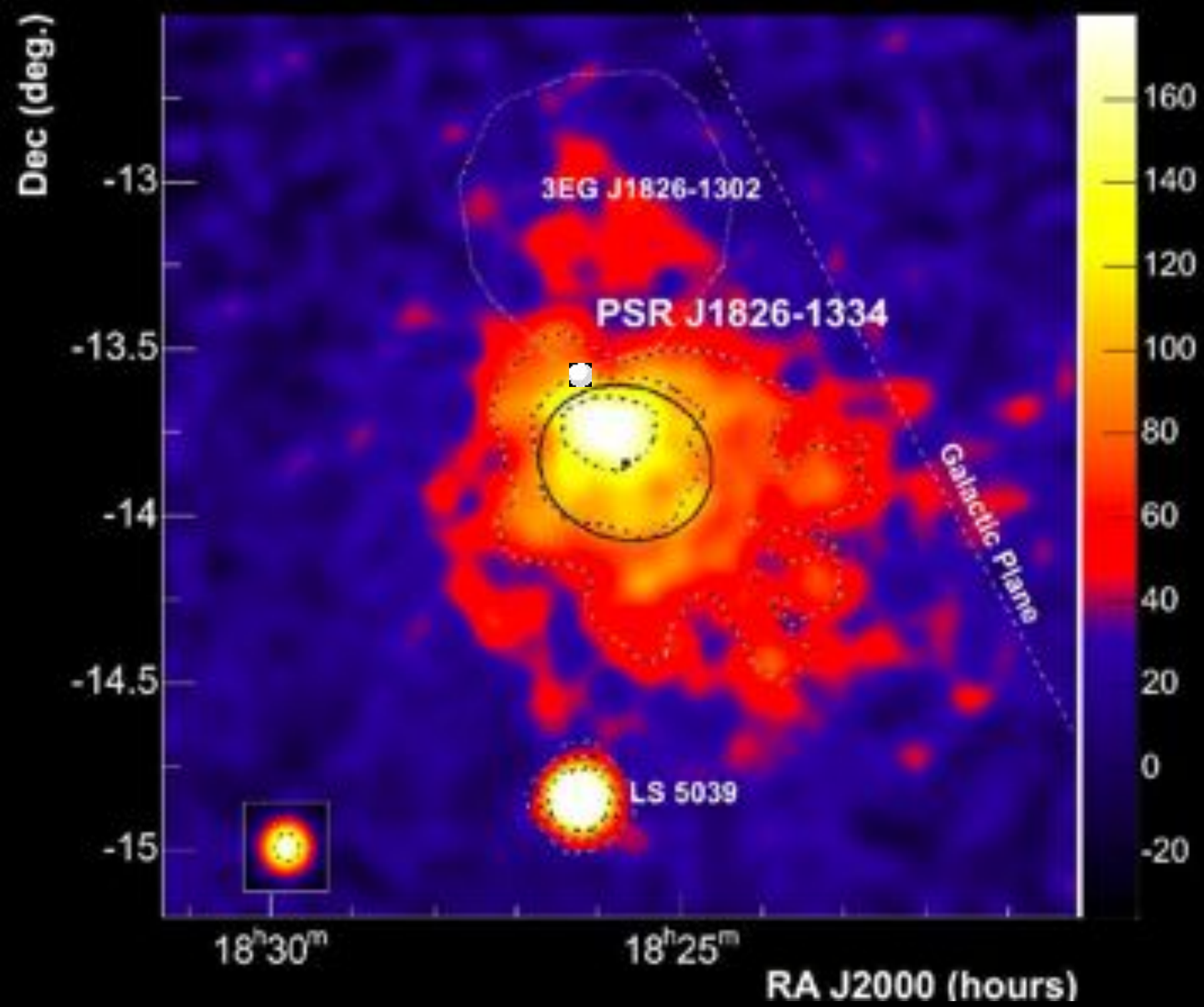

- correlate HESS scan with PSRs from Parkes survey
  - ★ can start to predict which PSRs will produce VHE PWNe!

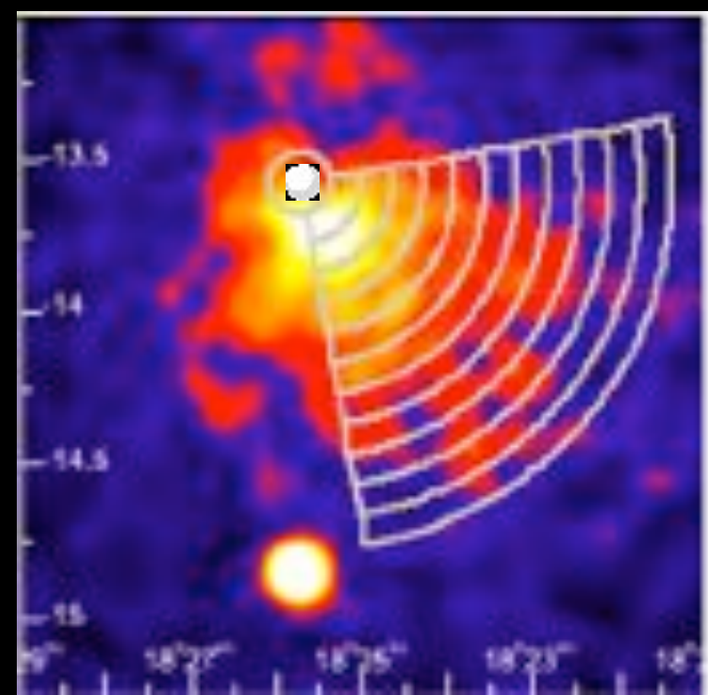


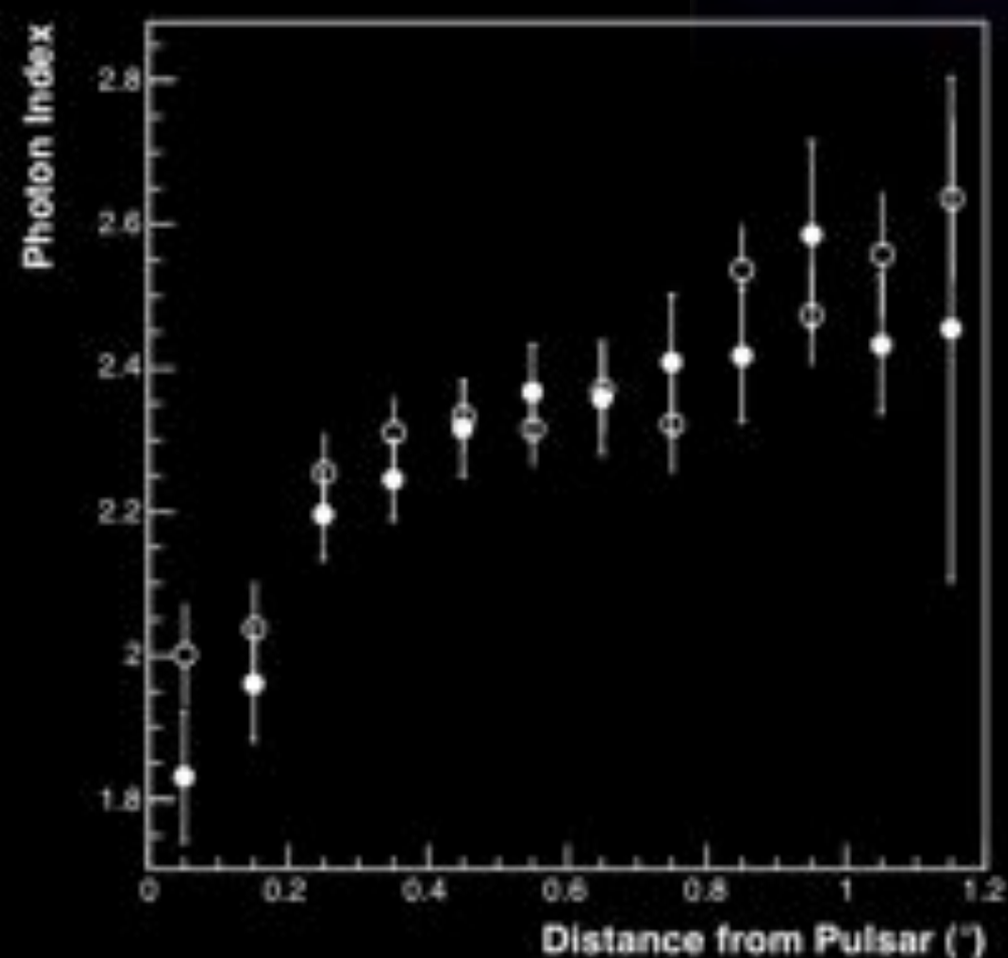



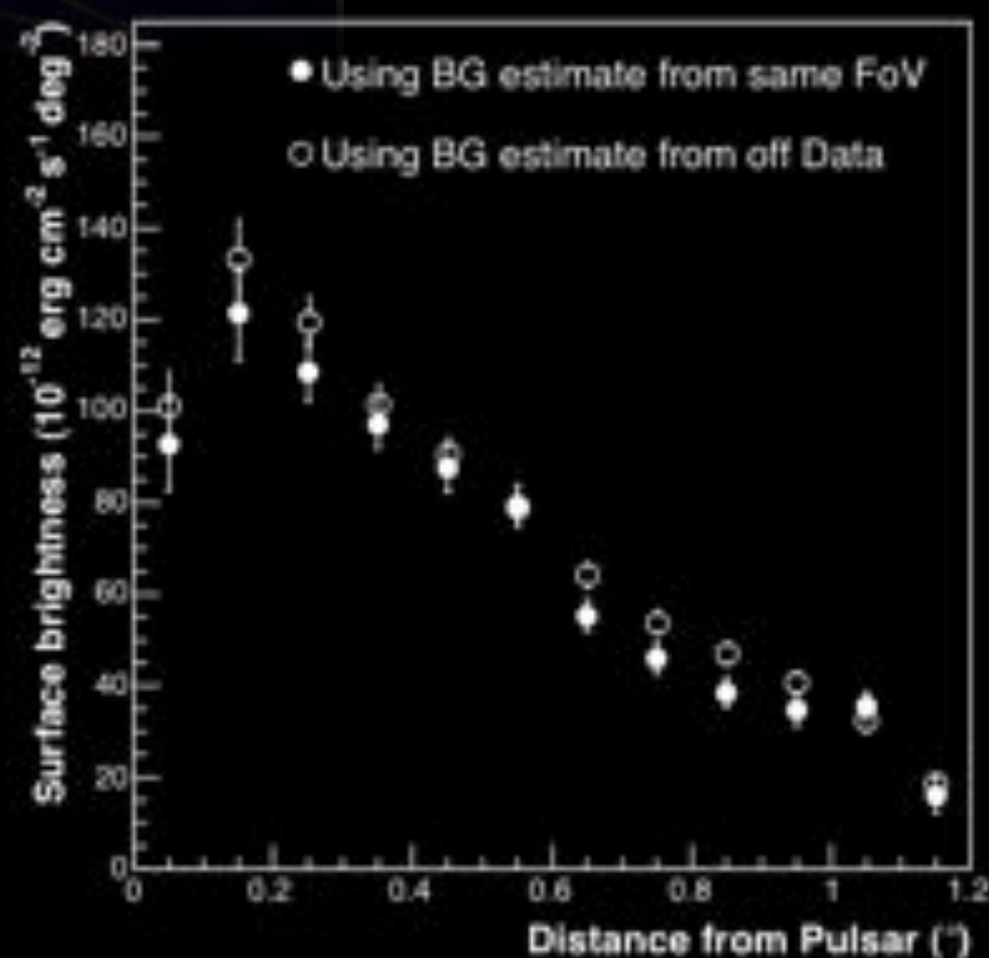

Svenja Carrigan, MPI-K

# HESS J1825

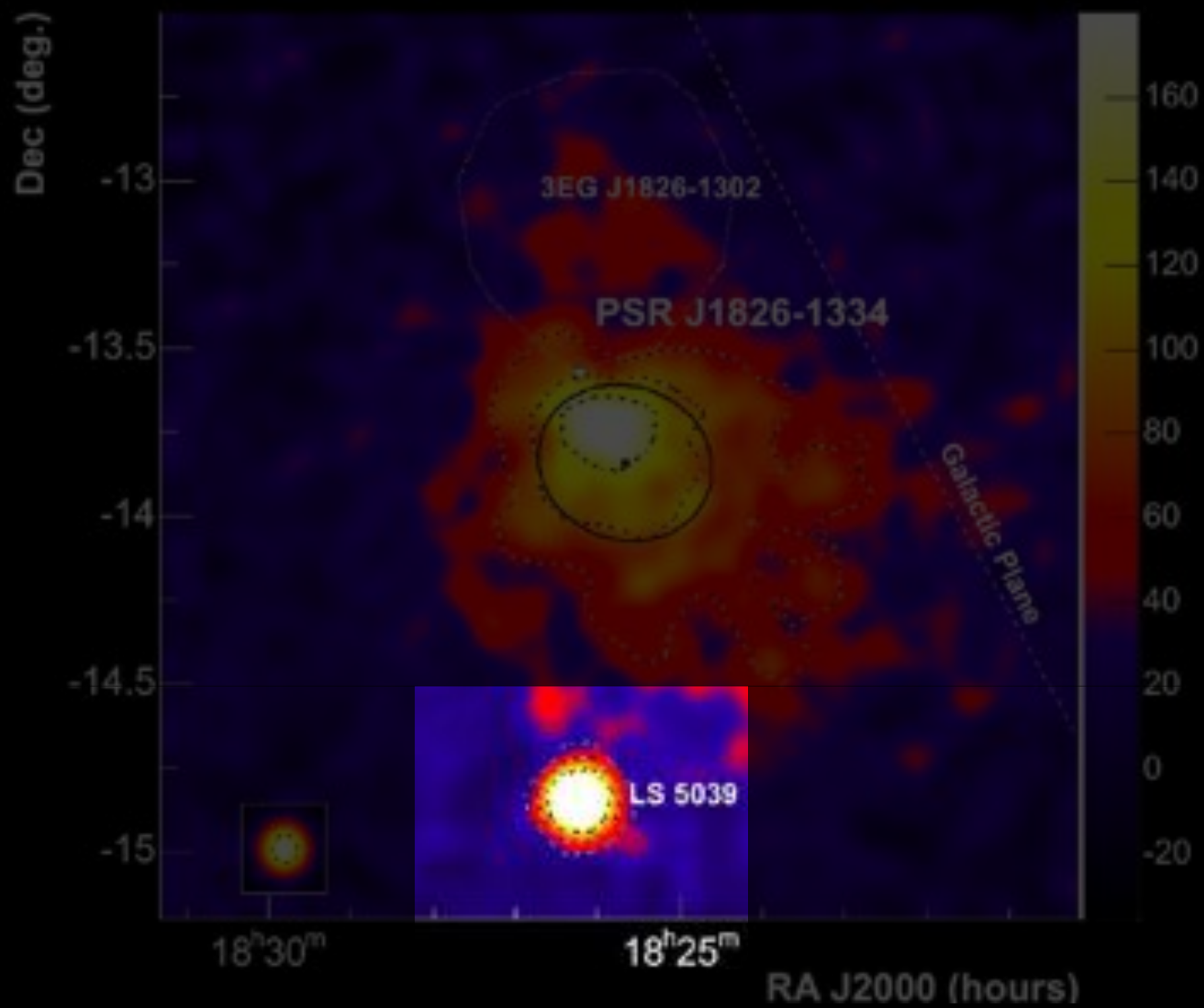

Dec (deg.)
-13
-13.5
-14
-14.5
-15
3EG J1826-1302
PSR J1826-1334
Galactic Plane
LS 5039
160
140
120
100
80
60
40
20
0
-20
18h30m
18h25m
RA J2000 (hours)



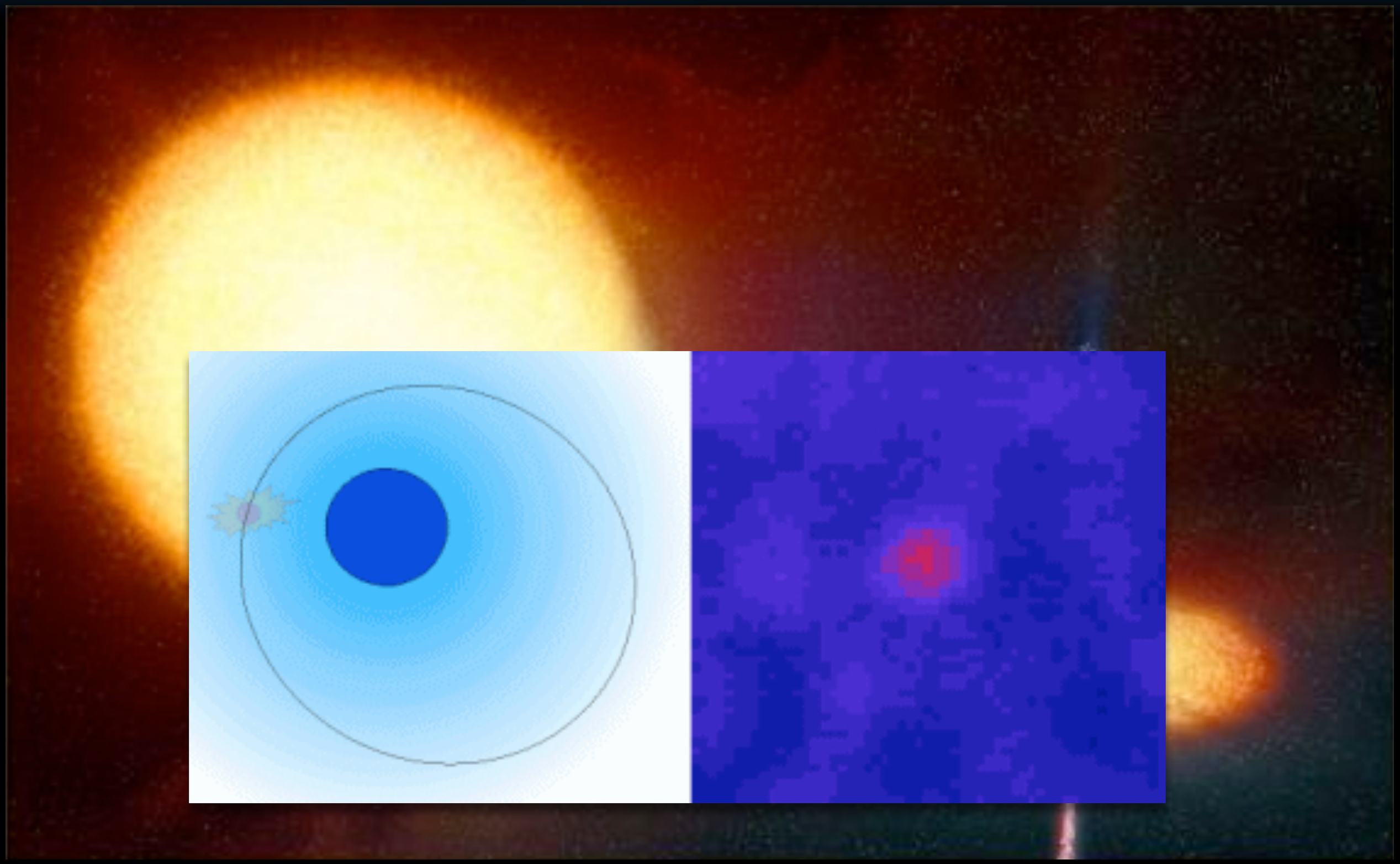

Photon Index
Distance from Pulsar (°)


Using BG estimate from same FoV
Using BG estimate from off Data
Surface brightness ($10^{-12}$ erg cm$^{-2}$ s$^{-1}$ deg$^{-2}$)
Distance from Pulsar (°)

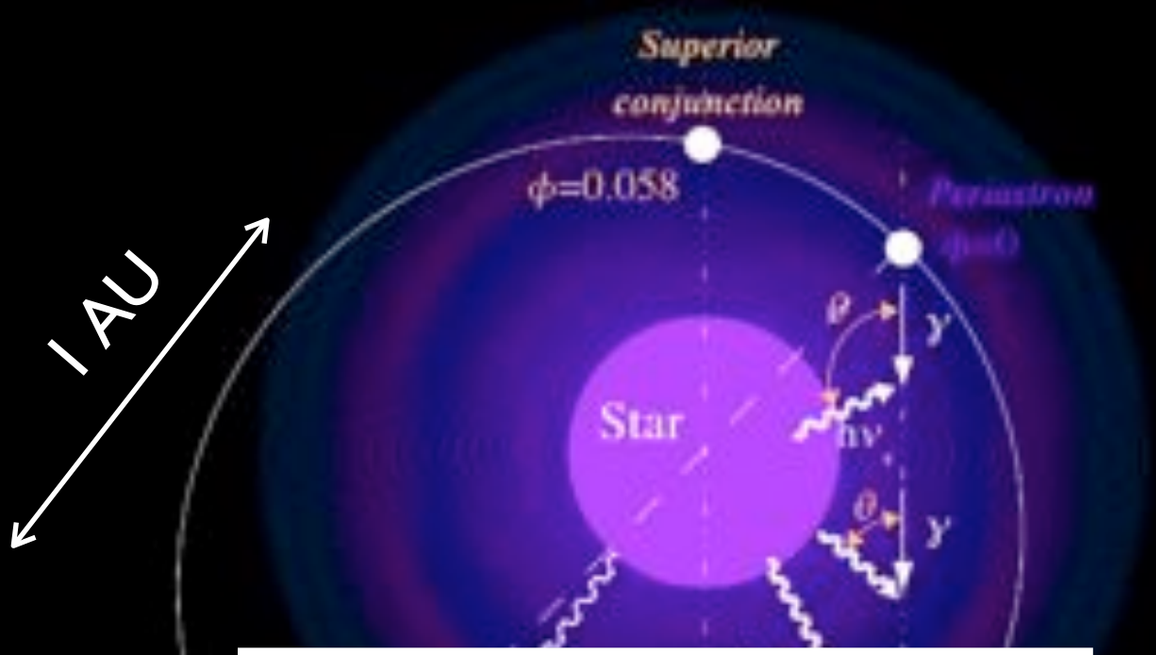
# HESS J1825


Dec (deg.)
-13
-13.5
-14
-14.5
-15
3EG J1826-1302
PSR J1826-1334
Galactic Plane
LS 5039
160
140
120
100
80
60
40
20
0
-20
18h30m
18h25m
RA J2000 (hours)

# Microquasar LS 5039

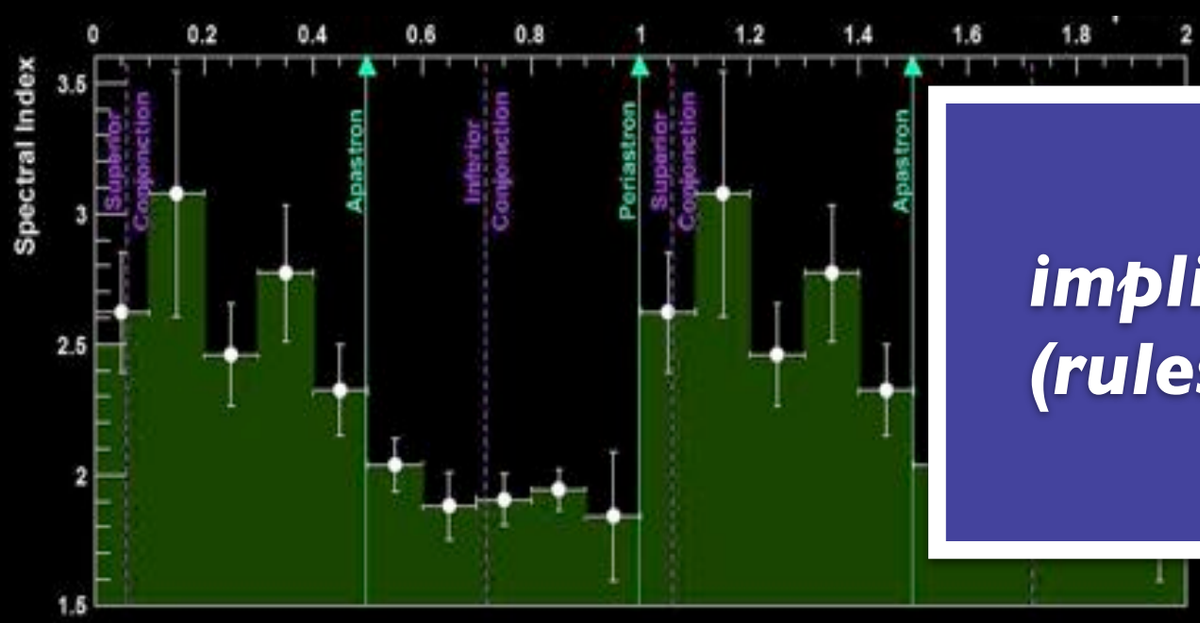


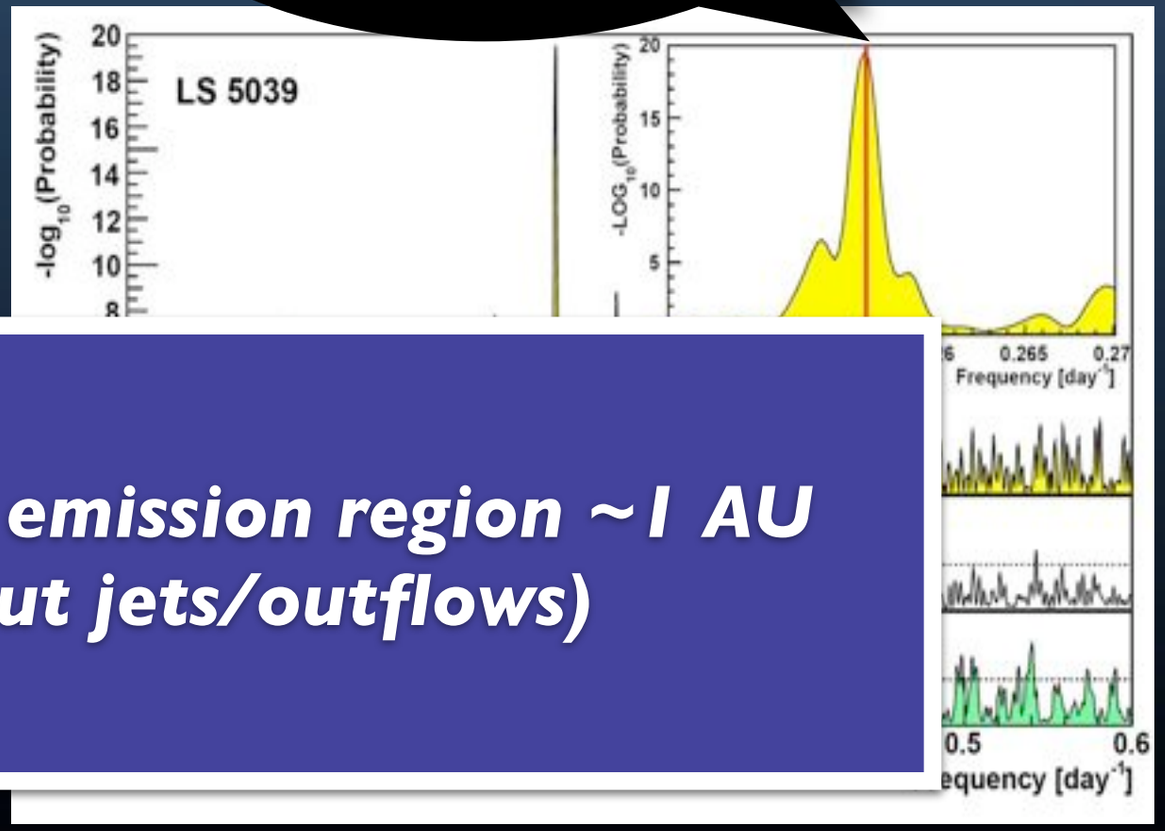
# LS 5039 Periodicity




***Period***:
HESS: 3.908(2) d
Optical: 3.9060 d

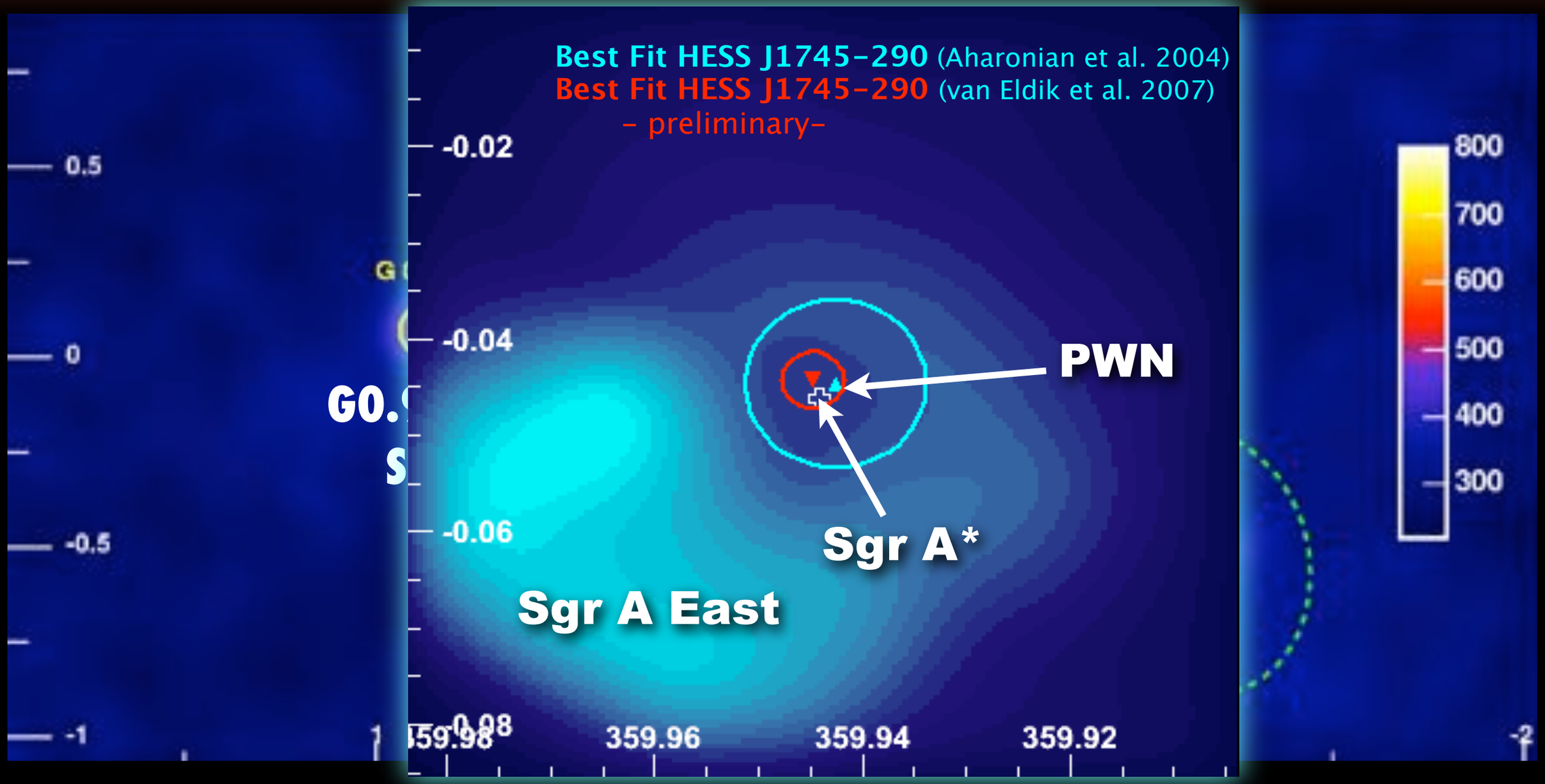
Chance probability: $<10^{-15}$ (incl trials)



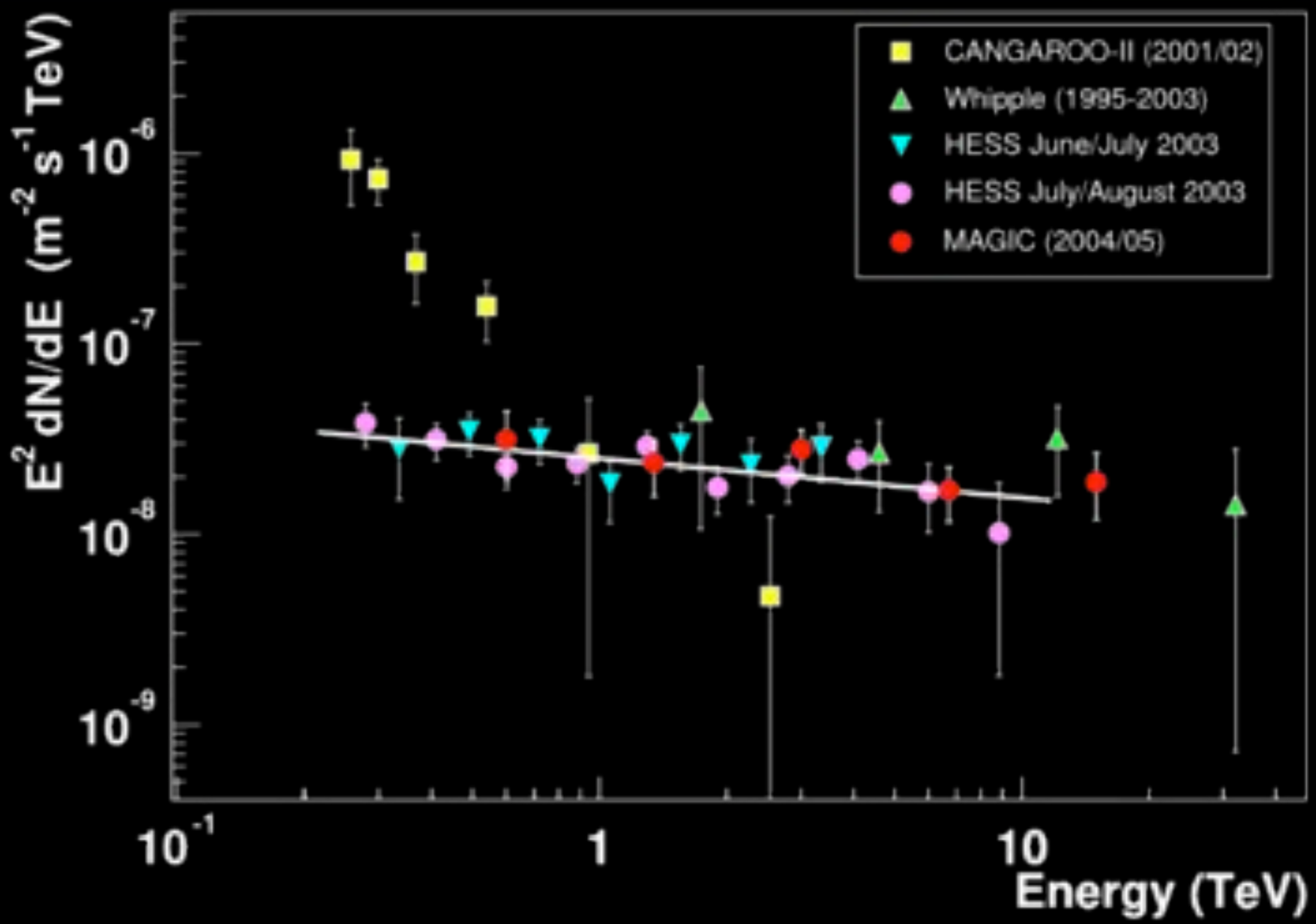

***implies emission region ~1 AU (rules out jets/outflows)***

# The Galactic Center



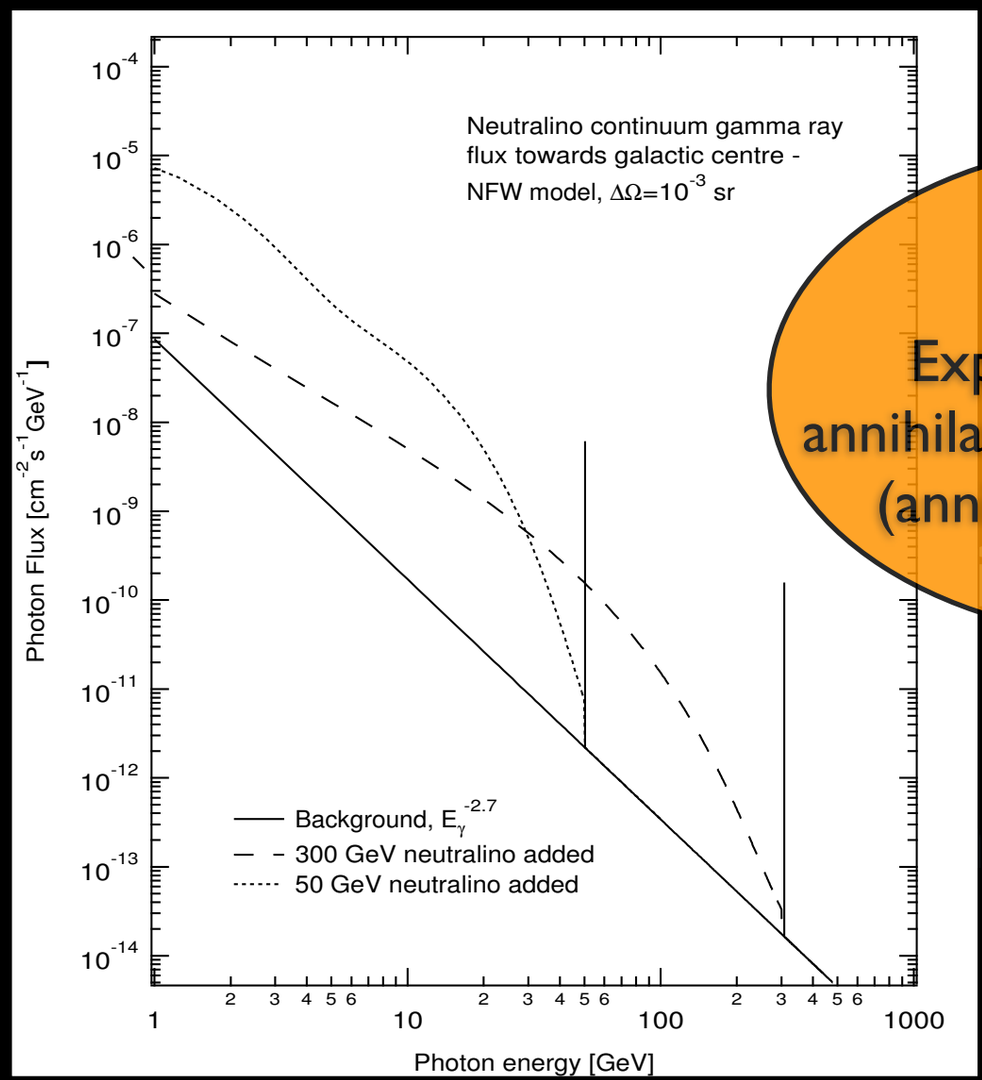

- Coincident with Sgr A* (supermassive Black Hole)?

# GC Spectrum 2003



# Dark Matter?

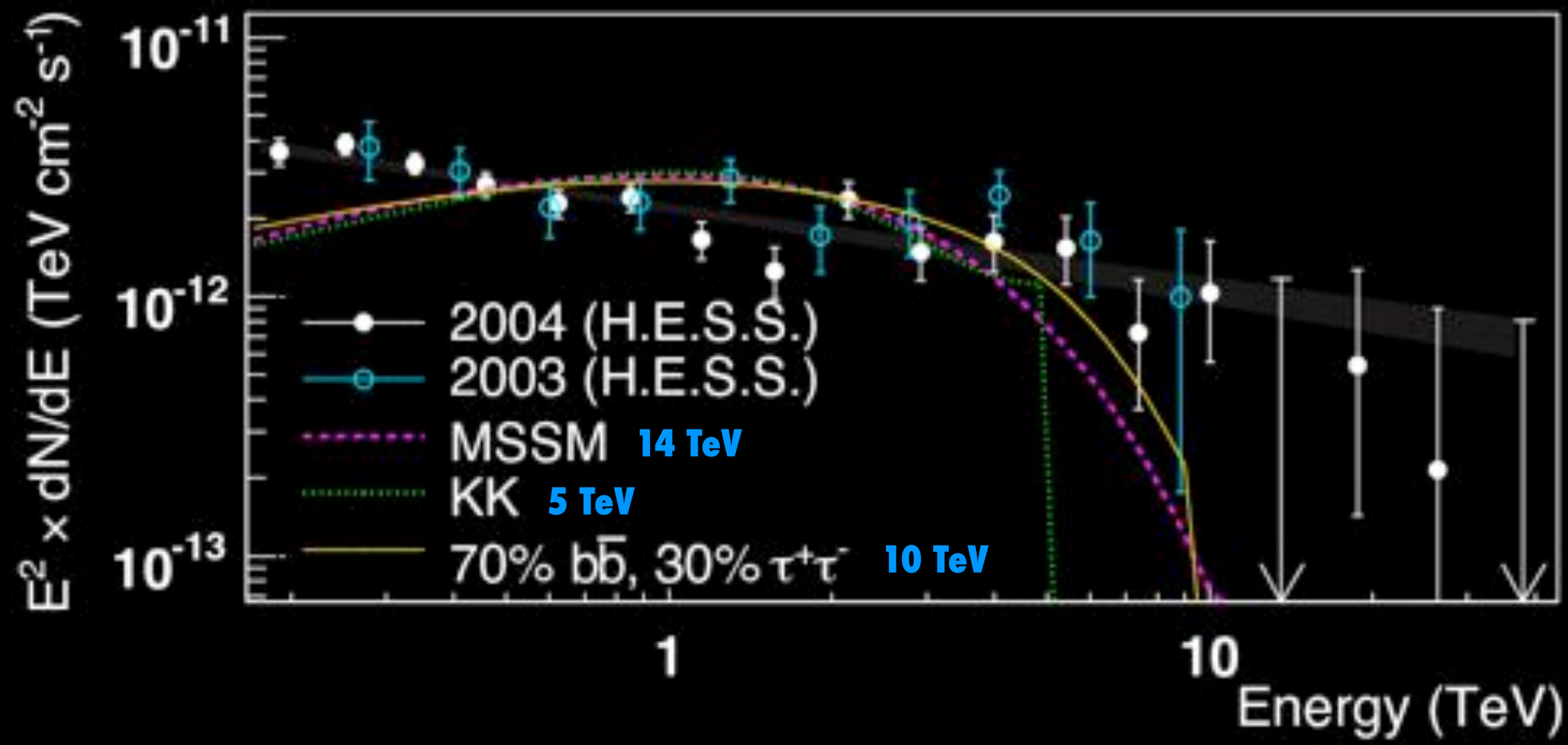
- **WIMPs**




Signature:

Expect a **line** (direct annihilation) + **continuum** (annihilation to quarks)

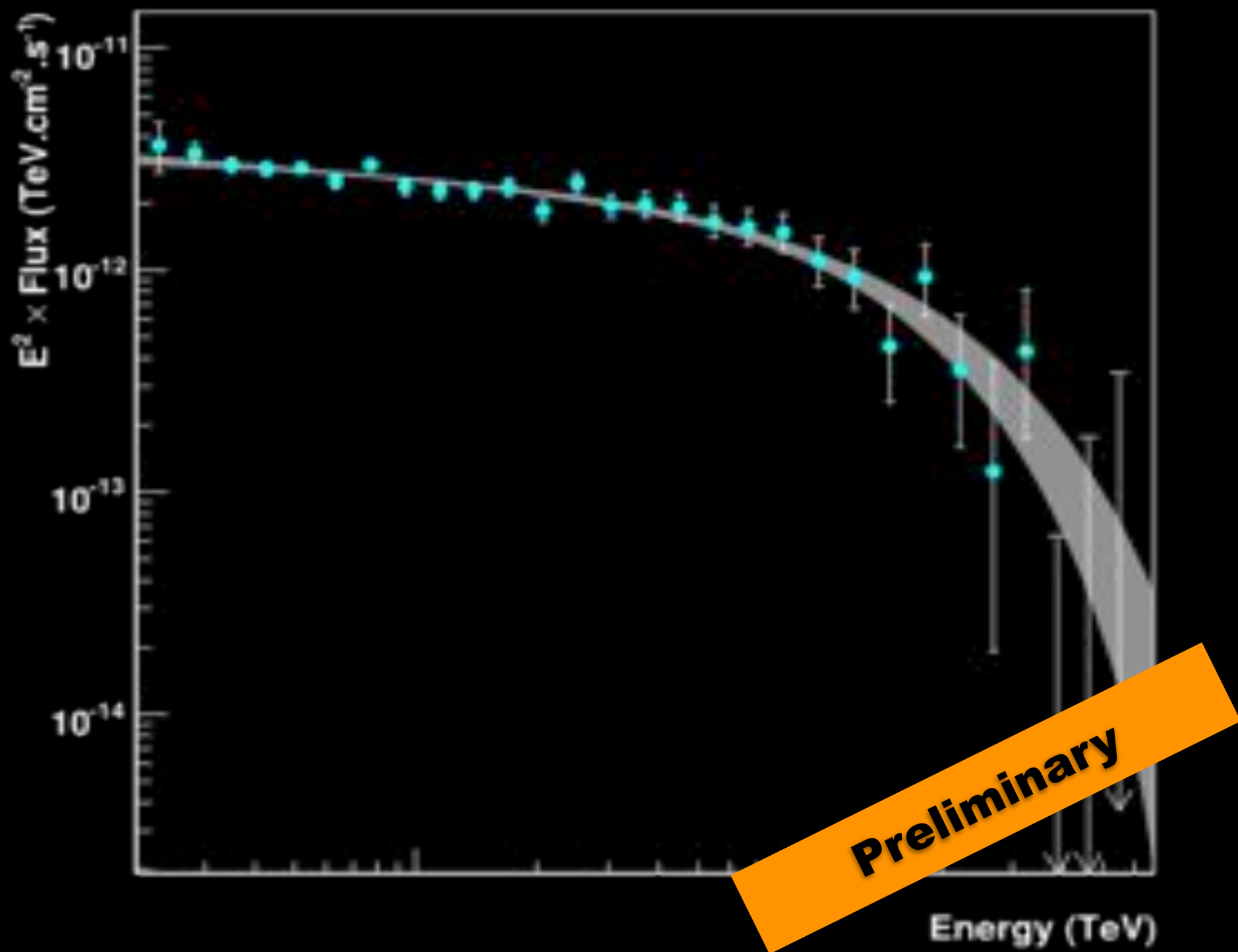
- **Candidate: Neutralino**
  - Stable, Mass in the GeV - 10s of TeV range
  - Would produce gamma-rays via annihilation
    - ★ Intensity $\propto \rho^2$
- **If...**
  - Density profile in galaxy has a *cusp* at GC, could be detected!




search also made for dark matter signal + power-law external signal

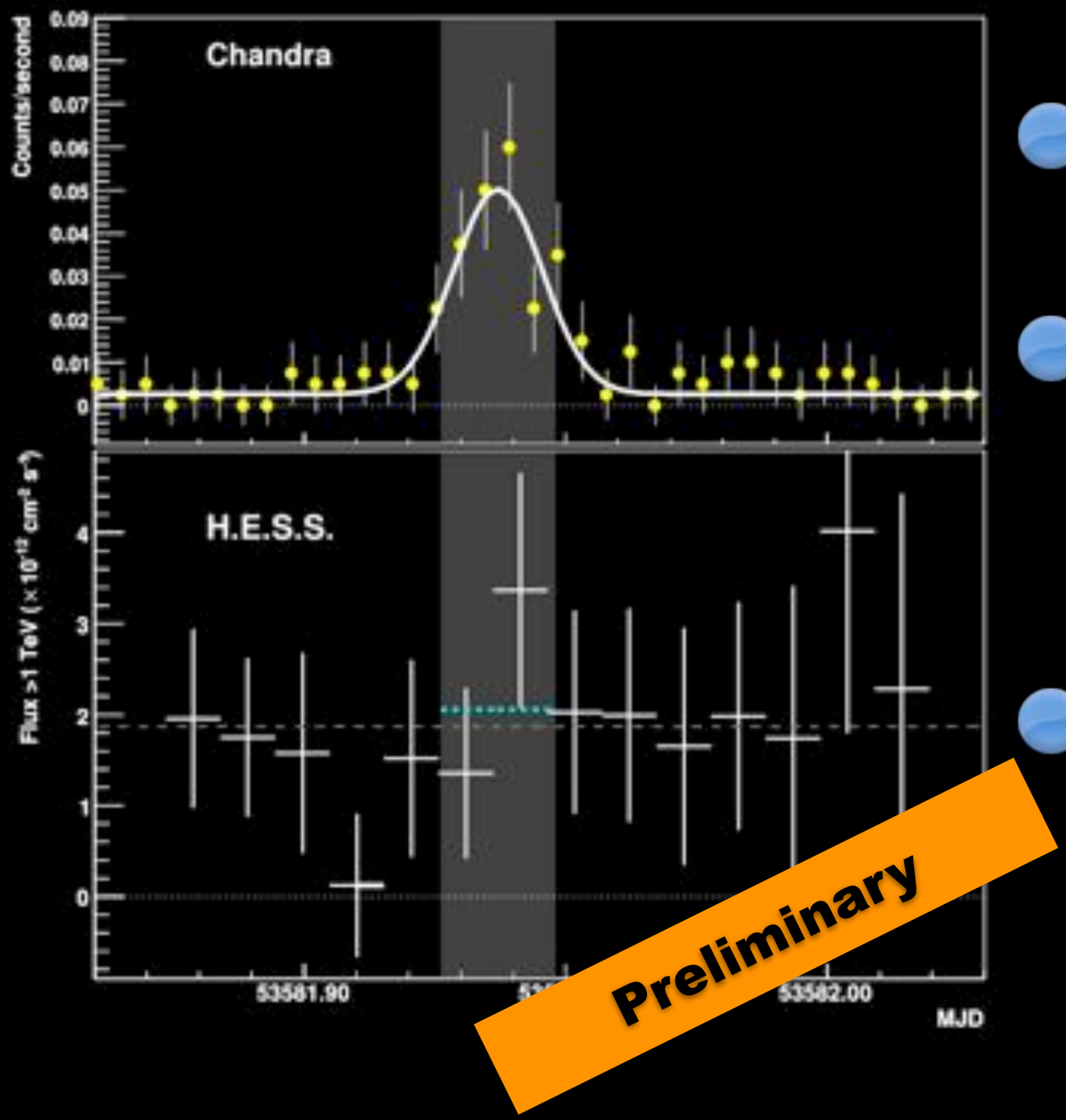
- no signal detected (upper-limit at 10% source flux)

**Phys. Rev. Lett. 97 (2006) 221102**



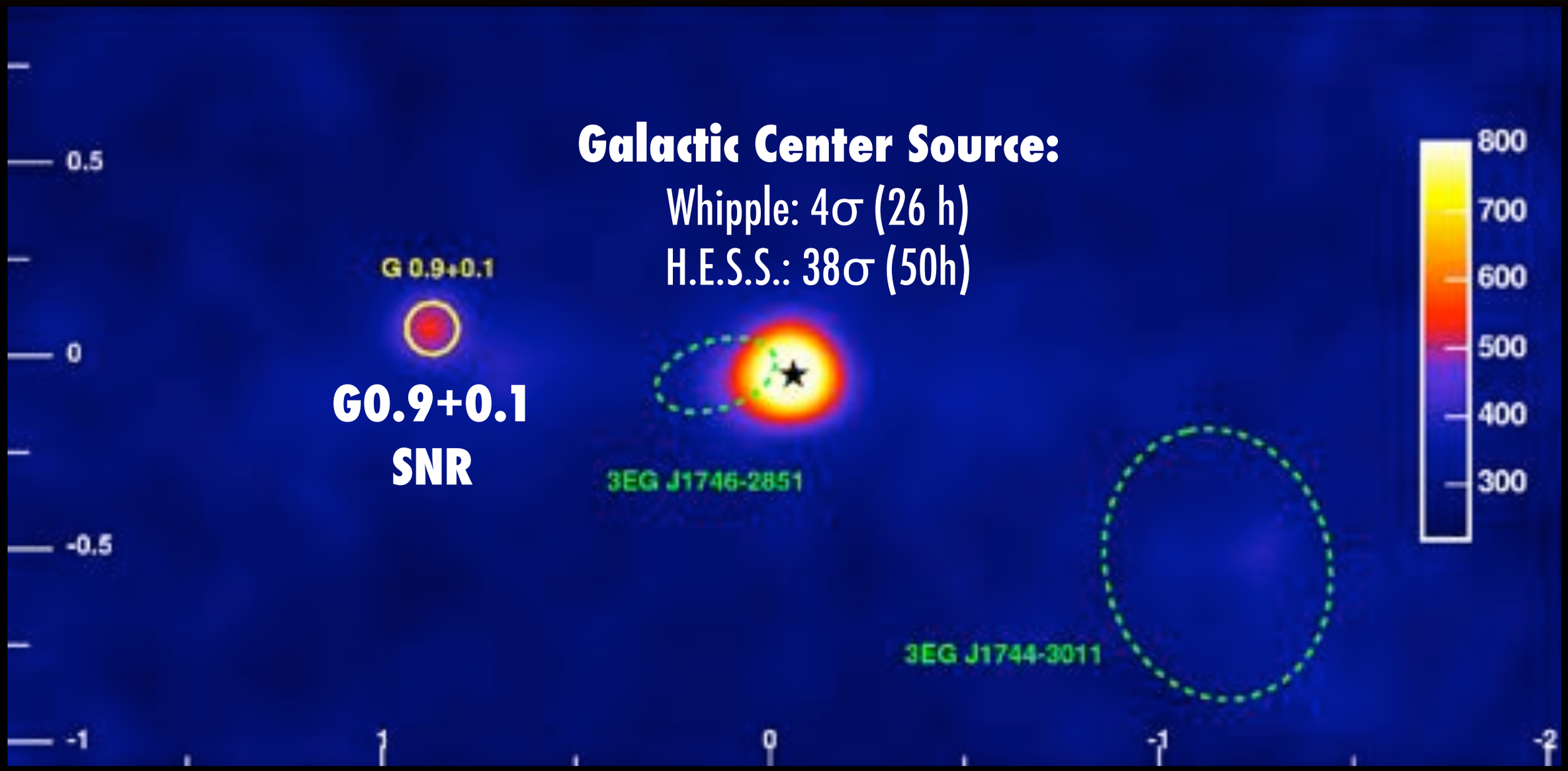

Courtesy the H.E.S.S. Collaboration
Aharonian et al., in preparation

# GC Variability?

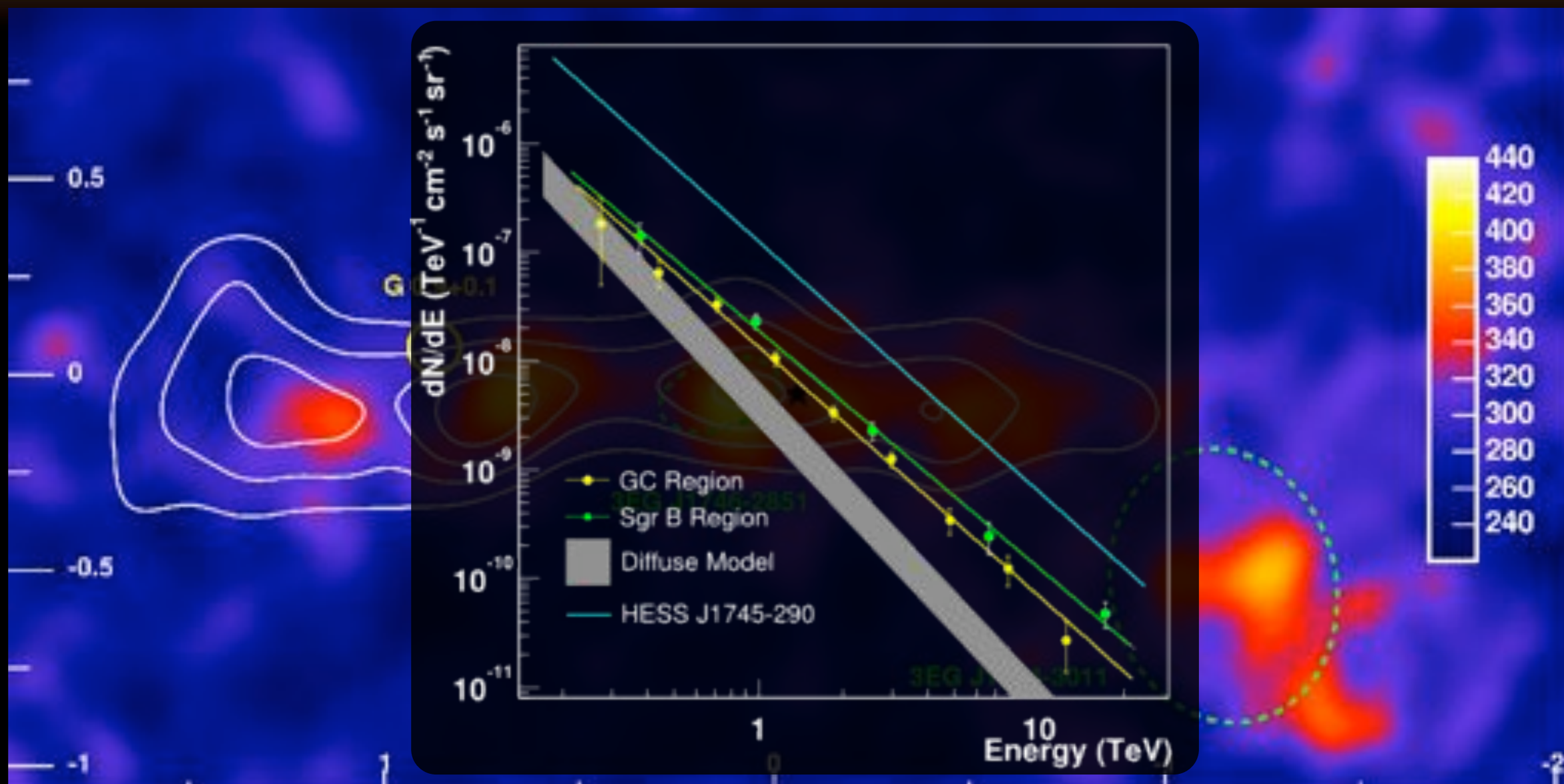



- **Simultaneous HESS/ Chandra observation**
- **X-ray flare**
  - 9x quiescent level
  - 1700 ksec
- **<u>No</u> increase in Gamma flux**
  - 100% flux increase ruled out at 99% confidence level

# The Galactic Center



# The Galactic Center




- **GC + G0.9 Subtracted: Diffuse emission!**
- **Interaction of CRs with molecular clouds**
  - not consistent with passive illumination (spectral index ≈2.3)

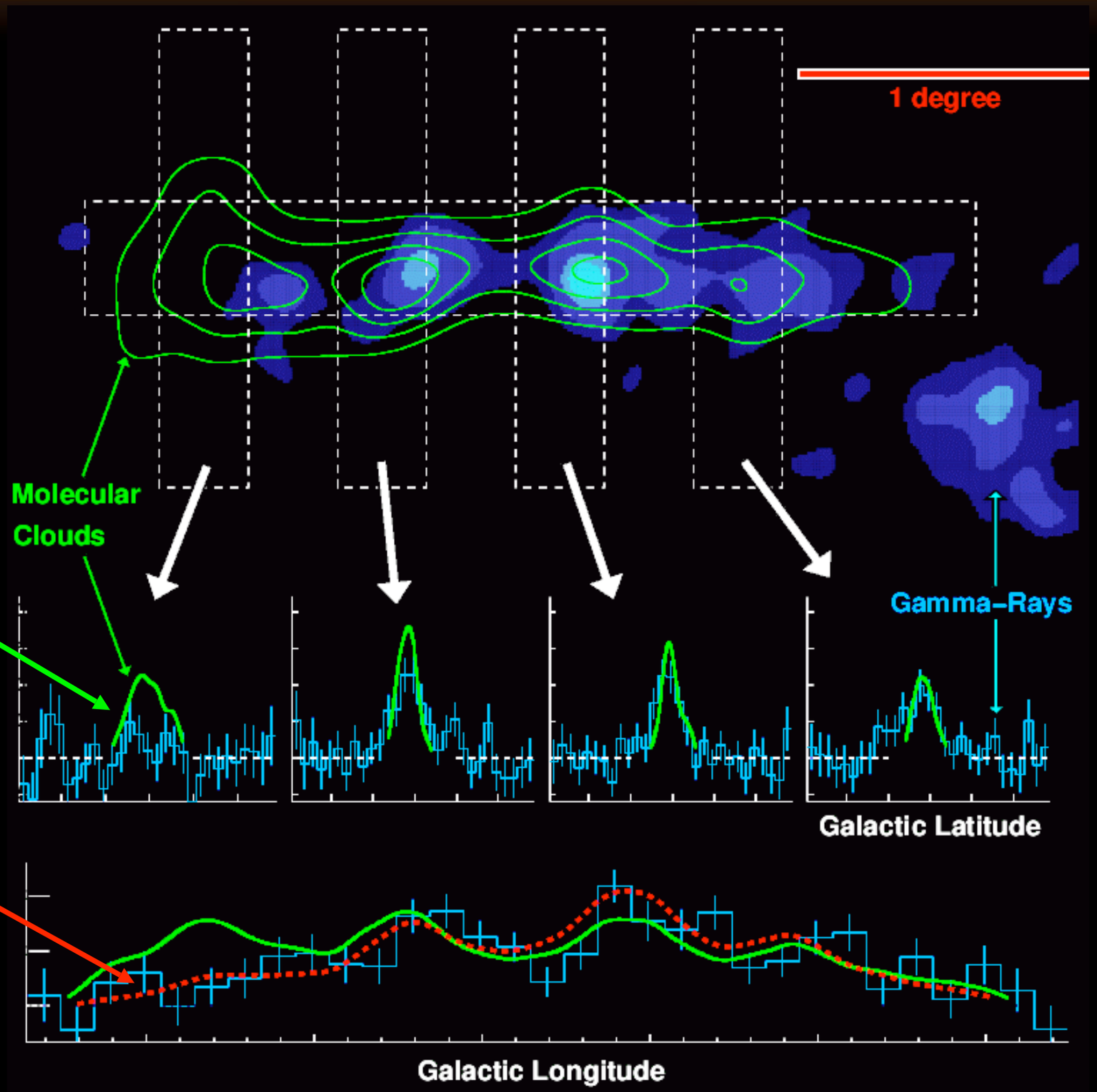
# GC Diffuse Emission

close correlation between γ-rays and molecular clouds

deficit in TeV γ-rays
source too young?

simulation
$10^4$ years old source @ GC

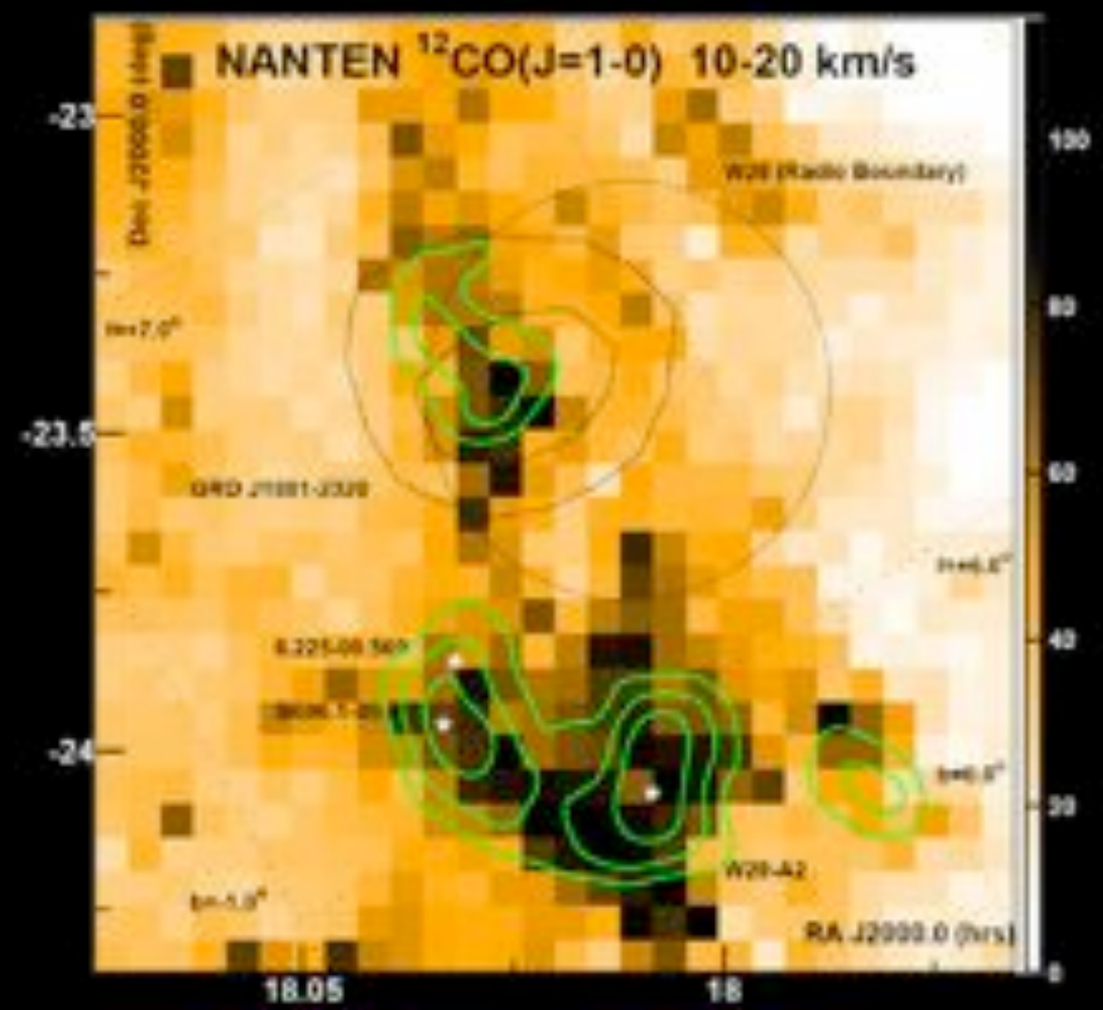
GC accelerates (nucleonic) cosmic rates!




★ **Nature** 439 (2006)

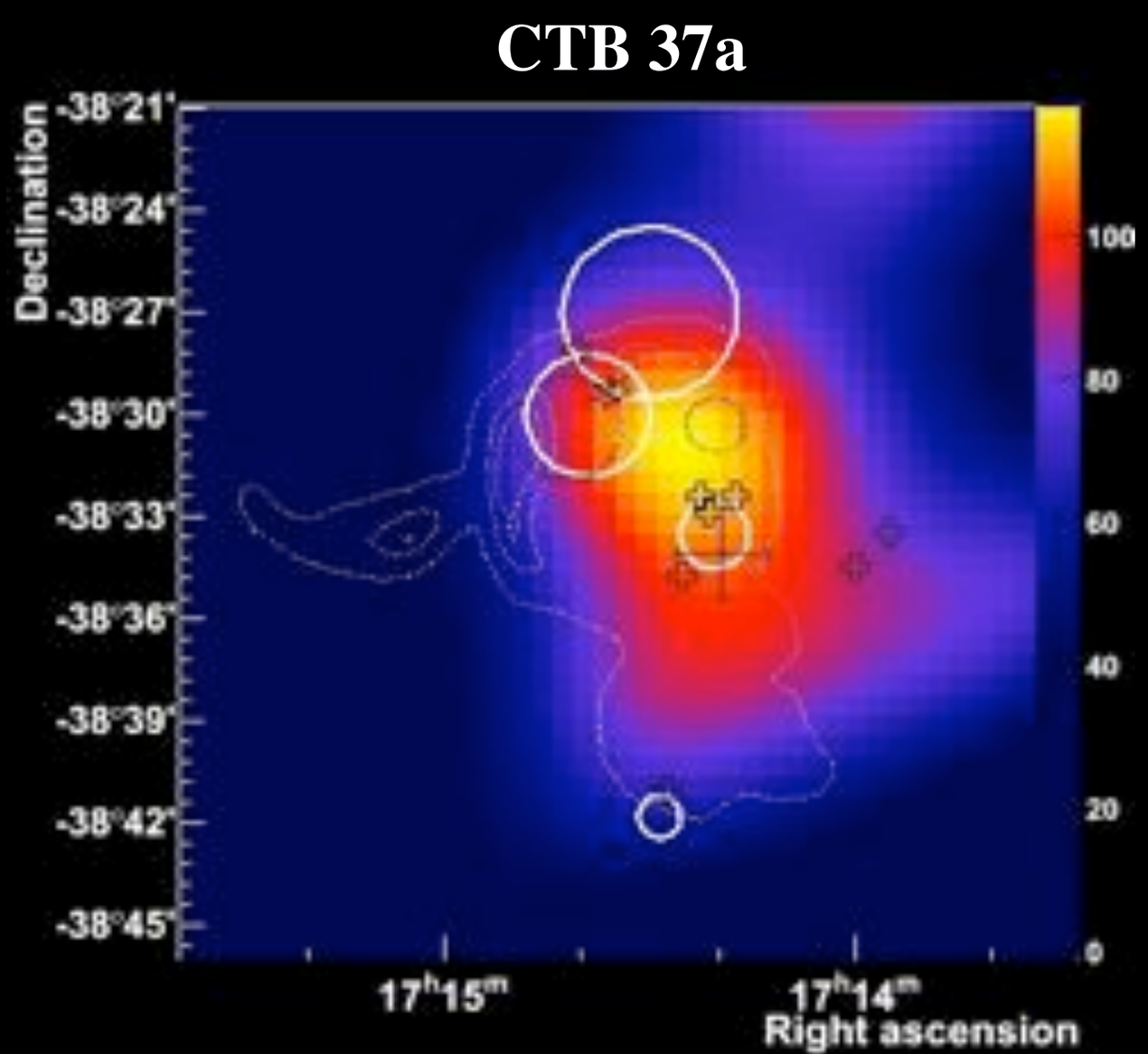
# Molecular Cloud Interactions

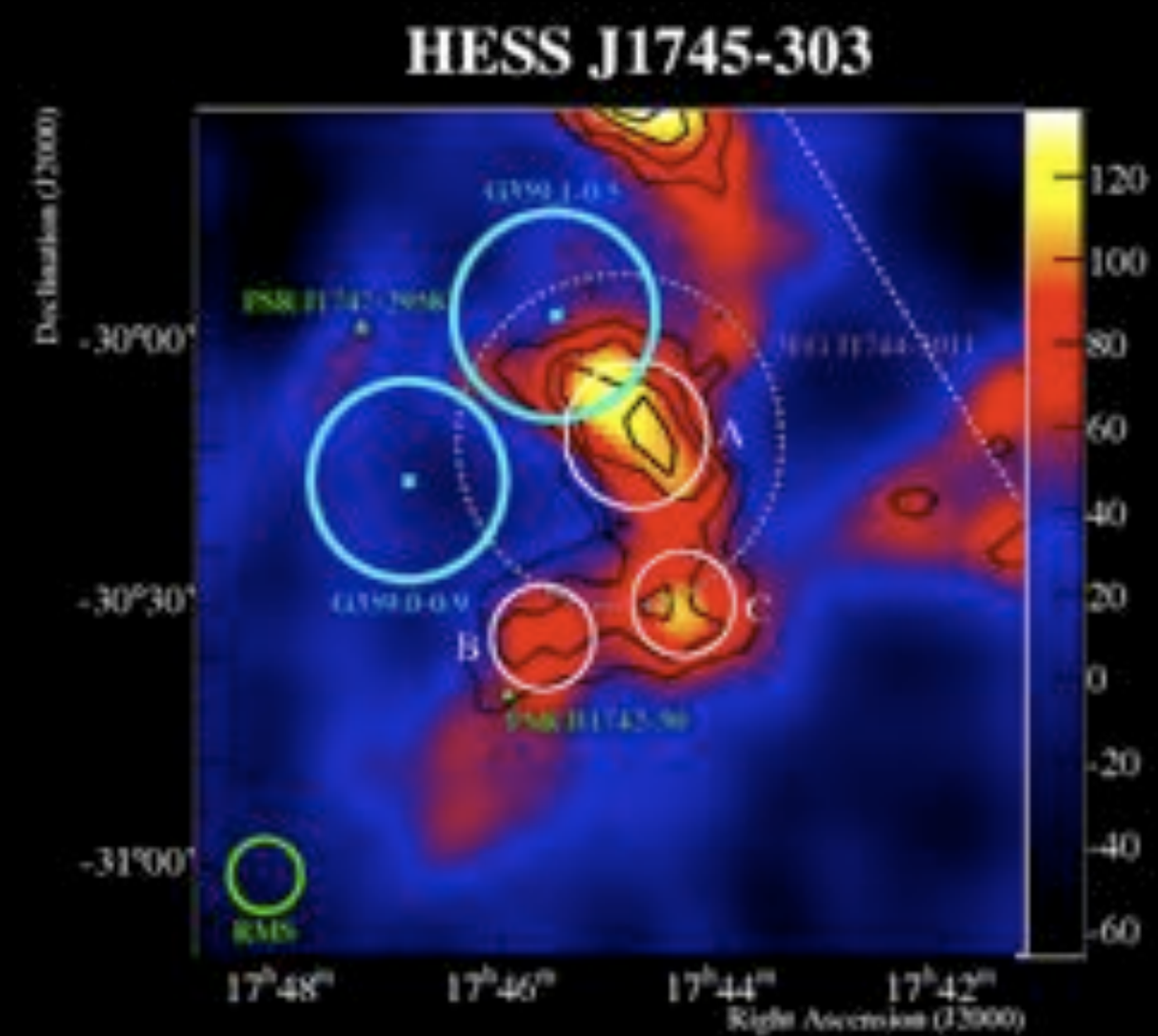
- **W28 region -** old SNR interacting with molecular clouds?
  - age ≈ 35000 - 150000 years, propagating into dense clouds
  - e- acceleration inefficient:  hadronic cosmic rays



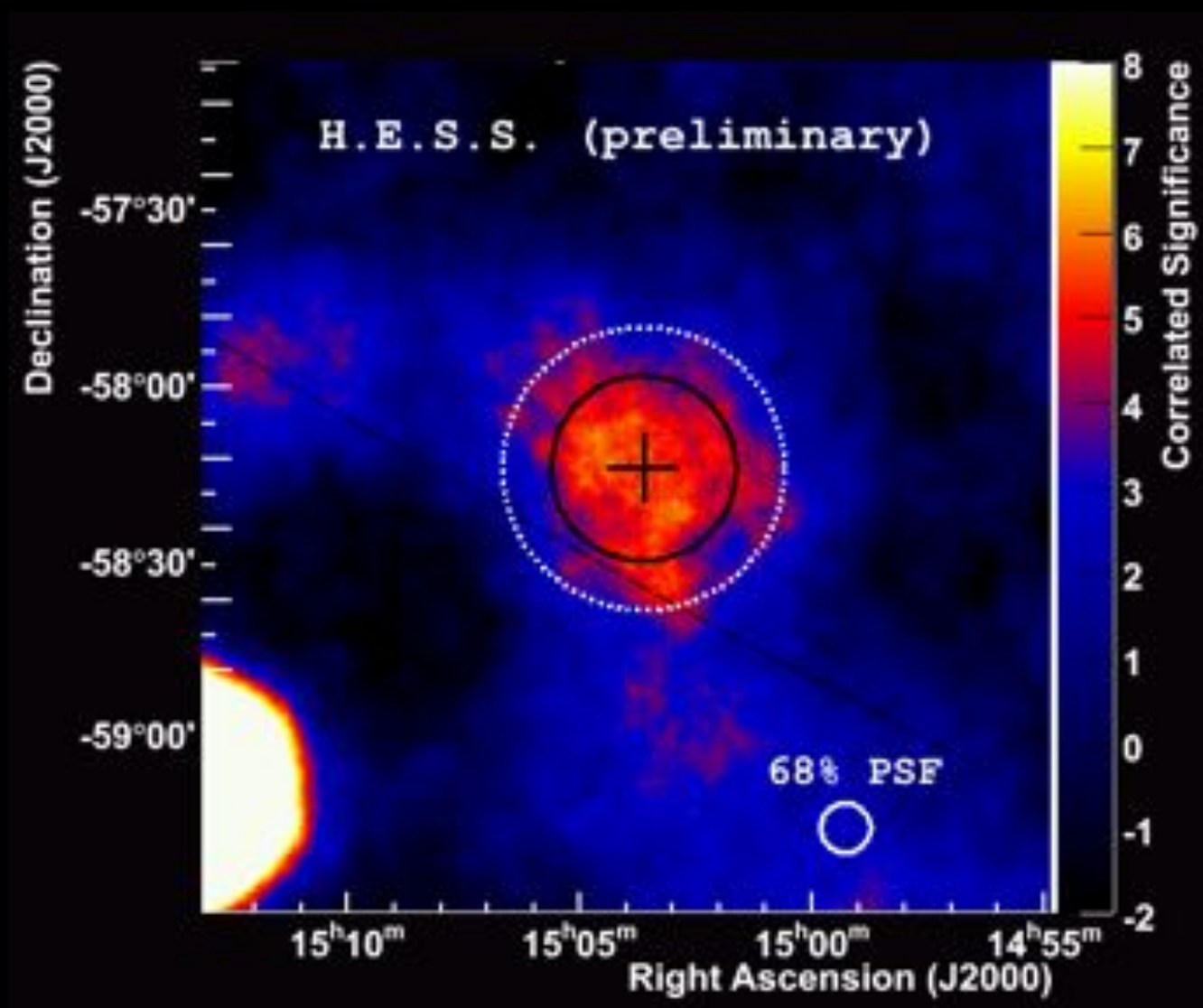
# More MC Interactions...

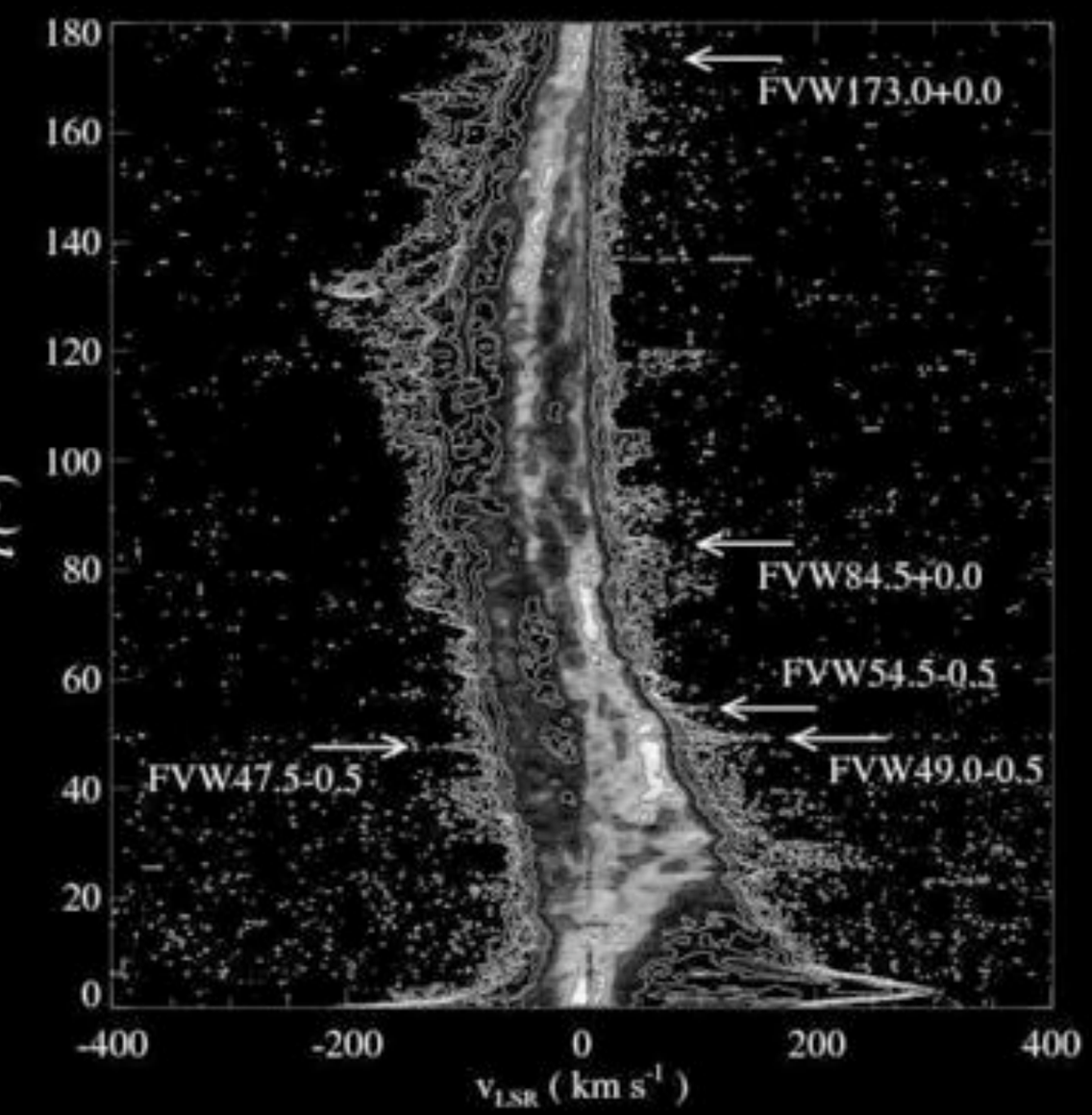
- HESS J1745-303: unidentified galatic center source



# HESS J1504-582

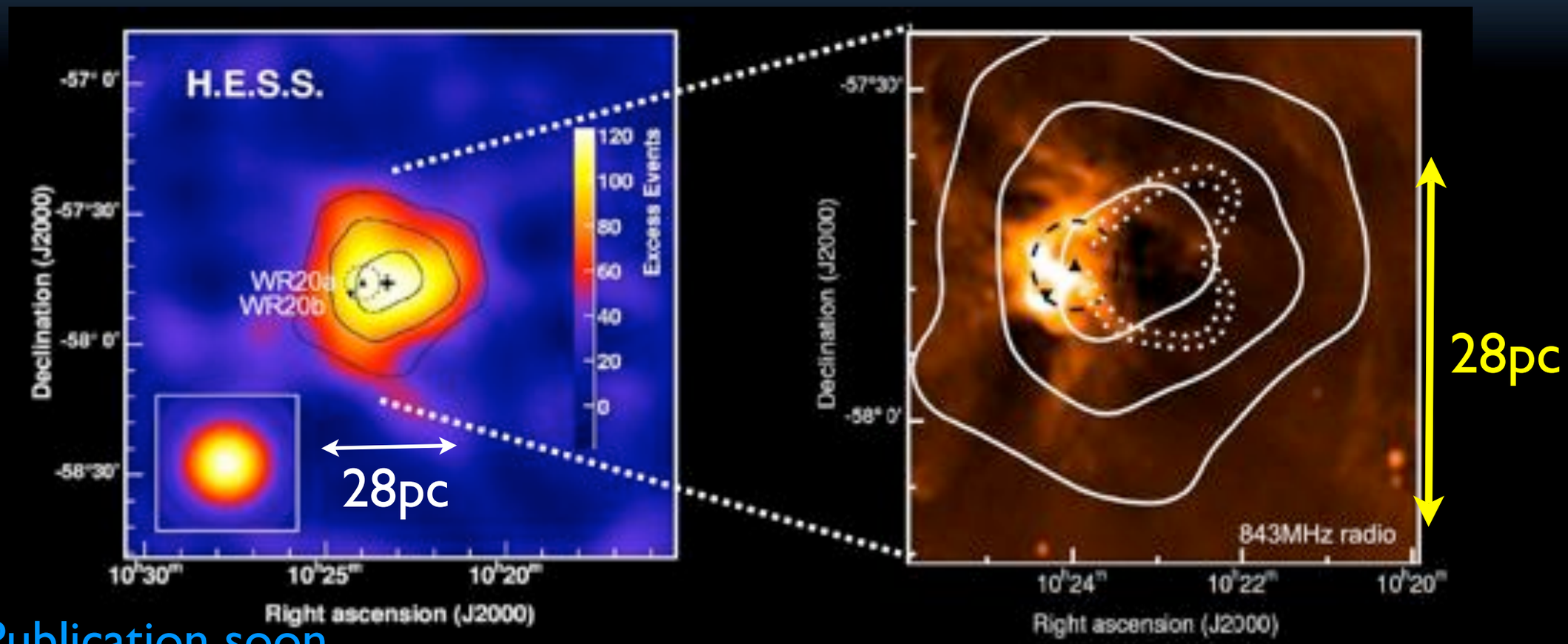


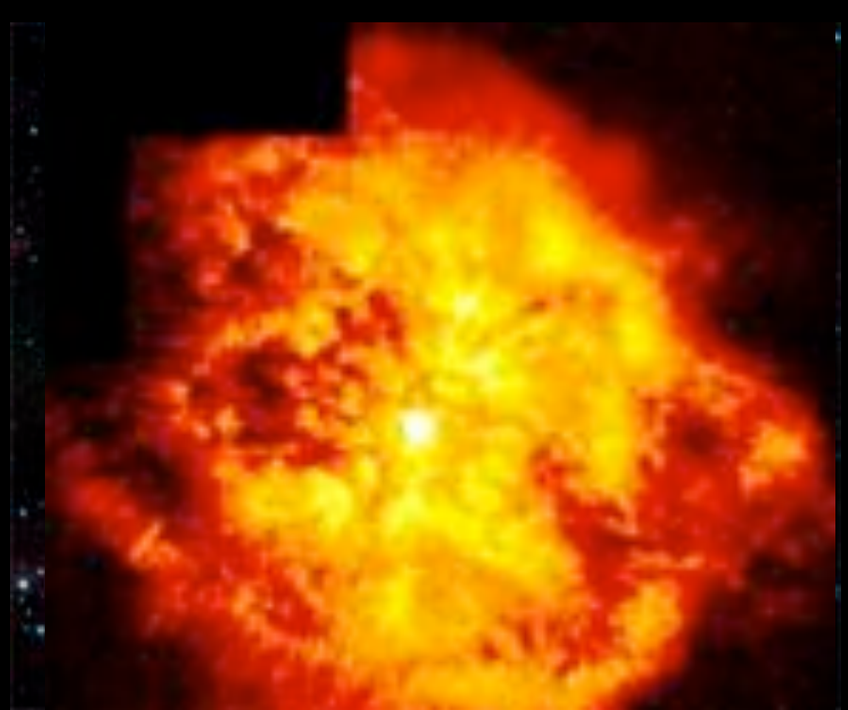

- **Coincidence with HI Structure: Forbidden Velocity Wing?**

# Star forming regions?

# HESS J1023-575: Westerlund2

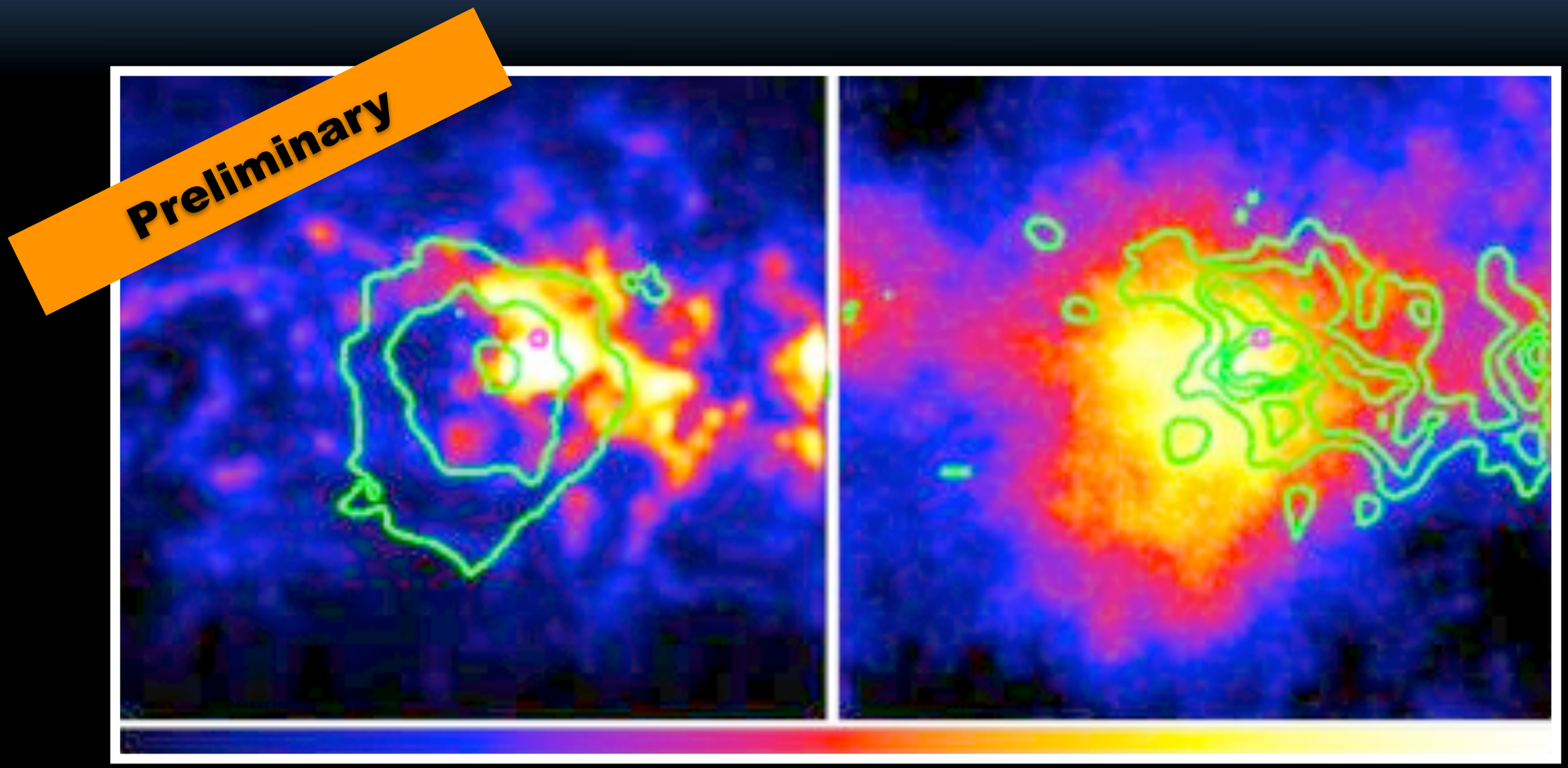



Publication soon

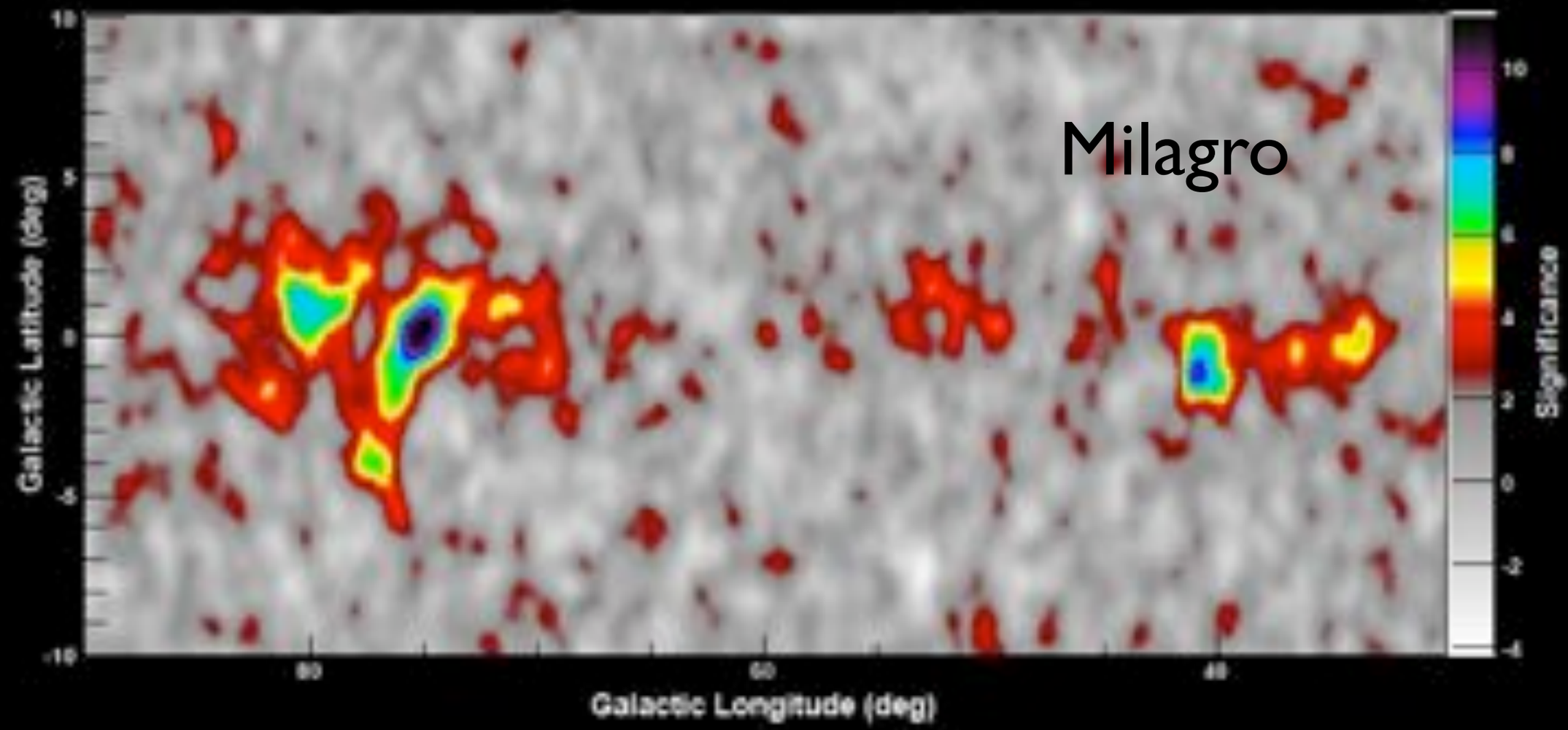


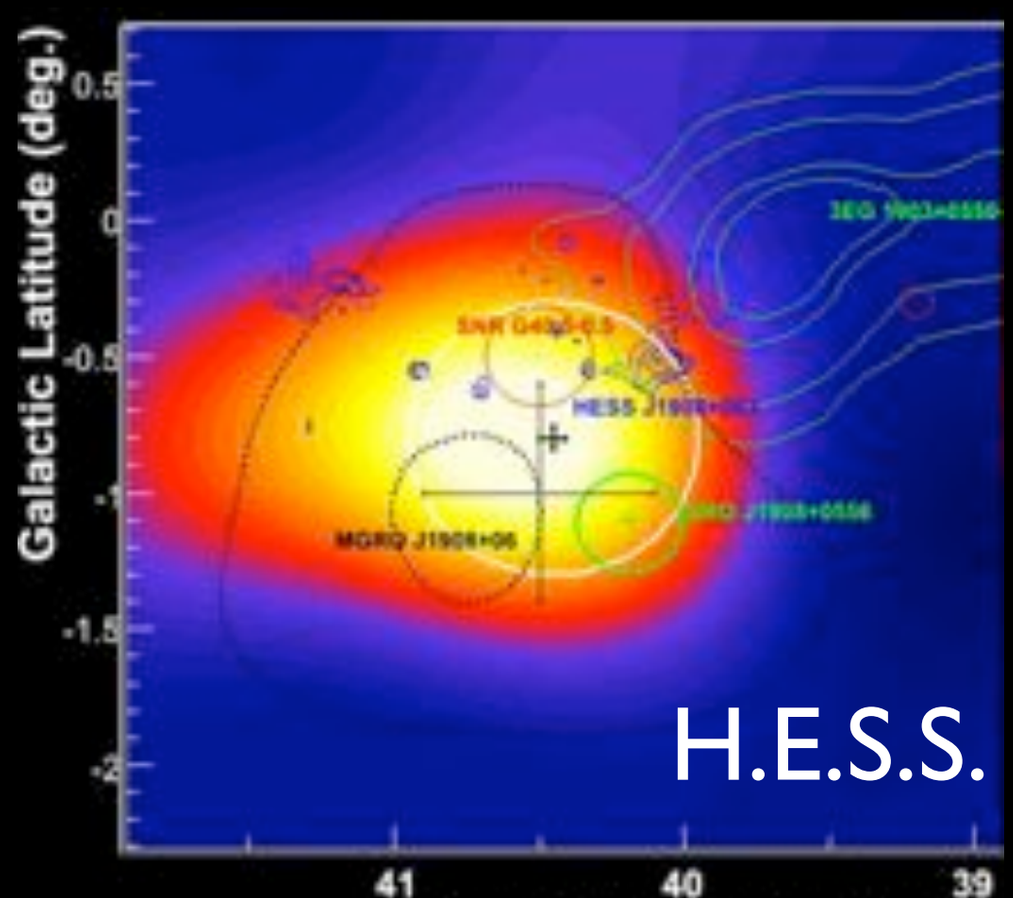
- **A new type of VHE Gamma-ray emitter:** Star-forming region! Wolf Rayet star? Wind Blown Bubble?
- **Extension much <u>larger</u> than WR system => bubble blown in ISM?**
  - shocks/turbulence in wind-blown bubbles accelerate CRs

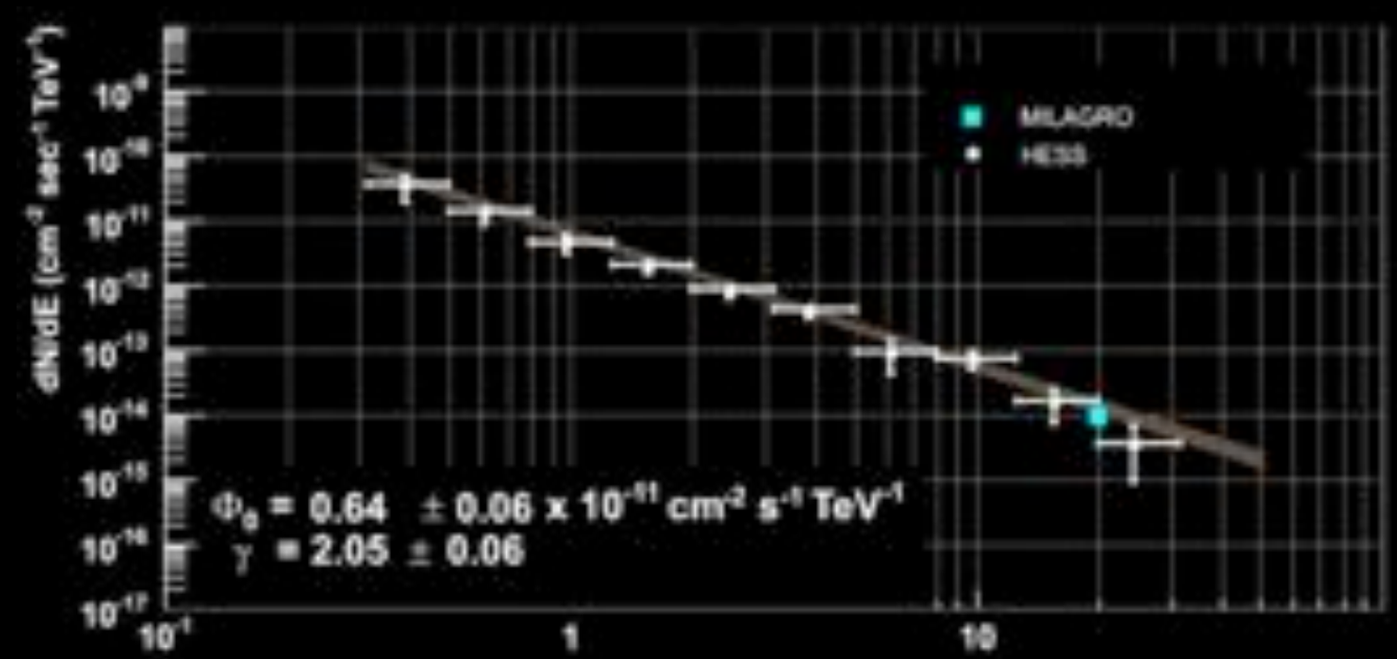
# HESS J1848-018



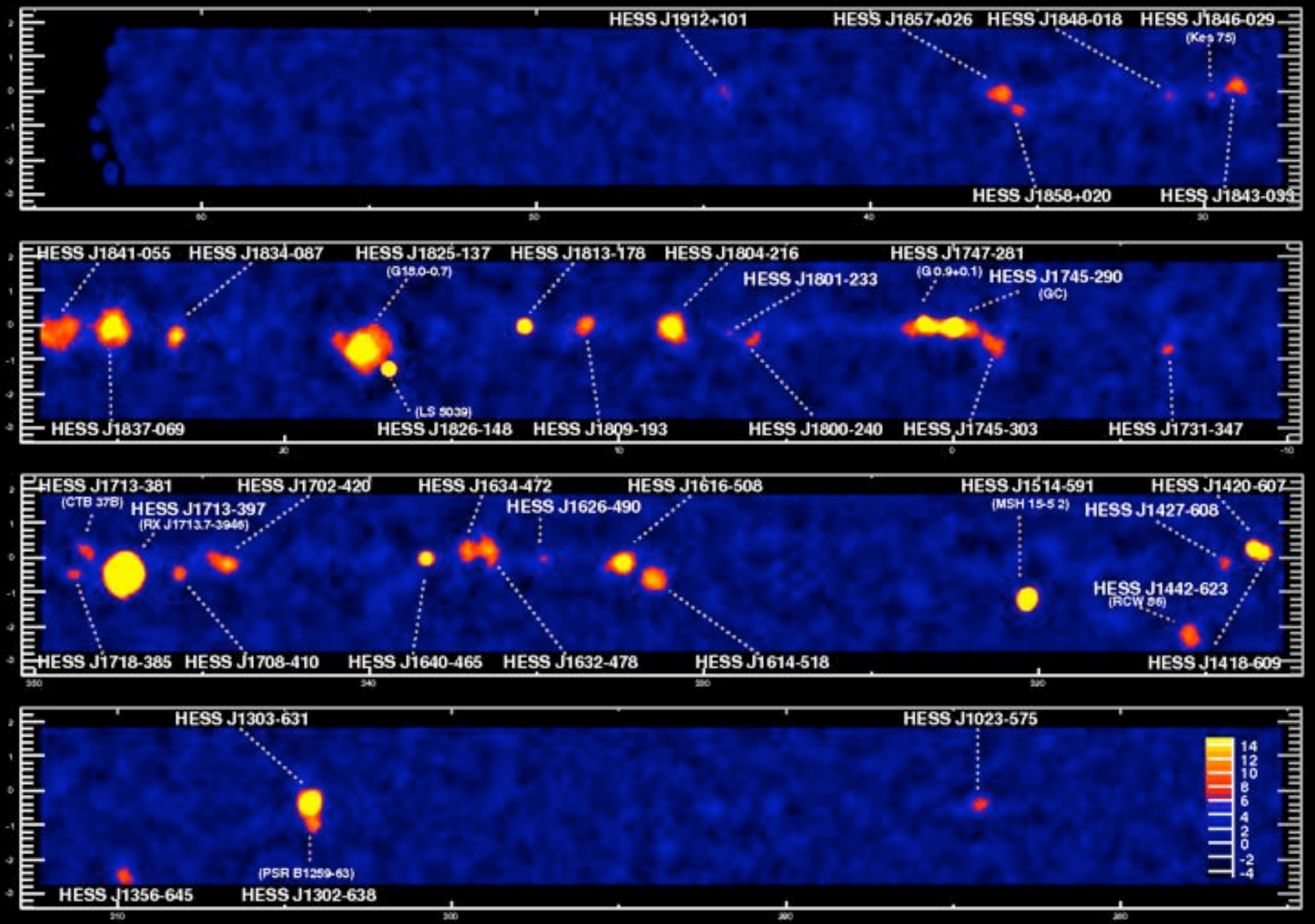

- Possibly associated with W 43 star-forming region (including WR 121a, a Wolf-Rayet star)




10 h of data, 9 sigma significance


HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G0.9+0.1)
HESS J1745-290
(GC)
(LS 5039)
HESS J1837-069
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-347
HESS J1713-381
(CTB 37B)
HESS J1702-420
HESS J1634-472
HESS J1616-508
HESS J1514-591
(MSH 15-52)
HESS J1420-607
HESS J1713-397
(RX J1713.7-3946)
HESS J1626-490
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1303-631
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(PSR B1259-63)
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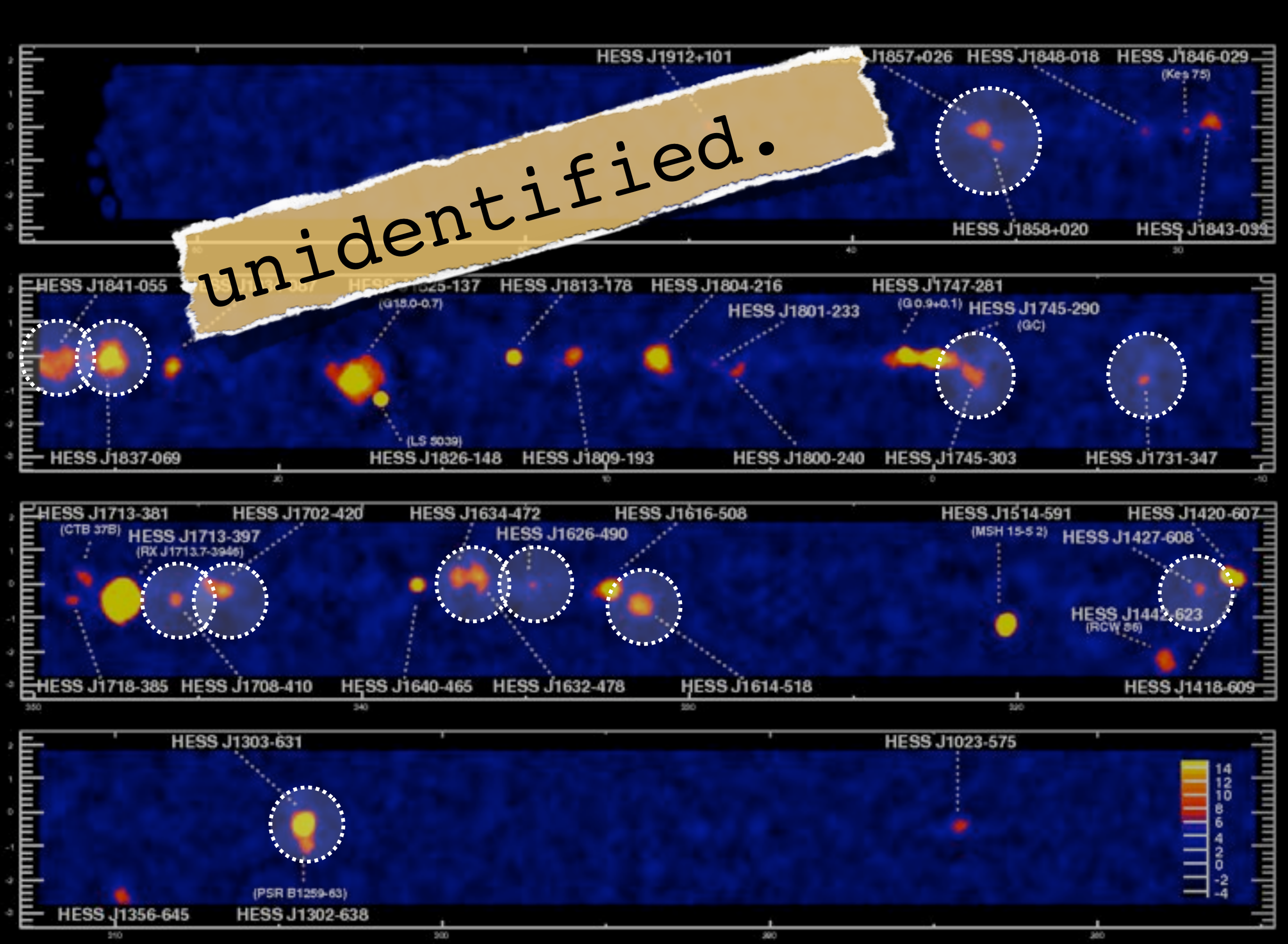
unidentified.
HESS J1912+101
J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HESS J1841-055
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(PSR B1259-63)
HESS J1356-645
HESS J1302-638
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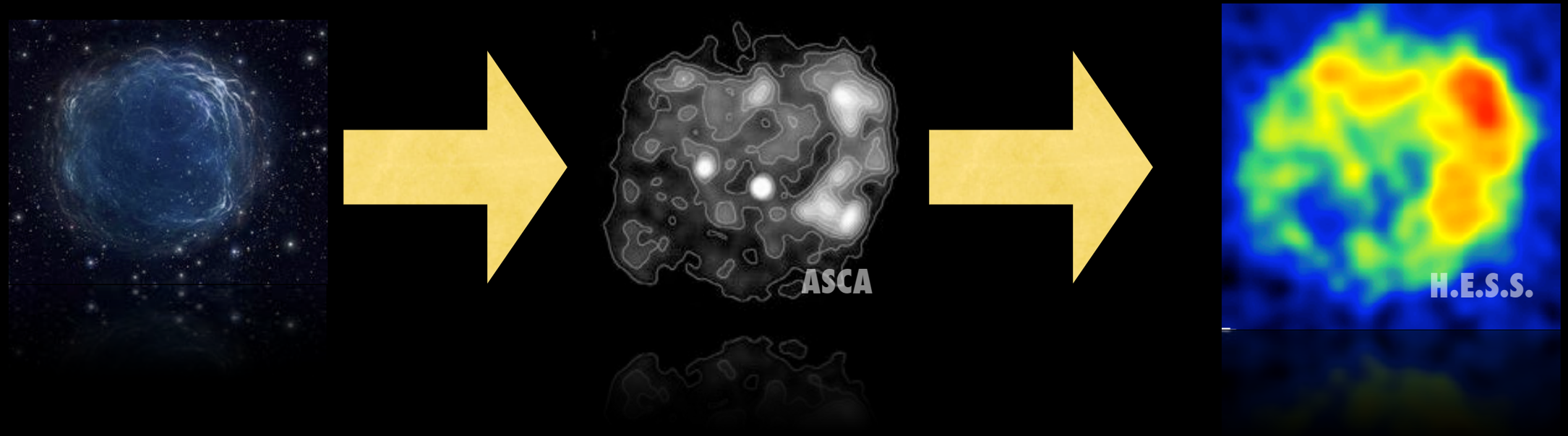
# Multiwavelenth view

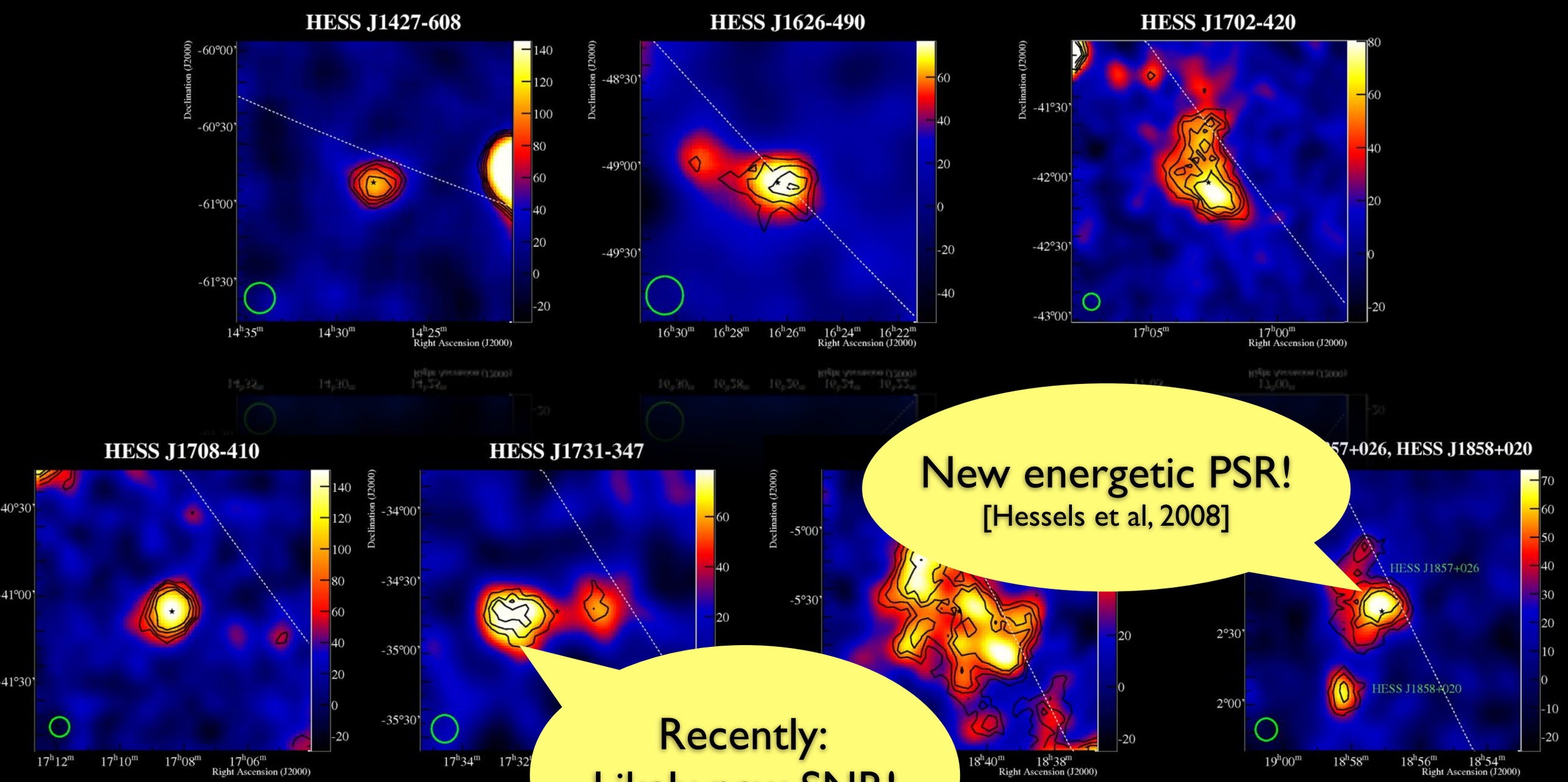
- *RECALL*: **Two-peaked emission predicted $I_x/I_\gamma \approx 1$**
- **We expect VHE sources to have obvious counterparts in Radio and X-rays.**




- **sources with no obvious X-ray/Radio counterpart are thus harder to explain...**

# Some Unidentified Sources

Aharonian et al 2008, A&A




New energetic PSR!
[Hessels et al, 2008]

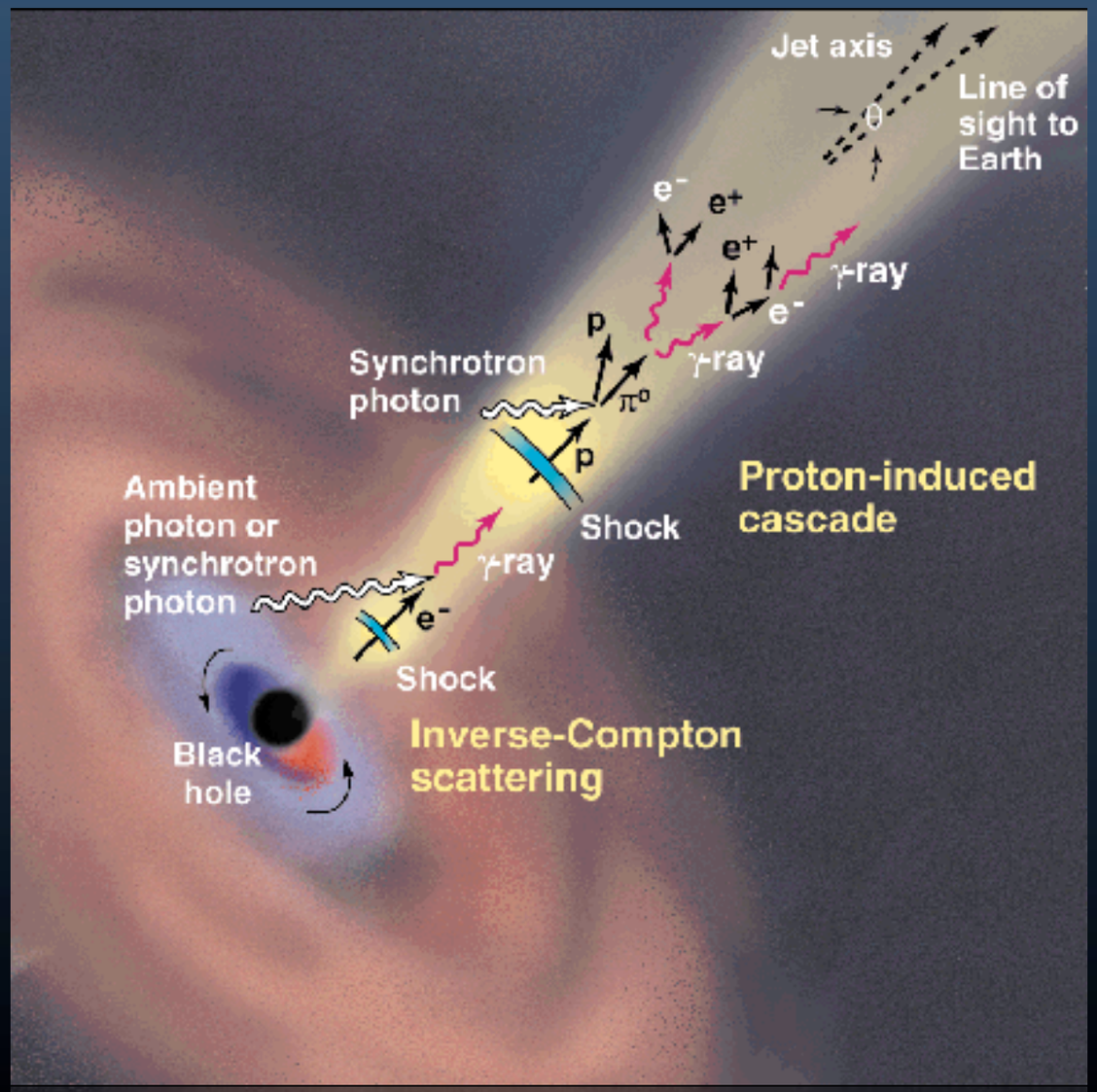
Recently:
Likely new SNR!
[Tian et al. 2008]

# Extra-Galactic Sources

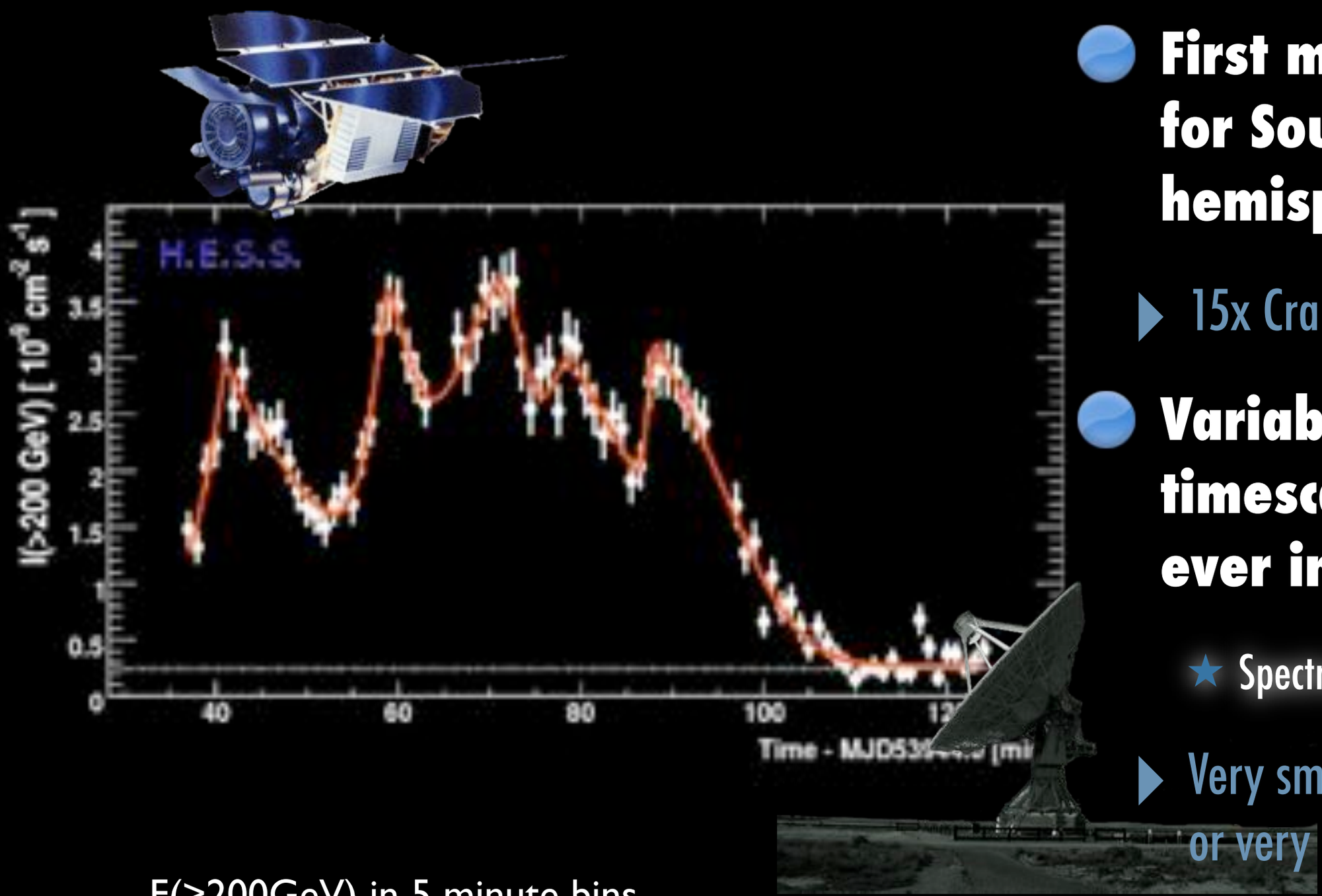
- **Active Galactic Nuclei**
  - Blazars
    - ★ Variability studies
  - Non-blazars (M87)
    - ★ Variability studies

# Active Galactic Nuclei (AGN)

- **Powerful object at the center of some galaxies**
  - Supermassive Black Hole
  - Relativistic Jet
  - Variable emission
- **Blazars:**
  - Jet is pointed at us
    - ★ 15 known TeV blazars as of 2008
    - ★ 7 Observed by HESS
    - ★ 5 Discovered by HESS



# PKS 2155 Flare



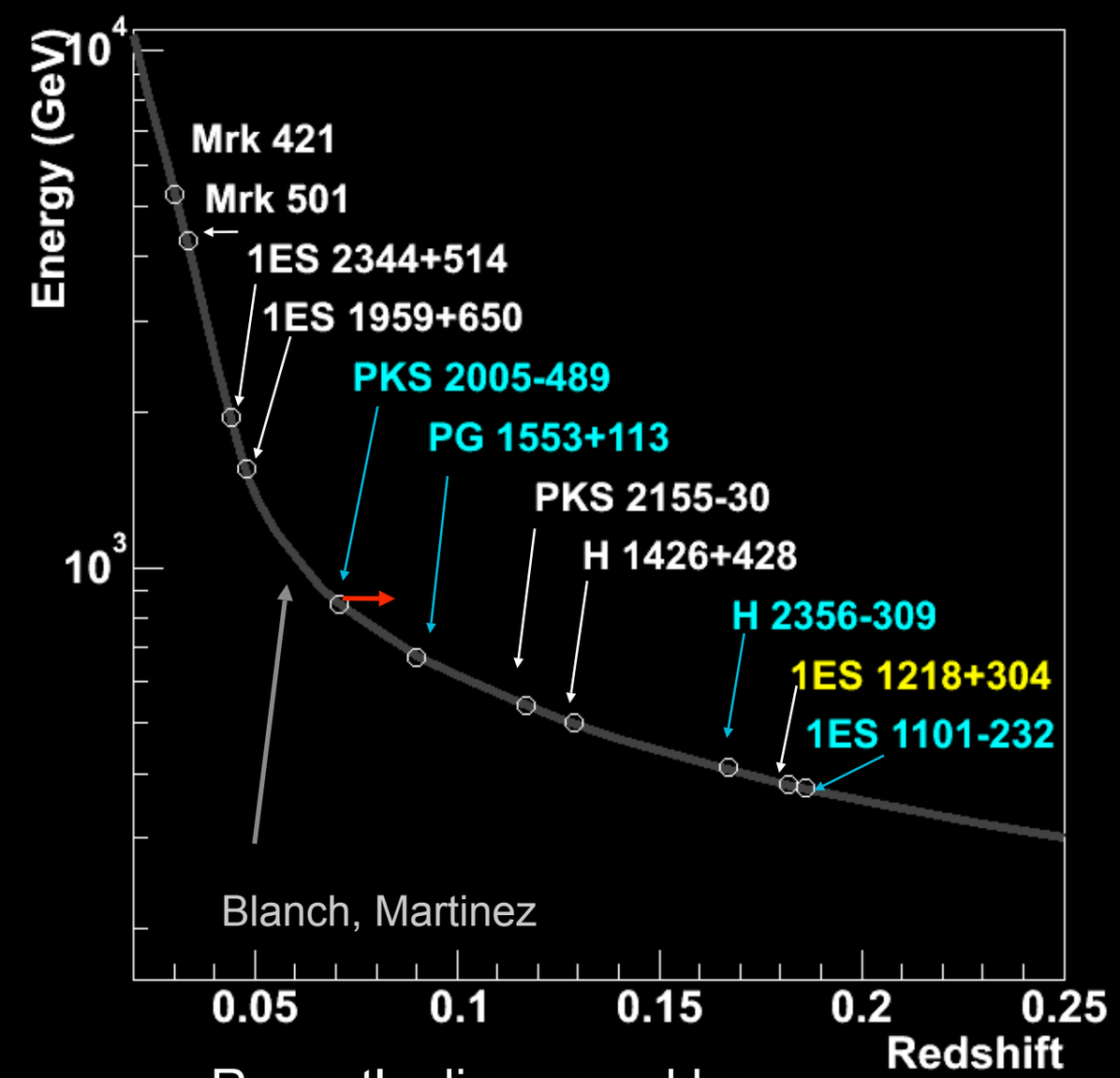

F(>200GeV) in 5 minute bins

*Aharonian et al ApJL 664, 2007*

- **First major AGN flare for Southern hemisphere source**
  - 15x Crab Nebula flux!
- **Variability on 200s timescales! (fastest ever in the field)**
  - ★ Spectra on same timescales!
  - Very small emission region or very high Lorentz factor!

# Extragalactic Background Light

- **Assume: AGN intrinsically not harder than Γ=1.5**
- **Measurements of distant AGN provide Upper-Limit on EBL absorption**
  - ★ Nature, 440 (2006)
  - HESS measurements imply:
    - ★ **EBL lower than previously thought!**
    - ★ Universe is more transparent to TeV emission! - we can see further...




Recently discovered by:

H.E.S.S. MAGIC

1ES 2356-309 1ES 1101-232 show relatively hard spectrum

# M87



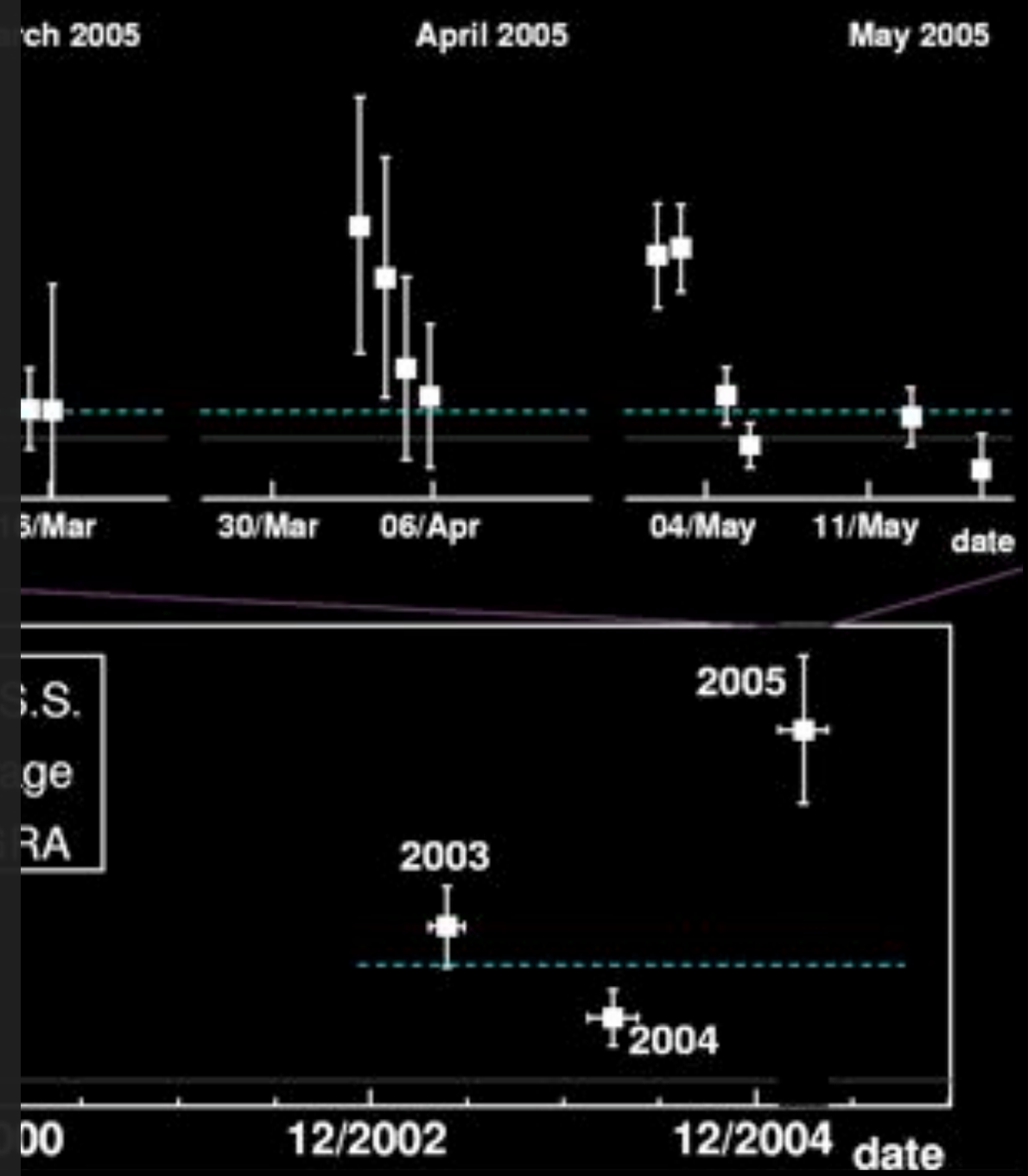
Hubble (optical)

X-ray (Chandra)

A new class of TeV object: a *non-blazar* AGN !

# M87: Variability

- **Variability (flux doubling) on Day timescales**
  - ★ NOTE: no boost from jet
- **Faster in TeV than in other wavebands!**
- **Emission close to $R_s$**
  - Rules out core of Virgo cluster and **jet**!
- **Challenges models!**




*Science* 314 (2006)

# Other Results

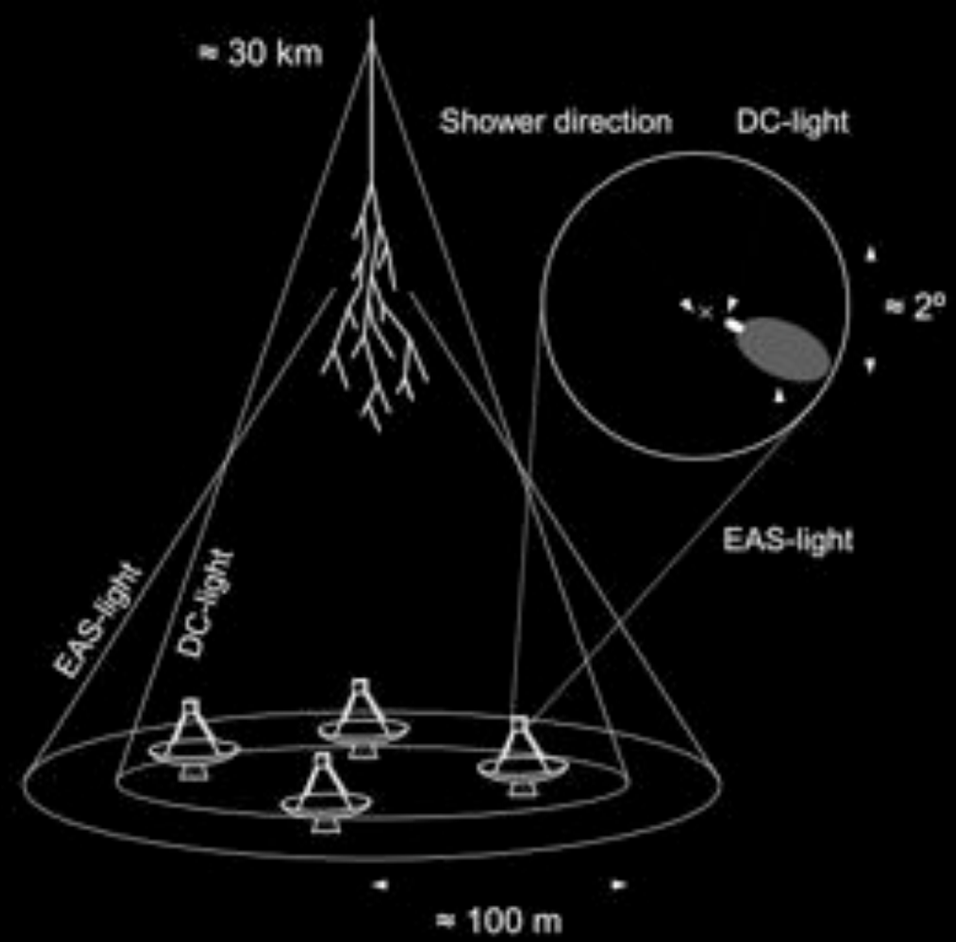
- Cosmic Ray Spectrum
- Electron Spectrum
- Extended extragalactic objects?

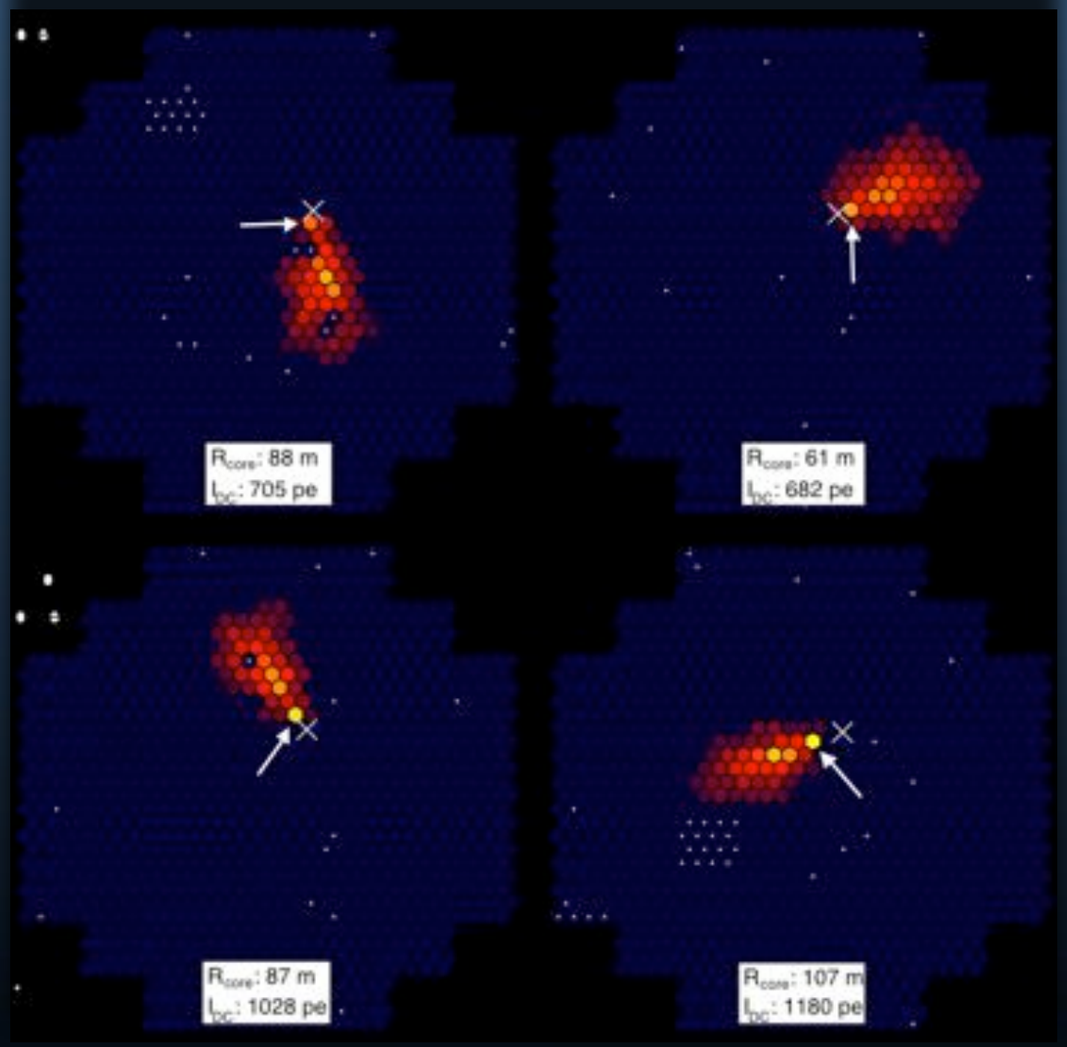
# DC-light from Cosmic Rays

- **Can we measure the Cosmic Ray Iron spectrum with HESS?**
- **Direct Cherenkov light:**

$$I_{\mathrm{DC}} \propto Z^2$$

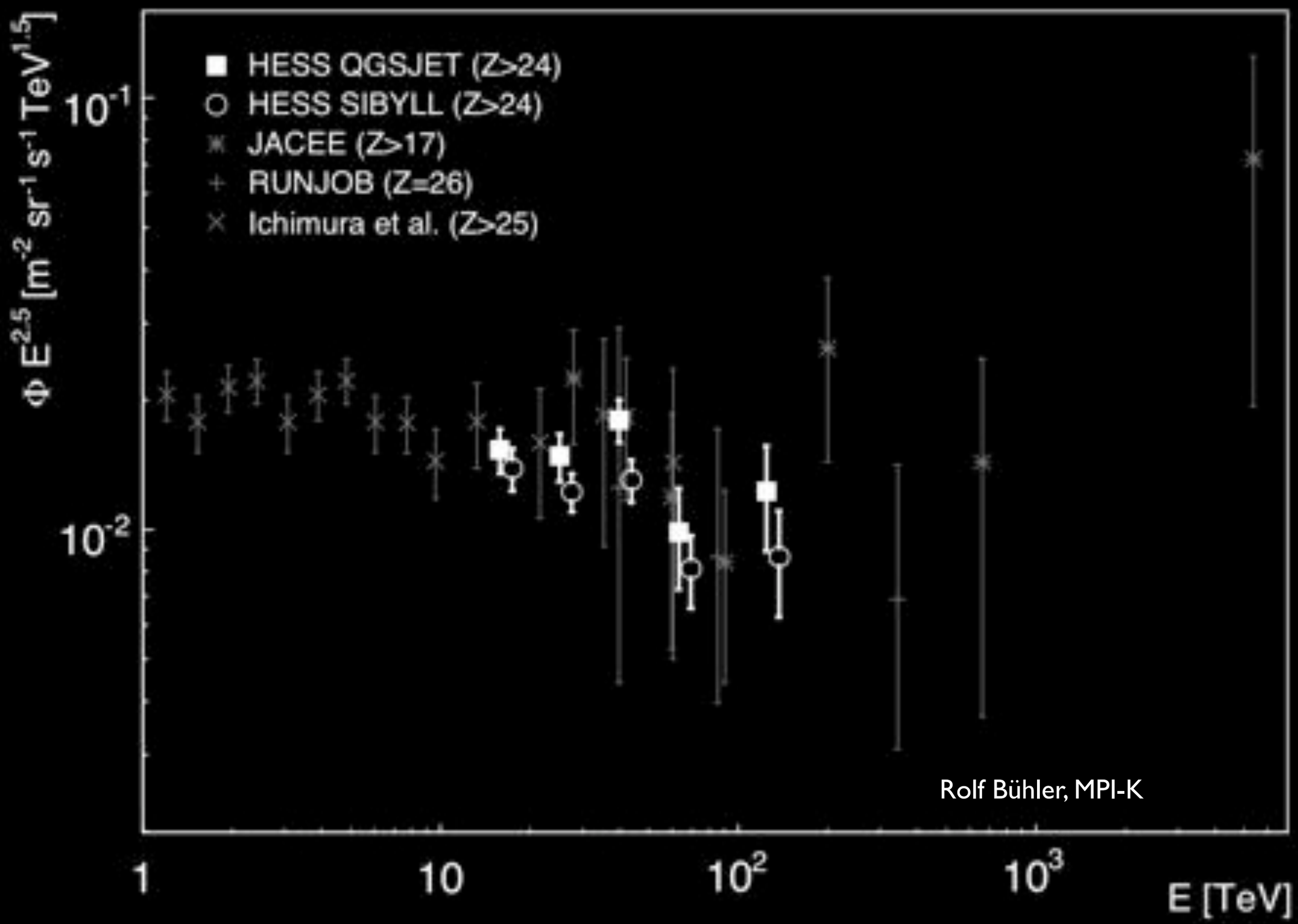
$$I_{\mathrm{shower}} \propto E$$



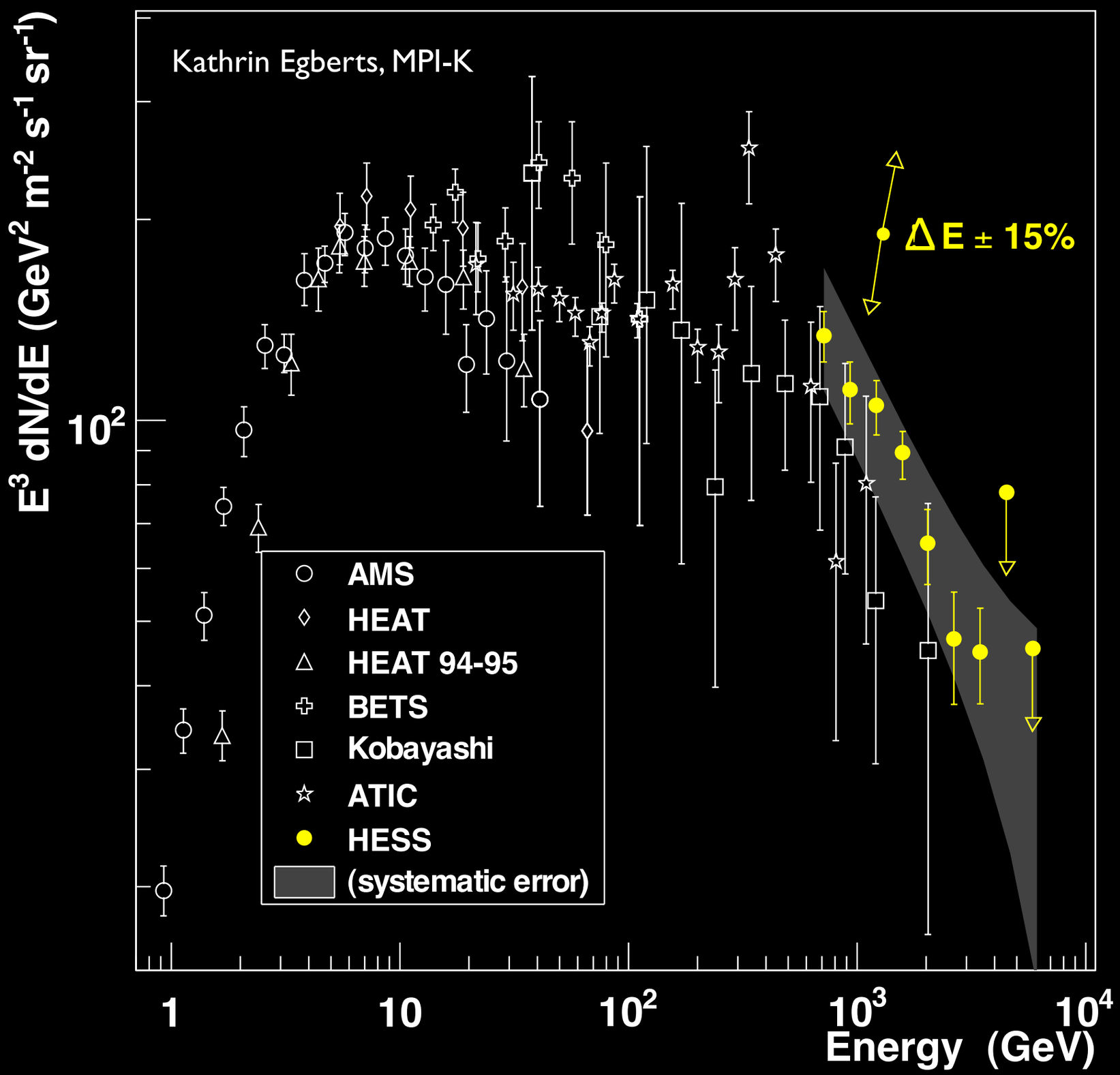

Technique: Keida, Swordy, Wakely. (2002)

# The H.E.S.S. Iron spectrum




**Aharonian et al, 2007, Phys Rev D**

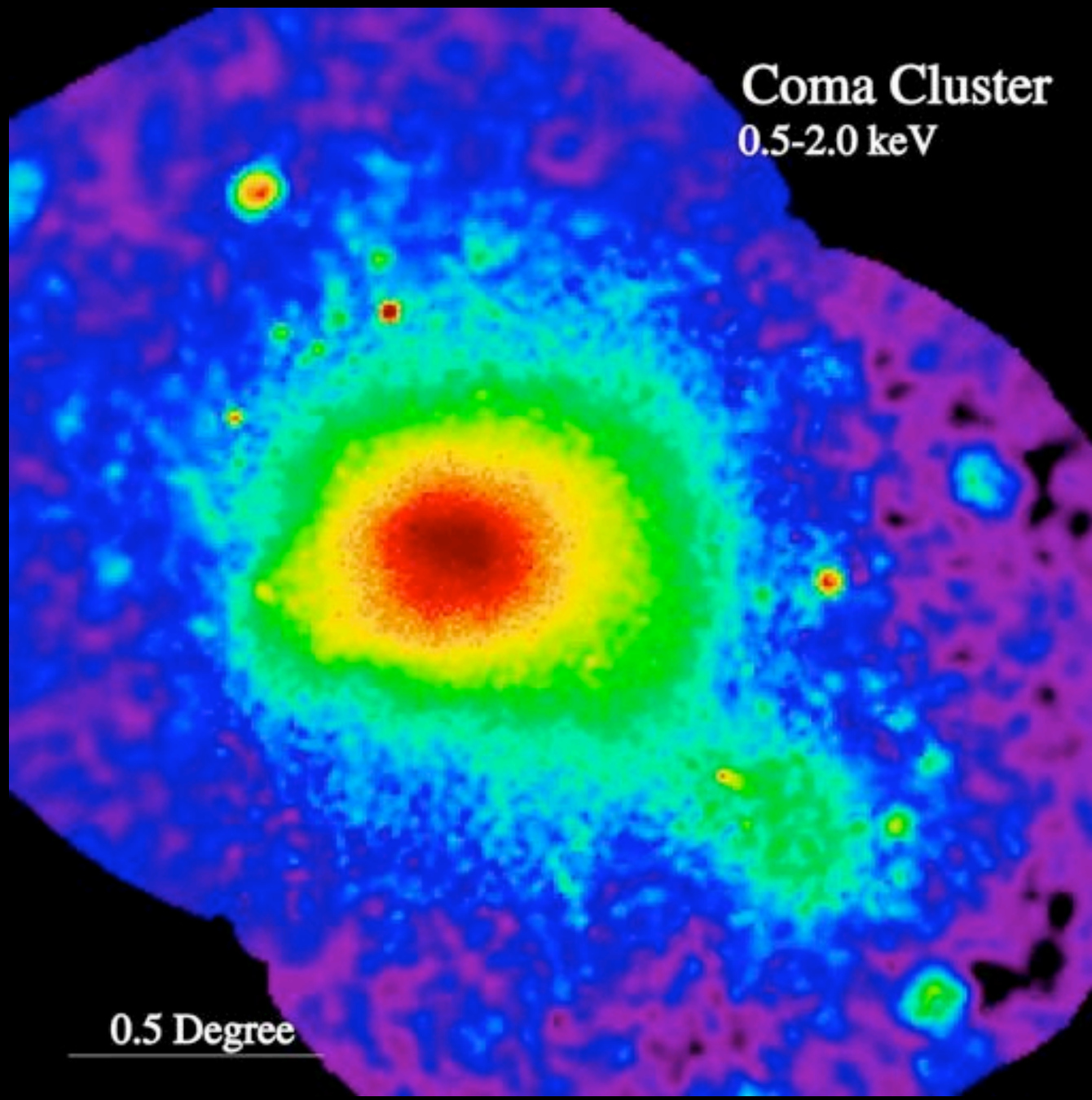
# Electron Spectrum




- Use random-forest method to develop cuts which select electron events

# Looking to the Future...

- **Extended Extragalactic Objects?**
- **e.g.: Galaxy clusters** powerhouses for high E cosmic rays!
  - Don't leak out over time as in a galaxy
  - Hadronic interactions with target material seen in X-rays, should produce gamma rays too!
    - ★ Not yet detected in VHE gamma rays

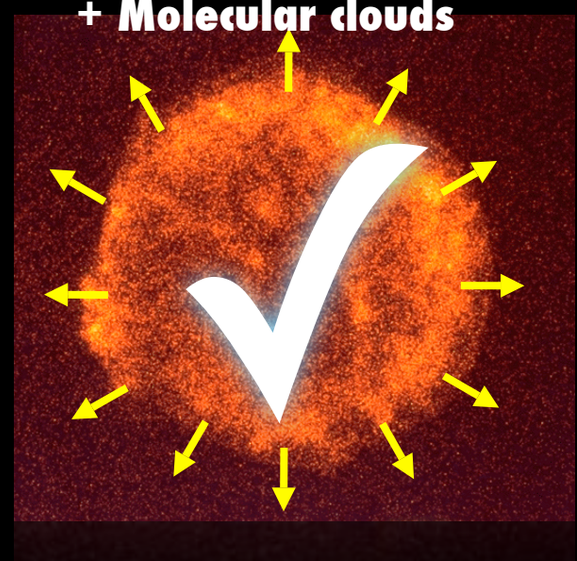


NO SIGNAL

# Detected VHE Sources

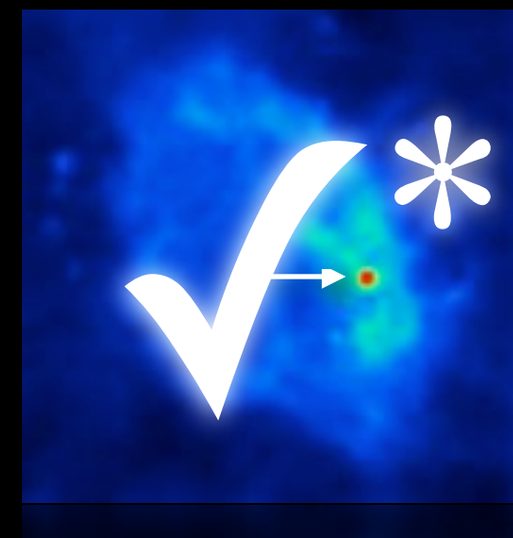
Active Galactic Nuclei

Shell-type Supernova Remnants
+ Molecular clouds

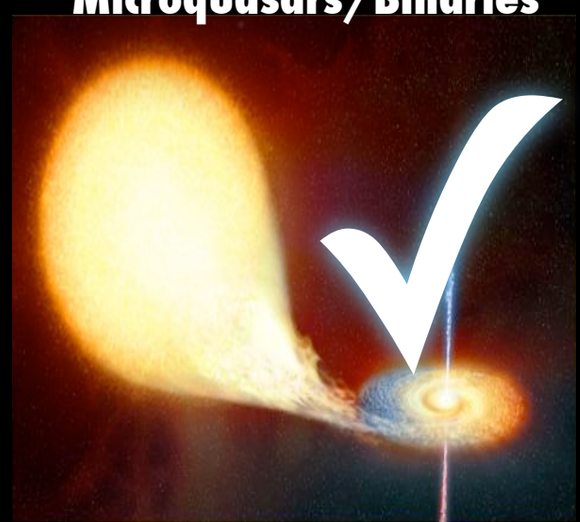


Pular Wind Nebulae

Supermassive Black Holes



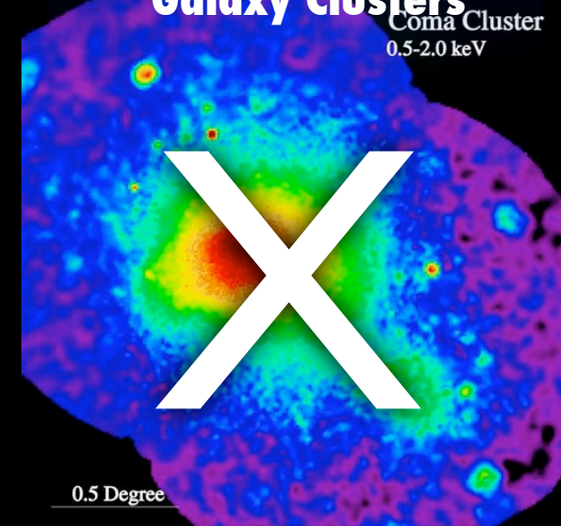
Microquasars/Binaries



Starforming regions/WR Stars

Gamma-ray Bursts

Galaxy Clusters




* possibly

+ ...?

# Overview

## The Instrument

- Technique
- Specifications

## Goals

## Scientific Results

- The Galactic Plane Survey
- Galactic Sources
- Extra-galactic Sources
- Other

## Future and Status

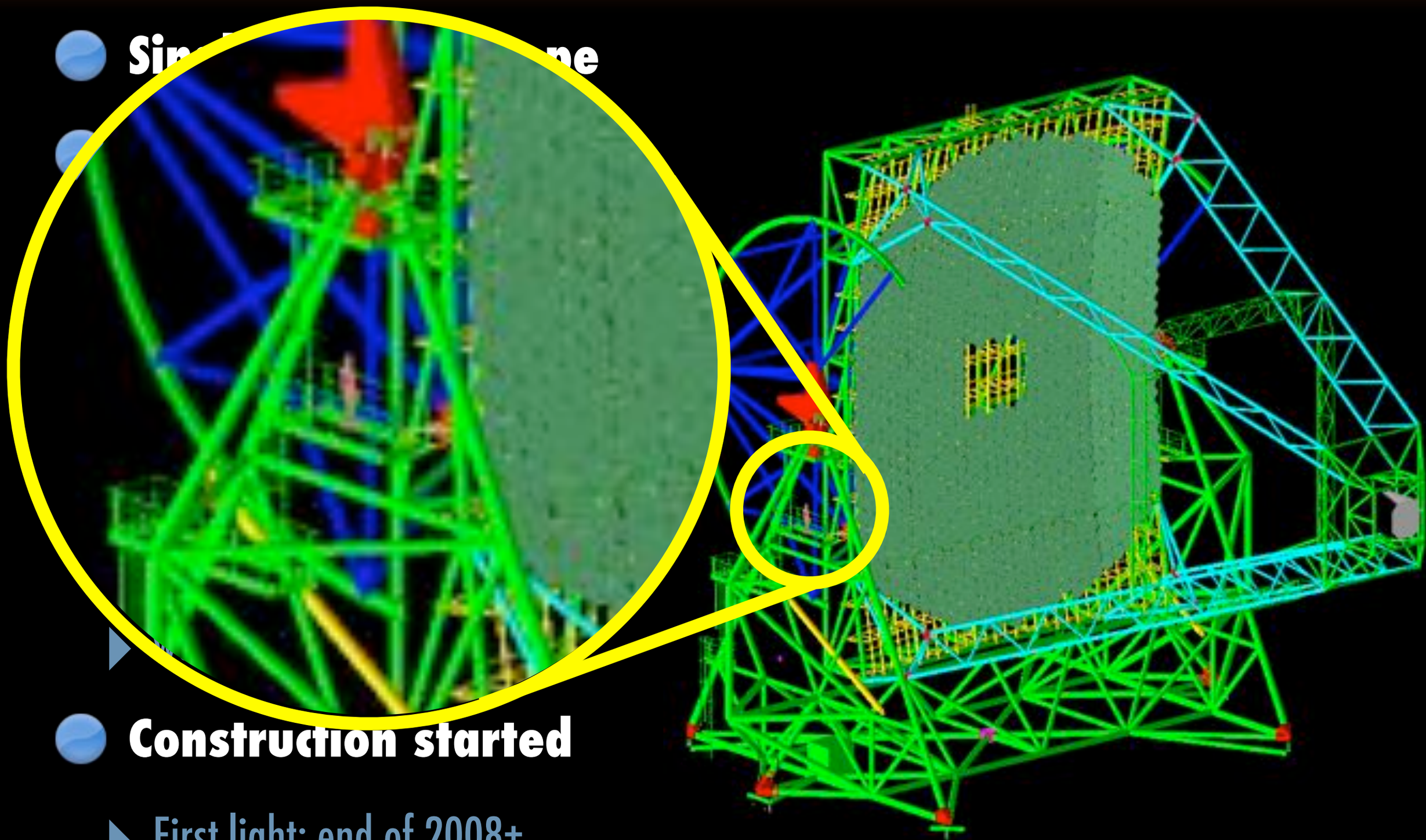
- HESS Phase II

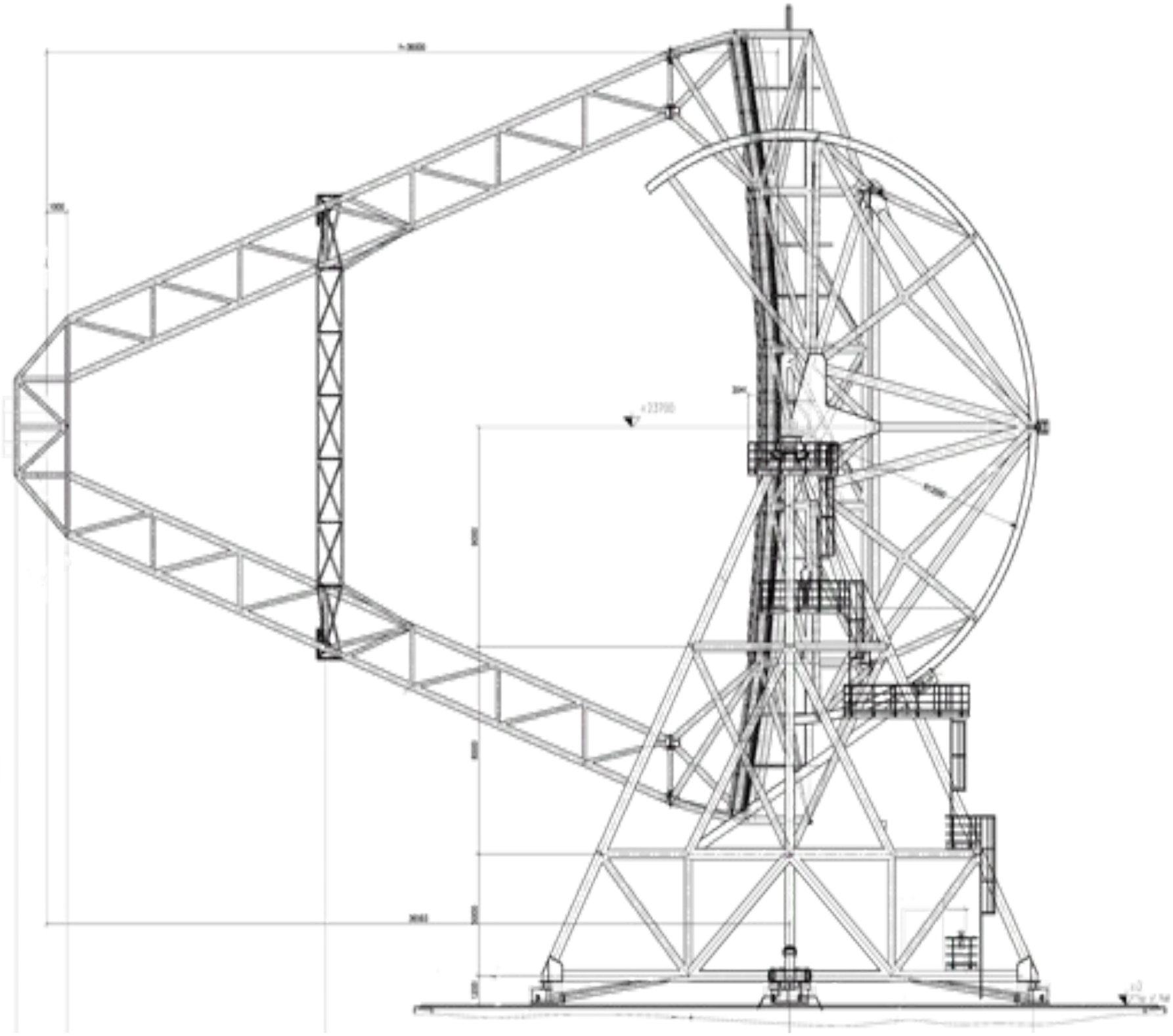
H E S S

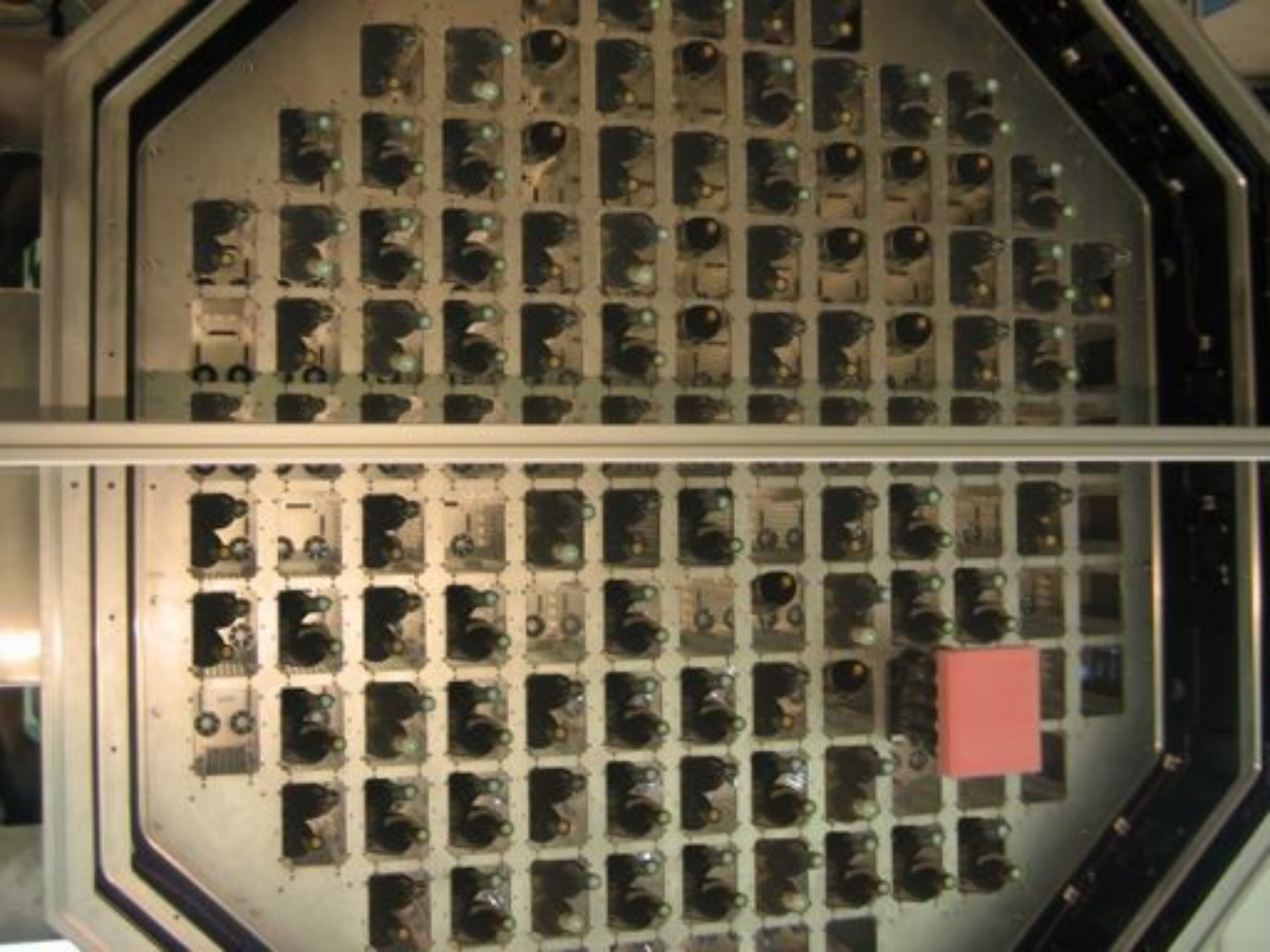
MAX-PLANCK-GESELLSCHAFT

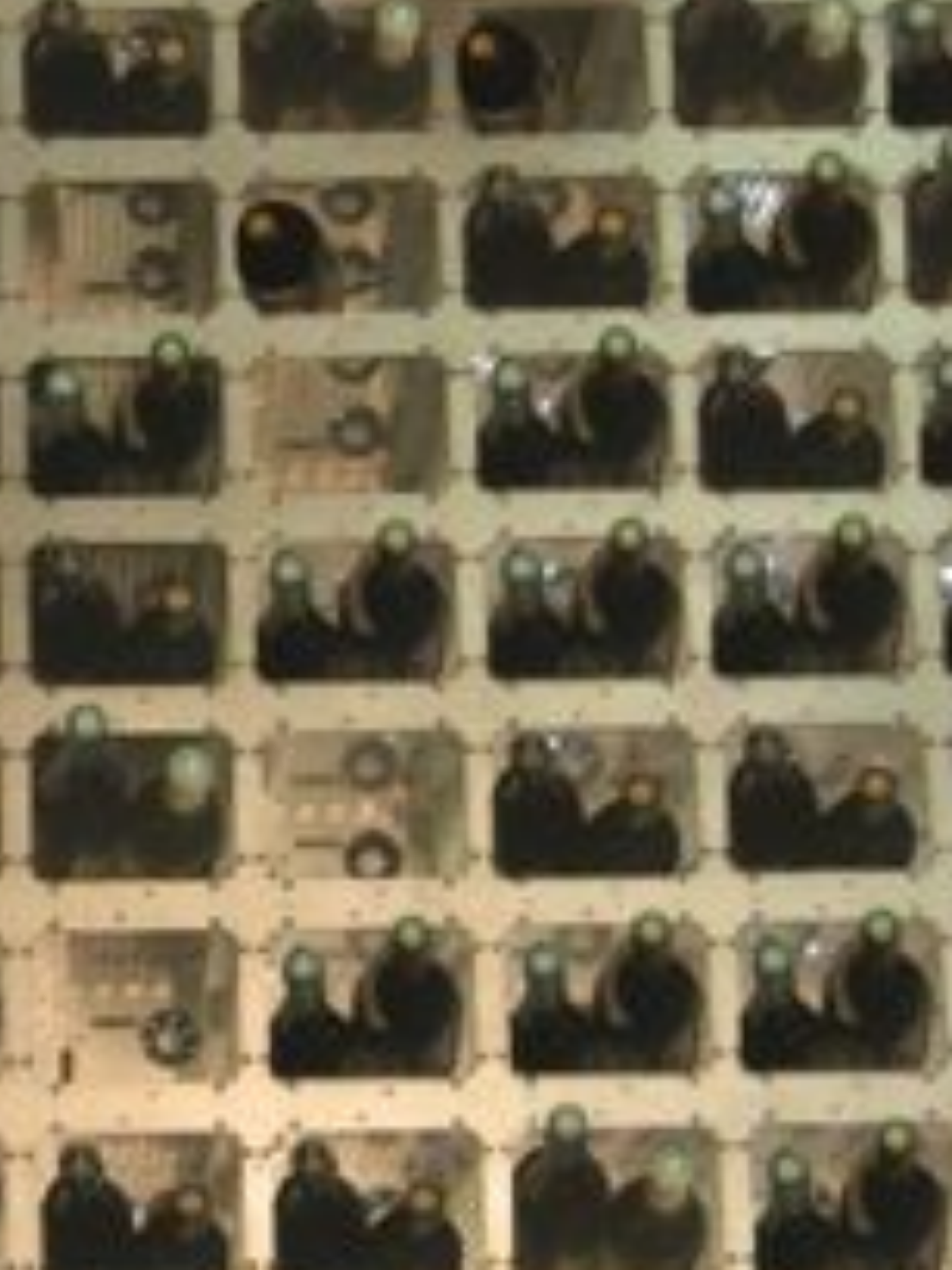
# HESS Phase II

- Sin[illegible]ne
- [illegible]
  - [illegible]
- **Construction started**
  - First light: end of 2008+

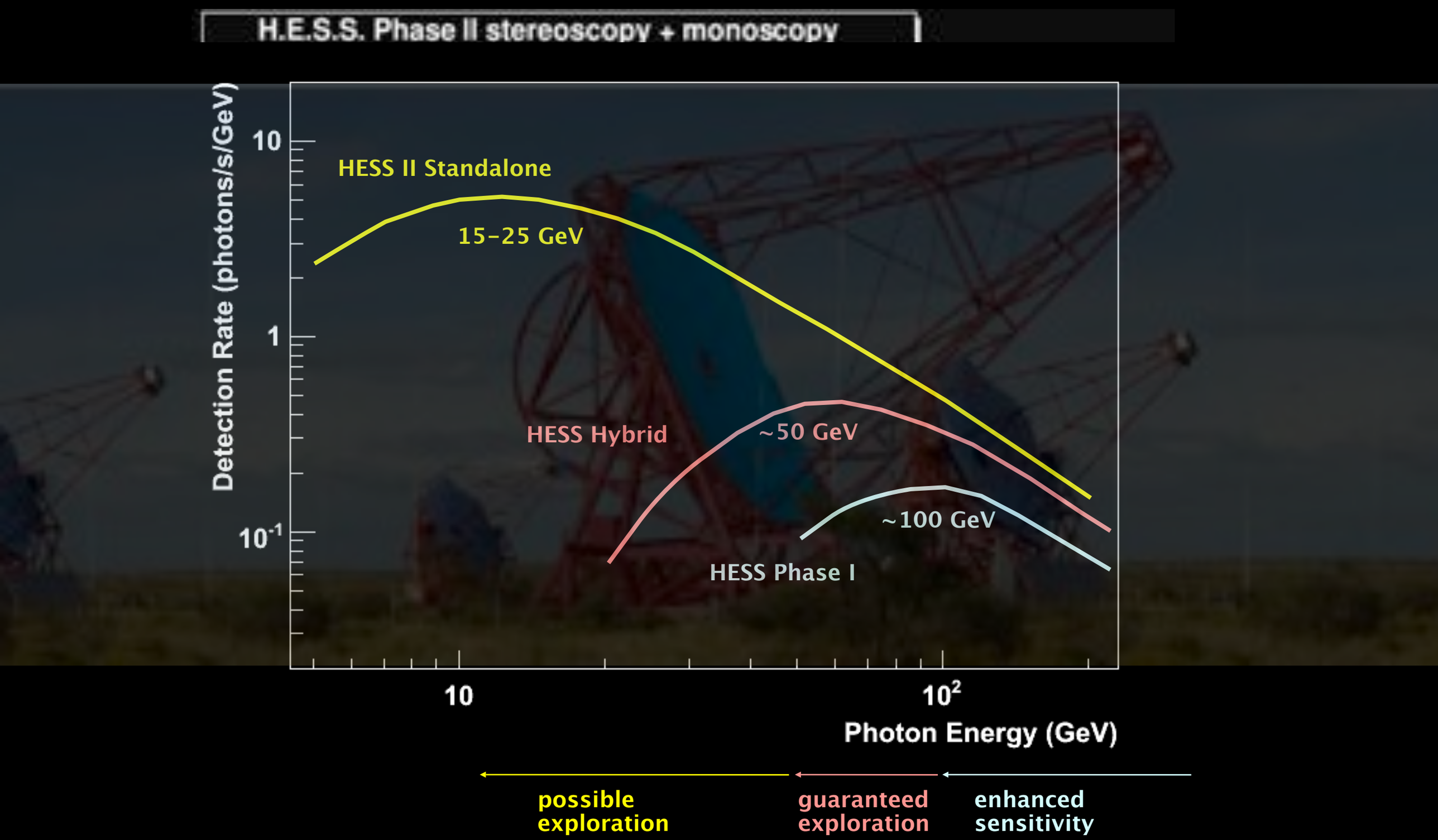








# HESS Phase II



# Conclusions

- **HESS has discovered a wide variety of VHE sources:**
  - extended, point-like, diffuse, periodic, variable, ...
  - the total number of VHE sources is now greater than 50! (close to 100 including unconfirmed hotspots)
- **VHE astrophysics is in a golden age of discovery ushered in by HESS and other next-gen ACTs**
- **Future upgrades and observatories will probe larger energy ranges and deeper**