

# The galactic very high energy $\gamma$ -ray sky: The diversity of acceleration sites revealed by H.E.S.S.

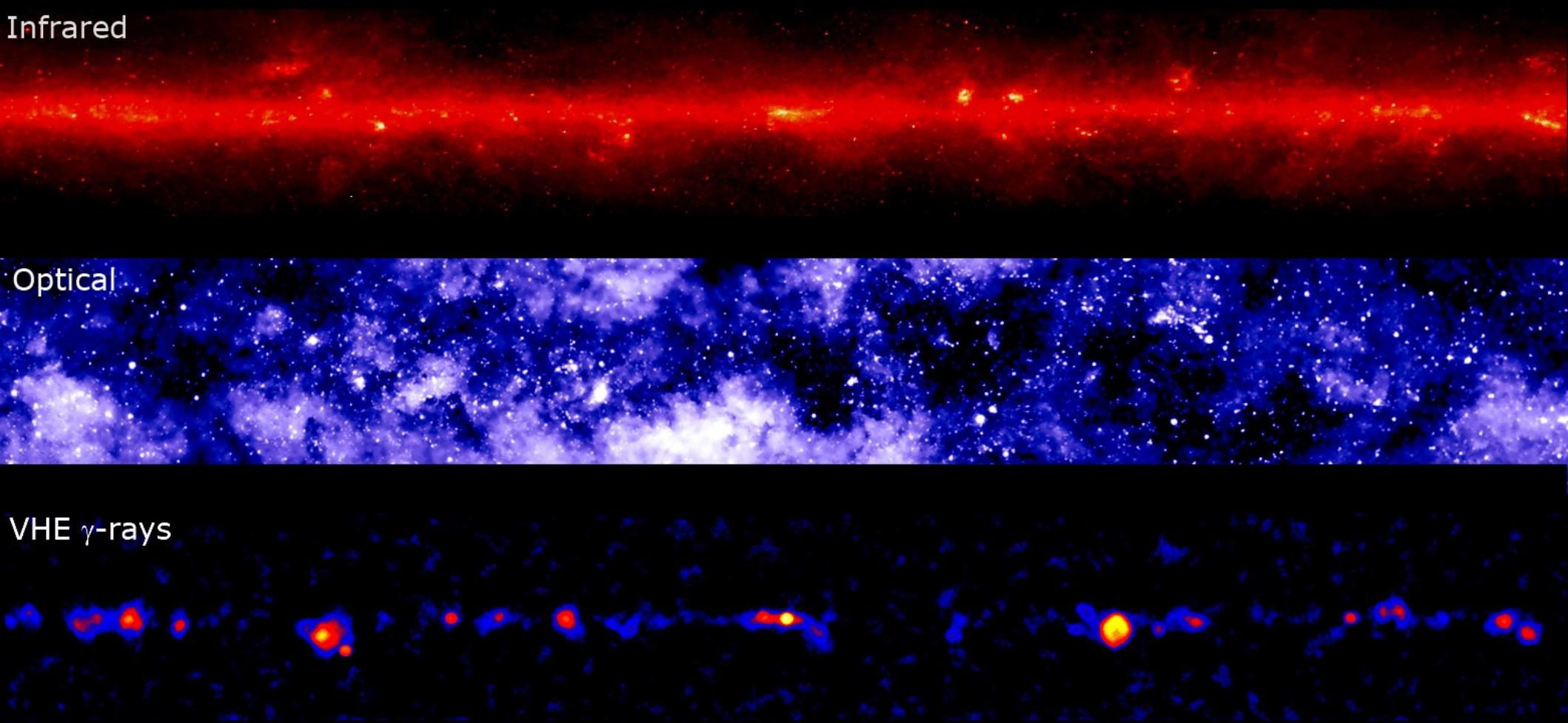
Arache Djannati-Ataï

Laboratoire d'Astroparticule et Cosmologie-APC  
CNRS, Université P7, Observatoire de Paris, CEA

Infrared

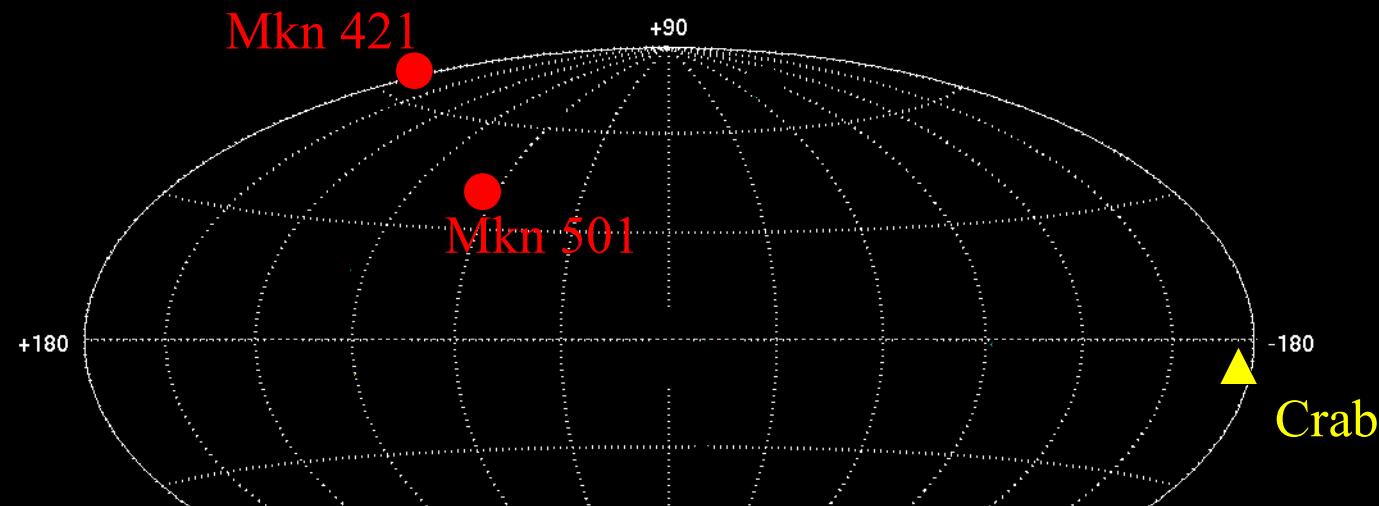
Optical

VHE  $\gamma$ -rays



# VHE $\gamma$ -ray Sky 1995

3 sources

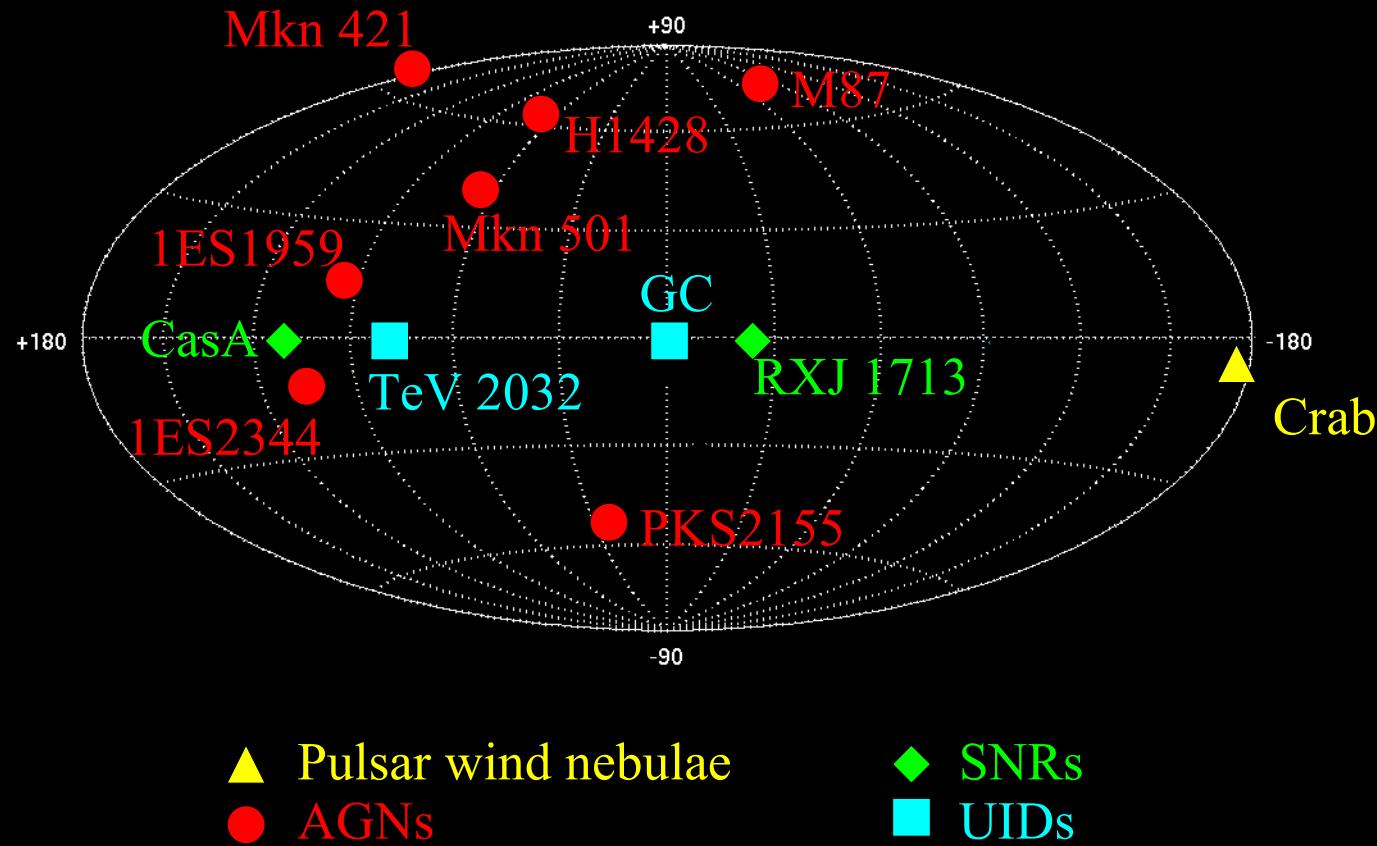


▲ Pulsar wind nebulae  
● AGNs

◆ SNRs  
■ UIDs

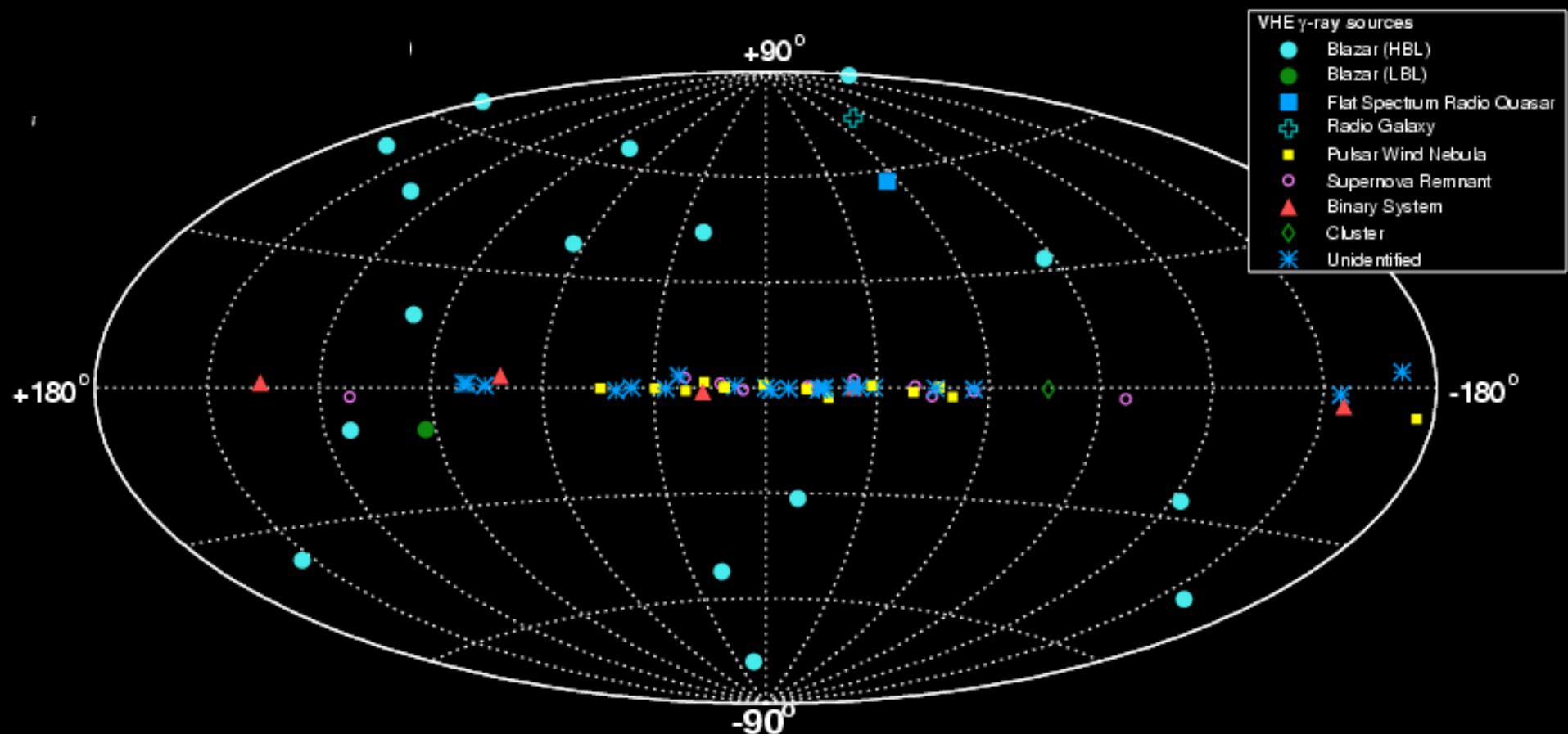
# VHE $\gamma$ -ray Sky 2003

12 sources, 6 firm detections

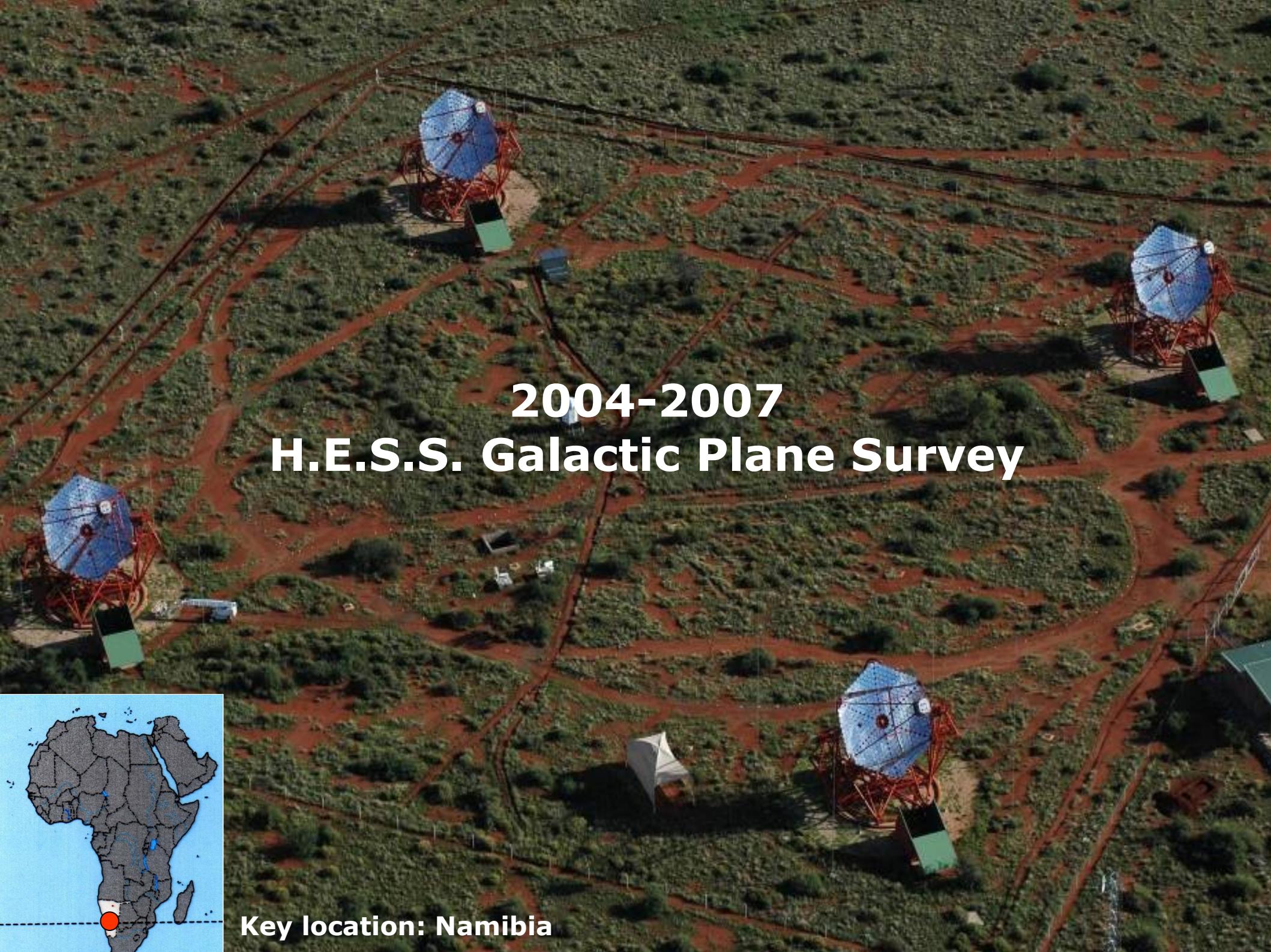


# VHE $\gamma$ -ray Sky 2008

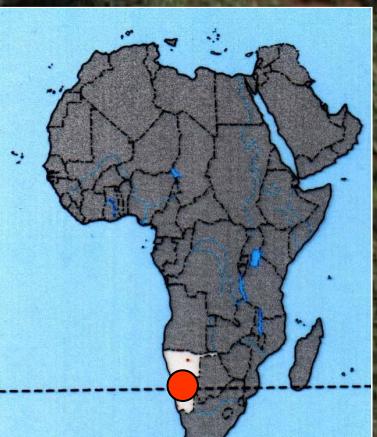
> 70 Sources



2007-09-15 - Up-to-date plot available at <http://www.mppmu.mpg.de/~rwagner/resources/>



**2004-2007**  
**H.E.S.S. Galactic Plane Survey**



**Key location: Namibia**

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

## HESS Galactic Scan 2004:

125 h  $-30^\circ < l < 30^\circ$   $-2.5^\circ < b < 2.5^\circ$

16 sources published ApJ 636

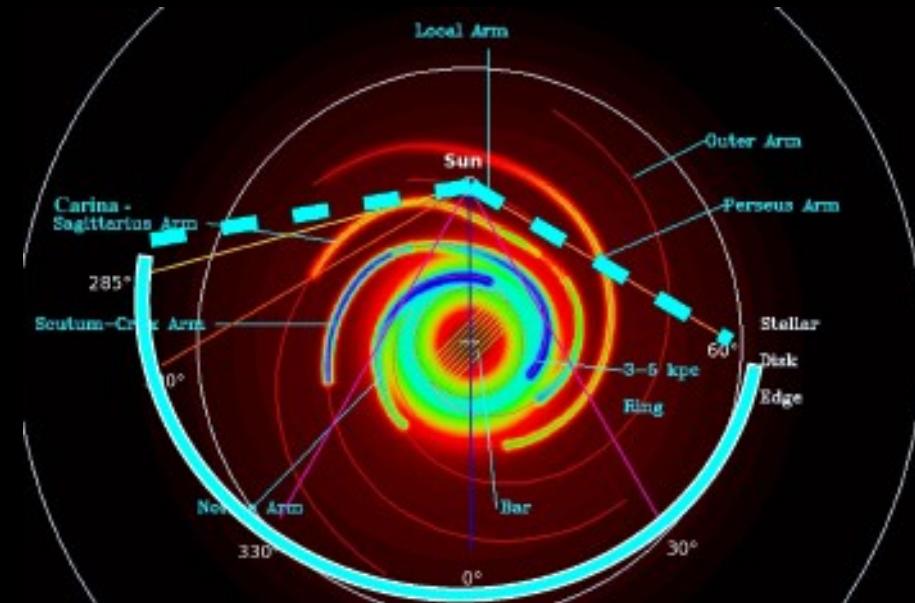
2006

14 other published separately

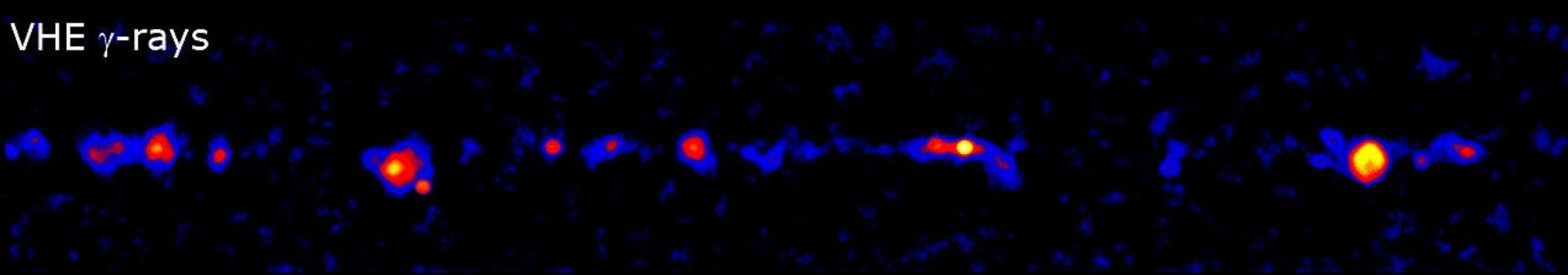
Extension 2005-2007 :

400 h  $-85^\circ < l < 60^\circ$   $-2.5^\circ < b < 2.5^\circ$

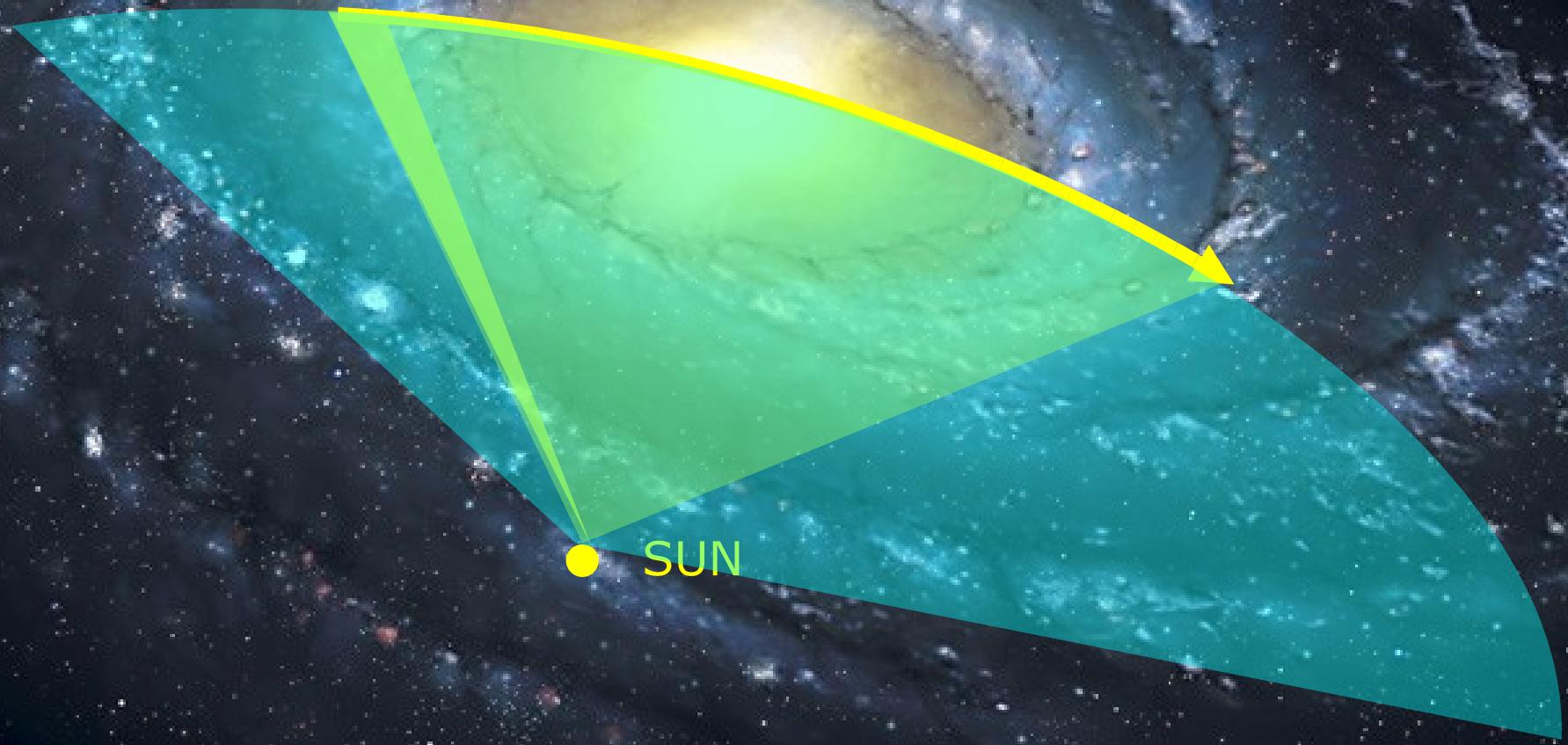
> 20 new sources discovered

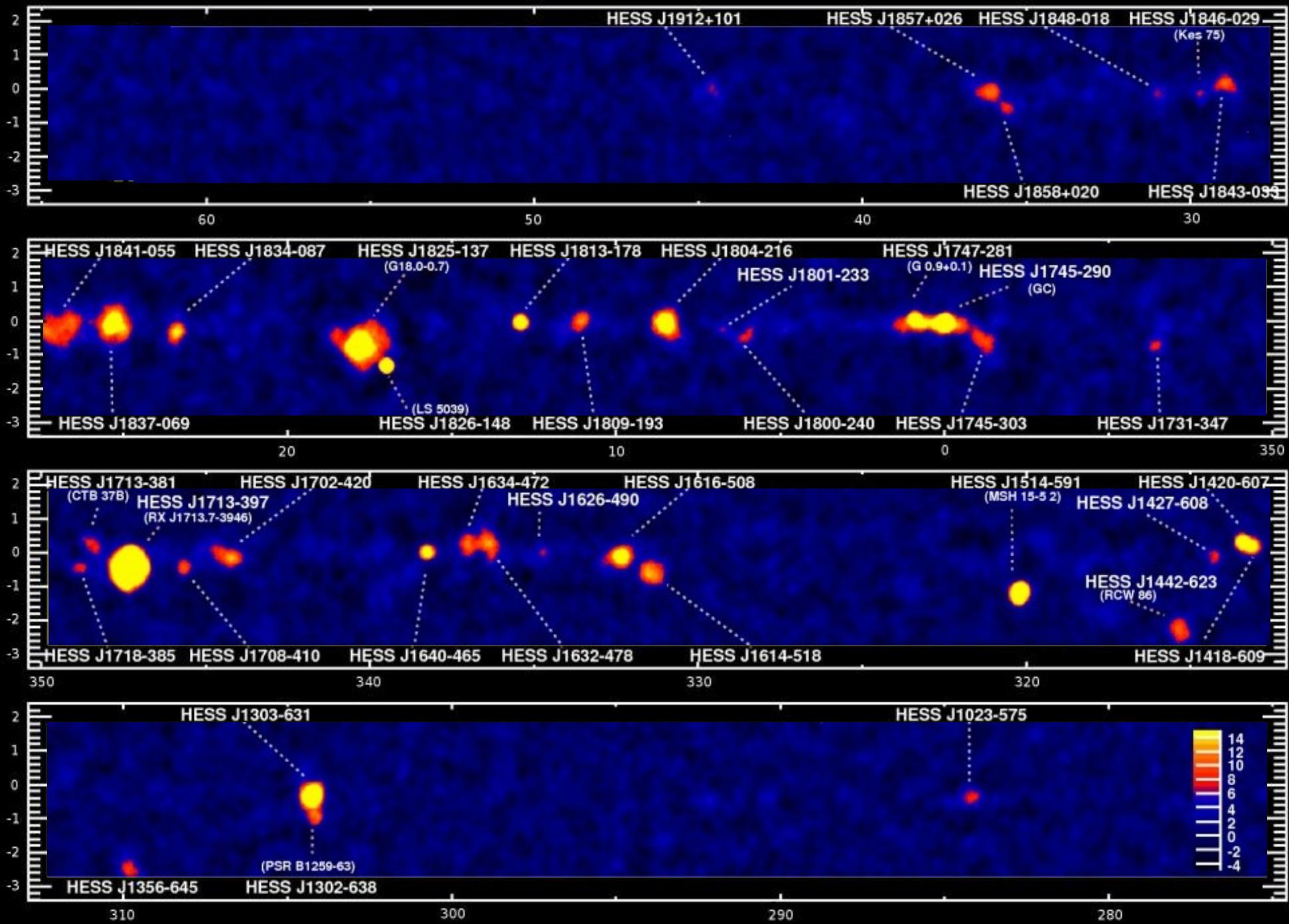


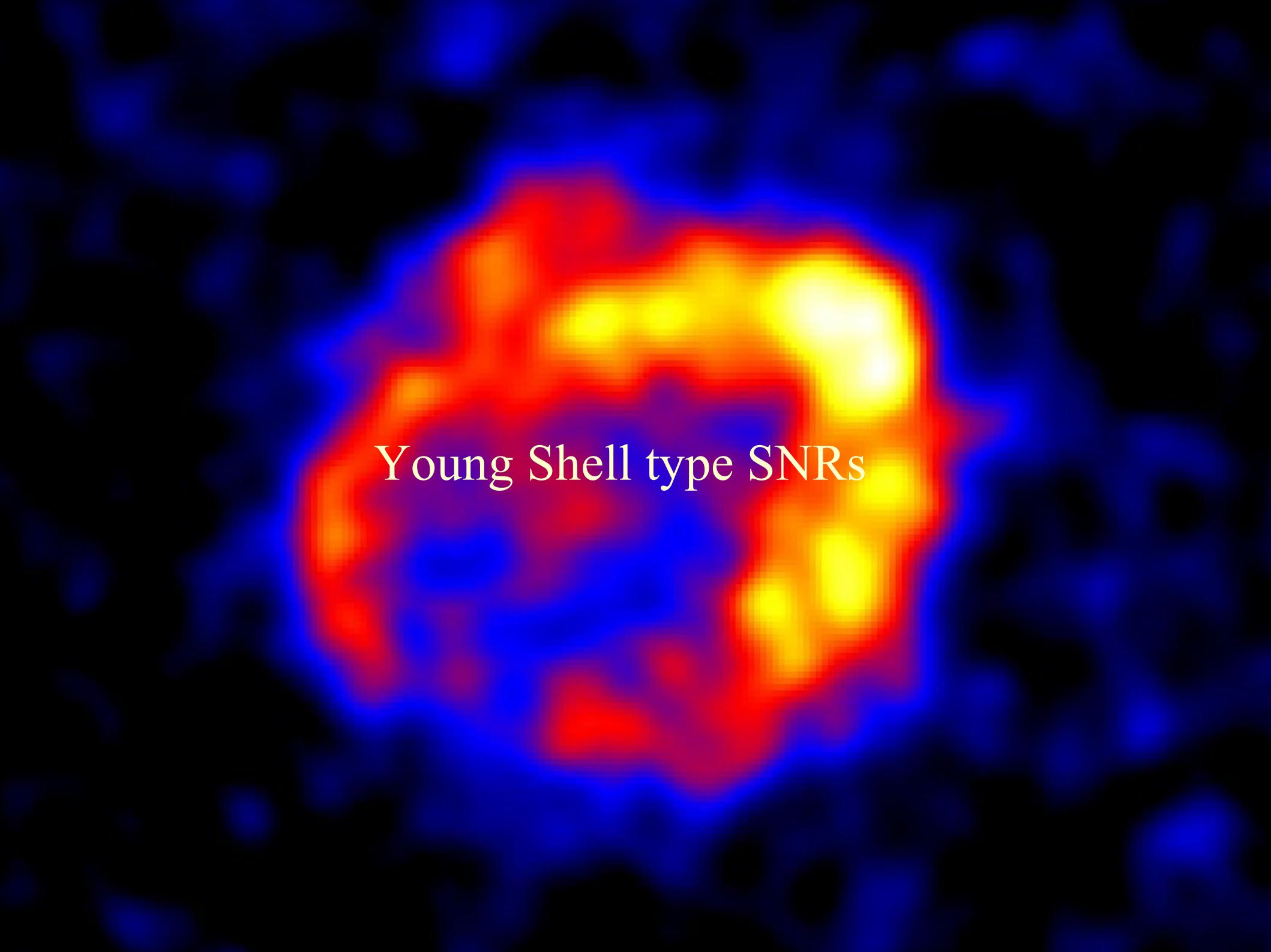
VHE  $\gamma$ -rays



# Galactic Plane Survey







Young Shell type SNRs

# Young Shell type SNRs

**RX J1713.7-3946:**  $\sim 1.3^\circ$

**1 (10) kyr : 1 (6) kpc**

**gal latitude  $b=0.5$**

**First-ever resolved  $\gamma$ -ray source**

**Strong correlation with X-rays:  $\sim 80\%$**

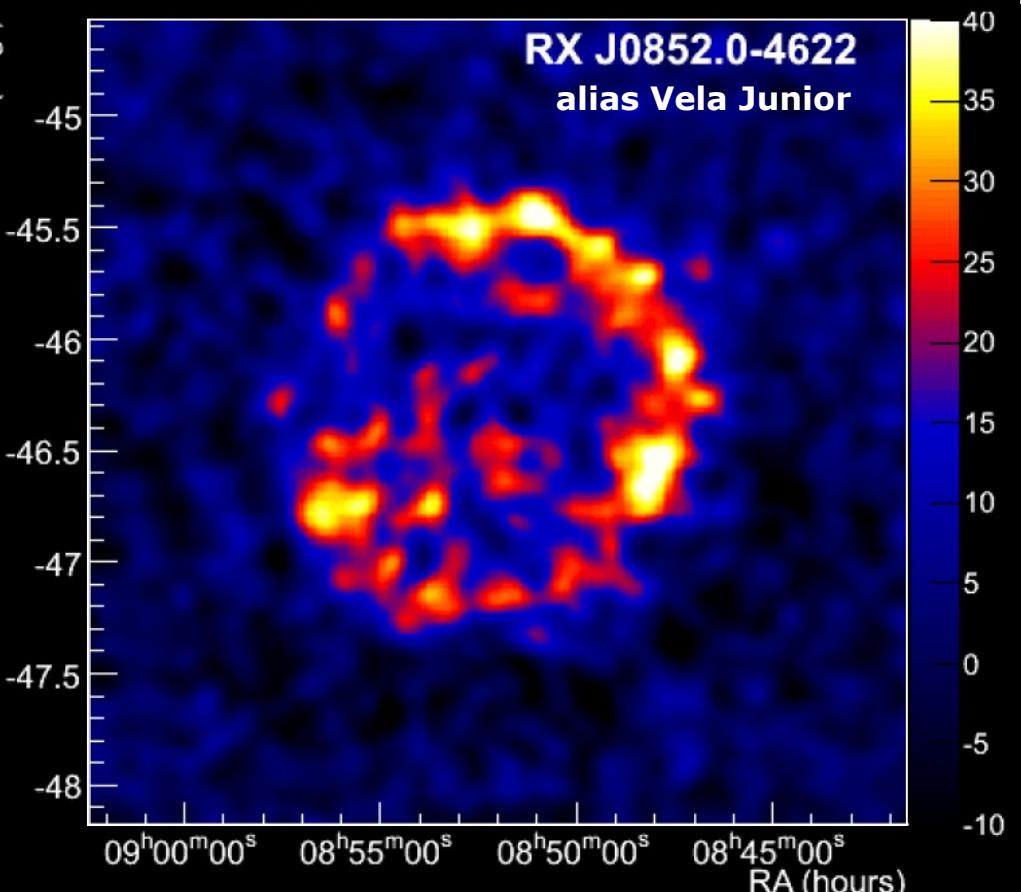
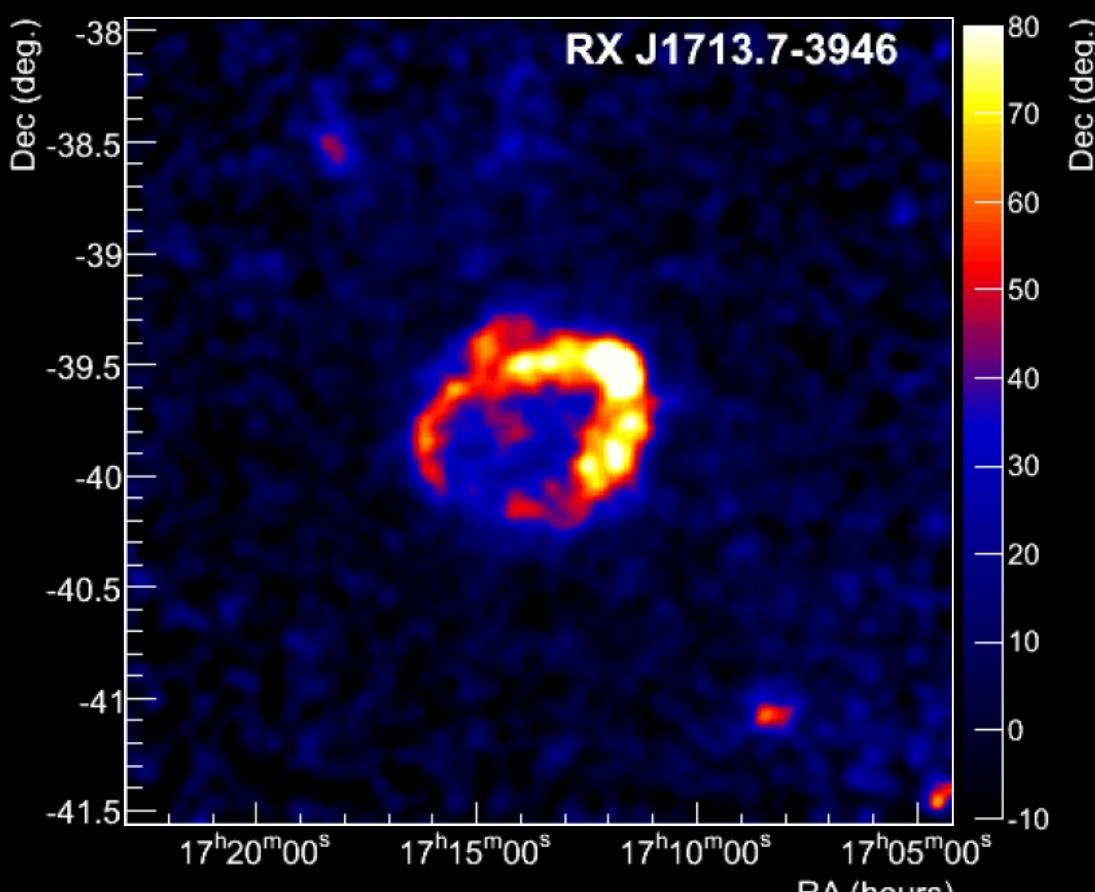
**RX J0852.0-4622:**  $2^\circ$

**0.7-1.1 kyr : 200-500 pc (1-2 kpc)**

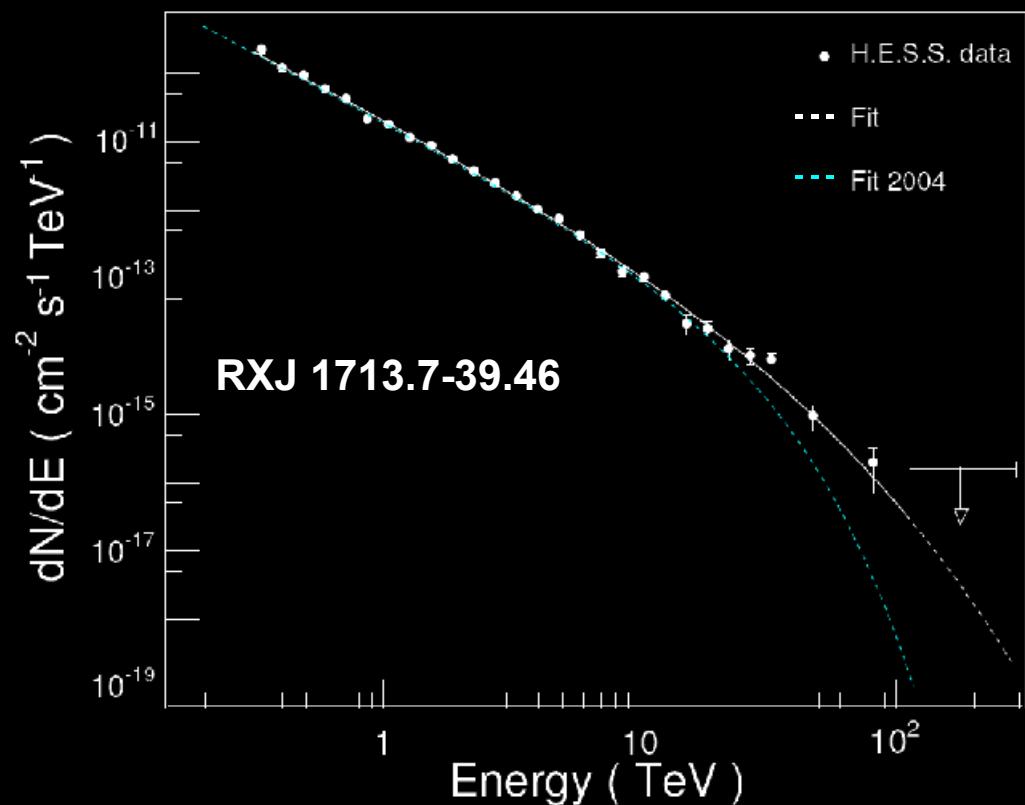
**gal latitude  $b=1.2$**

**Thin shell resolved with HESS**

**Correlation with X-rays:  $\sim 65\%$**

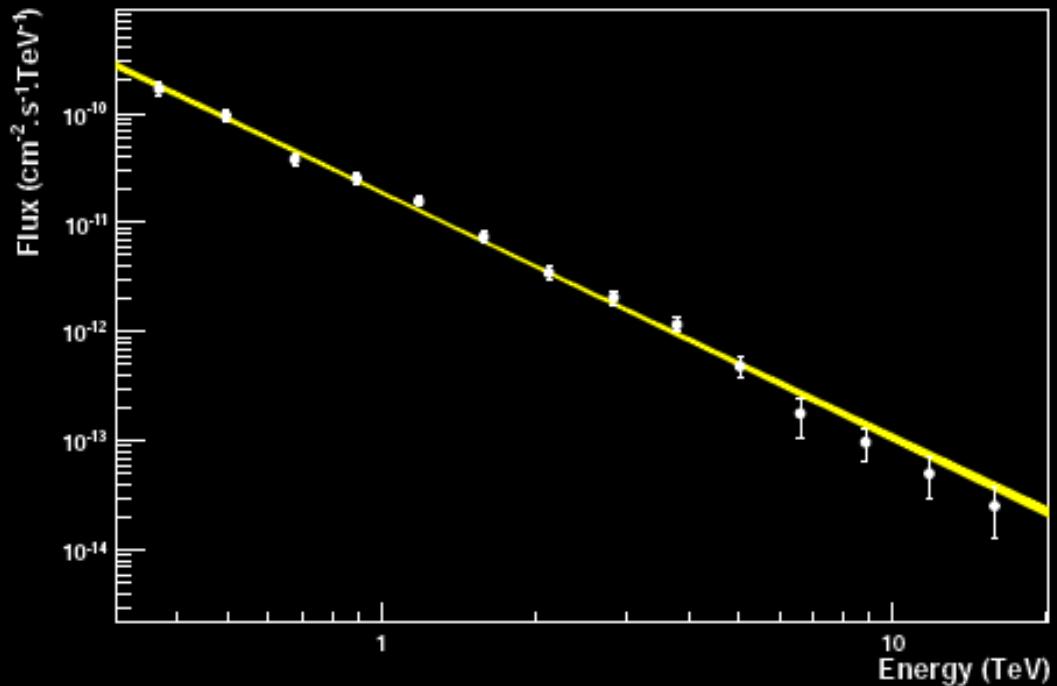


# RX J1713.7-39.46 : high energy spectrum end?



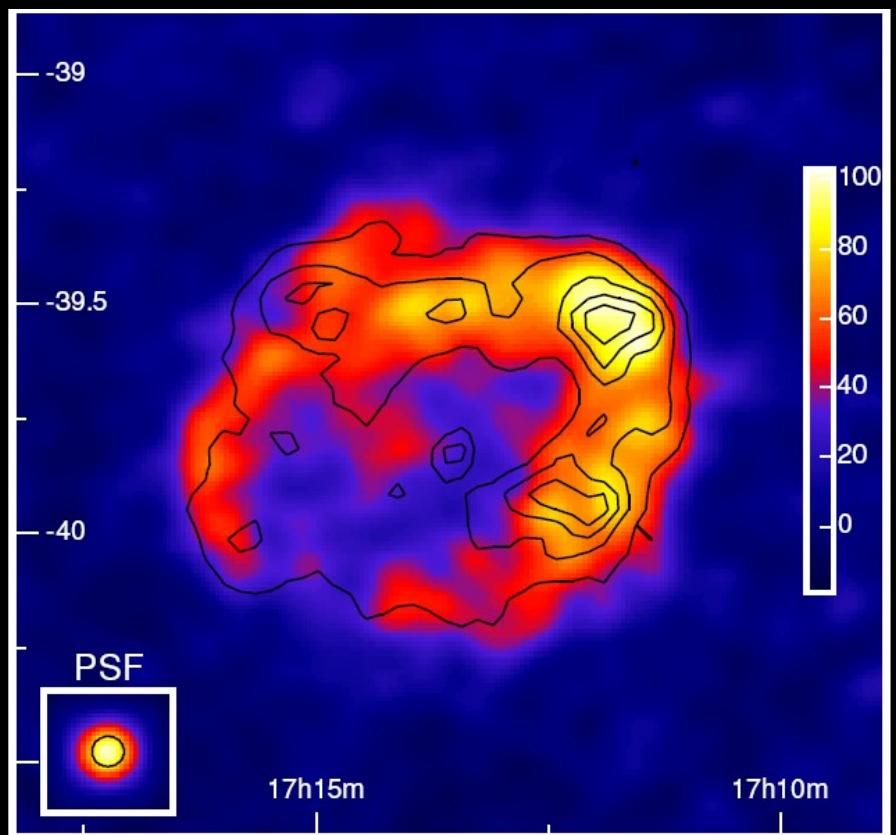
- Higher statistics :  $E > 40 \text{ TeV}$
- Particles up to  $>100 \text{ TeV}$
- If hadrons  
primary energy  $>200 \text{ TeV}$
- If leptons  
primary energy  $>100 \text{ TeV}$  (KN)
- Index  $\sim 2.1$
- Cutoff/break at  $\sim 20 \text{ TeV}$
- Constant index across SNR

# RX J1713.7-39.46 : high energy spectrum end?

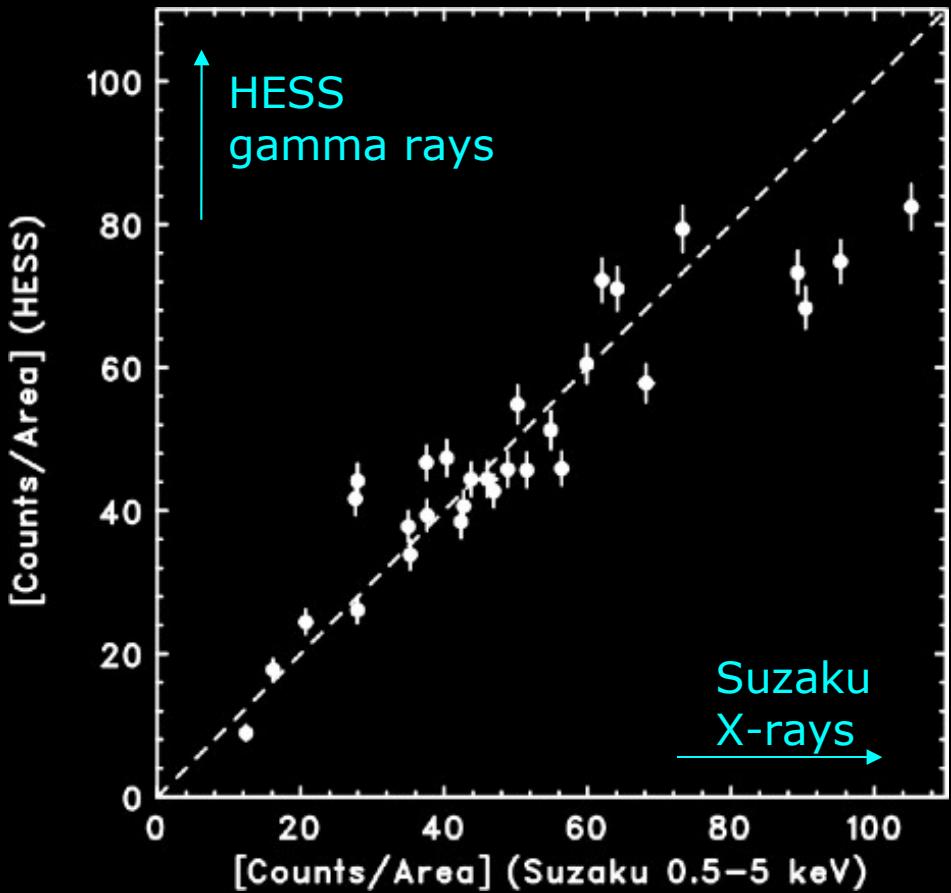


- Lower statistics :  $E \sim 20 \text{ TeV}$
- Index  $\sim 2.1$
- Cutoff/break ?
- Index variation across SNR?

# X-ray vs $\gamma$ -ray correlations



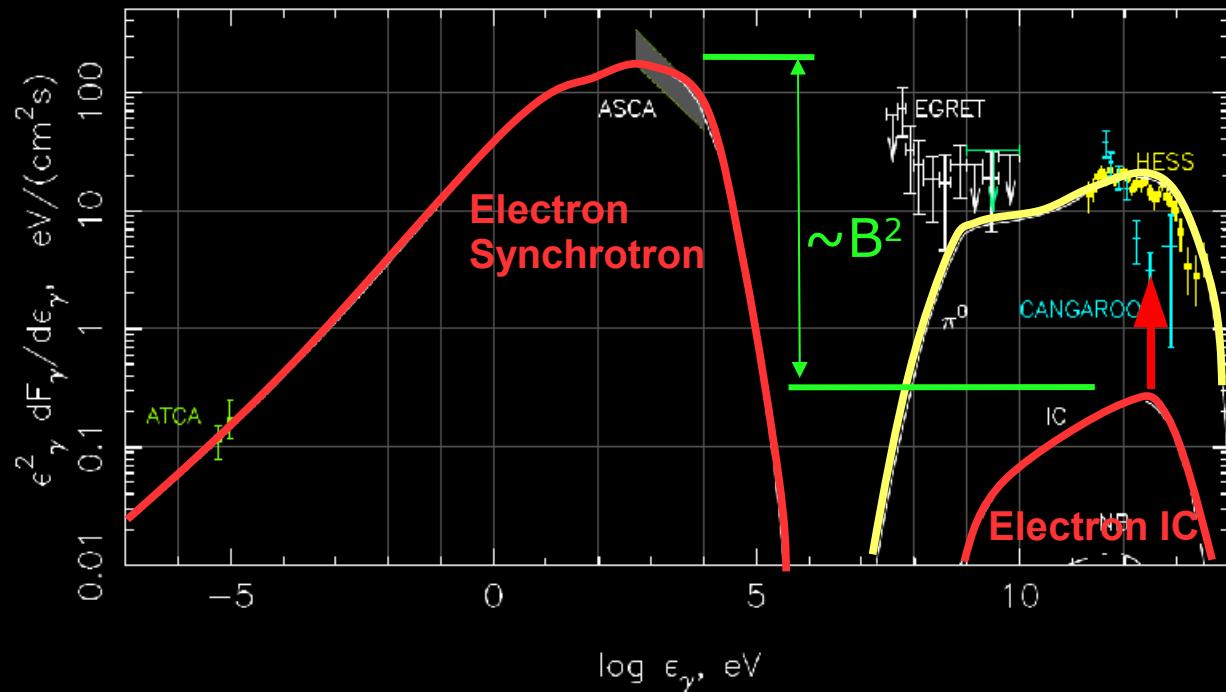
Contour lines: ASCA X-rays  
Y. Uchiyama et al. 2002



- Very close morphologies for X-ray &  $\gamma$ -ray
- 80% Correlation
- What does that mean?  
Leptonic domination?

- TeV (if hadronic) **protons  $\otimes \rho_{\text{gas}}$**
- keV (electrons) **electrons  $\otimes B^2$**
- TeV (if electrons) **electrons  $\otimes U$**
- **e/P ? B?**
- **$\rho_{\text{gas}}$ ?**
- etc

# Hadronic vs Leptonic emission: B-field strength



$$B = 126 \mu G$$

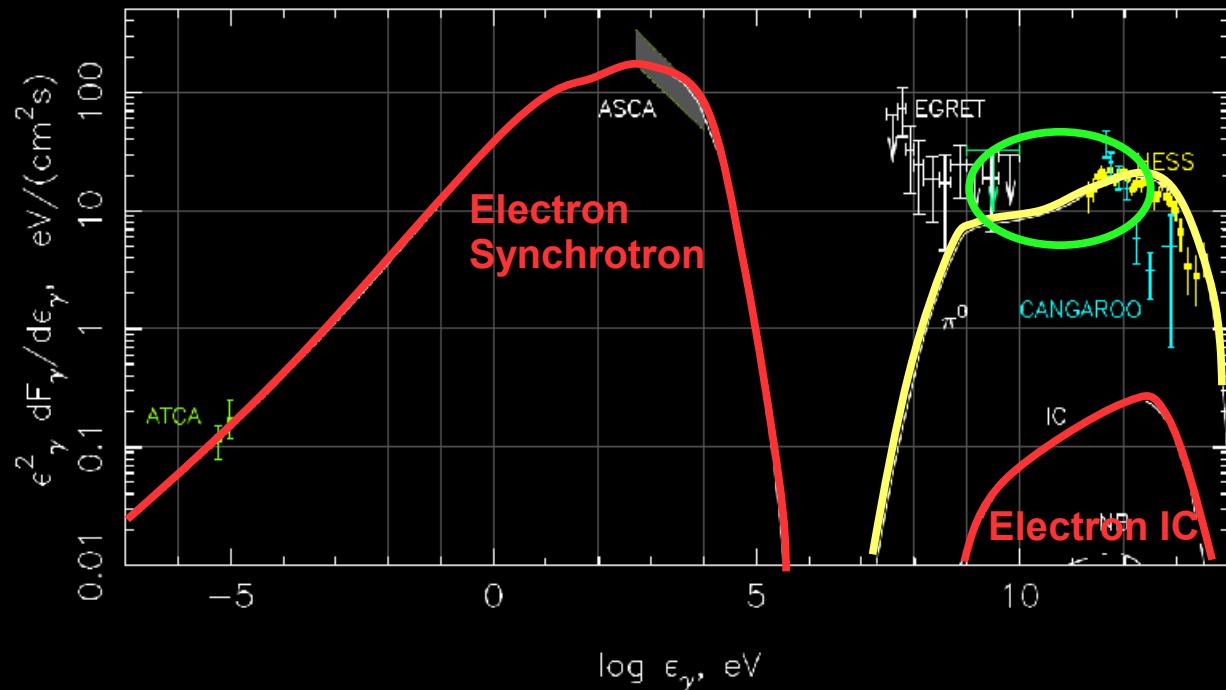
$$e/p = 10^{-4}$$

$$B \sim 10 \mu G$$

$$\begin{aligned} d &= 1 \text{ kpc} \\ E &= 1.8 \cdot 10^{51} \text{ erg} \\ M &= 3.5 M_\odot \\ \rho(r) &= 0.01 \dots \\ &10 \text{ cm}^3 \end{aligned}$$

- High B-fields suppress IC emission
- Non-linear effects of efficient CR acceleration can lead to B-field amplification (e.g. thin filaments in SN1006)

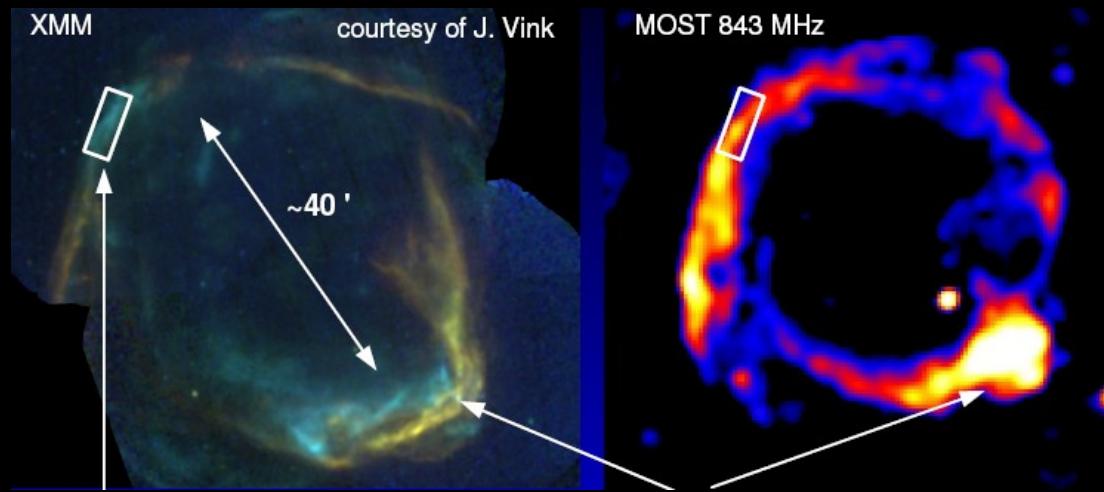
# B-field amplification signature?



- Lower energy particles do not experience the same shock front
- Acceleration less efficient
- Expect a dip in the power output

# New source : RCW86

**~1kyr young 40' Shell**

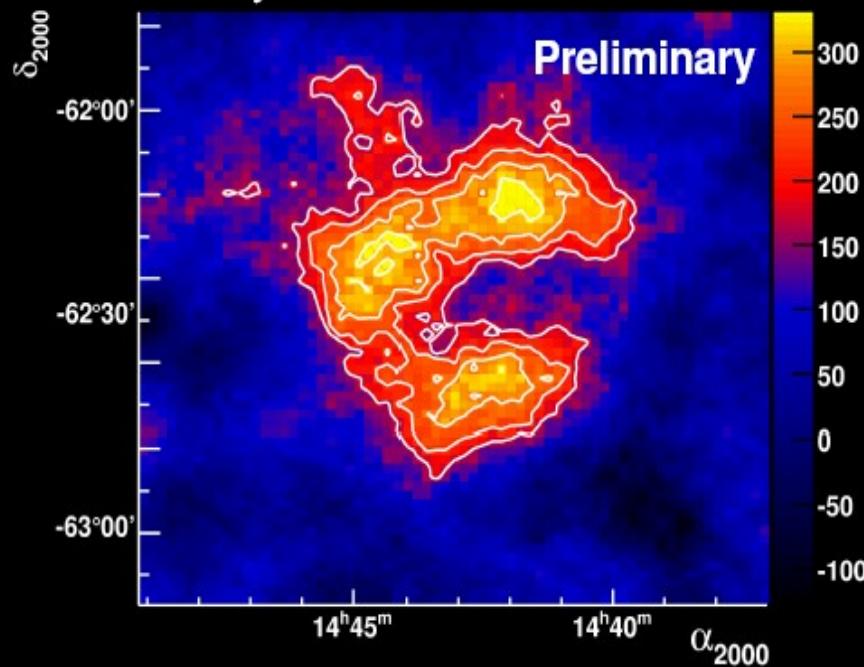


radio & X-ray synchrotron

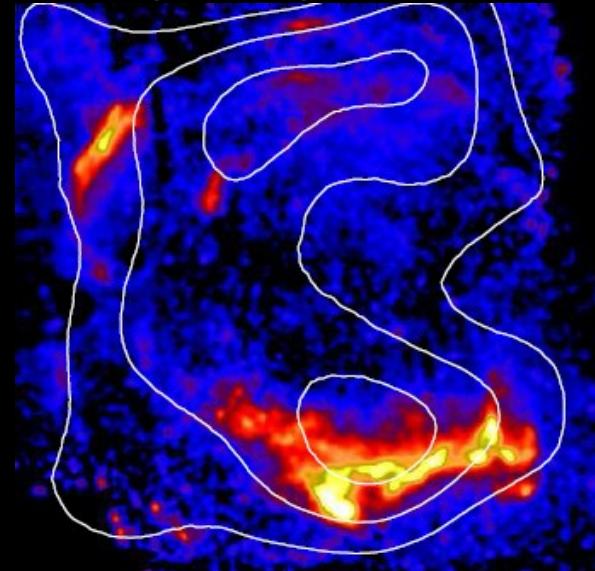
Expanding shell interacts with compact region

**Possibly associated to SN185**  
**Large density contrasts across SNR (N-S)**  
**1-2.8kpc : 1-10 kyr**  
**If TeV=IC B~30 $\mu$ G**

Model-analysis

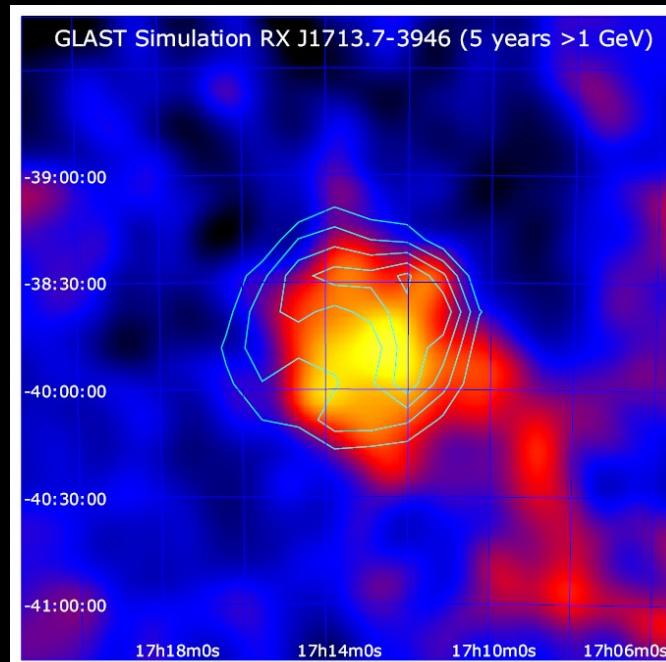
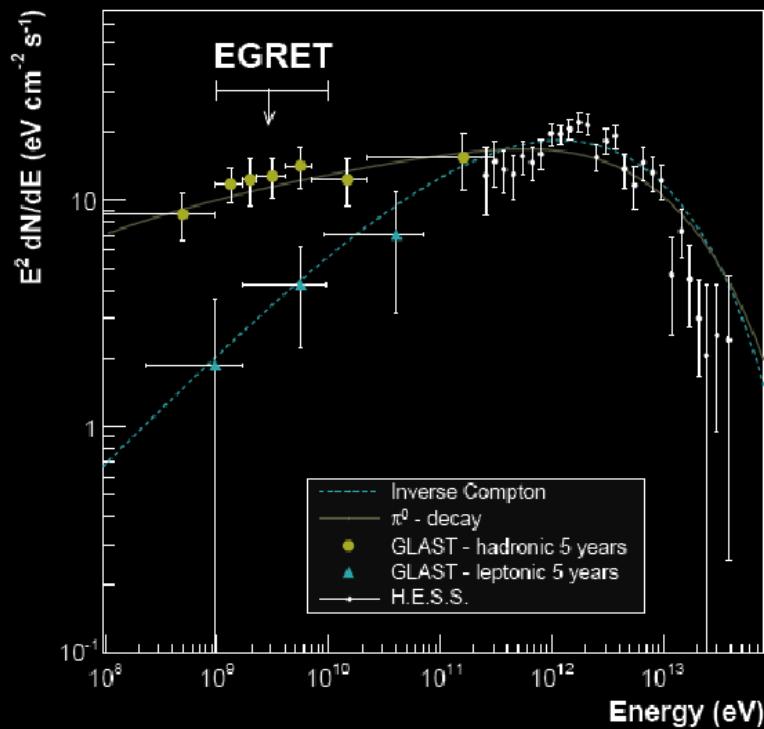


XMM (3-6 keV) + HESS Contours



# What will GLAST and v's tell us ?

**5 years, >1 GeV**



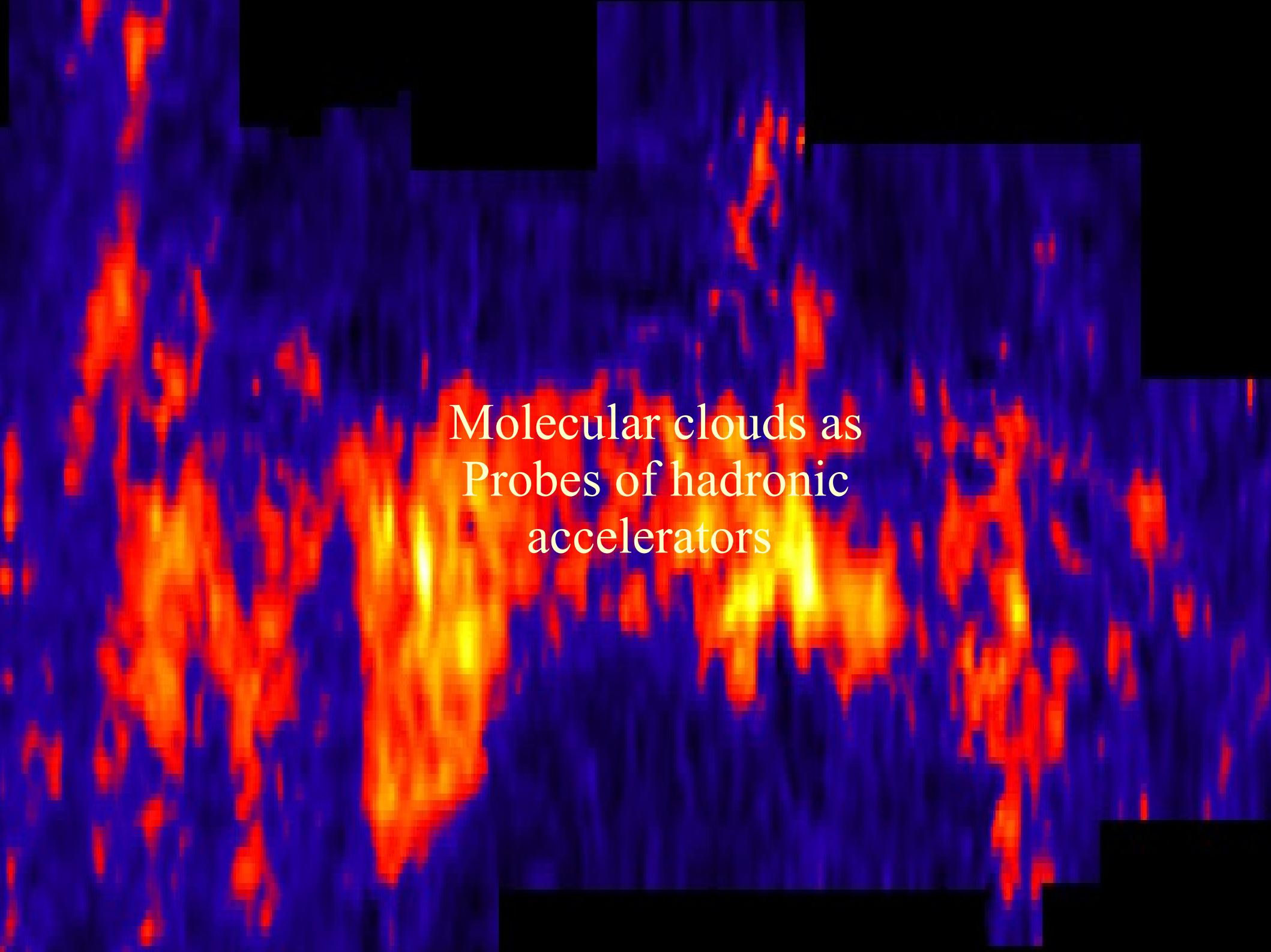
[S. Funk et al. 2007]

- Rather difficult source for GLAST:  
A 5xbright Egret source nearby
- Expected v rates (KM3NET, 5 yrs)

[A. Kappes et al. astro-ph/0607286v3] :

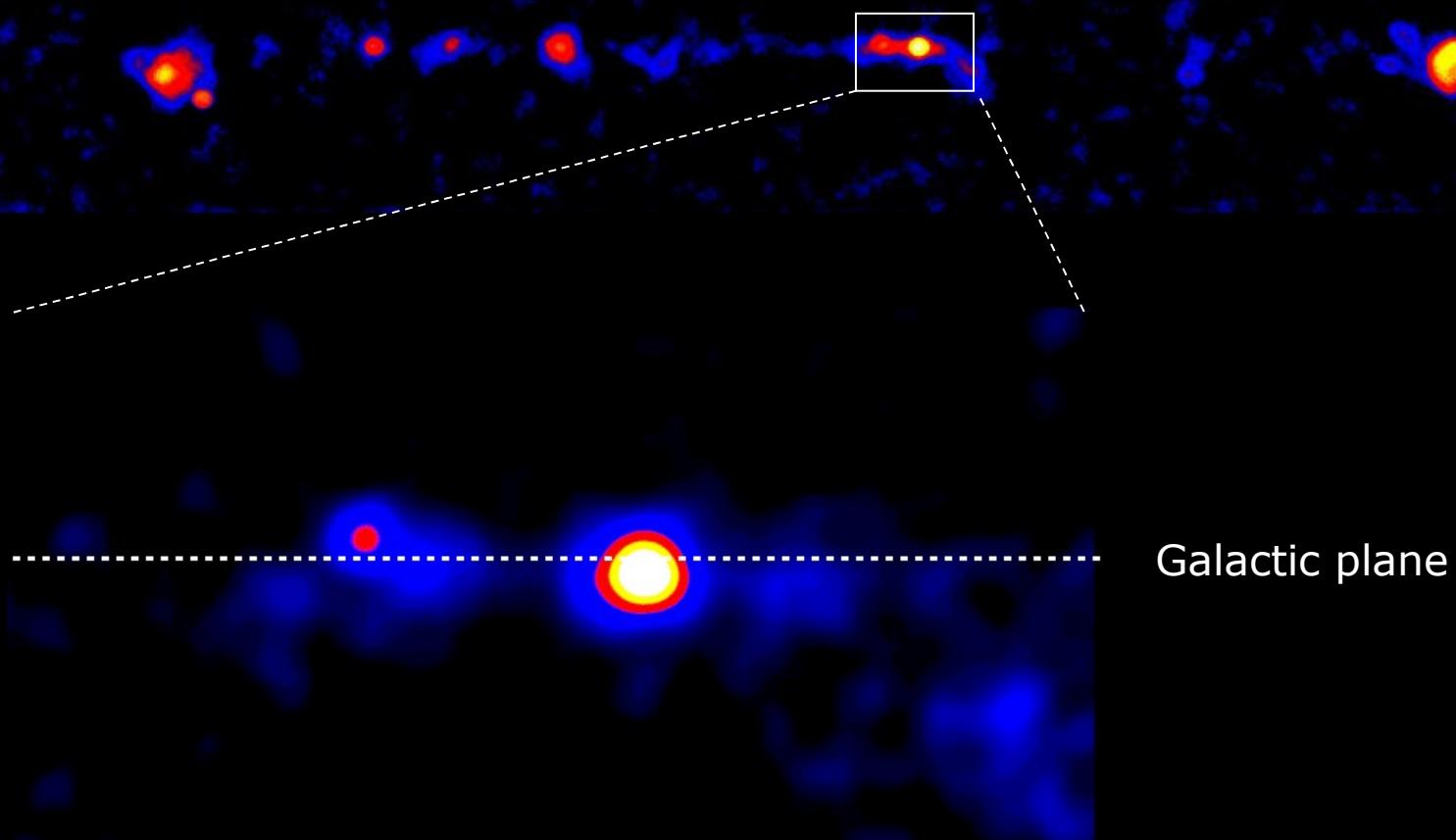
$E > 1$  TeV      11 over 41 bg. : 5 over 15 after reconstruction

$E > 5$  TeV      5 over 8 bg.

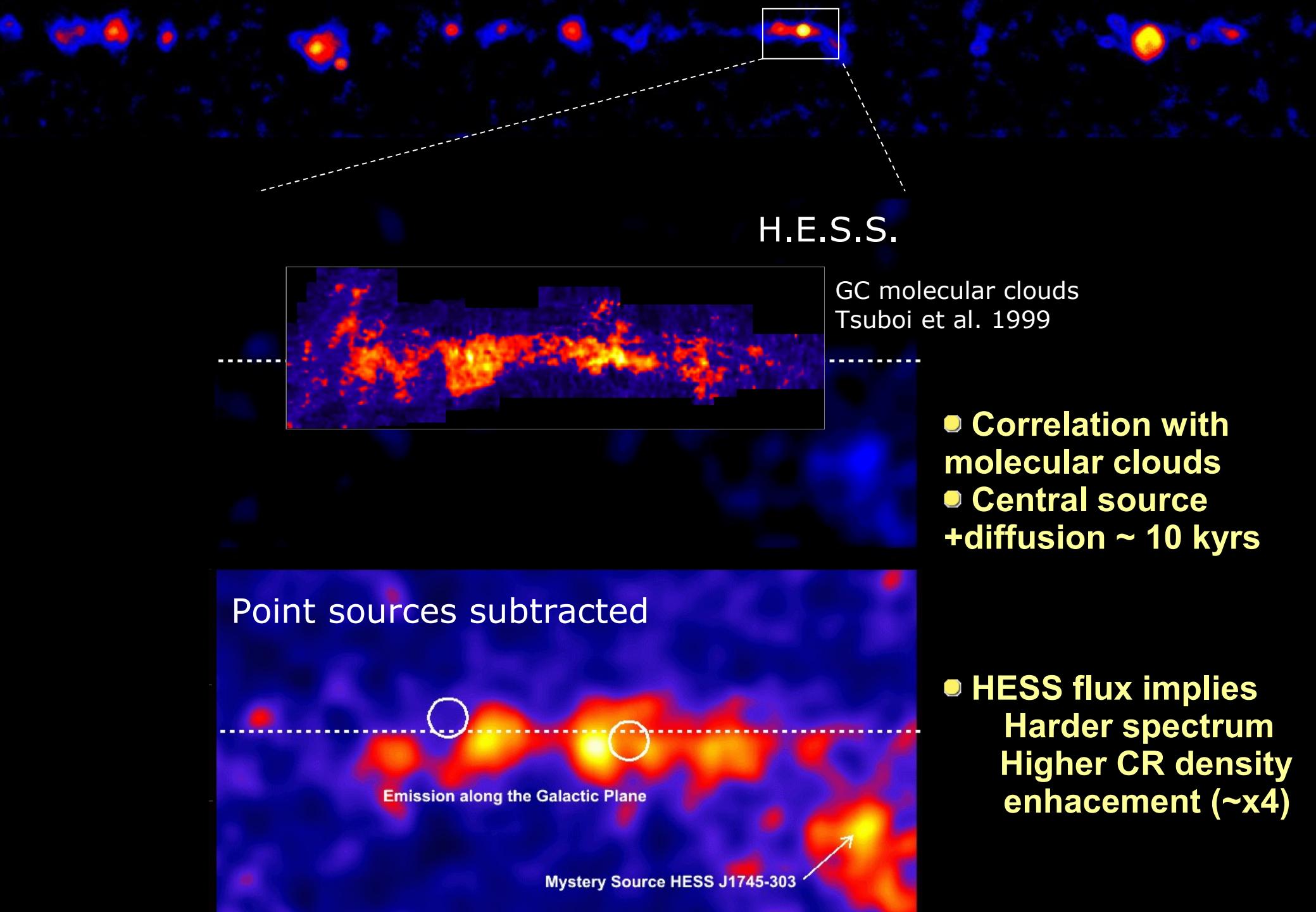


# Molecular clouds as Probes of hadronic accelerators

# The Galactic Center



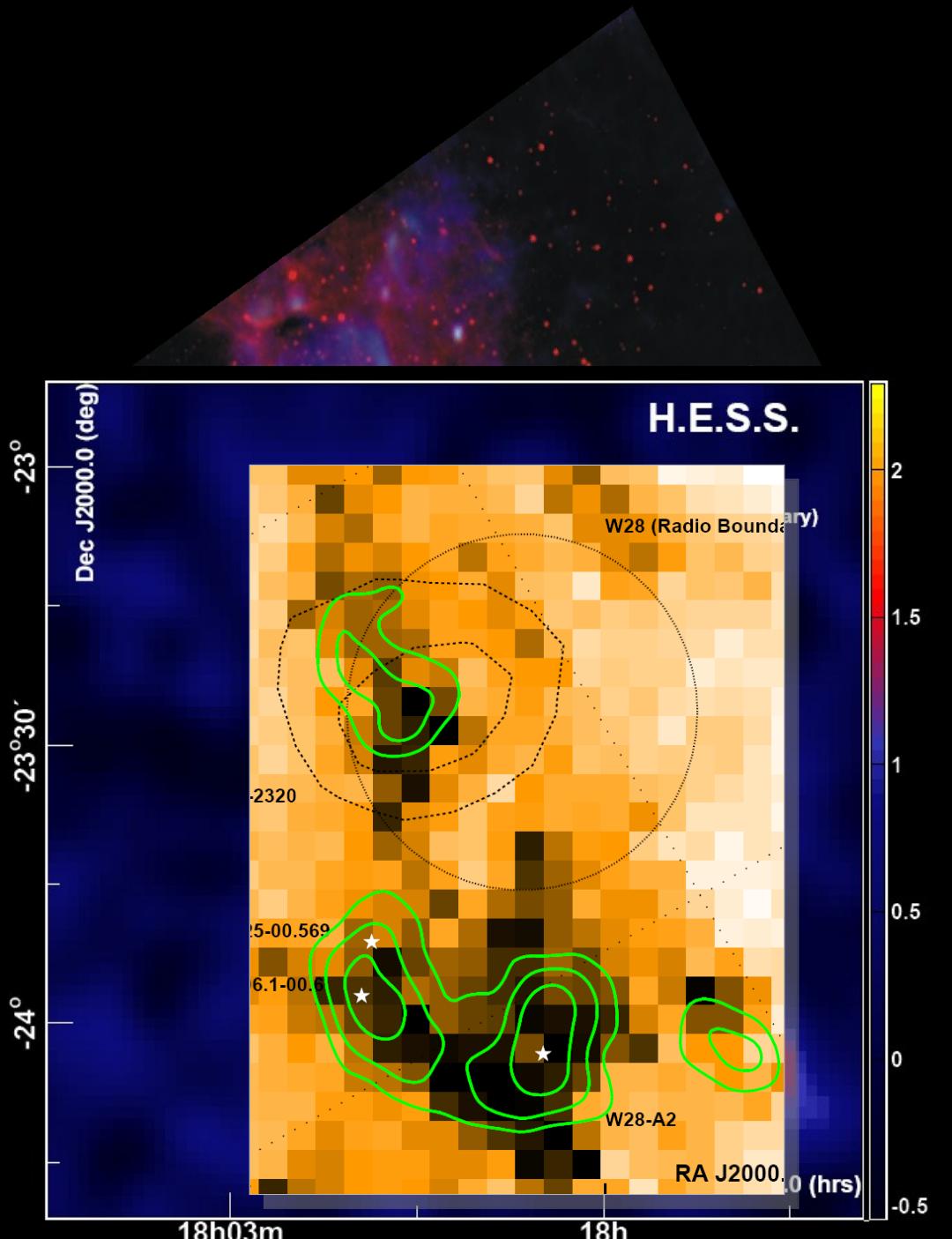
# The Galactic Diffuse emission @ central 100 pc



# Older Shell type SNRs : W28

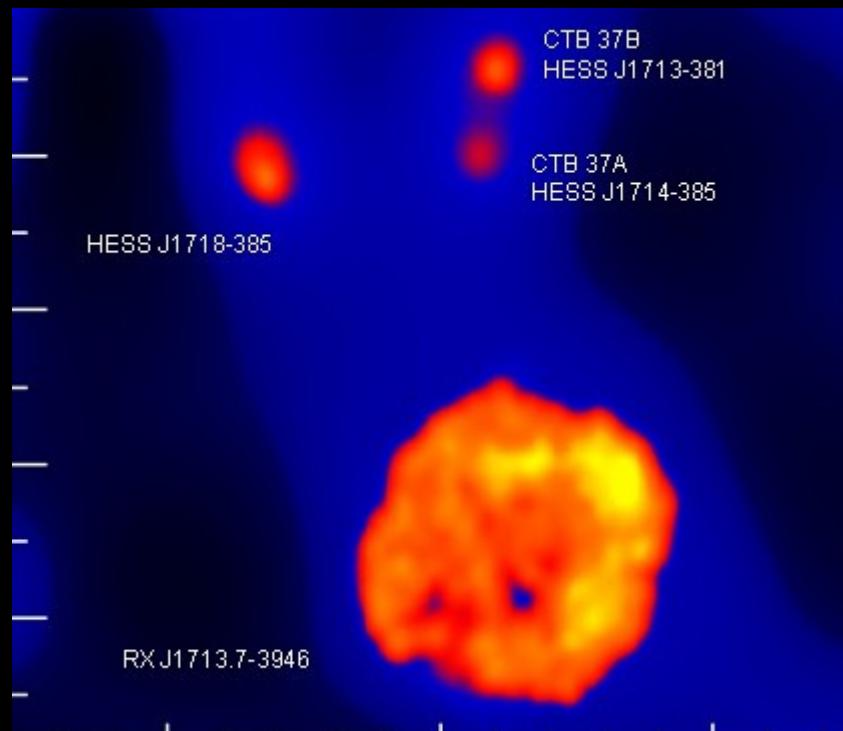
- W28 @ 2-3 kpc
- 35 – 150 kyr age

- TeV emission coincident with molecular clouds revealed by HESS
- Index varies 2.3-2.7
- OH masers trace shocks
- Expected B-field high →
- First evidence for p-p in SNR/ cloud interaction
- If @2kpc Implies 10-30 times CR enhancement wrt Solar System
- These CRs may be supplied by W28



# SNR Complex CTB37

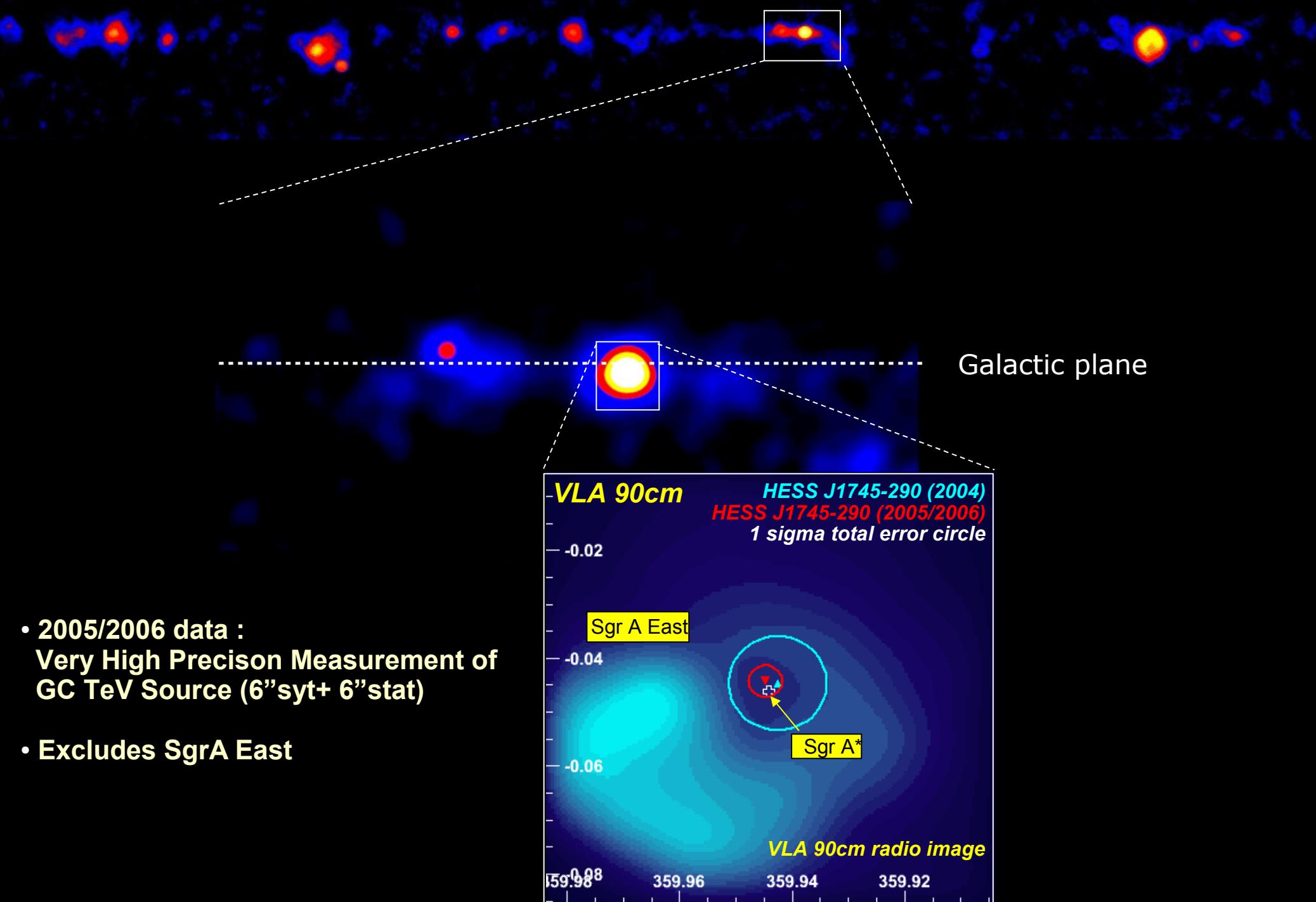
- CTB37B 5' shell
- 5-10 kpc
- 1500 – >10000 yr age
- TeV emission coincident with molecular clouds but extends beyond
- Several scenarios & candidates
- Some portion of VHE could trace CRs
- See Talk by Armand Fiasson





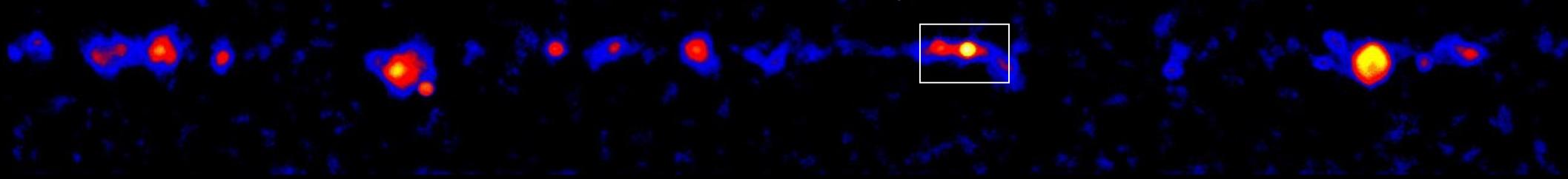
The Galactic Center

# The Galactic Center



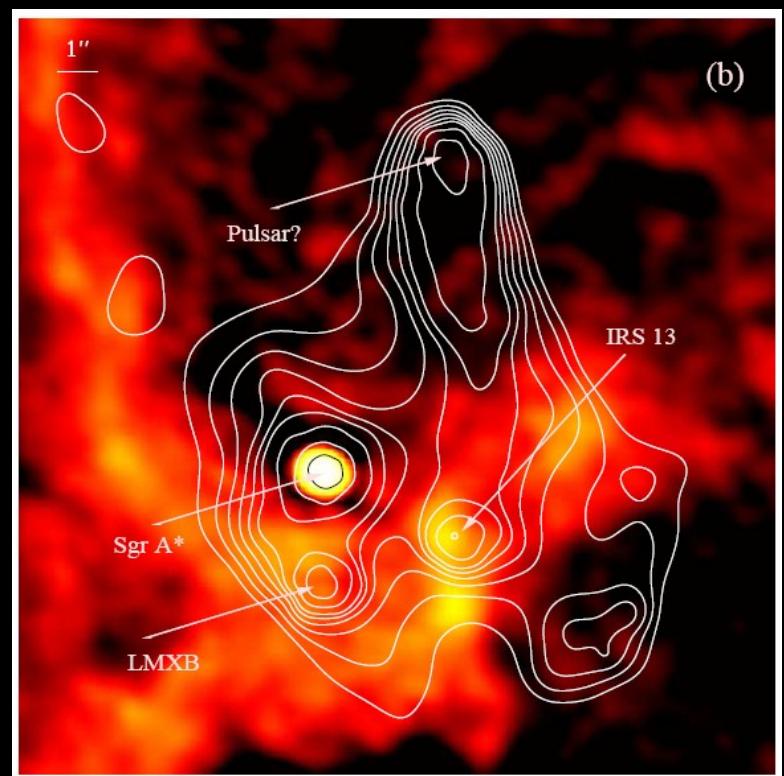
- 2005/2006 data :  
Very High Precision Measurement of  
GC TeV Source (6" syst + 6" stat)
- Excludes SgrA East

# ORIGIN OF GC TeV Gamma-Rays?



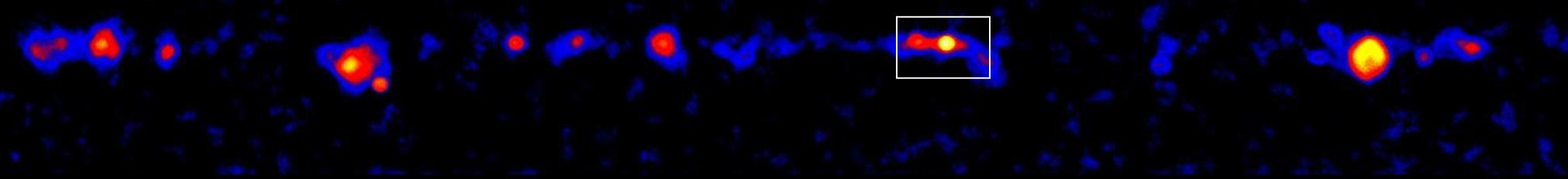
Normal :

- Curvature radiation of UHE protons near SgrA\* ?
- Shocks in SgrA\* accretion flow or wind?
- Decaying UHE neutrons?
- The PWN G359.95-0.04?



Chandra contours  
Weng et al. 2005

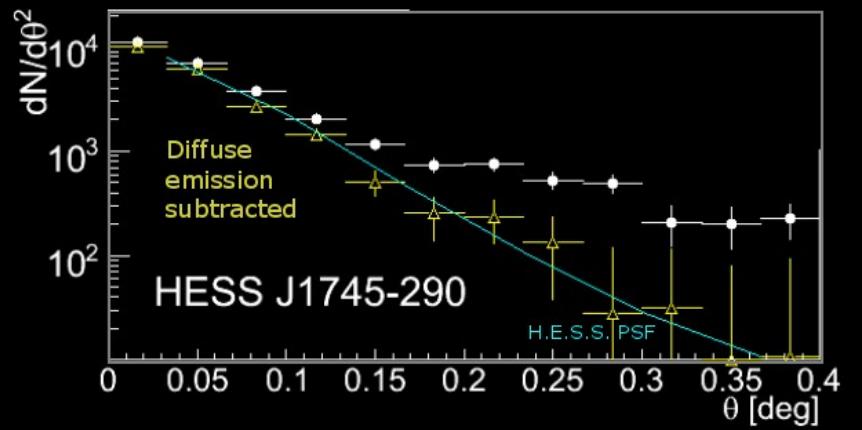
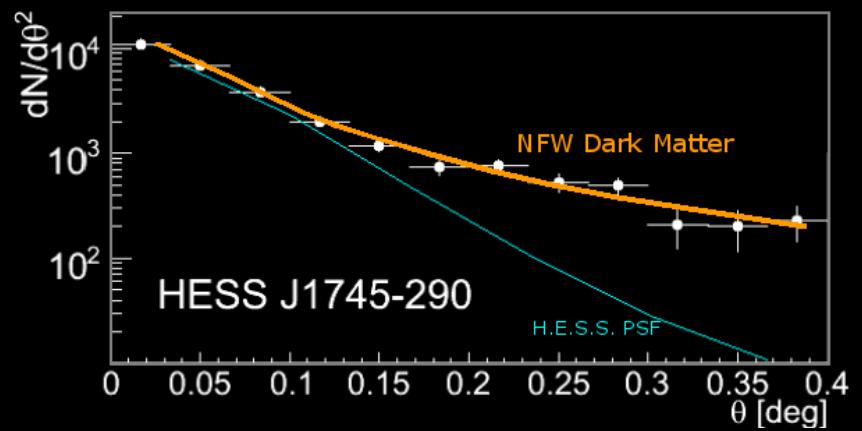
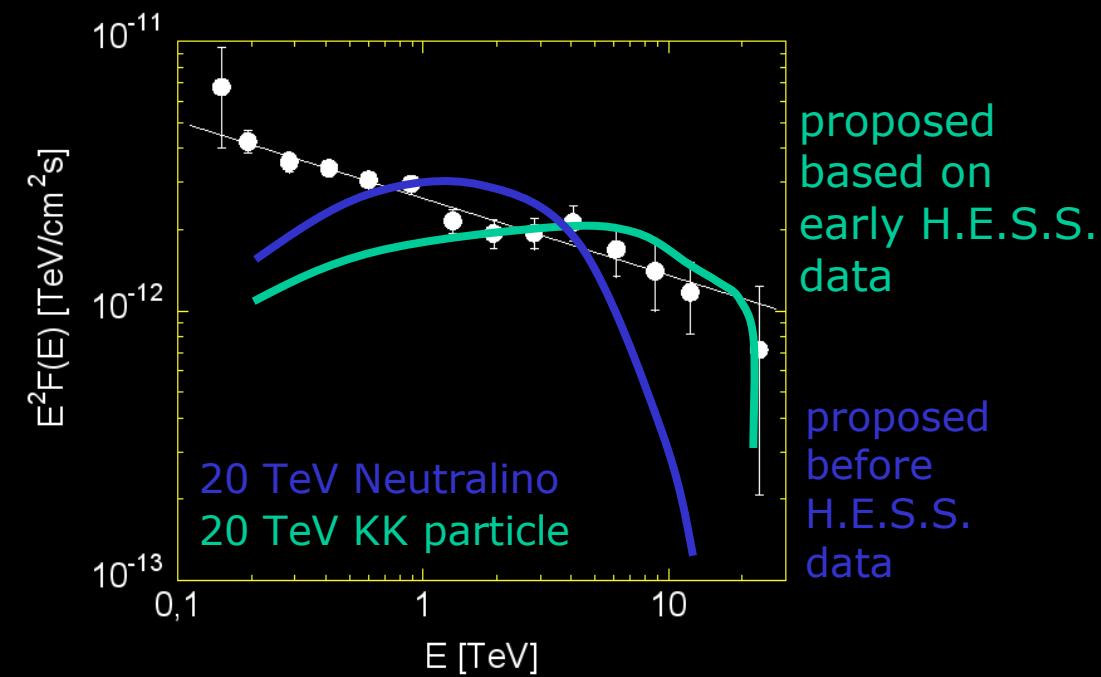
# ORIGIN OF GC TeV Gamma-Rays?



Top down:

- Annihilation of dark matter particles
- $\chi \chi \rightarrow \text{qq, gg}$
- Spectrum?

- Angular distribution?





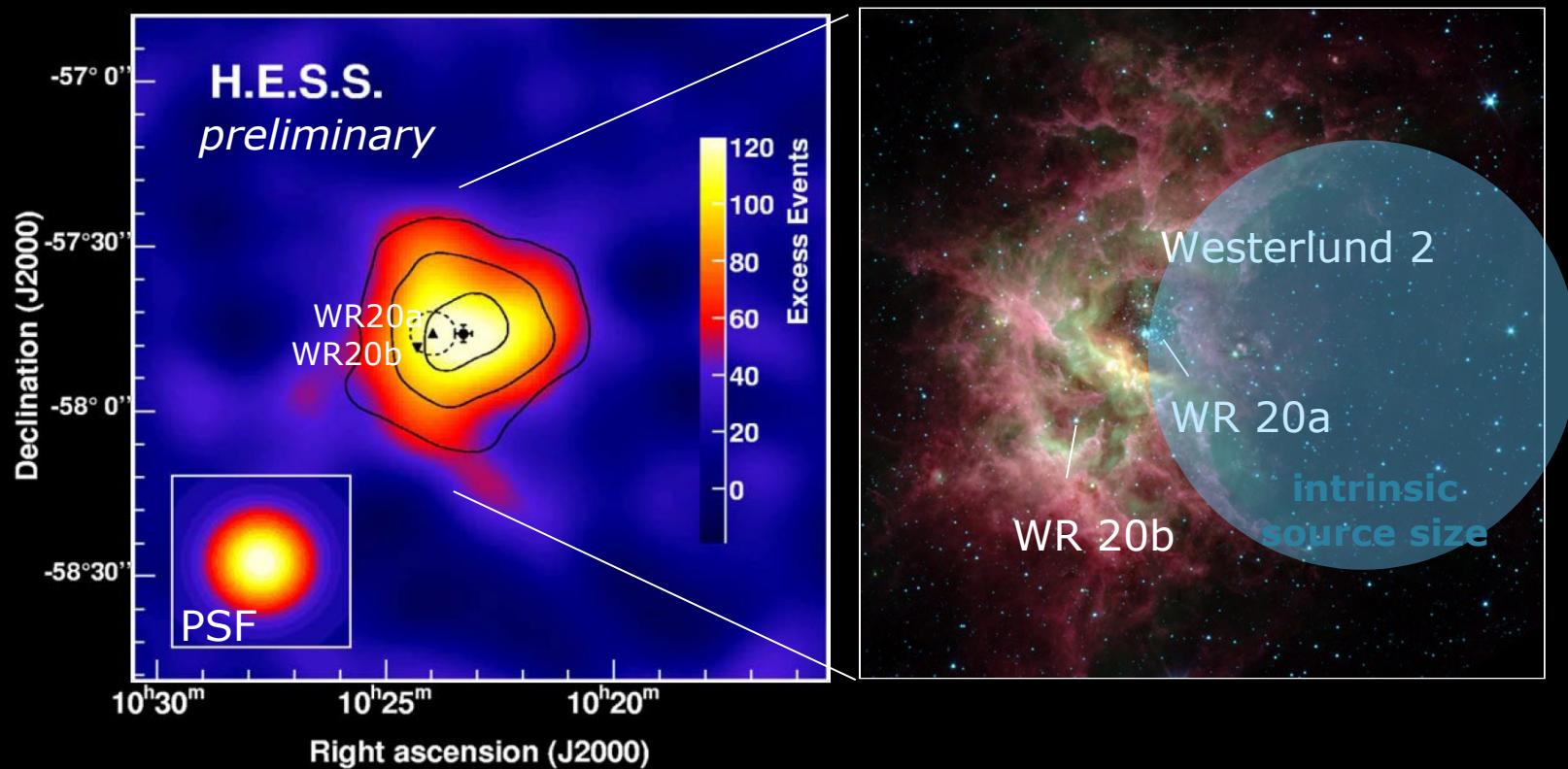
# Open Stellar Clusters

A new type of VHE source?

N44 Superbubble in LMC  
Gemini Obs., AURA, NSF

# Stellar clusters: A new type of TeV source?

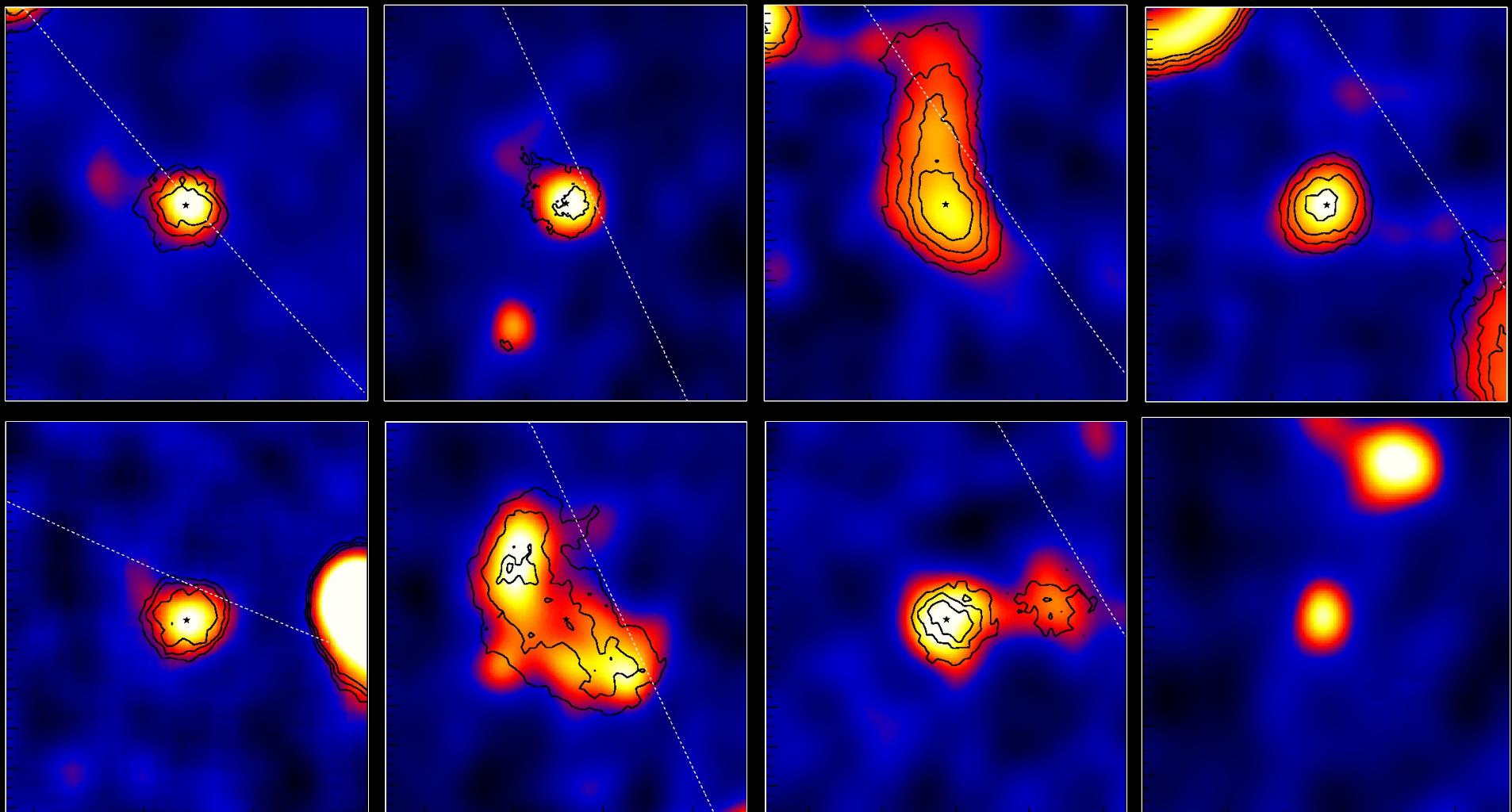
- Open Cluster Westerlund 2 : thousands of solar masses  
Wolf-Rayet & young stars
- Winds excavating bubbles in the ISM
- HESS source coincides with the most prominent one in RCW 49
- Acceleration through collective wind effects or DSA at the boundary?
- Systematic search program undertaken with HESS



# Dark Sources

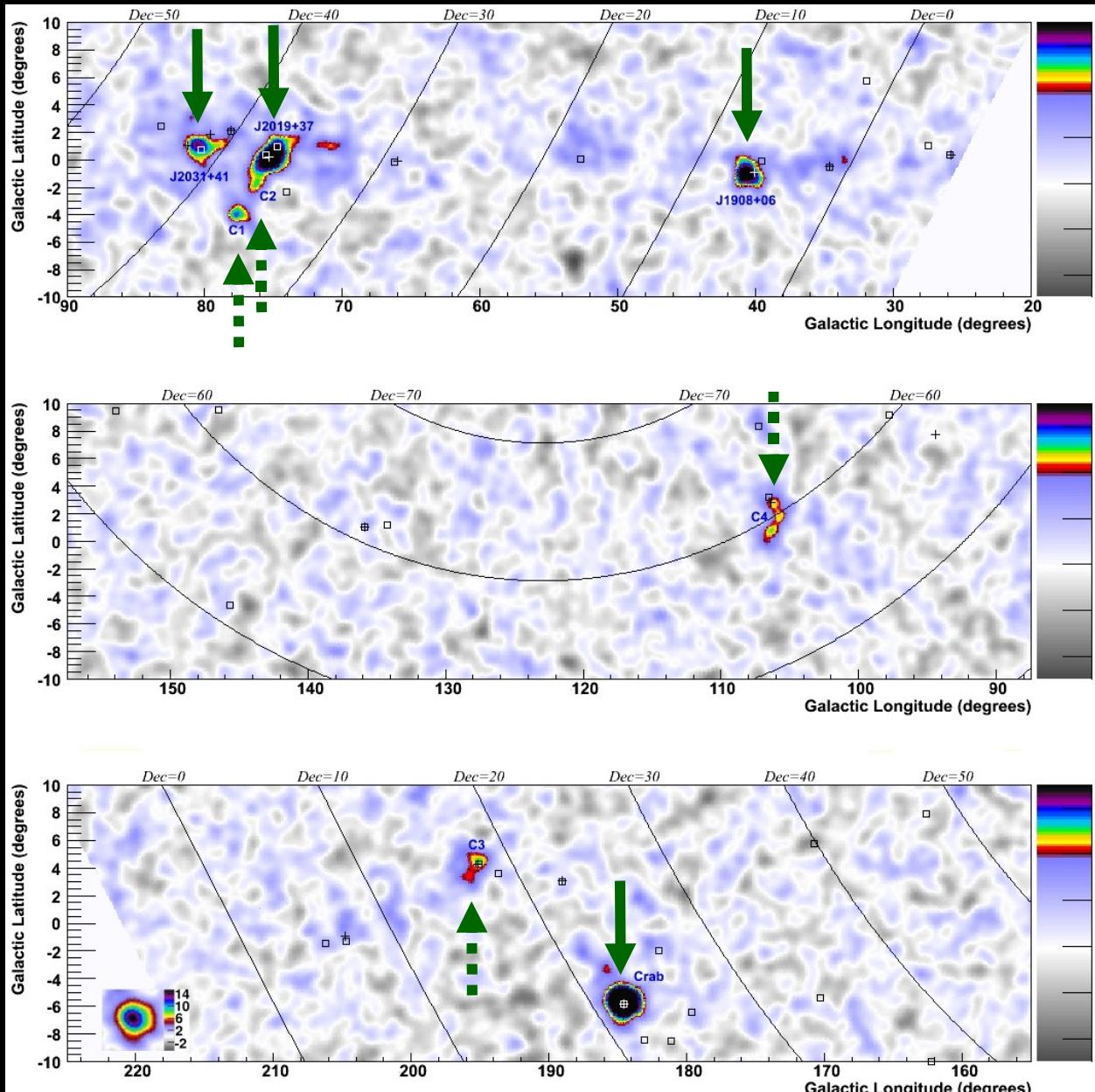
# Dark Sources!

- Seem to shine only in gamma-rays : rather hard spectra and mostly extended
- No plausible counterparts in radio, x-rays, ...
- 2 of HESS dark sources out of 10 have been identified recently:  
1 PWN (faint but young & energetic pulsar) , 1 SNR (composite source)
- New type of CR accelerators? (if leptons expect x-rays, radio !)



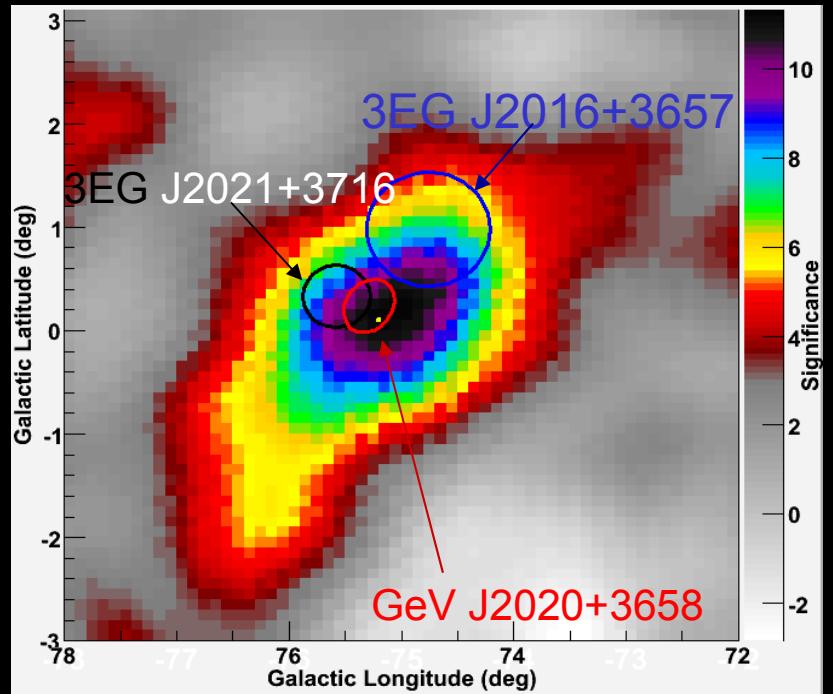
# MILAGRO sky-survey

- 7 years of integration
- Median energy  $\sim 20$  TeV due to  $\gamma$ /hadron separation cuts
- 3 new sources significant post-trials
  - J1908+06
  - J2019+37
  - J2031+41
  - Crab
- 4 'hotspots'
- Bright +Hard+extended sources : Pevatrons?
- Identification is difficult due to poor angular resolution (see HESS First confirmation below)

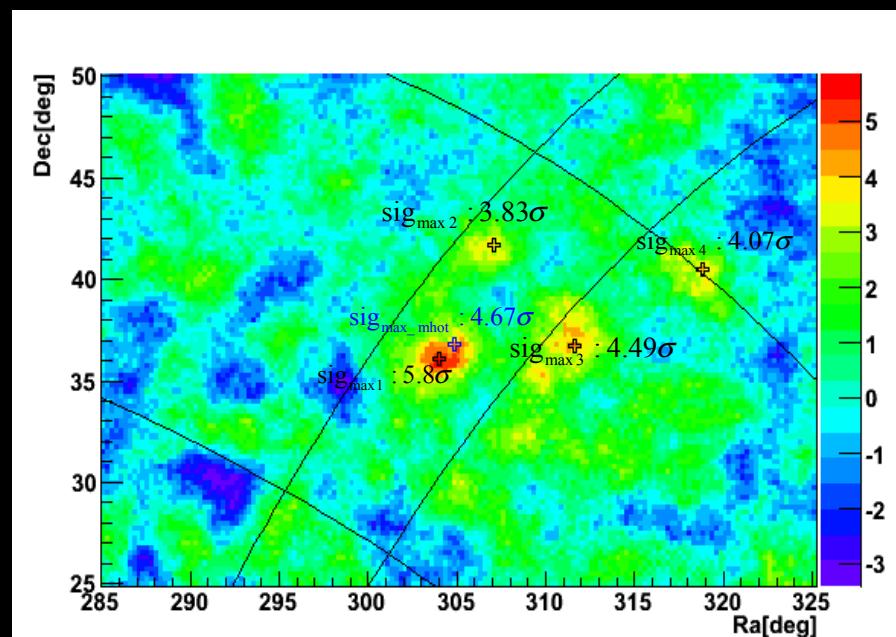


# Dark Sources : MILAGRO J2019+37

- MGRO J 2019+37:  
Bright extended source:  $9.3\sigma$   
In coincidence with GeV Egret source
- Tibet As $\gamma$  :  $5.3\sigma$  close to Milagro position

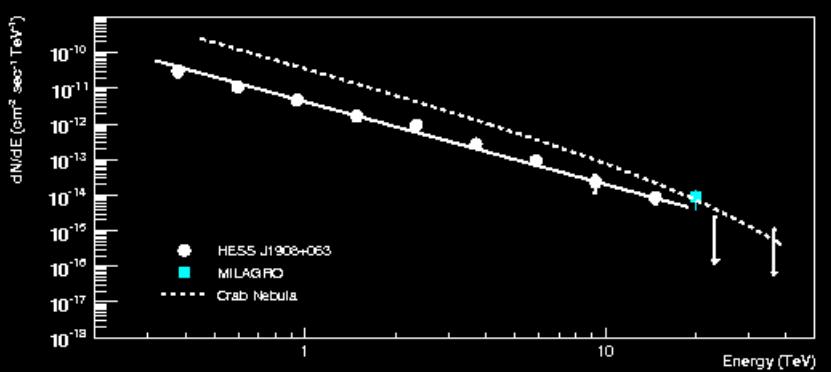
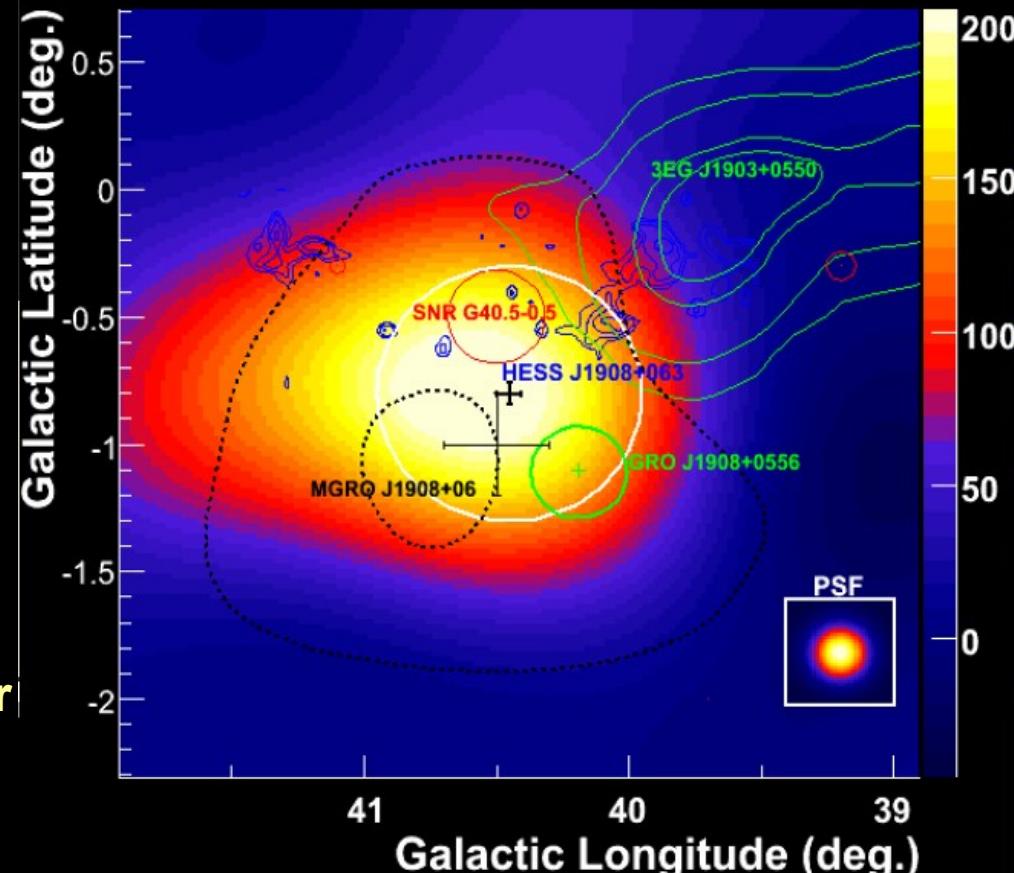


- Point source limits from MAGIC +VERITAS  
No contradiction to MILAGRO flux  
for hard+extended source
- Extended analysis pending



# Dark Sources : MILAGRO J1908+06

- MGRO J 1908+06:
  - Bright extended source:  $7.0\sigma$
  - In coincidence with another GeV Egret source
- HESS detects a strong source with a compatible position
- 30% Crab flux  $> 1 \text{ TeV}$
- First confirmation of a Milagro Source
- Source position and spectrum much better constrained by HESS
- Still no identification
- May be a composite source

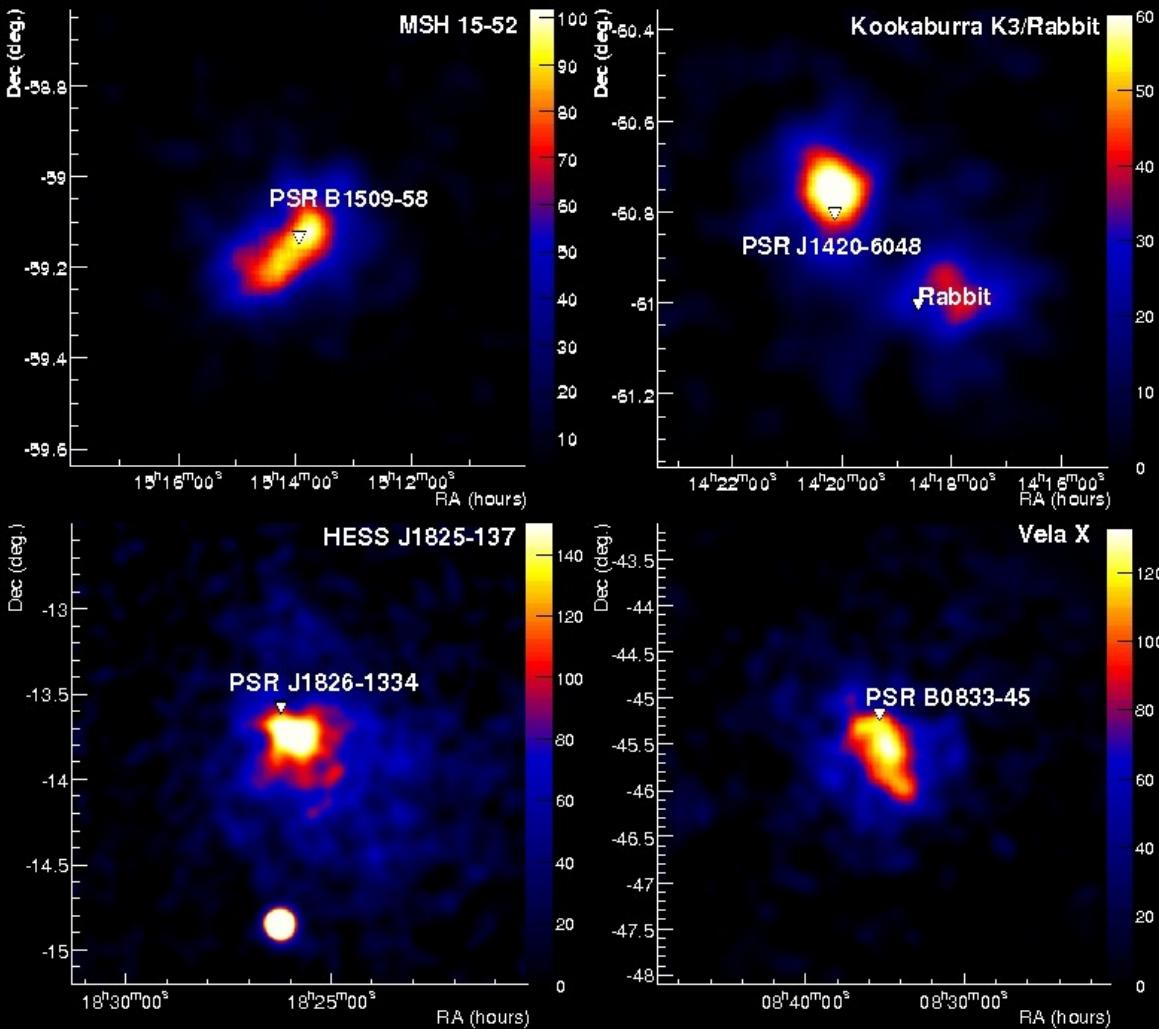
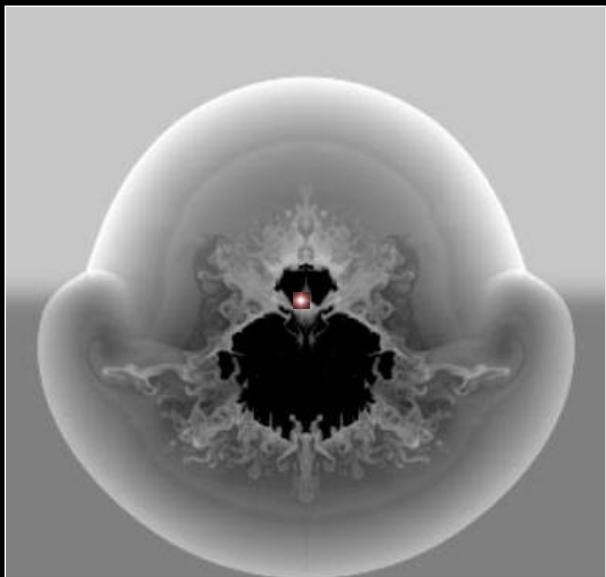


# PSR J1826-1334

Pulsar Wind Nebulae

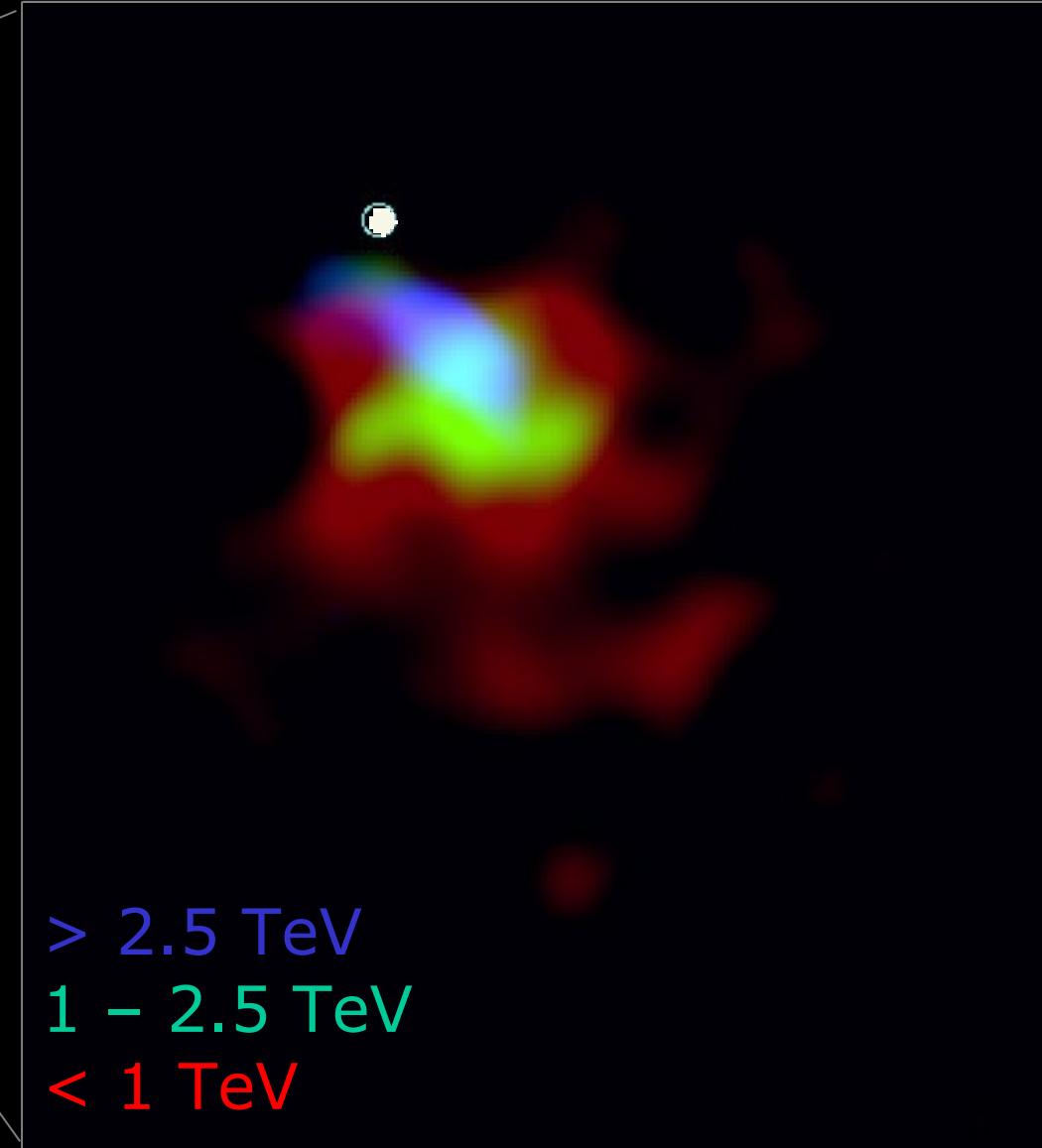
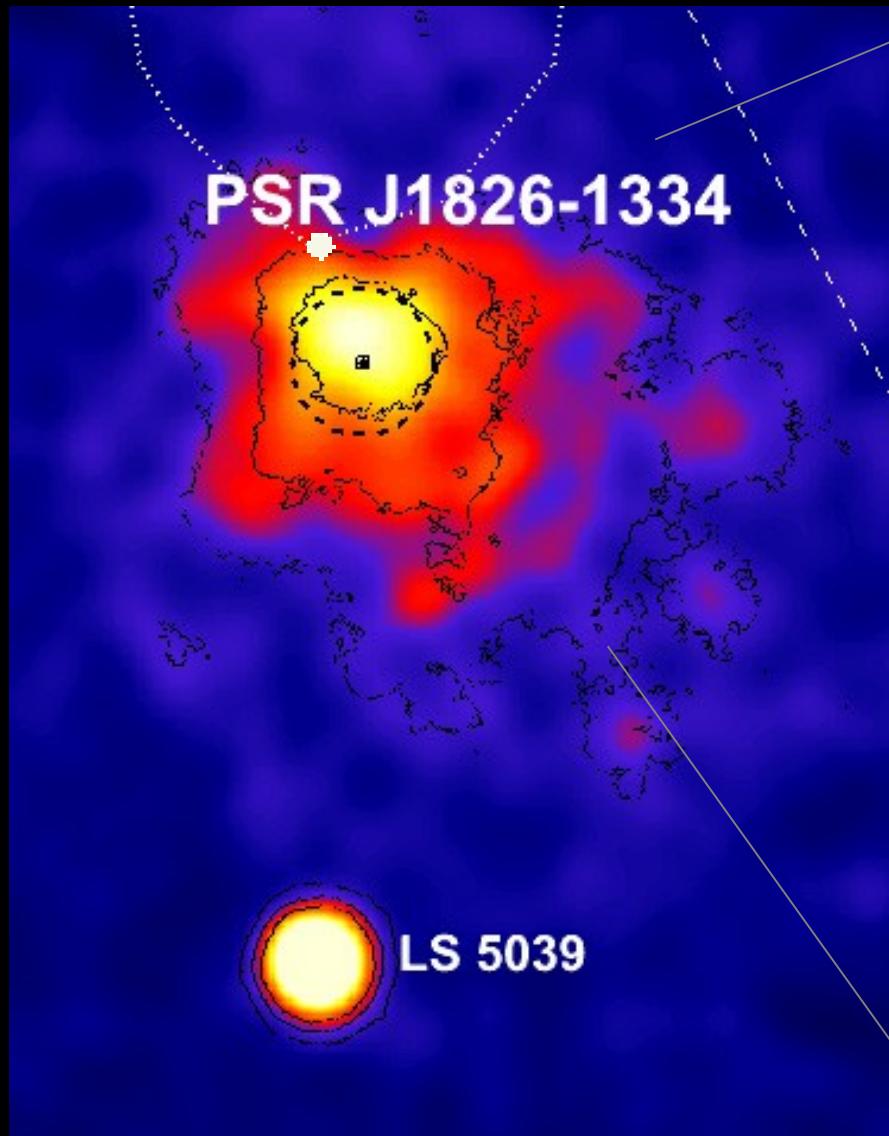
# Middle-aged Pulsar Wind Nebulae

- Major galactic source population revealed by HESS galactic scan
- Extented sources with irregular morphology
- Associated with pulsars:
  - young : age <  $10^5$  yrs
  - energetic:  $E_{dot} > 10^{35}$  erg/s
- Nebulae with huge characteristic sizes ~ few tens of pc
- TeV emission = Relicelectrons
- Mostly displaced TeV emission wrt pulsar position:  
“Crushed nebulae”



SN Explosion in inhomogenous medium→  
reverse shock pushes the nebula  
[Blondin et al. 2001]

# Morphology of PWNe: evidence for cooling Relic electrons at action: HESS J1825-137

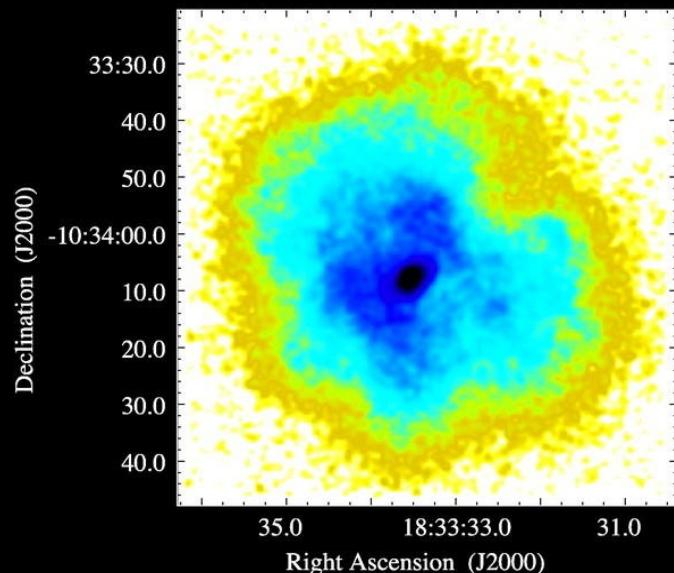


# VHE emission around youngest “Crab-like” pulsars in composite SNRs

**G21.5-0.9 / PSR J1833-1034**

**P=61.8 ms ;  $\tau=4.8$  kyr ; but <1000 yrs**

**Edot= $3.3 \times 10^{37}$  erg/s : 2<sup>nd</sup> strongest /Crab**

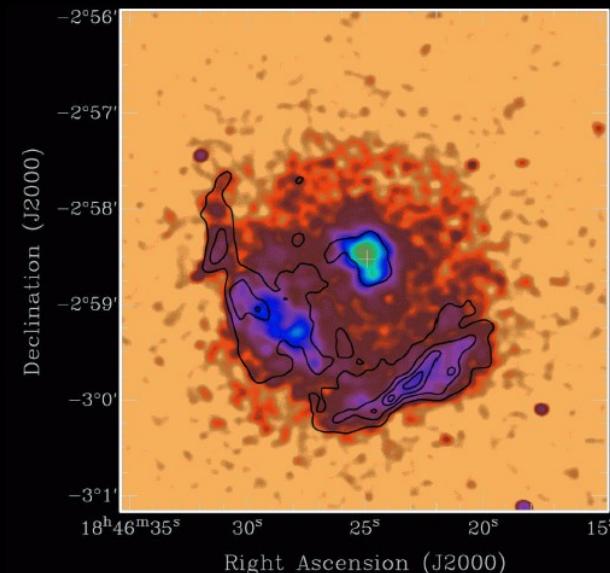


**Kes 75 / PSR J1846-0258**

**P=324 ms ;  $\tau=723$  yr**

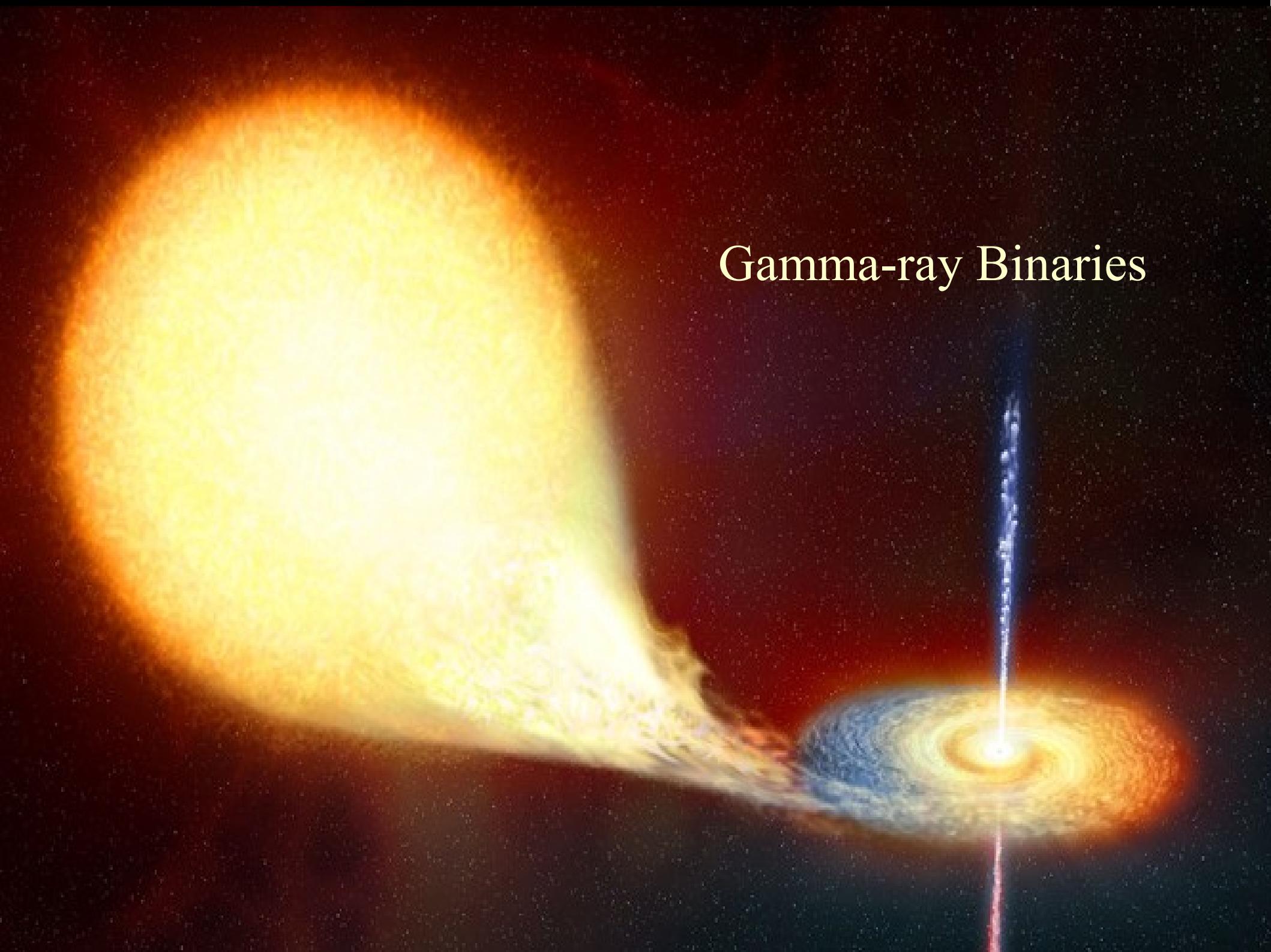
**Edot= $7.9 \times 10^{36}$  erg/s**

**B<sub>surf</sub> =  $4.8 \times 10^{13}$  G ! Magnetar limit**



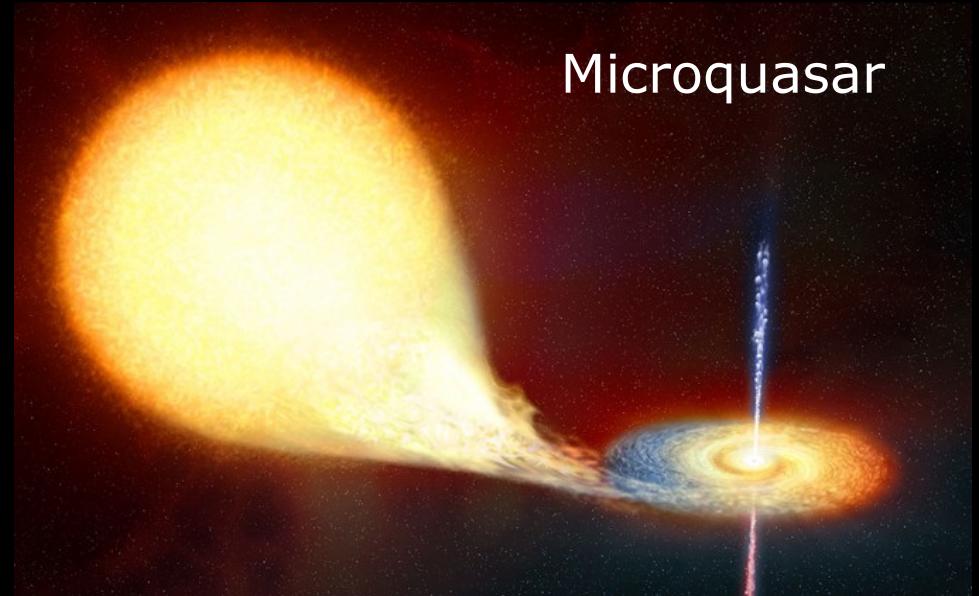
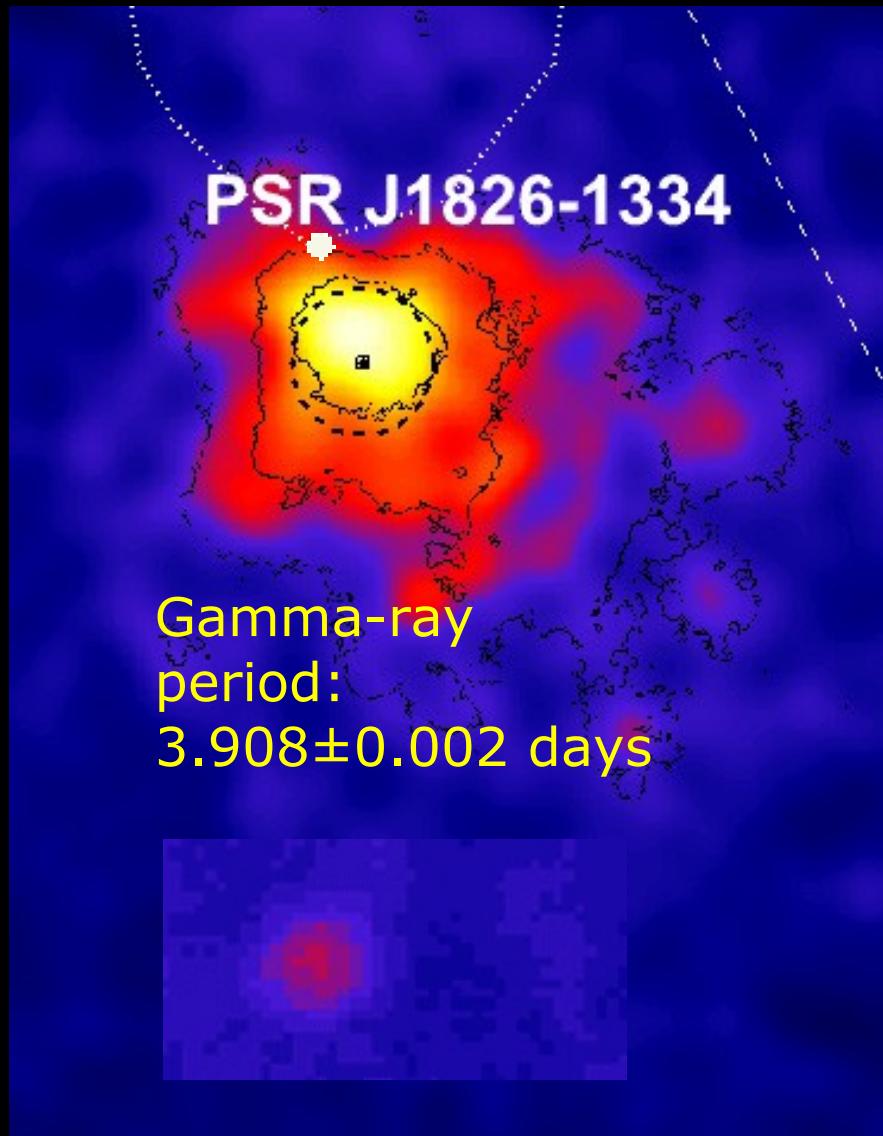
•

	$\Gamma_x$ (pwn)	$\Gamma_x$ (pulsar)	$\Gamma_\gamma$	Edot	Lx/E <sub>dot</sub>
Crab	2.14	1.85	2.6	$5 \times 10^{38}$	$29 \times 10^{-3}$
J1833-1034	1.43-1.93	nc	2.31	$3.3 \times 10^{37}$	$8.5 \times 10^{-3}$
J1846-0258	1.92	1.39	2.28	$7.9 \times 10^{36}$	$20 \times 10^{-3}$

A composite image of a galaxy. The left side shows a bright, multi-colored disk (yellow, orange, red) with a central black hole. The right side features a bright blue vertical beam of light, likely representing gamma-ray emission from a binary system.

# Gamma-ray Binaries

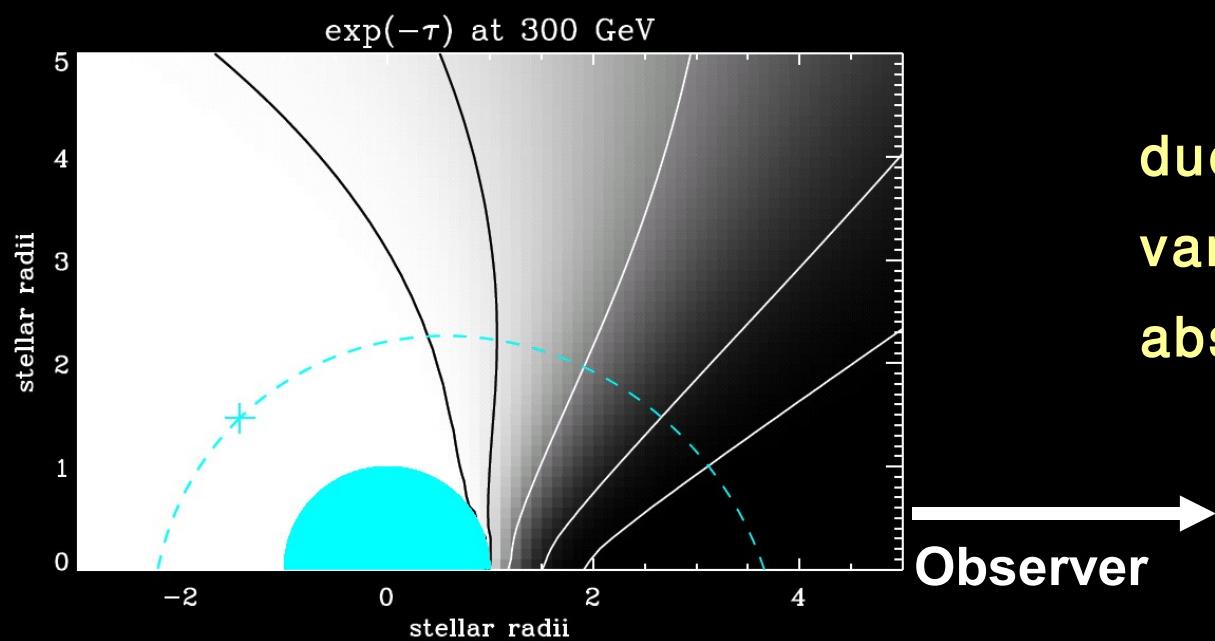
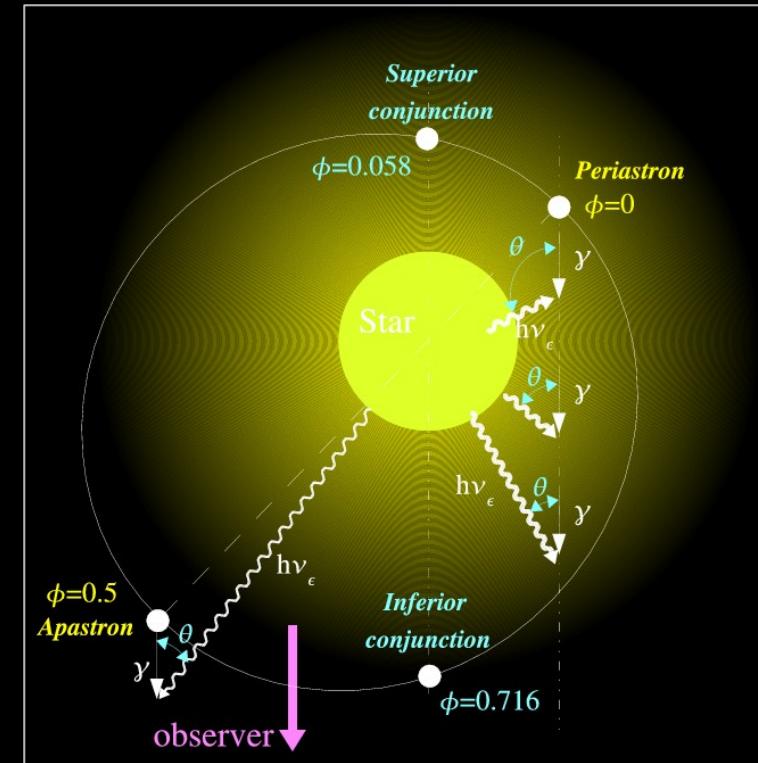
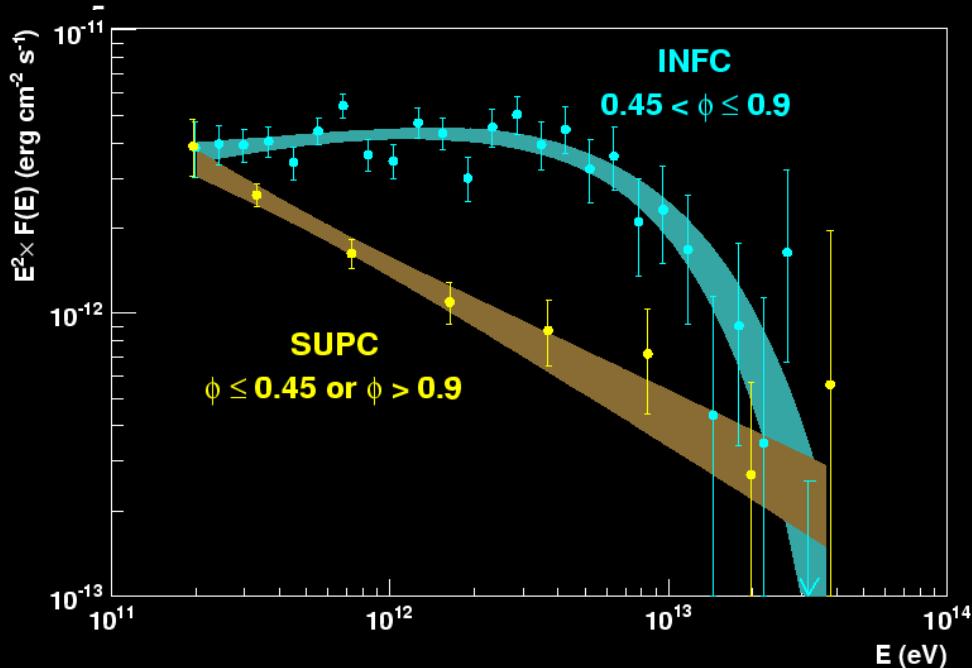
# Binaires : LS 5039 by HESS



## LS 5039

- 4 (?)  $M_{\odot}$  object in eccentric 3.906-day orbit around 20-30  $M_{\odot}$  star
- closest approach  $\sim 10^{12}$  cm or  $\sim 2$  stellar radii

# A Cosmic experiment



due to :  
varying acceleration  
absorption by  $\gamma \gamma \rightarrow e^+ e^-$

# Conclusions

**A wealth of sources of different types discovered**

- Young Shell type Supernova Remnants
- Older and/or Interacting SNRs
- Composite SNRs
- Pulsar Wind Nebulae (PWN)
- Gamma-ray Binary Systems (LS 5039)
- Variable PWN in binary
- Open Stellar Clusters
- Galactic Center
- Galactic diffuse emission
- Dark, Unidentified sources
- ....

→ Some answers ... but many questions remain or raised !

Infrared

Optical

VHE  $\gamma$ -rays

**THANK YOU**