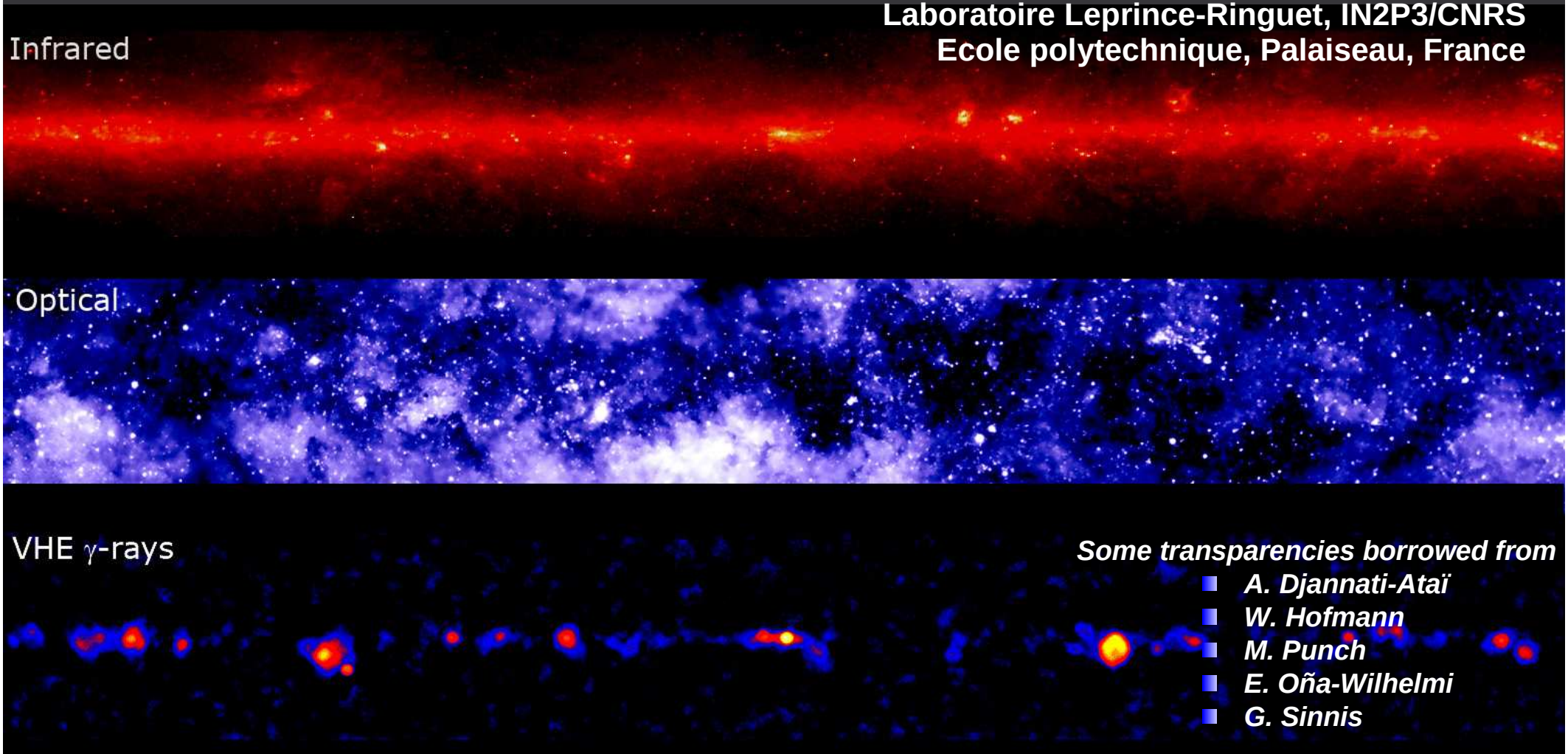
The galactic VHE gamma-ray sky:

the diversity of acceleration sites revealed by HESS

Bruno Khélifi, for the HESS coll.

Laboratoire Leprince-Ringuet, IN2P3/CNRS
Ecole polytechnique, Palaiseau, France



Some transparencies borrowed from

- *A. Djannati-Ataï*
- *W. Hofmann*
- *M. Punch*
- *E. Oña-Wilhelmi*
- *G. Sinnis*

HESS galactic plane survey

2004 Galactic scan:

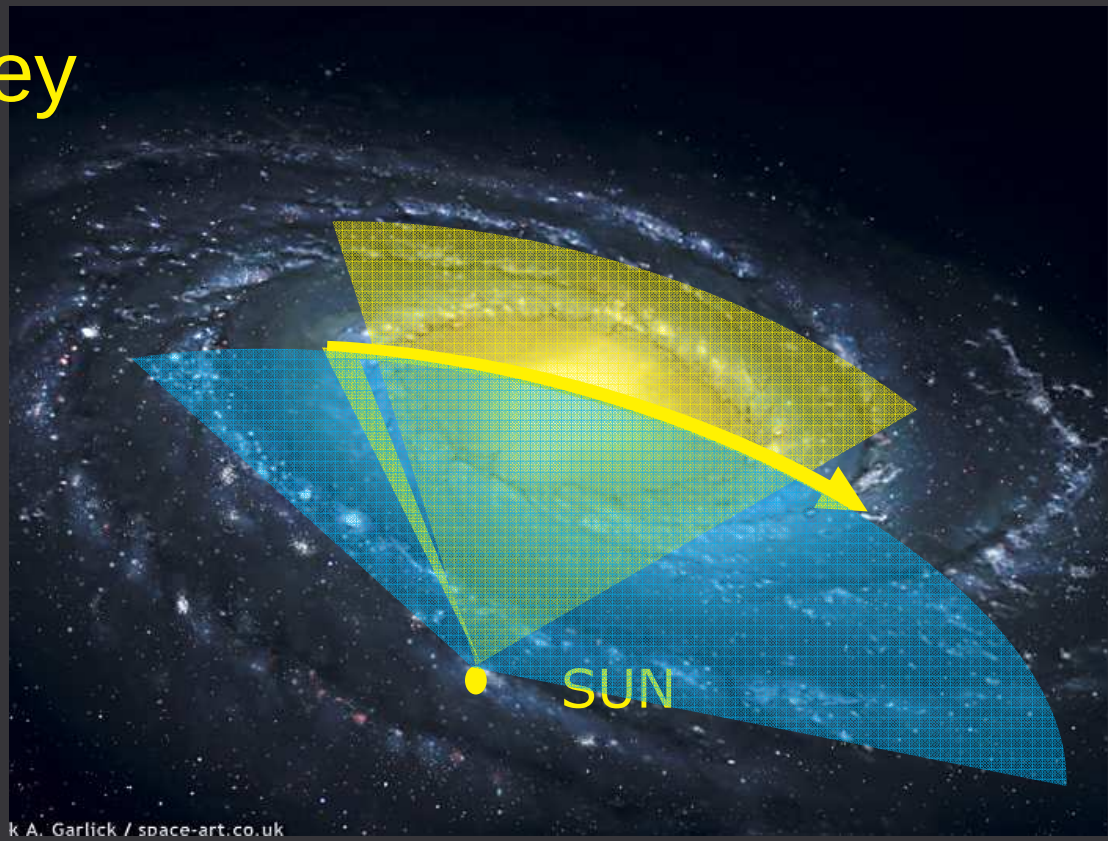
125h, -30°< l < 30° -2.5°< b < 2.5°
16 sources published (ApJ 636, 2006)

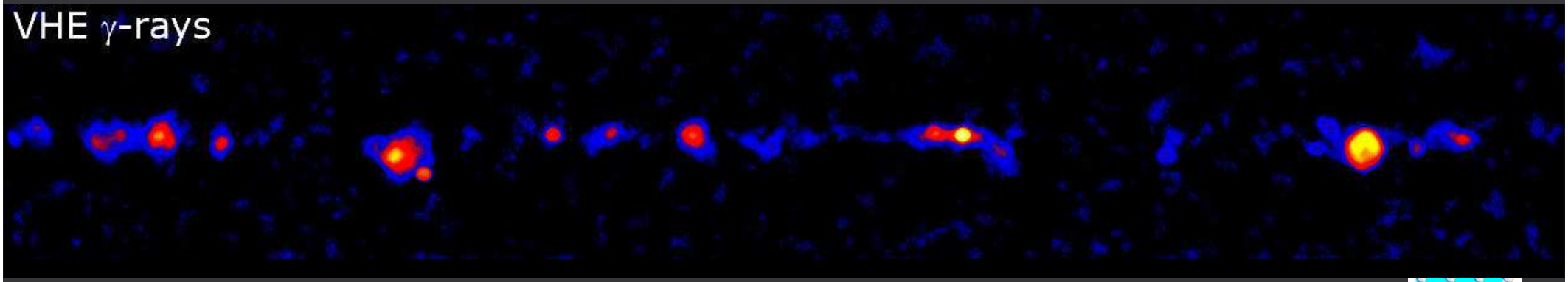
2006:

16 others published separately

Extension 2005-2007:

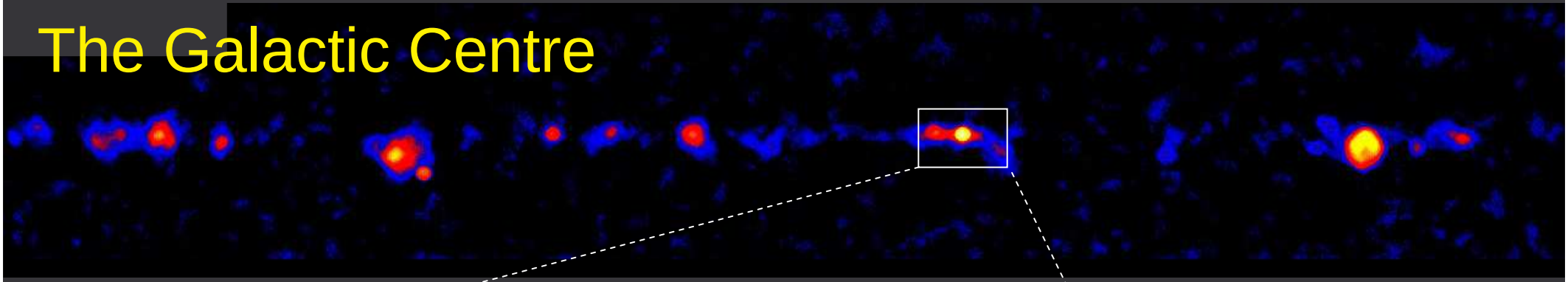
400h, -85°< l < 60° -2.5°< b < 2.5°
>20 sources discovered

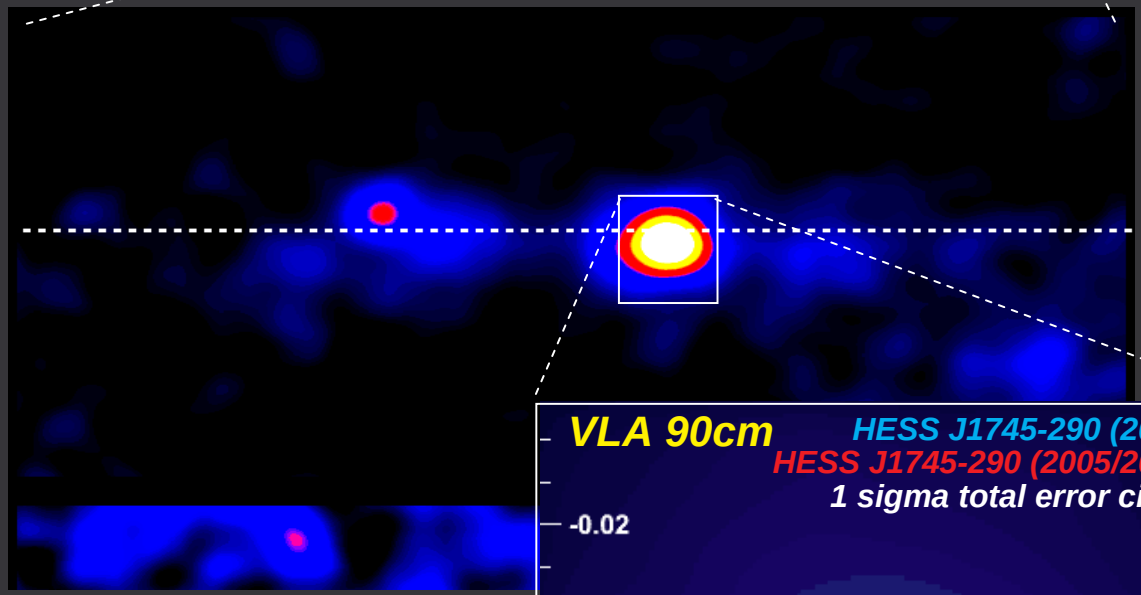




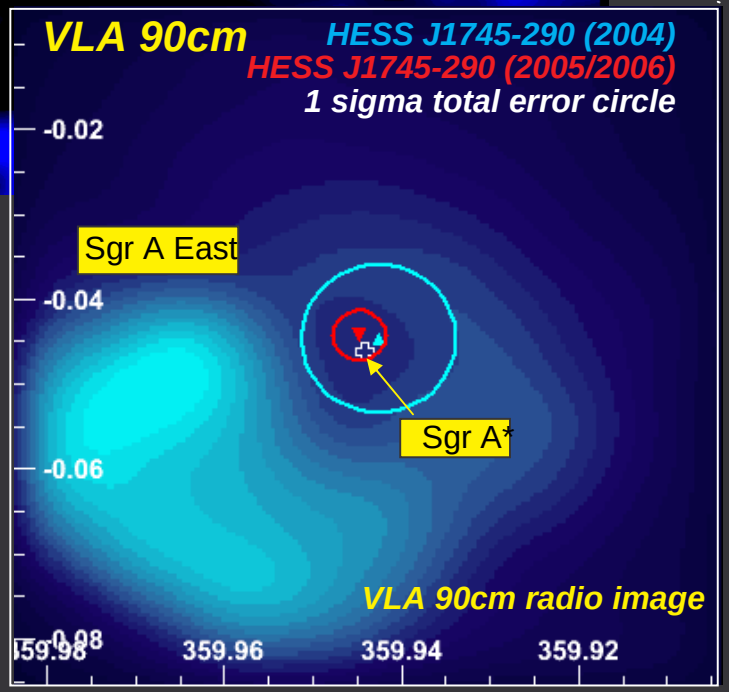

The Galactic Centre

The Galactic Centre



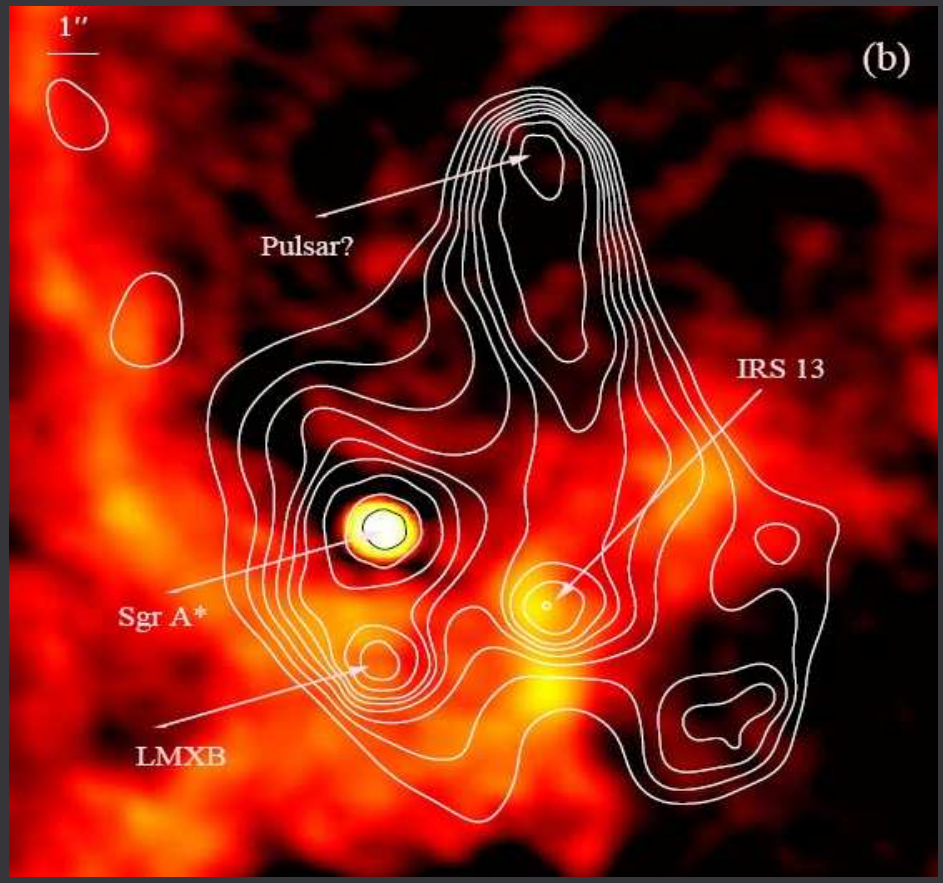


Galactic plane



- **Very High Precision Measurement of GC TeV Source (6”syst+ 6”stat)**
- **Excludes SgrA East**

The Galactic Centre: Origin of the TeV γ-rays?



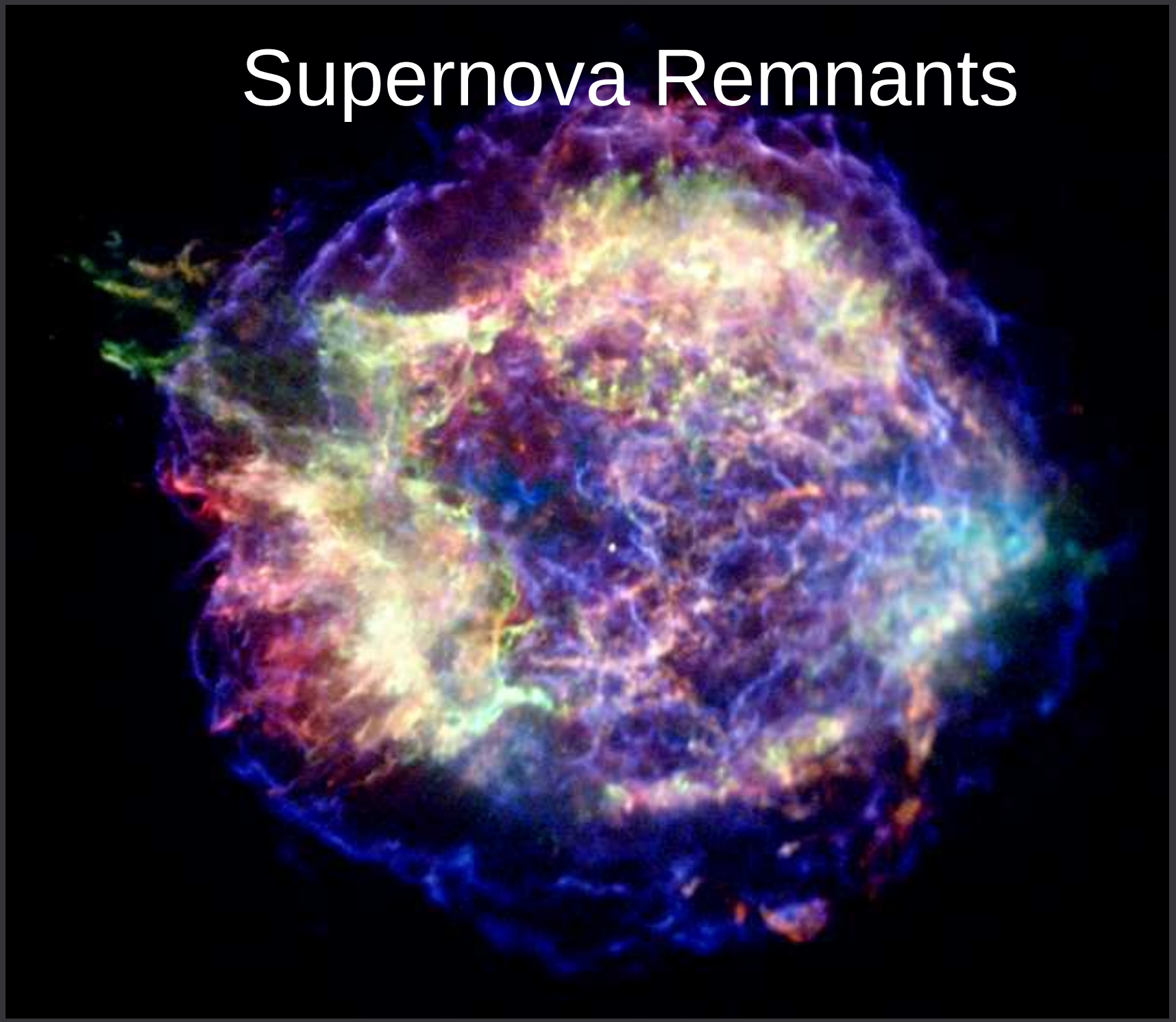
Origin is unclear!

A variety of interpretations:

- **Curvature radiation of UHE protons near SgrA***
- **Shocks in SgrA*'s accretion flow or wind**
- **Decaying UHE neutrons**
- **The Pulsar Wind nebula G359.95-0.04**

The Dark Matter interpretation is excluded **Cf. talk of G. Hermann**
(power-law spectrum from 160GeV to 30TeV)

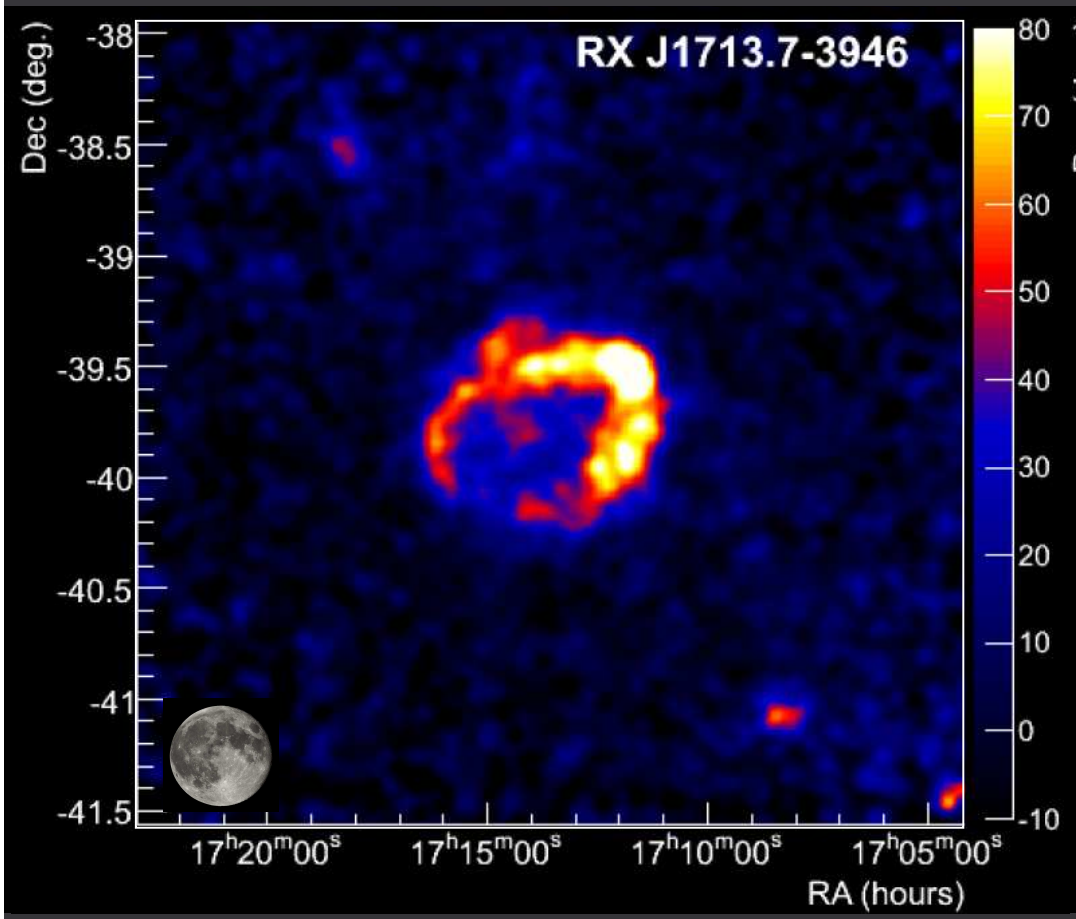
Supernova Remnants

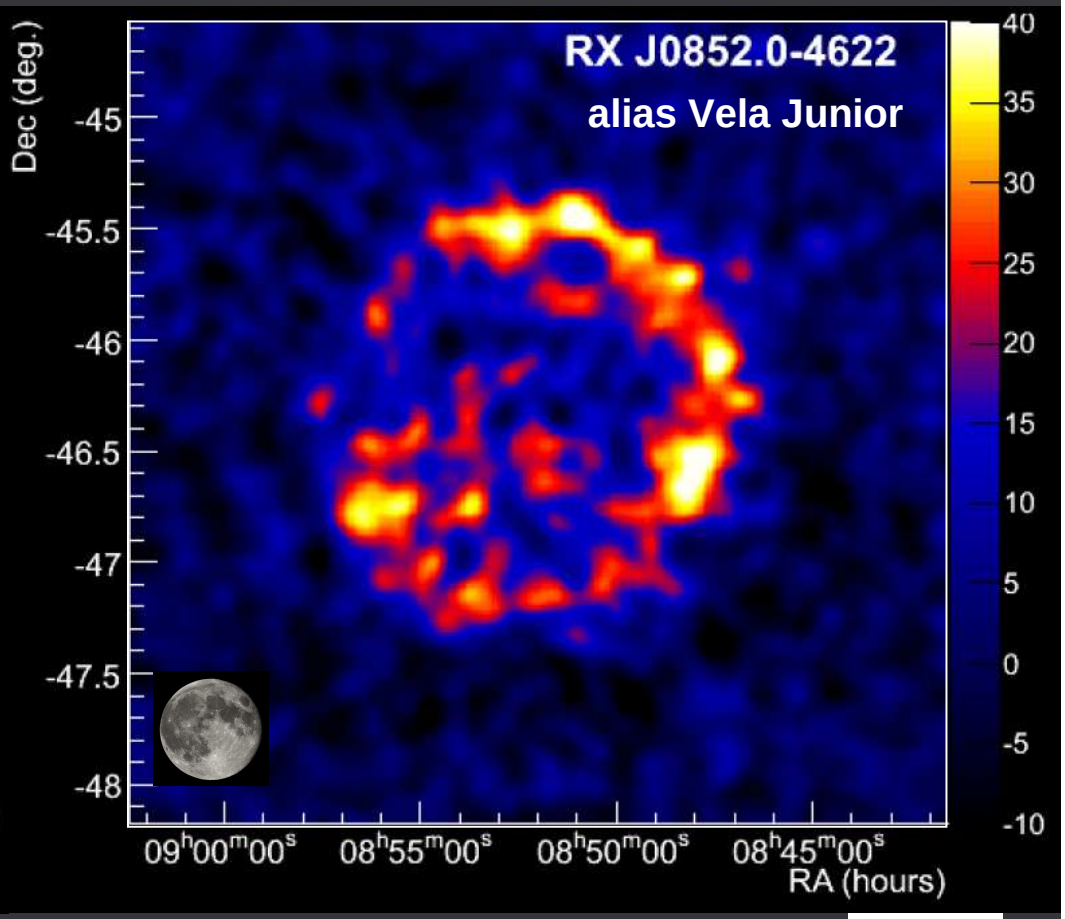


Young Shell type SNRs

RX J1713.7-3946
1-10 kyr, 1-6 kpc
First-ever resolved TeV SNR
Strong correlation with X-rays: ~80%

RX J0852.0-4622 (Vela Jr)
0,7-1.1 kyr, 0.2-2 kpc
Thin shell resolved with HESS
Correlation with X-rays: ~65%
+ Correlation with Radio



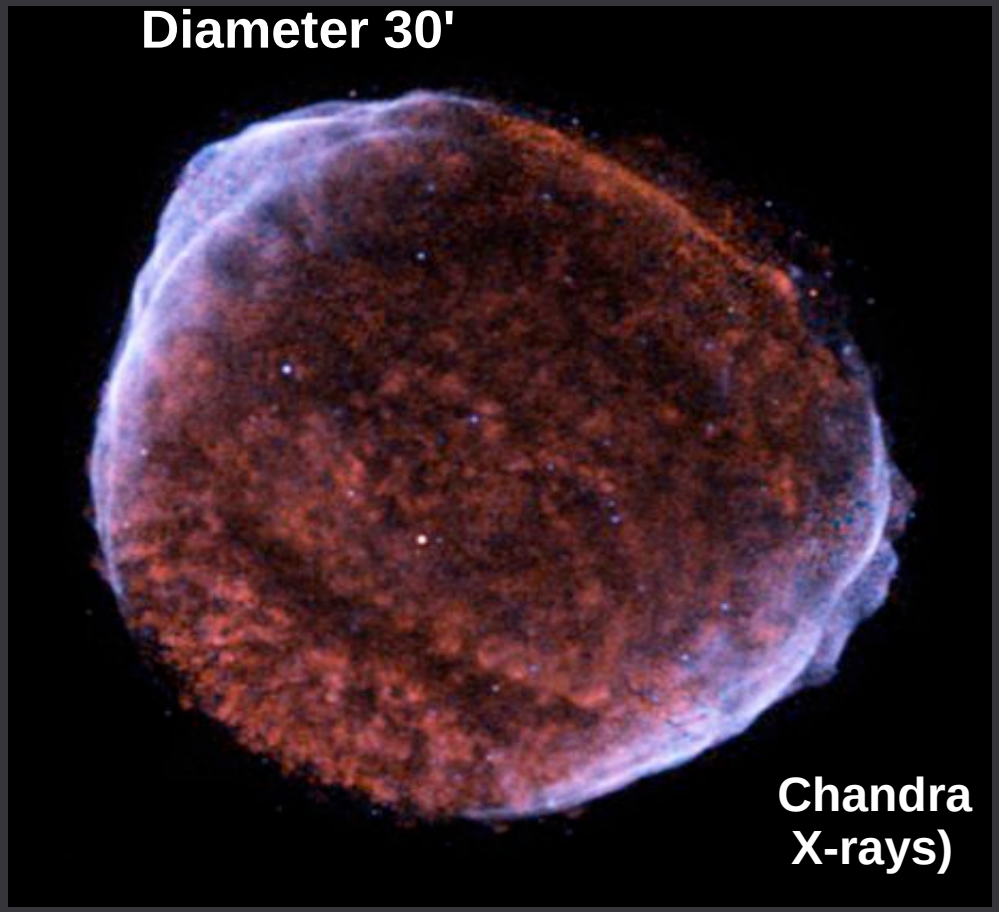


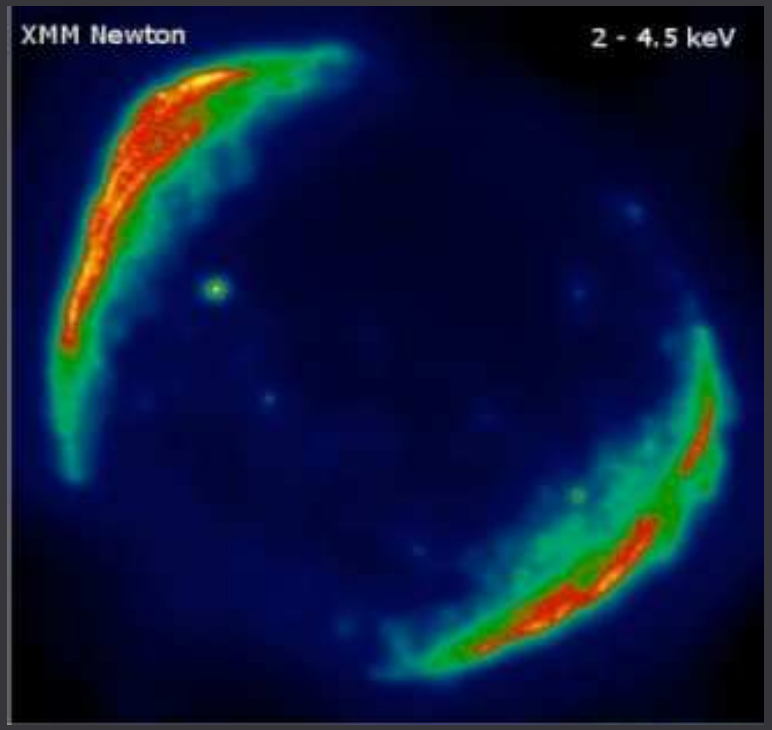
Young Shell type SNRs: Discovery of SN1006 at VHE energies

Type 1a SN

Distance 2.2 kpc

Diameter 30'



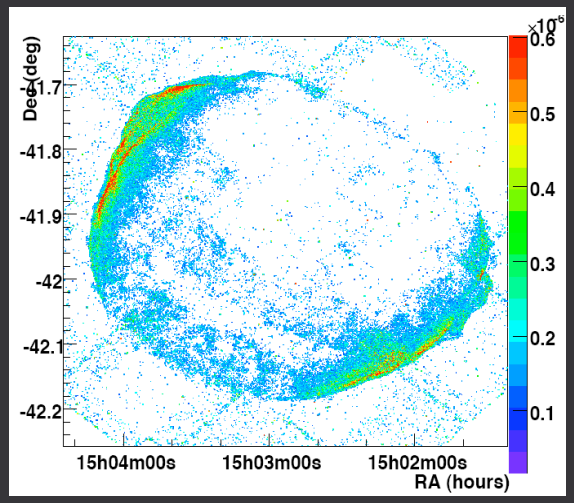


XMM-Newton
2 – 4.5 keV

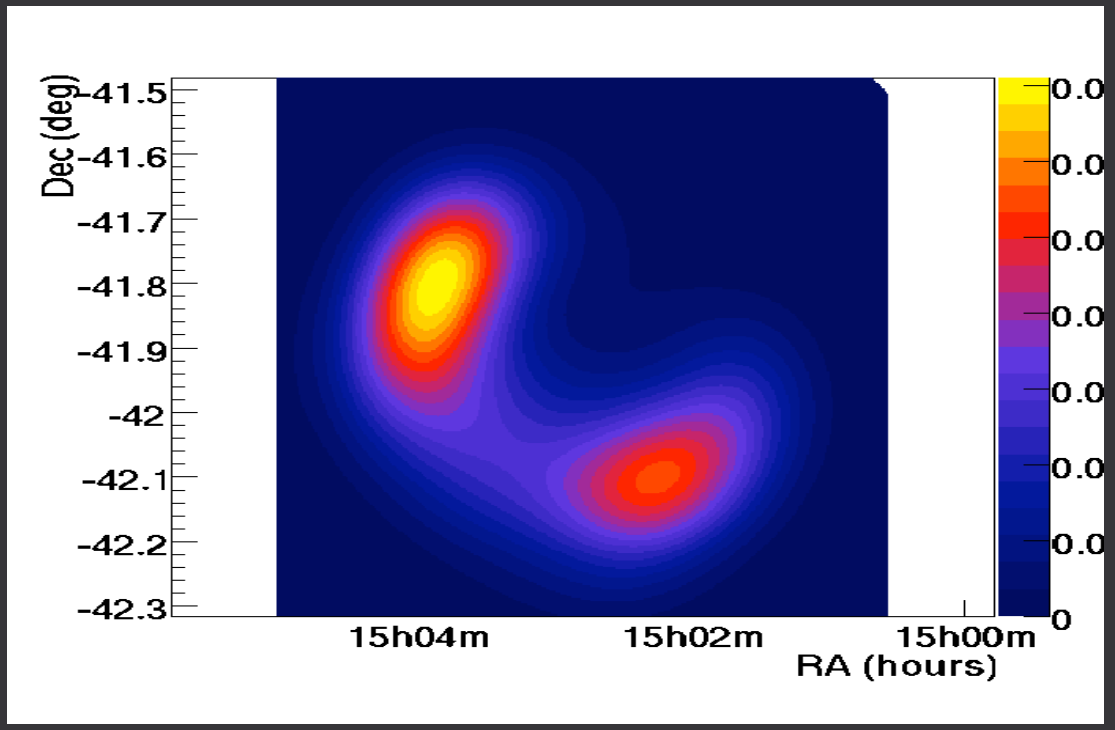
HESS-CHANDRA morphology of SN1006

Taking Chandra exposure-corrected map of SN 1006

Note: filaments seen in X-rays (= shock-waves)



Chandra map smoothed with HESS PSF (0.1°)



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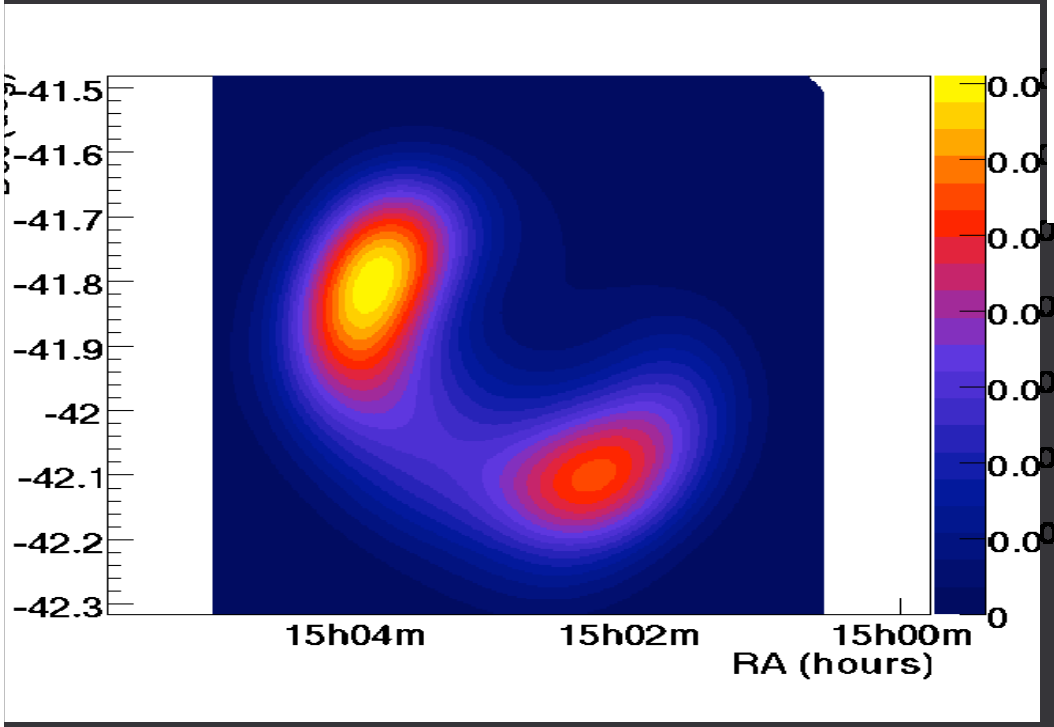
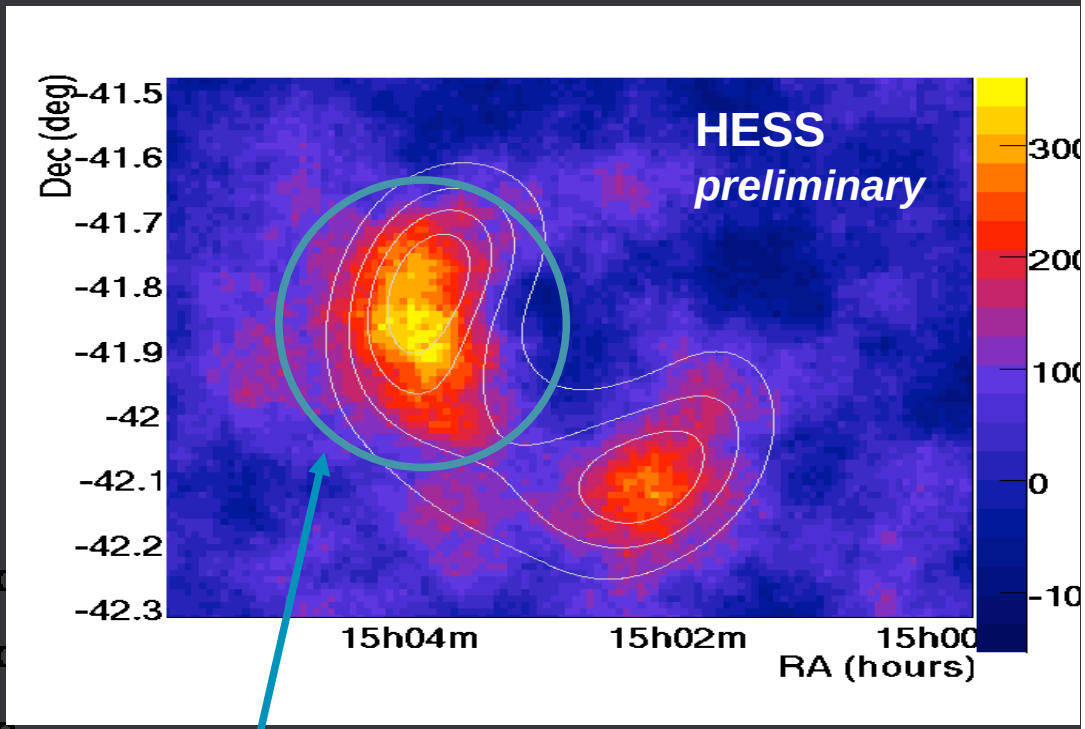
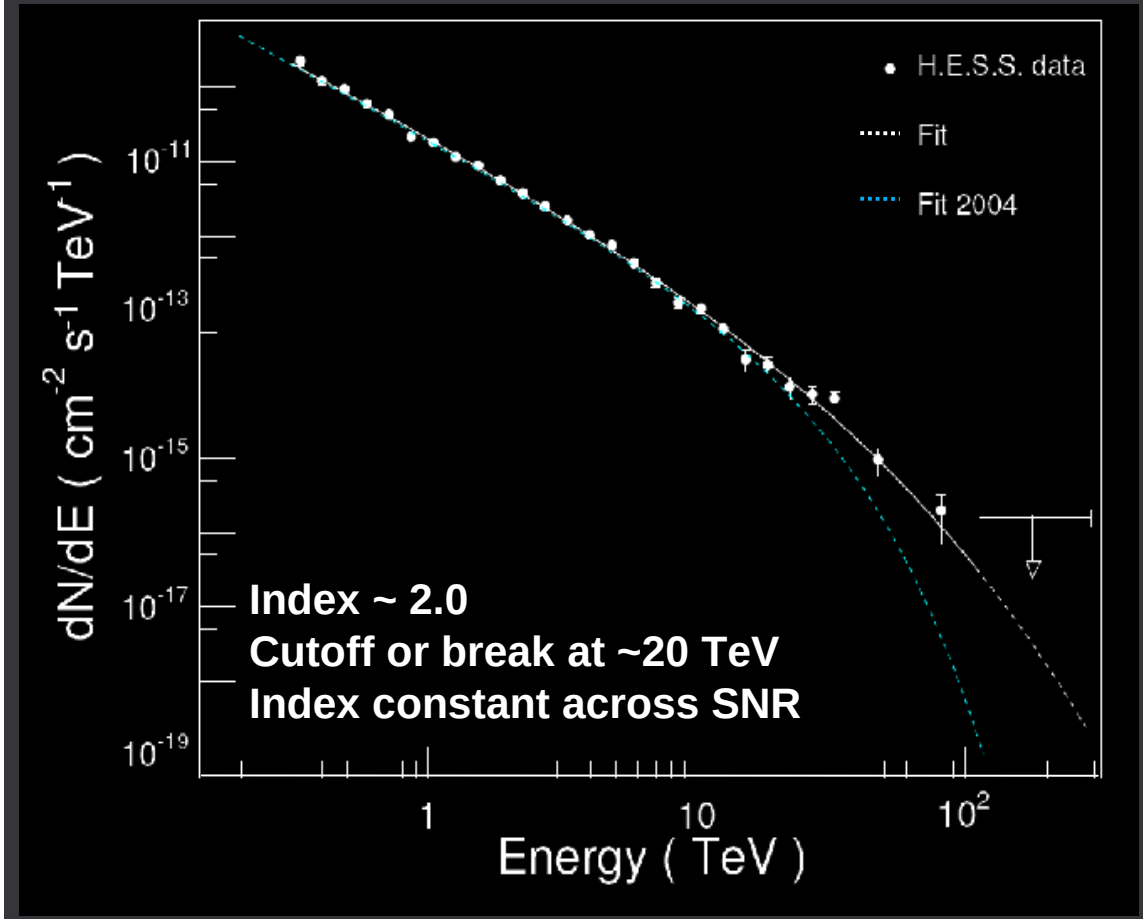




HESS map with Chandra map's smoothed contours

NE region pre-defined in the H.E.S.S. limit paper:
~5.9 sigma

Young Shell type SNRs: interpretation



Spectrum of RXJ 1713.7-3946

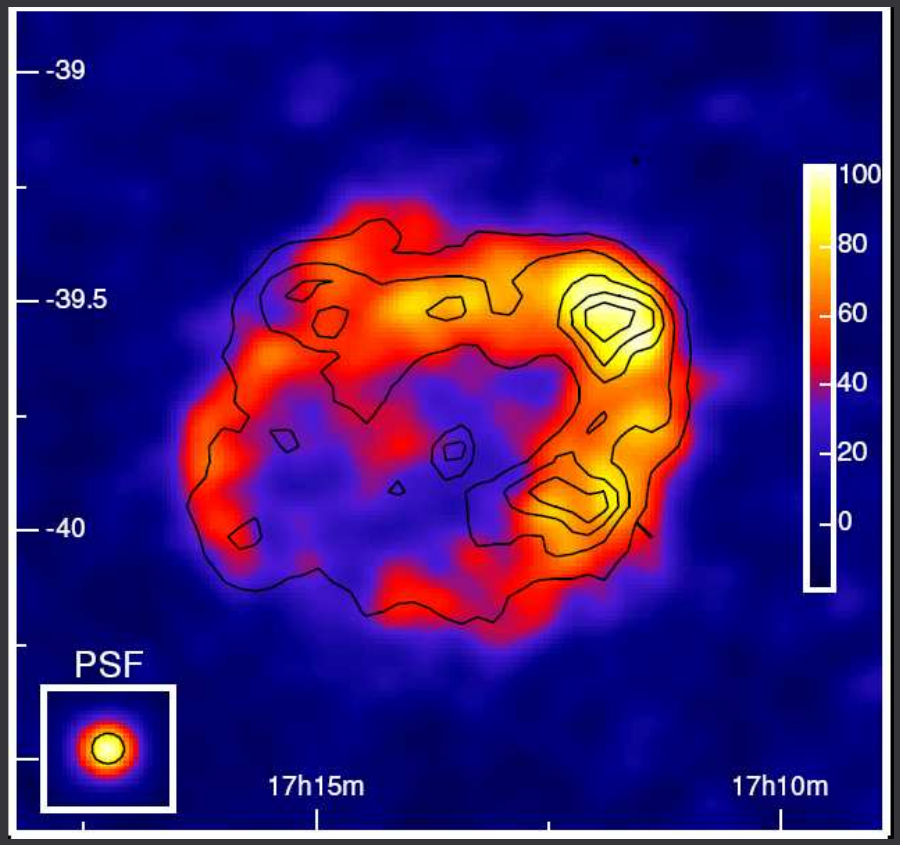
With the full statistics : E > 50 TeV

Particles up to >100 TeV

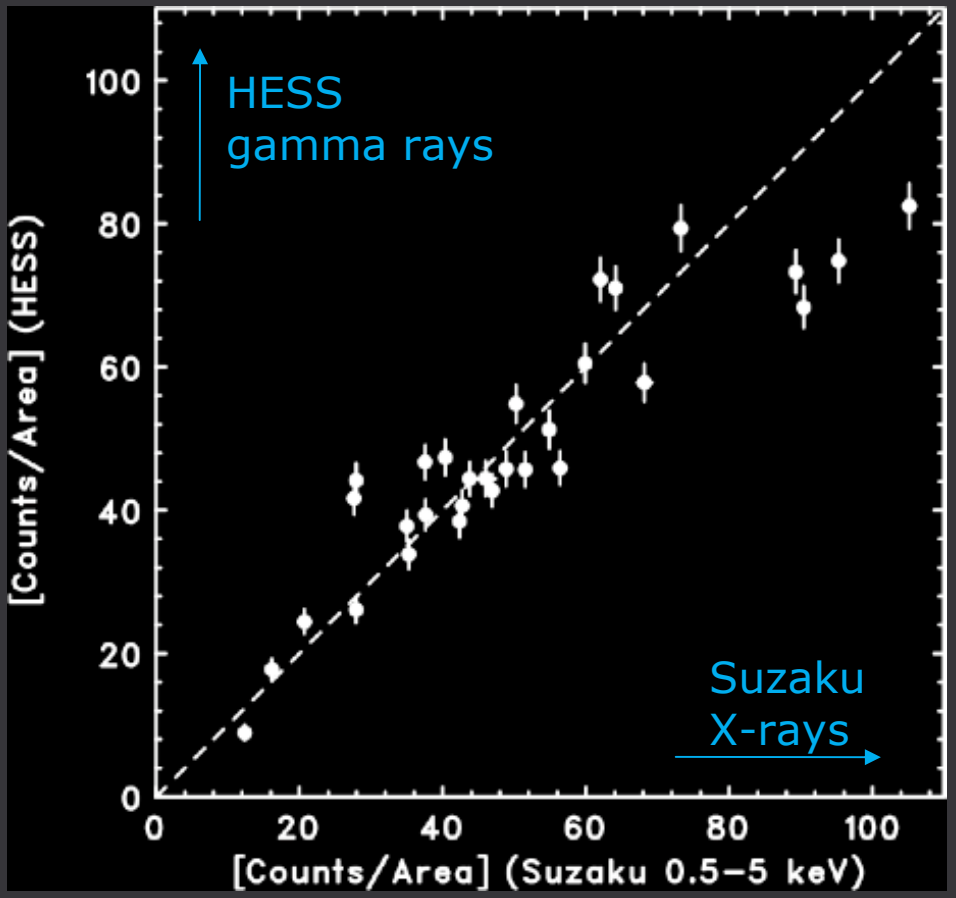
If hadrons:
primary energy >200 TeV

If leptons:
primary energy >100 TeV (KN)

RXJ 1713.7-3946: X-ray vs γ-ray correlations



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



- **Very close morphologies for X-ray & γ-ray**
- **80% Correlation**
- **What does that mean? Leptonic domination?**

- **Within a leptonic scenario**
  - **Deduced B ~ 10 μG**
  - **But X-ray filament: B ~ 50-100 μG**

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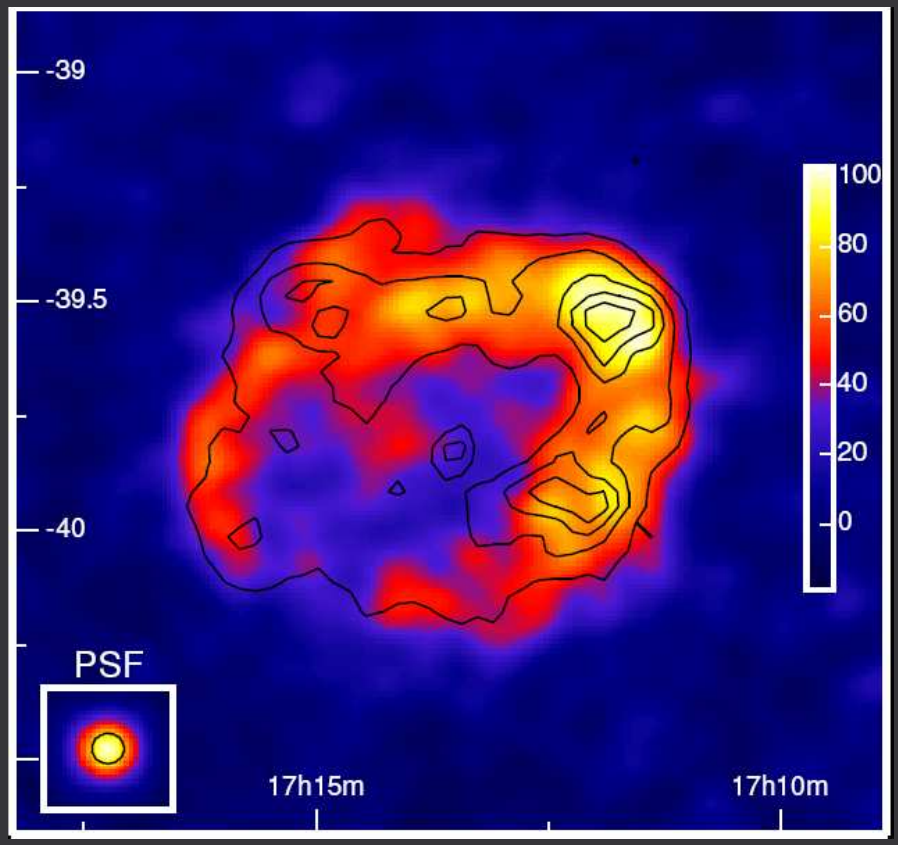

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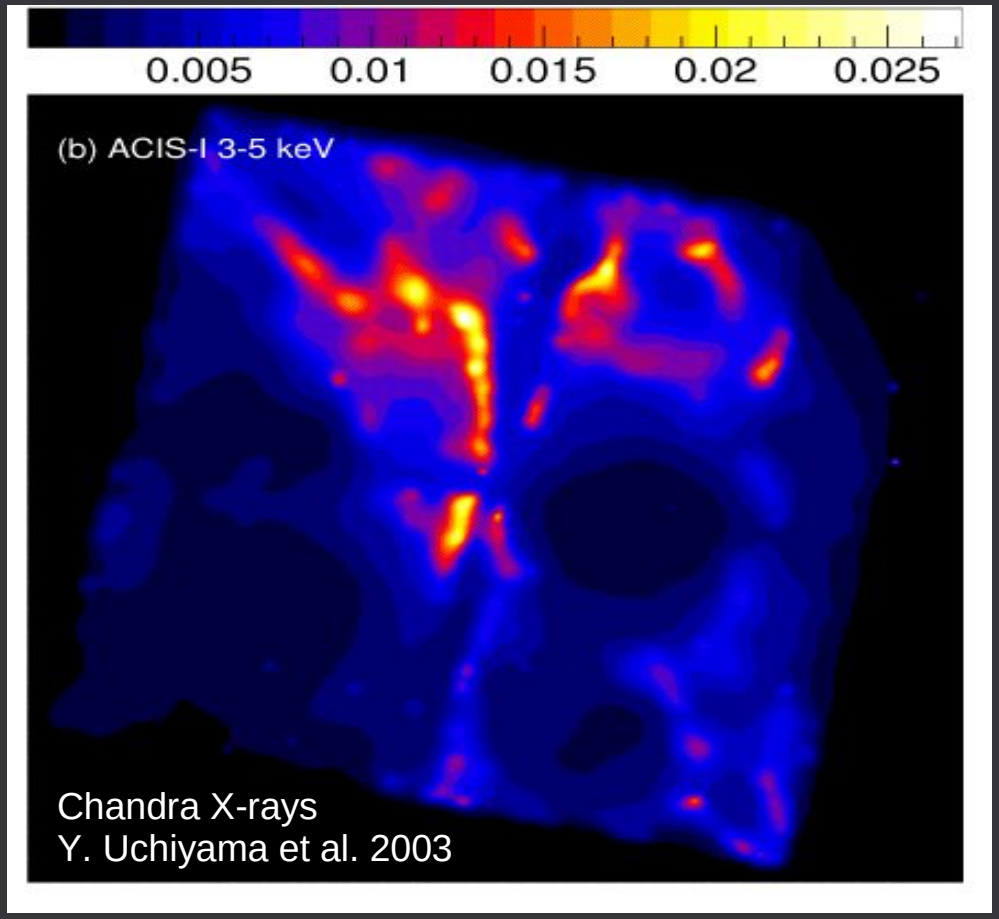

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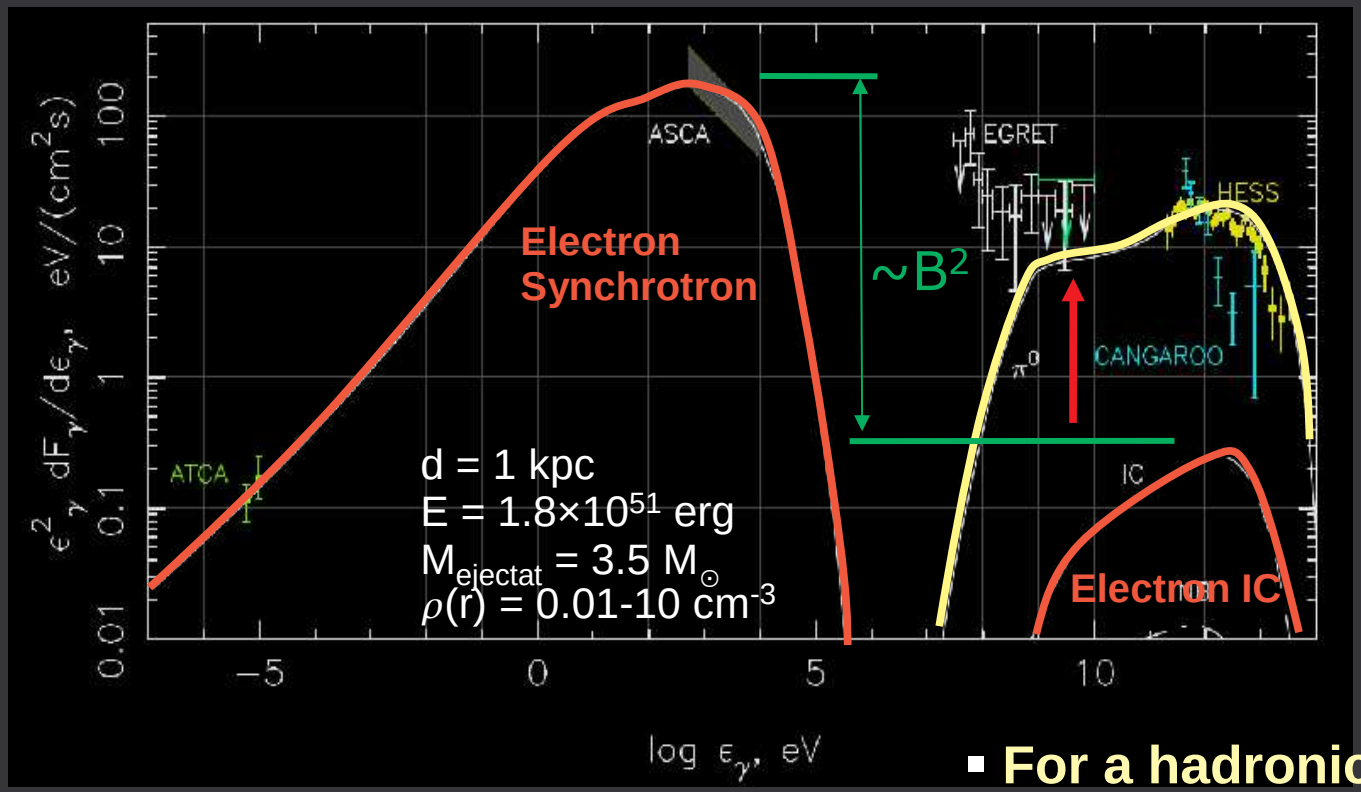
RXJ 1713.7-3946: Hadronic vs Leptonic emission



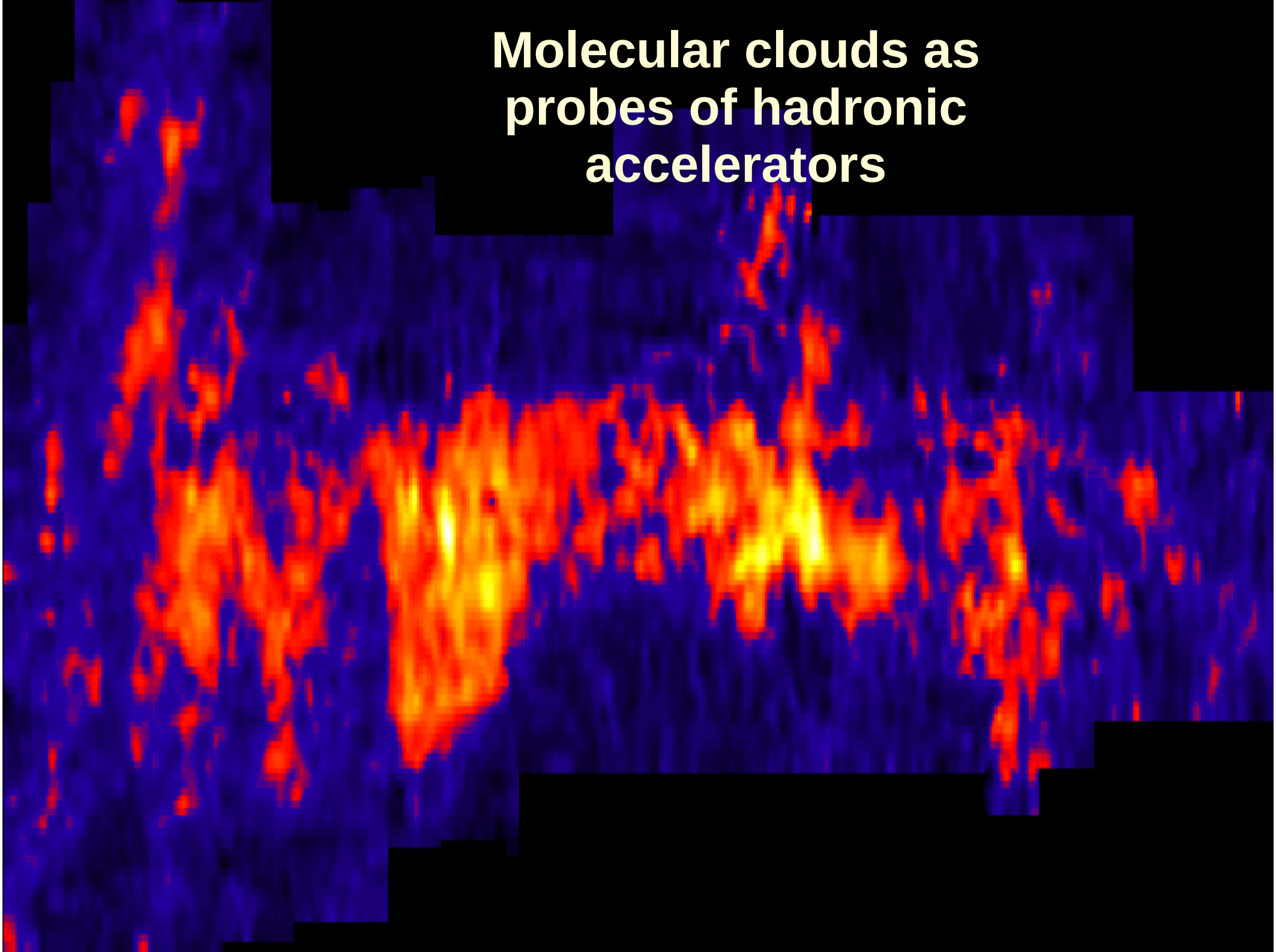
B = 126 μG
e/p= 10^{-4}

- **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, Cas A)**

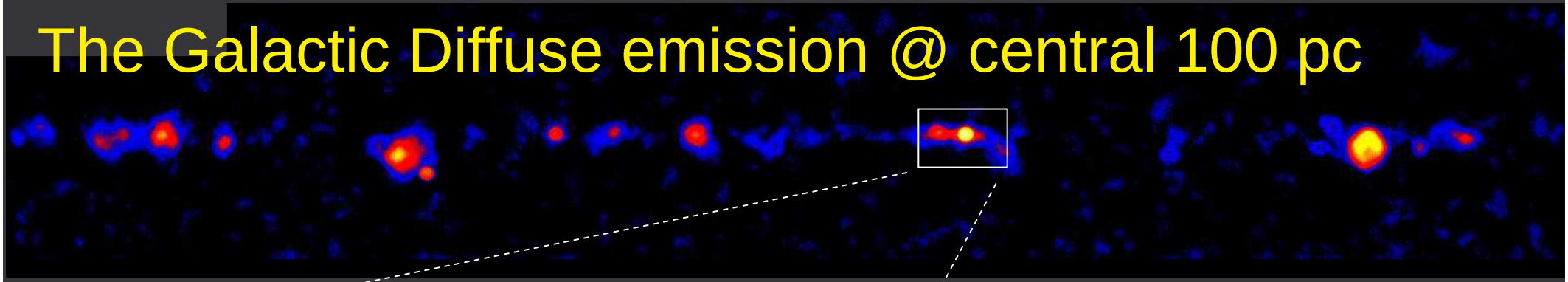
- **For a hadronic scenario**
  - **High B for acceleration and X-ray synchrotron emission**
  - **Low ratio e/p**
  - **Low target density (ρ~1cm^{-3})**
  - **But X-ray thermal spectrum: ρ<0.02cm^{-3}**

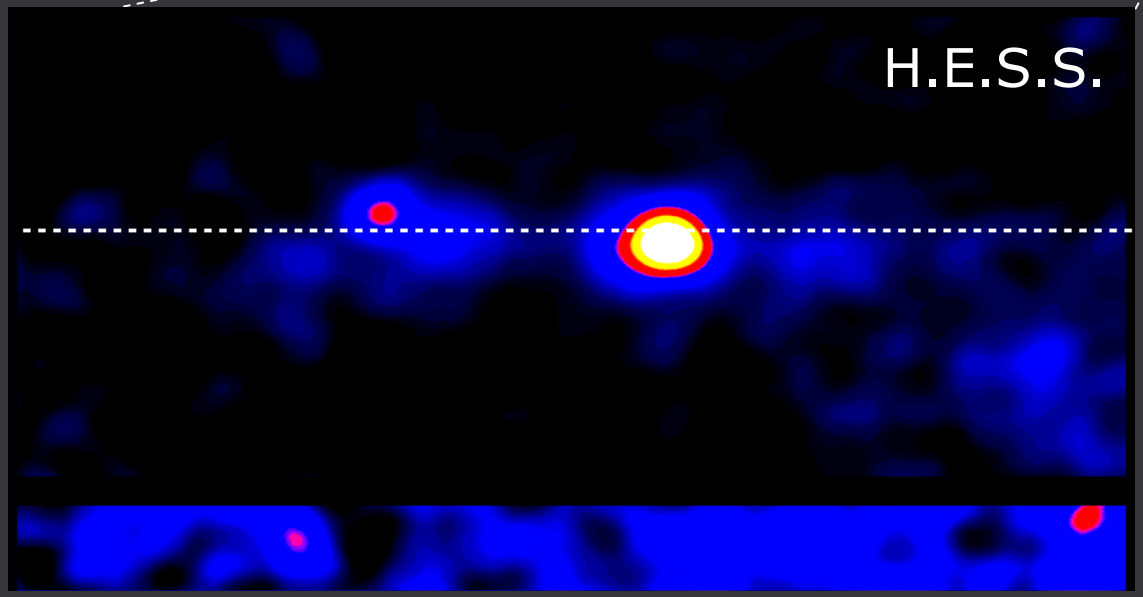
⇨ **Real Question : what proportion of leptons/hadrons i.e. hybrid modelling**

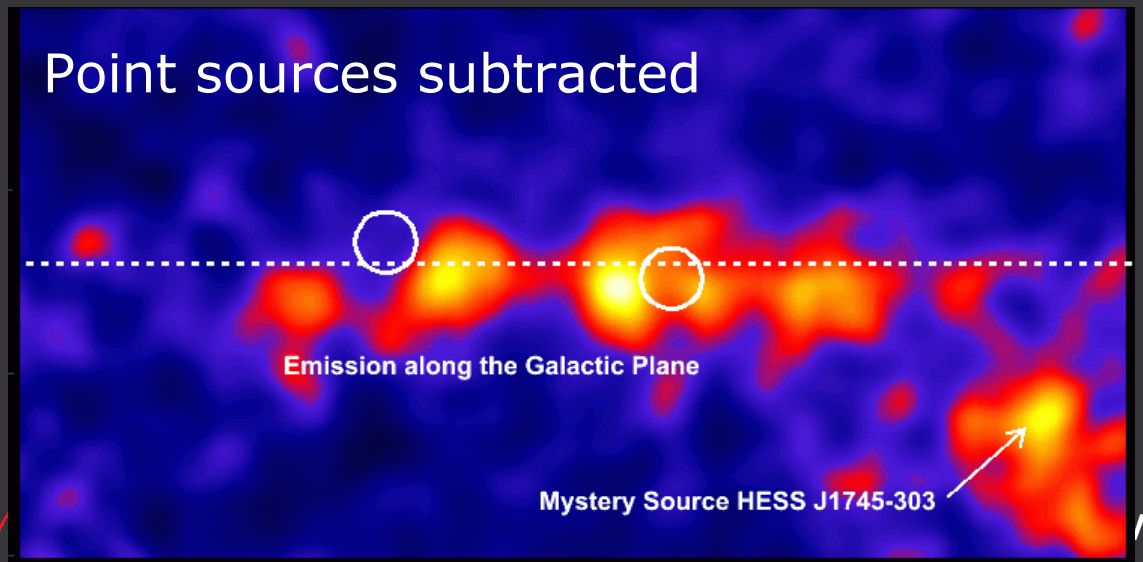
Molecular clouds as probes of hadronic accelerators



The Galactic Diffuse emission @ central 100 pc





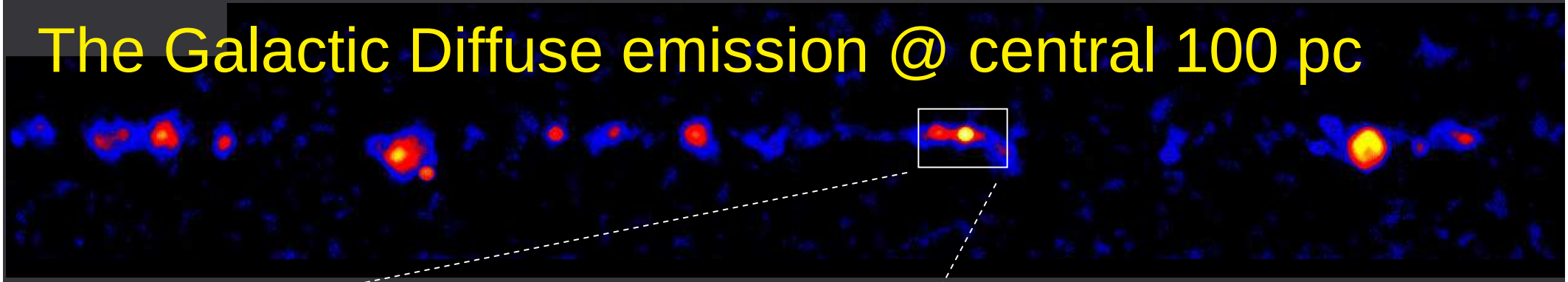


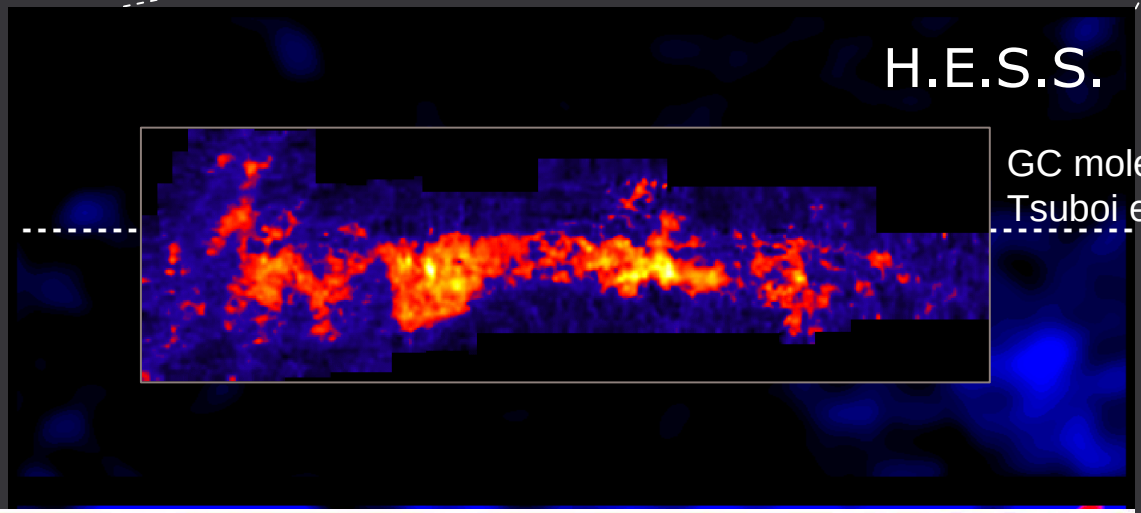
- **Correlation with molecular clouds**
- **$F_\gamma \propto F_{cr} \times \rho_{target}$**
- **$\Gamma_\gamma \propto \Gamma_{cr}$**
- **<u>Interpretation:</u>**

Central source(s) + diffusion ~ 10 kyrs ⇨ propag. of ~100 pc

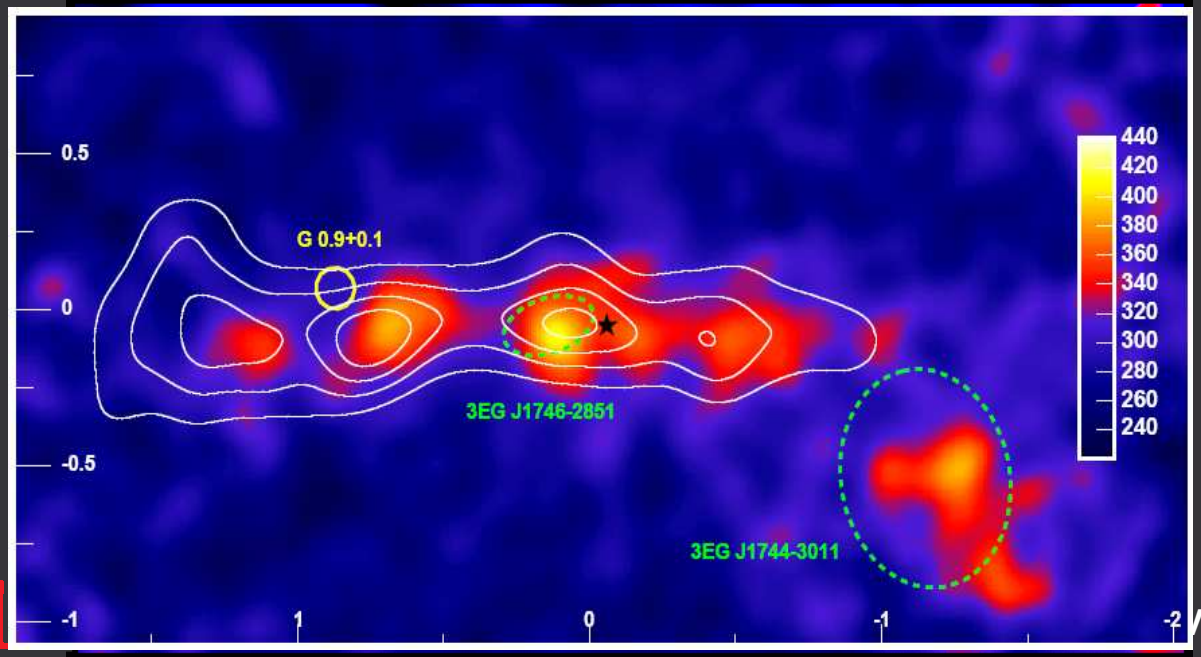
- **HESS flux implies:**
  - **➔Higher CR density**
  - **➔Harder spectrum**

The Galactic Diffuse emission @ central 100 pc





GC molecular clouds
Tsuboi et al. 1999



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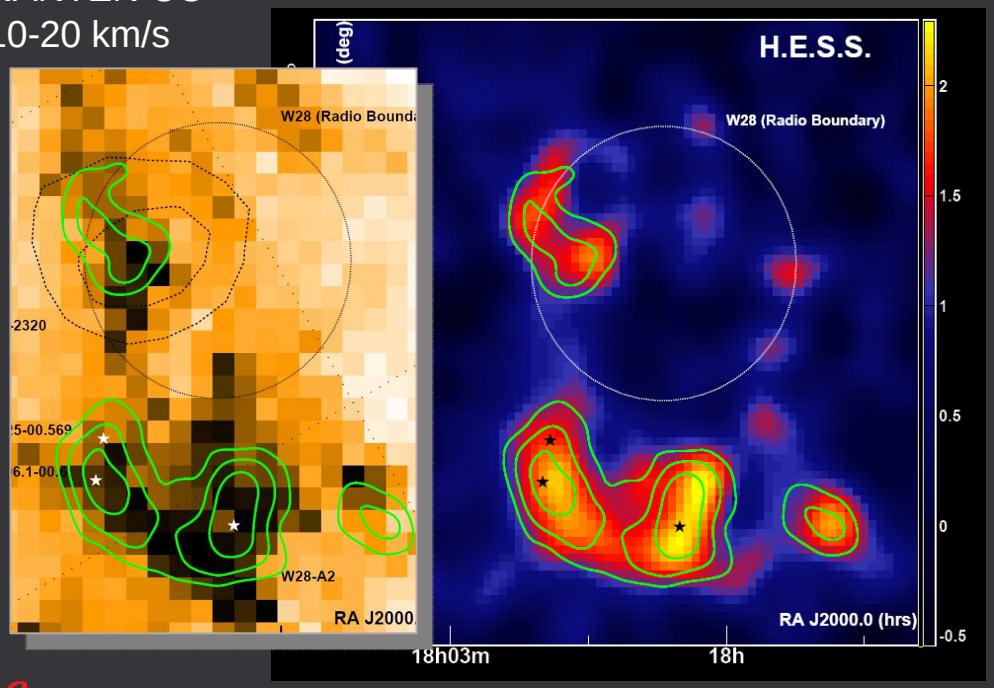
Older Shell type SNRs : W28

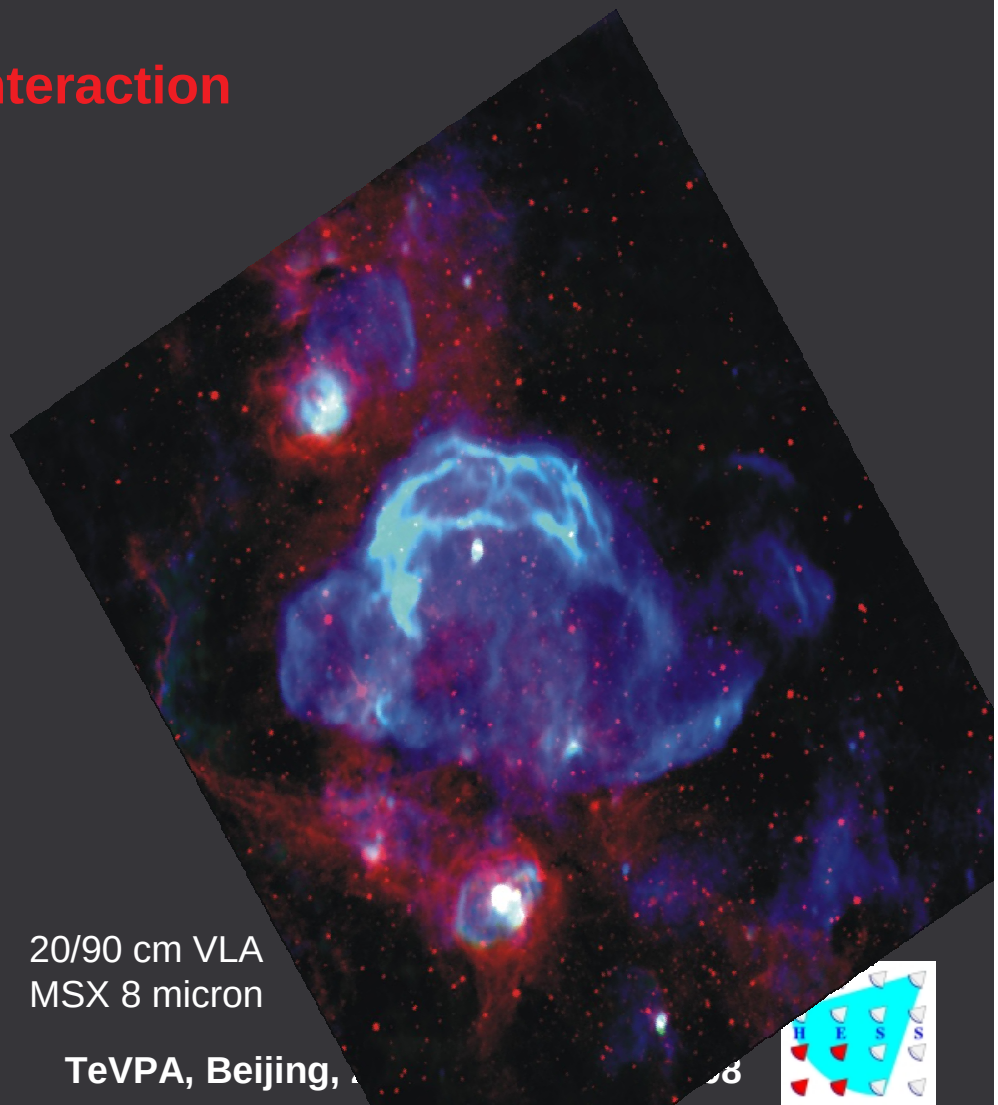
- **2-3 kpc**
- **35 – 150 kyr age**

- **TeV emission coincident with molecular clouds revealed by HESS**
- **OH masers trace shocks**

- **First evidence for p-p in SNR/Cloud interaction**

NANTEN CO
10-20 km/s





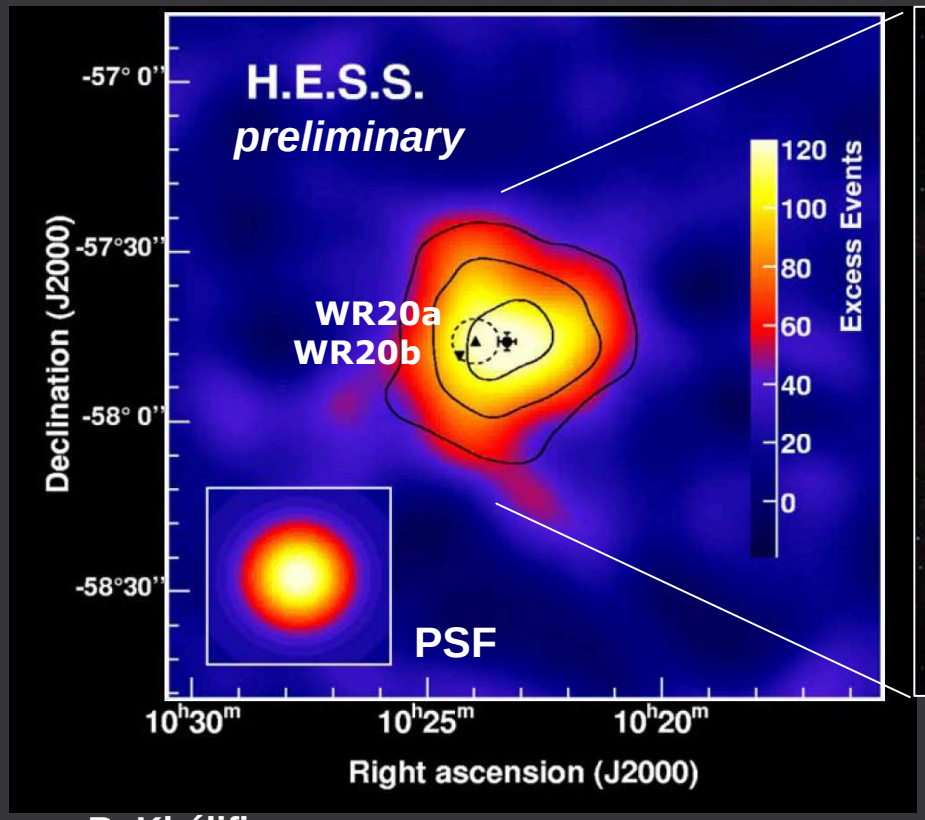
20/90 cm VLA
MSX 8 micron

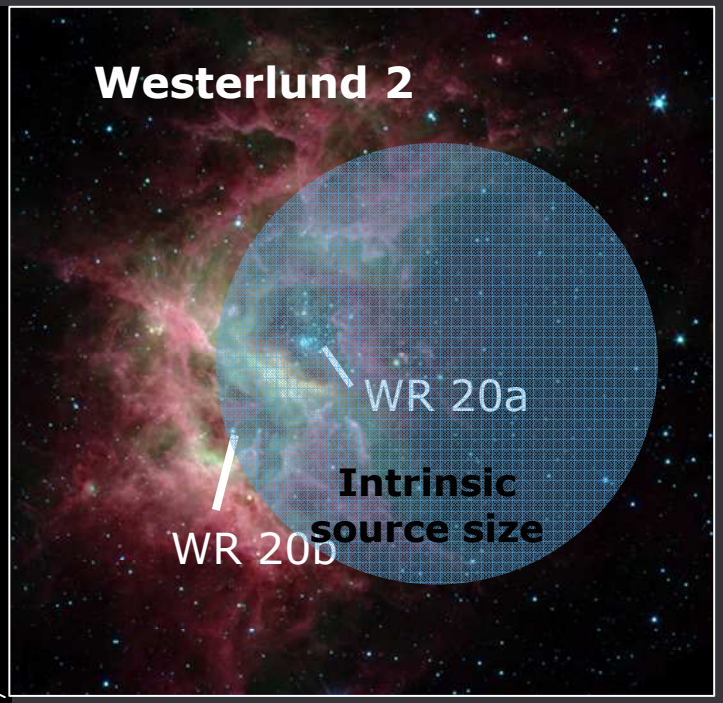
Stellar clusters: A new type of TeV source?

- **Open Cluster Westerlund 2 : thousands of solar masses**
  Wolf-Rayet & young stars
- **Winds excavating bubbles in the ISM**

- **HESS source coincides with the most proeminent one in RCW 49**
- **Acceleration through collective wind effects or DSA at the boundaries?**

⇨ **Systematic search program undertaken with HESS...**





Pulsar Wind Nebulae

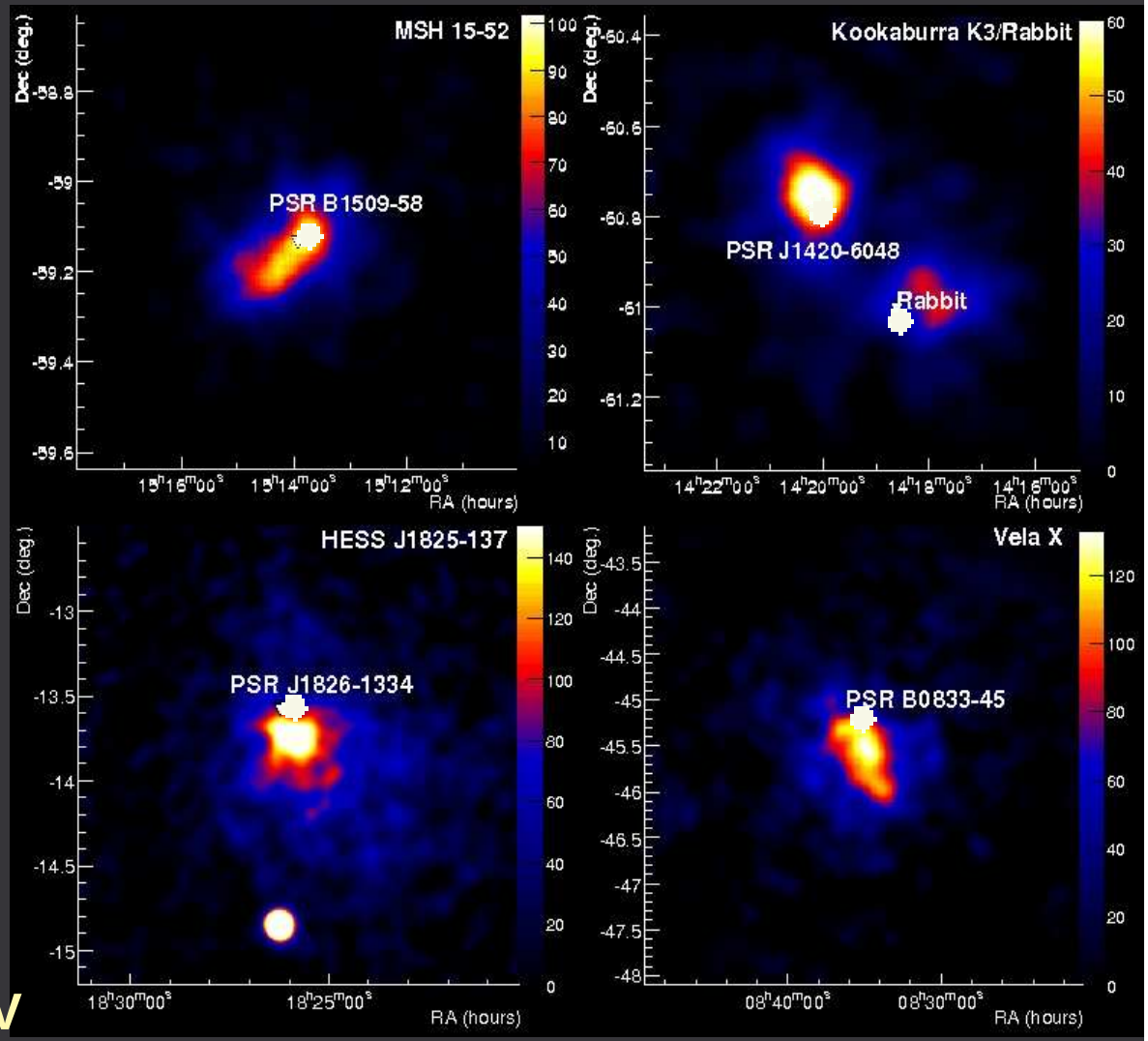
Pulsar Wind Nebulae

- **Major galactic source population revealed by HESS galactic scan**

- **Associated with pulsars:**
  - **very young : age < 10^5 yrs**
  - **energetic: Edot > 10^{35} erg/s**

- **Nebulae with huge caracteristic sizes of O(10 pc)**
- **Mostly displaced TeV emission relative to pulsar position: "Crushed nebulae"**

- **Spectra extend frequently >10 TeV (>50 TeV for some sources)**

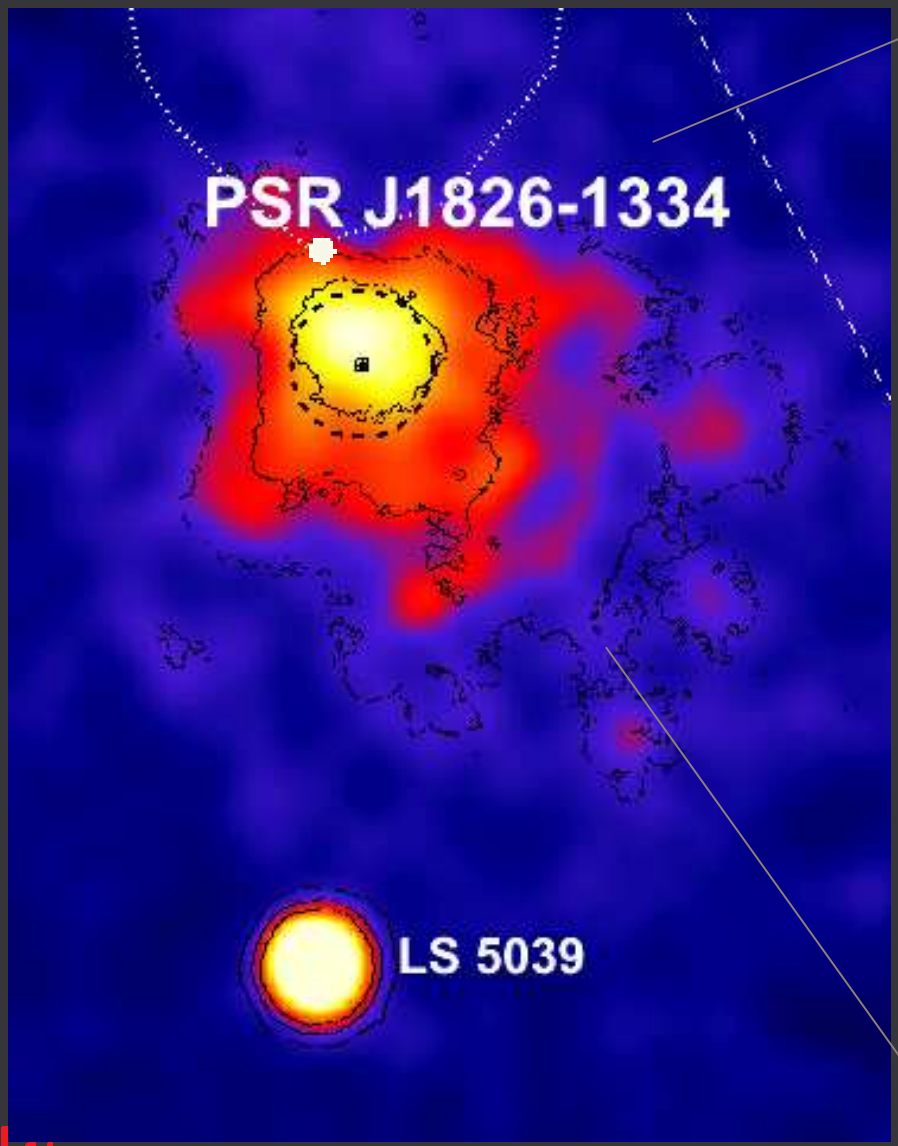


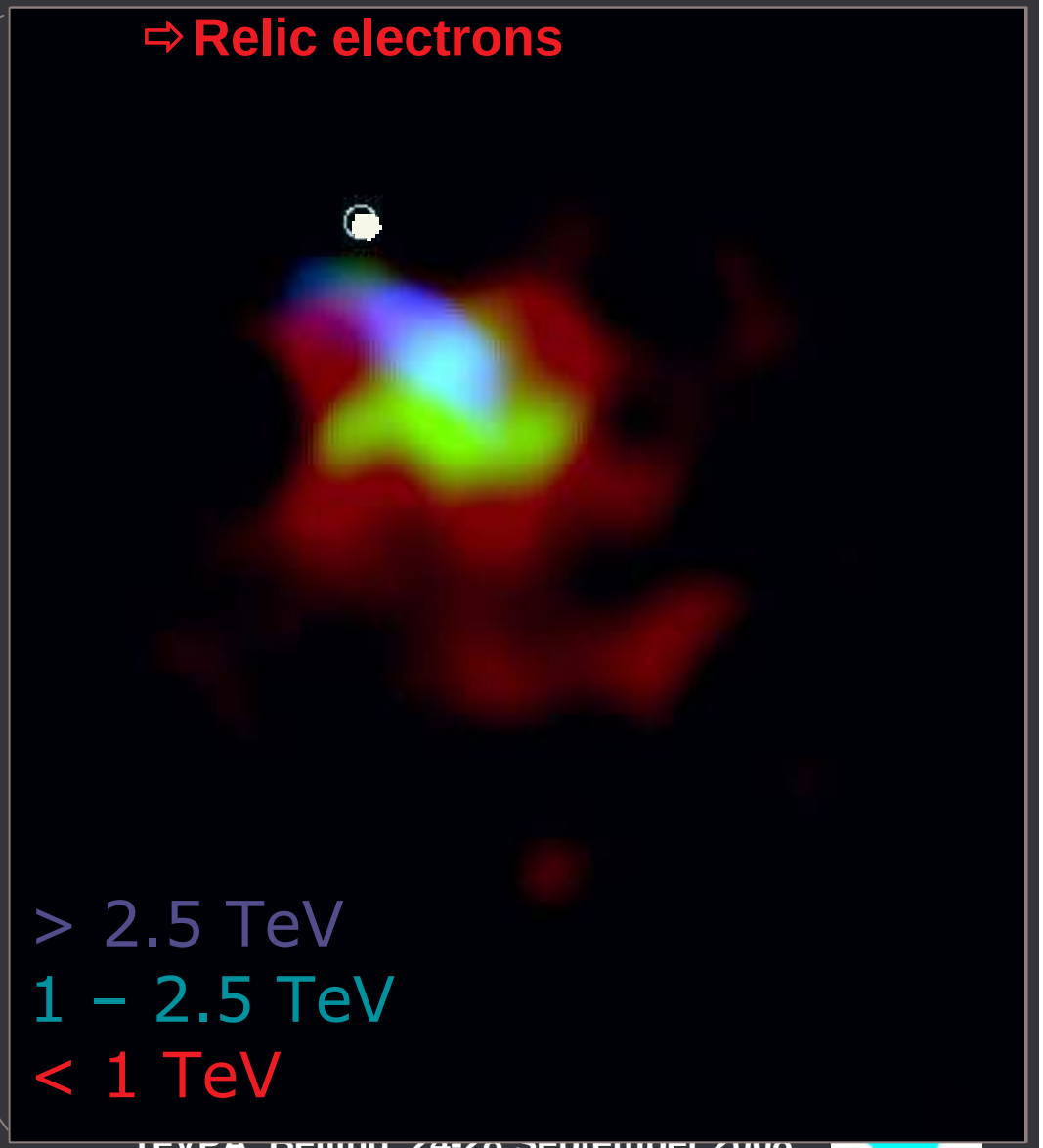
Morphology of PWNe: evidence for cooling

TeV emission:

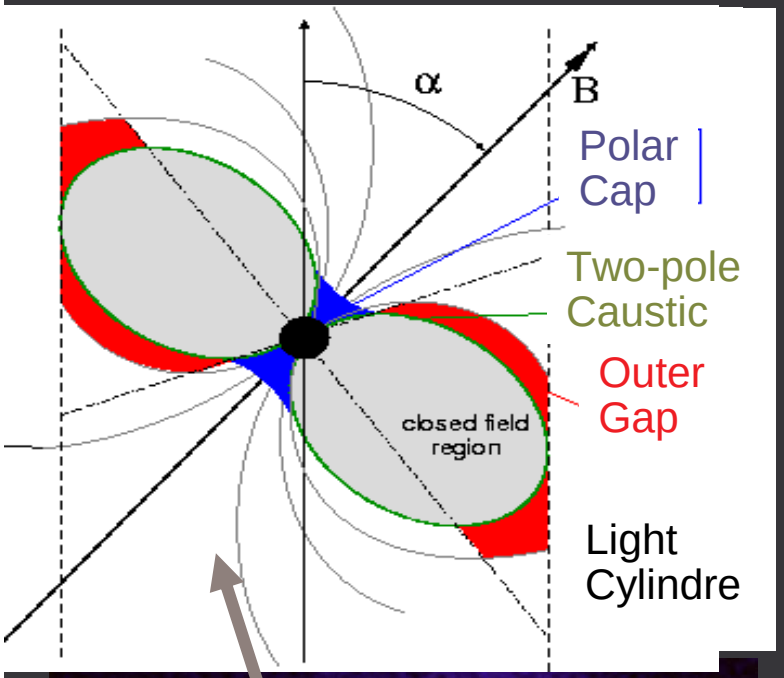
- **From charged particules rapidly losing their enery**

⇨ Relic electrons

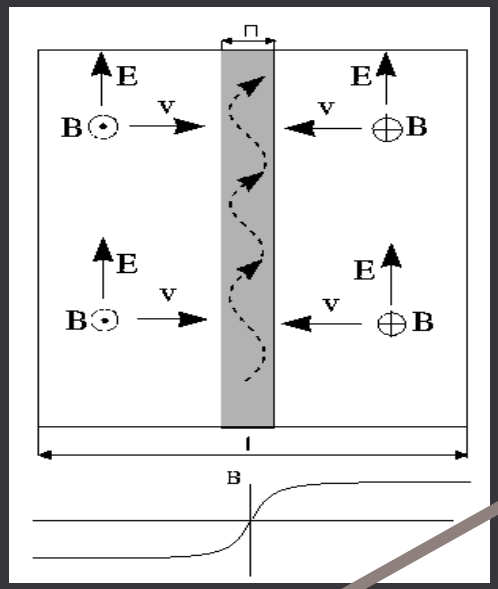




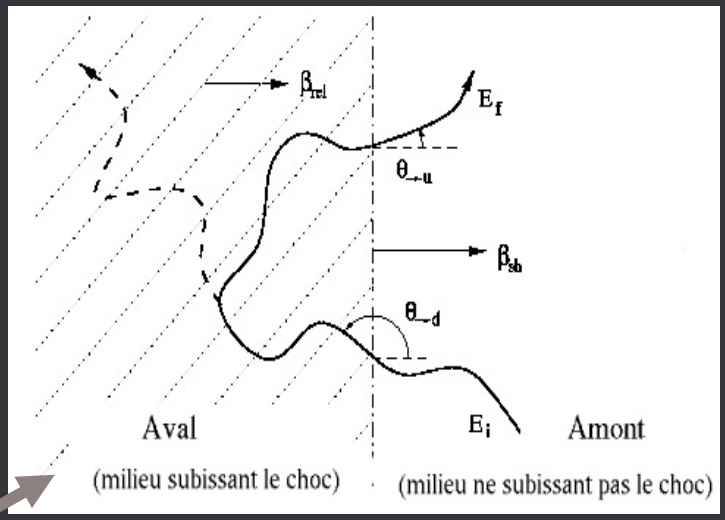
PWNe: particle acceleration and morphology



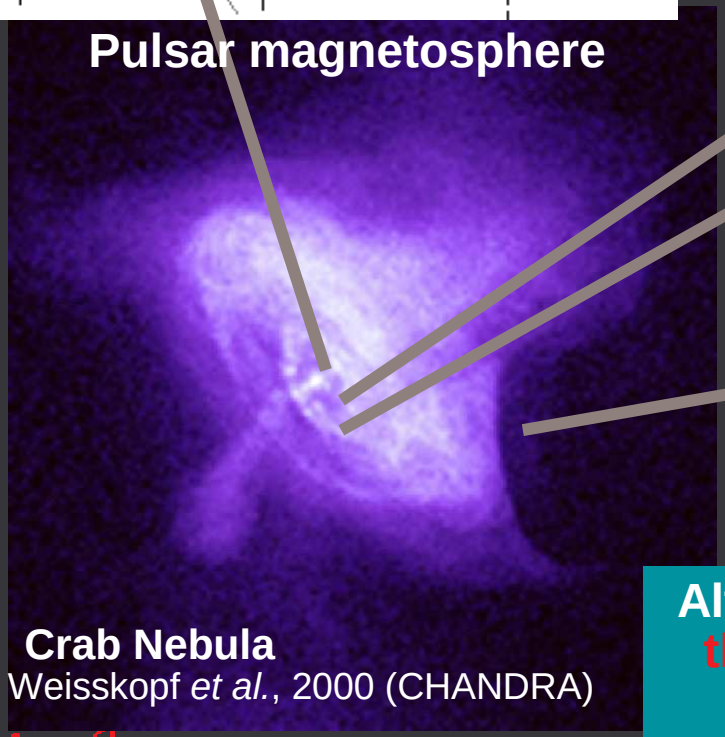
Striped wind



Relativistic shock

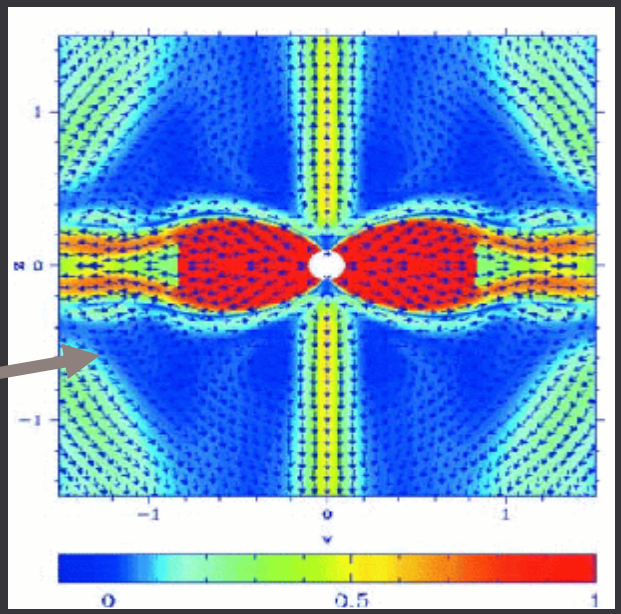


Pulsar magnetosphere



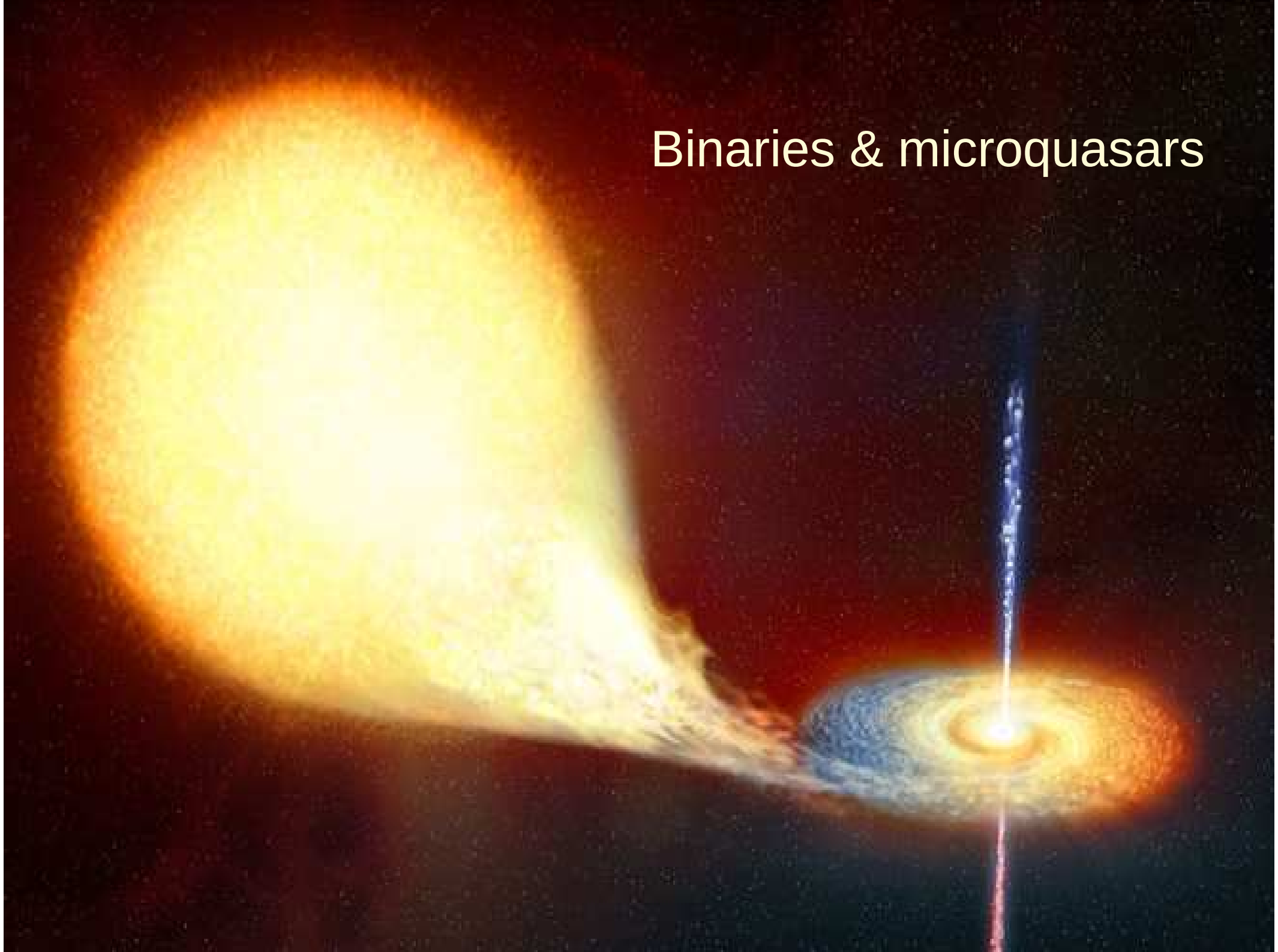
Crab Nebula
Weisskopf *et al.*, 2000 (CHANDRA)

Simulations of the plasma properties



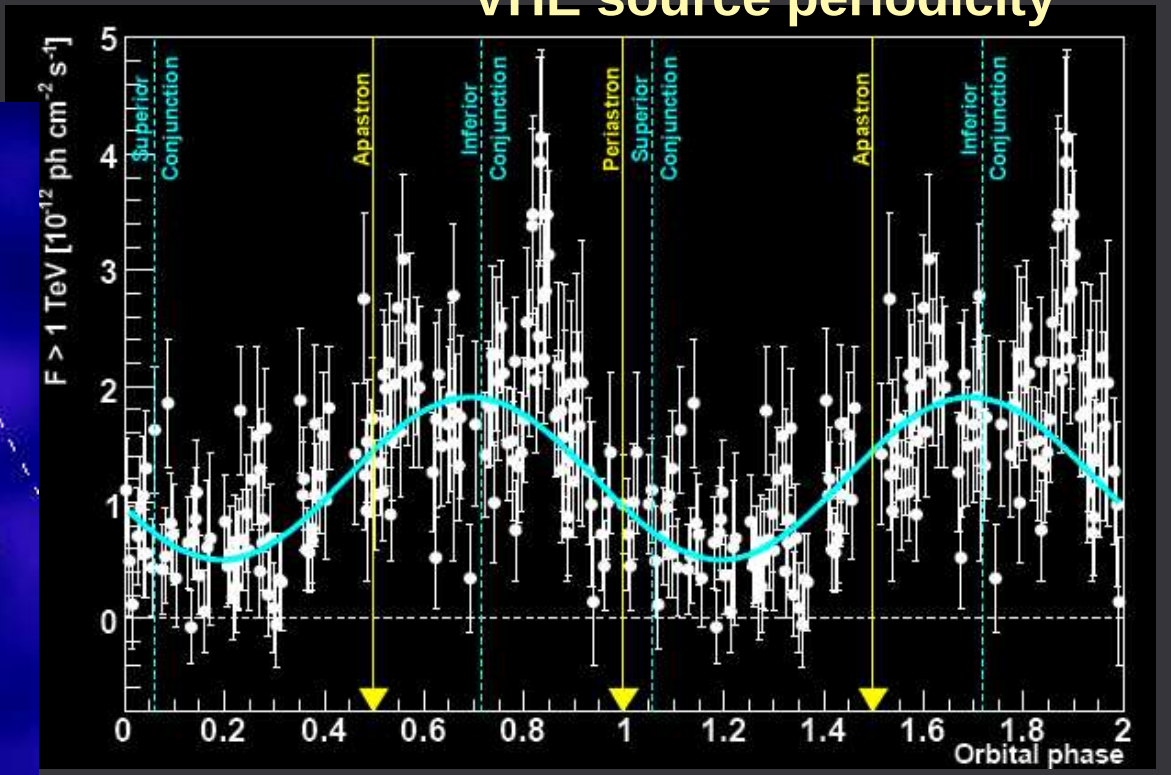
Although the plasma properties start to be well understood, the acceleration processes are poorly known … (E>100TeV)

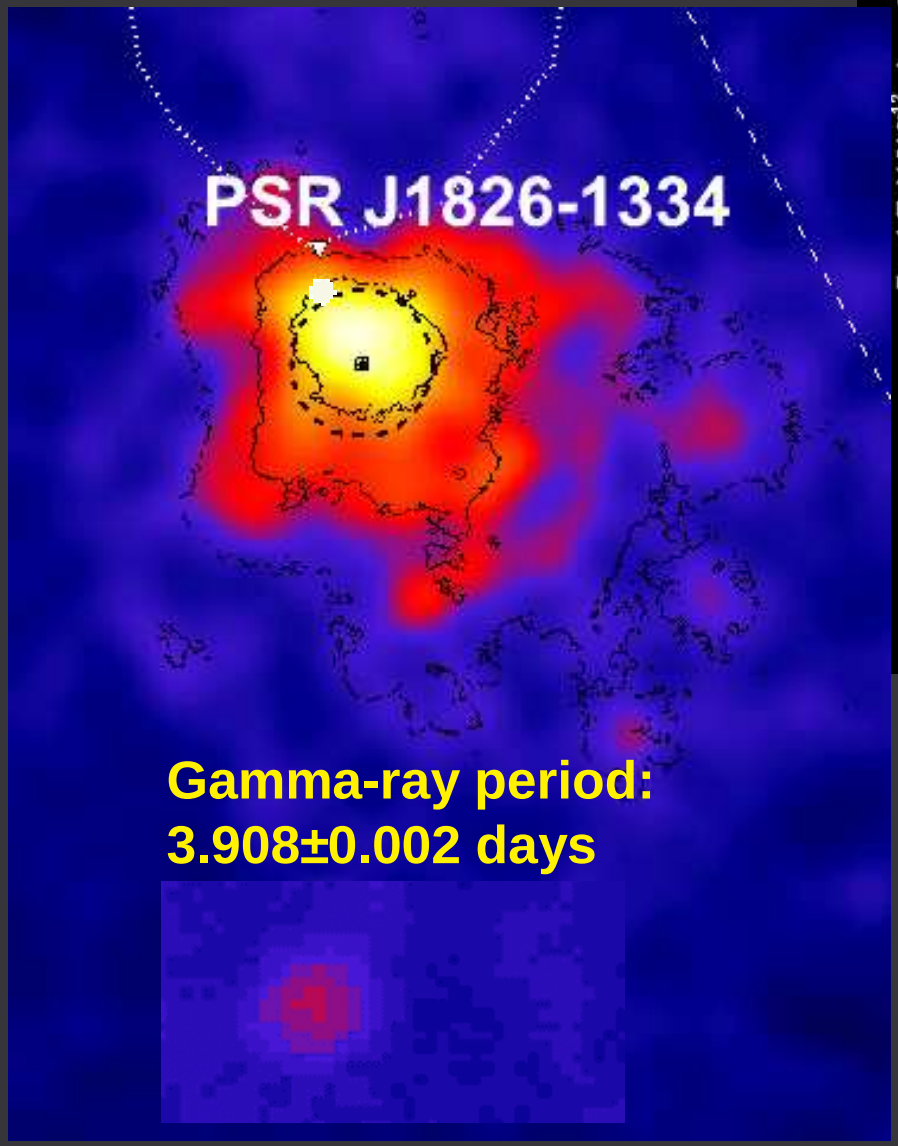
Binaries & microquasars



Binaires : LS 5039 with HESS

First detection of VHE source periodicity



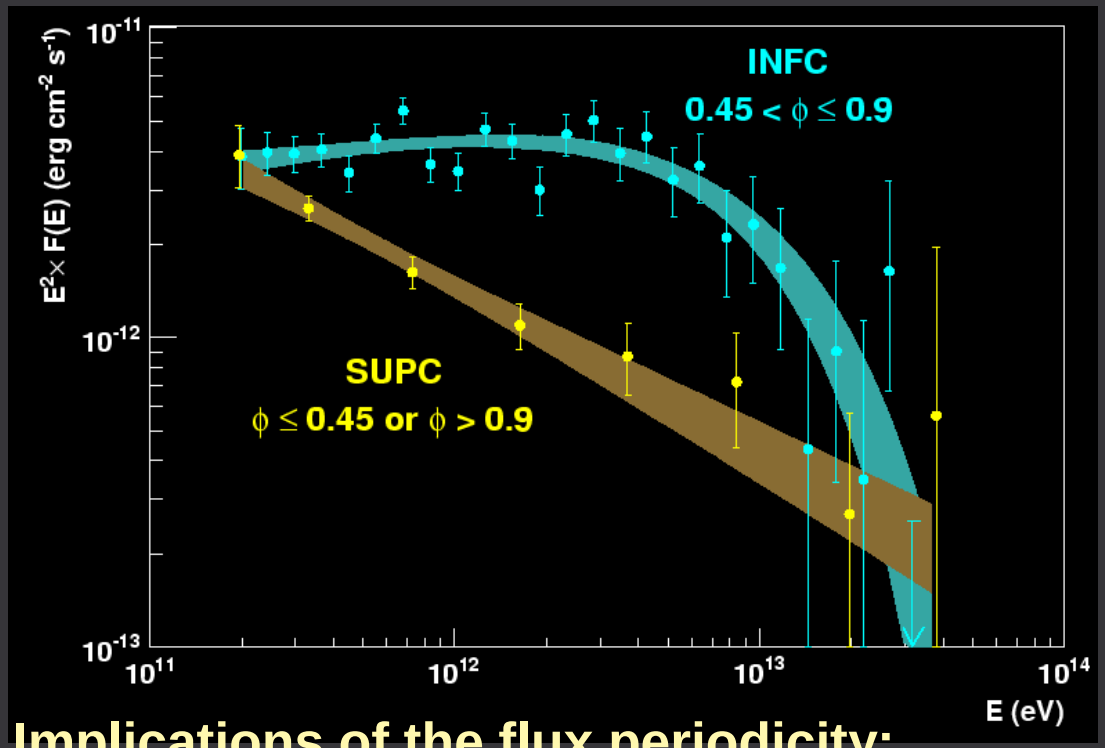


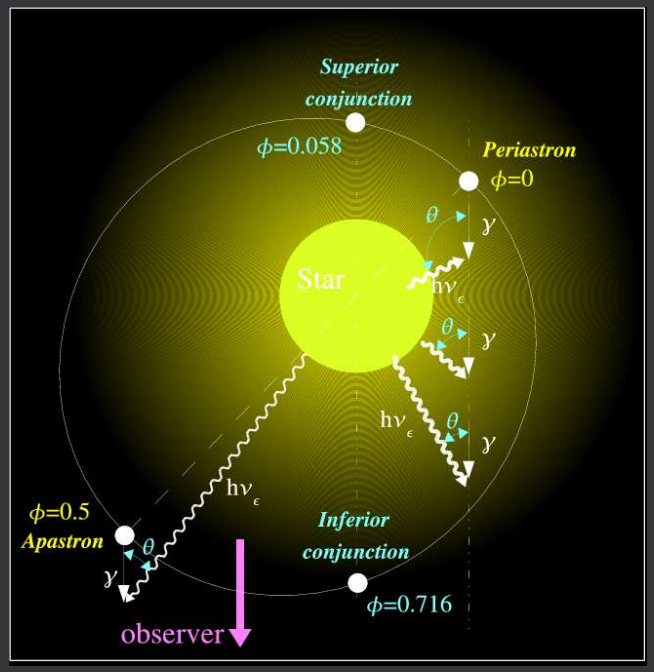
Gamma-ray period: 3.908±0.002 days

LS 5039:

- **4(?) $M_\odot$ object in eccentric 3.9-day orbit around a 20-30 $M_\odot$ star**
- **Closest approach ~10^{12} cm or ~2 stellar radii**

LS 5039: origin of γ-rays?





Implications of the flux periodicity:

- **Maximum flux at the apostron**
  - ⇨ **Major role of γ-hν absorption**
- **But strongest absorption in 0.2-2 TeV and flux at 0.2 TeV constant**
  - ⇨ **Other processes should occur (cascades, acceleration mechanism, …)**

Not yet possible to deduce the nature of accelerated particles

Summary and Conclusions

A wealth of sources of different types discovered
Shell, neutron star, black hole, stellar cluster, molecular clouds, …

In addition of a diversity of:

- **Astrophysical environments:**
  photon field, interstellar material density, B strength, …
- **Possible acceleration processes:**
  Fermi I/II, Diffusive Shock Acceleration, magnetic reconnection, collective wind effects, …

⇨ Some answers ... but many questions remain and new ones are raised !

Source type	HESS detections	Nature of charged part.	Max. en. of charged part.	Acceleration process
Gal. Centre	1	$e^{\pm}$/p	> 50TeV	?
SNRs	4 2 4(SNR/MoC)	$e^{\pm}$/p	> 100TeV	Fermi/DSA
Mol. Clouds	2 4(SNR/MoC)	Likely p	> 50TeV	None
Stellar Clusters	1	$e^{\pm}$/p	> 50TeV	Fermi
PWNe	9 7 5(PWN/SNR)	Likely $e^{\pm}$	> 100TeV	?+Fermi
Binaries	2 1	$e^{\pm}$/p	> 50TeV	?
« Dark »	10	?	> 50TeV	?

Firm association

Identified counterpart

Plausible counterpart

Key location: Namibia