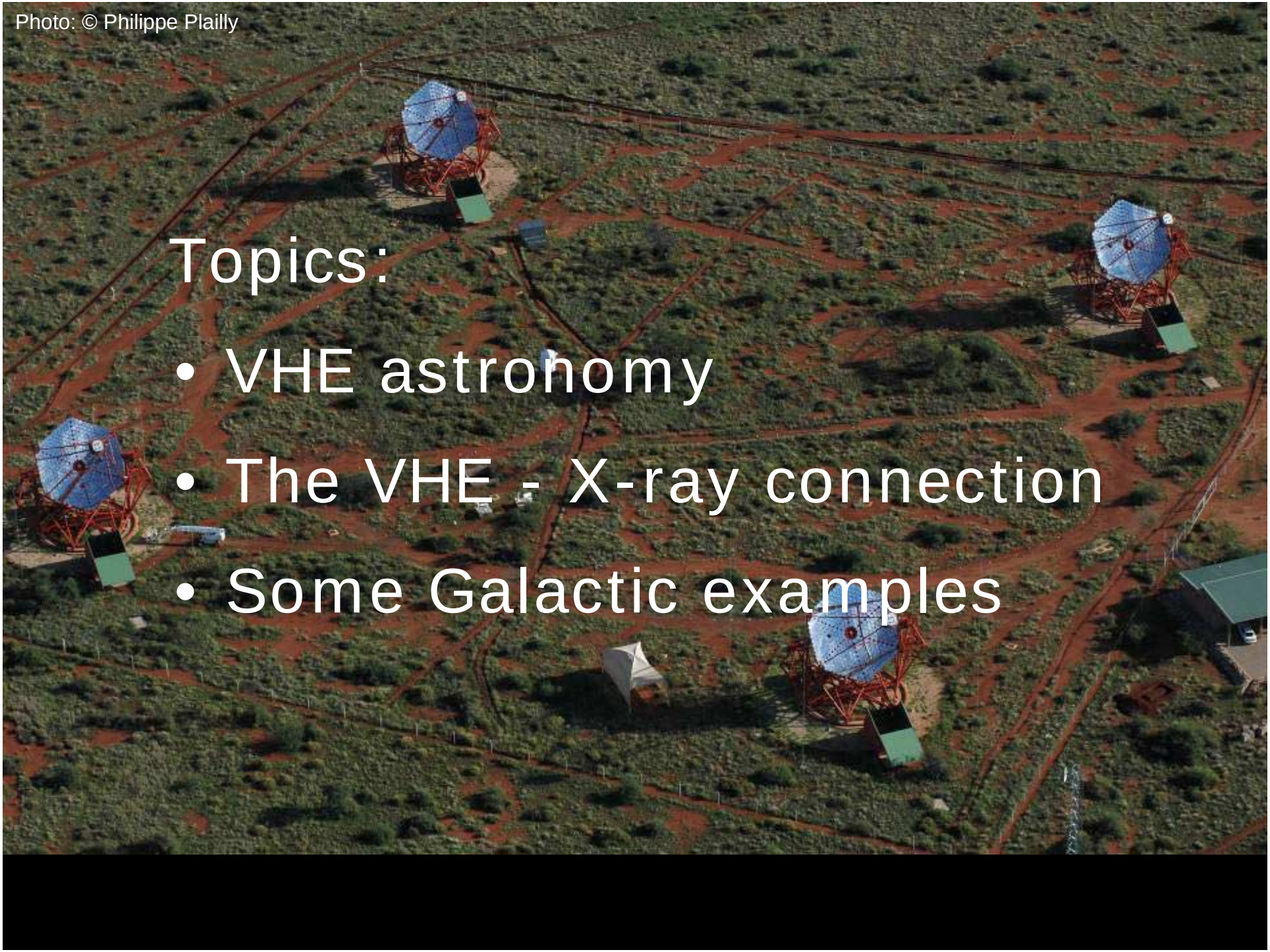
Photo: © Philippe Plailly

Gerd Pühlhofer,
Landessternwarte Heidelberg
H.E.S.S. collaboration

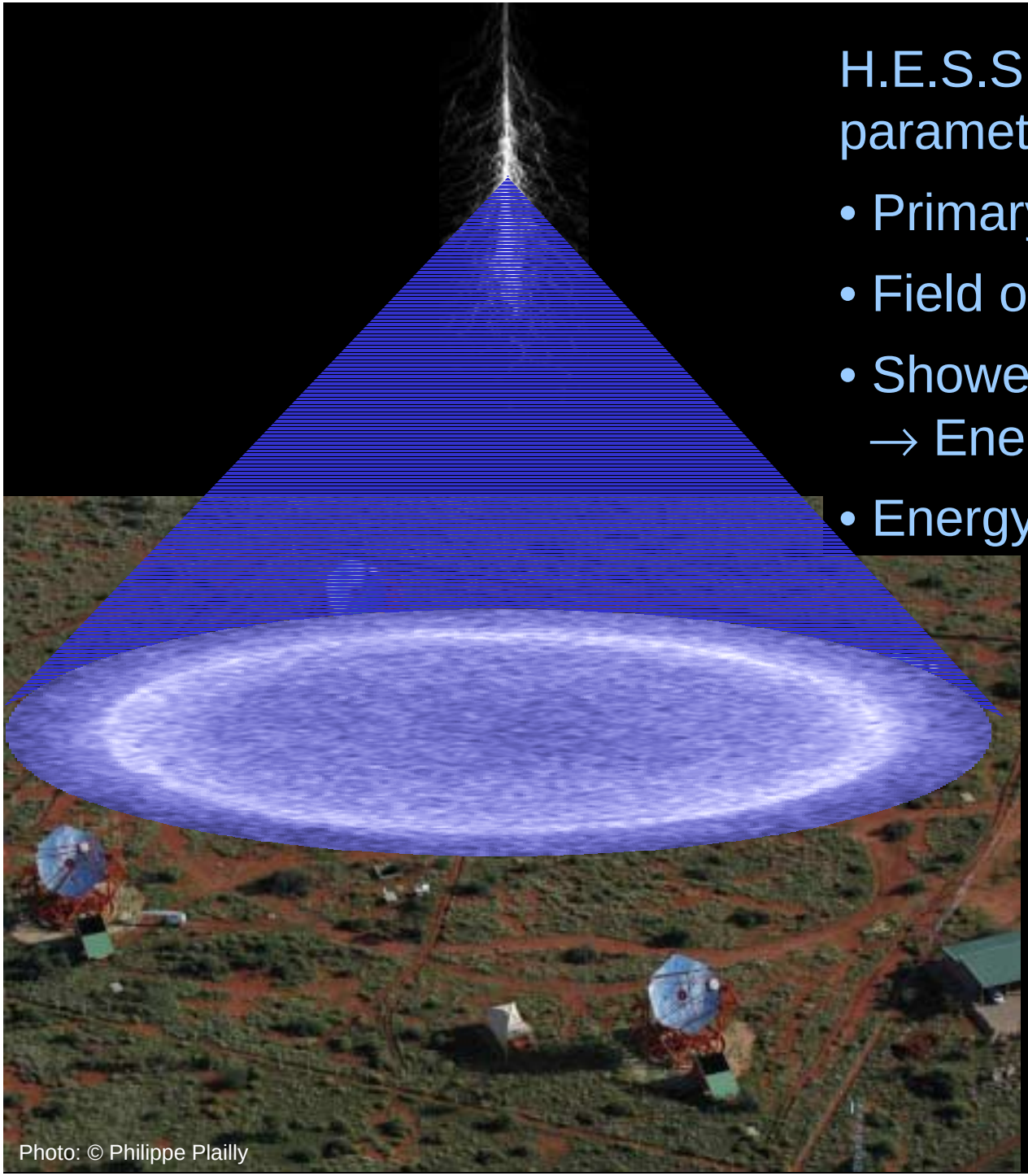
Using X-ray observations to identify the particle acceleration mechanisms in VHE SNRs and "dark" VHE sources

bmb+f - Förderschwerpunkt
Astrophysik
Großgeräte der physikalischen Grundlagenforschung



Topics:

- VHE astronomy
- The VHE - X-ray connection
- Some Galactic examples



H.E.S.S. event reconstruction parameters:

- Primary direction: < 0.1°
- Field of view: 3° FWHM
- Shower core: 10m
  $\rightarrow$ Energy resolution: 15%
- Energy range: 0.1–100 TeV

What is measured in VHE band (with H.E.S.S.)?

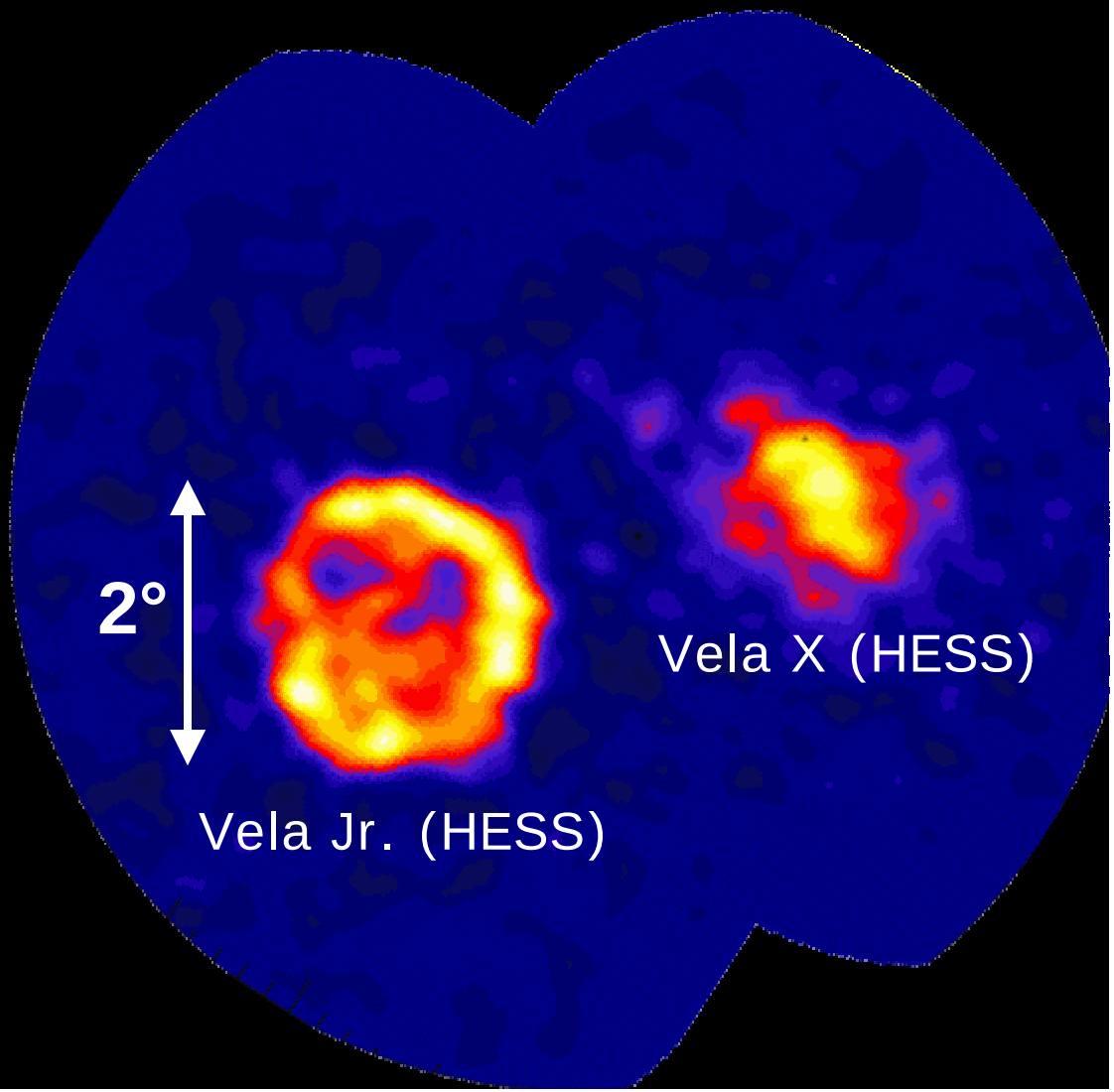
- **Morphology (if source >> 0.1°)**
- **Energy spectrum:**

0.1 – 100 TeV

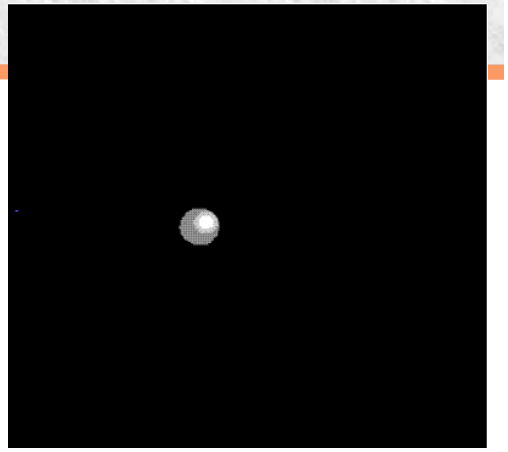
threshold (zenith angle)

statistics

- ***Variability (point sources only)***



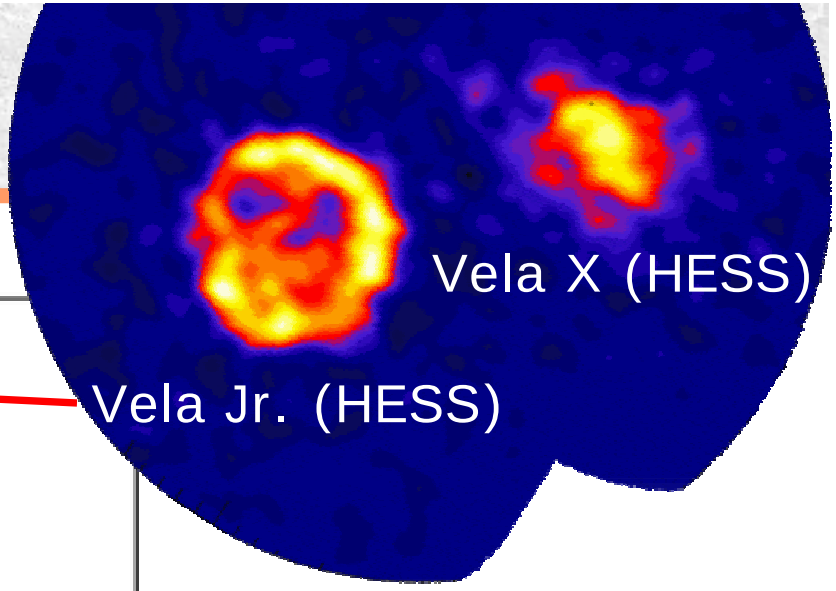
Particles producing γ-rays

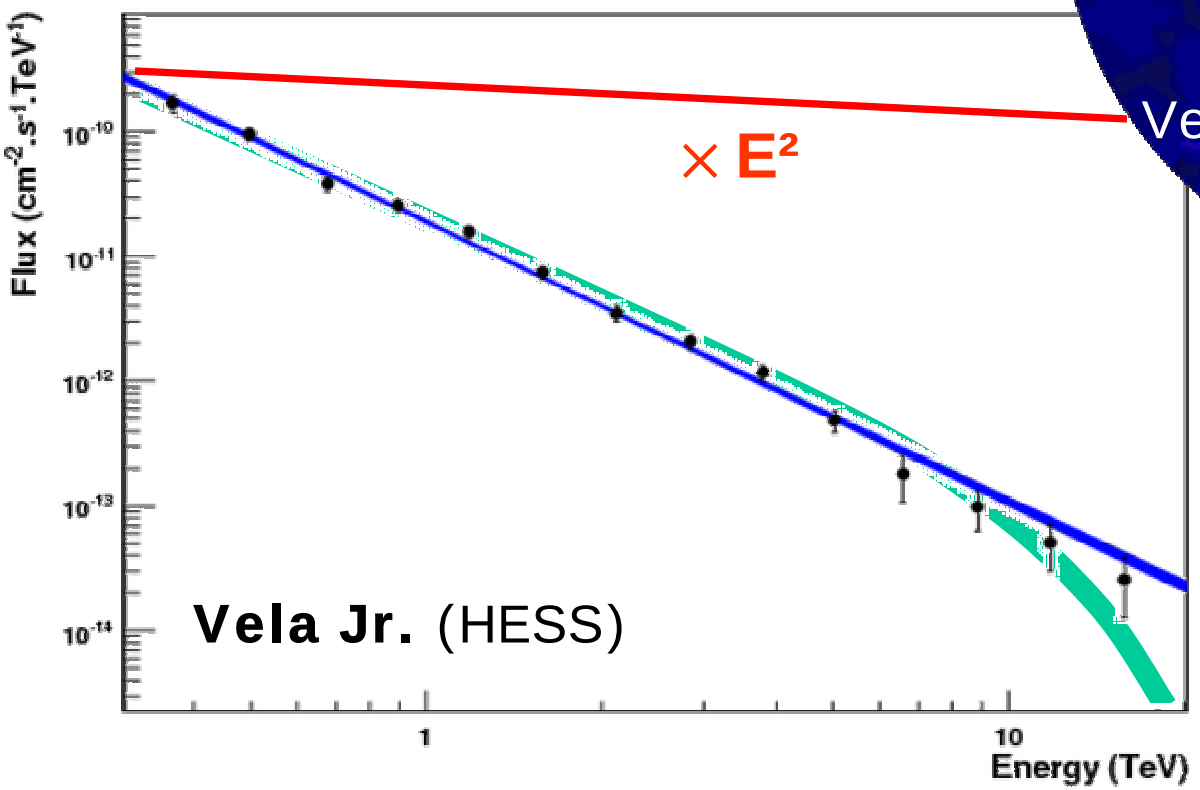


- **Hadronic:**
  - **CR proton + gas particle $\rightarrow \pi^0 \rightarrow 2\gamma$**
  - **$E_\gamma \approx 0.17\ E_p$**
  - **$E_{thr} \approx 300$ MeV $\rightarrow$ hadrons only visible in γ-ray band!**

- **Competing processes in γ-ray band: electrons**
  - **Inverse Compton (IC) scattering of ambient photons**
    $\rightarrow$ target mostly CMB, and stellar fields
    $\rightarrow$ in some sources, SSC dominant
  - *Bremsstrahlung*

VHE energy spectra



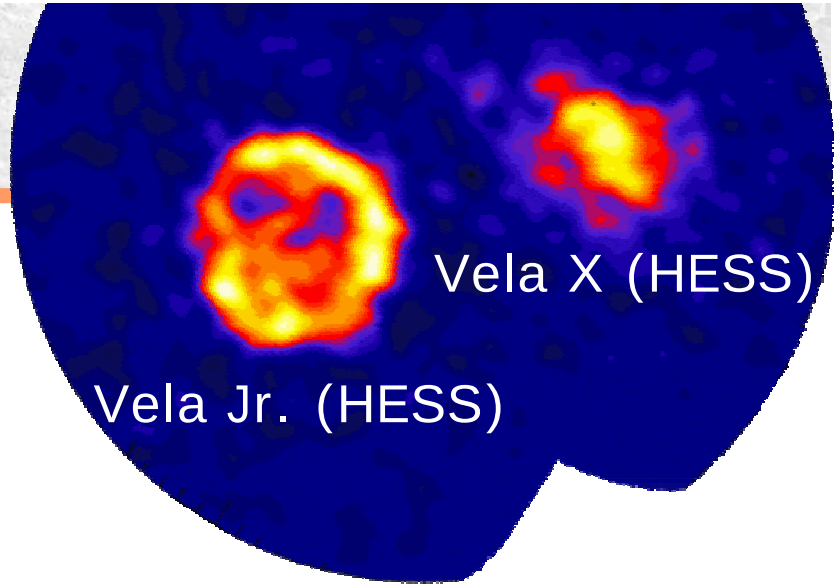


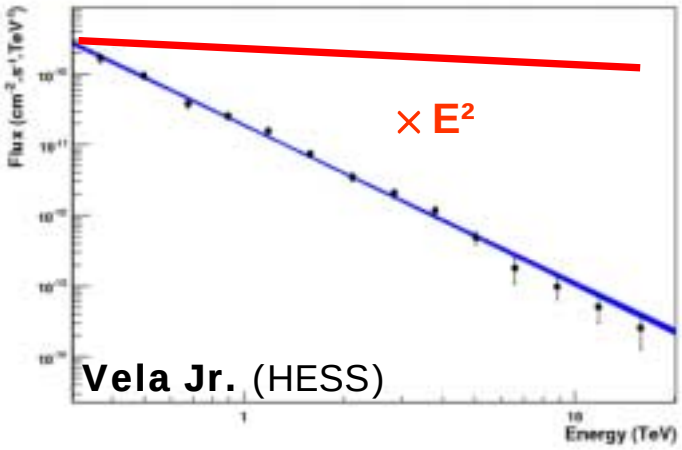
Power law: shock acceleration (?)

Cutoff: maximum particle energy

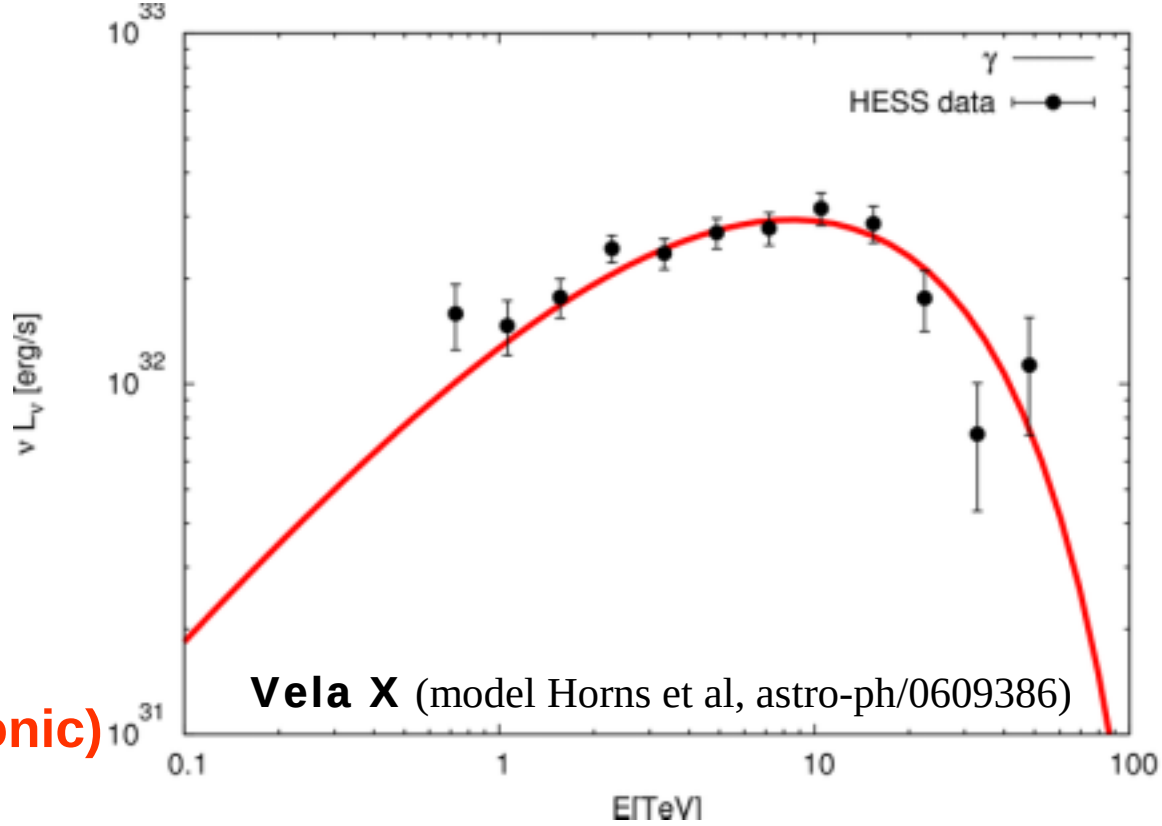
× E²: energy output per decade

VHE energy spectra



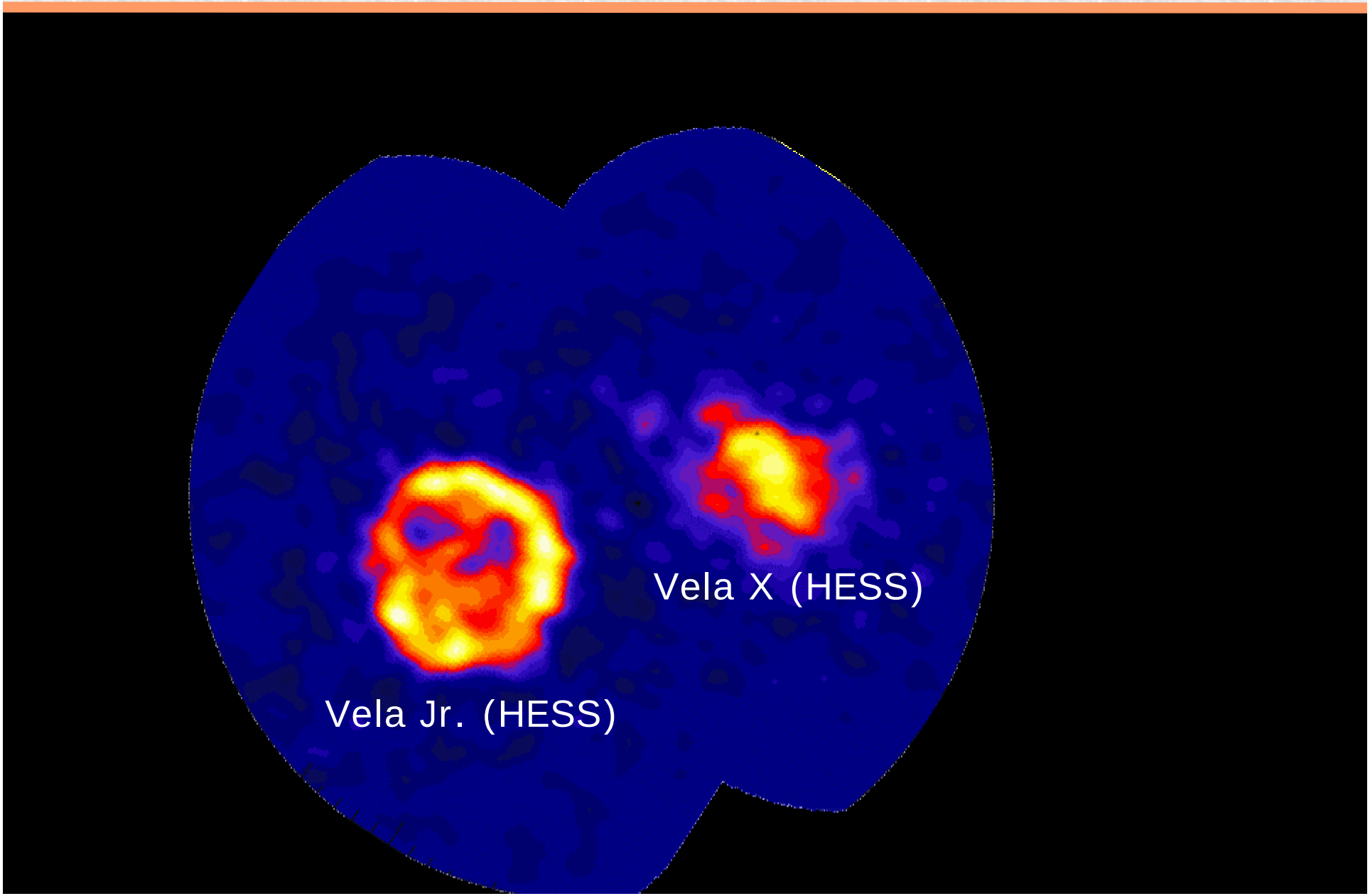


Power law: shock acceleration (?)
Cutoff: maximum particle energy
× E²: energy output per decade

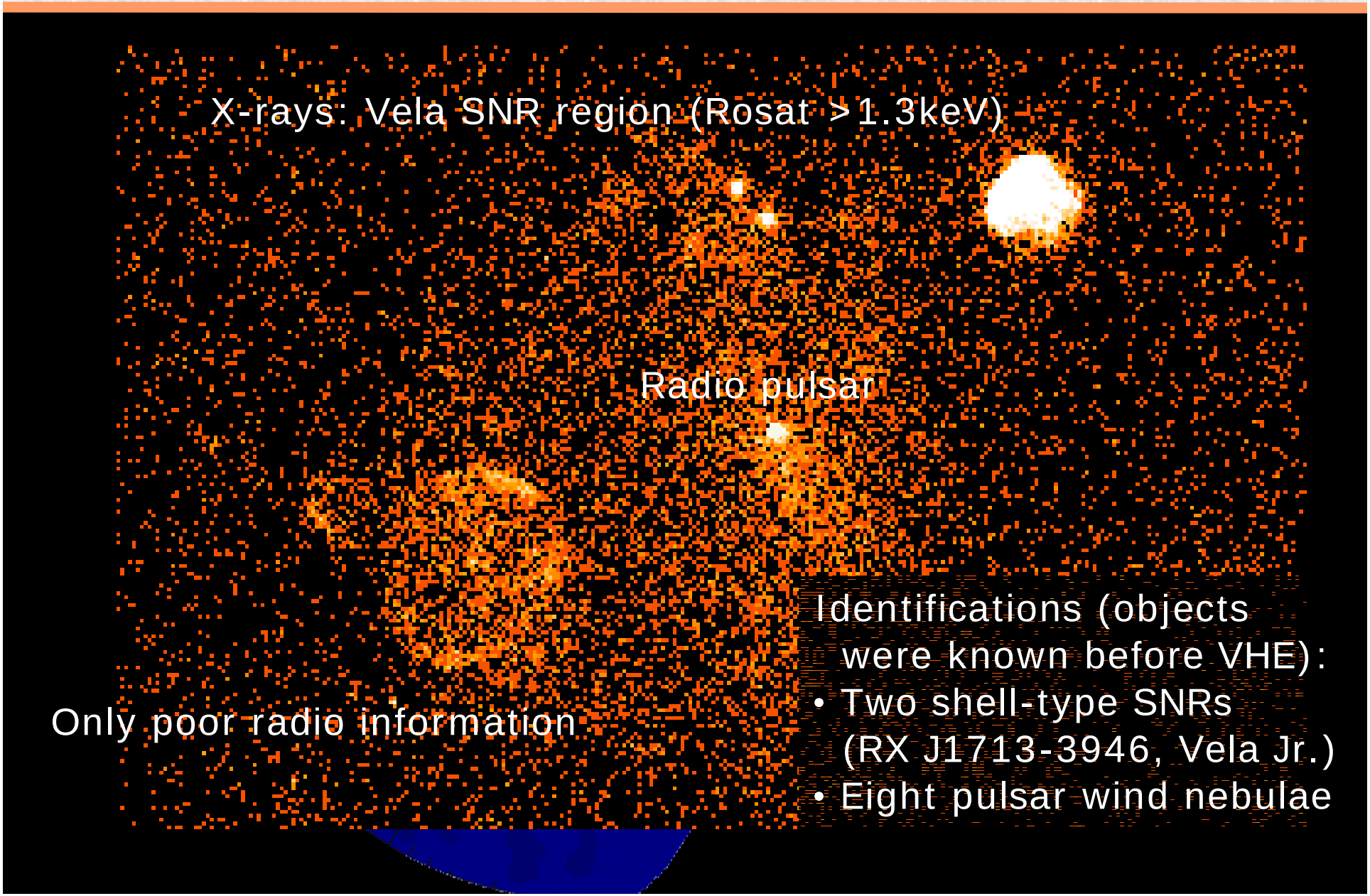


SED peak:
- **cutoff of a hard (IC ?) spectrum ?**
- **pileup spectrum? (shown Maxwellian, hadronic)**

The VHE – X-ray connection: Identification



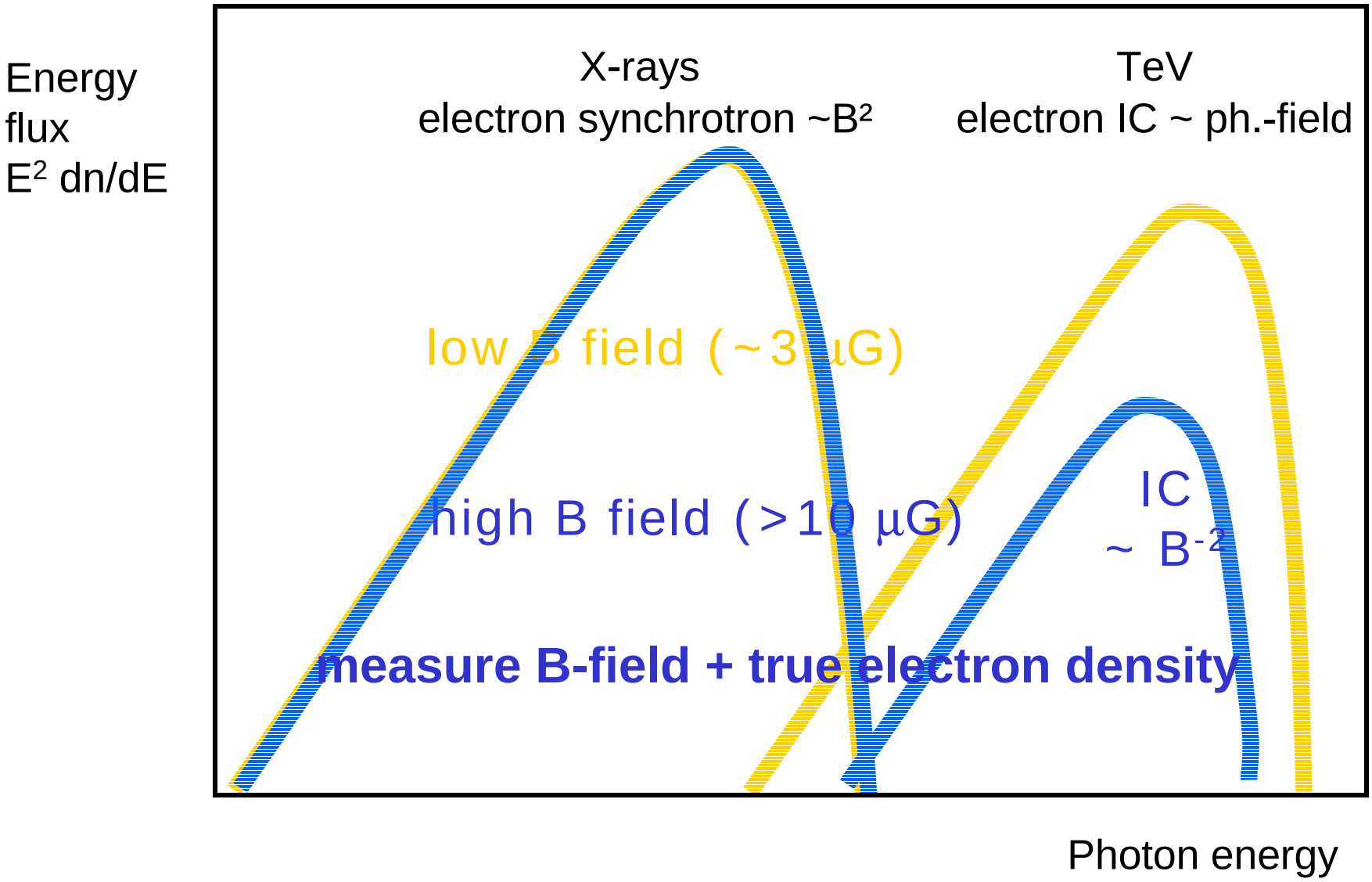
The VHE – X-ray connection: Identification



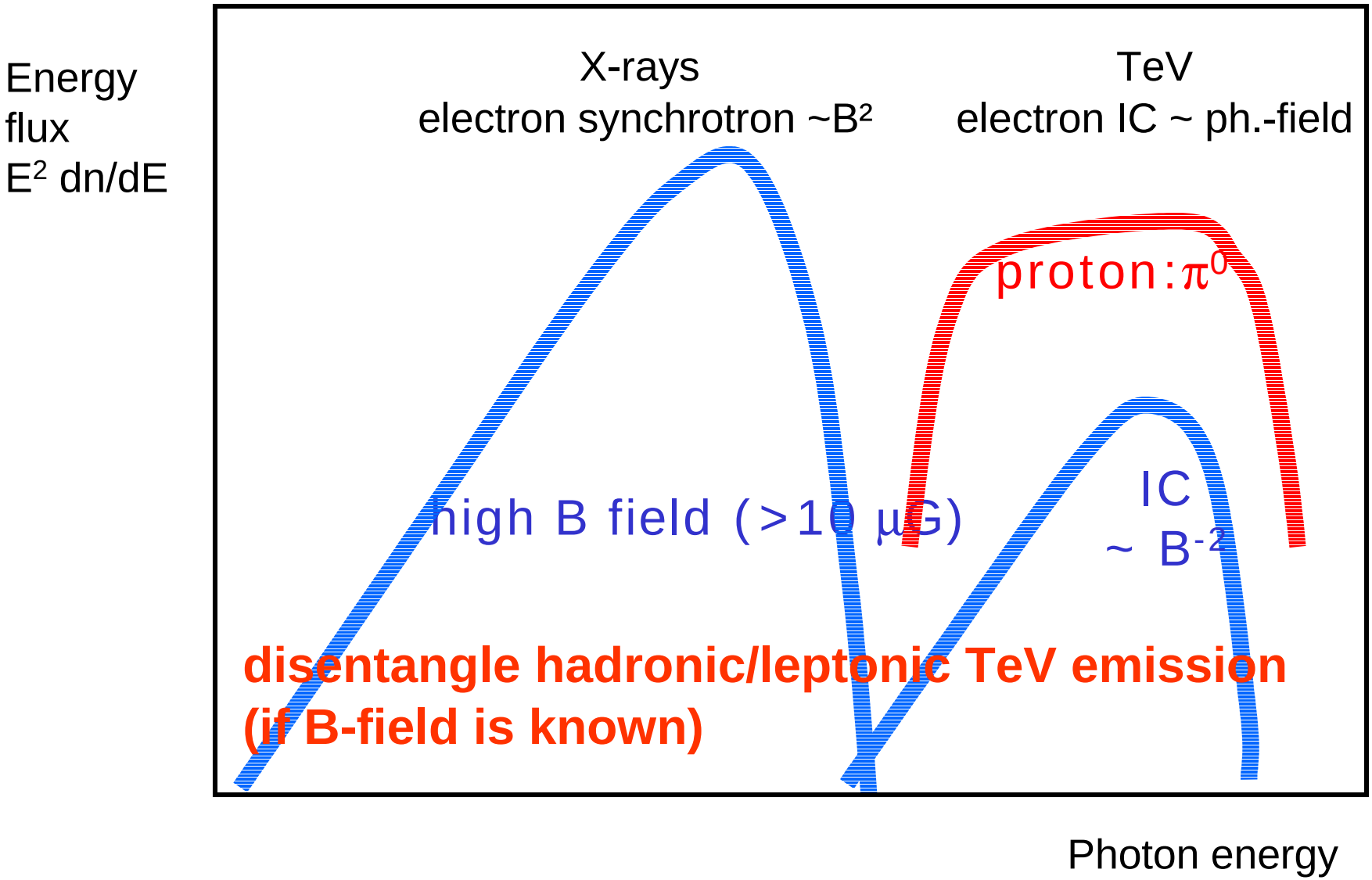
Identifications (objects were known before VHE):

- Two shell-type SNRs (RX J1713-3946, Vela Jr.)
- Eight pulsar wind nebulae

VHE + X-rays in case of a leptonic source



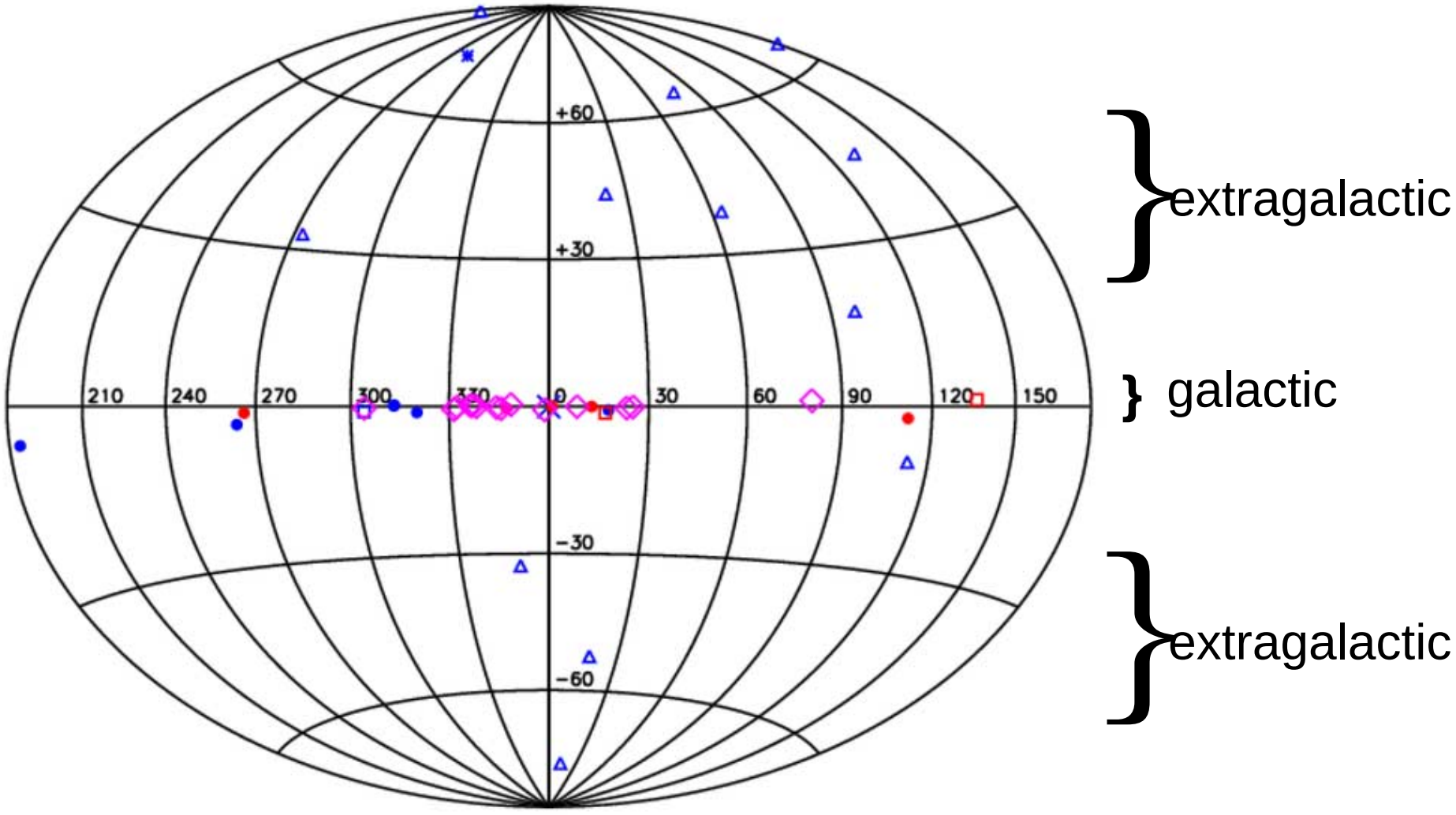
VHE + X-rays in case of a hadronic source



Conclusion X-rays

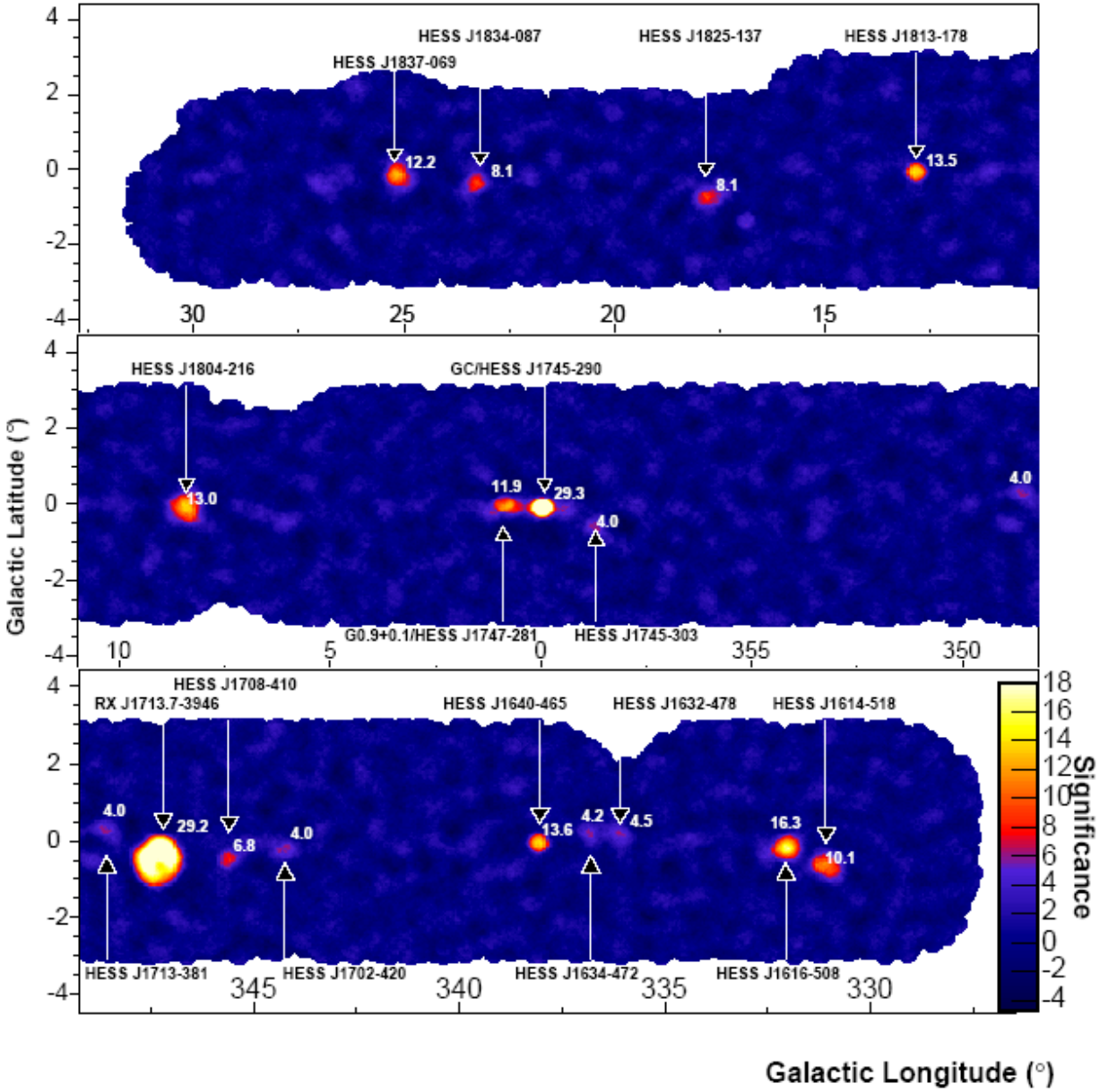
- → optimally, measure the whole synchrotron branch
- → at least measure X-rays:
  - → in most cases, electrons of the same (or at least similar) energy range produce TeV IC and X-ray synchrotron
  - → in many cases (e.g. typ. interstellar B-fields), TeV and X-ray energy flux levels are compatible

The VHE source catalogue

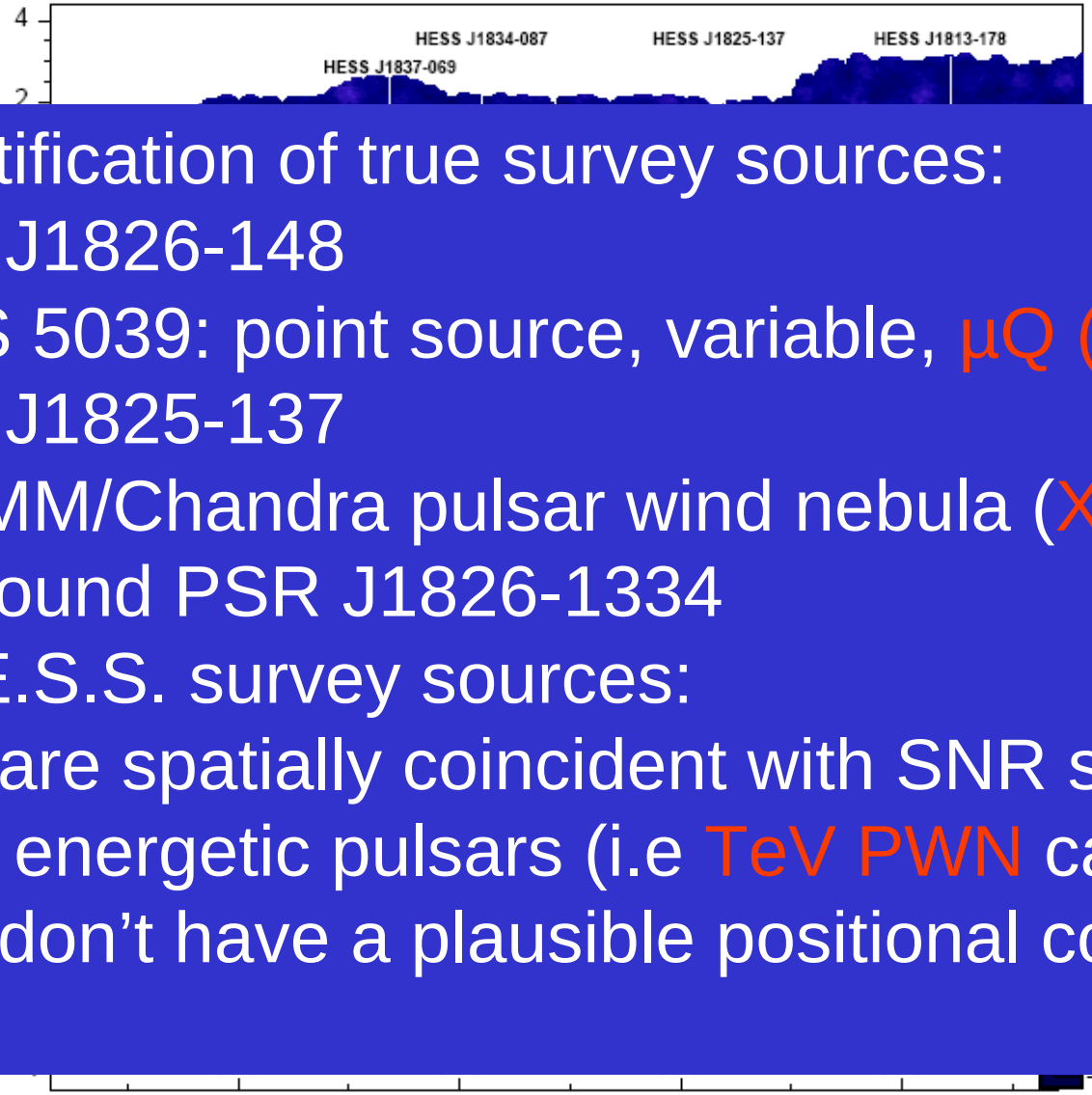


Cui, astro-ph/0608042: 42 VHE sources (13 extragalactic, 14 galactic id., 15 unid.)

H.E.S.S Galactic Plane Survey

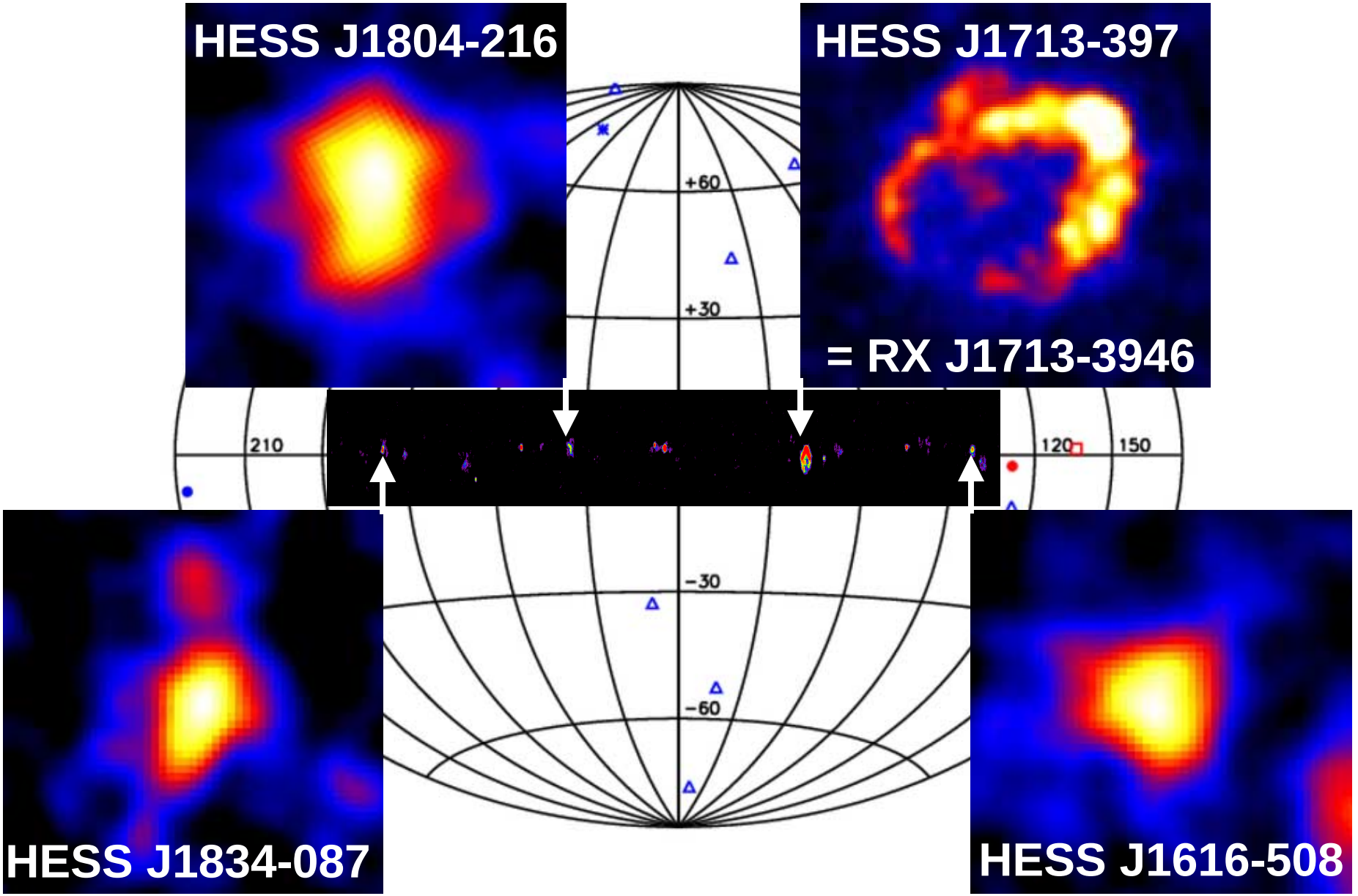


H.E.S.S Galactic Plane Survey

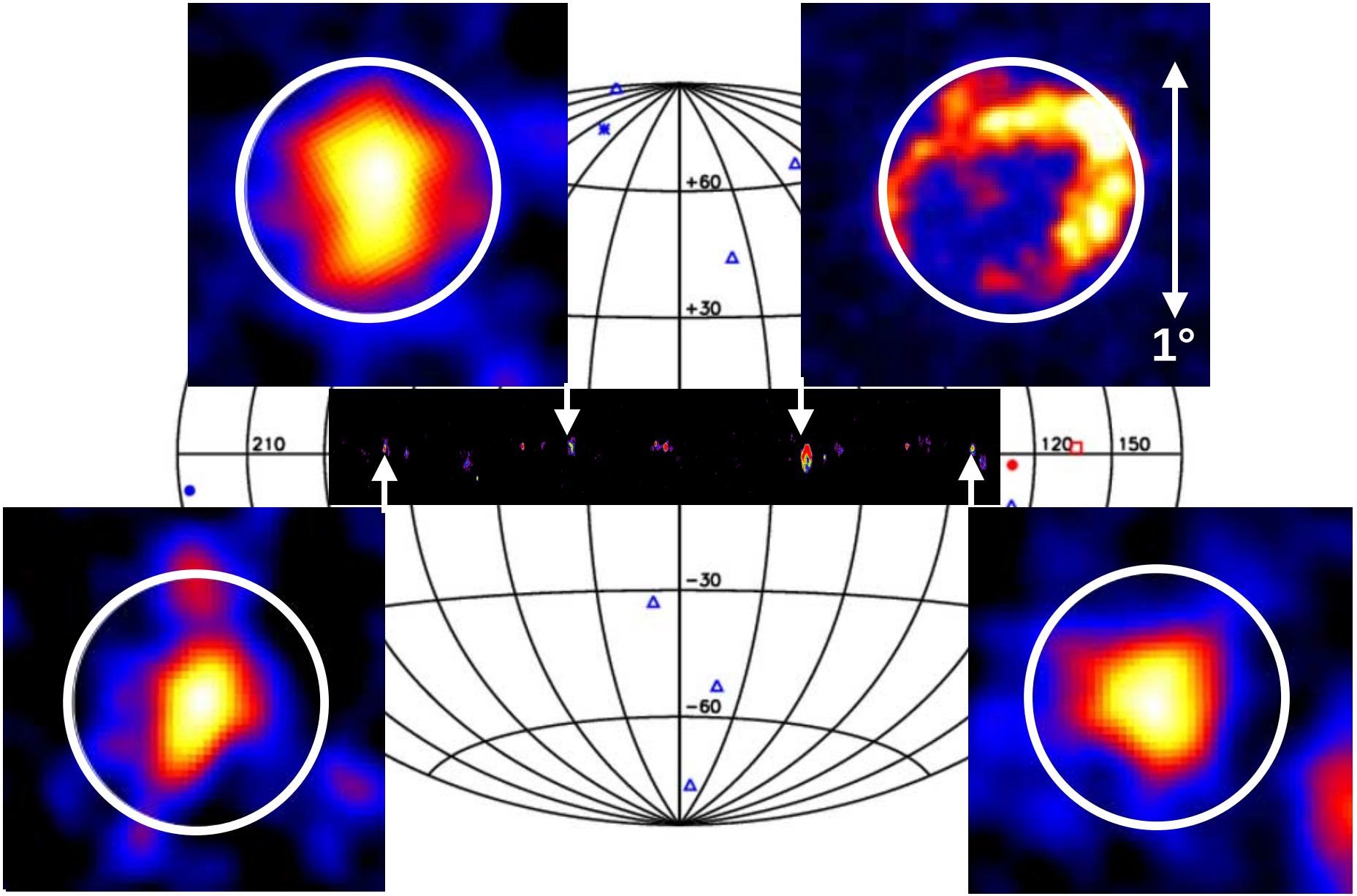


- Firm identification of true survey sources:
  - HESS J1826-148
    - ↔ LS 5039: point source, variable, μQ (?)
  - HESS J1825-137
    - ↔ XMM/Chandra pulsar wind nebula (X-ray PWN) around PSR J1826-1334
- Other H.E.S.S. survey sources:
  - Some are spatially coincident with SNR shells, and/or energetic pulsars (i.e TeV PWN candidates)
  - Some don't have a plausible positional counterpart at all

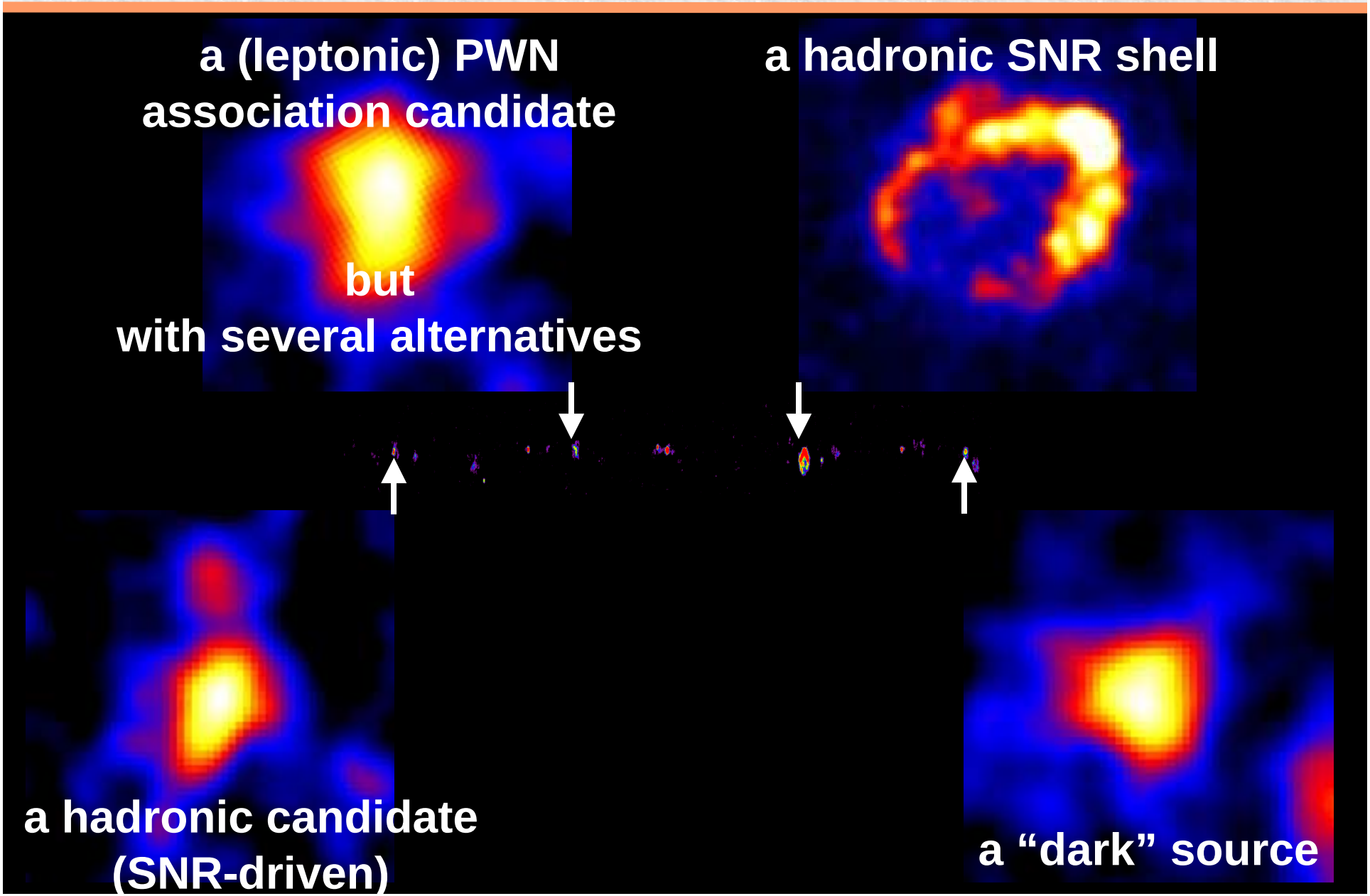
A few examples …



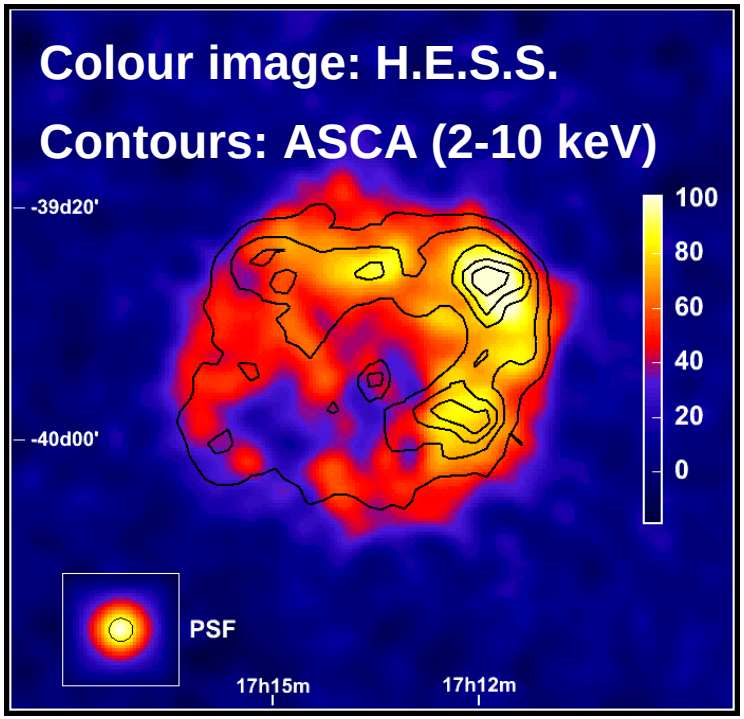
A few examples …



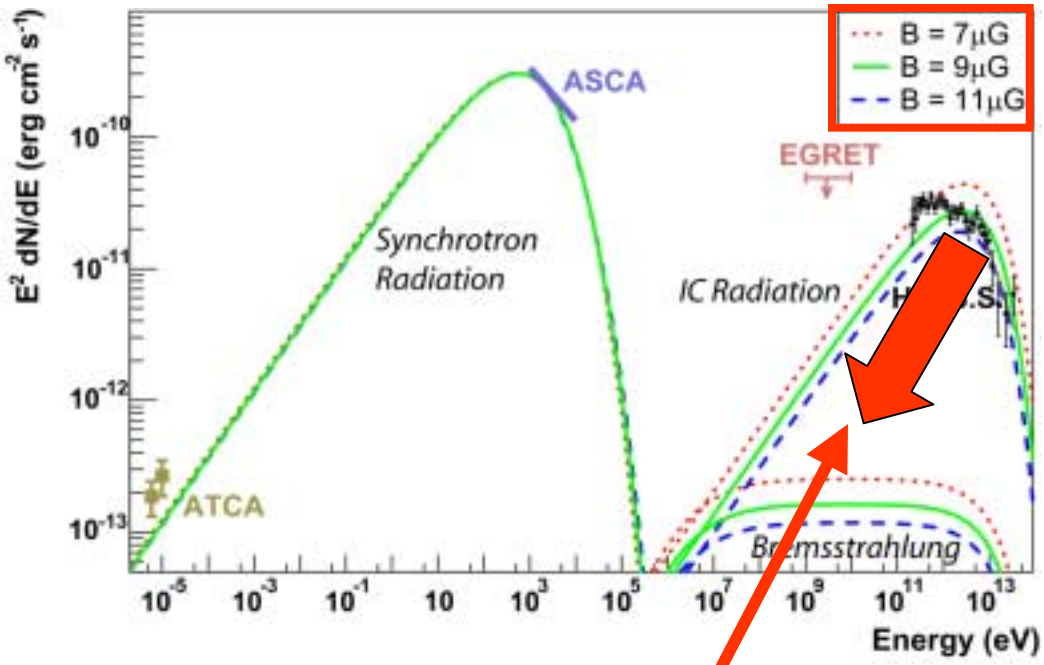
A few examples …



Leptonic VHE model of RX J1713-3946



Aharonian et al. (HESS collaboration), A&A 2006

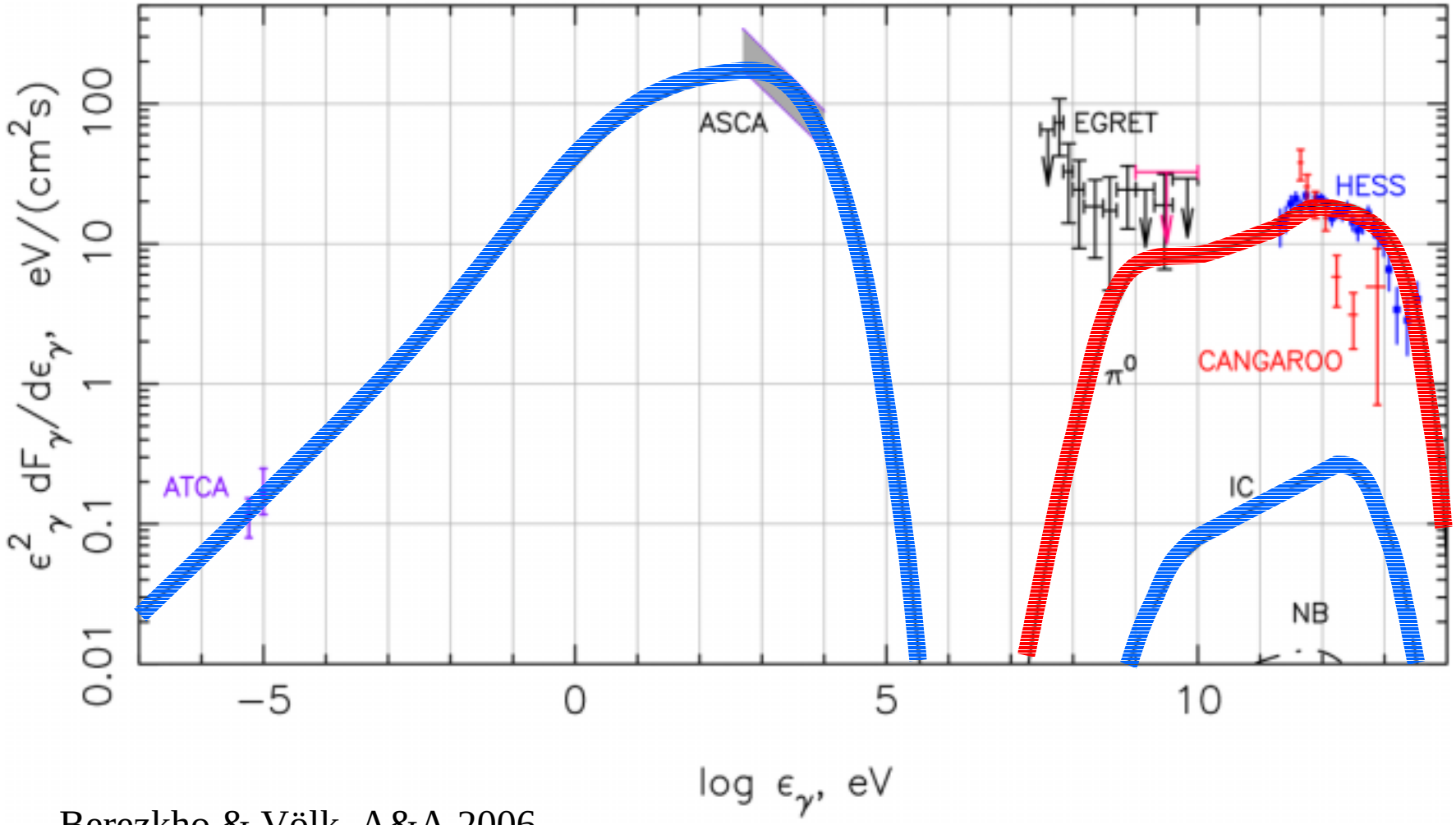


VHE spectrum is marginally compatible with an electron scenario

B-field required is in strong contrast to >100μG field seen in X-ray filaments

Increase B-field: TeV emission not from electrons!

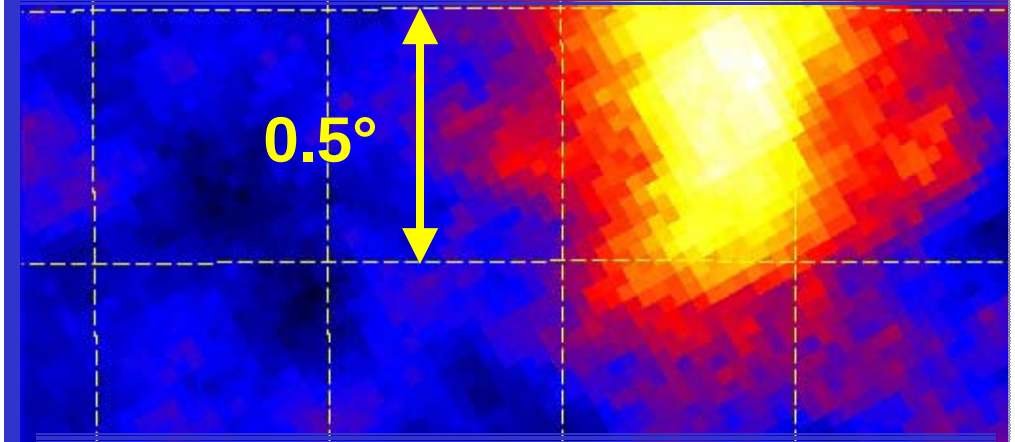
Hadronic VHE model of RX J1713-3946



Berezkho & Völk, A&A 2006

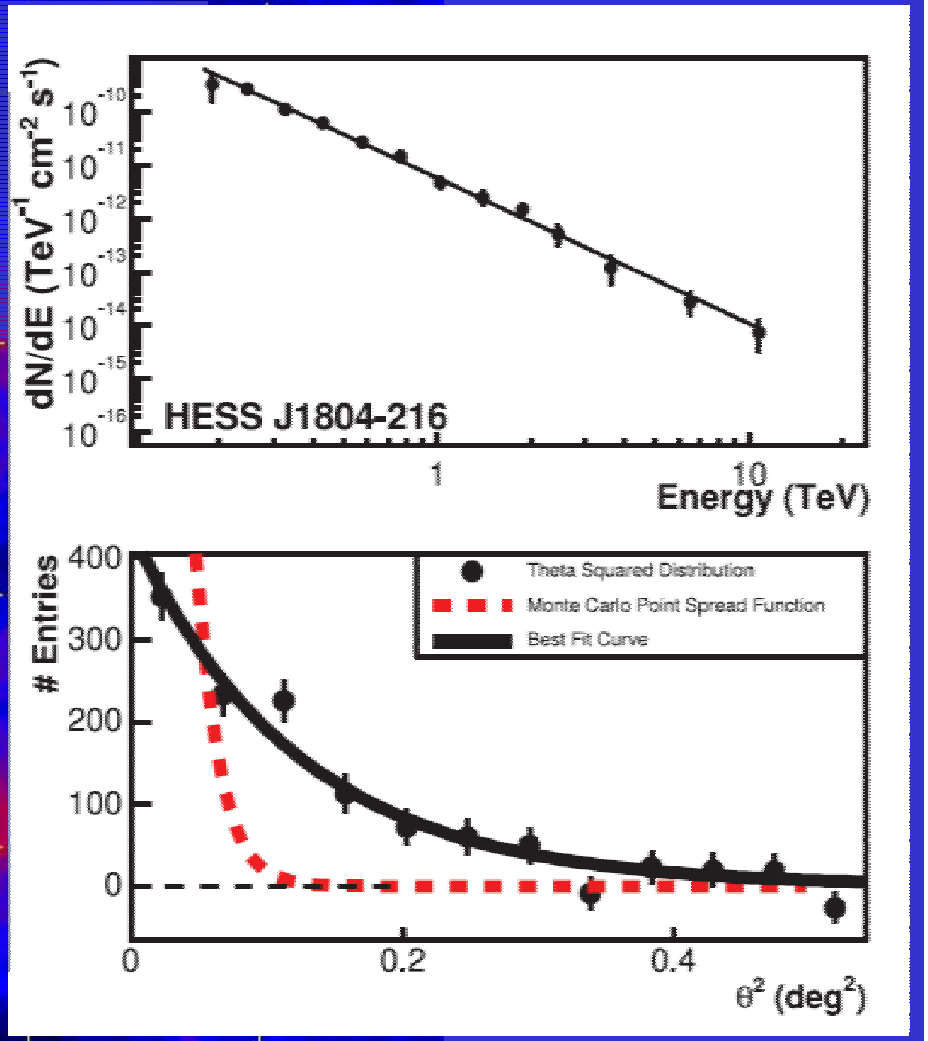
HESS J1804-216: a survey source showcase

- detection significance ~8 σ post-trial
- ~ 400 excess events
- 3rd largest and 2nd brightest survey source
- photon index Γ = 2.7 (soft)
- size σ = 0.2°

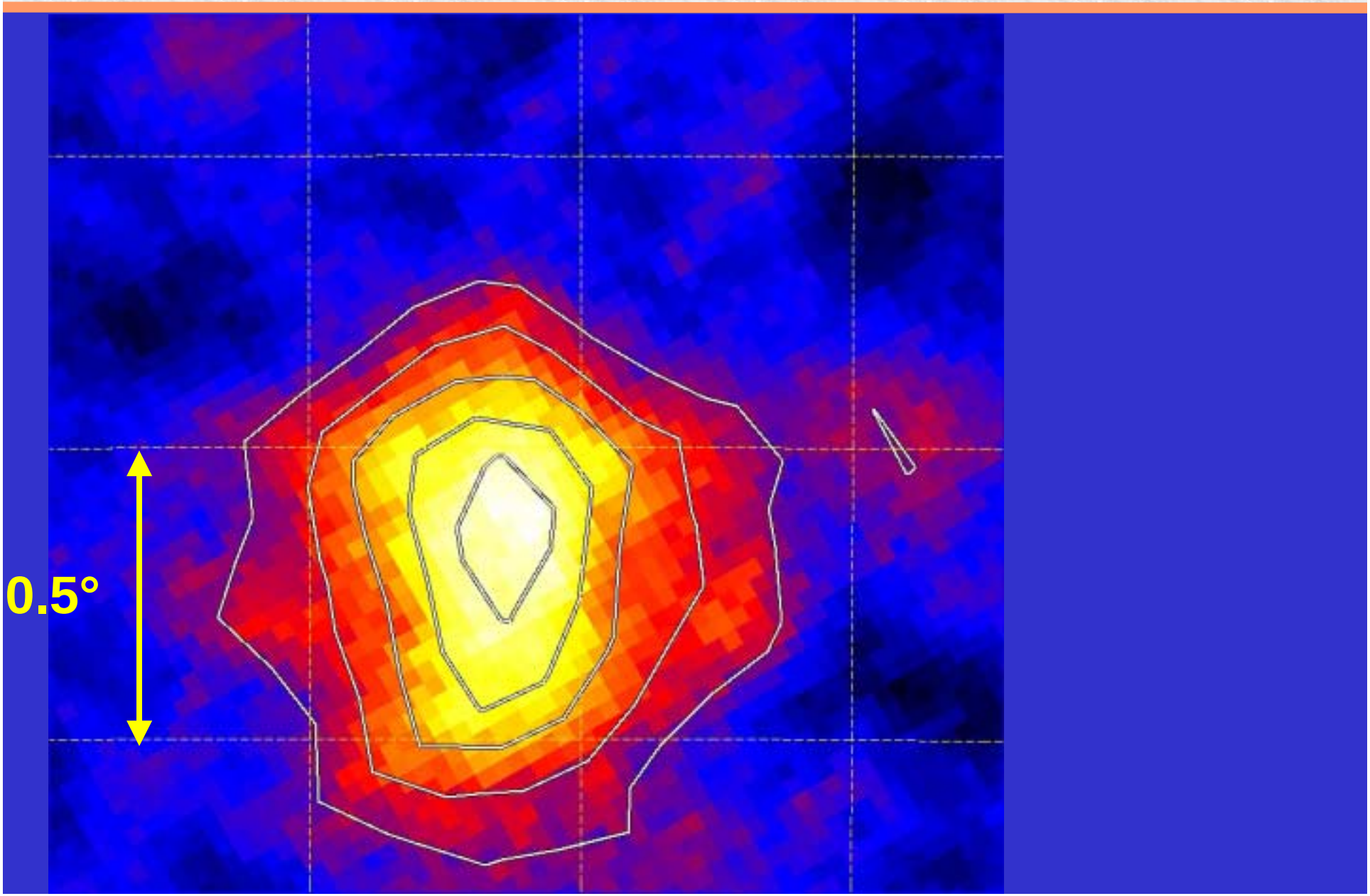


- galactic longitude = -0.64°
- extension

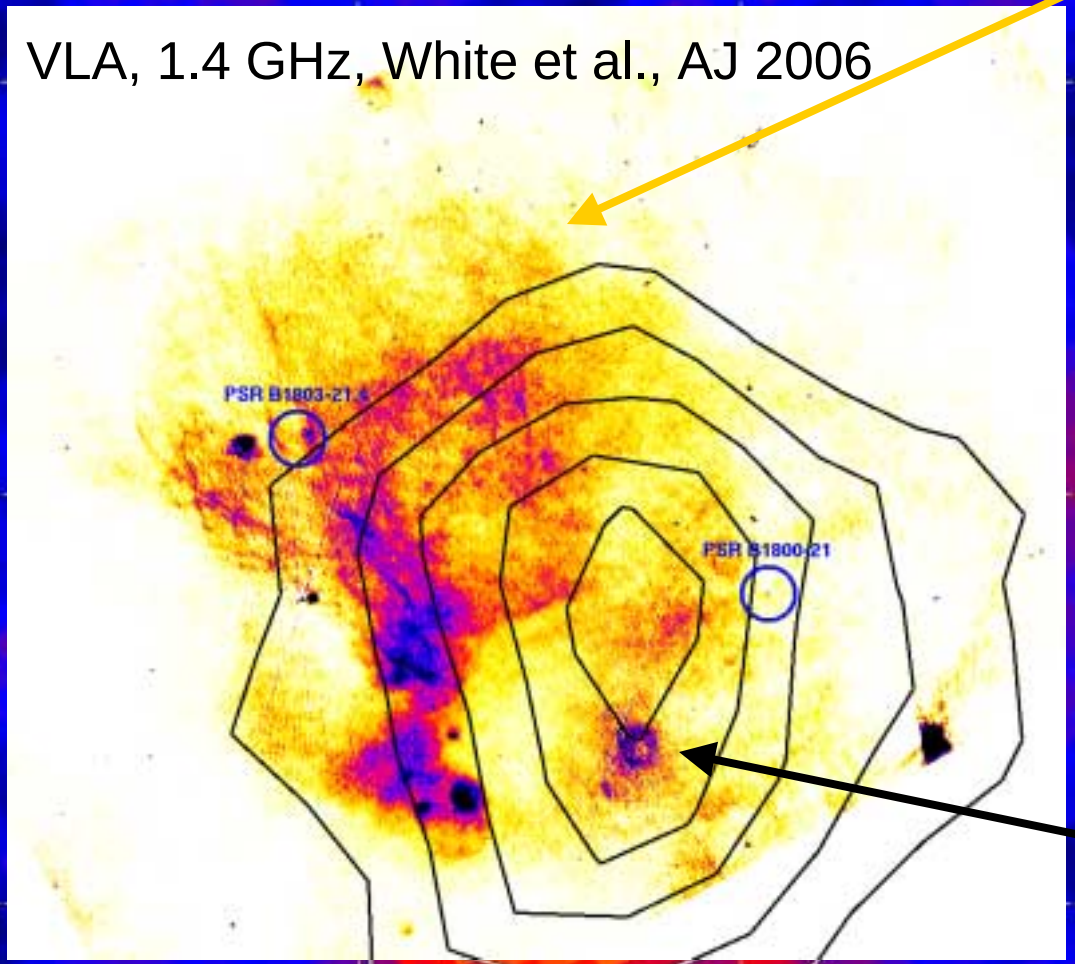
→ most probably Galactic



Scale and contours used in subsequent plots

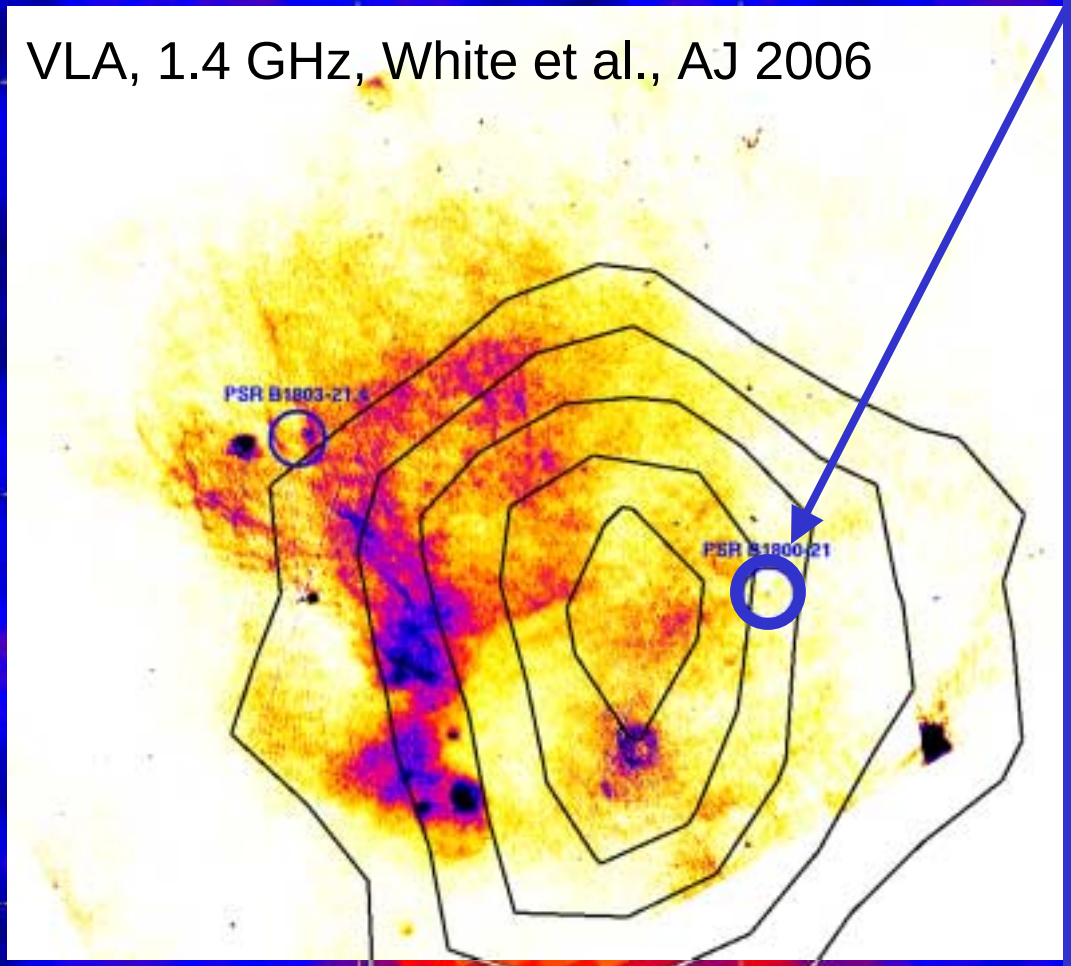


Radio continuum: SNRs



- "W30 – G8.7-0.1"
- D ~ 4.8 kpc
- Radio spectral index –0.53 (typical for SNR)
- Large SNR (~80 pc)
- No clear morphology (not limb-brightened, not plerionic)
- New compact shell (Brogan et al., ApJ 2006): G8.21-0.09

Energetic radio pulsar: could power TeV PWN

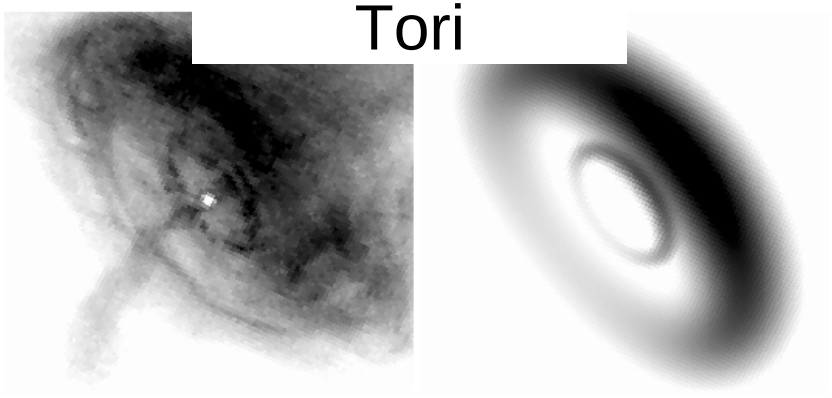


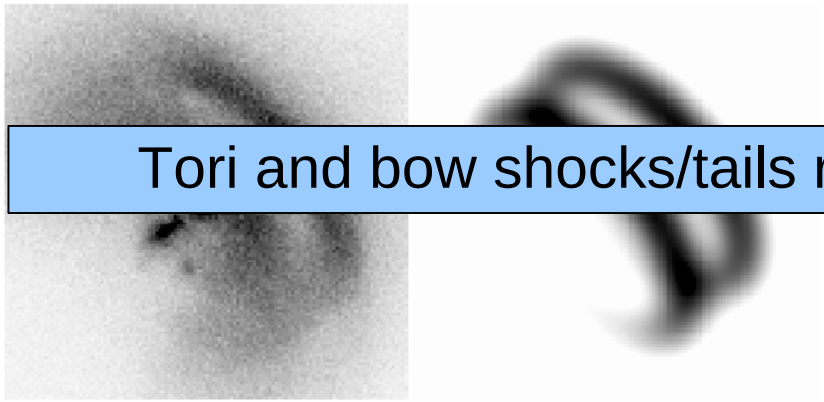
PSR B1800-21:

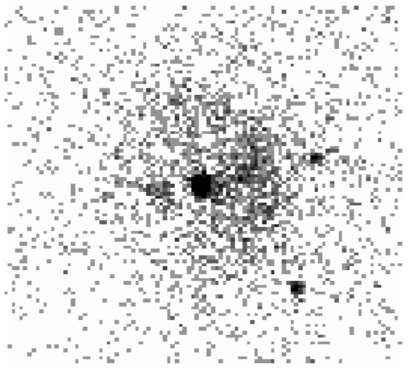
- Perhaps associated with G 8.9-0.1
- D ~ 3.9 kpc .. ~ 5.3 kpc
- Highly energetic: $dE/dt = 2.2 \times 10^{36}$ erg/s
- But 1700 km/s required $\rightarrow$ X-ray PWN expected
- Alternative scenario: SNR expands asymmetrically into a cavity (Finley & Ögelmann, ApJ 1994)

“Usual” X-ray PWN seen with Chandra

Tori

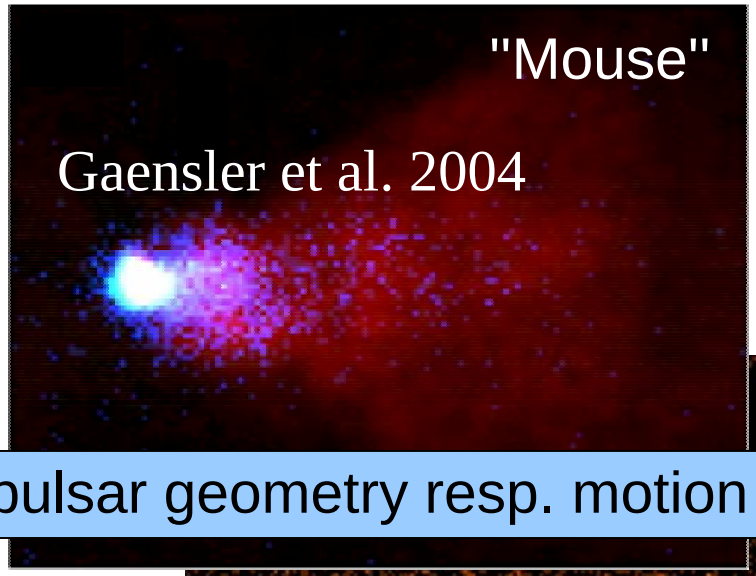


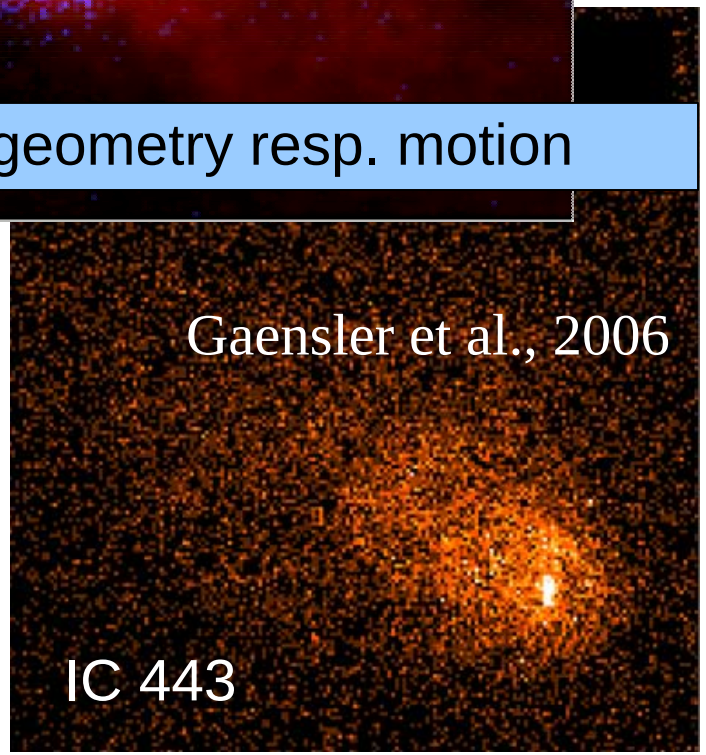




Ng & Romani 2003

Bow shocks and wakes

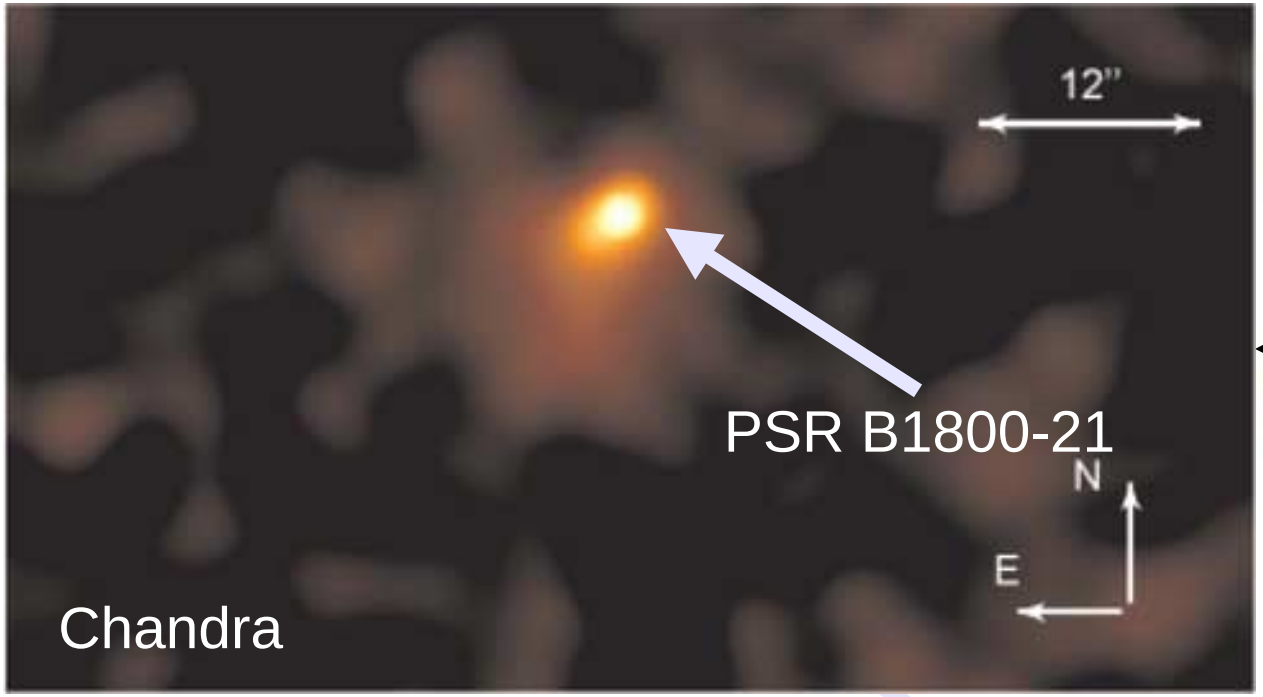


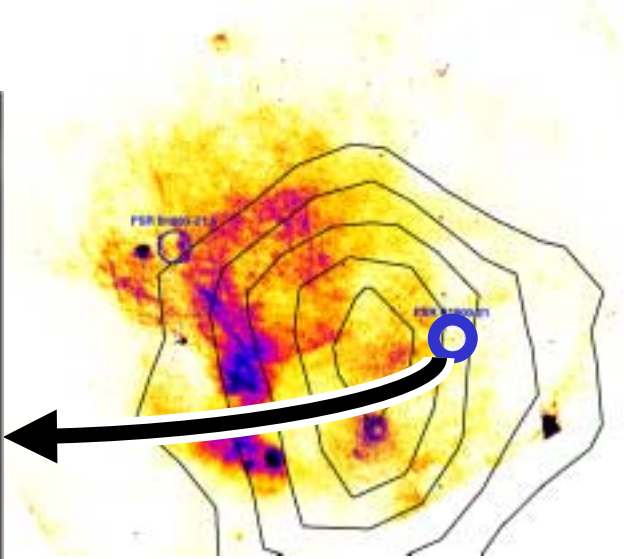


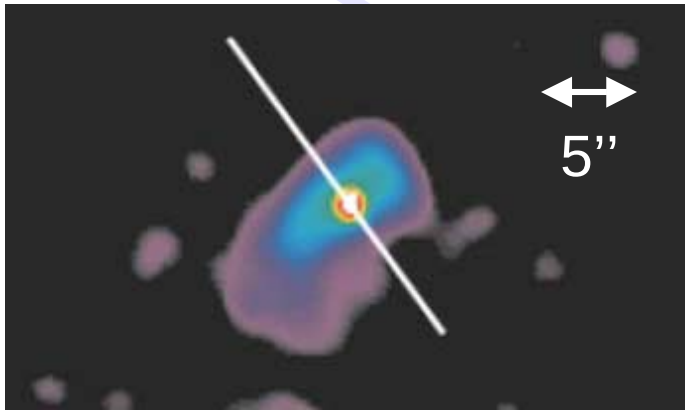
Tori and bow shocks/tails reflect pulsar geometry resp. motion

HESS J1804-216: Offset PWN association?

Kargaltsev et al., ApJ 2007



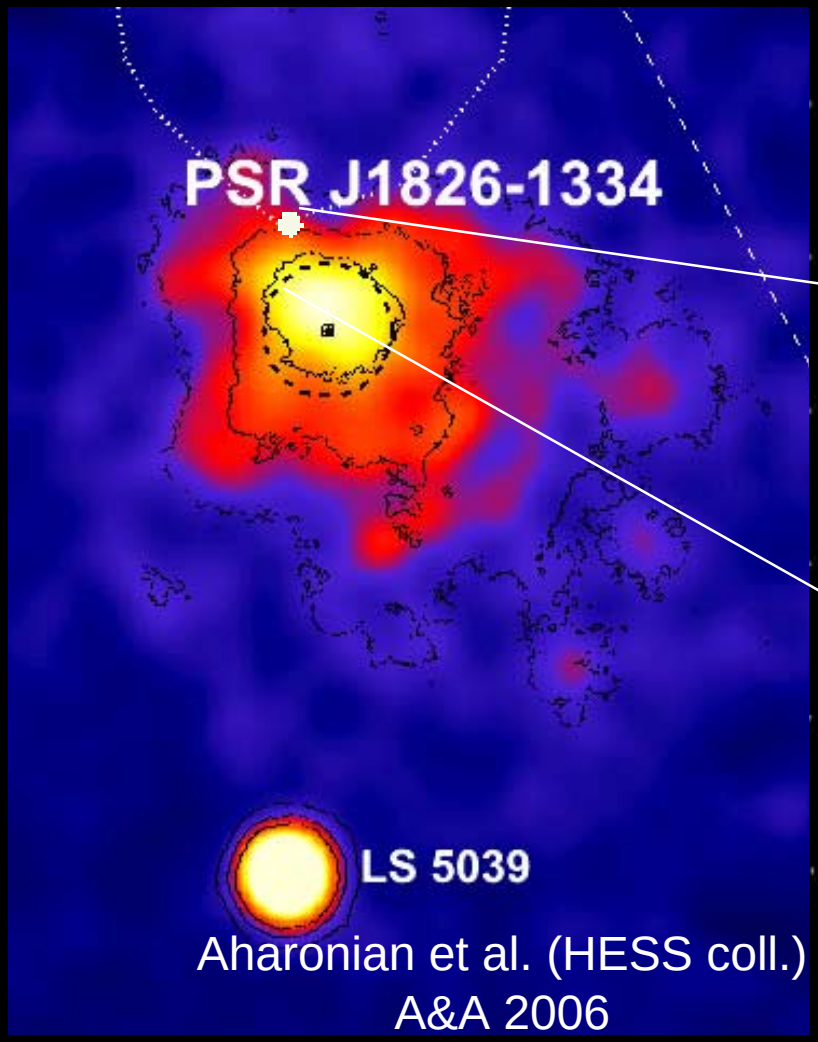




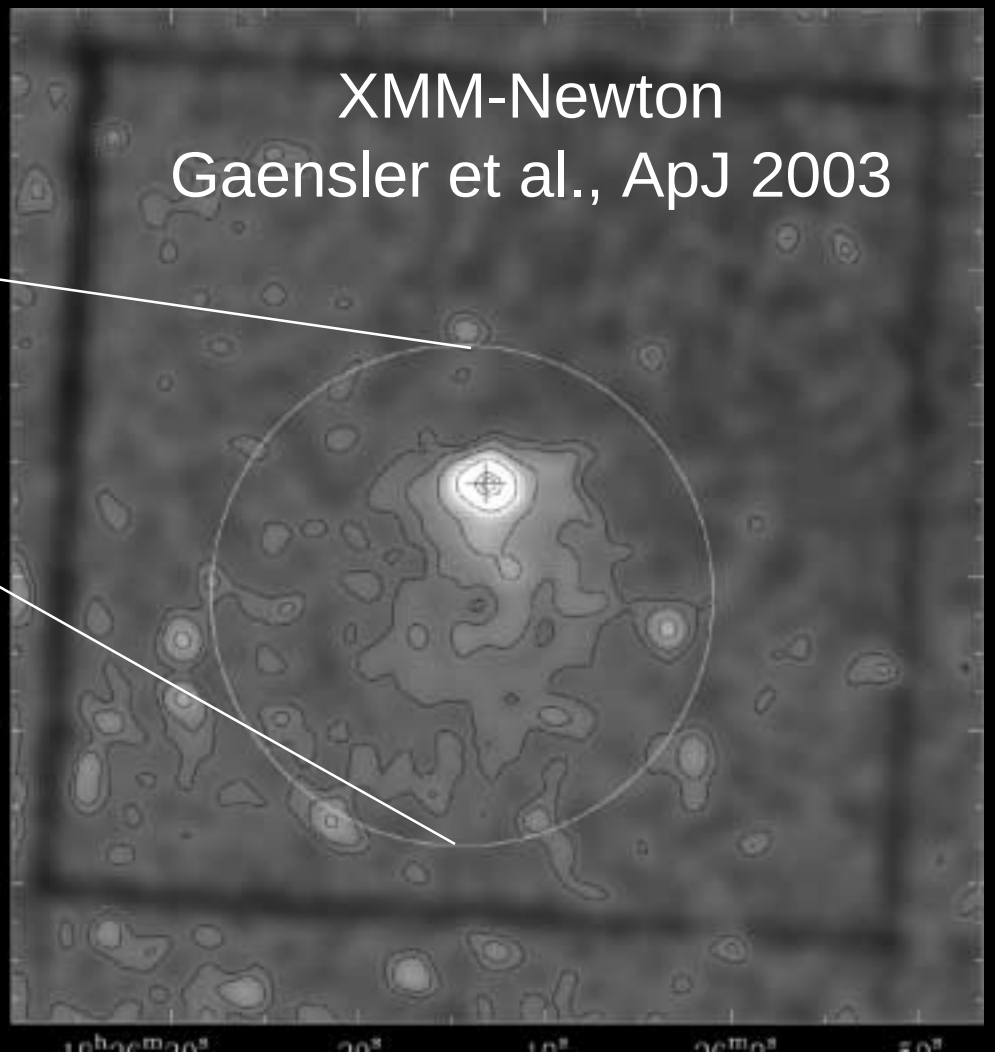
energetically, TeV ↔ X-ray PWN association is plausible

Archetype for a TeV – X-ray PWN association

HESS J1825-137:
Identification with X-ray PWN G 18.0-0.7



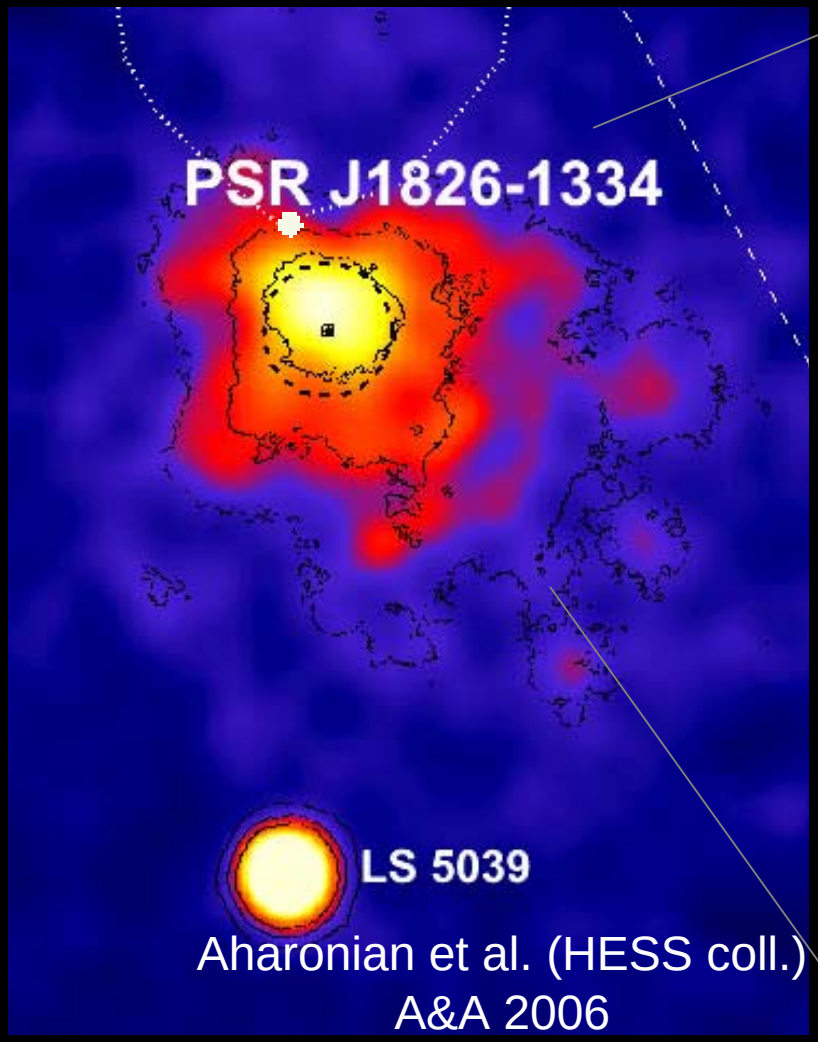
Aharonian et al. (HESS coll.)
A&A 2006



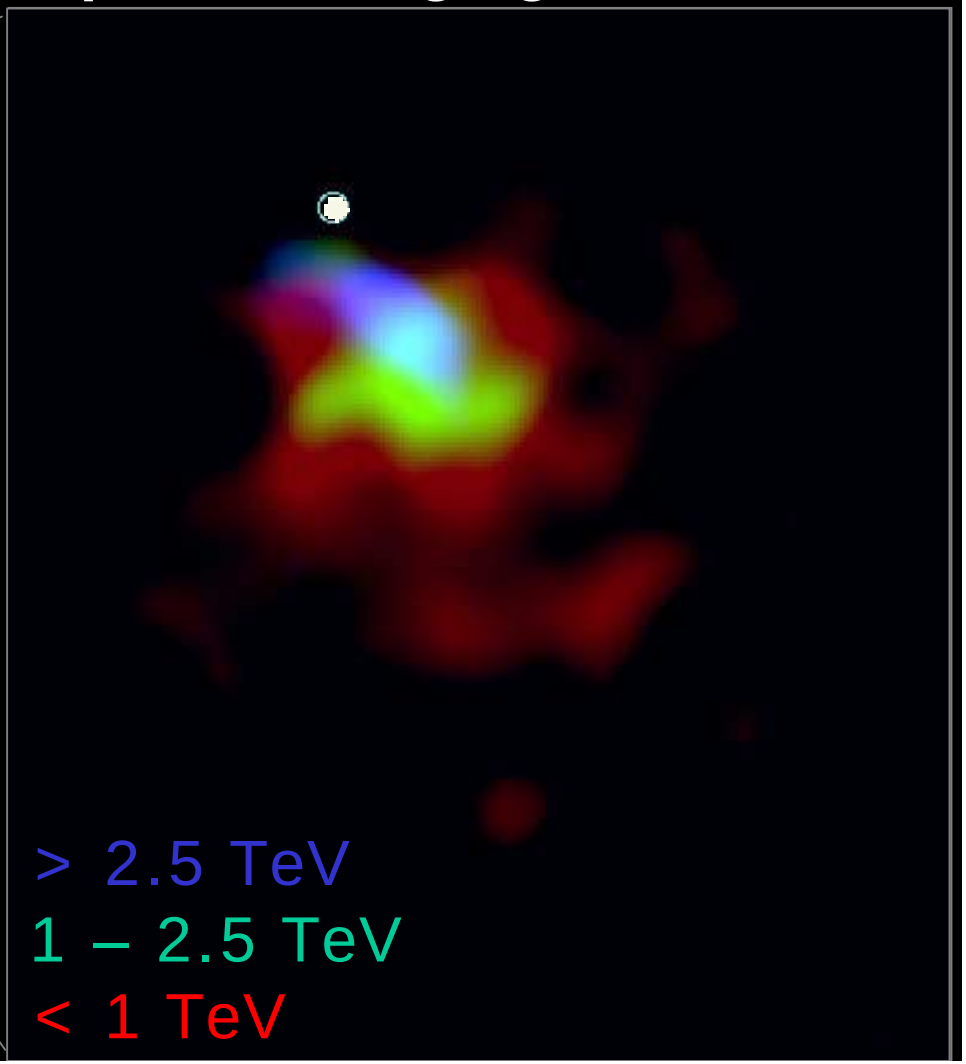
XMM-Newton
Gaensler et al., ApJ 2003

Archetype for a TeV – X-ray PWN association

HESS J1825-137:
Identification (mainly) by TeV spectral imaging

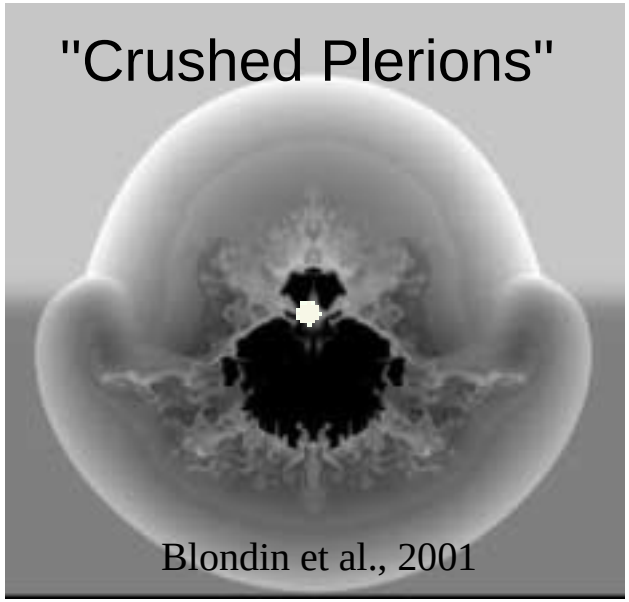


Aharonian et al. (HESS coll.)
A&A 2006



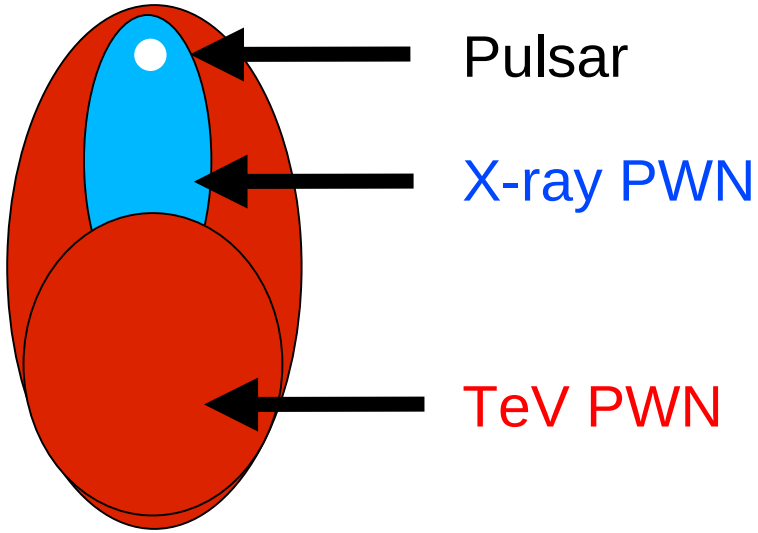
Asymmetric TeV Pulsar Wind Nebulae

"Crushed Plerions"



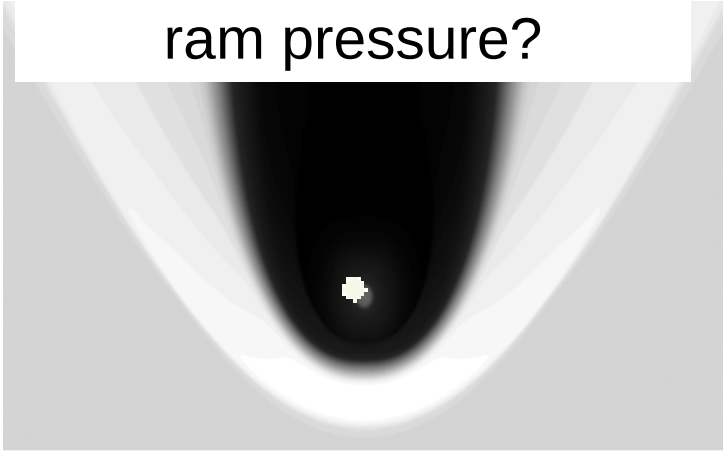
Blondin et al., 2001

Offset TeV PWN



+ IC electron lifetime larger than synchrotron lifetime
+ larger particle injection efficiency in the past

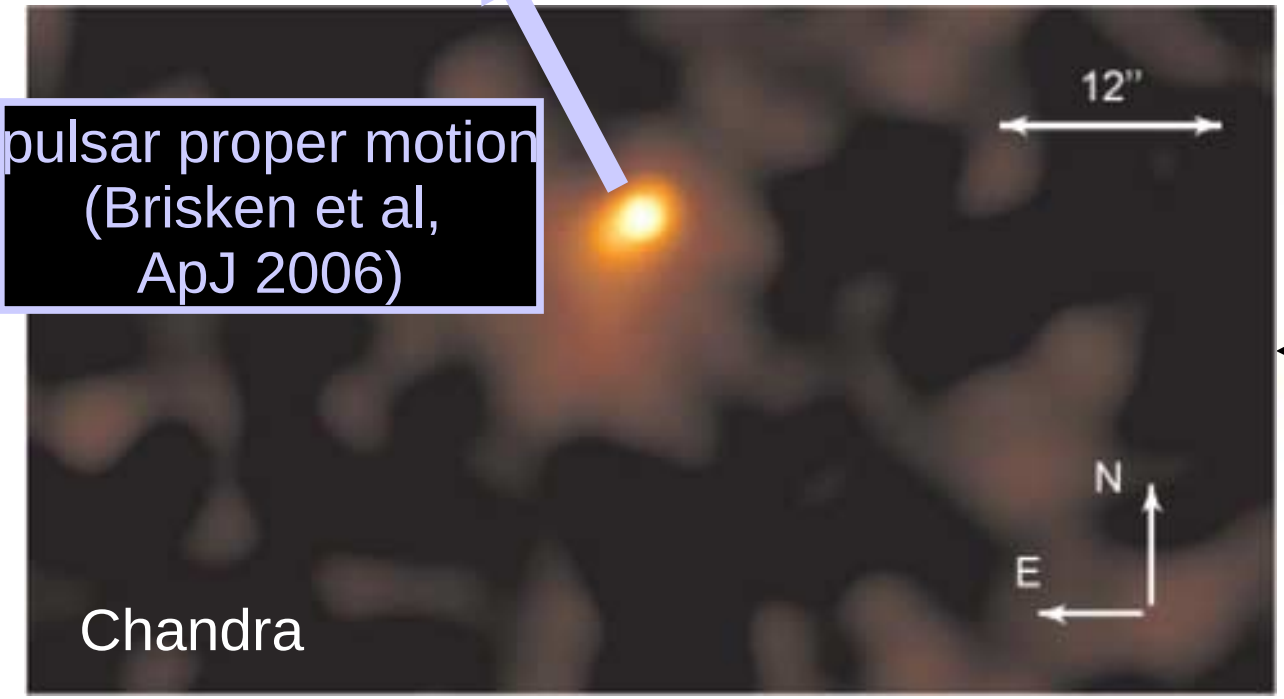
Or pulsar proper motion/ ram pressure?

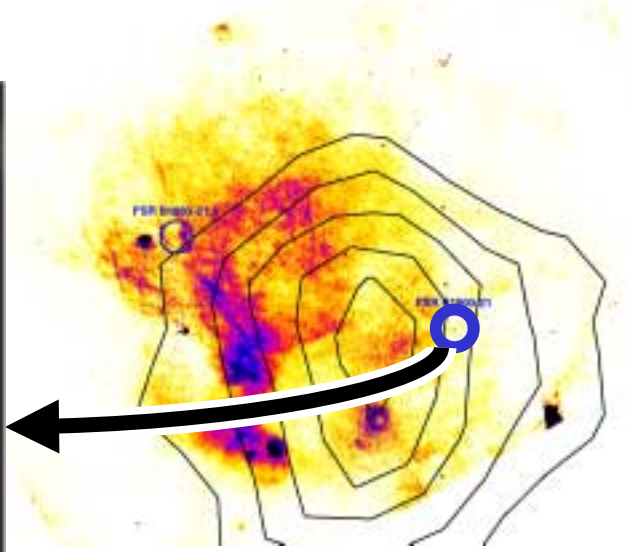


Electrons far off the acceleration site:
→ Low surface brightness: Need XMM!
→ Low B-field: X-ray detectability?

HESS J1804-216: Offset PWN association?

Kargaltsev et al., ApJ 2007



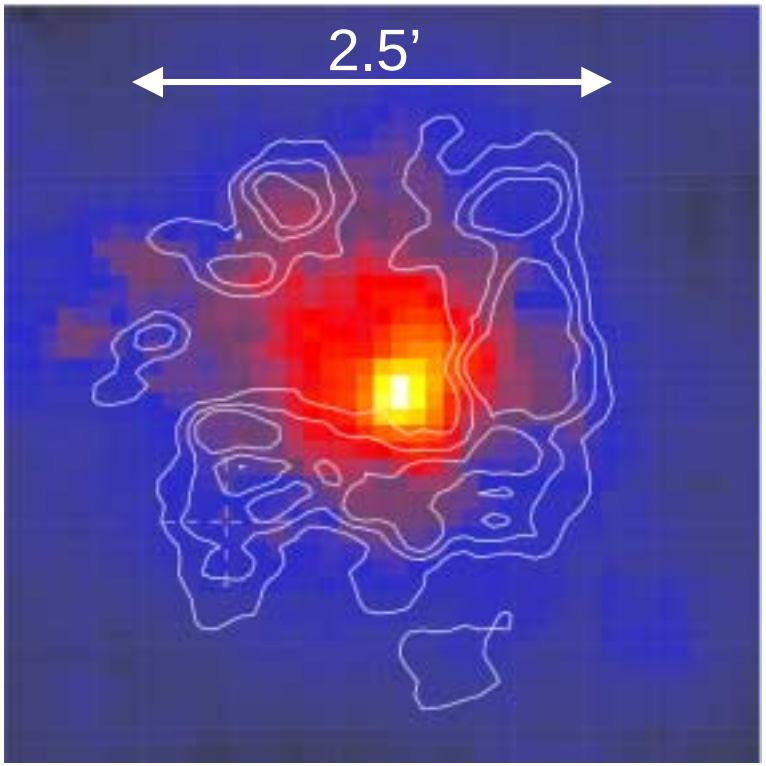


- Presumably no bow shock/wake geometry
- Asymmetric X-ray PWN / HESS association is o.k.
- But: PSR B1800-21 seems not to be associated with W30

→ Are there other pulsars/PWN candidates?

Cf. HESS J1813-178 + HESS J1640-465

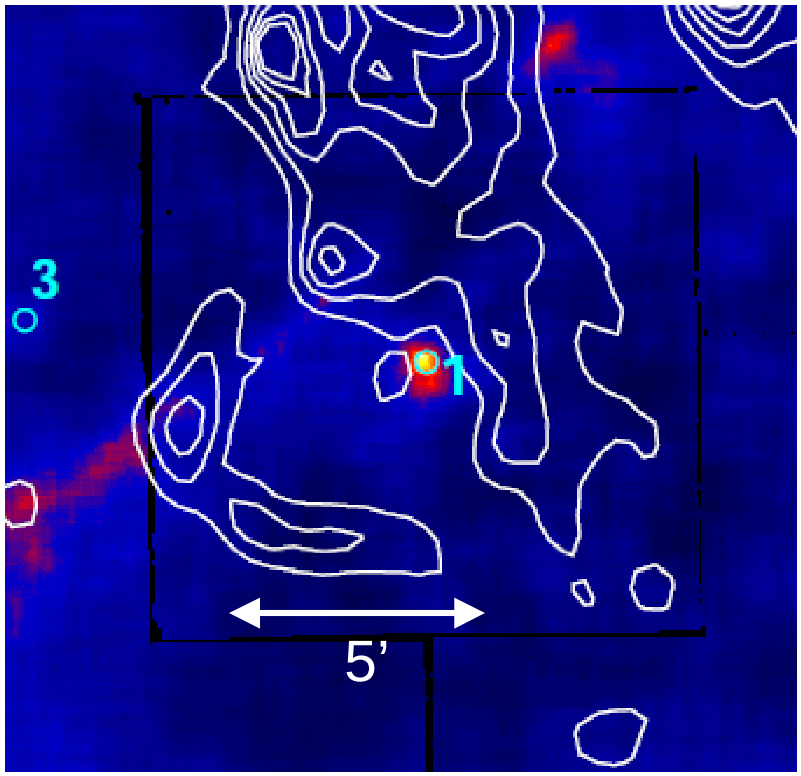
XMM-Newton: two X-ray PWN candidates without radio pulsars!



Color code: XMM 4.5-10 keV

Contours: VLA 20 cm

Funk, Hinton, Moriguchi, et al. 2007, A&A in press

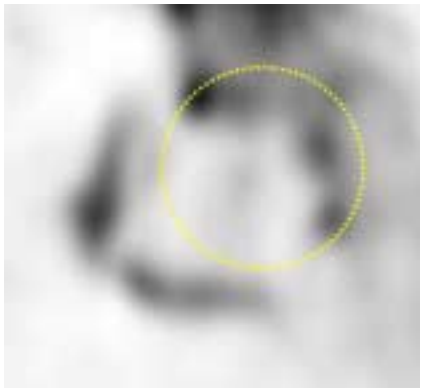


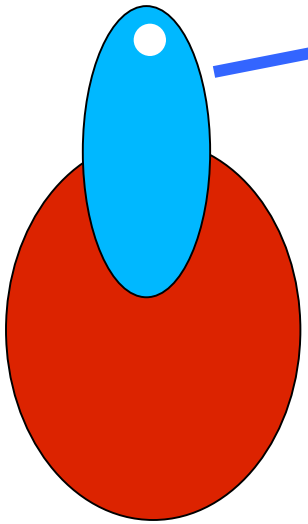
Color code: XMM 2-10 keV

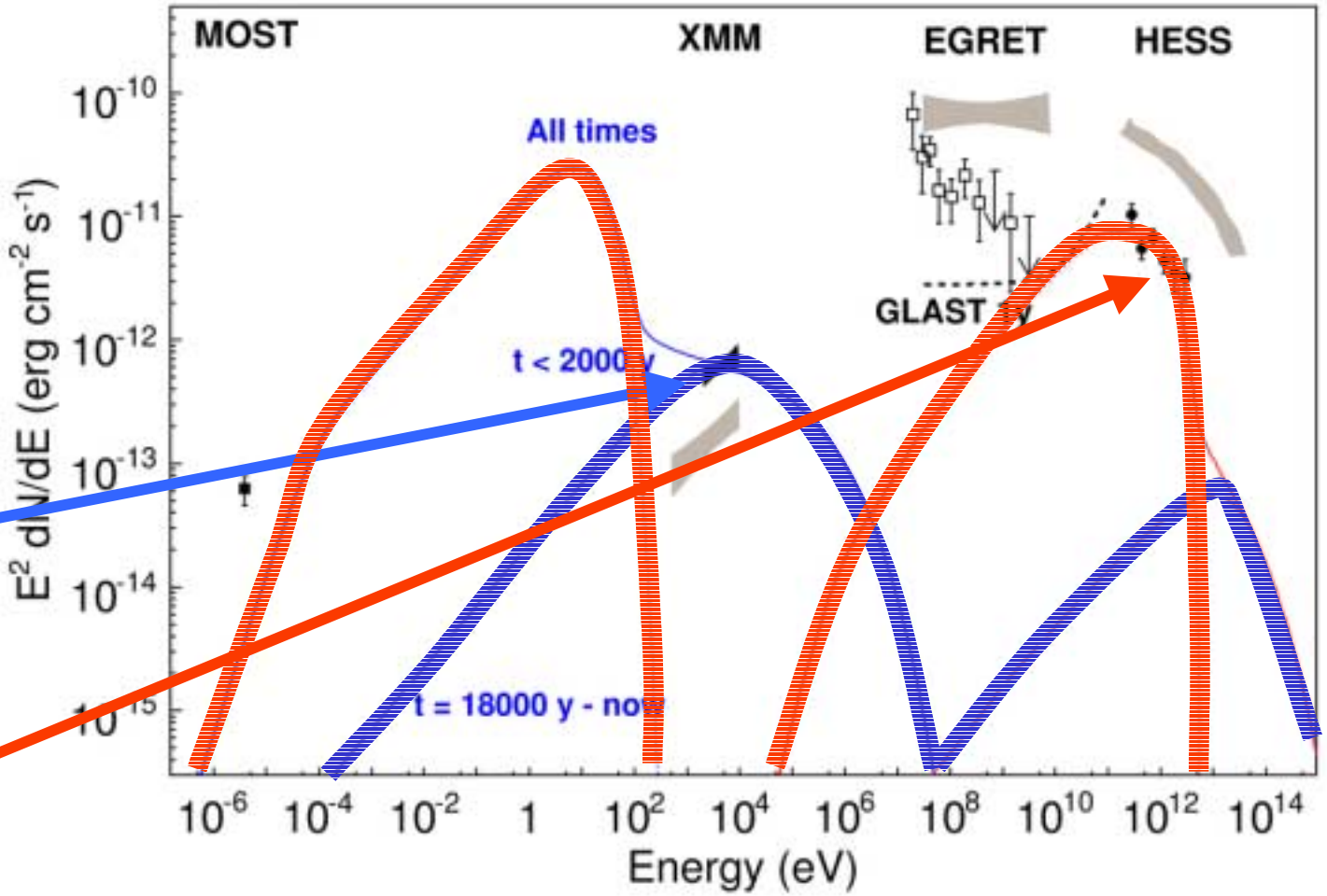
Contours: MOST

Funk, Hinton, GP, et al. 2007, ApJ in press

HESS J1640-465: a two-component model

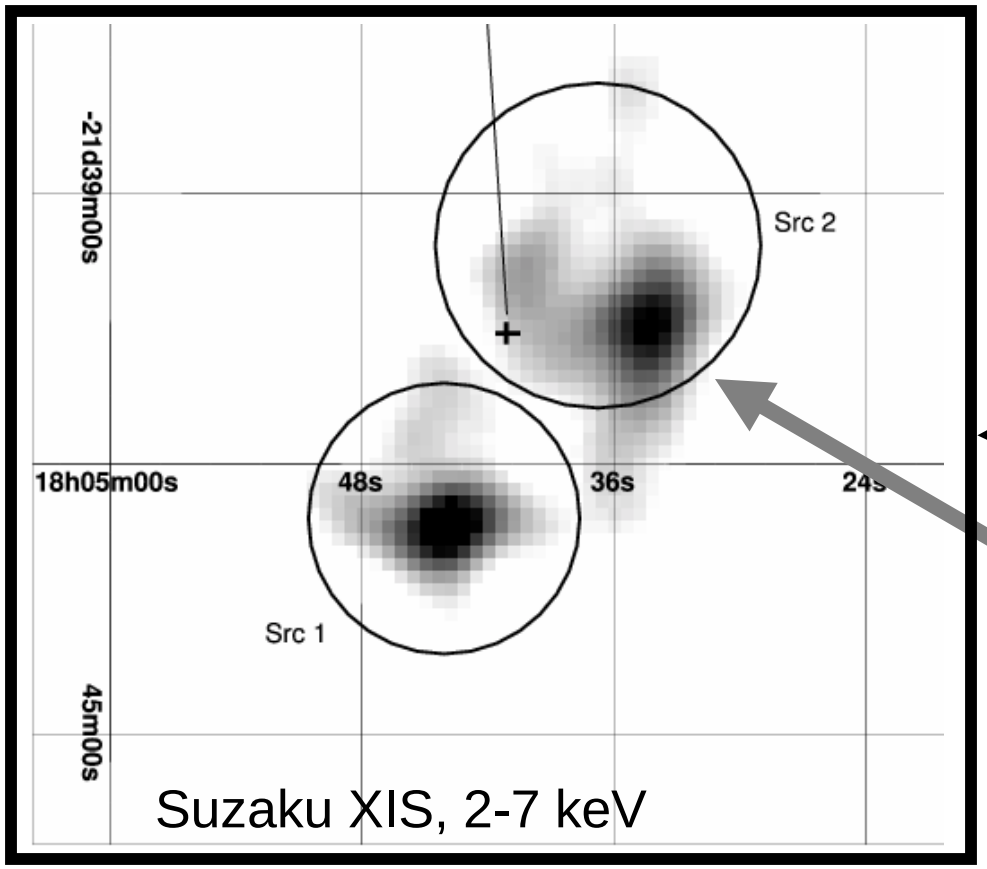


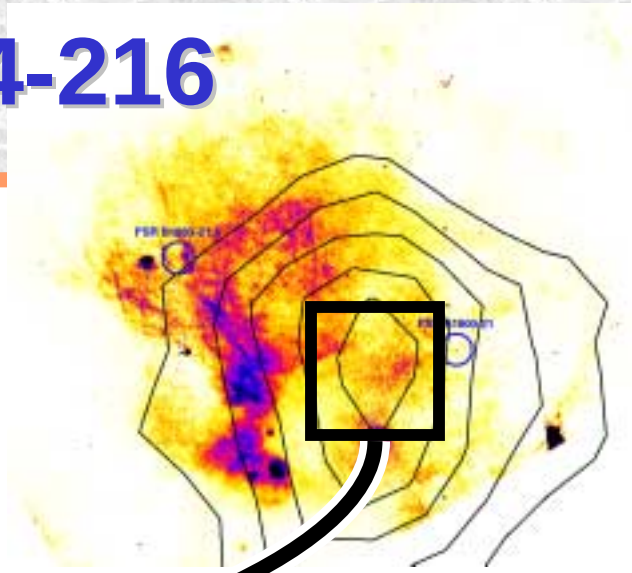




Funk, Hinton, GP, et al. 2007,
ApJ in press

Suzaku view of HESS J1804-216





Bamba et al. (ApJ, 2007):

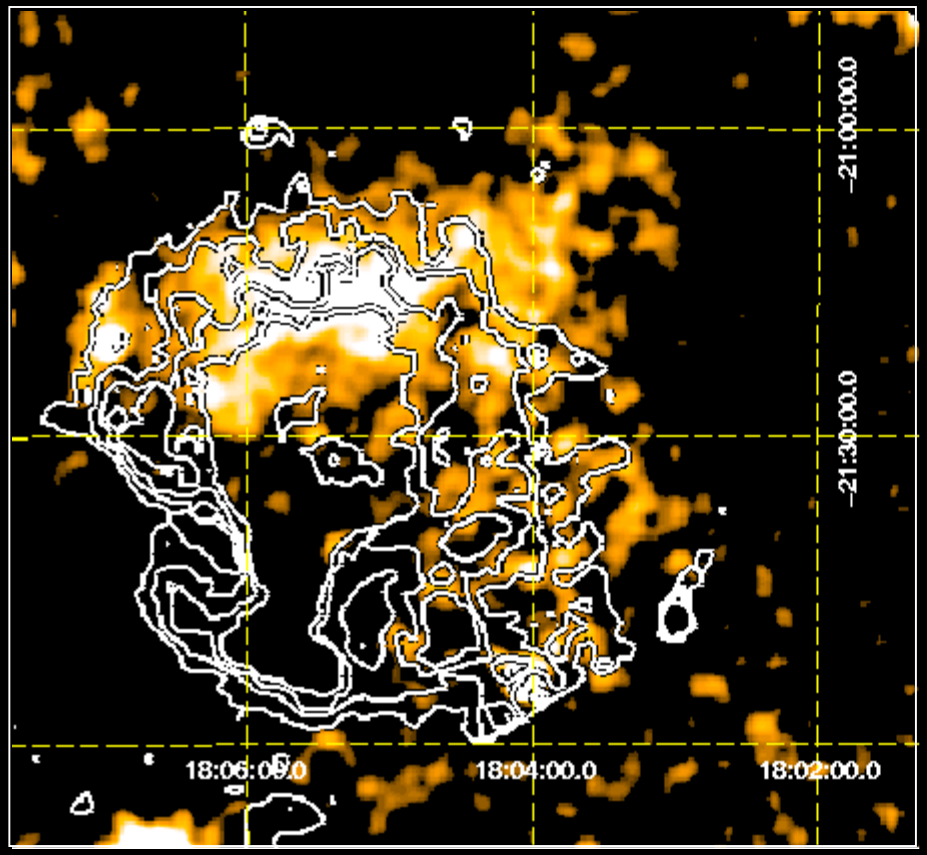
- Src 2 with diffuse component, strongly absorbed
- F(2-10 keV) = 4.3×10^{-13} erg/cm²/s
- counterpart candidate to HESS source (e.g. PWN)?

→ maybe not the most promising …

The ROSAT view of HESS J1804-216

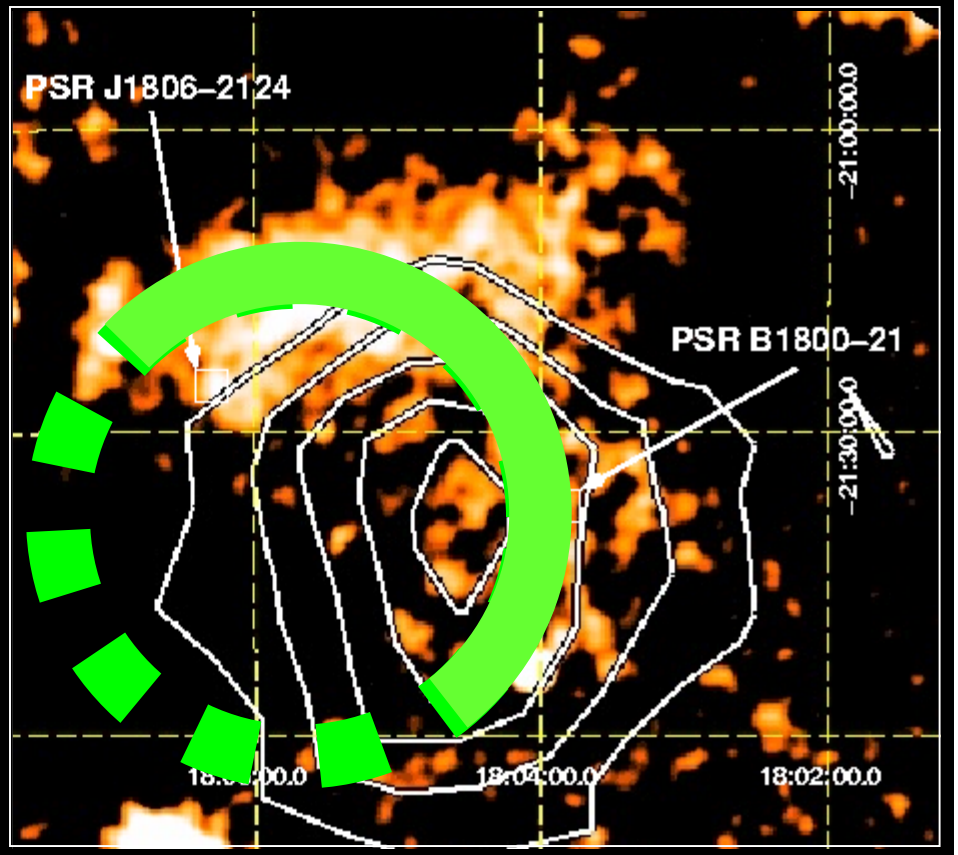
Color code: ROSAT PSPC flux: Interpreted as thermal X-ray emission

(see Finley et al., ApJ, 1994)



Contours: VLA 1.4 Ghz

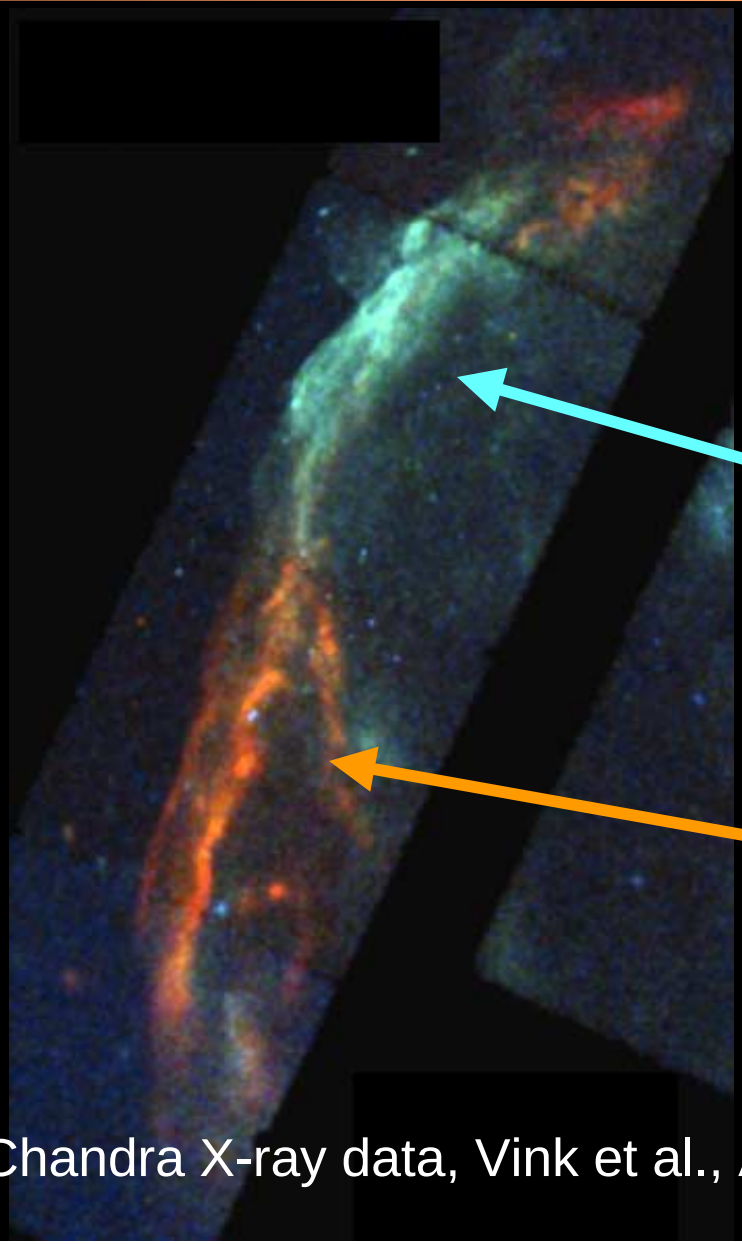
(MAGPIS survey, White et al., AJ 2006)



Contours: H.E.S.S. VHE

Partial shell??

NE rim of RCW 86



Other SNR shells have areas with

non-thermal

next to

thermal

parts, too …

Chandra X-ray data, Vink et al., ApJ 2006

XMM-Newton data on ROSAT source

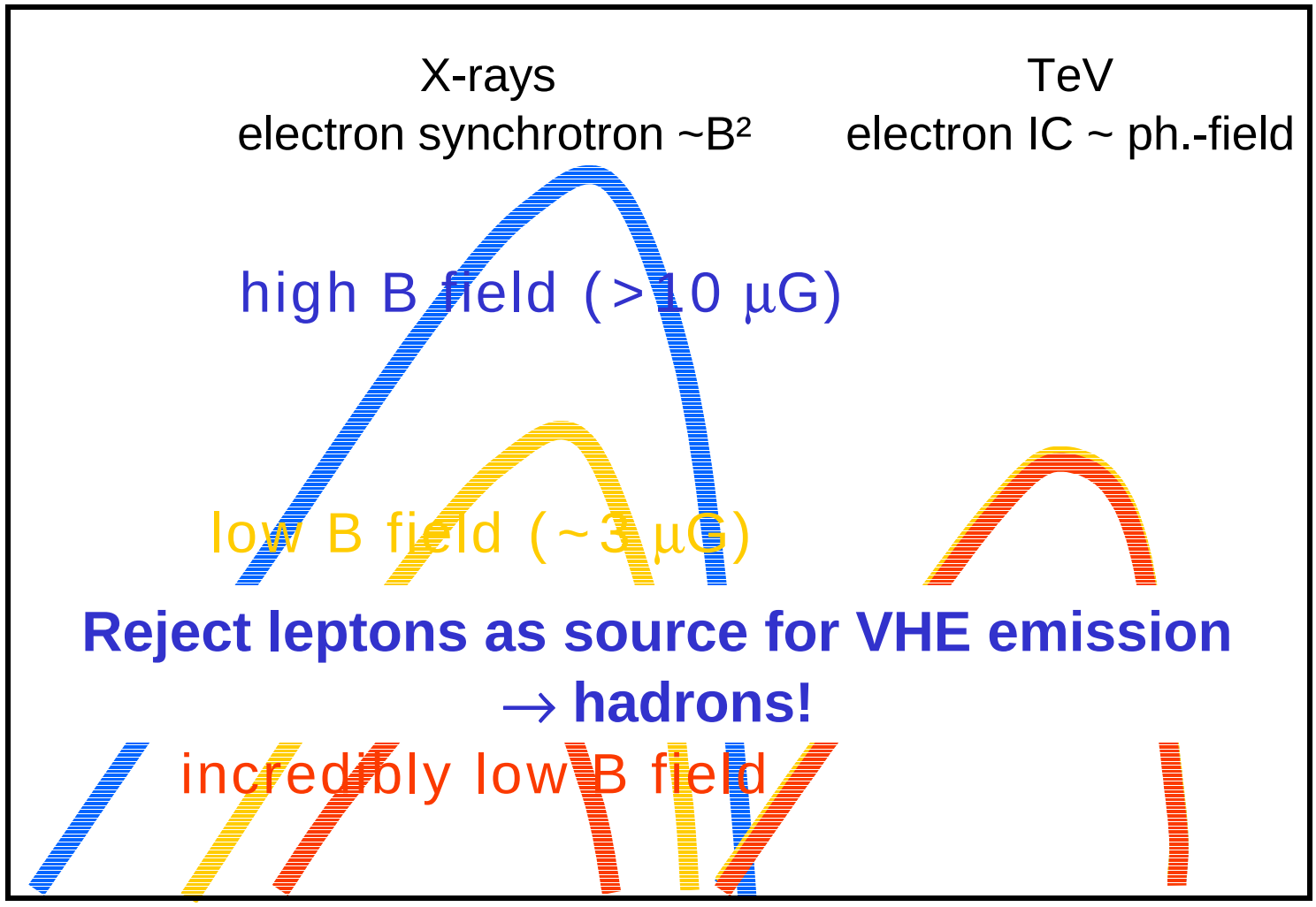
Very preliminary:

second pulsar surprisingly bright in X-rays

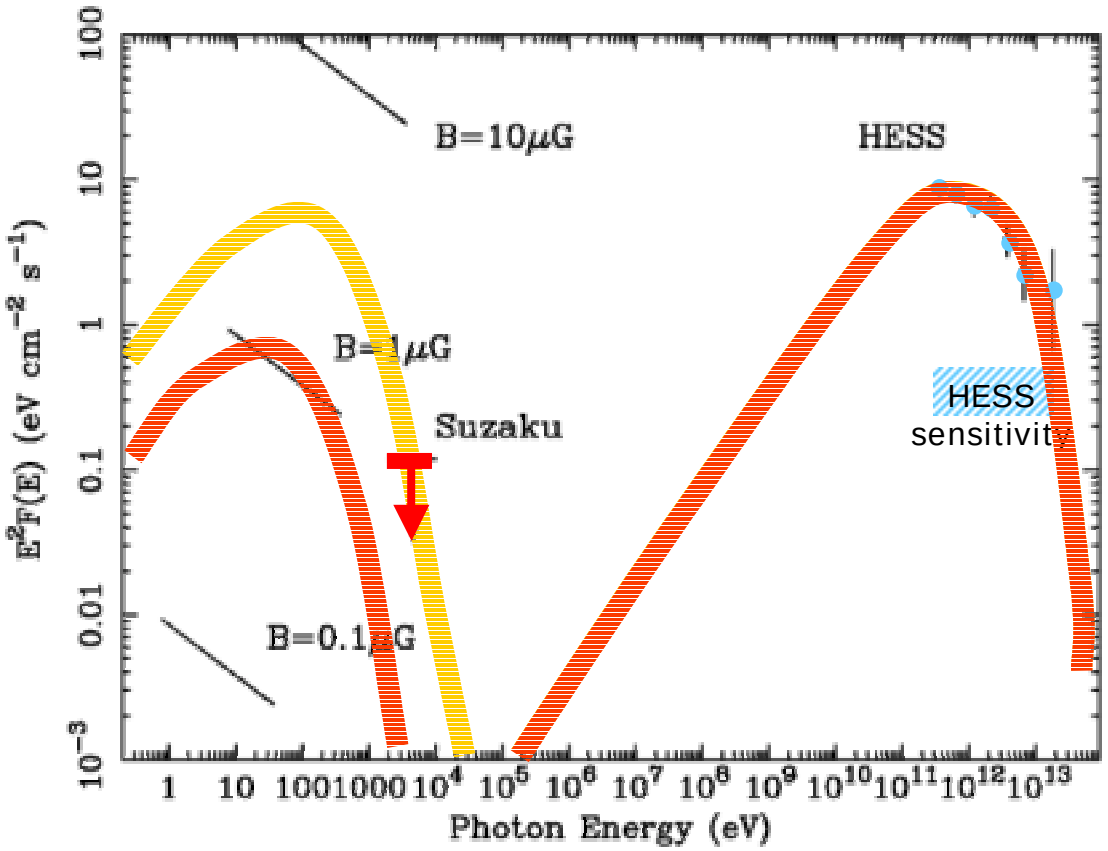
Nature of diffuse “shell”?

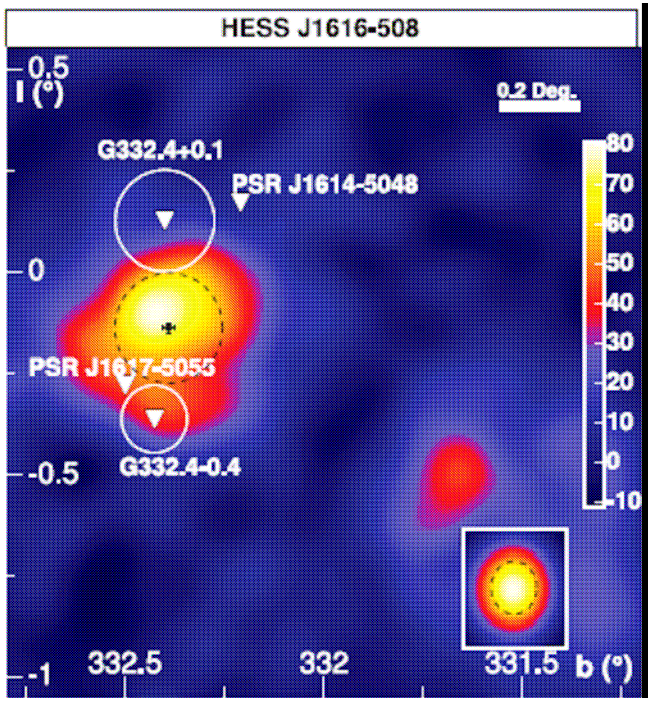
XMM: counts, all energies
PI: GP

Now: what are dark VHE sources?



HESS J1616-508: a “dark” TeV source?

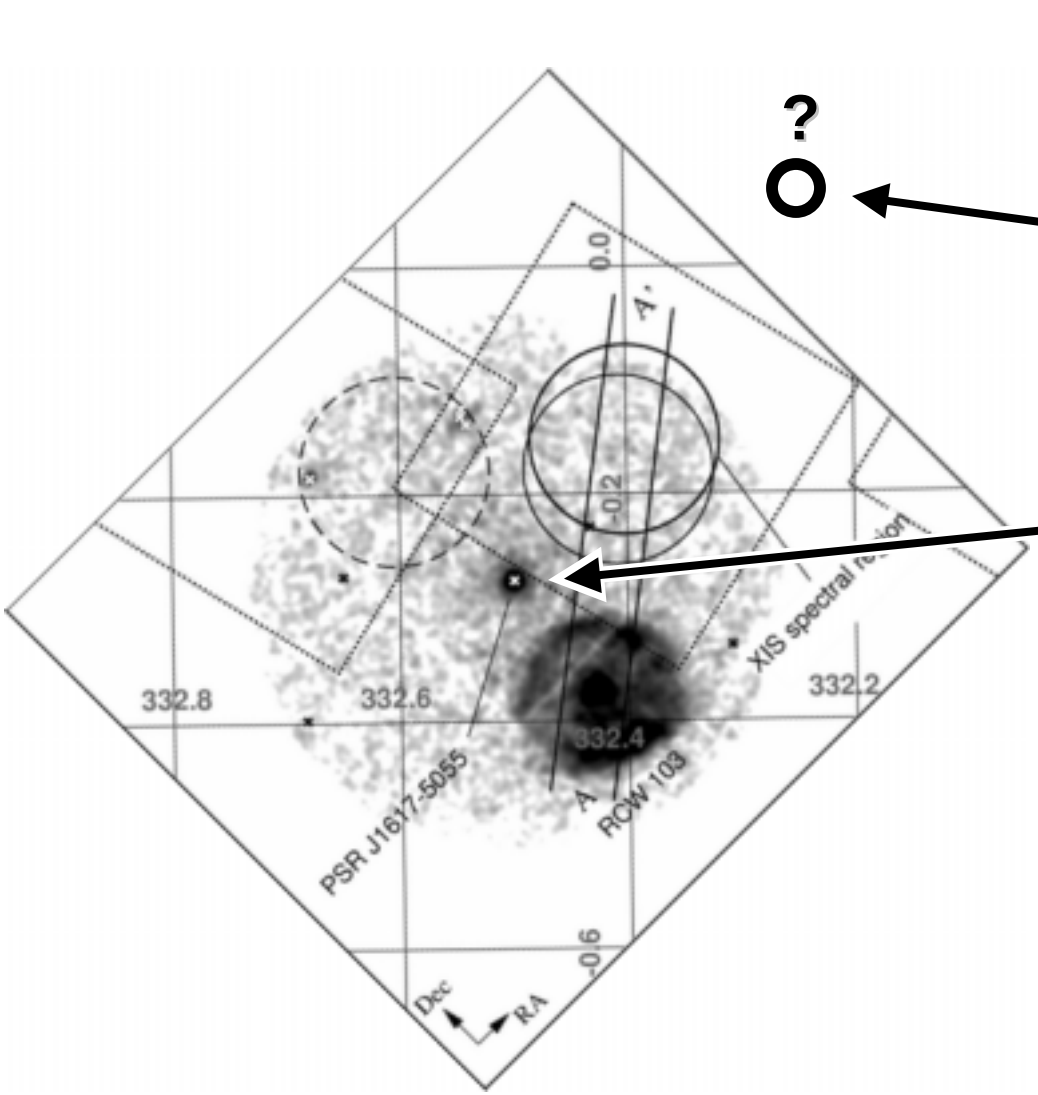


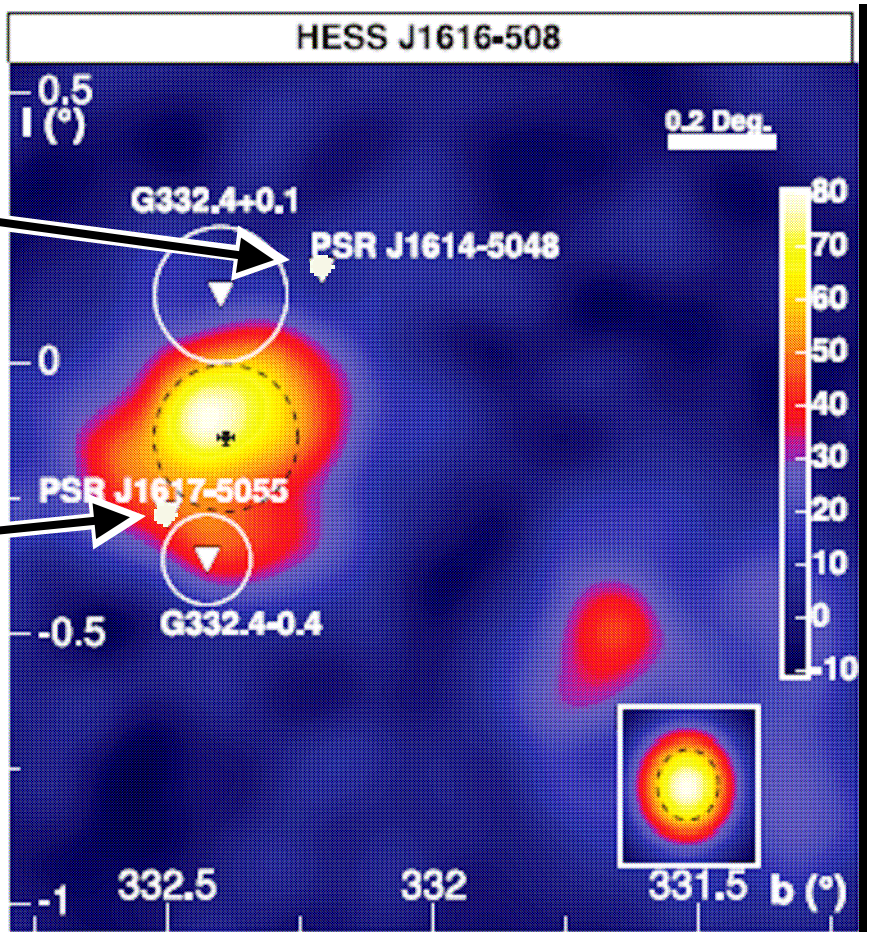


“Evidence for a dark particle accelerator”

Matsumoto et al., PASJ 2007

HESS J1616-508 : a “dark” TeV source?

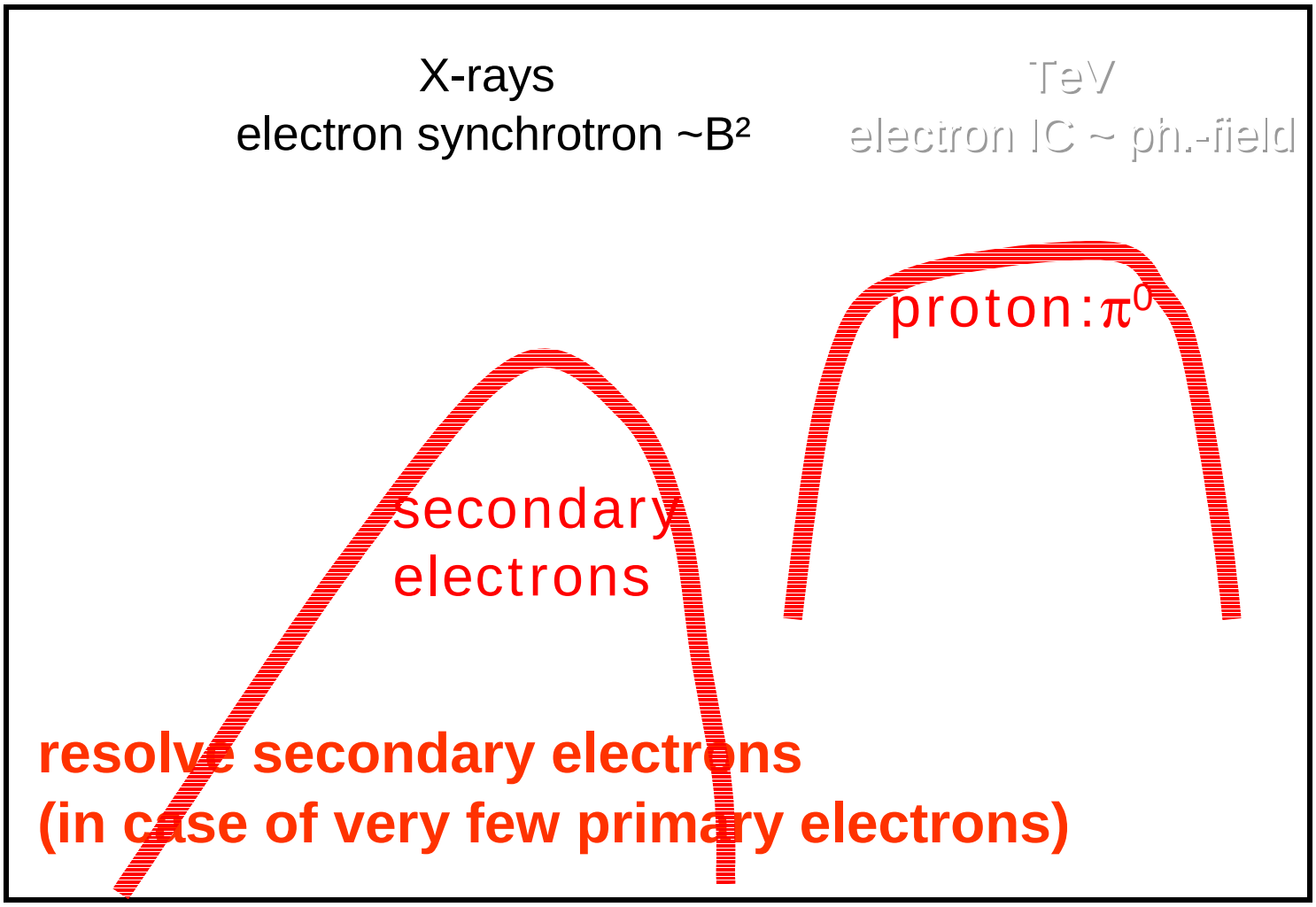




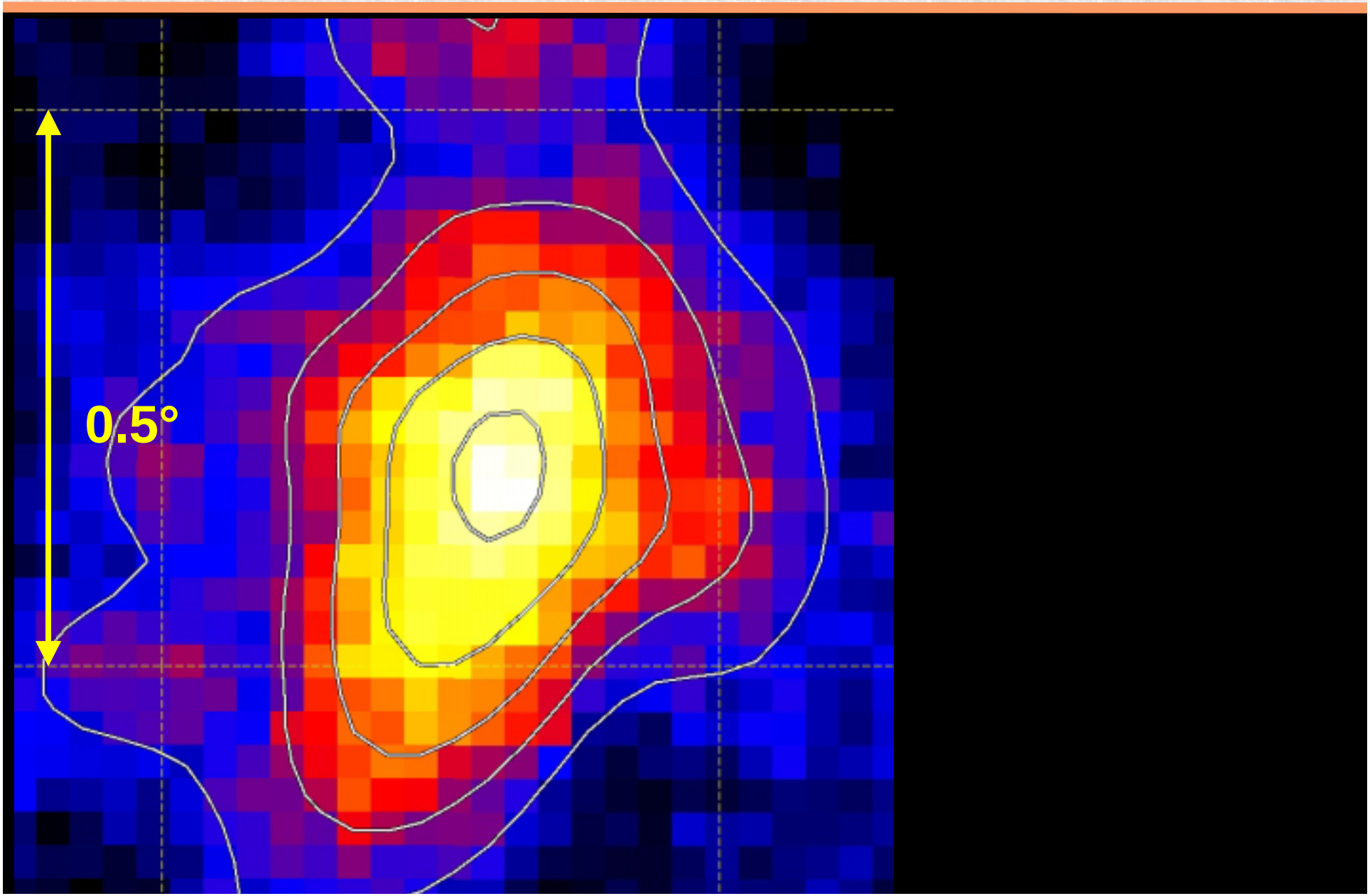
Matsumoto et al., PASJ 2007

Multiple association, needs to be tested

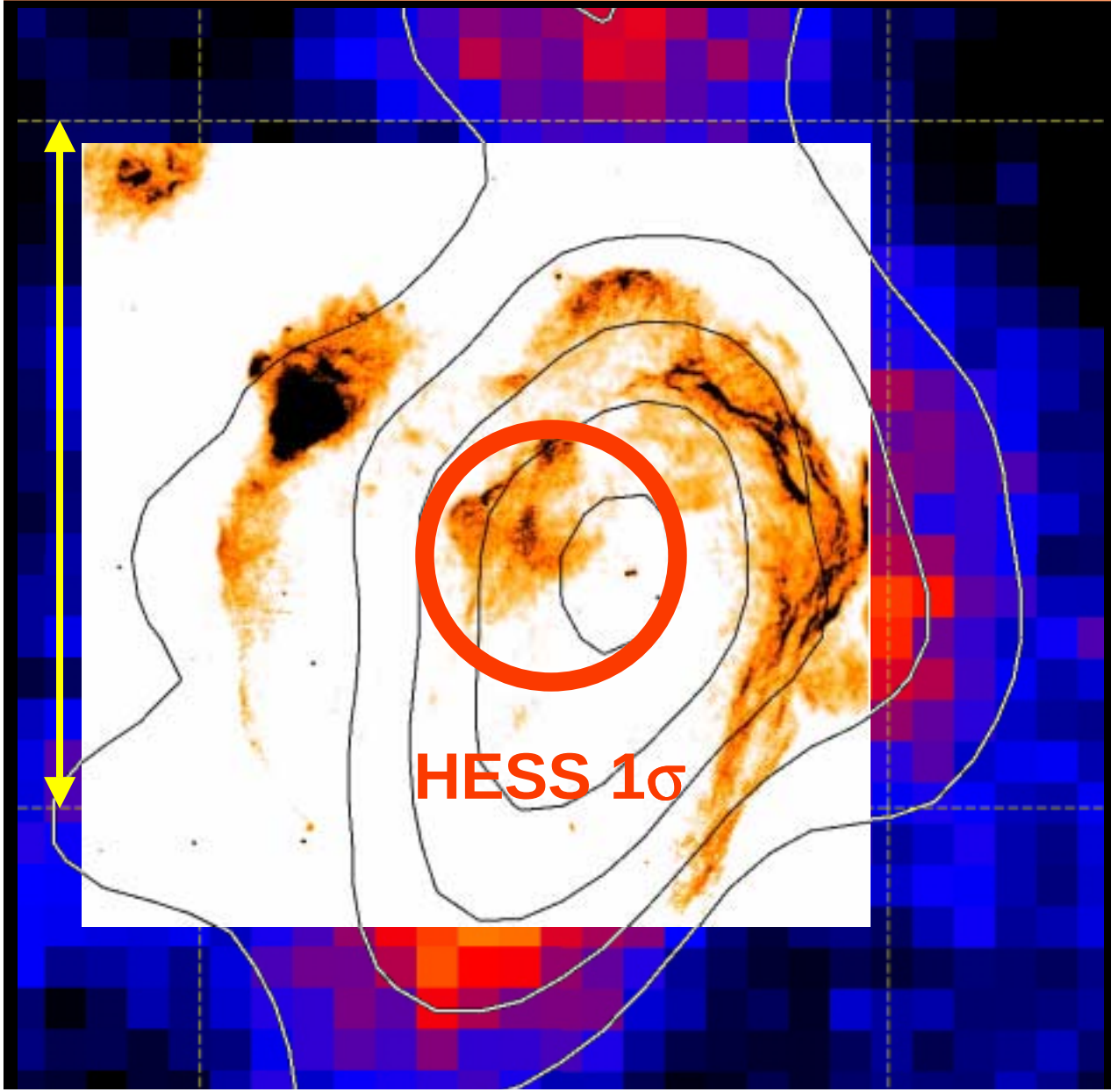
Another signature for hadronic sources?



HESS J1834-087



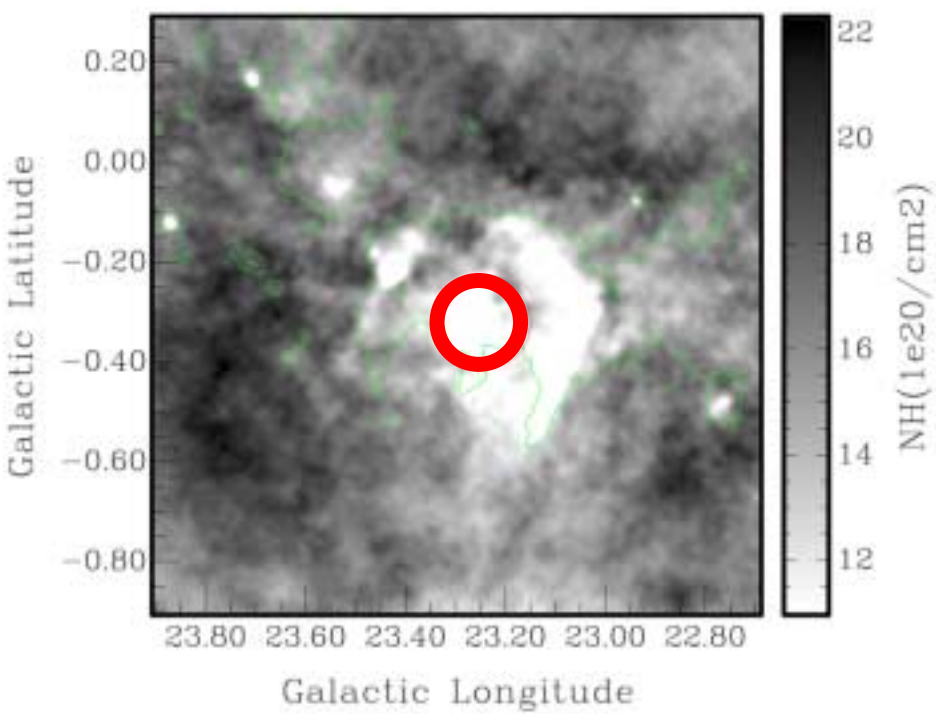
HESS J1834-087

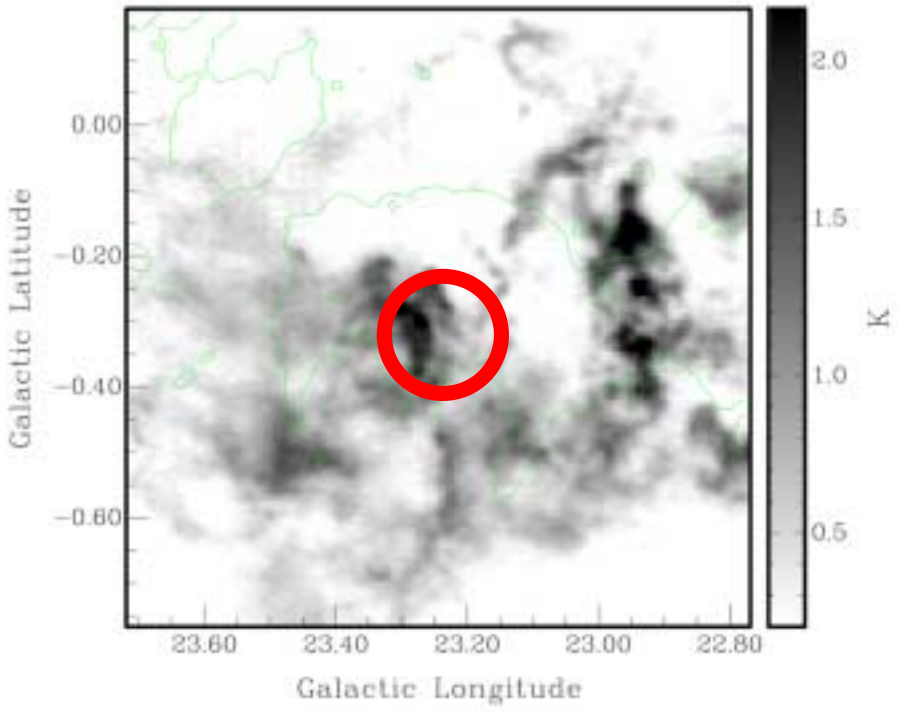


- VLA 90 cm continuum map
- W41 SNR shell, d≈4 kpc
- HESS source not compatible with SNR shell
- Central radio source?

HESS J1834-087

Tian et al., ApJ 2007 (see also Albert et al., 2006)





HI, 53-63 km/s

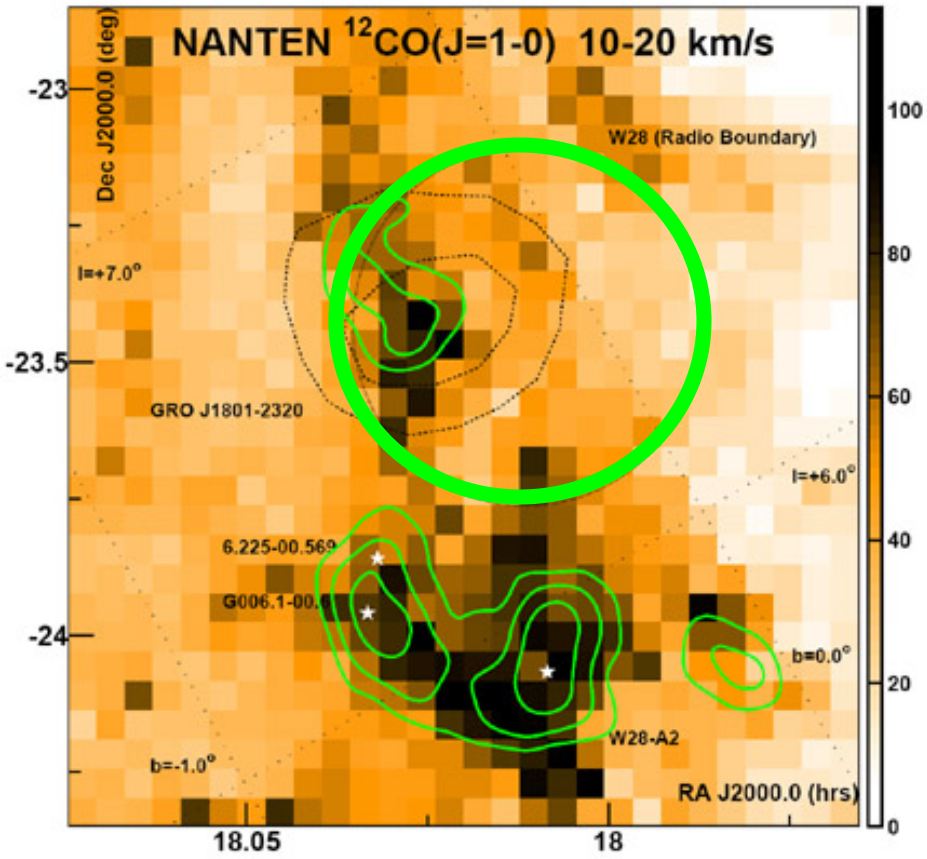
^{13}CO, 61-66 km/s

they conclude:
hadronic TeV emission from molecular cloud behind W41

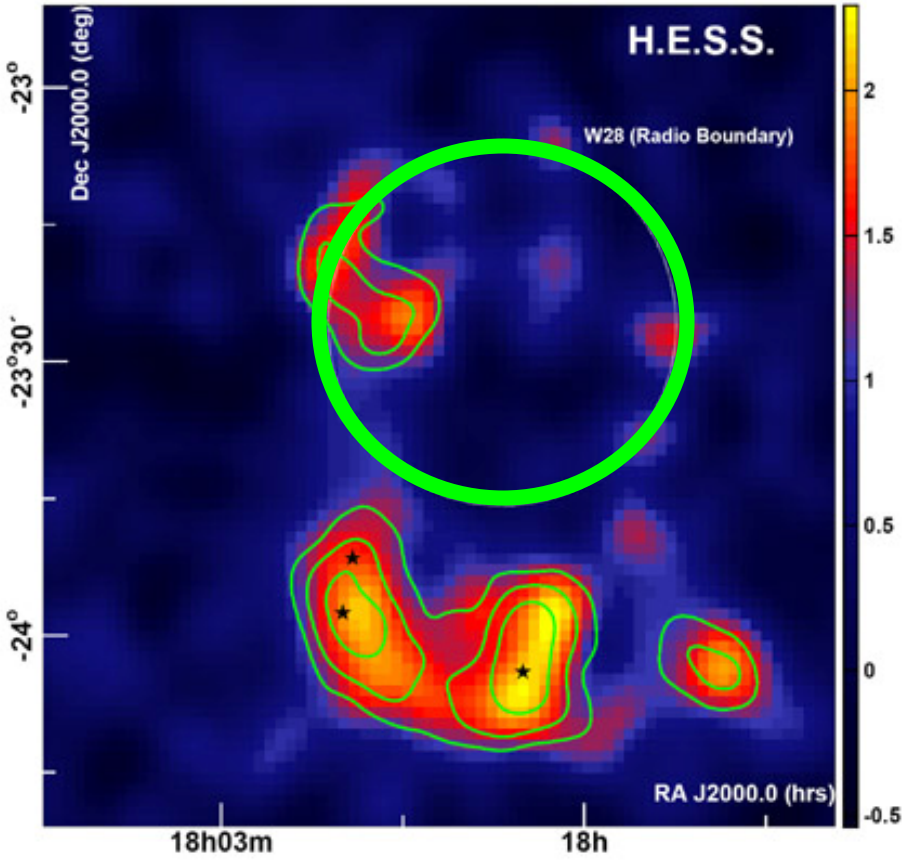
CO diagnostics of W28

Ref: H.E.S.S. source of the month April 2007

Color code: CO (gas density)
Green contours: H.E.S.S.



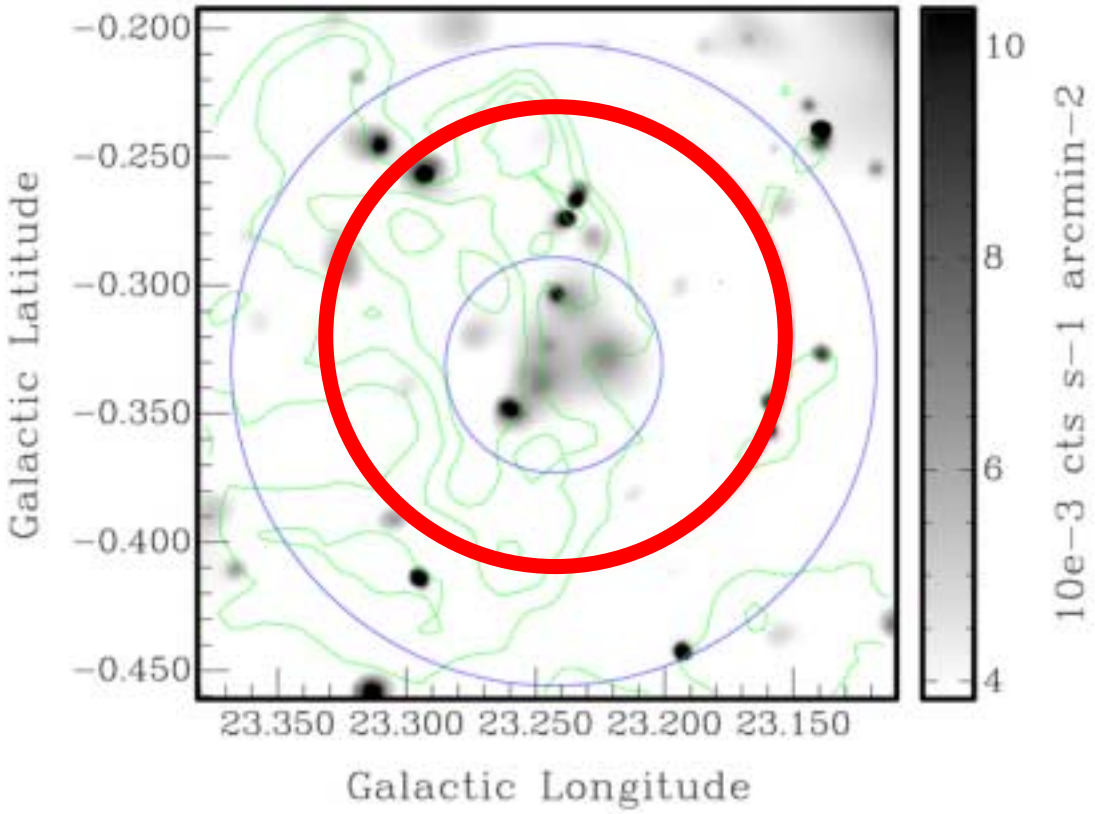
Color code: VHE (H.E.S.S.)

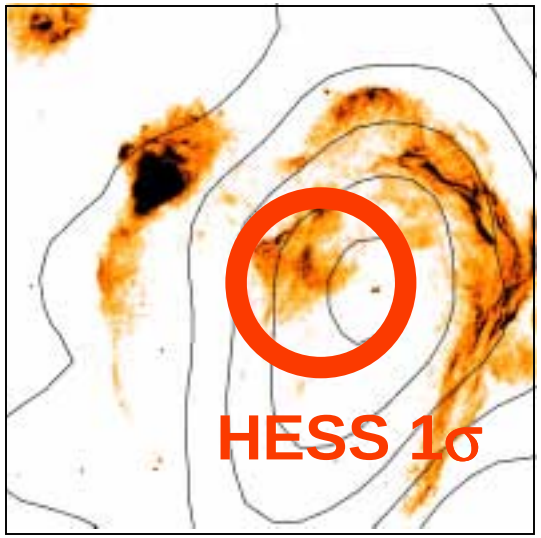


Back to HESS J1834-087

Tian et al., ApJ, 2007:

- **diffuse X-ray emission in XMM-Newton pointing (20 ksec) claimed**
- **interpreted as emission from secondary electrons**
- **N_H compatible with emission being behind W41**





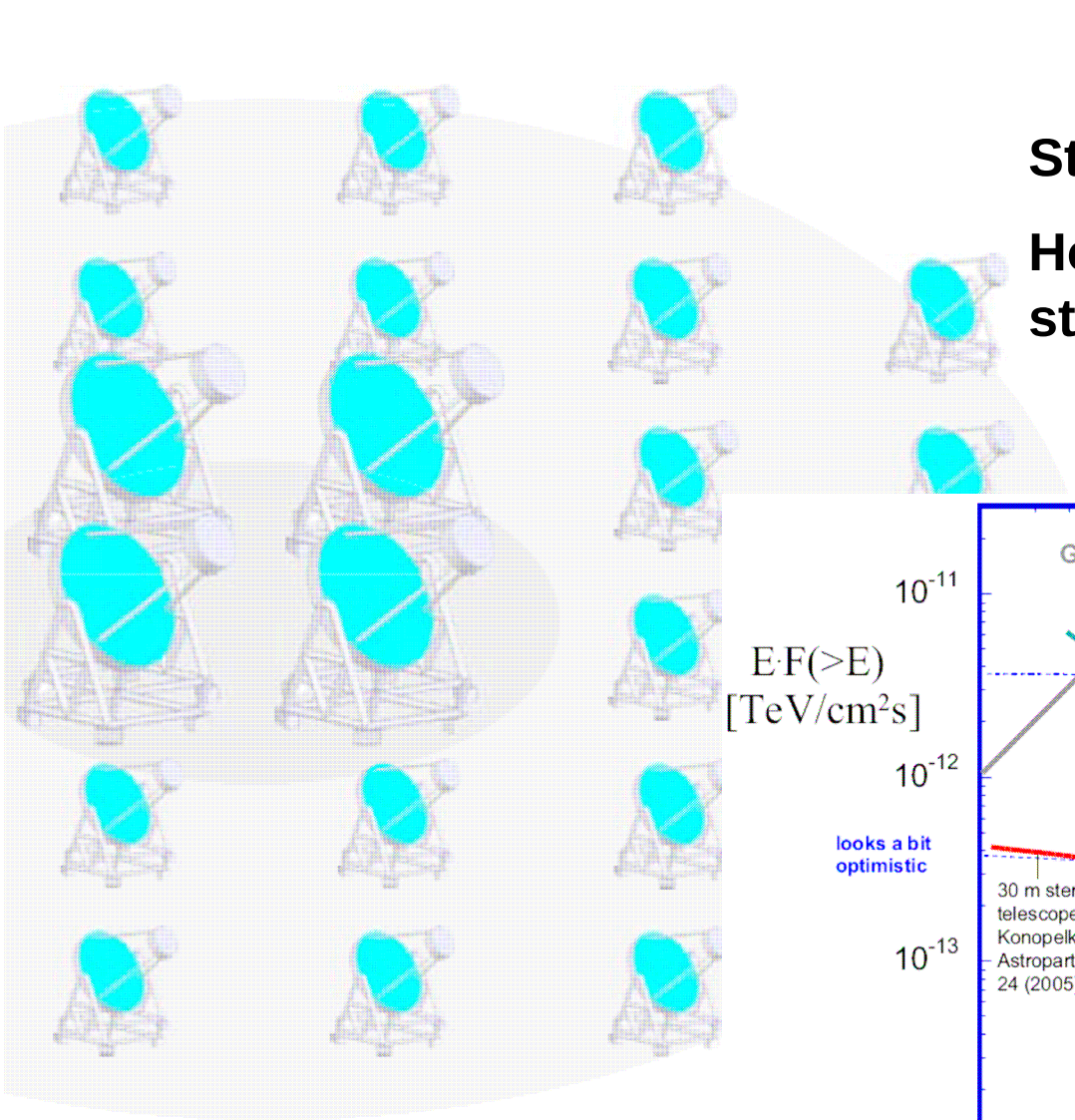
Summary

- A couple of HESS sources coincide with shell-type (or at least non-plerionic) radio-SNR:
  e.g. HESS J1804-216, HESS J1834-087
- one or several X-ray PWN plausible counterparts to individual HESS sources (but PWN / shell ambiguity)
- Proof for association could come from HESS data (e.g. spectral imaging like for HESS J1825-137)
- Coincidence with molecular clouds (CO emission) favours hadronic scenario, low but detectable X-ray emission from secondaries expected

Thanks to all HESS collaborators !

H.E.S.S. Phase II

The future: CTA (Cherenkov Telescope Array)



Not to scale !

Start of operation: 2012 + (?)

Hopefully, XMM-Newton will still be alive by that time ..