Supernova Remnants and Pulsar Wind Nebulae in the Cherenkov Telescope Array era

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for the CTA consortium

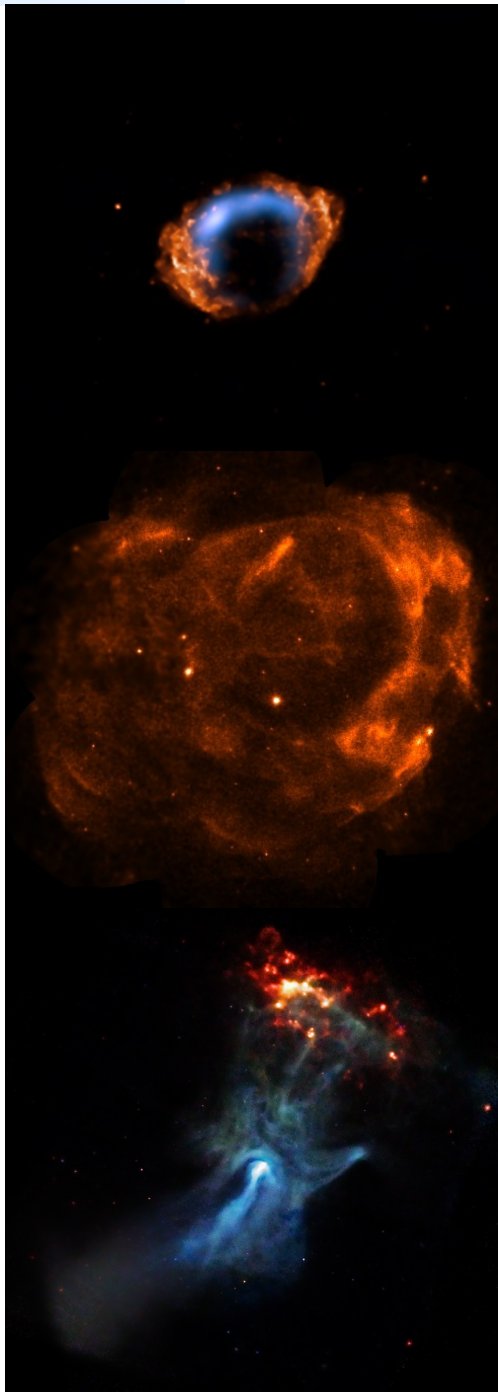
with contributions from F. Acero, A. Bamba, E. de Cea, S. Gabici, Y. Gallant, D. Hadasch, A. Marcowith, E. de Ona Wilhelmi, G. Pedaletti, D. Torres

CRISM workshop
Montpellier, 27th June – 01st July 2011

LABORATOIRE MONTPELLIER UNIVERS & PARTICULES

cta cherenkov telescope array

Outline



The Cherenkov Telescope Array

- Current IACTs & the TeV sky
- Status of the CTA project

Shell-type Supernova Remnants (SNRs)

- TeV spectra (cutoffs)
- Spectro-imaging analysis (X-ray/TeV correlation)
- Population studies

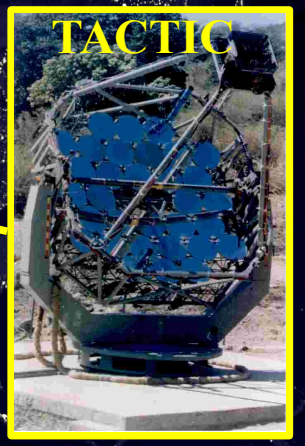
Pulsar Wind Nebulae (PWNe)

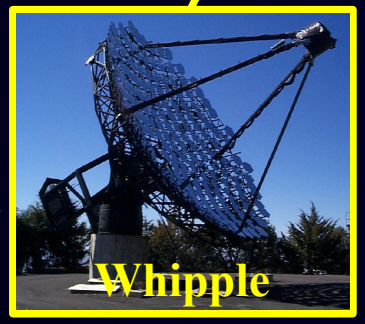
- Spectro-imaging analysis (aging of particules)
- Population studies

Conclusion & Perspectives

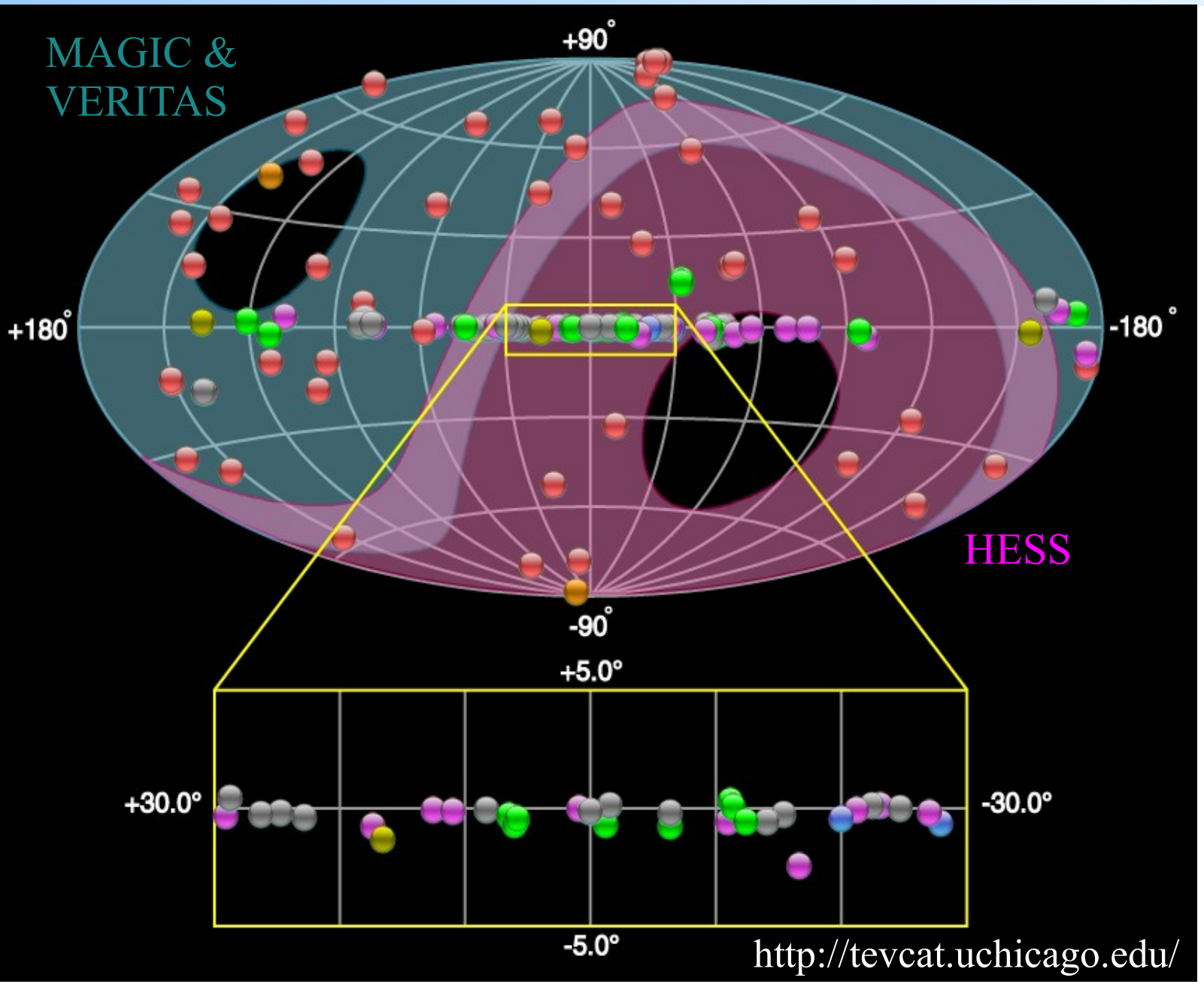
Current IACTs

Adapted from J. Hinton





The TeV sky

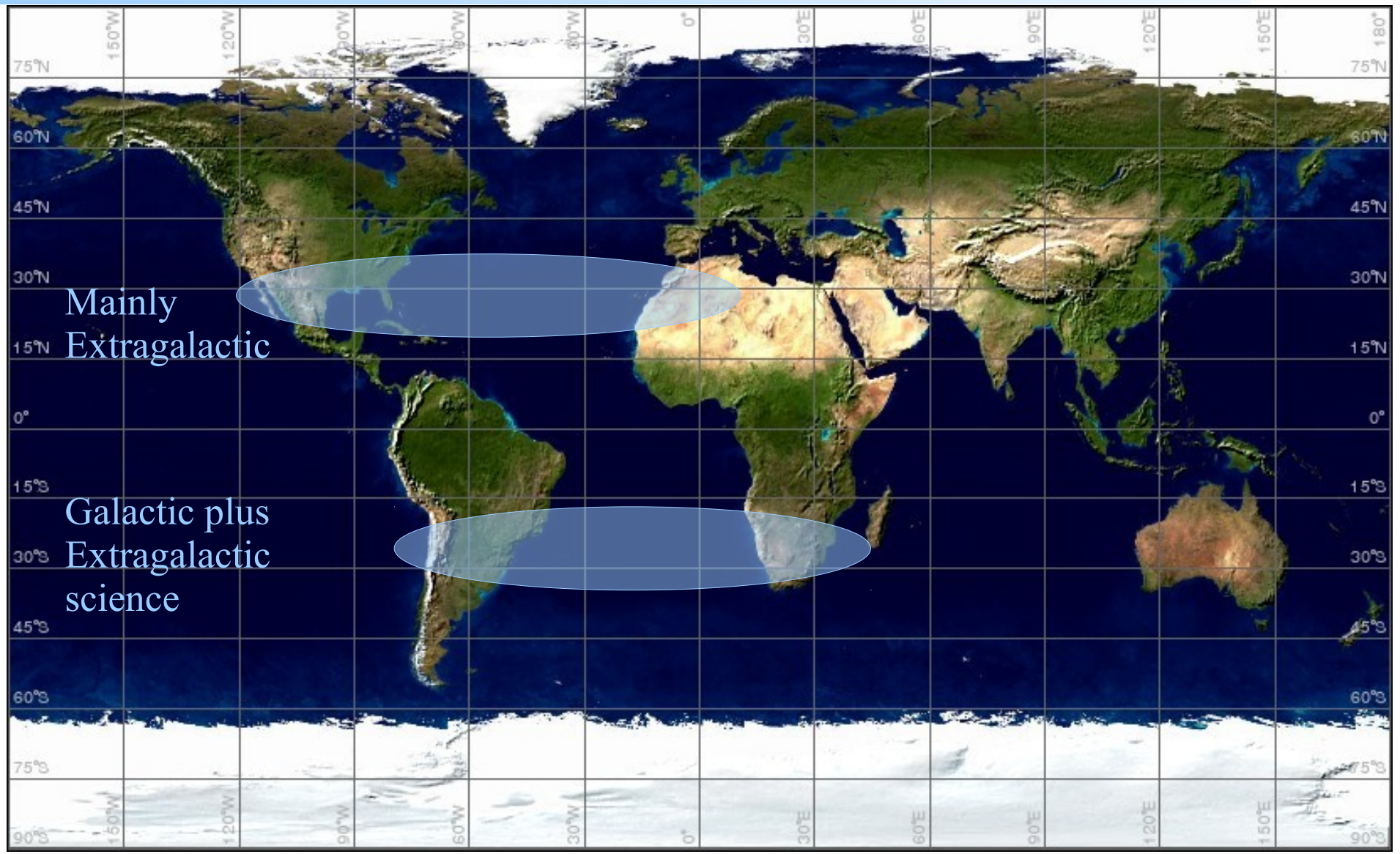


Source Types

25	PWN
4	XRB PSR Gamma BIN
45	HBL IBL FRI FSRQ LBL AGN (unknown type)
17	Shell SNR/Molec. Cloud
2	Starburst
25	DARK UNID Other
4	uQuasar Star Forming Region Cat. Var. Massive Star Cluster BIN WR

As of June 2011
122 sources
(75 Galactic
47 Extragalactic)

The CTA project



Selection of sites by 2012

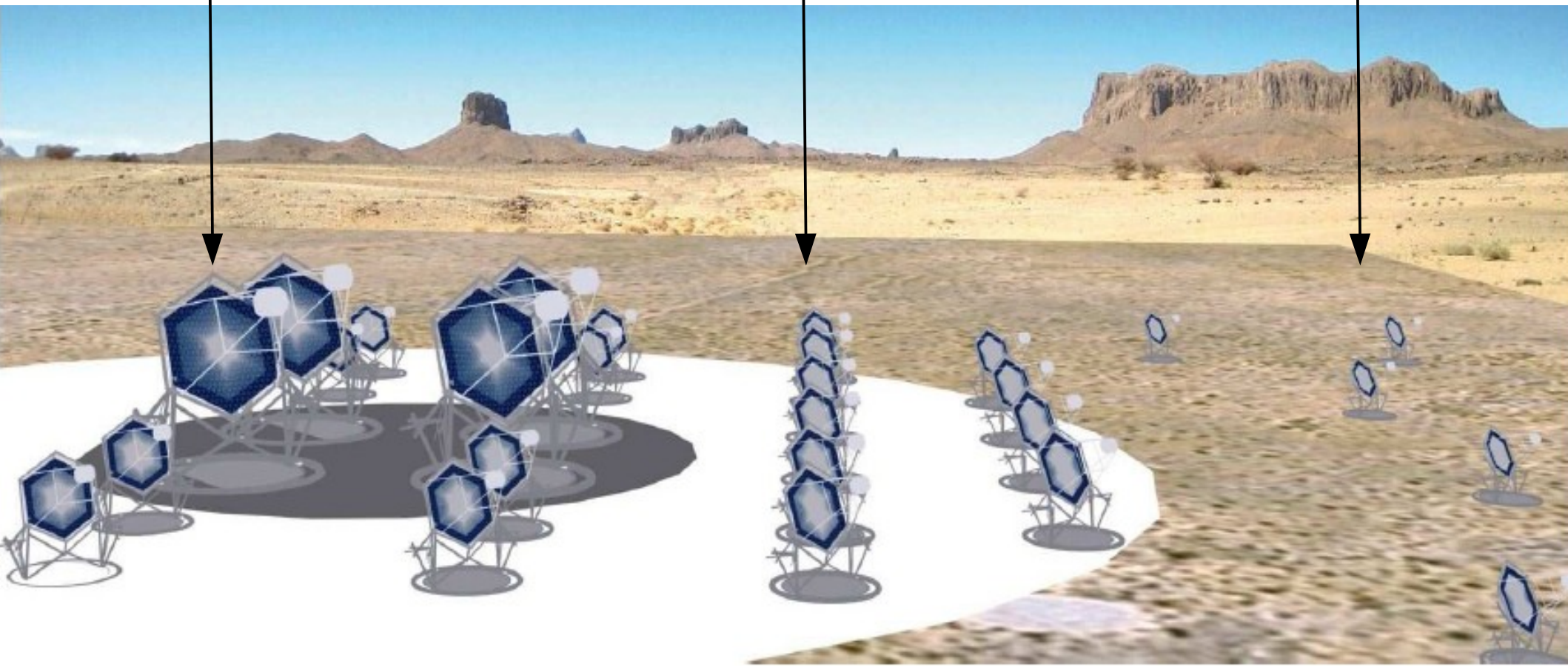
10 km^2 flat area, 1.5-4.0 km altitude, minimum cloud cover, easiest access, ...

The CTA project

Low-energy section
energy threshold
of ~ 20–30 GeV
23–24m telescopes

Medium energies
mcrab sensitivity
~100 GeV–10 TeV
10–12m telescopes

High-energy section
10 km^2 area at
multi-TeV energies
5–8m telescopes

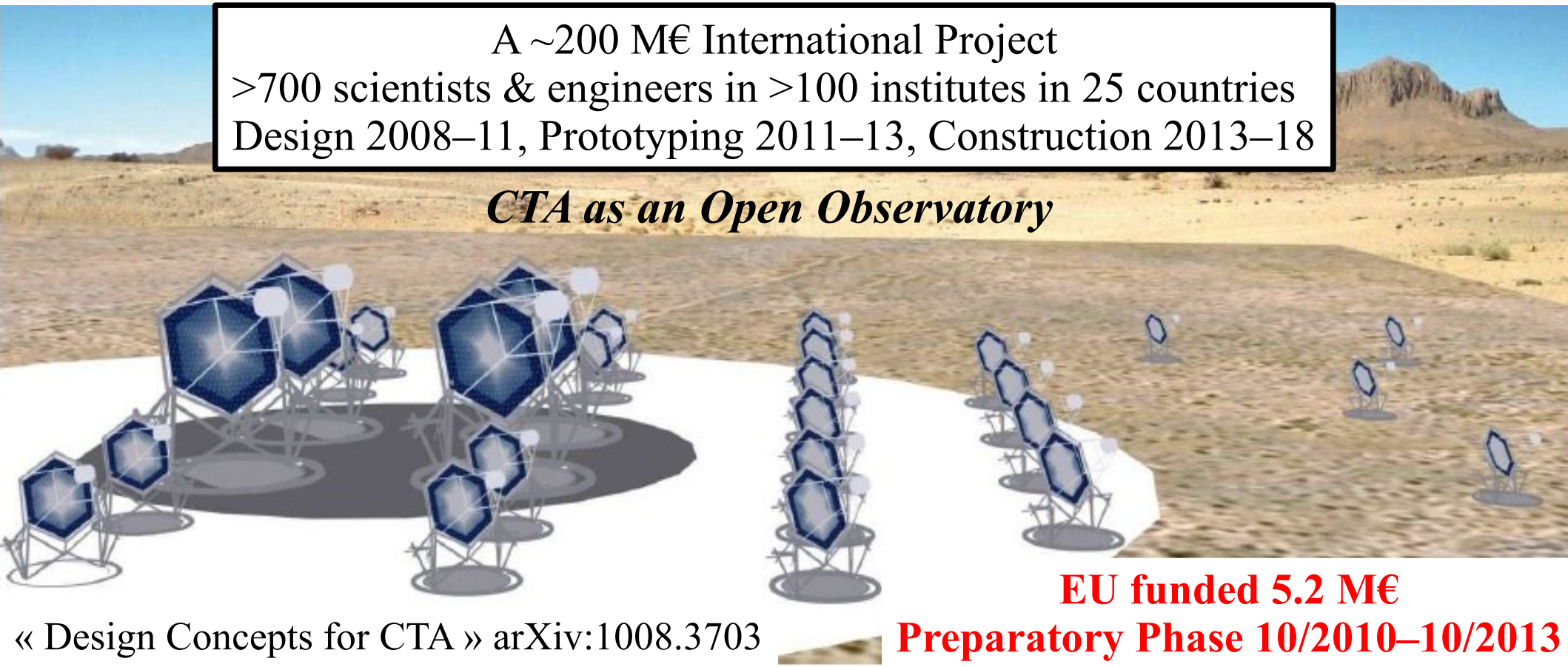


The CTA project

Higher sensitivity	→ 1000 sources? Pop. studies	~mCrab, 5σ, 50h @ TeV
Wider energy coverage	Spectr(o-imaging)al parameters	30 GeV – 300 TeV
Better angular resolution	Source identification & morphology	~2 arcmin @ TeV
Better energy resolution	Cutoffs & spectral features	rms < 10% @ TeV
Wider field-of-view	Extended sources & survey	6 – 8 degrees

A ~200 M€ International Project
>700 scientists & engineers in >100 institutes in 25 countries
Design 2008–11, Prototyping 2011–13, Construction 2013–18

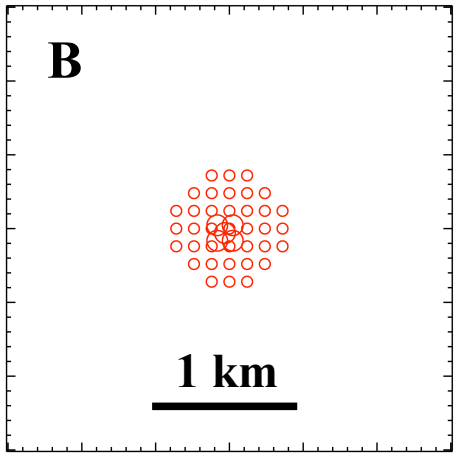
CTA as an Open Observatory

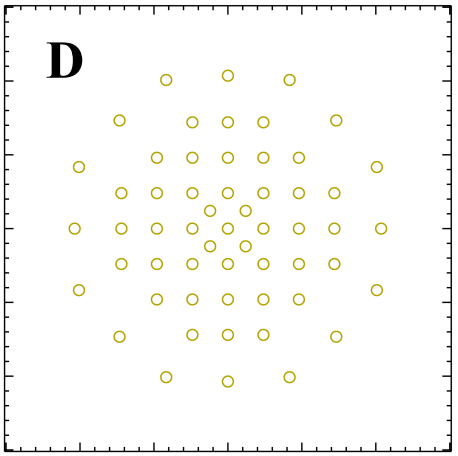


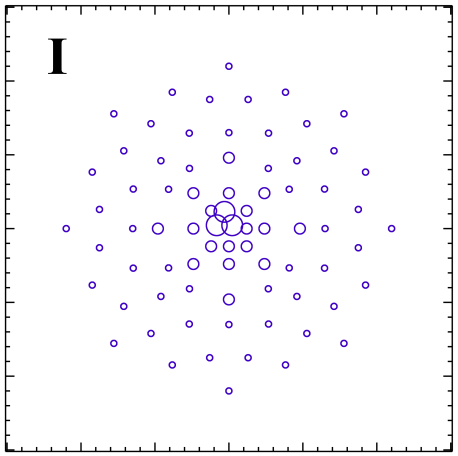
« Design Concepts for CTA » arXiv:1008.3703

EU funded 5.2 M€
Preparatory Phase 10/2010–10/2013

The CTA project



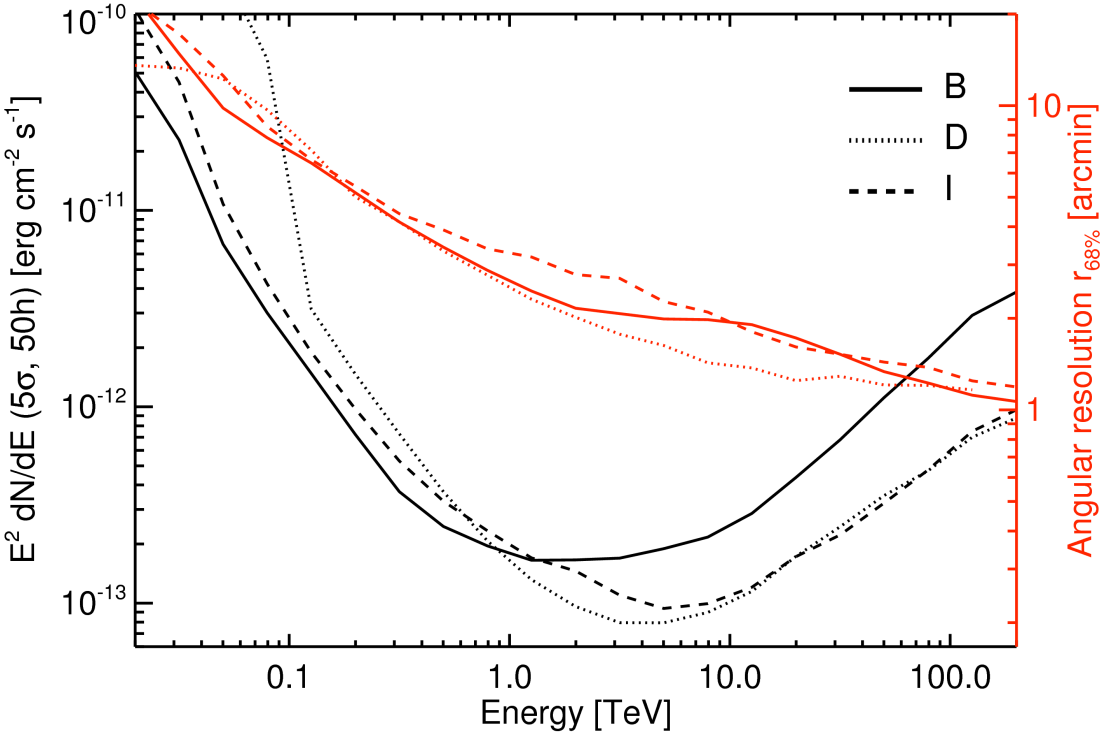




B: better performance at low energies

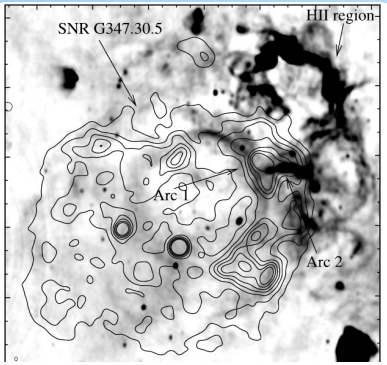
D: better performance at high energies

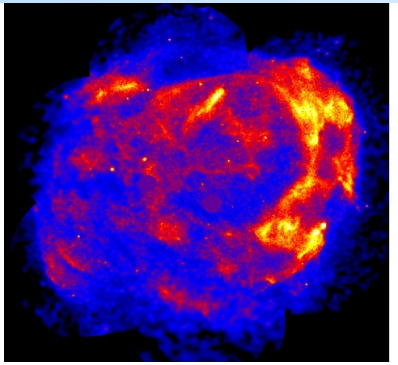
I: better performance over the whole range

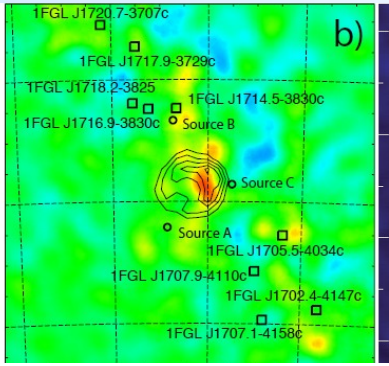


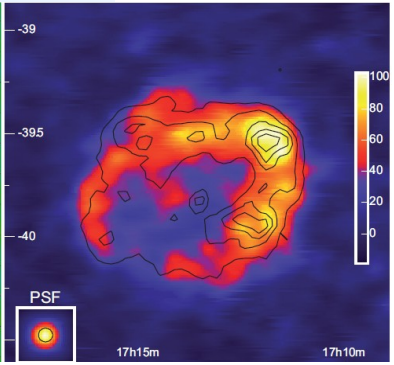
In what follows, compare quantitatively performance of three different CTA configurations, optimized for different energy ranges, for SNRs & PWNe

Seeking the CR *hadronic* sources









RX J1713.7-3946

Leptons (SC+IC)

Hadrons (p-p interactions)

$E^2\ dN/dE\ (erg\ cm^{-2}\ s^{-1})$

10^{-10}

10^{-11}

10^{-12}

10^{-13}

(Lazendic et al. 2004; Aharonian et al. 2007,2011;
Tanaka et al. 2008; Acero et al. 2009; Abdo et al. 2011)

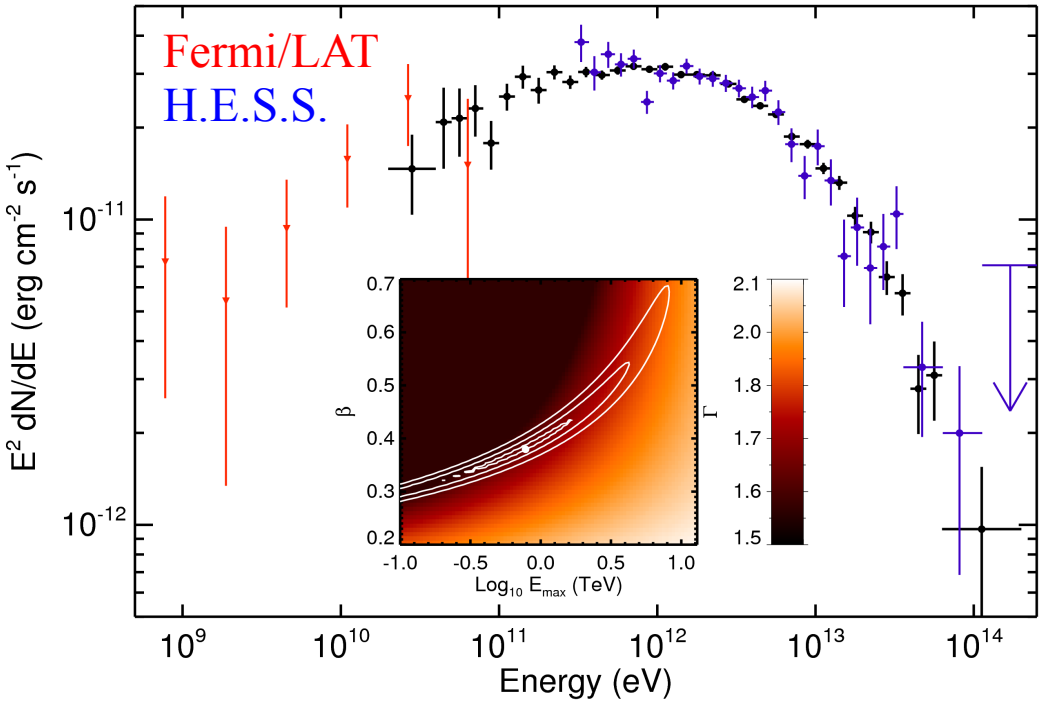
Energy (keV)

10^{-5} 10^{0} 10^{5} 10^{10}

Shell-type SNRs as seen with CTA

RX J1713 TeV spectra

CTA Configuration **I**, T = 50 h, Z.A. = 20°



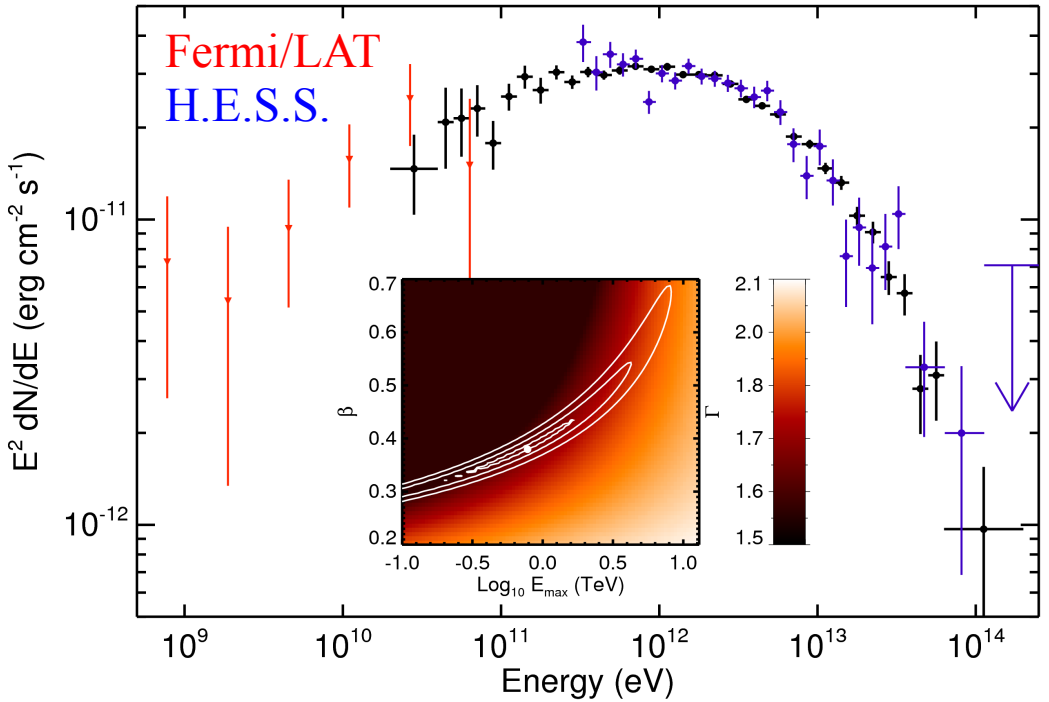
RX J1713.7-3946 spectral parameters

Best fit on the LAT-HESS data in the form:
$dN/dE = N_0 E^{-\Gamma} \exp(-(E/E_{max})^{\beta})$
$\{\Gamma, \beta, E_{max}\}$ well constrained

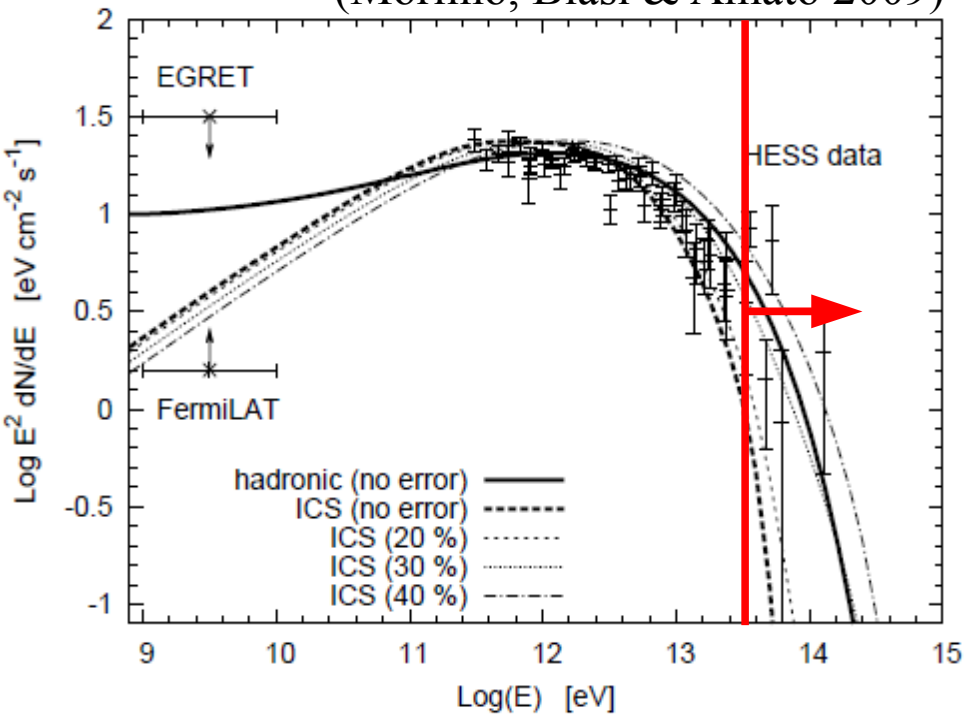
Shell-type SNRs as seen with CTA

RX J1713 TeV spectra

CTA Configuration **I**, T = 50 h, Z.A. = 20°



(Morlino, Blasi & Amato 2009)



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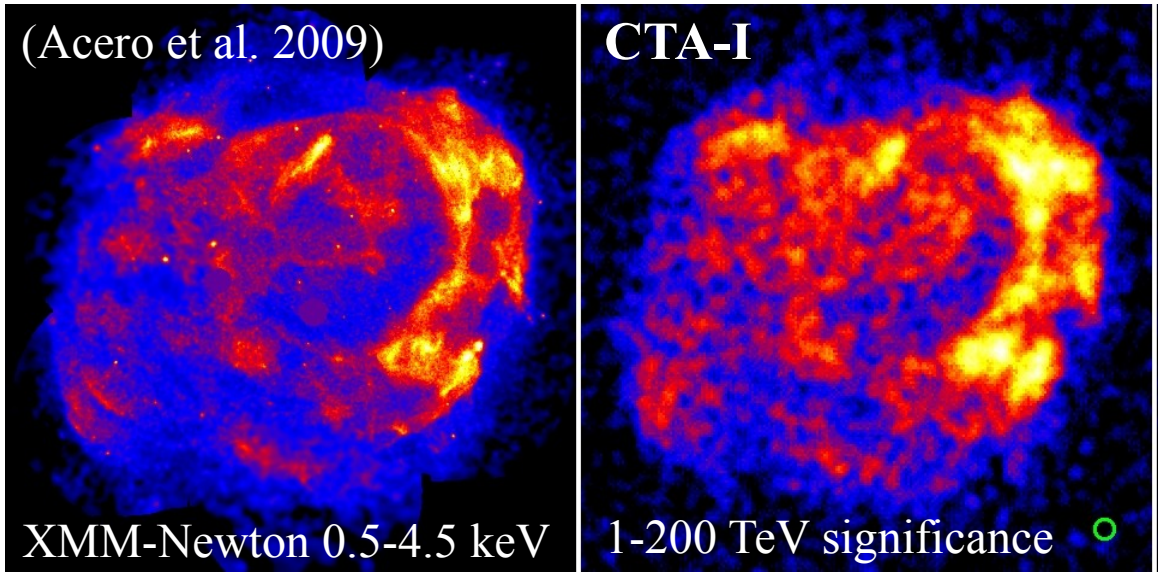
Nature of the VHE emission > 35 TeV ?

HESS data points >35 TeV : 2.5, 1.5 & 0.6σ
CTA simulations → $S/N_{>35TeV} \sim 7\sigma$ in 50 h

Shell-type SNRs as seen with CTA

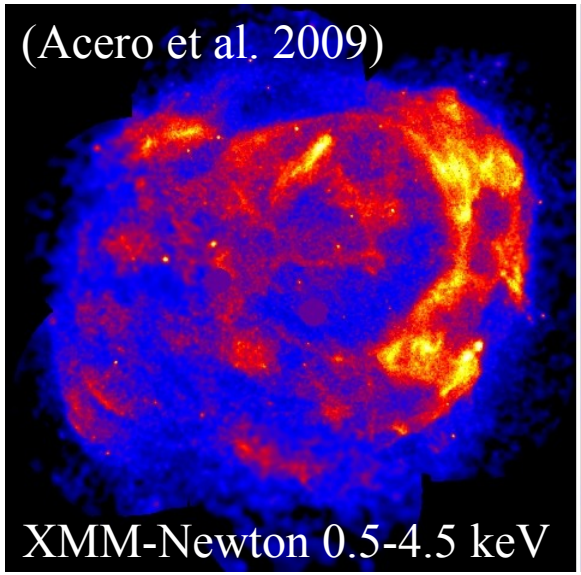
RX J1713 Spectro-imaging analysis

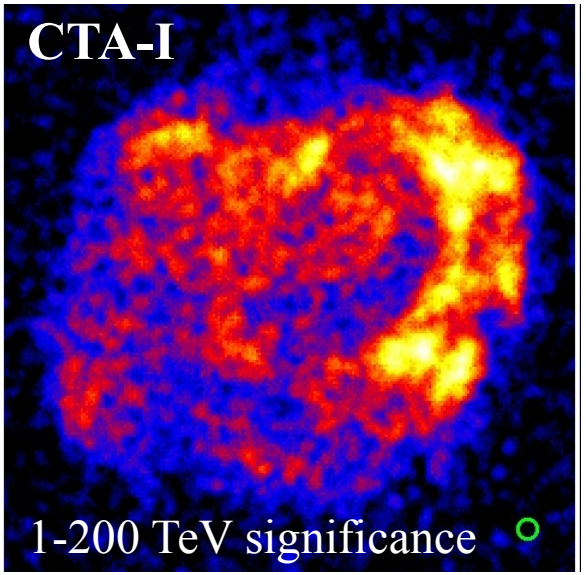


CTA simulation (T = 50h, Z.A. = 20°) of RX J1713.7-3946 as seen by XMM with best-fit values from the joint Fermi-LAT & HESS spectrum:
$dN/dE = N_0 E^{-\Gamma} \exp(-(E/E_{max})^{\beta})$

Shell-type SNRs as seen with CTA

RX J1713 Spectro-imaging analysis





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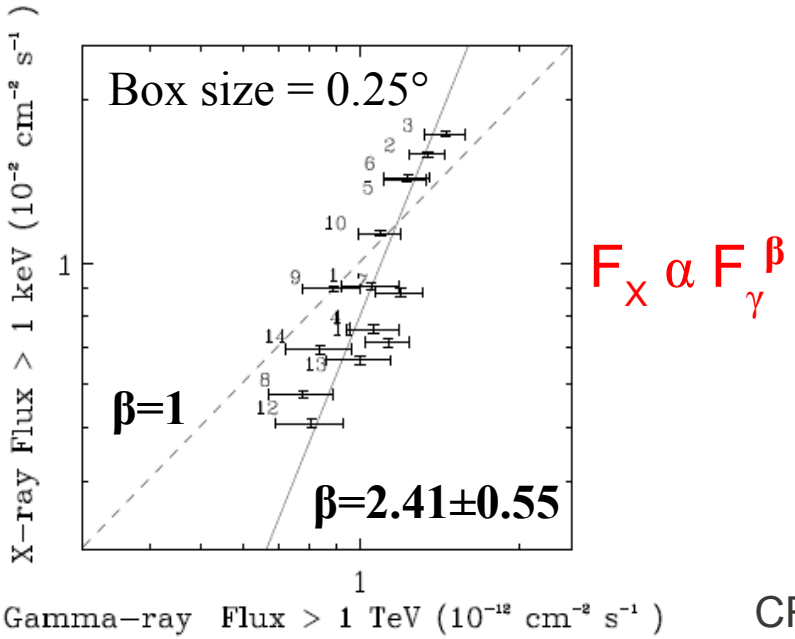
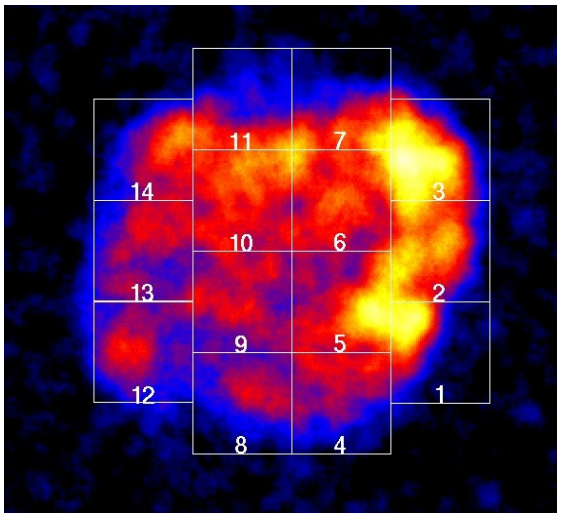


$F_X \propto F_\gamma^{\beta}$



Shell-type SNRs as seen with CTA

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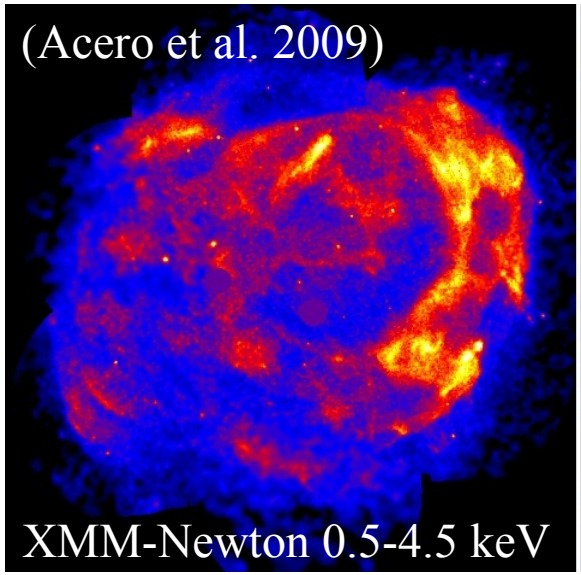

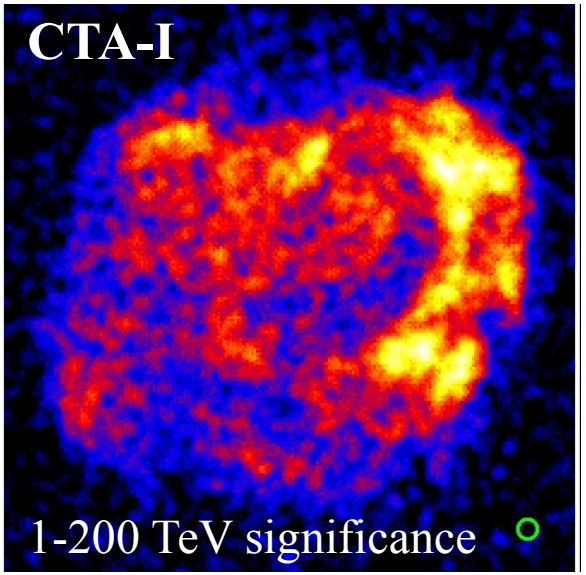

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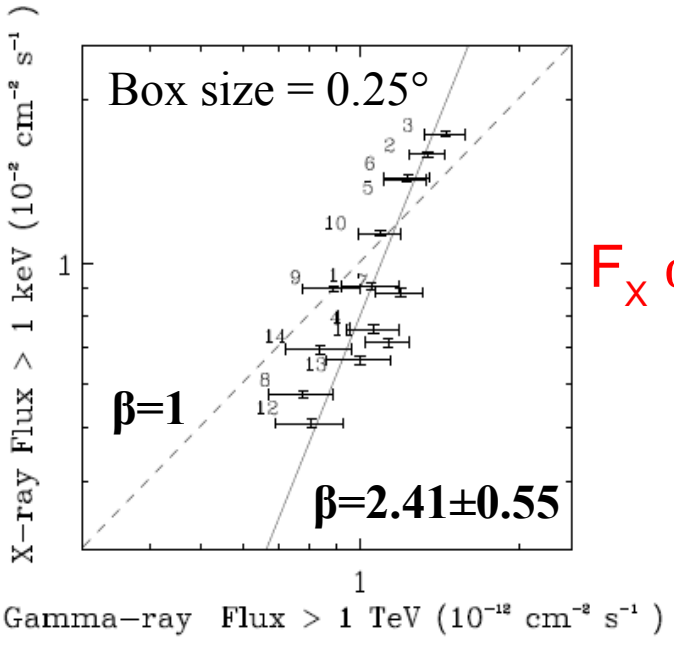
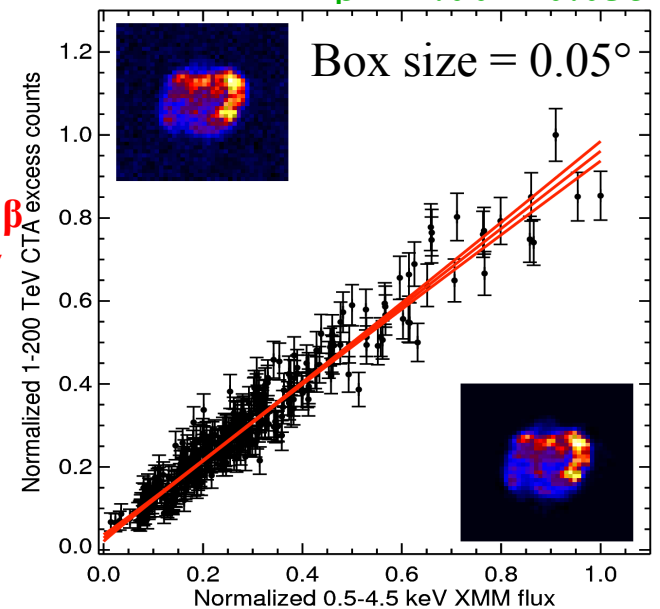
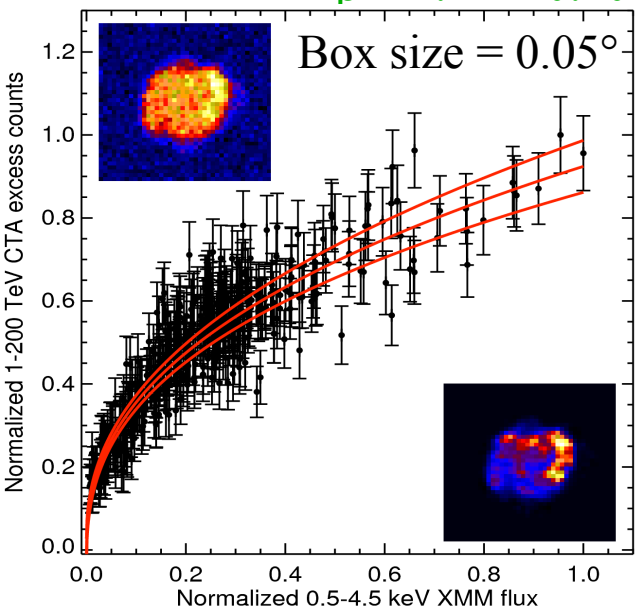


$F_X \alpha F_\gamma^{\beta}$

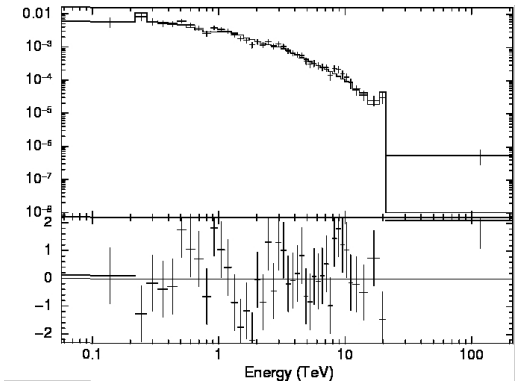
β = 1.00 ± 0.035

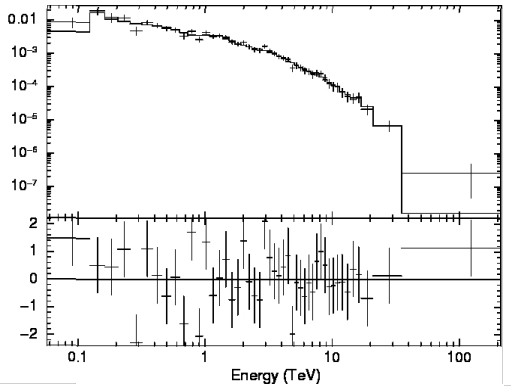


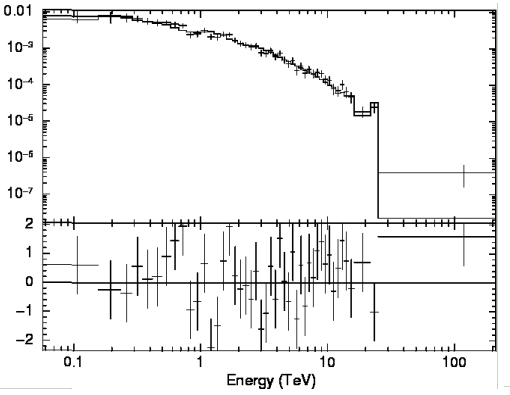
β = 2.41 ± 0.20

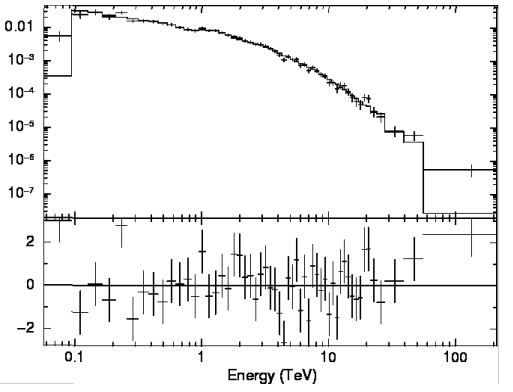


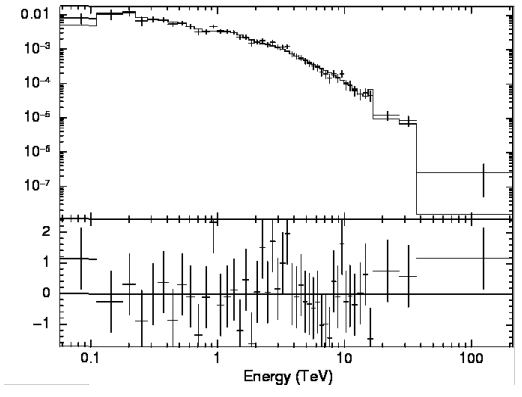
Shell-type SNRs as seen with CTA

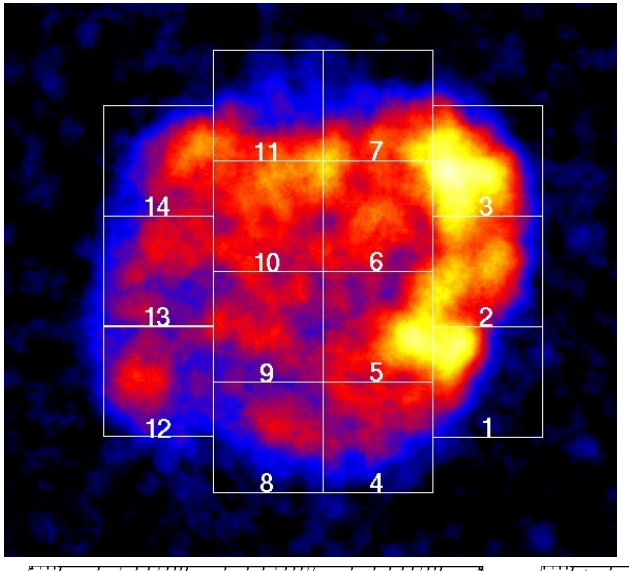










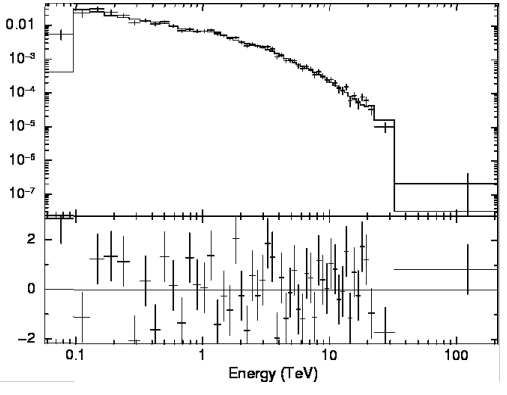


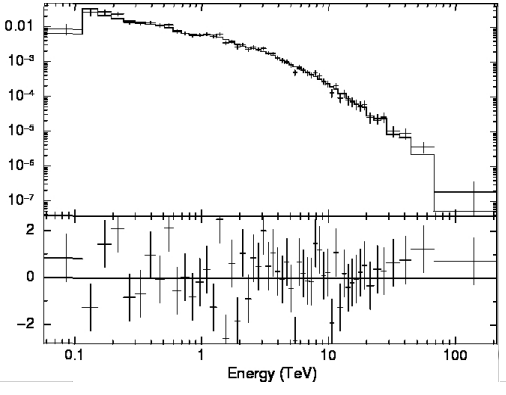
$\sigma_{\Gamma} = 0.08$

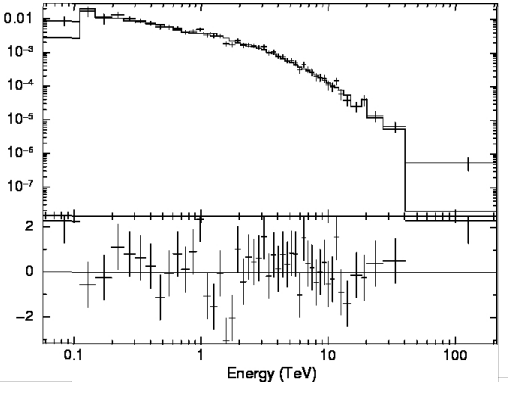
$\sigma_{Emax} = 0.3$ TeV

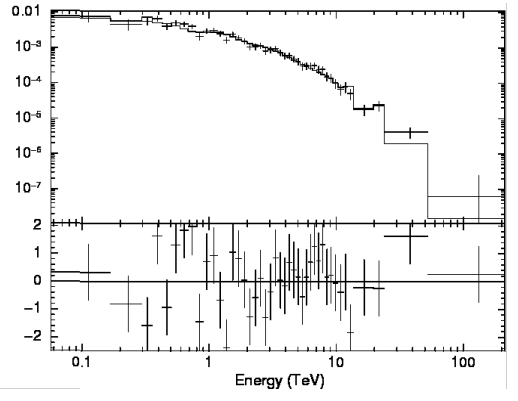
$\sigma_{N1TeV} = 25$ %

→ Possibility to explore azimuthal variations of E_{max}!





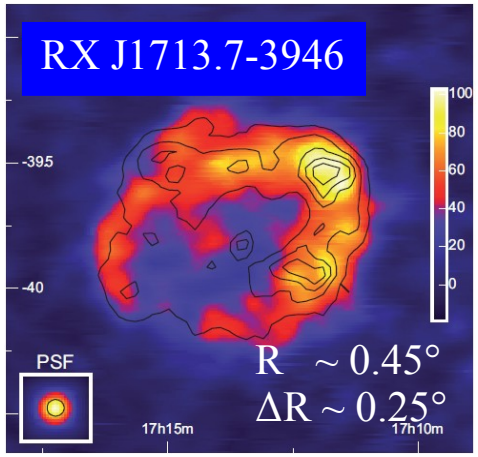


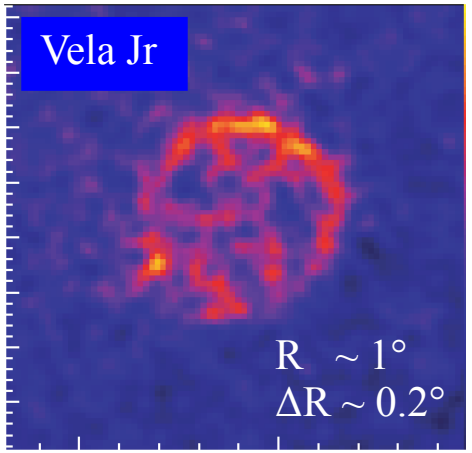


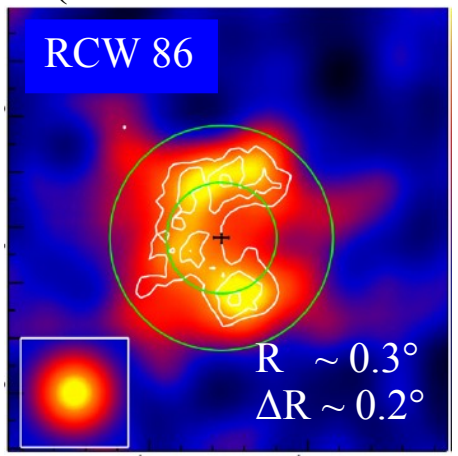
Shell-type SNRs as seen with CTA

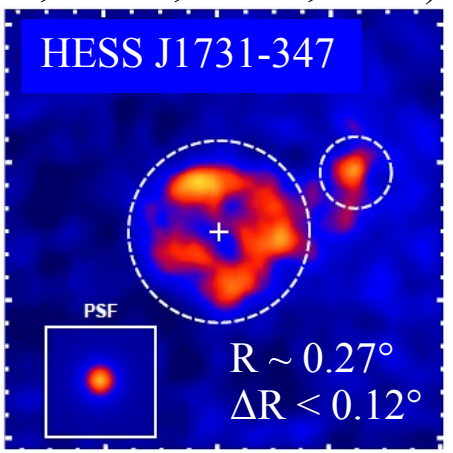
Population studies

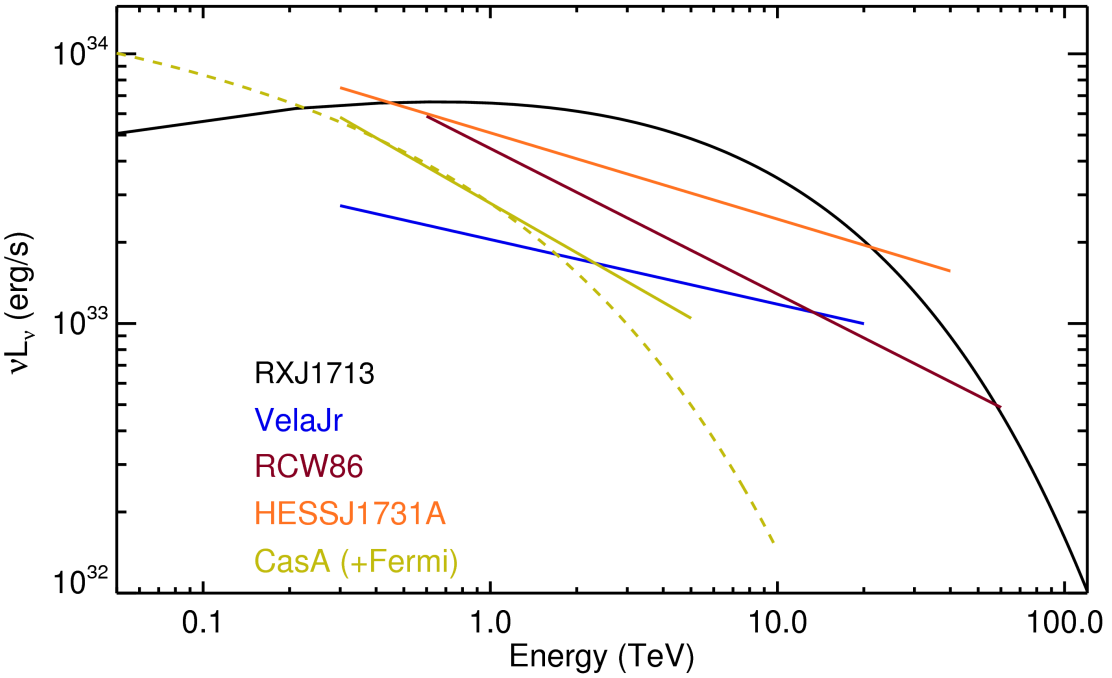
(Aharonian et al. 2006 ; 2007 ; 2009 ; 2011)











CTA simulations of RX J1713-, Vela Jr-, RCW86-, HESS J1731-like SNRs with their respective spectral and morphological properties as measured with H.E.S.S.

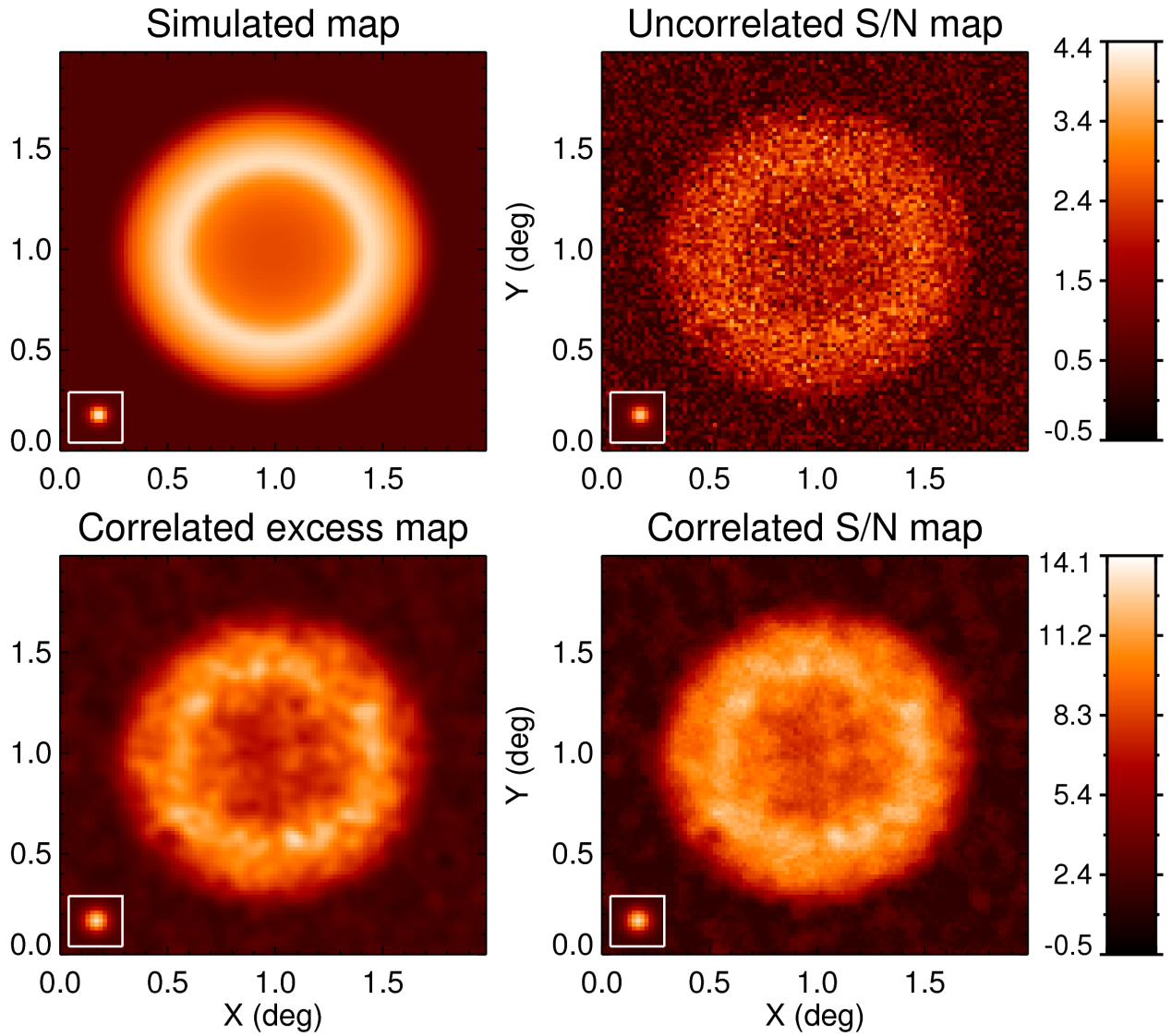
Horizons of :

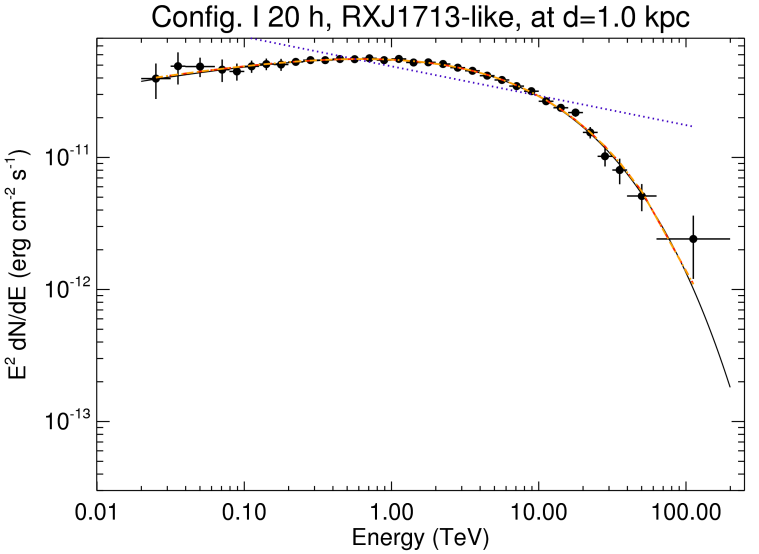
Detectability → d / S/N = 5σ

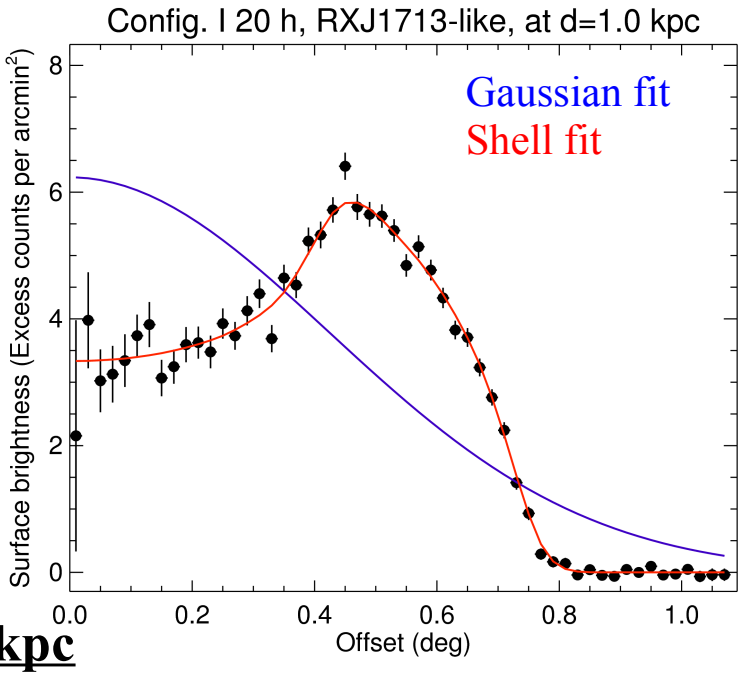
Resolvability → d / Shell favored over Gaussian fit

Shell-type SNRs as seen with CTA

Population studies



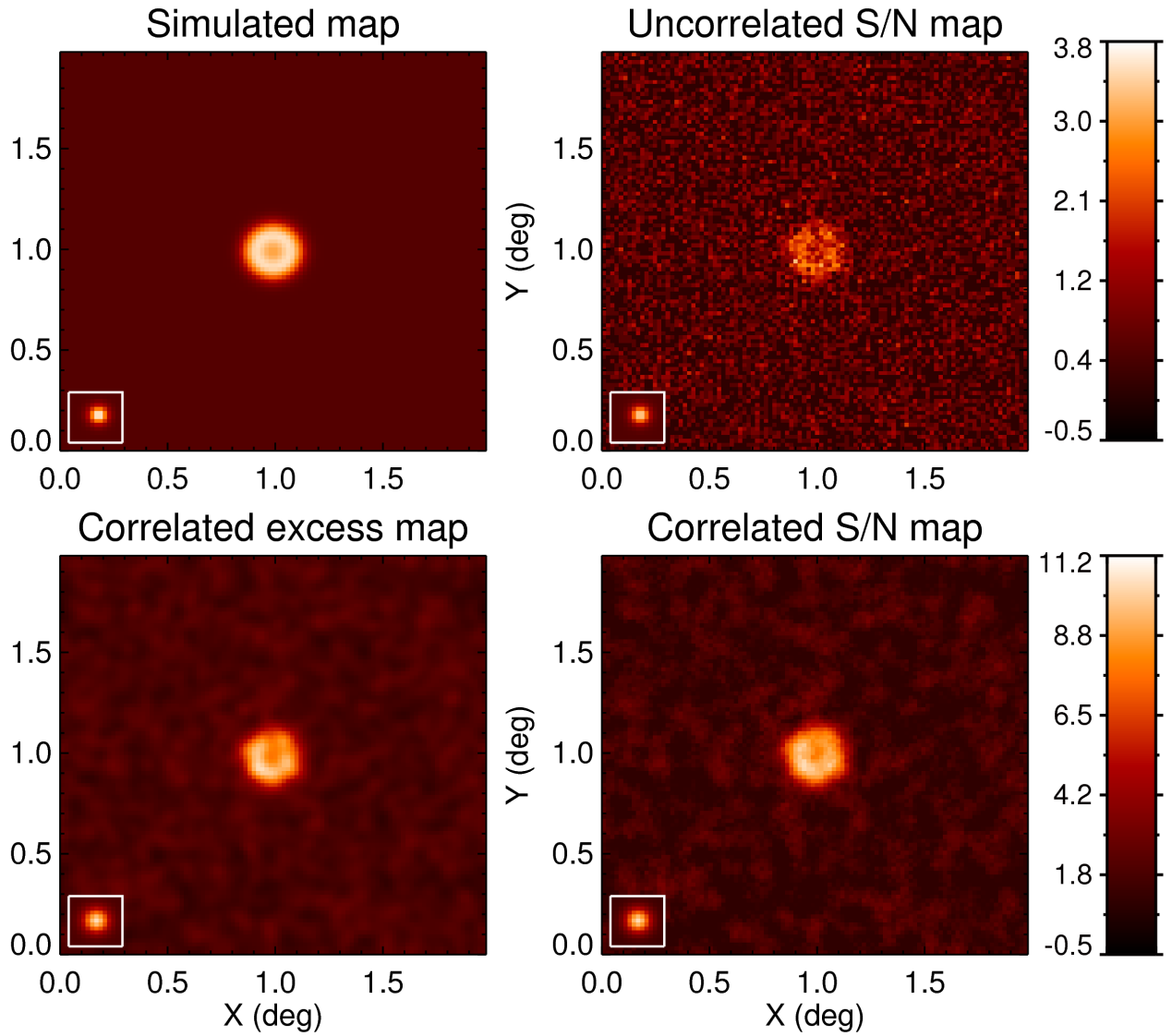


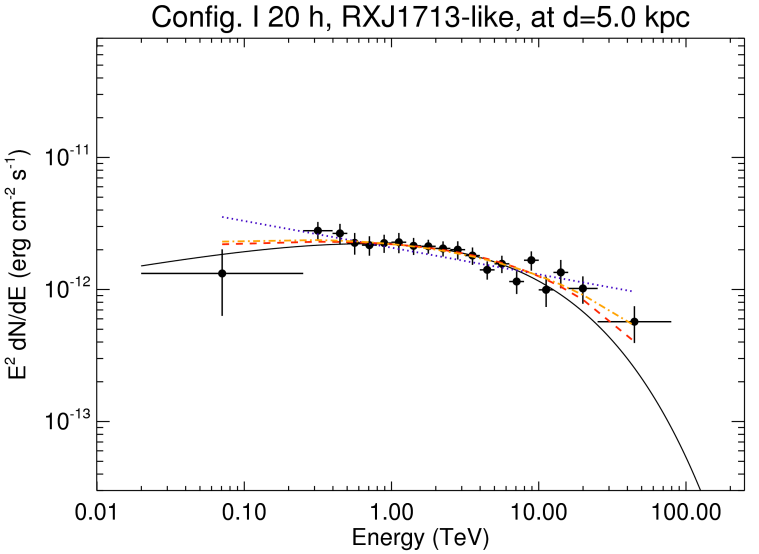


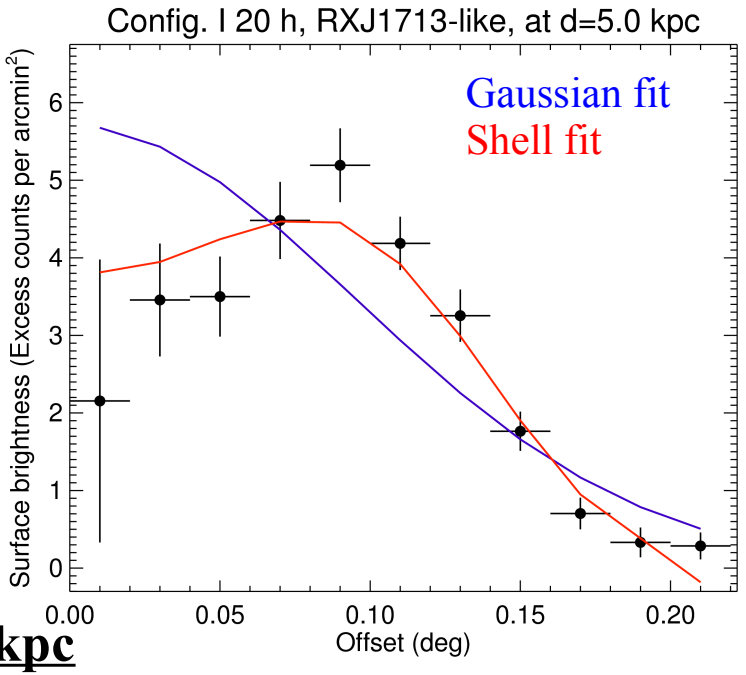
RX J1713-like SNR at 1 kpc

Shell-type SNRs as seen with CTA

Population studies



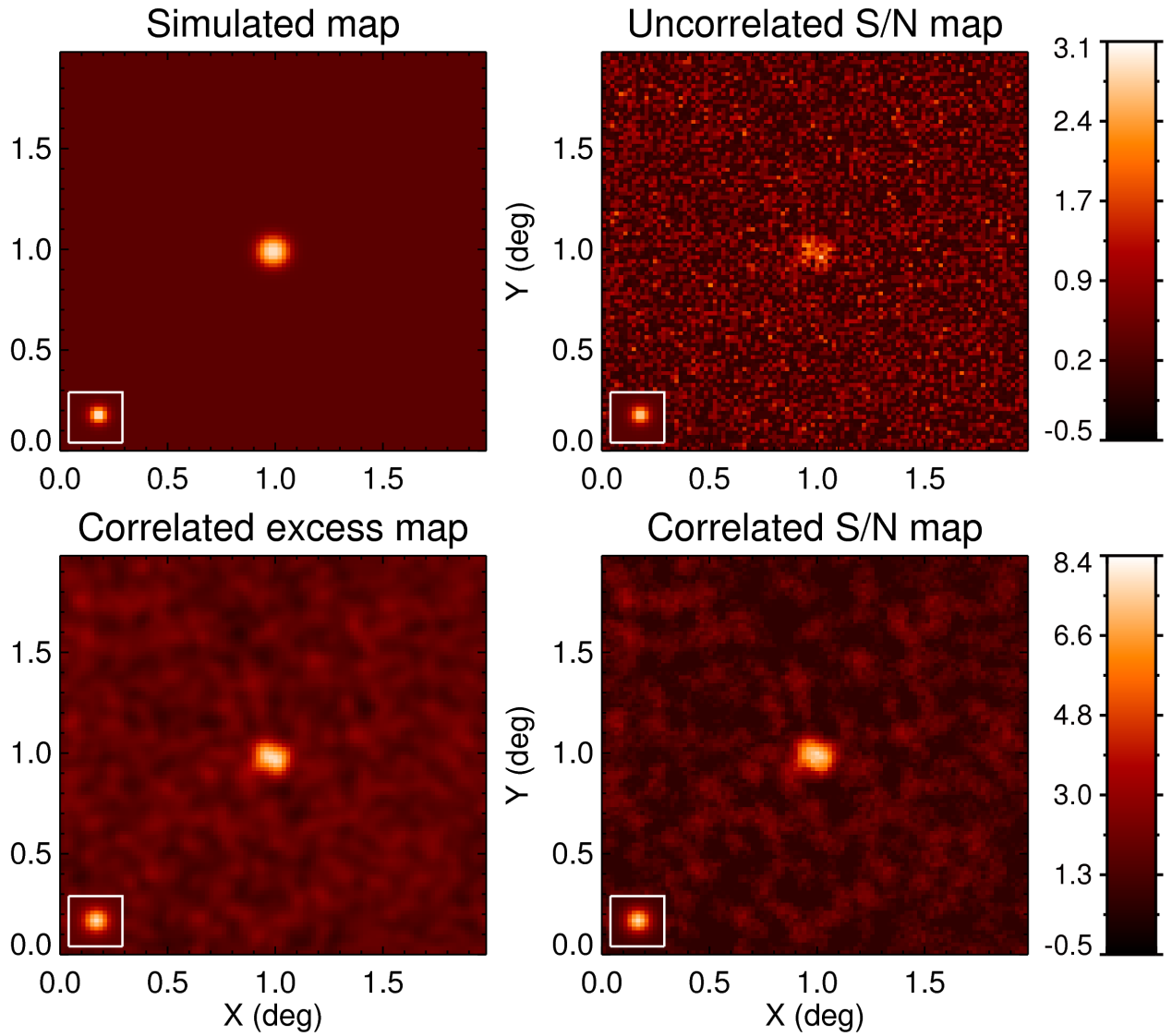


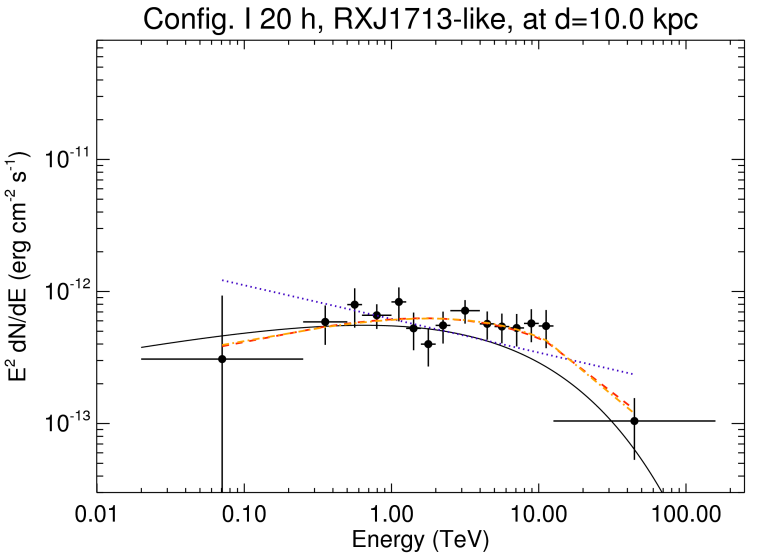


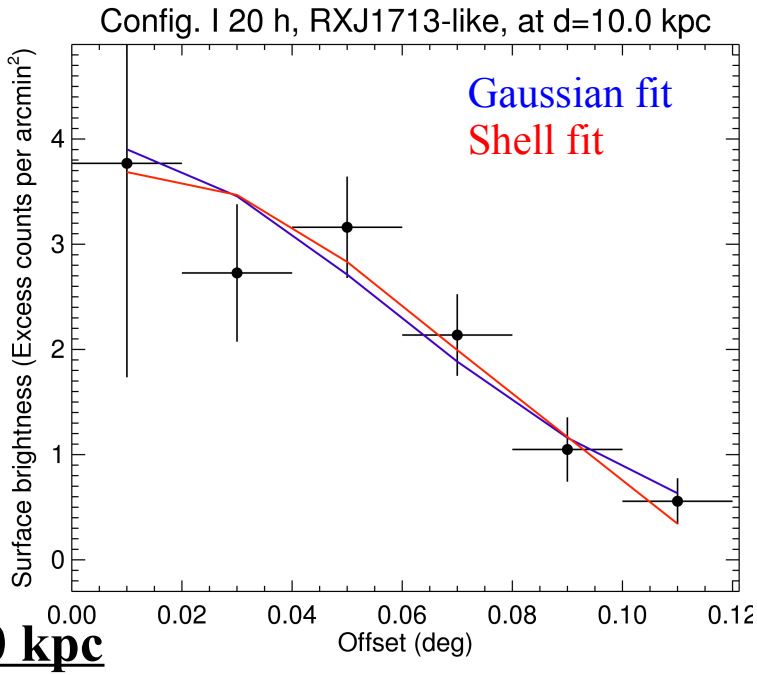
RX J1713-like SNR at 5 kpc

Shell-type SNRs as seen with CTA

Population studies







RX J1713-like SNR at 10 kpc

Shell-type SNRs as seen with CTA

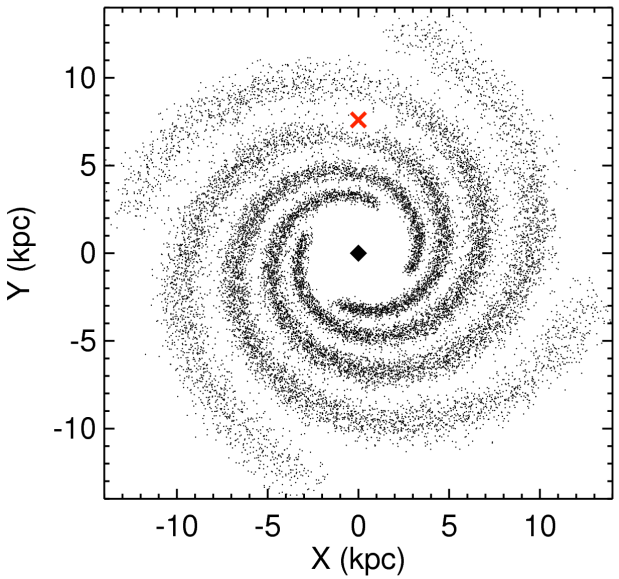
Population studies

Simulate Galactic (core-collapse) SNR distribution :

Assume R_{gal} distribution of Case & Bhattacharya (1998)

Concentrated around spiral arms as given by Vallée (2008), but see Dame & Thaddeus (2011)

With arm dispersion as in dust model of Drimmel & Spergel (2001)



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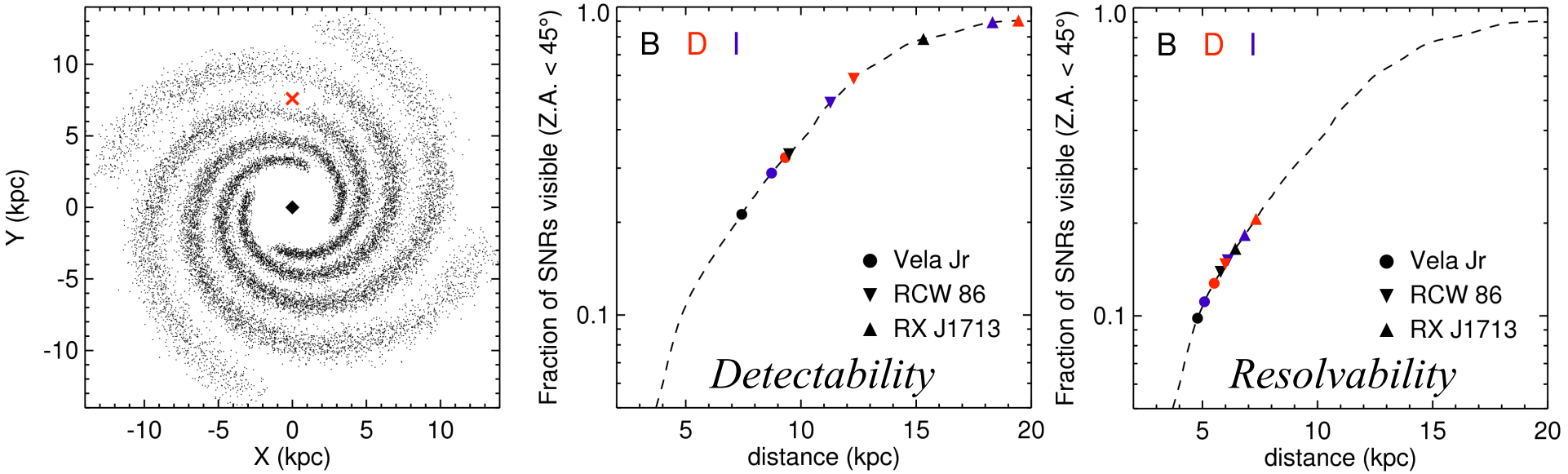


If all SNRs shine ~3000 yr in TeV → ~60 TeV shells !

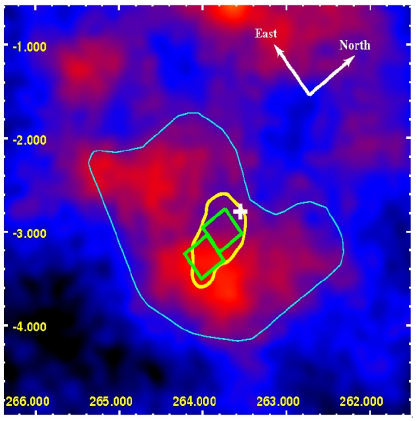
~20–55 would be detectable but only ~ **7–12** would be resolvable with CTA-**I**

More distant shells identified with MWL follow-up observations

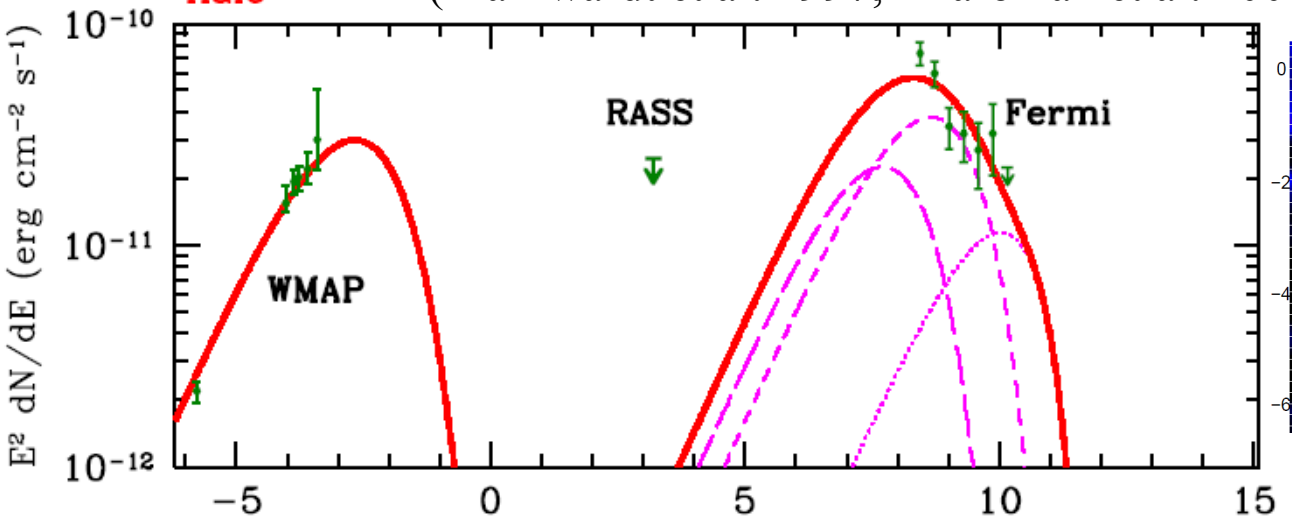
If CTA PSF improved by a factor of 2 → almost 2× more resolvable SNRs!

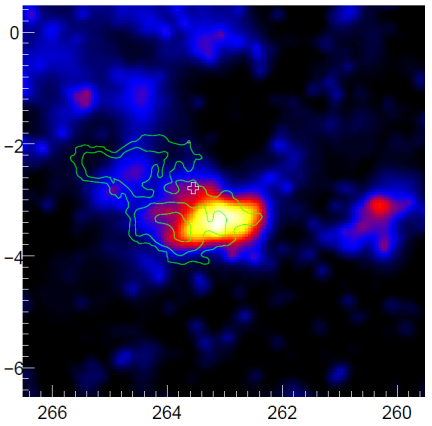
Seeking the CR *leptonic* sources

(Markwardt et al. 1997, Aharonian et al. 2006, Abdo et al. 2010)



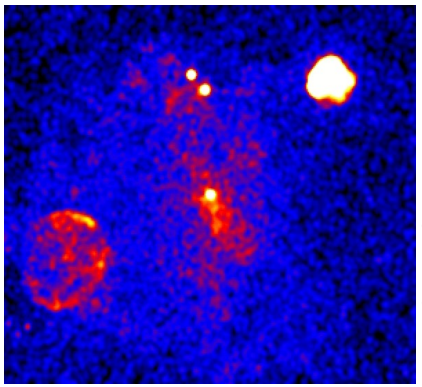
WMAP



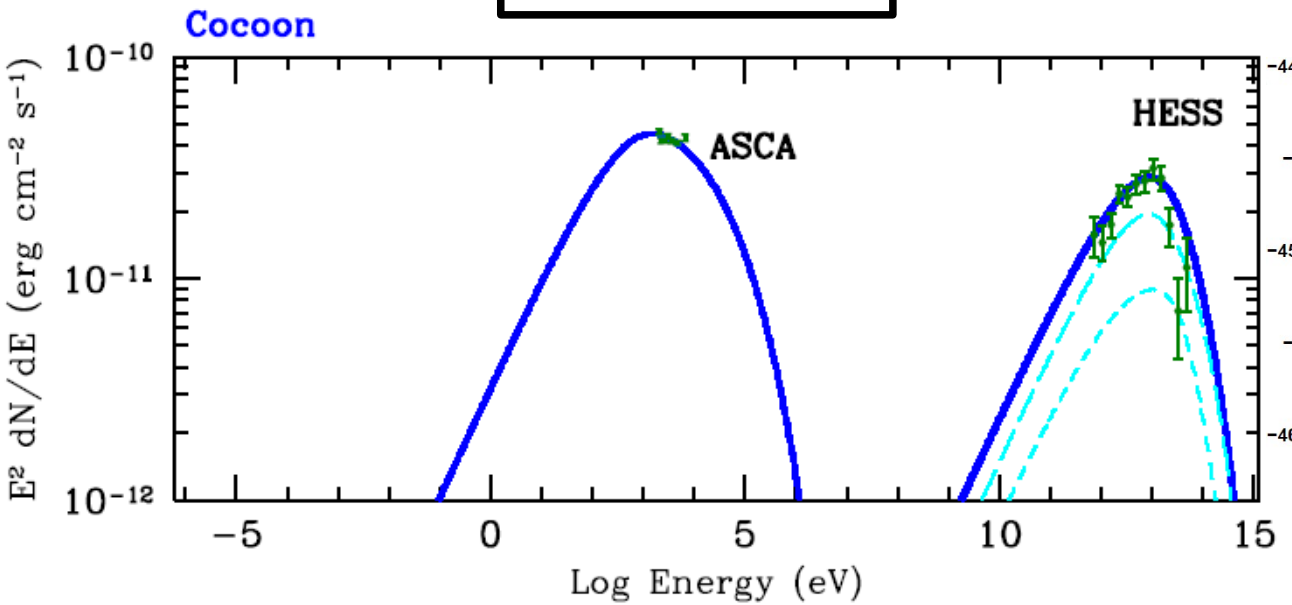


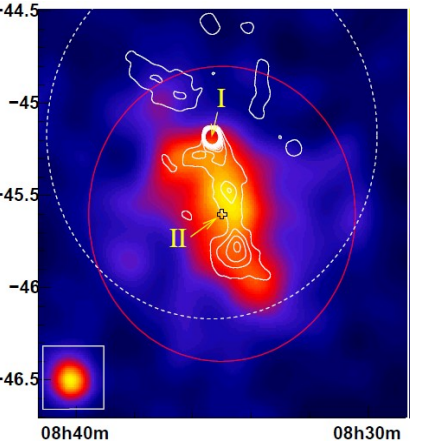
Fermi/LAT

Vela X - cocoon



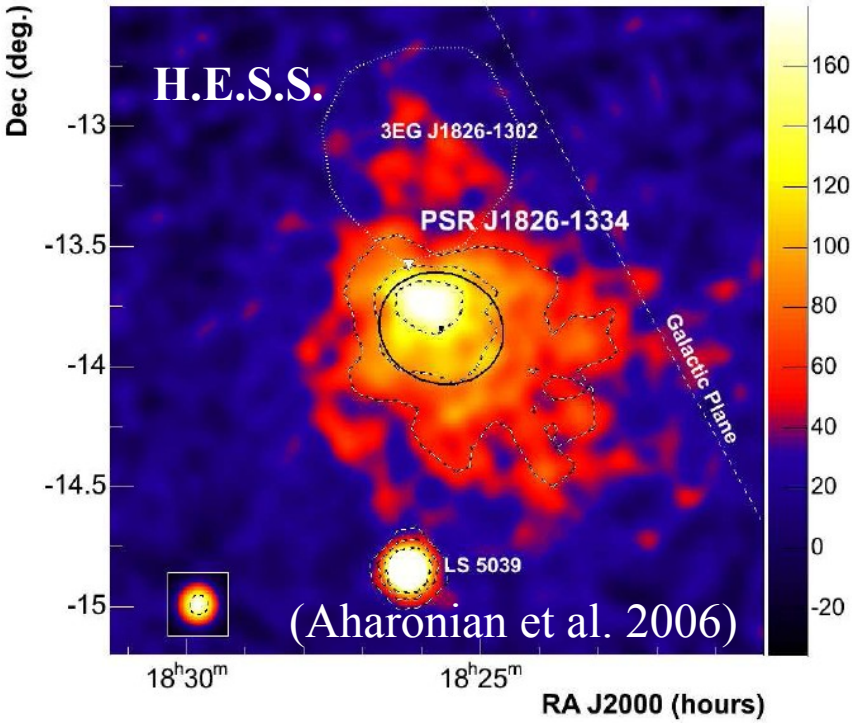
ROSAT

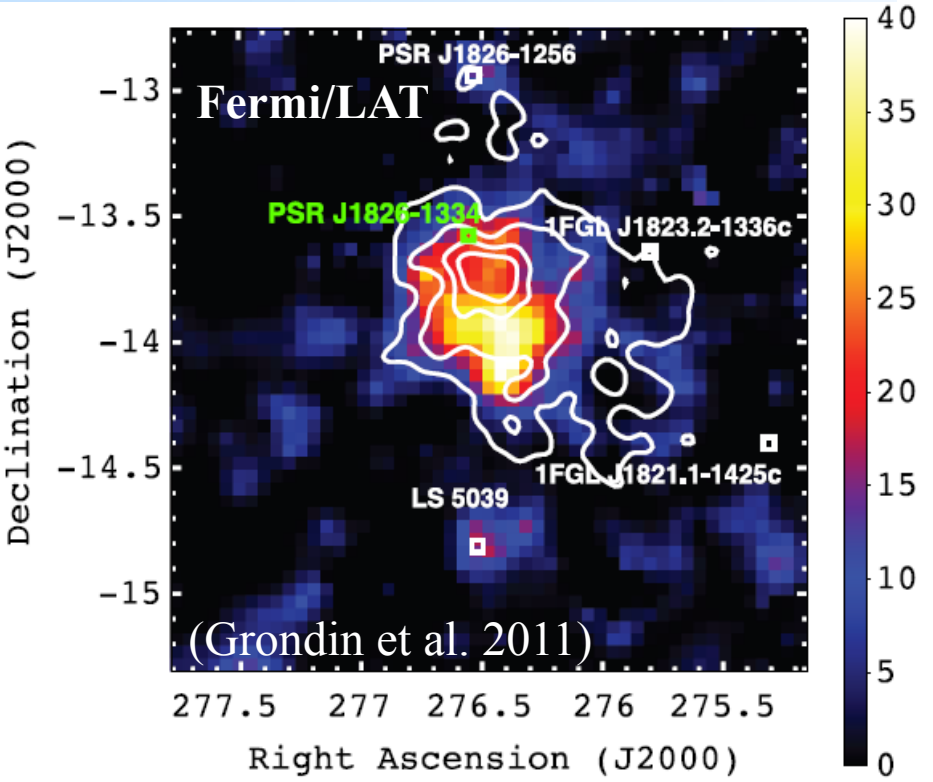


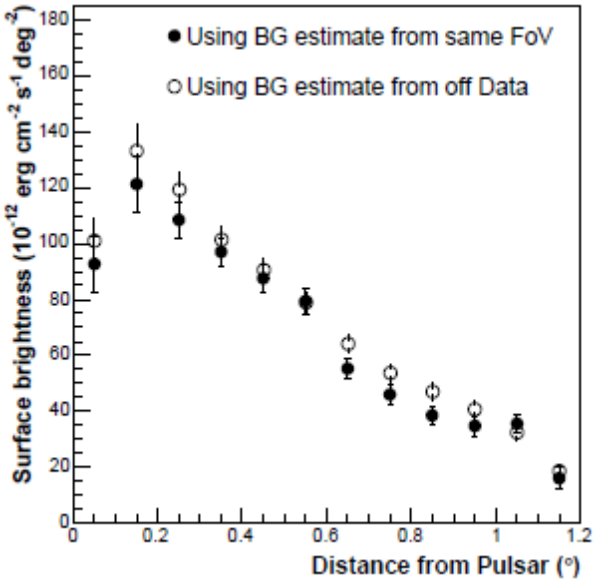


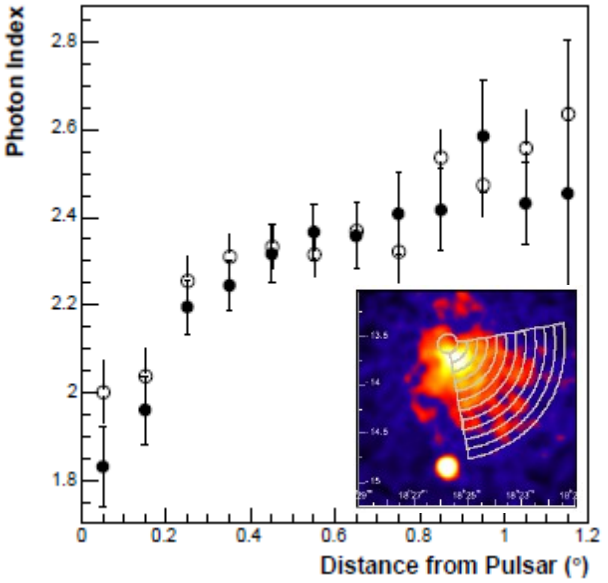
HESS

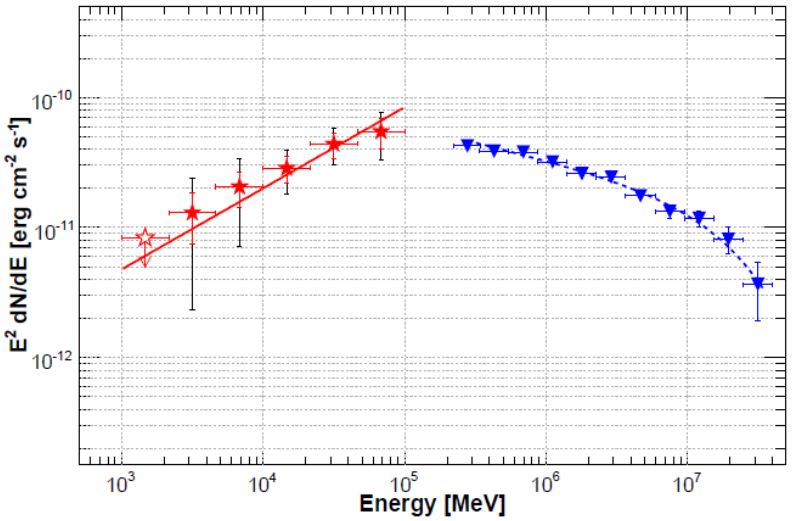
PWNe as seen with CTA



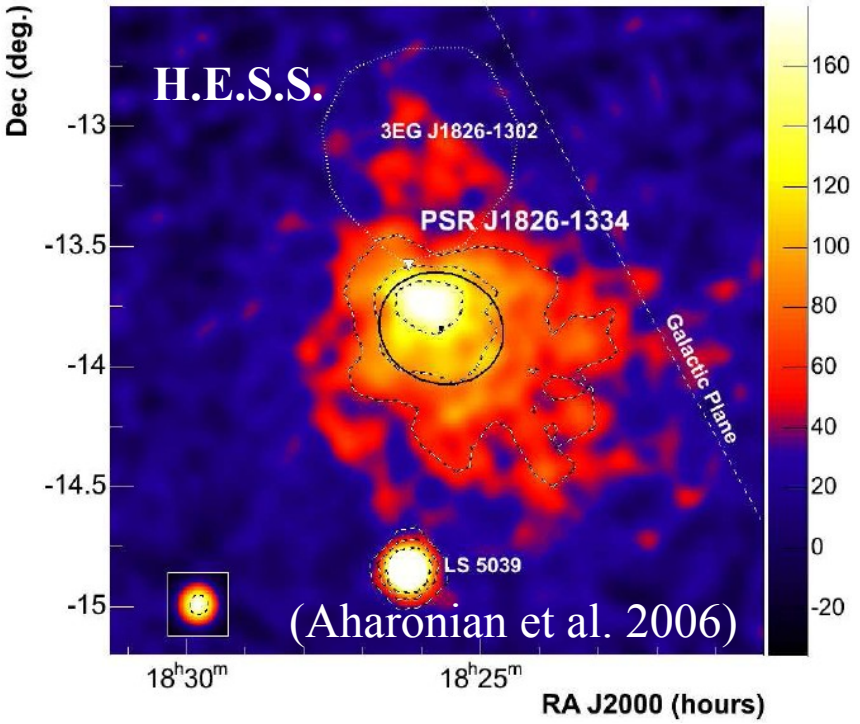


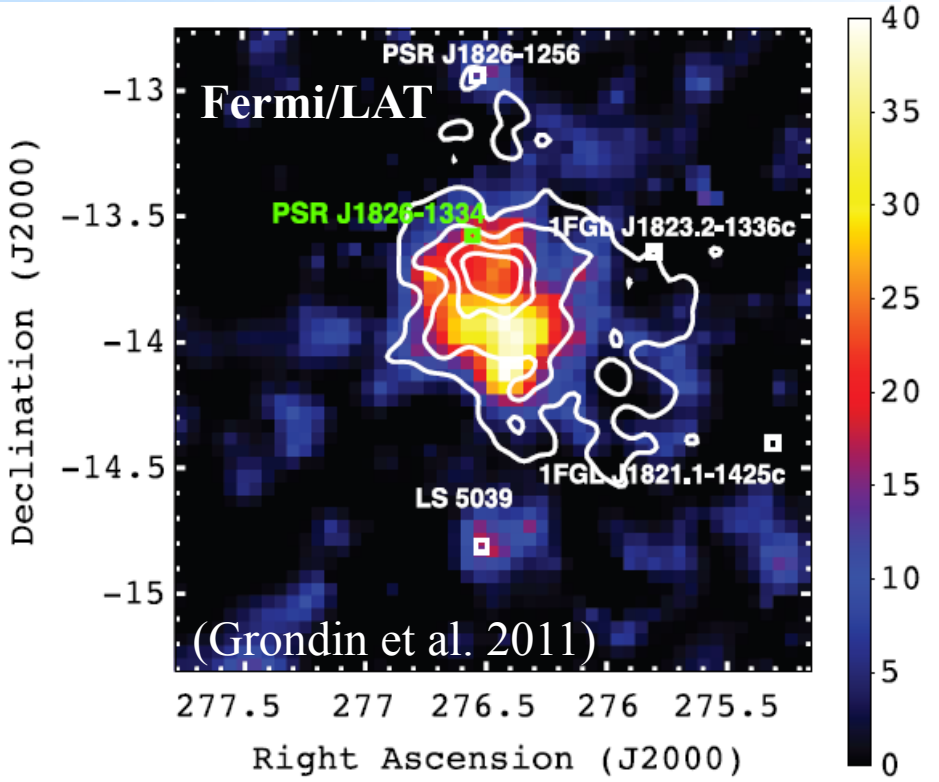


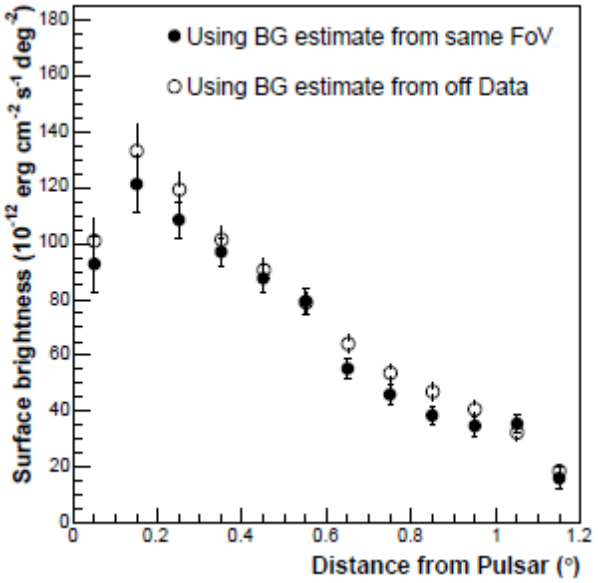


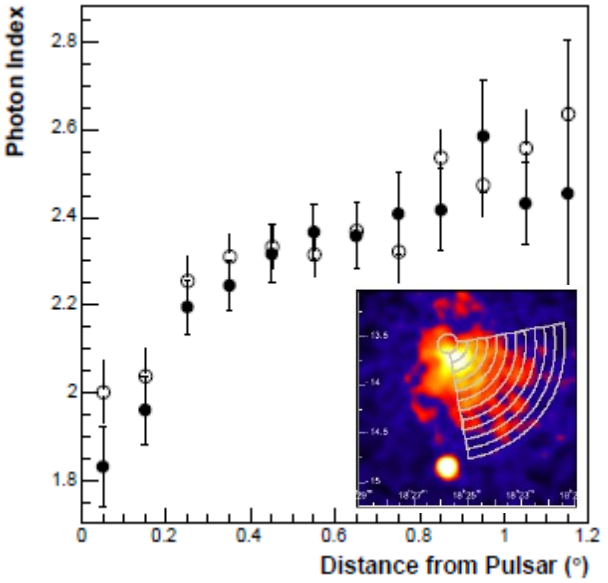


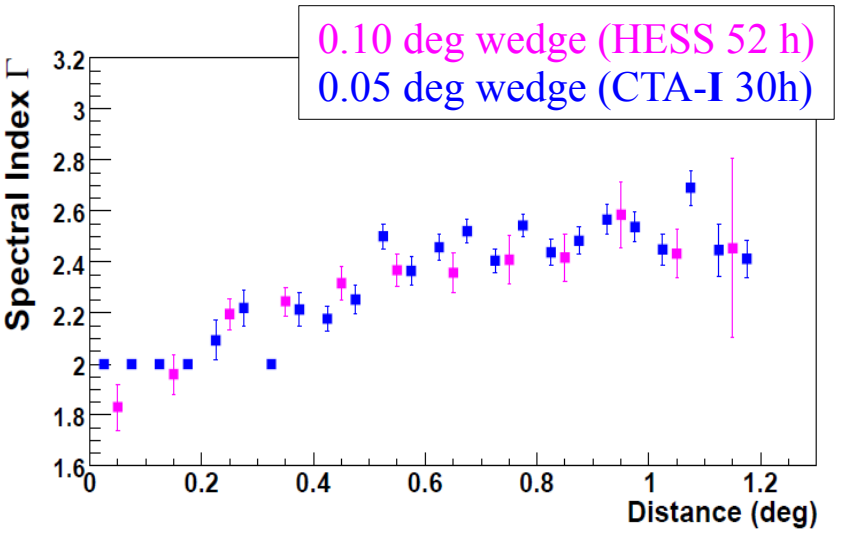
PWNe as seen with CTA











PWNe as seen with CTA

PWNe with Crab luminosity detectable (in 50h, 5σ) up to :

CTA-**B** (E > 205 GeV) → d = 54 kpc
CTA-**D** (E > 600 GeV) → d = 57 kpc
CTA-**I** (E > 250 GeV) → d = 53 kpc

⇨ Crab-like PWNe in the LMC !
(HESS detection of the composite SNR N 157B/PSR J05367-6910, Komin et al. 2010)

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⇒ Crab-like PWNe in the LMC !
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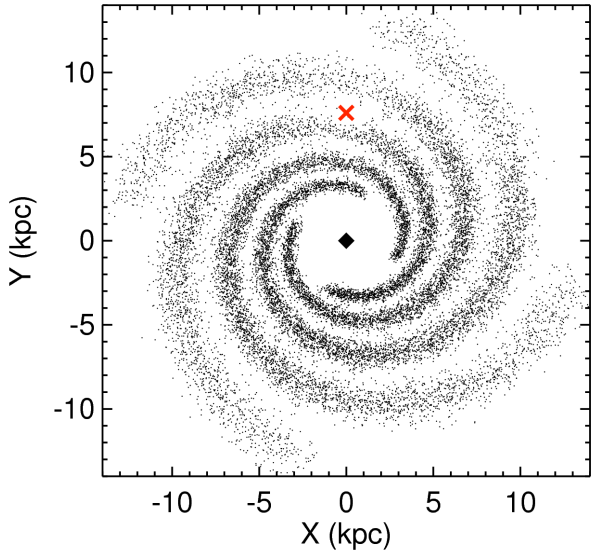
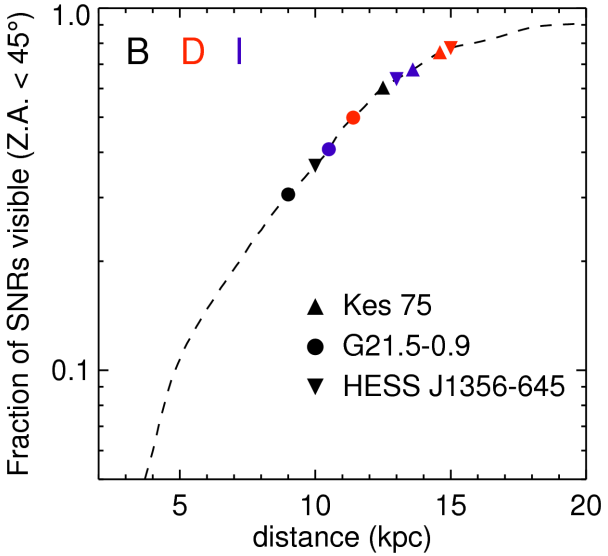
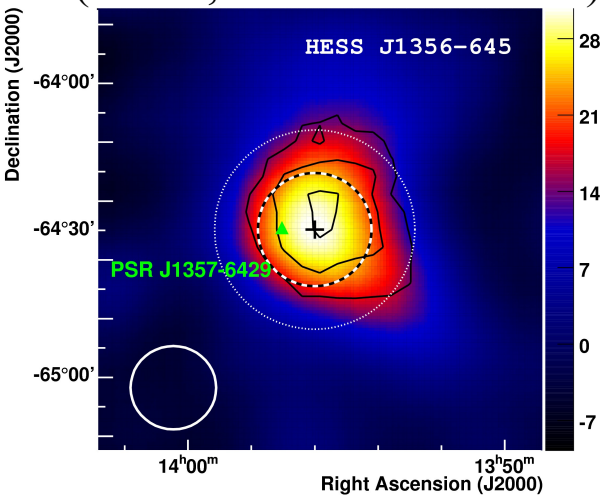
Population of fainter TeV PWNe ($L_{0.3\text{-}30TeV} \sim 10^{34}$ erg s^{-1}) :

Simulate Galactic (core-collapse) SNR distribution (as before)
Ignore displacement from pulsar birth place due to kick velocity





(HESS, submitted to A&A)



Fainter PWNe detectable to 10 – 15 kpc (depending on object, configuration)
$\tau_{\text{TeV-emitting leptons}} \sim 40$ kyr (B=3 μG, de Jager & Djannati-Ataï 2009), total of **~200-400** PWNe!

Conclusion & Perspectives

Precise TeV spectra of shell-type SNRs in order to discriminate between hadronic and leptonic emission, especially in the *cutoff region*

Spectro-imaging analysis (X-ray/TeV correlation studies & spatially-resolved TeV spectra) of the brightest SNRs (e.g. RX J1713.7-3946)

SNR/MC associations in order to constrain the properties of *CR propagation* in the vicinity of CR sources (& «passive» MCs as CR barometers → CR distribution)

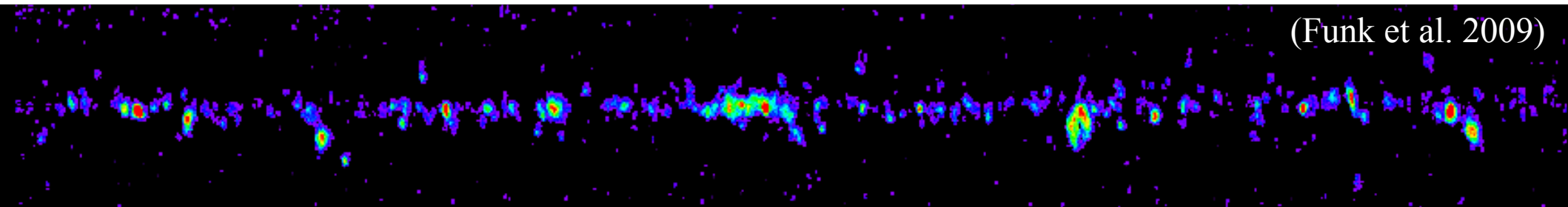
SNRs = CR *hadronic* sources? → Population studies & importance of the PSF to measure shell morphology & to mitigate source confusion along the Galactic Plane

---

Aging of particules in evolved PWNe (e.g. HESS J1825-137). May be used to shed light on the unclassified (so-called «dark») sources

Crab-like PWNe in the LMC

PWNe = CR *leptonic* sources ? → Population studies with ~200-400 evolved PWNe & importance of the PSF to mitigate source confusion along the Galactic Plane!



Highlights in TeV astronomy

Results from HESS, MAGIC and VERITAS

Adapted from J. Hinton

Pulsars : Science 322, 1221 (2008)

Supernova Remnants : Nature 432, 75 (2004)

The Galactic Center : Nature 439, 695 (2006)

Galactic Survey : Science 307, 1938 (2005)

Starburst Galaxies : Nature 462, 770 (2009), Science 326, 1080 (2009)

Microquasars : Science 309, 746 (2005), Science 312, 1771 (2006)

AGNs : Science 314, 1424 (2006), Science 325, 444 (2009)

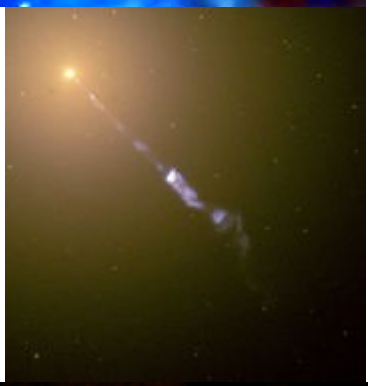
EBL : Nature 440, 1018 (2006), Science 320, 752 (2008)

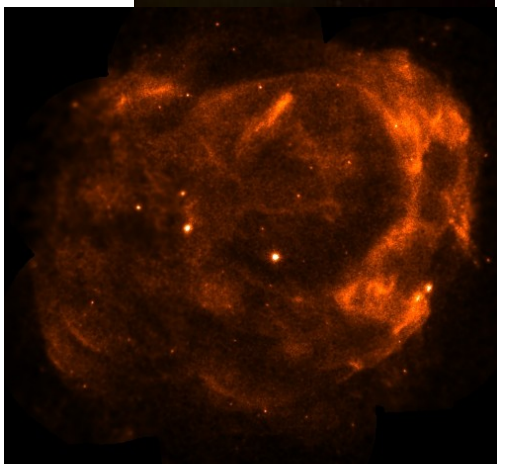
Dark Matter : Phys Rev Letters 97, 221102 (2006)

Lorentz Invariance : Phys Rev Letters 101, 170402 (2008)

Cosmic-ray Electrons : Phys Rev Letters 101, 261104 (2008)

Cosmic-ray Iron Nuclei : Phys Rev D 75, 042004 (2007)

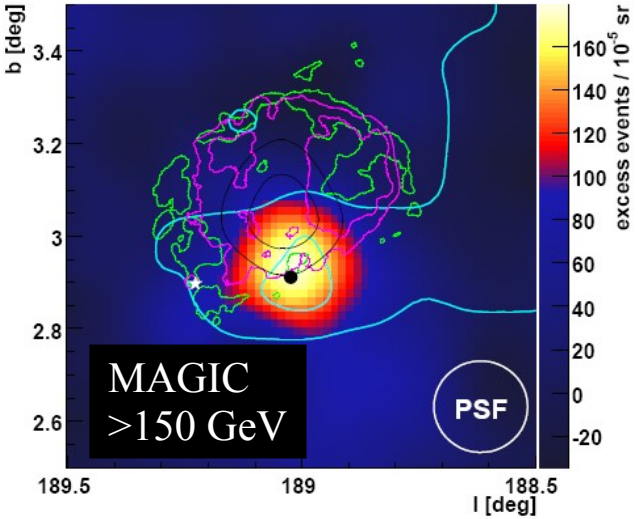


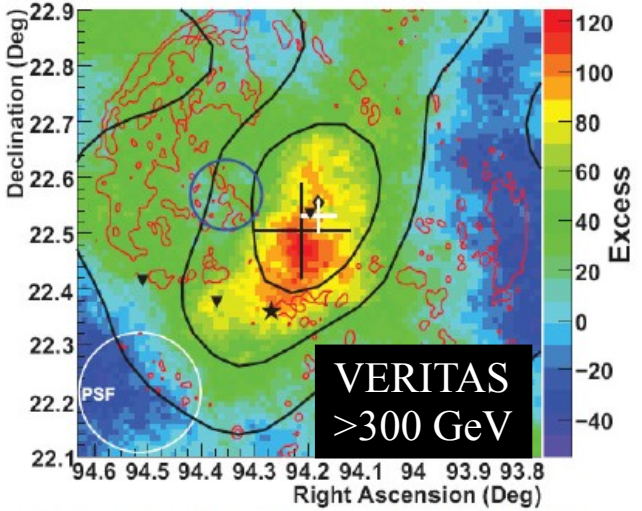


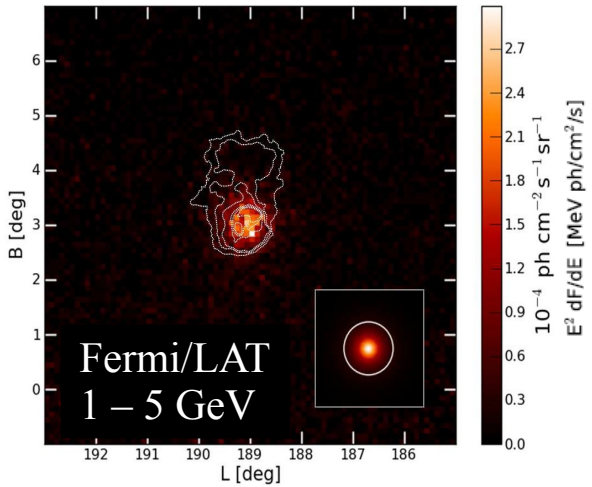
Shell-type SNRs as seen with CTA

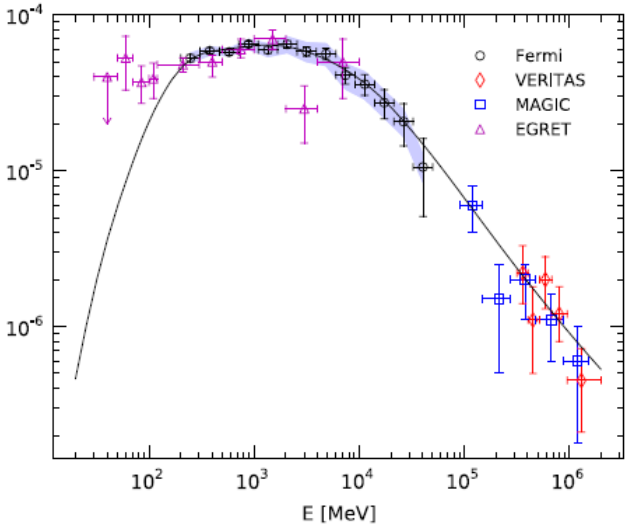
IC443 TeV spectra

(Albert et al. 2007, Acciari et al. 2009, Abdo et al. 2010)

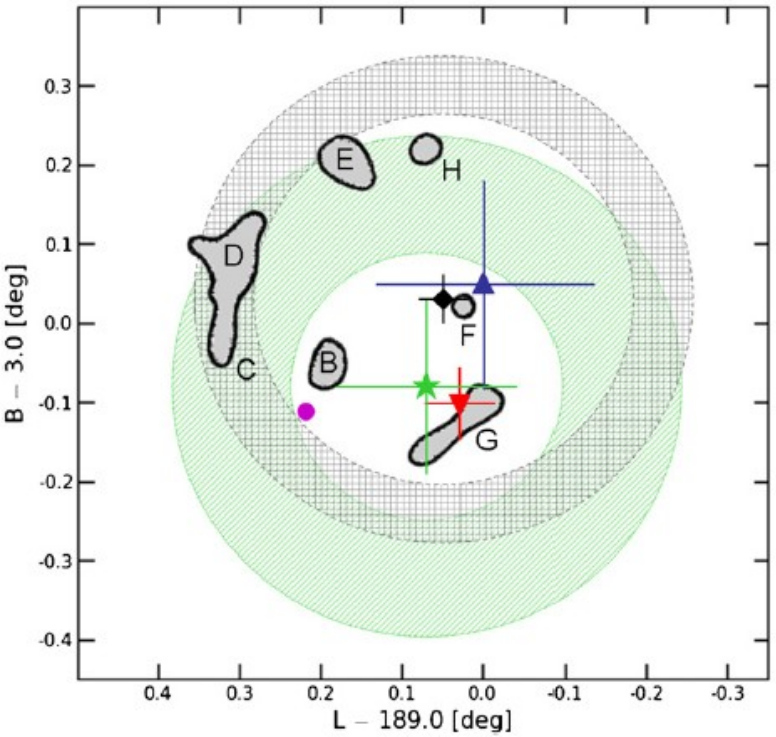








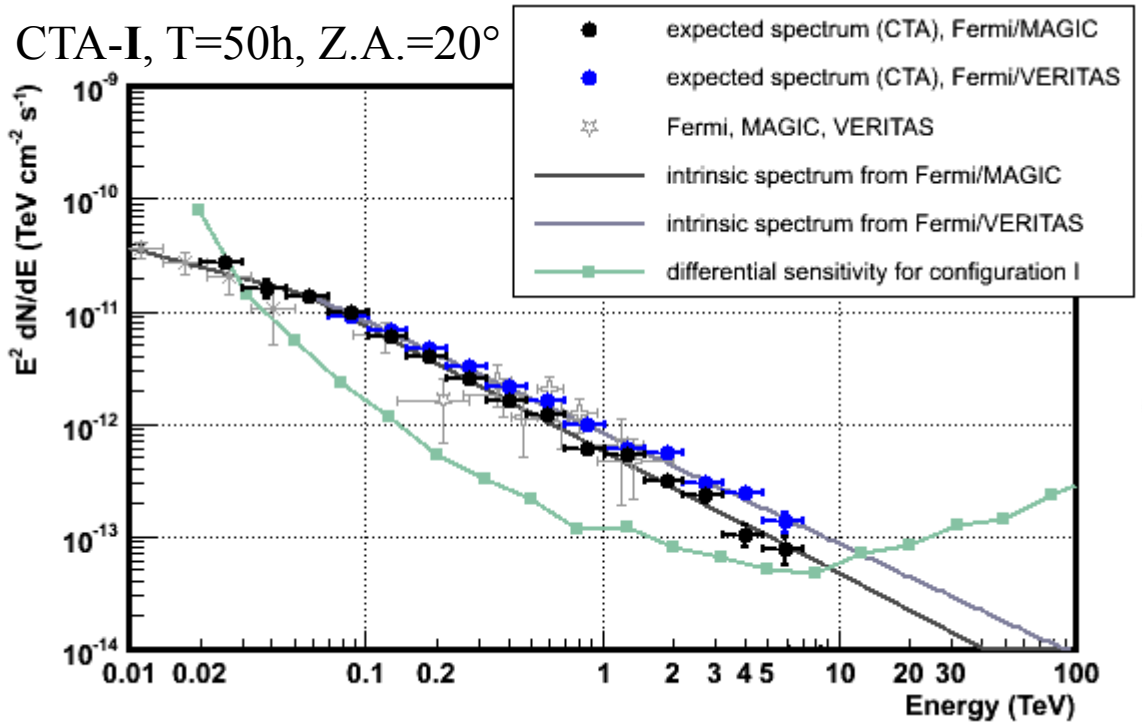
^{12}CO emission
PWN CXOU J061705.3+222127
EGRET, Fermi/LAT,
MAGIC, VERITAS
[1720 MHz OH masers]

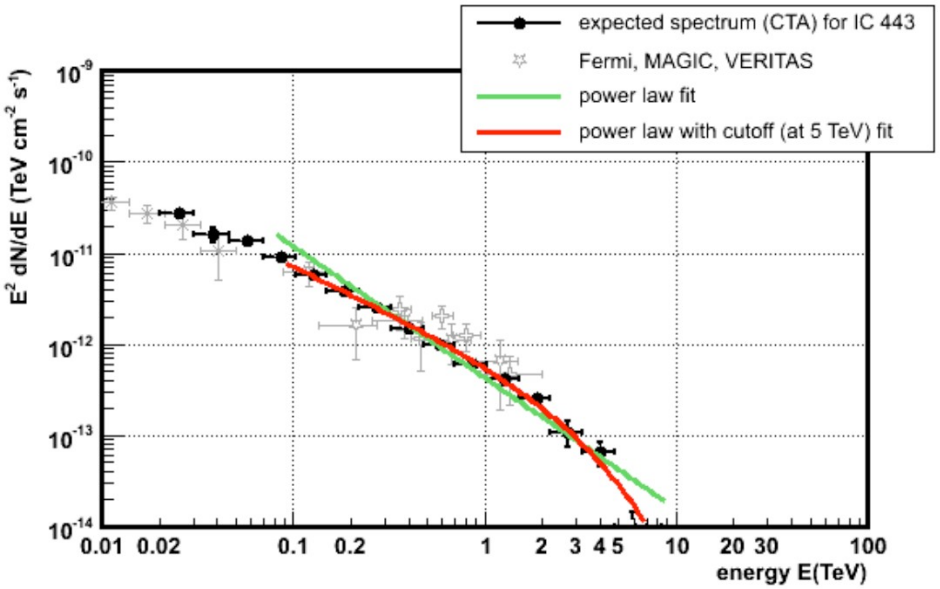


Shell-type SNRs as seen with CTA

IC443 TeV spectra

CTA-**I**, T=50h, Z.A.=20°



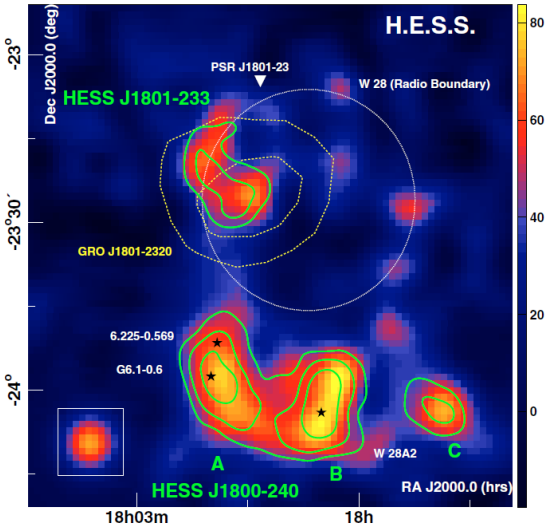


Broken power-law from Fermi/LAT – MAGIC/VERITAS spectra well constrained with CTA : $\sigma_{\Gamma,\ \text{high E}} = 0.03$, for T > 20h

Any cutoff will be measured significantly in 20–30 h, if $E_{cut} < 5$ TeV

Shell-type SNRs as seen with CTA

SNR/MC association



(Aharonian et al. 2008)

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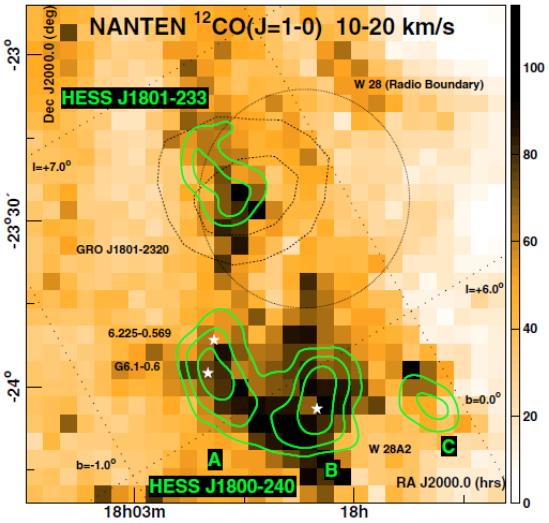

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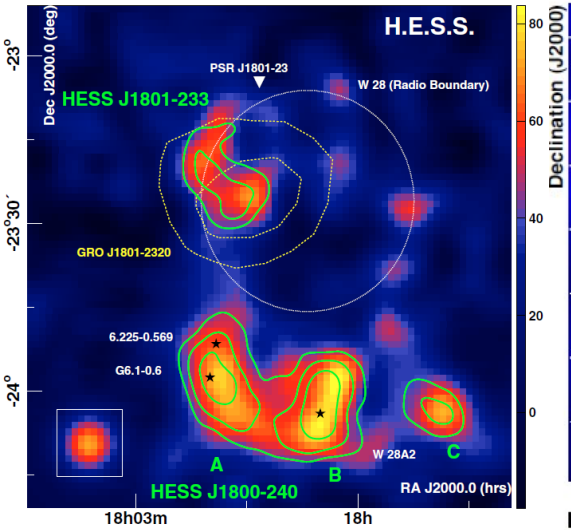
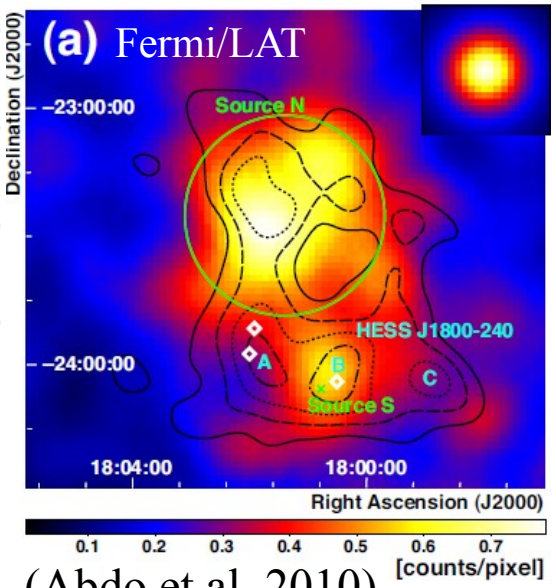
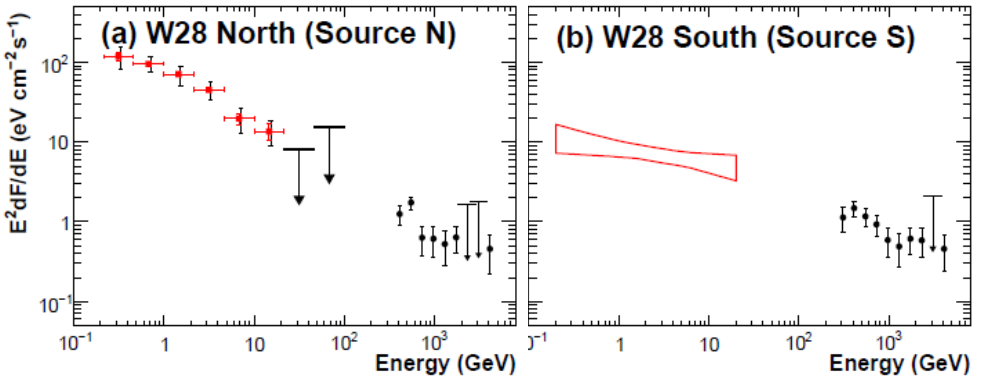


(Aharonian et al. 2008)

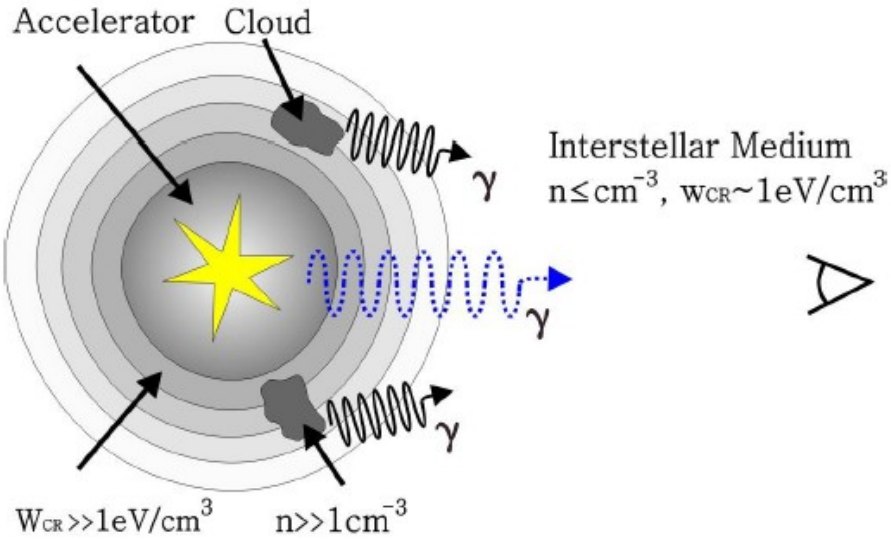


(Abdo et al. 2010)



HESS J1801-233 **(Source N)** on E rim of W28
Coincident with GeV source
Coincident with CO cloud
1720 MHz OH maser : shock/MC interaction

HESS J1800-240B **(Source S)** outside W28
Coincident with GeV source
Coincident with CO cloud & HII region W28A2
MC illuminated by CRs escaping W28...?



Shell-type SNRs as seen with CTA

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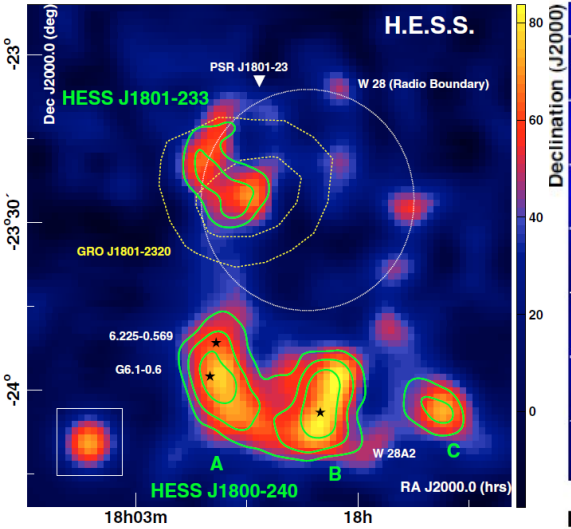
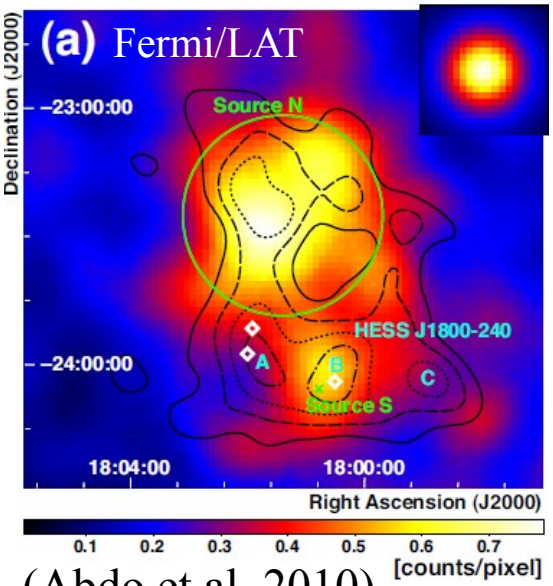
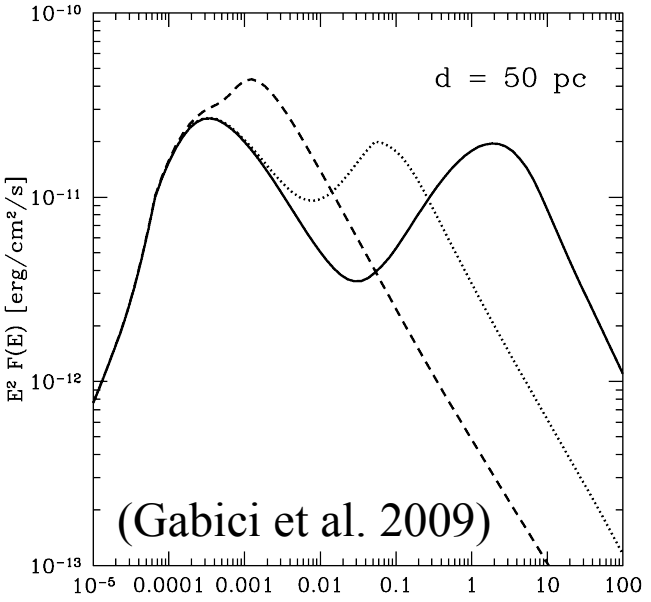


(Aharonian et al. 2008)



(Abdo et al. 2010)



Escaped CRs from a 2×10^3 yr-old SNR lying at 50, 100, 200 pc from a 10^5 M_0 MC at 1 kpc

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Coincident with GeV source
Coincident with CO cloud
1720 MHz OH maser : shock/MC interaction

HESS J1800-240B **(Source S)** outside W28
Coincident with GeV source
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MC illuminated by CRs escaping W28...?