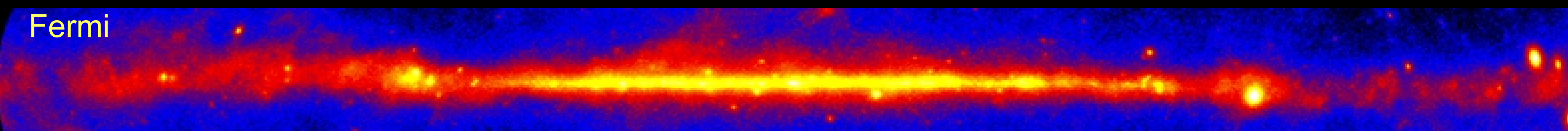
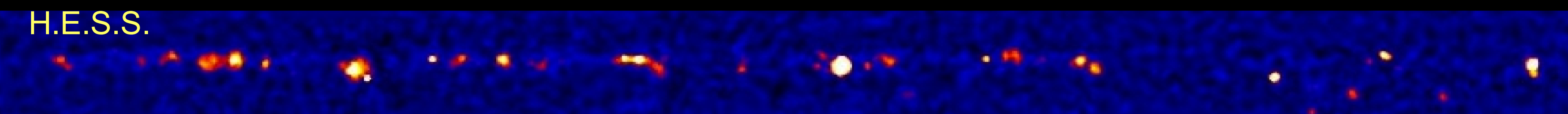
Fermi and H.E.S.S. results on Galactic sources & their link to cosmic rays





Marie-Hélène Grondin
(CENBG, Bordeaux)

on behalf of the Fermi-LAT & H.E.S.S. collaborations

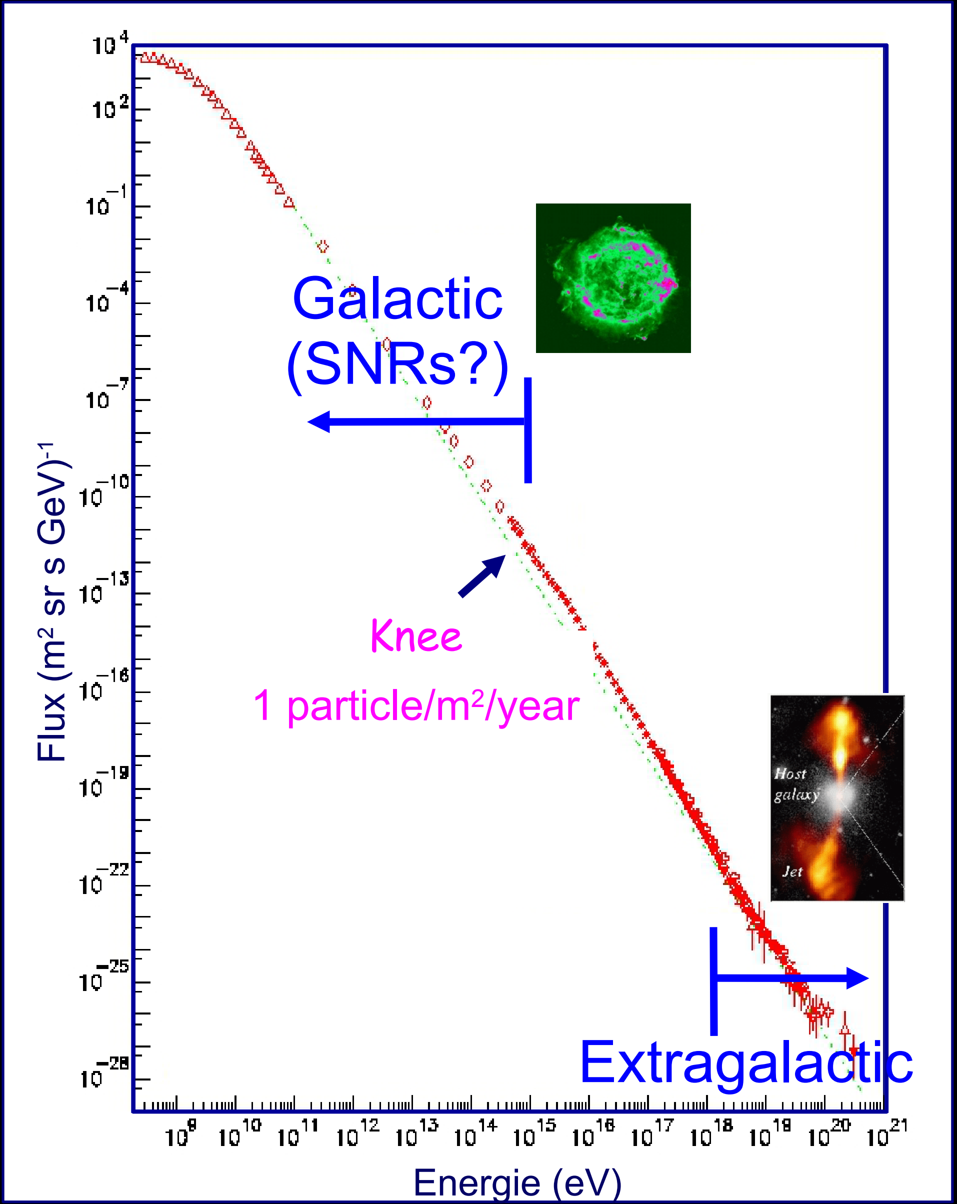
– Multi-messengers Approaches to Cosmic Rays :
Origins and Space frontiers (MACROS 2013) –

– Paris, 2013 November 28th –

The cosmic ray mystery

- Discovered by V. HESS in 1912
- Charged particles : 90% protons
- Spectrum : 30 orders of magnitude in flux, 10 in energy
- Origin : unknown

Galactic sources need to accelerate at least up to the knee !



Where are the Galactic CR accelerators ?

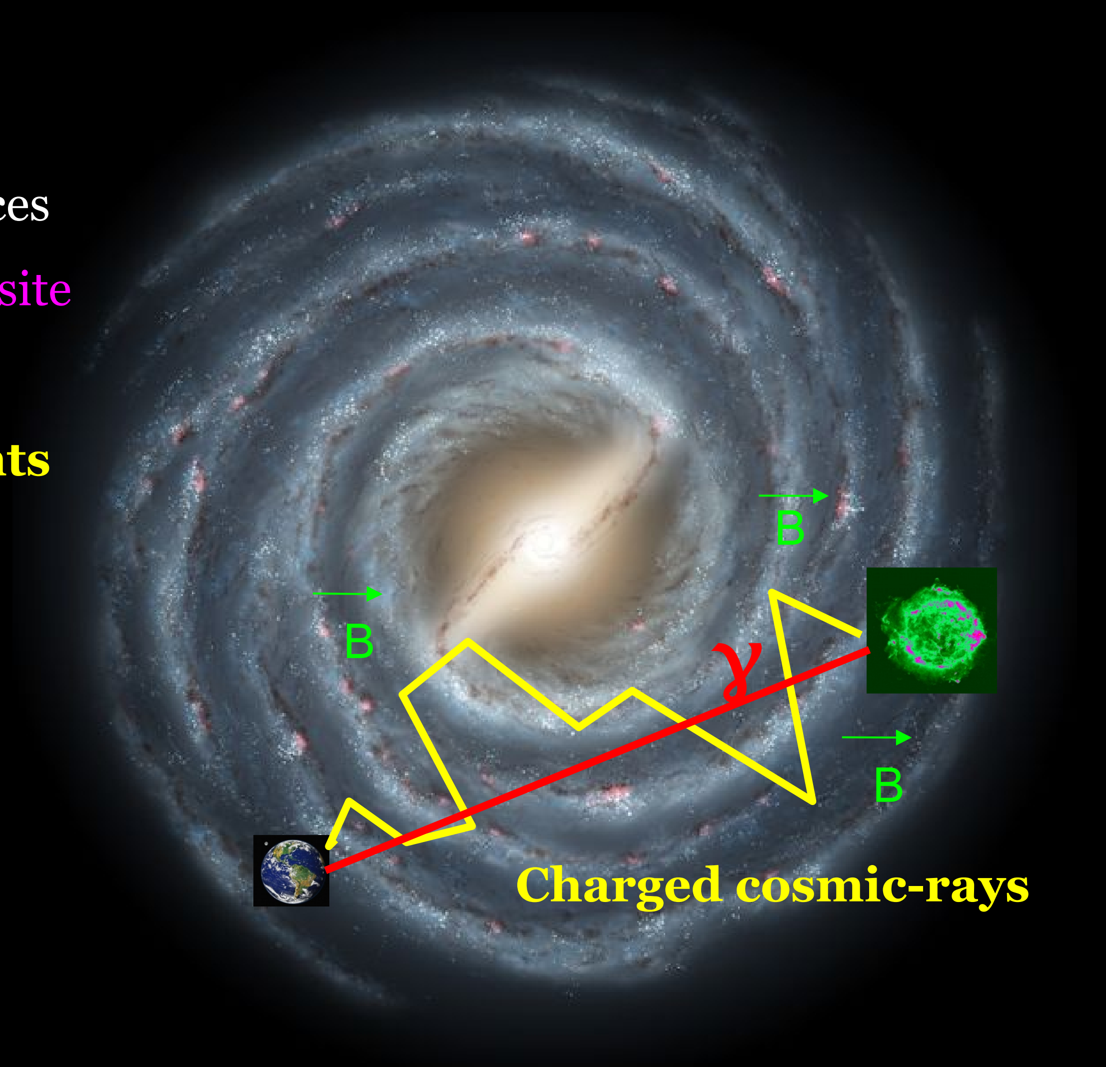
- Cosmic rays (CR): deviated by interstellar electromagnetic fields on their path

  => do not track back to sources

- Gamma rays produced at cosmic-ray sources

  => information on the acceleration site

- **Best candidates : Supernova remnants**

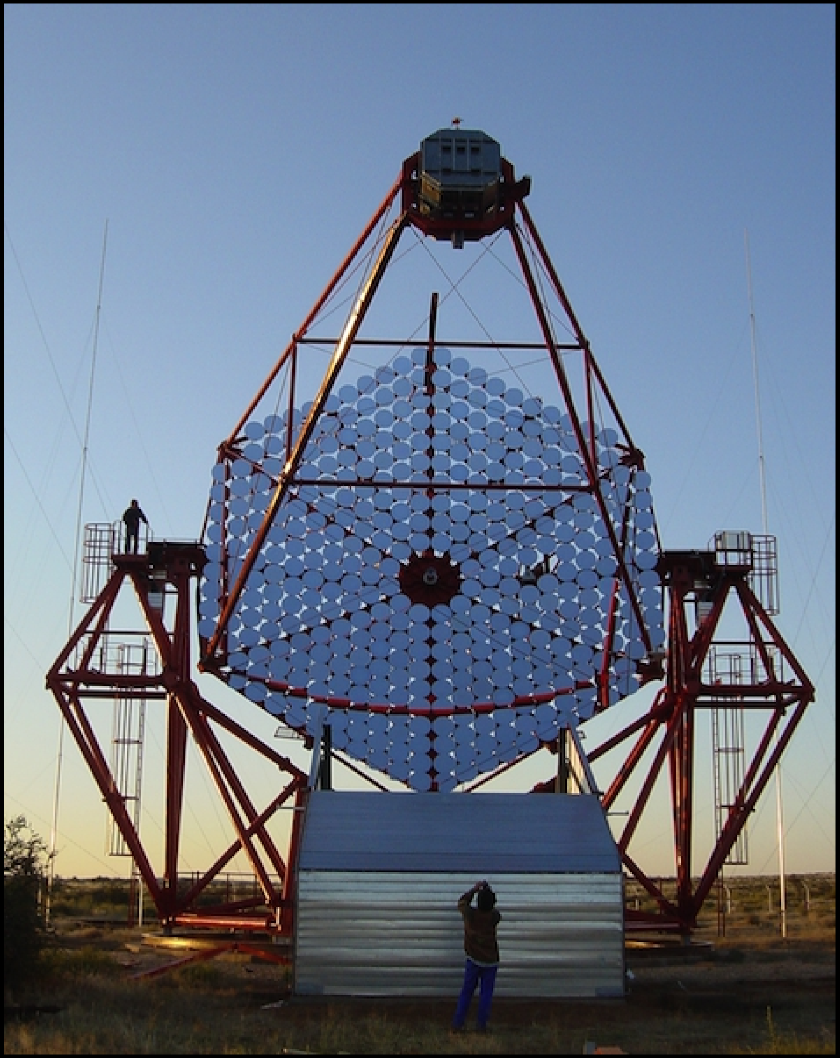


Gamma-ray astronomy : two strategies

Satellites

Fermi
(LAT : 20 MeV – >300 GeV)

Ground-based instruments



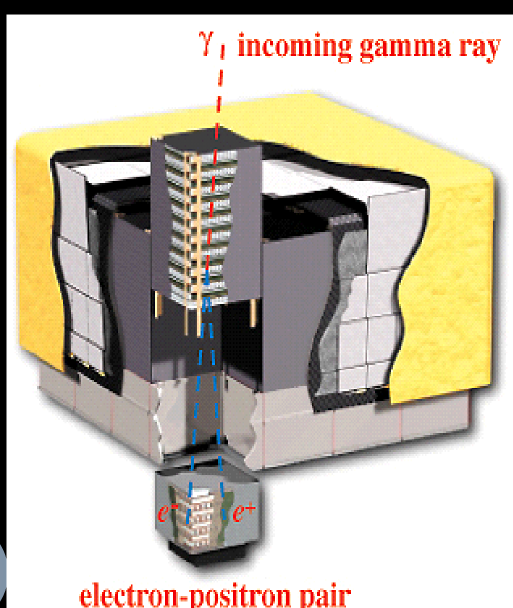
H.E.S.S.
(<100 GeV – ~100 TeV)

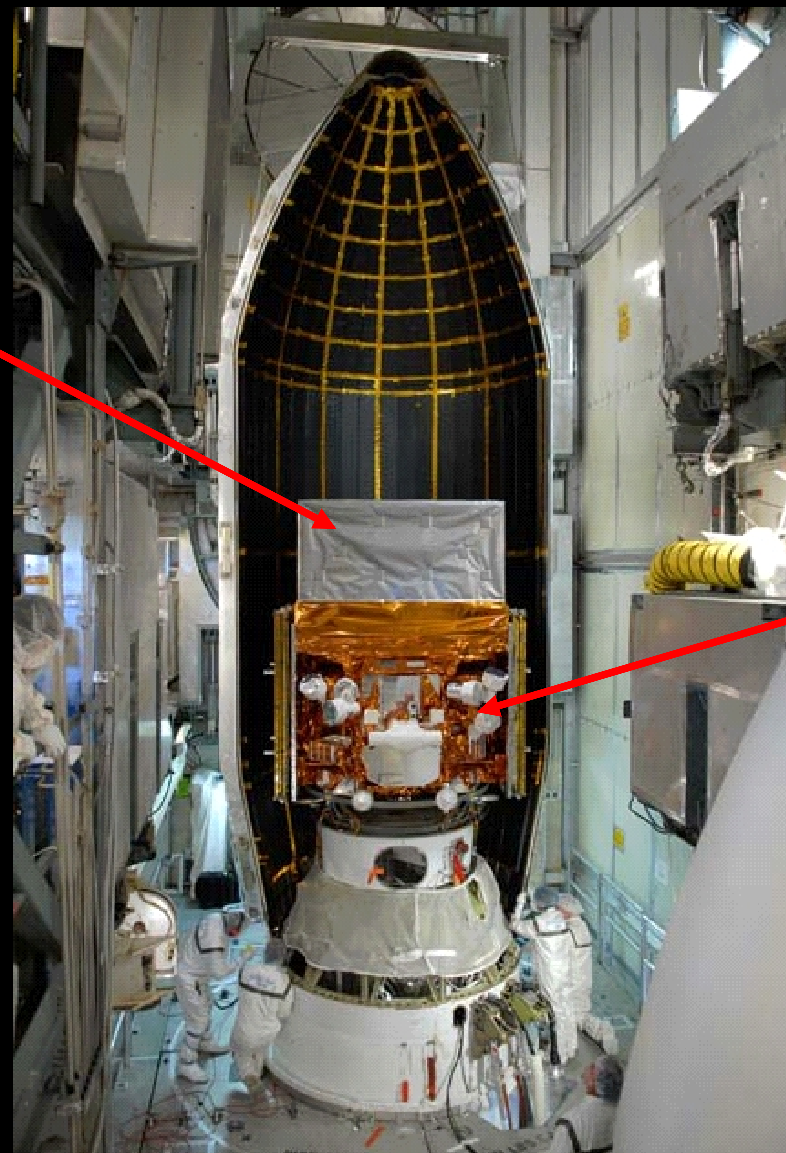
What is Fermi ?

Large Area Telescope (LAT) :

- *20 MeV – >300 GeV (including unexplored region 10 GeV – 100 GeV)*
- *conversion pair telescope*
- *survey mode*

→ scan of the sky in 3 hours



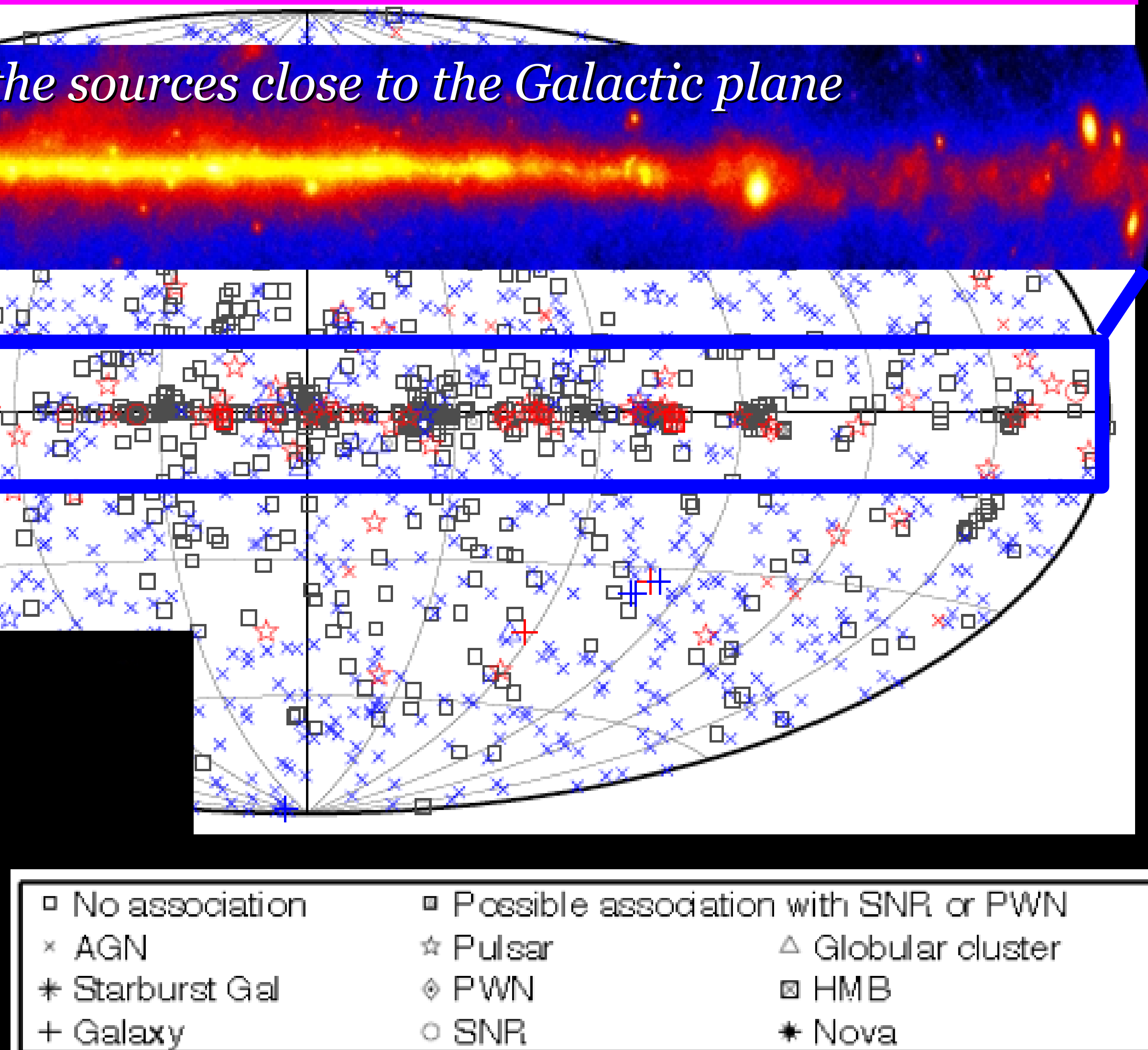


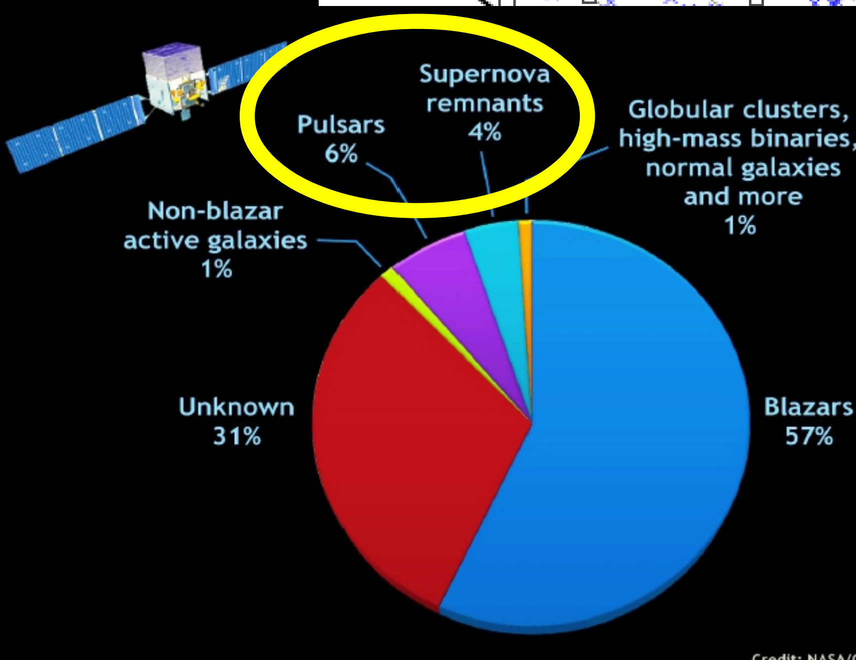
Gamma-ray Burst Monitor (GBM) :

- 8 keV – 40 MeV
- views entire unocculted sky

The GeV sky seen by Fermi

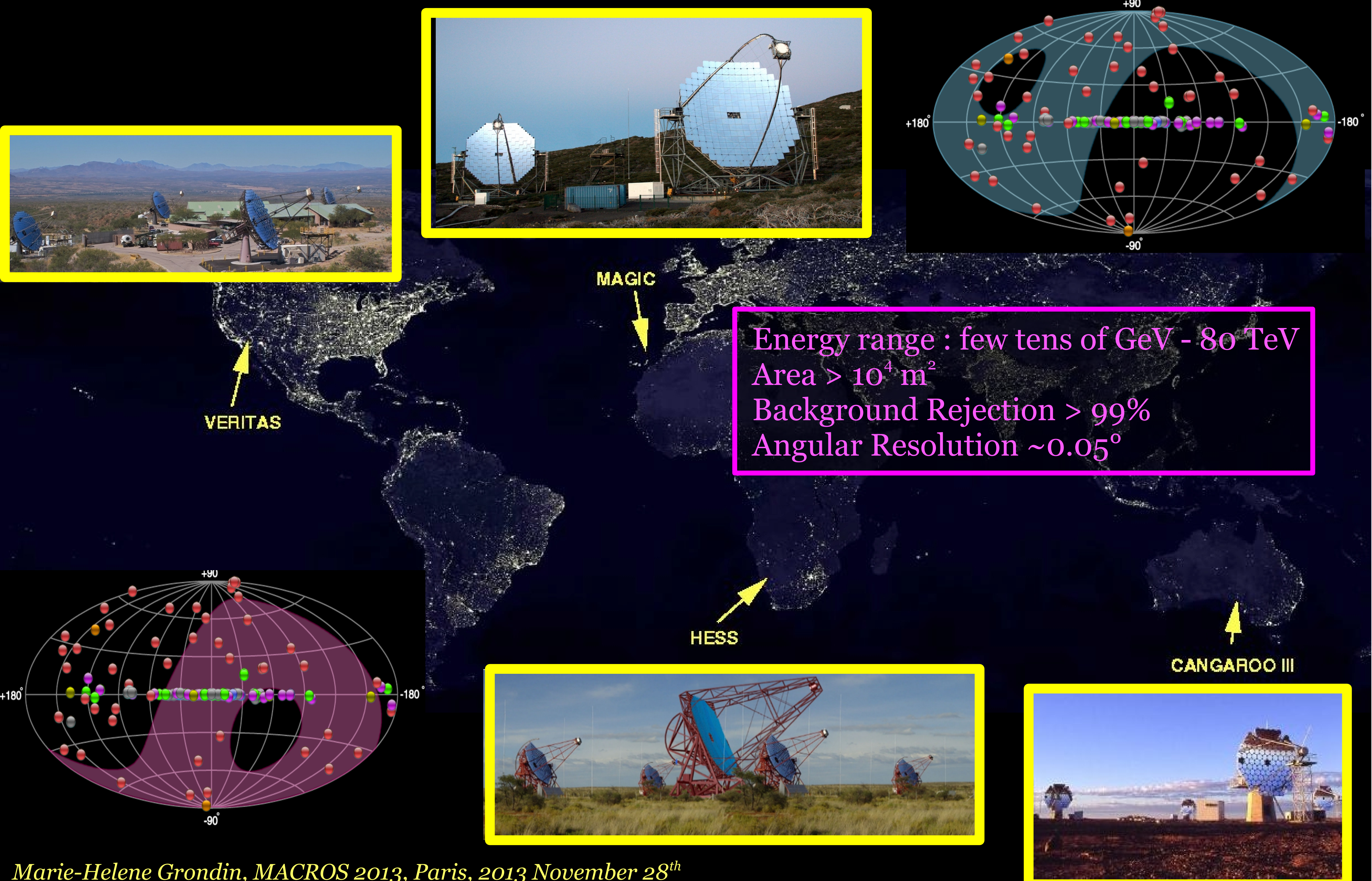
~1900 GeV sources detected after 2 years (Nolan et al, 2012, ApJS 199, 31)





Credit: NASA/DOE/International LAT Team

Imaging Atmospheric Cherenkov Telescopes



Energy range : few tens of GeV - 80 TeV
Area > 10^4 m^2
Background Rejection > 99%
Angular Resolution ~0.05°

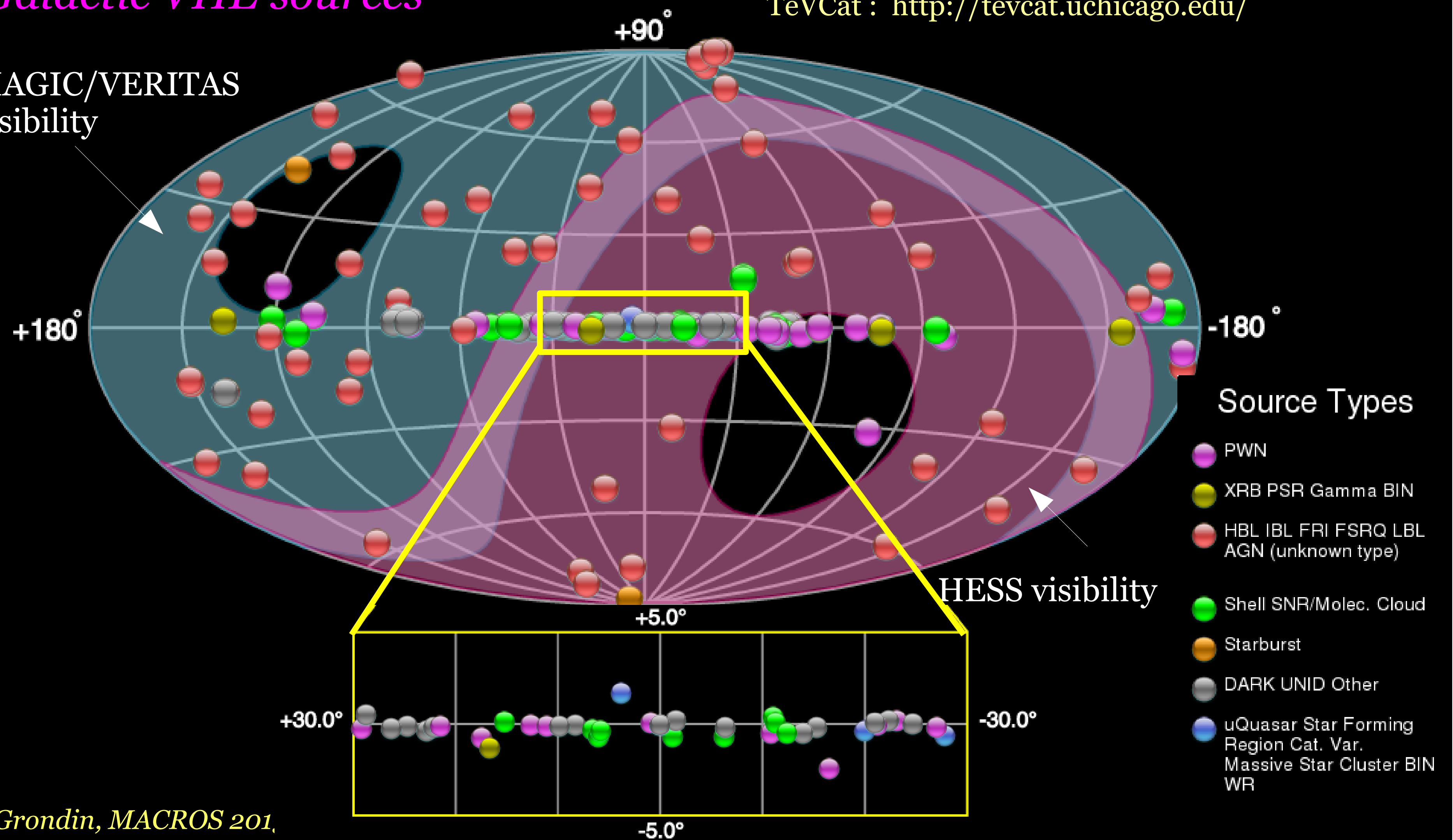
Status in the TeV range

Improved sensitivity of current generation of Imaging Atmospheric Cherenkov Telescopes (IACTs)

→ *detection of ~150 VHE sources*

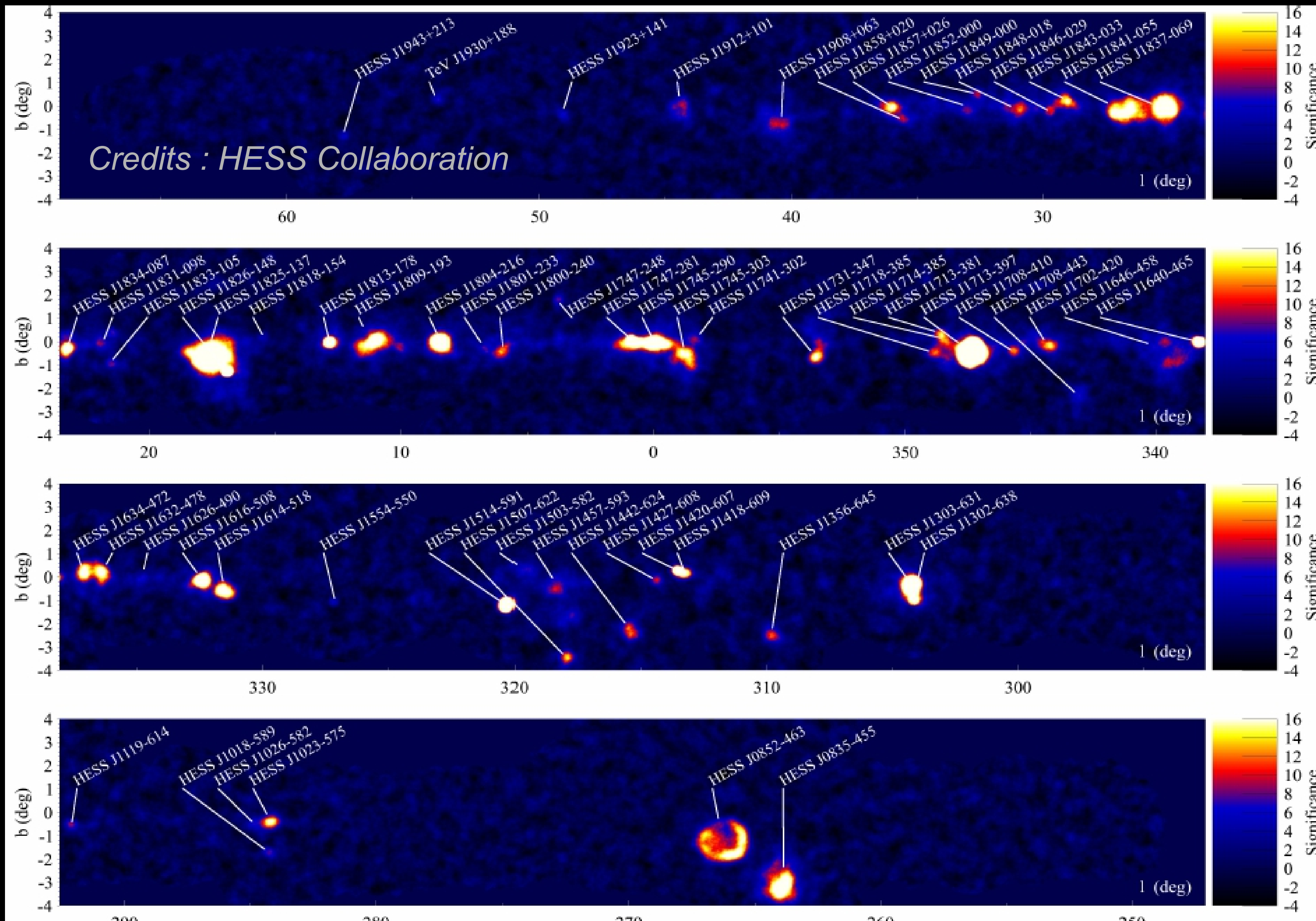
→ *~70 Galactic VHE sources*

TeVCat : http://tevcat.uchicago.edu/



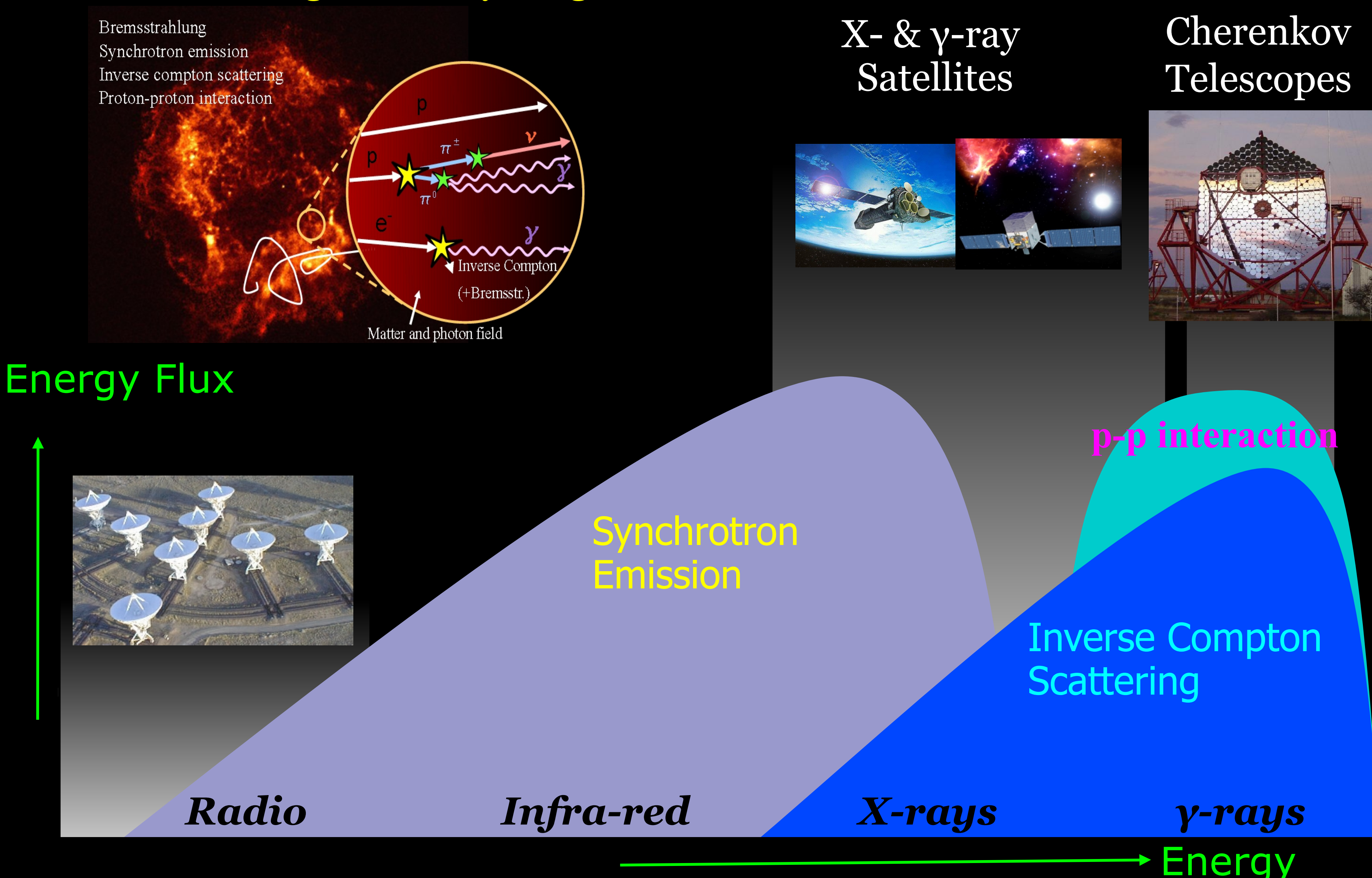
Marie-Helene Grondin, MACROS 201

HESS & the Galactic Plane Survey

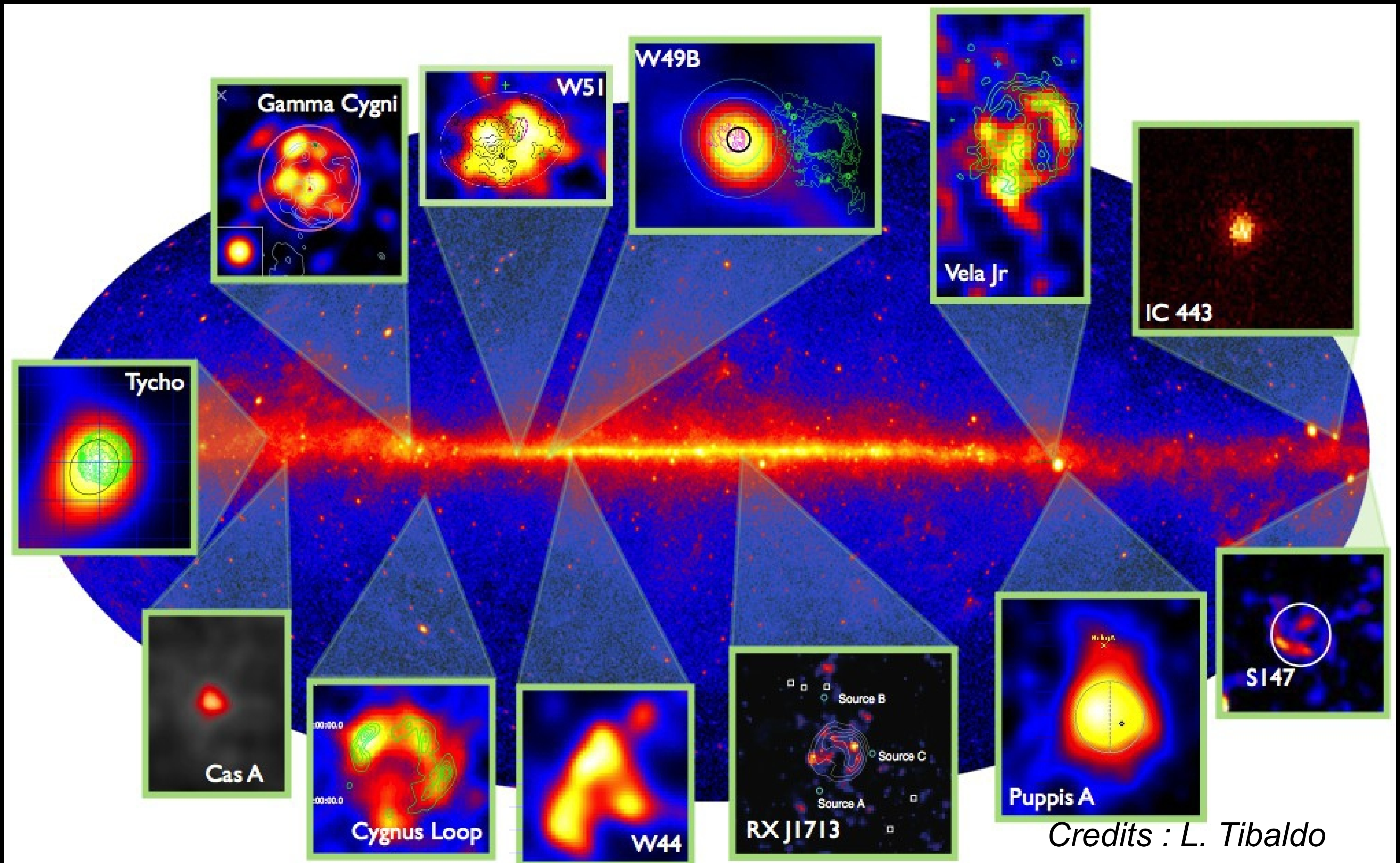


Non-thermal emission from SNRs & PWNe

Gamma-ray experiments : Potential to disentangle between protons and electrons in the gamma-ray range

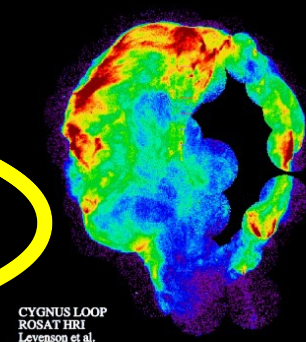


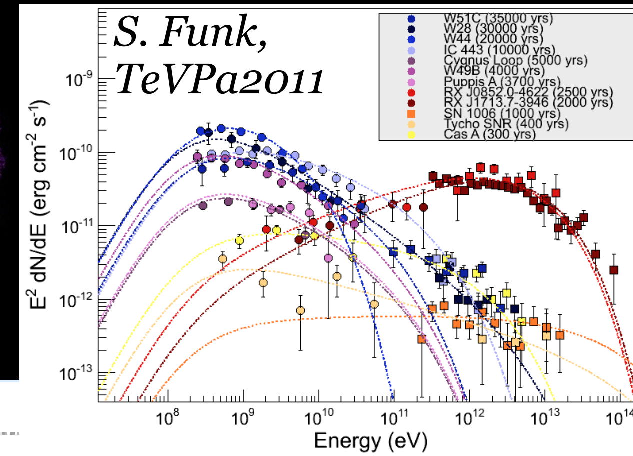
GeV-detected SNRs



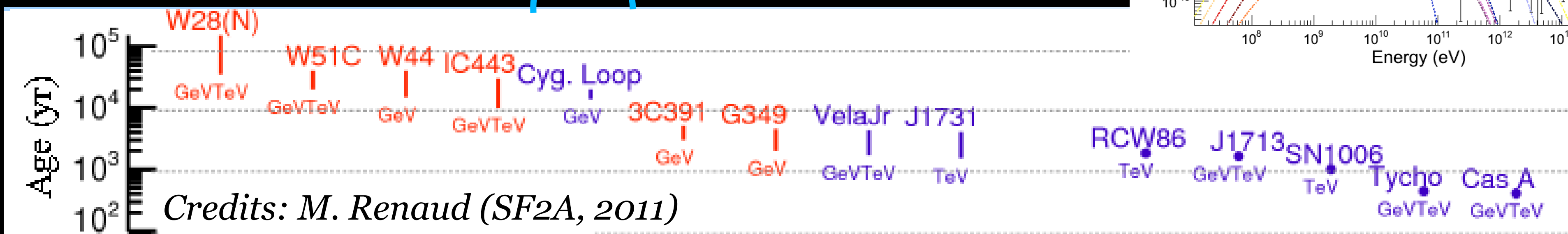
Gamma-ray emitting SNRs

Best candidates for hadronic processes





Evolved SNR without MC interaction

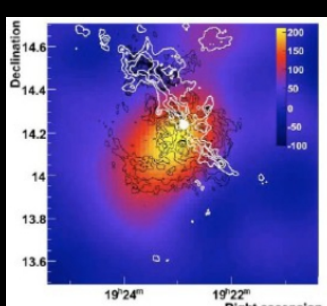


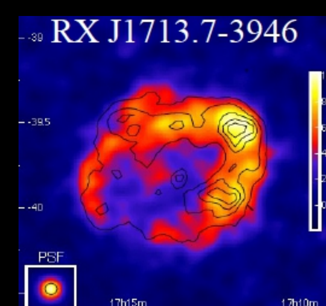
Evolved SNRs Interacting with Molecular Clouds

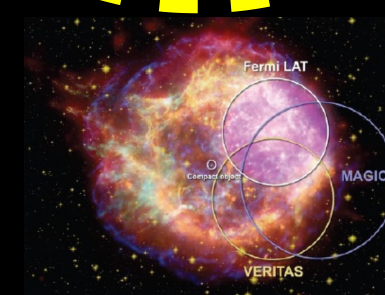
Young SNRs interacting with Molecular Clouds

Young shell-type SNRs

Historical SNRs







interaction/association with MC

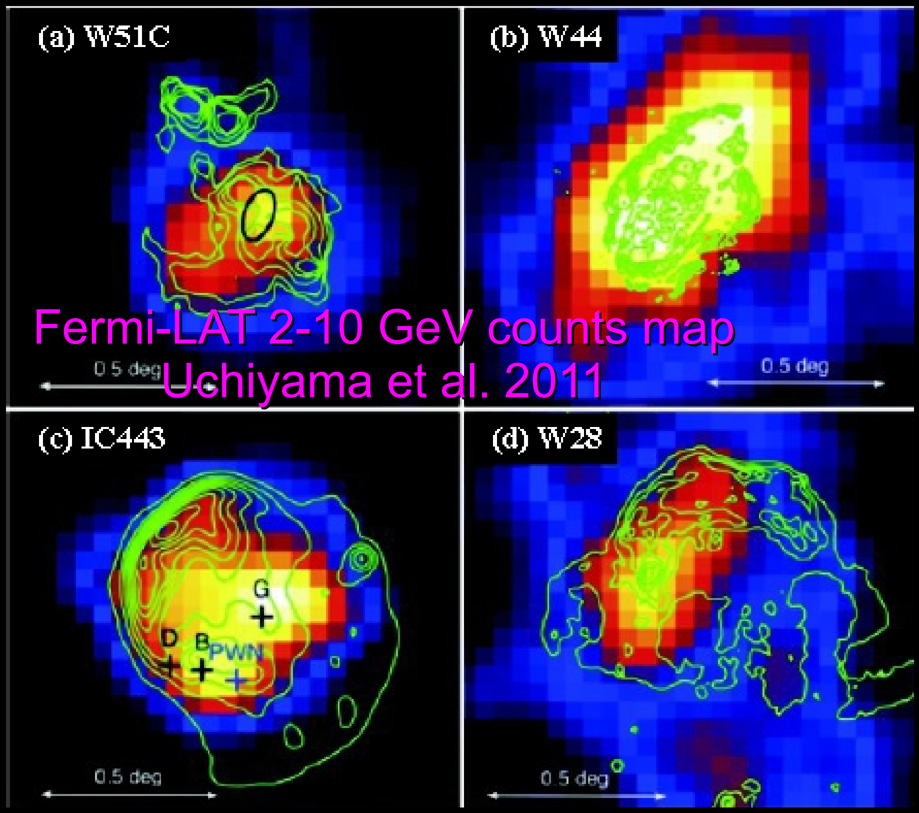
isolated

Marie-Helene Grondin, MACROS 2013, Paris, 2013 November 28th

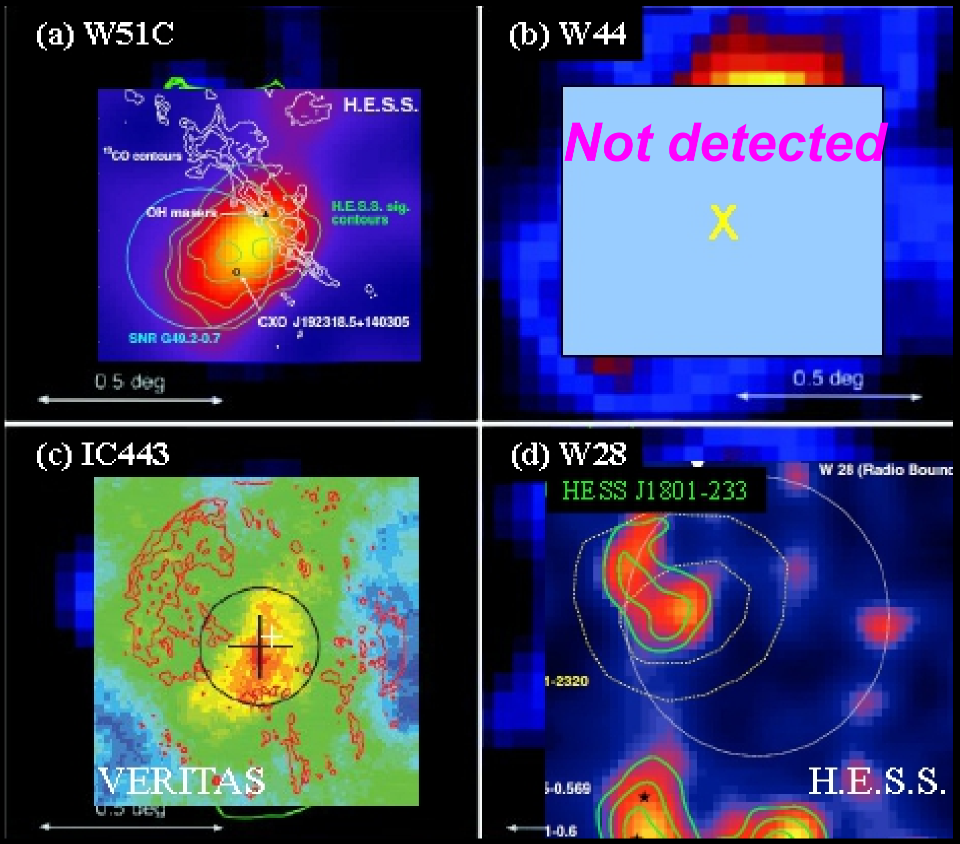
SNRs interacting with Molecular Clouds

- Ages of 3-100 kyr
- Interaction with MCs can act as target material for pion production
- Bright in Fermi-LAT range (luminosity up to 10^{36} erg/s), weak/not detected in TeV
- Usually extended with a size consistent with the radio emission

In the GeV range



In the TeV range



Marie-Helene Grondin, MACROS 2013, Paris, 2013 November 28th

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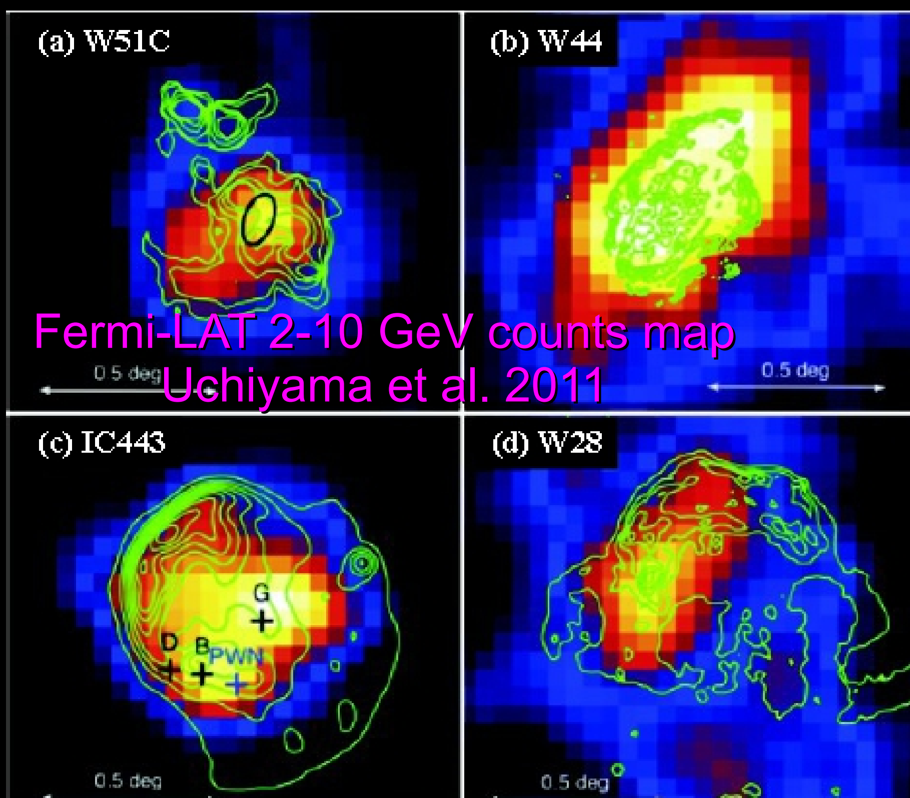
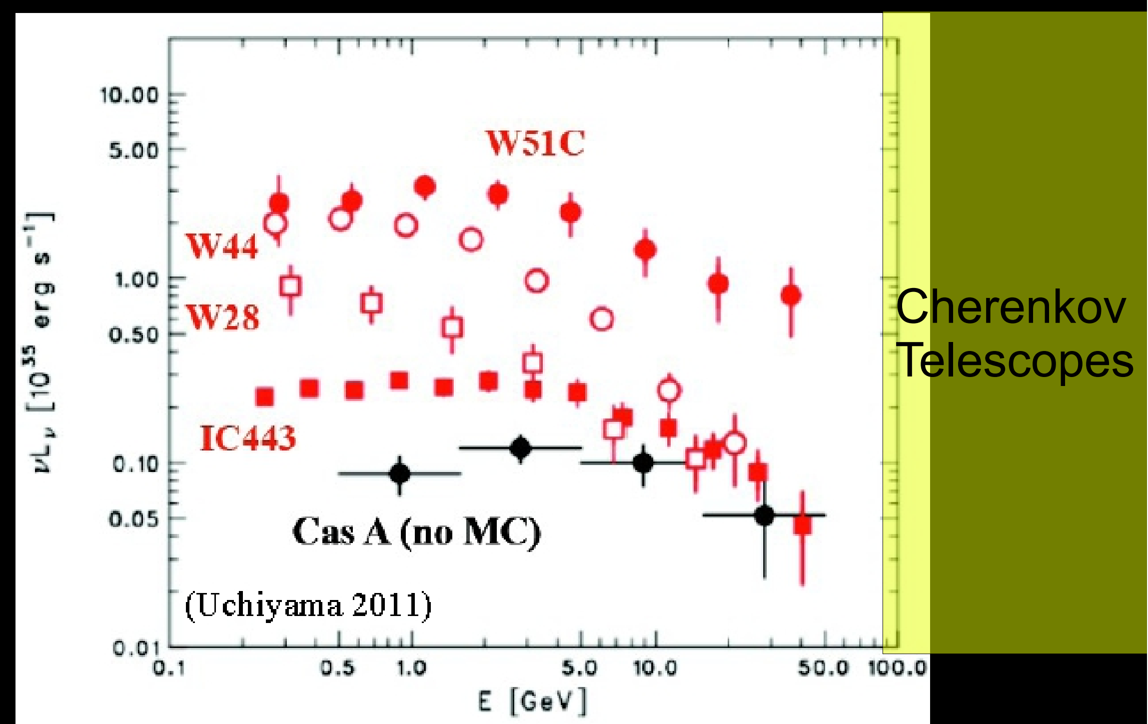
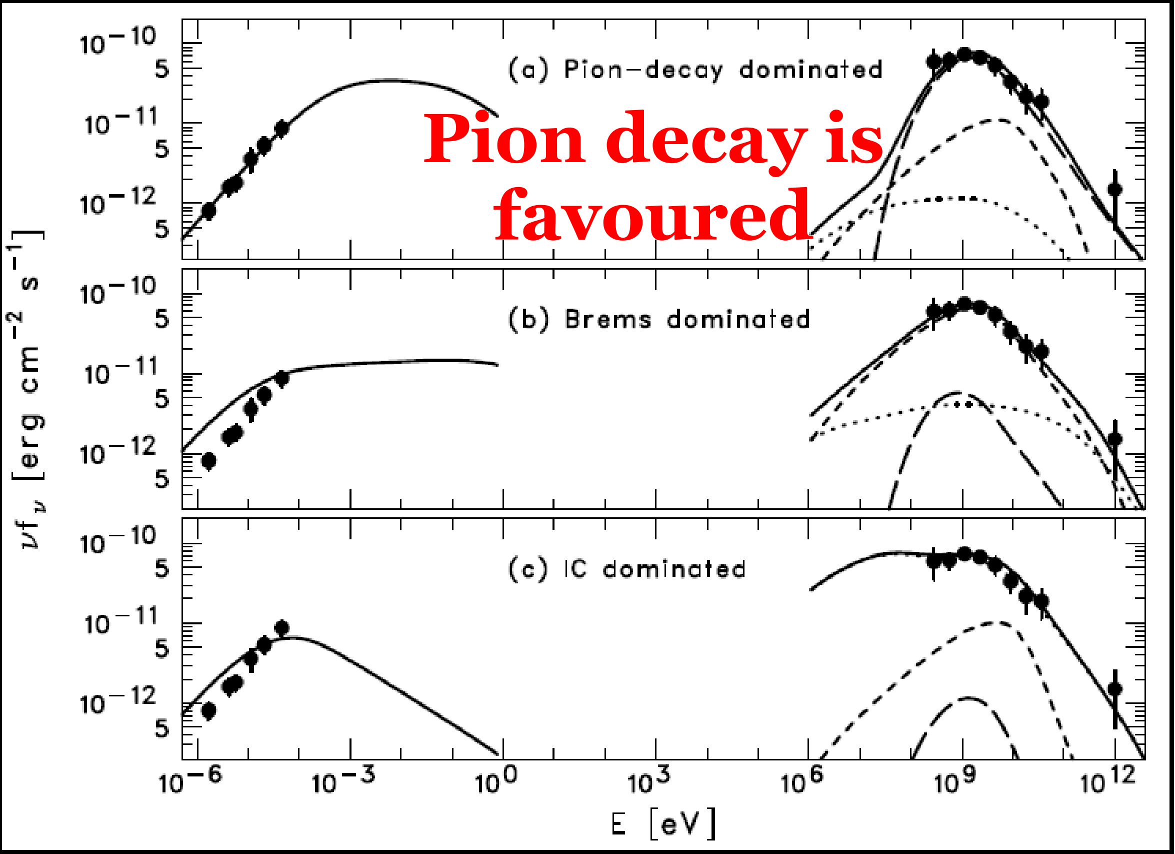




Broadband modeling of SNR W51C

- LAT spectrum well modeled with a broken power-law
- Leptonic models need large electron/proton ratios
→ pion-decay is favoured
- Bremsstrahlung : hard to reproduce the radio synchrotron spectrum
→ less likely but not fully excluded
- Inverse Compton : very large energy content in electrons and very low density
→ very unlikely



Model	Parameters					Energetics	
	a_e/a_p	Δs	p_{br} (GeV c^{-1})	B (μG)	$\bar{n}_H$ (cm^{-3})	W_p (10^{50} erg)	W_e (10^{50} erg)
(a) π^0-decay	0.02	1.4	15	40	10	5.2	0.13
(b) Bremsstrahlung	1.0	1.4	5	15	10	0.54	0.87
(c) Inverse Compton	1.0	2.3	20	2	0.1	8.4	11

First detections of the pion-decay bump

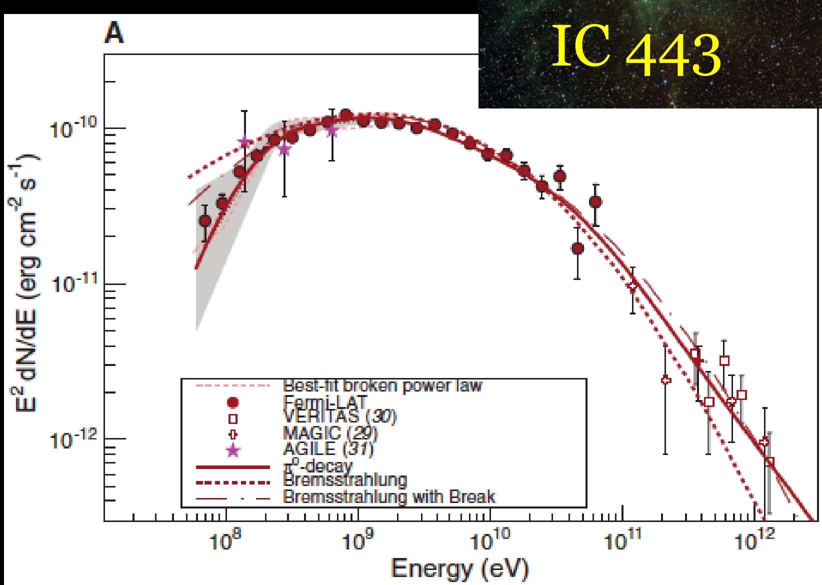
(Ackermann et al, 2013, Science 339, 807)

Investigating 2 bright SNRs, IC443 and W44, down to 60 MeV

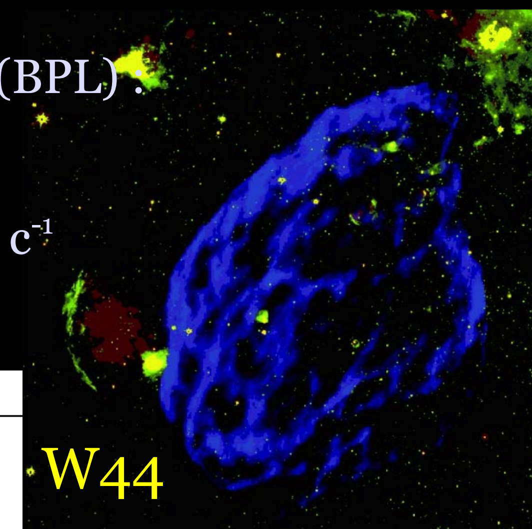
- detection of a significant (19 and 21σ) turn-over at ~250 MeV

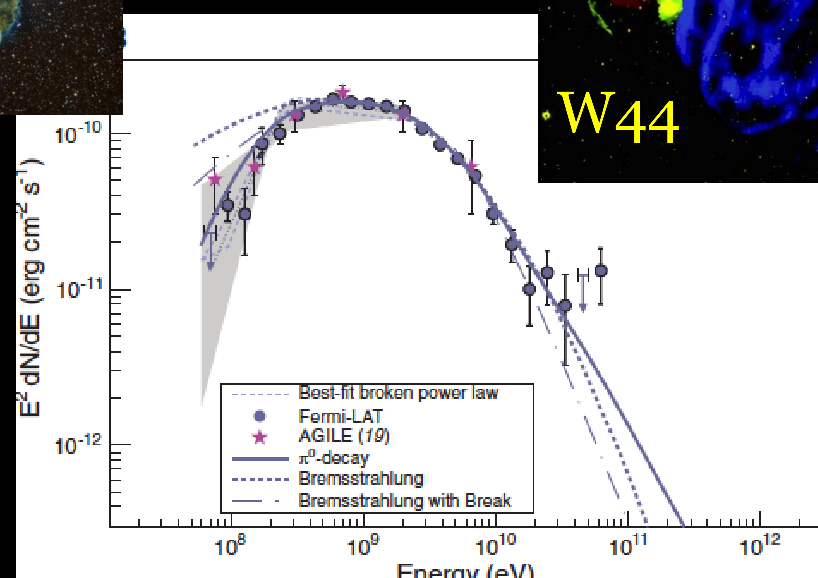
  => first clear evidence of the neutral pion decay and proof that SNRs accelerate protons

Proton spectrum (BPL) :
- s1 = 2.36±0.05,
- s2 = 3.1±0.1
- pbr =239±74 GeV c^{-1}

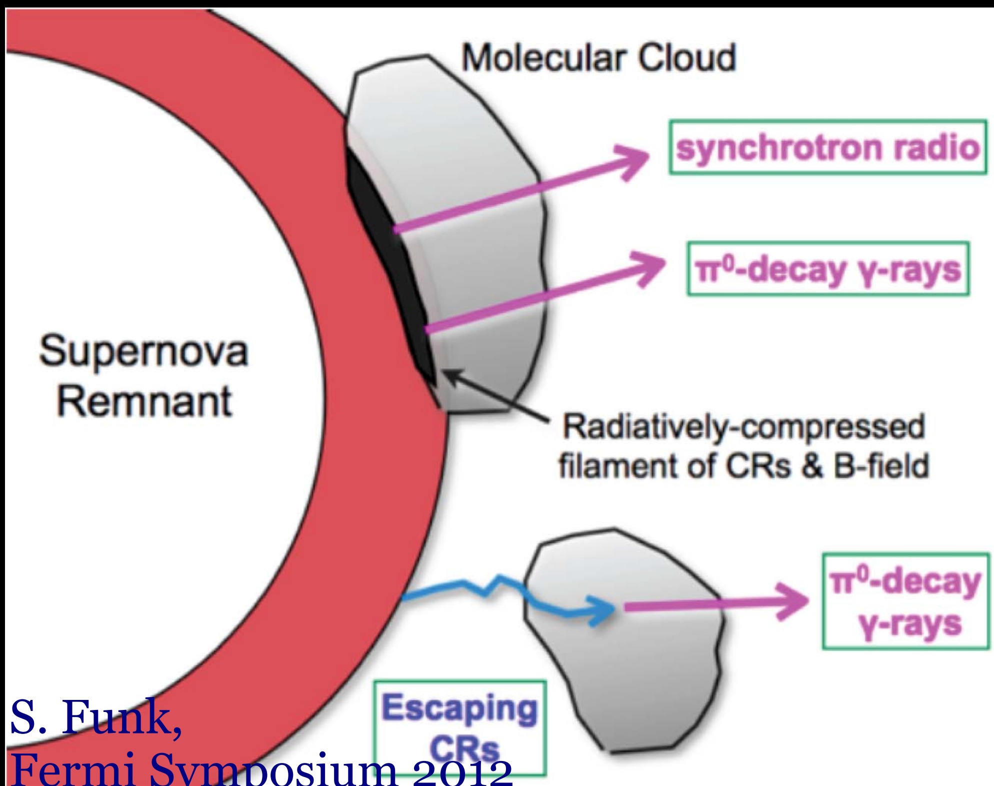


Proton spectrum (BPL) :
- s1 = 2.36±0.05,
- s2 = 3.5±0.1
- pbr = 22±8 GeV c^{-1}





Two scenarios



1. Crushed cloud («Uchiyama+10» type scenario) :

- CRs and molecular cloud simultaneously compressed.
- Reacceleration of the "sea" of CRs.

(See also Blandford & Cowie 82, Bykov+00)

2. Passive cloud («Atoyan & Aharonian» type scenario) :

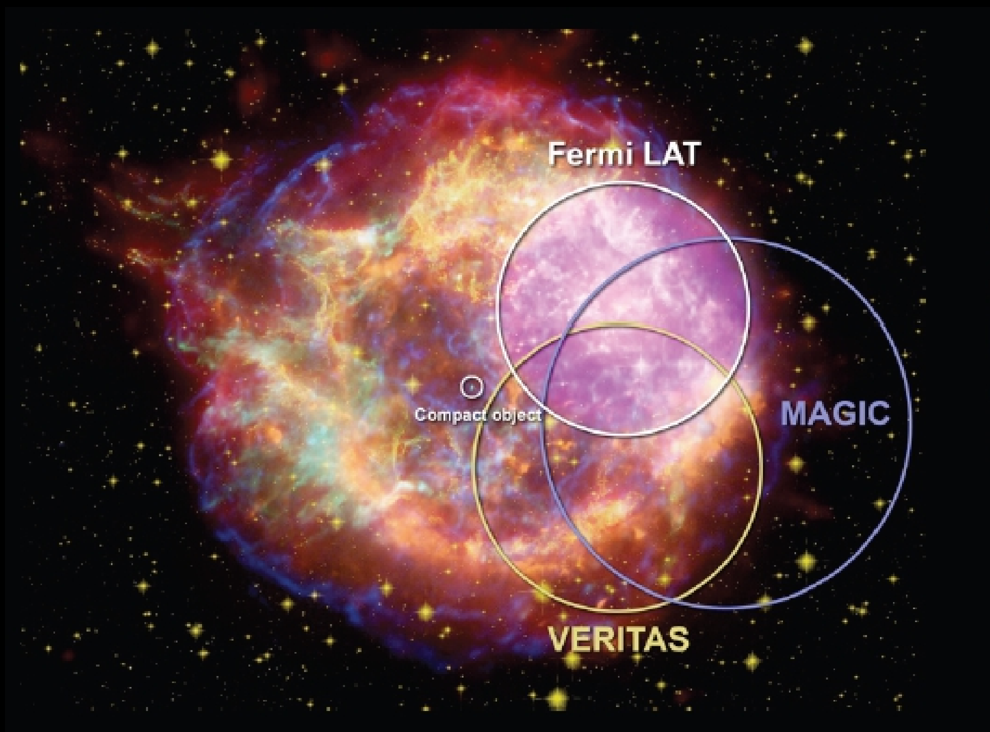
- CRs escaping from SNR and colliding with nearby MCs
- Fresh acceleration of CRs

(See also Gabici+09, Fujita+10, Ohira+10)

Historical SNRs

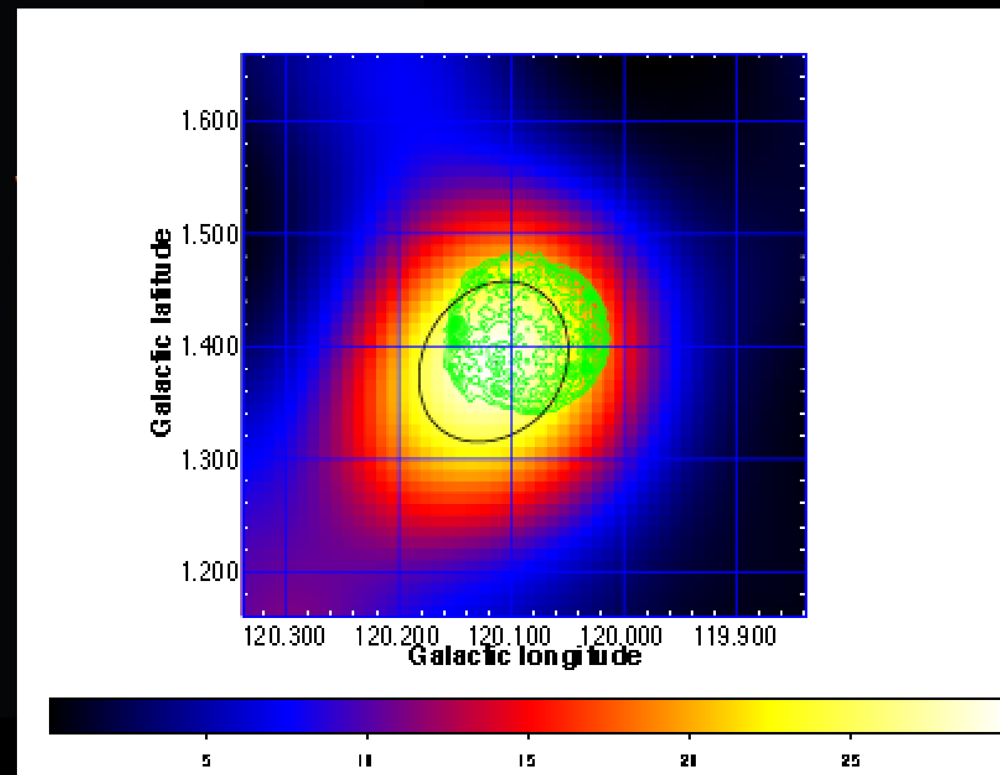
Cas A: Type II, ~AD1680
Detected by MAGIC, VERITAS & Fermi

Tycho: Type Ia, SN1572
Detected by VERITAS & Fermi



VLA - Radio
Spitzer - IR
Hubble - Optical
Chandra - X-rays
Fermi - γ-rays

Abdo at al., 2010, ApJL, 710, 92

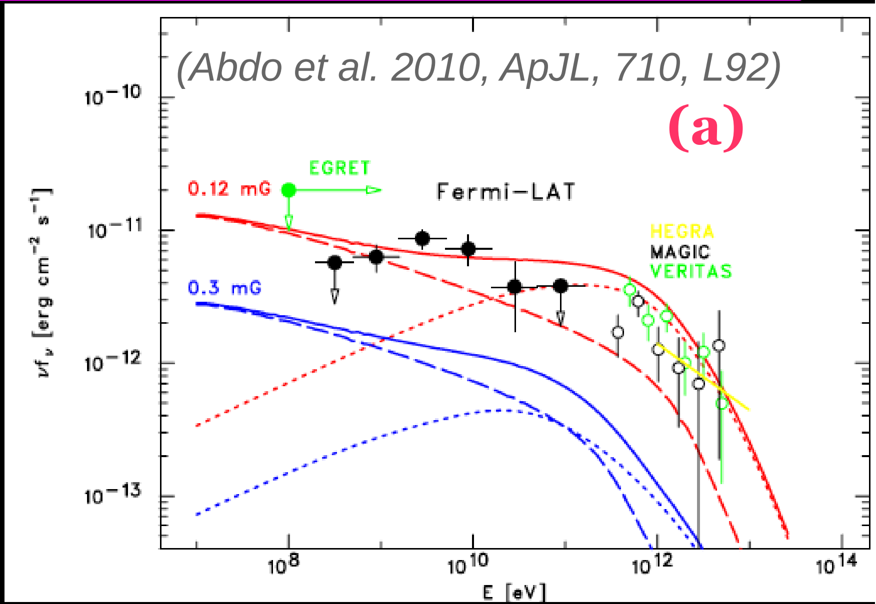


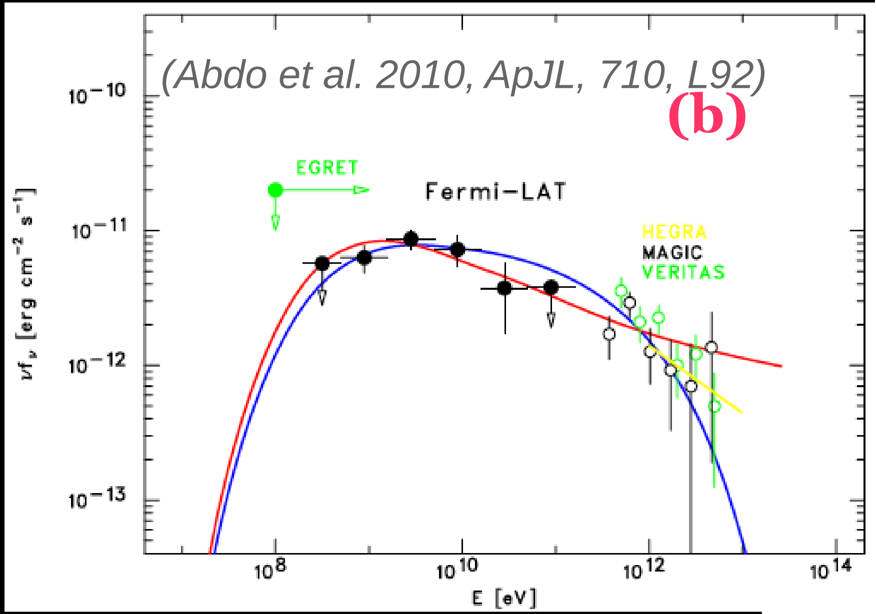
Fermi-LAT TS map with X-ray contours

A low energy content in Cas A

Requires a large magnetic field (≥0.12 mG) and an energy of ~1 – 4 % of the total kinetic energy of the supernova

- *Fermi data :*
  - *No pulsar detected*
  - *Spectrum modeled with a power law*
- *Spectrum can be explained by 2 scenarios :*
  - *(a) Leptonic : Bremsstrahlung + Inverse Compton*
    - *B = 0.12 mG*
    - *Energy injected to electrons : W_e=1 x 10^{49} erg*
  - *(b) Hadronic scenario : pion decay*
    - *B > 0.12 mG*
    - *Good fit with proton spectral index ~2.3 (red) or ~2.1 (blue) with cut-off at 10 GeV*
    - *Energy injected to protons : W_p=3.2-3.8 x 10^{49} erg*





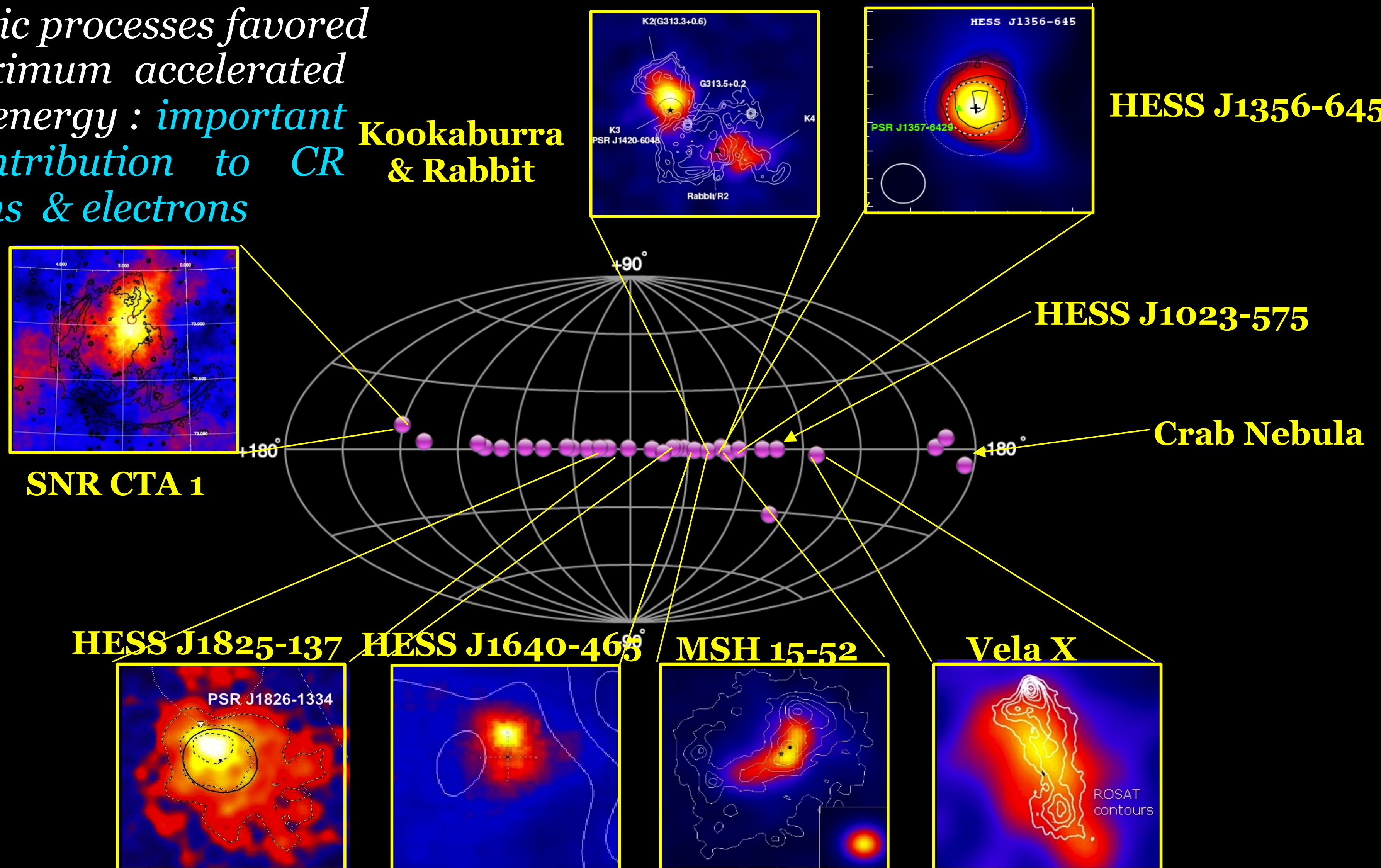
=> 100 TeV gamma-rays without cut-off would be a first evidence of PeVatron

Pulsar Wind Nebulae

- *Dominant class of TeV Galactic sources (35 PWNe + 12 candidates)*
- *6 PWNe firmly identified in the GeV range + 10 PWN candidates*

Gamma-ray PWNe preferentially associated to energetic and young pulsars

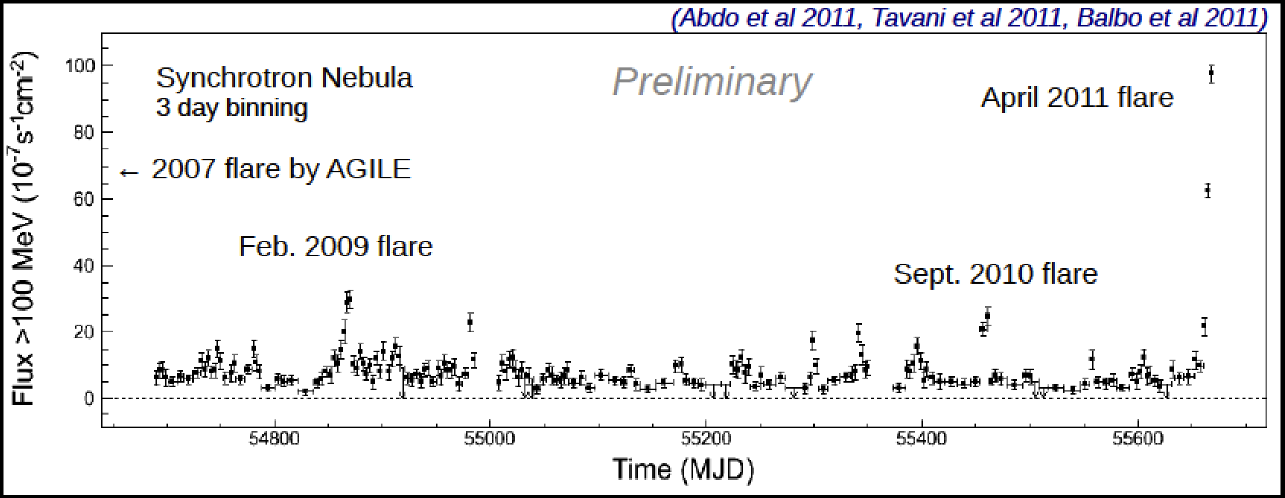
- *Leptonic processes favored => maximum accelerated lepton energy : important for contribution to CR positrons & electrons*



The Crab Nebula : no more a standard candle

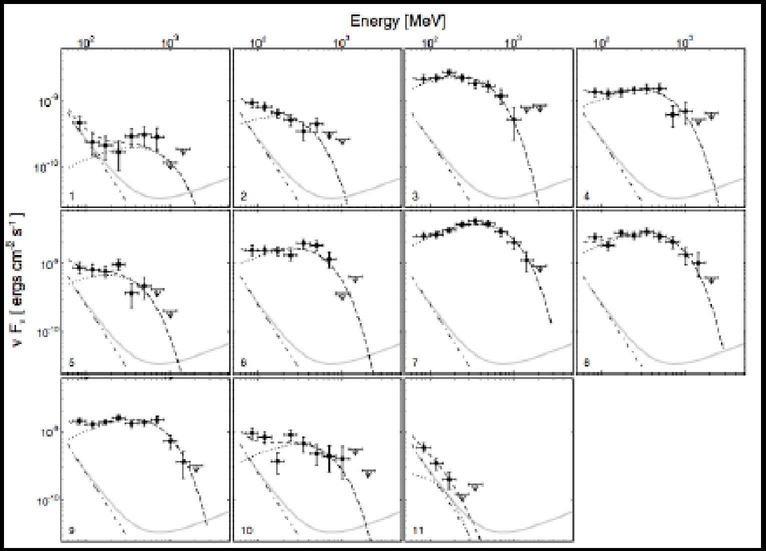
Recent flares of the synchrotron component (Oct. 2007, Feb. 2009, Sept. 2010, Apr. 2011, March 2013) :

R. Buehler, Fermi Symposium 2011



Three day Crab synchrotron light curve

(Buehler, R. et al. 2012, ApJ, 749, 26)



- Average flux ~6e-7 ph/cm2/s above 100 MeV, whith three flares as extremes of persistent variability

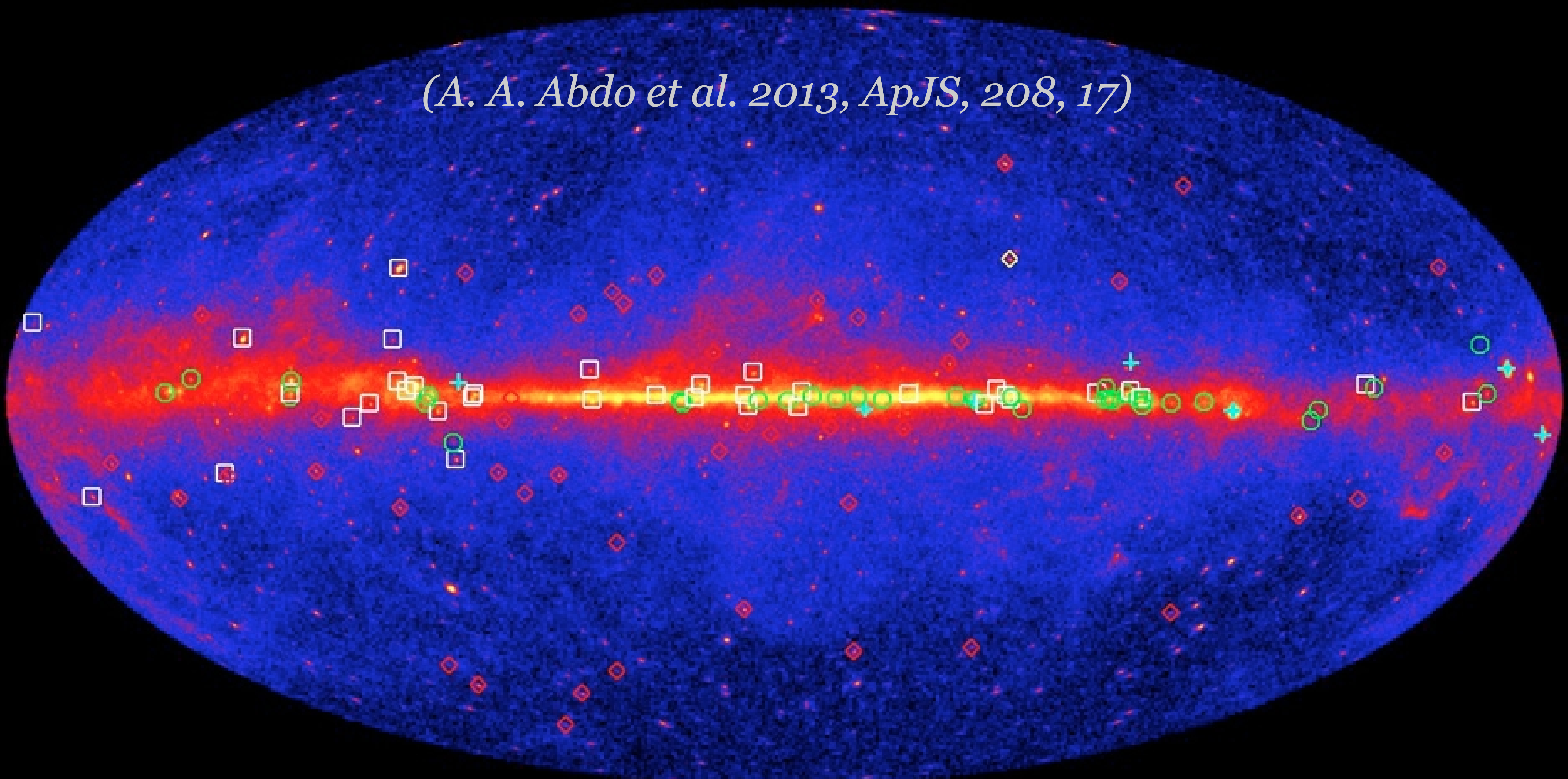
- Flux increase by ~5 during 2009, 2010 & 2013 flares, by ~30 during 2011 flare !

- Compact emission region < 0.0004 pc ~ 0.04'' (for D<4)

→ Emission from the inner nebula

Pulsars

- *Dominant class of Galactic sources in GeV* *(A. A. Abdo et al. 2013, ApJS, 208, 17)*



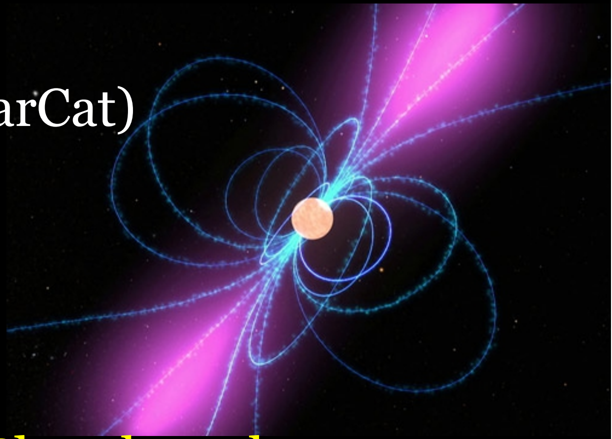
42 young radio- and X-ray-selected (green circles, cyan crosses)
36 young **γ**-ray-selected (white squares)
46 radio-selected MSPs (red diamonds) + 1 **γ**-ray-selected MSP (yellow diamond)
(+20 to be published!)

Gamma-ray pulsars seen by Fermi

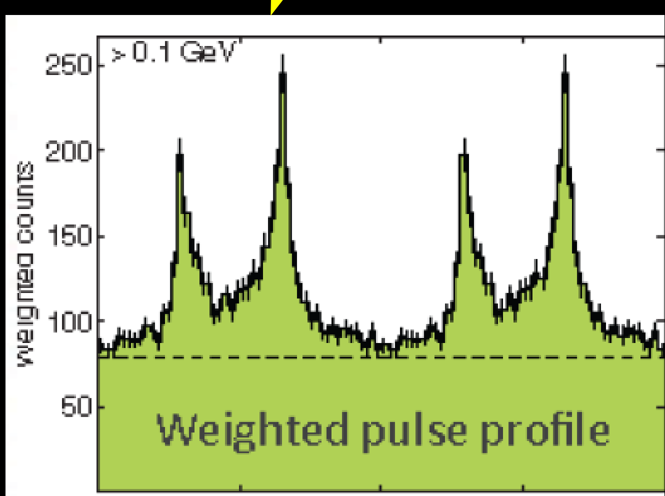
(A. A. Abdo et al. 2013, ApJS, 208, 17)

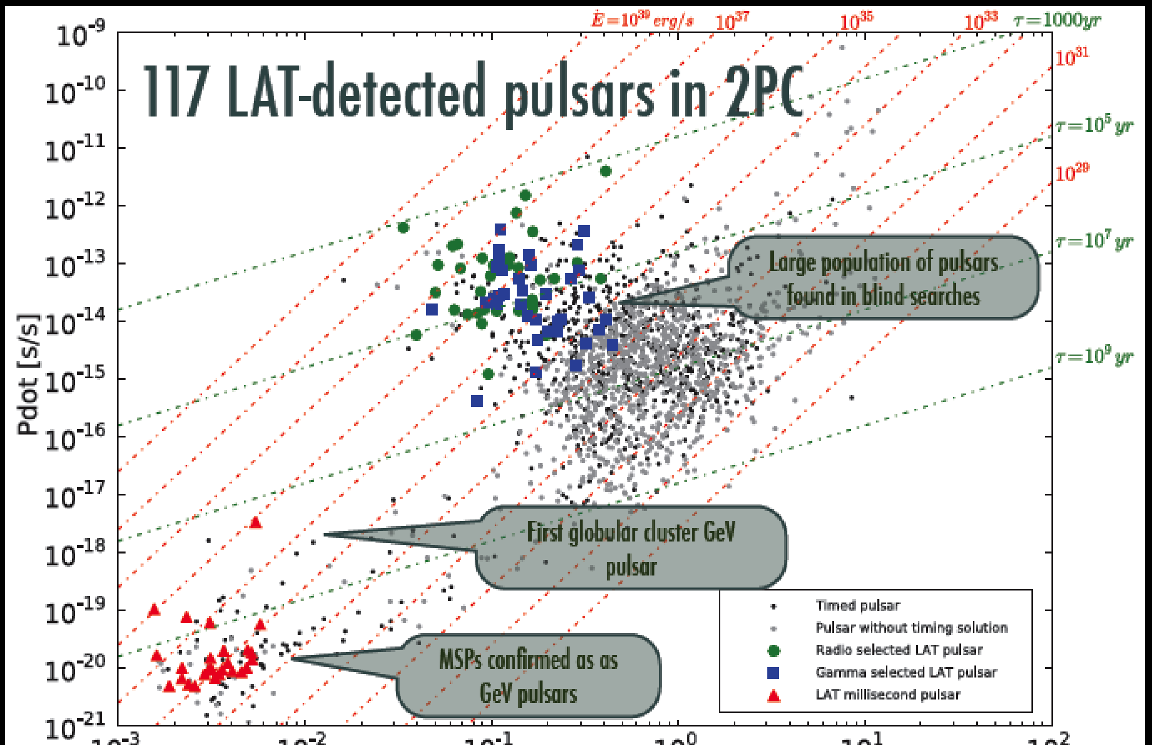
Before *Fermi*, 6+1 pulsars.

Currently, 124 γ-ray GeV pulsars (117 included in the 2nd PulsarCat)



- 1/3 young, radio-selected
- 1/3 young, gamma-ray selected *("radio quiet"?)*
- 1/3 recycled, millisecond (MSP)
- 1 MSP (PSR J1311-3430) discovered in blind search (Pletsch et al, 2012, Science, 338, 1314)



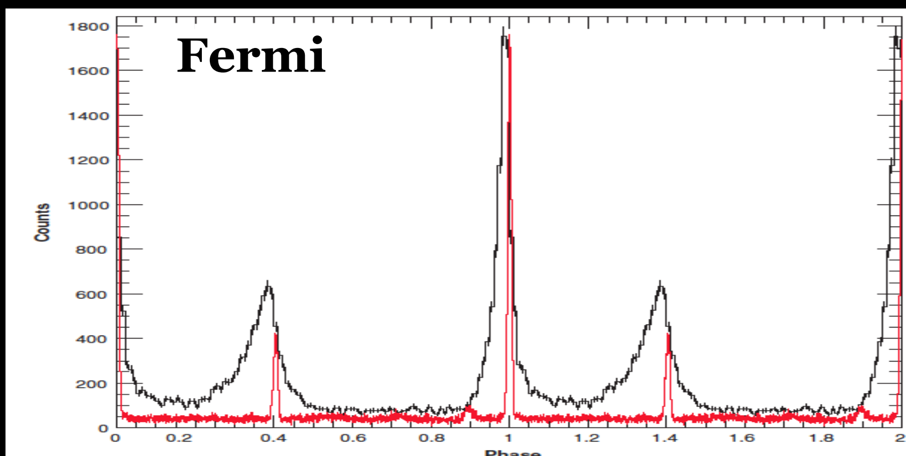


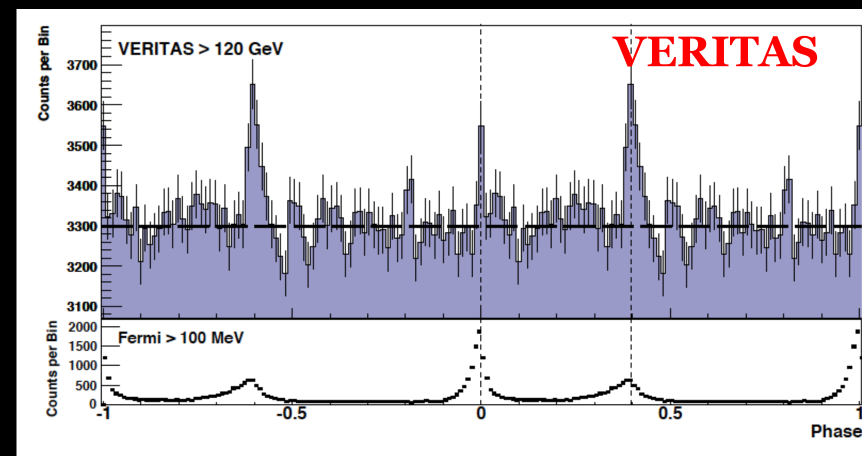
P. Ray, Fermi Symposium 2012

Pulsars : towards the highest energies

Crab Pulsar :

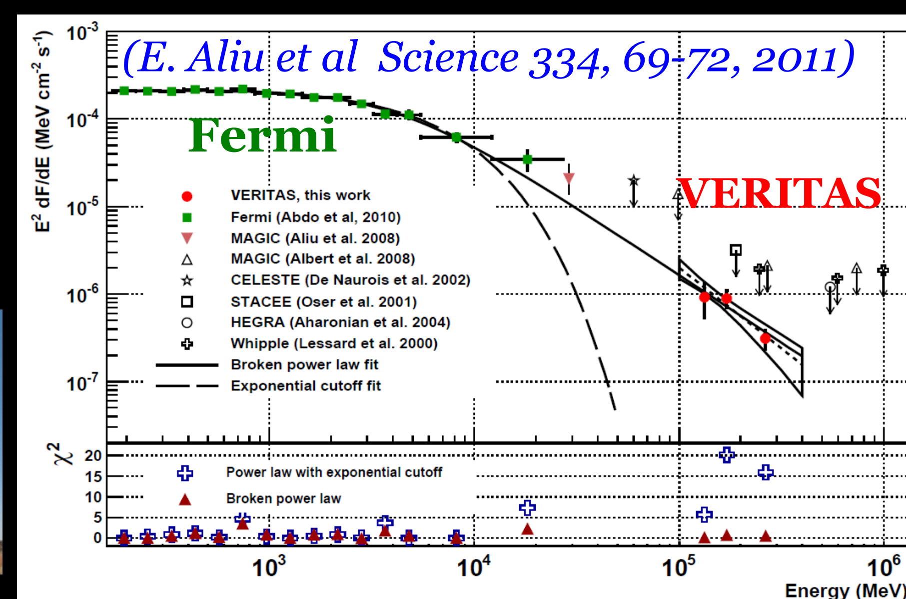
- *Detected by Fermi up to 20 GeV (Abdo et al, 2010, ApJ, 708, 1254)*
- *Only case detected by Cherenkov telescopes : MAGIC (> 25 GeV), VERITAS (>120 GeV)*





Interpretation :

- inverse Compton scattering (Outer Gap model, *Romani, 1996*) ?
- emission from the unshocked wind *(Aharonian & Bogovalov, 2003)* ?



The Crab : a lonely case or a new window of research ?

Marie-Helene Grondin, MACROS 2013, Paris, 2013 November 28th

Novae

(Abdo, A. A. et al. 2010, Science, 329, 817)

- *4 detected by Fermi-LAT*
- *The 3 1st **γ**-ray novae detected by Fermi share similarities (spectra, duration)*
- *Fermi acceleration in nova shell; interaction with massive red giant wind plays important role in V407 Cyg*
- *LAT as a nova finder; census within ~4-6 kpc*

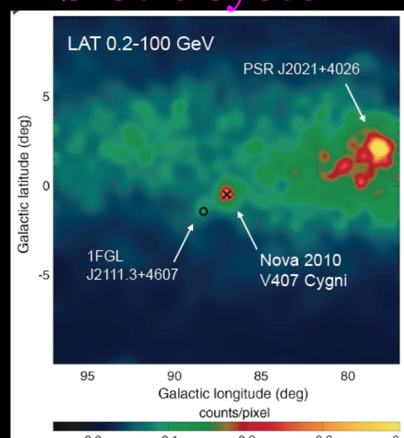
V407 Cyg 2010 : a symbiotic system

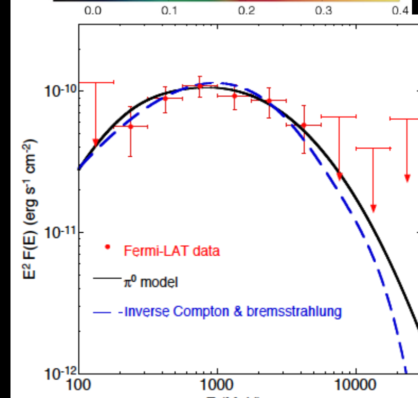
Massive WD + Red Giant

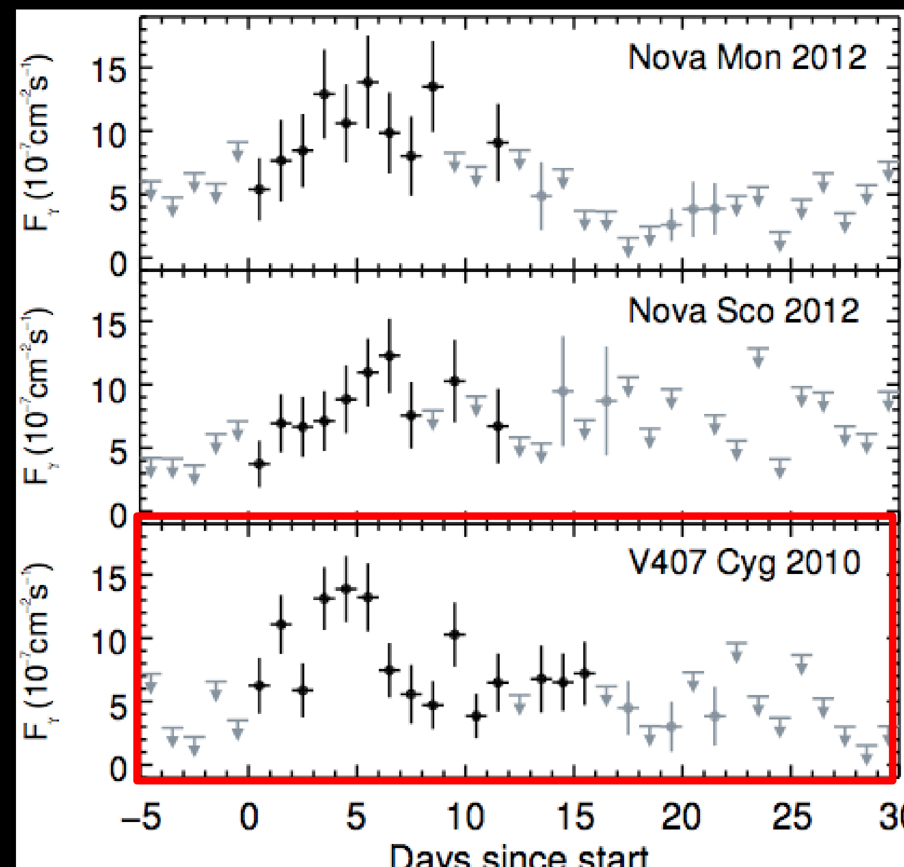
↓

accretion from a red giant wind

- a ~ 100's $R_\odot$
- P_{rec} <100 yrs; P_{orb}~years
- ~10 known







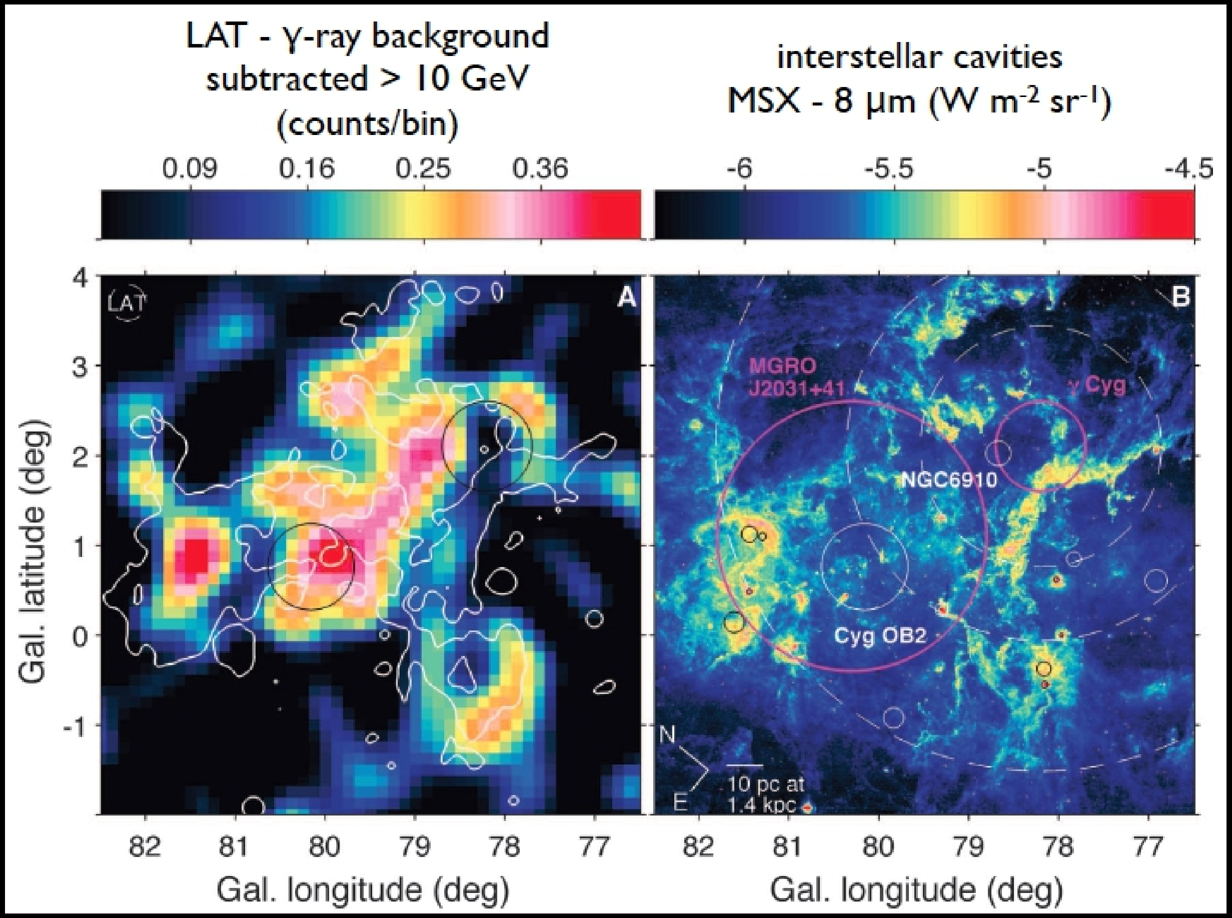
Star forming regions : the case of Cygnus X

(Ackermann+11, 2012, Science 334 1103)

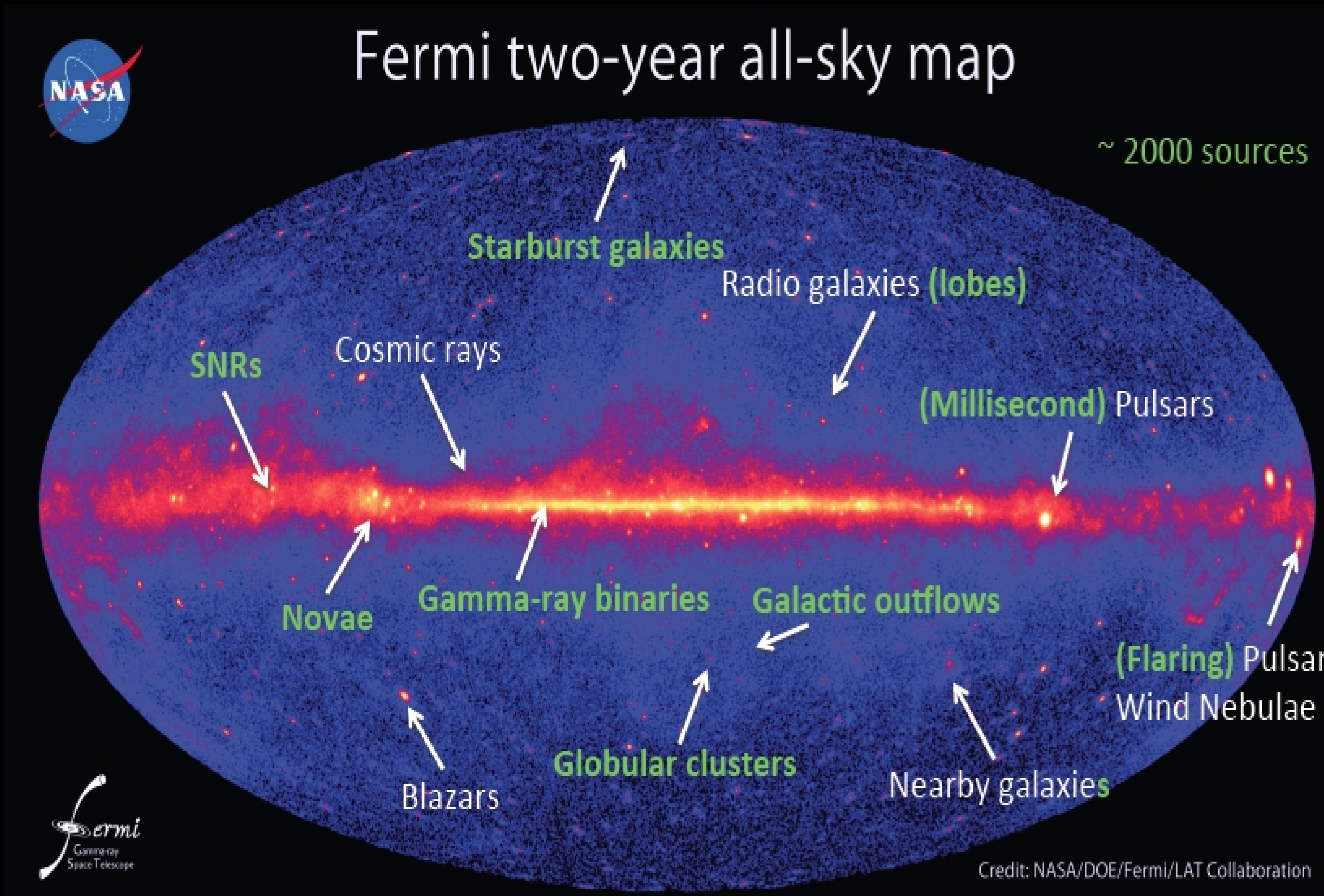
- *Bright emission from the region of Cygnus X :*
  - *Gamma Cygni SNR : unlikely*
  - *Stellar wind supper-bubble*

    => Acceleration of particles up to ~100 GeV

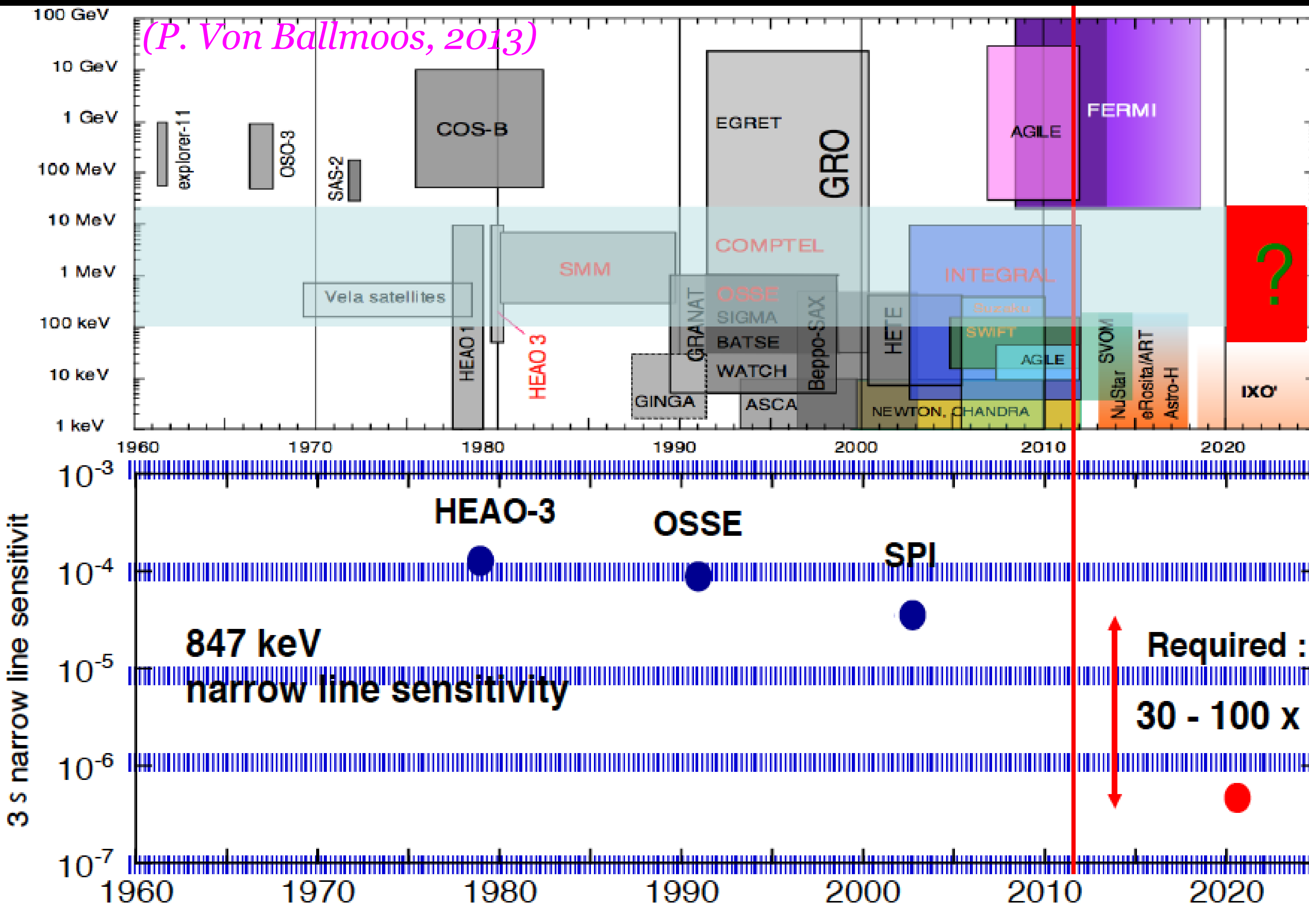
« A Cocoon of Freshly Accelerated Cosmic Rays Detected by Fermi in the Cygnus X super-bubble »



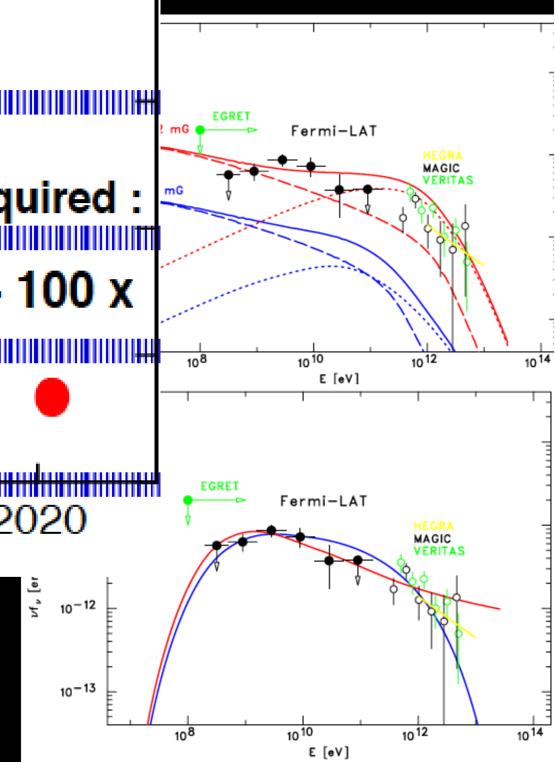
The diversity of the HE gamma-ray sky



The future of the MeV domain



SNR Cas A



Marie-Helene Grondin, MACROS 2013, Paris, 2013 November 28th

Perspectives with CTA

- *CTA = Cherenkov Telescope Array*

- *Array composed of a large (>50) number of Cherenkov telescopes :*
  - *international observatory with 2 sites (South & North)*

  - *2-3 different sizes of telescopes => 4 decades in energy*