
SciNeGHE 2012

# The Fermi LAT view of Cygnus: a laboratory to understand cosmic-ray acceleration and transport

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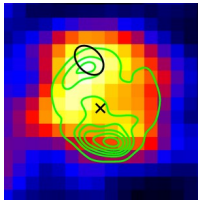
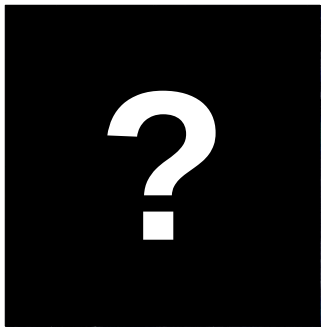
**on behalf of the *Fermi* LAT Collaboration**

# The cosmic-ray puzzle

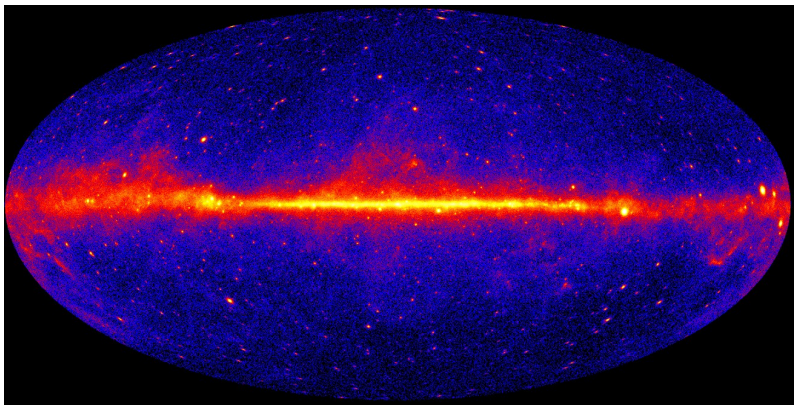
- **origin**:
  - best guess: diffusive shock acceleration in supernova remnants
  - isotopic composition → acceleration in OB associations/superbubbles
- **propagation**:
  - escape from sources
  - early propagation (in turbulent regions around massive stars)
  - merging into the older Galactic population





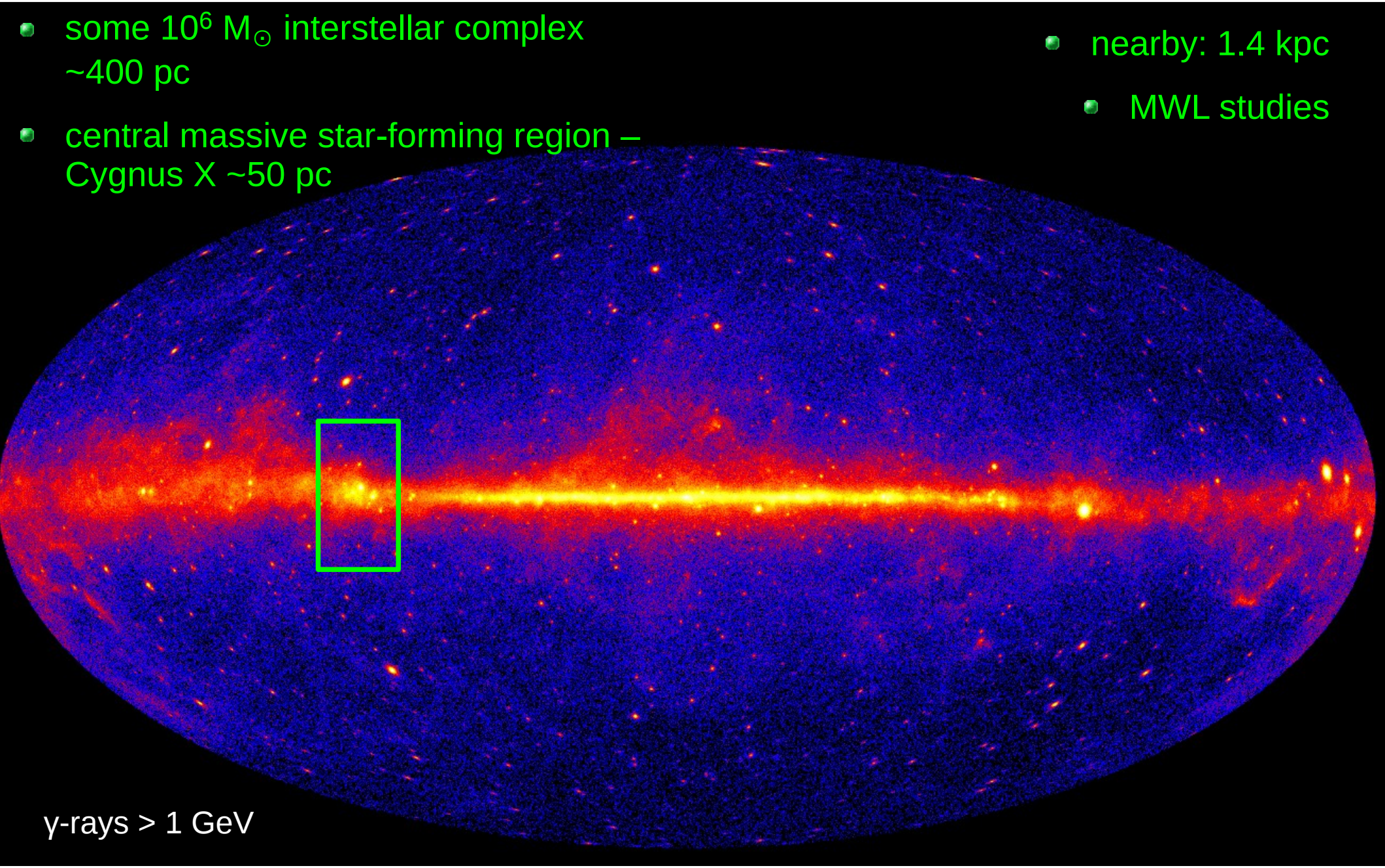




# The Cygnus region

- some $10^6$ $M_\odot$ interstellar complex ~400 pc
- central massive star-forming region – Cygnus X ~50 pc
- nearby: 1.4 kpc
- MWL studies



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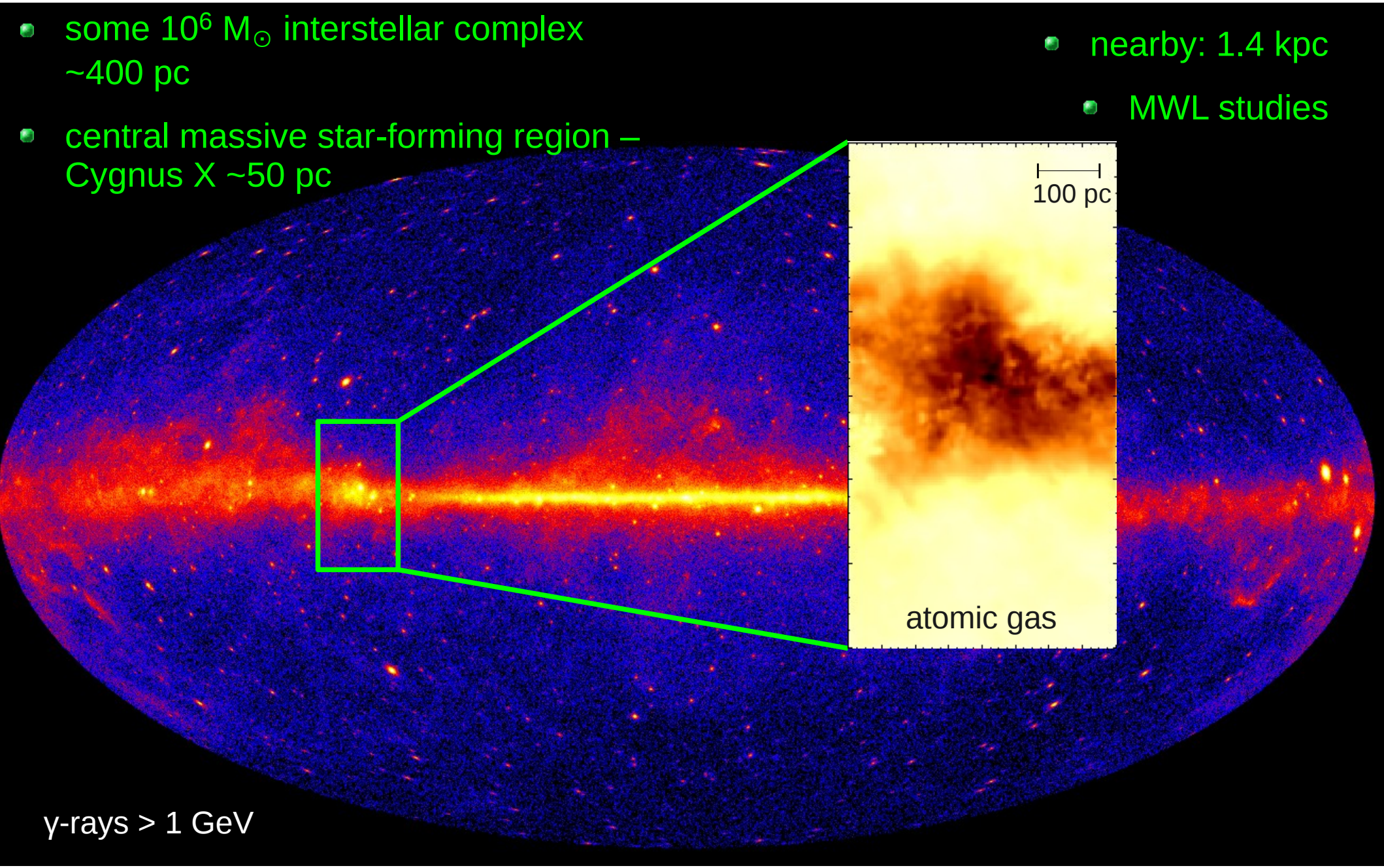

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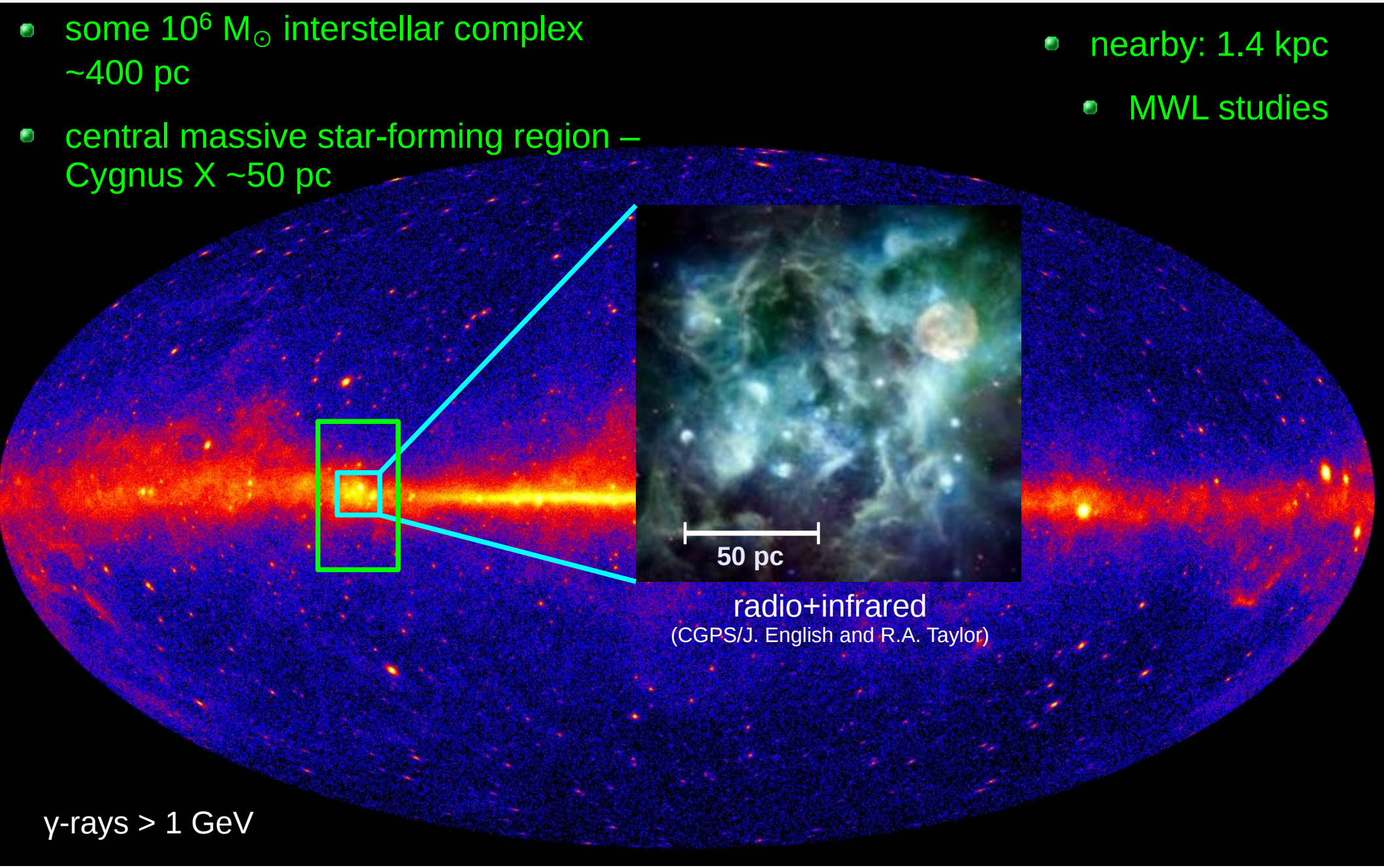
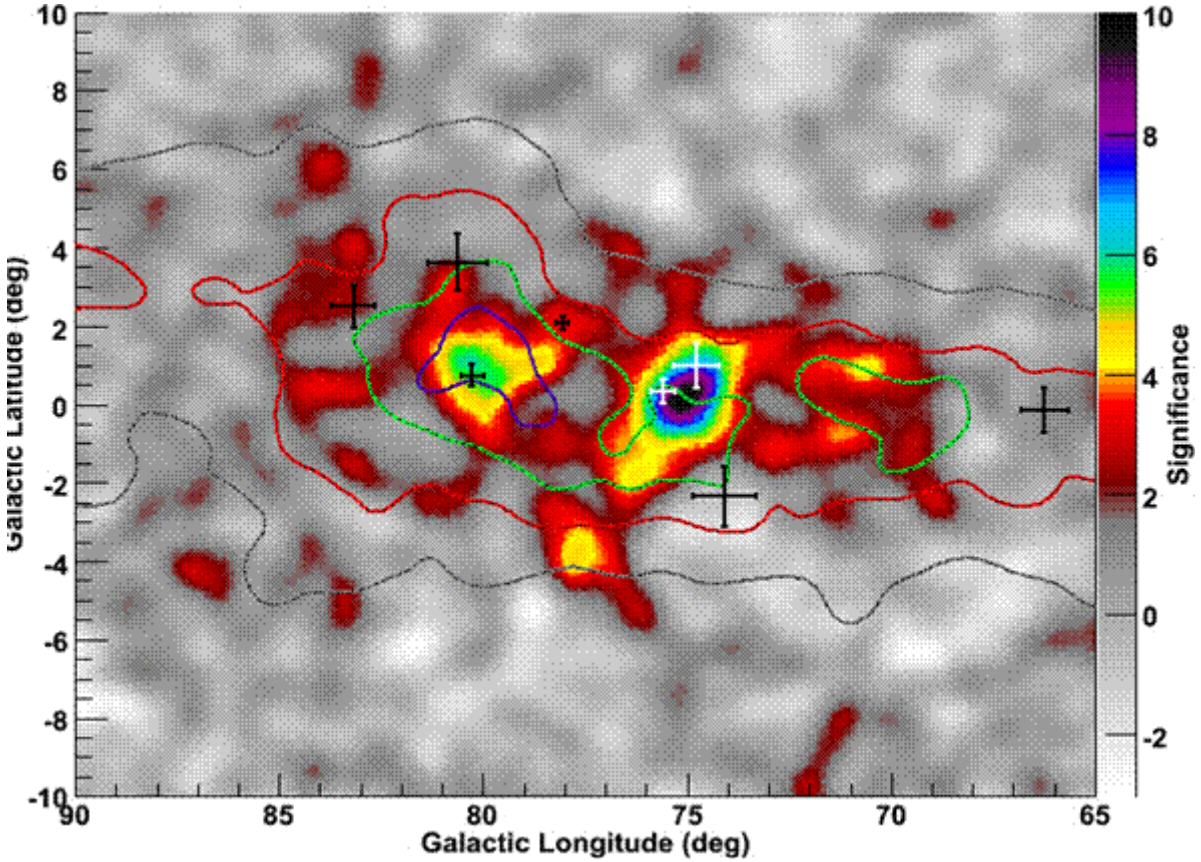


# Young cosmic rays in Cygnus?

- potential accelerators (e.g. gamma Cygni SNR)
- TeV γ-ray diffuse emission measured by Milagro

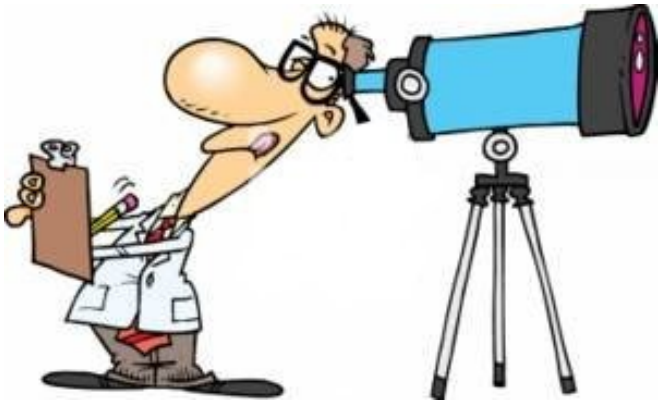
Abdo et al., *ApJL* **658**, 33 (2007)

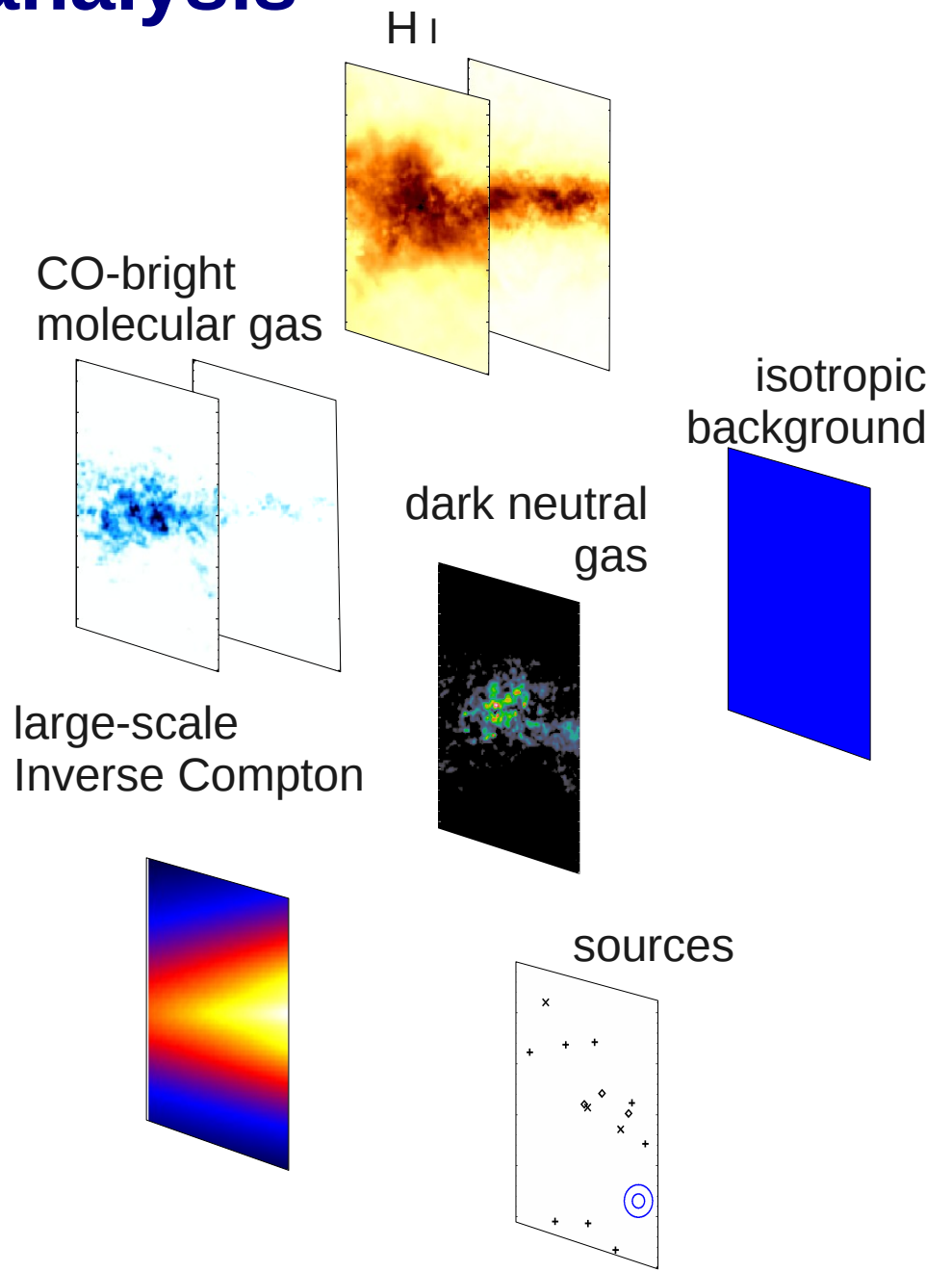


# LAT data analysis

- 2-yr data, 100 MeV-100 GeV tight background rejection criteria
- dimming of bright pulsars by phase selection (< 10 GeV)
- global modeling of the region

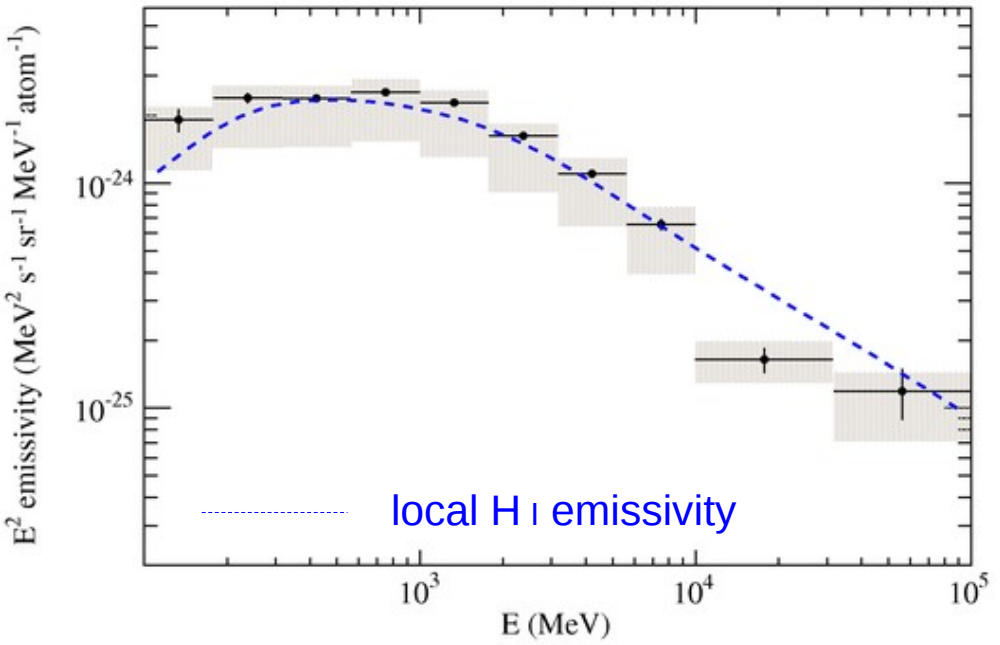
Ackermann et al., *A&A* **538**, A71 (2012)

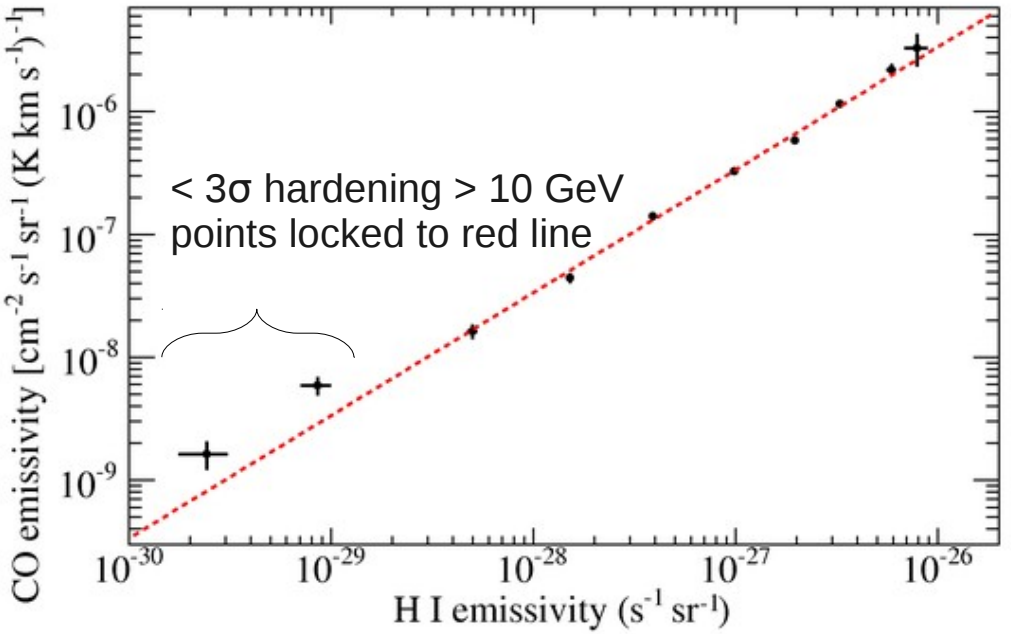




# γ-ray emission from the whole complex

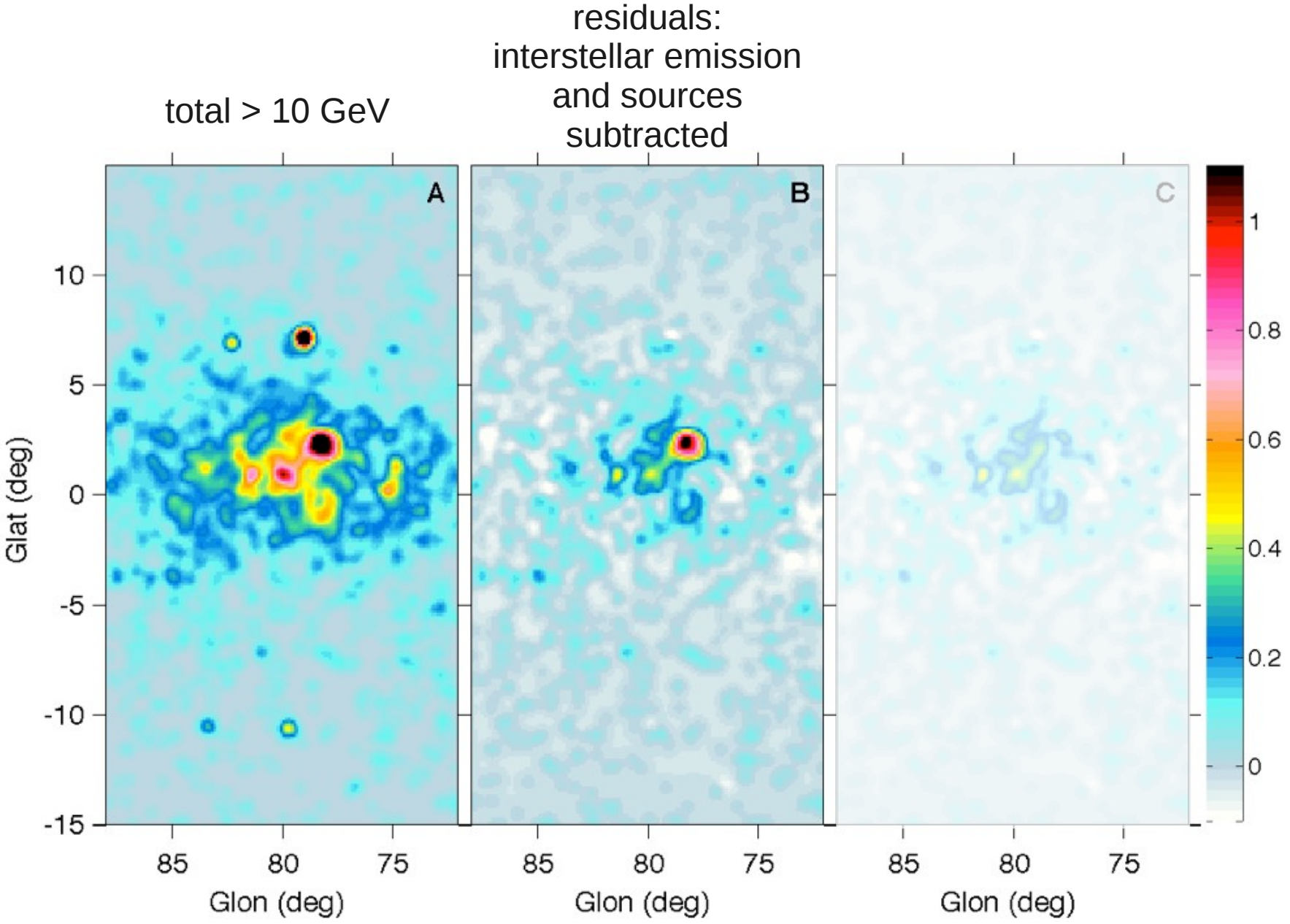
- cosmic-ray spectrum in atomic gas equivalent to solar neighborhood → uniform along local arm within ~20%
- slight hardening for molecular clouds near star-forming region



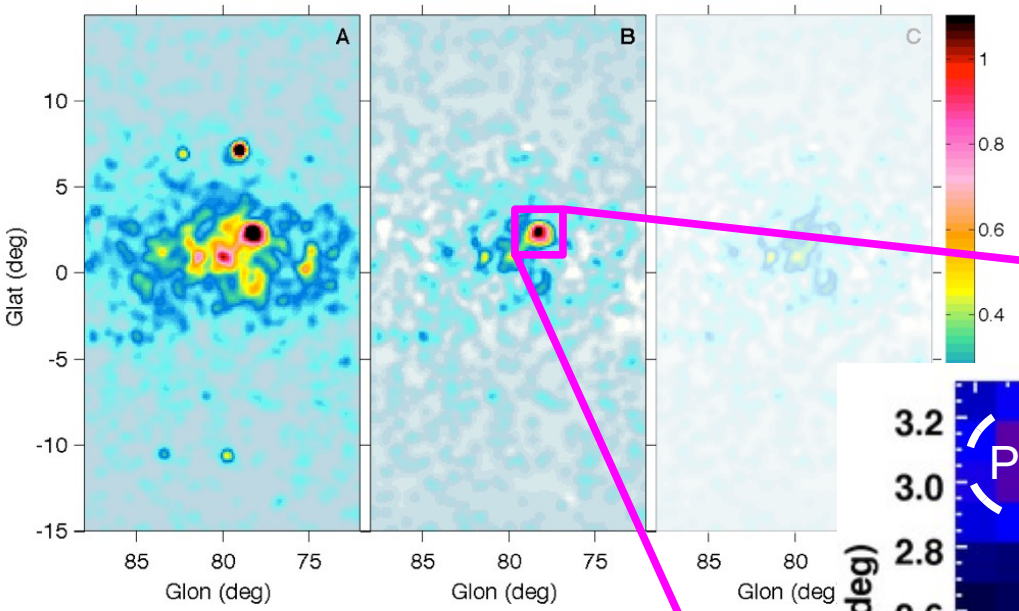

Ackermann et al., *A&A* **538**, A71 (2012)

# Cygnus striptease: an exciting start

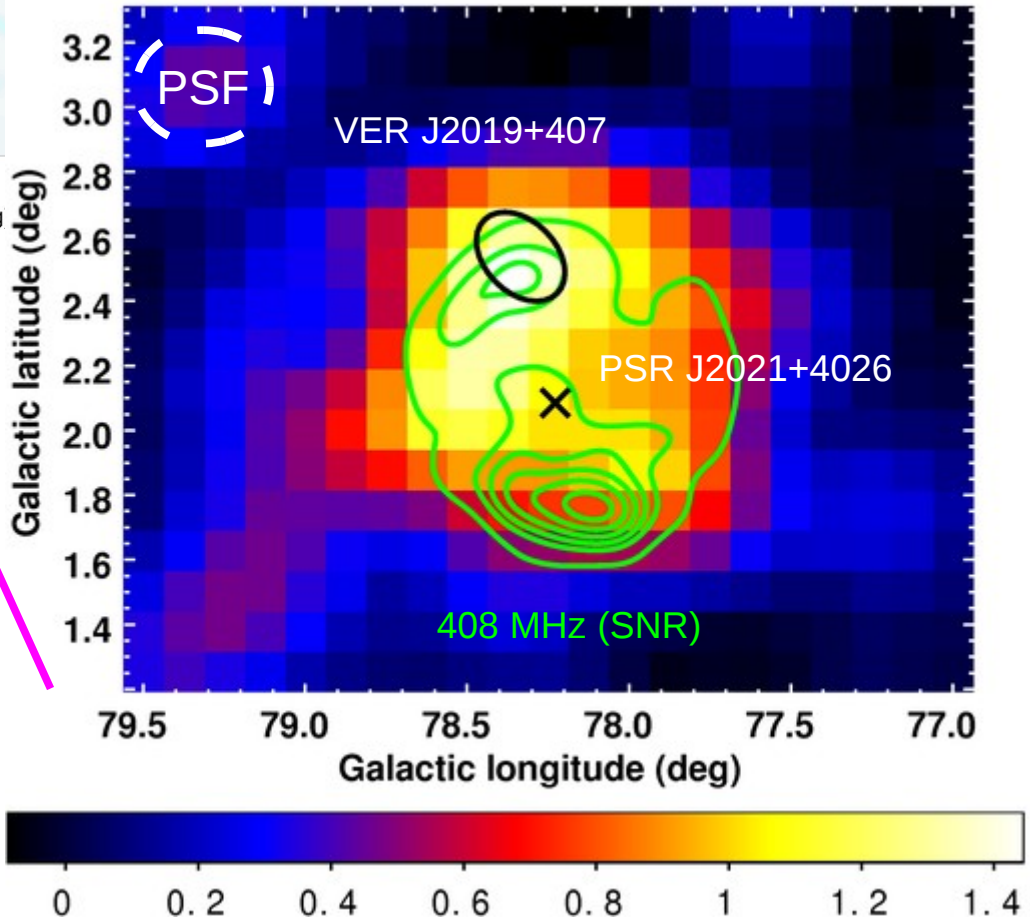



Ackermann et al., *Science* **334**, 1103 (2011)

# The supernova remnant in gamma Cygni

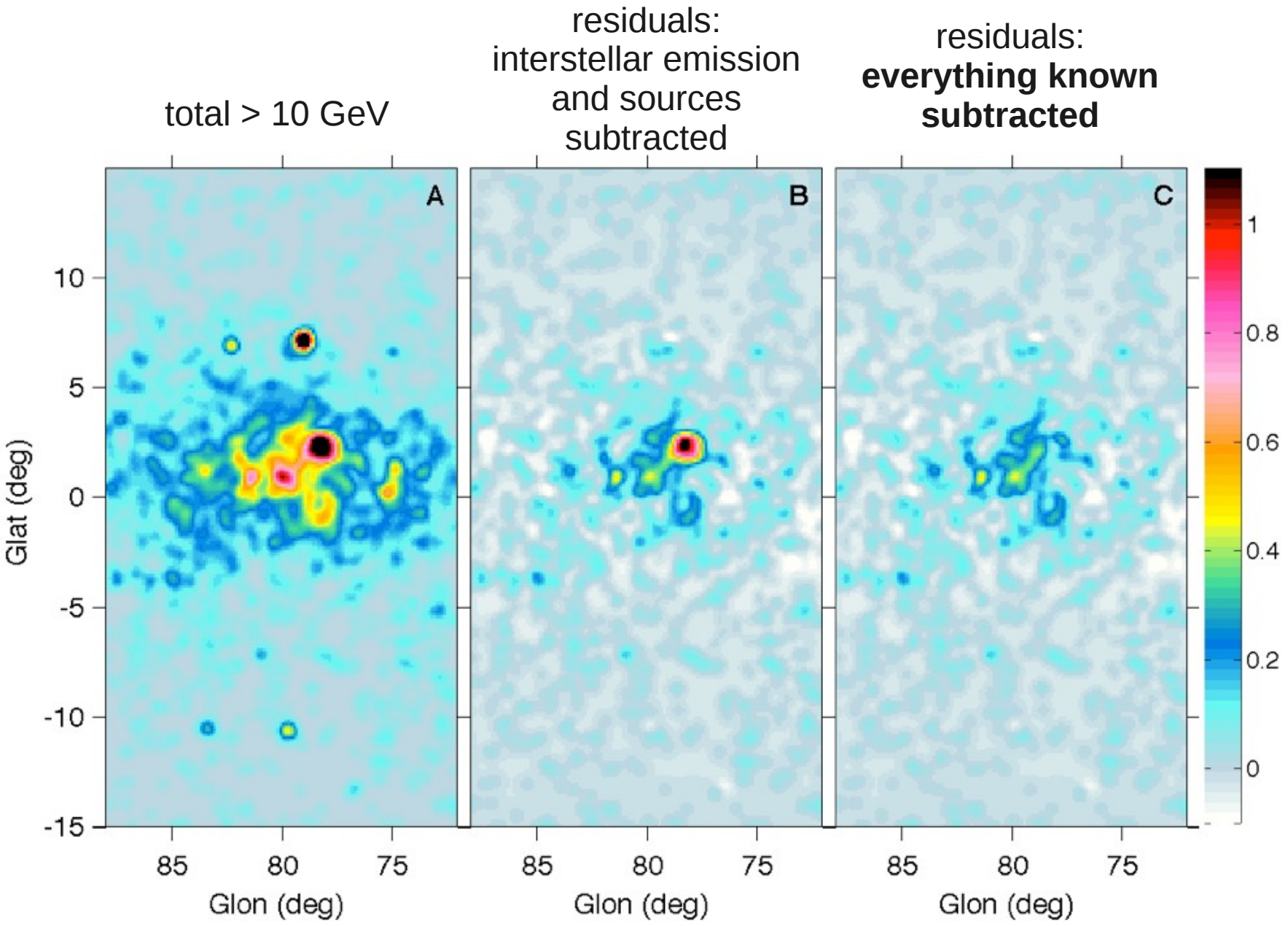



Ackermann et al., *Science* **334**, 1103 (2011)



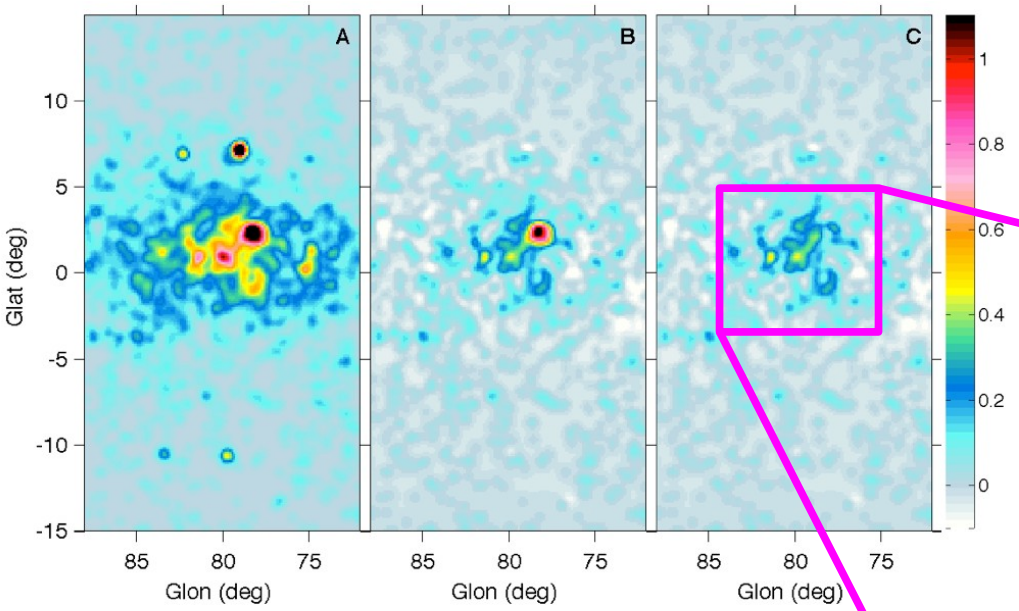

- added to model:
  - 2D Gaussian for VER J2019+407
  - Uniform disc (0.5° radius) for SNR → ~7σ detection
- both disc and VERITAS hot spot have hard spectra up to 100 GeV

# Cygnus striptease: the finale

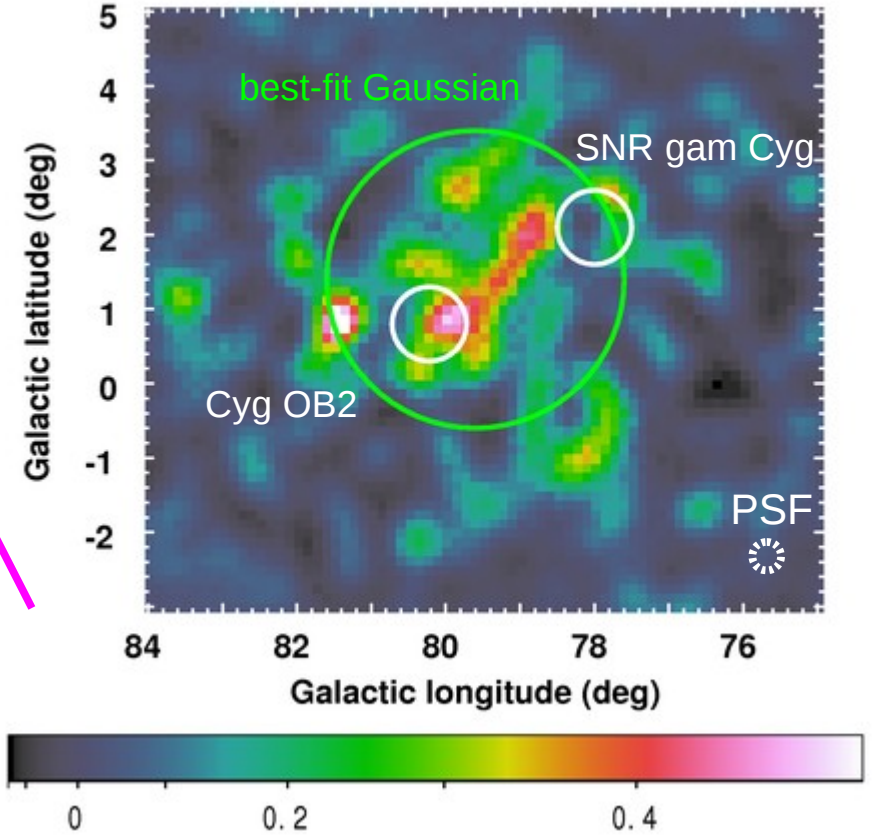



Ackermann et al., *Science* **334**, 1103 (2011)

# A mysterious extended excess




Ackermann et al., *Science* **334**, 1103 (2011)




- 2D Gaussian: 10σ detection
- width σ=2.0°±0.2°
- extended emission preferred over a bunch of sources

# The rich and complex Cygnus X region ...

massive star

massive-star cluster

SNR

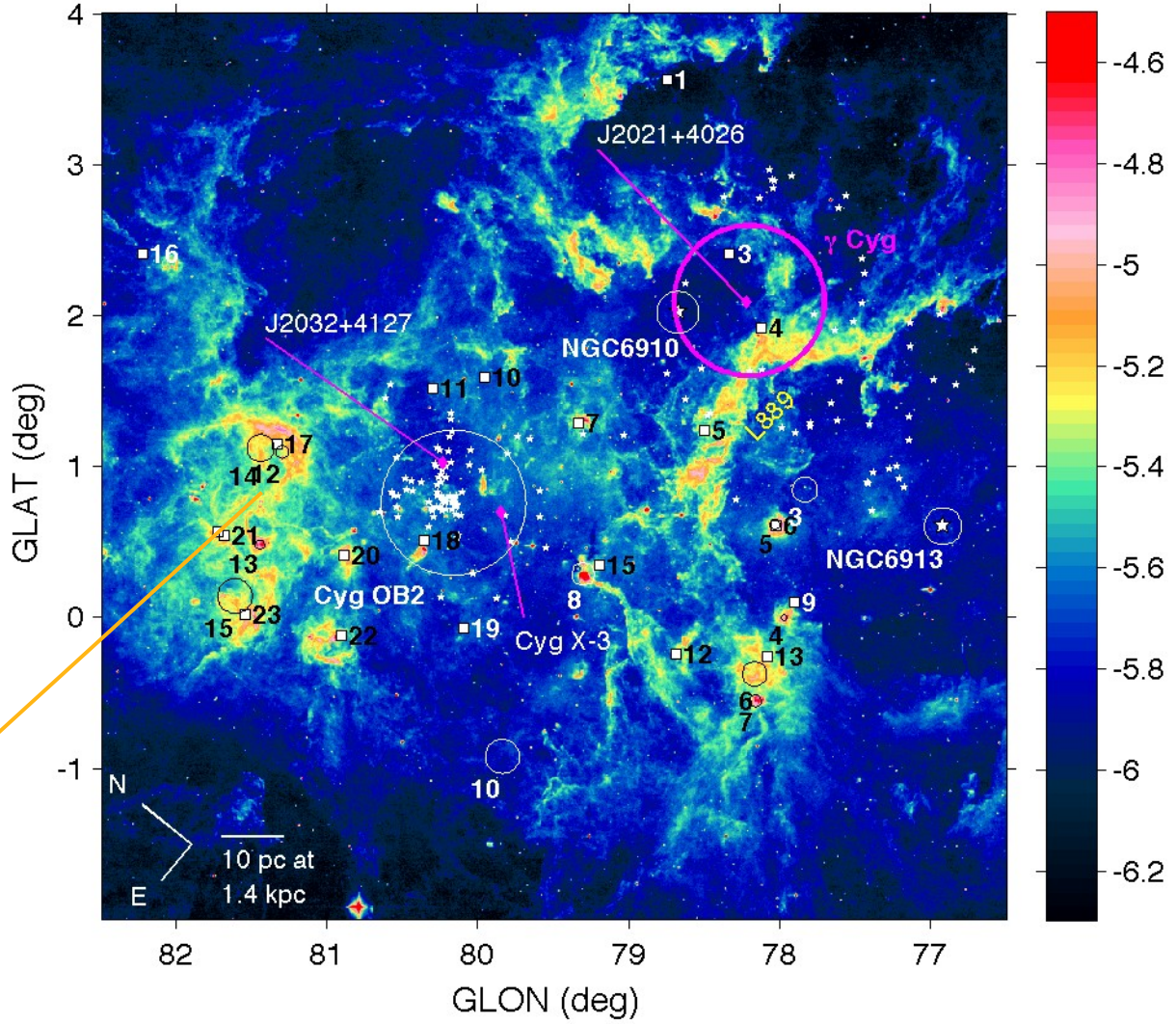
H II region

γ-ray point source

Photon-Dominated Regions (PDRs)

8 μm – MSX (W m$^{-2}$ sr$^{-1}$)

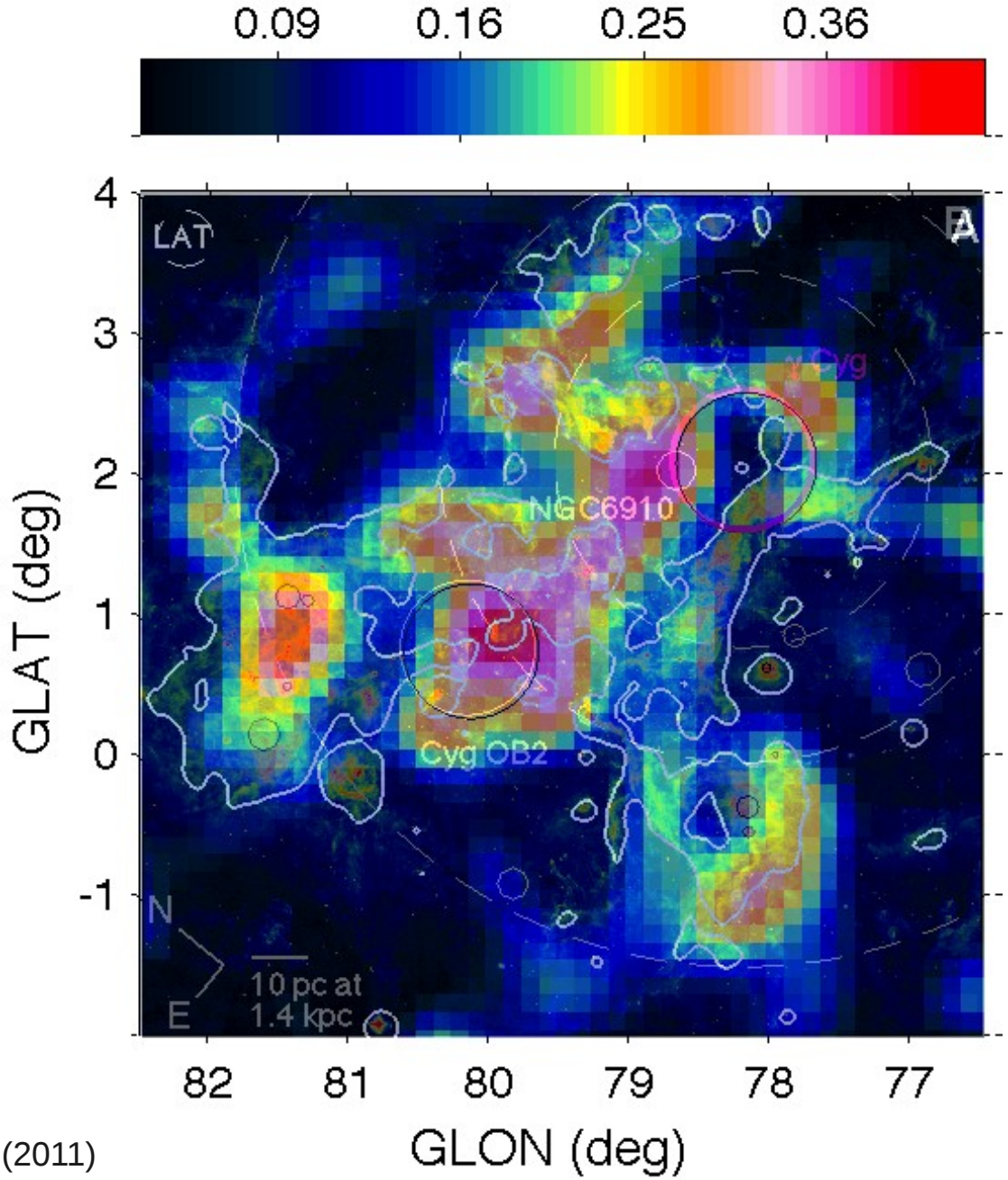
MSX = Midcourse Space Experiment




Ackermann et al., *Science* **334**, 1103 (2011)

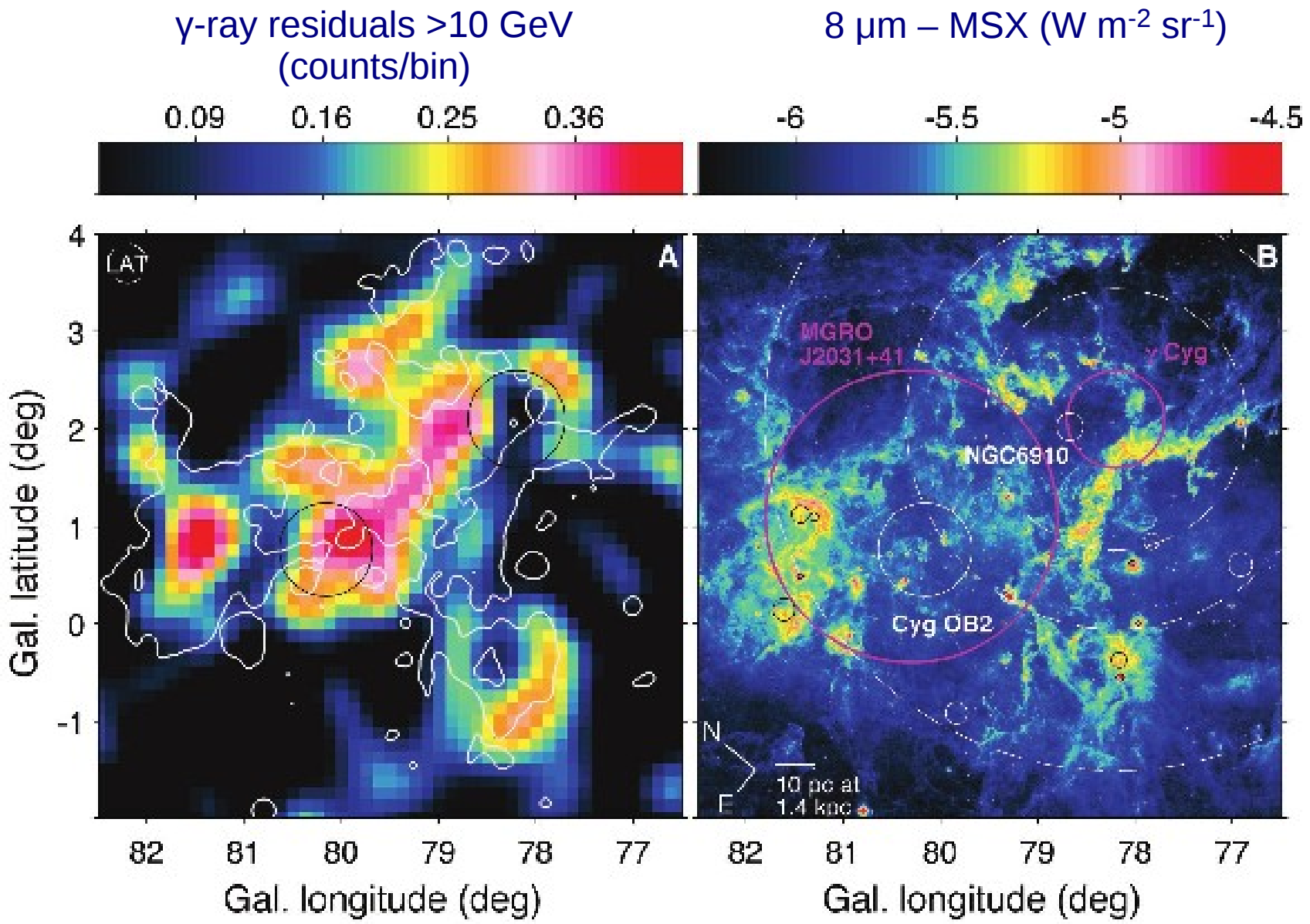
# … and the γ-ray excess

γ-ray residuals
>10 GeV
(counts/bin)




Ackermann et al., *Science* **334**, 1103 (2011)

# Interstellar origin!




Ackermann et al., *Science* **334**, 1103 (2011)

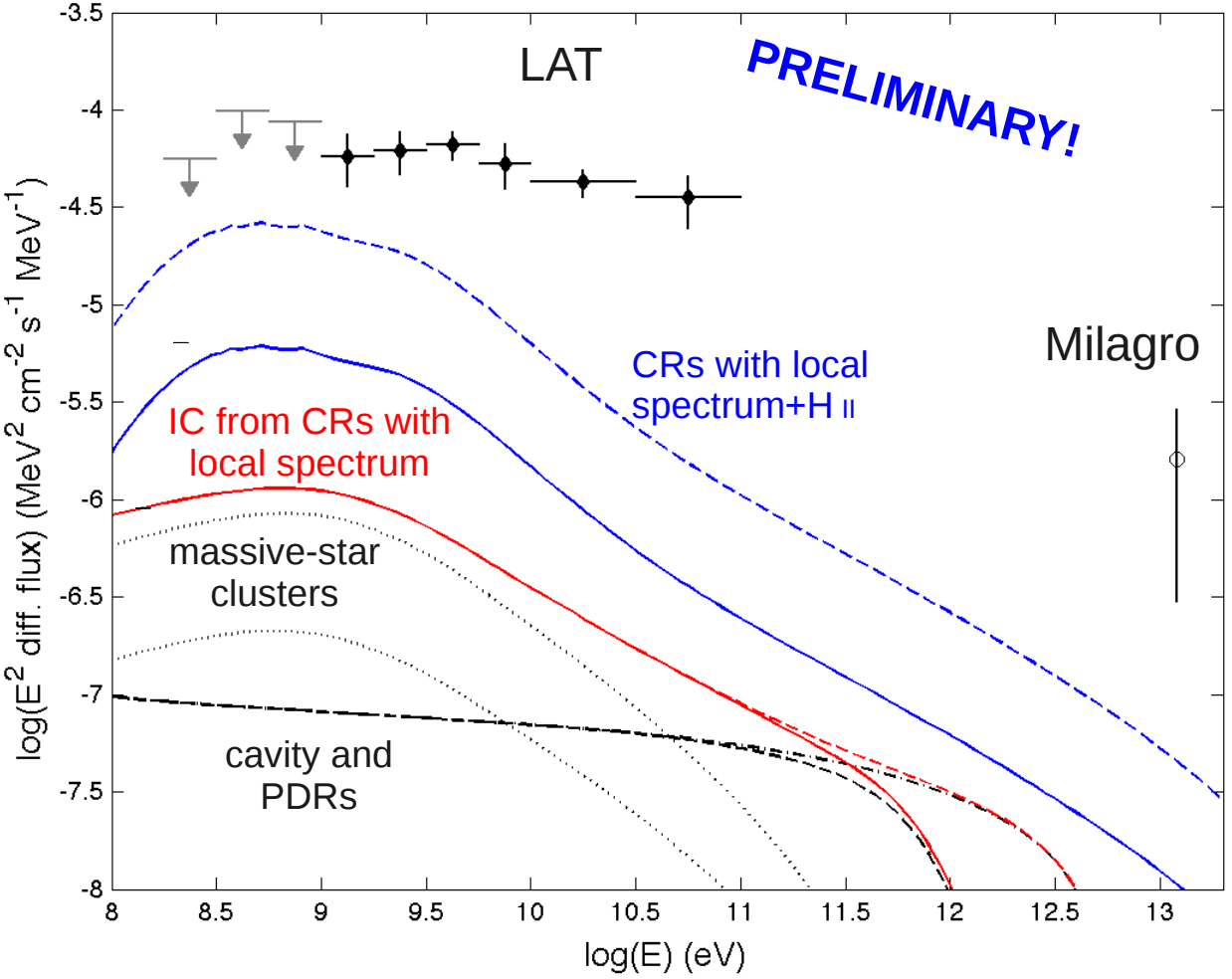
# A cocoon of freshly-accelerated cosmic rays

- hard → Milagro
- requires **freshly-accelerated particles**:
  - hadronic → too soft (any gas phase)
    - if purely hadronic

$$\frac{dN}{dE} \times (1.5-2) \left( \frac{E}{10\ GeV} \right)^{0.3}$$

  - leptonic → too faint and soft
    - if purely leptonic

$$n \times 60, E^{-2.7}\ at\ E > 4\ GeV$$



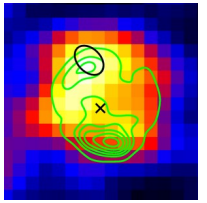

Ackermann et al., *Science* **334**, 1103 (2011)

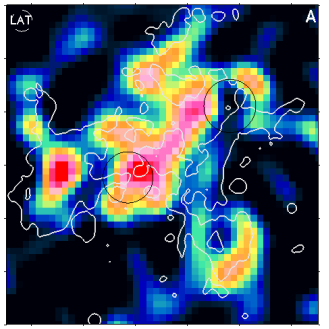
# Where do the particles come from?

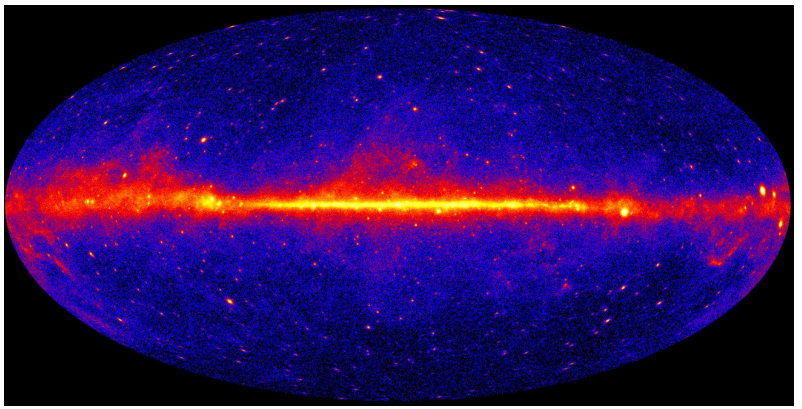
- gamma Cygni SNR
  - γ-ray bright
  - energetics OK
  - CRs spread over cocoon in ~5 kyr for diffusion in normal ISM
  - relation with Cygnus X unclear
  - anisotropic particle release
  - energy-independent size
  - strong turbulence → diffusion coefficient 100 times smaller than in the Galaxy at large
- superbubble
  - not many SNRs, stellar winds only
  - energetics OK
  - particles confined for ~100 kyr

# Final remarks

- massive star-forming regions host cosmic-ray factories
- first snapshot of young cosmic rays in superbubble environment
- over interstellar complex (~ 400 pc) cosmic-ray environment similar to the rest of the local arm



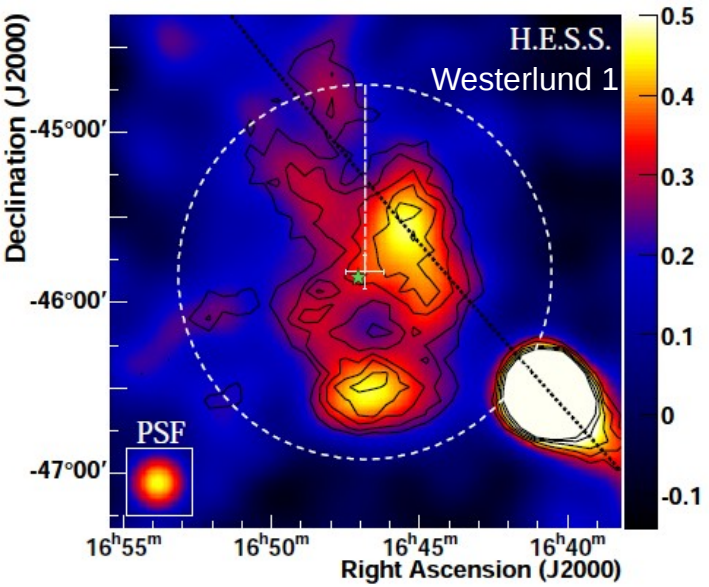


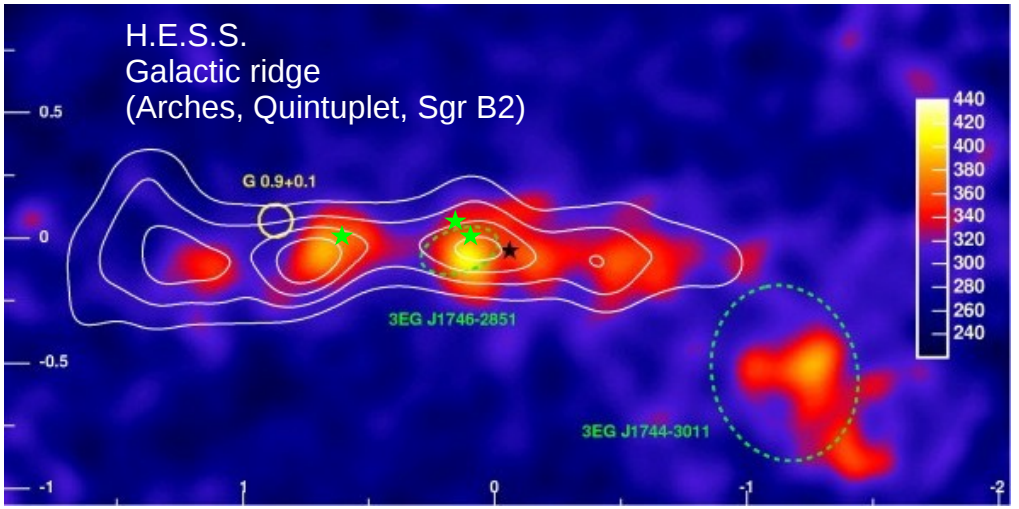
# Perspectives

- theory of acceleration/transport in superbubble environments
- with HE data: look for spectral variations → distributed process or single accelerator?
- understand VHE diffuse emission from massive star-forming regions (H.E.S.S., future CTA)

Abramowski et al., *A&A* **537**, A114 (2012)




Aharonian et al., *Nature* **439**, 695 (2006)



# Backup

# Cosmic-ray acceleration in gamma Cygni

- Now:
  - $v_{sh}$ ~ 800 km/s
  - $n_{ext}$ ~0.3 $cm^{-3}$
  - $B_{ext}$ ~5 μG
  - age ~7 kyr
- for massive star progenitor, $10^{51}$ erg
  - end of free expansion ~5 kyr ago
  - $E_{max}(p)$ ~ 80 – 200 TeV
  - $E_{max}(e)$ ~ 30 – 50 TeV (sync,IC)

# Superbubble scenario

- Each WR or O star
  - $v_w$ ~$10^3$ km/s
  - $10^{37}$ erg/s
  - 100 kyr
- for $p_{gas}$ ~1.4 $10^{-12}$ Pa (18 μG) the termination shock is at ~10 pc → distance between massive stars
- $E_{max}(p)$ ~ 150 TeV
- $E_{peak}(p)$ ~ 30-100 GeV
- acceleration time ~10 kyr
- diffusion coefficient 100 smaller