

MCELS



Particle accelerators in another galaxy
The Large Magellanic Cloud
observed with Fermi and H.E.S.S.

Pierrick Martin
(presenting the work
of many people in
Fermi and H.E.S.S.
collaborations)

Context

- Unprecedented sensitivity level in gamma-ray observations of the LMC
- 200h exposure with H.E.S.S. (TeV)
- 7 years allsky survey with Fermi (GeV)
- Detection of (exceptional) gamma-ray point sources

The exceptionally powerful TeV gamma-ray emitters in the LMC

H.E.S.S. collab., Jan 2015, Science, 347, 6220

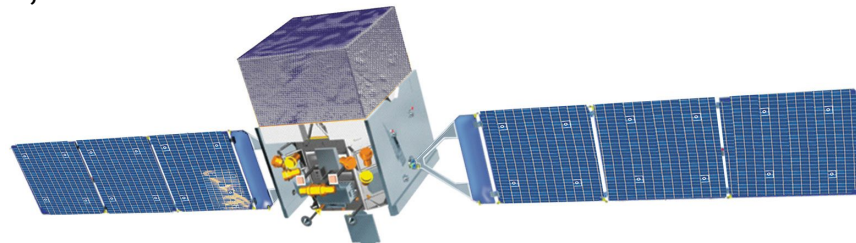
(Lead: Nukri Komin)



Deep view of the LMC with 6 years of Fermi-LAT observations

Fermi collab., Jan 2016, A&A, 586, A71

(Lead: Pierrick Martin)



The Large Magellanic Cloud

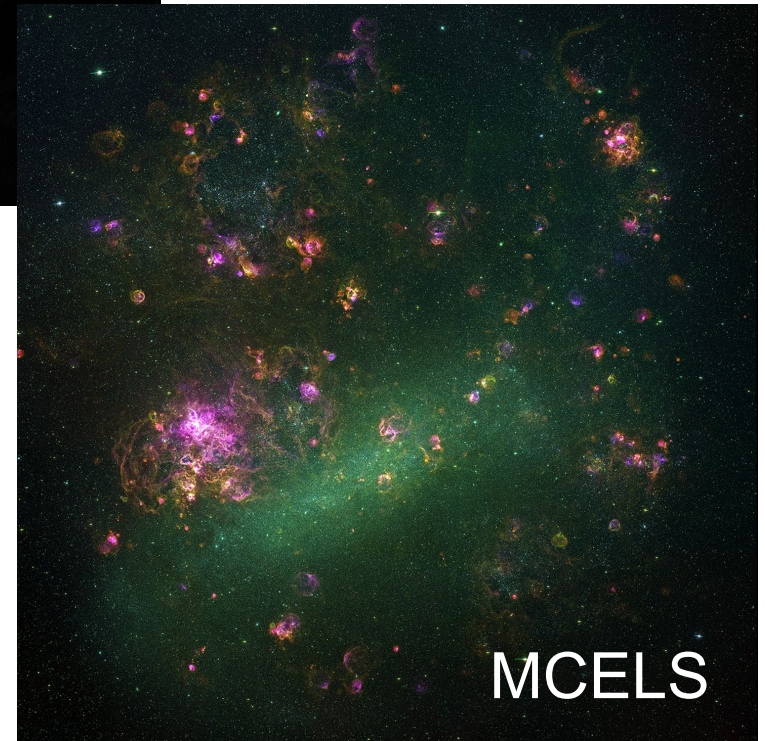


Properties

- Satellite dwarf galaxy
- Nearby ($50 \pm 1 \text{ kpc}$)
- Face-on ($i \sim 30^\circ$)
- Large ($7 \text{ kpc } \varnothing, 8^\circ$)
- Active ($0.2 M_\odot/\text{yr}$)

Why astronomers care

An entire galaxy
Clear line of sight
Accurate distance
Deeply surveyed
Exceptional objects



The Large Magellanic Cloud



Properties

- Satellite dwarf galaxy
- Nearby ($50 \pm 1 \text{ kpc}$)
- Face-on ($i \sim 30^\circ$)
- Large ($7 \text{ kpc } \varnothing$, 8°)
- Active ($0.2 M_\odot/\text{yr}$)

Why HE/VHE astronomers care

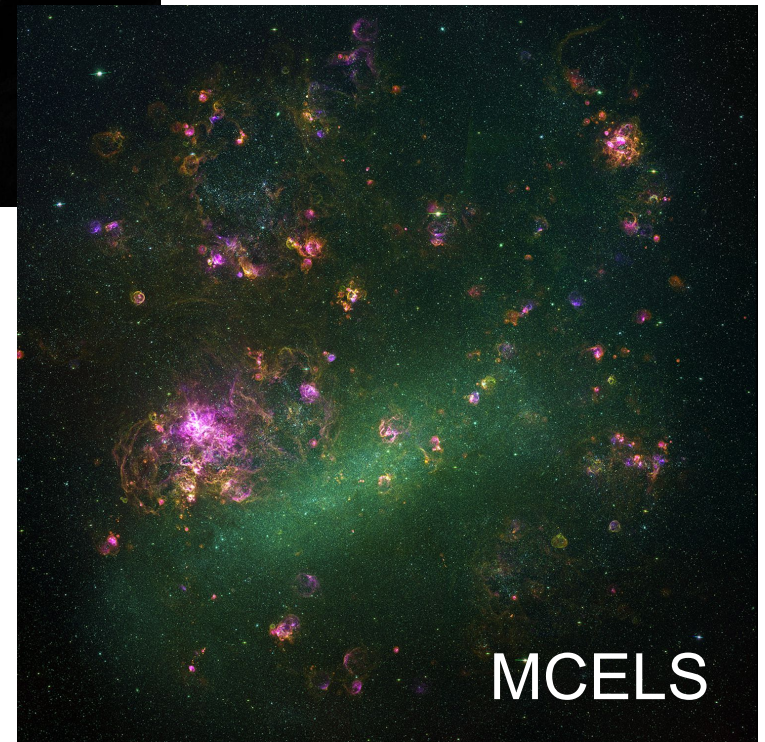
60 supernova remnants

25 pulsars

5 pulsar wind nebulae

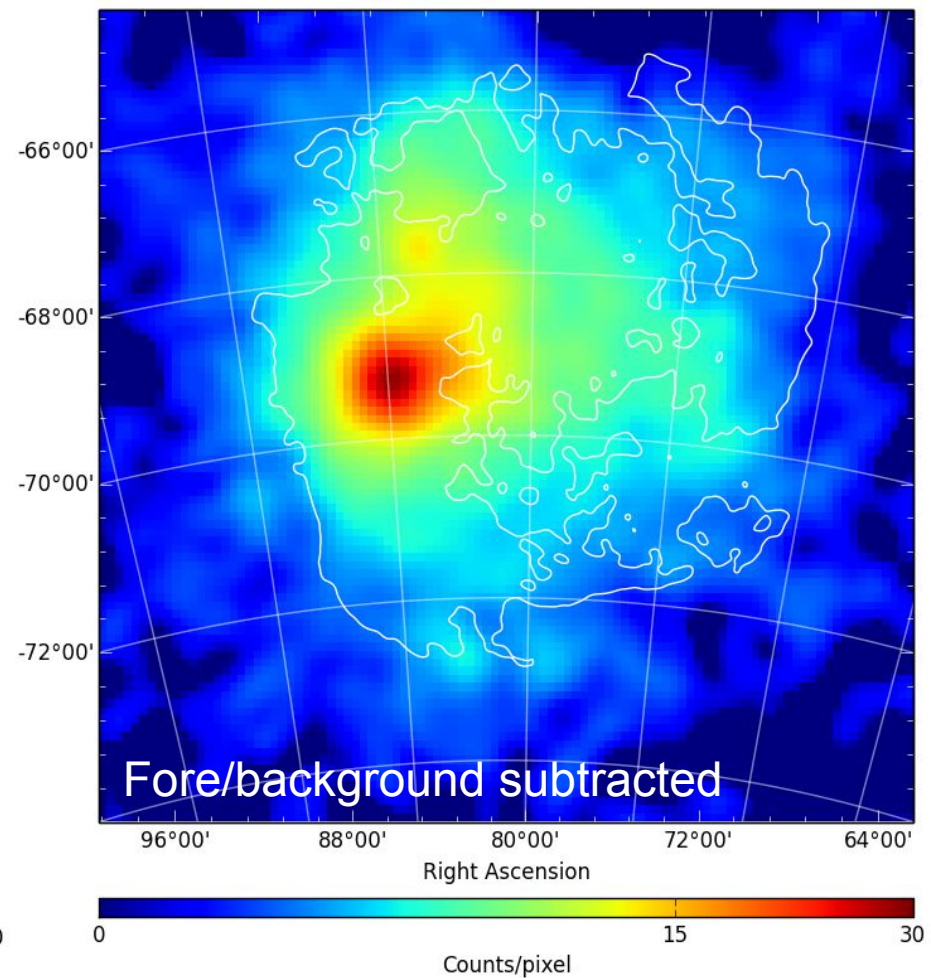
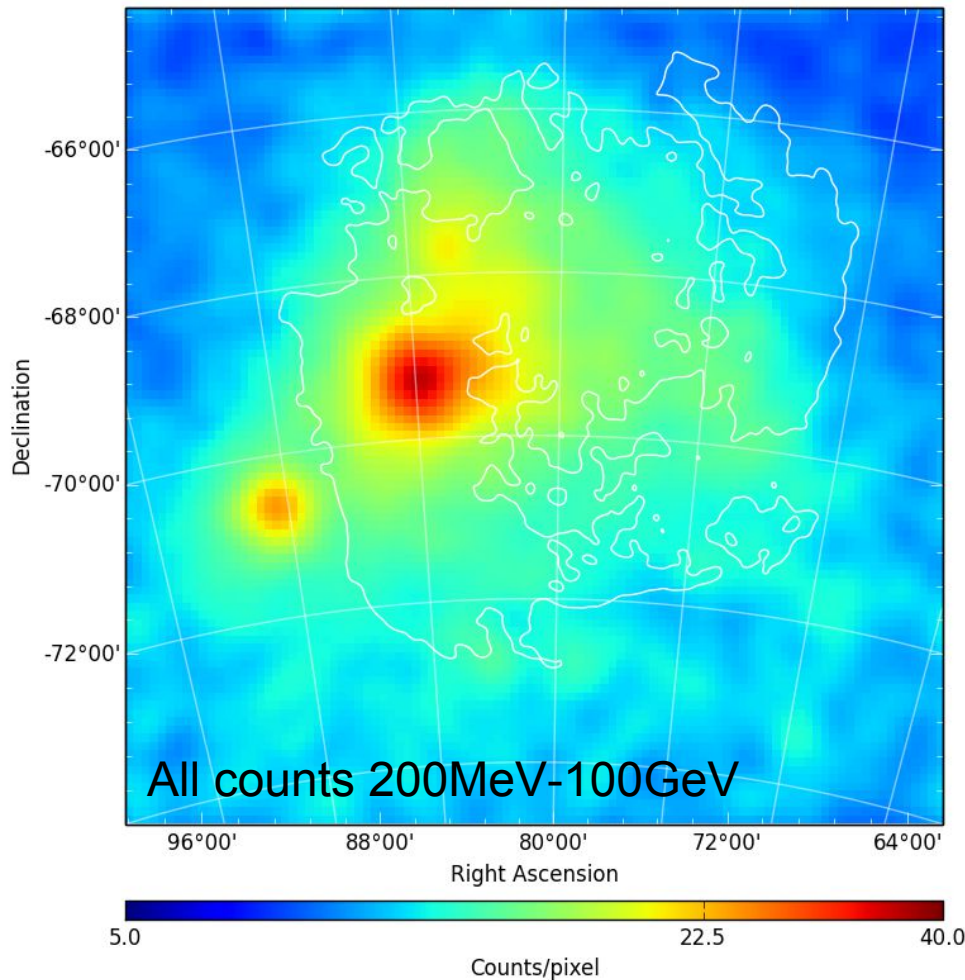
SN/SNR 1987A

30 Doradus region



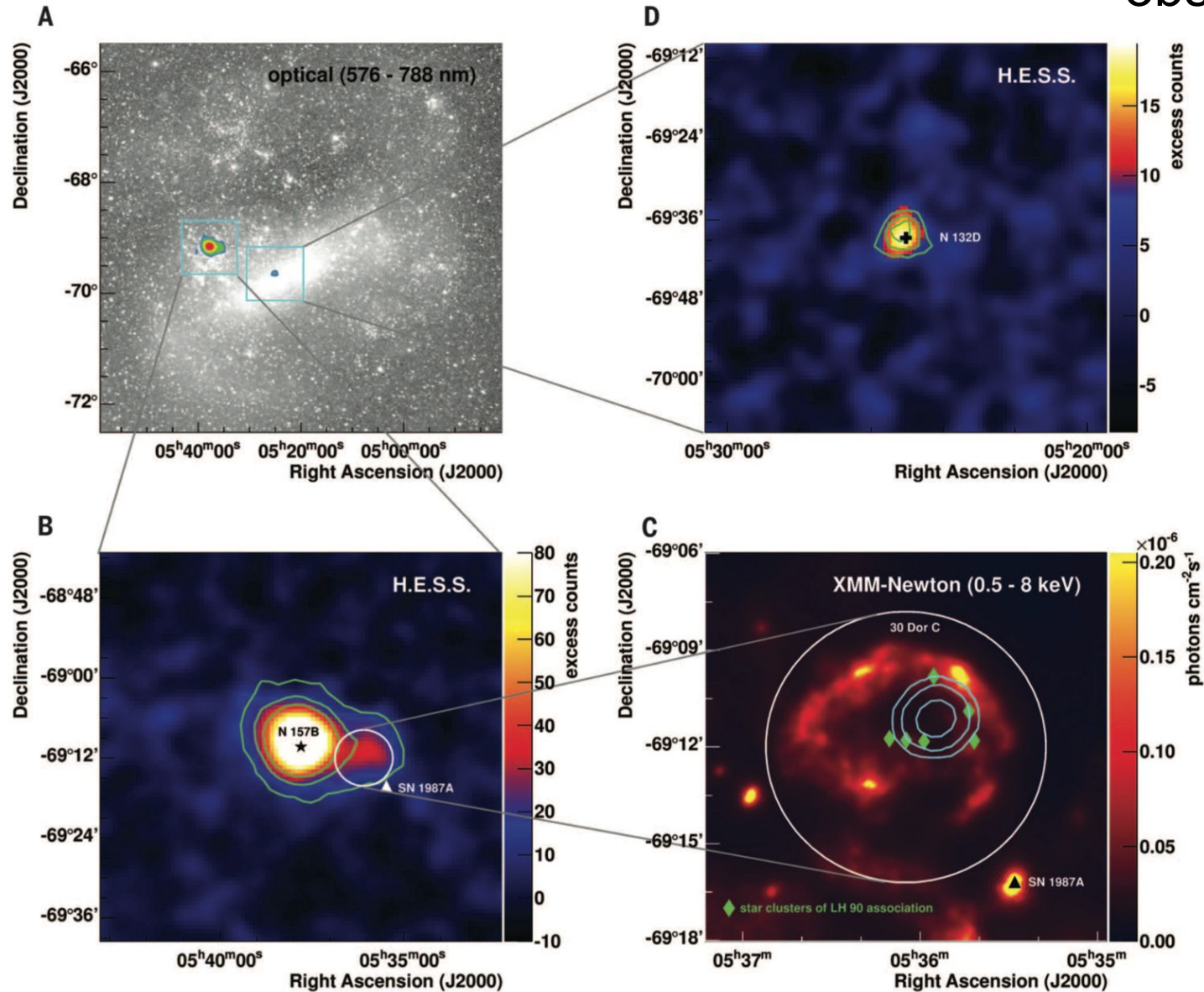
The LMC in GeV gamma-rays

6 years of all-sky survey data



The LMC in TeV gamma-rays

200h pointed observations

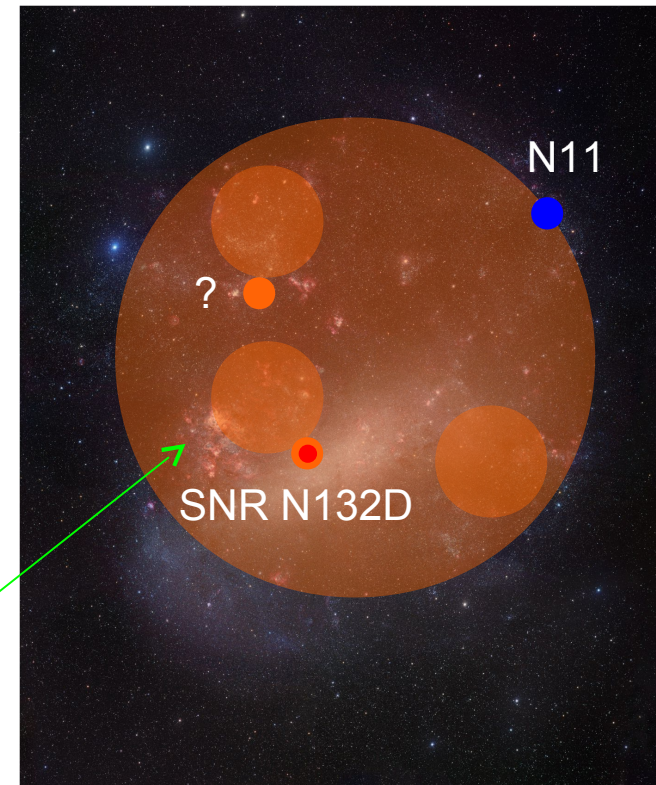
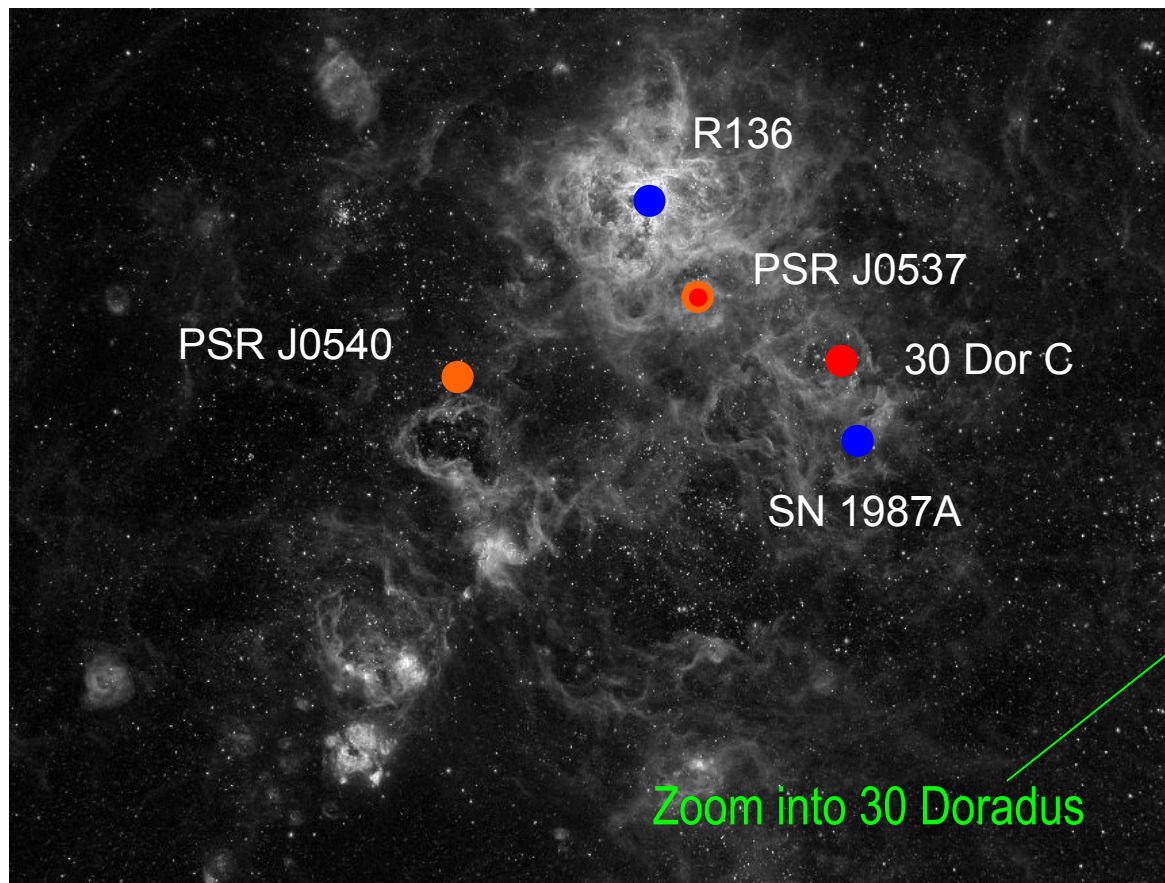


Schematic view

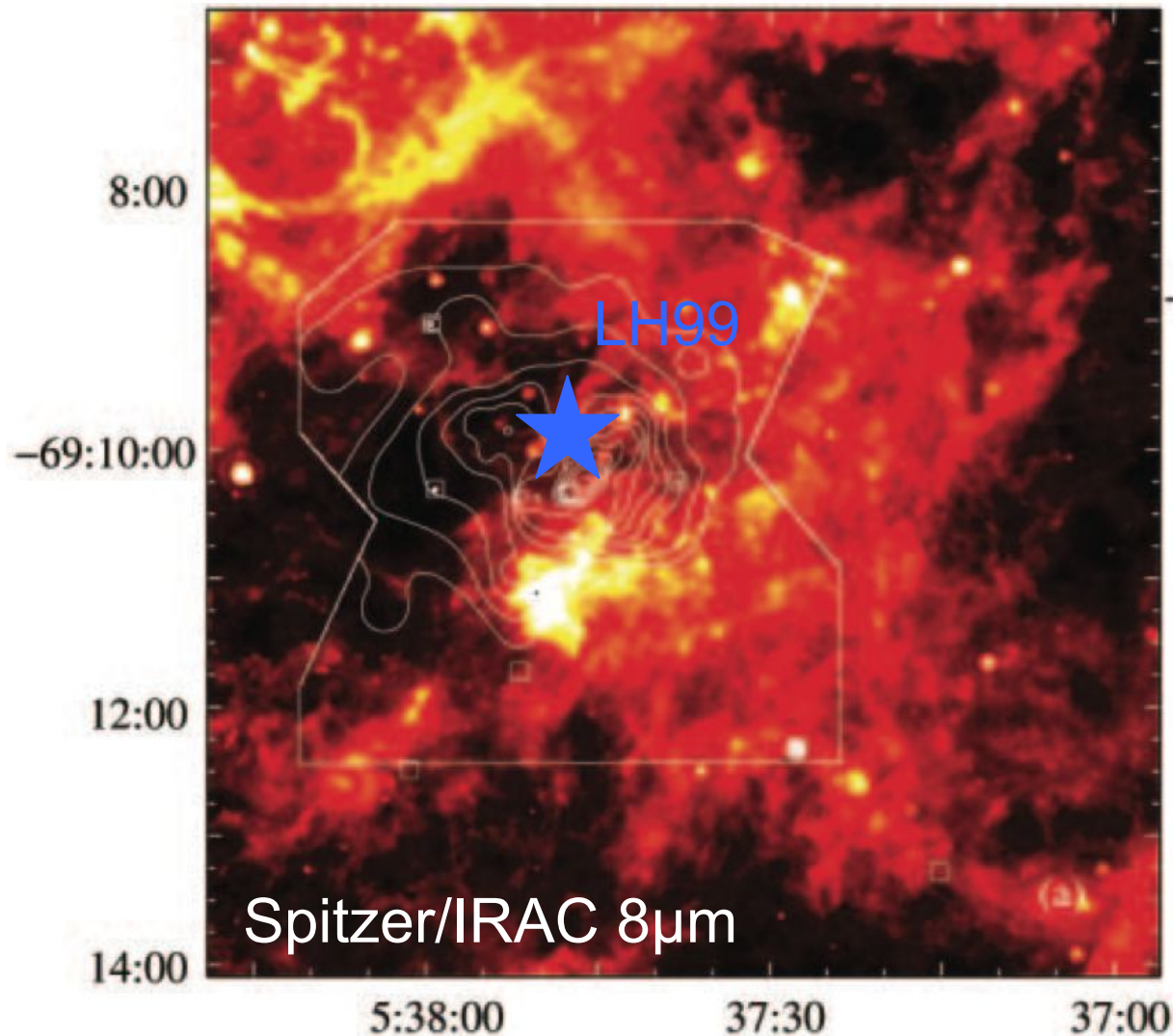
Fermi (6 yrs): 4 point sources, 4 extended emission regions

HESS (200h): 3 point sources

(possible) constraints on non-detected sources



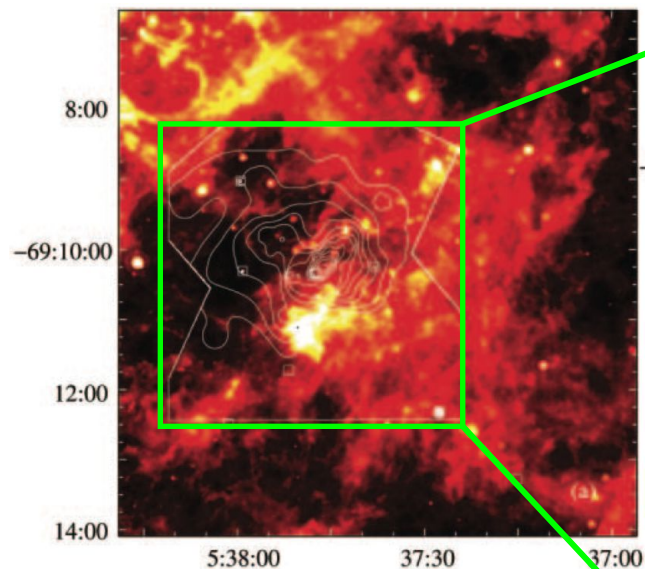
PSR J0537-6910 – N157B



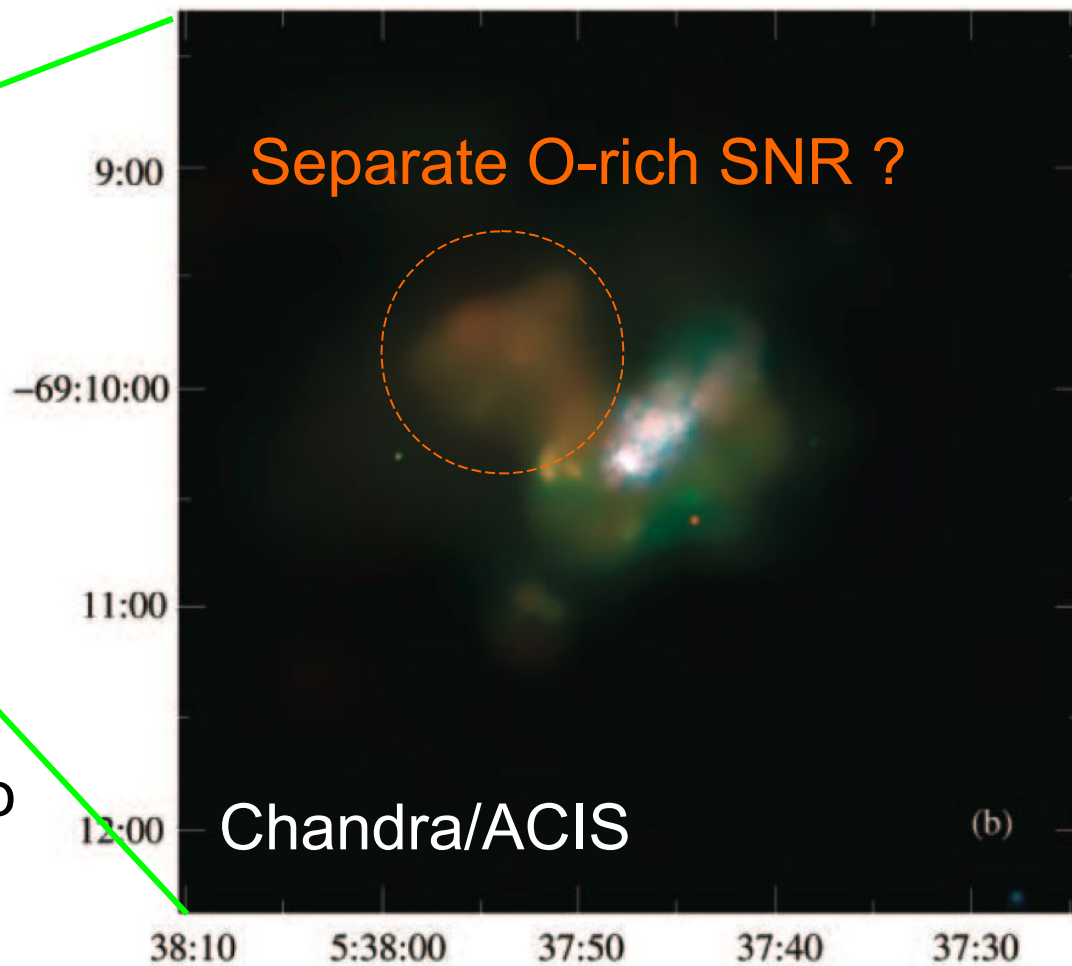
Superbubble carved
by young OB
association LH 99
(still containing O3
stars)

Uncertain shape of
cavity, projection
effects

PSR J0537-6910 – N157B



SNR from $\sim 25M_{\odot}$
progenitor expanding into
low-density volume
Very large size (30pc)



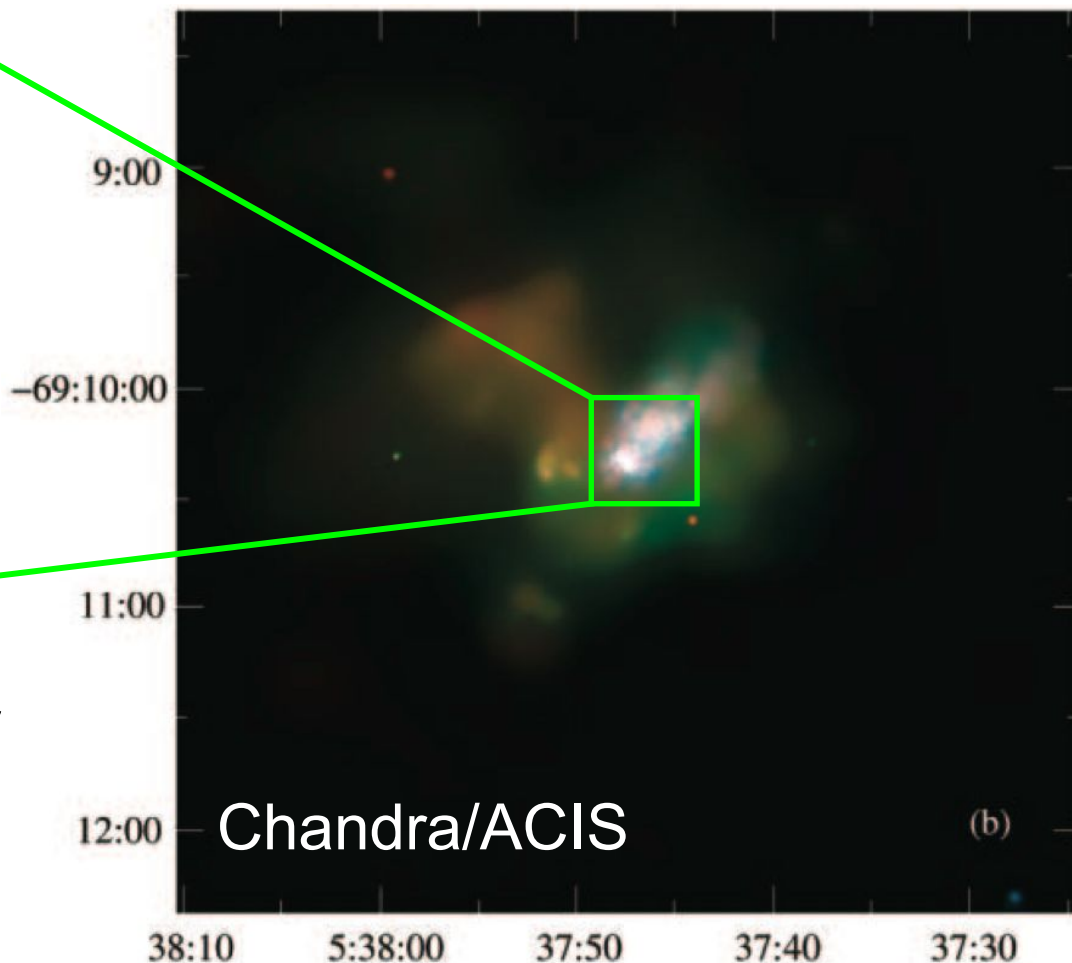
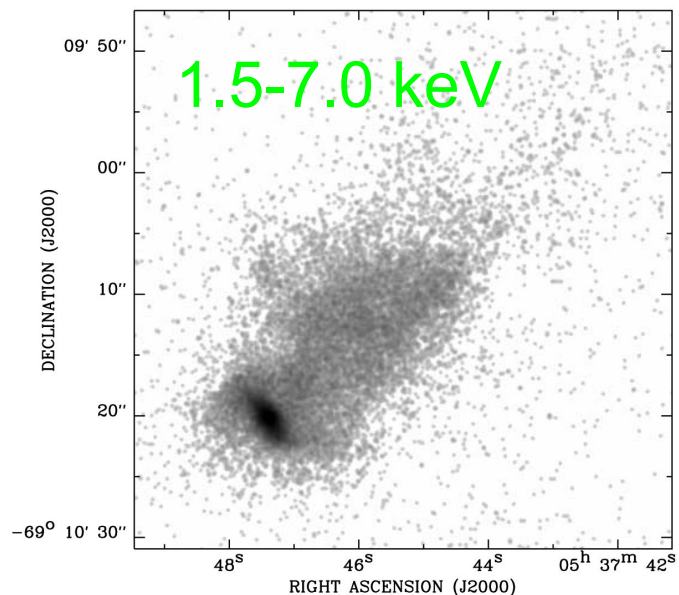
Separate O-rich SNR ?

Chandra/ACIS

No clear SNR outer shock

No evidence for shock/impact on cavity walls (*Micelotta-2009*)

PSR J0537-6910 – N157B



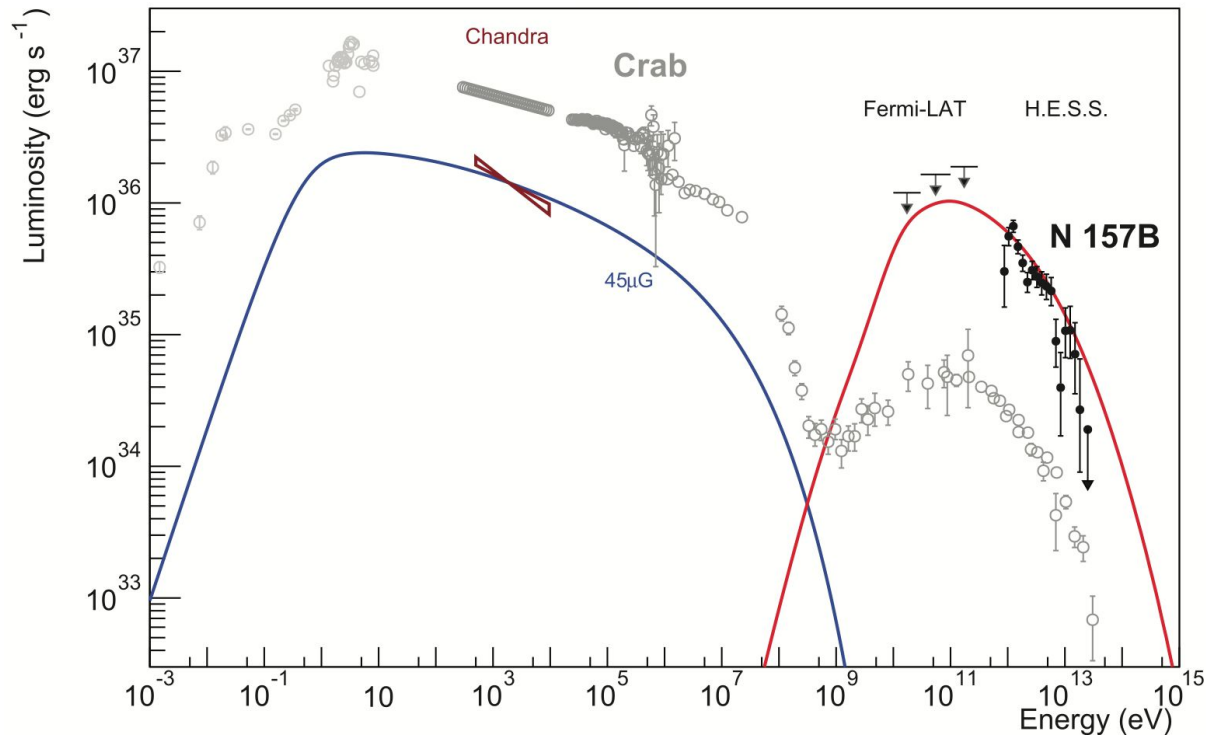
Powerful ~ 5000 yr pulsar
Large PWN expanding
into low-pressure SNR

Bar: torus, termination shock
Tail: synchrotron-cooling flow

(from one-sided pressure confinement and not pulsar kick)

(Chen-2006)

PSR J0537-6910 – N157B



Most luminous TeV PWN known

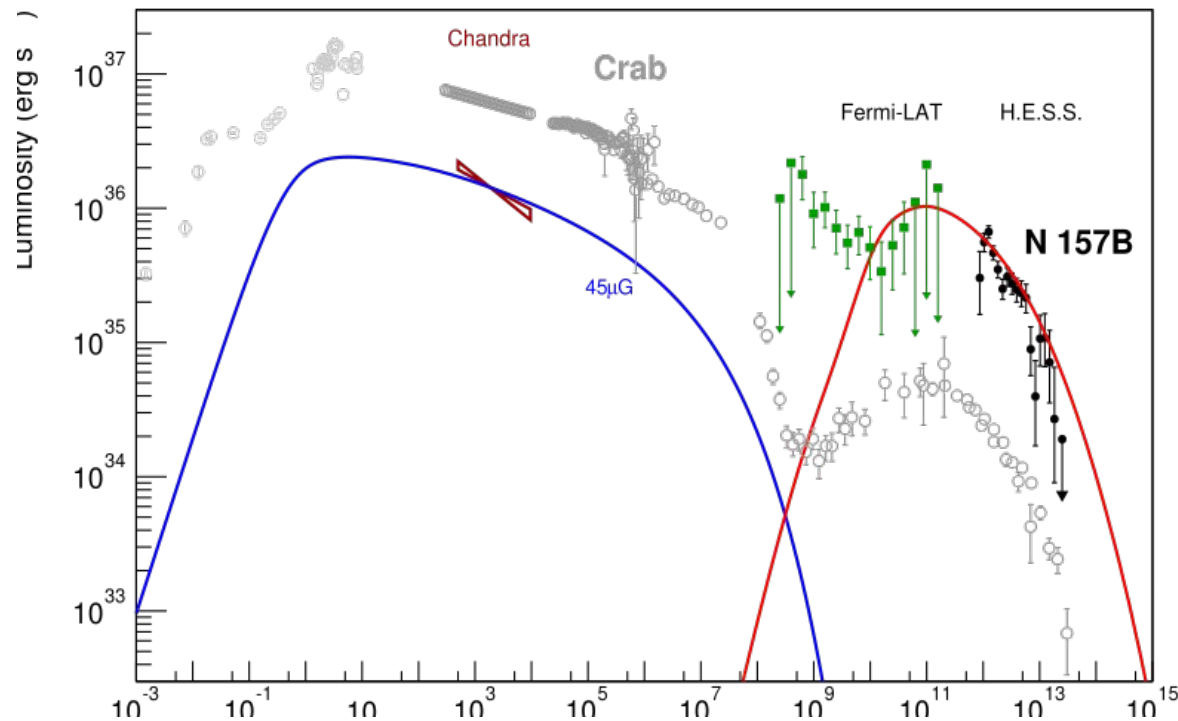
...because most powerful pulsar known (17ms, 4.9e38 erg/s)

... and rich photon field for IC (thanks LH99, 10-20 eV/cm³)

Still: inefficient particle accelerator: 11% into >400GeV pairs

Rest going into expansion, escape, lower energies ?

PSR J0537-6910 – N157B

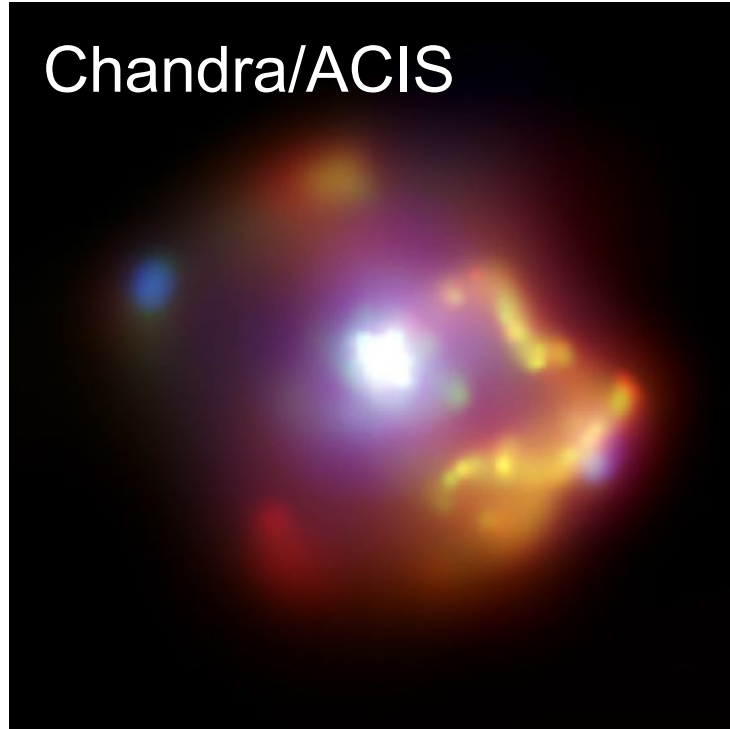


Fermi-LAT data suggesting a 2nd emission component
SNR contribution not favoured (weak shock in tenuous medium)
Pulsar may contribute at GeV with weakly-modulated emission

Need for dedicated modelling of PWN including all particle energies and the cooling tail

PSR J0540-6919 – SNR 0540-69.3 – N158A

Chandra/ACIS



700-1700yr plerion
O-rich remnant
 $\sim 25M_{\odot}$ progenitor

West:

Interaction with denser material
Thermal emission @ 0.5-1.5 keV
Shocked circumstellar medium

East:

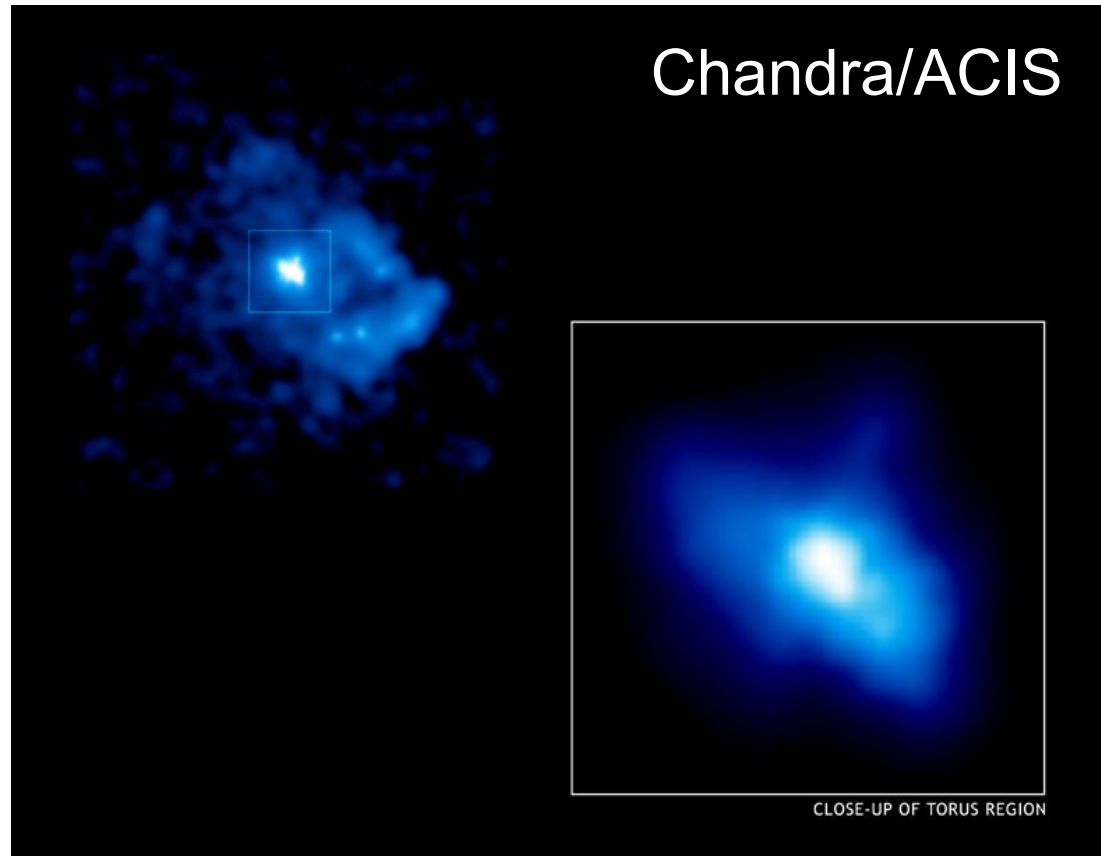
Unclear origin

Thermal emission @ 3keV
...or non-thermal power law

Shell interacting with local
clouds or progenitor's winds.
Symmetric blast wave
suggests dense phase
entered recently

(Park-2010, Brantseg-2014)

PSR J0540-6919 – SNR 0540-69.3 – N158A



(Petre-2007)

Crab-like synchrotron nebula

Powered by 3rd most powerful pulsar known (50ms, 1.5×10^{38} erg/s)

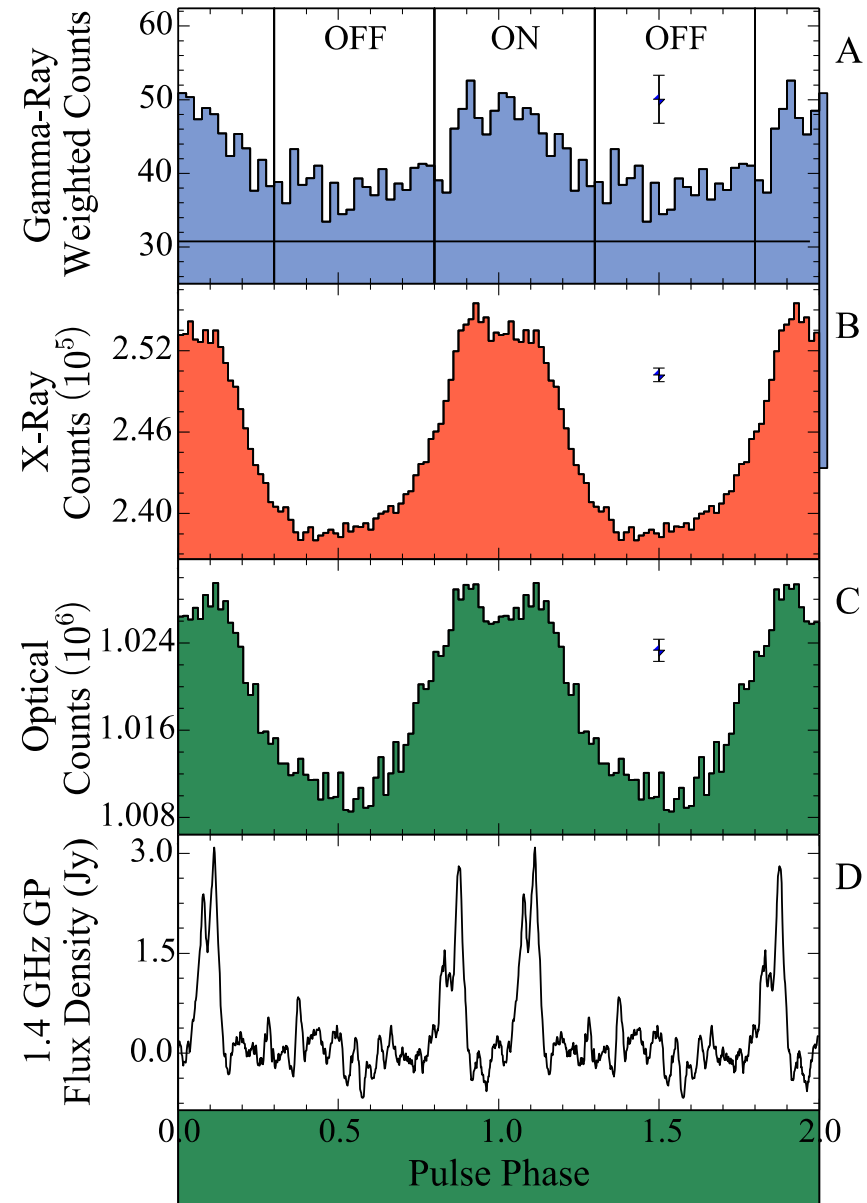
Driving shock in freely expanding remnant (OIII emission)

PSR J0540-6919 – SNR 0540-69.3 – N158A

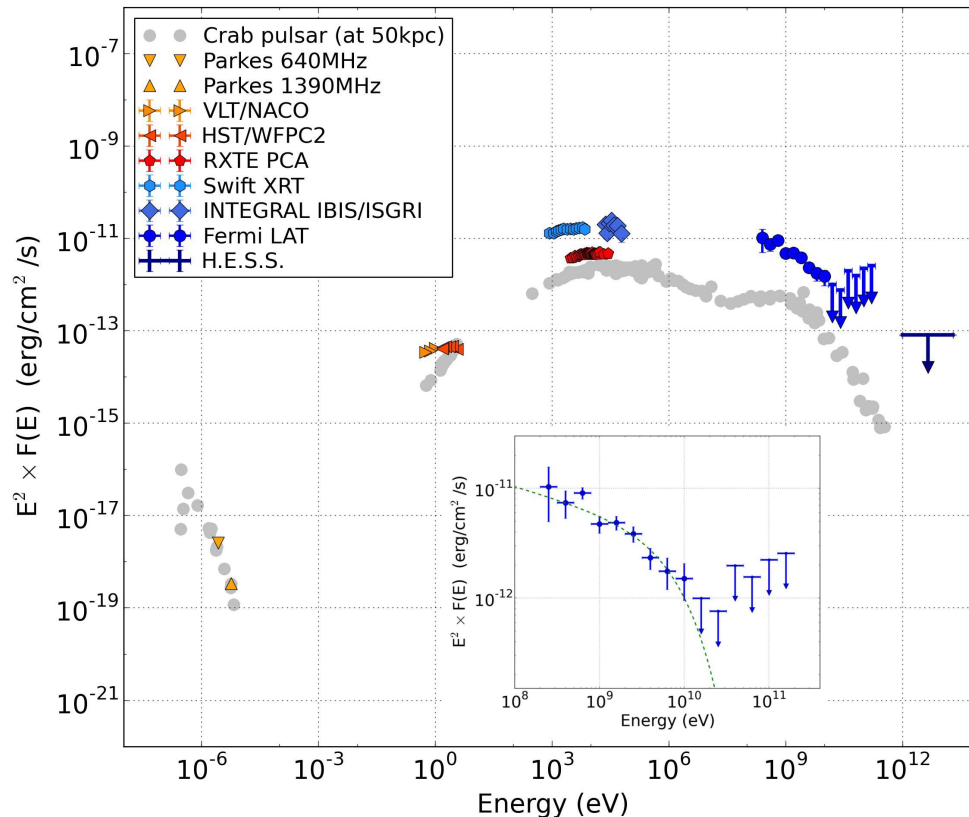
Pulsations detected at 6.8sigma
... thanks to better quality LAT data
... LMC diffuse emission modeling
... and RXTE ephemeris (until 2011)

Light curve profile suggesting high
viewing angle and low magnetic
inclination (for outer gap model)

(Ackermann et al. 2015, Science, 350, 6262)



PSR J0540-6919 – SNR 0540-69.3 – N158A



Most luminous gamma-ray pulsar yet observed:
20x more than Crab

Spectrum consistent with high pair densities in outer regions and broad synchrotron self-Compton emission (*Lyutikov-2012*)

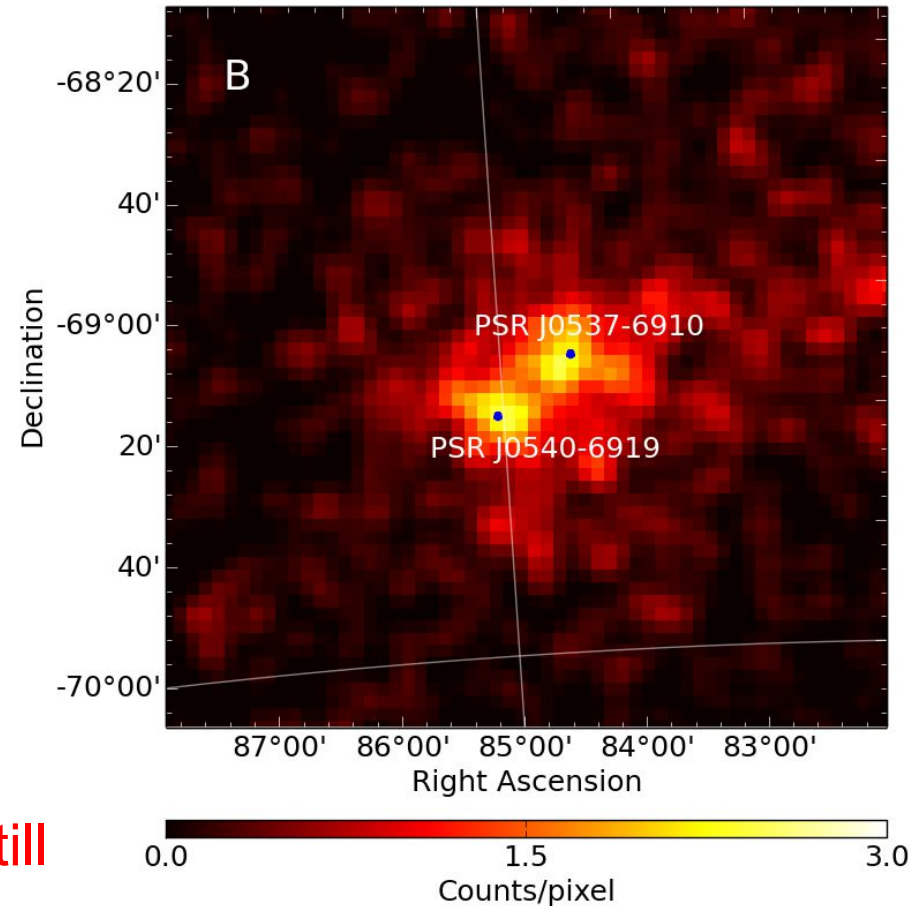
Open questions:

Is there any contribution from the SNR at GeV energies ?
Does 0540 have a very-high-energy tail in reach of CTA ?
Will PWN N158A be detectable with CTA (see *Martin-2008*) ?

Comparing PSRs 0540 and 0537

No pulsations detected from 0537
power-law spectrum up to 50GeV
not typical of pulsars

Pulsed luminosity $< 1.9 \times 10^{35}$ erg/s,
30x below that of 0540,
...or weak modulation

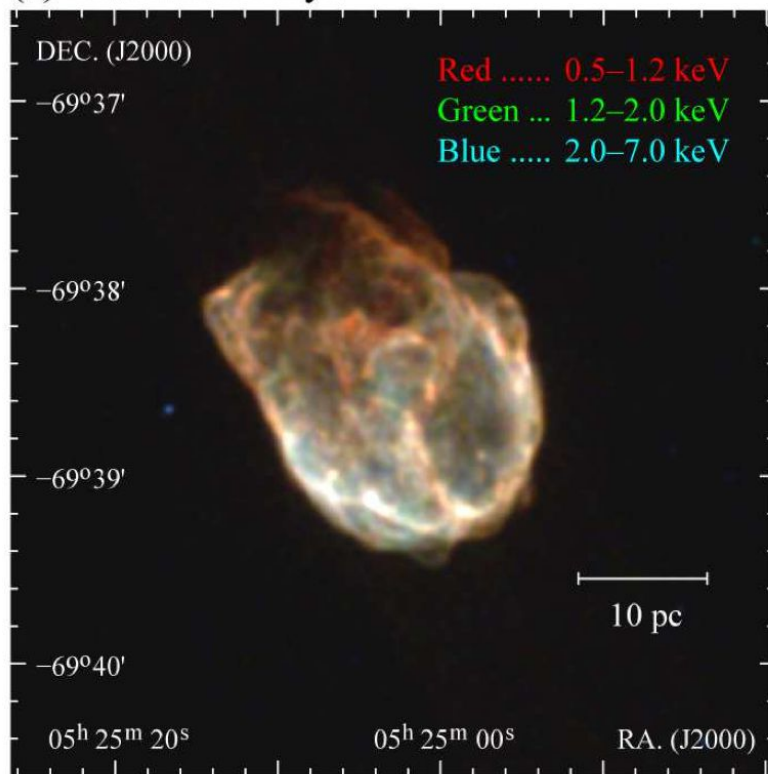


Difference between both pulsars still
to be accounted for

These observations may help
understanding rare very young pulsars

N132D

(a) *Chandra* X-rays



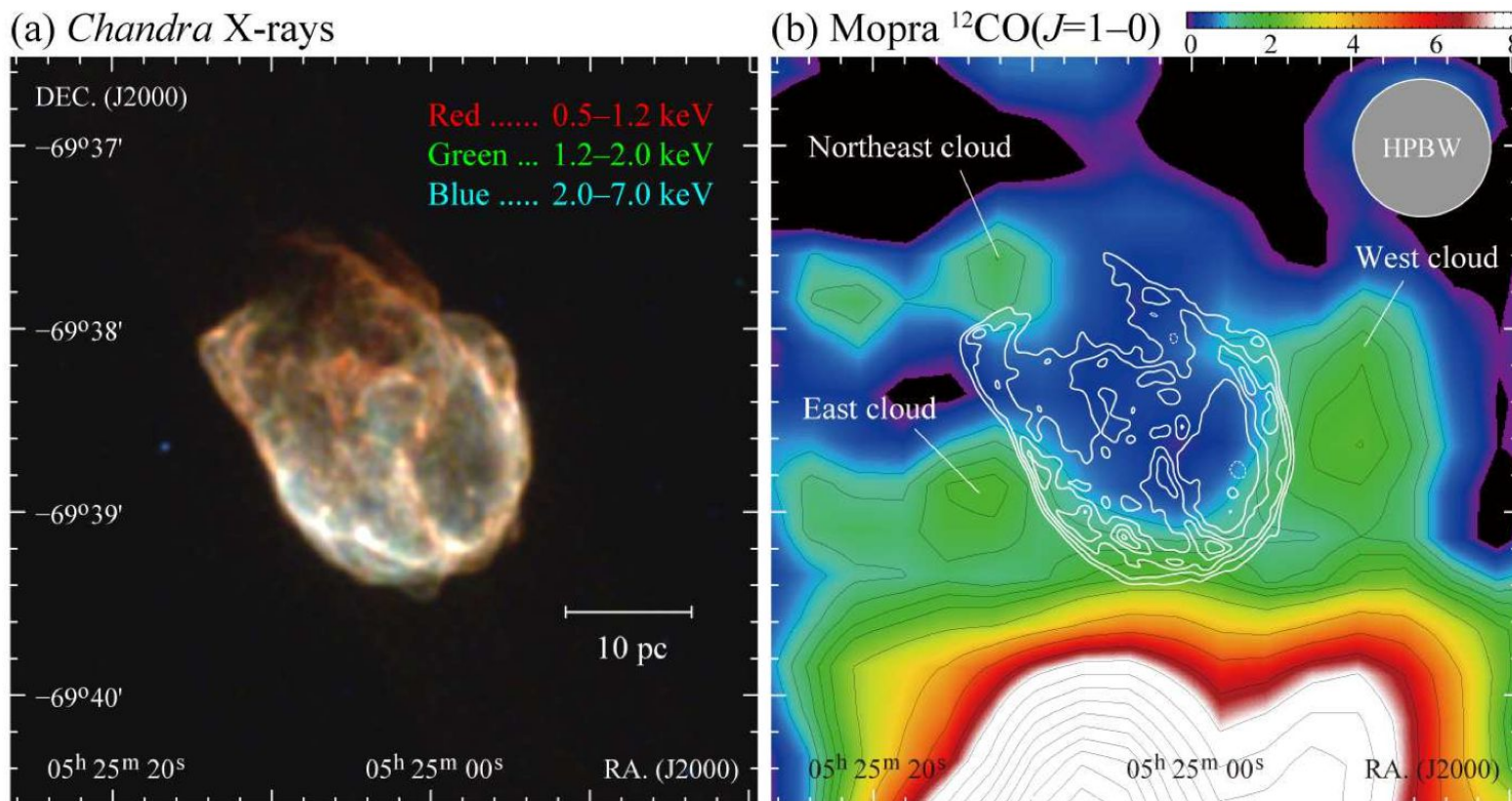
2500-3000yr SNR
O-rich remnant
Size ~25pc
~35-85M_⊙ progenitor
(*France-2009 and refs*)

Brightest X-ray SNR in LMC

Thermal X-ray emission to the south @ 0.6-0.7keV (~800km/s)
... from shocked inter/circumstellar medium
Central emission @ higher temperatures with Fe K lines
... possibly from reverse-shocked ejecta

N132D

(Sano-2015)

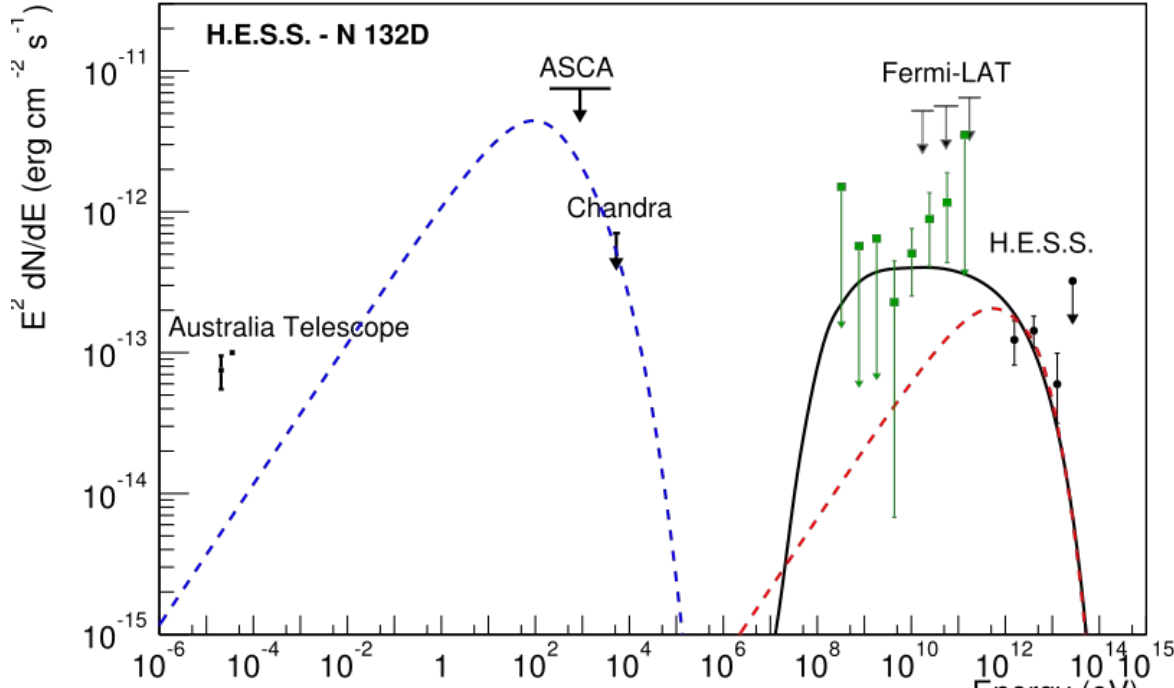


Expansion in cavity and collision with nearby clouds of $10^4 M_{\odot}$

Dynamical model by *Chen-2003*:

- 1) Blast in cavity at 1900 km/s over 2200 yr, sweeping up $60 M_{\odot}$
- 2) After hitting wall, speed decreased to 800 km/s by sweeping up $90 M_{\odot}$

N132D



A source at detection threshold in both GeV and TeV bands

Fermi data favour hadronic model with $\sim 10^{51}$ erg in relativistic protons: efficient accelerator and/or high explosion energy

Can complement SNR HE/VHE studies as Cas A older cousin or as transition object between young/GeV-hard/TeV-bright and older/GeV-bright/TeV-soft SNRs

Things I have no time to talk about

Other detected sources

Extended emission

- Dominant sources at GeV

- Unexpected morphology

- Implications on cosmic ray and sources populations

Superbubble 30 Doradus C

- Unique object at TeV

- Uncertain morphology and association (PWNe instead ?)

- Potentially crucial for acceleration up to highest energies

Undetected sources

SN1987A: TeV upper limit was below predictions !

Star-forming regions 30 Dor and N11: constraining ?

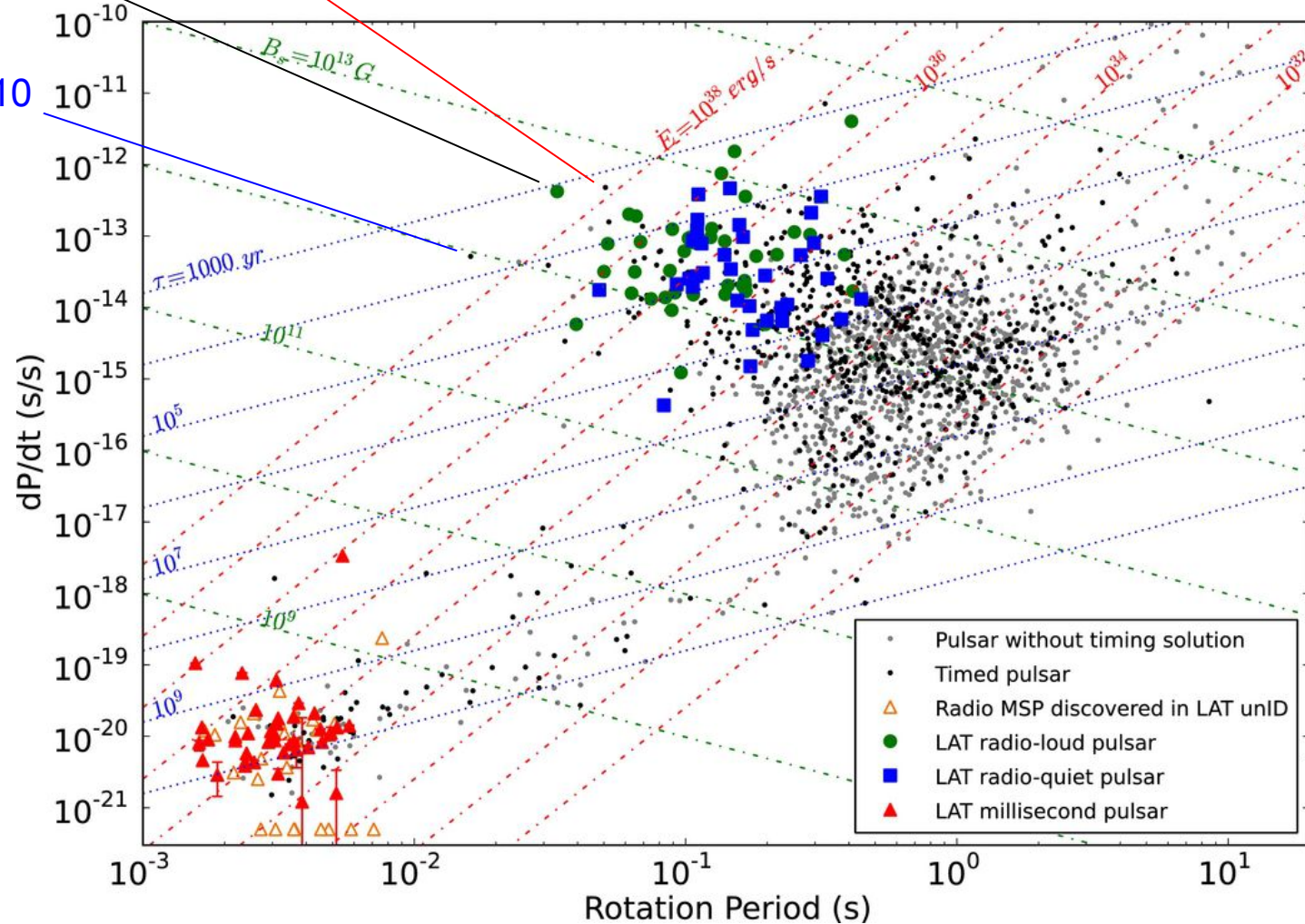
Supplementary material

J0540-6919 (Crab's twin)

Out of the 3 most powerful pulsars known,
2 are close neighbours in the LMC

Crab pulsar

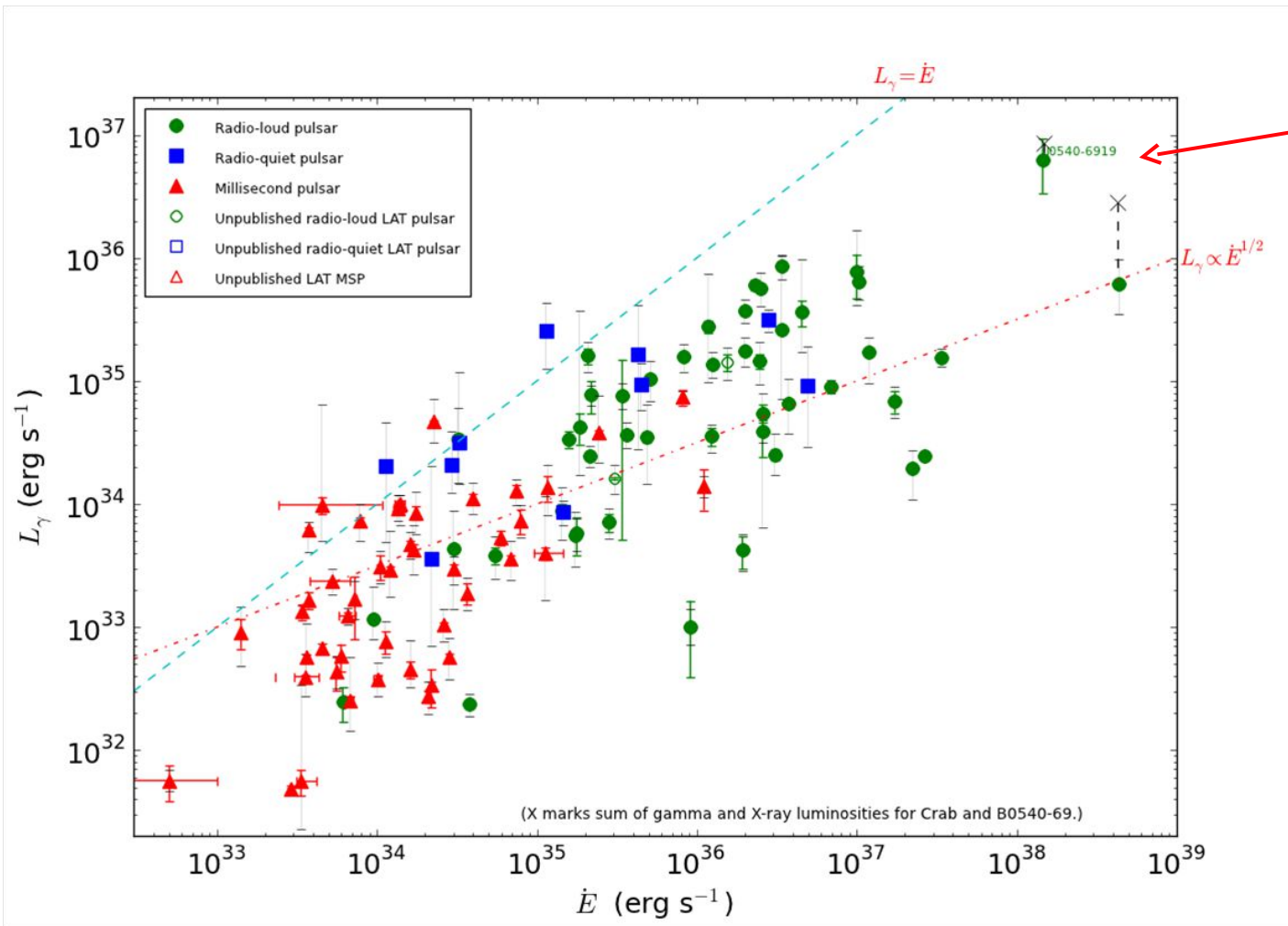
J0537-6910



An extremely bright gamma-ray pulsar in the Large Magellanic Cloud

Ackermann et al. 2015,
Science, 350, 6262
C.A.: Martin, Guillemot, Marshall

The Fermi LAT Collaboration*†



About extended emission

Expectation from Milky Way studies: GeV gamma-rays follow gas

Large-scale ($5\text{--}6^\circ$)
Probable CRs-ISM interaction
Spectrum consistent with it

Small-scale ($1\text{--}2^\circ$)
No correlation with gas
Hard GeV spectra

More energetic CRs, or
unresolved SNR/PWN
populations...but apparent
correlation with multi-Myr
cavities !

