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LHAASO and Galactic Cosmic Rays

Ruizhi Yang
University of Science and Technology of China
In collaboration with Felix Aharonian, Emma de Ona Wilhelmi, Xiaona Sun et.al

Outline

1.Sources of Galactic cosmic rays :

—LHAASO prospective on Young massive clusters (YMCs)

2.Distribution of Galactic cosmic rays:

—LHAASO prospective on diffuse gamma-ray emission and Giant molecular clouds (GMCs)

Galactic Cosmic Rays (GCR)

Current Consensus

- Single power law spectrum from 10 GeV up to 1 PeV

- Injection rate of ~ 10^{40} erg/s in the Galaxy

- Supernova remnants (SNR) as sources?

SNRs as CR source

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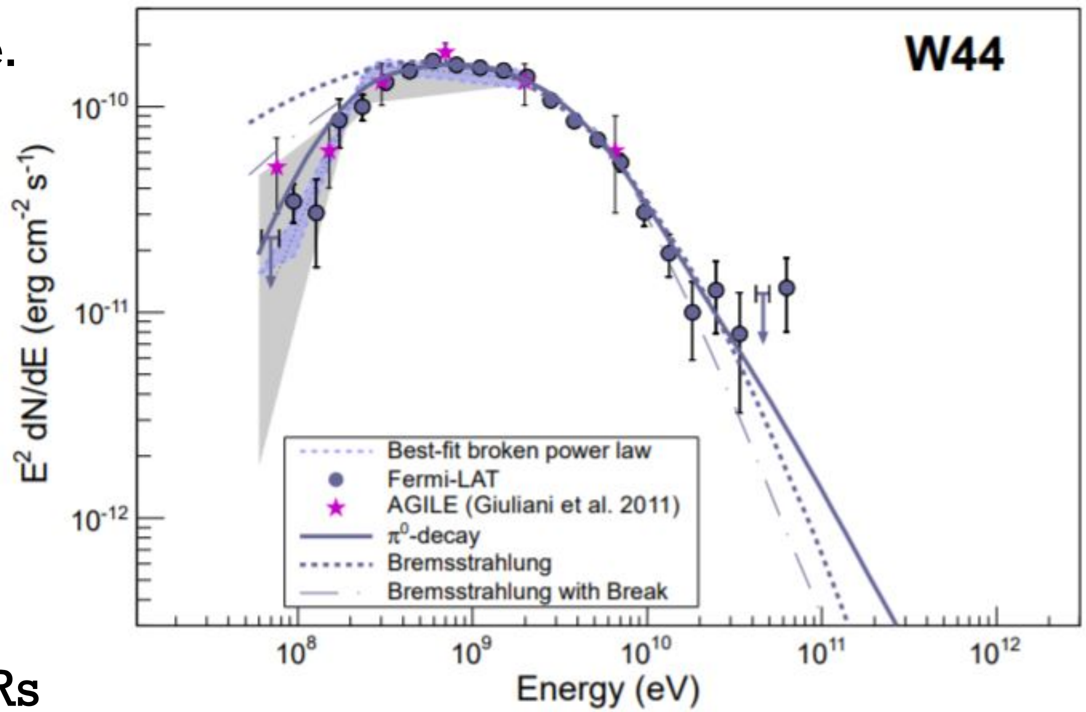
Mid-age SNRs

- Clear Pion-decay feature.
- Hadronic origin or Bremsstrahlung ?
- Break at ~ 10 GeV
- Cannot account for all CRs up to PeV



Fermi Collaboration 2013

Gamma-ray observation of Young SNRs

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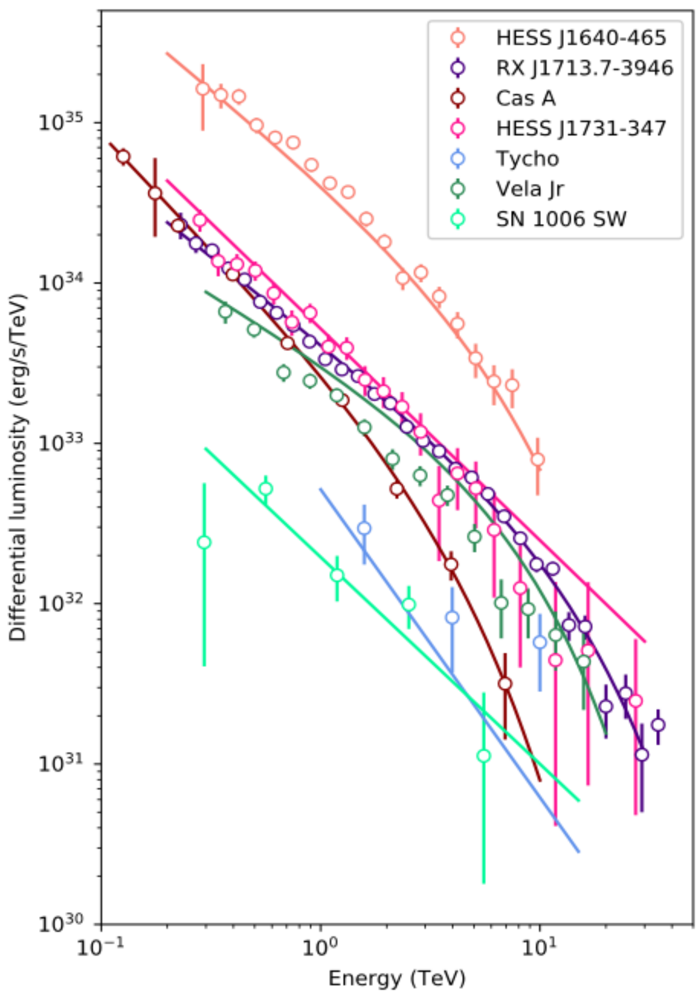

- All gamma-ray spectrum of young SNRs shows soft spectrum or early cutoff at ~ 10 TeV
- corresponding to CR energy of 100 TeV
- Hard to address a single power law spectrum of CRs up to PeV

Very young SNRs?

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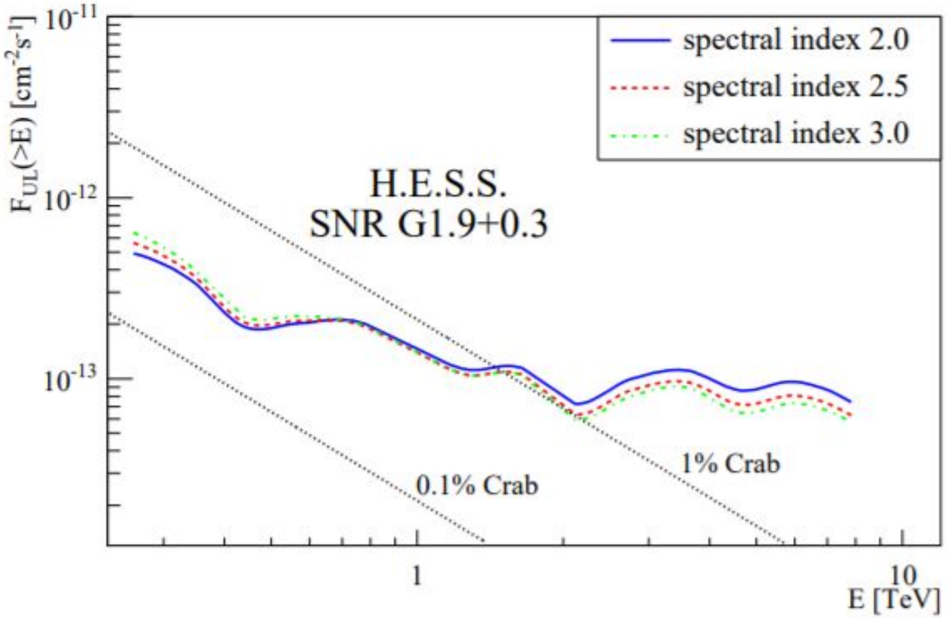
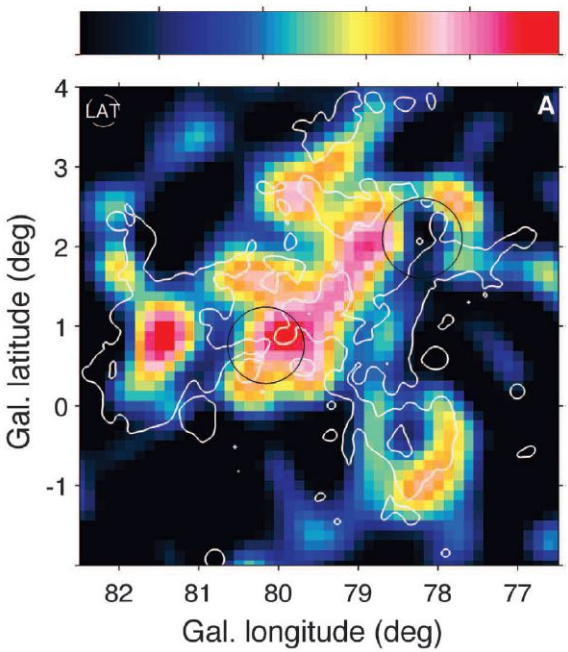
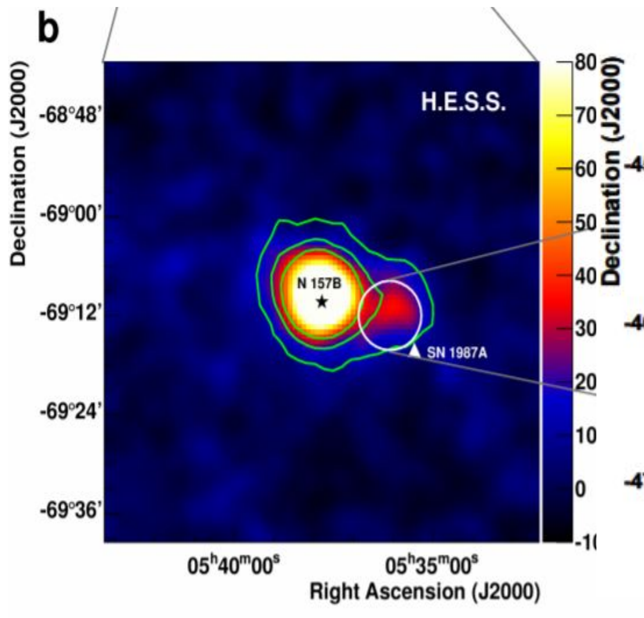
- PeVatron phase could be accomplished only during the first years of the explosion (e.g., Bell et.al 2013)
- The youngest SNR in the Galaxy: G1.9+0.3, t ~ 100 yr
- VHE protons cannot propagate more than 30 pc.
- HESS reveals L(>1 TeV) < 1e32 erg/s can be used to set limit on proton energy budget.
- Considering a high density in the vinicity (near GC), the total energy on VHE protons are below 1e45 erg. Not enough to account for the CR flux up to the knee.



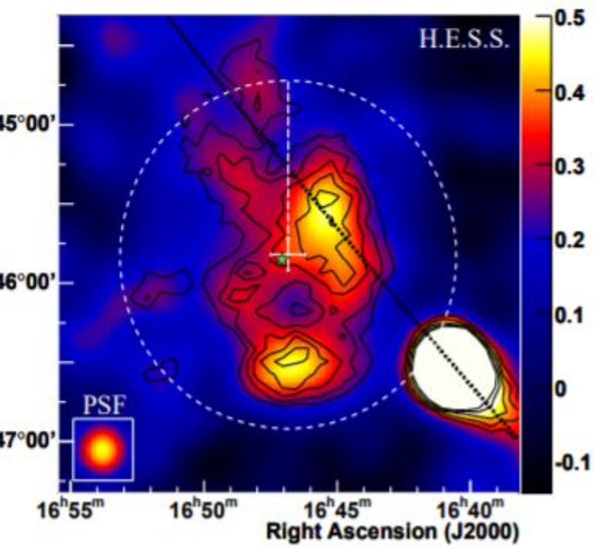
Alternative sources: Young massive clusters



Cygnus Cocoon
(Fermi Collaboration 2012)



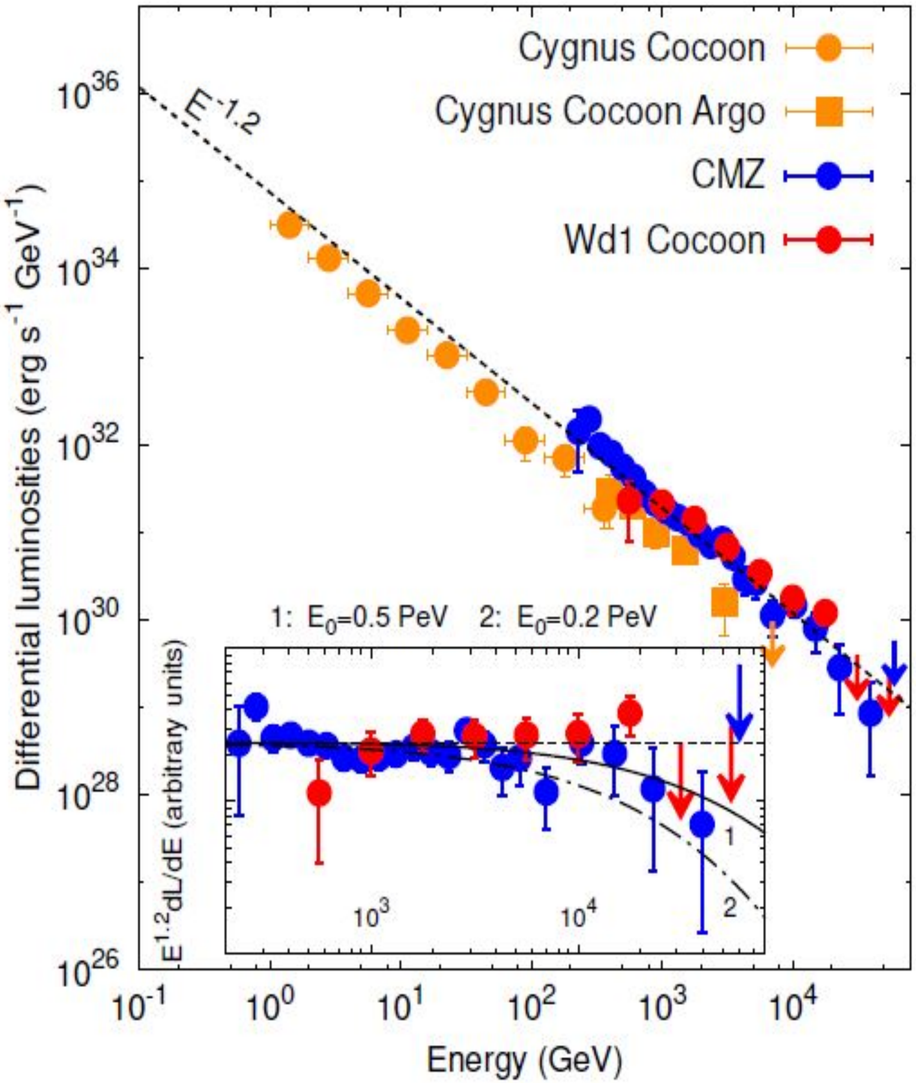
30 Doradus C
(H.E.S.S Collaboration 2015)



Westerlund 1
(H.E.S.S Collaboration 2011)

- Isotope measurement favor a superbubble origin. (W.R Binns 2016)
- Most of OB stars exist in associations or clusters, stellar wind can accelerate CRs (Cesarsky & Montmerle 83).
- Efficiency may even better than SNR (high speed wind lasts much longer than SNR shock)
- Sufficient wind power (10^{38} - 10^{39} erg/s for each cluster, more than -10^{41} erg/s in the Galaxy) to account for CRs

Massive star clusters



- Cygnus cocoon, Wd 1 and CMZ all emit multi-TeV gamma-ray.
- The spectrum of CMZ and Wd1 put lower limit of cutoff of parent proton spectrum to be several hundred TeV
- Difficult for IACT (large size)
- LHAASO is the ideal instrument!

Radial distribution of Cosmic Rays

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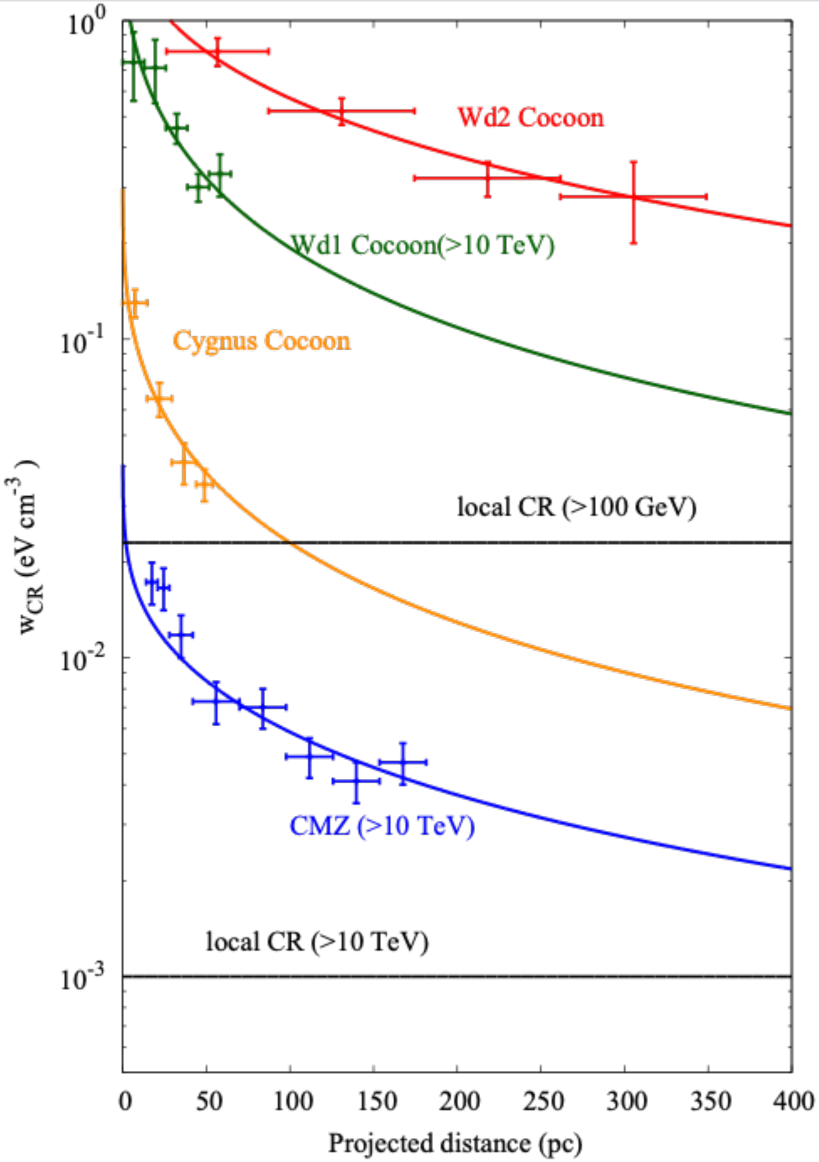

- CR distribution derived by gamma-ray profile and gas distributions
- All four sources (Wd1, Wd2, Cygnus cocoon, GC) show 1/r distribution of CRs
- In diffusion, 1/r profile implies a continuous injection (in the lifetime of clusters)

Targets for LHAASO

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Name	RA	DEC	GeV counterpart	Former TeV observation
Cygnus Cocoon	20 33 12.0	+41 19 00	Yes	Argo detection
W43	18 47 32.4	-01 56 31	Yes	HESS J1848-018?
W40	18 31 26.5	-02 04 22	Yes	No
RSGC 1	18 37 58.0	-06 53 00	G25.0	2HWC 1837-065
h+χ Per	02 20 30.0	+57 08 00	No	No
Mc 9	18 34 08	−09 14 02	No	HESS J1834-087?
Mc 20	19 12 25	+09 57 40	No	HESS J1912+101?
Mc 23	19 30 13	+18 32 15	No	No
Cl1900+14	19 07 23.0	+09 19 34	W 49B?	W 49B?

Cygnus cocoon

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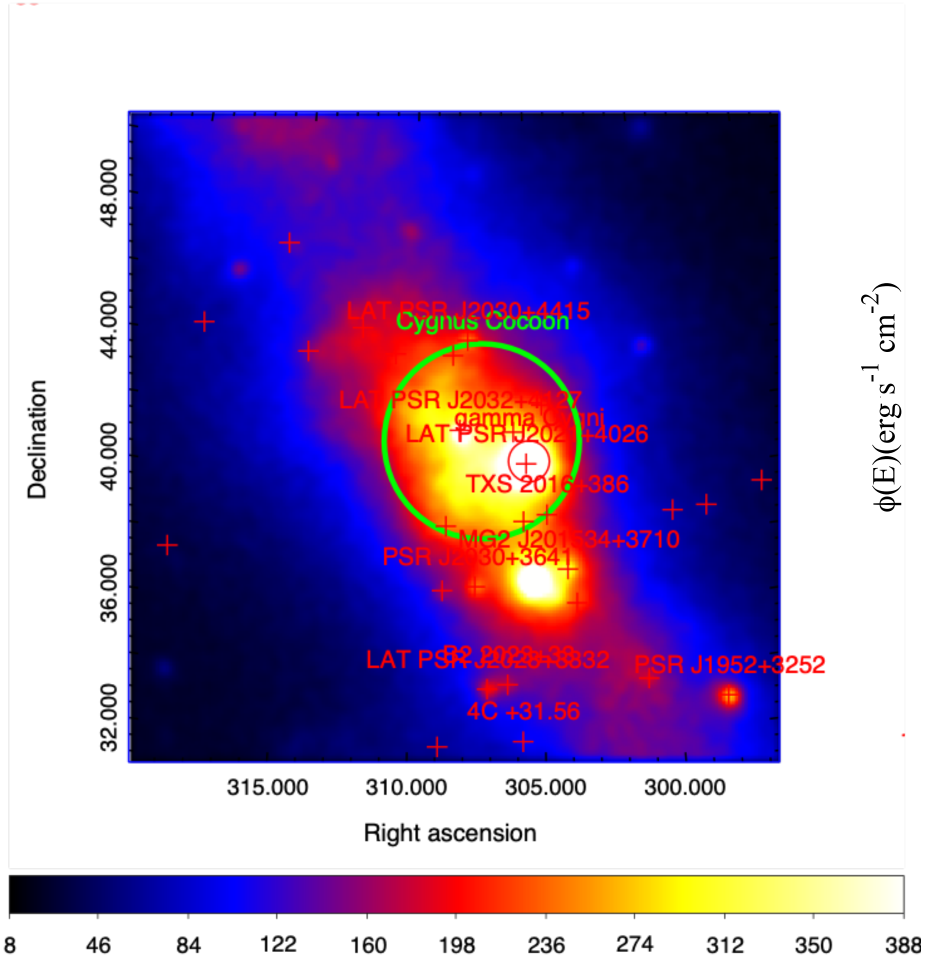
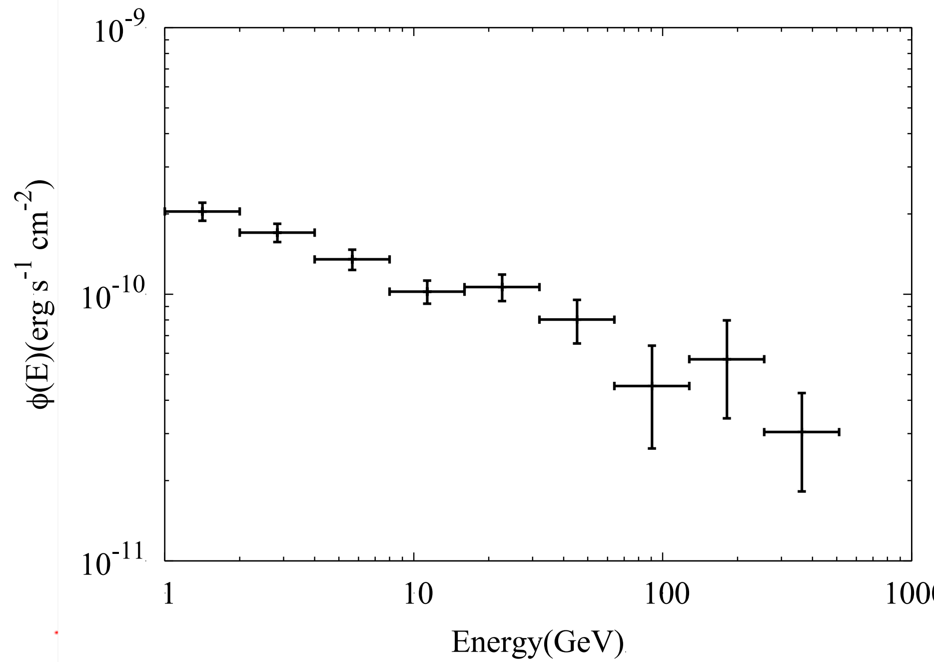


Fermi LAT counts map (>1 GeV)



Spectral Index of -2.2, up to 500 GeV with PASS 8 data.

W40

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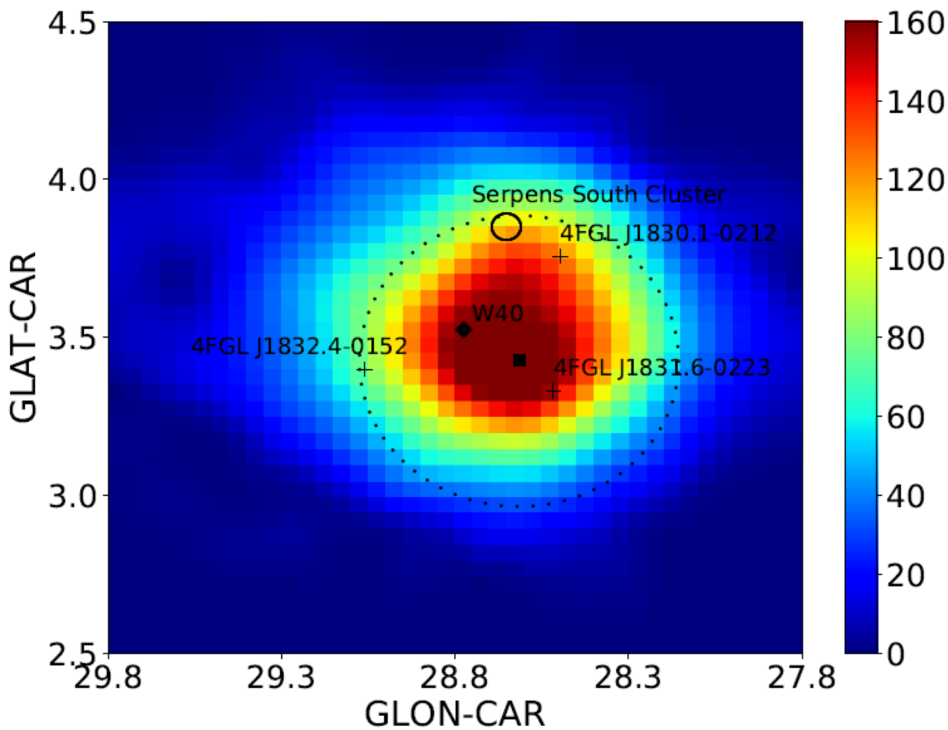
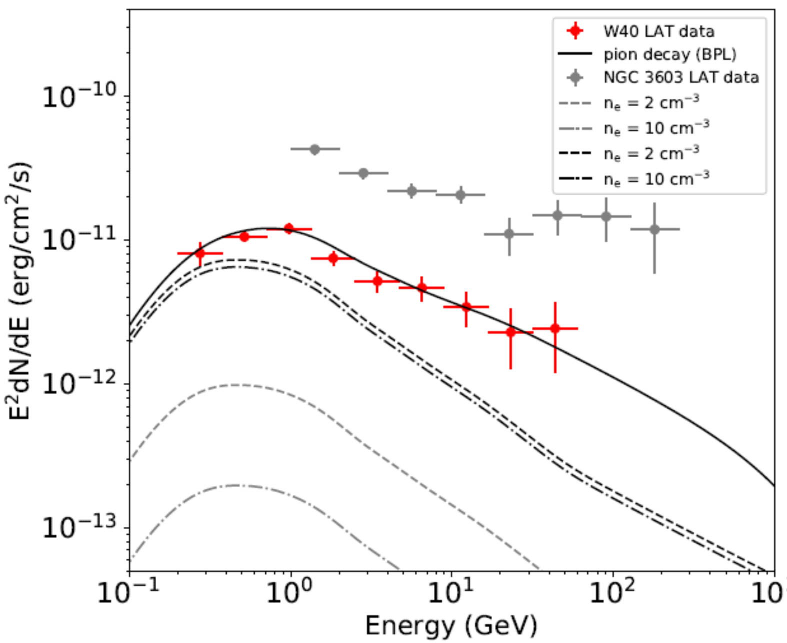
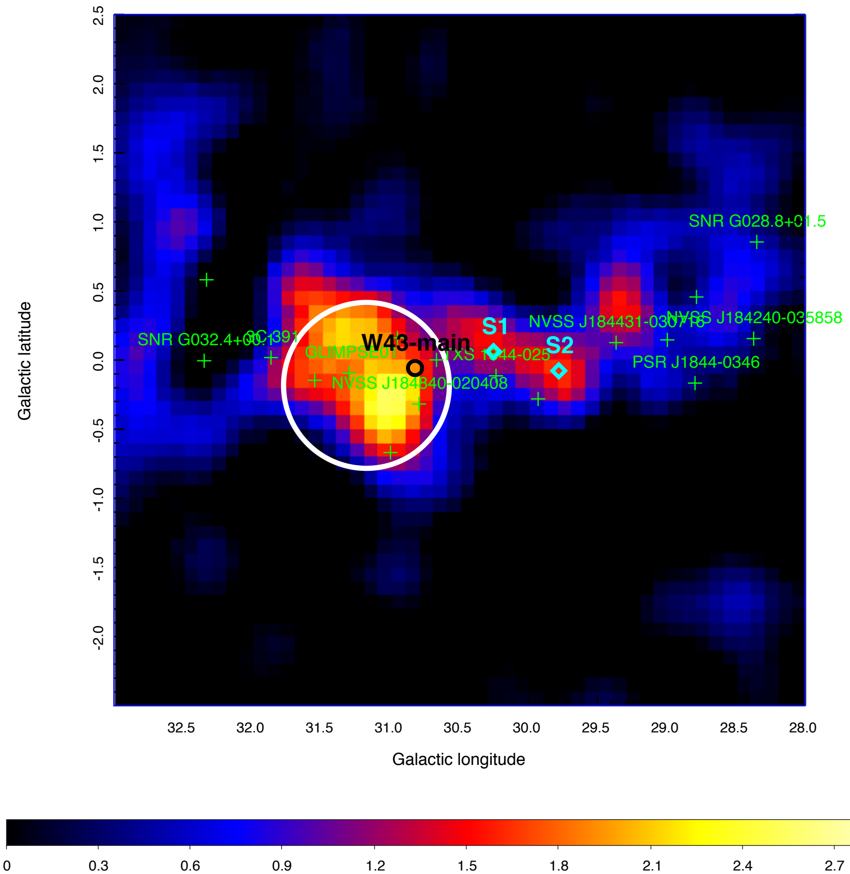
(Fermi LAT results, in prep)

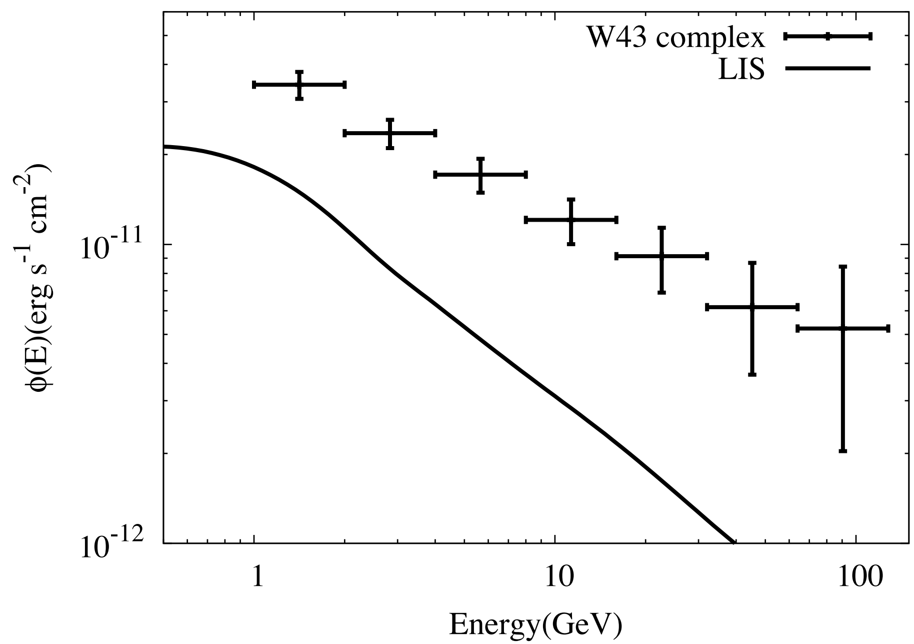




With an age of less than 10^6 yrs, definitely no SNe yet

(Fermi LAT results in prep)

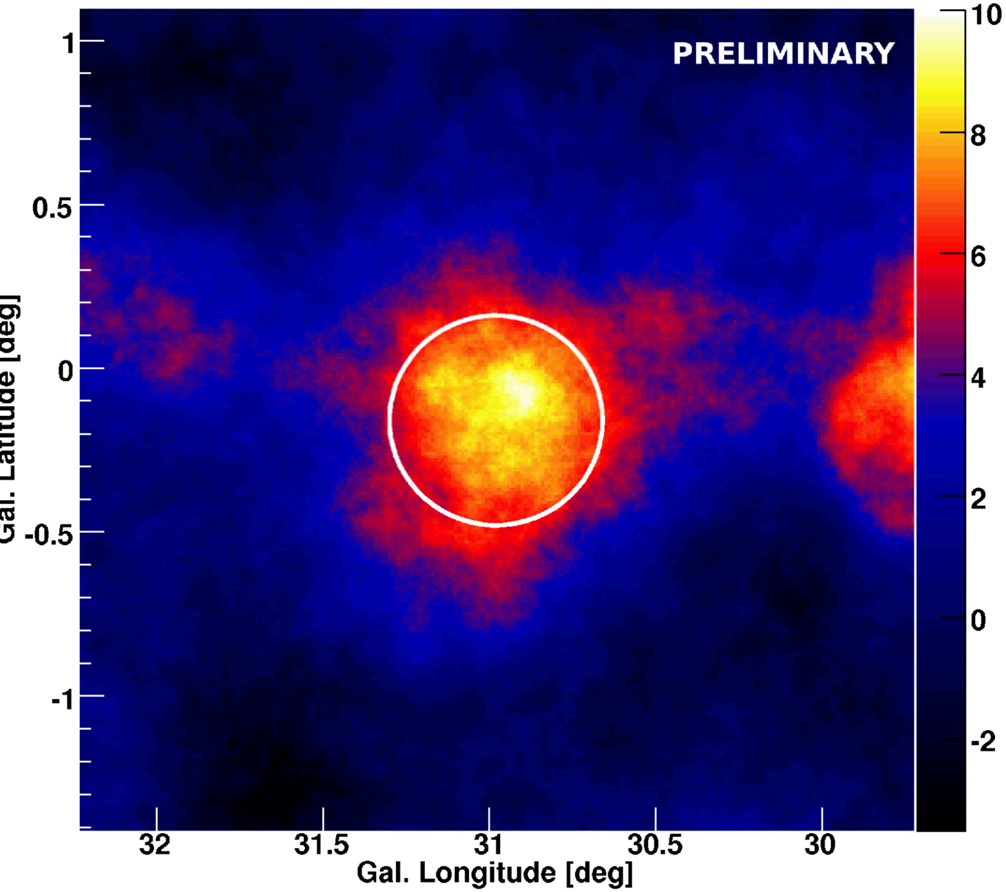


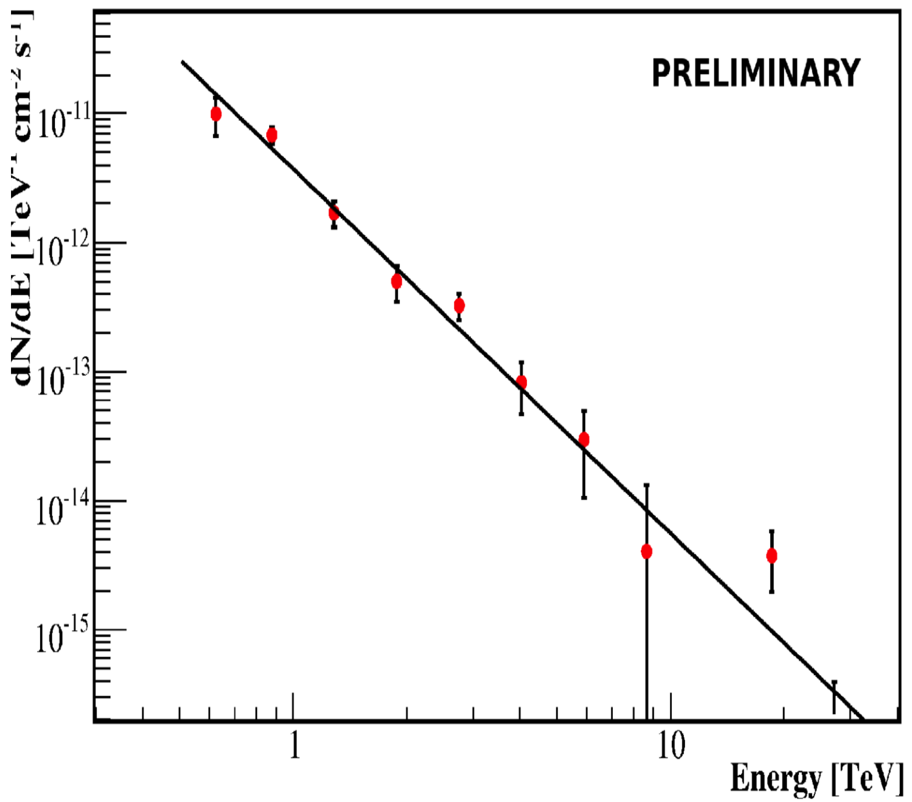


Galactic mini star burst, near HESS J1848-018

W43

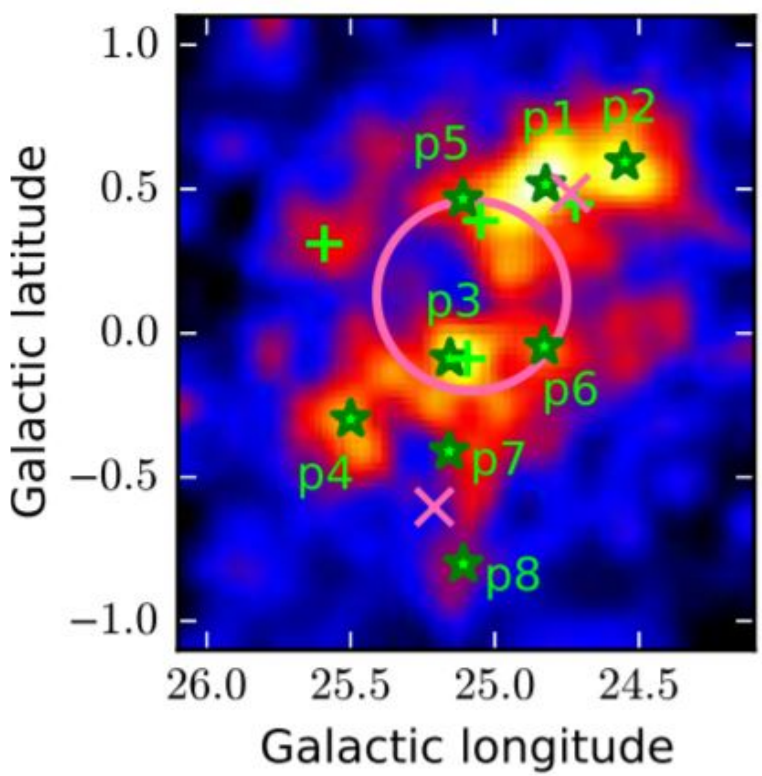
HESS results (Chaves et.al 2008)

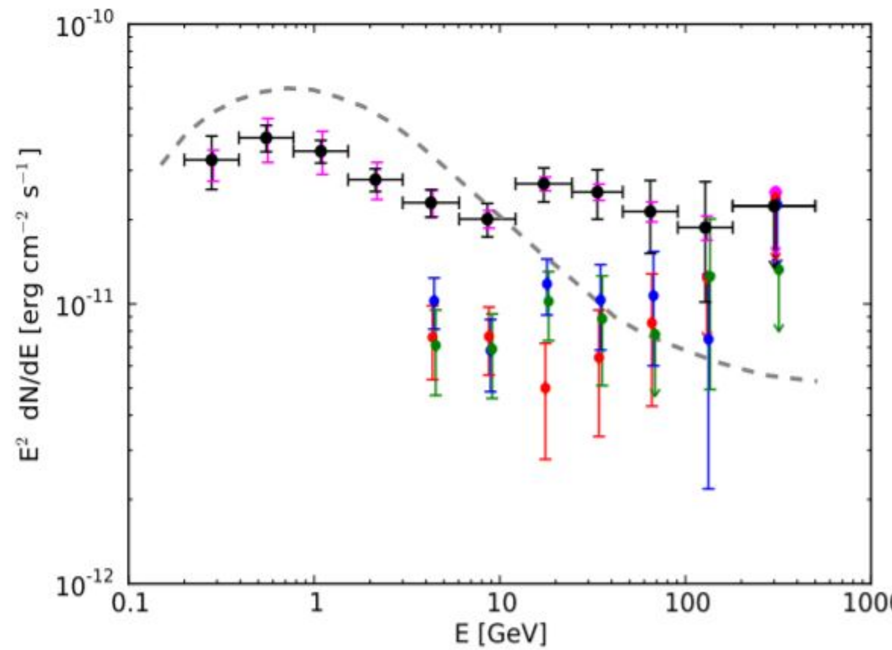




G25.0+0.0 (RSGC 1/W42)

Fermi results (Katsuta et.al 2017)





Index ~ 2.1, up to more than 500 GeV

G25.0+0.0 (RSGC 1/W42)

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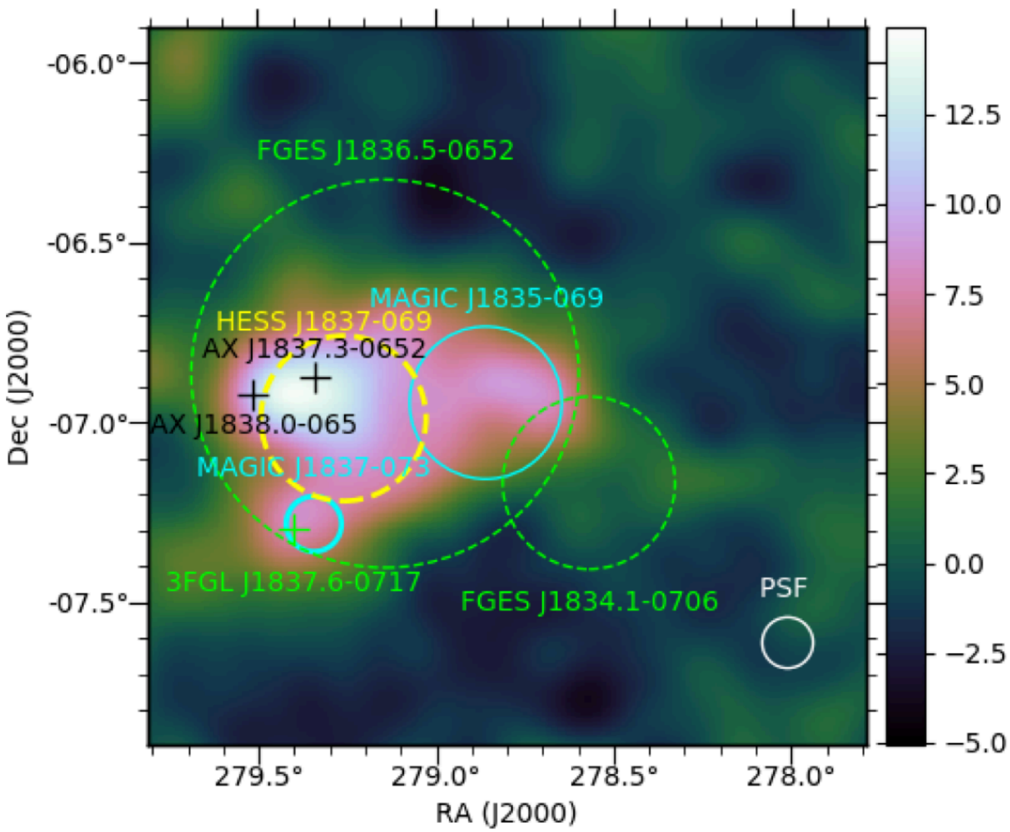
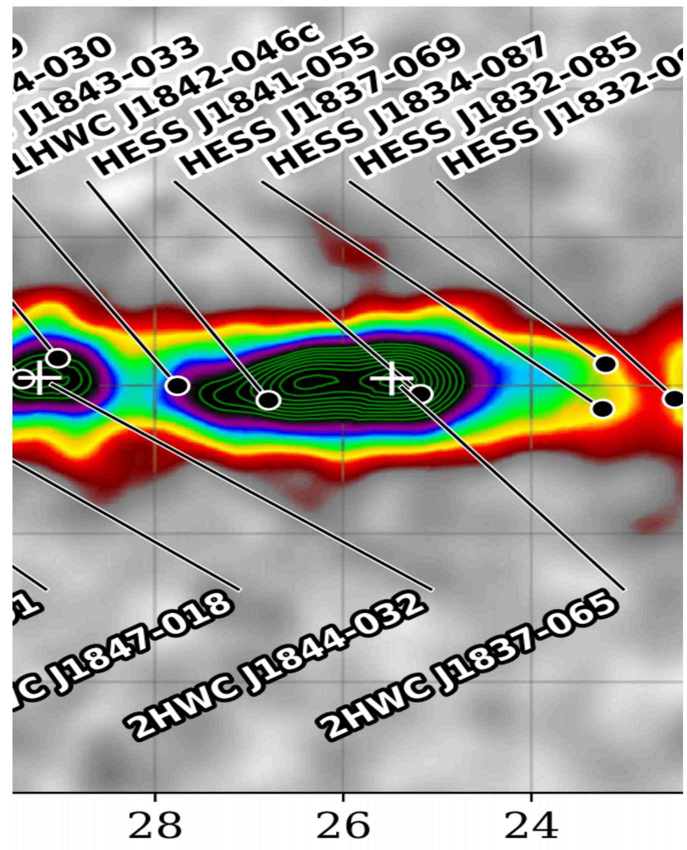
Also complex region for HAWC/HESS



MAGIC



HAWC

LHAASO sensitivity

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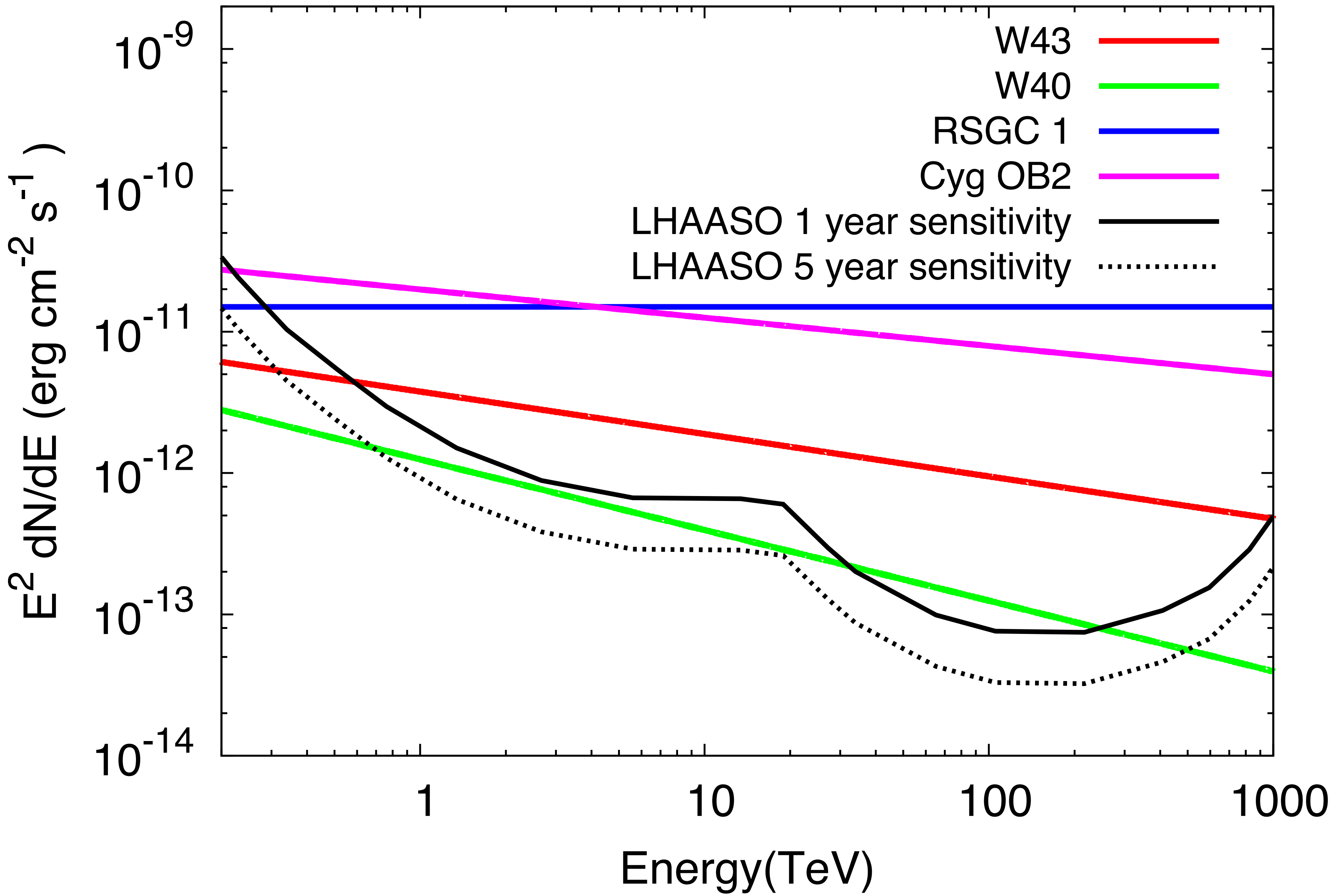

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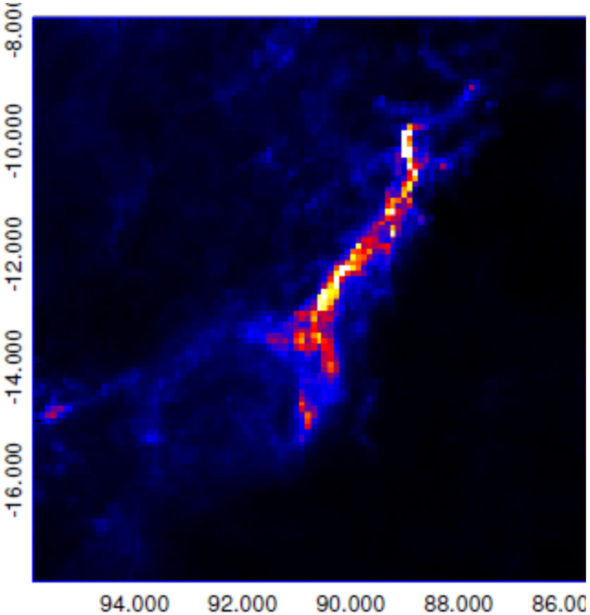
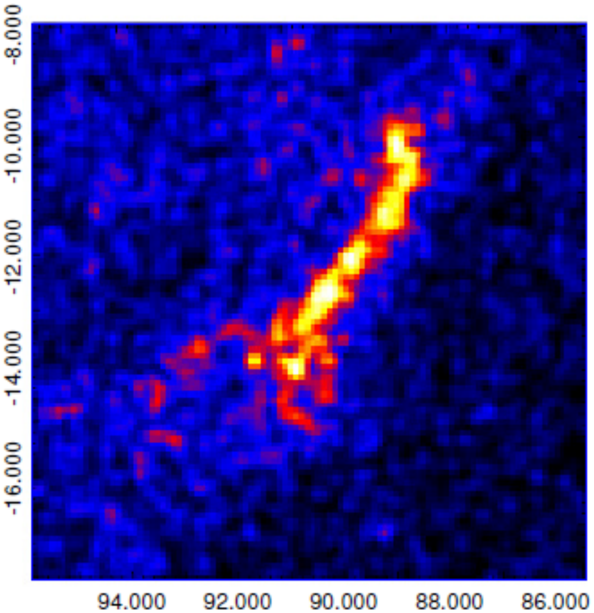
CR distribution with LHAASO

gamma-rays from GMCs



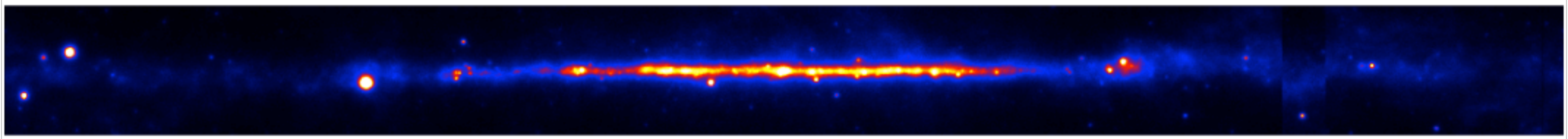
Gas (CO) distribution



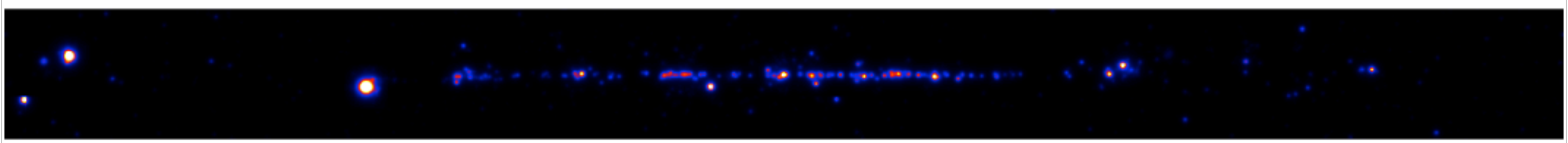
gamma-ray observations (GeV)

Diffuse gamma-ray emission

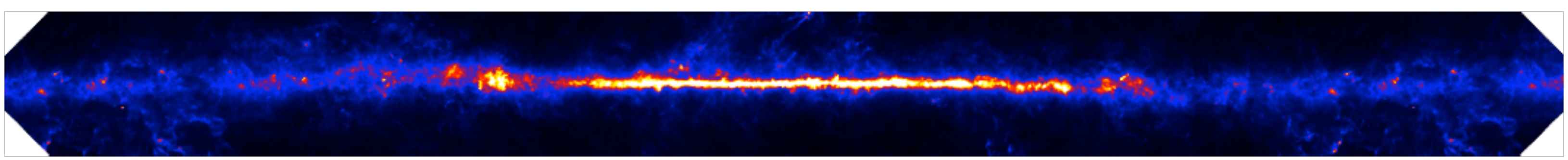
Gamma-ray counts map



Point source contribution



Dust opacity map (gas column)



CR Radial distributions

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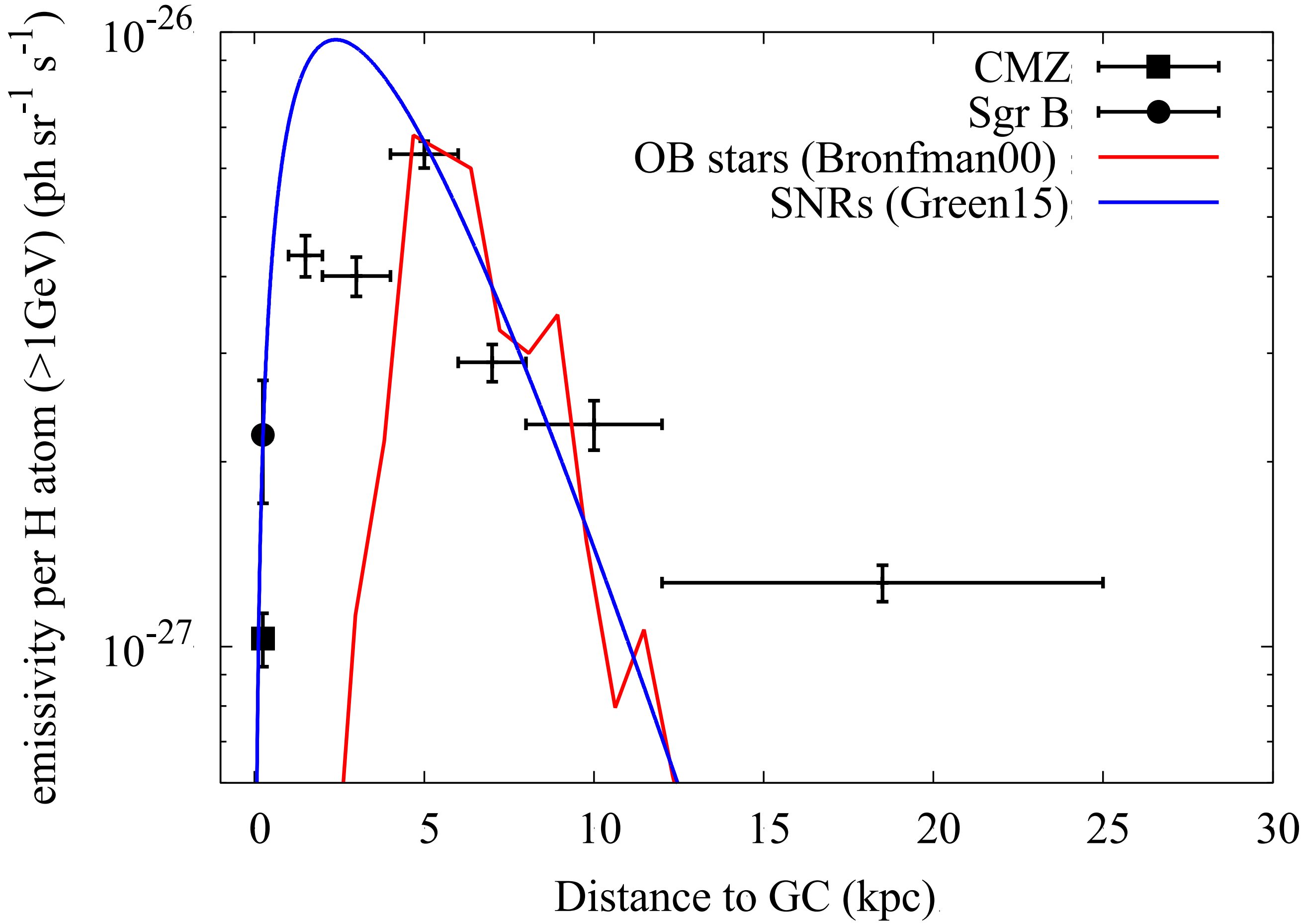
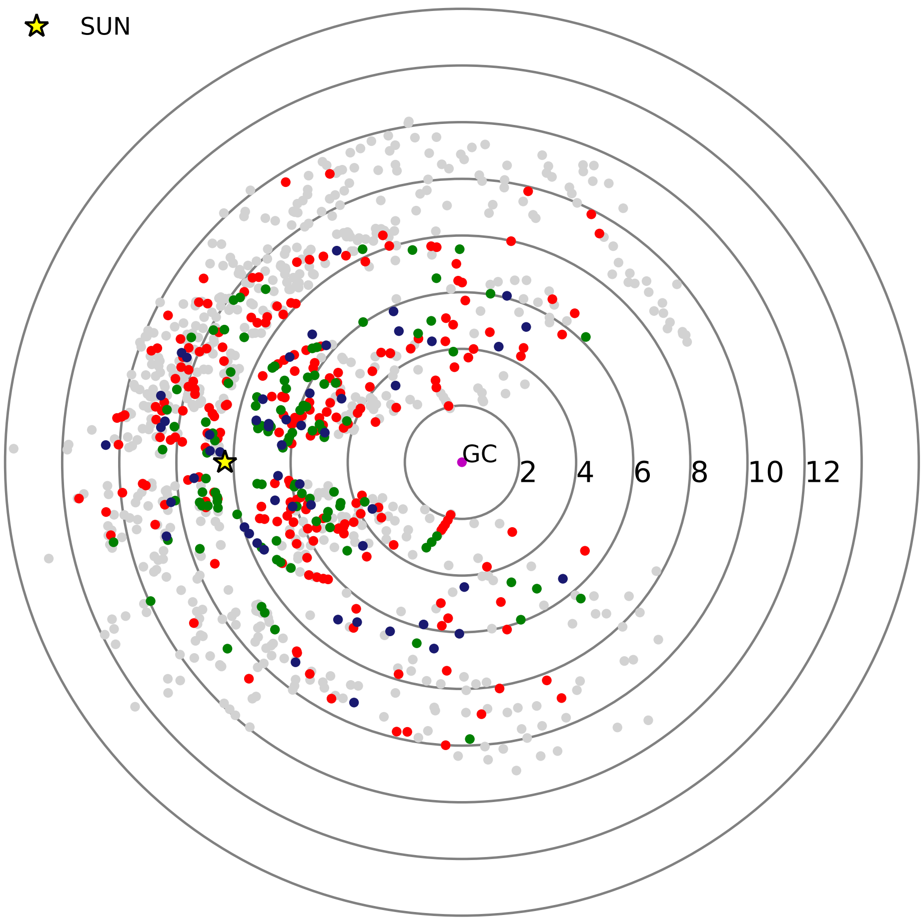


Yang et.al 2016

More clouds

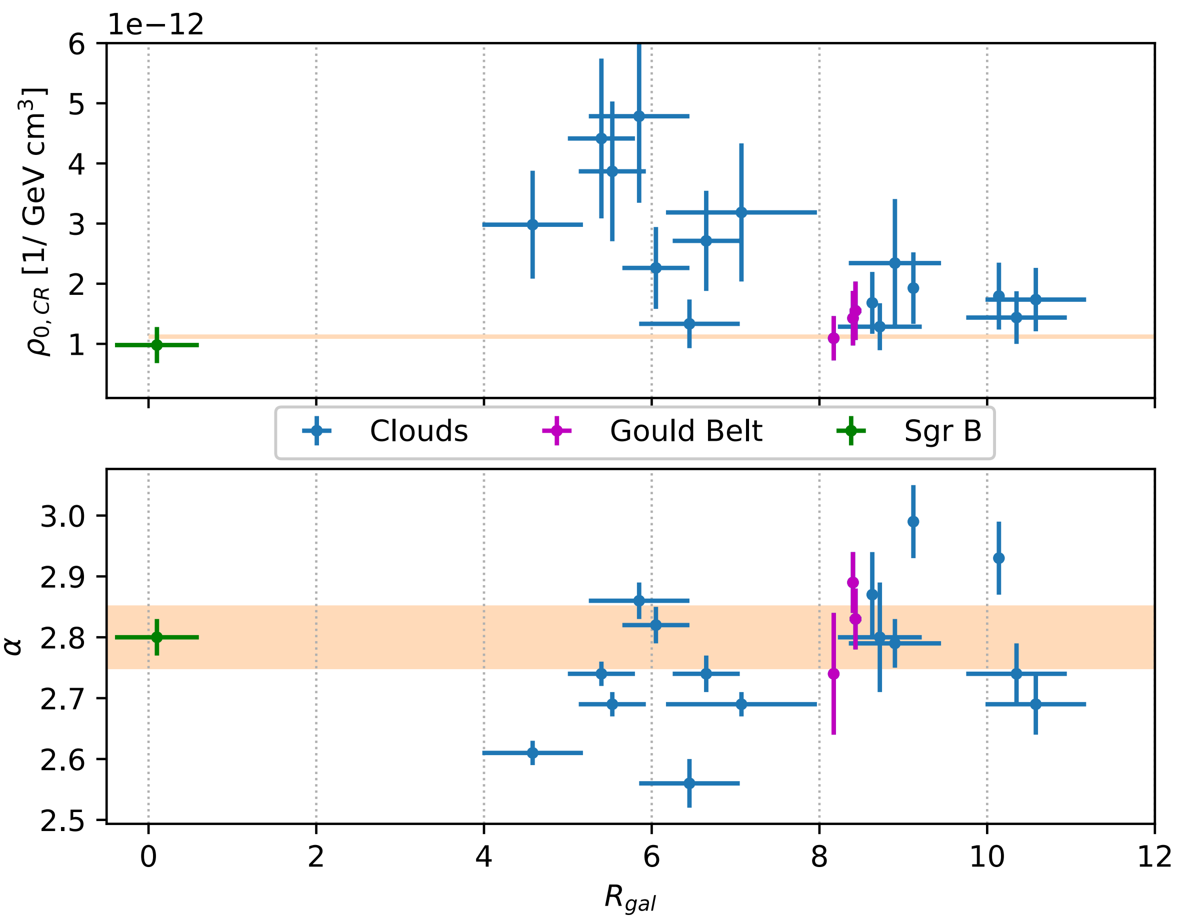


Aharonian et.al 2019

- Rice et.al (2016) have identified thousands of Molecular Clouds in the Galaxy
- Possible to measure CR density in each position of the Galaxy.

More clouds

- radial distribution of CR density and indices



Aharonian et.al 2019

GMCs in LHAASO FOV

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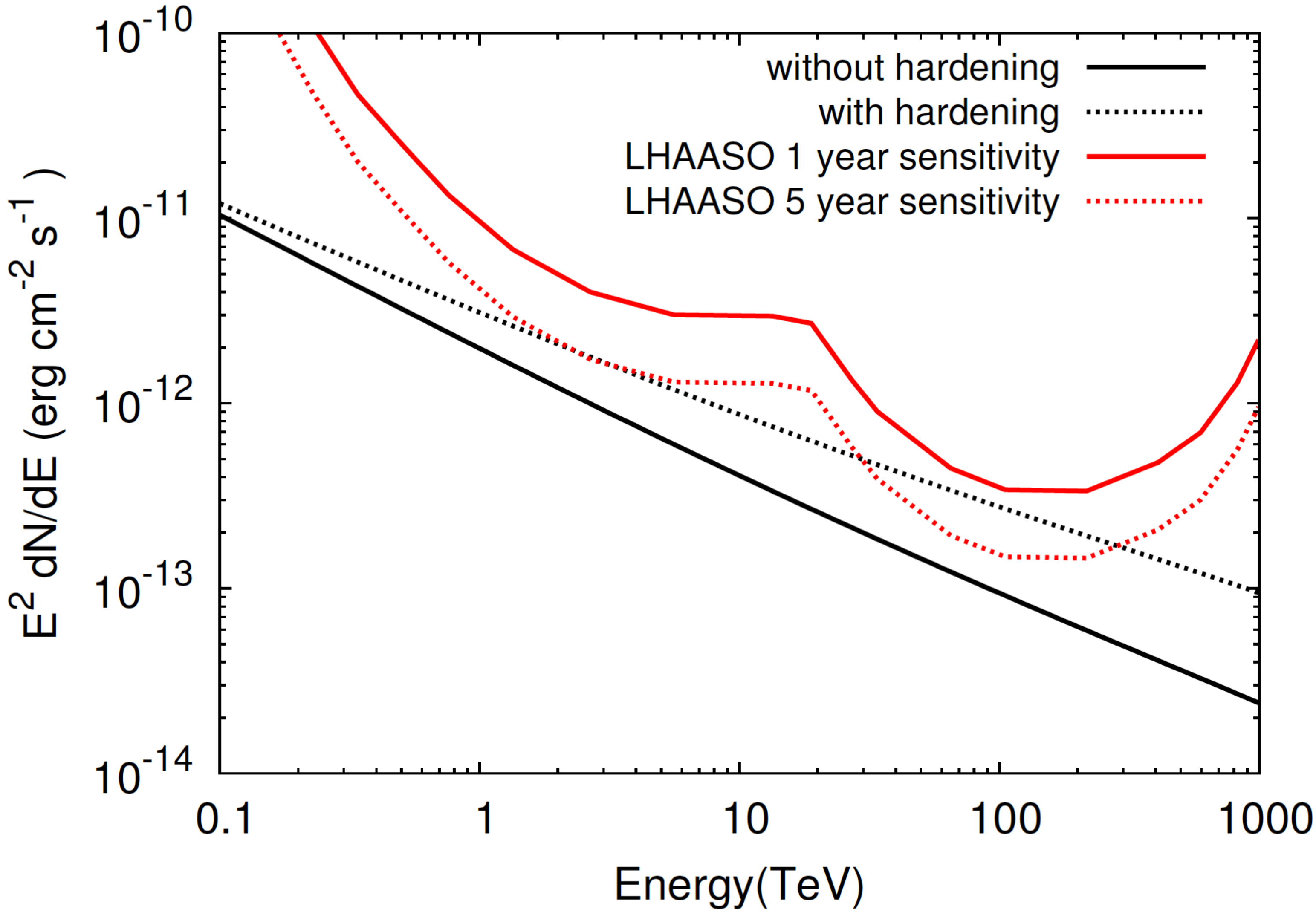
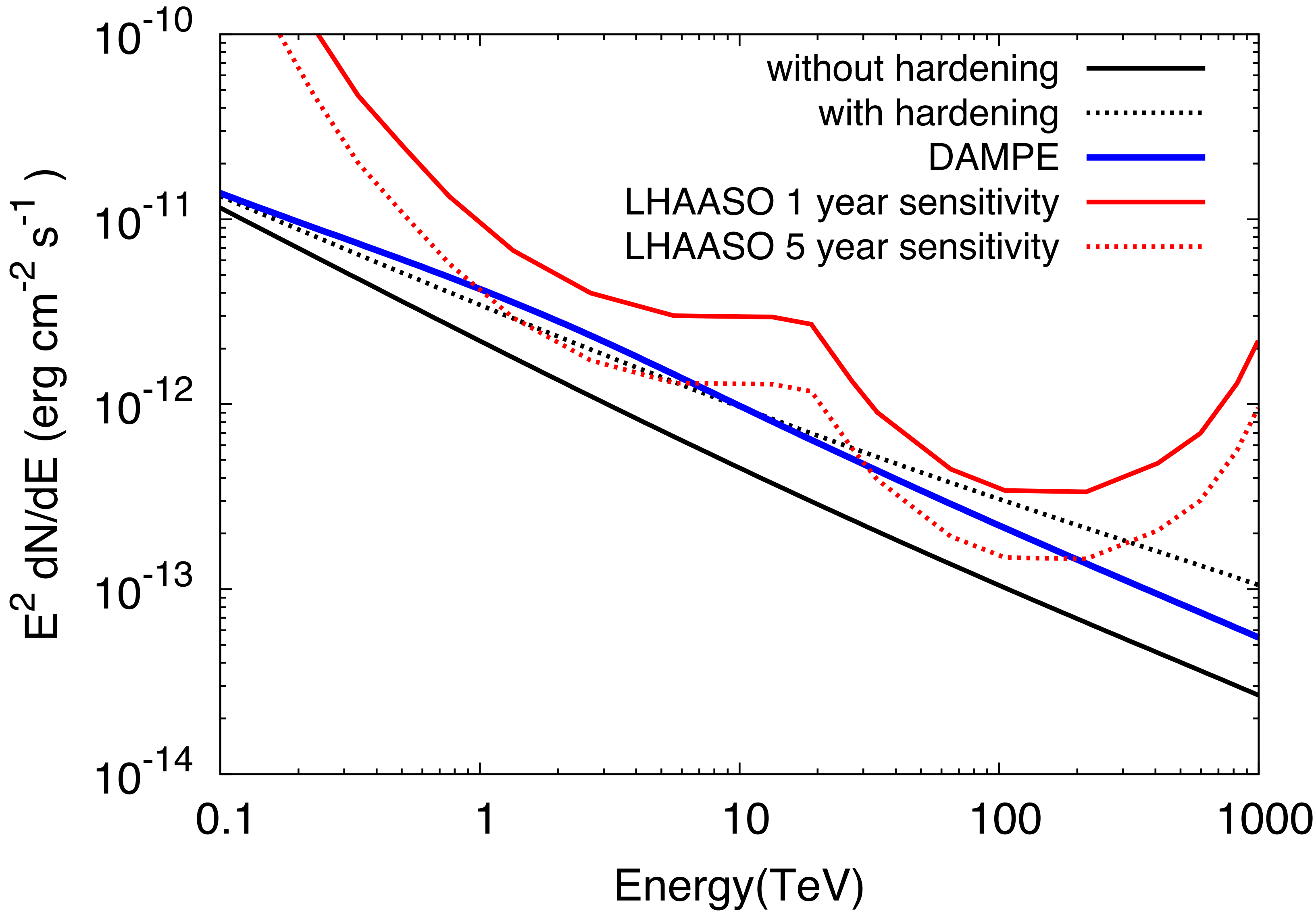
Region	Mass [10^5 $M_\odot$]	Distance [pc]	l [°]	b [°]	M/d^2 [(10^5 $M_\odot$/kpc^2)]	Angular size [arcdeg^2]
ρ Oph	0.08	165	356°	18°	8.4	68
Orion B	0.65	500	205°	-14°	3.9	22
Orion A	0.80	500	213°	-18°	5.2	28
Mon R2	0.80	830	214°	-12°	1.7	19
Taurus	0.23	140	170°	-16°	15.0	101
Polaris flare	0.055	230	130°	26°	0.96	40

LHAASO sensitivity

$$M/d^2 = 10^6 (M_\odot/kpc^2)$$



With DAMPE proton spectrum



Conclusions

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- Gamma-ray is a powerful tool to investigate Galactic CRs
- YMCs: radial CR distribution, PeVatron identification
- GMCs and diffuse gamma-rays: Measurement of CR distribution
- LHAASO is the ideal instrument: unprecedented energy range and large filed of view.

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Thanks!