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Radial distribution of Galactic Cosmic rays

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Sources of Galactic CRs
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Outline

- Diffuse gamma-ray emission in the Galactic plane (PRD 93, 123007, RY, F.Aharonian and C.Evoli)

- Extended gamma-ray emission towards young star clusters (arXiv:1612.02250, RY and F.Aharonian)

Diffuse emission in the plane

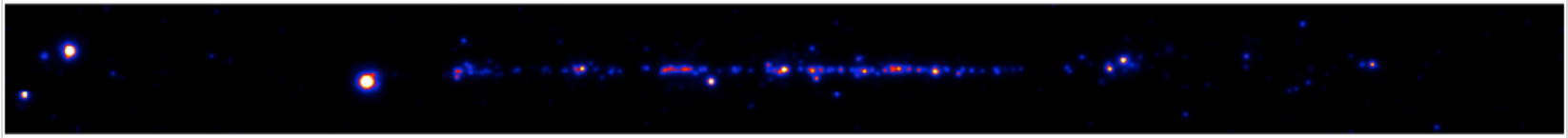
- Gamma-ray emission in the plane ($|b|<5^o$): Point sources + CR interaction with ambient gas + ICs +isotropic

- CR interaction with gas dominates in the plane.

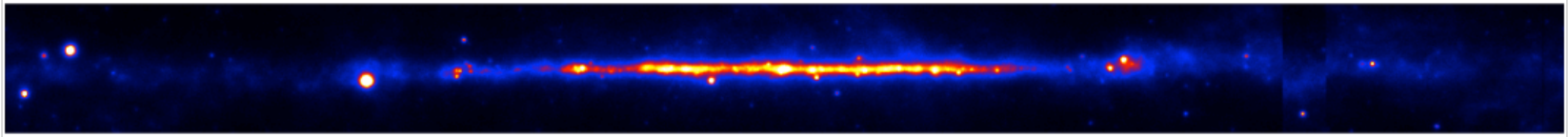
- Gamma-ray map + gas distribution -> CR distribution
  (See also C. Evoli's talk)

Gamma-ray sky

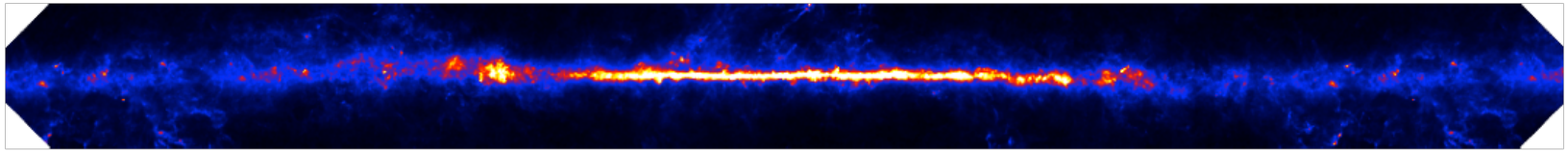
Gamma-ray counts map



Point source contribution



Dust opacity map (gas column)

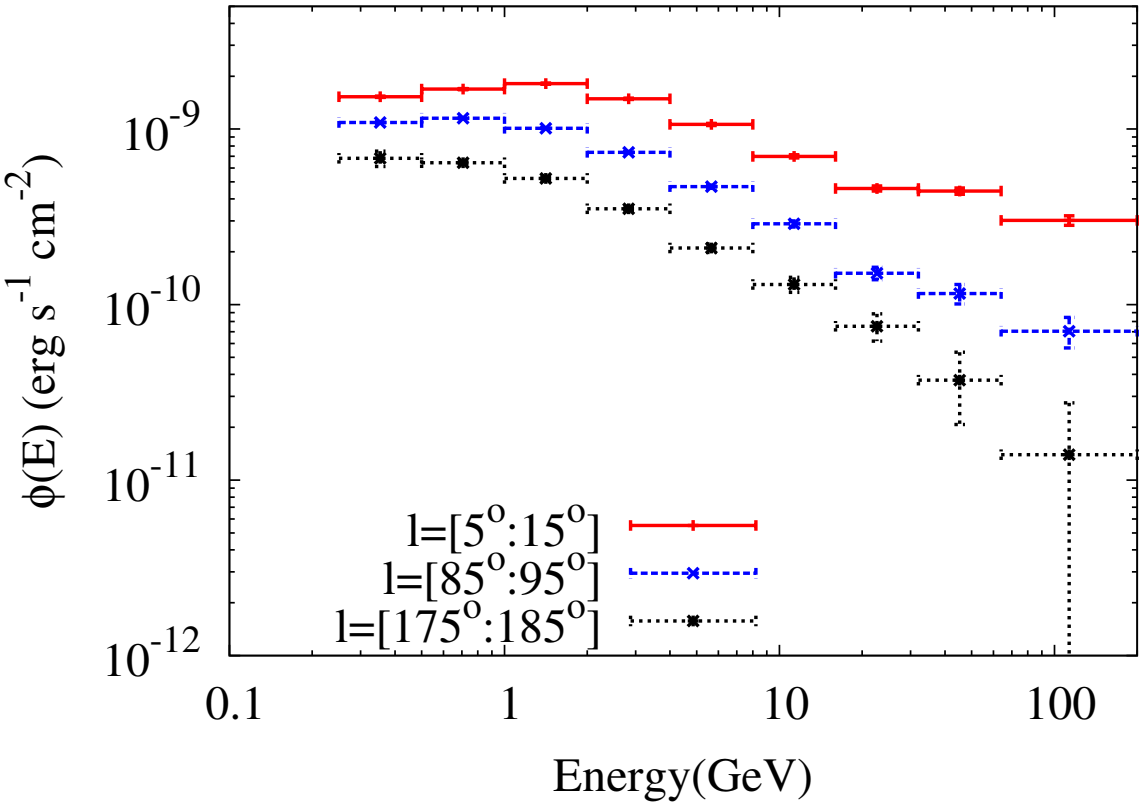


Gas tracers

- Dust opacity： all sky coverage, free of “dark gas” problem, without distance information
- HI and CO: With distance information. Various of biases.

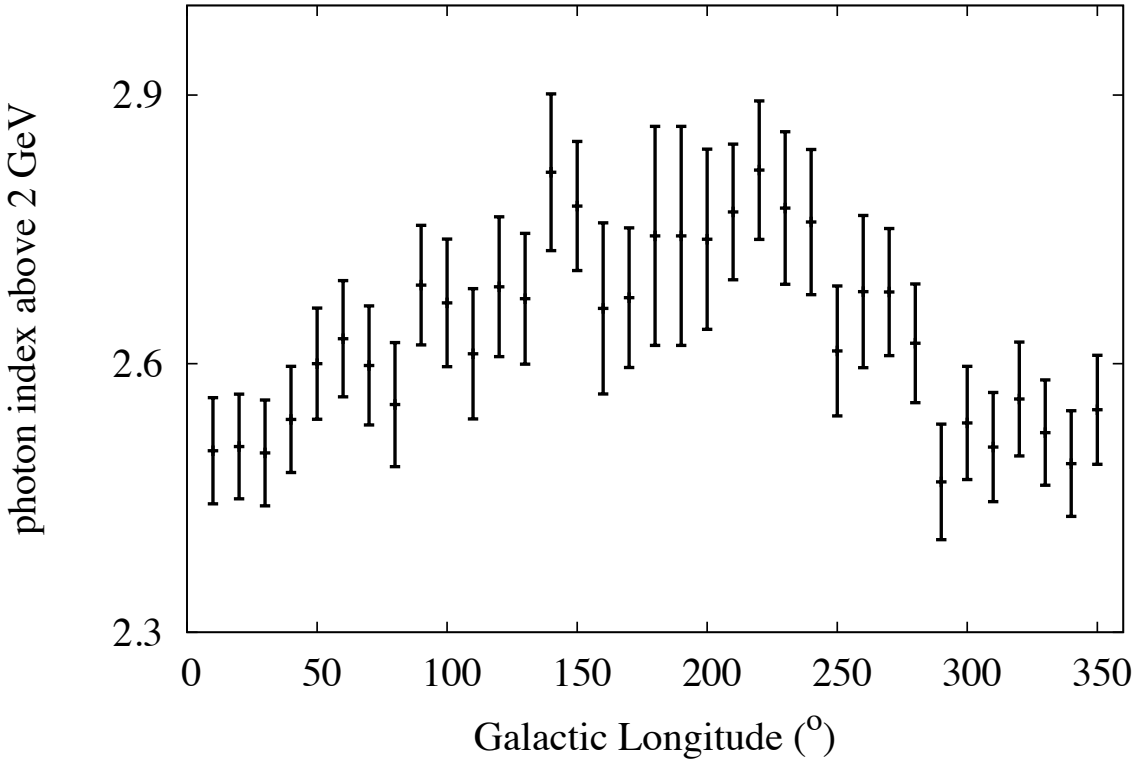
Fit with dust column template

Hardening of spectrum toward inner galaxy. (|b|<5°)

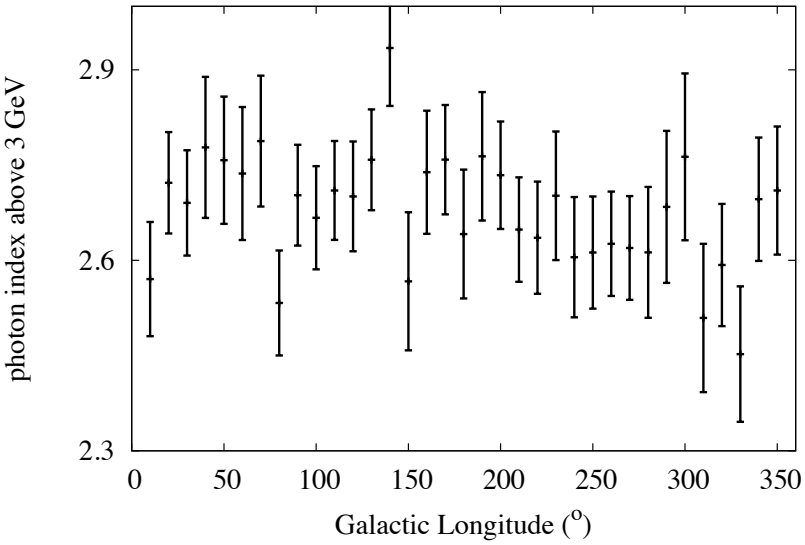


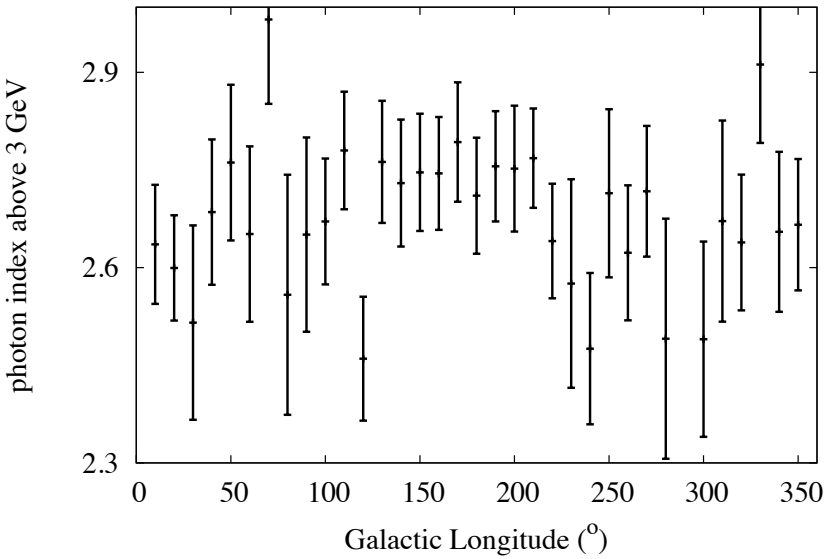
Fit with dust column template

Hardening of spectrum toward inner galaxy.
See also D. Malyshev's talk



Higher latitude?





$5^o < |b| < 10^o$

$10^o < |b| < 15^o$

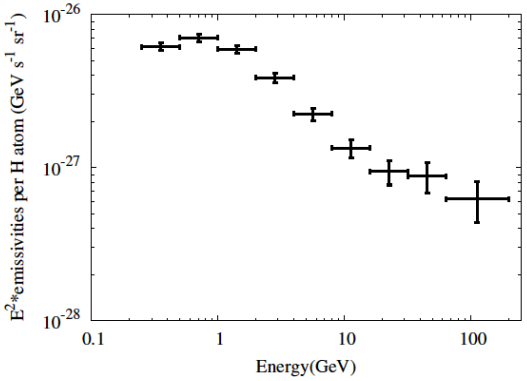
Hardening is only significant in low latitude

Fit with gas ring template

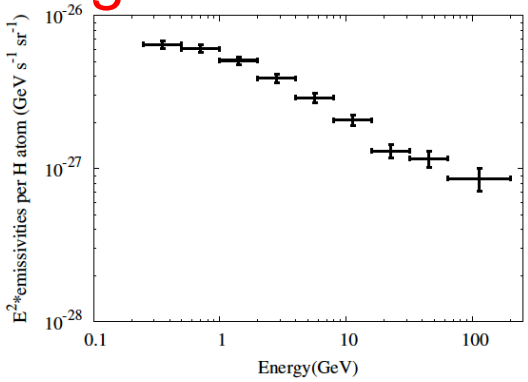
- Use kinematic distances.
- 6 Galactocentric gas rings ($|b|<5^{o}$).
- CO conversion factor left free in the fit.

Fit with gas ring template

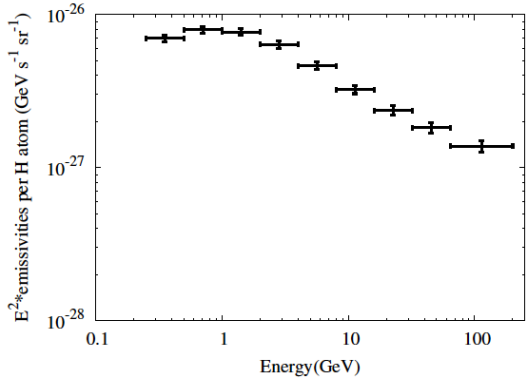
SED in different rings



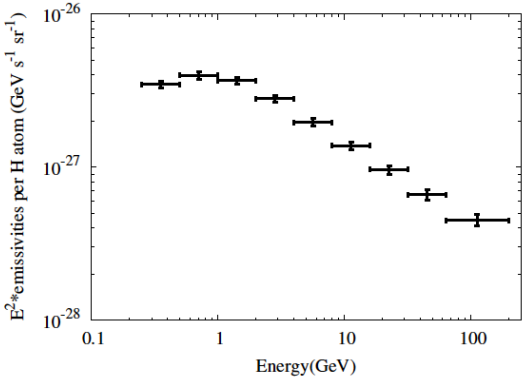
(a) 1 - 2 kpc



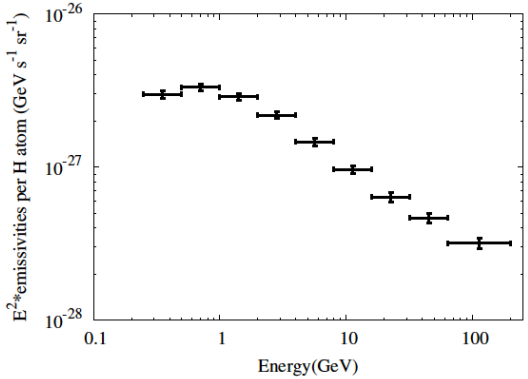
(b) 2 - 4 kpc



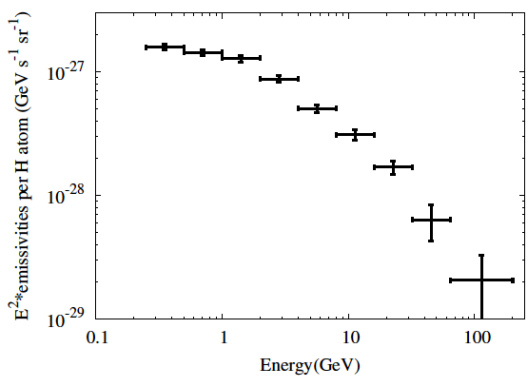
(c) 4 - 6 kpc



(d) 6 - 8 kpc



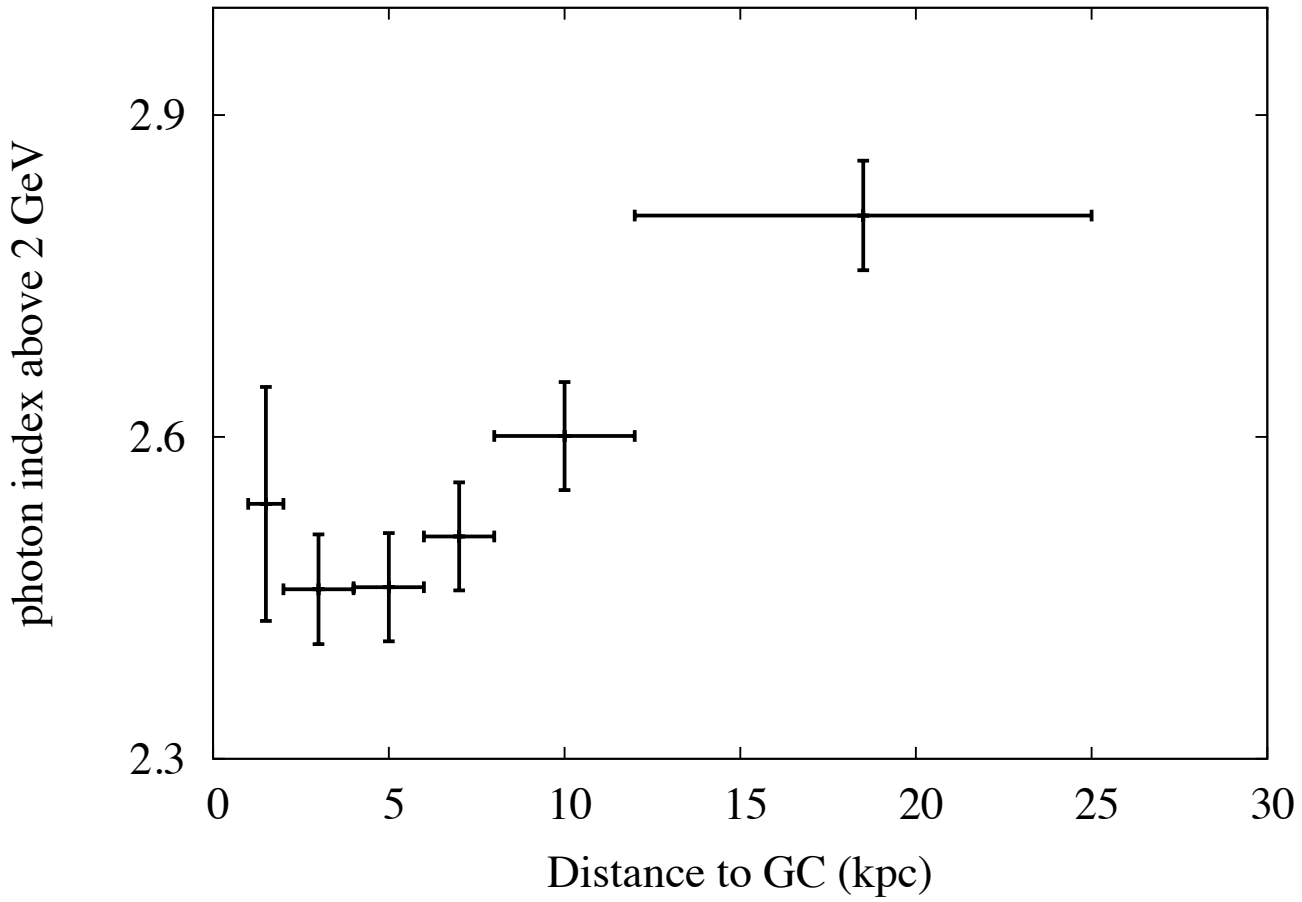
(e) 8- 12 kpc



(f) 12 - 25 kpc

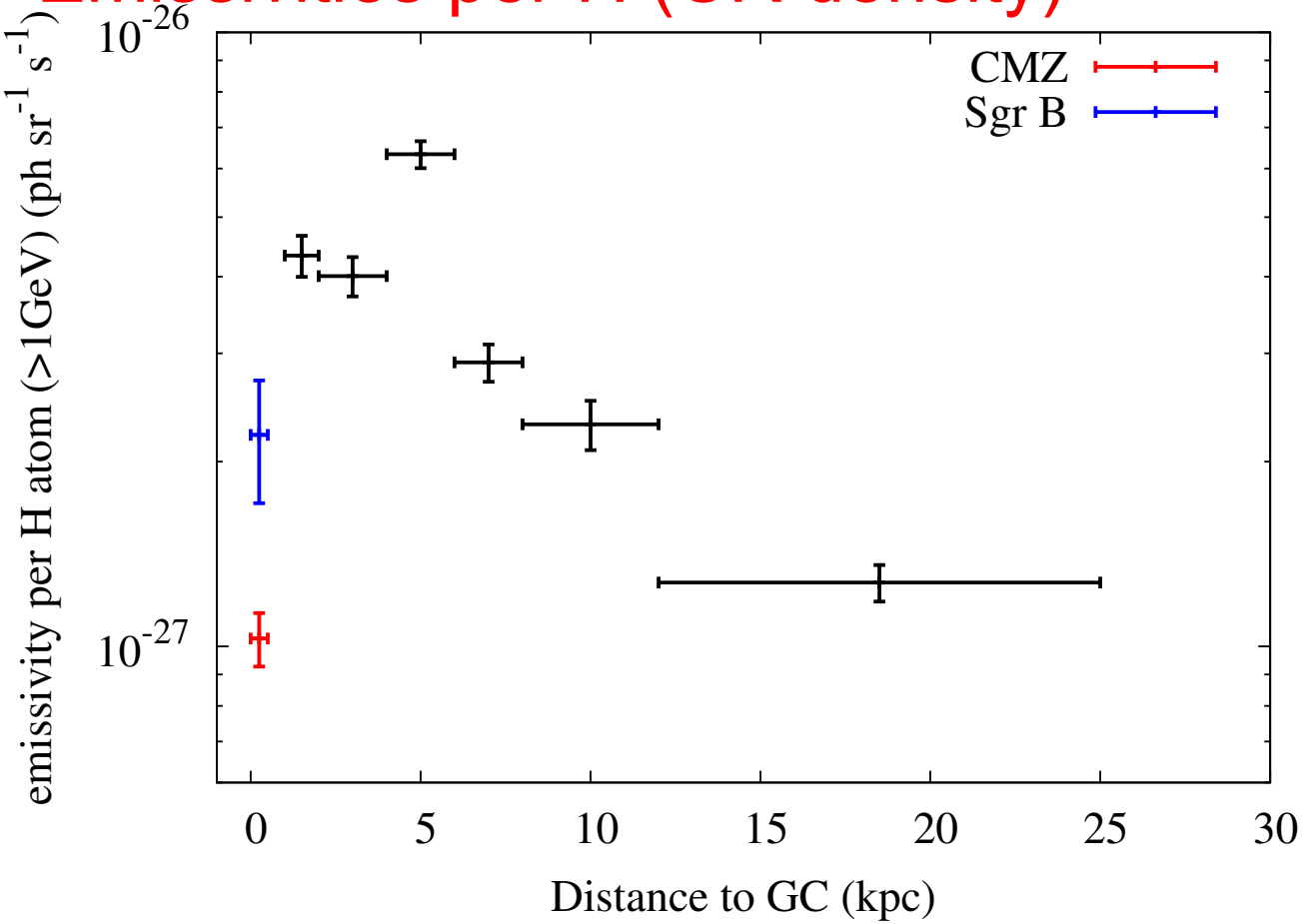
Fit with gas ring template

Index distributions



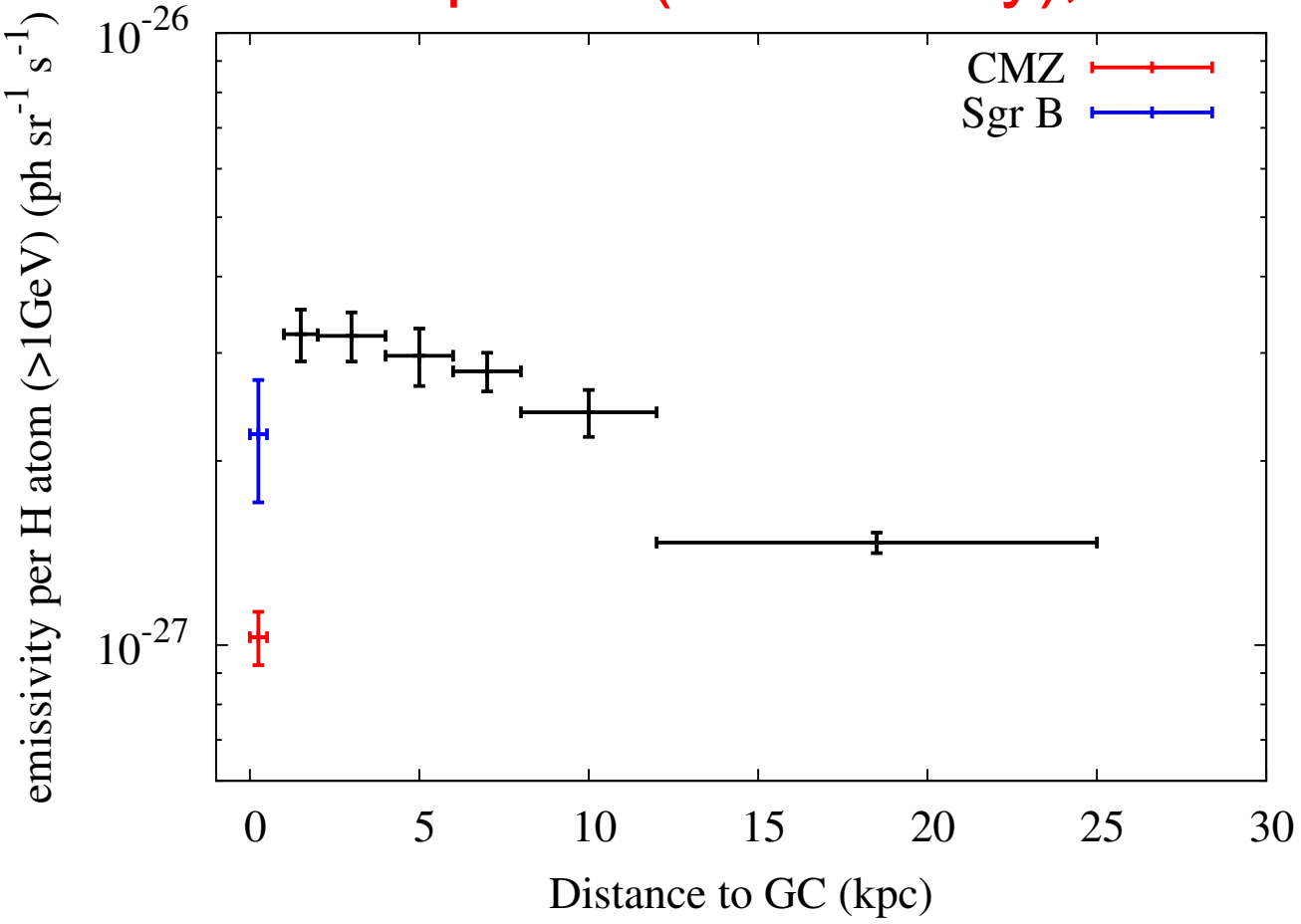
Fit with gas ring template

Emissivities per H (CR density)



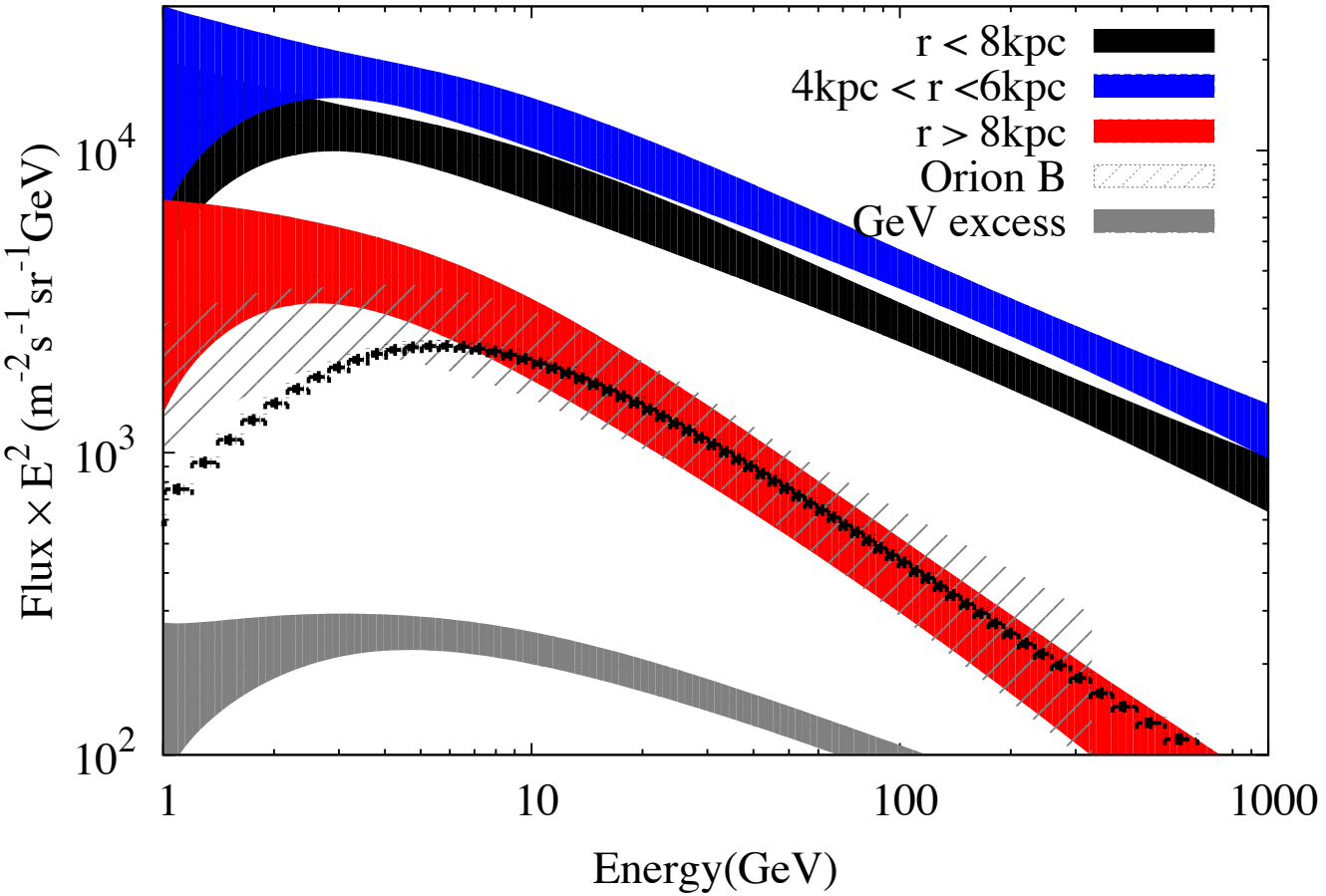
Fit with gas ring template

Emissivities per H (CR density), uniform X_co

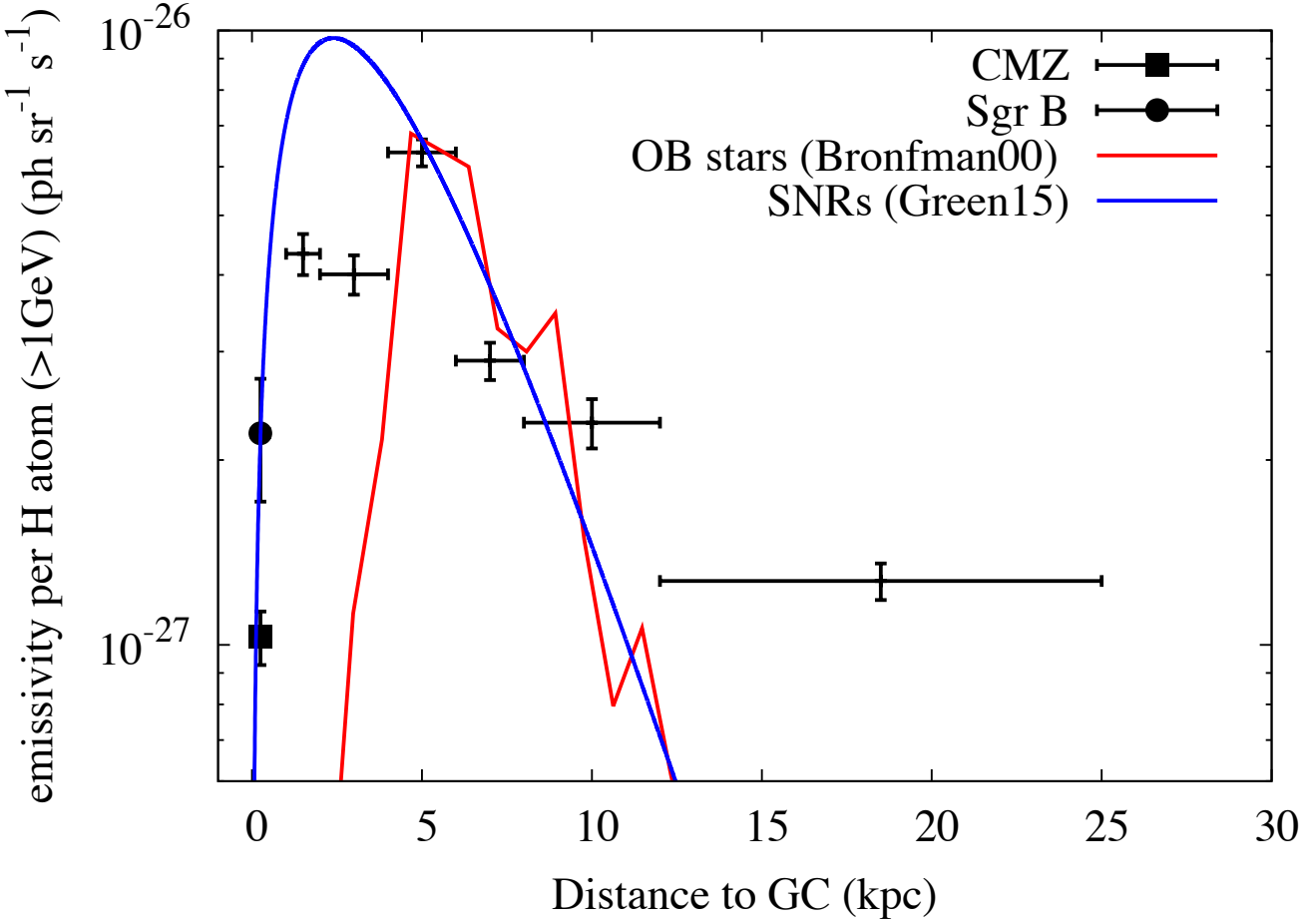


Fit with gas ring template

CRs SED in different rings.



Source distributions

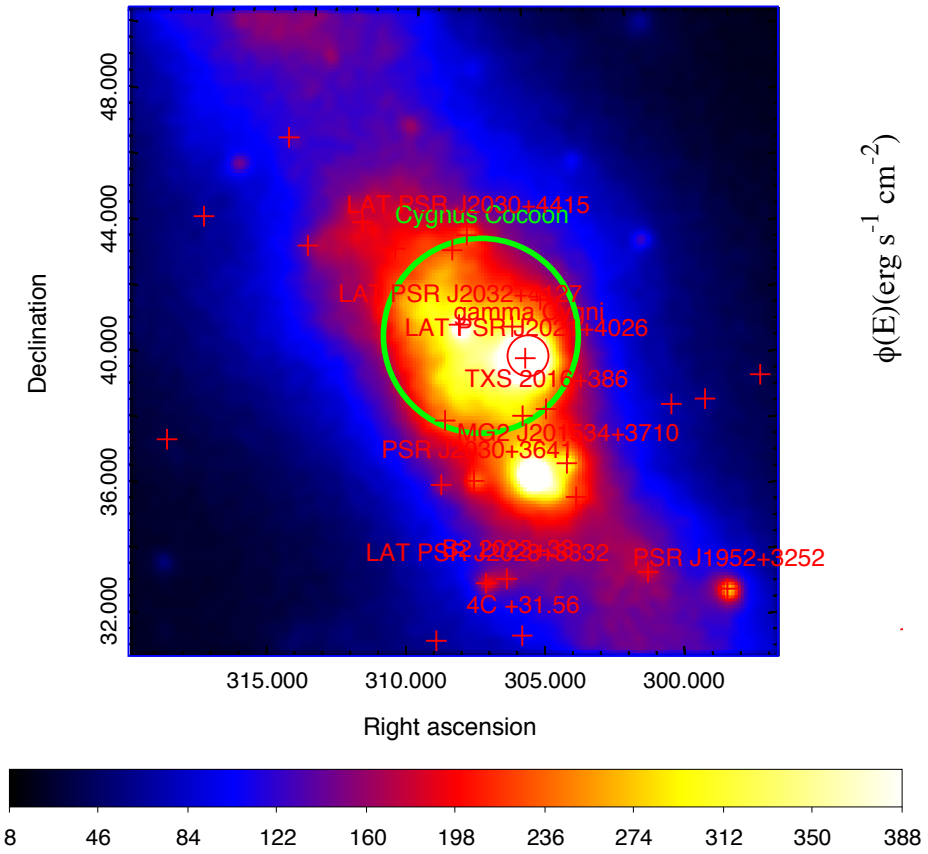


Peak coincide with OB stars

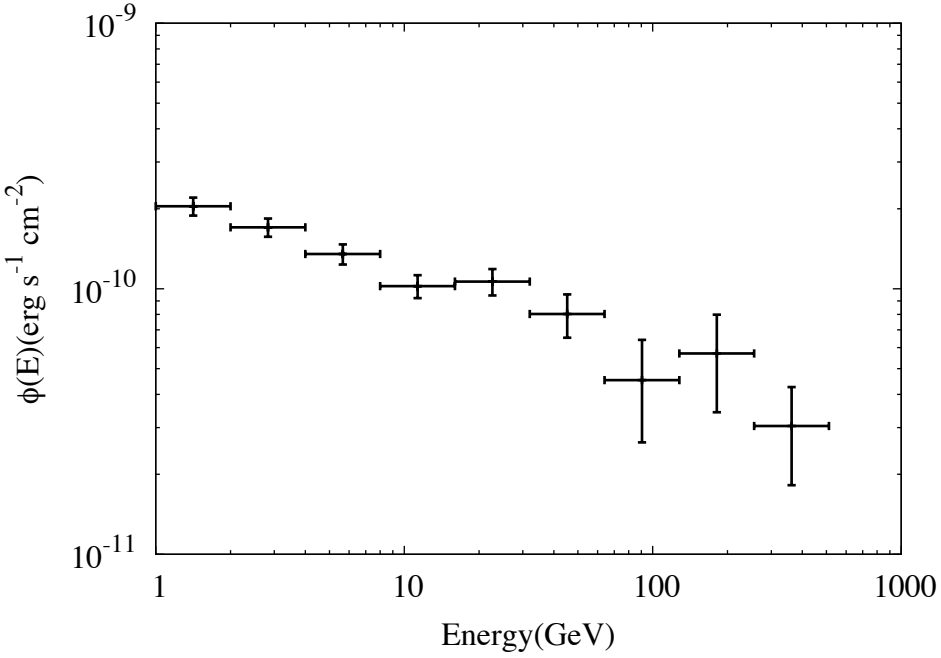
OB stars as CR sources

- Most of OB stars exist in associations or clusters, stellar wind/ SNRs in such structure form bubbles/superbubbles and can accelerate CRs (A. Bykov's talk).
- Isotope measurement favor a superbubble origin. (W.R Binns' talk)
- Could be visible in gamma-ray due to CR-gas interaction.
- So far the only detection is Cygnus cocoon. A few more powerful systems: NGC 3603, Westerlund 1, Westerlund 2. RSGC 1…..

Cygnus cocoon

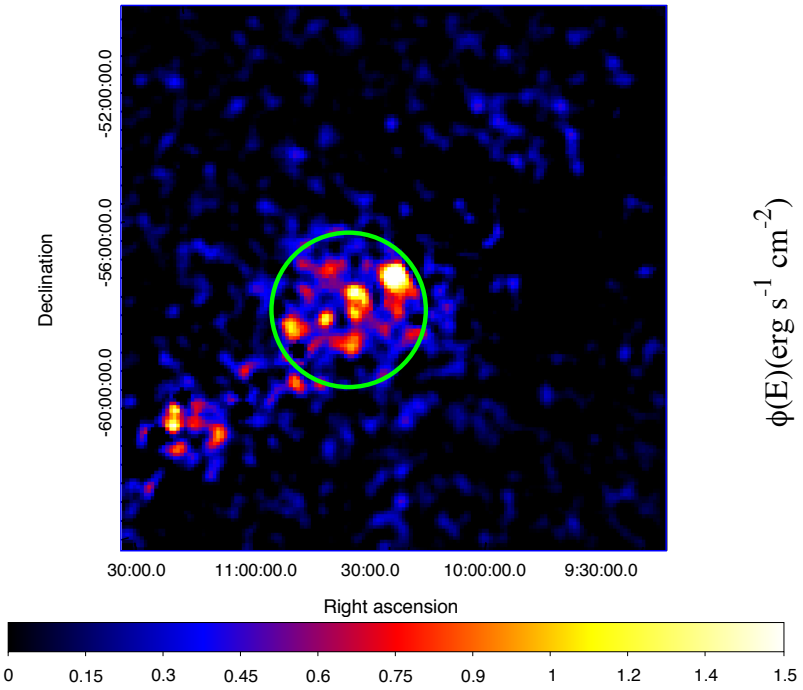


Fermi LAT counts map (>1 GeV)

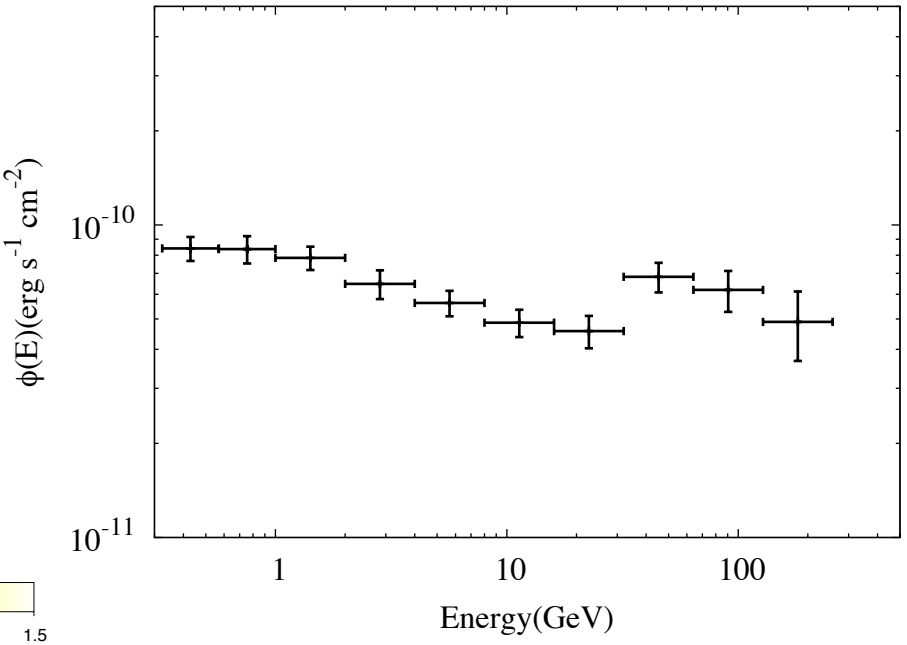


Spectral Index of -2.2, up to 500 GeV with PASS 8 data.

Westerlund 2 (Preliminary results)



Residual map (>10 GeV), known source removed



Index ~ -2.1, up tp 300 GeV

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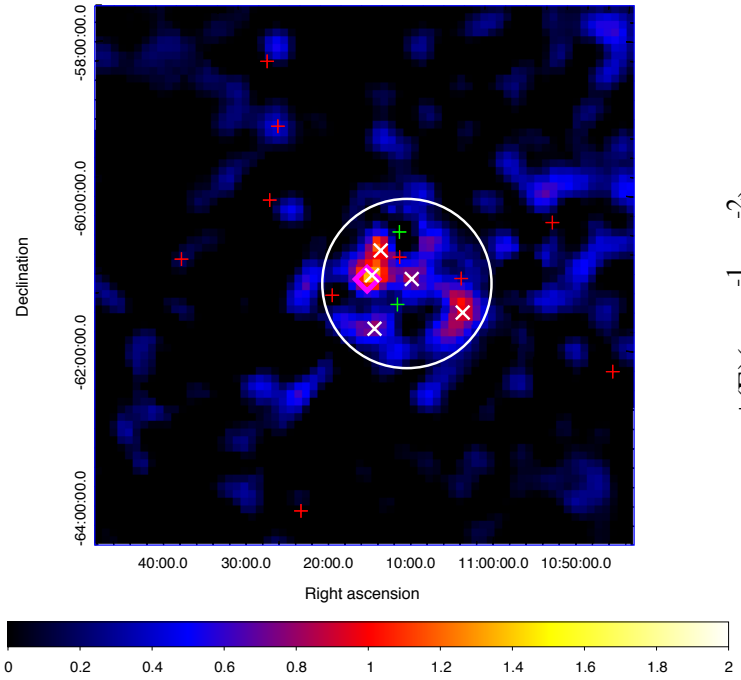
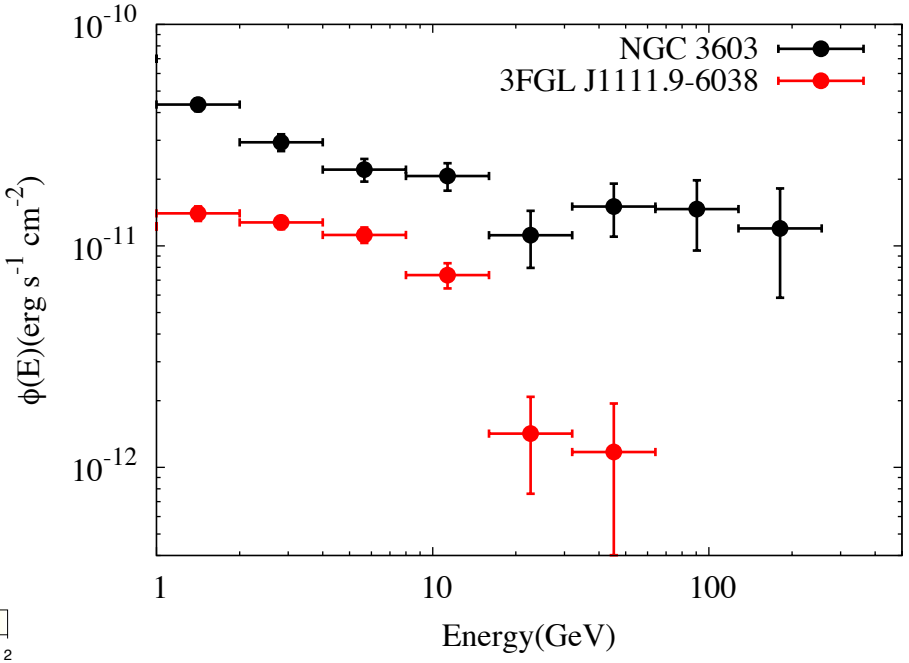
NGC 3603 (Preliminary results)



Residual map (>10 GeV), known source removed



Index ~ -2.3, up tp 300 GeV

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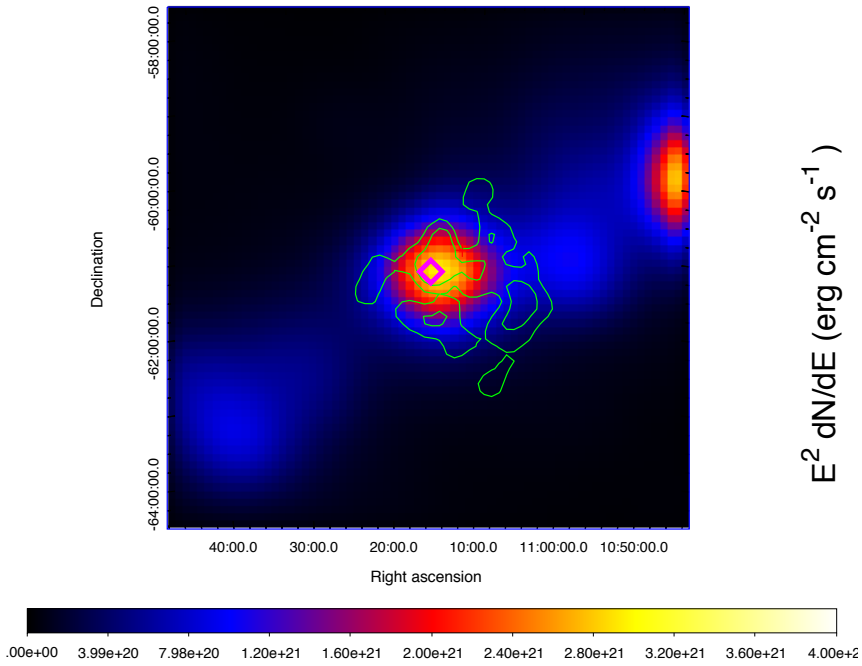
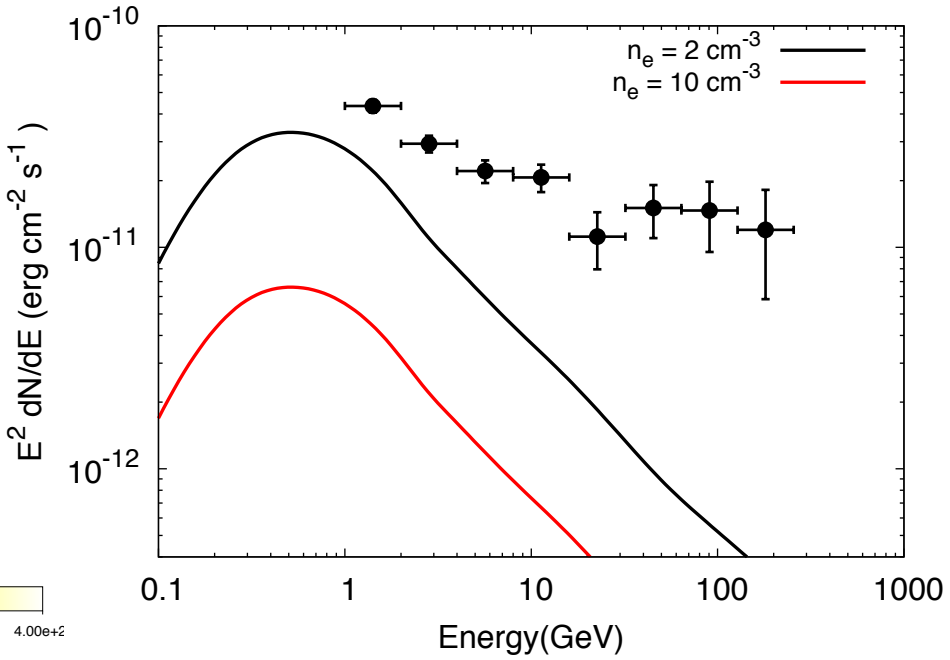
NGC 3603 (Preliminary results)





Association with the giant HII region

Enhanced CR density and harder spectrum

OB star clusters

- Cygnus cocoon revisited, hard spectrum extends to 500 GeV without cutoff.
- Very extended emission towards Westerlund 2 and NGC 3603 detected, hard spectra extends to ~ 300 GeV.
- CR energy ~ 1e49 – 1e50 erg in such structures if assuming hadronic origin of gamma-rays. Alternative CR sources in addition to isolated SNRs.
- Crowded region, need to check possible contribution from unknown PWNs.

Conclusions

- Spatial variation of CR density and spectral shape
- The results derived in outskirts of Galaxy is consistent with direct measurement
- A maximal CR density at 4-6 kpc.
- A lower CR level in GC region.
- More OB star clusters detected in gamma-rays.

Implications

- The maximal at 4-6 kpc is coincidence with the maximal of OB stars, may caused by higher injection rate by OB star clusters.
- In uniform X_co case, CR density monotonic rise toward GC. GC as a significant CR source? Connected with GeV excess, Fermi bubble?
- A lower CR density in GC region, may connected with strong advection therein.
- The hardening in the inner galaxy may also be caused by strong wind there (probably CR driven).
- Evidence for OB star cluster as an substantial (even dominate) CR source. Superbubble as Pevatrons?

Thanks!