Search for the GeV Counterpart of PeVatron LHAASO J1912+1014u using Fermi-LAT and FUGIN CO Data

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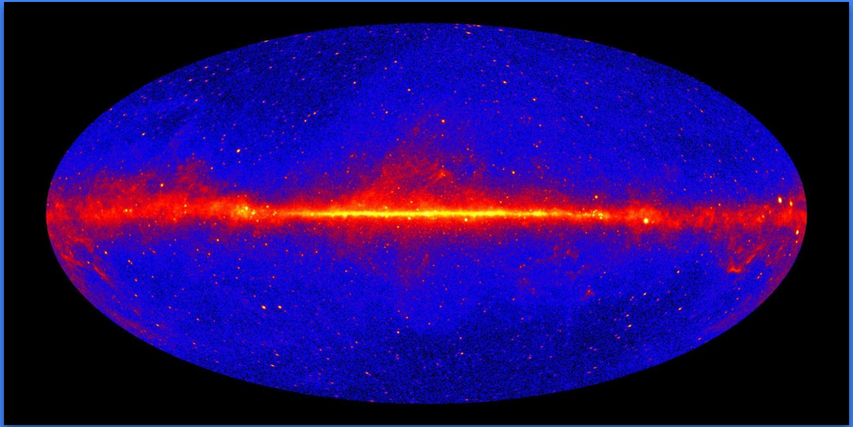
2025.11.03 @TeVPA 2025 (Valencia, Spain)



Scientific Objectives

LHAASO reported 43 ultrahigh-energy (UHE) sources (>4 σ in >100 TeV) that are either proton or electron PeVatron candidates (Cao+24)

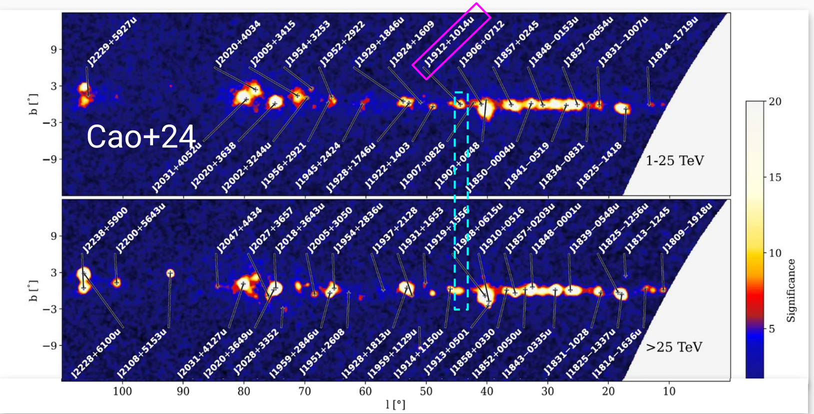
Multiwavelength data is crucial to examine particle type and CR spectrum. Here we search for GeV counterpart of LHAASO J1912+1014u using Fermi-LAT GeV data and high-resolution FUGIN CO data to investigate “proton PeVatron” scenario

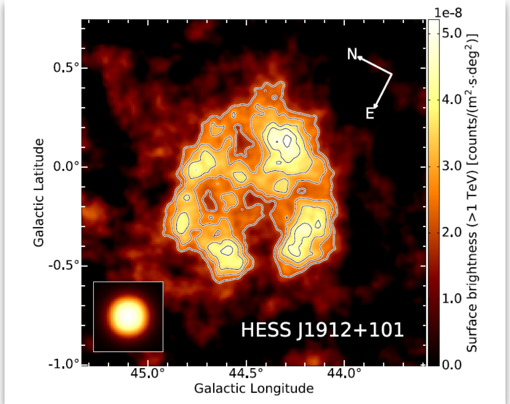
TeV Properties of the Target

LHAASO J1912+1014u is an extended UHE source with test statistics above TS_{100}~70 and size r_{39}~0.50 deg

It coincides in position with an extended H.E.S.S. source, HESS J1912+101 (r_{sep}=0.1 deg). Hereafter we assume they are the same object

Γ=3.26 (KM2A band), 2.68 (WCDA band) and 2.56 (H.E.S.S. band) with ΔΓ~0.1;
GeV counterpart will have Γ<2.5





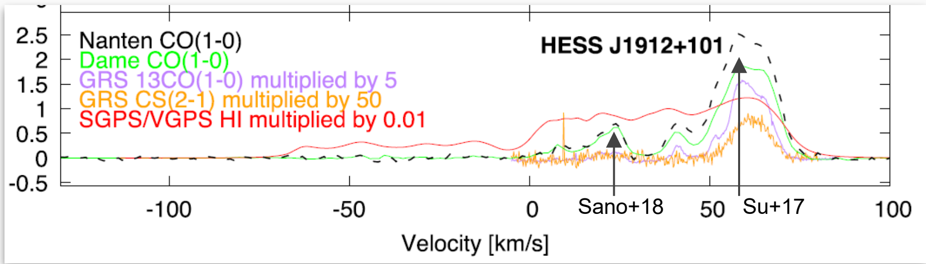
H.E.S.S. 2018

(Some earlier works of LAT data for HESS J1912+101; e.g., Green+19, Li+23)

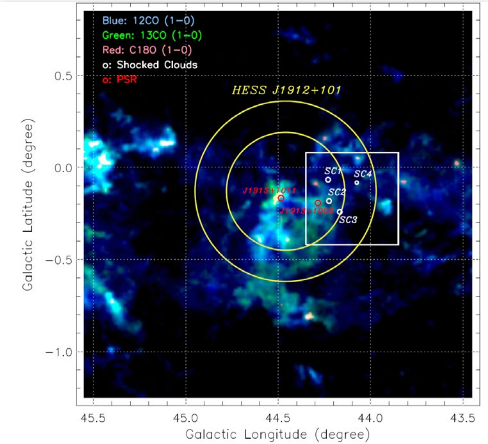
CO Data

<u>CO data toward the source show several peaks</u>. Su+17 proposed CO cloud with v~60 km/s corresponding to the H.E.S.S source and high-velocity shells are due to SN expansion. Sano+18 pointed out this may be due to outflow of H_{II} region along LOS and proposed alternative scenario, i.e., CO cloud with v~25 km/s is associated

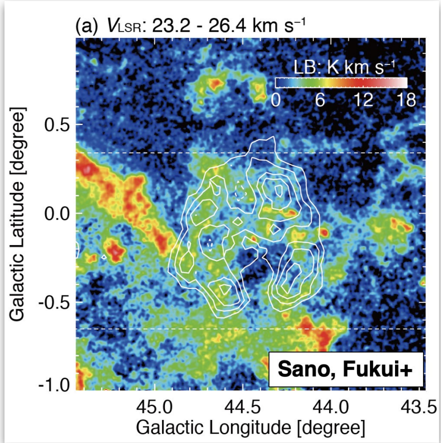
Here <u>we test three models against LAT data</u>, (1) LHAASO WCDA Gaussian, (2) ^{12}CO map of Su+17 velocity range, and (3) ^{12}CO map of Sano+18 velocity range



(H.E.S.S. 2018)



(Su+17)



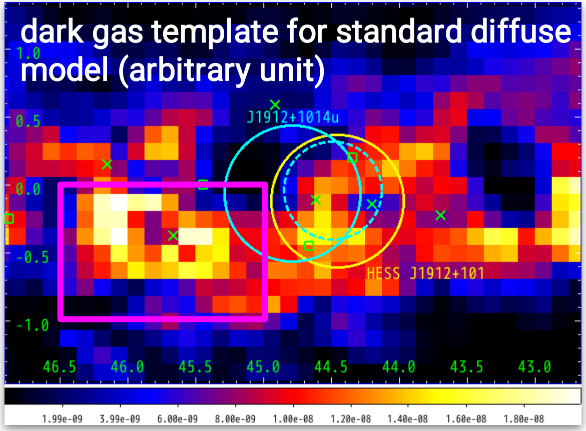
(Sano+18)

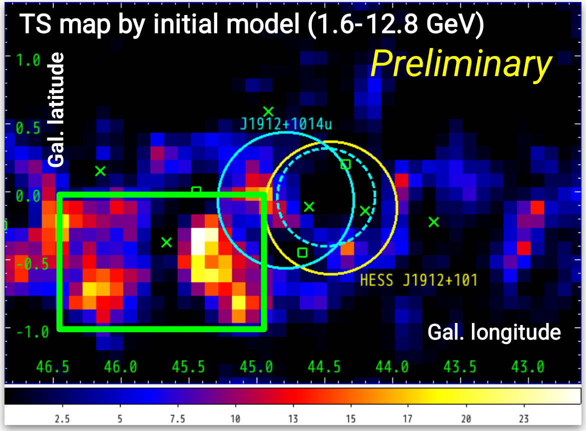
Construction of Baseline Model

We first employed standard diffuse model + 4FGL sources, and found large residual in 1-10 GeV, likely because dark gas template is not perfect

(ISM gas not traced well by H_I and CO lines)

We added additional template (magenta square) to construct “baseline model”





Construction of Baseline Model (Cont'd)

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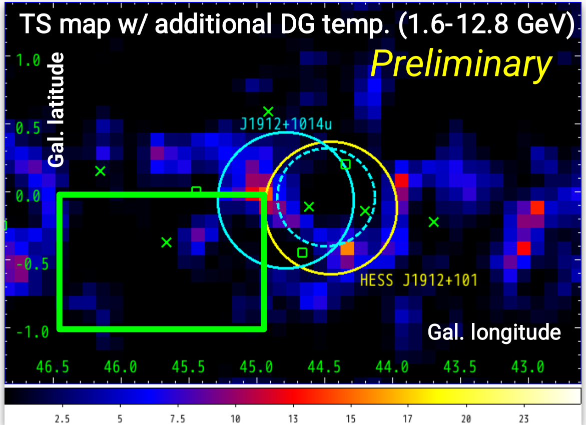
We added additional template (magenta square) to construct "baseline model"

- Residual reduced significantly in <10 GeV



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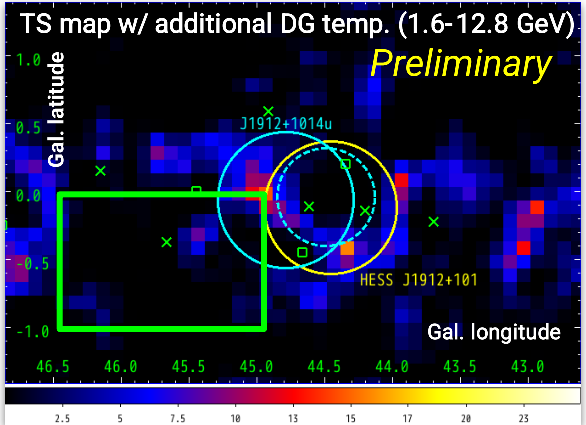
- Excess emission remain toward LHAASO/H.E.S.S. source in >10 GeV; we test 3 models



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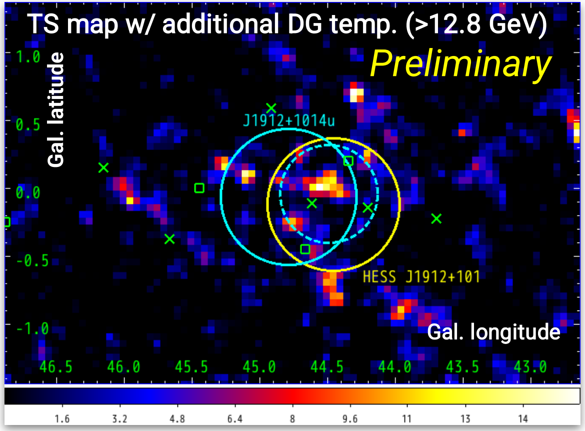
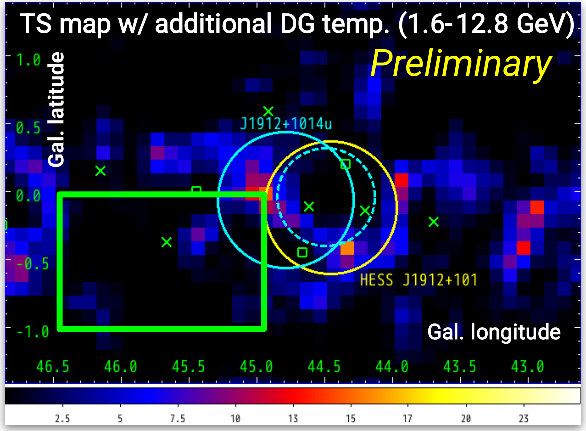




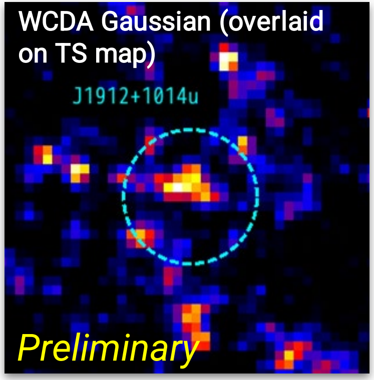
Models for Excess Emission

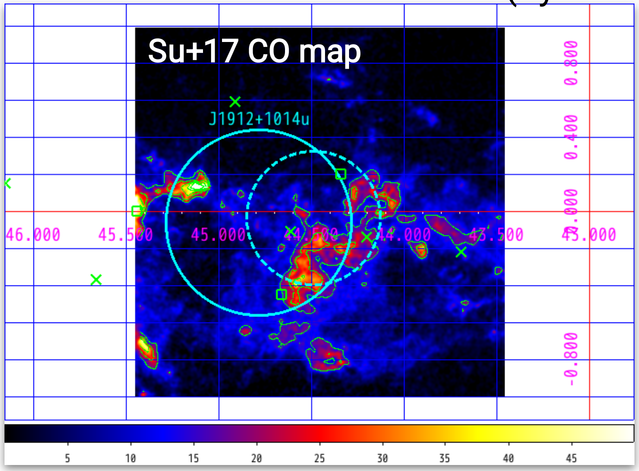
<u>We prepared three models for the excess:</u>

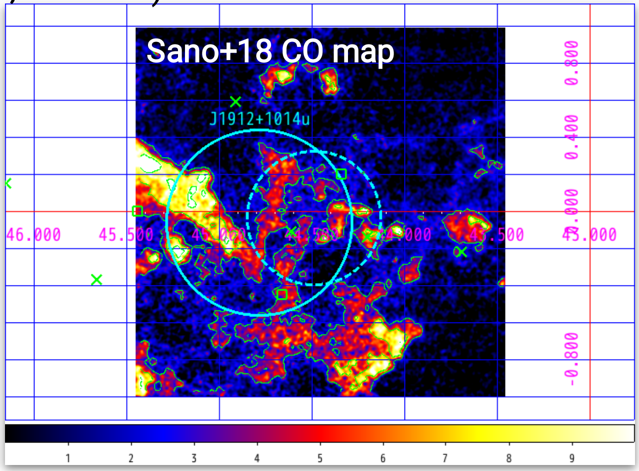
1) LHAASO WCDA Gaussian (dashed circle)
2) Su+17 CO map (58.6-62.2 km/s)
3) Sano+18 CO map (22.3-26.4 km/s)

} High-resolution FUGIN data

(by Sano, Murase)





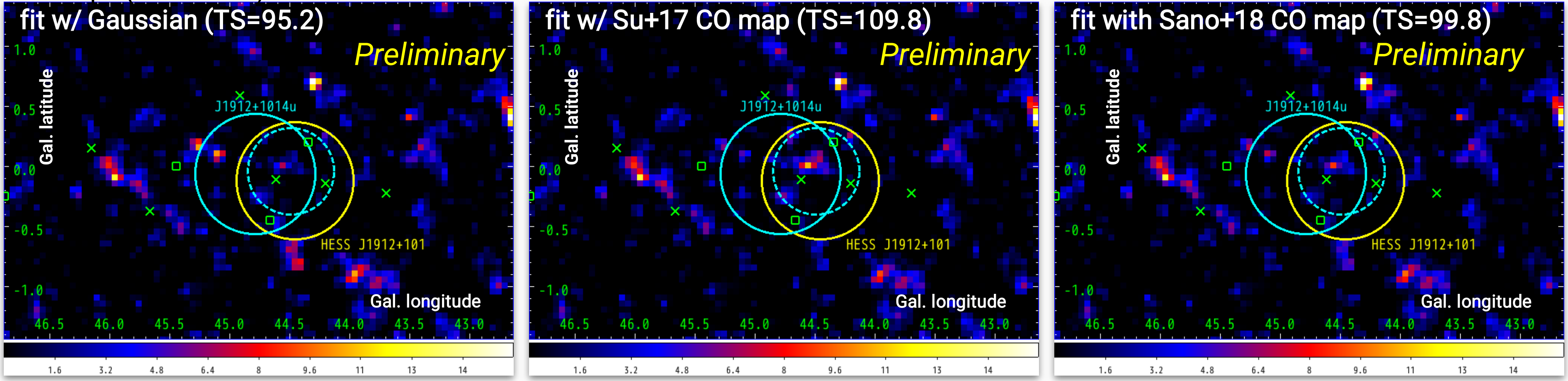


Results with Excess Emission Models

Models: (1) LHAASO WCDA Gaussian, (2) Su+17 CO map, (3) Sano+18 CO map

- (Sano+18 CO map prefers different norm. for inner/outer areas; we allowed them differ)
- (We also tested H.E.S.S. intensity map and KM2A Gaussian; they gave worse fits)
- <u>CO-map-based models</u> are <u>as good as, or better than</u>, LHAASO Gaussian
  - hadronic scenario preferred (leptonic not ruled out)

TS maps (>12.8 GeV)

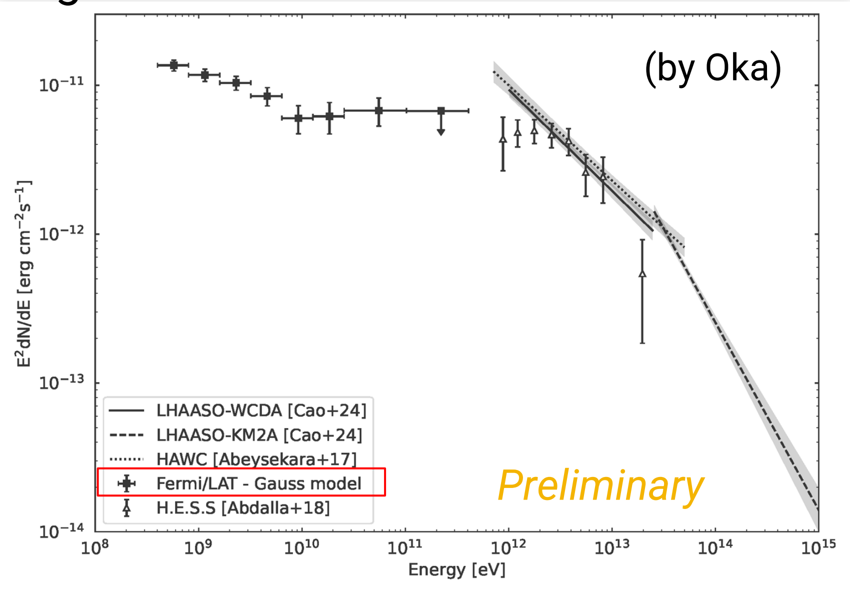


GeV/TeV Spectrum

3 models give similar spectrum that connects to TeV spectrum smoothly;
SED w/ LHAASO WCDA Gaussian as an example

LAT gives Γ~2.2 and F(>0.4 GeV)~60x10^{-12} erg/s/cm^2

- leptonic case (IC): α_e~3
- hadronic case: α_p~2.2
  - Su+17 CO (d=4.6 kpc):
    $M_{CO,H2}$~4x10^5 Msun
    W_p(>4GeV)~5x10^{49} erg
  - Sano+18 CO (d=1.7 kpc):
    $M_{CO,H2}$~2x10^4 Msun
    W_p(>4GeV)~10^{49} erg



Evaluation of H_I contribution (e.g., Fukui+17),
X-ray counterpart search, SED fitting in progress

Summary and Prospect

We searched for GeV counterpart of LHAASO J1912+1014u that is a Galactic PeVatron and positionally coincides with HESS J1912+101

We developed a dedicated diffuse model and succeeded in reproducing excess in LAT data

- CO-map-based model are as good as, or better than, gaussian model
  - proton PeVatron scenario is favored
- LAT gives $\Gamma \sim 2.2$ and F(>0.4 GeV)~60×10^{-12} erg/s/cm^2
  - If leptonic (IC), $\alpha_e \sim 3$
  - If hadronic, $\alpha_p \sim 2.2$ and $W_p \sim 10^{49}$ erg or 5×10^{49} erg (depends on distance)

Detailed modeling using multiwavelength data in progress; stay tuned

Thank you for your attention

References

- Abdollahi et al. 2024, ApJS 260, 53 (4FGL)
- Abdollahi et al. 2024, ApJS submitted (2FGES; arXiv.2411.07162)
- Abeysekara et al. 2017, ApJ 843, 40 (2HWC)
- Aharonian et al. 2008, A&A 484, 435
- Brand&Blitz 1993, A&A 275, 67
- Cao et al. 2024, ApJS 271, 25
- Chang et al. 2008, ApJ 682, 1177
- Fukui et al. 2017, ApJ 850, 71
- H.E.S.S. Collaboration 2018, A&A 612, 8
- Ranasinghe&Leahy 2023, ApJS 265, 53
- Sano et al. 2018, ASJ meeting (ISM-oriented paper in prep.)
- Smith et al. 2019, ApJ 871, 78 (LAT PSR catalog)
- Su et al. 2017, ApJ 845, 48
- Green et al. 2019, Proc. ICRC 2019; Zhang et al. 2020, ApJ 889, 12; Zeng et al. 2021, ApJ 910 78; Sun et al. 2022, A&A 659, 83; Li et al. 2023, ApJ 953, 100 (past studies of LAT data for HESS J1912+101)

Backup Slides (Appendix)

Alternative Scenario (Sano+18)

Su+17 proposed CO cloud with v~60 km/s is associated with HESS J1912+101

Sano+18 proposed alternative scenario (CO cloud with v~25 km/s) based on the following:

- expanding gas motion is observed
- good spatial correlation with H.E.S.S. source is observed
- (ISM-oriented paper in prep.)

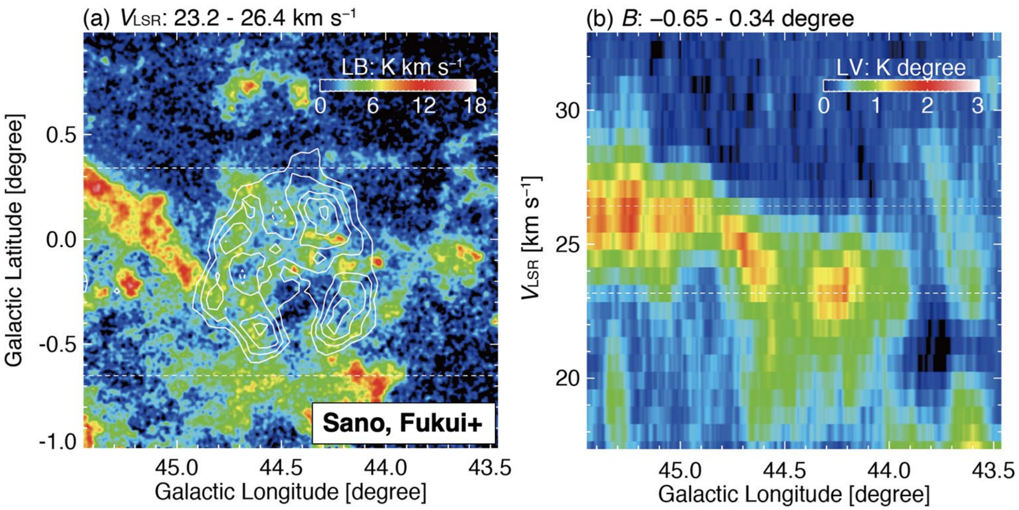
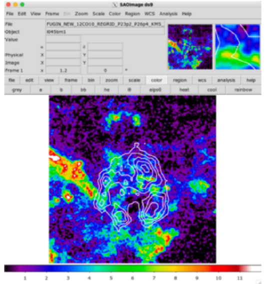


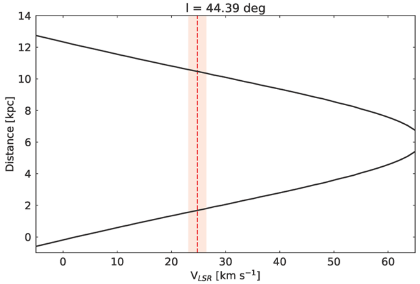
Image: FUGIN ^{12}CO(1–0), Contours: H.E.S.S. TeV gamma-ray

Distance to the Source

We refer to rotation curve by Brand&Blitz 1993 and <u>adopt the distances of near side</u>

✓ **Sano+18 CO model**: V_{LSR} = +23.2 - 26.4 [km/s]

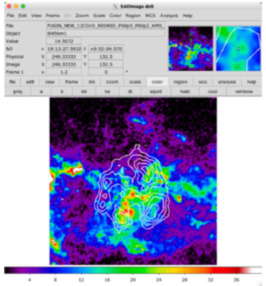


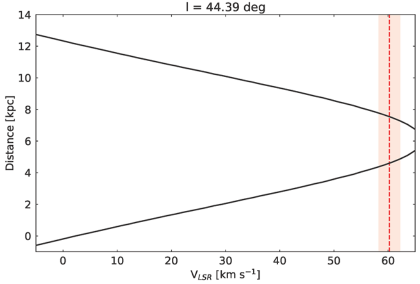


D=1.7 +/- 0.1 kpc

D=10.5 +/- 0.1 kpc

✓ **Su+17 CO model**: V_{LSR} = +58.3 - 62.2 [km/s]





D=4.6 +/- 0.2 kpc

D=7.5 +/- 0.2 kpc

(by Oka)

✓ **PSR J1913+1011**: D = 4.6 kpc

If the LHAASO (and LAT) source is SNR, D=1 deg corresponds to

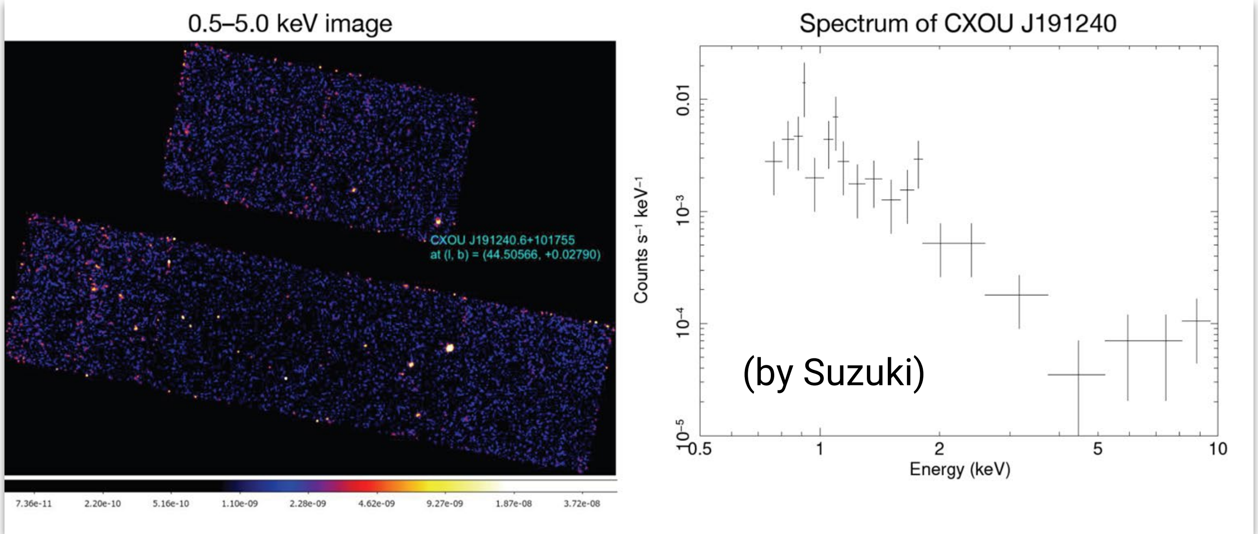
- ~30 ps (t~15 kyr) for Sano+18
- ~80 pc (t~120 kyr) for Su+17
  (D=9.5$t^{0.44}$ pc; Ranasinghe&Leahy 23)

X-Ray Observations

Chandra and XMM observed the area several times to study HESS J1912+101 (some affected by stray-light of GRS 1915+105)

Position of GeV residual peak (center of HESS J1912+101) observed by Chandra

- No apparent extended emission (cf. Chang+08); detailed study in progress



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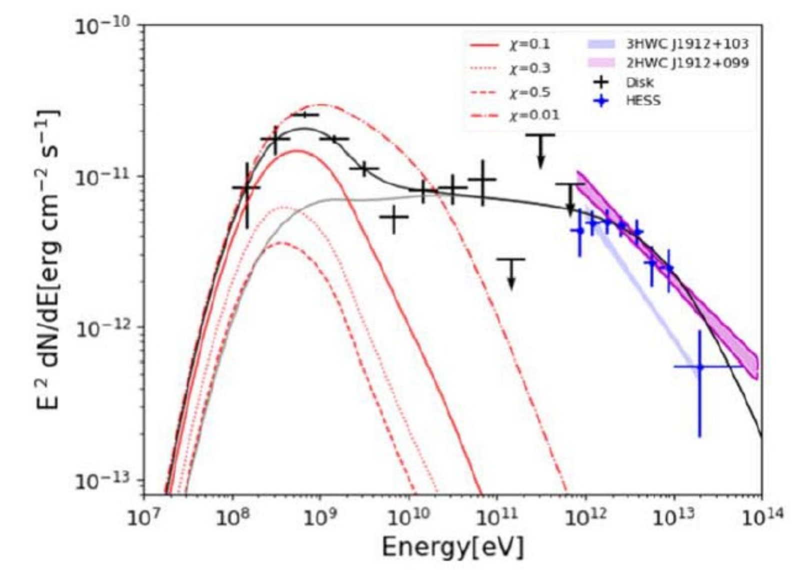
Past Studies of LAT Data

Several past studies of LAT data searching for GeV counterpart of HESS J1912+101

Most of these pioneering work used standard diffuse model and removed "c" flag sources

- They obtained soft spectrum (Γ~2.5) below 10 GeV and employed two-zone model or discussed only >10 GeV

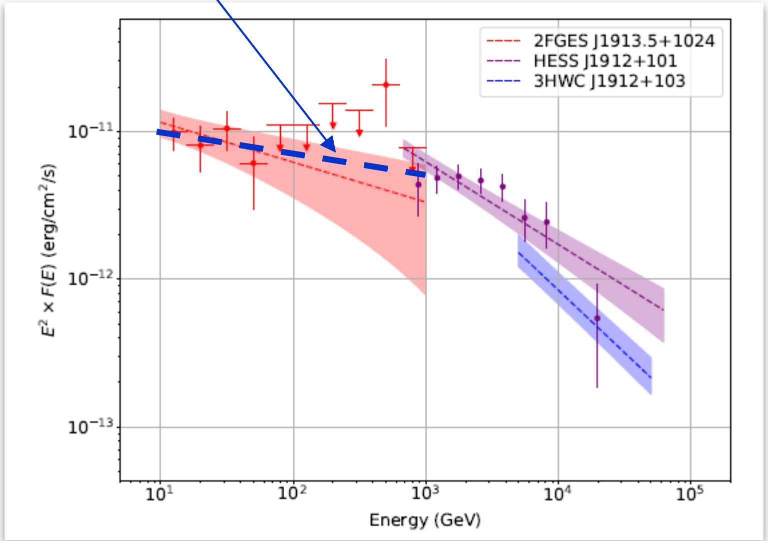
(LI+23)



2FGES Result of the Region

2FGES, led by Soheila and Pierrick, reported extended emission toward the region (r_{68}=0.77 deg, Gamma=2.27)

Our spectrum using LHAASO gaussian (r_{39}=0.50 deg) is similar to 2FGES result



Abdollahi+24