S8.8

Search for molecular clouds associated with PeVatrons by the Nobeyama 45-m radio telescope: the case of LHAASO J0341+5258

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The origin of PeV cosmic-ray factories ("PeVatrons") remains a long-standing problem in high-energy astrophysics. Recent progress in water Cherenkov telescopes, such as HAWC and LHAASO, opened up a new era of the study of PeVatrons. The first LHAASO catalog includes 43 gamma-ray emitters detected with E>0.1 PeV [2], and thus they are considered as PeVatron candidates. Most of these LHAASO sources are poorly explored at other wavelengths and yet to be identified. Such high-energy gamma rays (E>0.1 PeV) may favor the hadronic origin (i.e., pion decay) rather than the leptonic origin (i.e., inverse Compton scattering), of which high-energy photons are suppressed due to the Klein-Nishina effect. In the hadronic case, gamma rays are expected to coincide with dense environments, such as molecular clouds. Using the Nobeyama Radio Observatory (NRO) 45-m radio telescope, an extensive search for molecular clouds associated with PeVatrons is currently underway and planned. Our initial investigation, focusing on the PeVatron source LHAASO J0341+5258, has revealed the presence of molecular clouds within the gamma-ray emitting region. In this poster, we report detailed findings of LHAASO J0341+5258 and outline our observation plan for further PeVatron sources.

1. PeVatron Candidate LHAASO J0341+5258

- Discovery of LHAASO J0341+5258 [1,2]
  - Extended and no apparent counterpart
  - Some molecular clouds with V=0-10 km/s [3]
- LHAASO first catalog [4]
  - J0341 split into two sources; J0339+5307 and J0343+5254u
  - J0343 was significantly detected above100 TeV

Tab. 1: LHAASO sources in the J0341 region

Name	Size (deg)		Γ		$TS_{>100TeV}$
	KM2A	WCDA	KM2A	WCDA	
LHAASO J0341+5258	0.29	—	2.98	—	—
1LHAASO J0339+5307	<0.22	—	3.64	—	—
1LHAASO J0343+5254u	0.20	0.33	3.53	1.70	20.2

(WCDA in 1–25 TeV, and KM2A in >25 TeV)

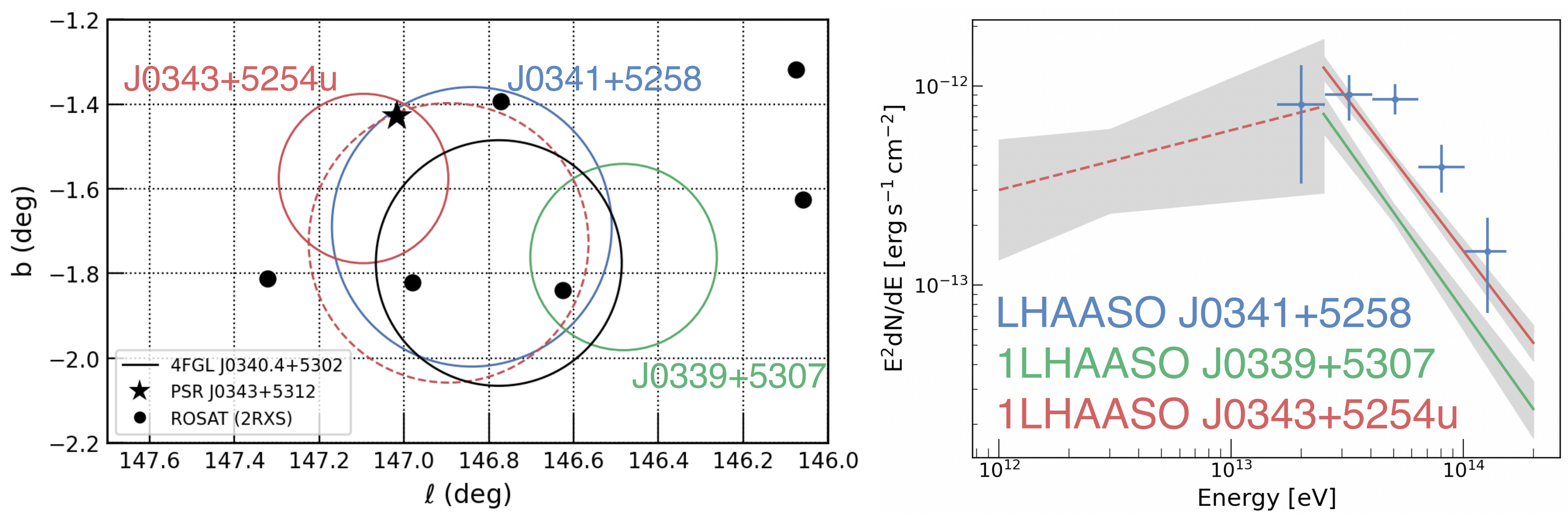

Fig. 1: Source locations (left) and spectra (right)

2. Observation by NRO 45-m Telescope

- We performed observations of molecular lines, ^{12}CO, ^{13}CO, and $C^{18}O$ lines (J=1–0), using NRO 45-m telescope [5] (Fig. 2)
- Observation overview
  - Configuration: four-beam receiver FOREST and autocorrelation spectrometer SAM45
  - Date: February 12, March 3, 4, and 9–11 in 2024
  - Time: ~30 hours in total
  - Pointing source: S-per (SiO maser)

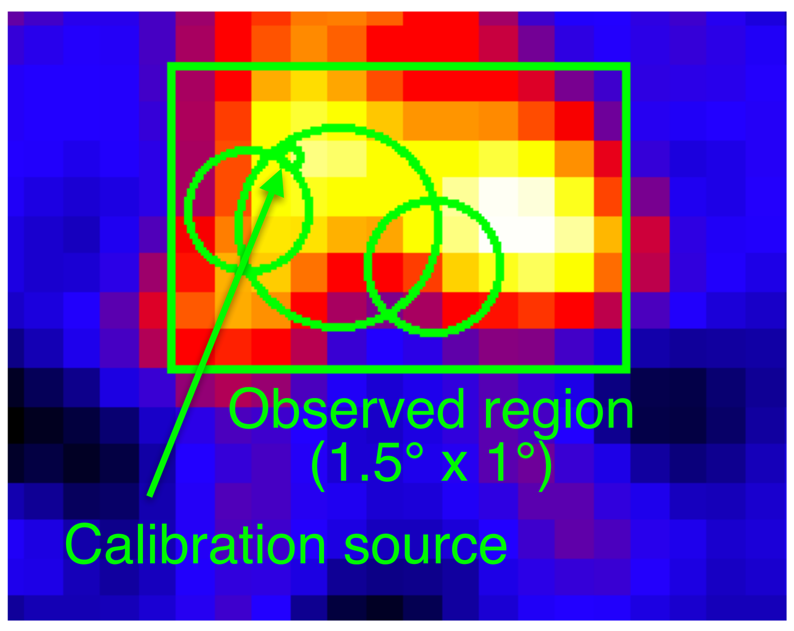

Fig. 2: NRO 45-m telescope (left) and our observation regions, shown on 7 km/s ^{12}CO map by the CfA 1.2 m telescope [6] (right)

3. Data Analysis

- Software: NOSTAR (split, base, and makemap)
- Base fitting range: -200 to -150 and 150 to 200 km/s
- Map: convolved using Bessel-Gaussian functions with grid of 7.5" x 7.5" x 1 km/s
- Conversion factor from antenna temperature (T^*_A) to mainbeam temperature (T_{MB}): η_{MB}= 0.35 (for ^{12}CO) and 0.40 (for ^{13}CO and $C^{18}O$)
- RMS level is 1.0 K (^{12}CO) and 0.28 K (^{13}CO)
- 3RMS-cut is applied
- Calibration source is almost constant

4. Results

4.1. Map and spectrum

- There are some molecular clouds, labeled as A to E, in Fig. 3
- Cloud A has been already identified as "half-shell" structure [2, 3]
- $C^{18}O$ is also slightly detected at cloud C
- Cloud E is likely an AGB star with CO envelope

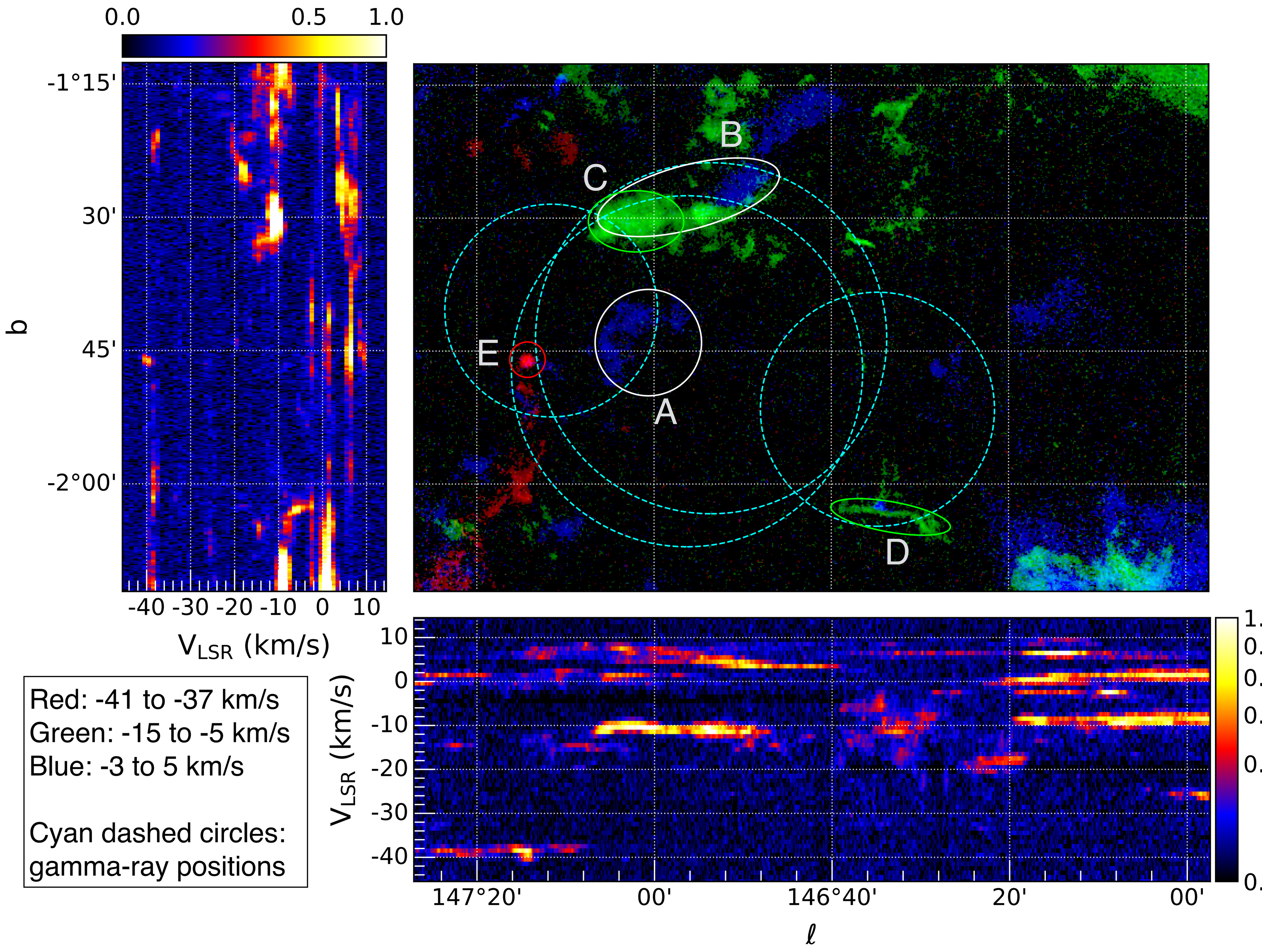

Fig. 3: ^{12}CO RGB image and b/l-v image

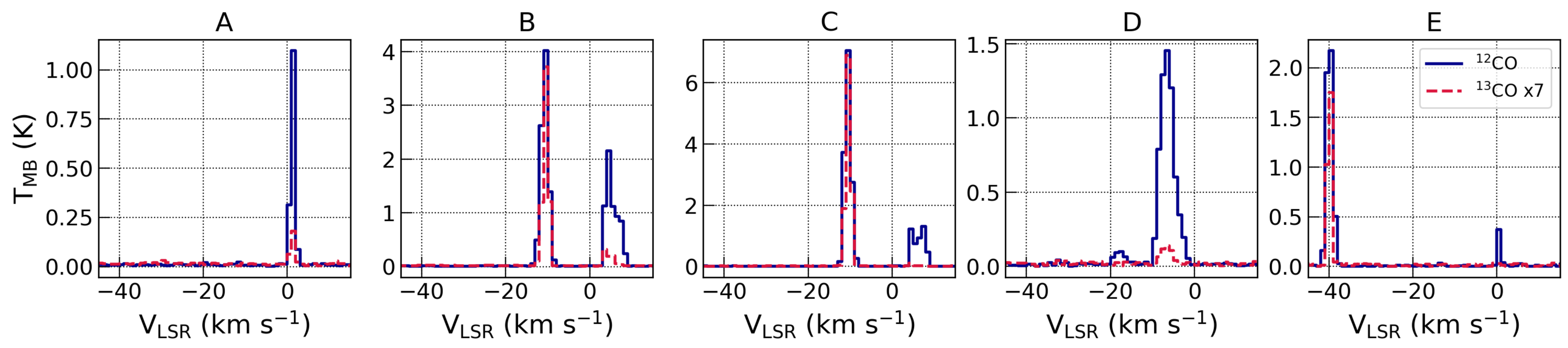

Fig. 4: ^{12}CO and ^{13}CO spectra of clouds A—E

4.2. Physical parameters of molecular clouds

- Estimation of distance
  - Kinematic Distance Calculation Tool [7] (rotation curve with updated parameters and Monte Carlo method)
- Estimation of column density
  - (1) ^{12}CO-to-H_2 factor $X_{CO} = 2 \times 10^{20}$ cm^{-2} (K km/s)$^{-1}$ [8]
  - (2) Assuming local thermodynamic equilibrium

Tab. 2: Molecular clouds in the J0341 region

src	V_{LSR} (km/s)	ΔV_{LSR} (km/s)	d (kpc)	Radius (pc)	$N(H_2)$ (10^{21} cm^{-2})	M (M_{sun})	n (cm^{-3})
A	1.3	1.2	<0.3	0.5	0.28	5.4	365
B	4.9	3.5	<0.3	0.9	1.2	25	323
C	-10.6	1.9	1.0±0.4	1.6	2.8	310	781
D	-6.6	3.9	0.5±0.4	1.0	1.2	21	210
E	-39.9	1.8	4.0±1.0	1.2	3.6	339	340

(ΔV_{LSR} indicates FWHM. The density n is estimated assuming a sphere.)

5. Summary and Future Plan

- In the J0341 region, we found some molecular clouds, which are nearby (<1 kpc), small, and relatively light (Fig. 3 and Tab. 2). Association with the gamma-ray emission will be discussed.
- With NRO, we will continue to search for molecular clouds near 1LHAASO J2229+5927u, HESS J1825-137, LHAASO J1956+2845 (tbd).

References

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