CO Observations for the enigmatic PeVatron LHAASO J2108+5157

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High Altitude Water Cherenkov Gamma-Ray Observatory

LHASSO J2108+5157

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Discovery of the Ultrahigh-energy Gamma-Ray Source LHAASO J2108+5157

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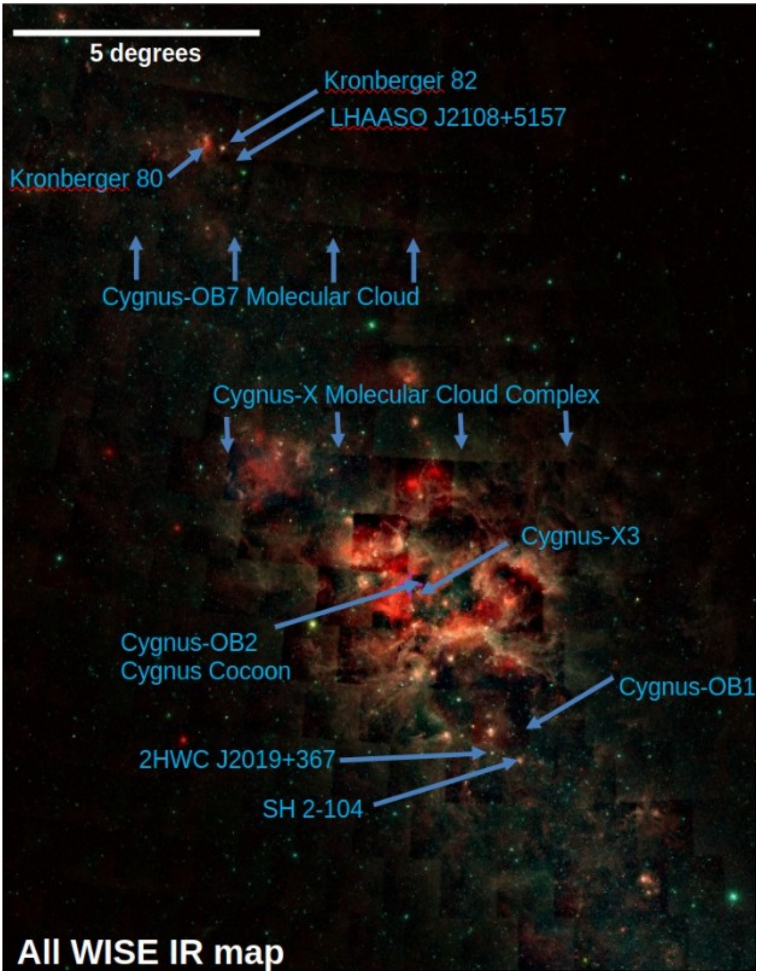


Parameter	10 GeV–1 TeV	1 GeV–1 TeV	Unit
R.A.	317.33 ± 0.18	317.01 ± 0.02	deg
Decl.	51.82 ± 0.15	51.92 ± 0.02	deg
Extension (σ)	$0.50^{+0.10}_{-0.09}$	$0.48^{+0.06}_{-0.06}$	deg
Flux	1.73 ± 0.40	49.1 ± 3.6	$\times 10^{-10}$ ph cm^{-2} s^{-1}
Index	2.05 ± 0.24	2.34 ± 0.08	
TS	25.3	318.0	
TS_{ext}	15.5	63.8	

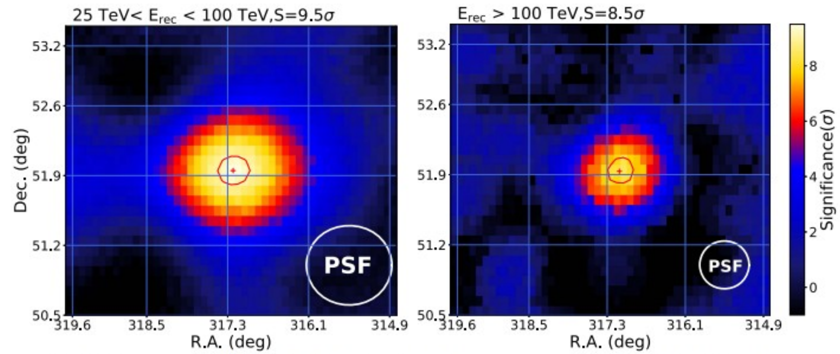
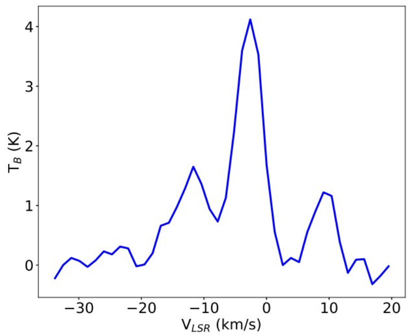
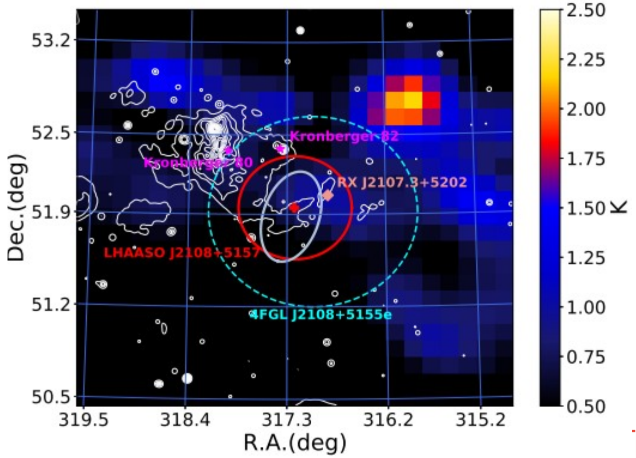


Figure 1. Left: significance map around LHAASO J2108+5157 as observed by KM2A for reconstructed energies from 25 to 100 TeV. Right: significance map for energies above 100 TeV. The red plus sign and circle denote the best-fit position and 95% position uncertainty of the LHAASO source. The white circle in the bottom right corner shows the size of the PSF (containing 68% of the events).

n(H2) = 30 cm^-3 @3 Kpc





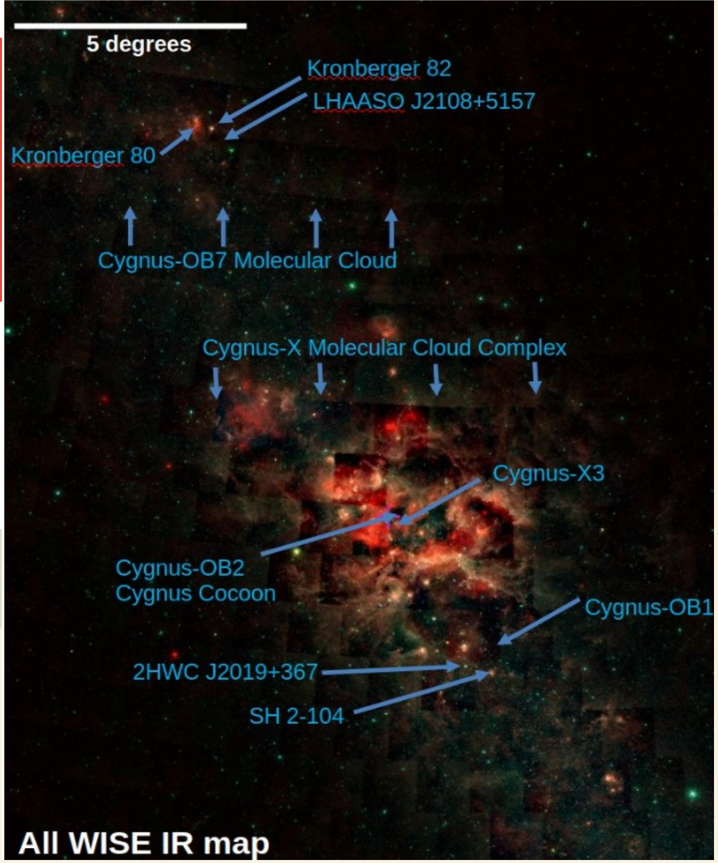
Optically thick12CO(1-0) using a 1.2 m radio-telescope with an angular resolution of 8.5′

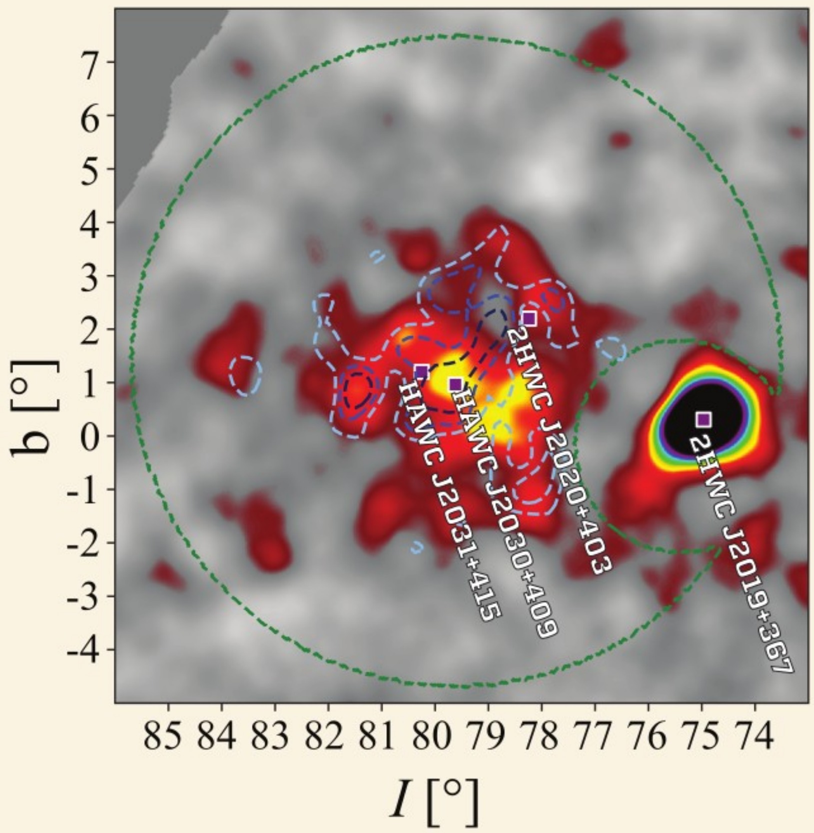
The 1.2 Meter Millimeter-Wave Telescope (MWT) at the CfA| Harvard &

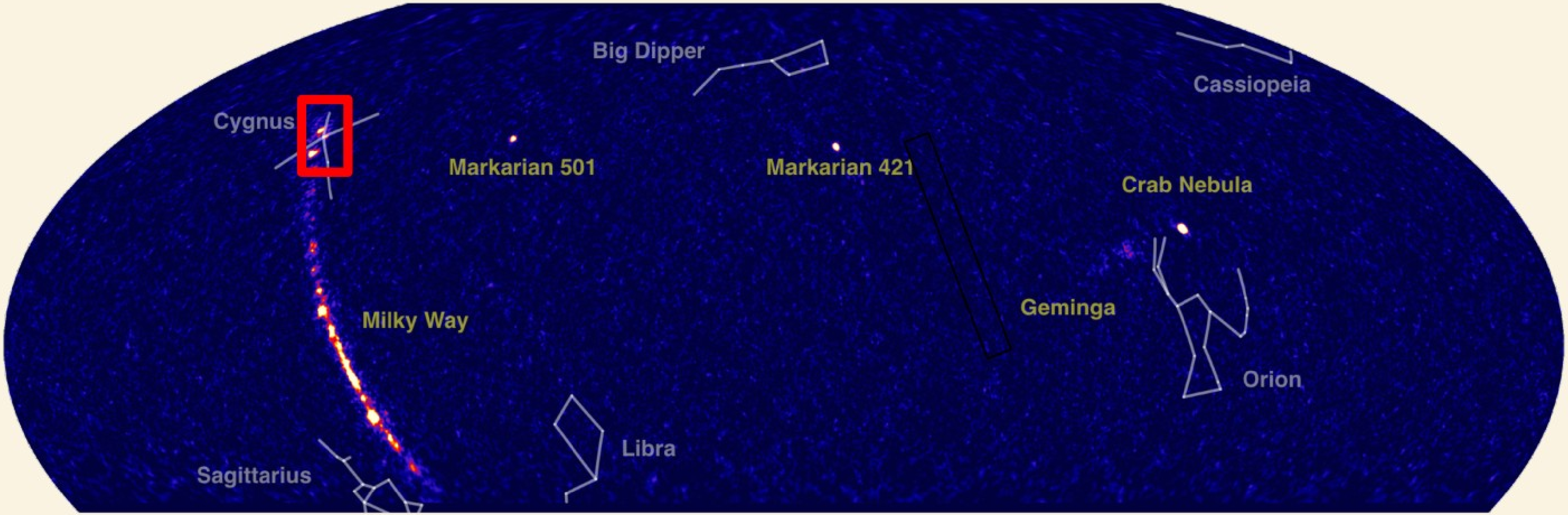
12CO(1–0) line survey integrated over a velocity interval between -14.3 and -9.1 km/seg

Dame 2001, ApJ, 547, 792

Cygnus Cocoon HAWC







The PeVatron Candidate LHASSO J2108+5157 (II)

PeVatrons as challenge in 21st century astronomy

A&A 673, A75 (2023)
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Astronomy & Astrophysics

Multiwavelength study of the galactic PeVatron candidate LHAASO J2108+5157

S. Abe[1], A. Aguasca-Cabot[2], I. Agudo[3], N. Alvarez Crespo[4], L. A. Antonelli[5], C. Aramo[6], A. Arbet-Engels[7],

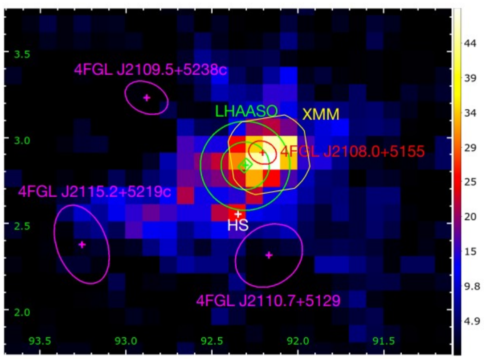


Fig. 3. *Fermi*-LAT TS map in Galactic coordinate above 2 GeV, which shows the sources present in the 4FGL-DR3 catalog with their 95% positional errors (magenta and red ellipses). The small green rectan-

Angular resolution of 8.5 arcmin
Optically thick observations

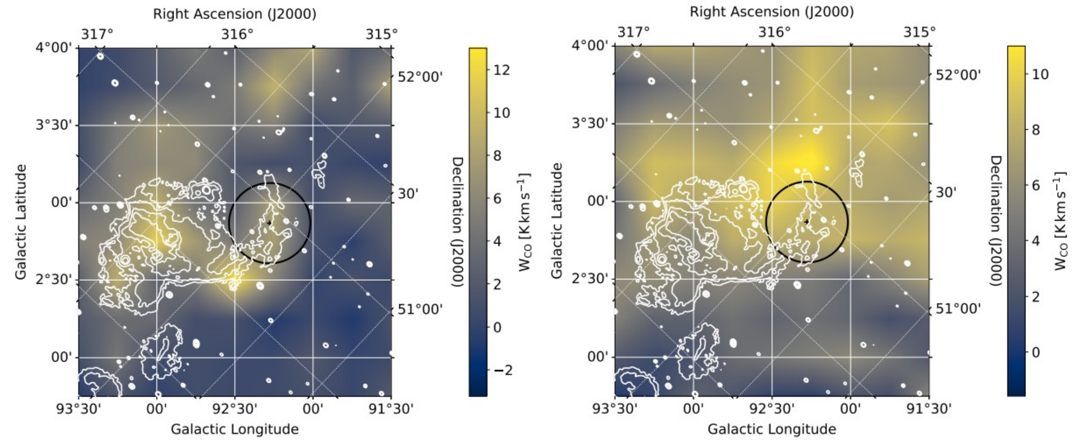
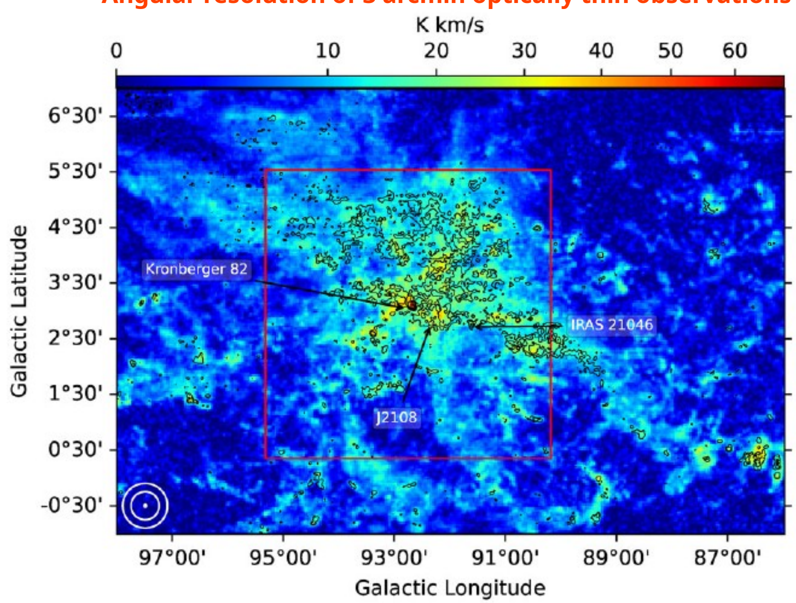
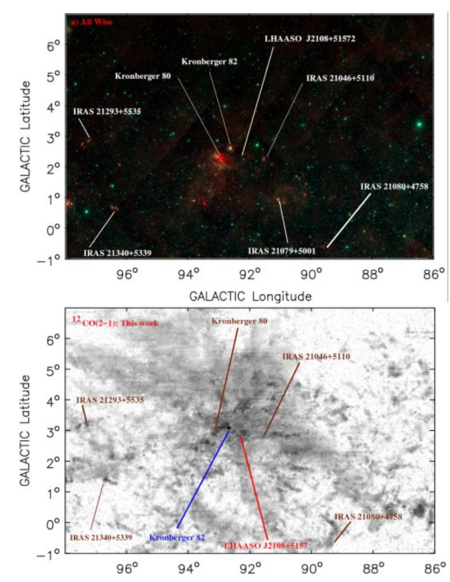


Fig. 6. Velocity-integrated ^{12}CO intensity (W_{CO}) of two molecular clouds spatially coincident with the direction of LHAASO J2108+5157. Left: Integrated velocity of the first Gaussian component peaking at $v_1 \approx -11.8\,\mathrm{km\,s^{-1}}$, with corresponding distance of $d_1 \approx 3.1$ kpc. Right: Integral of the second Gaussian component at $v_2 \approx -2.7\,\mathrm{km\,s^{-1}}$ and $d_1 \approx 2.0$ kpc. The white contour represents 1420 MHz continuum emission from the Canadian Galactic Plane Survey (Taylor et al. 2003). The position of LHAASO J2108+5157 is marked with a black cross, and 95% UL on its extension (0.26°) is indicated with a black circle (Cao et al. 2021a). Bilinear interpolation is used to smooth out the contributions from individual pixels.

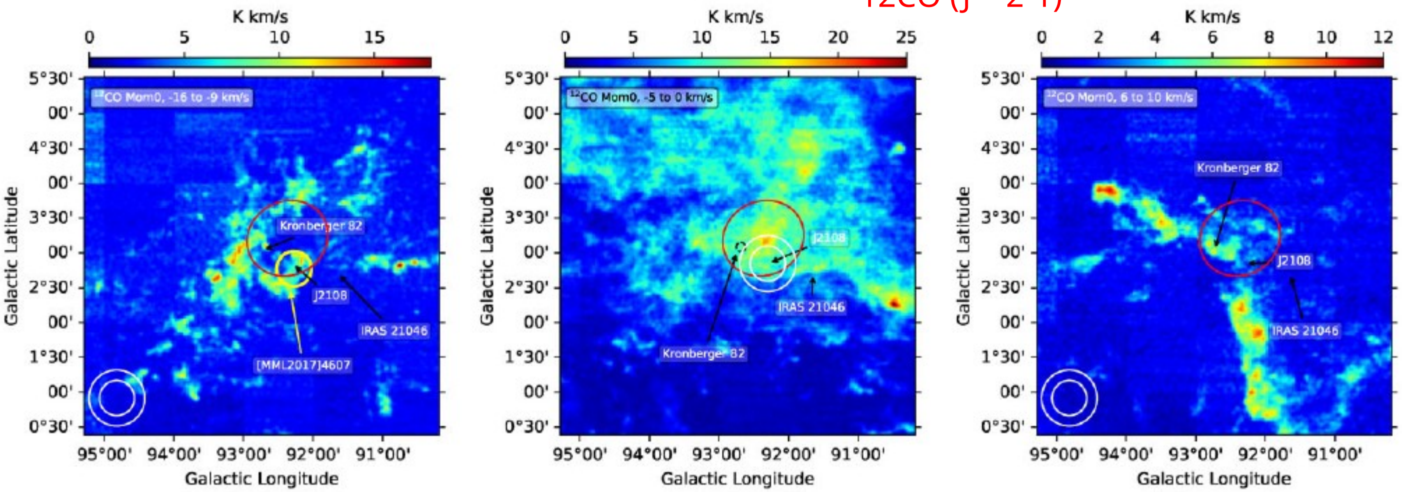
The 1.85m mm/sub-mm telescope (Osaka Prefecture University). 12CO, 13CO, and C18O (J = 2-1); 230 GHz; 3 arcmin; −100 to 80 kms−1 rms ~0.3K at a 0.3 kms−1.

Angular resolution of 3 arcmin optically thin observations





12CO (J = 2-1)

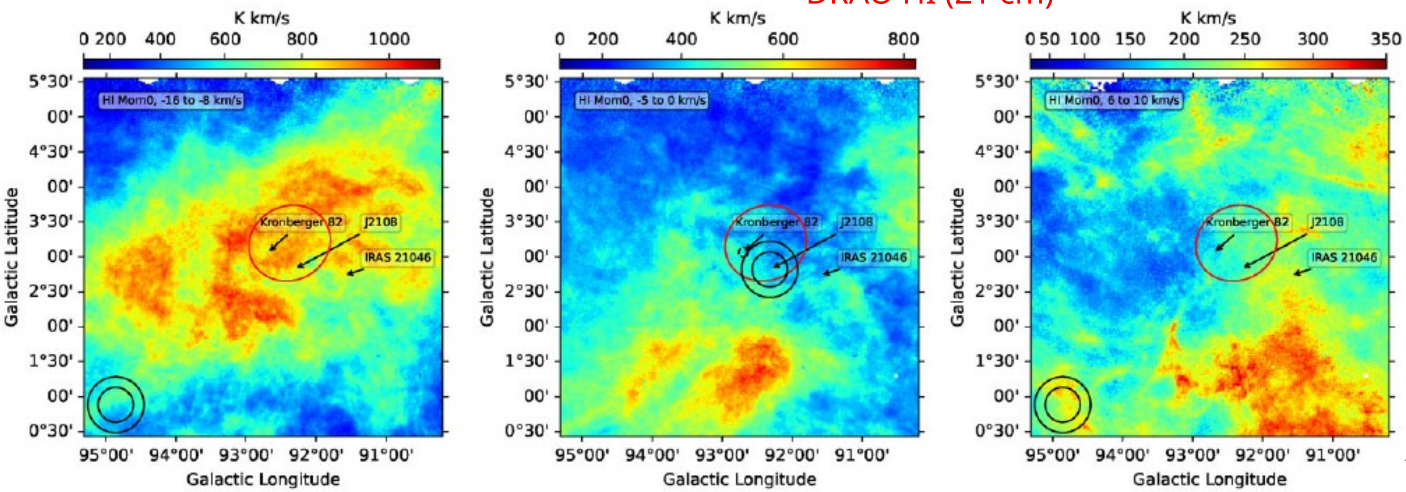


$$N_\gamma^{\rm had} = N_\gamma^{\rm obs} - N_\gamma^{\rm lep} \propto c\,n({\rm H})\,N_{\rm p}({\rm CR}),$$

$$N({\rm H}) = 2N({\rm H_2}) + N({\rm H\,I}),$$

[FKT-MC]2022 is situated at a distance of 1.7 ± 0.6 kpc. It is $\sim 1.^\circ 1$ in size and has nucleon densities (H I + H_2) of ~ 80 and 37 cm^{-3} for ^{12}CO (optically thick) and ^{13}CO (optically thin) emission, respectively. These values correspond to $M({\rm H\,I + H_2})$ of $\sim 4 \times 10^4\, M_\odot$ and $2 \times 10^4\, M_\odot$, respectively.

DRAO HI (21 cm)

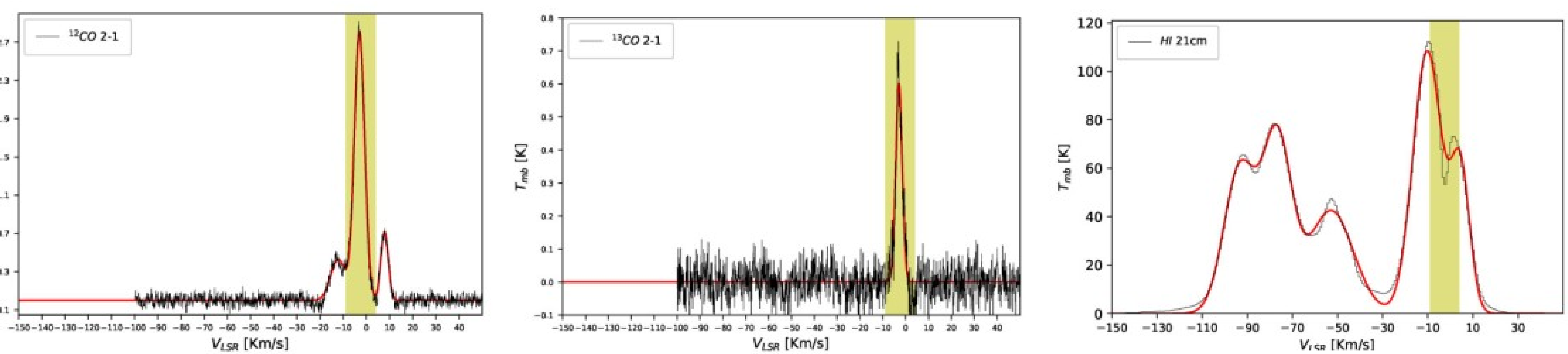


Miville-Deschênes, Murray, & Lee (2017)
https://ui.adsabs.harvard.edu/abs/2017ApJ...834...57M/

1.2 m telescopes; angular resolution of ∼8 5 armin at 115 GHz OPTICALLY THICK OBSERVATIONS 12CO(1--0)

ANSWER: Accurate determination of the nucleons density (Hydrogen; H_2 + HI)

Source	V_{LSR} [km s^{-1}]	D [°]	Distance [kpc]	$n(H_2)$ [cm^{-3}]	$M_{vir}(H_2)$ [$10^4\,M_\odot$]	$M(H_2)$ [$10^4\,M_\odot$]	$M(H\,I + H_2)$ [$10^4\,M_\odot$]	Projected size [°]
MML	−13.71	0.5	3.3	12.26	—	0.84	—	0.5 at 3.3 kpc
FKT-MC (^{12}CO)	-3.0 ± 0.1	1.1 ± 0.2	1.7 ± 0.6	31 ± 14	9.5 ± 0.1	3.0 ± 1.4	3.6 ± 1.6	1.1 at1.7 kpc
FKT-MC (^{13}CO)	-2.9 ± 0.1	1.1 ± 0.2	1.7 ± 0.6	9 ± 4	3.8 ± 0.2	0.9 ± 0.4	1.5 ± 0.6	1.1 at 1.7 kpc



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Detection of a new molecular cloud in the LHAASO J2108+5157 region supporting a hadronic PeVatron scenario†

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Astronomy & Astrophysics

LETTER TO THE EDITOR

Evidence for a gamma-ray molecular target in the enigmatic PeVatron candidate LHAASO J2108+5157⋆

E. de la Fuente[1,2], I. Toledano-Juárez[3], K. Kawata[2], M. A. Trinidad[4,5], M. Yamagishi[6], S. Takekawa[7], D. Tafoya[8], M. Ohnishi[2], A. Nishimura[9], S. Kato[2], T. Sako[2], M. Takita[2], H. Sano[10], and R. K. Yadav[11]

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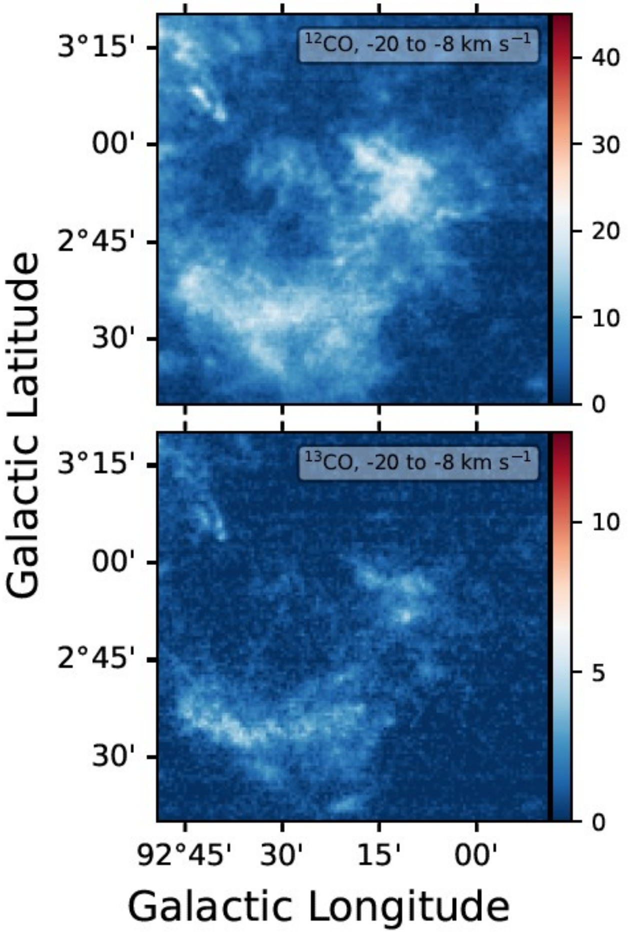
The PeVatron Candidate LHASSO J2108+5157 (II)

PeVatrons as challenge in 21st century astronomy

Ivan Toledano-Juarez, Ph. D. Thesis, CUCEI, Universidad of Guadalajara.



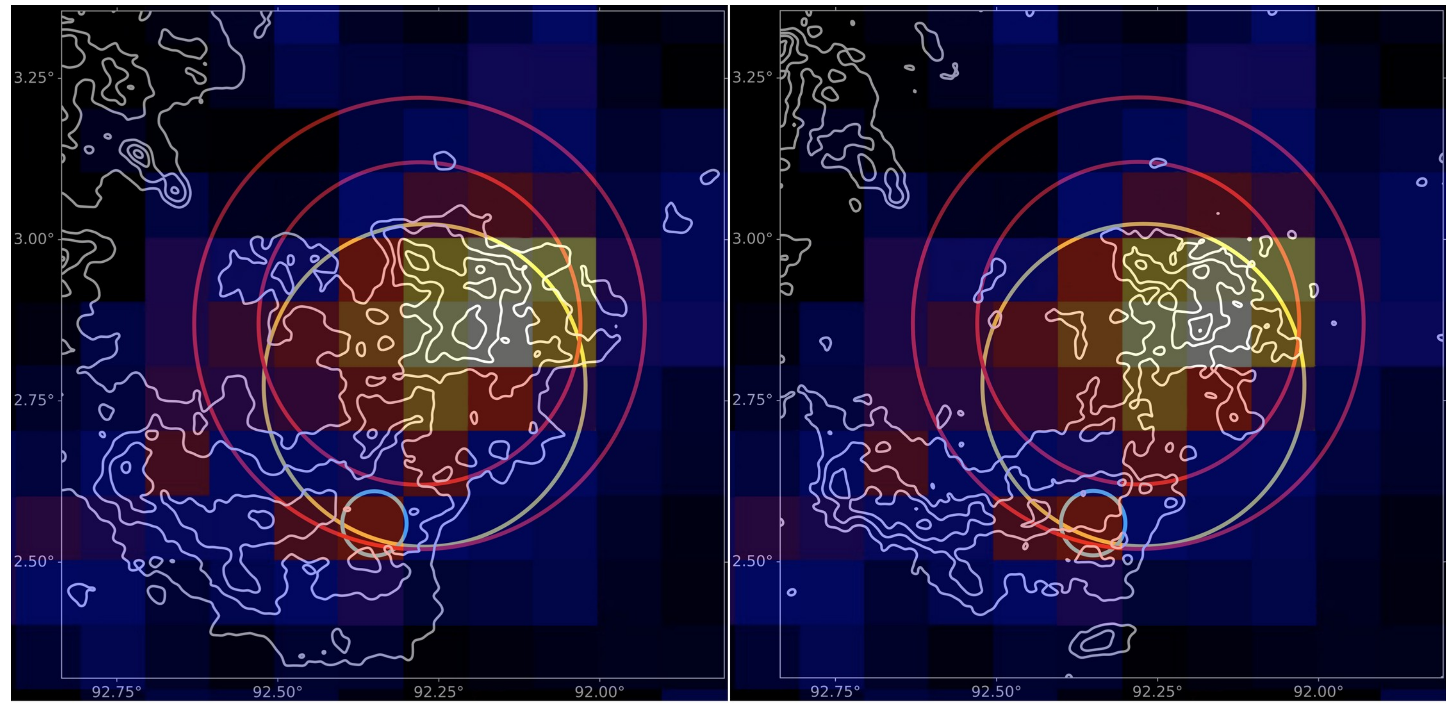


Table 4. Parameters and results of the hadronic model of Naima for the FTK molecular cloud

Distance [kpc]	$N(H)^a$ [10^{21} cm^{-2}]	n(H)^a [cm^{-3}]	Size [degree]	W_p [10^{46}erg]	Cutoff [TeV]
1.6±0.1	6.2±2.1	133±45	0.55±0.02	$4.3^{+2.0}_{-1.1}$	700^{+400}_{-300}

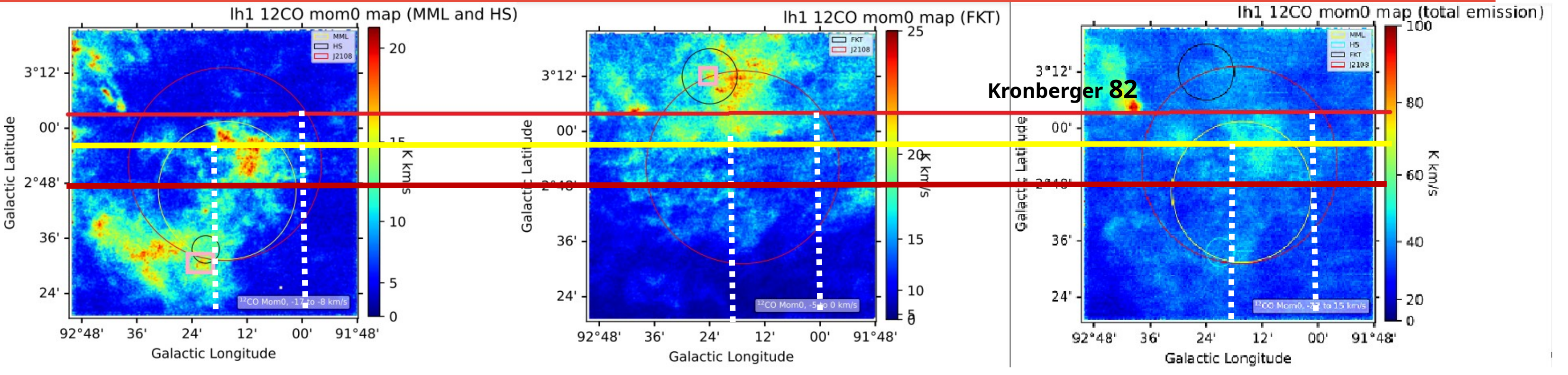
^{a} The column and number density of nucleons is calculated as N(H) = 2N(H_2) + N(HI) and n(H) = 2n(H_2) + n(HI), respectively.

Optically THIN Gas!!!
Tau = 0.2 in average

Angular resolution of 17 arcseconds!!

The PeVatron Candidate LHASSO J2108+5157 (III)

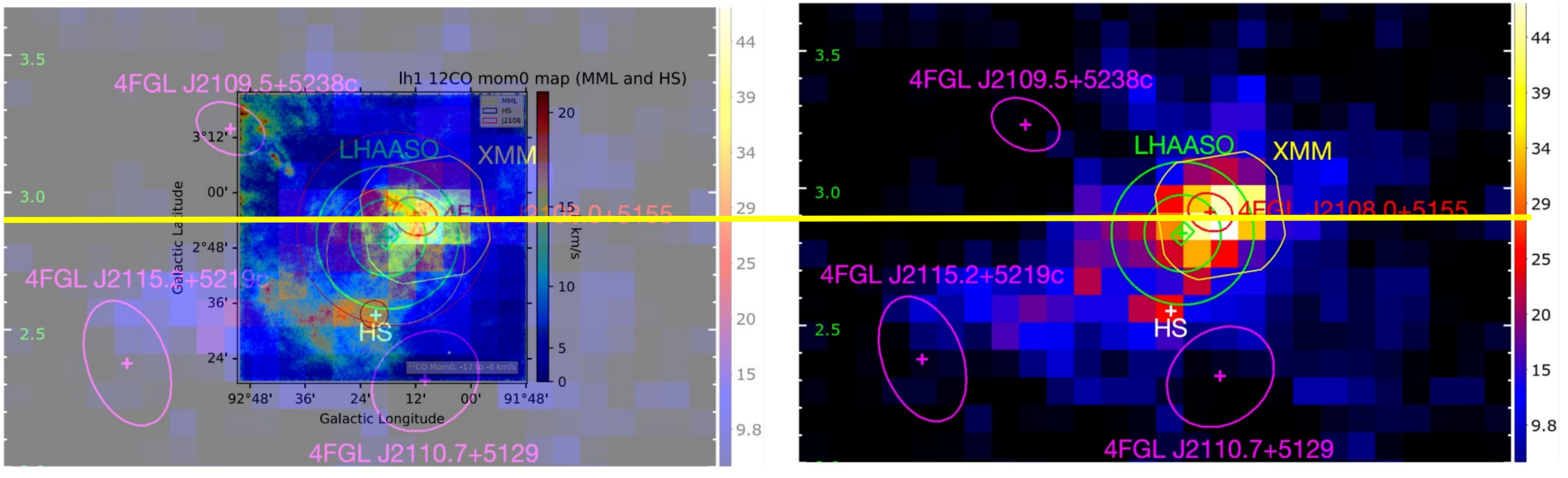
PeVatrons as challenge in 21st century astronomy



Nobeyama 45 m radio-telescope

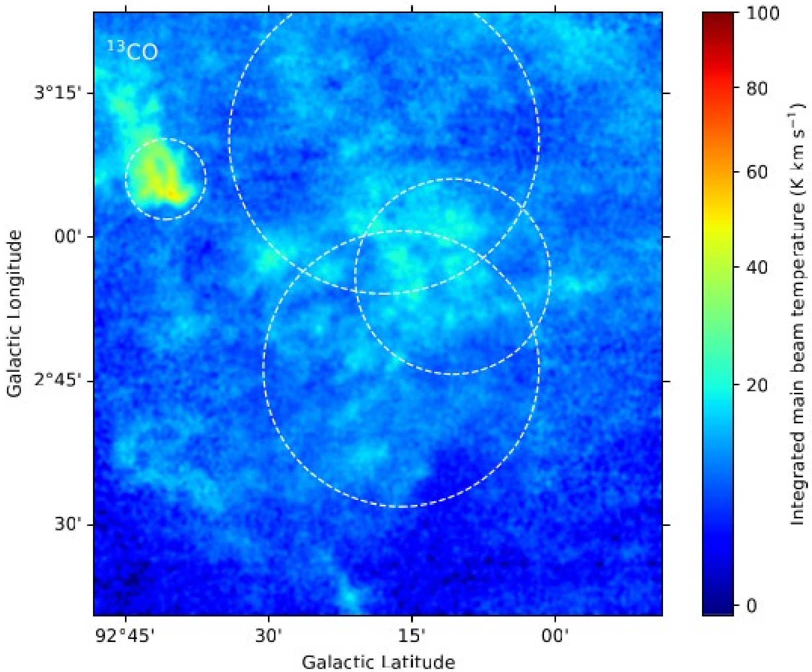
12,13CO(1-0), C18O (1-0)

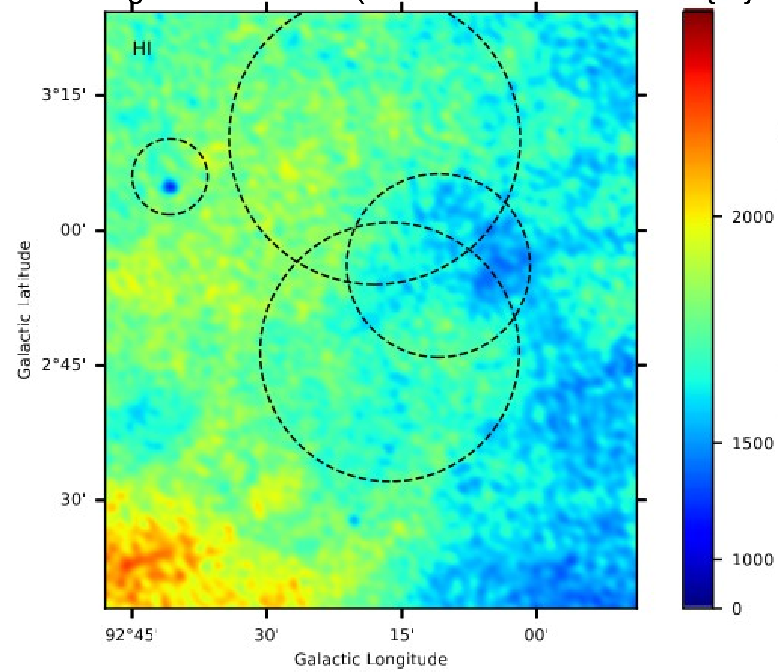
OPTICALLY THIN GAS



FKT (PASJ) and FTK (A&AL) SAME CLOUD!?

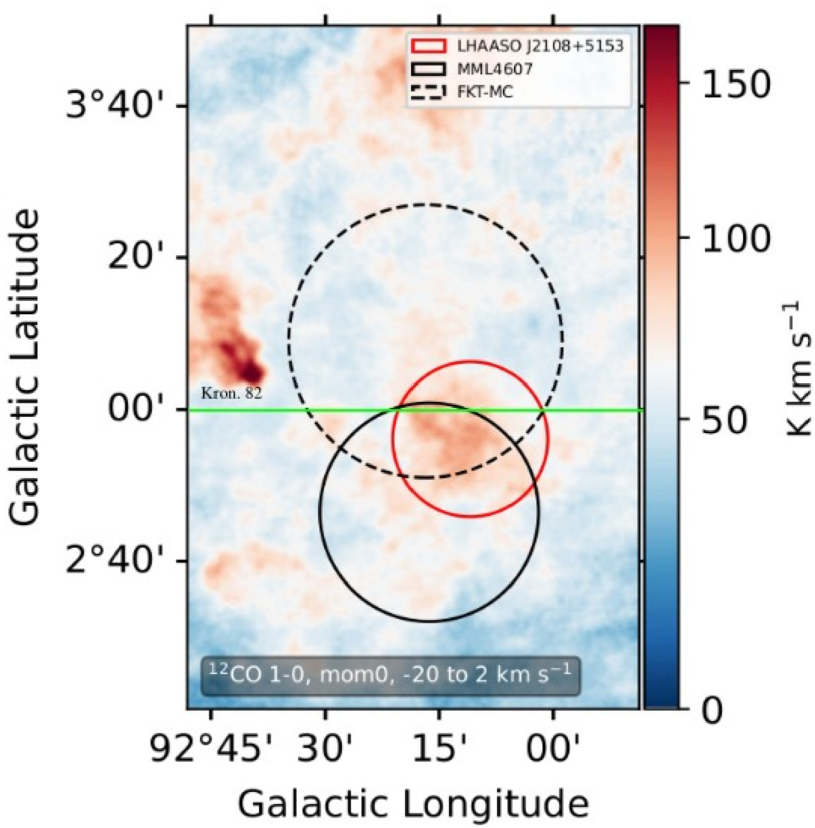
Center: HI DRAO observations with better angular resolution (1 arcmin or 0.82 km s^{-1})

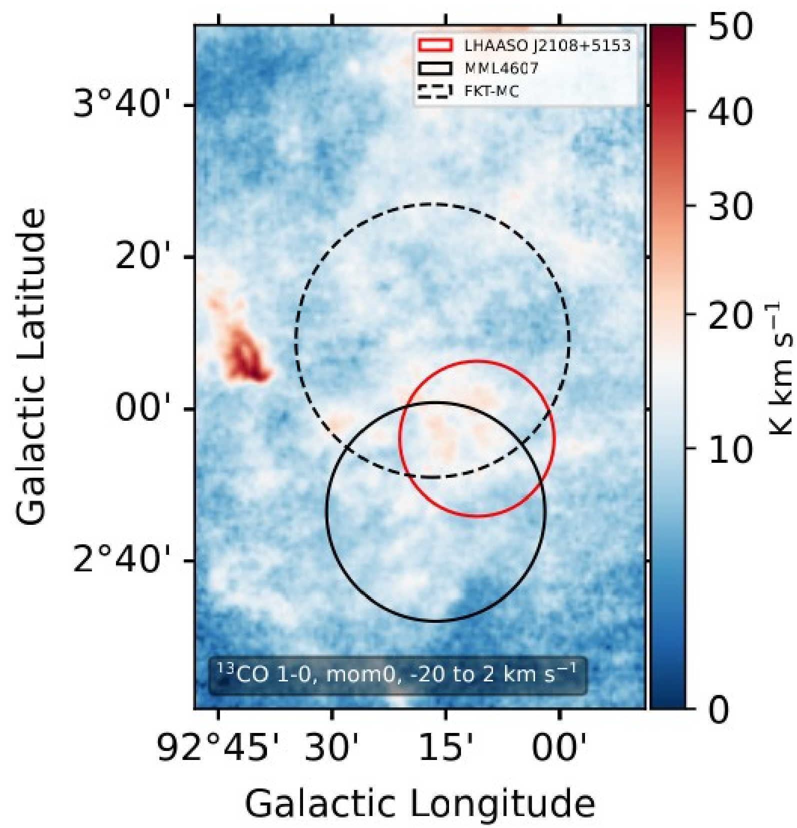




Paper 1: Kronbergers

Paper 2: To test Alison Mitchel's Model with CO observations

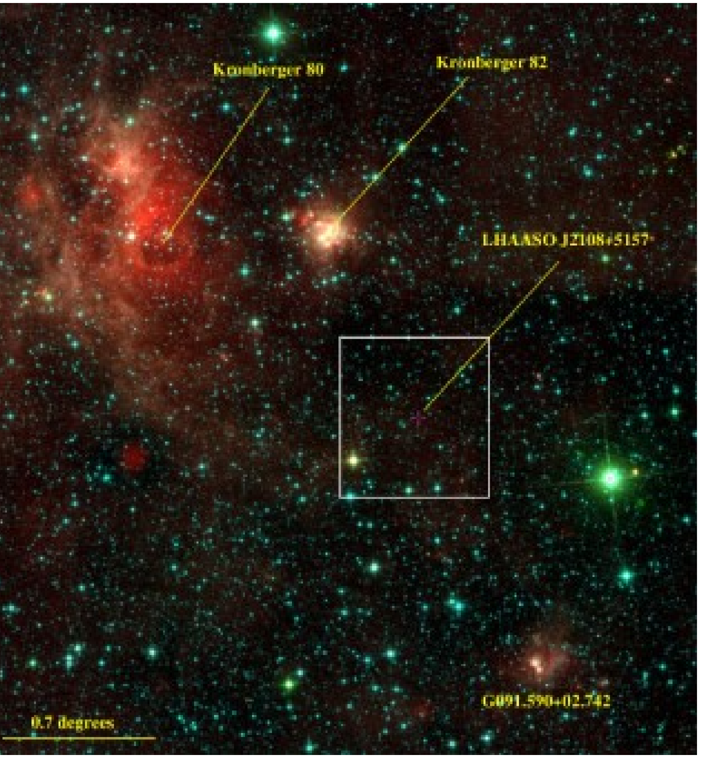




^{13}CO Gas Region	$n(H_2)$ [cm^{-3}]	$n(HI)$[a] [cm^{-3}]	$n(H_2+HI)$[a] [cm^{-3}]
[FKT-MC]2022[b]	85.0±25.0	40±8	210±50
MML[2017]4607	17.0±5.0	40±8	74±9
J2108 or IZ[c]	154.0±46.2	100±7	408±50
[FTK-MC][d]	43.0±22.0	48±7	133±45
Average three clouds[e]	48.3±17.0	43±8	139±35
Average two clouds[f]	30.0±10.0	44±7	104±27

[a] Calculated using DRAO3 21-cm line observations(Taylor et al. 2003), with $n(H) = n(H_2+HI) = 2n(H_2) + n(HI)$.
[b] This work using a cylindrical morphology with a length = size (diameter). Cao et al. (2021b) suggest a $n(H_2) = 30$ cm^{-3} from Miville-Deschenes, Murray, & Lee (2017); Dame et al. (2001).
[c] Zone where molecular gas from MML+[FTK-MC] and FKT2022 interacts covering the LHAASO emission. Following de la Fuente et al. (2023b), we use a cylindrical morphology with a diameter and length of 9.5 pc.
[d] From de la Fuente et al. (2023b).
[e] Average of [FKT-MC]2022+MML+[FTK-MC].
[f] Average of MML+[FTK-MC] (velocity ~ −12 km s^{-1}) discarding [FKT-MC]2022 due its velocity of ~ −3 km s^{-1}.

Kronberger’s paper: IR Photometry to test the stellar content



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ASJ OXFORD

Are Kronberger 80 and/or Kronberger 82 regions PeVatron candidates for LHAASO J2108+5157?

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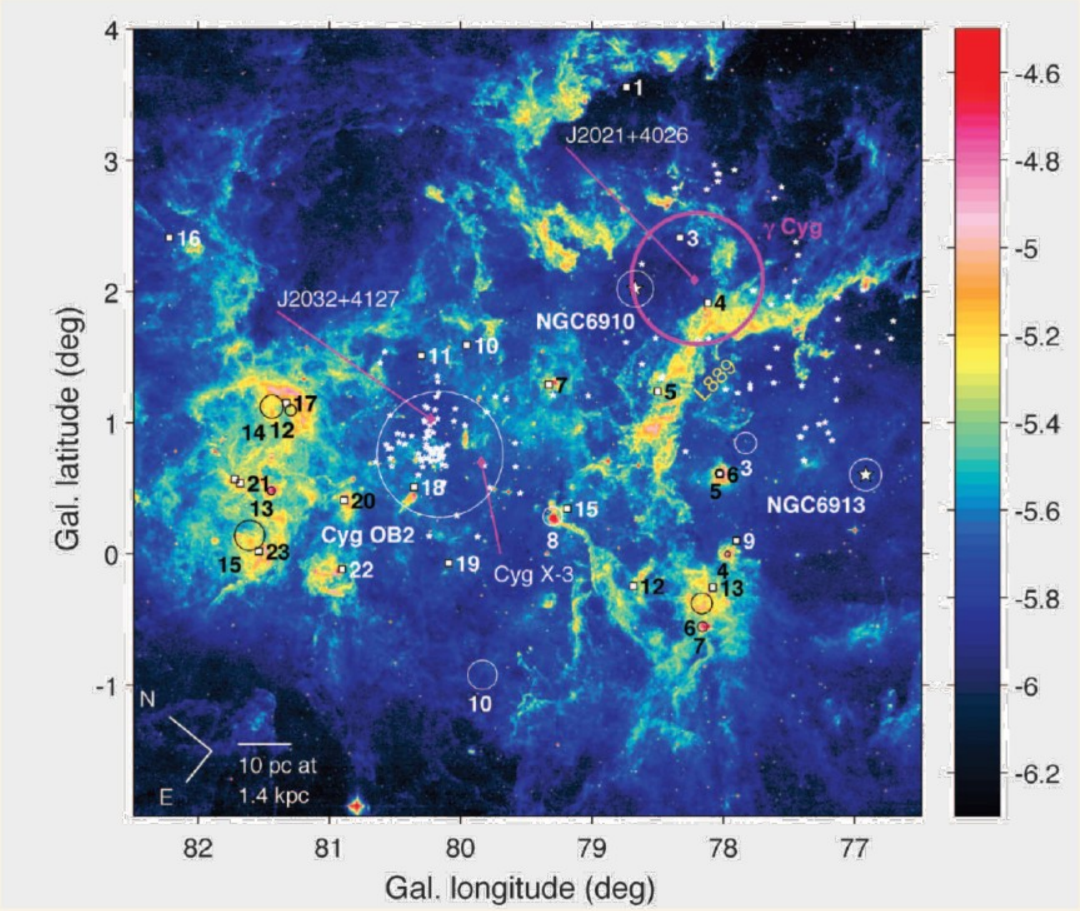
Abstract

High-energy gamma-rays have been detected in the region of LHAASO J2108+5157 by the Fermi–LAT, HAWC and LHAASO-KM2A observatories. Cygnus OB2 in Cygnus-X has been confirmed as the first strong stellar cluster PeVatron in our Galaxy. Thus, the star-forming regions Kronberger 80 and Kronberger 82, located in the field of LHAASO J2108+5157, are analyzed to evaluate their stellar population and potential as associated PeVatron candidates. A distance of 10 kpc is adopted for Kronberger 80, while ~1.6 kpc is estimated for Kronberger 82. Based on stellar densities, we report that their cluster radii are 2.′5 and 2.′0, while infrared photometry reveals poor stellar content in massive O-type stars in both cases. From optical data, the estimations of cluster ages are 5–12.6 and ≲5 Myr, respectively. We conclude that, in contrast to the stellar content of Cygnus OB2, it is unlikely that Kronberger 80 and Kronberger 82 are PeVatrons associated with LHAASO J2108+5157. The presence of a PeVatron in this region remains a mystery, but we confirm that the two Kronberger regions are star-forming regions undergoing formation rather than evolution.

Kronberger's paper: IR Photometry to test the stellar content

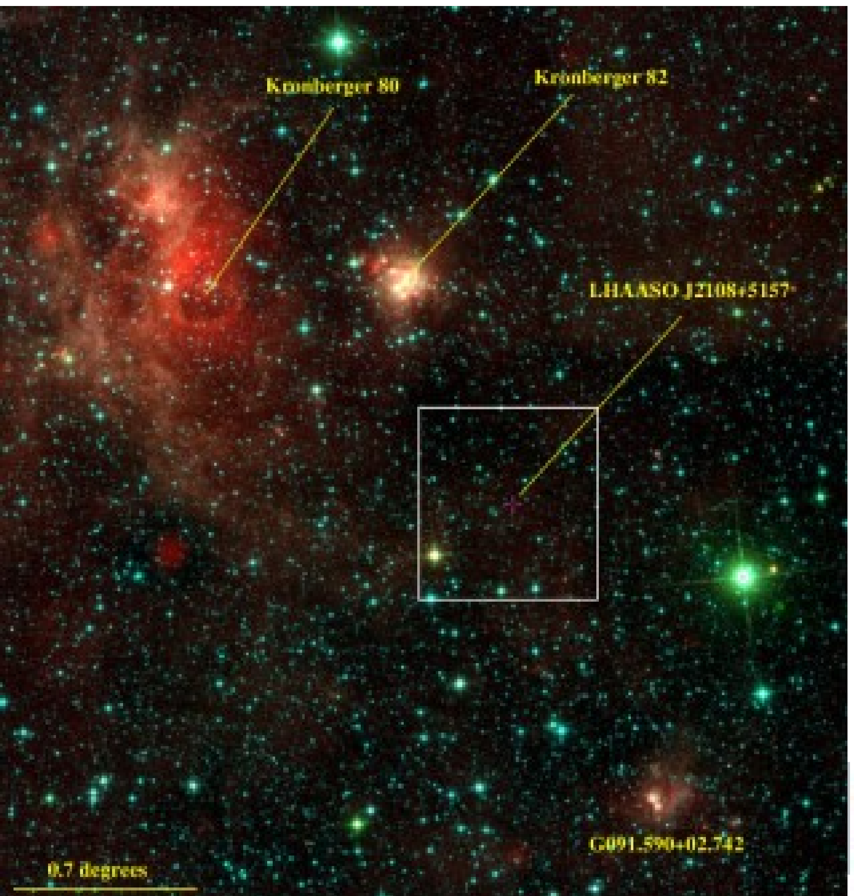
OB2 Association



- One of the most massive OB associations in our Galaxy
- Consists about ~120 type O stars
- Age: 1 to 7 Myrs
- Stellar wind power of a few 10^{39} erg/sec maintained for at least 2 Myrs *(Lozinskaya et al. 2002)*
- Motivation of studying this particular location

8 μm intensity map of the Cygnus X region (*Ackermann, M. et al., Science, 2011)*

Kronberger's paper



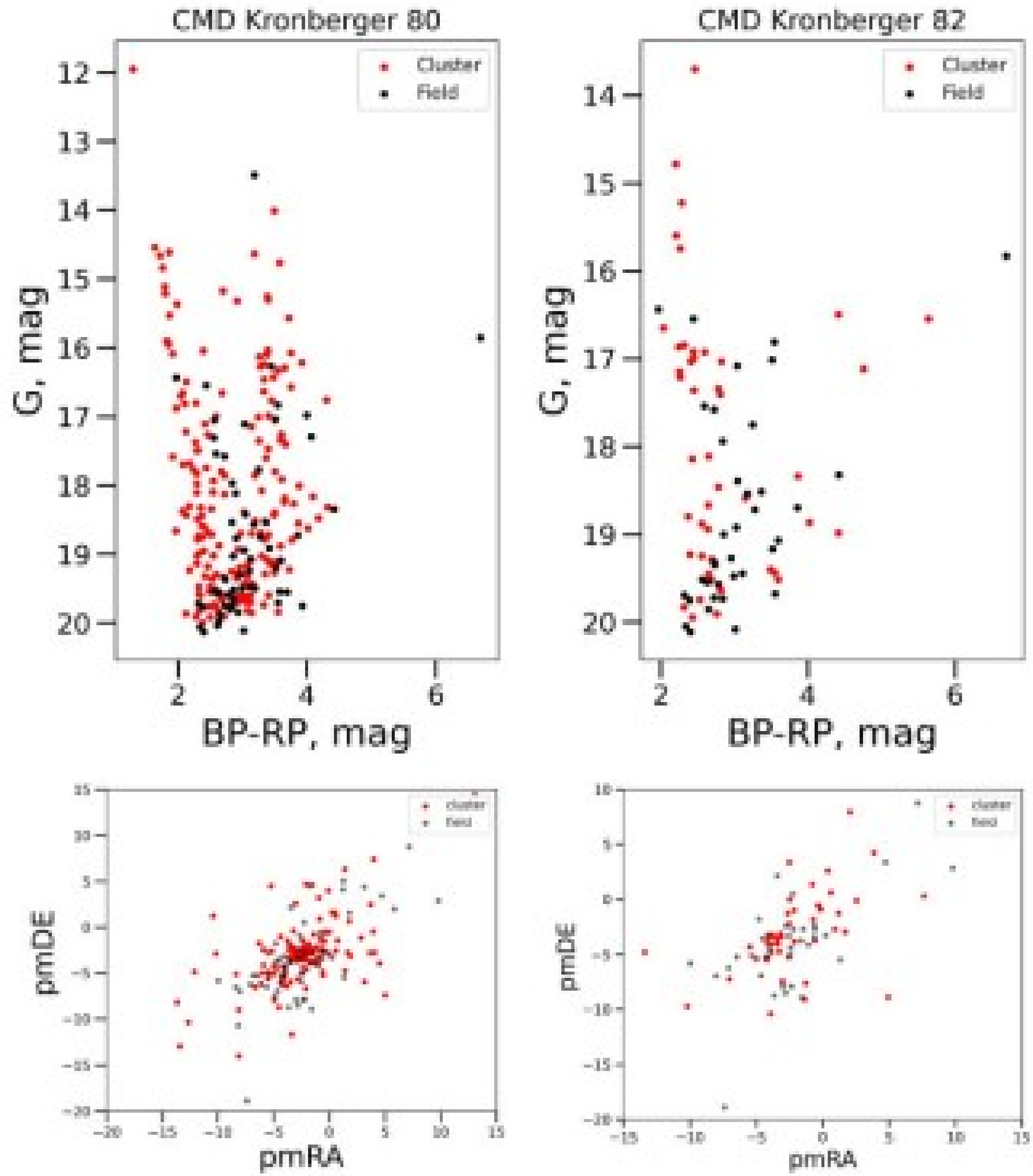
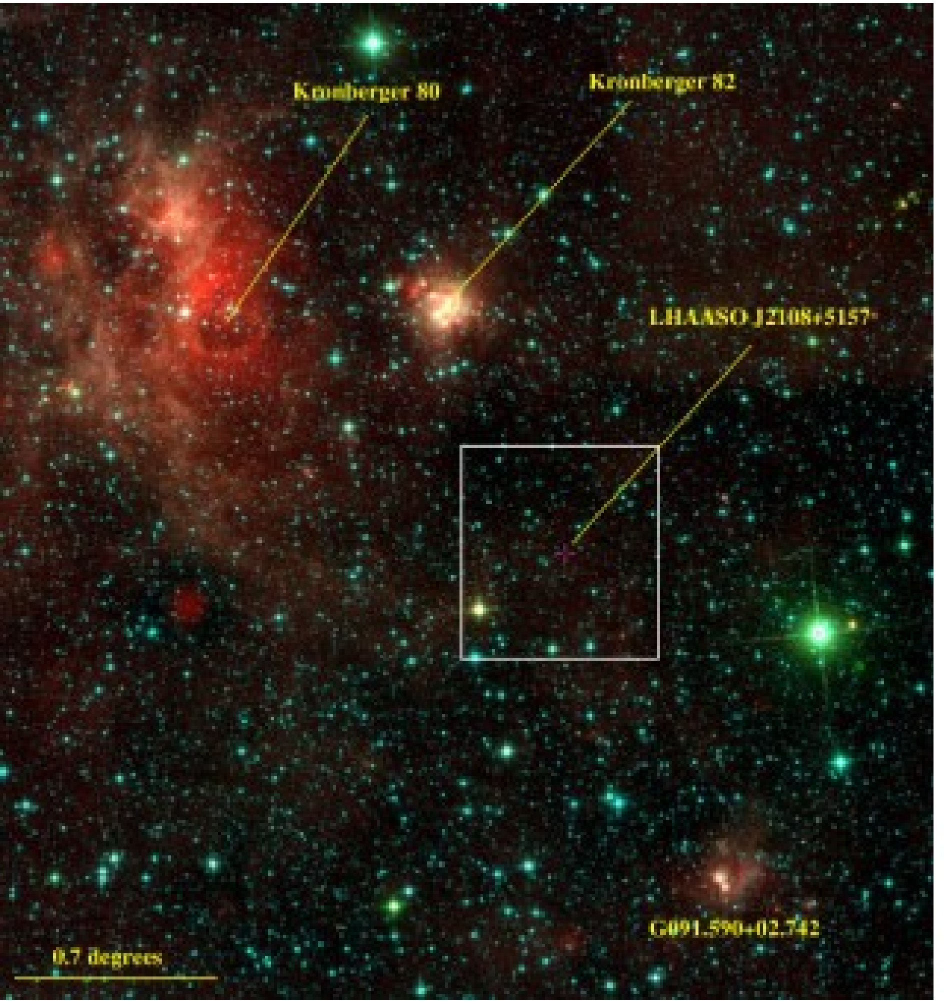


Fig. 4. Top panels: Gaia CMD for Kron 80 (left) and Kron 82 (right). Bottom panels: Respective vector plot diagram for Kron 80 (left) and Kron 82 (right).

Kronberger's paper



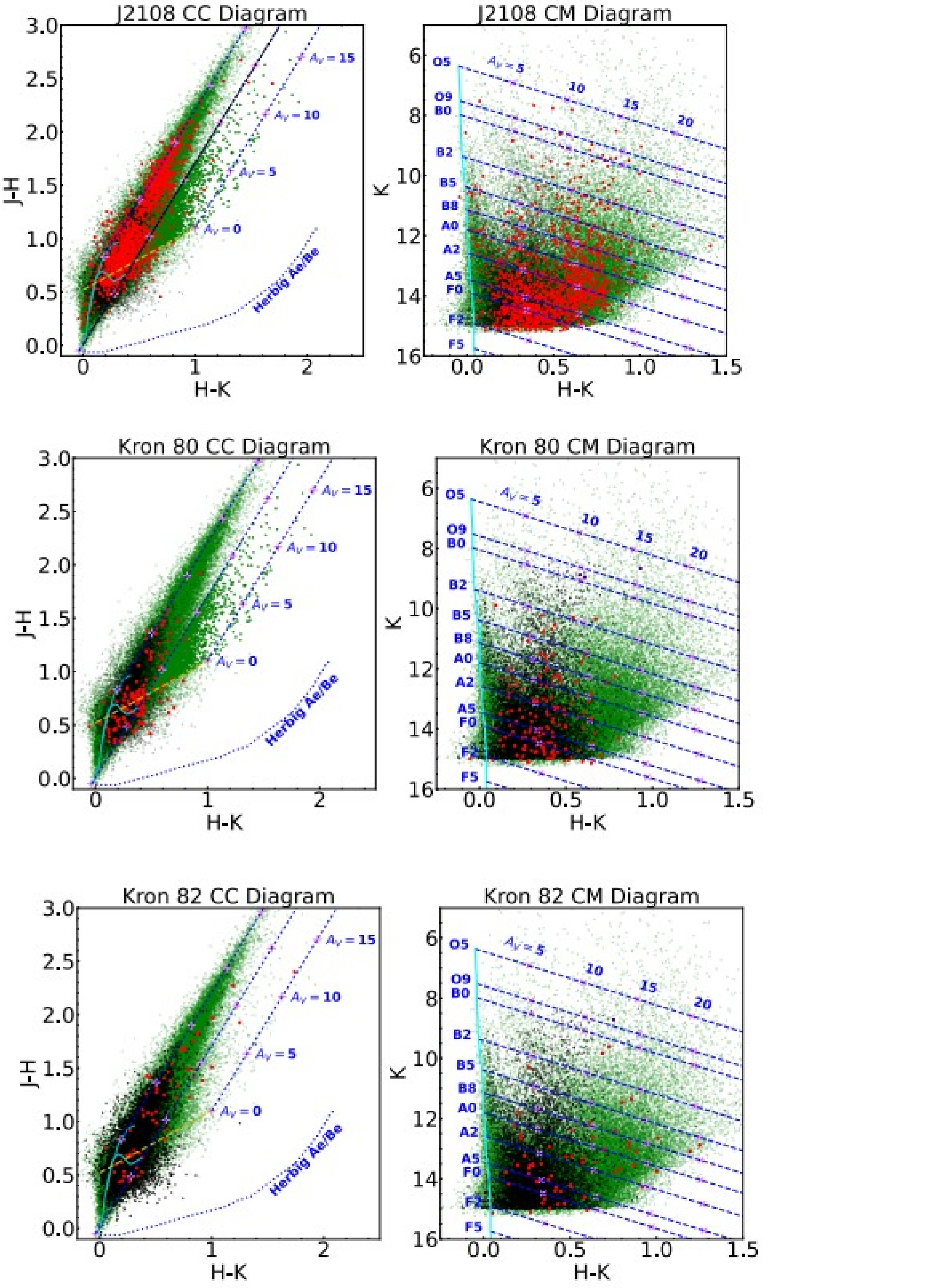


Fig. 5. Typical 2MASS CCDs and CMDs in the Bessell and Brett (1988) system for LHAASO J2108+5157 (top), Kron 80 (middle), and Kron 82 (bottom), all in red points and in comparison with Cyg-OB2 in green points. Black points are sources in a control field at 2°.0 distance from J2108, ($\alpha_{J2000.0} = 20^h58^m15^s.1$, $\delta_{J2000.0} = 53°07'41''.5$, with a size of 2°.0). Left panels: CCDs where the cyan lines show the location of the dwarf and giant main sequence (Bessell & Brett 1988; Koornneef 1983), the yellow dashed line represents the T-Tauri locus (Meyer et al. 1997), and the blue dotted line shows the limiting position of the YSO Herbig Ae/Be objects (Lada & Adams 1992). Blue dashed parallel lines represent reddening vectors according to the extinction law of Rieke and Lebofsky (1985) with $R_v \approx 3.09$. Magenta crosses represent the visual extinction A_V separated by 5 mag. Right panels: CMDs where the thick cyan continuum line indicates the location of the zero-age main sequence with spectral types labeled on it (Schmidt–Kaler 1982), and reddening vectors similar to the CCDs.

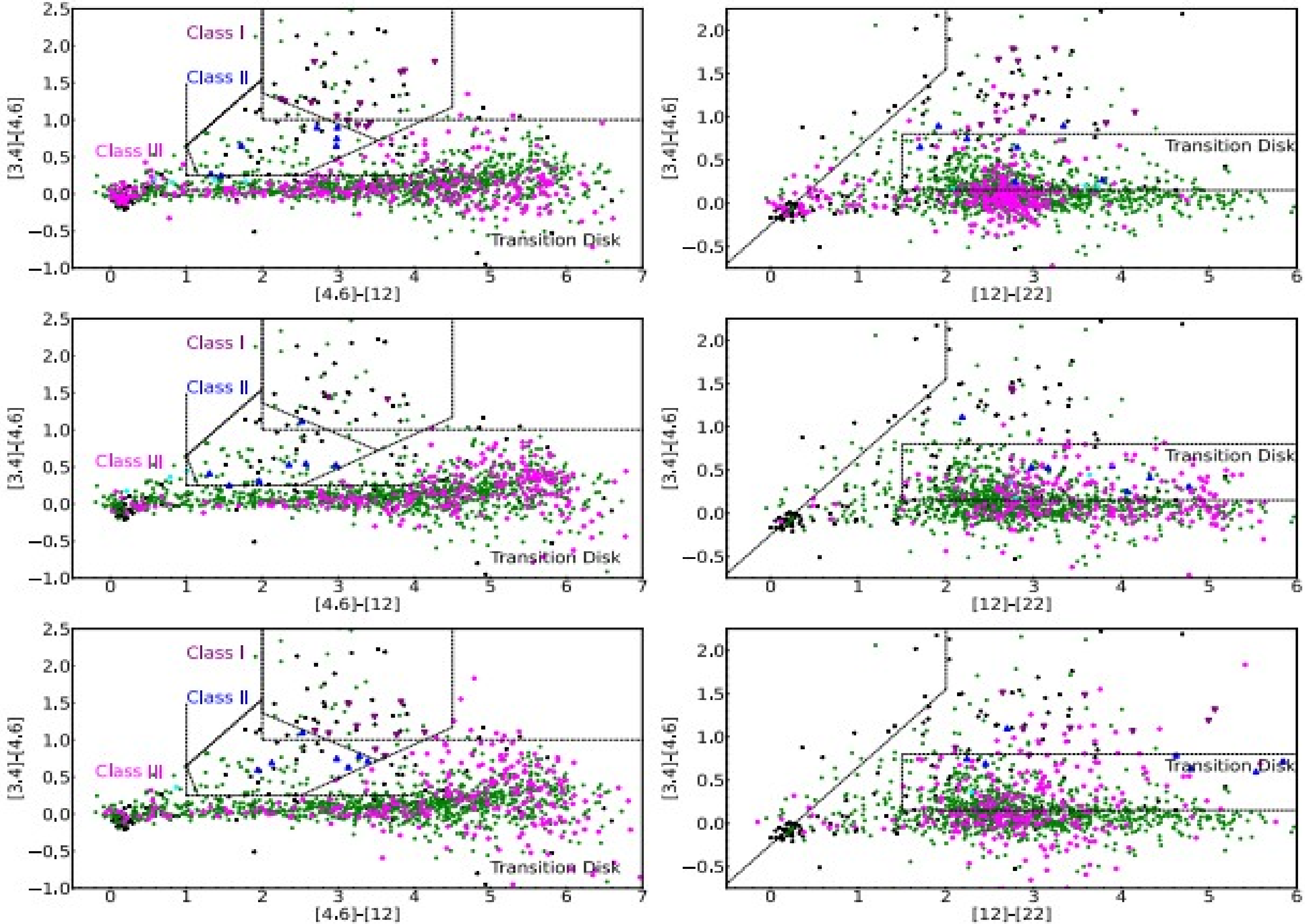
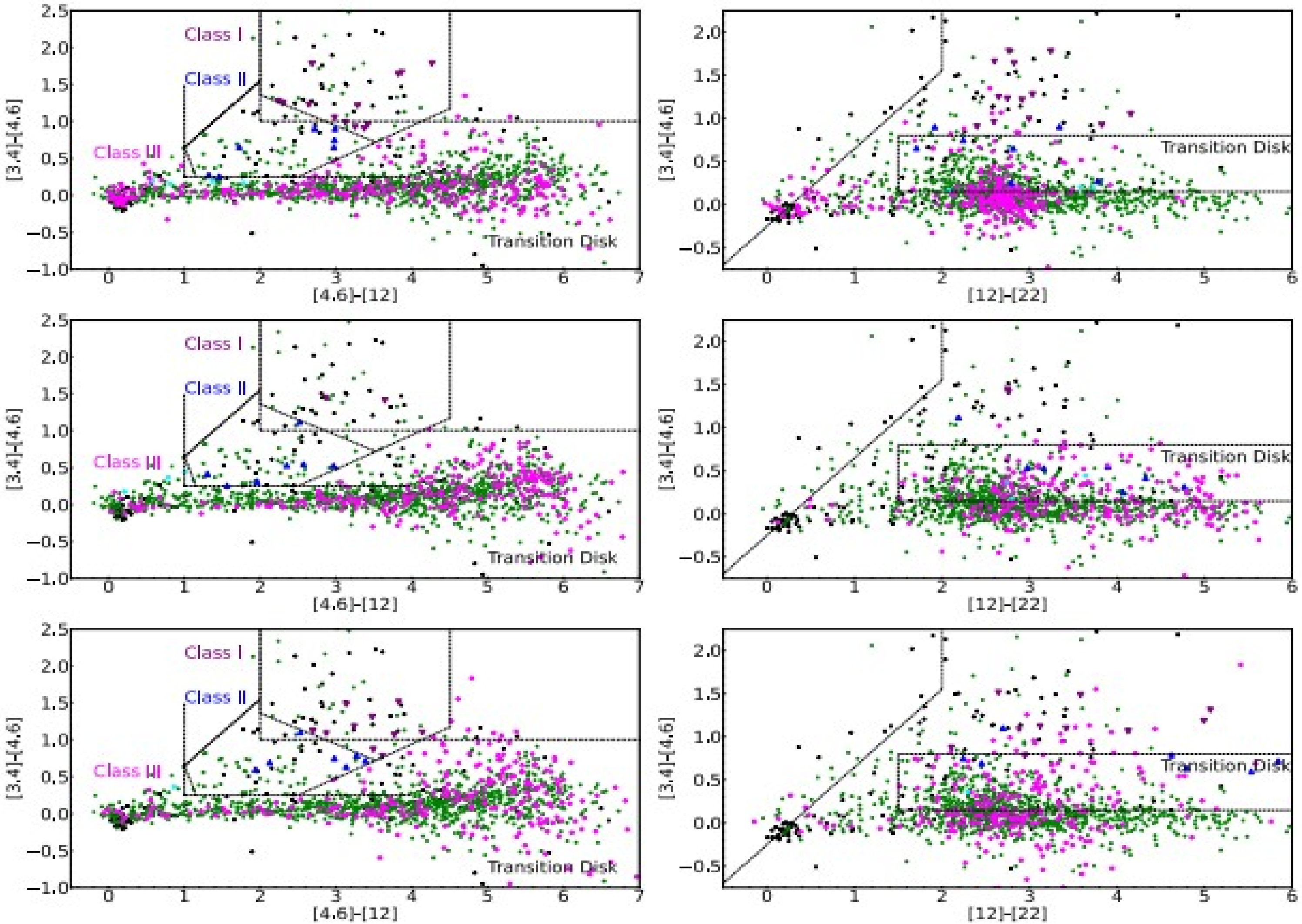


Fig. 6. Typical AllWISE CCDs for LHAASO J2108+5157 (top), Kron 80 (middle), and Kron 82 (bottom). Symbols are as follows: purple triangles, blue triangles, and magenta diamonds are Class I, Class II, and Class III plus transition disk YSOs, respectively. Green dots are YSO sources in Cyg-OB2, while black stars are from the control field objects, both for comparison. Dashed lines show limits for YSO classes and are marked following Kang et al. (2017) and references therein.

Kronberger's paper: YSOs

Table 1. YSO classification counts from WISE data.

Source	Cyg-OB2	J2108	Kron 80	Kron 82
Class I	19	14	2	10
Class II	40	7	7	7
Transition disks	939	270	230	242
Class III	17	4	3	1
Total	1015	281	242	260



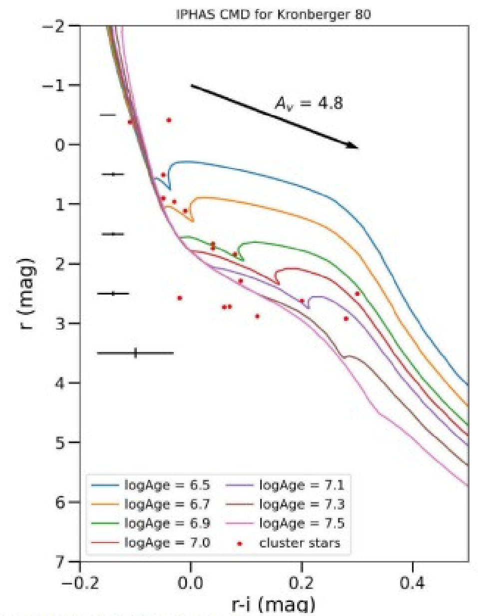


Table 2. Parameters of Kron 80 and Kron 82.

Cluster	*l*	*b*	Radius	Age
Kron 80	92°.9315	2°.7963	2′.5	5–12.6 Myr
Kron 82	92°.6879	3°.0468	2′.0	<5 Myr*

6. Typical AllWISE CCDs for LHAASO J2108+5157 (top), Kron 80 (middle), and Kron 82 (bottom). Symbols are as follows: purple triangles, blue gles, and magenta diamonds are Class I, Class II, and Class III plus transition disk YSOs, respectively. Green dots are YSO sources in Cyg-OB2, while stars are from the control field objects, both for comparison. Dashed lines show limits for YSO classes and are marked following Kang et al. (2017) eferences therein.

Microcuasar?

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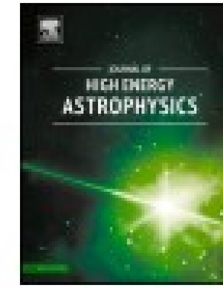

Letter

Low frequency radio observation of the dark PeVatron 1LHAASO J2108+5153u using uGMRT

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A R T I C L E I N F O

Keywords:
Radio continuum: jet
Methods: data analysis
Techniques: interferometry
Gamma rays: general- microquasar
PeVatron

A B S T R A C T

1LHAASO J2108+5153u, a PeVatron candidate detected by Large High Altitude Air Shower Observatory (LHAASO), has no known association in any other wavelength range. In this work we attempted to identify any possible association by observing the source region in low frequency radio band. 1LHAASO J2108+5153u was observed by upgraded Giant Metrewave Radio Telescope (uGMRT) at 650 MHz frequency. The data were analysed to map and spatially correlate the sources in the field of view with the LHAASO detected source. We identified a new extended source within the LHAASO PSF showing a distinct jet and core structure in radio band. The exact nature of the source could not be identified with the present observation. It can be a microquasar and the particles can be accelerated to PeV energies in the microquasar jet.

Microcuasar?

Table 1
Radio sources in the region of GMRT extended radio source obtained in the 650 MHz emission map. RA, Dec, and integral flux of the sources are taken from simbad database and CGPS catalogue survey (Taylor et al., 2003).

Source name	RA (J2000)	Dec (J2000)	Frequency (MHz)	Flux (mJy)
GMRT extended source	21:08:03.84	51:52:56.41	650	27.6±8.6
NVSS J210803+515255	21:08:03.99	51:52:55.3	1400	13.26±0.6
WN B2106.4+5140	21:08:03.44	51:52:52.8	325	40±5.9
CGPS J210804+515254	21:08:04.2	51:52:55	1400	16.1±0.72

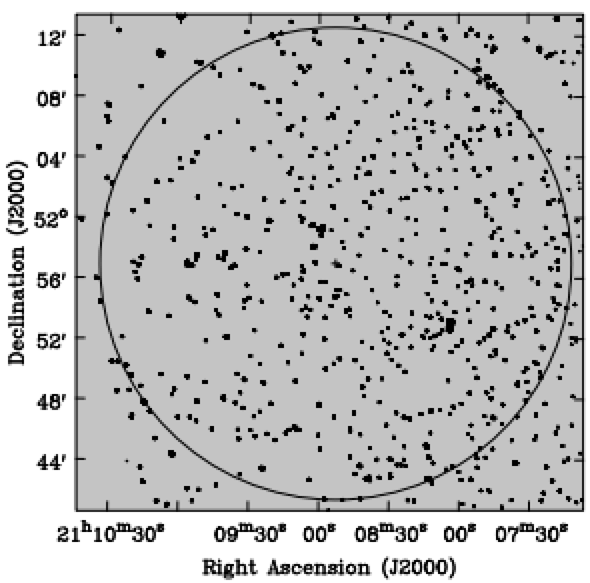

Fig. 1. uGMRT 650 MHz emission map of the source region 1LHAASO J2108+5153u. The image is characterized by a synthesis beam of 5.61″ × 4.02″ with position angle 57.7°, and average rms of 9 μJy beam^{-1}. Location of the PeVatron source along with its extension as quoted by Cao et al. (2021a) is shown by the black circle. Outermost contour shows sources with 5σ significance in the emission map.

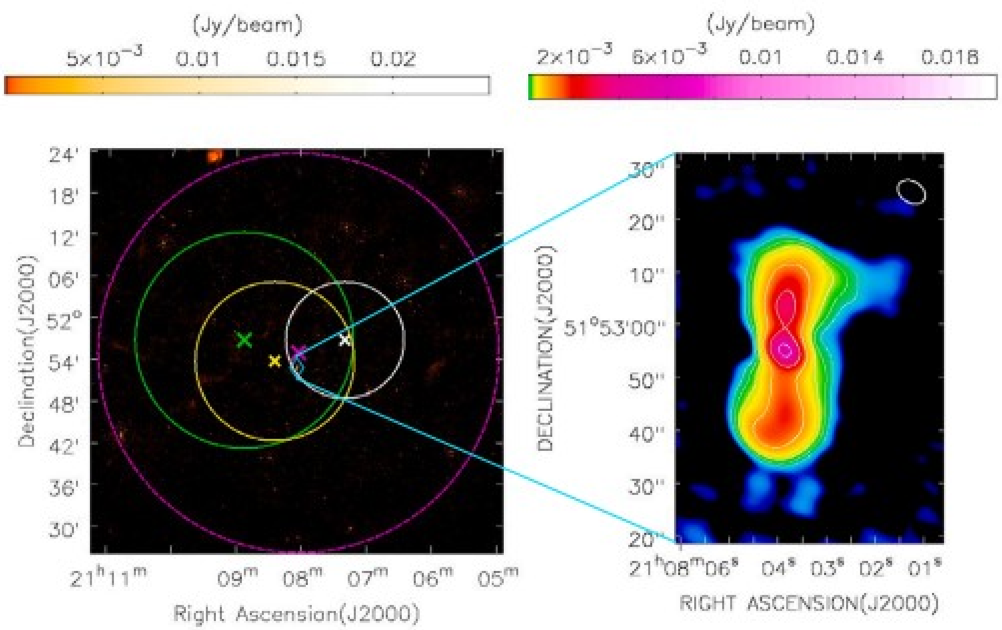

Fig. 2. Left: Position of the source 1LHAASO J2108+5153u in the 650 MHz emission map of uGMRT. Position of the source as quoted by Cao et al. (2021a) is shown by green cross. Green circle represents the upperlimit on the extension of the source. Yellow and white crosses represent the updated position of the source (1LHAASO J2108+5153u) given by KM2A and WCDA respectively (Cao et al., 2024). r39 radius of KM2A and WCDA is shown by the yellow and white circle respectively. Purple cross and circle show the location of Fermi source 4FGL J2108.0+5155e along with its extension. **Right:** Morphology of the extended structure obtained in 650 MHz emission map. Synthesis beam is shown the white ellipse in the upper right corner of the emission map.

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LHAASO J2108+5157 as a Molecular Cloud Illuminated by a Supernova Remnant

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Received –; accepted –

ABSTRACT

Context. The search for Galactic PeVatrons - astrophysical accelerators of cosmic rays to PeV energies - has entered a new phase in recent years with the discovery of the first Ultra-High-Energy (UHE, $E > 100$ TeV) gamma-ray sources by the HAWC and LHAASO experiments. Establishing whether the emission is leptonic or hadronic in nature, however, requires multiwavelength data and modelling studies. Among the currently known UHE sources, LHAASO J2108+5157 is an enigmatic source without clear association to a plausible accelerator, yet spatially coincident with molecular clouds.

Aims. We investigate the scenario of a molecular cloud illuminated by cosmic rays accelerated in a nearby supernova remnant (SNR) as an explanation for LHAASO J2108+5157. We aim to constrain the required properties of the SNR as well as which of the clouds identified in the vicinity is the most likely association.

Methods. We use a model for cosmic ray acceleration in SNRs, their transport through the interstellar medium and subsequent interaction with molecular material, to predict the corresponding gamma-ray emission. The parameter space of SNR properties is explored to find the most plausible parameter combination that can account for the gamma-ray spectrum of LHAASO J2108+5157.

Results. In the case that a SNR is illuminating the cloud, we find that it must be young (< 10 kyr) and located within $40 - 60$ pc of the cloud. A SN scenario with a low Sedov time is preferred, with a maximum proton energy of 3 PeV assumed. No SNRs matching these properties are currently known, although an as yet undetected SNR remains feasible. The galactic CR sea is insufficient to solely account for the observed flux, such that a PeVatron accelerator must be present in the vicinity.

Key words. Gamma ray: ISM – ISM: supernova remnants – ISM: clouds – (ISM:) cosmic rays

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Astronomy & Astrophysics

LHAASO J2108+5157 as a molecular cloud illuminated by a supernova remnant

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ABSTRACT

Context. The search for Galactic PeVatrons – astrophysical accelerators of cosmic rays to PeV energies – has entered a new phase in recent years with the discovery of the first ultra-high-energy (UHE, $E > 100$ TeV) γ-ray sources by the High Altitude Water Cherenkov (HAWC) observatory and Large High Altitude Air Shower Observatory (LHAASO). Establishing whether the emission is leptonic or hadronic in nature, however, requires multi-wavelength data and modelling studies. Among the currently known UHE sources, LHAASO J2108+5157 is an enigmatic source without clear association to a plausible accelerator, yet spatially coincident with molecular clouds.
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Results. In the case that a SNR is illuminating the cloud, we find that it must be young ($<$ 10 kyr) and located within 40–60 pc of the cloud. A SN scenario with a low Sedov time is preferred, with a maximum proton energy of 3 PeV assumed. No SNRs matching these properties are currently known, although an as yet undetected SNR remains feasible. The Galactic CR sea is insufficient to solely account for the observed flux, such that a PeVatron accelerator must be present in the vicinity.

The Main Criticism Against the Model

- No confirmed SNR counterpart
- No obvious shell structure
- Diffusion parameters uncertain
- Possible leptonic alternatives

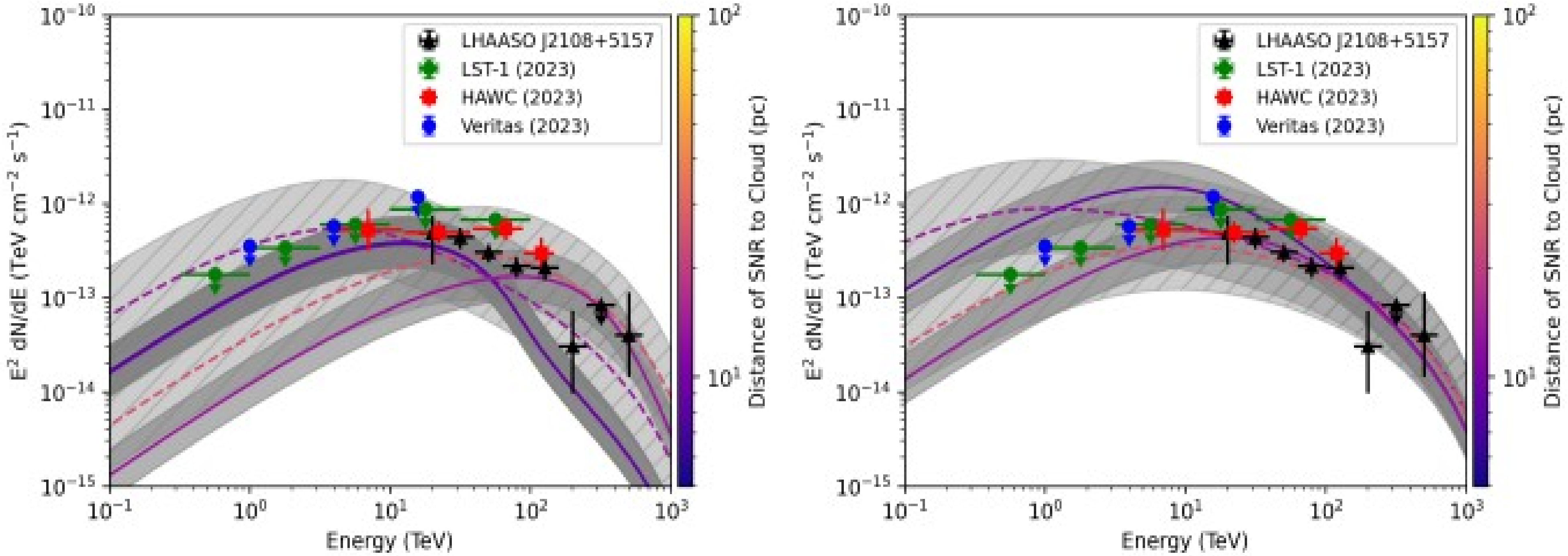
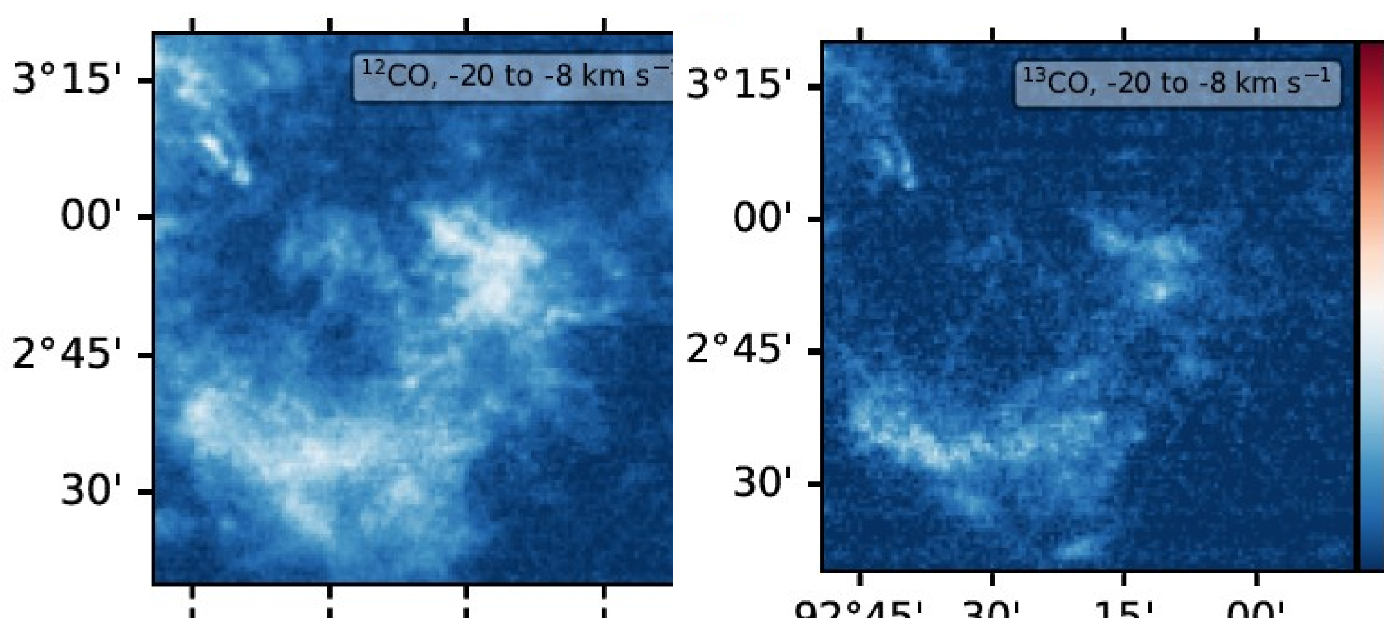


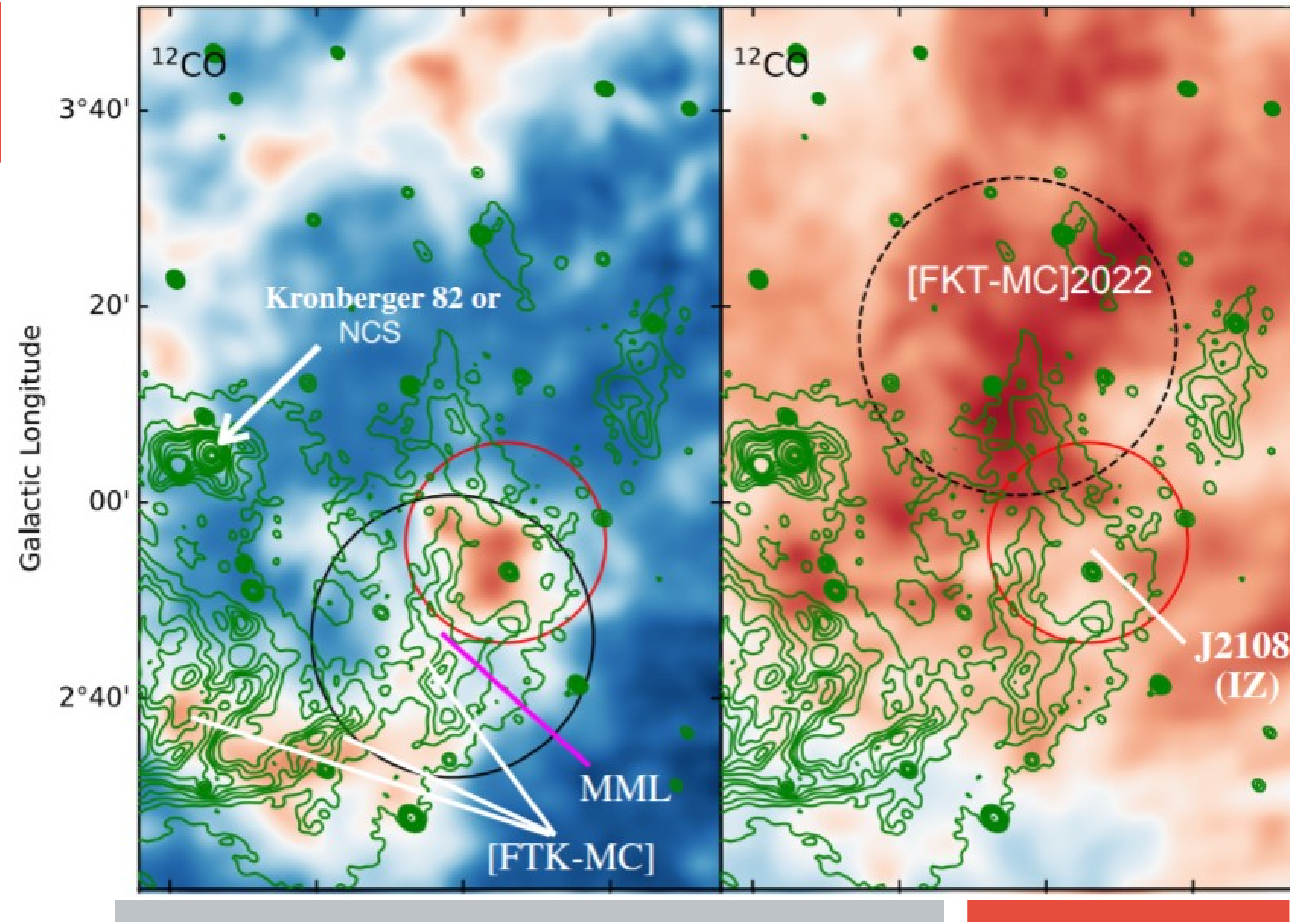
Fig. 3. Model curves corresponding to parameter combinations that best match data as listed in Table 3. Left: type II supernova remnant. Right: type Ia supernova remnant. Solid lines and shaded uncertainty band correspond to MML[2017]4607. Dashed lines and hatched region correspond to FKT[2022].

Table 3. Combinations of SNR age, t and separation distance, Δd for the model curves that best match the LHAASO data, listed in ranked order according to χ^2.

Cloud	t (kyr)	Δd (pc)	SN type	χ^2
MML[2017]4607	1	37	Ia	5.1
FKT[2022]	4	37 (*)	Ia	6.7
FKT[2022]	4	57	Ia	9.2
FKT[2022]	4	57	II	15.5
FKT[2022]	8	24 (**)	II	17.0
MML[2017]4607	4	24 (**)	II	24.4
MML[2017]4607	2	37	II	25.0
MML[2017]4607	1	24	Ia	28.2

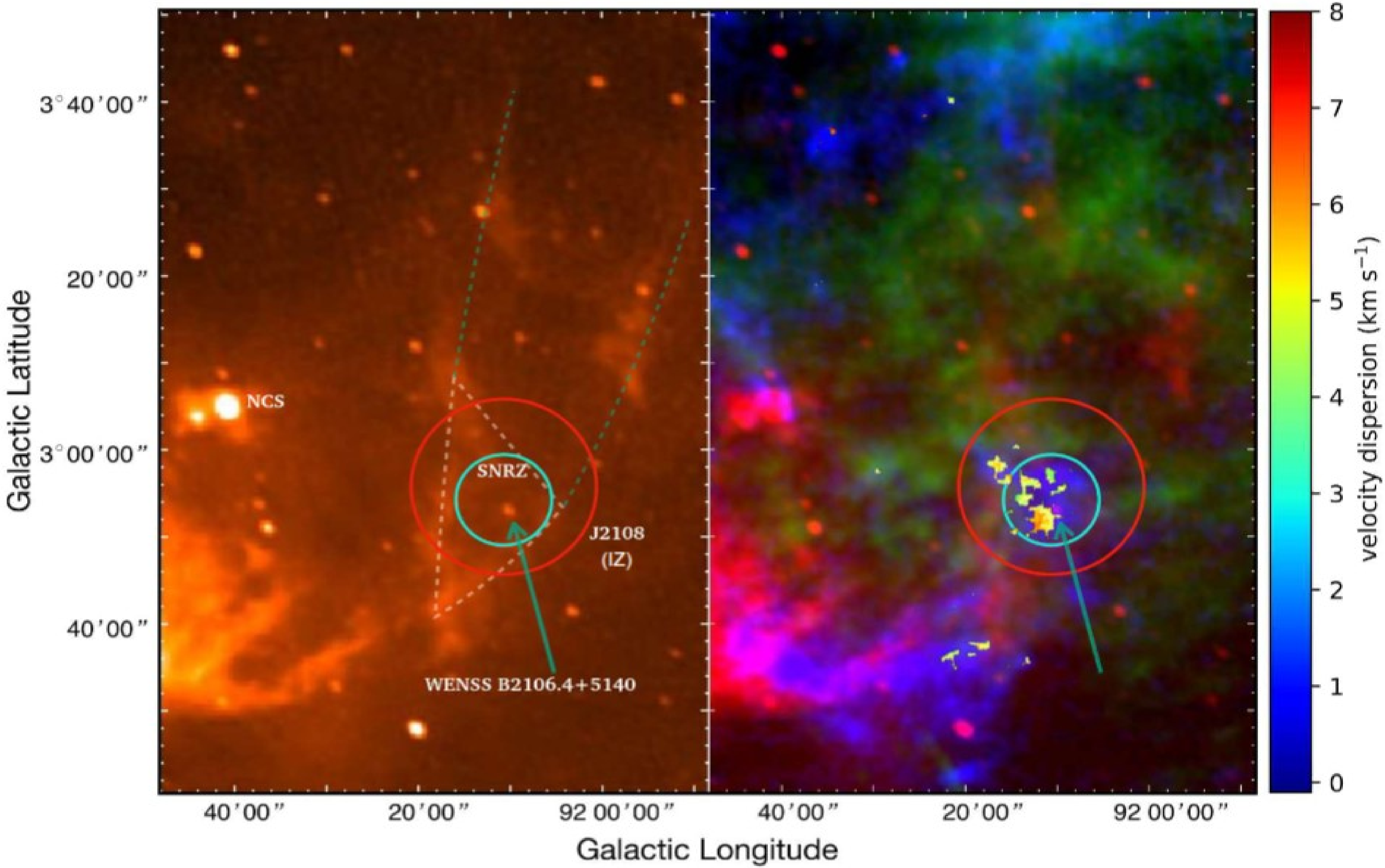
Notes. These curves are shown in Fig. 3. (*)Model curves for the same SNR age yet with smaller distances provided a comparable fit to the LHAASO data, but they severely overestimated the LST-1 upper limits and are hence not shown. (**)Model curves for the same SNR age yet with a distance of 10 pc and 15 pc were comparable to the 24 pc distance quoted.

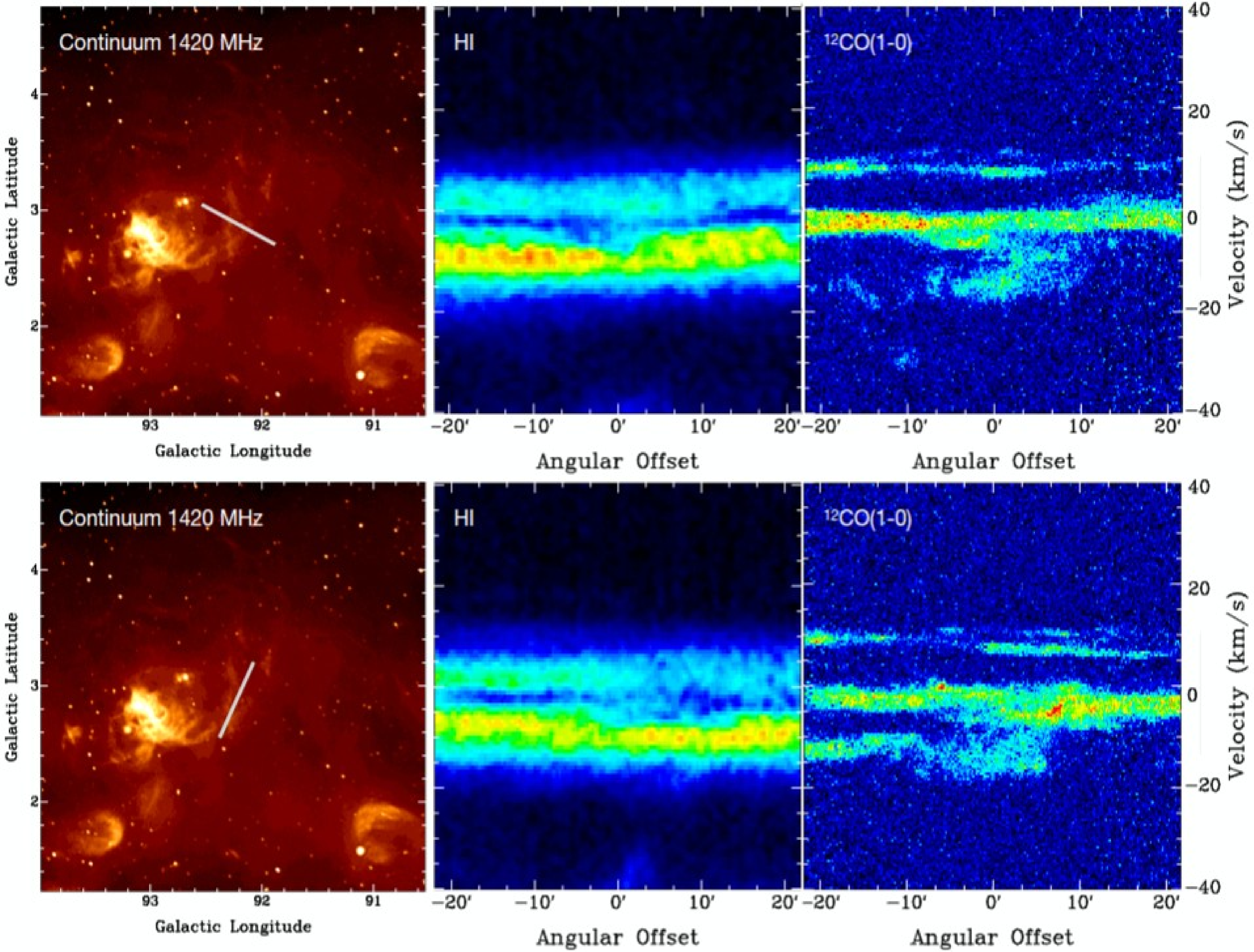




^{12}CO
^{12}CO
3°40'
20'
00'
2°40'
Galactic Longitude
Kronberger 82 or
NCS
MML
[FTK-MC]
[FKT-MC]2022
J2108
(IZ)

A NEW SCENARIO





Continuum 1420 MHz
HI
12CO(1-0)
Galactic Latitude
Galactic Longitude
Angular Offset
Velocity (km/s)
40
20
0
−20
−40
93
92
91
4
3
2
−20′
−10′
0′
10′
20′
Continuum 1420 MHz
HI
12CO(1-0)
Galactic Latitude
Galactic Longitude
Angular Offset
Velocity (km/s)

What the New Figure Adds

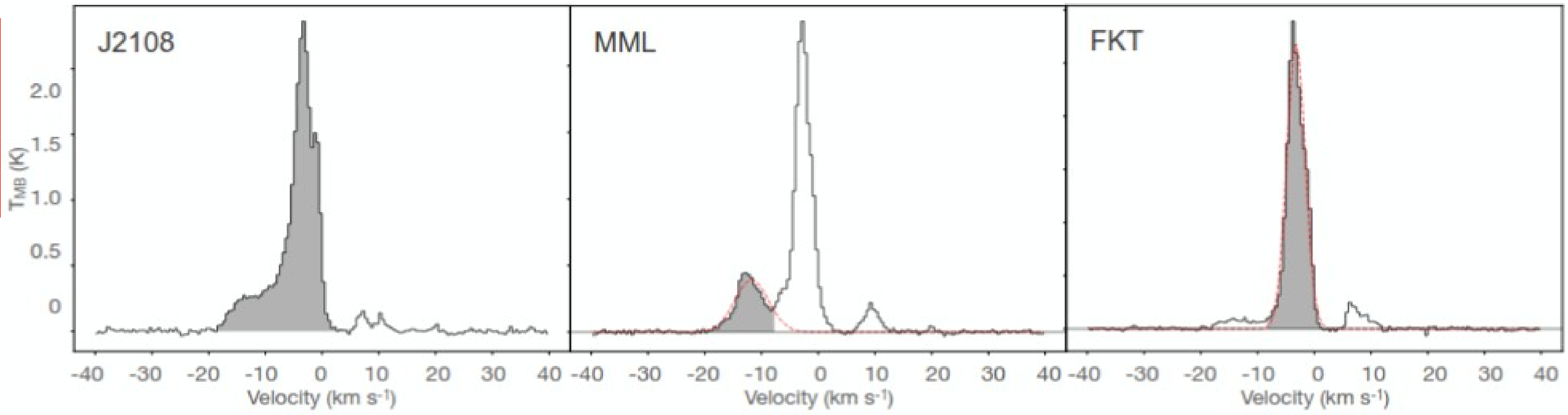
- Spatial coincidence between TeV emission and interaction zone
- Enhanced molecular velocity dispersion
- Radio continuum structures near the gamma-ray region
- Possible hidden SNR candidate (SNRZ)

What the New Figure Adds

- The gamma-ray emission is located inside the IZ
- Not randomly distributed in the molecular complex
- Suggests cosmic-ray illumination of dense gas
- Supports hadronic pp interactions

What the New Figure Adds

- Observed $\Delta v \approx 5$–6 km/s
- Possible signatures of turbulence or shocks
- Consistent with SNR-cloud interaction
- Difficult to explain in purely leptonic models



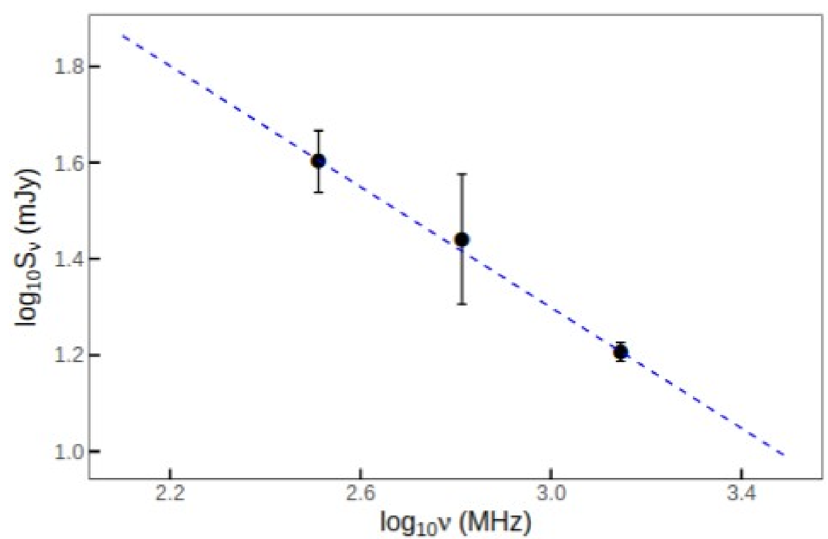


Fig. 8: Radio-continuum spectral energy distribution for the IZ zone favoring a spectral index α=–0.6 ($S_\nu \propto \nu^\alpha$).

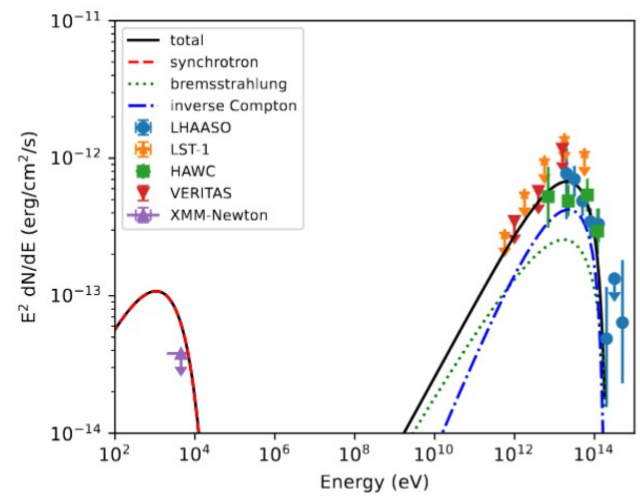


Fig. 9: A single electron population leptonic model compared to data using GAMERA Hahn et al. (2022). The upper limit from XMM-Newton is highly constraining, with synchrotron emission barely compatible with the upper limit even for a magnetic field strength of 1 μG.

Table 1: Observational parameters and column densities for the regions of interest (see Fig. 4), obtained from ^{13}CO gas observations considering a distance of 1.6 kpc and an excitation temperature T_{exc} = 7K (de la Fuente et al. 2023b).

^{13}CO Gas Region	l [°]	b [°]	V_{LSR} [km s $^{-1}$]	ΔV [km s $^{-1}$]	$\int T_{MB} d\nu$ [K km s $^{-1}$]	Size^a [°]	Size [pc]	τ	N(^{13}CO) [10^{15}cm^{-2}]	N(H_2) [10^{21}cm^{-2}]
[FKT-MC]2022	92.30	3.28	–3.23±0.50	3.79±0.50	10.78±0.70	0.54	15.3	0.80	0.58±0.17	0.29±0.08
MML[2017]4607	92.27	2.77	–11.72±0.50	7.04±0.50	2.46±0.50	0.48	13.4	0.10	0.14±0.08	0.07±0.40
J2108 or IZ	92.18	2.93	–4.67±0.50^b	7.40^c	13.41±0.50	0.34	9.5	0.70	0.82±0.03	4.87±1.64
SNRZ	92.19	2.91	–8.53±0.82	11.86±1.52	7.01±0.77	0.18	5.0	0.17	6.80±0.09	3.39±0.05

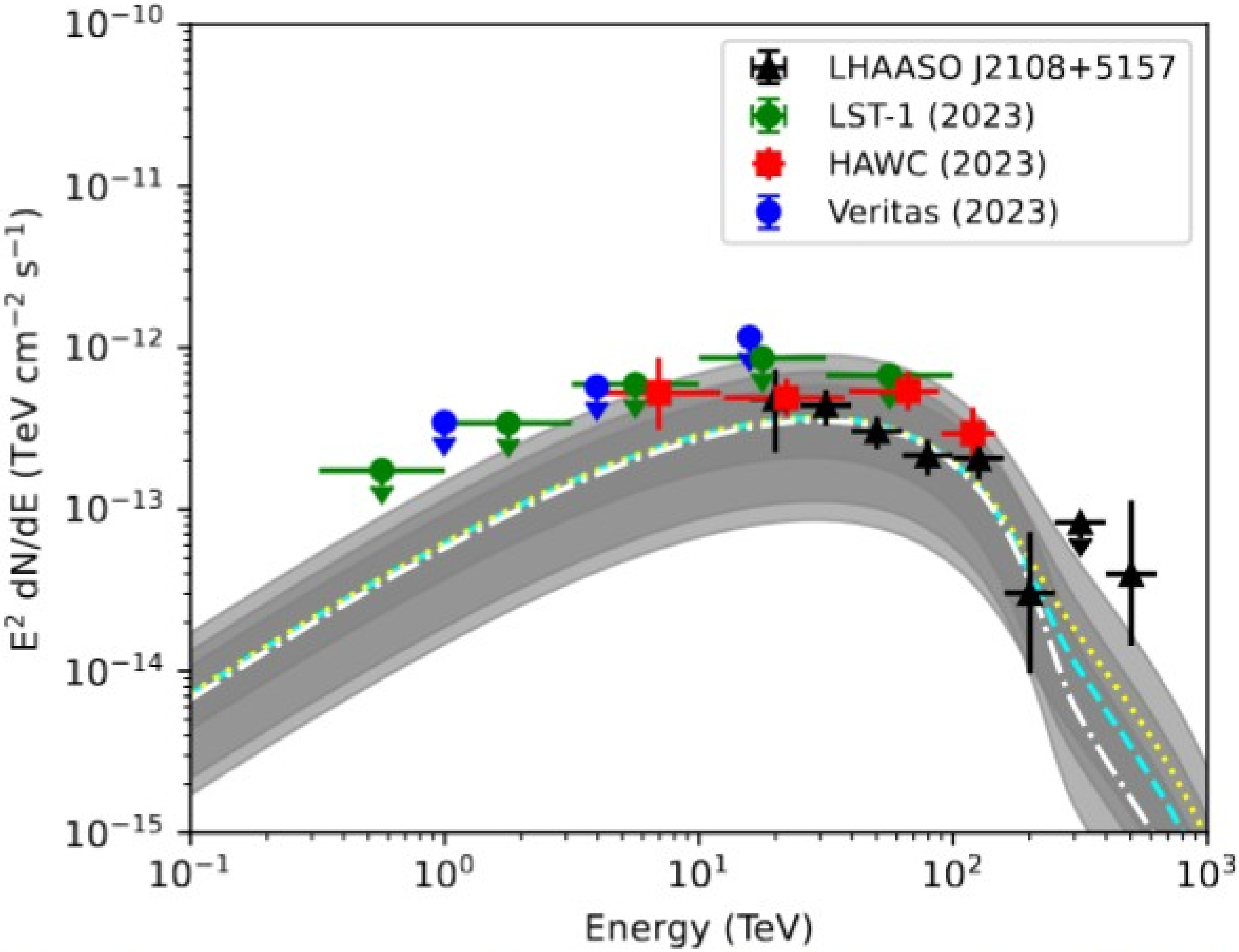


Fig. 10: γ–ray spectral energy distribution for LHAASO J2108+5157 considering densities reported in Table 2: 31 ± 5 cm^{-3} as the lowest estimated density corresponding to [FKT-MC]2022 (cyan dashed line); 435 ± 117 cm^{-3} corresponding to the IZ (yellow dotted line); and 898 ± 187 cm^{-3} as the highest estimated density from ^{13}CO (white dot-dashed line, see table 2). The best matching models to the LHAASO–KM2A data correspond to a SNR of $\sim 2.5-3$ kyr at a distance between 14 and 30 pc from the molecular gas.

The Emerging Picture

- Provides a plausible hidden accelerator environment
- Strengthens the molecular cloud illumination scenario
- Explains the TeV morphology naturally
- Links gas dynamics with gamma-ray production

Why This Favors Mitchell et al.

- Hidden young SNR + dense molecular gas
- Escaping CRs illuminating the cloud complex
- TeV emission tracing interaction regions
-
- J2108 may be an orphan Galactic PeVatron

TO BE CONTINUED….