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Probing PeVatron Candidates with CO/H I and IR/mm Data: V4641 Sgr & LHAASO J2108+5157*.

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Unveiling Galactic PeVatrons with frontier multi-messenger observations and theoretical models, Oct 8 – 10, 2025, Nevis Labs, Columbia University

OUTLINE AND CONTEXT

I.- The enigmatic and Bizarre PeVatron candidate source LHAASO J2108+5157:

-- Nobeyama's 45 m radio telescope observations (highest resolution observations to date)

- Reliable computation of the density of Hydrogen; $n(H) = 2n(H_2) + n(HI)$ at the highest angular resolution to test hadronic emission

- Where is the counterpart?. We test Allison Mitchell's hypothesis with these density values

II.- The amazing PeVatron microquasar V4641 Sgr:

-- Efforts to solve the distance problem between the binary system and the extended gamma-ray emission: Are they related? What do the IR-mm wavelengths say about it?

LHAASO J2108+5157: A pretty enigmatic source

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https://doi.org/10.1051/0004-6361/202245086

Astronomy & Astrophysics

Multiwavelength study of the galactic PeVatron candidate LHAASO J2108+5157

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Angular resolution of 8.5 arcmin Optically thick observations

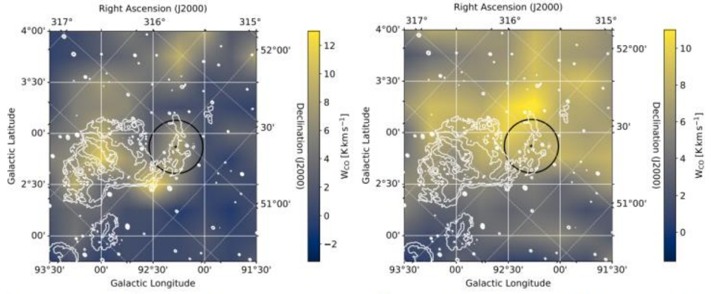

Fig. 6. Velocity-integrated ^{12}CO intensity (W_{CO}) of two molecular clouds spatially coincident with the direction of LHAASO J2108+5157. Left: Integrated velocity of the first Gaussian component peaking at $v_1 \approx -11.8\,\mathrm{km\,s^{-1}}$, with corresponding distance of $d_1 \approx 3.1$ 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.

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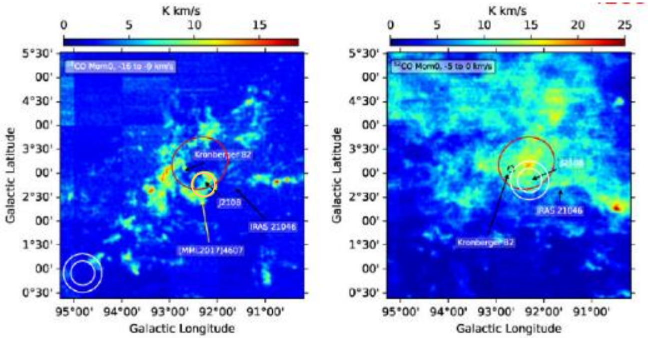
Detection of a new molecular cloud in the LHAASO J2108+5157 region supporting a hadronic PeVatron scenario†

Eduardo de la Fuente[1,2,*] Ivan Toledano-Juarez,[3] Kazumasa Kawata,[2] Miguel A. Trinidad,[4] Daniel Tafoya,[5] Hidetoshi Sano,[6] Kazuki Tokuda,[7] Atsushi Nishimura,[8] Toshikazu Onishi,[9] Takashi Sako,[2] Binita Hona,[10] Munehiro Ohnishi,[2] and Masato Takita[2]



Angular resolution of 3 arcmin optically thin observations

Angular resolution of 17 arcseconds!!

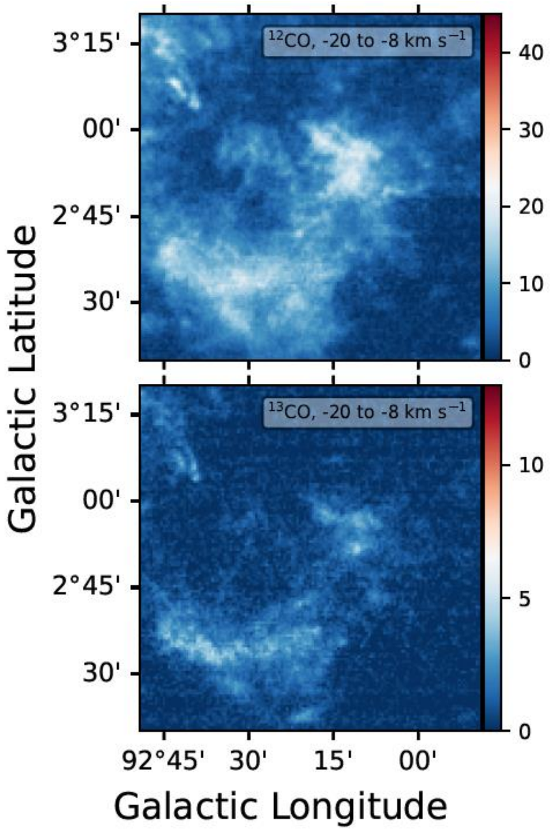
A&A 675, L5 (2023)
https://doi.org/10.1051/0004-6361/202346681

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]



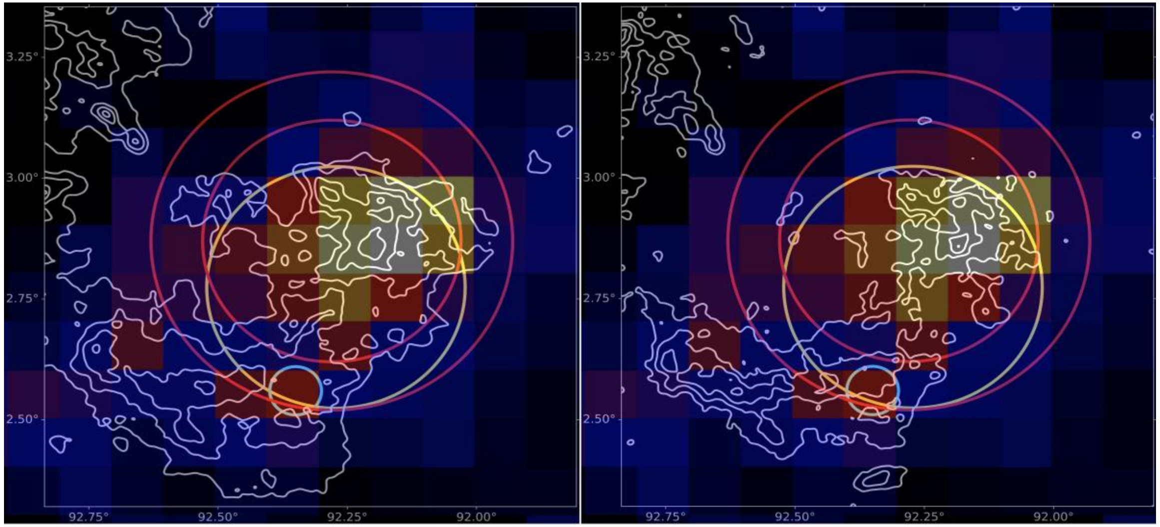
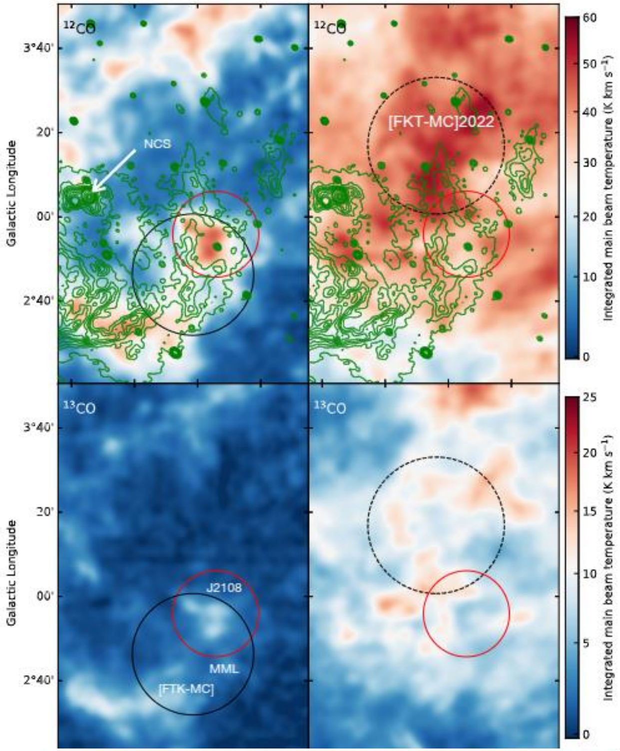


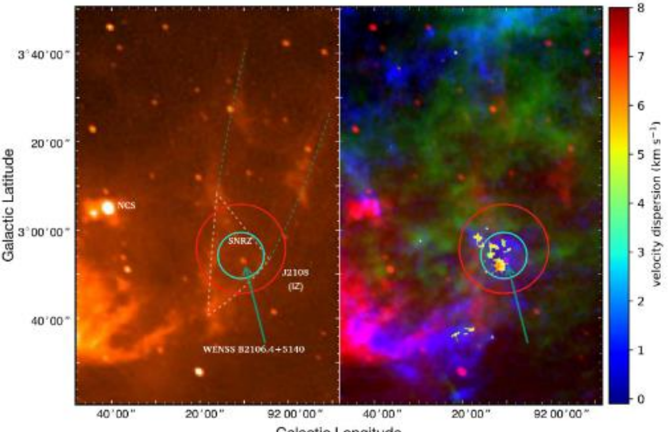
Table 4. Parameters and results of the hadronic model of Naima for the FTK molecular cloud

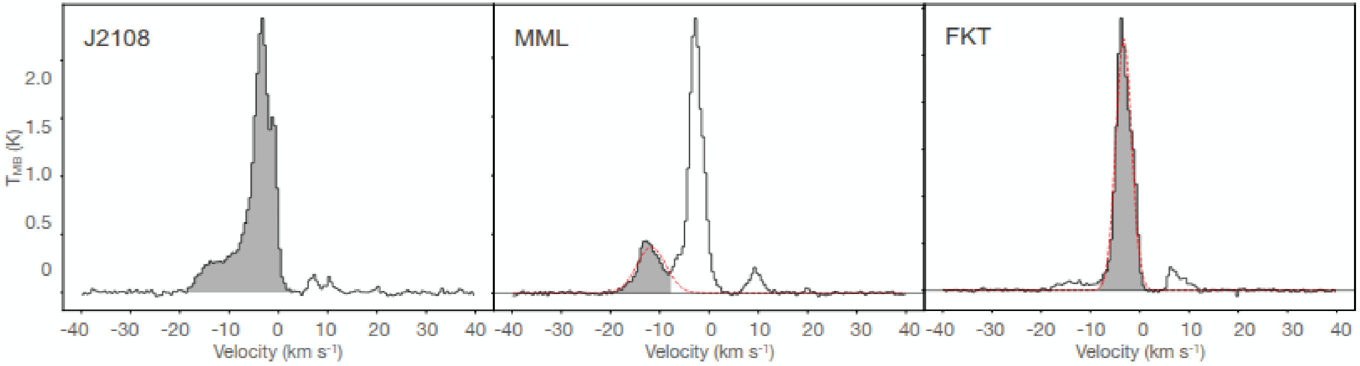
Distance [kpc]	$N(H)^a$ [10^{21} cm^{-2}]	$n(H)^a$ [cm^{-3}]	Size [degree]	W_p [10^{46}erg]	Cutoff [TeV]
1.6±0.1	6.2±2.1	133±45	0.55±0.02	$4.3^{+2.0}_{-1.1}$	700^{+400}_{-300}

[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.

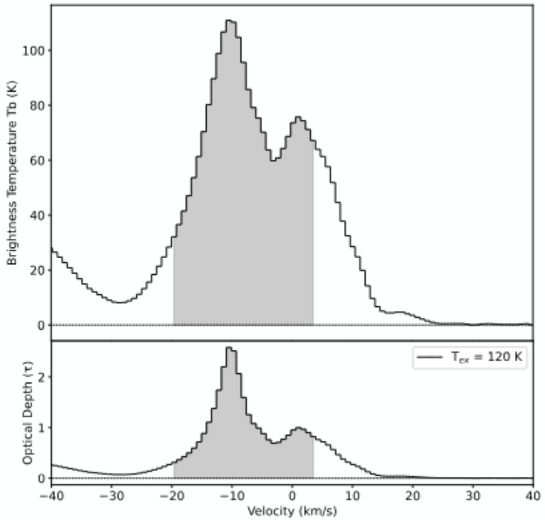
Optically THIN Gas!!!; tau = 0.2 on average







Work in progress!:



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https://doi.org/10.1051/0004-6361/202346473

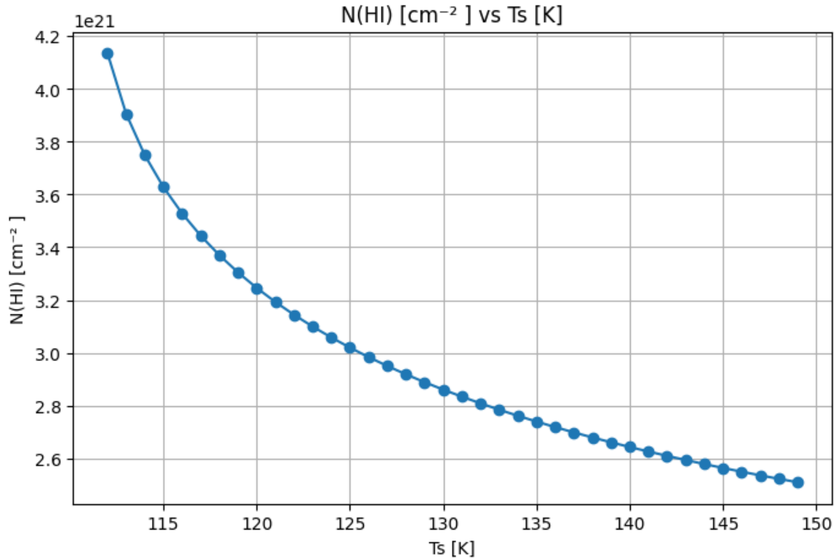
Astronomy & Astrophysics

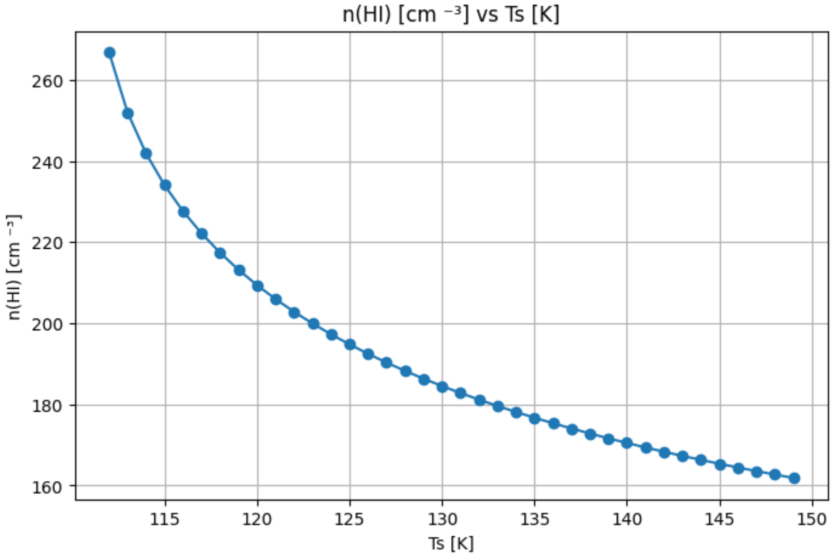
LHAASO J2108+5157 as a molecular cloud illuminated by a supernova remnant

A. M. W. Mitchell

LHAASO J2108+5157 is a dark UHE γ-ray source spatially coincident with two molecular clouds. We find that the γ-ray emission can be accounted for in terms of molecular cloud illumination by CRs from a nearby ($\lesssim$40–60 pc) young (< 10 kyr) SNR. Although no SNR is currently known that fulfills these cri-

^{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	3.40±0.05





n(H2) = 210 +/- 30 cm^{-3}

Ts = Tex = 120 K (fiducial)

$$\left[\frac{N(\mathrm{H\,I})}{\mathrm{cm}^{-2}}\right] = 1.8224\times10^{18}\left[\frac{T_{\mathrm{ex}}}{\mathrm{K}}\right]\int_{\mathrm{lines}} -\ln\left[1-\frac{T_{\mathrm{L}}(v)}{T_{\mathrm{ex}}}\right]\left[\frac{dv}{\mathrm{km\ s^{-1}}}\right].$$

Integral = 14.84 km/s (from data)

For -20 to -8 km/s (zone of interest),
tao = 0.3 - 2.6, with tao_avg = 1.24.

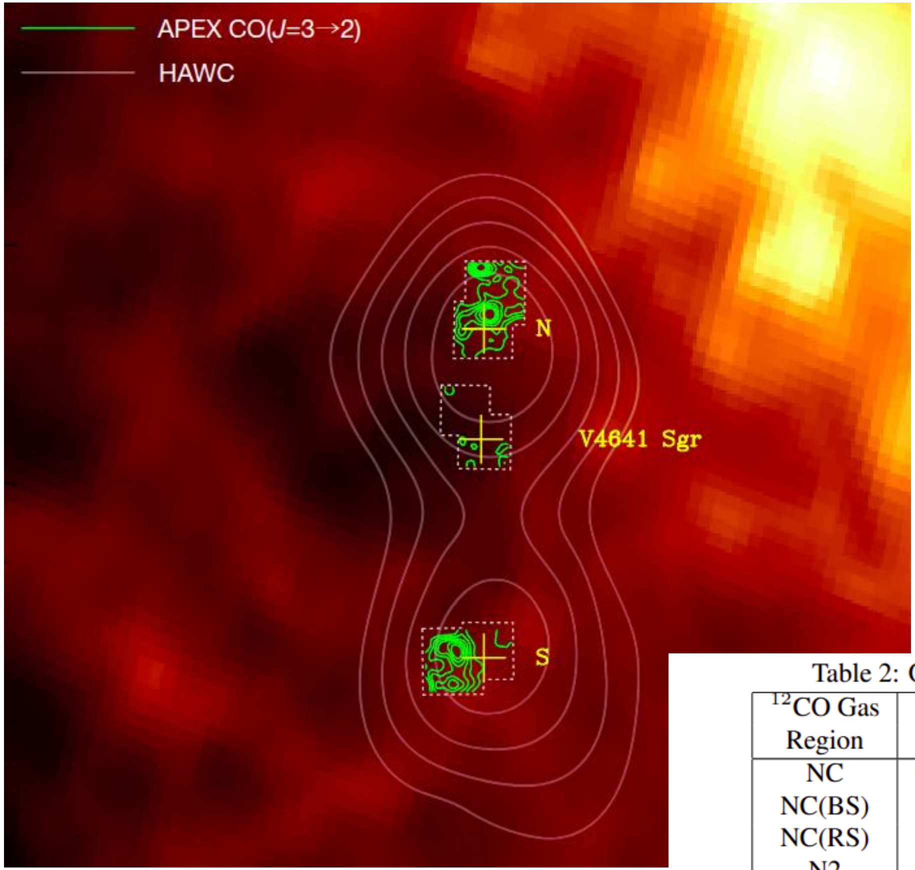
N(HI) = 3.25 x 10^{21} cm^{-2}
n(HI) = 209 cm^{-3}
n(H) = 2n(H2)+n(HI) = 629 +/- 60 cm^{-3}

THANK YOU MONTSERRAT!

OUTLINE AND CONTEXT

II.- The amazing PeVatron microquasar V4641 Sgr:

-- Efforts to solve the distance problem between the binary system and the extended gamma-ray emission: Are they related?, What the IR-mm wavelengths say about it?



II.- Radio, mm, and IR observations of V4641 Sgr

Molecular observations show large uncertainty in distance
How can we solve that?

A solution is with IR-mm analysis on HAWC emission region (distance and extinction), unfortunately there is no detailed IR-mm study in the HAWC region.

Are the Gamma-Ray lobes connected with V4641 Sgr or projection in the sky?

Table 2: Observational parameters from ^{12}CO gas observations considering excitation temperature T_{exc} = 40 K.

^{12}CO Gas Region	l [°]	b [°]	V_{LSR} [km s $^{-1}$]	ΔV [km s $^{-1}$]	$\int T_{MB} d\nu$ [K km s $^{-1}$]	Distance[a] [kpc]	Size (H_2) [°]	Size(HI) [°]	τ
NC	6.990	-4.643	–26.0±0.1	3.6±0.2	1.60±0.08	4 and 12	0.04	0.20	0.012
NC(BS)	—	—	–30.1±0.5	4.2±0.8	0.38±0.08	—	—	—	—
NC(RS)	—	—	–21.5±0.1	2.5±0.2	0.41±0.08	—	—	—	—
N2	7.085	-4.612	–32.7±0.1	3.7±0.1	2.67±0.08	4 and 12	0.03	0.20	0.018
N3	6.975	-4.609	+126.2±0.7	11.0±1.8	0.55±0.08	8.1	0.01	0.18	0.001
S6	6.374	-4.964	+110.9±0.4	4.8±0.8	0.33±0.08	8.1	0.01	0.22	0.002
S5	6.365	-5.035	+84.9±0.5	6.6±1.1	0.37±0.08	8.5	0.03	0.20	0.001
S4	6.373	-5.043	–30.5±0.7	7.6±1.7	0.33±0.08	4 to 12	0.02	0.20	0.001
S3	6.336	-5.098	–44.6±0.1	2.3±0.3	0.32±0.08	5 to 11	0.02	0.26	0.003
S2	6.395	-5.032	–2.6±0.2	5.6±0.6	1.21±0.08	2.0	0.03	0.24	0.006
SC	6.400	-5.030	+7.4±0.3	1.6±0.1	1.32±0.08	2.6	0.10	0.32	0.023
RP	6.367	–4.866	+28.9±0.1	2.7±0.1	2.68±0.03	6.0	0.05		

[a] Distance computed using the parallax-based distance calculator from Reid et al. (2019) and combined probability.

Work in progress!:

Pioner APEX observations

IR and mm observations in V4641 Sgr: RGB images

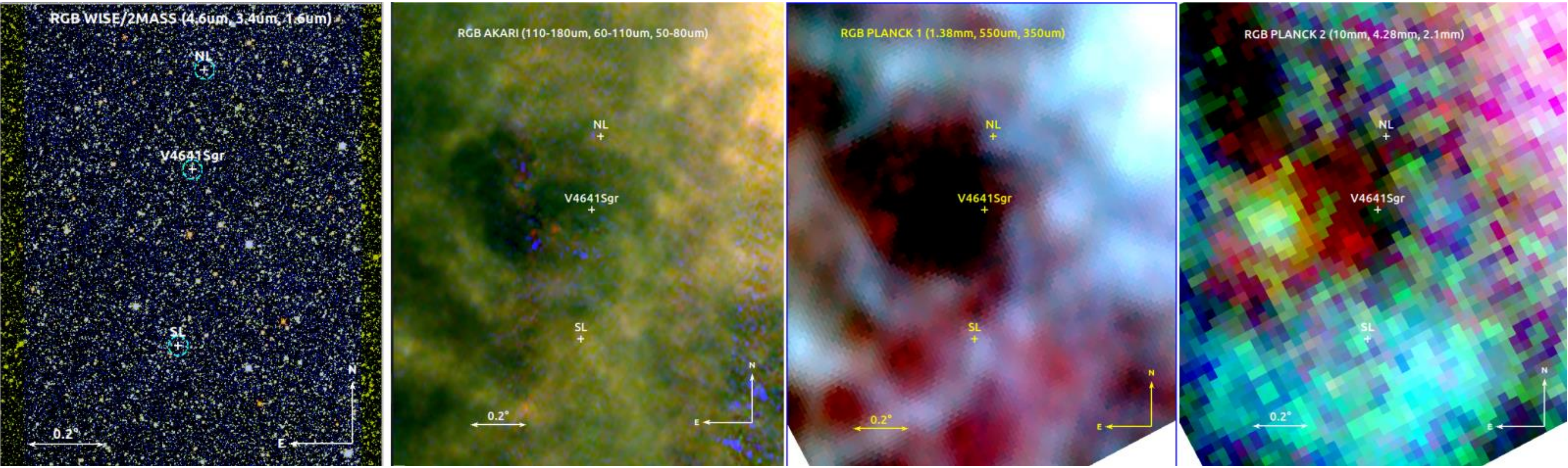


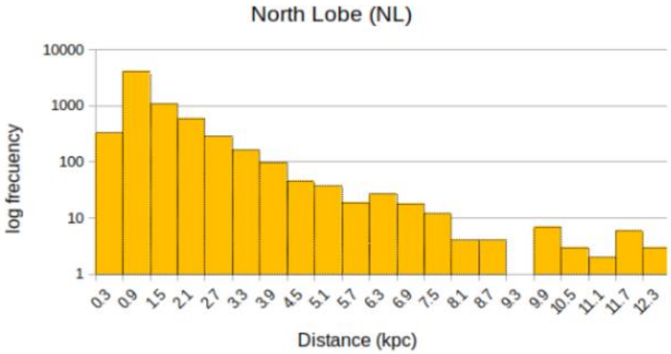
Table 1: Summary of distances based on GAIA DR3 stellar distributions

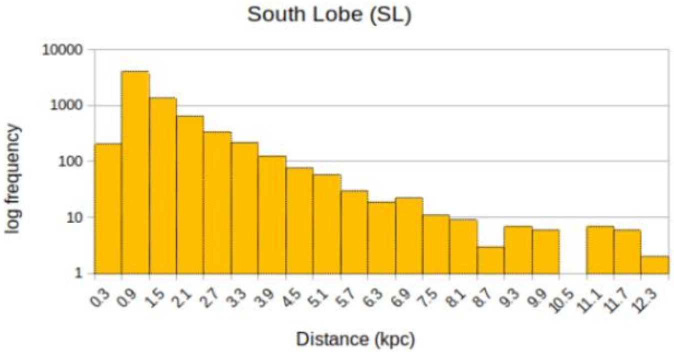
Target name	J2000 Coordinates RA(h:min:sec), Dec(deg:arcmin:arcsec)	Search radius (arcmin)	Number of GAIA sources[3]	$<\Delta d_{lower}>$[1] (pc)	$<\Delta d_{upper}>$[2] (pc)	Estimated distance (kpc)
North Lobe	18:19:13.3609 −25:08:24.891	7	6868 (113)	496	487	$6.02^{+1.31}_{-1.32}$
South Lobe	18:19:31.5671 −25:52:40.719	7	7163 (91)	661	469	$6.53^{+1.26}_{-1.45}$
V4641Sgr	18:19:21.6340 −25:24:25.849	7	7060 (130)	650	525	$6.19^{+1.57}_{-1.69}$
PCCS2E G006.88-05.14	18:20:59.4521 −25:28:35.493	10	13682 (243)	599	497	$6.18^{+1.56}_{-1.67}$

[1] $\Delta d_{lower} = d - d_{lower}$
[2] $\Delta d_{upper} = d_{upper} - d$
[3] In parenthesis are the number of sources in the addopted central range of histograms (see text).

Distances are estimated from GAIA DR3 public data

(https://gea.esac.esa.int/archive/)





Target name	Estimated distance (kpc)
North Lobe	$6.02^{+1.31}_{-1.32}$
South Lobe	$6.53^{+1.26}_{-1.45}$
V4641Sgr	$6.19^{+1.57}_{-1.69}$
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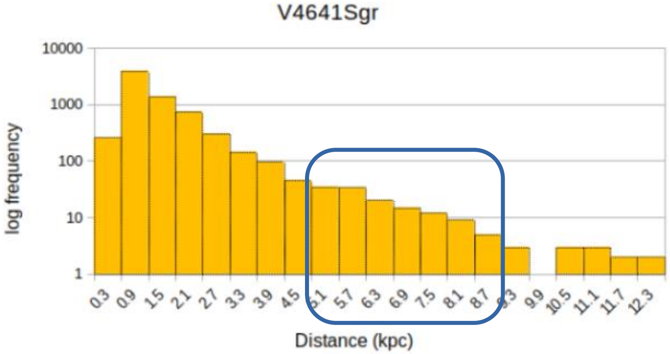
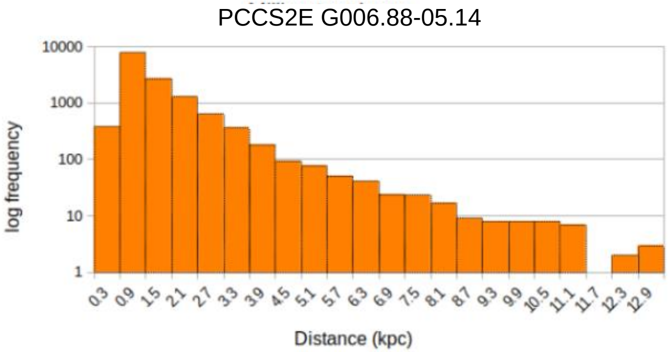
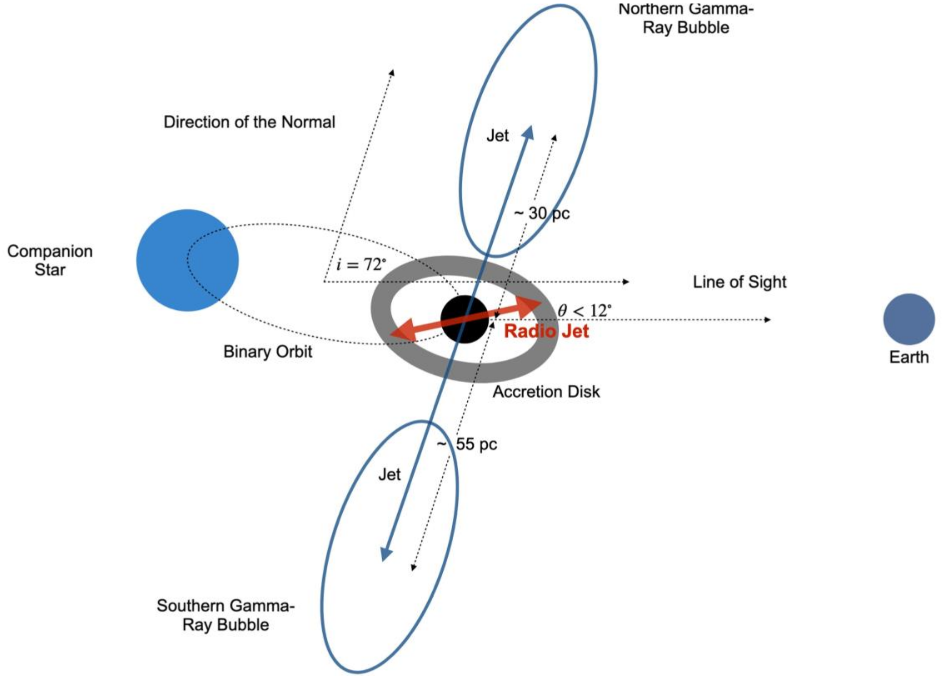




1. Estimated distance is the average distance of sources in the central part of the histogram

2. Errors are statistical and observational from GAIA (d, d_{lower}, d_{upper})

Target name	Estimated distance (kpc)
North Lobe	$6.02^{+1.31}_{-1.32}$
South Lobe	$6.53^{+1.26}_{-1.45}$
V4641Sgr	$6.19^{+1.57}_{-1.69}$
PCCS2E G006.88-05.14	$6.18^{+1.56}_{-1.67}$



Relevant points:

1. All 4 targets are at a similar distance

2. NL is slightly nearer than SL, in agreement with Alfaro et al. 2024 scheme

3. V4641Sgr and the millimeter clump PCCS2E G006.88-05.14 are at the same distance

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GRACIAS; THANK YOU

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