Constraining the nature of the emission in PeVatrons observed by Alpaca.

Dr. Eduardo de la Fuente Acosta

Departamento de Física, CUCEI, Universidad de Guadalajara, México
ALPACA Observatory Collaboration

eduardo.delafuentea@academicos.udg.mx

ICRR Inter-University Research Program FY2024
January 29, 2025

ALPACA Experiment
Andes Large area PArticle detector for Cosmic ray physics and Astronomy

UHE γ-ray Astronomy:

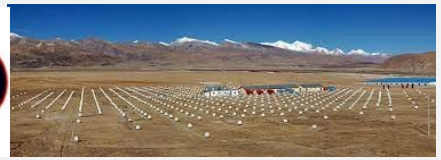
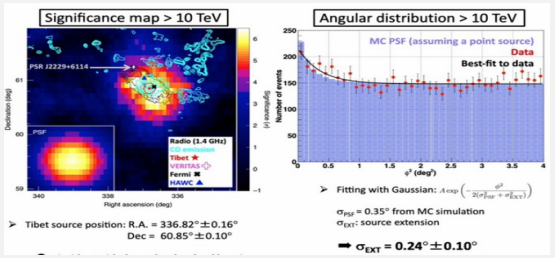
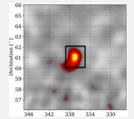
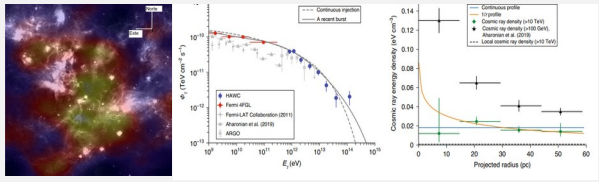
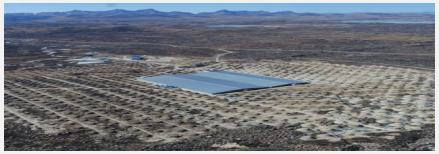
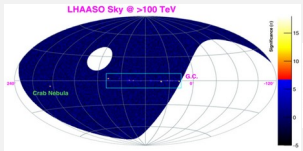
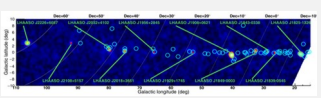
2021: A new window in Astronomy: A transition from Tevatrons to PeVatrons:

Gamma-Ray Ultra-High Energy (E >100 TeV).

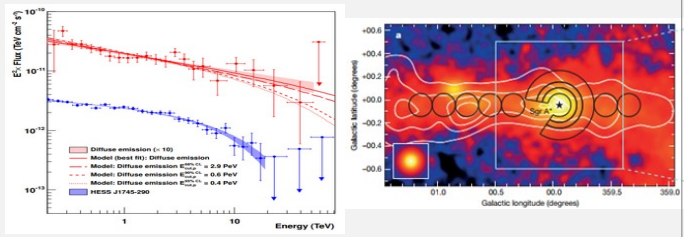
If we detect energies > 100 TeVs (gamma rays) from astronomical sources (*accelerator*), the expected particle acceleration is > 1 PeV (energy per beam**).**

The rise of the PeV era (Pevatrons)

Time-line Observationally speaking (high energy sensitivity):

High sensitivity observatory (By year pub.)	Remarkably Contribution Object: reference and year	Results	Comments and Remarks
Tibet AS γ  **Energy range: Beyond 100 TeV**	SNR G106.3+2.7 Nature Astronomy, 5, 460 (2021) Published: 2021/03/06 Confirmation as PeVatron		HAWC Coll. ApJL, 896, L20 (2020):  Crab Nebula paper: PRL, 123, 051101 (2019)
HAWC High Altitude Water Cherenkov Gamma-Ray Observatory  **Energy range: 100 GeV to 100 TeV**	Cygnus Cocoon (FERMI-LAT) Nature Astronomy, 5, 465 (2021) Published: 2021/04/06 Star-Clusters as PeVatron		Star forming región at Cygnus-X: Cyg-OB2 Association Crab Nebula paper: ApJ, 881, 134 (2019)
LHAASO 高海拔宇宙线观测站  **Energy range: 0.1 TeV to 0.1 EeV**	North Sky (> 1.4 PeV) Nature, 594, 33 (2021) Published: 2021/05/17 Sky map and 12 PeV candidates (galactic)	 First PeV sky map 	Crab Nebula as PeVatron: **Science, 373, 425 (2021/07/08)**

Reference work where the term “PeVatron” was coined by first time in 2016 (Obs+predictions):

Energy range:10s of GeV to 10s of TeV. H.E.S.S. 	Galactic Center Study Nature, 531, 476 (2016) Published: 2016/03/16 Suggesting Sag. A* black hole could be the PeVatron		This work is the first robust detection of a VHE cosmic hadronic accelerator As PeVatron, HESS refer to hadrons Previous GC observations by IACTs HESS: 2004, 2066 MAGIC: 2006, 2016 VERITAS: 2011

ALPACA Experiment

Andes Large area PArticle detector for Cosmic ray physics and Astronomy

The ALPACA experiment is a new project aimed at the observation of cosmic rays and gamma rays, launched between Bolivia and Japan in 2016. Its primary motivation is the continuous observation of ultra-high-energy gamma rays, for the first time in the southern hemisphere, with a wide field of view and with the world's best sensitivity. The participation of Mexico starts in 202

AIMS:

To participate in the construction and data analysis of the experiment focused in PeVatrons.

With a developed methodology, to determine the density of nucleons in order to test the hadronic nature emission of PeV gamma-rays in PeVatrons in the southern hemisphere, richer in Pevatrons than the northern hemisphere. This analysis needs molecular gas observations.

Synergy with other experiments and observatories including X-Ray observations

LHASSO J2108+5157

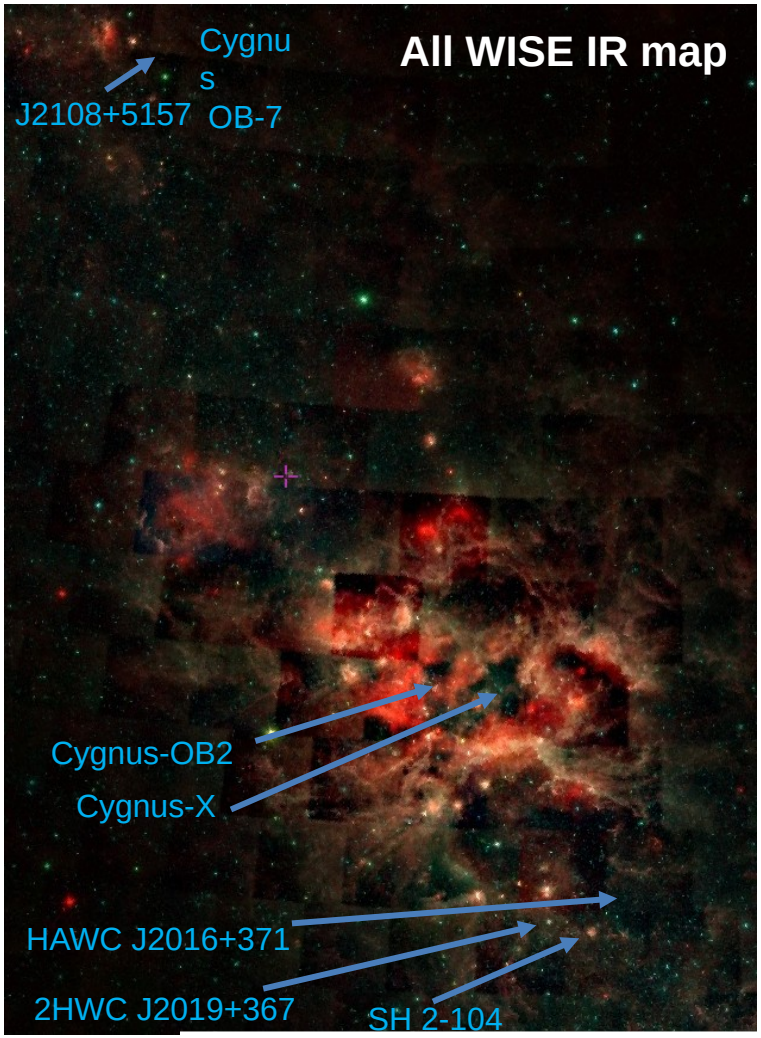
The Astrophysical Journal Letters, 919:L22 (9pp), 2021 October 1 https://doi.org/10.3847/2041-8213/ac2579

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

Zhen Cao[1,2,3], F. Aharonian[4,5], Q. An[6,7], Axikegu[8], L. X. Bai[9], Y. X. Bai[1,3], Y. W. Bao[10], D. Bastieri[11], X. J. Bi[1,2,3], Y. J. Bi[1,3], H. Cai[12], J. T. Cai[11], Zhe Cao[6,7], J. Chang[13], J. F. Chang[1,3,6], B. M. Chen[14], E. S. Chen[1,2,3], J. Chen[9],

19th Rencontres du Vietnam; TMEX 2023

Dr. Eduardo de la Fuente Acosta (CUCEI-UdeG)



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	

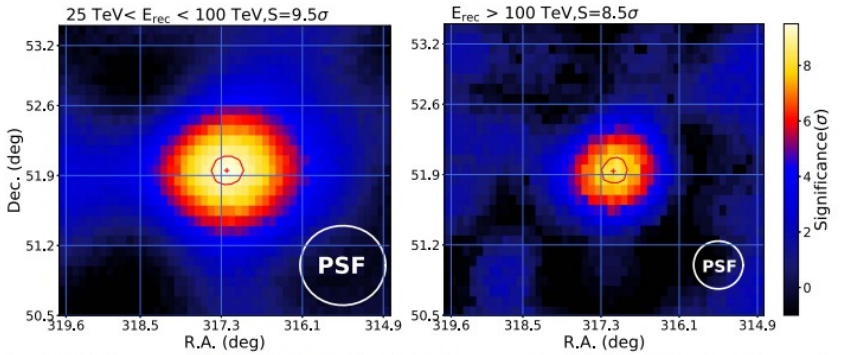
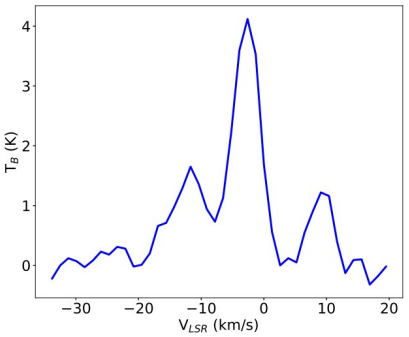
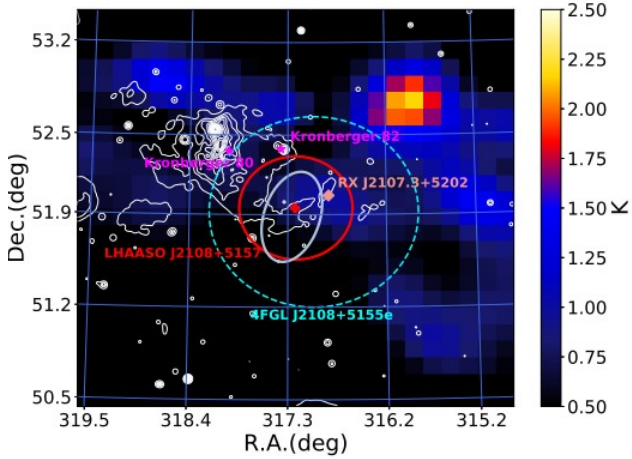


Figure 1. Left: significance map around LHAASO J2108+5157 as observed by KM2A for reconstructed energies from 25 to 100 TeV. Right: significance map for energies above 100 TeV. The red plus sign and circle denote the best-fit position and 95% position uncertainty of the LHAASO source. The white circle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

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

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





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

Dame 2001, ApJ, 547, 792

The PeVatron Candidate LHASSO J2108+5157 (II)

PeVatrons as challenge in 21st century astronomy

A&A 673, A75 (2023)
https://doi.org/10.1051/0004-6361/202245086

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],

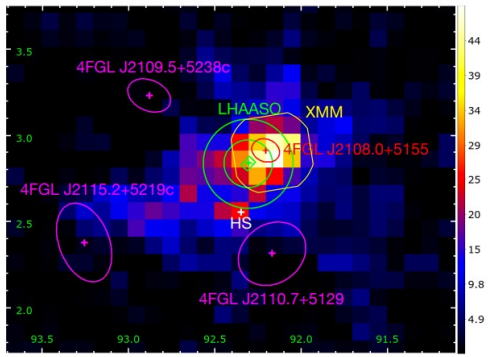


Fig. 3. *Fermi*-LAT TS map in Galactic coordinate above 2 GeV, which shows the sources present in the 4FGL-DR3 catalog with their 95% positional errors (magenta and red ellipses). The small green rectan-

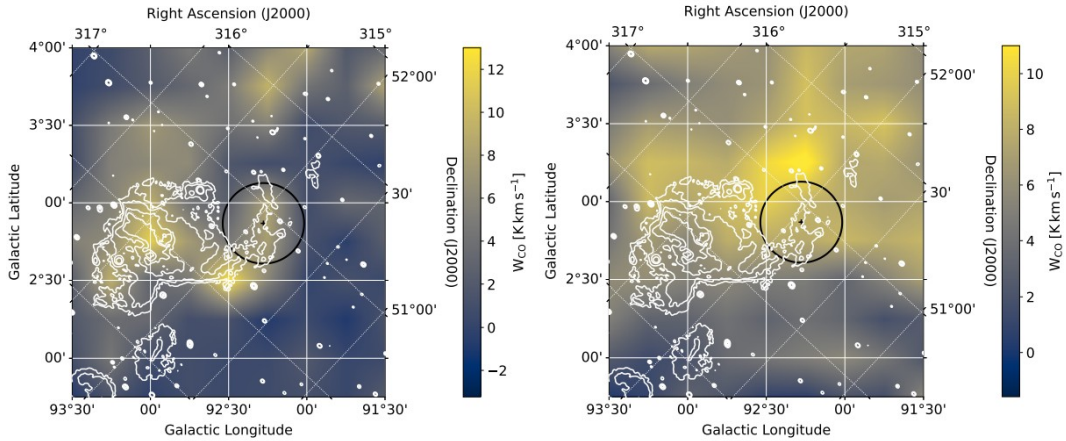
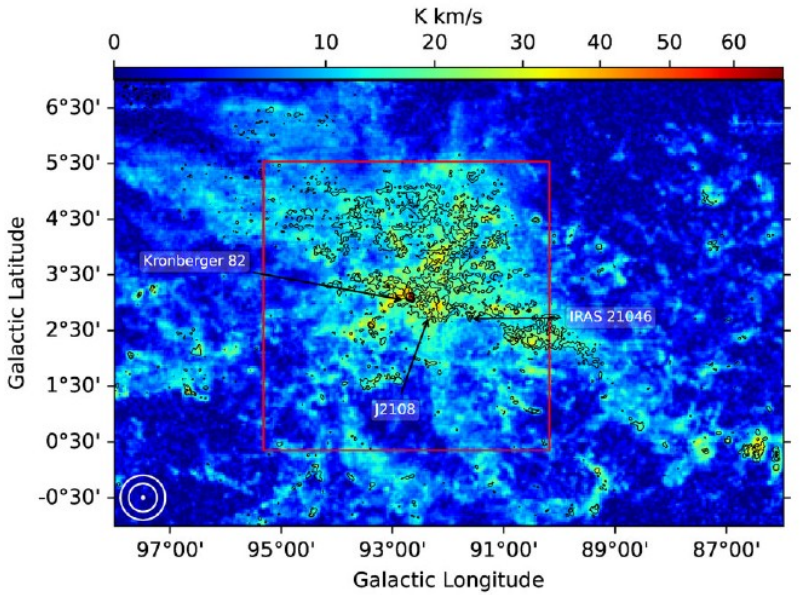
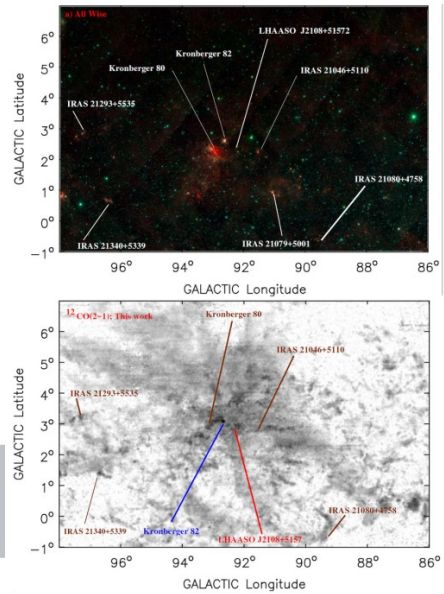


Fig. 6. Velocity-integrated ^{12}CO intensity (W_{CO}) of two molecular clouds spatially coincident with the direction of LHAASO J2108+5157. Left: Integrated velocity of the first Gaussian component peaking at $v_1 \approx -11.8\,\mathrm{km\,s^{-1}}$, with corresponding distance of $d_1 \approx 3.1\,\mathrm{kpc}$. Right: Integral of the second Gaussian component at $v_2 \approx -2.7\,\mathrm{km\,s^{-1}}$ and $d_1 \approx 2.0\,\mathrm{kpc}$. 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.





Publ. Astron. Soc. Japan (2023) 75 (3), 546–566
https://doi.org/10.1093/pasj/psad018
Advance Access Publication Date: 2023 April 12

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]

[1]Departamento de Fisica, CUCEI, Universidad de Guadalajara, Blvd. Marcelino García Barragan 1420, Olímpica, 44430, Guadalajara, Jalisco, México
[2]Institute for Cosmic Ray Research, The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa, Chiba 277-8582, Japan
[3]Doctorado en Ciencias en Física, CUCEI, Universidad de Guadalajara, Blvd. Marcelino García Barragan 1420, Olímpica, 44430, Guadalajara, Jalisco, México
[4]Departamento de Astronomía, Universidad de Guanajuato, Apartado Postal 144, 36000, Guanajuato, Guanajuato, México
[5]Department of Space, Earth, and Enviroment, Chalmers University of Technology, Onsala Space Observatory, 439 92 Onsala, Sweden
[6]Faculty of Engineering, Gifu University, 1-1 Yanagido, Gifu, Gifu 501-1193, Japan
[7]Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, Nishi-ku, Fukuoka, Fukuoka 819-0395, Japan
[8]Nobeyama Radio Observatory, National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences (NINS), 462-2 Nobeyama, Minamimaki, Minamisaku, Nagano 384-1305, Japan
[9]Department of Physics, Graduate School of Science, Osaka Metropolitan University, 1-1 Gakuen-cho, Naka-ku, Sakai, Osaka 599-8531, Japan
[10]Department of Physics and Astronomy, University of Utah, 201 Presidents Circle, Salt Lake City, UT 84112, USA

*E-mail: eduardo.delafuente@academicos.udg.mx

https://doi.org/10.1093/pasj/psad018

Publ. Astron. Soc. Japan (2023) 75 (3), 546–566

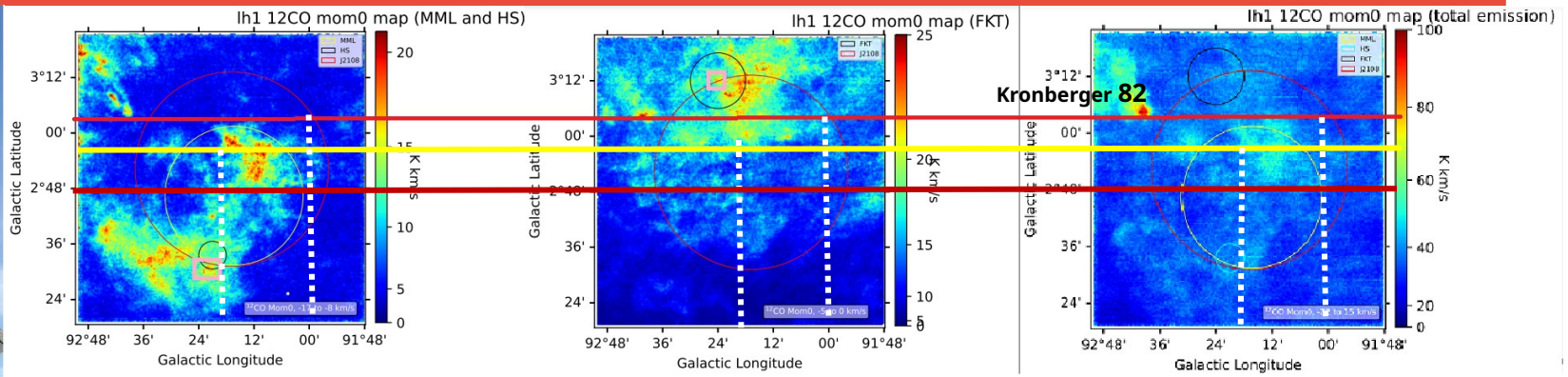
The PeVatron Candidate LHASSO J2108+5157 (III)

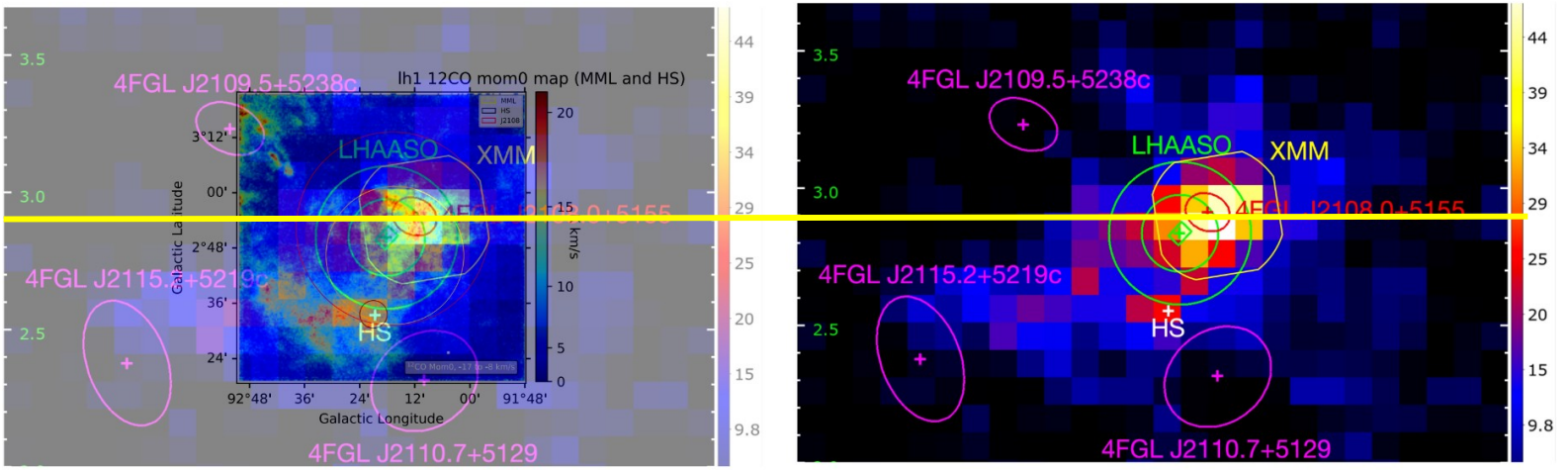
PeVatrons as challenge in 21st century astronomy

Nobeyama 45 m radio-telescope

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

OPTICALLY THIN GAS





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

Ongoing work.....

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]

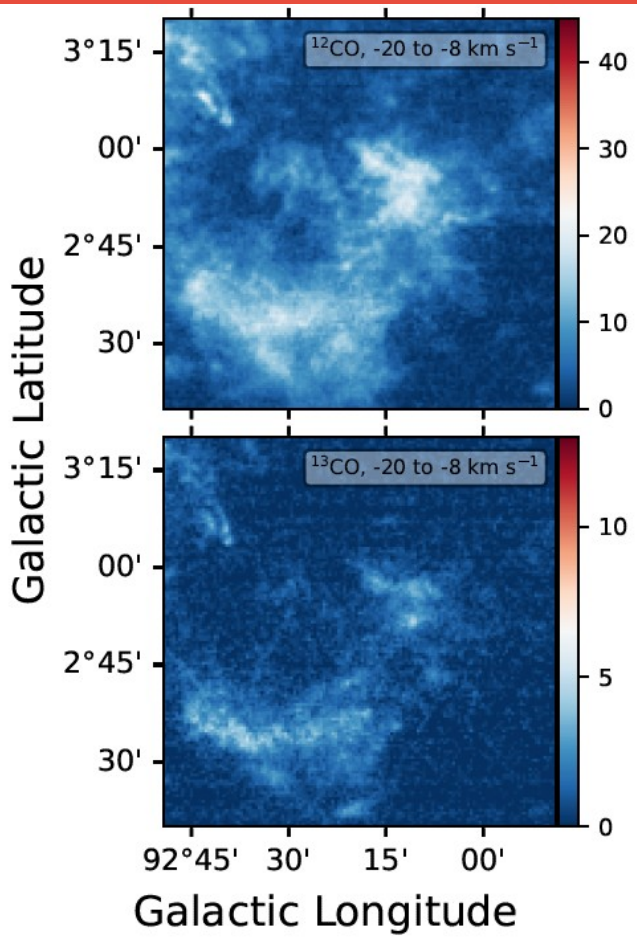
[1] Departamento de Física, Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara, Blvd. Marcelino García Barragán 1420, 44430 Guadalajara, Jalisco, Mexico
e-mail: eduardo.delafuente@academicos.udg.mx
[2] Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan
[3] Doctorado en Ciencias en Física, Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara, Blvd. Marcelino García Barragán 1420, 44430 Guadalajara, Jalisco, Mexico
[4] Departamento de Astronomía, Universidad de Guanajuato, Apartado Postal 144, 36000 Guanajuato, Mexico
[5] Department of Space, Earth, and Enviroment, Chalmers University of Technology, Onsala Space Observatory, Onsala 439 92, Sweden
[6] Institute of Astronomy, Graduate School of Science, The University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo 181-0015, Japan
[7] Department of Applied Physics, Faculty of Engineering, Kanagawa University, 3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama, Kanagawa 221-8686, Japan
[8] Department of Space, Earth, and Enviroment, Chalmers University of Technology, Onsala Space Observatory, Onsala 439 92, Sweden
[9] Nobeyama Radio Observatory, National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences (NINS), 462-2 Nobeyama, Minamimaki, Minamisaku, Nagano 384-1305, Japan
[10] Faculty of Engineering, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan
[11] National Astronomical Research Institute of Thailand (Public Organization), 260 Moo 4, T. Donkaew, A. Maerim, Chiangmai 50180, Thailand

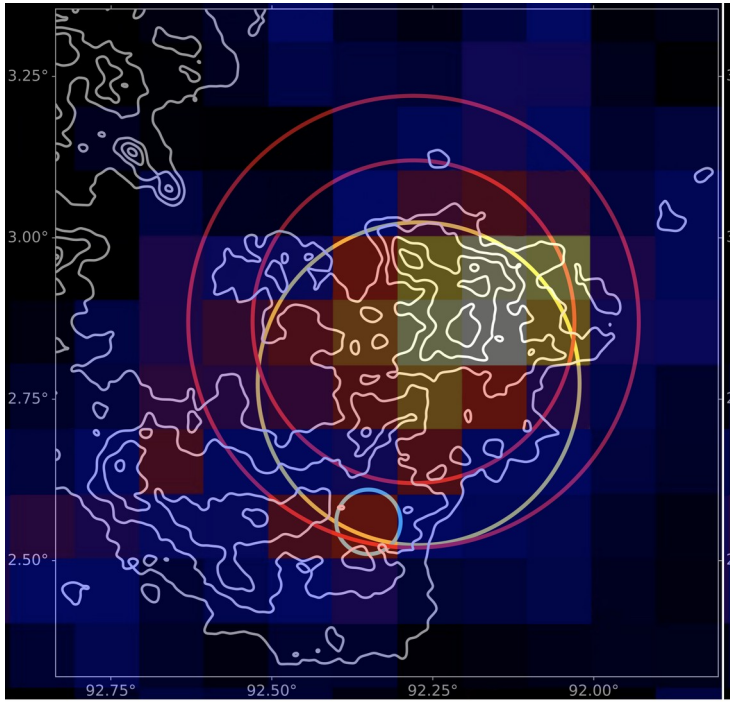
Received 17 April 2023 / Accepted 20 June 2023

The PeVatron Candidate LHASSO J2108+5157 (II)

PeVatrons as challenge in 21st century astronomy

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





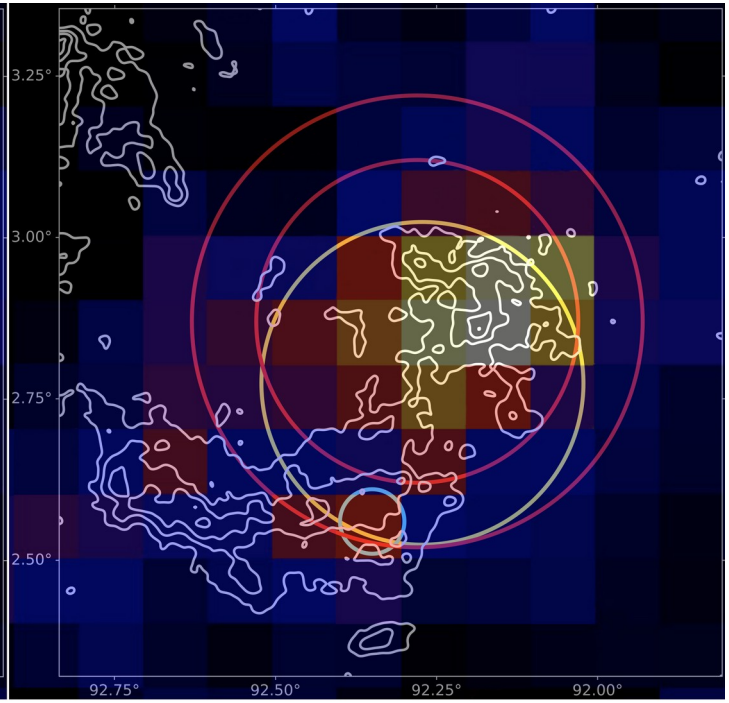


Table 4. Parameters and results of the hadronic model of Naima for the FTK molecular cloud

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

The PeVatron Candidate LHASSO J2108+5157; maybe the most enigmatic on PeVatrons in nothern hemisphere; what about the southern sky?

Through the successful investigation of PeVatrons in the Northern Hemisphere, such as LHASSO J2108+5157, perhaps the most enigmatic PeVatron in the Northern Hemisphere, supported by the Nobeyama 45m radio telescope and the OPU 1.8m radio telescope, we can study PeVatrons in the Southern Hemisphere in a similar way by combining Alpaca, radio (hadronic nature emission) and X-ray (leptonic nature emission) observations to contribute to the understanding of the physical mechanism and/or gamma-ray nature emission in PeVatrons.

Alpaca is under construction, Alpaquita, the prototype is taking data

THANK YOU!