西南交通大学 物理科学与技术学院
Southwest Jiaotong University
School of Physical Science and Technology

LHAASO J2028+3352: an elliptical pulsar halo candidate

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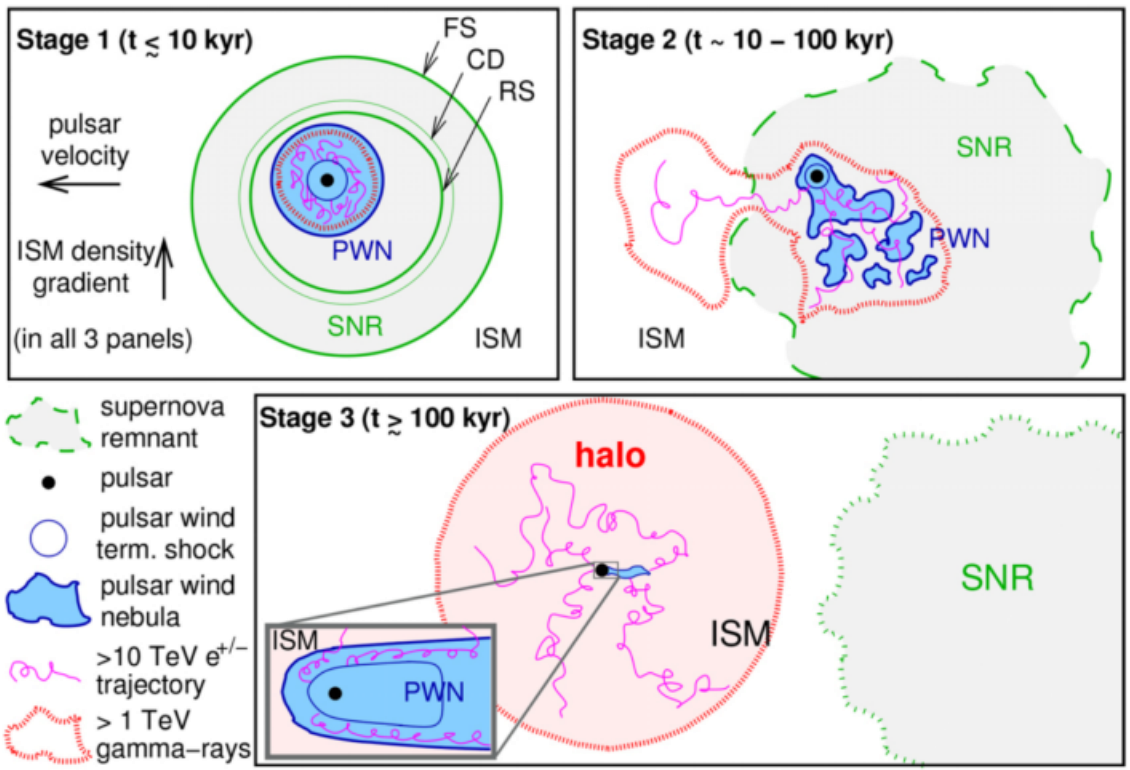
Part I

Background

Pulsar halo

$$D_G(100TeV) \sim 10^{30} cm^2/s$$
$$D_{halo}(100TeV) \sim 10^{28} cm^2/s$$

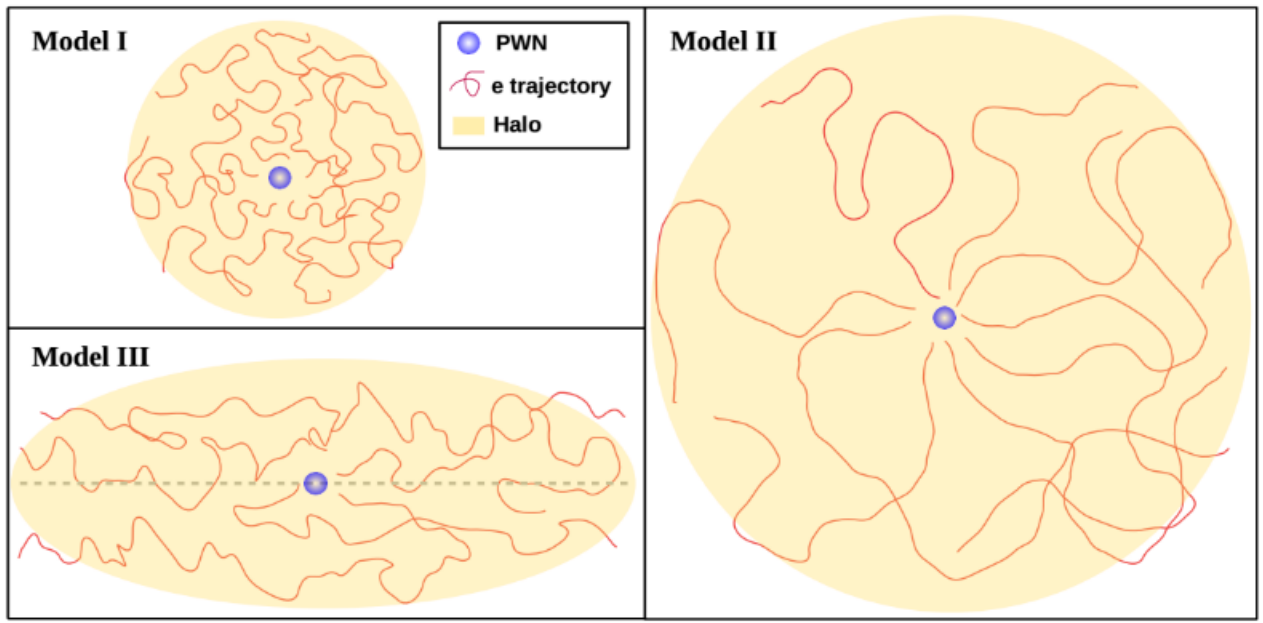


Halo model

Model I
Isotropic, Suppressed Diffusion

Model II
Isotropic, Unsuppressed Diffusion with the Transition from Quasi-ballistic Propagation

Model III
Anisotropic Diffusion



Background

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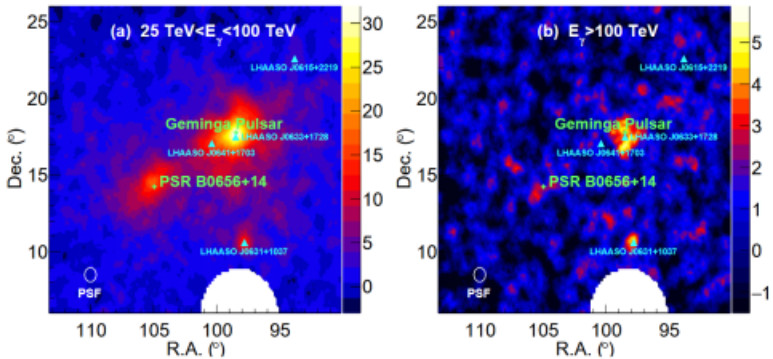
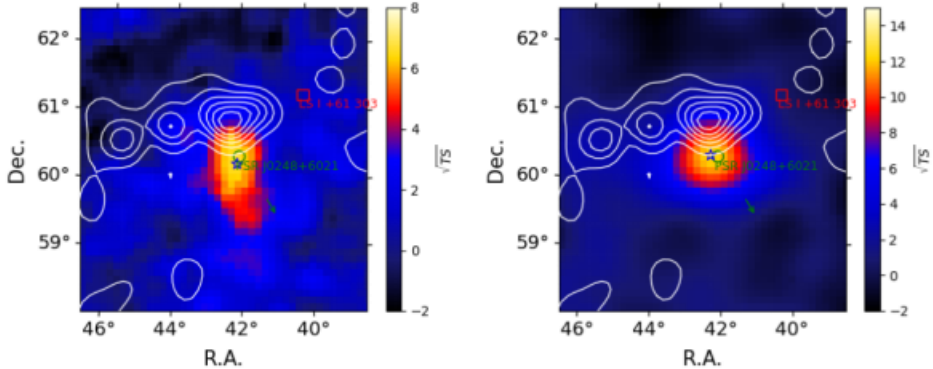
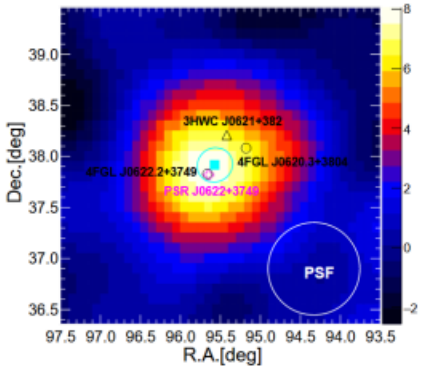
Geminga, Monogem



J0248+6021



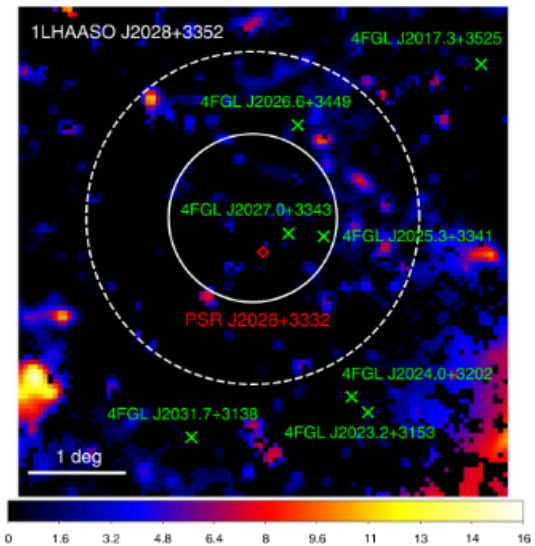
J0622+3749

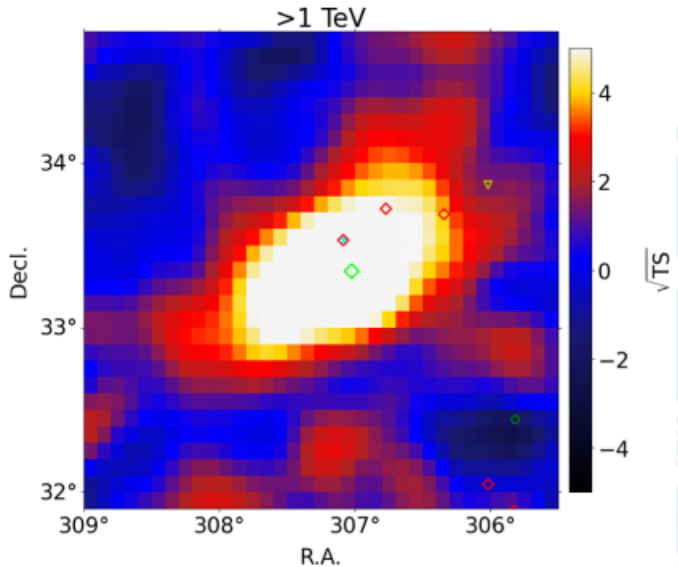


Name	diffusion coefficient($10^{27}cm^2s^{-1}$)
Geminga(100TeV)	$3.2(d/0.25kpc)^2$
Monogem(100TeV)	$15(d/0.29kpc)^2$
J0248+6021(160TeV)	$20.0(d/2.0kpc)^2$
J0622+3749(160TeV)	$8.9(d/1.6kpc)^2$

Background

PSR J2028+3332(radio quiet)





D. Zheng & Z. Wang, ApJ, 957, 79 (2023)

$$\begin{aligned} \text{pos} &\text{——} 20{:}28{:}19.860, +33{:}32{:}04.36 \\ \text{GL, GB} &\text{——} 73.361, -3.008 \\ \dot{E} &\text{——} 3.48e+34 erg/s \\ \tau_c &\text{——} 5.76e+05 yr \\ d &\text{——} 0.76 kpc \end{aligned}$$

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Part Ⅱ

LHAASO data analysis

Data selection

ROI: $[307.5°, 33.5°]$ $5° \times 5°$

Detector	Time range	live time(day)	Nhit or log10(E_rec/TeV)	bins	roi_e_range
WCDA	2021/03/05-2025/07/31	1484	30-2000	7	[7, -0.4, 1.0]
KM2A(full)	2021/07/20-2025/07/31	1438	1.0-3.4	12	[12, 1.0, 3.4]
KM2A(3/4)	2020/12/01-2021/07/19	216	1.0-3.4	12	[12, 1.0, 3.4]
KM2A(1/2)	2019/12/27-2020/11/30	289	1.0-3.4	12	[12, 1.0, 3.4]

LHAASO data analysis

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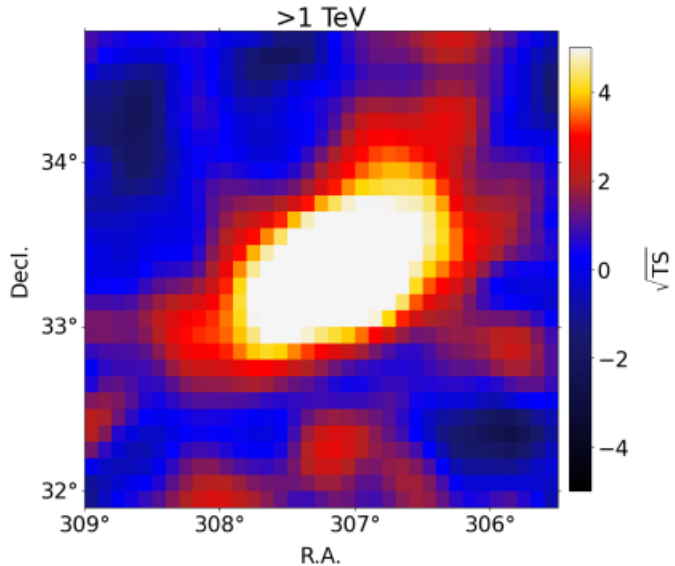
LHAASO J2028+3352

PSR J2028+3332

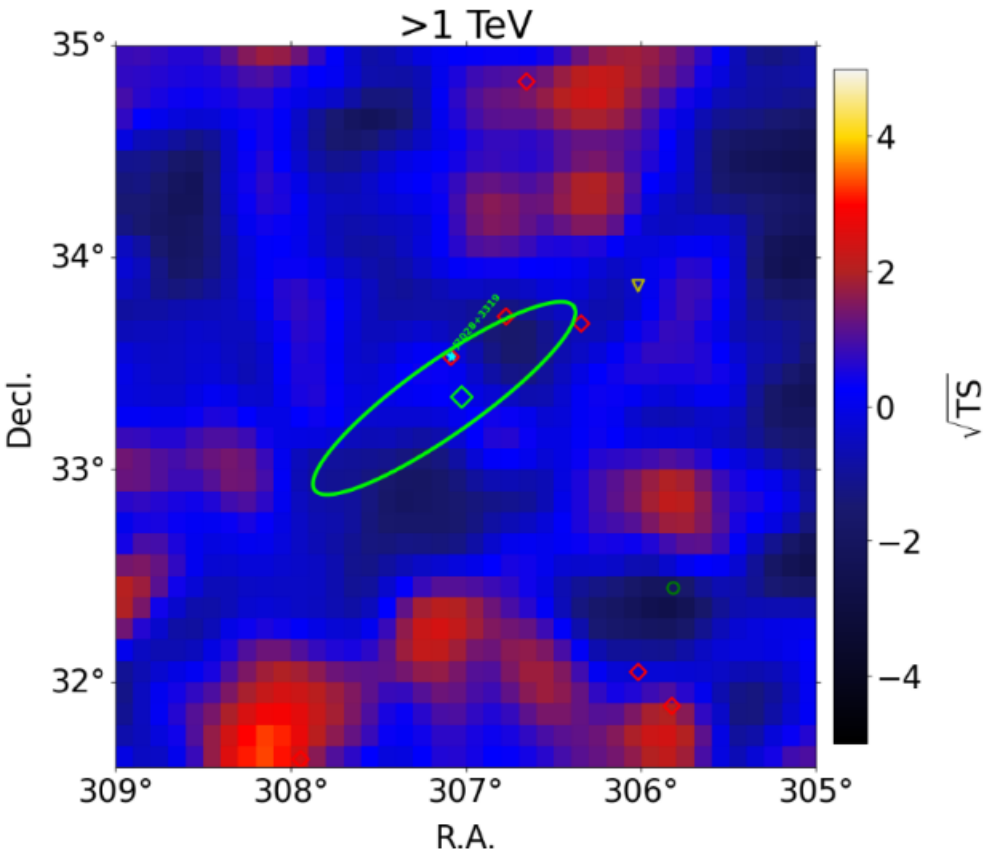
$\dot{E}$ = 3.48e + 34erg/s

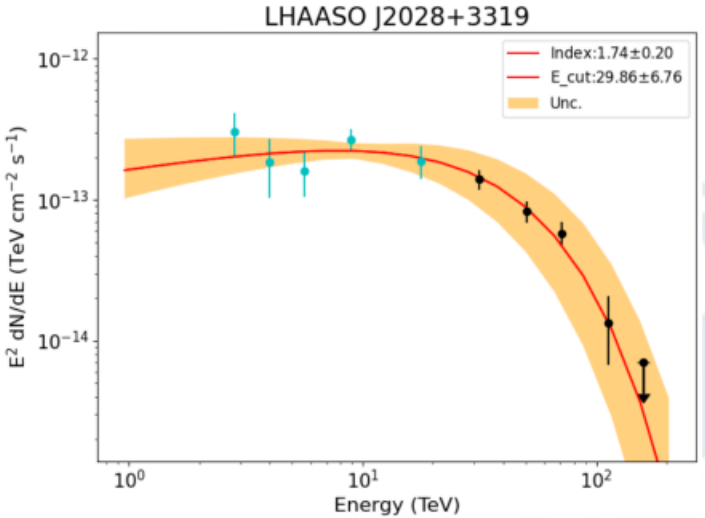
τ_c = 5.76e + 05yr



Template	Extension	RA	DEC	TS	Loglike
Gaussian	0.317±0.013	307.079±0.060	33.362±0.045	155.3	−660.233
halo	0.921±0.206	307.089±0.044	33.348±0.036	165.5	−664.070
Ellipse gaussian	a=0.499 b=0.114	307.126±0.062	33.339±0.042	180.9	−673.095
Ellipse diffusion	a = 2.10 b = 0.30	307.126	33.339	177.3	−671.253

LHAASO data analysis

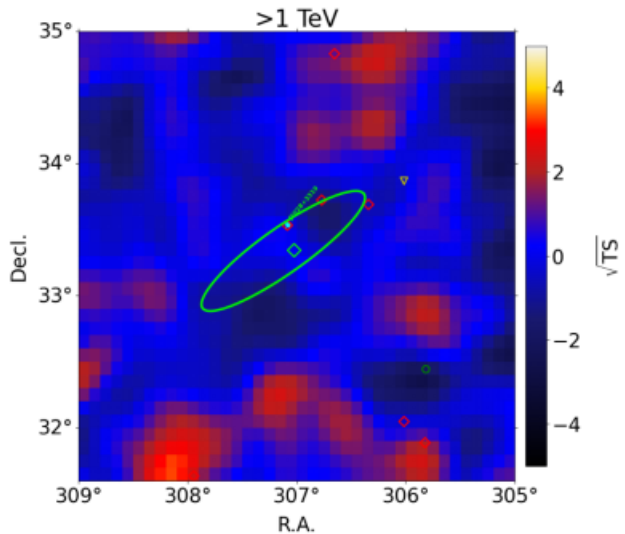


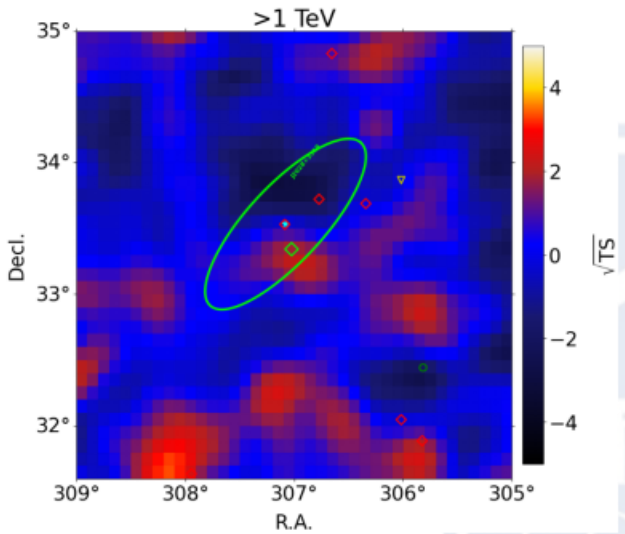


$$\mathrm{RA} = 307.126° \pm 0.062°$$
$$\mathrm{DEC} = 33.339° \pm 0.042°$$
$$a\_deg = 0.499° \pm 0.064°$$
$$b/a = 0.228° \pm 0.104°$$
$$\alpha = 34.906° \pm 5.674°$$
$$index = 1.738 \pm 0.197$$
$$E\_cut = 29.864 \pm 6.757\ \mathrm{TeV}$$

LHAASO data analysis

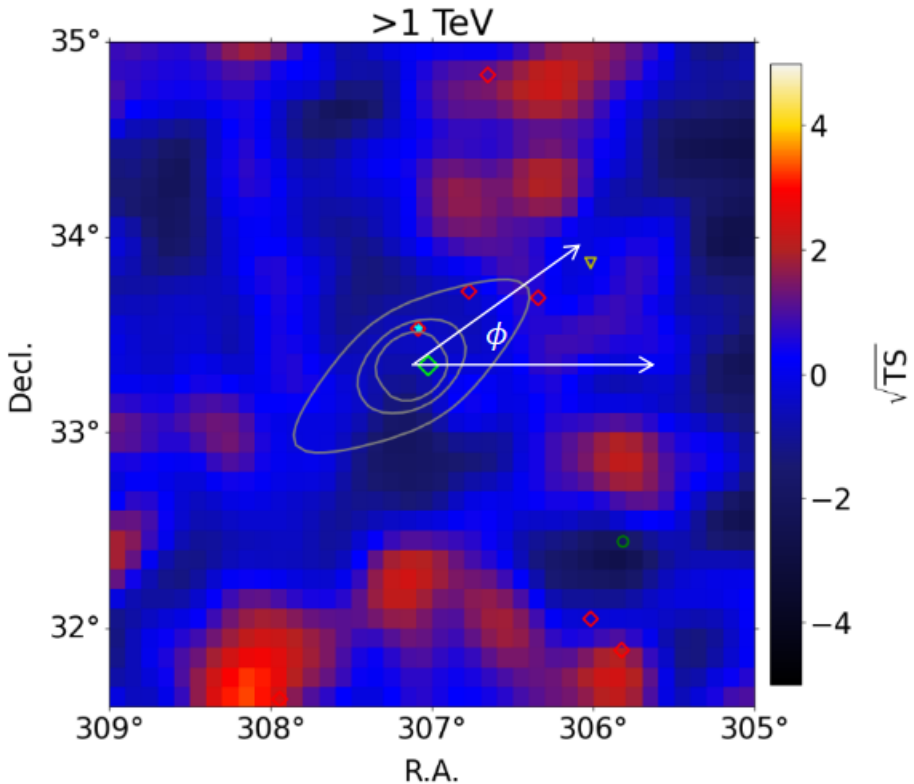
$offset{\sim}0.2°$





	RA	*DEC*	*TS*	*Loglike*
Ellipse gaussian (PSR)	307.083	33.535	161.5	−662.191
Ellipse gaussian	307.126	33.339	180.9	−673.095

LHAASO data analysis



$$f(\theta) = \frac{C}{\theta_a \sqrt{e}\,(\theta + 0.085\theta_d)}\, e^{-1.54(\theta/\theta_d)^{1.52}}$$

$$A = atan2\left(\frac{y - y_0}{(x - x_0)\cos(y_0)}\right)$$

$$B = atan2\left(\frac{\frac{\sin(A-\phi)}{e}}{\sin(A-\phi)}\right)$$

$$\theta_d = \sqrt{\theta_a^2 \cos^2(B) + \theta_a^2 e^2 \sin^2(B)}$$

$$\theta_a = 0.3$$

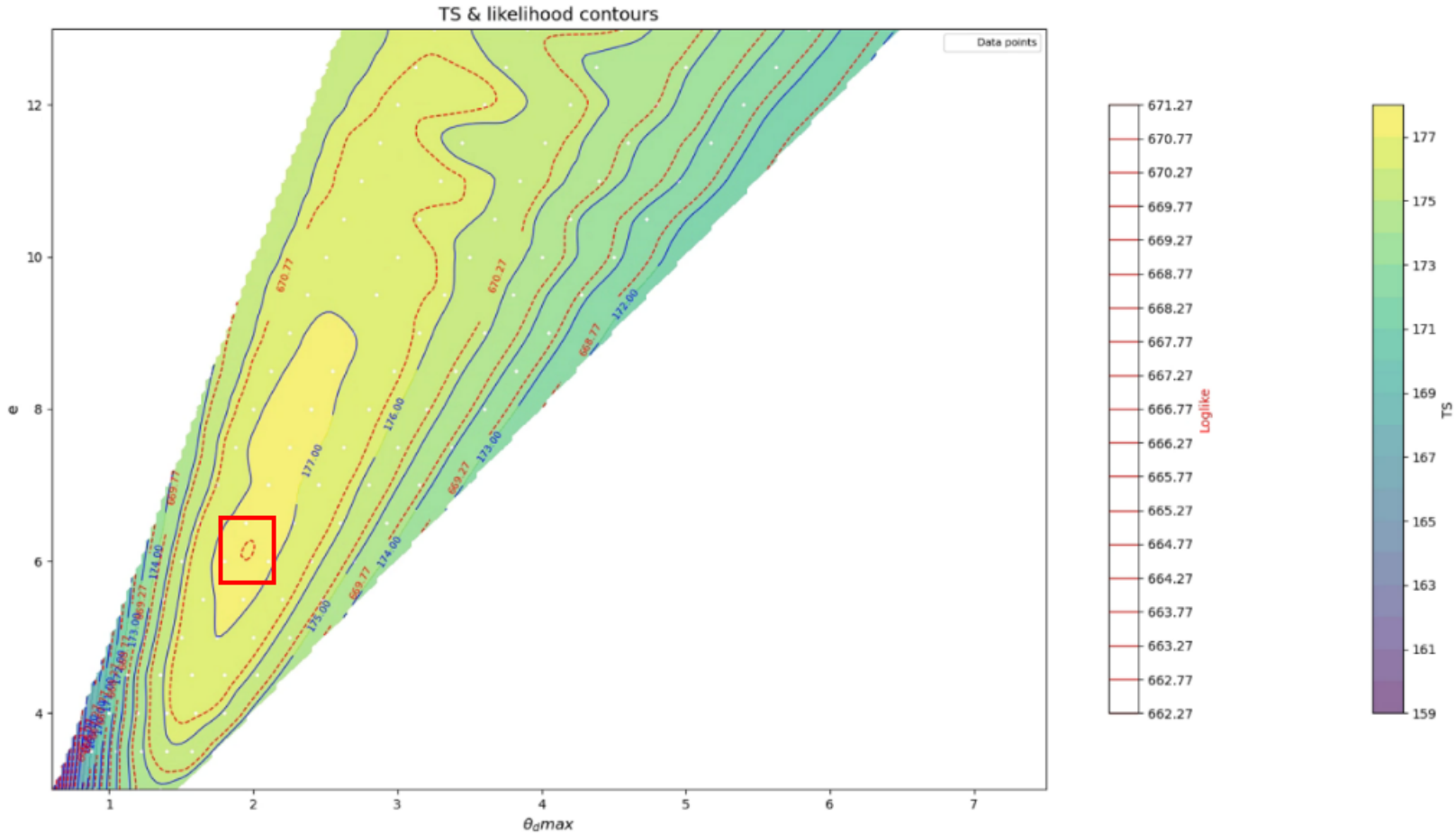
$$e = a/b = 7.0$$

$$\phi = 34.0°$$

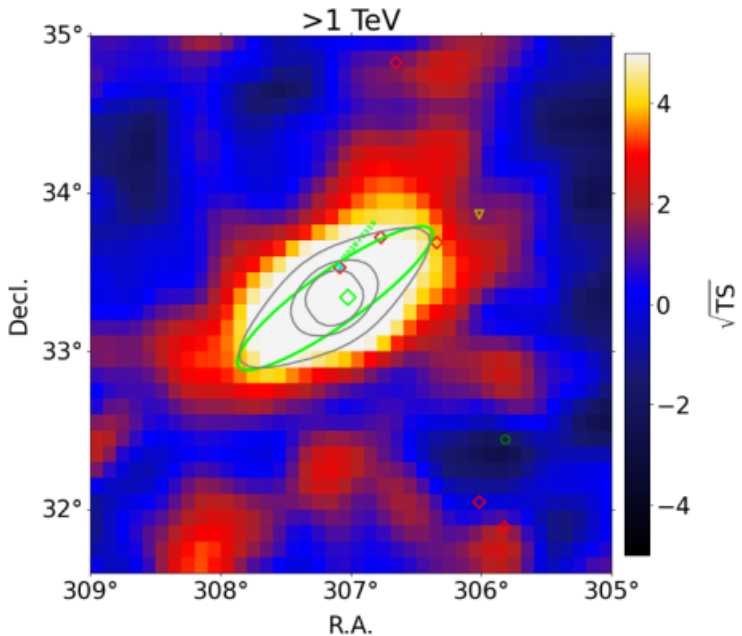
$$RA = 307.126$$

$$DEC = 33.339$$

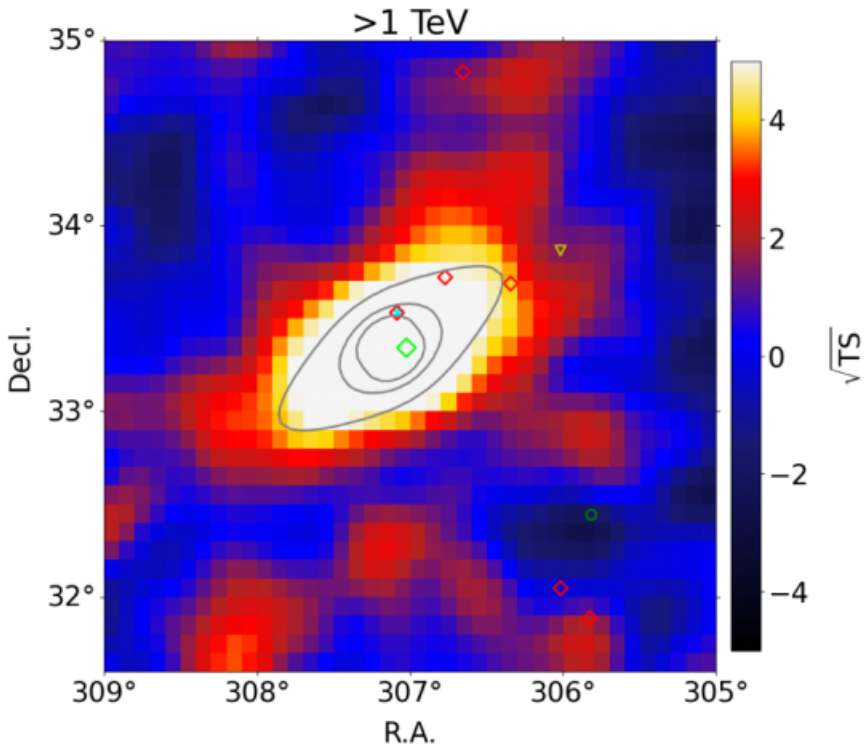
LHAASO data analysis



LHAASO data analysis



	gaussian model	*diffsion model*
RA	307.126 ± 0.062	307.126
DEC	33.339 ± 0.042	33.339
a_deg	0.499 ± 0.064	$2.10^{+1.50}_{-0.60}$
b/a	0.228 ± 0.104	$0.14^{+0.11}_{-0.05}$
α	34.906 ± 5.674	35^{+10}_{-12}



$$\theta_a = 0.30°$$

$$\theta_{dmax} = 2.10°$$

$$d = 0.76kpc$$

$$E_\gamma: 1 - 160TeV(30TeV)$$

$$E_e \approx 100TeV$$

$$\theta_d * d = 2\sqrt{Dt_{cool}}$$

$$D_{\theta_d}(100TeV) = 8.53 \times 10^{27}(\frac{d}{0.76kpc})^2 cm^2/s$$

$$D_{\theta_a}(100TeV) = 1.74 \times 10^{26}(\frac{d}{0.76kpc})^2 cm^2/s$$

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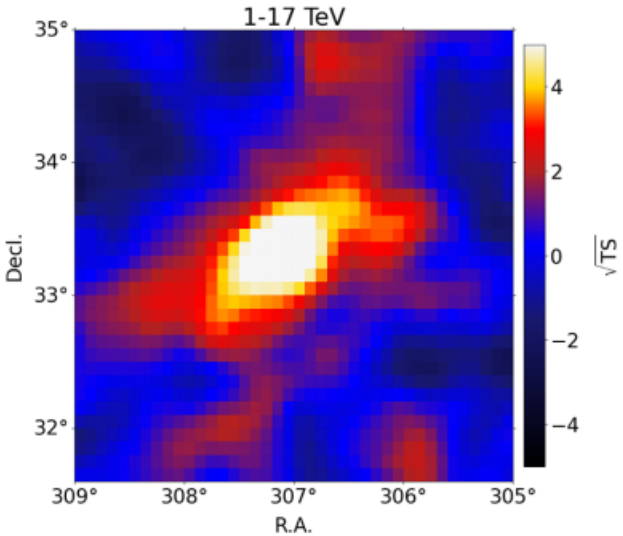
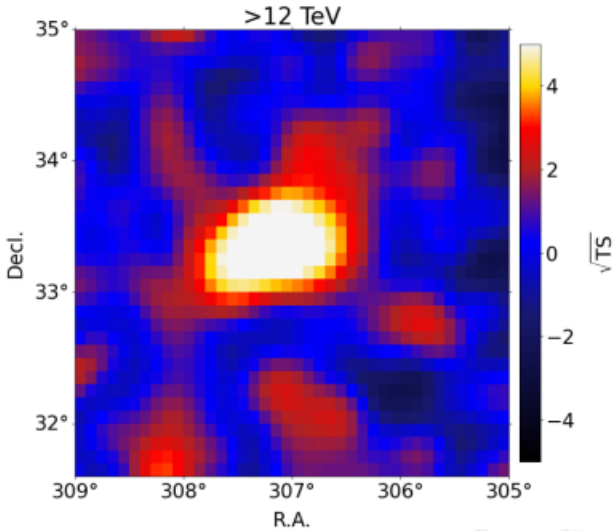
Name	$P(s)$	$\dot{P}(10^{-14} s\ s^{-1})$	$L_{sd}(10^{34} erg\ s^{-1})$	$\tau_c(kyr)$	$d(kpc)$
Geminga	0.237	1.098	3.3	342	0.25
Monogem	0.385	5.499	3.8	110	0.29
J0248+6021	0.217	5.509	21.3	62.4	2.00
J0622+3749	0.333	2.542	2.7	207.8	1.60
J2028+3352	0.177	0.486	3.5	576	0.76

Name	diffusion coefficient($10^{27} cm^2 s^{-1}$)
Geminga(100TeV)	$3.2(d/0.25kpc)^2$
Monogem(100TeV)	$15(d/0.29kpc)^2$
J0248+6021(160TeV)	$20.0(d/2.0kpc)^2$
J0622+3749(160TeV)	$8.9(d/1.6kpc)^2$
J2028+3352(100TeV)	$D_{\theta_{dmax}} = 8.5(d/0.76kpc)^2$ $D_{\theta_a} = 0.174(d/0.76kpc)^2$

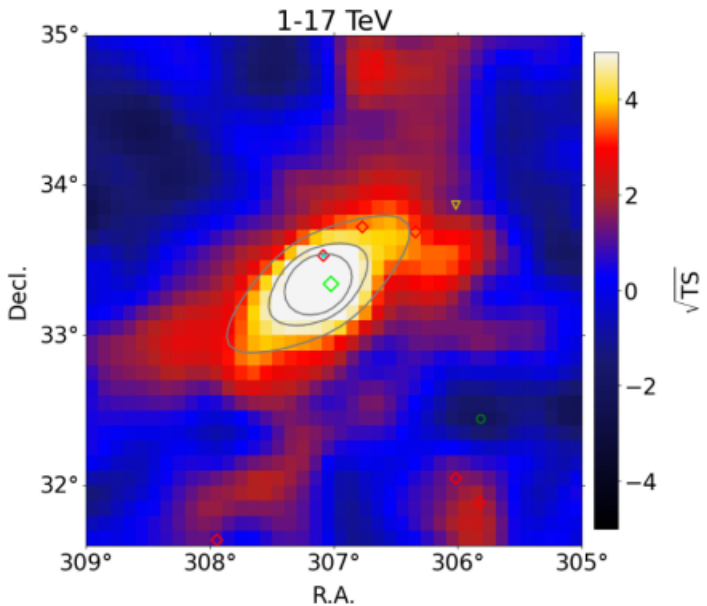
LHAASO data analysis

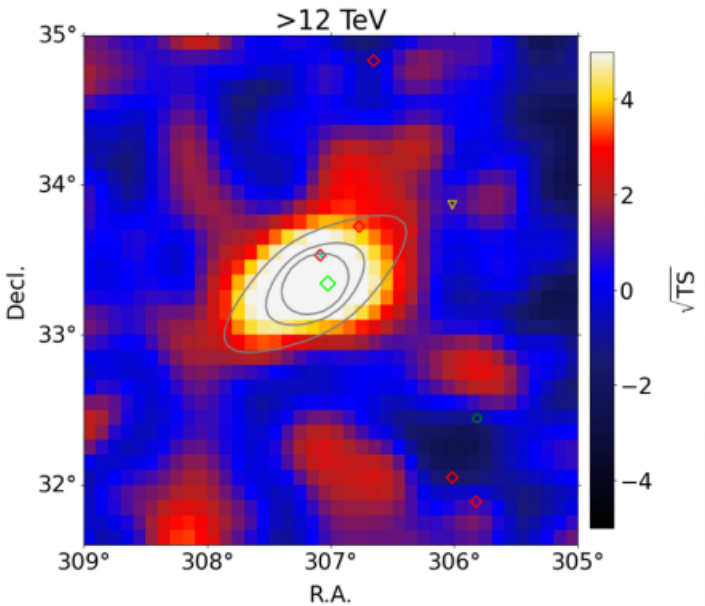




		RA	*DEC*	*major axis*	*TS*	*Loglike*
WCDA	Ellipse gaussian(fix)	307.126 ± 0.062	33.339 ± 0.042	0.499 ± 0.064	70.8	-380.12
	Ellipse gaussian	307.125 ± 0.095	33.342 ± 0.079	0.538 ± 0.099	72.7	-380.95
KM2A	Ellipse gaussian(fix)	307.126 ± 0.062	33.339 ± 0.042	0.499 ± 0.064	100.8	-299.89
	Ellipse gaussian	307.125 ± 0.082	33.349 ± 0.053	0.461 ± 0.076	101.4	-300.22

LHAASO data analysis





	RA	DEC	θ_{dmax}	b/a	α
$WCDA$	307.1260	33.3392	$2.70^{+2.60}_{-1.20}$	$0.10^{+0.12}_{-0.03}$	35.0 ± 5.0
$KM2A$	307.1260	33.3392	$1.60^{+1.40}_{-0.40}$	$0.20^{+0.08}_{-0.11}$	35.0 ± 5.0

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Part Ⅲ

Summary

Summary

- LHAASO J2028+3352 can be described with an elliptical gauss or an elliptical diffusion model
- The estimation of diffusion coefficients of the major axes is consistent with expectations for the pulsar halo
- The current data can not confirm the source is energy-dependent or not

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Thanks for listening!