

Origin of Galactic Cosmic Rays

Siming Liu

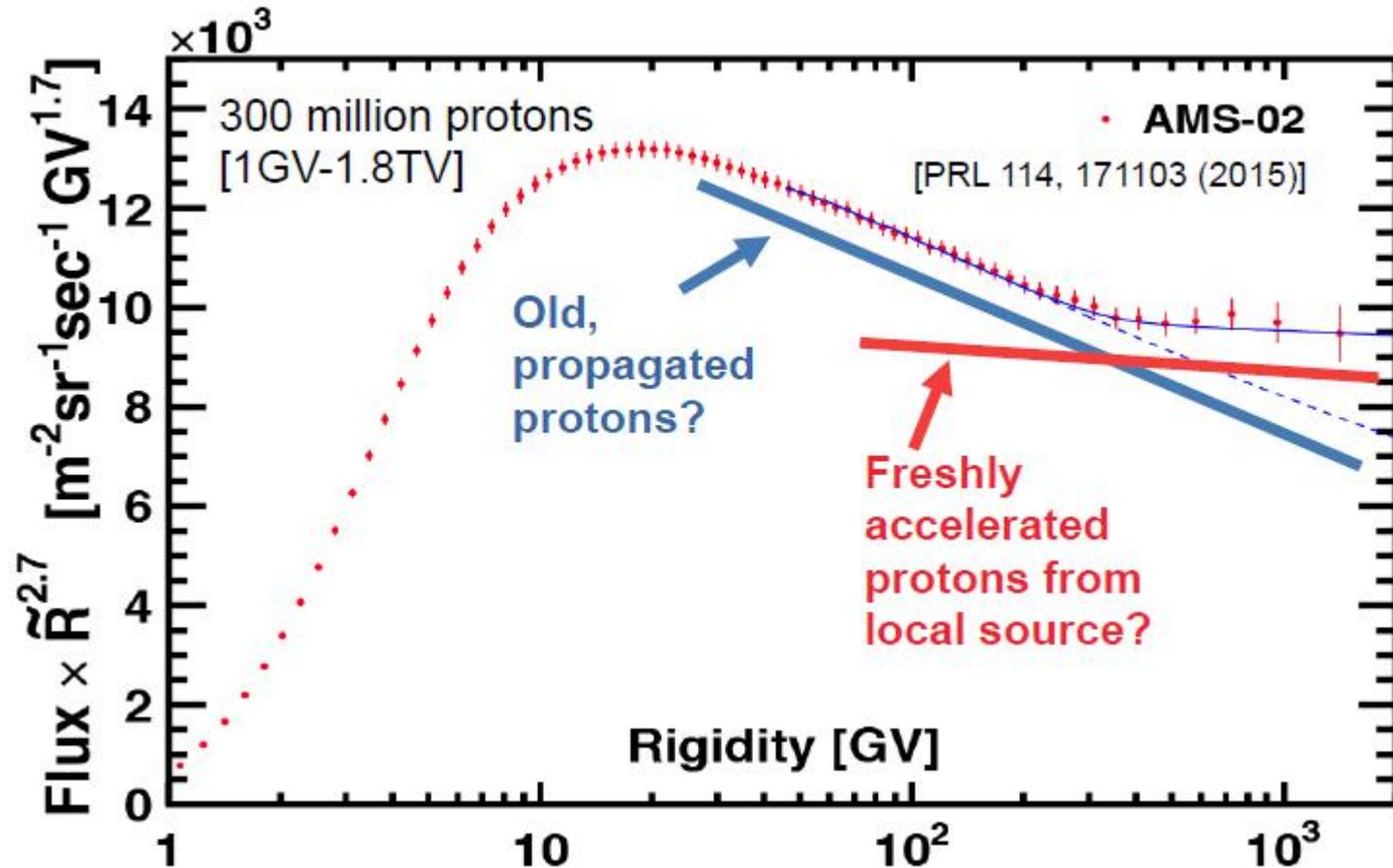
on behalf of team 3 on CR studies

The second LHAASO conference 2019, Zhuhai

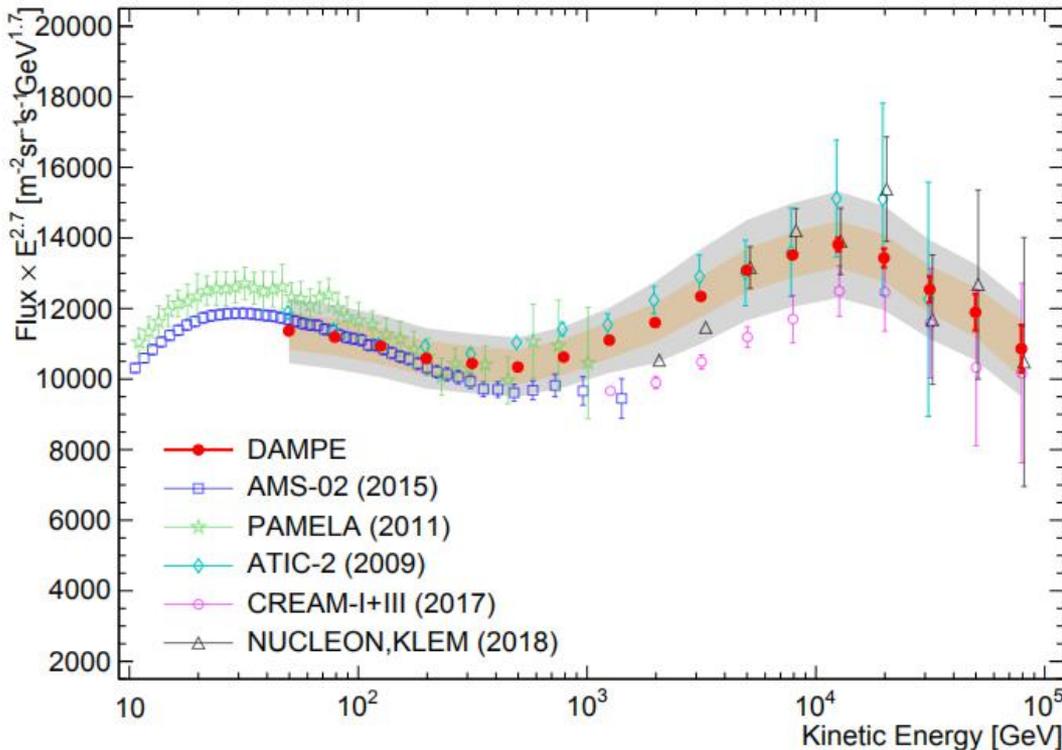
Outline

- 1. Nearby Sources, Isotropy, and PeV spectra**
- 2. Injection and Propagation of GeV Cosmic Rays**
- 3. Hadronic TeV Sources**

1: A Consensus



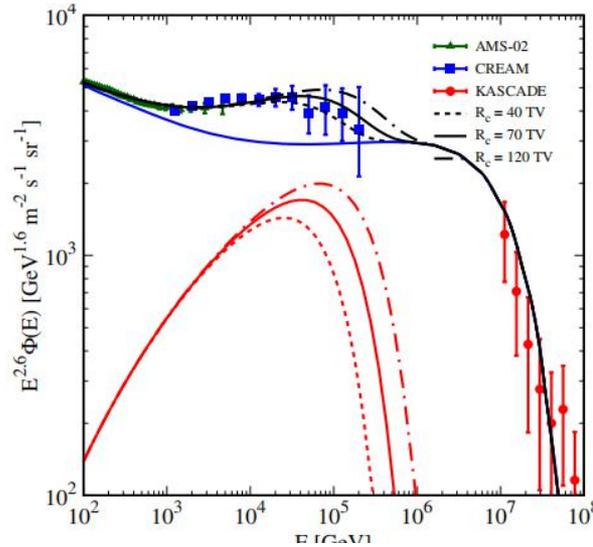
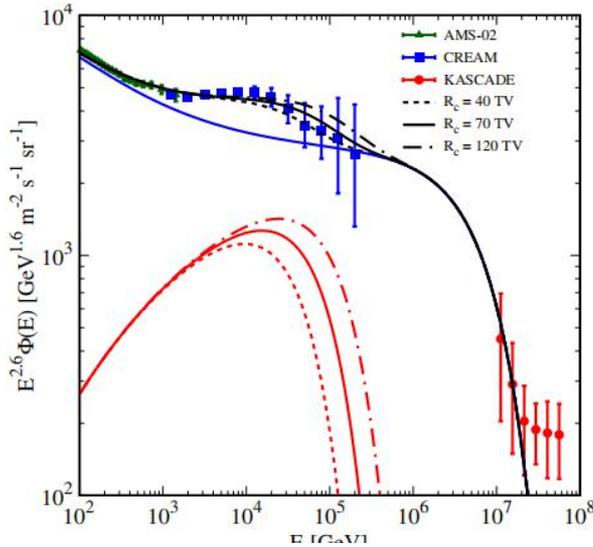
1: Proton Spectrum of DAMPE



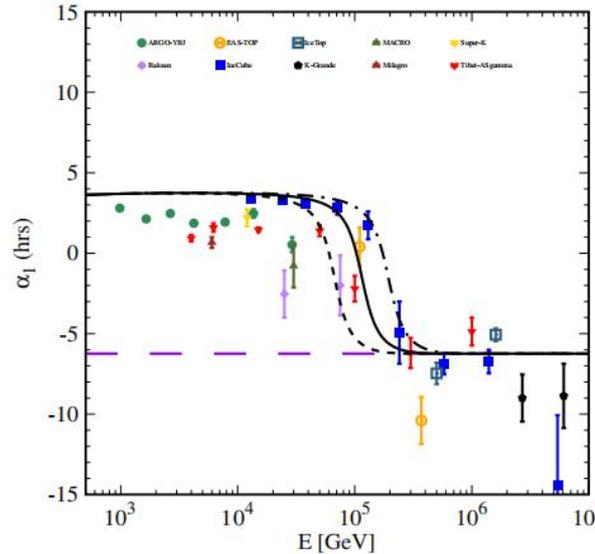
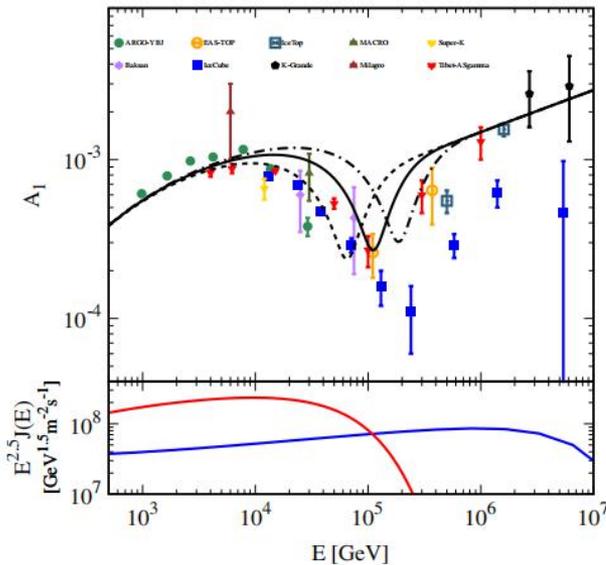
$$F(E) = F_0 \left(\frac{E}{\text{TeV}} \right)^{-\gamma} \left[1 + \left(\frac{E}{E_b} \right)^s \right]^{\Delta\gamma/s}$$

model compared with the PL model. The fit of the SBPL model gives $F_0 = (8.68^{+0.50}_{-0.45}) \times 10^{-5} \text{ GeV}^{-1} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, $\gamma = 2.60 \pm 0.01$, $E_b = 13.6^{+4.1}_{-4.8} \text{ TeV}$, and $\Delta\gamma = -0.25 \pm 0.07$. The comparison of the best-fit spectrum (11). The fitting model parameters are $F_0 = (7.58^{+0.36}_{-0.31}) \times 10^{-5} \text{ GeV}^{-1} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, $\gamma = 2.772 \pm 0.002$, $E_b = 0.48 \pm 0.01 \text{ TeV}$, and $\Delta\gamma = 0.173 \pm 0.007$. As comparisons, the fit to the PAMELA data (10)

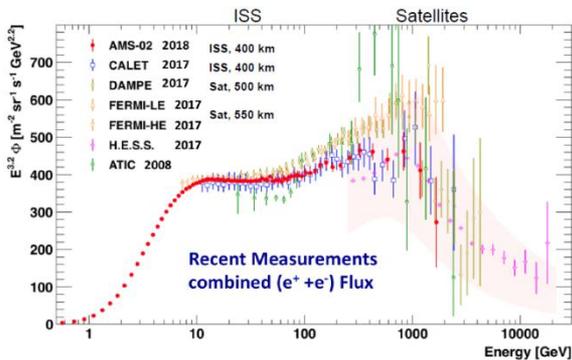
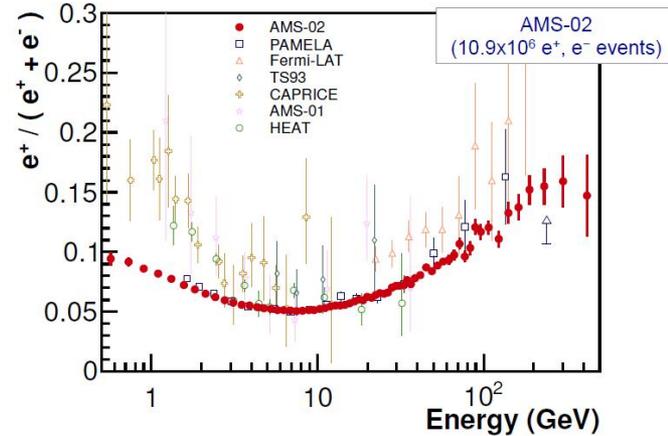
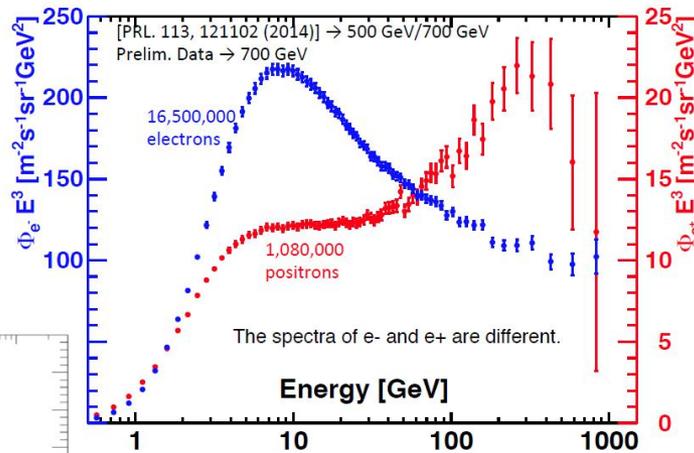
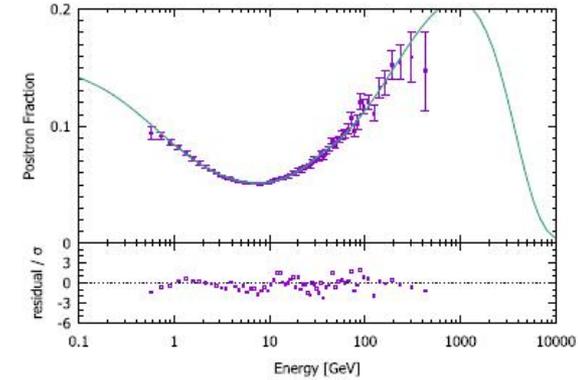
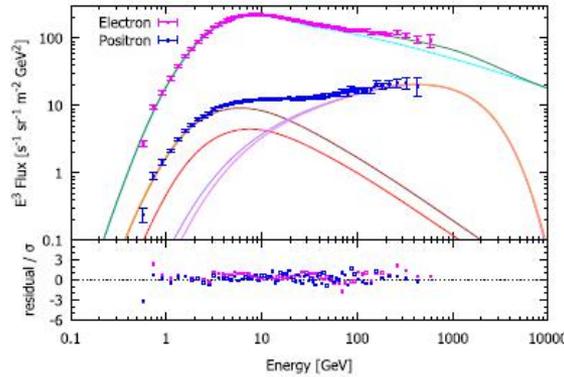
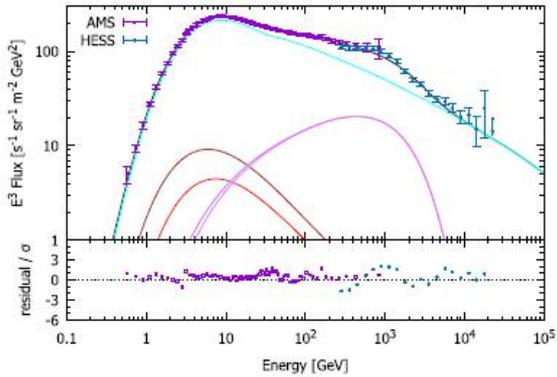
1: Spectrum and Isotropy



- Geminga SNR gives rise to the TeV hump
- Will Geminga PWN contribute to electrons and positrons

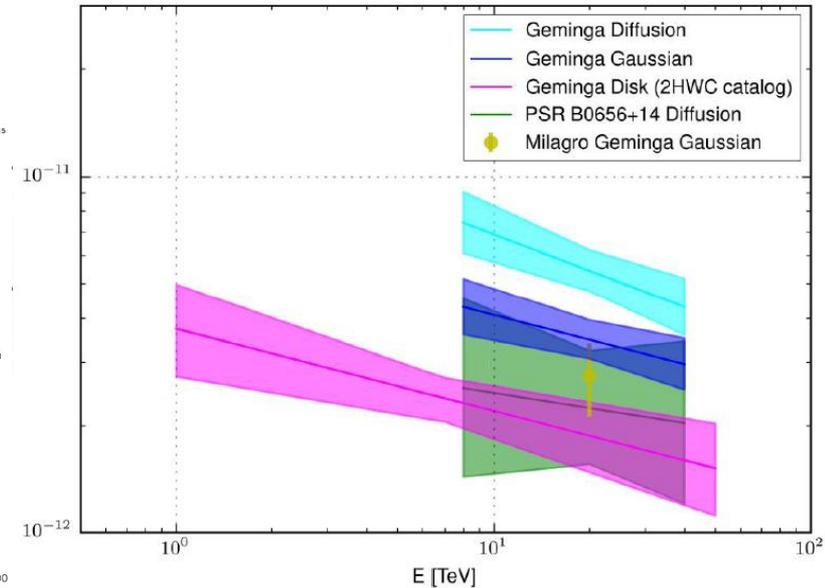
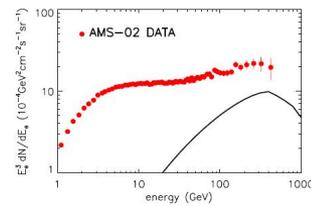
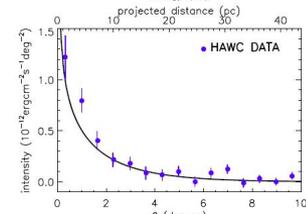
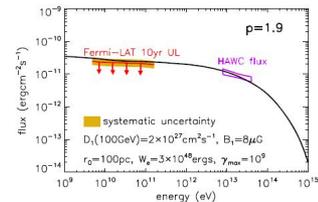
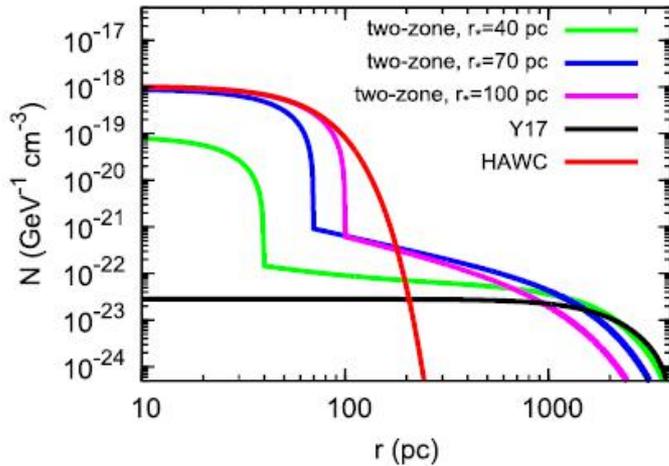
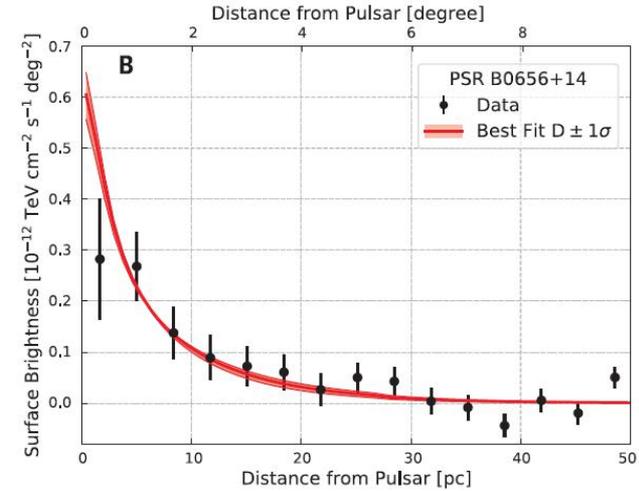
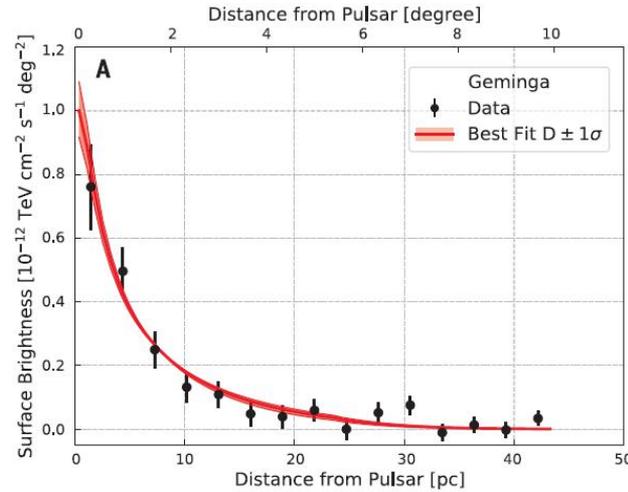
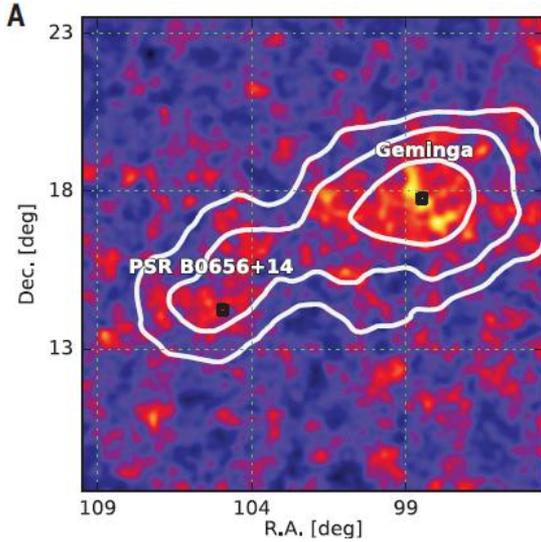


1: Electron and Positron Spectra



1: Geminga TeV Halo

340(110)kyr



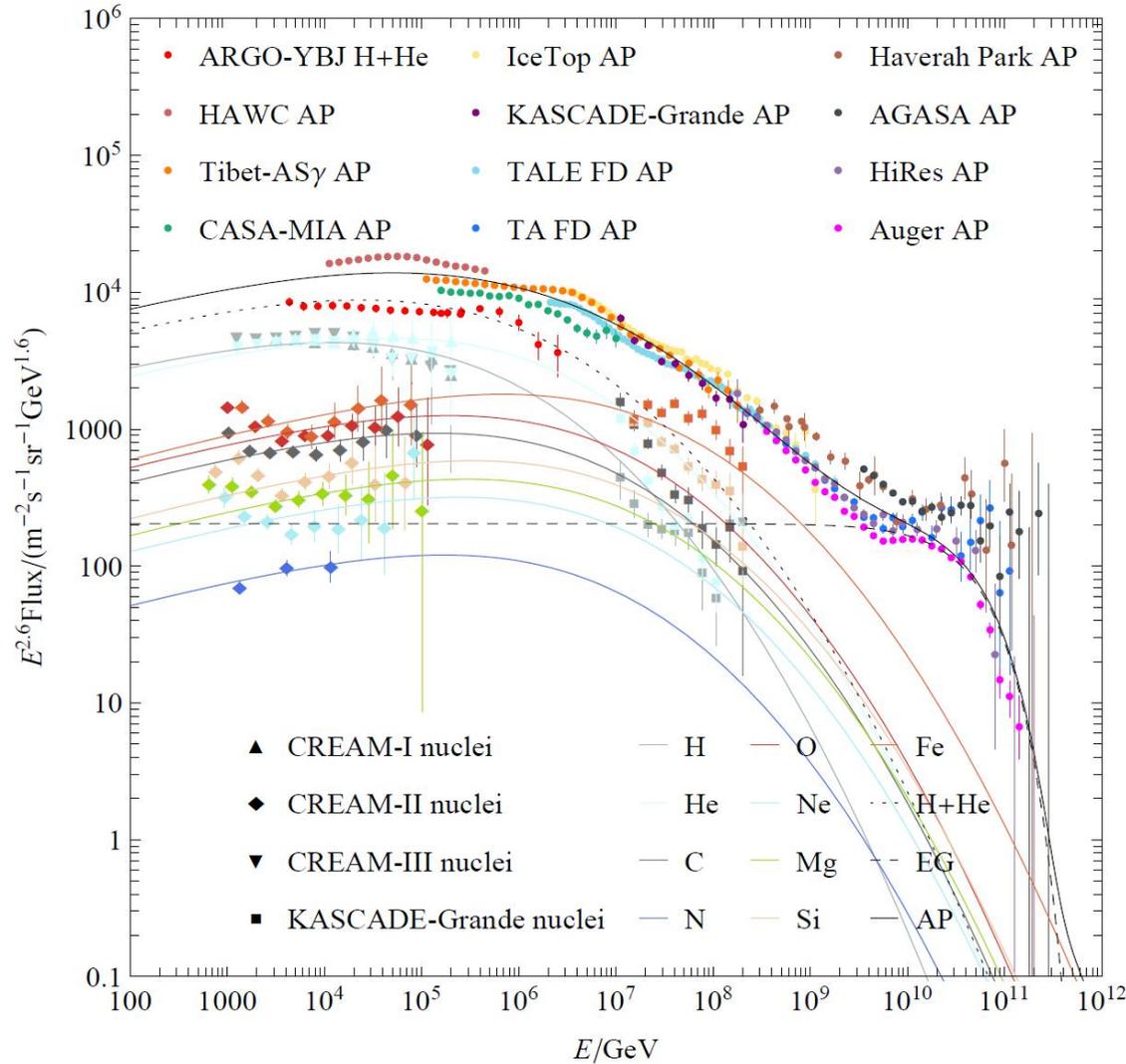
1: PeV Spectra

第60卷 第5期
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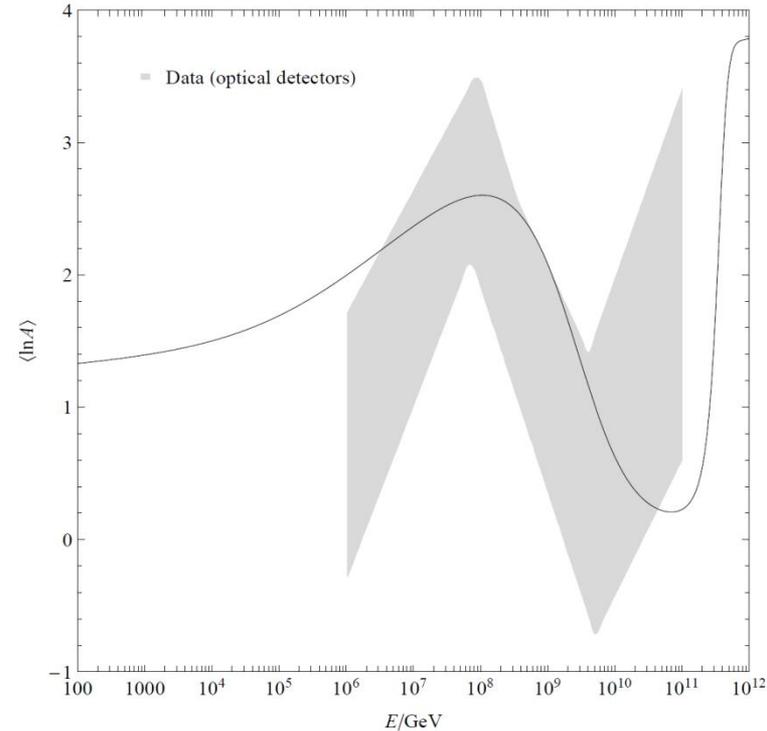
Vol.60 No.5
Sept., 2019

doi: 10.15940/j.cnki.0001-5245.2019.05.00x



宇宙线的超新星遗迹起源*

张轶然^{1,2†} 刘四明^{1,2†}



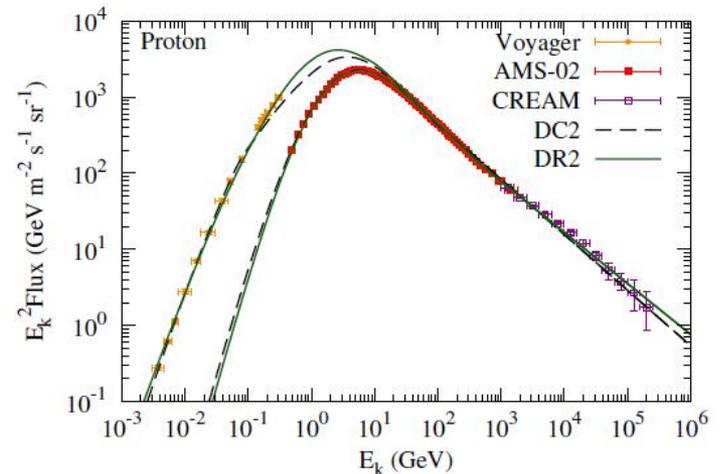
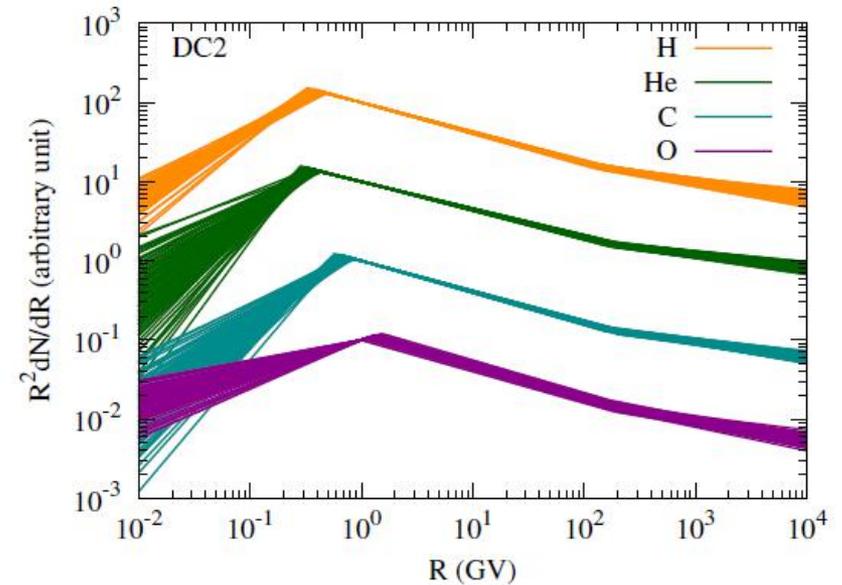
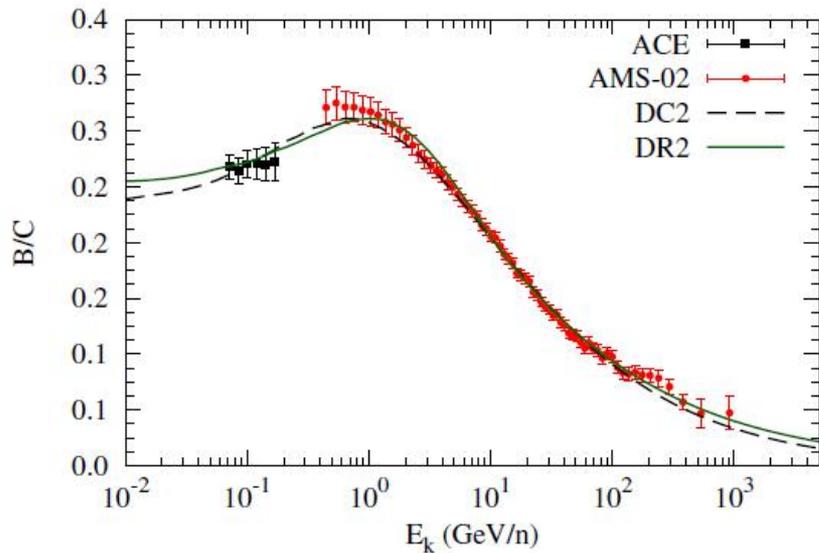
2: Injection and Propagation

Implications on cosmic ray injection and propagation parameters from Voyager/ACE/AMS-02 nucleus data

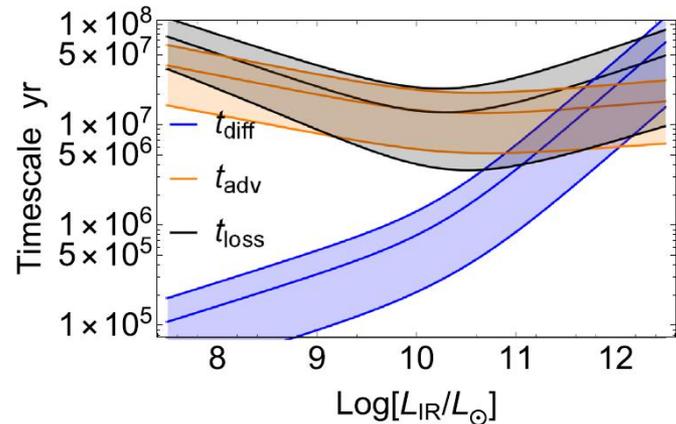
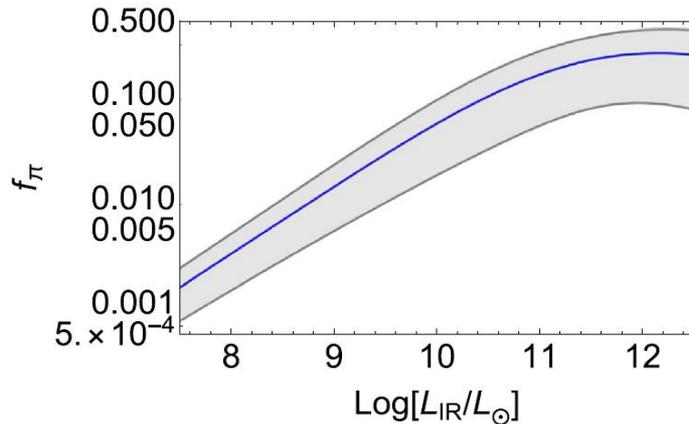
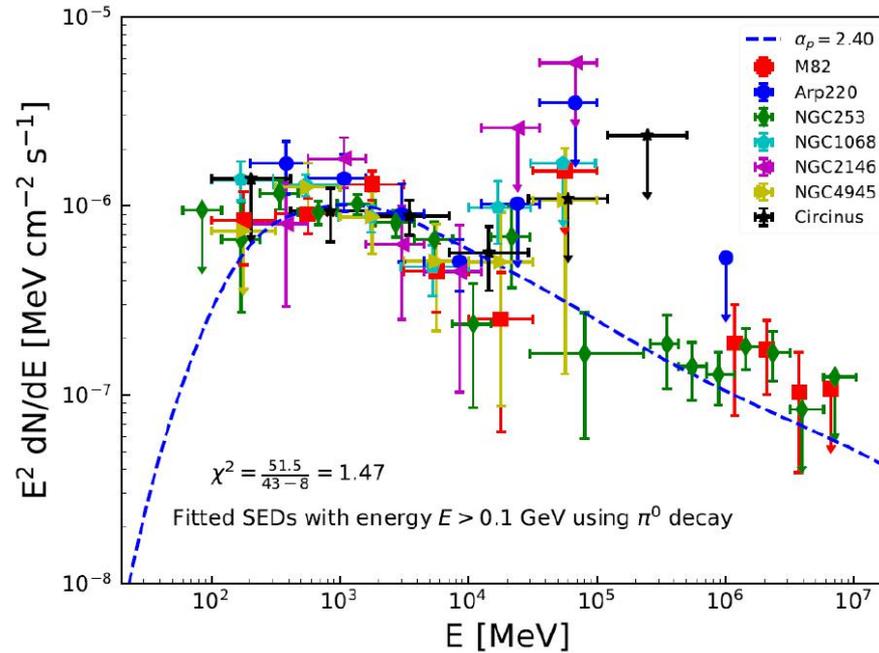
Qiang Yuan^{a,b,c*}

TABLE IV: Fitting parameters of the injection spectra.

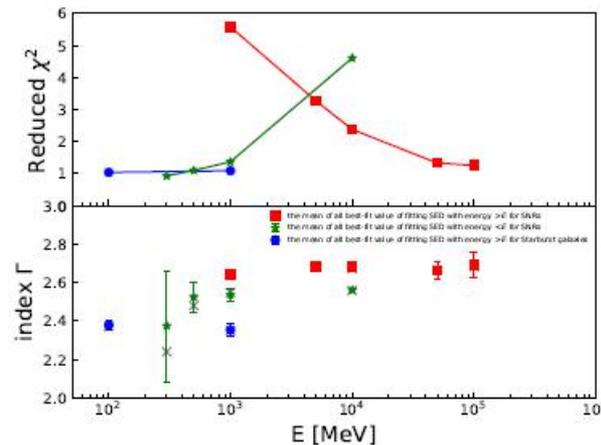
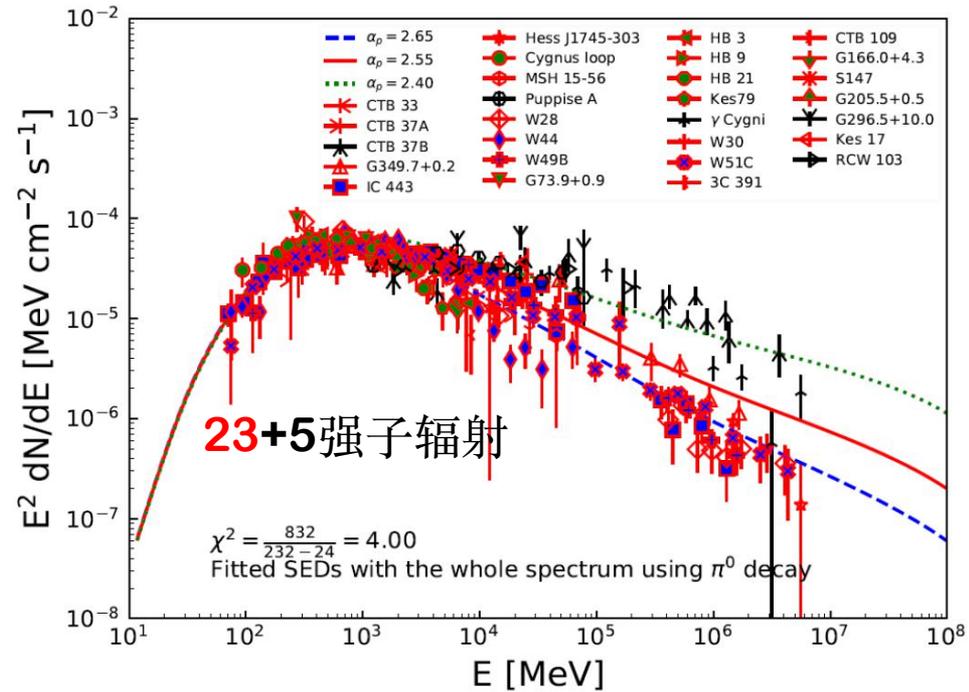
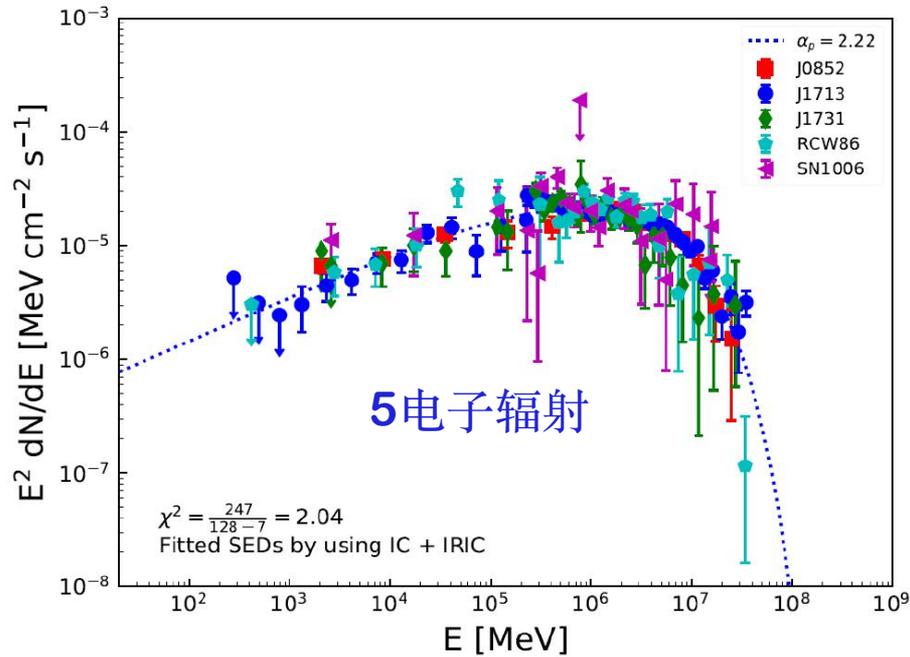
Para.	H	He	C	O
DC2 $X^\dagger (10^{-3})$	—	106.3 ± 1.5	3.77 ± 0.07	4.76 ± 0.12
ν_1	1.138 ± 0.097	0.857 ± 0.323	0.971 ± 0.206	1.580 ± 0.092
ν_2	2.379 ± 0.008	2.350 ± 0.008	2.390 ± 0.007	2.406 ± 0.008
ν_3	2.221 ± 0.021	2.167 ± 0.017	2.200 ± 0.023	2.230 ± 0.034
R_{br} (GV)	0.40 ± 0.03	0.35 ± 0.03	0.73 ± 0.06	1.25 ± 0.12
$R_{br,2}$ (GV)	136.4 ± 27.7	184.0 ± 20.4	173.1 ± 19.9	203.5 ± 33.0
Φ (GV)	0.480 ± 0.012	0.613 ± 0.016	0.727 ± 0.013	0.733 ± 0.014
$\chi^{2\ddagger}/\text{dof}$	591.0/92	205.2/89	24.6/81	25.4/81



2: Star Burst Galaxies

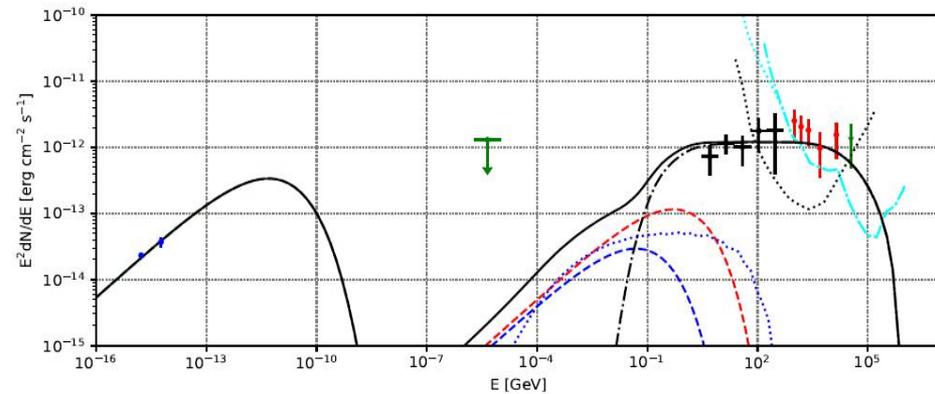
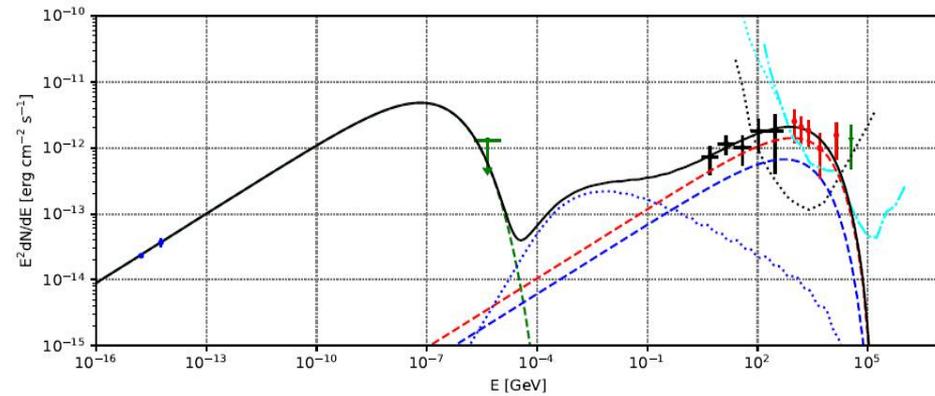
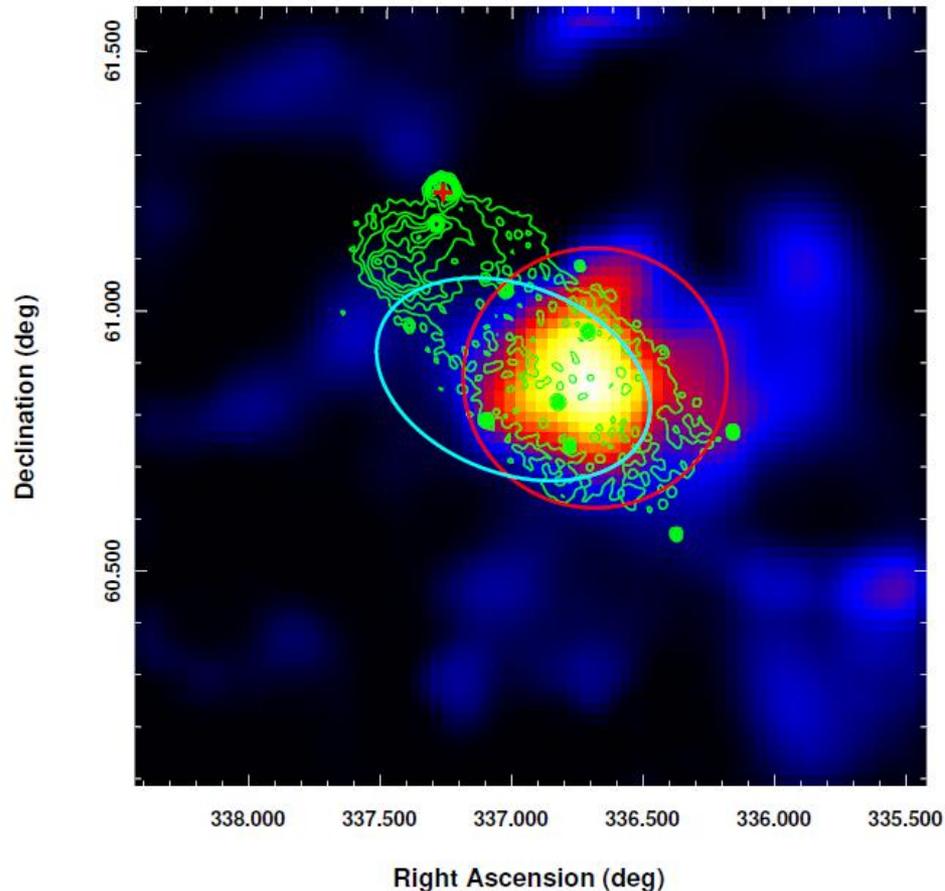


2: Injection of Cosmic Rays



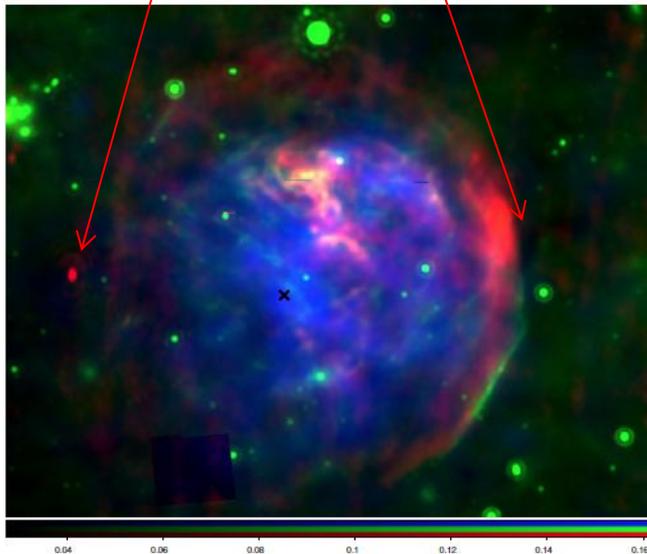
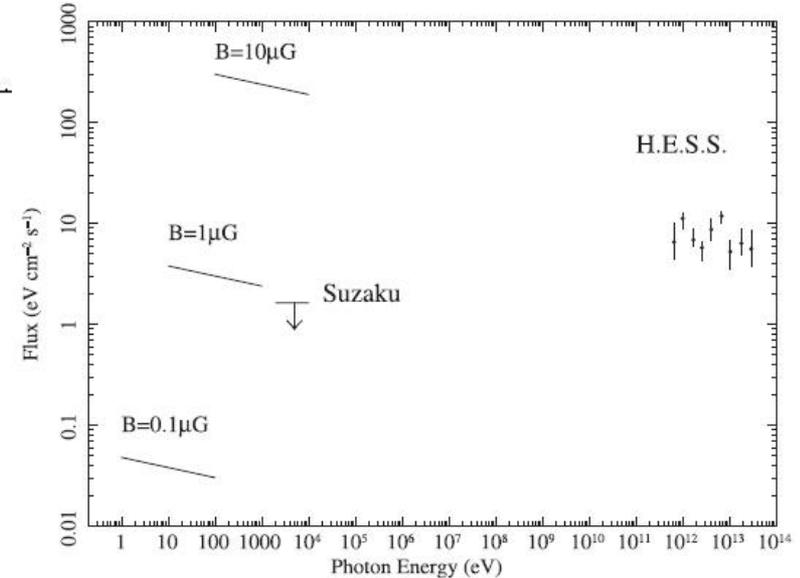
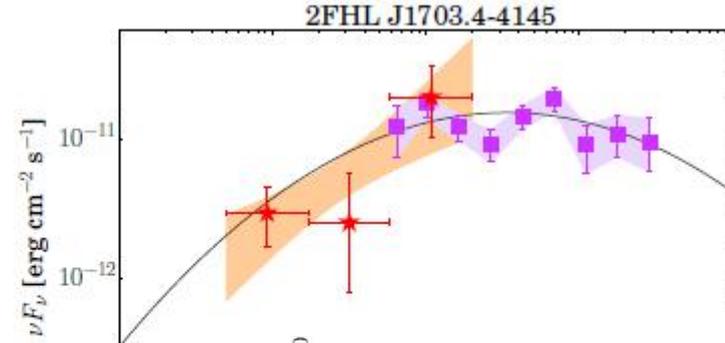
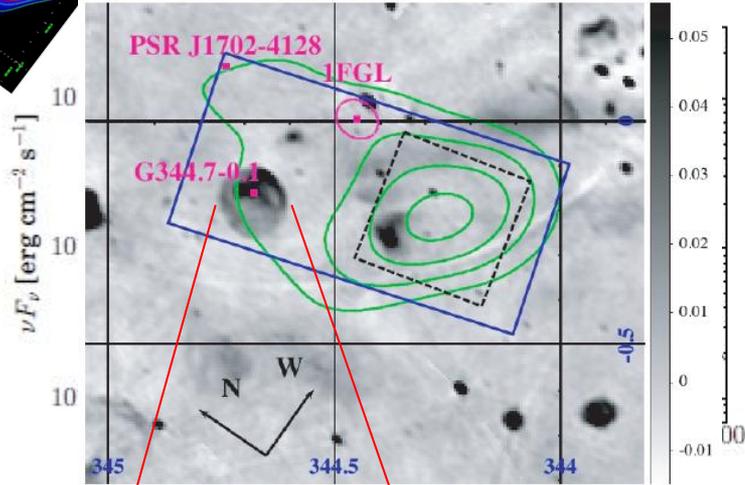
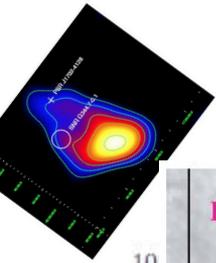
3: VER J2227+608:A Hadronic TeV Source?

10kyr [arXiv:1907.04972](https://arxiv.org/abs/1907.04972)



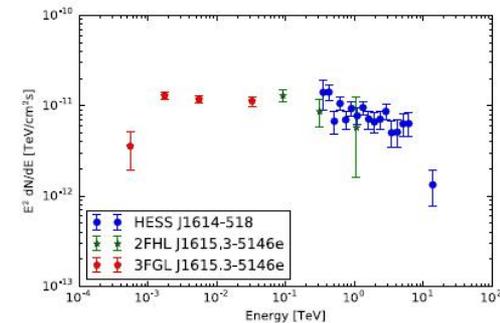
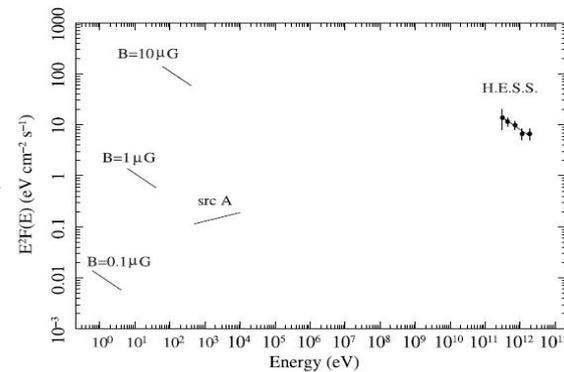
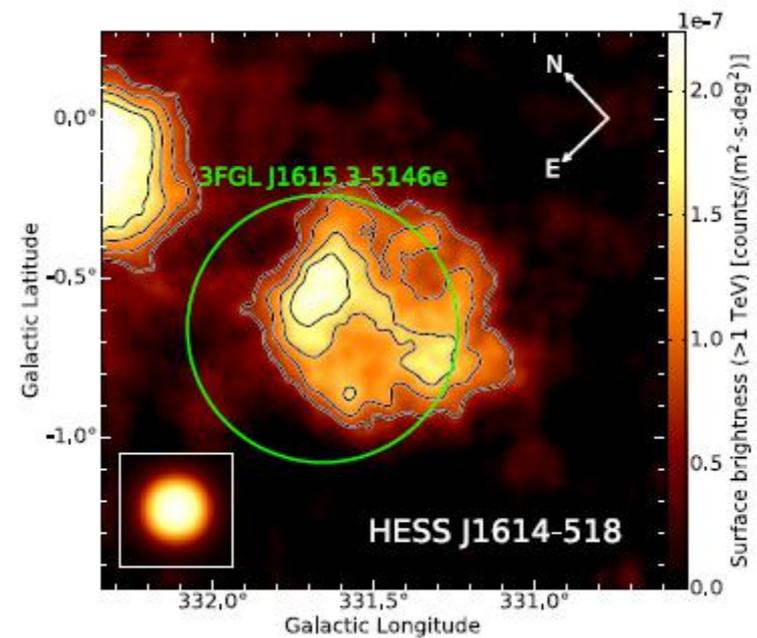
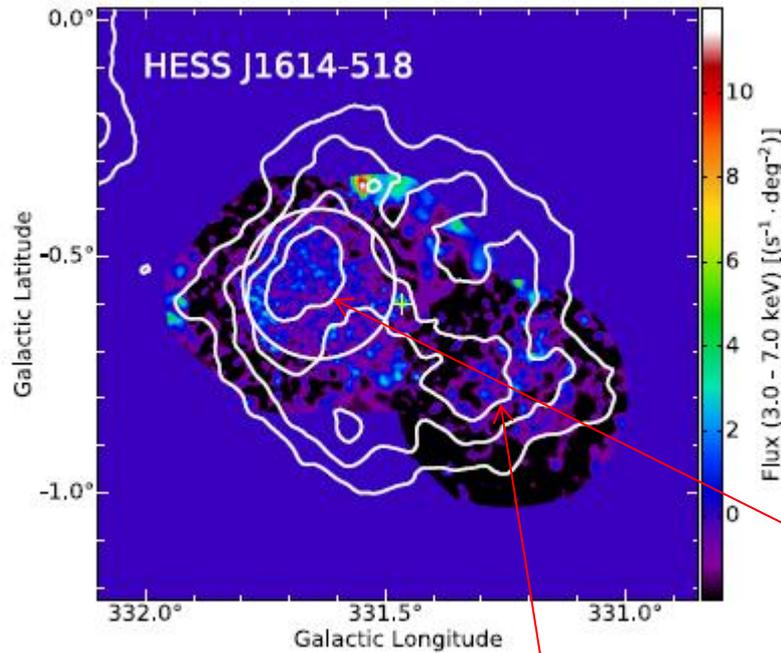
3: HESS J1702-420

55kyr



PSR J1702–4128, with an estimated age of ~ 55 kyr (Kramer et al. 2003), is located on the outskirts of the TeV source near the

3: HESS J1614



with Suzaku. There was no positive detection at the 2nd peak position, and we set an upper limit of 1.6×10^{-13} erg cm⁻² s⁻¹ to the 2–10 keV band flux. The high value of $f_{\text{TeV}}/f_X \sim 34$ may suggest that HESS J1614 is a proton accelerator. We

Conclusions

The Injection spectrum of GeV CR is consistent with a power-law with an index of 2.4.

The TeV spectral bump is likely caused by a nearby source, e.g. Geminga, which may also contribute to the electron and positron excess.

There is evidence that some of the extended TeV sources may have a hadronic origin and therefore are PeVtrons. Observations in the PeV range will be able to distinguish different models.

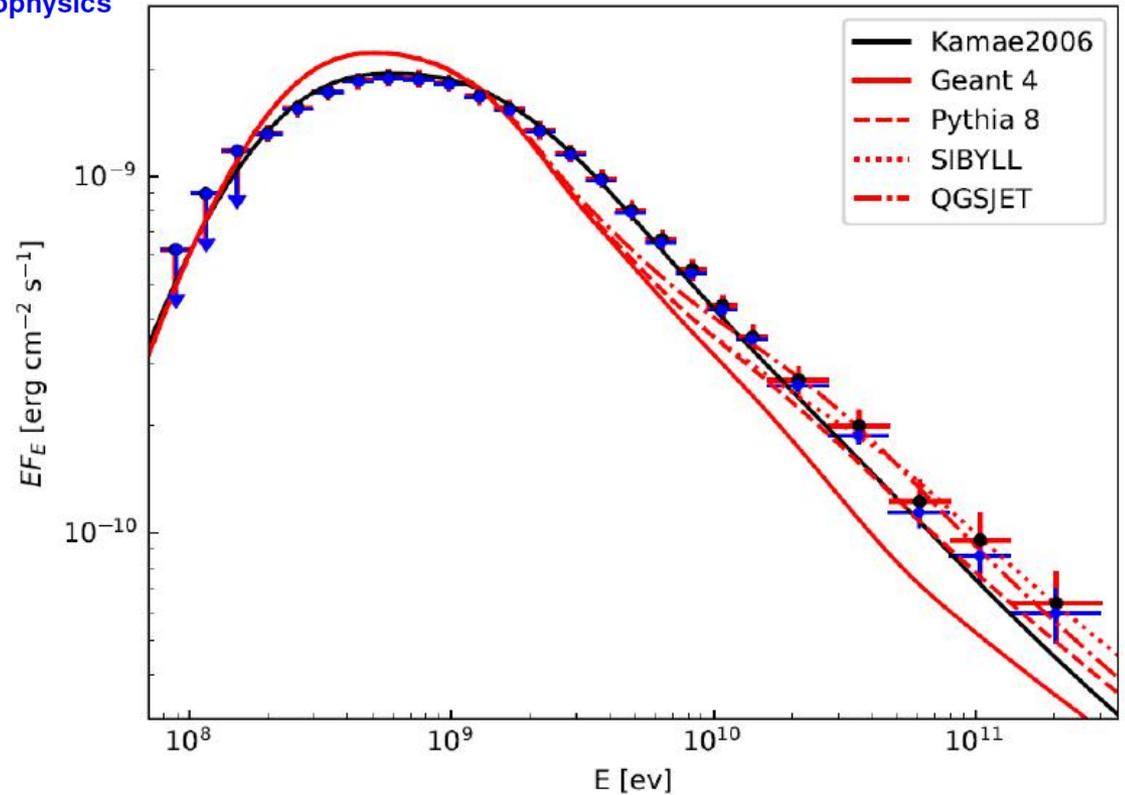
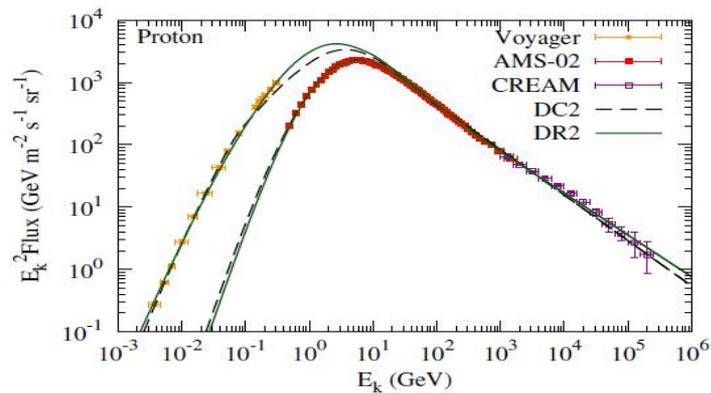
2: Gamma-Ray from Molecular Clouds

A&A 606, A22 (2017)
DOI: 10.1051/0004-6361/201731149
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Cosmic-ray spectrum in the local Galaxy

Andrii Neronov¹, Denys Malyshev², and Dmitri V. Semikoz^{3,4}



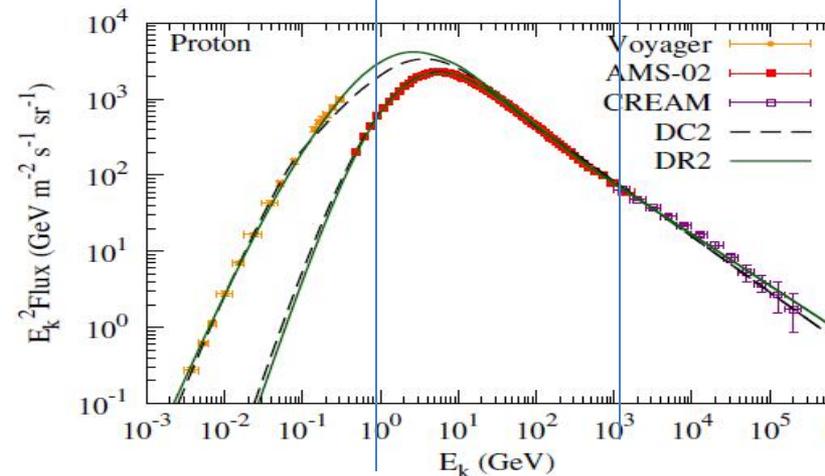
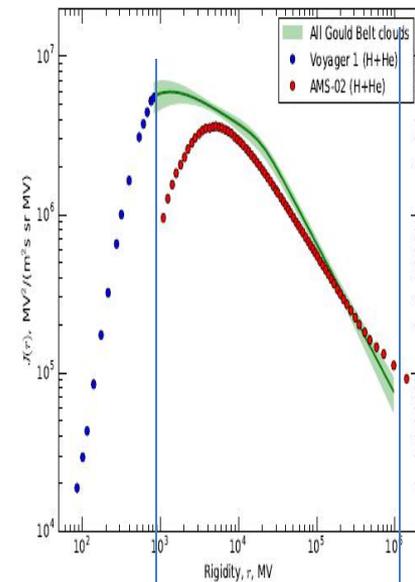
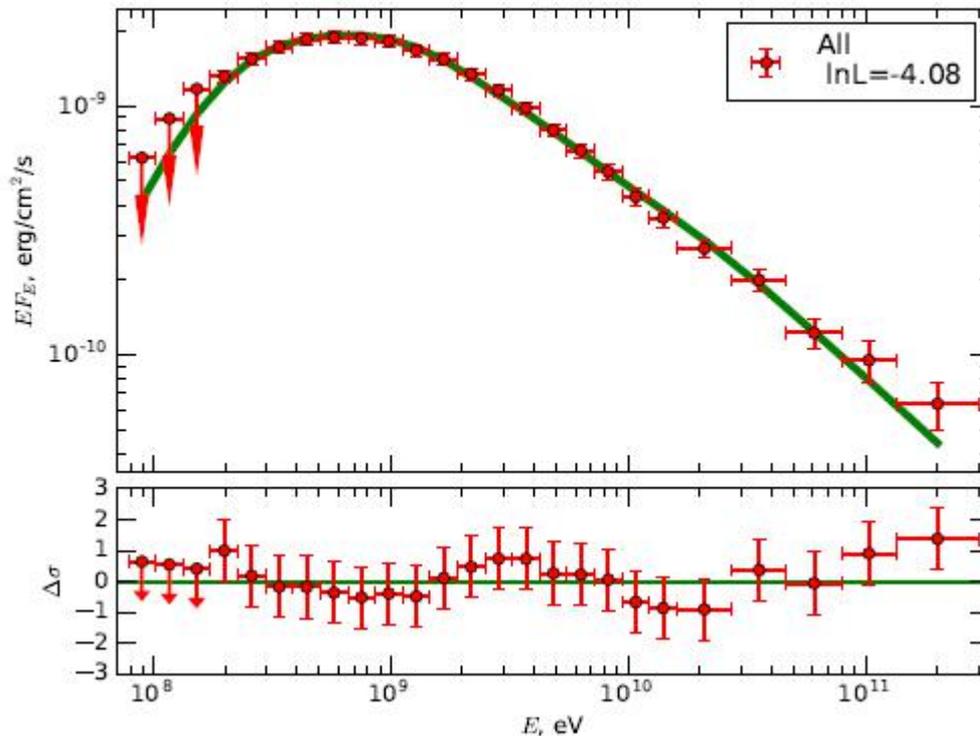
2: Gamma-Ray from Molecular Clouds

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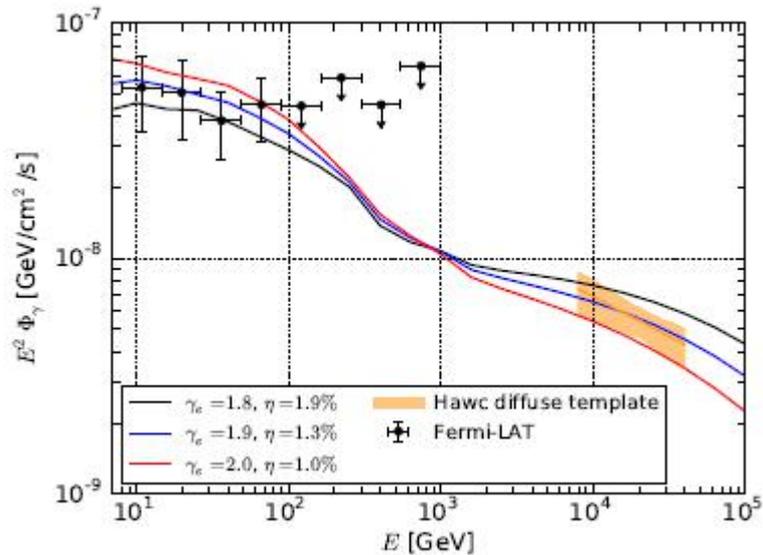
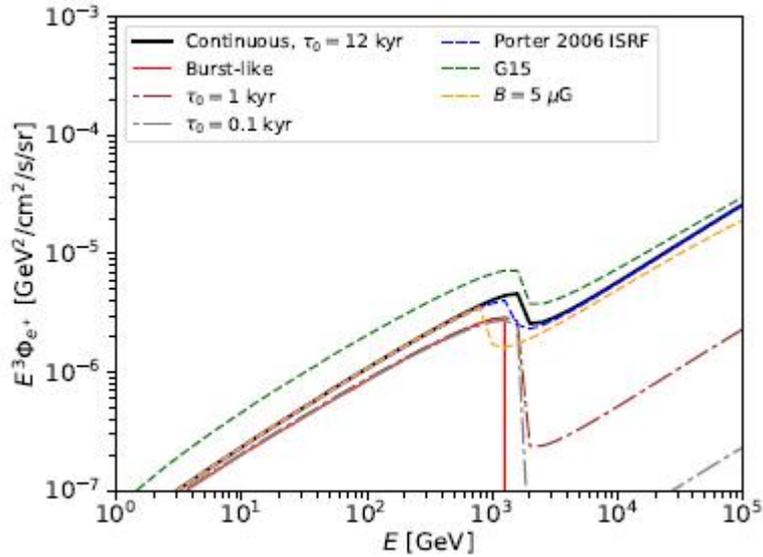
Astronomy
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Astrophysics

Cosmic-ray spectrum in the local Galaxy

Andrii Neronov¹, Denys Malyshev², and Dmitri V. Semikoz^{3,4}



3: Geminga TeV Halo $_{340(110)kyr}$

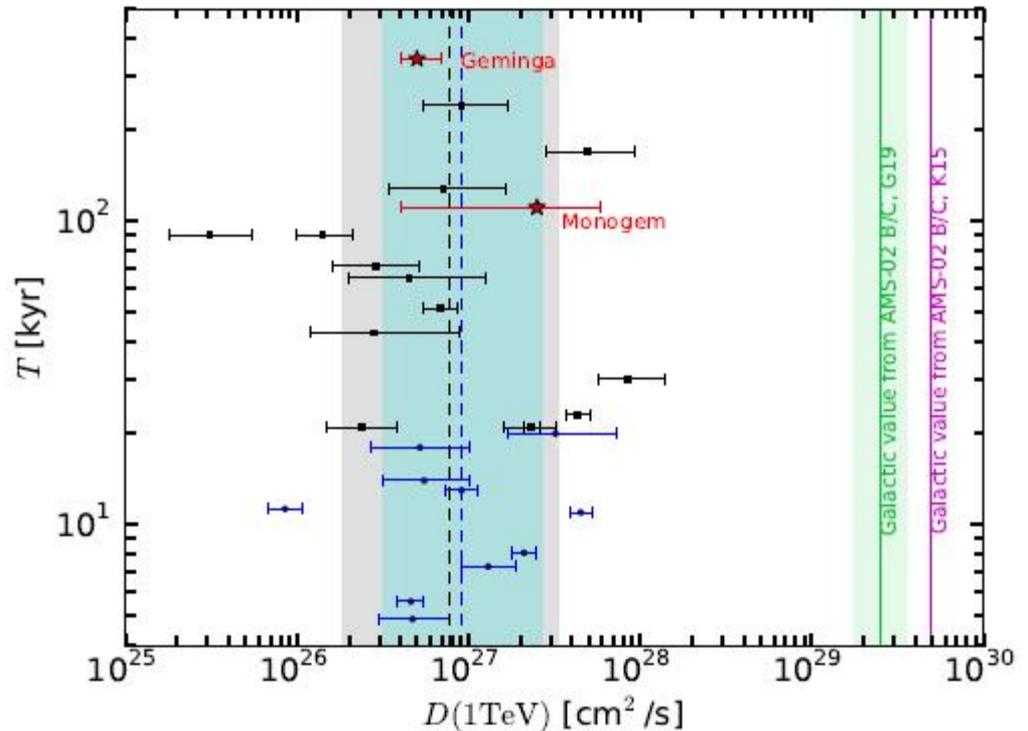


Detection of a γ -ray halo around Geminga with the *Fermi*-LAT and implications for the positron flux

Mattia Di Mauro,*
NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA and
Catholic University of America, Department of Physics, Washington DC 20064, USA

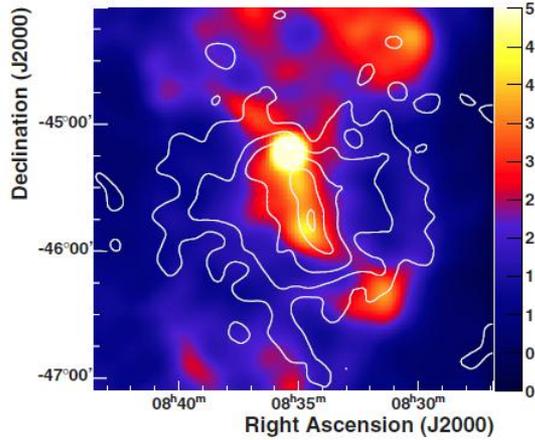
Silvia Manconi[†] and Fiorenza Donato[‡]

Evidences of low-diffusion bubbles around Galactic pulsars



3: Vela TeV Halo

12(4.5)kyr



THE ASTROPHYSICAL JOURNAL, 866:143 (8pp), 2018 October 20
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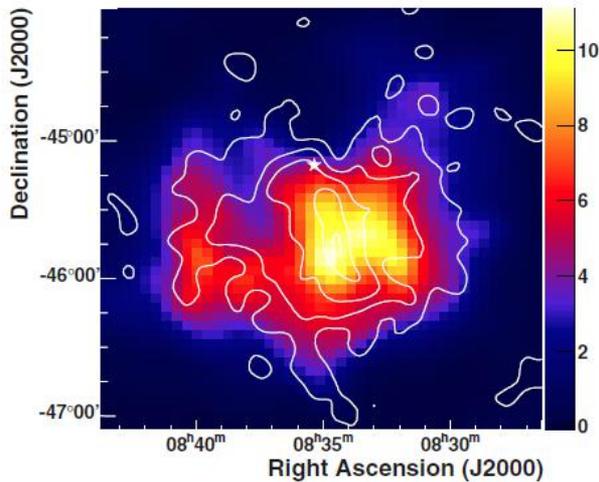
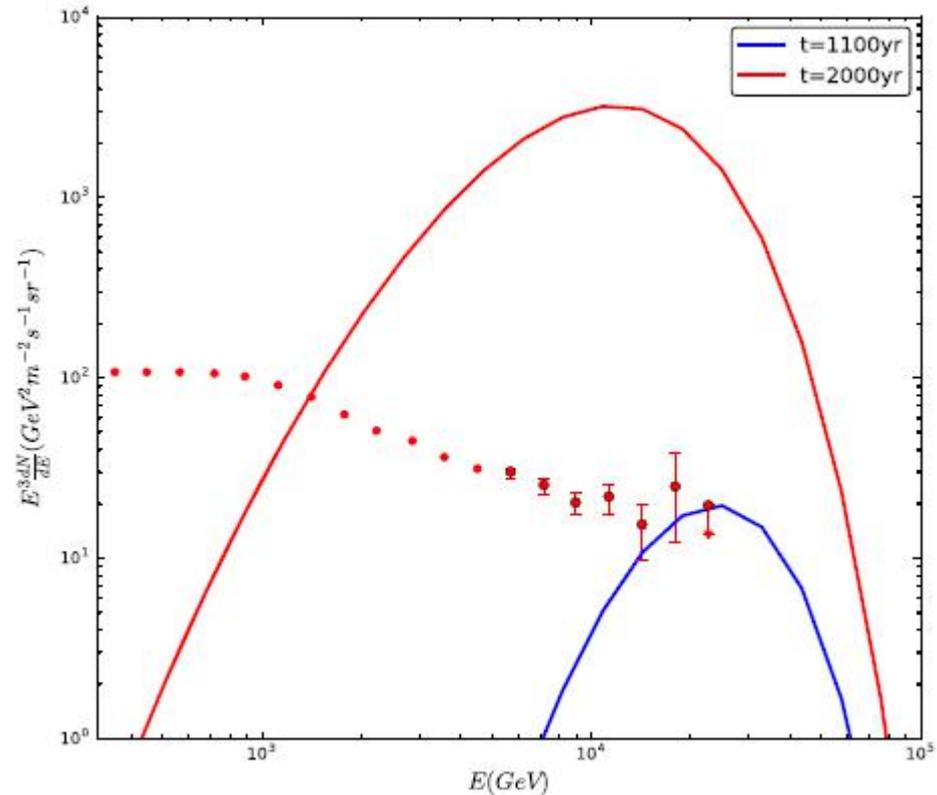
OPEN ACCESS

<https://doi.org/10.3847/1538-4357/aadfed>



Inefficient Cosmic-Ray Diffusion around Vela X: Constraints from H.E.S.S. Observations of Very High-energy Electrons

Zhi-Qiu Huang^{1,2}, Kun Fang^{3,4}, Ruo-Yu Liu⁵ , and Xiang-Yu Wang^{1,2}



4: Vela TeV Halo

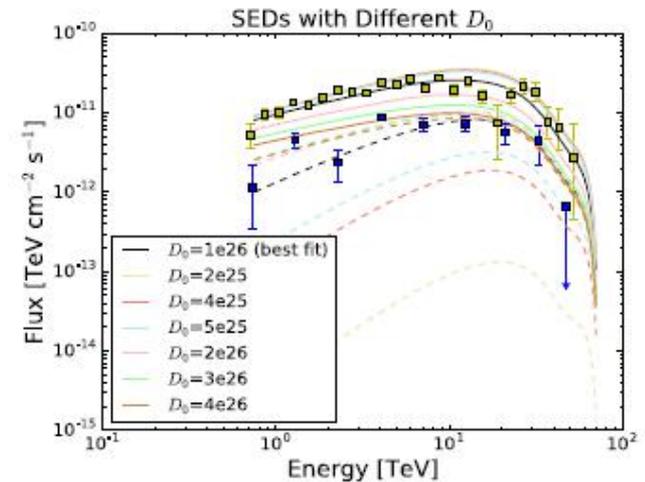
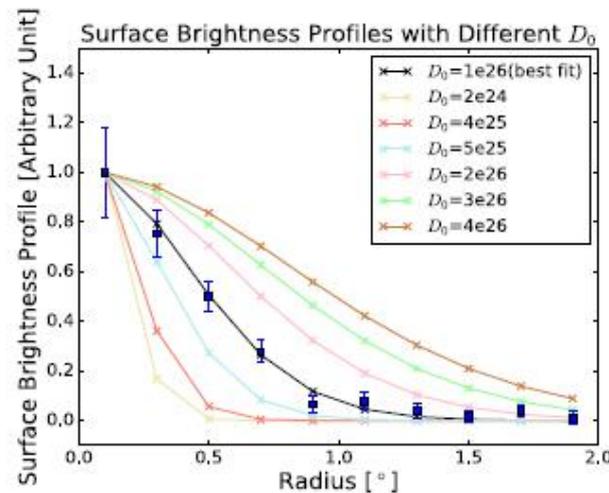
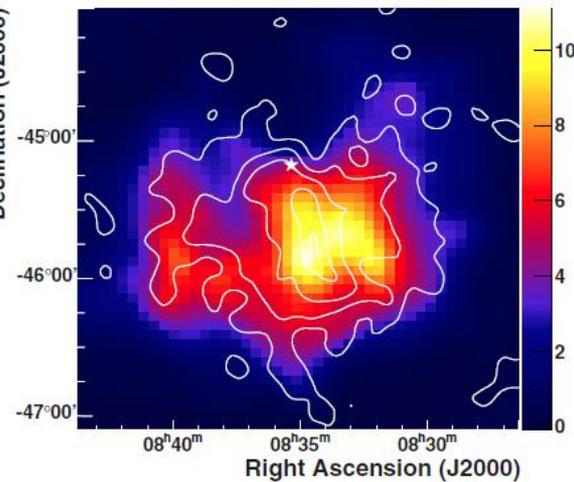
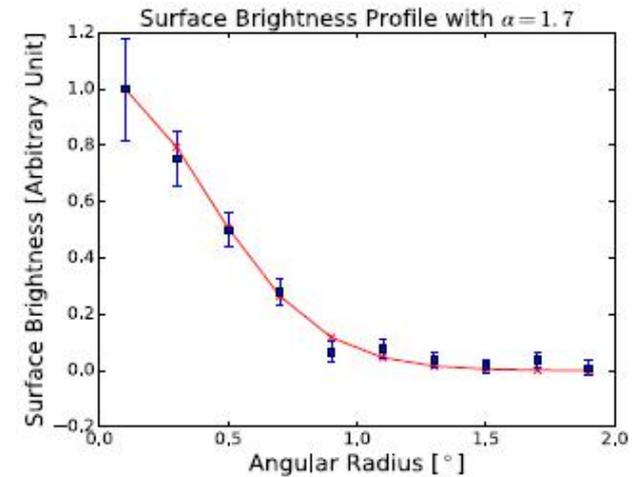
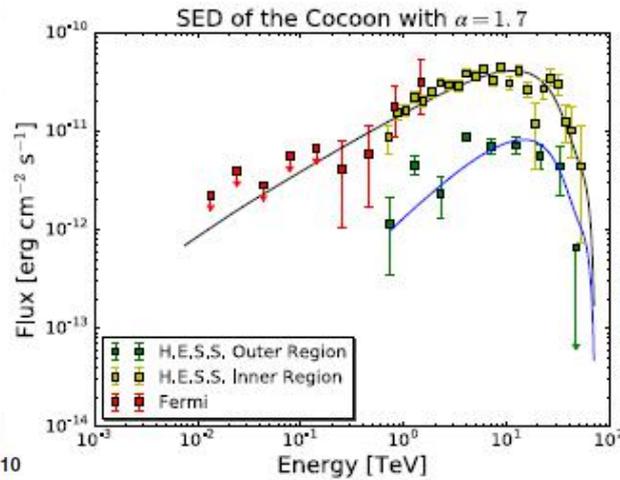
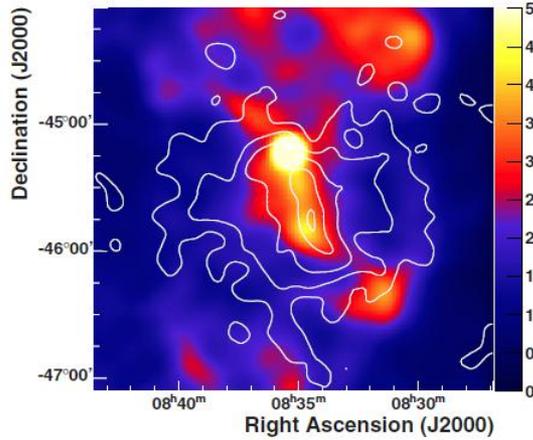
12(4.5)kyr

THE ASTROPHYSICAL JOURNAL, 877:54 (5pp), 2019 May 20
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<https://doi.org/10.3847/1538-4357/ab1908>



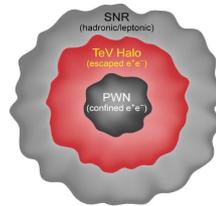
On the Gamma-Ray Nebula of Vela Pulsar. I. Very Slow Diffusion of Energetic Electrons within the TeV Nebula



4: Slow Diffusion vs Confinement Halo vs PWN

On the TeV Halo Fraction in gamma-ray bright Pulsar Wind Nebulae

G. Giacinti¹, A.M.W. Mitchell², R. López-Coto³, V. Joshi⁴, R.D. Parsons¹, J.A. Hinton¹



PHYSICAL REVIEW D **100**, 043016 (2019)

TeV halos are everywhere: Prospects for new discoveries

Takahiro Sudoh,^{1,2,*} Tim Linden,^{2,3,†} and John F. Beacom^{2,3,4,‡}

PHYSICAL REVIEW D **98**, 063017 (2018)

Self-generated cosmic-ray confinement in TeV halos: Implications for TeV γ -ray emission and the positron excess

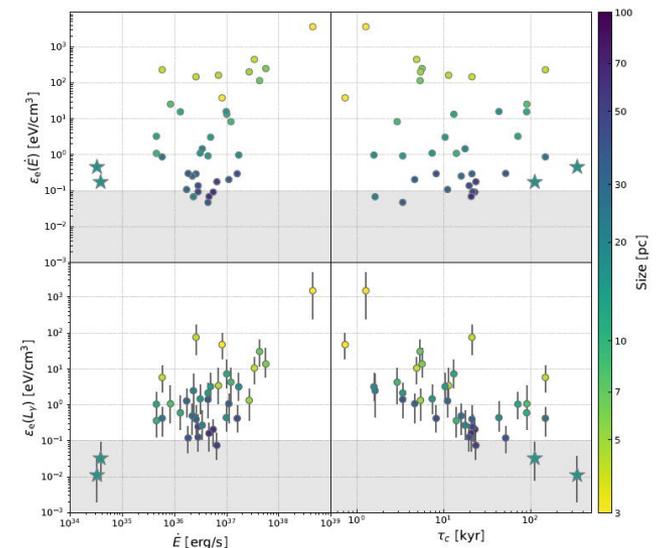
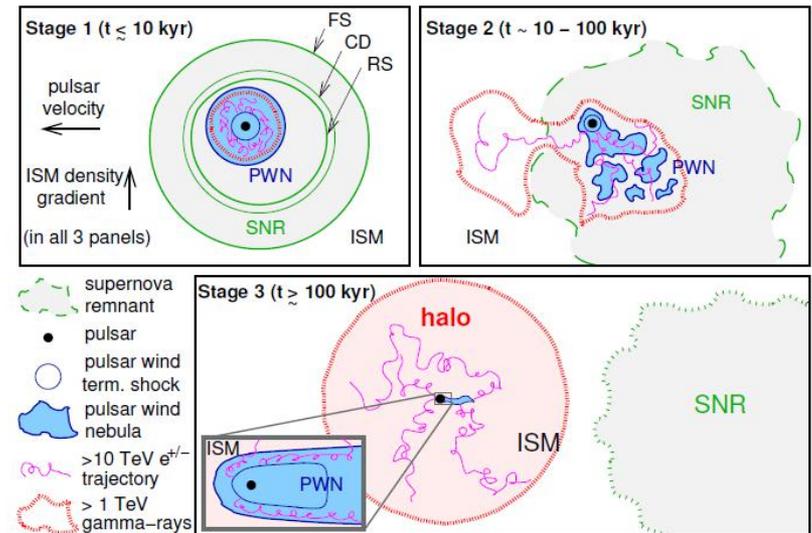
Carmelo Evoli,^{1,2,*} Tim Linden,^{3,†} and Giovanni Morlino^{1,2,4,‡}

MNRAS **488**, 4074–4080 (2019)
Advance Access publication 2019 July 26

doi:10.1093/mnras/stz1974

Possible origin of the slow-diffusion region around Geminga

Kun Fang,¹ Xiao-Jun Bi^{1,2,*} and Peng-Fei Yin¹



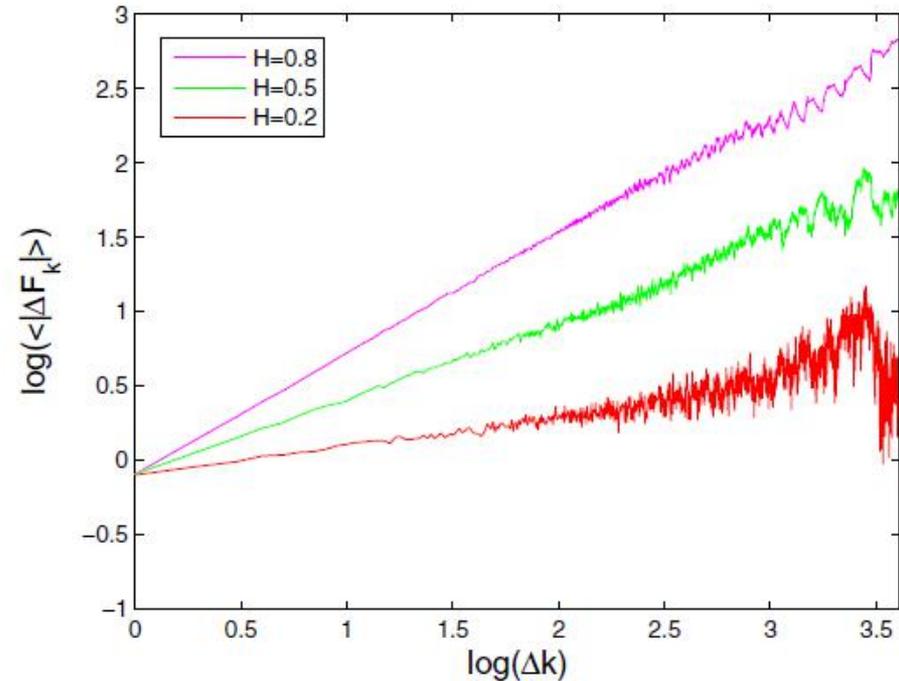
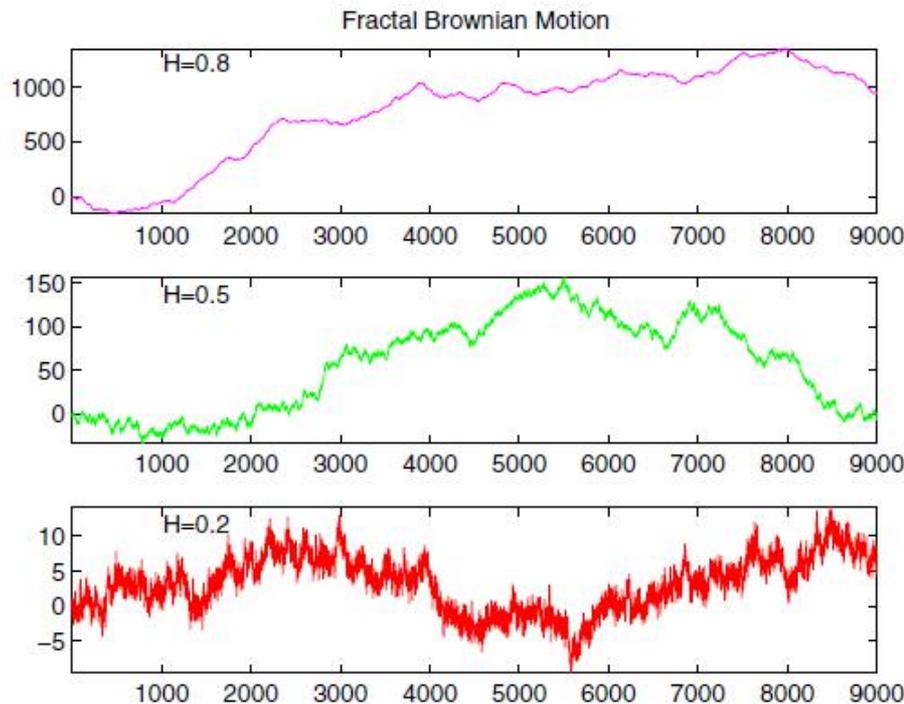
4: Anomalous Diffusion

Physics Reports 339 (2000) 1–77

www.elsevier.com/lo

The random walk's guide to anomalous diffusion:
a fractional dynamics approach

Ralf Metzler*, Joseph Klafter



Fractals, Vol. 21, Nos. 3 & 4 (2013) 1350018 (6 pages)

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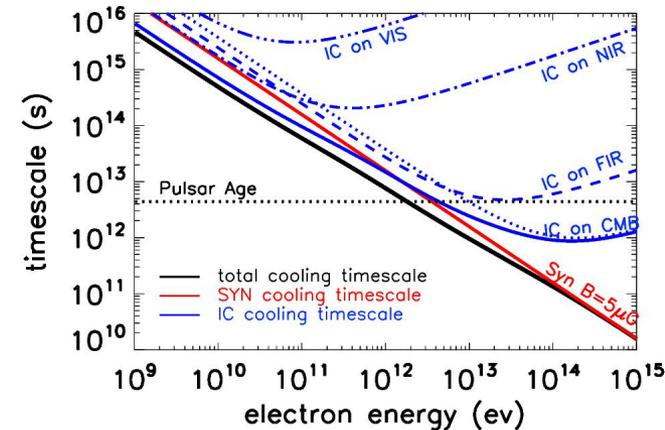
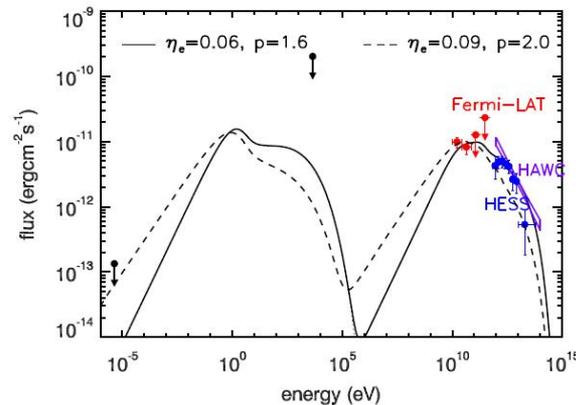
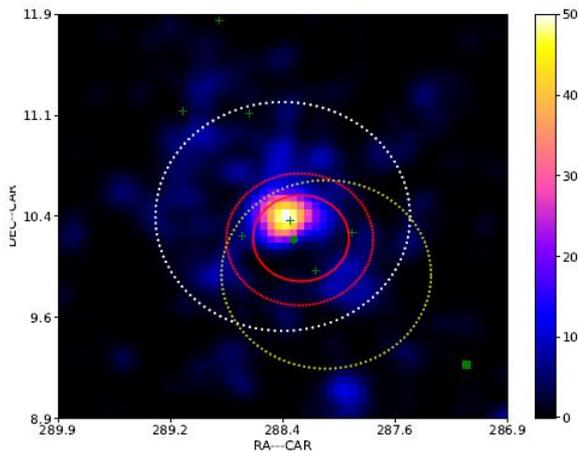
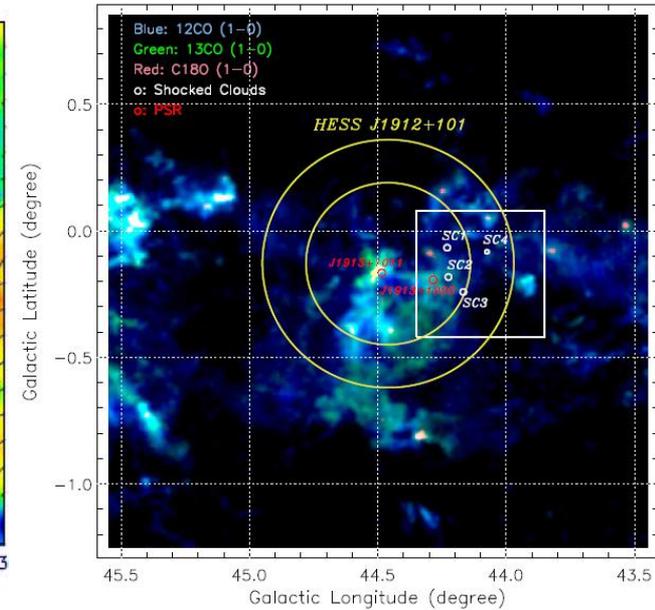
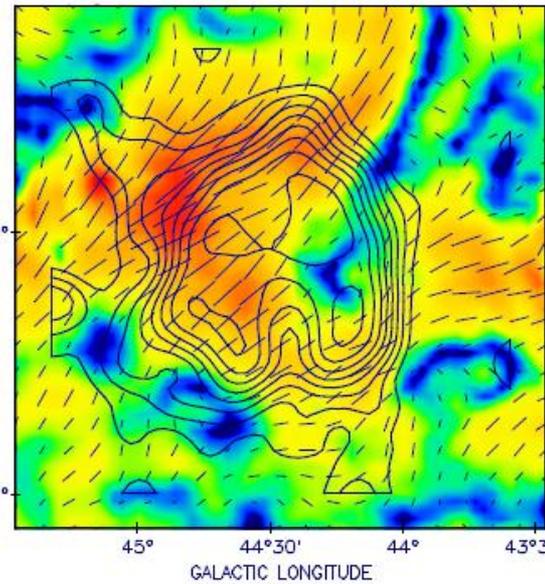
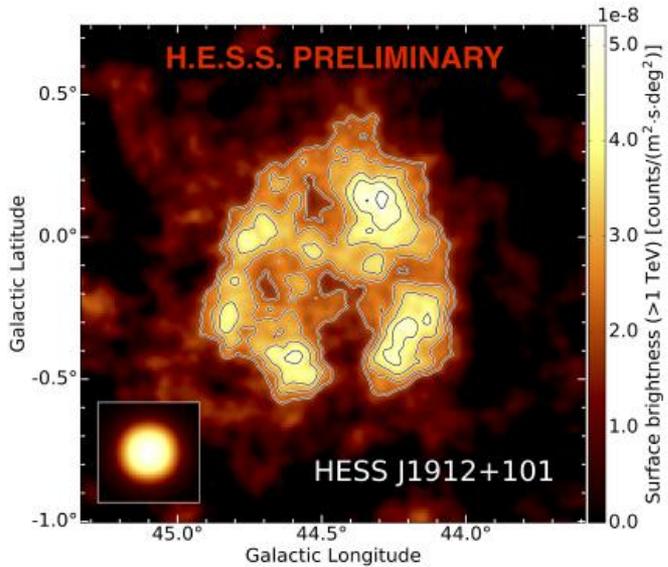
DOI: 10.1142/S0218348X13500187

**ERROR ASSESSMENT IN MODELING WITH
FRACTAL BROWNIAN MOTIONS**

BINGQIANG QIAO and SIMING LIU*

5: HESS 1912+101

70-200kyr



纲要

- (1) 邻近源和高能宇宙线
- (2) 宇宙线的注入和传播
- (3) 正负电子能谱与TeV源
- (4) 慢扩散(Halo)和磁约束(PWN)
- (5) 重子TeV扩展源

第三课题:宇宙线起源的唯象研究

围绕宇宙线的起源问题，负责研究**LHAASO**的宇宙线能谱和各向异性结果，以及来自扩展源和弥散伽马射线的观测结果，主要研究目标有：

(1) 发展相关的粒子加速理论，完善宇宙线的超新星遗迹起源学说。

(2) 分析脉冲星中高能粒子的加速和传播特征，确定其对宇宙线正负电子和膝区宇宙线的贡献。

(3) 发展Hillas宇宙线模型，确定该模型中各分量的起源天体。

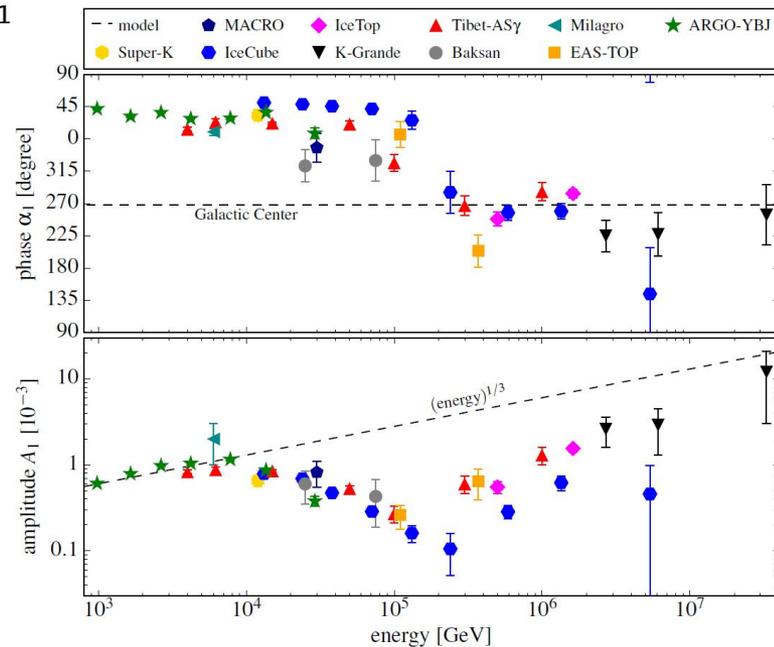
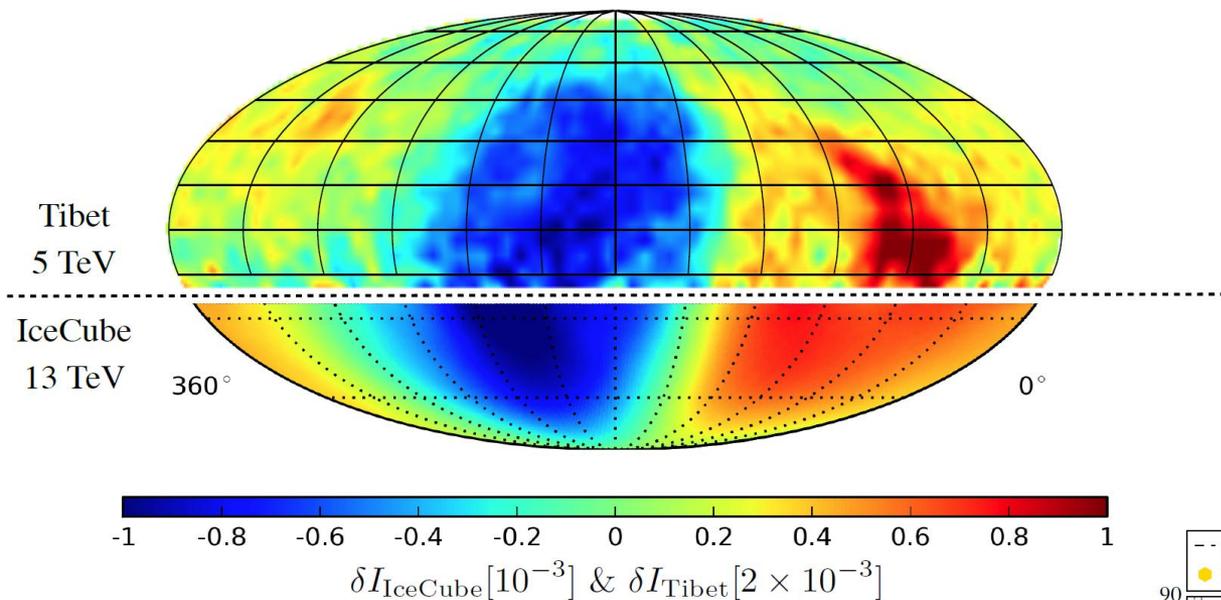
(4) 研究加速和传播过程对宇宙线能谱的影响，分析膝区宇宙线的起源。

(5) 利用数值模拟的方法，分析宇宙线的传播特征。

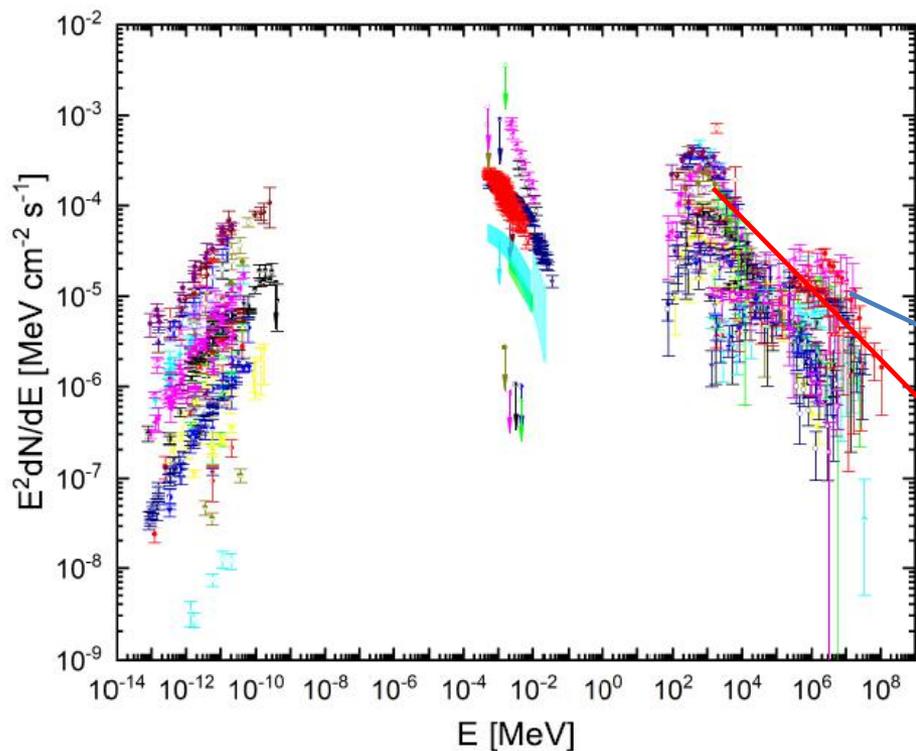
(6) 研究极高能宇宙线的起源并分析星爆星系中宇宙线的特点。

(7) 分析膝区以上宇宙线的起源，并用**SKA**观测测量散射宇宙线的湍流的特点

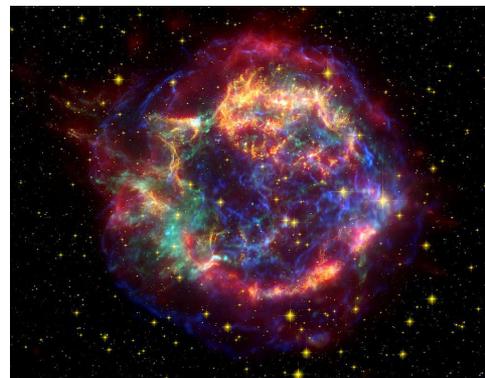
宇宙线各向异性



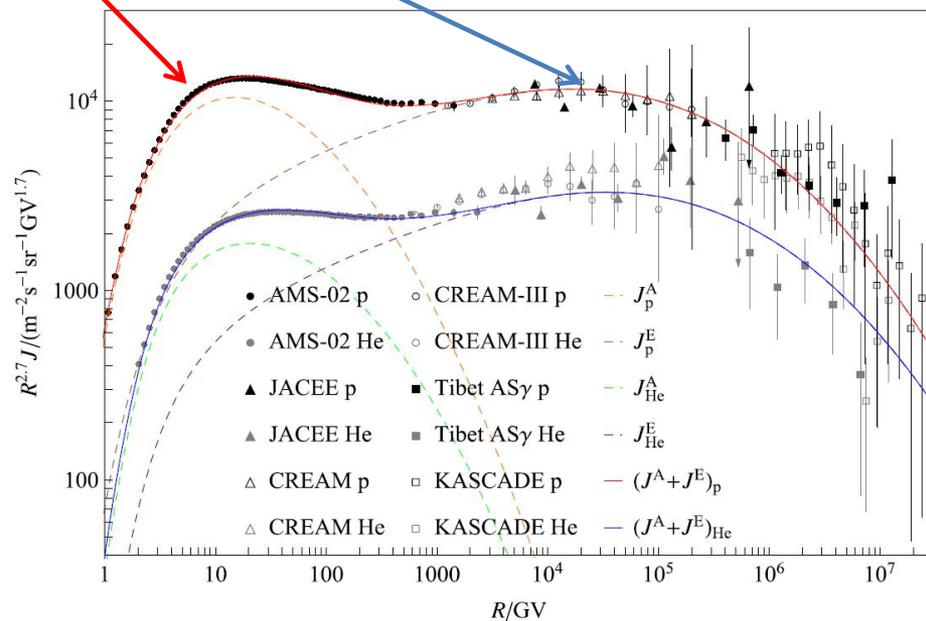
宇宙线和伽马射线源



34个超新星遗迹的能谱



宇宙线质子和氦核谱



实施方案

3个任务组:

- A** 宇宙线能谱和各向异性研究由刘四明，袁强和胡红波负责；
- B** 河外宇宙射线源的研究由王祥玉负责；
- C** 宇宙射线的多波段观测研究由朱辉和田文武负责。

实施方案

A 宇宙线能谱和各向异性研究：

负责人：刘四明、袁强、胡红波

核心成员：刘伟、辛玉良、郭义庆、曾厚敦、张轶然（博士）、石召东（博士）、包逸炜（博士）、张潇

具体研究任务：

- **A1:** 发展Hillas模型，开展超新星遗迹的多波段研究。

A1a对于已经探测到的30多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）

A1b利用一个TeV辐射由轻子过程主导的年轻超新星遗样本（总共约10个源），分析年轻遗迹中高能电子分布函数的演化规律（刘四明、张潇、曾厚敦）

A1c发展两分量的Hillas模型，将宇宙线总能谱和平均原子数谱与观测做比较（刘四明、张轶然）

- **A2:** 把宇宙线的能谱观测特征和各项异性观测相结合发展统一的宇宙线传播模型。

A2a结合空间直接探测实验和地面间接探测实验结果，构建统一的物理模型理解宇宙线能谱结构和各向异性特征（袁强、郭义庆、刘伟）

A2b考虑到有大尺度磁场时，宇宙线扩散系数表现出高度的各向异性，利用一个1维扩散模型分析宇宙线正负电子的能谱和各向异性特征（刘四明、石召东）

- **A3:** 分析超新星遗迹对宇宙线的贡献，完善银河系宇宙线的超新星遗迹起源学说。

实施方案

B 河外宇宙射线源的研究

负责人：王祥玉

核心成员：席绍强、薛瑞、黄稚秋、孙晓娜

具体研究任务：

- **B1**：利用高能中微子研究河外源对宇宙线源的贡献，包括分析跟河外源关联的高能中微子的产生过程、以及分析它们对于宇宙线的贡献。
- **B2**：利用河外天体的伽玛射线辐射研究河外源对宇宙线的贡献，包括分析河外源的高能伽玛数据，分析高能伽玛辐射的起源机制以及对宇宙线的贡献。
- 献。

实施方案

C 宇宙线的多波段观测研究

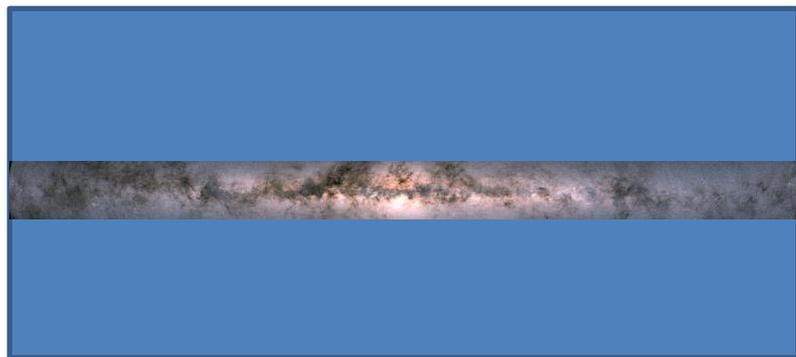
负责人：朱辉、田文武

核心成员：张海燕、崔晓红、周新霖、吴丹、苏洪全、杨媛媛、张孟飞、单素素、雷贤欢、张少博

具体研究任务：

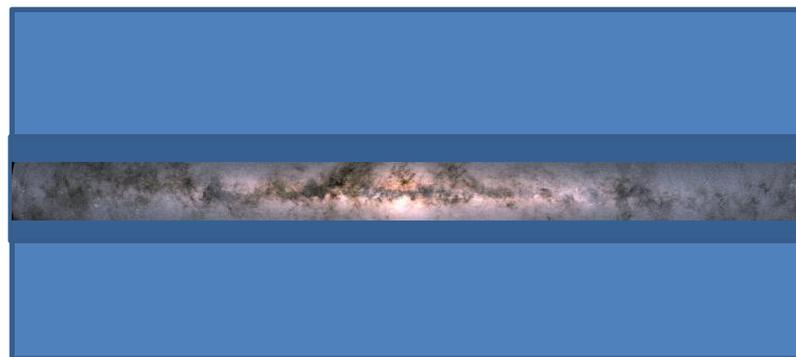
- **C1**: 利用非线性激波加速理论构建超新星遗迹同步辐射的射电能谱，使用多波段射电观测检验伽马射线观测给出的结果。
- **C2**: 寻找与超新星遗迹成协的中性氢气体云（**FAST**），尝试利用**HI**的塞曼分裂测量超新星遗迹激波处的磁场强度，检验磁场放大理论。
- **C3a**: 宇宙线与星际介质相互作用。
- **C3b**: 宇宙线的扩散系数与介质湍动的关系。
- **C4**: 搜寻已知和**LHAASO**新发现伽马射线源在射电波段的对应体。
- **C5**: 利用**SKA**和**LHAASO**在宇宙线 10^{16} eV - 10^{18} eV能段的重叠，相互检验结果的准确性。。

A2a：结合空间直接探测实验和地面间接探测实验结果，构建统一的物理模型理解宇宙线能谱结构和各向异性特征（袁强、郭义庆、刘伟）



传统图像

- 连续分布的宇宙线源
- 均匀、各向同性扩散
- 可以**大致**解释宇宙线能谱、次级粒子谱、弥散伽马射线等数据



新图像

- 连续分布的宇宙线源 + 个别邻近分立源
- 空间依赖扩散、各向异性扩散
- 宇宙线和伽马射线的精确测量结果、各向异性观测等

A1a: 对于已经探测到的30多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）

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Evolution of High-energy Particle Distribution in Supernova Remnants

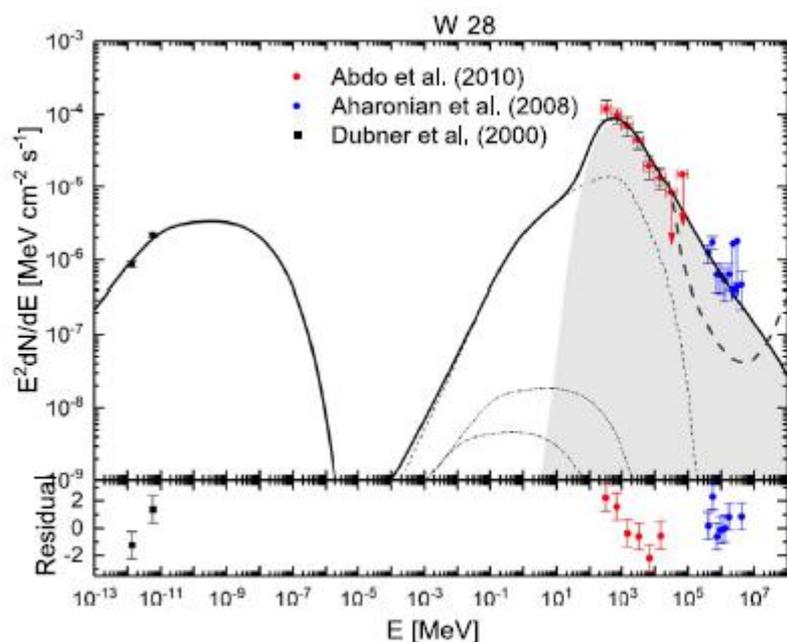
Houdun Zeng , Yuliang Xin, and Siming Liu 

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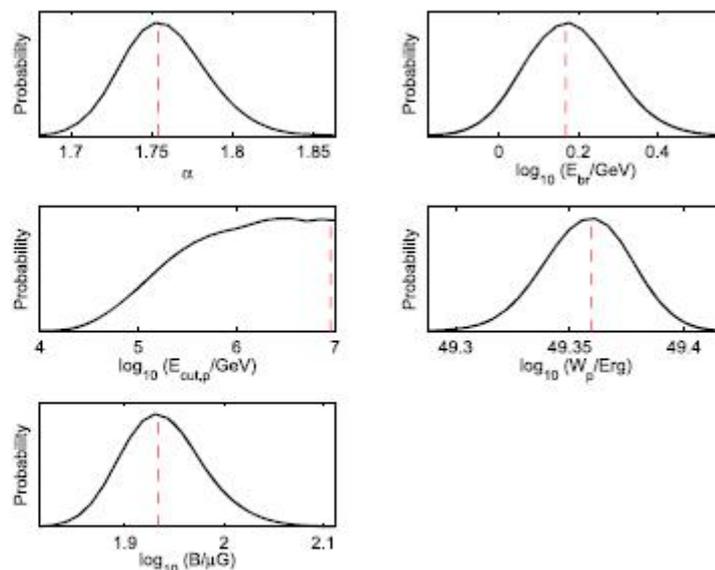
Table 1
 The Sample of SNRs and Related Physical Information

SNR Name	Other Name	Radius (pc)	Distance (Kpc)	Age (kyr)	Density (cm ⁻³)	Shock Speed (km s ⁻¹)	Radio	X-Ray	GeV	TeV	References for Related Physical Information
G006.4-00.1	W28	~13	~2.0	40(33-150)	~100	60-80	✓		✓	✓	1-4
G008.7-00.1	W30	~26	~4.0	25(15-28)	~100	530-750	✓		✓		5, 6
G031.9+00.0	3C 391	~7	~7.2	~4	~300	620-730	✓		✓		7-10
G033.6+00.1	Kes 79	~9.6	~7.0	~4.4-6.7	~3(1-5)	400 ± 5	✓		✓		11-13
G034.7-00.4	W44	~12.5	~3.0	~20	~200	100-150	✓		✓		14-16
G043.3-00.2	W49B	~5	~10	~5.7(5-6)	~700	~400	✓		✓	✓	17, 18
G049.2-00.7	W51C	~18	~4.3	~30	~10	~100	✓	T	✓	✓	19-22
G073.9+00.9		~16/5.2	~4.0/1.3	~11-12	~10	~200-300	✓	T	✓		23, 24
G074.0-08.5	Cygnus loop	~16	~0.54	~14	~5.0	240-330	✓		✓		25-28
G078.2+02.1	γ Cygni	~17	~2.0	~8.25(6.8-10)	~2.5(0.1-20)	700-1100	✓	T	✓	✓	29, 30
G089.0+04.7	HB21	~26	~1.7	~40(36 or 45)	~15	~125	✓	T	✓		31-35
G109.1-1.00	CTB109	~16	~3.1	~9.0(9.0-9.2)	~1.1	~230 ± 5	✓	T	✓		36, 37
G120.1+01.4	Tycho	~3.3	~3.0	~0.44	~10/0.3	4600-4800	✓	✓	✓	✓	38, 39
G132.7+01.3	HB3	~26.4	~2.2	~30.0	~2.0	303-377	✓		✓		40-42
G150.3+04.5		~9.4	~0.40	~1.5(0.5-5)	~1.0	<2500	✓	T	✓		43
G160.9+02.6	HB9	~15	~0.8	5.3(4-7)	~0.1	~740	✓	T	✓		44, 45
G166.0+04.3		~26	~4.5	24.0	~0.01	~680	✓		✓		46, 47
G180.0-01.7	S147	~38	~1.3	30(20-100)	~250(100-500)	~500	✓		✓		48, 49
G189.1+03.0	IC 443	~11	~1.5	~30	~140	60-100	✓		✓	✓	50-52
G205.5+0.50	Monoceros	~63.36	~1.98	~30	~3.6	~50	✓		✓		53-55
G260.4-03.4	Puppis A	~15	~2.2	4.45(3.75-5.20)	~4.0	700-2500	✓		✓	T	56-59
G266.2-01.2	RX J0852-4622	~13	~0.75	2.7(1.7-4.3)	~3.8	~3000	✓	✓	✓	✓	60, 61
G296.5+10.0		~26	~2.1	~10.0	~13.0	<1000	✓		✓		62, 63
G304.6+00.1	Kes 17	~10	~10	4.2(2-5.2)	~10	150-200	✓	T	✓		64, 65
G315.4-02.3	RCW 86	~15	~2.5	~1.8	~0.1-2.0	700-2000	✓	✓	✓	✓	66-68
G326.3-01.8	MSH 15-56	~22.2	~4.1	~10.0(10-16.5)	~0.1/1.0	500-860	✓		✓		67, 69, 70
G327.6+14.6	SN 1006	~9.0	~2.2	~1.0	~0.085	3200-5800	✓	✓	✓	✓	71, 72
G332.4-00.4	RCW 103	~5	~3.3	~2.0	~10	~1100	✓		✓		73-75
G337.0-00.1	CTB 33	~2.55	~11.0	~5.0	~60	<200	✓		✓		76-78
G347.3-00.5	RX 1713.7-3946	~10	~1.0	~1.6	~0.01	~5000	✓	✓	✓	✓	78-81
G348.5+00.1	CTB 37A	~10	~7.9	~30	~100	75-100	✓	T	✓	✓	82-86
G348.7+00.3	CTB 37B	~20	~13.2	~5	~10/0.5	~800	✓	T	✓	✓	85-88
G349.7+00.2		~3.3	~11.5	~2.8	~35.0	700-900	✓	T	✓	✓	89-92
G353.6-00.7	Hess J1731-347	~14.0	~3.2	~2-6	~0.01	~2100	✓	✓	✓	✓	93, 94
G359.1-00.5	Hess J1745-303	~16.0	~4.6	~70	~100	~300	✓	T	✓	✓	95-98

A1a: 对于已经探测到的**30**多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）



W28 (a)



W28 (b)

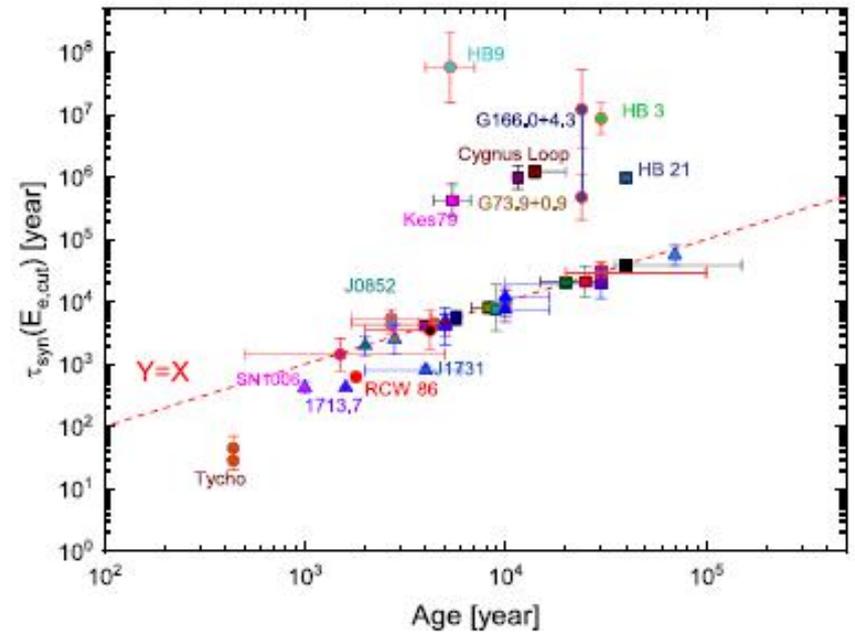
A1a: 对于已经探测到的30多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）

Table 2
Spectral Fitting Parameters

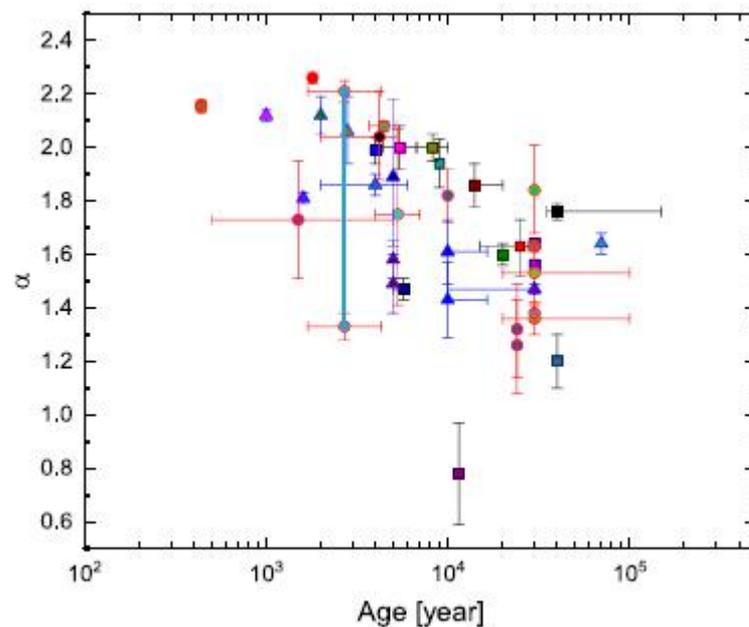
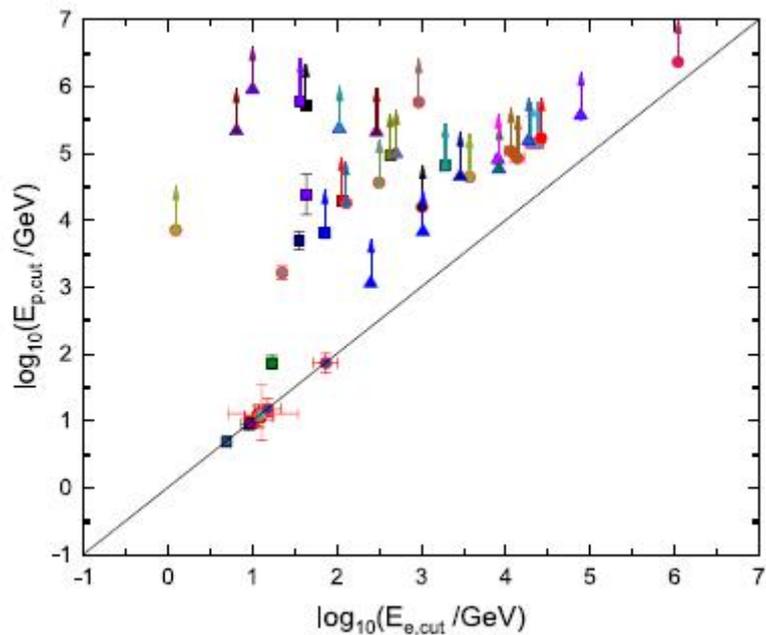
Source Name	α	$\log_{10} \frac{E_{90}}{\text{GeV}}$	$\log_{10} \frac{E_{e,cut}}{\text{GeV}}$	$\log_{10} \frac{E_{p,cut}}{\text{GeV}}$	$\log_{10} \frac{B}{\mu\text{G}}$	$\log_{10} \frac{W_p}{\text{erg}}$	$\frac{W_B}{W_e}$	$\frac{n}{\text{cm}^{-3}}$	$\frac{\chi^2}{\text{NDF}}$
W28	$1.76^{+0.03}_{-0.03}$	$0.18^{+0.11}_{-0.11}$	1.63	>5.72	$1.94^{+0.04}_{-0.04}$	$49.36^{+0.02}_{-0.02}$	3000	100	$\frac{24.3}{10} = 2.43$
W30	$1.63^{+0.10}_{-0.11}$	$0.24^{+0.33}_{-0.33}$	2.06	>4.29	$1.86^{+0.12}_{-0.12}$	$49.69^{+0.07}_{-0.07}$	736	100	$\frac{6.0}{7} = 0.86$
3C391	$1.99^{+0.05}_{-0.05}$	$1.15^{+0.14}_{-0.14}$	1.86	>3.81	$2.31^{+0.04}_{-0.04}$	$49.03^{+0.03}_{-0.03}$	619	300	$\frac{37.1}{19} = 1.95$
Kes79 ^a	$2.00^{+0.08}_{-0.08}$	NA	$E_{p,cut}$	$1.07^{+0.16}_{-0.16}$	$1.70^{+0.05}_{-0.05}$	$49.47^{+0.04}_{-0.04}$	21.3	100.0	$\frac{64.2}{24} = 2.68$
W44	$1.60^{+0.04}_{-0.04}$	$0.73^{+0.09}_{-0.09}$	1.23	$1.87^{+0.11}_{-0.11}$	$2.28^{+0.03}_{-0.03}$	$49.43^{+0.01}_{-0.01}$	1480	200	$\frac{44.4}{48} = 0.93$
W49B	$1.47^{+0.04}_{-0.04}$	$-0.21^{+0.23}_{-0.23}$	1.55	$3.70^{+0.13}_{-0.13}$	$2.40^{+0.06}_{-0.06}$	$49.43^{+0.02}_{-0.02}$	235	700	$\frac{18.9}{20} = 1.00$
W51C	$1.56^{+0.02}_{-0.02}$	$0.31^{+0.08}_{-0.08}$	1.64	$4.39^{+0.30}_{-0.29}$	$2.08^{+0.03}_{-0.03}$	$49.83^{+0.01}_{-0.01}$	708	100	$\frac{50.7}{29} = 2.06$
W51C ^b	$1.64^{+0.02}_{-0.02}$	$0.32^{+0.05}_{-0.05}$	1.57	>5.78	$2.02^{+0.03}_{-0.03}$	$49.79^{+0.01}_{-0.01}$	201	100	$\frac{34.9}{29} = 1.20$
G73.9+0.9 ^c	$0.78^{+0.10}_{-0.10}$	NA	$E_{p,cut}$	$0.96^{+0.09}_{-0.09}$	$1.57^{+0.05}_{-0.05}$	$49.34^{+0.04}_{-0.04}$	393	10	$\frac{22.4}{13} = 1.72$
Cygnus Loop ^d	$1.86^{+0.08}_{-0.08}$	NA	$E_{p,cut}$	$1.09^{+0.10}_{-0.10}$	$1.46^{+0.03}_{-0.03}$	$48.72^{+0.02}_{-0.02}$	197	5.0	$\frac{20.5}{20} = 1.03$
ω Cygni	$2.00^{+0.05}_{-0.05}$	$3.17^{+0.17}_{-0.17}$	2.63	>4.97	$1.78^{+0.05}_{-0.05}$	$50.25^{+0.02}_{-0.02}$	61.5	2.5	$\frac{23.6}{18} = 1.31$
HB21 ^e	$1.20^{+0.12}_{-0.12}$	NA	$E_{p,cut}$	$0.69^{+0.04}_{-0.04}$	$1.71^{+0.01}_{-0.01}$	$49.42^{+0.01}_{-0.01}$	564	15	$\frac{36.2}{23} = 1.57$
CTB109	$1.94^{+0.09}_{-0.09}$	$2.66^{+0.38}_{-0.38}$	3.28	>4.82	$1.47^{+0.17}_{-0.17}$	$49.84^{+0.12}_{-0.12}$	19.6	1.1	$\frac{20.9}{8} = 2.61$
Tycho	$2.15^{+0.02}_{-0.02}$	$3.37^{+0.12}_{-0.12}$	$4.14^{+0.08}_{-0.08}$	>5.04	$2.15^{+0.04}_{-0.04}$	$49.01^{+0.08}_{-0.08}$	23.5	0.3	$\frac{55}{35} = 1.57$
Tycho	$2.16^{+0.02}_{-0.02}$	$3.36^{+0.11}_{-0.11}$	$4.06^{+0.07}_{-0.07}$	>4.93	$2.29^{+0.04}_{-0.04}$	$48.78^{+0.07}_{-0.07}$	92.2	10.0	$\frac{44}{35} = 1.26$
HB3 ^f	$1.84^{+0.17}_{-0.16}$	NA	$E_{p,cut}$	$1.08^{+0.17}_{-0.17}$	$1.04^{+0.04}_{-0.04}$	$50.04^{+0.03}_{-0.03}$	6.4	2.0	$\frac{16.4}{19} = 0.86$
G150.3+4.5	$1.73^{+0.23}_{-0.23}$	$2.65^{+0.26}_{-0.26}$	6.04	>6.37	$0.45^{+0.13}_{-0.13}$	$48.33^{+0.05}_{-0.05}$	1.42	1.0	$\frac{11.5}{12} = 0.96$
HB9 ^g	$1.75^{+0.32}_{-0.34}$	NA	$E_{p,cut}$	$1.11^{+0.43}_{-0.40}$	$0.61^{+0.07}_{-0.06}$	$50.25^{+0.08}_{-0.08}$	0.07	0.1	$\frac{7.3}{12} = 0.61$
G166.0+4.3 ^h	$1.32^{+0.17}_{-0.18}$	NA	$E_{p,cut}$	$1.87^{+0.14}_{-0.13}$	$0.57^{+0.24}_{-0.24}$	$50.92^{+0.26}_{-0.26}$	0.12	0.01	$\frac{6.92}{5} = 1.38$
G166.0+4.3 ⁱ	$1.26^{+0.17}_{-0.18}$	NA	$E_{p,cut}$	$1.18^{+0.16}_{-0.16}$	$1.62^{+0.10}_{-0.10}$	$49.18^{+0.07}_{-0.07}$	717	10.0	$\frac{7.70}{5} = 1.54$
S147	$1.36^{+0.06}_{-0.06}$	$-0.14^{+0.13}_{-0.13}$	0.09	>3.86	$2.77^{+0.09}_{-0.09}$	$47.71^{+0.05}_{-0.05}$	2.7×10^8	250	$\frac{17.3}{17} = 1.02$
S147	$1.53^{+0.11}_{-0.11}$	$0.51^{+0.12}_{-0.12}$	3.57	>4.65	$1.03^{+0.05}_{-0.05}$	$49.94^{+0.04}_{-0.04}$	31.6	1.0	$\frac{19.8}{17} = 1.16$
IC 443	$1.38^{+0.03}_{-0.03}$	$0.12^{+0.07}_{-0.07}$	1.35	$3.22^{+0.10}_{-0.10}$	$2.14^{+0.02}_{-0.02}$	$48.96^{+0.01}_{-0.01}$	2280	140	$\frac{92.0}{64} = 1.44$
Monoceros Loop	$1.63^{+0.02}_{-0.02}$	$0.74^{+0.11}_{-0.11}$	2.97	>5.77	$1.31^{+0.03}_{-0.03}$	$50.29^{+0.03}_{-0.03}$	224	3.6	$\frac{42.5}{16} = 1.63$
Puppis A	$2.08^{+0.02}_{-0.02}$	$3.23^{+0.48}_{-0.48}$	2.50	>4.57	$1.97^{+0.02}_{-0.02}$	$49.53^{+0.04}_{-0.04}$	500	4.0	$\frac{48.8}{30} = 1.46$
RX J0852-4622 ^d	$2.21^{+0.04}_{-0.04}$	NA	$4.30^{+0.06}_{-0.06}$	>5.15	$1.03^{+0.04}_{-0.04}$	$49.61^{+0.05}_{-0.05}$	2.79	0.01	$\frac{26.0}{15} = 1.73$
RX J0852-4622	$1.33^{+0.03}_{-0.03}$	$1.13^{+0.18}_{-0.18}$	$4.38^{+0.06}_{-0.06}$	>5.15	$1.04^{+0.04}_{-0.04}$	$49.70^{+0.04}_{-0.04}$	2.6	0.01	$\frac{16.6}{14} = 1.19$
G296.5+10.0 ^h	$1.82^{+0.10}_{-0.10}$	NA	2.11	>4.26	$2.01^{+0.10}_{-0.11}$	$49.74^{+0.23}_{-0.23}$	6770	1.0	$\frac{34.8}{6} = 0.58$
Kes 17 ^a	$2.04^{+0.12}_{-0.12}$	NA	3.01	>4.20	$1.77^{+0.16}_{-0.16}$	$50.39^{+0.13}_{-0.13}$	7.6	10.0	$\frac{1.06}{3} = 0.35$
RCW 86	$2.26^{+0.02}_{-0.02}$	$3.92^{+0.08}_{-0.08}$	$4.42^{+0.04}_{-0.04}$	>5.23	$1.44^{+0.02}_{-0.02}$	$49.82^{+0.03}_{-0.03}$	15.3	0.01	$\frac{31.5}{22} = 1.43$
MSH 15-56	$1.43^{+0.14}_{-0.14}$	$2.13^{+0.08}_{-0.20}$	2.40	>3.06	$1.81^{+0.08}_{-0.08}$	$51.05^{+0.13}_{-0.13}$	34.3	0.1	$\frac{10.1}{7} = 1.44$
MSH 15-56	$1.61^{+0.12}_{-0.12}$	$1.17^{+0.08}_{-0.11}$	3.02	>3.83	$1.60^{+0.10}_{-0.10}$	$50.75^{+0.06}_{-0.06}$	9.7	1.0	$\frac{8.0}{7} = 1.14$
SN 1006 ^d	$2.12^{+0.02}_{-0.02}$	NA	$3.91^{+0.04}_{-0.04}$	>4.91	$1.78^{+0.03}_{-0.03}$	$48.94^{+0.05}_{-0.05}$	150	0.085	$\frac{66.0}{39} = 1.69$

Table 2
(Continued)

Source Name	α	$\log_{10} \frac{E_{90}}{\text{GeV}}$	$\log_{10} \frac{E_{e,cut}}{\text{GeV}}$	$\log_{10} \frac{E_{p,cut}}{\text{GeV}}$	$\log_{10} \frac{B}{\mu\text{G}}$	$\log_{10} \frac{W_p}{\text{erg}}$	$\frac{W_B}{W_e}$	$\frac{n}{\text{cm}^{-3}}$	$\frac{\chi^2}{\text{NDF}}$
RCW 103 ^d	$2.12^{+0.07}_{-0.07}$	NA	3.92	>4.77	$1.44^{+0.08}_{-0.08}$	$50.04^{+0.06}_{-0.06}$	0.41	10	$\frac{1.1}{7} = 0.16$
CTB 33	$1.89^{+0.29}_{-0.26}$	$1.02^{+0.44}_{-0.45}$	3.46	>4.66	$1.50^{+0.09}_{-0.08}$	$49.50^{+0.07}_{-0.07}$	0.17	600	$\frac{6.02}{5} = 1.38$
RX J1713.7-3946 ^g	$1.81^{+0.02}_{-0.02}$	$3.10^{+0.05}_{-0.05}$	$4.89^{+0.004}_{-0.004}$	>5.57	$1.29^{+0.004}_{-0.004}$	$49.46^{+0.03}_{-0.03}$	6.0	0.01	$\frac{445}{240} = 1.85$
CTB 37A	$1.47^{+0.02}_{-0.02}$	$0.36^{+0.19}_{-0.17}$	1.0	>5.96	$2.40^{+0.12}_{-0.10}$	$49.82^{+0.02}_{-0.02}$	607	100	$\frac{23.4}{16} = 1.46$
CTB 37B	$1.49^{+0.11}_{-0.11}$	$2.40^{+0.33}_{-0.34}$	0.81	>5.34	$2.84^{+0.15}_{-0.15}$	$50.51^{+0.04}_{-0.04}$	1.04×10^5	10	$\frac{15.6}{14} = 1.11$
CTB 37B	$1.58^{+0.07}_{-0.07}$	$3.06^{+0.19}_{-0.20}$	2.47	>5.32	$1.97^{+0.06}_{-0.06}$	$51.60^{+0.04}_{-0.04}$	28.3	0.5	$\frac{14.1}{14} = 1.00$
G349.7+0.2	$2.06^{+0.13}_{-0.12}$	$2.82^{+0.30}_{-0.38}$	2.70	>5.00	$2.00^{+0.12}_{-0.12}$	$50.09^{+0.04}_{-0.04}$	1.30	35	$\frac{5.2}{10} = 0.52$
Hess J1731-347	$1.86^{+0.04}_{-0.04}$	$3.65^{+0.10}_{-0.10}$	$4.27^{+0.02}_{-0.02}$	>5.19	$1.46^{+0.02}_{-0.02}$	$49.42^{+0.04}_{-0.04}$	45.1	0.01	$\frac{283.9}{322} = 0.88$
Hess J1745-303	$1.64^{+0.04}_{-0.04}$	$0.52^{+0.20}_{-0.18}$	2.03	>5.37	$1.66^{+0.08}_{-0.08}$	$49.53^{+0.08}_{-0.08}$	167	100	$\frac{3.62}{8} = 0.45$



A1a: 对于已经探测到的**30**多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）



A1a: 对于已经探测到的30多个伽玛射线超新星遗迹，结合射电和X射线观测，通过多波段辐射能谱拟合分析超新星遗迹中高能粒子分布函数演化的规律（刘四明、曾厚敦）

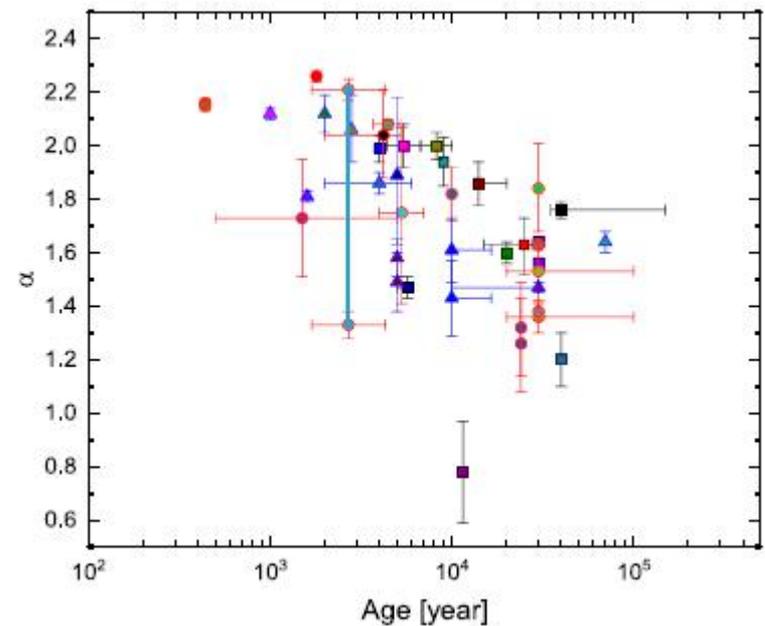
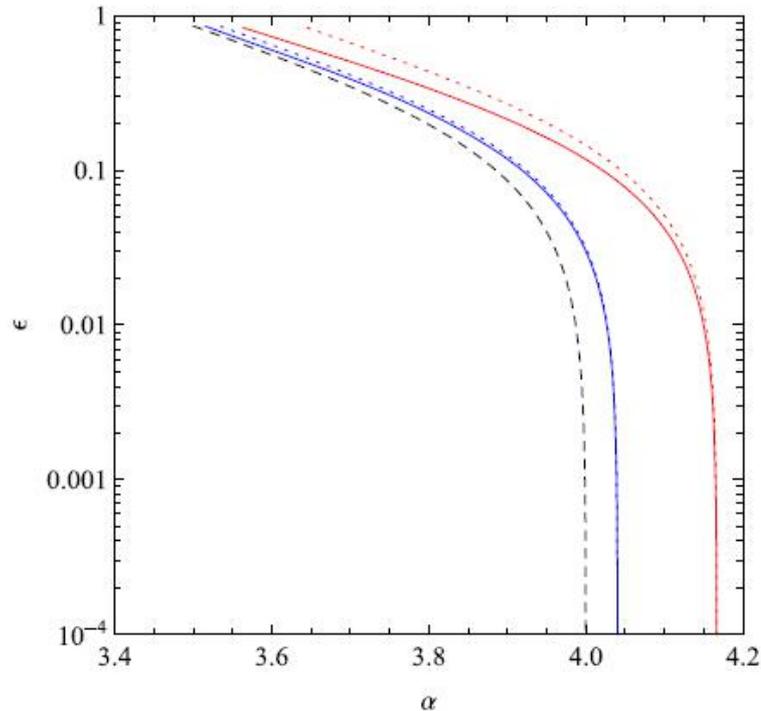
MNRAS 482, 5268–5274 (2019)

doi:10.1093/mnras/sty3136

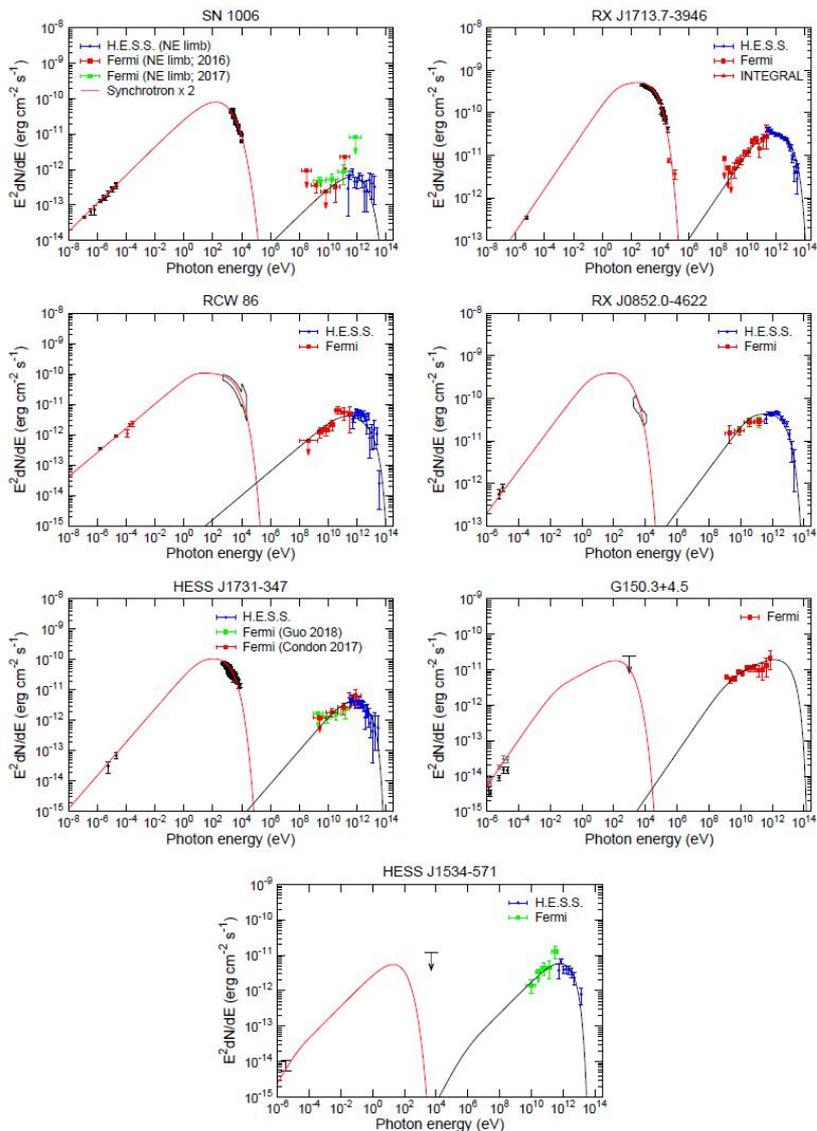
Advance Access publication 2018 November 19

Global constraints on diffusive particle acceleration by strong non-relativistic shocks

Yiran Zhang^{1,2★} and Siming Liu^{1,2★}



A1b：利用一个TeV辐射由轻子过程主导的年轻超新星遗样本（总共约10个源），分析年轻遗迹中高能电子分布函数的演化规律（刘四明、张潇）

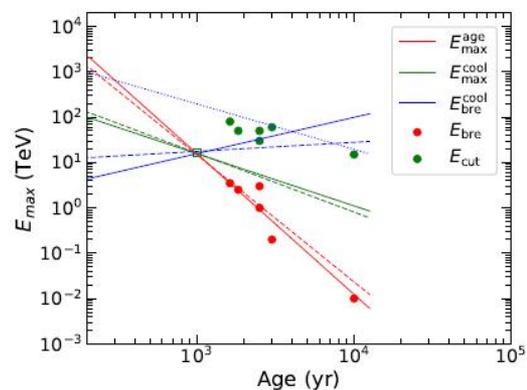
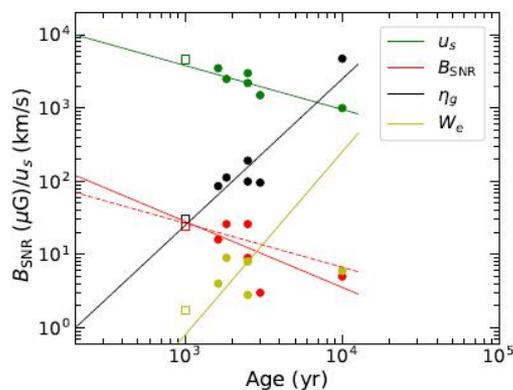


Electron acceleration in middle age shell-type γ -ray supernova remnants

XIAO ZHANG¹ AND SIMING LIU²

¹School of Astronomy & Space Science, Nanjing University, 163 Xinlin Avenue, Nanjing 210023, China

²Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, 8 Yuanhua Road, Nanjing 210034, China



A1b：利用一个TeV辐射由轻子过程主导的年轻超新星遗样本（总共约10个源），分析年轻遗迹中高能电子分布函数的演化规律（刘四明、张潇、曾厚敦）

THE ASTROPHYSICAL JOURNAL, 874:98 (6pp), 2019 March 20

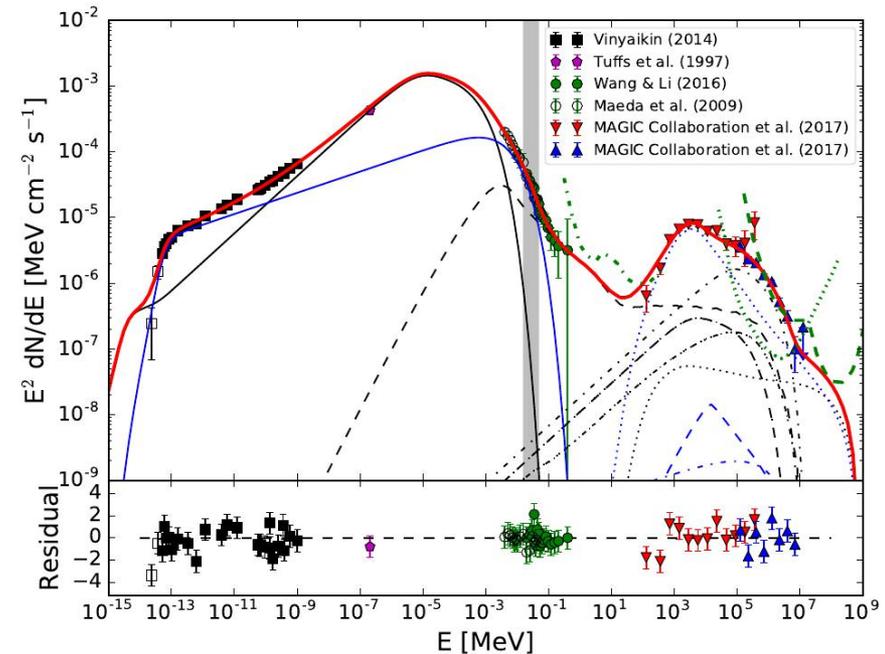
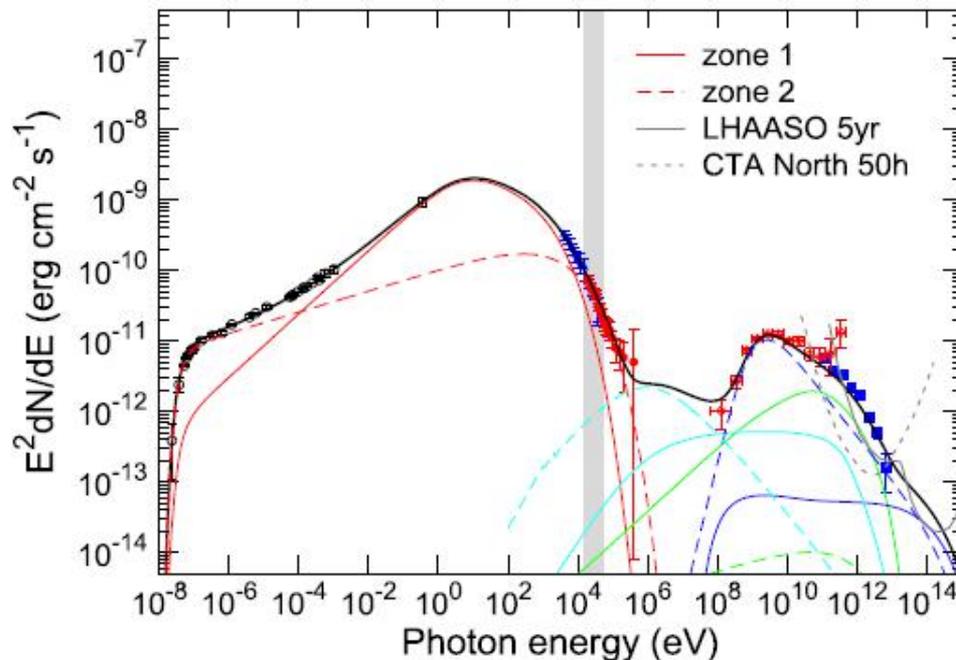
<https://doi.org/10.3847/1538-4357/ab09fe>

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Is Supernova Remnant Cassiopeia A a PeVatron?

Xiao Zhang^{1,2}  and Siming Liu³ 



A1c : 发展两分量的Hillas模型，将宇宙线总能谱和平均原子数谱与观测做比较 (刘四明、张轶然)

第 xx卷 第 x期
2019年x月

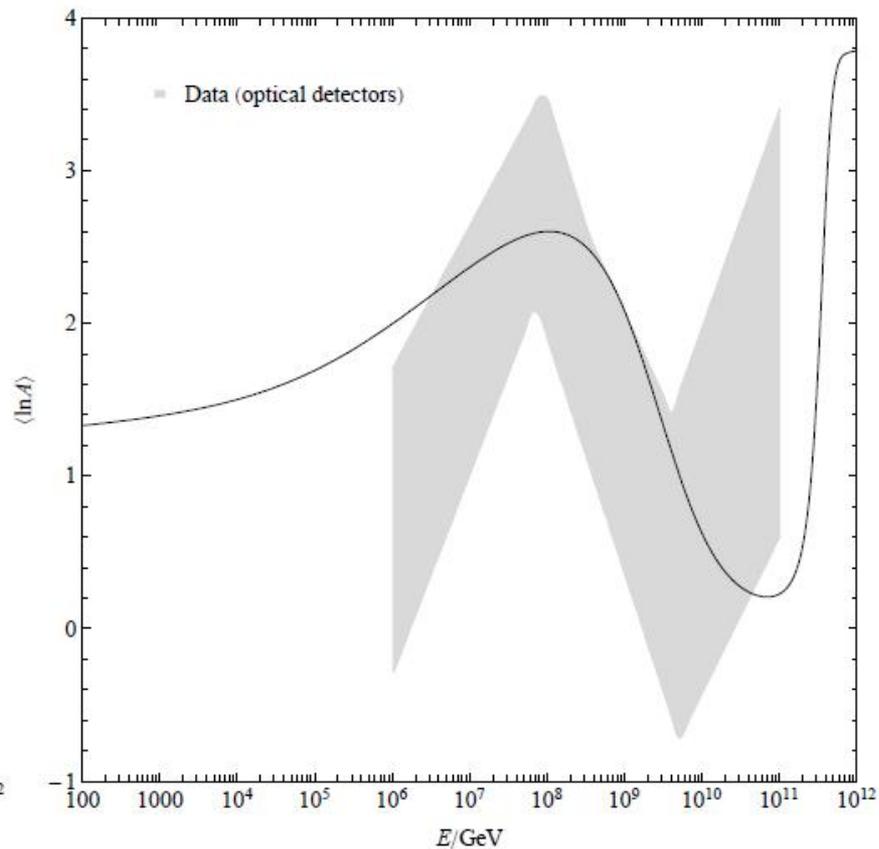
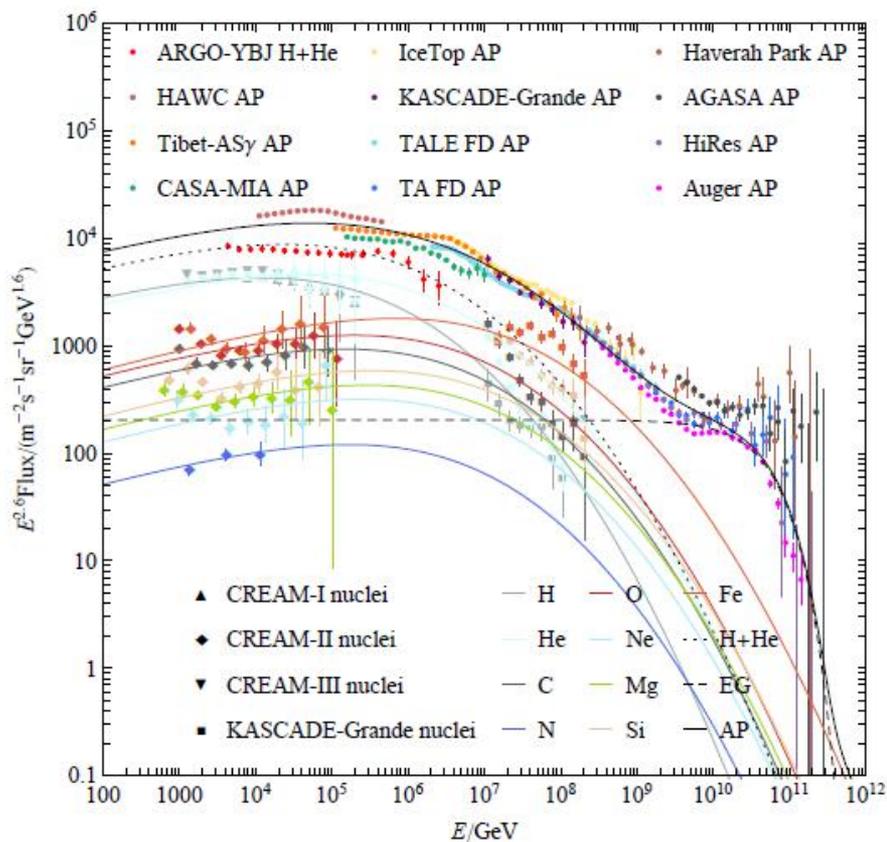
天 文 学 报
ACTA ASTRONOMICA SINICA

Vol.xx No.x
Xxx, 2019

doi: xxx...

宇宙射线的超新星遗迹起源*

张轶然^{1,2†} 刘四明^{1,2‡}



A2b：考虑到有大尺度磁场时，宇宙线扩散系数表现出高度的各向异性，利用一个1维扩散模型分析宇宙线正负电子的能谱和各向异性特征（刘四明、石召东）

Monthly Notices

of the

ROYAL ASTRONOMICAL SOCIETY



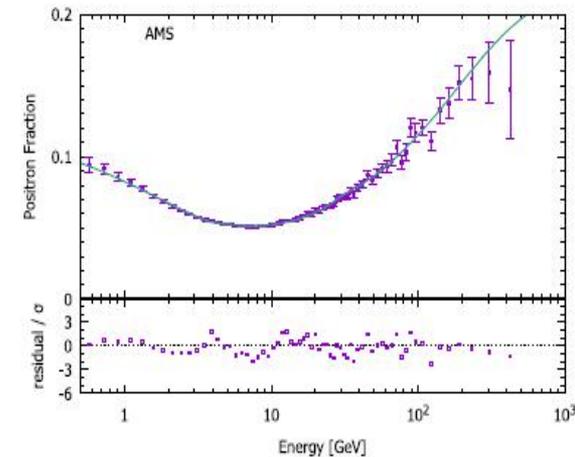
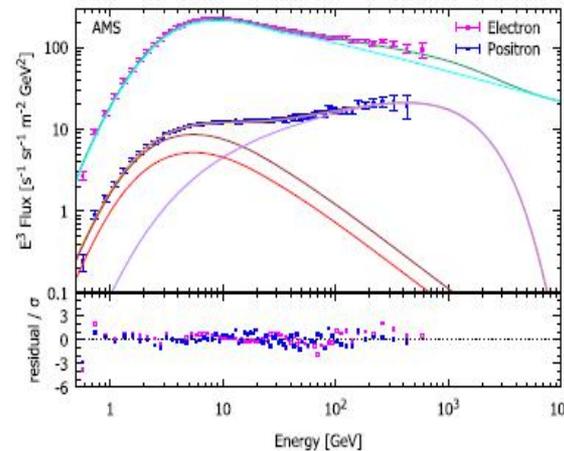
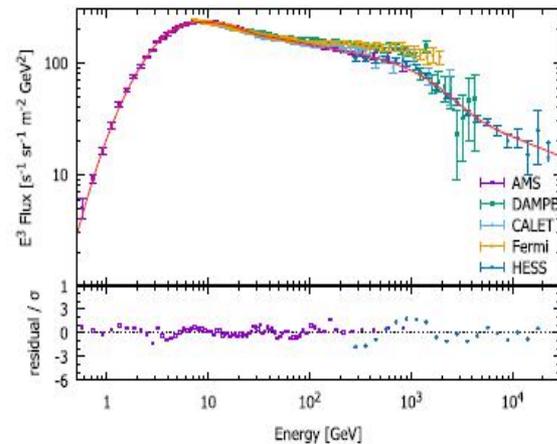
MNRAS **485**, 3869–3875 (2019)

Advance Access publication 2019 March 11

doi:10.1093/mnras/stz684

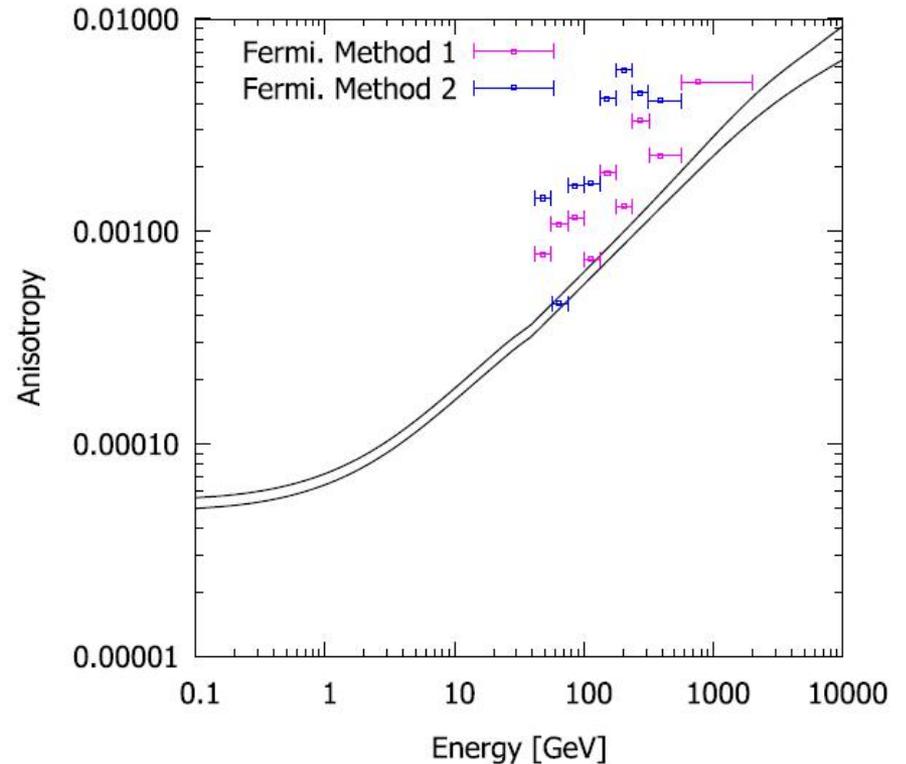
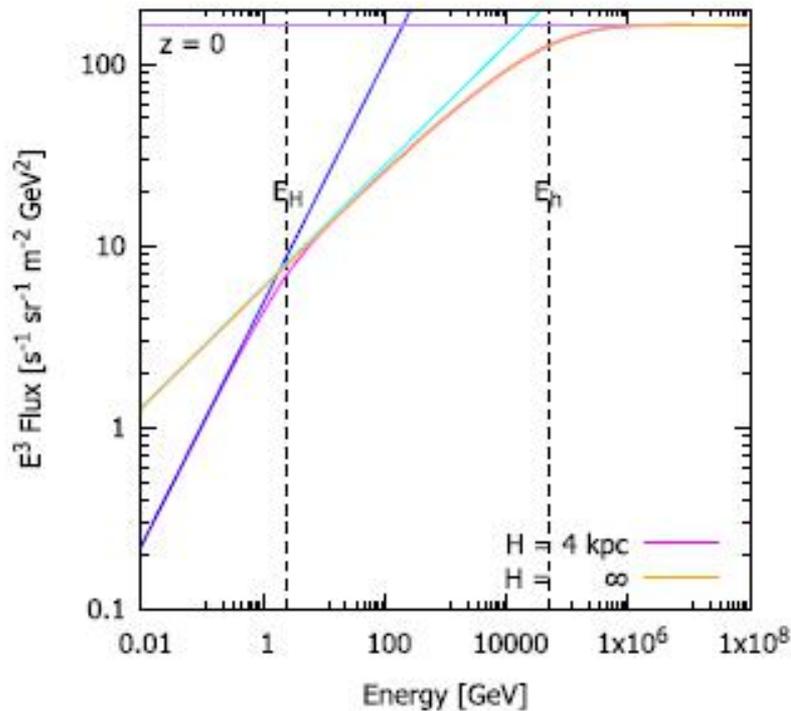
Origin of cosmic ray electrons and positrons

Zhao-Dong Shi^{1,2}★ and Siming Liu^{1,2}★



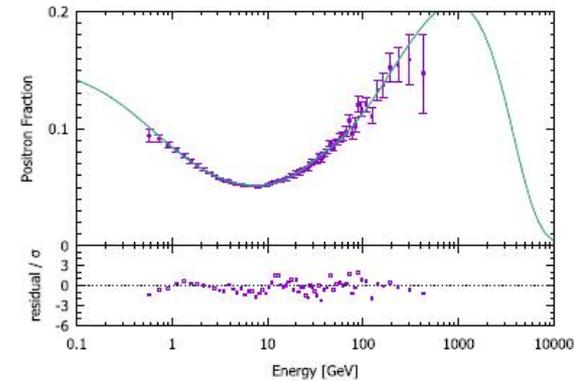
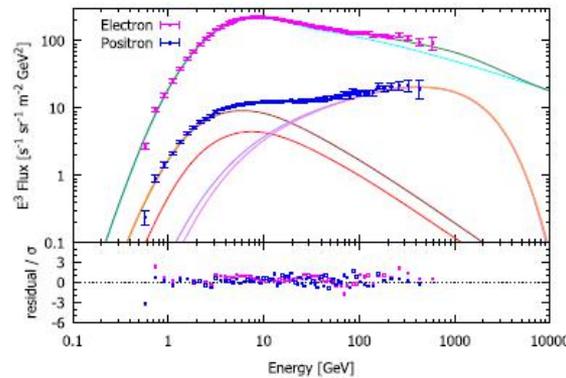
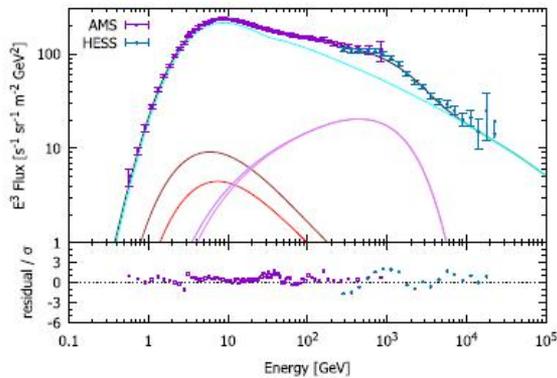
A2b：考虑到有大尺度磁场时，宇宙线扩散系数表现出高度的各向异性，利用一个1维扩散模型分析宇宙线正负电子的能谱和各向异性特征（刘四明、石召东）

Model	$C_{e^-}^{-a}$	$\gamma_{e^-}^1$	E_{br1}	$\gamma_{e^-}^2$	E_{br2}	$\gamma_{e^-}^3$	$C_{e^+}^{+a}$	γ_{e^+}	C_s^a	γ_s	E_{cut}						ϕ^f
M	1.06×10^3	3.35	4.96	3.64	32.4	3.37	163	4.05	3.14	2.62	1.10×10^3						1.14
Model	$C_{e^-}^{inj,b}$	$\gamma_{e^-}^{1,inj}$			E_{br}^{inj}	$\gamma_{e^-}^{2,inj}$	$C_{e^+}^{inj,b}$	$\gamma_{e^+}^{inj}$	$C_s^{inj,b}$	γ_s^{inj}	E_{cut}^{inj}	D_0^c	b_0^d	h^e	H^e	ϕ^f	
P1	6.04×10^{41}	3.05			41.4	2.63	1.03×10^{41}	3.72	1.15×10^{39}	2.08	2.80×10^3	153	8.67	0.242	3.25	1.28	
Model	$C_{e^-}^{inj,b}$	$\gamma_{e^-}^{1,inj}$			E_{br}^{inj}	$\gamma_{e^-}^{2,inj}$	$C_{e^+}^{inj,b}$	$\gamma_{e^+}^{inj}$	$C_s^{inj,b}$	γ_s^{inj}	E_{cut}^{inj}	D_0^c	b_0^d	h^e	H^e	$\phi_{e^-}^f$	$\phi_{e^+}^f$
P2	7.25×10^{41}	3.08			39.3	2.66	3.61×10^{40}	3.22	3.54×10^{38}	1.84	1.68×10^3	166	7.04	0.205	3.60	1.30	1.02



A2b：考虑到有大尺度磁场时，宇宙线扩散系数表现出高度的各向异性，利用一个1维扩散模型分析宇宙线正负电子的能谱和各向异性特征（刘四明、石召东）

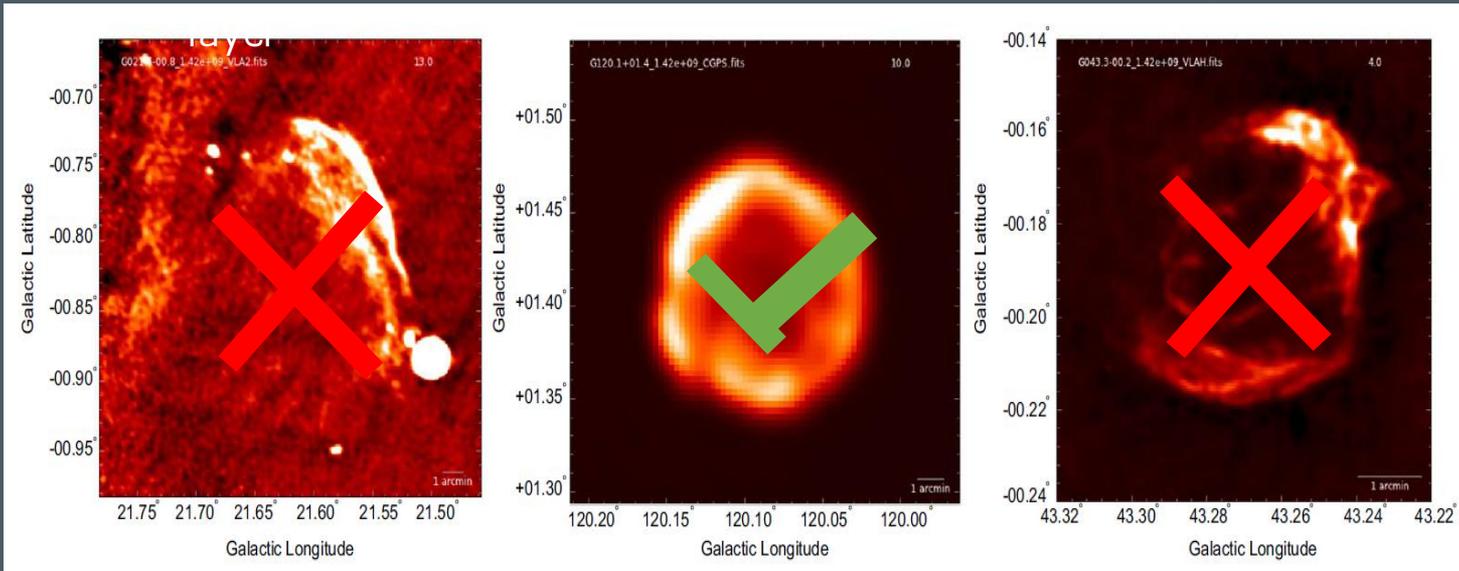
Model	$C_{e^-}^a$	$\gamma_{e^-}^1$	E_{br1}	$\gamma_{e^-}^2$	E_{br2}	$\gamma_{e^-}^3$	$C_{e^+}^a$	γ_{e^+}	C_s^a	γ_s	E_{cut}					ϕ^f	
M	1.06×10^{41}	3.35	4.96	3.64	32.4	3.37	163	4.05	3.14	2.62	1.10×10^{41}					1.14	
Model	$C_{e^-}^{inj,b}$	$\gamma_{e^-}^{1,inj}$			E_{br}^{inj}	$\gamma_{e^-}^{2,inj}$	$C_{e^+}^{inj,b}$	$\gamma_{e^+}^{inj}$	$C_s^{inj,b}$	γ_s^{inj}	E_{cut}^{inj}	D_0^c	b_0^d	h^e	H^e	ϕ^f	
P1	6.04×10^{41}	3.05			41.4	2.63	1.03×10^{41}	3.72	1.15×10^{39}	2.08	2.80×10^{41}	153	8.67	0.242	3.25	1.28	
Model	$C_{e^-}^{inj,b}$	$\gamma_{e^-}^{1,inj}$			E_{br}^{inj}	$\gamma_{e^-}^{2,inj}$	$C_{e^+}^{inj,b}$	$\gamma_{e^+}^{inj}$	$C_s^{inj,b}$	γ_s^{inj}	E_{cut}^{inj}	D_0^c	b_0^d	h^e	H^e	$\phi_{e^-}^f$	$\phi_{e^+}^f$
P2	7.25×10^{41}	3.08			39.3	2.66	3.61×10^{40}	3.22	3.54×10^{38}	1.84	1.68×10^{41}	166	7.04	0.205	3.60	1.30	1.02



Multi-

Circular

Irregular

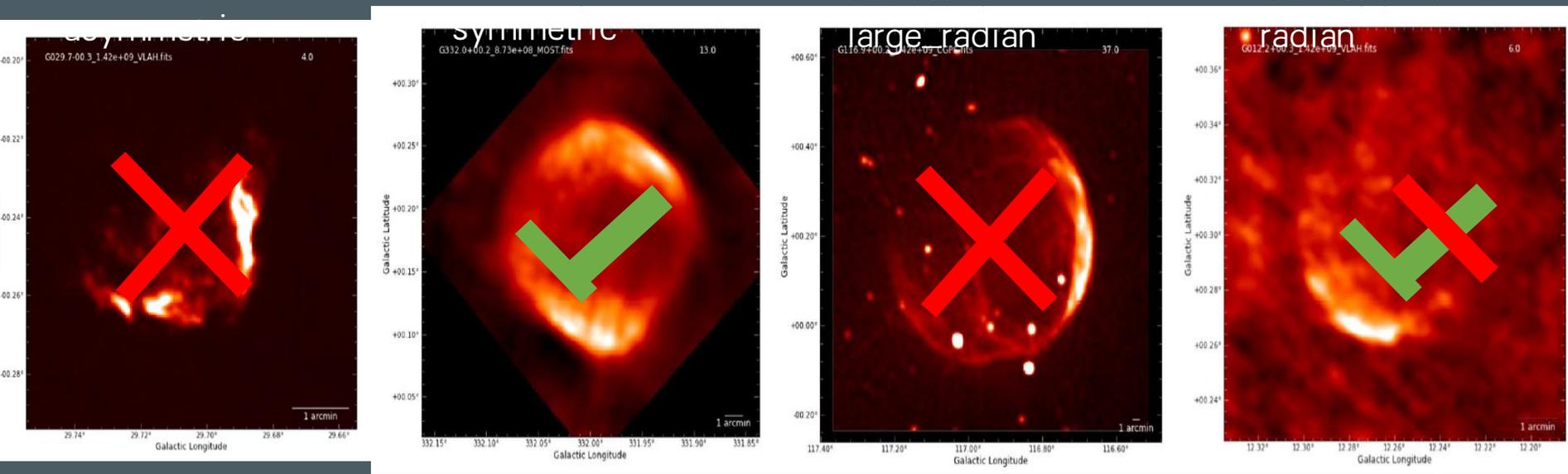


Bilateral

Bilateral

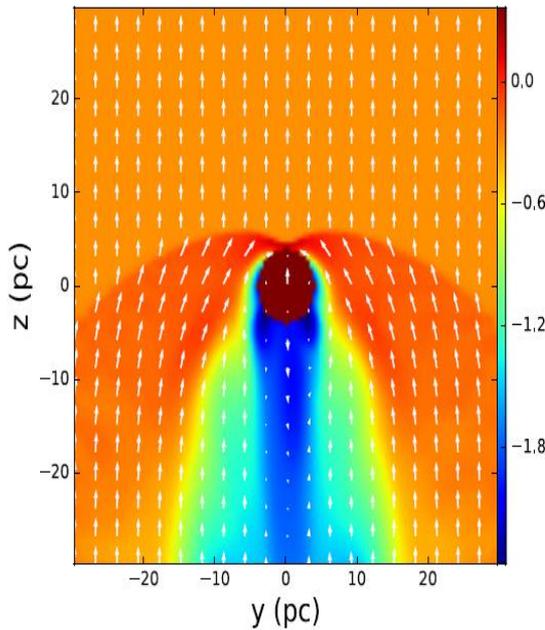
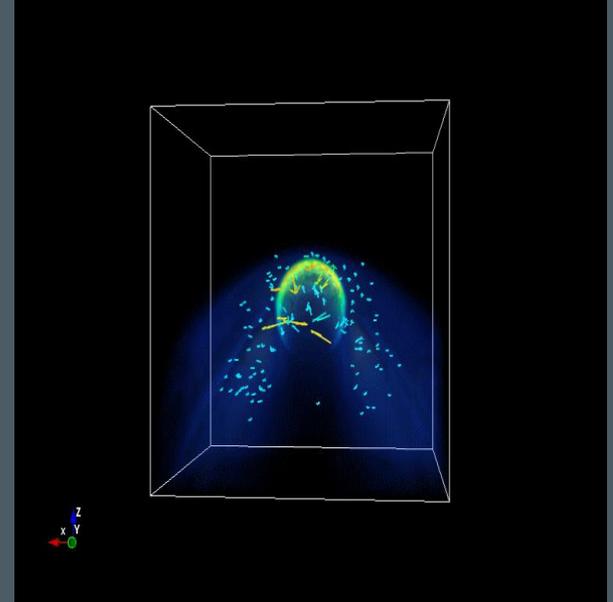
Unilateral

Unilateral small-

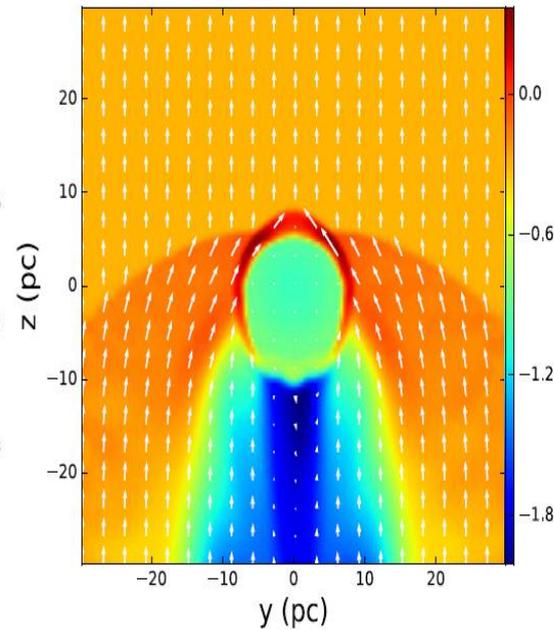


Consider different:

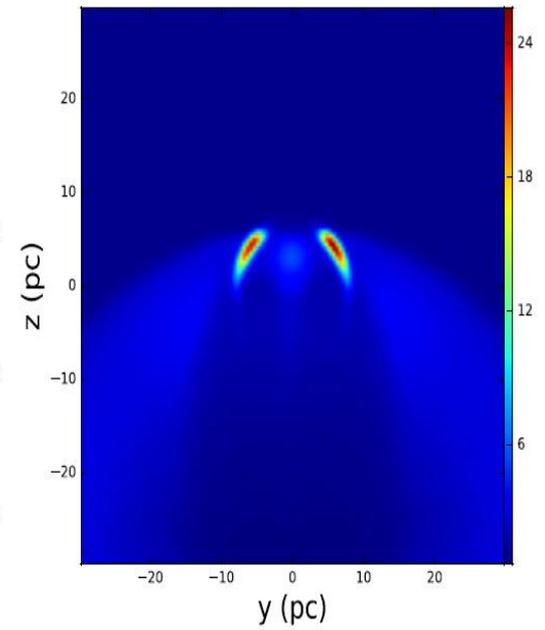
- 1) Progenitor mass
- 2) Stellar wind and proper motion
- 3) Magnetic field (direction and strength)



Stellar wind
density and
magnetic field



Supernova
remnant
density and
magnetic field



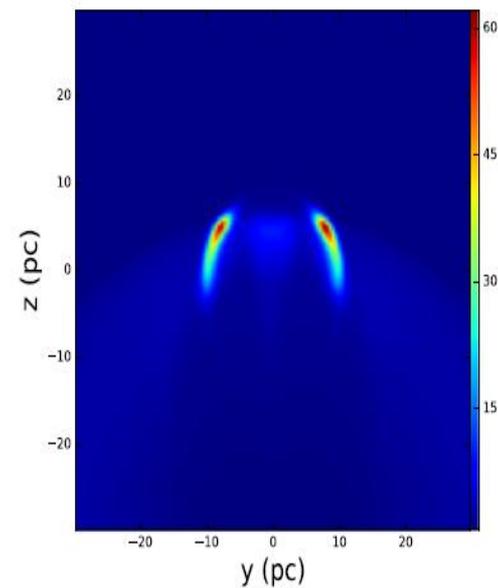
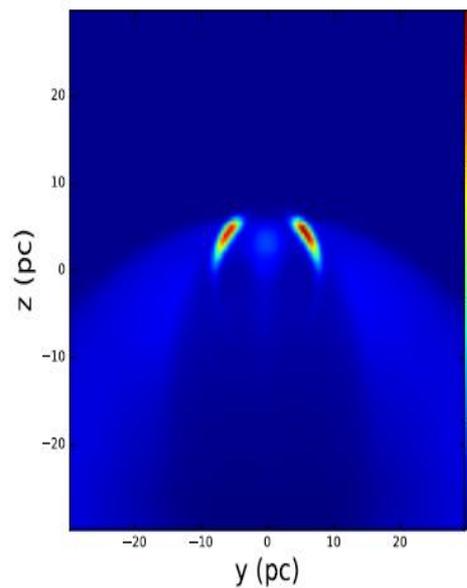
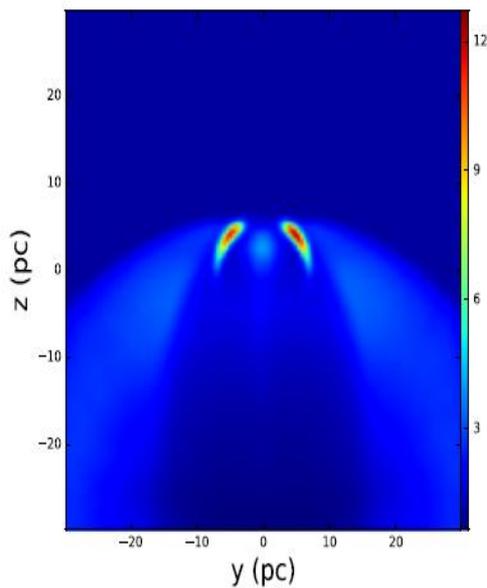
Supernova
remnant
density

1450yr

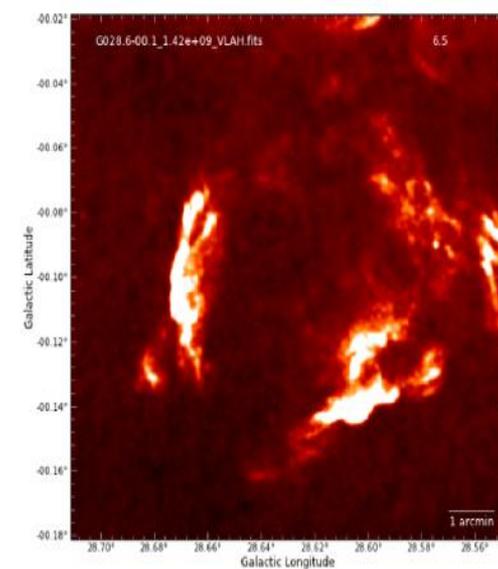
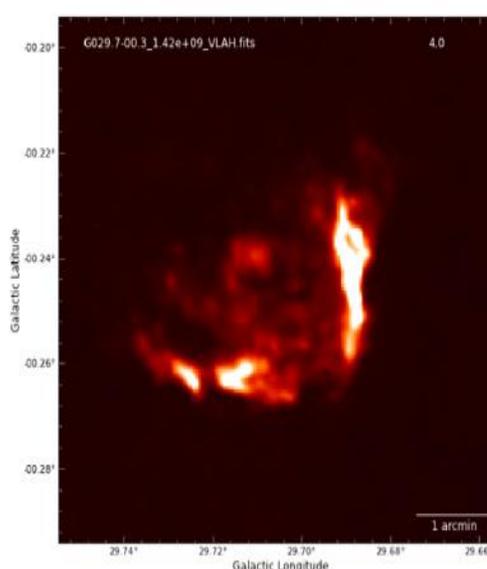
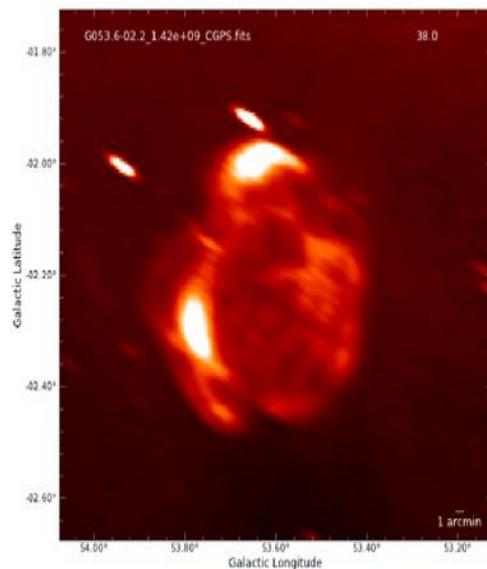
1850yr

3050yr

Radio
morphology
from simulation



Radio
morphology
from observatio



第三课题组年度考核指标

论文指标

研究方向	宇宙线的加速和传播	超新星遗迹和脉冲星的多波段研究	河外宇宙射线源的相关研究	宇宙线的多波段观测研究
2019	2	2+2	1+1	1
2020	2	2	2	0
2021	2	2	1	1
2022	2	2	2	0
2023	2	2	1	1
汇总	10	10	7	3

会议交流

每年做一次国际会议报告，组织一次会议，其中国内会议4次，国际会议1次；

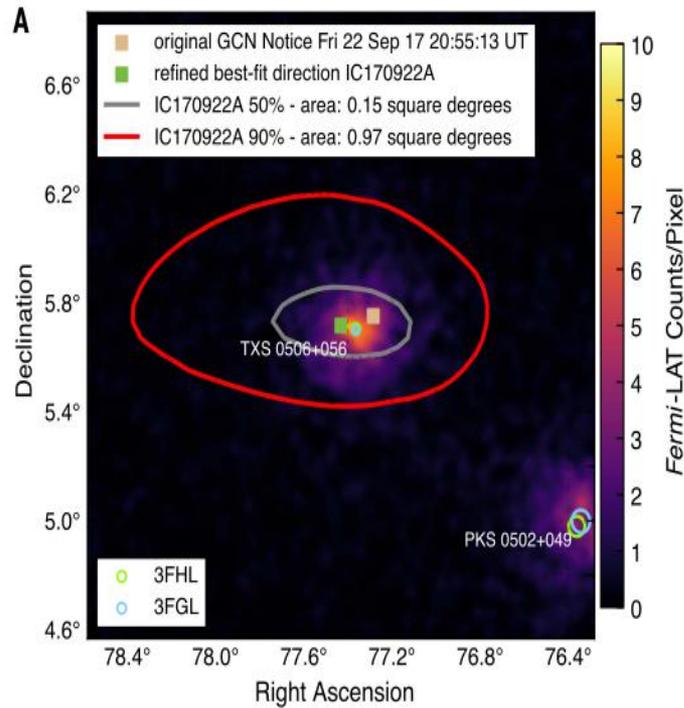
2019年发表的文章

- 1. Zeng, Houdun; Xin, Yuliang; Liu, Siming;** Evolution of high-energy particle distribution in supernova remnants. *ApJ*, 874, 50 (2019)
- 2. Zhang, Xiao; Liu, Siming;** Is Supernova Remnant Cassiopeia A a PeVtron? *ApJ*, 874, 98 (2019)
- 3. Shi, Zhaogong; Liu, Siming;** Origin of cosmic ray electrons and positrons. *MNRAS*, 485, 3869 (2019)
- 4. Bao, Yiwei; Liu, Siming; Chen, Yang;** On the gamma-ray nebula of Vela pulsar-I. constraining diffusion coefficient within the TeV nebula. *ApJ*, 877, 54 (2019)
- 5. Zhang, Xiao; Liu, Siming;** Electron acceleration in middle age shell-type gamma-ray supernova remnants. *ApJ*, 876, 24 (2019)
- 6. Zhang, Yiran; Liu, Siming;** Global constraints on diffusive particle acceleration by strong non-relativistic shocks. *MNRAS*, 482, 5268 (2019)

总结

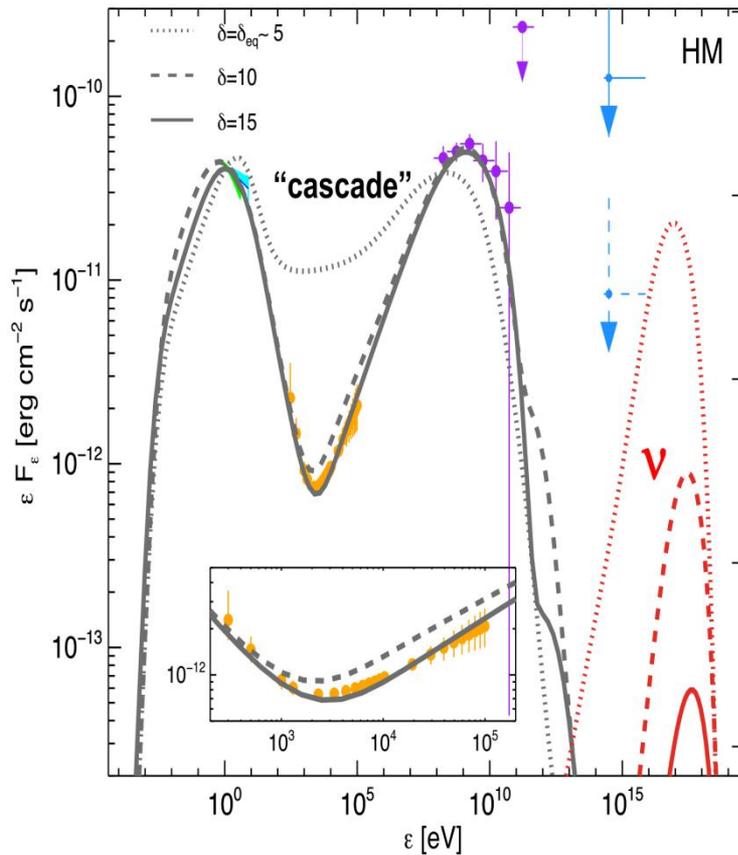
围绕宇宙线的起源和加速问题，本课题负责研究LHAASO的宇宙线能谱和各向异性结果，以及来自扩展源和弥散伽马射线观测结果，项目组按照实施方案顺利开展了第一年的研究工作。

Neutrinos from blazar TXS 0506+56



IceCube观测到一个300TeV的中微子事件与Blazar TXS 0506+56的多波段flare在 3σ 的置信度上成协

传统的Photomeson ($p\gamma$) 模型



Keivani et al. 2018

• 拟合存在问题:

• 1) cascade 辐射超过X-ray观测

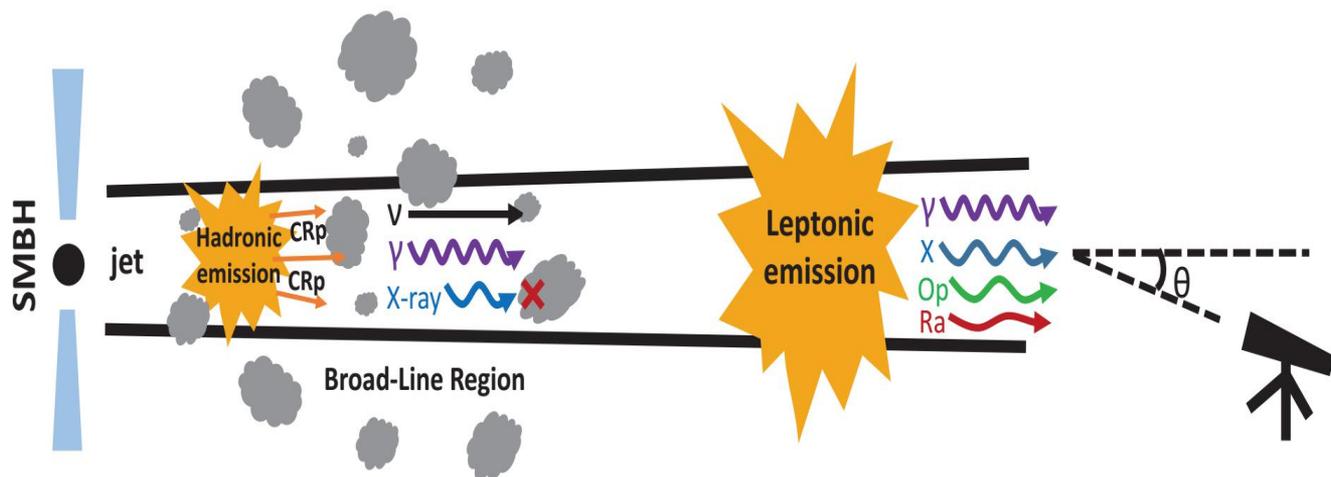
• 2) inefficient: 要求jet光度超过中心黑洞的Edd光度:

Lucky
Detection

pp interaction model

Liu et al. 2019

- 假定存在broad-line region

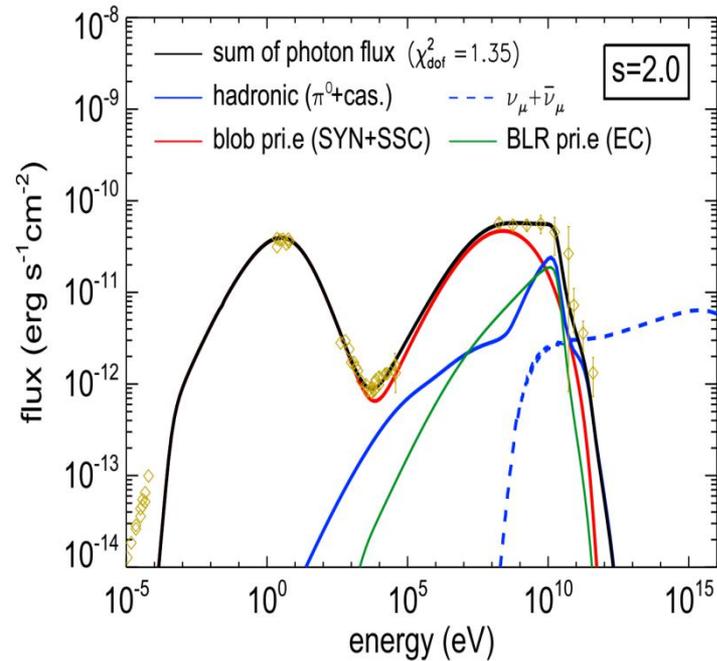
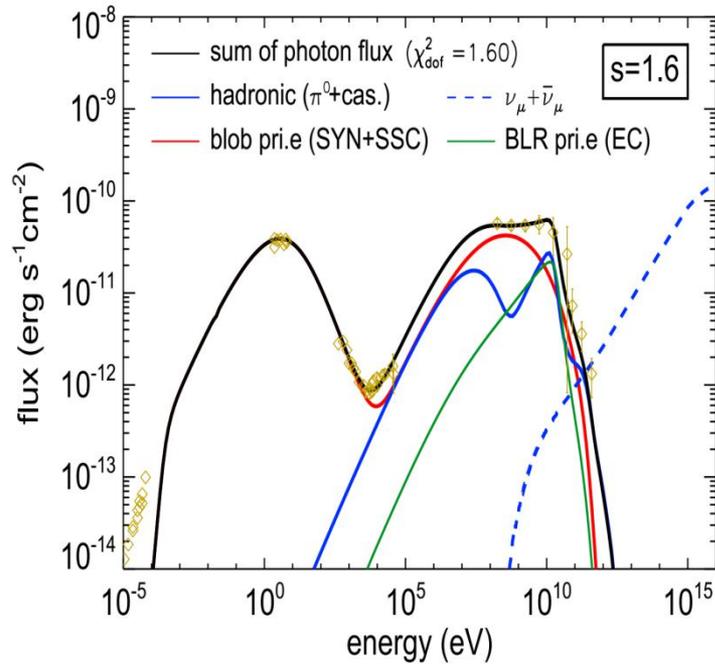


相比于传统模型：

1. 较高的中微子产生率 \rightarrow 宇宙线质子光度降至爱丁顿光度之下
2. 宽线区云团中被电离的电子提供康普顿光深，减少X射线流量，提高中微子流量

Modelling the SED

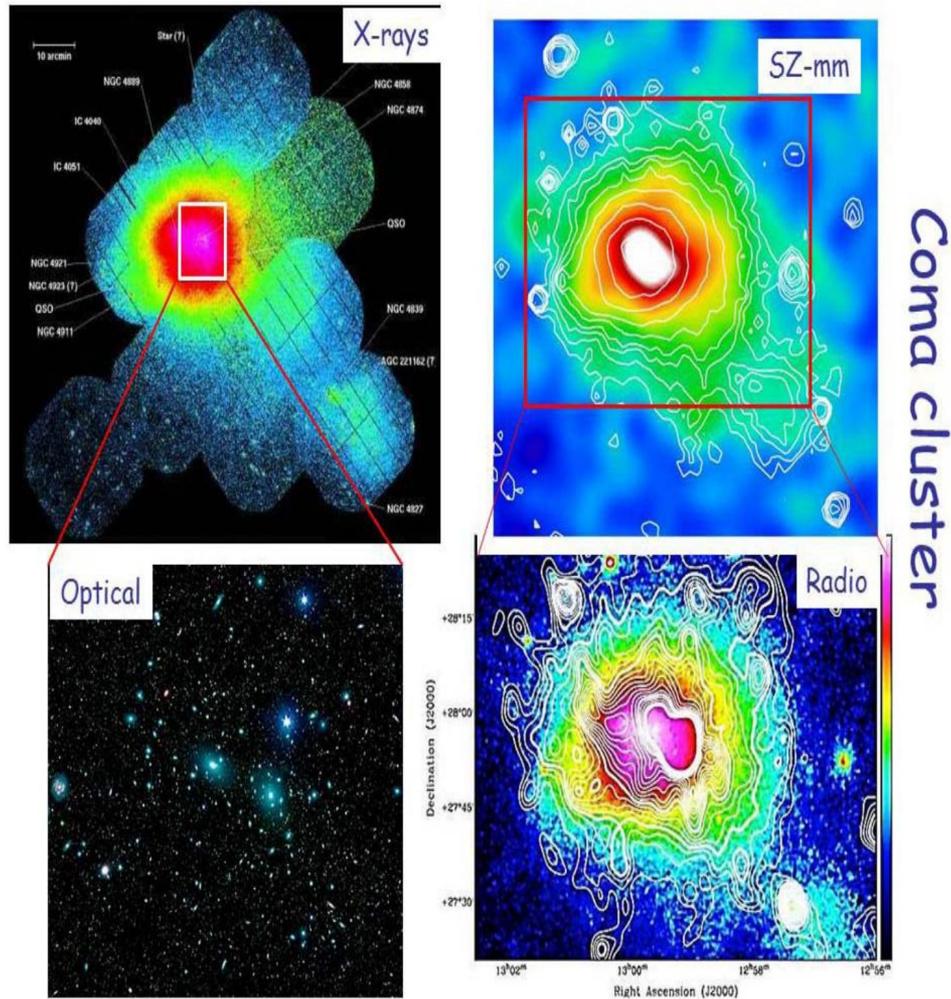
Liu et al. 2019, PRD



$s=1.6$: 1 (anti-)muon event / 80 days

$s=2.0$: 1 (anti-)muon event / 3.2 yrs

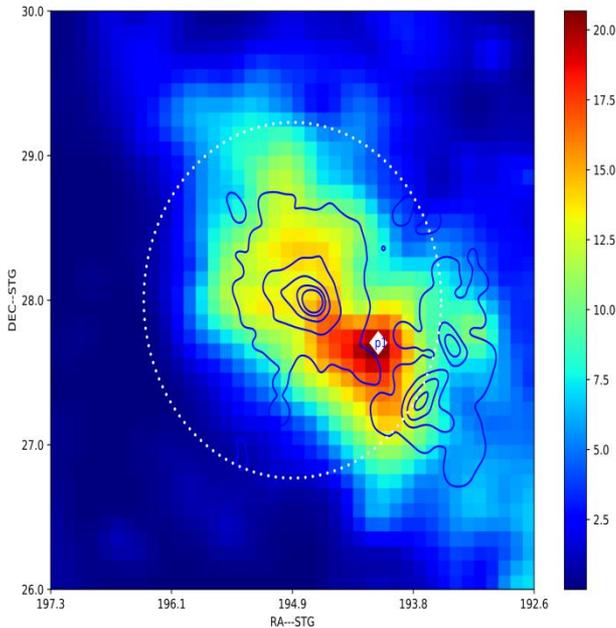
星系团中的宇宙线



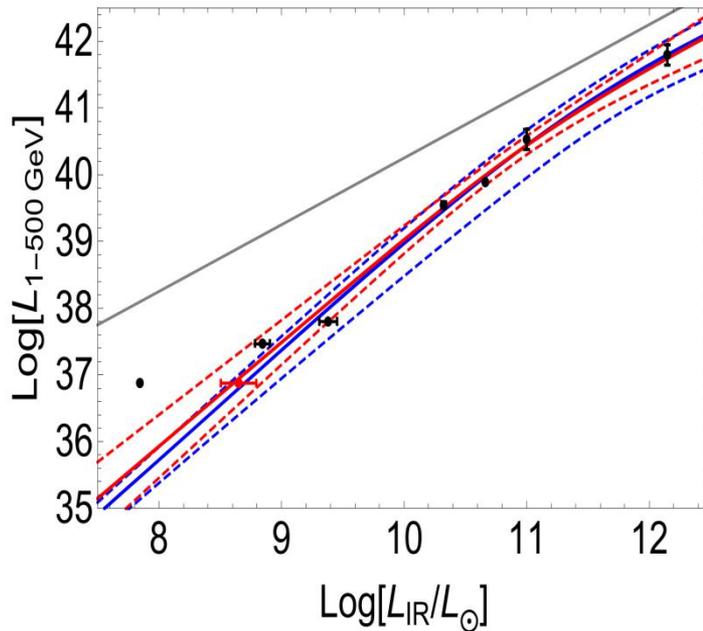
Fermi 9 years of data – unbinned likelihood analysis (0.2–100 GeV)

TABLE I. Unbinned likelihood analysis results for energy band 200 MeV–300 GeV.

Spatial model	Photon flux ($\times 10^{-9}$ ph cm $^{-2}$ s $^{-1}$)	Energy flux ($\times 10^{-12}$ erg cm $^{-2}$ s $^{-1}$)	Power-law index	TS
Disk	3.14 ± 0.54	2.52 ± 0.59	2.65 ± 0.25	38.9
Core	3.08 ± 0.52	2.50 ± 0.59	2.64 ± 0.25	40.1
Radio	2.74 ± 0.48	2.11 ± 0.43	2.70 ± 0.24	42.9
X-ray	2.39 ± 0.44	1.70 ± 0.35	2.81 ± 0.28	37.2
Point Source A (p _{center})	1.94 ± 0.42	1.12 ± 0.43	3.24 ± 0.94	23.4
Point Source B (p1)	1.92 ± 0.43	1.45 ± 0.26	2.73 ± 0.19	41.3
Disk + p1	2.45 ± 0.65	1.78 ± 0.81	2.78 ± 0.53	53.4
	0.67 ± 0.35	0.82 ± 0.31	2.30 ± 0.26	
Core + p1	2.43 ± 0.63	1.82 ± 0.76	2.73 ± 0.46	54.3
	0.65 ± 0.35	0.80 ± 0.30	2.30 ± 0.27	
Radio + p1	2.25 ± 0.55	1.66 ± 0.49	2.76 ± 0.36	56.5
	0.53 ± 0.30	0.75 ± 0.30	2.22 ± 0.27	
X-ray + p1	1.79 ± 0.53	1.23 ± 0.44	2.81 ± 0.28	52.9
	0.72 ± 0.37	0.85 ± 0.29	2.33 ± 0.27	
p _{center} + p1	1.13 ± 0.51	0.65 ± 1.08	3.23 ± 4.00	45.7
	1.14 ± 0.42	1.08 ± 0.38	2.49 ± 0.27	



Interpreting the correlation



- ◆ Changing slope, $\alpha \rightarrow 1.5$
- ◆ gamma-ray data is well consistent with such a steepening
- ◆ The steepening suggests that CR escape is important in low-SFR galaxies

会议安排

- 通过每年两次的合作组会议，汇报课题进展。
- 课题每月召开一次学术会议，邀请项目组所有成员和专家参加，可以视频参加。
- 3个任务组每个礼拜安排组会，根据需要邀请相关人员参加。

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590-v1	Global constraints on diffusive particle acceleration by strong non-relativistic shocks	Siming Liu	Publications [已发表文章] 银河系宇宙线 (紫台)	29 Dec 2018
589-v1	12月20组会	Siming Liu	银河系宇宙线 (紫台)	29 Dec 2018
576-v1	多波段研究组会---2018-11-15	Hui Zhu	多波段研究 (国台)	10 Dec 2018
575-v1	多波段研究组会---2018-12-07	Hui Zhu	多波段研究 (国台)	10 Dec 2018
546-v2	宇宙线三维各向异性扩散讨论---10月22日	Hongbo Hu	3D CR propagation [3D宇宙线传播]	30 Nov 2018
545-v1	宇宙线三维各向异性扩散讨论---11月15日	Hongbo Hu	3D CR propagation [3D宇宙线传播]	30 Nov 2018
544-v1	宇宙线三维各向异性扩散讨论---11月01日	Hongbo Hu	3D CR propagation [3D宇宙线传播]	30 Nov 2018
542-v1	Plasma Waves	Hongbo Hu	3. Third topic [宇宙线起源的唯象研究]	29 Nov 2018
518-v3	宇宙线三维各向异性扩散讨论---10月25日	Hongbo Hu	3D CR propagation [3D宇宙线传播]	29 Oct 2018

第三课题组年度考核指标

研究生和**博士后**培养指标
每年参与项目的研究生和**博士后**人数

培养单位	紫金山天文台	国家天文台	高能物理研究所	南京大学
2019	4+1	4	1	1+1
2020	4+1	4+1	2	1+1
2021	3+2	3+2	2	1
2022	2+2	3+2	2	1
2023	2+2	2+2	1	1
毕业或出站总人数	3+2	4+2	2	3+1

宇宙线能谱

