Statistical Study of the Optimal Local Sources for Cosmic Ray Nuclei and Electrons

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Abstract

Local sources, such as the Geminga supernova remnant (SNR), may have played an important role in the anomaly of protons, electrons, and anisotropy in past works. In fact, there exist 12 SNRs around the solar system within 1 kpc. One question is whether other SNRs also possibly contribute to the spectra of nuclei and electrons, and explain the special structure of the anisotropy. In this work, under spatial-dependent propagation, we systematically study the contribution of all local SNRs, within 1 kpc around the solar system, to the spectra of nuclei and electrons, as well as the energy dependence of the anisotropy. As a result, only the Geminga, the Monogem, and the Vela SNRs have quantitative contributions to the nuclei and electron spectra, and the anisotropy. Here, the Geminga SNR is the sole optimal candidate and the Monogem SNR is controversial due to the tension of the anisotropy between the model calculation and the observations. The Vela SNR contributes to a new spectral structure beyond TeV energy, hinted by the HESS, the VERITAS, the DAMPE, and the CALET measurements. More interestingly, the electron anisotropy satisfies the Fermi-LAT limit below TeV energy, but rises greatly and reaches 10% at several TeV. This novel structure will shed new light on verifying our model. We hope that the new structure of the electron spectrum and anisotropy can be observed by the spaceborne DAMPE and HERD, and the ground-based HAWC and LHAASO experiments in the near future.

Unified Astronomy Thesaurus concepts: Cosmic anisotropy (316); Galactic cosmic rays (567); Supernova remnants (1667)

1. Introduction

It is well known that supernova remnants (SNRs) are the dominant sources of Galactic cosmic rays (GCRs; Boulares 1989; Ackermann et al. 2013; Blasi 2013). In this scenario, the expanding diffusive shocks accelerate cosmic rays (CRs) to very high energy (VHE). The electrons and nuclei are concomitant and can both be accelerated to VHE simultaneously. This means that the nuclei and electrons should have some common origins (Yuan & Bi 2013). The combined study for such a multimessenger topic is important to unveil the enigma of the origins of the CRs. And the typical properties are required to be observed to support this viewpoint.

The measurements of CRs are stepping into a high precision era with the new generation of spaceborne and ground-based experiments. A series of new phenomena are revealed by these precise measurements. First, a fine structure of spectral hardening at 200 GeV for nuclei was discovered by the ATIC-2, the CREAM, and the PAMELA experiments (Panov et al. 2007, 2009; Ahn et al. 2010; Adriani et al. 2011; Yoon et al. 2017). Then, the AMS-02 experiment confirmed this with unprecedented precision (Aguilar et al. 2015a, 2015b). More interestingly, the spectral break off around ∼14 TeV was observed by the CREAM, the NUCLEON, and the DAMPE experiments (Akin et al. 2017, 2018; Yoon et al. 2017; An et al. 2019; Alemanno et al. 2021). Three categories of models such as the local sources model (Vladimirov et al. 2012; Sveshnikova et al. 2013; Liu et al. 2017, 2019), the combined effects from different group sources model (Malkov & Moskalenko 2021), and the spatial-dependent propagation (SDP) model (Guo et al. 2016; Jin et al. 2016; Guo & Yuan 2018; Liu et al. 2018) are proposed to explain these new structures. Similar to that of the nuclei, the electrons should also exist as such a component of spectral break off above ∼100 GeV. The recent precise spectrum measurement shows a sharp drop-off at 284 GeV for positrons, but no obvious change until TeV for the total spectra of electrons and positrons (Aguilar et al. 2019). The deficit of positrons above 284 GeV requires the compensation of primary electrons. This means that the excess of electrons exists in a way similar to the fine structure of nuclei, which is possibly accelerated by the SNRs scenario (Mertsch 2011; Bernard et al. 2012; Serpico 2012; Di Mauro et al. 2014; Fang et al. 2018b; Tang & Piran 2019).

What is more important is the anisotropy evolution with energy. Though the arrival directions of GCRs are highly isotropic due to their diffusive propagation in the Galactic magnetic field, a weak dipole-like anisotropy is consistently observed, with difference in intensity of up to ∼10−4−10−3. So far, a large amount of observations with anisotropies ranging from TeV to PeV have been carried out by the ground-based experiments, for example, the Super-Kamiokande (Guo et al. 2016; Bartoli et al. 2013, 2015), the Tibet (Amenomori et al. 2005, 2006, 2010, 2017), the Milagro (Adbo et al. 2008, 2009), the IceCube/Ice-Top (Abbasi et al. 2010, 2011, 2012; Aartsen et al. 2013, 2016), the ARGO-YBJ (Bartoli et al. 2013, 2015), and the HAWC (Abeysekara et al. 2014). It is clear that the phase of the anisotropy below 100 TeV energy roughly directs to the Galactic anticenter, which is totally paradoxical with the conventional propagation model (CPM). However, above 100 TeV, the phase gradually turns to the direction of the Galactic center, until about 100 PeV energies. This is consistent with the expectation of the CPM.
Correspondingly, the amplitude has experienced similar transition at the critical energy of 100 TeV. In addition, what is most important is that there exists a common transition energy scale between the structures of the energy spectra and the anisotropy. The local sources possibly play a very important role in resolving the conjunct problems of the spectra and the anisotropy (Liu et al. 2019; Qiao et al. 2019).

Based on the above discussion, the local sources are required to reproduce the multimessenger anomaly for the spectra of protons and electrons and the nuclear anisotropy. In our recent work, we propose a local source under the SDP model to reproduce the coevolution of the spectra and the anisotropy. We find that the Geminga SNR at its birthplace could be a preferred candidate (Liu et al. 2019; Qiao et al. 2019; Zhang et al. 2021). One natural question that follows, is that there exist dozens of SNRs near the solar system within 1 kpc, as shown in Figure 1, but what is the contribution from the other SNRs? In this work, we systematically study the contribution of all the local SNRs within 1 kpc around the solar system to the spectra of nucleons and electrons; the detailed parameters of these local SNRs are shown in Table 1. The paper is organized as follows: Section 2 describes the model description, Section 3 presents the calculated results, and Section 4 gives the conclusion.

2. Model Description

After entering the interstellar space, CRs undergo random walks within the Galactic magnetic field by bouncing off the magnetic waves and magnetohydrodynamic turbulence. The diffusive region, which is called the magnetic halo, is approximated as a flat cylinder with a radius of $R = 20$ kpc, equivalent to the Galactic radius. The half-thickness of $z_H$ is unknown, and is typically constrained by fitting the B/C ratio. The Galactic disk, where both the CR sources and the interstellar gas are mainly spread across, is located in the middle of the magnetic halo. The width of the Galactic disk is approximated to be invariant spatially and equals 200 pc. In addition to diffusion, CRs may also go through convection, diffusive reacceleration, fragmentation, radioactive decay, and other energy losses before arriving at the solar system. In fact, the process of convection is ignored in this work. The CR nuclei lose their energy principally via ionization, Coulomb scattering, and adiabatic expansion. For electrons and positrons, their major energy loss mechanisms are the bremsstrahlung, synchrotron radiation, and the inverse Compton scattering. This comprehensive process can be described by the propagation equation as

$$\frac{\partial \psi(r, p, t)}{\partial t} = q(r, p, t) + \nabla \cdot (D_{xx} \nabla \psi - V_c \psi)$$

$$+ \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{2} \psi - \frac{\partial}{\partial p} \left[ \rho \psi - \frac{p}{3} (\nabla \cdot V_c \psi) \right] - \frac{\psi}{\tau_f} - \frac{\psi}{\tau_r}$$

where $q(r, p, t)$ is the acceleration source, $\psi(r, p, t)$ the density of CR particles per unit momentum $p$ at position $r$, $V_c$ the convection velocity, $\rho \equiv dp/dt$ the momentum loss rate, $\tau_f$ and $\tau_r$ the characteristic timescales for fragmentation and radioactive decay, respectively, and $D_{xx}$ and $D_{pp}$ the diffusion coefficients in the coordinate and the momentum space, respectively.

2.1. Spatially Dependent Propagation

The SDP of CRs has received a lot of attention in recent years. It is first introduced as a two halo model (Tomassetti 2012) to explain the spectral hardening of both protons and helium above 200 GeV (Adriani et al. 2011). Afterwards, it is further applied to the secondary and heavier components (Tomassetti 2015; Feng et al. 2016; Guo et al. 2016; Liu et al. 2018; Tian et al. 2020; Yuan et al. 2020a), diffuse gamma-ray distribution (Guo & Yuan 2018), and large-scale anisotropy (Liu et al. 2019; Qiao et al. 2019). For a comprehensive introduction, one can refer to Guo et al. (2016) and Liu et al. (2018).

In the SDP model, the whole diffusive halo is divided into two parts. The Galactic disk and its surrounding area are called the inner halo (IH) region, in which the diffusion coefficient is spatially dependent and relevant to the radial distribution of background CR sources. The extensive diffusive region outside the IH is named as the outer halo region, where the diffusion is regarded as only rigidity dependent. The spatially dependent diffusion coefficient $D_{xx}$ is thus parameterized as

$$D_{xx}(r, z, R) = D_0 F(r, z) \beta^\gamma \left( \frac{R}{R_0} \right)^{\delta(r, z)}$$

where $r$ and $z$ are cylindrical coordinates, $R$ the particle’s rigidity, $\beta$ the particle’s velocity in units of light speed, and $D_0$ and $\gamma$ are constants. For the parameterization of $F(r, z)$ and $\delta(r, z)$, one can refer to Tian et al. (2020). The total half-thickness of the propagation halo is $z_H$, and the half-thickness of the inner halo is $z_{H0}$.

In this work, we adopt the common diffusion-reacceleration model, with the diffusive-reacceleration coefficient $D_{pp}$ coupled to $D_{xx}$ by $D_{pp} D_{xx} = \frac{4 p^2 v_A^2}{3 \delta (4 - \delta)^2 (4 - \delta)}$, where $v_A$ is the Alfvén velocity, $p$ is the momentum, and $\delta$ the rigidity-dependence slope of the diffusion coefficient (See & Ptuskin 1994). The numerical package DRAGON is used to solve the SDP equation to obtain the distribution of the CR positrons, electrons, and protons. Lower than tens of GeV, the CR fluxes are impacted by the solar modulation.
The well-known force-field approximation (Gleeson & Axford 1968; Perko 1987) is applied to describe such an effect, with a modulation potential \( \phi \) adjusted to fit the low-energy data.

### 2.2. Background Sources

SNRs are regarded as the most likely sites for the acceleration of GCRs by default, in which the charge particles are accelerated to a power-law distribution through diffusive shock acceleration. The distribution of the SNRs is approximated as axisymmetric, which is usually parameterized as

\[
    f(r, z) = \left( \frac{r}{r_0} \right)^\alpha \exp \left( -\frac{\beta(r - r_c)}{r_0} \right) \exp \left( -\frac{|z|}{z_s} \right),
\]

where \( r_0 = 8.5 \) kpc represents the distance from the solar system to the Galactic center. The parameters \( \alpha \) and \( \beta \) are taken as 1.69 and 3.33, respectively, in this work (Green 2015). The density distribution of the SNRs decreases exponentially along the vertical height from the Galactic plane, with \( z_s = 200 \) pc.

Past studies, for example, (Trotta et al. 2011; Boschini et al. 2017; Yuan et al. 2020b), have pointed out that the assumption of a single power-law injection spectrum could not reproduce the observations very well, especially in the diffusion-reacceleration model. Furthermore, this low-energy break has also been indirectly supported by the observations of nearby molecular clouds, see Neronov et al. (2012). Therefore, we introduce a break at low energy of the injection spectrum, where

\[
    q(R) = q_0 \left( \left( \frac{R}{R_{br1}} \right)^{\nu_1} \right), \quad R \leq R_{br1}
\]

\[
    q(R) = q_0 \left( \left( \frac{R}{R_{br1}} \right)^{\nu_2} \exp \left( -\frac{R}{R_{c}} \right) \right), \quad R > R_{br1},
\]

where \( q_0 \) is the normalization factor, \( \nu_{1,2} \) the spectral indices, \( R_{br1} \) break rigidities, and \( R_{c} \) the cutoff rigidity.

### References

(1) Smith et al. (1994); (2) Gorham et al. (1996); (3) Mavromatakis et al. (2002); (4) Xiao et al. (2009); (5) Green (2014); (6) Kothes et al. (2006); (7) Kothes et al. (2008); (8) Blair et al. (2005); (9) Sun et al. (2006); (10) Yar-Uyanik et al. (2004); (11) Reich et al. (2014); (12) Jonas et al. (1989); (13) Leahy & Tian (2006); (14) Reich et al. (1992); (15) Yamauchi et al. (2000); (16) Xu et al. (2007); (17) Katsuda et al. (2009); (18) Reich et al. (2003); (19) Leahy & Tian (2007); (20) Plucinsky et al. (1998); (21) Brinken et al. (2003); (22) Cha et al. (1999); (23) Alvarez et al. (2001); (24) Caraveo et al. (2001); (25) Miceli et al. (2008); (26) Aschenbach (1998); (27) Iyudin et al. (1998); (28) Redman & Meaburn (2005); (29) Katsuda et al. (2008); (30) Lazendic et al. (2004); (31) Morlino et al. (2009).

### Table 1

Characteristic Parameters of the Nearby SNRs within 1 kpc

| Number | SNR      | Other Name | Distance (kpc) | Radio Index \( \alpha \) | Age (kry) | Pulsar | References |
|--------|----------|------------|----------------|--------------------------|-----------|--------|------------|
| 1      | G194.3-13.1 | Geminga    | 0.33           | 0.58 ± 0.07             | 26 ± 1    |        | J0633+1746(1) |
| 2      | G65.3-5.7  |            | 0.9 ± 0.1      | 1.0 ± 0.4               | 16.75 ± 3.25| Unknown| (2–5) |
| 3      | G65.7+1.2  | DA 495     | 1.0 ± 0.4      | 0.45 ± 0.1              | 10 ± 1    | B1952+3252| (5, 8, 9) |
| 4      | G74.0-8.5  | Cygnus Loop| 0.54 ± 0.08    | 0.4 ± 0.06              | 7.7 ± 0.1 | B0450+55| (5, 6, 10, 11) |
| 5      | G114.3+0.3 |            | 0.7            | 0.49 ± 0.25             | 25 ± 5    |        | (5, 6, 11–13) |
| 6      | G127.1+0.5 | R5         | 1.0 ± 0.1      | 0.43 ± 0.1              | 10 ± 1    | B0458+46| (5, 6, 11, 18, 19) |
| 7      | G156.2+5.7 |            | 0.8 ± 0.5      | 2.0 ± 1.1               | 5.5 ± 1.5 | B0458+46| (5, 6, 11, 18, 19) |
| 8      | G160.9+2.6 | HB 9       | 0.8 ± 0.4      | 0.48 ± 0.03             | 86 ± 1    | B0656+14| (20–21) |
| 9      | G203.0+12.0| Monogem Ring| 0.288 ± 0.033 | 0.1 ± 0.5               | 11.2 ± 0.1| B0833-45| (5, 22–25) |
| 10     | G263.9-3.3 | Vela(XYZ)  | 0.295 ± 0.075  | Variable                | 3.5 ± 0.8 | J0855-4644| (5, 26–29) |
| 11     | G266.2-1.2 | Vela Jr     | 0.75 ± 0.01    | 1 ± 0.3                | 4.9       |        | (5, 30–31) |
| 12     | G347.3-0.5 | SN 393     | 1 ± 0.3        |                        |          |        |            |
The local SNRs may accelerate primary nuclei and electrons during their early evolution stage. This contribution of primary electrons from local sources may be necessary given the different spectral behaviors of the positrons and the electrons (Zhang et al. 2021). The injection process of the SNRs is approximated as burst-like. The source injection rate is assumed as the following,

\[ Q_{\text{int}}(t) = q_{\text{int}} \varphi(t - t_0), \]

where \( t_0 \) is the time of the supernova explosion. The propagated spectrum from the local SNRs is thus a convolution of Green’s function and the time-dependent injection rate \( Q(t) \) (Atoyan et al. 1995):

\[ \varphi(r, R, t) = \int_{t_0}^{t} G(r - r', t - t', R)Q_0(t')dt'. \]

### 3. Results

In this work, both the propagation and the injection parameters are fitted manually. By fitting the B/C ratio, the diffusion coefficient parameters are \( D_0 = 4.87 \times 10^{28} \text{ cm}^2 \text{s}^{-1} \), \( \delta_0 = 0.55 \), \( N_m = 0.6 \), \( n = 4 \), \( \xi = 0.1 \), and \( \eta = 0.05 \). The half-thickness of the propagation halo is \( z_0 = 5 \) kpc, and the Alfvén velocity is \( v_A = 6 \) km s\(^{-1}\). The comparison of the B/C ratio between the model prediction and the observation data is given in Figure 2, which indicates that the relevant parameters are reasonably matched. In order to determine which nearby SNRs are the appropriate candidates on the basis of their contributions to the proton and electron spectra, respectively, we carry out more detailed analyses in the following:

#### 3.1. Spectra of All the Local SNRs

Figure 3 presents the calculated proton and electron spectra for all the SNRs as listed in Table 1. Here, it can be seen that only the Geminga, the Monogem, and the Vela SNRs have significant contributions to the proton and electron spectra, respectively. Whereas most others have very limited contribution to the spectra. To appear in the same figure, we multiply a scale factor in the fluxes for the faint SNRs to show them properly, as shown by the dashed line in Figure 3. The detailed parameters of the local sources are listed in Table 2. In the following subsection, we give detailed studies on the contribution to the spectra and anisotropy by the Geminga, the Monogem, and the Vela SNRs. By doing so, we can expect to pinpoint the optimal local SNR.

#### 3.2. Spectra and Anisotropy of the Geminga SNR

Figure 4 illustrates the calculated energy spectra and anisotropy of protons and primary electrons, respectively. The blue solid lines are the fluxes from the background sources. Taking into account the contributions of the Geminga SNR as shown in Figure 3, the model predictions of the proton and primary electron spectra are in good agreement with the experimental data, as shown in the upper panel of Figure 4. Table 2 shows the relevant background and local source parameters. In fact, the anisotropy is a more effective factor to determine the dominant local SNRs from their direction, age, and distance. The bottom panel of Figure 4 shows the model-calculated anisotropy for CRs and electrons, respectively. It is obvious that the model-calculated anisotropy is consistent with that of the observations of CRs. And the electron anisotropy is roughly at the same level and far below the Fermi-LAT limit. Therefore, the results support our previous conclusion of the coevolved spectrum and anisotropy for the Geminga SNR (Liu et al. 2019; Qiao et al. 2019; Zhang et al. 2021).

#### 3.3. Spectra and Anisotropy of the Monogem SNR

Similar to the results of the Geminga SNR, the model calculations of the Monogem SNR are presented in Figure 5. The proton spectrum is also consistent with the observations. However, the calculated anisotropy greatly overthrows the observations. Obviously, there exists tension between the spectrum and the anisotropy. In addition, the cutoff energy of the electron spectrum is also beyond the TeV energy.
It should be noticed that the spin-down energy of the Monogem pulsar is lower than that of the Geminga pulsar with the value of $1.8 \times 10^{48}/1.25 \times 10^{49}$ erg. It is possible that the injection power of the Monogem SNR is much lower than that of the Geminga SNR. In fact, the $\gamma$-ray emission at TeV energy is much lower for Monogem compared with that of Geminga (Abeysekara et al. 2017). In Figure 5, the dashed line shows the corrected injection energy resulting from the spin-down energy. Under these circumstances, the contribution from the Monogem SNR can be ignored.

Another reason is the propagation effect in the source region. It is well known that the propagation coefficient in the source region is much lower (Abeysekara et al. 2017). This means that the CRs spend more time disentangling from the source. The age of Monogem is at the level of 86 kyr and only a limited part of the CRs from Monogem arrive at our solar system.
Figure 5. The calculated energy spectra (top) and anisotropy (bottom) for protons (left) and primary electrons (right) from the Monogem SNR, respectively. The implication of different colored solid lines is the same as that in Figure 4 and the different colored dashed lines display the corrected injection energy in accordance with the spin-down energy of the Geminga and the Monogem pulsars.

Figure 6. Left: the calculated total positron and electron spectra of the Vela SNR. The blue solid line is the total background flux. The yellow solid line with shadow indicates the Geminga SNR flux. The light-red dashed line with shadow represents the flux from the Vela SNR for different injected energies. The corresponding solid line is the sum of the background, the Geminga, and the Vela fluxes. The green squares are the measurements from the DAMPE experiment (DAMPE Collaboration et al. 2017). Right: anisotropies of electrons with the Geminga and the Vela SNRs under the SDP model. Both the black and red markers are the upper limits set by the Fermi-LAT experiment (Abdollahi et al. 2017).
On the other hand, the regular magnetic field could also regulate the CR flux from the local source. The observations (McComas et al. 2009; Schwadron et al. 2014; Zirnstein et al. 2016) have revealed that the phase of anisotropy less than 100 TeV is consistent with the effect of the local regular magnetic field. Ahlers (2014) has pointed out that the local regular magnetic field and the corresponding anisotropic diffusion have to be considered when accounting for the evolution relation of the amplitude, and phase of the anisotropy with energy. When the regular magnetic field is taken into account, the CR flux is projected into the regular magnetic field line and propagates along the magnetic field. If the sources are far away from the regular magnetic field, their fluxes to the solar system could be suppressed by the regular magnetic field. This will be investigated in detail in the coming work.

In a word, the contribution from the Monogem SNR is possibly limited. Other information is still required to check our model further on this point.

### 3.4. Spectra and Anisotropy of the Vela SNR

The Vela SNR is very young and is the nearest celestial body. It can provide very important clues to check our model in

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**Table 3**

| Background (DAMPE) | Normalization $^a$ | $\nu_1$ | $R_{\nu_1}$ | $\nu_2$ | $R_{\nu_2}$ |
|--------------------|-------------------|-------|-----------|-------|-----------|
| Electron           | $2.55 \times 10^{-1}$ | 1.60  | 5.10      | 2.72  | 1200      |
| SNR                |                   |       |           |       |           |
| Geminga            | 0.33              | $3.45 \times 10^5$ | 2.13    | 55    | $2.30 \times 10^6$ |
| Vela               | 0.30              | $1.12 \times 10^4$ | 2.10    | 55    | $5.00 \times 10^4$ |

Note. $^a$ The normalization is set at kinetic energy per nucleon $E_k = 10 \text{ GeV} \, n^{-1}$.

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**Figure 7.** Our model expectations of the total electron and positron spectra compared with the experiments of DAMPE (left top), CALET (right top), VERITAS (left bottom), and HESS (right bottom), respectively. The blue solid lines represent the fluxes from the background sources, the yellow lines are the fluxes from the Geminga SNR, the red lines with shadow are the fluxes from the Vela SNR, and the black lines indicate the corresponding sums of the above components.
terms of the CR spectrum and anisotropy. Figure 6 shows the expected spectrum and anisotropy for electrons. The related parameters are shown in Table 3. It is obvious that there exists a bump structure in the spectrum and sharp rising in the anisotropy above the TeV energy. In fact, the bump structure in the spectrum has been hinted by the HESS, the VERTITAS, the DAMPE, and the CALET observations (Aharonian et al. 2008; DAMPE Collaboration et al. 2017; Archer et al. 2018; Motz et al. 2022), as shown in Figure 7. In addition, the electron anisotropy reveals a remarkable hoist, which reaches 10% at several TeV. What makes the fact more convincing is that those abnormal phenomena can be tested soon. First, the spaceborne experiments DAMPE and HERD will be observing the new spectral structure in the short run. Simultaneously, the anisotropy is overwhelmingly larger for the electrons than for the CRs, which makes it easily observed by the ground-based experiments HAWC and LHAASO-WCDA.

Considering the importance of the Vela SNR, it is necessary to perform further study, such as on the effect of different ages. Figure 8 shows the spectra and anisotropy at 10, 100, 300, and 500 kyr for protons and electrons, respectively. It is obvious that the flux reaches its maximum at 100 kyr and then decreases smoothly. When the source age becomes as old as 500 kyr, the contribution can be ignored. In a word, the Vela SNR plays a similar role to Monogem at ∼100 kyr, and to that of Geminga at ∼300 kyr, and then disappears above 500 kyr.

4. Conclusion

With the operation of new generations of spaceborne and ground-based CR experiments, the measurements of CRs have stepped into a precise era. More and more fine structures have been unveiled in the CR energy spectra and anisotropy from hundreds of GeV to hundreds of TeV. To reproduce these observational phenomena, the local sources have to be involved in the model calculation.

In this work, we systematically study the contribution of all the local SNRs within 1 kpc around the solar system to the spectra and anisotropy of CR nuclei and electrons. We demonstrate that three local SNRs, i.e., Geminga, Monogem, and Vela, could have important contributions to both proton and electron spectra, as inferred from their distances and ages, assuming a common injection energy. However, the expected anisotropy from Monogem is obviously inconsistent with the observations. One of the possibilities is that its injection power is lower, considering that the spin-down energy of the Monogem pulsar is lower at about an order of magnitude than that of the Geminga pulsar. When the total injection energy is lowered by 1 order of magnitude, the influence from Monogem
can be safely neglected. That leaves the Geminga SNR as the dominant source responsible for the observational anomalies of the nuclear spectra and the anisotropy.

Furthermore, we expected that there is a new bump in electron spectrum above several TeV, which could stem from the young Vela SNR. Simultaneously, the magnitude of the excesses from the Vela SNR in the spectrum and the anisotropy are still observable. We hope such excesses are going to be checked soon by the spaceborne DAMPE and HERD and the ground-based HAWC and LHAASO experiments.

One has to note that the CR diffusion adopted in the above calculation is approximated as isotropic, in which it corresponds to the case of an ideal turbulent magnetic field in plasma. In fact, it is well known that there exists a large-scale component is taken into account, the diffusion coefficient is converted to a tensor, i.e., the diffusion coefficients parallel and perpendicular to the regular magnetic field have to be considered, respectively (Cerri et al. 2017; Liu et al. 2020). In the coming work, we would like to further study the influence of the regular magnetic field on the energy spectra and anisotropies.

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Note added. While this paper was ready to submit, another similar calculation is approximated as isotropic, in which it corre-
