Probing runaway protons using diffuse γ-ray emission surrounding the young supernova remnant RX J1713-3946

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Introduction: We expand on the work done by us in [1], and present predictions for the expected diffuse γ-ray emission near the supernova remnant (SNR) RX J1713-3946 using a plausible model of particle escape as a function of energy [3]. (For more information, see Casanova, et al., 2009; [2].) The hadronic cosmic rays (CRs) are then propagated through the interstellar medium (ISM) using energy-dependent diffusion (for different diffusion coefficients), whereby they interact with the ambient (atomic and molecular) ISM and produce γ-rays through neutral pion decay. We use recently published NANTEN II ^{12}CO and LAB H I data to accurately reproduce the structure of the ISM as a function of heliocentric distance. We discuss the ability of current (i.e., Fermi & H.E.S.S.) and future (i.e., CTA) instruments to observe and distinguish the resulting γ-rays from that of the omnipresent sea of CRs permeating the Galaxy.

Method: We have used the SNR solution of [3] with the characteristics of the historic SNR -- believed to be associated with the radio source -- of AD393. We use a total energy of order ~ $E_{SNR}=10^{51}$ erg for the SNR explosion. The molecular and atomic gas was modeled using results from the NANTEN II and LAB surveys and converted to heliocentric distance assuming a flat rotation curve ([1] and references therein). The molecular material within a radius of 10' corresponding to the extent of the radio shell, was removed so as not to bias our results. Protons (and heavier CRs) are then diffused away for 1600 years using a diffusion coefficient described by:

$$D(E_p) = \sqrt{a\left(\frac{E_p}{10\mathrm{GeV}}\right)^{0.5}}\ \mathrm{cm^2 s^{-1}}$$

where E_p is the proton energy. We have taken 'a' to be 10^{26}, 10^{27}, or 10^{28} $cm^2\ s^{-1}$. The γ-ray emissivity is then calculated by convolving the ambient gas density with the CR density as a function of position and distance. The CR density is simply the sum of the CR-sea and SNR produced CR density.

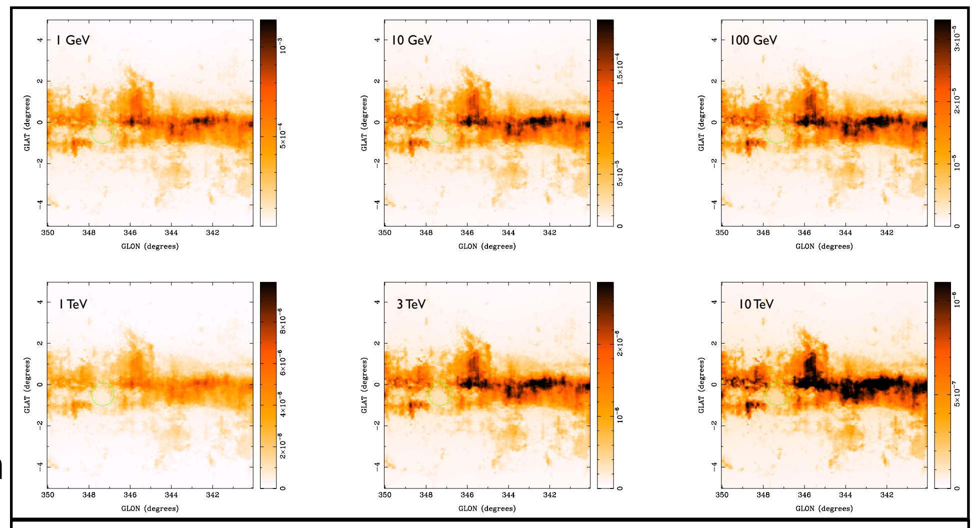

Figure 1: The CR sea as computed by convolving the atomic and molecular gas density with the local CR spectrum. The figure has units of GeV cm^{-2} sr^{-1} s^{-1}.

Results: Figure 1 shows the flux of γ-rays from the region surrounding RX J1713-3946 computed by convolving the ambient matter and CR densities. Using this basis, we have computed the expected γ-ray emission from the SNR after 1600 years, assuming different diffusion coefficients, which are shown in Figures 2 (a), (b) and (c) for an energy of 100 GeV. Although useful for morphological studies (i.e., correlation with radio maps), of more use is the ratio of the CR-sea+SNR to the CR-sea emission. This is illustrated in Figures 3 (a), (b) and (c) for the three chosen diffusion coefficients at energies of 1, 10 and 100 GeV and 1, 3 and 10 TeV. Finally, Figure 4 shows the spectra as a function of energy for four chosen regions, as shown in Figure 2(b) using diffusion coefficients of 10^{26}, 10^{27} and 10^{28} $cm^2\ s^{-1}$.

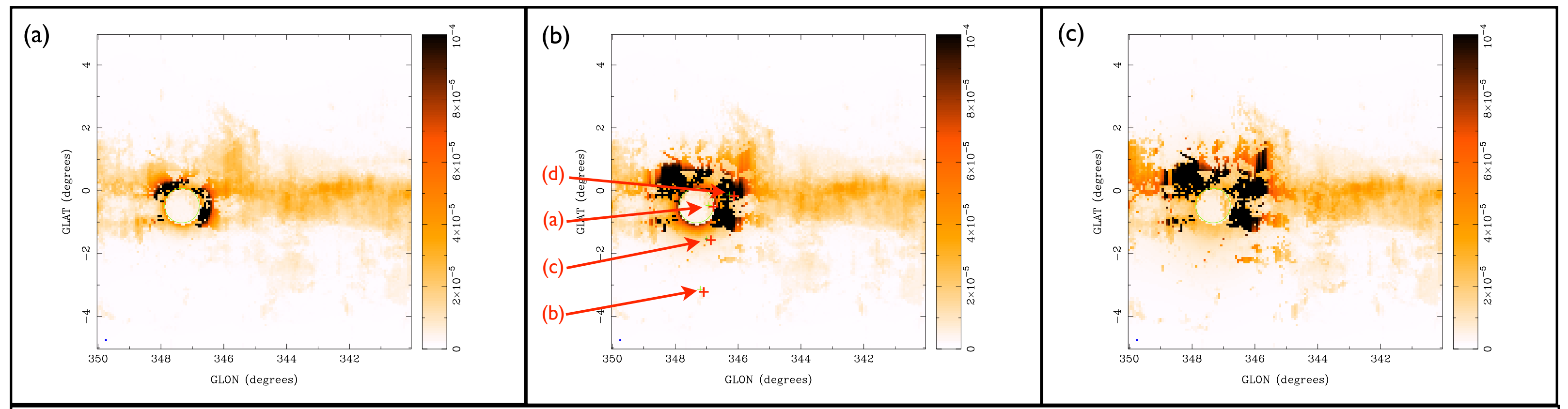

Figure 2: Diffuse γ-ray emission using the CR-sea + protons at 100 GeV using a diffusion coefficient of (a) 10^{26}; (b) 10^{27}; and (c) 10^{28} $cm^2\ s^{-1}$.

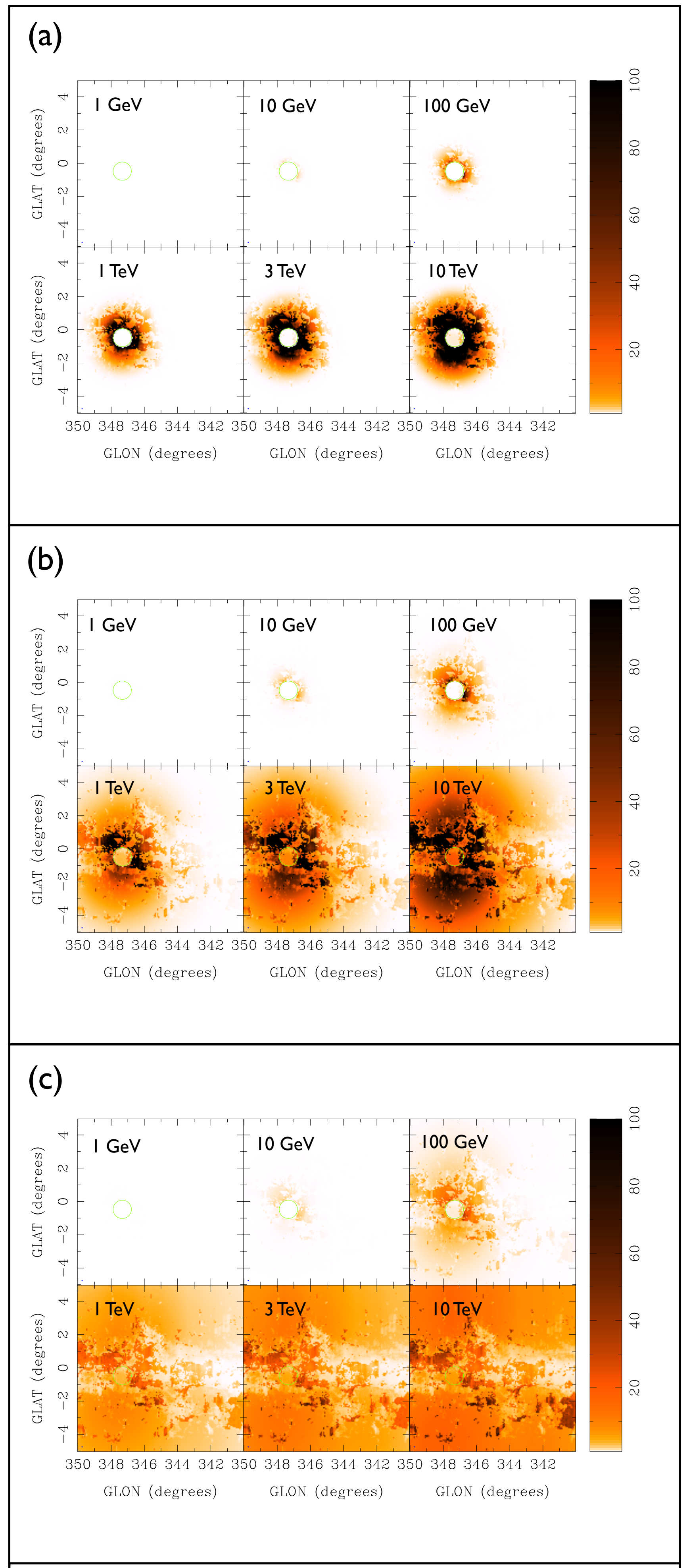

Figure 3: Ratio of the predicted γ-ray to that of the CR-sea at energies as labelled using diffusion coefficients of (a) 10^{26}; (b) 10^{27}; and (c) 10^{28} $cm^2\ s^{-1}$.

Bibliography:

[1] Casanova, S.; Aharonian, F. A.; Fukui, Y., et al., PASJ submitted, arXiv:0907.2887

[2] Casanova, S., Jones, D. I., Aharonian, F. A., et al., to be submitted to PASJ

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Discussion: Figure 1 shows a fairly typical segment of the Galactic Plane (this is the same region used in [1]; see poster P4-118 for more details), with much of the emission confined along the plane with a half-height of ~2 degrees. Whilst we have deliberately shown similar levels in Figure 1, comparison of the scale on the right, with the slope of the lines in Figure 4 shows that the spectrum of γ-ray emission is commensurate with the local CR spectrum (local here implies the CR flux as observed at the top of the Earth's atmosphere). Figure 2 allows one to observe the effects of the diffusion coefficient at 100 GeV; a diffusion coefficient of 10^{26} $cm^2\ s^{-1}$ shows little emission away from the remnant, whereas a diffusion coefficient of 10^{28} $cm^2\ s^{-1}$ allows particles to diffuse father away. Figure 2 also illustrates the importance of the distance information in calculating the resultant γ-ray emission; regardless of the diffusion coefficient, only molecular material which is co-located with the particles can contribute to the emission. This can lead to the situation where small, but dense clouds can be bright in γ-ray emission, whilst massive, but less dense clouds can appear under-luminous. This is a fact best illustrated in Figured 3 (a), (b) and (c), which shows that the ratio of calculated γ-ray emission to that expected due to the CR-sea can be a powerful diagnostic tool. This illustrates that particles in the 1-10 GeV range cannot diffuse away from the SNR effectively after just 1600 years, *no matter what the value of the diffusion coefficient*. Probing higher energies however, illuminates some interesting features of the emission. The high energy emission (1-10 TeV) shows that if the diffusion coefficient is 10^{27} $cm^2\ s^{-1}$, then the resulting γ-ray emission should be mostly located perpendicular to the Galactic plane, since the bulk of the molecular material is located at distances greater than the maximum diffusion distance. However, if the diffusion coefficient is closer to 10^{28} $cm^2\ s^{-1}$, then because the maximum diffusion distance is approaching the size of the region we are considering, the ratio is lower, and so distinct γ-ray emission may not be detectable. A high diffusion coefficient, at high energies also produces a considerable ratio of what may be mistaken for background emission, but which is actually emission from a source and not due to CR-sea. This serves, then, as an illustration of the possible in-homogeneity of the background γ-ray flux. Finally, Figure 4 shows that at different positions near a source, the resulting γ-ray spectra can vary wildly. This could possibly lead to detections of a sources near to sources such as RX J1713-3946 at some energies, whilst providing null detections at others, even if the source is producing high energy γ-ray emission.

Conclusions: We have presented predictions from [2] for the γ-ray emission from the region surrounding RX J1713-3940 due to the sea of CRs and that of the SNR. To calculate the γ-ray flux, we have used a realistic model of particle escape from the SNR [3] and diffused protons away from the SNR using a range of reasonable diffusion coefficient values. Furthermore, we have shown that a powerful diagnostic tool is the ratio of the expected γ-ray flux from the SNR+CR-sea to the CR-sea for discerning which molecular clouds could be observable to current and future γ-ray telescopes.

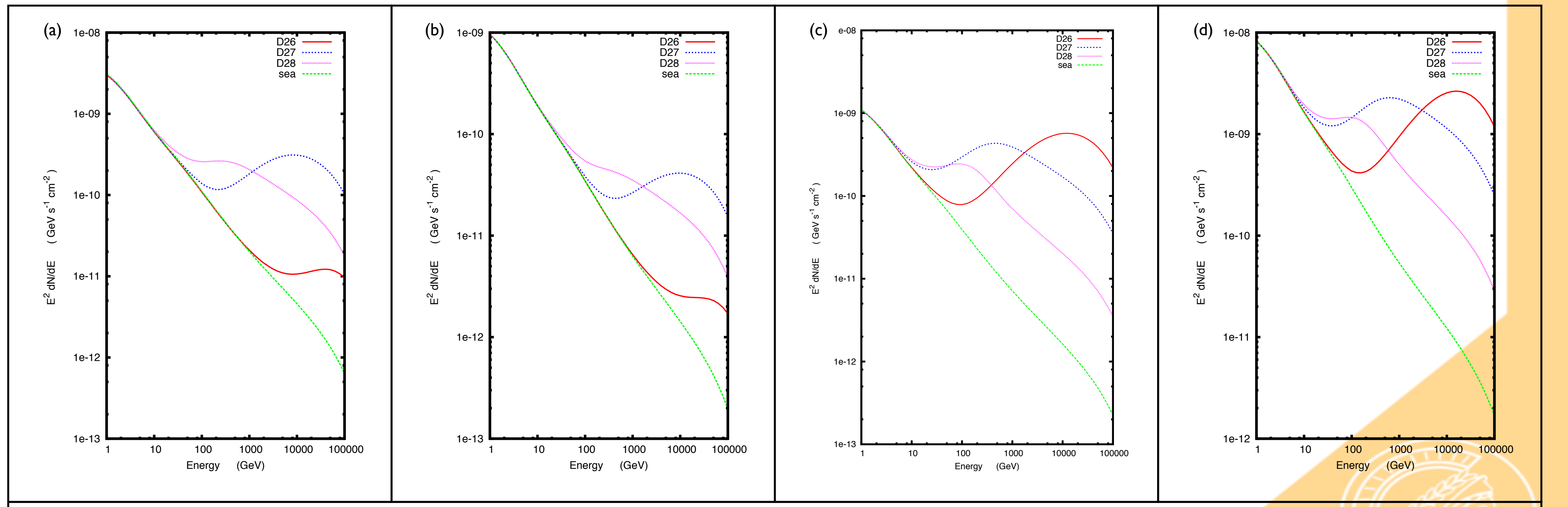

Figure 4: Spectra taken from different 0.2° x 0.2° regions near RX J1713-3690 for the different regions labeled (a), (b), (c) and (d) in Figure 2. Each plot shows the spectra for the different diffusion coefficients overlaid on the level of the CR -sea