Searching for Cosmic Ray Anisotropy
from the Vela SNR with CALET

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Introduction
The Calorimetric Electron Telescope (CALET) on the ISS measures the spectrum of electron-positron cosmic rays well into the TeV range. A main goal of CALET is to identify a signature of a nearby SNR in electrons-positrons cosmic-rays. The Vela SNR may create a spectral feature in the TeV region and/or a detectable anisotropy. Using the numerical cosmic-ray propagation code DRAGON, the expected anisotropy caused by Vela was calculated depending on injection and propagation conditions, and the ability of CALET to detect this signature studied.

Method of Anisotropy Calculation with DRAGON
The expected anisotropy from the Vela SNR is derived by numerical cosmic-ray propagation calculation, which includes detailed effects such as energy losses, secondary particle production, and anisotropy of the diffuse background. DRAGON features a non-equilibrium spatial grid, allowing for a fine spatial binning near the observation point and sources required for calculation of anisotropy. From the differences in cosmic ray density $F$ between the grid points around the Solar System, the flux $\Phi_{\text{ps}}$, from a direction of a given grid point $s_1$ can be calculated as shown by the formula to the left. Using the TeV$\delta$Tev grid points in the cube up to 4 steps of 5 parsecs away from the Solar System, the directional flux is calculated in 642 different directions, forming the dense mesh in galactic coordinates shown in the upper figure to the right. The predicted directional fluxes are then interpolated between these directions to fill a 50k pixel Headmap's map, and multiplied by the exposure of CALET (aperture 1200 cm$^2$ sr, detection efficiency 90%). To derive the expected events per pixel in CALET for five years of observation. An example of this anisotropy map is shown in the lower plot to the right, selecting events above a minimum energy of 100 GeV. While the anisotropy $\Phi_{\text{ps}}/\Phi_{\text{bkg}}$ generally rises with energy, the number of detected events falls, so that detection sensitivity can be maximized by tuning the minimum energy of selected events.

Scenario for Comparison with Analytical Calculation
We aim to reproduce the results of reference [3], which are based on a model from reference [4]. The propagation and injection conditions are $b = 0.6, D(E/V) = 1.5 \times 10^{29} \text{ cm}^2/\text{s}$ with an injection power law index of $\gamma = 2.7$ and $\alpha = -2.1$, yielding $D(\delta E/V) = 4.10^{28} \text{ cm}^2/\text{s}$ as quoted in reference [3]. The left figure above shows that the electron-positron spectrum for Vela obtained with DRAGON largely matches the results in [4] for similar parameters ($\gamma = 2.7$ and $\alpha = -2.1$). The plot on the right shows the agreement on the expected anisotropy as a function of galactic longitude (upper plot) and the expected maximum measured anisotropy as a function of minimum energy (lower plot) with the results in reference [3].

Anisotropy Analysis and Detectability of Vela with CALET
Based on the combined background-Vela event map, 5000 samples of 5-year CALET data are simulated using the poisson distribution to randomly determine the measured number of events in each pixel. A monopole and dipole with free direction are fitted to the samples, and the logarithm of the likelihood ratio to the monopole-only null-hypothesis histogrammed (left plot above), with the critical pixel. A monopole and dipole with free direction are fitted to the samples, and the logarithm of the probability of $\sigma_1$ is normalized to a total output of $10^9 \text{ erg}$ in electron CR above 1 GeV. The background from distant SNR is higher in the TeV-region due to the spiral-arm shaped source function in DRAGON, compared to the complete removal of nearby sources in [4]. The plots on the right show the agreement on the expected anisotropy as a function of galactic longitude (upper plot) and the expected maximum measured anisotropy as a function of minimum energy (lower plot) with the results in reference [3].

Conclusion
- The first direct measurement of the TeV-region electron-positron spectrum by CALET has a possibility to detect a significant anisotropy signal from the Vela SNR.
- The measurable anisotropy from Vela depends strongly on the propagation and injection parameters, which could thus be constrained by the (non-)detection of anisotropy.
- Numerical calculation of anisotropy by DRAGON reproduces analytical results and allows for detailed prediction of the expected anisotropy as a combination of multiple sources.

References