The shape of the gamma-ray line from radioactive $^{26}\text{Al}$, at 1808.7 keV energy in the frame of the decaying isotope, is determined by its kinematics when it decays, typically $10^6$ y after its ejection into the interstellar medium from its nucleosynthesis source. Three measurements of the line width exist: HEAO-C’s 1982 value of $(0 + 3)$ keV FWHM, the GRIS 1996 value of $(5.4 \pm 1.3)$ keV FWHM, and the recent RHESSI value of $(2.0 \pm 0.8)$ keV FWHM, suggesting either “cold”, “hot”, or “warm” in the ISM. We model the line width as expected from Galactic rotation, expanding supernova ejecta, and/or Wolf-Rayet winds, and predict a value below 1 keV (FWHM) with plausible assumptions about initial velocities and expansion history. Even though the recent RHESSI measurement reduces the need to explain a broad line corresponding to $540\text{ km s}^{-1}$ mean velocity through extreme assumptions about grain transport of or huge interstellar cavities, our results suggest that standard ejection models produce a line on the narrow side of what is observed by RHESSI and INTEGRAL. Improved INTEGRAL and RHESSI spatially-resolved line width measurements should help to disentangle the effects of Galactic rotation from the ISM trajectories of $^{26}\text{Al}$ nuclear reactions, nucleosynthesis, abundances – gamma rays: observations – supernovae: general – ISM: supernova remnants – stars: formation.

Introduction

Current Galactic nucleosynthesis reveals itself through the decay of $^{26}\text{Al}$, one of its radioactive by-products with a mean lifetime of $1.04 \times 10^6$ y. undergoes $\beta^+$-decay into an excited state of $^{26}\text{Mg}$, which de-excites through emission of a gamma-ray photon at 1808.7 keV. This gamma-ray line has been observed and imaged throughout the Galaxy mahoney82,diehl95,oberlack97,knoedlseder99,plueschke01. Sources of may be AGB stars and novae, but massive stars (via core-collapse supernovae and winds from Wolf-Rayet stars) have been found the most plausible and probably dominating sources prantzos96. The rather irregular emission along the plane of the Galaxy, and its consistency with the patterns of tracers of massive-star activity, is the main argument for favouring massive stars as the sources diehl96,knoedlseder99,plueschke01. Flux measurements have been employed to study the nature of the sources, comparing with predicted yields from models of the source types. The amount of present in the ISM of the Galaxy has been estimated at $\approx 2\text{ M}_\odot$, and used to argue for the roles of different source types. But the uncertainties about the spatial distribution and total number of nucleosynthesis events add to source yield uncertainties, providing only qualitative arguments for the nature of sources prantzos96. Therefore, locally constrained candidate source populations have been studied, such as in the Cygnus region knoedlseder00, plueschke01. In such a case, the distance to the sources is constrained to a smaller interval, along with the radial velocity due to Galactic rotation.

Measurements of Galactic with high-resolution spectrometers have produced somewhat controversial results: The initial discovery with the space-borne HEAO-C Ge spectrometer had reported a narrow line [intrinsic width (FWHM) $(0 + 3)$ keV];mahoney84. But the GRIS balloon-borne Ge spectrometer found the line to be significantly broadened (intrinsic FWHM $(5.4 \pm 1.4)$ keV; naya96). Such a broad line, however, cannot be explained easily [see]chen97. If the origin of the line broadening was thermal, the decay region would need to be at a temperature of $\approx 4.5 \times 10^8$ K. Alternatively, isotopes would have to maintain a mean velocity around 540 km s$^{-1}$ over their 1 My decay time, travelling kpc distances at those speeds. One may either assume that a substantial fraction of is injected into such rather large interstellar cavities, or that a substantial fraction of condenses onto dust grains before deceleration, so it maintains its momentum throughout passages of supernova remnant shells or other obstacles. The velocity could also be a result of re-acceleration of dust grains by interstellar shocks in the neighbourhood of the source, allowing them to maintain a high velocity over the decay time scale sturner99. None of these explanations is straightforward or without problems. A firm measurement of the gamma-ray line width is desirable, before questioning our understanding of fate from its production sites until decay in interstellar space.

New measurements have been obtained recently with Ge spectrometers aboard the high energy solar spectroscopy imager RHESSI smith03 and the INTEGRAL observatory. The RHESSI result was derived
through Earth occultation analysis of data while pointing at the sun. They obtain an intermediate intrinsic line width of about \((2.0 \pm 0.8)\) keV FWHM. The preliminary INTEGRAL measurement also suggests a narrow line, but systematic uncertainties are still large diehl03. Within the given uncertainties, the current set of measurements is mildly inconsistent. But more measurements have been recorded with INTEGRAL’s SPI Ge spectrometer already, so that longitude-resolved line width results are at the horizon.

We explore the potential of decay line shape measurements for diagnostics on the sources of and their interstellar environment. We follow up on earlier analysis by gehrels96, who showed that the structure of the Galaxy should be reflected in the position of the line due to Doppler shift from Galactic rotation. In this paper we employ an updated spatial distribution model for the plausible sources of in the Galaxy. We also account for the fate of ejected in interstellar space through different model variants which reflect ejections by winds and/or supernovae into cavities of plausible sizes for the massive-star environment of the sources. Our aim is to illustrate the diagnostic power of measuring the gamma-ray line’s position and width; this should be feasible with current instrumentation through imaging spectroscopy, even if a detailed decomposition of the line shape may still be beyond reach.

Sources in the Galaxy

Our model for the distribution of in the Galaxy is based on two separate aspects: the distribution of nucleosynthesis events in the Galaxy, and the distribution of in interstellar space following an individual nucleosynthesis event. For each of these, spatial as well as velocity-space densities have to be considered.

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