^{26}Al Radioactivity in the Galaxy

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Abstract. ^{26}Al radioactivity is believed to originate predominantly from massive stars, ejected into interstellar medium in wind phases and/or supernova events. With its million-year decay time, penetrating γ-rays from ^{26}Al decay measure the massive-star history averaged over a time scale of $\simeq$million years, thus extending times cales accessible otherwise. The COMPTEL 1.809 MeV all-sky data from 5 years of observations show irregularities and features at intermediate latitudes, which may have a more local origin ($\simeq$ 1 kpc). We find that the large scale emission can be characterized by a Galactic scale height of $\simeq$ 130 pc, and a Galactocentric scale radius of $\simeq$ 5 kpc, with features from spiral structure. Catalogues from massive-star related objects do not significantly improve the description of COMPTEL data above this. Emission associated with nearby structures such as the Gould Belt, Loop I, or stellar aggregates, is indicated, yet cannot be clearly detected. Combined with our imaging results, this suggests that ^{26}Al yields from massive star ensembles depend on specifics of those stars and their history. Further ^{26}Al γ-ray studies are underway to help mapping of the massive star history in the solar vicinity.

1 Introduction

Massive stars in the nearby region of the Galaxy have been detected through a variety of observables, such as their optical and UV brightness and unique spectral lines from the stellar photosphere, coronal X rays, and emission over a wide range of frequencies from their wind-blown bubbles and their interaction with the ambient gas. Even if stars cannot be detected directly due to obscuration, regions of high space density of massive stars have been identified indirectly, through, e.g., HII regions, Hα emission, infrared emission from massive protostars and circumstellar dust, and supernova remnants visible in radio through X rays. More directly, however, observation of nucleosynthesis products became now feasible, through penetrating gamma-rays emitted during decay of radioactive trace elements which are freshly produced (Prantzos & Diehl 1996). ^{26}Al radioactivity is believed to originate predominantly from massive stars, ejected into interstellar medium through the wind phases and/or supernova events. With its million-year decay time, gamma-rays from

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^{26}Al decay measure the massive-star formation history averaged over a time scale of several million years, thus extending time scales accessible otherwise.

2 Gamma-Ray Results

The COMPTEL all-sky data from 5 years of observations (Figure 1) have been translated into an image in the 1.809 MeV gamma-ray line, using the Maximum Entropy deconvolution method and a background model based on simultaneous measurements in adjacent energy bands (Oberlack et al. 1997). The image shows dominant emission from the plane of the Galaxy, yet also contains irregularities and features at intermediate latitudes, which may have a more local origin ($\leq$1 kpc). Therefore these have been investigated for correlation with formation sites of massive stars in the nearby region of the Galaxy, after accounting for the Galaxy-wide emission to first order. We find

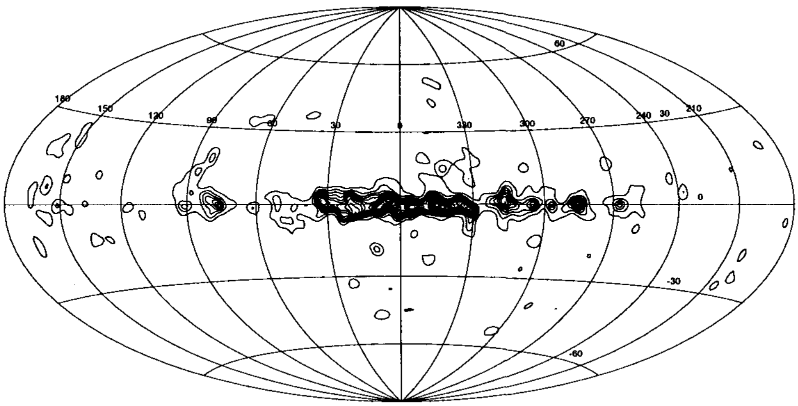

Fig. 1. COMPTEL all-sky image of 1.8 MeV emission (Oberlack et al. 1997)

that the large scale emission can be characterized by a Galactic scale height of 130 ($^{+100}_{-75}$) pc, and a Galactocentric scale radius of 5 ($^{+1.5}_{-0.8}$) kpc, with features from spiral structure(Diehl 1997). We fit a set of plausible large scale models to COMPTEL data: geometrical disk models with exponential scale height and Galactocentric scale radius dependancies (Diehl et al. 1995), spiral arm models derived from free electron measurements with exponential scale height as parameter (Taylor & Cordes 1993), molecular gas data as measured in CO (Dame et al. 1987), and stellar light- through dust-dominated measurements of the whole Galaxy in the infrared (Sodroski et al. 1994). Globally, we find

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that exponential disks are among the best generic models of our measurement, insignificantly inferior to the best-fitting spiral model based on free electrons; therefore we quote the scale radius determined from optimizing this model. Note that this may be biased by up to 1.5 kpc to high values due to structures such as the Cygnus/Vela/Carina regions. For determination of the scale height, we use the slightly better fitting spiral arm model, and optimize the fit through scale height variation. Note also here that this assumes a generic scale height value for the Galactic plane emission, averaging specific features along the plane.

There are emission features far outside the inner Galaxy regime, in the Cygnus, Vela, and Carina regions, each region by itself detected at significances $\geq 5\sigma$. This suggests significant deviations from a large scale symmetric and smooth ^{26}Al emission pattern. Those regions have been studied for candidate sources, each of them found to have special characteristics, which are compatible with a localized enhancement of star formation/^{26}Al : the Cygnus region with the Cygnus superbubble as remnant of possibly 60 recent supernovae as well as several Wolf Rayet stars along the line of sight (del Rio et al. 1996), the Vela region with the Vela supernova remnant and the closest Wolf Rayet star in the system 'γ Vel' (Oberlack et al. 1994), and the Carina region with η Car but also the largest space density of young open clusters in the Galaxy (Knödlseder et al. 1996). We take this as evidence that massive stars are among the most promising candidate sources of ^{26}Al, rather than novae or AGB stars.

Therefore we invert the argument, and attempt to constrain the massive-star population in the Galaxy and specific regions by the measurement of radioactive ^{26}Al ejected through their winds and supernovae. Globally the estimated total mass of ^{26}Al produced in the Galaxy is consistent with the star formation rate (or supernova rate) of the Galaxy (Timmes et al. 1997). A more specific search for correlation with catalogues from massive star related objects was not successful, however: neither Wolf Rayet star (van der Hucht et al. 1988) or OB star catalogues (Garmany & Stencel 1992), nor catalogued radio supernova remnants (Green 1996) do significantly improve the description of COMPTEL data above our first-order model. We note that object catalogues are strongly biased in all cases, however: the completeness limit for massive star catalogues does not extend beyond $\simeq$3kpc, and radio supernova remnants can only be detected in less confused directions. Therefore, since our main ^{26}Al emission arises from the inner Galaxy and integrates over all source regions throughout the Galaxy, we can expect that a dominating correlation for our measurement cannot be found with these catalogues; ^{26}Al measurements rather may provide a more realistic map of massive stars. Yet, for nearby regions ($\leq$ 500pc), specifically those outside the general direction of the inner Galactic plane, additional emission at intermediate or high latitudes may be identified by modelling plausible candidate sources in more detail:

The Gould Belt has been found to describe a local structure of O stars deviating from the plane of the Galaxy, modelled by a disk with $\simeq 20°$ inclination to the plane (Comeron et al. 1994). The origin and precise inclination and center of the Gould Belt are subject to some discussion, depending on modelling it from O stars or HI gas structures. We adopt a geometrical model encompassing the O star population of the belt, described as a Gaussian belt (θ=22.3°, ϕ=284.5°). This model indicates a slight improvement of our fit ($\simeq 2\sigma$), yet insufficient to claim detection. We note however that testing an "inverted Gould Belt" (i.e., a model belt reflected on the Galactic plane) yields an *anti*correlation of similar significance.

The closest OB association to the Sun, the Sco-Cen association, is related to one of the most prominent large scale radio structures on the sky, the North Polar Spur/Loop I, through supernova activity originating from the most massive stars of this association. The last supernova event may have occurred as late as $\simeq 2\ 10^5$y ago, enriching the Loop I bubble with nucleosynthesis products including ^{26}Al. Being so nearby, this could result in low surface-brightness 1.809 MeV emission barely detectable by COMPTEL (see Knödlseder et al., this volume). Our search with a geometrical model of Loop I (depositing the ^{26}Al in a thin outer shell, due to the age of the supernova) reports a minor hint ($\simeq 1.5\sigma$) only.

The ^{26}Al production from the Sco-Cen association as a whole is under study: ages of stellar subgroups lend themselves to separatable features on the sky, detailed HI maps help to clarify how those may relate to low-significance structures of the 1.8 MeV image (Blaauw 1964, deGeus 1992).

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