^{26}Al in the Local Interstellar Medium

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Abstract. We estimate the 1.8 MeV luminosity of the Sco-Cen association due to radioactive decay of ^{26}Al to $(4 - 15)\,10^{-5}$ph cm^{-2} s^{-1}. We propose a low surface brightness, limb brightened bubble for the 1.8 MeV intensity distribution. The detectibility of this distribution with existing γ-ray telescopes is discussed.

1 Introduction

Gamma-ray line astronomy is a young, promising discipline which is on the way to become a powerful diagnostic tool of nuclear astrophysics. It allows the unambiguous identification of isotopic species in the interstellar medium (ISM) by their spectral fingerprints: the characteristic nuclear de-excitation lines. The history of recent Galactic nucleosynthesis activity can be studied by measurements of the 1.809 MeV line arising from the decay of radioactive ^{26}Al. Possible sources of ^{26}Al are core collapse supernovae (SNe), metal rich novae, and massive stars with strong stellar winds (see review by Prantzos & Diehl 1996). The distribution of ^{26}Al was mapped by the γ-ray telescope COMPTEL aboard the Compton Gamma-Ray Observatory (CGRO). The 1.8 MeV all-sky map (Oberlack et al. 1996) clearly shows that almost all emission is concentrated in the Galactic plane. The irregular structure of the COMPTEL image with some intermediate-latitude features, and the appearance of distinct emission in the nearby Vela and Cygnus regions, had led to speculations about a source distribution, where a global Galactic nucleosynthesis glow underlies emission from relatively few localized source regions with particular recent nucleosynthesis activity (Diehl et al. 1996; Oberlack et al. 1996). Local ^{26}Al sources had been proposed before: Morfill & Hartquist (1985) suggested a SN event in the solar vicinity, Blake & Dearborn (1989) proposed SNe in the Sco-Cen association – the OB association nearest to the Sun – as possible origin of the observed ^{26}Al. The purpose of this paper is to revisit the ^{26}Al contribution from Sco-Cen based on recent nucleosynthesis calculations and new observational constraints on the Sco-Cen history, and in view of the latest COMPTEL 1.809 MeV measurements.

2 Loop I

Berkhuijsen et al. (1971) summarize observational evidence that Loop I, a giant radio continuum loop centered on Sco-Cen, was created by supernova explosions in the association. Fejes & Wesselius (1973) observe a HI shell surrounding the radio continuum loop some 5°-15° outside the best-fitting small circle. Using ROSAT X-ray data, Egger (1993) developed a more detailed scenario. He claims that Loop I (the radio structure and surrounding HI shell) is a superbubble formed by stellar winds and SN explosions of the stars in Sco-Cen; a recent supernova ($2\,10^5$yr ago) within the superbubble may have re-heated the gas, leading to the observed X-ray emission.

Based on Egger's model we estimate the ^{26}Al production of Sco-Cen from two components: ^{26}Al from the recent *re-heating* supernova and ^{26}Al from the *older* supernovae (and Wolf-Rayet stars) which formed the Loop I superbubble. The ^{26}Al yield of the recent SN can be estimated from the earliest spectral type B0V in the association which corresponds to an initial progenitor mass of 15-20 $M_\odot$. According to nucleosynthesis calculations for type II SN about $(3-9)\,10^{-5}$ $M_\odot$ of ^{26}Al is expected for such a star (Timmes et al. 1995). The ^{26}Al production of the events which formed the superbubble is estimated by means of an analytic OB association evolution model which predicts the ^{26}Al output of an association as function of the association age. Stars in the mass interval 10-40 $M_\odot$ explode as type II SN and release ^{26}Al into the ISM at the end of their life. Stars more massive than 40 $M_\odot$ are assumed to exhibit a Wolf-Rayet (W-R) phase during which they eject ^{26}Al into the ISM by stellar winds. Stellar and W-R lifetimes were taken from Schaller et al. (1992). ^{26}Al yields for W-R stars as function of initial stellar mass were taken from Meynet et al. (1997), type II SN yields from Timmes et al. (1995).

The resulting ^{26}Al light curve for Sco-Cen is shown in Fig. 1 for different initial mass function (IMF) slopes Γ and upper mass limits M_{up}. The IMF was normalized to 42 stars with spectral type between B3 (7 $M_\odot$) and B1 (13 $M_\odot$) (Bertiau & Bertiau 1958). The general feature of the light curve is a short luminosity peak between 5 and 7 Myr after the formation of the assocation due to the explosion of massive stars as supernovae. The peak is preceded by a small bump due to ^{26}Al ejection by W-R stars and followed by a tail up to 21 Myr due to less massive supernova events. After 21 Myr all stars more massive than 10 $M_\odot$ exploded as supernovae, hence the supply of potential ^{26}Al sources is exhausted – ^{26}Al decays exponentially ($\tau_{26} = 1.04\,10^6$yr). It is clear from Fig. 1 that the actual age of the association is the most crucial parameter in the ^{26}Al yield estimate – the slope of the IMF being of minor importance. Taking an IMF slope of $\Gamma = -1.5$ and the age of Sco-Cen between 10-20 Myr (as estimated from the most massive member, Antares) results in an ^{26}Al yield of $(4-20)\,10^{-5}$ $M_\odot$. We also applied the OB evolution model to the data of de Geus (1992) who determined membership and age for each of the three subgroups of Sco-Cen separately. Combining

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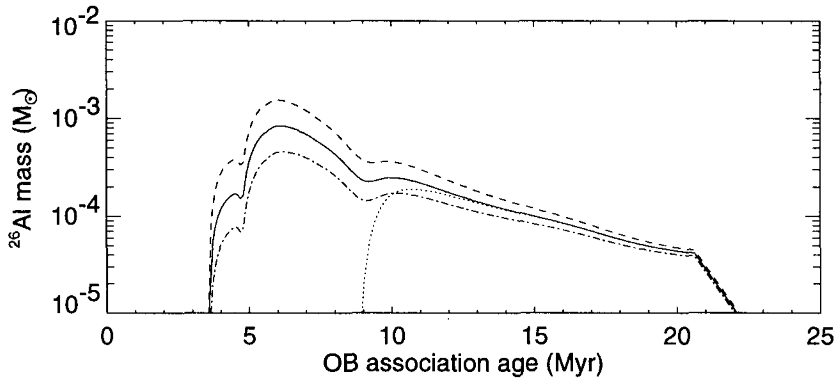

Fig. 1. ^{26}Al light curves for the Sco-Cen OB association. Solid: $\Gamma = -1.5$, $M_{up} = 60$ $M_\odot$; dashed: $\Gamma = -1.0$, $M_{up} = 60$ $M_\odot$; dashed-dotted: $\Gamma = -2.0$, $M_{up} = 60$ $M_\odot$; dotted: $\Gamma = -1.5$, $M_{up} = 20$ $M_\odot$.

the ^{26}Al light curves of the different subgroups gives a today ^{26}Al mass of $(5-10)\,10^{-5}$ $M_\odot$. The processed material from the early SN explosions which created the superbubble was probably swept up by subsequent explosions and could now be in a shell on the wall of the superbubble. The ejecta of the most recent event, however, are expected to fill the bubble more homogeneously due to turbulent mixing in the remnant interior (Tenorio-Tagle et al. 1991). This scenario can be translated into a characteristic signature in the angular distribution of 1.8 MeV γ-rays: a low surface brightness bubble would be surrounded by a circular emission limb. The 1.8 MeV limb would dominate the intensity distribution since ^{26}Al is concentrated in a much smaller region on the sky. Taking the distance to Sco-Cen of 170 pc as the center of the bubble, a bubble radius of 160 pc and a shell thickness of 10 pc yields expected 1.8 MeV fluxes of $(3-11)\,10^{-5}$ph cm^{-2} s^{-1} and $(1-4)\,10^{-5}$ph cm^{-2} s^{-1} for the shell and the bubble component, respectively.

The above scenario, however, is based on a spherically symmetric SNR. The ROSAT X-ray image of the Vela SNR shows deviations from a spherical shell, which have recently been interpreted as high-velocity supernova ejecta (Aschenbach et al. 1995). If Loop I obeys a similar morphology, presence of supernova-generated ^{26}Al far outside the classical Loop I boundary would be possible.

3 Observations

The observation of diffuse low-intensity 1.8 MeV emission as expected from Loop I is difficult with COMPTEL. Simulations show a tendency of our imaging techniques to translate extended low-intensity emission into spot-like image noise (Knödlseder et al. 1996). Consequently weak emission features in the COMPTEL all-sky map at medium and high Galactic latitudes could be an indication of local ^{26}Al (Knödlseder et al. 1997). The question on the presence of a diffuse ^{26}Al component could be addressed by combining observations of various telescopes: large FOV instruments like SMM or GRIS give complementary information since they are more sensitive to diffuse low intensity emission (Diehl et al. 1997). Indeed, the total 1.8 MeV flux from the general direction of the Galactic Center is higher for these two instruments then the flux obtained with COMPTEL for the Galactic plane, which indicates that a diffuse component is possibly missed in the current COMPTEL analysis (Diehl et al. 1997). The flux discrepancy may be resolved with our ^{26}Al predictions for Loop I. Improving COMPTEL's sensitivity to diffuse emission, and simultaneously analyzing data of COMPTEL, SMM and GRIS are in progress.

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