

Deriving a Galactic Star Formation Rate from ^{26}Al Gamma-rays

Radioactive ^{26}Al is produced and dispersed throughout the Galaxy at various sites of nucleosynthesis, and decays with a mean life of $\tau = 10^6$ yrs. This process is dominated by ejected matter from core collapse supernovae and their preceding winds during the Wolf-Rayet stage. The relatively long mean life in comparison to the time between supernovae (~ 100 yrs) implies that a very large number of events contributes to a steady state abundance, which in turn results in a diffuse glow of the Galaxy in the 1.8 MeV gamma-ray line from the decay of ^{26}Al . The basic idea of the “ ^{26}Al method” is the conversion of the observed total gamma-ray line flux for ^{26}Al to the corresponding supernova rate (SNR), and consequently to the average star formation rate, SFR. The main advantage of this method is the lack of extinction corrections in the gamma-ray band, so that we can see the full disk of the Galaxy and are not limited to a small sampling volume around the Sun. It is also worthy to note that averaging over a few million years implies a large number of events, which provides a better statistical ensemble in comparison to other methods in which the tracers have a much shorter observational lifetime and often very significant selection effects and highly uncertain evolution corrections [pulsars, radio supernova remnants, historic SN record, HII regions].

The ^{26}Al method relates the observed line flux to the steady state equilibrium mass of ^{26}Al in the Galaxy via a spatial distribution model. Since the observed map at 1.8 MeV indicates that massive stars are the dominant contributors to this radioactive species in the ISM, we go beyond a simple axis-symmetric model, and include spiral structure of our Sbc-type Milky Way. The dynamic evolution of the injected ^{26}Al should also be accounted for, as stellar winds and explosive outflows cause the density distribution to be more extended than what one would infer from the known spatial distribution of massive stars. The resulting density map is somewhat uncertain; but perhaps the largest source of potential error is the overall scale of the Galaxy: The official IAU distance of the Sun to the Galactic centre is 8.5 kpc, but a recent reviews of measurements^{1,2} does indicate values as small as 7 kpc. Flux scales as the inverse square of distance, therefore such a global reduction in size of the Galaxy would decrease the inferred mass of ^{26}Al by 34%.

The amount of ^{26}Al is maintained in steady state by a core-collapse supernova rate (SNR) via $M_{eq} = \text{SNR} \cdot \tau \cdot Y$, where the rate is measured in events per year, τ is the mean life of ^{26}Al , and Y is the IMF-averaged ^{26}Al yield in units of M_{\odot} per supernova. It must be emphasized that the yield in this context must include the explosive yields from the supernova model as well as any ^{26}Al ejected in the Wolf-Rayet wind phase. Yields are moderated by the steep initial mass function (IMF), $\xi \sim m^{-\alpha}$, in our relevant mass range ~ 10 - $120 M_{\odot}$. We use the Scalo IMF ($\xi \sim m^{-2.7}$) for this higher-mass range, supported by a wide range of astronomical constraints⁶. Y is obtained from the high-mass initial mass function (IMF) and the nucleosynthesis yields of models (see Online Supporting Information). The resulting ^{26}Al yield per massive star is $1.4 \cdot 10^{-4} M_{\odot}$, with an estimated uncertainty of 50% based on various published yields as a function of progenitor mass (see Online material on ^{26}Al yields). The corresponding supernova rate is $\text{SNR} = 1.92$ events per century (this does not include

supernovae of type Ia, which have been found to be negligible sources of ^{26}Al), with an uncertainty of $\sim 60\%$ (from 30% due to Mass and 50% due to yield, added in quadrature). The resulting range of one to three core collapses per century coincides with the recent values obtained from on a survey of local O3-B2 dwarfs³, extrapolated to the Galaxy as whole with spatial distribution models, and the study of the luminosity function of OB associations⁹.

The conversion from core-collapse supernova rate, which assumes that all stars more massive than ten solar masses end their lives as supernovae⁸, is given by $SFR = SNR \cdot \langle m \rangle \cdot f_{SN}^{-1}$, where $\langle m \rangle$ is the average stellar mass in a star formation event, and f_{SN} is the fraction of all stars that become supernovae.

Stars are predominantly formed in clusters with a quasi-universal IMF^{6,7} (narrowly distributed about the canonical Salpeter power law), but that the integrated galaxial initial mass function (IGIMF) must be steeper than the canonical IMF. A steeper IGIMF implies a reduced supernova fraction in general, and implies a dependence on galaxy mass and the much less established cluster mass distribution function. It is thus possible that the true SFR could be significantly larger than the rate derived from the canonical IMF. We leave the application of such a correction to the reader, and report a SFR based on the conversion choice made by McKee and Williams⁹. With an average stellar mass of $\langle m \rangle = 0.51 M_{\odot}$ and $f_{SN} = 2.6 \cdot 10^{-3}$ we find $SFR = (3.8 \pm 2.2) M_{\odot} \text{ yr}^{-1}$, which agrees with the value derived from the luminosity functions of OB associations⁹, and implies a stellar production rate of $\dot{N}_{*} = SFR \cdot \langle m \rangle^{-1} = 7.5$ stars per year.

References

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