Monte Carlo simulations of propagation and annihilation of nucleosynthesis positrons in the Galactic disk

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Abstract

We modelled the spatial and spectral distributions of the annihilation emission induced by positrons that are released in the decay of ^{26}Al, ^{44}Ti and ^{56}Ni nuclei in the Galactic disk, which are historically assumed to be the most likely origin of galactic positrons via their β^+-decay. This was carried out through Monte Carlo simulations that take into account the propagation of positrons in the interstellar medium. The ^{26}Al and ^{44}Ti distributions were assumed to follow the free-electron spatial distribution that is strongly correlated with the massive stars distribution. The ^{56}Ni distribution was assumed to follow a young and old stellar population linked to the SNIa population. The gas distribution is based on the model given by Ferrière (1998). Due to large uncertainties in the regime of positron transport in the ISM, we only tested the collisional transport mode in order to test if galactic disk positrons could reach the inner regions of the Galaxy. We also tested several galactic magnetic field models and several escape fractions of positrons released by 56Ni in SNIa ejecta. We then compared all of our simulations to the INTEGRAL/SPI observations.

INTRODUCTION

The origin of positrons responsible for the 511 keV emission in the Galaxy remains unclear. Many assumptions have been made for decades about their sources: decay of π^+ produced by interaction of cosmic rays with the ISM, exotic explanations like dark matter decays, β^+ radioactive decays of radioisotopes produced by massive stars or supernova explosions, etc…

The second question concerns the propagation modes of MeV positrons once injected into the Galaxy. That is to say: does the spatial distribution of the annihilation emission reflects the spatial distribution of positron sources? Recent studies ([1], [2] and [3]) suggest that positrons could propagate far away from their sources before annihilating. However, propagation processes are not well understood for MeV particles except the collisional/ ballistic transport where positrons propagate along steady state magnetic field lines, their pitch angles being scattered in collisions with gas particles.

Positrons from β^+-decays have often been cited as the major contributors of this galactic population. ^{26}Al is for instance a positron source secured by the detection of the 1809 keV emission. The ^{56}Ni yield of type-Ia supernovae could explain alone all the 511 keV emission but the escape fraction of positrons from the ejecta remains an open question.

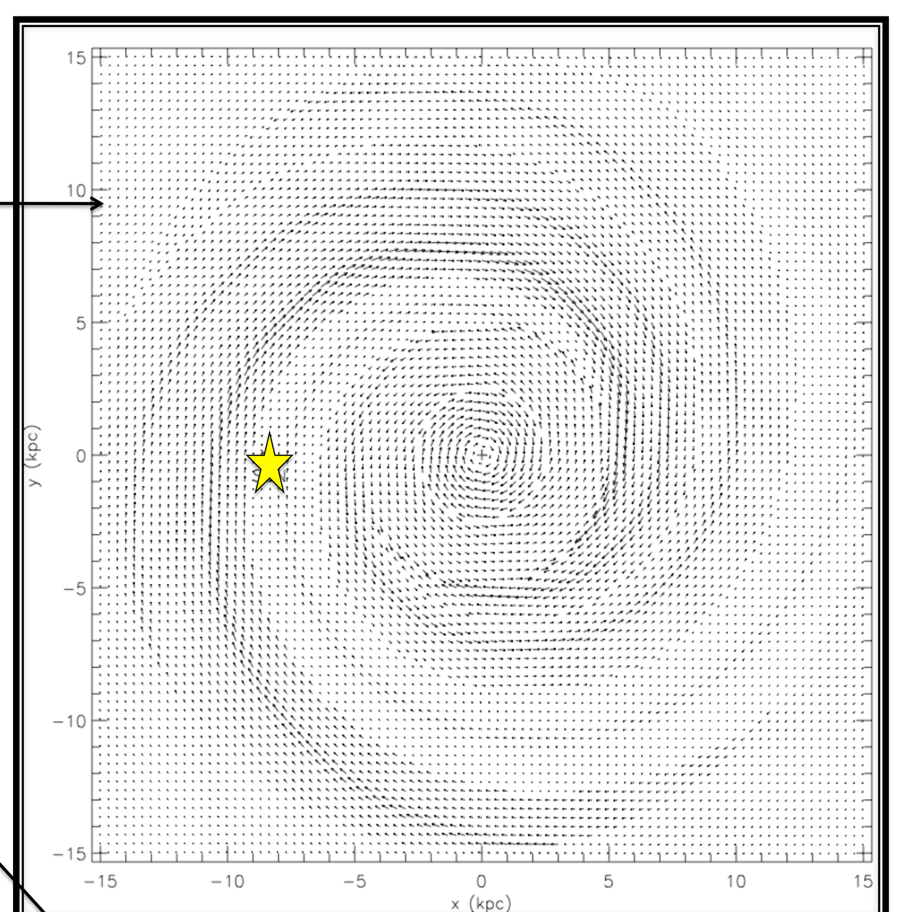
In this study, we then simulated the ballistic propagation and death of nucleosynthesis positrons to assess their impact on the morphology of the 511 keV emission, by comparing their spatial distribution to INTEGRAL/SPI observations.

MODEL AND PARAMETERS

✓**Monte Carlo code**

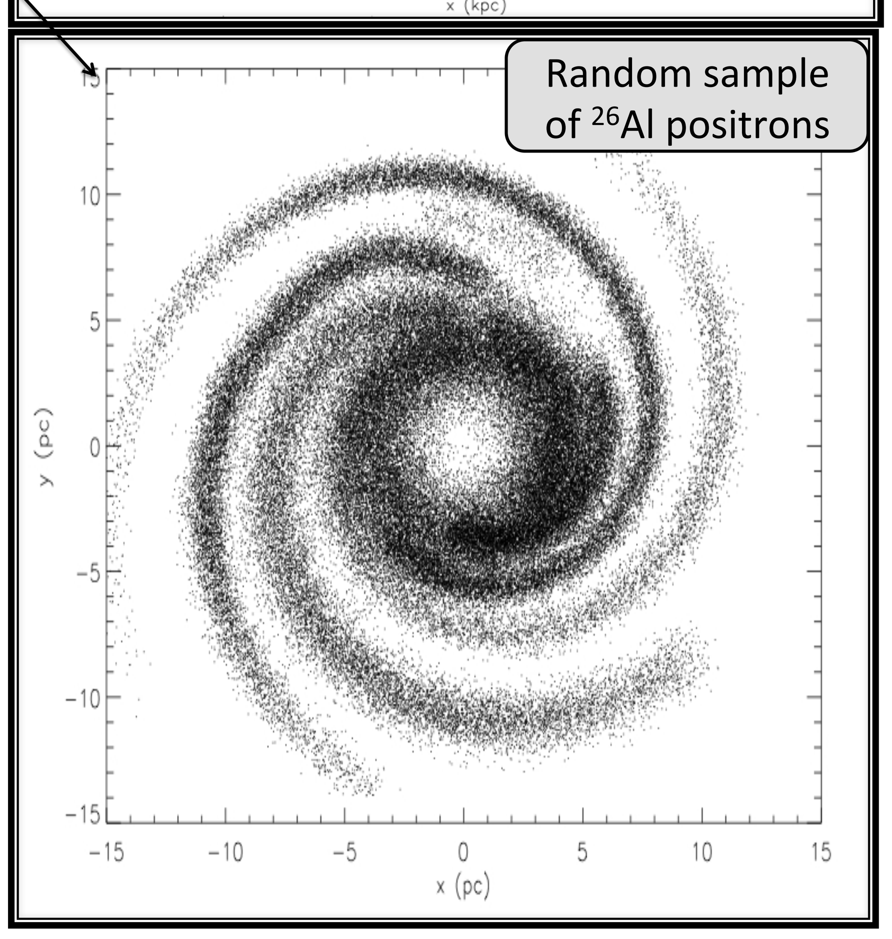
✓ Modelling the Galaxy :

- Disk regular galactic magnetic field [4]
- Generation of a turbulent GMF [5]
- Finely-structured ISM from a space-averaged gas distribution [6] using the filling factor of each ISM phase.
- Inner bulge (< 1.5 kpc) excluded



✓ Modelling positron physics :

- Spatial distributions of ^{26}Al and ^{44}Ti sources [7] and ^{56}Ni [8] + Energetic distributions of e+ linked to the sources
- Collisional transport regime [1]
- Energy losses and inelastic collisions
- Direct Annihilation e^+e^- and annihilation via Positronium formation



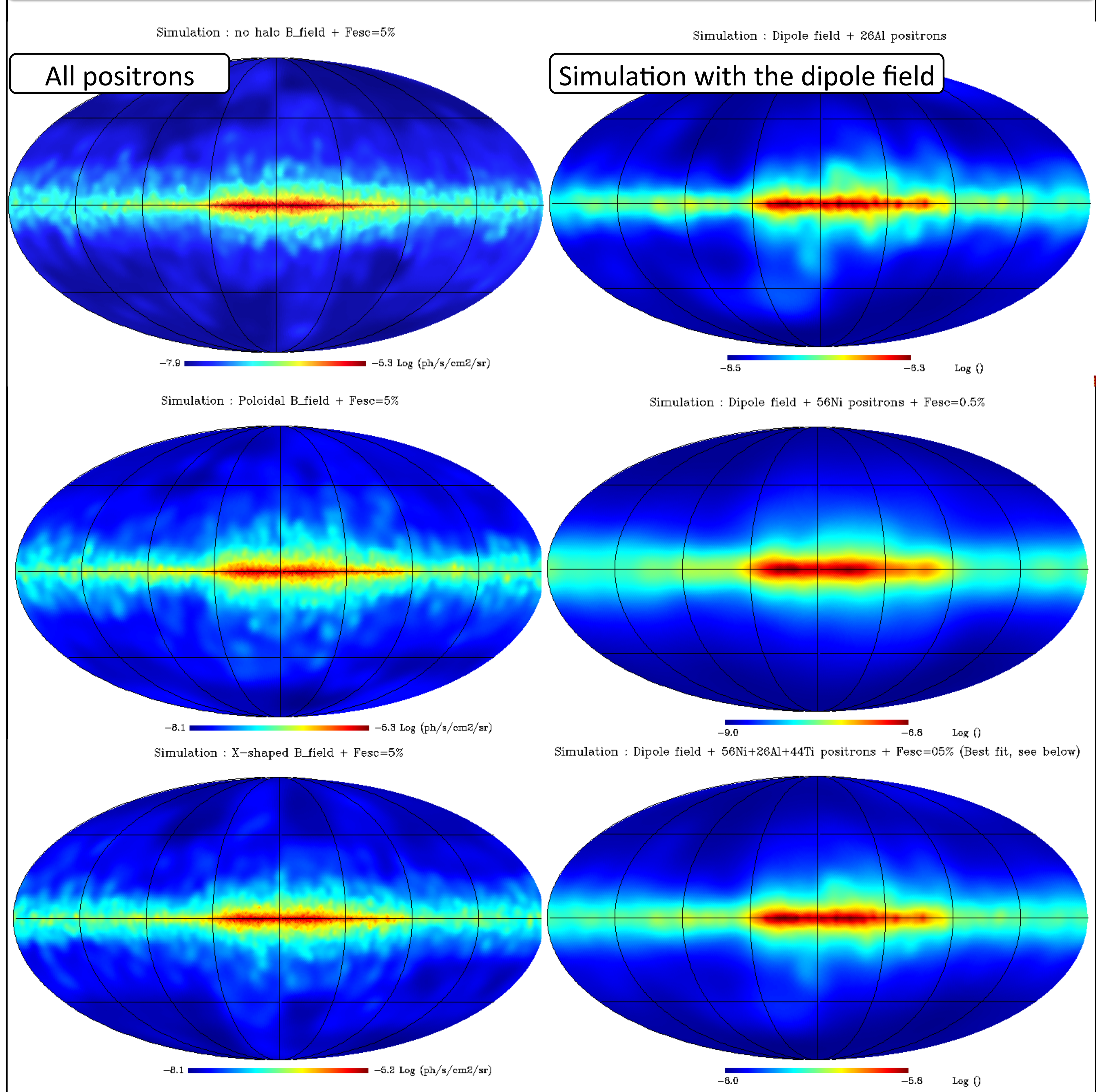
✓ Parameters of the simulations :

- Halo regular magnetic field (HMF):
    - No halo GMF
    - Dipole GMF
    - X-shaped GMF
- Escape fraction (f_{esc}) of ^{56}Ni positrons from the SNIa ejecta (0.5, 5, 10%) and their associated computed β^+-spectrum [9]

✓ **MC simulation for each HMF and each f_{esc} for all sources (20000 e^+ per source) -> 9 total simulations**

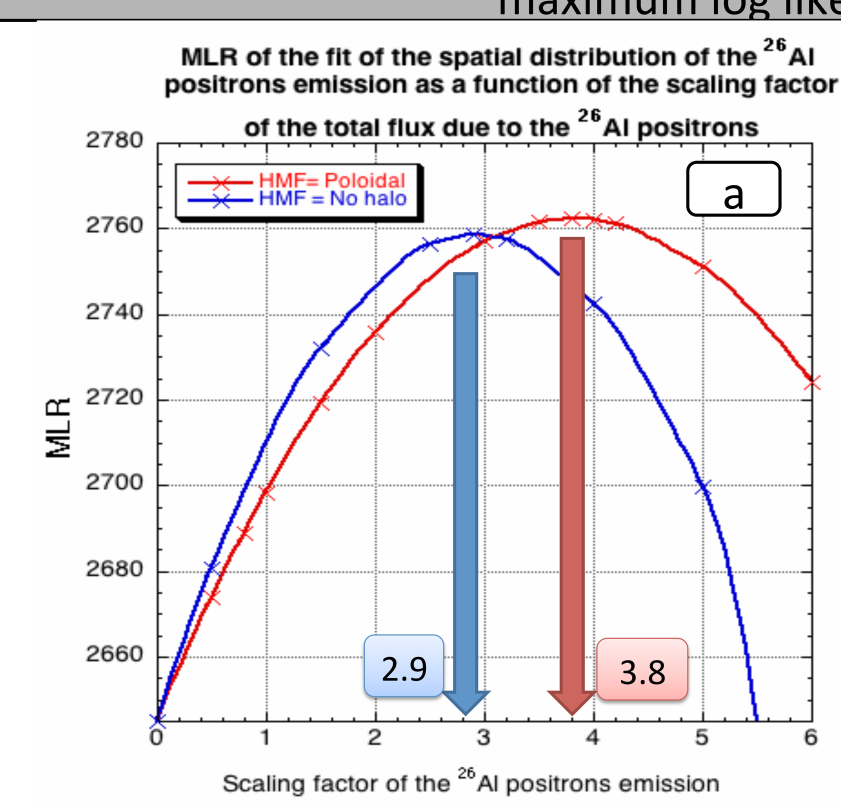
RESULTS : SPATIAL DISTRIBUTIONS

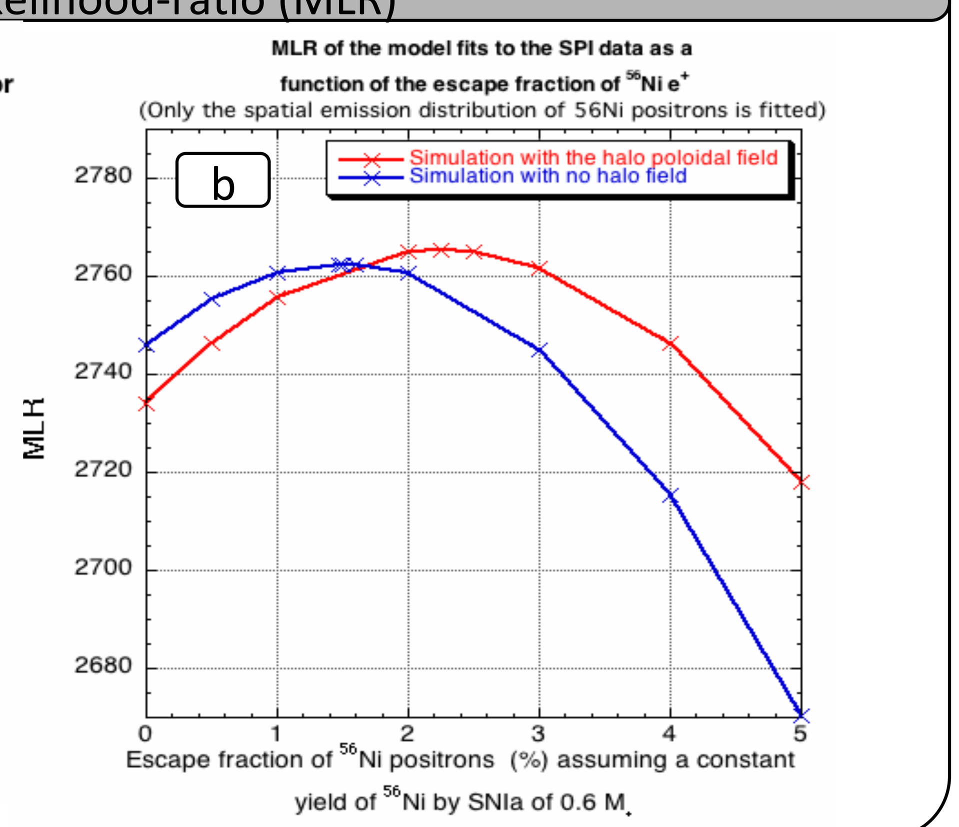
Intensity distribution of the 511 keV emission for various simulations



COMPARISON to the SPI data

Using a maximum likelihood multi-component model fitting algorithm calculating the maximum log likelihood-ratio (MLR)





CONCLUSIONS

✓ Nucleosynthesis positrons do not go into the bulge (a few % for all the simulations except 16% for the simulation with the poloidal field and f_{esc}=10%)

✓ Nucleosynthesis positrons do not escape the Galaxy (<0.5% for all simulations)

✓ Emissions of ^{44}Ti and ^{26}Al positrons are described by the same spatial distribution. Taking the upper limits of each isotope positron yield (M_{26}=2.8±0.8 M_* [10] & $N_{e+,44}$≈3x10^{42} e$^+$/s at ±50%), these two isotopes could quasi-explain the total disk 511 keV emission for the simulation with no halo magnetic field (see plot a)

✓ We obtain a better MLR considering the contribution of ^{56}Ni positrons (see plot b) fixing the spatial distribution of the 511 keV emission of ^{26}Al and ^{44}Ti e$^+$ (in comparison with f_{esc}=0)

➢ An escape fraction of ^{56}Ni positrons of ≈ 1.5-2% would be expected whatever the simulation assuming a ^{56}Ni yield of SNIa constant at 0.6 M_*.

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