SLR disk enrichment through AGB interloper stars

Joseph W. Eatson · Richard J. Parker

University of Sheffield · The Royal Society

Context

- **Short-Lived Radioisotopes (SLRs; such as ^{26}Al and ^{60}Fe) drive out-gassing and devolatilization in planetesimals.**
- $\sim 1/10^{\text{th}}$ of initial Solar ^{26}Al abundance can remove volatiles from planetesimals (Eatson et al., 2024a; Lichtenberg et al., 2019).
- The source of these SLRs is not well established, there are issues with each theory:
  - Cosmic ray spallation causes inhomogeneous SLR distribution and insufficient yields.
  - Massive stars do not produce enough ^{60}Fe (Eatson et al., 2024b), and their UV flux disrupts protoplanetary disks (Patel et al., 2023).
  - Supernovae occur after the bulk of planetesimal production (Eatson et al., 2024b).
- **Parker and Schoettler (2023) found an example of an AGB star "interloping" with a cluster, which could produce Solar-like SLR enrichment in low-mass cluster disks without hypersonic winds or destructive levels of UV flux.**

Methodology

- **We performed a rigorous parameter space search to determine the conditions necessary for efficient SLR enrichment.**
- AMUSE (Pelupessy et al., 2013) was used to produce a series of 100-star clusters.
- A $7\,\mathrm{M}_\odot$ AGB was then added to each simulation, travelling in the direction of the cluster.
- SLR outflow was modelled by a series of cylindrical segments from the interloper's path.
- Disks that intersected cylinder segments sweep up available SLRs.
- Simulations were repeated numerous times in order to build up a statistical population of low-mass clusters.
- AGB SLR yields were derived from Karakas and Lugaro (2016).

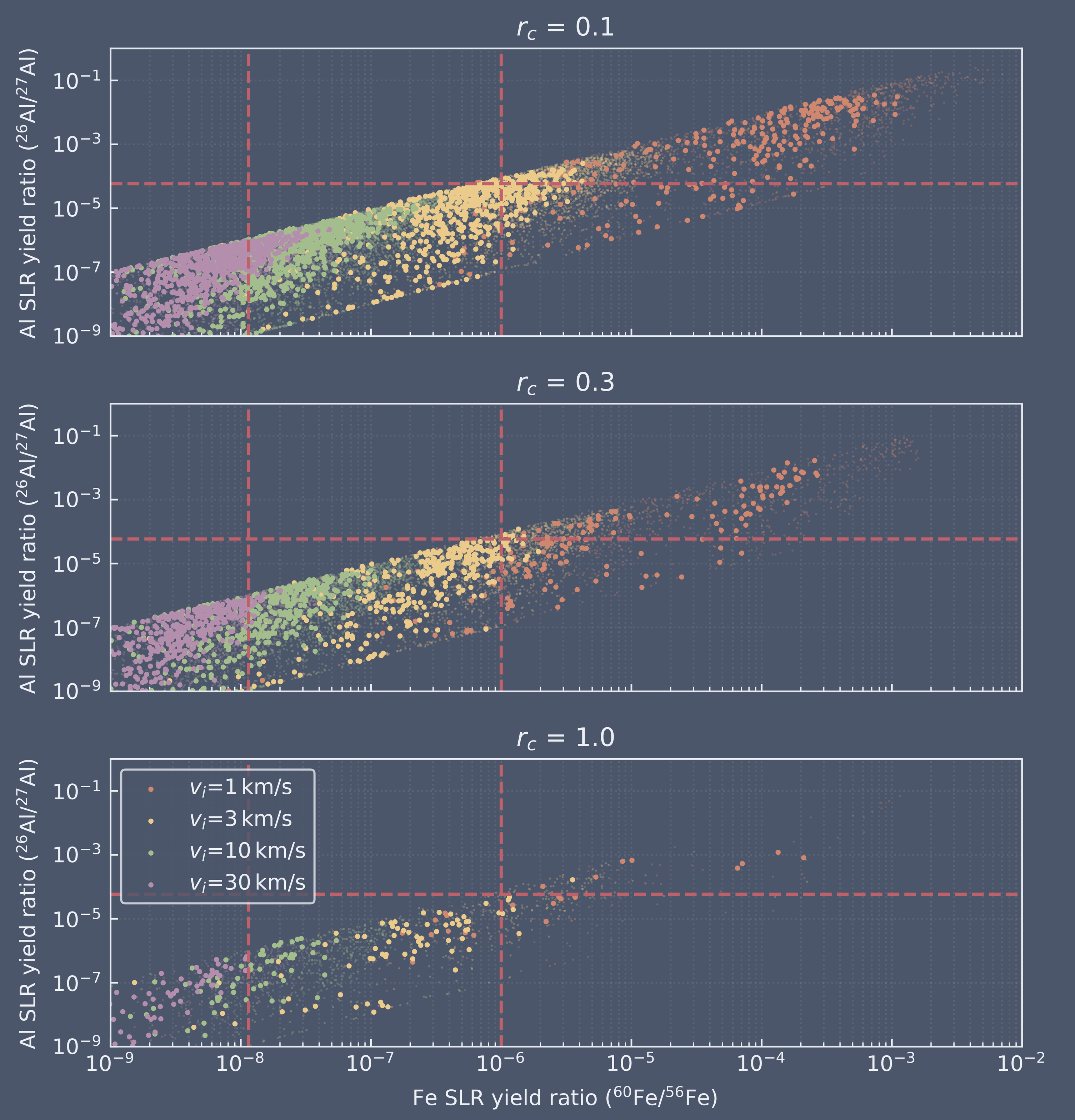

Figure 1. A comparison of the SLR abundance ratios for ^{26}Al and ^{60}Fe where interloper velocity and cluster radius were varied. Dashed lines represent accepted Solar System formation abundance ratios for ^{26}Al and ^{60}Fe. ***Maximum enrichment is highly dependent on initial interloper velocity, with near-Solar ^{26}Al enrichment becoming improbable above 10 km s^{-1}***

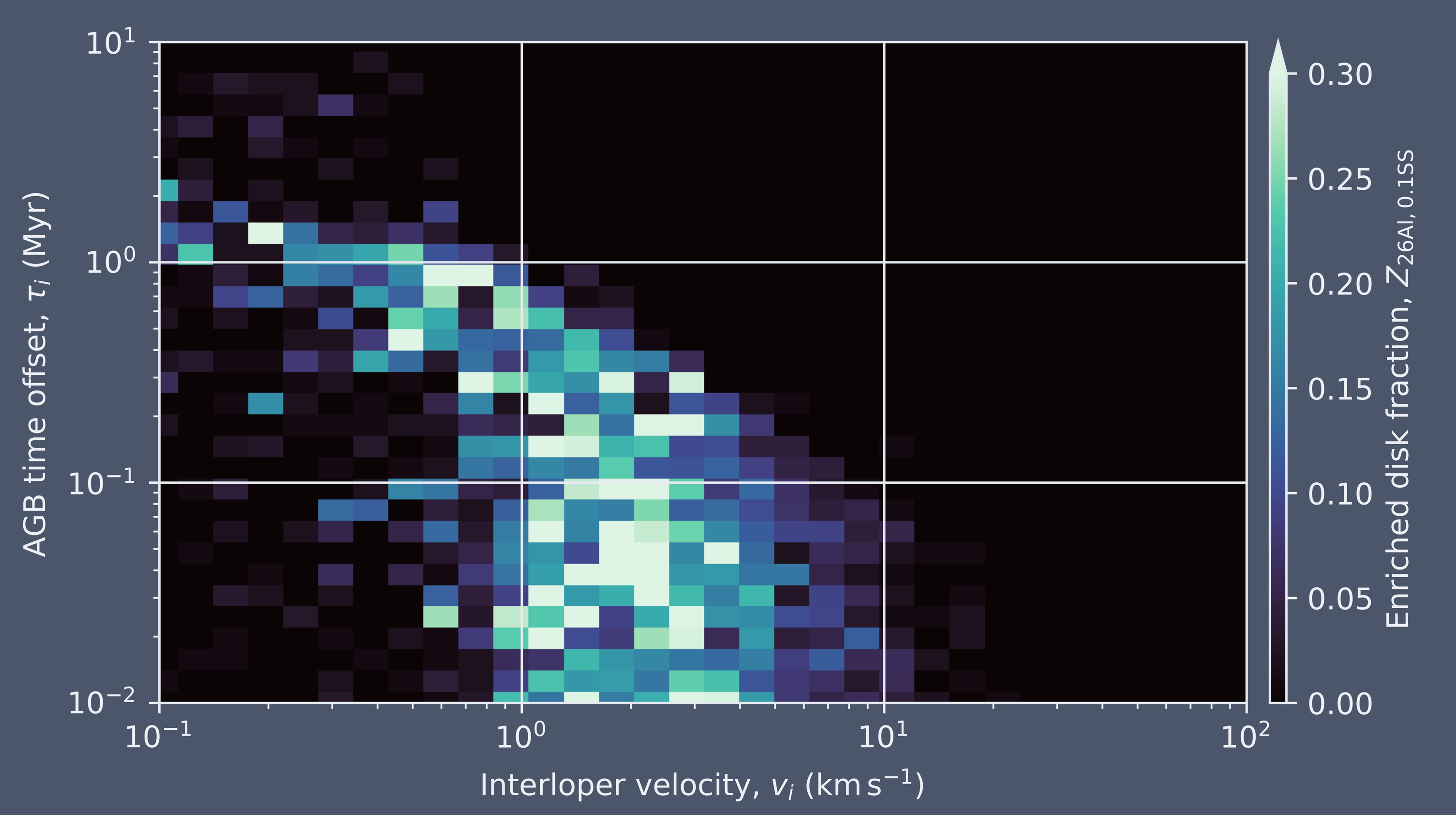

Figure 2. A comparison of interloper initial velocity and time offset and their effect on ^{26}Al enrichment. ***Velocities above 10 km s^{-1} are less likely to significantly enrich, while velocities in the 1 km s^{-1}-10 km s^{-1} range are likely to produce enriched disks.***

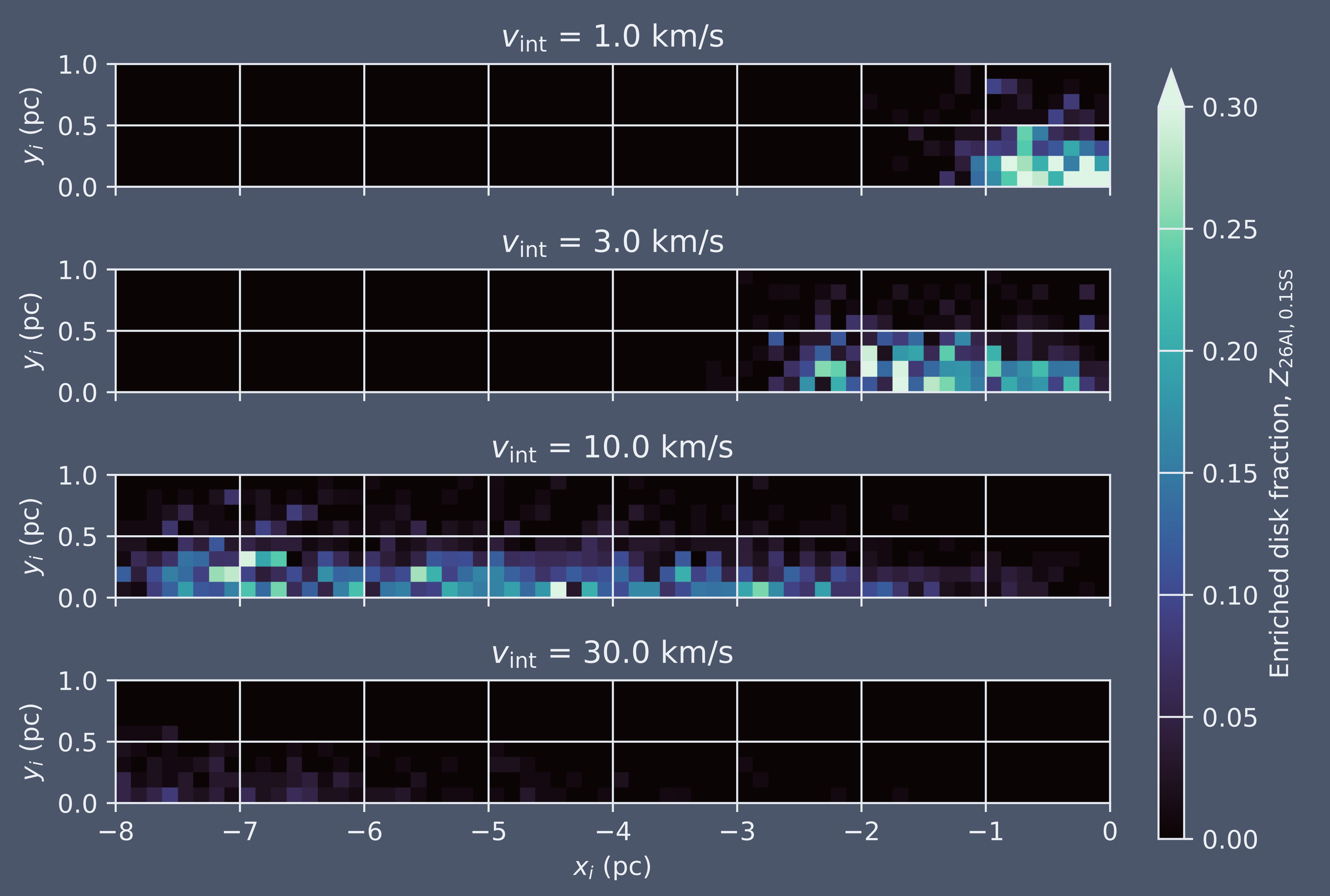

Figure 3. ^{26}Al significant disk enrichment fraction influence due to changing initial interloper x and y position relative to the cluster CoM. ***High-velocity interlopers can still enrich disks, and 10 km s^{-1} interlopers can readily enrich disks assuming they enter the AGB phase some distance before they encounter the cluster.*** *y_i "near-misses" still cause enrichment.*

Results

- Fig. 1 shows the wide range of enrichments possible with AGB interlopers.
- **Enrichment is highly dependent on velocity, but can result in near-Solar enrichment levels, even with faster AGBs.**
- Fig. 2 further shows this velocity dependence, with a decrease in enrichment above 10 km s^{-1} in the case of interlopers with an initial distance of 1 pc.
- Fig. 3 shows the importance of timing for AGB enrichment, with AGBs with velocities typical of the Solar neighbourhood producing near-Solar enrichment given enough time for the interloper to reach the end of the AGB phase.
- We also find that enrichment can still reasonably occur in the case of a "near-miss".

Discussion

- **Interloper enrichment is a very generous mechanism of SLR enrichment, even with high-velocity AGBs.**
- The slower winds and gentler UV flux of AGBs would be less disruptive to disks in a low-mass cluster.
- Future work could determine the probability of interloper encounter as well as use more accurate, hydrodynamically driven models.

References

Eatson, J. W., Lichtenberg, T., Parker, R. J., and Gerya, T. V. (2024a). Devolatilization of extrasolar planetesimals by 60Fe and 26Al heating. *MNRAS*.

Eatson, J. W., Parker, R. J., and Lichtenberg, T. (2024b). Toward a Unified Injection Model of Short-lived Radioisotopes in N-body Simulations of Star-forming Regions. *ApJ*.

Karakas, A. I. and Lugaro, M. (2016). Stellar Yields From Metal-Rich Asymptotic Giant Branch Models. *ApJ*.

Lichtenberg, T., Golabek, G. J., Burn, R., Meyer, M. R., Alibert, Y., Gerya, T. V., and Mordasini, C. (2019). A water budget dichotomy of rocky protoplanets from 26Al-heating. *Nat. Astro.*

Parker, R. J. and Schoettler, C. (2023). Isotopic Enrichment of Planetary Systems from Asymptotic Giant Branch Stars. *ApJ Letters*.

Patel, M., Polius, C. K. M., Ridsdill-Smith, M., Lichtenberg, T., and Parker, R. J. (2023). Photoevaporation versus enrichment in the cradle of the Sun. *MNRAS*, 525(2).

Pelupessy, F. I., van Elteren, A., de Vries, N., McMillan, S. L. W., Drost, N., and Portegies Zwart, S. F. (2013). The Astrophysical Multipurpose Software Environment. *A&A*.

jweatson.github.io