Galactic Cosmic Ray Attenuation in Dusty Cometary Environments

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Introduction

During the nominal mission around Comet 67P/Churyumov–Gerasimenko (67P), the Rosetta Standard Radiation Environment Monitor (SREM) [1] likely recorded at most an **8-10% decrease in the number of galactic cosmic rays (GCRs) that hit the spacecraft** (Figure 1, from [2]). Three preliminary hypotheses for causes of GCR attenuation are magnetic field fluctuations, outgassing of volatiles, and/or dust grain production by 67P. While not an exhaustive list, these factors contribute to altering the surrounding environment Rosetta was exposed to. **The goal of this work is to investigate whether or not dust grains in the coma of 67P can be a possible explanation for this attenuation feature.**

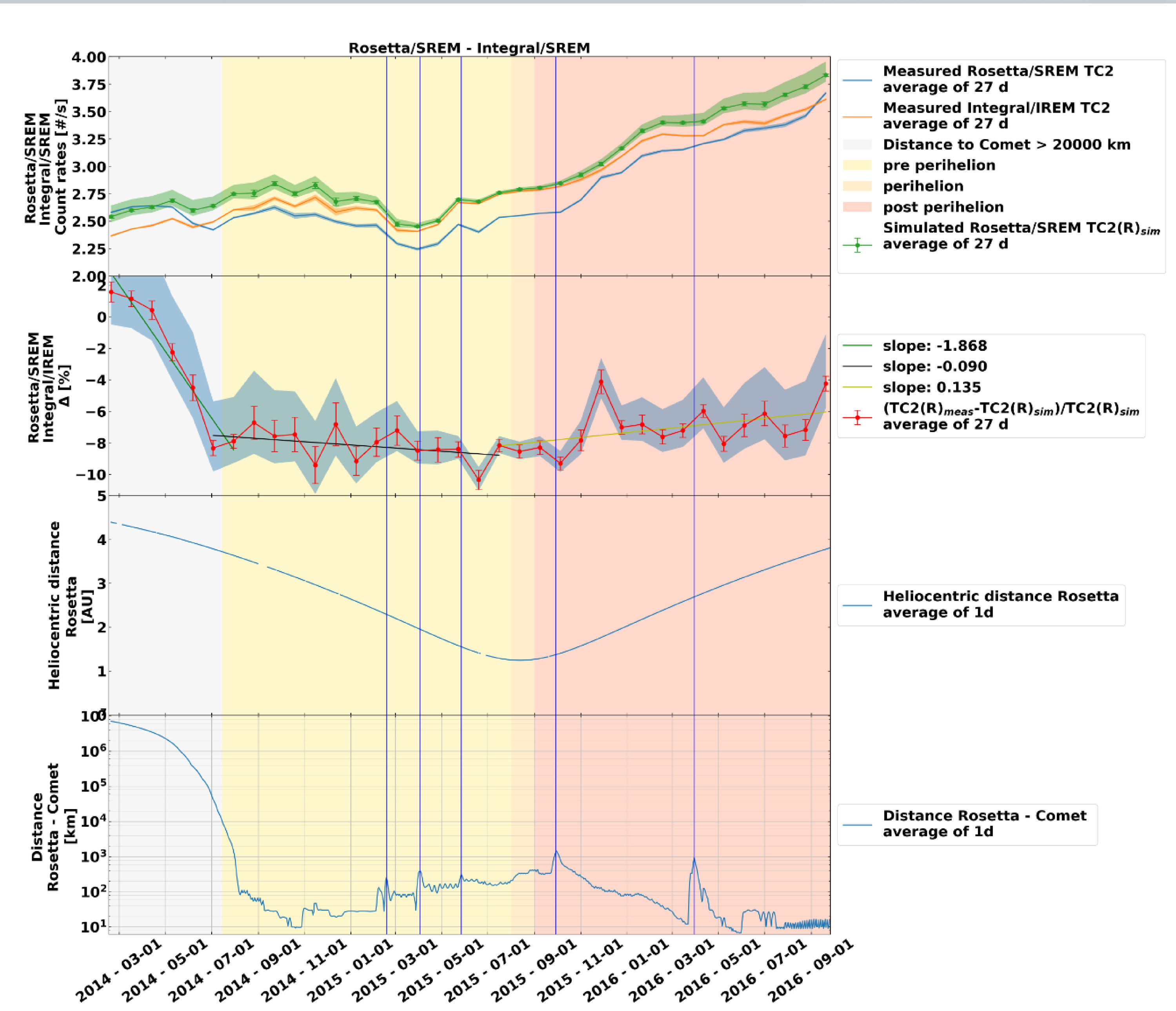
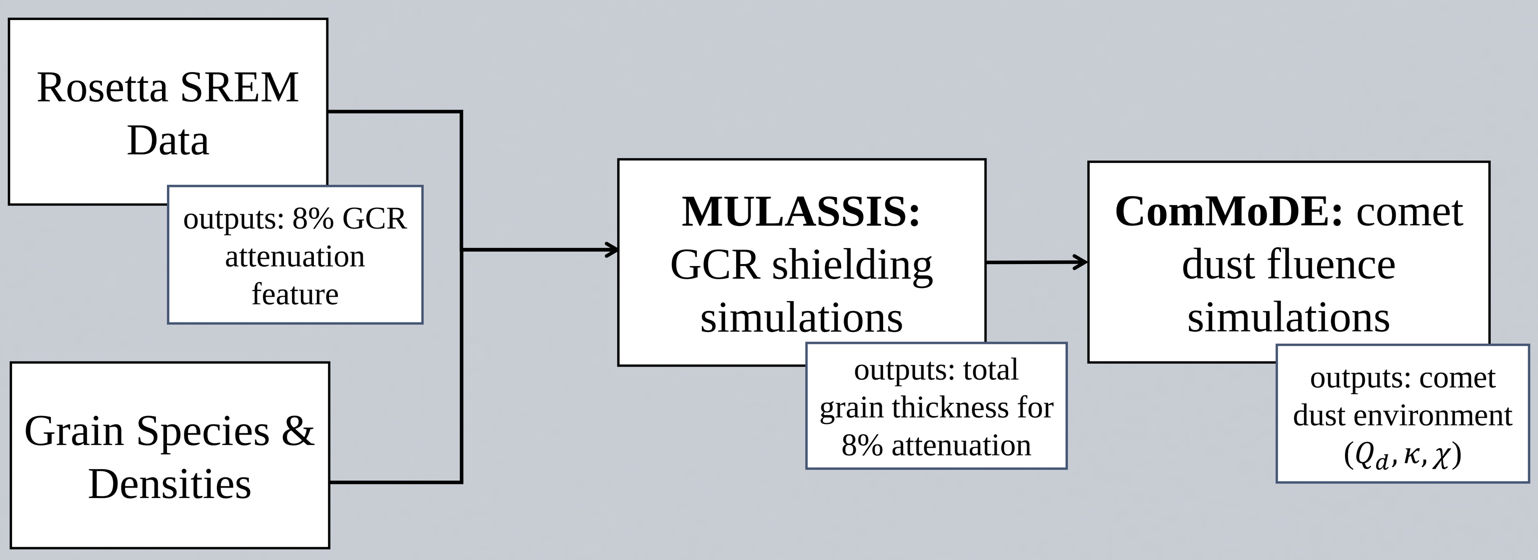


Figure 1: SREM GCR count rates, from Honig et al. (2019) [2]. Top: measured Rosetta (blue), Integral (orange), and simulated Rosetta (green) count rates. Upper middle: difference between the measured and simulated Rosetta count rates. Lower middle: heliocentric distance of Rosetta. Bottom: Rosetta-comet distance. Coloured backgrounds indicate mission stages.

Methodology

1. The main species possibly responsible for GCR attenuation are identified from previous literature studies of the environment of 67P – including ice, refractory, and gaseous species.
2. The GCR energy loss caused by interacting with these materials are quantified using the **Multi-Layered Shielding Simulation Software (MULASSIS)** [3]. Column density of gaseous species is varied between $10^{-3} - 10^{2}$ g cm^{-2}, while refractory thickness is varied within $10^{-6} - 10^{2}$ cm. For each simulation, a spectrum of incident GCRs impacts the material. The total amount of material required to create an 8% energy attenuation is recorded.
3. Simulated GCR trajectories through coma environments are performed using the **Cometary Model for Dust Environments (ComMoDE)** [4] to determine the total number of grains that incident GCRs likely interact with. The grain size distribution (κ), dust production rate (Q_d), and dust-to-gas mass ratio (χ) are all varied. For each simulated environment, the total accumulated grain thickness is recorded and compared to thicknesses derived by MULASSIS. The compatible environments are then compared to observed environmental conditions of 67P for validation.



References: [1] Evans, H.D.R., et al. (2008). *Advances in Space Research, 42(9), 1527-1537.*; [2] Honig, T., et al. (2019). *Annales Geophysicae, 37(5),* 903-918.; [3] Lei, F., et al. (2002). *IEEE Transactions on Nuclear Science, 49(6),* 2788-2793.; [4] Haslebacher, N., et al. (2025). *CEAS Space Journal.* [5] Bockelée-Morvan, D. (2015). *A&A,* 583(A6)., [6] Choukroun, M. et al. (2020). *Space Sci. Rev., 216(3), 44.*

Results

MULASSIS Results:

- In order to reproduce an 8% attenuation detection, the required column density for H_2O, CO_2, and CO gas was found to be **7-8 magnitudes higher** than that observed by Rosetta surrounding 67P (Fig. 2, left) [5]. **This indicates that gaseous species are not likely the primary attenuating agent.**
- A slab of refractory material with a **thickness of δ_M = 1.36±0.66 cm** averaged over various common grain species is capable of causing an 8% attenuation of incident GCRs (Fig. 2, right). It is expected that the attenuating thickness of dust grains lies closer to the upper bound of this value, due to the majority of 67P refractory composition being carbonaceous [6].

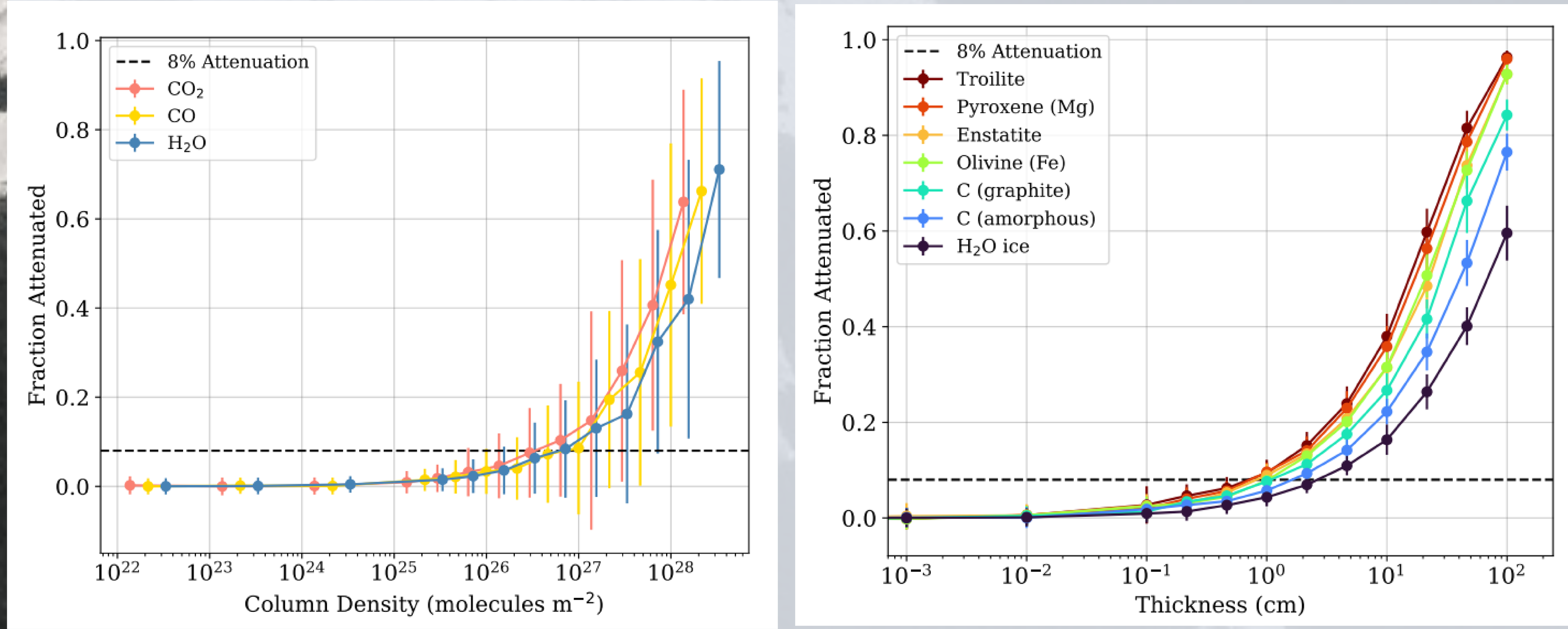


Figure 2: MULASSIS GCR fraction attenuation results for primary gas (left) and refractory (right) species. The dashed black line indicates the 8% attenuation feature [2].

ComMoDE Results:

There are two cases in which the cumulative grain thickness δ_M = 1.36±0.66 cm is compatible with 8% attenuation (Fig 3, intersection of red and blue curves with the shaded green region):

- **GCRs may suffer from frequent, low-energy loss collisions with small (sub-μm) grains (red)**
- **Attenuation via few, high-energy loss collisions with large (μm – mm) grains (blue).**

Under these two cases, the cumulative thickness experienced by GCRs reaches the 1.36±0.66 cm threshold within typical grain size limits (≤10^3 μm). This indicates that within such conditions the coma dust environment may be a compatible contributing cause of GCR attenuation.

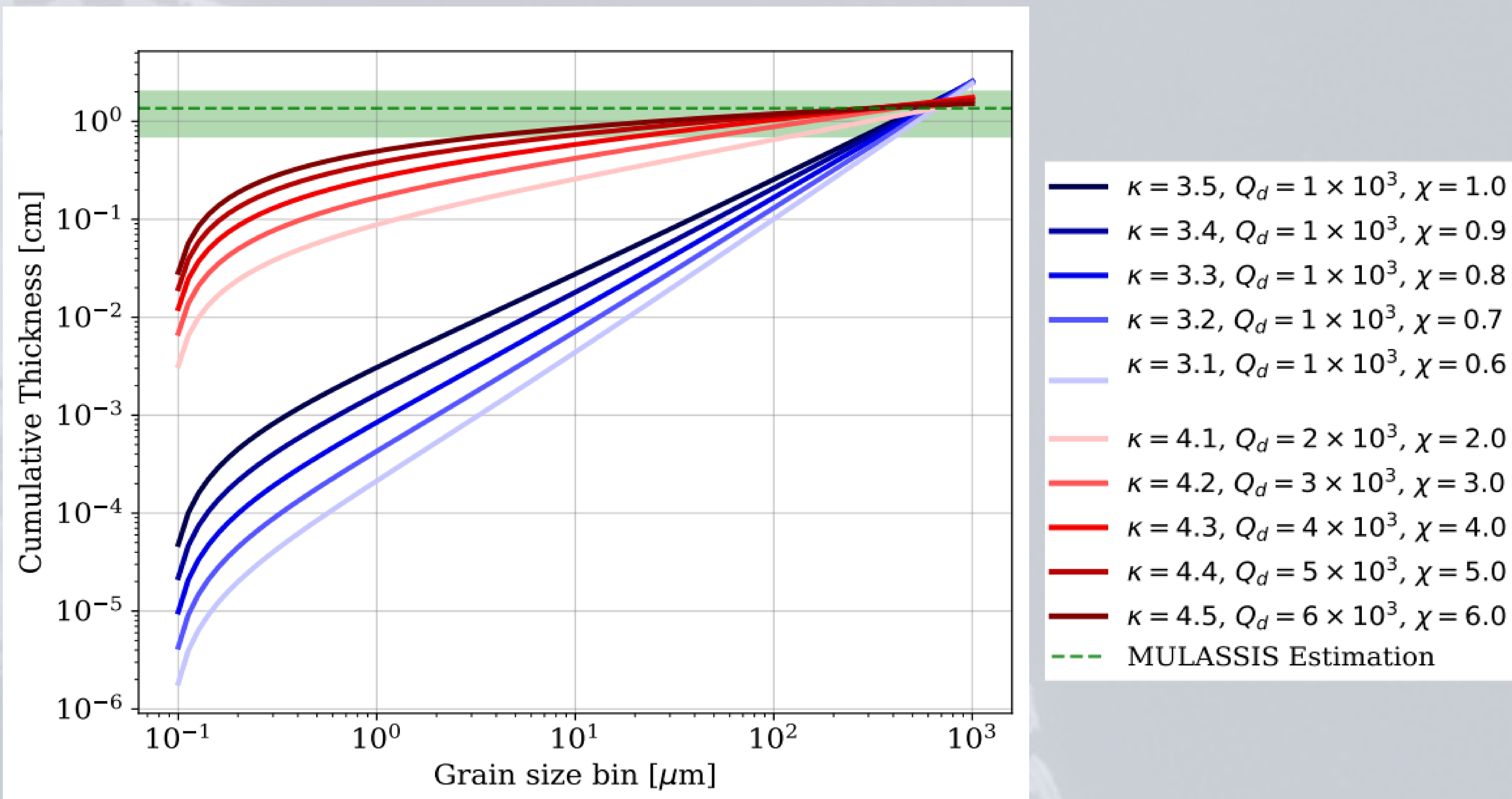


Figure 3: Cumulative thickness for two scenarios in which parameters intersect with δ_M: low κ, Q_d, χ (blue), or high κ, Q_d, χ (red). Q_d is measured in kg s^{-1}. The green dashed line represents δ_M (1.36 cm) and shaded area represents 1σ of this value.

Conclusions

It is possible that attenuation due to dust accounts for only a fraction of the total observed GCR attenuation.

- Induced magnetic field and Forbush decrease events are possible to occur as well throughout Rosetta's mission and may account for a percentage of the attenuation.
- Attenuation levels reported by [2] may have been affected by temperature and voltage fluctuations aboard Rosetta. A uniform reduction over time is not likely, from what we know of comet activity behaviours. 8% is the maximum likely attenuation, occurring at perihelion.

Dust environments are extremely complex, and the intricacies of grain-GCR interactions could only be approximated using MULASSIS and ComMoDE.

- Mixtures of different grain and ice compositions, non-spherical and porous shapes of grains, and GCR trajectories and scattering behaviours were not taken into account. These are areas for future study.

We conclude that the dusty environment of 67P is a possible compatible explanation for the 8% attenuation in GCR count rates. With the planned launch of the Comet Interceptor mission, new opportunities to study grain-GCR interactions will present themselves in the future.