ESTIMATION OF THE RECYCLING RATE OF DUST IN THE MARTIAN ATMOSPHERE USING POLONIUM-210 AS A RADIOACTIVE TRACER.

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Introduction: The radioactivity of airborne aerosols, which originates from the attachment of radionuclides produced by radon disintegration, Galactic Cosmic Rays (GCR) or anthropogenic activities, can be used to measure the aerosols residence time in the atmosphere and their deposition rate. It is also used to characterize soils erosion rates [1] or to investigate the origin of desert rock varnish [2], to name only a few terrestrial applications. A translation of these nuclear methods to the Martian atmosphere, which is characterized by a very active dust cycle, can provide a unique insight into the present-day recycling of the Martian surface.

Polonium-210 (^{210}Po) is a long-lived decay product of radon-222 (^{222}Rn), a radioactive gas produced in the ground and eventually released into the atmosphere. The long apparent half-life of ^{210}Po is such that its unsupported fraction (i.e., the fraction not in equilibrium with its parents within the grains) is almost entirely attached to the particles that have been in suspension in the atmosphere, especially those characterized by a large specific surface area or by a long atmospheric residence time. Each particle traveling in the atmosphere accumulates some ^{210}Po, and this process is much more efficient than on the ground, because the collection volume around each particle is much greater in the atmosphere. The amount of ^{210}Po attached to the atmospheric aerosol depends on the amount of ^{222}Rn released from the ground over the past few decades (due to the 22.3 year half-life of the intermediate radionuclide ^{210}Pb) and the recycling rate of the dust cycle. Polonium-210 is therefore a valuable tracer of the dust cycle, especially on Mars where no other technique is available to track dust particles.

Presence of a ^{210}Po signal in Spirit and Opportunity alpha spectra: The presence of radon in the martian atmosphere was first inferred by the detection of ^{210}Po on the dust magnets of the rover Opportunity [3]. The presence of ^{210}Po is characterized in the alpha spectra of the Alpha Particle X-ray Spectrometer (APXS) by the presence of a peak at ~5.3 MeV, corresponding to the energy of the alpha particles emitted by this radionuclide. This energy is above the energy of backscattered alpha particles (emitted by a ^{244}Cm source) which are of interest for the APXS chemical analysis. The signal at these energies is dominated by GCRs and the detection of a radiogenic signal is much more challenging at the surface of Mars than of the Earth because of a much more severe radiation environment. Hence, in the absence of a background rejection system, long integration times are required. Moreover, the detection efficiency of the APXS was not optimized for this type of passive measurement. Nonetheless, the accumulation of dust on the Capture and Filter magnets concentrates the (possibly) radioactive source on a small area, which makes its detection easier.

An analysis of Spirit alpha spectra (totalizing 3638 hours of integration) was also carried out, following an approach very similar to that described in [3], except in the treatment of an anomalous signal at high energies, which was found to be correlated with the sensor head temperature, and selectively removed. The spectra acquired on the dust magnets were compared to several independent blank spectra. This comparison revealed in all four cases a statistical anomaly above the 99% detection threshold, at the same position as the ^{210}Po peak detected in Opportunity spectra of the dust magnets. This anomaly is absent from all other targets' types (rocks, atmosphere, soils). The net signal was then converted into surface activity (Bq.cm^{-2}) and specific activity (Bq.g^{-1} of dust).

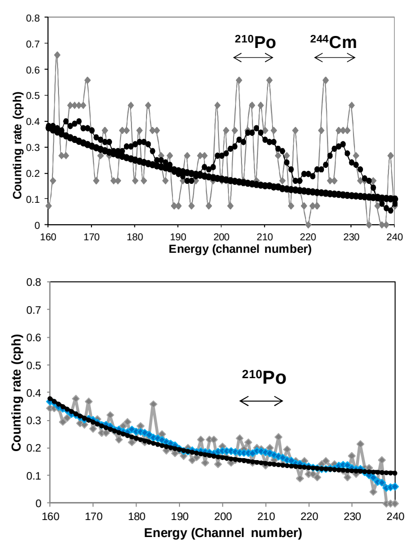

Figure 1: Alpha spectra measured by Opportunity (top) and Spirit (bottom) on the dust Filter and Capture magnets (black and blue lines are running averages, and the continuum is a fit of the spectra over channels [160-200; 215-255]). The similarity between the two continua confirms that Opportunity and Spirit spectra had similar energy calibration.

The dust radioactivity measured at Meridiani Planum is six times larger than at the Gusev site. This could be indicative of different dust transport histories (e.g., transport through regions characterized by different ^{222}Rn atmospheric concentrations, or differences of average residence time) and/or physical properties, possibly related to the differences in brightness/mineralogy/composition already noted on the dust magnets at the two sites [4]. For instance, smaller dust particles, or particles with greater specific surface area, would collect more ^{210}Po during their atmospheric journey, dust collected on Spirit magnets was found to be brighter.

Although spatial variations are observed, averaging the values measured at two locations on opposite sides of the planet is the most reasonable way to estimate the average ^{210}Po-induced radioactivity of the martian dust, until additional measurements are made at the surface of Mars.

Estimation of the load of the active dust reservoir and its recycling rate: The knowledge of both the average ^{210}Po-induced radioactivity of dust particles and the average radon exhalation rate can yield an estimate of the load of the active dust reservoir (i.e., the load of the reservoir that has been exchanged with the atmosphere over the past few decades) and its recycling rate (i.e., the average time spent by dust particles on the ground before being lifted again). To this purpose, we used a box model made of two reservoirs: a surface reservoir (q_s), characterized by a residence time τ_s, and an atmospheric one (q_a), characterized by a residence time τ_a (Fig. 2). Combined with independent estimates of τ_a and q_a (e.g., from [5] and [6]), the measurement of dust ^{210}Po-induced radioactivity and of the exhalation rate of radon by Mars Odyssey Gamma-Ray Spectrometer [7] provide the missing parameters, τ_s and q_s.

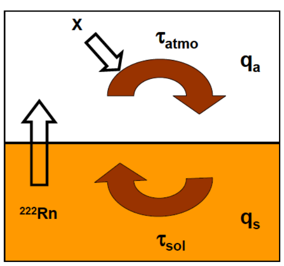

Figure 2. Box model representing the dust cycle: exchange between the surface and atmospheric reservoirs and corresponding residence times.

The load of the dust reservoir that has been active over the last few decades is found to represent a global equivalent layer which is only ~14 µm thick. This is only about 7 times the amount of dust injected in the atmosphere during the 2001 global dust storm [6]. We conclude that the martian dust cycle is not in an “open loop” configuration, in which dust particles are transported only once from their emission to their deposition site on a timescale of a few decades. Without recycling, i.e. if only “fresh” dust was injected into the atmosphere, the reservoir would be exhausted after only ~5 years. A large fraction of dust particles present in the atmosphere are therefore dust particles that have been recycled. This is in stark contrast with the Earth, where the recycling of aerosols is negligible (in comparison to the injection of “fresh” particles).

The reason for this is unknown (although it is worth noting that arid regions on Earth are in a “supply-limited” configuration [8]), but this result has strong implications for the understanding of the Martian dust cycle.

Implications for the Martian dust cycle: For instance, results from GCM that simulate the dust cycle have shown that “infinite” dust reservoirs are required to maintain the observed annual opacity cycle: limited reservoirs are rapidly exhausted, leading to a “low opacity” atmospheric state [9]. Since the source regions are not predicted to be efficiently replenished, “fresh” dust needs to be injected to maintain the dust cycle stable over the years [9]. Our analysis, however, shows that the Martian dust cycle is not in such an “open” configuration. This means that some feedbacks are not currently modeled properly, or that feedbacks not yet taken into account are actually important. Kahre et al. [9] mention the possible feedback effect of albedo and surface roughness, for instance. The efficiency of lifting processes may also need to be reconsidered.

GCM models also fail to reproduce the inter-annual variability of the dust cycle, characterized by the occurrence of global or planet-encircling dust storms [9, 10, 11]. However, a “limited” dust reservoir, as supported by this study, necessarily implies inter-annual variability, because a substantial fraction of the reservoir is redistributed every year. This observation therefore suggests that the occurrence of global dust storms is constrained by the time taken to replenish the main source regions, which itself is constrained by the average residence time τ_s which we find to be a few years.

Finally, estimates of net deposition rates, and hence estimates of the age of some dust-rich regions, may also need to be reconsidered.

References:

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