ANALYSIS OF URANIUM AND THORIUM LINES IN MARS ODYSSEY GAMMA SPECTRA AND REFINED MAPPING OF ATMOSPHERIC RADON. P.-Y. Meslin[1], D.K. Hamara[2], W.V. Boynton[2], J.C. Sabroux[3], O. Gasnault[1], Institut de Recherche en Astrophysique et Planétologie (IRAP), 9 avenue Colonel Roche, BP 44346, 31028 Toulouse, France ; pmeslin@irap.omp.eu; [2]Lunar and Planetary Laboratory (Tucson, AZ), [3]Institut de Radioprotection et de Sûreté Nucléaire (Gif-sur-Yvette, France)

Introduction: A comparison between preliminary *Mars Odyssey* Gamma Ray Spectrometer (GRS) data and results from a radon transport model has shown in the past that the presence of radon in the atmosphere can explain, at least to first order, the main spatial features of the apparent U/Th ratio observed by *Mars Odyssey* GRS [1]. It confirmed the fact that the exhalation of radon from the subsurface, where it is produced by the radioactive decay of uranium, is not negligible on Mars, which was first evidenced by the detection of unsupported polonium-210 on atmospheric dust by *Opportunity* APXS [2]. Another piece of evidence came from an analysis of six gamma ray lines from ^{214}Bi (at 609, 769, 1765 and 2204 keV) and from ^{214}Pb (at 294 and 351 keV), two short-lived decay products of radon, which revealed an energy dependence of the apparent uranium concentration consistent with the presence of these radionuclides in the atmosphere. This insight into the vertical distribution of radon enabled us to establish a preliminary map of radon atmospheric column densities [3]. It has been improved (and the overall approach confirmed) by a refined analysis of all extractable uranium and thorium lines, both in background and gross spectra. Time variations of the signal were also investigated.

Peak fitting: The analysis of the 6 gamma ray lines mentioned above was reassessed by taking into account a more complete set of interfering lines, and 8 new lines were added to the existing set, ranging from 242 to 2448 keV (all of which having branching ratios > 1%). To check if the data could be affected by a systematic bias (i.e., a decrease of the concentration with energy not related to a non-uniform vertical distribution of radon decay products), we also extracted a large set of thorium lines (14 lines ranging from 209 to 2615 keV). Indeed, the very limited mobility of radon-220, a decay product of ^{232}Th with half-life of 55 s, is not expected to displace efficiently its products to the atmosphere. Therefore, the analysis of thorium lines should yield a concentration that is independent of their energy. Peak fitting was performed on the sum of all GRS spectra (per acquisition epoch). Figure 1 illustrates a few examples of some complex regions where rather weak U and Th were successfully fitted.

Conversion to U and Th abundances: To extract the signal originating from the regolith, a background subtraction was performed. To do so, a new background spectrum was used, which was obtained over all regions where the H gamma ray line intensity was attenuated by more than 90% (later called H90 regions), in order to improve its statistics compared to a mere sum of spectra obtained over the permanent polar caps.

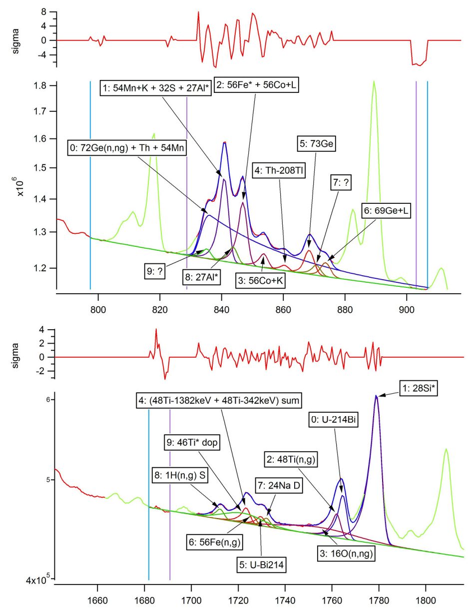

Fig. 1: Peak fitting of the Th-^{208}Tl (861 keV) and U-^{214}Bi (1730 and 1765 keV) lines

This new background spectrum was compared to the background spectrum measured during the cruise phase, and some statistically significant differences were obtained, most likely related to the presence of radon in the atmosphere above H90 regions. Indeed, at high γ energies, the intensities of U lines measured over H90 regions are weaker than during the cruise phase, which is consistent with the fact that the boom was not deployed during the cruise, but they are similar to cruise intensities at low energies, where U lines intensities are most sensitive to the contribution from atmospheric radon (on a relative basis), while they should remain lower if no radon was present in the atmosphere. This means that our analysis using the H90 background probably slightly underestimates the amount of radon present in the atmosphere.

Time-integrated forward calculations were performed at all the energies of interest to estimate the conversion factor necessary to convert peaks area to abundances expressed in ppm (this factor depends on the position of the spacecraft, the γ total attenuation coefficients and the GRS detection efficiency). These calculations were made for two scenarios: first by assuming that all uranium decay products were confined in the subsurface (vertically uniform distribution in the soil), second by assuming that all the γ signal was coming from the atmosphere (vertically uniform mixing ratio). The corresponding abundances are shown in Fig. 2 as a function of energy. A very marked decrease with energy is observed for the first scenario, and an opposite result is obtained for the second scenario. This confirms that radon is present both in the subsurface and in the atmosphere. The first scenario was applied to thorium lines, but no such trend with energy is observed. Thus, the result obtained with U lines does not come from a systematic effect in the measurement or analysis process.

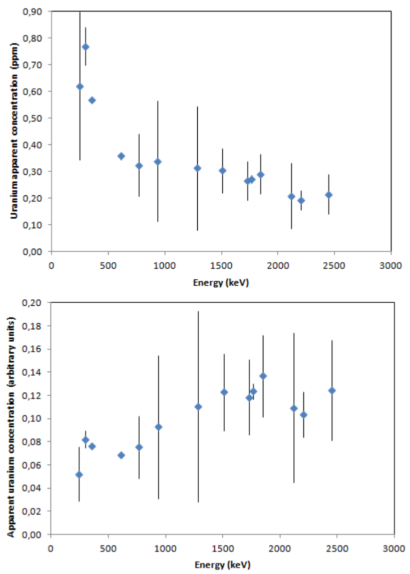

Fig. 2: Apparent uranium concentrations as a function of energy for two scenarios: Top: assuming all uranium decay products are in the soil; Bottom: assuming they are in the atmosphere.

Mapping of radon atmospheric column densities: Because the attenuation of γ photons depends on their energy, analyzing γ-ray lines at different energies provides an insight into the vertical distribution of the radionuclides from which they originate. Therefore, it is possible to extract the atmospheric mixing ratio of these radionuclides from the total signal. We were thus able to derive a 10°x10° map of time-averaged radon atmospheric column densities assuming a uniform mixing ratio with height (Fig. 3). The spatial variability of this gas remains to be explained, but could result from differences in subsurface U concentrations, in surface temperatures, in water content, and from the global atmospheric circulation [4].

Time variations over Syrtis major: We also looked at time variations of the signal over the very same region where a plume of methane was supposedly detected [5], using the 609 keV ^{214}Bi line.

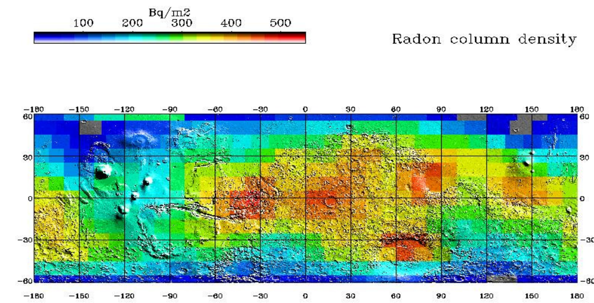

Fig. 3: Time-averaged map of atmospheric radon column densities (Bq.m^{-2}).

First, this analysis reveals statistically very significant time variations of the apparent U abundance over the course of a Martian year, and well above its value predicted by a Th/U ratio of 3.8. Both facts are a clear signature of the presence and variability of radon in the atmosphere. However, although there is an increase of the radon column density observed during the methane plume event, this is not a very strong one. A better understanding of the variability of atmospheric radon in this region will be necessary before drawing any conclusion and any constraint in the debate related to the detection of this plume.

Conclusion: This study confirms that radon is an interesting tracer of subsurface atmosphere exchanges, which can address key objectives of the Martian exploration program related to the detection of atmospheric trace gases and the characterization of their spatial and temporal variations.

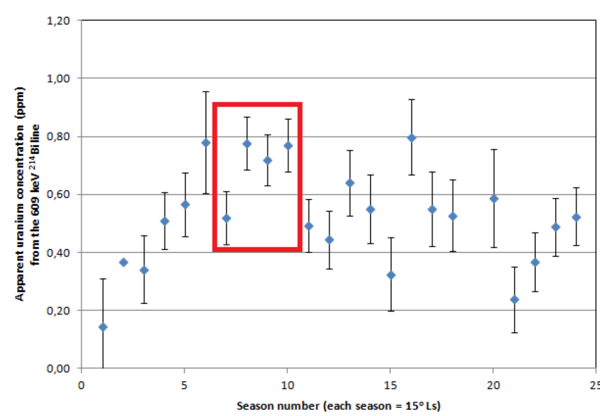

Fig. 4: Time variations of the apparent uranium concentration over the region where a methane plume was reported (red box : timeframe of the plume event).

References: [1] Meslin, P.-Y. et al. (2008), "*3rd Mars atmosphere: Modeling and Observation*" *Conference*, Williamsburg, abstract #9122. [2] Meslin, P.-Y. et al. (2006), *JGR*, 111(E9). [3] Meslin, P.-Y. et al. (2011), "*4th Mars atmosphere: Modeling and Observation*" *Conference,* Paris. [4] Meslin, P.-Y. (2008), PhD thesis, Université Pierre et Marie Curie. [5] Mumma M. et al. (2009), *Science*, 323(5917), 1041-1045.