MARS ATMOSPHERE ARGON DENSITY MEASUREMENT WITH THE ALPHA PARTICLE X-RAY SPECTROMETER ON MER MISSIONS.

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Introduction: The Alpha Particle X-ray Spectrometer (APXS) on both rovers on the MER mission is an analytical instrument that obtains the elemental chemical analyses of martian soil and rock samples [1], [2]. It determines all elements heavier than sodium with very good accuracy. For some trace elements the detection limit is a few tens of ppm. In addition to the results from the martian surface samples, the APXS is also capable of determining the abundance of the element argon in the Martian atmosphere.

Method of the Ar Detection: The composition of the Martian atmosphere, as it was determined at 7.5 mbars of pressure by the Viking mission [3], consists of about 95.3% of CO_2, 2.7% N_2, 1.6% Ar and small traces of other light gases. The APXS uses radioactive alpha sources to produce characteristic fluorescence lines that enable quantitative analyses of all the elements in the sample. Fig. 1 is an example of the X-ray spectrum obtained by the APXS from a typical basaltic surface sample. Each element is determined from its characteristic elemental line in the spectra. The origin of the line described as Ar in Fig. 1, however, is not from the sample itself, but from the volume of the martian gas that is contained between the sample and the x-ray detector at the distance of about 4 cm. Since the APXS acquires its data in the martian ambient environment, all the X-ray spectra contain this Ar line.

An attempt was made to determine the Ar abundance in the martian atmosphere from this line using the Ar peak intensity in the X-ray spectra from the surface samples. Fig. 2 shows the results of the analyses over a period of 900 sols. As it can be seen, there is a considerable scatter in the data that can be attributed to the following reasons: a) the Ar peak lies on a relatively large background that is caused by all the peaks above the Ar and by scatter of the Pu lines from the curium alpha source; b) the Ar peak is between the chlorine and potassium peaks that are not constant in all samples; and c) the relative distance from the sample to the detector is not known accurately to make any correction for change in the gas volume that contributes to the Ar peak.

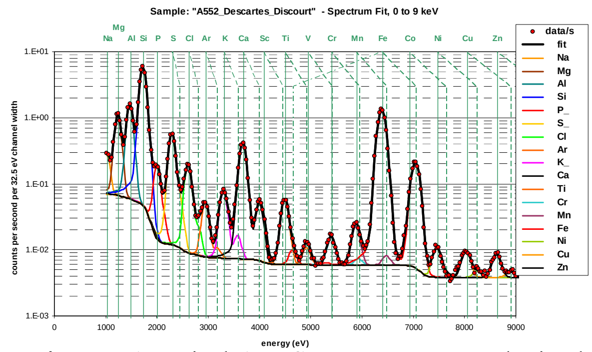

Fig. 1. A typical APXS X-ray spectrum obtained from a martian surface sample. In all such spectra, the origin of the Ar peak is not from the surface sample but from the argon in the martian atmosphere between the sample and the APXS detectors.

For all these reasons, it was realized that the accuracy to determine the variation of the Ar in the atmosphere as a function of a seasonal change is not very good. However, even with such scatter in the data, there is an indication of a variation in the amount of Ar in the atmosphere over a long time period corresponding roughly with change of seasons.

The situation is quite different when we started to make dedicated APXS measurements of the atmosphere.

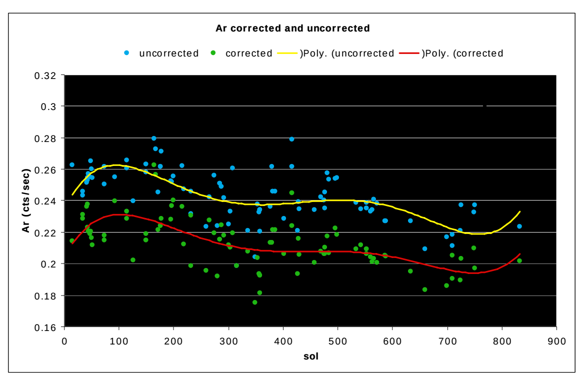

Fig. 2. .Ar amount in the martian atmosphere as determined from the Ar peak area in the surface samples. Due to significant interferences there is a large scatter in the data for reasons stated in the text.

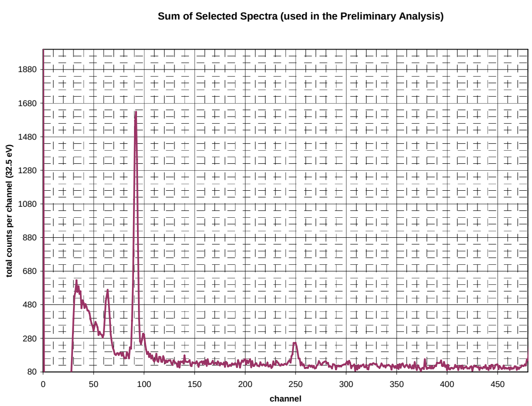

Fig. 3. An APXS x-ray spectrum obtained during the dedicated APXS atmosphere measurement. The Ar peak is the only detected atmospheric component, without any interference from other elements and with relatively very low background.

In this case, the only real peak in the X-ray spectrum is the Ar line at 2. 957 keV. The APXS resolution is so good that even the Ar K_{β} line at 3.192 keV is visible.

Fig 3 shows such a case of X-ray spectra from the atmosphere alone. In that case, with the Ar peak being very narrow and with elimination of all the causes contributing to the already mentioned uncertainties, accuracies of about 3.7% can be achieved by an hour APXS acquisition and accuracy of about 2% in a 4 hour data acquisition. A late decision was made by the project (at about sol 1000 on MER B, sol 1100 on MER A) to start dedicated and systematic atmospheric Ar measurements with the APXS on both rovers, Spirit and Opportunity.

Results: Significantly more accuracy has been achieved in determining the Ar abundance in the martian atmosphere since we have started dedicated atmospheric measurements with the APXS. Fig. 4 shows the Ar intensity in the atmosphere spectrum as a function of time from the beginning of the mission for MER B (Opportunity). For the first 1000 sols only a few dedicated atmosphere measurements have been obtained. Since the start of the dedicated and systematic measurements have started, weekly or bi-weekly Ar measurements have been obtained regularly. The data in the Fig. 4 clearly indicate that there is a variation in the amount of Ar in the martian atmosphere that roughly corresponds to seasonal variations with a periodicity of one martian year.

Analysis: To a good approximation, the APXS count rate is proportional to the number of argon atoms in the sensing volume, and hence measures the atmospheric density of argon, ρ_{Ar}. Assuming a near-ideal gas, this is proportional to the partial pressure of argon and inversely proportional to the temperature: $\rho_{Ar} \sim P_{Ar}/T$. Thus, dividing the APXS Ar count by temperature measures the argon partial pressure. Argon does not condense at Martian temperatures, and since Ar is inert, adsorption by the soil at Martian temperatures is expected to be small. Hence, the total mass of Argon in the atmosphere of Mars is constant. If the atmosphere were perfectly mixed, the argon partial pressure would be constant. If we define the *Local Mixing Ratio* (MR_{local}) as equal to the ratio of the local Ar partial pressure to the global average, then the measurement P_{Ar}/T is proportional to the local mixing ratio. The APXS Argon experiment thus gives a direct measurement of the local mixing ratio at the near-surface at the MER landing sites.

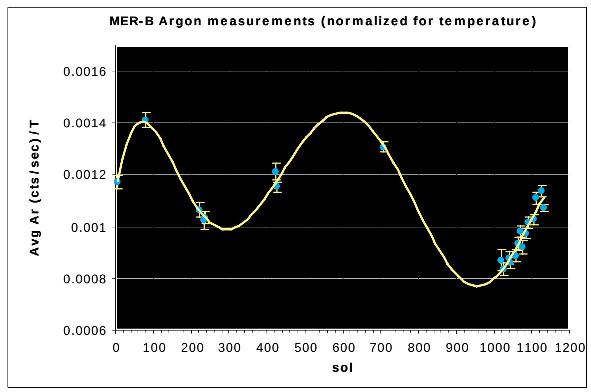

Fig. 4. Argon abundance in the Martian atmosphere as a function of time at the MER B site, from the dedicated APXS measurements of the atmosphere. The data are fitted to a polynomial function that has a periodicity of about one Martian year.

Although the total Ar in the atmosphere is constant, the amount of carbon dioxide changes by as much as 30% [4] over a period of martian year. Polar condensation of CO_2 causes massive movement of atmosphere from the equatorial regions. As the CO_2 freezes, the remaining air is enriched in argon (and nitrogen). The GRS experiment on the Odyssey orbiter around Mars has observed a six-fold enrichment in the Ar/CO_2 mixing ratio [5,6] in the south pole region during the winter period.

During the summer season, the opposite occurs: sublimating CO_2 lowers the local Ar/CO_2 mixing ratio and pushes the air mass with an enriched Ar fraction towards the equatorial regions. The measurement of the Ar mixing ratio at the Spirit and Opportunity landing sites is thus a direct probe of the global circulation between the polar CO_2 sources/sinks and the equatorial regions.

The reason that the Ar density in the atmosphere is changing is ultimately due to condensation and sublimation of CO_2 gas in the polar regions during the Martian winters and summers, respectively. The winter poles becomes so cold that atmospheric CO_2 (the main constituent) freezes out. This ends up reducing the global atmospheric pressure by about 30% [4], twice a year (with the extremes near both northern and southern winters). The total amount of Ar in the atmosphere is conserved (since it doesn't condense), but because the CO_2 changes so much, this can either enhance or dilute the abundance of Ar in the vicinity of the rovers. At the winter pole, the CO_2 is condensing, a global flow is setup to equalize this localized pressure decrease from the condensation. This draws in both CO_2 and Ar, but the Ar doesn't condense. Thus, Ar is enhanced over the winter pole. The GRS experiment on the Odyssey orbiter around Mars has observed a six-fold enrichment in the Ar/CO_2 mixing ratio [5,6] in the south pole region during the winter period. Similarly, over the summer pole, puer CO_2 sublimes off the seasonal cap, creating a high that pushes the air mass towards meridional regions and that process is reducing the local abundance of Ar .

The actual Ar abundance that is realized at the near-equatorial location of the rovers is controlled principally by the efficiency with which the atmosphere can mix away the Ar abundance gradients that occur from the localized condensation of CO_2 at the poles. While we understand the overall condensation/ sublimation cycles of CO_2 in Mars' atmosphere, we do not have a good understanding of the meridional mixing that controls the equatorial abundance of Ar that we are measuring on the rovers with their APXS instruments.

We expect that (at least) two factors are important in controlling this mixing that smooths the Ar gradients. The first is the Hadley-cell type circulation of the Martian atmosphere that moves the bulk of the atmosphere between the regions it is heated (near the equator) and more poleward latitudes where it is cooled. This bulk flow also ends up smoothing gradients, and thus controlling the Ar abundance measurements by the MER rovers. However, the Hadley cell meridional circulation only extends up to ~60 degrees latitude near the winter pole. At this point, a polar vortex of fast zonal winds exists, and the Hadley cell circulation is closed off from the winter pole. On earth, we have a similar wintertime polar vortex that confines and enables the ozone hole to occur each winter. Transport across Mars' polar vortex is not well understood, and indeed not only important for Ar abundance on Mars, but also the transport of H_2O and dust to the polar regions of Mars. Thus, by studying the Ar abundance at the equator on Mars, we will have some insight into the meridional circulation and mixing present on Mars, not only in the organized Hadley cell, but also across the polar vortex.

References: [1] R. Rieder, et al., JGR **108**, doi : 10.1029/2003JE002150 (2003), [2] R. Gellert, et al., Science **305** (2004) pp 829-832. [3] Owen et al. (1977) JGR **82**, 4635-4639, [4] P.B. James, H.H. Kiefer and D. A. Paige, *Mars*, U. Arizona Press, 934-968. [5] Sparauge et al. (2007) JGR, 112 EOS02, [6] Spruage et al., Planetary Science XXXVIII (2007), 2400.pdf.

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