ARGON PARTIAL PRESSURE MEASUREMENTS WITH THE ALPHA PARTICLE X-RAY SPECTROMETERS: END OF MISSION RESULTS FROM THE MARS EXPLORATION ROVERS AND ONGOING WORK AT GALE CRATER. S. J. VanBommel[1], R. Gellert[2], B. C. Clark[3], D. W. Ming[4], C. Schröder[5], A. S. Yen[6], J. A. Berger[2], N. I. Boyd[2], C. D. O'Connell-Cooper[7], and L. M. Thompson[7], [1]Washington University in St. Louis, St. Louis, MO, USA, [2]University of Guelph, Guelph, ON, Canada, [3]Space Science Institute, Boulder, CO, USA, [4]Johnson Space Center, Houston, TX, USA, [5]University of Stirling, Stirling, UK, [6]California Institute of Technology, Pasadena, CA, USA, [7]University of New Brunswick, Fredericton, NB, Canada.

Introduction: The Alpha Particle X-ray Spectrometers (APXS) on the Mars Exploration Rovers (MER) *Spirit* and *Opportunity* as well as the Mars Science Laboratory (MSL) rover *Curiosity* were designed to precisely quantify rock-forming elements through principles of X-ray spectroscopy [1-3]. In addition to spectral lines sourced from a target on the Martian surface, background signals from the APXS instrument exist, as do argon (Ar) K_α and K_β peaks [4] from the ~2% v/v Ar in the Martian atmosphere [5].

Ar peaks are visible in every spectrum due to the unavoidable air column between the APXS instrument face and the solid sample being interrogated. The magnitude of the Ar signal depends on the separation between the APXS and its target [4]. The APXS can also acquire spectra when stowed, resulting in measurements entirely of the atmosphere.

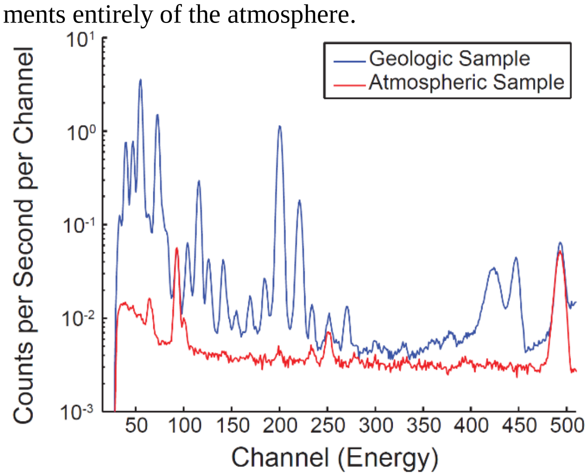

Figure 1: APXS spectra acquired by the MER rover *Opportunity*. Atmospheric spectrum (red) corresponds to a measurement duration of 16 hours. Geologic spectrum (blue) corresponds to a measurement duration of 11.5 hours. The argon peak is visible around channel 100, especially in the atmospheric spectrum [4].

Given the APXS method directly measures elements with Z>11, the only atmospheric signal expected is from Ar (see Figure 1). Without any variability in air column length, changes in Ar peak area are representative of changes in the density of Ar in the Martian atmosphere. Such measurements provide low-latitude ground-truthed data for climate models through the use of Ar as a tracer for the condensation flow of noncondensable gases (NCGs).

Since early in their respective missions, both MER rovers acquired dedicated measurements of the Martian atmosphere with the APXS. Recently, the MSL APXS has adopted a similar cadence. Here we summarize the end-of-mission (EOM) results of the MER APXS atmospheric monitoring campaign and present ongoing work from MSL that will combine data from the APXS with other instruments (REMS, SAM) designed, at least in part, to monitor the Martian atmosphere.

Method and Results: A post-flight calibration and model test was conducted using high-frequency long-duration measurements by *Spirit* conducted while it was stuck and had ample spare power. A channel sum over background model produced stable results with smaller uncertainties than models that relied on least-squares fitting [4]. This model was applied to monitor the change in Ar peak area on both MER and MSL. When corrected for temperature, the Ar peak area is proportional to the Ar partial pressure (p_{Ar}).

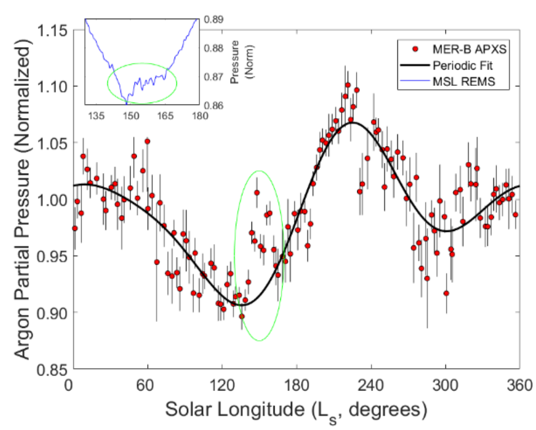

Figure 2: *Opportunity* APXS argon partial pressure measurements reduced through summation by similar L_s. A periodic least-squares fit is applied. A short-term deviation is observed around L_s 155. A parallel observation was made by MSL REMS on MY 32.

Atmospheric measurements prior to sol 1200 were excluded from the analyses of MER atmospheric spectra due to the increased background associated with active Mössbauer instrument sources [4]. Data acquired at temperatures warmer than -50°C were also excluded to ensure the Ar peaks were well resolved. Of the 2230.5 hours of atmospheric data acquired by *Opportunity* during its 5111 sol mission, 1764.8 hours were of sufficient quality for this study. The results are presented in Figure 2. A periodic function has been fit to the acquired data. Deviation from the periodic trend is outlined in Figure 3. Individually, the strongest spikes in Ar density were observed on Mars Year (MY) 29 and 32. A sharp rise in p_{Ar} was not observed on MY 33. MY 30, 31, and 34 were inconclusive.

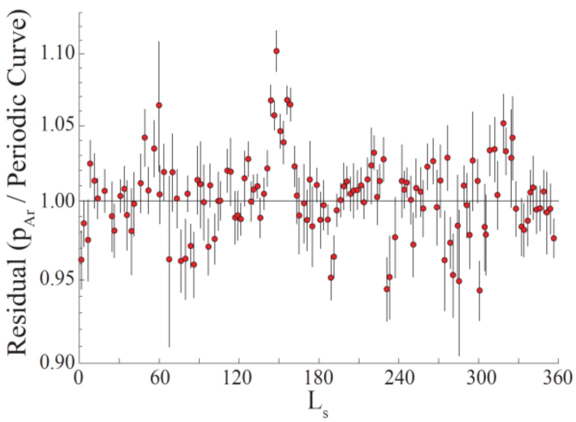

Figure 3: Deviation from a periodic curve of *Opportunity* APXS argon partial pressure measurements reduced through summation by similar L_s. A short-term deviation is observed around L_s 155.

Atmospheric measurements with the MSL APXS follow a similar trend to those of MER presented in Figure 2. Recent measurements were acquired centered around MY 35 L_s 0 to provide a normalization point. However, *Curiosity* has climbed over 400 m in elevation during its traverse to, and ultimately up, Mt. Sharp. Thus, Ar measurements with the MSL APXS will be subject to variation as a result of elevation. These corrections will be applied using a model in combination with absolute pressure data acquired by the MSL REMS pressure sensor.

Interpretation: The short-term enrichment in p_{Ar} around L_s 150 is consistent in timing with a migrating air mass sourced from the southern polar cap similar to that observed by [6] from orbit at high-latitudes. As CO_2 is deposited at the south winter pole, a global pressure gradient drives circulation southward. NCGs, such as Ar, are enriched in the air above the polar cap [6]. As CO_2 sublimates from the southern cap the subsequent spring, the pressure gradient drives the now-Ar-enriched air to lower latitudes.

The *Opportunity* Ar-enrichment observation is paralleled by MY32 REMS measurements that capture a ~0.5% non-periodic change in absolute pressure around L_s 150 (Figure 2, inset), consistent with a ~10% enrichment in NCGs that comprise ~5% of the atmosphere. Likewise, work by [7] shows a spike in the argon volume mixing ratio in their global climate models. The authors are currently working on a higher fidelity model that may potentially resolve this feature further and demonstrate its nascence. NCG enrichment due to southward tracer flux would be expected to manifest around L_s 320, albeit weaker given the more prominent southern winter. Evidence of an enrichment is present in Figure 2 around L_s 320, but would have benefited from improved statistics.

Mars Year 34 Global Dust Storm: A global dust storm (GDS) encompassed Mars in early 2018, ultimately leading to the EOM for *Opportunity*. During this time, *Curiosity*, not dependent on solar illumination for power generation, acquired several APXS atmospheric measurements. The atmospheric measurements acquired during the MY 34 GDS do not display any spectral signatures of dust – the only differences are instrument effects (e.g., source decay). This is consistent with the density of dust expected in the atmosphere, even during the peak of the MY 34 GDS.

Outlook: The MSL APXS will continue to acquire atmospheric measurements. In addition to facilitating the demonstrated science, atmospheric measurements also provide engineering value for monitoring instrument performance. A typical cadence of approximately one atmospheric measurement per month will be sustained outside of the L_s 150 and L_s 320 enrichment periods observed by *Opportunity* – an increased frequency will be utilized during these times. Collaboration with SAM and REMS will continue. Work is planned in concert with the authors of [7] where results may guide changes to the current MSL APXS Ar cadence.

Conclusions: The results presented herein would not be possible without the remarkable endurance of the MER mission. The MER legacy lives on through its acquired data and scientific results, as well as through the professionals and subsequent missions they inspired. MER's APXS atmospheric investigations live on through an international collaboration involving multiple instruments on MSL and in climate models.

References: [1] Gellert & Clark (2015) *Elements*. [2] Gellert et al. (2006) *JGR*, 111. [3] Rieder et al. (2003) *JGR*, 108. [4] VanBommel et al., (2018) *JGR*, 123. [5] Franz et al., (2017) *PSS*, 138. [6] Sprague et al., (2012) *JGR*, 117. [7] Lian et al. (2012) *Icarus*, 218.

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