High-Spectral Resolution, May 2013 Ground-Based Observations of the Lunar Sodium and Potassium Exosphere. R. J. Oliversen[1], E. J. Mierkiewicz[2], D. C. P. Kuruppuaratchi[2], N. J. Derr[3], D. D. Gardner[3], O. L. Lupie[1], F. L. Roesler[3]. [1]NASA Goddard Space Flight Center, Greenbelt, MD (ronald.j.oliversen@nasa.gov), [2]Embry-Riddle Aeronautical University, Physical Sciences Department, Daytona Beach, FL (mierkee@erau.edu), [3]University of Wisconsin, Physics Department, Madison, WI (roesler@physics.wisc.edu).

We apply high resolution spectroscopy to investigate the lunar exosphere by measuring sodium and potassium spectral line profiles to determine the variations in exospheric effective temperatures and velocities as a function of time, solar conditions and geometries. Observations are made with a dual-etalon Fabry-Perot spectrometer from the National Solar Observatory McMath-Pierce Telescope. The spectrometer has a Field of View (FOV) of 3 arcmin (~336 km at semi-major axis = 384,400 km) and a resolving power of 180,000 and 150,000 to measure the line widths and radial velocity Doppler shifts of the sodium D2 (5889.951 Å) and potassium D1 (7698.965 Å) emission lines, respectively. We first measured the sodium profile in March 2009 [1] followed by the first potassium line profile measurements in June 2012 (Fig. 1) during the moon's waning gibbous phase. As previously reported [2], [3] potassium has a smaller scale height than sodium (Fig. 1). We only detected the potassium emission within ~0.25 R_{moon} of the lunar limb while we measure sodium out to ~1 R_{moon}. A lunar scattered light gradient underlying the Fabry-Perot circular interference fringes is the dominant continuum source and limiting factor in the precision of these measurements.

During the May 2013 full moon period, we obtained our first data set that covered both pre- and post-full moon phases. For these observations, we developed a scattered light removal algorithm that was an iterative fit of a two-dimensional 5th degree polynomial and radial Gaussian distributions. The subtraction eased the fitting process by significantly flattening the image before the annular ring summing which creates the spectra, thereby increasing the accuracy and sensitivity. The instrument's 3 arcmin FOV was positioned at several locations, centered 1.5 arcmin off the limb. Observations near 1st and 3rd quarter (phase angles 70° - 110°) have temperatures of 1100° K and 2100° K for sodium and potassium, respectively. As the phase angle decreased for both the waxing and waning phases the measured line width and corresponding temperature increased (Fig. 2). However, the relative increase is more pronounced for sodium when compared to potassium. While the sodium in the Earth's magnetotail region (phase angle < 30°) has followed the familiar pattern of being fainter and hotter [6]. It is about 30%

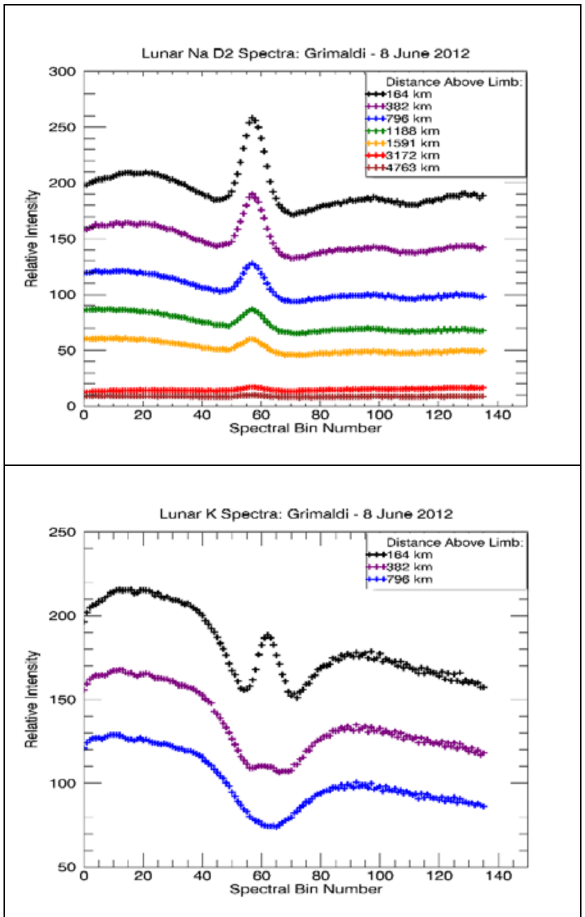

*Figure 1. Lunar Na D2 and K D1 emissions measured with a 327 km FOV (moon range = 375,000 km) off the limb near Grimaldi crater (68.3° W, 5.5° S). The Na spectra are comprised of the solar Na Fraunhofer line (5889.9509 Å), the lunar s-resolved Na emission doublet (5889.9386, 5889.9584 Å) and 3 terrestrial H_2O absorption features (*5889.637, 5890.090, 5890.227 *Å)[4]. The K spectra contains the solar K absorption line (7698.9646 Å) and the lunar s-resolved emission doublet (7698.9586, 7698.9681 Å) [5]. The dip on the left side of the spectra is an image artifact due to not being flat field corrected. Wavelength scale decreases to the right (red → blue) with a spectral bin = 0.3097 km/s. Integration times were 300 sec per exposure. Lunar phase angle = 52º (illumination 81%).*

fainter than when compared to the 1st and 3rd quarter phase intensities with temperatures just inside the magnetometer of order 3000° K increasing to over on 6000° K at full moon (Fig. 3). Although potassium emission was not detected in the magnetotail, there are indications that it was hotter pre-magnetotail passage as compared to post-magnetotail passage. Additionally, the potassium intensities were 1/3 brighter following the post-magnetotail passage. Figure 3 shows examples of sodium line width as a function of distance off the limb. The moon was deep within the magnetotial on May 24 and 25 while observations taken on May 28 are after the moon had exited the magnetotail. This work was partially supported by the NASA Planetary Astronomy programs, NNX11AE38G and NNX13AL30G.

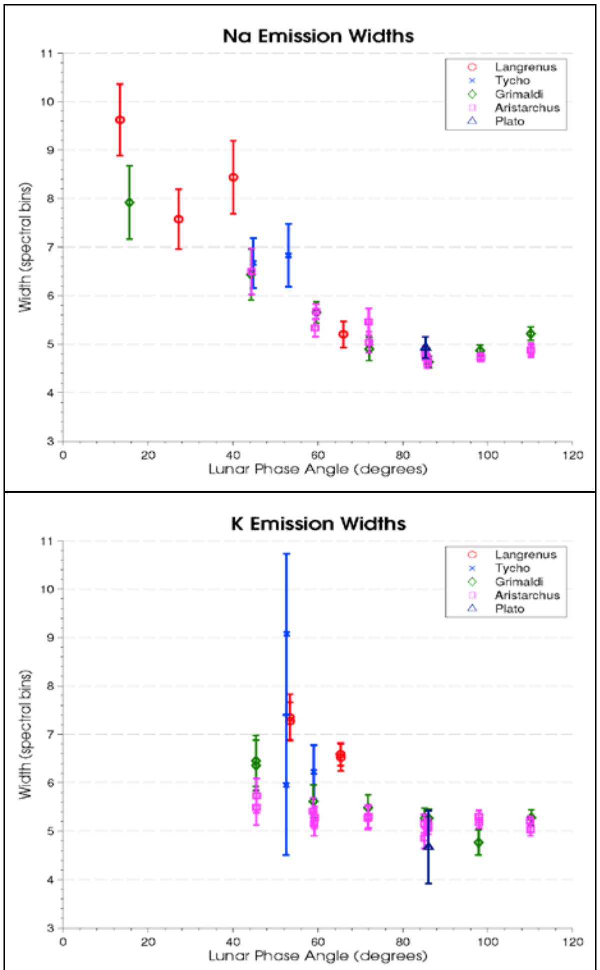

Figure 2. Na (K) spectral fits include the 6 (3) components listed in Figure 1. The Na and K s-resolved doublet wavelength spacing and intensity ratios are fixed [4], [5]. Observations off the Langrenus (Grimaldi, Aristarchus) limb(s) are taken during the waxing (waning) phase. A spectral bin = 0.3097 km s^{-1}. The line width is the deconvolved line width (FWHM) where a thorium line is used to measure the instrument profile. The errors correspond to the model fit errors. Temperature ($T_{eff}(K)$) is calculated from the Doppler width (δV_{FWHM}(km/s)) by $T_{eff} = C(m) \times \delta V^2$ where C(Na) = 501 and C(K) = 850.

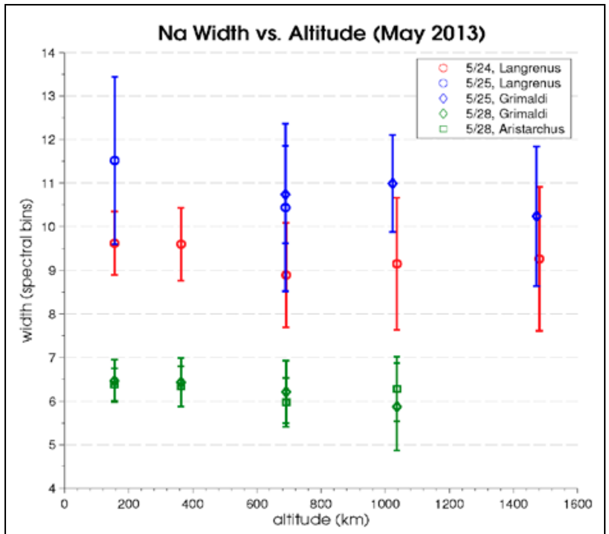

Figure 3. The Na widths (FWHM) are plotted vs the distance to the center of a 3’ FOV (312 km). The FOV was moved from the limb due East of the Langrenus crater (61.1° E, 8.9º) and due West of the Grimaldi crater (68.3° W, 5.5° S) and the Aristarchus crater (47.4° W, 23.7° N). The full moon was May 25 at a distance of 356,000 km. The lunar phase angles were 13º, 2º and 44º for May 24, 25 and 28, respectively.

References:

[1] Mierkiewicz, E. J. et al. (2014), JGR-SP, 119, 4950 - 4956. [2] Porter, A. E. and Morgan, T. H. (1988), Science, 241, 675 - 680. [3] Sprague, A. L. (1992), Icarus, 96, 27 - 42. [4] McNutt, D. P. and Mack, J. E. (1963), JGR, 68, 3419 -3429. [5] Von Zahn, U. and Hoffner, J. (1996), GRL, 23, 141 - 144. [6] Potter, A. E. et al. (2000), JGR, 105, 15073 - 15084.