SPECTRAL OBSERVATIONS OF COMETS C/2012 S1 (ISON) AND 2P/ENCKE OBTAINED BY MESSENGER. Ronald J. Vervack, Jr.[1], Aimee W. Merkel[2], William E. McClintock[2], Gregory M. Holsclaw[2], Noam R. Izenberg[1], Larry R. Nittler[3], Richard D. Starr[4], Sean C. Solomon[3,5], [1]The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099, USA, Ron.Vervack@jhuapl.edu; [2]Laboratory for Atmospheric and Space Physics, Boulder, CO 80303, USA; [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [4]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; [5]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction: Comets are essentially leftover material from the formation of the solar system. As such, the study of comets plays a critical role in understanding the conditions in the protosolar nebula. Spectral observation of comets provides detailed compositional information and is the primary tool used to investigate comet chemistry. However, pristine as they may be, all comets have likely undergone some processing, whether it be during their extended stay in a cometary reservoir such as the Oort cloud or during multiple solar passages as they orbit the Sun. To disentangle the effects of such processing, it is key to obtain spectra of both Oort cloud and short-period comets.

From late October to early December 2013, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft had the opportunity to observe two such comets: C/2012 S1 (ISON) and 2P/Encke (hereafter ISON and Encke). ISON was an Oort cloud comet on its first trip into the inner solar system, and one that did not survive its encounter with the Sun. Encke, in contrast, is a highly evolved Jupiter-family comet with an orbital period of 3.3 years, the shortest period of any known comet.

The circumstances of the MESSENGER opportunity were highly favorable for spectral observations. Most ground- and space-based telescopes cannot observe comets when they are close to the Sun, but MESSENGER was able to observe both ISON and Encke at relatively small heliocentric distances of 0.47 AU and 0.35 AU, respectively, thereby enabling the chance to investigate the chemistry of both comets over an otherwise poorly sampled range of heliocentric distance. Both comets also passed quite close to Mercury: 0.24 AU (~ 36 million km) on 19 Nov 2013 for ISON and 0.025 AU (~ 3.7 million km) on 18 Nov 2013 for Encke (all dates in UTC). Furthermore, MESSENGER viewed the comets from a perspective quite different from that of ground-based observatories, providing complementary data to those acquired from Earth over the same time period. Here we present preliminary results of the spectral campaign.

Description of Spectral Observations: Two instruments on MESSENGER conducted the spectral campaign. The first was the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), which has two channels. The first channel is the Ultraviolet and Visible Spectrometer (UVVS), a scanning grating monochromator covering 120–600 nm at an average spectral resolution of 0.6 nm that is primarily used to study Mercury's exosphere. The second channel is the Visible and Near-Infrared Spectrograph (VIRS), which measures the wavelength range 300–1450 nm simultaneously at lower resolution (~ 5 nm) and is used to study the surface of Mercury. The second instrument was the X-Ray Spectrometer (XRS), which covers the energy range 1–10 keV and is used to measure Mercury's surface elemental composition. Both ultraviolet and X-ray observations of comets are rare because they can be made only from space, so the opportunity to conduct both, and to do so simultaneously, was particularly valuable.

Because of spacecraft pointing restrictions, the comets could not be viewed continuously over the time period when observations were favorable. Instead, there were two observing windows for ISON and three windows for Encke. The ISON windows were 4 Nov and 19–21 Nov (closest approach). The Encke windows were 28 Oct, 18–19 Nov (closest approach), and 30 Nov to 4 Dec. The first two Encke windows were pre-perihelion, whereas the third was post-perihelion. Encke has a light curve that is asymmetric about perihelion for reasons that are not understood. The opportunity to make observations both before and after perihelion may ultimately shed light on the responsible processes. Fortunately, both ISON windows were pre-perihelion given the comet's ultimate demise.

Because of pointing and ephemeris uncertainties, care had to be taken to ensure that the MASCS slits were positioned on the comets. For UVVS, the center of the 0.04º×1º slit was targeted 0.1º ahead of the predicted comet positions and repositioned once it trailed the predictions by the same amount, thereby allowing the comets to drift across the slit at each targeted position. The 0.023º circular field of view of VIRS is so small that the aperture was simply pointed at the predicted comet positions and integrations kept short, but this procedure required an accurate comet ephemeris. Pointing and ephemeris uncertainties were not an issue for XRS with its large 12º hexagonal field of view.

A further complication for UVVS was its scanning nature. UVVS is controlled by macros, which set a specific range of wavelengths to scan with a 0.25-s integration per wavelength step. Scanning the full wavelength range was not feasible; instead, a better strategy was to use specific macros to maximize the integration time at any one wavelength. Because of time restrictions, comet-specific macros could not be developed, but many of the macros used routinely to study Mercury's exosphere overlap known cometary emission lines and band systems. Owing to the importance of the ultraviolet observations, more time was devoted to wavelengths less than 300 nm with fewer scans at longer wavelengths.

Preliminary Results: Example UVVS spectra of both ISON and Encke are shown in Fig. 1. Clear differences are seen in the relative strengths of the emission lines from both comets (e.g., compare O at 130.4 nm to C at 165.7 nm), and there is only weak evidence of emission from C^+ in Encke whereas it is quite prominent in ISON. Differences such as these provide important clues to the chemical pathways by which parent molecules that derive directly from the nucleus ices (e.g., H_2O, CO_2, CO) break apart in the coma to produce the observed daughter or granddaughter species (e.g., O, C, C^+). The lack of strong C^+ emission in Encke suggests that a particular pathway is unimportant in that comet or that the responsible parent molecule is either depleted or absent.

UVVS provided the majority of the spectra of both comets, with confirmed detections of H, O, C, C^+ (ISON only), S, CS, C_2, OH, CN, NH, and Na; tentative detections of emission from CO and CO^+ have been identified for ISON. For many of these species, the signal is sufficiently high to search for short-term variability, particularly for OH, which was sampled often in a search for variations with comet rotation.

X-ray emission (< 1 keV) was previously observed from Encke [1], leading to the expectation that emission from elements Mg and Si might be detected at higher energy. An example XRS spectrum of Encke is shown in Fig. 2, and there is no clear sign of emission above the cosmic-ray-induced detector background. Whether this result points to changes in Encke or solar wind conditions that were unfavorable for X-ray emission requires further analysis.

Some Encke XRS observations and all the ISON XRS observations during the closest approach of the comet were hampered by a series of solar flares that affected MESSENGER during the observations. These flares induced high and variable background levels in the spectra, effectively swamping any potential cometary emission; however, analysis is ongoing to see if periods with lower backgrounds can be identified.

Emission from OH and CN was identified in a few VIRS spectra of ISON, but no detections were confirmed for Encke. Although the sensitivity of VIRS, designed to observe the bright Mercury disk and not faint comets, is likely the dominant reason for the scarcity of detections, high thermal backgrounds may have compromised the spectra at longer wavelengths because observations occurred during the hottest period of the Mercury year for MESSENGER. There is also the chance that VIRS was not centered on the comets; this possibility will be tested using images of the comets obtained simultaneously once all such images are downlinked from the spacecraft.

References: [1] Lisse C. M. et al. (2005) *Astrophys. J., 635,* 1329-1347.

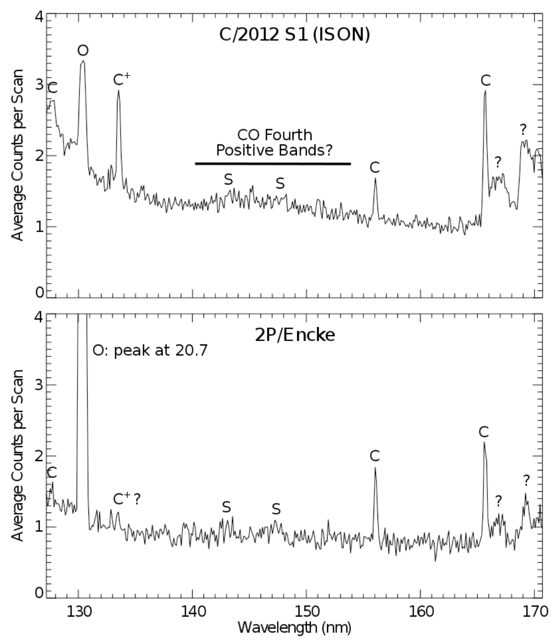

Figure 1. UVVS spectra of ISON (top) and Encke (bottom) during their closest approaches to Mercury. Several emission lines are noted in each spectrum, and clear differences between the two comets may be seen. The continuum in each spectrum is dominated by instrument dark counts (constant level across spectrum) and scattering from the strong H Lyman α line at 121.6 nm (downward trend from left to right). The structure on the right side of the spectra is currently under investigation and could be instrumental in origin.

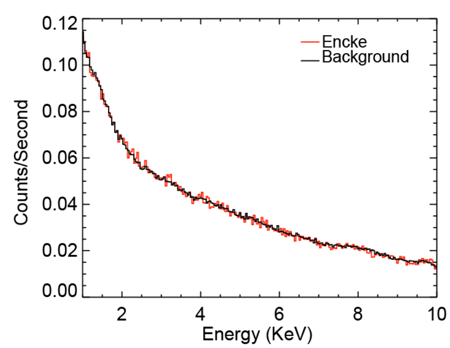

Figure 2. XRS spectrum (sum of three XRS detectors) of Encke during its closest approach to Mercury. There is no clear evidence of emission above the background, which contrasts with previous, lower-energy X-ray detections of Encke.