RESULTS FROM THE MESSENGER IMAGING CAMPAIGN OF COMETS C/2012 S1 (ISON) AND 2P/ENCKE. Ronald J. Vervack, Jr.[1], Peter M. Tamblyn[2], Clark R. Chapman[2], William J. Merline[2], Scott L. Murchie[1], Nancy L. Chabot[1], Brett W. Denevi[1], Hari Nair[1], Nori R. Laslo[1], Robert J. Steele[1], Sean C. Solomon[3,4], [1]The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099, USA, Ron.Vervack@jhuapl.edu; [2]Southwest Research Institute, 1050 Walnut Street, Boulder, CO 80302, USA; [3]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; [4]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA.

Introduction: From late October to early December 2013, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft was in position to observe two very different comets: C/2012 S1 (ISON) and 2P/Encke (hereafter ISON and Encke). ISON, which did not survive its close approach to the Sun, was an Oort cloud comet making its first trip into the inner solar system, whereas Encke is a Jupiter-family comet with the shortest period of any known comet at 3.3 years.

The MESSENGER opportunity was particularly unusual owing to the observing circumstances. ISON passed 0.24 AU (~ 36 million km) from the planet while at a heliocentric distance of 0.47 AU on 19 Nov 2013 (all dates are UTC). Encke passed a mere 0.025 AU (~ 3.7 million km) from Mercury – 10 times closer than ISON – on 18 Nov 2013, while at a heliocentric distance of 0.35 AU. Because most ground- and space-based telescopes cannot observe comets when they are close to the Sun, the MESSENGER observations afforded a chance to investigate both comets over a range of heliocentric distance that is not often probed in comet studies. Furthermore, because of its orbit about Mercury, MESSENGER was able to view the comets from a perspective quite different from and complementary to that of Earth-based observatories. Given the additional factor that the closest approaches of the comets to Mercury were small, especially for Encke, MESSENGER was well positioned to carry out an observing campaign with the potential to compare and contrast the pristine ISON and highly evolved Encke. Here we present preliminary results of the imaging portion of the campaign.

Imaging Campaign Description: Images of the comets were acquired by the two cameras of the Mercury Dual Imaging System (MDIS): the wide-angle camera (WAC) and narrow-angle camera (NAC). The WAC's large field of view (10.5º) provided the best opportunity to capture coma and tail morphology over the longest period of time. The NAC's smaller field of view (1.5º) was best utilized to study smaller-scale structure, particularly during the closest approaches when spatial scales were optimal (approximately 900 km/pixel for ISON and 100 km/pixel for Encke). To draw out fainter features of the comets, the maximum possible integration time of 10 s was used for all images, whereas to minimize the introduction of artifacts, compression was used sparingly.

Three separate campaign elements were designed. The first of these was the long-term monitoring campaign. Starting on 26 Oct for ISON and 28 Oct for Encke, daily image sets of each comet were acquired with the WAC. A set consisted of three broadband images taken in a clear filter (400–1050 nm) to provide the best images, three narrowband images taken in a 430-nm filter that passes minimal light (offset from the comets to provide a measure of the background level; referred to below as "darks"), and three narrowband images taken in a 558.9-nm filter to provide potential information on chemistry (because the filter passband overlaps the wavelength of C_2 emission seen in comets). Three images were taken in each filter to allow for median calculation to eliminate transient image features (e.g., cosmic ray hits) in each resulting composite image. Our strategy transitioned from these daily sets to sets acquired each 8-h MESSENGER orbit as the comets approached Mercury. NAC images (three comet, three off-comet darks) were added to the monitoring campaign when the predicted brightness of each comet was sufficient for detection. During 12–15 Nov for ISON and 10–16 Nov for Encke, no images were acquired because both comets passed outside the limits of spacecraft and instrument pointing capabilities. The monitoring campaign continued until 24 Nov for ISON and 4 Dec for Encke.

The second campaign element was the use of the full set of 12 WAC filters during the closest approach periods. Although the filters were designed to observe Mercury's dayside surface and are not generally aligned with cometary emissions, our objective was to explore the comets' chemistry to the greatest extent possible. To this end, two filter sets were acquired for each comet, at the beginning and end of its closest approach window. Three images were taken in each filter along with a set of three off-pointed darks.

The third and final campaign element was a series of NAC images taken at regularly spaced times during each closest approach period. These images can be merged to make a movie with the potential to sample coma variability as the comet rotates. Encke is known to have a rotational period of 11.3 h, so the NAC movie spanning approximately one Earth day sampled two rotations. The rotational period of ISON is uncertain, but most comets have periods shorter than 20 h, so the two Earth days of the ISON movie are likely to have sampled at least one complete rotation. The image spacing was 15 min for Encke and 30 min for ISON. Observations were not made when the spacecraft was on the dayside of the planet owing to spacecraft thermal restrictions, but the sequences still sampled the rotational phases of each comet well.

Processing of Images: The MDIS instrument was designed to study the dayside of the resolved disk of Mercury, which has a per-pixel brightness orders of magnitude greater than the unresolved nuclei of these comets. However, searches for Mercury satellites and Vulcanoid asteroids with MDIS have provided detailed information on the performance of the cameras on unresolved point sources embedded in dark sky (stellar) backgrounds and prepared us to analyze comet images.

The initial image processing included corrections for bias, dark current, and scattered light. Bias is monitored on an unilluminated part of the detector. Dark current is highly variable and dominates the image noise. Prior experience staring at dark sky has shown that this current depends strongly on camera temperature, but in a manner that can be tracked over time. Off-target images (see above) were used to characterize the dark current at most of the camera temperatures encountered during the comet imaging. Scattered light was removed from the images by subtracting a two-dimensional surface fit to the image after filtering to remove stars and noise spikes. Flat-field corrections for these cameras are minor and have not been applied.

After these steps, sufficient background stars are detectable in clear-filter WAC images to allow accurate astrometric fits with star catalog positions. These astrometric solutions were also assigned to successive images in other filters provided they were taken with the same spacecraft orientation. Some narrowband WAC images do not have accompanying broadband images, and most of the NAC images do not have detectable background stars. For those images, spacecraft and MDIS pivot orientations from the telemetry were used to determine camera pointing and orientation.

Preliminary Results: Table 1 lists the number of images acquired and the dates on which they were taken for each comet. As of this writing, many of these images have not yet been downlinked from the spacecraft. However, example images of both comets illustrate the richness and scientific value of the data.

The image of Encke in Figure 1 shows a long, narrow tail behind a fairly symmetric coma. At the same time, NAC images of Encke (not shown) hint at small-scale structure in the coma. The combined WAC and NAC datasets reveal how the coma and tail evolved as the comet passed through perihelion, perhaps shedding light on the origins of Encke's asymmetric light curve.

In contrast, the ISON images in Figure 2 show an asymmetric coma that exhibits "wing-like" structures in the upper and lower right directions. These are often jets seen in projection but are also potential signs of fragmentation events. The full set of NAC images will allow investigation of the two possibilities. Although not shown, the full filter set of ISON images shows variations in the size and structure of the coma as a function of wavelength that will yield insights into the chemistry of ISON, whereas the WAC images have provided an interesting view of ISON's tail, perhaps in the early stages of its ultimate disintegration.

Table 1. Summary of the images acquired of each comet

	ISON		Encke	
	Number	Dates	Number	Dates
NAC	94	19-24 Nov	209	5-9 Nov
				17-22 Nov
WAC				
Clear	57	26 Oct – 11 Nov	96	28 Oct – 8 Nov
		16-23 Nov		17 Nov – 4 Dec
430 nm	57	26 Oct – 11 Nov	60	28 Oct – 8 Nov
		16-23 Nov		17-24 Nov
12-filter	72	19 and 21 Nov	66	19 Nov

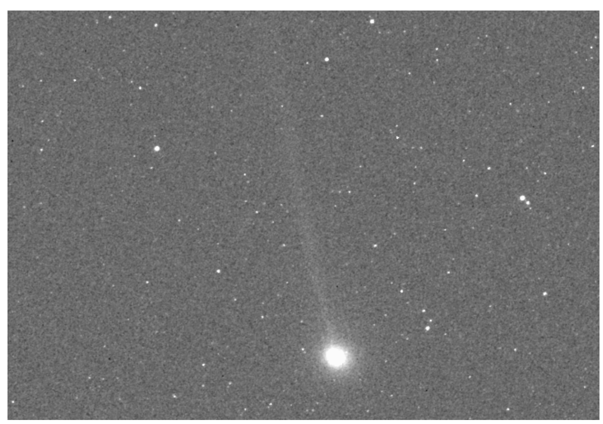

Figure 1. WAC clear-filter image of Encke on 18 Nov 2013. The projected vertical scale is ~300,000 km at the comet, and the bright coma is ~15,000 km in size. The grayscale has been stretched to enhance the tail, which can be seen to extend across the image.

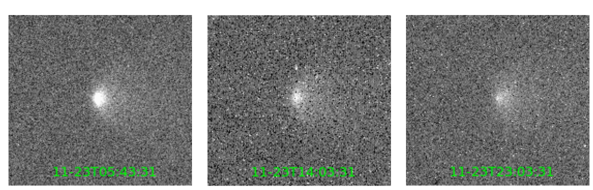

Figure 2. Example NAC images of ISON on 23 Nov 2013. The projected vertical scale of each frame is ~178,000 km at the comet. Changes in the coma structure and brightness are evident over the 17 hours spanned by the images. The grayscale is normalized across the images to allow direct comparison among frames.