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CLEMENTINE: ANTICIPATED SCIENTIFIC DATASETS FROM THE MOON AND GEOGRAPHOS;

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Introduction

The Clementine spacecraft mission is designed to test the performance of new lightweight and low-power detectors developed at the Lawrence Livermore National laboratory (LLNL) for the Strategic Defense Initiative Office (SDIO) [1]. A secondary objective of the mission is to acquire useful scientific data, principally of the Moon and the near-Earth asteroid Geographos. The spacecraft will be in an elliptical polar orbit about the Moon for about 2 months beginning in February of 1994, and it will fly by Geographos on August 31. Clementine will carry seven detectors, each weighing less than about 1 kg: two Star Trackers, wide-angle uv/vis, wide-angle Short Wavelength IR (SWIR), Long-Wavelength IR (LWIR), and LIDAR (Laser Image Detection And Ranging) narrow-angle imaging and ranging (see Table 1). Additional presentations about the mission, detectors, and related science issues are in this volume [1-4].

If fully successful, Clementine will return about 3 million lunar images, a dataset with nearly as many bits of data (uncompressed) as the first cycle of Magellan, and more than 5000 images of Geographos. The complete and efficient analysis of such large datasets requires systematic processing efforts. Described below are concepts for two such efforts for the Clementine mission: global multispectral imaging of the Moon and videos of the Geographos flyby. Other anticipated datasets for which systematic processing might be desirable include (i) multispectral observations of Earth; (ii) LIDAR altimetry of the Moon with high-resolution imaging along each ground track; (iii) high-resolution LIDAR color along each lunar ground track, which could be used to identify potential titanium-rich deposits at scales of a few meters; and (iv) thermal-IR imaging along each lunar ground track (including nighttime observations near the poles).

Global Multispectral Imaging of the Moon

The lunar orbit has been designed to enable global coverage with the uv/vis and SWIR cameras at the highest feasible resolutions and with sufficient overlap between frames to enable automated frame matching. To the extent possible, the uv/vis and SWIR filters were selected to optimize the compositional mapping of the Moon and Geographos [see ref. 3], except for the 2780-nm filter (required by SDIO) and (most likely) a clear filter on the uv/vis camera (for optical navigation to Geographos). The image scales will be about 100 m/pixel (uv/vis) and 150 m/pixel (SWIR) at +30° and -30° latitude (e.g., at periselene, 400 km altitude); 120 m/pixel (uv/vis) and 180 m/pixel (SWIR) at the equator; and 190 m/pixel (uv/vis) and 285 m/pixel (SWIR) at the poles. Global coverage will require 120 wide-angle frames per orbit times 300 orbits times up to 12 filters, for a total of 432,000 image frames. Rather than attempt to analyze nearly half a million small images, most lunar scientists would undoubtedly prefer to do their science analyses on a single global 12-wavelength image cube (separated into "tiles" or map quadrangles), following geometric and radiometric calibrations and photometric normalizations.

The task of processing this dataset into a calibrated global image cube will not be trivial. Processing steps will include (1) decompression of the data, (2) radiometric calibration, (3) removal of camera distortions, (4) co-registration of 12-filter sets of images (see below), (5) replacement of bad or missing data, (6) along-track frame matching, (7) geometric reprojection, (8) photometric function normalization, (9) mosaicking into single-orbit strips, and (10) mosaicking orbit strips into map quadrangles. This processing task must be largely automated if it is to be completed within a reasonable time (preferably within about 2 years from when the data is available).

Pixel-to-pixel misregistration between images acquired through different spectral filters can be a major source of error in the spectral analysis and mapping of lunar soils. Although high frame rates will enable acquisition of images through all 12 filters in about 1 s, the orbit velocity (as high as 1790 m/s) will offset frames by up to 18 pixels/s. A series of new programs have been developed in PICS (Planetary Image Cartography System) that resample highly correlated images for co-registration to an accuracy of 0.2 pixel. These procedures, which are fully automated for filter sets that are initially matched to within about 30 pixels, were applied to the Galileo lunar images [5] with excellent results. Subpixel registration of 90 Galileo frames (800 x 800 pixels) required about 20 hr on a Vax 4000/60. Even with scaling to the size of Clementine frames, 3.4 yr of continuous processing on a single Vax 4000/60 would be needed for subpixel registration of the full wide-angle dataset. Furthermore, this task could be much more difficult than with Galileo images if the camera distortions are not well described. The thin lenses on the Clementine sensors are likely to cause significant geometric distortions, and the distortions may vary with temperature. The other processing steps will at least double the computer requirements, so several capable workstations (or CPUs) running simultaneously will be needed to complete the systematic processing within 2 years.

Once completed, the global image cube will enable a wealth of scientific studies. A series of global or regional compositional maps can be derived that show the distribution and relative abundances of pyroxenes, olivine, anorthosite, shocked anorthosite, norite, troctolite, glassy materials, and titanium. Maps of soil crystallinity can be derived and used to determine relative ages of Copernican-age geologic units [6]. The compositions of excavated or uplifted crater materials can be used to determine subsurface compositions and stratigraphy. These and other datasets could be the basis for a new lunar geologic mapping program. Lunar Orbiter (LO) images are particularly complementary to Clementine's, because LO provides nearly global coverage at high sun angles, which accentuates topography and morphology at about the same resolution (50-300 m) as the Clementine global multispectral coverage. Clementine's orbit was designed to image at low sun and phase angles (except near the poles), which is best for compositional studies but not for topography and morphology.

Videos of Geographos

Clementine is expected to acquire continuous imaging throughout the closest-approach sequence at Geographos with frame rates of 4.5 frames/s for the SWIR, LWIR, and LIDAR detectors and 9 frames/s for the uv/vis camera. For comparison, the highest frame rate on Galileo is 0.4 frame/s in summation mode (400 x 400 pixels), and there was no imaging near closest approach to Gaspra. The relevant capabilities of Clementine include high electronic readout rates, automated tracking, fast data compression (Matra DCT chip), and 200 Mbytes of on-board storage. The high frame rates and continuous imaging are ideal for production of computer "movies" of the flyby, which can be recorded onto video tapes. These movies will consist entirely of actual image data, except where data dropouts are filled, rather than simulated sequences generated from a shape model, as was the case for the Gaspra rotation movie. The use of actual images enables the viewer to see all of the details of the topography, morphology, and distribution of compositional units as the viewing and illumination geometries change.

Several different Geographos video sequences are anticipated, including separate sequences for each imaging system and for merged datasets. The LIDAR will provide the highest spatial resolutions, in four colors, but it cannot image the night side, and Geographos will more than fill the LIDAR field-of-view within about 75 s of closest approach. (With the automated tracking, the LIDAR is expected to image the central portion of the illuminated area throughout closest approach; high-resolution mosaicking will not be possible unless the pointing errors fortuitously provide the appropriate coverage.) The LWIR will provide nightside imaging, so this dataset could be combined with the LIDAR to provide the best topography/morphology video. The viewing and phase angles change most rapidly near the time of closest approach, so the uv/vis camera will provide the highest resolution of the entire visible and illuminated surface during the 75 s before and after closest approach. Although the LIDAR has four filters with wavelengths of 400 to 750 nm, the 1000- and 2000-nm regions provide the best mineralogic information, so the uv/vis and SWIR datasets could be used to map compositional variations; this color-coded compositional data could then be merged with the high-resolution LIDAR sequence.

References

1. Shoemaker, E.M., and Nozette, S., 1993, this volume.
2. Vorder Bruegge, R., et al., 1993, this volume.
3. Lucey, P., 1993, this volume.
4. Spudis, P., and Lucey, P., 1993, this volume.
5. McEwen, A.S., et al., 1993, this volume.
6. McEwen, A.S., et al., submitted to JGR.

Table 1. Characteristics of Clementine's Sensors

Sensor	Field of View (°)	Frame X Y	Filters	Wavelengths (nm)
Star Tracker	28 x 43	576 384	1	450-1000
UV/Vis	4.2 x 5.6	288 384	6	340, 415, 750, 900, 950, 1000 *
SWIR	5.6 x 5.6	256 256	6	1100, 1250, 1500 2000, 2600, 2780
LWIR	1.0 x 1.0	128 128	1	8000-10500
LIDAR imager	0.3 x 0.4	288 384	5	400, 560, 650, 750, Clear
LIDAR laser	0.3 circular	--	1	1064

* One of these may be replaced by a clear filter.