AMOS DEBRIS OBSERVATIONS

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ABSTRACT

Observations of the orbital debris environment at the Air Force Maui Optical and Supercomputing (AMOS) detachment of the Air Force Research Laboratory (AFRL) are entering a new era. Located at the 3000 meter summit of Haleakala on the island of Maui, this site occupies an ideal location for observations of orbital debris. This site, the Maui Space Surveillance System (MSSS), is operated by the AFRL's Directed Energy Directorate. Several systems support debris observations, including the radiometer and spectrograph on the 3.6 meter telescope, the spectrograph on the 1.6 meter telescope, the Near-Earth Asteroid Tracking (NEAT) camera on the 1.2 meter telescope, and several Raven-class (small autonomous) telescopes. In addition, a renovated Baker-Nunn telescope will be available for observations in the Summer of 2001. Specific observation programs include a search program using the 1.4 degree field of view NEAT camera, and characterization programs using the multi-channel imaging radiometer on the 3.6 meter telescope, as well as spectrographs on the 1.6 and 3.6 meter telescopes. Observations of debris simultaneously at several wavelengths (visible to near IR, MWIR, LWIR, and VLWIR) allow determination of albedo and size. These observations are collaborations between NASA and AFRL. Results of these observation programs will be discussed, as well as future plans for increasing the capabilities of the site.

1. NEAT OBSERVATIONS

The Air Force Maui Optical and Supercomputing (AMOS) detachment of the Air Force Research Laboratory (AFRL) collaborates with NASA's Jet Propulsion Laboratory on the Near-Earth Asteroid Tracking (NEAT) program.[2] These observations are

NEAT is searching for debris which is not man made. NEAT searches for potentially hazardous asteroids (PHAs) and comets, which may impact the Earth in the future. Because one of the goals of each program is similar, searching the sky for unknown objects, there is an efficiency to be gained by combining both searches. One can take observations from one program, and scan that existing data for additional observations. One can also modify the search routines, optimizing telescope time by making observations compatible with both search goals. Both of these approaches are being studied.

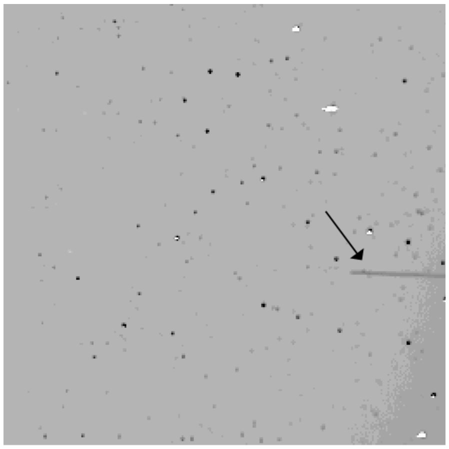

Figure 1. Typical NEAT field with satellite.

The NEAT system consists of a 4k x 4k x 15µ CCD camera mounted at prime focus of one of the twin 1.2 meter telescopes. The field of view of the telescope is 1.4 degrees square, with a pixel size of 1.25 arcseconds. Limiting magnitude for stationary objects in the image is approximately $M_v = 20$ for a 10 second exposure, somewhat brighter for a satellite, depending on its apparent motion. Fig. 1 shows a field which was taken in support of the asteroid search. Although no asteroid was detected in this field, a deep-space

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approximately 20% of the NEAT images taken in support of the asteroid program also include satellite images. These images are particularly useful for detecting debris in geosynchronous orbit. Similarly, observations made in support of the space debris program can be scanned for asteroids and comets.

Observations can also be scheduled to optimize the resulting observations for simultaneous asteroid and satellite detection. Because the apparent motion of asteroids and comets is much smaller than that for satellites, several observations of the same stellar position must be made to detect the slow motion of PHAs. Careful scheduling of geosynchronous satellite observations can result in observations at the same field in equatorial coordinates but at different times, which satisfies the asteroid mission as well.[3] A simple modification of this concept will be used later this year to simultaneously search for space debris and PHAs.

2. RAVEN

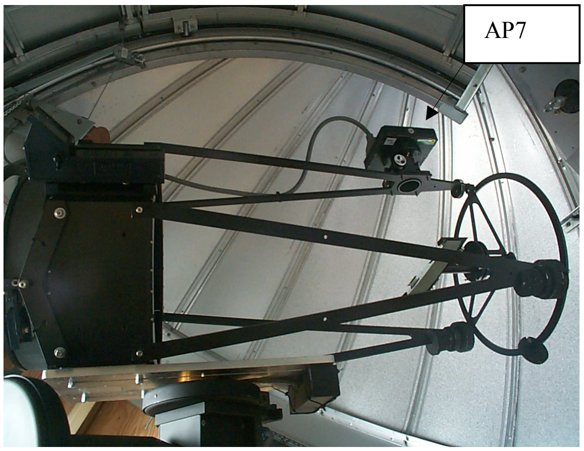

Fig. 2. Raven telescope

Raven-class telescopes are small, commercially-available telescopes, one of which is used operationally at AMOS in support of the satellite metric observations. Fig. 2 shows the 37 cm AMOS Raven Torus Optics telescope with the Apogee AP7 CCD, at the top. These telescopes operate every night of the year, obtaining metric positions for deep-space satellites. This operation is autonomous; the telescopes open at sunset, make observations and reduce the data automatically, and close at sunrise. The telescopes are supported by a weather-monitoring system, which safeguards the telescope in the event of inclement weather.[4] The AMOS Raven telescope uses a 512 x 512 x 24μ CCD camera on a 37 cm diameter telescope. This telescope has a field of view of 0.8 degrees square, with a pixel size of 4.4 arcseconds. Limiting magnitude is approximately M_v = 17 for a 20 second

fiducial marks for both satellite positions and satellite brightness. The result is a database of satellite magnitudes. Fig. 3 illustrates the brightness distribution of correlated objects and UCTs. This distribution is very similar to the NASA CDT brightness distributions.[5]

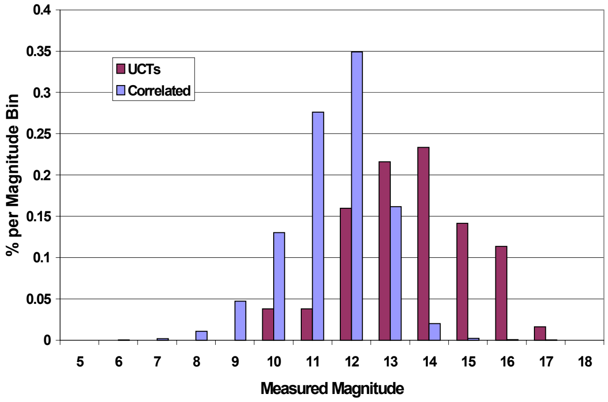

Fig. 3. Brightness distribution of objects observed by the Raven telescope

3. IMAGING WITH ADAPTIVE OPTICS

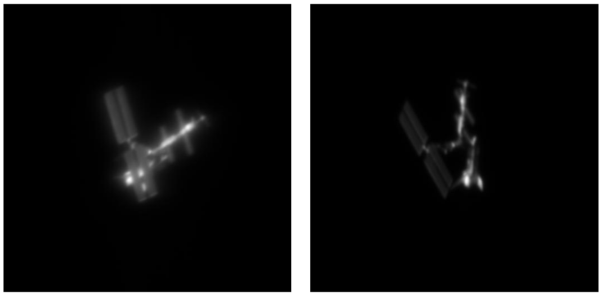

Fig. 4. International Space Station using AEOS

The adaptive optics (AO) system installed on the 3.6m Advanced Electro Optical System (AEOS) telescope is a state-of-the-art system that can achieve the .25 μradian diffraction limit of the telescope. It can be used to image objects in Low Earth Orbit (LEO). An example of the powerful imaging capabilities of the AO system on AEOS is shown in Fig 4. The Visible Imager, which makes use of the AO compensated light, has 3 fields of view ranging from 10 arcseconds to 60 arcseconds, a spectral response from 700nm to 1100nm, and has the potential for application to the study and tracking of orbital debris. One concept for the use of the AO system would be to image the breakup of LEO objects, and to guide follow up observations by other metric instruments such as the 1.6m and 1.2m telescopes located at the site. This could contribute significantly to the identification and accurate tracking of debris objects from their initial creation, and could therefore serve to reduce the amount of untracked orbital debris.

4. ALBEDO OBSERVATIONS

To obtain albedo, one observes the object in visible light as well as infrared light. Ideally this is done simultaneously, to eliminate the effect of satellite rotation on the results. The concept is that objects with high albedo will be brighter in the visible (reflected sunlight), while objects with low albedo will be brighter in the infrared (warmer, emitting infrared).

The reflected (optical) brightness of an object is related to the albedo (A), which is defined as the fraction of incident solar energy that is reflected from the surface or

$$\text{Optical Brightness} \propto A\pi r^2 \qquad (1)$$

The thermal radiation from the object is related to (1-A), which is the fraction of the solar energy absorbed by the object or

$$\text{Thermal Brightness} \propto (1-A)\pi r^2. \qquad (2)$$

Eqs. 1 and 2 can be combined to solve for the albedo and radius.[5]

Two instrument packages are being used for determination of satellite albedo, which in turn can be used to determine satellite size. The Contrast Mode Photometer and Advanced Multicolor Tracker for AMOS share the light path on one of the twin 1.2 meter telescopes[1], and can be used simultaneously. NASA and AFRL are currently collaborating on a program to determine the albedos of 100 satellites in near-Earth orbit, chosen to provide a wide variety of both size and composition. Preliminary data indicate the albedos fall in a range from 0.02 to 0.5, which is consistent with previous measurements on large objects.[6] A report on the outcome of this set of observations will be published in the future.

The other, and more powerful, instrument which will be used to obtain albedo measurements, is the Advanced Radiometer System which is at a trunnion position on the 3.6 meter telescope. This system collects data simultaneously in four spectral bands, from 0.4 μ through 23 μ. There is a separate focal plane array supporting each of the four spectral bands, each with its own set of filters.[1]

5. SPECTROSCOPY

Spectroscopy is valuable in determining the functional satellite, or space debris. AMOS uses two spectrographs for this purpose, Kala on the 3.6 meter telescope and Spica on the 1.6 meter telescope and Kala. AMOS has been collecting data using spectrographs for several years, primarily in the past for satellite identification[7]. They are being used today on space debris objects, to determine surface composition from the reflected spectra. The spectrographs are basically identical, each being comprised of an Acton SP-500 spectrometer with various possible gratings including 150, 300, and 1200 lines/mm gratings. Examples of the utility of Spica and Kala in the collection of surface characterization data are shown in Figs. 5 and 6.

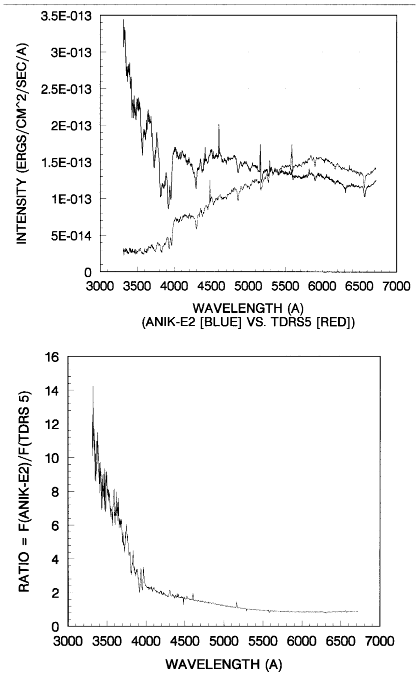

Fig. 5. Satellite spectra

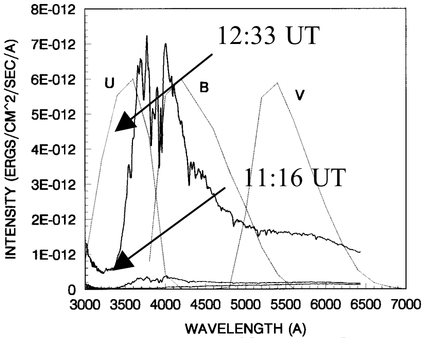

Fig. 6. Spectra for satellite glint

Fig. 5 shows the satellites TDRS-5 and ANIK-E2, both illuminated by sunlight. There are considerable differences in their spectra due to differences in the satellite bus types. ANIK-E2 is much "bluer" than TDRS-5, indicated by the higher intensity at the left of the upper plot. The lower plot shows the ratio of the two spectra. By taking the ratio, solar features divide out leaving only the signature differences between the two objects. Fig. 6 shows the fully calibrated set of spectra of the glint event observed for satellite #23467 (UHF-4), shown along with the passbands of the U, B, and V filter system. The solar panel signature is overwhelmingly clear.

6. OBJECT DETECTION AND ASTROMETRY

In 1993, AMOS developed an automated video object detection system using a Datacube MaxVideo20 image processing system and a SPARCstation10 workstation for statistical post-processing for the Air Force Orbital Debris Measurements Program[8]. A recursive background subtraction algorithm was programmed on the Datacube to eliminate stationary objects while enhancing moving objects as streaks. In the algorithm, the *N*th output frame, g(N), resulted from the difference of the raw input frame, f(N), from the previous raw input frame, f(N-1), summed with the previous output frame, g(N-1), scaled by a constant, k, expressed concisely as:

$$g(N) = f(N) - (1-k)\sum_{i=1}^{N-1} k^{(i-1)} f(N-i) \qquad (3)$$

Using the SPARCstation 10, the resulting output frame is then divided into a grid of detection cells. A detection event occurs if the pixel sum of current detection cell is significantly larger then a time-averaged sampled mean of the cell. Detection events are then correlated over time to produce tracks of moving objects. Recently, the orbital debris detection system was rehosted on a SGI workstation, providing higher bandwidth statistical processing while eliminating specific image processing hardware, and may be used to support NASA's Liquid Mirror Telescope in its orbital debris survey program.

While the orbital debris detection system works well for video sources, AMOS needed object detection capability for single-frame CCD-based systems such as NEAT, CDT, and the Raven systems. In addition, accurate subpixel astrometric positions are needed for both asteroid orbital determination and satellite catalog maintenance. Building upon the IRAF package developed at National Optical Astronomy Observatories, the *astro* tool was written to detect and

objects for single CCD frames. *Astro* correlates detected star positions against astrometric star catalogs, such as the Hubble Guide Star Catalog, to produce a "plate solution" for each image to transform from detected pixel positions to equatorial coordinates. The software works with both sidereal and fixed (stare) telescope tracking. Stellar-like objects are detected with conventional PSF, Gaussian, and Wavelet-based kernel correlation, while known streaking objects are detected using template matching against predicted streak pixel patterns. Differential photometry is used to compute object magnitudes from pixel sums based on matched star catalog magnitudes. Object detections are correlated against the satellite catalog for identification[9,10]. Recently, a standalone application called *AstroGraph* has been developed, providing near realtime processing capability. *AstroGraph* can correlate detections between a sequence of CCD images, generated by systems such as the CDT. This comparison allows lower detection thresholds, while eliminating false alarms. Arbitrary streak objects are detected using pixel dilation and filtered using normalized shape parameters.

7. WFOV

Since the launch of Sputnik in 1957, trackable space objects have increased to more than 9000 objects. As commercial, military/government, research, and academic agencies discover new ways to harvest the benefits of our Earth's space environment, the number of orbiting satellites and its associated debris increase. The importance of protecting manned and unmanned space-based assets becomes more evident. The most straightforward method to preserve the safety of on-orbit assets is to keep them from colliding with other assets and debris in the environment. Thus, it is imperative to have the ability to measure, determine, and catalog, with high accuracy, the orbits of all objects in the space environment.

With this heightened awareness of the space environment, AFRL Detachment 15 has initiated a project to develop and integrate a suite of wide field of view (WFOV) sensor systems, fields of view that are greater than one degree. There are currently three WFOV telescopes in that arsenal: 1) Phoenix Sensor System, 2) NEAT, and 3) GEODDS auxiliary.

7.1 Phoenix Sensor System

One of the original Baker-Nunn camera sensor systems is back on Maui being redesigned to be one of AMOS's widest field of view optical sensor systems. This Phoenix Sensor System is being developed and integrated at the Remote Maui Experimental site in Kihei

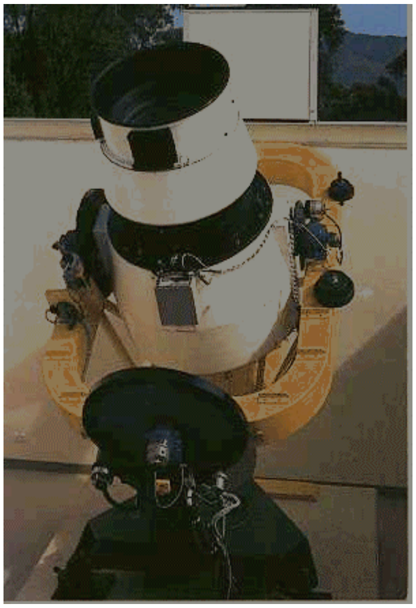

Fig. 7. Baker-Nunn telescope

The original Baker-Nunn system, designed by James Baker and Joseph Nunn, was implemented in 1957 by the Smithsonian Institute as a global network of twelve telescope/camera systems dedicated to tracking the Vanguard satellite. These large telescopic cameras, based on the Schmidt telescope, were designed specifically to provide space object tracking information on satellites. Haleakala was one of the global sites. The current Ground-Based Electro-Optical Deep Space Surveillance System (GEODDS) replaced the Baker-Nunn system in 1982.

Fig. 8. Baker-Nunn first light

The Baker-Nunn telescopes were stored for several decades. It was decided this past year to "resurrect" the original Baker-Nunn telescope, Fig. 7, and to retrofit it with a state-of-the-art CCD.

Because the original Baker-Nunn camera was based on curved photographic plates, retrofitting it with a flat-faced CCD was not trivial. The new CCD allows for digital imagery with very high sensitivity (~90% quantum efficiency). The Lockheed-manufactured CCD will have 4096 x 4096, 15 μ pixels and will provide approximately six degree field of view. First light with a surrogate CCD was obtained on December 1, 2000, Fig. 8.

7.2 GEODDS Auxiliary

The GEODDS Auxiliary, which is the successor to the Baker-Nunn, was brought down from Haleakala and is being stored at the RME site to be integrated into the WFOV sensor suite at a later date. The GEODDS Auxiliary has 15 inch aperture with roughly a 6 degree field of view.

CONCLUSION

Observations of the orbital debris environment at AMOS are entering a new era and span a wide range of debris related activities. Several advanced systems such as the Near Earth Asteroid Tracking (NEAT) camera on the 1.2 m telescope, and the autonomous Raven-class telescopes support debris detection and orbit determination. Other systems at the site such as the radiometer and the spectrographs on the 3.6m and 1.6m telescope, handle surface characterization and debris identification. The Phoenix system centered around the restoration of a Baker-Nunn telescope will combine the advantages of a large field of view with new CCD technology. The unique adaptive optics system on the 3.6m telescope can be used for the innovative observation of orbital-breakup events to track debris from their inception. These programs are collaborations between NASA and AFRL.

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