PRELIMINARY RESULTS FROM THE U.S. PARTICIPATION IN THE 2000 BEAM PARK EXPERIMENT

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ABSTRACT

The United States participated in the 2000 Beam Park Experiment (BPE) conducted in late October, 2000 under the auspices of the Inter-Agency Space Debris Coordination Committee (IADC). The U.S. participated using several sensors which have participated in previous campaigns: Haystack, TRADEX, and COBRA DANE radars, and the Liquid Mirror Telescope. New to the BPE experiments this time are the GBR-P radar located at Kwajalein Atoll and the Haystack Auxiliary (HAX) radar located in Massachusetts.

This paper will present and discuss preliminary results from each of the participating U.S. sensors.

1. BACKGROUND

The 2000 BPE is the fourth international campaign of this type conducted. The goal of the campaigns is to characterize the low earth orbit space debris environment, and any changes to it over time, using some of the most capable debris sensors available. By employing multiple instruments, biases due to such things as location of the instrument and sensitivity can be better understood and a more complete picture of the environment can be developed. Prior campaigns were conducted in 1996 and twice in 1999. Ideally, each instrument simultaneously collects data over a 24 hour contiguous period. However, there is no reason to expect the debris environment to significantly change over a 1-2 week interval unless there is a major on-orbit breakup, so there is considerable leeway in the simultaneity of the measurement from different sensors. Operating contiguously for 24 hours ensures that all right ascensions are sampled. This is not possible for optical sensors since they can only operate during twilight hours. This must be taken into consideration when interpreting optical data. Even radars do not typically operate for 24 hours contiguously, but take small breaks for system tests and calibration.

2. CONTRIBUTING SENSORS

Table 1 lists various parameters for the USA sensors participating in the 2000 BPE.

2.1 Haystack and Haystack Auxiliary

The Haystack Observatory, including both the Haystack and Haystack Auxiliary (HAX) radars, is located in Tyngsboro, Massachusetts. Operation of the radars is conducted by the Massachusetts Institute of Technology's Lincoln Laboratory for the U.S. Air Force and other elements of the Department of Defense.

The Haystack radar has been NASA's primary source of debris data in the centimeter size range since measurements were begun there in 1990. Haystack is a X-band radar operating at a 3 cm wavelength. In 1994, the HAX radar became operational and has supplemented the Haystack measurements since. HAX is a Ku-band radar operating at a wavelength of 1.8 cm. The two radars share much of the data processing and

Table 1. Attributes of U.S. Participating Sensors

	Haystack	HAX	TRADEX	Cobra Dane	GBR-P	LMT
Sensor Type	Dish Radar	Dish Radar	Dish Radar	Phased Array Radar	Phased Array Radar	Telescope
Operation	N/A	Stare	Stare & Chase	Stare & Chase	Stare	Stare
Wavelength	0.03 m	0.02 m	0.23 m		.03 m	Optical
Location	42.6 deg. N 288.5 deg. E	42.6 deg. N 288.5 deg. E	9.4 deg. N 167.5 deg. E.	52.7 deg. N 174.1 deg. E	8.7 deg N 167.7 deg. E	33.0 deg. N 254.3 deg. E
Staring Angle	N/A	75 deg. EL 90 deg. AZ	65.3 deg. EL 186.2 deg AZ	50 deg. EL 319 deg AZ	45 deg. EL 132/192 deg. AZ	90 deg. EL
Beam Width	0.058 deg.	0.1 deg.	0.61 deg.	0.6 by 60 deg.	0.55 deg.	0.25 deg
Effective Range Window	N/A	417-1165 km	300-1200 km	415-2501 km	400-2050 km	up to 4000 km

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power supply hardware and cannot, therefore, operate simultaneously. Further, the Haystack antenna can be configured either as a radar or a radio telescope. During late October, 2000, Haystack was involved in an international radio astronomy experiment and was unavailable for the BPE-2000. The plan was to operate HAX during the campaign and to add Haystack observations when it became available in November. Unfortunately, after several attempts, Haystack was not able to collect a significant contiguous data set approaching 24 hours in length. Therefore, only HAX data is presented.

HAX collected a total of 23.0 hrs of debris data from day 300 00:00Z to day 301 15:45Z. HAX collects "staring" data. The antenna is pointed to specified angles (in this case 75° EL and 90° AZ), and orbiting objects pass through its field-of-view (FOV). If the integrated radar signal return from the object is strong enough, data received during the objects crossing of the FOV is saved for later analysis. Very rough orbital elements can be estimated by using the open loop monopulse signals from the radar.

For this experiment, the radar collected data on objects from 417 to 1165 km slant range. 17 objects were detected of which eight were correlated targets (i.e. objects in the USSPACECOM catalog of orbiting objects).

2.2 TRADEX

The Target Resolution And Discrimination Experiment (TRADEX) radar is operated by the U.S. Army at Kwajalein Atoll (USAKA). The radar is a dual frequency radar operating at L-band (22.7 cm wavelength) and S-band (10.2 cm wavelength). Only L-band data is reported here. The radar collected stare & chase data from day 300, 1909Z to day 301, 2010Z [1]. The extra hour covered time lost due to periodic calibrations, sensitivity checks, and chase operations. During stare operations, the radar was pointed at an elevation angle of 65.3º and an azimuth of 186.2º. Data was collected over the slant range of 300-1500 km.

TRADEX also participated in the BPEs conducted in 1996 and 1999. It is an important sensor for both its low latitude location, which allows sampling of low inclination orbits, but also its stare & chase operation which allows it to measure orbital elements of UCTs with some precision. For stare & chase, the stare operation is similar to that used for HAX except that the monopulse data is processed in real time and the antenna is directed toward the calculated direction of object travel. Once locked onto the object, the radar collects data as any other tracking radar. Note that the detection that significant staring time is not lost with the few tracks performed.

During the BPE 2000 campaign, TRADEX experienced 89 "hits," or instances where a preset signal to noise threshold was crossed. Of these, 32 were identified as cataloged objects. Once an object is correlated, the object is dropped and the antenna returns to its staring pointing. Of the 57 UCT "hits," TRADEX successfully tracked 12. A legal orbit could not be fit to one of these 12.

Significantly, of the 11 remaining tracked UCTs, four of them were in low inclination (6º-8º), high eccentricity orbits. None of the correlated targets were in similar orbits.

It should be noted that the location and pointing of the TRADEX during this experiment bias the results to detection of low inclination orbits. Therefore, although four of eleven of the tracked UCTs represents a significant population, one cannot conclude that nearly 40% of the UCT population is in this orbit.

2.3 COBRA DANE

The Cobra Dane radar is an L-band phased array radar. It was operated from day 300 00:00Z to day 301 00:04Z. The radar is operated by the U.S. Air Force at Patrick AFB. The Cobra Dane data is some of the most interesting collected during the test. Although it is not as sensitive as the X-band radars, it deploys a very wide (50º EL, 289°-349° AZ, 417-2501 km slant range) fence enabling the detection of 100s to 1000s of detections in the 24 hour period. Further, the radar operates in a stare & chase mode which allows it to get good orbital elements on detected objects while still maintaining the fence. Cobra Dane and TRADEX were the only sensors used by the U.S. which were able to collect meaningful eccentricity measurements on the debris detections.

Another advantage of the Cobra Dane radar's high detection rate is that non-homogeneous groupings of debris orbits are readily apparent. When a satellite or rocket body experiences a fragmentation, the debris spreads out along the orbit of the parent body. For some months after the fragmentation, the debris orbits form a toroid around the earth. Over longer periods in time, the toroid will spread out in right ascension until it eventually forms a shell around the earth. Uniform distribution of debris orbits in right ascension is a fundamental assumption of randomly sampling the orbital debris environment. These 24 hour campaigns are important for determining how much bias may be introduced into a measurement by making this

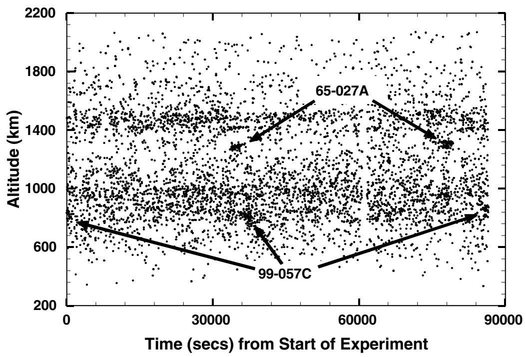

Fig. 1. Distribution of the altitude of detected particles as a function of time .

Cobra Dane identified two debris families that were still significantly grouped in right ascension. The parent body for the first group is 1999-057C which was a Long March 4 3rd stage rocket body that fragmented on 11 March, 2000. The second family originates from 1965-027A, commonly known as Snapshot. Snapshot has never been considered to have experienced a fragmentation, but has experienced numerous "anomalous" debris events [2]. Figures 1 and 2 show altitude and inclination of detected objects as a function of time from the beginning of the Cobra Dane collection period and identifies the groupings of detections from the two families.

2.4 GBR-P

The Ground Base Radar – Prototype (GBR-P) is an X-band phased array radar mounted on a pointable platform. GBR-P is located on Kwajalein Atoll approximately 75 km. south of TRADEX. The radar set up a search pattern which gave it an effective beamwidth of 0.55°. It performed stare operations for close to the 24 hour duration and detected a number of objects. However, this radar is still in development and the 24 hour test was a low priority. Therefore, verified data has not yet been transferred to NASA.

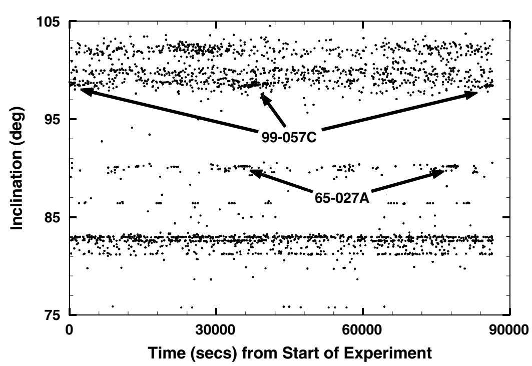

Fig. 2. Distribution of the inclination of detected particles as a function of time .

2.1 LMT

NASA has operated the Liquid Mirror Telescope (LMT) for debris observations since 1996. The telescope features a 3-meter diameter main mirror utilizing a spinning liquid mercury reflective surface. The telescope is located in Cloudcroft, N.M. at an elevation of 2772 m. Due to its unusual construction, it is limited to pointing in the direction of the local vertical. Also, being an optical telescope, it can only operate during twilight hours when the ground and atmosphere are in the earth's shadow and the debris or satellites are sunlit. This limits data collection to about 6 hours per night (3 hours during dusk and 3 hours during dawn twilight), far less at lower altitudes. Data was collected during several consecutive nights in order to collect 18.3 hrs of data. However, by repeating the same time periods each night, not all right ascensions were sampled. These potential biases must be taken into account during any detailed analysis of the data.

LMT data was collected on days 300, 301, and 304. An automated debris detection computer program [3] was used to identify potential debris and meteor detections. An analyst determines which objects are likely meteors and performs astrometric measurements on the remaining targets. For this paper, the diameter of UCTs is estimated using an albedo of 0.2 to convert from the absolute magnitude of the object. During the 18.3 hrs of data collection, 28 orbital objects were detected, of which 19 were uncorrelated.

3. COMPARISON OF DEBRIS DETEC-TION RATES

Figure 3 shows a comparison of debris detection rates for the various sensors over the common altitude range of 500 to 1000 km. The data from each sensor is scaled by its beamwidth and the number of hours of data collection. Other factors, such as elevation angle and sensor location have not been accounted for. Also, all of the sensors with the exception of Cobra Dane have small pencil beam FOVs. Therefore, it may not be correct to compare results from these sensors with the results from Cobra Dane which established a large azimuth fence.

4. CONCLUSIONS

U.S. participation in the BPE 2000 campaign was very successful. Four radars (Haystack Auxiliary, TRADEX, Cobra Dane, and GBR-P) and NASA's LMT optical telescope successfully collected debris data. The suite of sensors allow data collection over a wide range of debris size and inclination. Results from TRADEX indicate that there is a non-trivial population of UCTs in low inclination, high eccentricity orbits. Data from Cobra Dane show that debris from 1999-057C and

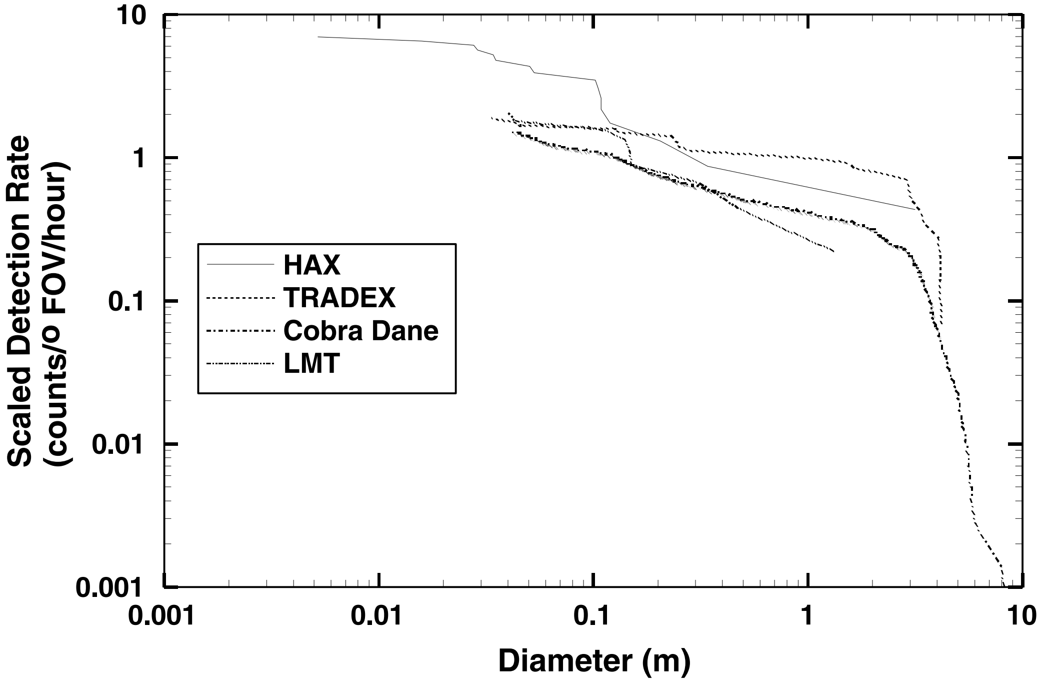

Fig. 3. Comparison of the detection rates of participating sensors scaled by the beamwidth.

1965-027A still exist in identifiable toroids around the earth and have not yet reached background states. Further BPE are expected to continue to provide useful information on the space debris environment.

5. ACKOWLEDEMENTS

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