UNKNOWN DEBRIS AT 1400 KM ALTITUDE

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ABSTRACT

During radar measurements with the FGAN 34-m antenna at Wachtberg, Germany unknown objects were repeatedly detected at an altitude of about 1400 km with orbital inclinations of about 50°. This is the orbital region were the Globalstar constellation is located (plus a few rather old satellites). The observed range and range rate data does not support the hypothesis of debris stemming for instance from a breakup. The data rather suggests that large objects are passing through side-lobes of the radar beam. But comparison with the USSpaceCom catalogue produced only 37 correlations. The other 45 out of a total of 82 detections in this region remain a mystery. A Stare-and-Chase mode is planned to be installed at the FGAN radar to resolve this open question.

1. INTRODUCTION

Since 1994 FGAN and ESA perform beam-park experiments to observe the space debris environment (Leushacke and Jehn, 2005). Radar pulses of typically 1.5 MW power are transmitted at 1.333 MHz and if an object of a few centimetres is crossing the parked radar beam a series of echoes is received at the 34-m antenna. The first 24-hour experiments were limited to an altitude range of about 400 to 1200 km. With increased data recording and processing power the observed altitude range was extended to the interval from 300 to 2000 km in the year 2000. Since then six 24-hour beam-park experiments were performed with identical parameter settings. The elevation of the radar beam was chosen to be 75° whereas the azimuth was 90° which means the antenna beam is pointing a bit to the East from the nadir direction. This pointing direction has the advantage that objects are detected at short distances (compared to a pointing towards the horizon) and that the range rate gives a clue about the orbital inclination (as explained below). Figure 1 shows range versus range rate of the objects detected in these 6 beam-park experiments for a range interval between 1200 and 1600 km.

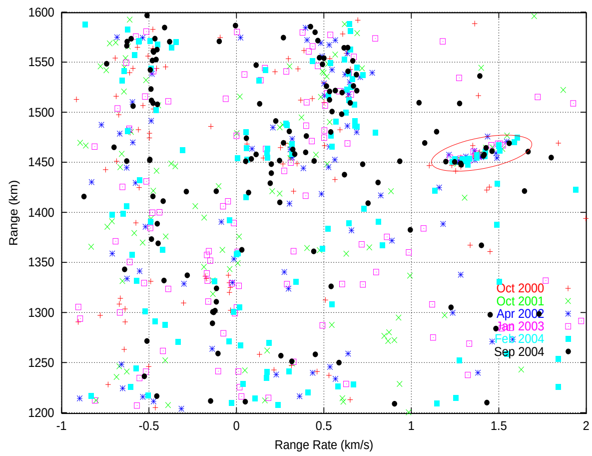

Figure 1. Range and range rate of the objects detected by FGAN during six beam-park experiments in the range window from 1200 to 1600 km.

In all six observation campaigns, a consistent cluster of objects was observed at a range of about 1450 km and a range rate of 1.2 to 1.6 km/s. 82 such objects were detected during the 142 hours of the six beam-park experiments, which is a bit more than one object every two hours. The 82 objects are shown in Figure 2 which is just a close-up of Figure 1.

2. CONVERSION TO DOPPLER INCLINATION

To find out what these objects are, their orbital elements will give a hint. However, only incomplete orbit information can be deduced from the radar data. Earlier analysis by Kaiser and Jehn (1996) has shown that it is impossible to derive any meaningful estimate for the semimajor axis and eccentricity from an observation arc which is about 0.03 % of the full orbit (the objects pass in about 2 sec through the radar beam). However, the orbit inclination can be estimated with an uncertainty of a few degrees. This can be done either by analysing the individual

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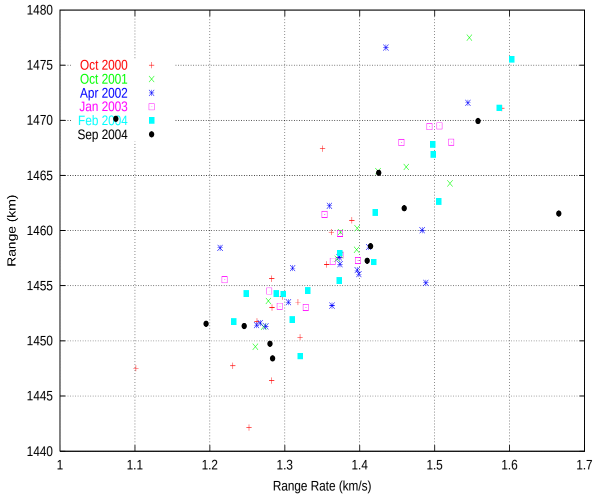

Figure 2. Range and range rate of the 82 objects detected by FGAN during six beam-park experiments in this specific range/range-rate window.

echoes as they move through the radar beam (see Kaiser and Jehn, 1996) or by exploiting the nearly one-to-one relation between range rate and orbital inclination in case of an East (or West) staring radar. Figure 3 shows the range rate of objects in circular orbits as function of their orbital inclination when seen from FGAN (geographic latitude of 50.6°) with the radar pointing East at an elevation of 75°. An object in a 55°-inclination orbit gives a range rate of 1.254 km/s at 1400 km altitude which corresponds to a range of 1450 km.

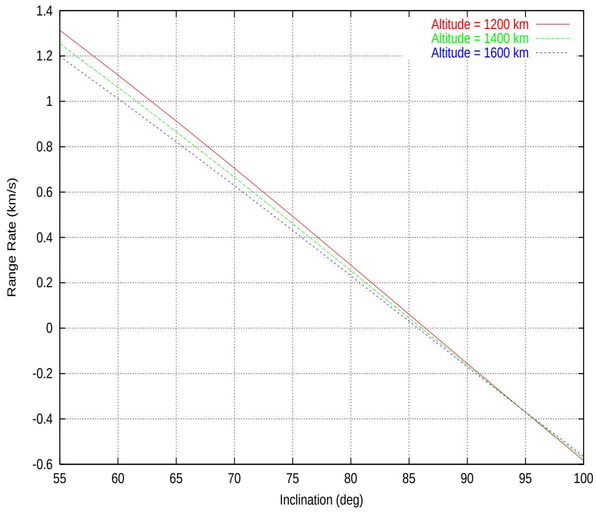

Figure 3. Range rate of objects in circular orbits as function of their orbital inclination when seen from FGAN with the radar pointing East at an elevation of 75°.

If we convert the range rate measurements to inclination using the relation shown in Figure 3, we can re-plot the detections of the six beam-park experiments in a altitude-versus-Doppler-inclination diagram. It is called Doppler inclination because the inclination is actually not measured but derived from the Doppler frequency shift (proportional to the range rate) assuming circular orbits. How accurate this conversion is, can be seen in Figure 4 where the Doppler inclination is plotted against the true inclination for the catalogued objects detected in the beam-park experiment of Oct 2000. It becomes evident, that the errors are very small for objects in nearly circular orbits, but they can become as large as 5 or even 10 degrees for objects in orbits with eccentricities larger than 0.01. Fig. 5 shows the altitude and Doppler inclination of the objects detected by FGAN in the altitude window from 1200 to 1600 km. In this plot the aforementioned cluster manifests itself at an altitude of 1400 to 1420 km and an Doppler inclination of 45 to 55°.

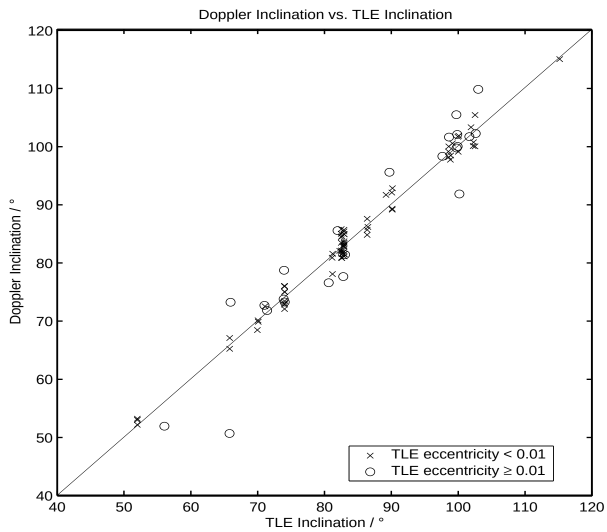

Figure 4. Doppler inclination vs inclination provided in the USSpaceCom Two-Line-Elements for the catalogue objects detected in the beam-park experiment of Oct 2000 (Banka et al., 2003).

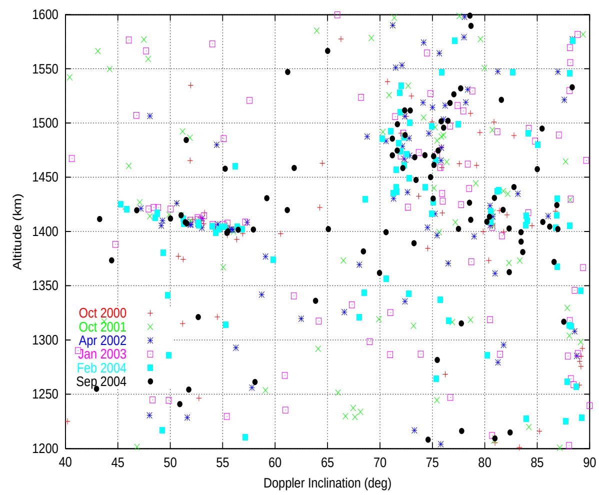

Figure 5. Altitude vs Doppler inclination of the objects detected by FGAN during six beam-park experiments from 2000 to 2004.

3. POSSIBLE SOURCES

However, in the past there were not many objects launched into this altitude region with this kind of inclination. There are about 50 Globalstar satellites (52° inclination) and a few Kosmos satellites launched in 1965 (all 56°). Two Japanese spacecraft together with its H-I upper stage were launched in 1986 (50°), but at a slightly higher altitude (1480 km).

Table 1 gives the number of the detected objects in this altitude-inclination cluster during the six beam park experiments. The fourth column gives the number of objects which could be identified as either Globalstar or Kosmos satellites. Indeed 37 of the 82 objects are known objects. The other 45 objects could not be identified and are the subject of this paper. The sizes derived from the radar cross-sections were mostly between 4 and 5 centimetres.

Table 1. Number of detected and catalogued objects in the 1400 km, 50° inclination cluster

	Date	Detected	Catal.
BPE 2000	27/28 Oct 2000	15	6
BPE 2001	16/17 Oct 2001	11	8
BPE 2002	12/13 Apr 2002	17	8
BPE 2003	20/21 Jan 2003	13	5
BPE 2004/1	05/06 Feb 2004	16	5
BPE 2004/2	20/21 Sep 2004	10	5

The first idea was that the unknown objects were debris released from the Globalstar satellites, because the size, altitude and inclination match quite well. Therefore, we have simulated the range and range rate measurements of objects in slightly eccentric orbits with orbital inclinations of 52 and 55°. Figure 6 shows the results of these simulations together with the observed objects of the last four beam-park experiments. For relatively large eccentricities, the detections should line up along vertical stripes in a range vs range rate plot (see red lines for e = 0.01). Also for small eccentricities (e = 0.00162 gives an altitude range from 1400 to 1425 km, corresponding to a range between 1450 and 1475 km) vertical stripes are drawn: the two lines give the range rate of objects on their outgoing leg (true anomaly between zero and 180° with a positive flight path angle) and the range rate of objects on their incoming leg. When the inclination increases the stripe moves to the left, i.e. the range rate decreases.

Figure 6 shows that there is no orbital family that could explain the observed data. The objects need to be in nearly circular orbits (difference between perigee and apogee less than 10 km) with a really peculiar relation between semimajor axis and inclination. That is not a very probable hypothesis.

Of course FGAN is not the only radar in the world to observe the space environment at this altitude range. Figure 7 shows the Haystack data collected from October

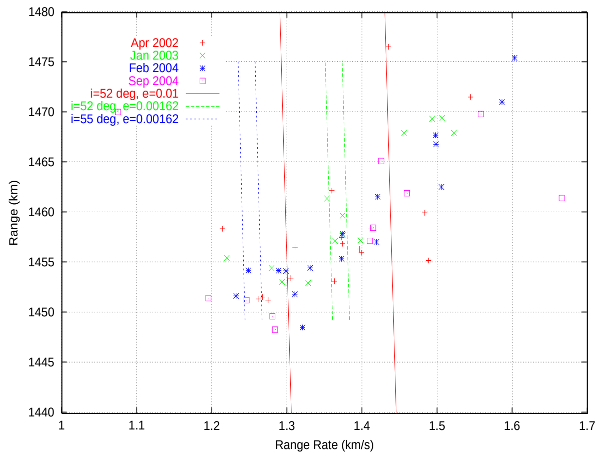

Figure 6. The vertical lines show range and range rate of simulated objects in eccentric orbits. The symbols show objects detected by FGAN during four beam-park experiments from 2002 to 2004.

2002 to September 2003 at 75° elevation and 90° azimuth (i.e. East staring). 633 hours of data are included in the dataset and only detections with an estimated size above 2 cm are shown. The cluster seen in the FGAN data does not appear in the Haystack data.

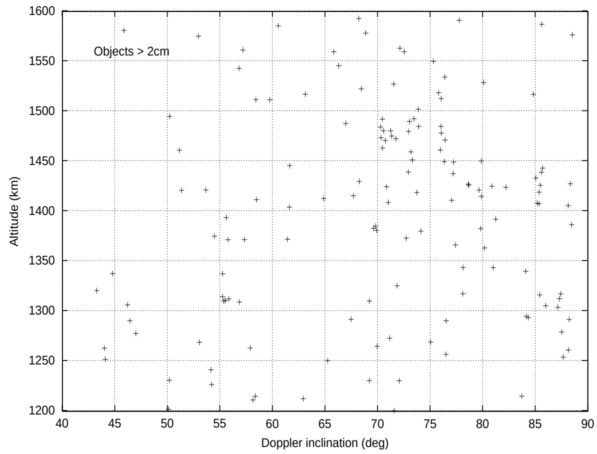

Figure 7. Altitude vs Doppler inclination of objects larger than 2 cm detected by Haystack between October 2002 and September 2003.

4. SIDE-LOBE DETECTIONS

E. Stansbery and M. Matney pointed out that the supposedly small objects detected at FGAN could be side-lobe detections of bigger objects. Indeed a few of the detections could be correlated to Globalstar satellites that passed a few degrees off the radar beam centre and created an echo that resembled small objects passing through the centre of the radar beam. If an object in a 52°-inclination orbit at an altitude of 1408 km passes through a side lobe of the radar beam at an elevation of 76.5° it may be detected at a range of 1448 km and a range rate of 1.238 km/s. If it passes at an elevation of 73.5° it may be detected at a range of 1468.5 km and a range rate of 1.497 km/s. At other elevations range and range rate fall on the line shown in Figure 8. This line nicely fits the range/range-rate relation observed by FGAN.

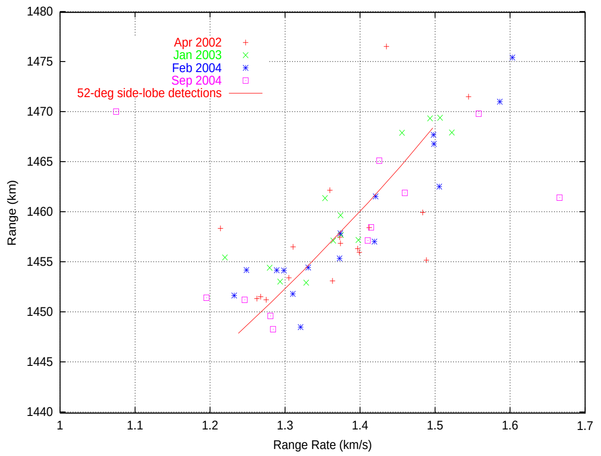

Figure 8. The line shows the calculated range and range rate of objects in a 52°-inclination orbit passing through side lobes of the FGAN radar beam at different elevations. The symbols show the measurement data of the last four beam-park experiments.

However, in order to have side-lobe detections there must be big objects passing nearby the radar beam. Such big objects are usually contained in the USSpaceCom catalogue and should be identified by the catalogue cross-check algorithm. We have lowered the matching thresholds to see if there were catalogue objects passing within 5 degrees of the radar beam close to the time of our detections, but still the 45 unknown objects could not be correlated and remain a mystery.

5. STARE-AND-CHASE

A solution to the problem is expected when the Stare-and-Chase mode is implemented at FGAN, which is planned for the year 2006. Then the radar will be able to track those objects once they have appeared in the radar beam. Having a significant part of the passage recorded, it will be possible to determine quite accurate orbital elements. Then the question can be answered whether the unknown debris are real or just side-lobe detections.

In July 2002 first experiments were made to test whether the current tracking system allows to follow an object when the a-priori Two-Line-Element (TLE) information is wrong (Banka et al., 2003). The TLEs of a Globalstar satellite were modified such that the true passage and the virtual passage crossed each other at an elevation of 14° (see Figure 9). The radar beam was parked at this position, but when the Globalstar satellite passed, the radar was not able to acquire the signal and follow the spacecraft. Some further tests were made, but it was realised that a proper Stare-and-Chase mode needs to be developed.

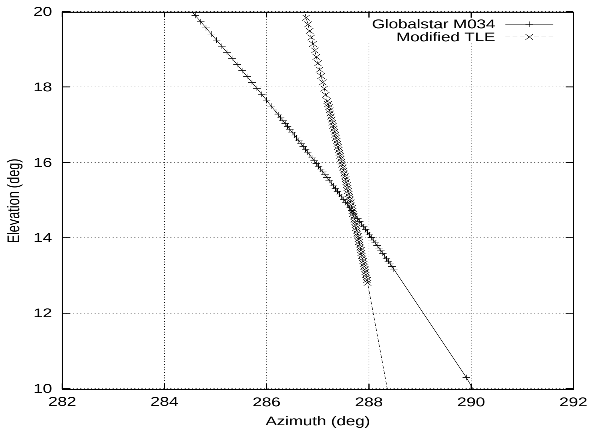

Figure 9. Approach trajectory of Globalstar M034 on 11 July 2002 as seen from Wachtberg, Germany. The Two-Line-Elements were modified to test whether the radar can track the object with wrong a-priori information. In the Stare-and-Chase mode the radar needs to track objects without any a-priori information.

6. CONCLUSIONS

The observed cluster of detections at 1400 km altitude and range rates of 1.2 to 1.5 km/s cannot be explained by debris released during a breakup or released at low velocities from Globalstar (or other) satellites. The conspicuous relation between range and range rate suggests a significant number of objects that should have passed through the side lobes of the FGAN radar beam. However, a comparison with the Two-Line-Element catalogue failed in more than half of the cases to produce objects that passed anywhere near the direction of the radar beam. Therefore no explanation for the source of the observed objects can be provided. Only a Stare-and-Chase measurement campaign will be able to solve this question. This is planned to be carried out in the year 2006.

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