Experimental Return Strengths from Optus-B and GPS

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Abstract

The return signal strengths from the retroreflector arrays on the Optus-B satellites in geostationary orbits have been compared with those from GPS targets using the High Energy Laser on the 1.8 metre space debris tracking system adjacent to the Mount Stromlo SLR. In the experiments conducted in mid-2006, we performed alternate ranging to an Optus-B then to a GPS while the two targets were in close proximity to minimize atmospheric differences. Each measurement was the setting of the receive-path Neutral Density filter required to extinguish returns, having first maximized the return rate by fine pointing adjustment.

The ratios of the results, after judicious editing of outliers, were in broad agreement with Dave Arnold's calculations of the respective array cross sections. They suggest that this could be a viable technique for calibrating actual performance of arrays in their space environment.

Satellite Retroreflector Arrays

The constellation OPTUS-B1 and OPTUS-B3 constitutes the space segment of the Australian satellite communications system. They are in geostationary orbits. B1 was launched in 1992 and is at longitude 160^{o}E. B3 (1993) is at 156^{o}E. B2 crashed after launch. Each contains a 20cm x 18cm tray of 14 solid cubes of Herseus fused silica, Amasil grade. Their front faces are tri-roundular with inscribed diameter 38 mm coated with indium tin oxide (ITO) over an anti-reflection dielectric layer. Their rear faces are also coated with ITO and have dihedral angles of 0".8 (James et al, 1990; Luck, 1994). The cross-section of each array is $\sigma_O = 46x10^6$ m^2 (Arnold, 2006).

GPS-35 and GPS-36 each host trays of 32 solid hexagonal cubes 27 mm across with aluminium-coated rear faces. The cross-section of each array is $\sigma_G = 20x10^6$ m^2 (Arnold, 2006). The theoretical ratio of cross-sections is therefore $\kappa = \sigma_G/\sigma_O = 0.43$.

Experimental Method

The method was to range to a pair of satellites, one Optus and 1 GPS, in "bursts" in rapid succession while the selected GPS satellite was "close" to the Optus satellite. During each burst, the Neutral Density (ND) filter was adjusted so that returns were just extinguished. The measurement was the ND value at extinguishment. The UTC, ND setting and GPS elevation angle were recorded at that instant. This method relies on the assumption that the photon detection threshold of the detector is both significant and constant.

"Close" means within a few degrees (<10^o) in elevation, to minimize variations in atmospheric attenuation, and also in azimuth to minimize cloud attenuation variation. A "burst" was just long enough to optimize the pointing for maximum return rate, then to adjust the ND until extinguishment, ideally less than 5 minutes. Then a burst was done on the other target.

Observations were made on the 1.8 metre space debris-tracking telescope STRK (7826) adjacent to Stromlo SLR at wavelength 1064 nm, power 2-12 W at 50 Hz.

Data Reduction

Define "brightness" B as the return signal strength (e.g. photons/sec at the detector) when pointing is optimized, and let B_e be the brightness at extinguishment so that it corresponds to the detection threshold. B_e is assumed constant. Let P be the measured average power, effectively equivalent to energy per shot since pulse-width, fire rate etc. are constant. Also let N be the transmission through the ND filter, T be one-way atmospheric transmission, R be the range from station to satellite, and S be the actual array cross-section. Then:

$$B = \alpha PNT^2.S/R^4$$

where α is a proportionality constant. The observed ratio of cross-sections is then:

$$k = S_G/S_O = (R_G/R_O)^4.P_O N_O T_O^2 / P_G N_G T_G^2$$

where subscripts G and O refer to GPS and OPTUS respectively. We used $N = 10^{-ND}$ where ND is the Neutral Density wheel setting, and:

$$T = \exp[-0.21072\exp(-h/1.2)/\sin E]$$

where *h* is height above sea level (0.8 Km for Stromlo) and *E* is target elevation angle (Degnan, 1993). The two-way transmission is illustrated in Fig.1.

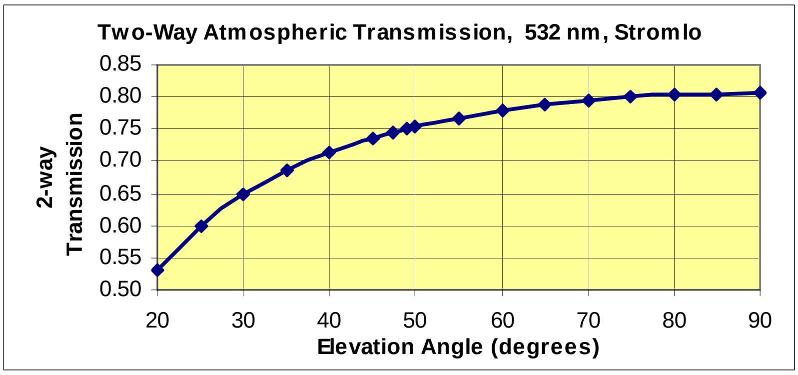

***Figure 1**: Standard atmospheric transmission as a function of elevation angle, Stromlo*

A "standardized brightness" V can be defined for a satellite observed on a given ranging system, as if there was no atmosphere and no ND filter and the transmitted power was 1, normalized to the detection threshold. Thus:

$$V = B_e/PNT^2 \text{ and hence } S=R^4V/\alpha.$$

The ratio $\beta = V_G/V_O$ gives the relative standard brightness. Its expected value with R_O = 37180 km (B3, nominal) and RG = 20931 km (GPS36, typical at 49° elevation) is β = 4.28.

Results

Measurements made on 4 clear nights in May 2006 are shown in the Table 1. The column R_G/R_O is the ratio of range (Stromlo to GPS) relative to range (Stromlo to OPTUS). Column S is the cross-sections in square metric (but otherwise arbitrary) units, and column V the standardized brightnesses. There are huge variations, so the greatest and least values of S_G and of S_O were discarded, as were those of V_O and V_G, yielding mean values of:

$S_G = 14.2$ $V_G = 145.8$

$S_O = 34.6.$ $V_O = 34.6$

The ratios of averaged observed cross-sections, and of standardized brightnesses, are:

$S_G/S_O = 0.41$ $V_G/V_O = 4.2.$

The observed cross-section ratio is remarkably close to the predicted κ = 0.43 given above. The observed brightness ratio similarly is also remarkably close to the predicted β = 4.28.

Conclusion

It may be that this excellent result is a fluke, but we certainly did not continue observing until we got the right answer! It suggests that this technique might indeed be viable for determining relative cross-sections of retroreflector arrays in actual orbit, provided that a sufficient number of measurements are taken.

***Table 1**: Summary of observations and resulting cross-sections. Optus cross-sections are in green. Rejected outliers are flagged in the right-hand column.*

Date May-06	UTC hh	mm	Sat	R/R(Opt)	El (deg)	P (Watts)	ND	T (1-way)	V	S	Rej
10	9	50	GPS36	0.544	75.9	9	2.75	0.894	78.10	6.84	
	11	2	B1	1	47.4	9	2.15	0.863	21.06	21.06	
	11	9	GPS36	0.598	39.5	9	0.50	0.844	0.49	0.06	*
	11	26	B3	1	48.9	9	4.00	0.866	1480.67	1480.67	*
13	11	0	B3	1	48.9	2	2.00	0.866	66.63	66.63	
	11	10	GPS 36	0.610	40.9	2	3.00	0.848	695.81	96.34	*
	11	20	B3	1	48.9	2	2.00	0.866	66.63	66.63	
15	9	20	B3	1	48.9	12	3.00	0.866	111.05	111.05	
	9	33	GPS36	0.545	85.0	2	1.90	0.897	49.35	4.35	
	9	42	B3	1	48.9	2	0.90	0.866	5.29	5.29	
	9	59	GPS36	0.556	63.6	2	2.30	0.886	127.02	12.14	
	10	3	GPS36	0.560	61.7	2	2.90	0.884	507.80	49.94	
	10	9	B3	1	48.9	2	0.60	0.866	2.65	2.65	
	10	19	GPS36	0.568	55.6	2	2.40	0.877	163.25	16.99	
	10	26	B3	1	48.9	2	0.80	0.866	4.20	4.20	
	10	32	GPS36	0.580	46.2	2	2.10	0.861	84.95	9.61	
	10	42	B3	1	48.9	2	0.80	0.866	4.20	4.20	
	10	44	B3	1	48.9	2	1.00	0.866	6.66	6.66	
	11	0	GPS36	0.603	33.6	2	1.00	0.822	7.39	0.98	
16	9	28	GPS36	0.546	74.8	12	3.50	0.894	329.76	29.31	
	9	44	B3	1	48.9	12	0.60	0.866	0.44	0.44	*
	10	0	GPS36	0.559	62.0	2	1.70	0.885	32.02	3.13	
	10	27	B3	1	48.9	12	2.80	0.866	70.07	70.07	
	10	35	GPS36	0.583	44.4	2	1.20	0.857	10.80	1.25	
	10	42	B3	1	48.9	12	2.30	0.866	22.16	22.16	

Further Suggestions

- Repeat the experiment at 532nm wavelength.
- Extend to GLONASS, GIOVE, ETS-VIII, LARES and others.
- The GPS array is theoretically about 1500 times brighter than Apollo 15, corresponding to ND 3.2, so if GPS is still observable at a station with this setting then LLR should also be acquirable.

- Systems having readouts for return signal strength would be well suited to doing an equivalent of this experiment, more easily. In fact, by using our method as well as their own, our method could be tested.
- Similarly, comparisons of return rates in controlled experiments might assist in validation of the technique.

References

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