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Bistatic Optical Observations of GEO Objects[1,2]

Patrick Seitzer
Department of Astronomy
University of Michigan
pseitzer@umich.edu

Edwin S. Barker
LZ Technology, Inc.

Heather Cowardin
Jacobs

Susan M. Lederer
NASA/JSC

Brent Buckalew
Jacobs

ABSTRACT

A bistatic study of objects at Geosynchronous Earth Orbit (GEO) was conducted using two ground-based wide-field optical telescopes. The University of Michigan's 0.6-m MODEST (Michigan Orbital Debris Survey Telescope) located at the Cerro Tololo Inter-American Observatory in Chile was employed in a series of coordinated observations with the U.S. Naval Observatory's (USNO) 1.3-m telescope at the USNO Flagstaff Station near Flagstaff, Arizona, USA.

The goals of this project are twofold:

1. Obtain optical distances to known and unknown objects at GEO from the difference in the observed topocentric position of objects measured with respect to a reference star frame. The distance can be derived directly from these measurements and is independent of any orbital solution. The wide geographical separation of these two telescopes means that the parallax difference is larger than ten degrees.
2. Compare optical photometry in similar filters of GEO objects taken during the same time period from the two sites. The object's illuminated surfaces will present different angles of reflected sunlight to the two telescopes.

During a four-hour period on the night of 22 February 2014 (UT), coordinated observations were obtained for eight different GEO positions. Each coordinated observation sequence was started on the hour or half-hour, and was selected to ensure that the same cataloged GEO object was available in the field of view of both telescopes during the thirty minute observing sequence. GEO objects were chosen to be both controlled and uncontrolled at a range of orbital inclinations, and the objects were not tracked. Instead both telescopes were operated with all drives off in GEO survey mode to discover un-cataloged objects at GEO. The initial photometric results from this proof-of-concept observing run will be presented with the intent of laying the foundation for future large-scale bistatic observing campaigns of the GEO regime.

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1. INTRODUCTION

Surveys of objects in the GEO regime are normally made by a single wide field telescope which can follow an object for only a short time (usually minutes) [1][2]. This results in an orbit that is not well defined unless an assumption is made that the orbit is circular, for example. Candidate GEO objects are then followed up with a second telescope to refine the orbit with a much longer time arc (usually hours) and determine all six orbital parameters.

However, it is possible to observe the same region at GEO simultaneously with two telescopes and measure an object's apparent position with respect to the background star field, and its brightness. This offers interesting possibilities for orbit determination and photometric studies. References [3] and [4] have reported on previous experiments in this area as well as the potential advantages and disadvantages of this method.

2. OBSERVATIONS

Observations reported here were made from two widely spaced optical telescopes: the 1.3-m telescope in the northern hemisphere at the U.S. Naval Observatory's Flagstaff Station (USNOFS) outside of Flagstaff, Arizona, and the 0.6-m Michigan Orbital DEbris Survey Telescope (MODEST) at Cerro Tololo Inter-American Observatory in Chile. The linear distance between the two telescopes is 7800 km, and at GEO (altitude of 35786 km) the angular difference (parallactic angle) between the two lines of sight to a GEO object is greater than 10 degrees.

For this experiment, we observed such that both telescopes pointed to the same region at GEO for 30 minutes with the telescope stationary (all drives off). Controlled GEO objects will be point sources in the 3-second exposures, while uncontrolled GEO objects will be short streaks, the length depending on the inclination of the object's orbit, and the object's location in its orbit.

After 30 minutes of observing one GEO field, and starting on the hour or half-hour, both telescopes were moved to pointing to another region at GEO. Since these observations were our first attempts at coordinating observations over such a long baseline, the pointings were chosen such that the same cataloged GEO object passed through the center of the field of view of each telescope during each 30-minute sequence. We observed 8 cataloged objects: one controlled and seven uncontrolled objects with a range of orbital inclinations.

Unfortunately there were not matching filter sets at both observatories. On MODEST the observations were obtained through the standard GEO survey filter: a broad R filter (200 nm wide centered at 630 nm), while on the USNOFS 1.3-m a Sloan r filter (150 nm wide centered near 650 nm) was used. All observations at both sites were calibrated to the Kron-Cousins R band as defined by observations of Landolt standards [5].

The sampling interval for 3 seconds exposures was one exposure every 18 seconds at MODEST, and one exposure every 37 seconds at the USNOFS 1.3-m telescope.

When observing the GEO regime, the following criteria had to be met for an object to be observed:

1. The sun was more than 12 degrees below the horizon at both sites. Translation – it was dark at both observatories.
2. The object was in direct sunlight and out of Earth shadow.
3. It was more than 30 degrees above the horizon at both sites. Observing above this elevation minimizes the effects of atmospheric refraction and extinction on the observations.
4. It was clear at both observatories.

Fig. 1 shows the geometry of our observations, which began on 22 February 2014 at 0230 UT (just after sunset at Flagstaff, Arizona) and ended four hours later at 0630 UT (just before sunrise in Chile). It was clear and photometric at both observatories.

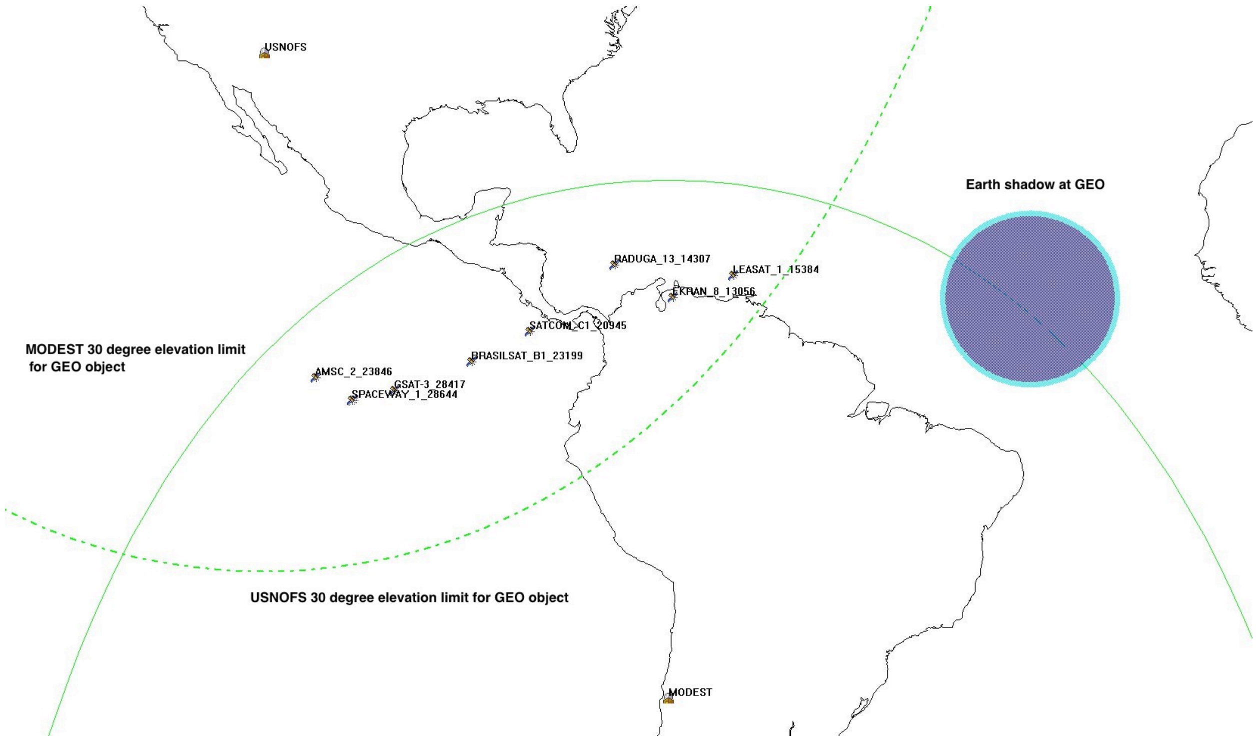

Fig.1. Observing geometry at the start of the bistatic campaign at 0230 UT on 22 February 2014. The eight GEO objects observed are plotted along with the location of Earth shadow at the start of the observing. The two green lines show the 30-degree elevation limits for GEO objects at each observatory. Objects between the two green lines are in the sweet spot of bistatic observations: above 30-degrees elevation at both observatories.

3. PHOTOMETRIC RESULTS

In the figures that follow are shown the calibrated magnitudes for the 8 observed GEO objects, beginning with the station-keeping object (28644) and then the uncontrolled objects. Only measurements that are not contaminated by a star trail are shown, and in the case of the USNOFS mosaic CCD camera, measurements which do not fall in the inter-CCD gaps. The reader is urged to look at the differences between the two light curves for each object.

The photometric errors for all observations of these bright objects are small: typically less than 0.05 magnitude or smaller than the size of a point in the plots.

No corrections to a standard range nor a standard phase angle have been made. The purpose of this initial study was to look for differences between the two light curves for each object, and it is probable that over a 30 minute observing window changes in brightness due to range and phase angle differences will be small. Making such corrections may decrease the difference in brightness between the two sets of observations for some cases.

SSN 28644 – SPACEWAY 1 (inclination = 0.03 deg)

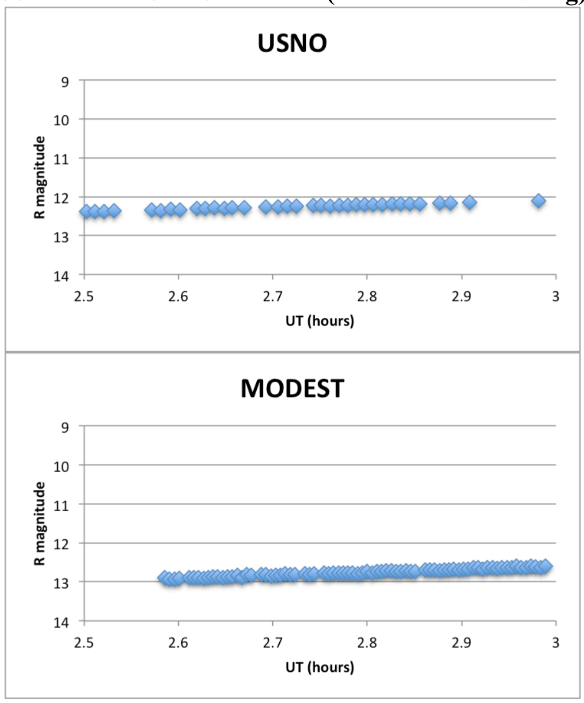

Fig 2. Calibrated R magnitudes as a function of time for the controlled object SSN 28644. Both sites obtained very similar light curves, with the possibility of a small shift in brightness.

SSN 14307 RADUGA13 (inclination = 15.6 deg)

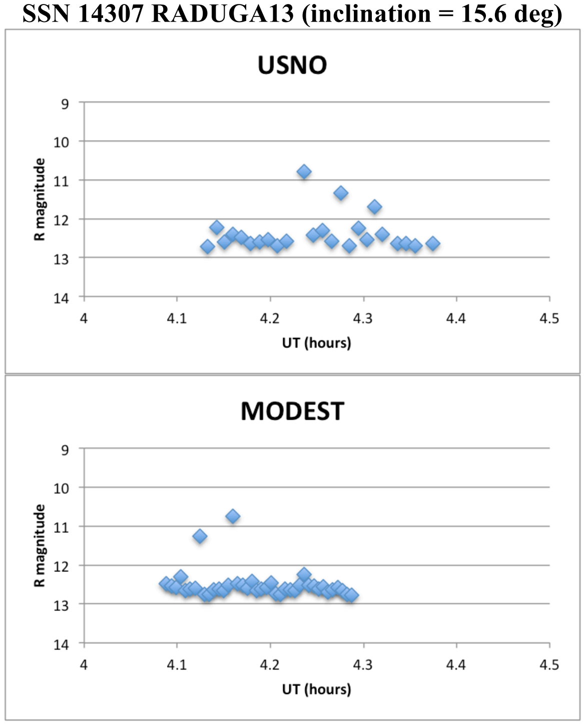

Fig. 3. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 14307. Note that the sudden increases in brightness occur at different times at the two observatories. This object was moving at a large angular rate in a southerly direction and thus stayed in the field of view for only part of the 30-minute sequence.

SSN 13056 EKRAN 8 (inclination = 14.7 deg)

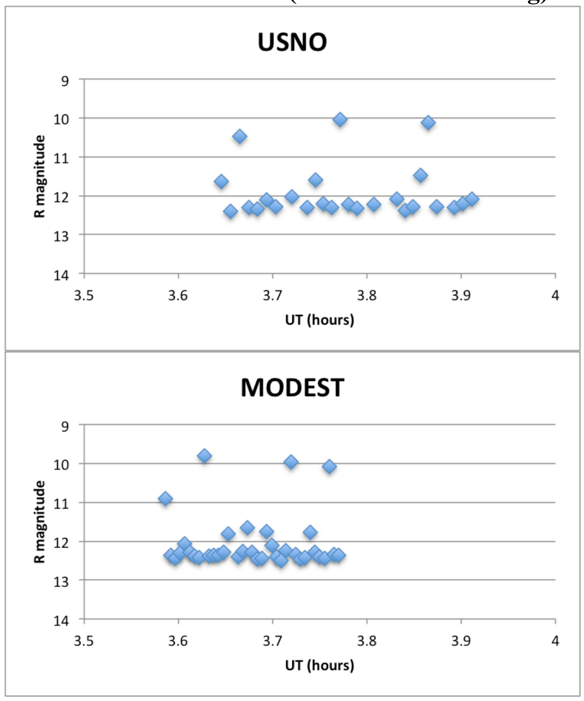

Fig. 4. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 13056. Like SSN 14307, the sudden increases in brightnesses occur at different times for the two observatories.

SSN 15384 LEASAT 1 (inclination = 13.7 deg)

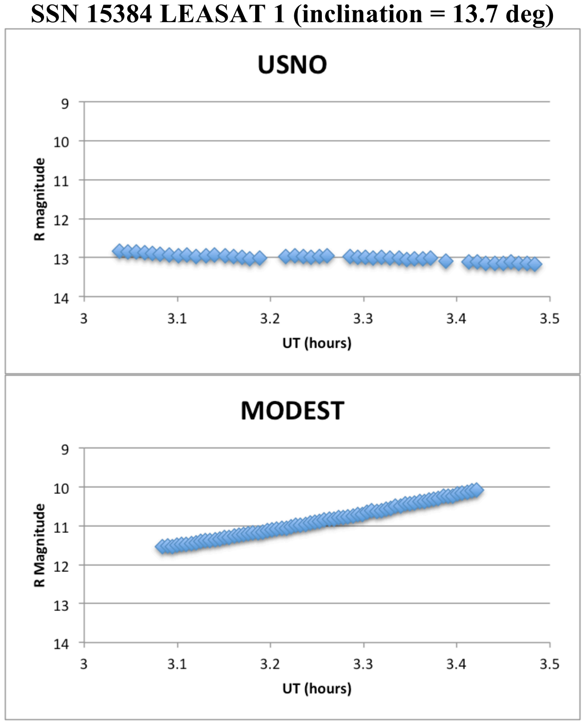

Fig. 5. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 15384. There is a significant difference between the brightness of this object as observed from the two sites and a difference in the slope of the light curves.

SSN 20945 SATCOM C1 (inclination = 8.9 deg)

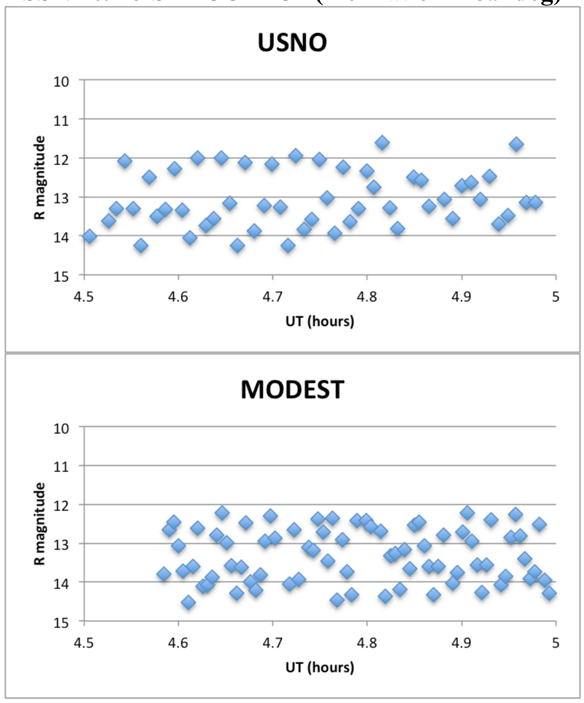

Fig 6. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 20945. Both sites observed a large scatter in brightness, possibly changing more rapidly than the sampling interval of 18 seconds for MODEST.

SSN 23199 BRAZILSAT B1 (inclination = 6.4 deg)

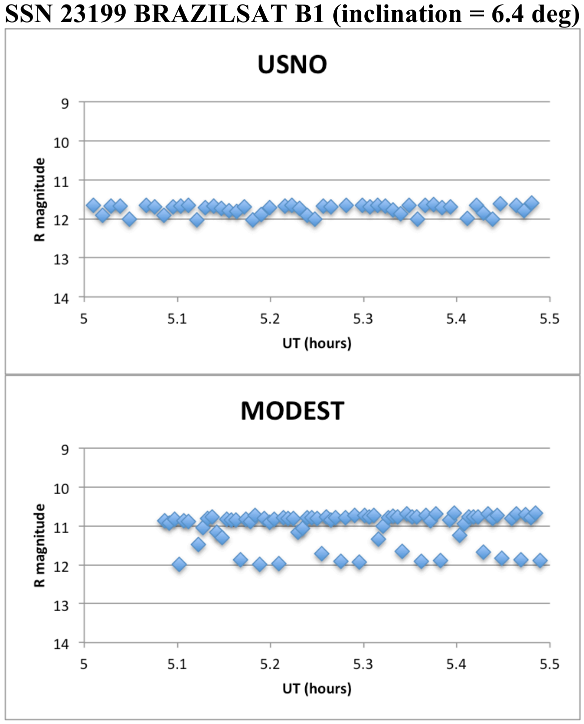

Fig 7. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 23199. For this object there is a significant difference in the observed brightness of almost a magnitude (factor of 2.5), and the range in brightness is greater for MODEST than it is for the USNOFS observations. Note that there are frequent decreases in brightness (larger magnitude), whereas for previous objects there were increases in brightness.

SSN 23846 MSAT M1 (inclination = 6.1 deg)

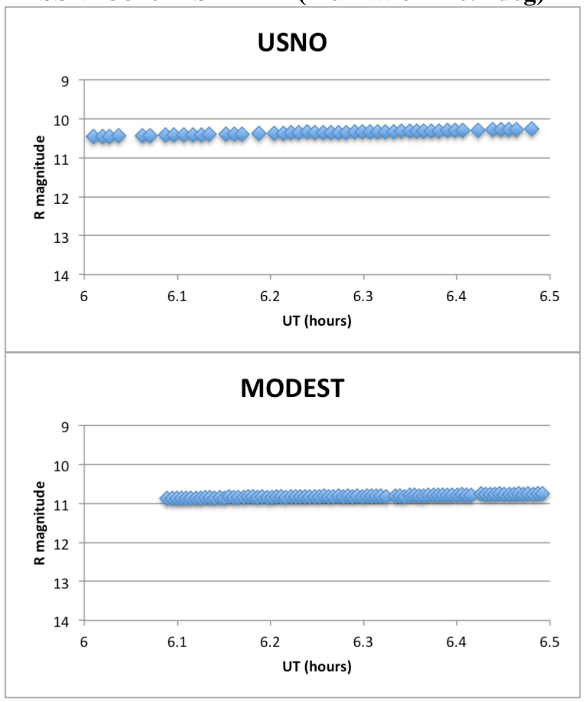

Fig 8. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 23846. Of all the uncontrolled objects, this has the most well behaved light curve, showing very small variations in brightness as a function of time. However, there is an almost 0.5 magnitude difference in brightness between the two sets of observations.

SSN 28417 GSAT 3 (inclination = 3.2 deg)

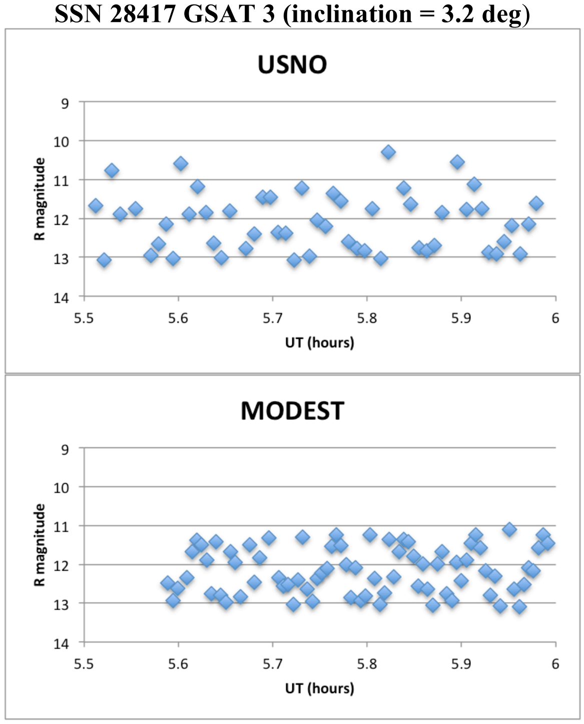

Fig. 9. Calibrated R magnitudes as a function of time for the uncontrolled object SSN 28417. Like SSN 20945, the there is a large variation in brightness frequently exceeding 2 magnitudes between subsequent exposures. It appears that the range in brightness is larger at USNOFS than at MODEST.

4. DISCUSSION

An inspection of the above figures shows that the observed photometric behavior of objects depends on both the time of observation and the location of the observer. This is not surprising when one imagines how an irregularly shaped object would appear from two different lines of sight. If the object tumbles, then the observed light curve would be different for two different observers. If the above objects are intact spacecraft, and have maintained their solar panels and antennas, then presumably it would be possible from the above light curves to understand the attitude motion of the spacecraft.

What is surprising is that uncontrolled objects like 15384 and 23846 show very little change in brightness with time. If these objects are no longer attitude controlled, then the question is why they don't show large brightness variations due to the solar illumination of irregular shapes and shadowing effects from solar panels and antennas. Both these objects show very little change in brightness with time from both observatories.

5. SUMMARY

In this paper the photometric information obtained from optical bistatic observations of GEO objects has been studied for 8 objects: 7 uncontrolled and one controlled. The photometric signatures are generally consistent between the two sites. In no case do we see large brightness variations from one site only. If the object has large brightness variations, it is seen from both sites. These brightness variations may be as rapid as the sampling is (18 seconds for MODEST), or with occasional flares to as much as two magnitudes brighter.

6. REFERENCES

1. Schildknecht, T., Optical Surveys for Space Debris, Astron. Astrophys Rev., Vol. 14, 41-111, 2007.
2. Seitzer, P. et al, An Optical Survey for GEO Debris in High Inclination Orbits, Proceedings of the 2005 AMOS Technical Conference, Maui, Hawaii, 224-229, 2005.
3. Maskell, W.P., Satellite Position Determination Technique Using Synchronous Observations from Optical Sensors, A Project Report Submitted to the Faculty of the Royal Military College of Canada, 2006.
4. Porfilio, M., Piergentili, F., and Graziani, F., Two-site orbit determination: The 2003 GEO observation campaign from Collepardo and Mallorca, Advances in Space Research, Vol. 38, 2084-2092, 2006.
5. Landolt, A., UBVRI Photometric Standard Stars around the Celestial Equator: Updates and Additions, Astronomical Journal, Vol. 137, 4186–4269, 2009.