PHYSICAL CHARACTERIZATION OF OBJECTS IN THE GEO REGION WITH THE LOIANO 1.5 M TELESCOPE

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ABSTRACT

A pilot program for the physical characterization of the space debris population in high Earth orbits was started at the 152cm G.D. Cassini Telescope in Loiano, operated by the INAF Astronomical Observatory of Bologna, Italy.

Several BVRI photometric images of active satellites, disposed spacecraft and upper stages were acquired during 4 nights in the year 2011 along with a number of photometric calibration fields and Solar analogue stars (spectral standards) for calibration purposes. A few High Area to Mass Ratio, HAMR, objects were observed and lightcurves were obtained for them. The paper presents the obtained data and the discussion on how to establish the physical nature and hence, possibly, the origin of the targets.

Key words: GEO; photometry; HAMR.

1. INTRODUCTION

The Geostationary region, harbors the large telecommunication and meteorological satellites which are now considered common and fundamental assets for our everyday life. This vital zone of the circumterrestrial space is nonetheless crowded with old non-operational spacecraft and debris which jeopardize the future use of this resource. On top of the usual debris historically known, in the last decade a peculiar population of space debris, having mean motion around 1 and high eccentricity, was discovered by the ESA OGS telescope [9]. It was shown that these objects have a very high area to mass ratio [6] (of the order of several m^2/kg and larger) hence their dynamics is strongly perturbed by the solar radiation pressure effect, in a way usually not observed for "normal" objects. These objects are believed to be remnants of thermal blankets or multi-layer insulation (MLI) either detached from aging spacecraft or ejected by explosive fragmentations of old spacecraft. At the present their exact nature, as well as, the nature of many space debris in GEO, remains elusive due to lack of physical, spectroscopic and photometric studies.

Thus, a pilot program for the physical characterization of the space debris population in high Earth orbits was started at the 152cm G.D. Cassini Telescope in Loiano, operated by the INAF Astronomical Observatory of Bologna, Italy. The results of the first few nights are described in [7] and [8]. In this paper we will concentrate on the objects observed during the August 2011 runs. In the first part of the paper a description of the instruments and of the strategies used are recalled, together with an overview of the objects observed. In the second part the description of data reduction techniques is given along with the description of the technique used to derive the reflectance as a function of wavelength (i.e., very low resolution, four-point, spectra) based on photometrical measurement is described. Finally, the results achieved are shown and discussed also in comparison with respect to literature.

2. INSTRUMENTS AND OBSERVATIONS

All the observations were performed from the LOIANO observatory, operated by the INAF Astronomical Observatory of Bologna (http://www.bo.astro.it/loiano/). The observatory is located in the northern part of Italy at Latitude 44° 15′ 33" N and Longitude 11° 20′ 02" E at the elevation of 785 m. The observatory is located in a quite dark region, with a quite low light pollution, the average measured seeing all over the year being about 2 arcsecs. The telescope used is G.D. Cassini Telescope, a 152 cm diameter Ritchey - Chretien configuration, system with f/number 3 at the primary focus and 8 at the secondary (this last was used during the campaign). The telescope has an English mount and can only track in sidereal mode. This represents a serious limit of the system for our purposes, since the absence of differential tracking does not

Proc. '6th European Conference on Space Debris'
Darmstadt, Germany, 22–25 April 2013 (ESA SP-723, August 2013)

Table 1. List of observed objects considered for this paper

Name	Type of object	Date of Observation
Meteosat 7	GEO Satellite	Feb. 2011
Meteosat 9	GEO Satellite	Feb. 2011
SICRAL 1	GEO Satellite	Feb. 2011
SICRAL 1B	GEO Satellite	Feb. and April 2011
SL12 28240	Rocket Body	Feb. 2011, 24-8-2011, 25-8-2011
SL12 26397	Rocket Body	Feb. 2011
SL12 13983	Rocket Body	24-8-2011
SL12 28256	Rocket Body	24-8-2011, 25-8-2011
90085	HAMR object	April 2011
95452	HAMR object	April 2011
84983	HAMR object	April 2011
84964	HAMR object	24-8-2011, 25-8-2011
84967	HAMR object	24-8-2011, 25-8-2011
84980	HAMR object	24-8-2011, 25-8-2011
84993	HAMR object	25-8-2011

allow the continuous tracking of drifting objects (e.g., the High Area to Mass Ratio, HAMR, objects), thus reducing the objects dwelling time in the spectrograph slit and, as a matter of fact, prevented us to obtain spectra of the observed objects until the time of writing. The telescope is equipped with BFOSC (Bologna Faint Object Spectrograph and Camera), a multipurpose instrument for imaging and spectroscopy, with an EEV CCD (1340×1300 pixels) capable to cover a field of view of $13' \times 13'$. This is an instrument designed to be used both as spectrograph and as imaging system. The configuration used for taking spectra of observed objects include a 2" slit (large enough to permit a longer object dwelling time in the field of view) and a grism essentially focused on the visible light.

The project goes on since the year 2011. Partial results of the first nights of observations are described in [7] and [8]. In this paper we concentrate on the observations performed on August 24^{th} and August 25^{th} 2011. Note that part of the results of August 24^{th} were already shown in [8], but those data have been fully re-analyzed with a new processing pipeline, also due to a detected problem in the calibration. Therefore the results shown here are superseding those shown in [8]. For comparison purposes, also objects observed in the nights of February and March 2011 are shown in Figs. 1 - 3 (see [7] for details).

Table 1 summarizes the objects considered in the paper.

3. DATA PROCESSING

The CCD images were reduced and calibrated with a standard method plus the addition of some *ad-hoc* procedures to correctly handle the more peculiar ones, showing strong fast and irregular variations in magnitude.

Bias and flat-field corrections were performed: a master flat field was computed as a median of several dome flat fields. The instrumental magnitudes were measured using aperture photometry with an integrating diameter typically about six times the FWHM. This was deemed optimum since it is large enough to include most of the point spread function, yet small enough to minimize background sky noise. Source detection and sky subtraction were performed using the *SEXtractor* software package [2][4]. For peculiar objects (like some of the HAMRs) the IRAF task *polyphot* was used. This task allows to perform aperture photometry using a poligonal aperture whose vertex are user defined. We used 4 or 6 vertex, accordingly to the kind of object, i.e., large enough to include the whole objects without considering too much sky background. For every object the same aperture was always used.

For magnitude calibration, observations of different standard stars [5] were obtained over a wide range of airmasses and stellar types. A quality check on the stars is performed mainly to be sure that they are not saturate, the S/N is larger than 100 and the effective airmass at the exact epoch of the image is used (i.e., not the one at the beginning of the exposure). The zero point, and color terms obtained from the Landolt fields were then used to convert instrumental magnitudes to apparent magnitudes. B and V filters have been calibrated using the B-V color; R filter has been calibrated using the V-R color; I filter has been calibrated using the R-I color. The color terms calibration of the HAMR data was particularly cumbersome due to the large variations observed. A multi step averaging procedure was performed to obtain the average colors from the single calibrated magnitudes.

The errors quoted take into account both the instrumental errors given by photon statistics alone and the calibration errors.

3.1. Reflectance

Once the magnitudes at different wavelengths are computed, the reflectance values at each wavelength can be obtained using the following equation:

$$R(\lambda) = 10^{-0.4[(M_F - M_V) - (M_F - M_V)_\odot]} \qquad (1)$$

where (M_F) and $(M_F)_\odot$ are the magnitudes of the object and Sun, respectively, at the central wavelength of filter F (specified to be BVRIJHKs). The equation is normalized to unity at the central wavelength of filter V using M_V and $M_V\odot$, i.e., the V magnitudes of the object and Sun (see, e.g. [7]).

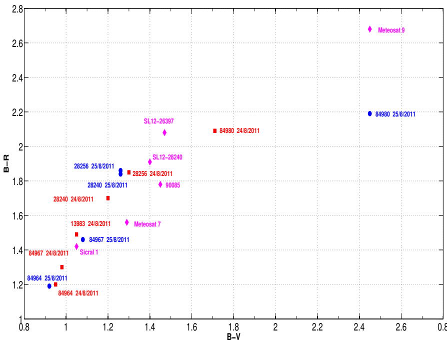

Figure 1. Photometric B-R vs. B-V color indices

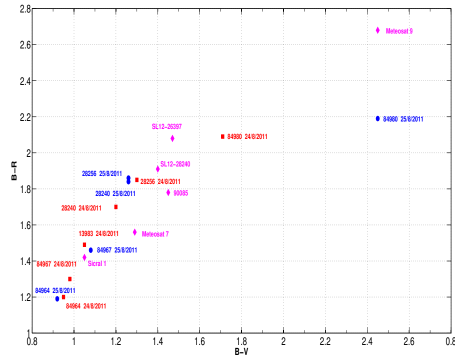

Figure 2. Photometric B-R vs. R-I color indices

Figures 4 and 5 show the reflectance computed with Eq. 1 for the objects observed on the 24^{th} and the 25^{th} of August, respectively.

4. RESULTS

Comparing the color index of the observed objects with those of some laboratory sample it is possible to get hints on the physical nature of the observed targets. Figure 1 show the distribution of the B-R vs. B-V index while in 2 the R-I vs. B-R index are shown. The magenta diamonds refer to the objects observed in the February and April 2011 runs. The red squares and the blue circles refer to the objects observed, respectively, on August 24 and August 25 2011. Note that some of the objects were observed in multiple nights mostly to check consistency between the measurements and also possible physical variations. It can be said that in most of the cases the data taken in different nights are consistent well within the error bars of the indices. Both in Fig. 1 and 2 the position of Meteosat 9 is clearly outside the bulk of the other targets and, in particular, shows clearly different indices with respect to its analogous Meteosat 7. While the most probable explanation for this discrepancy is a possible problem with the data analysis (calibration) it is worth noting how actually Meteosat 7 and Meteosat 9 belong to two different generations of Meteosats and are placed on orbits with significantly different inclinations (which might be responsible for different aspect angles)[S. Pessina, *personal communication*].

In order to compare with laboratory sample the results of Cowardin *et al.* [1] were used. Fig. 3 shows our data points superimposed on Fig. 1 from [1]. Our data are plotted with the following marks: It can be noticed how all the objects of the present study lie within the main group of the laboratory sample analyzed by Cowardin. This, again, is an indication of the consistency of our data and gives an indication on the possible physical nature of the objects.

Figures 4 and 5 show the reflectance computed for the

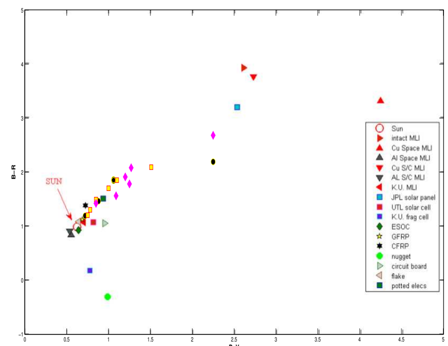

Figure 3. Photometric B-R vs. B-V color indices of our target superimposed to the Figure 1 of [1]

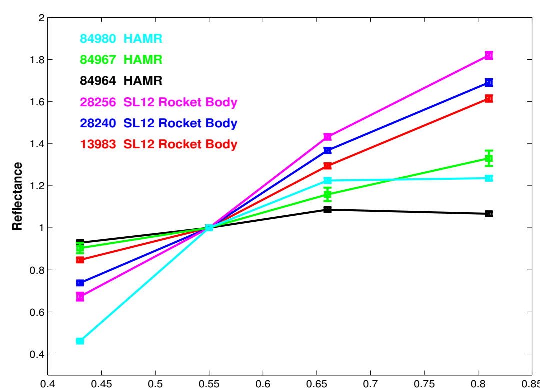

Figure 4. Normalized reflectance of the objects observed on August 24th

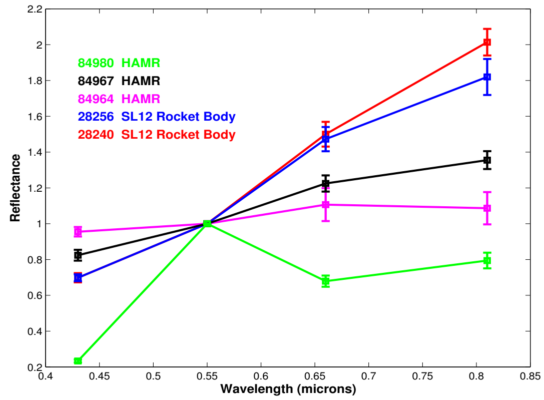

Figure 5. Normalized reflectance of the objects observed on August 25th

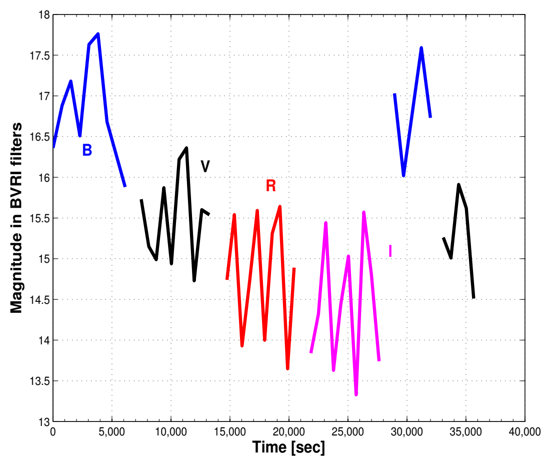

Figure 6. Sample lightcurves of the object 84980 HAMR in the four filters, as observed on August 24th

objects observed on the 24^{th} and the 25^{th} of August, respectively. It can be immediately noticed how the objects divide into two distinct groups with different slopes. The rocket bodies have distinctly higher slope with respect to the HAMR objects. This behavior makes us confident that the reflectance, as computed from Eq. 1 is consistent and is probably indicative and directly related to the different materials that cover the two classes of objects: mostly MLI-like materials for the HAMR and probably more "classical" composition for the rocket bodies.

The observations were not intended to and optimized for the production of lightcurves. On the other hand, plotting the derived magnitudes as a function of time shows us the variations associated with the objects which is another indication of the very different physical nature of out targets. In Figs. 6–8 the lightcurves, in the four different filters of the HAMR object 84980 (as observed on August 24 and August 25) and of the Rocket Body 28256 SL12 are shown. The much higher variation in magnitude in all the filters, typical of HAMRs objects, is apparent in

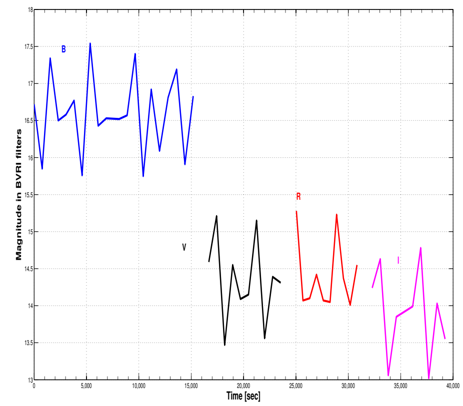

Figure 7. Sample lightcurves of the object 84980 HAMR in the four filters, as observed on August 24th

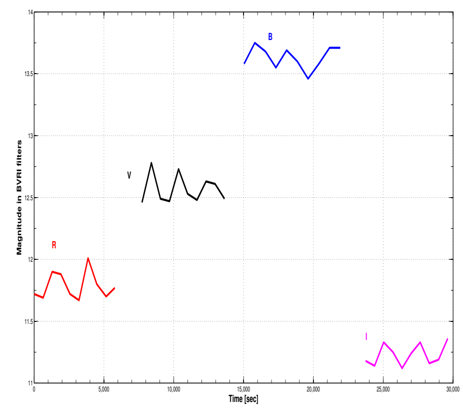

Figure 8. Sample lightcurves of the object 28256 SL12 Rocket Body in the four filters, as observed on August 25th

Figs. 6 and 7, while a nearly periodic variation, possibly related to a rotational motion of the target can be seen in the case of the RB, in Fig. 8.

5. CONCLUSIONS AND FUTURE WORK

The results of the two August 2011 nights of photometric observations from the Loiano telescope confirm that this telescope can be an interesting instrument for this kind of studies. The measurement acquired in these nights are in good agreement with the data from other groups and allow to give a first idea of the physical nature of the targets. Two clearly distinct slopes in the reflectance were identified for large intact RB and for HAMR objects.

Beyond the data shown in this paper, three more nights of data already acquired are currently under analysis. More-over, the project is continuing and two more observation nights are scheduled in May 2013. This will allow us to build a significant database of objects and to check our conclusions, e.g., on the slopes of the reflectance, on a significant sample of GEO targets.

ACKNOWLEDGMENTS

We thank the Observatory of Bologna for assigning us the observation time. We warmly thank the staff and technicians of the Loiano Observatory for their invaluable help during the observing sessions. The observations of the HAMR objects would not have been possible without the collaboration of J. Stansbery and T. Kelecy from NASA that continuously support our efforts with updated HAMR objects TLEs. We also wish to thank Stefano Pessina for his valuable comments on the Meteosat data.

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