The puzzling case of the deep-space debris WT1190F: a test bed for advanced SSA techniques

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Summary

We report on somewhat unique photometric and spectroscopic observations of the deep-space debris WT1190F, which entered Earth atmosphere off the Sri Lanka coast, last 2015 November 13. This striking case has been imposing to the worldwide SSA community as an outstanding opportunity to effectively assess origin and physical nature of such extemporary impactors and appraise their potential threat for Earth. Our observations indicate for WT1190F an absolute magnitude R = $32.45_{\pm 0.31}$, with a flat dependence on the phase angle, and slope $0.007_{\pm 0.002}$ mag deg^{-1}. The detected short-timescale variability suggests a "four-facet" geometry, with the body likely spinning with a period P = $2.9114_{\pm 0.0009}$ s.

In the BVRI color domain, WT1190F closely resembled the Planck deep-space probe, a feature that points to an anthropic origin of the object. This match, together with a depressed reflectance around 4000 and 8500 Å may be suggestive of a "grey" (aluminized) surface texture. An analysis is in progress to assess the two prevailing candidates to WT1190F's identity, namely the Athena II upper stage of the Lunar Prospector mission, and the ascent stage of the Apollo 10 lunar module (LEM LM-4) "Snoopy", by comparing observations with the synthetic photometry from accurate mock-up modeling and reflectance rendering.

Keywords: *Space debris – Deep-space impactors – Space situational awareness techniques – Astrometry – Reflectance characterization.*

1 Introduction

A common drawback when dealing with deep-space impactors (intending all those natural and artificial objects heading Earth at roughly escape velocity), is that they are usually discovered hours or just minutes before reaching our planet. The small asteroids 2008 TC_3, 2014 AA, or even the disrupting Chelyabinsk event are remarkable examples in this sense[1,2,3,4].

In this framework, the case of WT1190F offered a somewhat unique opportunity of deeper investigation as object's recognition, and in particular its fatal orbital evolution was successfully assessed[5] weeks in advance of its final fate over the sky of Sri Lanka[6]. This left room, therefore, for a wider and much deeper study of the inherent properties of this quite unusual and still mysterious body.

Discovered by the Catalina Sky Survey[7], on 2015 October 3 (and then pre-covered in different sky surveys back to year 2009), WT1190F was first recognized as a possible small (metric-sized) NEO asteroid captured in a prograde chaotic motion around the Moon-Earth system. The object moved on orbital timescales between 19 and 40 days, along a very eccentric ($0.33 \leq e \leq 0.98$) translunar ($490\,000 \leq a \leq 655\,000$ km) trajectory with strongly variable inclination ($3^o \leq i \leq 78^o$).

A forward-integrated orbit[8] led eventually to predict for WT1190F an Earth impact on 2015 November 13, at 06:18 UT, entering atmosphere with a steep incident angle about 20^o, at a speed of 10.6 km s^{-1}. This would be the first predicted impact of space debris on such an eccentric asteroid-like orbit. The strongly perturbed orbit led to infer[5] a large Area-to-Mass ratio (AMR) in the range $0.006 \leq AMR \leq 0.011$ m^2 kg^{-1}, a feature that better pointed to an anthropic origin of the object, possibly a relic of some lunar mission, although of fully unknown origin.

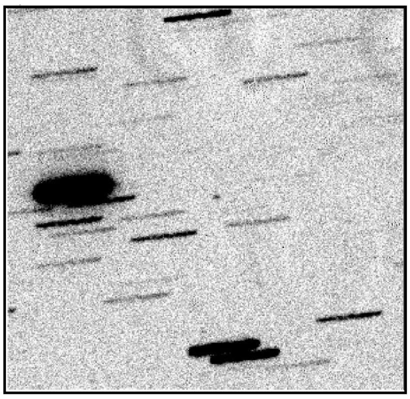

Figure 1 - An illustrative frame of WT1190F from the Loiano observatory in the night of 2015 November 7-8. The image is taken in the Johnson-Cousins R band with a 420s exposure time. The object was 518 000 km away from us. Thanks to the "on-target" telescope tracking, WT1190F is clearly detected as a point source near the field center, with an apparent magnitude R = 20.45.

2 The observing dataset

As a part of the WT1190F worldwide observing campaign, we have been tracking this so puzzling object using the 1.52m “Cassini” telescope of the Loiano Observatory (Italy, MPC code 598)[9,10] (see Fig. 1) and the two 0.40 m and 0.28 m DESS telescopes of the DEIMOS Observatory of Mt. Niefla (Spain, code Z66)[11]. Our observations covered the returning leg of WT1190F’s last orbit up to very late moments before Earth impact, with the aim to physically characterize the body and shed light on its real nature.

In addition to the Mt. Niefla V photometry and the Loiano BVRI observations, in the night of 2015 November 12-13 we also took advantage of the “on-target” tracking capabilities of the “Cassini” telescope to acquire a low-resolution ($R=\lambda/\Delta\lambda$ ~250) spectrum of the object, about three hours before the final atmosphere entry. The spectrum covered the full optical and NIR wavelength range, nominally between 3500 and 9500 Å at 35 Å px^{-1} dispersion, and allowed us to obtain a quite accurate measure of WT1190F’s relative reflectance.

3 Absolute magnitude and spinning properties

A first striking result of our analysis, when matching our observations with the full magnitude database, as from the DASO Circulars, is that WT1190F's brightness displayed a quite flat dependence on phase angle, φ (some $0.007_{\pm0.002}$ mag deg^{-1}), leading to an absolute magnitude R = $32.45_{\pm0.31}$. The flat magnitude trend with the phase angle, and the lack of any “surge effect” of object brightness when approaching the $\varphi \rightarrow 0^o$ configuration, can be regarded as an important signature of the artificial origin of WT1190F. Man-made space artifacts tend, in fact, to level out their reflectance properties with changing the illumination conditions[12,13], partly due to a smoother surface texture and to the averaging action of quick body spinning.

The enhanced apparent luminosity of WT1190F during its final Earth approach made possible a unique investigation of its short-timescale variability. A direct evidence for a flashing behavior just appeared in the final images of the November 13 observations, both from Loiano and Mt. Niefla (see Fig. 2). These results were also confirmed by independent observations of the two amateur telescopes of Campo dei Fiori (Italy, code 120)[14] and Great Shefford (UK, code J95)[15] observatories.

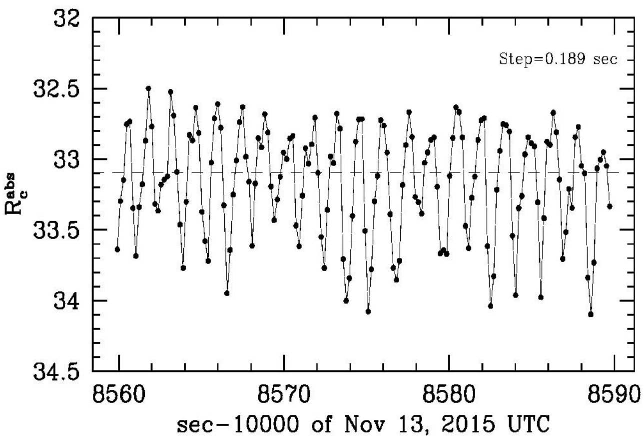

Figure 2 – The derived photometry (in absolute magnitude scale) from a 30 s R trailing image of WT1190F taken with the “Cassini” telescope of Loiano observatory along the 2015 November 13 observations. The object appears to “flash” with an apparent period shorter than ~1.5 s, likely as a consequence of a quick spinning motion. The photometric behavior is sampled in time with a step of 0.189 s, as reported in the plot. The dashed line marks the mean absolute luminosity along this set of observations.

The combined analysis of the data points to a flashing period $P_{flash} = 1.4557_{\pm0.0013}$ s with the photometric signature consistent with the presence of four orthogonal mirroring facets in object’s geometry. Simple symmetry arguments lead eventually to conclude that WT1190F was in fact spinning with a period $P_{spin} = 2P_{flash} = 2.9114_{\pm0.0009}$ s, that is twice the flashing period.

4 Colors and reflectance

According to our extended BVRI photometry, no appreciable color variation for WT1190F was detected along the full orbit, from translunar distances down to Earth, in spite of any change of the phase angle. As shown in Fig. 3, in the B-V vs. V-R color diagram, the object appeared slightly "redder" than the Sun and fully consistent in color with a star of spectral type K3.

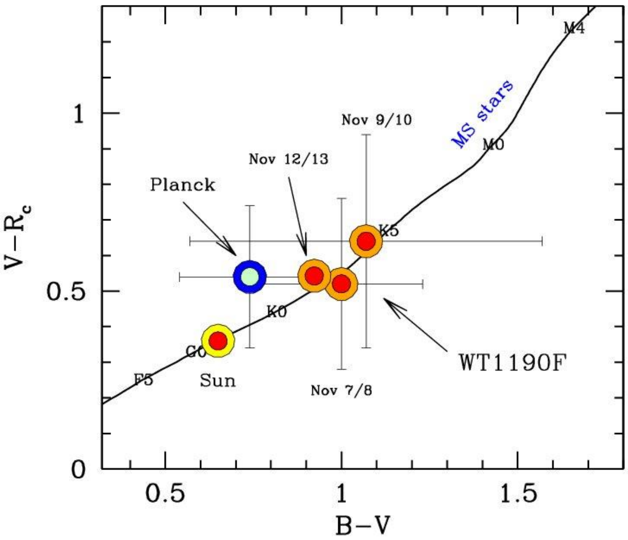

Figure 3 – The (B-V) versus (V-R) average colors of WT1190F along the three observing runs of 2015 November, from Loiano (red/orange dots). The target colors are compared with other reference objects, namely the Planck spacecraft, the Sun, and the locus of Main Sequence stars[16] (solid curve, labeled with the stellar spectral type). Note that WT1190F appears to be slightly "redder" than the Sun, but very close in color to Planck. It would also quite well match the colors of a star of spectral type K3.

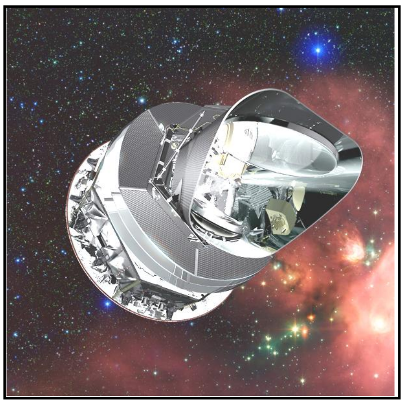

Figure 4 – The deep-space astronomical observatory Planck. The probe, in operation between 2009 and 2013, was placed in an Earth-corotating orbit around the Sun-Earth Lagrangian point L2, some 1.5 million km away. Note the prevailing grey color of the surface texture.

When compared, with other relevant deep-space spacecraft, like the L2 probes Planck and Gaia[17], the target displayed a substantially similar color as for the Planck spacecraft, characterized by a polished aluminized surface (see Fig. 4). These conclusions are corroborated also by the the reflectance curve of WT1190F, as obtained from the Loiano low-resolution spectroscopy (see Fig. 5). To a closer analysis, the curve shows, in fact, two significant "dips" around the 4000 and 8500 Å spectral regions, possibly a signature of "grey" (aluminized) material onboard[18].

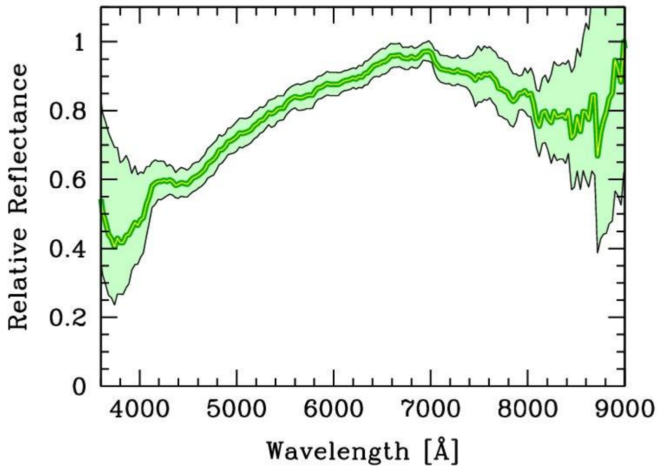

Figure 5 – The WT1190F reflectance curve, together with its ±1σ statistical uncertainty band, as obtained from the Loiano spectroscopy. The curve is normalized at the 7000 Å value. Note two clear "dips" in the curve about 4000 and 8500 Å, a possible signature of some "aluminized" material onboard.

5 Toward assessing WT1190F's identity

The wide observing evidence hereby collected clearly points for WT1190F to be a man-made artifact, most probably a relic of a past lunar mission. In addition, a still remarkable residual spin of the body may call for a relatively young age of WT1190F. The chaotic orbital motion may even support this scenario, as longer in-orbit lifetime would have greatly increased the chance of a Moon impact.

On the other hand, the same weak gravitational boundaries with the Earth-Moon system could also provide opposite evidence, by setting the case in a more historical context. It could be, in fact, that in its 2009 discovery WT1190F was in a returning path to Earth, after being recaptured from a heliocentric orbit. If the latter is the case, then the object could be much older and its origin should be moved back to the pioneering lunar missions of the 60's.

According to these two possible scenarios, the current debate on WT1190F's ultimate identity has been focusing on two prevailing candidates. In particular, the Athena II Trans-Lunar Injection Stage (TLIS), that carried the Lunar Prospector probe to the Moon in year 1998, could be the most viable "young" contender. On the other hand, a 47 year old best candidate could be identified in the ascent stage of the lunar module (LEM LM-4) “Snoopy”, released in heliocentric orbit on 1969 May 23, after completion of the Apollo 10 mission.

To consistently assess the two different scenarios, accurate mock-up modeling (relying on the 3D CAD design software SolidWorks) and reflectance rendering (through the open-source suite MeshLab for mesh rendering) is in progress in order to reproduce synthetic photometry to be compared with the observed dataset. Each target is rendered in our models as a composite structure of ~10 000 planar facets. An illustrative example of our preliminary meshing assembly of the TLIS and “Snoopy” mock-up[19] is shown in Fig. 6. A detailed analysis of the resulting synthetic photometry is deferred to a forthcoming exhaustive paper[20].

6 Summay and conclusions

The case of WT1190F, the first Earth impactor discovered with more than a day of advance notice, provided an ideal real life test case for how to quickly organize an observing campaign with multiple instruments and techniques. To shed light on WT1190F’s ultimate nature we relied on a combined observational strategy that used the 1.52m “Cassini” telescope of the Loiano Observatory, in Italy, to track the most distant orbital arc of the object, eventually accompanied by the DEIMOS telescopes at Mt. Niefla (Spain) for the very last approaching phase to Earth. We aimed at characterizing the body both from a dynamical and physical point of view, via astrometry and multicolor BVRI photometry and low-resolution spectroscopy.

According to our observations, WT1190F displayed a quite flat luminosity dependence on the phase angle, leading to an absolute magnitude of R = 32.45±0.31 mag at “opposition” geometry (i.e. $\varphi \rightarrow 0$). Both the photometric trend with phase angle, together with a somewhat chaotic dynamical regime, as from the available astrometry, appear to be clear signatures of WT1190F’s artificial nature as a man-made space artifact, possibly a metric-sized device related to some lunar mission. Our diagnostics is also corroborated by the evident spinning properties of the body, as caught by our observations along the final approaching leg to Earth, with a flashing period (possibly half the physical spinning period) of P = 1.4557±0.0013 s,

The study of object’s colors and reflectance revealed that WT1190F looked like a star of spectral type K3, although with two significant “dips” in its reflectance spectrum around 4000 and 8500 Å, likely a signature of “grey” (aluminized) material onboard.

These elements may provide an important piece of evidence to the current debate on WT1190F's identity. Two prevailing candidates are in fact under scrutiny. While the 1998 Lunar Prospector TLIS upper stage could be the most viable contender, a much older scenario may however be invoked dealing with the ascent stage of the Apollo 10 lunar module “Snoopy”, released in heliocentric orbit in 1969, and possibly re-captured by Earth in the recent years. In-progress accurate mock-up modelling and reflectance rendering of both candidates, carried on by our group, will soon provide supplementary data allowing us to better constrain the distinctive photometric signatures of both the TLIS and “Snoopy” spacecraft, to be compared with the observations and eventually lead, we hope, to conclusive arguments about WT1190F’s nature.

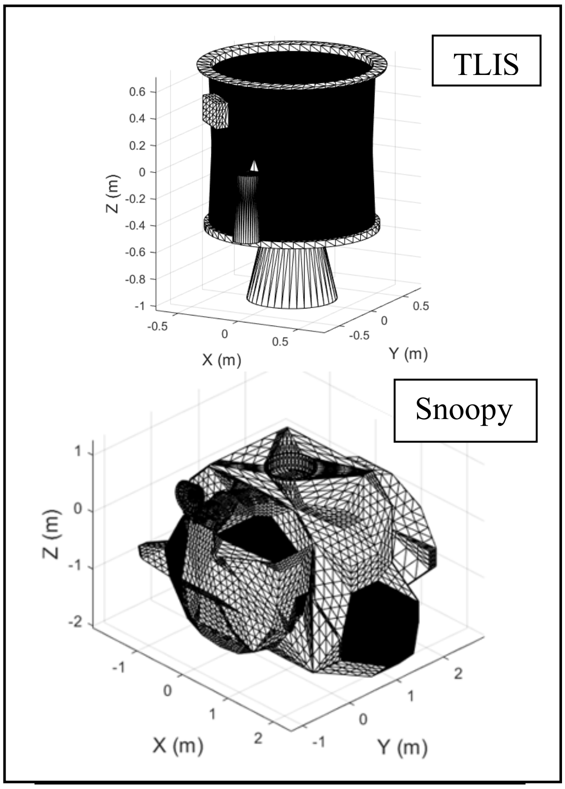

Figure 6 – Our preliminary mock-up modeling of the Lunar Prospector TLIS (upper panel) and the Apollo 10 LEM “Snoopy” (lower panel). The derived synthetic photometry may likely provide an effective tool to assess the ultimate nature of WT1190F.

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