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ANALYSIS OF THE RE–ENTRY PHASE OF STARLINK–1353 SATELLITE

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Abstract. Eighty-three percent of all operational satellites are deployed in Low Earth Orbit (LEO), where Starlink is the largest mega-constellation with 5 233 satellites in working phase (data available for June 2024) (Planet4589, 2023). To date, SpaceX has launched the first 6 505 Starlink satellites out of 11 908 units planned (with a possible supplement of 22 488 units). One of the failed satellites was the Starlink–1353 (2020–025G) unit, for which the controlled decay above Hokkaido Island, on February 21, 2023, was in the field-of-view of one telescope from Kitasubaru Astronomical Observatory. Luckily, in that moment the telescope was performing observations on the Orion Nebula region, in a live streaming session (Kitasubaru, 2024). The major break-up was captured by the video camera of the telescope and based on the frame–by–frame image analysis, we identified 15 fragments after the atmospheric re–entry. According to our analysis based on Debris Assessment Software (DAS) (NASA), the major breakup occurred at 64.4 km above the sea level and some fragments were spread over an area of 15.13 m^2. The paper presents hypothesis about the composition of the fragments that crossed the sky above Japan and if these can reach the sea level. In order to study the dynamical behaviour of Starlink–1353, before the moment of planned re–entry maneuvers, the observation recorded by Berthelot Observatory (IAU Code L54) were used. Orbital evolution of the satellite is presented using numerical integration for the available Two Line Elements (TLE) values. Using the last TLE, published five hours before re–entry, an estimated time 10:46 UTC, February 21, 2023 was computed.

Key words: Starlink, re–entry, Low Earth Orbit, debris, satellite, DAS, break–up.

1. INTRODUCTION

In the past five years, the number of operational satellites placed in orbits around the Earth has tripled, the biggest increase being noticed in low orbits (LEO), where data communications satellites are deployed. Their number is increasing rapidly and approximately 100 000 satellites will be active until the year 2030 in low orbits around the Earth, organized in some mega-constellations of satellites (Boley and Byers, 2021; Williams *et al.*, 2021).

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This unprecedented increase in the number of satellites deployed on low Earth orbits brings many benefits for worldwide communication. The idea of deploying satellites in low orbits has a significant impact on the access of the population to various communication services in certain isolated areas of the Earth, especially where a terrestrial infrastructure would not be justified. A techno-economic analysis applied for the largest constellations of satellites: Starlink, OneWeb, and Kuiper is presented by paper (Ogutu, 2021). This increase in the number of satellites deployed in low orbits around the Earth has an undesirable impact for the for astronomical community. One plausible effect will be the impaired on ground astronomical observations, by disturbing the images captured for researching purposes with "satellite trails" (Hainaut and Williams, 2020; McDowell, 2020). Indeed, in operational orbit, Starlink satellite has a "shark–fin" configuration during sunset and sunrise.

The increasing number of satellites deployed around the Earth will lead to an unprecedented overpopulation of lower orbits and will considerably escalate the conjunction alerts occurrences and, inherently, the orbital maneuvres for collision prevention. Thus, eight manoeuvres per hour is the estimated number of maneuvres at the end of this decade (Hearey, 2020). Consequently, the risk of debris generating orbital collisions will also increase, thus creating the premises for the predicted Kessler effect (Kessler and Cour-Palais, 1978).

Nowadays, the Starlink mega–constellation is identified as the number one source of future collisions within LEO objects, according to Professor Hugh Lewis, leader of Astronautics Research Group, University of Southampton (Pultarova, 2021). In 2021, the estimation for the rate of close encounters of Starlink satellites is about 1 600 events (within 1 km or less) per week, which accounts for about half of the total number of operational LEO orbits incidents (Pultarova, 2021). Put into perspective, the context appears even more alarming, because just only a fraction of the satellites have been launched so far, out of the 11,908 units approved for the Starlink mega-constellation (Planet4589, 2023), with the prospect of supplementing up to approximatively 35 000 units. Professor Hugh Lewis was estimating that about 90% of close approaches on LEO orbits will be presumed to implicate the satellites of Starlink, once this mega-constellation will be completed (Pultarova, 2021). These information was published constantly, especially on X (former Twitter), containing relevant statistics related to the development of the Starlink constellation.

In this context, the paper presents the case study of Starlink–1353 (2020–025G), a rare occasion when the re–entry and the break–up of a satellite were recorded by camera mounted on a telescope. Our analysis has two objectives, namely: i) the analysis of frames of recorded during the atmospheric re–entry, thus making scenarios for the amount of material which did not vaporized in the atmosphere; and ii) the dynamical parameters of satellite's orbit just before the atmospheric re–entry. The paper presents known elements related to the Starlink–1353 satellite, as well as the last TLEs recorded before the re–entry in the Earth's atmosphere. We analyzed the first predictions made regarding the ground track and which matched with the real descending phase of the Starlink-1353. The "frame–by–frame analysis" based on a image collage with the most important moments of the descending phase is shown. Following this analysis, we identified the major break-up and 15 fragments which continued the descent phase to the sea surface. Knowing the total mass of the satellite (official data) and based on assumptions related to the mass distribution of the internal components, as well as the materials used, we performed a re–entry analysis. In this step the Debris Assessment Software (DAS) (NASA) was used and two scenarios are presented. We estimated that the major break–up occurred at an altitude of approximately 64.4 km, which is mostly confirmed by the video images taken by the Kitasubaru telescope. We also presented a dynamical analysis using STK software (AGI) based on the images taken by our RO–HARET telescope from Berthelot Observatory (IAU Code L54), short time before the moment of planned re–entry.

2. GENERALITIES ON STARLINK–1353

Starlink is and will remain at least for the next decade the largest constellation of satellites placed in orbits around the Earth. Since the launch of TinTin A prototype on February 22, 2018 some of the Starlink satellites are no longer on the orbits, for varying reasons – early deorbitation, complete disposal or re–entry after fail (Planet4589, 2023). SpaceX is currently in the construction phase of a true mega–constellation, approximatively 35 000 satellites would be deployed in overlapping positions to create an interlaced network. As the number of satellites increases, these "eyes" of this interlaced network will be smaller and the result on the ground will be better coverage and lower latency in data transfer. For reasons of industrial secrecy, the technical data of the Starlink satellites are not communicated by the SpaceX, the owner and operator of the constellation. It is very difficult to find the information in the specialized literature, thus certain data on our analysis being classified as speculation only. In the documentation stage of this article, the authors contacted Jonathan McDowell and Hugh Lewis, two of the most reputable analysts of the Starlink constellation, in order to obtain some clarifications and directions of study. In the article, an exhaustive search for information was made, in which public data from the mass media or various working groups on the X media platform (former Twitter) were used. We started from Professor Hugh Lewis estimates published on X platform to determine the dimensions of the body and the solar panels of the satellite. The authors consider the estimation methods as reasonable to be used for this investigation. The authors also found on Internet some rendering images with Starlink satellite which are helpful to identify some components and the basis of materials. Our ob-

Table 1

The last parameters recorded in the database (11)

1	45537U	20025G	23052.247769	.22290404	12035–4	39887–2	9997
2	45537	52.9444	316.5842	0008981	225.8577	227.9971	16.3169

jective was to create the model of satellite correctly as much as possible. The rate of survivability upon re–entry of a satellite into the Earth's atmosphere depends on two principal parameters, namely: i) the shape of the satellite and ii) the materials used. In this particular case, the monitored satellite Starlink–1353 had a mass of 260 kg (DISCOSweb, 2023). Most of the components were aluminium based, aluminium completely desintegrating upon re–entry into the Earth's atmosphere. The process of ablation is similar to the one of meteoroid. The re–entry generates alumina in the superior atmosphere layers which can affect the ozone layer (Boley and Byers, 2021). The modelled re–entry took into account the velocity and the inclination of the satellite in the re–entry phase, which are 7.79 km $\cdot$ s^{-1} and 52.9° respectively (OrbitIng, 2023) and (SpaceTrack, 2024). Starlink–1353 (2020–025G) was a satellite from the v1.0 generation. For this generation of satellites SpaceX claims that this generation of satellites are composed of materials that completely demise or burn up in the Earth's atmosphere after the re–entry stage (Garrity and Husar, 2021). The satellite it was part of the last launches (L6) that lacked visors to block sunlight from reflecting off parts of the satellite.

The Starlink–1353 was launched on April 22, 2020 but it had some issues during the insertion phase into orbit. Thus, less than two months after launch, on June 9, it was declared as failed by SpaceX operator. Based on European Space Agency (DISCOSweb, 2023), we identified some characteristics of the Starlink–1353 satellite: the box shape + 1 pan, width 3.7 m, height 0.1 m, depth 1.5 m, the span 8.86 m. With the information regarding average cross section of 13.5615 m^2, we calculated the area–to–mass of 0.05216 $m^2 \cdot s \cdot kg^{-1}$, an important parameter for estimating the Delta–V for decay orbit.

From the last TLE of Starlink–1353, we noticed that the orbit eccentricity in the re–entry phase was 0.0008981, very close to a circular orbit. This orbit circularization is typically for the largest part of the artificial objects in the re–entry phase.

The substantial decrease of the apogee altitude to a value close to that of the perigee altitude results to a re–entry velocity very close to the first cosmic velocity. Based on the last parameters of the Starlink–1353 (2020–025G) satellite were made the predictions of ground track and possible impact area (Aerospace, 2023).

According to the simulation, time and geographic location fits with the re–entry values: 10:26 UTC, 40.7 (North latitude), 147.3 (East longitude). That means in the re–entry phase, the satellite crossed the Hokkaido Island into South–East direction, through the field–of–view of Kitasubaru telescope (IAU code Q33) which was making astronomical observations in live–streaming (Kitasubaru, 2024).

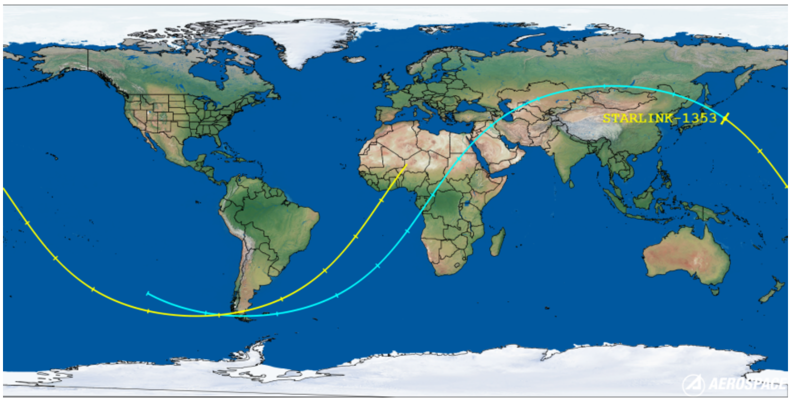

Fig. 1 – Prediction Ground Track for Starlink-1353 satellite (Aerospace, 2023)

3. FRAME–BY–FRAME ANALYSIS

The passage of the Starlink–1353 fragments through the FOV of the telescope of Kitasubaru Astronomical Observatory (located near Nayoro City) lasted six seconds in the interval 19:26:26 – 19:26:32 (local time), meaning from 10:26:26 to 10:26:32 (UTC) on February 21, 2023. After that, few long trails could be observed, which are called “trains” in technical terms, that glowed for approx five seconds. These two stages are the key–moments of the event of re–entry into terrestrial atmosphere of the Starlink–1353 (2020–025G) satellite, a behavior quite similar to that of a meteor shower (Colas *et al.*, 2020).

In the collage made based on the frames taken from the live broadcast can be identified 15 fragments obtained after the break–up of the Starlink–1353 satellite upon re–entry into the Earth’s atmosphere. In the first area (red arrow number 1) there are four fragments that can be observed, one of which very bright. In the second area, in the perimeter of Orion Nebula (M42), three more fragments can be easily identified. The cumulative seven fragments from the first two areas were observed at local time 19:26:27 (10:26:27 UTC). The most fragments of Starlink–1353 components were in these two specific areas. Also, we can assume that these seven fragments have the highest resulting mass after the break–up upon re–entry into the atmosphere. In the other areas marked in the collage only one fragment per area was identified, the exception being arrow number 7 where two debris can be observed. The passage of the last fragment resulted from the defunct communications satellite of SpaceX ended at local time 19:26:32 (10:26:32 UTC), according to the frame by frame analysis. The glowing trails after the debris passed the field–of–view of the camera mounted on the telescope are mostly ionized gas from the atmosphere caused by the friction of the satellite components during its descent.

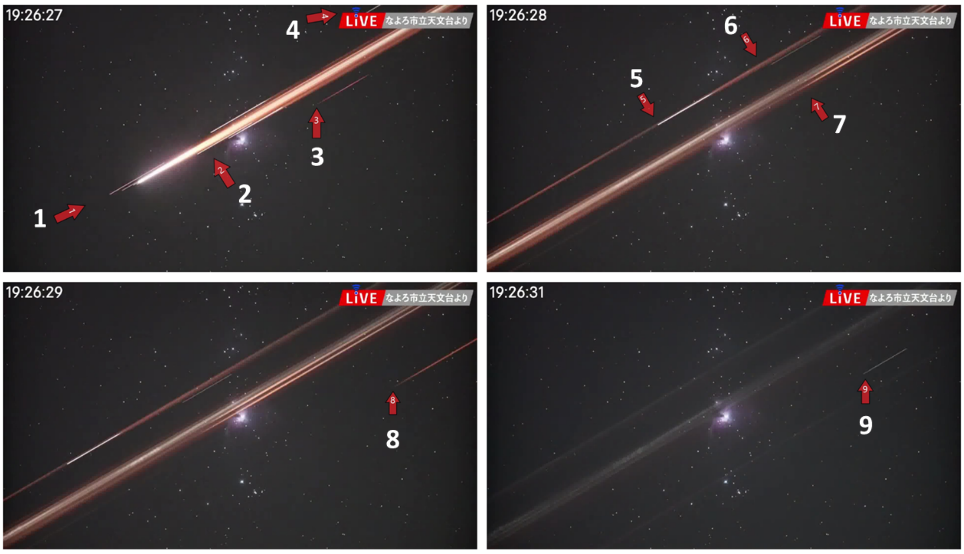

Fig. 2 – Based on the live footage, a collage with the key–moments of the re–entry was made. Through that method we analysed fragments resulting after break–up.

From the frame–by–frame analysis of the footage, we can also assume that the major break–up of the Starlink–1353 was captured in the two first frames, due to the aerodynamic forces that determined the exceeding of permitted structural loads of the central body of the satellite. In this hypothesis it is possible to estimate the altitude of the fragments which crossed the field of view of the Kitasubaru telescope in the evening of February 21, 2023. We mention that in the relevant documentation the break–up altitude is usually between 75 and 85 km (Choi, 2017).

4. RE–ENTRY SURVIVABILITY

Starlink satellites are usually built from materials that naturally decay upon re–entry into the Earth's atmosphere, such as aluminium, FR–4, or carbon fiber. However, some sub–assemblies have a higher melting point and survive by friction with the atmospheric layers, but their mass is very small. So the impact with the ground will occur at relatively low speeds, that means the kinetic energy does not represent a major danger, in the scenario of a controlled re–entry. To estimate the origin of these fragments observed in live footage from Kitasubaru Astronomical Observatory, we analyzed separately each component of a Starlink satellite of the v.01 generation. Based on this method, we assume that the components with a high probability of survival upon re–entry into the Earth's atmosphere are the few parts of those 4 reaction wheels, made by titanium or other types of hard alloys. Also Li–ion batteries do not completely disintegrate by burning, as well as certain sub–assemblies of ion engines, the parts made of tungsten or tantalum, materials with melting points over 3 000° Celsius. The cylindrical supports used for stacking the satellites in the Falcon 9 rocket, components made of Inconel, also have a high probability of survival at the re–entry stage. The same behavior we can assumed for the fastening systems (screws), made of titanium, aluminum or magnesium, often used in the aeronautical industry. We consider as a reasonable assuption that the cumulative mass of these fragments after break–up did not exceed 10% of the initial mass of the Starlink–1353 satellite, also considered in the literature (Ailor, 2019).

It should be mentioned that at re–entry a satellite deposits more aluminum in the upper atmosphere than a meteoroid (Boley and Byers, 2021). Thus, it should be noted that the increase of the number of satellites de–orbited to re–enter the Earth's atmosphere causes an increase in the risk of contamination of the upper atmosphere with alumina, which is particularly dangerous for the ozone layer (Boley and Byers, 2021).

5. RE–ENTRY ANALYSIS

To estimate which are the fragments that reached the Earth's surface (the sea in this case), in the next phase several assumptions regarding the construction of the satellite have been made. While the mass of each components of the satellite is unknown, some assumption of the range of mass were accounted. Quantitative estimations of the probability of hitting the sea surface for each component or their residuals are presented in Table 2.

Table 2

Estimation of mass distribution

Generic component	Number of items	Generic materials	Min. – Max. mass per unit [kg]	Probability of hitting Earth	Potential residuals
Solar panel	1	aluminium alloy silicium EVA + PVF film	70 – 100	0	alumina
Satellite body	1	aluminium alloy	90 – 130	0	alumina
Thruster internals	1	iron	3 – 1.5	high	iron
Ion thruster	1	aluminium alloy graphite tungsten/ tantal	7 – 2.5	high	alumina graphite tungsten/ tantal
Reaction wheel	4	stainless steel	1 – 0.25	high	stainless steel
Comms. components	4	silicon carbide	1 – 0.25	high	silicon carbide
Comms. antenna	2	aluminium alloy	1 – 0.25	low	alumina
Li–Ion batteries	4	aluminium alloy silicium / iron	18 – 5	high	alumina iron
Onboard electronics	1	aluminium alloy FR4 / tantal silicium / tungsten	3 – 1.5	medium	alumina tantal tungsten
Stacking racks	3	Inconel	1 – 0.33	medium	stainless steel/ alumina
Fastening systems	1	Inconel	1 – 0.5	medium	stainless steel/ alumina
Cables	1	cooper alloy aluminium alloy PVC/ PE	1 – 0.5	0	alumina

Table 3

Estimation of demise altitude and total DCA for the plausible scenario

Generic component	Number of items	Generic material	Demise Alt [km]	Total DCA [m^2]
Root Object	1	Aluminum (generic)	0	15.12
Solar panel	1	Aluminum (generic)	14.5	0
Satellite body	1	Aluminum (generic)	64.4	0
Thruster internals	1	Iron	0	0.38
Reaction wheel	4	Stainless Steel (generic)	0	2.38
Comms comp	4	Silicon Carbide	0	1.98
Comms antenna	2	Aluminum (generic)	0	2.18
Li–ion batteries	4	Aluminum (generic)	0	4.4
OnBoard electronics	1	Aluminum (generic)	0	0.99
Ion thruster	1	Tungsten	0	0.6
Stacking racks	3	Inconel 600	0	1.79
Fastening systems	1	Inconel 600	0	0.43
Cables	1	Copper Alloy	50.9	0

To estimate the materials from which certain sub–components of the satellite are made, we used public information about relatively similar satellites.

These are materials generally used in the construction of satellites and the proportions are purely estimated, based on public images of the Starlink v.1 satellites.

Using data collected from (SpaceTrack, 2024), we extract the information about the inclination angle (52.9°) at re–entry phase and in the next step we made some simulations with Debris Assessment Software (DAS) (NASA). Two of these scenarios derived from presented computation, one plausible scenario and another less–plausible.

In the first scenario based on minimum estimated mass per unit, we obtained plausible values: the demise altitude for solar panel was approximately 14.5 km above the sea level, while the central body of the satellite was disintegrated at 64.4 km above sea level. Also, the demise altitude for the cables was at 50.9 km altitude. Fragments of all other components of the satellite reached the sea level over a total area estimated at 15.12 m^2. The value for DCA (Debris Casualty Area – 100% impact chances) can be explained mainly due to the inclination of the satellite. The estimations for Total DCA are shown in the Table 3.

In the second scenario based on maximum estimated mass per unit, we obtained less–plausible values because both the solar panel and the central body of the satellite did not disintegrate at re–entry phase. According to this scenario, the two main components of the satellite fully reached the sea and the values are shown in the Table 4.

Table 4

Estimation of demise altitude and total DCA for the less–plausible scenario

Generic component	Number of items	Generic material	Demise Alt [km]	Total DCA [m^2]
Root Object	1	Aluminum (generic)	0	9.62
Solar panel	1	Aluminum (generic)	0	0.52
Satellite body	1	Aluminum (generic)	0	9.1
Thruster internals	1	Iron	0	0
Reaction wheel	4	Stainless Steel (generic)	0	0
Comms comp	4	Silicon Carbide	0	0
Comms antenna	2	Aluminum (generic)	0	0
Li–ion batteries	4	Aluminum (generic)	0	0
OnBoard electronics	1	Aluminum (generic)	0	0
Ion thruster	1	Tungsten	0	0
Stacking racks	3	Inconel 600	0	0
Fastening systems	1	Inconel 600	0	0
Cables	1	Copper Alloy	0	0

The estimation of demise altitude and total DCA for the less–plausible scenario presented in the Table 4 is less probable because it is not in agreement with the images captured by the Kitasubaru telescope. As can be seen in the images presented in Figure 2, the satellite Starlink–1353 was disintegrated on the re–entry phase, only certain fragments reaching sea level. However, this scenario could be an indicator of maximum values of mass distribution of some internal components of the Starlink satellite.

6. DYNAMICAL ANALYSIS

In order to study the dynamical behaviour of Starlink–1353, before the moment of planned re–entry maneuvers, we used the Berthelot Observatory to acquire FITS images with the satellite. Berthelot Observatory (IAU Code L54, Birlan *et al.*, 2021) is a Romanian infrastructure owned by the Astronomical Institute of the Romanian Academy that is used for the Space and Surveillance Tracking (SST) program, and is part of the EUSST network (EUSST, 2024). The telescope is used to perform survey and tracking observations of all visible artificial satellites and space debris that are orbiting on Medium–Earth Orbits (MEO) and Geosynchronous Earth Orbits (GEO) regions. Astrometric data obtained by the asset are used to populate the common database of the consortium. In November 2022, the Berthelot station, consisting in a 0.4 m, f/8, Ritchey–Chretien Telescope (Berthelot–T04) was upgraded with the widefield Riccardi–Honders telescope (HARET–T20) with a diameter of 20 cm and a focal length of 60 cm (f/3). The detector is an Andor Marana sCMOS camera (2048 × 2048 px) with a diagonal of 32 mm. The field of view of the telescope is $2.2 \times 2.2^\circ$ with an image scale of 3.78”/px. Even if HARET–T20 configuration is optimized for objects in medium and high orbits observations, we managed to detect the Starlink–1353 satellite (COSPAR ID: 2020–025G) in 4 consecutive images acquired in sidereal tracking mode, with an exposure time of 0.1 seconds (Figure 3). At the observation time, the satellite was orbiting the Earth at an altitude of 341 km above the surface. On a preliminary visual inspection of the images, the satellite trail exhibited no brightness variations, meaning that the spacecraft was still under altitude control maneuvers.

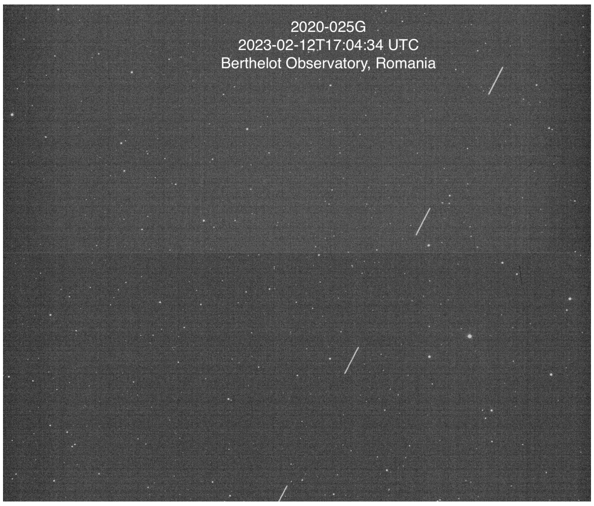

Fig. 3 – Starlink–1353 satellite images acquired with RO–HARET Telescope of Berthelot Observatory.

Based on the latest TLE published on (SpaceTrack, 2024), on February 21, 2023 at 05:56:47 UTC, we have started the orbit propagation of the spacecraft. For the re–entry prediction we used The High–Precision Orbit Propagator (HPOP) (AGI) which allowed us to consider several parameters characteristic of the satellite and the atmosphere. For the computation of atmospheric drag accelerations on the satellite, we used NRLMSISE2000 atmospheric density model, because it has a range valid between 0 to 1 000 km, the satellite A/m ratio of $0.05216\ \mathrm{m}^2 \cdot \mathrm{kg}^{-1}$ and a spherical drag model with $c_D = 2.2$. We used the satellite’s characteristics and the atmospheric parameters to compute the Latitude–Longitude–Altitude state of the object (Figure 4) in order to verify the predictions obtained using our in–house developed tool. According to the computation, the satellite started to descend below 100 km in altitude, thus the re–entry epoch resulted was February 21, 2023 at 09:55:00 UTC.

This result aligns with other predictions, for example Aerospace Corporation

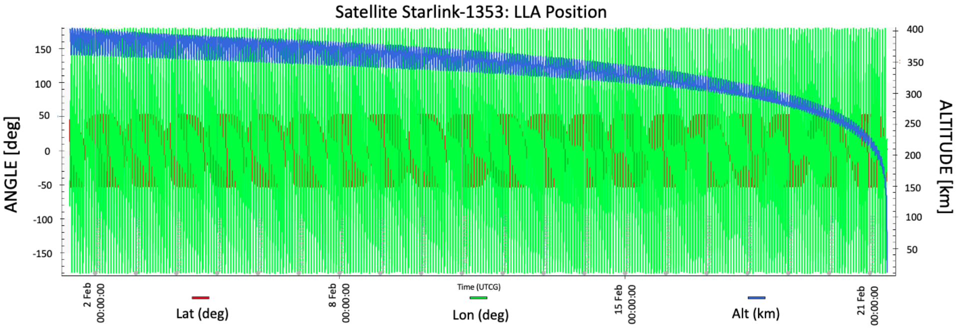

Fig. 4 – Re–entry analysis of Starlink–1353 satellite using STK software. (AGI)

obtained re–entry epoch February 21, 2023 10:28 UTC ± 1 hour (Aerospace, 2023) and with the last Tracking and Impact Prediction Message (TIP) published on (Space-Track, 2024).

In order to further explore the orbital evolution of the object, we used a numerical integrator to propagate its initial state obtained from all the available TLEs published by (SpaceTrack, 2024). TLEs cover the interval from the initial deployment of the satellite up to reentry (April 29, 2020 – February 22, 2023).

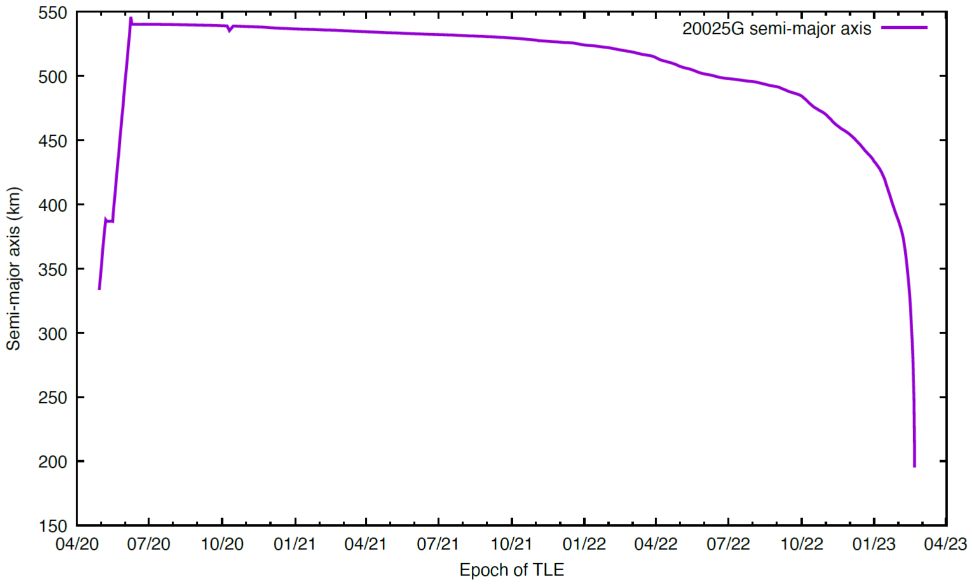

Fig. 5 – Starlink–1353 semi–major axis evolution extracted from all available TLEs.

The semi–major axis evolution leading to the orbital decay, extracted from all TLEs, is presented in Figure 5. Each initial state was propagated for 120 days, or up to the reentry, using a Runge–Kutta–Fehlberg method of order 7(8) numerical integrator with adaptive step size. The dynamical model includes the Sun, Moon, Venus, Mars, and Jupiter. The Earth gravitational potential is modeled using J2 and J3 terms. The atmosphere was modeled using a simple exponential model (Szucs-Csillik, 2017) and we used TLE's ballistic coefficient to calculate the drag force.

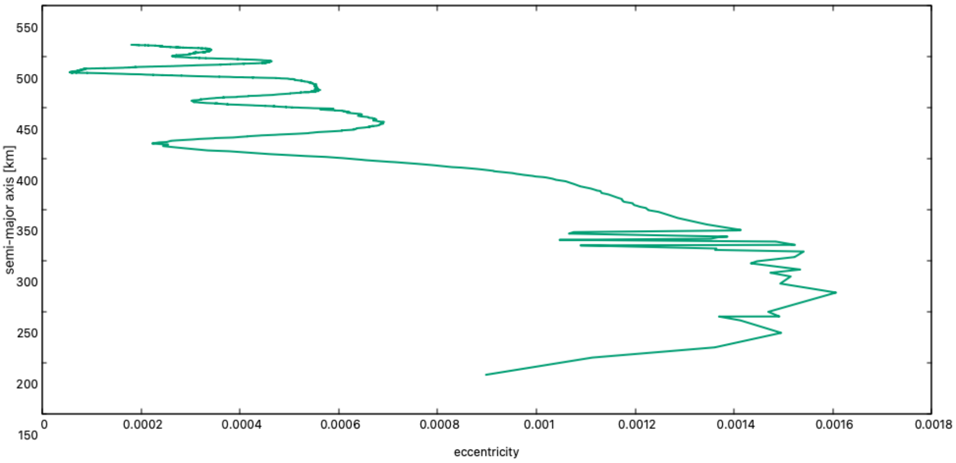

Fig. 6 – Starlink–1353 semi–major axis and the eccentricity of the orbit.

Using the satellite TLEs from its final operational year, we represented the semi–major axis and the eccentricity of its orbit. It can be seen that the eccentricity was small from the beginning of the analysis, as Starlink satellites typically operate in circular orbits. During the analyzed period, several maneuvers were performed to decrease the altitude of the satellite as it was preparing to re–enter the atmosphere. During the last day in orbit, the most significant drop in eccentricity occurred, leading to a rapid descent toward atmospheric re–entry.

The earliest TLE leading to a reentry within the 120 days timeframe was the one from October 9, 2022. We note that B* ballistic coefficient for this TLE has the highest value for October 2022 (3.73440RE–03). Starting with November TLEs, we obtained reentries dates on early 2023. All TLEs published within 10 days prior to the actual reentry indicate a reentry on February 20/21, 2023. Using the last TLE, published 5 hours before re–entry, the estimated time for re–entry is February 21, 2023 10:46 UTC. Which means a difference of approximately 20 minutes between our prediction and the real re–entry time, which can be explained by the atmospheric drag in that area and the different parameters used in the orbit propagator (HPOP), atmospheric model, satellite size, re–entry window published by Aerospace or other variables mentioned above.

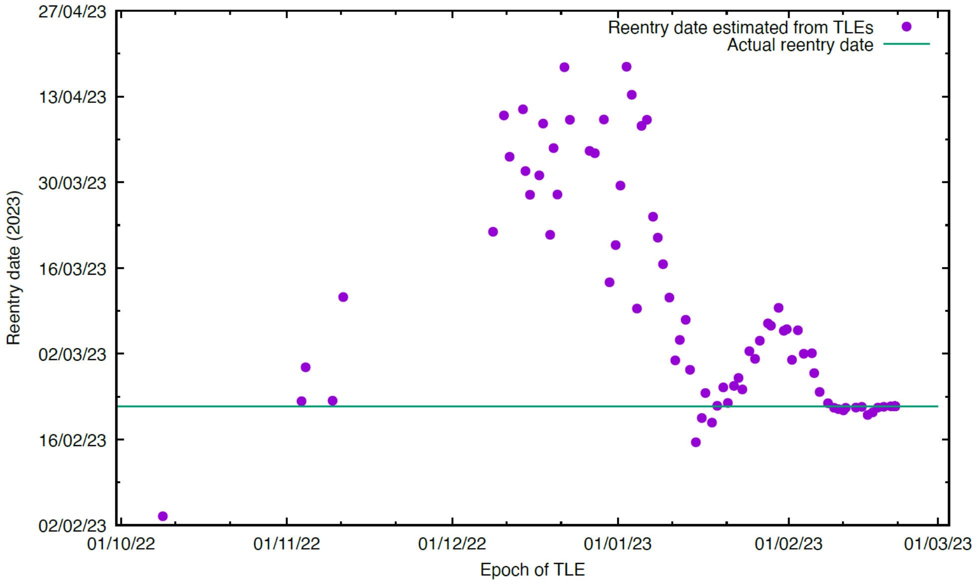

Fig. 7 – Starlink–1353 reentry date estimated from all available TLEs.

7. DISCUSSION

Even though all operators are managing and adjusting TLE, specifically to avoid dangerous situations, in the last year a few unpredictable events have happened, that carried the potential for a catastrophically outcome.

One of these critical incidents took place on February 4, 2022, when, one day after the preliminary orbit launch (210 km altitude), 38 Starlink satellites were destroyed after a geomagnetic storm, caused by a solar corona ejection, and failed to reach the Starlink constellation. The shock–wave of the solar wind interfered with Earth's magnetic field and led to a 20–30% increase in particle density in the respective altitude. The incident made it clear that accurate forecasts of the space weather and a tighter collaboration between aerospace and weather industries are important for the success of the missions (Kataoka *et al.*, 2022).

Another pointful episode happened on July 9, 2022, when a piece of a SpaceX capsule was found lodged in the ground, in a vertical position, at a farm in Snowy Mountains, Southern New South Wales. The Australian Space Agency (ASA) has inspected the fragment and confirmed it to belong to one of the SpaceX rockets launched in November 2020 (the Crew–1 mission); the fragment re–entered Earth's atmosphere at 7 AM that day, approximately 20 months after the launch (May, 2022).

A further incident that could have had serious consequences occurred on the November 4, 2022, when the first step of the Long March 5B rocket, transported a few days prior the Mengtian module of the Tiangong Chinese space station, entered Earth's atmosphere in an uncontrolled procedure, above the Pacific Ocean (D.Ramirez, 2022). This was actually one of the most hazardous and potentially dangerous re–entries of a space debris, due to the considerable mass of the fragment; the incident was highly covered in the media, all over the globe.

In the past years, information and details about such events and incidents are shared globally much faster through social media channels, particularly X, the former Twitter (information) and YouTube (video images). Gradually, Twitter has become an important real time communication vector for the science community, as its popularity among professionals and other interested audiences grew. Very often, brief announcements (tweets) are followed by extensive discussions, where hypothesis and theories are debated with arguments ranging from cold facts data to assumptions and speculations.

Therefore, a series of Twitter threads about to the Starlink–1353 re–entry were audited, verified from several sources and served as documentation for directions and work hypotheses in elaborating this paper.

This article is solely a case study based on a series of assumptions that we consider relevant and several sets of simulations. The authors acknowledge that certain aspects may have escaped them, particularly due to the fact that the satellites making up the Starlink mega–constellation are only tangentially known, as they represent a private program.

Another problem in obtaining predictable data would be collision avoidance predictions. Many times the probability simulations of the various entities that monitor the activity of the satellites in the orbits around the Earth do not coincide. An example is the event between Aeolus (ESA) and Starlink 44 (SpaceX), in September 2019. ESA requested by email the SpaceX perform a correction of the orbital parameters for the Starlink 44 satellite because there was a non–zero possibility of collision, but SpaceX refused because their monitoring software does not indicate this. ESA was forced to perform the safety maneuver to protect Aeolus, the first satellite mission to acquire profiles of Earth's wind on a global scale. This operation had the effect of unscheduled fuel consumption, so the life of the Aoelus was reduced. For this reason, it is very important to perform simulations as often as possible based on assumptions from several sources, such as our work in this article, in order to determine a plausible scenario as possible.

CONCLUSIONS

Based on the frame–by–frame analysis of the images taken by the camera mounted on the Kitasubaru Astronomical Observatory telescope, 15 fragments from the Starlink–1353 (2020–025G) were counted. Also we concluded that the camera recorded the major break–up of the satellite, when the fragments were at a height of 64.4 km, according our plausible scenario. Also we determined that the descending phase after re–entry was into direction South–East, above Hokkaido Island.

The re–entry phase of Starlink–1353 was entirely controlled by the operator with an inclination angle 52.9°. If the re–entry phase had been uncontrolled, and the inclination angle close to the zero value, the major break–up would likely have occurred at a much lower altitude, if it occurred at all, according to a few of simulations.

Following the analysis with Debris Assessment Software (NASA) we can conclude that in the plausible scenario a consistent mass of the satellite disintegrated as a result of friction with the atmospheric layers. The fragments that survived the major break–up, estimated to have occurred at an altitude of 64.4 km, continued their descendent trajectory, some of them being completely disintegrated afterwards. Thus, at an altitude of 50.9 km, the cables were completely melted, the same thing being noticed in the case of the solar panel elements, but at a lower altitude of 14.5 km. The rest of the fragments arrived in the North Pacific Ocean, according to our estimates, they were scattered over an area of about 15.12 m^2.

We consider that our results obtained are conclusive, and they are correlated with the video images recorded by the Kitasubaru observatory, which confirms that our assumptions can be classified as plausible. After validating the plausible scenario we could draw the conclusion that the cumulative mass of the fragments that reached the North Pacific Ocean are rather insignificant, the notable impact being the pollution with alumina (small amounts) of the upper atmosphere, a result of the burning of the components made of aluminum during the first steps of re–entry.

In order to obtain the most reliable results, we also performed a dynamic analysis of the trajectory of Starlink–1353, as well as testing the routines developed by AIRA. The simulation on the satellite dynamics during the pre–entry phase is robust using several algorithms and routines, and very close in time and dynamical parameters with the values of the re–entry phase.

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