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Hazardous Asteroids and Space Situational Awareness – Do Look UP !

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Abstract. We present in the following the introductory talk on "Hazardous asteroids and the Hera mission", made during the round table on Space Awareness. It reminds the context of our awareness for near-Earth objects, the characterisation of risk, current international surveillance programmes, and mitigation measures in particular with space missions, and last, a *rendez-vous* with Apophis to note in your agenda for 2029.

Keywords. Asteroids, Space Situational Awareness, DART, Apophis

1. Some examples of asteroid impacts

Near-Earth Objects are asteroids and comets orbiting in the vicinity of the Earth, defined more precisely by a perihelion distance of less than 1.3 astronomical unit. NEOs, as for asteroids, are of general scientific interest and typically present no threat to Earth. Nevertheless we have numerous records on astronomical/geological time scales of asteroids impacts, with craters present on the surface of the Earth and other planetary bodies in the Solar System. At the beginning of the 20th century, the Tunguska event didnt provoke a crater, but a vast zone of Siberian land was devastated by a supposed blast from the hypervelocity entry of a celestial object. The international asteroid day, now held every June 30th, is an anniversary of this event.

Closer in time, additional events are also hitting the head-lines of our present time news and media. One example is the impact of comet SL9 fragments on the gas-giant Jupiter in July 1994, about 30 years ago†. Infrasound and optical monitoring of bolides entry show that many meter-sized objects are entering our atmosphere, sometimes hitting the ground and ending as meteorites exposed in our museums of natural history. Or sometimes hitting a car trunk, like in 1992 Ms. Michelle Knapp's Chevy in the USA‡.

Last, I will finish this short and very limited introductory inventory by the event of February 2013 in Chelyabinsk, Russian Federation. A little less than 20 meter large asteroid unpredictably entered the atmosphere at a speed of approximately 19 km/s; Its catastrophic disruption at 30km altitude generated a bright light and a blast on ground early morning over the city of Chelyabinsk. Some constructions were damaged from the high pressure blast, many building windows were broken, and about twelve hundreds people were injured mostly from glass breaking in their face, burns, and falls, with nevertheless no direct fatalities. The overall cost of the damages was estimated to more than thirty million euros.

† Let us pretend that it is recent event, since I was writing my PhD manuscript at that time !
‡ Presently in France, in this beginning of July 2023, asteroid/meteorite falls are not the largest threat to cars

2. Is there a risk?

Among the Near-Earth Objects, a class named Potentially Hazardous Asteroids (PHAs) can get closer to Earth, with an inter-orbit distance (MOID) of less than 0.2 Lunar distance. Those NEO asteroids show many similarities with space debris situational awareness presented just before by Dr. Aaron Rosengren: In tracking, detecting, monitoring, orbit computation, orbit & uncertainty propagation, risk assessment, and avoidance manoeuvres... I will not repeat them here, or point the differences and necessary adaptations. Our common dictionaries define risk as "a situation involving exposure to danger" or "the possibility that something bad or dangerous will happen". A more physical standardised view of risk (although not unique!) combines the likelihood and severity of a hazardous event.

Are we at risk of an asteroid impact? Yes, indeed, as it was in the recent past. Thus, asteroid impact risk is the product of the frequency of an impact event with its cost or our vulnerability to such impact. Tiny pebbles hitting the Earth on millennium scales is zero risk, while big killer-asteroids hitting the Earth every decade is a very-very high risk!... Of course these are unrealistic hypothetical illustrative cases. With asteroids originating from a dynamically collision population, the size distribution of NEOs is such that we are actually in-between those extreme situations. Some 50-80 tons of extraterrestrial material are falling on Earth every day, as small mostly micro-meteorites and dust, still totally harmless.

3. Know your enemy, near Earth Asteroids surveys

So, astronomers started to look for the largest NEOs, larger than approximately 1 km, to assess their impact probability, before looking for those of most probable risk. Lets remind that this population of Near-Earth asteroids—with the first one (433) Eros discovered in 1898—was still mostly unknown at the end of the '90s. One key element here is the detection of PHAs, and we now have curves of detection rate from dedicated surveys showing that almost all asteroids larger than approximately 1 km have been catalogued. Moreover, their orbits present no impact risk in the coming Century hence no major catastrophic mass extinction event is foreseen in the near future. On the other side of the (size-) detection spectra, we have presently a record of seven imminent impactors. These are generally small (1-5 meter sized) harmless† asteroids, discovered in space less than 24 hours before their predicted entry in the atmosphere. The last in date—asteroid 2023 CX1 in February this year discovered in space with a T1m Schmidt telescope in Hungary—did a luminous bolide seen and recorded by many observers that were alerted of the entry. The asteroid ended its course in France Normandy, making many colleagues happy with several meteorites collected now at the museum of natural history MNHN in Paris, France. The rate of such imminent impactors detection should increase in the future with current and new dedicated surveys (from ground and space).

The situation is still not favourable for intermediate size objects, showing risks at regional/continental level, the next goal is to detect more than 90% of objects larger than approximately 140 m (or say absolute magnitude $H < 20$). In fact, only 50% of NEOs capable of doing regional/continental damages have been discovered so far. Surveys—mostly driven by the USA—presently detect about 3000 new NEOs per year, with a total cumulative number of 36,000 NEOs end August 2023. Keeping in mind that the 10,000th NEO was discovered mid-June 2013, we see the progress made in just ten years. This rate of detection and catalogue completion will even considerably increase, thanks

† Or a priori harmless : in contrast to the micro-meteorites, some decimeter large meteorite might hit a car trunk, construction roof, animal or part of a human body, as recorded in the past.

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to the venue of the ground-based Vera Rubin Telescope LSST survey in 2025, and future NEO-surveyor space mission: if we are looking for them... we'll get them !

4. Mitigation of a threatening NEA

Many activities are hence devoted to detections, surveys, and catalogue completions. These are completed by orbit and uncertainty computations, with risks assessment (see for instance CNEOS at NASA/JPL or NEOCC at ESA) and international coordination through UNOOSA. Now, would we face a real threat of a future impacting event much larger than the small imminent impactor, one would need to put in place mitigation measures. For 1/ a very dangerous impact, i.e. with major effects on ground (from blast, or impact crater, or tsunami), and 2/ with enough warning time, a mitigation in space is the most likely option. The aim of such mitigation mission is to slightly modify the asteroids orbit. A so-called kinetic impactor will transfer a small amount of linear momentum, preferably along the motion. With this principle, the asteroids orbital period is modified, so that the future collision can be avoided, even if the trajectories still intersect. Several studies have analysed the mitigation scenario; at the European level we can mention NEOshield 1&2, Stardust 1&R, and NEOmap.

5. The DART mission

In addition to these research works and risk assessment, one needs to ensure that all steps of a risk management chain can be mastered. In particular the space mission for the mitigation process. The role of the Asteroid Impact and Deflection Assessment (AIDA) collaboration is to probe the kinetic impactor mitigation technique – starting with the Double Asteroids Redirection Test (DART) mission. It is a test on real scale, to measure the linear momentum imparted to an asteroid through the change in the orbital period of the Didymos/Dimorphos binary systems relative orbit. It mimics all aspect of a real mitigation mission that would change the heliocentric orbital period, while the sensitivity of momentum transfer is much higher on the relative orbit. A 600 kg probe was launched en-route toward the moon Dimorphos which it impacted on November 2022. The mission was a great success hence validating the kinetic impact as planetary defence option. Results of the collision were impressive with autonomous targeting of a 160 m large target at 6 km/s speed, an ejecta plume observed by cubesat LiciaCUBE, a large beta factor momentum enhancement, and a significant change of the orbital period, ... "This marks humanitys first time purposely changing the motion of a celestial object and the first full-scale demonstration of asteroid deflection technology" says NASA's PR. More insight will be given on the craterisation and the secondarys mass thanks to the follow-on mission Hera that will visit the asteroid end 2026, so stay tuned.

6. Rendez-vous with Apophis 2029

Last, let me invite you to take a rendez-vous with the near-Earth asteroid (99942) Apophis. This PHA will have a close encounter with the Earth, at a distance below the altitude of our geostationary satellites 36,000 km. It is not the first time a NEO gets very close to the Earth, but Apophis is approximately 400 m large in size, large enough on that occasion and distance to be visible by naked eye (during night in Europe and part of Northern hemisphere). The rendez-vous date is on 2029 April, 13, a Friday !..

7. A final note

I have made a reference in my presentations title to the recent box-office movie "Dont look UP" (Adam McKay dir., 2022) which scenario is explicitly based on such an impact threat, and another reference to an older issue of the Italian magazine Domenica del

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Corriere (21 August 1966). The cover page of this magazine titled "La fine del Mondo non ci sara" shows a comet miraculously missing its impact over Rome. Moreover, and of special interest to us, there is an article of a young high-school student that just got a national award: this teenager is Andrea Milani (1948–2018); one of Heras cubesat is named in his honour.

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