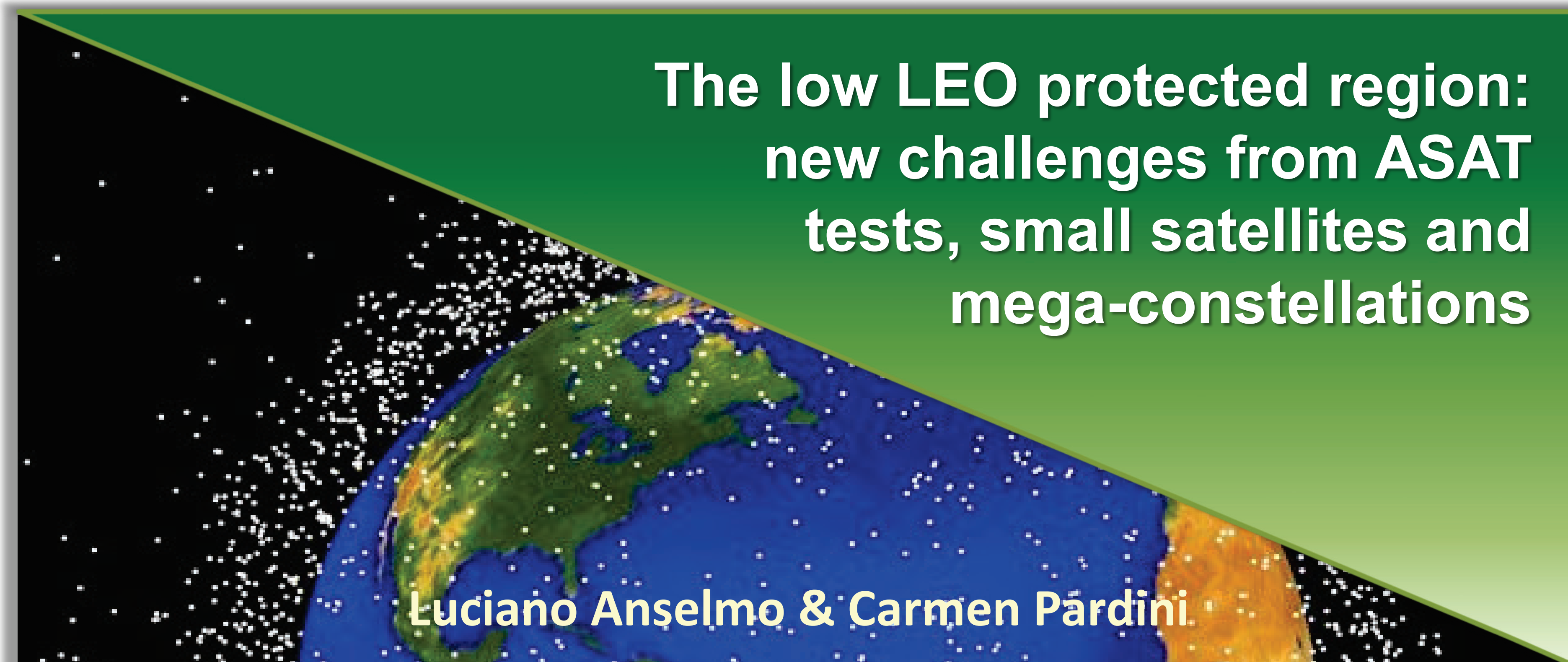
IAA ITALIAN REGIONAL SYMPOSIUM ON SPACE DEBRIS OBSERVATIONS FROM BASILICATA



The low LEO protected region: new challenges from ASAT tests, small satellites and mega-constellations

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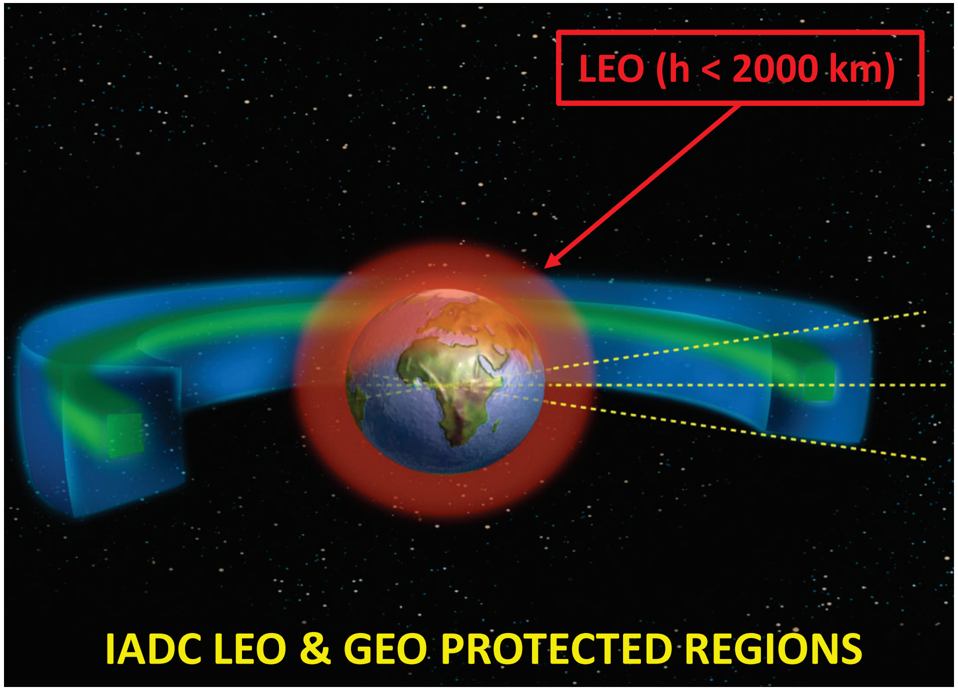
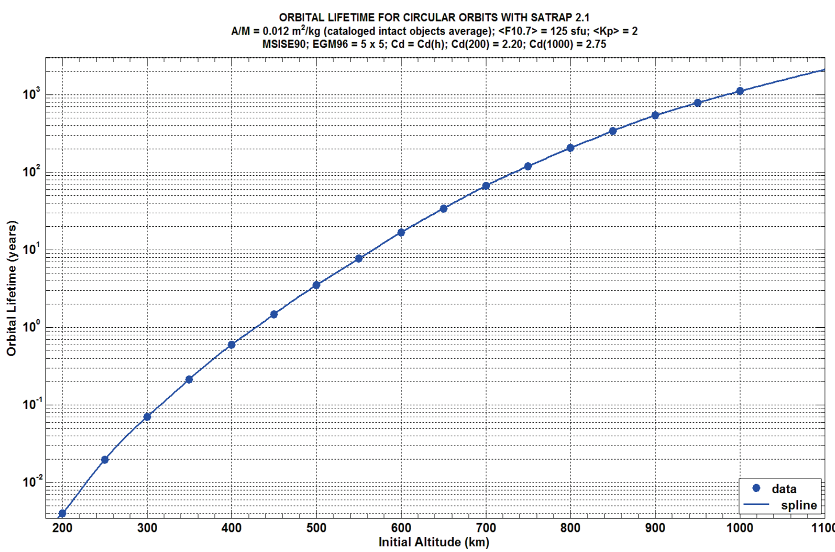
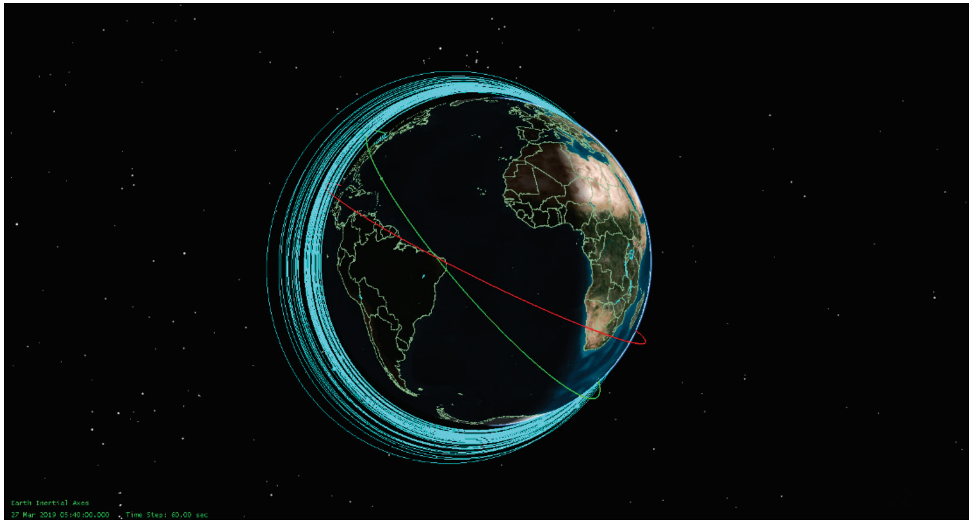
Introduction





- Since the definition of a Low Earth Orbit (LEO) protected region, at the beginning of the 2000s, most of the attention of the space debris mitigation community was focused on heights greater than 600 km (impact on long-term evolution, 25-year IADC residual lifetime rule)
- Above 600 km, in fact, the average residual lifetimes of inert satellites and rocket bodies become typically higher than 20 years and the highest concentrations of functional satellites and cataloged space debris are found, specifically between 600 and 1000 km (2.0×10^{-8} km^{-3} $\leq \rho \leq$ 5.6×10^{-8} km^{-3}), and between 1400 and 1500 km (0.8×10^{-8} km^{-3} $\leq \rho \leq$ 1.4×10^{-8} km^{-3})
- The low LEO region, below 600 km, even though currently characterized by lower cataloged object densities ($\approx 6 \times 10^{-9}$ km^{-3}, on average) is however extremely important for space applications
- In fact, since the last Apollo mission to the Moon, in December 1972, all human spaceflight was carried out there, the International Space Station (ISS), the planned large Chinese space station and the Indian crewed program are making and will make use of this region of space, and also absolutely critical scientific missions, like the Hubble Space Telescope (HST), are orbiting below 600 km

New challenges

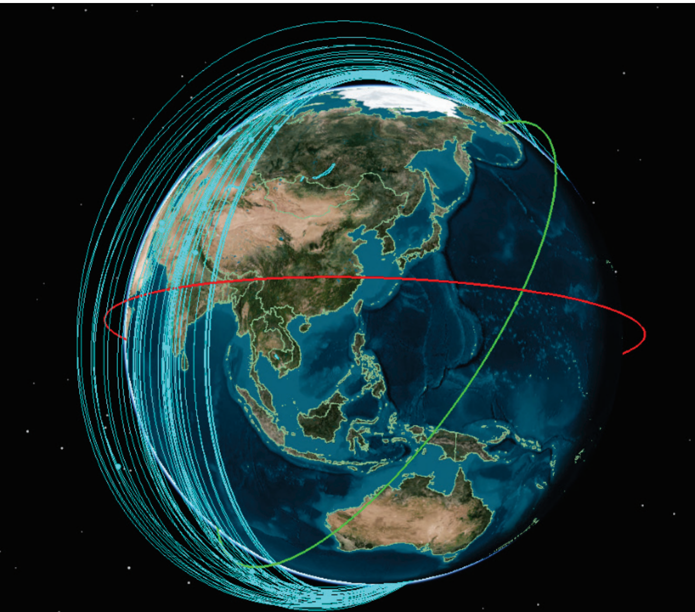


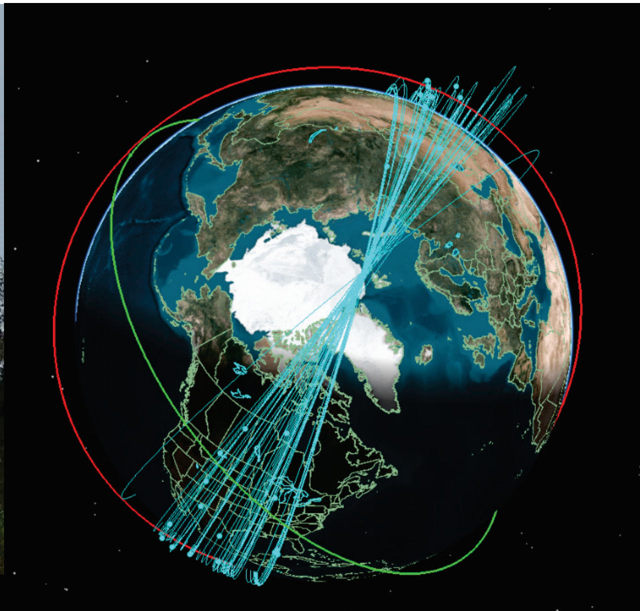
Indian ASAT debris cloud on 27 March 2019

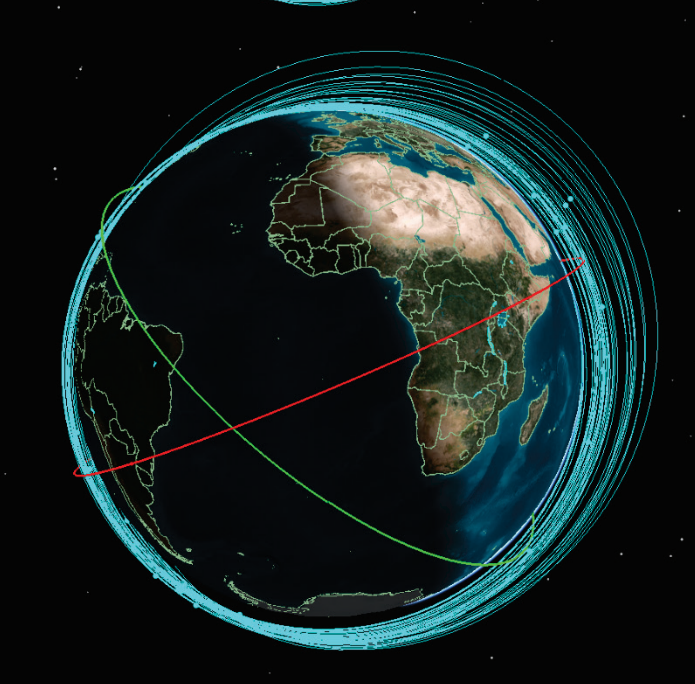
Starlink satellites before the deployment

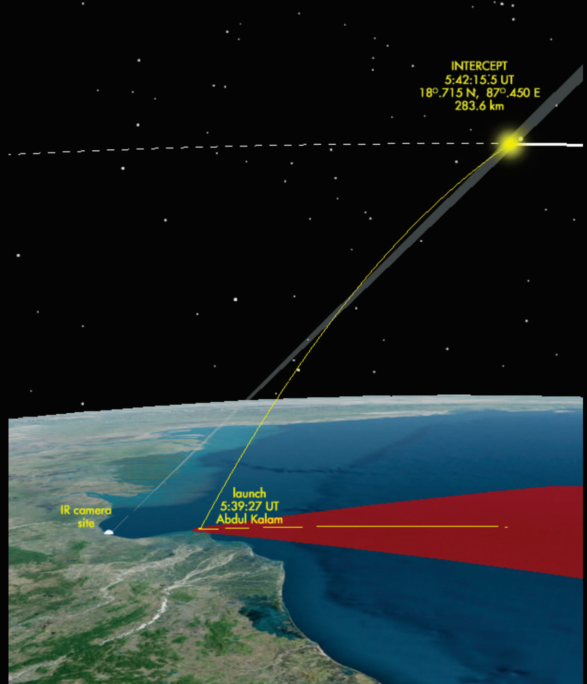
- The Indian ASAT test carried out on 27 March 2019, destroying the Microsat-R spacecraft at the altitude of about 300 km, produced several tens of cataloged fragments crossing the altitude of the ISS, and at least one year will be needed to have the situation coming back to the pre-test conditions, due to the low minimum of the solar activity cycle
- In recent years there was a dramatic increase in the launch rate of small satellites and cubesats in low LEO, boosting the number of potentially risky objects to be tracked and monitored
- But the most worrying development currently going on is the recent (26 April 2019) decision by the US Federal Communications Commission (FCC) to grant SpaceX permission to deploy the first segment of the company's Starlink mega-constellation broadband network into much lower orbits than originally planned
- The regulatory commission, in fact, approved the SpaceX proposal to fly more than 1500 of its Starlink satellites at an altitude of 550 km, with an inclination of 53 degrees, instead of the 1150 km originally planned
- The first 60 Starlink satellites were launched on 23 May 2019 and after five weeks 5% had already failed, 8% were still undergoing tests in their initial orbits and 8% were raising their altitude

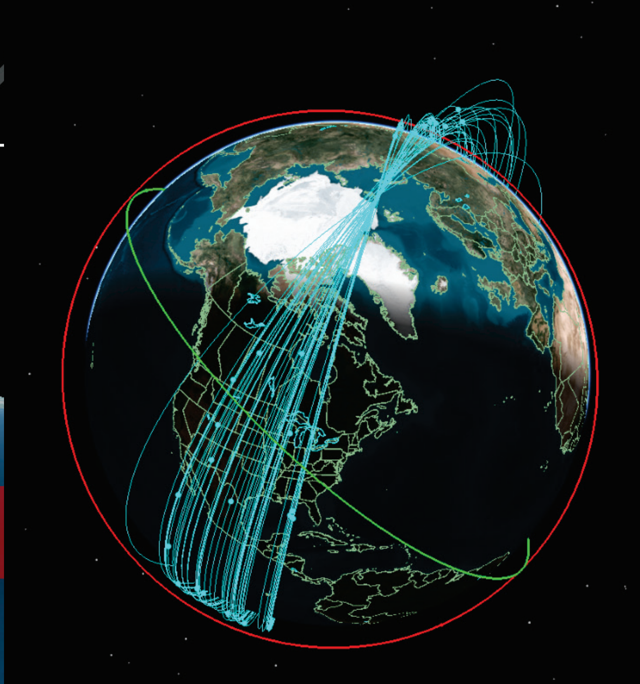
Indian ASAT debris cloud on 27 May 2019



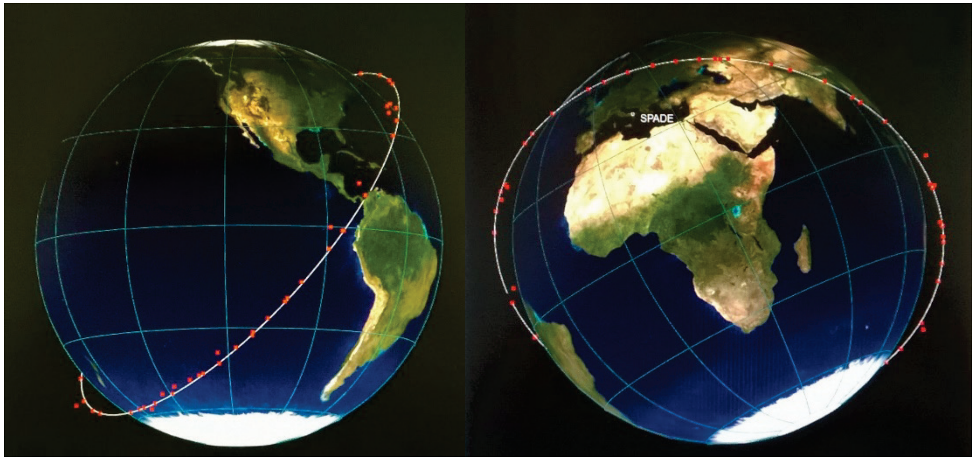


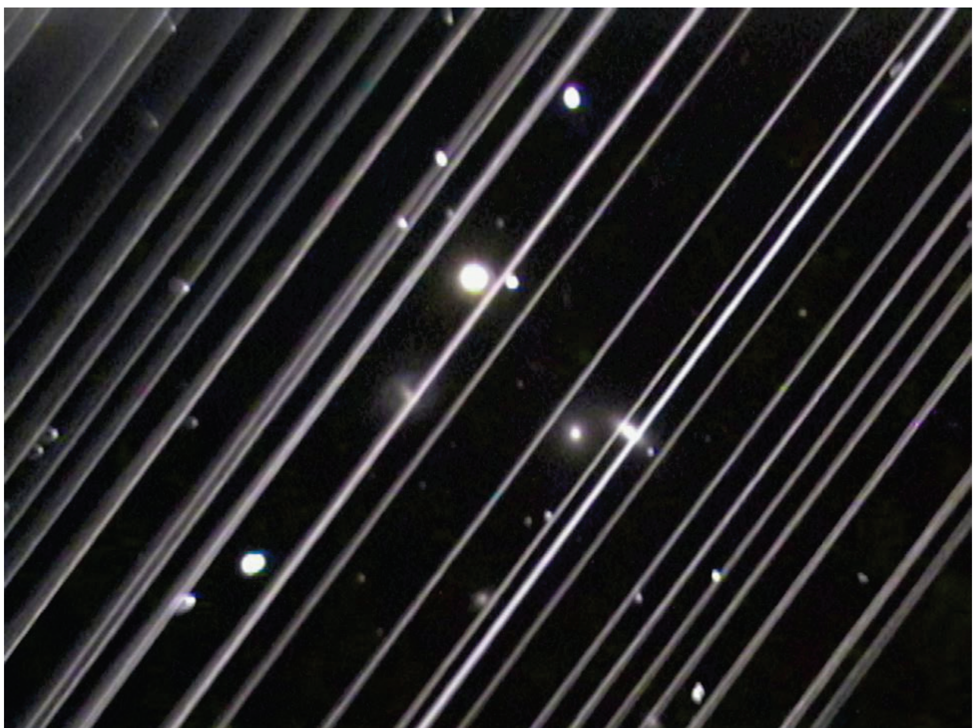






The impact of the Starlink satellites



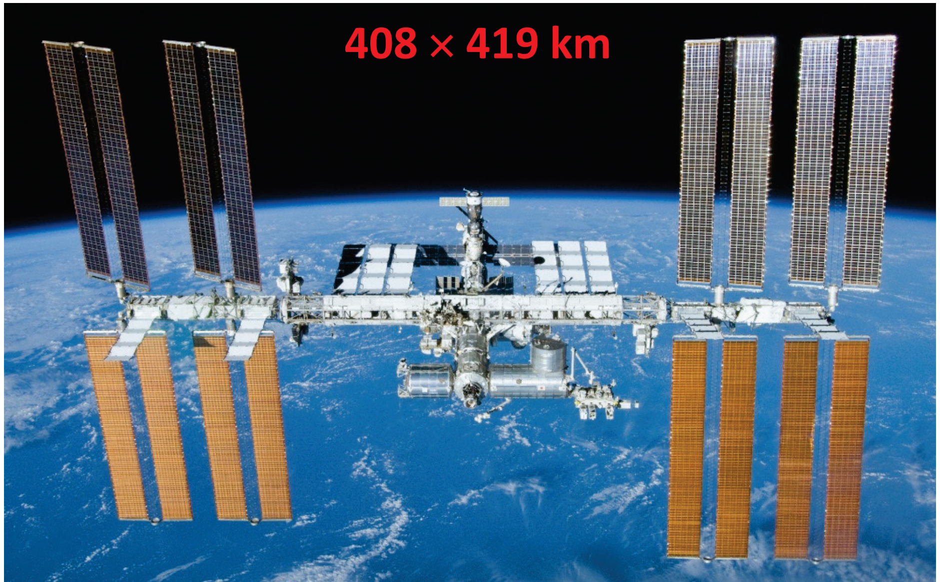


- Even though any failed satellite of the planned mega-constellation will decay from orbit in less than 25 years, therefore formally complying with international space debris mitigation guidelines, it is realistic to expect a relatively high number of failures, considering the experimental nature of spacecraft tested in space, and in great numbers, for the first time
- The short and medium term consequences for the HST, orbiting just 10 km lower and basically non-maneuverable, and for the ISS, just to take a couple of extremely valuable and high priority spacecraft in low LEO as an example, will be probably far from negligible
- An image of the NGC 5353/4 galaxy group made with a telescope at Lowell Observatory, in Arizona, on the night of 25 May 2019, gives a visual representation of some of the problems to be faced by astronomers in the coming years
- The diagonal lines running across the image are trails of reflected light left by more than 25 of the 60 recently launched Starlink satellites as they passed through the telescope's field of view
- On 8 June 2019, at the 234th meeting of the American Astronomical Society (AAS) in St. Louis, Missouri, the AAS Board of Trustees adopted a position statement on satellite constellations

AAS statement on mega-constellations

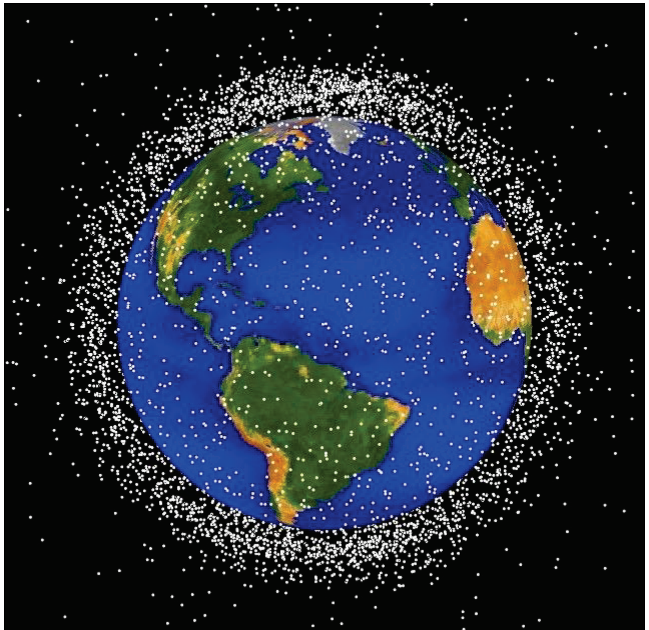
- «The American Astronomical Society notes with concern the impending deployment of very large constellations of satellites into Earth orbit. The number of such satellites is projected to grow into the tens of thousands over the next several years, creating the potential for substantial adverse impacts to ground- and space-based astronomy.
- These impacts could include significant disruption of optical and near-infrared observations by direct detection of satellites in reflected and emitted light; contamination of radio astronomical observations by electromagnetic radiation in satellite communication bands; and collision with space-based observatories.
- The AAS recognizes that outer space is an increasingly available resource with many possible uses. However, the potential for multiple large satellite constellations to adversely affect both each other and the study of the cosmos is becoming increasingly apparent, both in low Earth orbit and beyond.
- The AAS is actively working to assess the impacts on astronomy of large satellite constellations before their numbers rise further. Only with thorough and quantitative understanding can we properly assess the risks and identify appropriate mitigating actions.
- The AAS desires that this be a collaborative effort among its members, other scientific societies, and other space stakeholders including private companies. The AAS will support and facilitate the work by relevant parties to understand fully and minimize the impact of large satellite constellations on ground- and space-based astronomy.»
- In the 1970s and in the 1980s (consider, for instance, the original *raison d'être* of the COSPAR Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS)), among the main concerns raised by space activities there were the adverse consequences for ground- and space-based astronomy, from satellite trails crossing the fields of long exposure photographic plates, still used by ground observatories, to space nuclear reactors disturbing the gamma ray detectors of astrophysical spacecraft
- Since mid-1980s, the space debris problem overshadowed the impact on astronomy, but the advent of mega-constellations, in particular in low LEO, could bring back again the negative consequences on the observation of the sky at the center of the scene

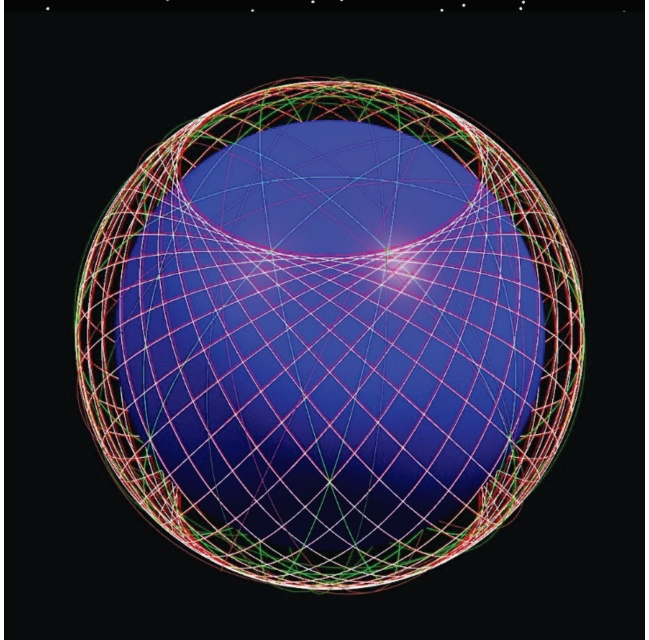
Cataloged objects below 600 km



- At the end of 2010 there were ≈ 920 cataloged objects below 600 km
- On 20 June 2019, i.e. approximately 9.5 years later, this number has become ≈ 1647
- The increase over the last 9.5 years was around 79%
- The objects below 600 km represent (on 21 June 2019) about 8.4% of the cataloged objects in orbit around the Earth
- Space activity and launch patterns are changing just now: since 2014 there was a dramatic surge in the launch of cubesats and small satellites, many of them below 600 km
- From 1 January 2018 to 21 June 2019, 363 satellites were launched and are still in orbit
- They represent more than 22% of all the cataloged objects below 600 km
- They should be compared with the 93 cataloged debris produced by the Indian ASAT test, of which 49 were still in orbit on 21 June 2019 (< 3% of the cataloged objects below 600 km)
- Moreover, from 1 January 2018 to 21 June 2019, i.e. in less than 18 months, India alone launched 95 small satellites below 600 km for several countries
- This number was comparable with the debris produced by the ASAT test, but with significantly higher lifetime

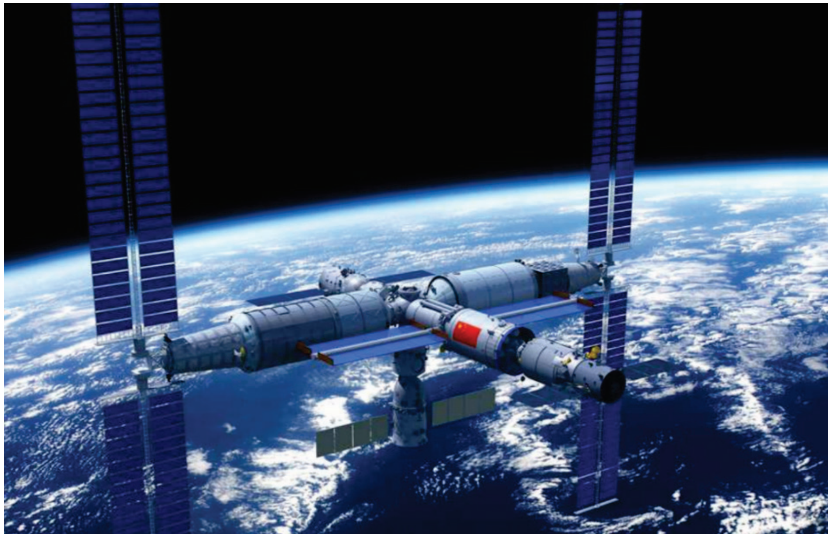
Average conjunction rate





- Order of magnitude estimation with the particle-in-the-box approach
- In a given volume of space *V*, the average rate of close approaches, within a given distance *d*, among all the objects filling the same volume, is proportional to $\sim \rho^2 \cdot V \cdot V_R$, where $V_R \sim 10$ km/s is the average relative velocity among the objects
- Below 600 km, the overall conjunction rate, within a given distance, is still ~ 16 times less than between 750 and 850 km, where the object density is currently maximum
- Presently ~ 10,000 conjunctions with $d < 1$ km should be expected in one year, below 600 km, and ~ 100 with $d < 100$ m
- Between 750 and 850 km, the corresponding numbers are ~ 160,000 conjunctions with $d < 1$ km and ~ 1600 with $d < 100$ m
- The situation below 600 km is therefore still manageable, but it could get worse quickly if the growth of small, micro- and nano-satellites will proceed unchecked and substantially unregulated
- In particular, special attention should be paid to the evolution of human space activities in low LEO, in order to avoid adverse operational consequences on space operations (e.g. too frequent collision avoidance maneuvers) and safety (e.g. catastrophic collision risk)

Human space activities in low LEO



- Circular orbits below 550 km are particular attractive for human spaceflight
- Even if still very close to the Earth's surface, are in fact just on the border of the deep "energy well" or "barrier" that each payload must exceed to reach space from our planet
- In energetic (or ΔV) terms, a low Earth orbit is further from the surface of our planet than it is from the surface of the Moon or Mars
- Orbits below 550 km guarantee a good protection from solar and cosmic radiation, due to the shielding effect of the magnetosphere, and avoid most of the South Atlantic Anomaly (SAA), i.e. the low point of the inner Van Allen belt
- Orbits above 300-350 km allow the practical compensation of atmospheric drag for sufficiently long periods of time
- These and several other reasons, some including safety aspects as well, concur in making the region below 550 km very attractive for human spaceflight and human-tended activities
- In addition to the ISS and Tiangong operations, the coming years will see a new large Chinese space station, the debut of the Indian crewed spacecraft, and several private companies active in orbital and sub-orbital operations, human-tended facilities and habitable modules
- A better attention to this important region of space is therefore well deserved to leave all the possibilities of human access to space open

Conclusions

- About 15 years ago, Mikhail Yakovlev, of the Russian delegation, proposed to the IADC the creation of a special "human spaceflight protected region" below 550 km
- The proposal was motivated by the accurate prediction of a dramatic surge in the launch rate of small satellites and cubesats in such volume of space
- Unfortunately, the large majority of the IADC delegations rejected the suggestion, mentioning, among other things, the expected progresses in tracking and conjunction assessment as a way to offset the increase of small satellites
- We are now at a juncture of dramatic changes, transitioning from hundreds of new objects launched every year to thousands of objects
- Even though the total mass will remain basically comparable, increasing by one order of magnitude the number of objects injected in LEO will result in detrimental effects on the orbital debris environment if the satellite reliability will remain at current levels
- Below 600 km, even though the present situation is still manageable, a very fast degradation might be possible, adversely affecting either human spaceflight and, possibly, the observation of the sky from the Earth
- A new, strong and wide traffic management initiative is therefore necessary to focus the attention on the preservation of the orbital region below 550 km for safe, sustainable and efficient human spaceflight