

Concerns about ground based astronomical observations: A STEP TO SAFEGUARD THE ASTRONOMICAL SKY

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Abstract

This article aims to highlight the impact for ground based astronomical observations in different windows of the electromagnetic spectrum coming from the deployment of fleets of telecommunications satellites.

A particular attention is given to the problem of crowding of circumterrestrial space by medium/small size orbiting objects. Depending on their altitude and surface reflectivity, their contribution to the sky brightness is not negligible for professional ground based observations. With the huge amount of about 50,000 new artificial satellites for telecommunications planned to be launched in Medium and Low Earth Orbit, the mean density of artificial objects will be of >1 satellite for square sky degree; this will inevitably harm professional astronomical images.

Only one of these project, Starlink@SpaceX's, was authorized by US Federal Communication Commission, F.C.C. and plans to deploy about 42,000 not geostationary satellites, which will shine from the 3rd to the 7th magnitude in sky after sunset and before sun dawn.

All satellites will leave several dangerous trails

in astronomic images and will be particularly negative for scientific large area images used to search for Near Earth Objects, predicting and, eventually, avoiding possible impact events. Serious concerns are common also to other wavelengths eligible for ground based investigation, in particular for radio-astronomy, whose detectors are already saturated by the ubiquitous irradiation of satellites communication from Space stations as well as from the ground. Not to exclude the significant increase in the risk of hitting into the "Kessler syndrome" scenario with the deployment of all of these satellites.

Understanding the risk for astronomical community, a set of actions are proposed in this paper to mitigate and contain the most dangerous effects arising from such changes in the population of small satellites. A dedicate strategy for urgent intervention to safeguard and protect each astronomical band observable from the ground is outlined.

Keywords: Satellites constellations, ground based astronomical observations, ground based radio astronomy.

1 Introduction

The deployment of large fleets of small satellites planned or ongoing for the next generation of global telecommunication networks can severely harm ground based astronomical observations.

For centuries ground based astronomical observations have led to exceptional progresses in

our scientific understanding of the Laws of Nature. Currently, the capability of ground based astronomical instrumentation is endangered by the deployment of satellite fleets of unprecedented size.

Astronomers all over the world are concerned for the sky coverage and light/radio pollution produced by artificial satellites, which represent a dramatic degradation of the scientific content for a huge set of astronomical observations.

The same concerns have been expressed by the **International Astronomical Union, IAU** [1] and other institutions since the sky degradation is not only due to light pollution in the sky near cities and the most populated areas, but it is also due to large artificial satellite fleets crossing the sky producing bright parallel streaks/trails at all latitudes.

This paper is organized as follow: section 2 describes the substantial and complementary characteristic between ground based astronomical facilities and those in orbit; satellite constellations are introduced in section 3; section 4 illustrates how such constellations may affect ground based observations; section 5 is devoted to discuss possible mitigations; conclusions are in section 6.

2 Ground Based and Space Based Astronomy

The advent of space based astronomy (i.e. UVES, HST, Spitzer, Herschel, Planck to cite just some of well known space telescopes) did not dismiss ground based astronomy. On the contrary ground based astronomy and space based astronomy complement each other. Without ground based observations most of current space based astronomy would be useless or impossible. The reasons for this statement are shortly outlined below.

The effort of developing, deploying and operating a space based telescope is bigger, even of more than an order of magnitude, than the effort required for a ground based telescope of

similar size (quantified by the diameter of its main mirror). As an example it took more than twenty years to develop the next large space telescope, the JWST planned for launch in 2021, with a 6.5 meters mirror at the cost of the order of ten billions euros. In the meantime the VLT, with four giant 8.2 m telescopes, two Magellan telescopes with 6.2 meters mirrors, and other telescopes of similar size entered in service. The next generation of new giant ground based telescopes as the GMT with a 25.5m mirror, the ESO/eELT with a 39m mirror is expected to be putted online in about half the time required for the JSWT and with a cost of about one billion euros per telescope.

As the ability of a telescope to reveal small, weak, far objects increases with the area of its mirror which collects light, the sensitivity of a telescope increases with the square of its diameter. So in ideal conditions, the eELT will be able to collect thirtysix times the amount of light collected by the JWST.

Compared to a ground based telescope, a space based telescope has the strong advantage of observing the sky outside the Earth atmosphere. In some bands, as an example the X rays, the Far UV or the far IR, the atmosphere blocks completely the incoming radiation. So that a ground based telescope in those bands would be completely blind or severely limited, but this is not true in other bands. As an example: in visible light our atmosphere is quite transparent, so that to observe in visible light from space is of little advantage with respect to the case of observing from ground, save for the disturbance introduced by atmospheric turbulence. However this last problem has been largely mitigated in the last decades through a careful selection of the sites where telescopes are installed, and by the adoption of technological innovations such as the adaptive optics.

A major limitation of space based telescopes is that they can not be maintained, refurbished or repaired after launch. In this respect HST has been a ‘unicum’ that hardly will be possible to repeat. The obvious consequence is that the operational lifetime of such telescopes is lim-

ited by the amount of consumables which can be stored onboard (example coolant for the instruments) and by the resilience of the instruments to the degradation induced by ageing, radiations, micro meteoroids and so on. Compared to ground based observatories, the average life-time of space based telescopes is of the order of a couple of decades or less. On the contrary ground based observatories lasts for several decades, with telescopes installed at the beginning of the space era again working in a profitable manner. Being impossible to replace its components, space based telescopes suffer technological obsolescence when compared to ground based observatories. In general space based telescopes are too expensive to be used to validate new observing technologies, which usually are developed on ground based telescopes first.

There are strong limitations on the mass, the size, the technology which can be sent in space, putting severe constraints on designing and operating space telescopes. On the contrary, we are virtually allowed to plan as large a ground telescope as we want, provided it will not break under its own weight, it will be of practical use, and its cost will be sustainable.

Before to conclude it is important to stress that the arguments presented above have not to be misused or misinterpreted as arguments against space based astronomy. On the contrary in the modern professional practice both kinds of astronomy are equally important, so that astronomers involved in ground based astronomy are often involved in space based astronomy and vice-versa. Our aim is to disprove the quite common misunderstanding that ground based astronomy can be dismissed because of the advent of space based astronomy.

3 What are Satellites' Constellations

Over the past decades, considerable effort has gone into designing, building, and deploying

satellites for many important purposes. Recently networks, known as satellite constellations, have been deployed and are planned in ever greater numbers mainly in low-Earth orbits for a variety of purposes, including providing communication services to underserved remote areas. Until 2019, the number of such satellites was below 200, but that number is now increasing rapidly, with plans to deploy potentially tens of thousands of them. If no action will be put in place, several problems will soon arise in Astronomical observations.

3.1 The Iridium Satellite Constellation

The Iridium satellite constellation provides L-band voice and data information coverage to satellite phones, pagers and integrated transceivers over the entire Earth surface. The band used to provide communication services are proper of LTE-Advanced and UMTS/HSDPA services and operates from 1452 to 1492 MHz.¹

The constellation consists of 66 active satellites in orbit, required for global coverage, and additional spare satellites to serve in case of failure. Satellites are in Low Earth Orbit, LEO at a height of approximately 781km and inclination of 86.4°. Orbital velocity of the satellites is approximately 27,000km/h. Satellites communicate with neighboring satellites via Ka band inter-satellite links. Each satellite can have four inter-satellite links: one each to neighbors foreground and afterground in the same orbital plane, and one each to satellites in neighboring planes to either side. These satel-

¹In Europe, the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) has harmonized part of the L band (1452–1492 MHz), allowing individual countries to adopt this spectrum for terrestrial mobile/fixed communications networks supplemental down-link (MFCN SDL). By means of carrier aggregation, an LTE-Advanced or UMTS/HSDPA base station could use this spectrum to provide additional bandwidth for communications from the base station to the mobile device; i.e., in the downlink direction.

lites will cover an entire orbit around the Earth within roughly 100 minutes.

3.2 The SpaceX Starlink Constellation

The US company SpaceX plans to put in orbit a very huge constellation of 42,000 satellites, called Starlink. This constellation is aimed to provide internet access. These satellites work in conjunction with ground trans-receiver stations. A small set of Starlink satellites is planned to be dedicated to military airforce [26] and/or research purposes. This satellites fleet will be displaced in three orbital shells:

1. about **10,000** satellites at 1150-kilometers-altitude orbit shell using the Ku band (from 12 to 18 GHz) and Ka bands (from 26.5 to 40 GHz).
2. about **6,000** satellites in a 550-kilometer-altitude orbit shell, using the same Ku and Ka bands.
3. about **26,000** satellites in a 340-kilometer-altitude orbit shell using the V-band (from 40 to 75 GHz).²

The first phase of deployment will put in orbit first the 550km-altitude satellites, then those at 1150km-altitude. To the first phase a second phase will follow with the deployment in orbit of the remaining inner satellites at 340km-altitude.

Because the Starlink satellites can autonomously change their orbits, observations cannot be scheduled to avoid them.

²The 5th generation mobile networks (28, 38, and 60 GHz) will also partially overlap with Ka and V bands. The V band at 60 GHz was used by the world's first cross-link communication between satellites in a constellation between the U.S. Milstar 1 and Milstar 2 military satellites. The 60GHz frequency band is attractive to secure satellite crosslinks because it allows high data rates, narrow beams and, lying in a strong absorption band of oxygen, provides protection against intercept by ground-based adversaries.

3.3 The OneWeb Satellite Constellation

Is a UK project to provide global satellite Internet broadband services to people everywhere and it is composed of a constellation of about **5260** satellite displaced in a circular LEO orbit shell of about 1,200km-altitude. It will transmit and receive in the Ku band.

There are about 6 testing satellites in orbit; in February 2020 other 34 satellites are planned to be launched from the Baikonur Site. Other launches are scheduled in 2020.

3.4 Other Constellations

In the next years there could be over 50,000 new satellites encircling the Earth (at different altitudes) for various telecommunication purposes but mainly delivering broad band internet from Space and, considering the closeness to the Earth, internet signals will be provided fast and with very low-latency. Table 1 is a non-exhaustive list of principal satellite-constellation.

A so large number of new self-driving satellites in different low-altitude orbiting shells could also impact on the capability to send in the outer space new science related missions, since it would be impossible to exactly predict the single positioning of each constellation satellite, so that impact risk will strongly increase during scientific mission launches.

4 The impact of large satellite constellations on ground based astronomy

The ground-based observatories with their large optical telescope currently working (Very Large Telescope, VLT [2], Large Binocular Telescope, LBT [3], ...) and those in construction (e.g. the Extremely Large Telescope, ELT [4], with a main 39-meter diameter mirror) are essential complements to astronom-

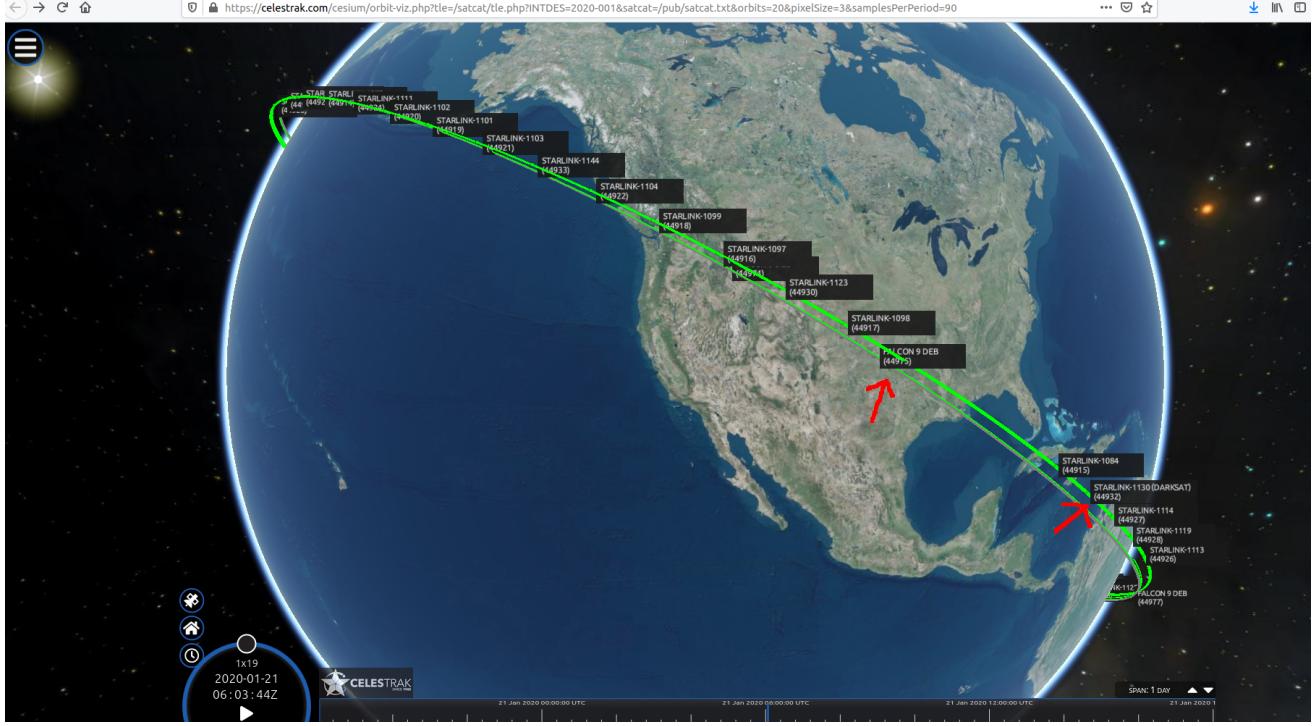


Figure 1: First orbital planes of Starlink satellites after the 21 January 2020 launch of 60 satellites by the Falcon-X rocket to reach the total number of orbiting satellites of 240. Starlink@SpaceX systems will be turned on at 420 satellites, while the first broad band internet service will be provided once \sim 1000 satellites will be deployed. The red arrows indicates the Falcon9 orbiting bucket and the experimental Starlink DARKSAT, with an experimental coating to make it less reflective, and thus impact ground-based astronomical observations less.

ical satellites, which are not affected by reflections of the satellites. As introduced in the second section, for astronomical satellites, missions costs and limitations on size/weight preclude the launch of particularly large telescopes, thus the difficulty in repairing and maintaining telescopes in space means that the newest, most revolutionary technologies are implemented only on ground-based telescopes. Ground based telescopes are fundamental to astronomy and the international community and single states have invested for these ground based projects in past years several tens of billions of dollars/euro trillions of dollars, therefore they are requested to produce high rate of scientific results to repay the initial public investment received.

What is really damaging such scientific results is the sky degradation. This is not only due to sky-glow / light pollution in the sky near cities

and the most populated areas (see Fig. 2), but it is also due to artificial satellite fleets crossing and scarring observations with bright parallel streaks/trails at all latitudes.

Astronomers are extremely concerned by the possibility that sky seen from Earth may be blanketed by tens of thousands of satellites, which will greatly outnumber the approximately 9,000 stars that are visible to the unaided human eye. This is not some distant threat: it is already happening. As seen in section 3, the US private company SpaceX has already put 240 of these small satellites, collectively called Starlink, in the sky and plans to constellate the whole sky with about 42,000 satellites. Thus, together with other telecommunication space projects in the near future (see §1.1), in a very short term there could be over 50,000 small satellites encircling the Earth (at different altitudes) each of them damaging

Constellation Name	n. Satellites	Altitude [km]	Bands	Serv.Start
SpaceX - Starlink (USA)	42,000	1150, 550, 340	Ku, Ka, V	2020
OneWeb (UK)	5,260	1200	Ku	2020
Telesat (CAN)	512	~1000	Ka	2022
Amazon - Kuiper (USA)	3236	590, 630, 610	?	2021
Lynk (USA)	thousands		?	2023
Facebook (USA)	thousands	500-550	?	2021
Roscosmos (RU)	640	870	?	2022-2026
Aerospace Sci.Corp. (CHI)	156	~1000	?	2022

Table 1: Satellite-Constellation projects comparison.

astronomical observations.

The closeness of satellites in LEO makes them more visible, and brighter in the night sky especially when lighted by the Sun (e.g. satellites launched by SpaceX are brighter than 99 percent of the population of objects visible by the Earth orbit).

As comparison, the current total number of catalogued objects in Earth orbit is less than 20,000 among spacecrafts, rocket bodies, fragmented mission and other related debrids, so with only the nominal Starlink fleet the total number of orbiting objects will increase of 300% (see Fig. 2 and 3).³

In the mid and long term, this will severely diminish our view of the Universe, create more space debris and deprive humanity of an unblemished view of the night sky.

It has been considered that most of these satellites will be visible to the naked eye (with a brightness between the 3rd and 7th magnitude) particularly in the time after sunset and before sunrise. Consequently they will reach

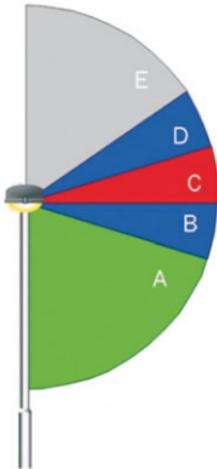
³It has been estimated that here are over 500,000 non-catalogued pieces of space debris from the size of one square cm (or larger) orbiting the Earth traveling up to 17,500 mph; millions of others are untraceable, in addition to the around 20,000 catalogued objects in Earth orbit. In 1978 this scenario was predicted by D.J Kessler, [30], warning governments about the devastating cascading effect of collision-induced debris creation (the so-called Kessler syndrome). The increase number of LEO satellites makes the creation of a dense debrids network belt around the Earth a possible scenario with devastating consequences for the future of space exploration and telecommunications too.

the brightness of the stars in the Ursa Minor constellation. There are only 172 stars in the whole sky exceeding the expected brightness of Starlink satellites (see Tab. 2). Higher altitude LEO satellites (e.g. over 1000km-altitude) will be visible all the night reaching approximately the 8th magnitude.

Visible to typical human eye	Apparent magnitude	Brightness relative to Vega	Number of stars (other than Sun) brighter than apparent magnitude in the night sky
Yes	-1.0	251%	1 (Sirius)
	0.0	100%	4
	1.0	40%	15
	2.0	16%	48
	3.0	6.3%	171
	4.0	2.5%	513
	5.0	1.0%	1602
	6.0	0.4%	4800
	6.5	0.25%	9100 ^[4]
No	7.0	0.16%	14 000
	8.0	0.063%	42 000
	9.0	0.025%	121 000
	10.0	0.010%	340 000

Table 2: Stars Apparent Magnitudes comparisons.

The most important contribution on pollution of astronomical images comes from the satellites in the higher orbits since the light directly reflected by the Sun make them brighter during the night, instead lower altitude satellites



E 120° – 180° Critical area for skyglow experience from within urban and all areas but proportionally less impact to rural areas, distant from main light sources;

D 95° – 120° Significant contributor to skyglow, especially in rural areas. Less likely to be obstructed;

C 90° – 95° Critical zone for skyglow and obtrusion seen at tens of km (in rural areas) where it is strongly dependent on aerosol scattering;

B 85° – 90° Significant contributor to skyglow seen at a distance through reflection but reflected light more likely to be obstructed by buildings, trees and topography. Produces also glare in the roadway users;

Bbis 75° – 85° Produces glare in the roadway users;

A 0° – 75° Ideal light distribution.

Figure 2: Effect of Sky-glow and cut-off angle, showing the relative impact of a luminaire’s output contribution to skyglow. Picture taken from “Starlight: a Common Heritage”, Cipriano Marin, IAC - ESP

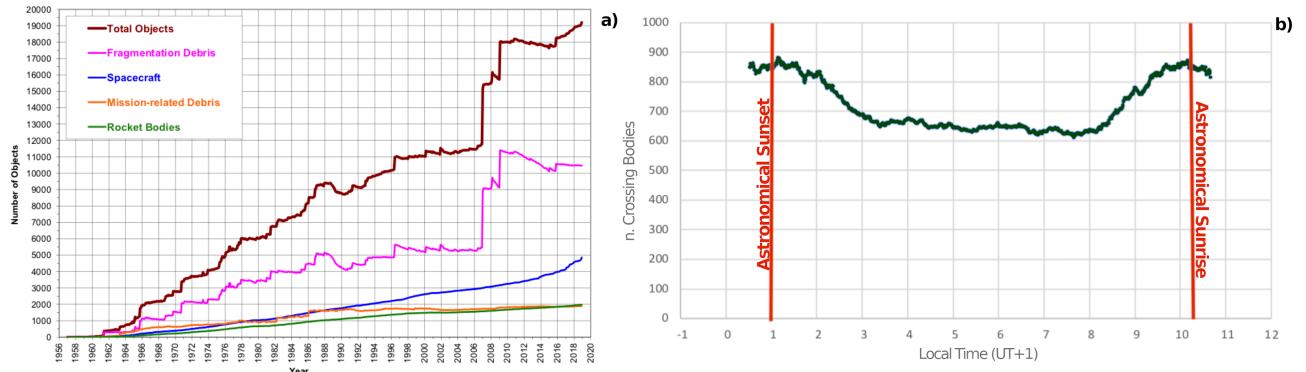


Figure 3: a) Number of objects in the Earth’s orbit and b) Number of artificial crossing bodies during an observing night.

are foreseen to contribute negatively only few hours after sunset and before sun dawn. It is possible to predict the range of variability of apparent magnitudes of the LEO satellites depending on the position and the altitude considering a mean density of about 1 satellite per square degree (see Fig. 4a and 4b and [12] for a whole sky simulation of 12,000 Starlink satellites at three different altitudes).

In Fig. 4b, illustrates how starlink orbital shells (shown in red) are illuminated by the Sun when it is at different altitudes below the horizon. We can see that the lower the sun is only the more distant satellites will be illuminated. At certain stages the lowest shells won’t be visible at all, but the higher shells

will be visible in the northern part of the sky. Also the swarm of the satellites near the horizon will be mostly invisible due to their distance and atmospheric effects. It should be noted that the "worst case" will be experienced during the summer, in northern half of the sky, in the northern hemisphere, where the satellites will be visible during the entire night, though their brightness will probably be lower than the bright overhead passes after the sunset and before the sunrise. The "best case" will be during the winter, at midnight, when the sky will be virtually free of any satellites, except for the horizon; for details see [28].

Thus with 50k satellites the "normality" will be a sky crowded with artificial objects: every

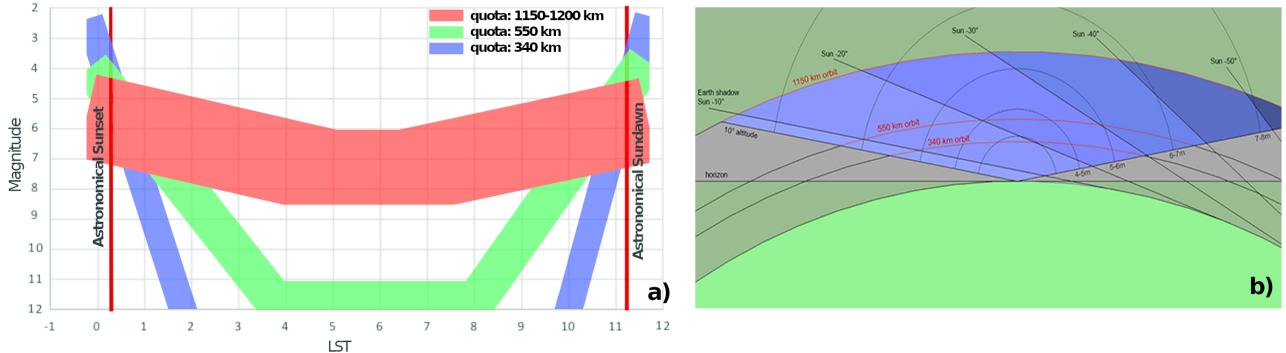


Figure 4: a) Apparent magnitude of satellites during an observing night depending on the altitude; b) Illumination factor depending on the Sun altitude of the three orbital shells for Starlink satellites. For OneWeb satellites the expected illumination fraction will be the same of highest starlink orbital shell, see [28].

square degree of the sky will have a satellite crawling in it along the whole observing night accessible and visible by astronomical cameras and not only by professional instrumentation. It should also be noted that during nominal service operations SpaceX expects to dismiss and replace from 2,000 to 8,000 Starlink satellites every year, disintegrating them in the lower atmosphere, with all related issues, see [27] page 4-5 for details.

4.1 Impacts on ground based optical astronomy

Wide-field survey telescopes will be particularly damaged, by the presence of multiple saturated trails within camera images:

- LSST [5], capable to scan and perform a survey of the entire sky in three nights
- VST [6], with its 268MegaPixels camera and a FOV of 1 square degree
- Pan-STARRS [7], with its FOV of 7 square degrees and 1.4 Giga pixels camera

Also deep/long exposures with small-field facilities will be unavoidably impaired, see Fig. 5 and [12].

This have also a dramatic impact on our safety because large area astronomical observations

and sky surveys are commonly used in search for Near Earth Objects, NEOs, asteroids monitoring and other related searches to guard the Earth from potential impact events: such satellite constellations could negatively impact on the ability to prevent and warn the whole humankind.

The light pollution is extremely damaging for astronomical observations at all wavelengths. To minimize the quantity of light reflected by LEO satellites, Starlink has put in orbit an experimental version of the Starlink satellites (Starlink satellite n.1130 DARKSAT, see Fig. n.1) making use of a non-reflecting paint on the body. It is not clear how this coating will reduce the brightness of the satellite since it is not possible to cover solar panels, which represents 75% of the satellite reflecting surface.

If the satellite body will be inhibited to reflect the sun light, it will absorb radiation warming too much with possible failures, thus will probably increase the risk management for the whole fleet and make the dark-coating solution ineffective or even counterproductive.

Moreover even if the brightness of the experimental satellite would be below the naked eye sensitivity, astronomical images will continue to see them (with resulting damage to their scientific content).

Thus degradation for scientific observations will remain high also with coating for three dif-

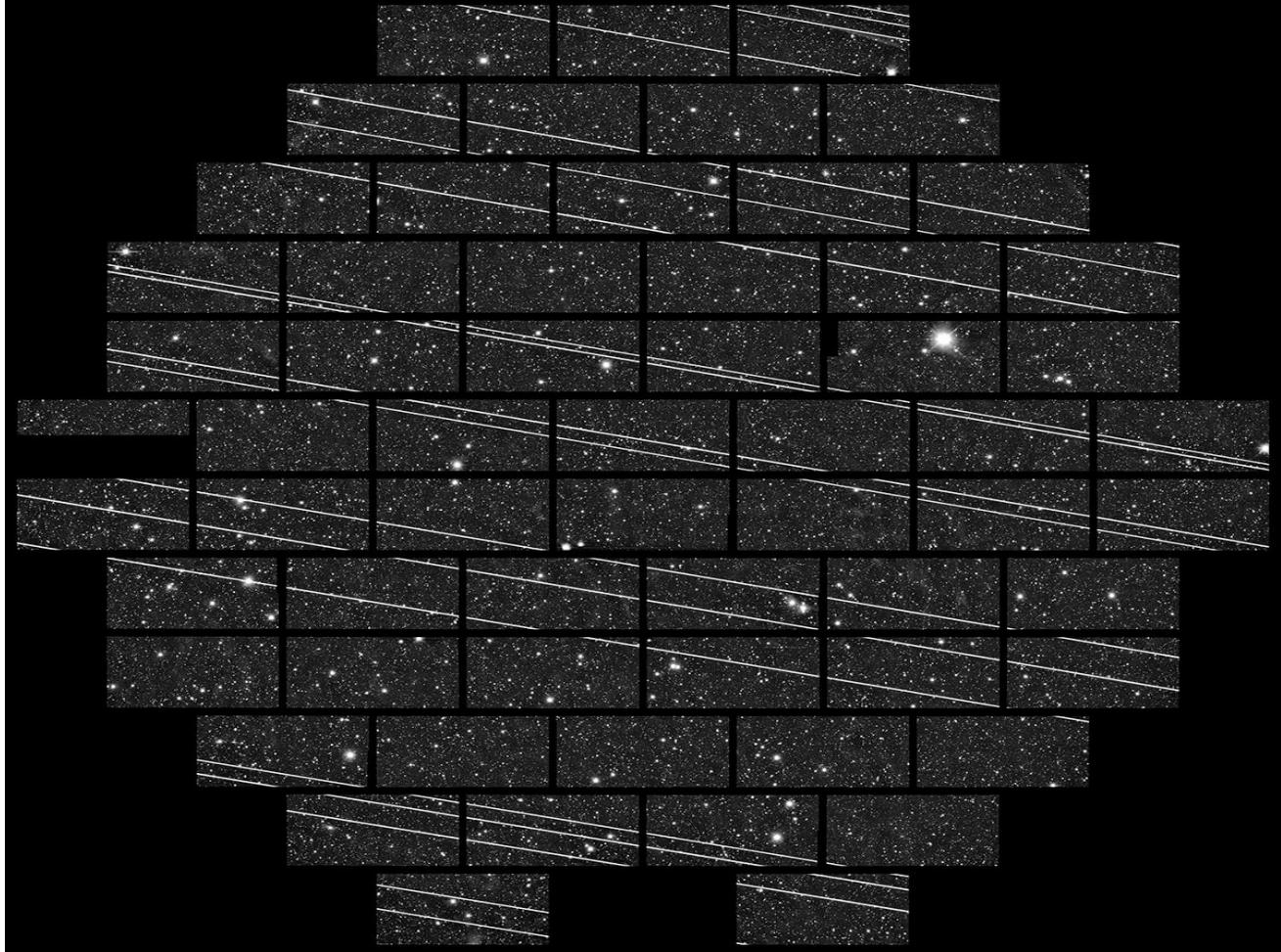


Figure 5: Few Starlink satellites visible in a mosaic of an astronomical image (courtesy of NSF’s National Optical-Infrared Astronomy Research Laboratory/NSF/AURA/CTIO/DELVE)

ferent reasons:

1. Astronomical deep field camera images will continue to have trails in long exposures depending on the filter limiting magnitude.
2. Astronomical objects in the sky will be eclipsed, this will probably harm time-dependent (variability) studies.
3. The reflectivity of a surface depends on the observational wavelength, so what becomes dark in one part of the spectrum (e.g. visible), will remain bright in other parts of the spectrum (e.g. infrared or radio).

4.2 Impacts on ground based radio-astronomy

Even with best coating and mitigation procedures to decrease the impact on visual astronomical observations, what is often omitted or forgotten is that telecommunication constellations will shine in the radio wavelengths bands, observable from the ground.

The scientific needs of radio astronomers and other users of the passive services for the allocation of frequencies were first stated at the World Administrative Radio Conference held in 1959 (WARC-59). At that time, the general pattern of a frequency-allocation scheme was:

1. that the science of radio astronomy should be recognized as a service in the Ra-

- dio Regulations of the International Telecommunication Union (ITU);
2. that a series of bands of frequencies should be set aside internationally for radio astronomy⁴
 3. that special international protection should be afforded to the **hydrogen line** (1400-1427 MHz), the **hydroxyl (OH) lines** (1645-1675 MHz), and to the predicted **deuterium line** (322-329 MHz)...

Since 1959 a large number of spectral lines from a wide variety of atoms and molecules in space have been discovered, then the frequency range of radio astronomy now extends to at least 500 GHz. In particular frequencies of the CO molecule (at 115, 230, and 345 GHz), isotopes (at 110, 220, and 330 GHz) and the maser of H₂O at 22,235GHz [29], are critical to many aspects of astronomy, see also [21].

Radio astronomers have been engaged for decades in the work of the United Nations Agency ITU to regulate the international use of the radio frequency spectrum. Their efforts ensured a limited number of narrow bands of the spectrum received protection to allow radio astronomy to develop and conduct essential and unique research.

Despite the special international protection for Radio-astronomy, some sources of radio frequency interference (RFI) are inescapable. While radio astronomers can minimize the effects of many terrestrial sources by placing their telescopes at remote sites, none can escape from RFI generated by satellite transmitters, such as those of the Iridium System, SpaceX, and others.

Whilst there is legislation in place where radio observatories are placed (e.g. at the two SKA sites in Australia and South Africa) to protect the telescopes from ground-based radio interference at those frequencies, the use of air and

⁴These bands should lie at approximately every octave above 30 MHz and should have bandwidths of about 1 percent of the center frequency.

space-borne radio communications is regulated on a collaborative international basis.

What is not widely acknowledged is that the development of the latest generation telecommunication networks (both from space and from Earth) already has a profound impact on radio-astronomical observations (at all sub-bands): with LEO satellite fleets it is quite sure that the situation could become unbearable.

In particular, low Earth orbit satellite's spectral windows identified to communicate with earth stations in the Ku (12-18GHz), Ka (27-40GHz) and V (40-75GHz) bands will overlap with the nominal radio-astronomy bands and so will interfere with ground radio telescopes and radio interferometers, making the radio detectors enter in a non-linear regime in the K band (18-26.5GHz) and in Q band (33-50GHz). This fact will irreparably compromise the whole chain of analysis in those bands with repercussions on our understanding of the Universe, or even, making the astrophysics community blind to these spectral windows from the ground, see Fig 6.

There are different projects in development for ground based radio-astronomy that will significantly overlap with telecommunication signals coming from the satellites' constellations in orbit:

- The **Next Generation Very Large Array, ngVLA and ngVLA Long Baseline Array, LBA** [18]: located in New Mexico, west Texas, Arizona, and northern Mexico. The VLA will use 6 radio-bands: 2,4GHz, 8GHz, 16GHz, 27GHz, 41GHz and 93GHz.
- The **Square Kilometer Array, SKA** [19], [23] will interfere with Ku satellites communication bands.
- The **Atacama Large Millimeter Array, ALMA** [22], the world-leading mm and sub-mm observatory built in Atacama, Chile, with enormous expenses spent by a broad international community, facility that has brought us many significant discoveries and played a crucial role

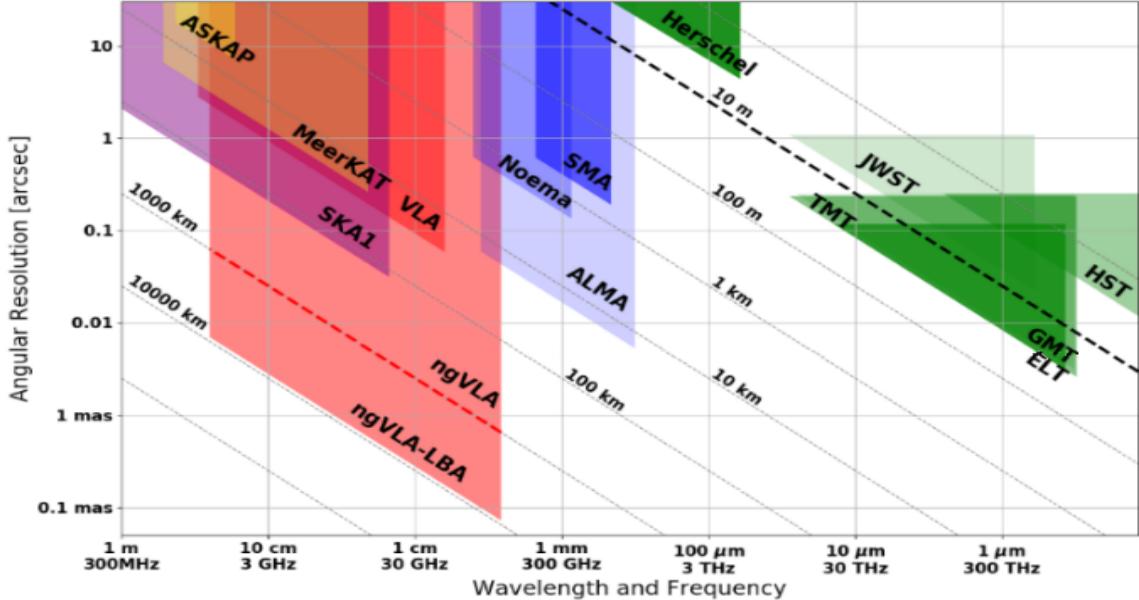


Figure 6: Spatial resolution versus frequency set by the maximum baseline of the ngVLA compared to other existing and planned facilities, see [18].

in the global system of EHT (first image of BH ever, published in April 2019), has its Bands 1, and 2+3 exactly in the potentially polluted part of the spectrum.

To aggravate the matter, with the current technological development, the planned density of radio frequency transmitters is impossible to envisage. In addition to millions of new commercial wireless hot spot base stations on Earth directly connected to the about 50,000 new satellites in space, will produce at least 200 billion of new transmitting objects, according to estimates, as part of the Internet of Things (IoT) by 2020-2022, and one trillion of objects a few years later.

Such a large number of radio-emitting objects could make radio astronomy from ground stations impossible without a real protection made by countries' safe zones where radio astronomy facilities are placed.

We wish to avoid that technological development without serious control turns radio astronomy practice into an ancient extinct science.

5 How to protect the Astronomical Sky?

To answer this question, we must remember some International Conventions and Treaties.

The Preamble of the **World Heritage Convention** holds that “the deterioration or disappearance of any item of the cultural or natural heritage constitutes a harmful impoverishment of the heritage of all the nations of the world” This protection appears again in the 1994 Universal Declaration of Human Rights for Future Generations:

PERSONS BELONGING TO FUTURE GENERATIONS HAVE THE RIGHT TO AN UNCONTAMINATED AND UNDAMAGED EARTH, INCLUDING PURE SKIES; THEY ARE ENTITLED TO ITS ENJOYMENT AS THE GROUND OF HUMAN HISTORY OF CULTURE AND SOCIAL BONDS THAT MAKE EACH GENERATION AND INDIVIDUAL A MEMBER OF ONE HUMAN FAMILY.

The **UNESCO** has undertaken activities for the safeguarding of cultural heritage related to astronomy under the “Astronomy and World Heritage” project launched by the World Heritage Centre in 2003. This concept was taken

up again by UNESCO in 2005 as:

THE SKY, OUR COMMON AND UNIVERSAL HERITAGE, IS AN INTEGRAL PART OF THE ENVIRONMENT PERCEIVED BY HUMANITY. HUMANKIND HAS ALWAYS OBSERVED THE SKY EITHER TO INTERPRET IT OR TO UNDERSTAND THE PHYSICAL LAWS THAT GOVERN THE UNIVERSE. THIS INTEREST IN ASTRONOMY HAS HAD PROFOUND IMPLICATIONS FOR SCIENCE, PHILOSOPHY, RELIGION, CULTURE AND OUR GENERAL CONCEPTION OF THE UNIVERSE.

This in turn led to the following concepts:

ASTRONOMICAL OBSERVATIONS HAVE PROFOUND IMPLICATIONS FOR THE DEVELOPMENT OF SCIENCE, PHILOSOPHY, RELIGION, CULTURE AND THE GENERAL CONCEPTION OF THE UNIVERSE... DISCOVERIES OF ASTRONOMERS IN THE FIELD OF SCIENCE HAVE HAD AN INFLUENCE NOT ONLY ON OUR UNDERSTANDING OF THE UNIVERSE BUT ALSO ON TECHNOLOGY, MATHEMATICS, PHYSICS AND SOCIAL DEVELOPMENT IN GENERAL... THE CULTURAL IMPACT OF ASTRONOMY HAS BEEN MARGINALIZED AND CONFINED TO A SPECIALIZED PUBLIC.

These protections for Starlight are necessary as the impact that Starlight has held on humanity has been expressed in works of religion, art, literature, science, philosophy, business, and travel.

Enforcement of the Right to Starlight:

INTERNATIONAL LAW ENFORCES INTERNATIONAL LEGAL OBLIGATIONS, INCLUDING PROPERTY INTERESTS. HERE, WORLD HERITAGE IS THE PROPERTY OF ALL HUMANKIND, AND WHILE THERE MAY BE PROTECTIVE LAWS, ENFORCING THIS IS ANOTHER MATTER, AS ONLY STATES CAN SUE OTHER STATES UNDER THIS TYPE OF INTERNATIONAL TREATY. **A STATE IS RESPONSIBLE FOR THE ACTIVITIES THAT OCCUR WITHIN ITS JURISDICTION – WHETHER THEY ARE AUTHORIZED OR UNAUTHORIZED.**

Thus:

WITHIN THE FRAMEWORK OF INTERNATIONAL LAW AND STATE BASED LEGAL INSTRUMENTS, PROTECTION OF STARLIGHT COULD THEN BE IMPLEMENTED IN THE SAME MANNER:

1. REAFFIRMS THE SOVEREIGN RIGHTS AND RESPONSIBILITIES, TOWARDS THE INTERNATIONAL COMMUNITY, OF EACH STATE FOR THE PROTECTION OF ITS OWN CULTURAL AND NATURAL HERITAGE;
2. CALLS UPON THE INTERNATIONAL COMMUNITY TO PROVIDE ALL THE POSSIBLE ASSISTANCE NEEDED TO PROTECT AND CONSERVE THE CULTURAL AND NATURAL HERITAGE OF STARLIGHT;
3. INVITES THE AUTHORITIES OF STATES TO TAKE APPROPRIATE MEASURES IN ORDER TO SAFEGUARD THE CULTURAL AND NATURAL HERITAGE OF STARLIGHT;
4. FURTHER INVITES THE STATES TO CO-OPERATE WITH UNESCO, THE WORLD HERITAGE COMMITTEE, THE UNWTO, AND THE STARLIGHT INITIATIVE WITH A VIEW TO ENSURING EFFECTIVE PROTECTION OF ITS CULTURAL AND NATURAL HERITAGE IN STARLIGHT.

Having established these rights under international law, the conclusion is that there exist duties for both States and international organizations to protect the World Heritage Right to Starlight, as well as, their duties to foster the rights of travelers, hosts, and providers of travel to enjoy this Starlight “property interest” that belongs to all humanity. The existing legal instruments demonstrate the protection for the Right to Starlight, but it is the States that act as custodians of World Heritage that are charged with ensuring these rights are enforceable, and in turn made available to all of humanity.

5.1 On the legal side

SpaceX private company has received permission from many USA government agencies (e.g. Federal Communication Commission, FCC) to launch these satellites into orbit. So there

could be a legal claim, within the US legal system, to halt the progress of Starlink.

Also, as it turns out, according to the Outer Space Treaty and its progeny, there are no private companies operating in outer space, but only governments can operate in outer space. And the legal process is that the state government, this time the USA government, is legally responsible for all objects sent into outer space that launch from USA borders. That means, that it is the USA government that is responsible for the harm caused by its corporation, Starlink, sending objects into orbit that cause harm.

So under this international law, any country that suffers harm by Starlink can sue the United States government in the International Court of Justice in the Hague. The harm here is damage to our cultural heritage, the night sky, and monetary damages due to the loss of radio and other types of astronomy. For the scientists, the owners of the observatories have a legal argument that they have and will continue to lose money spent for their research based on Earth based observatories. Furthermore, Universities that own the observatories are state owned universities, so it is the government that owns the observatories that have lost financially because of their interruption of study of the night skies.

So it is essential that a government, like Chile, Italy or France, sues the USA in the International Court of Justice.

If no national or international entity will stop this displacement the right of the private company SpaceX will become acquired at the beginning of March 2020.

How should the international astronomical community mobilize in order to stop further Starlink launches?

1. Sue in court for luminous pollution not taken into account by US FCC: The FCC's lack of review of these commercial satellite projects violates the National Environmental Policy Act, NEPA, which obligates all federal agencies to consider the environmental impacts of any projects they

approve. So in the most basic sense, SpaceX's satellites displacement authorization would be unlawful, see [31].

2. Sue in court for lack of jurisdiction and jurisprudence of US FCC to authorize private not geostationary satellites over other states and nations.
3. Sue in the International Court of Justice, ICJ the USA government to put on hold further Starlink launches to quantify the loss of public finances in damaging national and international astronomical projects.⁵

5.2 From the astronomers' side

An **international appeal/petition from astronomers** was launched in January 2020 and, at the time of writing, thousands of astronomers involved with astronomical observatories and facilities, have subscribed the appeal, see [25]. Another **open letter** has been prepared regarding same concerns on the

⁵Though there are no international law that restrict mega constellations, to deploy and dispatch mega constellations an international agreement among states is needed, since satellites can not be located only over a single state (e.g. USA) but, being in LEO, they move around the globe passing over different states/nations/continents. This is a lack of jurisdiction of FCC authorization. In particular the International Court of Justice, ICJ, can be called into question whenever there is a dispute of international jurisdiction or between member states of the United Nations on the basis of international norms, treaties and / or their violations. In the beginning of chapter 5 it was explained how the World Heritage Convention regarding the "right of night sky / starlight" belongs to universal human rights and so no state can decide to contravene this convention if it interferes with the enjoyment of that right for other states. The pretext for appealing to the United Nations and the International Court of Justice (ICJ) is the loss of scientific value of the investments made for ground based projects by each state (damaged by SpaceX). Each damaged state, being damaged as consequence of a violation for an international treaty, the issue cannot be settled with a simple money compensation, but with an inhibition of the damage before the same occurs (and not after).

satellites constellations deployment for the further space missions and to raise awareness to US Senate, and US commissons on the possibility that occurs the Kessler Syndrome, which is a realistic scenario with all these orbiting objects, see [32].

Requests from the astronomical community to governments, institutions, and agencies all around the world are:

1. to be committed to provide legal protection to ground astronomical facilities in all of the available observation electromagnetic windows.
2. to put on hold further Starlink launches (and other projects) and carry out an accurate moratorium on all technologies that can negatively impact astronomical space based and ground based observations, or impact on the scientific, technological and economic investments that each State engages in astrophysical projects.
3. to put in place a clear evaluation of risks and predictive impacts on astronomical observatories (i.e. loss of scientific and economic value), giving stringent guidelines to private individuals, societies and industries to plan satellite investments without clearly understanding all of the negative effects on outstanding astronomical facilities.
4. that the US Federal Communications Commission (FCC) and any other national agency be wary of granting permission to ship non-geostationary low-orbit satellites into orbit or alternatively to limit the authorization of only satellites being above the airspace of the “home country”.
5. to demand a worldwide orchestration, where national and international astronomical agencies can impose the right of veto on all those projects that negatively interfere with astronomical outstanding facilities.
6. to limit and regulate the number of telecommunication satellite fleets to the “strictly necessary number” and to put them in orbit only when old-outdated technology satellites are deorbited, according to the Outer Space Treaty (1967) - the Art IX [8], and the United Nations Guidelines for the Long-term Sustainability of Outer Space Activities (2018) – guideline 2.2(c) [9], requiring the use of outer space be conducted “so as to avoid [its] harmful contamination and also adverse changes in the environment of the Earth” and [...] omissis...] risks to people, property, public health and the environment associated with the launch, in-orbit operation and re-entry of space objects”.

6 Conclusions

Avoiding damages in astronomical ground based observations arised from the displacement of satellite constellations is absolutely mandatory for safeguarding not only the economic and scientific investment, committed by international institutions and single nations, but also to continue efficiently to monitor possible impact events to guard and alert the humankind.

All of these requests come from the heartfelt concern of scientists arising from threatens to be barred from accessing the full knowledge of the Cosmos and the loss of an intangible asset of immeasurable value for humanity. In this context it is absolutely necessary to put in place all possible measures to protect the night sky right also on the legal side as stated by the Universal Declaration of Human Rights for Future Generations.

To ensure this safeguard action it would be desirable to adopt contingent and limiting resolutions to be ratified as shared international rules, which must be adopted by all space agencies to ensure protection for astronomical bands observable from the ground. All of this to continue to admire and study our Universe, for as long as possible.

In the meanwhile all private displacement of satellites constellation project must be put on hold; every “national” authorization to launch not geostationary LEO satellite fleets must be withdrawn and avoided as well.

"One person's freedom ends where another's begins". The public authorities (of every state) are entitled (and obliged) to enforce regulations, which take care that the above statement comes true. The right to see the sky in natural state belongs to our rights and freedoms alike the right to breath unpolluted air, drink clean water or sleep in a quiet environment during the night.

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