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Protection of dark and quiet skies

Working paper prepared by Chile, Slovakia, Spain, the International Astronomical Union, the European Southern Observatory and the Square Kilometre Array Observatory

I. Introduction

1. During the past six decades, the science of astronomy has benefited from a tremendous boost associated with the peaceful use of outer space. Tens of scientific satellites have given access to the entire range of cosmic electromagnetic signals, from microwaves to the most energetic gamma rays. The new data were used by scientists to build a comprehensive model of the whole universe and of its history, but they also allowed them to describe new high-energy phenomena that are well beyond the reach of any current and future terrestrial experimental facilities. Outer space has turned out to be an irreplaceable laboratory for the advancement of fundamental physics.

2. However, space astronomy alone would not have achieved those feats without the essential complementary contribution of large ground astronomical facilities. Only the combination of space and ground data is making possible real progress in our knowledge of physical reality. Likewise, the exploration of solar system bodies, from asteroids to planets, critically depends on detailed observations from ground- and space-based astronomical facilities. It is therefore in the interest of the entire international scientific community to protect global astronomical observing capabilities from adverse and significantly disruptive and harmful artificial interference.

3. There are three categories of artificial interference that negatively impact astronomical observations: (a) urban illumination or artificial light at night; (b) optical/infrared trails of the satellites in low Earth orbit; and (c) radio transmission by ground and space emitters, especially from the satellites in low Earth orbit.

4. Of these, the most recent is related to the deployment of large numbers of communication satellites in low Earth orbit, an innovative technological feat. Their main purpose is to provide Earth-space-Earth low latency communication networking to any inhabited region of the globe. This offers great promise for connectivity and may be an important piece of the world broadband system.

5. The large constellations of satellites present a new challenge to astronomy owing to their number, their brightness in the sky (due to optical reflections or thermal emission), their ubiquitous location in the sky (compared with satellites in geostationary orbit that are confined to a single “belt”) and their proximity (which is a driver of low latency).

6. All of the above-mentioned categories of interference were the main subjects of the workshop and conference on the theme “Dark and quiet skies for science and society”, which were organized by the Office for Outer Space Affairs, the Government of Spain and the International Astronomical Union (IAU). The report of the workshop, which was held online from 5 to 9 October 2020, is available at www.iau.org/static/publications/dqskies-book-29-12-20.pdf.

7. A summary of the conclusions of the workshop was presented to the fifty-eighth session of the Scientific and Technical Subcommittee in a conference room paper entitled “Recommendations to keep dark and quiet skies for science and society” (A/AC.105/C.1/2021/CRP.17), submitted by the delegations of Chile, Ethiopia, Jordan, Slovakia, Spain and the International Astronomical Union. A related conference room paper, entitled “Proposal for a single issue/item for discussion at the fifty-ninth session of the Scientific and Technical Subcommittee in 2022 on ‘General exchange of views regarding satellite system effects upon terrestrial-based astronomy’” (A/AC.105/C.1/2021/CRP.24) was presented by the delegations of Canada, Japan and the United States of America. The Subcommittee, in its report on the fifty-eighth session, encouraged the Office for Outer Space Affairs to engage with all relevant stakeholders, such as IAU and others, on the matter of dark and quiet skies, and noted that the conference to be held in 2021 could provide input for a focused discussion on opportunities for international cooperation (A/AC.105/1240, para. 233).

8. The Conference on Dark and Quiet Skies for Science and Society, which was held online from 3 to 7 October 2021, analysed the results of almost two years of investigations into the above-mentioned interference and, in a fruitful discussion with the astronomical community and the space industrial sectors, focused on the implementation of feasible measures that could mitigate the negative impact on science and society. The report of the Conference is contained in document A/AC.105/1255, and the detailed technical report of the working groups that prepared the event is available at https://noirlab.edu/public/products/techdocs/techdoc051. The present working paper is focusing on those measures that fall under the remit of the Committee on the Peaceful Uses of Outer Space.

II. Artificial light at night

9. Interference by artificial light at night with astronomical observations, which affects both amateur and professional astronomers, has become an acute problem with the advent of light-emitting diodes, particularly those with a high level of blue light. IAU has established a recommended maximum tolerable threshold of light pollution for astronomical sites of 10 per cent above natural background levels. Light pollution is growing globally at an estimated rate of 2 to 6 per cent per year and is reducing darkness everywhere, including at observatory sites: world-class sites risk hitting the 10 per cent threshold in the next decade, and many smaller sites are already impaired. In addition to the impact on astronomy, artificial light at night may have significant biological impacts on flora and fauna, both vertebrates and invertebrates, which requires further study by appropriate experts.

10. Artificial light at night has a serious negative impact on the science of astronomy in general and consequently also on space astronomy. Therefore, delegations are encouraged to consider adopting the detailed and quantitative recommendations contained in the reports of the online workshop and the Conference, particularly in the area of ground astronomical facilities.

III. Satellite constellations and optical/infrared astronomy

11. The International Telecommunication Union (ITU) and national regulatory filings indicate that nearly 100,000 satellites could be launched into low Earth orbit in the coming decade, and several companies have already begun constructing and launching satellite constellations.

12. Notwithstanding the undisputed merit of the communication constellations, the unprecedented large number of satellites that will populate the low Earth orbital shell is creating a new situation which poses several challenges, including to the pristine visibility of the night sky and to the science of astronomy.

13. As established by the workshop and the Conference on Dark and Quiet Skies for Science and Society, large satellite constellations create a challenge for optical/infrared astronomy owing to the light interference generated as a result of the reflectivity and thermal factors of the spacecraft. This is a new problem for astronomy owing to the large increase in the number of satellites, their ubiquity in the sky and their proximity to Earth. The visibility and brightness of a satellite during the night depends on the altitude of its orbit (currently ranging from approximately 350 to 1,200 km) and on its surface reflectivity and attitude with respect to the observer, as well as the orbital configuration of the system. On orbit, a fraction of the satellites are visible to the naked eye (those with magnitude less than seven), but all of them are potentially detectable during orbit-raising and -lowering and in orbit by highly sensitive telescope detectors, where they leave traces of their transit on astronomical images, significantly decreasing the scientific usability of the collected data. Post-processing of the affected images does not prove to be a solution: the brighter trails (magnitude less than seven) may saturate the detectors, making portions of images unusable, while the removal of the fainter trails leaves residual effects that seriously affect important scientific programmes, such as statistical automatic surveys of faint galaxies.

14. The mitigation of the impact can be achieved by following two main directions: (a) steps astronomers can take by acting at the observational end; and (b) steps the satellite industry and regulatory authorities can take by acting on the design and operation of the constellations. Experience gained so far indicates that the most effective results are obtained by close collaboration between the astronomical community and industrial actors.

15. Steps astronomers can take to mitigate the impact of the constellations are outlined in the reports of the workshop and the Conference and include, among others: (a) coordinated observations of individual satellites from multiple sites; (b) the development of algorithms for identifying and masking streaks and predicting satellite passages through specific planned observational pointings; (c) developing “smart” optical/infrared detectors and radio receiver systems; (d) software solutions and data post-processing; and (e) disseminating information and supporting the implementation of observational and data-processing best practices.

16. The Satellite Constellation Working Group of the Conference, in the industry-related section of its report,[1] concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architecture, spacecraft design or operations could be introduced with less cost or schedule impact. A set of best practice guidelines are summarized in the Conference report, covering five priority areas: (a) addressing the visible brightness of satellites as seen from the ground; (b) addressing the visibility impact on astronomical sciences of large constellations of low Earth orbit satellites with altitudes above 600 km; (c) providing access to high-accuracy public data on predicted locations of individual satellites (ephemerides) to be used by astronomers to avoid the satellites’ traces during their observations; (d) orbit-raising and deorbit

[1] Available at https://noirlab.edu/public/products/techdocs/techdoc051.

considerations, minimizing disruptions to astronomical observations from satellites immediately post-launch and during deorbit/re-entry phases; and (e) continued collaboration between the astronomical observation and satellite communities. The Working Group also developed a draft action plan, which may form the basis of items to be discussed under a single action agenda item.

17. The final impact of a constellation on astronomy depends on the combination of all of the above factors. Therefore, rather than proposing specific limits on individual factors (e.g. orbit altitude, surface reflectivity, etc.), we suggest that the companies that intend to design, launch and operate a satellite constellation perform a quantitative study about the foreseen impact of the proposed constellation on astronomy. The recently constituted IAU Centre for the Protection of the Dark Sky from Satellite Constellations will produce and disseminate new data and information on the satellite impact on which any stakeholder group will be able to draw. The Centre, if so requested, could contribute to the study and suggest measures that, if voluntarily adopted in the early phase of the design, may mitigate the impact on astronomy without a substantial increase in the cost, while achieving the goals of the constellation.

18. There are still many unanswered questions and areas needing further study. The impact on optical/infrared astronomy has not yet been established: it is a multidimensional problem, and questions such as the total number of recommended satellites in various orbital configurations have not been answered. It is recommended that this and other related questions continue to be studied.

IV. Satellite constellations and radio astronomy

19. The management of the radio spectrum is a task of the Radiocommunication Sector of ITU. The Radio Regulations provide allocations for various services, including radio astronomy under the radio astronomy service. Indeed, radio astronomy has a long history of negotiation activity aimed at protecting frequency bands of astronomical interest from harmful interference generated by artificial radio emissions within the wavelength range of astronomical interest, including allocation, identifications and footnote protections in the Radio Regulations.

20. The situation created by the new large constellations of telecommunication satellites poses new threats to radio astronomy which deserve further study. A number of specific challenges were identified in the report of the Conference, highlighting how the existing protections are insufficient for the protection of radio astronomy, even within radio quiet zones. The recommendations outlined in the report of the Conference to protect radio astronomy include the following: (a) satellite designs should have the capacity to avoid direct illumination of radio telescopes and radio quiet zones; and (b) the equivalent power flux density of the unintended electromagnetic radiation, including aggregate, out-of-band, harmonic and spurious emissions, should be kept below the limit agreed by ITU (for individual and aggregate cases). The report highlights the importance of raising general awareness of the vulnerability of radio astronomy.

21. Beyond the above recommendations for radio astronomy, special attention is required to protect the ground-based investigations of the cosmic microwave background, whose observing facilities utilize bolometers, which are sensitive to any energy within its bandwidth. It is suggested that the cosmic microwave background community and the satellite operators jointly assess the impact expected from the cumulative microwave emission by the constellations and suggest mitigating strategies.

V. Conclusion

22. The online 2020 workshop and the 2021 Conference on Dark and Quiet Skies for Science and Society, organized by the Office for Outer Space Affairs, the Government of Spain and IAU, scientifically and technically assessed the impact that the large satellite constellations in low Earth orbit will have on astronomy. They also suggested viable mitigating measures, a current set of best practices guidelines and an outline of future work to mitigate the negative impact that the constellations may have on astronomical observations.

23. In this working paper, we present for consideration by the delegations to the Committee on the Peaceful Uses of Outer Space a high-level summary of the Conference report and a number of proposals for the rational implementation of mitigation measures and best practices guidelines that may be practicable for implementation by satellite constellations.

24. In particular, we would like to suggest that delegations consider and eventually concur with all or part of the following proposed actions:

(a) Include astronomical research, from ground and space, as an instrumental part of space activities;

(b) Raise the attention of their respective governmental authorities to the harm created by the uncontrolled expansion of artificial light at night, not only to astronomy but also potentially to other realms;

(c) Support the adoption of the set of voluntary best practices guidelines for low Earth orbit satellite constellations and the astronomical community that are outlined for both radio and optical/infrared astronomy in the reports of the workshop and the Conference;

(d) Include an item on the agenda of the Scientific and Technical Subcommittee entitled “Impact of satellite constellations on astronomical facilities”. The deployment of satellite constellations is in rapid evolution and, consequently, the impact on astronomy will increase, posing new challenges which may require new mitigating strategies. The agenda item would offer an adequate forum for delegations to present and discuss their respective position on the matter, technical updates and modifications to the current set of best practices guidelines. The agenda item could be removed once the situation has reached a satisfactory equilibrium.