THE DARK SIDE OF SATELLITES

As satellite mega-constellations such as Starlink and OneWeb get increasingly bigger, they are radically altering the night sky. This has consequences for astronomy. The satellites reflect sunlight and, alongside their intended communication signals, they also emit unwanted radio waves towards the Earth. This interferes with the work of astronomy, which measures very weak radio waves from the cosmos.

Problems like this are not exactly new. For decades, light pollution has been so extensive throughout the world that astronomical observatories are now only built in the most remote regions on Earth, such as Chile's high-altitude desert. Radio astronomy also has to battle radio waves caused by humans. Around 100 years ago, astronomers opened up a completely new window into the cosmos with the first radio telescopes. These devices allowed them to observe celestial objects in a completely different light by using radio waves. Today, this enables the investigation of physical phenomena that remain hidden to optical astronomy. In addition, radio astronomy techniques also play an important role in geodetics. When researchers direct radio telescopes distributed across the world toward a distant galaxy with an energetic and radio-emitting core, the measurements will only reveal a detection in the combined stream of data if the position of the individual telescopes is known down to the millimeter. By observing such active galaxies with well-known positions, scientists use this effect to measure the Earth's surface with high precision. Not only does this data record how the continental plates are moving in relation to one another using the universe as a reference system; it also sup- →

VIEW POINT

BENJAMIN WINKEL AND GYULA I. G. JÓZSA

Benjamin Winkel and Gyula I. G. Józsa are research associates at the Max Planck Institute for Radio Astronomy in Bonn. In addition to using radio telescopes to study our Milky Way and distant galaxies, they are leading the way in protecting radio astronomy from human-made radio-interference. To this end, they measure the sources of interference and, as delegates of the European expert committee CRAF (Committee on Radio Astronomy Frequencies), they discuss with other stakeholders from industry and administrations about compromises, aiming for the best possible protection of the radio frequencies used by astronomers to observe space.

plies information on minute changes in the position of the Earth's axis and its rotational speed. Consequently, this data is of vital importance for navigation systems and space travel.

Although some of the processes that generate radio waves are among the most energy-intensive in the cosmos, the radiation that reaches Earth is extremely weak due to the enormous distances involved. It is only the giant antennas used in radio astronomy alongside the very latest technology that allow scientists to look far into the depths of the universe. To provide a comparison: from our standpoint, a simple cell phone on the moon would be one of the very brightest radio sources in the sky. So, it's not surprising that anthropogenic radio waves complicate the work of radio astronomy. However, it's impossible to envisage modern society without radio signals: mobile and wireless communications, GPS navigation, and radar-based parking tools and distance sensors in cars are just a few examples.

A CELL PHONE ON THE MOON WOULD BE ONE OF THE BRIGHTEST RADIO SOURCES IN THE SKY

Global light pollution continues to increase rapidly. This not only affects astronomy but also the animal and plant world. The first countries are beginning to introduce regulations to tackle it – but progress is slow. By contrast, the radio part of the electromagnetic spectrum is extremely well regulated across the globe. In general, this benefits radio astronomy, but only to a limited extent. More on this shortly. The regulations primarily serve to prevent disruptions in everyday life, as radio applications can interfere with each other. Anyone who has been to a concert and heard the crackle of a cell phone through the speakers will be aware of this. Without the conscientious efforts of thousands of specialists in the radiocommunication sector, our modern societies would likely cease to function.

Conventional coordination methods consist of assigning non-overlapping frequency ranges to the different applications. However, there are only a finite number of these, as nature has given us a radio spectrum with a limited bandwidth. This ranges from frequencies of several hundred gigahertz (wavelengths of less than one millimeter; as used in body scanners at airports) down to a few hertz (wavelengths of around 100,000 kilometers; as used in communication with submarines). In practice though, even high-quality transmitters will leak some power into adjacent frequency blocks. Consequently, one additional mitigation measure is to ensure certain distances between devices. This is effective because radio waves, like any other form of radiation, become weaker the further away the transmitter is; the radiated energy is thus spread across a larger area. Balancing these different aspects requires a great deal of experience and work, since the available radio frequency spectrum should of course be distributed between the many stakeholders as efficiently as possible. Radio astronomy is just one of many actors here.

To be more specific: the Radiocommunication Sector of the International Telecommunication Union (ITU-R) is a specialized agency of the United Nations and is responsible for regulation of the radio spectrum. The ITU Radio Regulations have the status of an international treaty, and all member states of the ITU-R mostly adhere to the agreements put in place. At the heart of the Radio Regulations is the frequency allocation table, which designates one or more radio services to every hertz of the radio spectrum. These include mobile communications and satellite broadcasting, as well as scientific services such as Earth observation or radio astronomy. Numerous other articles in the Radio Regulations, plus resolutions and recommendations of the ITU-R, also govern the interplay of radio services.

Decades ago, several frequency blocks were reserved for radio astronomy, and these still enjoy a high protection status. However, the allocated frequencies fall well short of satisfying the requirements of modern astronomy. At present, only a small percentage of the long-wave radio spectrum is available to astronomy, while a massive 30 percent has been re-purposed for cell phone networks in recent years. But the universe doesn't care about radio spectrum allocations on Earth, and radio astronomy is increasingly losing its ability to see through the radio noise.

ONLY A SMALL PERCENTAGE OF THE RADIO SPECTRUM IS AVAILABLE TO ASTRONOMY, 30 PERCENT HAVE BEEN RE-PURPOSED FOR CELL PHONES

Dozens of engineers and scientists throughout the world are devoting their efforts to managing the frequencies that they use to reveal the secrets of the universe. After all, the economic pressure on the radio spectrum has increased enormously in recent years, especially with the expansion of wireless communications, including those assisted by satellites in orbit.

With this in mind, some countries have introduced radio quiet zones for their radio astronomy observatories to complement the existing protection enjoyed by the few available frequency bands. However, for legal reasons these only apply within a given country's sovereign territory. For frequency coordination with other countries or satellite systems, only the Radio Regulations apply. This means that, even for the largest research projects, such as the Square Kilometre Array Observatory (SKAO) and the Atacama Large Millimeter/submillimeter Array (Alma), both of which have seen investments of more than one billion euros, only limited protection can be guaranteed. Without the Alma observatory in Chile's Atacama Desert, which consists of 66 antennas of between 7 and 12 meters in diameter, the first image of the shadow of a black hole would not have been possible. This image made headlines worldwide in 2019.

The Max Planck Institute for Radio Astronomy is Germany's leading organization within the field. We are the delegates of the Institute, enjoying membership in the Committee on Radioastronomy Frequencies (CRAF) of the

→

European Science Foundation. CRAF organizes the spectrum management activities of European radio astronomers and geodesists.

In addition to extensive committee work in numerous national and international groups, we investigate the potential that new radio applications have to interfere with radio astronomy observations. Such investigations have become increasingly complex in recent years. Topographical maps – elevation profiles of the landscape, and the extent to which this landscape is developed or covered by forests and meadows – are important for calculation purposes. All of this influences the extent to which radio waves spread. In some cases, we also use data on population density in the vicinity of telescopes as well as street maps to estimate how many cell phones or car assistance systems are transmitting in the area. If the resulting interference potential is too high, one option is to establish coordination or exclusion zones. For instance, within a radius of 6.5 kilometers of the Effelsberg radio telescope in the Eifel mountains, cars are normally not allowed to use certain radar systems.

TODAY, EVEN THE MOST REMOTE RADIO OBSERVATORIES HAVE A HOST OF TRANSMITTING AND INTERFERING SATELLITES IN THEIR VIEW

When dealing with interference from satellites in orbit, implementing an exclusionary approach is naturally more complex. Now even the most remote observatories have a host of satellites in their view. Protection zones are difficult to enforce in this context. Of course, a regulatory authority could ask operators to switch off satellites on a voluntary basis when they fly over an observatory. However, this would severely restrict the operation of a satellite constellation, and cross-border cases are complex to handle, too. This means that the easiest solution remaining to administrative bodies is to ensure the effective separation of the frequencies over which astronomers receive signals and satellites are allowed to transmit. They have to weigh up scientific, economic, and, in some cases, geostrategic interests as part of this process. It should come as no surprise that some states are currently giving priority to the latter. Unfortunately, the effect of this is that radio astronomy is increasingly limited to conducting measurements within allocated frequency bands – with appreciable consequences for astronomical research.

Modern technology also brings advantages as satellite operators have new options to limit interference. When satellites communicate with one another and with ground stations, a lower transmitter power output is now required, as receivers have become more sensitive. It is also possible to control the direction in which a satellite emits radiation – ideally only in the direction of the receiver ground terminals and not toward a radio telescope. However, it remains to be seen whether these technologies – if they are actually put to use – can offset the enormous growth in satellite numbers.

Unfortunately, there is one additional problem with the satellite systems that has largely been ignored by the International Telecommunication Union to date. The electrical and electronic subsystems of a satellite unintentionally generate electromagnetic leakage radiation that is completely independent of the actual transmission of the communication signals. This phenomenon is also present in the consumer electronics we use every day. While the latter are subject to mandatory standards, these do not currently apply to satellites. Certain limits are specified by space agencies and the military, but these are not intended to protect radio astronomy. Their sole aim is to prevent subsystems from disrupting one another. The launch system, for instance, needs to work perfectly and ensure that satellites enter into orbit safely. A recent research paper has shown that such leakage radiation may cause serious issues for certain radio astronomy projects, even in frequency ranges that are reserved for radio astronomy.

So, what can be done? What actions can be taken in the interest of basic astronomical research? The wheels of international diplomacy and regulation are famous for turning slowly. The Telecommunication Union may be one of the best functioning international institutions, yet there are still three to four years between World Radiocommunication Conferences, which is the only place where changes to the Radio Regulations can be made. And an additional four years of preparation time is usually required before a topic can be added to the World Radiocommunication Conference agenda. During this time, leading new-space companies such as OneWeb and SpaceX can launch thousands of satellites into orbit, where they remain for years or even decades without the option for improvements.

THE WORLD RADIOCOMMUNICATION CONFERENCE IS THE ONLY PLACE WHERE CHANGES TO THE RADIO REGULATIONS CAN BE MADE

At the last World Radiocommunication Conference in Dubai in 2023, the European Committee on Radioastronomy Frequencies, alongside sister organizations from other continents, did at least draw sufficient attention to the problems facing astronomy. The community of states has placed two items onto the agenda of the upcoming Radiocommunication Conference in 2027 which look at improved protection for radio astronomy with respect to satellite constellations. But this is only the first step in a long journey, because the aim of these agenda items is to better enforce existing protection criteria and streamline procedures. Unfortunately, new frequency allocations to radio astronomy are still a distant prospect. For that reason, science is currently reliant on space companies voluntarily taking measures to protect astronomy, until the regulatory situation has improved. For this purpose, the International Astronomical Union has founded the Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference. Science, industry, and administrators come together here to seek new solutions for enabling the coexistence of astronomy and satellites. There’s little time left to act. ←