Astronomy and the Environment

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Recommendations

- Astronomy groups and universities to support dark sky conservation and light pollution mitigation tactics and research
- Astronomy groups and observatory sites to work with government and satellite companies to mitigate satellite disruption to observatories
- That the Decadal Plan addresses the increasing impacts of climate change on astronomy alongside the impacts of astronomy on the climate, including specific recommendations on improving the way we measure our impact on climate (e.g. auditing, reporting, sustainability targets), reducing the carbon impact of astronomy in Australia and adapting astronomy practices to be resilient to a low-carbon world

The environment's impact on astronomy

Dark skies

Our ability to conduct astronomy is deeply linked to the surrounding environment. With the growing issues of light pollution, atmospheric interference, and wavelength congestion, the practice of astro-environmentalism has become essential for the future of astronomy.

The preservation of dark skies is crucial not only for astronomy but also for the environment, public access to the night sky, and human well-being. The Siding Spring Observatory, Australia's largest optical astronomy observatory is located over 500 kilometres from Sydney and is Australia's first and only certified Dark Sky Park. However, despite its remote location, it still suffers from skyglow caused by light pollution from Sydney and other surrounding metropolitan areas (The Warrumbungle's Dark Sky Project, 2016). Such drastic artificial lighting of the night sky not only impacts astronomical observations but can also have tragic effects on native species (e.g. Aulsebrook 2020, Department of Environment and Energy 2020). Further, for those who wish to engage in the night sky organically, less than 5% of Australians live in areas where they can view the Celestial Emu or the Milky Way due to light pollution (Falchi et al., 2016).

Currently, Australia has six designated dark sky locations, including communities, parks, reserves, and sanctuaries, that collectively preserve over 4,000 square meters of dark sky (Dark Sky 2024). Despite these efforts, the vastness of Australia's landscape presents a significant opportunity for expanding dark sky conservation, ensuring that all Australians can access and appreciate the night sky.

In Coonabarabran, the town nearest to the Warrumbungle's Dark Sky Park light pollution has remained relatively stable, thanks to the local council's dedicated dark sky preservation efforts. their strategies include shielding lights and directing them downward, using timers, and eliminating unnecessary lighting within the Dark Sky Park (National Parks NSW 2024). However, these mitigation practices shouldn't be limited to designated Dark Sky Places. Expanding these efforts across Australia would benefit both its people and ecosystems, safeguarding the unique natural resource of the southern sky.

Satellites

The recent surge in satellite launches, particularly those forming large constellations, pose an additional threat to astronomy. Companies SpaceX, Amazon and Eutelsat OneWeb have collectively launched approximately 7,000 satellites into Earth's orbit in the past six years but aim to launch close to 50,000 satellites in total in the coming decade. These satellites are primarily intended to provide global high-speed internet and telecommunication services. However, these satellites also present significant challenges for astronomers. The vast number of reflective objects in orbit not only intensifies global skyglow, affecting even the darkest observatories, but also creates streaks in astronomical images as they pass overhead, leading to data loss. Additionally, the scattered light from these satellites causes radio interference, further complicating radio observations.

Numerous telescopes worldwide are already feeling the impact of these satellite megaconstellations. The Hubble Space Telescope experienced at least one satellite streak in 2.7% of its observations prior to 2021, a figure expected to rise to 50% in the coming decade (Kruk 2023). The Zwicky Transient Facility in the United States reported that 18% of its observations were contaminated by satellite streaks in 2021, a sharp increase from 2019, with projections suggesting that 100% of twilight observations will be affected once Starlink reaches 10,000 satellites in orbit (Mróz 2022). Similarly, the Vera C. Rubin Observatory in Chile estimates that 32% of its observations will be impacted if Starlink achieves its goal of 42,000 satellites (Vera C. Rubin Observatory 2022). These growing concerns underscore the urgent need for strategies to mitigate the loss of valuable data and the waste of substantial financial investments in cutting-edge telescopes due to the adverse effects of satellite megaconstellations.

The increase in skyglow caused by these megaconstellations is another major concern. Kocifaj et al. (2021) found that after Starlink's first megaconstellation launch, the sky's brightness increased by 10% due to reflected and scattered light from the satellites. This is troubling, as scientific observations require that skyglow not exceed 10% of Earth's natural skyglow (Cayrel 1979: 215).

Radio astronomy is also impacted by these satellite constellations. The Australian SKA-LOW instrument detected signals from Starlink satellites, showing a range of behaviours including periodic bursts and steady transmissions at 137.5 and 159.4 MHz (Grigg et al. 2023), despite being located in a radio quiet zone. Similarly, the LOFAR instrument in the northern hemisphere has reported contaminated observations in the 110 and 188 MHz bandwidths, two orders of magnitude lower than the intended telecommunications bandwidth (Vruno2023). This underscores the need for regulatory bodies to extend terrestrial radio regulations to include non-terrestrial sources.

The International Astronomical Union has emphasized the importance of increased collaboration with satellite operators and regulatory bodies to address these challenges (Vruno, & Isidro. 2023). While companies like Starlink have begun consulting with astronomy groups and implementing measures to reduce their impact on astronomical observations, these efforts are still limited. For example, Starlink has tested signal redirection and signal cessation to avoid interference with telescopes, but these measures have only been applied to a few observatories worldwide (SpaceX 2024). Additionally, while Starlink initially introduced visors to reduce light scatter from its satellites, these were later discontinued due to issues with the satellite's laser communications (Crane 2023). Other companies, like OneWeb, have opted for fewer satellites than originally planned, but even a relatively small number of satellites can have a significant impact on astronomical observations.

In conclusion, the rapid increase in satellite megaconstellations presents a growing threat to both ground-based astronomy and the natural environment. It is essential that efforts to mitigate the impact of these satellites on dark skies continue and that regulatory bodies take stronger action to protect the night sky for future generations.

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Climate change

As well as affecting global society, climate change is already impacting the astronomy profession in significant and quantified ways. Extreme weather events alongside the increasing intensity of weather more generally can be linked directly to observatory damage, such as storms at Arecibo Observatory and Maunakea and fires at Mount Stromlo Observatory, Siding Spring Observatory, Lick Observatory and Mt Graham Observatory (for details, see Chapter 17 of "Climate Change for Astronomers" by Rector et al. 2024 and references therein). In addition to these damaging and destructive consequences of climate change, daily operations of facilities and observatories are also being affected by environmental changes including increasing winds, more extreme temperature conditions, increasing atmospheric turbulence and increasing particulate matter in the atmosphere. These changes to climate impact both the staff of institutions and, in the observatory context, the quality and amount of data that can be collected. It is expected that the effects of climate change on astronomy will only grow in the coming decade, though the rate at which the severity of the impacts increase is yet to be understood. Thus, it becomes critical, when thinking about the future of astronomy in Australia, to consider ways in which we prepare our institutions, facilities and observatories to maximise their resilience and robustness to climate change.

Astronomy's impact on the environment

Carbon footprint of astronomers

Studies over the last decade (and especially the last five years) have sought to characterise the carbon footprint of astronomers in detail, with the goal of understanding where the largest gains can be made. Stevens et al. 2020 showed that the biggest contributions to carbon footprint for a case study of Australian astronomers came primarily from supercomputing/observatories and from travel (especially by senior astronomers). Other studies globally have corroborated this result, although the relative fraction varies depending on location and facility (e.g. van der Tak et al. 2021, Knodlseder et al. 2022, Martin et al. 2022, McCann et al. 2022). Since then, Australia has shifted towards greener computing powered by renewable energy (including OzStar becoming 100% renewable powered from July 2020 joining the already sustainable NCI infrastructure, and Pawsey Supercomputing Centre reducing its net emissions via the addition of rooftop solar power and other optimisations), and future observatories are increasingly obliged to consider their carbon footprint as demonstrated by sustainable pledges e.g. by SKAO. Some of the more extreme stances suggest that the future growth and development of the astronomical observational facility landscape should be heavily tempered by the need to reduce climate impact (e.g. Knodlseder et al. 2024), while others note the need to balance the societal good of astronomy against its cost and impact on the broader environment (e.g. Hennebelle et al. 2024).

Considering travel, a detailed study by Gokus et al. 2024 comprehensively examined the carbon contributions from astronomy conferences in 2019. They found that the summed carbon amounted to 42,500 tons of CO_2e and that the summed distance travelled by astronomers in 2019 was 1.5x the distance from Earth to the Sun. It is worth noting that this carbon contribution is heavily imbalanced when considering the impact of wealth and privilege, in that the data showed a strong correlation between human development index (HDI) and the number of conference attendees at meetings (and thus, in summed carbon impact). This means that astronomy-related travel, particularly for conferences, is not just connected to considerations of future sustainability, but also to the future of accessibility and inclusivity in astronomy, since this current mode of collaboration largely excludes a large fraction of the world. The widespread increase in adoption of hybrid and online modes of meeting since 2020 has had a significant impact on improving accessibility (e.g. Sarabipour 2020, Wu et al. 2021), and improving technologies offer many opportunities for effective online interaction (e.g. Moss et al. 2021, Lowell et al. 2022, Frost et al. 2022, Tasker et al. 2024).

Considerations for observatories

Both current and future observatories will need to be increasingly robust to the impacts of worsening weather conditions and extreme events as evidenced by the examples outlined above. This requires improved monitoring and assessment of environmental conditions around sites and of possible supply chain risks due to local or global disruption to characterise any significant changes as early as possible, as well as the proactive preparation of both sites and instrumentation to be resilient to the most impactful predicted changes they will experience (e.g. temperature, storms, wind conditions). The carbon accountability of observatories and facilities, both in individual cases and as a collective astronomical landscape in Australia, will become more important, resulting in more emphasis on accurately measuring the carbon cost of facility operations and seeking ways to optimise or reduce the cost as well as a shift towards more sustainable practices in the construction, operations and eventual shutdown of facilities.

Considerations for collaboration

The impact of astronomy travel and modern ways of working is a complex issue to resolve, in that there are currently limited sustainable means to replace air travel, particularly when it comes to traversing continents. While in some contexts increased overland modes (e.g. trains, electric vehicles) can be a solution for local travel, this does not scale well to the global context, nor is it currently particularly viable in the Australian context. There remains within the community a need to meet in person for particular forms of interaction, though the optimised fraction required is yet to be determined. Technology has already greatly improved the ability for collaborations to function effectively across large distances, especially over the last decade, and many (if not the majority) meetings in astronomy are hybrid or online by default. The next decade will see an increasing need to utilise different modes of communication to their best impact, optimising our approaches to be maximally useful for the minimum cost in carbon, budget and effort. Given current predictions, it is not unfeasible to consider that astronomy research itself may become existentially threatened under evolving world conditions (e.g Thierry et al. 2023, Rees 2023), and thus future-proofing the field to the greatest extent possible is vital in the coming decade.