Part 10. The IAU in the future

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Astronomy and the IAU in the next century

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Abstract. The first hundred years of the IAU have witnessed scientific and technological progress in astronomy beyond anything imagined at the time the IAU was founded in 1919. What will the next hundred years bring? How do we engage with other sciences, now that our field is becoming more multidisciplinary? How do we convince governments to continue funding our field, in particular the ever more powerful telescopes? And how do we continue to inspire and involve people worldwide in our exciting adventure through space? A brief forward look into the next decade and beyond is presented, with some challenges highlighted.

Keywords. history of astronomy, telescopes, sociology of astronomy, miscellaneous

1. Introduction

The past century has seen remarkable achievements in astronomy. One hundred years ago, the foundations of physics were undergoing a fundamental transformation and our understanding of our place in the Universe has subsequently expanded explosively, as illustrated vividly in the IAU 100 years *Above and Beyond* exhibition (van Dishoeck *et al.* 2018). For example, in 1919 we did not know what makes our Sun and other stars shine, nor how the elements in our bodies were formed. Stars were thought to have eternal life, rather than going through a cycle of birth and death. Our Universe was thought to be relatively small and static at that time. And speculations about planets around other stars and the possibility for life elsewhere in the Universe were mostly in the realm of philosophy and science fiction, rather than based on hard scientific evidence.

Progress in astronomy is driven by technological advances. Table 1 summarizes a handful of examples of how much further, deeper and sharper we can now see into the Universe compared with a century ago (van Dishoeck *et al.* 2018). Moreover, not only telescopes on the ground at visible wavelengths are used, but observations across the full range of the electromagnetic spectrum are exploited – from gamma and X-rays to far-infrared and radio waves – thanks also to the advent of astronomical observatories in space over the last 60 years. Satellites have visited and taken close up pictures of all of the planets in our Solar System and their moons, and have even landed on comets and asteroids. Photons are no longer our only probe of the Universe: cosmic rays, neutrinos and gravitational waves also reveal an important part of the story of the astrophysics of stars and galaxies.

We now know that our Universe is 13.7 Gyr old and that it is composed for 96% of mysterious dark energy and dark matter. Radiation from the earliest galaxies emitted when our Universe was only a few hundred million years old has been detected and demonstrates much more vigorous star formation at that early stage. A supermassive black hole may well be lurking in the center of nearly every large galaxy. Large scale simulations provide increasingly realistic insight into the physical processes that shape and assemble galaxies. Supernovae and mergers of neutron stars produce the most powerful explosions in the Universe, and the origin and composition of the cosmic rays produced

Table 1. Some comparisons between 1919 and 2019[a]

Item	1919	2019
No. of IAU members	207	13569
No. of research observatories	100	2100
Distance reached by optical observations [Mpc]	1	10000
No. of known planets	8	$\sim$4000 + 8
No. of known galaxies	1	few $\times 10^{11}$

[a]Adapted from *IAU 100 years Above and Beyond* exhibition

in some of these explosions is being unraveled. The formation history of our Milky Way and neighboring galaxies is being revealed through detailed studies of the motions and elemental abundances of individual stars.

Within our own Galaxy, nearly 4000 exoplanets orbiting stars other than the Sun have been found, the majority of which have masses between that of Earth and Neptune, surprisingly different from our Solar System planets. New facilities allow astronomers to zoom in on the construction sites of new stars and planets, where water and increasingly complex organic molecules – the precursors of life – are found. Astronomy clearly continues to thrive in all its aspects, and the IAU has played a role in making this happen by bringing people together worldwide.

What will the next century bring for astronomy and the IAU? Below a brief glimpse into the next decade and beyond is presented.

2. The IAU in the next decade

The mission of the IAU is to promote and safeguard astronomy in all its aspects (research, communication, education and development) through international collaboration. To mark a century of the IAU and prepare for the next decade, the IAU Strategic Plan 2020–2030 has been approved at the XXX'th General Assembly in Vienna. It presents an overview of all of the activities of the IAU along with priorities, key goals, mandates, and specific actions for the next decade.

Following the highly successful *International Year of Astronomy 2009*, the IAU has moved from an organization focused primarily on advancing the field of astronomy to one that increasingly shares its knowledge with society and promotes the use of astronomy for development, teaching and education across the world. The IAU does so through a number of Offices in its member countries (Fig. 1), specifically (i) the *Office for Young Astronomers* (OYA, Norway), which has as its main activity the *International School for Young Astronomers* (ISYA), (ii) the *Office of Astronomy for Development* (OAD, South Africa), (iii) the Office for *Astronomical Outreach* (OAO, Japan) and (iv) the still to be established new *Office for Astronomical Education* (OAE).

The new Strategic Plan includes five overarching goals that relate to the activities of the Executive Committee (EC), Divisions, and Offices as follows:

- *Goal 1*: The IAU leads the worldwide coordination of astronomy and the fostering of communication and dissemination of astronomical knowledge among professional astronomers (EC, Divisions, Commissions, Working Groups).
- *Goal 2*: The IAU promotes the inclusive advancement of the field of astronomy in every country (all; OYA; ISYA).
- *Goal 3*: The IAU promotes the use of astronomy as a tool for development (OAD).
- *Goal 4*: The IAU engages the public in astronomy through access to astronomical information and communication of the science of astronomy (OAO).
- *Goal 5*: The IAU stimulates the use of astronomy for teaching and education at school level (the new OAE).

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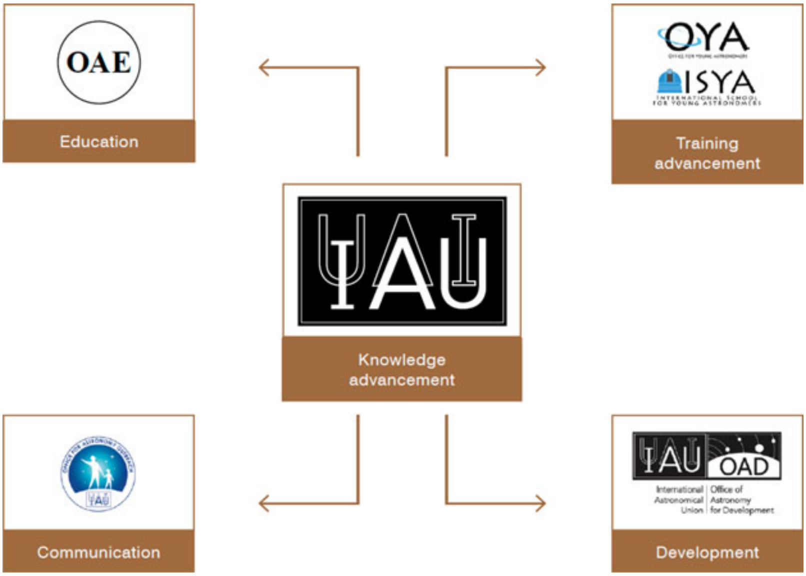

Figure 1. Interconnection of the Offices of the IAU.

Goal 1 on advancing astronomy includes not only stimulating and facilitating the sharing of astronomical knowledge among professional astronomers worldwide through IAU General Assemblies (GAs), regional meetings, symposia and co-sponsored meetings, but also the coordination of professional tasks such as dark and quiet sky protection, setting astronomical standards and naming of astronomical objects. The IAU recognizes excellence in astrophysics through prizes at senior and junior level and aims to diversify its portfolio. The IAU maintains interactions with other fields, most notably through representation at the International Science Council.

This new IAU structure is flexible enough that it can adapt to new developments in astronomy and society over the next decade. It also matches well with several of the United Nations Sustainable Development Goals. However, it requires significant effort from its members to make it work, given its broad and distributed scope. In the following, a personal view on three longer-term challenges for astronomy and the IAU over the next century are highlighted.

3. New facilities

Astronomy needs a continuous stream of new facilities to flourish and advance. In 1919 the most powerful optical telescope was the 2.5-m Hooker Telescope at Mt. Wilson. In 2019, a dozen 8–10-m class optical telescopes are operative across the world, and 20–40-m telescopes are being planned and constructed. Joint partnerships on major instruments, observatories and missions are already common on an (inter)national and continental scale. As these facilities become larger and more expensive to design, build and operate, global collaboration becomes increasingly important to make them happen. A recent example is the *Atacama Large Millimeter/submillimeter Array* (ALMA), the first global partnership in modern astronomy merging plans from three continents. The IAU has already set up a strategic working group on global coordination of ground and space astrophysics to foster international planning and explore how such partnerships can be built. This includes finding ways to engage small countries in international efforts, small and big. Increasing the activities of the working

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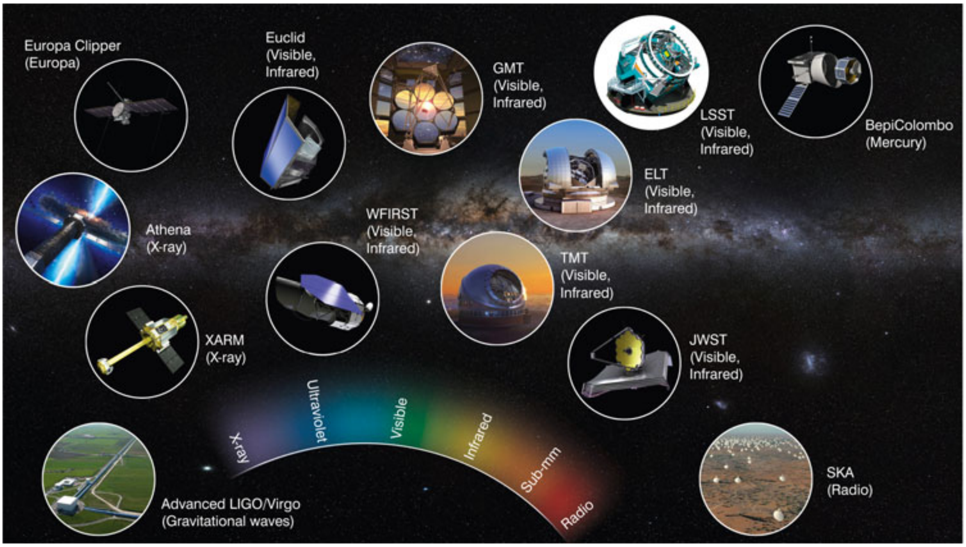

Figure 2. Major new facilities planned to come on line in the 2020–2030 timeframe. Source: *IAU Strategic Plan 2020–2030*, van Dishoeck and Elmegreen (2018).

group in the coming decade will be important. Part of this discussion also centres on how to handle and analyze the rapidly increasing data volumes from big survey telescopes.

Looking at the next decade, the astronomical community is fortunate to have several new powerful facilities come on-line in the 2020–2030 timeframe, as illustrated in Fig. 2, fully opening up new fields such as time-domain astrophysics and gravitational wave studies. Here one of the challenges will be to maintain the policy of open data archives (after a short proprietary period), which has been so successful in stimulating astronomy worldwide over the past decades.

The longer term future of facilities beyond 2030 is unclear: there are many dreams for even bigger telescopes on the ground and in space, but they become increasingly difficult to afford, even through global collaboration. Other fields besides physics and astronomy these days also require big research infrastructures to do frontline science, from atmospheric sciences and oceanography to life sciences, humanities and social sciences. Given the societal pressure to address environmental, climate and energy challenges, it is not surprising that these other fields increasingly have the ears and eyes of funding agencies. Astronomy has to continue to convince society of its unique inspirational nature and benefits for mankind and stress that our field requires long-term planning, not the short-term goals that politicians often want.

4. Multidisciplinary landscape

The Universe provides a unique laboratory in which to test the laws of physics under extreme conditions. Einstein's theory of relativity was verified using the deflection of rays from the Sun during a solar eclipse exactly a century ago. Astronomers now study phenomena involving enormous scales of length and mass (the size of the Universe), huge densities exceeding those that can be made on Earth (neutron stars), enormous gravitational fields (black holes), ultra-high vacua more empty than that of any Earth-based laboratory experiment (interstellar clouds) and immense energies and intense fluxes of particles and radiation (gamma-ray bursts and supernovae). Conversely, discoveries and advances in basics physics regarding detectors (e.g., CCDs,

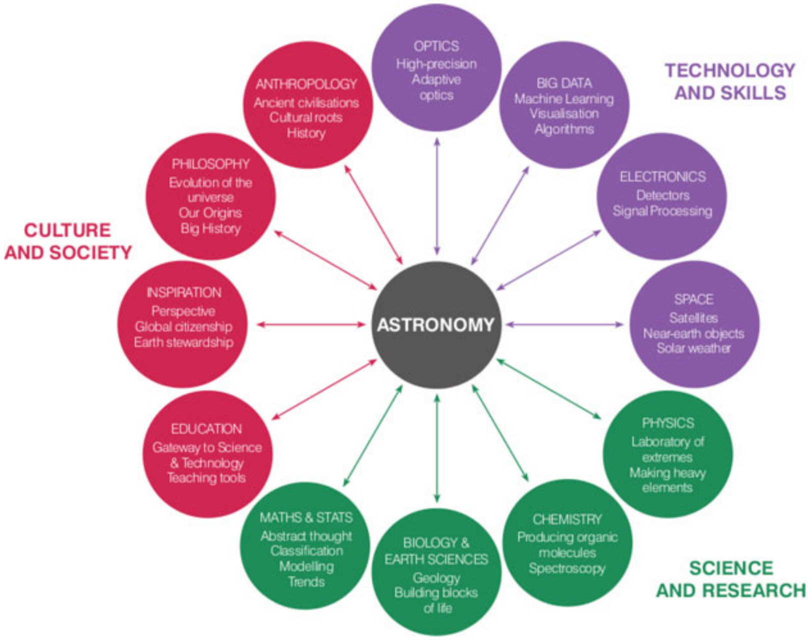

Figure 3. Connections of astronomy with other disciplines. Source: *IAU Strategic Plan 2020–2030* (van Dishoeck and Elmegreen 2018), based on a similar figure on the cover of the *2011–2020 Astronomy for Development Strategic Plan* (Miley 2009).

SIS junctions, TES, MKIDS), electronics, materials (filters, light-weight structures), ... have driven astronomy forwards. Thus, astronomy and physics have long progressed hand in hand.

Mathematics is a neighbouring field that has been at the foundation of astronomy since its earliest beginnings, from the computation of orbits and ephemerides using celestial mechanics to using Fourier transforms to analyze interferometric radio data.

Over the last decades, it has become clear that deep knowledge from additional disciplines needs to be included as well: informatics, chemistry, biology and geology are obvious examples. Interdisciplinary topics such as astroparticle physics, computational astrophysics, astrochemistry and astrobiology are emerging worldwide. Moreover, astronomers have long-standing connections with historians, philosophers, anthropologists and other humanities scholars, and are starting to engage with the social sciences. Figure 3 illustrates these many connections.

The IAU and astronomers worldwide need to adapt to this changing and increasingly multidisciplinary landscape in the coming decades. As a start, this involves inviting increased numbers of scientists from other fields to astronomy meetings on a regular basis and making them feel welcome, so that collaborations can start and flourish. The IAU should set an example by encouraging multidisciplinary symposia such as IAUS 345 on Origins.

No scientific community can function without sufficient funding to carry out its research, analyze the increasing amounts of data, and train new young people in the field. Astronomy has done well over the past decades, partly because of funding associated with large space missions (in some countries) on top of that available through national science foundations. However, multidisciplinary collaborative programs are emerging worldwide, sometimes at the expense of monodisciplinary grants, so astronomers need to position themselves for such programs. Fortunately, astronomy has much to offer

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in these broad collaborations, but it requires time investment and efforts to learn to speak each others' language and to formulate the right questions that can be addressed jointly.

5. Diversifying the astronomical family and beyond

The IAU has been the focal point for astronomers from across the world to come together and exchange ideas. The IAU will continue to stimulate this worldwide interaction through its travel grants to IAU symposia, General Assemblies and regional meetings. The IAU strives to be an inclusive organization in which all astronomers, regardless of nationality, ethnicity, religion, gender or disability are welcome at all activities (van Dishoeck and Elmegreen 2018). It also encourages the younger generation to participate more actively in IAU matters through the new Junior Members category.

A major challenge for the next decade and beyond will be to improve the balance of IAU members to better reflect the worldwide population. The IAU working group on Women in Astronomy has been active for many years and efforts to improve the gender balance have been ongoing in many countries, but the fraction of women in the IAU is still disappointingly low, less than 20%. The same holds for other groups. The ISYA schools aimed at students in developing countries have been very successful in advancing the careers of astronomers from those countries. Much more work is needed, not only to stimulate more women and minorities to enter the field, but especially to retain them and make them part of a more diverse astronomical family.

At the same time, it should be recognized more broadly that training in astronomy prepares students for much more than a career in astronomical research or instrumentation. The skills acquired in analyzing big data sets, performing large scale simulations, building and working with front-line technology and/or solving inherently complex problems makes astronomy students attractive to a wide range of sectors in society. Such a flow of people from astronomy to society is healthy for both sides and should be stimulated by preparing students and postdocs better for a possible career transition. The challenge for the OAD will be to implement the concept of 'Astronomy for Development' more prominently in developing and developed countries.

6. Conclusions

Astronomy is as exciting as ever, with new discoveries happening on a daily basis that address some of the biggest questions that mankind has. It also engages with society in many different ways, with the IAU having an important role in stimulating that interaction (Fig. 2). Astronomy has traditionally always been ahead of the curve compared with many other fields in new developments such as international collaboration on big projects, open data, open access, outreach and development, and it should stay so. Nevertheless, astronomy is still often regarded by politicians and funding agencies as a fundamental science with little use for society, even though the past century has demonstrated the opposite. Astronomers should continue to tell our discoveries and stories to the entire world, and stress the fact that astronomy provides a special perspective that can help broaden the mind and stimulate a sense of global citizenship and tolerance, increasingly important in modern society.

What will the next century bring? Nobody can predict, but wise words by Antoine de Saint Exupéry (1900–1944) may be appropriate†, here freely adapted to astronomy: 'If you want to do astronomy, don't drum up people to collect components and don't assign them tasks and work, but rather teach them to long for the endless immensity

† '*If you want to build a ship, don't drum up people to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea.*'

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and beauty of the Universe.' As long as we keep this long-term vision, inspiration and passion in mind, astronomy and the IAU will continue to flourish throughout the next century.

7. Discussion

Unidentified: You haven't mentioned the manned exploration of space ... but you mention that, taking into account the possible impact on society, humanities, etc. that are also (obviously) important for astronomy in general?

van Dishoeck: Most scientific questions in astronomy can be answered best by unmanned satellites at distant locations from Earth like the L2 point. Manned spacecrafts have been particularly valuable for servicing missions, most notably to the Hubble Space Telescope to replace and upgrade instruments and repair components. For solar system research, having actual samples from Mars, asteroids or comets brought back to Earth is highly valuable, but so far unmanned sample return missions appear to be simpler and less costly to implement.

Simmons: Comment on value of historical telescopes in outreach based on my experience at Mt Wilson Observatory over 35 years.

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