**Global Coordination of Ground and Space Astrophysics: Triennial Report 2021-24**

Co-Chairs: Roger Davies and Rachel Somerville

29th April 2024

## Summary

The Working Group's programme 2021-24 focused on preparing for and delivering the sessions for the 2022 Busan General Assembly, the 2024 Kavli workshop on *Probing the Universe from Far-infrared to Millimeter Wavelengths* and planning for the Working Group sessions at 2024 General Assembly in Cape Town. This report focuses on the Kavli workshop and planning for the Cape Town sessions, we include our report on the 2022 GA and our latest annual report as Appendices to cover the remaining activities.

## Report

### 1. 2024 Kavli workshop on Probing the Universe from Far-infrared to Millimeter Wavelengths: Future facilities and their Synergies.

The workshop was held in the Hameetman Auditorium, Cahill Center for Astronomy and Astrophysics, at Caltech from March 26-28th 2024. We are very grateful to the organisers of the workshop: Ewine van Dishoeck, George Helou and Jonas Zmuidzina. *The following description is taken from the meeting website.*

Scientific rationale: The physical conditions and structure of interstellar and circumstellar media dictate where and how stars and planets can form. Both the feedback from star formation and black hole driven activity are important processes in galaxy evolution that have a dramatic effect on the physics of the ISM. Important cooling lines of the ISM and key molecular diagnostics are found in the far-IR to mm wavelength region of the spectrum. This is also where the thermal emission from cold dust, and more generally the energy output from star-forming clouds and galaxies, peaks. These wavelengths therefore provide unique probes of relatively cool, dense interstellar material, central to the study of forming stars, protoplanetary disks, and young forming exoplanets. On larger scales they probe dust and dense neutral gas in the ISM of galaxies and around highly obscured accreting supermassive black holes. This spectral region thus offers key diagnostics of the physical conditions that are important for further progress across a broad canvas of astrophysics. The far-IR to mm region is also particularly rich in lines of a wide variety of molecules in gaseous and solid form, from simple species like water to increasingly complex molecules such as sugars, ethers, cyanates, and aromatic hydrocarbons. Following the trail of molecules from clouds to planet-forming disks and mature planets will elucidate the role they play in the emergence of life elsewhere in the universe.

Goal of the Workshop: Planning is underway for a new generation of facilities operating from the far-IR to mm wavelengths. The James Webb Space Telescope is now operating, probing the mid-IR out to 30 μm, hopefully for the next 10-20 years. ALMA continues to operate at mm wavelengths, and will be upgraded by 2030, but there are no plans yet for further enhancements in the 2030+ era. Following on from the pioneering work of the Spitzer and Herschel Space Observatory, there is great interest across multiple space agencies in a probe class/medium class far-IR space mission, and multiple mission concepts are being developed. The ngVLA is a proposed mm-cm class facility that may have 10x the sensitivity of the JVLA. At the lowest frequencies where ALMA operates, it may have 30 times longer baselines, yielding milli-arcsecond angular resolution.

The goal of this workshop is to examine the needs and requirements for different facilities at wavelengths from far-IR to cm in the 2030+ era (taking financial and programmatic constraints into account), to consider the synergies and complementarities among these facilities, and to explore how to maximize the scientific insights from the data they will yield.

The programme can be found at
https://conference.ipac.caltech.edu/Kavli-IAU/system/media_files/binaries/6/original/032524_Agenda_for_Printing.pdf?1711410095
The report for the workshop is in advanced draft and forms the basis of the programme for one session of the Working Group programme at the Cape Town GA.

**2. Planning for Working Group sessions at the Cape Town GA.**
The draft programme for the Working Group sessions is:
Tuesday, August 13: WG1-1 10:30-12:00: Session I: Future space missions
Chair: Richard Green

NASA programme: Mark Clampin (15 min)
ESA programme: TBD (15min)
ISAS/JAXA programme: TBD (15min)
Short presentations from other space agencies: India? China?
Discussion (20 min)

Tuesday, August 13: WG1-2 13:30-15:00 Coordination of future ground-based facilities,
Chair: Roger Davies/Matthew Colless

Optical/IR extremely large telescopes
US-ELT – Pat McCarthy (15 min)
ESO ELT – Bruno Leibundgut (15 min)
Possibly contributions from GMT & TMT
Discussion (15 min)

Radio Telescopes
Square Kilometre Array Observatory – Philip Diamond (15 min)
ngVLA project – Tony Beasley (15 min)
Discussion (15 min)

Tuesday, August 13: WG1-3 15:30-17:00 Future far IR + mm facilities:
Chair Ewine van Dishoeck (based around the outcomes of the Kavli workshop)

Introduction and overview: Ewine van Dishoeck (NL) (15 min)

Science panel with brief 8+2 min (50 min)
- High-redshift universe: Itziar Aretxaga (Mexico)
- Nearby galaxies: Eva Schinnerer (Germany)
- Variability: Lynn Hillenbrand (USA)
- Star formation: James Chibueze (South Africa/Nigeria)
- Planet-forming disks: speaker TBD

Discussion 25 min perhaps to include input from various countries (India? China? Australia?); brief comments from agencies/observatory directors and comments from audience.

Recap recommendations from Kavli-IAU workshop (2 min)

Wednesday August 14: WG1-4 10:30-12:00 Session IV: Co-ordination of transient follow-up: focus on O4 follow-up and planning for Rubin operations.
Chair: Samaya Nissanke
The programme is under construction.

**3. Working Group matters**

Roger Davies has been Chair/co-Chair of the Working Group since 2012 and will step down after the Cape Town GA. Matthew Colless has agreed to step into the Co-Chair role and has played a significant role in building the programme for the Cape Town GA. The Working Group wishes to continue functioning beyond the GA and request confirmation that the Executive wishes us to continue.

**Appendix 1**: Report of the IAU GA sessions of the Working Group on Global Coordination of Ground and Space Astrophysics, 8-10 August 2022

**Appendix 2**: IAU Working Group on Global Coordination of Ground and Space Astrophysics: Annual Report 2022-23

## Appendix 1

**Report of the IAU GA sessions of the Working Group on Global Coordination of Ground and Space Astrophysics, 8-10 August 2022**

*Co-Chairs: Roger Davies and Rachel Somerville*

**Summary**

The sessions spanned a wide range of topics. This summary lists the main conclusions taken from the sessions. There were a number of new aspects to the structure of the sessions, not least the greatly increased online participation. The effectiveness of these new approaches is discussed in the overarching commentary of the annual report. The programme is included as the Appendix.

- There was broad support for "Open Data", but it was recognised that there is no one definition or standard for Open Data -- there is a big difference between making raw data available and providing science-ready products.

- The move towards big interdisciplinary teams that are assembled to address multi-faceted problems and that include expertise in hardware, software, theory and simulations is driving a need for specific routes for recognition in each of those areas as well as through publications.

- Some common challenges came up again and again: increasing data volume and complexity; increasing importance of multi-wavelength and time domain science; increasing importance of Machine Learning and Data Science as tools for understanding data.

- There is an ever-present need for coordination in proposing for telescope time on multiple space and ground-based facilities, and securing the supporting funding needed. A topical example is PLATO's requirement for hundreds of nights of ground based, small telescope access to solve for orbital elements of transiting exo-planets. These have not yet been secured. While some small-scale programmes exist, multi-wavelength, multi-messenger investigations continue to suffer multiple jeopardy in telescope time assignment. This coordination will be increasingly important in the future and should perhaps be promoted more powerfully by the IAU.

- Archives are more likely to meet their goals when there is "funding and a mandate" for inter-operability and Open Data.

- There is a growing requirement for training students and early career researchers in different skills such as Machine Learning and working in large teams. This is perhaps an area where the IAU could lead.

All presentations are available at:
https://drive.google.com/drive/folders/1cEsXbFpyvpY06ztw-PIlYcCCtlO08Nw8?usp=sharing

### 1. The Working Group sessions

#### 1.1 Large facilities in the 2020's and beyond (ground and space)

We organised this session differently from earlier GAs. We asked three leading scientists to present an overview of current and upcoming space and ground facilities and their co-ordination. The motivation for this was partly time pressure (there wasn't enough time to hear from all the key agency heads) and partly an attempt to get a synthesis of activities across the range of international programmes. The individual presenters co-ordinated with a large number of project/mission heads in formulating their remarks and did an excellent job both summarising and synthesising.

Rachel Osten tackled the coordination of large space missions. She started by summarising the current programmes and future plans of NASA, ESA, JAXA/ISAS, and ISRO. The main challenges to overcome in international co-ordination and collaboration are:

- aligning the science goals – the same science needs to be high priority at a time when multiple agencies can gain funding for it.
- the diverse budget cycles of space agencies – they need to be able to commit to projects at the same time.

- the different appetite for risk amongst agencies. It was noted that JAXA saw international collaboration as a means of mitigating risk.
- the need for agencies to have an appropriate balance of leading missions and contributing to the missions led by others.
- finding a common fit to national space science culture, for example utilising the heritage of national programmes and (re-)using specific rockets.

The strong common message was that co-operative/collaborative programmes need to be led by a strong commitment to common science goals. One official described the approach to establishing a new partnership in space science as `a bit like dating' – it can be challenging, even painful, but in the end the outcome can be wonderful!

It is perhaps illustrative of the challenges faced by the space community that no observatory class X-ray and far-IR missions are planned for launch until the mid-2030s.

Osten also explored the approach different agencies have taken to open data. There are multi-faceted approaches to this: raw data is rarely scientifically useful except to experts; curated data has real value but some investment needs to be made in this, and those investing often wish to have exclusive or at least priority access. Time allocation models where PIs compete for data often allow the PI team a proprietary period. All these models are adopted by different agencies/missions – we return to this topic in session III.

Matthew Colless took on the Coordination of Large Ground-based facilities, limited to the optical-infrared ELTs and in the radio to the SKA + ngVLA and their precursors. There is much common ground in the science cases for these facilities. All ELTs stress the $D^4$ gains associated with diffraction limited performance in the infrared, in particular with reference to imaging exoplanets and characterising their atmospheres, and studies of star formation at high redshift.

ESO-ELT with an initial complement of three instruments, all fed by various type of adaptive optics (AO), is scheduled for first light in 2028. TMT also has AO at first light and three instruments. GMT utilises an adaptive secondary and the science case has more emphasis on relatively wide field applications. The governance models for these three projects are strikingly different. Whereas ESO is an international treaty organisation funded by annual subscriptions, GMT is an international consortium of institutions that pay into a central fund and can also offer `in kind' contributions that are co-ordinated by the project team. TMT is a partnership of institutions and national agencies with partners providing 'in kind' contributions from home base. There is much sensitivity surrounding the site choice for TMT, between Hawai'i and La Palma, and until that is settled there is necessarily uncertainty over the timing of first light. Both TMT and GMT will need NSF funding through the NOIRLab-run US-ELT program that is yet to be secured, though they were given very high priority by the US Astro2020 Decadal Survey. There is a consensus that ESO-ELT will start observing at least a few years ahead of either TMT or GMT.

These projects have for some time co-ordinated developments in particular technologies such as segment alignment, AO strategies, and coatings. The instrument complements are not the same, but there is considerable overlap. The proponents stress that there is much benefit to independent confirmation of major results with similar key instrumental capabilities on different telescopes. All-sky coverage is perhaps the major prize to be gained when TMT settles on a site in the northern hemisphere. GMT & TMT are co-ordinated by the US NOIRLab to work together on operational models (from proposals to data archives) and in the pursuit of key projects.

Turning to the radio, the gains available here over current facilities are enormous, with SKA and ngVLA potentially offering up to 10x improvement in sensitivity and 100x faster survey speed with 100x better image fidelity than current radio arrays. SKA is in the early stages of construction, while ngVLA is still in the design and development stage.

The two facilities have complementary science goals, with SKA focussed on lower (<15 GHz) frequencies for wide-field surveys of both non-thermal and thermal sources, while ngVLA is focussed on higher frequencies (>10 GHz) to produce higher-resolution images of thermal sources. Together they provide all-sky coverage and overlapping frequencies (between 1.2 and 15.4 GHz). Their complementary frequency coverage will enable individual sources from 50 MHz to 116 GHz to be characterised, enabling complementary tracer studies such as atomic (SKA) and molecular (ngVLA) gas. They can be used together as part of a global VLBI facility.

In terms of co-ordination, discussions between SKAO and NSF/NRAO are underway to explore a reciprocal access arrangement, but exploration of common approaches to data management, archiving, software development etc. remains to be initiated. At least three upcoming meetings will focus on coordination between these facilities and the science that can be achieved by using them together.

Co-ordination of ground- and space-based facilities was discussed by Ewine van Dishoeck. She stressed that many science investigations can only be fruitfully pursued if ground and space-based data for objects are available, yet this remains a difficult goal to achieve in practice. Ideally the two domains work together to produce insights that are greater than either can achieve separately – a good example being understanding gamma-ray bursts. Ewine highlighted topical examples such Euclid's dark energy investigation where the cosmic shear measurements come from space but the photometric redshifts required are measured on ground-based telescopes. Similarly, to probe resolved stellar populations in giant elliptical galaxies, the inner fields require AO corrected photometry from the ELTs to overcome the crowding, whereas the sensitivity of JWST is needed to characterise the outer fields.

The study of proto-planetary disks presents an interesting case study as the temperature gradients imply the need for both ground and space-based telescopes. ALMA has revealed abundance anomalies in C/O and C/H in dust traps embedded in the disks. While ALMA can probe the origin of these in the outer disks, JWST is needed for the inner disk.

The need for ground-space co-ordination is well illustrated by the PLATO mission that will observe planetary transits from space but needs radial velocity measurements from small ground-based telescope to solve for the orbits – 800 nights of 1-2m telescope time and 240 nights of 8m telescope time. This has not yet been secured and represents a major challenge for the scientific mission.

The study of exoplanets, particularly the aspiration to characterise the atmospheres of Earth-like planets with the next generation space telescopes, will not only require co-ordination across the two domains, but a multi-disciplinary study that encompasses not only astronomical facilities but also organic chemistry, atmospheric physics, microbiology, and life science disciplines to identify bio-signatures.

Session II opened with a discussion of these topics which, logically, is reported here. There was further discussion of the importance of `open data' with more elucidation of what it means to different groups. For example, while the NSF-funded part of GMT/TMT will be required to make data available in an archive, those with private funding will not be required to do so. The default for the ESO-ELT is for open access to data after a one-year proprietary period, although there will be special arrangements for time critical follow-up observations.

PLATO's need for ground-based observations underscored the requirement that such arrangements need to be put in place during the scientific planning of missions, perhaps even a decade before launch.

Sarah Pearce raised the interesting issue of training students and early career researchers for multi-messenger, multi-wavelength investigations. Such projects generally are also pursued by very large teams of researchers. Are we preparing students to have the skills necessary to be successful in such large diverse teams? This involves learning to work together and build trust in the contributions of other team members. There is a significant social preparation needed to make such teams succeed. Increasingly a wider range of skills are needed to make these teams work, including high level statistical prowess, familiarity with artificial intelligence & machine learning, and high-performance computing and software development. No team members will have all these skills but they all need to be brought together to attack the most import questions in astrophysical research. There are some excellent examples of very successful large teams, notably the Sloan surveys, but it is worth giving more thought to how we can train future researchers to do this most effectively. The reward system in our discipline will need to evolve to recognise the contributions from team members that are focused in critical areas beyond astrophysics.

**1.2 Global coordination for the next decade of science**

In this session, we asked scientists from a range of sub-domains to give short presentations on what kinds of coordination would be necessary to achieve the science goals of the next decade in their area. This session was quite effective, and the speakers identified positive examples of coordination and highlighted coordination mechanisms that would be impactful for their science. For example,

Laura Kreidberg stressed the importance of better estimation of the probability of finding exo-Earths around Sun-like stars. Such estimates feed into the design of a next generation large-UVOIR flagship space telescope that would be able to characterize the atmospheres of these Earth-like exoplanets. The most promising way to do this would be to build a global network of extreme high-precision radial velocity instruments. However, achieving this is hampered by the restrictions on funding between the ground and space agencies and clashes in priorities.
Another example from Scott Trager highlighted the importance of having a common calibration and uniform data across spectra from different telescopes and instruments. One needs to be able to combine the physical parameters about stars and stellar populations from these spectra without worrying about which survey or analysis method they came from! This is a very general point of great importance. He presented examples of successful efforts to mitigate this issue, e.g. from the asteroseismology and the GAIA project, and mentioned a new group (led by M. Valentini) that is working on cross-survey calibration and homogenization of data from SDSS-V, 4MOST, WEAVE, and DESI for galactic archaeology. They welcome involvement from other surveys.
John Silverman described how the next decade of black hole science will require high spatial and spectral resolution, will need to probe a broad range of scales, and will need broad wavelength coverage. This requires facilities both on the ground and in space, operated by different agencies and countries, and coordinating these will be challenging. Silverman also emphasized the need for coordination of computation, analysis, and theory with observational programs.
Lisa Kewley described how galaxy formation and ISM science requires a deeper understanding of gas accretion, star formation, and the interaction between galaxies and their ecosystems. As with the black hole science, this will be achieved by synthesizing data from a diverse array of facilities on the ground and in space, including JWST, LSST/VRO, ELTs, the Nancy Grace Roman space telescope, SKA/ngVLA, and Athena-X.
Ofer Lahav discussed the landscape for cosmology in the coming decade. He highlighted the challenges of coordinating very large surveys with imaging from the ground and photometric and spectroscopic redshifts from space. He also emphasized the potential of analyses that will be "everything cross everything" -- cross correlation studies of all available tracers of large-scale structure with one another, including CMB, galaxies, lensing shear signal, Sunyaev-Zeldovich effect, Lyman-alpha and X-ray. Lahav also emphasized the increasing importance of Machine Learning and other advanced statistical methods in all areas of astrophysics.
A point that came up in discussion was the inefficiency of having to write separate proposals for telescope time on different facilities, and often to have to write additional proposals for funding as well. There are some opportunities for joint proposals for key pairs of facilities -- for example we heard from Rachel Osten that a joint JWST-ALMA proposal opportunity is in the works -- but these are typically for small amounts of observing time. A coordinated opportunity that could support large programs requiring multiple facilities, which would provide the supporting funding at the same time (as with NASA GO proposals), could address some of these problems.

### 1.3 Global Coordination for Multi-messenger astronomy

The main activity of the Working Group between the Vienna and Busan General Assemblies was the organisation of the Kavli–IAU Workshop on the *International co-ordination of multi-messenger transient observations in the 2020s and beyond* held in Cape Town in February 2020. This was reported on by Brad Cenko and a complete description can be found in the white paper: https://arxiv.org/ftp/arxiv/papers/2007/2007.05546.pdf. The workshop was attended by 50 people from 18 countries, and discussed existing and potential bottlenecks for transient and multi-messenger astronomy, identifying eight broad areas of concern. Some are similar to the challenges faced by international collaborations generally, for example, data access policies, funding, theoretical and computational resources and workforce equity. Others, including, alerts, telescope coordination and target-of-opportunity implementation, are specific to the time domain. The workshop produced thirty-five specific recommendations to address these issues. The recommendations were not only aimed at collaborative groups and individuals, but also at the various organizations that are essential to making transient collaborations efficient and effective: including the International Astronomical Union, observatories, projects, scientific journals and funding agencies. The aim was to encourage

those involved in transient research to develop collaborations with greater impact and form more inclusive teams.

The session continued with presentations on gravitational wave facilities by Patrick Brady (ground based) and Kelly Holley-Bockelmann (LISA). Brady described the International Gravitation Wave Observatory comprising five stations in operation: LIGO (Hanford and Livingston), Virgo, GEO and KAGRA, with a sixth, LIGO India, under construction. The projected sensitivity and estimated number of detections of binary neutron stars for O4 (2023-4) and O5 (2027-8) runs into the thousands. If funding continues to be available it is planned to operate these facilities beyond 2028. The next generation facilities are the Einstein telescope, an underground facility in Europe with 10km arms that is in the ESFI 2021 roadmap, and Cosmic Explorer which is proposed to have two 40km arms using technology based on current ground-based detectors. Kelly Holley-Bockelmann reported that the LISA space interferometer will be sensitive to much lower frequency GWs ($10^{-2}$ – $10^{-4}$ Hz) produced by merging white dwarfs (all those in the Milky Way can be detected) or compact objects falling in to supermassive black holes. LISA's sensitivity will enable binary BHs between $10^4$ – $10^8$ solar masses to be detected to z=20 thus tracing the merger history of galaxies. It is planned for launch in the mid-2030s.

Multi-messenger observations triggered by high energy neutrino detection have proven to be a powerful tool to identify transient sources that radiate cosmic rays. Among them are AGN, GRB, core-collapse supernova, and TDE. From 2016 the IceCube neutrino observatory has operated a real-time alert system for fast ToO follow-up observations at all wavelengths from radio to gamma rays. The on-site analysis selects events that are likely to be astrophysical in origin, filtering out the vast background of atmospheric neutrinos, and sends them to the alert stream. The alert streams are categorized by "signalness", the probability of being astrophysical (not atmospheric). The "gold" alert stream constitutes neutrino events with `signalness' higher than 50%, there are around 10 such events per year. A new alert stream formed by multiple neutrino events from a same direction is planned for near future. This is sensitive to nearby (z<0.15) sources, which sufficiently reduces contamination for optical/NIR follow-up observations.

Gamma ray and cosmic ray facilities were discussed by Michael Backes. While introducing the still unknown origin of the highest-energetic cosmic rays as major motivation of the field, he highlighted the cross-connection between the different messengers of high-energy astrophysics: cosmic rays, neutrinos, and gamma rays. He exemplified this both for galactic sources of gamma-rays, like a young, massive stellar clusters, and for extragalactic sources, like blazars, as possible sources of high-energy neutrinos. He introduced the leading facilities for research into the highest energy cosmic rays, namely the Telescope Array (TA; in Utah/USA) and the Pierre Auger Observatory (AUGER; in Patagonia/Argentina) as well as the current generation of ground-based gamma-ray telescopes: the imaging atmospheric Cherenkov telescopes (IACTs): VERITAS (in Arizona/USA), MAGIC (on La Palma/Spain), and H.E.S.S. (in Namibia) as well as the surface detector arrays HAWC (in Mexico) and LHAASO (in China). The next generation instrument will be the Cherenkov Telescope Array, increasing the energy coverage as well as the differential sensitivity ten-fold over the current generation IACTs. A tenfold increase in sensitivity will also be achieved by the next-generation surface detector array, SWGO. Funds permitting, a continued operation of the current generation IACT in the Southern hemisphere will be highly beneficial for temporal coverage. The presentation concluded with highlighting the multi-wavelength connections particularly of the transient science cases through the entire electromagnetic spectrum.

In the discussion which followed panel members Yossi Shvartzvald, Zeljko Ivezic, Samaya Nissanke, Victoria Kaspi, Solomon Tessema were asked four questions.

1. What is one scientific problem in multi-messenger astrophysics that is ripe for progress in the next decade?
2. What data are needed to make that progress?
3. What facilities and coordination mechanisms are in place to get that data?
4. What further facilities and coordination mechanisms would be required for full realization?

A range of interesting answers emerged.

Shvartzvald addressed the origin of origin of heavy elements beyond iron which requires (i) fast localization of electromagnetic counterparts of NSBH/BNS GW events to a precision of a few arcminutes or better still arcseconds (ii) early ultraviolet images and spectra, as MMA events are hot.

Ivezic identified the origin of neutrinos detected by IceCube Observatory as the one problem to follow up. He proposed that this requires rapid optical follow-up of IceCube alerts as ToO observations with the Rubin Observatory. Once Rubin has localised the event, spectroscopy across a wide wavelength will be needed to determine the nature of the source of accelerated particles.

Nissanke proposed to use gravitational wave standard sirens to measure the Hubble constant. This would require 100s of GW sources to be identified in galaxies and followed up with spectroscopy to give redshifts. This requires fast and accurate localisation of GW sources, likely utilising machine learning and AI techniques, and dedicated follow-up as the number of triggers will increase dramatically in the coming decade.

Kaspi addressed the problem of Fast Radio Bursts, and their utility as novel probes of Large Scale Structure. This will need 100-1000s of FRB detections from CHIME with outriggers for wide-field and produce sufficiently well localized positions to identify host galaxies. A multi-wavelength alert system will allow these to be followed up in the optical/IR to determine the galaxy type and redshift – and in turn wide-field optical/IR imaging and spectroscopic galaxy surveys are needed to determine the nature of the sources. The challenge is to measure redshifts for 1000s of FRB counterparts.

Tessema addressed variability in the total solar flux based on an investigation using Helioseismic and Magnetic Imager data and the total solar irradiance measured by SOHO/VIRGO.

**1.4 Archives & Access**

Session IV opened with a panel discussion on the role of current facilities in the coming decade, as larger and more capable facilities come online. We heard from Marc Balcells representing ING, who reported that these facilities would be used for a mix of very large surveys, open time calls, time domain, and supporting programme on larger facilities. ING facilities will also be important for training. Marc stressed the importance of flexibility. A challenge they face is making 30 years of raw data in their archives available as user friendly "open data".

Yashwant Gupta discussed the future role of the GMRT, which remains the most sensitive facility at meter wavelengths. It will play an important role as a pathfinder for the SKA, and once SKA is in operation, will provide complementary northern sky coverage, and detailed follow-up of interesting objects such as pulsars and transients. They will support open data through the SKA regional centre in India.

Alberto Bolatto reported on the NRAO facilities. NRAO has appointed an advisory committee to evaluate VLA operation modes during the construction of, and transition to, ngVLA. One possibility under consideration is to offer a single waveband only. The use of NRAO facilities is proposal driven and will continue to be so. The advisory committee is considering a proposal to reserve time during the transition for follow-up of transients discovered with the Vera Rubin Telescope.

Michitoshi Yoshida discussed the Subaru telescope. Subaru will be a more survey-orientated facility over the next decade enhanced with several new instruments, including the multi-object Primary Focus Spectrograph (PFS) and the ground layer adaptive optics system ULTIMATE-Subaru. The Subaru Strategic Program (SSP) will provide 200-300 nights for large survey programs using the new instruments. Subaru will also provide support for the Roman and Rubin facilities, and will continue to offer Open Use Time.

Adam Bolton discussed the future of the NOIRLab portfolio of telescopes. The focus of NOIRLab's current facilities, including Kitt Peak, Gemini, and Cerro Tololo, will be providing support for surveys and data science with DESI at the Mayall telescope, and DECam and NEWFIRM at the Blanco telescope. They plan to support time domain astrophysics through the Astronomical Event Observatory Network (AEON). At the WIYN telescope a precision radial velocity spectrometer, NEID, will measure stellar radial velocities to a precision better than 30cm/s, potentially detecting earth-like planets.

We heard from Petri Vaisanen on the future role of SALT and MeerKAT in South Africa. These facilities are relatively new and still growing and are keen to enter into further international collaborations and partnerships. They are ideally suited for training and capacity development. The plan is that facilities on the Sutherland Plateau will work together as a giant transient AI machine, following up alerts.

The second part of Session IV covered the challenges and priorities connected to coordination of archive facilities around the world. Bruce Berriman presented the IVOA perspective. The IVOA was established in 2002 and contains 23 national VO projects. The VO is an ecosystem of interoperating tools and services that enable multi-dataset analysis. The IVOA is planning for the challenges associated with the data of the next decade, which they characterize with the 5 V's (volume, velocity, value, variety & veracity). These will require new analysis techniques, new formats, and new technologies. Engagement from the community is critical, and the IVOA has carried out a survey of data providers to better understand their requirements. Their technical work is expanding into areas such as Radio Astronomy, Time Domain Astronomy, and Machine Learning.

Vandana Desai presented the perspective from the NASA archives that span a broad range of wavelengths and domains, and include ADS (literature), HEASARC (high energy), IRSA (Infra-red), MAST (Hubble, JWST, Kepler, K2, TESS), NED, and NEA/ExoFOP (exoplanets). NASA works closely with the IVOA on protocols, data models, and metadata conventions. The NASA Astrophysics Data Executive Council advises on how to enhance coordination among NASA's archive centers. Some of the challenges facing the NASA archives in the coming decade include: large and complex datasets, new messengers and instrument modes, time domain, novel data types, importance of simulated data, and the importance of Artificial Intelligence, Machine Learning, and advanced data analysis techniques. Desai reported that coordination and collaboration *within* NASA astrophysics has improved greatly in the past few years, and cited the importance of "funding and a mandate" to do so!

Adam Bolton presented the NOIRLab archives perspective. NOIRLab combines all NSF funded assets under a single organization, and was started in October 2019. Some of the challenges facing NOIRLab archives are 1) the explosion of data-driven research opportunities, which require synthesizing massive datasets; 2) the explosion of time-domain science and the need for real-time follow-up 3) the rise of massive spectroscopic datasets, which require new software for data reduction and analysis. Inclusivity and enabling broad access to data and science is a priority for NOIRLab.

Magda Arnaboldi gave us the ESO perspective. The ESO archives have diverse holdings from multiple facilities at different wavelengths (UV, OPT, NIR, MIR, mm). ESO archives the raw data and calibrations from 20 years of science operations, and also serves science ready high level data products. Data interoperability is a high priority, and ESO adopts IVOA standards to enable this. ESO archives face challenges from the influx of very high-resolution data (in space, time, and wavelength), and from the increasing data complexity.

**The programme: Global Coordination of Ground and Space Astrophysics, 8-10 August 2022**

Monday 8/8 15:15-16:45

Session I: Large facilities in the 2020's and beyond (ground and space)

Key issues: What is the landscape of facilities coming online in the next decade, and status of longer-term planning? What are the key challenges for the Agencies around coordination? How are different agencies working towards the goal of Open Data?

Moderator: Debra Elmegreen

(a) Coordination of Large Space Missions: Rachel Osten (30 minutes)
(b) Coordination of Large Ground-based facilities: Matthew Colless (30 minutes)
(c) Coordination across ground and space: Ewine van Dishoeck (20 minutes)

Monday 8/8 17:30-19:00

Session II: Global coordination for the next decade of science

Key issues: What kinds of coordination are needed to achieve our science goals in these areas? What are the specific challenges? Are there types of coordination that would benefit multiple areas?

Moderator: Roger Davies

(a) discussion of topics from session I (17:30-17:50)
(b) Global coordination for the next decade of science (17:50-19:00)

- Exoplanets -- Laura Kreidberg
- Stellar Populations-- Scott Trager
- Black Holes -- John Silverman
- Galaxies/ISM -- Lisa Kewley
- Cosmology -- Ofer Lahav

Tuesday 8/9 15:15-16:45
Session III: Global Coordination for Multi-messenger astronomy
Key issues: What is the landscape for multi-messenger facilities in the coming decade? What unique challenges are posed by the needs of multi-messenger astronomy?
Moderator: Richard Green

(a) Report from Kavli-IAU meeting in Cape Town – Brad Cenko (15 minutes)

(b) Facilities presentations (7+3 minutes each):

- Ground based Gravitational Wave facilities – Patrick Brady
- LISA – Kelly Holley-Bockelmann
- Neutrino – Shigeru Yoshida
- Gamma ray/cosmic ray: Michael Backes

(c) Panel discussion (35 minutes): Yossi Shvartzvald, Zeljko Ivezic, Samaya Nissanke, Victoria Kaspi, Solomon Tessema

Wednesday 8/10 10:30-12:00
Session IV: Archives & Access
Moderator: Ajit Kembhavi
(i) Future Role of Current Telescopes (45 minutes)

Key issues: How do you see the use of your facilities evolving over the next decade as more capable systems come into operation? Do you see them focusing on particular specialisations e.g. wide field surveys or transient follow-up? To what extent will you provide direct support for programmes on the new facilities compared to pursuing a complementary programme? How will you support Open Data?
Discussion by facility leaders

- ING (Marc Balcells or representative)
- GMRT (Yashwant Gupta)
- NRAO (Alberto Bolatto)
- Subaru (Michitoshi Yoshida)
- NOIRLab portfolio (Jen Lotz/NOIRLab)
- SALT/MeerKAT/African Astronomy (Petri Vaisanen)

(ii) Future Role of Archives (45 minutes)

Key issues: What efforts are currently being undertaken to coordinate archiving of data from different facilities, agencies, and wavelengths? How can archive coordination be improved in the future? What challenges are posed by the datasets from the next generation of facilities?
Moderator: Rachel Somerville
IVOA perspective -- Bruce Berriman
NASA perspective -- Vendana Desai
NOIRLab perspective -- Adam Bolton
ESO perspective -- Magda Arnaboldi
Q&A and discussion

## Appendix 2

**IAU Working Group on Global Coordination of Ground and Space Astrophysics**

**Annual Report 2022-23**

*Working Group Co-Chairs : Roger Davies & Rachel Somerville*

This report has three parts:

(i) a commentary on the organisation of the programme of the Working Group and specifically on the sessions at the Busan General Assembly.
(ii) the summary of those sessions including, as an appendix, the programme.
(iii) the proposal and plan for the next Kavli Workshop *Probing the Universe from Far-IR to mm wavelengths: future facilities and their synergies* to be held in Caltech, Pasadena. March 26-28, 2024.

**Commentary**

Overall the sessions were well attended in-person and the online participation was good. The online presentations went well without major issues. One limitation was that online 'speakers' generally only attended the session they spoke in. Discussion was largely initiated in the room, with less from online participants, despite regularly seeking input from them. Several sessions would have benefitted from having more time for discussion.

There were four Working Group sessions:

**Session I**: Large facilities in the 2020's and beyond (ground and space). Moderator: Debra Elmegreen

**Session II**: Global coordination for the next decade of science. Moderator: Roger Davies

**Session III**: Global Coordination for Multi-messenger astronomy. Moderator: Richard Green

**Session IV**: Archives & Access Moderator: Ajit Kembhavi

The way these sessions were organised has evolved over the last couple of General Assemblies.

For session I we invited speakers to provide an overview of the ground based and space programmes, rather than having a sequence of speakers from the major international and national agencies each describing their own programme. We identified three speakers to cover ground-based projects, space missions and co-ordination between the two. Each provided an excellent overview, managing to summarise the relevant extensive programmes succinctly. This was the first time we had identified non-agency speakers to summarise the status of space and ground based projects. It transpired that as a consequence senior agency people were largely missing from the sessions. This definitely compromised the usefulness of the discussions arising from this session. We need to find a way to ensure the participation of key figures in future – that is likely to involve reverting to the previous style, which will require more dedicated time, at the expense of sacrificing other topics.

In session II we started with a discussion of the presentations in session 1 which covered the degree to which large projects plan to provide curated data openly, the need to co-ordination between space and ground based observations to be planned many years I advance of launch, and the interesting question of how students and ECRs are trained to work in large collaborations as well as the sociological accommodations that will be required to recognise those that make pivotal contributions but who are not PhD astronomers. While this has been an issue for some time in several technical specializations, the importance of very large collaborations for generating ground breaking results and the emergence of the critical role of techniques such as AI and machine learning has underscored the

need for new avenues to recognise multi-disciplinary contributions, not through papers in the astronomical literature alone.

Session II continued with five talks designed to explore critical areas of astrophysics where future advances are expected. A common theme was the challenges of bringing together diverse data sets to address specific problems. This included uniformity of calibration across different surveys, multiple jeopardy of multi-wavelength and time critical observations, and the need to bring together ground and space-based data to address key problems.

Session III on the global coordination of multi-messenger astronomy opened with a discussion of the Kavli–IAU Workshop on the *International co-ordination of multi-messenger transient observations in the 2020s and beyond* held in Cape Town in February 2020. It continued with presentation on gravitational wave astronomy from ground and space; multi-messenger investigations triggered by neutrino alerts, gamma ray events and cosmic ray detections. A panel discussion followed with participants each asked to identify one scientific problem in multi-messenger astrophysics that is ripe for progress in the next decade and consider (i) what data are needed to make that progress? (ii) what facilities and coordination mechanisms are in place to get that data? (iii) What further facilities and coordination mechanisms would be required for full realization?

Session IV on Archives & Access comprised two panel discussions led by presentations from leaders in these areas. The presentations themselves were interesting and are reported in the attached paper but the in the ensuing discussion it was not always straightforward for online participants to contribute as much as those in the room. Perhaps there is a better way of organising this, or perhaps this is an inherent limitation of hybrid discussion that span a wide range of communities.

**Notes and actions for the Co-Chairs and IAU**

The Korean organisers did a terrific job of supporting these sessions. The online participation was well organised and as effective as any we have experienced. Despite these efforts the large time difference between Korea and both Europe and America was a practical limitation to the level of online participation.

We collect together here the key lessons we learned from organising these sessions together with some issues that the co-chairs will brainstorm about over the next few months (items 1-9) and some issues for the IAU to ponder (10-11) and some for both.

1. The in-person sessions were well attended by a variety of people.

2. Online presentations worked remarkably well.

3. Online speakers usually only attended the session in which they were speaking.

4. Discussion was largely initiated in the room with less from online participants, despite regularly seeking input from them.

5. This was the first time we had identified non-agency speakers to summarise the status of space and ground based projects as well as space-ground synergy. Those chosen did an excellent job but a consequence was that senior agency people were largely missing from the sessions. We need to rectify this in future.

6. Panel discussions in hybrid format did not work so well – despite good facilities it was hard for online panel members to contribute equally.

7. Several sessions would have benefitted from having more time for discussion.

8. The co-chairs need to involve other Working Group members in the organisation and chairing the sessions.

9. The co-chairs plan to re-consider the format of the sessions so that we do a better job of reaching those individuals who can be influential in addressing the issues that arise in these discussions.

10. Partly because of the way we chose to organise these sessions key individuals involved in governance and leadership roles, such as Agency Heads and Directors of Observatories, project managers etc., were less well represented than at previous GAs. As their presence is vital if we are to have a productive discussion the Co-chairs will ponder on how to address this for Cape Town.

11. These WG meetings are to do with the organisation and co-ordination of astronomy globally. Unlike the Symposia associated with the GA, they are not primarily scientific research meetings. It is perhaps unrealistic to expect participants to have to pay the "full fare" of GA registration if this is the only, or primary reason for them attending. The "day pass" process we had to use for the Busan meeting was terribly inefficient.

The first Appendix is a summary of the sessions of the Working Group held in Busan.

The second Appendix is a copy of the successful proposal for the next Kavli Workshop *Probing the Universe from Far-IR to mm wavelengths: future facilities and their synergies* to be held in Caltech, Pasadena. March 26-28, 2024.