J. Astrophys. Astr. (2024) 45:2
https://doi.org/10.1007/s12036-023-09984-2

Square Kilometre Array—India Consortium: Education and Public Outreach

NIRUJ MOHAN RAMANUJAM[1,*], PRASUN DUTTA[2], INDULEKHA KAVILA[3], MANONEETA CHAKRABORTY[4], SAMIR DHURDE[5], ANANDA HOTA[6], CHIRANJIB KONAR[7], DIVYA OBEROI[8], MAMTA PANDEY-POMMIER[9] and MAYURI SATHYANARAYANA RAO[10]

[1]Indian Institute of Astrophysics, Bengaluru 560034, India.
[2]Indian Institute of Technology (BHU), Varanasi 221005, India.
[3]Mahatma Gandhi University, Kottayam 686560, India.
[4]DAASE, Indian Institute of Technology, Indore 453552, India.
[5]Inter-University Centre for Astronomy & Astrophysics, Pune 411007, India.
[6]UM-DAE Centre for Excellence in Basic Sciences, University of Mumbai, Mumbai 400098, India.
[7]Amity Institute of Applied Sciences, Amity University, Noida 201313, India.
[8]National Centre for Radio Astrophysics, TIFR, Pune 411007, India.
[9]LUPM, Universite de Montpellier, 34095 Montpellier, France.
[10]Raman Research Institute, Bengaluru 560080, India.
*Corresponding author. E-mail: niruj.mohan@iiap.res.in

MS received 27 June 2023; accepted 22 August 2023

Abstract. This paper presents a report on the activities and the proposed action plan of the Education and Public Outreach Working Group (EPO WG) of Square Kilometre Array–India Consortium (SKAIC). Details of a set of flagship programs as well as supporting activities are presented, in consonance with the scale of India's involvement in Square Kilometre Array Observatory (SKAO), as well as the educational and science literacy contexts in the country. Ongoing independent EPO activities by some of the member institutions are also included.

Keywords. Radio astronomy—radio telescopes—SKAO—SKAIC—education—outreach.

1. Introduction

1.1 *Radio astronomy*

Astronomy is one of the oldest sciences. It is driven by natural human curiosity about the night sky–the mysteries of the celestial sphere. Electromagnetic waves of all frequencies can carry information from far away astronomical sources to the Earth. Of these, the visible band is one of the few wavebands that can reach the Earth's surface through its atmosphere without being absorbed/scattered too much, and the only one to which our eyes are sensitive to. The other major waveband that our atmosphere is transparent to is the radio band, and hence, after optical astronomy, radio astronomy was the field of observational astronomy that developed next in the modern era. Nowadays, information from the near as well as far universe is collected via telescopes (ground as well as space-based), neutrino and gravitational wave detectors and space missions to the Moon, planets, asteroids and the Sun. Astronomy developed from single person efforts with telescopes operating in a single waveband to multi-wavelength, multi-messenger, multi-tracer astronomy and multinational megaprojects. Radio astronomy kept pace, with advances in technology and analytical, data-related and computing techniques. The Square Kilometer Array Observatory (SKAO) is the next generation radio telescope–the next major step that is being taken in the field of radio astronomy. This introduction further discusses briefly the history of radio astronomy and the SKAO, and also the Key Science Projects (KSPs) envisaged with the SKAO. Section 2 briefly traces the history of radio astronomy in India and

Published online: 22 December 2023

presents some details about the SKA–India Consortium (SKAIC), which looks after SKAO-related activities in India. Details of Education and Public Outreach (EPO) program of the SKAIC are given in Section 3. Sections 4–6 present a resume of the various radio astronomy-related EPO activities carried out by members of the SKAIC and conclusions are presented in Section 7.

Radio waves from astrophysical sources were first detected by Jansky (1933). The initial investigations of the radio sky by Grote Reber opened up the possibility of using the radio frequencies to investigate astrophysical phenomena. Soon radio waves were detected from the Sun by Southworth (1945) and Hey (1975). These discoveries were followed by the setting up of a large number of single dish radio telescopes and later, radio interferometers across the world. For a detailed account of the initial history see Kraus (1981) and Sullivan (2009).[1] Observation of the cosmos in radio frequencies ranging from a few tens of MHz to a few hundreds of GHz led to the discovery of a plethora of new astrophysical objects and phenomena like the cosmic microwave background, radio galaxies, supernova remnants, pulsars, neutral hydrogen in nearby and far away galaxies, fast radio bursts and many more. Studies of these have played an important role over the last century in advancing our fundamental understanding of the Universe (Sullivan 1984; Burke *et al.* 2019).

1.2 *Square Kilometre Array Observatory*

After the successful completion of the Very Large Array and its huge impact in our understanding of the radio Universe, the first steps towards the realization of a telescope commensurate with further aspirations of radio astronomers were taken at the 1993 meeting of the International Union of Radio Science (URSI). A working group was set up to assess the possibility of a suitable project. This was soon followed by the setting up of a memorandum of agreement among eight institutions from different countries to cooperate in the technical investigation required and the International Square Kilometre Array Steering Committee (ISSC) was established in 2000. In subsequent years, it was decided that the telescope, with a total of one square kilometer of collecting area, would cover the frequency range from 50 MHz to 14 GHz. In 2011, an inter-governmental organization, the SKA Organization (which has since become SKAO) was formed[2] and in the following year, it was decided that two telescopes will be built, the SKA-low array in Australia with frequency coverage from 50 to 350 MHz and the SKA-Mid array with frequency coverage from 350 MHz to 15.4 GHz (with a goal of 24 GHz) in South Africa and nearby countries. Due to the large constructional and other challenges, the telescopes are being built in two phases, with Phase I providing 10% of the total collecting area at low and mid frequencies by the end of 2023 (see Fanaroff 2022 for more details).

1.3 *Key science projects*

A set of KSPs has been identified for the SKA telescopes. These include (a) extreme tests of general relativity using pulsars and black holes, (b) probing cosmic dawn and the epoch of reionization, (c) galaxy evolution, cosmology and dark energy, (d) origin and evolution of cosmic magnetism and (e) search for extraterrestrial life (see 'Advancing Astrophysics with the SKA', 2015). Astronomers from around the world, including India, are members of the SKA Key Science Working Groups. Building up expertise for working with such a complex and sensitive telescope is being done by utilizing existing telescopes called the SKA precursors/pathfinders,e.g.,GMRT, India (Swarup *et al.* 1991, Gupta *et al.* 2017), MWA, ASKAP, APERTIF, etc.[3], as well as by using mock SKAO data in various data challenges.

2. Radio astronomy in India

Radio astronomy in India started in 1952 with solar observations using Yagi antennas at the Kodaikanal Observatory (Ramesh 2011), which was followed by many more instruments (an early history of radio astronomy in India can be found in Padmanabhan 2014). Research into other areas of radio astronomy blossomed with the team started by Govind Swarup at TIFR in the 1960s. As indigenous telescope facilities like the Kalyan Radio Telescope, the Ooty Radio Telescope (ORT) (Swarup *et al.* 1971), the Ooty Synthesis Radio Telescope (OSRT), the Gauribidanur Radio, Observatory (GRO) and later the Giant Metrewave Radio Telescope (GMRT) were built, radio astronomy in India started flourishing. At present, India hosts the

[1] Interested readers can also see https://public.nrao.edu/news/jansky-90-the-origins-of-a-new-window-on-the-universe/.

[2] https://www.skao.int.

[3] For details see https://www.skao.int/en/explore/precursors-pathfinders.

Figure 1. A map of India highlighting the member organizations of the SKA–India consortium in salmon pink. Other institutions actively involved in the research related to the construction and science of the SKA Observatory are highlighted in green. Image courtesy: Shilkumar Meshram (NCRA).

upgraded GMRT (uGMRT), one of the most sensitive radio interferometers in the world. The Ooty Radio Telescope is also being upgraded to work as the Ooty Wide-Field Array in the coming years and is expected to play a significant role in probing the evolution of neutral hydrogen in the post-reionization era. Multiple radio instruments at Gauribidanur study the Sun everyday. Indian astronomers, across a spectrum of research and educational institutions, are actively involved in research in almost all aspects of radio astronomy science, technology and data analysis.

2.1 *Square Kilometre Array–India Consortium*

Given such a strong background and expertise in radio astronomy, India has been an integral part of the SKA project from the very beginning. Recently, the uGMRT was declared as one of the SKA pathfinder telescopes (as well as an IEEE milestone) and is being used as a test-bed to understand and develop new technology, and observational techniques related to the SKAO. Pathfinder telescopes have played a key role in arriving at the final design of SKA telescopes. SKAO-related activities in India are overseen by a consortium of educational and research institutions, formally known as SKAIC. These include 22 regular member institutions and three additional individual associate members (see Figure 1).[4]

2.2 *Working groups of SKAIC*

Several working groups (WG) for science as well as for technology have been set up by the SKAIC. Details are given in Table 1. The WGs report to the Science and Technical sub-committees of the SKAIC, respectively.

[4] http://www.ncra.tifr.res.in/ncra/skaindia/ska-india-consortium.

Table 1. Different Science and Technical Working Groups of the SKAIC.

Science working groups	Technical working groups
EoR and Cosmology	Telescope Manager and other software
Radio Transients	Signal Processing
Neutron Stars	Low Frequency Aperture Array
Cosmic Magnetism	SKA Regional Center in India
Continuum Surveys	Antennas and receivers for SKA-Mid
HI and Galaxy evolution	
Solar, Heliospheric and Ionospheric Physics	
Our Galaxy	

The Science Working Groups have given definition to the interests of the Indian astronomy community in the SKAO (see ‘Science with the SKA: Indian Perspective’, 2016).

3. EPO program of the SKAIC

The practice of astronomy, like any other branch of science, is a social endeavor, which implies that a project as vast as the SKA should have a well structured, sustainable and socially relevant public engagement component as an integral part (Lorenzo & Garnier 2015). Keeping this in mind, the SKAIC recently set up a Working Group to focus on matters related to Education and Public Outreach (EPO) for the SKAIC, which it will work in close collaboration with the SKAIC sub-committees. This group currently has 17 members from different institutes and universities across India and from abroad. Over the last few months, the group has formulated and presented a well-defined EPO proposal to the SKAIC. In this paper, the EPO program, its objective, mode of operation and the involvement of different stakeholders will be discussed.

3.1 *Scope of EPO project*

The objectives of the EPO program are identified as follows:

- To promote awareness and interest in astronomy, particularly in radio astronomy, among students and teachers at various levels. This will support and augment existing outreach programs about general astronomy, and incorporate concepts from radio astronomy and the multi-wavelength sky.
- To promote scientific temper in the country, and develop public literacy about basic radio science as well as the ubiquitous technologies based on it, which are used in daily life. Astronomy is a great tool for inculcating critical thinking and rationality (Narlikar 2003) and employing astronomy for this purpose will be a key part of this EPO program.
- To communicate the highlights of the activities of the SKAIC as well as science and technology advances made by individual SKAIC member institutions. These will be appropriately tailored for the general public, students, policymakers and the media.

3.2 *Structure of EPO program*

Reflecting the full range of SKAIC activities, the WG, is devising programs that pertain to SKA science, the technology being developed for the SKA, as well as aspects of data science related to the SKA. The WG will therefore work closely with the SKAIC communities working in each of these three domains. The EPO Working Group has the responsibility of conceptualizing various projects, and overseeing their implementation. It will facilitate the hiring of full-time EPO staff and work with them to achieve its objectives. However, the key stakeholders in content production are the member organizations and working groups of the SKAIC. This includes the faculty, students, associated staff, engineers and industry. Their inputs will be reshaped appropriately by the WG for various media, and will be made public. The WG will also collaborate with individuals and organizations in their own outreach initiatives, as required. Hence:

- The WG will collaborate with the science, engineering, as well as the data science teams to generate content for its programs. The SKAIC working groups and its members, as well as the SKAIC industry partners, will have to work closely with the EPO WG.

- The WG will design a range of programs, differing in scale, scope and duration, and will create a plan of action for each of them.
- The WG will collaborate with the national EPO teams of other megaprojects (e.g., TMT, LIGO-India) to implement a coherent set of shared activities that each project can then build on.
- Keeping in mind the large diversities in India (language, delivery of education, socio-economic conditions, disabilities, etc.), there will be a focus on creating multilingual and inclusively accessible resource material, e.g., sonification of radio data and textured models (De Leo-Winkler 2019; Garcia 2019; Perez-Montero 2019; Villamizar 2021).
- There will be full-time staff that work under the supervision of the EPO committee, and the program shall have a separate budget.

3.3 *Elements of EPO program*

The following elements are envisaged for the EPO program of the SKAIC: A small number of Flagship Programs (FPs) (see Section 4) directly tuned towards the EPO objectives and smaller individual projects (see Section 5) which aid and support the common goals of the FPs. These programs are ambitious in scope, and can accommodate multiple activities as well as the diverse expertise and interests of the SKAIC members. These are expected to operate over a timescale, which is coterminous with the main project itself, and will require dedicated staff and funding.

4. Flagship programs

Amateur radio astronomy: This program is to support the construction and usage of simple radio telescopes in high schools, colleges and amateur astronomy associations across the country. This will involve designs for simple telescopes, tutorials on construction, support for student groups, DIY kits, creating a network of users and guidance for experiments. The project will partner with existing programs like the Astronomy Center for Educators, Teaching Learning Center and National Resource Center at IUCAA, and Radio Physics Lab at NCRA,[5] the Sky Watch Array Network (SWAN) project,[6] the lab in Abhinav Vidyalay in Mumbai,[7] as well as the Amateur Radio Society of India[8] and other ongoing amateur radio projects.

[5] https://www.youtube.com/@NRCIUCAA/playlists, http://www.ncra.tifr.res.in/rpl.

[6] https://wwws.rri.res.in/SWAN/SWANRRI.html.

[7] https://astro.abhinav.ac.in.

Educational portal on radio astronomy: This project will develop an online portal that will host material graded by age, both for students and teachers. This will have guided and structured routes to learn about radio astronomy in an interactive way. The contents will have texts, tutorial videos, demos, data and online tools for data analysis, questions to answer, ideas for small projects and so on, at different levels of comprehension (see e.g., Lundgren *et al*. 2019). Archival data from the existing Indian radio telescopes will be used for this in the initial stages. This portal will be supplemented with interactive events like workshops for trainers and supporting media like mobile-based apps.

Radio technology literacy: Modern devices in daily use (e.g., cellphone, GPS and Wi-Fi) work using radio physics. But there is very little public understanding of how they work. This project aims to increase general literacy regarding the science and engineering behind these technologies among the general public. This will promote scientific temper in society and demystify this aspect of the world around us. Engineering colleges in India and national organizations for electronics and communications will be our natural partners in this project.

Radio astrophysics online courses: This project is to collate as well as create online video course material on radio physics and engineering, radio astronomy, and data science. These courses will be aimed at college and university students and can be modeled on MOOCs or Swayam[9] courses. Many of the radio astronomy schools that have been conducted before, have uploaded their lectures online as well. Partners for this project include resource persons from the SKAIC member institutions, subject experts from other organizations, as well as organizations that offer online infrastructure support.

5. Other programs and supporting activities

Online repository of content for SKAIC members: This project will collect and maintain an online repository of images, text, slides, etc. that SKAIC members can use in their public presentations. The contents will be obtained from, and updated by, each science WG and engineering team in the SKAIC.

[8] https://arsi.info.

[9] https://swayam.gov.in.

Citizen science projects: This is to create, support and publicize citizen science projects using existing radio data from GMRT, ORT and GRO, and complements the second Flagship Project described above (Educational Portal on Radio Astronomy). Collaboration with the RAD@home Collaboratory (Hota *et al*. 2014, 2016) is also envisaged in this context.

Outreach and publicity—material and strategy: This project will facilitate the creation of resource material in print (e.g., posters and brochures), digital (e.g., images and videos) and new technology (e.g., augmented reality and virtual reality), with an emphasis on multilingual content. It will also create common publicity material for display in conferences, workshops and college technology festivals. The WG will also maintain a strong presence on social media. Additionally, an independent ongoing project, partially funded through the IAU Office of Astronomy Outreach and SKAO through IUCAA, aims to put together a prototype 'kit' with simple, low-cost educational resources along with DIY ideas, with which children in the ages of 10–15 years would have fun learning elements of basic astronomy and highlights of radio astronomy. This project is complementary to the proposed EPO activities of the SKAIC.

6. Resume of educational and public outreach activities carried out by SKAIC members

The EPO activities of the SKAIC are planned against the strong backdrop of educational and outreach activities carried out over the years by various member institutions of the SKAIC. A brief account of the activities of some of these institutions is presented below along with a description of Vigyan Samagam (which was a national effort to showcase India's participation in seven megaprojects, including the SKA, to the public).

6.1 *Indian Institute of Science*

The astronomy community in Indian Institute of Science (IISc) engages with outreach programs conducted by the institute (e.g., IISc Open Day), where the astro-group faculty members, students and post-doctoral fellows take part in demonstrations with hands-on devices and experimental set ups, display of science posters and organizing popular science talks and screening documentaries for the visitors. Some activities are also undertaken with the IISc Kendriya Vidyalaya.

6.2 *Indian Institute of Space Science and Technology*

Indian Institute of Space Science and Technology (IIST) has been co-hosting the 'Ask an Astronomer' online public lecture series online along with the ASI-POEC, which includes talks related to SKA. Faculty members have presented astronomy talks and demonstrations at Thiruvananthapuram Planetarium and local schools and colleges.

6.3 *Indian Institute of Technology Indore*

At Indian Institute of Technology Indore (IIT Indore), there are several undergraduate and postgraduate programs (MSc in Astronomy, MS (research) in Space Sciences and Engineering, MTech in Space Engineering, BTech minor program in Astronomy) running in Department of Astronomy, Astrophysics and Space Engineering (DAASE), and the curricula include the physics and technical aspects of the SKAO. The department has a few radio astronomy facilities including a four-element instructional radio interferometer and a radio instrumentation laboratory.

DAASE has organized several lectures and workshops to popularize SKAO and teach the basics of radio astronomy. The members of DAASE regularly take part in National Science Day activities and have made videos explaining the working principles of radio telescope arrays using the in-house IIT Indore Radio Interferometer (IIRI). DAASE has also been involved in outreach programs in schools and colleges in Madhya Pradesh in collaboration with the MP Council of Science and Technology and Nehru Planetarium, New Delhi. DAASE plans to expand these activities further, particularly in and around central India (MP and Chattisgarh).

6.4 *Inter-University Center for Astronomy and Astrophysics*

Inter-University Center for Astronomy and Astrophysics (IUCAA) hosts one of the most active science and astronomy EPO programs that is run by a research institute in the country. Started by Jayant V. Narlikar, the program has reached millions of people over three decades. Its regular events include National Science Day, 2nd Saturday lectures, School Students' Summer Program, weekly campus visits and sky-watching. Along with these, the IUCAA outreach department, popularly known as SciPOP, has an average annual direct reach of about 75,000 students. This is via events, such as teacher training programs, school workshops, public talks, and sky shows conducted across the country. Many of these events are specifically designed to reach rural or remote areas. Considerable support is also given to amateur astronomy enthusiasts, with telescope making workshops and training in conducting observations and citizen science projects. IUCAA SciPOP also contributes significantly to outreach for mega-projects like AstroSat, LIGO-India, TMT, SKAO and regularly collaborates with organizations like ASI POEC and Vigyan Prasar. With a significant presence on social media even before the restrictive times of the pandemic, IUCAA's online EPO efforts have gathered a large viewership and have even won awards from the IAU. In collaboration with NCRA, IUCAA started the unique Radio Physics Laboratory (RPL), which has developed several study modules and hands-on experiments with a radio astronomy focus. The Astronomy Center for Educators, consisting of the Teaching Learning Centre and the National Resource Center at IUCAA conducts a number of activities and creates resources (online and offline) for formal and informal astronomy educators across the country. The IAU's Office of Astronomy for Education has also set up the India Center in IUCAA with activities that focus on astronomy teaching methods and tools of assessment for students and teachers, along with language inclusiveness.

6.5 *National Center for Radio Astrophysics–Tata Institute of Fundamental Research*

National Center for Radio Astrophysics–Tata Institute of Fundamental Research (NCRA–TIFR) has been running a set of dynamic outreach and education programs since many years. Its annual National Science Day celebrations at the Giant Metrewave Radio Telescope (GMRT) is perhaps the largest Science Day event in the country, attracting more than 25,000 people and students from hundreds of schools and colleges over two days, primarily from rural neighborhoods. The weekly visitor program at GMRT is heavily oversubscribed by schools and colleges. It regularly conducts outreach programs (in Hindi and Marathi) in the villages around GMRT. The staff frequently interact with schools, colleges and amateur astronomers in Pune and Ooty as well, and collaborate with other national and regional EPO committees. Recently, NCRA–TIFR has developed a GMRT themed traveling exhibit which has visited various fora, including Vigyan Samagam (Delhi, Mumbai, Kolkata and Bengaluru 2019), Pravasi Bharatiya Diwas (Varanasi 2019) and India International Science Fair (Goa 2021). A DIY model for a GMRT dish has also been developed in collaboration with commercial partners.

NCRA–TIFR runs many education programs geared towards hands-on astronomy and radio astronomy experiments for college students. These include a winter school (by the RPL, in collaboration with IUCAA), and the Camp for Hands-on Experience in Radio Astronomy (CHERA) program which is hosted at the Ooty Radio Telescope campus and is led by RRI. Another very successful program run by NCRA is the Pulsar Observatory for Students (POS). It provides undergraduate students an opportunity to learn about radio astronomy and pulsars at NCRA–TIFR and then visit the Ooty Radio Telescope to apply what they have learnt by carrying out observations and analysing the data (Joshi *et al.* 2012). In addition, NCRA–TIFR has been running long-standing programs for undergraduate students, like the Radio Astronomy Winter School run in collaboration with IUCAA, and the Visiting Student Research Program for final year students, where these students get an opportunity to spend about two months at NCRA–TIFR working on a real-life research problem under the mentorship of NCRA faculty. These programs have played a pivotal role in defining career choices for many of the professional astronomers in the country. NCRA–TIFR faculty is also actively involved with the National Initiative for Undergraduate Studies program and the training program for the International Astronomy Olympiad, both run by the Homi Bhabha Center for Science Education, Mumbai.

6.6 *Raman Research Institute*

Raman Research Institute (RRI) outreach efforts include a novel podcast series generated with minimal tools, HOLI Byte, where PhD students talk on their area of research in a simple manner in a language of their choice. The SWAN,[10] spearheaded by Avinash Deshpande from RRI, has trained several batches of students, particularly at the annual CHERA organized in collaboration with NCRA. RRI also organizes regular school visits to the Gauribidanur Observatory, and a number of popular talks are given by faculty members.

6.7 *Vigyan Samagam*

Vigyan Samagam,[11] a multi-venue mega-science exhibition, was organized jointly by the Department of

[10] https://wwws.rri.res.in/SWAN/SWANRRI.html.
[11] https://vigyansamagam.in/.

Atomic Energy (DAE), Government of India (GoI) and Department of Science and Technology (DST), GoI in association with the National Council of Science Museums (NCSM), GoI, to showcase India's contribution to international collaborations aimed at fundamental science and research. India's collaboration with the SKAO was one of the seven projects showcased at the Vigyan Samagam, which was organized in Delhi, Mumbai, Bengaluru and Kolkata. India's technical contributions to the SKAO through partnerships between research institutes and industry were highlighted, along with the work done by the various SKAIC Science Working Groups, including the usage of the upgraded GMRT (uGMRT), which is a pathfinder facility. During the week allotted to the SKA project at each of the cities, contests and workshops (e.g., QASTRO: GMRT-image contest and citizen science research workshop by RAD@ home), public talks, demonstrations with working models, etc., were organized, in a joint effort by a number of SKAIC member organizations.

7. Conclusion

The SKA—India consortium comprises a diverse range of organizations and individuals engaged in astrophysics, engineering and data science. A large endeavor like that of India's participation in the SKAO needs a well-structured EPO program with its own personnel and finances, as an integral part. The SKAIC EPO WG has defined a number of flagship projects as well as many supporting activities, and has analysed them in terms of timelines, resources needed and collaborating organizations. Many of these activities build on existing EPO work being done independently by member institutions. The projects discussed here have the potential for making a substantial impact on radio science-related education and science literacy in the country.

Acknowledgements

We are thankful to the referee for comments and suggestions. We acknowledge inputs about institutional outreach efforts from Nirupam Roy (IISc) and Jagadheep Pandian (IIST). We acknowledge discussions with the Public Outreach and Education Committee (POEC) of the Astronomical Society of India (ASI), and with the SKAIC, Tirthankar Roy Choudhury (NCRA–TIFR) and the members of the SKAIC EPO Working Group. DO acknowledges support of the Department of Atomic Energy, Government of India, under the project no. 12-R&D-TFR-5.02-0700. AH acknowledges University Grants Commission (UGC) for salary grants under Faculty Recharge Program. MPP acknowledges the support of the CEFIPRA foundation under project 6504-3.

References

Advancing Astrophysics with the Square Kilometre Array, ed SKA Organisation, 2015
Burke B. F., Graham-Smith F., Wilkinson P. N. 2019, An Introduction to Radio Astronomy. Cambridge University Press
De Leo-Winkler M. A. 2019, Nature Astronomy, 3, 576
Fanaroff B. 2022, Resonance, 27, 529
Garcia B. 2019, EPJ Web Conf. ISE2A 2017, 200
Gupta Y. *et al*. 2017, Current Science, 113, 707
Hey J. S. 1975, Radio Universe, 2nd edition. Pergamon Press
Hota A. *et al*. 2014, ASI Conference Series, 13, 141
Hota A. *et al*. 2016, JoAA, 37, 41
Joshi B. C., *et al.* 2012, 29th COSPAR Scientific Assembly Proceedings, Vol. 39, p. 843
Jansky K. G. 1933, Electrical disturbances apparently of extraterrestrial origin. Proc. IRE, Vol. 21, p. 1387
Kraus J. 1981, The First 50 Years of Radio Astronomy, Part 1: Karl Jansky and His Discovery of Radio Waves from Our Galaxy, North American AstroPhysical Observatory (NAAPO), Cosmic Search, Vol. 3
Lorenzo R., Garnier W. 2015, IAU General Assembly Meeting, p. 29
Lundgren B. *et al*. 2019, BAAA, 61A, 261
Narlikar J. V. 2003, Highlights of Astronomy, 13, 1052N
Padmanabhan T. 2014, Astronomy in India: a historical perspective (New Delhi: Springer) p. 86
Perez-Montero E. 2019, Nature Astronomy, 3, 114
Ramesh R. 2011, ASI Conference Series, Vol. 2, p. 55
Science with the SKA: Indian Perspective 2016, JoAA Special Issue, 37, 4
Southworth G. C. 1945, Journal of the Franklin Institute, 239, 285
Sullivan W. T. 1984, The Early Years of Radio Astronomy, Cambridge University Press
Sullivan T. W. III, 2009, Cambridge University Press, 1st edn
Swarup G. *et al*. 1971, Nature Physical Science, 230, 185
Swarup G. *et al*. 1991, Current Science, 60, 95
Villamizar G. M. I. 2021, Proceedings of the IAU, 15. Symp, 5376, 298