THE LOW-FREQUENCY RADIO UNIVERSE

COVER ILLUSTRATION:

One of the GMRT antennas

Drawing courtesy of B. Premkumar, National Centre for Radio Astrophysics, TIFR, Pune

ASTRONOMICAL SOCIETY OF THE PACIFIC CONFERENCE SERIES

A SERIES OF BOOKS ON RECENT DEVELOPMENTS IN ASTRONOMY AND ASTROPHYSICS

Volume 407

PO Box 4666, Room C454 – ESC, Brigham Young University, Provo, Utah, 84602-4666
Phone: 801-422-2111 Fax: 801-422-0553
E-mail: aspcs@aspbooks.org E-book site: http://www.aspbooks.org

ASPCS Volumes may be found online with color images at http://www.aspbooks.org.
ASP Monographs may be found online at http://www.aspmonographs.org.

A list of recently published volumes may be found at the back of this volume.

For a complete list of ASPCS Volumes, ASP Monographs,
and other ASP publications see http://www.astrosociety.org/pubs.html.

ASTRONOMICAL SOCIETY OF THE PACIFIC
CONFERENCE SERIES

Volume 407

THE LOW-FREQUENCY RADIO UNIVERSE

An Event Commemorating the Birth Centenary of Dr. Homi J. Bhabha

Proceedings of a conference held at
National Centre for Radio Astrophysics (NCRA), TIFR, Pune, India
8–12 December 2008

Edited by

D. J. Saikia
National Centre for Radio Astrophysics (NCRA), TIFR, Pune, India

D. A. Green
Cavendish Laboratory, University of Cambridge, Cambridge, UK

Y. Gupta
National Centre for Radio Astrophysics (NCRA), TIFR, Pune, India

and

T. Venturi
INAF—Istituto di Radioastronomia, Bologna, Italy

SAN FRANCISCO

ASTRONOMICAL SOCIETY OF THE PACIFIC
390 Ashton Avenue
San Francisco, California, 94112-1722, USA

Phone: 415-337-1100
Fax: 415-337-5205
E-mail: service@astrosociety.org
Web Site: www.astrosociety.org
E-books: www.aspbooks.org

First Edition

ASP Conference Series

ISBN: 978-1-58381-694-3
e-Book ISBN: 978-1-58381-695-0

Library of Congress (LOC) Cataloging in Publication (CIP) Data:
Main entry under title
Library of Congress Control Number (LCCN): 2009932154

Printed in the United States of America by Sheridan Books, Ann Arbor, Michigan.

This book is printed on acid-free paper.

Contents

Part 2. Extragalactic Neutral Hydrogen and OH

Part 3. Extragalactic Radio Sources

Part 7. Sun and Planetary Studies

Part 8. Instrumentation and Techniques

Preface

During the last couple of decades or so there has been a strong resurgence of interest in low-frequency radio astronomy to address many outstanding and challening problems and issues. These include: mapping the distribution and evolution of neutral and ionised gas with cosmic epoch, and thereby understanding the time dependence of reionisation; probing large-scale structure and galaxy evolution including the star-formation history of the Universe; exploring the origin and evolution of cosmic magnetism; detecting many new and exotic pulsars to test theories of gravity, and possibly detecting gravitational waves via accurate timing of millisecond pulsars; constraining theories of acceleration and propagation of high-energy particles, and finding and understanding transients in our Universe. The Giant Metrewave Radio Telescope has been in operation for close to a decade, early results have been reported from LOFAR, while the next generation of telescopes such as the Long Wavelength Array (LWA), Murchison Widefield Array (MWA), MeerKAT, Australian SKA Pathfinder (ASKAP) and the Square Kilometer Array (SKA) should provide exciting results and opportunities in this region of the radio spectrum.

It seems an opportune time to take stock of the results obtained so far at low radio frequencies, discuss exciting astrophysical problems as well as a wide range of technical issues such as high dynamic range and wide-field imaging at low frequencies, mitigating the effects of radio frequency interference, high-performance computing needs, and designing new antenna elements, feeds, correlators for the challenges that lie ahead.

With these objectives a conference and workshop titled 'The Low-Frequency Radio Universe' was held at the National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research (TIFR) from the 8th to the 12th of December 2008 at Pune, India. For the purpose of this conference, low frequency has been defined to be less than approximately 1400 MHz. This conference also commemorates the birth centenary of Dr Homi J. Bhabha (October 30, 1909 – January 24, 1966), founder of TIFR and India's atomic energy programme, and who contributed immensely in both the sciences and the arts. Despite the tragic events in Mumbai towards the end of November 2008, the conference was well attended and a large number of papers on a wide variety of topics were presented.

We thank all the members of the LOC and the SOC, and the entire staff of NCRA whose untiring efforts led to the success of the conference. We would like to specifically thank Reena Shrikumar, secretary of the conference, B. Premkumar, NCRA's photographer who designed many of the posters and publicity material and looked after the auditorium facilities, and Anna Bhat Joshi who helped put the abstract book and the proceedings together. One of us (DJS) thanks CSIRO ATNF for hospitality during the final stages of editing the volume.

The Editors

2009 July 21

Scientific Organizing Committee

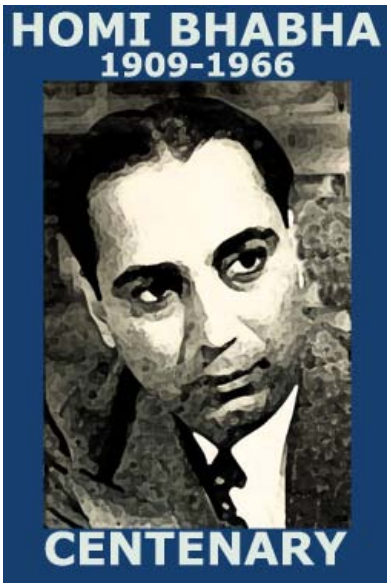
K. S. Dwarakanath
Dave Green
Yashwant Gupta
Judith A. Irwin
T. Padmanabhan
Ue-Li Pen
D. J. Saikia (Chairperson)
Lister Staveley-Smith
Tiziana Venturi

Local Organizing Committee

T. V. Ananthasubramanian
Jayaram N. Chengalur (Chairperson)
C. H. Ishwara-Chandra
Subhashis Roy
R. V. Swami
Yogesh Wadadekar

Jayaram Chengalur, Ananthasubramanian and Swami

Homi J. Bhabha



Homi Jehangir Bhabha (1909–66) started his career as a theoretical physicist at Cambridge in the nineteen thirties and distinguished himself by his researches in the then emerging areas of high energy physics and cosmic rays. Later he excelled as a builder of institutions in India devoted to modern science and technology. He founded the Tata Institute of Fundamental Research (TIFR) in 1945 at Bombay, a premier institution devoted to excellence and the pursuit of research in the frontier areas of science. He was the motive force behind the creation of the Atomic Energy Commission (AEC) by the Government of India in 1948 and became its first Chairman. When the Department of Atomic Energy (DAE) of the Government of India was set up in 1954, he was appointed as its Secretary. The AEC and DAE were responsible for establishing a chain of research laboratories, including the Atomic Energy Establishment at Trombay (later renamed Bhabha Atomic Research Centre) and for the commissioning India's nuclear reactors for research and for the generation of power. These activities also led to the growth of electronics technology in the country and, somewhat later, to those related to space technology. Bhabha, more than any other person, was responsible for introducing and nurturing the growth of modern nuclear science and technology in India. His was a multifaceted personality equally at home in the world of arts.

Bhabha was likened to 'a man of renaissance.' He was a man of science and technology. He was a great administrator of science. He was equally at home in the world of arts. Bhabha grew up listening to his father's and his aunt's excellent collection of

recorded western classical music. Later he developed a taste for classical Indian music and dance also. The choice of Vienna as the headquarters of the International Atomic Energy Agency was to a large extent decided by Bhabha's desire to combine attendance at its meetings with an opportunity to attend the fine musical concerts there. He enjoyed sketching and painting and left behind a number of these. As M F Hussain noted, 'Though a scientist by profession, he was an artist by nature ... To a great extent Bombay is what it is today because of Bhabha. In the early fifties he conceived the idea of starting a collection of painting at TIFR... and Bombay witnessed the birth of modern art.' He was also uniquely qualified to edit a special issue of the Indian art magazine Marg on the occasion of the five hundredth anniversary of Leonardo da Vinci, the original renaissance man. He designed the buildings of the Tata Institute of Fundamental Research with great care and attention to every minute detail. The glass windows had frames of a special new aluminium alloy to withstand sea breeze corrosion, and this alloy was manufactured for the first time in India at Bhabha's initiative. The buildings are not only functional but also beautiful. As Helmut Bartsch, the architect, noted, 'In this development the architect worked with a client rather than for a client. The client displayed unending interest and encouragement and constantly added intelligent suggestions and advice. The result, it is hoped, is a building which will not only fulfil its function but should afford a great deal of enjoyment. The siting of the Atomic Energy Establishment is such that the island of Elephanta, which contains beautiful seventh century cave temples, is directly visible. The same juxtaposition occurs between Kalpakkam reactor centre and the famed Mahabalipuram temples. He also had a keen sense of landscape and the Tata Institute of Fundamental Research and the Bhabha Atomic Research Centre are surrounded by beautiful trees and gardens.

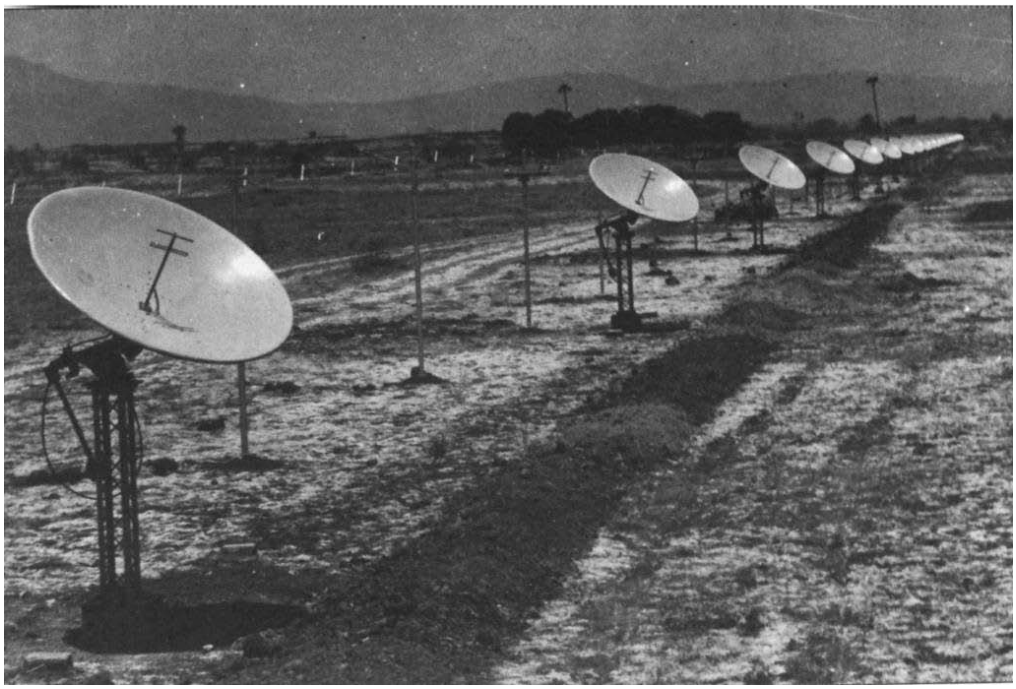
Excerpts from an article on Homi Bhabha by Virendra Singh in 'The Scientist in Society' published by Thema, Calcutta, 2000. Reproduced with their permission.

Beginnings of Radio Astronomy in TIFR

Excerpt from a lecture titled 'Science and the problems of development' by Homi Bhabha, at a meeting of the International Council of Scientific Unions in 1966.

Another example is provided by the Radioastronomy Group. Four Indian radioastronomers had jointly written identical letters to the Chairman of the University Grants Commission, the Director General of the Council of Scientific and Industrial Research, and to me as the Chairman of the Atomic Energy Commission offering to return to India as a group and establish radioastronomy here, if facilities and support could be given to them. Having ascertained that the members of the group had considerable original work to their credit and were of sufficient maturity to be able to work on their own in India, it was decided to take up radioastronomy at the Institute. Thirtytwo parabolic dishes presented by CSIRO of Australia, which had been lying unpacked for several years at the National Physical Laboratory, were handed over to the Institute through the willing cooperation of Dr. Husain Zaheer and have been installed not far from Bombay for solar radioastronomical work. In ths meantime a project has been developed for the large cylindrical radiotelescope for studying quasars and other radio sources and locating them accurately by lunar occultation. The telescope, which will have four to five times the collecting area of Jodrell Bank, will be designed and built entirely by Indian scientists and engineers and is expected to be in operation within two years. A site for it has been selected after a very extended study as the axis of the telescope, which is

1,700 feet long, has to be parallel to the axis of the earth. Work on the site at Ooty has already started. It is proposed to make this radio telescope one of the centres for inter-university work.



Kalyan Radio Telescope

Ooty Radio Telescope

Participants

Sk.Saiyad Ali, Department of Physics, Jadavpur University, Kolkata - 700 014, India ⟨saiyad@physc.jdvu.ac.in⟩

Subramanian Ananthakrishnan, University of Pune, Ganeshkhind Road, Pune - 411 007 India ⟨subra.anan@gmail.com⟩

Rabbi Angiras, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨rangiras@rri.res.in⟩

Tigran Arkshakian, MPIfR, Aut dem Huegel 69, 53121, Bonn Germany ⟨tarshakian@mpifr-bonn.mpg.de⟩

Ramana Athreya, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨rathreya@ncra.tifr.res.in⟩

Willem Baan, ASTRON, PO Box 2 NL 7990 AA Dwingeloo Netherlands, The Netherlands ⟨baan@astron.nl⟩

Joydeep Bagchi, IUCAA, Post Bag 4, Pune University Campus, Pune 411 007, India ⟨joydeep@iucaa.ernet.in⟩

Manjari Bagchi, Department of Astronomy and Astrophysics, TIFR, Homi Bhaba Road, Colaba, Mumbai - 400 005, India ⟨manjari@tifr.res.in⟩

Ramesh Balasubramanyam, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨ramesh@rri.res.in⟩

Arunima Banerjee, Department of Physics, IISc, Bangalore - 560 012, India ⟨arunima_banerjee@physics.iisc.ernet.in⟩

Aritra Basu, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨aritra@ncra.tifr.res.in⟩

Rahul Basu, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨rbasu@ncra.tifr.res.in⟩

Anil Bhardwaj, Planetary Sciences Branch, Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum 695 022, India ⟨Anil_Bhardwaj@vssc.gov.in⟩

Sanjay Bhatnagar, NRAO, 1003 Lopezville Road, Socorro, NM 87801, USA ⟨sbhatnag@aoc.nrao.edu⟩

Rosella Cassano, Istituto di Radioastronomia, INAF, c/o CNR, Via Gobetti 101, 40129 Bologna, Italy ⟨rcassano@ira.inaf.it⟩

Yogesh Chandola, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨chandola@ncra.tifr.res.in⟩

Subhrojyoti Chaudhuri, TRDDC, Tata Consultancy Services, 54 B Hadapsar Industrial Estate, Pune 411 013, India ⟨subhrojyoti.c@tcs.com⟩

Jayaram Chengalur, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨chengalu@ncra.tifr.res.in⟩

Jayanth Chennamangalam, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨jayanth@rri.res.in⟩

Mousumi Das, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨mousumi@rri.res.in⟩

Kanan K Datta, Centre for Theoretical Studies, IIT Kharagpur - 721 302, West Bengal, India ⟨kanan@phy.iitkgp.ernet.in⟩

Erwin de Blok, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa ⟨edeblok@ast.uct.ac.za⟩

Ger de Bruyn, ASTRON, Postbus 2, 7990 AA Dwingeloo, The Netherlands ⟨ger@astron.nl⟩

Shuji Deguchi, NAOJ, Nobeyama Radio Observatory, Minamimaki, Minamisaku, Nagano 384-1305, Japan ⟨deguchi@nro.nao.ac.jp⟩

Avinash Deshpande, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨desh@rri.res.in⟩

Mukund Deshpande, Persistent Systems Limited, Bhageerath, 402 Senapati Bapat Road, Pune 411 016. India ⟨mukund_deshpande@persistent.co.in⟩

Prasun Dutta, Centre for Theoretical Studies, IIT Kharagpur - 721 302, West Bengal, India ⟨prasundutta151@gmail.com⟩

K. Dwarakanath, RRI, C.V.Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨dwaraka@rri.res.in⟩

B. Ekta, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨ekta@ncra.tifr.res.in⟩

Vishal Gajjar, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨gajjar@ncra.tifr.res.in⟩

R. T. Gangadhara, IIA, Koramangala, II Block, Bangalore - 560 034, India ⟨ganga@iiap.res.in⟩

Agalya Gangaputhiran , RAC, NCRA, P. O. Box 8, Ooty - 643 001, India ⟨gkagali@gmail.com⟩

V. Girish, Space Astronomy & Inst Div, ISRO Satellite Center, Airport Road, Bangalore - 560 017, India ⟨giri@isac.gov.in⟩

Gopal-Krishna, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007 India ⟨krishna@ncra.tifr.res.in⟩

Arti Goyal, ARIES, Manora Peak, Nainital 263 129, Uttarakhand India ⟨arti.aries@gmail.com⟩

David Green, Astrophysics Group, Cavendish Laboratory, 19 J. J. Thomson Avenue, Cambridge CB3 0HE, UK ⟨dag@mrao.cam.ac.uk⟩

Neeraj Gupta, CSIRO-ATNF, PO Box 76, Epping, NSW 1710, Australia, ⟨Neeraj.Gupta@atnf.csiro.au⟩

Yashwant Gupta, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨ygupta@ncra.tifr.res.in⟩

Sukhpreet Guram, University of Calgary, Department of Physics and Astronomy, 2500 University Drive, NW Calgary AB T2N IN 4, Canada ⟨gurm.sukhpreet@gmail.com⟩

Martin Hardcastle, School of Physics, Astronomy and Mathematics, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK ⟨m.j.hardcastle@herts.ac.uk⟩

Jason Hessels, ASTRON, P.O. Box 2, 7990 AA, Dwingeloo, The Netherlands ⟨J.W.T.Hessels@uva.nl⟩

C. H. Ishwara-Chandra, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨ishwar@ncra.tifr.res.in⟩

Joe Jacob, Department of Physics, Newman College, Thodupuzha PO, Kerala 685 585, India ⟨drjoephysics@yahoo.co.in⟩

Marek Jamrozy, Jagiellonian Univ, ul. Orla 171, 30-244, Krakow, Poland ⟨jamrozy@oa.uj.edu.pl⟩

Jayanti Prasad, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨jayanti@ncra.tifr.res.in⟩

Nazirah Jetha, CEA-SACLAY, France ⟨nazjetha@gmail.com⟩

B. C. Joshi, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨bcj@ncra.tifr.res.in⟩

Sanhita Joshi, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨sjoshi@ncra.tifr.res.in⟩

Ruta Kale, RRI, Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 080, Bangalore ⟨ruta@rri.res.in⟩

Atish Kamble, Astronomical Institute "Anton Pannekoek", Kruislaan 403, 1098 SJ Amstedam, The Netherlands ⟨atish.vyas@gmail.com⟩

Nissim Kanekar, NRAO, 1003 Lopezville Road, Socorro, NM 87801, USA ⟨nkanekar@aoc.nrao.edu⟩

Nimisha Kantharia, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨ngk@ncra.tifr.res.in⟩

Prabhu Kesavan, RAC, NCRA, P.O.Box≠ 8, Ooty - 643 001, India ⟨kes.prabhu@gmail.com⟩

Jaroslaw Kijak, Institute of Astronomy, Univ. of Zielona Gora, ul.Lubuska, 65 265, Zielona Gora, Poland ⟨jkijak@astro.ia.uz.zgora.pl⟩

Chiranjib Konar, IUCAA, Post Bag 4, Pune University Campus, Pune 411 007 India ⟨chiranjib.konar@gmail.com⟩

Krzysztof Krzeszowski, Institute of Astronomy,Univ. of Zielona Gora, ul. Lubuska, 65 265, Zielona Gora, Poland ⟨chriss@astro.ia.uz.zgora.pl⟩

Vasant Kulkarni, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007 India ⟨vasant@ncra.tifr.res.in⟩

Dharam Vir Lal, MPIfR, Auf dem Huegel 69, 53121, Bonn Germany ⟨dharam@mpifr-bonn.mpg.de⟩

Yogesh Maan, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨yogesh@rri.res.in⟩

Jerzy Machalski, Jagiellonian Univ, ul. Orla 171, 30-244, Krakow, Poland ⟨machalsk@oa.uj.edu.pl⟩

Ravi Manchanda, TIFR, Colaba, Mumbai 400 005, India ⟨ravi@tifr.res.in⟩

P.K. Manoharan, RAC, NCRA, P.O.Box≠ 9, Ooty - 643 001, India ⟨mano@ncra.tifr.res.in⟩

Visweshwar Ram Marthi, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨viswesh@ncra.tifr.res.in⟩

Paul Mason, University of Texas at EI, 4240 Holiday Lane, Las Cruces, NM 88007, USA ⟨pmason@nmsu.edu⟩

Alka Mishra, Department of Physics, D.D.U. Gorakhpur University, Gorakhpur - 273 009, U.P, India ⟨alkam7@gmail.com⟩

Dipanjan Mitra, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨dmitra@ncra.tifr.res.in⟩

Vivek Mohile, Persistent Systems Limited, Bhageerath, 402 Senapati Bapat Road, Pune 411016, India ⟨vivek_mohile@persistent.co.in⟩

Vivekananda Moosani, Persistent Systems Limited, Bhageerath, 402 Senapathi Bapat Road, Pune 411 016, India ⟨vivekananda_moosani@persistent.co.in⟩

Sumana Nandi, ARIES, Manora Peak, Nainital 263 129, Uttarakhand, India ⟨sumana@aries.ernet.in⟩

Arvind Nayak, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨arvind@rri.res.in⟩

Rajaram Nityananda, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨rajaram@ncra.tifr.res.in⟩

Ewan O'Sullivan, Harvard-Smithsonian Centre for Astrophysics, 60 Garden Street, MS - 67, Cambridge, MA 02138, USA ⟨ejos@head.cfa.harvard.edu⟩

Divya Oberoi, MIT Haystack Observatory, Off Route 40, Westford, Massachusetts 01886-1299, USA ⟨doberoi@haystack.mit.edu⟩

Amitesh Omar, ARIES, Manora Peak, Nainital 263 129, India ⟨aomar@aries.ernet.in⟩

Alain Omont, Institute d'Astrophysique de Paris, 98bis Bd ARAGO, 75014, Paris, France ⟨omont@iap.fr⟩

T. Padmanabhan, IUCAA, Post Bag 4, Pune University Campus, Pune 411 007, India ⟨paddy@iucca.ernet.in⟩

Sabyasachi Pal, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨spal@ncra.tifr.res.in⟩

Vishambhar Nath Pandey, Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV, Groningen, The Netherlands ⟨pandeyvn@gmail.com⟩

M. V. Pandurangarao, TRDDC, Tata Consultancy Services, 54 B Hadapsar Industrial Estate, Pune 411 013, India ⟨mvpandurangarao.m@tcs.com⟩

Revathi Paramasivam, RAC, NCRA, P.O.Box≠ 8, Ooty - 643 001, India ⟨k.p.revathi@gmail.com⟩

Josep M. Paredes, Universitat de Barcelona, Department d' Astronomia i Meteorologia, Facultat de Fisica, Planta 7a, Universitat de Barcelona, Marti-i Franques 1, 08028-Barcelona, Spain ⟨jmparedes@ub.edu⟩

Chaitral Purkar, Persistent Systems Limited, Bhageerath, 402 Senapati Bapat Road, Pune 411 016, India ⟨chaitral_purkar@persistent.co.in⟩

Narendra Nath Patra, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨narendra@ncra.tifr.res.in⟩

Ue-li Pen, CITA, University of Toronto, Canada ⟨pen@cita.utotonto.ca⟩

Jeffrey Peterson, Department of Physics, Carnegie Mellon University, USA ⟨jeffreyb.peterson@gmail.com⟩

S.A.Petrova, Institute of Radio Astronomy, NAS of Ukraine,4, Chervonopraporna Str., 61002 Kharkov, Ukraine ⟨petrova@ri.kharkov.ua⟩

Akash Pirya, ARIES, Manora Peak, Nainital 263 129, Uttarakhand, India ⟨akash@aries.ernet.in⟩

Roberto Francesco Pizzo, Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV, Groningen, The Netherlands ⟨pizzo@astro.rug.nl⟩

Peeyush Prasad, Astronomy and Astrophysics, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560000, India ⟨peeyush@rri.res.in⟩

Wasim Raja, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 000, India ⟨wasim@ncra.tifr.res.in⟩

Pramesh Rao, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨pramesh.rao@gmail.com⟩

Somak Raychaudhury, School of Physics and Astronomy, University of Birmigham, Edgbaston, Birmingham B15 2TT, UK ⟨somak@star.sr.bham.ac.uk⟩

Russ Taylor, Department of Physics and Astronomy, University of Calgary, 2500 Univ Dr NW, CA Calgary AB T2N 1N4, Canada ⟨russ@ras.ucalgary.ca⟩

Jayanta Roy, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨jroy@ncra.tifr.res.in⟩

Nirupam Roy, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨nirupam@ncra.tifr.res.in⟩

Subhashis Roy, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨roy@ncra.tifr.res.in⟩

Sambit Roychowdhury, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨sambit@ncra.tifr.res.in⟩

D. J. Saikia, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨djs@ncra.tifr.res.in⟩

Lakshmi Saripalli, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 000, India ⟨lsaripal@rri.res.in⟩

Chandreyee Sengupta, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007 India ⟨sengupta@ncra.tifr.res.in⟩

Senthil Rajan Sakthi Ganapathi, RAC, NCRA, P.O.Box ≠8, Ooty - 643 001, India ⟨sakthisenthil.rajan@gmail.com⟩

Ramya Sethuram, Indian Institute of Astrophysics, 2nd Block, Koramangala, Bangalore - 560 034 India ⟨ramya@iiap.res.in⟩

Shaik Shaheda Begum Shaik Khaia, RAC, NCRA, P.O.Box≠ 8, Ooty - 643 001, India ⟨shahi803@gmail.com⟩

Prajval Shastri, Indian Institute of Astrophysics, Sarjapur Road, Bangalore - 560 034 India ⟨pshastri@iiap.res.in⟩

Ashok Singal, Astronomy & Astrophysics, PRL, Navarangapura, Ahmedabad - 380 009, India ⟨asingal@prl.res.in⟩

Veeresh Singh, Indian Institute of Astrophysics, 2nd Block, Koramangala, Bangalore - 560 034, India ⟨veeresh@iiap.res.in⟩

Sandeep Sirothia, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨sirothia@ncra.tifr.res.in⟩

Anoop Srivastava, Department of Physics, D.D.U Gorakhpur University, Gorakhpur - 273 009, U.P, India ⟨srianoop@gmail.com⟩

Dhruwa Srivastava, Department of Physics, D.D.U Gorakhpur University, Gorakhpur - 273 009, U.P, India ⟨dcs@iucaa.ernet.in⟩

Shweta Srivastava, Department of Physics, D.D.U Gorakhpur University, Gorakhpur - 273 009, U.P, India ⟨srivasweta@gmail.com⟩

Lister Staveley-Smith, University of Western Australia, 35 Stirling Highway Crawley WA 6009, Australia ⟨Lister.Staveley-Smith@uwa.edu.au⟩

Jeroen Stil, Centre for Radio Astronomy, Department of Physics and Astronomy,University of Calgary, Canada ⟨stil@ras.ucalgary.ca⟩

Ravi Subrahmanyan, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 000, India ⟨rsubrahm@rri.res.in⟩

Prasad Subramanian, IISER, Sai Trinity Building, Garware Circle, Pashan, Pune - 411021, India ⟨p.subramanian@iiserpune.ac.in⟩

Govind Swarup, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨gswarup29@gmail.com⟩

Reji Thomas, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨mathew@ncra.tifr.res.in⟩

Peter Thomasson, The University of Manchester, Jodrell Bank Observatory, Macclesfield, Cheshire, SK11,9DL, UK ⟨pt@jb.man.ac.uk⟩

Nithyanandan Thyagarajan, Columbia University, 419 West 119th St., Apt ≠762, New York, NY 10027, USA ⟨t_nithyanandan@astro.columbia.edu⟩

Udaya Shankar N, RRI, C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 080, India ⟨uday@rri.res.in⟩

Ujjwal Kumar, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007 ⟨ujjwal@ncra.tifr.res.in⟩

Suresh Venkatesh, RRI, Telescope Building, Sadashivanagar, Bangalore - 560000, India ⟨sureshv@rri.res.in⟩

Tiziana Venturi, Istituto di Radioastronomia, INAF, c/o CNR, Via Gobetti 101, 40129 Bologna, Italy ⟨tventuri@ira.inaf.it⟩

Marc Verheijen, Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV, Groningen, The Netherlands ⟨verheyen@astro.rug.nl⟩

Rashmi Verma, Instituto di Radioastronomia (CNR), Via P. Gobetti, 101, 40129, Bologna, Italy ⟨rashmi018@gmail.com,⟩

Harrick Vin, TRDDC, Tata Consultancy Services, 54 B Hadapsar Industrial Estate, Pune 411 013, India ⟨harrick.vin@tcs.com⟩

Mahalakshmi Kasi Viswanathan, RAC, NCRA, P.O.Box≠ 8, Ooty - 643 001, India ⟨kmahee@gmail.com⟩

Jan M. Vrtilek, Harvard-Smithsonian Centre for Astrophysics, MS-3, 60 Garden Street, Cambridge, MA 02138, USA ⟨jvrtilek@cfa.harvard.edu,⟩

Yogesh Wadadekar, NCRA-TIFR, Pune University Campus, Ganeshkhind Road, Pune - 411 007, India ⟨yogesh@ncra.tifr.res.in⟩

Nitin Wadnerkar, S. R. T. M. University, School of Physical Sciences, Swami Ramanand Teerth Marathwada University, India ⟨wadnerakar_nitin@yahoo.com⟩