DOOT

Quarterly Magazine of the Indian Institute of Astrophysics

Issue 03
February 2021

"Bright Days Ahead for Radio Astronomy"

Interview with Prof. Yashwant Gupta

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DOOT

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Invitation for the next issue

For the next issue of DOOT, we are inviting your contributions under the following categories:

Review articles:

Scientific and technical publications (recent publications in academic journals from the IIA family, IIA technical reports, breakthroughs in Astronomy, book review, Journal club discussions, milestones of IIA projects; to be published in simple language) are invited. Project interns and summer school project students can submit an overview of their work. (Word limit: 2000 words)

Individual experiences and substation stories:

In this section, we invite stories of your personal experience, maybe with a scientific project, an experiment, attending a conference/workshop, a collaborative visit, visit to an observatory, or even a coffee break with a prominent scientist. We also invite interesting stories from our substations at Hanle, Kodaikanal, Kavalur, and Gauribidanur about the ongoing activities and valuable memories. (Word limit: 1400 words)

Physics concepts made easy:

For this section, we invite write-ups discussing interesting concepts of Physics in a very simple and enjoyable way, without using much of technical jargons. The main motive is to reach a wider audience by making it easy to understand, relate, or appreciate Physics, without having any technical background in the subject. (Word limit: 1400 words)

Alumni and retired staff/faculty stories:

IIA Alumni students and retired staff/faculty can share their experiences during their association with IIA. (Word limit: 1400 words)

Creativity corner:

Splurge on your creativity here! For this section, we invite all kinds of artworks including but not limited to paintings, poems, short stories, and graffiti. (Word limit: 800 words)

NOTE: Attach a brief bio along with the article. Submissions should be in editable text files (doc/odt).

High resolution images should be given separately with the filename same as figure numbering (eg: Fig1.jpg)

Disclaimer: *Any article received will be published only after strict screening. The chief editor's decision will be final. Submitting your article to DOOT implies your consent to edit and publish the article and the work is bonafide.*

We would like to improve the content of the magazine.

Please send your generous feedback and contibutions for next editions to

magazine.iiabengaluru@iiap.res.in

From the Editor

We are happy to bring the first issue of the DOOT magazine for the year 2021. Like our previous issues, this time too we have received enormous contributions from the IIA family. In the current issue, we are featuring articles on the Black Holes, which received wide attention among the scientific community due to the Nobel Prize 2020 in Physics. They include the basic overviews of the current field of research and the flavor of work done at IIA on the black hole physics. The second article on the TMT instruments series discusses the actuators, which plays a key role in the primary mirror of any large telescope. There is also an article discussing one of the mysterious components of the universe, widely known as the Dark Energy, the discovery of which was awarded with the Nobel Prize 2011 in Physics. The issue also includes the last article in the sequel of glimpses on making of the Indian Astronomical Observatory (Hanle) and the experience of the scientists engaged with the society through outreaches.

This issue features the interview of one of the pioneers in Indian Radio Astronomy, Prof. Yashwant Gupta. The interview features the recent IEEE recognition of GMRT, the uGMRT capabilities, India's role in mega Radio Astronomy projects, visions for the future of Indian Radio Astronomy, the surging role of scientists in national Science and Technology policy-making processes and finally, the opportunities in astronomy for young bright minds of India. Furthermore, this issue also features articles on various astronomy and science concepts as well as the creativity imprintation of the researchers at IIA.

As great scientist and astronomer Prof. Carl Sagan has rightly pointed out: "Every kid starts out as a natural-born scientist, and then we beat it out of them. A few trickle through the system with their wonder and enthusiasm for science intact." We hope that this magazine keeps on working in the direction to sustain scientific enthusiasm among the wider part of the society. It was a wonderful experience to serve for this magazine for quite some time and it's time to sign off. I would like to pass on the baton to Suman Saha to lead the magazine team and convey my best wishes to the whole team for the future endeavours.

Happy Reading !

DOOT
Quarterly Magazine of the Indian Institute of Astrophysics

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The cover picture

Image Credit: Yogesh/IIA.

India-TMT Optics Fabrication Facility (ITOFF)

The Vice President of India Shri. Venkaiah Naidu visited the Center for Research and Education in Science & Technology (CREST) campus of the Indian Institute of Astrophysics in Bengaluru on 29th December 2020 to inaugurate two new facilities which are set to play a critical role in larger multinational astronomy projects. The units inaugurated include a newly built India-TMT Optics Fabrication Facility (ITOFF) for the Thirty Metre Telescope (TMT), a proposed extremely large telescope due to take shape on Mauna Kea on the island of Hawaii. The second unit is the Environment Test Facility (ETF), which has been set up at the M G K Menon Laboratory for Space Sciences, a state-of-the-art cleanroom. The ETF will help with the integration and calibration of space payloads.

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Glimpses of memories at IAO

B. C. Bhatt
Dorje Angchuk
Man Singh

In the final part of this series "Glimpses of memories at IAO, Ladakh", I will start with the installation of the 2m telescope. The telescope consignment journey from EOST, Tucson (USA) to Hanle, Ladakh was over on 18/19th of August, 2000. During this period, all the civil/mechanical/electrical works of the telescope dome were completed, and the telescope pier was ready to take the assembly over it. In the meantime, few engineers from EOST also reached IAO-Hanle in different time slots. One of the Mechanical engineers,

Mirror box being lifted to top floor inside the dome

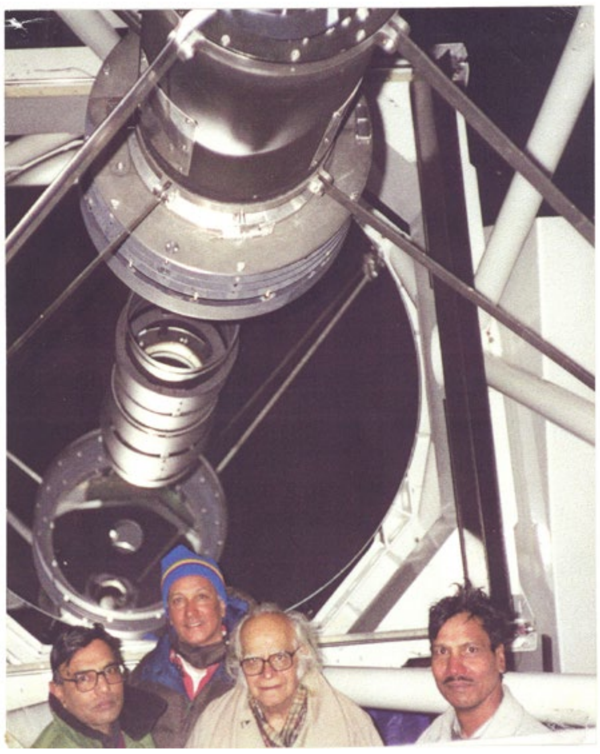
Mr. Michel, arrived first, and in his presence, the installation of the telescope started on 25th August (2000) onwards. Later some more engineers from EOST joined the installation/testing work. A complete team comprising of IIA engineers, technicians, and scientists was also available at the site to learn about the installation/assembly of different mechanical/optical and electrical/electronics parts of the telescope. Within one month, the telescope was ready to point to the sky and get the first glimpse of the night sky at Hanle.

The IIA team and administration also anticipated this event of first light well in advance. They planned to make it ceremonial and organised the Third Indo-Japan Seminar in Astronomy & Astrophysics at Leh (Ladakh) from September 27 to October 1, 2000. Four scientists from Japan and many Indian scientists/Head

Mirror support system being fixed above pier

of Institutions reached Ladakh to participate in the event. The first light observations were taken with the 2-m telescope in the gracious presence of eminent Prof. Yashpal in the late evening of September 26, 2000. On September 27, Prof. Yashpal inaugurated the newly built Meghnad Saha Astronomical Archive Building for office and guest house at the base camp of IAO, Hanle.

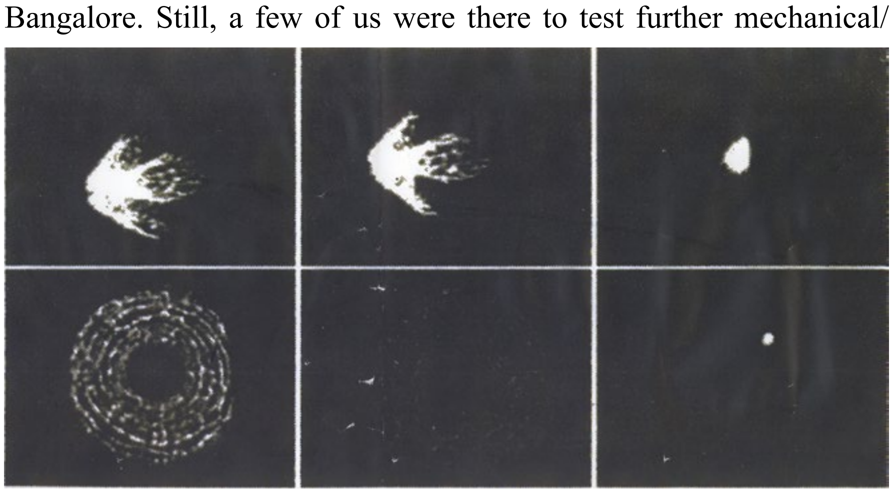
Prof. Yashpal and other IIA scientists reached Leh the same evening. At Hotel La-Galdan, Leh, the Indo-Japan Seminar was inaugurated by Prof. Yashpal by lighting the lamp and recital of Saraswati Vandana by local women. The workshop ran different



First light observations of 2-m Telescope on September 26, 2000, witnessed by Prof. Yashpal and others.

sessions, and one night tour of IAO-Hanle was organised for the interested visitors. Despite the tight schedule of long travel and stay at 15,000ft, all the visiting scientists appreciated the arrangement made at IAO, Hanle, for their visit and the efforts IIA put into developing one of the best astronomical sites in India.

EOST engineers completed the installation of the telescope by the second week of October 2000. It was too cold at IAO-Hanle as well in Leh. Most of the IIA working teams also went back to Bangalore. Still, a few of us were there to test further mechanical/



The first-light comatic image of B Cassiopeiae observed at the2-m Telescope. The telescope was brought to good focus by aligning the secondary and examining the trial images.

optical and software parts of the telescope and assess this newly installed facility's performance. The winters were harsh, but we got excellent quality sky during this period. So with a small 1024x1024 pixels CCD system, we continuously operated the telescope to test the complete system. Though the dome was complete, automation was not there. The control room was poorly insulated for the cold temperature. Some observing assistants from Leh helped the dome's movement manually, thereby wrapping themselves the whole night in blankets on the telescope floor.

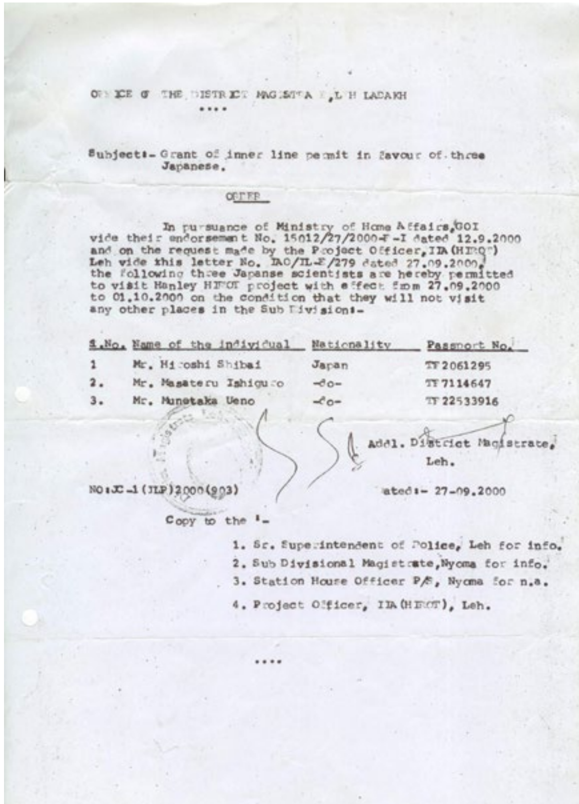
Somehow we managed despite the extreme cold from October to April and took rigorous observations to test the telescope capability, which provided an excellent performance all the time. First scientific observations of the GRB 010222 afterglow were recorded with the telescope on February 22, 2000. The results were published in BASI (Bull. Astron. Soc. of India, 2001, 29, 157). Our first year's challenge operating the telescope all night during the winter months at IAO-Hanle, without much of automation, was a great experience and success.

At Base camp, IAO Hanle, the newly built facility for Office and Guest House, inaugurated by Prof. Yashpal as Meghnad Saha Astronomical Archive on September 27, 2000, 0800AM.

After March 2001, IIA teams started coming back to Ladakh for various telescope operation works, automation of dome, network connections. The new first light instrument HFOSC (Hanle Faint Object Spectrograph Camera) also reached Hanle in May 2001 and was later installed on the telescope. Dome automation software was installed and also tested during this time. The local area network was established and tested with the CREST-Hoskote campus network via an Indian communication satellite. The telescope and data acquisition systems at Hanle are connected with CREST Campus, Hoskote, for remote operation of this facility.

H.E. Farooq Abdulla, then Chief Minister of J&K, visited IAO-

Inauguration of 3rd India-Japan Seminar on Astronomy & Astrophysics on September 27, 2000, 0700PM at Hotel La-Galdan, Leh.



OFFICE OF THE DISTRICT MAGISTRATE, LEH LADAKH

....

Subject:- Grant of inner line permit in favour of three Japanese.

ORDER

In pursuance of Ministry of Home Affairs, GOI vide their endorsement No. 15012/27/2000-F-I dated 12.9.2000 and on the request made by the Project Officer, IIA (HIROT) Leh vide this letter No. IAO/IL-F/279 dated 27.09.2000, the following three Japanse scientists are hereby permitted to visit Hanley HIROT project with effect from 27.09.2000 to 01.10.2000 on the condition that they will not visit any other places in the Sub Division:-

S.No.	Name of the individual	Nationality	Passport No.
1	Mr. Hiroshi Shibai	Japan	TF 2061295
2.	Mr. Masateru Ishiguro	-do-	TF 7114647
3.	Mr. Munetaka Ueno	-do-	TF 22533916

Addl. District Magistrate,
Leh.

NO: JC-1 (ILP) 2000 (903)   Dated:- 27-09.2000

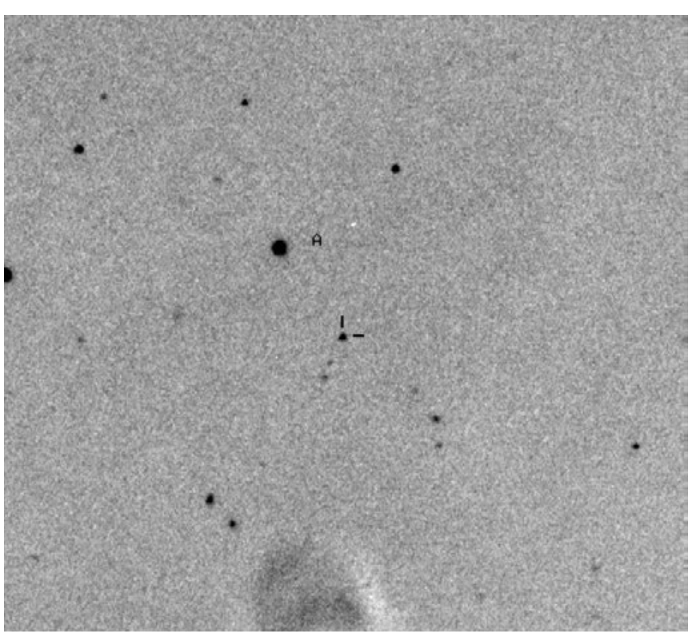
Copy to the :-

1. Sr. Superintendent of Police, Leh for info.
2. Sub Divisional Magistrate, Nyoma for info.
3. Station House Officer P/S, Nyoma for n.a.
4. Project Officer, IIA (HIROT), Leh.

....

A file photo of Inner-line permit for Japanese scientists for their visit to IAO-Hanle.

Hanle and inaugurated this communication link between IAO-Hanle and CREST, Hoskote, on June 2, 2001, in the esteemed presence of Prof. B. V. Shreekantan, the then Chairman of the Governing Council of IIA, from CREST-Hoskote campus. Later that afternoon, H.E. Farooq Abdulla laid the Raman Science Center's foundation stone at the newly acquired campus of IAO in Leh town.

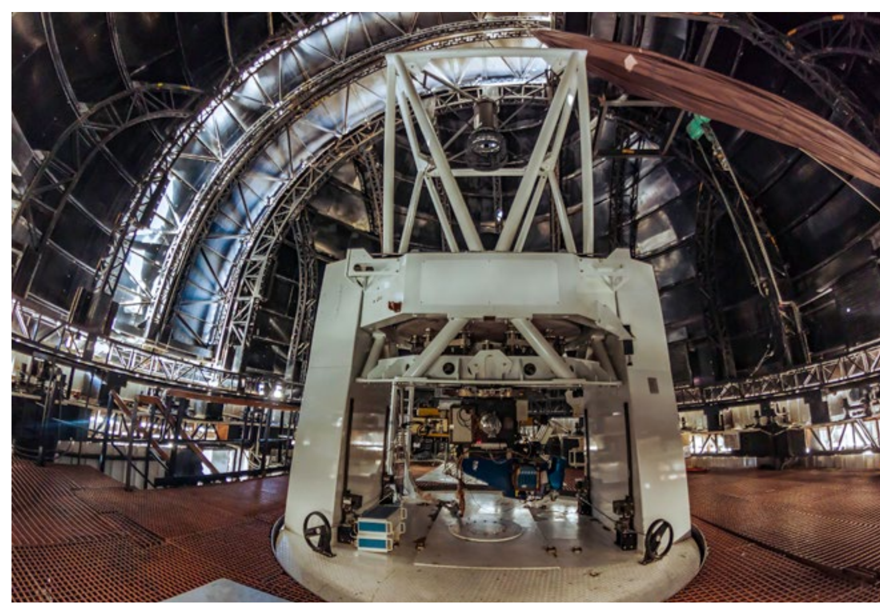


First Scientific observations of 2-m Telescope, the afterglow of GRB010222 on February 22 2001.

Meanwhile, all other work at IAO-Hanle continued during the 2001 summer to make it a comfortable workstation for Observatory operation. The EOST team also visited to work on the 2m telescope performance check and software update. Our experiences with the telescope operation were discussed, and necessary upgradation works on the telescope system were performed. The HFOSC system was also installed, and the testing started. On August 29, 2001, a dedication ceremony was planned to name this telescope as Himalayan Chandra Telescope (HCT) and dedicate it to the nation. For this occasion, many scientists from India and abroad visited IAO, Leh/Hanle, and witnessed the ceremony.

Inauguration of Raman Science Center, Leh by H.E. Farooq Abdulla, then Chief Minister of J&K state on June 2, 2001.

All other tests on software and hardware of the complete telescope, data acquisition system, and communication system continued again from 2001 winter to April 2003 and finally, this 2m Himalayan Chandra Telescope is open for the user community in India and abroad with its remote operation center at CREST-Hoskote, Bangalore.



Inside dome view of 2-m Himalayan Chandra Telescope with HFOSC at the direct focal port.

B. C. Bhatt joined IIA in 1994 and was part of the first team of IIA that did the site-testing and characterization of Hanle, Ladakh in November 1994. He was the Project Officer for setting up the 2 meter HCT at Leh/Hanle. Currently he is a professor at IIA and Scientist-in-Charge CREST campus, Hoskotte.

Dorje Angchuk was the first person from Ladakh to join IAO as a Trainee Engineer during its initial phase. He contributed to the installation and commissioning of the 2 meter HCT, later getting a permanent position there. Presently he is Engineer-in-Charge, IAO.

Man Singh joined as Cook/Caretaker at IIA's transit guest house, and was later posted as Caretaker, IAO, Leh. During this time, he supported the guest houses at Leh and Hanle including office related work. He is currently a UDC at Raman Science Centre, IAO, Leh.

Soft actuators for the Thirty Meter Telescope

Prasanna Deshmukh

India's participation in the TMT project will provide Indian astronomers with an opportunity to carry out frontline research in astronomy. Another primary reason to participate in this scientific endeavour, which integrates the latest innovations in segmented mirror design, precision control and adaptive optics, is to bring home some of this engineering expertise through international collaboration. Primary mirror (M1) segments are the most critical components for the TMT project. There are 492 (574 including spares) segments, each with a diameter of 1.44 m and thickness of 45 mm. All the segments are needed to be cut hexagonally and polished to the roughness of about 22 Å RMS or to about 20 nm peak-to-valley (PV), and without any subsurface damage. All the segments are off-axis and aspheric. To achieve very high spatial resolution and sensitivity, all the 492 hexagonal mirror segments of the TMT must be precisely positioned within a few nanometres with respect to each other to form a 30-meter hyperboloid primary mirror.

The segmentation of the primary mirror enables us to construct large telescopes, but on the other hand, brings an increased level of control challenges. A typical Segmented Mirror Telescope (SMT) equipped with Adaptive Optics (AO) has several control loops working at different temporal and spatial frequencies and are responsible for the final image quality. The architecture of different loops of SMT depends on the amplitude and the frequency range of different disturbances acting on it. Major disturbances include: (a) the gravitational deformation of the telescope, (b) the thermal expansion of the telescope structure, (c) the wind-induced deformation of the telescope, and (iv) the wavefront deformation due to atmospheric turbulence. (Angeli, Cho and Whorton 2003).

The relatively slower main axis loop (telescope mount control) ensures that the telescope is pointing toward the field of interest in the sky. Typically, it involves two axes of rotation, namely altitude and azimuth, both running in the closed-loop tracking mode at predefined track rates. The fact that the primary mirror is segmented demands all the segments to be co-aligned and co-phased initially to act as a single mirror surface, and further needs to be maintained in the presence of different disturbances. The initial alignment is typically done using an Alignment and Phasing System (APS), and once done, this loop is disconnected for a few weeks until realignment of the entire M1 is necessary. The role of maintaining the mirror shape is done by the global control system, which continuously monitors the edge sensor readings (two edge sensors per inter-segment edge), and commands the actuators below each segment (three actuators per segment) to correct for any deviation of edge sensor readings compared to the reference. Further, a relatively faster loop at the individual actuators (local controllers) makes sure that incoming set points from the global controller are maintained continuously by the actuator. This local closed-loop controller is necessary to maintain the actuators' position to the desired set point, in the presence of

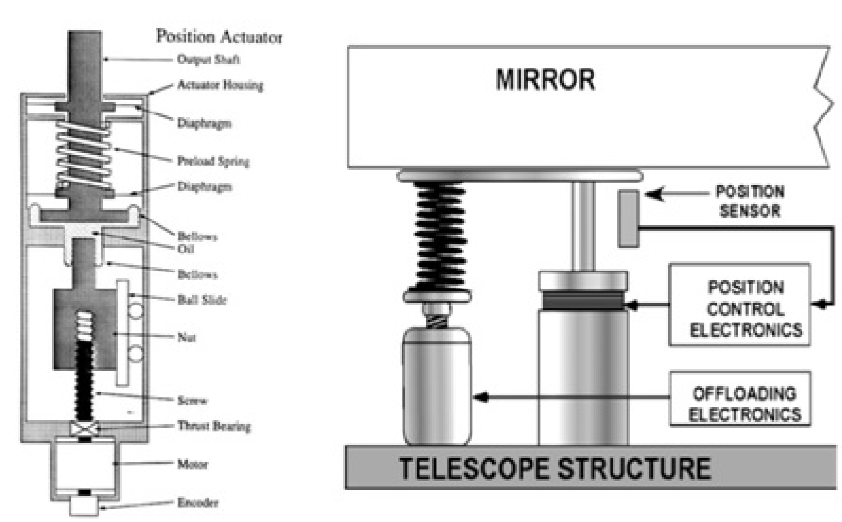


Figure 1: Schematic of Hard actuator of the KECK (left) and Soft actuator of the TMT (right). (Graphics adopted from (D. G. MacMartin 2003) and (Lorell, Aubrun, et al. 2006))

wind & vibration disturbances.

The actuators used in the Segmented Mirror Telescope are responsible for providing the tip, tilt, and piston to the individual mirror segments. Such actuators can be classified into two broad categories: hard/rigid actuator and the soft actuator. The actuators used in existing segmented mirror telescopes, such as the W. M. Keck Observatory (Keck) (Meng, et al. 1990), the Southern African Large Telescope (SALT) (Swiegers and Hitesh 2004), the Gran Telescopio Canarias (GTC) (Lefort and Castro 2008), the Large Sky Area Multi-

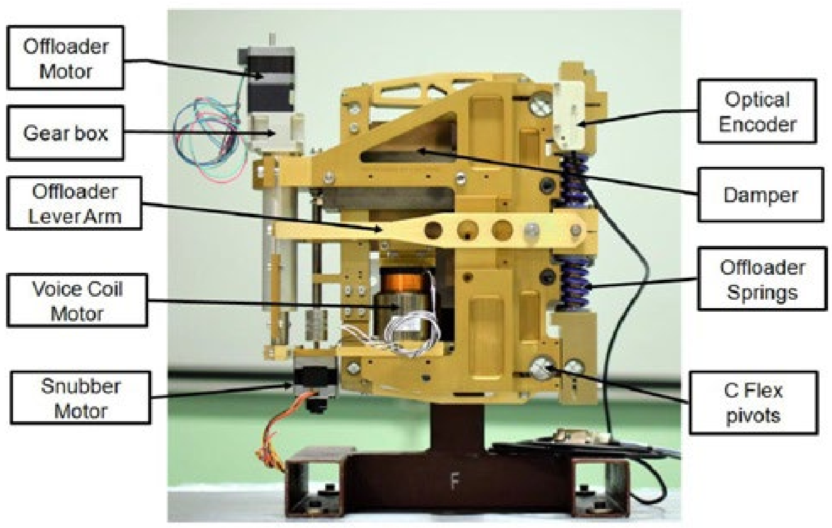


Figure 2: Soft actuator of TMT M1CS. (Image credit: ITCC/ Prasanna Deshmukh)

Object Fibre Spectroscopic Telescope (LAMOST) (Xu, Xu and Jin 2003), and the Hobby-Eberly Telescope (HET) (Krabbendam, et al. 1998), are hard/rigid actuators and have extremely high axial stiffness. One of the main drawbacks of a hard actuator is that it supports very low control bandwidth, which results in poor active dynamic interactions between the actuator and the mirror segment, and hence cannot suppress high frequency disturbances induced by wind and other structural vibrations. Whereas, the soft actuators proposed for upcoming SMTs like the Thirty Meter Telescope (TMT) (Lorell, Aubrun, et al. 2006, J. Nelson 2005) and the European Extremely Large Telescope (E-ELT) (Jimenez, et al. 2010) use a Voice Coil Motor (VCM)

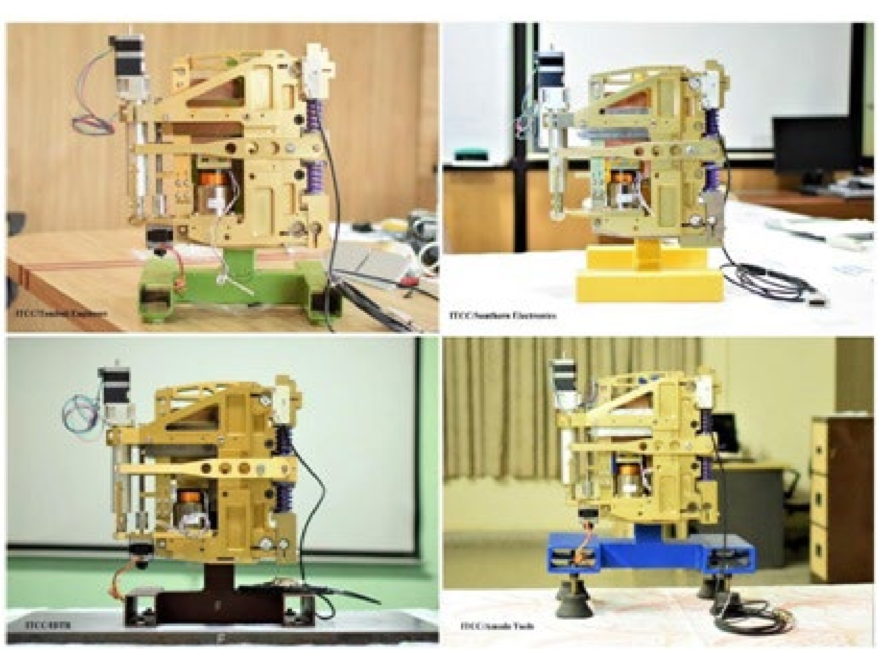


Figure 3: Actuators (P2e) manufactured at 4 industries in India. (Image credit: ITCC/Prasanna Deshmukh)

that gives high bandwidth actuation. The soft-actuator is fairly straightforward to implement, relatively inexpensive, lightweight and compact. It has very few moving parts, is capable of producing a large force, can provide a large mechanical range, and does not require lubrication.

The TMT actuator (Lorell, Aubrun, et al. 2006) is an off-axis mechanism with VCM as its prime mover and an offloader for taking care of static loads. The VCM and stepper motor based offloading mechanism are linked to the actuator output shaft through the lever arm, hence providing amplification in the force as well as in displacement. In the TMT actuator, for effective rejection of high-frequency disturbances, a passive eddy current based damper which uses two powerful magnets and a copper plate has been incorporated. The TMT actuators use flexural elements for vibration isolation and for reducing the wear and tear due to friction. The local control loop runs at a very fast rate and uses a very high-resolution optical encoder directly coupled with the actuators' output shaft.

All the 492 hexagonal mirror segments of the TMT need to be precisely positioned with respect to each other to form a 30-meter hyperboloid primary mirror. The M1 control system (M1CS) performs this task, with the help of actuators that correct

Figure 4: Actuators (P2e) undergoing Functionality testing at Southern Electronics, Bangalore, using ITCC's actuator functionality test equipment. (Image credit: ITCC/Prasanna Deshmukh)

for the segments' tip-tilt and piston errors measured by edge sensors. Actuator corrections are critical to retain the mirror's shape that is otherwise disturbed due to wind and vibrations. Three actuators will drive each mirror segment, and altogether 1,476 actuators are required to keep all the segments aligned. These actuators are made up of several precision manufactured components put together to act as a soft actuator working to nano-metric accuracy and can provide tip, tilt, and piston to each mirror segment with an accuracy of 4 nm.

India-TMT is responsible for manufacturing all the 1,476 (1,536 including spares) actuators required for the TMT project. In 2018-2019, 20 P2e actuators were successfully fabricated and functionality tested at 4 Indian industries (Indo Danish Tool Room (IDTR), Jamshedpur; Southern Electronics, Bangalore;

Tamboli Engineers Pvt. Ltd., Pune; and Amado Tools, Bangalore). These actuators were shipped to TIOPO in the USA for further performance testing (at Jet Propulsion Laboratory (JPL), Pasadena, CA) and Accelerated Life Testing (at The Pilot Group, Monrovia, CA).

Figure 5: ITCC Team with actuators (P2e) manufactured in India being shipped from ITCC to TMTPO. (Image credit: ITCC/ Prasanna Deshmukh)

Figure 6: Actuators (P2e) installed on the Accelerated Life testing setup at The Pilot Group, California. (Image credit: TMT/TPG)

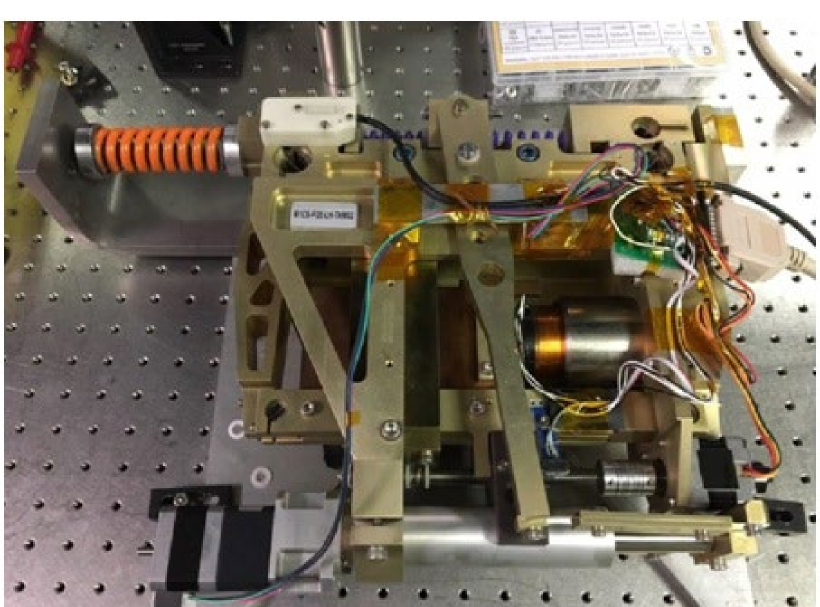


Figure 7: Actuators (P2e) (manufactured by Tamboli Engineers, Pune.) undergoing Performance testing at JPL, California. (Image credit: TMT/JPL)

All 20 P2e actuators manufactured in India, underwent Functionality Testing at the respective vendors' labs. All the

Figure 8: Actuators being life tested in cold conditions loaded into the freezer at The Pilot Group, California. Custom control boxes shown at right. (Image credit: TMT/TPG)

actuators passed the functionality requirements. Performance testing of 7 actuators was done in Warm and Cold (-15ºC) conditions; no issues were found, and the results were satisfactory. Out of 20 P2e actuators manufactured in India, Life Testing on 12 P2e actuators (3 warm, 9 cold) was conducted at The Pilot Group in Monrovia, CA. All 12 actuators successfully completed the required cycles.

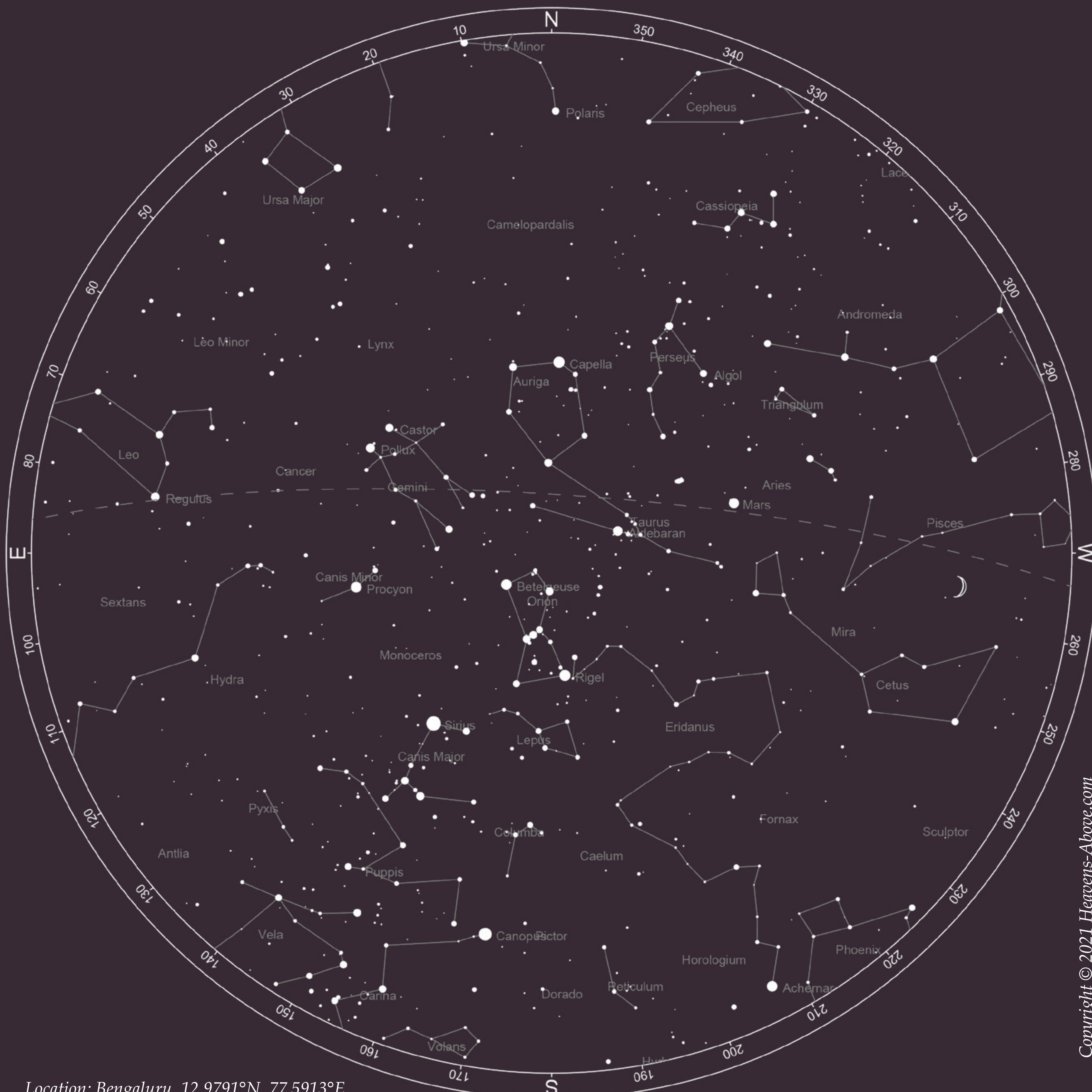
The actuators manufactured in India have successfully undergone the performance tests and lifetime tests conducted at The Pilot Group in Monrovia and at Jet Propulsion Laboratory (JPL) in Pasadena, USA. Based on the outcomes of P2e actuator Manufacturing and Testing, improvised P3 actuators design is realised and is planned to be manufactured in India in 2021.

(To be continued...)

[India-TMT M1CS Actuator Team: Prasanna Deshmukh, Viswanatha N, P K Mahesh, Varun Saraswat, Lalit Kumar, Jayakumar P S, Jeevan V, Surojit Roy, S Hari Prasath, Sudharsan K, Vaishaly, Snehashis Bhattacharya, Vaishaly Nigam]

Prasanna Deshmukh is an Engineer at IIA. His research interests include primary mirror control system for segmented mirror telescopes, control system, astronomical instrumentation and astronomy outreach.

Sky-Chart
February 2021



Location: Bengaluru, 12.9791°N, 77.5913°E
Time: 15 February 2021 20:00 (UTC +05:30)

Watchout for:

February 19 - Close approach of the Moon and Mars. The Moon and Mars will make a close approach, passing within 3°28′ of each other. The Moon will be at mag -11.7; and Mars will be at mag 0.8. Both objects will lie in the constellation Aries. Visible in the evening as the dusk sky fades, 74° above your north-western horizon.

The empty space is not "Nothing"

The mystery of Dark Energy

Image Credit: NASA, ESA, M. J. Jee and H. Ford et al. (Johns Hopkins Univ.)

Subinoy Das

Discovery

It all started when astronomers from the Supernova Cosmology Project and the High-Z Supernova Search Team were independently trying to measure the expansion rate of empty space by looking into the motion of very distant supernovae. Astronomers and theoretical physicists expected that though space has been expanding since the Big Bang, the speed of expansion should slow down due to attractive gravity between galaxies, stars, intergalactic gas, etc. But these teams found that expansion of the Universe is speeding up! On 8th January 1998, they officially announced this utterly unexpected discovery of the accelerating expansion of space through a press conference. The 2011 Nobel prize of physics was awarded to Saul Perlmutter of the Supernova Cosmology Project. Brian Schmidt & Adam Riess from the High-Z Supernova Search Team jointly for their stunning discovery. This discovery not only confirmed the unexpected speeding up of space, but also pointed out that a significant fraction (almost 70%) of the total energy of the Universe is not matter, but is stored in the form of an unseen energy (known as the dark energy), whose fundamental character is still a mystery.

Understanding Dark Energy

To understand dark energy, one needs to know what makes space expand. Einstein's general relativity (GR) theory of gravity answers this question through two elementary equations known as Friedmann equations. It tells us gravity is nothing but dynamics of space and time. So once one understands the gravitational pull between matter present in space, one can predict space's expansion rate. The Friedmann equations (the equation of GR in the expanding Universe) tell us that gravity depends not only on the mass or energy density but also the pressure. This itself is unexpected when we try to compare it with Newton's theory of gravity. The gravitational field generated by a uniformly distributed massive fluid only depends on the mass density in Newton's theory. But in reality (with GR), even objects with the same mass but at different states of matter (like gas, solid, etc.) can generate different gravitational pulls and cause different expansion rates of space!

That is why space expanded differently when the Universe was filled with radiation fluid in the early time just after the Big Bang (which has non-zero pressure density), compared to later epochs of galaxy formation when the Universe is dominated by matter and dark matter (zero pressure density). It can be shown through a simple one-line calculation that one needs an all-pervading, negative pressure fluid to speed-up space! And there is NO such known fundamental particle that can do that! Physicists have searched in all possible theories to generate a fluid with a negative pressure with known particles but could not succeed! Only one hope is there, but there is also a huge problem with that candidate of dark energy, which we will discuss now!

The vacuum energy of empty space and the biggest mismatch in the history of physics

From quantum mechanics or from the theory of quantum field, we know that the lowest energy state of a simple harmonic oscillator is not zero (known as zero-point energy), and Richard Feynman showed that our Universe or empty space could be thought of as a combination of an enormous number of simple harmonic oscillators. With the similar analogy of creation and annihilation operators of quantum mechanics, empty space is continuously creating and annihilating virtual particles, and the ground state energy of this empty space is not zero. This energy is known as the Cosmological Constant, and it has a negative pressure, and it is all-pervading! Eureka! So, scientists thought they had found the candidate of dark energy, and immediately calculated its energy density by using the tools of quantum field theory.

Once they compared their calculated value with the experimental value given by the Nobel Prize winners mentioned above, they found that the theoretically estimated value is 10^{120} (yes, this is not a typo!) times higher than the experimentally observed value of dark energy density. This is the biggest mismatch between theory and experiments in the history of physics! At this point, the readers must be thinking why we don't dump this idea of vacuum energy and look for something else as a candidate of dark energy!

There are two problems with that. First, if we let go of vacuum energy, then there is nothing in our hand which has negative pressure! Second, even if we come up with another candidate of dark energy, we have to explain why vacuum energy does participate in gravity, since this vacuum energy must be present in the Universe according to the calculation of quantum field theory, which has explained many other fundamental phenomena very accurately over the last few decades. So, physicists tried and came up with one way out, which is also problematic to many! Once one calculates vacuum energy, one gets some constant of integration which can be hand-picked (with no proper reason though!) with 120 orders of fine-tuning to cancel the huge value (10^{120} times higher than observed), and come up with an extraordinarily small number! This is known as the cosmological constant problem and is still a mystery in theoretical physics.

Cosmological coincidence with dark energy

There is another mystery with this very very tiny value of dark energy. With this tiny value of dark energy, one can show by a simple calculation that dark energy density only started to dominate the Universe very recently (3 to 4 billion years back). The Universe spent most of the time before that in matter-dominated epoch (around 10 billion years), and only the first one million years was radiation dominated epoch. So accelerated speed up is a recent phenomenon, and for 10 billion years, the Universe was indeed slowing down its expansion speed!

This is very graceful, because only when the expansion of space slows down, galaxies can form, and life can come into existence! For example, if the dark energy density had been just a little higher, say 10-118 times the theoretical QFT calculated value (which is highly possible in theory), dark energy would have started dominating the Universe much earlier, and no galaxies would have been formed! Carbon-based life forms couldn't have appeared!

Why Nature chose such a fine-tuned value of the Cosmological Constant is a mystery! These are all open research questions from the theory side. But from the experimental side, the DES and LSST surveys will also measure the exact negative pressure value of dark energy in coming years, and it will be confirmed whether dark energy is indeed a Cosmological Constant or something else (of course unknown too!).

Subinoy Das is an Associate professor at IIA. He got his PhD in Astro-Particle physics from New York University in 2008. He is mainly working on dark matter cosmology. Apart from science, Subinoy plays the guitar, writes songs, and likes to spend time in the silence of Nature.

"Bright days ahead for Radio Astronomy"

Prof. Yashwant Gupta speaks about his association and achievements with the Giant Metrewave Radio Telescope (GMRT), his own research work, about the upcoming large projects in radio astronomy, and how India can play a major role in global endeavours such as the SKA.

Prof. Yashwant Gupta is the Centre Director of National Centre for Radio Astrophysics (NCRA-TIFR, Pune). Prof. Gupta obtained his M.S. and PhD in Radio Astronomy from the University of California, San Diego in 1990, after completing his Bachelor's degree in Electrical Engineering from IIT-Kanpur in 1985. Since 1991, he has been working at NCRA where he currently holds the position of Senior Professor. Since 2010, he has been the Dean of the GMRT Observatory – a world class radio observatory built and operated by NCRA-TIFR, located about 80 km from Pune.

For DOOT magazine, Prof. Yashwant Gupta speaks about his association and achievements with the Giant Metrewave Radio Telescope (GMRT), his own research work, about the upcoming large projects in radio astronomy, and how India can play a major role in global endeavours such as the SKA.

Let's begin with your science journey as a radio astronomer. After completing your studies from IIT Kanpur and UC, San Diego, you have spent a large part, almost three decades, of your scientific career at NCRA. We would like to know briefly about your academic life and research works.

Yes, it has been almost three decades since I joined NCRA at the end of 1990. I graduated in electrical engineering from IIT Kanpur, but I was always interested in astronomy since school days. So, I decided that it was the right time to make the switch and move over to astronomy. The electrical engineering background was quite helpful because then I could pick radio astronomy as a direction of growth, as it is one branch of astronomy where electrical engineering is perhaps most tightly coupled to astronomy.

For my PhD, I worked on the topic of studying pulsar signals. Pulsars are exotic objects – rapidly rotating neutron stars which emit beams of radio signals from their magnetic poles. So, it's a bit like a lighthouse: as the beam rotates and sweeps round, it intersects our line of sight, and we see a flash of signals. While travelling through our Galaxy, these pulsar signals are affected by the interstellar medium (ISM). It's like the twinkling of stars – the turbulence in the atmosphere causes the electromagnetic radiation coming from the star to be affected, making the stars twinkle. Similarly, the pulsar signal fluctuates, and by studying those fluctuations, which are called scintillations, we can understand the properties of the ISM of our Galaxy that lies between us and the pulsar. In this particular case, the physics shows that it is the electrons in the plasma of the ISM that cause this corruption of the signal and therefore we learn about the electron density distribution in the plasma of the ISM, its fluctuation properties, what kind of random fluctuations are present and how they are distributed in the Galaxy, which all adds to our overall understanding of the ISM, complemented by other studies.

Later, I joined NCRA with the dual aim of contributing to the development of the instrumentation at the GMRT observatory, as well as continuing my research in areas related to pulsars and the ISM. We built the GMRT in the 1990s and used it for early science, where I focussed mostly on different aspects of pulsars. In between, I also used the Ooty Radio Telescope (ORT) for studying pulsar scintillations after we set up a receiver system there, in collaboration

A panoramic view of the GMRT antennas in the central square region. (Image Credit: NCRA archives)

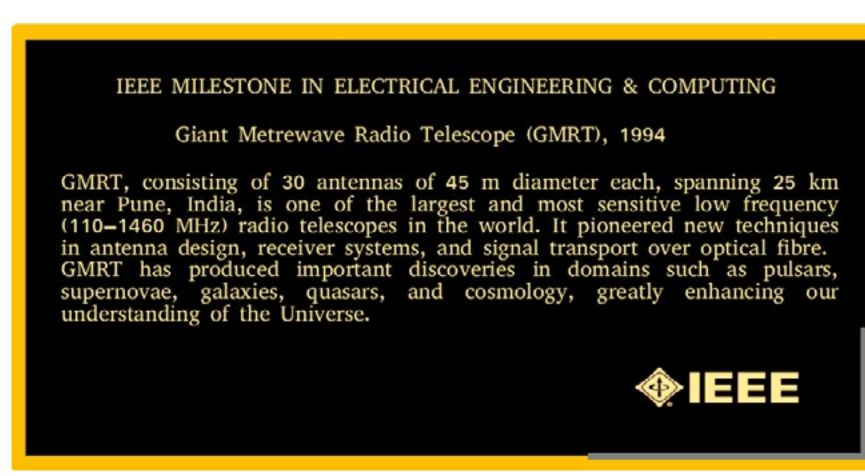
with colleagues from the Raman Research Institute, to record pulsar signals. Working with one of my first PhD students, we were able to carry out a more advanced study of the kind of work that I had done for my PhD thesis, and that led to some new conclusions about the structure of the plasma around us in our Galaxy. One of the interesting things that we found strong evidence for is that our Sun resides in a local bubble: there is a cavity of the very rarefied interstellar medium which is literally like a bubble, with a well-defined boundary. Such bubbles are often created by supernova explosions: when a star explodes as a supernova, it drives out the material around it and creates a low-density medium, and the material gets piled up at the boundary of the bubble where this explosion is pushing the things out. We could show that there is enhanced scintillation produced by the material at the boundary of this bubble structure around the Sun. As it turns out, there are other such bubbles known in the ISM of our Galaxy, and so it was interesting to be able to show clear evidence for enhanced density fluctuations from the boundary of such a bubble.

I continue working on some aspects of studying the ISM using pulsars. But in between, I have done a lot of work on other aspects of pulsars. We used the early days of the GMRT to search for new pulsars in our Galaxy, and since then, every so often, we have been finding new interesting pulsars using GMRT and more recently, the upgraded GMRT. We have also used the GMRT to probe the detailed characteristics of pulsar signals, using well known and well studied pulsars whose signals are strong and hence, can be studied easily. We have gone in great detail to probe the fine nature of the signal so that we can understand the physics of what happens in the pulsar magnetosphere, such as the possible locations of the regions from where these radio signals are generated. Of course, all of these fields keep evolving, and we also then have to adapt and see which is the most interesting and most relevant science problem to tackle.

My own interest in pulsars combined with the instrumentation techniques and capabilities we developed at the GMRT, enabled us to apply them in a completely different field called the Epoch of Reionization (EoR). This is the study of the very early Universe when the first stars and galaxies formed, and the Universe started transitioning from being neutral to becoming ionized by the radiation from these first sources. There is a lot of work that goes on to try and detect the signals from these early phases of the Universe. At the GMRT, we carried out such an experiment a few years ago, in collaboration with colleagues from Canada and the United States. There are instrumental effects which need to be calibrated properly to be able to detect these very faint signals from the EoR. We were able to work out some clever ways, in which we used pulsars as a calibration tool to remove the effects of unwanted artefacts and see if we can probe deeper to pick up the EoR signal.

Under your leadership, GMRT has bagged the prestigious IEEE 'Milestone' status. Congratulations to you and the whole team of GMRT for this unique achievement. We are excited to hear from you about GMRT and a brief overview of the background work behind this award.

Thanks for those comments. It's indeed a very prestigious achievement for us to have the GMRT accorded this IEEE Milestone status. The IEEE is one of the biggest professional bodies in the world, which encompasses all activities related to electrical engineering, computing, software etc., and in fact, the broader aspects of technology. This milestone is given to achievements in areas related to IEEE, which have had a significant demonstrated impact at the global level. In India, this has been given only to two other achievements before this,



Text of the IEEE milestone plaque to be installed at the GMRT. (Image Credit: Yashwant Gupta)

Close-up view of a 45m parabolic dish antenna of the GMRT. (Image Credit: NCRA archives)

which I think is a rather unfortunate state of affairs because there are other achievements in India in the fields of technology which ought to have this recognition. Nevertheless, we are extremely proud that the GMRT has been recognized in this manner. It is interesting to see the details of how it came about.

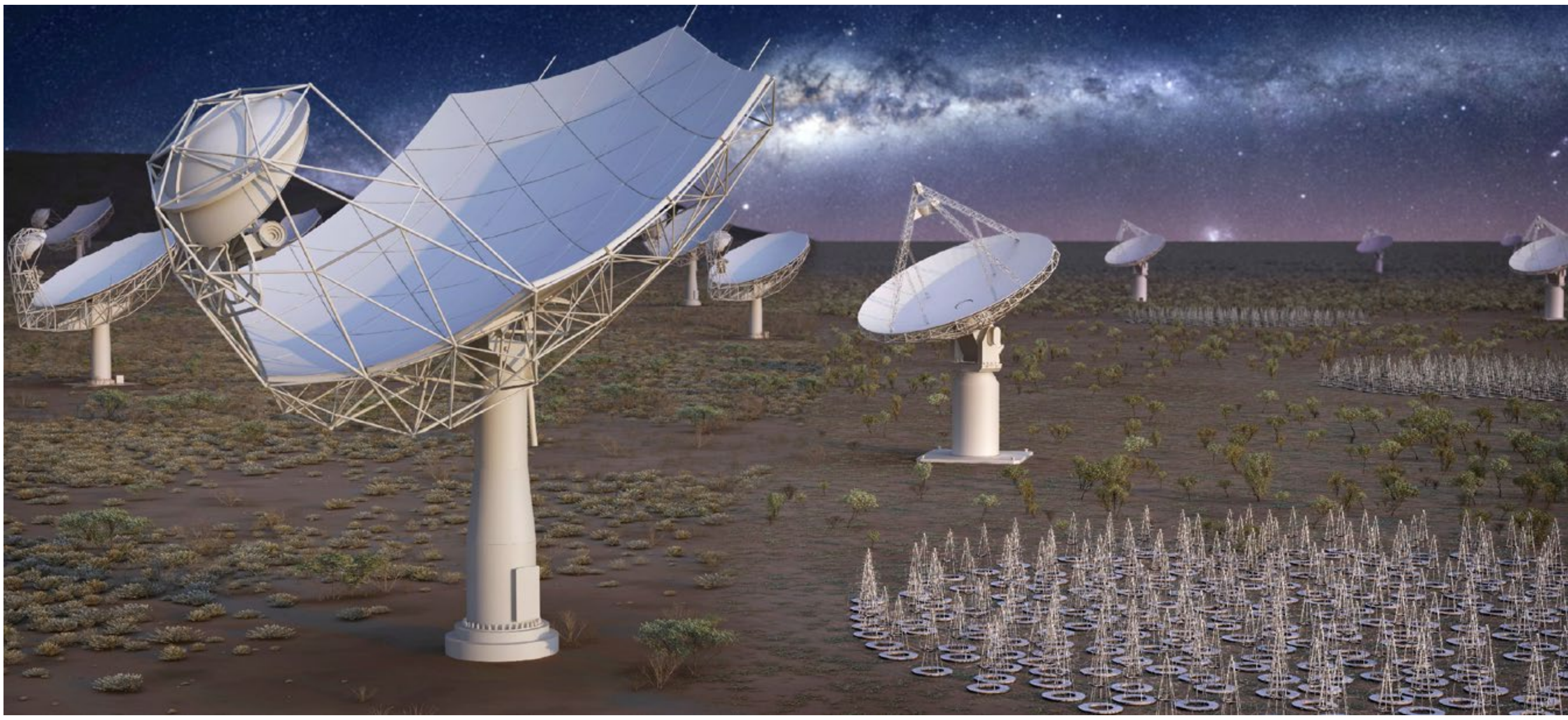
When I first heard about the IEEE Milestone scheme, I contacted my good friend and a senior member of IEEE, Prof. K.V.S. Hari at the Indian Institute of Science, who put me in touch with the relevant officials of IEEE in India - Mr.Harish Mysore and his team. They took a keen interest in the idea, and a team from IEEE visited the GMRT to make their own assessment, after which they came back recommending a joint proposal to the IEEE History Committee, applying for the Milestone status. The application was fairly detailed, including highlighting what was unique and innovative about the GMRT, and bringing out the scientific, technical and societal impact it has had. Let's take a look at some of these aspects now.

The GMRT has been a major achievement not only in the Indian context but also at the global level. To build a facility of this size and complexity on a fairly lean budget (compared to international levels) was quite a major challenge. In those days – 1985 to 1995 – the various technologies needed for setting up such a facility were not easily available in the country. The group that Prof. Govind Swarup had at that time was relatively small and, though they had built the Ooty Radio Telescope and the Ooty Synthesis Radio Telescope, building the GMRT was a much bigger step with many more and different challenges. The group took up the challenges and came up with very innovative solutions. One example is the antenna design itself: a clever concept, quite appropriately called SMART (Stretched Mesh Attached to Rope Trusses) was evolved, which made it possible to build large 45m size antennas at relatively low cost.

Moreover, GMRT was one of the first interferometer radio telescopes to use optical fibres to connect the antennas to the central processing station. At that time, though optical fibres were thought to be the way to go for the future, hardly anybody in the world had used it for radio telescopes. For us, it was not very clear how easily the technology would be understood and be adaptable for use with the GMRT; but we took up the challenge and made it a success. In this way, there were a few different innovative things about the GMRT as well as the fact that pretty much all of it was conceived and built in-house within the country. All of these aspects made it a unique project.

GMRT was built to cover the range of frequencies which would have a very significant scientific impact at the international level, given that there were no big radio astronomy facilities operating in that range. It did have that impact, as many new interesting results have been produced and, over the years, astronomers from more than 35 countries have used the GMRT for various cutting edge research. It also motivated the global community to set up more low frequency telescopes, to further explore this part of the radio spectrum which had been neglected for a while. All of that, combined together, made it a unique facility, and that is what struck the right chord with the IEEE history committee.

That said, the IEEE had a fairly detailed and rigorous review of the proposal. It went through various levels of evaluation - the history committee appointed a member who went through it in great detail, and then became the advocate for the proposal, presenting his findings to the higher committee of the IEEE for the milestone approval. We also had to show that the GMRT facility has been operational for at least two decades, indicating that the facility is a stable, long-lived entity which has worked and produced interesting results for many years. We were able to show how over the years, the GMRT has grown and improved, including the



Artist's view of the SKA (Image Credit: SKA Organisation)

recent upgradation that we completed in 2019. All of that actually worked out well, and on 24th November of 2020, the IEEE Board finally gave the approval for according the IEEE Milestone status to the GMRT.

The only sad thing about this achievement is that it happened a few months after Prof. Swarup passed away. It would have been great if he had been able to witness this special milestone being announced for the GMRT.

Radio astronomy is achieving new milestones by each passing day, for example, the first direct image of a black hole captured recently. In view of that, can you shed light on the upgradation of GMRT and some of the upcoming megaprojects in radio astronomy globally?

One of the first big things that we are doing right now is, of course, the upgraded GMRT. As mentioned earlier, GMRT was built in the 1990s, inaugurated in 2002 and has been working well for many years. But around 2010, we decided that we should do a major upgrade to keep it competitive in the international arena, which we did from 2012 onwards. We increased the sensitivity of the telescope by building better quality receivers as well as increasing the frequency coverage and the bandwidth. The frequency coverage was increased to go continuously all the way from about 110 MHz to around 1500 MHz, and the instantaneous bandwidth that we could handle was increased from 32 MHz to up to 400 MHz. All these innovations made it a much more powerful and versatile instrument for various kinds of studies.

The GMRT upgrade, which has been quite successful, is a natural progression towards the next step, which is Indian participation in large international projects like the Square Kilometer Array (SKA). This is the trend now-a-days, for most next generation facilities - global partnerships to build new instruments that are much bigger and better than any existing facility, and the SKA is a step in that direction, e.g. the GMRT

Explaining the SKA project to Dr. Harsh Vardhanan, Honourable Minister, Department of Science and Technology, Governemnt of India at the SKA pavilion at Vigyan Samagam, Bangalore. (Image Credit: Yashwant Gupta)

has 30 antennas, the SKA will have 100s of antennas. The SKA will have locations in South Africa and Western Australia, which are regions of the Earth where man-made interference, one of the biggest enemies of radio astronomy, is very low.

India has been actively taking part in this next generation major radio astronomy project since 2012. We took up one of the design work packages of SKA as an area where we could lead, called Telescope Manager, which is like the brain and the nervous system of the entire observatory. India led this design work, with members from seven of the SKA nations, from 2014 to 2018. I was the leader of the team, and it was an interesting

Team SKA India with the SKA Director General, Phil Diamond, at the SKA pavilion at Vigyan Samagam, Bangalore. (Image Credit: Yashwant Gupta)

experience, working in a big international collaboration with people from different countries spread out all over the world, to manage such a team and steer them in the right direction so that the main goal could be met. The work got finished in early 2018, and we were one of the first design consortia to finish the work.

Given that the Telescope Manager is one of the complicated systems of the SKA, as it interacts with every other system of the observatory, it requires special care in the design, and hence this had specific challenges. We were able to overcome these challenges by working with partners from industry - a lot of the design work was done in collaboration with professionals from IT industries. Now, when we go to the construction phase, where India has been given the leadership role for the construction of this system, we will again collaborate with industry in India to build this large system.

There are other technological challenges SKA poses and one of them is about having high-quality electronics – development of the antenna itself, the low noise amplifiers, the ability to transport large volumes of data from the antenna to the central processing station, the ability to handle this large volume of data and do the required signal processing etc. Fortunately, various design teams have put great effort to tackle all these issues, and in early 2020, the final design review for the SKA was held, which was declared to be successful. The final design is adopted and the plan for how to build the facility has been created. Now, it is the stage where different countries are getting ready to join the SKA construction phase, and in India, we are also in the process of getting the approval of our ministries to join this phase of the project.

Being involved in various projects as a leader, did you face any challenges due to the nation's policies? Are they science-oriented? Now a new policy on STI (Science, Technology and Innovation) is coming up. What changes would you have liked to see there?

That is an interesting question. Certainly, the policies that are there are encouraging in general, except that you know, as a nation, there may be some constraints about how much one can spend on big projects in fundamental areas of science. I would say that government policies are supporting; for example, sufficient funds were allocated for the construction of GMRT, and also for its recent upgradation. There are, of course, the things about how important different areas of science are, for the government. Obviously, for a developing country like India, any government would like to see that science should bring direct benefits to society. As you know, astronomy is not something that brings direct benefits, though the tools and knowledge of understanding the Universe do bring indirect benefits to the society. That creates a bit of conflict sometimes, but it has not been so bad that we have not been able to do good work in astronomy in the country, including developing new facilities.

As far as the new policy is concerned, I have been involved in some aspects of it when the discussions on the initial drafts were going on, especially on the issue of large mega projects and what should be the policy approach in India. This is again something very important when you ask where does India stand today in terms of scientific growth and development, how much emphasis should we give to being part of these large international projects which take a fair bit of resources, etc. I do believe that as a country, we should be able to pick a few specific areas where we are good and strong enough and want to have a prominent position on the global stage. This is because overall, India is in a position today that certainly, it can take some global leadership roles. Hence, the policy should encourage to idenfity key areas where, with appropirately modest amount of investment of resources, our country can have a strong standing on the global stage.

James Bond's "GoldenEye" featuring Arecibo in one of the scenes which cannot be shot again. The great Arecibo telescope is no more. What is your reaction to this loss?

A lot of people got attracted to Arecibo and similar radio telescopes by watching movies like "GoldenEye" and "Contact". All of a sudden, Arecibo collapsed, and it was a major loss to have such a sensitive facility which has given some breakthrough results, including Nobel Prize-winning work, especially in the areas of pulsars which is my own area of study, to be no longer available. It also had planetary radar facilities meant to target space objects like asteroids and even bouncing back radio beams from our moon and the nearby planets. The loss of Arecibo was also personally sad for me, as I had spent a good part of a year there on sabbatical during 2002, along with my family, and we have fond memories of the observatory.

As far as shooting scenes like "GoldenEye" are concerned, there are enough exciting new radio observatories where such scenes can be shot. In fact, we are trying to see if we can get somebody who can do a similar feature using the GMRT!

We have recently lost pioneer astronomer Prof. Govind Swarup. He has a tremendous contribution to radio astronomy in India, which is beyond one's imagination. As you have been very closely associated with Prof. Swarup and currently serving as his successor, it would nice if you can tell us more about him and his visions.

The sad demise of Prof. Govind Swarup was a major loss for us in 2020. For many of us, it was the loss of a very close friend, a father figure. For India, it was the loss of a pioneering person -- he was like a trailblazer in his own way, having built up a major activity in India, almost from scratch. For the world, it was the loss of an iconic figure in astronomy and astrophysics (particularly in radio astronomy) – he was well known and respected all over the world.

For somebody like me, it was also a personal loss because, to a very large extent, he (along with Prof. Ananthkrishnan and Prof. Kapahi) was responsible for me coming and joining

An aerial view of the Arecibo telescope before its collapse. (Image Credit: Arecibo Observatory) here (NCRA) after my PhD. He learnt about me doing a PhD at San Diego, and called me up, saying "we want you to come back and join here". It was a bit of a surprise for me as I was not much aware of what was happening in India. So, I made a visit to NCRA when I was still in my pre-final year of PhD and gave a talk about my research work. I also took stock of what was happening at NCRA. It was those early days when GMRT was just approved as a project, and planning as well as early activities were going on to start the work. I was happy to see the developments, and in the late afternoon, Prof. Swarup asked me to meet him in his office. In that meeting, I realized how serious and passionate he was about building something like GMRT, and bringing about a transformation in the scene of radio astronomy in India. That really motivated me to say "okay, I will come back and join here, and work, and see what difference we can make".

Govind Swarup at one of the GMRT antennas. (Image Credit: NCRA archives)

When I look back, I can say with some sense of pride and satisfaction that we have made a significant difference. In the early years, I worked closely with him on some of the more tricky problems of building the GMRT. One of them was the digital hardware (the digital correlator), the back-end which processes the signals from all the 30 antennas. When all the antennas were built in 1996, most of the electronics were in place, but the digital correlator was giving trouble to be built and made ready. That is when he and Prof. Kapahi said to me, "You have to take charge and make this work". It was both challenging and tough, but also interesting. It took us about one and a half years to build the first version, which was for eight antennas and was later followed by the full 30-antenna system. He was always there to guide and support us, and was always available whenever we needed some help – he would find the right kind of mechanism to help in moving forward and solving the problems. It was very interesting to work with him. I learnt a lot from him, like how to manage big groups, how to work with people and how to try and achieve what one is aiming for. All that has helped me greatly subsequently, in taking up leadership roles. It had helped me a lot in work for the upgraded GMRT, which was something I led from the beginning all the way up to the final stage.

The vision that he had of building big facilities and improving upon them, is something that was quite remarkable, which we have inherited. Of course, he also had visions in other areas, such as improving science education in India, and he worked very hard for setting up the background for what have now become the IISERs in the country.

What is your vision for radio astronomy in India?

The important point to note is that we have a solid base in radio astronomy, the field is quite mature in the country, thanks to the work done by people like Prof. Govind Swarup and his team, and Prof. V. Radhakrishnan at RRI Bangalore, who set up a group there and also made significant achievements. We are well placed to play a fairly major role in the international arena. One way that we have done this is, of course, with the GMRT and the upgraded GMRT, which are widely used by astronomers all around the world for carrying out cutting edge science and have led to various collaborations between Indian astronomers and those abroad. But more importantly, we are now in a position to diversify and grow further. One of the areas in which we would like to grow to some extent is to expand to higher frequencies than what is available in GMRT. We would also like to start very long baseline interferometry where we are able to correlate the data from GMRT with other antennas, whether it be in India or abroad. There are also plans for expanding the GMRT to a much more powerful facility.

We are also well poised to be a part of large international projects like SKA, as another direction of growth. We need to be able to do that while seeing what are the best ways in which we can further improve our own facilities in a manner which is complementary to what is happening in large international facilities that we are joining and contributing to. Overall, our activities should lead to the growth of knowledge and capabilities in the country. It is thus important to reach out to the wider community, and see that growth of radio astronomy happens in more institutions, whether they be IITs, IISERS or the engineering colleges, or universities. In addition, reaching out to the general and the wider public is also very necessary -

this was one reason I was happy to give this interview because I am hoping that the DOOT magazine can reach out to a wider audience than we at NCRA normally manage to make contact with. These are the main areas where I think there is need and scope to grow and improve. The broad vision is to be able to take bigger steps now, based on our experience and confidence that we have got from our achievements in radio astronomy in the country in the last 50 years, and I see a bright future here for us.

We find astronomy is not the mainstream of education in our country. Students get interested in it at the school level, but the enthusiasm is lost somewhere in between. So what advice would you like to give to youngsters, so that more people from the new generation turn up for astronomy?

There are various reasons for this relatively smaller number of people in astronomy. However, compared to my early days, I see that the situation is changing now – more youngsters are turning to choose astronomy as a career. Of course, the competition from other career choices, which give more options, is one of the bigger challenges – be it medicine or engineering, they provide more opportunities, and there is always peer pressure from family and friends. I can give my own example. Though interested in astronomy from childhood, I joined IIT for engineering because of peer pressure. Fortunately, I could get a chance to change directions, combine both of my interests, and build up a career in radio astronomy.

These days, information is readily available, and it's just a matter of making a considered proper choice. What I advise is that do a careful consideration of all the choices and options, and you will find that there are good opportunities if you take up astronomy as a career. In case, if you still have some doubts or concerns or lack of understanding, feel free to contact any professional astronomer in the country, including me, working in any one of the institutions. You will definitely get useful and relevant advice, which will help you to make your own considered decision properly on how to move forward, factoring in all aspects. The last part of this is: don't let your initial enthusiasm fade away. Even if you make a decision that some other path is better, so be it, you can still be a hobby astronomer, and it can also give a lot of excitement and satisfaction. The important point to keep in mind is that the growth potential of astronomy in the country is very large, and we can see that from how it has developed over the last few decades. I think the future is very bright.

This interview was prepared by Fazlu Rahman, Rishabh Teja, Sandeep Kataria and Suman Saha.

The Vice President of India Shri. Venkaiah Naidu inaugurating the ITOFF and ETF

A geometric origin for light oscillations observed in astrophysical Black-hole systems

Prerna Rana
A. Mangalam

The black holes in our Universe are present over various mass scales: (i) millions of stellar-mass black holes with mass range 4 - 30 solar mass in each galaxy, (ii) intermediate-mass black holes having mass ranging from a few hundred to thousand solar mass, which are still being discovered in various galaxies, and (iii) supermassive black holes with mass range 10^6 - 10^9 solar mass at the nucleus of each galaxy. The variability signatures [properties of the light variations] in these systems directly reflect the behavior of the motion of matter near a black hole, for example, quasi-periodic oscillations [QPOs], which are broad peaks, detected in the Fourier power spectrum density [PSD, distribution of signal power in the temporal frequency spectrum] of the X-ray flux from black hole X-ray binaries [BHXRB, which are stellar-mass black holes in a binary system with a main-sequence star, which is in the long hydrogen burning phase] and from active galactic nuclei [AGN, which are active and luminous supermassive black holes at the center of galaxies, ~10^{42} - 10^{48}erg/s]. Another important aspect is the characteristic bending-power law shape of the X-ray PSD observed in certain AGN. The similarity between the variability behavior of X-ray signatures from these systems, having different black hole mass range, suggests that the underlying physics of motion and in-fall of matter around a black hole should be the same.

The general relativistic study of black hole orbits by P. Rana and A. Mangalam, from IIA which has been published (Astrophysical Journal, 2020, 903, 121; [1], and Galaxies, 2020, 8(3), 67; [2]) can help map the motion of the plasma in the region very close to a rotating black hole. It is found that the orbits followed by the plasma which is in non-equatorial and eccentric motion are likely to produce QPOs and the typical PSD shapes observed in the astrophysical black hole systems [like BHXRB and AGN]. This study probes the geometric origin of the sharp frequencies and their general distribution due to the relativistic trajectories that are precessing in the radial and vertical directions around a rotating black hole. In an earlier article (Classical and Quantum Gravity, 2019, 36, 045009; [3]), analytic forms of bound trajectories were found that are extremely useful for various other applications including building orbits of stars orbiting closely around a black hole, generating gravitational signals from binaries, constructing pulsar waveforms, gyroscope precession, and besides general dynamical studies of spinning black holes. These numerically efficient formulae were put to use in this study to generate probable orbits that give rise to the observed signals from the black hole systems in AGN or BHXRB.

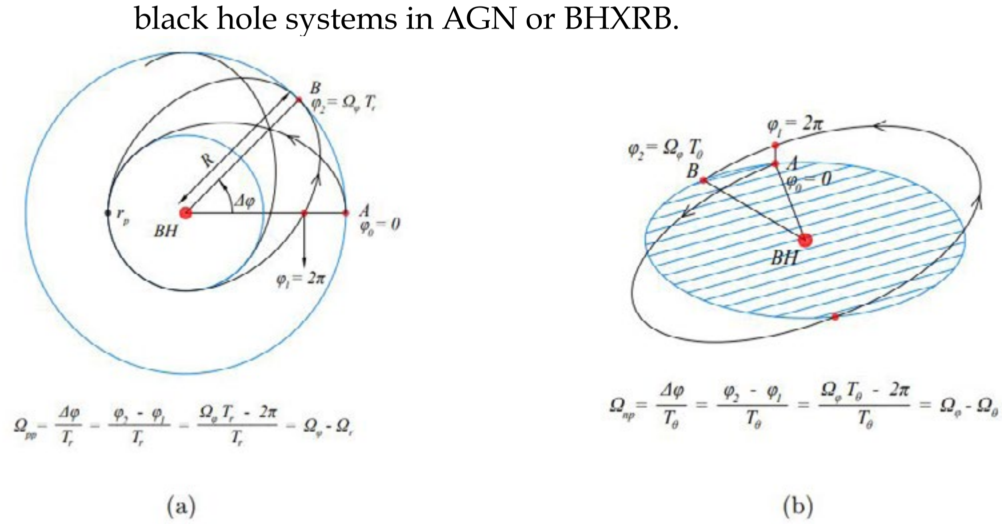


Figure 1: The figure represents the generalized relativistic precession phenomenon for $Q \neq 0$, near a black hole [BH] at the center, rotating anti-clockwise, where Ω_{pp} represents the periastron precession and Ω_{np} represents the nodal precession frequency. The initial point of the trajectory is indicated by point A, from where the particle follows an eccentric trajectory before completing one (a) radial, or (b) vertical oscillation to reach point B. The particle sweeps an extra $\Delta\phi$ azimuthal angle during one (a) radial, or (b) vertical oscillation since the azimuthal motion is faster than the radial or vertical motion causing the periastron or nodal precession.

The key inputs to the model called the general relativistic precession model [GRPM], are analytic formulae for the fundamental frequencies of the most general non-equatorial and eccentric bound geodesics [particle trajectories] near a Kerr black hole. The precession frequencies of these orbits match with the QPO frequencies observed in BHXRB and AGN under the framework of GRPM; the azimuthal, ν_ϕ, and periastron precession, $\nu_{pp} = (\nu_\phi - \nu_r)$, frequencies of orbits source the high-frequency QPOs [HFQPOs, ~50 - 500Hz], and nodal precession, $\nu_{np} = (\nu_\phi - \nu_\theta)$, frequency source the low-frequency type-C QPO [~mHz to 10Hz; see Figure 1, where $\Omega = 2\pi\nu$], where ν_r is the radial frequency and ν_θ is the vertical oscillation frequency of motion.

It is also found that the origin of these QPO signals is a torus region spanned by the non-equatorial and eccentric geodesics followed by the plasma blobs [see Figure 2]. A study of fluid flow indicates that it overlaps with the edge region of the accretion disk and the geodesic region between the inner edge of the accretion disk, r_{in}, and the black hole horizon. The high value of the gas to radiation pressure ratio gives further insight that the edge region acts as a launchpad for the plasma to follow geodesics spanning the torus region. The GRPM is also shown to fit a known tight correlation between the QPO frequencies and the broad noise components observed in the PSD of BHXRB. The GRPM also suggests that HFQPOs originate when r_{in} comes very close [near innermost stable circular (spherical) orbit (ISCO/ISSO)] to the black hole during the soft spectral state [dominated emission in 1-2keV energy

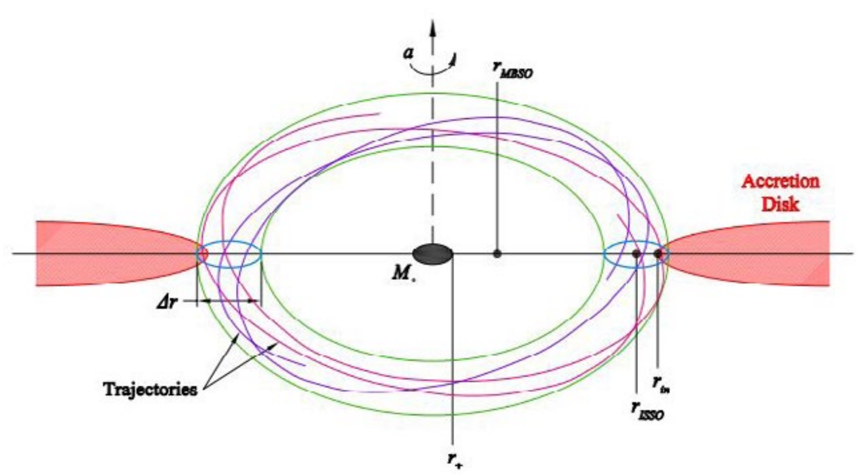


Figure 2: A geometric model representing the region of origin of QPOs where different general non-equatorial eccentric trajectories having similar fundamental frequencies span a thin torus according to the GRPM. These trajectories together show a strong peak in the power spectrum. The inner radius of the circular accretion disk is expected to be close to this torus region in such a scenario. This torus region is expected to be outside the marginally bound spherical orbit [MBSO] radius, and the ISSO radius is expected to be in between the torus region.

range] of the X-ray outburst, a high-luminosity [~10^{38}erg/s] phase, observed in BHXRB, whereas r_{in} is farther out during the hard spectral state [dominated emission at > 2keV] when the type-C QPO frequency is of the order of millihertz. The increase in type-C QPO frequency with hard to soft spectral transition during the X-ray outburst is also explained as an increase in ν_{np} when r_{in} decreases in the GRPM.

In [2], a relativistic orbit model [ROM] for the X-ray PSD was developed assuming a power-law distribution for the orbital energy of the plasma following circular and spherical geodesics in the outside and inside corona regions respectively [see Figure 3]. The key idea is to implement the Hamiltonian [energy preserving] formulation of [3] to correlate the orbital energy of the moving plasma with the orbital frequency. The resulting Fourier PSD is found to have a break at the innermost stable circular orbit [ISCO], and the shape is well fit by a bending power-law. The connection formulae between the energy

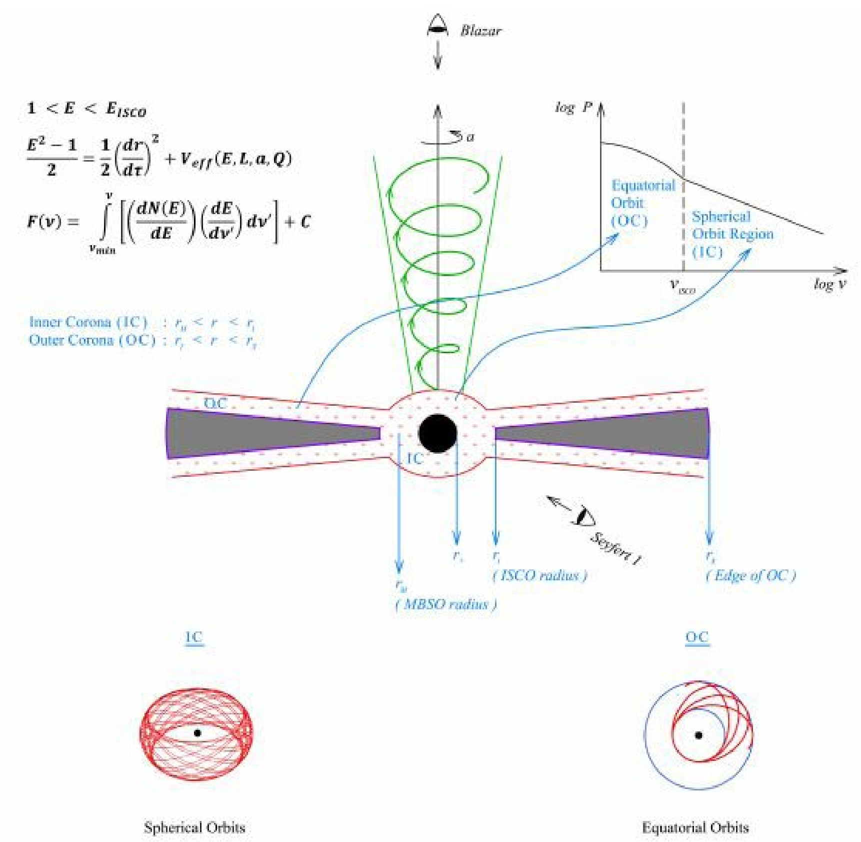


Figure 3: A unified picture of the models for X-ray, optical, and γ-ray QPOs and the origin of X-ray PSD shape in AGN. The X-ray QPOs observed in NLSy1 galaxies are associated with the fundamental frequencies of the equatorial orbits in the outer corona [OC] region, $r_I < r < r_X$, sandwiching the accretion disk; the inner corona [IC] region, $r_M < r < r_I$, is associated with the fundamental frequencies of the spherical orbits around a Kerr black hole. The optical and γ-ray QPOs in Blazars are shown as the harmonics of the timescale of a blob of matter moving along the jet. The shape of the PSD is studied using the fundamental frequency of matter in IC and OC regions to derive the energy distribution of the orbiting matter which is directly related to the observed intensity. For details of the PSD and the associated formulae, please see [2].

distribution and slopes of the PSD provides a way to estimate the spin and mass of the black hole, which can be obtained by fits to the observed X-ray PSD of AGN. Hence, this model can be tested against several observed PSD of various AGN. The calculation of the total power of a PSD using the frequency distribution of the ROM, lends itself to estimates of the spin and mass of the black hole from measurements of the time signal variance above the noise of the observed light curve, as the disk cuts off near a characteristic ISCO radius. A kinematic origin of the jet based γ-ray and optical QPOs observed in the Blazars [certain AGN with relativistic jets beamed towards us] is also shown to be possible in a general relativistic MHD [GRMHD] framework [see Figure 3]. The calculations involving numerical operations, like the generation of PSD and the identifcation of torus region as the origin of QPOs, were performed using the high-performance computing facility of IIA.

These models for the QPO frequencies and X-ray PSD shape in BHXRB and AGN shed light on the geometric origin of these temporal signatures near a rotating black hole. It is expected that detailed GRMHD models will be useful for future simulation studies probing the non-equatorial fluid flow. This will improve our understanding of the underlying physics to the next step and provide more precise estimates for the spin and mass of the black hole.

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Prerna Rana is a post doctoral researcher at the Indian Institute of Astrophysics. Her work involves the analytic study of bound trajectories around a rotating black hole using general theory of relativity, and application to astrophysical black hole systems.

Arun Mangalam is currently a professor and the chair of the theory group at the Indian Institute of Astrophysics, Bangalore. Arun does research in theoretical astrophysics: gravitational dynamics, relativistic astrophysics, gas dynamics and magnetic fields. His interests include relativistic, high energy, stellar dynamical and hydromagnetic processes concerning black hole systems, galaxies, cosmology and solar plasma.

Artist: Maya Prabhakar

My experience with IIA outreach

Varun Kumar

After joining IIA for Integrated M.Tech - PhD course in July 2013, I and my four other batch mates left for Kolkata for mandatory one-year course work at the *University of Calcutta.* During my stay at Kolkata, the IIA outreach photos uploaded on social media by our seniors attracted me towards IIA outreach. Those photos were quite amazing, and I would often imagine myself one among them learning and explaining to school kids. After returning from Kolkata, I joined the group immediately. During the Beginning days, I just used to accompany them as a *12th Man*.

Later once I was through, I became an active member; in fact, a student representative for almost 2.5 years. I must say this has been so far a very memorable experience for me. Through the IIA outreach, I have learned many things, most prominent being "how to speak in public". It was during one of our outreaches on lunar eclipse (Jan. 31, 2018) which we planned on "Lalbagh Kempegowda Tower" that gave me real experience of "public speaking". A crowd of around 5000 was eagerly waiting to watch the eclipse which was happening during the beginning hours of the night, and we had a small hand mic to address them. Once a copper moon appeared in the sky, people started shouting and moving here and there to find a place to watch it happening. It was tough to manage the crowd with a small hand mic. I still remember one of the parents who has come with her 5-year-old daughter to watch the event, asking me "Have you guys thought of crowd management while organising this event?" I had no answer because we haven't thought about it and not planned as well. I was literally praying to God to pass the event smoothly. This event has given me immense satisfaction and courage to do more public events.

A group Image after Total Lunar Eclipse Event. Photo Credit: Mayuresh & Prasanna

Apart from regular IIA outreach, which includes visiting Govt. schools, organising school visits to IIA campuses, and National Science Day celebrations, Sandeep and me (both were Outreach student representatives) always tried to expand our outreach activities at IIA. We introduced a "teacher training program" at IIA for the first time. We felt that especially science and maths teachers in Govt. schools are only engaged in black/whiteboard teaching. Students of class 7th to 9th have literally no experience of small science experiments related to their subjects. These small experiments develop scientific

Left Photo: Explaining "Frog Race" to school kids during one of our outreaches at Vikasana NGO, Birur City in 2015.

thinking among them. We thought why not train middle and high school teachers to teach the subject in class with small experiments such that students will take more interest in learning them. Arvind Gupta's "Toys from Trash'' for learning influenced this idea. We drafted the plan and presented it to our director through outreach in charge, and he agreed with the required IIA funding as well. The Next daunting task was to contact the Govt. School teachers. We have made several rounds to DSERT, DIET offices to meet the directors and convince them to allow Govt. school teachers to attend this program. We successfully convinced them, and in return, we got a list of 50 school teachers from different parts of Bangalore. Though we have got the teachers' list, we were doubtful about their attendance on that day (17th June 2017). To ensure attendance, we contacted them over the phone one day prior to the event.

The group image of 3rd Teacher Training Program in 2019 in collaboration with IAU. (Image Credit: Prasanna Deshmukh)

In parallel, we PhD students were also working tirelessly on the content to keep the training simple, very informative, and interesting. We successfully conducted this program with 45 teachers and provided them with certificates and experiment kit bags so as to perform the basic experiment with students and encourage them to make their kits. This event gave me personal satisfaction and readied me as an "event manager".

We have successfully conducted this event consecutively three years before this COVID-19 pandemic and hope that we will resume it in the coming days when things will be normal. To summarise this program's effectiveness, we keep getting phone calls from teachers requesting to visit their school and conduct an outreach program.

The other benefit which I gained from the IIA outreach program is knowledge enhancement. These school kids have several interesting questions, which we sometimes fail to answer, and in this process, you keep exploring yourself to answer next time when you encounter such questions. Later in 2018, I passed the outreach baton to juniors who are continuing with outreaches with the motto of "*service to our society*".

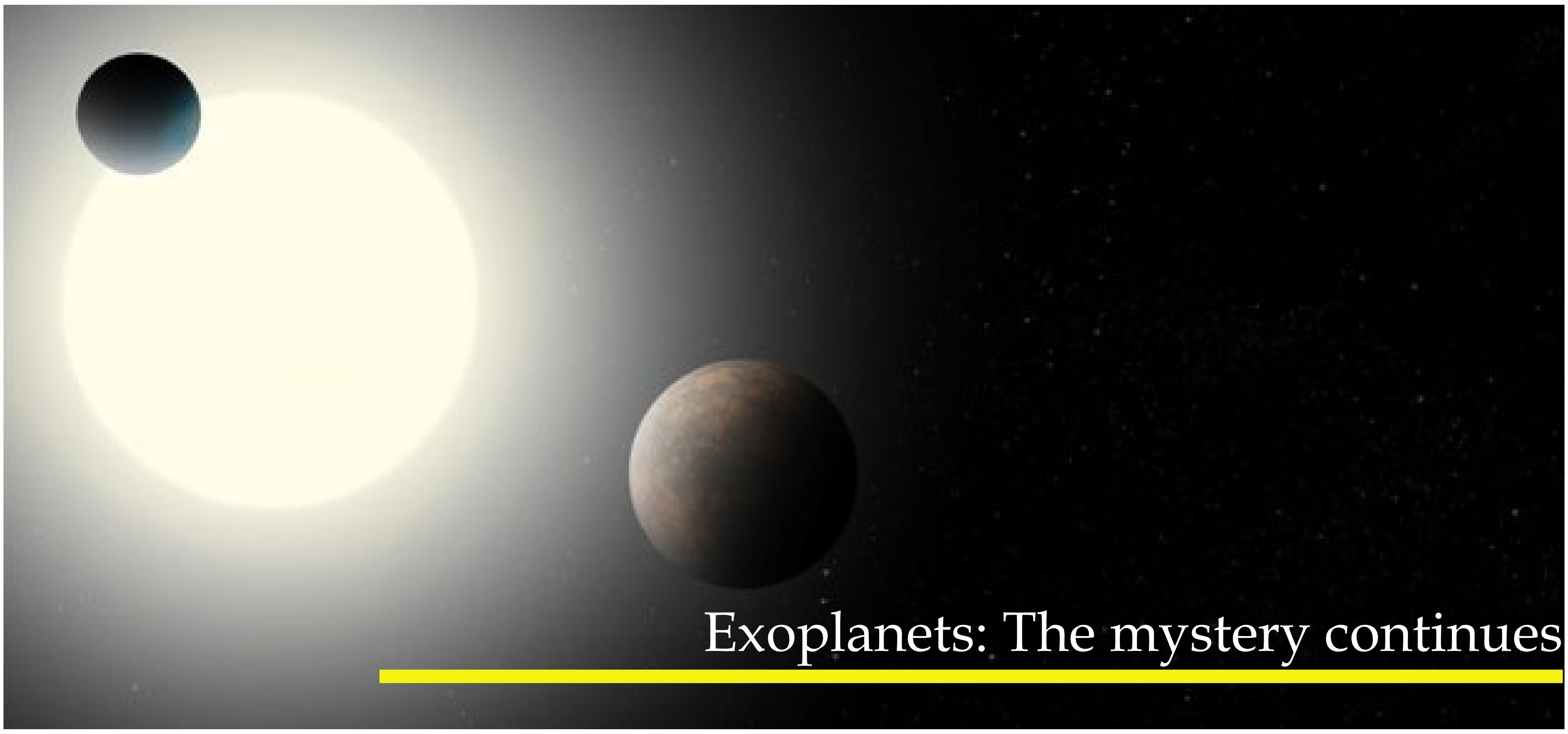
Varun Kumar is a Project Engineer in Visible Emission Line Coronagraph (VELC) on-board ADITYA-L1 mission (an ISRO mission to study Sun's Corona) at IIA, Bengaluru. He has completed M.Tech. in Astronomical Instrumentation and pursuing PhD from University of Calcutta. His research interests include designing and developing instruments for astronomical observations from the ground as well as the space.

Prof. Vainu Bappu

The only Indian astronomer to have a Comet and an Asteroid named after him.

Artist: Ekta Sharma

Ekta is a post-doctoral researcher at the Indian Institute of Astrophysics. She works on investigating star-forming regions using observational probes.



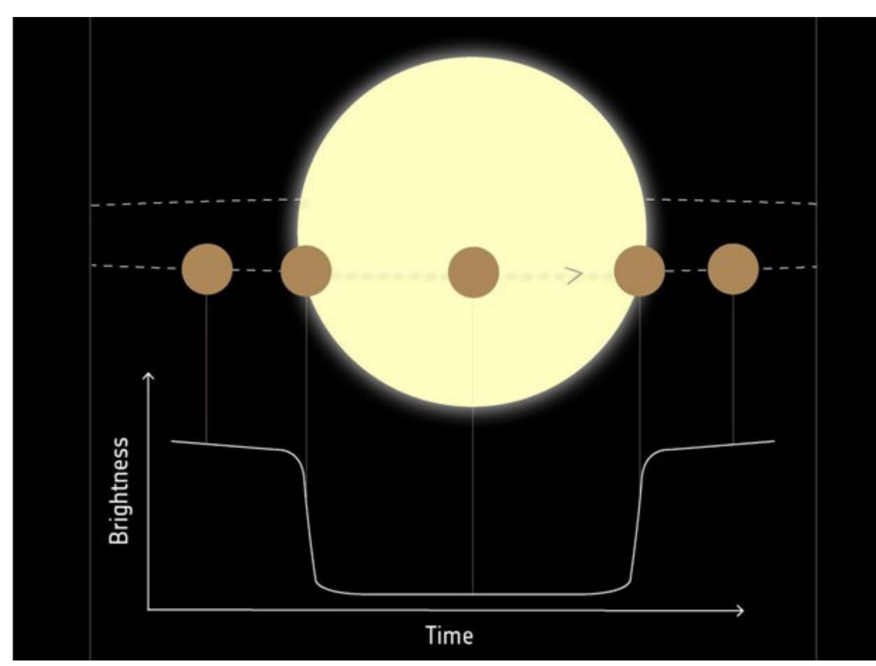
(Credit: ESA)

Exoplanets: The mystery continues

Suman Saha

Exoplanets are the mysterious worlds, the planets, orbiting around stars beyond our Solar-system. In the last issue of this magazine, I had talked about the nature of exoplanets, the first discoveries and the fascinating hot-Jupiters under the title "The mysterious Exoplanets", which you should probably read before going through this article. And as promised, here I'll continue the story of exoplanet explorations and the unfolding mysteries.

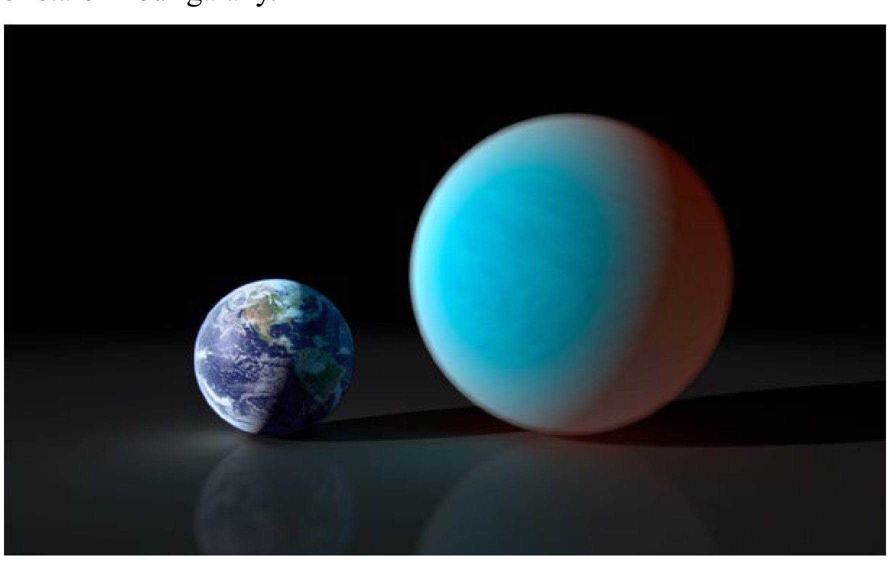
The Radial Velocity (RV) method provided an important foundation for the technological advancement of exoplanet detection techniques. However, this technique has notable limitations. The RV method can only be used to detect larger exoplanets, as the net radial-velocity shift of the host-star due to the smaller planets is too small to be detectable using existing technologies. Another limitation comes from the fact that RV is a spectroscopic technique, and only a single or a few couples of stars can be monitored at a time during a spectroscopic survey, which makes it too resource and time-consuming. Also, the RV method is more biased for the detection of exoplanets in close-in orbits, as they take much less time (below ten days) to complete a full rotation around the host-star. As the planets in far-away orbits take much longer to complete the orbital rotation, it gets cumbersome to monitor any star for such a long time. Just imagine how long it will take to detect Jupiter, which takes around 12 years to complete one orbital rotation; or Saturn, which takes around 29 years for it! Again, the net radial-velocity shift of the host-star reduces with the distance of the planet (remember the inverse square law?), making it practically impossible to detect them. The radial-velocity shift of the host-star also decreases with the decrease of the inclination angle, i.e. increase of the angle between the orbital plane and the line-of-sight, making it hard to detect exoplanets with a lower inclination angle. All these limitations have severely limited the number of exoplanets discovered using the RV method, which stands around 800 now, most of them being the hot-Jupiters.



Transit Method (Credit: ESA)

Within a few years after the first detection of exoplanet using the RV method, another method made its way into the league of exoplanet detection methods, known as the *transit* method. It was used for the first time in 1999 for the confirmation of the exoplanet HD209458b, which was discovered almost at the same time by the RV method. When a planet transits a star (i.e. passes in front of it), it occults the brightness of the star by a small amount. Detecting this dip in the brightness is the major principle of the transit method. The transit method is very useful in the sense that it uses the photometric technique, which unlike spectroscopy, can be used to monitor a large number of stars at the same time depending upon the field of view of the telescope. Also, the signal-to-noise ratio of photometry is much better than the spectroscopy, and hence exoplanets even smaller than the earth can be detected using the transit method. The only shortcoming of this method is that non-transiting exoplanets cannot be detected; however, transiting exoplanets' statistical ratio is not less given the number of observable stars is very high. The transit method has been extensively used in the last two decades using both ground-based and space-based telescopes to discover more than 3000 exoplanets. The famous Kepler space mission, which was launched in 2009 and was decommissioned in 2018 after an extensive life-cycle of 9 years, has used the transit method to discover more than 2000 exoplanets alone. The next big dedicated exoplanet mission by NASA, the Transiting Exoplanet Survey Satellite (TESS), was launched in 2018 and is now operating into its fourth year of operation. More than ten thousands of exoplanets are expected to be discovered using the TESS observations.

The most prominent of the discoveries from the transit method, especially from the Kepler and the subsequent TESS missions, is the presence of a large number of smaller exoplanets with a size between the size of the Earth and that of Neptune. The terrestrial exoplanets with a size larger than the Earth are known as the super-Earths, and the gas dwarfs with a size smaller than the Neptune are known as the mini-Neptunes. Combined together, the super-Earths and the mini-Neptunes form the largest chunk, accounting for more than 60% of all known Exoplanets. This discovery is significant to understand the planet formation and evolutionary processes, which can take many different paths, much different from how our Solar-system has evolved. Also, the discovery of a large number of multi-planetary systems has confirmed the presence of more planets than the number of stars in our galaxy.



Earth and Super-Earth (Credit: NASA)

Planets are among fascinating objects in the universe due to the fact that they may harbour life, just like our Earth. Especially the terrestrial planets, i.e. the planets with not only atmosphere, but also with a solid surface or ocean with sharp boundaries between them, are of particular interest for harbouring life. Since our current technologies don't allow us to send an interstellar probe to distant stars to study them, the only way is to analyse the electromagnetic signal. When an exoplanet transits its host star, a small portion of the star-light also passes through the planet's atmosphere, which contains the information of the composition of the exoplanetary atmosphere. This signal is studied using spectroscopic methods, also known as *transmission spectroscopy*, to understand the atmospheric composition. As we know, water is an important ingredient for the formation of life on Earth, and aerobic life is dependent on oxygen, their presence on other planets can signify the possibility of life. Similarly, the presence of other gases, such as methane, methyl halides, sulphides etc., which are directly or indirectly related to life on Earth can signify the presence of life on other planets. These gases are combinedly known as biosignature gases and are of particular interest in search of life using transmission spectroscopy.

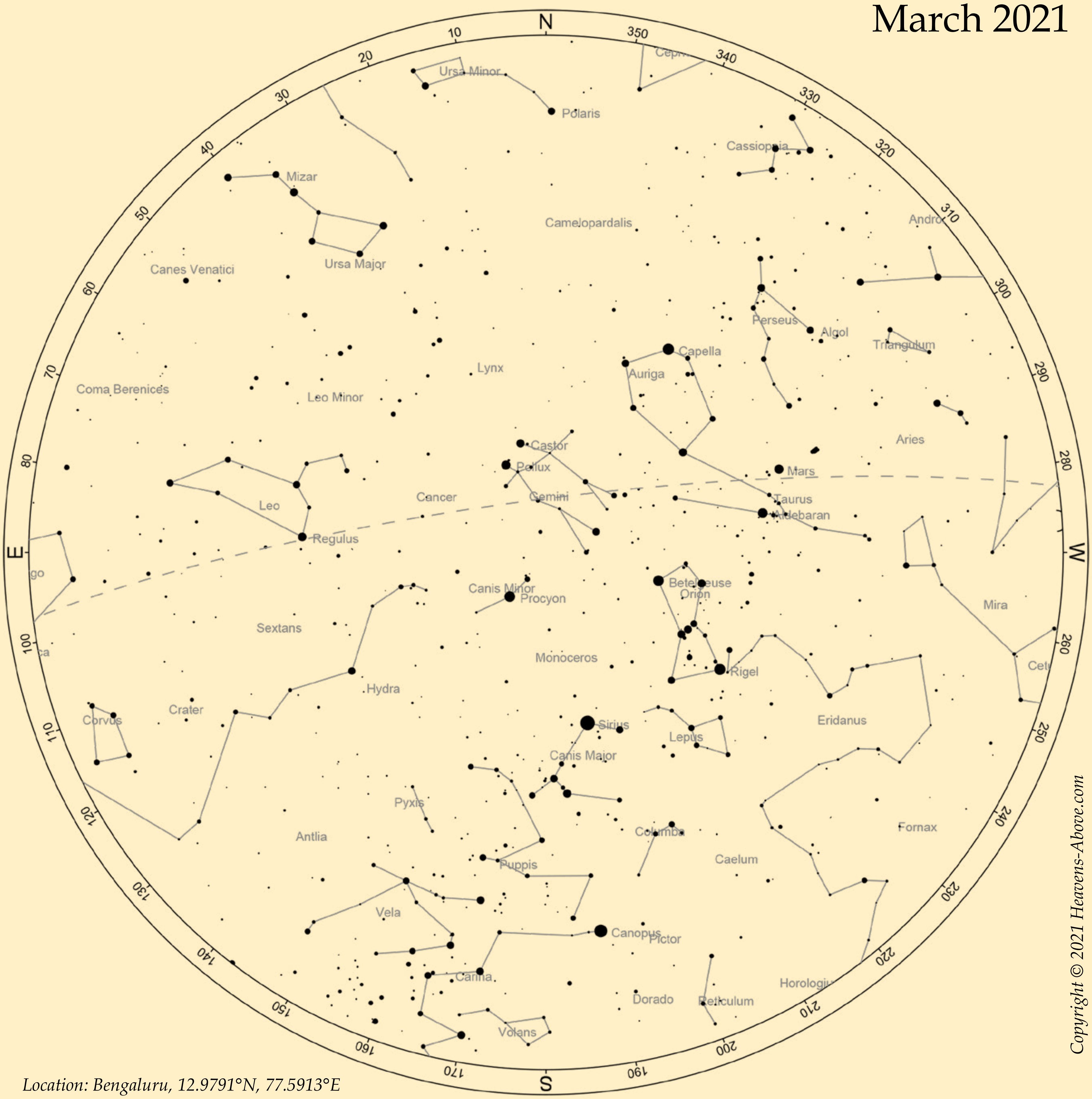
Full-scale model of JWST (Credit: NASA/JWST)

The detection of the biosignature gases in exoplanet atmospheres is very difficult due to the minute nature of the signal, and it requires very sensitive and precise instruments. Although the transmission spectroscopy has been used for several gas giants using the existing observational facilities, characterising terrestrial exoplanets' atmospheres remains out-of-reach. However, within the next decade, the next generation large observatories, such as the James Webb Space Telescope (JWST), the Thirty Meter Telescope (TMT), the Giant Magellan Telescope (GMT), the Extremely Large Telescope (ELT), and many dedicated space-based observatories, will be ready to shed light upon the undiscovered mysteries of these exoplanets.

The science of exoplanets is rapidly expanding, and within a small time-span of three decades, we have accomplished a lot, owing to the rapid technological advancement. Within our lifetime, there is a lot for you and me to see as the mystery of the exoplanets continues to unfold itself, slowly but steadily.

Suman is a young researcher and future enthusiast. He works on Exoplanets as a SRF at IIA and is involved in various public awareness activities for science and technology.

Sky-Chart
March 2021



Location: Bengaluru, 12.9791°N, 77.5913°E
Time: 15 March 2021 20:00 (UTC +05:30)

Watchout for:

March 6 - Mercury at Greatest Western Elongation. The planet Mercury reaches greatest western elongation of 27.3 degrees from the Sun. This is the best time to view Mercury since it will be at its highest point above the horizon in the morning sky. Look for the planet low in the eastern sky just before sunrise.

March 10 - Close approach of the Moon and Saturn. The Moon and Saturn will make a close approach, passing within 3°35′ of each other. Visible in the dawn sky, rising around 2 hours before the Sun – and reaching an altitude of 27° above the south-eastern horizon before fading from view as dawn breaks.

March 20 - Venus at Greatest Western Elongation. The planet Venus reaches greatest eastern elongation of 46.6 degrees from the Sun. This is the best time to view Venus since it will be at its highest point above the horizon in the morning sky. Look for the bright planet in the eastern sky before sunrise.

Eclipse Hide-and-Seek

U S Kamath

"Mom wants to talk to you," she said, raising her eyebrows and handing over the phone to him.

He anticipated the subject matter of the conversation; his mother had already spoken to him about it. There was a solar eclipse on Sunday morning, though only a partial one in their city. The call was to reiterate the precautions they should take to avoid its evil effects. Fast during the eclipse, do not store cooked food, have a ritual bath after the eclipse, pray, and eat freshly cooked food afterward.

Stored food was not a problem. Six months back, he had found a seller for "Ganga water directly from Gangotri". Two drops of that in a glass of boiled water taken on an empty stomach in the morning ensured that the body was purified. That's what it said on the bottle.

And more importantly, not to watch the eclipse or venture out during that time. Somebody (he was not paying attention) did not listen to her elders and went out during the eclipse when pregnant. Now, look at her son!

He was nodding and saying "yes, yes" at intervals.

"She will not listen to me. You must ensure all of this" was his mother-in-law's closing words.

"What was that about?" his wife asked.

"The eclipse ..."

"Did they finally give you those special glasses? Or we can go to your institute and watch. I want to see the telescopes and all the science instrument things."

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They were at the clinic for the regular check-up. The baby was doing good.

"Is it safe to watch the eclipse, considering the harmful rays and all that? It may not be good for the baby." He knew it sounded stupid, but he had to ask. He was desperately trying to spike the idea of watching the eclipse.

"There is no scientific evidence for this ...," the doctor said. He strangled her figuratively. "... but why take a chance?" Since it was all figurative, he quickly 'un-strangled' her.

"Of course, it is up to you. Whatever makes the mother happy is good for the baby." He did not know what to do.

****

"Our team is very excited," Biju said to him. "We plan to make this a grand event. Refreshments will be served during the eclipse watch."

These rationalists, he said to himself, always itching to cross paths with Rahu, Ketu, Saturn, Mars....

"You must bring your family," Biju continued.

Hiding his anger, he managed to smile politely and said, "Who wants to come to the institute on a Sunday?! We will just relax at home." All of you must also stay home, he left it unsaid.

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The Apartment Owners' Association announced that they were organizing an eclipse watch.

"Oh, good," his wife said, "saves us the trip to your institute."

Staying at home was not an option any longer. What was he to do? Suddenly, the doctor's words, "Whatever makes the mother happy..." sparked an idea. After some frantic searches on the internet, he was able to book a weekend package at a resort close to the city. Check-in Saturday noon and check-out Sunday evening, with several services and activities included for free or a discount. It was a somewhat expensive but elegant solution. She was excited and happy when he told her about the trip. The romantic side of her husband was a real surprise.

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He put both bags in the trunk of the car and drove to the gate of the apartment complex. Then he turned the car around and drove back to their parking space, and waited for her. So, technically the journey has started before Rahu Kala; this was just a stop on the way.

The lovely weather made the journey quite pleasant. Surprisingly, the traffic was less than usual. The entrance and reception areas of the resort were aesthetically appealing. The welcome drink was refreshing, and the check-in was quick. Along with the room key, the receptionist handed them a thick envelope marked 'Welcome Kit'.

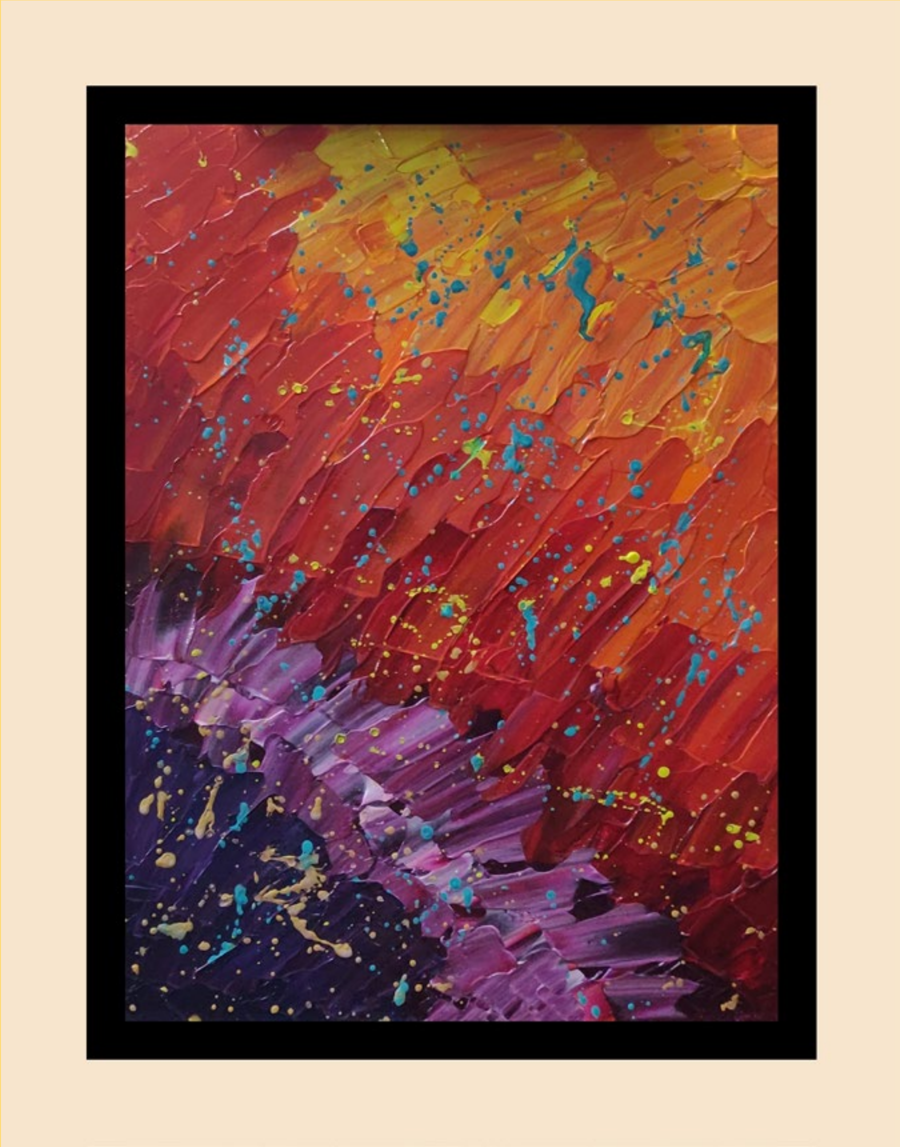
"This contains information on the resort, brochures, meal vouchers and discount coupons," she explained. "And this is on behalf of our local Science Forum."

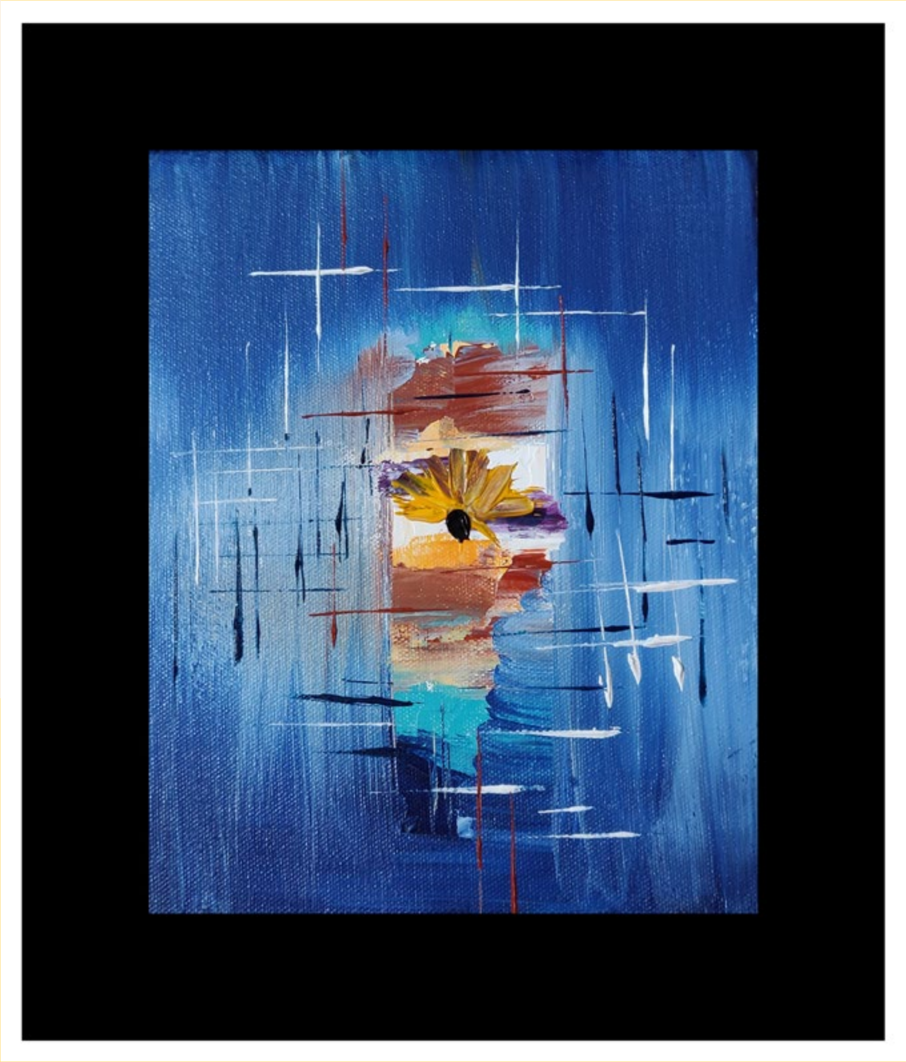
She handed them two eclipse viewing glasses.

"Enjoy your stay."

THE END

U S Kamath is an Associate Professor at the Indian Institute of Astrophysics.





Artist: Maya Prabhakar

Maya is a DST WOS-A Fellow at the Indian Institute of Astrophysics.

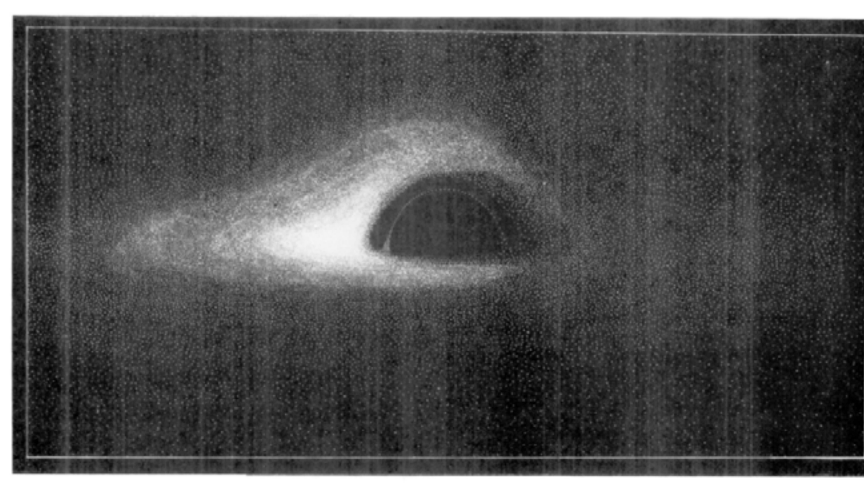
Historical journey of Black-holes

Prerna Rana

Today, we began to understand several mysteries in the Universe starting from the neighboring planets to the distant galaxies, from exoplanets orbiting around the stars to dying stars becoming black holes. Black holes are the exotic astrophysical objects of our Universe, which are thought to be formed due to the collapse or merging of very massive stars. The gravitational pull near a black hole is so high that the escape velocity (velocity required to escape from the surface of a gravitating object) at the surface of a black hole, called the event horizon, reaches near to the speed of light $\sim 3\times10^8$ m/s. For comparison, the escape velocity for our planet Earth is merely ~ 1.12×10^4 m/s. This implies that even the light can not escape from a region inside and from the event horizon surface, which makes this region causally disconnected from the rest of the Universe. This fact led to the origin of the term "Black hole" by an American physicist Robert Henry Dicke, and later popularized by John Wheeler.

The General Theory of Relativity (GTR), developed by Einstein in 1915, accurately describes the behavior of gravity in the strong-field regime, for example near a black hole. The GTR manifests gravity as a consequence of the curvature of space-time due to a massive body. The first solution of the space-time around a non-rotating black hole was derived by Karl Schwarzschild in 1916, whereas the solution for a rotating black hole was given by a mathematician Roy Kerr in 1963.

The last decade has been a golden era in the field of black hole astrophysics with astonishing discoveries and Noble prize awards. The first discovery of gravitational waves (ripples in the fabric of space-time) was reported in 2016 by Laser Interferometer Gravitational-Wave Observatory (LIGO) when two merging black holes were identified. This discovery won the 2017 Physics Nobel prize for astrophysicists Kip Thorne, Rainer Weiss, and Barry Barish. The first image of a black hole at the center of the M87 galaxy was unveiled by the Event Horizon Telescope (EHT) team in 2019. In the year 2020, a mathematical physicist and mathematician, Roger Penrose was awarded half of the Nobel prize in physics for his discovery in 1965 that the formation of black holes is a natural prediction of the GTR. In this work, Roger Penrose proved that the gravitational collapse of mass, due to its gravitational pull, cannot prevent collapse to a single point, called the space-time singularity. Hence, the formation of a black hole is consequential to any gravitational collapse. The other half of the physics Nobel prize of the year 2020 was shared by the astrophysicists Andrea Ghez and Reinhard Genzel for their remarkable discovery of a supermassive black hole of ~10^6 times mass of the sun ($M_\odot$), called Sagittarius A, at the center of our host galaxy, called the Milky Way. This was concluded by observing the orbits of stars very close to the Sagittarius A.



The first simulated photograph of a spherical black hole with a thin accretion disk (Image Credit: Luminet 1979)

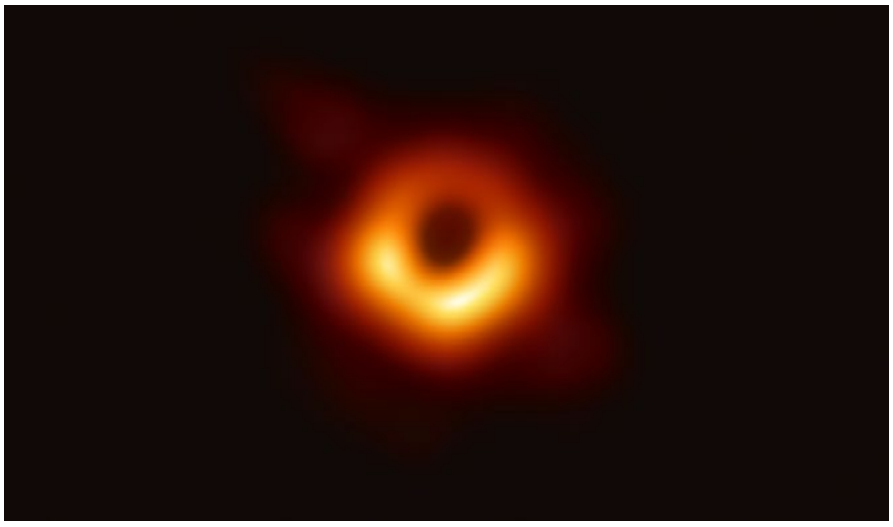
The identification of the first black hole is dated back to 1963 when an astrophysical object, called 3C 273, was discovered in a distant galaxy with extraordinarily high luminosity and having an emitting region of near one parsec. This started the revolution in the field of observations of black holes. The most natural explanation for its remarkable luminosity could only be the release of gravitational potential energy due to accretion of matter onto a supermassive black hole of mass $\sim 10^8 M_\odot$. This was the first evidence of an astrophysical black hole. The further boost to black hole astronomy came in 1972 when a compact object in a binary system, called Cygnus X-1, having predominant emission in the X-ray wavelength band, was discovered to have a mass high enough to be a stable star, hence it was inferred to be a black hole of mass ~14 $M_\odot$. The observation of black holes is a challenging task for astronomers. However, astronomers have come up with some creative ideas to observe these confounding objects, that are:

(i) Gravitational waves (ripples in the fabric of space-time) observations,

(ii) Observations of orbits of stars close to a black hole,

(iii) Observations of accretion of matter/plasma (a gas or fluid of ions and electrons), which emits in the electromagnetic spectrum, and peaking in X-ray wavelength band, just before falling onto the black hole.

Today, we have identified many astrophysical black holes present in our Universe using the methods mentioned above.



The first ever image of a black hole at the center of the M87 galaxy (Image Credit: EHT).

Prerna Rana is a post-doctoral researcher at the Indian Institute of Astrophysics. Her work involves the analytic study of bound trajectories around a rotating black hole using general theory of relativity, and application to astrophysical black hole systems.

IIA head office campus, Koramangala, Bangalore. (Image Credits: T K Muralidas, IIA, 1981 - 2016)

Our new eyes: CCD detectors

Manoj Varma

How many of you remember those old film-based cameras? I definitely do, because I had a terrible experience with one of those. I was responsible for taking pictures with that camera during my cousin's birthday party, and I thought I did a great job. But when the photos came out, they were all just dark. I forgot to remove the cap! But now, we do not have any such problems with our 25 Megapixels dual mobile camera. We can see and edit any picture we take instantly. So, what has changed? Let's find out.

Figure 1: Smith and Boyle in the press conference after winning the Nobel prize in 2009 for their work that led to the discovery of CCD. (Image Credits: commons.wikimedia)

Let's thank them

It all started during the late 1960s at Bells lab when Williard Boyle and George Smith got an idea of storing electric charge in a MOS capacitor. This idea resulted in the invention of CCD in 1969. After six years, the first digital camera using a CCD was invented by Steven Sasson, an engineer in Kodak. After 40 years, Boyle and Smith got Nobel prize in Physics for their greatest invention.

Catching light!

A CCD can catch what our eye sees (It can also detect what our eyes can't!). But before we understand how it does, let's start with a fundamental question. How do we see something? We know in order to see something, we need light. More specifically, we need light coming from that object to reach our eyes. This is why we cannot see when it is dark. The light is made of photons and everything we see, like the sun, stars, bulb, your mobile screen, book, animal and so on are either producing these photons or reflecting them from their surface, to be visible to us. It is these photons that make the object to be captured by the CCD as well. Any digital camera consists of a lens assembly and a detector. These lenses are similar to what we use in the spectacles. They direct the photons towards the detector. And the detector must capture and store these photons and produce an image. A detector can be a CCD, CMOS or a photo film strip (like the old film cameras, which we call a negative). So, the difference between film cameras and mobile cameras (digital cameras) is the detector that is used.

Let us now go one step further and understand how a CCD detector catches the photons. A CCD consists of a Silicon wafer arranged into an array of tiny units called pixels. Each pixel acts as an individual unit that can catch and store the photons in the form of electricity (electric charge). This phenomenon is called the Photoelectric effect—such a sweet name, explains itself (Photons, electricity, got it?). After falling on this Silicon material, photons get absorbed and emit electrons (that form electricity). This effect is discovered by non-other than Einstein. *Few of you might be surprised to know that Einstein, though very famous for his theories on Relativity (Special and General), won the Nobel prize in Physics for his discovery of Photo-electric effect.* Each pixel is also connected with a voltage that acts like a magnet and holds on to the produced electrons. So, when the photons coming from an object hit the CCD, they are converted into electrons and are stored in the pixels until they are read. If the

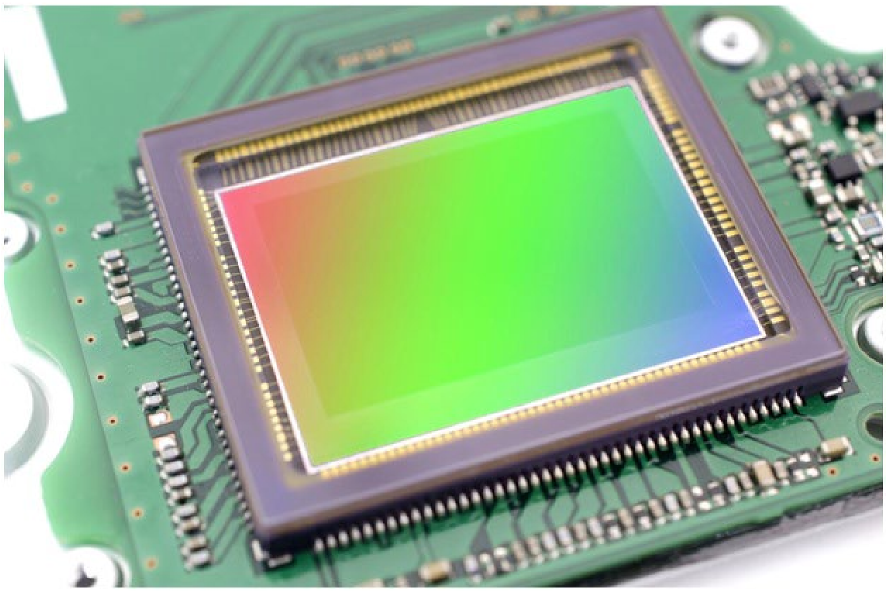


Figure 2: A CCD detector (Source: visiononline)

object is bright, more photons come and hit, and more electrons are produced. A comparatively darker object will produce a lesser number of electrons. The CCD is exposed to the photons for some time, called exposure time. If we want to capture an object at night, we keep higher exposure time so that more photons can come and hit the detector. A very bright object needs a shorter exposure time. After the exposure time is over, each pixel will contain a specific number of electrons that picture how the object looks. The pixels are then read one by one in an orderly fashion by a process called clocking and the electric charge stored in each pixel is converted to a number (this is called Digitization and hence the name digital camera). *You can read more about the process of clocking and digitisation and get back to me if you want to discuss it.* Finally, these digitized numbers are given a grey level (black to white), and we see the picture of the object we captured. I think you might be wondering how a colour photo is created. That, I want you to read it for yourself!

(*It is important not to get confused between a CCD and an LCD. CCD is a detector that catches the image while LCD is a display that displays the image caught by the CCD. Just like a CCD, an LCD also has pixels which define the resolution of that display. So, just take a look at your mobile phone. The screen is an LCD while the CCD hides behind the lens in the camera.*)

Why so many pixels!

We know a 25 Megapixels camera is better than a 10 Megapixels one. So how do more pixels make the photos better? As I told you, each pixel acts as one individual capture and storage unit of photons. So, each pixel stores the photons coming from one specific part of the object we are capturing. Having a greater number of pixels in CCD makes it possible to see the object in more detail. Figure 3 makes things clearer. The top right image is how the object looks like with only 150 pixels. The photo looks very hazy with few pixels. The bottom left image is with 500 pixels, and we begin to see the object. The bottom right is the image with 3000 pixels, and the object is very clear. With a greater number of pixels in the CCD, we can capture more details of the object, and hence we get better photos. Note that a 25 Megapixel camera has 25000000 pixels on its CCD. But it is not just the number of pixels that determines the quality of the image. There are other factors like dynamic range, sharpness, noise in the detector etc. that determines the image quality.

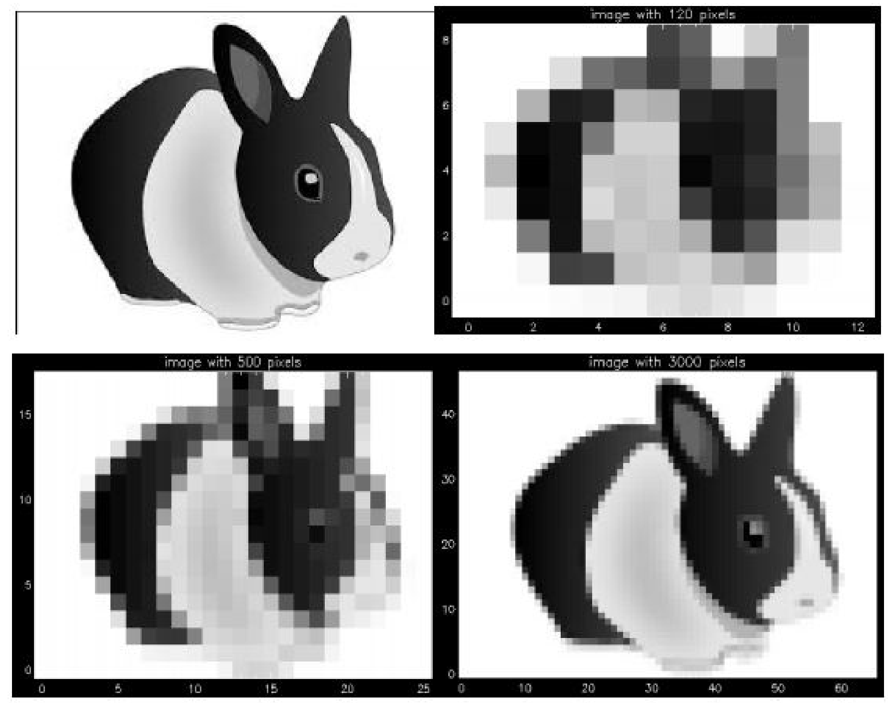


Figure 3: The top left is the image of a rabbit that we want to capture in a CCD. The top right is how it looks if the CCD has only 120 pixels. The bottom left is with a CCD of 500 pixels and bottom right is with 3000 pixels. We can notice how having more pixels allows us to see better details in the rabbit. (Image Credit: Manoj Varma)

CCDs are everywhere

When we look around, we can see how widespread are the uses of CCD in imaging applications. Any visual-based medical examination equipment like X-ray, endoscopy etc. has a CCD. The surveillance cameras that we use in CCTV, the telescopes that we use to study stars and other astronomical sources, and the digital cameras in our mobile phones, all use CCD detectors. CCDs paved the way for many breakthroughs in the fields of medicine and astronomy. Next time when you appreciate an image of the Milky Way galaxy or Instagram picture of your favourite actress, spare a thought for CCD! They are our new eyes with which we see the world and beyond.

Oh wait, I never told you what a CCD stands for, right? It's '**Charge Coupled Device**!'

Manoj Varma is a Senior Research Fellow at IIA, Bengaluru. He works on Ultraviolet detectors for Solar Astronomy and is currently working on Solar Ultraviolet Imaging Telescope (SUIT), which is one of the payloads onboard ISRO's Aditya L1 mission that is set to fly soon.

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Kavalur early days (1969-1984)

Part II

IIA Library

KAVALUR 1969 - 1970

15inch, Kavalur 1969

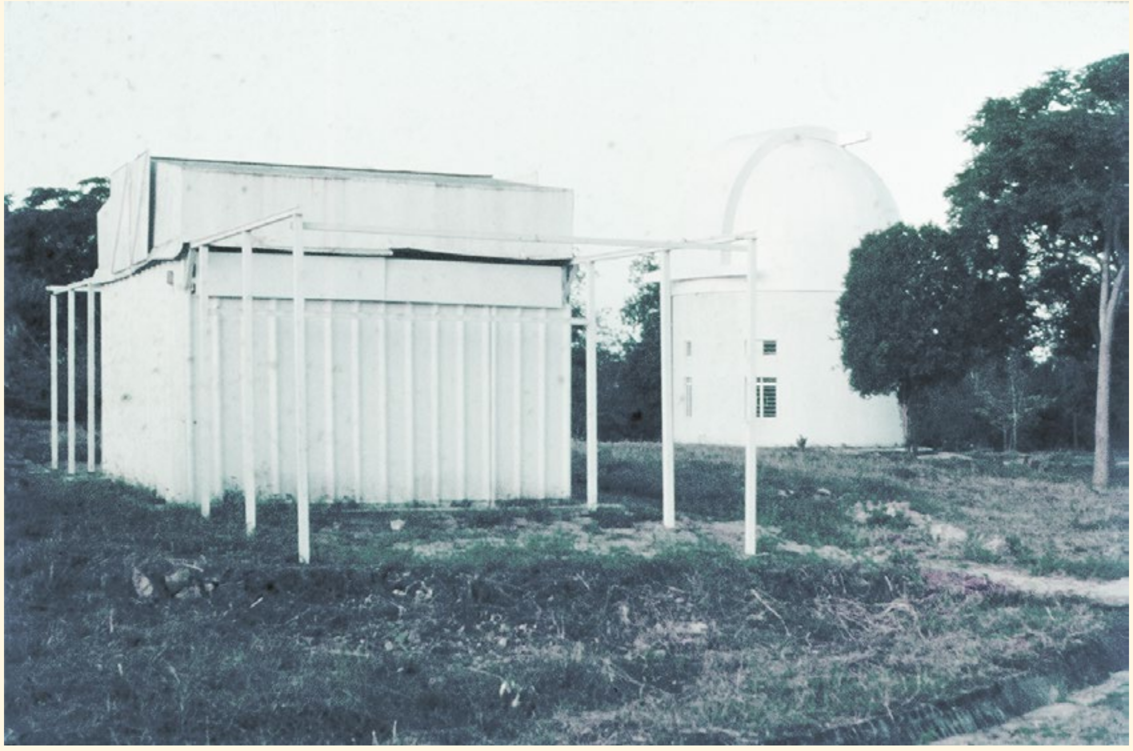
Kavalur, Foundation for 24inch dome, Oct.26, 1970

Kavalur, Oct. 26, 1970

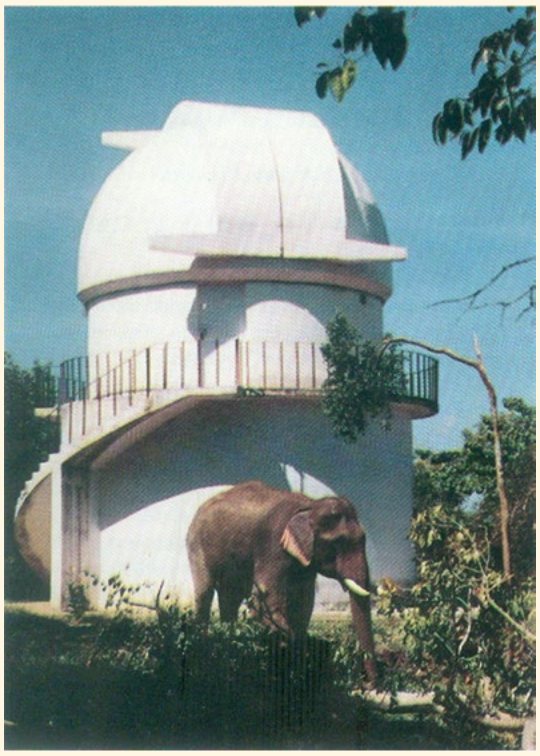
KAVALUR 1984

Kavalur Village- View from 40inch. Jan.1984

Gate-Kavalur, Jan.1984



30inch and Sliding Shed, Kavalur



The 45cm Schmidt - an additional tusk to blink1

** All these images are collected by IIA Library team during VBO-50 celebrations and shared to DOOT by Venkatesh, JRA,Kavalur.*
*** In the previous edition credit for these images was wrongly given to Venkatesh alone. Team DOOT is sorry for that and we have corrected that in this edition.*

The mathematics of music

Samrat Sen

This article is dedicated to showing how mathematics is related to music. No need to worry if you don't like maths (or find it difficult)! I have tried to explain the correlation using simple school level mathematics to realise that our sensitivity to sound is linked to the logic of our brains.

Most of us know that the sound is a wave and the musical notes are the (particular) frequencies of the sound. But what is the frequency? It is the number of repetitions of a pattern in a second. Imagine, a cartwheel is spinning one revolution in a second, so we say that the cartwheel's frequency is 1 Hertz (Hz). Great, but what that has to do with the music? The answer to this question is: the sound is a wave that oscillates with some frequency. If it oscillates once per second, it's frequency is 1 Hz, similarly, if it oscillates 440 times per seconds, it's frequency is 440 Hz, and this frequency is traditionally called the 'A' note. But what's the role of mathematics in this scenario? Well, if a note frequency is multiplied by 2, the note remains the same. For example, both 440 Hz and (440 x 2) 880 Hz denote the 'A' note, but the latter is in the next higher octave. Similarly, 220 Hz also corresponds to the 'A' note. So, we can say that the ratio of the frequencies of the same note to its next higher octave always maintains the factor of 2*.

** It's a nice (and simple) experiment you can do with a frequency tuner software (available in any android mobile): Play the same notes in different positions of any musical instrument like guitar, keyboard, sitar, etc., you should find that the frequencies are following the same pattern as discussed above.*

Historical Overview: Pythagoras' Experiment

Okay, so before going further, let's go back to the ancient Greek philosopher, Pythagoras, who made an important contribution to mathematics (and in music theory). He realized that different sounds can be made with different weights and vibrations, which lead to the discovery that the pitch (or frequency) of a vibrating string is proportional to its length and can be controlled by it.

Now imagine a taut string. If the string is plucked, it will vibrate [see Fig. 1(a)] and generate a monochromatic sound (a single frequency sound). Pythagoras decided to divide the

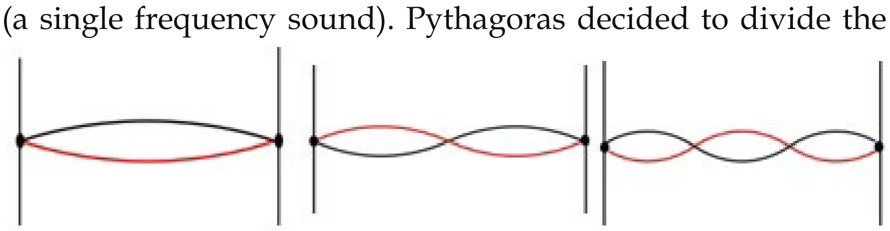


Fig 1: Different length divisions of a taut string for generating different sounds (Pythagoras experiment).

string into two equal halves and touch each end again [see fig 1(b)]. He noticed that the sound created in the second case is exactly the same but with the next higher octave. He didn't stop there. He decided to try what the sound would look like if the string was divided into three equal parts [see Fig. 1(c)]. He noticed that the sound created was not the same note in the higher octave, but had a different identity, which needed to be renamed. Despite the sounds being different from each other, the combined sound seemed pleasant harmony to the ear because the human brain is accustomed to prefer logical relationships (which are the 1/2 and 2/3 divisions in this case). He continued this experiment with more subdivisions of the string to draw a correlation of the sound creating scales, which later motivated us to build musical instruments that could reproduce these scales.

The Mathematics of musical scales

Many people and cultures have created their own musical scales. For example, Indian and western music work with twelve notes: A, A# (read as A-sharp), B, C, C#, D, D#, E, F, F#, G and G# (and this pattern repeats for the next octave as well). The ratio of the frequencies of any note to its immediate lower octave is 2 as discussed above, and the distance between the two consecutive notes (semitones) should be the same for creating a scale. So, we can find the factor that has to be multiplied by the frequency of any note to obtain the next note of the scale, as $2^{1/12} = 1.0595$. Hence, we can calculate the frequencies of every note to form a chromatic scale. For example, the frequency of the A# note is (220 Hz x 1.0595) 233.09 Hz [recall the frequency of A note is 220 Hz], the frequency of the B note is (233.09 Hz x 1.0595) 246.9 Hz, and so on.

So, after understanding this, let's discuss another interesting thing about the musical scale through maths: finding the notes from frequencies. The best way to understand this is to look at the piano notes. Let's assume the frequency of the leftmost C note (see Fig. 2) to be f, then the next C note in the higher octaves will have the frequencies of 2f, 4f, 8f, and so on. But what about the 3f, 5f, 6f, 7f notes? What are their positions? Well, let's do some maths. It's naturally clear that the 3f note is in between the 2f and 4f notes. Now, if we need to advance p semitones from 2f to achieve the 3f note, we can say that the following relation holds: $2f. (1.0595)^p = 3f$, which implies, $p = \log_{1.0595} (3/2) = 7$. Hence, we have to advance seven semitones up from 2f to obtain the 3f note, which is the G note in this case. The same approach automatically ensures the positions of the 5f, 6f, and 7f notes (see Fig. 2).

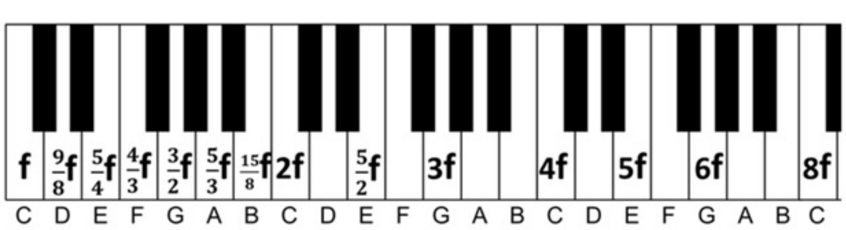


Fig. 2: The chromatic scale and the frequencies of the notes in a piano

Now, our next task is to analyze the notes in the first octave. So far we have advanced in the next octave by multiplying by 2, but here we want to find the notes in the backward order. To do that, we just reverse the process, i.e. divide by 2. For example, by dividing the 5f note (E) by 2, we obtain another E note in the lower octave which has the frequency 5f/2 and repeating this process again, we get another E note in the next lower octave with frequency 5f/4 (see Fig. 2). We can continue the same exercise to accurately find the frequencies in the first octave, and carry forward to obtain the frequencies of the entire piano.

Logarithms in music

If you have gone through the article carefully, you must have noticed that when we were doing the calculations of the frequencies and the root notes, we were intrinsically working with the logarithms. For this reason, the piano builders make the body of the piano in the form of a logarithmic function (see Fig. 3) to refer to this mathematical-musical discovery.

Fig. 3: The shape of the body of the piano looks like a logarithmic function.

The Fibonacci sequence in the piano scales

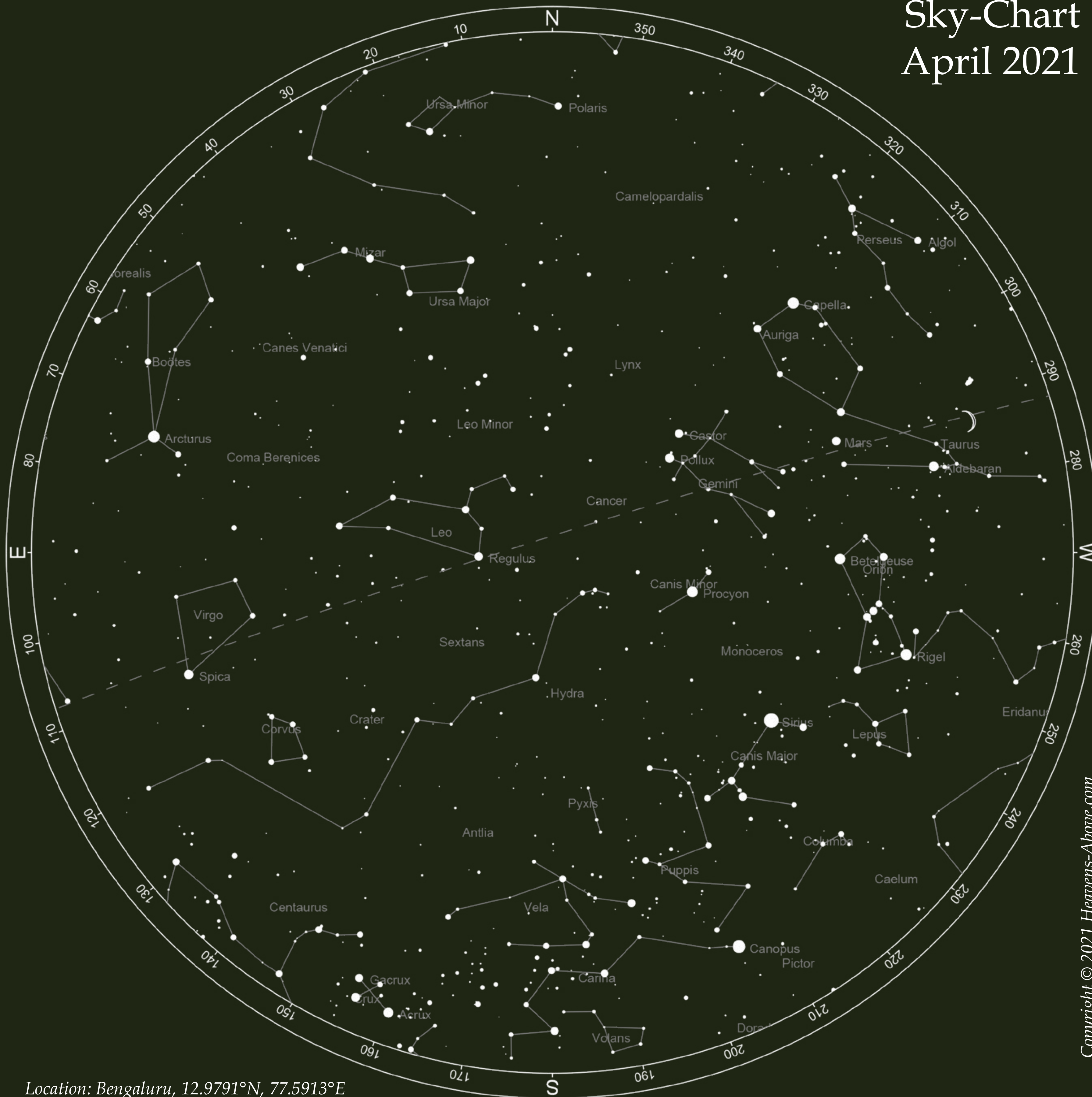
The Fibonacci sequence is a famous sequence that follows the sequence: 1, 1, 2, 3, 5, 8, 13, 21, ... where the n^{th} term of the sequence is the sum of the $(n-1)^{th}$ and $(n-2)^{th}$ terms [for $n > 2$]. The Fibonacci sequence can be seen in the piano scales. For example, the C scale on the piano consists of 13 keys from C to the next C; 8 white keys and 5 black keys with black keys arranged in groups of 3 and 2 (see Fig. 2). Notice, all the numbers: 13, 8, 5, 3, and 2 are part of the Fibonacci sequence.

Concluding Thoughts

The closest knot between music and mathematics is the patterns. Our brain likes to find patterns or similarities, and that's why we enjoy the rhythm in music and get headaches for random noise. The bottom line of this article is that if you are a musician, then you are a mathematician too (in one way or another) as when you get the feeling of pleasure at the time of listening to music, your brain also does the calculations of rhythms and notes in the subconscious mind.

Samrat Sen has just finished the PhD from IIA and Joined Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital as a Research Associate. Currently working in the field of solar astrophysics.

Sky-Chart
April 2021



Location: Bengaluru, 12.9791°N, 77.5913°E
Time: 15 April 2021 20:00 (UTC +05:30)

Watch-out for:

April 7 - Close approach of the Moon and Jupiter. The Moon and Jupiter will make a close approach, passing within 4°10′ of each other. Visible in the dawn sky, rising around 3 hours before the Sun – and reaching an altitude of 36° above the south-eastern horizon before fading from view as dawn breaks.

April 22, 23 - Lyrids Meteor Shower. The Lyrids is an average shower, usually producing about 20 meteors per hour at its peak. It is produced by dust particles left behind by comet C/1861 G1 Thatcher, which was discovered in 1861. The shower runs annually from April 16-25. It peaks this year on the night of the 22nd and morning of the 23rd. These meteors can sometimes produce bright dust trails that last for several seconds. Best viewing will be from a dark location after midnight. Meteors will radiate from the constellation Lyra, but can appear anywhere in the sky.

April 27 - Full Moon, Supermoon. The Moon will be located on the opposite side of the Earth as the Sun and its face will be will be fully illuminated. This phase occurs at 03:33 UTC. This is the first of three supermoons for 2021. The Moon will be near its closest approach to the Earth and may look slightly larger and brighter than usual.

Prasanta K Nayak

My journey at IIA

I joined IIA post my Masters in Physics from IIT Kharagpur in January 2014. The batch of 2014 consisted of five brilliant batch-mates. When I joined IIA for the five-year PhD program, I had very little knowledge about research, let alone Astrophysics. However, the one-year coursework at IIA was a turning point in my life. As a bunch of strangers, we had the opportunity to travel to the Indian Institute of Sciences (IISc) and the Raman Research Institute (RRI) for attending course work. Those frivolous days, as an amateur researcher, are still sweet memories in my heart. Those were the days when a bunch of strangers made their way into an integral part of my life. And yes, of course, the classes! That was an excellent opportunity for a beginner like me to be amidst the magnificent campus and veteran professors. They not only encouraged me to learn more but also pushed me towards being a better researcher.

Later in that academic year, I also had an excellent opportunity to visit the prestigious observatories under IIA. Our batch, accompanied by Prof. Avinash Deshpande from RRI, visited Gauribidanur Radio Observatory. This historical landmark was always mentioned in magazines and research articles, and now I was a part of it. I couldn't be more proud of myself. I may not have realised it at the time, but those sessions were advantageous to me throughout my PhD life.

I also had the opportunity to visit an X-Ray lab at RRI under Prof. Biswajit Paul's supervision. With the academic year coming to an end with this, I couldn't ask for more. It was undoubtedly one of the best years I ever had. During my second year, I visited Kavalur Observatory and Kodaikanal Solar Observatory. At Kavalur observatory, Prof. Ram Sagar conducted classes on coordinate systems and optical astronomy, which were top notch classes that I would have missed had I not been part of IIA.

In contrast to the visual experience, I got a tan at Kodaikanal Solar Observatory. From attending internal workshops conducted by senior PhD colleagues, to spending hours inside telescope rooms, I was enthralled by the various resources and excited for the next three years of my PhD life. My frivolous days culminated with a short project "Identifying star clusters in the nearby galaxies, Magellanic clouds".

After a brilliant academic year and fun times with my batch mates, it was time for me to pursue a thesis which I needed to defend no matter what. Winter was indeed coming! After a much-needed brainstorming session, I joined with Prof Annapurni Subramaniam, the then BGS head and now the Director of IIA. My thesis was titled "Study of star cluster populations in the Magellanic clouds''. As heavy as it sounds, there was no looking back. It was time to prove myself. I was provided a computer, high-speed internet facility and an office space which became my pseudo-apartment for the next three years. Monday mornings started with a minimum one hour-long discussion with my supervisor. Those discussions inundated my week with astronomical data and research journals.

Amidst my thesis work, I did spend a good time amongst my seniors. Those interactions helped me to clear my doubts and engaged me with constructive discussions. The Journal club was another excellent platform present to keep me updated with recent research in various areas of astrophysics and amongst my peers. It also provided me with an opportunity to meet eminent researchers with whom I could develop collaborative relations. I was soon a part of an esoteric world where I was invited to present my work at talks, colloquiums and seminars. I was quite the phoenix bird which was given multiple CPRs during this time.

My life at Bhaskara, the IIA hostel, was quite the fire for my revival. We celebrated all national and local festivals under one roof with one heart and mind. Those days helped me not to miss home food and get over homesickness. Late-night stargazing and "other" episodes on the terrace of Bhaskara are never to be forgotten. I was also quite involved in the public outreach activities conducted at various schools and public gatherings. Students often visited IIA on National Science Day, and other annual functions conducted by IIA. I was in the frontline to conduct workshops, classes and talks for them. With much-needed vacations at times, I also travelled in and around Bangalore and also took a quick peek at my long-lost home-sweet-home.

Struggles are harder as you go through them and don't see the bright and shining light at the end of the tunnel. The tunnel was still quite long for me. However, the acceptance of my first research paper was quite a satisfying moment for me. I was invited to conferences, both national and international ones, to present my work. This was quite a proud moment for me, in front of all the veterans, peers and young talents. I was quite the astrophysicist I had thought of.

"PhD is not a sprint, rather a marathon." Though not a time-varying Usain bolt, I did my best for the four most important years of my career. Yes, the academic life is quite daunting and frustrating and feels like being stuck in the time loop of "Doctor Strange" from The Avengers. Things will go beyond your control; there will be sand in your shoes. You will be crying for "PLEH". Yet, you will come through the other side. All you need is patience with persistence. Your supervisor would be your knight in shining armour in all those dark nights. One should have the courage to accept all those failures as steep learning curves. Escape velocities of those curves would fill the acknowledgement page of your thesis. I was lucky to have a supervisor like Prof Annapurni Subramaniam, without whom I would not have been able to be the person I am today.

When I defended my thesis in November 2019, the first person I had to thank was myself for never giving up and then my wonderful family and friends for their constant moral support. The independence and freedom you attain in research are unmatched to any other industry. I could not have imagined myself anywhere else other than research. After all, isn't the Journey the best part of the trip to Ithaka? Cherish your pains and gains, one day it would be useful to write a journal like this, and you will smirk at it as I do now.

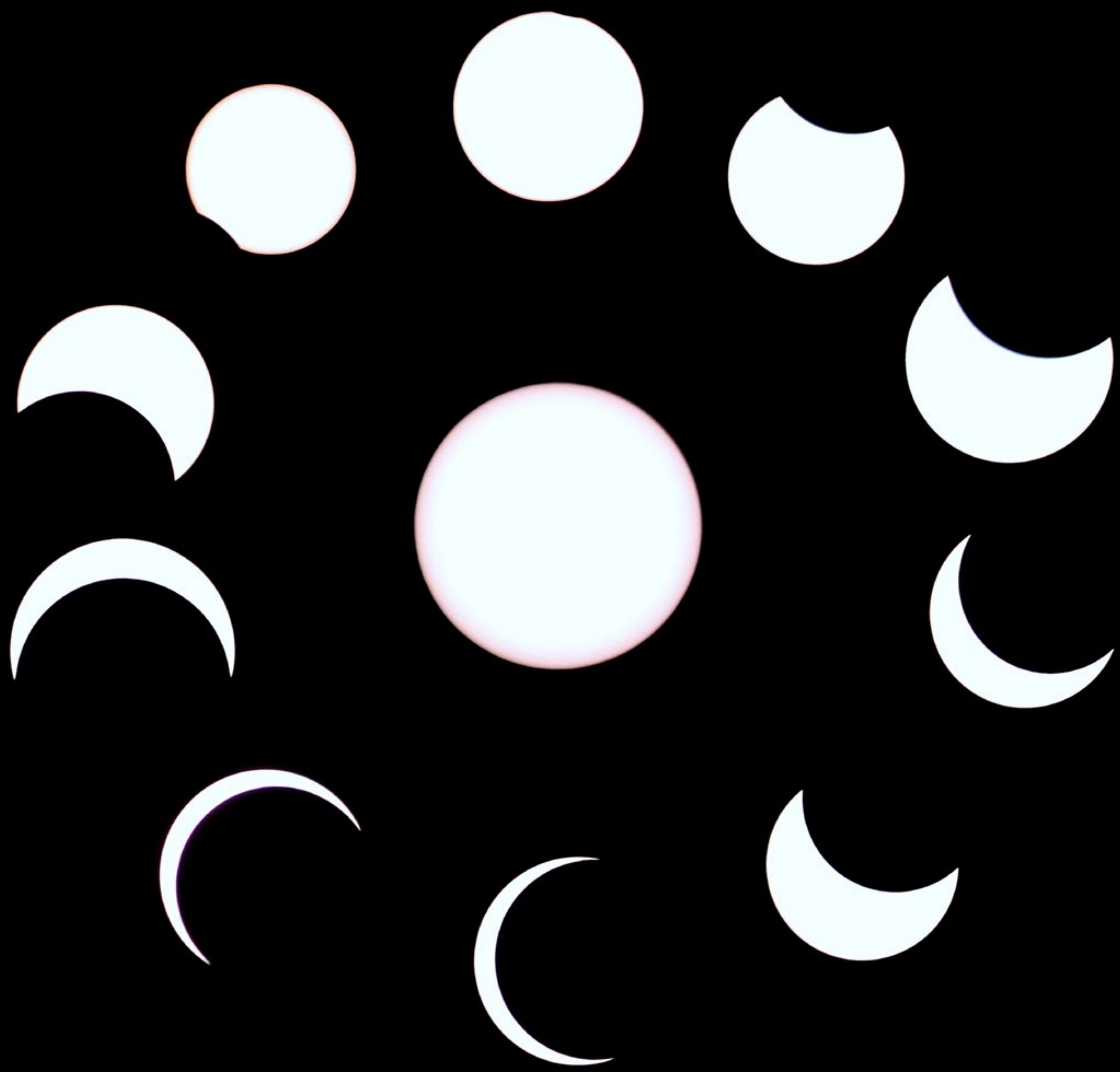
Prasanta Kumar Nayak is a postdoctoral fellow at Tata Institute of Fundamental Research (TIFR), Mumbai, India. His research interests include star formation history in the Milky Way and nearby galaxies, and the study of star clusters and their connections with galaxy evolution. He completed his PhD in 2019 from IIA, Bangalore.

Colorful Saturn

Artist: Snehalata Sahu

PDR, Indian Institute of Astrophysics.

Partial solar eclipse, 26 December 2019



About the image

Location: Gauribidanur Radio Observatory
Camera: Canon EOS 600d, 55-255mm lens with solar white light filter and tripod.
The image shows different phases of the Solar Eclipse

It was the first Solar Eclipse that I was going to capture through my camera. In fact, it was the first Solar eclipse of this proportion I was going to witness. About 90% of the Sun was going to be eclipsed by the Moon from Gauribidanur Observatory, which is about 100 km north of Bangalore. Naturally, I was excited and had done the preparations to capture this celestial event. I had got a solar filter sheet and made a cover for my camera lens using some cardboard- a low cost 'jugaad'. I had set up my camera with a tripod on the terrace of the student hostel at the observatory. Before the eclipse day, it was cloudy at Gauribidanur every morning, so my hope was shaking. But luckily on the morning of 26 December, it was clear. Together with the staff of the observatory, I witnessed this beautiful event and captured my first solar eclipse!

Acknowledgment: Thanks to Sarthak Choudhary for providing the solar filter sheet and Lakshitha N M for helping me make the cover.

- Kshitij Bane

Kshitij is a Junior Research Fellow at the Indian Institute of Astrophysics and currently building a Radio Telescope at Gauribidanur Radio Observatory to study Pulsars.