Azadi Ka Amrit Mahotsav

DOOT

A STUDENTS' INITIATIVE FROM THE INDIAN INSTITUTE OF ASTROPHYSICS

Issue 7

December 2022

DOOT
A students' initiative from the Indian Institute of Astrophysics

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Invitation for articles

We invite 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 field-station 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 that the work is bonafide.

We would like to improve the content of the magazine.
Please send your generous feedback and contibutions to
doot@iiap.res.in
magazine.iiabengaluru@iiap.res.in

From the Editor

DOOT is a students' initiative to share contributions from any person at IIA to the complete IIA family, and to the wider interested public.

In this 7th issue of DOOT, we have an interview with Prof. Urbasi Sinha, from RRI, who takes us on a journey through the wonderland of Quantum Mechanics, and we have our Dean, Prof. Eswar Reddy, sharing his PhD and post-PhD experiences with us as an IIA alumnus. We also have multiple people collaborating to tell us about their experiences of the recent solar eclipse, along with technical articles on solar physics, galaxies, supernovae, and many more. We hope you enjoy them.

We are trying to update DOOT to a more user-friendly and easily accessible format. Efforts to this end have already seen some results, and we hope we can bring a better, brighter DOOT to your hands soon! Do follow our social handles to know more.

We welcome all IIA staff with open arms, to contribute an article, whether academic or non-academic, to DOOT. We would also sincerely love to hear your feedback and suggestions to improve DOOT further.

Vishnu Madhu

Chief Editor, DOOT

DOOT

A STUDENTS' INITIATIVE FROM THE INDIAN INSTITUTE OF ASTROPHYSICS

Contents

Star trail image from Poombarai village, Kodaikanal

A star trail is a type of photograph that uses long exposure times to capture diurnal circles, the apparent motion of stars in the night sky due to Earth's rotation. A star-trail photograph shows individual stars as streaks across the image, with longer exposures yielding longer arcs.

Star trail photographs are captured by placing a camera on a tripod, pointing the lens toward the night sky, and allowing the shutter to stay open for a long period of time. Typical exposure times range from 15 minutes to many hours long, depending on the desired length of the star trail arcs for the image.

In the modern digital cameras, longer exposures causes thermal noise, also the images may get over exposed the sky brightness caused by the light pollution. So to avoid these situations, photographers takes multiple images of a few seconds exposure at short interval and stitch them using the different software.

Poombarai is a tiny village that is famous for its production of garlic. It is comfortably nestled among terraced fields and lush greenery. It stands at the height of 1,920 m in the Palani Hills and offers a picturesque view of the surroundings.

(Credits to en.wikipedia.org and holidify.com for the details)

Camera	:	Nikon D7500	Exp	:	30 sec x 17 subs
Lens	:	Nikon 50mm F/1.8 @ F/4	Location	:	Poombarai village view point
ISO	:	800	Image credit	:	Anand M N, IIA

Discovery of diffuse star forming galaxy

Jyoti

A galaxy is a gravitationally bound system containing stars, interstellar matter, and dark matter. Nature has provided an immense variety of galaxies, ranging from faint, diffuse dwarf objects and elliptical to spiral-shaped giants. Galaxies vary in size from supergiant galaxies which contain one hundred trillion stars, to Dwarfs, which are smaller galaxies that, on average, contain 100 million stars. We have come a long way where, till the 20th century, we used to think that the universe had only one galaxy, which is our Milky Way, and every other celestial object that we see is a part of the Milky Way. With the advent of better telescopes, we have now discovered trillions of galaxies.

Some galaxies are so faint that their central brightness is dimmer than the night sky. These are called Low Surface Brightness (LSB) galaxies. There are observational challenges in detecting them because of their inherent low luminosities. These galaxies have common properties, such as poor star formation rates, low metallicities, diffuse stellar disks, and extended gas disks. Although these galaxies are faint, their fraction in the universe may be 30-60%. The universe contains a large treasure of these LSB galaxies, which are hidden just below the detection limits of current large-area surveys. So the study of LSB galaxies is of great significance for our exploration of the universe.

NGC6902A was previously known as an interacting galaxy. We observed this galaxy using the UltraViolet Imaging Telescope (UVIT) onboard ASTROSAT, which is India's first space-based observatory, and the InfraRed Survey Facility (IRSF) telescope in South Africa. UVIT observes in far-ultraviolet (FUV) wavelength, and IRSF observes in the near-infrared (NIR) wavelength. NGC6902A is also observed by Multi Unit Spectroscopic Explorer (MUSE) and as a part of the Dark Energy Camera Legacy Survey (DECaLS). MUSE is mounted on the Very Large Telescope (VLT), which is in Chile, and it provides imaging and spectroscopic data over the wavelength range of 4800-9300 Angstrom.

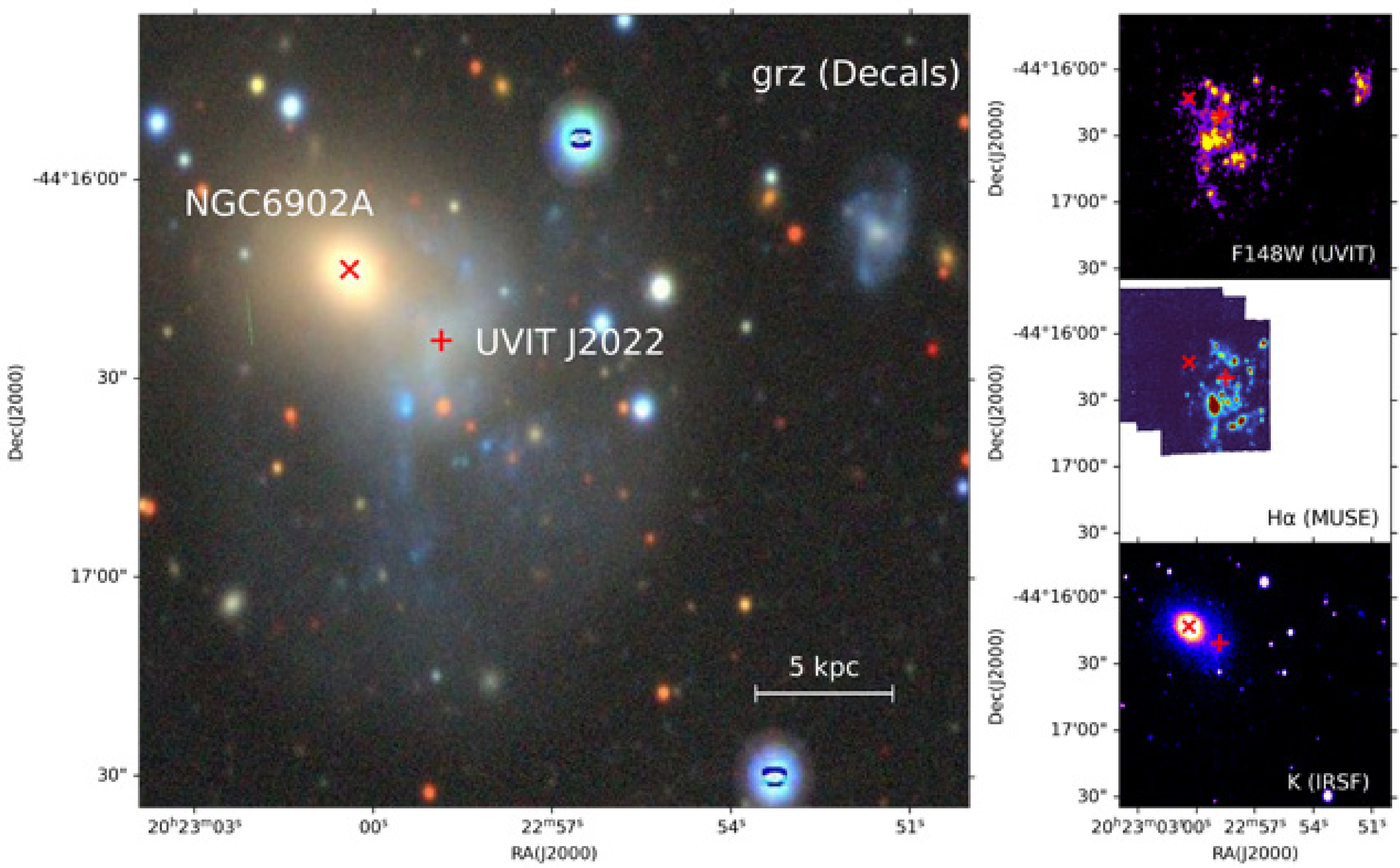


Figure 1: Multi-wavelength images of UVIT J2022. The grz image shows the background galaxy, NGC6902A, and the foreground galaxy, UVIT J2022. Star-forming regions in UVIT J2022 are prominent in FUV and Hα. The K band image reveals the emission from old stars in NGC6902A. The + and × symbols in red indicate the kinematic center of UVIT J2022 and NGC6902A, respectively.

We noticed that the southwest outer region of galaxy NGC6902A in the DECaLS color image shows diffuse blue emission. This southwestern region shows prominent star-forming regions in the FUV image. Most of the FUV emission in galaxies is due to young, massive stars of types O and B, which have been emitted in FUV for 100 million years. This prompted us to investigate the peculiar feature present in the southwestern region in more detail to understand if the star formation is due to another galaxy that merged with NGC6902A. We used emission lines using MUSE data of various star-forming regions in the southwestern region for distance estimation. We found that these star-forming regions are at a distance of around 136 million light-years, whereas the distance of NGC6902A is around 825 million light-years. This means that the diffuse blue emission is from a foreground galaxy, and NGC6902A is a background galaxy. They were mistakenly identified as interacting galaxies because of their visual overlapping. We have named it UVIT J202258.73-441623.8 (or UVIT J2022 for short) based on the Indian UVIT telescope that helped us to discover the galaxy. UVIT J2022 is a low surface brightness galaxy.

We also measured other properties of UVIT J2022, such as the neutral gas content, stellar mass content, metallicity, and star formation rate (SFR). The galaxy has neutral gas and stellar content of 1.32×10^{9} $M_{\odot}$ and 8.72×10^{8} $M_{\odot}$. The SFR of the galaxy is 0.18 $M_{\odot}$ yr^{-1} Kpc^{-2} in FUV. The metallicity of UVIT J2022 is

~8.6 ± 0.1 dex. The galaxy has gone through three bursts of star formation. The latest episode of star formation is currently happening in the galaxy, which is also evident from the massive star-forming regions in FUV and Hα maps. We also found that this galaxy is almost face-on with an inclination of 13°.

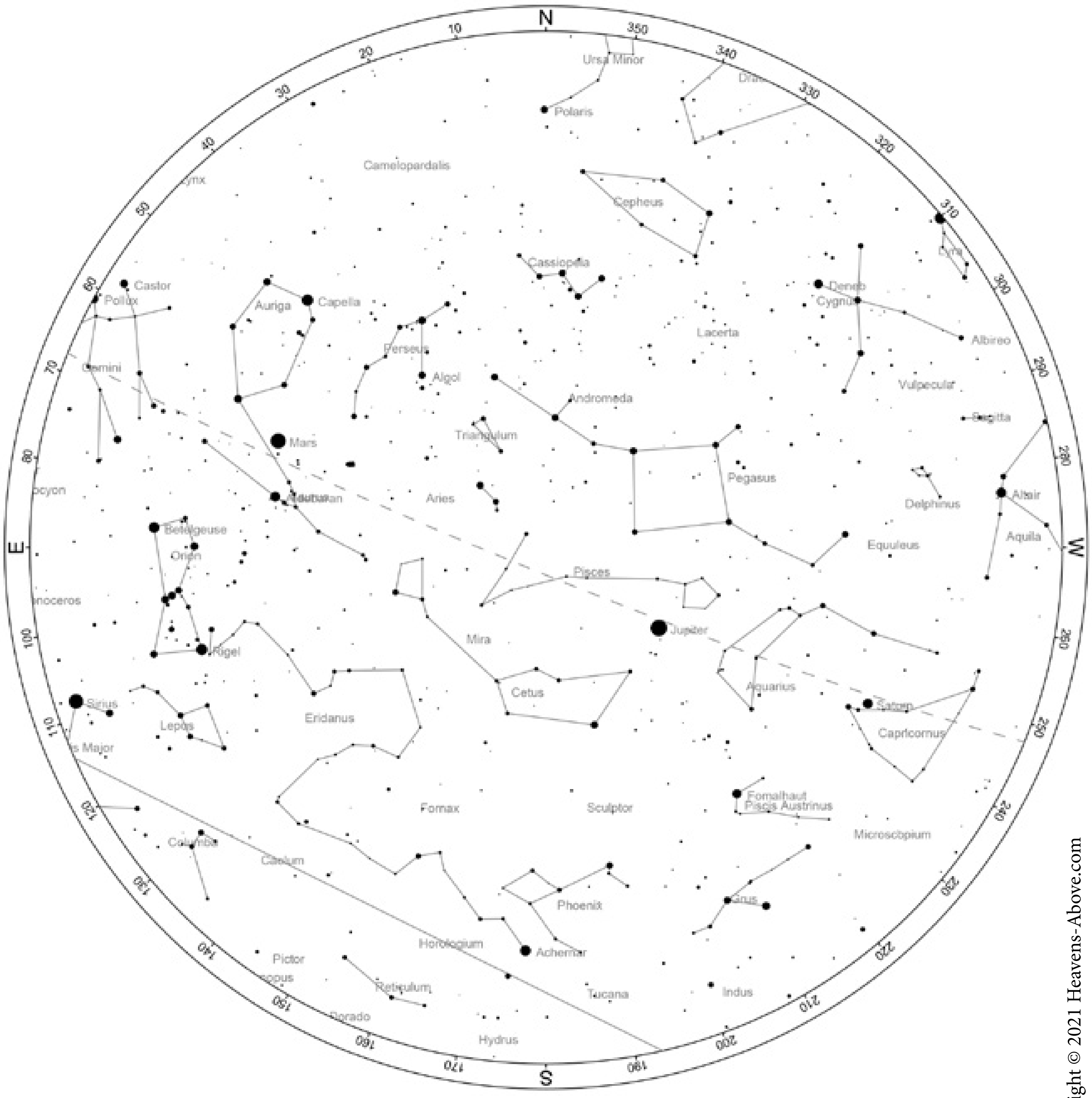
Our results show that blue diffuse tidal features in interacting galaxies may not always be due to a merger, but instead, they can be separate foreground and background galaxies. With the help of spectroscopic data, we can differentiate between an interacting system and visually overlapping galaxies at different distances. This study also shows that FUV and Hα emission are powerful tracers for detecting diffuse star-forming galaxies.

Reference:

1. *J. Yadav et al., 2022, A&A 657, L10(2022)*

Jyoti is a senior research fellow at the Indian Institute of Astrophysics. She works on star formation and AGN activity in isolated and interacting galaxies.

Artist: Abinaya



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Skychart December 2022: (As on December 15, 2022. 20.00hrs Bangalore)

December 2022

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1 Mars at perigee	2 Conjunction of the Moon and Jupiter Pheonicid meteor shower 2022	3
4	5	6 December ϕ-Cassiopeid meteor shower 2022	7 Puppid-Velid meteor shower 2022	8 Conjunction of the Moon and Mars Mars at opposition	9 Monocerotid meteor shower 2022	10 1 Ceres at perihelion
11	12 σ-Hydrid meteor shower 2022	13	14 Geminid meteor shower 2022	15	16 Comae Berenicid meteor shower 2022	17
18	19	20 December Leonis Minorid meteor shower 2022	21	22 Mercury at greatest elongation east December solstice Mercury at highest altitude in evening sky Ursid meteor shower 2022	23	24 Mercury at dichotomy
25	26 Conjunction of the Moon and Saturn	27	28	29 Conjunction of the Moon and Jupiter	30	31

Credit: in-the-sky.org

A cabin in the snow (Artist: Meenakshi P)

A search for the progenitors of the Carbon-Enhanced Metal-Poor (CEMP) stars

Meenakshi P

Metal-poor stars are the most treasured candidates for galactic archaeologists. This is because these objects offer a window into the epochs of the very first stars and help to trace the formation and history of the Milky Way. Metal-poor stars form the oldest stellar populations in the Milky Way. They got the name 'metal-poor' as they are iron-deficient ($[Fe/H] < -1$), which points towards their early formation. They are formed from the remnants of the very first stars in the Galaxy and thus they represent a fossil record of the nucleosynthesis products of the first-generation stars. Due to these unique features, metal-poor stars are one of the most hunted groups by many sky survey programs.

Most of the sky survey programs have shown that a substantial fraction of metal-poor stars shows enhancement of carbon ([C/Fe] > 0.7). This group of metal-poor stars is called Carbon-Enhanced Metal-Poor (CEMP) stars. Further high-resolution spectroscopic analysis of these objects revealed that many of them exhibit enhancement of neutron-capture elements. CEMP stars that are found to be enhanced in the slow neutron-capture process (s-process) and rapid neutron-capture process (r-process) elements are called CEMP-s and CEMP-r stars, respectively. CEMP stars that are enhanced in both s- and r-process elements are called CEMP-r/s stars. In contrast, CEMP-no stars are another sub-group of CEMP stars that do not show any enhancement of neutron-capture elements.

It is found that CEMP stars are mostly dwarfs, sub-giants or giants, and are not expected to show such enhancements. Then, how do they exhibit enhancement of carbon and neutron-capture elements? Is there any unknown mechanism behind this or do they get it from any external sources? If there is a common source behind the CEMP stars that enrich them with heavy elements, why don't all the CEMP stars exhibit similar enhancements? These are some of the most debated questions among galactic archaeologists. Although various scenarios were speculated to explain the abundance anomalies, it remains a puzzle without much observational evidence.

I had been working towards this line with Prof. Aruna Goswami. We carried out a detailed high-resolution spectroscopic analysis for a sample of nine CEMP stars. We have obtained the high-resolution spectra (R~60,000 and 50,000) using the high-resolution fiber-fed Hanle Echelle SPectrograph (HESP) attached to the Himalayan Chandra Telescope (HCT) as well as the High Dispersion Spectrograph (HDS) of the 8.2 m Subaru Telescope. Program stars are selected from the list of metal-poor candidates of the Hamburg/ESO survey (Christlieb, 2003).

The radial velocities estimated at different epochs can give important clues regarding the binary nature of the stars. So our first step was to determine the radial velocity of the stars and to compare our estimates with the literature values, if available for these stars. Luckily, radial velocity estimates are available for eight of the program stars. We could see that our estimates of radial velocities of these objects show a difference of ~ 1.6-11.8 km s^{-1} from the corresponding literature values, which may be a clear indication of the stars being in binary systems. That means if these objects are binaries, then it can clearly sort out the problem of the observed abundance anomalies in these objects. To confirm it further, we have derived the abundances of various elements as well as elemental abundance ratios for the sample.

We have made use of MOOG (Sneden 1970, updated version 2013) for the analysis under the assumption of local thermodynamic equilibrium. We have used alpha normal model atmospheres ([α/Fe] = 0) for our analysis, and the model atmospheres are adopted from the Kurucz grid of model atmospheres with no convective overshooting. The procedures that we have adopted to derive the stellar atmospheric parameters as well as the abundances of various elements, can be found in our papers.

From our analysis, we found that our sample contains five CEMP-s, two CEMP-r/s, and two CEMP-no stars. All of them exhibit enhancement of neutron-capture elements except the two CEMP-no stars, as expected. Carbon is found to be enhanced in all of them. However, these stars are in the giant phase of evolution (found from our luminosity estimations for these stars) and are not expected to exhibit the observed enhancement. Keeping in mind the indication of the stars being in binary systems from the radial velocity estimates, we have located the stars in the absolute carbon abundance A(C) vs. metallicity [Fe/H] diagram which is a valuable tool to predict the binarity of the CEMP stars (Figure 1). We have used the corrected value of absolute carbon abundance to locate the stars in this diagram, i.e., as the program stars are in a giant phase of evolution, internal mixing processes might have diluted the initial carbon abundance, and hence we need to apply the correction to the estimated value of carbon abundance corresponding to the dilution. We have applied corrections to the estimated carbon abundances using the public online tool by Placco et al. (2014) available at http/://vplacco.pythonanywhere.com/. Many studies have found that the CEMP stars exhibit bimodal distribution in the A(C) vs. [Fe/H] diagram and the stars clustered around A(C) ~ 7.96 (Group I stars) are mostly binaries. We found that all of the CEMP-s, CEMP-r/s, and one CEMP-no star fall in the Group I category and might be in binary systems, similar to their Group I companions.

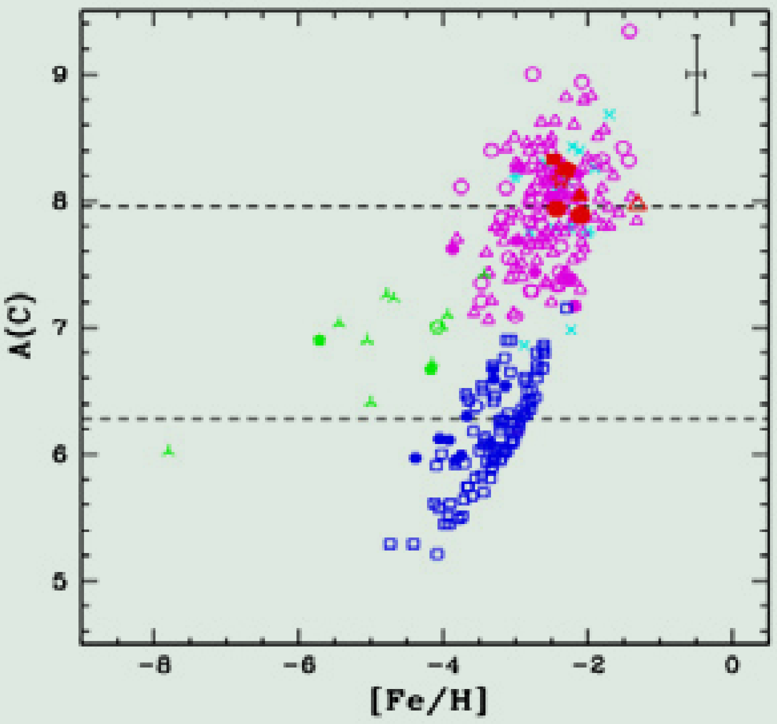


Figure 1: Corrected A(C) vs. [Fe/H] diagram for the compilation of CEMP stars taken from Yoon et al. (2016). The plot is shown for the CEMP-s and CEMP-r/s stars of our sample. Magenta, Cyan, blue, and green symbols indicate respectively CEMP-s, CEMP-r/s, Group II CEMP-no, and Group III CEMP-no stars from the literature. Red symbols represent our program stars. [Reference: Purandardas and Goswami, 2021, ApJ, 922,28]

The next step is to examine various elemental abundance ratios such as [Sr/Ba], [O/Fe], [hs/ls], [Mg/C], etc. to understand the possible progenitors and the pollution events that the stars had suffered if any. Various diagnostic elemental abundance ratios estimated in the program stars indicate AGB stars as possible progenitors for the CEMP-s, CEMP-r/s, and one CEMP-no star of our sample, and it also supports that the different diagnostic elements in our program stars do not originate from the previous supernova and may be attributed to their binary companion. This means that these objects are in a binary system and the binary companion once passed through the AGB phase and synthesized the heavy elements that then accreted to the secondary star which we currently observe.

It was quite amazing to us for finding two CEMP-no stars in our sample with similar atmospheric parameters showing extremely different surface chemical compositions. We have checked the abundance ratios in these two objects to derive clues regarding their progenitors. While the abundance ratios measured in one of the CEMP-no stars of our sample indicates an AGB star and the resulting mass transfer as the possible source, a fast-rotating massive star appears as the possible progenitor for the other (this means that the object is formed from a medium which is polluted from a previous

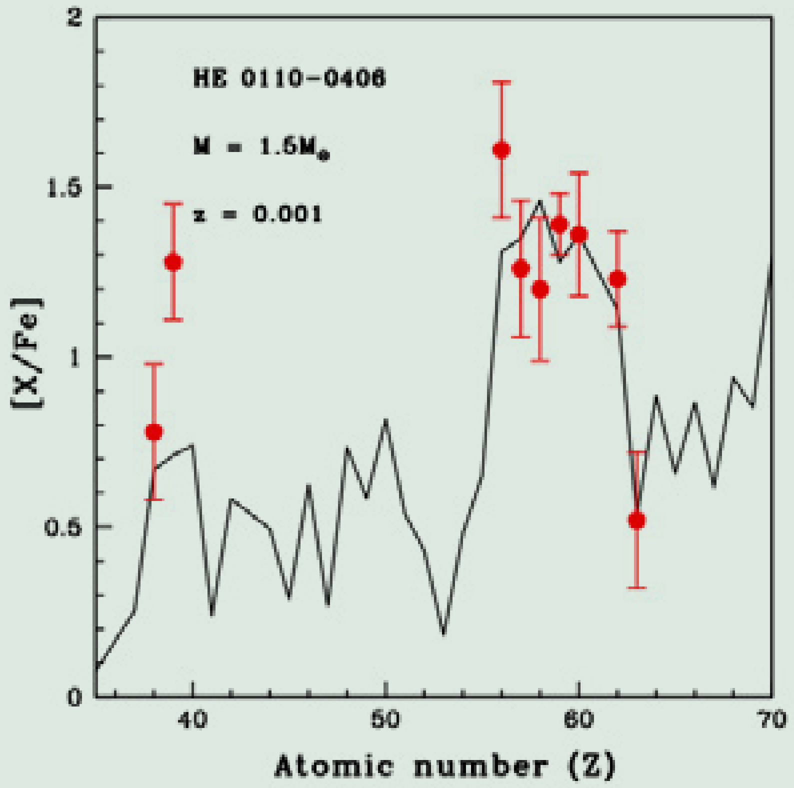


Figure 2: An example of the best-fitting FRUITY model (solid black curve) for the CEMP-s star HE 0110−0406 of our sample. The points with error bars indicate the observed abundances. [Reference: Purandardas and Goswami, 2021, ApJ, 922,28].

fast rotating massive star). This result shows the existence of different production mechanisms among CEMP-no stars irrespective of the same class. The next question will be, how the CEMP-no star can accrete materials from an AGB companion without showing any enhancement of heavy elements? That is definitely a good question, but the reason is not yet clearly known. It is not unlikely to find a CEMP-no star in a binary companion. Arentsen et al. (2019) suggests that the CEMP-no stars may be in a binary system with an extremely metal-poor companion that once passed through the AGB phase and had not produced any significant amount of s-process elements.

We have also compared the observed abundances of various heavy elements in our program stars with the model predictions of AGB stars provided by FRANEC Repository of Updated Isotopic Tables & Yields (FRUITY) models (Cristallo et al. 2009B, 2011, 2015) and we could find a better match for all the stars except the two CEMP-no stars. One example is shown in Figure 2. From this study, we give observational evidence for an AGB star as the possible progenitor for CEMP-s and CEMP-r/s stars.

For CEMP-r/s stars, we have compared the

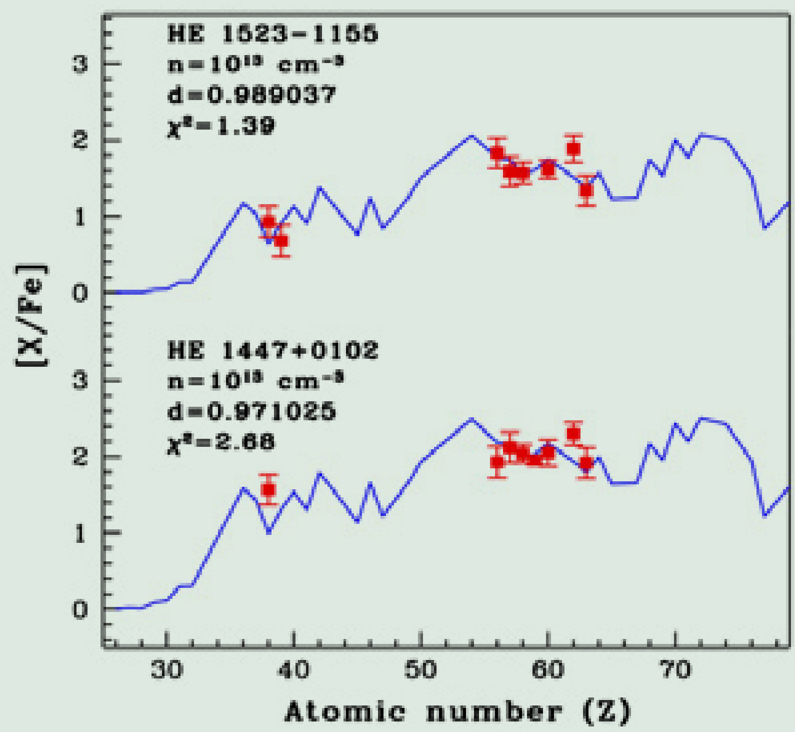


Figure 3: Best-fitting i-process model (solid blue curve) for two CEMP-r/s stars of our sample HE 1447+0102 and HE 1523−1155. The points with error bars indicate the observed abundances. [Reference: Purandardas and Goswami, 2021, ApJ, 922,28]

abundances of various heavy elements with the yields of heavy elements from i-process nucleosynthesis provided by Hampel et al. (2016). We find that the abundances of neutron-capture elements in the two CEMP-r/s stars show a good match with the yields from the i-process nucleosynthesis at a neutron density, n ~ 10^{13} (Figure 3), and we have also found the AGB star as the progenitor for this group. In fact, this is an important result that gives observational support for the AGB star as the possible site of i-process nucleosynthesis which is a debated topic. You can find more results on this work in Purandardas and Goswami, 2021, ApJ, 912,74, and Purandardas and Goswami, 2021, ApJ, 922,28.

Meenakshi P is a Post Doctoral Researcher at IIA. Her research interest lies in studying the carbon stars and other metal-poor stars to understand their origin, the early galactic nucleosynthesis and the galactic chemical evolution from their chemical imprints.

A sunny morning view, a typical village house in Kerala.

Artist: Meenakshi P

A Solar Eclipse Public Campaign for Our Times

Akhil Jaini

Contributed by: Anand M N, Dorje Angchuk, Ebenezer Chellasamy, Niruj Mohan, Sanjiv Gorka, and Tsewang Stanzin

"Any public engagement program for the eclipse had to be designed for these parameters. An essential component of any eclipse outreach is to educate and reassure the public that there are no harmful effects of the eclipse on human beings. Keeping all this in mind, we designed a program, which was implemented with the help of all sections of IIA staff across our field stations."

- Niruj Mohan, Head, IIA SCOPE

The people of India were excited to celebrate the annual festival of lights, Diwali. While most people were thrilled to burst crackers and rejoice to victory of good over evil, it was the science aficionados like you and me, who were going to have a double dhamaka this year! Just the day after Diwali, on the 25th of October, India was in the path of a partial solar eclipse! This was a sunset eclipse and the more north you were in the country, more would be the eclipsed portion of the Sun, and longer the duration before the local sunset.

Ladakh is one of the northernmost regions of India and where the eclipse could be viewed best. Since we have a substantial infrastructure in Ladakh, the Science Communication, Public Outreach and Education (SCOPE) section of the Indian Institute of Astrophysics (IIA) arranged to transmit a live feed from the Indian Astronomical Observatory (IAO), Hanle. Our intrepid astronomers found that the hills would eclipse the eclipsed Sun for a bit, and hence a second feed was also set up at Leh. In addition, with great optimism about the weather in Bengaluru, we arranged for a third feed from the IIA headquarters.

We provided one live feed to the national media and OTT platforms as a service for their own broadcast. We also organized a 2-hour long YouTube live session where we had eminent astronomers and solar experts from IIA commenting on the eclipse while showing the eclipse feed from the three locations as well. The astronomers also answered questions live from YouTube, which went really well except for one person who was using our channel to constantly apologize to his partner for some wrong he had committed! The feed was widely popular and accumulated more than 2.5 lakh views. BBC also carried our feed on several of their regional YouTube channels, which acquired around 3 million views in total. Fame at last!

A student-led initiative that went viral was a set of three 90-second videos created in the popular short vertical video format for Instagram Reels and YouTube Shorts. Of the three videos, one was on solar eclipses, one was on superstitions and myths that people generally associate with eclipses, and one was about the details of this year's eclipse. Each of these videos was made in English and 12 Indian languages and was spoken by an IIA student native to that region! These videos garnered thousands of views, with viewers spread all across the country. A prime national newspaper, The Deccan Herald, also covered this effort.

As part of the myth-busters video, we explained that several beliefs that people associate with eclipses are false and that eclipses are just natural phenomena that can be viewed safely using the right gear. As part of this, we floated a hashtag, #EclipseEating, for Twitter and Instagram that urged people to take a selfie while eating with the eclipse in their background to bust the myth that eating during the eclipse is harmful. IIA staff and students also indulged in snacking during the solar eclipse.

Collage of various solar eclipse images from Bengaluru, Leh and Hoskote campuses. [Prepared by Akhil Jaini]

This was a wonderful campaign, with different elements catering to different sections of the public. We were extremely happy about it, and we hope you were too! But this event would not have been as fruitful without the enthusiastic participation of staff and students not only from the IIA Bengaluru campus but from the various IIA field stations as well. Let us now travel to these field stations and learn about the experiences of the staff who partook in organizing this uber-successful event.

"The nation was ablaze with excitement. The significant event that was approaching had been the topic of much discussion over the previous week. Numerous articles on safety precautions, prior solar eclipses, how an eclipse happens, where to see it, how to see it, etc. were published on social media and other news sources, with IIA SCOPE being the forerunner."

-Sanjiv Gorka, Engineer, CREST, IIA

Indian Astronomical Observatory, Hanle

The eclipse viewing preparations at Hanle started long before the actual event, wherein we surveyed the most appropriate location for the live broadcast of the eclipse. Hanle does not have access to mobile networks for the internet, so we had to rely on the direct satellite link we had set up for the Himalayan Chandra Telescope (HCT). Keeping these constraints in mind, the peak of Mt. Saraswati was chosen as it had the longest observation visibility and a stable internet connection.

On the eclipse day, four 8" Dobsonian telescopes were carried to the observatory hill. To all our disappointment, clouds covered the Hanle morning sky, but that did not stop us from hoping for the best. We started preparing for the eclipse by setting up filters on the Dobsonian telescopes and obtaining perfect focus. A Meade 12" telescope was also set up for tracking and piggybacking a 300 mm Nikon lens. The best part was that, just as the eclipse began the sky started clearing up, and we could get an unhindered view of the eclipse till the Sun went behind the Himalayan hills.

"A day earlier, on October 24th, we invited school students through their headmaster for a visual observation of the eclipse. On that same day, scientists from the outreach team (SCOPE) and IIA reached. They bought hundreds of solar eyewear and filters. We started cutting and preparing filters for the lenses and telescopes for the eclipse broadcast and showcasing to the public. We went to the mountaintop to set up and test the internet network and confirm the exact timing of the sunset; it was 5:08 PM."

-Tsewang Stanzin, Engineer, IAO Hanle, IIA

Over a hundred students showed up from Govt. High School and the Tibetan Children's School at Hanle. We briefed them about the event and how a solar eclipse occurs and so on. The teachers were also very excited, as most had never seen it through

Photos from the solar eclipse viewing at IAO, Hanle

Photos from the solar eclipse viewing at IAO, Hanle

a telescope before. Refreshments like tea and biscuits were served to them during the eclipse. It was amazing to see the enthusiasm of students and teachers to see the eclipse.

"A few days earlier, we came to know about this event. We learned about eclipses during the recently concluded astronomy workshop at IAO Hanle. But it was a great experience to see what we learned through telescopes and filters," said Rangol Dorjey, one of the four Astro ambassadors of the Hanle Dark Sky Reserve (HDSR), present at IAO during the eclipse.

> *"All in all, it was a fantastic experience for all of us at Hanle to witness this visual event along with students and teachers through amazing solar glasses and telescopes."*
>
> -Dorje Angchuk, Engineer, IAO Hanle, IIA

IIA SCOPE activity at Leh

Initially, the plan was to live stream only from IAO Hanle, where we were getting 52% peak obscuration for the eclipse. But when we realized that the Sun would go behind the hills at Hanle by 5:08 PM, much earlier than the peak eclipse time, we started looking for alternate locations. We found that at Leh, we could get nearly 10 minutes of extra viewing before the Sun gets occulted by the hills, and the greatest obscuration will be almost 55%. Considering these, we decided to include an additional stream from Leh as well and chose the Leh Monastery parking site to set up our instruments.

Initially, the sky was cloudy, with only a few people around us. Later, a group of tourists gathered, and it was their first experience seeing an eclipse or a telescope. Whenever the Sun came out of the clouds, they jumped around and screamed in excitement. They broke the silence out there and boosted our energy. Slowly, the sky cleared, and I connected my

Photos from the solar eclipse viewing at Namgyal Tsemo, Leh

imaging camera to the second telescope to capture better images. We served tea and biscuits to the gathering while explaining the science behind a solar eclipse.

> *"On the eclipse day, we reached the site before local noon and marked the true north to align the telescope for better tracking. We had two 8" Dobsonian telescopes from the HDSR stock for live streaming and imaging purposes. As planned, at 16:00 hours, the live streaming started using a DSLR connected to a solar tracking telescope as a webcam, and luckily, I was able to capture the first touch. Though I had traveled many times to see an eclipse, this was my first experience seeing and capturing an eclipse so clearly."*

-Anand M N, Research Assistant,
KSO Kodaikanal, IIA

Centre For Research & Education in Science & Technology, Hoskote

"I started looking up the Hoskote weather forecast before the event day. Thunderstorms, partly overcast days, and bright days were among the frequently changing forecast elements. I also asked my daughters to accompany their mother to CREST because I wanted them to see this partial solar eclipse phenomenon up close. The experience for my children was fantastic in every way because they witnessed the solar eclipse for the first time. They loved it! In the end, we had a wonderful view of the Sun because the eclipse was clear the entire time."

-Sanjiv Gorka, Engineer, CREST, IIA

Everyone at CREST Campus was eager to see this celestial event, including the students, gardeners, canteen staff, security, engineers, and scientists. Around 5 PM, everyone was eagerly waiting for the

Photos from the solar eclipse viewing at CREST campus, Hoskote

solar eclipse to begin. People were on the terrace of the CREST main building with their solar eclipse goggles; one person got a welding shield too!

When we spotted the initial contact, everyone in the area fell silent and turned their welding shields and solar eclipse glasses toward the sky. A group of fifty individuals stayed motionless for the following few minutes, gazing up at the sky and mesmerized by a sight they do not often witness. Soon, it was time for sunset. The skyline shimmered with orange, yellow, pink, and blue hues as the partial solar eclipse and sunset took place, giving the phenomenon the impression of a painting. A large crescent shape dominated the skies.

Credit: Sanjiv Gorka

Kodaikanal Solar Observatory, Kodaikanal

Kodaikanal Solar Observatory (KSO) organized an open day for the public to view the last solar eclipse of 2022. We made entry into the observatory accessible to the general public, and the response we got was excellent. A team of 42 members came all the way from Maharashtra, along with several more students and visitors. A public lecture on the title "Solar Eclipse – Science & Myths" was delivered by Dr. Ebenezer Chellasamy, Resident Scientist, KSO, which was followed by a very enthusiastic Q&A session.

Eclipse goggles were distributed to the visitors for free by the IIA SCOPE team. Press and media were present for the entirety of the event. The historic 6" telescope of KSO was also opened to students. The Chief Guest, Member of the Legislative Assembly (MLA) Kanchipuram, Mr. Ezhilarasan, spent over an hour with the observatory staff and encouraged their activities.

Interactive session during solar eclipse at Kodaikanal campus

Indian Institute of Astrophysics, Bengaluru

"Initially, I was worried that, as usual, Bengaluru would be plagued with clouds all over the sky. But pleasantly enough, the sky was the clearest ever. I could clearly see the Sun being eclipsed, and I could even capture a few photos with my phone! Overall, it was an exhilarating experience that I can never forget."

-Akhil Jaini, PhD Student, IIA

The partial solar eclipse on October 25th was a big deal for astronomy enthusiasts: it is the final major astronomical event of 2022 and the last solar eclipse India will witness till 2031. We had been planning for weeks to make this event special, coordinating with the various field stations and other astronomy and space research institutes all over the country.

When the day finally arrived, we, as part of the SCOPE section, assembled with bated breaths in our makeshift control room in the IIA main building. Everyone had their work cut out for them: some were handling the live stream, while others were preparing for the live discussion session, some were working on setting up the telescopes and cameras, while others were preparing posts for social media.

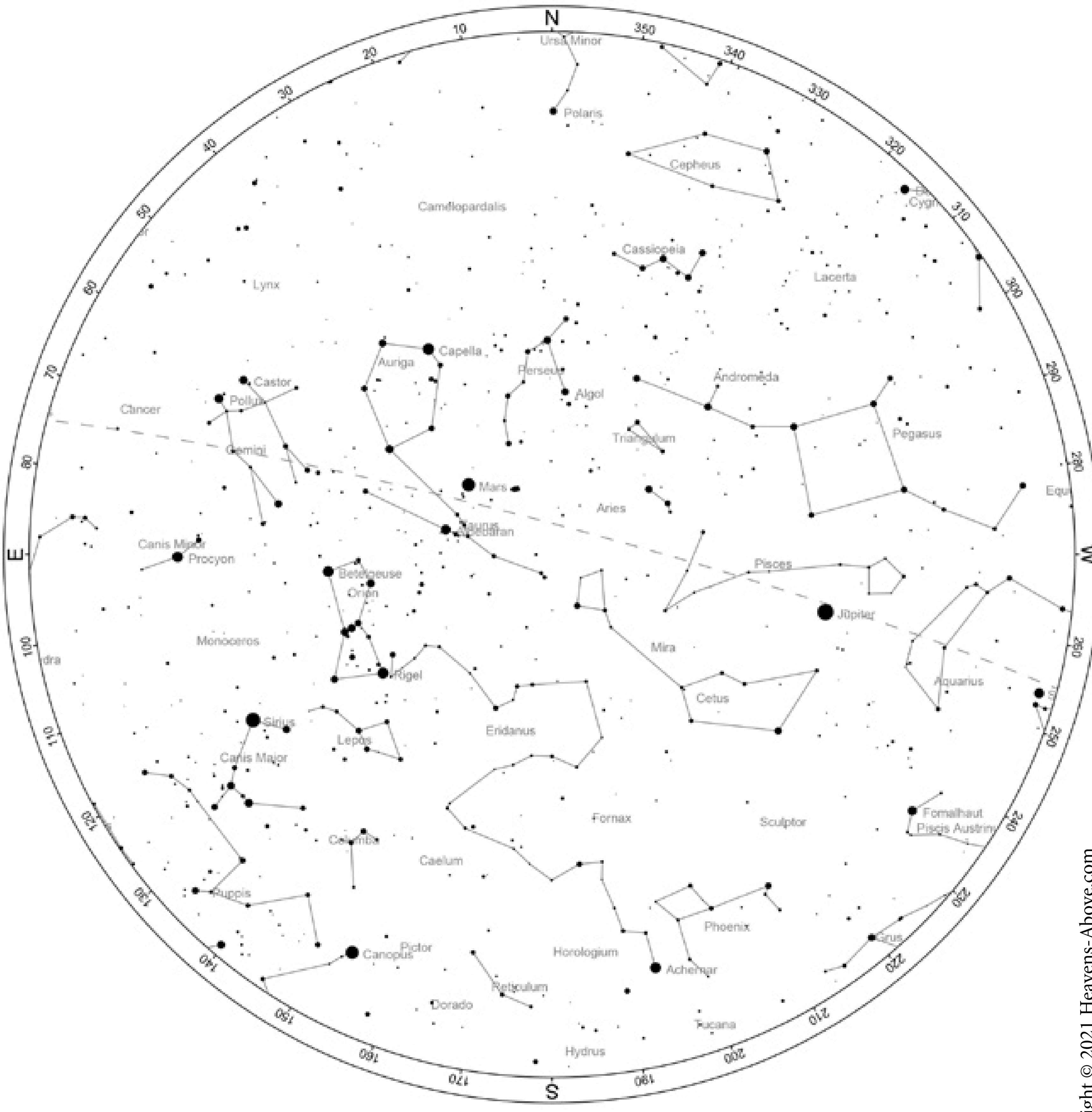
We started the live stream at 4.00 PM sharp, and it was hosted by Dr. Niruj Mohan. The rather lively

Photos from the solar eclipse viewing at Bengaluru campus

discussion was joined by the director of IIA, Prof. Annapurni Subramaniam, who spoke about the science behind a solar eclipse and urged viewers not to believe in baseless, false news about eclipses. The discussion was also joined by several solar astronomers and engineers from IIA, who discussed the solar eclipse in detail and answered the viewers' questions.

Students and staff of IIA enjoying refreshments at the peak of eclipse at Bengaluru campus

At 5 PM, over a hundred staff and students of IIA gathered on the terrace to witness the eclipse. We distributed eclipse glasses and refreshments to the attendees. Everyone eagerly watched the Sun get eclipsed by the moon for the next forty minutes, after which the Sun set behind the skyscrapers of Bengaluru. At the same time, a few students also volunteered to visit the Bengaluru Townhall to attend a solar eclipse myth-busting event and provide a scientific perspective to people.



Skychart January 2023: (As on January 15, 2023. 20.00hrs Bangalore)

January 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4 Conjunction of the Moon and Mars Quadrantid meteor shower 2023 The Earth at perihelion	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19 γ-Ursae Minorid meteor shower 2023	20	21
22	23	24 Mercury at dichotomy	25	26 Conjunction of the Moon and Jupiter	27	28
29	30 Mercury at greatest elongation west	31 Conjunction of the Moon and Mars IC2391 is well placed				

Credit: in-the-sky.org

Chromospheric heating by acoustic shock waves

Harsh Mathur

The chromosphere is the most dynamic layer of the solar atmosphere, located between the bright solar surface and the million-degree hot corona. It is the region above the photosphere where the plasma is not in radiative equilibrium, and hydrogen is predominantly neutral, resulting in the characteristic Hα spectral line. The non-thermal energy that heats the solar corona and drives the solar wind propagates through the chromosphere into the outer layers of the solar atmosphere. Most of that energy is converted to heat and radiation, with only a small portion remaining to power the hot corona and solar wind. Thus, sustaining the chromosphere requires almost two orders of magnitude more energy than the corona and heliosphere combined [1, 2].

Many questions remain about the physical mechanism of chromospheric heating and how energy is supplied to the outer layers of the solar atmosphere. Magnetic reconnection and wave heating are widely accepted candidates for explaining chromospheric and coronal heating. Magnetic reconnection is a physical process in which the topology of the magnetic field lines is rearranged from a higher potential to a lower potential. The difference is converted to kinetic and thermal energy and particle acceleration. The other proposed mechanism is through waves; observations and theoretical modeling have suggested three types: acoustic waves, magneto-acoustic waves, and Alfvén waves. Acoustic waves are mechanical waves that propagate upwards in solar plasma through compression and rarefaction. Magneto-acoustic waves are acoustic waves that are altered by the presence of the magnetic field. Alfvén waves are transverse waves that propagate in the magnetic

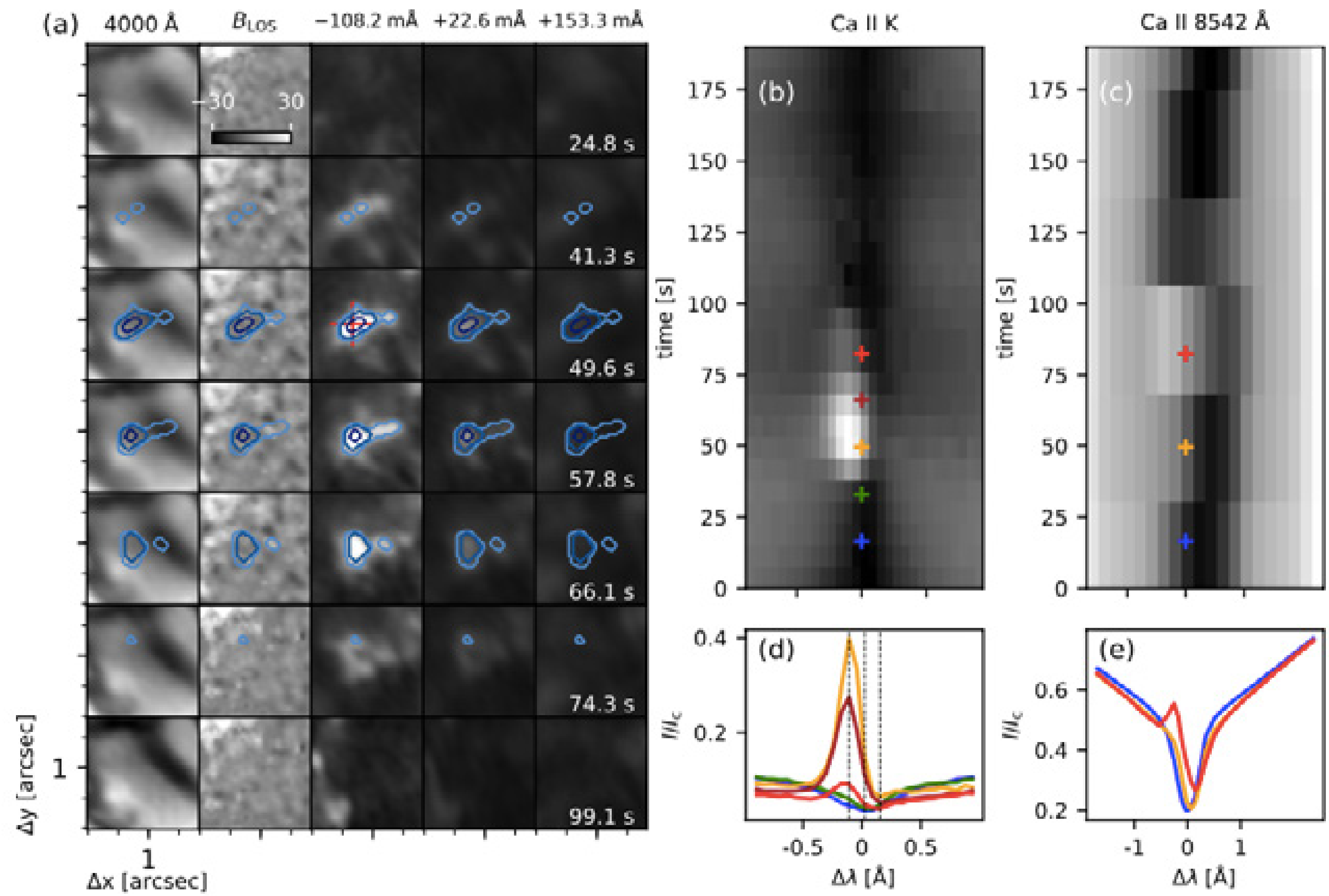


Figure. 1: Evolution of a grain: (a) The time evolution of the continuum at 4000 Å, LOS magnetic field (BLOS), and images at wavelength offsets of −108.2 mÅ, +22.6 mÅ, and +153.3 mÅ from the core of the Ca II K line are shown column-wise. Panels (b) and (c) display λ–t diagrams for the pixel marked with a "+" in panel (a) in the Ca II K and Ca II 8542 Å lines, respectively. A few selected profiles marked in panels (b) and (c) are shown in panels (d) and (e). The outer contour (cyan), the middle contour (azure blue), and the inner contour (navy blue) in panel (a) show the region of grain in the order of increasing enhancement in intensity. The dashed vertical lines in panel (d) show the position of the narrowband images in panel (a). Reference: [3]

field direction, with magnetic tension acting as a restoring force. Although it is well established that waves can transport energy from the lower to the upper atmosphere, how they dissipate energy remains debated.

In this article, we will focus on the region of the Sun with little to negligible magnetic activity, called the internetwork region. Due to the absence of magnetic activity, acoustic waves remain the likely candidate to heat the chromosphere. Earlier theoretical works have shown that acoustic waves propagate upwards from the lower to the upper atmosphere; when they reach the chromosphere, they turn into shocks due to a steep decrease in density. Shocks dissipate their energy into the medium by compressing the local plasma, increasing pressure, density, and thus temperature. These acoustic shock waves in the chromosphere appear as small-scale brightenings in the narrowband images of the blue wing, also called the K_{2V} position, of the Ca II H & K lines, and are called grains.

Earlier observational studies of grains to quantify temperature enhancements and line-of-sight (LOS) velocities had limitations like limited spatial resolution and less optimal assumptions like local thermodynamic equilibrium (LTE). In our recently accepted article for publication, we used high spatial and spectral resolution spectropolarimetric observations of the grains (quasi-) simultaneously recorded in the Ca II K 3933 Å, Ca II 8542 Å, and Fe I 6173 Å lines to infer the evolution of stratified atmospheric properties such as temperature and line-of-sight (LOS) velocity during acoustic shock events in non-LTE using STockholm inversion Code (STiC).

The inversion codes infer the stratification of the atmospheric properties, that is, variation with depth, from the observed spectral profiles. For each spectral profile, starting with an initial guess atmosphere, the inversions perturb the atmosphere at predefined specific depth locations called nodes, then interpolate to the full depth grid. Providing an initial guess atmospheric model close to the solution helps reduce the time it takes for inversion codes to converge. We grouped the spectral profiles into 100 clusters using the k - means clustering algorithm to derive the initial guess atmospheres for inversions for all spectral profiles. The mean profile of each of the groups was inverted to derive the stratification of atmospheric parameters. Then the stratification was used as the initial guess atmosphere to invert the actual spectra. The approach described above significantly reduced computation time. The inversions and the k - means algorithm were run on the Indian Institute of Astrophysics's NOVA supercomputer cluster.

We found that the lifetimes of presented grains range between 25 and 67 seconds. The Ca II K profiles of grains show emission at the nominal K_{2V} position of the spectral line. We found an average enhancement in temperature at the lower chromosphere of 1.1 kK (kilo-Kelvin) and a maximum enhancement of up to

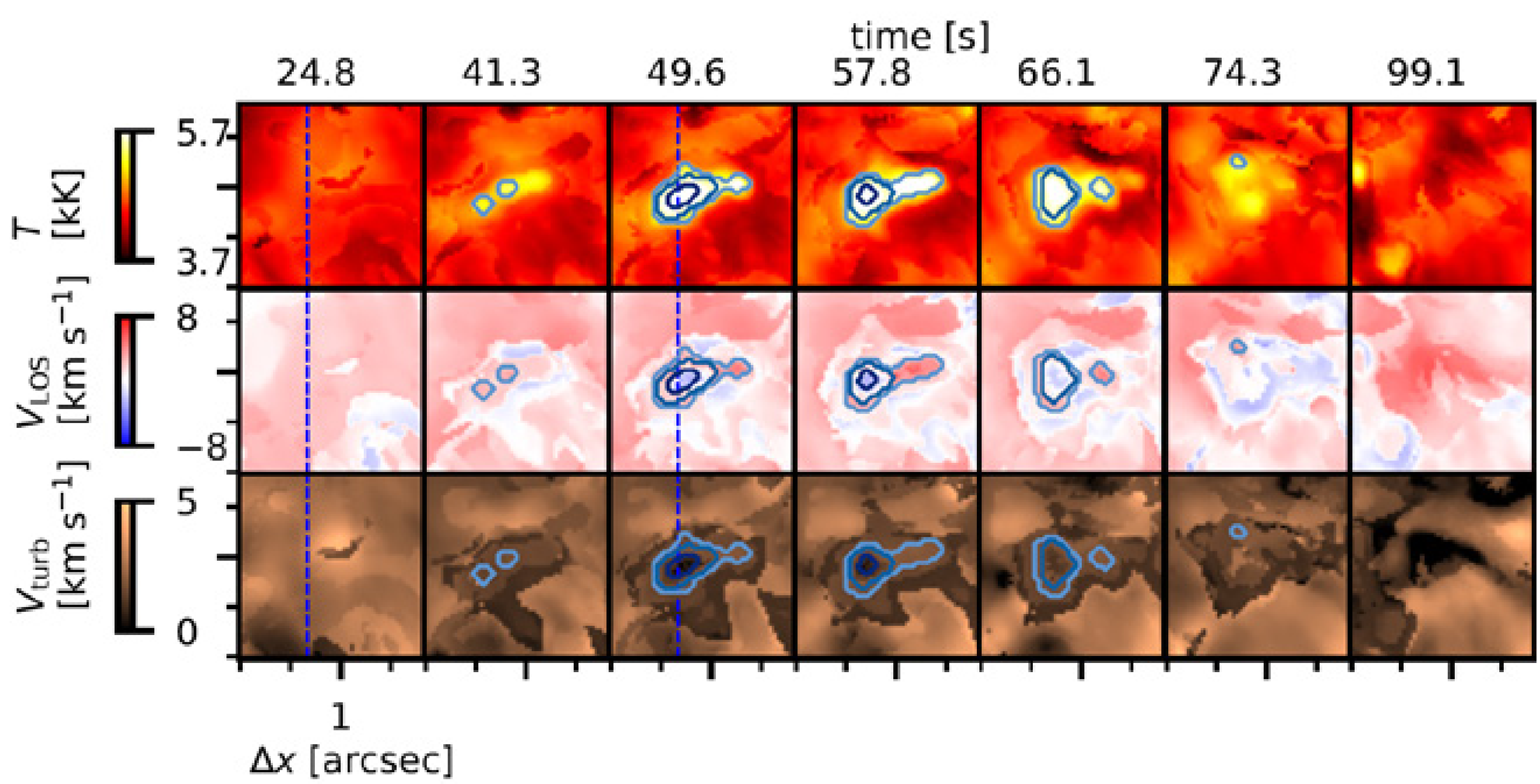


Figure. 2: Maps showing the time evolution of temperature, velocity, and microturbulence (row-wise) in the lower chromosphere. The contours indicate the location of the grains (acoustic shocks). At the location of acoustic shocks at t = 49.6, 57.8, and 66.1 seconds, there is an enhancement in temperature of about 2000 K and upflows of about –3 km s^{-1}. Reference: [3]

4.5 kK. These enhancements were co-located with upflows in the direction of the LOS. The average strength of these upflows is about –2.5 km s^{-1} and can be as large as –6 km s^{-1}. At the higher chromosphere, we found strong downflows greater than +8 km s^{-1}. Our value of temperature enhancement is three times higher than the estimate provided by earlier studies.

These results can be explained as follows. The upflows in the lower chromosphere shift the opacity at which atoms emit and absorb to the blue wing (nominal K_{2V} position) of the Ca II K line. These upward propagating acoustic shock waves enhance the gas density in the lower chromosphere, which couples the Ca II populations to local atmospheric conditions. The local temperature enhancements at the lower chromosphere enhance the source function at the nominal K_{2V} position. Since the upper chromosphere is downflowing, the opacity to which atoms emit and absorb is red-shifted; that is, there is little opacity to absorb the blue-shifted emission from the lower chromosphere, resulting in an enhanced emission at the K_{2V} wavelength position.

The study supports the interpretations from earlier simulations that the grains are manifestations of upward propagating acoustic shocks against a background of downflowing atmospheres.

References:

1. *https://www.annualreviews.org/doi/10.1146/annurev-astro-081817-052044 (Review paper on chromosphere)*

2. *https://link.springer.com/article/10.1007/s41116-020-0024-x#Sec17*

3. *https://ui.adsabs.harvard.edu/abs/2022arXiv221001045M/abstract (our work accepted to be published in A&A)*

Harsh Mathur is a senior research fellow working with Dr. K. Nagaraju on interpretations of spectropolarimetric observations of the solar chromosphere through forward modeling and inversions using non-local thermodynamic equilibrium (non-LTE) radiative transfer. His thesis project is about inferring the chromospheric magnetic field using simultaneous multi-line spectropolarimetric observations.

The boys of GRO

Shaik Sayuf

The Gauribidanur Radio Observatory (GRO) is located near the villages Kotaldinne and Bommasettihalli, which are almost 10 km from the nearest town, Gauribidanur, and 100 km towards north of the Indian Institute of Astrophysics (IIA) Bangalore head office. During the early 1970s, the observatory was started by IIA and RRI collaboratively, and the initial telescope was the GEETEE array. Later, IIA started its own radio telescope at this site, the GRAPH (Gauribidanur Radio Heliograph) array, during the late 1990s. Presently the GRAPH array is operated with 384 LPDA (Log periodic dipole array) antennas arranged in '+' configuration with effective array lengths of 2.5 km in the East-West direction and 1.7 km in the North-South direction. Additionally, there are various other radio systems dedicated to solar observations in low radio frequencies below 500MHz, which IIA operates. There are Radio Spectrograph (GLOSS), Radio Spectro-polarimeter (GRASP), and Radio Interferometric polarimeter (GRIP) systems as well as; a new system for observing pulsars and other transients is being developed. With nearly 600 LPDA antennas spread across such a vast area, connected through thousands of cables that pass under the ground, numerous power supplies, and RF analog and digital modules in the field as well as in the receiving rooms, it is quite a task to build and maintain this observatory.

When I first came to the observatory for my MTech project, the enormity of the arrays was what interested me about the observatory. But it has a small technical group with a large group of workers. At that time, there were only two engineers and a technical assistant headed by a scientist in charge of maintaining such a big observatory. Its smooth running mainly depends on the working power of the 'Observers' and the 'Workers.' There are three observers, workshop boys, security guards, cleaning staff, and two cooks. They are the wheels of the observatory.

The observer trio is responsible for regular observations, generating coronal images, radio spectrums, system monitoring, data management and archiving, etc. They work in 3 shifts a day, and one observer will be present at the observatory at any time of the day. They work irrespective of holidays and festivals, helping the observatory run and make everyday observations that will be helpful for the researchers. Even during the pandemic, they were present, and the observations were carried out regularly. It is essential to observe the Sun on a daily basis because the space weather around the Earth depends on solar events. For example, because of solar activity, the particles of a coronal mass ejection (CME) traveling toward our Earth can damage the space or ground-based electronic equipment necessary for humanity. So, regular solar observations are important, and we must maintain that. I remember once there was a

Our cooks: Prakash (left) & Anand(right)

situation where two observers were unavailable because of medical emergencies, and one observer had worked for almost 14 hours a day for a week to carry out observations smoothly. Because of things like these, I have massive respect for them, and their contribution to the scientific community is acknowledgeable.

We generally refer to the workers as 'the Boys'; it doesn't matter how old they are. The workshop boys are the muscle of the observatory; they do everything, and their assistance is what makes things happen at GRO. They make the antennas, do the mechanical works, welding, cutting, soldering, electrical works, coaxial cable works, plumbing, civil works, field works, grass cutting, etc., and anything that's necessary for the observatory. By working for many years, they have gained much knowledge about the finer details of radio astronomy instrumentation and how to make it work. For example, they may not know all the antenna science, but with their experience, they know how an LPDA has to be built, small adjustments and tuning techniques to make it work, etc. They are also involved in the discussions regarding any systems development, mechanical designs, procurement of items, usage of resources, etc., and their inputs are also considered. During my MTech project, their inputs helped me make a tracking setup for the LPDA. In many ways, they have contributed to the development of the observatory. They are the 'Dependables.'

The security boys guard different locations of the observatory. They patrol and safeguard the antenna arrays and associated modules at all times, even on hot summer days, cold winter nights, and thundery rainy times. Two regular cooks work in 2 shifts a day, and additionally, one security boy comes in whenever any cook is on an off day. These cooks were not professional; they were put forward when there was a necessity for cooks, and they learned in the process. It feels like home food; they keep us healthy and happy, and they put a little smile on our faces with their food even on a bad day at work. One cook told me once - 'It is my work to give you good food and help you in achieving what you have come for, and that makes me happy.'

All these people are from the villages around, making them accessible to the observatory whenever needed. They are always generous, helpful, and kind to us. I have attended many of their family occasions upon invitation and greatly respect their culture. Here ragi is the staple food like rice and wheat in other parts of India. Apart from their employment at the observatory, all these workers do some additional work at their homes. Many of them do agriculture in their lands; some have cattle, small general stores, tiffin centers, etc. They have taken me to their agricultural fields a couple of times, and it was a good experience. Because of the kind of land here, they mostly grow maize, millets like ragi, caster plants, and some other crops depending on the irrigation facilities.

Group photo of some of our boys (From the left: Seena, Shivaji, Venkatesha, Sidharaju, Chandra, Shankara, Amreesh, Arjun, Murthy, Manjunath, Shankara, Suresh, Nagaraju)

As it has been 50 years since the observatory started, it has become a part of the village and its people. Many boys are associated with the observatory from a young age, and some of their parents have also worked there. For them, life is about their home, their work, and the observatory. May humankind bless these 'Boys' for contributing to the observatory and the astronomy community.

I thank Kshitij Bhai for helping me with this article.

Thank you all,

Shaik.

Shaik Sayuf is currently a Junior Research Fellow at the Indian Institute of Astrophysics, Bangalore. His research interests lie on Radio Astronomy.

Let the white flowers bloom all over the world! Dawn Earth! Dawn for peace!

Artist: Abinaya

Potsdam days

Abinaya Omkumar

"Two roads diverged in a wood, and I took the one less traveled by. And that has made all the difference" - Excerpt from The Road Not Taken by Robert Frost.

I was looking through my window from the metro, and all the buildings looked different from what I used to see. I noticed none of the trees had leaves in them. The next thing that caught my attention was the announcements that were going on. I started listening to them but soon knew there was no point since I failed to decipher them. It was then it occurred to me that I was miles away from home, physically far from the place and the people I knew all along. After musing for a while, I reached my final destination for the day, which is a place I will be sharing with people I know only through a few emails and be calling 'home' for the next 365 days. But I felt a tinge of satisfaction, having made it through this long journey myself. The world was in the middle of a pandemic, and I knew that it would not make things easier for me in this strange land. Despite that, I was so looking forward to my Potsdam days.

After my quarantine days, I was finally prepared to step out of the house and reach the institute. I was more nervous about traveling a mere 3 km from my 'home' to the institute than for the few thousand miles I traveled alone. Even though I found it challenging to communicate with some people because of the language barrier, people were friendly and understanding, and that helped a lot. Things took time since most of the people were working from home. After all the paperwork was done, I could finally breathe and started focusing on my work. I became a member of the Dwarf Galaxies and the Galactic Halo group, one of the sections in the Extragalactic Astrophysics branch.

It was the peak of the third wave in Germany. We were not allowed to work from our office spaces

Leibniz Institute for Astrophysics, Potsdam.

unless we had to. The pandemic made all of us realize how much we miss human interactions. All the meetings have to be online. Despite that, what I enjoyed the most was the meeting with my group members. Biweekly we met online, and we made sure all of us were on the same page regarding the happenings in the institute and around. Members can share any science highlights/updates from their respective fields or works. We get to share information about any workshops/conferences we attended or upcoming ones. We also vote for our favorite papers that are interesting and relevant to our group and select the paper that gets the most votes. Who is the better person to speak about their works rather than themselves? In these meetings, we also invite the first authors of recent papers to give a talk. It was a great opportunity to interact with them and learn about their paper.

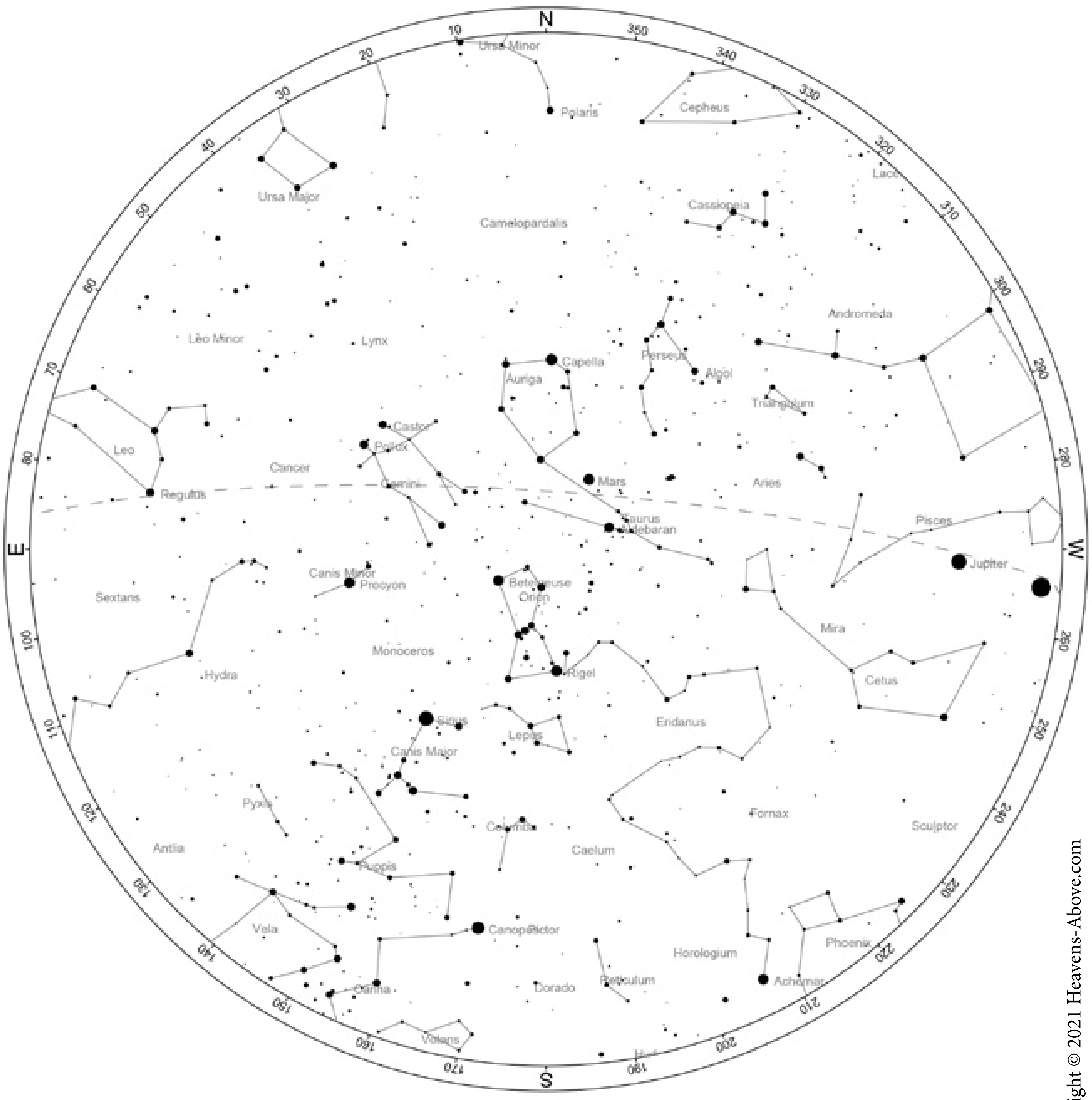
Every other week, we also conduct a joint meeting with Milky Way and the Local Volume group members. Other than the general discussion, one of the members in the group will have their turn to talk about their work. This way, everyone in the group is aware of each other's work and can get suggestions, comments, and so on. You learn how different people have different views over the same aspects. It's always great learning when you have experts around, and they are kind to you.

Meanwhile, I slowly got used to the German weather, their work culture, and everything in between; I started to realize how true Goethe said, "Everything is hard before it's easy." Weren't you scared? How did you manage everything alone?- was one of the questions I have been asked very often when I say I lived in Germany for a year. Everything was indeed hard as it was entirely new. I started to look at it as a new experience. I now think it was those opportunities that were trying to teach me how independent I can be. My non-work hours were enjoyable too. I got to meet so many wonderful people who helped me in several ways, and I am forever grateful to them. They made my stay a beautiful experience. This one year of my PhD journey was a good start. I will cherish those beautiful memories forever. Thank you for traveling along this memory road with me.

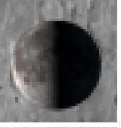
Abinaya O. Omkumar is currently a Junior Research Fellow at the Indian Institute of Astrophysics, and is associated with Leibniz Institute for Astrophysics Potsdam (AIP). Her research interests lie in Galaxy evolution, and she is currently working on the Magellanic Clouds.

Waves during sunset (Acrylic painting)

Artist: Maya Prabhakar



Skychart February 2023: (As on February 15, 2023. 20.00hrs Bangalore)

February 2023						
Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3	4
5	6 	7	8 α-Centaurid meteor shower 2023	9	10	11
12	13 	14	15	16	17	18
19	20 	21	22 Conjunction of the Moon and Venus	23 Conjunction of the Moon and Jupiter	24	25
26	27 	28 Conjunction of the Moon and Mars				

Credit: in-the-sky.org

Quantum Technologies

The Wonderland of Alice

"Interview with Prof. Urbasi Sinha, the head of the Quantum Information and Computing (QuIC) Laboratory at Raman Research Institute (RRI), Bengaluru"

Urbasi Sinha is a Professor at the Raman Research Institute (RRI) in Bengaluru, India. She heads the Quantum Information and Computing (QuIC) laboratory at RRI. Prof. Sinha is a Simons Emmy Noether Fellow at the Perimeter Institute, Canada, as well as an associate faculty member at the Institute for Quantum Computing (IQC), University of Waterloo, Canada, and the Centre for Quantum Information and Quantum Control, University of Toronto, Canada.

Prof. Sinha completed her PhD at Cambridge University, UK, on experiments in high-temperature superconductivity. She completed her MSc in Physics also from Cambridge. She has been a Gates Cambridge scholar during her PhD and a Nehru-Chevening scholar during her master's. She was a post-doctoral research associate in the Cavendish labs, Cambridge, as well as at IQC, Canada.

Her lab at RRI specialises in experiments on photonic quantum information processing, including quantum computing and quantum communication, primarily using single and entangled photons. Prof. Urbasi is heading India's first project on satellite-based secure quantum communications. Her scientific recognitions include the Homi Bhabha Fellowship in the year 2017 as well as the 2018 ICTP-ICO Gallieno Denardo Award in Optics. She was recognised as one of Asia's Top 100 scientists by the Asian Scientist for the year 2019 and has also been awarded the Simon's Emmy Noether Fellowship at the Perimeter Institute, Canada.

Saraswathi: We're sure our readers have come across many words like quantum entanglement, quantum key distribution (QKD), quantum teleportation, quantum computers, etc. Could you please give a brief introduction to quantum technologies by explaining these concepts?

An explanation of quantum technologies is not small; it can become a whole talk by itself. It suffices to say that all that you just mentioned makes use of quantum mechanics. Essentially, the idea is that everything is quantum, as we know it, but sometimes some of the applications that we work on actually make use of these quantum properties, whereas certain things don't. We can bring all these terms under two main topics – quantum computing and communication.

Quantum computing is a whole new way of computation that primarily makes use of the quantum superposition principle. Think of a switch that can be OFF or ON. The OFF and the ON states would give the 0 and 1, which we call a binary digit or a bit. When we go to quantum computing, we talk about not just 0s and 1s but a little bit of both, which means you now have to think of the switch as being OFF and ON at the same time. And this is the quantum superposition – it gives us access to a space, which, in principle, is of infinite dimension. So, as opposed to the two-dimensional space in the classical picture, we can have an infinite-dimensional space called Hilbert space. Now, we have to come up with new algorithms so that we can work with these objects, and that is where the speed lies. This is the general understanding of how the quantum computer will be able to do a certain class of problems in a much faster time scale than even current supercomputers are capable of. Having said this, one has to understand that a quantum computer will not replace the classical computer. Instead, we may have a quantum-enabled device attached to the classical computer at some point in the future for specific problems. That's what quantum computing is about.

Quantum communication is something that actually affects all of us a little more than quantum computing. If you have a credit card or use online banking, you should be familiar with the concept of a key and a password. When you share any information with your bank, you expect the bank to get it without reaching any third party. How do we do it now? We use what is called classical cryptography. When I give the information, which is, let's say, some digits, it gets encrypted with a key. That forms a message which is very difficult for someone else to decipher as it's all guarded. Then it goes to the bank, the intended receiver. The bank has a copy of the key and decrypts the message. In this way, only the bank and I know the information, but a third party doesn't. Classical cryptography makes use of the mathematical hardness of problems. We use factorization as a means of making our information secure. Classical computers could take years to solve this. However, a quantum computer will be able to run a Shor's algorithm and can get the factorization done, say, in a minute. So, once this is achieved, all our security will go down the drain. We need a quantum solution to address this problem, and that is quantum communication. Quantum communication involves replacing the whole key distribution by using the laws of quantum mechanics to keep information secure, like Heisenberg's uncertainty principle, no-cloning theorem, and quantum entanglement.

Quantum entanglement is about the correlation of particles, which prevails even if they are far away from each other. It is something that does not have any classical explanation. We use quantum entanglement to make our information secure. And, as you know, it was the topic of the physics Nobel Prize this year.

Quantum teleportation is also a means of communication. Suppose I have a quantum state; I'm just transferring the state from A to B without moving towards B, while A and B are not in the same location. By using quantum entanglement as a resource, I can actually transfer an unknown quantum state from one party to another party. That is teleportation. So essentially, it is a means of information transfer, but not necessarily key distribution.

Vishnu: As we know, the 2022 physics Nobel prize was awarded to Alain Aspect, John Clauser, and Anton Zeilinger for their work on entangled photons, which laid the foundation for new technologies based on quantum information. Why were the experiments conducted by the winners considered groundbreaking? What important insights did we gain from them?

This was a long overdue prize. We have been hoping all these years that the trio would get the Nobel Prize. The Nobel citation goes as "for the studies in quantum entanglement, violation of Bell inequalities and for laying the foundation for quantum information science". This is the overall picture. Historically quantum entanglement did not start off with everybody accepting the idea. For instance, in the famous paper from Einstein–Podolsky–Rosen, the EPR Paradox, they put forth their scepticism about this idea of two particles which share a correlation even when they are far away from each other. It's quite natural not to accept an idea when it looks incomplete. It also signalled the possibility of faster-than-light communication, which is why it is a paradox.

Then John Bell came up with what is called Bell's inequality. If you satisfy Bell's inequality, then you prove local realism. What is local realism is, again, a very vast topic, but the idea is like this. Right now, you're listening to me, and your state of listening is independent of me looking this way or that way. Similarly, the tree outside remains there even when I don't look at it. This was famously said by Einstein that the moon should be there even when I don't look at it. All of us have this notion that objects should retain their property irrespective of whether we are looking at it or not. This is our common perception. This is called realism. However, this does not happen in quantum systems. A quantum system does not have any predefined property, which is independent of the act of measurement. So you could be sitting or standing or dancing; you are in a superposition of all the possibilities. Only when I look at you do I know which of it you are doing. This is the fundamental difference between quantum and classical perceptions. So Bell's inequality violation disproves local realism, which means that there are correlations between particles existing at a non-local distance. From relativity, we know that information exchange is possible only when one particle is within the light cone of the other, as you cannot travel faster than light. In this way, Bell's inequality violation is both non-local and also violates realism, and thus, it violates local realism.

Then came John Clauser, who wanted to do an experiment to test Bell's inequality. And in fact, he received a lot of objections from famous people. However, he stuck to his idea and did the first Bell's inequality violation experiment. So that is why he's the first among the Nobel winners. Synchronisation of the measurement was something that was missing in Clauser's experiments; the measurements should happen with Alice and Bob at the same time. Alain Aspect's experiments solved some of these technical issues. And so, in some sense, he is the first person who did these experiments, leaving fewer questions on the validity of the experiments. Then, we need to consider what are called loopholes. There could be other possible explanations for these inequality violations than we think. For example, a detector does not detect all radiation that falls on it. So if it's 60% efficient, those 60 out of 100 photons violate Bell's inequality. But what about the 40 you didn't detect? Those could then get together and not violate. So you can never say that you have done this in a full-proof way. This is called the detection efficiency loophole. Similarly, there are many others. With the existence of these loopholes, you do not trust the experiment beyond a point because there are other ways in which you can perhaps come up with an explanation.

In 2015, Anton Zeilinger and his group conducted a loophole-free violation of Bell's inequality using entangled photons. Anton Zeilinger was also the first person to show quantum teleportation as well as entanglement swapping. He is, therefore, the person who made all this come to modern technology. Together, they deserve the prize for Bell's inequality violation and entanglement, but regarding laying the foundations of quantum information science, Anton Zeilinger has played more of a role by actually doing things in that domain. With his group, he went beyond the philosophical questions of whether the moon is there or not and made secure quantum communications and some other quantum technologies possible through his loophole-free Bell's inequality violation experiment.

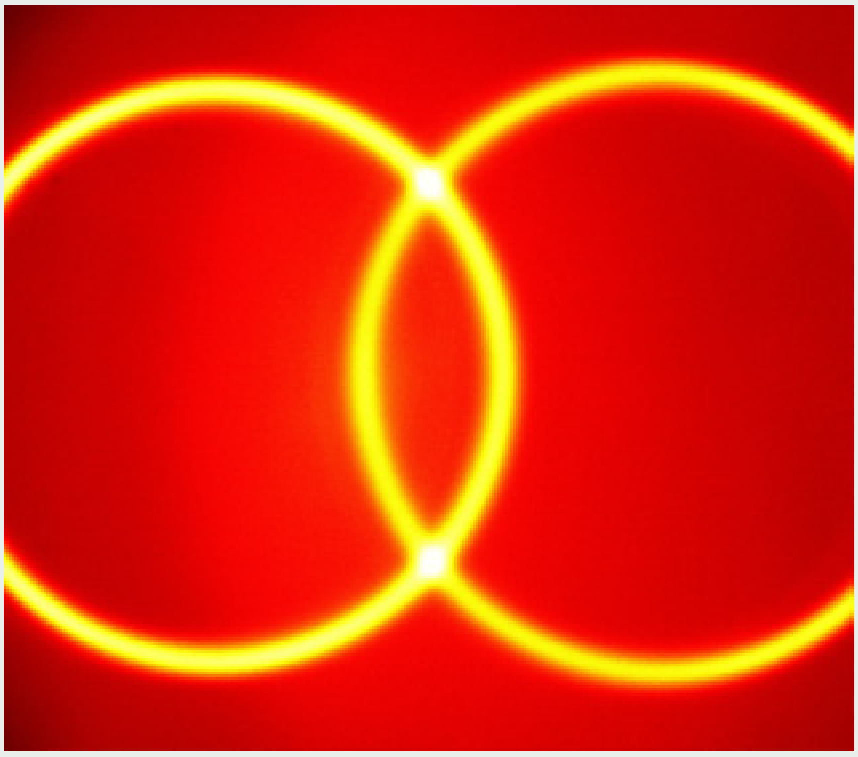
Suman: You are the head of the Quantum Information and Computing laboratory at RRI. The awarding of this year's Nobel prize must have created quite the buzz in your lab. How does this tie in with your current research work?

This year's Nobel prize in physics has been extremely morale-boosting for everyone in our lab. We have been working on entangled photons, inequality violations, quantum communications, etc. both at the fundamental and technological levels. As we saw earlier, the foundation for all such experiments was laid by the works of these Nobel winners. A lot of our work is based on what they have laid the basis for, but now with more modern facilities, different variations, lots of improvements, as well as chartering new ideas and dimensions. It's very inspiring for the younger people as well; you require these motivations sometimes.

Entangled photon source in QuIC lab

Credit: U Sinha

We spoke about Bell's inequality violations, which disprove local realism. We have been working on a parallel set of inequalities, which is called the Leggett–Garg inequality. Sir Anthony Leggett, who is a Nobel Prize winner as well, and his postdoc Anupam Garg in the 1980s came up with a new set of inequalities. While Bell inequalities talk about spatially separated objects, Leggett–Garg inequalities are about objects which are separated in chunks of time. For Bell's inequality, as we discussed earlier, you need two parties, if not more. Now, what about a single particle and its quantumness? How will you figure out whether it is satisfying realism or not? For a single particle, you make use of superposition, and that is what gives rise to a new set of inequalities called the Leggett–Garg inequalities.



Cones of entangled photons in QuIC lab
Credit: U Sinha

There have been several Bell's inequality violation experiments since its proposal, and it took a number of decades to do a loophole-free experiment to disprove the inequality. This year, we have done a loophole-free violation of the Leggett-Garg inequality, which is again a first global experiment. It makes us feel like a small percentage of this huge contribution as this is a loophole-free violation of a parallel inequality. We are now starting to make use of it in technologies, and I am sure this work is going to lead to a lot of technologies. So, we have just done a loophole-free experiment this year, and the prize for the loophole-free experiment for Bell's inequality also came this year. That's a nice coincidence.

Neeraj: One of your recent projects is in collaboration with ISRO for quantum experiments with satellite technology. Can you please elaborate on this?

We just talked about quantum communication and key distribution. We have done several of these experiments, which are all within the lab. In fact, our lab has done the first published free space QKD experiment from India. However, these are more of an academic interest. Things become more exciting and useful when you can increase the distance between the sender and the receiver, i.e. implementing long-distance quantum communication between different countries or cities within the country. This is what we would like to enable in the future, and the focus of our lab has been on building technologies for this. The Earth's horizon becomes an issue if you want to communicate over a distance of 200-300 kilometres. Here, you have to come up with out-of-the-box solutions to increase the distance. And one way to do this is to use a satellite as a trusted node. So I have a satellite. When it comes on top of my ground station, I exchange a key with it. It keeps moving in its orbit, and when it comes across your ground station, you may be in Hanle, for instance (it's a great site for this experiment, we had done the analysis there), or you could be in some other

With visiting dignitaries from UR Rao Satellite Centre, ISRO: (Left to Right): Prabhakaran (QuIC lab), Bela (QuIC lab), Sujatha (QuIC lab), Dr. KR Yogesh (URSC), Prof. Urbasi Sinha (QuIC lab), Shri Venkata Ramana (Deputy Director URSC), Shri M Shankaran (Director URSC), Kaumudi (QuIC lab)

Credit: U Sinha

country, the key can be shared with you. In this way, using a satellite as a trusted node, we can increase the distance of communication to thousands of kilometres. This is the idea of quantum experiments with satellite technology. We are now working with ISRO towards enabling satellite-based quantum communication using entanglement.

We have done entanglement-based quantum communication between two buildings, with the atmospheric-free space channel, inside RRI. That was the first experiment of its kind from India. And there have been follow-ups. We are now increasing the complexity of the problem. Earlier, the sender and the receiver were stationary. Now, we are moving the receiver so that we can do pointing acquisition and tracking, moving up towards satellite-based communication.

Parvathy: Our readers are primarily interested in the field of astronomy and astrophysics. How will quantum technology help in furthering astrophysics research?

Quantum technology has become a buzzword in recent times. Every scientist I know is trying to become quantum relevant. Astrophysics is also a part of that. Gravitational wave experiments such as LIGO use "squeezed" light, a form of light that is a type of quantum optics state. Using quantum entanglement/squeezing, one can enhance the sensitivity of interferometry. This will also be implemented in the upcoming LIGO-India project. Thus, quantum light sources can find themselves naturally useful in improving the sensitivity of any instrument.

Quantum entanglement is found useful in terms of what is called quantum imaging. One of the PhD students of Anton Zeilinger did an experiment on ghost imaging. Suppose you have a pair of entangled photons, one of them is with you and the other one is at a distance. By measuring the properties of the light, you can figure out what is happening to the other particle as they're correlated. And this has usefulness in quantum radar. These applications are useful for the astrophysics community and beyond. If somebody plans a payload with a LIGO interferometer to space, like LISA, that could carry an entangled photon source or squeezed light source, it will increase the sensitivity of the detectors, which is highly relevant for all large-scale precision measurements. So naturally, astronomy and precision cosmology are the fields that benefit a lot from quantum technology.

Again, the reverse is also true. Hanbury Brown and Twiss interferometry is an experiment which was actually proposed to measure the angular size of stars. Interestingly, this technique is now quintessential in quantum optics and is widely used in characterising single photons in the lab. To summarise, there is already a lot of cross-talk between astrophysics and quantum technologies. We are all dealing with light, and in fact, interferometry comes in as a natural resource for many things we do.

Saraswathi: We are eager to know about your career path. Were you interested in science in your school days?

I was always inclined towards science and mathematics from very early on in school. I went to seven different schools in different parts of the country and then finally settled for higher secondary in Kolkata. Further, I did my Bachelor of Science in Physics (Honors) from Jadavpur University in Kolkata. After that, I went to the University of Cambridge, UK. There I did what's called the Natural Sciences Tripos. This is a four-year course, but if you have a BSc degree, you can join in the second or third year. So I joined in the third year. I did part II and part III, as they call them. It's a very well-known program, which gives you a master's degree at the end. I did my PhD also in Cambridge and then my first postdoc. Later, I went to the Institute for Quantum Computing in Waterloo, Canada, where I did my second postdoc. And finally, I came here to RRI in 2012.

Saraswathi: What was your PhD work on?

My PhD was on nanotechnology-based quantum devices. I worked on the Josephson effect, which is technically a macroscopic quantum phenomenon. When you have a superconductor, you can actually form a Josephson junction, allowing current to flow through it without any resistance. I worked on high-temperature superconducting materials such as the YBCO compound, a new high-Tc (transition temperature) material at that time. I made devices using the Josephson effect and used them to measure the dielectric properties of different kinds of materials. This technique is called Josephson Broadband Spectroscopy (JOBS). To measure dielectric properties, we can either use microwave techniques up to 50 GHz or terahertz techniques above 1 THz. In the intermediate frequency bands, there were no techniques available to probe these properties. With the AC Josephson effect ($\omega_J = 2eV/\hbar$), we can access this gap by using reasonable voltages.

Vishnu: Would you like to recall any particular event that made you choose your career in quantum mechanics?

Quantum mechanics is quite intriguing when you study it at the school or college level. It was the same for me too. When I went to Cambridge, in part II, I was told to do an experiment, given two weeks and given all the apparatus. With no instruction sheet provided, I was asked to measure something. So, my plan was to make a Josephson junction using a niobium-tip and use it to measure e/h; with ($\omega_J = 2eV/\hbar$), e/h can be measured using what's called Shapiro steps. This entire thing has to be done in two weeks, including setting up the junction. Nothing worked for the first 12 days, but I got some results on the 13th day. I was able to set up something from scratch, and it worked very well with a precision of about 1 in 10^{16}. That is when I started liking precision experiments. Then, I did a particle physics experiment for my next project. Later, I did my master's thesis on SQUIDs (Superconducting Quantum Interference Devices), where there are two Josephson junctions in a ring used to make very precise magnetic field sensors called gradiometers (not radio!). So in some sense, it was those 13 days of the first experiment that made me choose my career in quantum-related experiments.

Neeraj: How close have we come in the field of quantum with respect to the applications seen in many sci-fi movies/shows?

That is a good question. In fact, I have done a panel discussion on the importance of science fiction in science. I like science fiction, mainly Star Trek and Star Wars kind of movies. The concepts of science fiction movies are nice unless they go too far-fetched. I believe that this sort of imagination can help people working in the field to come up with ideas that may make part of it true. So it can feed to science if you are not going to hang onto every word of it. It amuses you at some level and also makes you think that something may be possible.

Teleportation is an example. In Star Trek, Scotty's character is very famous. "Beam me up, Scotty" is a dialogue that you would hear in many scenes. This instant transfer of humans or non-humans could be brilliant, but that does not happen. Of course, quantum teleportation has been established; we are working on a related project in the lab. What we can do is to transfer a quantum state from one particle to another, but we can't have the particle itself reappearing instantly in a different location. This is the imagination part where they take it too far. So, property transfer has definitely happened, and in fact, a part of Anton Zeilinger's Nobel prize is for the first teleportation experiment. Some Chinese experiments were also able to do quantum teleportation between two distant locations in China using a satellite called Micius.

Parvathy: What are the threats or challenges that we should expect once these technologies are fully developed? Are there plans/measures to prevent them?

Like the great potential of quantum technologies, the threats are also huge. Quantum computing is one example. Currently, the Shor's algorithm to break, say, RSA 2048, does not exist. However, with the way in which progress is happening (the number of qubits is increasing very quickly), I am quite sure

With dignitaries at the launch event of the RRI Platinum Jubilee Celebrations - (Left to Right): Prof. Tarun Souradeep (Director RRI), Shri S. Somanath (Chairman ISRO), Urbasi Sinha (QuIC lab), Dr. Kiran Kumar (ex Chairman ISRO, Chairperson RRI Council)

Credit: U Sinha

that it can happen soon. Once this is achieved, it can make all our security compromised. And a quantum computer in the wrong hands is definitely a big threat. This brings us to the concept of open quantum research.

In this direction, we have launched the Open Quantum Institute (OQI) in Geneva recently. I am a member of its core task force. The idea here is to enable different countries to work on research in quantum technologies which are useful for mankind. The United Nations has what is called the Sustainable Development Goals (SDGs), such as peace, food etc. Under the banner of the OQI, we are preparing an agenda for making quantum technologies useful for achieving these goals; after all, these goals are not going to be a threat to anyone. In this way, we can make sure that quantum research is done in a society-friendly way rather than coming up with not-so-desirable applications. Nevertheless, you cannot prevent people from misusing it, like every coin has two sides - and you need to be prepared for that.

Suman: What are your words of guidance for young researchers, especially those who have aspirations in the field of quantum technology?

There are various factors that guide us in choosing a career. One important factor is the possibilities it opens in the future. In that way, quantum technologies have a lot of scope, not only in academia but also in industry and government sectors. There is a lot of quantum-enabled research happening globally. Industries are becoming more quantum-based. There are opportunities in government agencies, defence labs and many other fields. If you are trained in software, you have, let's say, quantum machine learning. If you have engineering skills, you can build machines with quantum. If you want to do physics, you have a lot of interesting theoretical and experimental problems to solve. In short, quantum is not something that demands you to be a physicist to work on it. Regardless of whether you studied quantum mechanics in your undergrad, you can contribute a lot to quantum. For example, in our lab, we have people from engineering backgrounds who work on control systems and contribute tremendously to the projects; they need not know Heisenberg's uncertainty principle. You need not be trained in all the aspects, and there could be other areas which are relevant to the overall quantum ecosystem.

Parvathy: What is India's position in the quantum world? Where are we headed?

I think we are well placed in the domain of quantum technologies. We have a quantum-enabled science and technology program which is an umbrella program of the Department of Science and Technology (DST), that started in 2017 but picked up in 2019. This umbrella program funded 51 projects; our free space teleportation project is one of them. We have been working with the Department of Space and ISRO for satellite-based communication. Now, we have the National Mission on Quantum Technology and Applications coming up, which was declared in the 2020 union budget. I have been a member of the draft project report committee. Once it is approved, we will have a lot more opportunities than what we have now. As a country, we will definitely develop a quantum ecosystem here.

We just need to be a bit cautious that we don't oversell things. We should know what is possible and what is not. We don't need to say more than what is possible because that's bad for future funding. So, I think people like us need to be cautious to ensure that the rest of the community also goes in a little bit of a realistic manner.

Neeraj: How much do we understand quantum mechanics? And to phrase it in a different way, "Is nature truly deterministic or probabilistic?"

Quantum mechanics is probabilistic, and everything is quantum. An example I would take is if you want to walk out of your room, will you tunnel through the door? That is impossible. But why is that so? What is quantum mechanics about? We actually don't have a complete picture here. What we can do is take it down to the de Broglie hypothesis, λ is h/mv, everything has a wavelength associated with it. When wavelength becomes comparable to the size of the object, quantum laws start to appear. Otherwise, we should all tunnel, which we don't because we (our 'm') are just too big.

I would then say that since everything is quantum, everything is probabilistic. Of course, we've just spent a lot of time discussing experiments where we've disproven realism. But then, how would I argue about the Moon? I can't subject it to the Leggett-Garg inequality - increasing the size of the object to see the point beyond which quantum

Members of QuIC lab celebrating 10 years of QuIc lab in March 2022.

Credit: U Sinha

laws do not manifest themselves. Quantum classical boundary is an important problem and is an active area of research. Many people are approaching it in different ways. In our domain as individuals, things seem more deterministic. But, ultimately, we break it down to what we are made of, where the laws are different. So I hope your question and answer are proportional to each other in the vagueness!

Suman: Using quantum computation, can we simulate things that are not possible now? For example, is it possible to simulate a system which is completely deterministic?

If you are using quantum computing to do something, you always have many answers until the wavefunction collapse happens. When you do the measurement, you will get one answer. Even if your quantum algorithms are giving you access to this huge space of states as you're going from the preparation to the measurement, the measurement will always find one state. Ultimately, your measurement is deterministic. So it's not like when I measure, you will be standing and sitting at the same time. What is probabilistic is, then, the various possibilities before that, depending on your problem. And the determinism is achieved once we do the measurement. So, we don't need to simulate something which is already there.

Moreover, you cannot simulate something that breaks the laws of quantum mechanics. For instance, the complementarity principle says that there are complementary observables which cannot be observed with equal precision at the same time. For example, in the double slit experiment, you cannot see the slit and the interference in the same round. When you see the slits, you just see two humps. If you don't see the slits, you see the interference. So these are complementary to each other. So whatever you do, you cannot just suddenly start seeing both. But there are ways around it. People do what is called weak measurements; they are able to see both the trajectory and interference in a statistical ensemble sense. We are also working on weak measurements in our lab.

In fact, there is something called the quantum Cheshire cat. You know the Cheshire cat (from Alice in Wonderland) – the cat without the grin and the grin without the cat. This can actually be observed for quantum objects by using weak measurements. Essentially my photon is here, but its polarisation is elsewhere in the absence of the photon. This is very counterintuitive – the properties separate from the object. Several experiments have happened so far in this. What people have done is, in one run of the experiment, they've seen the property in one place, while in a different run of the experiment, they've seen the object in another place. Now, in the same run of the experiment, you need to see both, which requires a joint measurement. And we have done this for the first time, a quantum Cheshire cat experiment, which is undergoing peer review right now. So, it is just an example of a counterintuitive phenomenon, which otherwise might seem impossible, but we have shown that it is possible.

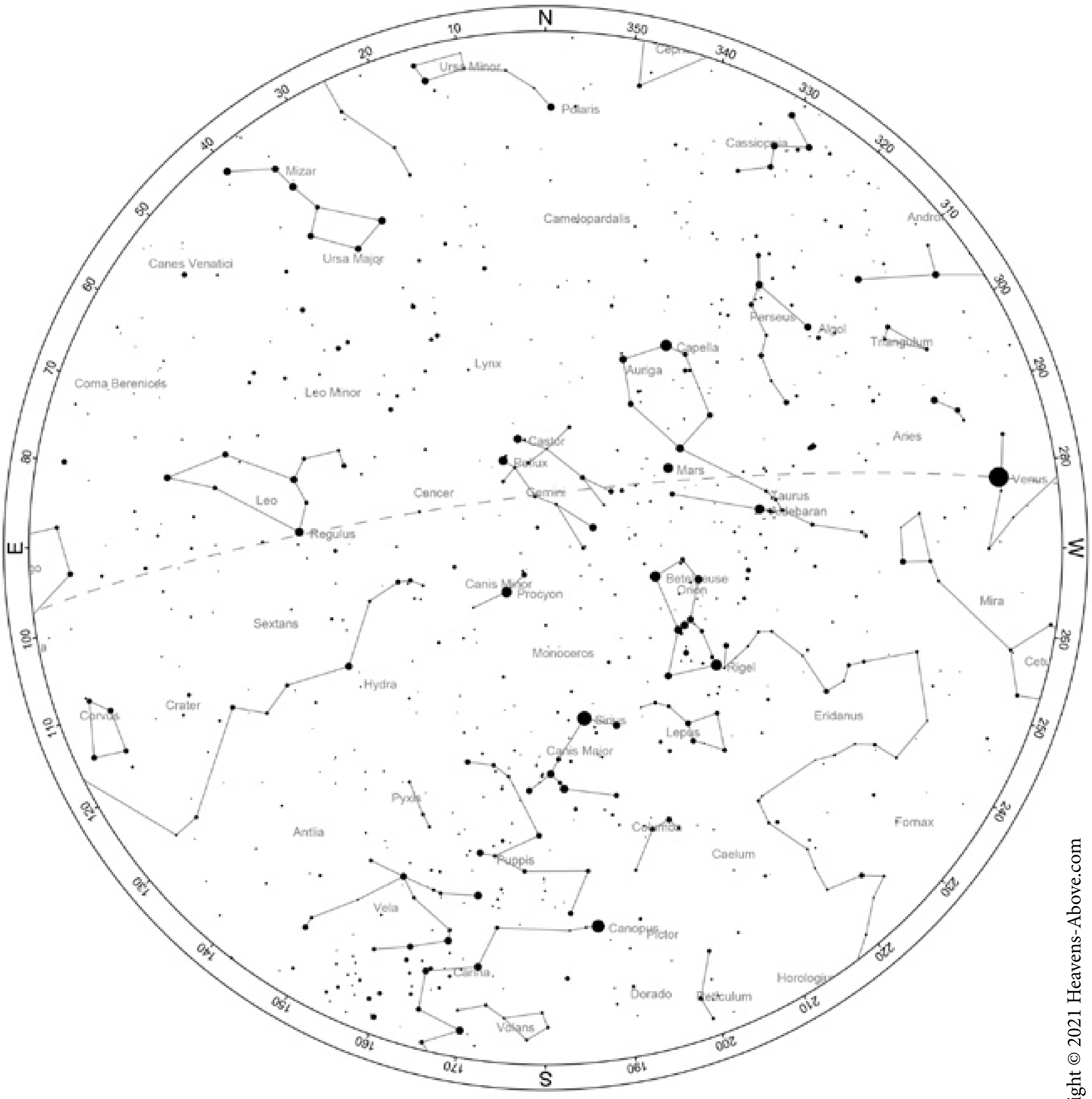
Interview team:

Fazlu Rahman, Neeraj Singh Rawat, Parvathy M, Raveena Khan, Rishabh Teja, Saraswathi Kalyani, Suman Saha, Vishnu Madhu

Interview panel with Prof Urbasi Sinha and her students.

Credit: U Sinha

Photographer: Judhajeet Basu



Skychart March 2023: (As on March 15, 2023. 20.00hrs Bangalore)

March 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2 Conjunction of Venus and Jupiter	3	4
5	6	7	8	9	10	11
12	13	14	15 γ-Normid meteor shower 2023	16	17	18
19	20	21 March equinox	22	23	24 Conjunction of the Moon and Venus	25
26	27	28 Conjunction of the Moon and Mars	29	30	31	

Credit: in-the-sky.org

Galactic star formation and the magnetic fields as a key ingredient

Archana Soam

"Twinkle Twinkle little star, how I wonder what you are!"

The above line of the poem always inspired us to know more and more about the stars shining in our universe. Although the advent of high-sensitivity telescopes and the jump in technology have answered many of our questions, we still have many unanswered ones. There is plenty of evidence that stars form in the cores of densely bound molecular clouds, but a lot more is to be known about the dynamics of these regions and the role of different ingredients (i.e., magnetic fields, turbulence and gravity) in the whole process.

In this article, I will provide highlights of the roles of magnetic fields in the formation of stars in different density regions and at different spatial scales. But before diving deep into that, the summary of the

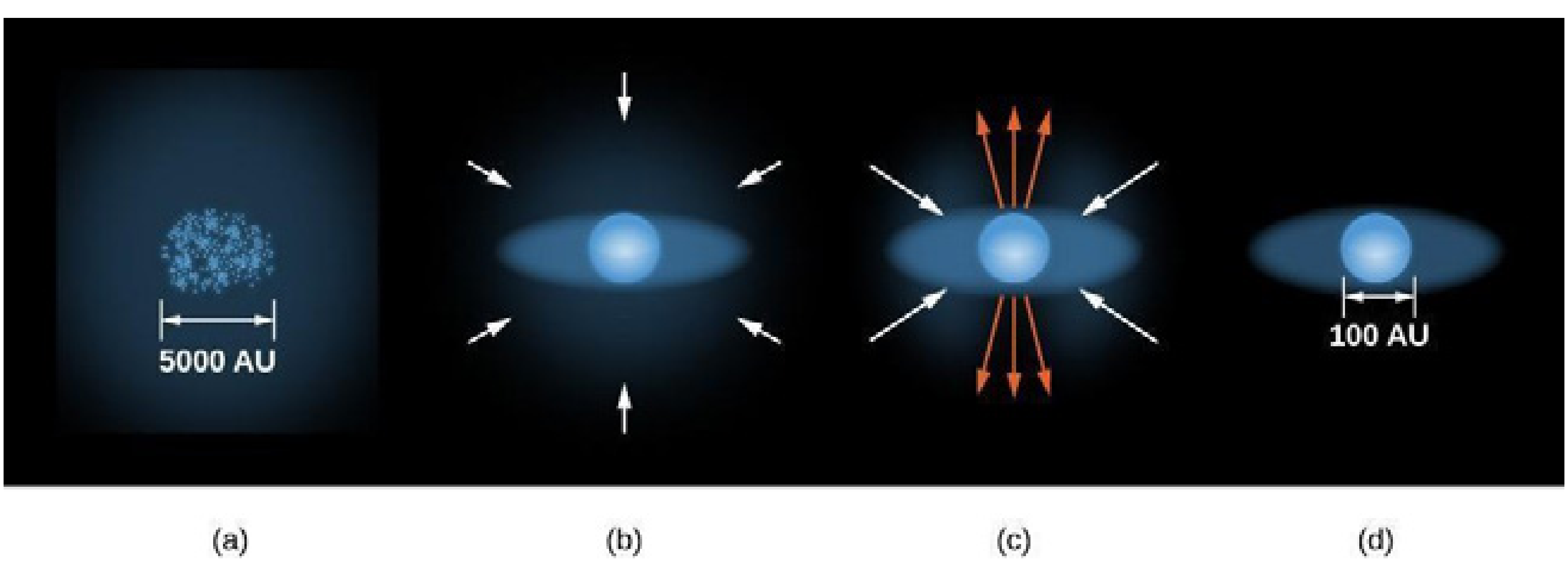


Figure 1: Cartoon diagram to depict the formation of a star. Process (a) shows the dense core formed within the molecular cloud. (b) A protostar with a surrounding disk of material forms at the centre of this dense core, and the material falls from the cloud envelope. (c) Stellar winds ejecting from a disk-like structure are visible now. (d) Eventually, the winds/outflows sweep the envelope away and halt the further accretion, and the newly formed star in the centre becomes visible. The cartoon is adapted from OpenStax CNX.

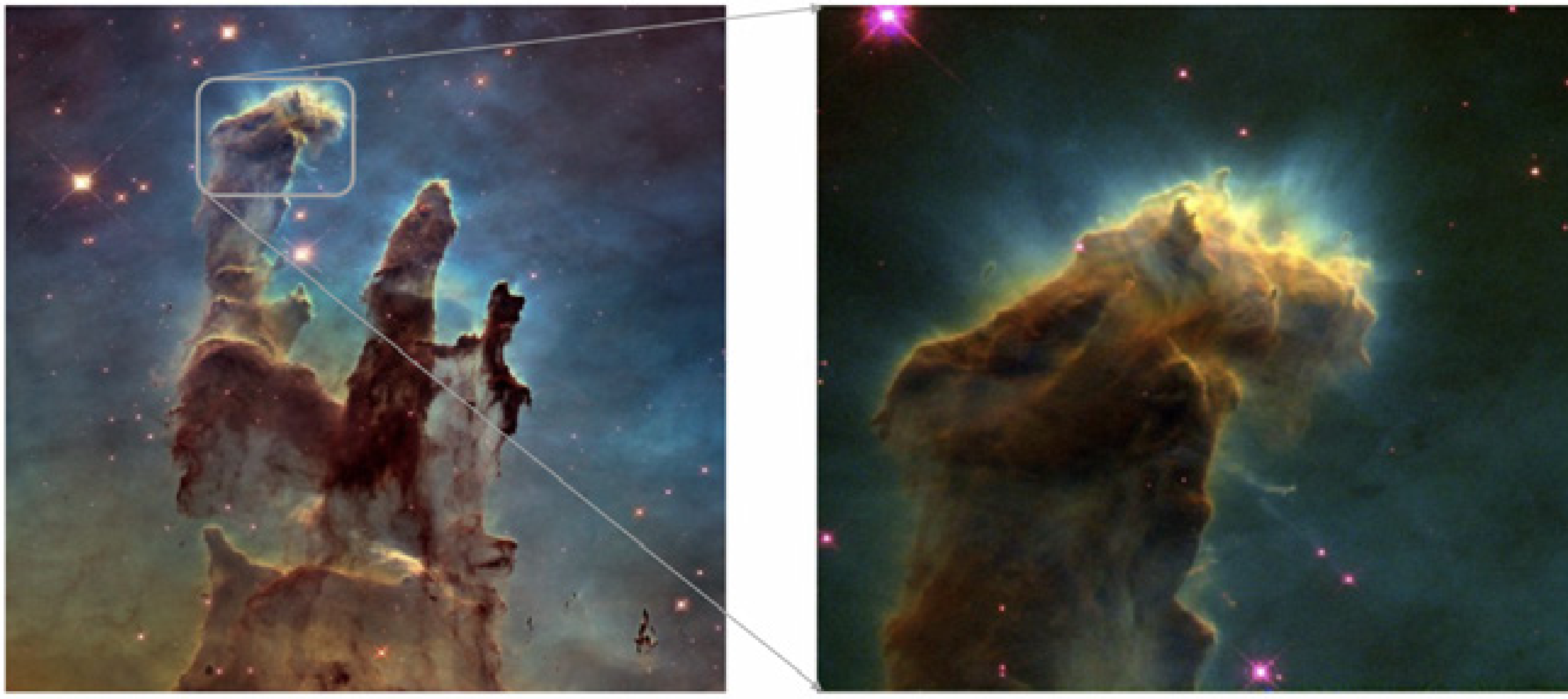


Figure 2: The pillars of dust and dense globules (zoomed-in) in M16. The left panel shows the Hubble Space Telescope (HST) image of M16 (a.k.a. Eagle nebula) [Credit: modified image by NASA, ESWA and HST team (STScI/AURA)]. The huge column of dust and gas, mainly molecular hydrogen, is clearly visible. The head part of one of the leftmost pillars is zoomed-in in the right panel. The finger-like structure and globules can be seen in the image. [Credit: NASA, ESA, STScI, J Hester, P. Scowen of Arizona State Univ.]

star formation process should be looked at in the cartoon in Figure 1.

Now that we know stars form in molecular clouds, to observe star formation, we must look in places that have plenty of raw material (gas and dust) for these clouds. Since star-forming cores are made of dense gas and dust, we focus on the inner cold regions of molecular clouds, as shown in Figure 2. This figure shows spectacular pillar-like structures made of gas and dust. These pillars have star formation going on in their very tip, which is facilitated by high-energy UV radiation (that is potentially responsible for radiation-driven implosion in these clouds).

The question now is, what are the main ingredients in this star formation process, or what helps such low-density ISM (density ~ 1/cc) or molecular cloud cores (density ~ 1000/cc) to become a star? There are two schools of thought to describe this. One suggests that turbulence in the ISM plays a crucial role in the formation of cloud cores and, subsequently, in the formation of stars (Nakano & Nakamura 1978).

According to the turbulence-dominated star formation scenario, the star-forming cores are prevented from gravitational collapse by the pressure of turbulent [Krumholz et al. (2007, 2014)], supersonic gas motions (i.e., gas moving faster than the speed of sound). A few decades ago, scientists noticed that the turbulent velocity of the gas in clouds seemed to increase with increasing cloud size. This correlation has been used to argue that at small spatial scales, where gas is ready to collapse, the supersonic turbulence has dissipated. This behaviour would be consistent with newer observations in the far infrared, which discovered that stars tend to develop along confined filamentary structures. These small-scale structures would be difficult to hold together if they contained fast-moving, turbulent gas.

The other school of thought came from the following observation - the huge masses of galaxies (including

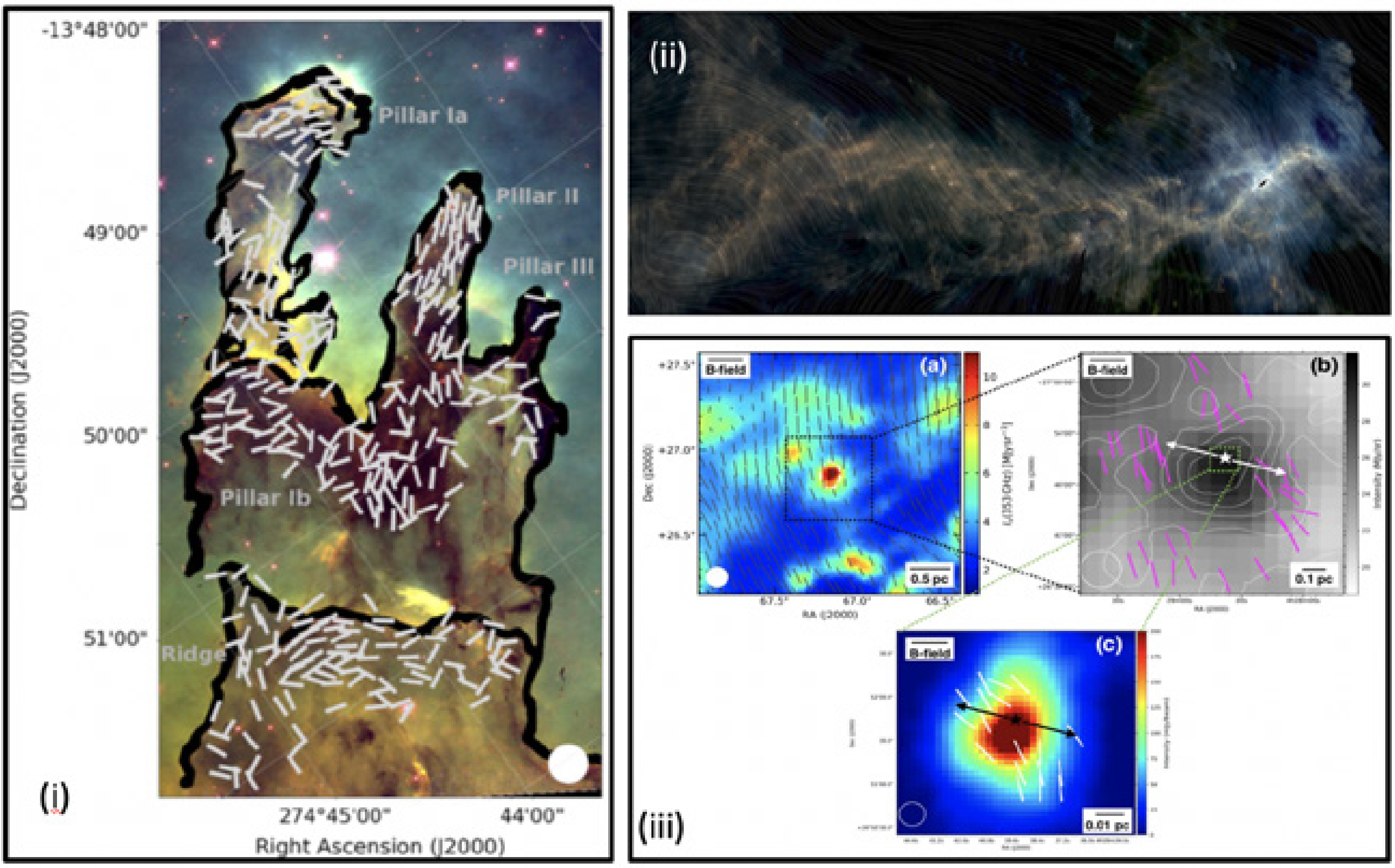


Figure 3: Panel (i) Magnetic field morphologies mapped in the Pillars of Creation in M16 using sub-mm 850 μm polarisation observations (Pattle et al. 2018). Panel (ii) shows the field morphologies seen in a Galactic bone G47 using FIR 214 um observations (Stephens et al. 2021). Panel (iii) shows the change of B-fields seen at various spatial scales in a star-forming core L1521F using sub-mm (Planck and JCMT) and optical polarisation observations (Soam et al. 2019a).

our own Milky Way) are capable of converting only 1% of their mass into stars. Why is the rate of formation of stars so low? This question led people to think of interstellar magnetic fields (B-fields) as a key driver in regulating the star formation process (Nakano & Nakamura 1978, Allen & Burton 1993, Offner & Liu 2018). Several studies, including a recent review article by Pattle et al. (2022), lay the role of magnetic fields in star formation, in various environments and on various spatial scales (Soam et al. 2019a, Arzoumanian et al. 2021). Interstellar magnetic fields are mapped using polarimetry techniques in different wavelengths. The shorter wavelength polarimetry probes the B-fields in warmed and diffused regions, while the longer wavelength polarimetry probes the high-density cooler regions (Figure 3). The three examples in Figure 3 show the B-field morphologies seen in the Pillars of Creation (Pattle et al. 2018), G47 (a very long filamentary structure in the Milky Way, called a Galactic bone) (Stephen et al. 2021), and low-mass star-forming core L1521F (Soam et al. 2019a) at different spatial scales.

There is always competition between gravity, B-fields, and turbulence in these regions. Several studies using high-sensitivity polarisation observations have now proved that B-fields help molecular clouds to transit from being magnetically dominated to being gravitationally dominated, leading to the formation of stars. B-fields are found to play crucial roles in making these structures at different spatial scales (Soam et al. 2019a). Most of the investigations done on understanding the roles of B-fields are nicely compiled by Pattle et al. (2022) in their review article, where they find that low-mass star formation may proceed in environments close to magnetic criticality; high-mass star formation remains less understood but may proceed in more supercritical environments. The interaction between magnetic fields and (proto)stellar feedback may be particularly important in setting star formation efficiency.

There needs to be more than just knowing the B-field morphologies to understand their role in star formation; their strengths in different environments and on different scales are also essential. The most frequently used field strength estimation technique comes from the Davis-Chandrasekhar-Fermi relation (DCF; Davis 1951, Chandrasekhar & Fermi 1953a, b). This technique is based on the equipartition between kinetic and magnetic pressures in the region. Investigating the magnetic fields in the ISM is an increasingly growing field. Many highly sophisticated instruments (polarimeters) on facilities in India and abroad are now available, and many more are under development for these studies.

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Nostalgia (Watercolors)

Artist: Maya Prabhakar

Village scene (Watercolors)

Artist: Maya Prabhakar

Project: Cosmos

Amlan Chakraborty

Ever since the existence of humankind, every person, irrespective of the era, civilization, caste, or creed, has at least once in their lifetime gazed upon the starry night sky with joy and appreciation for nature's creation. While some believed in a supernatural being behind this creation, for others, it kindled their curiosity to investigate the mystery behind this, which gave birth to one of the most enriched and exotic fields: Astronomy. Although there are still debates on 'whodunnit', the 'howdunit' has been the most logical stepping stone towards unraveling this conundrum.

Astronomy is a science that analyzes the origin and evolution of celestial objects, e.g., stars, galaxies, etc. Within this broad subject, the science of the origin and evolution of the whole universe is called cosmology. It is pretty different from other fields because a tiny little species sitting on the balcony of a small house on earth can't possibly take a snapshot of the whole universe at different times and make a conclusion about its evolution. This makes cosmology challenging to formulate and comprehend, contrary to other major fields within astronomy.

Cosmologists have devised a brilliant method to solve this problem: The Backward Approach. Based on the knowledge of the present-day observation of the sky, in this method, the universe has to be evolved backward to find out about its initial state. This process is similar to the trick children use to solve mathematical problems when they know the answer beforehand.

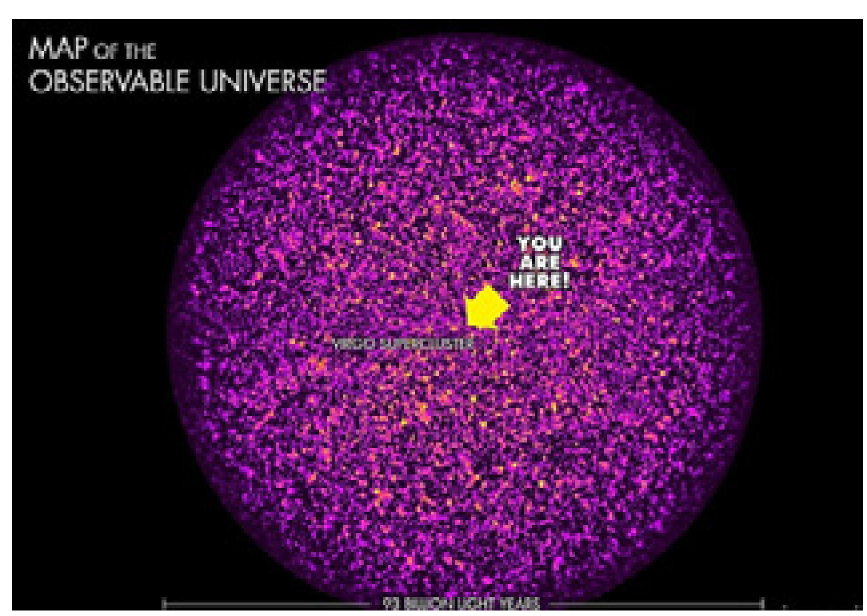


Figure 1: Map of observable Universe.
Credit: Redbubble

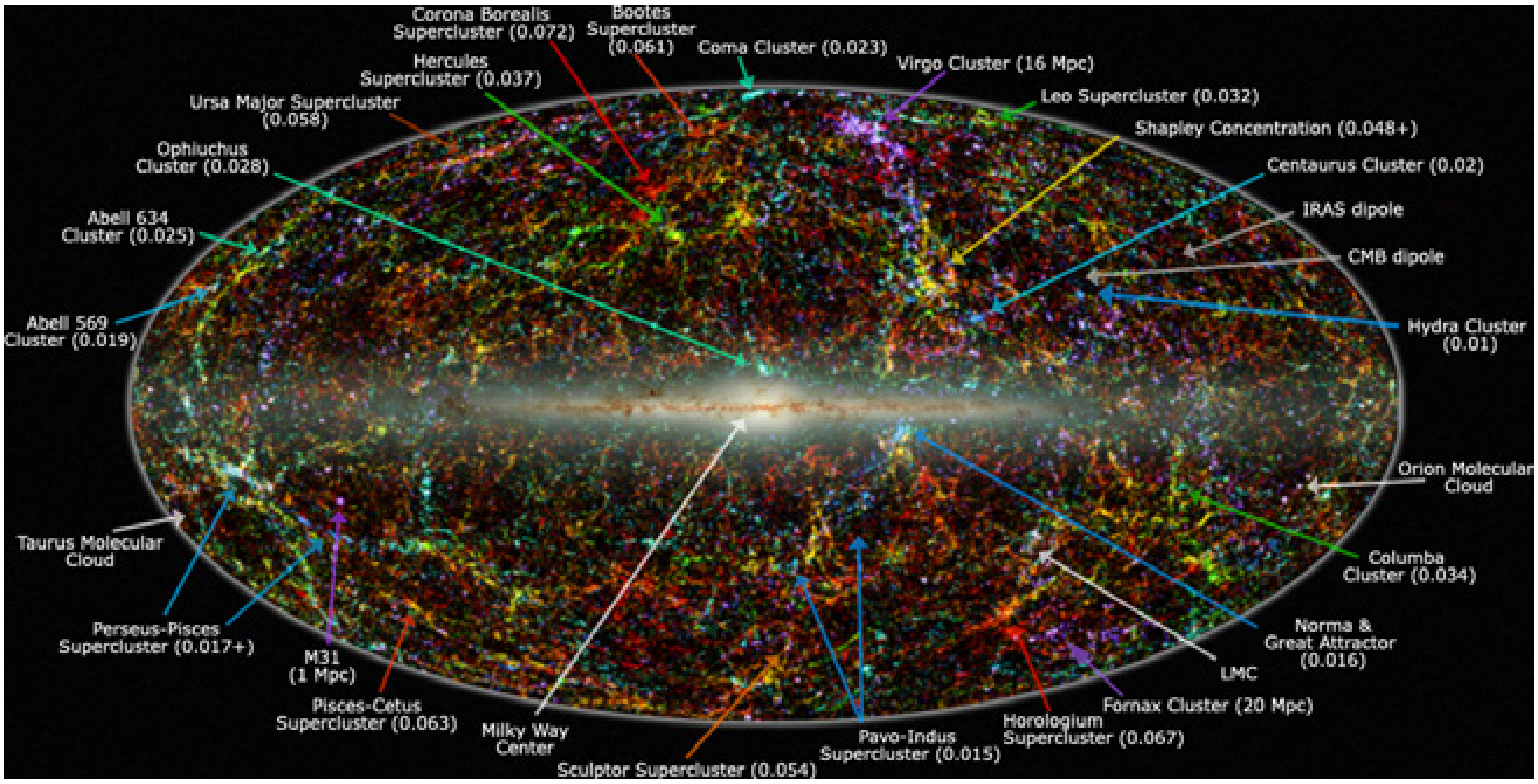


Figure 2: Panoramic view of the entire near-infrared sky revealing the distribution of galaxies beyond the Milky Way. Credit: Wikipedia

Now, observing the sky daily can be cumbersome and require a lot of resources. So the method can be further simplified, considering the dynamics of the celestial objects within a fraction of the sky to conclude the evolution of the whole universe. This simplification requires the assumption that the universe should look the same at every point and in every direction. This property is called homogeneity and isotropy, which led to the famous Copernican Principle. It states that there is no preferred center of the universe, so any two points are equivalent. This principle laid the foundation of cosmology.

A clear idea about a system's length scale to analyze its dynamics is crucial. The length scale related to a system's dynamics is analogous to a car's mileage. Still, in cosmology, the relevant scale is what makes the universe homogeneous and isotropic. So, analysis of the dynamics of planets or the sun does not provide a valid conclusion about the universe's evolution using the simplified backward approach. The universe is simply not homogeneous and isotropic at a scale of the distance between the sun and earth, i.e., Astronomical Unit (AU) or 150 million kilometers. As a result, consideration of a larger length scale is required for cosmology.

An essential key to finding out about the relevant scale in cosmology is the knowledge of the building blocks of the present universe. The earth is a part of the solar system of radius 39 AU. The solar system is a part of a more extensive system called the Milky Way galaxy [Figure 2]. Its radius is almost 3 billion times greater than the solar system's. A galaxy primarily consists of stars revolving around a supermassive black hole at its center. A typical distance between two galaxies is around 1000 times the radius of a galaxy. The galaxies and galaxy clusters are the universe's building blocks, and observation states that almost ten times the typical distance between two galaxies is the relevant scale at which the universe seems homogeneous and isotropic [Figures 1 and 2].

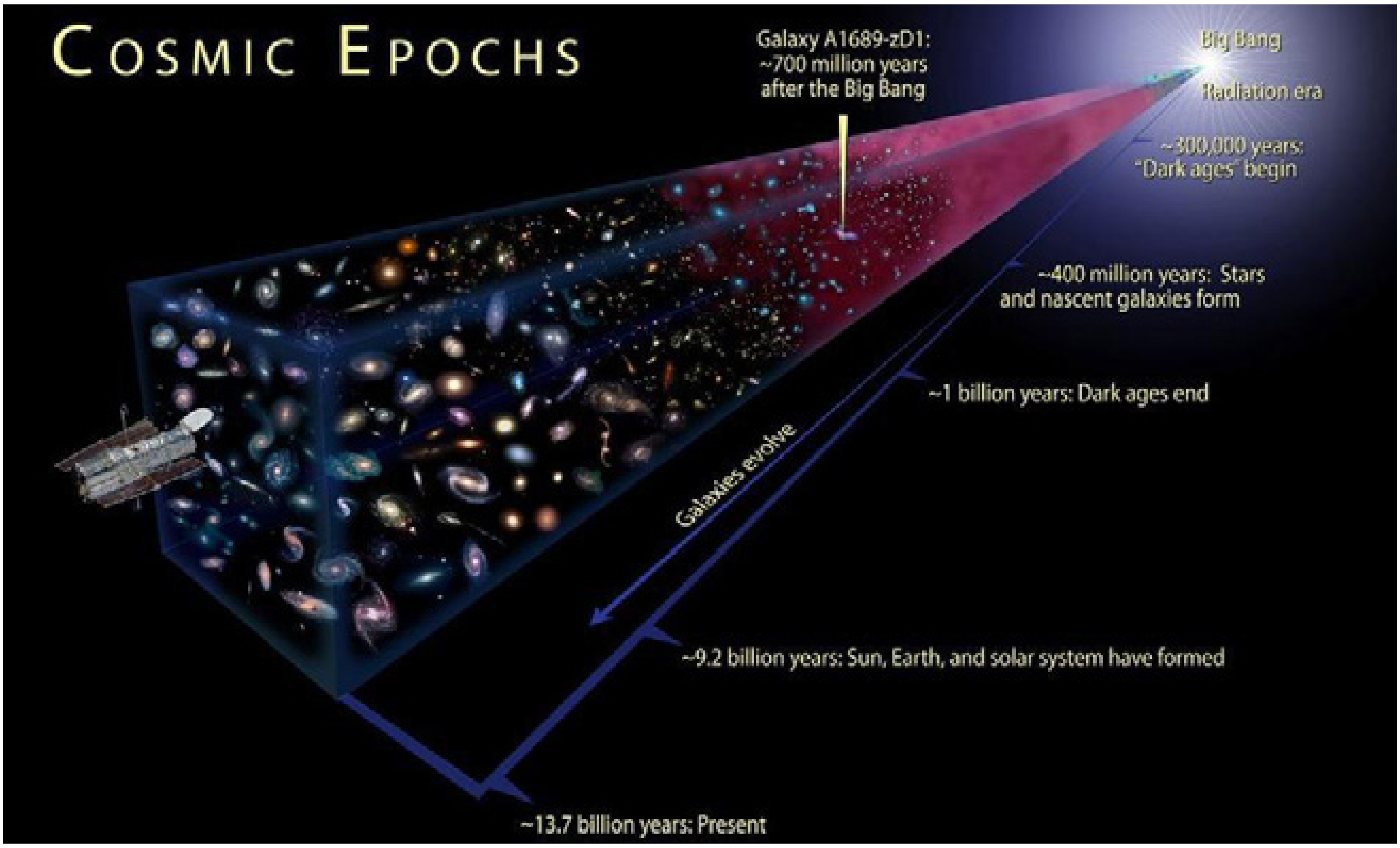


Figure 3: Cosmic Timeline of the Universe

Credit: Forbes

In 1929, Edwin Hubble observed that the galaxies were receding from each other. He discovered that the farther away a galaxy is, the faster it moves away from Earth. This observation led to the conclusion that the universe continuously expands with time. Although it immediately raises a concern regarding the validity of the Copernican principle, observations indicate a unique characteristic of the universe's evolution: it stays homogeneous and isotropic at all times as it expands.

Due to the expansion, extrapolating backward in time, the size of the universe gets smaller, resulting in a highly concentrated cosmos preceded by a singularity where space-time loses its meaning. This is known as The Big Bang Singularity, and the model that describes the universe's evolution from an initially hot, dense state is called The Big Bang Theory.

In the beginning, the universe was a hot and highly dense plasma consisting of photons, electrons, and other fundamental particles like quarks. As the universe expanded, it cooled down, and the quarks bounded to each other and formed neutrons and protons. The following example can help to understand the cooling process: Steam rising from the boiling surface feels hotter near rather than far from it. From the beginning of time, the universe went through some very rapid processes. Fundamental elements like hydrogen, helium and their isotopes were formed in the first three minutes. Still, they stayed in ionized form for a long time because highly energetic photons kept electrons and nuclei separated by frequent collisions. This period is called the "Radiation Dominated Era" (RDE) [Figure 3]. After that, the universe expanded further, and the density of photons got diluted. Finally, it did not have enough energy or time to knock the electron out of the atom's orbit. Hence, the universe started forming stable atoms and molecules at 0.38 million years. Then due to gravity, the first stars and galaxies began developing, and the whole structure of the universe, as it is now, was formed gradually. The photons decoupled from the rest of the system, and their relic can be observed today in its colder form called "The Cosmic Microwave Background", which was discovered in 1964. Between the photon decoupling and the birth of the first stars, there was no visible light in the universe. Hence it is referred to as the "Dark Age". The period of structure formation is called the "Matter Dominated Era" (MDE).

From present-day observation, it has been found that the universe consists of only 4% of the standard or known matter that the standard laws of physics can describe, along with a negligible amount of photons. The majority of its constituents come from two mysterious entities known as "Dark Matter" (26%) and "Dark Energy" (70%).

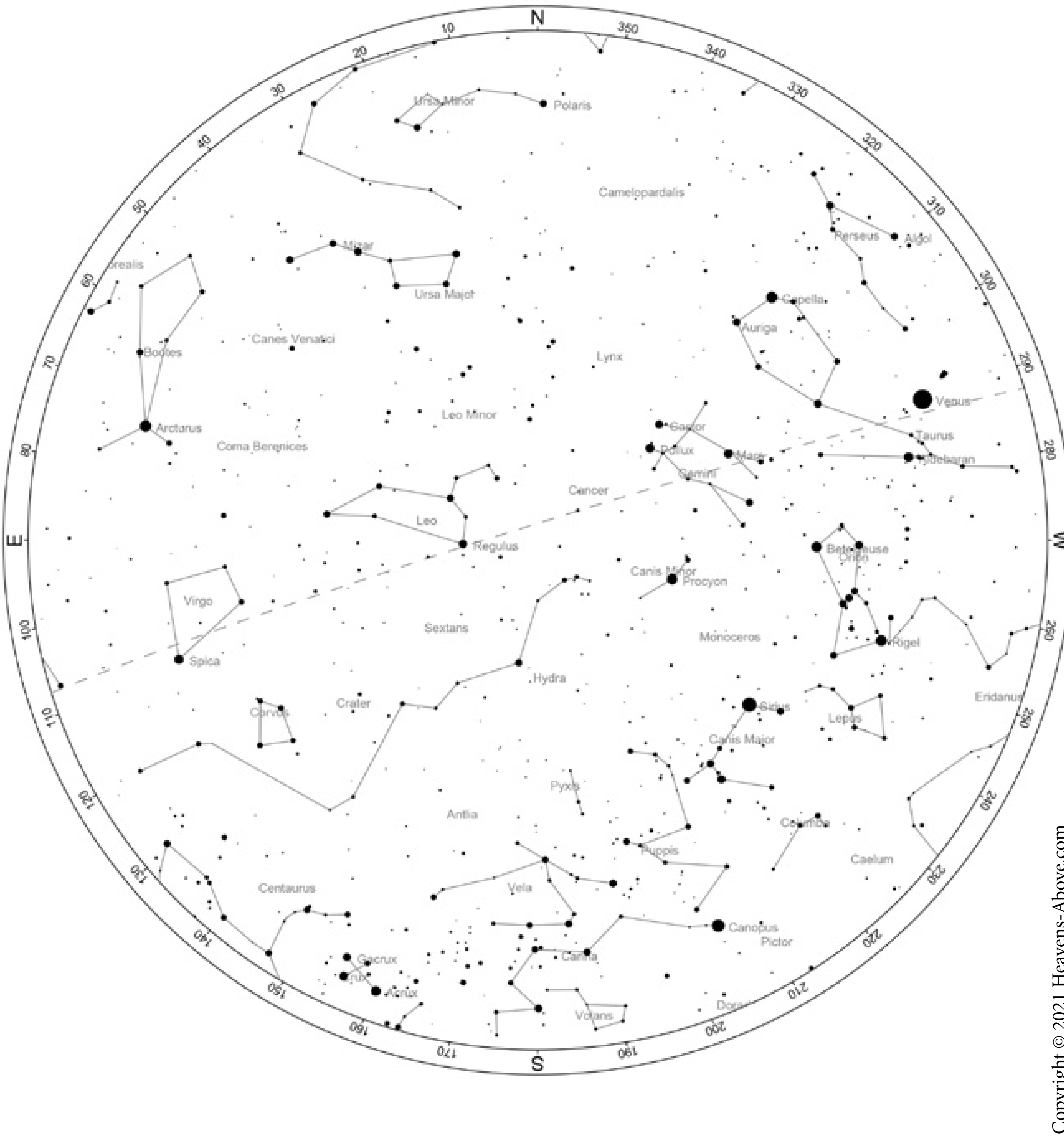
One of the biggest mysteries and open problems of physics is the nature of Dark Matter (DM). To date, there is no clear idea about the interaction of DM particles and being invisible to even the best telescopes makes it hard to detect. Still, its presence can be felt gravitationally through the bending of light around it, a classic result of Einstein's general relativity; thus, it has become an active field of research today.

Another biggest mystery is Dark Energy (DE), which is thought to be the reason behind the universe's expansion. Initially, the galaxies moving away from each other against their gravity was considered analogous to throwing an apple in the sky with initial energy. For the universe, DE plays the role of this initial energy. To explain the expansion, Einstein introduced an ad-hoc "Cosmological Constant" in his theory. But in the case of an apple, it slows down as it goes high, which means that the expansion should slow down with time, i.e., decelerate. However, in the late 1990s, observationally, it was proved otherwise, i.e., accelerating the expansion of the universe.

In the past, vacuum energy was considered DE. Still, it gave a massive mismatch of the order of 10^{120} between the theoretical and observational values, which was the biggest blunder of physics. This problem is known as the "Cosmological Constant Problem". Also, a slightly increased value of the cosmological constant would shorten the period of MDE, resulting in the non-existence of life in the universe. This means that the formation of life and even the existence of humans is a miracle. It is known as the "Cosmological Coincidence Problem".

The present universe is going through the Dark Energy Dominated (DED) phase. After 500 million years, humans will only be able to see a night sky consisting of only the stars in the Milky Way galaxy because all other galaxies visible today will have moved beyond the seeing ability of the best telescopes. So one should be thankful for their existence in this world and feel lucky enough to get the opportunity to uncover the universe's most profound mysteries and its origin.

Amlan Chakraborty a Senior Research Fellow at IIA. His research interests include theoretical cosmology—especially Primordial Black Holes as a potential dark matter candidate, its formation, and cosmological implications.



Skychart April 2023: (As on April 15, 2023. 20.00hrs Bangalore)

April 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
30						1
2	3	4	5	6	7	8
9 Mercury at dichotomy	10	11 Mercury at highest altitude in evening sky	12 Mercury at greatest elongation east	13	14	15
16 Conjunction of the Moon and Saturn	17	18	19	20 Hybrid solar eclipse	21	22
23 Lyrid meteor shower 2023 Conjunction of the Moon and Venus	24 π-Puppid meteor shower 2023	25	26 Conjunction of the Moon and Mars	27	28	29

Credit: in-the-sky.org

My Time at IIA

Eswar Reddy

Often, people ask me how I entered this field. Let me admit. I chose astronomy as a career, not by design but partly accidentally and partly due to necessity. After our final year M.Sc at Venkateswara University, Tirupati, in 1990, my friends and I stayed back at our hostels for a couple more weeks. During that period, one of our batch mates informed us that there was an advertisement in the library hall about the PhD programme in astronomy at the Indian Institute of Astrophysics (IIA). Importantly, we noticed that IIA provided travel allowance (TA) and accommodation for the written test and interviews. We jumped at the opportunity and filled up the applications. There were six of us, and we thought it was an opportunity not to be missed - not for getting into the programme but to tour Bangalore!

We were accommodated at a rooftop hotel near Check Post (opposite Forum mall). Close to a hundred people wrote the exam. The next day, they put up a notice board announcing the results. I was surprised to find that I was one of the 10 candidates shortlisted for the interview. I stayed back. I can't say I did a great job. Still, I did impress some of the committee members with my various constants, such as the Avogadro number, and plugged it into the equations without help.

Figure 1: A 1991 picture at the IISc Campus; with our mentor Prof. Arnab Rai Choudhuri at the end of his course on Radiative Transfer. From right to left: Nimisha Kantharia, Annapurni Subramaniam, Uma Gorti, Sujan Sen Gupta, Sumit Banerjee (unfortunate he passed away untimely, a bright and jovial fellow), Dipankar Banerjee, myself (Eswar), Ramachandran. Arnab is at the extreme left.

Post interview, I was on my way to Hyderabad, to prepare for the Union Public Service Commission (UPSC) exams, with a stopover at Tirupati to collect some of my belongings from the hostel. At that point, I had absolutely no idea of getting into research. Then, I saw a letter from IIA addressed to me. It said that I was selected for the PhD programme with a monthly stipend of Rs 1800 and a hostel facility. I was in a great dilemma: should I go for the PhD or go ahead with preparing for the UPSC examination?

I talked to a few of my Physics teachers. One of them, Prof. Jayaram Reddy, head of the thin film section, said without any hesitation that I should go to IIA. He also said that astronomy and astrophysics are emerging areas for research, and to prove his point he cited Dr. Subramaniam Chandrasekhar's recent Nobel Prize for his work in stellar astrophysics. He also said that preparing for the UPSC exams does not guarantee that one gets selected. Furthermore, even if one is selected, the nature of the work does not suit everyone. On the other hand, in PhD, one could pursue their research interests and contribute to the field. I was convinced by that sound advice. Of course, back in the 1990s, Rs 1800 per month was a lot of money. Almost like a job in hand.

I was a bit raw in every sense, having come from a rural background and with all my education being in small towns. Some people at IIA asked how I was going to do research with that poor English, while some encouragingly said that it was just a matter of a few months before I got hold of the situation. To me, IIA still looked like an elite place and I was unsure I could fit in. With that self-doubt, I talked to Prof. Periah, one of the senior faculties at IIA, who also came from Andhra Pradesh. I expressed all my doubts about myself, including my 3-year age gap (I had joined 1st standard at the age of 8 years) and whether I could be successful. He told me not to worry and that I had 5-6 years to prove myself. Most importantly, he told me that I'd enjoy it. That is precisely what happened to me.

Of the four selected from the national exam at IIA, only two of us joined - myself and Mahadevan from Kerala. He, too, left for M.Tech after a couple of months. A few months later, IIA took students from the Joint Astronomy Programme (JAP) of the Indian Institute of Science (IISc). From that pool came Annapurni Subramaniam (Current Director of IIA), Dipankar Banerjee (current Director of ARIES - Aryabhatta Research Institute of Observational Sciences, Nainital), and Uma Gorti (currently a research scientist at the University of California). Later, R. D. Prabhu joined as a JAP student (he moved on to IBM later), and Sujan Sengupta (currently a senior professor at IIA) joined as a CSIR (Council for Scientific and Industrial Research) fellow. We had three seniors: Ranganatha Rao, who came through a project on atmospheric sciences (he went on to become a professor at Mysore University), G. C. Anupama (former Dean at IIA and former President of ASI - the Astronomical Society of India) and Diwakar Mayya (currently a faculty at the Institute of Astronomy, Mexico).

All of us except Uma were given accommodation at the campus behind the current India TMT (Thirty Meter Telescope) office. Each room was allotted to two people, and the rooms were big enough. That was the first time that IIA had so many students on campus at the same time. We were almost treated like faculty members. They generously provided us with transport to Bangalore University, IISc or RRI (Raman Research Institute) for our coursework or to attend scientific talks.

One of the best things about that time was cooking dinner at the pantry (currently the room is used as the resource room for the auditorium, opposite the auditorium). Of course, most of the time, the menu used to be noodles or egg-based recipes. Those used to be long dinners spent discussing either world affairs or talking seriously about data reductions, quality of data, etc. Our unofficial mentor was Diwakar Mayya, an expert in observational astronomy.

Of course, all good times must still come to an end. Most of us got married just after our coursework. Night-out dinners and walking in the middle of the Koramangla roads ended abruptly. I joined Prof. Parthasarathy for my PhD in the Study of Post-Asymptotic Giant Branch (post-AGB) stars which are highly evolved low and intermediate mass stars in the transient phase between AGB and planetary nebulae. Studying post-AGB stars was a hot topic then: to understand the evolution of planetary morphology and also nucleosynthesis in their AGB progenitors. Working with Dr. Parthasarathy was one of the most wonderful things that happened to me. He was a thorough gentleman.

My first observation was with the 2.3-m Vainu Bappu Telescope (VBT), then India's and Asia's largest as well. Staying there all night with the assistants was a fantastic experience. Other observers at other

Figure 2: Around 1994, different teams were formed to scout potential sites for establishing the Indian Astronomical Observatory around the Himalayan region. This picture was taken when our team (in-charge of Hanle) was returning from Leh to Delhi via Manali after a month-long search.

telescopes at Vainu Bappu Observatory (VBO) and myself were monitoring the skies for humanity - that was the kind of feeling we had. However, that euphoria did not last long. Most nights, the skies were not clear; and even if they were clear, Mr Selvakumar, then observing assistant, told us that it was time to close the dome because of high humidity, which is not good for Charge-Coupled Devices (CCDs). Sometimes it was frustrating waiting endlessly for the clouds to go out. However, there was always one thing to look forward to - the morning breakfast at the VBO canteen. Though tired and sleepy after long hours of observations/waiting for clear skies, most of us never wanted to miss that early morning breakfast of fresh and crispy dosa and chutney or hot pongal and vada. Breakfast at VBO was unique. Most of us (including me) doing observational astronomy used to stay weeks or even months at a stretch at VBO to get data and also to reduce and analyse the results. We used to have a well-equipped computer room at VBT with VAX computer machines. My brush with data reductions was to learn "RESPECT", a spectral reduction package (pre-IRAF era) developed in-house by Prof. T. P. Prabhu and his students G. C. Anupama and Mayya. The best part of staying at VBO those days was meeting and discussing with the faculty members of other institutions who used to come for observations with the 2.3-m VBT and other facilities. Most of the breakfast conversations used to be about the previous night's observation: humidity and seeing values at various facilities at VBO and issues we faced with CCDs or electronics or problems with the dome not functioning well. Of course, local and national politics too entered the chat now and then. Now, when looking back to those days, VBO was a great hub for learning and socialising.

During observations, if there was any problem, the first person to be called was Mr. Gabriel (from the mechanical division). Once the problem was identified, we used to call either Mr. Ravi (for electronics-related queries) or someone with related expertise. These were all wonderful people with an extraordinary commitment to the facilities.

Coming back to my PhD work, I was involved in identifying potential post-AGB stars using Infrared (IR) data. I used the fluxes from the IRAS (InfraRed Astronomical Satellite) catalogue to identify potential transition objects and then looked for their optical counterparts for observations with VBO facilities. We used the star's coordinates to identify the area on optical Palomar Sky Surveys. Then, the identified regions were photographed and developed in a dark room. We used the pattern in the IRAS star maps and the potential post-AGB star's coordinates to determine the visible counterparts of IRAS sources. We then prepared our observing chart with these coordinates. Some were bright while some were very faint and in crowded regions. So it was a lot of work at the telescope end to identify the right candidate. Getting the right one at the telescope was another story.

One of my daily activities, other than worrying about data qualities and strengths of spectral lines, was playing table tennis above the IIA canteen or at VBO. I learned it at IIA from Diwakar, and it became a hobby. Playing with Dipankar was always competitive.

I left for the USA in 1997 after obtaining my provisional PhD from Bangalore University. I continued my post-AGB work during my two-year stint with Dr. Hrivnak at Valparaiso University, and got opportunities to go to Kitt Peak National Observatory, Arizona and Cerro Tololo Inter-American Observatory (CTIO), Chile. Following this, it was at the University of Texas, Austin, during my four years with Prof. David Lambert, that I expanded my research areas, thanks to the observing facilities at McDonald Observatory, Texas. It was one of the best places for stellar astronomy, particularly for work involving stellar spectra.

I was one of the avid observers using the 2.7-m Harlan Smith Telescope at McDonald Observatory. I spent many long winter nights obtaining high-quality spectra for 400 dwarfs, two spectra for each, to understand Galactic chemical evolution. The two original papers based on these observations are some of the seminal studies in the literature in this field, with more than 600 citations for each. Winter nights are very long in northern latitudes, about 14 hours; during these times, I would enter the observatory dome at about 5 PM, fill up liquid nitrogen and open a number of mirrors to direct the light to the Coudé focus where an Echelle spectrograph was present. When all was ready, we would open the dome and take all test spectra. I was used to coming out at about 7 AM the following day. One Mr. Daivd Doss, an all-in-one expert, used to visit us at about 10-11 PM to check if everything was alright. Apart from this, there used to be no night support during these observations. The observers were basically on their own. At the astronomy department in Austin, there used to be a regular

Figure 3: Taken in October 2007, along with colleagues Drs. Parihar and Bhatt (from left) while we were scouting for potential sites around Hanle for National Large Optical and IR Telescope.

seminar every Tuesday. Attending those seminars helped me get into newer research areas: the high Lithium (^{6}Li) abundance puzzle in red giants, and the testing of host stars that had engulfed planets using ^{6}Li as a tracer.

I moved back to IIA in 2003 and continued my work on Li in red giants and Galactic chemical evolution. Initially, most of the new recruiters were posted at the Centre for Research and Education in Science and Technology campus (CREST, Hosakote). It didn't take long to sink in that lack of facilities severely hinders what one would like to do. Most of the young faculty members started discussing ways to get a larger facility, since we only had 2-m class telescopes at the time in India. We used to meet weekly, and finally, we convinced Prof. Siraj Hasan, then Director of IIA, to fund for systematic search and characterization of the site around the existing Indian Astronomical Observatory (IAO, Hanle).

This was in 2007: A small team of us, Drs. Parihar, Bhatt, myself, and Mr. Angchuk scouted several potential sites and set up weather stations . On 30th October 2007, post-dinner we received an email forwarded by Prof. Hasan. The mail was sent by Prof. Lambert to Prof. Hasan about India's participation in the Giant Magellan Telescope (GMT, upcoming at Chile). The email said, *"... I have learned of the interest in building a large telescope at Hanle. Indeed, Reddy has been emailing me this week from Hanle where he and others are climbing local peaks .... A reasonable share of GMT time costs about the same as the Hanle telescope, and the timescale for completion would be no different".* This prompted IIA to look into other international projects like the Thirty Meter Telescope (TMT) and the 40-m European Extremely Large Telescope (E-ELT) projects along with the GMT. A national group was formed in 2008 consisting of major astronomy institutes in the country including ARIES, IUCAA, RRI, IIA, and TIFR. Since then, I have been heavily involved in this project: first, in 2010, as a national coordinator along with Prof. Ramaprakash for selecting one of the three projects (TMT, GMT, and E-ELT - European-Extremely Large Telescope) and then later following India's decision to participate in the TMT project in 2014, as the Programme Director of the India TMT project overseeing India's in-kind contributions to the project.

Looking back, IIA has its own unique selling point of nurturing students in a more collegial way which is not that easy to find in many institutes. Joining IIA is the best thing that happened to me.

Prof. Eswar Reddy completed his PhD at IIA on the studies of evolved stars. Afterwards, he moved to the USA where he spent six years working on spectroscopic studies of stars to understand galactic evolution and nucleosynthetic aspects of evolved stars. He joined IIA in 2003 as a faculty member. Currently, he is a senior professor and the Dean of the faculty of sciences at IIA. He is also the program director of India TMT Center since its inception in 2014, and India's designated governor in the board of governors of the TMT International Observatory for India TMT.

Credit: Judhajeet Basu

High-Resolution Optical Spectrograph for the Thirty Meter Telescope (TMT)

Amirul Hasan

In the earlier issues of DOOT, several subsystems of TMT have been discussed elementarily. In this issue, we will introduce you to one of the second generation instruments of TMT, the High-Resolution Optical Spectrograph (HROS).

In the past few decades, the world has seen the rise of several 10 meter class telescopes [Keck, Gran Telescopio Canarias (GTC), Southern African Large Telescope (SALT)]. Telescopes with bigger apertures were built to collect more light from the fainter and farther Universe. Now we have reached a point where a further increase in the diameter of a monolithic mirror is not possible. The not-so-new technique to achieve a larger aperture is to make smaller sub-apertures and then co-align, co-focus and co-phase to act as a single large mirror. The concept of building such a telescope was introduced by Dr Jerry Nelson at the Berkeley Labs and the University of California, United States, in the 1980s. The 10m Keck telescope atop Mauna Kea, Hawaii, was the first ever telescope to be built in this configuration. Since then, several telescopes have been constructed based on this technique, and the very recent James Webb Space Telescope (JWST) is also based on segmented mirror design.

The TMT (Thirty Meter Telescope) is a global effort with USA, Canada, Japan, China, and India as its partner countries. The thirty meter aperture consists of 492 hexagonal mirror segments, and each mirror is 1.44 meters in diameter. These segment mirrors are supported by 1476 actuators and 2772 capacitive edge sensors to sense any misalignments. TMT is an alt-azimuth mount, 3-mirror Ritchey-Chretien telescope in Nasmyth configuration. The objective of the telescope is to gather more light and feed it into several adaptive-optics-fed instruments and seeing-limited instruments on the Nasmyth platform. One of these instruments is the HROS.

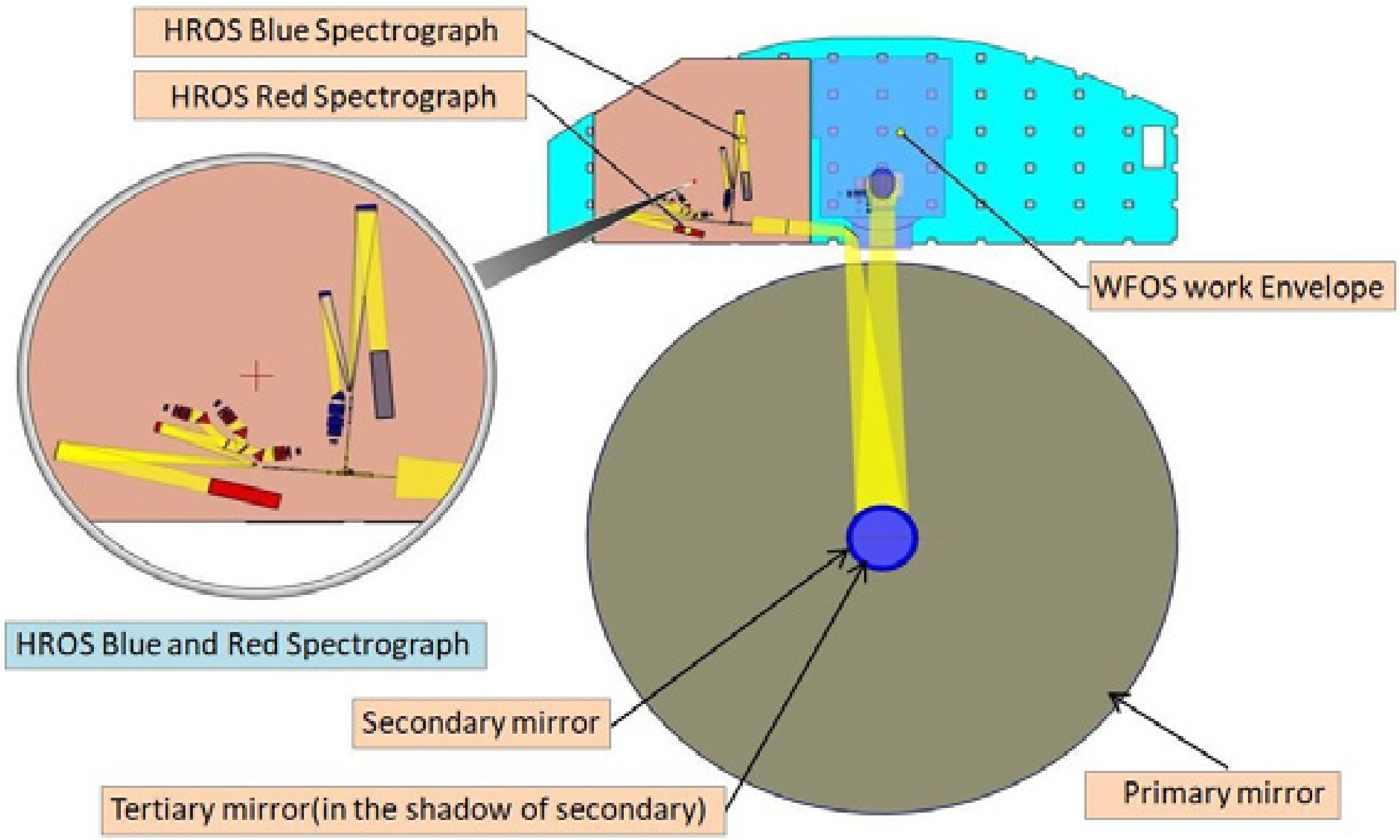


Figure 1: (Top view of HROS with TMT) Figure shows the location of HROS on the Nasmyth platform where all the seeing limited instruments are placed.

A high-resolution optical spectrograph generally serves as a workhorse instrument for most observatories. It can take advantage of poor seeing conditions when other instruments cannot be used. Some of the key science drivers of HROS with TMT are Galactic archaeology, inter-galactic and circum-galactic medium studies, and exoplanet transit spectroscopy. India is the lead/PI country to design and develop the high-resolution spectrograph. India bagged this prestigious design project largely due to the heritage of building high-resolution spectrographs within the country.

HROS is a second generation seeing limited high-resolution optical spectrograph to be installed on TMT (see Figure 1 for its location on the Nasmyth Platform). The two major design considerations for HROS are: (1) to operate in the wavelength band from UV 310 nm to near-infrared (NIR) 1100 nm, and (2) with a velocity precision of 1m/s. HROS will be used to study the sites of the first metals that were produced in the early Universe by the Pop-III stars and can trace their evolution to the present-day exoplanet atmospheres. High stability and precision calibration of HROS will facilitate studies of characterizing Earth-like planets around nearby stars and possible variations of fundamental constants at different redshifts.

Modes of Operation

HROS will be a versatile instrument capable of operating in two modes: single-object spectroscopy and multi-object spectroscopy. Hence, the design of HROS must be flexible to easily accommodate multiple objects in a 5′ (arcmin) field-of-view with no major changes in the baseline design.

Modes	Configuration	Resolution	Slit width (seeing/sliced)	Pixel Sampling (no binning)
Single object spectroscopy	High resolution	100K	1'' sky/0.2'' (19 fibers)	3.5
	GLAO Mode	100K	0.6'' sky/0.2'' (7 fibers)	3.5
	Standard Mode	50K	1.2'' sky/0.4'' (7 fibers)	7
	High Thoughput Slit Mode	40K	0.5'' x 5''/On-Axis FOV	8.75
Muli-object spectroscopy	Low Resolution	20K	1.0'' sky/1'' (1 fiber)	17.5
	Mid Resolution	40K	0.5'' sky/0.5'' (1 fiber)	8.75

Table 1: Various modes of operation possible with HROS - details about spectral resolution, slit width and pixel sampling achieved through image slicing using fibers.

Optical Design of HROS Spectrograph

Since TMT is a ground-based telescope, it suffers from atmospheric dispersion, and being in an Alt-Az configuration, the effects of field rotation are also present. The design of the HROS fore-optics takes care of these corrections.

The size of an echelle spectrograph scales with the size of the telescope. Designing a spectrograph for an extremely large telescope having a broad wavelength coverage is very challenging since the size of optical elements has to be very large, and it is not always possible to fabricate high-quality optical elements of this scale. Another issue to address is to correct all aberrations, such as spherical, coma, astigmatism, and chromatic dispersions. In this article, we provide a birds-eye view of the 6 major subcomponents of HROS and an overview of the spectrograph, fore-optics and camera design (see Figure 2 for the optical design).

The major components of HROS are:-

- Atmospheric Dispersion Corrector
- Image de-rotator
- Image slicer (to achieve a higher resolution)
- Beam expander
- Spectrograph with Echelle gratings
- Camera

Atmospheric Dispersion Corrector (ADC): The performance of any ground-based telescope is limited by atmospheric seeing and atmospheric dispersion. When the light from an object enters the earth's atmosphere at an angle, it undergoes refraction. The amount of refraction depends on various physical parameters, like temperature, humidity, and the height of the telescope above sea level. Earth's atmosphere acts as a prism dispersing light, making point objects look blurry. Designing a suitable atmospheric dispersion corrector for HROS is a real challenge because of its wide wavelength coverage from near UV 310 nm to NIR 1100 nm, and

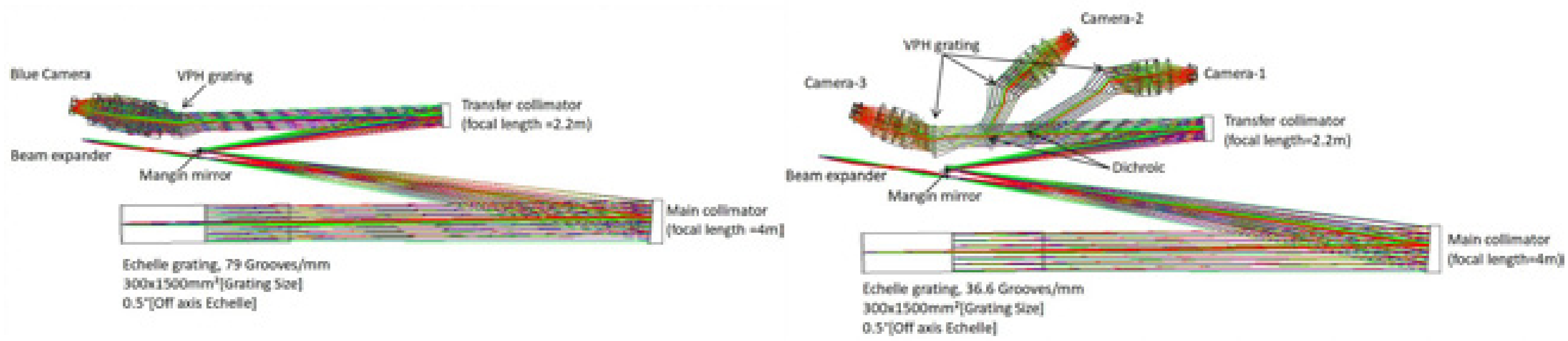


Figure 2: HROS design of two spectrographs. The blue-spectrograph (left) covers the wavelength band from 310 to 450 nm, while the red-spectrograph (right) covers from 410 to 1100 nm in three different channels.

the placement at mechanically tight spots of the instrument.

ADC can be of two types: Linear ADC and Rotational ADC. During the correction, care should be taken that the ADCs do not introduce beam deviation to the optical path.

Linear ADC consists of two identical prisms placed closely but aligned opposite to their apex angle for zenith correction. When the telescope tracks away from the zenith, the prisms are moved away to achieve the best correction.

Rotational ADC has two sets of identical counter-rotating prisms to correct for atmospheric dispersion as the telescope tracks the object away from the zenith. At Mauna Kea, Hawaii, the atmospheric dispersion can be as large as 4'' (arcsecond) in the wavelength band of 310-1100 nm. For HROS, the most suitable ADC is the Rotational ADC which is compact and simply made of CaF2 (Corning) and 7054 (Nikon i-line glass), which corrects a dispersion of 4'' to ~0.2'', bringing it well within the seeing limit (0.5'').

Image de-rotator (K mirror): Image rotation is the apparent rotation of a celestial object as it is being observed via a telescope. All off-axis images appear

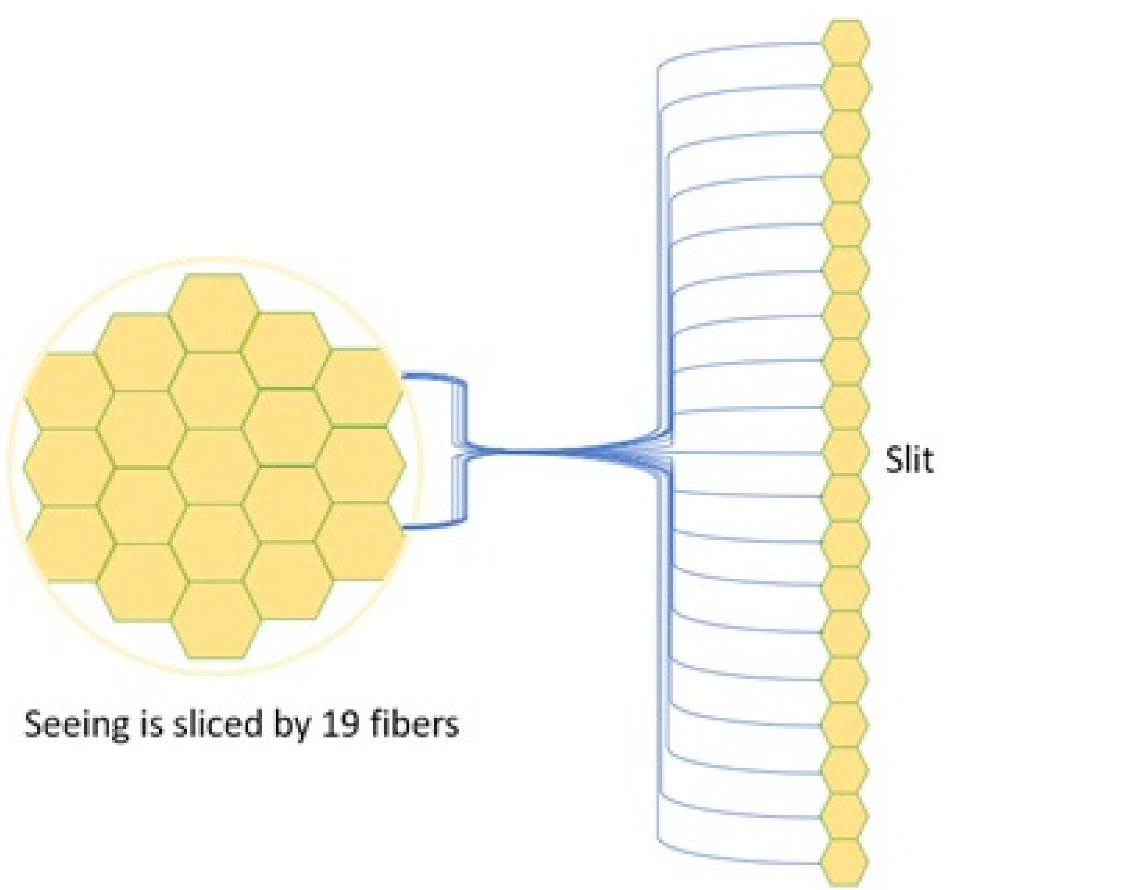


Figure 3: Image sliced through fibers to achieve a higher resolution.

to be rotating in an arc. This field rotation during observation is corrected using a three-mirror optical derotator. This three-mirror derotator is also known as a K-mirror.

Slicing and sampling of the image: There are a couple of very well-developed methods for image slicing using either mirrors or fibers that can achieve higher resolution in spectrographs. The seeing limited image is sliced into narrow slits to achieve a higher resolution. In HROS design, to achieve a resolution of 100,000, a point source of 1" seeing is sliced by 19 optical fibers (as shown in Figure 3 below) with 3.5-pixel sampling at the detector. Similarly, a 1.2" seeing image is sliced by 7 optical fibers to achieve 50,000 resolution with 7-pixel sampling. More details are provided in Table 1.

Beam expander: Since the fabrication of larger optical elements is a challenge, the large beam footprint of the spectrograph can be reduced by using the beam expander. The available standard size of echelle grating mostly lies in the range of 50 x 100 sq. mm to 320 x 420 sq. mm, and the ruled area is between 46 x 96 sq. mm to 306 x 410 sq. mm. The required size Echelle grating for TMT/HROS would be 365 x 1500 sq. mm to achieve 100,000 resolution and cannot be fabricated, at least with existing technology. The beam expander solves this issue by compressing the beam in the cross-dispersion direction, thus reducing the necessity of using extremely large gratings. The beam expander which we have designed decreases the beam footprint of the Echelle Spectrograph by 30% (~1.5 m).

Echelle Spectrograph: The double-pass white pupil is a novel feature of the echelle spectrograph design. In this design, a collimated beam forms the pupil at a mosaic R4-Echelle grating, and dispersed light is reflected back to the same collimator (double-pass) and focused close to a cylindrical Mangin mirror that performs the necessary field correction. The reflected light beam falls onto the transfer collimator, which is further dispersed by VPH (Volume phase holographic) grating in the cross-dispersion direction and is finally focused onto the detector.

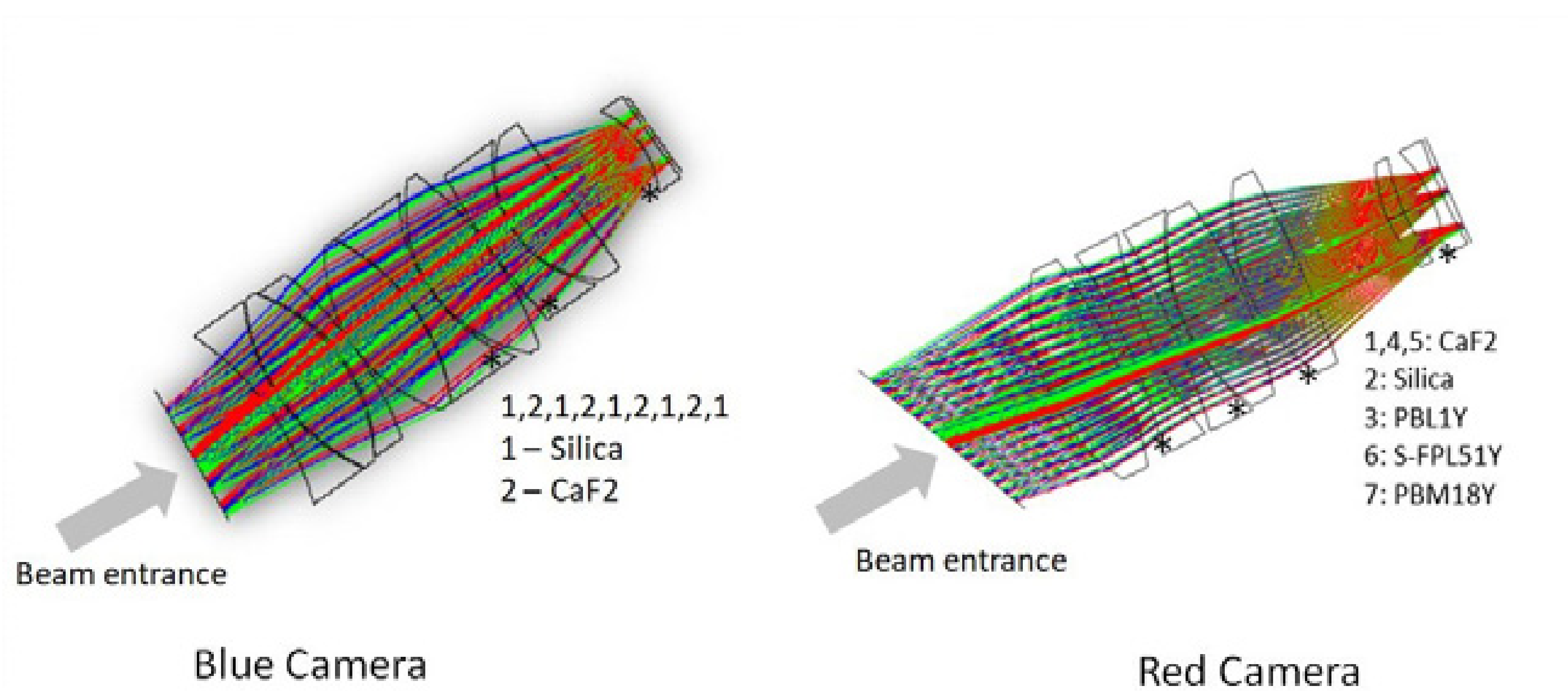


Figure 4: Camera designs of HROS: Blue camera on the left panel, Red camera on the right panel, "" represents the aspheric surface.*

Camera: Two sets of cameras are used at each of the (blue and red) spectrographs. For the blue camera, the choice of glass material is limited due to the unavailability of high transmittance glass in this wavelength band and due to the large size of the lens (350 mm) that is required. So the Blue camera is designed using only CaF2 and Silica, and it has 9 elements with three aspheric surfaces marked with the asterisks[*] (see Figure 4 for the designs). In the case of the red camera, it is designed with seven lens elements of lens material Silica, CaF2, PBL1Y, S-FPL51Y, and PBM18Y with 4 aspheric surfaces marked with asterisks. Currently, both blue and red cameras are being optimized to use fewer elements providing better throughput.

Currently, the team of engineers is looking into various possibilities for feeding the light from the M3 tertiary mirror into the HROS. The system design is currently in the Conceptual Design Phase and will enter into the Preliminary Design Phase once the construction at the site begins. We assume that the HROS is expected to see the first light within the first 5 years of operation of the TMT.

To Be Continued...

Team:

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Amirul Hasan is an Optical Engineer working with the India-TMT project at ITCC/IIA. He is the primary optical designer of TMT/HROS and SCALES/Keck-imager, as well as working on the design and development of a calibration system for the SCALES spectrograph. He is also performing end-to-end design analysis of the calibration system of TMT/WFOS (Wide Field Optical Spectrograph).

Cosmic explosion due to violent mergers of white dwarfs

Anirban Dutta

The explosive death of a star is known as a Supernova (SN). SNe are mainly of two types - the one that arises from compact objects like white dwarfs (WDs) is called Type Ia (Jha, Maguire & Sullivan 2019), and the rest that arise from the collapse of the core of massive stars [stars having mass greater than 8 times the mass of the Sun ($M_{\odot}$)] are called Type Ib, Ic, and II (Smartt 2009). A star is a powerhouse of nuclear energy. Different elements, starting from hydrogen (H), burn (get converted to other elements in nuclear reaction) to form heavier elements. When H burns to helium (He), the core of the star contracts and the temperature rises, giving the opportunity for the next nuclear reaction, i.e. He burning to carbon (C). After each such burning stage, the core contracts and the density increases - until the distance between two atoms is smaller than the de-Broglie wavelength. At this point, the electrons become degenerate (electrons are less massive than protons, so they reach degeneracy earlier). Such a stellar core consisting of electron degenerate matter is known as a White dwarf (WD).

A single, isolated WD is inert and almost dead (devoid of nuclear reaction), radiating indefinitely. But in a binary system (two stars orbiting each other), the WD can gather mass from its companion by a process called accretion. As the mass of the WD nears about ~ 1.4 $M_{\odot}$ [Chandrasekhar mass (M_{ch}) limit], the pressure due to electron degeneracy is not sufficient to counter the gravitational contraction (see also Gamezo et al. 2003). So as the mass of the WD approaches the Mch limit, any small increase in mass results in the contraction of the core, and hence the density and temperature rise. The equation of state of the degenerate matter is different from ordinary matter. The temperature rise is not regulated by a change in pressure or expansion of the star, which can quench the increase in temperature. This starts a thermonuclear (TN) reaction at the centre of the WD (where the density is maximum), and the released energy further increases the temperature - also called a TN runaway. This TN reaction liberates about 10^{51} ergs of energy. For an initial carbon-oxygen (CO) WD, the burning produces oxygen (O), magnesium (Mg), silicon (Si), sulphur (S), calcium (Ca), iron (Fe) and nickel (Ni). It stops at $^{56}Ni_{28}$ - since it has the same number of protons and neutrons and is at the peak of the binding energy curve. The energy released in the explosion is converted into kinetic energy of the expanding material (called ejecta) and thermal energy. When these two surpass the gravitational potential energy of the white dwarf, the WD becomes unbound, and the ejecta expands forever. This TN reaction is able to provide energy for the expansion but not for the luminosity we see. The radioactive decay of $^{56}Ni_{28}$ is what powers the SN.

It has been well established that Type Ia SN (also referred to as 'SN Ia') arises from the explosion of WDs in binary systems. However, the exact nature of the progenitor system (type of WD, binary companion, etc.) is still debated. The most promising pictures are - single degenerate (SD); where the companion of the WD is a non-degenerate star, and double degenerate; where the companion is another WD.

I (a final year PhD student), along with our team at the Indian Institute of Astrophysics, have observed SN 2011aa with the 2.0m Himalayan Chandra Telescope. The SN showed some peculiar features - it was declining (intensity is decreasing with time) very slowly after the peak and is the slowest ever observed. We set out on an adventure to understand

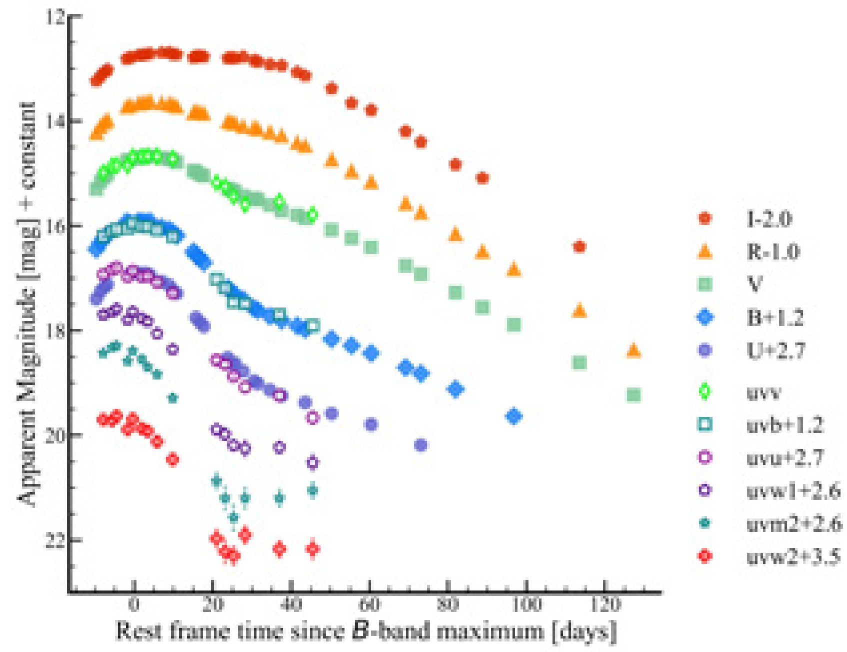

Figure 1: Light Curves of SN 2011aa in Optical and UV

the progenitor system that can give rise to such an explosion.

The light curve (change of flux with time, see Fig. 1) has two important characteristics among others - the peak and the decline. The peak luminosity is mostly related to the amount of $^{56}Ni_{28}$ synthesised, and the decline is related to the diffusion time of the photons (how long it takes for the photons to escape). This diffusion time depends on the mass of the ejecta and on the elements produced in the explosion, e.g. Fe-group elements increase the opacity (in other words, decrease the ability of photons to pass through). The gamma-ray photons produced in the $^{56}Ni_{28}$ decay now get reprocessed (distribution of wavelength) efficiently and go to longer wavelengths (optical and infrared), which keep the light curves declining slowly.

First, we modelled the light curves with a radiation transfer model to find that the supernova ejected a lot of material - more than the M_{ch} limit (Super-M_{ch} mass ejecta). The density, abundance and distribution of elements in the ejecta are other parameters which can constrain an explosion model. We considered several models which can account for such large ejected mass from a WD explosion, like rotating WD (Fink et al. 2018) - which can essentially increase its mass of ignition beyond M_{ch} limit, collision of WD in dense stellar systems (Raskin et al. 2009), and violent mergers (VMs) of WD (Pakmor et al. 2010). We find that most of the observed properties can be understood in terms of a violent merger scenario.

VMs of two CO WDs can produce a SN Ia explosion. The material from the secondary WD is violently accreted on the primary and gets compressed, due to which temperature rises (these are capable of exploding, as opposed to dynamical mergers, which sometimes form a single object which does not explode). This rise in temperature causes C ignition. The ignition flame propagates through the final merged object and releases enough energy to unbind the system. Depending on the masses of the WDs, these systems can produce super-M_{ch} mass ejecta. We find that the VM explosion model explains the following - the luminosity, ejected mass and decline. Encouraged by this, we performed Monte Carlo radiative transfer simulations with the density profile and abundance distribution as found in three-dimensional hydrodynamical simulations of VM of WDs with dissimilar masses. We generated model spectra (intensity as a function of wavelength) and light curves to find that the abundance distribution predicted in violent merger models matches the observations quite well. This work supports the double degenerate scenario as the progenitor of SN 2011aa. The work has been published in The Astrophysical Journal Letters, Volume 938, Number 2.

References:

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3. *Gamezo et al., Science, Volume 299, Issue 5603, pp. 77-81, January 2003.*

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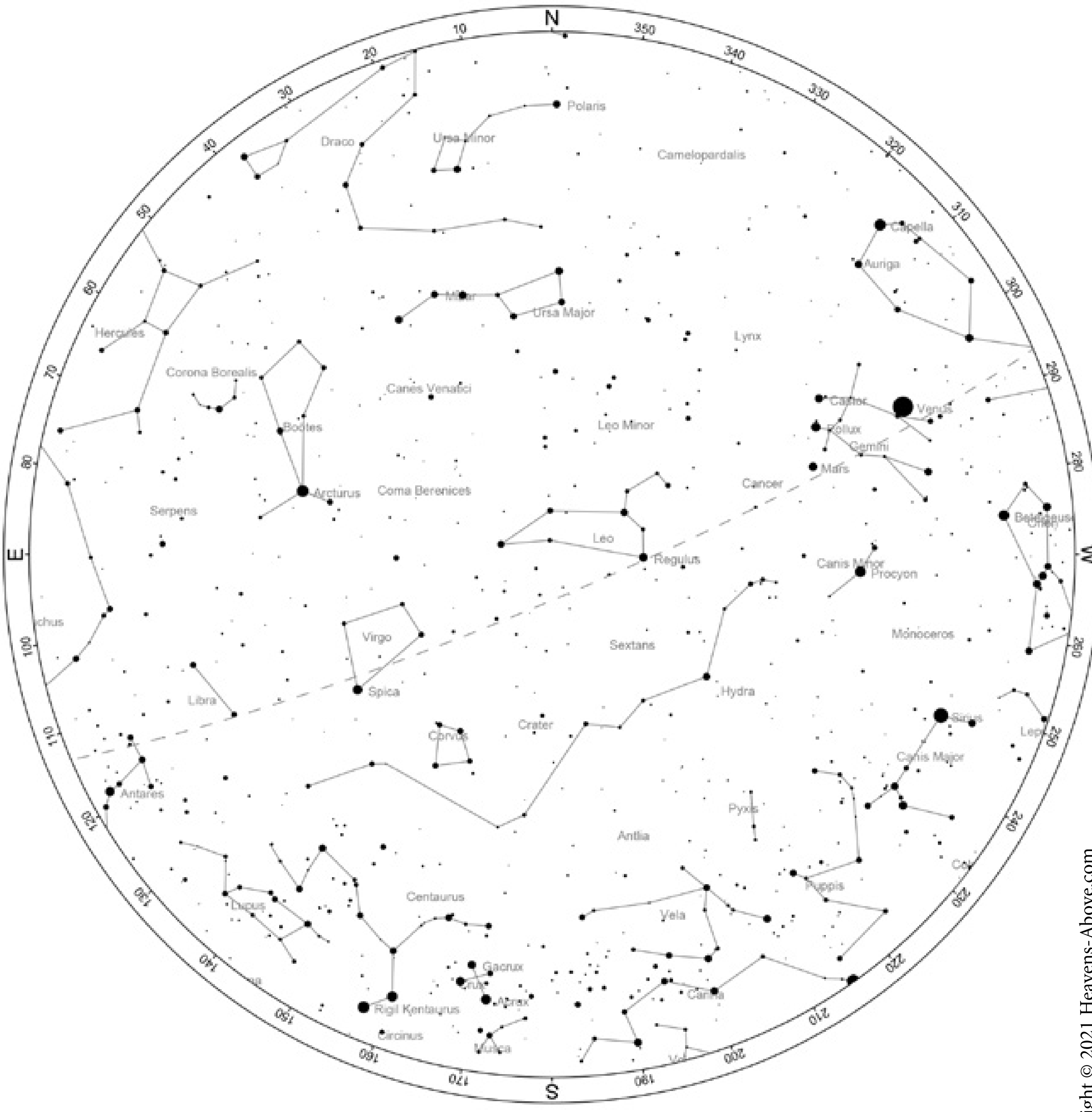
6. *Pakmor et al., Nature, Volume 463, Issue 7277, pp. 61-64 January 2010.*

Anirban Dutta is a final year PhD student at the Indian Institute of Astrophysics, who is trying to understand cosmic explosions by observations and radiative transfer modelling.

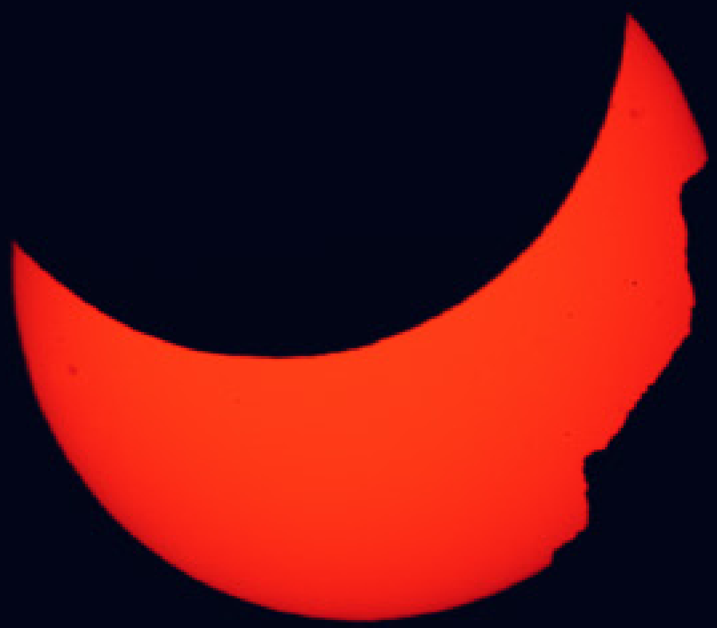


Skychart May 2023: (As on May 15, 2025. 20.00hrs Bangalore)

May 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5 Penumbral lunar eclipse	6 η-Aquariid meteor shower 2023
7	8	9 η-Lyrid meteor shower 2023	10	11	12	13 Conjunction of the Moon and Saturn
14	15	16	17	18	19	20
21	22	23 Conjunction of the Moon and Venus	24 Conjunction of the Moon and Mars	25 Conjunction of the Moon and Mars	26	27
28	29 Mercury at greatest elongation west	30 Venus at highest altitude in evening sky	31			

Credit: in-the-sky.org



On 25th October 2022, the world witnessed a wonderful celestial event – a partial solar eclipse. In India, the best view was from the Himalayas. The outreach team of IIA organized wide-spread activities including live streaming from the Hanle and Leh regions of Ladakh. This photograph of the maximum obscuration was captured from Leh by Mr Anand M N of IIA. The Sun hiding behind the Himalayan peak made the scene more dramatic.

Camera	:	Nikon D5100	ISO	:	800
Telescope	:	Skywatcher 8'' Dobsonian GOTO	Exposure	:	1/50 sec
Filter	:	1000 oaks solar filter	Location	:	Namgyal Tsemo, Ladakh