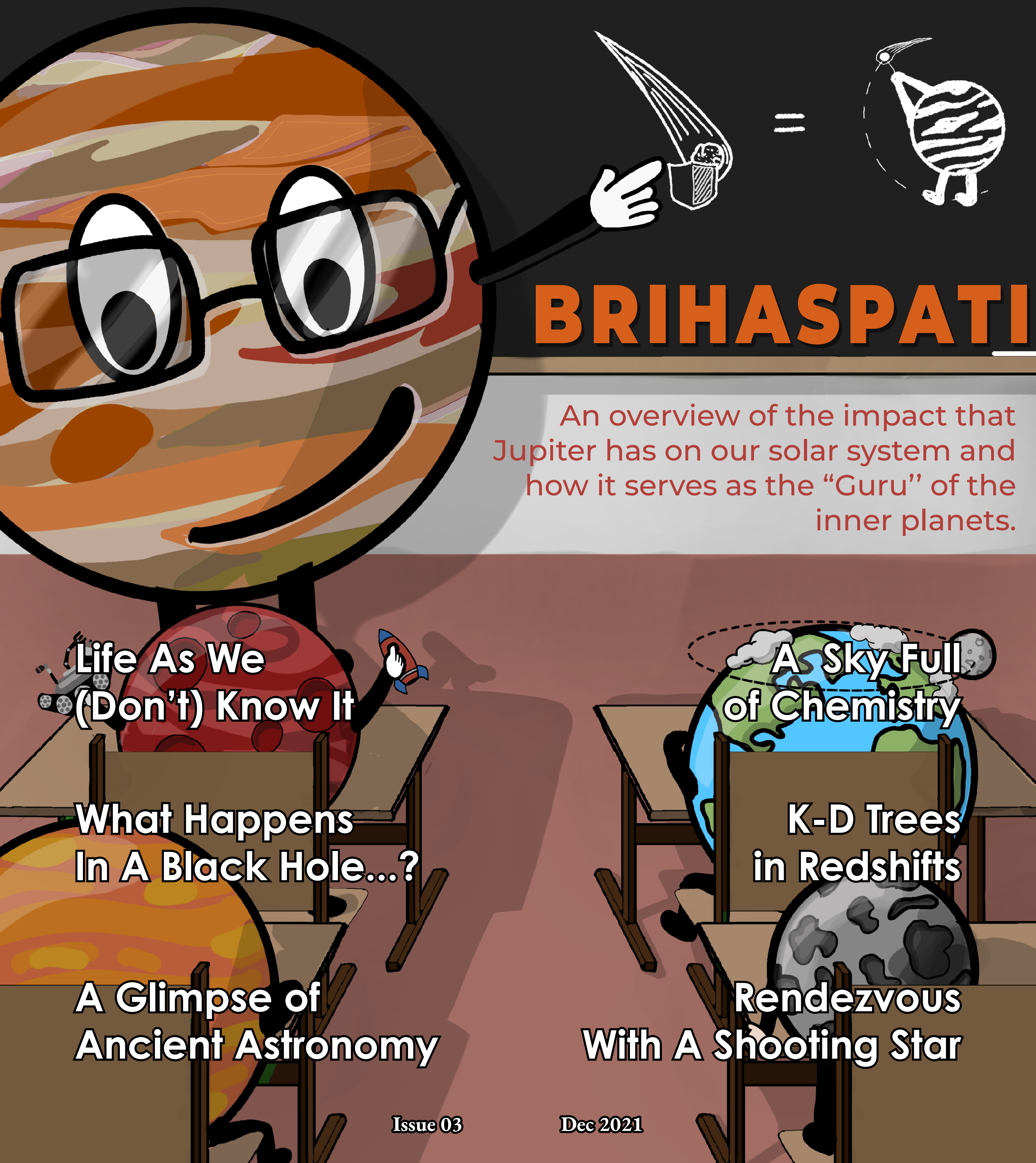
kshitij

NISER ASTRONOMY CLUB MAGAZINE



BRIHASPATI

An overview of the impact that Jupiter has on our solar system and how it serves as the "Guru" of the inner planets.

Life As We (Don't) Know It

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Issue 03 Dec 2021

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Kshitij
NISER ASTRONOMY CLUB MAGAZINE

The NISER Astronomy Club

Issue 03 | Dec 2021

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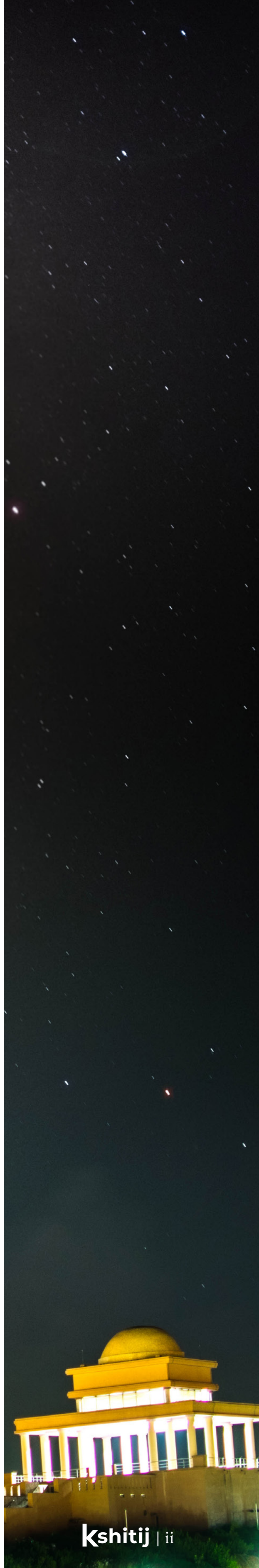
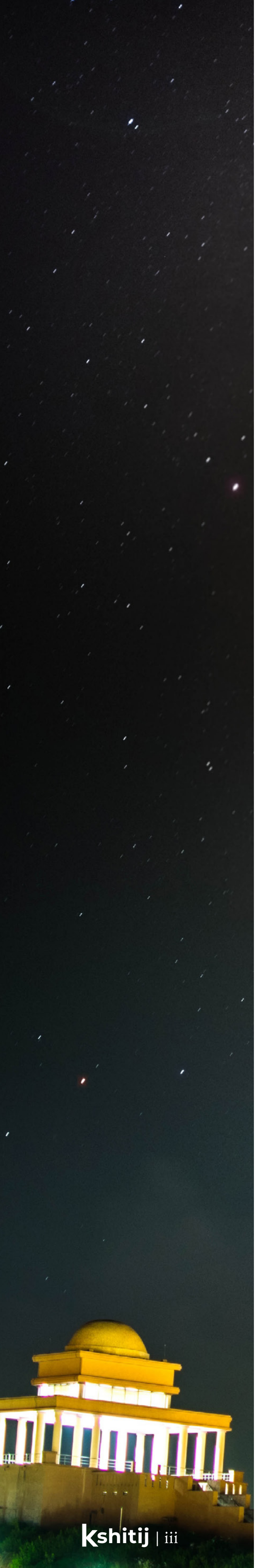
PROFESSOR'S NOTE



Dear Astronomy club members. It is a delight to see the third issue of Kshitij being released. It has already been one and a half years since the first issue, and most of us did not even notice. Congratulations for making it to these milestones!

I, being mostly interested in the terrestrial world, have not had a dedicated chance to stare upwards. Nature clubs, National Service Schemes, conservation volunteerism, forest monitoring and now climate change monitoring have been the major concerns on my list so far. And I must admit, pure joy is a rarity to find when you make yourself busy with worldly matters. As a famous astrophysicist has rightly said, "To confine our attention to terrestrial matters would be to limit the human spirit". Astronomy relieves that spirit as astronomy is joy at its best. Every young inquisitive mind has fallen for this science at some time in their lifetime. And there is immense support in the present world, both ideological and financial, for keeping this hobby, the latter of which at least was not available even a couple of generations ago. However Rome wasn't built in a day. The 'Rome' of astronomy, on that, has taken ages to establish, especially in the west. But incredibly, in only a couple of generations it has managed to enter our backyards, a feat which probably no other science has achieved. Our generation has indeed been privileged. These same privileges, however, have turned us unsuspecting towards a greater challenge that stares us in the face currently, and nothing in our recent history has prepared us for it. Sir David Attenborough narrates the story of Chernobyl and the message hits you like a truck - that the awe is not just in the discovery of the natural world and the realisation of the fragility of it but also in the recognition of the Midas in us who is doomed to destroy everything it touches. Anthropogenic climate change is a reality and there is no running away from it. Us climate scientists, unlike astronomers, have the uncomfortable jobs of being the whistleblowers of our own delinquencies. Also unlike astronomy, our job is far from being blissful, and is frequently dubbed as being 'moralising'. Thank God for the brave hearts like Galileo, Astronomy does not have to bear a similar type of burden any more.

On a lighter note, however dismal climate scientists may make it sound like, we are still talking about a very resilient system, the Earth, which will probably stand the test this time as well. I feel that the Phoenix in Greek mythology is 'life' itself as it endures and resurrects from all mythological floods, fires, world wars and climate changes; as has Chernobyl where the more robust life forms have already returned. Wisdom says so should be the case with life on Earth which has already survived several climate changes. However, it will once again take us ages to get the telescopes back into our backyards, and so hopefully the intelligentsia will spare some time for future planning as well :) And as bleak the chances may seem like, the intelligentsia world over is already recalculating their greenhouse footprints and revisiting their part in the problem. Astronomers, to my amazement, form one of the most active groups, outside the Earth science community, who are stepping up for the change - several articles in leading journals stand testament to their efforts. And evidently so, because all their un-



derstanding of the universe (using terrestrial instrumentation) hinges upon good air quality and the vulnerability of their sophisticated instruments necessarily exposed to the elements (which are changing as the climate warms). This is also because they are the first to understand that, so far, we only have one planet Earth! Therefore, it gives immense pleasure to see articles on astrobiology and astrochemistry finding their due space in astronomy magazines like *Kshitij*. So I congratulate the students for keeping a broad vision unlike their academic predecessors. I hope these articles will also cover in the future 'habitability' not just as an exciting prospect but also as the rarest find in this universe and how all stars have aligned to make it possible on our lovely planet.

This note wasn't meant to be that long, but if we've had the patience to reach the fourth paragraph of it, I am sure we will endure climate changes and keep our backyards safe from them. Good luck!

Dr. Jaya Khanna
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EDITOR'S NOTE

It has been almost two years since the world was struck by a microscopic virus that shook the lives of many ever since. As we look into the history of such pandemics over the past centuries, we have managed pretty well as the intellectual species of the globe all thanks to the technology and knowledge that has been accumulated to date. As the world attempts to recover from the pandemic so does our NISER family. With the most delight and contentment, we present to you the third issue of the NISER Astronomy Club's magazine, "Kshitij", an opportunity the NISER Astronomy Club (NAC) created for a free expression of love and passion for astronomy.

The recovery from the pandemic has been mentally and emotionally strenuous as we tried to academically catch up while dealing with the second wave of the pandemic which was a bit crueler than the first one. Hence came the challenges with it in creating content and time to work on the magazine. Although the club couldn't make as many memories, through events, like it used to, we still stayed connected through social networking tools. The club has continued to conduct talk sessions online and has been actively managing social media. NAC has also managed to pick up its glory and has been organising various events and competitions online with exciting cash prizes, something that has become scarce for a while. We have managed to conserve one of our objectives that is to have diversity in the contents. It was fascinating to see various topics of astronomy, astrophysics, astrochemistry and astrobiology explored in this edition of Kshitij. It was also a great honour for us to be able to interact with the Chairperson of the School of Earth and Planetary Sciences (SEPS) at NISER and share his valuable experiences and advice with the student community through Kshitij. There is also an astronomy puzzle that could give your brain good exercise. I express my sincere gratitude to the School of Earth and Planetary Sciences (SEPS), the School Of Physical Sciences (SPS) and NISER for supporting and encouraging the NAC family. The NAC finds itself honoured and motivated by the generous words of the Director of NISER, Dr Sudhakar Panda, mentioned in his speech during the convocation. I am forever grateful to the club for making me realise how fun it is to stargaze. I am indebted to the seniors of the club for their guidance and patience with us. I express my thanks to the members of the club who have shown interest in expressing themselves through Kshitij. I am grateful to the members of the magazine team for their work in making the magazine more polished and a visual delight to read. And last but not least, I am thankful to the readers of Kshitij for their love and support and we hope this edition will spark your interest.

Thank you.

D. Raga Sahiti
Chief Editor

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A Glimpse of Ancient Astronomy via Almagest

On 21st December 2012, the fourth of the "world age", each age consisting of a 5126 year cycle, was coming to an end as per the Mesoamerican Long Count calendar. While no classic Mayan literature forecasted a doomsday, people in various parts of the world had several interpretations. Some believed that humanity will experience positive spiritual transformations as a new age begins, others believed the world is to come to an end, while some communities in the countries sharing Mayan heritage had festivities to mark the end of an age and the beginning of a new one. All of these believers were in for a big disappointment as their eschatological beliefs had to submit to the sad reality of having to continue living in the same world.

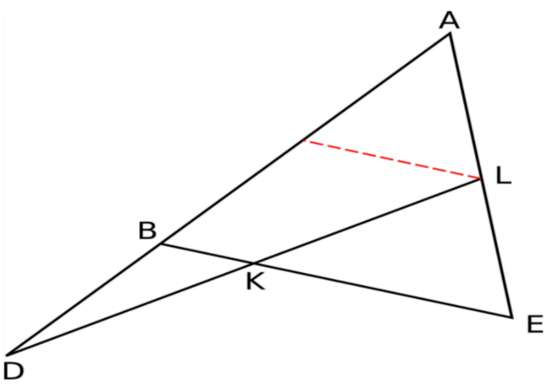
Figure I: A circular stone (3.7 metres in diameter) uncovered in Mexico City in 1790 depicts the Aztec calendar (one of the mesoamerican calendars). (Image credits: pixabay)

While it was funny to watch the news channels going on about it around those days, the information and explanations were inadequate and also, many times, misleading. I kept wondering how they made a calendar precise enough for more than a thousand years to come. Certainly, Astronomy is the oldest of the sciences. From around 33,000 year old cave and mammoth-tusk engravings depicting some prominent constellations, to star catalogues found in around 1000 BCE Babylonia, to the modern day space telescopes providing the data needed to understand galaxies and star formations, we have come a very long way. One cannot help but wonder how people would have done astronomy in the early days without much mathematical or technological advancements. The Egyptians are known to have possessed technical skills in observing astronomical events. This was in the 3rd millennium BCE. Around the same time the Indian civilisations were cataloguing astronomical events. Thousands of years later, historians would date Rig Veda to be at least as old as the astronomical observations mentioned in it. Several civilizations made contributions to astronomy in various ways. From initial cataloguing of annual events for time-keeping, to meticulously detailed cataloguing of several stars, eclipses and comets, and then proposing models to predict these events, we became better and better at it. The early Indian, Egyptian and Mayan civilizations had numerological models that could predict events to a fair degree of correctness. A numerological model, put simply, is where one knows periods of various cyclic events and then by considering various interdependencies, one is able to make predictions of those events happening again. The models to systematize and predict astronomical events continually improved as the mathematics and technology became available. The Greeks gave geometrical models, as opposed to the preexisting numerological ones. Such a model involves ascribing a geometry to the cosmos and then making calculations using geometrical methods at the disposal. A geometrical model cannot escape trigonometry even if one assumes a simplistic universe with bodies performing circular motions. This is because even simple calculations of rising times or setting times of celestial bodies would require one to know arc lengths on their paths and their projections on a given latitude where the observation is to be made. And as we shall see, the Greeks did use trigonometry, though not in the form we know today. When historians look back, they note Euclid's Elements and Appolonius's study of conics as epitomical contributions of Greeks. These systematic geometrical methods immediately saw applications in astronomy. In the second century AD, Claudius Ptolemy, an Egypt based Greek scholar published Almagest, a treatise on astronomy that would be used as a standard text for more than 1500 years to come. The success and popularity of the book also outshadowed several older Greek works like the heliocentric model of the universe by Aristarchus. More than a thousand years later, in the light of more precise observational data, new models were proposed and the Greek geocentric models were put away, but while they were in use, they were quite a scientific feat in themselves.

Figure II: Claudias Ptolemy Alexander (Image credits: Wikipedia)

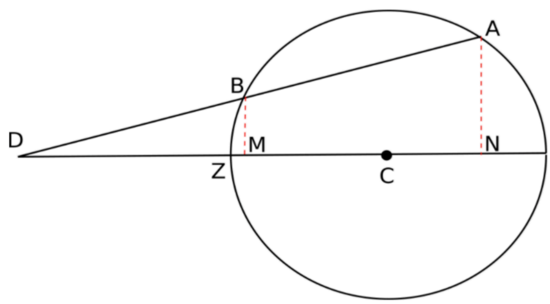
Almagest can offer an interesting read even to a high-school student, as the only knowledge the book presumes is of Euclid's Elements. The book prepares the reader with proofs of a few specialised theorems and then goes on to apply them to astronomical calculations with elegant geometric constructions. Following the book's pedagogy, without further ado, let's take a cursory look at some preliminary

Theorem 1



Using theorems on similarity of triangles, one can prove:
(EA:AL) = (EB:BK).(KD:DL), and
(EL:LA) = (EK:BK).(BD:DA).
Note the appearance of a similar looking triangle in figure (II).

Theorem 2



Again using similarity of triangles and elementary theorems on arcs of circles, one can prove:
BD:DA = Crd.arc(2BZ):Crd.arc(2ZA)

Notation: Crd.arc(AB) means chord corresponding to the arc(AB).

Figure III: Two theorems that are used to develop the working formulas for astronomical calculations.

theorems, and derive a working formula out of them. To an observer on Earth, the cosmos appears as a big far-away sphere concentric with the Earth, called the celestial sphere. Positions of objects can then be specified using two angles (θ, φ) as the two coordinates, and their paths will be arcs on the celestial sphere. These arcs need not be in the same plane and hence, having only the Greek geometrical treatise at their disposal, Greek astronomers could not have obtained relations between them as the available theorems were for figures in the same plane. However, they found a way around it by constructing chords in a special way as in figure (IV).

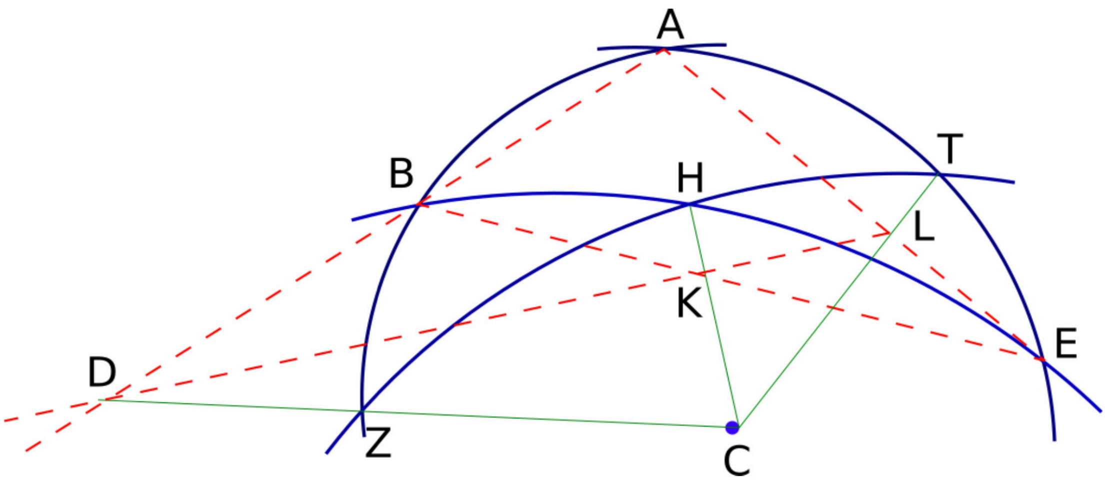


Figure IV: The diagram looks complex, but we need only see and appreciate that the arc(ATE), arc(ZBA), arc(ZHT) and arc(BHE) (all in solid blue line) are constructed on the surface of a sphere with centre at C, and when the chords are drawn in the fashion shown (dashed lines in red), the resulting figure (DBALEKD) lies in one plane (to convince yourself, analyse the planes of individual arcs and their chords. Refer Almagest for more details).

The construction is used to derive the following theorem, known as the Menelaus's theorem [1].
From theorem 1 in the figure (III):

$$EL:LA = (EK:KB).(BD:AD)$$

But from theorem 2 in figure (III):

$$EL:LA = Crd.arc(2ET):Crd.arc(2TA)$$

similarly,

$$EK:KB = Crd.arc(2EH):Crd.arc(2HB), \text{ and}$$

$$BD:DA = Crd.arc(2BZ):Crd.arc(2ZA)$$

Combining these, one obtains:

$$Crd.arc(2ET):Crd.arc(2TA) = [Crd.arc(2EH):Crd.arc(2HB)].[Crd.arc(BZ):Crd.arc(2ZA)] \qquad (1.a)$$

A similar derivation offers:

$$Crd.arc(2EA):Crd.arc(2TA) = [Crd.arc(2EB):Crd.arc(2BH)].[Crd.arc(HZ):Crd.arc(2ZT)] \qquad (1.b)$$

To go back and forth between chord lengths and arc lengths is an easy exercise in trigonometry, but the Greeks had to develop it tediously from the available theorems. Imagine a square inscribed in a circle of radius R, it is immediately clear that the four chords forming the square, each of length $R\sqrt{2}$ shall subtend four right-angles at the centre. Keep inscribing regular n-gons in the circle and you shall have a list of arc lengths for which you know the corresponding chord lengths (in some units). The Greeks developed a theorem here which provided a way to calculate the chord length corresponding to the sum and difference of two arcs, provided one knows the chords subtended by the two given arcs. They also gave a theorem to obtain the chord corresponding to half of an arc, provided one knows the chord of the given arc. Powered by these two theorems and the prescription of inscribing n-gons in a circle, they could construct tables of chord lengths versus arc lengths. These tables of chords so developed are equivalent to having a trigonometric table. Since you, a modern reader, is equipped with trigonometry, I shall skip the chord table calculations. You can use the formula:

$$Crd.arc(2\theta) = 2R\sin(\theta) \qquad (2)$$

For calculations in this article, we shall use circles of diameter 120 units.

Calculation of arcs between the equator and the ecliptic.

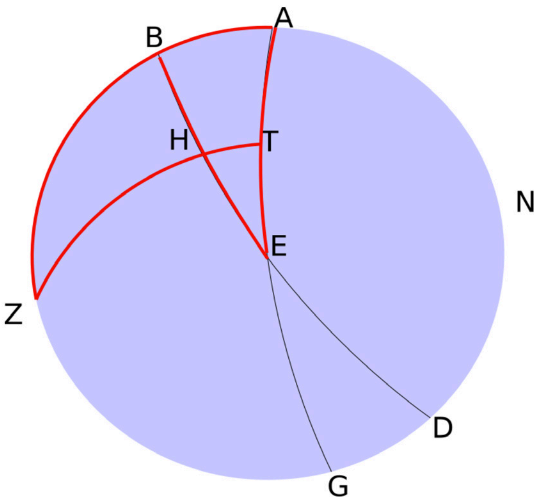


Figure V: A geometrical construction on the celestial sphere that allows one to use equation (1.b).

Suppose the shown sphere to be the celestial sphere (figure V), the points N and Z are the celestial North and South poles, respectively. Semicircle AEG represents the equator and BED represents the ecliptic, and the intersection of the two is the spring equinox at E. Evidently then, D and B are the summer and winter solstices.

The question at hand is to determine the angular separation of the ecliptic and the equator, given a day of a solar year. That is, to obtain arc(HT) given arc(EH).

Since the three points B, E and D mark three special points in a year, we can calculate where the Sun is on the ecliptic on a given day. For example, on 18th February, the Sun is 30 days away from the spring equinox (20th March) and hence, if H denotes the Sun, arc(EH) is roughly 30° (Sun travels 360° on the ecliptic in 365 days).

Applying Menelaus's theorem,

Crd.arc(2ZA):Crd.arc(2AB) = [Crd.arc(2TZ):Crd.arc(2TH)].[Crd.arc(2HE):Crd.arc(2EB)].

Note that arc(AB) = 23.5°, is the Earth's tilt. arc(AZ) = arc(ZT) = arc(EB) = 90° by construction, and arc(HE) = 30°, derived from the problem statement.

In a unit system where the diameter is 120 units, one can calculate the chords corresponding to an arc either from the chords table or using trigonometry (using equation(2)). For example, Crd.arc(90°) = 60 √2. Then the equation solves to give Crd.arc(2TH) ≈ 42 units (in which the diameter is 120). And hence, arc(TH) = 20°30'9'' on 18th February, and because of the four-fold symmetry in the problem, also on19th April, 24th August and 23rd October (each date being 30 days away from an equinox).

Calculation of longest/shortest day at a given latitude.

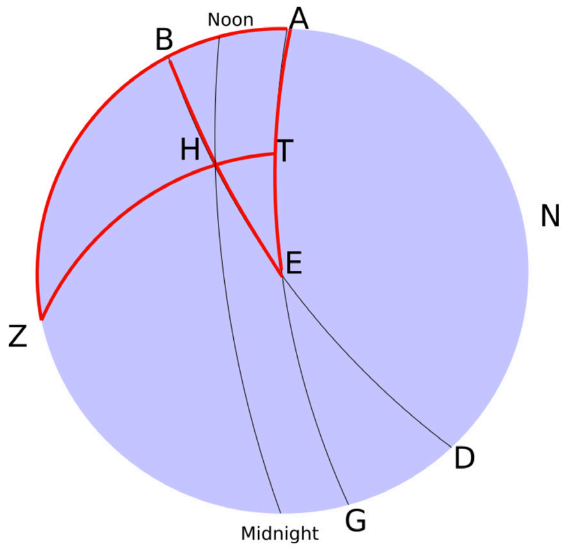


Figure VI: A geometric construction to find the length of the shortest day.

Consider the same figure, but this time with a different interpretation (figure VI). The circle ABGD represents the meridian at a given point on the surface of the Earth. (The meridian at a place, by definition, is a great circle passing through the poles N and Z, and the nadir at the place.) The arc(AEG) represents the eastern half of the celestial equator and arc(BED) represents the eastern half of the observer's horizon. The point E is the true east, and similarly B and D are true south and north in the plane of the observer's horizon.

Elevation of the pole star from the horizon is equal to the latitude of a place, hence given the latitude, we know the arc(DN).

To calculate the length of the shortest day, one has to note that a day will be the shortest when the Sun rises farthest south from the true east, at the winter solstice. Hence if H is the point of sunrise on the day of winter solstice, then arc(HT) is ≈ 23.4°, the maximum arc between the ecliptic and the equator. This day falls short from a day at the equator by an amount equivalent to the time taken in traversing arc(2TE). This is because while arc(TE) rises from the horizon, the corresponding arc on the Tropic of Capricorn (Sun's celestial latitude for the day) lies beneath the horizon. This happens again in the evening, hence the problem statement at hand is to find the arc(2TE) given arc(DN).

Let the latitude be that of NISER, 20.17° N. Then, arc(2ZB) = arc(2DN) = 40.34° $\Rightarrow$ Crd.arc(2ZB) $\approx$ 41.38 units. Arc(2AB) = 139.66° $\Rightarrow$ Crd.arc(2AB) $\approx$ 112.64 units.

Arc(HT) = 23.436° $\Rightarrow$ Crd.arc(2HT) = 47.73 units, and arc(2ZH) = 133.127° $\Rightarrow$ Crd.arc(2ZH) = 110.10 units.

Arc(2EA) = 180° $\Rightarrow$ Crd.arc(2EA) = 120 units.

Using the above data in: Crd.arc(2ZB):Crd.arc(2BA)=[Crd.arc(2ZH):Crd.arc(2HT)].[Crd.arc(2TE):Crd.arc(2EA)] gives Crd.arc(2TE) = 19.11 units $\Rightarrow$ arc(2TE) = 18.33°.

Since the Sun travels 360° on a celestial latitude in 24 hours, the 18.33° will be covered in 73 minutes. The shortest day is therefore around (720 - 73) minutes = 10 hours 47 minutes long. As can be confirmed from various internet sources, the shortest day at NISER's latitude is indeed 10 hours 54 minutes long. The small error is mainly due to the atmospheric refraction which makes the Sun rise 2 minutes earlier and continue to appear two minutes after sunset.

In fact, daylight hours on any given day and latitude can be calculated in the above manner by taking the Sun to be in the appropriate celestial latitude. The latter can be known with the first calculation, that gives the angular separation between the Sun's apparent path on a given day, and the equator.

References

1. Almagest by Claudius Ptolemy, translated and annotated by G. J. Toomer.

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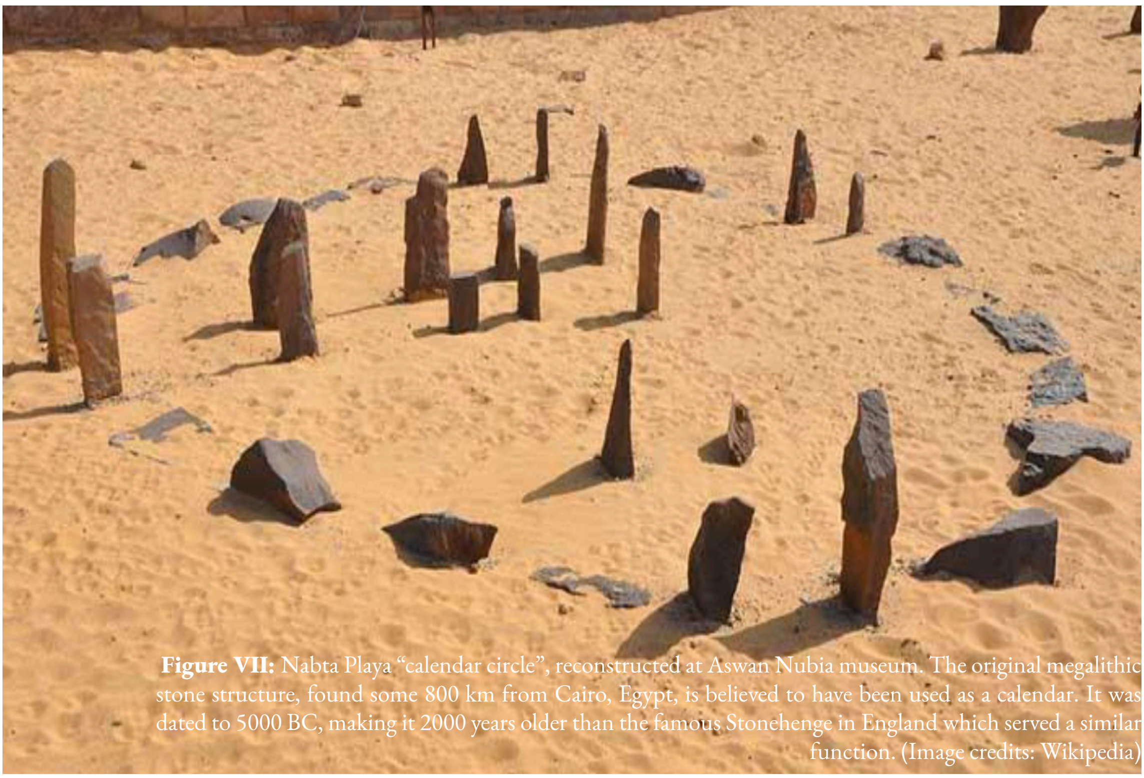


Figure VII: Nabta Playa "calendar circle", reconstructed at Aswan Nubia museum. The original megalithic stone structure, found some 800 km from Cairo, Egypt, is believed to have been used as a calendar. It was dated to 5000 BC, making it 2000 years older than the famous Stonehenge in England which served a similar function. (Image credits: Wikipedia)

K-D Trees in Redshifts

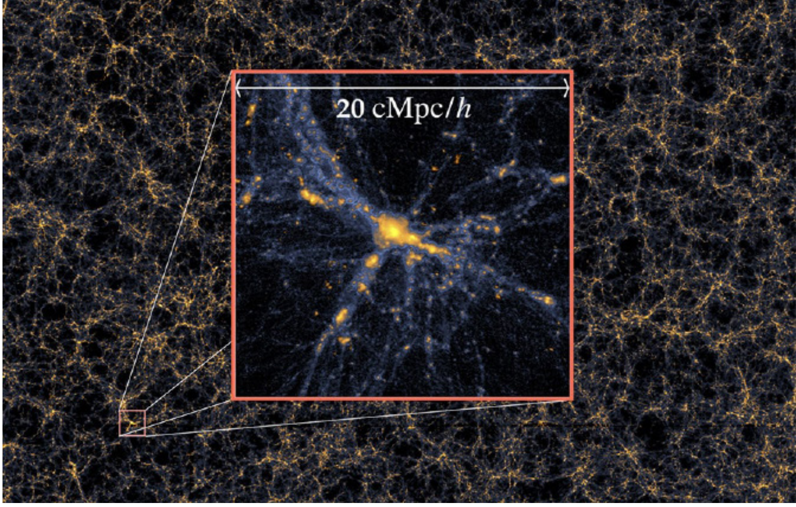
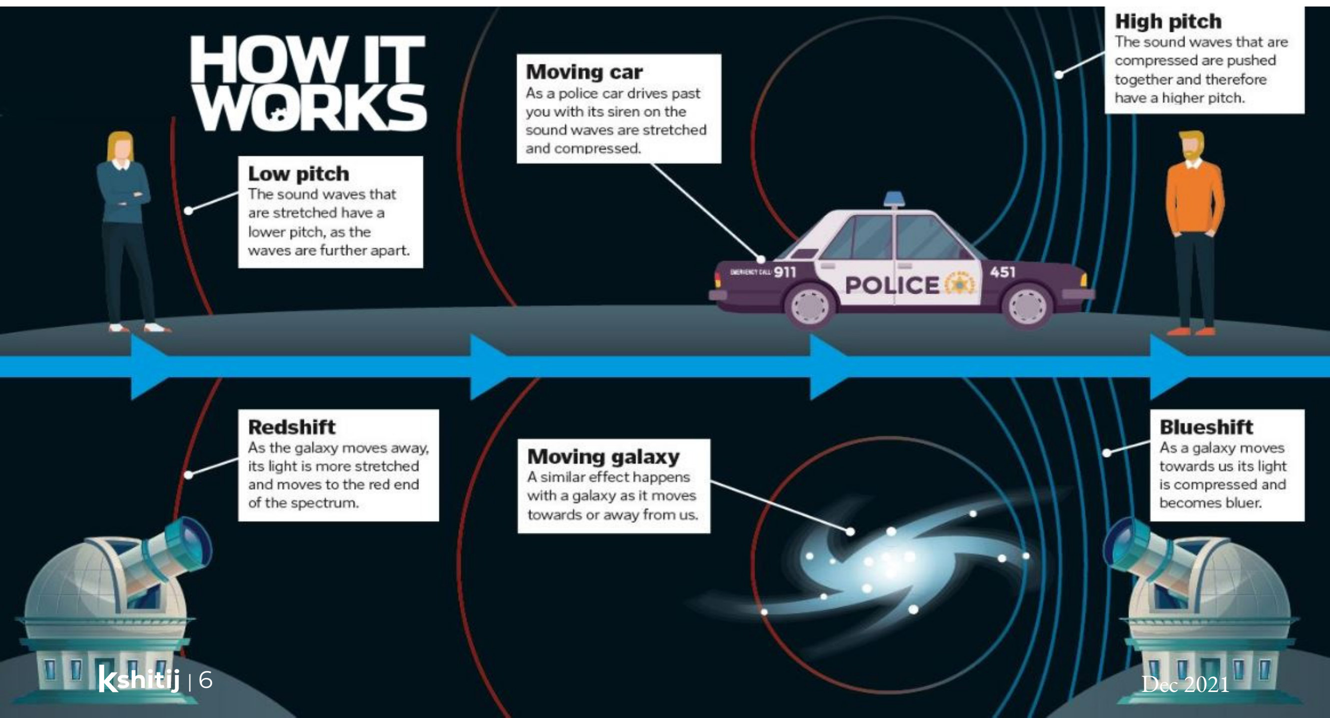


Figure I: Simulation of a region of space 100 million square light years. (Image credits: Carnegie Mellon University)

Astronomers use redshifts to measure how the universe is expanding and thus determine the distance to our universe's most distant (and therefore oldest) objects. Photometric redshifts, the recessional velocity of such astronomical objects, are important for many scientific works and investigations related to them, such as estimating their distances from the Earth. The redshifts are estimated by measuring the intensity of light radiated by the objects or the radiant flux, which is the energy crossing a unit area in unit time(unit, joules/m2/s). This technique is called photometry. It was developed in the 1960s and by the 1980s, it was replaced by the use of spectroscopy to observe the wavelength of the spectrum resulting from the absorption or emission of light from the object. [1]

Often, the data we collect from those techniques contain inaccuracies that can produce errors in the redshifts, and it becomes a necessity to identify and eliminate these errors. Now, how to do this? With advancements in computational techniques, more ways have evolved to minimize those inaccuracies that can produce redshifts with a much lower range of errors. Here we shall discuss the use of something known as the K-D tree algorithm, which

Figure II: The difference between redshift and blueshift. (Image credits: Future PLC)



can be used to organize the input data used in finding redshifts. This is done by analysing the photometric data from the galaxies and organizing and partitioning them using the K-D tree structure, and then using an algorithm to efficiently process the required data. Since the method involves some advanced astronomical and computational processes, we will keep the discussion simple.

There are certain aspects that we need to be aware of. The data collected from the sky surveys form the basis for the process of finding out redshifts. The sky survey is done by different survey organizations. We may later take an example of the analysis of the data from one such organization, Sloan Digital Sky Survey (SDSS).

Indexing the data

As there are large amounts of data associated with the spectral measurements of galaxies, there comes the challenge of handling multiple terabytes of data. Spatial data, or the data associated with any location in space, requires data structures for indexing so that we can access any spatial object efficiently. In simple terms, indexing is a technique used to efficiently process a query, hence optimizing the performance of the database.

Spatial data can be in different forms, be it in points, lines or regions in the space. The spatial index is a data structure that is used by spatial databases for indexing. Most of the time, the scientific queries are related only to a fraction of the whole data volume and concerned with only a finite volume of 3D space. An indexing technique is considered good if it reduces the data volume that needs to be processed for our query. There are several data structures that serve this purpose. The K-D tree is one such example.

What is a K-D tree?

It is important to know the definition of a *tree* before we further proceed. Formally, a tree is defined as a finite set of one or more nodes such that: (1) There is a designated node called the *root*. (2) The remaining nodes are partitioned into n ≥ 0 disjoint sets T_1, ..., T_n where each of these sets is a tree and called subtrees of the root. For example, if we have set S ={8, 9, 4, 1, 3, 5, 10, 7, 2, 6} and if we choose the root to be 8 and the number of partitions to be 9, then the rest of the nodes from set S forms subtrees.

As we can see, a tree is a hierarchical (or nonlinear) data structure and so, it becomes convenient to search,

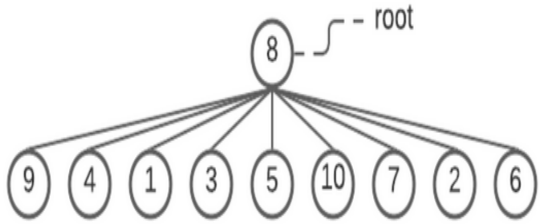


Figure III: A 2-D structure. [2]

manipulate and analyse any information. A K-D tree (short for K-Dimensional tree) is a space partitioning binary search tree where data in each node is a K-Dimensional point in space, i.e., the location of any point can be described with K orthogonal axes. For example, a 2-Dimensional K-D tree can be called a 2-D tree.

The data points in a K-D tree space are arranged in such a way that whenever a query arrives requesting a list of all points in a neighbourhood, the query can be answered quickly without the need to scan every single point.

A non-leaf node (node that is further split into other nodes) in the K-D tree divides the space into two parts, called half-spaces.

In a K-D tree with k levels as 0, 1, 2, ...,k-1, the dimension d of any level i is given by $d = i \text{ modulo } k$, or the remainder of the division of i with k. This dimension is also called the cutting/splitting dimension. At each step, while traversing through the tree, we compare the nodes at each level at the splitting dimension. If it compares less than the current node, we proceed and branch to the left. Else, we branch to the right of the current node.

We will try to illustrate through a simple example. Let's take a data set S in 2D space, S = {(8, 6), (10, 1), (5, 8), (9, 7), (2, 1), (3, 5), (1, 7), (7, 10), (2, 9), (6, 2)}.

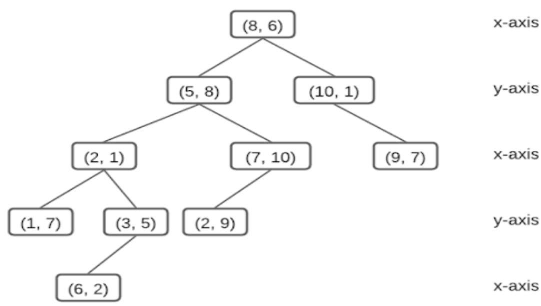


Figure IV: A 2-D tree constructed from set S. [2]

At level 1, the splitting dimension is x and a comparison occurs between 10 of (10,1) with 8 of (8,6) at the x-axis. As 10 is greater than 8, so (10,1) branches to the right. At the same time another comparison between (5,8) and (8,6) occurs and as 5 is less, so (5,8) branches to the left.

This procedure gets repeated recursively and the tree forms with the sorted data. As we are talking about spatial dimensions here, let's visualize this data in the corresponding 2D space. (This is a basic two dimensional visualisation. The data structure works in higher dimensions.)

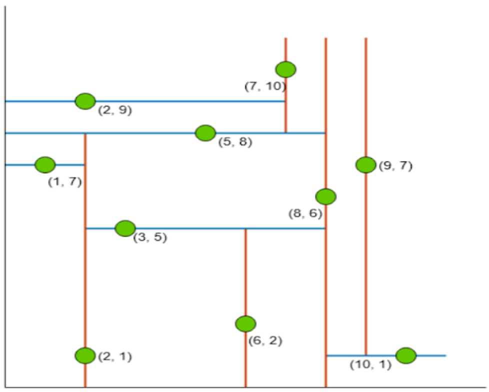


Figure V: Set S visualised in 2-D space. [2]

Here, in the above diagram, let's take red and blue lines to partition the region. The red lines partition the space in x dimensions and the blue lines partition it in y dimensions. This is created from the above tree, and we have now sorted and indexed this data. The 2D space as a whole is getting partitioned here, and that's why the K-D tree is also called the space partitioning data structure. We can apply this to any number of dimensions. Here, the blue and red lines partition the space into different regions and are called hyperplanes. A hyperplane is a plane of dimension one less than that of its ambient space [3]. For example, the above space is 2 dimensional, and so the hyperplanes or the red/blue lines are 1 dimensional.

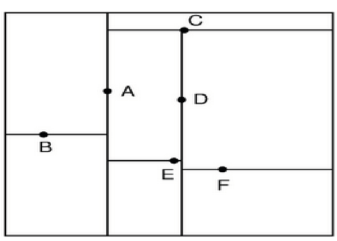


Figure VI: The decomposition of a K-D tree in space.

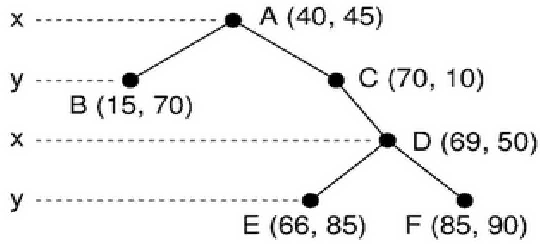


Figure VII: The K-D tree for the previous region.

Here is another example of the formation of a K-D tree structure from the data set, P = {(40,45), (15,70), (70,10), (69,50), (66,85), (85,90), (66,85)}.

Now, as we partition our input data, what if we are required to find the data points that are similar to a given point?

This can be done by a Nearest Neighbour Algorithm, which aims to find the point in the tree that is nearest to a given input point.
The searching algorithm proceeds as follows:

1. It starts with the root node and goes down the tree recursively. It goes left/right depending on whether the point is lesser or greater than the current node in the spliting dimension.

2. When it reaches a leaf/extreme node, it checks that node point and if the distance is better, that node point is saved as the 'current best'.

3. The algorithm then goes back and performs checks at each node. If that 'current node' is closer than the 'current best', then it becomes the 'current best'.

4. When the algorithm finishes the comparison at the root node level, then the search is complete [5].

Use in Astronomy

The surveys in modern astronomy are getting larger to expand the examination of fundamental cosmological questions (such as: What is dark matter? Dark energy? Is the universe expanding? Why is it expanding?). But that results in very large amounts of data that need to be organized and analysed.

Astronomical catalogues are a result of those surveys. They are databases where the rows correspond to the observed objects (stars and galaxies) and the column contains the measured characteristics of those objects such as position, shape, luminance, etc. An operation that Astronomers perform on the catalogue data is catalogue cross-matching. This means checking whether the measurements from two or more catalogues correspond to the same object [6]. One of the ways that astronomers can classify objects without spectroscopic data is to examine their colours (the difference in brightness between two filters), but sometimes different types of objects can have similar colours. For example, stars and quasars (a massive celestial object of very high luminosity found in the centres of some galaxies) are mixed in the spectral data obtained from spectroscopy due to similarity in colours and there is no clear linear boundary to separate them, though the two entities are different and are at different distances. When astronomers analyse telescope images, they check whether newly observed objects appear in the catalogue of known objects.

Since positions of objects may change slightly due to atmospheric and optical distortions, astronomers need to retrieve close approximate matches. The current astronomical catalogues, e.g. Sloan Digital Sky Survey, contain about 230 million objects, and a straightforward linear matching would be impractically slow. The computational complexity of conventional cross-match algorithms is O(N2), issues such as memory limit and speed bottleneck occur and make the cross identification infeasible [11].

Here the K-D tree algorithm comes into the picture as it partitions the point data set into different regions by hyperplanes (as discussed above) and stores the partitioned data in a binary tree. That is how it can be used to identify the neighbours of the desired location (through the Nearest Neighbour Search algorithm) and classify the astronomical object from huge catalogues (the data from the sky survey).

Now we have an idea of how to take care of and index the huge data from the databases. But what about those astronomical objects themselves? What should we do when we need to analyse a particular region of a galaxy? There is a method called The Hierarchical Triangular Mesh that is used to divide a spherical surface into triangles of similar shape and size. It comes along as a very efficient indexing method for objects with spherical coordinates.

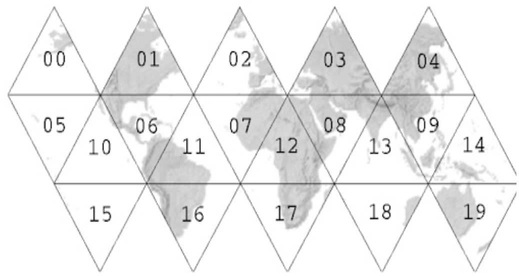


Figure VIII: Example showing the top-level triangle faces of an icosahedron corresponding to the surface of the earth; the continents are highlighted [9].

This is a powerful tool to find objects on the sphere by their location [7]. Given below the right side is an example of the implementation of The Triangular Mesh on the surface of the earth. This picture shows the top-level triangle faces of an icosahedron (polygon with 20 faces) corresponding to the surface of the earth [9].

As we need a fast access to astronomical catalogues, these catalogues can be partitioned into hierarchical triangular meshes and stored for the rest of the analysis. It has been shown that the K-D tree can be helpful in increasing accuracies in redshifts [10]. Hsieh et al. (2005) used the K-D tree algorithm to divide up their sample to improve the redshift accuracy of galaxies [11].

So, in case we want to find out accurate redshifts, we filter out a part of the bulk data by fixing certain criteria and then partitioning that data through the algorithm. We analyse parameters such as velocity dispersion (dispersion of velocities about the mean velocity of galaxies) with different coloured scenarios and try to minimize the errors in the redshifts.

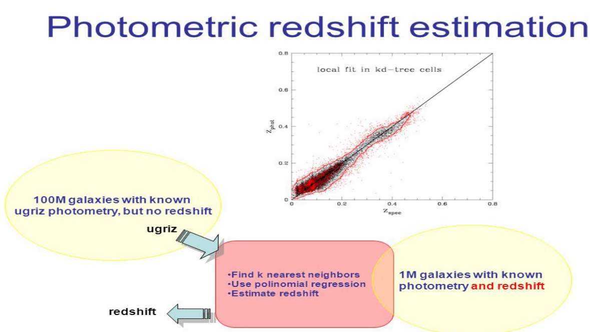


Figure IX: Photometric redshfit estimation through a photometric system with objects from SDSS data set [12].

A photometric system is a set of well-defined passbands(the range of frequencies and wavelengths that can pass through a filter).

Here, "ugriz" is short for U-band, G-band, R-band, I-band, and Z-band and designates a part of light of the electromagnetic spectrum [13].

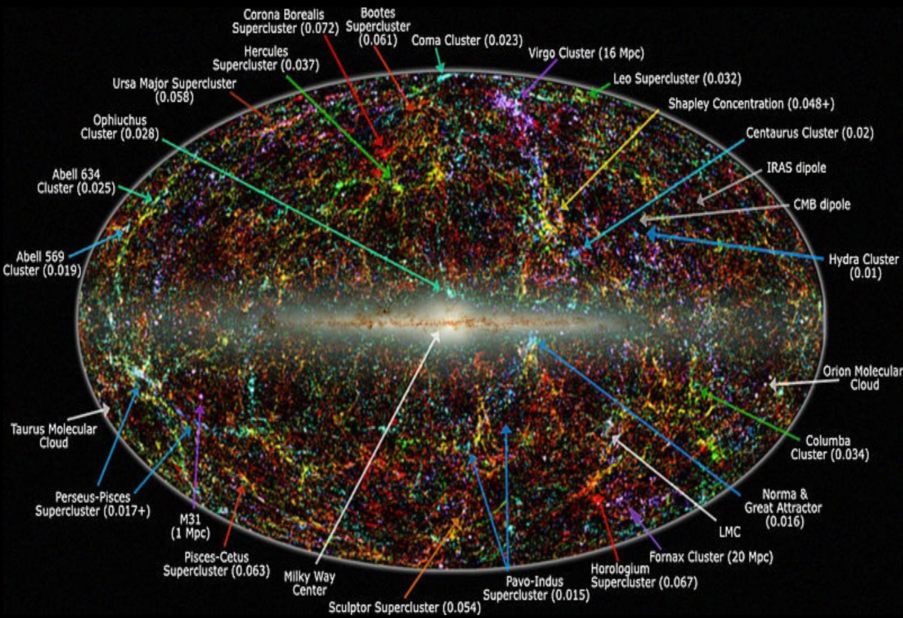


Figure X: Universe map in SDSS galaxy redshift survey. (Image credits: SDSS)

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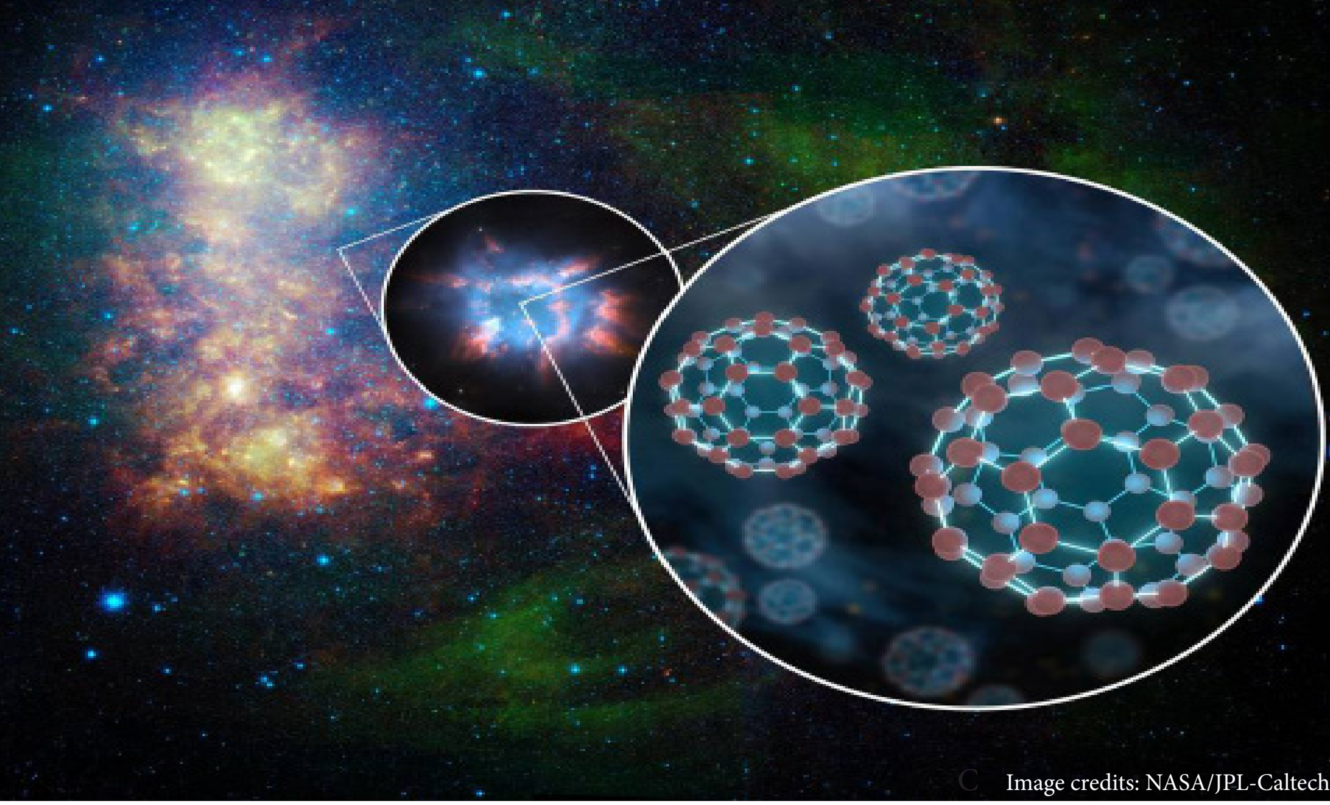
Image credits: NASA/JPL-Caltech

A Sky Full of Chemistry

The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of star stuff.
- Carl Sagan

Atoms are the basic building blocks that make up matter. The universe around us exists in its full glory, not because of magic or chance but by the step-by-step building of the chemical complexity of stars, planets and galaxies. If you look outside your window right now at the sky; every cloud you see, every star you spot, even the space between the stars, the vast interstellar medium is made up of countless tiny atoms which have come together on a chemical basis to exhibit multitudes of cosmic reactions. At the core of these stellar processes lies Astrochemistry.

Astrochemistry is the study of the formation, destruction and excitation of molecules in astronomical environments and their influence on the structure and evolution of other astronomical objects. It deals with all the molecules and reactions happening in space and how these reactions lead to multiple fascinating stellar affairs.

Earlier, it was believed that the interstellar matrix was nothing but a giant vacuum with planets and stars sprinkled here and there. At such high densities and temperatures of interstellar space, no chemistry was thought to occur. In fact, the only foreseeable elements known to exist in space were hydrogen and helium. But this spell was broken in the mid-1960s, with the discovery of very simple molecules in the space like ammonia, formaldehyde and even carbon monoxide. Today we have detected the presence of over 180 different molecules, including Large Polycyclic Aromatic Hydrocarbon molecules (PAHs) [1], Fullerenes such as C_{60} and even some prebiotic molecules [2] that are thought to be involved in the processes leading to living organisms.

The discovery of such complex macromolecules in space revolutionized the understanding of chemical evolution in space. It was proposed that the massive amounts of hydrogen available in space, fused into helium and other elements during the birth and death of stars.

Astrochemical Evolution in the Birth and Death of Stars

Early in the universe, before stars and planets existed, giant clouds of hydrogen and helium were formed [3]. These clouds then slowly collect enough mass and owing to their gravitational force, turn into extremely dense balls of gas. In other words, they formed stars.

This newly formed star experiences such strong gravitational force that it is in danger of collapsing in on itself. This inward pull of gravity is counterbalanced by the outward push generated by the fusion of Hydrogen nuclei into Helium, which prevents the star from collapsing in on itself.

Eventually, when the young star runs out of hydrogen, its core once again begins to collapse. The extreme forces on the core cause it to heat up [3]. Soon, enough temperature and pressure are established at the core to begin the fusion of helium into carbon and oxygen. Successively, the star fuses elements to form newer ones.

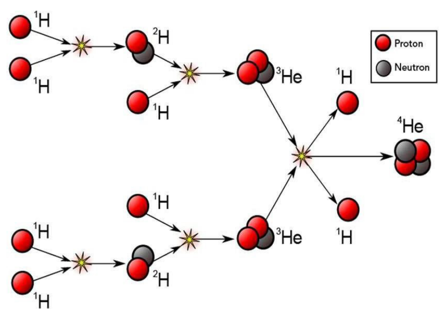

Figure I: Nuclear fusion showing the fusing of protons and neutrons to form helium [5].

This uninterrupted nuclear fusion along with keeping stars from collapsing creates new elements that had never existed before! Depending on their size, stars can create elements through fusion, up to iron, which has an atomic number of 26.

The elements heavier than iron come from something known as the "Death of Stars". To understand this phenomenon, we have to look at the lifecycle of a star [3].

How a star lives and dies depends on how large it is. The smallest stars, called brown dwarf stars, are unable to sustain the fusion of hydrogen because of their low mass, and are often called "failed stars." The next big stars, called red dwarf stars, have very long lives but they too eventually collapse, to become white dwarf stars, which cool off to become black dwarf stars.

When mid-sized stars run out of hydrogen, their cores contract and heat up. The outer layers of gas expand and the star becomes a red giant star. Ultimately when its core cools down, the remaining gas floats into space, forming a planetary nebula.

The largest of stars first become blue supergiant stars before dying dramatically. In fact, they create the biggest explosions in the universe when they collapse. These explosions, known as Supernovas, are the site of formation of the rest elements [3,4]. The initial explosion of a supernova has so much energy that it can split atoms apart, sending protons and neutrons flying into space. In the moments following the explosion, these particles crash into each other with enough energy to fuse back together.

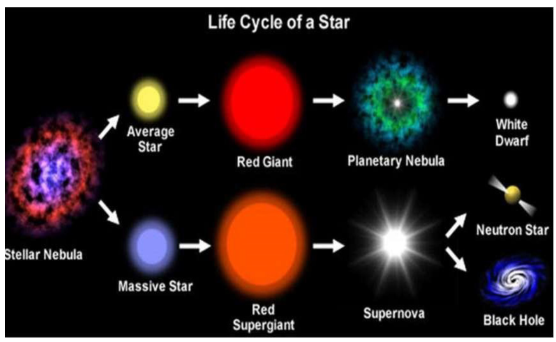

Figure II: Stars can transition into different life cycles depending upon their masses [5].

Light elements continue colliding with protons and neutrons in this way, constantly growing larger and larger by a process known as nucleosynthesis. The nucleosynthesis that occurs during the explosion of a supernova produces elements with a higher atomic number than iron. When the first stars died out this way, brand new elements, including gold, were formed. Eventually, those elements ended up here on Earth.

Astronomer's Periodic Table

Most of the elements have been traced in space though all of them are not present in equal proportions. Hydrogen is the most abundant. Whereas, some very heavy metals are not even present. And some, if present, are present in very negligible quantities. To keep a track of these diversities, Astronomers have something called as the astronomers periodic table, where they have classified all the elements present in space in the order of abundance.

Hydrogen and Helium are primordial elements, large quantities of which were produced in the early stages of the universe. The rest of the elements are categorized as "metals".

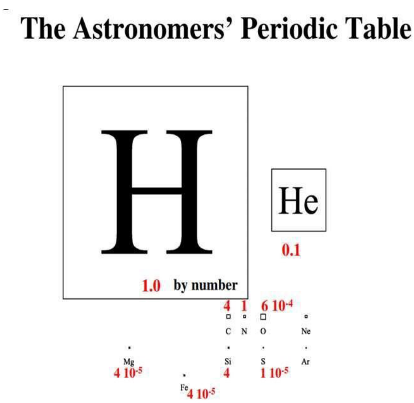

Figure III: Astronomer's periodic table. [6]

Since Hydrogen is the simplest and most abundant element in space, it was thought that the Hydrogen molecule will be the first one formed in space. Contrary to the-then belief, it was Helium Hydride (HeH^+) [7]. Although it is of limited importance on earth today, it marked the beginning of chemistry in the cosmos. Though Helium Hydride stopped forming after about 100 million years, these molecules were instrumental in the formation of the first stars.

Detection of the stellar molecules

One of the techniques used for making chemical discoveries in space is Infrared spectroscopy. Spectroscopy is the study of the absorption of light and other radiation by matter [8]. This process is highly dependent on the wavelength of the radiation.

The IR spectroscopy theory utilizes the concept that molecules tend to absorb specific frequencies of light that are characteristic of the corresponding structure of the molecules.

For example, in water molecules, electrons within the O–H bond are not equally shared. They are more closely attracted to oxygen than hydrogen. As electrons are negatively charged, this leads to a slight negative charge on Oxygen and a slight positive charge on Hydrogen. It is this charge difference that enables the IR light to be absorbed by this particular bond, giving rise to a peak within an IR spectrum [9,10]. Different bonds within functional groups absorb light at different areas of the IR spectrum.

Since the wavelength of light absorbed is specific for a given molecule, looking at the spectrum we can identify the compounds present in a given sample.

Another technology that makes the discovery of interstellar molecules possible is Telescope. Progress in astronomy is very much driven by large telescopes equipped with highly sensitive detectors that allow investigation of clouds at a variety of wavelengths across the electromagnetic spectrum. The European Southern Observatory (ESO), Very Large Telescope (VLT), and the Keck and Subaru Observatories [1,10] provide the most powerful collection of 8–10 m optical-infrared telescopes on Earth.

Along with spectroscopic techniques, we also have rock samples from the moon and mars that are analyzed [11] in the laboratories to reveal more detailed information about the celestial body's composition and physical conditions.

Basic Reactions in the Cosmos

There are three main types of chemical reactions going on in space, as and where the physical conditions allow. These reactions are:
(i) gas phase processes between atoms, ions and molecules,
(ii) reactions taking place on the surfaces of bare grains,
(iii) accumulation of molecular ices on the surfaces of dust inside clouds.
Out of these, the reaction on the surface of bare grains is a fundamental process as it leads to the formation of hydrogen which is the basis of all the other elements

and reactions happening in space. All the interstellar reactions have been replicated in labs to provide detailed insight about the stellar chemistries.

(i) Gas phase reactions

Most of the interstellar gas is at such a low temperature that the direct combination of atoms into molecules is not possible because of energy barriers but in certain localized regions of higher temperature, the chemical reactions may proceed efficiently.

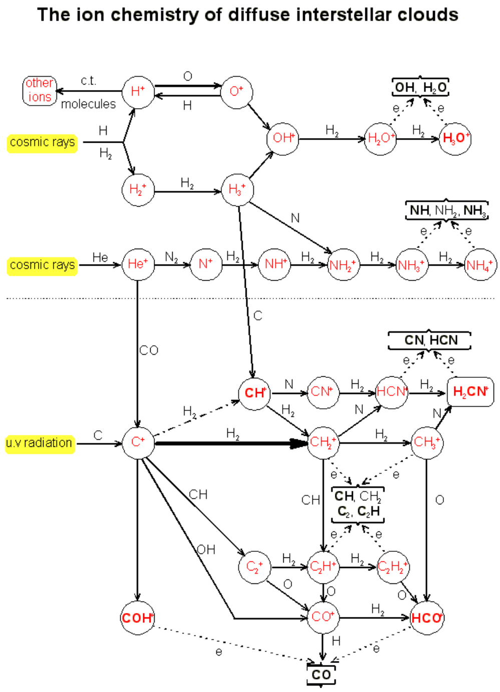

Figure IV: Ion chemistry of the interstellar clouds. [14]

These reactions are initiated by charge transfer between H^+ and O^+ which are quickly converted to complex cluster ions like H_2^+. OH^+, H_2O^+, H_3O^+ via a sequence of ion- molecule reactions [12,13]. This starts a series of reactions leading to the formation of CO, N_2, OH, and NH_3. Theoretically, the timescale to attain a chemically steady state for these processes takes several million years. So, this pathway comes secondary to all others [13,14].

(ii) Surface Processes on Bare Interstellar Grains:

Since the formation of stellar molecules through gaseous reactions is not rapid enough to compete with their fast destruction by starlight, there must be another way of the generation and propagation of these molecules. It has been accepted that H_2 and other molecules were formed in reactions on the surfaces of the bare dust grains of graphite, silicate, carbon or other particles that were present in the interstellar clouds.

Conditions similar to those in interstellar medium have been replicated in labs to see exactly how these reactions occur. The evidence suggests that the initial interaction is of a physisorption bond of the hydrogen atoms on the surface of graphite or silicates or interstellar ice [13]. The Hydrogen atoms collide with and stick to the surfaces of these grains. Multiple collisions of the bound Hydrogen atoms with incident Hydrogen atoms produces H_2 molecules with high efficiency.

There have been other experimental studies that indicate subsequent hydrogenation of nitrogen atoms takes place in a similar manner forming NH, NH_2 and NH_3 [15,16]. Hydroxides have also been obtained in similar conditions.

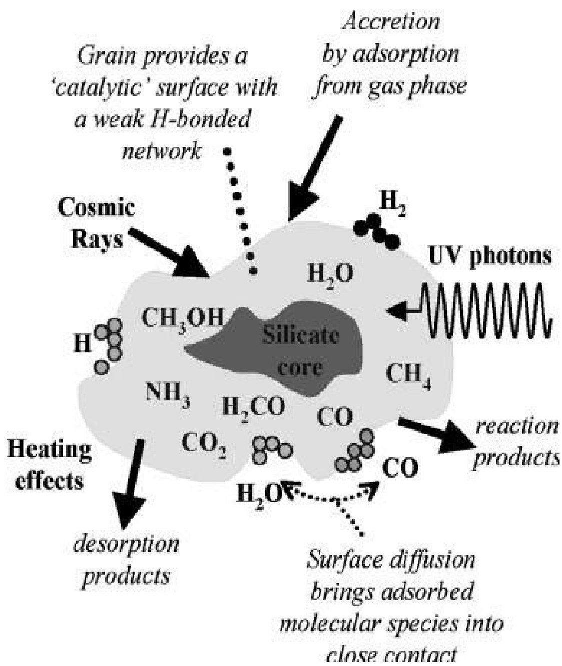

Figure V: Illustration of the makeup of an icy dust grain in the interstellar matrix and the typical energetic processes to which it is exposed [17].

Taking together gas-phase reactions with molecular hydrogen provided by surface reactions gives viable formation routes of many molecular species found in interstellar clouds. However, both these types of chemistries fail while arguing about larger molecules, the ones with up to 10 atoms. For instance, there is an abundance of propylene in space, which cannot be explained by any of the above methods and thus there is a need to explore another route.

(iii) The chemistry on interstellar ices:

In darker regions of the interstellar medium, dust grains collect chunks of ice containing simple molecules. These small, simple molecules can be used to build larger molecules. Under cosmic rays, water might be a source of the negatively charged hydroxide ion (OH^-), methane a source of the positively charged methyl ion (CH_3^+). They may combine to form methanol, CH_3OH. This methanol can become a source of hydroxy methyl radical CH_2OH^-, which might react with a methyl radical CH_3^+ to form ethanol, CH_3CH_2OH. Methanol might also be a source of the methoxy radical CH_3O^-, which could combine with methyl CH_3^+ to form CH_3OCH_3, dimethyl ether [13].

All these molecules have been detected in the interstellar medium. Thus, building of molecules on interstellar ice seems as a very plausible explanation of their existence. And in principle, quite complex species can be built with radical mechanisms under appropriate conditions.

Astrochemistry is deeply embedded in astronomy and chemical physics, helping us understand the physical conditions of exoplanets, other moons and shedding light through the chemistry occurring in space. This understanding of how molecules are formed and evolve might help to set the stage for understanding the emergence of life on Earth and elsewhere.

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(Image Credits: en.wikipedia.org/wiki/Jupiter)

BRIHASPATI

“I do not feel obliged to believe that the same god who has endowed us with sense, reason and intellect has intended us to forgo their use” - Galileo Galilei

As far as we know, Jupiter is that one planet which has affected almost everything in our solar system, ranging from small asteroids in the asteroid belt, comets at the extremities of the solar system, to the planets, and even the sun itself! Easily observable from the naked eye, it has had a reputation of challenging our current theories and hence enhancing our understanding of the solar system. With a telescope at hand, Galileo Galilei observed the four massive moons of Jupiter revolving around it; it became the first concrete evidence of the Copernican model, that every celestial body does not rotate around the earth. Like every other planet, it has revealed to us the mysteries of this solar system whenever we take a closer look at it.

As telescopes got more advanced and popular, astronomical observations increased tremendously and with a much better telescope at hand, Cassini was the first person to notice different bands and spots on Jupiter, the largest spot being the famous Great Red Spot. He also calculated the time period of rotation of Jupiter accurately within three minutes of the currently accepted value. Although, upon observing the data, he found in them some discrepancies, which he attributed to the speed of light being finite. But his traditional views made him discard his own conclusions, an example of how one's beliefs can bias their decisions even when they have concrete evidence against it. Of course, today, after theoretical justification and experimental verification, we accept that the speed of light is finite.

"It's like Jupiter and Earth are in a love-hate relationship."

Contrary to common belief, all the bands of Jupiter do not rotate in the same direction, a phenomenon that is not understood well enough [1] . Also, these bands do not rotate with the same angular speed and this phenomenon, called differential rotation, is common for all gas giants of the solar system. The dark bands are belts and light ones are zones (generally thicker than belts). Zones extend higher up in the atmosphere than belts. The primary reason why zones are lighter in color is because of ammonia and their altitude. No matter what the color of a cloud is, the presence of ammonia lightens that color. At high altitudes, atmospheric gases are cooler because they have dissipated heat in the process of rising to higher altitudes, hence being able to combine into small droplets to form clouds. Since zones lie at higher altitudes, they allow the formation of dense clouds of ammonia and hence have a light color. Being at a lower altitude, belts do not provide the right environment for ammonia to form clouds, which then dissipates towards zones and hence they appear dark.

Figure I: The physical scars of the cataclysmic collision of Jupiter with Shoemaker Levy-9 (Image credits: Hubble Space Telescope Team and NASA)

Another interesting observation about Jupiter is that it gives off more heat than it absorbs through sunlight! The reason is the Kelvin-Helmholtz [2] mechanism. The outer surface of a gaseous planet or star is cool because it is at a high altitude, radiation and some other phenomena. This leads to a drop in the internal pressure (because gas expands as it reaches high altitudes) but since Jupiter's gravitational influence is much stronger, it eventually shrinks. This compression causes the core to heat up, and this heat is then slowly dissipated as gases rise to the surface and continue the cycle. Hence it is the battle between pressure and gravity which causes the core to continuously dissipate heat. This may stop the moment the gravitational effect is not strong enough to cause enough compression to generate any heat. This may happen as Jupiter loses its mass by radiation and other phenomena. Jupiter is very much like a star. In fact, some sources even go so far as to claim that Jupiter is a failed star. In truth, it would need 75 times the mass it currently has to start nuclear fusion in its core and become a star [3].

A planet's mass is generally calculated through Newtonian mechanics. Specifically, one resorts to Kepler's Laws. Since the orbits of Jupiter's moons are almost circular, the orbital distance will simply be the radius of their orbits. It is proportional to the cube of the moon's orbital radius divided by the square of its time period. The mass of Jupiter is seen to be about 320 times the mass of earth. But considering the initial history of evolution of the solar system, its mass was expected to be less than the calculated one. Years of research, with the help of computer simulations, has revealed the possibility of a solid core inside of Jupiter. The only problem is that it doesn't exist in the way expected. NASA's Juno orbiter successfully entered Jupiter's orbit on July 4, 2016. Since then it has revealed crucial information about Jupiter that has caused a stir in the planetary sci-

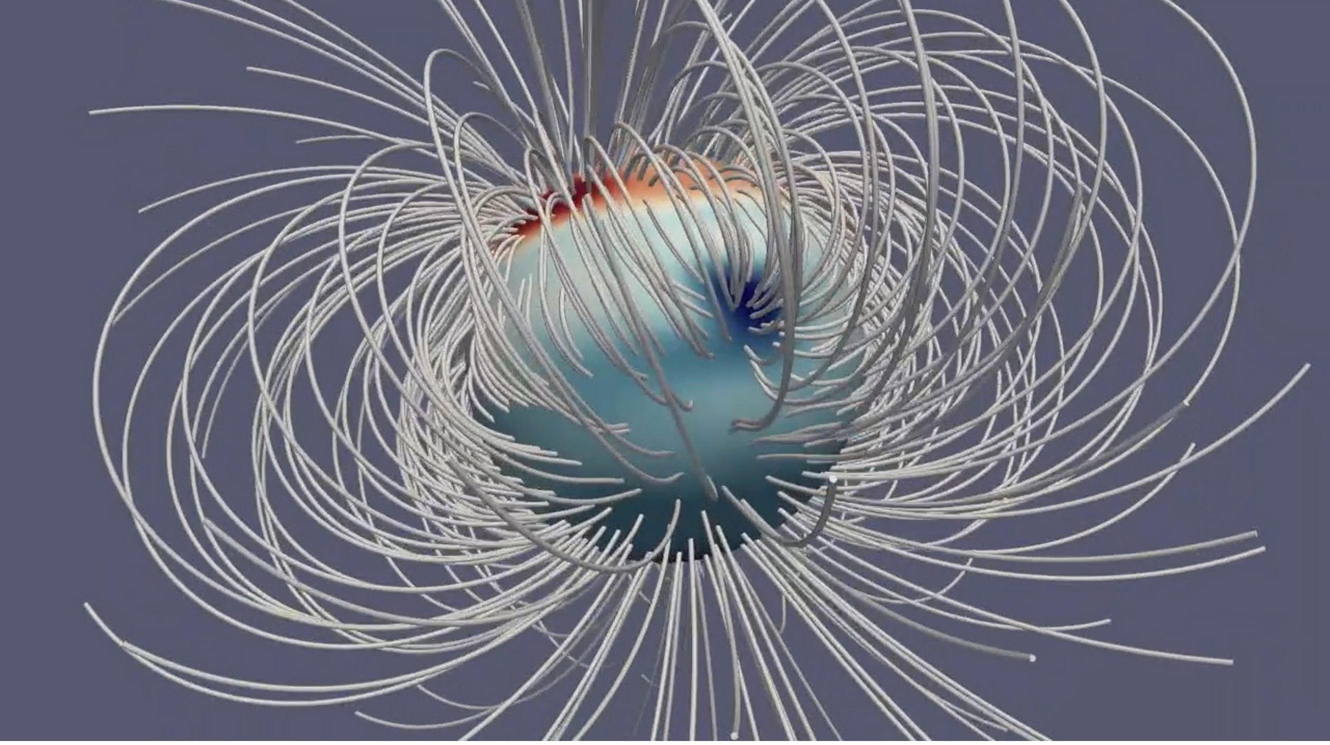

Figure II: Image demonstrating the North (red) and South (blue) polarity regions on the surface of Jupiter. A darker region indicates a larger magnetic flux (Image credits: NASA/JPL-Caltech/Harvard/Moore et al.)

ence community because of its incompatibility with the known theories. Juno found the core of Jupiter to be diffused, not solid. This certainly calls for modifications in our understanding of Jupiter. An interesting theory has been proposed, that Jupiter probably encountered a head-on collision with an object with approximately the mass of Earth during its formation, which shattered its core and mixed the heavy elements with the inner envelope [4].

Jupiter's mass is greater than twice the mass of all the planets of our solar system combined! It is so massive that its centre of mass with the sun lies outside the surface of the sun. But surprisingly, astronomical data of Jupiter-like exoplanets suggest that gas giants are generally much more massive than it. Surprises! Also, Mars is much less massive than expected. An explanation for these discrepancies is The Grand Tack hypothesis [5]. It proposes that after some formation at 3.5 A.U. (1 A.U. is Earth to Sun distance), Jupiter migrated to 1.5 A.U. and then reversed course due to gravitational interactions with Saturn, before achieving a stable orbit at 5.2 A.U. Saturn probably saved everything in the inner solar system from being engulfed by this gigantic planet and also stopped its growth. During its migration inwards to 1.5 A.U., where Mars is today, Jupiter must have engulfed a lot of mass in that region, hence limiting the growth of Mars.

Juno also observed the bizarre nature of Jupiter's magnetic field. Apparently, Jupiter has two south poles! There is a region near its equator that has some outward flux of the magnetic field, hence it is like another south pole. In the above image, the red region a north polarity and the blue region has south. A magnetic field is formed when the charged ions inside a planet move due to heat and planetary rotation, giving rise to currents, hence leading to a magnetic field. The internal structure of Earth is simple - a solid core surrounded by a liquid mantle but Jupiter's core is diffused. It is also a mixture of helium and hydrogen, which do not dissolve well into each other. These factors might be able to explain the emergence of 'another' south pole.

If you're interested in astronomy, you've probably heard that Jupiter has saved our planet from many potential dangers of the solar system. But is that really true? We know for a fact that Jupiter has deflected the paths of many asteroids and comets towards itself and has perhaps saved earth from being hit by them. Like the comet Shoemaker Levy-9 which collided with Jupiter in July 1994, being the first observed collision of such kind in our solar system. But this same process can deflect the paths of comets and asteroids towards earth as well, which might have occurred a lot during the early years of our solar system. It would have deflected many comets towards earth which contained most of the water on earth. It also might have deflected the suspected object which hit earth and led to the extinction of dinosaurs. At present the solar system is mostly empty and less chaotic than before, so earth is relatively safe from any such calamity. But Jupiter is also partially the reason why we have an asteroid belt between earth and Mars. It holds them there through its strong gravitational influence and prevents them from collapsing into a planet or becoming a part of another one. These asteroids are generally small, but the big ones can be disastrous to earth. So there is really no concrete answer to whether Jupiter is a savior. Sometimes Jupiter likes us and sometimes not. It's like Jupiter and Earth are in a love-hate relationship.

Jupiter has always captivated the observant mind. Almost everything about it is weird and exciting at the same time. Due to its great distance from earth and its enormous blanket of gas, we don't know much about its internal structure. Look at the following image. It is an image of the south pole of Jupiter. It is not yet understood how something so symmetric and beautiful has emerged there. We understand only the tiniest amount of things about Jupiter and, day by day we keep finding out more we don't know about it. In Indian Astronomy, this planet is known as Brihaspati, the Guru or teacher, and it surely does live up to its name.

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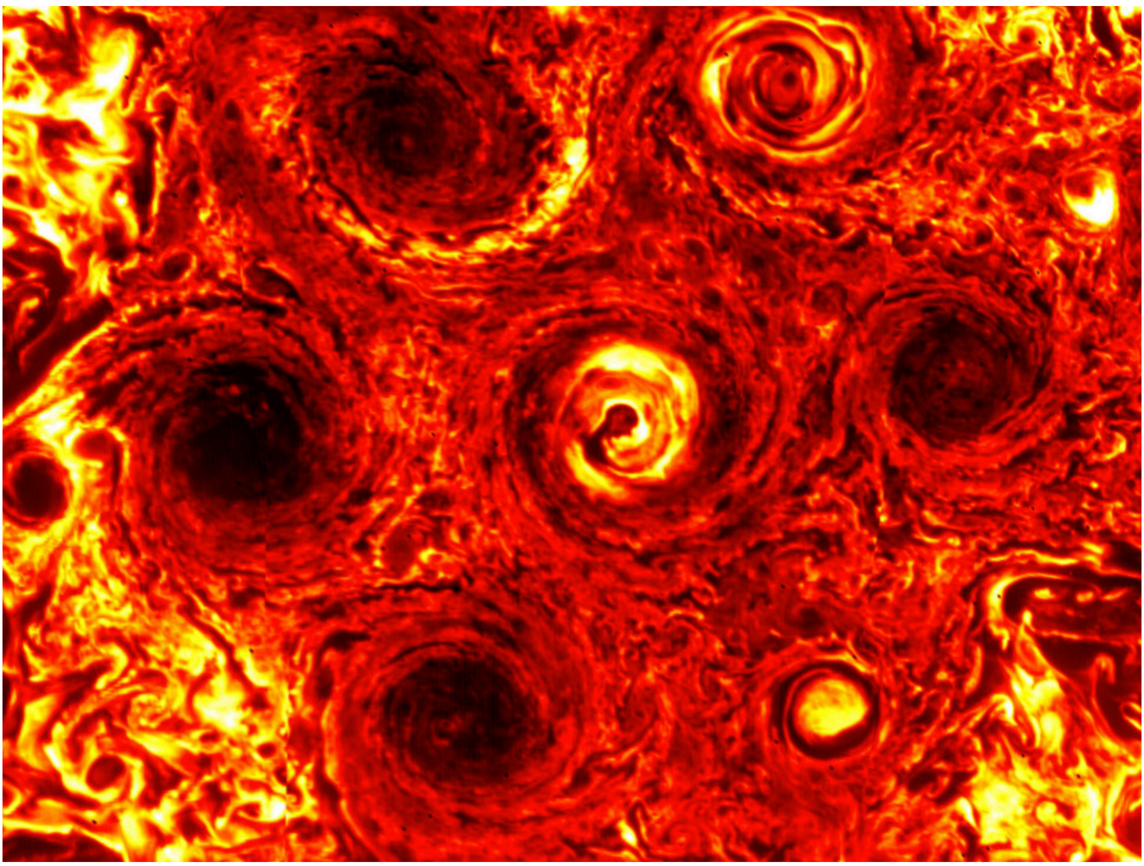
Figure III: Seven storms forming a symmetrical, hexagonal pattern on the south pole of Jupiter. (Image credits: NASA)



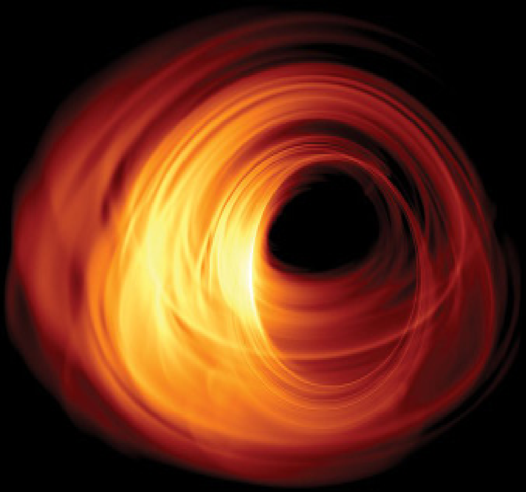


Figure I: Simulated image of an accreting black hole. The event horizon is in the middle of the image, and the shadow can be seen with a rotating accretion disk surrounding it. (Image credits: Radboud University)

What happens in a Black Hole...?

"What happens in Vegas stays in Vegas." So goes the saying. Classically, the saying may be extended to astronomical black holes. The event horizon of a black hole is thought to be the ultimate boundary, beyond which even light cannot escape. Intuitively, one is led to believe that all a black hole can do is eat meals of stars and celestial objects and grow fat without excreting anything at all. For the most part, they wouldn't be wrong, because anything falling inside the black hole's event horizon would need to be faster than light to escape and hence violate special relativity. Therefore, the black hole grows more massive. However, a black hole is indeed predicted to lose energy, albeit extremely slowly (cannot stress this enough), through Hawking radiation.

In 1973, two Russian physicists Starobinsky and Zeldovich proposed to Stephen Hawking that a rotating black hole should emit radiation. Later Hawking realized that all black holes should emit radiation. This was only a year after Jacob Beckenstein had proposed that black holes should thermodynamically radiate energy just like any black body. But how could this happen?

How can a body that lets nothing escape from it emit radiation?

There are many models proposed to explain this, but we shall begin with a simple explanation using virtual particles and vacuum fluctuations.

Figure II: The first-ever image of a black hole. This particular black hole is located at the center of the galaxy M87. What we see in the image is the emission coming from hot gas swirling around the hole.
(Image credits: EHT Collaboration)

According to the uncertainty principle [1], the energy time uncertainty can be given as,

$$\Delta E \Delta t \geq \frac{\hbar}{2} \tag{1}$$

because of which, fluctuations can arise in a vacuum with a temporary change in its energy. This basically means that as long as it is for a short time, a random change in the energy of the vacuum may give rise to elementary particles. These fluctuations manifest themselves physically in the form of virtual particle-antiparticle pairs with energy ΔE and a lifetime Δt within which they must annihilate so as not to violate the principle energy conservation.

So, imagine that a particle-antiparticle pair of photons formed near the event horizon of a black hole. The photon with positive energy barely manages to escape falling into the event horizon and goes to infinity, while its counterpart with negative energy falls in and is thus trapped inside the black hole. It so happens that the gravitational effects of the black hole causes a huge gravitational redshift in one of the photons which is outgoing. As a result, the other photon can be considered as a partner wave with negative frequency that falls into the black hole. Because of its negative frequency it has negative energy which it adds to the mass of the black hole and, following the mass-energy equivalence principle, the addition of negative energy causes a decrease in the net mass of the black hole. At the same time, the escaped photon goes into the universe and to an observer it appears as if the black hole just emitted radiation. Keep in mind that the virtual particle-antiparticle pair was formed outside the event horizon, so technically nothing escaped the event horizon.

Another way of thinking about the aforementioned over-simplification is with the concept of Unruh effect [4]. First described in the seventies independently by three scientists Fulling, Davies and Unruh, it states that the vacuum of an inertial observer would appear to be hotter for an accelerating observer. This makes sense from a quantum field theory point of view, where the vacuum is the lowest possible energy state of the quantized fields that make up what we consider as 'empty space'. Therefore, two mutually accelerating observers will see different quantum states and hence vacuum at different temperatures. The acceleration dependent temperature of vacuum, is given by the equation,

$$T = \frac{\hbar}{2\pi c k_B} \tag{2}$$

where, T is the temperature of the inertial background recorded by the observer at an acceleration a, ħ is Planck's constant, c is the speed of light, k_B is Boltzmann's constant.

The Hawking temperature T_H, which is the temperature that a black hole emitting Hawking radiation would appear to have, to an observer near the event horizon, essentially has the same form given by,

$$T_H = \frac{\hbar g}{2\pi c k_B} \tag{3}$$

Here, acceleration 'a' is replaced by 'g', the surface gravity at the event horizon of the black hole. One can think of the Unruh effect as the near horizon form of the Hawking radiation.

For a Schwarzschild black hole, i.e. an uncharged non-rotating black hole,

$$g = \frac{1}{4M} \tag{4}$$

Where M is the mass of the black hole. In Planck units, where c = h=G=k_B = 1, the Hawking temperature would be,

$$T_H = \frac{1}{8\pi M} \tag{5}$$

For a rotating black hole, the surface gravity g would be replaced by $g\text{-}M\omega^2$ [1], where ω is its angular velocity. For a charged black hole, the formula for surface gravity is a little complicated because it depends on the charge Q as well as the angular momentum J (if the black hole is rotating) and of course, its mass M. So basically, from Hawking radiation, one can determine a black hole's mass, angular momentum as well as its charge.

General Relativity enthusiasts would identify the connection to the no-hair theorem according to which no information can be extracted from a black hole other than its mass, charge and angular momentum [2]. This is the point where we distinguish Hawking radiation from thermal radiation because thermal radiation would contain information about the body that emitted it, but Hawking radiation on the other hand contains no such information except for its dependence on the three previously mentioned quantities M, Q, L. This brings us to the black hole information paradox, concerned with the irretrievable loss of information about the objects falling into the black hole. However, what we're going to see now is the connection of

Hawking radiation with black hole thermodynamics and black hole evaporation.

In accordance with the second law of thermodynamics, which states that for an irreversible process the combined entropy of a system and its environment must increase; hence a black hole's entropy must increase when energy or mass is added to it. But how do we measure this entropy? Let's say we added an infinitesimal amount of heat dQ to the black hole. Then the infinitesimal change in its entropy would be,

"Our universe is only around 13.8 billion years old, which is not even a blink in the lifetime of a blackhole."

$$\mathrm{d}S = \frac{\mathrm{d}Q}{T_H} = 8\pi M \,\mathrm{d}Q \tag{6}$$

By the mass-energy equivalence, the heat energy simply adds to the black hole's mass. Replacing dQ with small mass element dM, we have,

$$\mathrm{d}S = 8\pi M \,\mathrm{d}M = 4\pi dM^2 \tag{7}$$

Integrating over the total mass of the black hole we'll have the total entropy,

$$S = 4\pi M^2 \tag{8}$$

In Planck units the radius of a black hole is twice its mass, therefore the surface area of the event horizon is just $16\pi M^2$, then the entropy

$$S = \frac{A}{4} \tag{9}$$

Thus, a black hole's entropy can be known from its surface area.

Finally, let's talk about the most peculiar consequence predicted by Hawking radiation: **Black Hole Evaporation**. To explain it with vacuum fluctuations, the particle with positive energy escapes to the universe while the one with negative energy falls into the black hole and hence its mass gets reduced. This gradual reduction in the mass of the black hole through Hawking radiation will eventually cause the black hole to completely evaporate and its mass to entirely vanish [3].

Our universe is only around 13.8 billion years old, which is not even a blink in the lifetime of a black hole. The rate of evaporation of a black hole is inversely proportional to its mass, so smaller black holes will evaporate sooner.

For a black hole having the sun's mass, it would take 10^{64} years to evaporate. Some supermassive black holes even take 10^{100} years to completely evaporate. This is one of the motivations behind looking for primordial black holes, formed in the early universe which might have been light enough to have evaporated within the lifetime of the universe.

Till now, there has been experimental evidence for neither Hawking radiation nor micro black holes. There are several open problems concerned with Hawking radiation and black hole evaporation such as the aforementioned black hole information paradox, the trans-Planckian and others, most of which would require a quantum mechanical description of gravity. Therefore, the study of Hawking radiation is a step towards the development of a theory of quantum gravity and in consequence a unified theory of all basic forces.

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Rendezvous With A Shooting Star

Dr Guneshwar Thangjam is a faculty at the School of Earth and Planetary Sciences (SEPS) at NISER, Bhubaneswar. He is currently an Assistant Professor and also the Chairperson of the department. He started working at NISER soon after his post-doctorate at Max Planck Institute for Solar System Research (MPS) in Goettingen, Germany. On 11 June 2021, he spared a few hours to have a chat with our interviewers, Abhipsa and Raga, via Zoom. What followed was a candid conversation about his life and career until that day.

What would you say first sparked your interest in the field of geology?

My interest in geology started during my MSc, but that interest was actually job-oriented. My interest in research was realized when I was a Junior Research Fellow in the Space Applications Centre, Ahmedabad. By that time, I was working on the Chandrayaan-1 project. Then I tried exploring further, and I got the opportunity for a PhD. That's how I am into research.

As you said, you're involved in research about the solar system. What sort of problems have you worked on, or would like to work on?

Before my PhD, I was working on lunar geology and tried to understand how the lunar volcanic (complex) features formed and evolved over time (specifically in Oceanus Procellarum).

During my PhD, I worked on studying the geology of the second-largest asteroid Vesta. I tried to understand the mantle composition and its evolution. I did a remote spectral analysis of one of the mantle minerals called olivine. It was exciting to learn about this small asteroid that shares commonalities with the terrestrial planets.

I continue as a postdoc there working on the geology of the largest asteroid Ceres. Ceres is very interesting because it is found to be a water-ice rich primitive object that represents a planetary body formed in the very early solar system and remained largely unchanged since its formation (compared to Vesta or the terrestrial planets). The focus was mainly on understanding the composition and geologic nature of the so-called bright materials that are composed of carbonates.

At present, I am continuing my work mainly on two projects- Max Planck India Partner Group project (for asteroid Ceres) and Chandrayaan-2 (the Moon). My Max Planck project is aimed to understand whether the asteroid Ceres formed in the asteroid belt itself in the inner solar system or formed outside the solar system and then migrated to its present location. In this regard, I use NASA Dawn VIR spectrometer data (0.4-5 micron) and I look for a particular spectral absorption feature at 3.1 microns that is attributed to ammoniated phyllosilicates. The underlying idea is that NH4+ is thermally stable in the outer solar system and it is important to understand the formation mechanism. Therefore, proper calibration of the data based on radiative transfer equations is very important (thermal correction, photometric correction, etc.). The second project from Chandrayaan-2 is for understanding the nature of water on the Moon- either H2O/water-ice or OH-. The IIRS (Imaging Infrared Spectrometer) data (0.8-5 micron) data is capable of answering such an important question because it provides the full 3-micron absorption band for the first time from such an orbiter mission on the Moon.

Figure I: Prof. Guneshwar Thangjam
(Image credits: ResearchGate)

In this time of the COVID pandemic, can you walk us through an average day in your office? Is there a schedule that you follow or is there a fixed amount

of work you try to get done in a day?

Well, I simply follow the timetable for my classes. I also spend time reading textbooks and preparing/studying teaching materials. Because this is my first time teaching, I have to spend a lot of time trying to understand whatever I am going to teach. At the same time, I have my research work which includes attending meetings for Chandrayaan-2 and the Dawn projects. I don't have a particular schedule or table to follow, but I just keep going.

How has the experience of handling a new department been for you so far?

It's been a very nice experience. Lots of things to bear, learn and experiment with. As a new department, we have to work together designing the curriculum and so on. We are also working on our building proposal.

How have online classes been so far?

We've taken half of the semester in offline mode. When we switched to online mode, we had to struggle to make classes more interactive. I request the students to turn their videos on so that I can make a better assessment of their understanding. I need to improve myself in many aspects.

We're in the second wave of this pandemic at the moment. How would you say COVID-19 affected your work schedule and research in particular?

Yes, it is affecting both the research and academic life but also our social life. And, research is something that gets more fruitful when we work together. But, we have to adapt. I would say, somehow I am lucky and, this time I got some interesting students from SPS who are working on my projects. Working with them is really nice.

What would you say is your ultimate goal as a researcher?

As a researcher, my ultimate goal is to keep working on interesting science questions and understanding the answer. I try to ask myself whether it is going to convey a message or contribute to the scientific community. At the same time, it's also my aim to build an independent research group.

As a faculty in a department, which one do you enjoy doing more, teaching or doing your research work?

I would say, I enjoy teaching because when I teach I learn a lot. Many times, our students ask a lot of difficult questions, and many times I fail to answer them. I encourage them to keep asking questions and keep searching for the answer.

At the same time, I enjoy my research. Keeping engaged in the work is something that makes me very fresh and satisfied.

Now for some field-specific questions. What do you think is the future of planetary and non-planetary object exploration within the solar system?

When I talk about planetary exploration, I mean not only planets but also asteroids, comets, exoplanets, etc. In terms of a career, I would say that planetary exploration is going to expand. ISRO is planning for further exploration missions to the Moon, Mars, and Venus. Various NASA/ESA missions are coming (e.g., ARTEMIS missions on Moon, with plans even more rigorous than Apollo project, and it has even plans for setting up outpost; various missions to Venus- DAVINCI+, VERITAS, EnVision; Plans for missions to unexplored planetary systems and moons of Uranus and Neptune, etc.). Again, there are commercial exploration concepts (e.g., mining on Moon, asteroids, etc.). Various planetary astronomy (from ground-based and space-based observations) programs are also there. Well, these are just a few of them. Overall, I would say, it is an emerging field.

You talked about explorations on Venus and Mars and these inner planetary bodies. What about the future scope for exploration of the jovian planets?

Ah, for the Jupiter system, there is JUICE by ESA, mainly for Jupiter's moons, and there's also Europa Clipper (and DragonFly for Saturn's moon Titan). It is really interesting and worth mentioning that the outer solar system is hardly explored. For the Jupiter system, we have the Galileo mission and the Juno mission, and for the Saturn system, we have the Cassini mission. There is a mission named Lucy that is going to fly the Trojan asteroids, the asteroid family of Jupiter. The New Horizons mission on the Pluto system and the Kuiper Belt objects is also worth mentioning.

That was quite informative and fascinating. How worthwhile do you think it is to invest massive amounts of resources in missions and planetary ex-

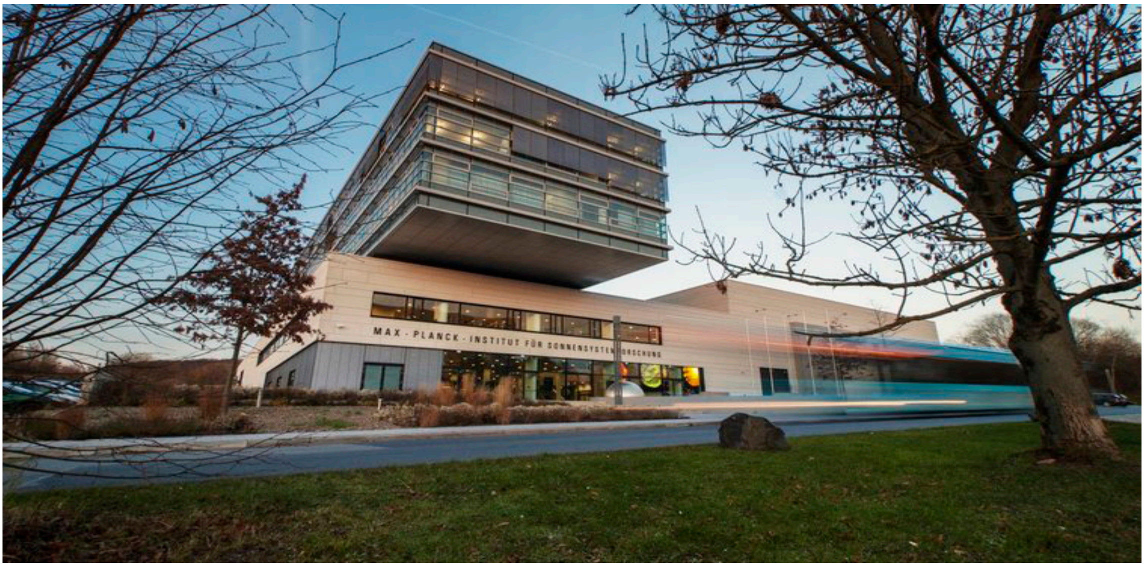


Figure II: Max Planck Institute for Solar System Research. (Image credits: mps.mpg.de)

plorations by means of space probes or rockets? Do you feel that our efforts should be directed more towards making our lives easier on earth itself? Quite a controversial topic, what is your take on it?

I do appreciate such a question even though my answer may not be proper or satisfactory. I do understand why such a question is asked, and as a scientist or engineer or a faculty or a govt employee, we need to have an in-depth understanding of such a question, and we should act our part with due responsibility.

Well, I think it is worth investing that massive resources in planetary explorations by means of space probes or rockets because the value of the returns in terms of science & technology & engineering to mankind is priceless. Each and every mission is into place after a very thorough review in several competitive levels keeping in mind the past, present, and future aspects of science, technology, and engineering, and also considering the societal/political/economic impacts/situations. It is worth mentioning the Apollo missions/program, one of the planetary exploration programs that are considered the most significant achievement in the history of mankind. In my opinion, the cost of making lives easier on Earth itself is something not proper to compare with the cost or expenditure of the planetary missions. And, I don't think life is going to be easy even if we spend that money for that cause, because that is a different problem with different nature. Again, having successful planetary missions or programs is driven by innovative brains whose visions remain immortal in the history of mankind.

But these missions not only demand monetary resources, but they are also a test of our patience because of the time it takes to fly out equipment, especially to the outer solar system.

Yes, that's true. It takes time. The time taken is not only for sending or reaching the spacecraft to the target. Enormous time and a tremendous amount of effort are invested right from the conceptualization to the approval/selection process, then, building the rocket/spacecraft and the payloads or onboard science instruments, testing and quality control, etc., and then launching. And, again, consistent mission operations and precise calculations and command/communication, etc., will go on to keep the mission alive, and then data acquisition, processing, calibration, analysis, etc. Therefore, you can imagine, it is indeed very challenging and very time-consuming teamwork, and it demands not just the time or the patience or the cost/expenditure, but most importantly the vision, the hard work, and the dedication to make that successful, in my opinion.

As students in this institute, it was awe-inspiring and exciting to find out that you have an asteroid named after you. Could you take us through your achievements so far in your career? What do you feel has been a highlight so far?

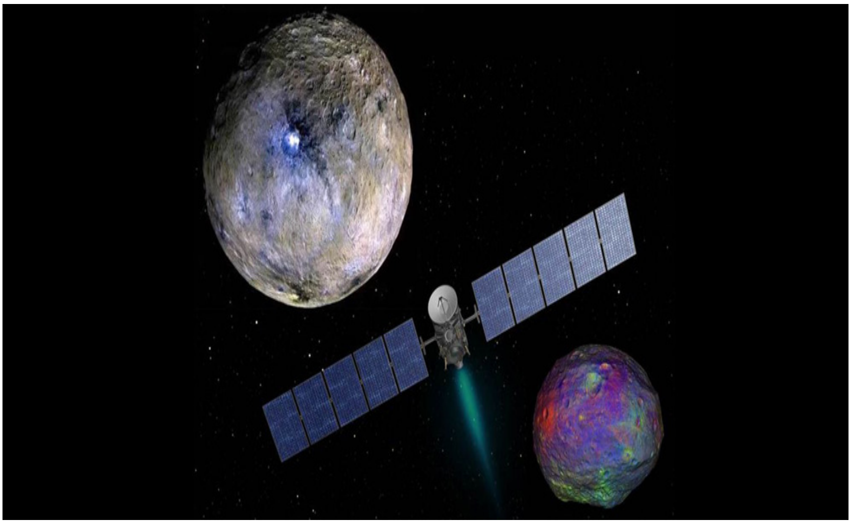


Figure IV: An artistic view of the spacecraft and RGB composite imahges of asteroid Ceres (left) and asteroid Vesta (right) using images from Dawn Framing Camera. (Image credits: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA)

Thanks for the appreciation. And, thanks to my Max Planck Dawn Framing Camera team and the entire Dawn team for the motivation and inspiration, and also IAU for that encouragement. Frankly speaking, that was just luck for me. My contribution being a team member in the Dawn team is, I think, very small and insignificant. And, as I mentioned, I am still struggling to keep working on it.

You have been taking so much academic and administrative responsibility in your department. We would like to know about your interests outside academia.

I like sports. I love playing badminton and tennis. I also like exploring nature (for example, one of my wild dreams is to wake up in the Indian Antarctic station where I can go meteorite hunting and also feel how deadly would be those icy moons in the outer solar system!!).

How have you found NISER, as an institute and the campus life it provides, so far?

I really like NISER and I find myself very lucky. The support I get from NISER and the research environment at NISER is beyond my words. The campus life is amazing.

I'm glad you find NISER comfortable. Do you think there is scope for burnout for people pursuing research in your field? If so, what is your advice for dealing with such a stage in life?

Yes, I think, NISER is a place that provides that scope, not only in my field but for those who are in deep research. Well, I advise myself to keep working on understanding the science problem and come out with answers in time.

Do you have any specific advice for people who want to get involved in your field of work?

If any of the students or researchers want to work in my field of research or my group, the point I would be suggesting or looking at is the deep interest in research, deep understanding of the science problem and the approach/methodology/technique, and the dedication and enjoyment to the work. That's what I can tell.

Do you have any advice for us undergraduates who still haven't decided on their specific field of interest and are still trying to figure it out?

What I can tell is very simple- you are at NISER and you know what is at NISER, ask yourself what you enjoy the most while working or doing the research, and decide accordingly; once you decide, then deliver your promise.

The last question - do you have any suggestions or criticism towards NISER Astronomy Club as a functioning body?

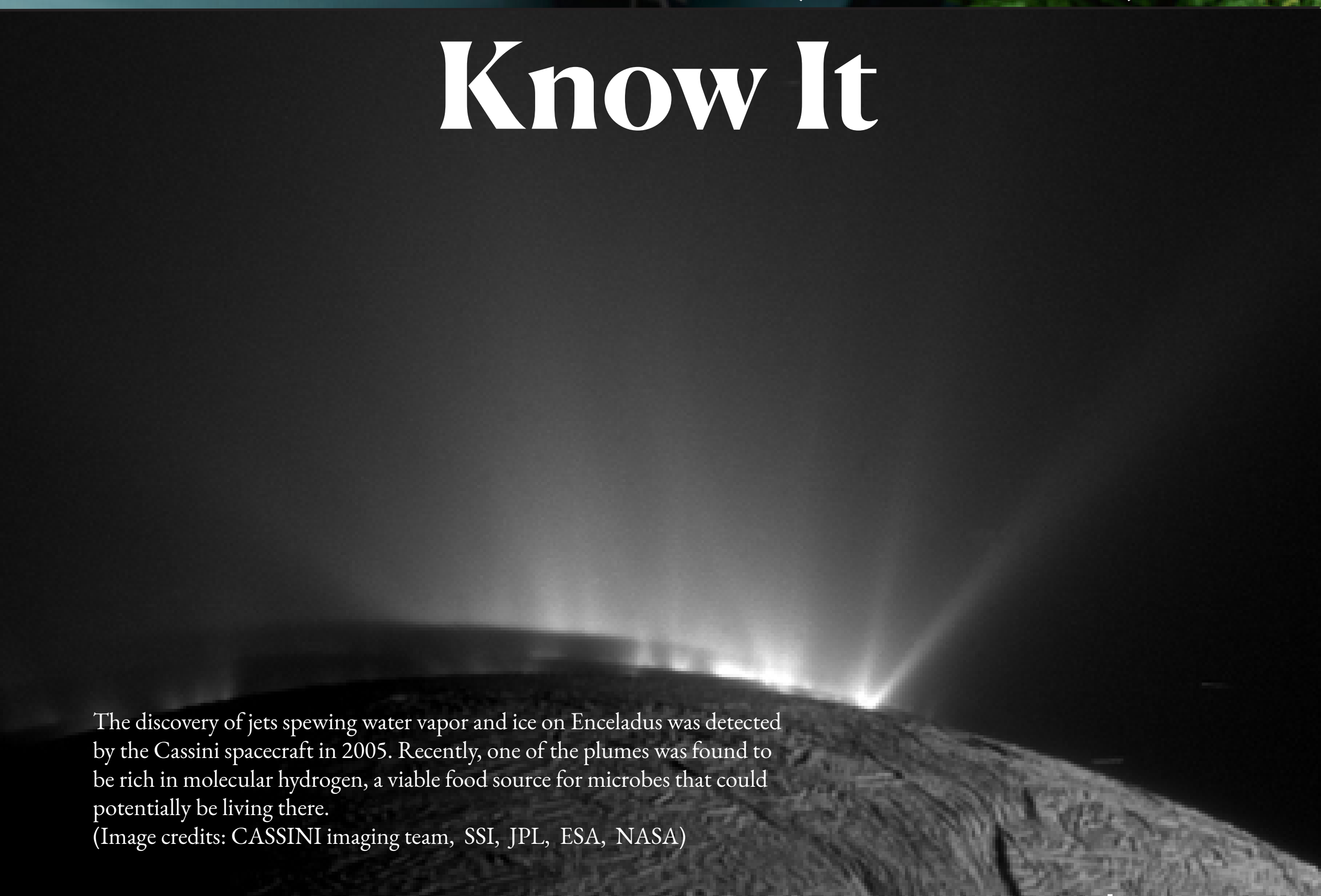
In my experience, NAC's works, ideas, and contributions are very significant and it is worth appreciating. Keep up the good work and keep excelling in your career and research.

We thank you for those encouraging words for our readers. Thank you so much for making time for this interview.

Thank you very much for giving me this opportunity. It is my pleasure. And wish you all the best.

The survivability of tardigrades has been tested 'outside' an orbiting space shuttle. (Image credits: NASA)

Life As We (Don't) Know It



The discovery of jets spewing water vapor and ice on Enceladus was detected by the Cassini spacecraft in 2005. Recently, one of the plumes was found to be rich in molecular hydrogen, a viable food source for microbes that could potentially be living there.
(Image credits: CASSINI imaging team, SSI, JPL, ESA, NASA)

"In very different ways, the possibility that the universe is teeming with life, and the opposite possibility that we are totally alone, are equally exciting. Either way, the urge to know more about the universe seems to me irresistible, and I cannot imagine that anybody of truly poetic sensibility could disagree."

—— Richard Dawkins, Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder

When we look around us we see many objects and we almost immediately recognize which of them are living entities and which of them are inanimate objects. The cellular organisation, metabolism, homeostasis, growth, reproduction, response to an external stimulus and evolution are the properties we look for to declare something as living. NASA defines life as a self-sustaining chemical system capable of Darwinian evolution [1]. As simple and accommodating as the definition seems, it is based on life as we know it. When we use the phrase "life as we know it" in astrobiology, we mean the life forms that we are familiar with. The idea of the necessity of "optimal" environmental conditions comes to us naturally from the conditions that we observe the majority of life forms dwelling in. The biomolecules in our bodies are highly influenced by their immediate environment such as temperature, pH, salinity, etc; for their structural conformation and hence their function. Such organisms that live in optimal conditions are called mesophiles/neutrophiles.

It is believed that life had originated in deep hydrothermal vents at astounding depths and high temperatures around 4.5 billion years ago. Such conditions seem almost impossible to support life and yet life originated and survived in such conditions and had managed to evolve till today, completely changing the face of the once inhabitable planet. In today's world, many organisms are discovered that can survive, live, thrive in extreme unimaginable environmental habitats, some of which could shed light on the primordial life forms. These organisms that live in extreme environments give us hopes of the existence of extraterrestrial life on the moons of the gas giants of our solar system, exoplanets in the habitable zones of star systems and even beyond.

Extremophiles

Extremophiles, as the name suggests, are those organisms that live in what we call "extreme" environments. However, the idea of extreme habitats is quite anthropological and these organisms find these extreme habitats normal and often necessary for their survival. Most extremophiles are microorganisms that belong to the domain Archaea but there are also certain extremophiles with higher levels of organisation such as Pompeii worms and tardigrades that belong to the animal kingdom [2].

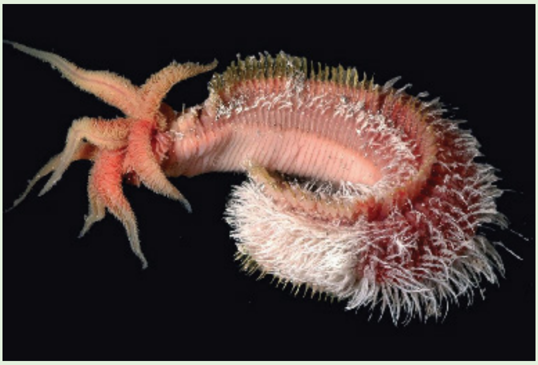


Figure I: Alvinella pompejana (common name: pompeii worm). It belongs to the phylum Annelida of kingdom Animalia. It is an extremophile found in hydrothermal vents of the Pacific ocean. (Image credits: Kanijoman)

Figure II: (a) A hot geyser in Yellowstone National Park which is a hotspot to thermophilic bacteria, one of which is Thermus aquaticus. (b) Thermus aquaticus. (Image credits: (a) wallpaperaccess.com (b) Public domain image)

Based on the environmental parameters the extremophiles are classified into thermophiles, psychrophiles, barophiles, piezophiles, alkaliphiles, acidophiles, etc.

Environmental parameters

Temperature:
Temperature is one of the most influential factors for sustaining life. The structural integrity of proteins/ biomolecules, which are essential for the catalytic activity of most biological functions, and the fluidity of lipid membranes are maintained at an optimum temperature. The biomolecules denature and the lipid membranes become too fluid at extremely high temperatures. While at lower temperatures, below 0 degrees Celsius, water freezes and forms ice crystals that destroy the cell membrane and biomolecules of the cell. Deprivation of water at such low temperatures can also lead to a decline of metabolic activity (biochemical reactions) of the cell as water plays an important role not just as a solvent but also as a substrate or product of metabolic reactions.

Figure III: *Riftia pachyptila* - giant tube worm (Image credits: Wikipedia)

Organisms that thrive in temperatures >80 degrees Celsius and >100 degrees Celsius are known as thermophiles and hyperthermophiles respectively. These organisms can be found in hot springs and geysers. One popular example is the *Thermus aquaticus* that lives in hot geysers of the Yellowstone National Park. The organisms that live at 15 degrees Celsius and below are considered to be psychrophiles and are found in glacial and polar regions of the planet.

pH:
The concentration of hydrogen ions is important for the maintenance of necessary metabolic processes as they influence the structure and catalytic properties of enzymes. A pH range of 5 to 8.5 is considered normal for biological processes by humans. However, some organisms can live in an extreme acidic habitat (<5 pH), called acidophiles, and some organisms can live in extreme alkaline habitats (>8.5). These organisms have passive (does not require energy) and active (requires energy) mechanisms, such as hydrogen pumps, to maintain a near-neutral pH inside the cell [3]. *Helicobacter pylori* is a bacteria that can grow in the human stomach, where the pH is ~2, and cause ulcers. Octopus spring lake is an example of an extreme alkaline habitat. It is an alkaline hit geyser in the Yellowstone National Park and is home to microorganisms such as cyanobacteria, green sulfur bacteria and green non-sulfur bacteria.

Pressure:
Pressure influences the volume change of living organisms and extreme pressure can decrease the fluidity of the cell membrane and mobility of biomolecules thereby rendering the metabolic activities of the cell.

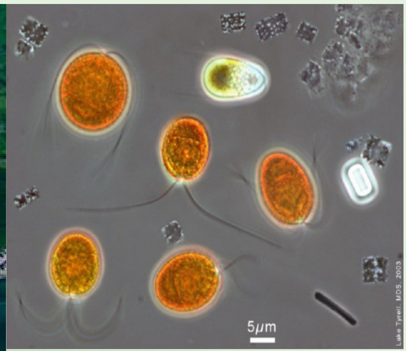



Figure IV: (a) Lake Hillier, Australia. (Image credits: Wildlight Photo Agency / Alamy.)
(b) Microscopic picture of *Dunaliella salina* (Image credits: Wikipedia)

The temperature at deep-sea hydrothermal vents can reach up to 400 degrees Celsius, where one would have thought the liquid state of water would be impossible, but the hydrostatic pressure at such great depths (~130MPa) is what keeps the water from evaporation. Hydrothermal vents are a habitat for a diverse group of organisms that belong to annelids (*Riftia pachyptila* - giant tube worm), gastropods, crustaceans etc.

Salinity:
Water is an important component to sustain life. Most of the volume of a cell is contributed by water as it acts as a medium for the movement of ions, ligands, biomolecules etc; and their metabolic activity. At high saline concentrations (hypertonic environment) the water moves out from the cell due to high osmotic pressure. This leaves the cell dehydrated. Microorganisms that can grow in high osmotic stress are known as "halophiles" and "osmophiles". Saline lakes across the world serve as a niche for a variety of cyanobacteria and algae. The famous Pink lake (Lake Hillier) of Australia gets its peculiar colour from the alga *Dunaliella salina* that has extreme salt tolerance of up to 35% NaCl (the salinity of seawater is only 3% NaCl).

Desiccation:
Scarcity of water leads to desiccation and the environment temperature can range from very hot to very cold. Organisms that live in these dry, arid conditions have interesting adaptations for survival. These organisms enter a state of anhydrobiosis which is characterised by little content of intracellular water and therefore low metabolic activity. These organisms immediately recover, grow and reproduce at the availability of water. Species of nematodes that live in dry valleys of Antarctica remain in an anhydrobiosis state for most of their life, occasionally taking water from a very scarce amount of molten ice.

Oxygen:
The first early forms of life were anaerobic respirators as there was no oxygen in the atmosphere until the origin of photosynthetic organisms. Anaerobic respiration means utilising non-oxygen species such as sulfate, nitrate or sulfur for the production of energy (ATP). However, as the earth's atmosphere transitioned from reducing to oxidising most organisms have evolved to respire aerobically (energy production utilising oxygen) as it is thermodynamically more efficient.

Other extreme conditions:
Other extreme conditions include resistance to high metal toxicity, radiation and nutrient deprivation. Microorganisms developed different mechanisms to survive such conditions. While extremophiles mean an extreme environment "loving", some organisms just "tolerate" such conditions, especially high radiation and vacuum.

Most of the above-mentioned habitats have more than one parameter in their extremes. Hence most extremophiles are adapted to multiple conditions making them polyextremophiles. For example, deep-sea hydrothermal vents have very high temperatures and pressure therefore the organisms that live there are both hyperthermophiles and piezophiles.

Earth is a vast planet with many diverse ecosystems most of which are yet to be explored. While some ecosystems are easy for humans to reach out to and explore, there are many we can't, like the deep sea, eastern portion of Antarctica, etc; due to physical constraints.

Astrobiological perspective

The study on extremophiles helps scientists make stronger speculations about the challenges and constraints extraterrestrial life forms could have in other worlds. Analogies can be made between extreme habitats of our planet to similar worlds on other planets and moons of other planets. For example, the Antarctic Dry Valleys are akin to speculation of what Mars could have been once [5]. As humans continue to explore extremophiles, the once considered limitations for life have significantly expanded. It has given us a strong base to the argument that life does exist elsewhere at least in the form of unicellular/microorganisms.

Figure V: (a). McMurdo Dry Valley, Antarctica. (Image credits: coolantarctica.com)

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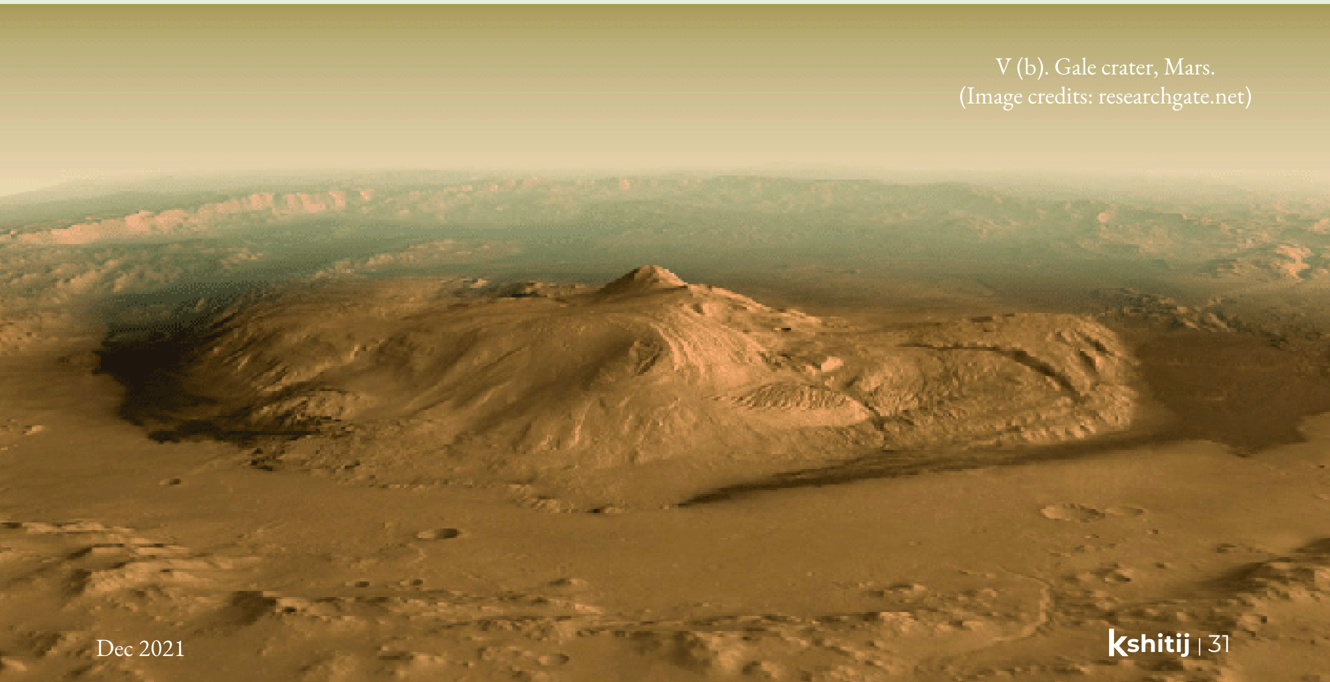
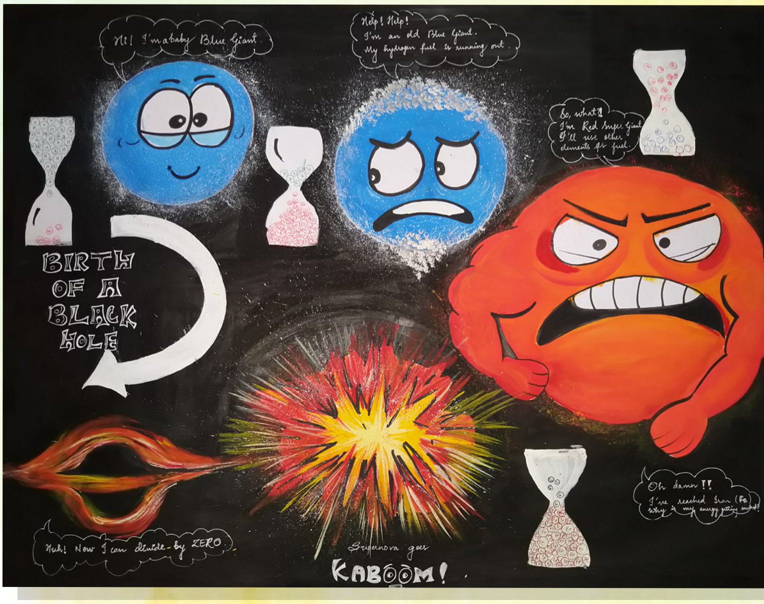


V (b). Gale crater, Mars. (Image credits: researchgate.net)

ASTRO ART

Here's a peek into the works of the artistic minds of NISER, from the astro-art poster making contest, organized jointly by the NISER astronomy club (NAC) and arts club (arC).



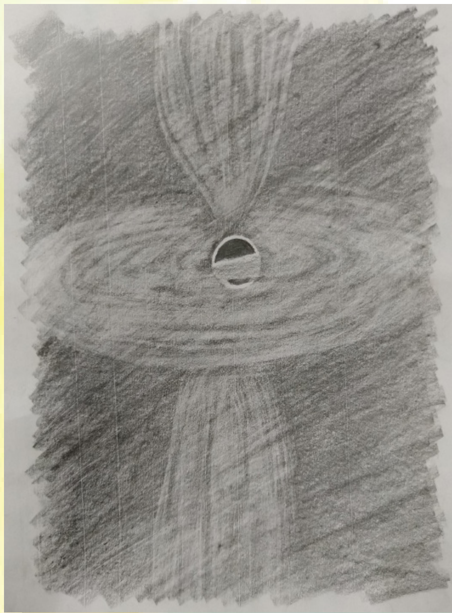
Birth Of A Black Hole
Isha Dwivedi (B18)
Shikta Priyadarshini (B18)

Birth Of A Black Hole
Shaswat Sourav Sahoo (B20)
Ritesh Ranjan Badhai (B20)

Birth Of A Black Hole
Lipsa Sahoo (PhD 2nd Year)

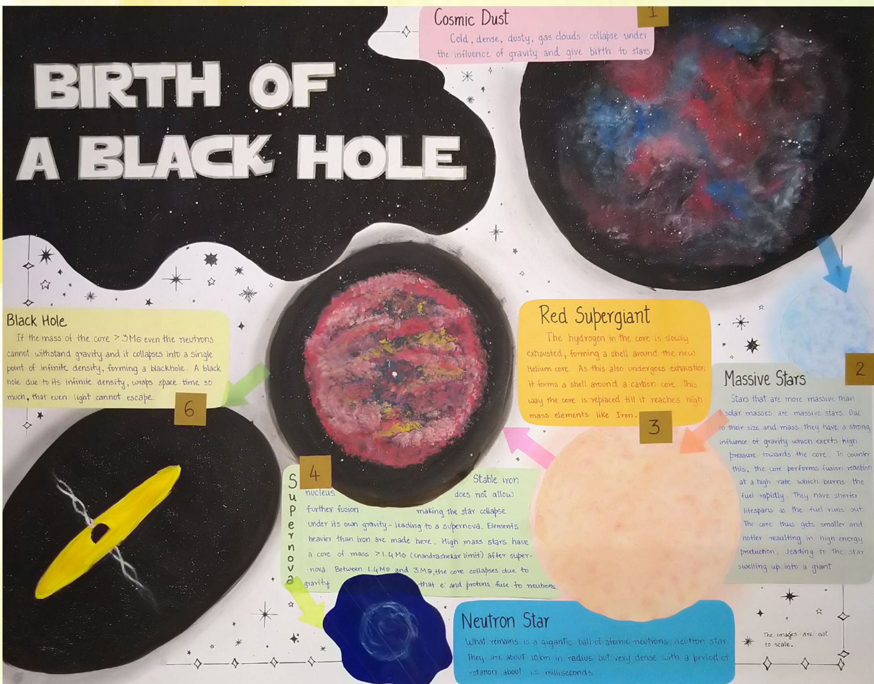
Perspective: Viewing The Solar System From Outside It
Alex M. (B17)
Anagha C. (B17)

Birth Of A Black Hole
Gitanjali Bhoi (B18)



Perspective: Viewing The Solar System From Outside It
N. Devnand (B19)

Birth Of A Black Hole
Senjit Ram Behera
(Project Student)



Birth Of A Black Hole
Irene Aniyan Puthethu (B18)
Raga Sahiti (B18)

Astro Puzzle

You are on a quest to unveil a legacy left by a long-lost extraterrestrial civilization, millennia ahead of your planet. You find that they know of your planet and have left the means to record information about you, along with a message. You uncover a script, but only questions remain. Answer them and unveil the truth.

Q. The ancient one asks, "Tell me the number of constellations added among our ranks. The sum of the digits is the number of letters of your first and second rune."

◇◇

The First Rune

Q: Two dogs follow this mighty hunter. The last of his name is the first of your first rune.
Q: This individual was the first one to consolidate stellar patterns among you. The first of his name is the second part.
Q: The third part occupies the position, in the key of this language, of the number of letters in the name of the person who rules the dreams.
Q: The next part occupies the position of the maximum number of zodiac constellations which find their names with common origin.

◇◇

The Second Rune

Q: The first, as well as last, of one name of the smallest constellation is the first part of this rune. It's the last of the name of the small one's counterpart.
Q: The biggest prime number dividing the number of all constellations is the position in the key of the next part.
Q: The highest member of the Pythagorean triplet containing the number of letters in the event of alignment of three celestial bodies, is the position in the key of the next part of this rune.
Q: This enigmatic celestial body had this place in your closest astronomical system. This is the position of the last part of this rune.

◇◇

The Last Rune

Q: The first of an AGN with a supermassive black hole with surrounding accretion disk.
Q: The first of the colors of which no star humans can see.
Q: The first of the largest brothers of Earth.
Q: The number of planets which emit less than what they receive from the sun. This is the position, in the key, of the next part.
Q: The first of the smallest moon of the god of war, ruling over dread and terror himself.
Q: The first of his name is the next part. A great astronomer, known for his observations, assisted by the one who said that the rate at which the planets sweep the area is constant.
Q: The first of this phenomenon is one of the best ways to know something about the observed celestial body. It is about what you see and how well you see it.

You find that you can't decode the rune script. You search around and find a program called 'The Riddler' which displays the following message when executed.

◇◇

The Riddler

"The cosmos is ever changing. One star dies, one more forms. This goes on. See what is happening to the universe".

◇◇

You have got the final piece, the key to decode the script and unveil what's left behind.

◇◇

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◇◇

Answers to previous edition Astro Puzzle

A Starry New-Moon Night

I lay motionless as I see
a thousand suns in my sight
You say it ain't possible, but
I see a starry new-moon night!

New moon? Yes, the moon
is no longer the 'star' of the show.
But now I feel it never indeed was,
the stars have been the 'stars' since long ago!

It's hard to keep up the stone face
as I now see a dusty trail of stars.
Perhaps the moonless night has more stories,
To let heal my deep knit scars.

I often revisit the days long gone,
while looking at and admiring the moon.
But today I don't miss it!
The stars promise me a good time to follow soon.

I lay speechless as I see
A painting hanging in the air full bright.
You say it ain't possible, but
I see a starry new-moon night!

Anshuman Padhi
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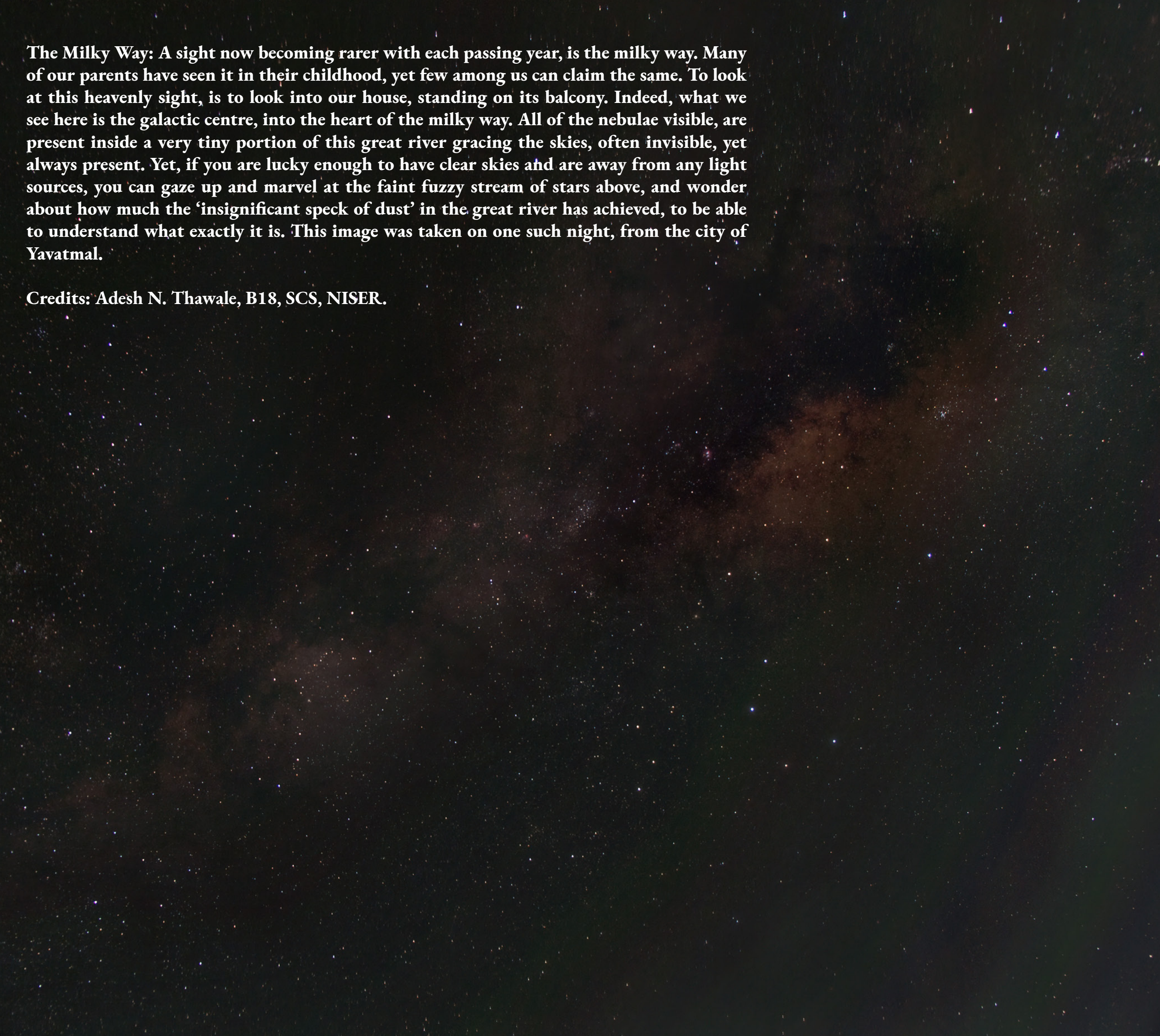
Image credits: wallpaper.mob.org



The Milky Way: A sight now becoming rarer with each passing year, is the milky way. Many of our parents have seen it in their childhood, yet few among us can claim the same. To look at this heavenly sight, is to look into our house, standing on its balcony. Indeed, what we see here is the galactic centre, into the heart of the milky way. All of the nebulae visible, are present inside a very tiny portion of this great river gracing the skies, often invisible, yet always present. Yet, if you are lucky enough to have clear skies and are away from any light sources, you can gaze up and marvel at the faint fuzzy stream of stars above, and wonder about how much the 'insignificant speck of dust' in the great river has achieved, to be able to understand what exactly it is. This image was taken on one such night, from the city of Yavatmal.

Credits: Adesh N. Thawale, B18, SCS, NISER.

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Feedback

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