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ASTRONOMY AND AI

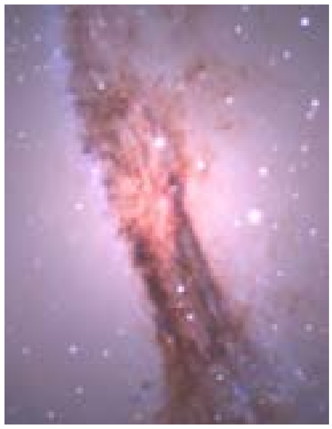
Beyond Conventional Astronomy

From time immemorial, humans have looked up at the night sky and have aspired to learn more about it. Their passion for learning about space was so great that they discovered celestial objects that we are still learning about and exploring. The first nebula to be observed ,Orion, a colourful mass of ionized gases and the birthplace of stars, was discovered in 150 AD. The Andromeda galaxy, which is our closest large galaxy was discovered in 1000 AD. Fascination towards space has only increased over time. Not only is astronomy being pursued by academicians, but even a layman with no formal education can appreciate and enjoy it. The success of films like "Interstellar" and "Gravity" are testaments to this fact.

But as the saying goes, "Curiosity killed the cat". As we learn more about ourselves and the universe, we have become aware of dangers that can limit the survival of humanity as a species. Not only are we being endangered by threats like global warming, we are also becoming aware of dangers that might come from outer space. Though threats like asteroid impacts, rogue planets, and gamma-ray bursts have the potential to wipe humanity in a blink of an eye, they are exceedingly rare events which we believe that we may never see. The recent geomagnetic storms in Feb 2022, which sent 40 SpaceX satellites plummeting towards earth is cautioning that though probability is low, it doesn't mean that it will not happen. So, the age-old wisdom, "Prevention is better than cure" still holds good and cautions us to be prepared.

One right step towards the preparation is betting on technological advancements. With the advent of data, we now have capabilities to store and process information about the universe which is growing at an astronomic rate. Scientists can now not only send robots to nearby planets but can also see if exoplanets ,which are located light years away can support life. All these applications require astronomers to analyze vast amounts of data. JW space telescope, a replacement of the Hubble telescope, which was launched in December 2021 generates around 235 GB of Data daily. The ability of AI and machine learning to sift through these huge amounts of data and analyze it, has made it an extremely attractive option for astronomers.

Amitesh Kumar



The art of clicking pretty pictures of space

Astrophotography

The night sky is a colourful place, even though it might seem otherwise. Millions and billions of stars, galaxies, supernova remnants, and nebulae shine in the night sky above. Yet, we are not able to see them just because our eyes are not sensitive enough at night.

Fortunately, technology comes to mankind's rescue once again. Using an image processing technique known as "stacking", amateur astrophotographers can enhance the brightness of astronomical objects so that humans can visualize the object as it were present in the night sky.

Creating pretty pictures of space has lot of uses other than just scratching people's creative itch. Pictures clicked by the Hubble space telescope have been instrumental in learning about the universe. In 2008, Hubble captured the first photograph of an exoplanet, planet in orbit around a star other than our sun. With its ability to look at galaxies millions of light years away, it acts as a time machine, allowing us to see what the universe looked like in the past. It has also bolstered evidence for super-massive black holes being present at the centre of all galaxies.

Role of machine learning in Astrophotography

Removing noise from astronomical images:-
At some point in our life, we would have tried to click a photograph using our cell phones at night and found out that the images are significantly worse than the photos taken during the day. This is due to an artifact called "Noise". Noise is a visual distortion which is apparent in the image of the object but is not present in the object itself.

Since astrophotography is done exclusively at night, it is a frequent problem faced by amateur astrophotographers. While there are a lot of softwares for removing noise from photographs, they often come at the cost of removing the fine details in the photograph, essentially blurring it. Topaz Labs, the creator behind the popular noise reduction software, Denoise AI, has a different approach for solving this problem. It has trained the plug-in using thousands of photographs, which allows it to distinguish between noise and details present in the image. This allows the user to denoise images while retaining important details.

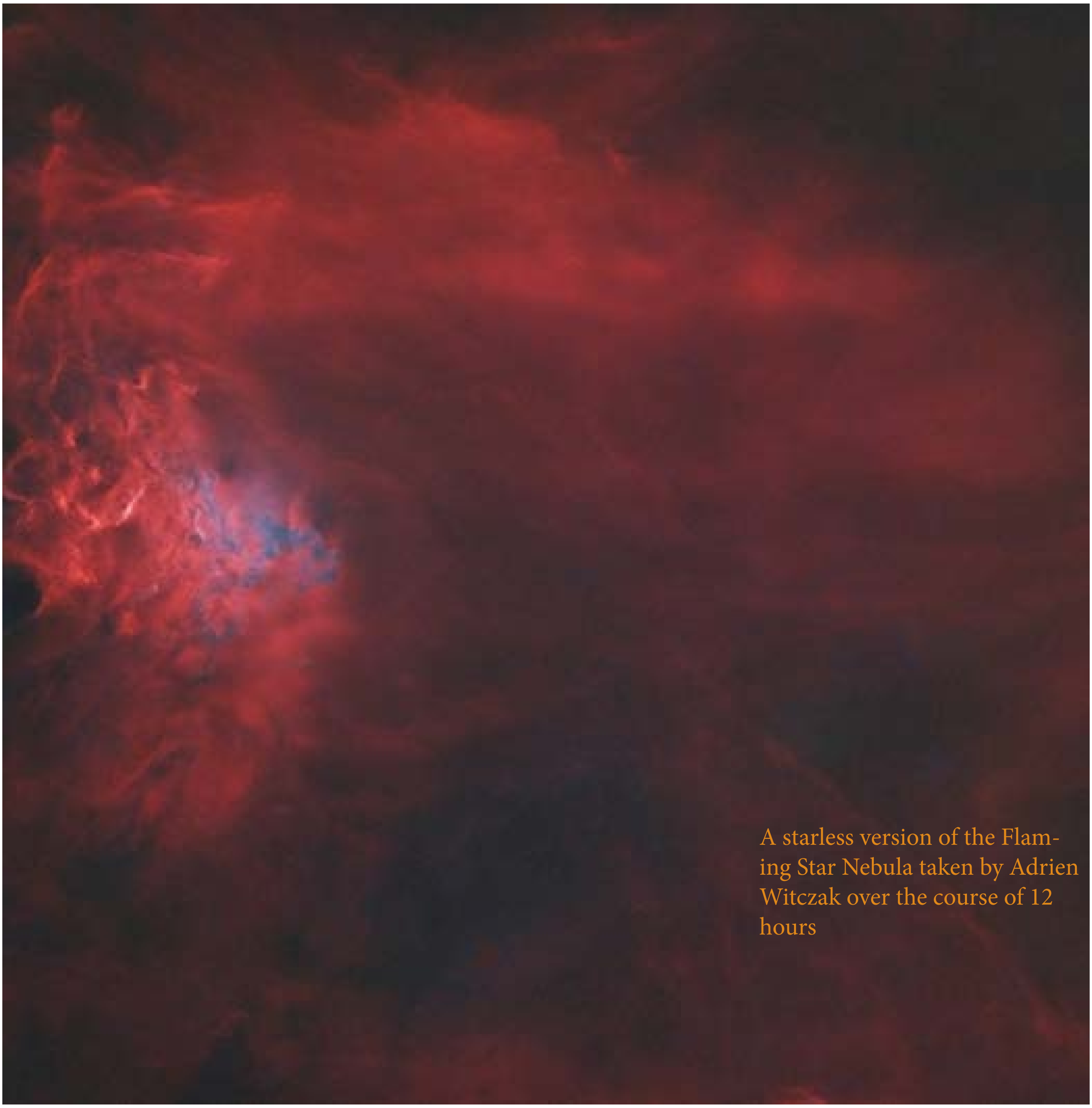
Astronomers who undertake research using images from various space-based and terrestrial objects face a similar issue, albeit due to different underlying reasons. Distinguishing a galaxy's shape using its image becomes difficult when the image is distorted due to the gravitational effects of galaxy clusters. To solve this, a group of Japanese astronomers led by Masato Shirasaki from the National Astronomical Observatory of Japan created 25,000 mock galaxy models based on the images obtained from Subaru telescope which was used to train a GAN (generative adversarial network) model. This model was able to recover the fine details in the images of the galaxies.

Reducing brightness of stars :-

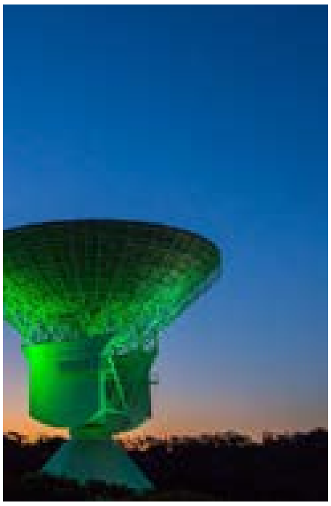
One common problem astrophotographers face while editing images is a huge variation in the brightness of objects present in the picture. This variation is due to stars being much brighter than other objects present in the photograph. So, when a user wants to brighten the image, the brightness of the star overpowers the brightness of the object present in the image. To prevent this, astrophotographers brighten the image after removing the stars in the image. After the astrophotographer has finished processing the image , the stars are then added back into the photograph .

Some astrophotographers choose to not add the stars to the image, aiming more towards an “abstract” look in their photos. Not adding stars back also helps the viewer to observe some of the "details" (like faint integalactic dust clouds) present in the image which would have been overpowered by the brightness of the stars, had it been added back in.

A recent research study along these lines was conducted by the Berkeley AI Research (BAIR) Laboratory on Image-to-image translation using advanced concepts of CNN which led to the development of a software called StarNet ++. This software recognizes stars in images and removes them, leaving all other small bright things intact whose shape and colour is significantly different from that of a typical star, like small spiral galaxies .



A starless version of the Flaming Star Nebula taken by Adrien Witczak over the course of 12 hours



Detecting the composition of an exoplanet's atmosphere using machine learning

Search for extra-terrestrial life

Humans are obsessed with the concept of finding "aliens". We have always wondered whether we are alone in this universe. We like to fantasize about it, make TV shows & movies about it and spend billions of dollars making giant radio telescopes just so that we can get a tiny ping on our instruments from intelligent beings. Answering this question would help us answer questions about our place in the universe, where we come from and where we are headed.

As technology has advanced, we have expanded our search for extra-terrestrial life from objects inside the solar system to ones that lie outside it. Since discovering the first exoplanet (a planet that revolves around a star other than the Sun) in 1992, we now know more than 4,000 exoplanets. We now estimate that there exists as many planets in the galaxy as stars in it. Given the large number of stars in our galaxy, astronomers believe that it is extremely likely that there exists at least one planet in our galaxy that would support life.

For a planet to support life, it needs to meet few criteria such as having liquid water on the surface along with carbon and nitrogen. These elements are required since they are the building blocks for organic compounds. In addition to these elements , phosphorous is also necessary since it is the building block for ATP which is the how energy is generated in cellular organisms.

But how do we find out if a planet has these compounds if it is located trillions of kilometres away?

This is currently being done by a process called atmospherical retrievals, which is performed when a planet passes in front of the star it is revolving around. When the planet passes in front of the star, the intensity of the amount of light falling on our sensors falls slightly. The drop in the amount of light that falls will be higher if the planet is big and less if the planet is small. This can be used to estimate the size of the planet.

Astronomers also measure the amount of light blocked across different wavelengths. If a planet has no atmosphere, the amount of light blocked will be the same regardless of wavelengths. However, this won't be the case if a planet has an atmosphere. Depending on the molecules present in the atmosphere, the planet will reflect a particular light wavelength more than other wavelengths. Using this information, we can say if the atmosphere can support life.

Jupiter's atmosphere

How does machine learning play a role in this ?

Earlier, astronomers would try to fit the spectrum with a few existing models by hand and then conclude if a particular spectrum perfectly fits it. The issue here is that the wavelength and amount of light absorbed by molecules in the atmosphere can change depending on the atmospheric conditions present on the planet such as the presence of haze, cloud deck, water etc. This can change the spectrum considerably. This would lead to multiple models fitting the observed spectrum .

Astronomers and data scientists have simulated the atmospheric spectrum under various conditions to mitigate this problem. On observing a particular spectrum, the planet's parameters can be fed to a machine learning model, which can then estimate the probability of the test data fitting a particular spectrum. This will help us understand what elements are present in an exoplanet's atmosphere and help us determine if that planet can support life.

Recent research conducted by Nasa's FDL team , shows that an ensemble of Bayesian neural networks or BNNs can perform even better than previously used models. BNNs, when used with Monte Carlo approximations, are a good model for atmospheric retrievals as they offer the powerful function-approximating capability of deep neural networks with the additional advantage of providing probability distributions over their outputs and scaling to high dimensional data.

Kepler-186f was the first rocky exoplanet to be found within the habitable zone -- the region around the host star where the temperature is right for liquid water. This planet is also very close in size to Earth.

Defending the planet from the interstellar

Planetary defense

Imagine getting up in the morning and going to your office. You brush your teeth, have a bath, get into your car and drive to work. On your way, you see a ball of light streaking across the sky. Amazed at this sight, you stop your car and get a better look. Suddenly, the streak of light explodes with a brightness greater than 30 suns. You cover your eyes and rush into a neighbouring building to seek cover. Seconds later, a huge shock wave reaches you, shattering the glass windows and covering you in pieces of broken glass.

If this feels like a low-budget Hollywood sci-fi film story, then you are mistaken. This incident happened in a city called Chelyabinsk in Russia in 2013 when a 20m meteor entered the Earth's atmosphere and burst 30 km above the Earth's surface. The explosion was visible even 100km away and is estimated to be 30 times more powerful than the atom bomb detonated at Hiroshima. The resulting blast wave was so powerful that it damaged buildings in a 200 square mile area. Around 1500 people were injured due to the secondary effects of the blast. The injuries caused due to the meteor were varied ; some suffered from broken spines while others had ultraviolet burns on their skin. Some people also reported temporary flash blindness from looking directly at the meteor.

Astronomers estimate that the damage would have been much worse had the meteor fallen on the surface. Meteorites in the 50 to 140-meter diameter range are a local threat if they hit a populated region and can potentially destroy city-sized areas. Asteroids in the 140m to 1 km size range could cause continent wide destruction, potentially killing millions of people .

How to detect asteroids/comets that might collide with Earth?

Comets are icy rocks that orbit the sun. They heat up and spew gases and dust into a glowing head as they approach the sun. The dust can then travel to the Earth's atmosphere, where they form meteor shows. Nasa and the Seti institute have set up a network of low-light video cameras called Cameras for Allsky Meteor Surveillance (or CAMS) which can detect meteors. CAMS uses the meteor's path and it's brightness to detect if the meteors are debris from a known asteroid/comet or an unknown one. This will help us focus our attention on the unknown comet and will give us additional warning time if it turns out the comet is on its way to Earth.

The meteor exploded above Chelyabinsk city that caused damages of buildings and hundreds of people injured.

" If the Earth gets hit by an asteroid, it's game over. It's control-alt-delete for civilization"

Bill Nye

Processing and analysing the image captured by CAMS is currently being done by a human. The astronomer would receive about 500 detections per camera on a given night , most of which turn out to be false positives such as satellites, aeroplanes , insects and birds. Since each site has 16 cameras, an astronomer has to analyse 8000 observations per night which consumes a lot of his time.

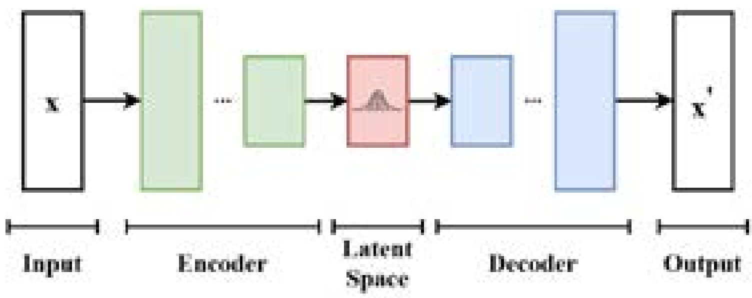
Aerospace.org researchers have used over 100 TB of data provided by the Catalina Sky Survey team to build and train a multimodal neural network model called NEO AID (Near Earth Object Artificial Intelligence Detection) to correctly identify moving objects from false positives. The model is currently being tested at Catalina Sky Survey. The initial results obtained are promising and the model has increased the detection rate by 10 percent. NEO AID will identify that an observation has a high probability of being a true positive and will alert the astronomer of the same. This will free up time for the astronomers.

the asteroid to maximize the chances of deflection of the asteroid from its original path .

In order to speed up the process of shape modelling , Nasa is researching on using deep neural networks. They first created a few simulated asteroid shapes and corresponding fake radar data, to train a neural network with a variational autoencoder (VAE) to learn how to interpret the real raw radar data as 3D shapes. The VAE has 2 parts to it ; an encoder and a decoder. The encoder will describe the asteroid shape as latent variables vectors in a probabilistic manner. The decoder will use the vectors to reconstruct the 3d shape of the asteroid. Once the encoder and the decoder part of the VAE has been trained, the encoder part is dropped and the decoder is given the output obtained from radar images which then generates the 3d shape of the asteroid. Their new algorithm ran significantly faster than the original method, finishing in a matter of hours rather than days.

Now that we know about the potentially hazardous asteroids, we can deploy various planetary defense mechanisms to stop or deflect the asteroid. At the end of 2022, the DART impactor will be launched by NASA whose mission will be to deliberately crash a space probe into the moon Dimorphos of the double asteroid Didymos . This will be used to assess the future potential of a spacecraft's impact to deflect an asteroid on a collision course with Earth. Asteroid shapes are critical for asteroid deflection techniques as any mitigation plan needs to know the center of

Architecture of a Variational autoencoder



"Astronomy is on the cusp of a new data revolution"

Brant Robertson

The increase in the amount of data generated and computation power has led to the field of AI the world of astronomy by storm.

AI has transformed how astronomers analyse data and also has the potential to take over the tasks traditionally done by astronauts which will minimize the exposure of astronauts to harsh conditions of outer space.

We are close to unlocking the puzzle of the survival of our species and AI is one of the most important pieces of the it. It will ensure that our next generation can look at the beauty of the night sky without worrying about what the future holds.