



# Ravi Kumar

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Student member of the Astronomical Society of India  
Student member of the LIGO Scientific Collaboration

## Education

Indian Institute of Technology, Bombay

Dept. of Aerospace Engineering

Bachelor of Technology in Aerospace Engineering with Minor in Data Science and Artificial Intelligence

October '21 - Present

CPI: 8.23/10

## Publications & Conferences

- J. Basu, **R. Kumar** et al., “Discovery and Detailed Study of the M31 Classical Nova AT 2023tkw: Evidence for Internal Shocks” Submitted to the Astrophysical Journal
- D. Chatterjee, E. Marx, W. Benoit, **R. Kumar** et al., “Rapid Likelihood Free Inference of Compact Binary Coalescences using Accelerated Hardware” Accepted in Machine Learning: Science and Technology
- Tomás Ahumada, Shreya Anand, ..., **Ravi Kumar** et al., “Searching for gravitational wave optical counterparts with the Zwicky Transient Facility: summary of O4a” Accepted in Publications of the Astronomical Society of the Pacific
- Avinash Singh, R.S. Teja, ..., **R. Kumar** et al., “Unravelling the asphericities in the explosion and multi-faceted circumstellar matter of SN 2023ixf” Accepted in the Astrophysical Journal
- R. Kumar** et al., “Semi-transparent coded aperture masks with Daksha” manuscript under preparation
- R. Kumar** et al., “Lunar elemental ratios as derived from Chandrayaan-2” manuscript under preparation
- V. Swain, **R. Kumar** et al., “Rapid follow-up of GW events with a robotic optical telescope” Poster presented at the 32<sup>nd</sup> General Assembly of the International Astronomical Union at Cape Town, 2024

## Research Experience

Simulation Based Inference for Parameter Estimation with LIGO

May '24 - Present

Guide: Prof. Michael Coughlin, School of Physics and Astronomy, University of Minnesota

- Worked with **JAX** and **Torch** to implement the **Sine Gaussian** and **IMRPhenomP** waveforms for inference on GPUs
- Performed statistical analysis on **Qp transformed** simulated timeseries strain data to obtain best-fit Q and p values
- Applied **Likelihood Free Inference** (LFI) and **Normalizing Flows** for **Parameter Estimation** (PE) of **Burst** and **Compact Binary Coalescence** (CBC) events using synthetically generated Binary Black Hole waveforms
- Implemented a multimodal model, using temporal and frequency data, achieving a  $\sim 20\%$  lower validation loss
- Working to extend the existing PE infrastructure, allowing for inference of **Binary Neutron Star** (BNS) events

Optimization of Pipelines for GROWTH India Telescope

May '23 - July '24

Guides: Profs Varun Bhalerao (IITB), G.C. Anupama (IIA, retired), Sudhanshu Barway (IIA)

**Data Reduction**

- Improved the **image subtraction** pipeline by making use of **contour masking** techniques for diffraction spikes
- Implemented **weighted stacking** of images using variance **weight-maps** to deliver improved **limiting magnitudes**

**Technical Experience**

- Developed an **API** to transmit client requests for automating camera exposures and temperature control to a server using **HTTP** via **Flask**, executed with a **Visual Basic Script** (VBS) backend and synced the images using **SCP**
- Performed **on-site** maintenance by migrating from **Py2** to **Py3** and upgraded the **Telescope Control Software**
- Developed **Slack** bots to complete the transition of the existing GCN alert system to the **Apache Kafka** protocol

**Observational Experience**

- Discovered a nova **AT2023tkw** in **Andromeda** and published the results as AstroNote 2023-255, and ATel 16311
- Working with the international **GROWTH** collaboration on **EMGW** followups of LVK events – GCN 36080, 36246
- Performed optical follow-ups of **15+** GRBs and published the results as **NASA GCN Circulars** – GCN 37312, 37125, 37086, 35354, 35089, 35055, 35041, 35027, 34984, 34839, 34833, 34780, 34576, 34514, 34500, 34460, 34420
- Carried out observations and ephemeris calculations for multiple **possible comet** and Near Earth Objects (**NEOs**) and published the results on the **Minor Planet Center** as MPEC 2023-S264, 2023-R197, 2023-R115, 2023-O51

## Semi-Transparent Coded Aperture Masks with DAKSHA

August '24 - Present

Guides: Profs Varun Bhalerao (IITB), A.R. Rao (TIFR, retired)

- Obtained analytical expressions of uncertainty for Coded Aperture Mask (CAM) and Dispersed Detector localizations
- Simulated the Detector Plane Histogram, using **Cosmic X-ray Background** and the **Band spectrum** of GRBs
- Developed a **novel technique** for localization by considering only low energy ( $<50$  keV) photons to maximize contrast
- Achieved a  $\sim 1^\circ$  localization of  $3 \times 10^{-7}$  erg fluence sources, with plans to enhance the results using simulated background, denoising techniques and data from multiple detectors

## Statistical Analysis and Coverage Estimation with GIT

August '23 - November '23

Guide: Prof. Varun Bhalerao, Dept. of Physics, IITB

- Collated over **1500** Fermi GRB localization maps spanning over **6 years** using web-scraping techniques in Python
- Performed simulations to optimize for total telescope time spent on follow ups based on probability coverage estimates
- Results include the follow-up of GRBs **231018A** (GCN 34839) and **231122A** covering  $\sim 20\%$  of the probability map

## Workshops

### Zwicky Transient Facility Summer School

July '24 - August '24

5-day workshop on Artificial Intelligence in Astronomy - ZTF & University of Minnesota

- Attended lectures on Mixed Integer Linear Programming (MILP), Simulation Based Inference and Anomaly Detection
- Performed object detection using a **Region based CNN** and applied **MILP** for optimal scheduling of telescopes
- Implemented binary classifier with **VGG16** model to detect light echoes, stars in images and analyzed feature maps
- Trained models for transients, binary merger detection, and understood **DBSCAN** and **Gaussian Mixture Models**

## Key Projects

### Mapping the Lunar Surface with Chandrayaan-2 | GitHub

November '24 - December '24

InterIIT Tech Meet 13.0: ISRO Problem Statement

- Lead a team of **15**, securing the **first** position amongst 23 other IITs
- Studied X-ray Fluorescence (XRF) physics and elemental detection methods related to solar flares incident on Moon
- Utilized Chandrayaan-2 Large Area Soft X-ray Spectrometer (**CLASS**) data to develop and implement a **novel algorithm** to detect solar flares based on strengths of elemental XRF lines and quality of their gaussian fits
- Created the **first** high-resolution map of XRF line ratios using **GeoTIFF** files, identifying **compositional groups**

### Statistically Detecting Gamma Ray Bursts in CZTI | GitHub

May '23 - July '23

Krittika Summer Projects, IITB

- Studied physics of Gamma Ray Bursts (**GRBs**) and working of **AstroSat's** Cadmium-Zinc-Telluride Imager (**CZTI**)
- Analyzed the unknown distribution of noise data present in the light curves by fitting various known distributions, namely the **Gaussian**, **Poisson**, **SkewNorm** and **Gamma** distributions and statistically determined the best fit
- Developed a robust algorithm to determine the **real/bogus** nature of a given signal by maximizing Signal-to-Noise Ratio (SNR) across timebins and eliminate outliers with **SNR**  $> 3$  in different energy bands, obtaining **90%** accuracy

### Time Series Analysis of Magnetic Cataclysmic Variables | Report

May '23 - July '23

Krittika Summer Projects, IITB

- Studied the physics governing **binary stars** and cataclysmic variables (**CVs**) with emphasis on **magnetic** CVs
- Processed **Astrosat's** **UVIT** data to generate light curves using the custom library **curvit**, and accurately obtained the **orbital period** of the Magnetic Cataclysmic Variable **BL Hyi** by analyzing its **Lomb-Scargle Periodogram**
- Performed **phase folding** and correction of **ephemeris** on the obtained light-curve, furthermore, calculated the magnitudes, fluxes, and luminosities associated with each phase to determine the **physical state** of the system

### Stellar Analysis of Clusters using Gaia | Report

May '23 - July '23

Krittika Summer Projects

- Employed parallax and proper motion quality cuts in a dataset of **1 billion+** stars to find distances of 5 open clusters
- Studied **phase space distribution** of spectral types in open clusters and obtained the Salpeter Initial Mass Function (**IMF**) by fitting **PARSEC isochrones** on its **HR diagrams** and found the age and metallicity for globular clusters

### Representations of VQVAE Models on Parallel Datasets | GitHub

November '24

IE643 Course Project, Guide: Prof. P Balamurugan, IEOR, IITB

- Developed and analyzed **VQVAE models** to evaluate the impact of noise distributions in parallel datasets on latent space representations, by using **PCA**, **t-SNE**, **MDS** and **Isomap** as dimensionality reduction techniques
- Utilized statistical methods like **Kernel Density Estimation**, **Cosine Similarity**, **Mahalanobis Distance**, clustering to quantify and visualize the effect of **Gaussian**, **Poisson**, **Speckle** noise in the codebook vectors
- Built an interactive GUI with the dynamic evolution of codebook vectors during training, to compare noise effects

## Analysis of Solar Flares and Prediction of Solar Activity | GitHub

November '22

Data Analysis (DS203) Course Project, Prof. Amit Sethi, Prof. Manjesh K. Hanawal

- Studied the underlying physics associated with **solar flares and activity** and collected datasets for further analysis
- Trained the **LSTM** and **Autoregressive** models on time series data from the **RHESSI** and **Konus-Wind** missions
- Achieved mean squared error of **0.014** and **0.024** on average using the Autoregression and LSTM models respectively

## Recurrent Feature Reasoning for Image Inpainting | GitHub

April '24

CS736 Course Project, Guide: Prof. Suyash Awate, Computer Science and Engg. Dept., IITB

- Analyzed a novel **Recurrent Feature Reasoning** model for medical image inpainting on custom masked datasets
- Conducted experiments on various mask types and dataset variability, demonstrating **out-of-sample** generalizability
- Evaluated performance using **SSIM**, **PSNR** and **RMSE** metrics on Chest X-ray and SARS-COV-2 CT-Scan datasets

## Weather Classification via Computer Vision | GitHub

April '24

Self Project

- Implemented a **ConvNet** model for transfer learning with **VGG16** backbone pre-trained on the **ImageNet** dataset
- Achieved an unprecedented validation accuracy of **85.61%**, seeing an improvement of **5.34%** over the original model.
- **Fine-tuned** the model with a head consisting of **flatten**, **dense** and **dropout** layers to improve accuracy by **4.38%**

## Animal Classification using CNNs | GitHub

April '23

DS303 Course Project, Guide: Prof. Biplab Banerjee, CSRE, IITB

- Implemented a **Deep Learning** based research paper to classify animal species, achieving a training accuracy of **98%**
- Deployed **7 layers** with multiple filters, **dropout regularization**, **Adam optimizer** and **ReLU** activation function

## Professional Experience

### Digantara | Technology Consulting Intern

May '24 - August '24

Working with a team of engineers on developing advanced telescope automation systems

- Integrating **GNSS** modules to establish **microsecond-level** accurate automated exposures for a **CCD camera**
- Spearheading **knowledge transfer** to company engineers on topics of astronomy, telescope working and automation
- Integrating **ASCOM Alpaca** and **PlaneWave Interface (PWI4)** APIs using Python, setting up a system of multiple telescopes to enable automated scheduling, slewing and tracking for wide-field nightly survey of **non-sidereal** targets

## Positions of Responsibility

### Team Krittika - Volunteer

December '22 - April '23

The Astronomy Club of IIT Bombay

- Increased astronomy awareness in the institute by conducting a stargazing session by employing Electronically Assisted Astronomy (**EAA**) to display live footage of **comet C/2022 E3 (ZTF)** for an audience of **250+** students.
- Assisted in club outreach by regularly capturing and posting images of deep sky objects such as the **Orion Nebula**, **Leo Triplet**, and **Omega Centauri** along with a **transit** of the **International Space Station** across the Sun.

## Scholastic Achievements

- **99.27 percentile** in Joint Entrance Examination, Mains among over **0.9 million** candidates February '21
- **Top 1.15%** in Joint Entrance Examination, Advanced among over **0.14 million** candidates October '21

## Courses Undertaken

<b>Data Science</b>	Deep Learning, Machine Learning, Medical Image Computing, Data Analysis and Interpretation
<b>Mathematics</b>	Numerical Analysis, Partial Differential Equations, Multi-Variable Calculus, Linear Algebra
<b>Other</b>	Quantum Physics and Application, Basics of Electricity and Magnetism, Electrical and Electronics Circuits, Modelling and Simulation, Navigation and Guidance, Computational Fluid Mechanics, Control Systems

## Technical Skills

<b>Languages</b>	Python, C++, SQL, HTML5, CSS, Java Script, $\text{\LaTeX}$ , Visual Basic Script
<b>Softwares</b>	DOLPHOT, CCDLAB, SWarp, SExtractor, DS9, Siril
<b>Utilities</b>	Git, Apptainer, PyTorch, JAX, Poetry, AstroPy, Flask, OpenCV, NumPy, SciPy, TensorFlow, Matplotlib

## Extra-Curricular Activities

- Contributed photographs displayed in **Kaladarshan**, the annual art exhibition of IITB March '22, '23 and '24
- Secured **second position** in the Photo Story competition at the **Inter-IIT Cultural Meet**, 6.0 December '23
- Devoted **80+ hours** of social service work under **Green Campus** department, National Service Scheme, IIT Bombay November '21 - June '22

## References

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### **Prof. Varun Bhalerao**

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