Caltech
Student-Faculty Programs

# Session Q Abstract

**A live modern interactive dashboard to display KOA's metrics at scale**
Min Phone Myat Zaw
*Mentors: Graham Berriman and Judy S. Adler*

Since 2004, the Keck Observatory Archive (KOA) has operated as a NASA-funded collaboration between the NASA Exoplanet Science Institute( NExScI) and the W.M. Keck Observatory. It ingests, curates and serves all data acquired by the twin 10m Keck telescopes on Mauna Kea, Hawaii. In the past three years, KOA has begun a modernization program that will replace the architecture and systems, used since the archive opened, with a new infrastructure. This infrastructure will position KOA to respond to the rapid growth of new and complex data sets that will be acquired by new instruments now in development. And to respond to the rapid follow-up needed to identify the deluge of alerts of transient sources expected by new survey telescopes such as the Rubin Observatory. Since 2002, KOA has ingested new data in near-real time, generally within one minute of creation, and makes them immediately accessible to observers through a dedicated web interface. The archive is now deploying a new scalable Python-based, VO-compliant query infrastructure built with the Plotly-Dash framework and R-tree indices to improve performance (x20).

This project will exploit the new query infrastructure to develop a dashboard that will return, in near real-time, metrics on the performance and growth of the archive (growth in size, monitor growth in the number of users, ...). These metrics assess the current health of the archive, and guide planning future hardware and software upgrades. This single dashboard will enable, for example, monitoring of real-time ingestion, as well as studying the long-term growth of the archive. Such a metrics dashboard is an essential part of the new architecture. Current methods of gathering metrics are inadequate to support the archive as it scales going forward. These methods suffer from high latency, are not optimized for on-demand metrics, and are scattered among various tools.

**An interactive framework for determining hypervelocity star origins in a dynamic galactic potential**
Andrew S. Qin
*Mentors: Ana Bonaca and Kareem J. El-Badry*

Hypervelocity stars (HVSs), ejected from galactic centers via the Hills mechanism, serve as powerful probes of galactic dynamics and the processes occurring near supermassive black holes. While many HVSs have been presumed to originate from the Milky Way (MW), recent evidence suggests a significant fraction may be linked to an intermediate-mass black hole (IMBH) within the Large Magellanic Cloud (LMC). Investigating these origins requires sophisticated numerical simulations, yet current methodologies to enable such analysis are often narrow in scope, as they typically rely on fixed potential models that do not allow for the exploration of uncertainties in the underlying parameter space. Our project addresses this gap by developing a novel, interactive simulation software for the 3D Virtual Reality VizLab at Carnegie Observatories. The software enables users to manually tune key physical parameters of the Milky Way and LMC potentials—such as bulge, nucleus, and dark matter halo masses as well as scales—and immediately visualize the resulting impact on HVS trajectories. Underpinning this visualization is a high-fidelity, time-varying gravitational potential that models the dynamic evolution of the MW-LMC system using interpolated N-body simulation data. If time permits, this software will be used to analyze data from 56 recently surveyed HVS candidates, which were identified using deep u-band photometry from the SMASH survey. This analysis could provide valuable new constraints on the mass of the LMC's central IMBH and its surrounding environment.

**Incorporating uncertainty in the radio interferometry measurement equation**
Ethan Feng
*Mentors: Gregg W. Hallinan and Ruby L. Byrne*

Radio interferometry allows astronomers to obtain detailed sky maps by combining signals from an array radio antennas. Currently, there lacks a statistical approach to account for beam model errors in gridding-based imaging. This has led to the reliance of manual tuning of hyper parameters to compensate for variations in the antenna beam. To tackle this problem we developed a principled approach that directly incorporates beam error into the measurement equation. This framework provides quantitative uncertainty measurements and eliminates dependence of hand tuning. Our method enables robust and statistically principled interpretation of radio interferometry data. This will pave the way for high precision image reconstructions, necessary for applications such as 21 cm cosmology which is fundamental for studying the birth of the first luminous objects in the universe.

**Investigating the origin of radio emission in SN 2021bmf: Off-axis GRB or circumstellar interaction?**
Grace Showerman
*Mentors: Gregg W. Hallinan and Jessie M. Miller*

We present a multi-wavelength analysis of the broad-lined Type Ic supernova (SN Ic-BL) SN 2021bmf aimed at determining the origin of its bright radio emission. Using observations from the Karl G. Jansky Very Large Array (VLA) in L, S, C, and X bands, we construct a broadband radio spectrum from twelve sub-bands after careful flagging and calibration. The spectrum is well described by a synchrotron self-absorption model, with a peak flux density of $S_{\max} = 14.6 \pm 0.2$ mJy at 6.5 GHz. Parameter estimation using nested sampling with dynesty constrains both the spectral indices and peak properties, confirming that the observed emission is inconsistent with expectations for an off-axis gamma-ray burst (GRB) jet. Instead, the data is best explained by strong interaction between the SN ejecta and a dense circumstellar medium (CSM). This conclusion is supported by Keck LRIS spectroscopy, which reveals emission line evolution that is consistent with ongoing CSM interaction. Taken together, our results demonstrate that the luminous radio emission in SN 2021bmf likely arises from a dense CSM environment rather than a hidden GRB.

**Enhancing astronomical spectrographic efficiency through automated and modular mask-cutting software infrastructure**
Maylin D. Chen
*Mentors: William Schoenell and Charles C. Steidel*

Mask-cutting is a crucial component of multi-object spectroscopy and astronomy as a whole. Spectrographs capture light from far-away objects to analyze a variety of phenomena, such as velocity dispersions and chemical makeup. With multiple objects often within the capturing scope of spectrographs, masks are extremely important to eliminate interference from other objects. Despite its importance, the current process for cutting masks remains largely manual, time-consuming and prone to human error because there is no way to automate the process, which requires many specific parameters to be input repeatedly. In this project, we aim to create an open-source, modular software framework that incorporates existing applications to create a more efficient workflow by enabling automation and more rigorous error-checking through an API and web interface. While our goal is to eventually support multiple mask-cutting softwares in our infrastructure, we're focused on first creating a working proof-of-concept for Carnegie Observatory's two spectrographs: IMACS and LDSS3. I'll be using a popular Python framework called Django, which has extensive infrastructure to create REST APIs, which are uniquely suited for interactions from website interfaces due to the HTTP protocols they use. Moreover, Django has an app-based organizational system, where apps are groups of code contributing to the same goal. By simply creating a modifiable app template that specifies all the API functions a mask cutting program would need, this system allows support for additional spectrographs to be instantaneously integrated with the existing codebase. In our finalized prototype, we simplified the workflow into one continuous process that implemented stronger organizational conventions such as naming restrictions and mask grouping, while also retaining all of the original functionality of the mask cutting software. We also added more user feedback, such as a visual schematic showing the slit placements overlaid on sky catalog images. Given its modularity, ease of integration, and improved user experience, this system holds strong potential for broader implementation across observatories.

**Investigating dust production in two unusual supernovae with JWST**
Daria S. Hajimiri
*Mentors: Mansi M. Kasliwal and Jacob Jencson*

The James Webb Space Telescope (JWST) provides a new opportunity to study the origins of dust in high-redshift galaxies by observing core-collapse supernovae (CCSNe), which are considered strong candidates for major sites of dust production in the Universe. As part of a growing sample of dusty CCSNe observed with JWST/MIRI, we present mid-infrared imaging observations between 7 and 21 micron of AT2016bse and SN2017gkp. These two CCSNe were selected for their unusual optical light curves and late time infrared excess emission seen by NEOWISE. Flux measurements were obtained through manual aperture photometry and automated point-spread-function photometry, allowing for cross-validation and the identification of systematic errors, particularly in background estimation. These calibrated fluxes were used to construct spectral energy distributions and to test single- and multi-component dust models. This work contributes to a broader effort to develop precise photometry methods for CCSNe with JWST, deriving mid-IR fluxes and constraining dust content over time. The upcoming Roman Space Telescope, with its wide field and infrared sensitivity, will be a powerful discovery engine to build larger samples of dusty CCSNe. Leveraging JWST results, this research advances our understanding of astrophysical dust formation in explosive stellar environments.

**Optimizing transient recovery and analysis for simulated Roman observations**
Daria Alice Ciobanu
*Mentors: Jacob Jencson and Lin Yan*

The Roman Alerts Promptly from Image Differencing (RAPID) pipeline is being developed to enable near-real-time discovery of astrophysical transients and a broad range of time-domain science for the upcoming Roman Space Telescope, set to launch before May 2027. To test and validate the pipeline's performance, RAPID makes use of the OpenUniverse2024 data set of simulated images with injected transient events based on the planned Roman High-Latitude Time-Domain Survey. We began by assessing photometric accuracy using manual aperture photometry on the difference images produced by the pipeline and comparing results to automated photometry and the "true" injected transient light curves, identifying systematic biases due to aperture size and residual background structures. As the project progressed, the focus shifted to evaluating detection completeness and reliability across two state-of-the-art subtraction algorithms, ZOGY and SFFT. Using matched catalogs and diagnostic cutouts, we found that SFFT recovers fainter injected sources at the cost of more false positives, while ZOGY provides cleaner samples but misses a larger fraction of dimmer transients. These findings inform ongoing development of detection thresholds, masking strategies, and subtraction methods in the RAPID pipeline, thereby optimizing future transient science with Roman.

**Finalizing the characterization of Lyα emission from a sample of low luminosity, broad-line QSOs with KCWI**
Charis M. Hall
*Mentors: Charles C. Steidel and Evan Nuñez*

Investigating the circumgalactic medium (CGM) of distant galaxies with actively accreting supermassive black holes (QSOs) is important for understanding the role of extended gas in galaxy evolution. The CGM is very diffuse and therefore intrinsically faint. It is therefore particularly useful to observe bright emission lines such as Lyman-Alpha (Lyα), a recombination line of neutral hydrogen that can be radiated by the CGM.Due to its role as a tracer of both photoionized and neutral Hydrogen, the presence of diffuse Lyα emission can tell us more about the structure of cool gas within the CGM and the sources responsible for ionizing it. Studying Lyα emission from low luminosity, broad-line

QSOs will aid in the broader goal of defining exactly what constitutes a faint QSO. In this study, we characterize the spatially extended Lyα emission of a sample of 7 faint, broad-line QSOs at z = 2.1 – 2.6. Using integral field unit (IFU) data cubes observed using the Keck Cosmic Webb Imager (KCWI), we make a comprehensive comparison of Lyα emission within the sample, investigating: 1) the kinematics of the extended emission 2) the spatial extent, surface brightness distribution, and asymmetry of the emission, 3) the luminosity of the extended emission compared to that of the central QSO. Additionally, our analysis of these fainter QSOs provides opportunities for definitive comparisons with studies of emission from star-forming galaxies and hyper-luminous QSOs (HLQSOs), obtained from literature.

The broader goals of this work include better defining existing constraints as well as exploring open questions surrounding this fainter, broadline class of QSOs – e.g. investigating why these objects are so intrinsically faint yet still display many characteristics of more luminous QSOs (broad-lines, bright Lyα emission from these broad-line regions, etc.).

**Type II AGN at z~2-3**
Ricardo J. Mendez
*Mentor: Charles C. Steidel*

The discovery of ubiquitous Lyα emission around quasars (QSOs) at redshifts (z) ~2-3 has allowed for direct probes of the Circumgalactic medium (CGM). This project aims to characterize ultraviolet (UV) emission at CGM-scales around Type II active galactic nuclei (AGN). The role of AGN feedback in regulating galaxy evolution is still largely misunderstood, and this project aims to improve our understanding of AGN at peak star-formation. We primarily use Keck Cosmic Web Imager (KCWI) integral field unit (IFU) observations in the UV rest frame we are able to characterize both the spatial and spectral dimensions of the Lyα nebulae. In addition to KCWI, ancillary optical spectroscopy and imaging from Keck/MOSFIRE and *Hubble Space Telescope* Wide Field Camera 3, are utilized in order to better constrain the kinematics and physical properties of the CGM around these objects. These observations will then be compared against the nebulae of Type I AGN in the sample. Comparisons of kinematics, linewidths, and spatial extent will be made. The strength and shape of the emission at radial distances will also illuminate clues about the ionization sources and physical morphology of the host galaxies.