Session R Abstracts

Beyond statistical isotropy in 3D galaxy surveys
Adam El-Hindi
Mentors: Olivier P. Doré and Henry Gebhardt

Statistical isotropy is the assumption that the Universe has no preferred direction and it underlies most analyses of large-scale structure. We develop an observer-centered, three-dimensional test of this assumption for wide-area galaxy surveys, with SPHEREx as the principal application. The galaxy density field is expanded in spherical Fourier-Bessel modes, and its full two-point function is decomposed into bipolar spherical-harmonic coefficients. The isotropic power spectrum appears as the monopole of this decomposition, while higher multipoles describe general direction-dependent correlations across angular and radial scales. We derive quadratic estimators for these coefficients and model their coupling through the survey geometry, radial selection, shot noise, catalog normalization, and redshift-space distortions. The estimator and covariance framework are validated on simulations with an anisotropy signal injected. As a first survey application, we apply our estimator on the quadrupolar sector of the eBOSS DR16 quasar sample and find no significant departure from isotropy. This work provides the basis for a general multipolar analysis of SPHEREx, capable of testing cosmic isotropy in three dimensions and constraining a broad range of possible directional patterns in the galaxy distribution.

Extreme long-duration Be star outbursts discovered with NEOWISE
Ming To Suen
Mentor: Lynne Hillenbrand

Be stars are classically defined as B-type stars that exhibit Balmer line emission, indicative of circumstellar gas. They rotate rapidly, ejecting material from their equatorial regions to form a decretion disk. A subset of Be stars undergoes episodic outbursts associated with disk formation and dissipation, typically with amplitudes of 0.5–1 magnitude and durations of less than 1–2 years. We identify a new class of extreme Be star outbursts using NEOWISE data, characterized by larger amplitudes and significantly longer durations, with brightenings of up to 2.5 magnitudes lasting 5–15 years. Multiwavelength light curves from optical and infrared surveys are used to characterize their variability. Most targets become redder as they brighten in the infrared, consistent with circumstellar disk formation, while optical behavior ranges from correlated brightening to anti-correlated dimming, suggesting inclination-dependent effects. Additional evidence for circumstellar material includes Hα emission and infrared excess that increases with wavelength. Spectroscopic data, including Gaia XP and ground-based observations, support early-type classifications and the presence of emission-line features. These results suggest that the observed variability is driven by sustained mass injection and long-term disk growth, representing an extreme and previously underexplored regime of Be star activity.

Breaking orbital degeneracies of directly imaged companions using KPIC relative radial velocities
Tyler N. Tuttle
Mentors: Dimitri P. Mawet and Clarissa R. Do O

Directly imaged substellar companions often occupy orbits with centuries-long periods, making our 10- to 20-year baseline astrometric observations insufficient for accurately determining the orbital architectures of these systems. To further constrain these companions' orbits, this study uses newly reduced high-resolution radial velocities (RVs) derived from spectroscopic observations of the Keck Planetary Imager and Characterizer (KPIC) for a selection of 10 substellar companions. The companion orbits were fit using the Bayesian orbit fitting package Octofitter.jl with joint modeling based on published relative astrometry, stellar RVs, the new KPIC relative RVs, and absolute astrometry derived from the Hipparcos-Gaia Catalogue of Accelerations (HGCA) and the Calibrated Gaia DR2, DR3, and

Hipparcos Catalogue (G23H). The addition of these line-of-sight velocities successfully resolves longstanding degeneracies in orbital plane architectures, eliminating unphysical high-eccentricity orbital families. Furthermore, we propose the first-ever orbital solution for the HIP 79098 system ($a \approx 464$ AU, $P \approx 5321$ yr) while drastically tightening the posterior distributions for targets such as HD 1160 B and DH Tau B. Overall, this project updates the orbital parameter posterior distributions over the 10 benchmark targets, offering crucial dynamical constraints to inform companion formation models while contributing open-source tools to the scientific community.

Probing far-from-equilibrium strangeness-driven bulk viscosity in binary neutron star inspirals
Melvin Storbacka
Mentors: Elias R. Most and Jiaxi Wu

Constraining the high-density equation of state is one of the main goals of gravitational-wave and X-ray observations of neutron stars. Specifically, such observations could help probe the presence of strangeness in the cores of neutron stars. While strangeness is expected to affect static properties of neutron stars, it could also alter their dynamical properties. In particular, if oscillations during inspiral drive strangeness out of equilibrium, significant bulk viscosity can result, which may damp the oscillations. To probe the impact of these dynamical effects, the microphysical evolution of strangeness and beta equilibration must be resolved. To this end, we have developed the first reaction network for strangeness equilibration in neutron-star matter capable of capturing far-from-equilibrium regimes and dynamical coupling between reactions. With this approach, we find that neutron star matter may be driven far from equilibrium during inspiral, giving rise to substantial strangeness-driven bulk viscosity that could affect the orbital evolution and gravitational-wave signal. These findings motivate more careful modeling of nonequilibrium strangeness dynamics during the inspiral.

Accelerating simulations of black hole accretion using time dilation
Grant D. Van Gerpen
Mentor: Elias R. Most

Black holes grow by accreting matter from their environments, but modeling this process across the full range of physically relevant spatial and temporal scales is computationally demanding. In general relativistic magnetohydrodynamics (GRMHD) simulations, higher characteristic speeds near the black hole restrict the global timestep, limiting how long the system can be evolved at fixed computational cost. To address this limitation, we are testing and extending a time-dilation algorithm in the GRMHD code H-AMR. The method slows fluid evolution near the black hole, enabling larger global timesteps while preserving the system's large-scale, time-averaged behavior. Unlike previous discrete implementations for stationary black holes, our analytic formulation allows the dilation factor to vary continuously throughout the domain and extends the method to moving black holes. We have tested this approach using magnetized Bondi–Hoyle–Lyttleton accretion, in which a black hole moves through a uniform medium, and are conducting convergence studies to identify parameter choices that reproduce the expected behavior. We are also generalizing the method to a black hole following a prescribed orbit in a time-dependent metric, providing a step toward accelerated simulations of accretion in systems such as binary black holes.

Radio holography for the Deep Synoptic Array
Ngoc Thach Dang
Mentor: Stephen Padin

We developed an on-field holography method to measure surface accuracy of the Deep Synoptic Array (DSA) antennas using signals from bright astronomical objects, with a proof of concept established using DSA's 5m prototype antennas at the Owens Valley Radio Observatory. The DSA is a radio telescope array under construction in Spring Valley, Nevada consisting of 1650 6m diameter antennas with a broad frequency range of 0.7-2.0 GHz. Surface irregularities on a radio antenna distort its angular response, compromising its ability to perform high-fidelity observations, so accurate surface characterization is essential. Holography on small antennas at low frequencies poses particular challenges, primarily due to low signal-to-noise and severe radio-frequency interference from cell phone communications. To address the SNR limitation, we use a long-duration holography technique in which integration time is increased for off-source grid points, with measurements split across multiple days.

A reduced-order thermal model and multi-input controller for the HISPEC spectograph
Andrey Korolev
Mentor: Jake Zimmer

Cryogenic astronomical instruments such as the HISPEC spectrograph must hold large optical assemblies at a stable operating temperature near 55 K, yet their thermal behavior is set by hundreds of thousands of coupled conduction and radiation pathways, far too many states to simulate in real time or to design a controller against. This project develops an end-to-end pipeline that turns a CAD assembly into a lumped thermal-network model and reduces it to a compact form suitable for on-board control. From the instrument geometry an octree mesh builds a multi-million-node thermal graph; the linearized dynamics are projected onto their 120 slowest physical modes and then reduced by balanced truncation to a 30-state model that keeps only the jointly controllable and observable dynamics. On this reduced model I design a multi-input linear-quadratic-regulator controller with a static state estimator and a regularized steady-state feedforward for its 33 heaters and 28 controlled sensors. The 30-state model reproduces the full plant's heater-to-sensor step response to within about 0.15%, small enough to design against while remaining light enough to run on a microcontroller. Remaining work adds surface-to-surface radiation and hardware deployment.

Optimizing FRB observations with the Deep Synoptic Array
Oliver R. Jones
Mentors: Vikram Ravi and Kaitlyn Shin

Fast Radio Bursts (FRBs) are mysterious energetic radio transients, typically with burst durations on the order of a millisecond. They are common — yet difficult to observe — astronomical phenomena, and can be utilized to investigate the energetic events that cause these transients and to probe the diffuse universe. In order to best investigate the topics above, large numbers of FRB observations and localizations are necessary for accurate population statistics. The Deep Synoptic Array (DSA) radio telescope, set to start full science operations in 2029, will provide these necessary FRB observations. In this project, we have simulated FRB populations and a DSA instrument model to understand what DSA parameters are predicted to produce the most detected FRBs. For the FRB populations, we are using the parameters acquired by the CHIME/FRB DR2 catalog to create a baseline population, and modelling how these burst parameters are affected by the DSA detection system. By altering these populations and DSA parameters (bandwidth, time resolution, frequency resolution and beam size), we should be able to optimize the number of detectable FRBs. Our simulations framework can also be used to enable further optimizing for certain sub-populations of FRBs, such as distant sources.