TEXAS PAARE Research Mentors

All four research mentors of this program work in the field of extragalactic astrophysics, with an emphasis on SMBHs and galaxies (see Fig. 1 for a gallery of our research focuses). Our expertise covers theory, simulations, and observations. Below, we describe in more detail our areas of research, relevant mentoring experiences, and possible projects for bridge fellows.

Yuan Li (UNT)

Li works in the general field of galaxy evolution, with a focus on numerical simulations related to massive galaxies, galaxy clusters, and SMBHs. She also analyzes observational data. She currently co-leads a project funded by the NSF to study the kinematics of cool filaments in galaxy groups/clusters and their relation to SMBH feedback in both observations and numerical simulations. Bridge fellows are invited to get involved in either the analysis and interpretation of the observational data or help with simulation analysis. The simulations will be performed and stored on the Texas Advanced Computing Center (TACC), to which Li's group has exclusive access through a new agreement between UNT and the University of Texas at Austin. In addition, Li has regular awards with various national computing facilities to which students can have access, including the NSF Extreme Science and Engineering Discovery Environment (XSEDE).

Other example projects include (1) SMBH-host galaxy scaling relations in cosmological simulations such as Illustris, IllustrisTNG, EAGLE, and Simba, (2) numerical studies of SMBH feeding in the presence of multiphase gas from galaxy scales to accretion disk scales, and (3) analyzing turbulence in the interstellar medium traced by young stars using GAIA and APOGEE data [1]. All of them are collaborative projects with astronomers outside UNT and will help bridge fellows expand their network. Most of the analysis is carried out using Python. Analysis of simulation results usually involves the open-source yt package [2], and students will be connected to the yt user and developer community.

Li is currently leading a diverse research group consisting of two graduate students and several undergraduate students as well as high school students from the Texas Academy of Mathematics and Science (TAMS) at the University of North Texas. She served on the Diversity and Inclusion Committee of the Physics Department at UNT from 2020 to 2021, and has led many public outreach activities both before and after joining UNT.

Ohad Shemmer (UNT)

Shemmer has an active research group, typically consisting of up to four graduate students, working on a variety of multiwavelength studies of active galactic nuclei. The main themes of his research group involve estimating the masses and accretion rates of supermassive black holes in the centers of active galaxies and quasars, particularly at the highest redshift. The group utilizes data from a variety of ground-based observatories, such as the Gemini Observatory or the Very Large Telescope, as well as space-borne observatories such as the Chandra X-ray Observatory and the Hubble Space Telescope. Bridge fellows working with Shemmer can be expected to master the basic skills required for observational astronomy such as photometric and spectroscopic data reduction and analysis, data modeling, and statistical analysis.

A major research effort that bridge fellows can participate in involves spectroscopic analysis of the large dataset obtained from the recent Gemini Near-Infrared Spectrograph - Distant Quasar Survey (GNIRS-DQS) and follow-up multiwavelength observations of sources from that survey. These investigations include 1) comparisons of accretion-rate diagnostics across the rest-frame ultraviolet-optical band in the largest area of the luminosity-redshift parameter space, 2) studying the rest-frame optical spectroscopic properties of extreme quasars (such as broad absorption line and weak-emission line quasars) at "cosmic noon", and 3) connecting the rest-frame ultraviolet-optical spectral properties of low- and high-redshift quasars that have been enabled by

GNIRS-DQS.

Additional investigations involve either new X-ray imaging spectroscopy or X-ray spectroscopic analysis of similar archival data, of high-redshift quasars in an effort to identify the most robust accretion-rate indicator through measurements of the hard X-ray power-law spectral slope and the optical-X-ray spectral energy distribution.

Lindsay King (UTD)

King's research focuses on understanding the composition and properties of massive objects in the Universe, and their formation and evolution. Her research group combines computational studies (primarily using TACC through UT System access) with multiwavelength data analysis, in particular using strong and weak gravitational lensing as a probe of mass. She is also interested in the role that baryonic physics (e.g. feedback from supermassive black holes) plays in shaping the mass distributions of the inner parts of galaxy clusters, and the impact on observables. One current interest is galaxy cluster mergers. Her interests span topics covered by NSF AST and PHY and she is Co-PI on an NSF Gravitational Theory project with Kesden as PI to investigate constraints from lensing of gravitational waves from compact objects, and lensing of electromagnetic waves from their host galaxy.

King is committed to breaking down barriers to full participation in astronomy education and careers faced by underrepresented students. King and Kesden (along with biophysicist Jason Slinker) are PIs of the NSF REU physics program at UTD, the first program to be awarded in the school of Natural Sciences and Mathematics. King has also been an affiliated astronomer at the Maria Mitchell Observatory for three years and acted as a research mentor for their REU program in astronomy (PI Dr Regina Jorgenson). King serves as the faculty advisor for the undergraduate physics program at UTD. For several years she has served on the UTD university committee for the support of diversity and equity. In support of inclusion at the faculty level, she has recently been appointed as a faculty liaison for the new NSF ADVANCE program ASPIRE^2 at UTD.

Research projects will be decided closer to the time of advertisement. A project currently being undertaken by a senior undergraduate student is given as an example: The project involves computer simulations of idealized merging galaxy clusters, to explore the evolution of their dark and luminous matter distributions. The simulations are analyzed, and synthetic maps of mass (idealized, and obtained via gravitational lensing), X-ray, and Sunyaev-Zeldovich signals are obtained. Markov Chain Monte Carlo techniques are used to obtain parameterized mass models of the clusters from the lensing mass maps. The impact of realistic cluster structure, shape and large-scale environment on the findings are explored, by extracting merger systems from cosmological simulations and repeating the analysis and modeling. This type of project involves use of TACC and also develops coding skills, especially in Python. The student also gains experience of working with external international collaborators.

Michael Kesden (UTD)

Kesden and his research group investigate two exciting phenomena involving black holes: binary black-hole (BBH) mergers and stellar tidal disruption events (TDEs). Bridge fellows will develop projects on these topics in consultation with Co-PI Kesden. Gravitational waves (GWs) emitted during the inspiral and merger of stellar-mass BBHs have been observed since 2015 by ground-based GW observatories such as the Laser Interferometer Gravitational-wave Observatory (LIGO). The Laser Interferometer Space Antenna (LISA), a proposed space-based GW observatory, will observe GWs from the merger of supermassive BBHs. The scale-free nature of general relativity implies that scaled versions of the same gravitational waveforms can describe the signatures of both stellar-mass and supermassive BBH mergers. According to the "no hair" theorem, isolated BHs are fully described by their masses and spins. In binary systems, these spins will generally be misaligned with the orbital angular momentum of the binary, causing them to precess as the BBHs inspiral towards merger. Kesden and his group explore the dynamics of BBH spin precession, and how spin precession modulates the spectrum of emitted GWs. This modulation, which has been tentatively detected in several LIGO events, will be measured much more accurately in supermassive BBH mergers, which will be observed by LISA with much higher signal-to-noise ratios. BBH spin precession is both a fundamental test of general relativity and a probe of BBH formation mechanisms that give rise to misaligned spins. Kesden and his collaborators use simulations of binary stellar evolution and cosmological structure formation to predict BBH spin misalignments in both the stellar-mass and supermassive regimes and thus assess the ability of LIGO and LISA to constrain astrophysical BBH formation scenarios.

Supermassive black holes (SMBHs) reside in the centers of most large galaxies. If a star gets too close to the galactic center, it will be disrupted when the tidal gravitational field of the SMBH overwhelms the self gravity of the star. Debris produced in the disruption can be accreted by the SMBH, fueling a TDE in which the SMBH radiates like an active galactic nucleus. This can only occur however if: (1) the SMBH tides are strong enough to disrupt the star, (2) the stellar debris can successfully circularize into an accretion disk, and (3) this debris can avoid direct capture by the SMBH event horizon. All three of these factors depend on the SMBH spin and the stellar orbit, so TDEs provide a unique probe of SMBH mass and spin distributions, the dynamics of accretion-disk formation, and orbits within nuclear star clusters. Kesden and his group create models using the Kerr metric that describes spinning black holes to predict TDE rates and their observed properties.

Kesden is also interested in developing software for STEM education and outreach. He is Co-PI of an NSF STEM+C grant that supported the creation of the Scaffolded Training Environment for Physics Programming (STEPP), a series of educational modules that synergistically teach introductory mechanics and computational thinking. STEPP was assessed during the 2019 - 2020 academic year at both UTD and several DFW-area high schools with diverse student populations. Kesden has also created Virtual Interaction with Gravitational waves to Observe Relativity (VIGOR) [3], an interactive simulation of BBHs and the GWs they emit designed for public outreach. VIGOR is publicly available and has been presented at the UTD Women in Physics summer camp and several STEM education conferences.

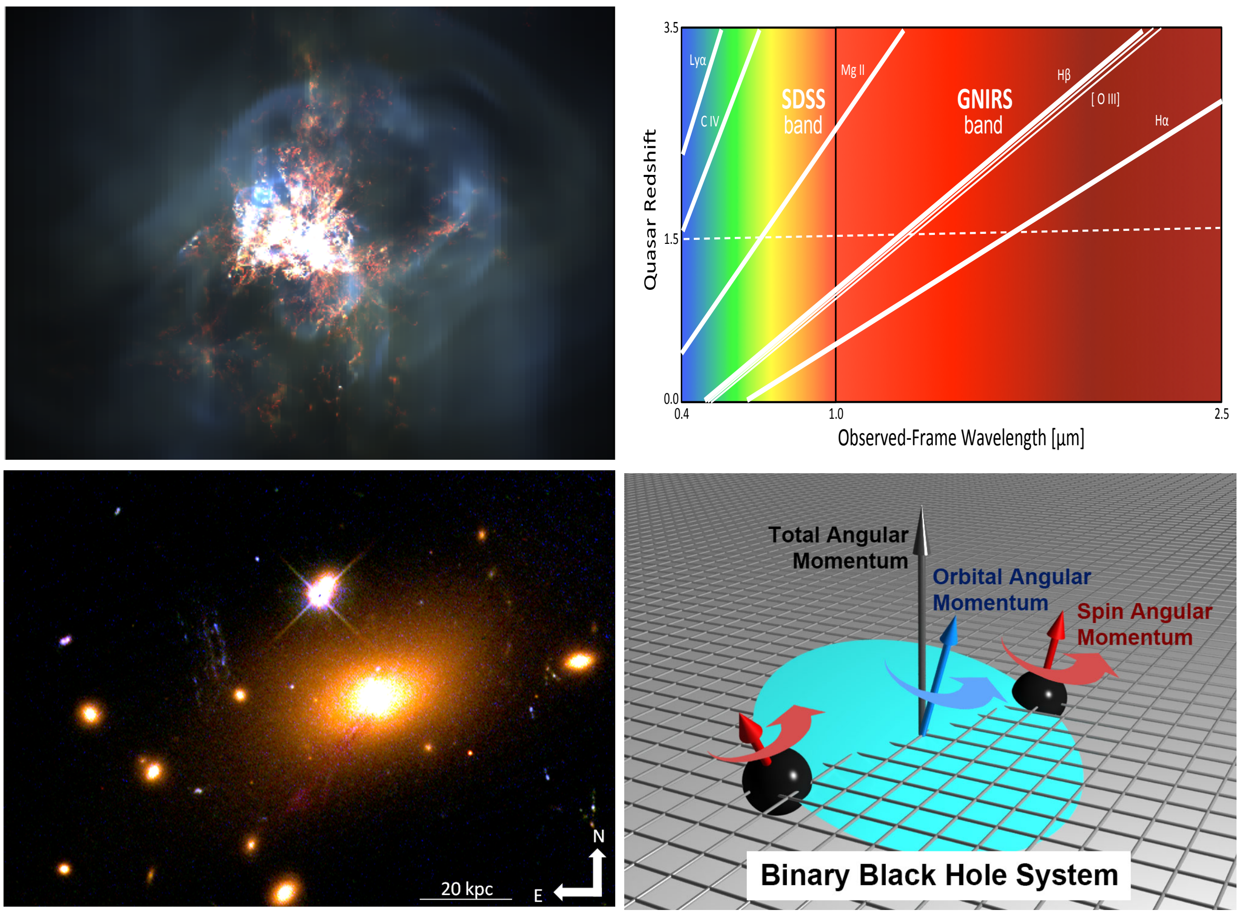

Figure 1: Upper left: A composite mock X-ray image of a simulated galaxy cluster by PI Li [4]. The hard X-ray (blue) reveals shock waves generated by SMBH jets, while the soft X-ray (red) traces the cool filaments condensing out of the hot intracluster medium. Upper right: Co-PI Shemmer and his group are extending the spectroscopic view of distant quasars beyond the optical, e.g., the Sloan Digital Sky Survey (SDSS) band, into the near-infrared, e.g., the Gemini Near-Infrared Spectrograph (GNIRS) band, in order to cover crucial diagnostic emission lines. Lower left: The central region of a massive galaxy cluster that recently underwent a major merger, studied by Co-PI King and collaborators using observations and computer simulations. The false color image made from *HST* data reveals strong gravitational lensing features as well as a stream of ionized gas. Lower right: A schematic of a binary black-hole system studied by Co-PI Kesden, with two BH spins (red arrows) and orbital angular momentum (blue arrow) precessing about the total angular momentum (grey arrow).

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