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Scientific Organizing Committee

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Abstracts

Danica Adams
Harvard University

Photochemistry at Mars (and Exoplanets) Through Time

Extensive evidence on the Mars surface suggests that the planet once hosted large volumes of surface liquid water, but the composition and surface pressure of the atmosphere that sustained the warm climate remains unknown. Previous works suggest a thicker CO2 atmosphere with a few percent of H2 or CH4 may have warmed the climate. This presentation will examine the following four questions about Mars' atmosphere and habitability overtime: (1) What chemistry could have supported this atmosphere, and what atmospheric chemistry is expected at early Mars through time? My work hypothesizes that crustal hydration (loss of surface water to rock) would have released enough H2 to warm the climate for 10s of millions of years. Previous works suggested transient events (e.g., volcanism and impacts) to source H2, but the lifetime of H2 to chemistry and atmospheric escape is 100,00 years. This makes my work the first to explain warming on timescales longer than the lifetime of H2. Yet, in this hypothesis, Mars must have been cool for the majority of its history. During cool climates, the atmosphere may have lost oxidants to the surface, causing CO to buildup in the atmosphere on long timescales, and I found this would take 10s of millions of years. I hypothesize two new ways to transition from a cool to warm climate including the buildup of hydrocarbons in a CO-runaway state as well as the release of H2 from ice clathrates after a short-lived geologic event. This hypothesis suggests Mars' atmosphere may have experienced great changes in redox overtime, in agreement with previous hypotheses (e.g., Wordsworth et al., 2021). (2) Is there any evidence for such redox changes? Sulfur mass independent fractionation (S-MIF) may result from photochemistry, but in the presence of oxidants S-MIF is known to be small. Therefore, fluctuations in S-MIF may suggest changes in Mars' redox state. This presentation will make predictions of S-MIF at Mars under different atmospheric redox conditions, in preparation for Mars Sample Return. (3) What do changes in atmospheric redox mean for the planet's habitability? Nitrogen fixation is key to habitability. N2 has a strong triple bond, meaning nitrogen fixation requires high energy inputs such as lightning or solar energetic particles (SEPs). In two papers, I estimate the rate of nitrogen fixation at warm and cool CO2 atmospheres under different mechanisms. I find both mechanisms can explain the current Mars Science Laboratory (MSL) measurements, but each would create a discrete signal: warm climates form nitrate and cool climates form nitrite. Additionally, when the NOx was delivered would carry an isotopic signature, since lighter species escaped the atmosphere over time. The presentation will discuss ways that MSR could determine under what climate the NOx formed and its approximate age. Importantly, in cool climates I find nitrite builds up over time to amounts that exceed the MSL measurements, and I hypothesize an unknown loss mechanism remains unidentified. (4) If early Mars was habitable, could we determine if it was ever inhabited? All biotic processes fractionate O-isotopes in phosphate in a similar manner. At Earth, with many samples abundant, it is easier to identify a baseline O-isotope signal to compare biotic samples to; however, at Mars, the lack of data complicates this. This presentation will show estimates of forward-modeled O-isotopes through time. Photolysis and isotope exchange reactions may fractionate isotopes on short timescales, while atmospheric escape fractionates isotopes on geologic timescales. While this work is in progress, our timeline of O-isotopes may be useful to compare an abiotic baseline to meteorite samples and MSR samples. (5) Can similar chemistry be relevant to climate evolution at exoplanets? This work demonstrates that Mars' evolution may not have been linear. Similarly, exoplanets closer in the habitable zone may have undergone evolution like Venus did. At ancient Venus, sulfur chemistry (which I examined at Mars in Step 2 of this presentation) may directly influence its early climate, but this has not been fully investigated. I find sulfuric acid hazes may have cooled early Venus and slowed the onset of the runaway greenhouse, in opposition to the warming effect of nightside water clouds reported by Turbet et al. (2021).

Riccardo Arcodia
MIT

Repeating X-ray flares as probes for galactic nuclei dynamics

X-ray Quasi-Periodic Eruptions (QPEs) are high-amplitude X-ray flares recurring every several hours and originating near the central black holes in galactic nuclei of low-mass galaxies. Some of the latest models suggest that these eruptions are triggered by extreme mass ratio inspirals, in which the smaller secondary body interacts with the accretion flow around the primary. I will outline their basic properties and the latest attempts to use QPEs as probes for galactic nuclei stellar dynamics.

Jaren Ashcraft
UC Santa Barbara

Understanding the Impact of Polarization Aberration on Direct Exoplanet Detection

Next-generation astronomical telescopes will be equipped with high-contrast imaging instruments that aim to image faint stellar companions at smaller angular separations and deeper contrasts than ever before. This new frontier in direct imaging brings with it the challenge of a new source of error called "polarization aberrations," which predominantly arise from interactions between light and the telescope optics. This talk will review efforts in integrated modeling and laboratory characterization of polarization aberrations and their theoretical effect on direct exoplanet imaging for next-generation astronomical telescopes, including the ground-based ELTs (TMT, ELT, GMT) and the future space-based Habitable Worlds Observatory.

Vishal Baibhav
Columbia University

Which came first? Black-hole Spin or Supernova Kick

While the origins of black hole spins remain a mystery, it's commonly assumed that if black holes come from isolated massive star binaries, their spins should align with orbital angular momentum. However, this notion is often in conflict with observations. We will question this long-held viewpoint and explore various mechanisms that can spin up BHs before or during supernovae. In addition to natal spins, we will discuss methods that can spin BHs isotropically, parallel to supernova kicks, and perpendicular to supernova kicks. These different mechanisms leave behind distinct imprints in the observable distributions of spin magnitudes, spin-orbit misalignments and the effective inspiral spin of merging binaries. In particular, these mechanisms allow even the binaries originating in the field to exhibit precession and retrograde spin. This broadens the parameter space allowed for isolated binary evolution, which was previously thought to be exclusive to dynamically assembled binaries.

Sylvia Biscoveanu
Northwestern University

Astrophysical insights from the compact-object mass distribution inferred with gravitational waves

The ongoing fourth observing run (O4) of the LIGO-Virgo-KAGRA gravitational-wave detectors has already more than doubled the number of candidate gravitational-wave events from compact-object mergers, with over 200 total candidates observed. In this talk, I will present some of the astrophysical insights that we've gained from the compact-object mass distribution inferred with this growing catalog of gravitational-wave sources, focusing on the gaps in this distribution. While analyzing the population of events as a whole allows us to probe bulk features, individual events offer insight into corners of the parameter space. I will highlight the first event from O4, GW230529, the merger of a neutron star and a compact object whose mass lies in the lower mass gap between the most massive neutron stars and least massive black holes observed electromagnetically. Either the most massive binary neutron star merger or the least massive neutron star-black hole merger, this event has important implications for multimessenger prospects, compact object formation mechanisms, and electromagnetic selection effects.

Iryna Butsky
Stanford University

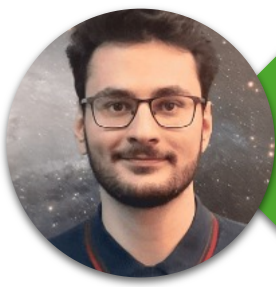
What in the Galaxy is Scattering Cosmic Rays?

Cosmic rays (CRs) with energies ≪ TeV comprise a significant component of the interstellar medium (ISM). Major uncertainties in CR behaviour on observable scales (much larger than CR gyroradii) stem from how magnetic fluctuations scatter CRs in pitch angle. Traditional first-principles models, which assume these magnetic fluctuations are weak and uniformly scatter CRs in a homogeneous ISM, struggle to reproduce basic observables such as the dependence of CR residence times and scattering rates on rigidity. In this talk, I will explore a new category of 'patchy' CR scattering models, wherein CRs are predominantly scattered by intermittent strong scattering structures with small volume-filling factors. These models produce the observed rigidity dependence with a simple size distribution constraint, such that larger scattering structures are rarer but can scatter a wider range of CR energies. I will present the physical properties any such structures would need to successfully scatter low-energy CRs and discuss future observational constraints that could test these models.

Michael Calzadilla
CfA

Evolution of Supermassive Black Hole Feedback in Galaxy Clusters

Galaxy clusters, the largest gravitationally-bound structures in the Universe, are superb laboratories for studying the baryon cycle that governs the evolution of all galaxies. The outer boundary of a galaxy's circumgalactic medium (CGM) should be the most sensitive probe of inflowing and outflowing material, but it is difficult to observe. Only in galaxy clusters, where the CGM gets hot enough to glow in X-rays, can the entire baryon cycle be observed - from the rapid cooling of the intracluster medium that contributes to the CGM and level of star formation in the central galaxy, to the eventual feeding and triggering of feedback from the largest supermassive black holes (SMBHs) residing in them. This cooling and subsequent feedback from these active galactic nuclei (AGN) is the primary driver of the baryon cycle and evolution of the largest, central cluster galaxies, quenching their expected levels of cooling and star formation by up to two orders of magnitude. In this thesis, I investigate how the AGN feedback cycle behaved in the early universe, where studies of this kind have not been possible until just recently. Using multiwavelength observations from radio to optical and X-ray, I study a unique, representative sample of SZ-selected galaxy clusters and their central galaxies and SMBHs spanning almost 10 Gyr of cosmic evolution. By examining how the largest galaxies and black holes in the universe co-evolve under extreme and chaotic environments, we can gain a great deal of insight into how the universe we see around us today came to be.



Andrei Cuceu
Lawrence Berkeley National Laboratory

Mapping the Cosmic Expansion History with DESI

The Dark Energy Spectroscopic Instrument (DESI) is the first Stage-IV dark energy experiment and is in the process of precisely measuring the redshifts of more than 40 million galaxies. One of its primary goals is to constrain the expansion history of the universe over the last 11 billion years using baryon acoustic oscillations (BAO). In this talk I will present the first DESI BAO results, which used data collected during the first year of observations, focusing in particular on the highest redshift measurements from the Lyman-alpha forest. I will also present cosmology results from these BAO measurements and their combination with other data sets, including the tightest constraints on the equation of state of dark energy, the Hubble parameter, spatial curvature, and neutrino mass. Finally, I will show preliminary results of an Alcock-Paczynski measurement using DESI Lyman-alpha forests that will improve distance measurements by a factor of two compared to the highest redshift DESI BAO constraint.

Tim Cunningham
Harvard University

New Accreting White Dwarfs Determined from X-ray Observations

X-rays provide a unique fingerprint of accretion onto compact objects. We have recently made the first direct detection of planetary material accreting onto a white dwarf using X-ray observations with Chandra. This discovery confirmed G29—38 - the prototype of all metal-polluted white dwarfs with detected debris disks – as a significant source of soft X-rays. Our detection provided the first direct evidence of ongoing accretion of planetary material onto a white dwarf and allowed the first independent constraint on the accretion rate at such a system, finding an instantaneous accretion rate consistent with modeling of observed photospheric abundances. I will present this system along with recent results from an ongoing search for more isolated white dwarfs with soft X-ray emission, including a new metal-polluted white dwarf and two low-state, long-period period-bounce polars. From an evolutionary perspective, these new polars – both with 2-hour periods and cool sub-stellar companions – are particularly interesting since angular momentum loss driven only by gravitational wave emission may not be sufficient to explain their evolution to such long periods, perhaps requiring additional angular momentum loss mechanisms such as residual magnetic braking.

Sanskriti Das
KIPAC, Stanford University

Multi-wavelength observation of the hot circumgalactic medium

The hot circumgalactic medium (CGM) is believed to host most of the baryons and metals that are missing from the stellar disk and interstellar medium. However, detecting the hot CGM is extremely challenging. By carefully selecting an optimum target, devising an efficient and rigorous method, and performing two independent analyses of our Suzaku and XMM-Newton data, we have been able to detect the integrated emission of the hot CGM of an isolated starburst spiral galaxy NGC 3221. The mass of the detected hot CGM is sufficient to account for the missing galactic baryons. The temperature of the hot CGM within 100 kpc of the stellar disk is super-virial and drops to the virial temperature beyond 100 kpc. The surface brightness distribution of the hot CGM indicates cavities along the minor axis. It is the first and only L* spiral galaxy (so far) with such intriguing findings. To complement observations of individual galaxies, we performed stacking analyses in mm using the thermal Sunyaev-Zeldovich Effect. We cross-correlated the WISE galaxy catalog with the Compton-y map derived from the CMB data of the Planck x Atacama Cosmology Telescope to estimate the thermal pressure of the CGM of 0.63 million z<0.3 L* spiral galaxies. Using a hierarchical Bayesian model for linear regression, we found that the thermal energy of the CGM of these galaxies evolves more strongly with mass than the self-similar relation of purely gravity-driven halos. We also detected a non-monotonic trend of baryon fraction with mass, with a certain mass range being baryon sufficient. Our results provide insights into the impact of galactic feedback on the hot CGM and set a benchmark for designing experiments with next-generation X-ray and mm facilities.

Jordy Davelaar
Princeton University

Tell-tale electromagnetic signatures of massive black hole binaries

Due to galactic mergers, massive black hole binaries are thought to reside in the cores of numerous galaxies. As the massive black holes migrate inwards, they will eventually emit gravitational waves, which are expected to be detected by LISA. A critical component to understanding where and how black holes merge and how they shape galactic evolution is host galaxy identification, which relies on electromagnetic (EM) observations. In my talk, I will show two novel tell-tale EM signatures that would provide strong evidence for a black hole binary before or during a merger. The first is when the binary is seen close to edge on; in that case, the binary produces self-lensing flares (SLFs) when one of the black holes moves in front of the background black hole. This causes the emission to be gravitationally lensed. This signal can additionally hold information on the size and shape of the emission morphology of the lensed black hole. Secondly, I will argue that when the binary is close to merger, the accretion is disrupted, turning the binary X-ray dark. I will argue that the upcoming time-domain surveys and

X-ray mission might be able to observe these signatures, and that they could be crucial for LISA source identification.

Thavisha Dharmawardena
New York University

Multi-scale multi-resolution 3D dust cartography of the Milky Way and its molecular clouds

The detailed 3D distributions of dust density and extinction in the Milky Way have long been sought after. However, such 3D reconstruction from sparse data is non-trivial, but is essential to understanding the properties of star-formation, large-scale dynamics and structure of our Galaxy. In this work I will introduce our new fast and scalable algorithm for 3D dust modeling. Using advanced ML methods such as sparse Gaussian Processes and Variational Inference, our algorithm maps the solar neighbourhood with millions of input sources in parsec scales within short timescales. Using this approach we map the inner 3 kpc of the Solar neighbourhood down to 1 pc resolution.We identify large-scale structures in the Galaxy and its Molecular clouds, while simultaneously peering into individual molecular clouds, providing insights into multi-scale processes such as fragmentation in molecular clouds. From these maps, we extract 3D boundaries, volumes, precise dust masses (12% statistical uncertainty) and filling factors to study fragmentation within many well known Galactic Molecular clouds. We recover a wider range of substructures such as new interconnecting and free standing filaments and star-formation feedback and supernovae cavities.

Alexander Dittmann
Institute for Advanced Study

Accretion onto Supermassive Black Hole Binaries

Supermassive black hole binaries form in the aftermath of galaxy mergers, and the gas expected to abound in the centers of post-merger galaxies may both expedite the coalescence of these binaries and facilitate electromagnetic observations of these systems. I will first review the state of our understanding of binary orbital evolution due to interaction with a circumbinary disk. I will subsequently illustrate how these systems evolve as gravitational waves begin to dominate their evolution and they travel through the LISA band, discussing their potential multi-messenger signatures.

Tarraneh Eftekhari
Northwestern

A Repeating Fast Radio Burst Localized to a Massive Elliptical Galaxy

The discovery of the first fast radio burst (FRB) in 2007 opened a new frontier in the field of time-domain astrophysics. FRBs are bright, millisecond-duration pulses of radio emission whose dispersed signals indicate an extragalactic origin. However, their physical origins remain a mystery, in large part due to the small number of precisely localized events and hence the lack of astrophysical context through host associations. In recent years, a growing number of host associations have revealed a population of primarily star-forming galaxies, lending support for progenitor models with short delay channels (e.g., magnetars formed through core-collapse supernovae) for the majority of FRBs. In this talk, I will present our discovery of the first quiescent elliptical FRB host galaxy. Through detailed spectroscopic and photometric modeling, we derive the stellar population properties of the host galaxy and compare them to the hosts of FRBs and other transient classes. Our results add to the growing diversity of FRB host galaxies, and suggest that some fraction of FRBs are formed through delayed channels that are not associated with recent star formation.

Adina Feinstein
Michigan State University

Young Planets in the JWST Era

Within the past decade, we have discovered only a dozen young (< 300 Myr) short-period exoplanets, compared to ~5,600 mature exoplanets. The majority of the young planets are gas-dominated, with planetary radii greater 4 REarth. The radii of these young planets are larger than older planets on similar orbital periods. The leading hypothesis is that these young planets have inflated atmospheres because they are still contracting and have not undergone significant atmospheric mass-loss. Therefore, the composition of young planetary atmospheres is believed to be a pristine tracer of its formation history and can inform our understanding of how and where short-period gas giants initially formed. In this talk, I will present the JWST NIRSpec/G395H (2.8 - 5 micron) transmission spectra of three young gas giants. We detect the presence of water and carbon dioxide, and do not detect a significant amount of sulfur dioxide. With these species, we constrain the carbon-to-oxygen ratio and atmospheric metallicity of these young systems. I will place these compositions into the context of mature exoplanets, and discuss what we can infer about the formation end evolution of short-period gas giants by observing their atmospheres at different ages.

Seiji Fujimoto
UT Austin

Primordial Rotating Disk Composed of $\geq$15 Dense Star-Forming Clumps at Cosmic Dawn

Early galaxy formation, initiated by the dark matter and gas assembly, evolves through frequent mergers and feedback processes into dynamically hot, chaotic structures. In contrast, dynamically cold, smooth rotating disks have been observed in massive evolved galaxies merely 1.4 billion years after the Big Bang, suggesting rapid morphological and dynamical evolution in the early Universe. Probing this evolution mechanism necessitates studies of young galaxies, yet efforts have been hindered by observational limitations in both sensitivity and spatial resolution. Here we report high-resolution observations of a strongly lensed and quintuply imaged, low-luminosity, young galaxy at $z=6.072$ (dubbed the Cosmic Grapes), 930 million years after the Big Bang. Magnified by gravitational lensing, the galaxy is resolved into at least 15 individual star-forming clumps with effective radii of $re \sim 10\text{-}60$ parsec (pc), which dominate $\sim 70\%$ of the galaxy's total flux. The cool gas emission unveils a smooth, underlying rotating disk characterized by a high rotational-to-random motion ratio and a gravitationally unstable state (Toomre $Q \sim 0.2\text{-}0.3$), with high surface gas densities comparable to local dusty starbursts with $\sim 10^{3\text{-}5} M_{sun}/pc^2$. These gas properties suggest that the numerous star-forming clumps are formed through disk instabilities with weak feedback effects. The clumpiness of the Cosmic Grapes significantly exceeds that of galaxies at later epochs and the predictions from current simulations for early galaxies. Our findings shed new light on internal galaxy substructures and their relation to the underlying dynamics and feedback mechanisms at play during their early formation phases, potentially explaining the high abundance of bright galaxies observed in the early Universe and the dark matter core-cusp problem.

Cristhian Garcia Quintero
Harvard University

Constraining Dark Energy and Modified Gravity with Galaxy Clustering and Weak Lensing

Recent measurements of Baryon Acoustic Oscillations (BAO) from the Dark Energy Spectroscopic Instrument (DESI), in combination with other datasets, have suggested that dark energy can be more complex than the standard model. This presentation reviews the analysis of BAO for the first year of DESI data and its impact on cosmological parameter estimation. Additionally, I emphasize the importance of utilizing the precise spectroscopic redshift measurements from DESI and showcase the science achievable by cross-correlating DESI with current and future imaging surveys overlapping the DESI footprint. The presentation also discusses future research directions in constraining dark energy and modified gravity with such data.

Thales Gutcke

University of Hawaii

Population III stars, globular clusters and self-interacting dark matter - What dwarf galaxies can teach us about our Universe

As small, ancient and dark matter-dominated systems, dwarf galaxies are a unique and scientifically valuable population. However, the study of dwarf galaxies at the faint end has been impeded by a severe lack of data beyond the Local Group. Euclid, JWST and Rubin, among others, are set to end this impediment and launch us into a new era of galaxy formation exploration. To place this wealth of data into a physically meaningful, theoretical context, high-resolution cosmological simulations with detailed small-scale physics treatments are indispensable. I present LYRA, the first cosmological galaxy formation model that resolves every single massive star and resulting supernova from first principles. I will demonstrate the efficacy of the model on a set of field dwarf galaxies that match the stellar mass, size, stellar kinematics and metallicity relations of Local Group dwarf spheroidals at z=0. It is also the only cosmological model that self-consistently predicts the formation of a population of ancient globular clusters (GCs) that are related to Population III sites. These match GC size – mass relation and the GC mass – halo mass relation well. Additionally, I will show current work on a self-interacting dark matter (SIDM) dwarf galaxy, where the central DM core affects observables such as central surface brightness and number of GCs in the central region. Finally, the SIDM causes some dark matter subhalos to undergo core-collapse.

Amelia Hankla

U. Maryland College Park

Explaining the mm excess in RQ AGN with a multizone outflow

Radio-quiet AGN exhibit an excess of compact, nuclear mm emission. Given the presence of a magnetically-powered compact X-ray corona, the mm excess plausibly originates from synchrotron emission by relativistic, nonthermal electrons in the corona. To explain the observed flat mm spectral slope, we propose a model of an outflowing corona with an inhomogeneous magnetic field. When integrated over the outflow's height, the total spectrum becomes flat, with a spectral index around 0.5 depending on the model parameters. This model predicts a constant ratio between mm and X-ray luminosity with a value sim 1e-5, in good agreement with the observed Lmm/LX correlation. We also discuss how the model addresses the observed mm and X-ray variability and the model's implications for dissipation mechanisms in the outflow.

Sultan Hassan
New York University

Pressure-Regulated, Feedback-Modulated Model of Star Formation: A Plausible Explanation for the Abundance of High Redshift Galaxies Observed by JWST

The detection of bright galaxies at high redshift by the JWST has sparked a lively debate about the ability of traditional models, which are calibrated to local Universe observations, to reproduce the elevated UV luminosity functions observed by JWST at high redshift. Reproducing JWST observations requires a natural mechanism to produce too efficient star formation at high redshift, which could be achieved through several cosmological and astrophysical modifications. We demonstrate that the too efficient star formation arises naturally by adopting a more physically motivated and predictive model of star formation, namely, the Pressure-Regulated, Feedback-Modulated Model (PRFM), which is based on various local environmental properties of the Interstellar Medium (ISM). We show that the PRFM model naturally reproduces the UVLF observations from the Deep Extragalactic Exploratory Public Survey (NGDEEP) at redshifts z=9-12. These results underscore the importance of accurately modeling star formation to probe the early Universe.

Ward Howard
University of Colorado Boulder

Unlocking the potential of optical sky surveys to constrain the radiation environment of every M dwarf with simultaneous UV and optical flare monitoring

TESS has measured the optical flare rates of essentially every bright M dwarf. However, a lack of simultaneous UV observations has prevented us from inferring the contribution of these flares to the radiation environments of orbiting planets. UV radiation drives atmospheric photochemistry now being observed with JWST, motivating the need for UV-optical scaling relationships. As part of a larger monitoring program of 460 M dwarf flare stars with 20 s cadence TESS observations, we explore the UV-optical connection in a subset of flares with simultaneous Swift NUV data. We find a 9000 K blackbody underestimates the NUV flux by 4X for 30% of moderate energy flares and up to 15X for some flares. We reduce the scatter present in optical-NUV relations by a factor of 2.0±0.6 when comparing the total NUV energy with the TESS energy during the flare peak due to the exclusion of the 5000 K tail. We show the NUV light curve can be used to remove flares from the optical light curve and consistently detect planets with 24.8% smaller radii than is possible without flare detrending. Finally, we demonstrate an order-of-magnitude increase in the literature number of multi-wavelength flares with the Early eVolution Explorer (EVE), an astrophysics Small Explorer concept to observe young clusters with simultaneous NUV and optical bands in order to detect young planets, assess their photochemical radiation environments, and observe accretion.

Yue Hu
Institute for Advanced Study

Magnetic Field in Galaxy Clusters: Insights from Synchrotron Intensity Gradient

Magnetic fields and their dynamical interplay with matter in galaxy clusters contribute to the physical properties and evolution of the intracluster medium. However, the current understanding of the origin and properties of cluster magnetic fields is still limited by observational challenges. In this talk, I will present the magnetic fields at hundreds-kpc scales of five clusters RXC J1314.4-2515, Abell 2345, Abell 3376, MCXC J0352.4-7401, and El Gordo using the synchrotron intensity gradient technique in conjunction with high-resolution radio observations from JVLA and MeerKAT. I will show that the magnetic field orientation of radio relics derived from synchrotron intensity gradient is in agreement with that obtained with synchrotron polarization. Most importantly, the synchrotron intensity gradient is not limited by Faraday depolarization in the cluster central regions and allows us to map magnetic fields in the radio halos of RXC J1314.4-2515 and El Gordo. Magnetic fields in radio halos exhibit a preferential direction along the major merger axis and show turbulent structures at higher angular resolution. The results are consistent with expectations from numerical simulations, which predict turbulent magnetic fields in cluster mergers that are stirred and amplified by matter motions.

Sara Issaoun
SAO

The First Polarized Image of Sagittarius A*

In 2022, the Event Horizon Telescope collaboration revealed the first images of the shadow of our Milky Way supermassive black hole, Sagittarius A* (Sgr A*). Since its detection in the mid-70s, this bright radio source in the Galactic center has been shrouded in a veil of mystery. The Nobel-awarded stellar orbits research in the Galactic center pinned down its mass and distance, showing evidence of an extremely compact 4 million-solar-mass object at the heart of our Galaxy. The EHT then provided the first direct evidence that this object is indeed a black hole and resolved its shadow for the first time. Earlier this year, the EHT revealed a whole new view of this black hole, in polarization. In this talk I will describe the latest polarization results of the EHT and the insights we gain into the mystery that is Sgr A*.

Kartheik Iyer
Columbia University

Can we constrain the impact of feedback using galaxy star formation histories (SFHs)?

Star formation histories (SFHs) are thought to encode the imprints of physical processes that regulate star formation over time, and are thus thought to be a key constraint in connecting (i) observations of populations of galaxies from current and upcoming galaxy surveys to (ii) the strength of the underlying physical processes responsible for driving and inhibiting star formation across different galaxy populations. While promising, SFHs are notoriously difficult to model and infer observationally, and multiscale processes acting over large ranges of timescales complicate the process of connecting the observables to physics. I will talk about the systematics on both sides of the problem, and propose ways to solve and/or mitigate these issues (better priors, non-parametric SFHs, population level inference, forward modeling with simulations, accounting for resolution, studying relative trends). This will open the way to using SFHs as a novel constraint on feedback physics using JWST observations coupled with suites of simulations like CAMELS.

Andres Izquierdo
University of Florida

Kinematic structures in planet-forming discs: results from exoALMA

Interferometric observations have allowed us to resolve a wealth of gas and dust substructures in the outer regions of large protoplanetary discs. This has opened a unique window to investigate the physical and chemical environment in which giant planets form and, more specifically, has enabled detailed modelling of the impact of planet-disc interactions on the evolution of the host disc. I will present results from the large program exoALMA, a planet-hunting campaign aimed at unveiling the dynamical structure of 15 planet-forming discs in unprecedented detail with ALMA.

Wynn Jacobson-Galan
Caltech

Final Moments: Pre-Supernova Emission and Flash Spectroscopy as Singular Probes of Late-Stage Red Supergiant Evolution

There is now an amalgam of observational evidence that massive stars undergo enhanced and/or eruptive mass-loss in their final years before explosion. In this talk, I will first present multi-wavelength observations of supernova (SN) 2020tlf, the first normal type II-P/L SN with confirmed precursor emission, as detected by the Young Supernova Experiment (YSE) transient survey. I will discuss the physical scenarios responsible for enhanced/eruptive mass-loss from the red supergiant (RSG) progenitor in the final ~year before explosion as well as present on-going work to discover more precursor events in present sky surveys and, in the future, with LSST. Next, I will present multi-wavelength observations of >40 type II SNe whose very early-time (“flash”) spectra showed transient, narrow emission lines from shock interaction with confined circumstellar material (CSM) around their RSG progenitor stars prior to shock breakout. I will discuss the observational properties of this “flash spectroscopy” SN sample, the largest to date, and how these objects compare to normal SNe II that arise from stars without significant mass-loss. This sample also includes the CSM-interacting type II SN 2023ixf, the closest and brightest SN of the decade, which was discovered within an hour of explosion. Lastly, I will present modeling of these SNe using non-LTE radiative transfer code CMFGEN, which allowed for the best constraints to date to be made on the CSM structure and mass-loss histories of the RSG progenitors responsible for these fascinating events.

Nicholas Kern
University of Michigan

Mapping the Universe with Hydrogen

A wealth of cosmological information spanning a wide range of redshifts remains currently undiscovered. Low-frequency radio telescopes probing the 21 cm transition from neutral hydrogen will soon provide access to this information, shedding light on a range of open questions in astrophysics and cosmology. In particular, telescopes like HERA and the SKA will reveal the formation of the very first stars and black holes in the early universe, complementing a tantalizing picture that is currently being revealed by JWST. In this talk, I will discuss some of this complementary science at Cosmic Dawn from current and future 21 cm telescopes, and the path towards making robust 21 cm measurements.

Peter Kosec
SAO

Revealing the physics of accretion disk winds with Hercules X-1

The accretion of matter onto black holes and neutron stars often leads to the launching of outflows that can greatly affect the environments surrounding the compact object. An important means of studying these winds is through X-ray absorption line spectroscopy, which allows us to probe their properties along a single sightline, but usually provides little information about the global three-dimensional wind structure, which is vital for understanding the launching mechanism and total wind energy budget.

In this presentation, I will talk about Hercules X-1, a nearly edge-on X-ray binary with a warped accretion disk precessing with a period of about 35 days. This disk precession results in changing sightlines towards the compact object, through the ionized outflow, thus uniquely revealing its vertical structure. Additionally, Her X-1 is powered by a highly magnetized neutron star, pulsating with a period of 1.24 seconds. The ionization response of the wind plasma to these periodic pulsations allows us to constrain its density, a crucial parameter to understand the wind location and energetics, nearly impossible to measure through other means.

I will present the results of our recent studies of this fascinating object. We carried out a large observational campaign on Her X-1 with XMM-Newton, Chandra and NuSTAR X-ray telescopes and tracked the properties of its wind with height above the disk, producing the first ever 2D map of a disk wind. Secondly, by performing the first time-dependent photoionization plasma analysis in an X-ray binary, we constrained the wind number density. These measurements allow direct comparisons with three-dimensional global wind simulations to reveal the outflow launching mechanism.

Charles Law
University of Virginia

Sulfur Chemistry in Protoplanetary Disks as a Window into Planet Formation

The abundance and distribution of sulfur-bearing molecules in protoplanetary disks directly influences the composition and potential habitability of nascent planets in addition to providing powerful probes of the physical gas conditions in the disks themselves. Thanks to the high resolution of ALMA, the molecular gas content of disks has now begun to be mapped in fine detail, but relatively few studies have targeted sulfur-bearing species. Here, I will present several new ALMA observations, demonstrating how certain sulfur-bearing molecules provide powerful tracers of embedded protoplanets and allow us to place unique constraints on the nearby gas environments from which planets are actively assembling.

Matthew Liska
Georgia Tech

How common are warped accretion disks?

The gravitational pull of a black hole attracts gas and forms an accretion disk where the interplay between hydromagnetic processes and the warping of space-time releases gravitational energy in the form of radiation, relativistic jets, and winds. Most gas falls into supermassive black holes when the accretion rate approaches the Eddington limit (L=Ledd), at which point radiation pressure overcomes gravity. To date, our knowledge of such luminous' black hole accretion disks mostly relies on semi-analytical models, supplemented by a very limited set of numerical simulations. In my talk I will discuss new insights gained from state-of-the-art radiative general relativistic magnetohydrodynamics (GRMHD) simulations of accretion near the Eddington limit where the rotation axis of the disk is misaligned with the spin axis of the black hole. I will demonstrate that such "tilted" accretion disks potentially provide a feasible avenue to explain the rapid luminosity swings observed in changing-look AGN.

Cassi Lochhaas
SAO

Galactic Feedback Affects Predictions for Emission from the Circumgalactic Medium

The Aspera NASA Pioneer Mission will be launched in 2025 to detect and map emission from warm-hot gas in the circumgalactic medium (CGM) of nearby galaxies. Predictions from cosmological simulations are essential both for determining the observation strategy as well as interpreting the eventual results. I will present predictions for O VI emission surface brightnesses from the FOGGIE (Figuring Out Gas & Galaxies In Enzo) simulations and show that the brightness and surface area of the emission is strongly affected by galaxy and CGM properties. In particular, galaxies with high star formation rates show brighter and more extended O VI emission in their CGM. However, the galactic winds in the simulation are too hot to be contributing strongly to the O VI emission -- instead, it is the cooler inflows and the circulating warm gas that emit the most -- suggesting that the mock emission is actually tracing the fuel for star formation rather than galactic outflows themselves. These results will provide the basis for interpretation of the eventual Aspera observations, or will suggest an interesting new investigation if the observational data do not match the simulation trends.

Feng Long
University of Arizona

JWST reveals a carbon-rich disk around a 40-Myr-old star

The outcome of planet formation is largely determined by how the disk dust and gas evolve. Recent studies have identified a new class of disks that surround late M type stars at ages of ~40 Myr and with spectroscopic evidence of active accretion. The presence of strong infrared excess and broad H alpha emission lines serves as distinct markers of gas-rich primordial disks. While considering the typical disk lifetime of 3-5 Myr, their survival poses a challenge to our understanding of disk dissipation and planet formation around M dwarfs. With our recently acquired JWST MIRI/MRS data, I will present the first characterization of inner disk molecular gas content at an advanced age of 40 Myr and assess the gas evolution by comparing to young M dwarf disks. With these results, I will discuss how our new observations may reshape our understanding of planet formation and evolution.

Rafael Luque
University of Chicago

Towards a holistic understanding of sub-Neptunes

The nature and origin of sub-Neptune-sized planets is arguably the hottest debate in the exoplanet field nowadays. Gas dwarfs, water worlds, Hycean planets all appear to explain current observational evidence from mass-radius measurements and demographic analyses. JWST promises to break those degeneracies, but atmospheric data will be limited to a few benchmark targets after battling the effects of stellar activity and aerosol obfuscation. In this talk, I will summarize the latest efforts in the community to look for non-degenerate answers on the origin and nature of sub-Neptunes and discuss the project that I will carry out during the fellowship.

Ryan MacDonald
University of Michigan

Atmospheres on Rocky Exoplanets: Promising Early Results from JWST Transmission Spectroscopy

To understand the habitability of terrestrial exoplanets, we must first determine what types of rocky worlds have atmospheres. Terrestrial planets orbiting small M-dwarfs are the focus of observational searches for atmospheres due to their favourable planet-star size ratio. However, the extreme-UV radiation and frequent flaring of M-dwarfs pose problems for the atmospheric survivability of such rocky worlds. A core goal of JWST is to provide the first observational evidence of atmospheres for terrestrial exoplanets.

Here, I will present JWST transmission spectra of three rocky exoplanets that provide our most promising evidence to date of rocky exoplanet atmospheres. Our results include tentative evidence of an atmosphere on a planet in the habitable zone. Finally, I will discuss near-term prospects to confirm these initial signs of rocky exoplanet atmospheres.

Hayley Macpherson
University of Chicago

The low-redshift distance-redshift relation beyond FLRW

Most cosmological data analysis today relies on the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric, which provides the basis of the current standard cosmological model. Within this framework, interesting tensions between our increasingly precise data and theoretical predictions are coming to light. It is therefore timely to explore the potential for cosmological analysis outside of the exact FLRW framework. I will briefly introduce Heinesen's generalised luminosity-distance series expansion in redshift --- which accounts for all effects of inhomogeneity and anisotropy in the distance-redshift relation for nearby objects. I will present our calculations of the effective observational 'Hubble' and 'deceleration' parameters in cosmological simulations performed with numerical relativity --- which consider a fully inhomogeneous space-time evolution. Anisotropies in these parameters exist for any universe which contains structure, and could potentially bias low-redshift constraints which assume an isotropic expansion law. Lastly, I will present constraints on a low-redshift quadrupolar Hubble expansion using the Pantheon+ supernova catalogue.

Jed McKinney
UT Austin

Does dust evolve with redshift?

It is a core assumption in extragalactic astronomy that the properties of dust do not evolve with redshift, and yet this is essentially unconstrained. Exotic dust can produce a significantly different attenuation law and fundamentally alter the coupling between stars and gas. This can have profound implications for how we measure galaxy-integrated quantities, and also provide insights into the efficient star-formation needed to grow early galaxies. In this talk I will discuss the implications of redshift-dependent dust and ongoing observational efforts with JWST and ALMA to improve constraints on the size, charge, and structure of dust grains at z>1 using statistical samples.

Lia Medeiros
Princeton University

Reconstructing multi-frequency movies of supermassive black holes with PRIMO

The sparse interferometric coverage of the Event Horizon Telescope (EHT) makes reconstruction of black-hole images challenging. The dictionary learning algorithm principal component interferometric modeling (PRIMO) builds a principal component basis from high-fidelity numerical simulations of low-luminosity accretion flows. This basis enables reconstruction of images that are both consistent with the interferometric data and that live in the space spanned by the simulations. So far, the EHT has only published images at 230 GHz, but recent and upcoming campaigns will also include simultaneous observations at 345 GHz. The EHT is also interested in probing the temporal variability of image morphology through a series of intermittent observations spanning several weeks to months (i.e., reconstruct a movie of matter swirling around the black hole). I will review the PRIMO algorithm and its application to EHT M87 data. I will then introduce the new multi-wavelength and multi-epoch version of PRIMO. This new version can simultaneously reconstruct multi-frequency images while accounting for correlations between the frequencies. The algorithm can therefore produce a single mass over distance measurement for multiple frequencies and/or observational epochs.

Keefe Mitman
Cornell University

The Universe Never Forgets: pushing Einstein's theory to the limits with memory effects

With the commencement of the LIGO-Virgo-KAGRA Collaboration's fourth observing run, the field of gravitational wave physics is uniquely poised to collect even more precise data from compact binary mergers and observe never-before-seen physics, like memory effects. These effects are nonlinear predictions of GR that physically correspond to the permanent net displacement that two freely-falling observers will experience due to the passage of gravitational waves. More interestingly, they are also intimately connected to the symmetry group of future null infinity—the final destination of outgoing radiation—and are thus potentially helpful probes of quantum gravity signatures. In this talk, I will highlight some recent advances in numerical relativity simulations of binary black hole mergers that has made the prospect for observing memory effects more promising. In particular, I will elaborate on how we extract and model memory effects in these simulations as well as what these models say about the detectability of memory in the near future.

Sarah Moran
NASA Goddard

Neglected Polymorphs of Silicate Clouds in Substellar Atmospheres

Silicate clouds in substellar atmospheres have been suspected since Spitzer observations of brown dwarfs. With the MIRI instrument on JWST, we can now more deeply probe silicate features from 8 to 10 microns, exploring specific composition, particle size, and particle structure of potential cloud materials. Recent characterization efforts have led to the identification in particular of silicon dioxide (SiO2) cloud features in both brown dwarfs and transiting giant exoplanets. Previous modeling has primarily focused on crystalline quartz or amorphous silica to match observations. Here, I explore the possibility of other silicates that may be more likely to form at the pressure and temperature conditions of substellar upper atmospheres. I show how these may be observationally distinguished from each other with current JWST observations. I ultimately propose that accounting for the distinct opacities arising from the possible crystalline structure of cloud materials may act as a powerful, observable diagnostic tracer of atmospheric conditions, where particle crystallinity records the history of the atmospheric regions through which clouds formed and evolved. Finally, I will highlight that high fidelity, accurate laboratory measurements of silica polymorphs are critically needed to draw meaningful conclusions about the identities and structures of clouds in substellar atmospheres. I will discuss several promising avenues to obtain these critical laboratory data.

Rohan Naidu
MIT

All the Little Things: Seeking Signatures of Pop III Stars and the Protagonists of Reionization with JWST

Dwarf galaxies in the first billion years hold the key to several frontiers of astrophysics. For instance, they are predicted to host the most metal-poor (perhaps metal-free) first generations of stars, and they may prove to be the long-sought protagonists of cosmic reionization. In this talk I will present results on these topics from a JWST survey which has acquired the deepest NIRCam grism spectroscopy yet, at JWST's most sensitive wavelength (3-4 micron), over the powerful gravitational lensing cluster Abell 2744 (mean magnification >2) to collect one of the largest samples of dwarf galaxies in the Epoch of Reionization.

Joel Ong
University of Hawaiʻi

Asteroseismology Reveals Core-Envelope Rotational Misalignment in Kepler-56

New theoretical developments in the treatment of rotation in asteroseismology permit the characterisation of internal differential rotataional misalignment between the rotational axes of different parts of a star --- in particular, between the core and envelope of a red giant, where angular momentum transport is inefficient enough to permit such misalignment to persist for long enough to be observable. I describe how I arrived at this new construction, and report the result of its application to the reanalysis of Kepler-56 --- the only known transiting multiplanet system in which the rotational axis of the host star is known to be out of alignment with (separately aligned) multiple planets. This analysis indicates that while earlier seismic characterisation has accurately captured the orientation of the core's rotational axis, the envelope of Kepler-56 is rotating around an axis which is consistent with being more aligned with the orbits of its planets. I finally discuss implications of this for our current understanding of planet formation and post-main-sequence evolution.

Viraj Pandya
Columbia University

New Puzzles in Galaxy Formation: From the Cosmic Web to the Origin of the Hubble Sequence

I will discuss three new puzzles in galaxy formation. First, I will show that galactic atmospheres must expand and contract due to imbalances between heating and cooling. One surprising consequence is that the commonly invoked "ejective feedback" scenario (highly mass-loaded outflows) cannot explain the observed inefficiency of star formation. Instead "preventative feedback" (highly energy-loaded outflows) may be the key but is poorly constrained observationally. Using my next-generation differentiable, modular Bayesian framework written in JAX ("sapphire"), I will highlight a few implications of this new paradigm for black hole growth, environmental effects and the quest to jointly infer cosmological and astrophysical parameters using galaxy surveys. Second, I will present our recent detection of strong alignments between high-redshift galaxies in a "blank" JWST deep field. This is surprising because there is no obvious bright foreground cluster that could be responsible for the alignments via lensing but there may be an overdensity at $z \sim 0.75$ causing a large-scale "cosmic shear" signal. Alternatively, we may be seeing evidence of intrinsic alignments of galaxies forming along high-redshift filaments. This latter scenario is naturally expected for intrinsically elongated Milky Way progenitors at $z>2$ whose early formation may be influenced by the tidal field of the filamentary cosmic web. This leads to my final puzzle where I will show that the majority of low-mass high-redshift galaxies observed with JWST appear elongated in projection with typical axis ratios b/a~0.4. One reasonable explanation is that there is a new dominant population of intrinsically prolate (cigar-shaped) or triaxial (surfboard-shaped) galaxies at high redshift. If confirmed, this new class of early elongated protogalaxies may hold unique clues about the origin of the Hubble Sequence and the properties of the proto-cosmic web. I will summarize how these seemingly niche puzzles bridge together many different areas of astrophysics and cosmology, how they unlock fresh science cases for NASA's future observatories including Roman and Habitable Worlds, and how they address one of NASA's fundamental driving questions: How Did We Get Here?

Ekta Patel
University of Utah

Revealing the Dynamics of Andromeda, Triangulum, and M32: Understanding Their Impact on Satellite Evolution and Structure

Nearly twelve years after Andromeda’s (M31’s) space motion was first measured by the Hubble Space Telescope, detailed 6-dimensional phase space data for nearly a dozen of its satellite galaxies are now available. In this talk, I will explore the complex interaction history involving M33, the most massive satellite of M31; M32, a prominent dwarf elliptical galaxy situated near M31's disk; and M31 itself. I will discuss preliminary findings on M32’s recent orbital history, focusing on two competing theories: one positing that M32 is a tidally stripped remnant of a larger galaxy, and the other suggesting it formed as a compact elliptical through alternative mechanisms, such as ram pressure stripping. Additionally, I will examine the role of M33 in influencing the displacement and motion of M31. Finally, I will emphasize how linking orbital dynamics with star formation histories and morphological features provides a comprehensive view of how these interactions have shaped the Andromeda galaxy's satellite population as a whole.

Justin Pierel

STScI

Type Ia Supernova Cosmology in the High-z Universe with JWST

Type Ia supernovae (SNe Ia) have now been used for decades as precise luminosity distance measures to z~2, enabling the discovery of dark energy and our best local measurement of the Hubble constant (H0). The exact nature of dark energy (comprising ~70% of the universe) is still one of the most confounding mysteries in astrophysics today, and next-generation SN Ia dark energy measurements (e.g., Roman) will rely upon SN Ia luminosities remaining constant with redshift to remain unbiased. Evolving luminosity distances could indicate dark energy and/or SN Ia intrinsic luminosity are changing with redshift, but beyond z~2 such behavior strongly indicates intrinsic SN Ia luminosity evolution, giving high-z SNe Ia unique leverage on SN Ia systematics. I will present JWST observations of the first set of spectroscopically confirmed SNe Ia at z>2. While this is a subset of the total high-z SNe Ia JWST will observe in the next couple of years, I will discuss the early indications of SN Ia luminosity variability with redshift and its implications for the Roman time domain survey.

Raluca Rufu

Southwest Research Institute

Origin of compact exoplanetary systems

A surprising discovery has been compact systems of Earth to super-Earth-sized planets. While compact systems are common, their origin is debated. A prevalent assumption is that compact systems formed after the infall of gas and solids to the circumstellar disk ended. However, observational evidence suggests accretion may commence earlier. We propose that compact systems are surviving remnants of planet accretion during the end stages of infall. In disk regions undergoing infall, a planet's mass is regulated by a balance between growth due to the supply of solids, and inward gas-driven orbital migration that becomes faster as the planet grows, replicating the intra-system planetary-size-similarly. We show that infall-produced planets can survive until the gas disk disperses and migration ends, and that the mass of surviving compact systems is regulated to between a few times 10^(-5) and 10^(-4) the stellar mass. This provides an explanation for the remarkably similar mass ratios of known compact systems.

Andrew Saydjari
Princeton University

Bayesian Component Separation for Ground Based Spectra: Transforming Diffuse Interstellar Bands into Precision Kinematic Tracers

A ubiquitous problem in astronomy is correctly assigning absorption or emission features in a spectrum to the multiple processes occurring along the line of sight within the spectroscopic field of view. I will introduce a general probabilistic component separation method we have been developing and its application to decompose ground-based spectra into components associated with the target star, terrestrial atmosphere, and dust along the line of sight. In this framework, the sum of the components is exactly equal to the data, meaning unexpected signals are exactly retained. We apply our method at scale to all 2+ million APOGEE DR17 visits.

This decomposition is obtained by modeling each component as a draw from a high-dimensional Gaussian distribution in the data-space (the observed spectrum)---a method we call “Marginalized Analytic Data-space Gaussian Inference for Component Separation” (MADGICS). This technique provides statistically rigorous uncertainties and detection thresholds, which allows better leveraging of low signal-to-noise spectra.

I will focus on applications to mapping Galactic dust via the 15273 Å diffuse interstellar band and removing kinematic biases arising from sky and stellar lines. I will also highlight the impacts on other science goals including spectroscopic binary (SB2) modeling and reducing telluric biases on radial velocity determination or stellar parameter inference.

Peter Senchyna
Carnegie Observatories

Unraveling the most distant massive star populations with our next-door neighbors

Our picture of the first galaxies is being revolutionized in real-time by JWST, revealing in many signatures of commingling hard ionizing radiation fields and peculiar enrichment patterns almost entirely without precedent. Questions abound about these puzzling observations, and the answers are likely linked to our incomplete understanding of massive star populations formed under early Universe conditions. I will discuss these new JWST results in the context of ongoing work closer to home with HST and other facilities. Observations of both individual metal-poor massive stars and unresolved clusters nearby point towards key physics, like the impact of binary mass transfer and winds at low metallicity, that may prove crucial to understanding both metal-poor stellar evolution and the very first phases of galaxy assembly.

Raphael Skalidis
Caltech

High precision magnetometry from dust polarization

The interstellar medium (ISM) magnetic field strength is notoriously difficult to measure. For this reason, there is a longstanding debate about its dynamical importance in star formation. The magnetic field strength can be directly measured, with the Zeeman effect, only in a limited number of cases, hence indirect methods have been developed. The most widely accessible (indirect) methods are based on dust polarization, which directly probes the plane-of-the-sky magnetic field morphology, but not its strength. These indirect methods are based on the energy balance of incompressible turbulence, contrary to observations which suggest that the ISM is highly compressible. This talk is about a novel method for estimating the magnetic field strength in the interstellar medium (ISM) of our Galaxy. The new method accounts for the compressibility of turbulence in the ISM. This allows us to estimate the magnetic field strength more accurately and reliably than previous methods. We tested the accuracy of the new method with synthetic data produced from a suite of numerical simulations and found that it achieves an accuracy better than a factor of two. The proposed method paves the way towards understanding the role of magnetic fields in the various processes that take place in the ISM, such as star formation.

Adam Smercina
STScI

A Portrait of the Triangulum: Advancing a New Frontier of Galaxy Evolution with Resolved Stars

In an exciting new observational paradigm, JWST and HST operate simultaneously, providing access to resolved stellar populations in individual nearby galaxies for transformative galaxy evolution science. The first large galaxy with panchromatic HST+JWST observations across its disk, the Triangulum Galaxy, M33, is among the most important members of the Local Group, and also exists at a mass where the physics driving the evolution of disks and spiral structure in galaxies is poorly understood. As a Hubble Fellow, I will conduct a targeted study of this benchmark local galaxy, allowing me to simultaneously fill an important gap in our understanding of the Local Group, and advance our understanding of low-mass spiral galaxy evolution. In this talk, I will briefly summarize our current understanding of M33, and show how the introduction of JWST resolved star data is transforming this understanding, and how it will help to establish a blueprint for a new era of studying resolved stellar populations in nearby large galaxies from space. Finally, I will introduce an upcoming JWST stellar population survey of the nearby galaxy M82 that will usher in this new era in the next several years.

Jessica Spake
Caltech

The NUV transmission spectrum of LTT9779

A large fraction of known exoplanets orbit their host stars at very short periods. Due to this close proximity to the parent star, their atmospheres are exposed to high levels of stellar radiation and stellar wind, as well as strong tidal interactions, which can lead to atmospheric escape that is much more efficient than in the Solar System planets. Efficient atmospheric mass loss has the power to radically transform planets by changing the atmospheric structure or by removing the atmosphere altogether. The process is believed to be responsible for shaping the so-called 'hot Neptune desert', the observed paucity of intermediate-sized planets at close orbital separations. LTT 9779b is a rare example of a planet residing well within this desert, meaning that it may be rapidly losing mass right now. We led a Hubble Space Telescope program to observe ongoing atmospheric escape for this ultra-hot Neptune through transmission spectroscopy at NUV wavelengths with STIS. The NUV wavelength range gives us the best opportunity to observe the upper atmosphere in multiple lines of different species, which is necessary in order to break modeling degeneracies and constrain the atmospheric mass-loss rate. I will present the first results from this program.

Jiayi Sun
Princeton University

Molecular Cloud Scale "Micro-physics" as Drivers of the Baryon Cycle and Galaxy Evolution

I will discuss recent advances in observational studies of the ISM and star formation physics on ~10-100 pc scales, characteristic of individual molecular clouds and star-forming regions. Thanks to systematic surveys of some 100,000 clouds / regions across nearby galaxies with ALMA, HST, JWST, and VLT, we have learned that (1) molecular cloud properties are governed by a combination of internal physics and environmental processes, (2) the baryonic matter cycle on such cloud scales features short timescales (<~10 Myr) and low star formation efficiencies (<~1% per free-fall time), and (3) these "small-scale" processes regulate the build-up of stellar populations and the cycling of baryonic matter within galaxies. I will also introduce a new collaborative program that leverage these recent progresses to understand galaxy quenching in the dense Virgo Cluster environment.

Maggie Thompson

Carnegie EPL

Unlocking the Rocky Exoplanet Interior-Atmosphere Connection via Laboratory Experiments

One of the most characterizable type of rocky exoplanet for the coming decades are magma worlds, those with extensive lava or magma oceans at their surfaces, due to their hot, extended atmospheres. At present, the nature and composition of these planets' atmospheres are poorly constrained because they are strongly connected to their interiors and are modulated by the solubilities of major gases in the magma. In preparation for upcoming observations of these exoplanets, we need to understand how volatile elements partition between the interior and atmosphere for diverse planetary compositions. To fill this gap, we performed new volatile (e.g., H, C, O) solubility experiments on planetary melt analog materials at high temperatures using a 1-bar H2-CO2 gas-mixing furnace and a novel aerodynamic laser levitation furnace coupled to an FTIR spectrometer. We will present the findings of our experiments and discuss their implications for the interior-atmosphere connection for magma worlds.

David Vartanyan

Carnegie Observatories

Core-Collapse Supernova: Bounce, Breakout, and Beyond

In the last decade, core-collapse supernovae theory emerged from half-a-century of shackled misconceptions. I present the largest, latest, and longest study of neutrino-driven supernovae simulations with robust yields including explosion energies, remnant properties, and neutrino and gravitational wave signatures. I then continue these models through shock breakout and present the rich morphology of explosions, showcasing diverse asymmetries, significant nickel mixing, and high-velocity ejecta. These models also present the first light curve and spectral templates informed by multi-dimensional simulations from core bounce to shock breakout.

Michael Wong
Carnegie Institution for Science

Student-Led Projects at the Astrobiological Frontier: Recent Advances in Origins, Habitability, and Biosignatures

Of all the amazing aspects of the NHFP Program, the freedom to mentor the next generation of scientists while advancing my research goals has been the most fulfilling for me. In my final symposium talk as an NHFP Sagan Fellow, I will highlight three student-led projects that I am proud to have mentored.

In the first project, Madeline Christensen et al. (2024) estimate the rate of nitrogen fixation (the transformation of atmospheric N2 into biologically useful molecules, like nitrogen oxides and HCN) on early Earth. Our model simulates lightning, solar energetic particle deposition, and photochemistry in a CO2–N2–H2O-dominated Hadean atmosphere. Such calculations set the redox and nutrient availability for nascent life on our planet.

In the second project, Lucas Fifer et al. (2024) estimate the biological productivity of a hypothetical chemotrophic community that could have lived in ancient Gale crater lake on Mars when the planet was warm and wet. We find that there was plenty of energy for life in that early Mars environment; microbes could have thrived. But the small amounts of organic matter that the Curiosity rover measured in the mudstones of Gale crater constrains the size of the microbial community to no larger than that of Earth’s subseafloor.

In the third project, Emersyn Slaughter et al. (in prep) evaluate a machine learning–based biosignature technique on planetary-analog samples of mixed biotic and abiotic components. This is relevant to the search for life on Mars, where a significant fraction of the organic matter may be due to meteoritic infall, or icy moons, where hydrothermal activity may create abiotic organics. We find that the technique can detect the biogenicity of samples even when the sample is only composed of <10% biological matter by mass.

Jessica Zebrowski
UC Berkeley

Probing the Middle Ages of Cosmic History with Line Intensity Mapping

Dark energy, the unknown cause that drives the accelerating expansion of the universe, is one of the great unexplained mysteries in current cosmological models. To understand the potentially evolving nature of dark energy, we must probe the gap between measurements of the early Universe, as traced by the cosmic microwave background (CMB) 13 billion years ago, and the Universe as we see it now through galaxy surveys, by making measurements of the years in between.

New spectrometer technology is just reaching maturity to enable a new probe of cosmology, Line Intensity Mapping (LIM), which would be able to probe these sparsely-measured middle ages to map an evolving 3D cube of time from 11 billion years in the past to the present. In this talk, I will describe the cameras and analysis techniques that we are developing at the Kavli Institute for Cosmological Physics at the University of Chicago to make some of the first LIM measurements. These first-gen cameras will be deployed on telescopes as far as the South Pole, and as high as near-space orbit. These data will have the potential for a first LIM science detection with CO or CII line emissions and will be a technological proof-of-concept that will set a precedent for technology and analysis techniques in this growing field for years to come.

Shangjia Zhang
Columbia University

Radiation-Hydrodynamics of Shadows on Transition Disks

Shadows are often observed in transition disks. While shadows leave apparent darkened emission as observational signatures, they impact the thermal structure differently than commonly studied axisymmetric stellar irradiated disks, and also leave further dynamical consequences. We use radiation hydrodynamics simulations to study shadows in transition disks and find that the temperature drop due to the shadow acts as an asymmetric driving force, leading to spirals in the cavity. These spirals transport mass through the cavity with $alpha sim 10^{-2}$ as a source of accretion. The cavity edge can also form spirals, vortices, and streamers that resemble those observed in near-infrared scattered light images. In the vertical direction, the pressure gradient is no longer balanced by the pressure gradient alone. Instead, an azimuthal convective acceleration term balances the difference, leading to azimuthally periodic upward and downward gas motion, which can be probed by ALMA line observations without assuming axisymmetry.

Zhoujian Zhang
UC Santa Cruz

Retrieving the Elemental Abundances of Self-Luminous Exoplanets and Their Host Stars

Measuring the compositions of exoplanets and their parent stars is crucial for understanding planet formation. Prevailing theories propose that planets, formed through various mechanisms, exhibit distinct elemental abundances compared to their parent stars. However, critical knowledge gaps persist, including (1) the lack of uniform composition measurements for both planets and their parent stars, and (2) the unquantified systematic errors in model-predicted compositions. To tackle these challenges, we are leading the "ELemental Abundances of Planets and brown dwarfs Imaged around Stars (ELPIS)" program. ELPIS aims to uniformly measure elemental abundances of imaged exoplanets, benchmark brown dwarfs, and their AFGKM host stars via spectroscopy. I will present new analysis results of remarkable planetary systems using ground-based and JWST data, including the newly discovered AF Lep A+b and the first directly imaged planetary system 2MASS 1207 A+b. Our planet analyses leverage a novel retrieval framework designed to characterize the atmospheres of planets and brown dwarfs. ELPIS will map compositions across various exoplanets and parent stars, furnishing a population-level understanding of planet formation pathways as functions of their masses and orbits. The upcoming ELTs will further enhance the precision and accuracy of abundance measurements, enabling a more comprehensive exploration of planet formation pathways.

Sebastian Zieba
CfA

Surface characterization of the rocky exoplanet LHS3844b with MIRI/LRS and NIRSpec/G395H on JWST

Rocky planets orbiting M-dwarf stars are among the most common planets known in the galaxy. While many of these worlds have similar densities to the Solar System terrestrial planets, they may have vastly different atmospheres and geology due to their short-period orbits. Here, I will present a recent result from JWST to characterize the surface of a rocky exoplanet: Previous Spitzer observations of the hot planet LHS3844b indicate that it is most likely a bare rock, inviting detailed study of the surface. We used MIRI/LRS (5 - 12 microns) on JWST to observe three eclipses of the planet, leading to a confident detection of thermal emission coming from the planet. Our emission spectrum tightly constrains the surface fractions of different rocks, including basalt (expected from volcanism akin to present-day Earth), ultramafic rock (expected from a solidified magma ocean), and granite (an indicator of crustal reprocessing). Furthermore, we have recently taken a phase curve of the planet with NIRSpec G395H. This additionally, constrains the surface composition between 2.7 and 5.2 microns. These JWST observations provide the first empirical constraints on the geologic history of a rocky exoplanet orbiting an M-dwarf.