2025 NRAO Postdoc Symposium Abstracts

Compact objects and stars at the end of their lifetime

Looking for imprints of the explosion mechanism of thermonuclear supernovae in their remnants

Soham Mandal

Type-Ia supernovae (SNe), or runaway thermonuclear explosions of white dwarfs, play a critical role in the chemical evolution of galaxies, and are important cosmological distance indicators due to their 'standardizable' lightcurves. Growing evidence, however, suggests greater diversity in their observed lightcurves (and spectra) than thought previously. This is usually attributed to a variety of WD explosion mechanisms and progenitor system properties, but a direct link between the explosion mechanisms and Type-Ia SN observables remains elusive. Here we present a novel approach to identify explosion mechanisms of Type-Ia SNe, by analyzing the sizes of small-scale turbulent substructures of different elements in their extended ejecta, i.e., in Supernova Remnants (SNRs). Our three-dimensional hydrodynamical models show that the relation between the typical substructure size in SNRs and the density scale height of the stellar ejecta can be used to determine the density profiles of different elements, which carry distinct imprints of the explosion mechanism. Applying this approach to Tycho's SNR, we find that its observed structure is most consistent with the explosion of a sub-Chandrasekhar mass WD via the double-detonation mechanism. Extending this method to other well-characterized SNRs can let us connect the inferred explosion mechanism to the associated historical SNe, which often have spectra reconstructed through light echo observations.

An Extreme Scattering Event Towards PSR B2310+42

Jacob Turner

We present evidence of an extreme scattering event (ESE) toward PSR J2313+4253 using high-cadence observations taken with the Green Bank Observatory 20m telescope. The high density of observations in time allow us to track the event in unprecedented detail. We observe a pair of caustic spikes along with the characteristic drop in scintillation bandwidth that is expected during an ESE. This pattern coincides with a sudden change in the estimated scattering screen distance. A secondary spectrum processed during the event shows a detached feature similar to those found in double lensing events from previously observed ESEs. This event originated from a scattering region with a screen distance of 1.03 +/- 0.01 kpc and a transverse size of 15.6 +/- 1.6 AU, and lasted approximately 220 days.

The largest* galactic transient search - with CHIME

Fengqiu Adam Dong

Pulsars have proven helpful in far-reaching fields outside of just astrophysics. They have been used to make stringent gravity tests and study our universe in extreme environments. Most recently, they've allowed us to measure nHz gravitational waves using pulsar timing arrays. Therefore, the search for new pulsars through various methods has been not only at the top of the scientific goals of SKA-pathfinders but the SKA itself. The Canadian Hydrogen Intensity Mapping Experiment is a rapid survey instrument that measures hydrogen across the universe. Serendipitously, it has proven extremely useful for fast radio transients like pulsars and fast radio bursts. The CHIME/FRB instrument was built to discover fast radio bursts by capitalising on the large field of view of CHIME and is now making the largest survey of single pulses from pulsars to date. Our survey is equivalent to $\sim$730,000 hours of Green Bank equivalent time per month, every month. With this vast survey available, we are discovering a host of new pulsars of all varieties. To date, we have discovered 84 new pulsars, with 2 long-period transients and intriguing binary systems. Our survey serves as a groundwork for future studies with more sensitive instruments like the SKA. For this talk, I will focus on our survey strategies, discovery pipelines, and lessons learned from managing a large amount of survey data in an automated fashion. I will further discuss our most significant discoveries and look forward to single pulse surveys with the SKA.

A New Mass Estimate for PSR J0348+0432

Alexander Saffer

Neutron stars are some of the most compact objects in the universe, second only to black holes. Their interior composition remains a mystery, but studies of neutron stars and pulsars can allow scientists to probe the dense nuclear regions within. These investigations often lead to bounds on a neutron star mass, which can be compared with a given equation of state to provide the physical characteristics of a star. In this talk, I'll speak about some work following up one of the most massive neutron stars ever measured, J0348+0432, and provide an update into the mass estimates. This work was carried out with the Canadian Hydrogen Intensity Mapping Experiment (CHIME) telescope as well as archival data provided by the Arecibo Observatory and the Green Bank Telescope. We have found that new estimates place a mass considerably lower than the original estimate likely due to a mis-modeling of the white dwarf companion mass.

Demographics of the Dynamic Radio Sky

Dillon Dong

The upcoming VLA Sky Survey (VLASS) transient catalog features ∼4,000 radio point sources that appeared (or disappeared) across 3 all-sky epochs spanning ∼7 years. When published, this catalog will ∼triple the number of known radio transients evolving on timescales from minutes to decades. These transients originate from a diverse range of astrophysical phenomena, including flares from highly-magnetized stars in the Milky Way, terminal explosions of massive stars in local-universe galaxies, and newly-launched jets from supermassive black holes at cosmological distances. In this talk, I will discuss our methods for identifying ∼3 million sources among ∼1 trillion pixels in VLASS, which we then distilled to find the ∼4,000 transients. Additionally, I'll present some simple techniques that can be used to identify and characterize radio transients using archival data instead of follow-up campaigns. These methods are scalable, and generalizable to a wide range of current and upcoming time-domain radio surveys. When applied to VLASS, they are enabling us, for the first time, to systematically characterize the demographics of the dynamic radio sky.

Keynote Speaker

Exploring a Black Hole Explorer - The Science and Technology of Millimeterwave Space/-Ground VLBI

Dan Marrone

Supermassive black holes sit at the centers of most galaxies, but their imprint on the structure and appearance of their hosts extends far beyond their gravitational reach. Energetic black hole feedback processes act over cosmic history to shape galaxies and even galaxy clusters on scales of tens to hundreds of kpc, using energy driven from regions the size of our Solar system. After decades of study, simulation, and observation, the details of black hole growth, their accretion flows, and the mechanisms that power their feedback are still not understood. To observe these processes requires exceptional (sub-milliarcsecond) angular resolution, which is possible through the technique of very long baseline interferometry (VLBI). Famously, the Event Horizon Telescope (EHT) collaboration has pushed VLBI to near its ground-based limits — observing the shortest radio wavelengths the atmosphere allows on Earth-spanning baselines — to see the event horizons of two black holes at ~20 microarcsecond resolution. While the EHT continues to advance its capabilities and analysis techniques to extract more and better information, entirely new information would be available from a VLBI array that extends beyond the Earth. In this talk I will discuss the science of the Black Hole Explorer (BHEX), a NASA Small Explorer mission concept that is currently being formulated. Implementing a space VLBI mission requires a great number of compromises to achieve the needed capabilities within the restrictive confines of a NASA mission budget, and I will explore how we have navigated these for BHEX. Because I have the rare pleasure of presenting this topic to an assemblage of brilliant radio-specialist postdocs, I will discuss these in more detail than I would in other venues.

Protoplanetary disks, planetary objects and AGN

Sulfur Chemistry as a Window into Planet Formation

Charles Law

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.

The ALMA Survey of Gas Evolution of PROtoplanetary Disks (AGE-PRO): Dust and Gas Disk Properties in the Ophiuchus Star-forming Region

Dary Ruiz

The ALMA survey of Gas Evolution in PROtoplanetary disks (AGE-PRO) Large Program aims to trace the evolution of gas disk mass and size throughout the lifetime of protoplanetary disks. In this talk, I will present Band-6 ALMA observations of 10 embedded (Class I and Flat Spectrum) sources in the Ophiuchus molecular cloud, with spectral types ranging from M3 to K6 stars, and their key observational characteristics, whose results contribute to our understanding of the disk gas evolution. I will conclude by discussing the main findings of the AGE-PRO focused on disk mass analysis.

A Radio Recombination Line View of the Orion Proplyds

Ryan Boyden

Proplyds are protoplanetary disks surrounded by cocoons of ionized gas with a cometary morphology. These disks are commonly found in nearby ($d = 400$ pc) star-forming clusters, and their morphologies indicate that protoplanetary disks are influenced by radiative feedback from massive OB stars. In this talk, I will present new ALMA observations that, for the first time, detect hydrogen and helium radio recombination lines from proplyds in the Orion Nebula Cluster (ONC). We have imaged the ONC at 3.1 mm with a spectral setup that covers the $n = 42$ to $n = 41$ transitions of hydrogen (H41a) and helium (He41a). We detect H41a from 17 proplyds. The detected H41a emission is spatially coincident with the locations of proplyd ionization fronts, indicating that proplyd H41a emission is produced by gas that has been photoevaporated off the disk and ionized by UV radiation from massive stars. The H41a line-to-continuum ratios reveal that proplyd ionization fronts have similar temperatures over a range of disk properties, while the H41a line widths indicate that the broadening of proplyd H41a emission is dominated by outflowing gas motions associated with disk photoevaporation. Finally, we detect He41a towards one H41a-detected proplyd and find that this proplyd's He41a to H41a line ratio implies a helium abundance that is two times greater than the canonical helium abundance of the Orion Nebula. This suggests that either proplyds are enriched in helium relative to the Orion Nebula, or the Orion Nebula is more chemically enriched via galaxy evolution than currently thought. Our study demonstrates that radio recombination lines are readily detectable in ionized photoevaporating disks, providing a new way to measure disk properties in clustered star-forming regions. Finally, this talk will conclude with a discussion on how radio recombination line-based studies of proplyds, winds, jets, and globules will be uniquely facilitated by ALMA's Wideband Sensitivity Upgrade.

Characterizing the Spectral Variability of the First Directly-Imaged Planetary-Mass Companion

Arthur Adams

The 2M1207 system is among the first entries in the catalog of directly-imaged planetary-mass objects, and it is also among the youngest systems to be resolved — both spatially and now in time. New JWST observations of the system with the NIRSpec IFU represent the first moderate- to high-contrast time-series spectroscopy of a planetary-mass companion. We present initial empirical characterizations of the structure of the variability in both objects. For the planetary-mass secondary 2M1207 b we present an updated fit of a cloud variability model to our new data which shows an agreement with previous measurements of variability using HST photometry. However, many areas of the near-infrared data cannot be fit with a simple cloud variability model, motivating a follow-up study to characterize its atmosphere more fully. The primary, 2M1207 A, shows a combination of periodic and non-periodic structures which motivates its own follow-up atmospheric study. The possible sources of spectral variability to consider in both objects includes starspots (particularly in 2M1207 A), more complex cloud features (particularly in 2M1207 b), and, potentially, the effects of ongoing accretion from circum-stellar and/or circum-planetary material.

Obscuration Variability in Nearby AGN

Núria Torres-Albà

Active galactic nuclei (AGN) are powered by accreting supermassive black holes, surrounded by a torus of obscuring material. The exact geometry of this material has been a subject of debate, as models have advanced from the initial homogeneous torus to a variety of possibilities, ranging from cloud distributions to warped disks, to outflows. It is clear, however, that this distribution is clumpy: X-ray determinations of line-of-sight (l.o.s.) obscuration show variability in timescales from <1 day to years. However, studies of large samples of sources tend to find variability in <50% of Sy2s analyzed; and it is unclear whether this result is compatible with our understanding of the clumpy torus. X-ray observations are the only way to probe the obscuring column density in the line of sight at any given time, and thus the optimal tool to place constraints on the exact distribution of this material. Here, I present our group's efforts in using archival X-ray data to characterize obscuration variability of a large sample of nearby AGN for the first time.

Star Formation

Phosphorus Chemistry at the Earliest Stage of Low-mass Star Formation

Samantha Scibelli

A necessary element for life on Earth, phosphorus is a critical component in DNA, RNA, ATP and a host of other biological molecules. Simpler phosphorus-bearing molecules, such as phosphorus mononitride or PN, have been known for decades to be present in the shells of evolved stars as well as in massive star-forming regions. Still, there are limited phosphorus observations throughout the different stages of low-mass (M < a few solar masses) star formation, especially toward starless and prestellar cores. Here we present the first detections of PN, PO and the ion PO+ toward a shocked low-mass starless core in the NGC1333 region of the Perseus Molecular Cloud. The kinematic correlation of these species to bright SiO(1-0) emission in a core with no active protostar supports the idea that 1) shocks are the main driver of releasing phosphorus from dust grains and into the gas-phase and 2) that the emission originates from gas not affiliated with the shock itself, but quiescent gas that has been shocked in the recent past. From radiative transfer calculations, the PO/PN abundance ratio is found to be 3, consistent with other high-mass and low-mass star-forming regions. This first detection of PO+ toward any low-mass star-forming region reveals a PO+/PO ratio a factor of ten lower than previously determined from observations of a galactic center molecular cloud, suggesting its formation can occur under more standard Galactic cosmic-ray ionization rates. Now that we are able to probe phosphorus across different environments (e.g., starless cores, protostars, and comets), we need increased detection statistics, spatially resolved observations, and updated chemical models of phosphorus-bearing molecules to better understand this precursor prebiotic chemistry.

THOR-GC: Characterizing the interstellar medium towards the Galactic Center

Michael Rugel

THOR-GC: Characterizing the interstellar medium towards the Galactic Center What are the dynamics, properties and star formation in the innermost regions of our Galaxy? How do molecular clouds form out of the atomic gas across our Galaxy? I will discuss new HI observations tracing atomic gas in and around molecular clouds: With the THOR-GC survey - an expansion of The OH, HI, Recombination Line survey (THOR) - we observed the Galactic center and its surroundings in HI, four OH, 12 radio recombination lines as well as the L-band continuum between 1-2 GHz in full polarization, to study the interstellar medium (ISM) in the extreme conditions of the Galactic Center. The new data provide maps of atomic hydrogen at high angular resolution closer to existing Galactic plane surveys of molecular gas and dust continuum tracers, allowing us to properly characterize the transition between phases of the ISM with observations of HI emission and self-absorption. I will present an overview of THOR-GC and first results.

Molecular gas fraction and dynamical equilibrium pressure in local and nearby galaxies

Cosima Eibensteiner

The molecular gas fraction and dynamical equilibrium pressure are key parameters governing how galaxies regulate star formation. These properties influence the balance between atomic and molecular gas and vary across galaxy environments, impacting how efficiently stars form. In this talk, I will present both published and ongoing work on molecular gas fractions and pressure in nearby galaxies. I will also highlight ongoing efforts to study galaxy centers.

Measuring Magnetic Field Strengths in Galactic Star Forming Regions via the Zeeman Effect

Tao-Chung Ching

Magnetic fields thread the interstellar medium of our galaxy from the smallest to the largest scales and are important in the evolution of molecular clouds and the regulation of star formation. Quantifying this requires measurements of the field strength, and the most direct and accurate technique for measuring field strengths is observations of the Zeeman effect in selective atomic and molecular transitions, such as HI, OH and CH3OH. While indirect magnetic field strength measurements via dust polarization and Faraday rotation observations support the view that magnetic fields are important in the evolution of star-forming clouds, measurements using the Zeeman effect are required to understand their degree of importance. The few existing Zeeman detections suggest clouds and cores are marginally supercritical (cannot prevent collapse, but can slow the rate of star formation), but may be biased due to small sample sizes. Zeeman measurements of spectral lines tracing different depths, densities, and star-formation stages within clouds can reveal the variation of field strengths from cloud-scales (1-10 pc) to dense cores ($\sim$0.1 pc) to protostellar envelopes ($\sim$0.01 pc), providing a critical test to answer the question of whether star formation is primarily regulated by magnetic fields or turbulence at different scales.

Instrumentation, tools and techniques

Room Temperature and Cryogenic Measurements of the 3D Printed Orthomode Transducer at Ka-Band

Priyanka Mondal

Orthomode transducers (OMT) are required to separate the incoming signal into two linear polarizations. Characterizations of the 3D printed Ka-band OMTs at room temperature and cryogenic temperature are going on at CDL. This talk will include the updates on the measurements. It will also include its insertion loss performance with respect to a machined OMT being used at Very Large Array over the same frequency band.

A quasi-linear Harmonic Balance model for studying the performance of 2SB millimeter and submillimeter wave SIS receivers

David Monasterio

The modeling of sideband-separating (2SB) receivers based on superconductor-insulator-superconductor (SIS) mixers is typically carried out by analyzing the RF and IF sections of the receiver separately. This division is necessary due to the frequency conversion introduced by the nonlinear mixing process, which complicates the application of standard linear analysis techniques. In this talk we will present a Harmonic Balance (HB) non-linear simulation for modeling the complex behavior of 2SB millimeter and submillimeter wave SIS receivers. By integrating nonlinear and frequency-dependent effects in a "quasi-linear" fashion, as well as practical component-level data, the proposed HB-based approach provides accurate frequency dependent behavior for several key parameters such as gain, noise temperature, and sideband rejection ratio.

Tropospheric Phase Correction Using Water Vapor Radiometers

Kyle Massingill

I present on the development of calibrations strategies for the next generation Very Large Array (ngVLA). The ngVLA is the planned large scale interferometric array that will be primarily based in the American Southwest, but will include outlying sites across the United States, Mexico and Canada. The continental sized baselines available to the array, combined with a densely populated core, will enable ngVLA to be an order of magnitude more sensitive than the current VLA, while being able to achieve sub-milliarcsecond-resolution. Temporally variable water vapor in the troposphere will introduce delay error to observations made with ngVLA. Calibration of this delay error is essential to ngVLA meeting science requirements. There are multiple established techniques for phase correction and the ngVLA team is exploring the feasibility of different approaches. Techniques such as fast switching and self-calibration have been deemed sufficient at lower frequencies but have severe limitations in the higher frequency bands. Due to this, a water vapor radiometer (WVR) system is being developed for ngVLA. This system will continually estimate changes in the water vapor column density in the main antenna beam. The WVR system will be sensitive to the pressure broadened 22 GHz water vapor line in a variety atmospheric conditions. I present on the development of techniques for tracking small changes in the tropospheric wet delay through observations of the 22 GHz water line. I give updates on our approach to using atmospheric modeling to write algorithms to translate WVR observations to precipitable water vapor (PWV). I compare the proposed ngVLA WVR to other 22 GHz instruments being developed for tracking water vapor column density.

Accelerating the major loop and minor loop of radio interferometric imaging

Hendrik Müller

Imaging in radio interferometry is typically organized around multiple loops nested around each other. The upcoming/proposed generation of radio interferometers will operate at much higher data rates, posing significant scalability challenges to data processing pipelines. A wide range of alternative deconvolution frameworks (among them by AI, Bayesian inference and compressive sensing) have been proposed, but not yet adapated widely in practice, or demonstrated robustness and scalability. I will discuss how ideas pioneered in these works could be translated into the classical (MS-)CLEAN major loop/minor loop iterative scheme, leading to significant accelerations. Particularly, I will discuss the use basis functions inspired by the autocorrelation function in an MS-CLEAN minor loop, and adding momentum acceleration and gradient conjugation to the major loop. The algorithms are straightforward, rooted deeply in traditional, and robust data processing frameworks, and in some cases just require a few lines of additional CASA code, but offer orders of magnitude of improvement over classical tclean regarding accuracy and runtime performance.