MONDAY CONTRIBUTED TALKS

Detecting Elusive Black Holes in the JWST Era

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The first black hole seeds likely formed when the Universe was younger than 500 Myr old and they played an important role in the growth of early (z=7) supermassive black holes. While much progress has been made in understanding their formation and growth, their observational signatures remain largely unexplored. As a result, we are yet to detect these sources. We present a novel photometric method to identify black hole seed candidates in deep multi-wavelength surveys. The method relies on infrared and X-ray observations and selects the only two objects with a robust X-ray detection found in the CANDELS/GOODS-S survey with a photometric redshift z>6. Moreover, we present the case of CR7, a Lyman alpha emitter at z=6.6 whose observational features are also compatible with our black hole seed model. To date, these objects represent the most promising black hole seed candidates, possibly formed via the direct collapse black hole scenario. While this result is based on the best photometric observations of high-z sources available to date, additional gains are expected from deeper spectroscopic and X-ray data. For this reason, we explore the role that JWST will play in the detection of the first black holes in the Universe.

Supermassive Black Hole Seeds in Cosmological Simulations

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Supermassive black holes are well understood to play an important role in galaxy evolution, as well as acting as an observational probe reaching back to the very early universe. One of the most uncertain aspects of supermassive black holes is the mechanism by which their initial seeds form and the efficiency and frequency with which this occurs. Using high-resolution cosmological simulations and post-processing analysis of black hole accretion and merger histories, I will discuss which observables are affected by changing the seed prescription. In particular, I will focus on how global properties such as the black hole mass function, global accretion rate density, and the quasar luminosity function depend on the fraction of halos capable of forming SMBH seeds and the types of halos in which they form (e.g. based on the metallicity and spin parameter of the halo), and the possible constraints we can determine from current and upcoming observational surveys.

Radiation-hydrodynamic Simulations of Obscured AGN: a Striking Correlation Between the Spectral Shape of Dust Thermal Emission and the Black Hole Eddington Ratio

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Recent observations show large amounts of dust around supermassive black holes (SMBHs) in the early Universe. However, the accretion mechanism of SMBHs in dusty gas is not well understood. In this talk I will present a study of the growth of massive black holes (MBHs) in dusty clouds by using one-dimensional radiative-hydrodynamics simulations.
We find that the accretion of dusty gas onto MBHs proceeds gently with small fluctuations of the accretion rate, whereas that of less dusty or pristine gas causes more violent periodic bursts. At dust-to-gas mass ratios similar to the solar neighborhood, the time averaged luminosity becomes smaller than that for primordial gas by one order of magnitude.

We derive spectral energy distributions at IR bands by calculating dust thermal emission and show that the flux ratio between $\lambda < 20 \mu m$ and $> 100 \mu m$ is closely related to the Eddington ratio, independently of the BH mass, gas density, metallicity, etc. Thermal emission from hot dust near the BH dominates only during the high accretion phase producing higher flux at $~20 \mu m$, while a warm dust component located further out, although fainter during the quiescent phases of the accretion, it is always present.

Testing this model observationally requires minimizing the contribution from warm dust associated with star formation using high resolution observations, some of which are already available using Hershel and Spitzer. We therefore suggest that the combination of MIR observations by JWST and FIR observation by ALMA may be used to estimate the Eddington ratio of obscured AGNs.

Properties of Active Galactic Nuclei in Dwarf Galaxies

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Searching for signs of black hole accretion is the best way of identifying black holes in dwarf galaxies. In the last several years, the number of dwarf galaxies with known active galactic nuclei (AGN) has increased by over an order of magnitude, thanks to large scale surveys such as the Sloan Digital Sky Survey. These objects comprise a new population of AGN. As such, it is important to characterize this population to understand how they compare to AGN in more massive systems, as well as to determine which factors influence the presence of AGN in dwarf galaxies. I will discuss X-ray and ultraviolet observations of a sample of dwarf galaxies with optical signatures of AGN activity (Baldassare et al. 2017). I will also discuss new results from Hubble Space Telescope WFC3 observations of RGG 118, a dwarf galaxy hosting an actively accreting 50,000 solar mass black hole in its core.

Hard X-Ray-selected AGNs in Low-mass Galaxies

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I will present properties of the sample of low-mass AGNs selected from the ~13 deg2 NuSTAR Serendipitous Survey. This z<0.3 sample of 10 low-mass AGN has median r-band absolute magnitude and 2-10 keV luminosity comparable to those of broad-line IMBH host galaxies selected from large optical spectroscopic surveys. One of the 10 galaxies in our sample, J115851+4243.2, shows evidence for heavy X-ray absorption and 30 (+16,- 9)% of our sample do not show AGN-like emission lines in their optical spectra, implying that a fraction of the low-mass AGNs might be missed by spectroscopic surveys in the optical wavelengths. The mid-IR colors of our sample also indicate that these optically normal low-mass AGNs cannot be efficiently identified with typical AGN selection criteria based on Wide Field Infrared Survey Explorer colors. While the hard X-ray-selected low-mass AGN sample size is still limited, our results show that sensitive NuSTAR observations are capable of probing faint hard (> 10 keV) X-ray emission originating from the nuclei of low-mass galaxies out to moderate redshift (z< 0.3), thus providing a critical step in understanding AGN demographics in low-mass galaxies. I will also present the results from the XSERVS-LSS survey, which is a deep XMM-Newton survey targeting the central 4 deg^2 of the XMM-LSS field.

The (Elusive) Fossil Record of Black Hole Seeds

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In principle, the black hole content of low-mass galaxies is a "fossil record" of black hole seed formation in the early Universe. But in practice, a black hole census in low-mass galaxies has remained elusive due to selection biases in standard AGN selection techniques. I will demonstrate and quantify how star formation "dilutes" and hides significant black hole growth in low-mass galaxies, along with an estimate of black hole content among SDSS galaxies after correcting for this bias. Spatially resolved spectroscopy greatly increases the efficiency of AGN selection by mitigating the dilution from extended star formation emission. I will show the current constraints on bimodal black hole seed formation from HST grism spectroscopy, and will also anticipate some of the observations we can expect from similar JWST and WFIRST grism spectra.

Intermediate Mass Black Holes Manifested as Low-Luminosity Active Galactic Nuclei

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presented by

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Intermediate mass black holes (IMBHs) with masses in the range of 500 to 200000 MSun represent a crucially important link between the populations of stellar mass black holes and supermassive black holes residing in galaxy centers. We have identified several low luminosity nearby active galactic nuclei in the SDSS legacy galaxy sample having X-ray counterparts and estimated their virial masses to be between 30000 and 200000 MSun. IMBH hosts are expected to have had poor merger histories without major mergers in the past and, therefore, might represent the relics of pristine galaxy population survived through the cosmic time almost intact. Here we present preliminary stellar population analysis of IMBH hosts made from their SDSS spectra. We seek answers to the following questions: (i) why didn't IMBHs grow? (ii) how do IMBHs affect their host galaxies? (iii) how did IMBH hosts evolve through the cosmic time? We plan to follow-up several IMBH hosts with the JWST NIRspec IFU and obtain: (i) spatially resolved star formation histories; (ii) maps of stellar and gas kinematics; (iii) maps of NIR emission line ratios in the narrow-line AGN region; (iv) improved IMBH mass estimates using AGN broad line region in H-alpha and Paschen-alpha.

TUESDAY CONTRIBUTED TALKS

Uncovering the Full Population of Elusive Growing Black Holes with X-ray and Multiwavelength Surveys

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Despite remarkable recent progress, our picture of black hole evolution has remained incomplete due to the challenges of detecting the elusive AGN that are highly obscured or hidden beneath the light of their host galaxies. It is now clear that AGN obscuration can be linked to processes in galaxy evolution, and that black hole growth is highly stochastic and variable, so that studying these weak or obscured AGN is essential to understanding the big picture of black hole evolution. I will review recent progress in uncovering the complete AGN population using deep, wide X-ray and multiwavelength surveys along with the next generation of black hole and galaxy evolution models. I will then point to the potential for the future with the next generation of extragalactic surveys, and forecast the exciting science that will be enabled by the Lynx concept X-ray mission.

A Universal Model for the AGN Phenomenon

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I present ongoing work on building a universal model for the AGN phenomenon. We forward model the luminosity and variability of AGN as they grow together with the galaxy population to give rise to the diverse phenomenology of Seyferts, quasars and radio galaxies. Using this forward modeling approach, we can constrain the physics driving black hole growth and the role black hole growth phases have in the evolution of galaxies. We find that the AGN phenomenon is largely insensitive to the particular features of their host galaxies, and is rather driven by physics near the AGN central engine, or even in the accretion disk itself. The only difference is the activity in blue and red galaxies, with some modification in the case of major mergers. I make the case that a full understanding of the AGN phenomenon requires consideration of the variability spectrum on all time scales, from seconds to the age of the universe.

Hiding in Plain Sight: AGN Echoes of Low-Redshift Lyman Alpha Blobs

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We have discovered extremely luminous optical nebulae whose ionization states are characteristic of active galactic nuclei (AGN), yet lack signatures of current powerful activity, such as X-ray emission. We identify these emission sources as ionization echoes of past activity, where the AGN have faded by three to four orders of magnitude in the last 10,000 to 100,000 years. They remain bright at mid-infrared (MIR) wavelengths, so offsets from standard X-ray–MIR relationships do not necessarily imply AGN obscuration. The properties of this group are related to the duty cycle of AGN and the time lag for dust reprocessing of the central emission. We use near-ultraviolet observations to demonstrate that these powerful galaxies, having Lyman alpha luminosities on the order of 10^43 erg/s, are low-redshift ($z \sim 0.3$) counterparts of “Lyman alpha blobs” (LABs). LABs were more common at $z > 2$ and are sites of massive galaxy formation. Most of the low-redshift hosts are interacting or merging galaxies, located in more isolated environments rather than in the massive structures that high-redshift LABs prefer. Although rare, the relatively nearby counterparts offer opportunities to measure physical conditions and processes including the escape of Lyman alpha photons, and most importantly, to determine their underlying sources of ionization and luminosity.

Characterizing Black Hole Growth Across the Galaxy Population Using Deep X-ray Data

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Deep X-ray observations are uniquely capable of identifying growing supermassive black hole accretion down to very low levels of accretion within various galaxy types that may be missed with other diagnostics, thus providing vital insights into the elusive population of AGN. I will present new measurements that push the limits of the deepest Chandra X-ray surveys to accurately characterize the distribution of black hole accretion rates within large samples of star-forming and quiescent galaxies spanning out to z~4. Our results reveal a broad distribution of accretion rates in both galaxy types, reflecting long-term variability in the level of AGN fuelling. We also find that the incidence of AGN in star-forming galaxies is higher than in quiescent galaxies and undergoes a strong, stellar-mass-dependent evolution. The probability of a quiescent galaxy hosting an AGN is generally lower and evolves differently with redshift. These results provide new insights into the physical mechanisms that drive the growth of supermassive black holes across the galaxy population and the potential impact of AGN on the different stages of galaxy evolution.

Obscuration/orientation Effects in the Chandra Observed Sample of Medium-Redshift (0.5<z<1) 3CRR Sources

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The level of accretion power in the Universe has fundamental implications both for cosmology and the physics of active galactic nuclei (AGN). Despite their intrinsically bright, multi-wavelength emission, an unknown AGN fraction remain under cover, their nuclei invisible due to orientation-dependent obscuration by massive amounts of material. One way to select AGN samples that are orientation-unbiased (although limited to radio-loud sources) is low frequency radio, where the selection is based on extended radio lobes. The radio data also provide an independent estimate of orientation via the radio core fraction.

We extend our studies of a complete, low-frequency (178 MHz) radio selected, Chandra observed sample of high-redshift (1<z<2) 3CRR sources (Wilkes et al. 2013) to medium redshifts (0.5<z<1). This medium-redshift, flux-limited and orientation unbiased sample includes: 13 quasars, 22 narrow-line radio galaxies (NLRGs) and one low-excitation radio galaxy (LERG), with matched radio luminosities (log L(5GHz)~44-45). The quasars show high X-ray luminosities, soft hardness ratios (HR<0), and high radio core fraction, which indicates low obscuration (log NH < 22) and face-on inclination. NLRGs, have 10-1000 times lower observed X-ray luminosities, a wide range of hardness ratios, and lower radio core fraction, indicating a range of obscuration (log NH > 21) and edge-on inclinations. These properties together with the observed trend of increasing NH with decreasing radio core fraction are roughly consistent with orientation-dependent obscuration as in Unification models. However, four NLRGs show low NH (log NH ~ 21-22), high quasar-like Lx/Lradio ratios, soft hardness ratios, and weak near-to-mid-IR emission which require an extremely thin and cool torus or obscuration by the host galaxy. The ratio of unobscured to Compton-thin to Compton-thick sources is: 5.5:4.5:1 (high-z sample: 2.5:1.4:1), where 11% of sources are Compton-thick (compared to 25% at high-z).

Is Black Hole Growth a Universal Process? Exploring Selection Effects in Measurements of Eddington Ratios and Host Galaxies of AGN

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Our understanding of the connection between AGN and their host galaxies and the underlying properties of the full AGN population is presently limited by complex observational biases that are difficult to untangle using conventional methods and theoretical models. Determining the Eddington ratio distribution in the optical, in particular, can be strongly influenced by selection effects and dilution from host galaxy star formation. Using spectroscopic galaxies from SDSS, we show that an optically selected AGN population is consistent with being drawn from an AGN Eddington ratio distribution in the form of the broad Schechter function when these selection effects are taken into account. A broad distribution is likewise observed in the X-rays to describe AGN accretion. To more completely explore selection effects, we use a semi-numerical galaxy formation simulation along with this universal Eddington ratio distribution to describe the multi-wavelength AGN population. With this model, we can probe the more elusive AGN that are not selected using conventional techniques. In particular, we explicitly model selection effects to produce the “observed” AGN population for comparison with both theoretical and observational X-ray data. We investigate the impact on the “observed” population of selecting AGN in the X-rays based on a thresholds in luminosity (as they are selected in most surveys). We find that we can broadly reproduce the host galaxies and halos of the X-ray AGN population, and that different AGN selection techniques yield samples with very different host galaxy properties.

Dependence of Optical AGN Identification on Stellar Population Models and Spectral Quality

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Optical emission lines provide a clear signature for the presence of an AGN. However, in order to to have a reliable measurement of the optical line ratios used in Type 2 AGN identification, the host galaxy contribution must be accurately determined. In a systematic study of empirical, theoretical, and mixed stellar populations models, using SDSS spectra, we find significant discrepancies in line ratios when using different stellar templates, with a larger impact on low luminosity AGNs. We also find that the detected AGN fraction depends on the signal-to-noise ratio of the spectra used. We quantify these effects on our all-sky, near-by, optical AGN catalog, uniformly selected from the parent sample of galaxies in the 2MASS Redshift Survey and cross correlate our catalog with all-sky AGN catalogs at other wavelengths to assess their impact on finding a complete sample of AGNs.

Unveiling the Elusive AGNs in Millions of SDSS and WISE Galaxies

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The advent of the Wide-field Infrared Survey Explorer (WISE) has given us the opportunity to study the complete obscured AGN population with a large-area multi-wavelength approach. We present the results of SDSS+WISE spectral energy distributions (SEDs) of over one million galaxies with optical detection and a single mid-IR color cut of W2-W3 > 2.0 to remove contamination from stars. We model our SEDs using a set of empirically derived stellar and AGN templates to derive the AGN luminosity and nuclear obscuration for the full detected galaxy population in our sample. By modeling all available galaxies we are unconstrained by selection biases inherent with any given color selection criterion, and instead opt to determine the characteristics of the broader obscured AGN population given the results of our models. The luminosities and WISE infrared colors are used to determine the underlying complete population of obscured AGN, including those that would go undetected and unselected with various selection criteria. We further explore the low- and high-redshift objects in our sample for difference in their photometry and rest-frame colors.

The Elusive Nature of the AGN in NGC 1266

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The role of AGN in the transition of galaxies from actively star forming to quiescence is still not fully understood, and is particularly challenging to study for AGN that are weak or hidden by obscuration or host dilution. NGC 1266 is a transitioning galaxy, home to massive molecular outflow driven by its AGN. The turbulence injected into its interstellar medium by the outflow, indicated by its shocked optical gas ratios, may account for the suppression of its star formation activity by a factor of at least 50. While the AGN clearly has an important mechanical impact on NGC 1266, its radiative qualities are more difficult to characterize. ALMA and CARMA measurements of dense gas tracers show that its nuclear region lies behind a column of N(H2) = 3 x 10^24 cm^-2. Continuum ALMA observations barely resolve a region of FIR emission within 30pc of the nucleus emitting L(IR) > 10^10 LSun, which could be heated either by a luminous AGN or an ultracompact nuclear starburst. We use a new deep Chandra observation combined with a NuSTAR observation of NGC 1266 to determine the radiative properties of its AGN and thereby its contribution to the dust heating observed by ALMA with implications on the distribution of the star formation suppression.

The Complete IR View of Swift/BAT 70 Month AGN Catalog

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We systematically investigate the near- to far-infrared (FIR) photometric properties of a nearly complete sample of local active galactic nuclei (AGN) detected in the Swift/BAT all-sky ultra-hard X-ray (14-195 keV) survey. Out of 606 non-blazar AGN in the Swift/BAT 70 month catalog at high galactic latitudes of |b| > 10^degree , we obtain IR photometric data of 604 objects by cross-matching the AGN positions with catalogs from the WISE, AKARI, IRAS, and Herschel infrared observatories. We find a good correlation between the ultra-hard X-ray and mid-IR luminosities over five orders of magnitude (41<log Lx < 46). Informed by previous measurements of the intrinsic spectral energy distribution of AGN, we find FIR pure-AGN candidates whose FIR emission is thought to be AGN-dominated with low star-formation activity. We also show that the completeness of the WISE color-color cut in selecting Swift/BAT AGN increases strongly with 14-195 keV luminosity.

WEDNESDAY CONTRIBUTED TALKS

Obscured and Reddened Quasars at the Peak of Galaxy Formation

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While classification of large samples of obscured and reddened quasars at the peak of quasar activity and black hole growth (z~2.5) remains challenging, their identification is imperative to advance our understand of galaxy evolution. This is the case because obscured and reddened quasars may represent not just a specific quasar orientation but instead a unique stage of quasar evolution that mediates the relationship between black hole activity and galaxy evolution.

Our group has developed several observational techniques to identify obscured and highly reddened quasars at z~2.5 using a combination of the SDSS spectroscopy and WISE photometry. Our sample contains objects with some of the most extreme ionized gas velocities observed (> 5000 km/s), indicating wind speeds too large to be contained by the galaxy potential though they are radio quiet. The most extreme of these objects may thus represent the “blowout phase” of AGN evolution that precedes or accompanies the cessation of star formation in the host galaxy due to the effects of radiatively-driven quasar winds.

I will present both our sample selection and results from multi-wavelength follow-up of this sample to search for the presence of multi-scale quasar winds. In particular, Keck spectropolarimetry reveals high levels of polarized light (reaching ~20% of the total continuum emission in some cases) and changes in the polarization fraction and position angle across emission lines that argues for the presence of dusty outflows on scales of the emission line region. I will also present new efforts using the VLA to study the molecular gas content of the galaxy using CO (1-0) to search for the presence of galaxy-scale winds launched by the quasar and capable of clearing the galaxy of molecular gas.

Obscured Quasars in the Cosmic Web: Dark Matter Halos and Unification Models

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Recent work has identified an important difference in the dark matter halo masses of IR-selected obscured and unobscured quasars, suggesting that these classes cannot be fully unified using orientation alone. However, the difference has not been strong, casting doubt on its significance. We expand the footprint of angular clustering and CMB lensing cross-correlations to the full SDSS footprint to improve the precision of previous measurements, correcting for position-dependent biases introduced in the larger area. In doing so, and by combining independent halo mass measurements, we confirm obscured quasars reside in halos a factor of 3 more massive than their unobscured counterparts at a significance of 5-sigma. We also utilize cross-correlations and analysis of 12 and 22 micron WISE data to confirm that the redshifts and luminosities of these populations are well-matched and allow for fair comparisons. Additional confirmation of the halo mass difference is found from cross-correlations with spectroscopic quasars. Finally, we provide a simple evolutionary model from obscured to unobscured quasar that, when combined with a luminosity cut, can explain these observed mass differences. It is increasingly likely that both orientation and evolution, and possibly additional factors, are required to fully understand luminous obscured quasars.

The High-Redshift (z>3) AGN Population in the Deepest Chandra Fields

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Deep X-ray surveys provide unprecedented access to the population of accreting supermassive black holes (SMBH) at high redshift. We will present our recent results on the 3<z<6 AGN population in the 7 Ms CDF-S and 2 Ms CDF-N, the deepest X-ray surveys to date. Analyzing both individually-detected sources and the stacked (i.e. average) emission from undetected galaxies, we put tight constraints on quantities such as the obscured AGN fraction and the number density of z>3 AGN. In particular, we derived a large fraction (50-80%) of heavily-obscured (logNH>23) AGN, which does not evolve significantly from z=3 to 6 but show a positive dependence on luminosity. Although this was already suggested by previous works, thanks to the use of the deepest X-ray data available we could investigate this behavior down to logL~42. We also found that the mass growth of SMBH at high-redshift is dominated by the fast and short AGN phase, with a possible low-rate, continuous accretion in galaxies playing a secondary role. Finally, we will show our findings on the high-redshift AGN X-ray luminosity function, focussing in particular on the slope of the faint end, accessible only by the deepest X-ray surveys. This is particularly important to assess the contribution of AGN to the cosmic reionization. All of these results will be placed in the context of SMBH seeds formation and growth, and comparison with expectations from simulations will be provided. We will also discuss how future missions like Lynx, Athena and JWST will boost our knowledge of the SMBH formation and evolution in the early universe.

The Deepest Radio View of AGN in the COSMOS Field: a Two-fold Population

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I will present the latest results obtained from the 3 GHz VLA-COSMOS Large Project, the deepest radio survey ever conducted over the COSMOS field (2.6 sq.deg.). We collected nearly 11000 radio sources down to unprecedented sensitivity (2.3 uJy/beam), and identified about 3000 AGN based on X-ray, mid-infrared (MIR) and radio diagnostics.
I will show how this AGN sample is an unique and ideal benchmark to track the impact of AGN feedback onto their host-galaxies across $0<z<5$. The key results delivered by our study confirm that X-ray/MIR AGN and radio AGN reside in different host-galaxies since $z\sim5$, as found in the local Universe. However, their preferred habitat changes throughout cosmic time: intriguingly, radio AGN - completely elusive in X-rays or MIR - seem to prefer the most massive galaxies at $z<1$, while they tend to populate less massive systems at $z\sim2$. We observe the opposite trend for X-ray/MIR AGN, suggesting that our two AGN populations might be following two different pathways of the galaxy life cycle. This dichotomy is strengthened by the different specific accretion rate distributions inferred for these AGN populations, with BH accretion in radio AGN being predominantly mechanical and less efficient compared to that inferred for X-ray/MIR AGN. Our results hint at a physical connection between BH accretion mode and host-galaxy type in AGN, that our survey allows to explore from a multifaceted perspective, paving the way towards the next-generation facilities.

MBH Growth in Gas-Rich Galaxy Mergers

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Massive Black Holes (> 10^8 Msun) are most likely to have been produced during major mergers (~L* - L*) of gas-rich spirals. I will review recent evidence which suggests that the major growth phase of these MBH (x30-100) occurs during a time interval of ~ few x 10^8 yrs, coinciding with an ultra-luminous infrared phase when the merger nuclei are still heavily enshrouded in dust.

Elusive Dual AGN, Revealed by WISE

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Since all (massive) galaxies are thought to host central supermassive black holes, close black hole pairs should be a natural by-product in the late stages of galaxy mergers. The merging of these close black hole binaries not only represents a major avenue for black hole growth, but should also produce the loudest gravitational wave signals. Fortunately, the galaxy merger process triggers inward gas flows that lead to AGN, potentially making accreting black hole pairs ripe for detection. However, only a handful of dual AGN with separations <10 kpc have been confirmed with X-rays, despite intensive systematic searches. In this talk, I will present the results from a pilot survey for dual AGN that uses mid-IR colour selection and in a single modest observing campaign with Chandra has increased the number of X-ray confirmed dual AGN by ~50%.

Near-IR Explorations of Buried AGN in Advanced Mergers

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Close separation dual AGNs provide unambiguous confirmation of ongoing mergers where the black holes experience their most rapid growth. Most of these systems have been discovered serendipitously, and confirmed cases remain, however, extremely rare. Here, we present the results of the analysis of new near-IR spectroscopy of nine advanced merger systems that display mid-IR colors suggestive of AGNs while lacking signatures of activity in the optical. We confirm the presence of broadened and/or high-excitation lines indicative of powerful AGN, reveal signs of hidden AGN feedback in the form of kinematic outflows, measure the properties of the host stellar populations, and begin to probe the gas-metallicities in these systems. Our results yield critical evidence that the epoch of peak black hole growth in mergers occurs in a highly obscured phase, consistent with theoretical predictions. This is one of the first detailed investigations into the physical environment of optically obscured dual AGNs, and provides key indications for finding and characterizing elusive black hole accretion.

The Triggering of z~1 Obscured AGN in Merging Systems

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Collisions and interactions between galaxies are thought to be pivotal stages in their formation and evolution, causing the rapid production of new stars, and possibly serving as a mechanism for fueling supermassive black holes (BHs). Harnessing the exquisite spatial resolution (0.3–0.7 arcsec) afforded by the Hyper Suprime-Cam (HSC) Survey, I will present our new constraints on the importance of galaxy-galaxy major mergers (1:4) in growing obscured BHs throughout the last ~7 Gyrs. Utilizing mid-infrared observations in the WISE All-Sky survey, we have robustly selected obscured AGN, starburst, and mass-matched control galaxy samples, totaling >150,000 spectroscopically confirmed systems at i<22 mag. Using our novel machine-learning technique, we identify galaxy interactions and use these data to map the growth of BHs as a function of interaction-stage, redshift and AGN luminosity, ultimately providing the necessary large-number statistics required to investigate merger-AGN triggering in the context of galaxy evolution out to z~1. Our large sample of late-merger-stage AGN will serve as an unbiased foundation for follow-up with upcoming sensitive and high-resolution instruments, such as the James Webb Space Telescope.

THURSDAY CONTRIBUTED TALKS

Near-infrared Spectroscopy of Nearby Hard X-ray Selected AGN

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Since the near-infrared (NIR) part of the spectrum is nearly ten times less obscured than the optical, NIR spectroscopy of active galactic nuclei (AGN) can potentially detect emission line regions that are hidden at other wavelengths, especially in obscured AGN. For instance, NIR coronal lines, by virtue of their high ionization potential, may be more effective in detecting heavily obscured AGN than classical optical diagnostic methods. Additionally, it may be possible to observe broad lines region in the NIR, that are not visible in the optical.
In this talk, I will present my study on the NIR spectroscopic properties of a sample of 100 nearby hard X-ray selected AGN. I will present the NIR AGN emission line diagnostics and I will compare the relation between X-ray, NIR and optical emission lines properties to better understand AGN variability and obscuration. I will also discuss the possibility to apply these results to the study of AGN at z~1 using the Near-Infrared Spectrograph (NIRSpec) on the James Webb Space Telescope.

A Near-Infrared Perspective on Disentangling AGN from Shocks and Uncovering Other Elusive AGN

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AGN and starbursts are the dominant power engines in the nuclei of infrared luminous systems, particularly in the local universe where they are often fueled by the influx of gas into the center through merger mechanisms. A powerful way to diagnose the ionizing sources is through a set of well-studied optical emission lines. However, significant contribution from shocks mimicking the line ratios for hard AGN ionization has come to light in recent years. The advanced optical tools used in these diagnostics encounter challenges at both physical and technical levels, e.g. shocks and other photoionization processes are difficult to discern using only optical lines, and that the nuclei of these merger systems are often dusty and optically thick. With high-resolution near-infrared integral-field observations taken with OSIRIS on Keck, I will demonstrate the power of near-infrared diagnostics such as H_2, Br g, and coronal lines (e.g. [Si VI]) in identifying and characterizing shocks as well as in distinguishing AGN in the obscured cases. We can employ similar techniques to reveal the presence of optically-elusive AGN. These tools and calibrations will become indispensable for understanding galaxy evolution as we enter the era of JWST and new infrared instruments on 30-meter class telescopes.

ALMA Molecular Line Observations as a Tool to Scrutinize Elusive Deeply Buried AGNs in Luminous Infrared Galaxies

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We present the results of our ALMA Cycle 0-4 observations of dusty luminous infrared galaxies (LIRGs) using dense gas tracers, HCN, HCO+, and HNC, at J=4-3 and 3-2. We aim to establish a reliable method to scrutinize elusive, deeply buried AGNs in the dusty LIRG population, based on molecular line flux ratios, at the dust-extinction-free (sub)millimeter wavelength range. We confirmed a trend that LIRGs with optically- or infrared-identified AGNs show higher HCN-to-HCO+ flux ratios at J=3-2 and J=4-3, than starburst-dominated LIRGs. Two LIRGs without infrared-identified AGNs show high observed HCN-to-HCO+ flux ratios, as seen in AGN-important galaxies, but our ALMA data suggest the presence of luminous infrared 14 micron continuum emitting energy sources (=AGNs) to vibrationally excite HCN/HNC to the v2=1f level by infrared radiative pumping. These LIRGs may contain extremely deeply buried AGNs which are still elusive in the infrared energy diagnostic methods, but first detected at the (sub)millimeter wavelength range, due to even lower dust extinction effects. An enhanced HCN abundance in molecular gas highly affected by AGN's radiation can explain the observational results, and is supported from our ALMA isotopologue molecular line observations. We also found that line-opacity-corrected intrinsic molecular line flux ratios can be an even more solid tool to unveil deeply buried AGNs in dusty LIRGs than observed ratios.

Mm/submm Energy Diagnostics in the ALMA Era

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Energy diagnostics at mm/submm can be vital to probe optically missed AGNs as these wavelengths do not suffer from dust extinctions. In this talk, I will first review our recent ALMA investigations of molecular diagnostics mainly using HCN and HCO+ pure-rotational lines. We suggested that HCN abundance is indeed enhanced in AGNs as compared to starburst (SB) environments at least by a factor of a few (likely >10), which can be a discriminator of AGNs and SBs. Radiative processes (i.e., XDRs) cannot solely reproduce the required abundance enhancements in AGNs. We may instead need to require mechanical heating induced by AGN jet and/or outflows to explain the HCN abundance enhancement, after taking into account the time-dependent nature of molecular chemistry as well. Hence, our HCN-based diagnostics may selectively identify AGNs with mechanical heating (i.e., those with significant “feedback” on the surrounding molecular environments). Next, I will introduce another, possible diagnostics at mm/submm regime that utilize atomic carbon emission lines. As X-ray photons much more efficiently dissociate CO molecules to C (or even ionise to C+) than UV photons, C/CO abundance ratio can be a robust, unbiased energy diagnostics. Indeed, chemical modelings proposed drastically higher C/CO ratio in XDRs than in PDRs (by a factor of ~1000). On the other hand, single-dish based observations have not shown such drastic [CI] intensity enhancement over 13CO intensity (both are optically thin, thus reflect abundance ratios) so far. This is likely due to the limited spatial resolutions of the past observations. I will thus summarize current (observational) understanding on this C/CO ratio, and discuss our strategy for high resolution interferometric observations provided with ALMA.

POSTER ABSTRACTS

Mid-IR Colors of Extreme Starbursts: Implications for JWST

Nick Abel
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Supermassive black holes (SMBHs) at the centers of galaxies, which manifest as active galactic nuclei (AGNs) when accreting, are now known to be a fundamental component of galaxies and play an important role in their evolution. Detecting complete samples of AGNs and understanding their connection to the properties of the host galaxies in which they reside has therefore been an extremely important goal of extragalactic astronomy.Over the past several decades, it has become clear that a large fraction of AGNs are missed in optical surveys due either to obscuration of the central engine, or contamination of the optical emission lines from star formation in the host galaxy.This is a significant deficiency, because these elusive AGNs are often found in key phases of galaxy evolution, such as late stage galaxy mergers, when the black hole is expected to grow most rapidly, or in low mass and bulgeless galaxies, a galaxy population that may place important constraints on models of SMBH 'seed' formation and merger-free models to SMBH growth. Mid-infrared color selection has been shown to be a powerful tool in uncovering optically hidden AGNs in a large population of galaxies. This is because the hard radiation field associated with AGNs can heat the dust to temperatures as high as the grain sublimation temperature, producing a strong mid-infrared continuum and an infrared spectral energy distribution (SED) that is clearly distinguishable from typical star forming galaxies that is independent of obscuration of the central engine. While the use of mid-infrared color selection in identifying powerful AGNs in which the AGN dominates over the stellar emission in the host galaxy is now on firm empirical ground, it is well-known that this method fails in galaxies in which the luminosity of the stellar emission from the host galaxy is comparable to the luminosity of the AGN.

In this work, we conduct a theoretical investigation of the mid-infrared spectral energy distribution produced by an extreme starburst. We employ an integrated modeling approach in which both the line and emergent continuum is predicted from gas exposed to the ionizing radiation from a young starburst and an AGN. We find that extreme starbursts can mimic AGNs in their mid-infrared colors under extreme ISM conditions. Since the star formation properties and ISM conditions become more extreme with increasing redshift, we discuss the implications of our work for AGN studies with JWST at high redshift.

Multiple Emission-Line Regions in the Nucleus of NGC 6744

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We present the analysis of a GMOS/IFU data cube of the nuclear region (5”x3.5”) of NGC 6744. This galaxy, located at 8.5 Mpc, is the brightest Milky Way twin in the southern sky. We detected four main emitting regions that have Seyfert and LINER characteristics; all emission lines are quite narrow (FWHM ~ 150 km/s). From stellar population synthesis, we also found that, although most of the stellar light comes from high metallicity old (12 Myr) population, this galaxy probably experienced a merger 1,3 billion years ago that generated a singular peak of stellar population of lower metallicity in the central part of the bulge.

Near-Infrared Spectroscopic Analysis of Galaxy Mergers: Revealing Obscured Accretion

Jason Ferguson
James Madison University

Galaxy interactions are ubiquitous and are believed to play a pivotal role in the formation and evolution of galaxies via facilitating gas inflows toward the central region of galaxies. These interactions are expected to trigger accretion of matter onto the central supermassive black holes, i.e., AGN activity. Nevertheless, despite decades of searching, observationally confirmed dual AGNs remain extremely rare. We present here a thorough near-infrared characterization of six examples of interacting galaxies with unambiguous confirmation of on-going mergers that are optically quiescent but have red mid-infrared colors that are associated with extragalactic sources with powerful AGN. We show Large Binocular Telescope spectra of nuclear regions that reveal a rich variety of emission and absorption features which allow us to explore several diagnostic tests for the AGN activity as well as for properties of the underlying stellar population. We find strong evidence for AGN emission in five out of these six interacting systems, which provides strong support for the efficiency with which the mid-infrared pre-selection technique finds dual AGN, and thus could exponentially increase the population of dual accretion systems in advanced mergers.

Hidden Black Hole Growth in Galaxy Mergers: Quantifying the Intrinsic Absorption Along the Merger Sequence

Erin Fierro
George Mason University

According to the current cold dark matter cosmological paradigm, galaxy interactions are an integral part of the cosmic history of galaxies and play a critical role in their evolution. Theory predicts that these interactions funnel gas toward the central regions of galaxies, potentially fueling nuclear star formation and triggering gas accretion onto the central supermassive black hole (SMBH). However, despite over three decades of extensive research, the observational merger-AGN connection is still a topic of vigorous debate. A major impediment that limits our ability to quantify the role of mergers in SMBH growth is that heavily obscured AGNs are not well-sampled by most previous studies, which are conducted at wavelengths sensitive to obscuration. In this work, we quantify the intrinsic absorption toward the AGNs in a sample of local mergers and study its dependence on merger stage.

Suzaku Observations of Moderately Obscured (Compton-thin) Active Galactic Nuclei Selected by Swift/BAT Hard X-ray Survey

Taiki Kawamuro
NAOJ

We report the results obtained by a systematic, broadband (0.5--150 keV) X-ray spectral analysis of moderately obscured (Compton-thin; 22 <= log N_H < 24$) active galactic nuclei (AGNs) observed with Suzaku and Swift/BAT. Our sample consists of 45 local AGNs at z < 0.1 with log L_14-195 keV > 42 detected in the Swift/BAT 70-month survey, whose Suzaku archival data are available as of 2015 December. The high signal-to-noise ratio spectra enable us to put strong constraints on the nucleus structures including the torus and the surrounding gas responsible for the un-absorbed scattered emission. Then, we obtain the important results. (1) The ratio of the iron-Kα line at 6.4 keV to X-ray luminosity, a torus covering fraction indicator, shows significant anti-correlation with luminosity. (2) The averaged reflection strength derived from stacked spectra above 14 keV is larger in less luminous or highly obscured AGNs than in more luminous or lightly obscured objects, respectively. (3) The [O IV] 25.89 μm line to X-ray luminosity ratio is significantly smaller in AGNs with lower soft X-ray scattering fractions, suggesting that the [O IV] 25.89 μm luminosity underestimates the intrinsic power of an AGN buried in a small opening-angle torus.

Deep IFS View of Nuclei of Galaxies – the DIVING3D Project

Roberto Menezes
IAG - Universidade de Sao Paulo

Galactic nuclei are important regions of galaxies, as they may reveal information about the formation and evolution of these objects. We are conducting the Deep IFS View of Nuclei of Galaxies (DIVING3D) survey of the nuclear regions of all galaxies in the southern hemisphere brighter than B=12.0, which correspond to a total of 170 objects. The observations are being taken in the optical, with the Integral Field Unit (IFU) of the Gemini Multi-Object Spectrograph (GMOS) at the Gemini South telescope. The data cubes have a field of view of 5” x 3.5” and a spectral coverage of 4300 A to 7000 A. At this moment, 79% of the data have been obtained. We have four main scientific goals. (1) The analysis of the emission line properties of the nuclear spectra, with the classification of the nuclei as Seyferts and LINERs, both with narrow and broad Halpha emission, as well as H II regions or transitions objects. (2) The analysis of the emission line properties in the circumnuclear regions, with the search for structures consistent with gaseous disks and ionization cones as well as the determination of the probable ionization mechanisms responsible for the extended emission lines. (3) The analysis of the stellar kinematics around the nuclei, including, whenever possible, a dynamical modeling with the purpose of determining parameters like the stellar mass-to-light M/L ratios and the masses of the central supermassive black holes. (4) Stellar population archeology, using spectral synthesis, for the study of the chemical compositions and of the star formation histories in the central regions of the galaxies. In this talk, we will present the main aspects of this survey and also the preliminary results, obtained for the galaxies brighter than B=11.0.

Detection of Enhanced Mass-to-Light ratios in Low Mass Early-Type Galaxies: Evidence for Black holes?

Renuka Pechetti
University of Utah

Low mass early-type galaxies (ETGs) typically contain low mass BHs that are difficult to observe, and few dynamical BH mass measurements exist in these galaxies. Measurements of BHs in late-type galaxies show a large scatter in BH masses which either steepen the low mass end of the M- σ relationship or suggest a large scatter in this relationship. Discovery of black holes in low mass ETGs thus would help in constraining the scatter in M- σ relationship, which in turn would help in understanding the evolution of black holes with its galaxy properties. Here we take an indirect approach to measuring BHs, by seeing if we can infer their presence based on the measuring the central M/Ls of galaxies.

I will present the detection of a statistically significant enhancement in the central dynamical M/L of a sample of 28 low mass early type ATLAS3D galaxies that have a mass range $9.5<\log(M/M_{\odot})<10.5$. These central dynamical M/Ls are higher than dynamical M/Ls derived at larger radii and stellar population estimates of the galaxy centers in ~80% of galaxies. We exclude the galaxies with obvious dust emission and central color gradients. We use high resolution HST images to derive mass models for the galaxies in the central region and combine this with the central velocity dispersion values from ATLAS3D data to obtain these best-fit central dynamical M/L. We show that the enhancement in central M/L can be best described by a black hole model and present the BH masses for these galaxies. We also constrain the scatter in M- σ relationship in the lower mass end based on Monte-Carlo simulations and the detected BH masses which is found to be < 1 dex. Finally, we present the simulations that show the possibility of these low mass ETGs acting as the progenitors for Ultra Compact dwarf galaxies (UCDs). This provides new insights into the theory that UCDs can be considered as tidally stripped remnants of low mass ETGs.

In Search Of Tiny Giants: Finding Supermassive Black Holes In Low Mass Galaxies

Ryan Pfeifle
George Mason University

Most, if not all, massive galaxies have a central supermassive black hole (SMBH) with a mass of up to 1 billion times the mass of the Sun. While the properties of SMBHs and their host galaxies have been well-studied in massive galaxies, very few SMBHs have been found in galaxies with low masses and those with small bulges. This is a significant deficiency since the study of this population allows us to gain an understanding of merger-free pathways to black hole growth, and to gain insight into the origin and growth efficiency of SMBH seeds, thought to have formed at high redshift. Most studies aimed at finding SMBHs have been conducted using optical spectroscopic studies, where active SMBHs (active galactic nuclei or AGNs) display distinctive optical emission lines indicative of accreting SMBHs. However, in low mass galaxies, the SMBHs will likely be less massive. As the black hole masses decreases, the Schwartzchild radius of the black hole decreases, and in response, the temperature of the surrounding accretion disk increases. The shape of the ionizing radiation field therefore changes with black hole mass, potentially affecting the optical spectroscopic signatures generally associated with AGNs. In this work, we investigate the effect of black hole mass on the emission line spectrum from AGNs, with a particular focus on the emission lines accessible by JWST.

A Stochastic Semi-analytic Model for SMBH Growth

Angelo Ricarte
Yale University

How and when AGN are fueled remain an open area of research. I discuss a semi-analytic model of SMBH growth in which AGN are fueled stochastically. Each SMBH random walks through an Eddington ratio distribution, occasionally bumped to high values via major mergers. I attempt to recreate the SMBH mass function and luminosity functions by tuning two parameters: the step size of this random walk, and the degree of ``flickering'' on sub-Myr time scales. I also explore consequences for the evolution of the M-sigma relation. I find that this model over-produces lower-luminosity AGN at high-redshift, suggesting that an additional component is necessary to prevent these lower-mass SMBHs from becoming AGN.

AGNfitter: An MCMC Approach to Fitting SEDs of Obscured and Unobscured AGN

Gabriela Calistro Rivera
Leiden Observatory

I will present AGNfitter: a tool to robustly disentangle the physical processes responsible for the emission of active galactic nuclei (AGN). AGNfitter is the first open-source algorithm based on a Markov Chain Monte Carlo method to fit the spectral energy distributions of AGN from the sub-mm to the UV. I will describe the relevance and the technicalities of the code, and show its capabilities in the context of obscured and unobscured AGN from the XMM–COSMOS survey.
The code makes use of a large library of theoretical, empirical, and semi-empirical models to characterise both the host galaxy and the nuclear emission simultaneously. The model consists in four physical components comprising stellar populations, cold dust distributions in star forming regions, accretion disk, and hot dust torus emissions. AGNfitter is well suited to infer numerous parameters that rule the physics of AGN with a proper handling of their confidence levels through the sampling and assumptions-free calculation of their posterior probability distributions.
The analysed data comprehend a sample of 714 X–ray selected AGN of the XMM–COSMOS survey, spectroscopically classified as Type1 and Type2 sources by their optical emission lines. The inference of variate independent obscuration parameters allows AGNfitter to find a classification strategy with great agreement with the spectroscopical classification for ~ 86% and ~ 70% for the Type1 and Type2 AGNs respectively. The variety and large number of physical properties inferred by AGNfitter has the potential of contributing to a wide scope of science-cases related to both obscured and unobscured AGN studies.

Theoretical Re-evaluations of Scaling Relations Between SMBHs and Their Host Galaxies

Hikari Shirakata
Hokkaido University

We present scaling relations between SMBHs and their host galaxies obtained from a semi-analytic model of galaxy formation combined with large cosmological N-body simulations. First, we explore the effect of varying the mass of a seed black hole on the resulting black hole mass -- bulge mass relation at z ~ 0. When the mass of the seed is set at 10^5 M_sun, we find that the model results become inconsistent with recent observational results of the black hole mass -- bulge mass relation for dwarf galaxies. On the other hand, when we employ seed black holes of $10^3 M_\odot$ or select their mass randomly within a 10^{3--5} M_sun range, the resulting relation is consistent with observational results including the dispersion. We also find that black hole mass -- bulge mass relations for less massive bulges at z ~ 0 put stronger constraints on the seed BH mass than the relations at higher redshifts. Second, we present the galactic stellar age -- velocity dispersion relation. We divide galaxies into two populations: galaxies which have over-massive/under-massive BHs against the best-fitting BH mass -- velocity dispersion relation. We find that galaxies with an over-massive BH have older stellar age. This result is consistent with observational results obtained from Martin-Navarro et al. (2016) and Merrifield et al. (2000). We also find that to obtain this result, AGN feedback is one of the key processes; without the AGN feedback, galaxies with larger velocity dispersion have younger stellar age.

Combining Radio and Optical Data to Gauge the Cosmic Evolution of Galaxies

Jesse Swan
University of Tasmania

The third data release from the Australia Telescope Large Area Survey (ATLAS) provides access to deep 1.4 GHz observations. Over the total 6.3 deg2 sky area of Chandra Deep Field South (CDFS), and European Large Area ISO Survey South 1 (ELAIS-S1). ATLAS reaches sensitivities of between 14 and 17 μJy beam−1. Using Spitzer infrared detections as an intermediary, these 5118 5σ radio detections are robustly combined with over 1300 targeted spectroscopic redshifts obtained via the OzDES program; and a further 767 redshifts available from literature. With these data, we are probing lower radio luminosities to more broadly gauge the cosmic evolution of galaxy density and luminosity.

Suzaku Observations of Compton-thick Active Galactic Nuclei Selected by Swift/BAT Hard X-ray Survey

Atsushi Tanimoto
Kyoto University

To reveal the nature of Compton-thick (log NH > 24 cm^-2) Active Galactic Nuclei (CTAGNs) is an important, yet unresolved issue in modern astronomy. We present a uniform X-ray broadband (0.5-100 keV) spectral analysis of 11 Swift/Burst Alert Telescope (BAT) selected CTAGNs observed with Suzaku. We fit the Suzaku and Swift/BAT spectra with models utilizing an analytic reflection code and those utilizing the Monte Carlo based model from an AGN torus by Ikeda et al. (2009). The main results are as follows. (1) An estimated intrinsic luminosity of a CTAGN strongly depends on the model: applying Compton scattering to the transmitted component in an analytic model may largely overestimates the intrinsic luminosity at large column densities. (2) Most of CTAGNs show small scattering fractions (< 0.5 %) implying the buried AGN nature. (3) Unabsorbed reflection components are commonly observed, suggesting that the tori are clumpy. (4) Comparison with the results of Compton-thin AGNs (Kawamuro et al. 2016a) suggests that the properties of these CTAGNs can be understood as a smooth extension from Compton-thin AGNs wth heavier obscuration: we find no evidence that they are distinct populations from less obscured AGNs.

The Clustering of Photometrically Selected High-z Quasars

John Timlin
Drexel University

We present the data from the Spitzer IRAC Equatorial Survey (SpIES) along with our first high-redshift (2.9<z<5) quasar clustering results using these data. SpIES is a mid-infrared survey covering ~100 square degrees of the Sloan Digital Sky Survey (SDSS) Stripe 82 (S82) field. The SpIES field is optimally located to overlap with the optical data from SDSS and to complement the area of the pre-existing Spitzer data from the Spitzer-HETDEX Exploratory Large-area (SHELA) survey, which adds ~30 square degrees of infrared coverage on S82. SpIES probes magnitudes significantly fainter than WISE; depth which is crucial to detect faint, high-redshift quasars. Using the infrared data from SpIES and SHELA, and the deep optical data from SDSS, we employ multi-dimensional machine learning selection algorithms to identify ~9000 high-redshift quasar candidates in this field, and estimate their photometric redshifts. We then combine these candidates with spectroscopically confirmed high-redshift quasars and measure the redshift space correlation function and the projected correlation function. Finally, using these results, we estimate the linear bias to try to constrain quasar feedback models akin to those in Hopkins et al. 2007.

Are Narrow Line Seyfert 1 Galaxies Highly Accreting AGNs with Low Mass Black Holes?

James K. Williams, Mario Gliozzi, and Ross Rudzinsky
George Mason University

It has been suggested that NLS1s are AGNs in their early phase, characterized by relatively small black hole masses and very high accretion rates, and hence may represent a key AGN class to investigate the growth of supermassive BHs. However, the standard application to NLS1s of optically based methods to determine the BH mass has been questioned on the basis that highly accreting objects produce large amounts of radiation pressure that partially counteracts the action of the BH gravitational pull, leading to values of BH mass that are systematically underestimated. In this work, we apply a novel X-ray scaling method, which is independent of any assumption on the optical emitting line region and accretion rate of the source, to determine the mass of a sample of NLS1s and compare its BH mass distribution to that of a sample of broad line Seyfert galaxies of similar X-ray properties.

Nustar Observations of Heavily Obscured Quasars Selected by WISE

Wei Yan
Dartmouth College

A key goal of the NuSTAR program is to find and characterize heavily obscured quasars, luminous accreting supermassive black holes hidden by gas and dust. Based on mid-infrared(IR) photometry from Wide-field Infrared Survey Explorer (WISE) and Sloan Digital Sky Surveys (SDSS), we have selected a large population of obscured quasars; here we report NuSTAR observations of four WISE-selected heavily obscured quasars for which we have optical spectroscopy from SALT. Three out of four objects are too faint to be detected with Nuclear Spectroscopic Telescope Array (NuSTAR), while the other has only a marginal detection. From the upper limit and net counts of our X-ray observations in different bands, we conrm that our objects are luminous quasars with observed hard X-ray (10-40 keV) luminosities at or below~10^43 erg s^-1. Below this order of magnitude is what would be expected, based on the observed mid-IR luminosity, for typical unobscured quasars. We find corresponding gas column densities N_H to be around 10^25 cm^-2, confirming that WISE and optical selection can identify very heavily obscured quasars that may be missed in X-ray surveys.

Radiation Hydrodynamics of Dust-Driven Galactic Winds

Dong Zhang
The University of Virginia

Galactic winds are ubiquitous in most rapidly star-forming galaxies. They are crucial to the process of galaxy formation and evolution, regulating star formation, shaping the stellar mass function and the mass-metallicity relation, and enriching the intergalactic medium with metals. Although important, the physics of galactic winds is still unclear. Many theoretical mechanisms have been proposed. Winds may be driven by the heating of the interstellar medium by overlapping supernovae explosions, or the radiation pressure by continuum absorption and scattering of starlight on dust grains. In this talk I will focus on molecular outflows driven by radiation pressure on dust. I will present radiation hydrodynamic simulations of momentum coupling between dusty gas and radiation field in a rapidly star-forming environment. In contrast to previous work using flux-limited diffusion algorithm, we apply the variable Eddington tensor algorithm which shows stronger momentum coupling between gas and radiation. The momentum transfer from the radiation field to the gas is not merely ~ L/c, but amplified by a factor of 1 + \eta \tau_IR, where L and \tau_IR are the radiation luminosity and the integrated infrared optical depth through the system, and \eta ~ 0.5 − 0.9. I will also talk about our recent hydrodynamic simulations of molecular cloud acceleration due to radiation force. We find that radiation pressure may be an important mechanism for driving winds in rapidly star-forming galaxies and starbursts.