'The Origin and Growth of Supermassive Black Holes (SMB)' Abstracts

Talks

Semi-empirical constraints on the high-z SMBH population and the implications for their early evolution.

Authors

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Abstract

JWST observations have unveiled a numerous population of low-luminosity active galactic nuclei (AGN) at $4 \lesssim z \lesssim 10$, many of which have masses orders of magnitude above the local black hole mass--stellar mass ($M_{\rm BH} - M_{*}$) scaling relations. These high-z measurements question the consistency of this previously unobserved population with our understanding of supermassive black hole (SMBH) evolution at both earlier and later times.
In this talk, I will present our findings on the consistency of these observations within a data-driven framework which connects the galaxy stellar mass function to the SMBH mass function and AGN luminosity functions via different $M_{\rm BH} - M_{*}$ relations and the observed Eddington-ratio distribution. By jointly matching the observed active SMBH mass functions and AGN luminosity functions at $z \sim 5.5$, we find that observations permit two broad classes of solutions: either highly-elevated $M_{\rm BH} - M_{*}$ relations paired with low duty cycles, or more moderate relations with higher duty cycles. Through applying the Sołtan argument and continuity-equation modelling, we find that the latter is favoured, but that the former cannot be robustly ruled out with current data.
I will then present our latest results, where we further test and expand on these findings by modelling the SMBH population and their host galaxies from $z = 10$ to present day within the semi-empirical model DECODE, enabling us to examine the conditions necessary to reproduce the AGN population observed by JWST at $z \sim 5 – 6$, while also tracking their evolution at both earlier and later times for each viable scenario. We compare the SMBH mass function, SMBH-galaxy scaling relations, and AGN clustering from each scenario, finding the $z \sim 0$ predictions to be broadly consistent, but with distinct evolutionary pathways and merger contributions, which has implications for the gravitational wave background. Future wide-field clustering and demographic studies will help break the remaining degeneracies.

Extreme AGN variability as a probe of SMBH growth

Authors

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Abstract

The process of accretion onto supermassive black holes is inherently stochastic, which is reflected in photometric variability seen in Active Galactic Nuclei (AGN). However, recent multi-epoch spectroscopic observations have uncovered a population of extremely variable AGN where Balmer emission from the broad line region is observed to appear or disappear on relatively short timescales. Such AGN have been called 'changing-state' AGN as in many cases the variability cannot be ascribed to variable obscuration and instead must be due to changes in the structure of the accretion disk and broad line region.

I will present results from the first systematic mutli-wavelength search for changing-state AGN, where we have contemporaneous 14-195 keV X-ray monitoring from Swift-BAT for a sample of 412 local AGN with multiple epochs of spectroscopic data. This ultra-hard X-ray band is less affected by obscuration, and changes in the 14-195 keV band confirm that the majority of our changing-state events must be due to changes in the structure of the accretion disk which feeds the SMBH.

I will conclude by looking to the future with the Rubin Observatory's LSST, and discuss the opportunities and challenges to better understand SMBH growth with the next generation of variability surveys.

Direct observation of supermassive black hole binaries with spaceborne VLBI

Authors

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Abstract

The Black Hole Explorer (BHEX) is a proposed spaceborne extension to ground-based VLBI arrays. Achieving the finest angular resolution in history, BHEX aims to detect the photon rings in M87* and Sgr A*, as well as perform supermassive black hole demographics and relativistic jet studies. Alongside the improved sensitivity of future ground-based arrays, such as the next-generation Event Horizon Telescope (ngEHT), BHEX raises the possibility of directly observing sub-parsec supermassive black hole binaries (SMBHBs).

A resolving observation of a sub-parsec SMBHB would be the first of its kind. As sources of gravitational waves, SMBHBs are expected to form in the process of galactic mergers. Characterising a population of supermassive binaries would enable evolutionary models to be constrained across the SMBHB lifecycle and improve predictions for the gravitational-wave background, thereby breaking model degeneracies.

Using a toy image model and synthetic data simulations, we find that BHEX and ngEHT binary detection requires a total source flux density of > 40 mJy, and a minimum angular separation of 2 μas. With only three annual observations, BHEX could constrain the semi-major axis and eccentricity of binaries with orbital periods < 10 years to within 0.06 dex. The observable parameter space in terms of total mass, mass ratio, orbital properties and redshift is also explored using a sub-millimetre, spectral energy distribution model. Finally, we propose a method for the identification of candidate sources in time for BHEX's launch. BHEX would make a powerful addition to multi-messenger astronomy, with strong synergies with gravitational-wave observatories. Direct observations of a sub-parsec SMBHB would be a major achievement given its relevance to some of the most important, ongoing research in astrophysics.

The low-metal Cliff - A path to understanding black hole growth in low-metallicity systems

Authors

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Abstract

The James Webb Space Telescope (JWST) has revealed a large population of massive black holes (BHs) in the early Universe with a variety of unusual properties, including v-shaped SEDs, compactness and optical redness. These findings have prompted the development of new models of BH formation and growth, and raised significant questions regarding black hole-galaxy co-evolution. An observational approach is key to understanding which models are realistic and for identifying key co-evolution mechanisms. In this talk, I report the findings from recent high-resolution JWST/NIRSpec-IFS observations of The Cliff, a Little Red Dot (LRD) at z~3.5 first identified and characterised in the RUBIES survey (de Graaff+25). With these new observations, we detect narrow [OIII]4959,5007 emission which was unresolved by earlier JWST PRISM and medium-resolution observations, and find the weakness of [OIII]5007 relative to narrow Hbeta is indicative of low metallicity in the host galaxy (Z < 0.1 ZSun). This low-metal hypothesis is confirmed by the non-detection of low-ionisation lines such as [NII]6548,6583, and I will discuss why other explanations for [OIII]5007 suppression (such as high density or peculiar ionisation scenarios) may be excluded. I will show that the observed properties of the Cliff, including its overmassive black hole, can be reproduced by some simulations of black hole growth and evolution down to z~3.5 (AESOPICA, Koudmani+in prep.). However, these simulation runs require high seed masses (10^4 - 10^5 MSun) and appear as rarely in the simulation volume as in the 3<z<4 RUBIES survey volume, highlighting The Cliff as a rare system even under the most conservative estimates of BH mass. I will place the Cliff in the context of the mass-metallicity relation (MZR) at 3<z<4 and discuss whether objects such as the Cliff, including local LRDs, pose a source of tension between the MZR and local Mbh-M* relations. Finally, I will evaluate how future simulations and numerical models can help to uncover how systems such as The Cliff manage to both grow massive black holes and remain so metal-poor across cosmic time.

Bar-driven supermassive black hole growth

Authors

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Abstract

Whilst mergers are known to be able to trigger and fuel active galactic nuclei (AGN), thus contributing to the growth of supermassive black holes (SMBHs), simulations have shown that they are only responsible for around 15 to 35 percent of SMBH growth since z=3. The main drivers of SMBH growth remain elusive. Since elliptical galaxies and/or bulges in disk galaxies are an inevitable result of a merger, we can examine merger-free growth by examining disk-dominated galaxies. Recent works have pointed toward large-scale galactic bars as a promising method of triggering AGN, since they can redistribute angular momentum, and drive gas towards the centre of a disk, where it can be accreted onto a black hole. We present a sample of 92 luminous, Type 1 (unobscured) AGN imaged in HST with robust 2D parametric fitting by GALFIT. By quantifying galactic bar strength using the axis ratio and luminosity of the bar compared to the host, we investigate how the presence and strength of a bar affects the AGN properties, including black hole mass and bolometric luminosity. We find that whilst according to the literature, the presence of a bar does lead to a higher likelihood of their being an AGN, stronger bars do not necessarily mean a higher black hole mass or bolometric luminosity than weaker bars. This indicates that bars can cause an AGN to switch on, but are not then responsible for fuelling the AGN.

TiDES-RM: Status Updates on the Time-Domain Extragalactic Survey Reverberation Mapping Program

Authors

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Abstract

The Time-Domain Extragalactic Survey Reverberation Mapping program (TiDES-RM) is a dedicated spectroscopic monitoring campaign with the 4-metre Multi-Object Spectroscopic Telescope (4MOST). TiDES-RM will monitor four LSST deep-drilling fields for at least five years starting in 2026, with a typical cadence of 10–14 days. Combining 4MOST spectroscopy (R~4000) with high-cadence LSST photometry, TiDES-RM is designed to measure multi-line reverberation lags and black hole masses for a sample of ~950 broad-line AGNs over 0.1 < z < 3.5. These data will enable improved single-epoch black hole mass estimators, constraints on BLR kinematics, and tests of the evolution of black hole–host scaling relations across cosmic time. In this talk, I will summarize the program design and sample characterization, present the current observing status, and highlight some of the key science topics that Tides-RM will be working on.

Statistical evidence for supermassive black hole recoils in active galactic nuclei

Authors

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Abstract

Supermassive black hole (SMBH) mergers are expected to produce recoil kicks due to anisotropic gravitational-wave emission. This can result in a subpopulation of active galactic nuclei with spatial and/or velocity offsets with respect to their host galaxies, but individual candidates remain difficult to confirm due to degeneracies with alternative astrophysical scenarios. Here we present evidence for a population-level signature of SMBH recoil. Using a sample of ~100,000 quasars from the SDSS DR16 catalogue, we identify a statistically significant positive correlation between dust reddening and the absolute line-of-sight velocity offset of the broad-line region relative to the host galaxy. We estimate velocity offsets from the difference between broad H beta redshifts and noise-weighted systemic redshifts derived from narrow lines, and adopt the redshift-relative (g–i) colour excess as a proxy for dust reddening. We interpret this correlation as a natural consequence of recoil dynamics: a recoiling SMBHB's velocity is largest when it is closest to the galactic centre, where lines of sight are more likely to intersect dense dust columns. While alternative explanations must be explored, our results suggest that statistical signatures in large quasar samples can provide indirect evidence for recoiling SMBHs. If confirmed, this approach opens a new avenue for constraining SMBH merger rates, recoil velocity distributions, and active galactic nuclei structure, with implications for understanding SMBH growth and assembly across cosmic time.

Exploring the accretion, jet and host connection for X-ray- and radio-selected AGN

Authors

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Abstract

An X-ray and/or radio detection of an extragalactic sources is a strong indication of the presence of an active galactic nuclei (AGN). Previous studies have shown that there is a 'Fundamental plane of black hole activity' that links the accretion disk and a relativistic jet in an AGN, traced by X-ray and radio emission, respectively. We take a sample of 1544 X-ray and radio detected sources in the Bootes and COSMOS fields and investigate the X-ray-radio luminosity correlation across different redshift bins, from which we find that an apparent correlation is introduced due to the sensitivity limits of the surveys. We explore the coupling between accretion, traced by X-rays, and the jet ,traced by radio, by measuring the multi-dimensional X-ray–radio luminosity function across redshift ($0 < z < 6$), from which we find a wide range of radio luminosities associated with a given X-ray luminosity, and vice versa, indicating little direct connection between the emission processes. We study how often jets form in accreting AGN across the population and find that towards the highest X-ray and radio luminosities the fraction of sources with both an X-ray and radio detection increases towards 100%, indicating that at the highest luminosities we are more likely to obtain a detection in both bands, though the source will not necessarily be bright in both bands. Thus, the most luminous accretion events are more likely to be associated with the production of a jet, despite the distinct physical structures that produce the emission and likely persist over very different timescales.

Further to this, we expanded the sample to include eROSITA data and have measured host stellar masses of X-ray and/or radio detected AGN via SED fitting with CIGALE and GRAHSP. Using these masses as a proxy for black hole mass, we look at how black hole mass varies with X-ray and radio luminosity across cosmic time for these X-ray and radio sources, to ascertain how black hole mass affects accretion and jet power.

Spacetime measurement using black hole photon rings

Authors

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Abstract

Event Horizon Telescope observations have provided unprecedented insights into black hole astrophysics and strong-field gravity. A central goal of future space-based VLBI missions is the detection of photon rings in M87* and Sgr A*. This talk will uncover how the black hole photon ring encodes critical insights into spacetime geometry, revealing new avenues for testing fundamental physics. I will show that their observable structure enables robust constraints on black hole parameters and potential deviations from the Kerr paradigm in the extreme-field regime.

[Ne V] Coronal Line Emission as a Probe of Black Hole Mass and Nuclear Conditions in AGN

Authors

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Abstract

Coronal lines, such as [Ne V], originate in the highly ionized gas of active galactic nuclei (AGN) and provide a unique window into the physical conditions of the nuclear environment. In this work, we investigate the relationship between [Ne V] emission properties and black hole mass in a sample of nearby AGN with a range of black hole masses. We focus on the [Ne V] flux and line ratios as tracers of the ionizing continuum and gas density in the coronal line region.

We find a statistically significant correlation between [Ne V] emission strength and black hole mass, suggesting a link where the black hole mass sets the shape of ionizing continuum that produces the observed coronal lines.

Our results highlight the potential of [Ne V] as a diagnostic of the ionising continuum of AGN, with implications for using coronal lines as indirect tracers of black hole properties in systems where traditional methods are not feasible.

Investigating the structure and accretion of the AGN NGC 4151, focussing on timescale-dependent reverberation signals.

Authors

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Abstract

We performed an intensive multi-wavelength monitoring campaign of NGC 4151 from 28 October 2024 to 5 May 2025. We collected photometric data in the X-ray, UV, optical, and infrared using Swift, Las Cumbres Observatory, Zowada Observatory, Liverpool Telescope, and Wise Observatory.

We investigated how the time delays between variability observed in different wavebands depend on the temporal frequency of the variations. These are our timescale-dependent reverberation signals. We applied two complementary methods, one in the time domain and the other in the frequency domain. This allowed us to study the accretion disc as well as extended reprocessing regions, such as the broad line region (BLR) and winds.

As expected, at short timescales we observe small lags, which are broadly consistent with standard accretion disc predictions. If the reprocessing structure was composed of a finite disc and no extended component, the lags would be expected to flatten at longer timescales. However, we find that, for almost all wavebands, the lags increase as we increase the timescales probed, suggesting that an extended reprocessing component must be present.

We obtained the BLR fraction in each waveband. These show an increase in BLR contribution at the Balmer jump, followed by a decrease after the jump, and then a rise and plateau round the Paschen jump and the H-alpha emission line.

When investigating the X-rays against UVW2, we find a very weak correlation for short X-ray leading lags. We find a more significant correlation for UV leading the X-rays by 34 days.

To extend on this, we will investigate whether the spectral energy distribution depends on the variability timescale probed. We will derive a mass accretion rate from the SEDs, which can be compared to the value found independently from the lag spectrum.

3D Hydrodynamical Simulations of Misaligned Circumbinary Disks Around SMBH Binaries

Authors

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Abstract

Within the ΛCDM paradigm, galaxies grow hierarchically through mergers. When merging galaxies host central supermassive black holes (SMBHs), they naturally form SMBH pairs on kiloparsec scales. Their subsequent orbital evolution is governed by processes that extract energy and angular momentum, ultimately driving the binary toward coalescence. While SMBH binary formation is a natural consequence of galaxy assembly, merger requires the binary to shrink by several orders of magnitude through interactions with stars and gas in the galactic nucleus—a challenge often encapsulated by the long-standing final parsec problem.

In gas-rich mergers, large-scale inflows can funnel gas into the nuclear region, where it settles into a circumbinary disk (CBD) that mediates angular momentum exchange with the binary. The disk structure and, in particular, its orientation relative to the binary orbital plane can profoundly influence the system's evolution, determining whether the disk and binary co- or counter-align and thereby affecting accretion, orbital decay, and merger timescales. Because accretion in galactic nuclei is likely chaotic and episodic, misaligned configurations may be common. Their evolution is analogous to Lense–Thirring precession in tilted disks around spinning black holes, with the binary orbital angular momentum replacing the spin vector and driving warps in the surrounding disk.

In this talk, I will review the key evolutionary stages of SMBH binaries and present preliminary results from ongoing high-resolution 3D hydrodynamical simulations of misaligned circumbinary disks. I will discuss how misalignment shapes binary–disk alignment, disk warping, and orbital evolution, and highlight the implications for the distinct electromagnetic and gravitational-wave signatures expected from these systems. Accurately modeling their coupled gas–binary dynamics is essential for predicting and interpreting future multi-messenger observations, particularly in the era of LISA.

Galaxy discs regulate the growth of supermassive black holes

Authors

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Abstract

We examine the relationship between the mass of present-day central supermassive black holes (SMBHs, MBH), and the stellar mass (M⋆) and halo mass (M200) of their host galaxies in the EAGLE simulation, and find that scatter about these relations correlates with both halo structure and galaxy morphology. EAGLE reproduces the observed MBH − M⋆ relation, including (qualitatively) its dependence on morphology: at fixed M⋆, disc-dominated galaxies host less massive SMBHs than ellipticals. We show that MBH correlates with M200, as expected if SMBHs are regulated by processes acting on the scale of the host dark matter halo, but exhibits a tighter correlation with the halo binding energy (E_bind), signalling that this quantity, which encodes information about both halo mass and halo structure, is more fundamental to MBH. As with MBH − M⋆, scatter about the MBH − E_bind relation is strongly correlated with morphology. Gas in the central few parsecs of galaxies with present-day discs retains strong rotational support as the galaxy grows, inhibiting inward transport and precluding periods of rapid SMBH growth by gas accretion. In galaxies destined to be present-day ellipticals, however, this rotational support is disrupted, enabling gas to be funnelled onto the central SMBH, triggering rapid growth. Evolution of the mass fraction of stars formed ex-situ indicates that this disruption is caused by galaxy-galaxy interactions and mergers. Our findings corroborate the conclusion of recent studies, based on controlled simulations of an ∼L⋆ galaxy, that prolonged secular galaxy evolution inhibits central SMBH growth.

Inferring massive black hole's origin and growth with multimessenger observation from extreme mass ratio inspirals and tidally disruptive event observations

Authors

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Abstract

Massive black holes (MBHs) residing in galactic centers are ubiquitous throughout the Universe, yet their formation pathways and subsequent evolution remain poorly understood. The dynamics of the compact objects and stars in the vicinity of the MBH are governed by the MBH's strong gravitational potential. From these environments, tidally disrupted stars (tidal disruption events; TDEs) and inspiralling compact objects (extreme mass ratio inspirals; EMRIs) can reveal MBH properties through electromagnetic and gravitational radiation. Although coincident TDE-EMRI detections for the same MBH will be rare to identify, combining gravitational wave observations from EMRIs and electromagnetic observations from TDEs across the entire MBH population can efficaciously uncover the demography and evolution of MBHs. In this work, we introduce a novel multi-messenger framework that combines EMRI and TDE observations to jointly constrain the MBH population. We work with a population model in which the dynamics of stars and compact objects in the nuclear star cluster are governed by a two-dimensional Fokker-Planck equation. Our results show that combining EMRI and TDE populations provides stronger constraints on MBH demographics than using a single observation type alone. EMRI and TDE observations offer complementary insights that, when combined, reveal new details on the MBH growth and evolution that neither messenger can provide separately.

Everything you ever wanted to do with null-geodesics of the Kerr exterior

Authors

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Abstract

Null-geodesics are the trajectories of photons in general relativity, and are distorted from straight line paths by gravity. For spinning (Kerr) black holes, the spacetime curvature effects are dramatic, enhancing the light travel time -- observed in e.g. X-ray reverberation features -- or modifying photon energetics due to the gravitational redshift -- attributed to the red-wing in (reflection) lineprofiles. All radiative processes ultimately must transport photons from the emitter to the observer, and so null geodesics are fundamental in spectral, timing, and polarimetry modelling of emission from the regions closest to the black hole. kerrz is a new, public, fast, and general purpose library for calculating photon trajectories in the Kerr exterior that can be easily embedded into spectral models to perform all ray tracing operations on the fly. It provides simple interfaces for convolving disc spectra with the curvature effects, for calculating (time-dependent) emissivity profiles of extended coronal geometries, creating polarimetric images, impulse responses, and much more. kerrz does everything you ever wanted to do with null-geodesics of the Kerr exterior!

A novel sub-grid model for super-Eddington accretion of spinning black holes in galaxy-scale simulations

Authors

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Abstract

Super-Eddington accretion has been proposed to explain the existence of black holes (BHs) with masses exceeding a billion solar masses within the first billion years after the Big Bang. We present a novel accretion disc-based sub-grid model for BH mass and spin evolution in the super-Eddington regime, implemented in the hydrodynamics code GIZMO. In our model, motivated by results of radiation-hydrodynamics simulations of accretion discs, the growth of the BH is mediated by a sub-grid accretion disc, comprising an inner photon-trapping region described by simulation-based fitting formulae and an outer thin α-disc with three regions. We incorporate a self-consistent spin evolution prescription that transitions between the Bardeen-Petterson effect and inner thick-disc precession, depending on the accretion rate. We perform a suite of idealised simulations of a BH embedded in a gaseous circumnuclear disc and a spherically distributed stellar component to explore the conditions under which super-Eddington accretion can be sustained in the environment of a realistic galactic nucleus. Simulations with misaligned gas inflows onto an initially aligned BH-disc system yield very high Eddington ratios, triggered by the rapid removal of disc angular momentum via inflows. These results highlight the importance of angular momentum misalignment in enabling super-Eddington accretion and suggest that such episodes are difficult to trigger unless the system resides in a highly dynamical environment -- a condition more likely to occur in high-redshift galaxies. Our model potentially provides a way to grow moderate-mass BH seeds to the sizes required to explain the bright high-redshift quasars. We have also implemented this model in the hydrodynamics code mini-RAMSES and will further explore its implications in combination with the newly developed DRAGON feedback model.

How Do the First Supermassive Black Holes Grow? Predictions for JWST from Simulations

Authors

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Abstract

The discovery of hundreds of quasars at z >= 6 hosting billion-solar-mass black holes within the first Gyr poses a significant challenge to models of black hole growth. Reconciling their rapid assembly with the effects of feedback remains a key open problem, particularly given tensions between high-redshift observations and established low-redshift black hole-galaxy scaling relations.

I present cosmological zoom-in simulations exploring black hole growth under different accretion sub-grid models, including Eddington-limited Bondi-Hoyle accretion, super-Eddington growth, and a modified model that enhances early accretion. I show that while super-Eddington accretion naturally arises in standard Bondi-Hoyle models, it is suppressed in modified prescriptions that instead promote rapid early growth, even when super-Eddington rates are permitted. These models produce significantly different evolutionary pathways, highlighting the need to revisit commonly used sub-grid prescriptions.

I further show that the stellar component of quasar host galaxies differs markedly between these scenarios, raising the possibility that upcoming James Webb Space Telescope observations can distinguish between black hole growth pathways. To explore this, I generate synthetic NIRCam images of quasar host galaxies and examine how observational effects, such as PSF subtraction, impact host recovery and inferred galaxy properties. These results demonstrate that observational systematics can significantly affect constraints on the black hole-host relation at high redshift.

Multi-Wavelength AGN Identification and Physical Parameter Estimation using machine learning in DESI survey.

Authors

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Abstract

Active Galactic Nuclei (AGN) play a key role in galaxy evolution, but identifying a complete, unbiased sample is complicated because it requires extensive, multi-wavelength detections. To address this, we apply a machine learning framework to the Dark Energy Spectroscopic Instrument (DESI) survey, utilizing the available rest-frame UV and optical range (3600–9800 Å) to leverage established, precise AGN classification methods.

Our methodology employs SPENDER, an unsupervised machine learning framework, to compress galaxy spectra into a multi-dimensional latent space. Using a classifier algorithm on a curated, balanced and diverse sample of galaxy spectra—spanning $0 < z < 3.5$, our framework achieves an AGN detection rate exceeding 75%. By analyzing the topology of the latent space, we isolate the specific spectral features driving classification and examine AGN co-evolutionary tracks that are typically obscured in standard projections. Furthermore, we perform traversals of the latent space, stacking spectra within local neighborhoods to study the transition of galaxy properties across different types of galaxies in our dataset. This process helps us understand the regions of confusion/misclassification with the classification algorithms, as the latent representation captures complex, non-linear behaviour of galaxy spectra.

Finally, we employ a Bayesian inference pipeline that maps the purely mathematical latent space to fundamental physical spectral properties, such as stellar mass, metallicity, age, and other parameters, derived from DESI survey. This approach serves as a high-speed, scalable infrastructure alternative to the traditional Spectral Energy Distribution (SED) fitting. Such an efficient methodology makes it suitable for the massive datasets anticipated in future DESI, and other wide-area spectroscopic surveys.

Posters

Reflection fractions for thick-disc geometries

Authors

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Abstract

X-ray reflection features from the innermost regions of the accretion flow serve as a tracer for the spins of (supermassive) black holes. The reflection fraction, defined as the ratio of reflected flux from the disk to the direct flux from the continuum, can similarly provide constrains on black hole spin. Previous work has shown that we can set limits on the spins of black holes based on maximal reflections fractions, assuming a razor thin disk and a lamp post corona (Dauser et al. 2014; Dauser et al. 2016). In this work, we use the general relativistic ray tracing software Gradus.jl (Baker and Young 2026) to extend these calculations to more realistic Shakura-Sunyaev disk geometries. We find that, although intuitively we might expect a difference in the reflection fractions for thicker disks, there is only a small change in the maximum reflection fraction. We will extend these methods to include calculations of reflection strength, based on the observed reflection dominated continuum, allowing direct comparisons to data. We would also like to explore the reflection fractions for accretion flows that approach the Eddington limit, where we might expect a bigger difference from the standard razor thin disk models.

Astrophysical Scenarios for the Periodic Modulation of the Gamma-ray Flux Emitted by the Blazar PG 1553+113

Authors

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Abstract

Jets from supermassive black holes (SMBHs) behave in mysterious ways. Results of more than 17 years of gamma-ray monitoring of the BL Lac object PG 1553+113 by the Large Area Telescope (LAT) on board the NASA Fermi Gamma-Ray Space Telescope are presented, even in comparison with optical, radio-band and X-ray multifrequency observations. A long-lived, 2.1-year gamma-ray/optical modulation is confirmed at a 4 sigma confidence level against stochastic red/brown noise. X-ray spectro-polarimetry snapshots observations are also performed by us with the NASA-ASI Imaging X-ray Polarimetry Explorer (IXPE).

Such high-energy gamma-ray oscillation modulates the rapid flares and the irregular variability. Our discovery opens prospects for investigating several astrophysical scenarios and models: pulsational accretion flow in a, sub-parsec, binary SMBH system; accretion flow instabilities and plasma kinks, disk and jet precession, jet rotation or nutation both in cases of a single or binary SMBH; perturbations by massive stars or compact objects in polar orbit around the central SMBH. PG 1553+113 is, therefore, emerging as a test bench to understand relativistic outflows and jets from SMBHs.