Testing Eddington Analogies with Observations of Supermassive Black Holes

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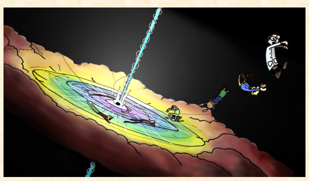
Trichas, Green et al. 2013

Abstract

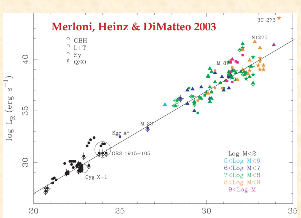
Similarities between the observational accretion signatures of X-ray Binary (XRB) systems and active galactic nuclei (AGN) are still ardently sought. XRB spectral states show an inflected correlation between X-ray spectral hardness Γ_x and Eddington ratio λ_{Edd}. Large AGN samples may also serve to catch supermassive black hole accretion in different states. We discuss and lambaste recent such tests, including our own using the Chandra Source Catalog and SDSS, of such analogies. Significant strides can and must be made, and we delineate related plans and hopes using SDSS spectroscopy and wide-area X-ray imaging.



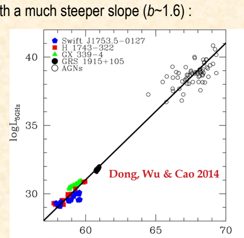
Fundamental Plane

X-ray emission of both XRBs and AGN is thought to originate in accretion flows (e.g., disk/corona and/or RIAF; Yuan & Cui 2005) or possibly from the base of a jet (e.g., Markoff et al. 2005).

A nonlinear universal scaling (slope b~0.6 below) over 10^8 in BH mass suggests analogous physics governing the accretion and ejection processes from XRBs to AGN:

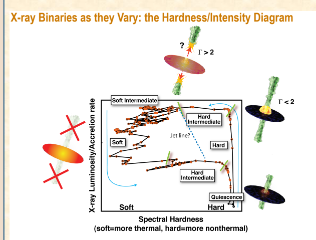


Fundamental plane of black hole activity holds for *radiatively efficient* XRBs and AGN as well, but with a much steeper slope (b~1.6) :



Scatter of σ_R= 0.88 is substantial.
A significant (but unknown) portion is due to uncertainties in M_{BH}.

Striking Analogies Between X-ray Binary and AGN Accretion



Corbel et al., Belloni et al., graphic by Sera Markoff

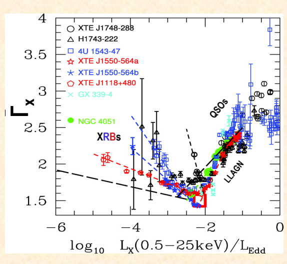
Do supermassive black holes do this too, scaled up by BH mass to *higher luminosities*, *cooler temperatures*, and *longer timescales*?

Falcke et al. (2004) suggested that different AGN classes can be identified with corresponding X-ray binary (XRB) states, where low luminosity AGNs (LLAGNs) are analogs of the XRBs in the "low hard" state, and Radio Quiet quasars are analogs of the XRBs in the "high soft" state.

The hypothesis is being tested in several ways, by contrasting:

1. Variability timescales ✔
2. Fundamental Plane (broadband SEDs) ✔
3. SED vs. accretion state ?

SEDs vs. Accretion State: Compton Component Γ_x vs. Eddington Ratio

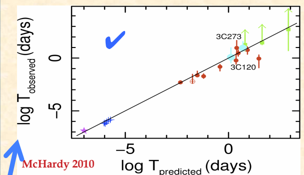


✪ The hard X-ray photon index Γ_x of individual XRBs varies *duotonically* with Eddington ratio L/L_{Edd}

✪ Linear least-squares fits shown for samples of
- LLAGN (Gu & Cao 2008)
- QSOs (Shemmer et al. 2006)

✪ Do different AGN types correspond to different accretion states? Need to look beyond these few hand-picked LLAGN.

Variability Timescale Trend Spans $>10^7$ in M_{BH}



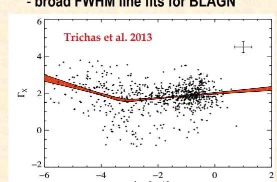
- PSD upper bend timescales from XRBs through AGN: best-fit relationship

$$\log T = 2.1 \log M_{BH} - 0.98 \log L_{Bol} + 2.3$$

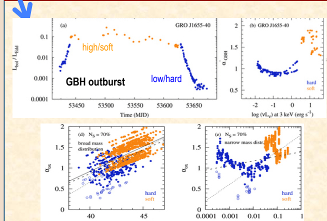
- Nice fit! But if T corresponds to R_{ISCO} then T should be smaller for high spin... but equation has no spin dependence! All spins ~maximal?

Hunting for the Γ_x vs. Eddington Ratio Relation in AGN

- In Trichas et al. 2013, we cross-correlate all Chandra Source Catalog (CSC1.1) detections with SDSS galaxies
- Best-fit X-ray powerlaw slope Γ_x represents Comptonized component
- Multiband SED template fitting to estimate L_{Bol} and L_{AGN}
- Estimate M_{BH} consistently using:
  - M_σ, for NELG+passive galaxies
  - broad FWHM line fits for BLAGN



SEDs vs. Accretion State: Disk vs. Comptonized Components α_{OX} vs. Luminosity



- Take a typical GBH outburst
- Scale by M_{BH} distribution to simulate the SEDs of an AGN population
- Reproduces well-known AGN $\alpha_{OX}(L_{UV})$ correlation
- Also yields double-sloped Γ vs. L/L_{edd} relation with inflection at ~1%

Where We Stand... and Fall

- PSD upper bend timescale trends look convincing, but have few AGN. Very expensive to measure X-ray PSDs for typical QSOs! (~200ks each, split up for monitoring).
- Fundamental plane looks convincing too, but seems to show significantly different trends for radiatively inefficient vs efficient accretion states.
- AGN trend of Comptonized component (X-ray powerlaw slope Γ_x) with Eddington ratio is ratty-looking at best.
- Trend of disk vs. Componized component (α_{OX})) with Eddington ratio needs further investigation: larger samples & better M_{BH}

For Typical QSOs, our Measurements Suffer From

Large Uncertainties in
1. SMBH masses
2. L_{Bol} estimates
3. Γx

Not to mention ***variability*** and non-simultaneous measurements (*sigh)*.

SDSS-IV Reverberation Mapping Project

- Reverberation mapping (measuring lags between continuum and broad emission line flares) yields the most reliable M_{BH} estimates for QSOs.
- Multi-epoch, multifiber spectroscopy with the upgraded BOSS spectrograph on the SDSS 2.5m at APO has begun (30 epochs to date).
- We expect to detect lags for ~200 of the 849 (Type 1 QSOs *i*<21.5) in our single BOSS field (7 deg[2]; Shen et al. 2014), which also boasts >400 epochs of PanSTARRS-1 multiband imaging (Kaiser et al. 2002).
- Remaining QSOs still have spectra of S/N>30, allowing highest quality single-epoch virial M_{BH} estimates, and important constraints on spectroscopic variability (Ruan et al. 2014).
- We have proposed for *XMM-Newton* time to image the entire field, offering potentially ***transformative*** improvements in all trends shown here! (PI Green)

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