Searching for Accreting Supermassive Black Holes in Bulgeless Galaxies

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Example of bulgeless galaxies (Satyapal et al. 2014)
Missing piece in galaxy evolution puzzle

• Only galaxies with a spheroidal bulge component are found to host super massive black-holes (SMBHs).
  • Do bulgeless galaxies host SMBHs?

• Linear trend between bulge mass and black hole mass
  • Expect to find a $10^5$-$10^6 \, M_\odot$ black hole, or intermediate mass black hole (IMBH), in bulgeless galaxies

• No evidence for IMBH has been found
  • IMBHs are theorized as an intermediary step for SMBHs based on merger free models of galaxy evolution
  • How do SMBHs become so massive?
  • Chicken or Egg
How do we find intermediate mass black holes?

- Are they actively accreting?
- Active Galactic Nucleus (AGN): Accretion of matter onto a super massive black hole

Accretion disk creates high energy photons

Torus of dust can completely obscure emission lines

Narrow Line Region (NLR) is rotating slower than the BLR (hundreds of km/s)

Broad Line Region (BLR) contains rapidly rotating gas clouds. Emission lines from the BLR are kinematically broadened to thousands of km/s.

http://imagine.gsfc.nasa.gov/Images/basic/xray/agn.gif
How to find AGN with IMBHs

- An AGN that hosts an IMBH is expected to be weaker than an AGN that hosts a SMBH
  - Dusty torus can completely obscure view of the AGN
  - High energy photons from the accretion disk heat the torus of dust, which then reemits mid-IR radiation.

- New strategy for identifying obscured AGN using mid-IR colors reveals over 300 bulgeless AGN candidates (Satyapal et al. 2014).
  - Mid-IR colors obtained with the Wide Field Infrared Survey Explorer (WISE)

Wise Color-Color Diagram

- In red box = 95% chance of hosting AGN
- Above blue line = 50% chance of hosting AGN (Jarrett et al. 2011)

Our sample of bulgeless AGN candidates:

- All have W1 – W2 > 0.5
- Bright radio emission
- Very Large Array (VLA) observations must be available
  - Radio observations are crucial for determining the amount of obscuration.
  - Quantitative constraints on strength and morphology of star formation
- Found in local universe
  - (z < 0.3)
- Marked by black squares in Color-Color Diagram
  - Located in obscured AGN region as classified by (Wright et al. 2010)
Hidden Clues in Near-IR

- AGN in bulgeless galaxies are not active in optical wavelengths
  - Optical observations are the traditional method for finding AGN

- No clear sign of AGN ionization present in optical spectra
  - Perhaps too obscured by surrounding dust
  - Need to go to longer wavelengths
    - Near-IR is less affected by dust extinction

- Look for broadened Paschen alpha emission line
  - Doppler broadened from rapidly rotating clouds of gas (along line of sight).
  - Only a black hole is massive enough to broaden emission features to thousands of km/s.

- The ratio of near-IR emission line flux to optical constrains the level of extinction and reddening along the line of sight
  - Compare observed flux ratio to intrinsic ratio (Calzetti et al. 2007)
Large Binocular Telescope

- Mount Graham, Arizona
- 8-10m telescope
- Two 8.4m mirrors on a single mount
  - First light: 2005
  - Fully operational: 2008
- LUCIFER (LBT NIR Spectrograph Utility with Camera and Integral-Field Unit for Extragalactic Research)
  - Wavelength range: $1.4 \mu m - 2.2 \mu m$
- Observations span Nov. 2013 – Mar. 2015
- The total integration time for each object was ~20 minutes.

http://www.nasa.gov/topics/universe/features/lbti20101206-i.html#.VvWOQ2M6bCj
Data Reduction Process

Raw data set = object spectrum + detector response + sky emission

Raw frame divided by flatfield to correct for intrinsic detector response function.

Use known wavelength of sky emissions to assign proper wavelength to each pixel on the x-axis. Skylines are removed by subtracting individual scaled frames.

Combine skyline subtracted frames into one 2-D spectrum.

A strong (but narrow) Paschen Alpha emission line is detected at 18751Å.

Extract the 1-D spectrum by adding the central 2 pixels (0.5”). Flux calibrate and correct for telluric absorption.

This is the final calibrated and Doppler corrected LBT spectrum of SDSSJ1224+5555 over the entire wavelength range measured by LBT.
Results: Final LBT Spectra

Name of galaxy & Date of observation

SDSSJ0833+1204 Nov. 28, 2014
SDSSJ0148+1354 Nov. 28, 2013
SDSSJ0148+1742 Dec. 02, 2013
SDSSJ0809+4736 Dec. 02, 2013
SDSSJ1224+5555 Mar. 28, 2015
SDSSJ0750+2928 Nov. 28, 2013

- All optical emission lines in SDSS spectra are narrow.
- No bulge component found in SDSS images.
- No evidence for gravitational interaction with other galaxies. They are isolated and unlikely to have undergone a significant merger event.
- No evidence for broad Paα emission line in LBT spectra (FWHM < 1000 km/s)
Conclusions and Future Research

• No significant evidence for broadened Paschen $\alpha$ emission lines.
  • Higher signal-to-noise observations needed.
  • If the AGN is oriented pole-on to our line of sight then there will be no Doppler broadening observed.

• AGN either too absorbed or too weak to be detected.
  • Currently investigating different methods to quantify dust extinction using detected near-IR emission features.
  • Extinction used to clarify whether or not the red wise colors are due to star formation or an obscured AGN.

• Follow-up observations in X-ray (**XMM-Newton**) and radio (**VLA**) wavelengths
  • Constrain the bolometric luminosities and thus the true origin of the red mid-IR colors.
  • Mass of the putative black hole and its accretion rate

• If there are no AGN found in the bulgeless galaxies:
  • Helps to constrain the fraction of local bulgeless galaxies that host AGN
  • Lends credibility to SMBH merger theories