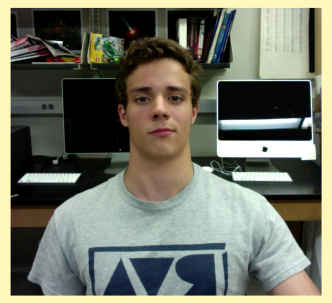

Searching for Accreting Supermassive Black Holes in Bulgeless Galaxies

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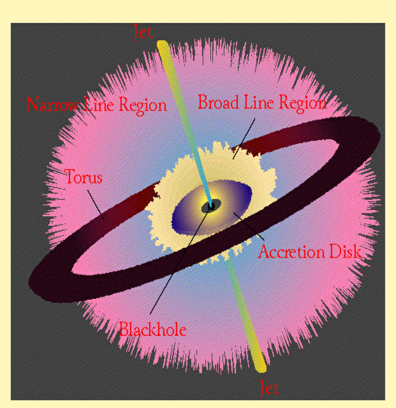
Bulgeless Galaxies and their Black Holes: A Summary

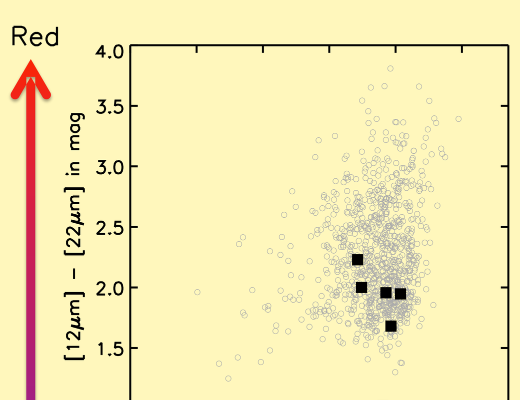
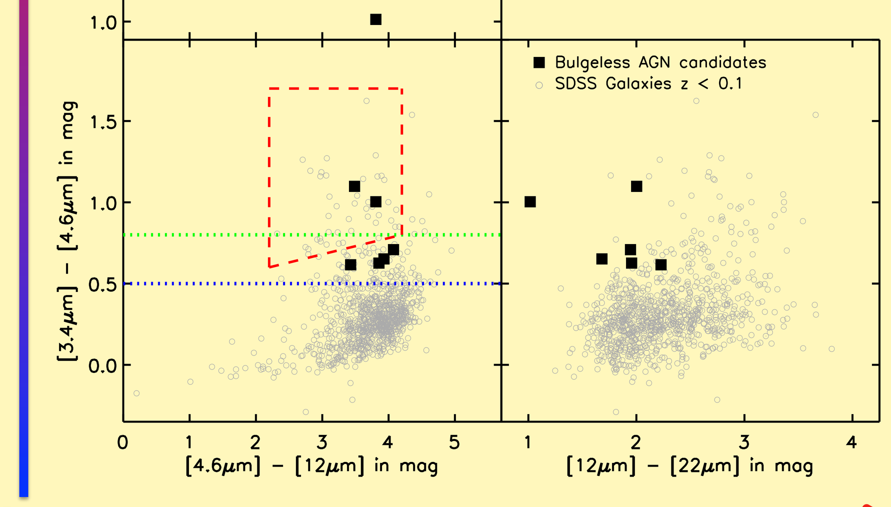
There is increasing evidence that massive galaxies with significant bulge components host black holes as massive as millions to billions of solar masses. Given the positive correlation between the masses of bulges and the masses of the black holes residing in their centers we expect to find in low-mass, bulgeless galaxies only the so called intermediate mass black holes. These objects are thousands to hundreds of thousands times the mass of the sun. Studying these intermediate mass black holes should provide important clues about the formation and growth of black holes in galaxy centers. Nevertheless, these exotic systems remain, to date, elusive. One way of detecting massive black holes is through their accretion activity, as well as the associated heating and cooling of the surrounding gas: high energy photons produced by accretion of matter onto the black hole heat up rapidly rotating clouds of gas which then cool down via electron de-excitation, and have emission lines that are kinematically broadened to thousands of km/s. We discuss here our search for broadened Paschen alpha emission lines in a sample of six bulgeless galaxies that have been found to exhibit very red colors in their mid-IR emission, similar to those of actively accreting supermassive black holes. We present here the data obtained with the *Large Binocular Telescope* (LBT), the reduction process, and a preliminary data analysis.

The Sample Selection & the LBT Observations

- Satyapal et al (2014) reported the discovery of over 300 local (z<0.3) bulgeless, disk galaxies with extremely red mid-infrared colors that are highly suggestive of accretion activity, i.e., an active galactic nuclei (AGN).
- **The red mid-IR colors** have been observed with the *Wide-Field Infrared Survey Explorer* (WISE; Wright et al. 2010) that surveyed the entire sky in four wavelength bands: W1 (3.4μm), W2 (4.6μm), W3 (12μm), W4 (22μm). Red colors of W1-W2 > 0.5 are best explained by dust that is heated to high temperatures by an AGN, although there could be alternative heating mechanisms (e.g. extreme star formation, low metallicity).



Cartoon representation of an AGN* showing how a dusty torus can obscure the line emission activity from fast rotating clouds of gas (Broad Line Region). The high energy photons from the accretion disk (in yellow) heat up the dusty torus (in black) which will emit mid-IR radiation that is measured by WISE.
*http://imagine.gsfc.nasa.gov/Images/basic/xray/agn.gif

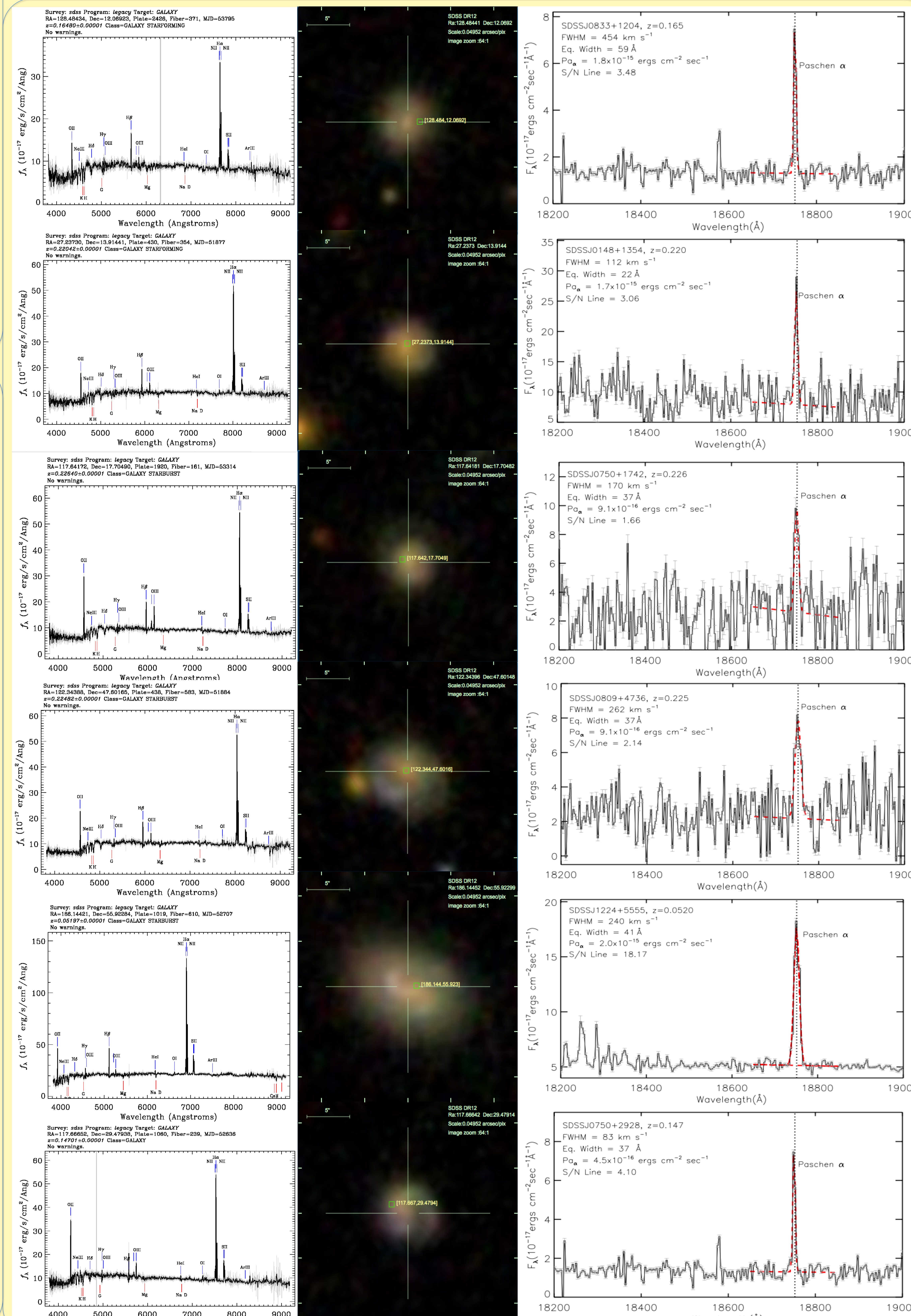
WISE color-color diagrams are used to identify red, AGN-like, galaxies. The dashed red demarcation is from Jarrett et al. (2011) AGN study, and is shown together with W1-W2 > 0.8 (the green dotted line) and W1-W2 > 0.5 (the dotted blue line) color cuts, corresponding to a 95% and 50% chance to host an AGN, respectively.

- **Our sample** presents LBT spectroscopy for the six bulgeless AGN candidates with the brightest radio emission and availability of Very Large Array (VLA) observations. Radio observations are crucial for determining the amount of obscuration in these nuclei which consequently will offer quantitative constraints on the strength and morphology of star formation activity.
- **LBT spectra** of these six galaxy nuclei were obtained with LUCIFER (LBT NIR Spectrograph Utility with Camera and Integral-Field Unit for Extragalactic Research) on Nov. 2013, Dec. 2013, Nov. 2014, and March 2015. We used a 0.50" wide slit, that obtained spectra covering 1.4μm-2.2μm at ~2000 resolution, with a 0.25"/pixel spatial scale. The total integration time for each object was ~20 minutes. The LBT is an 8-10m telescope that has two 8.4m mirrors on a single mount.

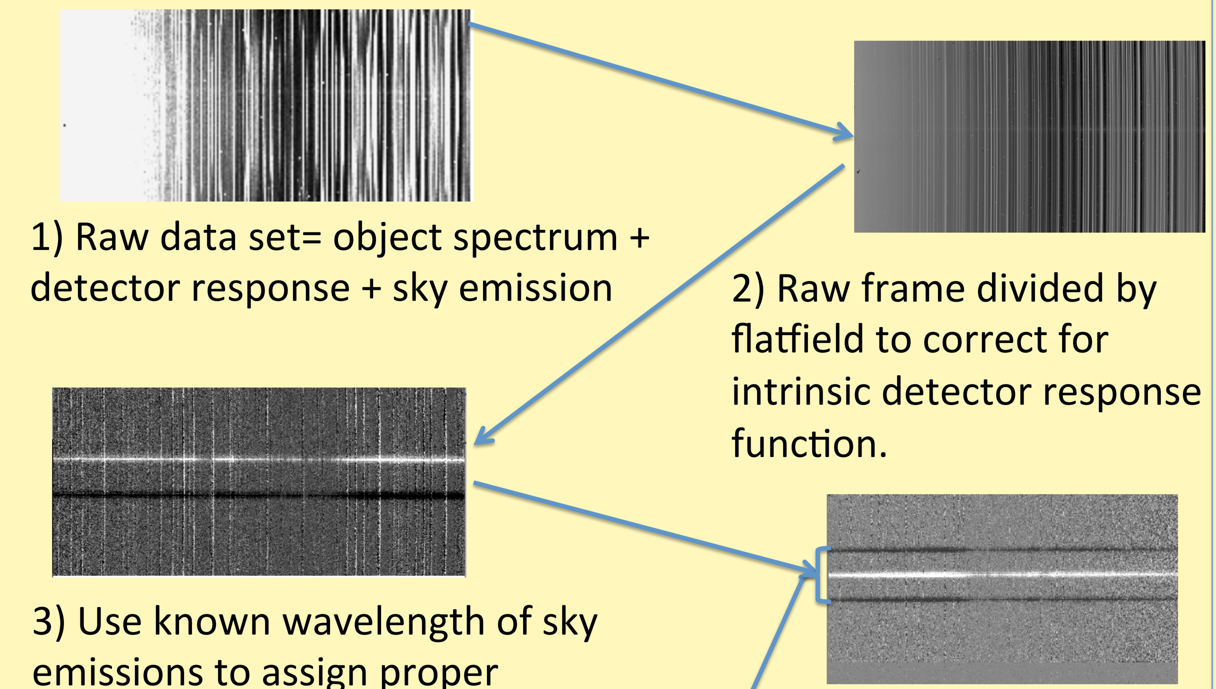
SDSS Optical Spectra
No AGN-like line flux ratios or broad Hα emission

SDSS Images
No obvious galactic nucleus

LBTO Near-Infrared Spectra
No broad Paschen Alpha Emission Line detected



LBT Data Reduction Process



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

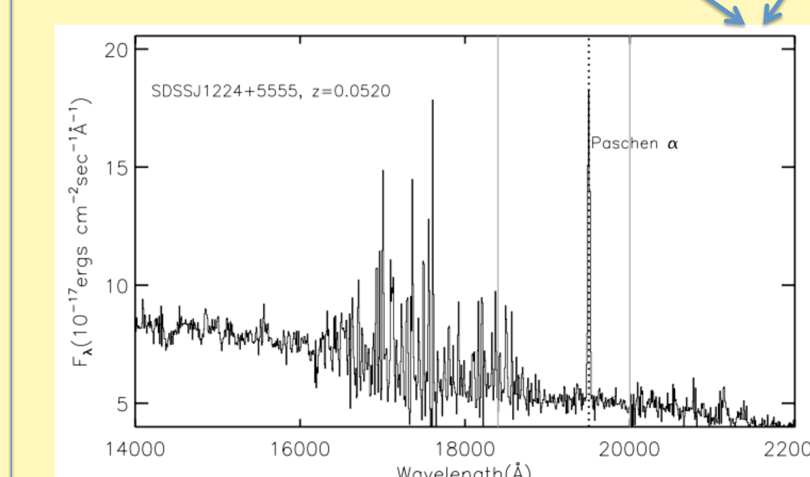
2) Raw frame divided by flatfield to correct for intrinsic detector response function.

3) 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.

4) Combine skyline subtracted frames into one 2d spectrum

5) Extract the 1-D spectrum by adding the central 11 pixels (2.75")

6) Flux calibrate and correct for telluric absorption using the IRAF XTELLCOR package Vacca et al. (2003)



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

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

Conclusions and Future Directions

- We found **no significant evidence for broad Paschen α** emission lines in these six bulgeless galaxies. Higher signal-to-noise observations are needed to clarify the presence or absence of these features.
- **If an AGN is responsible for the red mid-IR colors in these sources, it is either too absorbed or too weak to be detected in these spectra.**
- To **explore whether extreme star formation is responsible** for producing the observed red WISE colors we will compare the Paschen α fluxes with those of the Balmer Hα emission measured in their SDSS spectra in order to estimate the nuclear extinction, and thus whether we detect obscured star-formation or an obscured AGN.
- We are **pursuing follow-up observations in X-ray (XMM) and radio (VLA)** wavelengths in order to constrain further the bolometric luminosities of these sources, and thus the true origin of the red mid-IR colors, as well as the mass of the putative black hole and its accretion rate.

References:

1) Jarrett, T. H., Cohen, M., Masci, F., et al. 2011, *ApJ*, **735**, 112
2) Satyapal, S., et al. 2014 *ApJ*, **784**, 113
3) Stern, D., Assef, R. J., Benford, D. J., et al. 2012 *ApJ*, **753,** 30
4) Vacca, W, Cushing, M.C, & Rayner, J.T. 2003 PASP 115, 805.
5) Wright, E. L., et al. 2010 *ApJ*, **140**, 1868