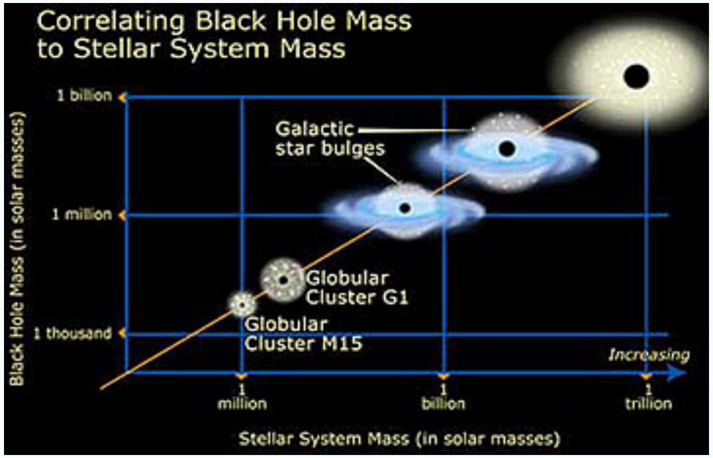

http://wtlab.iis.u-tokyo.ac.jp/~wataru/lecture/rst/Sect20/A6.html

Searching for Accreting Supermassive Black Holes in Bulgeless Galaxies

Jason Ferguson (JMU), Anca Constantin (JMU),
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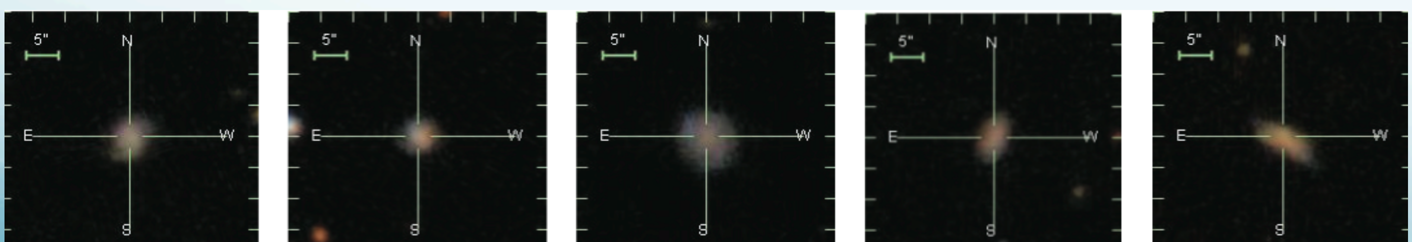
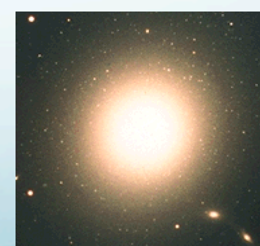


Example of bulgeless galaxies (Satyapal et al. 2014)



M87 Elliptical Galaxy

http://www.astro.cornell.edu/academics/courses/astro201/galaxies/types.htm

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

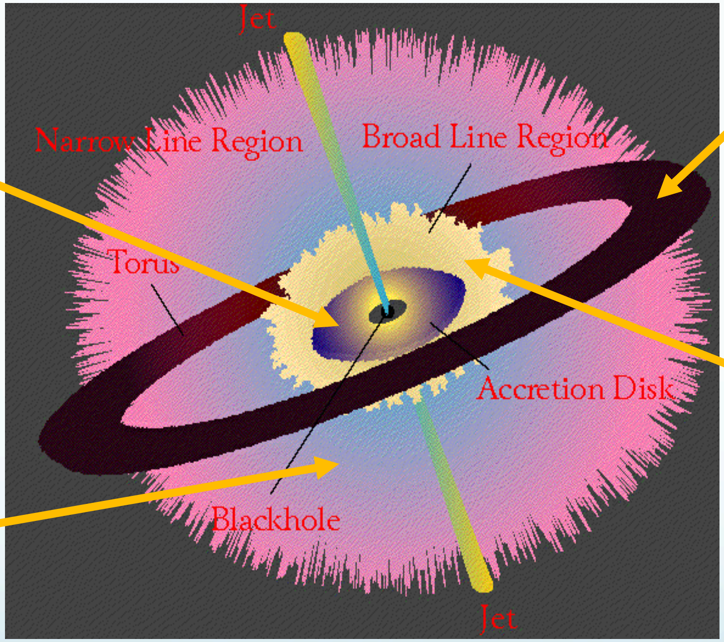
- No evidence for IMBH has been found
  - IMBHs are theorized as an intermediary step for SMBHs based on merger free models of galaxy evolution
  - How do SMBHs become so massive?
  - Chicken or Egg

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

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



http://imagine.gsfc.nasa.gov/Images/basic/xray/agn.gif

Torus of dust can completely obscure emission lines

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

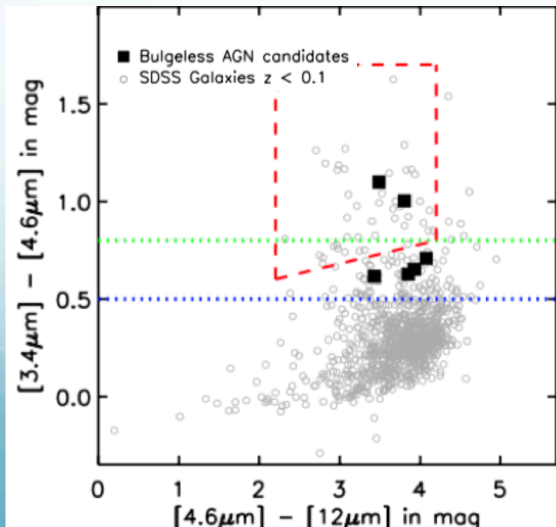
How to find AGN with IMBHs

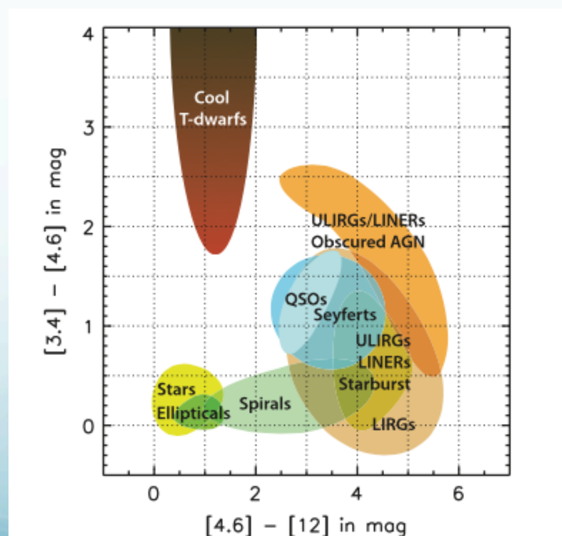
- An AGN that hosts an IMBH is expected to be weaker than an AGN that hosts a SMBH
  - Dusty torus can completely obscure view of the AGN
  - High energy photons from the accretion disk heat the torus of dust, which then reemits mid-IR radiation.

- 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)





(Wright et al. 2010)

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.

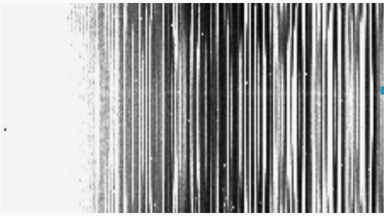
- The ratio of near-IR emission line flux to optical constrains the level of extinction and reddening along the line of sight
  - Compare observed flux ratio to intrinsic ratio (Calzetti et al. 2007)

Large Binocular Telescope

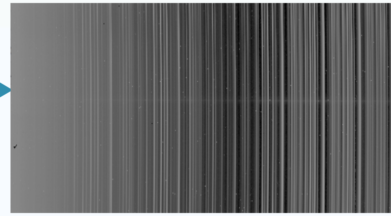
http://www.nasa.gov/topics/universe/features/lbti20101206-i.html#.VvWOp2MbCjg

- 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: 1.4μm-2.2μm
- Observations span Nov. 2013 – Mar. 2015
- The total integration time for each object was ~20 minutes.

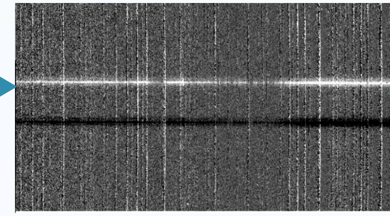
Data Reduction Process



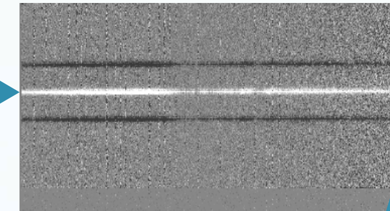
Raw data set = object spectrum + detector response + sky emission



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



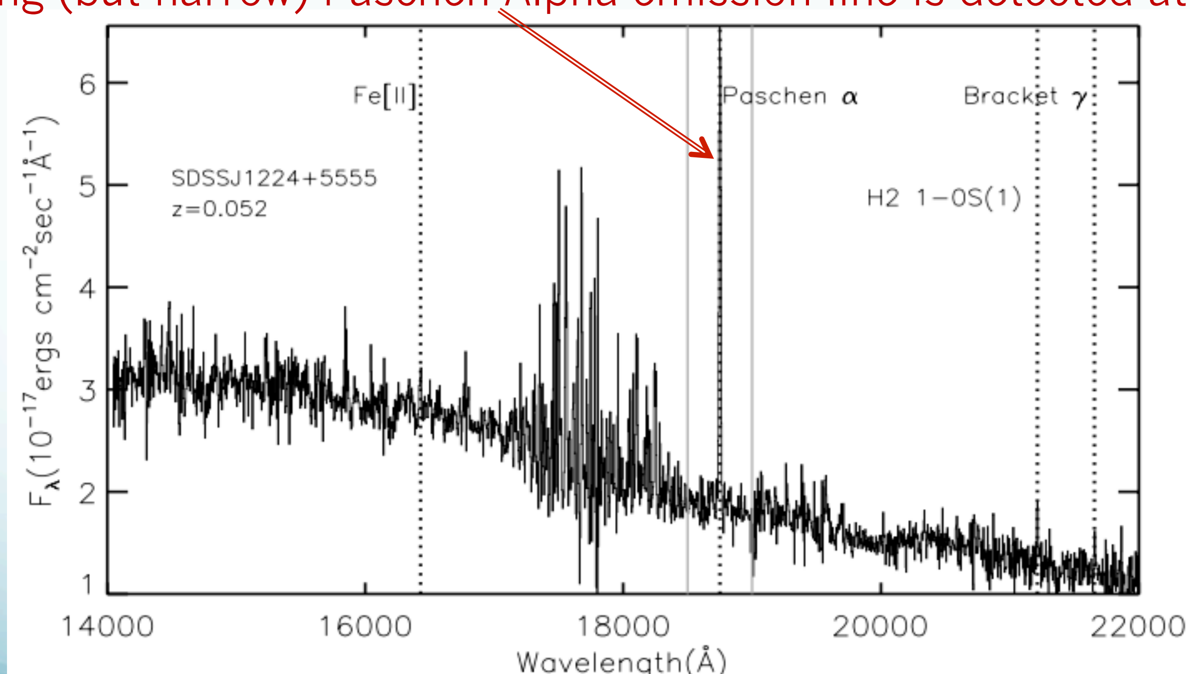
Use known wavelength of sky emissions to assign proper wavelength to each pixel on the x-axis. Skylines are removed by subtracting individual scaled frames.



Combine skyline subtracted frames into one 2-D spectrum.

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

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



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 | **SDSS Optical Spectra** | **SDSS Images** | **LBT Near-IR Spectra**

SDSSJ0833+1204
Nov. 28, 2014

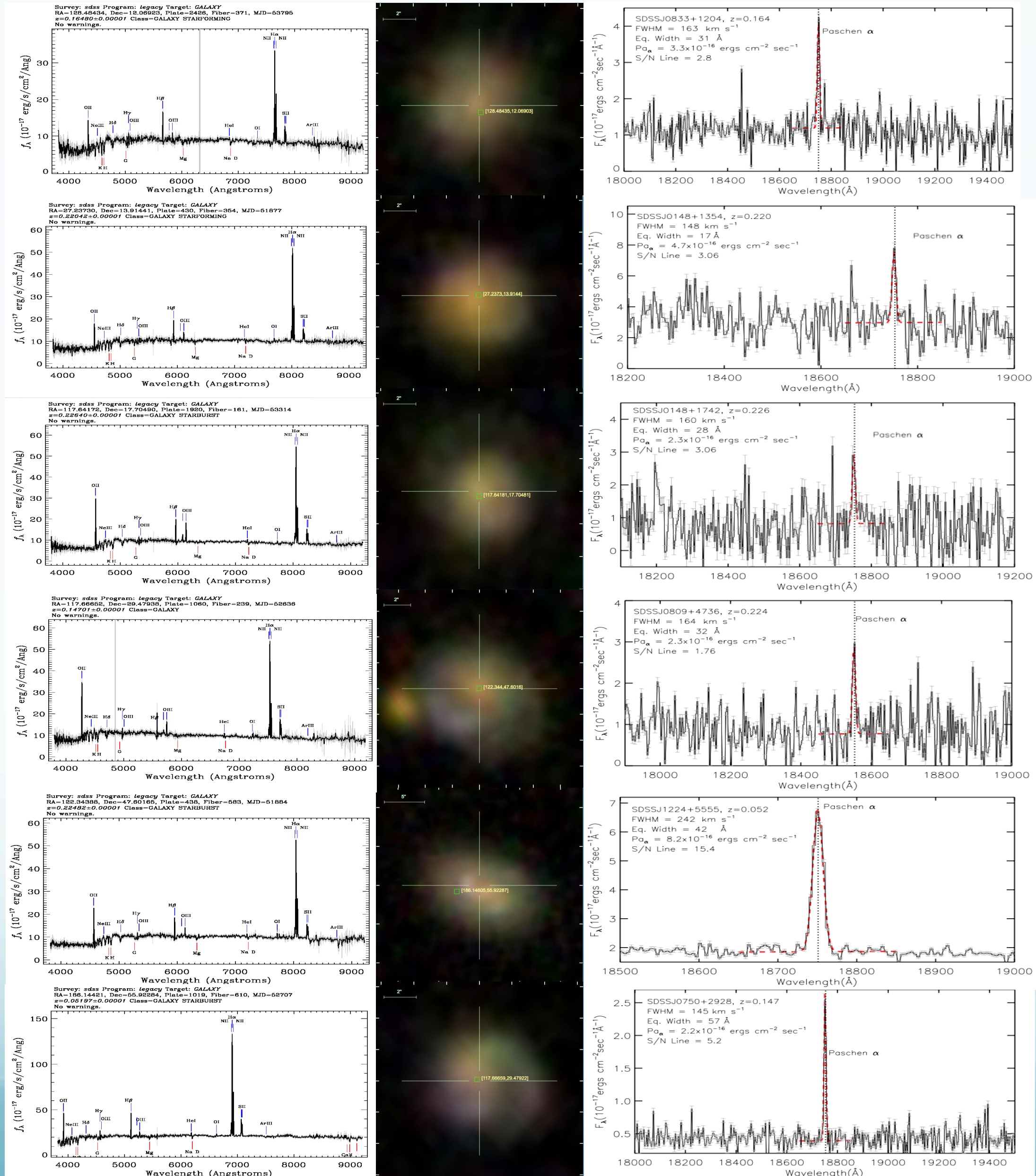
SDSSJ0148+1354
Nov. 28, 2013

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 of 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 α 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