Properties of active galactic nuclei in dwarf galaxies

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Elusive AGNs

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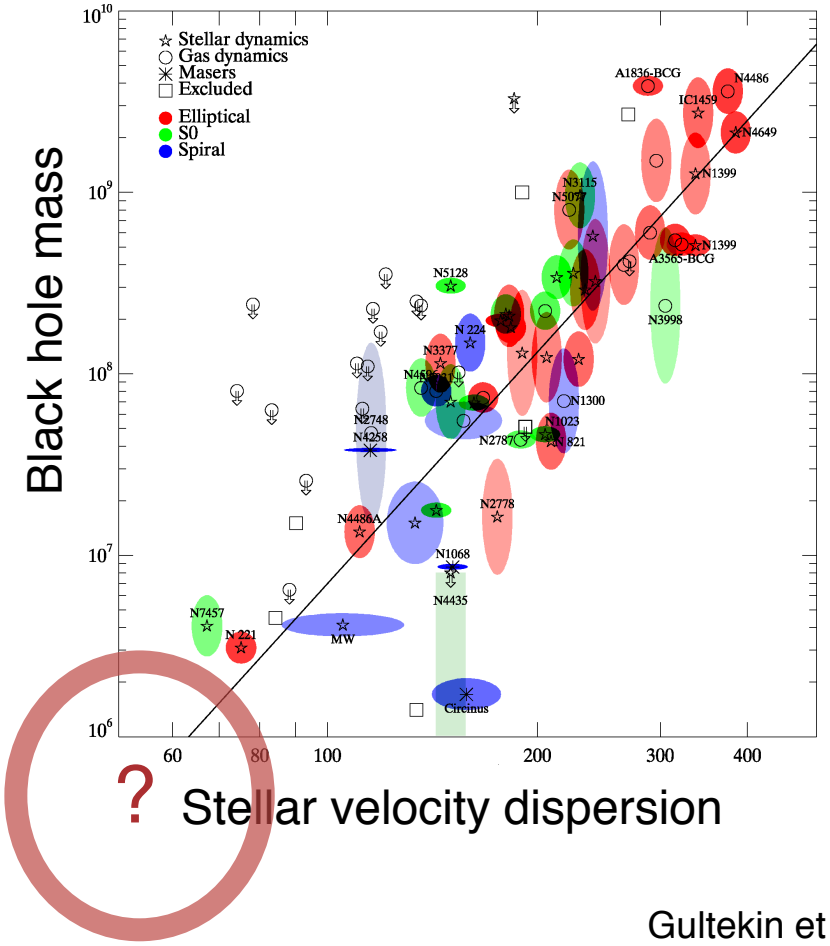
Joint work with: Amy Reines, Elena Gallo, Jenny Greene

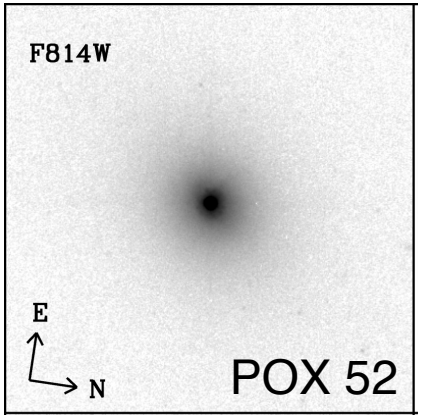
Scaling relations between BH mass and galaxy properties suggest co-evolution

- Tight correlations between black hole mass, large scale galaxy properties
- Growth of galaxy regulates growth of BH (and vice versa)
- Keys to BH formation and growth at the low mass end

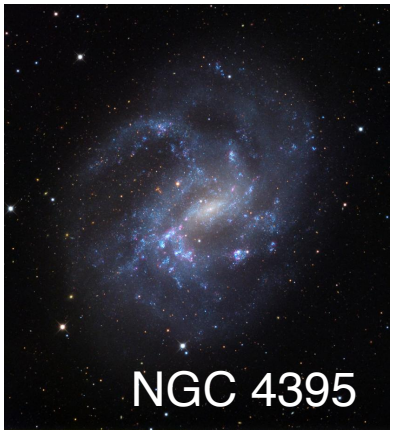


Gultekin et al. 2009

Until recently, few dwarf galaxies were known to contain AGNs



(Thornton et al. 2008)



(Credit: Mt. Lemmon SkyCenter)

- Barth et al. 2004: "… only two AGNs in dwarf galaxies have previously been identified"
- POX 52 (Kunth, Sargent, and Bothun 1987) and NGC 4395 (Filippenko and Sargent 1989) were serendipitious discoveries

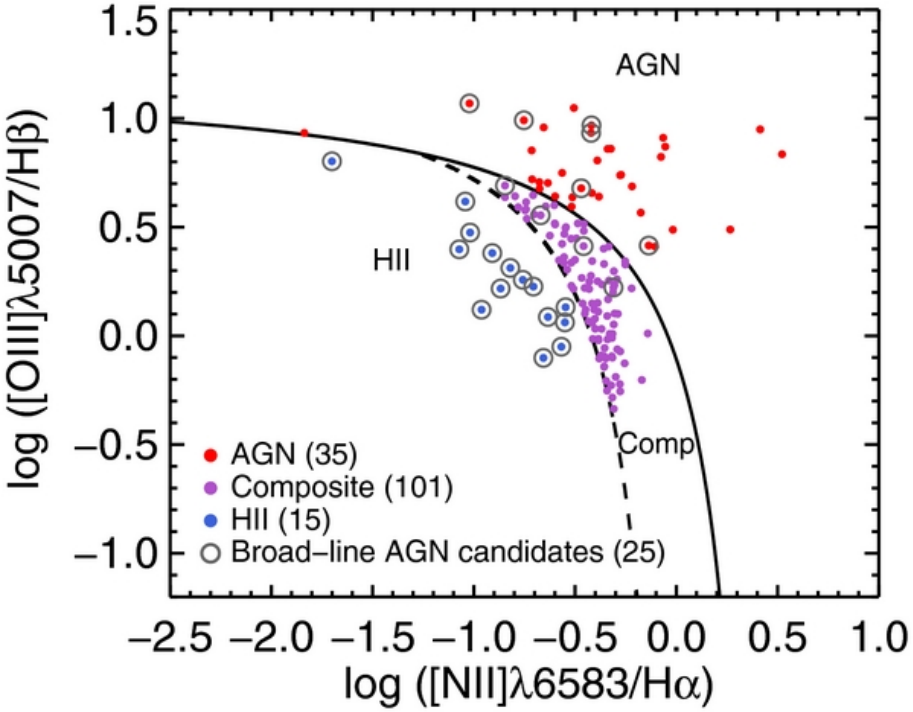
Large surveys have identified increasing numbers of AGN in dwarf galaxies

- Greene & Ho (2004; 2007): used Sloan Digital Sky Survey (SDSS) to search for broad H-alpha emission lines indicative of black holes with $M_{BH}<10^6\ M_\odot$
  - …most not in dwarf galaxies (Greene et al. 2008, Jiang et al. 2011)
- Reines et al. 2013, Moran et al. 2014 – optical spectroscopic signatures
- Sartori et al. 2015– IR/optical diagnostics (also see Hainline et al. 2016 about IR diagnostics)
- Pardo et al. 2015, Chen et al. 2017 – X-ray emission

Now know of ~200 total dwarf galaxies with AGN signatures

Finding AGNs in dwarf galaxies

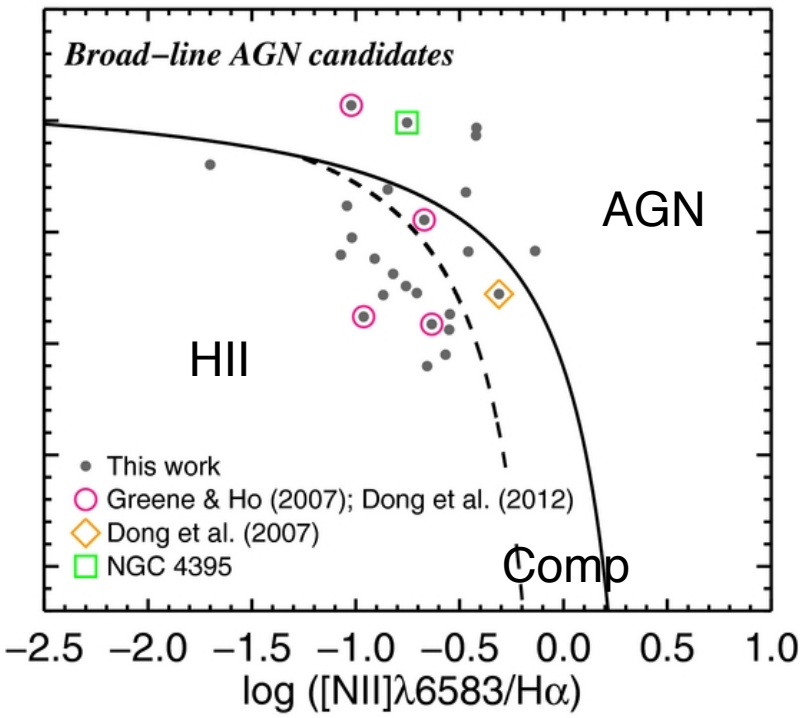
- Reines et al. 2013: First systematic study of AGN in dwarf galaxies



- Sample: 25,000 nearby ($z < 0.055$) dwarf galaxies ($M_* < 10^{9.5}\ M_\odot$) in the SDSS
- 136 galaxies with narrow-line AGN signatures
- 25 galaxies with broad Hα emission

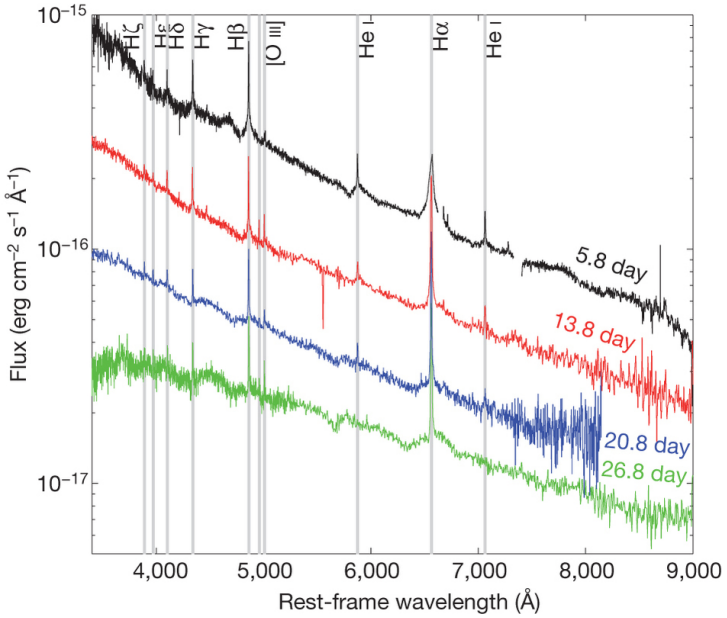
Multi-epoch spectroscopy of dwarf galaxies with AGN signatures

- Reines et al. 2013 identified 25 dwarf galaxies with broad H-alpha emission lines



Reines et al. 2013

- Type II supernovae also generate broad emission lines with similar widths



Ofek et al. 2013

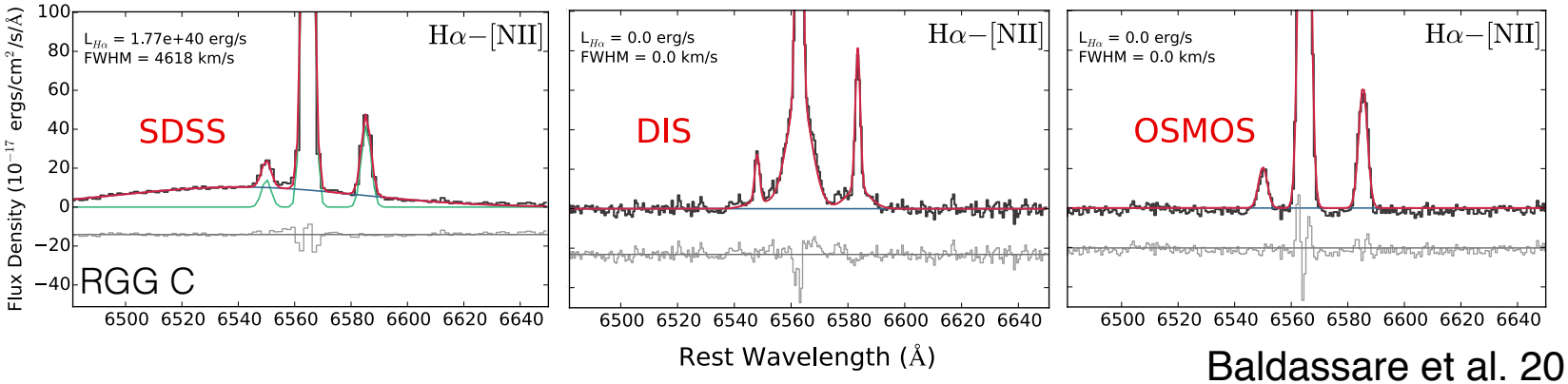
Multi-epoch spectroscopy of dwarf galaxies with AGN signatures

Goals:

- Galaxies with **broad** emission line evidence for AGN: determine whether broad emission is persistent/ consistent
  - 16 objects (14 star forming, 1 composite, 1 AGN)

- Galaxies with **narrow** emission line evidence for AGN: search for faint broad emission, measure stellar velocity dispersions
  - 15 objects (some overlap with broad sample)

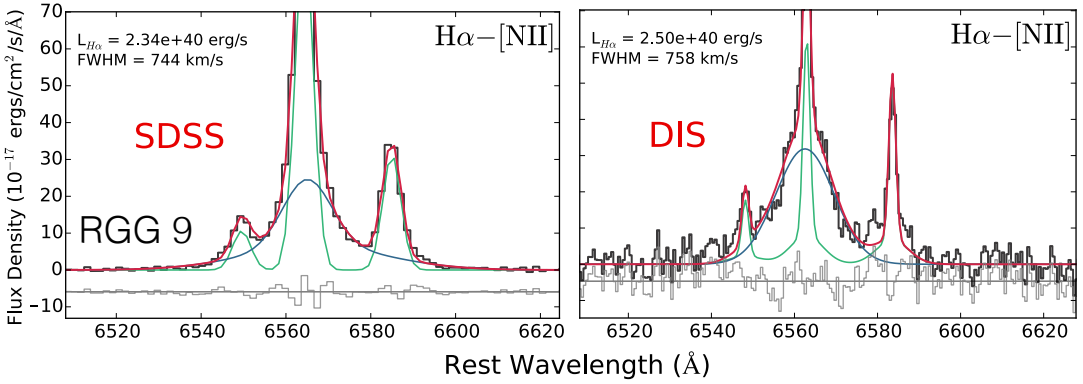
Broad Hα sample: for star forming dwarfs, broad Hα likely from stellar processes



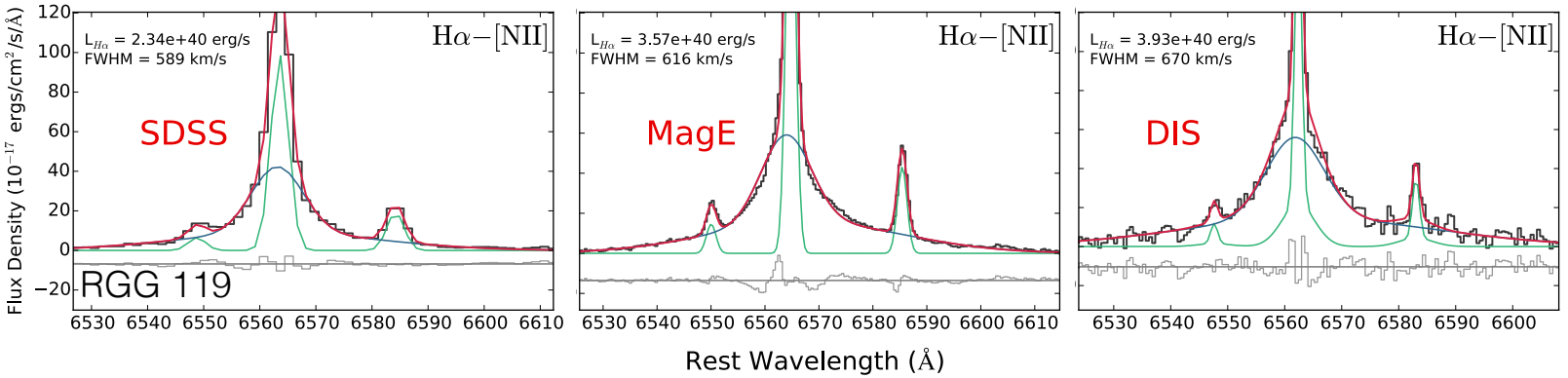
Baldassare et al. 2016

- In almost all star forming dwarfs, broad emission faded on timescales of 5-10 years
- Suggests broad emission generated by e.g., Type II supernovae (** for star forming galaxies **)

Broad Hα sample: broad emission persistent in objects with narrow line AGN signatures



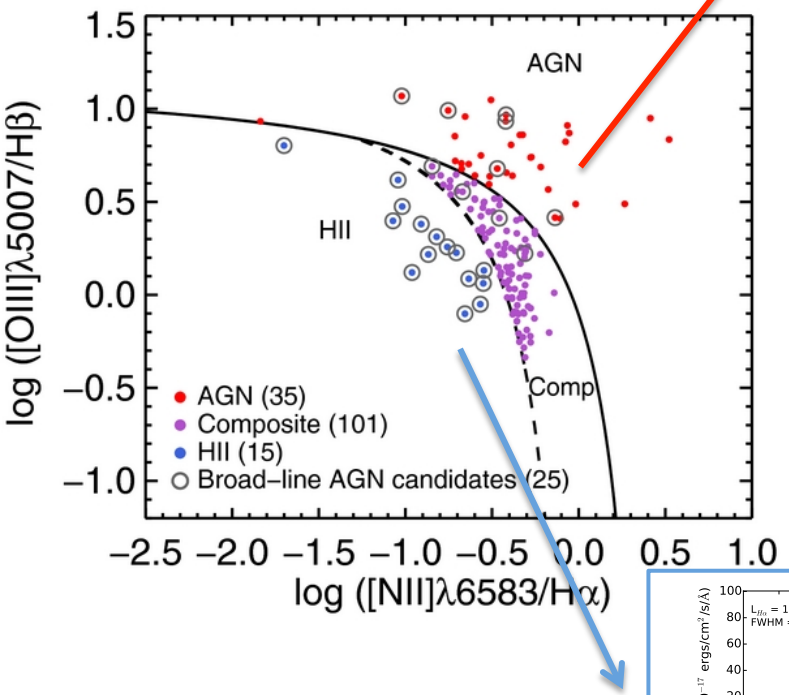
RGG 9: $M_{BH} = 3.6\times10^5\ M_\odot$

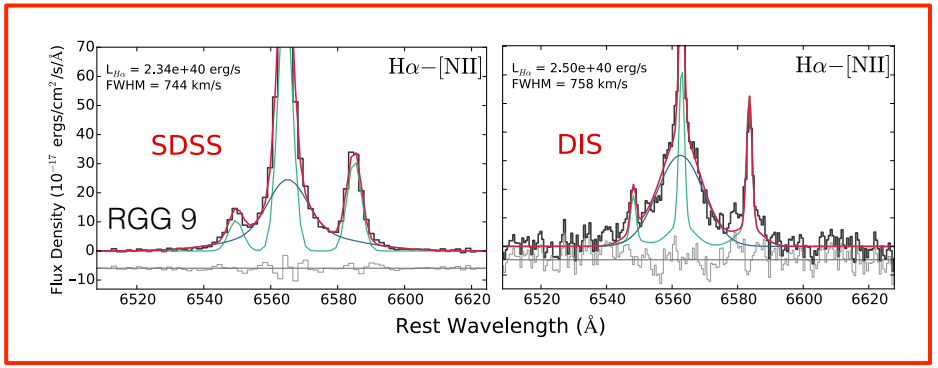


RGG 119: $M_{BH} = 2.9\times10^5\ M_\odot$

Baldassare et al. 2016

For dwarf galaxies, broad Hα alone is not evidence for an AGN

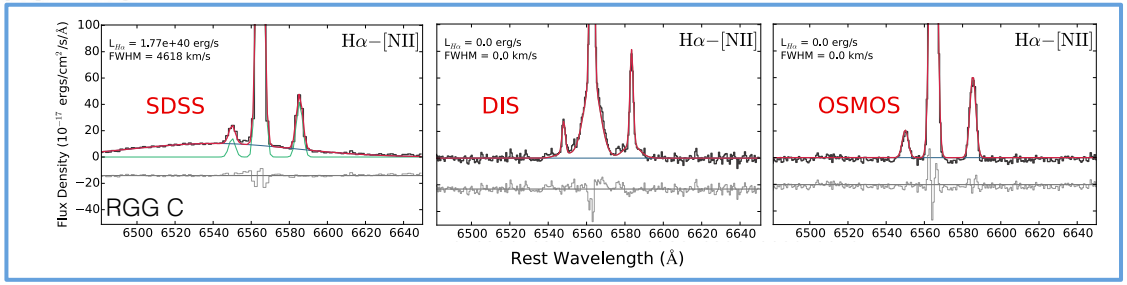




Broad emission from AGN

Baldassare et al. 2016

Broad emission not from AGN



Narrow-line sample: special case of RGG 118

- RGG 118 is a dwarf, disk galaxy ~100 Mpc away
- Stellar mass of $2.5 \times 10^9\ M_\odot$
- First identified as narrow-line composite in Reines et al. 2013
- Targeted for higher-res spectroscopy with Magellan Echellete Spectrograph on 6.5m Clay telescope at LCO

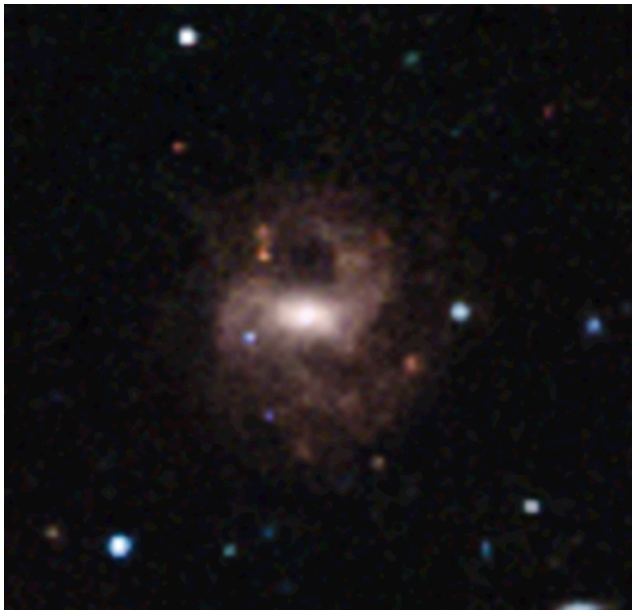
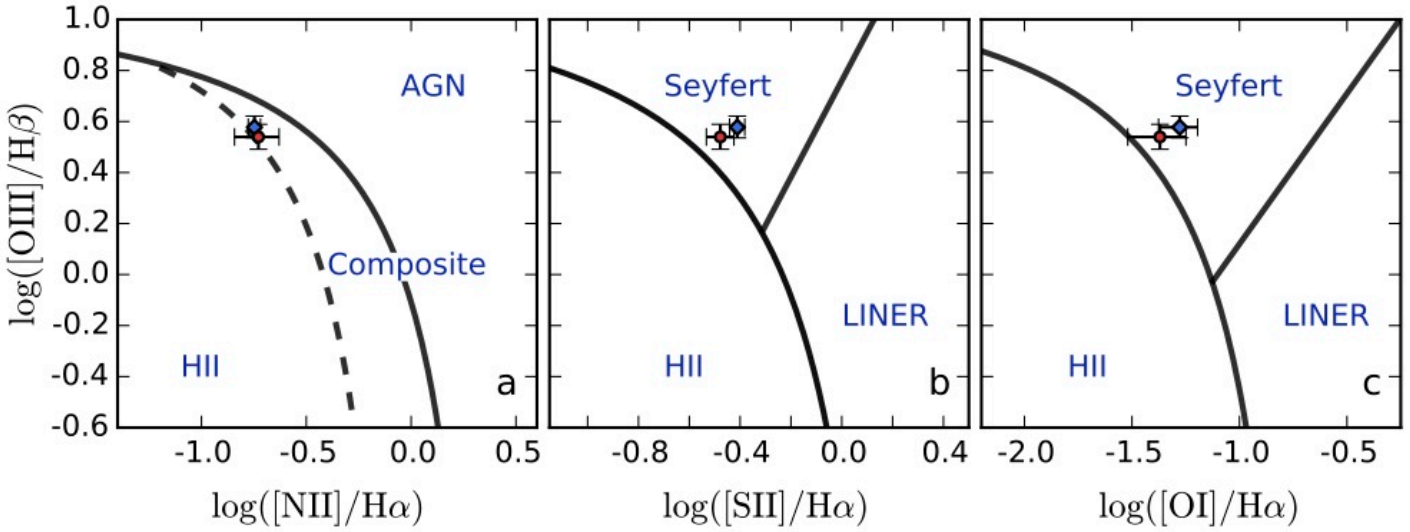


Image credit: SDSS/NASA/CXO

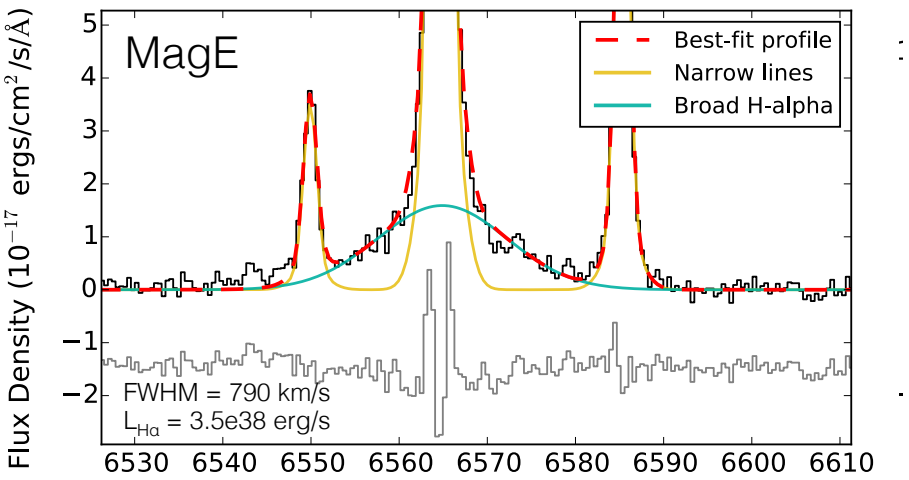
Narrow-line evidence for an AGN in RGG 118



Baldassare et al. 2015

- 6 years between SDSS spectroscopy and MagE spectroscopy
- All narrow line diagnostics point to presence of AGN

The mass of the BH in RGG 118



Baldassare et al. 2015

- Single epoch spectroscopic techniques: estimate BH mass using FWHM/luminosity of broad Hα
- Assume broad line region gas is virialized:

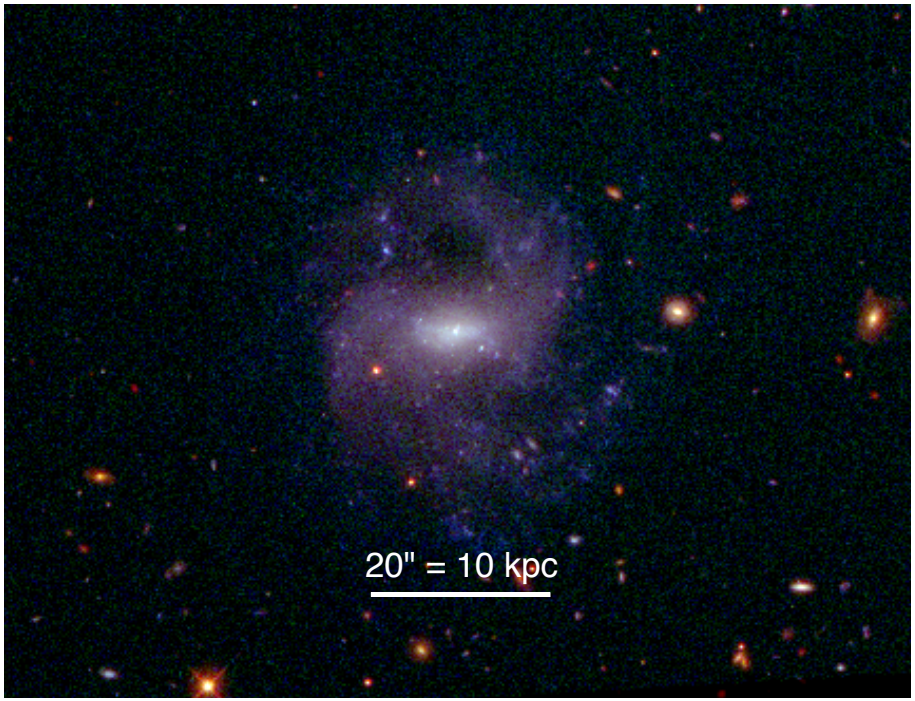
$$M_{BH} \sim \Delta V^2 R / G$$

RGG 118: $M_{BH} \sim 50{,}000\ M_\odot$

- Chandra X-ray Observatory DDT observations reveal hard nuclear point source ($L_{2\text{-}10kev} = 4\times10^{39}$ erg/s)
- Eddington fraction of 1%

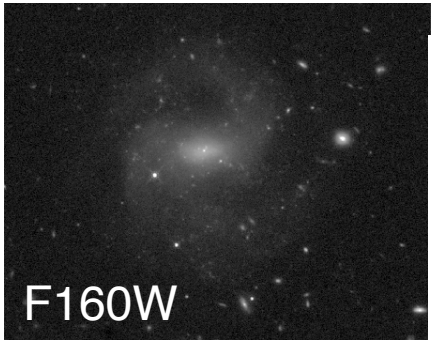
Hubble Space Telescope imaging of RGG 118

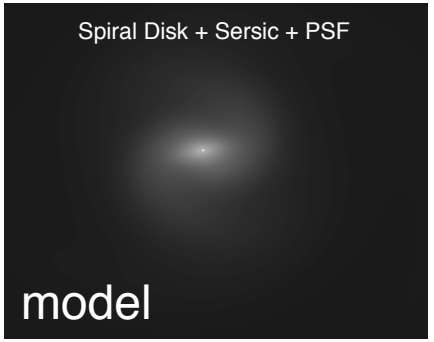
- Cycle 23, PI: Baldassare
- 3 orbits with UVIS and IR channels
- Imaging in F475W, F775W, F160W (equivalent of g, i , H)

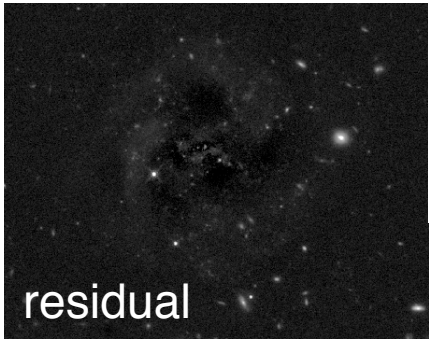


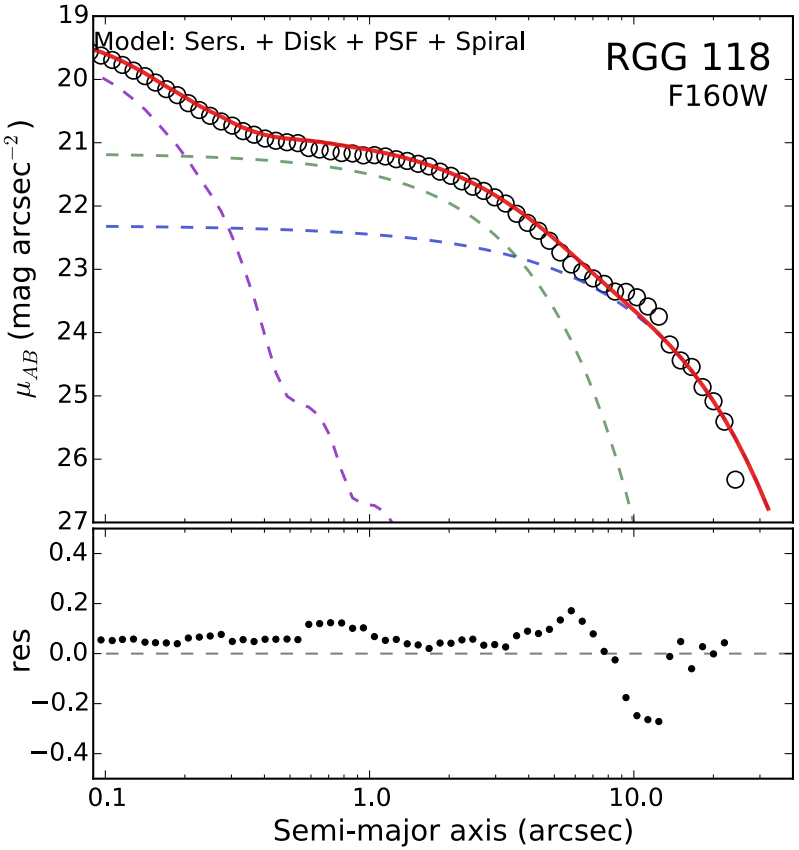
Baldassare et al. *submitted*

Analyzing the structure of RGG 118









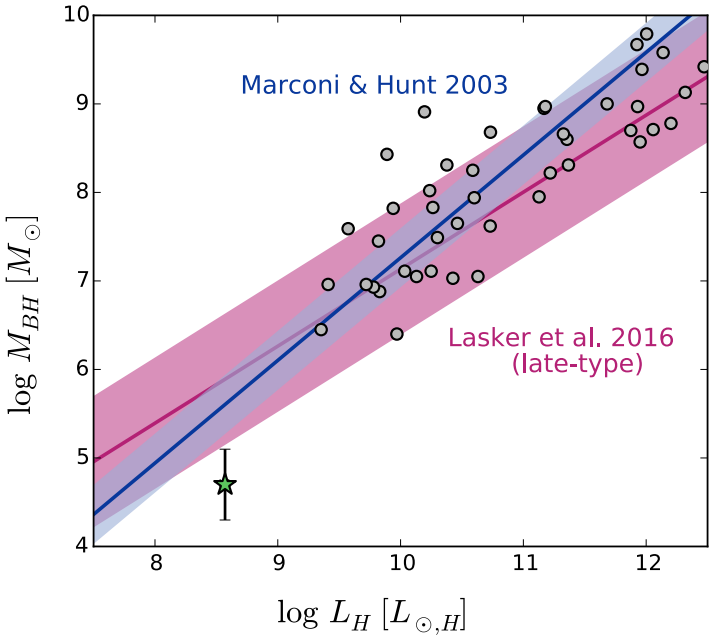
Best model includes:

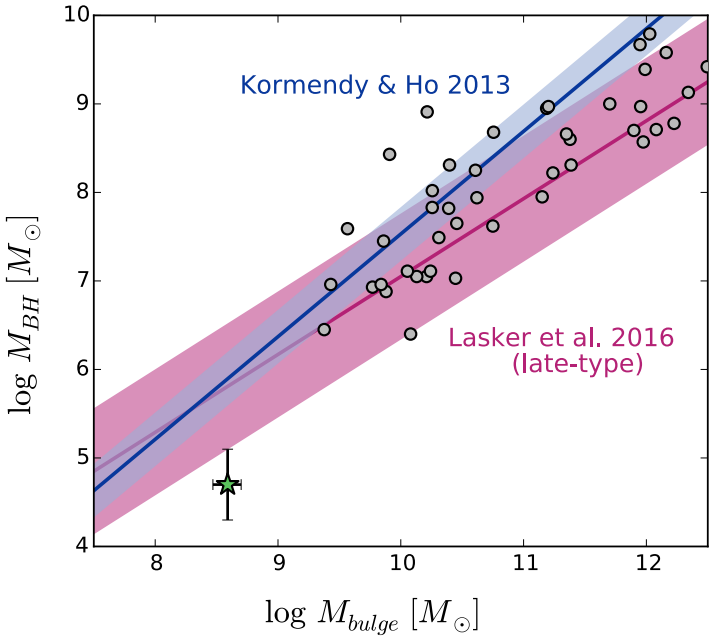
- an outer exponential disk w/ spiral structure
- inner "bulge" (n=0.8)
- central PSF

Baldassare et al. *submitted*

RGG 118 and scaling relations

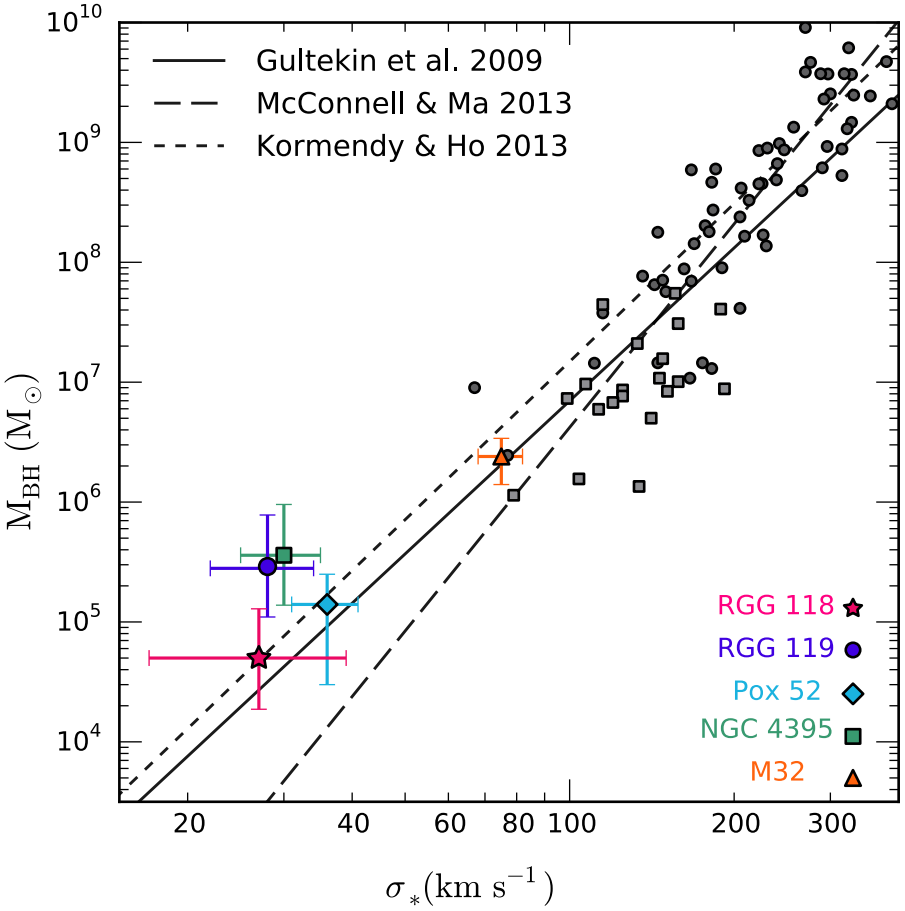
- RGG 118 sits below scaling relations between BH mass and “bulge” properties





Baldassare et al. *submitted*

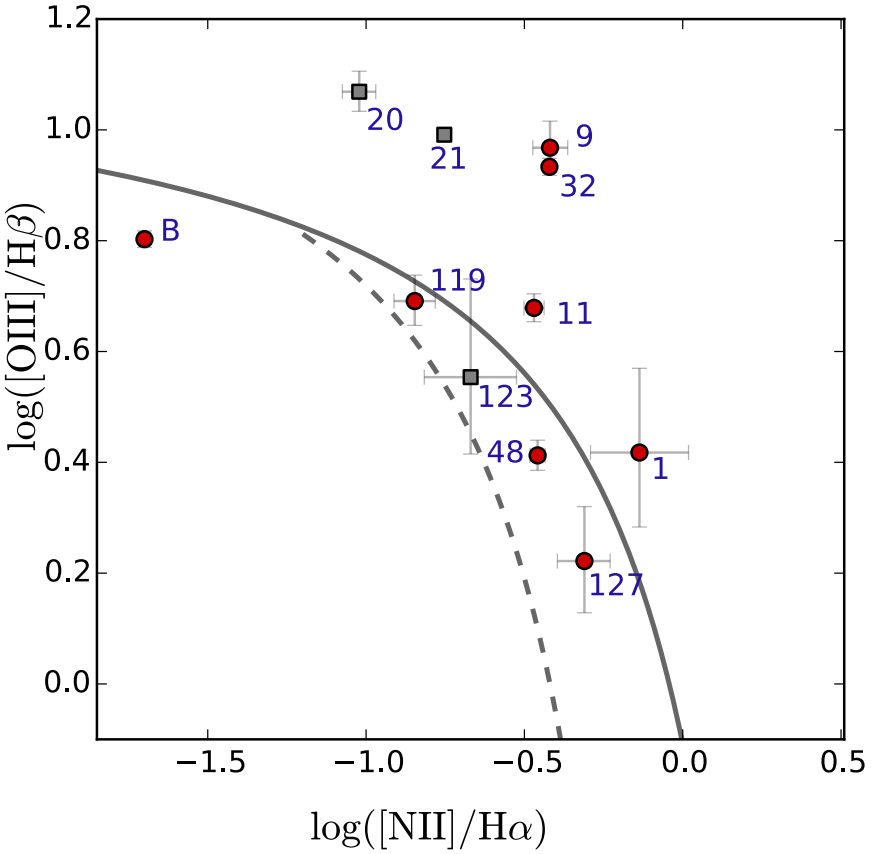
Low mass end of the M-sigma relation



Baldassare et al. 2016

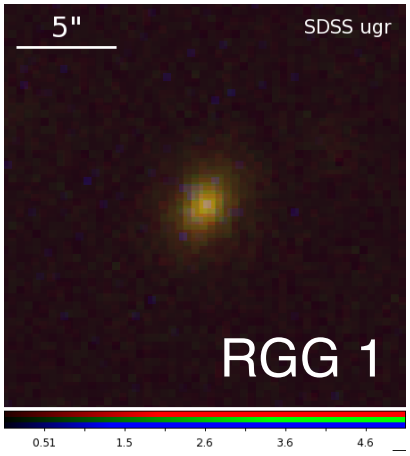
Characterizing X-ray/UV emission from AGN in dwarf galaxies

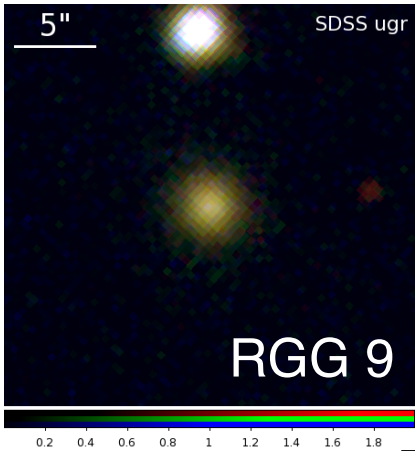
- 10 AGN/composite objects with broad emission from Reines et al. (2013)
  - 3 have archival Chandra observations
  - NEW Chandra/HST (WFC3 F275W) observations for remaining 7
  - +new observations of one star forming object with broad emission

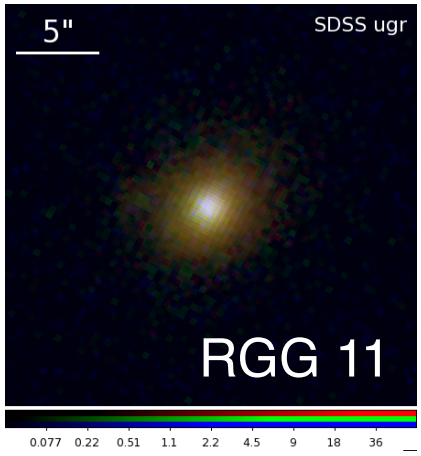


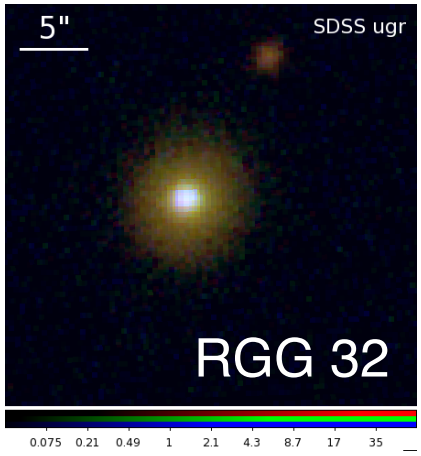
Baldasssare et al. 2017

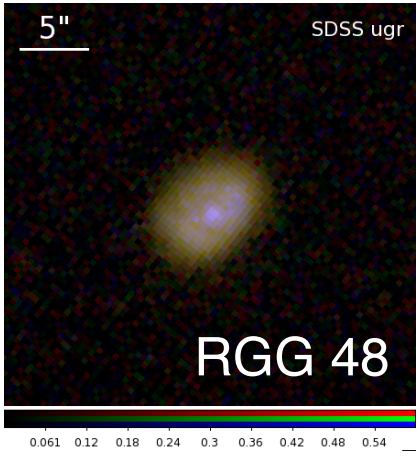
SDSS images of dwarf galaxies with AGN

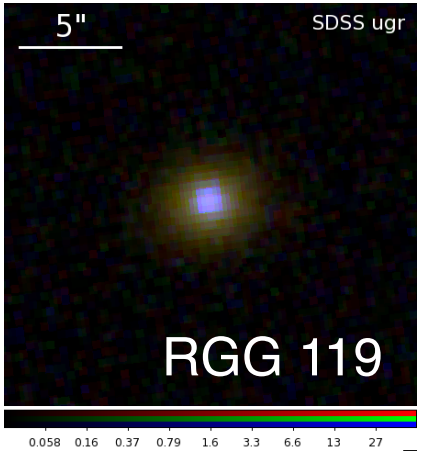


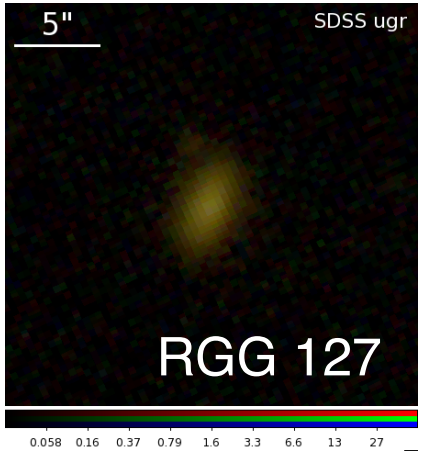


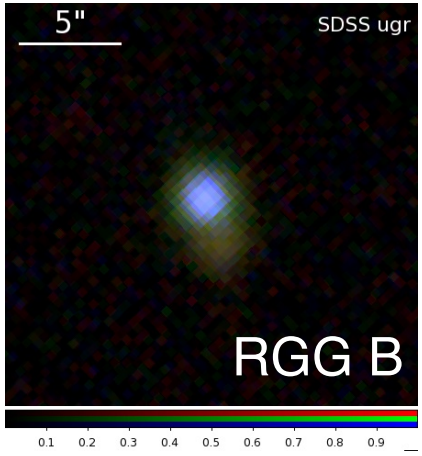




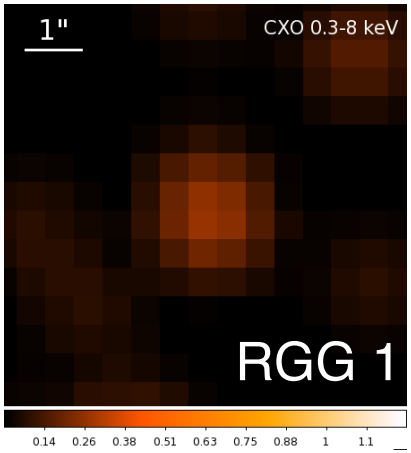


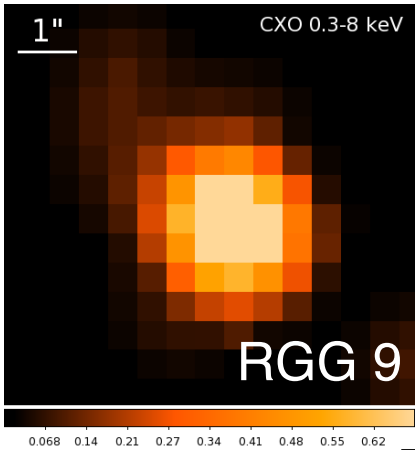


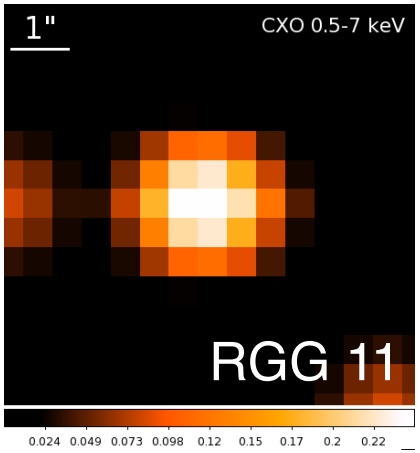


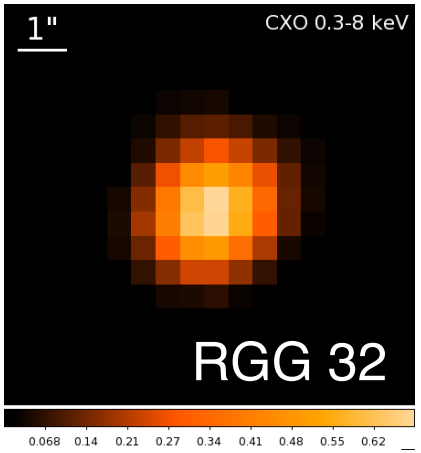


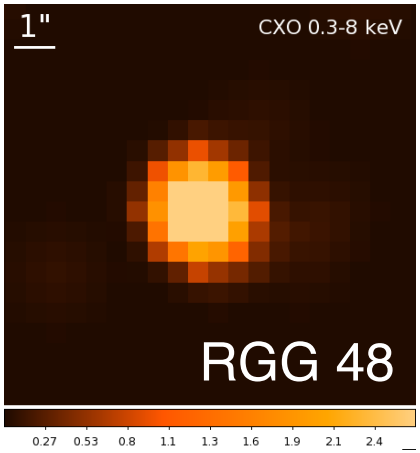
100% X-ray detection fraction

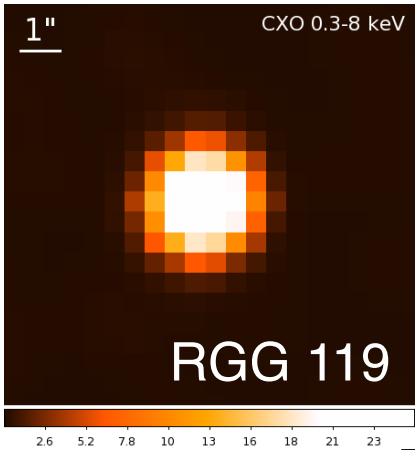


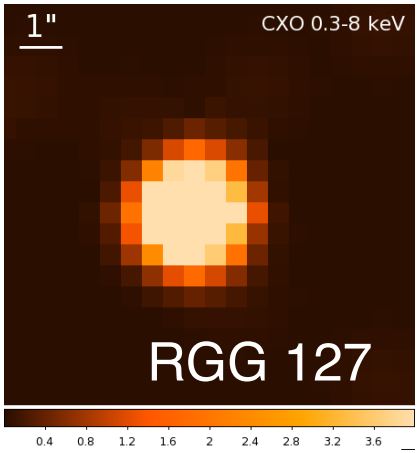


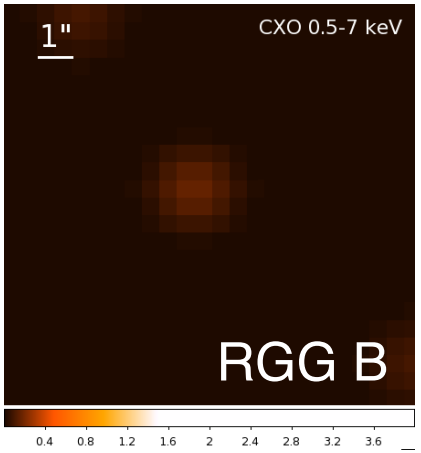






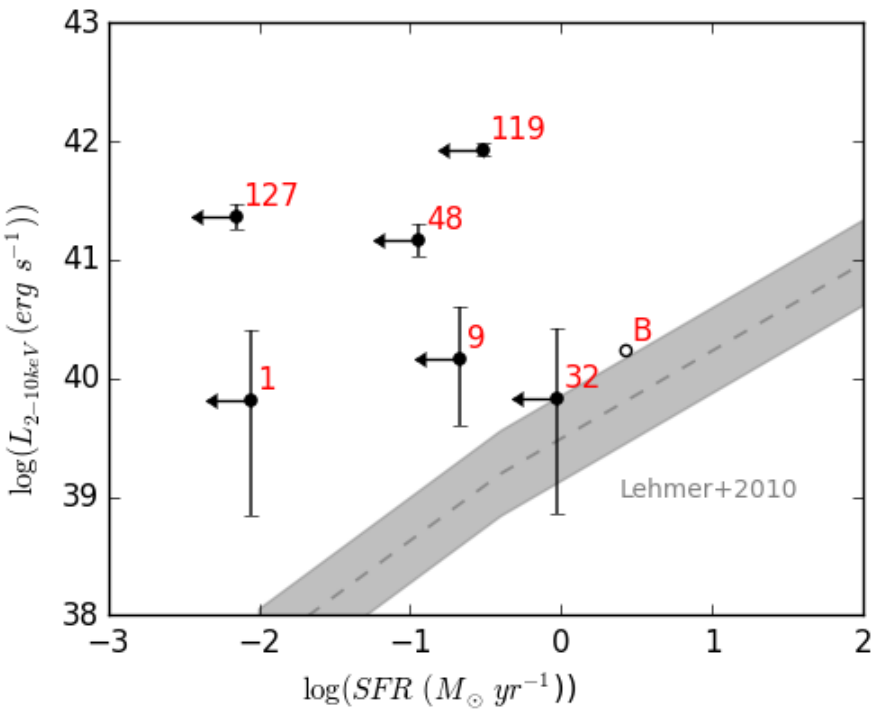






Baldassare et al. 2017

X-ray luminosities are high and greater than expected from star formation

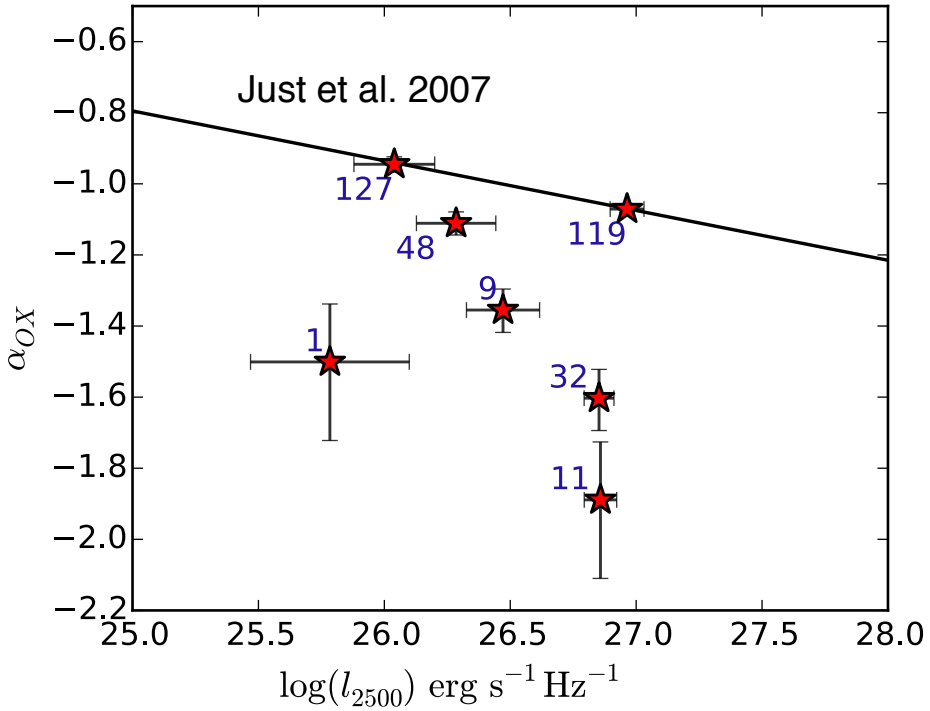


- 2-10 keV X-ray luminosities range from ~5×10^{39} to 1×10^{42} erg/s
- BH masses from broad Hα range from 8×10^{4} to 1×10^{6} $M_\odot$
- Eddington fractions range from 0.1-50%
  - Similar to massive broad-line AGN at higher z
- Strong confirmation that these galaxies host AGN (even composites!)

Baldassare et al. 2017

X-ray/UV diagostics

- α_{ox} = -0.383 log (l_{2500}/l_{2keV}) (Tananbaum et al. 1979)
- Quantifies relative power output in X-ray/UV
- Important diagnostic for accretion disk structure



Summary

- **Multi-epoch spectroscopy of dwarf galaxies with AGN signatures (Baldassare et al. 2015, 2016, submitted)**
  - Dwarf galaxies with broad emission lines and narrow line AGN signatures are secure AGN
  - Dwarf galaxies with broad lines and star formation are not
  - RGG 118: typical spiral galaxy with a 50,000 solar mass BH
- **X-ray/UV properties (Baldassare et al. 2017)**
  - AGNs in dwarf galaxies are accreting at high Eddington fractions
  - May be relatively UV bright compared to more massive AGNs