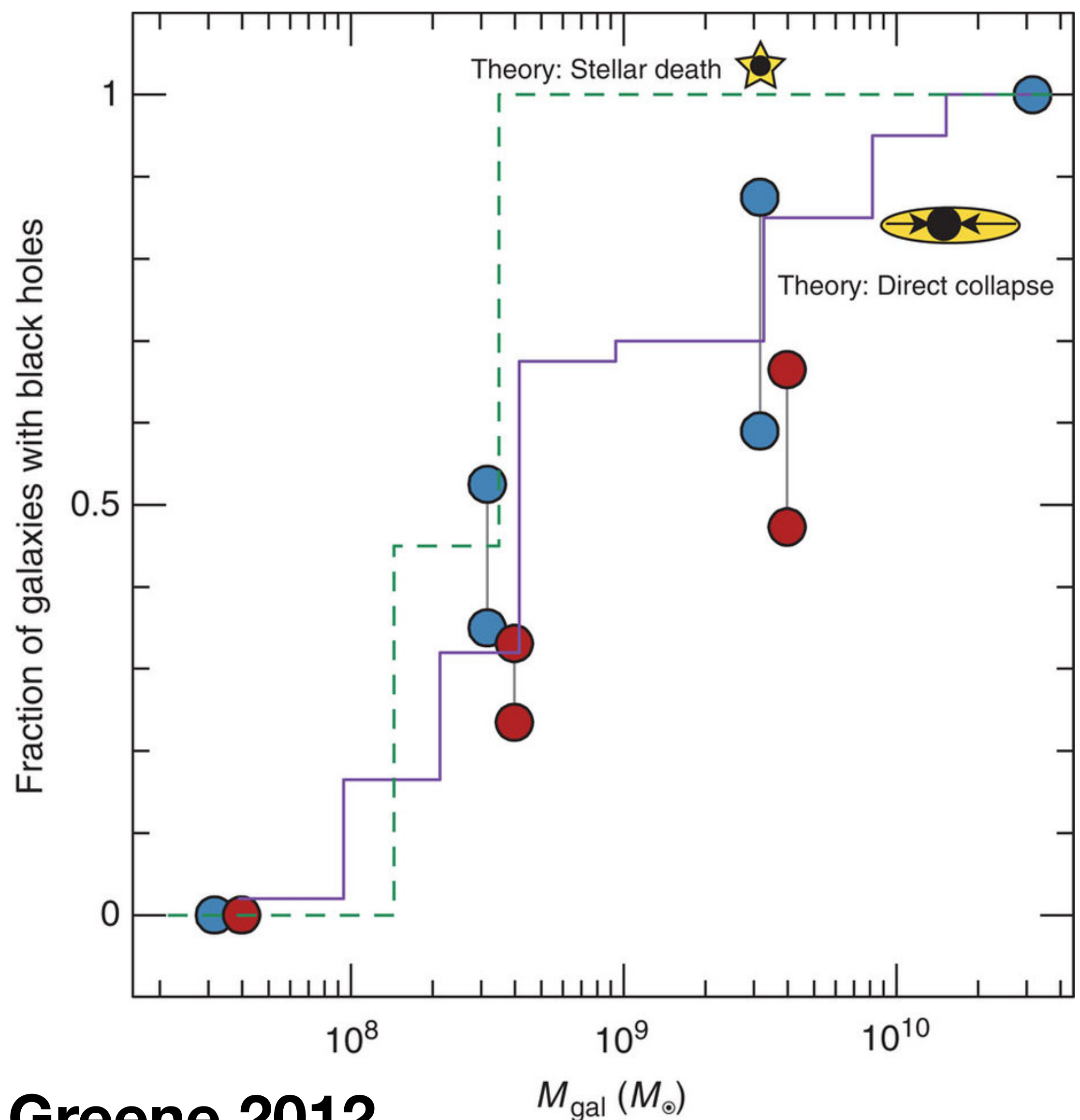
Long-term optical photometric variability as a selection tool for low-mass AGNs

arXiv: 1808.09578

Vivienne Baldassare

Yale University
Einstein Symposium 2018

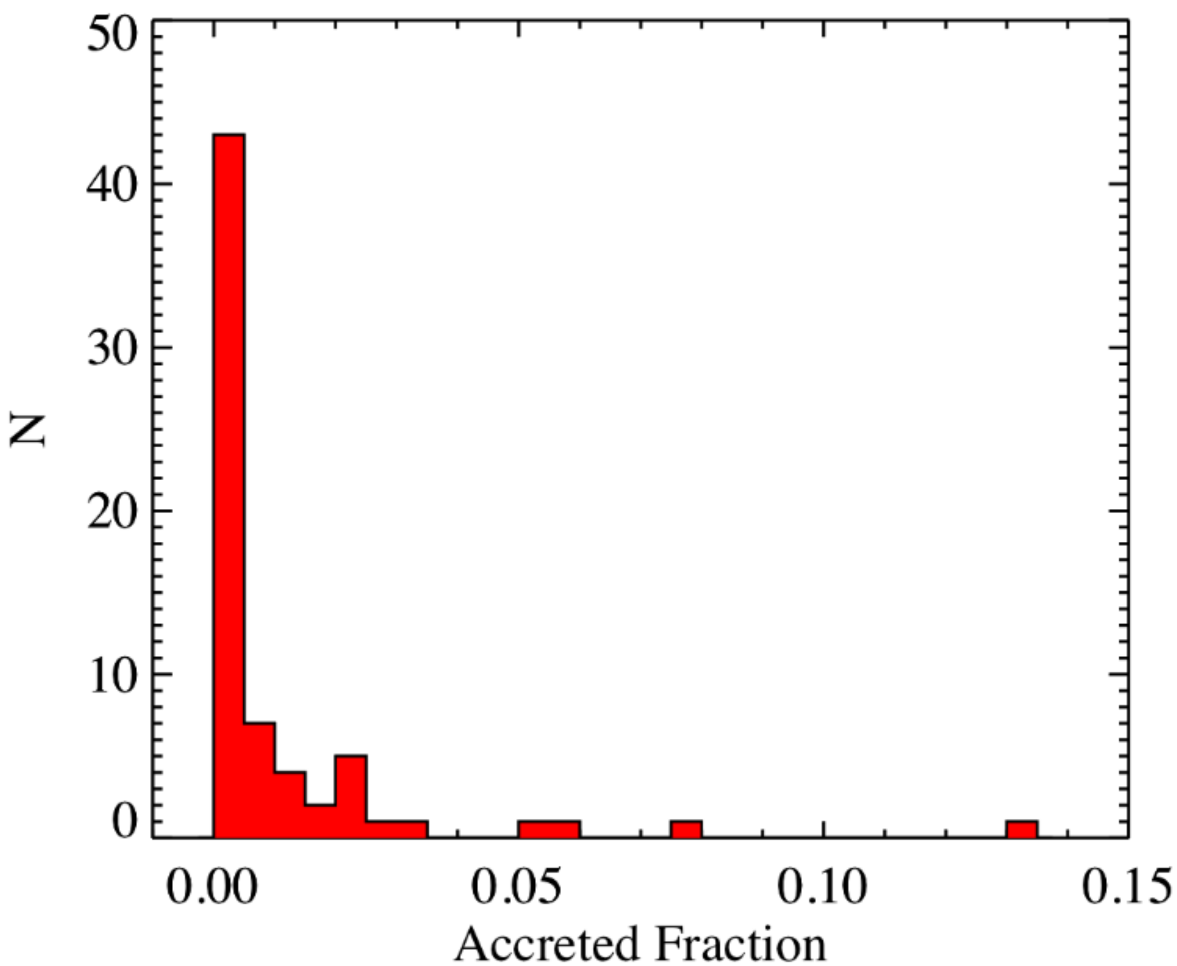
How do supermassive black holes form and grow?



Greene 2012

Fraction of BHs in low-mass galaxies is sensitive to BH seed mass/formation pathway

How do supermassive black holes form and grow?

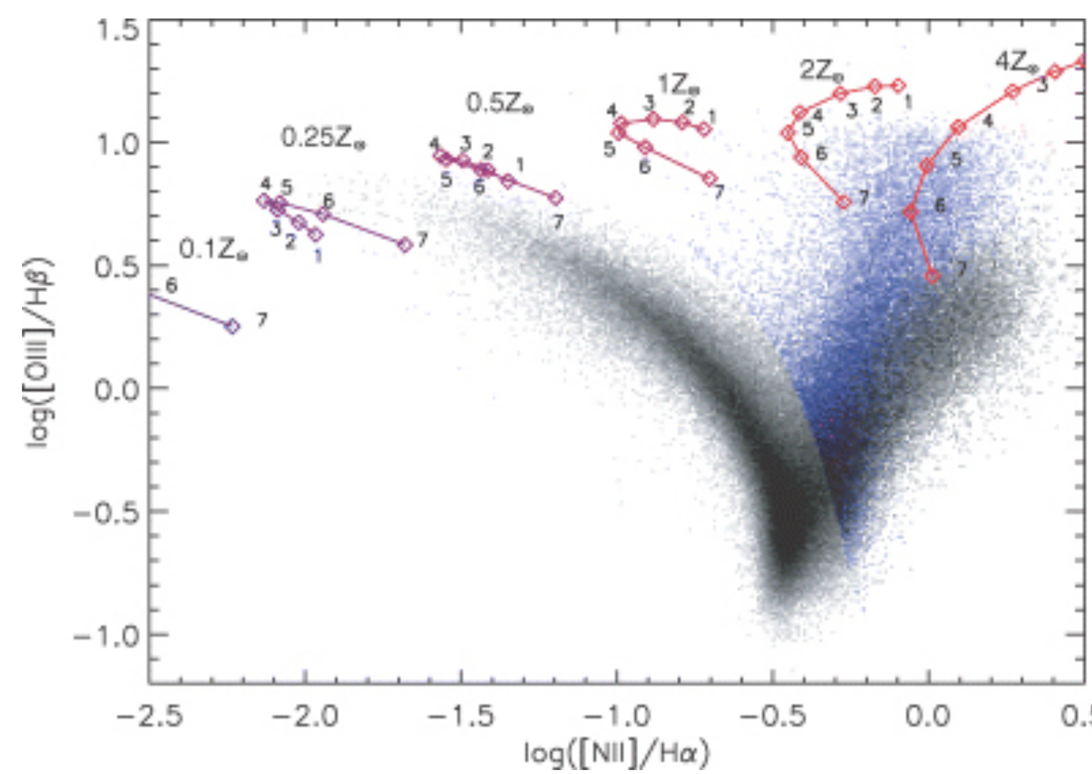


Bellovary et al. 2018

BHs in dwarf galaxies are expected to have masses similar to seed mass

Detecting massive black holes in low-mass galaxies is difficult

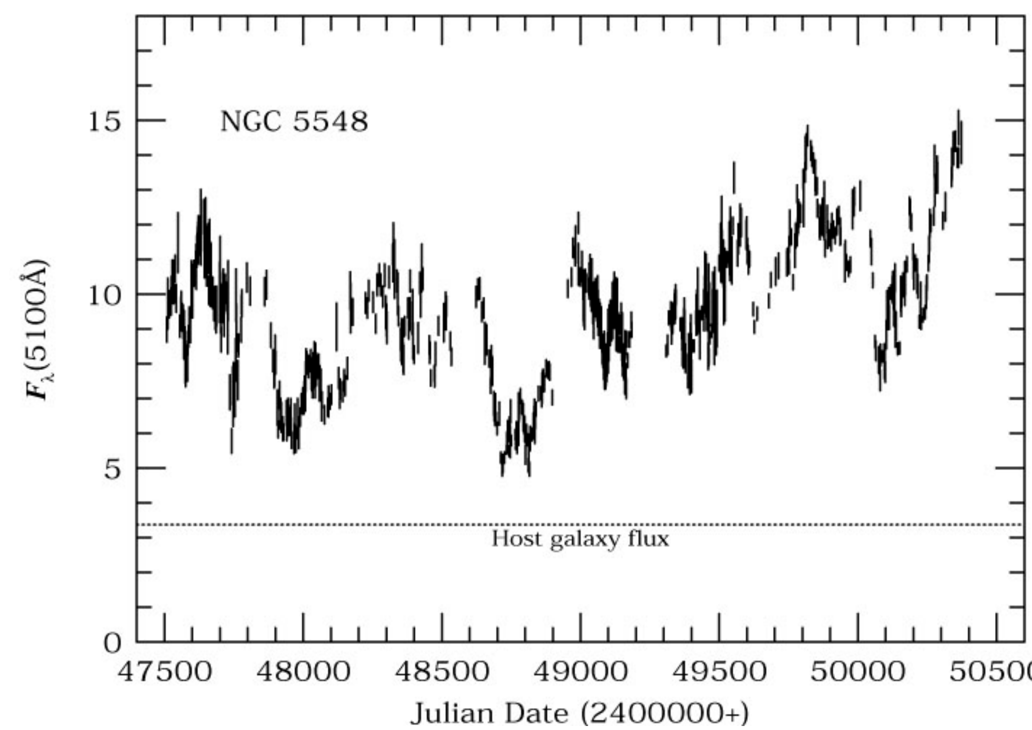
- Sphere of influence of 10^5 solar mass BH is just a few parsecs (unresolvable with HST outside Local Group)
- Low metallicity effects impact narrow line ratios (Groves et al. 2006)
- Strong star formation can dilute the contribution of AGN to narrow emission lines in low-mass galaxies (Trump et al. 2015)



Groves et al. 2006

Nuclear optical variability selection of active galactic nuclei

- AGN show aperiodic flux variations over a wide range in wavelengths on a variety of timescales
- Variability is aperiodic, amplitude of variability changes
- Origin of variability typically attributed to instabilities in the accretion disk



Peterson et al. 1997

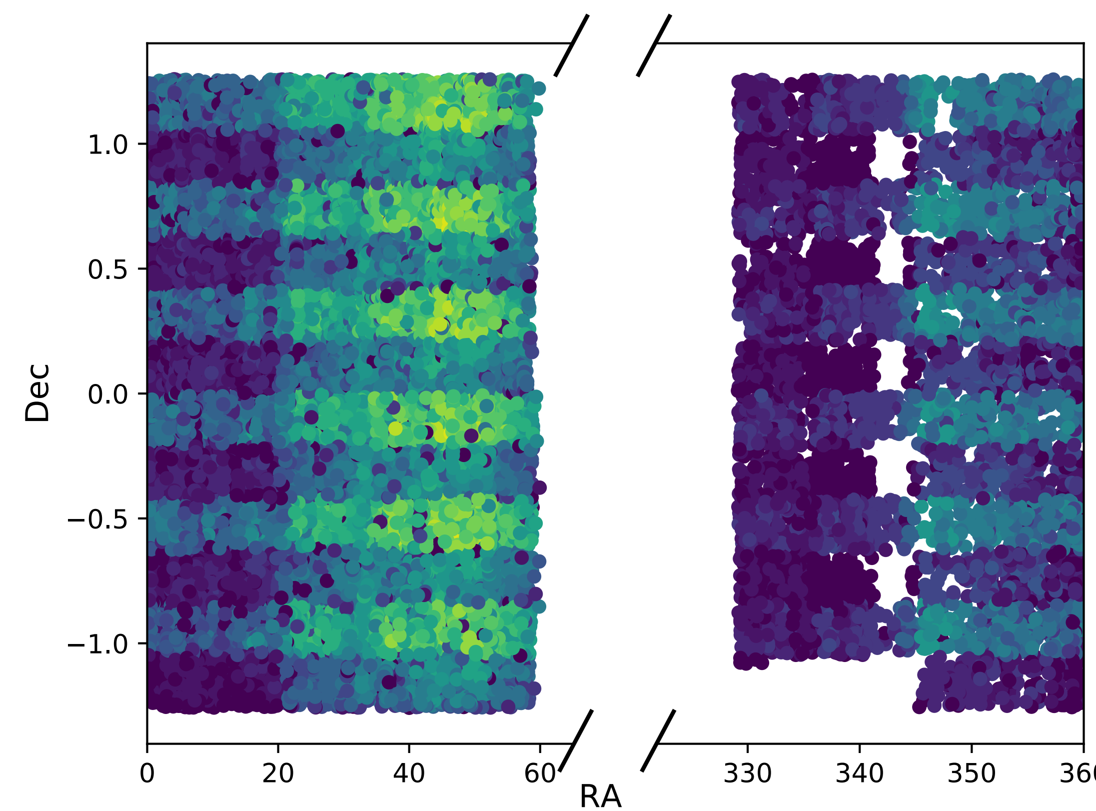
Searching for optical variability in NASA-Sloan Atlas x Stripe 82

Difference imaging analysis of 28,000 galaxies in NASA-Sloan Atlas + Stripe 82

All galaxies have stellar mass estimates and spec-z

$M_\star$ from ~10^7 - 10^{12} $M_\odot$

$z < 0.15$



Positions of NSA x Stripe 82 sample

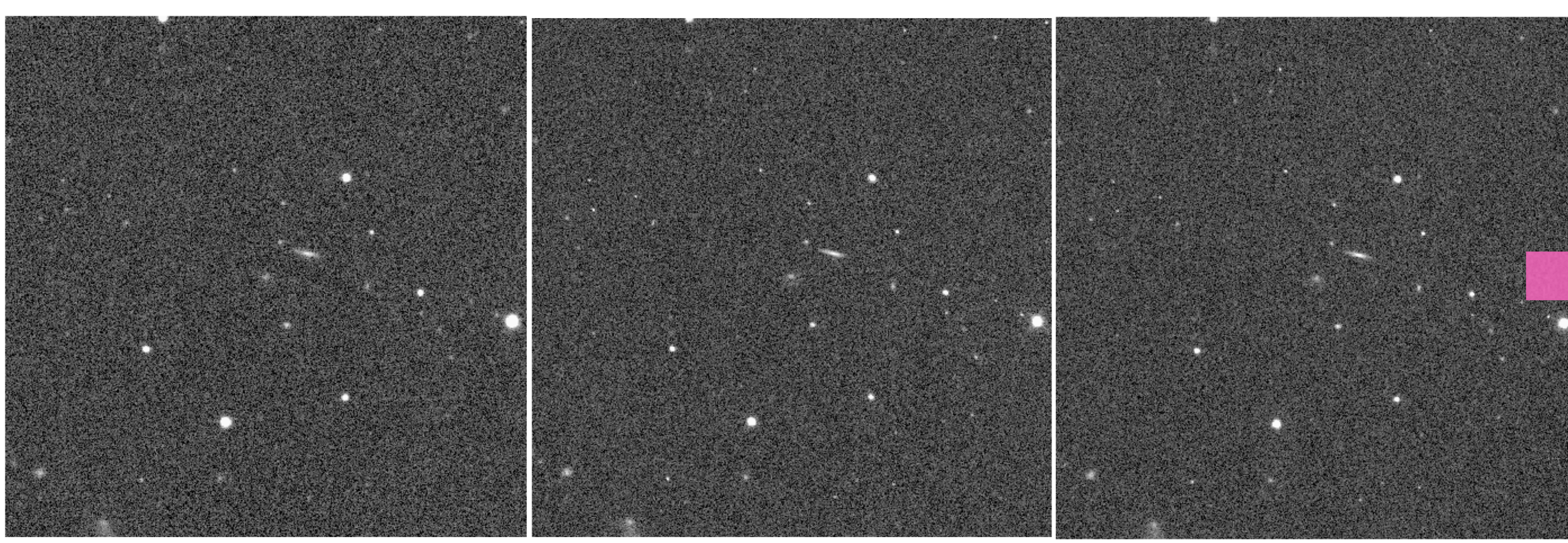
Baldassare et al. submitted

Light curve construction

- Use difference imaging photometry (Alard & Lupton 1998; Alard 2000, Wozniak 2000)

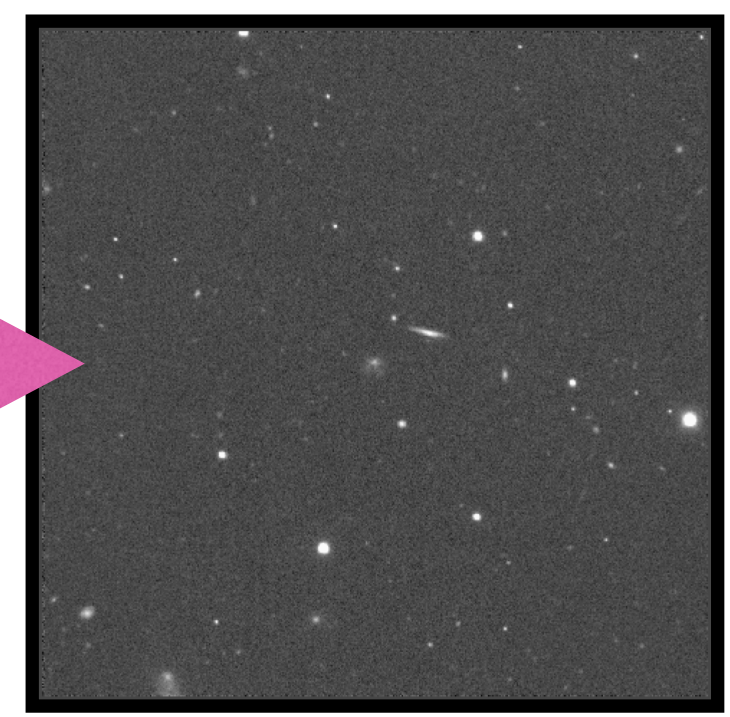
Basic steps

1. Construct a template image from the best frames



Individual exposures

Template

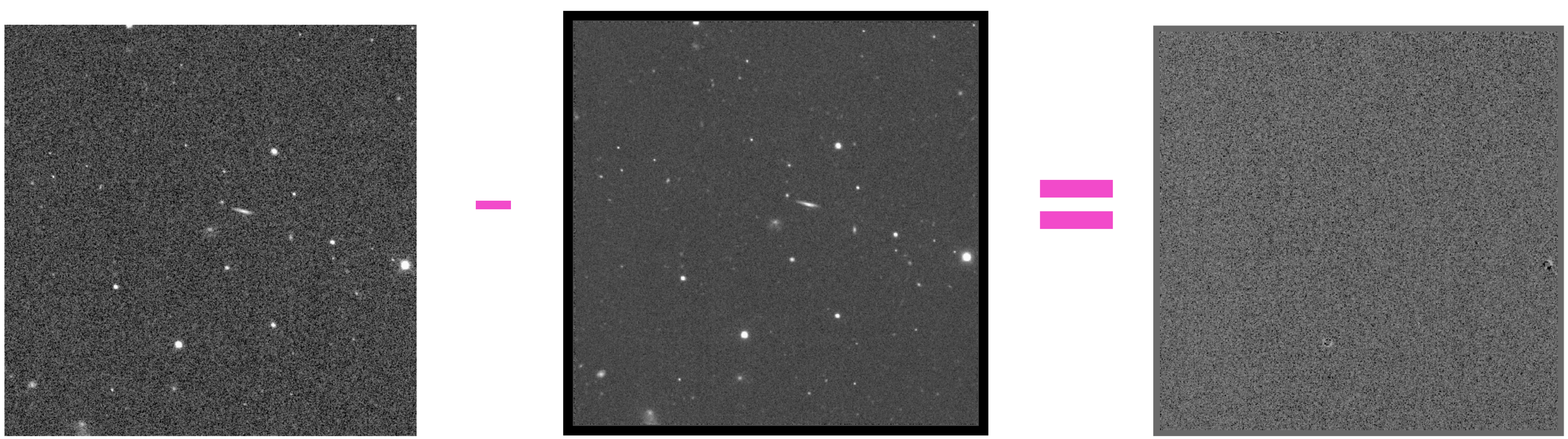


Light curve construction

Basic steps

1. Construct a template image from the best frames

2. For each individual exposure, template image convolved with a kernel to match the seeing. The convolved template is then subtracted from each exposure.



Individual exposure **Template** **Difference image**

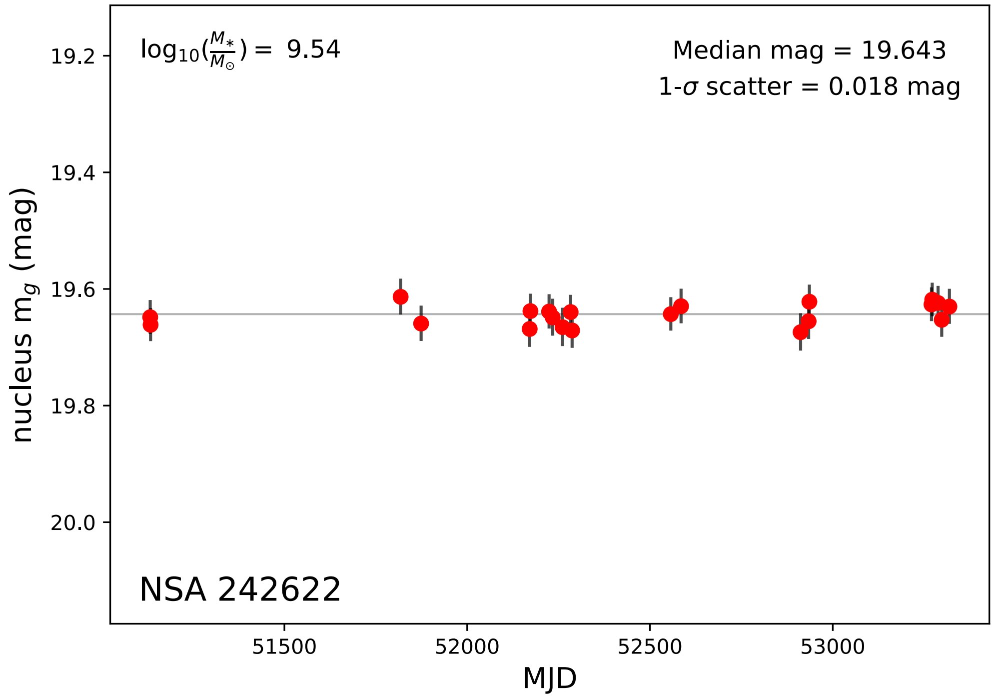
Light curve construction

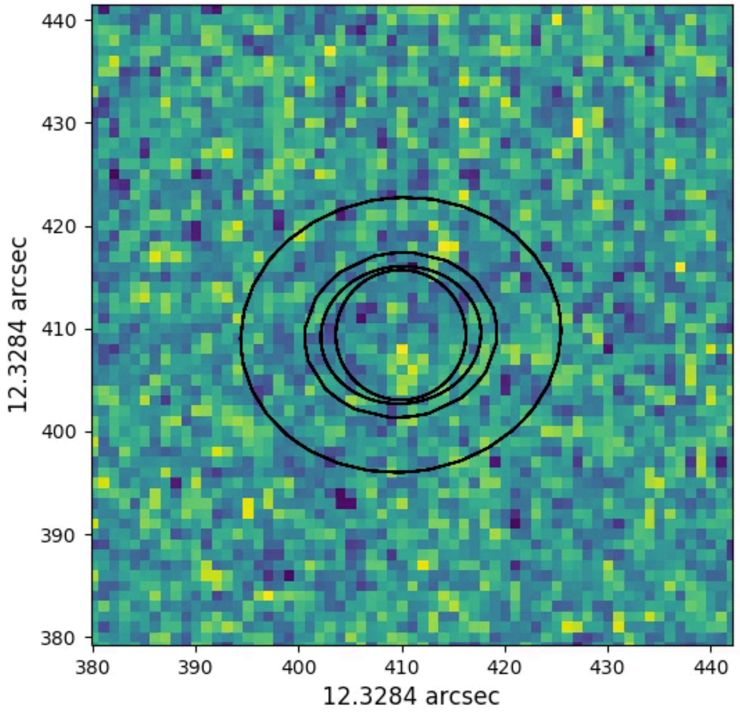
Steps

1. Construct a template image from the best frames

2. For each individual exposure, template image convolved with a kernel to match the seeing. The convolved template is then subtracted from each exposure.

3. Construct a light curve using forced photometry of template and difference images

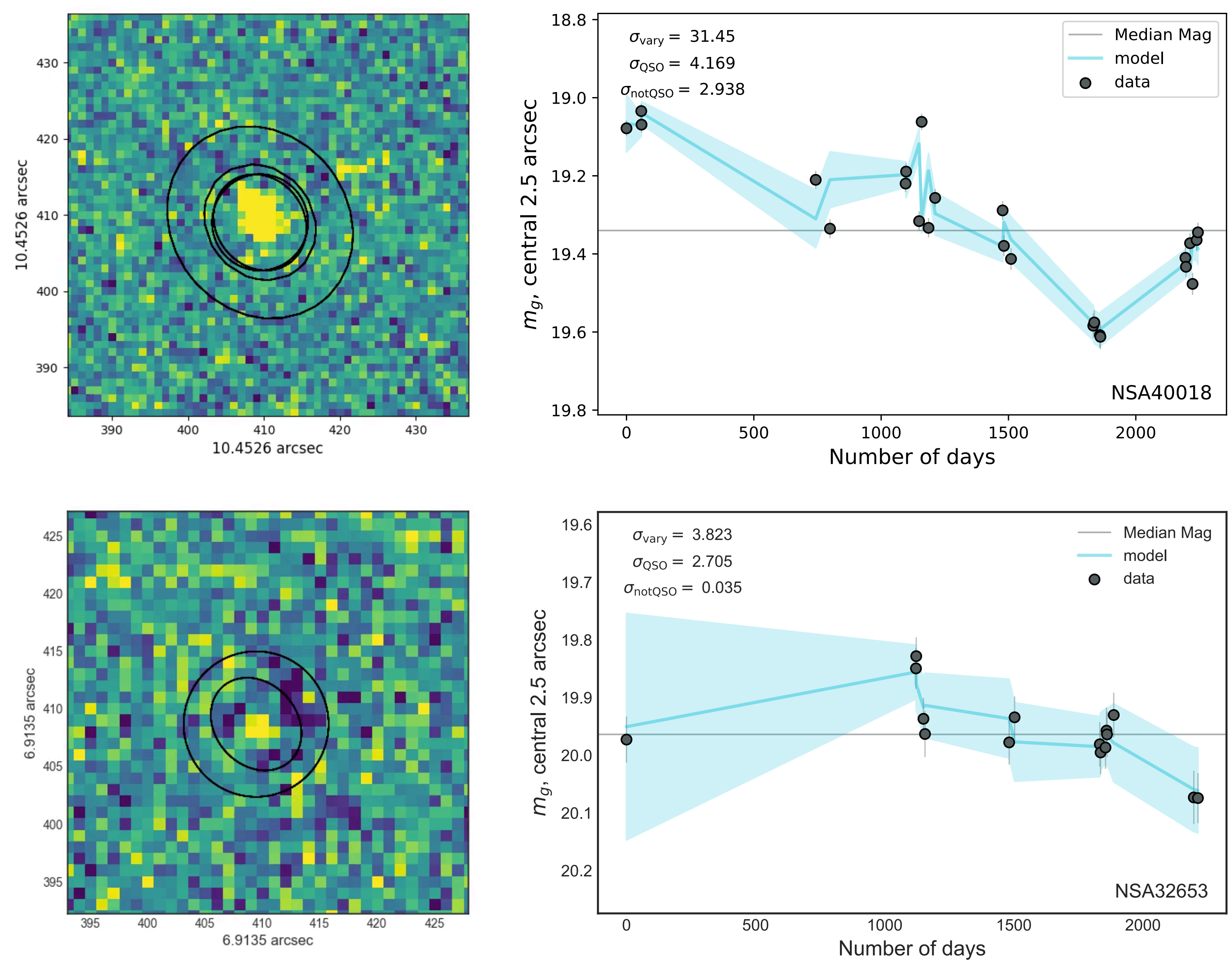




Selection of nuclei with AGN-like variability

- QSOfit code (Butler & Bloom 2011) determines the fit quality of the *damped random walk* model to a given light curve

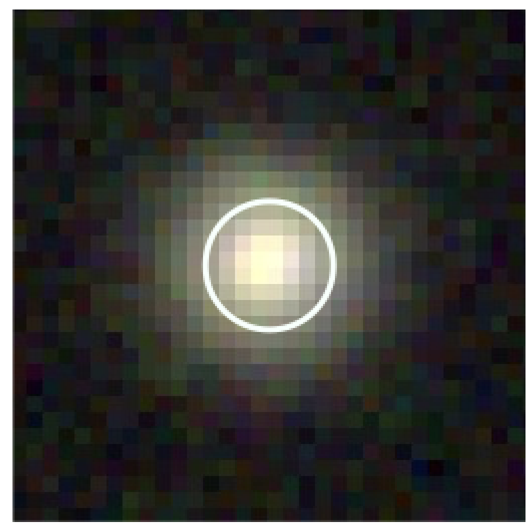
- Galaxies are selected as having AGN-like variability if they are:
    - Variable with >2-σ significance
    - Significance that the fit to a damped random walk model is better than random variability is > 2-σ

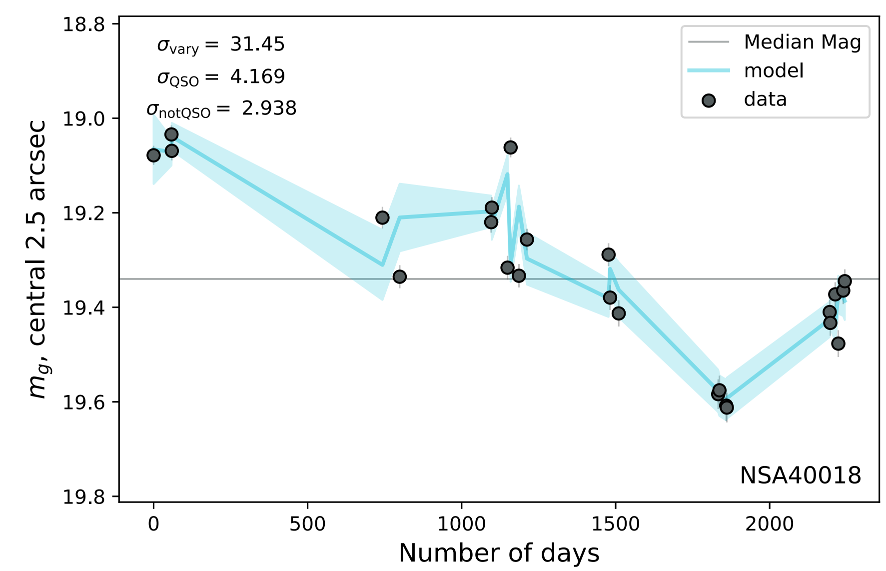


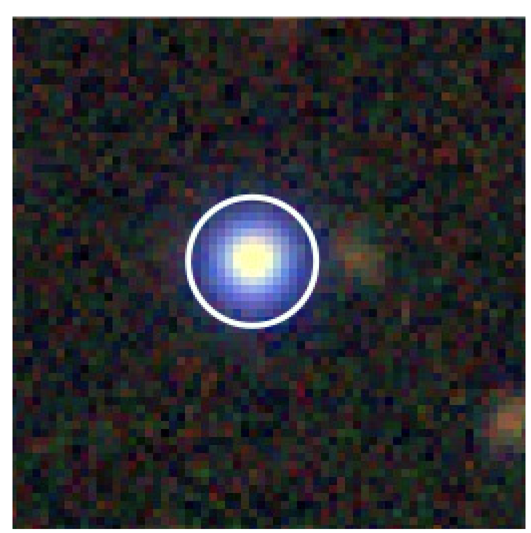
Selection of nuclei with AGN-like variability

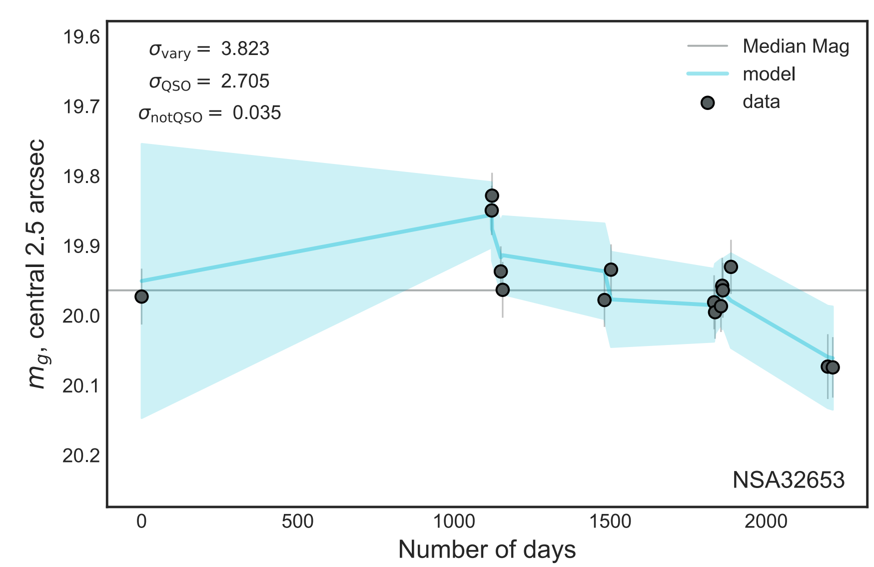
- QSOfit code (Butler & Bloom 2011) determines the fit quality of the *damped random walk* model to a given light curve

- Galaxies are selected as having AGN-like variability if they are:
    - Variable with >2-σ significance
    - Significance that the fit to a damped random walk model is better than random variability is > 2-σ

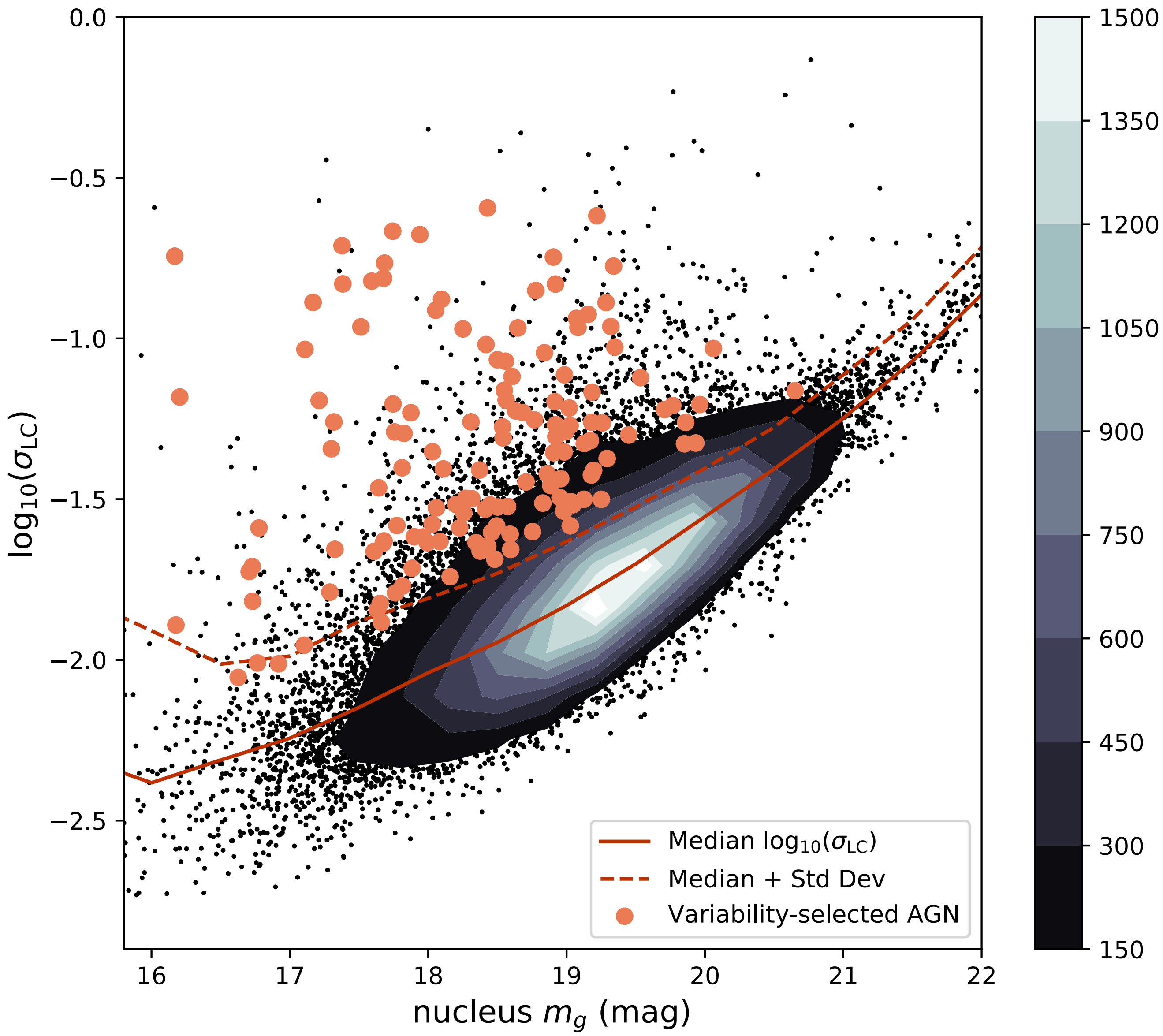


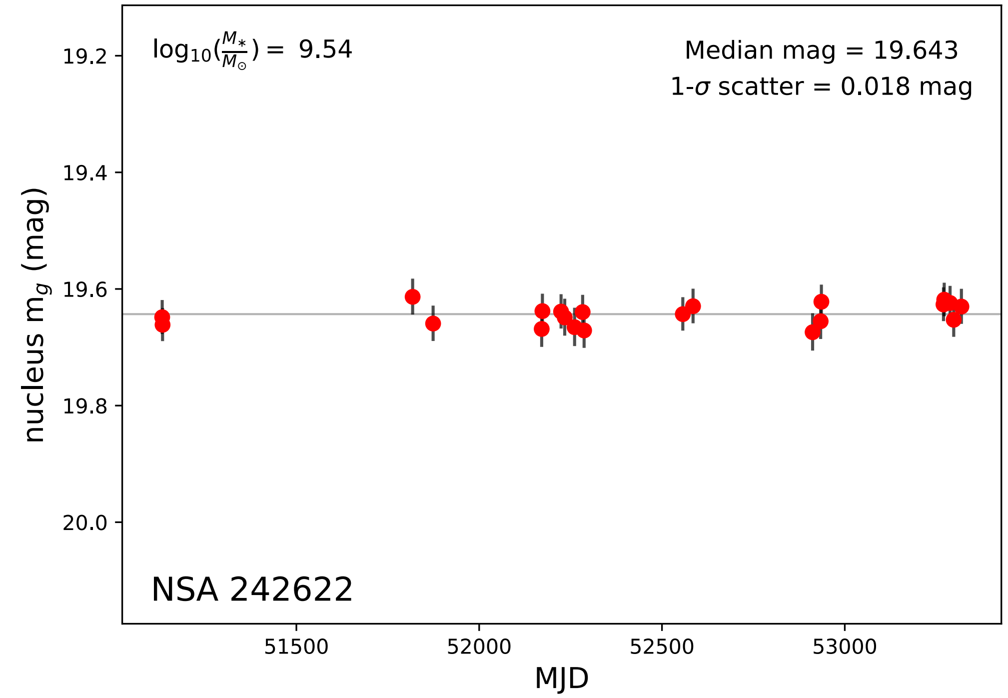


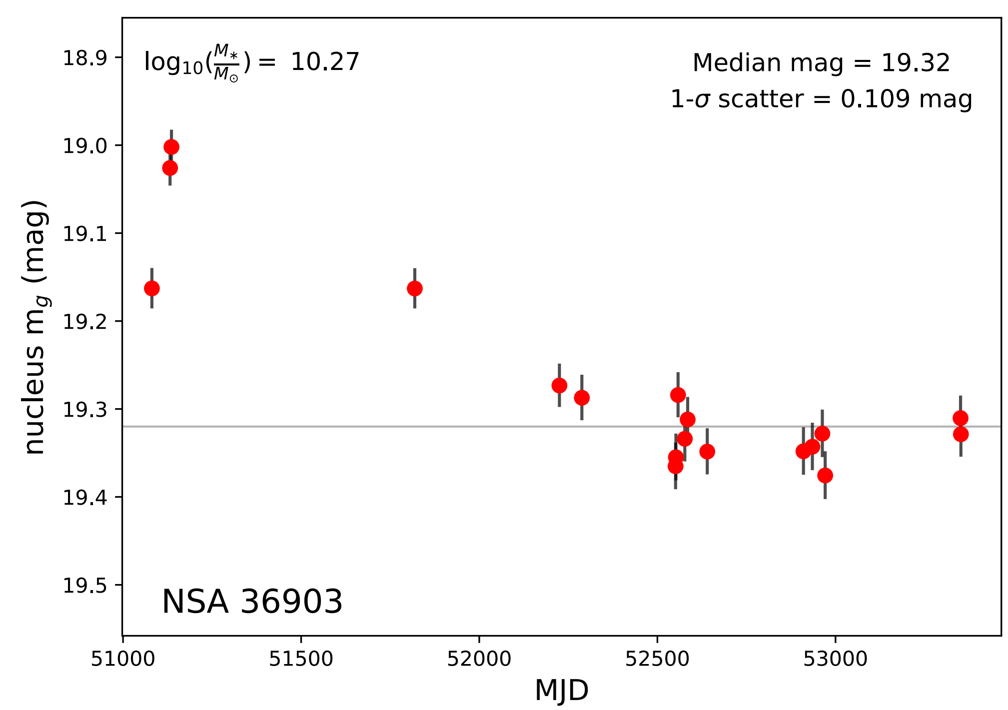




Selection of nuclei with AGN-like variability





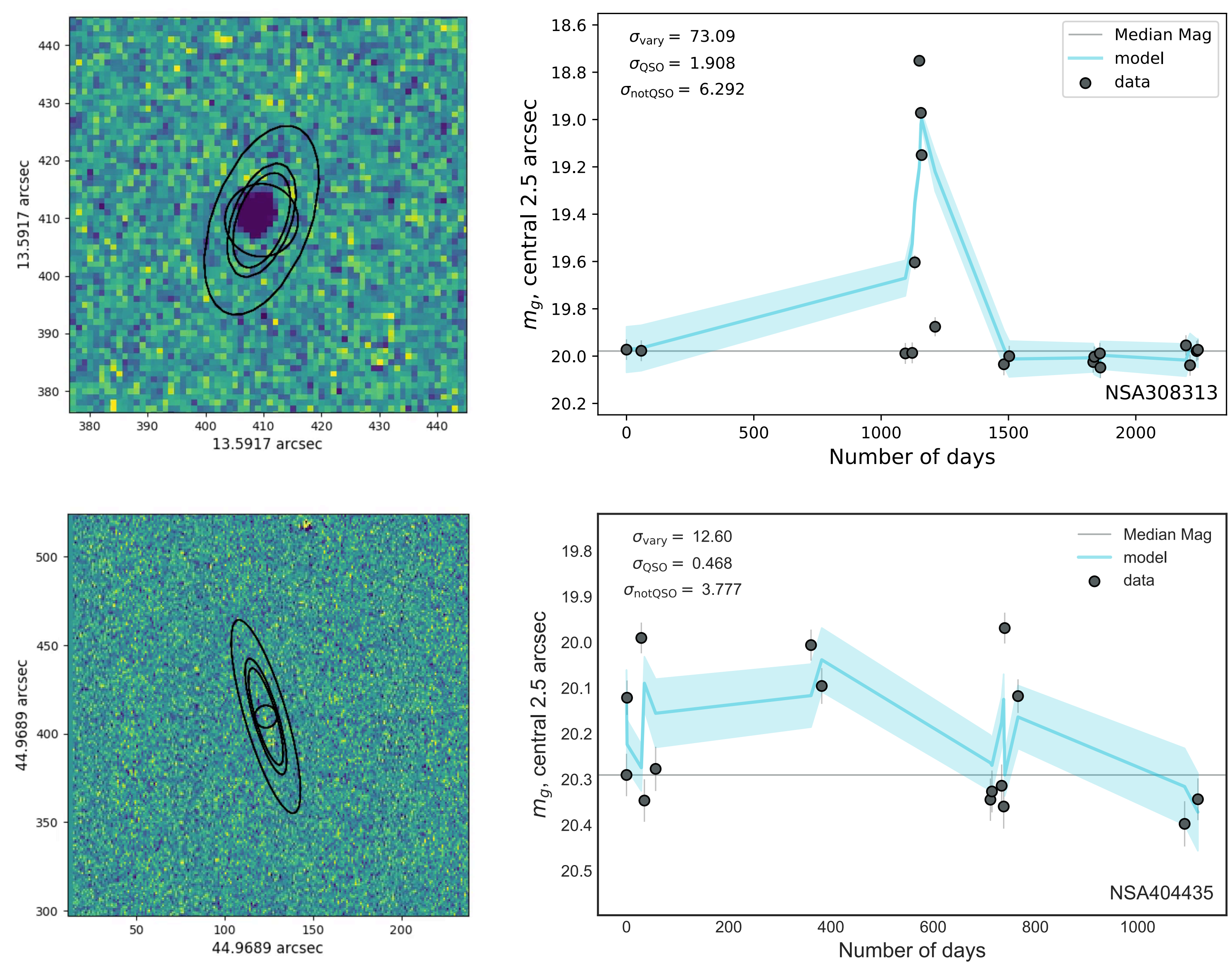


Baldassare et al. submitted

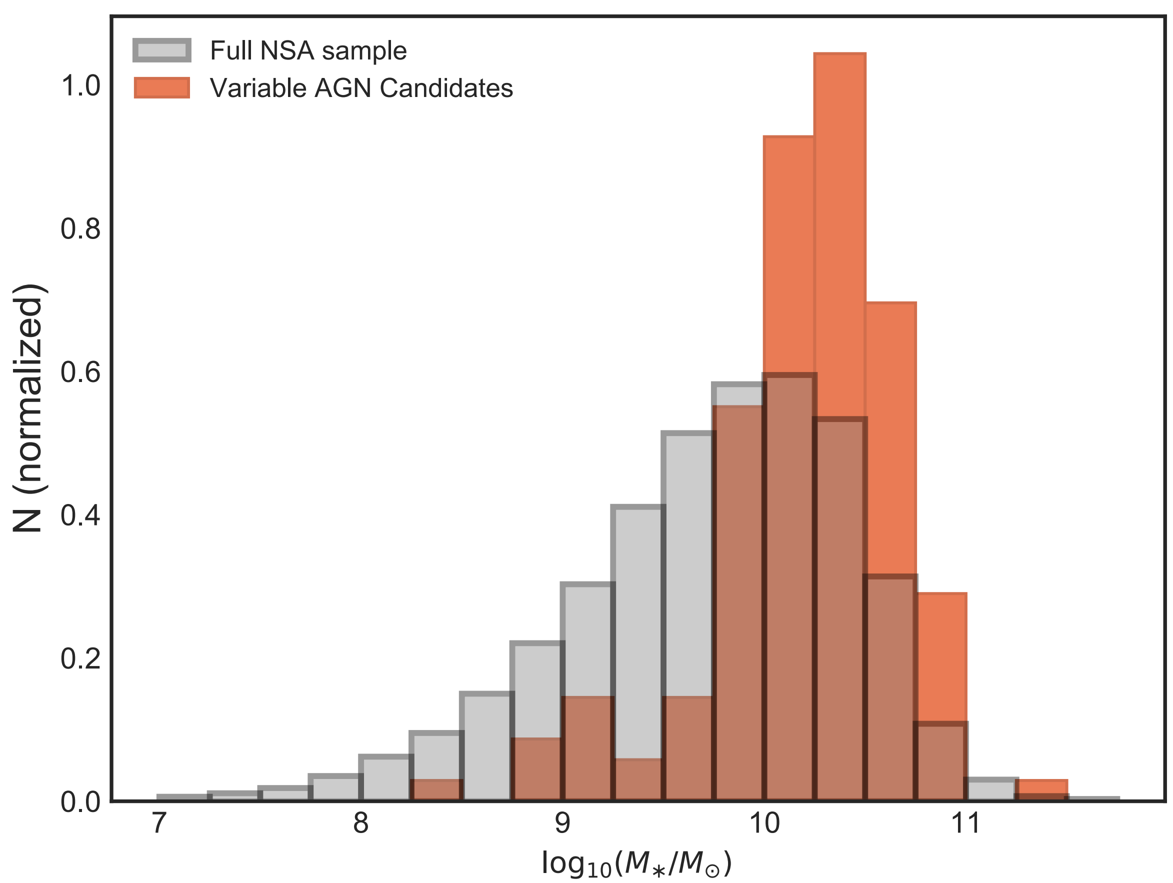
Galaxies with non-AGN like variability

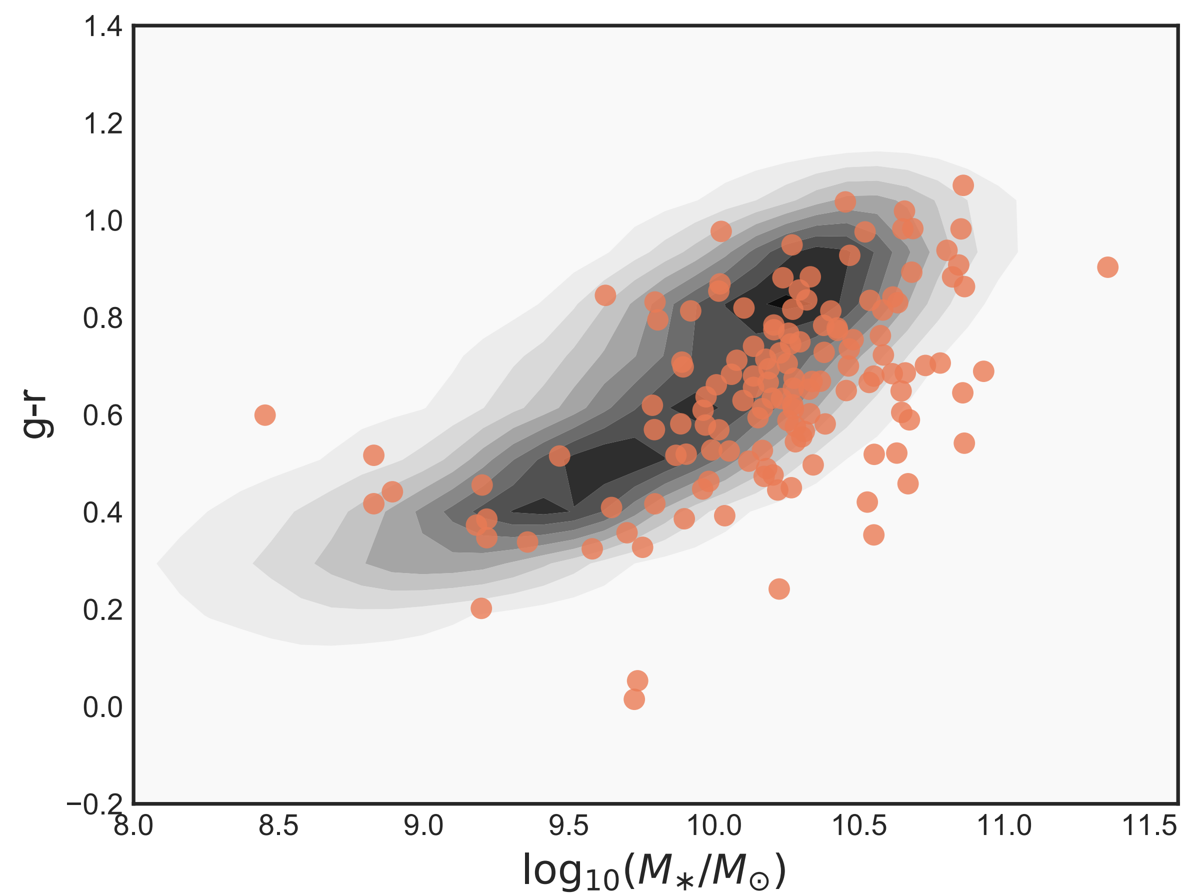
- QSOfit code (Butler & Bloom 2011) determines the fit quality of the *damped random walk* model to a given light curve

- Galaxies are selected as having AGN-like variability if they are:
  - Variable with >2-σ significance
  - Significance that the fit to a damped random walk model is better than random variability is > 2-σ



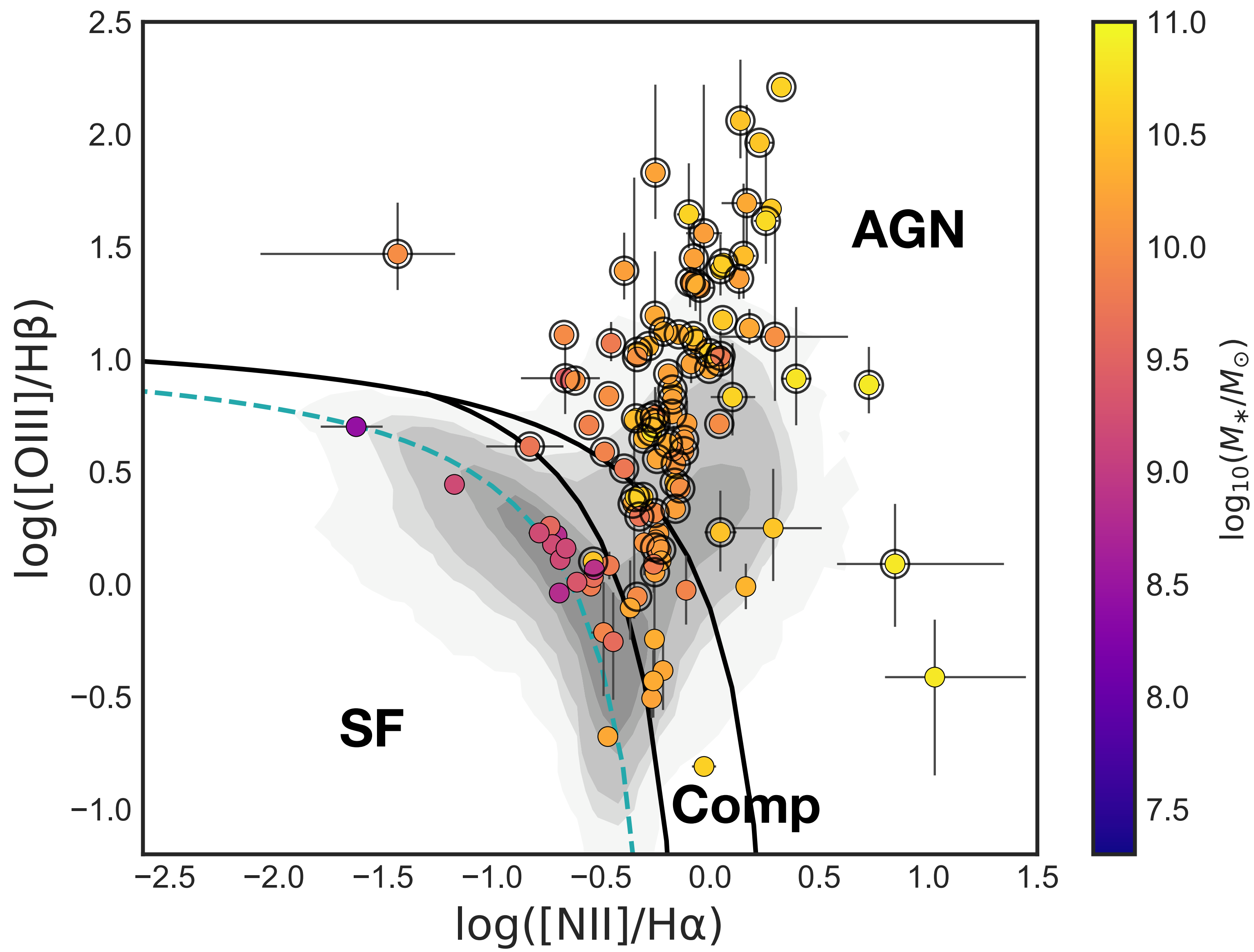
135 galaxies with AGN-like nuclear variability





Baldassare et al. submitted

Spectroscopic properties of variability-selected AGN candidates



Above 10^{10} $M_\odot$

- 86/88 galaxies in AGN or composite regions of BPT diagram
- 80% have broad H-alpha emission

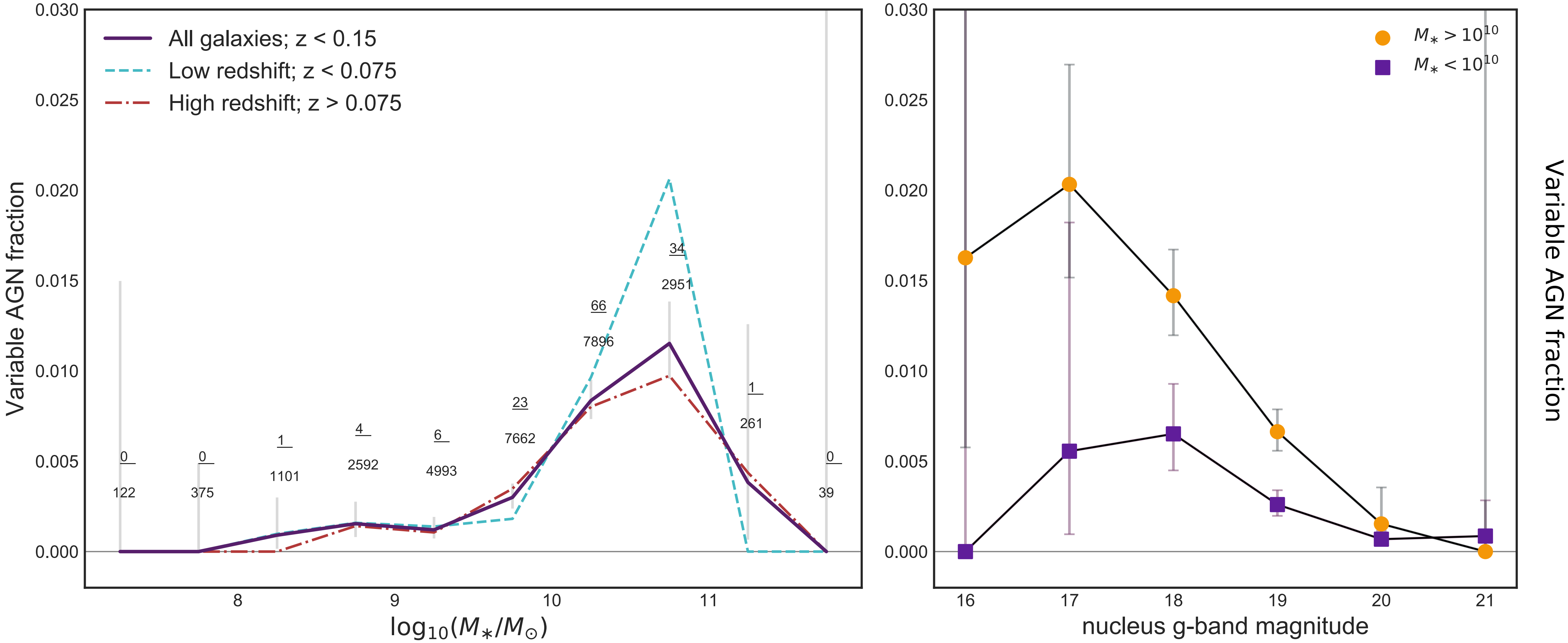
Below 10^{10} $M_\odot$

- 16/33 galaxies in star forming region of BPT diagram
- 50% have broad H-alpha emission

The variability selected AGN with SF-dominated narrow lines could be AGN missed by other selection techniques

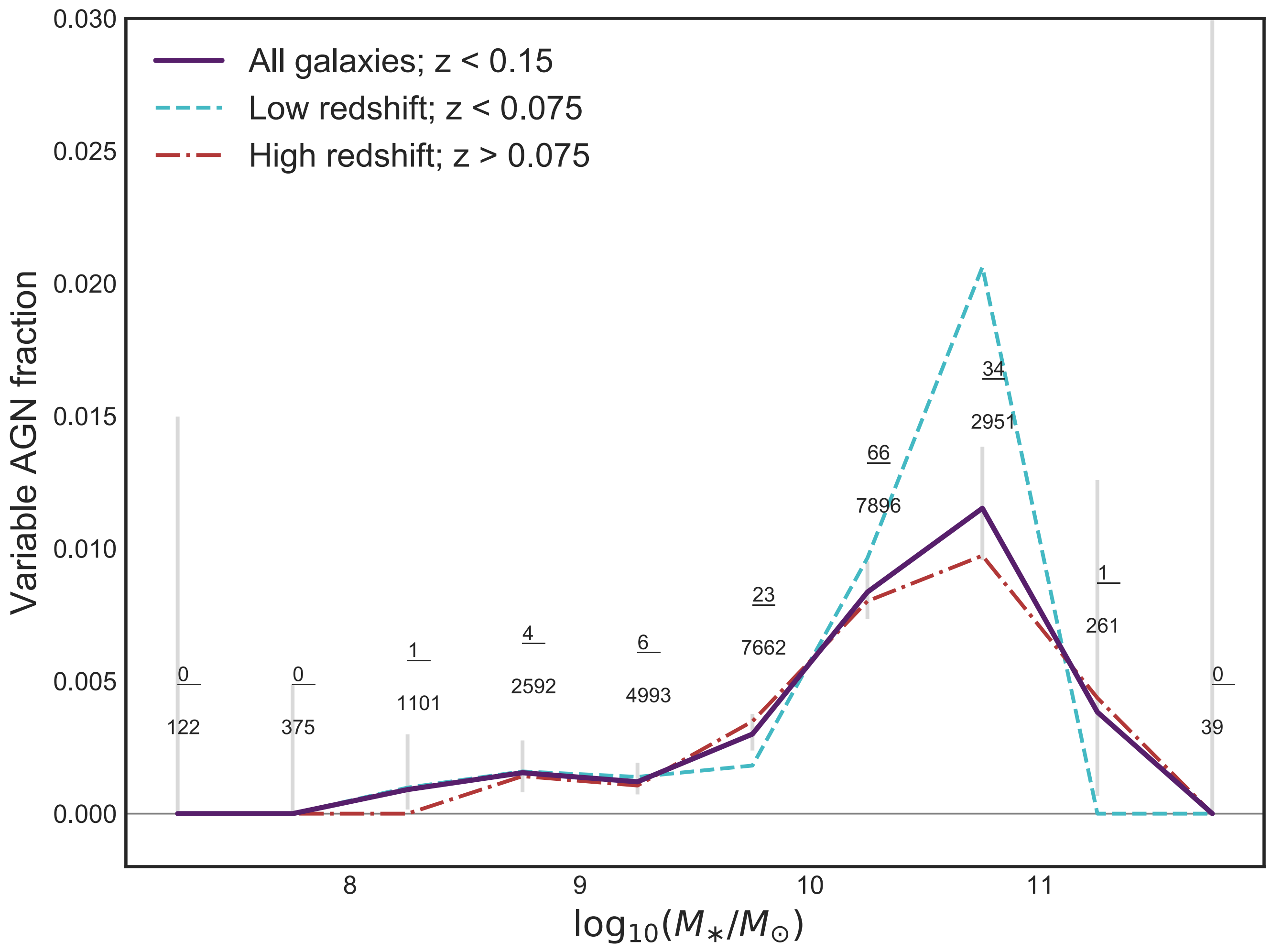
Baldassare et al. submitted

Nuclear optical variability as a function of $M_\star$



Baldassare et al. submitted

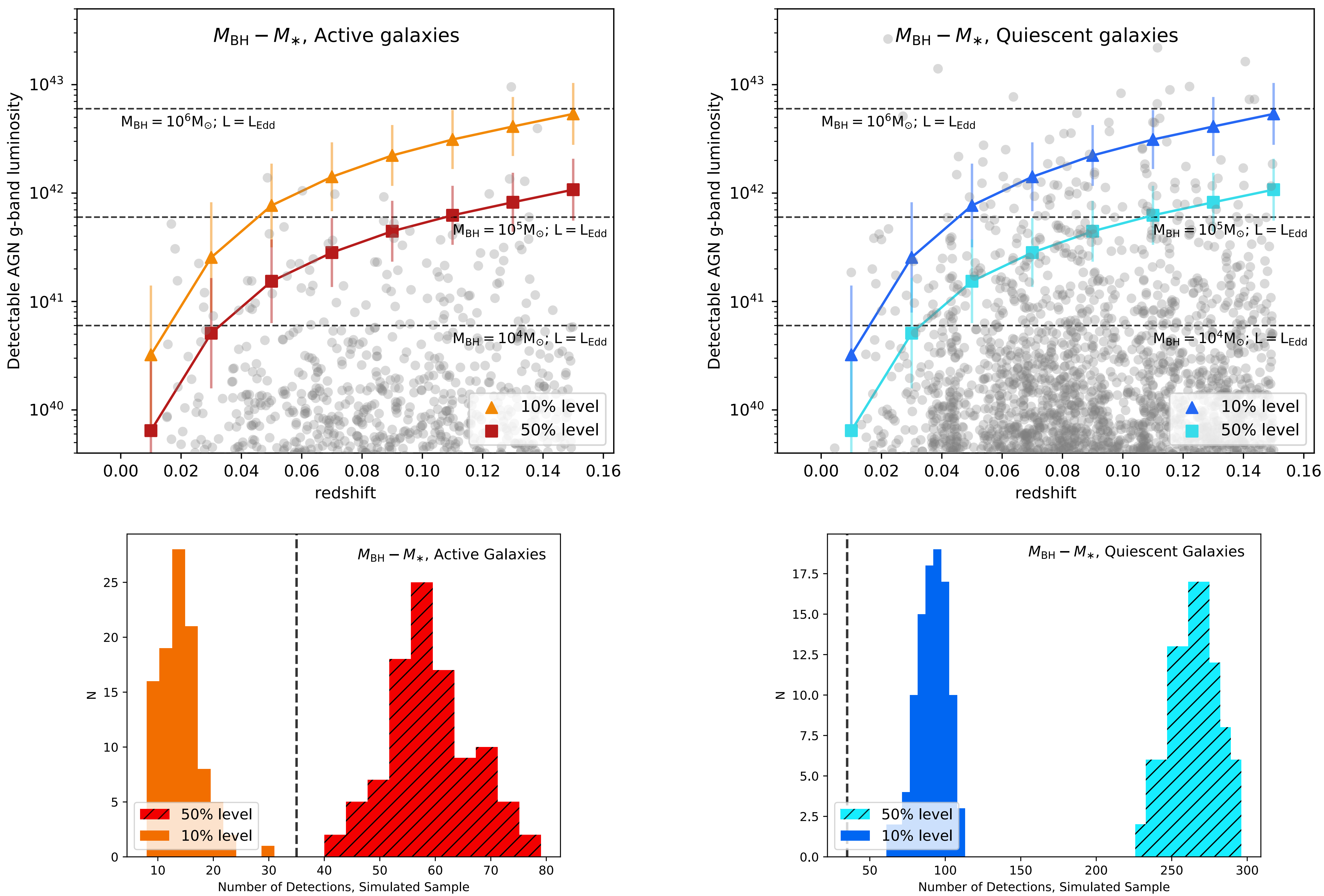
Nuclear optical variability as a function of $M_\star$



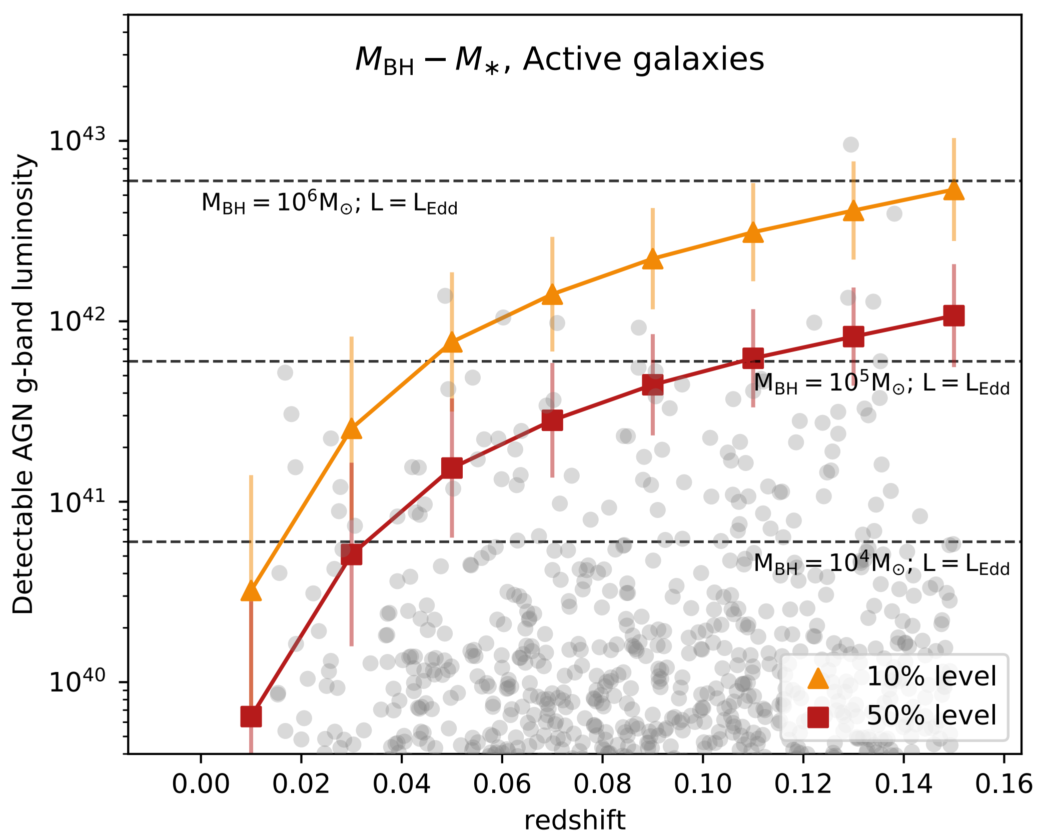
Why?

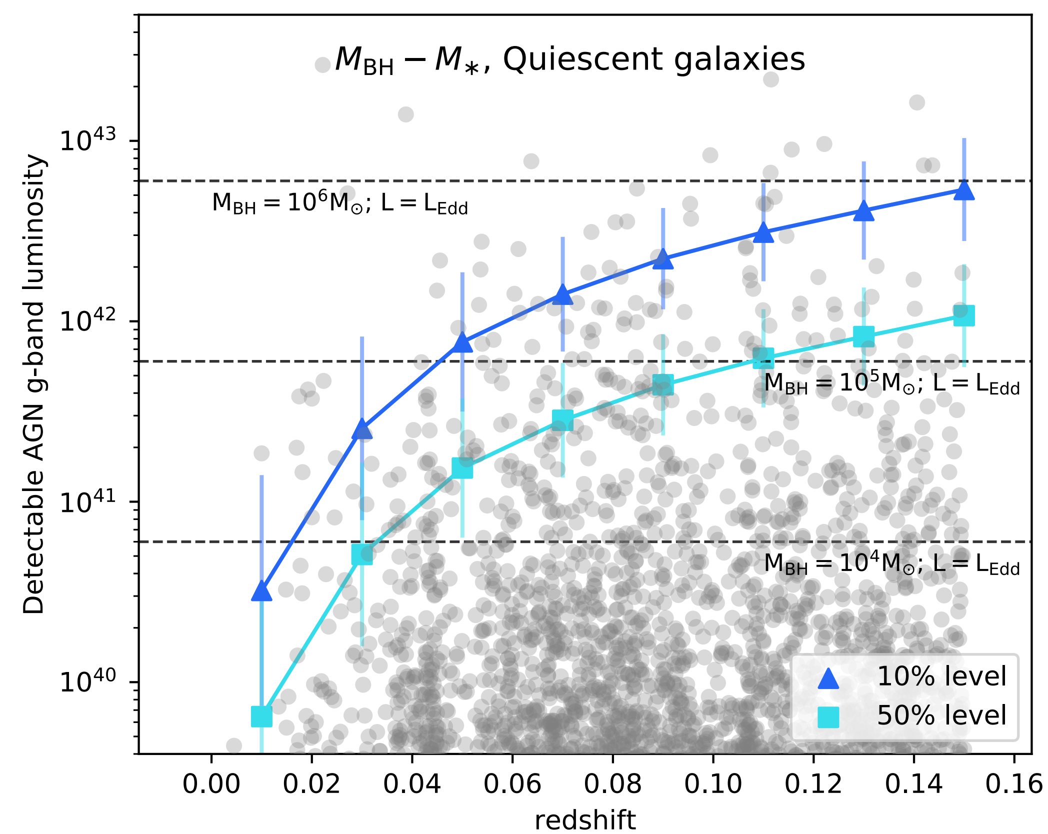
- Decline in occupation fraction
- Change in $M_{BH}/M_\star$ ratio with stellar mass (e.g., Reines & Volonteri 2015)
- Decrease in optical variability at low BH masses/luminosities and/or variability on different timescales

Detection limit of SDSS



Detection limit of SDSS





- SDSS is roughly sensitive to a 10^5 M_{sun} BH out to z=0.05 (if accreting at its Eddington ratio)
- LSST will do much better - single exposure depth g=25.0 mag

Summary + Future directions

- AGN in low-mass galaxies can be difficult to find due to star formation dilution, low-metallicity effects, etc.

- Optical photometric variability may identify AGNs in low-mass galaxies missed by other selection techniques

arXiv: 1808.09578

- Study variability properties of known low-mass AGNs

- Hunt for low-mass AGNs in additional repeat imaging surveys

- Explore detectability limits for LSST