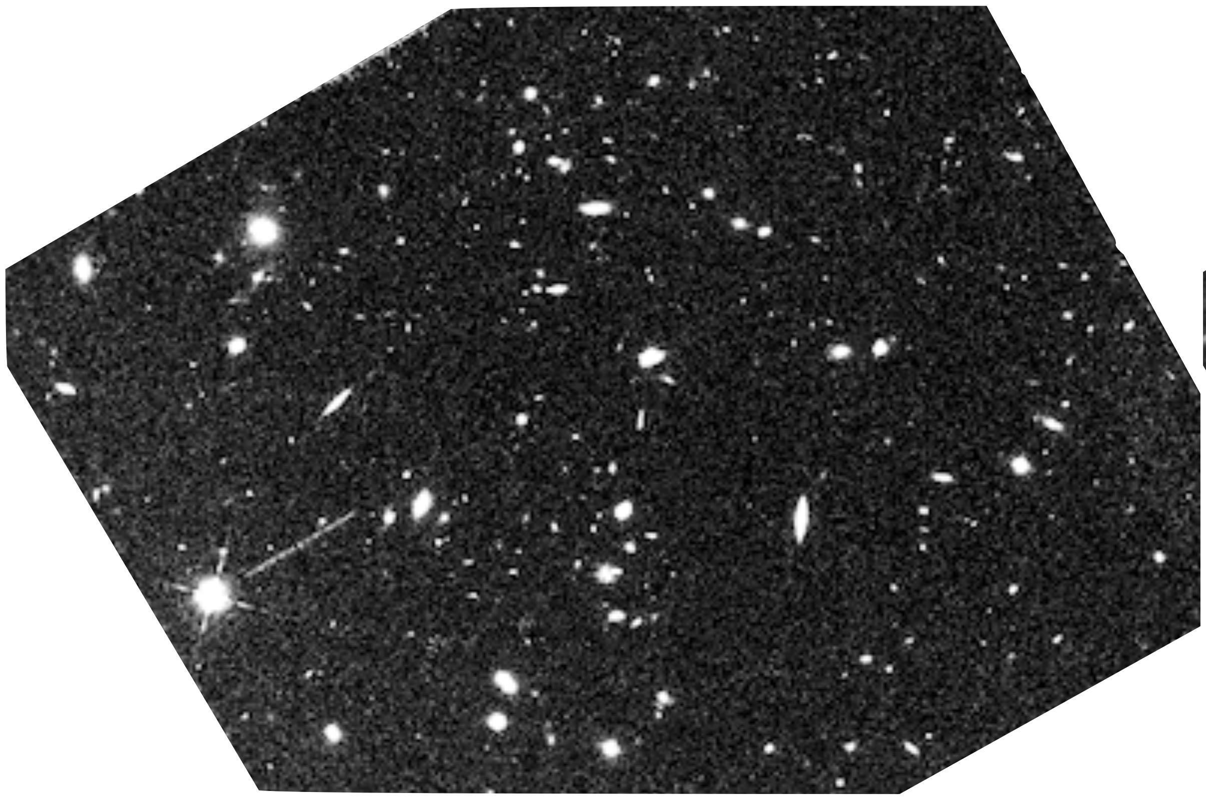
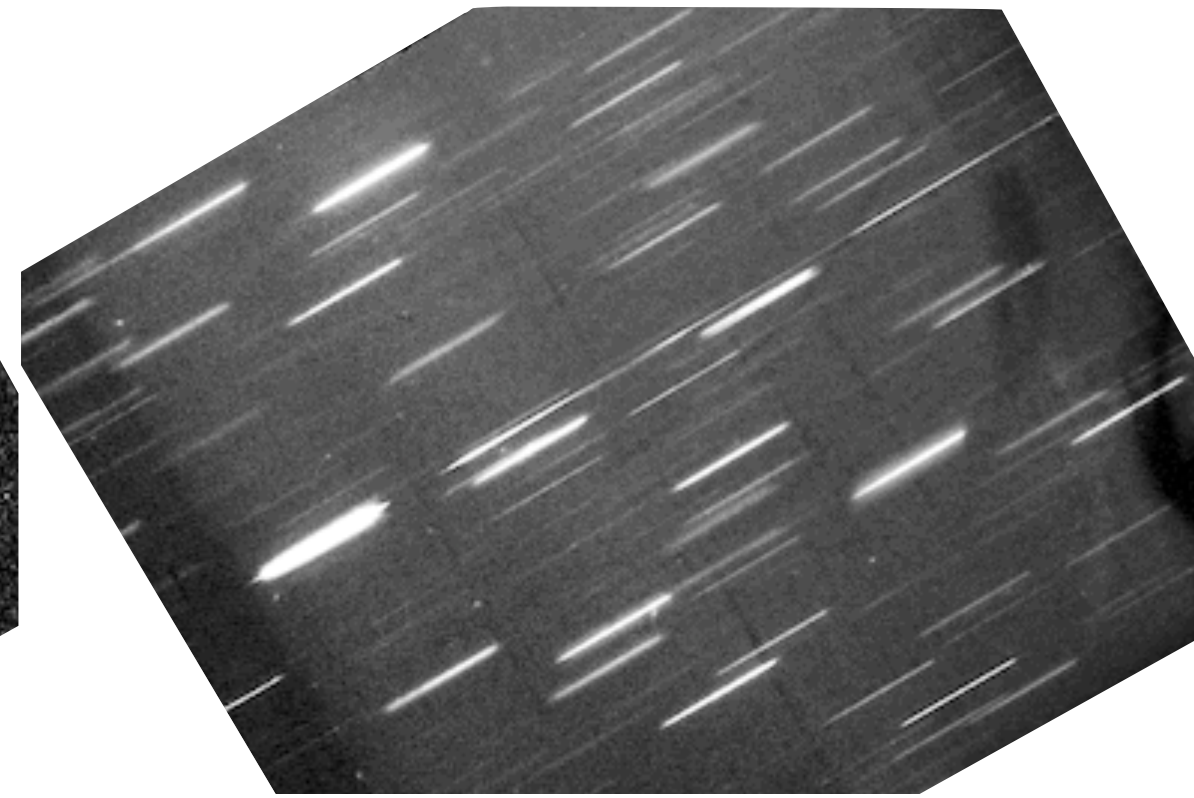
The (Elusive) Fossil Record of Black Hole Seeds





with Space Telescope Imaging Spectrographs

Jonathan Trump

(UConn)

w/ Joanna Bridge, Mouyuan Sun, Guillermo Barro, Niel Brandt, Sandy Faber, Steph Juneau, David Koo, Dale Kocevski, Bret Lehmer, Iva Momcheva, Ben Weiner, Kate Whitaker, Greg Zeimann

Birth and Growth of Black Holes

1. Black Holes and Galaxies: Background
2. The Census of Low-Mass AGNs
3. Coming of Age with Imaging Spectroscopy
4. Imaging Spectroscopy: The Next Generation

Birth and Growth of Black Holes

1. ***Black Holes and Galaxies: Background***
2. The Census of Low-Mass AGNs
3. Coming of Age with Imaging Spectroscopy
4. Imaging Spectroscopy: The Next Generation

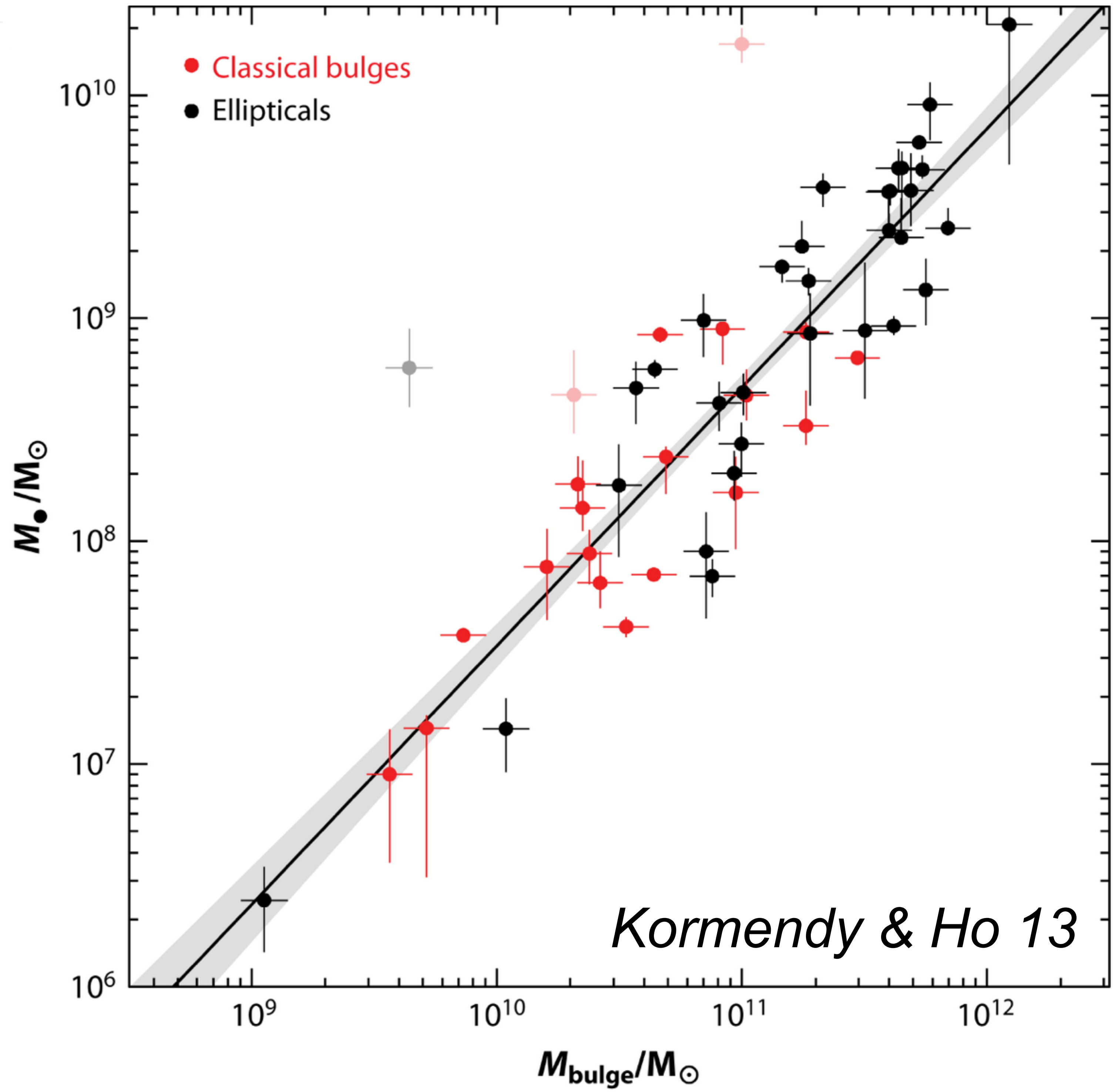
BH - Galaxy Coupling

BH mass is ~0.2% Galaxy (bulge) mass

Coevolution over 2-3 magnitudes of mass

Best correlation for BH and galaxy bulge (old star component)

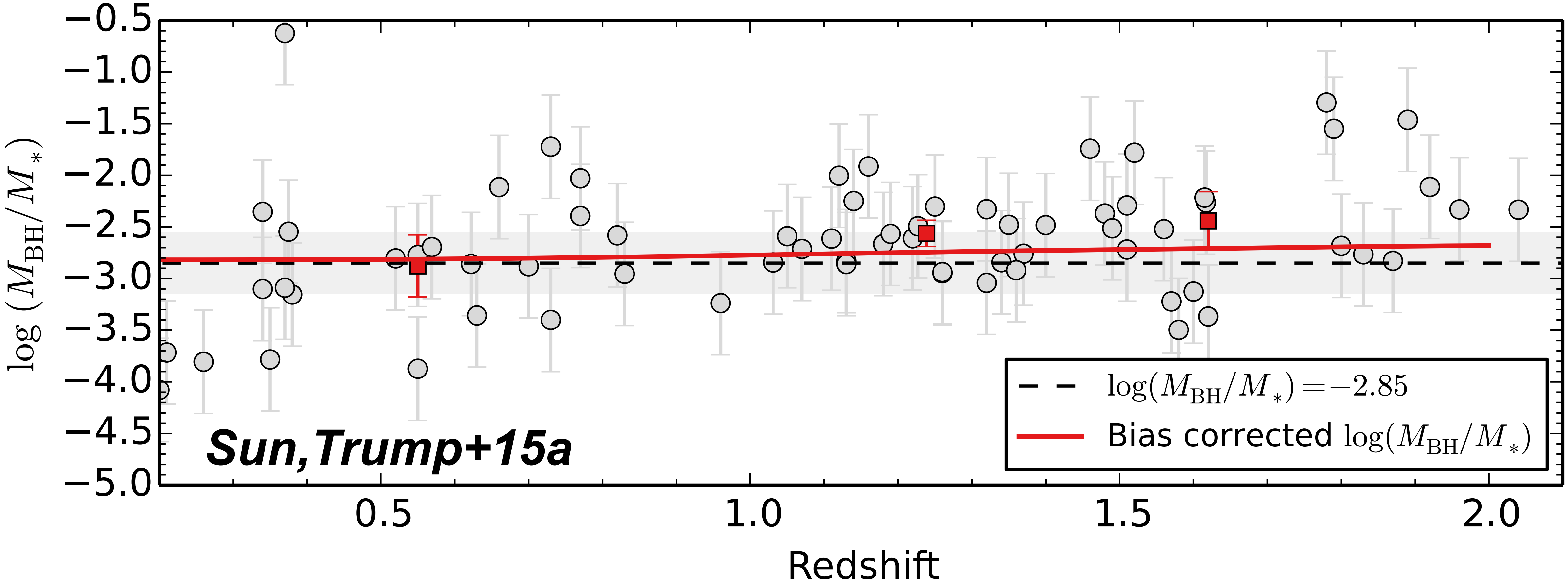
Only mature galaxies host SMBHs?



BH - Galaxy: Distant Universe

- No evolution in $M_{BH}/M_\star$ with redshift
- BH first couples to total galaxy mass, bulge grows later?
- see also *Jahnke+09, Cisternas+11* (COSMOS)

BH - galaxy coupling in place by teenage universe (z~2)



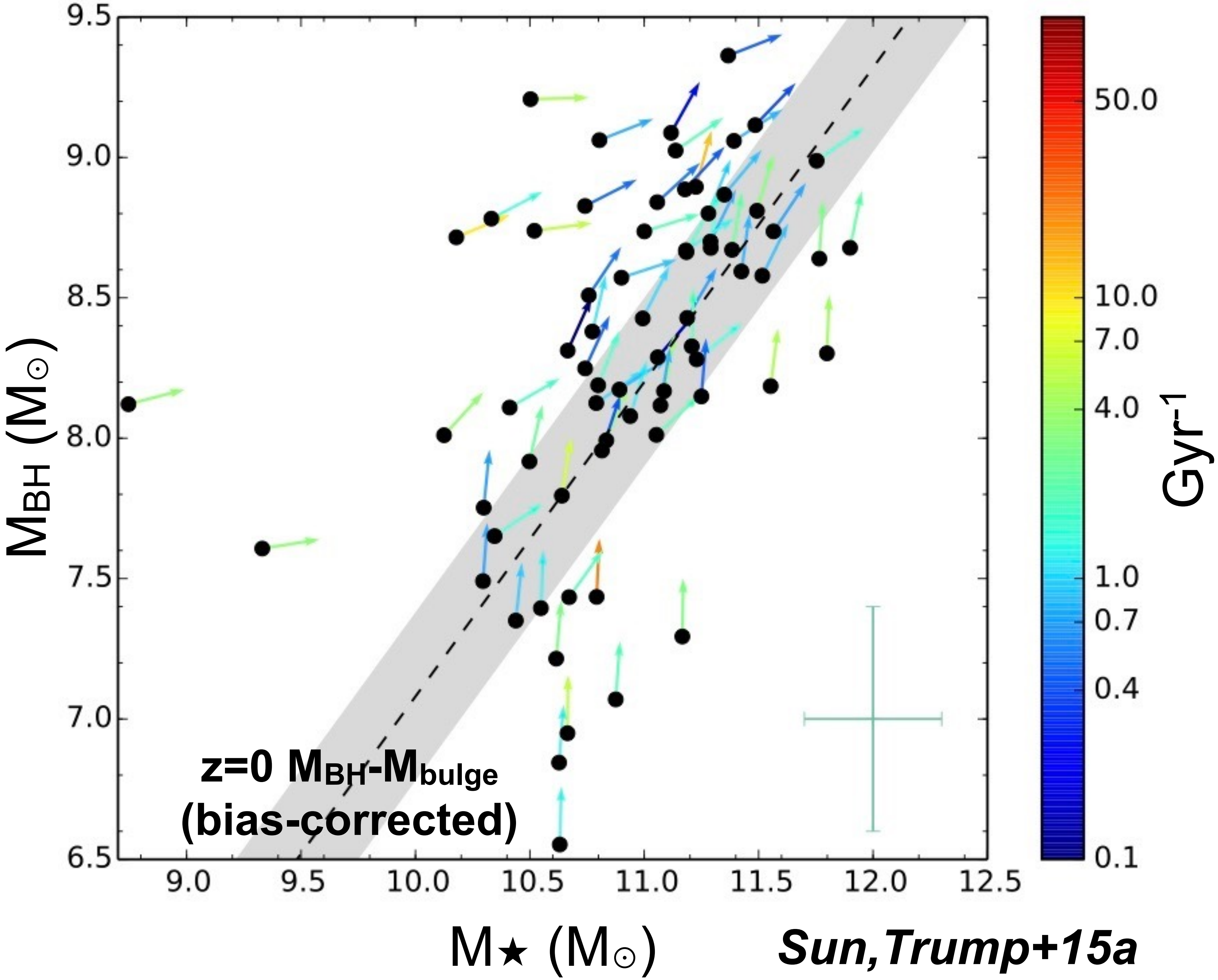
BH - Galaxy Flow Pattern

Herschel FIR
-> galaxy SFR

Chandra X-ray
-> BH growth

Outliers return to mean: "self-maintained"

Duty cycle for rapid accretion onto BH: ~10%

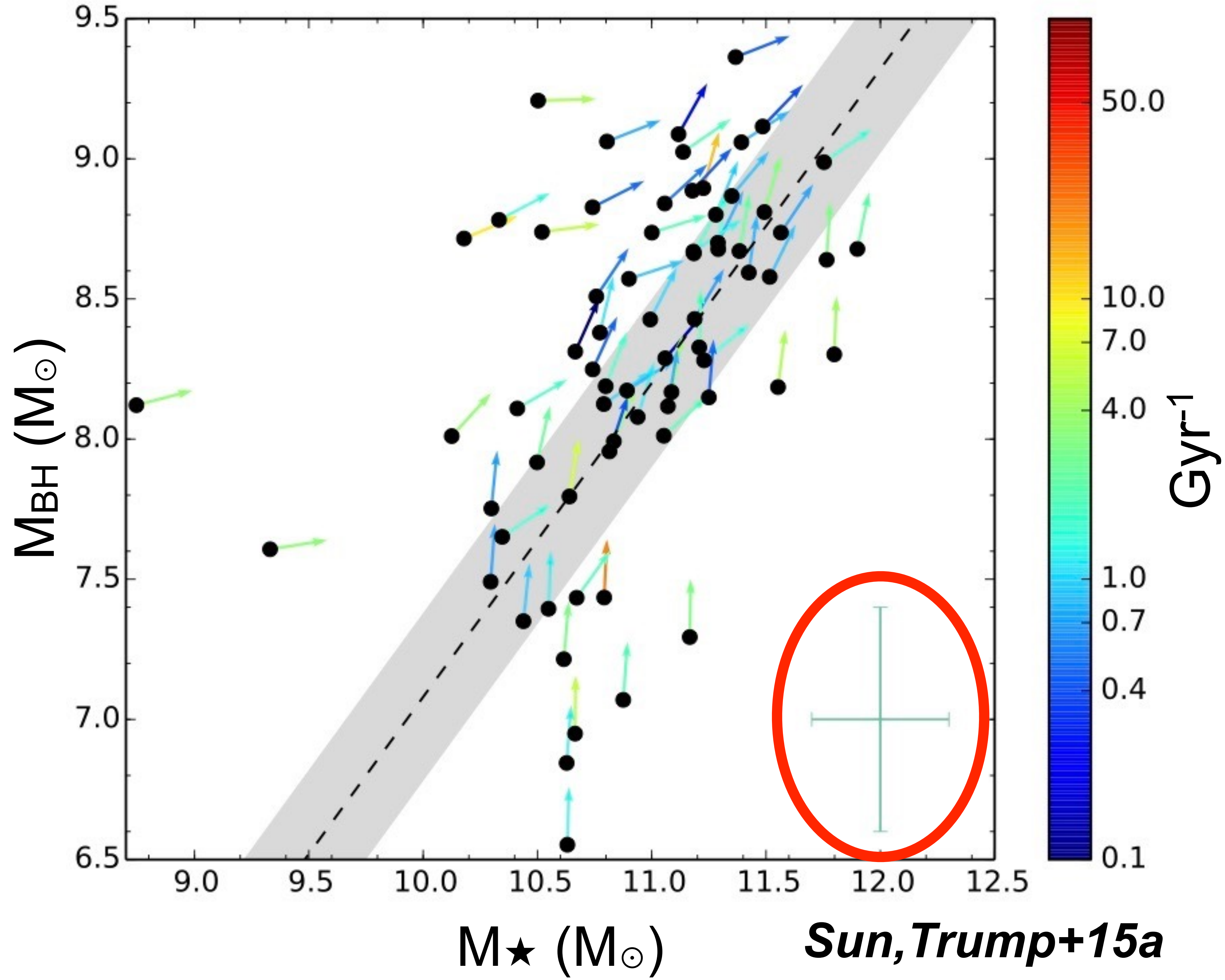


Sun,Trump+15a

BH - Galaxy Flow Pattern

How does it evolve?

Limited by uncertain BH mass estimates

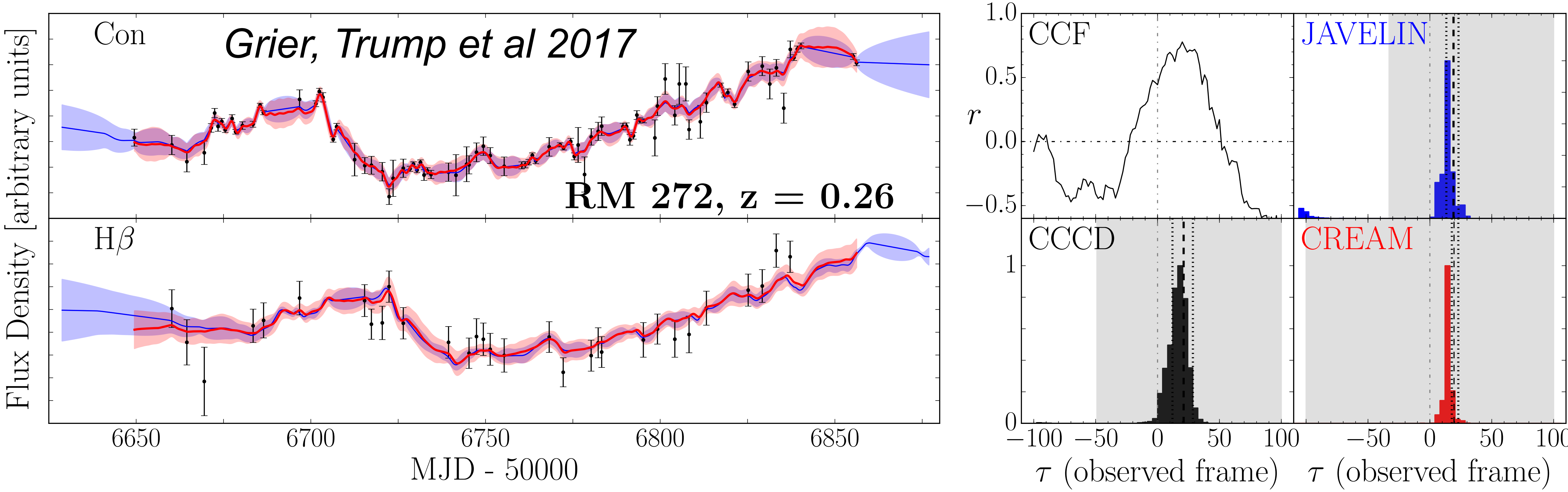


Sun,Trump+15a

Measuring BH Mass: SDSS-RM

The next generation of reliable BH masses:

Multi-Object Reverberation Mapping



~50 RM masses from SDSS-RM, at z<1.

(Full expected yield: ~200 masses at z<3.)

Coming soon: LSST! photometric RM for >10^6 QSOs…

BH - Galaxy Flow Pattern

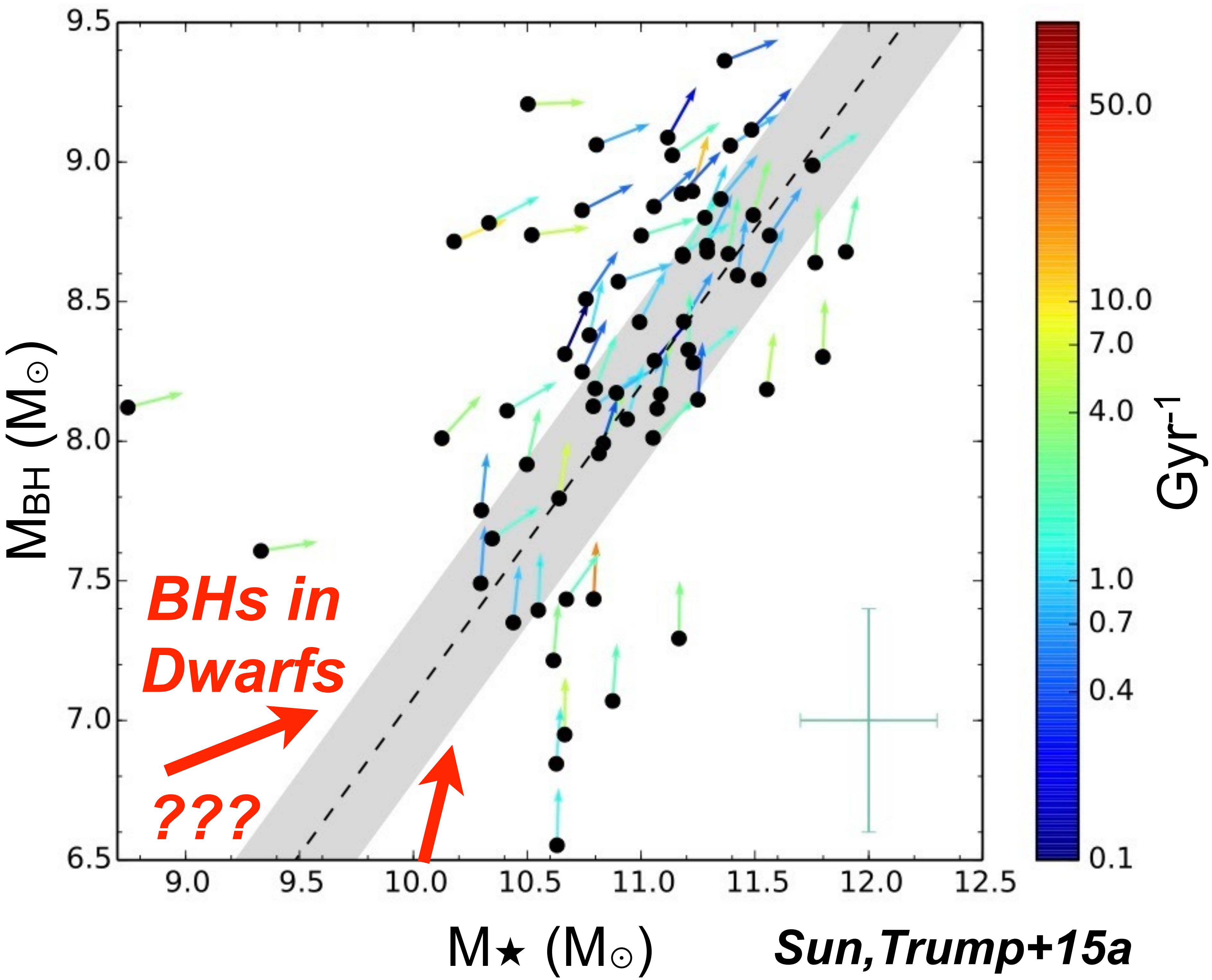
How does it work?

Shared gas supply fuels both SF and BH

Where does it come from?

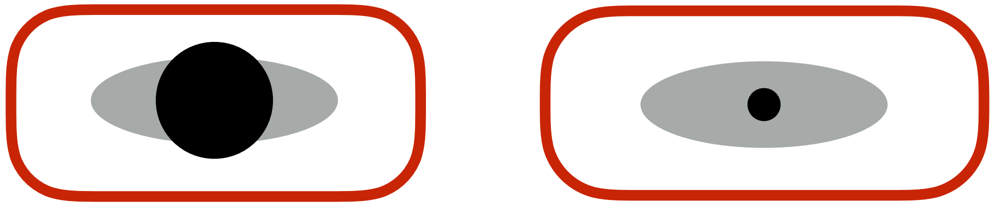
BH before bulge?

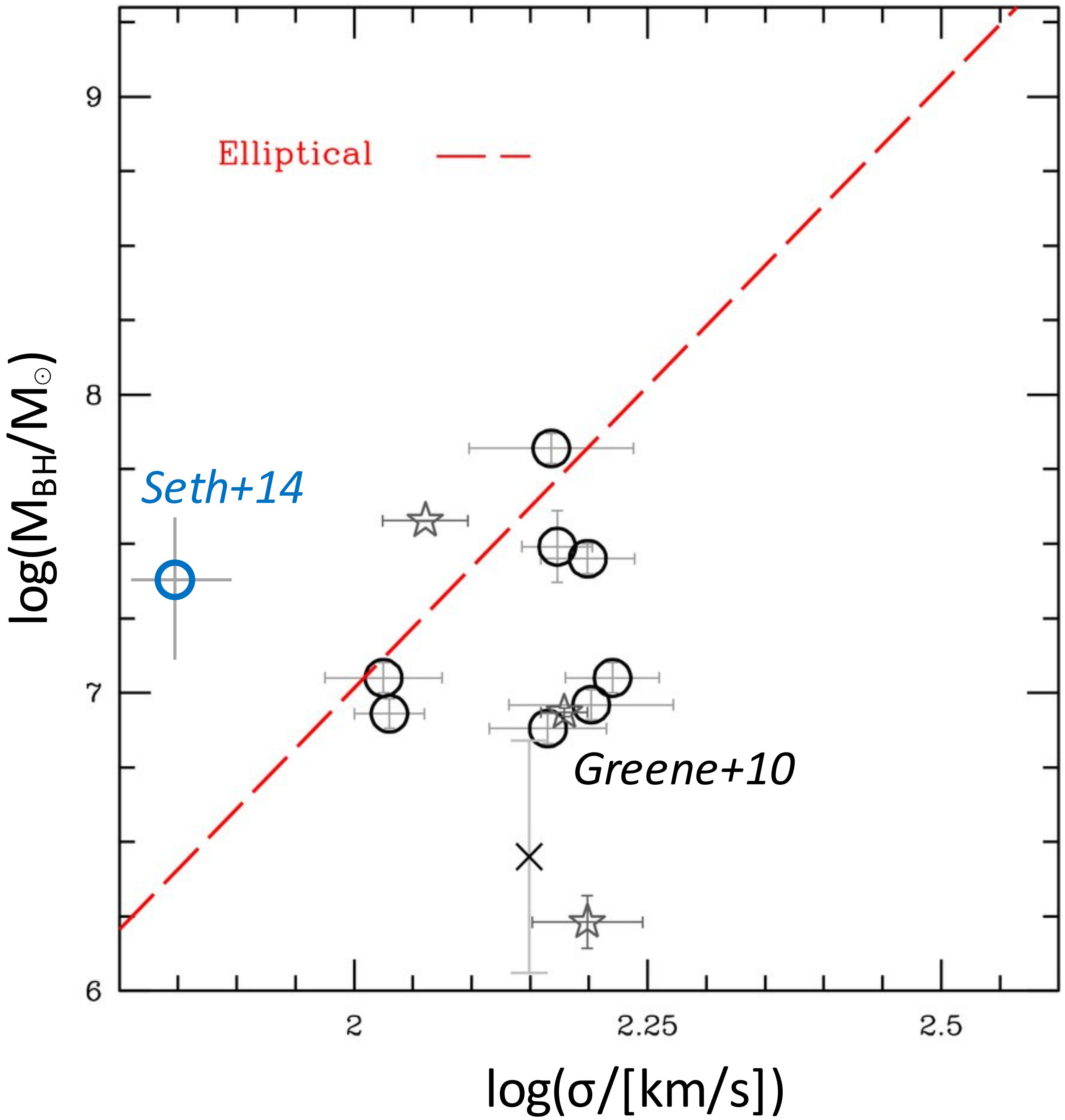
-> observe BHs at low-mass



Sun, Trump+15a

Mix of under- / over-massive BHs in few galaxies with dynamical M_{BH}





Birth and Growth of Black Holes

1. Black Holes and Galaxies: Background

2. ***The Census of Low-Mass AGNs***

3. Coming of Age with Imaging Spectroscopy

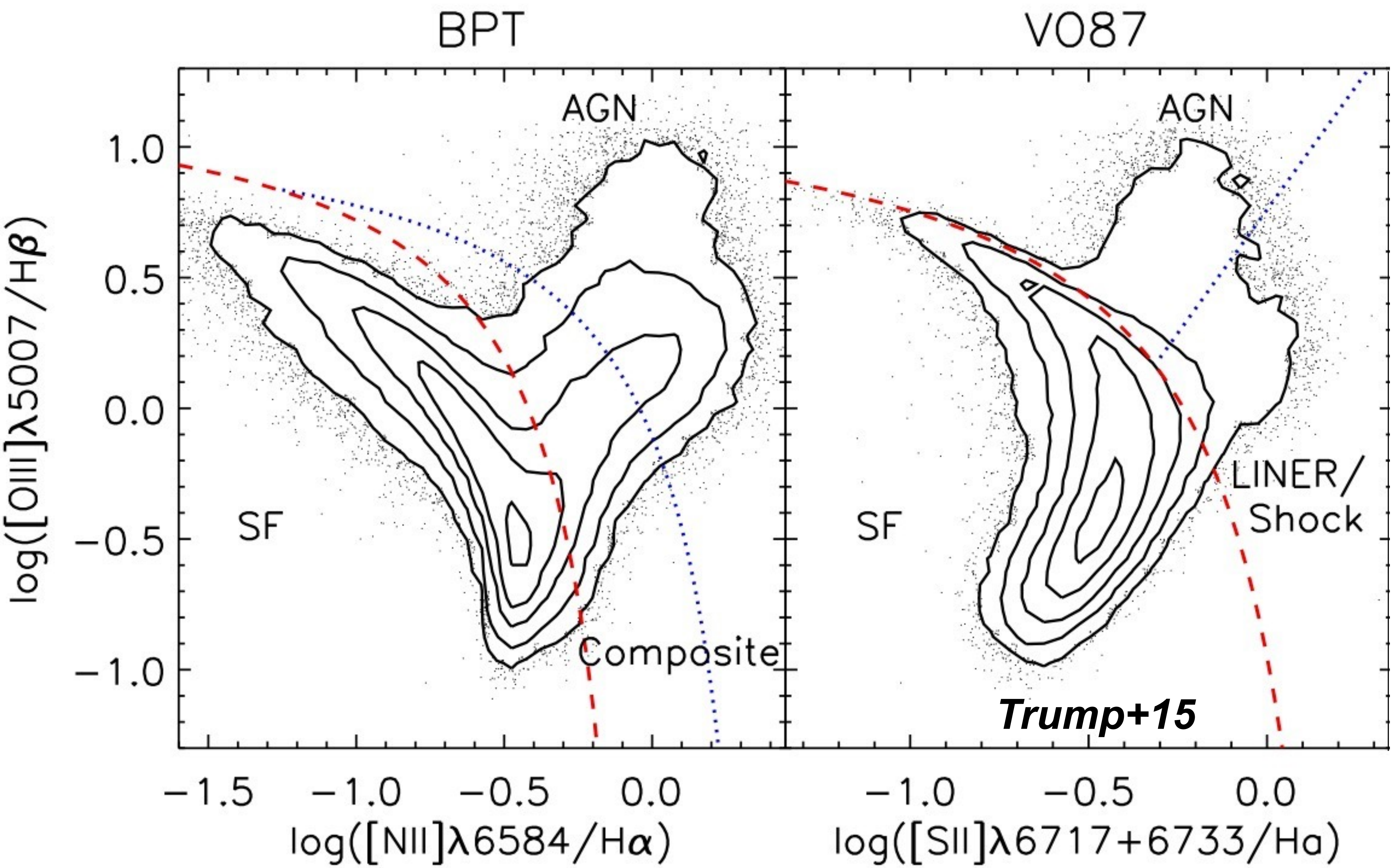
4. Imaging Spectroscopy: The Next Generation

Finding Accreting Black Holes

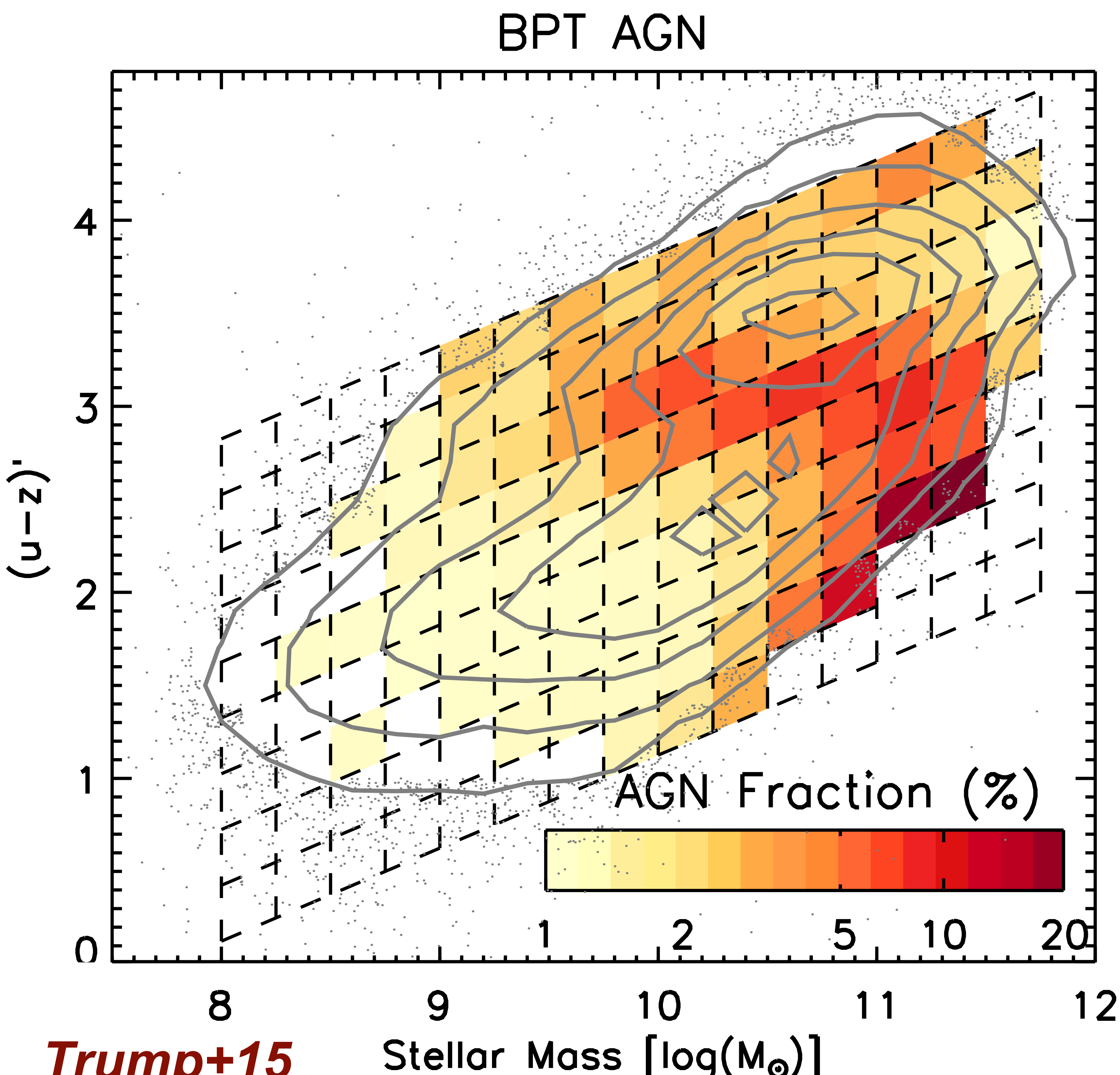
Optical spectroscopy: hard ionization signature

- massive wide-field surveys: ~10^3-10^5 galaxies
- (mostly) insensitive to dust reddening
- also gives redshift, black hole mass*
- inexpensive observations from the ground

(Accreting) BH Detection



Galaxies w/ Growing BHs: Apparent

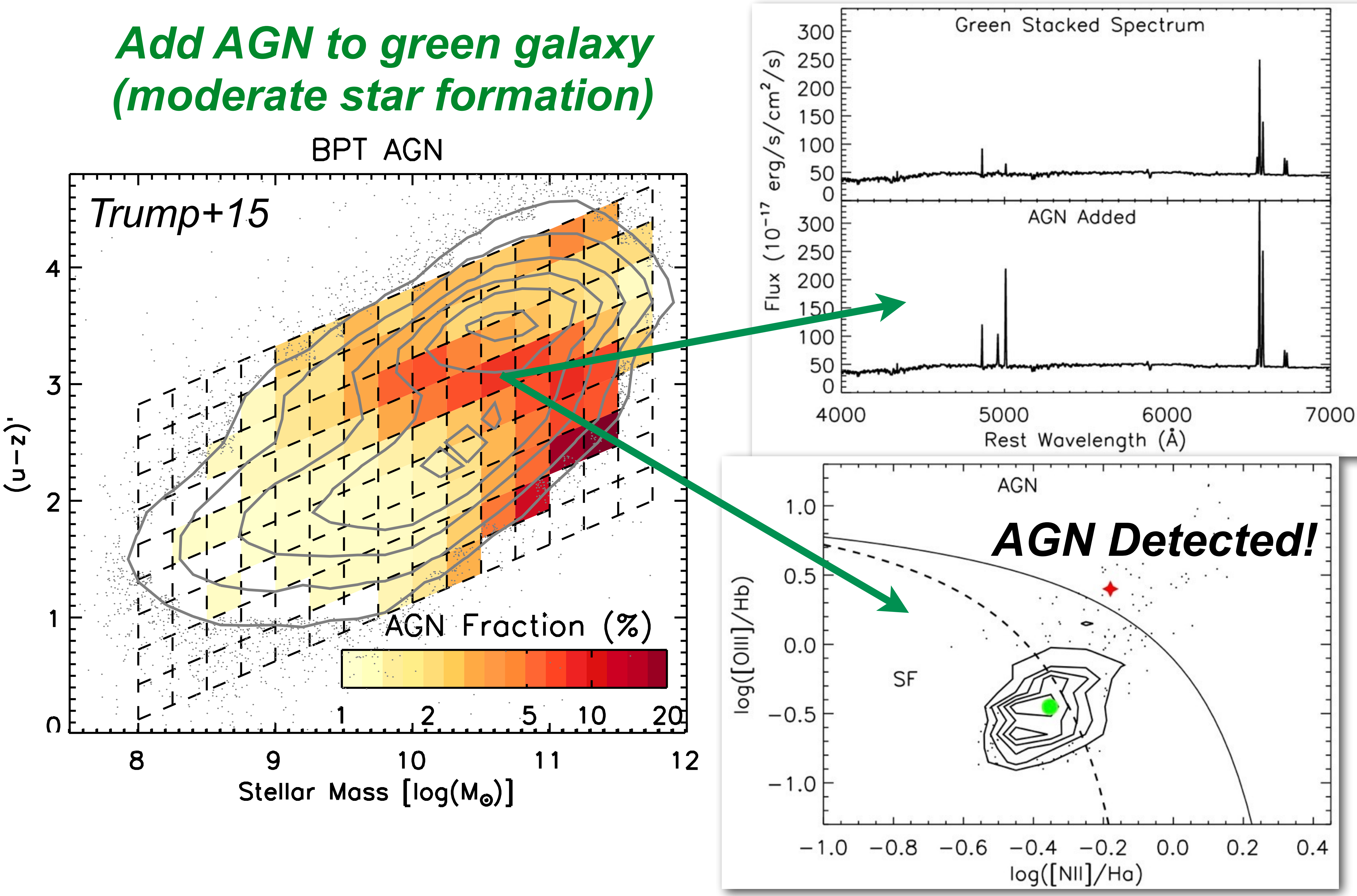


Trump+15

- 320,000 SDSS galaxies (S/N_{line}>3), 0.01<z<0.1
- AGNs selected by BPT line ratios
- Preference for high-mass green valley? (Kauffmann+03)
- ***Very few massive seeds in low-mass galaxies?***

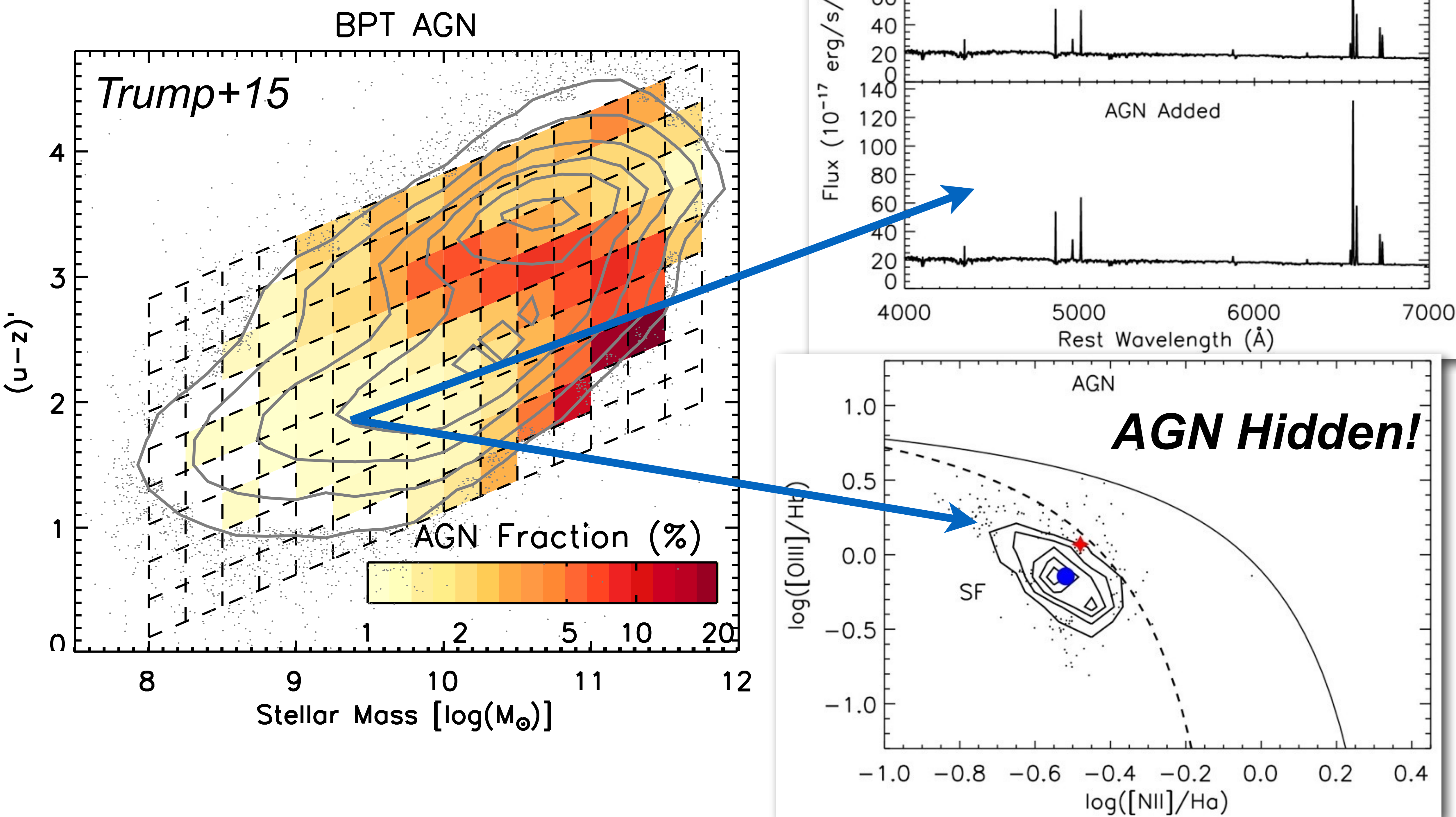
BH Detection: Galaxy (SF) Contrast

Add AGN to green galaxy (moderate star formation)

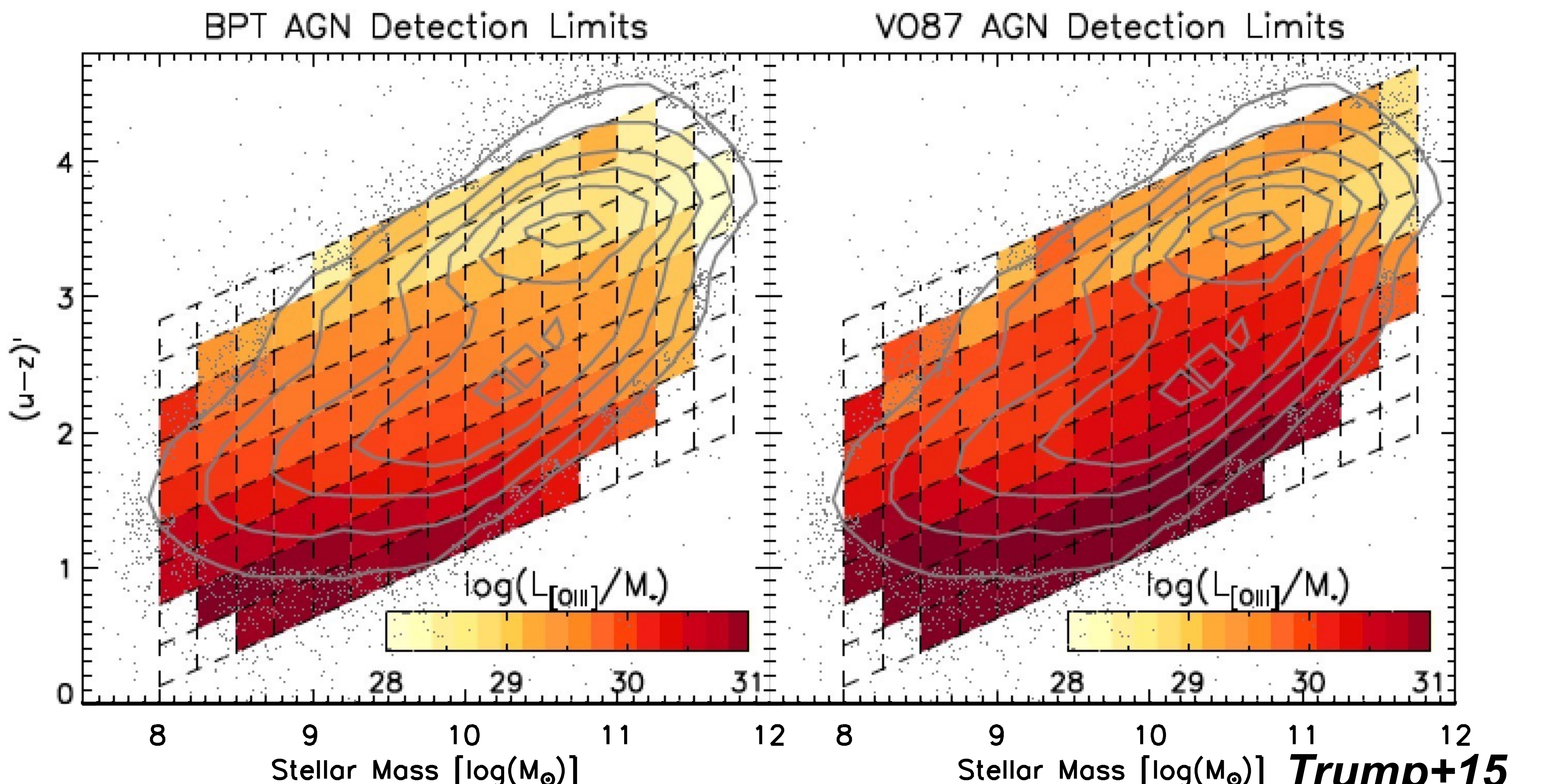


BH Detection: Galaxy (SF) Contrast

Add AGN to blue galaxy (high star formation)



BH Detection: Galaxy (SF) Contrast

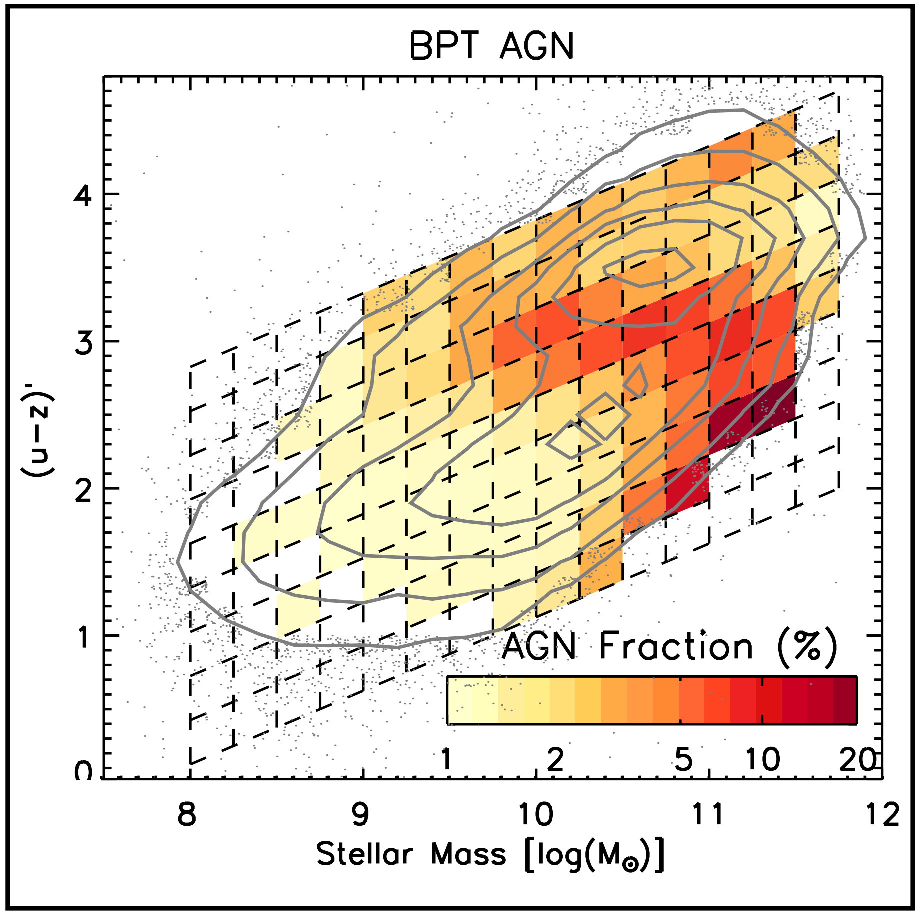


Trump+15

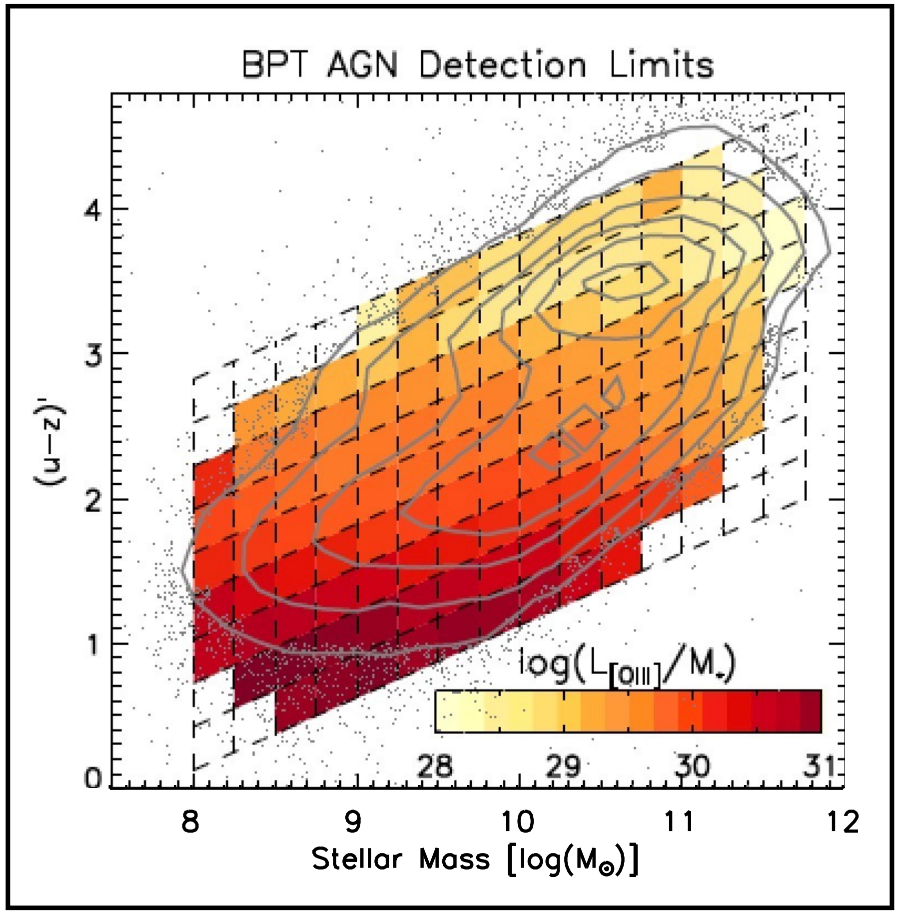
Strong bias against BH detection at low mass:
SF dilutes observed line ratios (also Moran+02)

Correct for BH Selection Bias

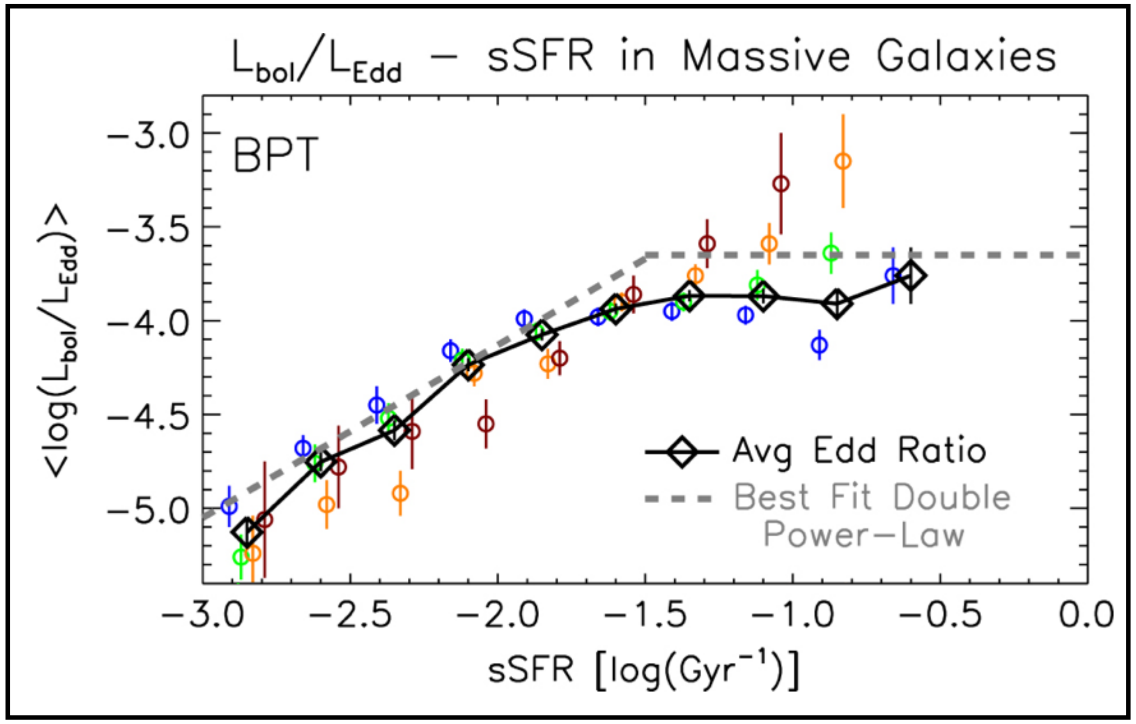
Observation



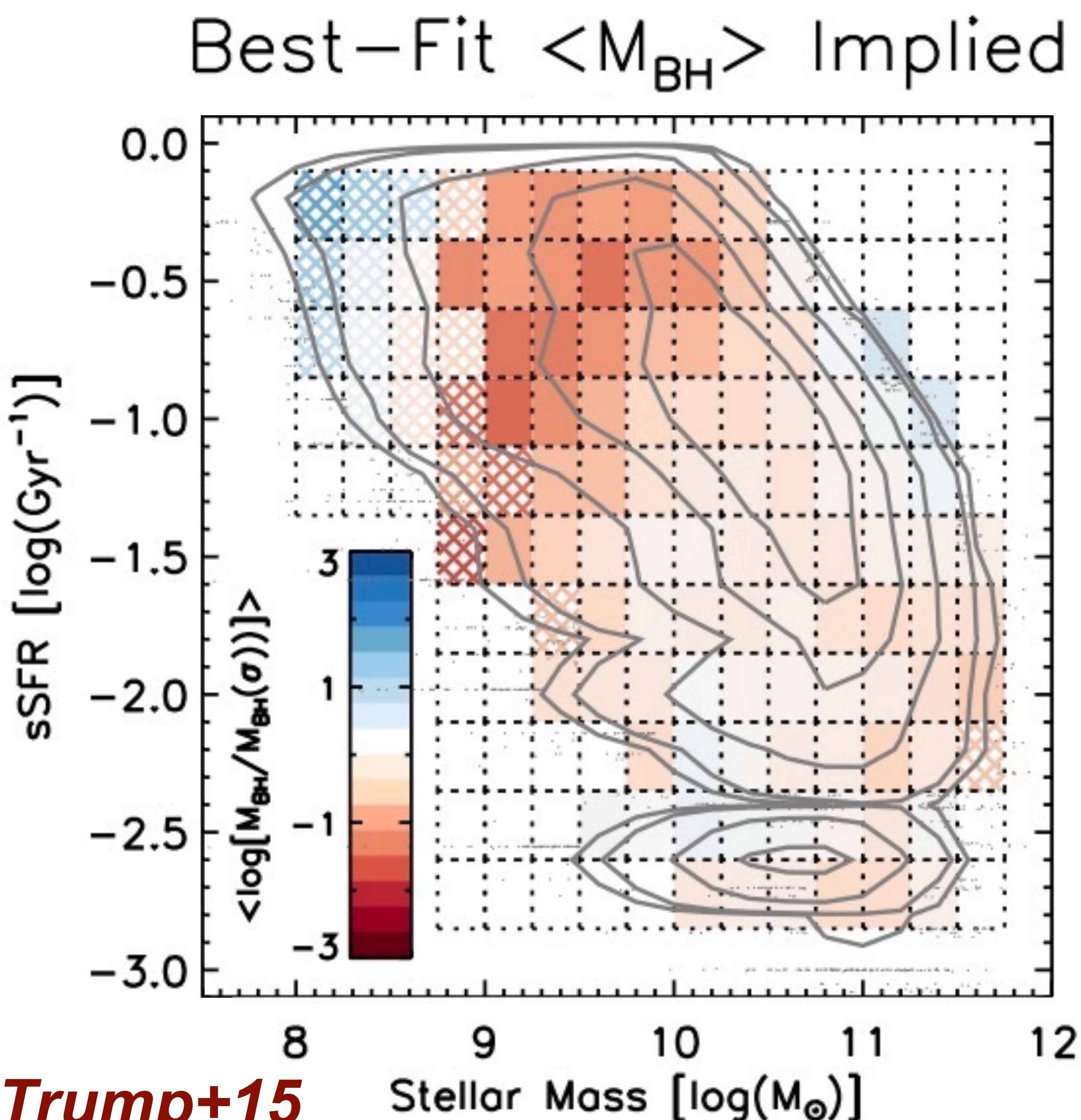
Bias



Light -> Mass



BH Seed Fossils: z~0 (SDSS)



Trump+15

320,000 SDSS galaxies with S/N_{BPT}>3, 0.01<z<0.1

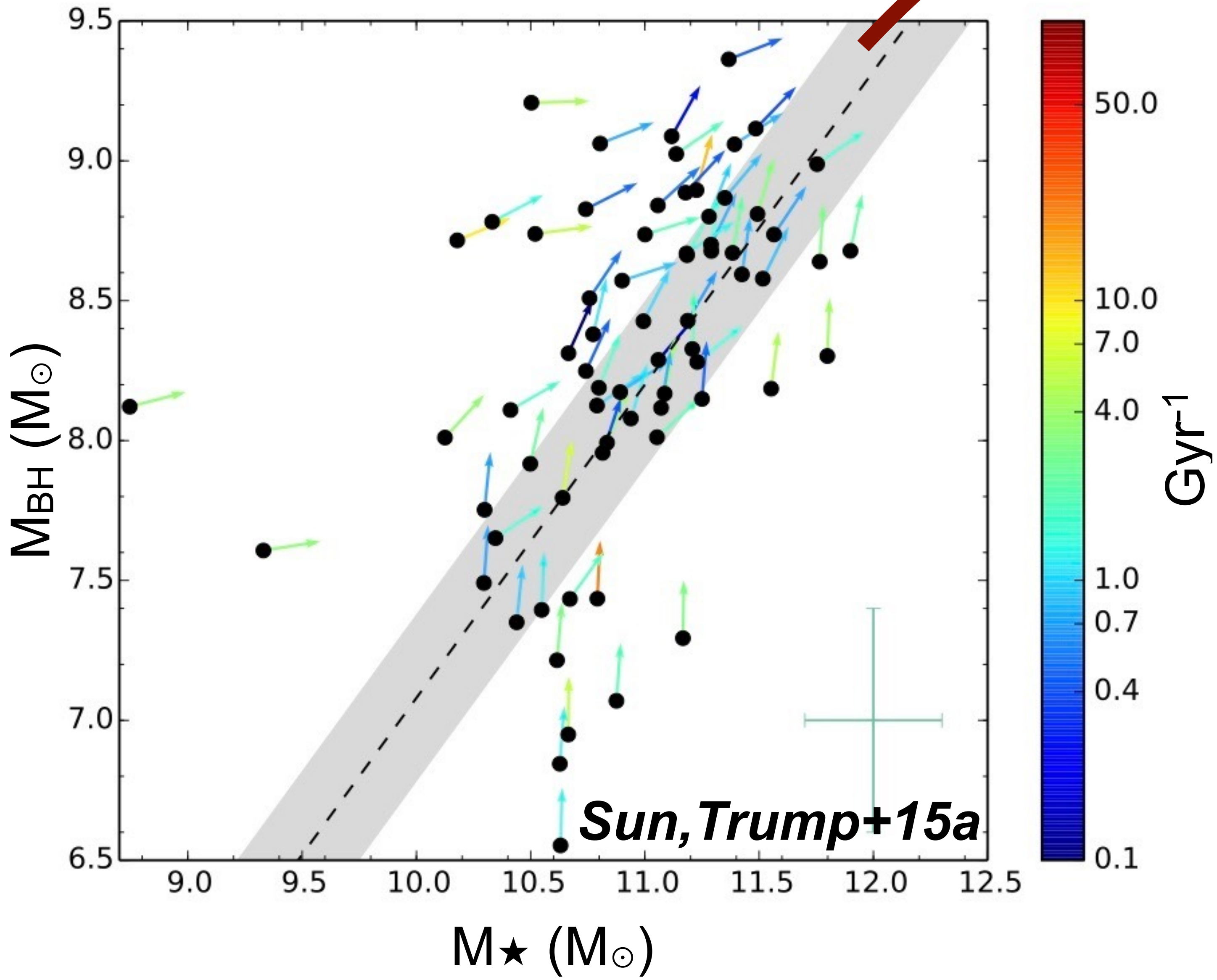
Monte Carlo simulations, adding AGN to SF galaxies in each bin

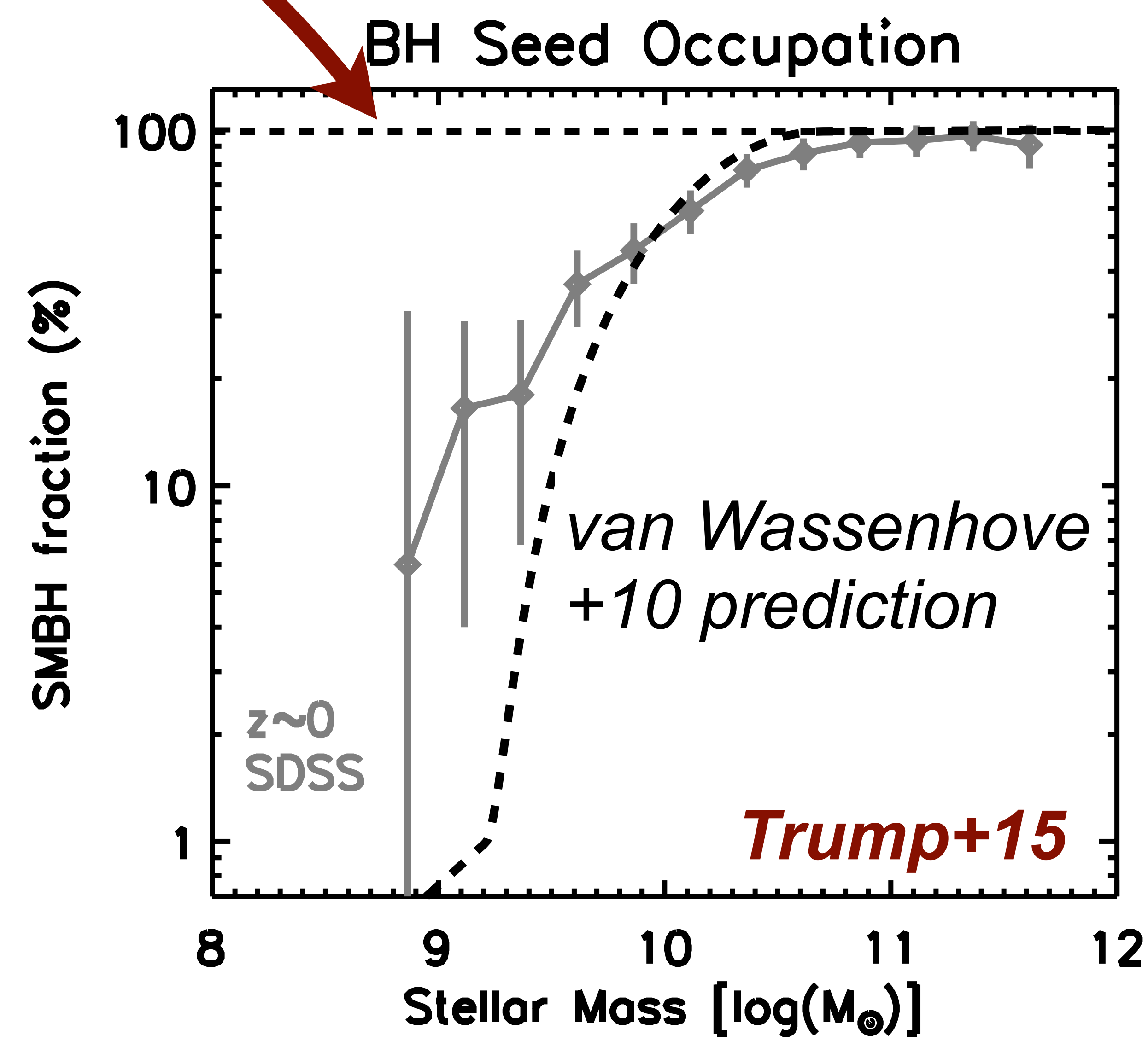
Assumptions:

- power-law Edd ratio
- $M_{BH} \sim \sigma^{4.2}$
- $L_{bol} = 112 L_{[OIII]}^{1.2}$
- "pure AGN" line ratios
- uniform dust
- avg AGN-SF correlation

BH Seed Fossil Record

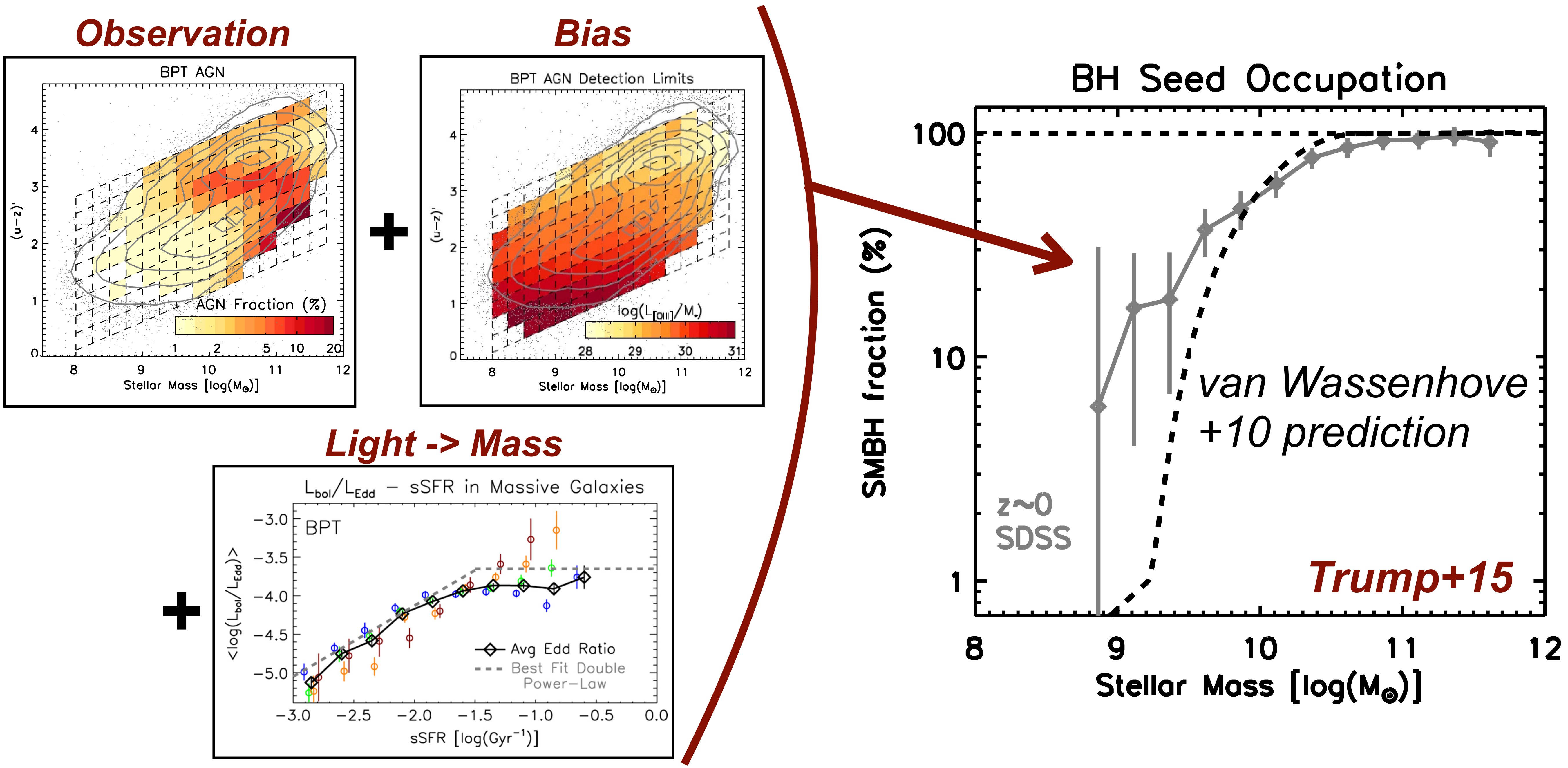
"BH occupation": deviation from M_{BH}-M_{bulge} relation (HR04)



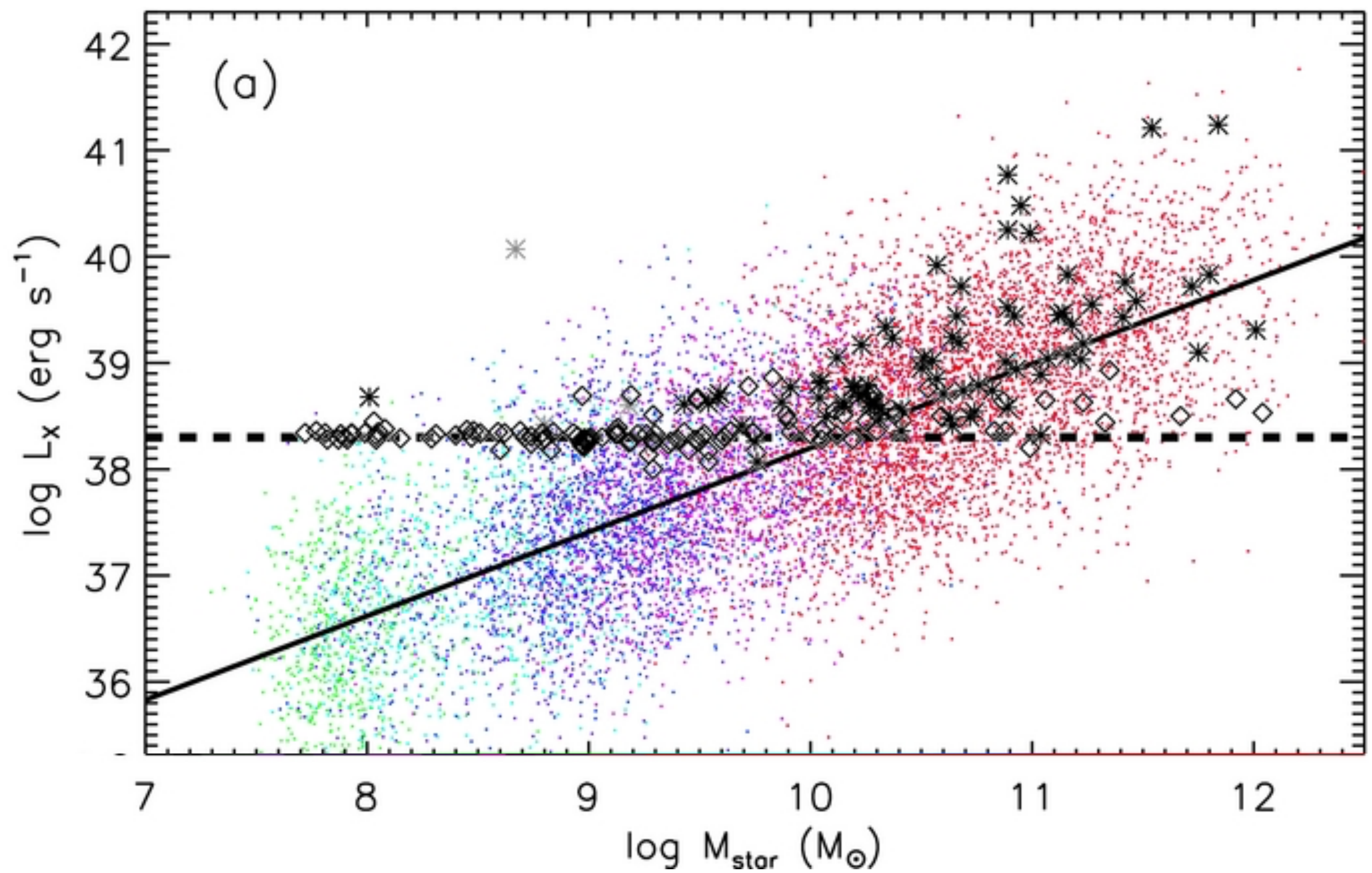


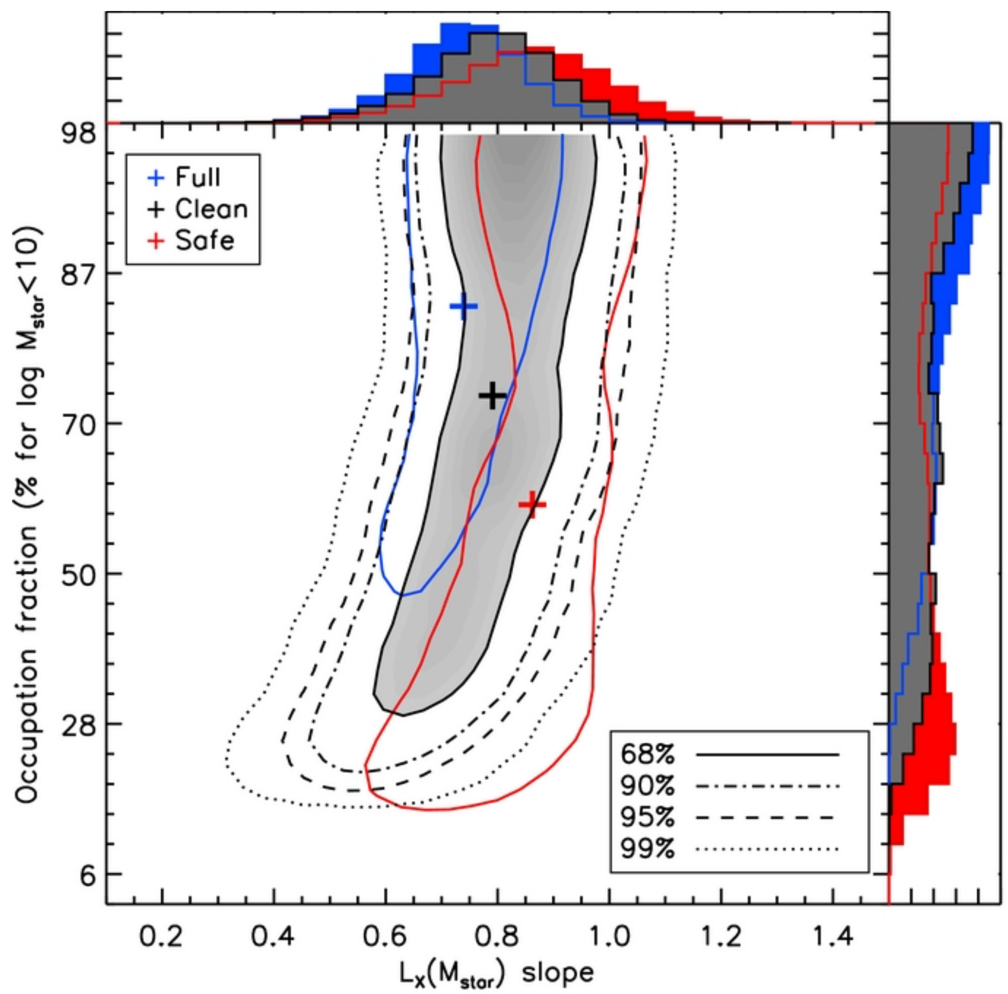
BH Seed Fossil Record

BH occupation from 320,000 SDSS galaxies.



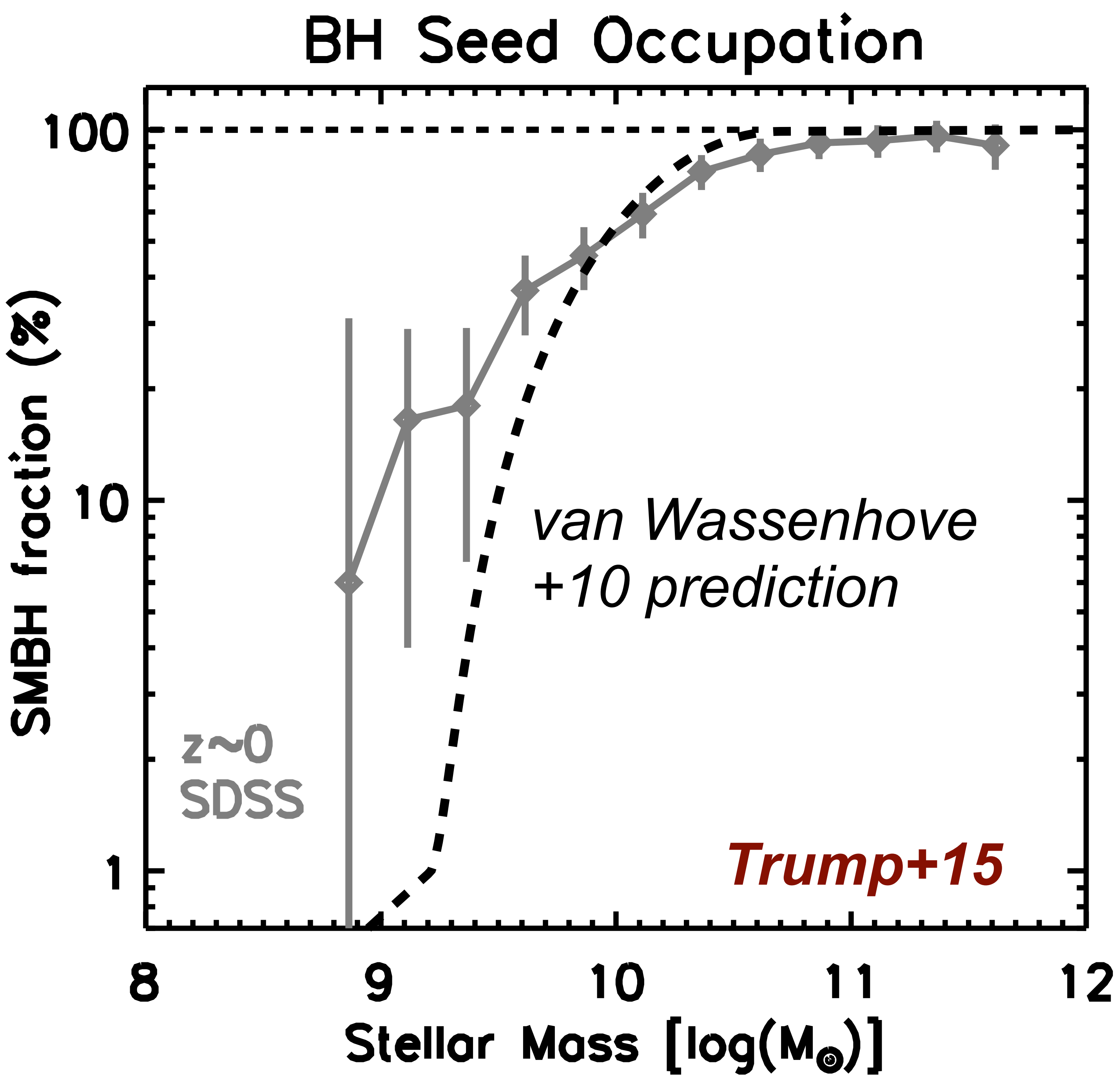
BH Seed Fossil Record, in X-ray





- ***See also Miller+15***: low-mass AGN census from AMUSE X-ray survey
- Consistent occupation fraction, with fewer assumptions / weaker constraints

BH Seed Fossils: z~0 (SDSS)



Lower BH occupation in low-mass galaxies

Bimodal BH seeding: direct-collapse SMBHs rare in low-mass halos

But:

- indirect record at z~0
- low mass unconstrained
- uncertain assumptions…
  - power-law Edd ratio
  - $M_{BH} \sim \sigma^{4.2}$
  - $L_{bol} = 112L_{[OIII]}^{1.2}$
  - “pure AGN” line ratios
  - uniform dust
  - avg AGN-SF correlation

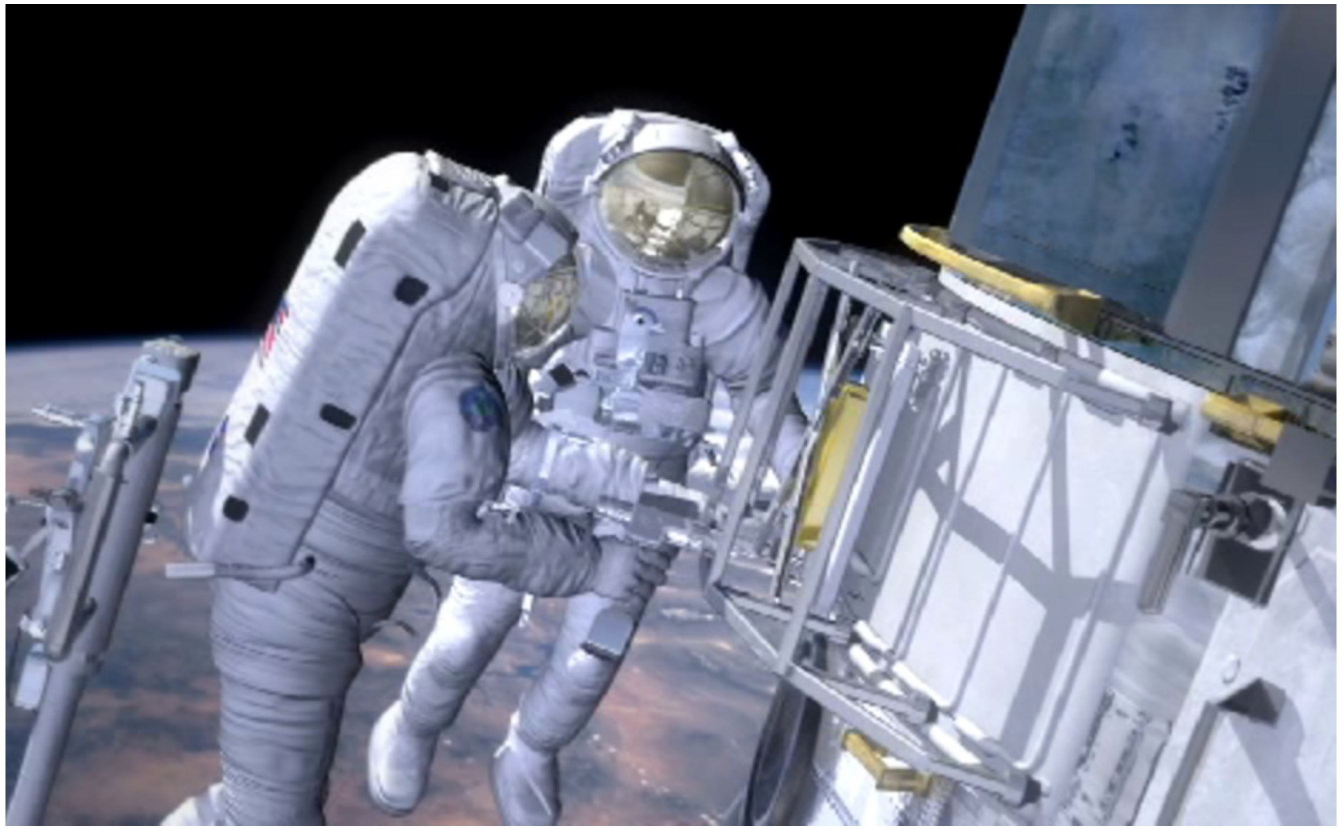
Birth and Growth of Black Holes

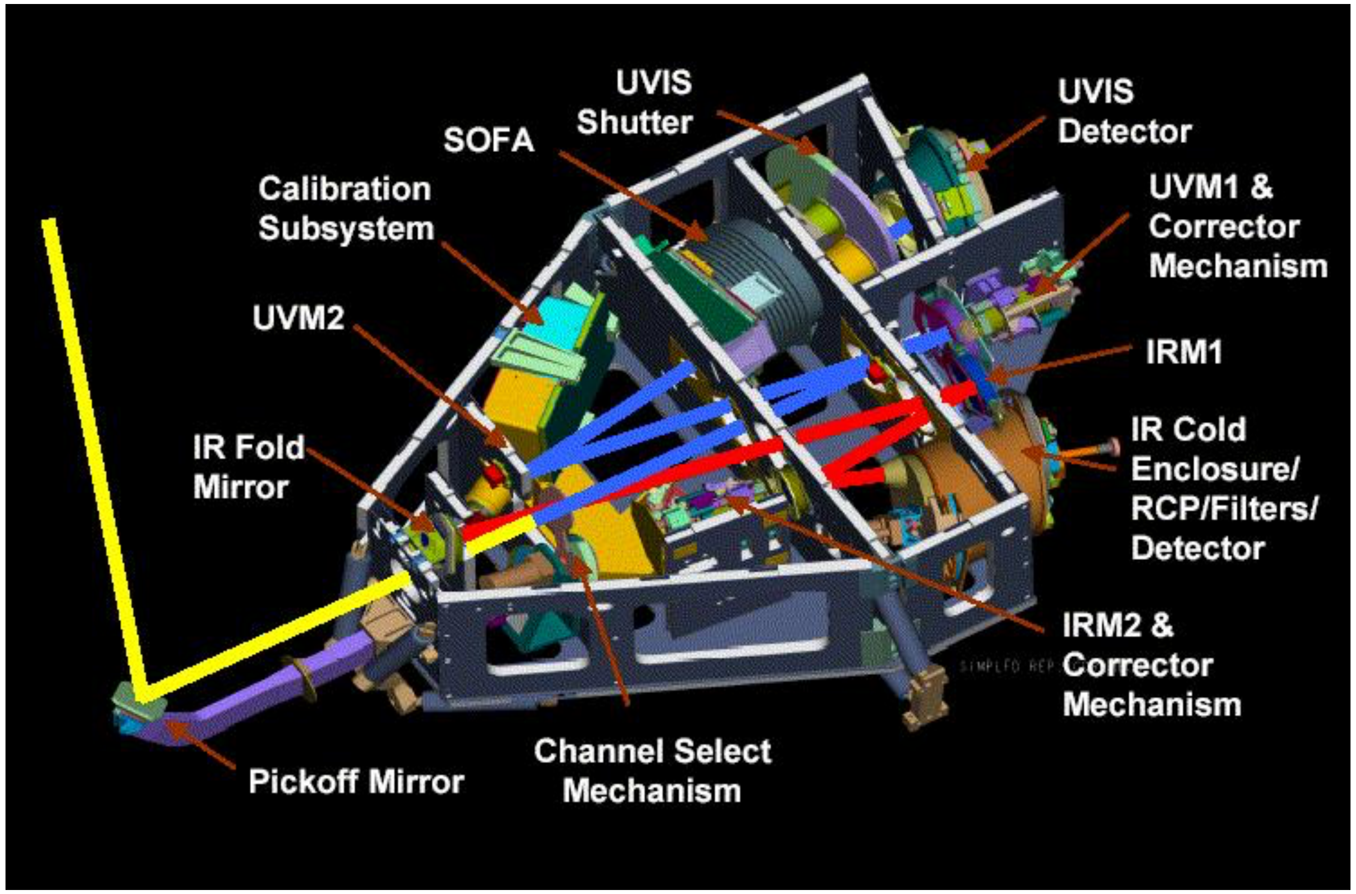
1. Black Holes and Galaxies: Background
2. The Census of Low-Mass AGNs
3. ***Coming of Age with Imaging Spectroscopy***
4. Imaging Spectroscopy: The Next Generation

HST Imaging Spectroscopy

Wide Field Camera 3

- Installed in 2009 (Service Mission 4)
- IR slitless grisms: G102 (0.8-1.15 μm) & G141 (1.1-1.7 μm)
- HST spatial resolution (0.06”/pix)!

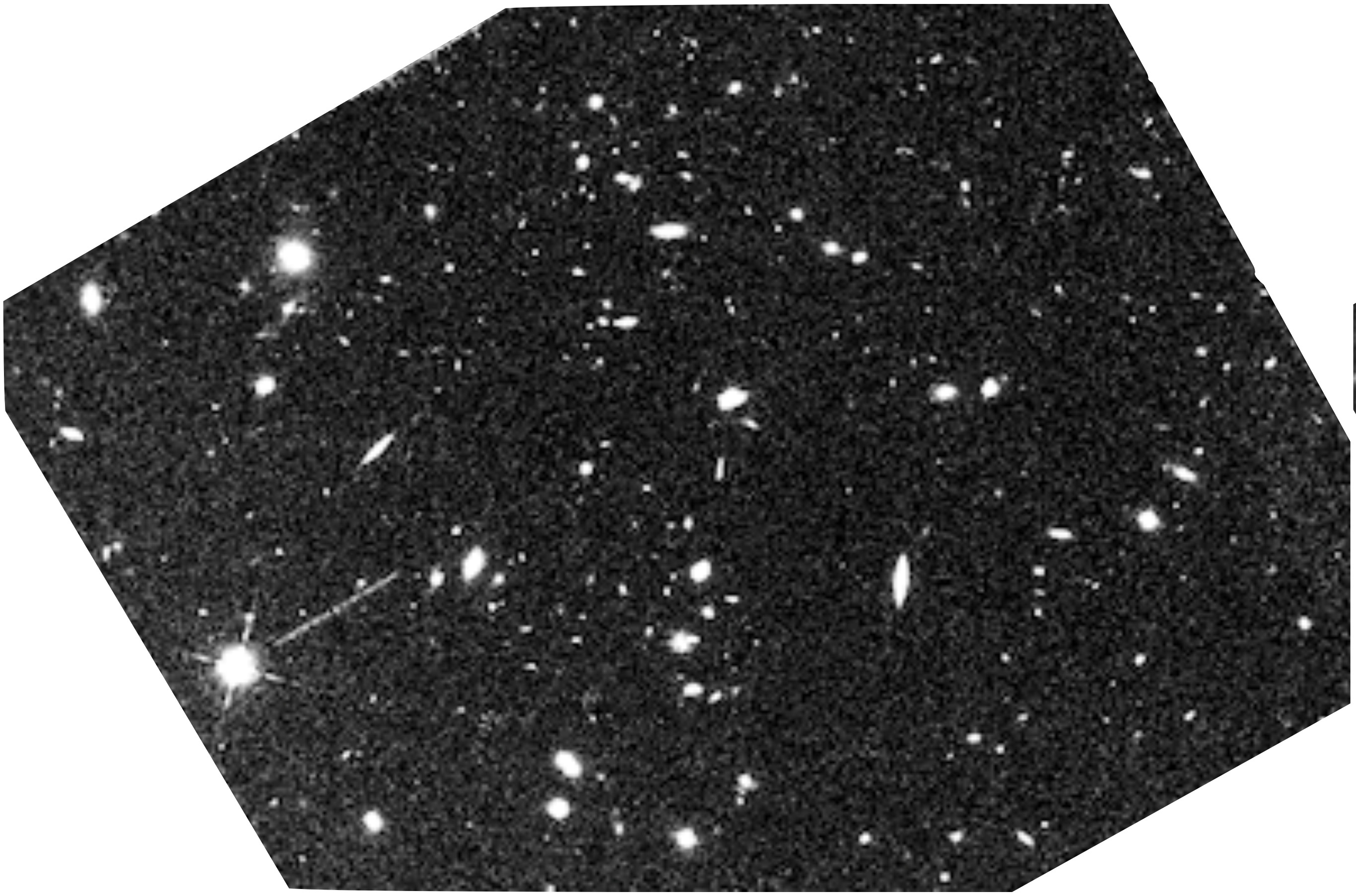


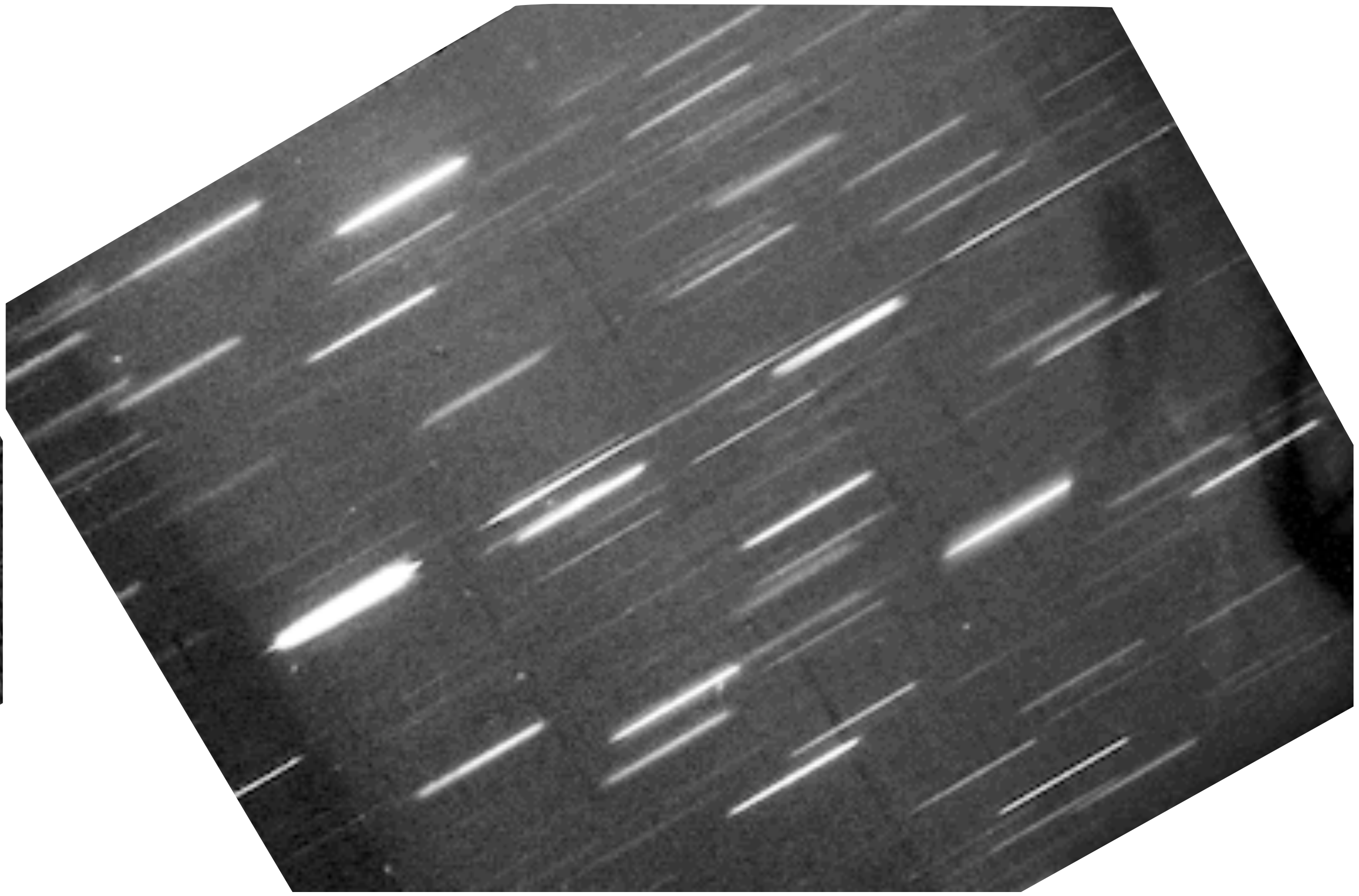


HST Imaging Spectroscopy

CANDELS + 3D-HST:

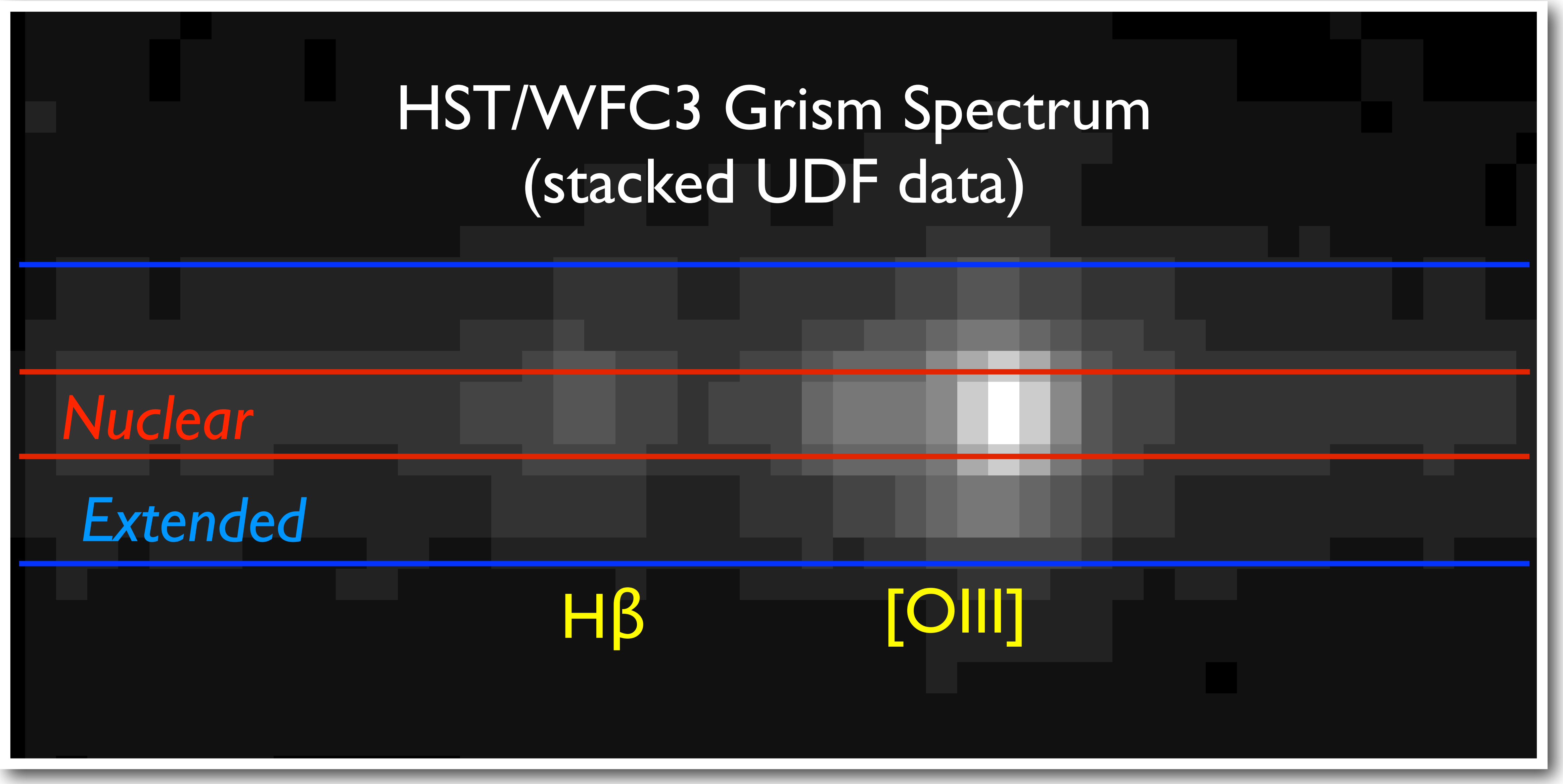
- 150 tiles (2’×2’) of G141 spectroscopy (1.1-1.7 μm)
- High spatial res (0.06”/pix), low spectral res (R~200)
- 50 useable galaxies / tile (with Hβ+[OIII], 1.3<z<2.4)





Spatially Resolved BH Detection

Compare ***nuclear*** and ***extended*** emission-line ratios

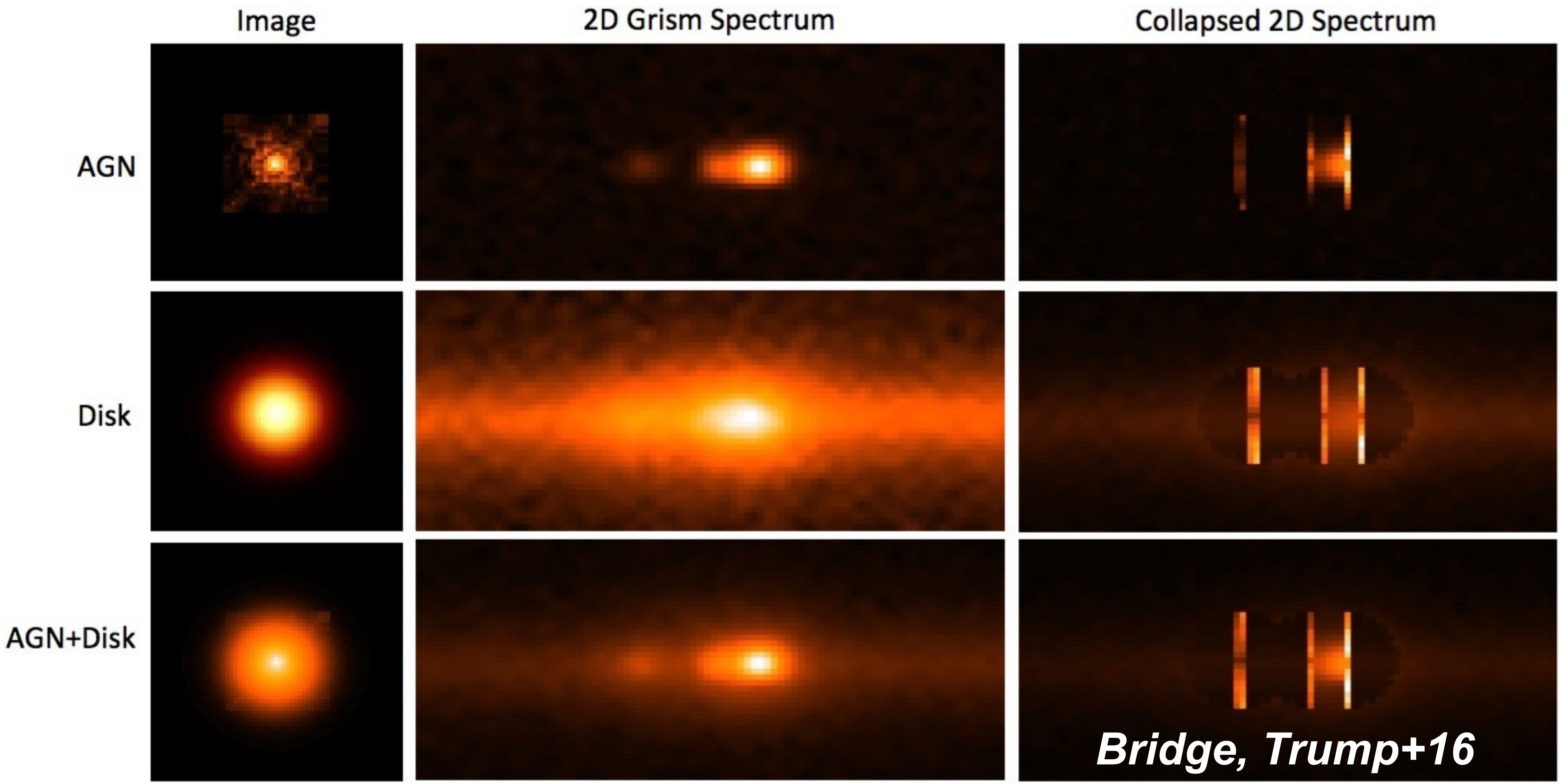


High ***nuclear*** ionization -> AGN

Simulated BH+Galaxy, HST spectra

Simulate accreting BH + galaxy, characterize BH growth:

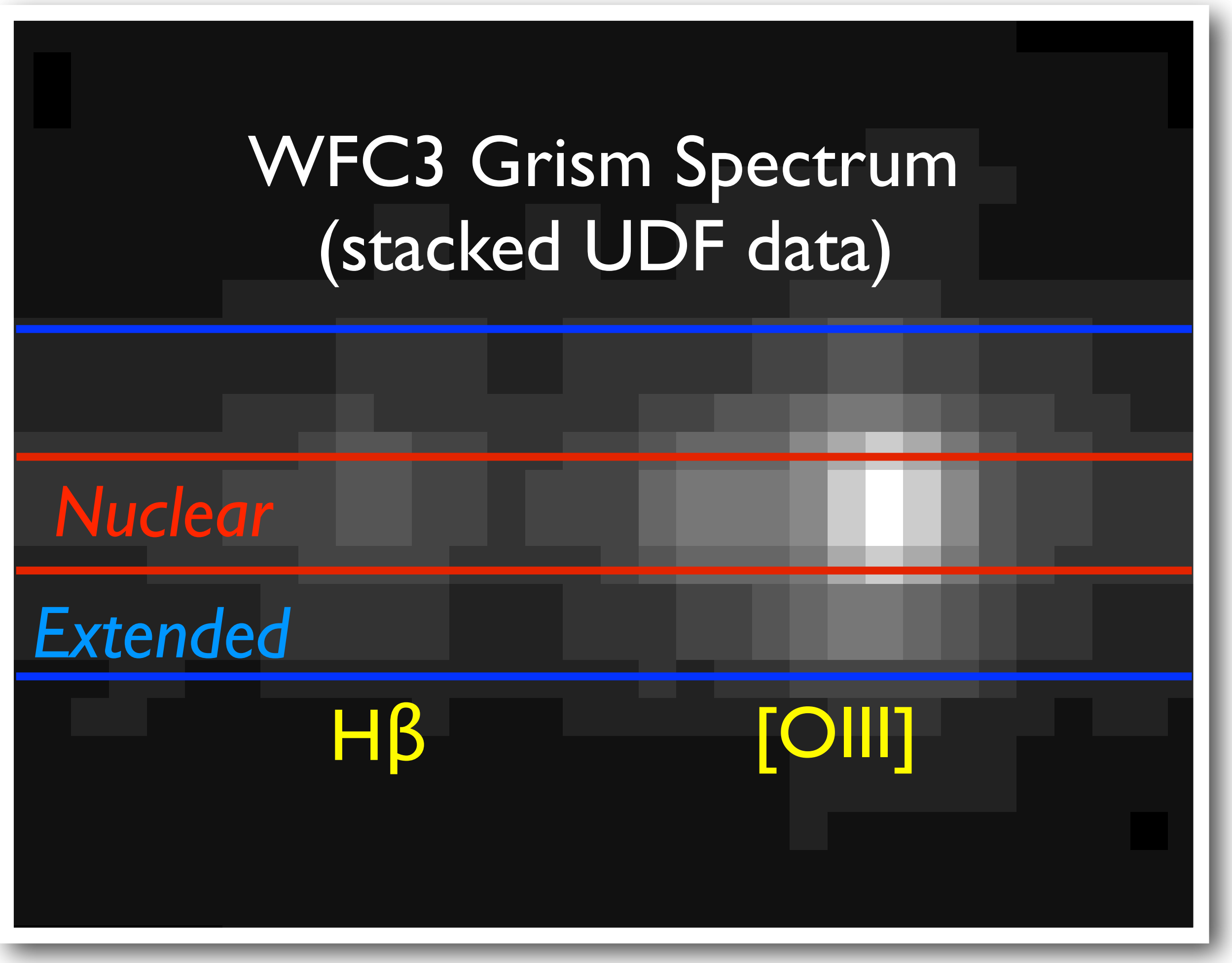
$$\log(\lambda_{\mathrm{Edd}}) = (-2.969 \pm 0.138) - (0.335 \pm 0.054)[\log(M_*) - 9] + (0.289 \pm 0.056)[\log(\mathrm{sSFR}) + 10] + (5.367 \pm 0.426)\Delta\log([\mathrm{O~III}]/\mathrm{H}\beta)$$

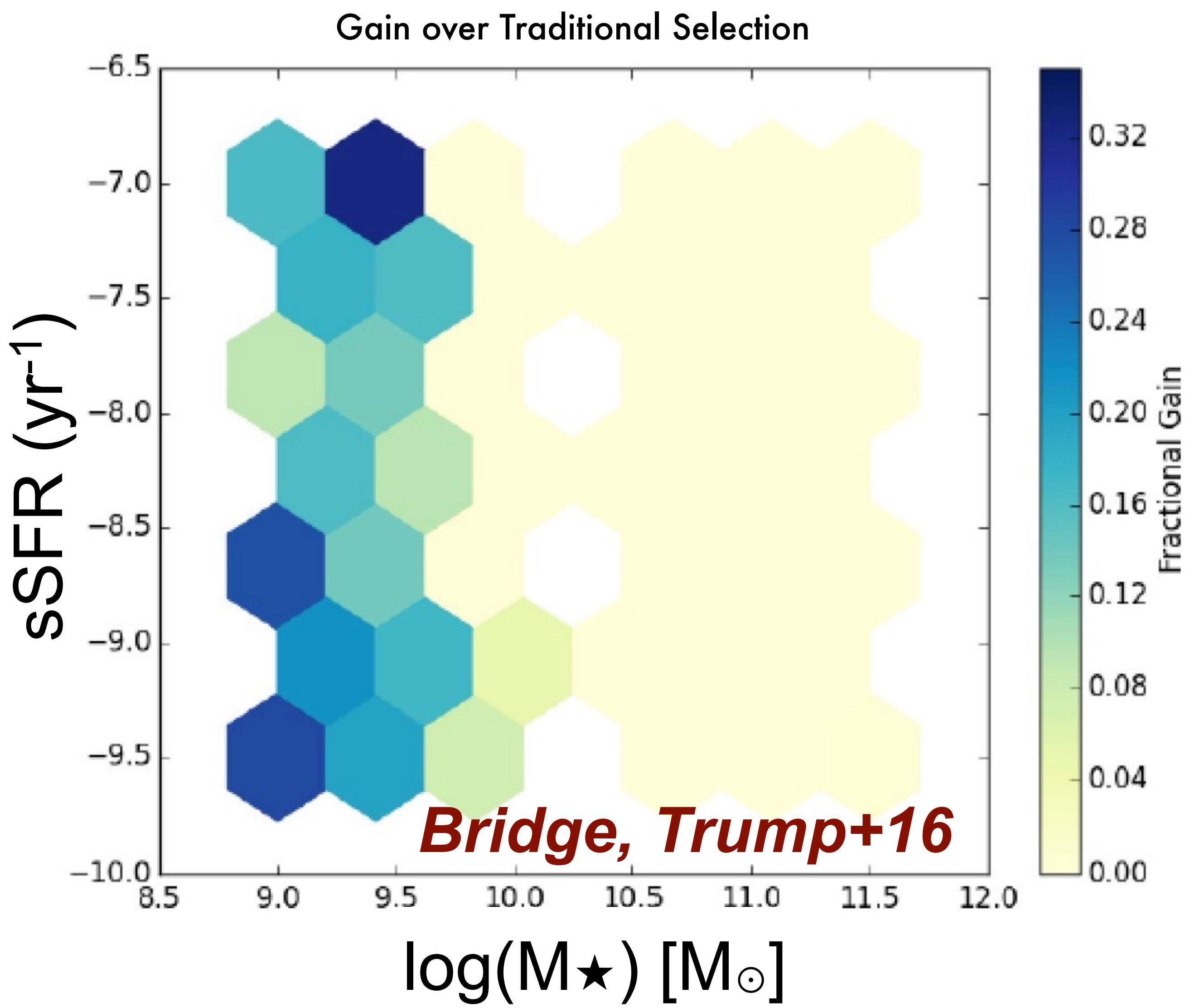


Spatially Resolved BH Detection

Much higher sensitivity than integrated BPT at low mass

(Simulation of 2-orbit HST/WFC3 grism data, exploring a wide range of AGN strength and galaxy properties)

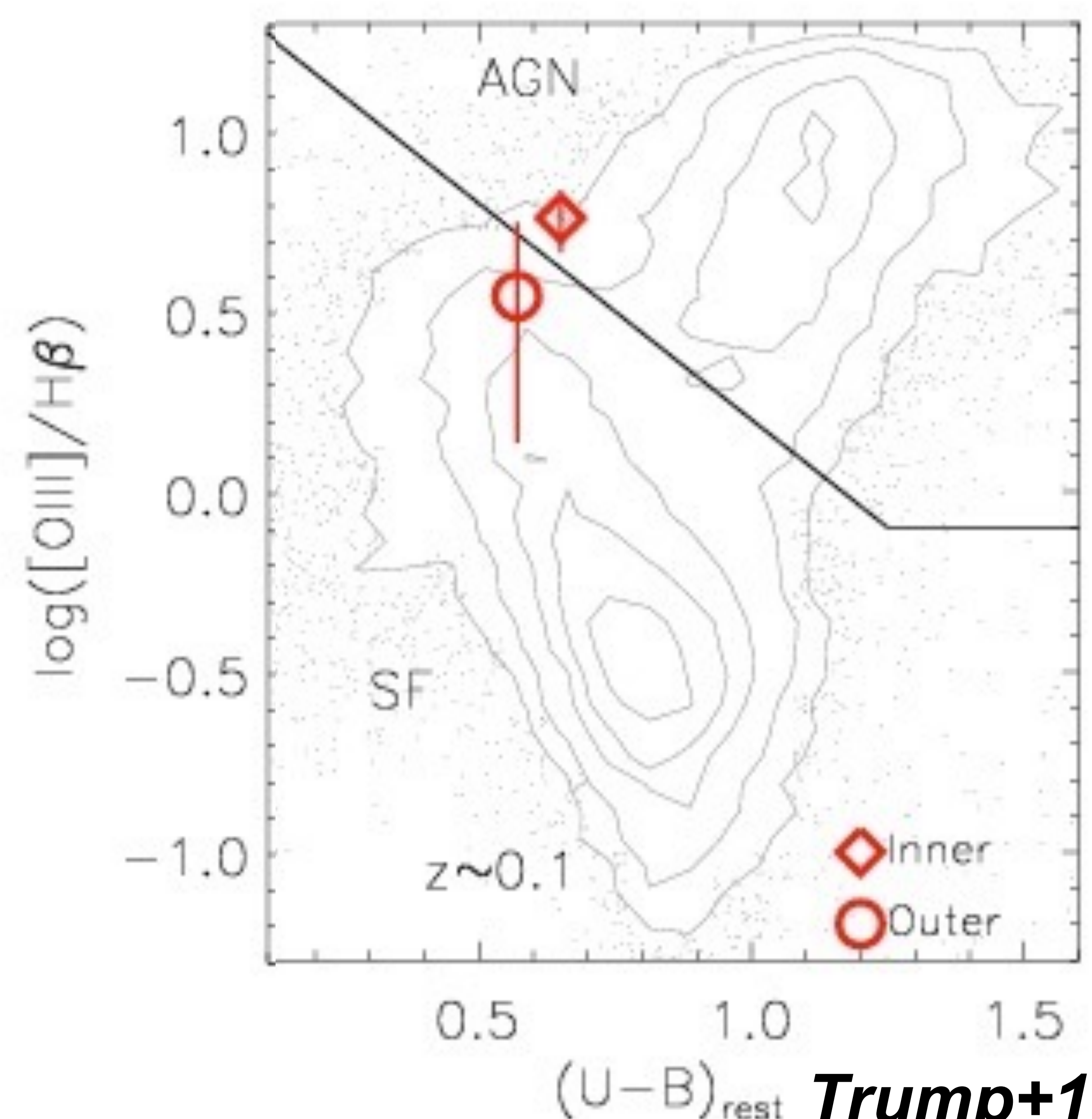




Spatially Resolved BH Detection

Nuclear BH emission in $M_\star$~10^9 galaxies

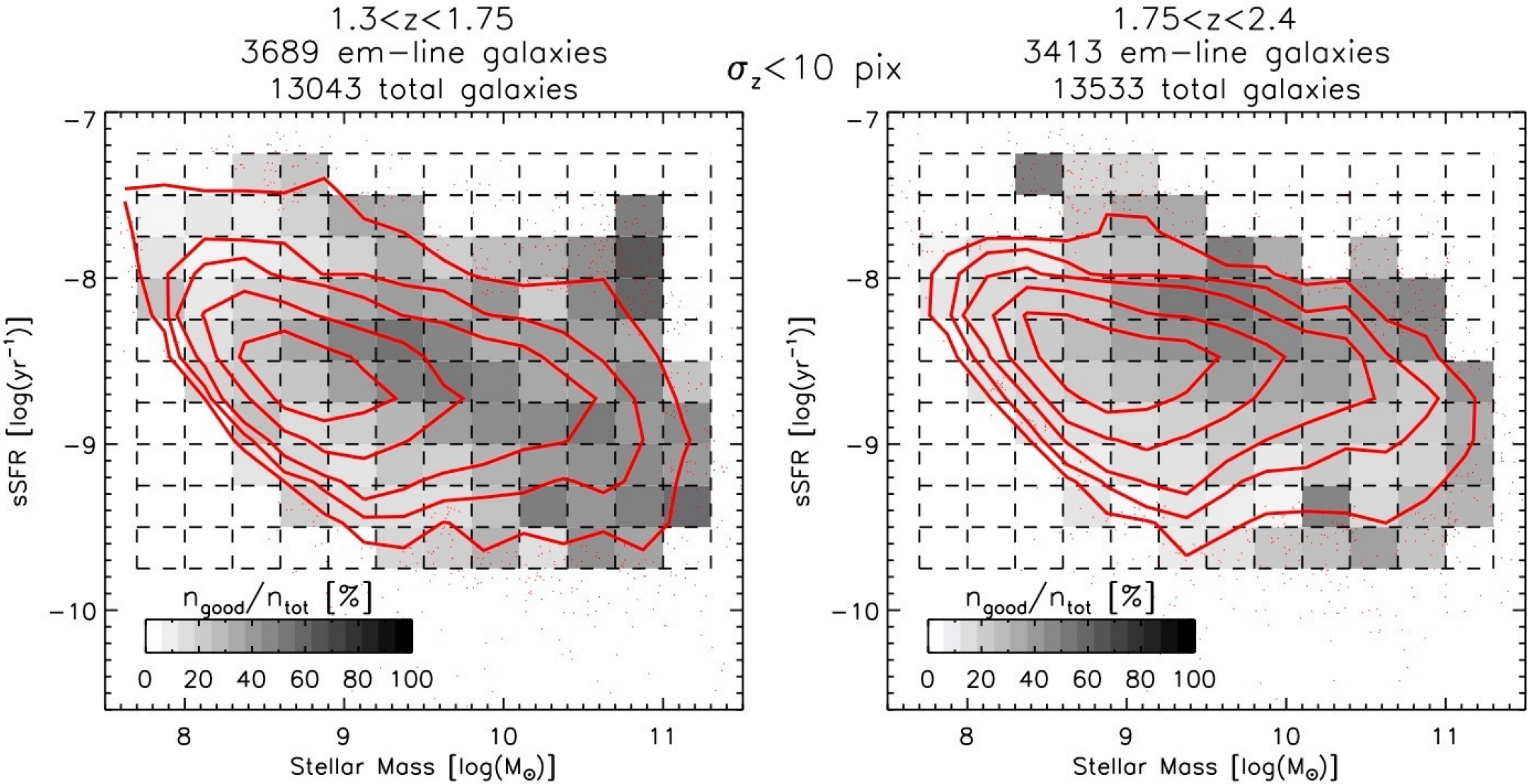
(28 stacked HST/WFC3 G141 spectra in HUDF)



Trump+11c

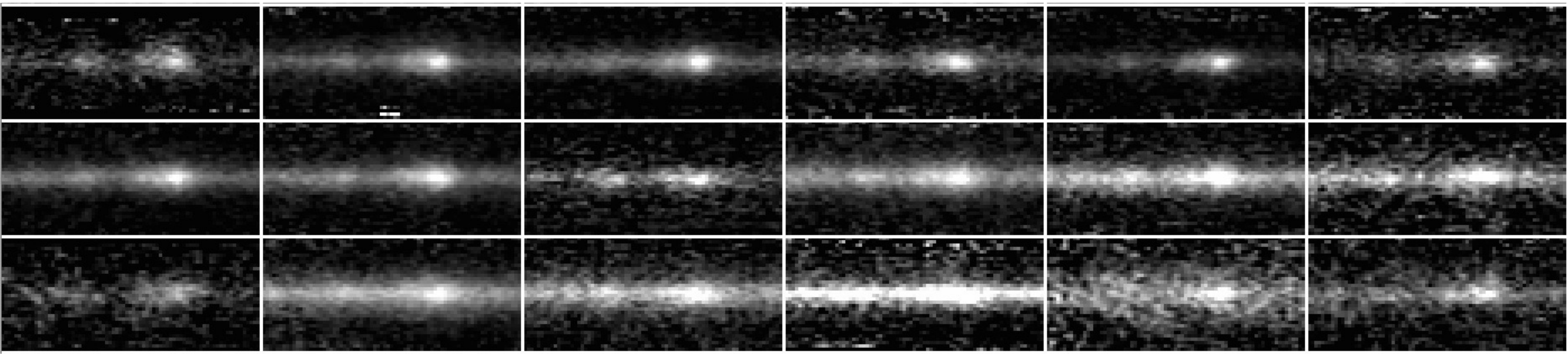
The Low-Mass AGN Census

7000 3D-HST galaxies, binned by mass and sSFR.

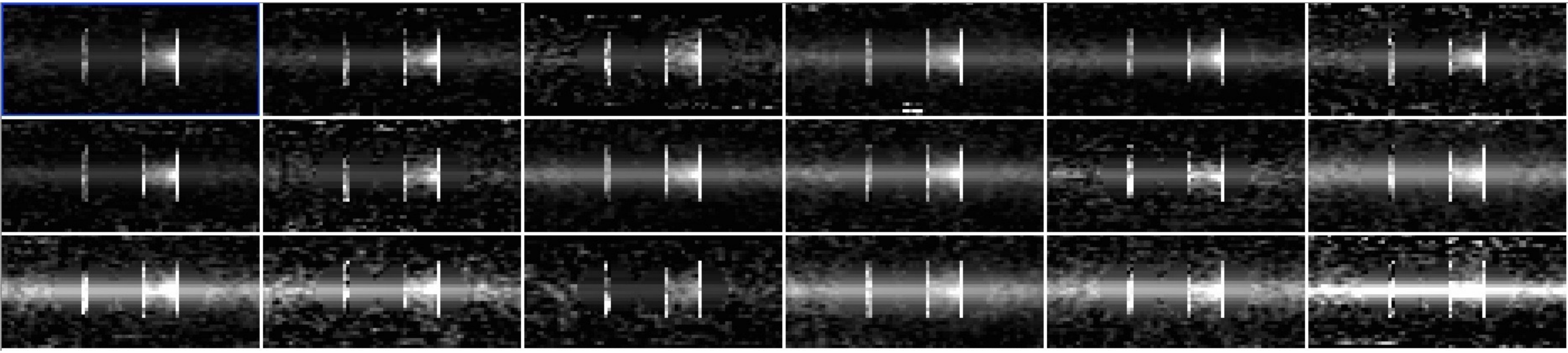


Spatially Resolved BH Detection: CANDELS + 3D-HST

Nuclear BH content by stacked galaxy mass and sSFR

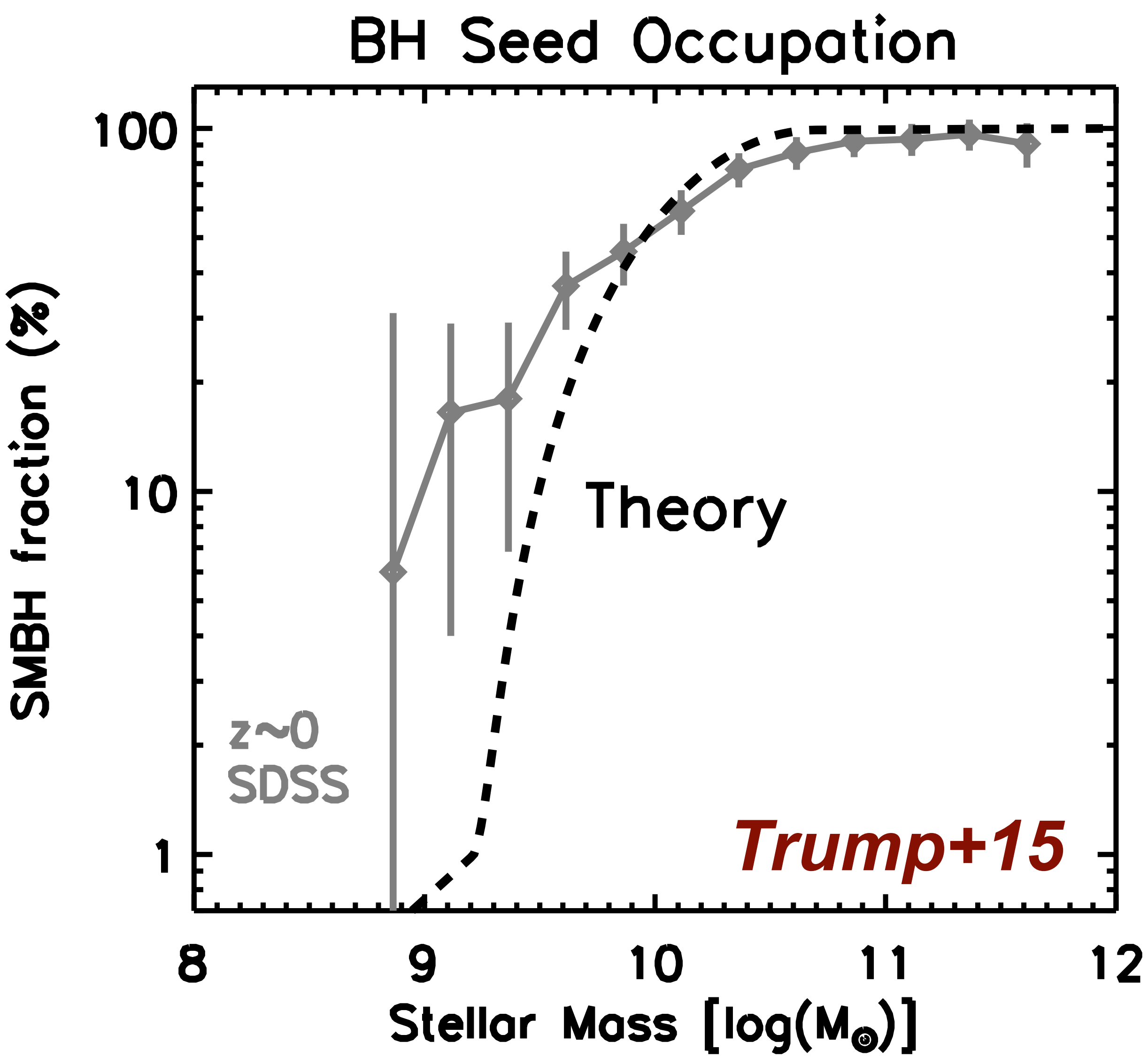


"Collapse" lines into one spatial dimension



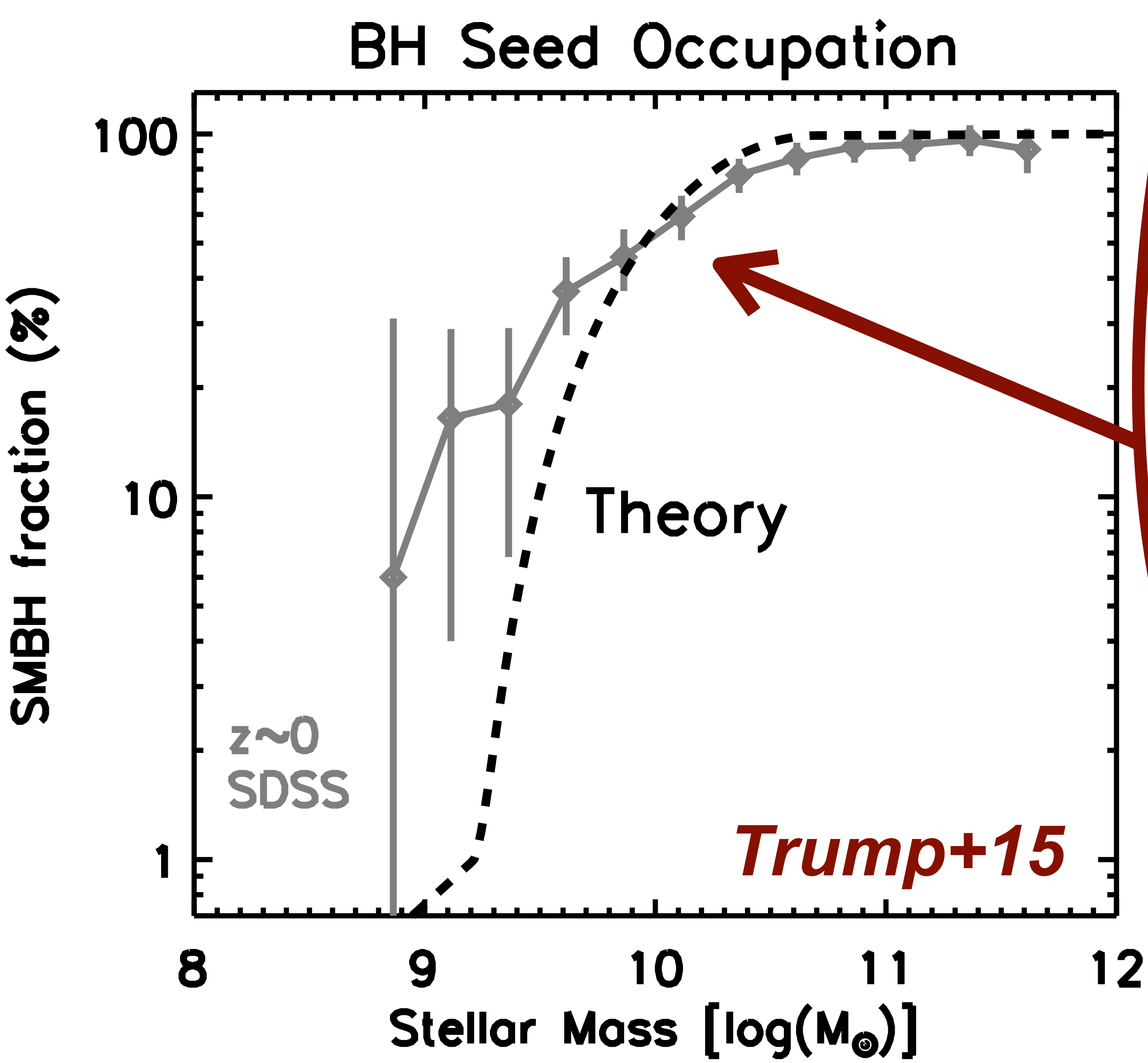
BH Seed Fossil Record

BH occupation from 320,000 SDSS galaxies… with many (uncertain) assumptions to correct detection bias

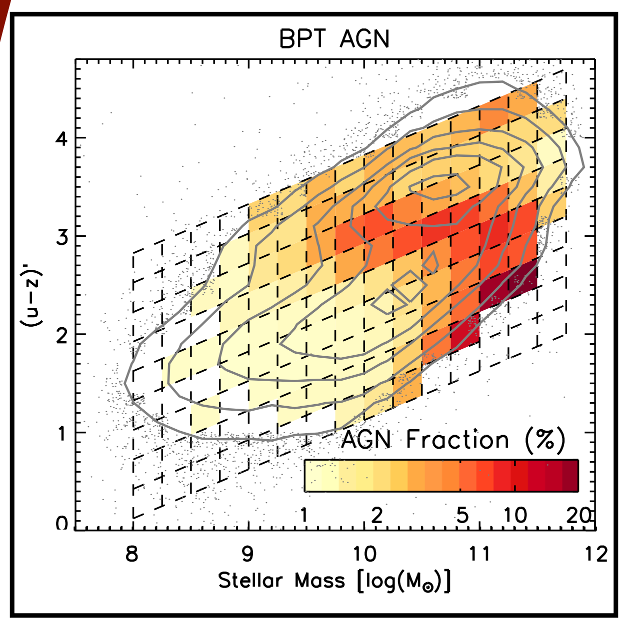


BH Seed Fossil Record

BH occupation from 320,000 SDSS galaxies… with many (uncertain) assumptions to correct detection bias

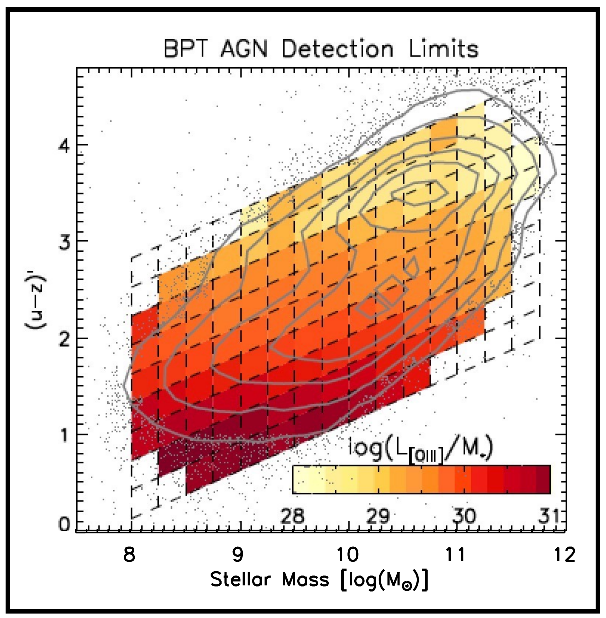


Observation



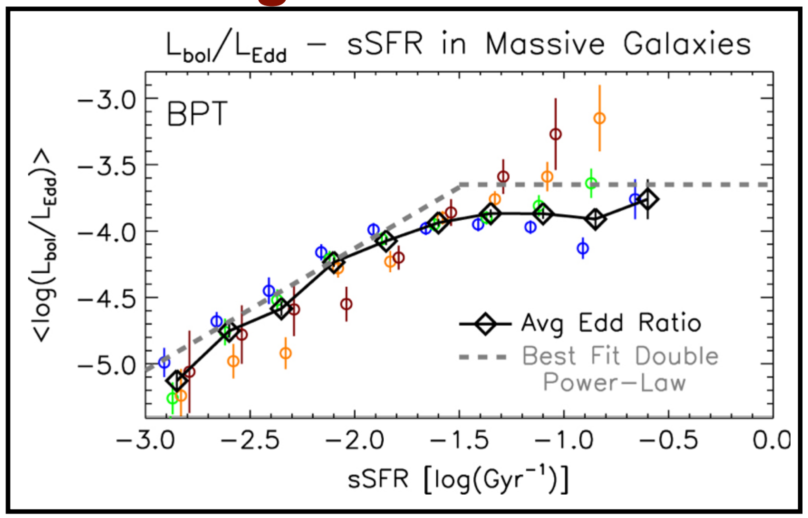
+

Bias



+

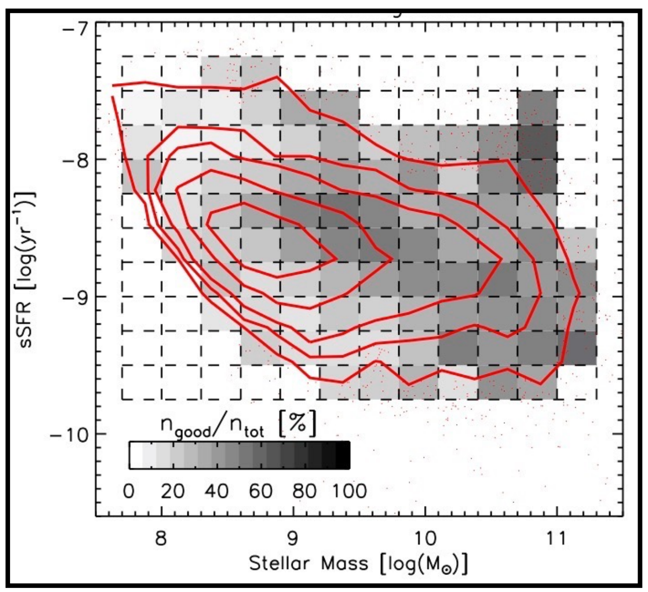
Light -> Mass



BH Seed Fossil Record

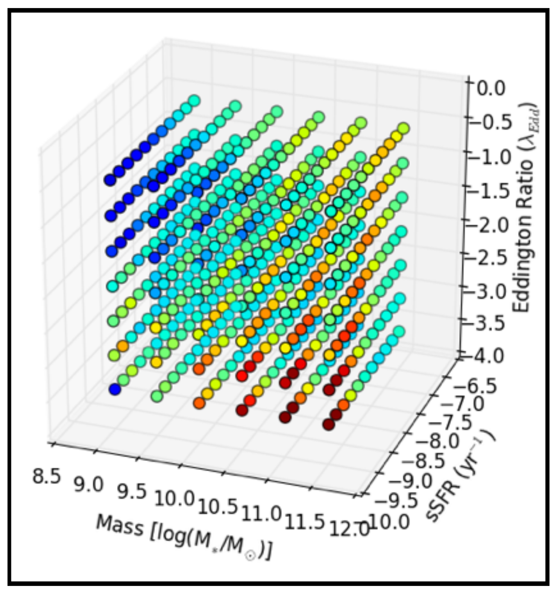
Spatially resolved HST spectra: superior constraints on BH seed occupation (*50x smaller sample than SDSS)*

Observation



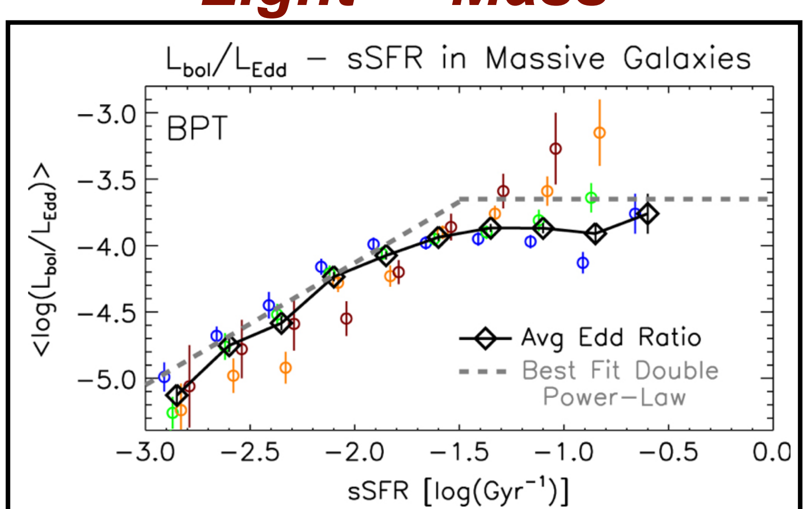
\+

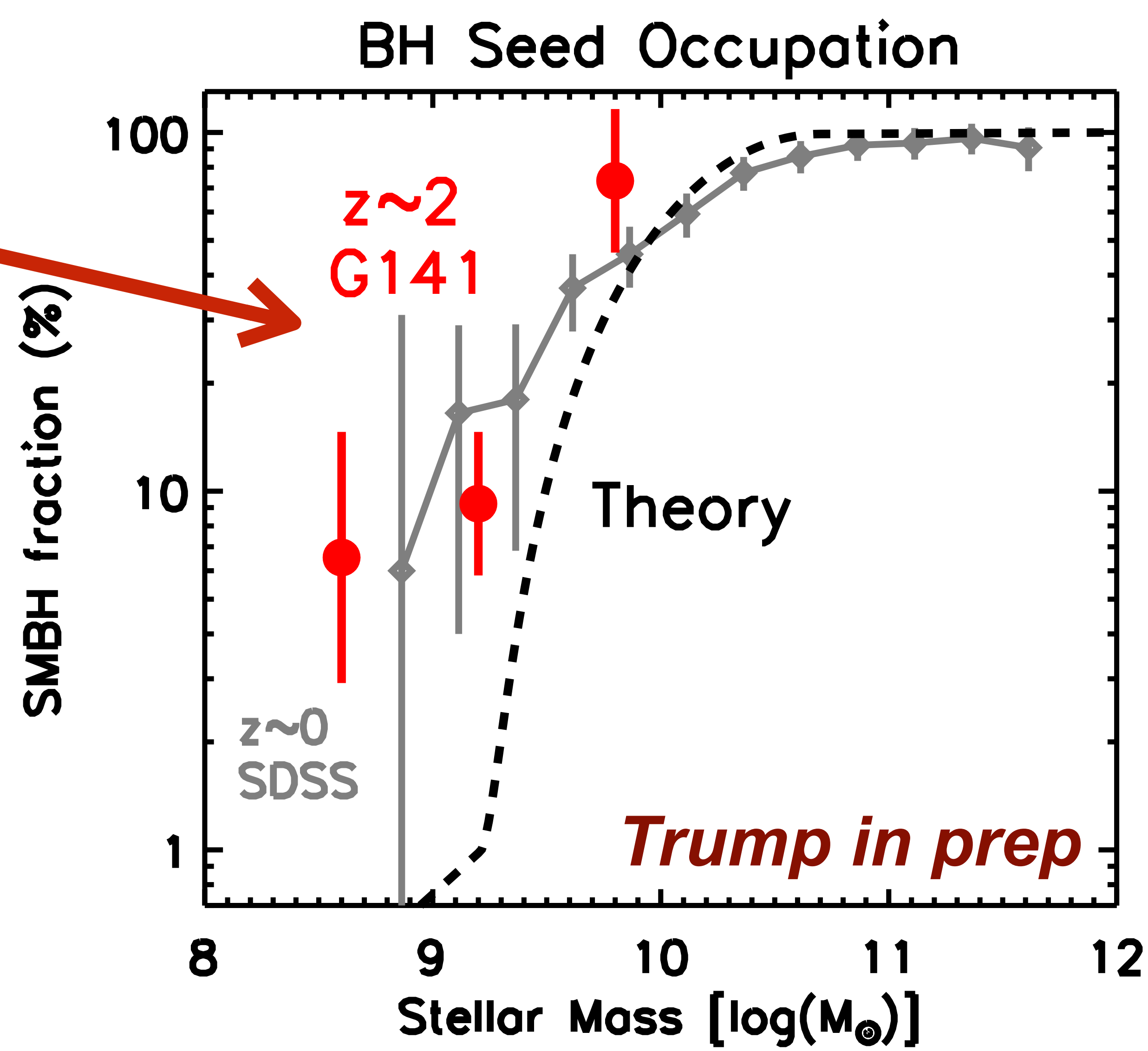
Detectability



\+

Light -> Mass

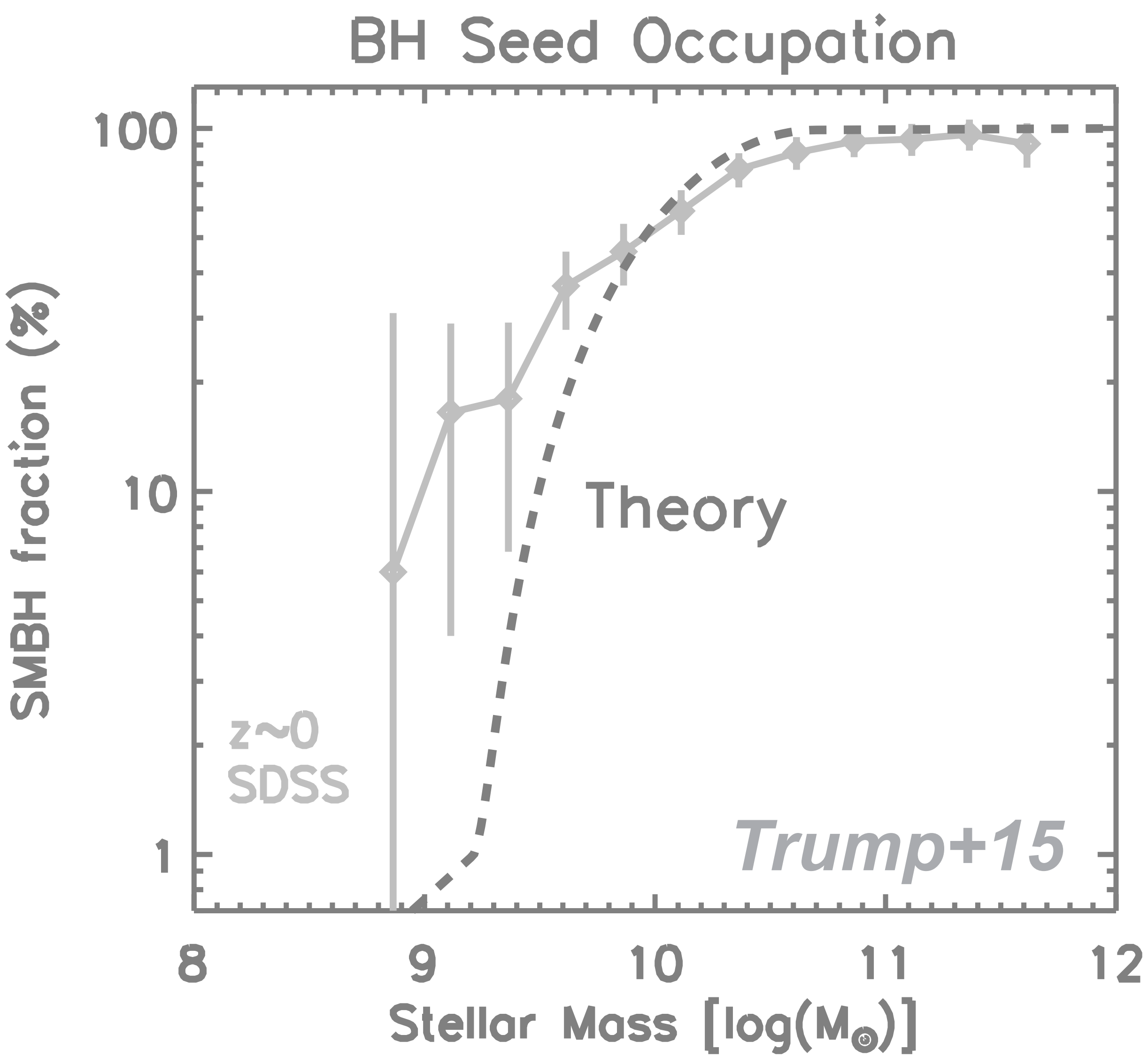


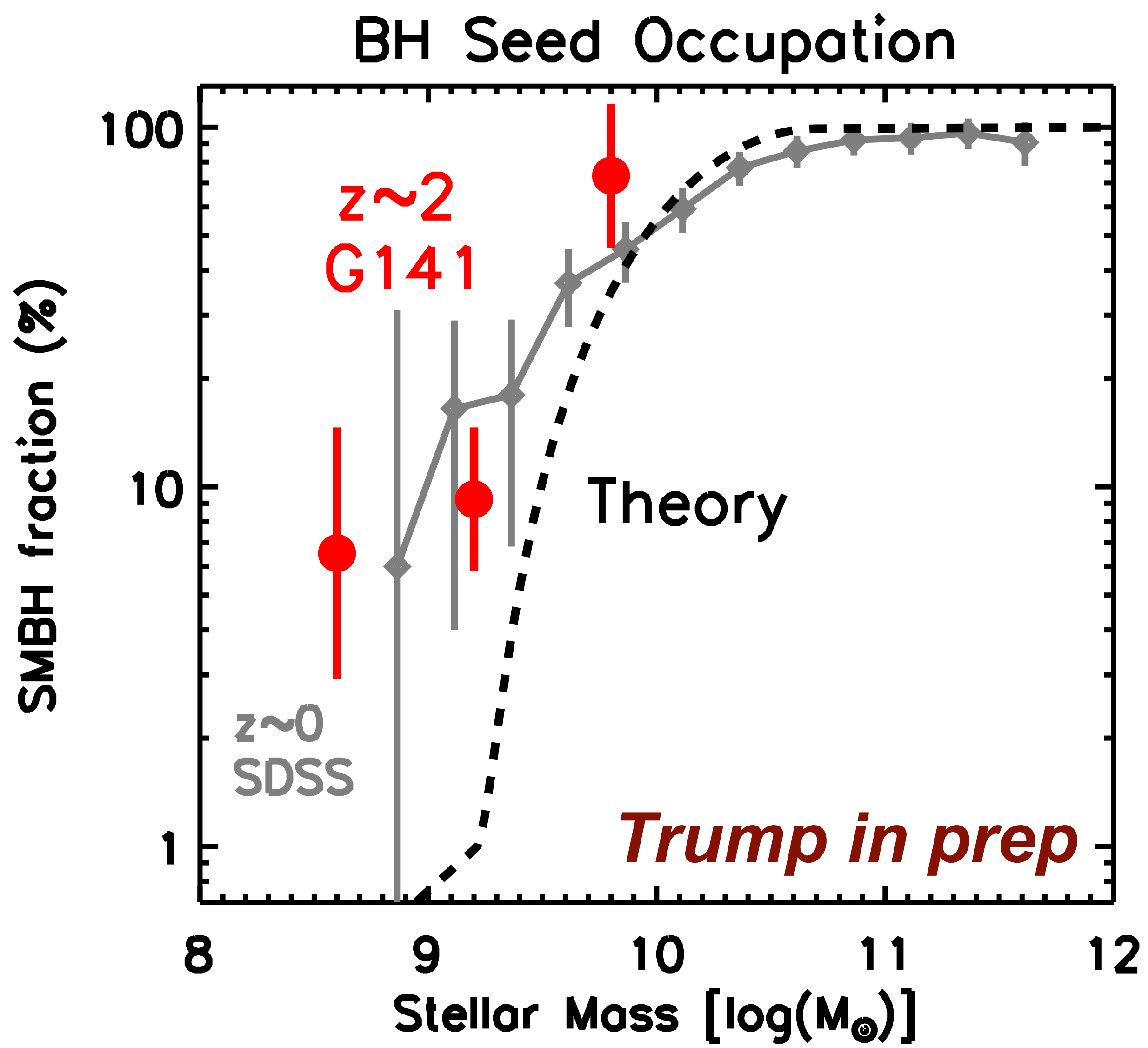


BH Seed Fossil Record

Spatially resolved HST spectra: superior constraints on BH seed occupation (*50x smaller sample than SDSS)*

Observational evidence for massive seeding

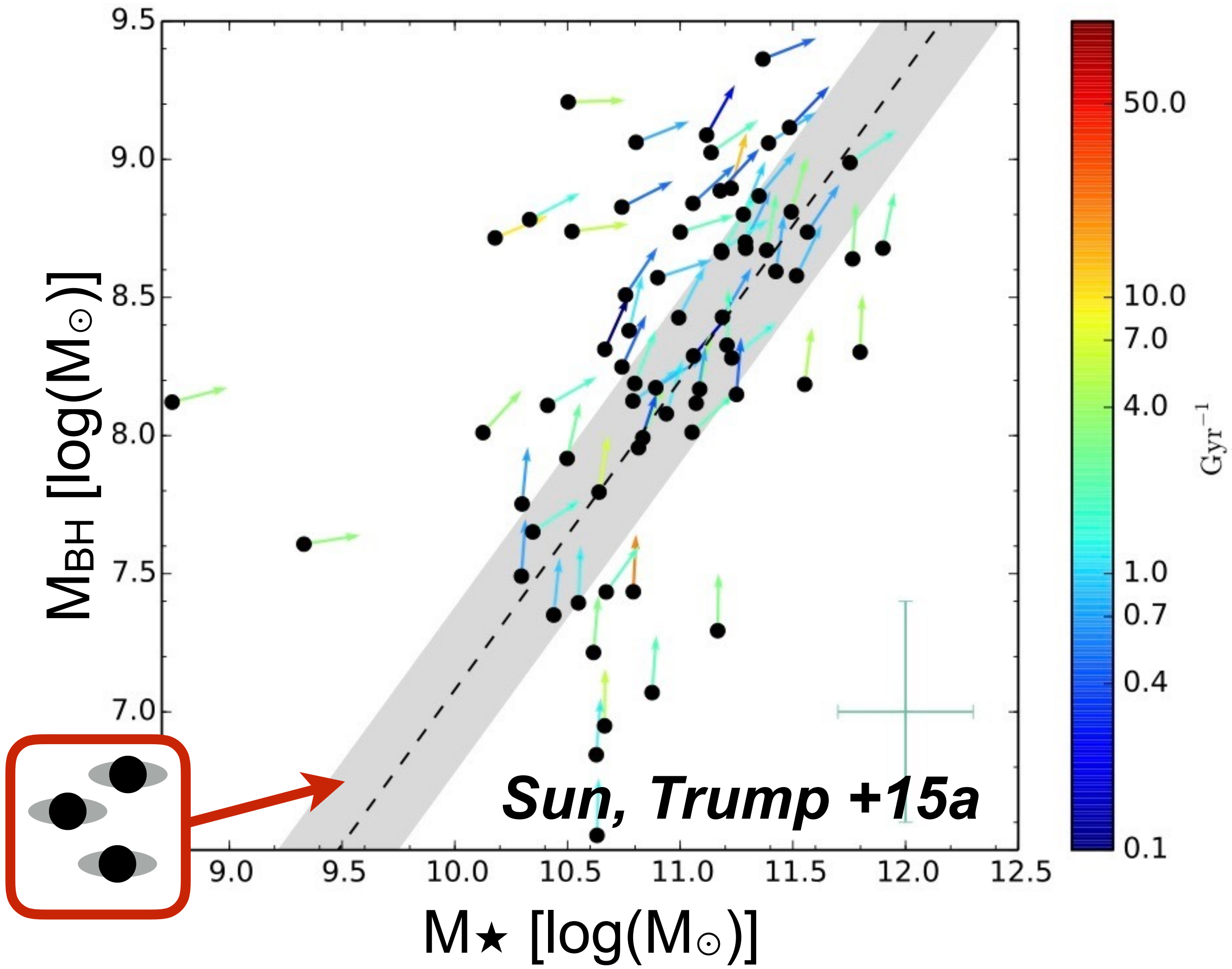


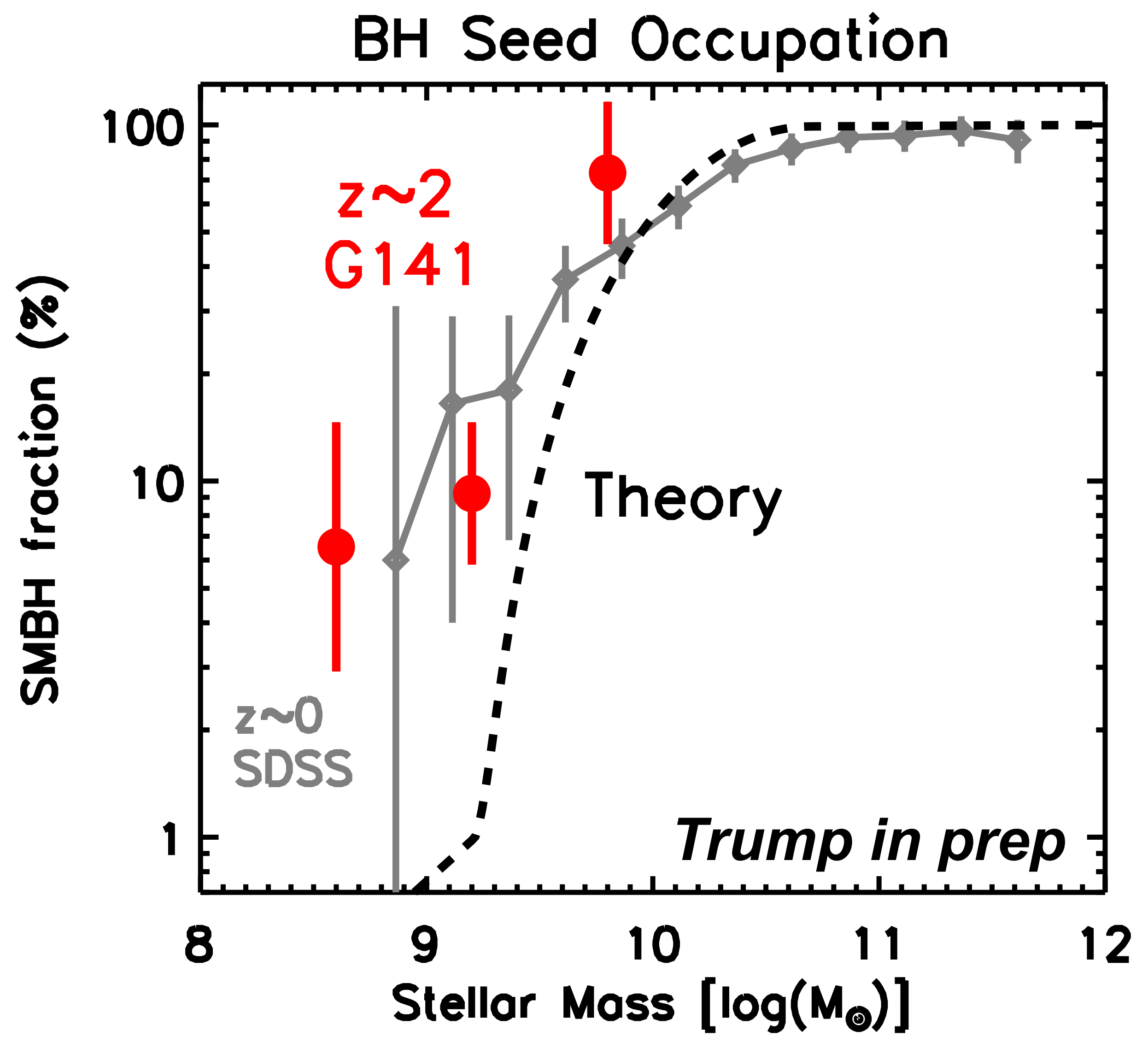


BH Seed Fossil Record

Many massive BH seeds:

- BH before galaxy: dominates primordial galaxy formation?
- BHs as missing reionization sources at z>6?
- Primordial BH collapse/merger gravitational wave signature



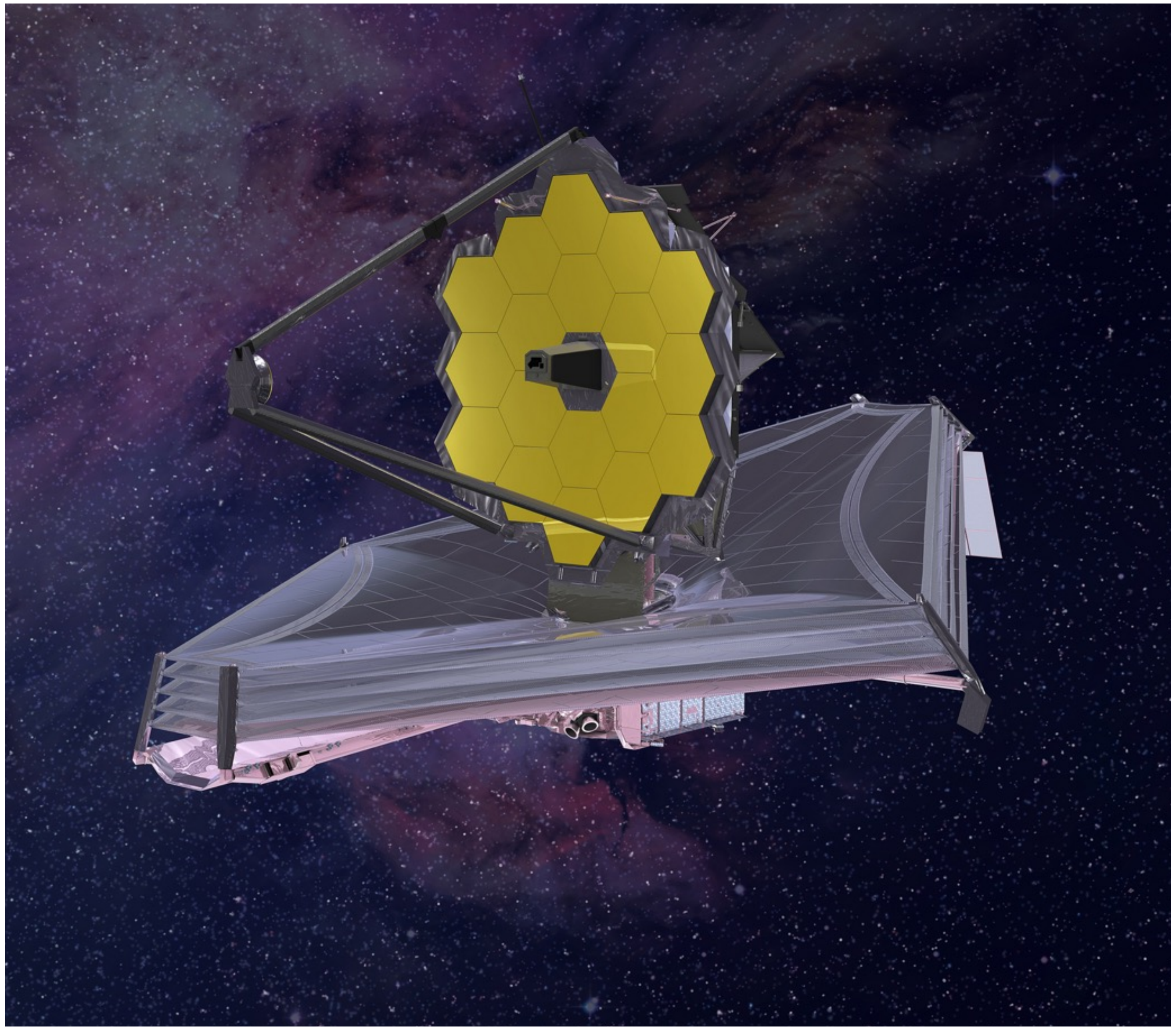


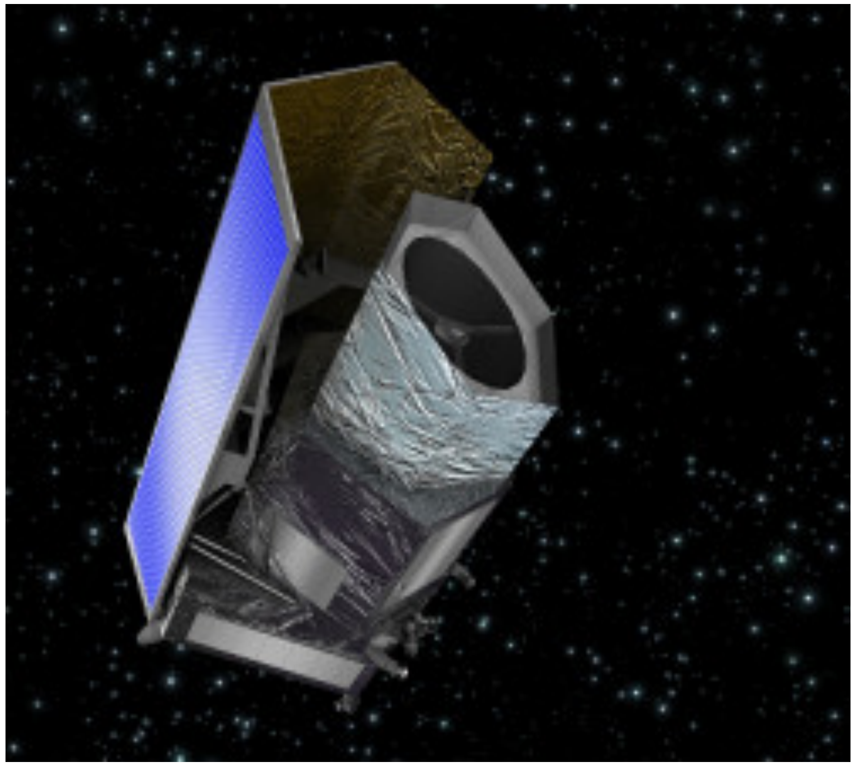
Birth and Growth of Black Holes

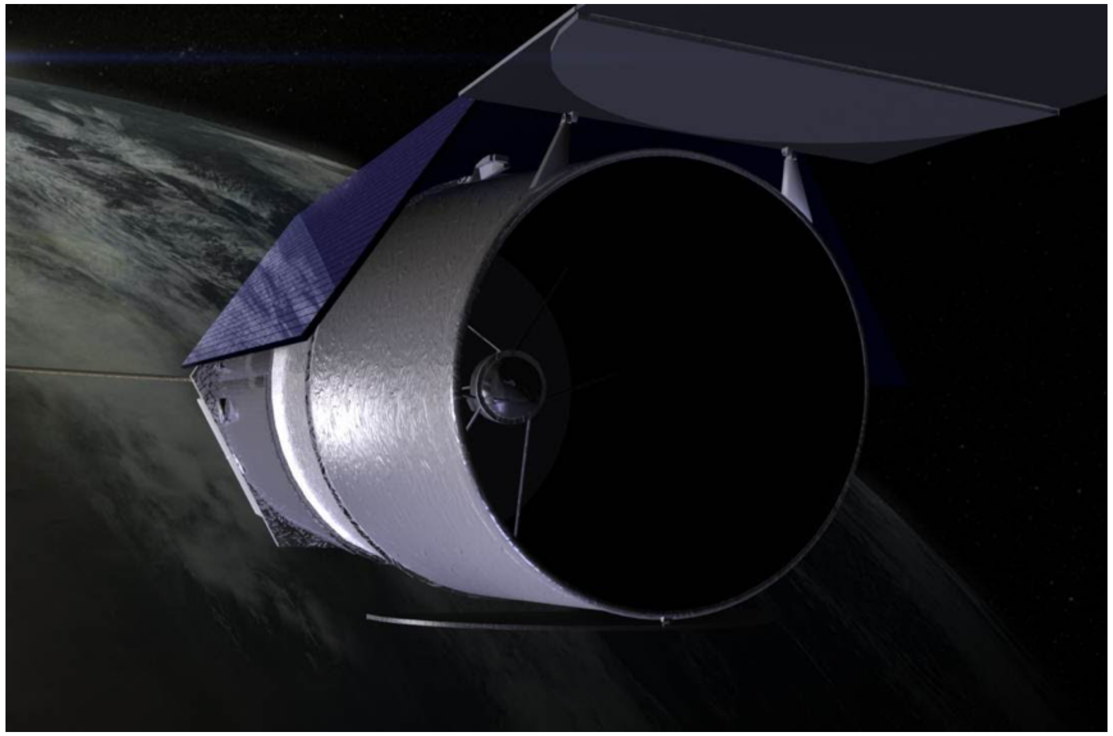
1. Black Holes and Galaxies: Background
2. The Census of Low-Mass AGNs
3. Coming of Age with Imaging Spectroscopy
4. ***Imaging Spectroscopy: The Next Generation***

Future of Imaging Spectroscopy

Flagship instruments on:

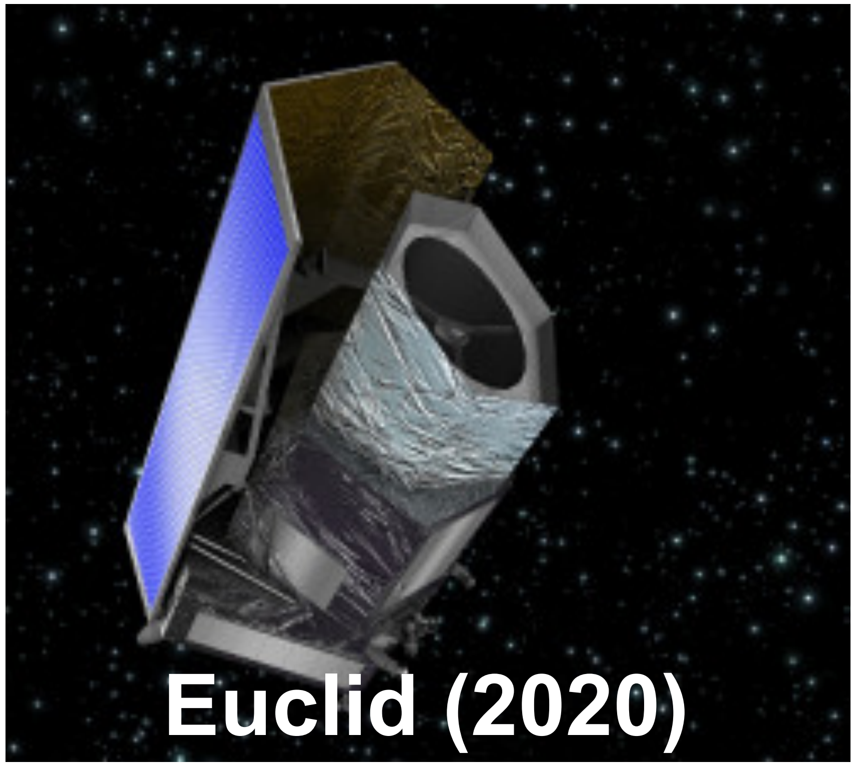


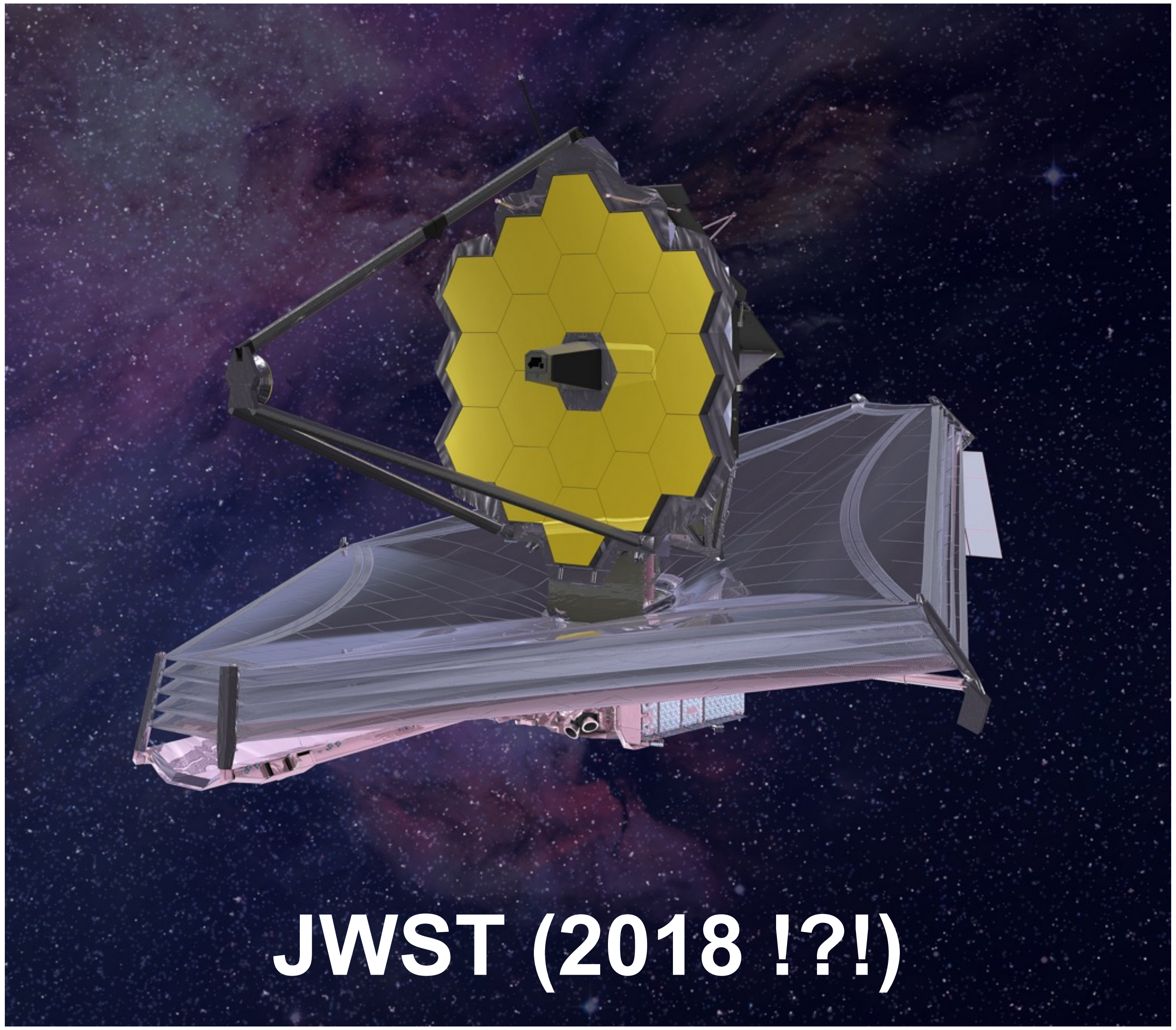


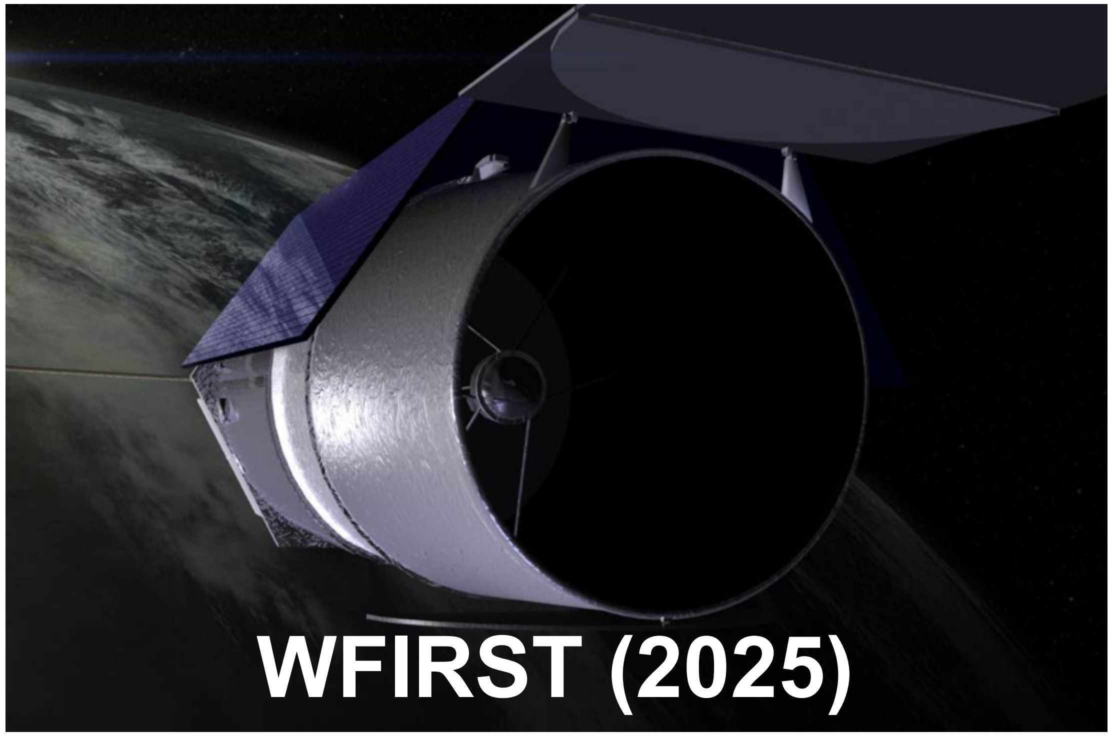


Future of Imaging Spectroscopy

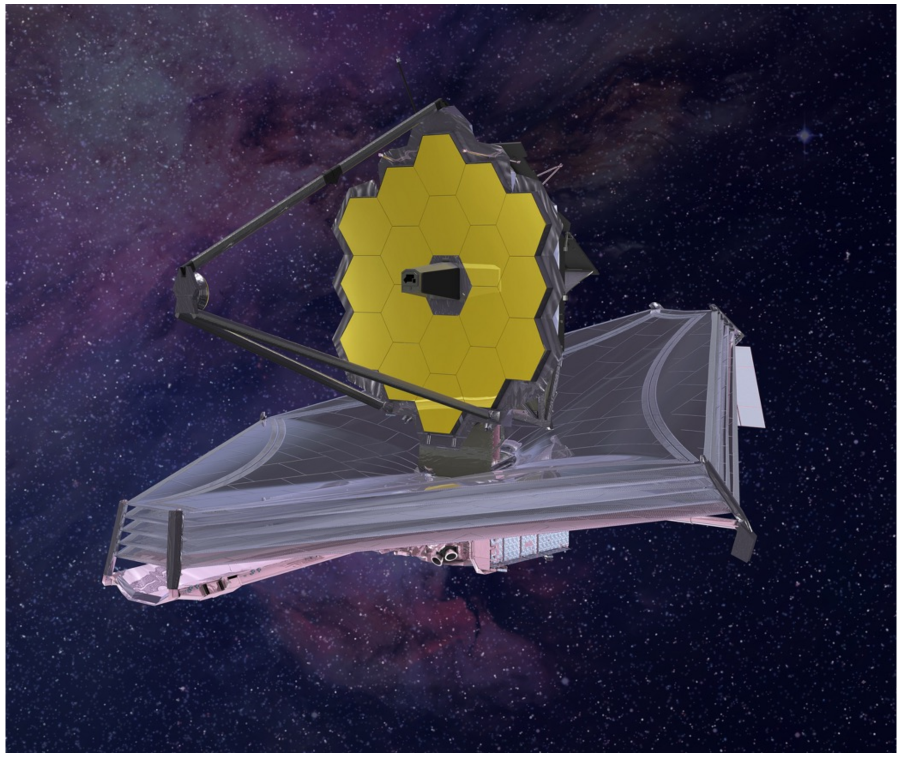
Flagship instruments on:





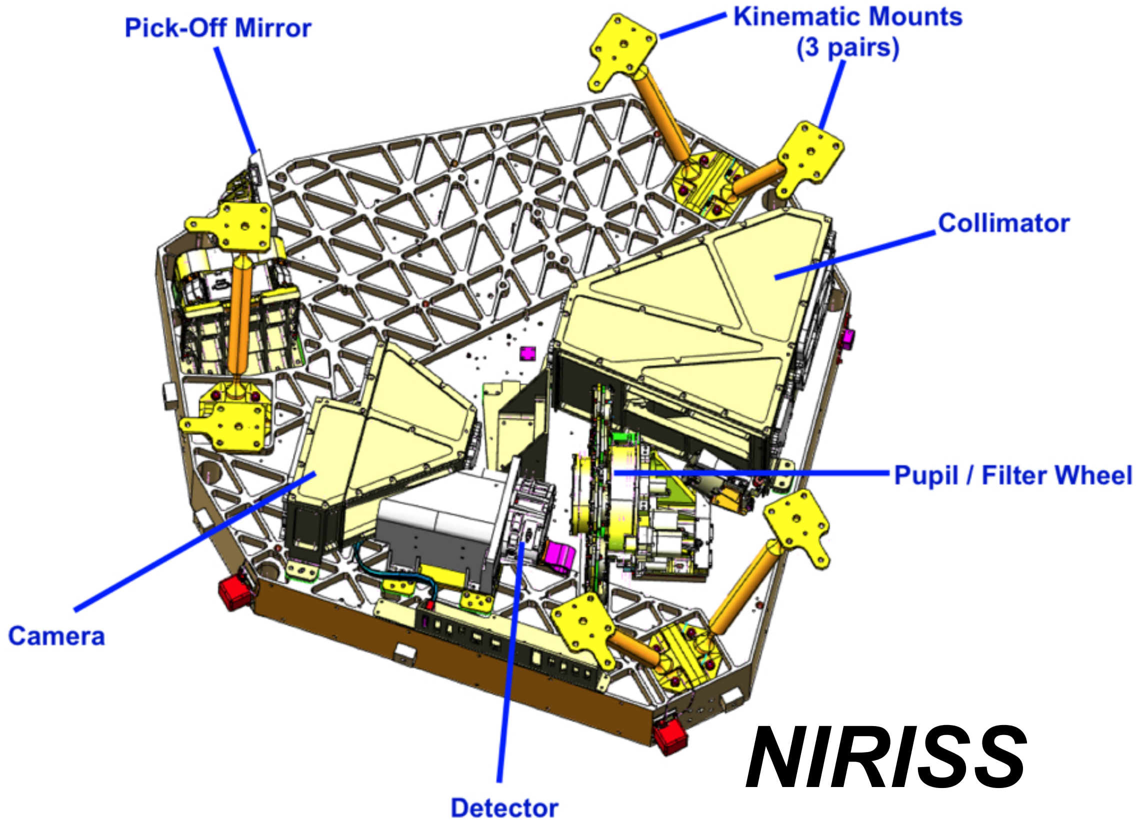


Future of Spatially Resolved Spectroscopy Surveys

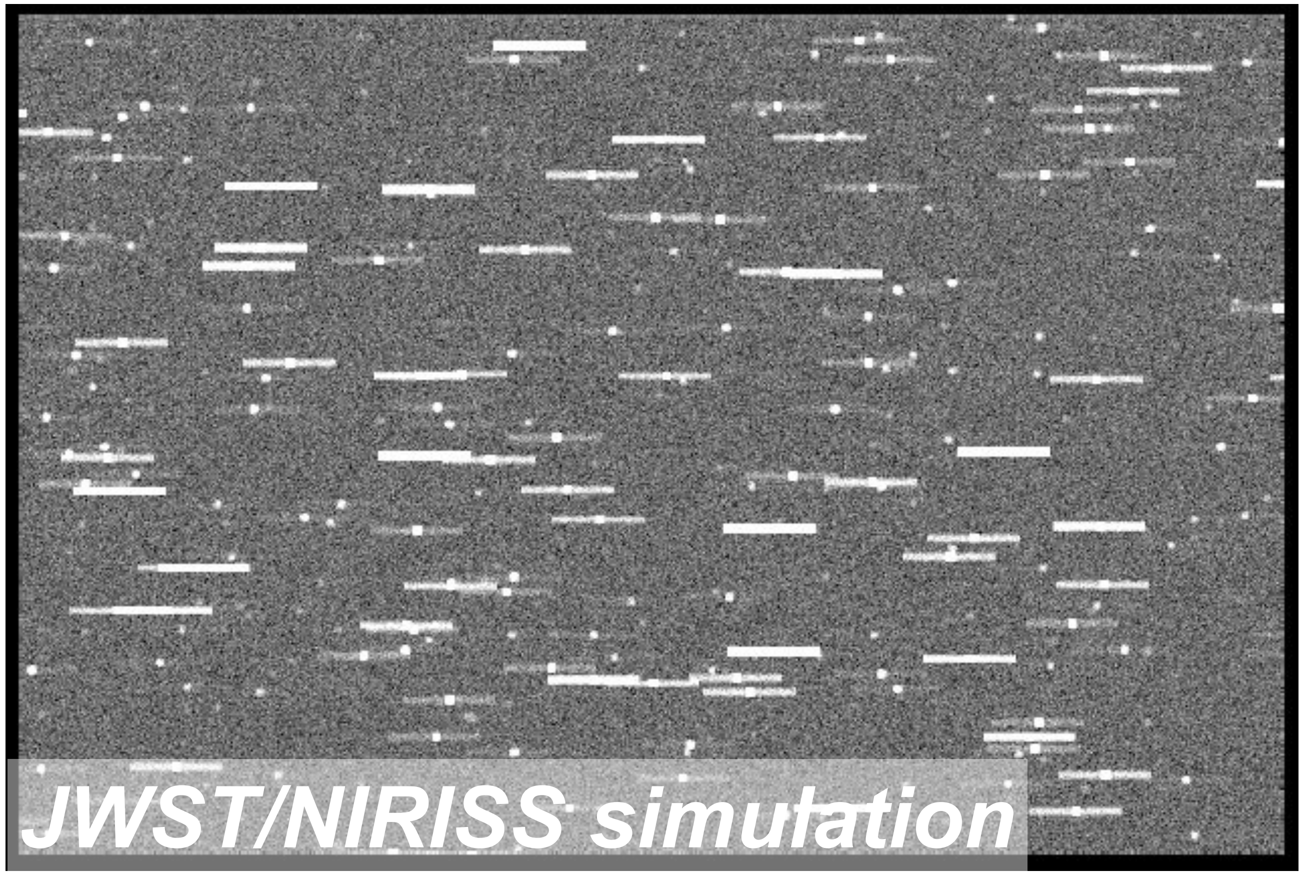


Sensitivity like Spitzer/IRAC… in spatially resolved spectroscopy!

- ***BH seed formation and growth***
- Extended shocks / outflows
- Inside-out galaxy evolution
- First galaxies, physical conditions

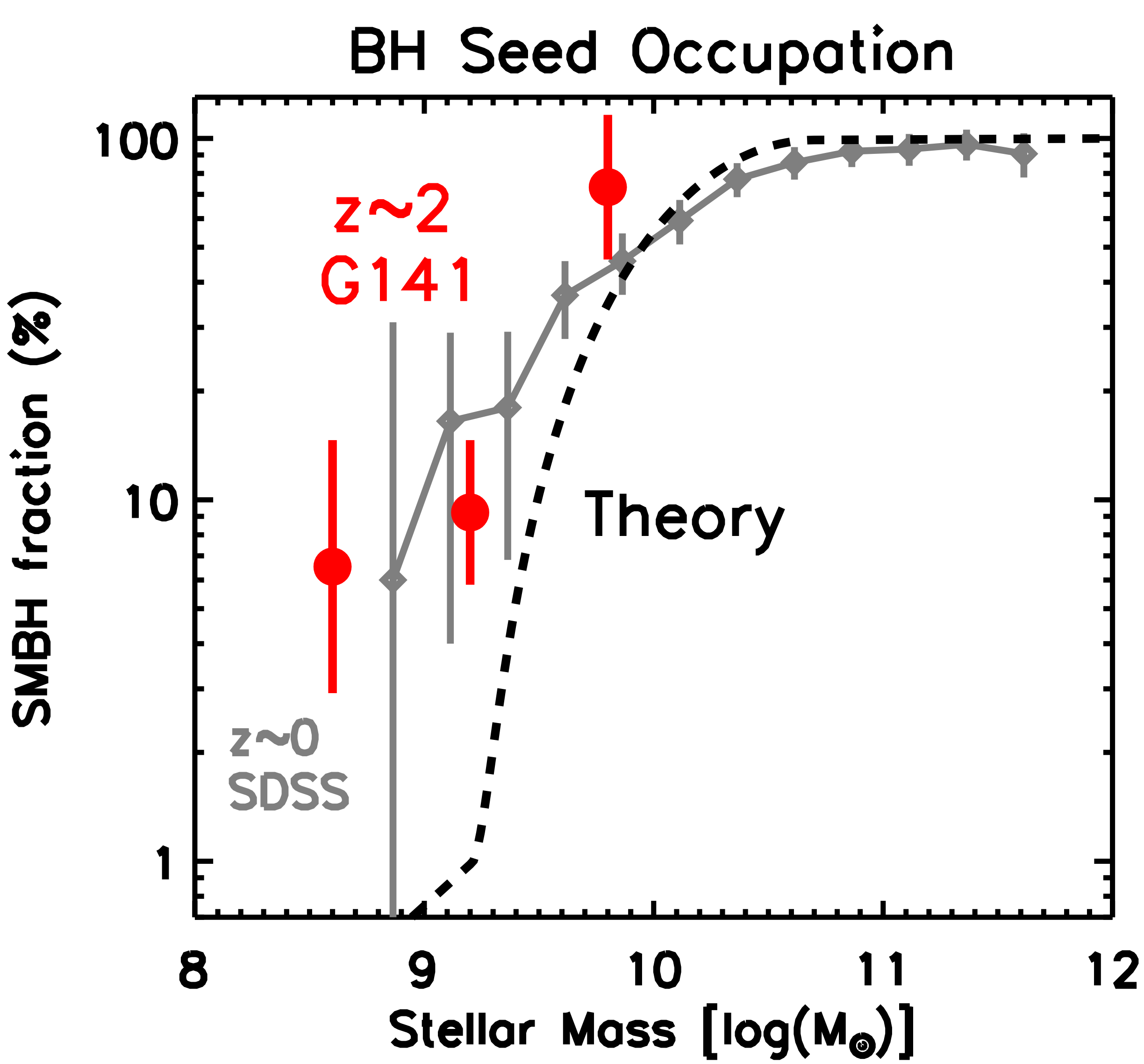


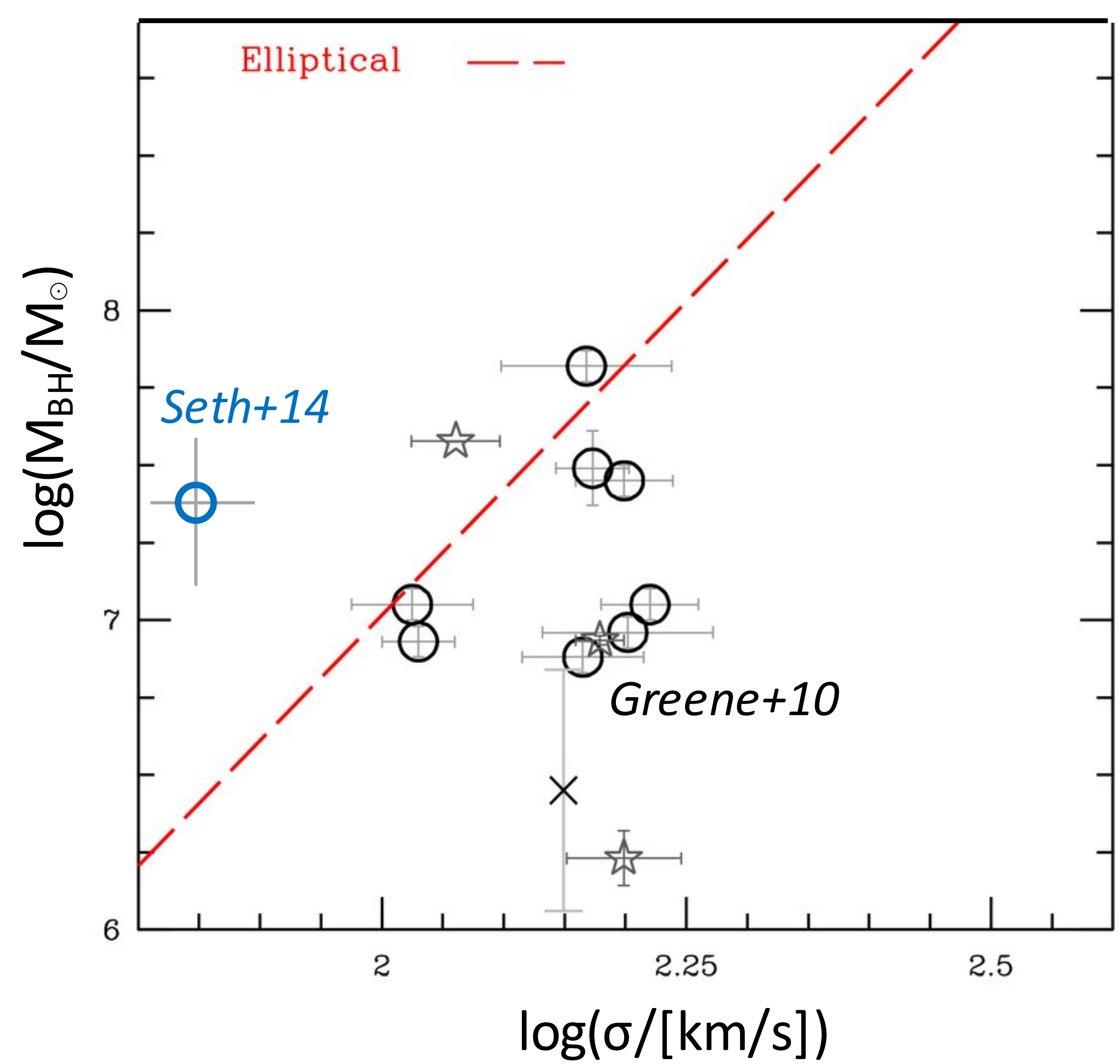
NIRISS



BH Seed Census with JWST

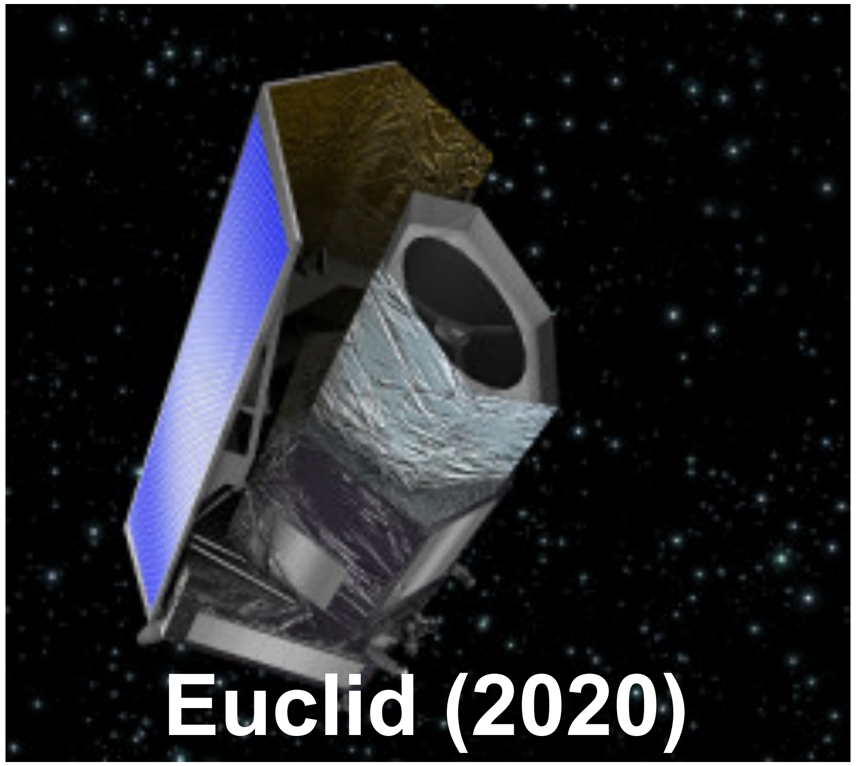
- Spatially resolved detections of *individual* AGNs in 10^8 M_{sun} hosts: direct census of seed distribution!

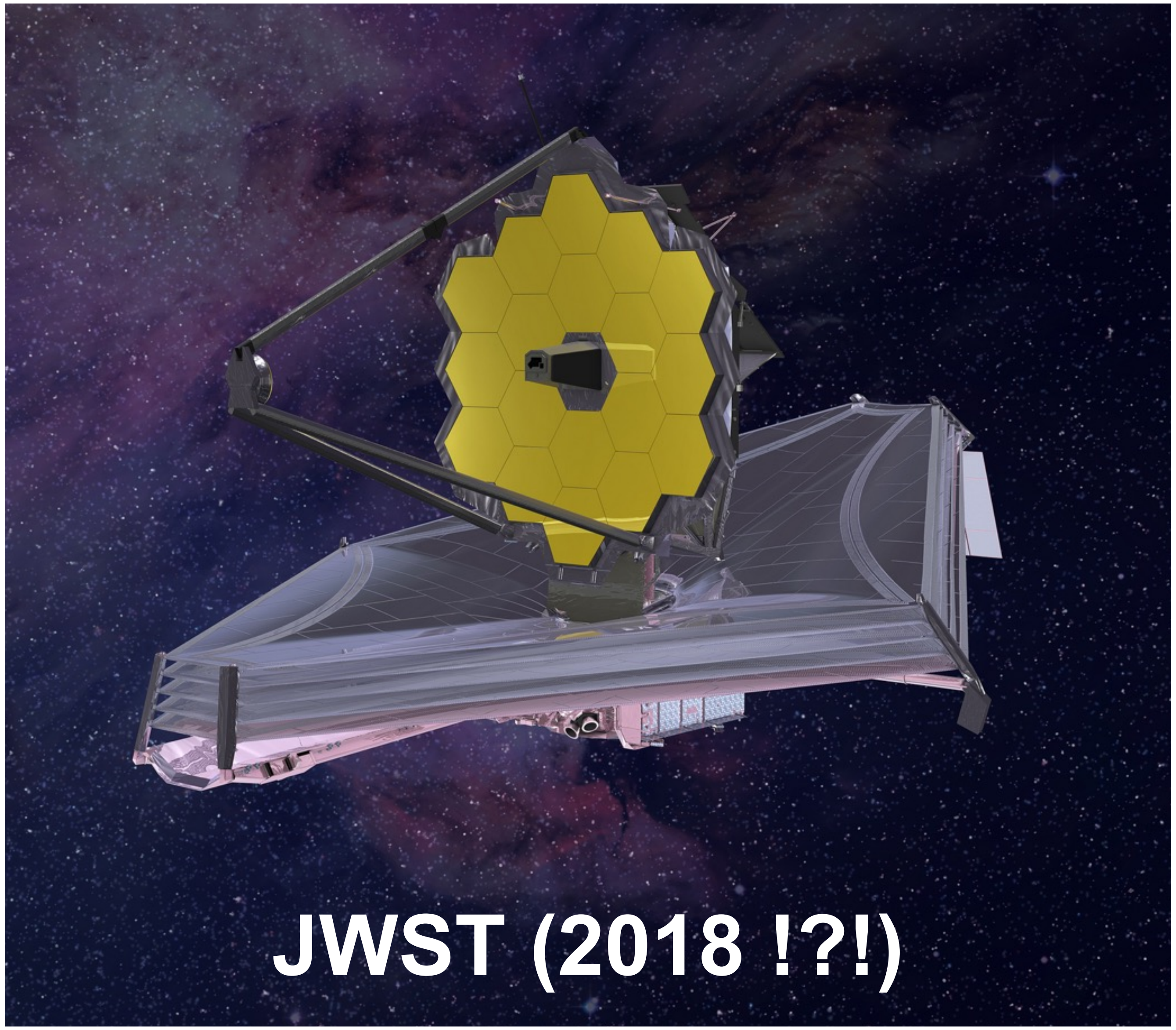


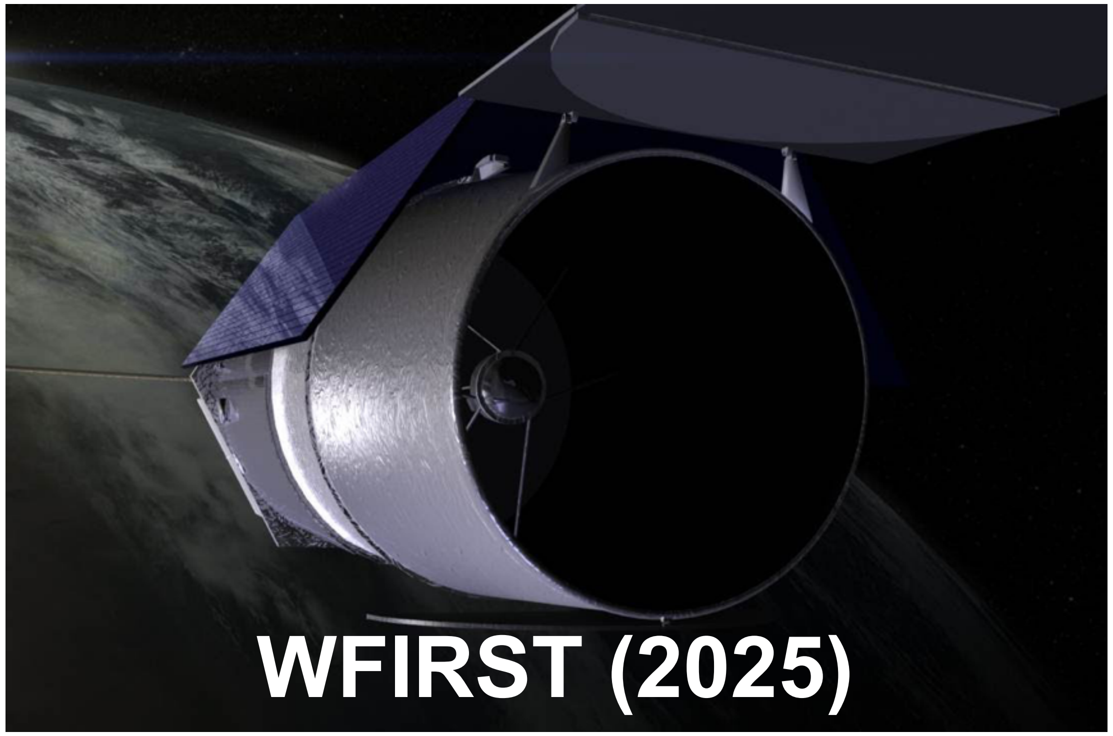


Future of Imaging Spectroscopy

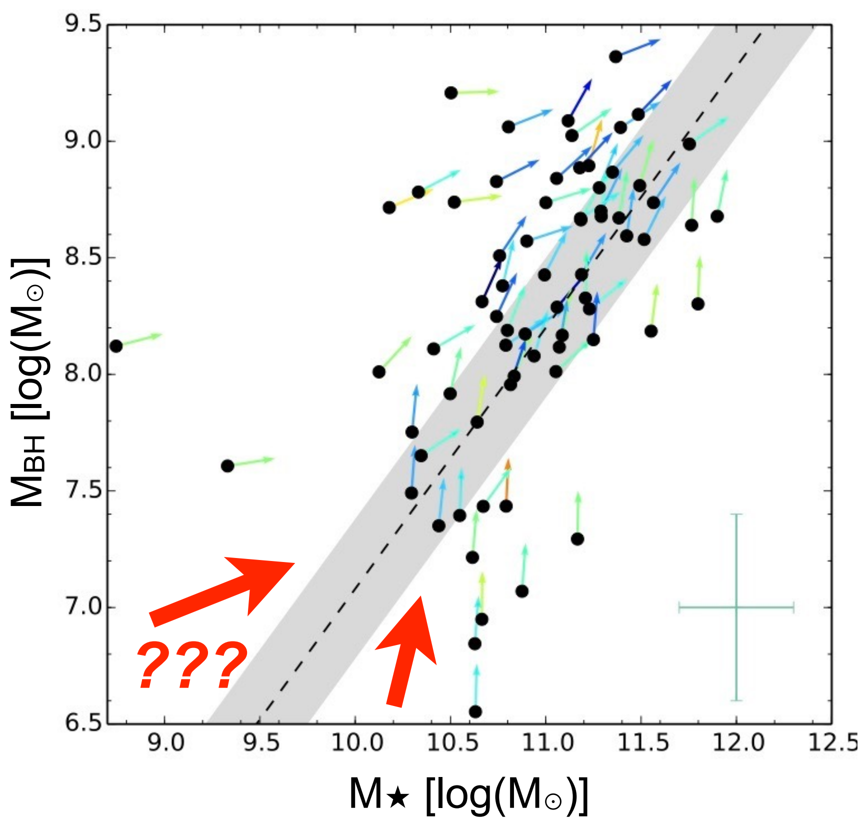
Flagship instruments on:

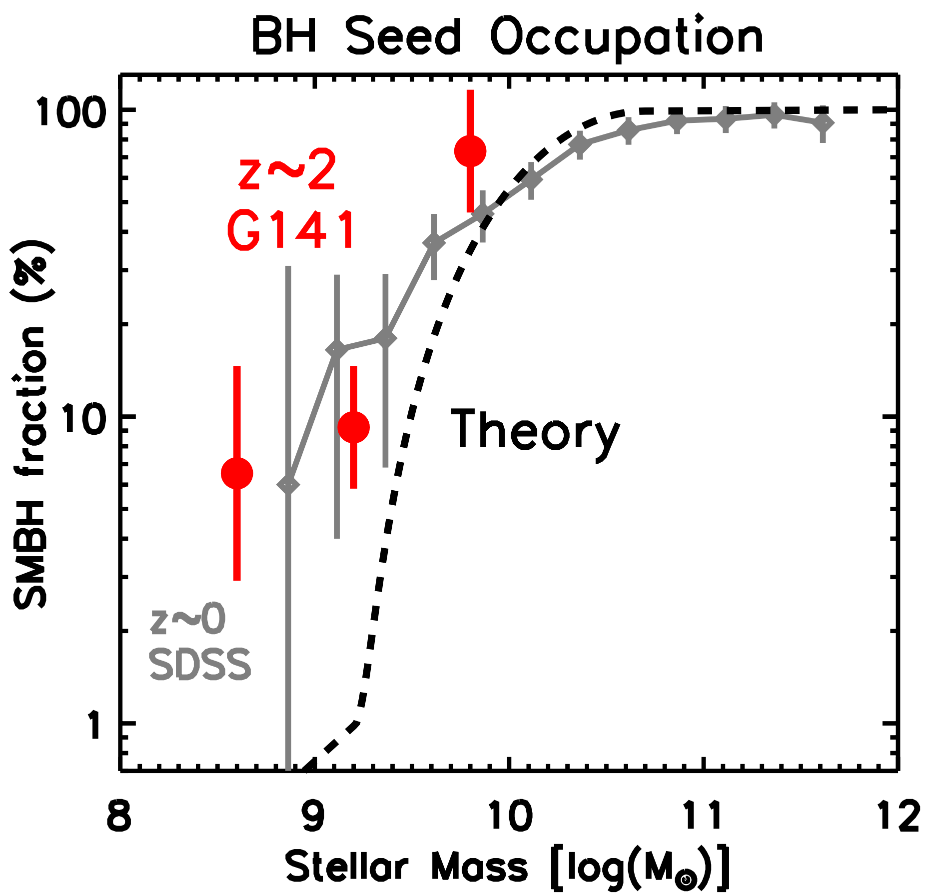


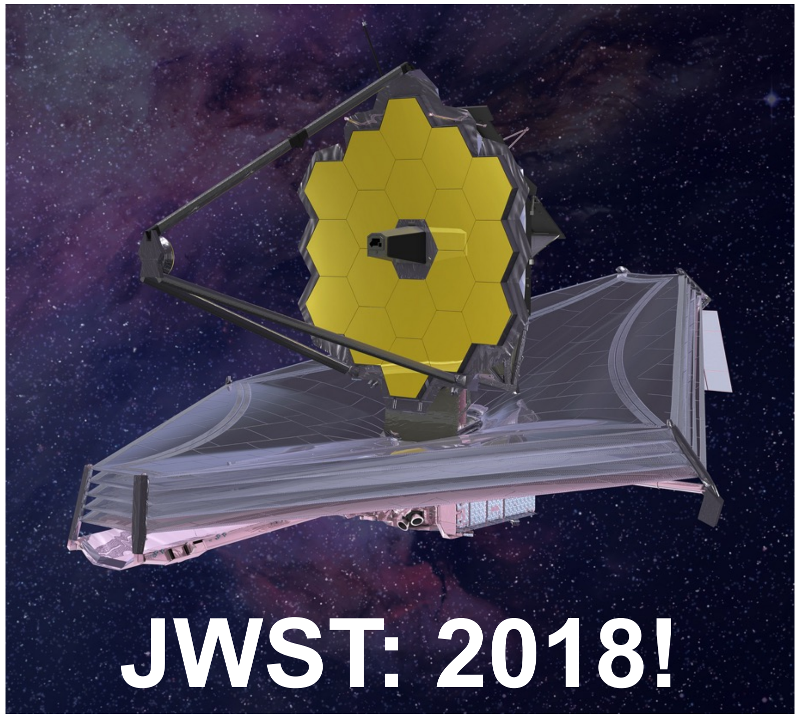




Imaging Spectroscopy and Black Hole Seeds







Jonathan Trump jonathan.trump@uconn.edu

UConn http://phys.uconn.edu/~jtrump