The smallest massive black holes in nearby galaxy nuclei

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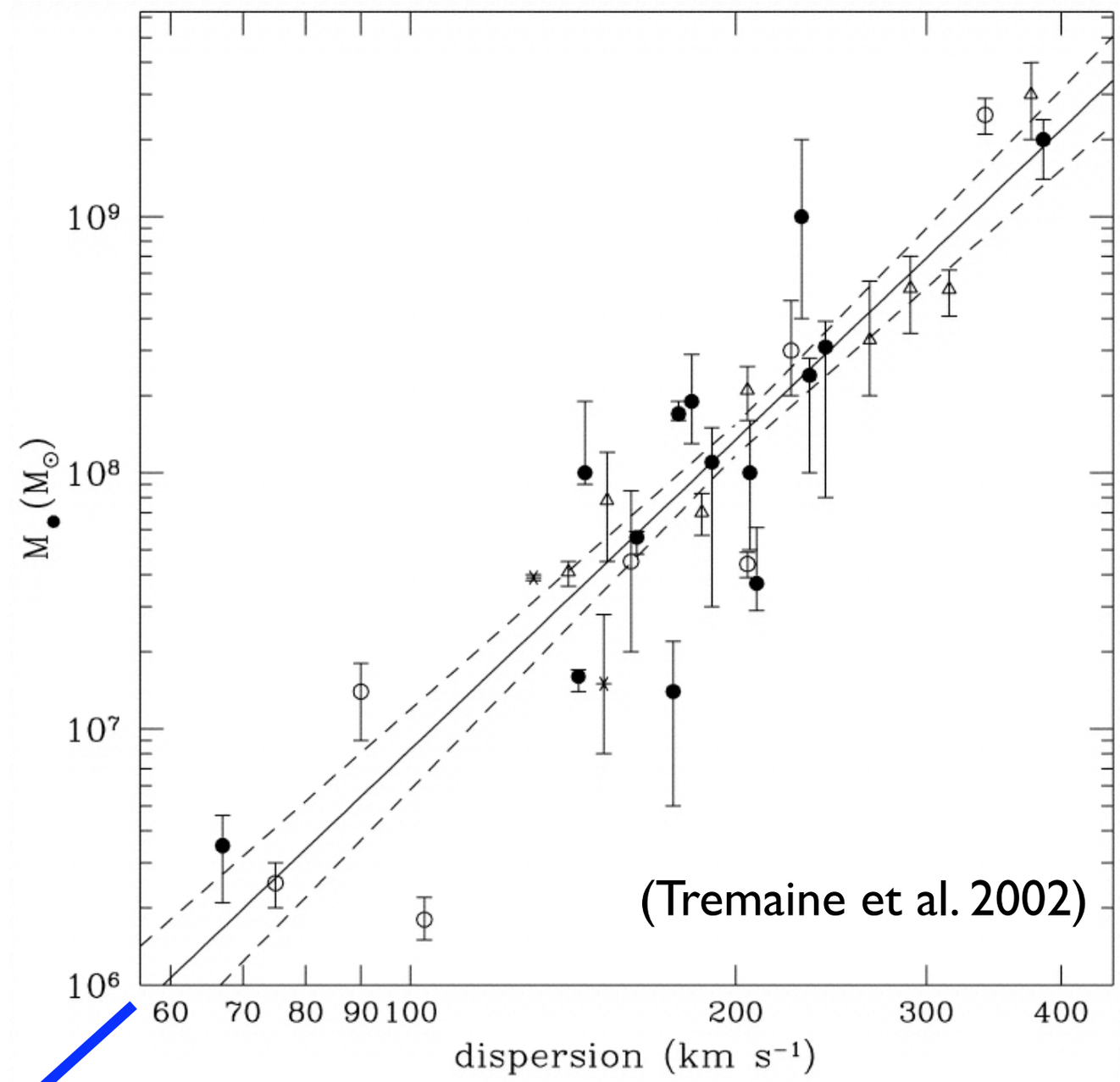
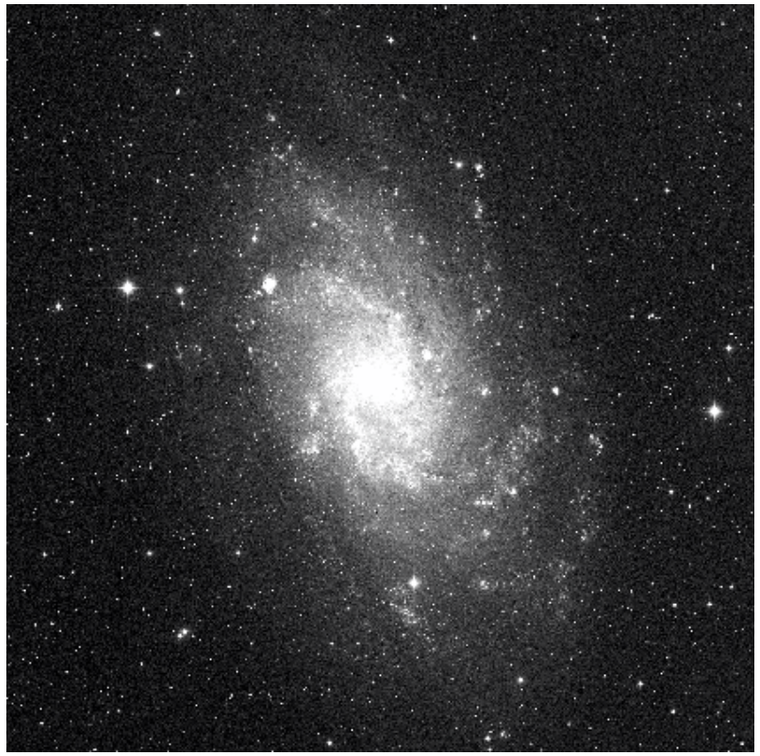
The census of massive black holes is mainly being carried out for masses of $10^{6.5}$ - $10^{9.5}$ $M_\odot$



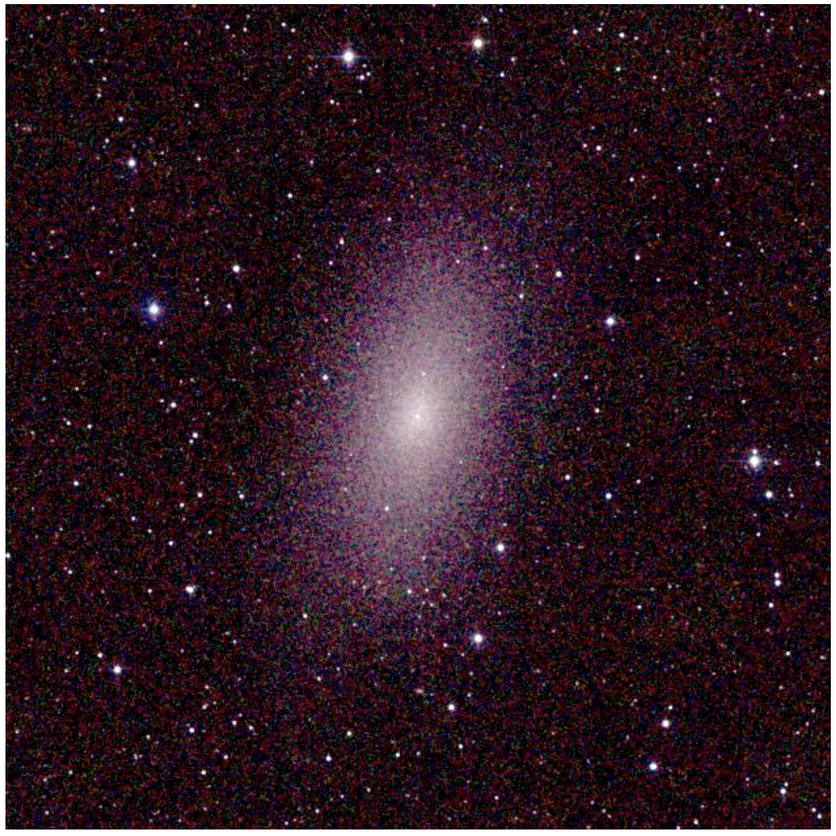
?

What can we learn about black hole demographics below 10^6 $M_\odot$?

Upper limits in Local Group galaxies from HST



M33: $M_{BH} < 1500\ M_\odot$
(Gebhardt et al. 2001,
Merritt et al 2001)



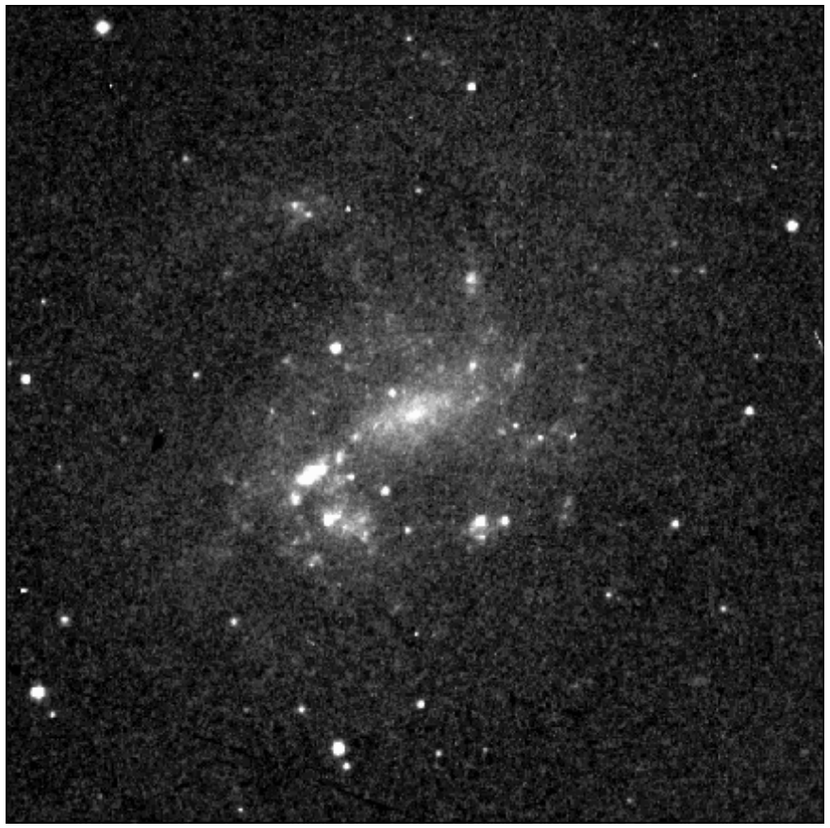
NGC 205: $M_{BH} < 3.8 \times 10^4\ M_\odot$
(Valluri et al. 2005)

AGNs with BH masses smaller than the Milky Way's black hole?

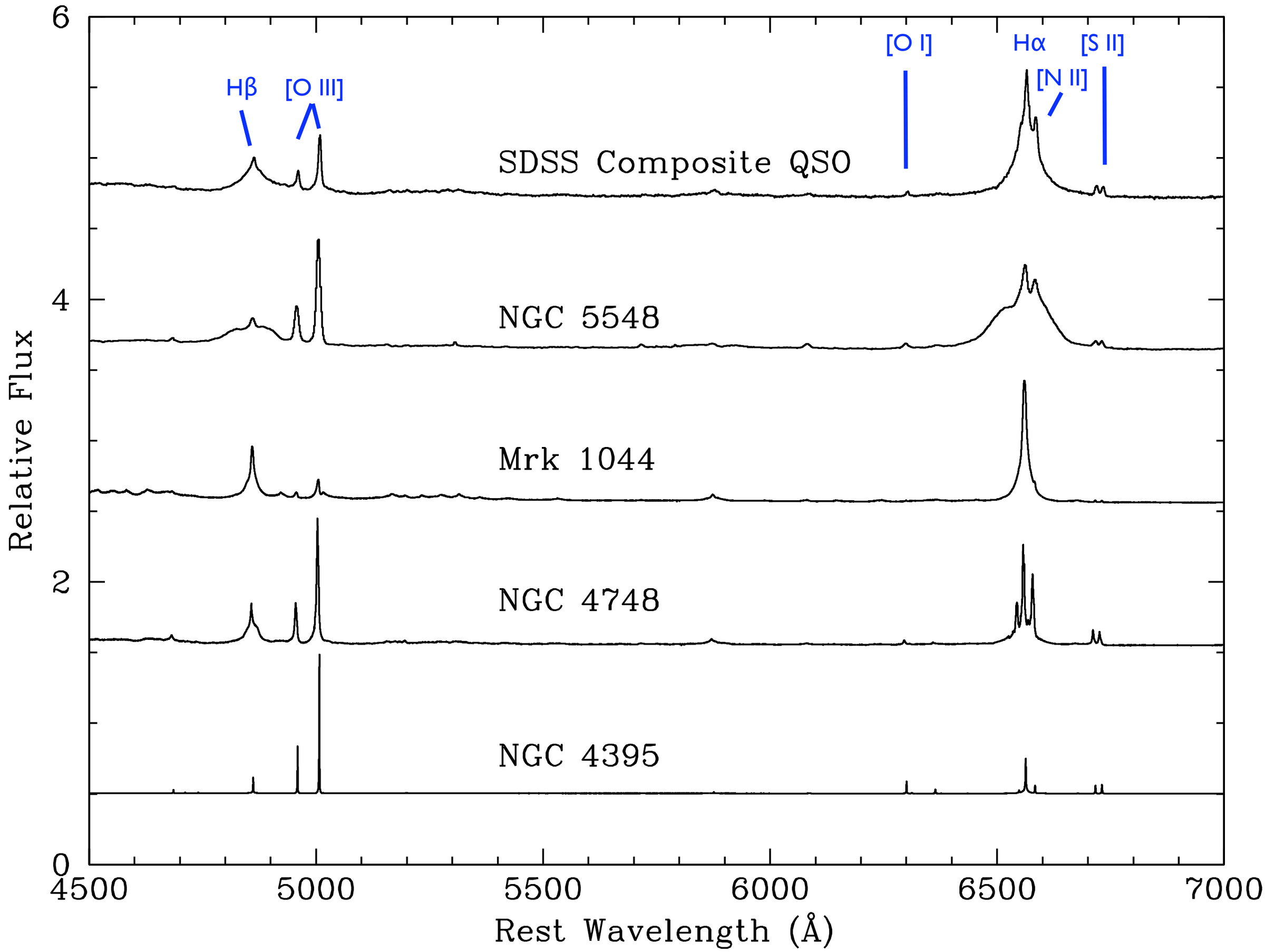
before Sloan searches, just a few examples:

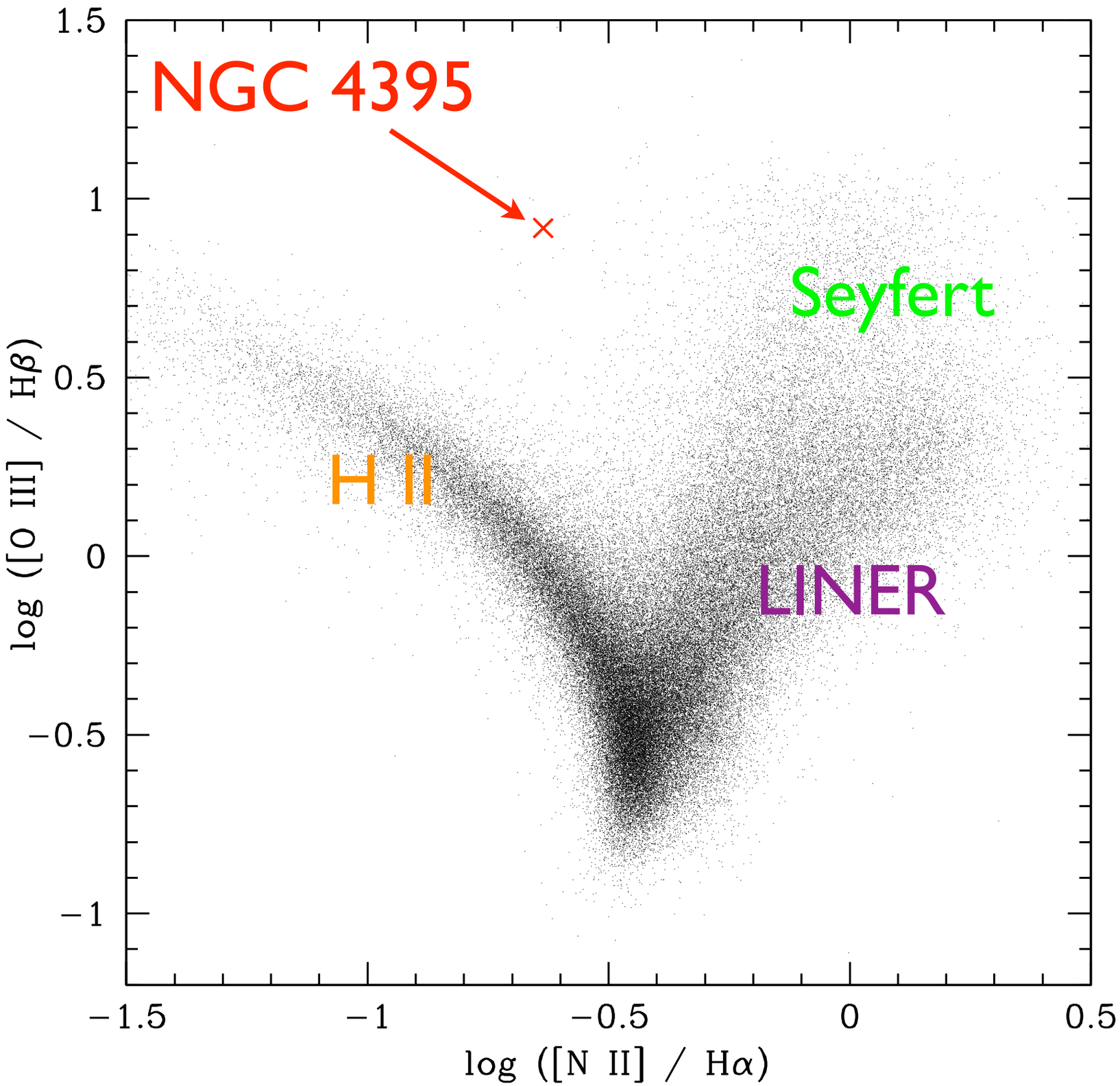
- NGC 4395 (Kraemer et al. 1999; Filippenko & Ho 2003; Peterson et al. 2005)
- NGC 4051:
  - $M_{BH} = (5\ ^{+6}_{-3}) \times 10^5\ M_\odot$ (Shemmer et al. 2003)
  - $M_{BH} = (1.9 \pm 0.8) \times 10^6\ M_\odot$ (Peterson et al. 2004)
- A few other NLS1s with mass estimates from single-epoch spectra (e.g., Barth et al. 2004; Grupe & Mathur 2004; Botte et al. 2004)

NGC 4395: the least luminous Seyfert 1 galaxy



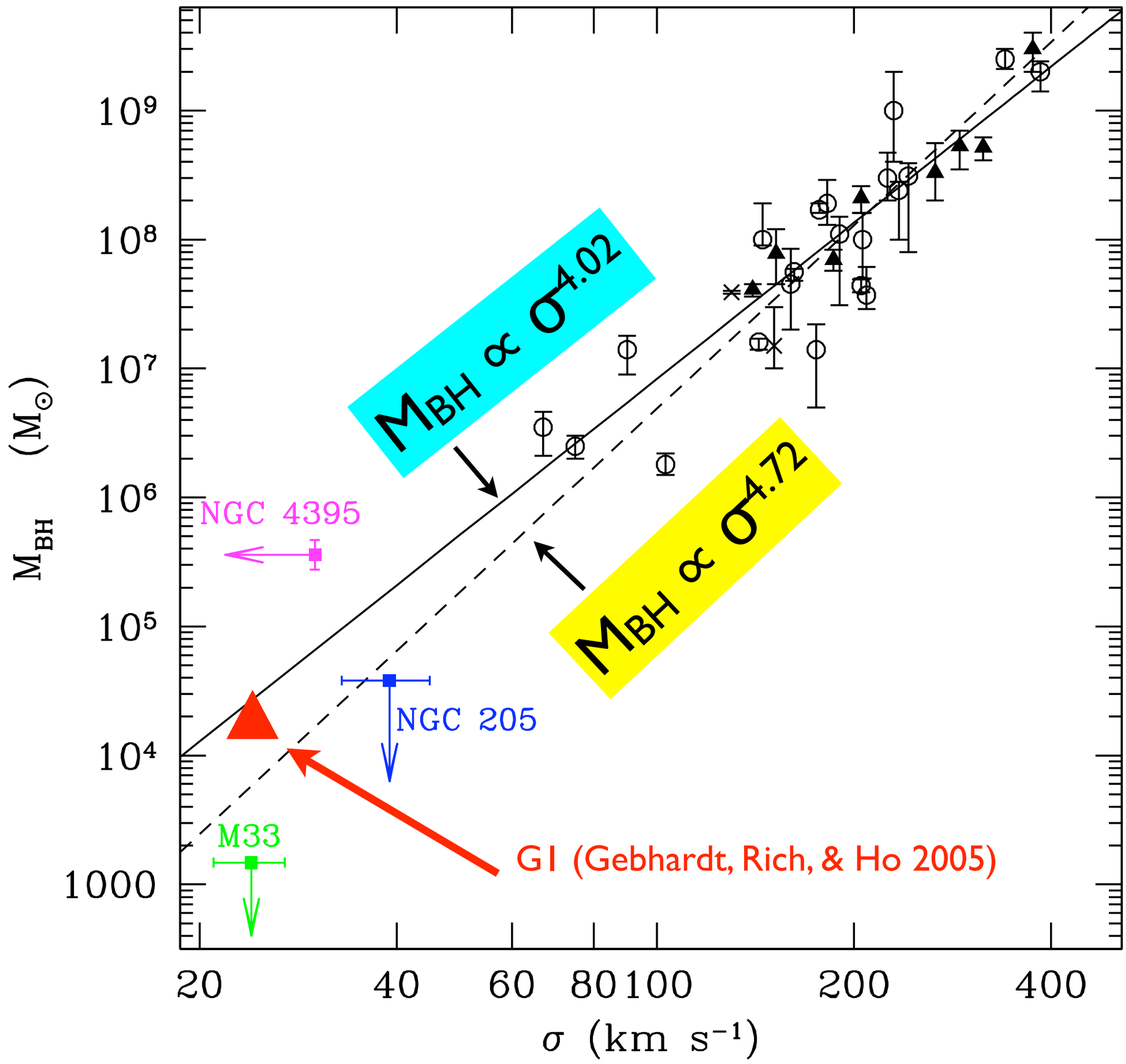
- Sdm host galaxy with M_B = -17.5 mag (Filippenko & Sargent 1989)
- Central star cluster has σ < 30 km/s (Filippenko & Ho 2003)
- L_{bol}(AGN) ~ 5 × 10^{40} erg/sec (Moran et al. 2005)
- New C IV reverberation mapping result from HST:
  M_{BH} = (3.6 ± 1.1) × 10^5 $M_\odot$ (Peterson et al. 2005)


Hβ
[O III]
[O I]
Hα
[N II]
[S II]
SDSS Composite QSO
NGC 5548
Mrk 1044
NGC 4748
NGC 4395
Relative Flux
0
2
4
6
4500
5000
5500
6000
6500
7000
Rest Wavelength (Å)



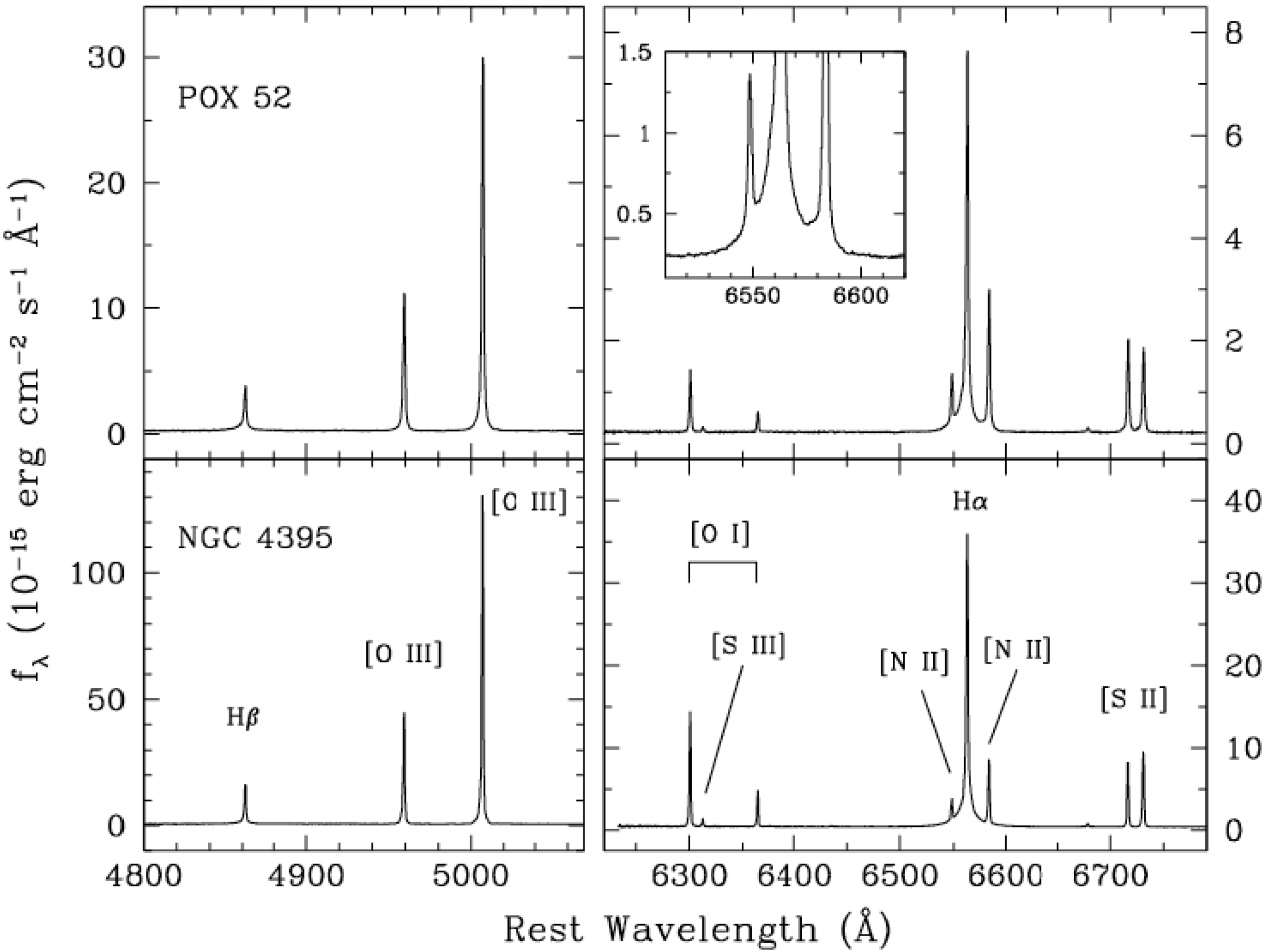
- low metallicity and subsolar N/O ratio (Kraemer et al. 1999)

(SDSS data points from Kauffmann et al. 2003)


$M_{BH} \propto \sigma^{4.02}$
$M_{BH} \propto \sigma^{4.72}$
NGC 4395
NGC 205
M33
GI (Gebhardt, Rich, & Ho 2005)
M_{BH} $(M_\odot)$
σ (km s^{-1})
10^9
10^8
10^7
10^6
10^5
10^4
1000
20
40
60
80
100
200
400

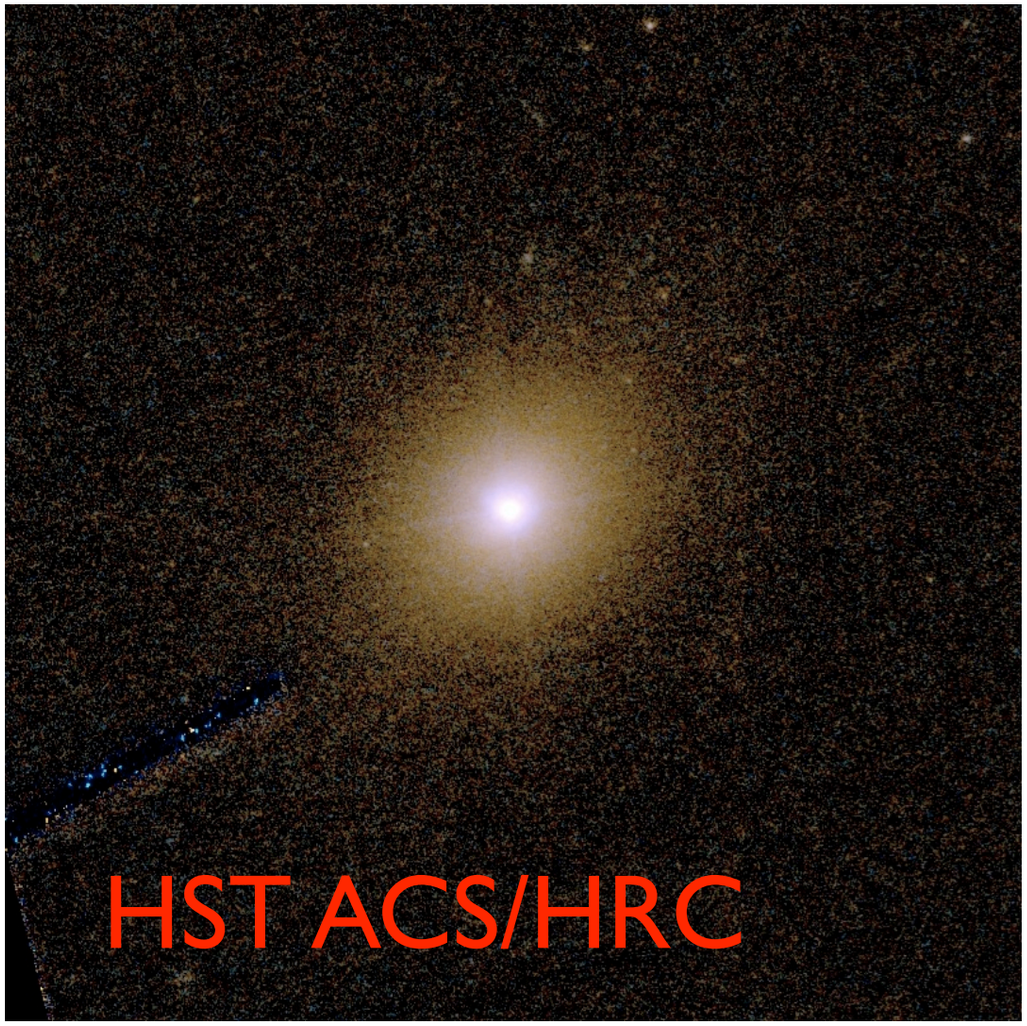
POX 52: another "dwarf" Seyfert 1 galaxy

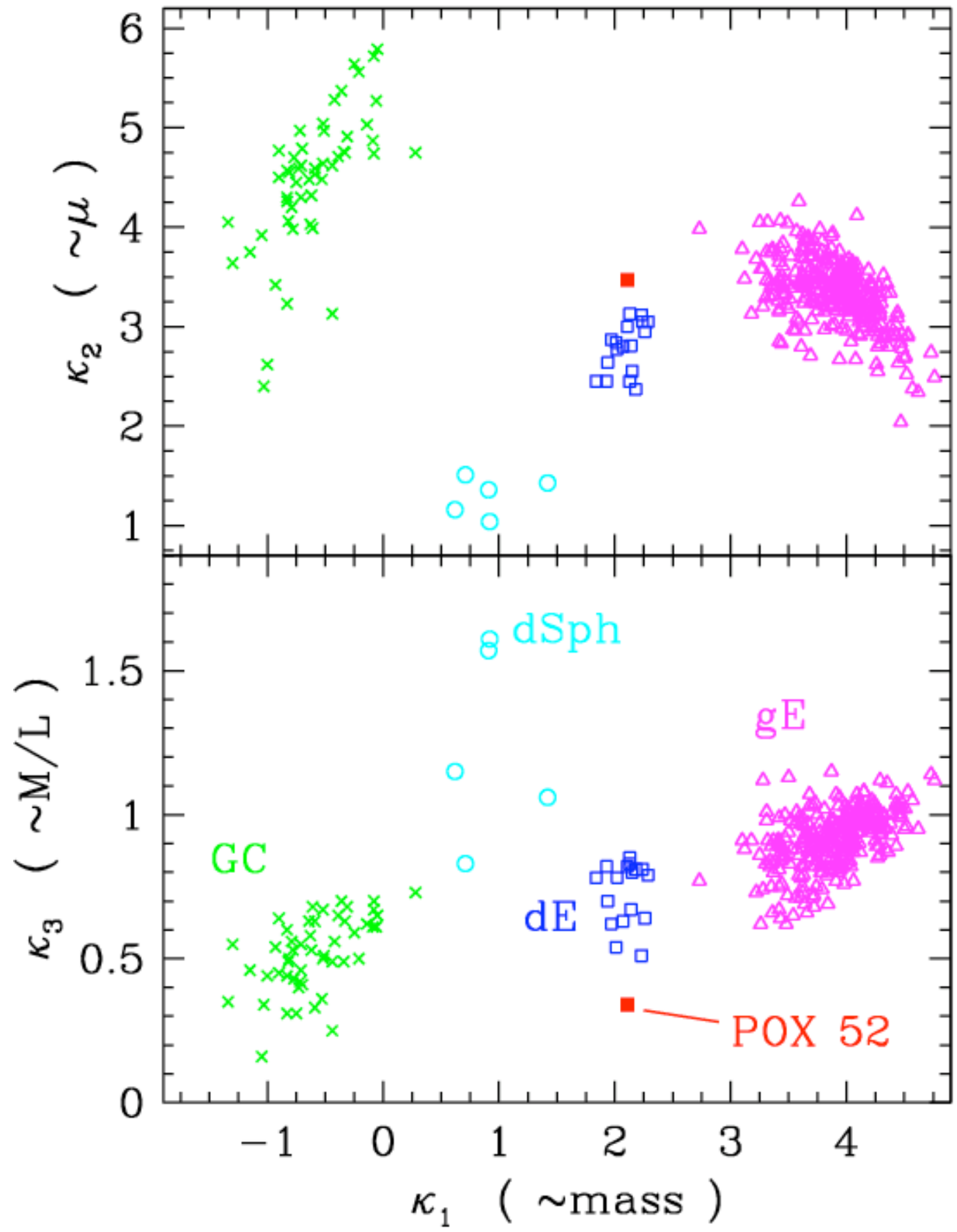
(AJB, Ho, Rutledge, & Sargent 2004)



POX 52

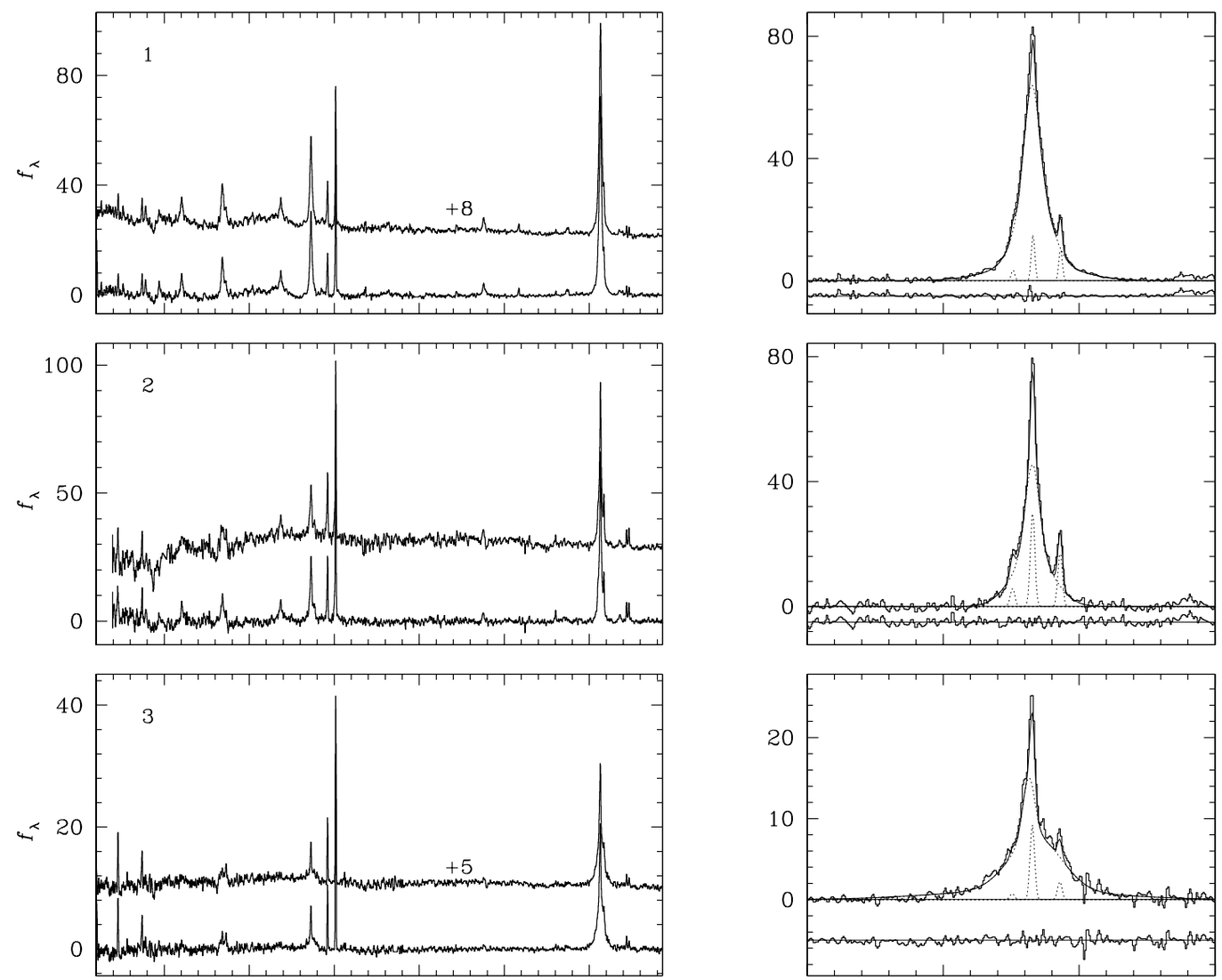
- Host galaxy has $\sigma = 36 \pm 5$ km/s
- From single-epoch Hβ width, $M_{BH} \sim 3\times10^5\ M_\odot$





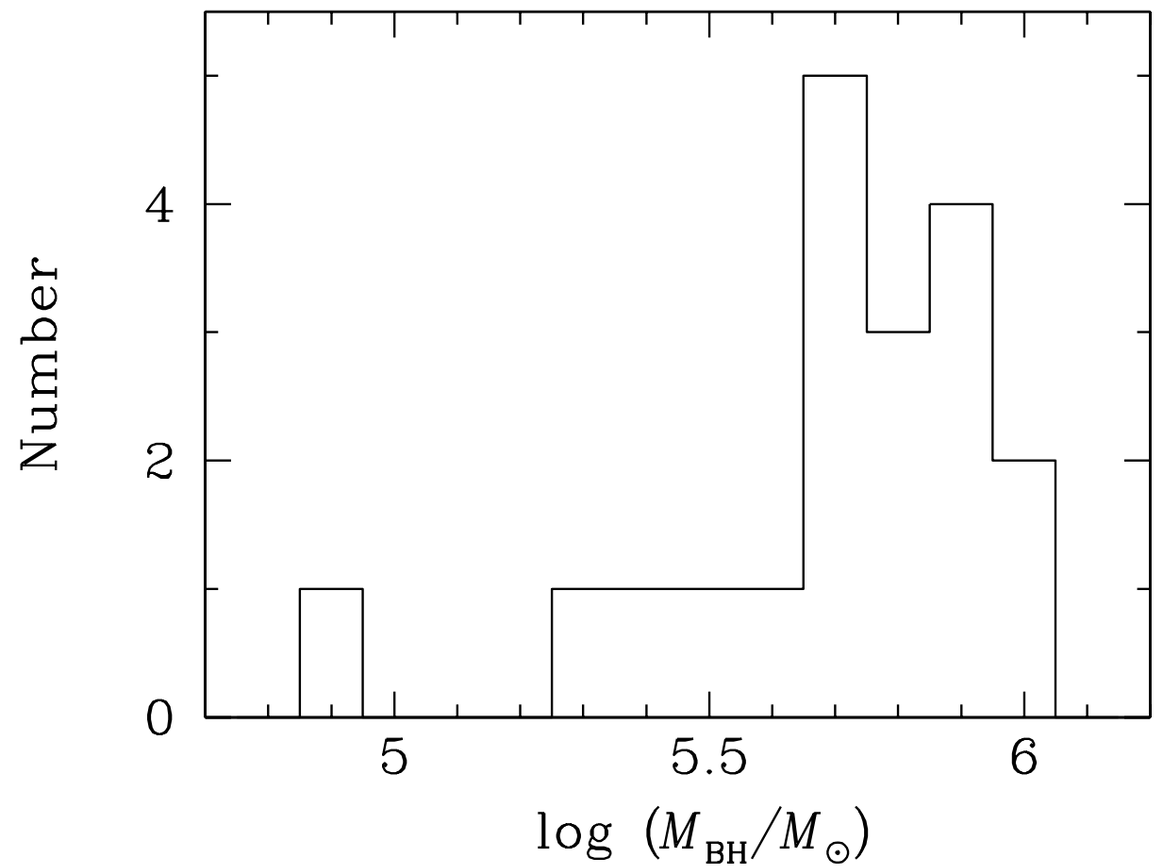
Finding More with SDSS

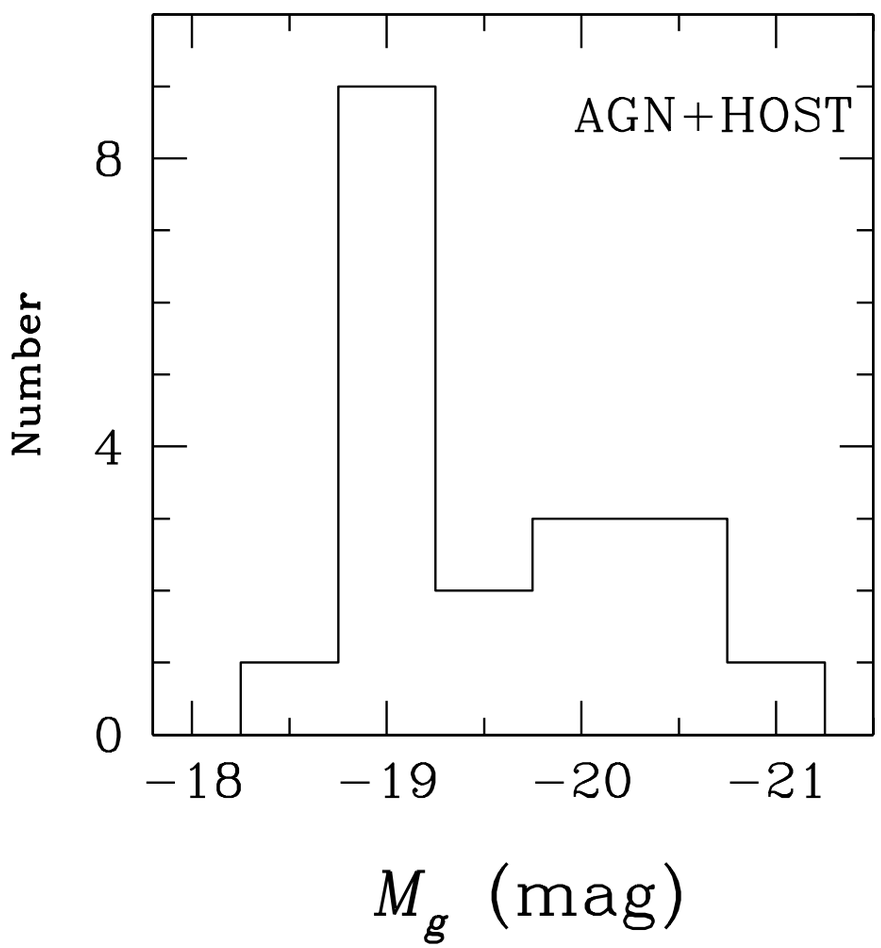
- Work by Greene & Ho (2004)
- Single-epoch virial method used to derive M_{BH} for *all* broad-lined AGNs in DR1 out to z = 0.3
- 19 Seyfert 1 galaxies with $M_{BH} < 10^6\ M_\odot$

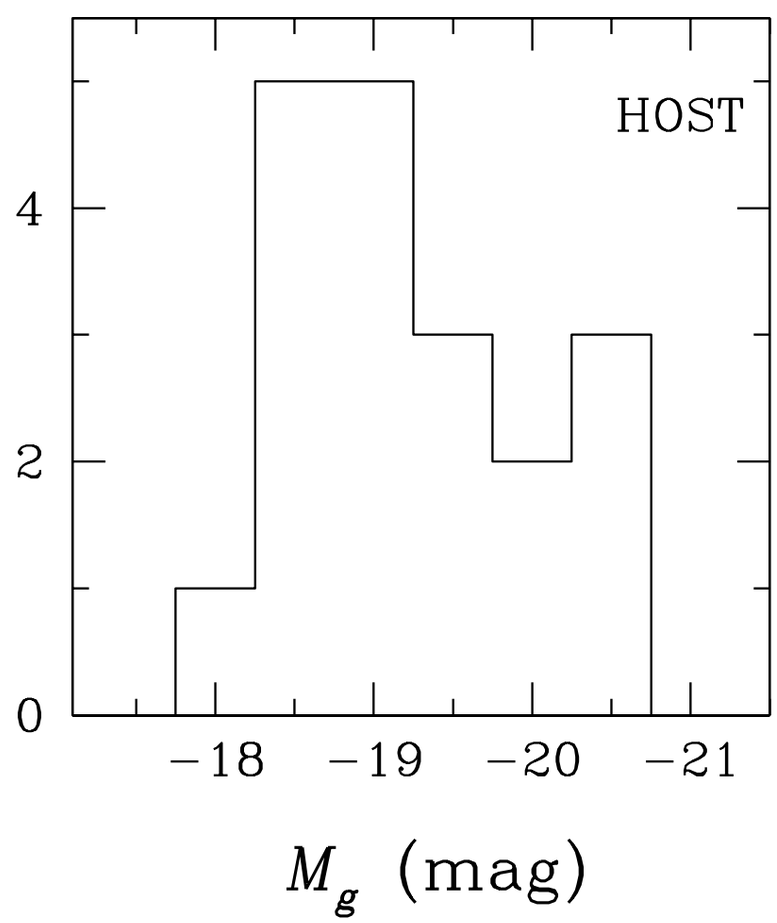


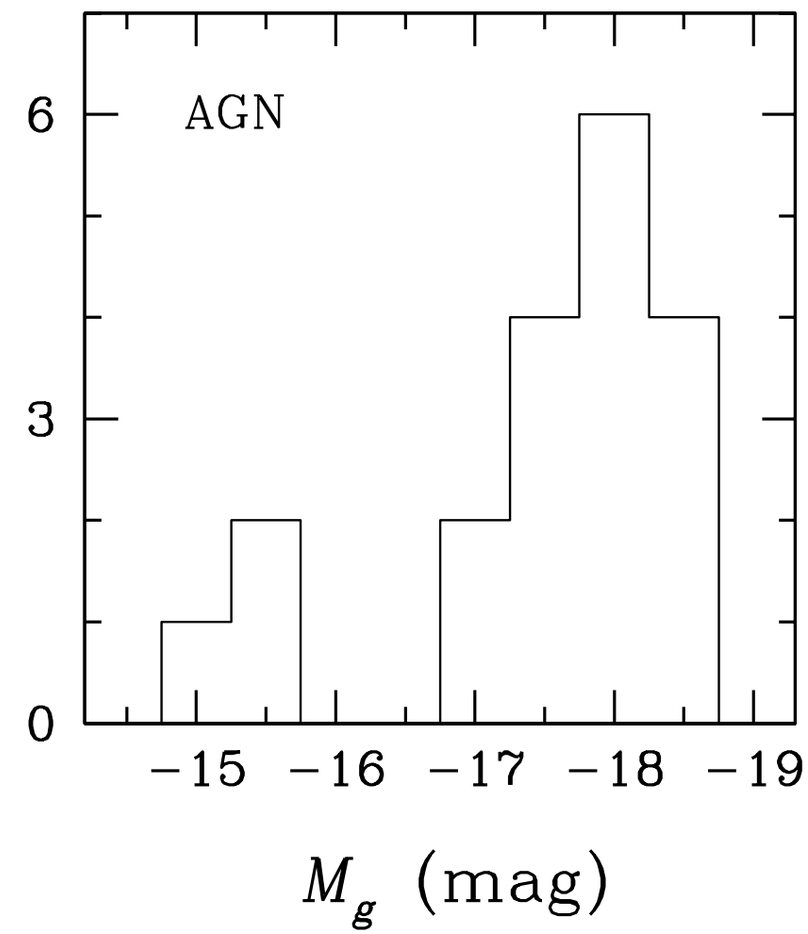
Sample properties

- redshifts range from 0.03 to 0.13

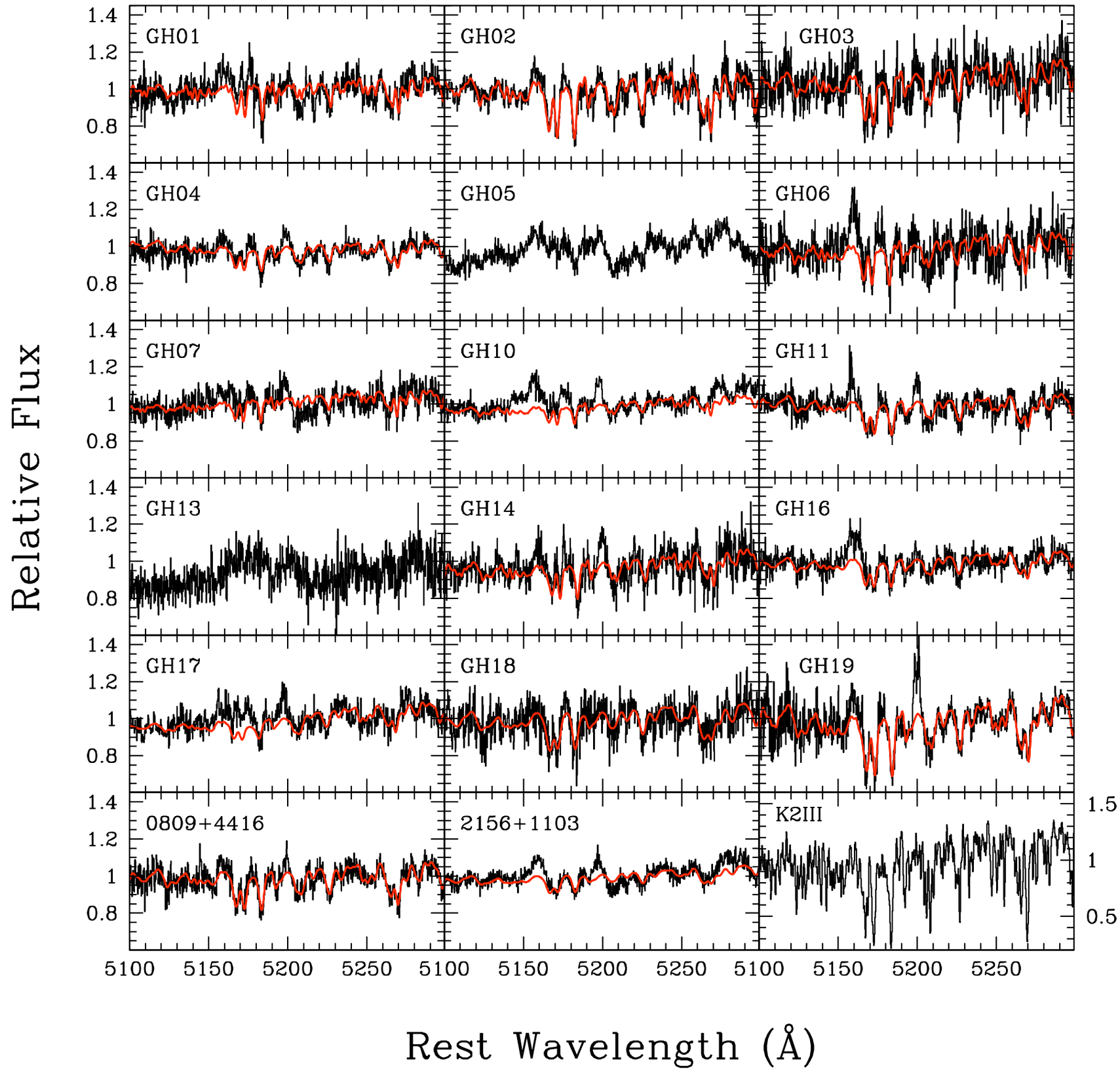








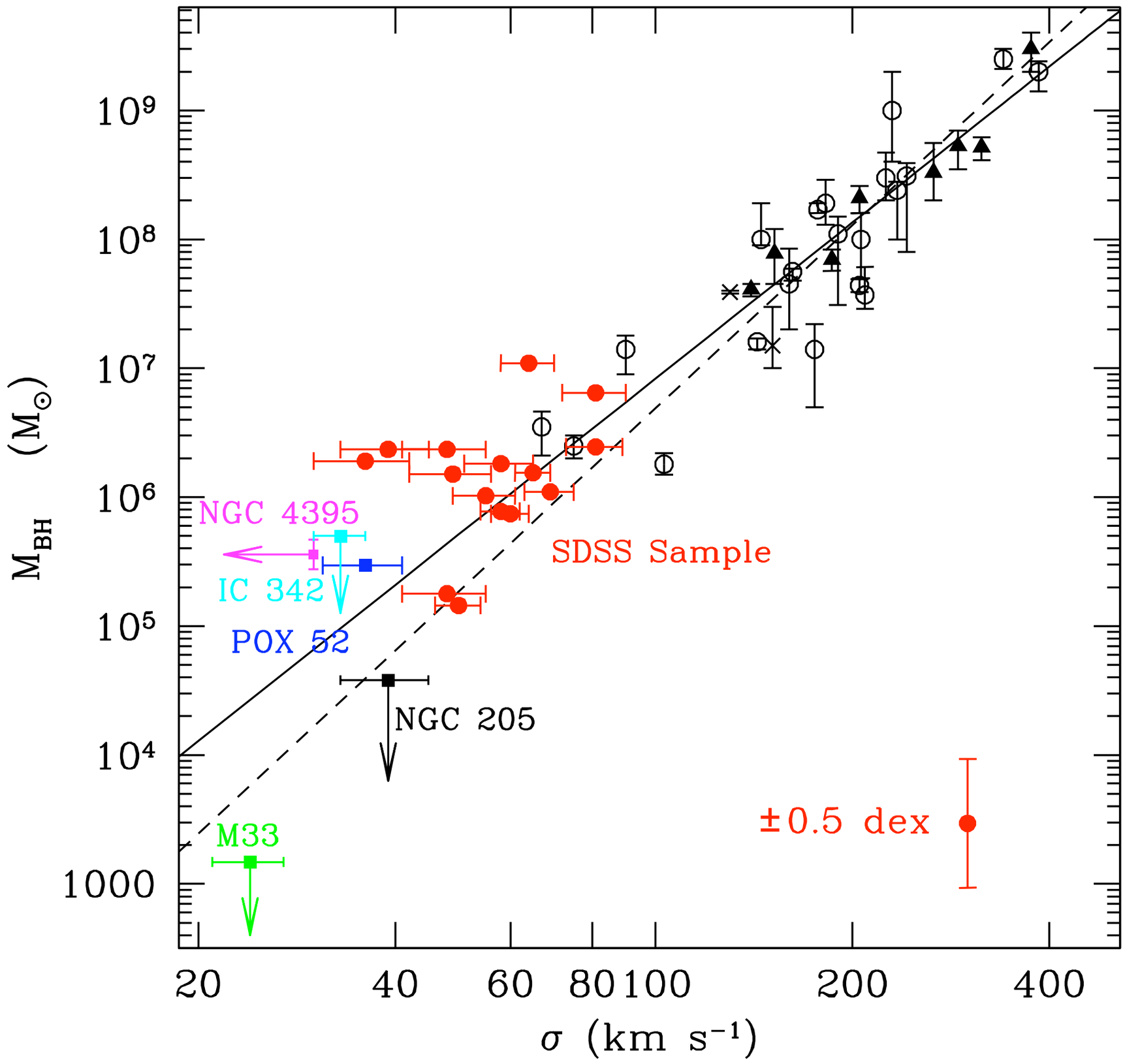
- New velocity dispersion measurements with Keck ESI spectrograph (σ_{inst} = 20 km/s)
- Velocity dispersions for these Seyferts range from 36 to 81 km/s

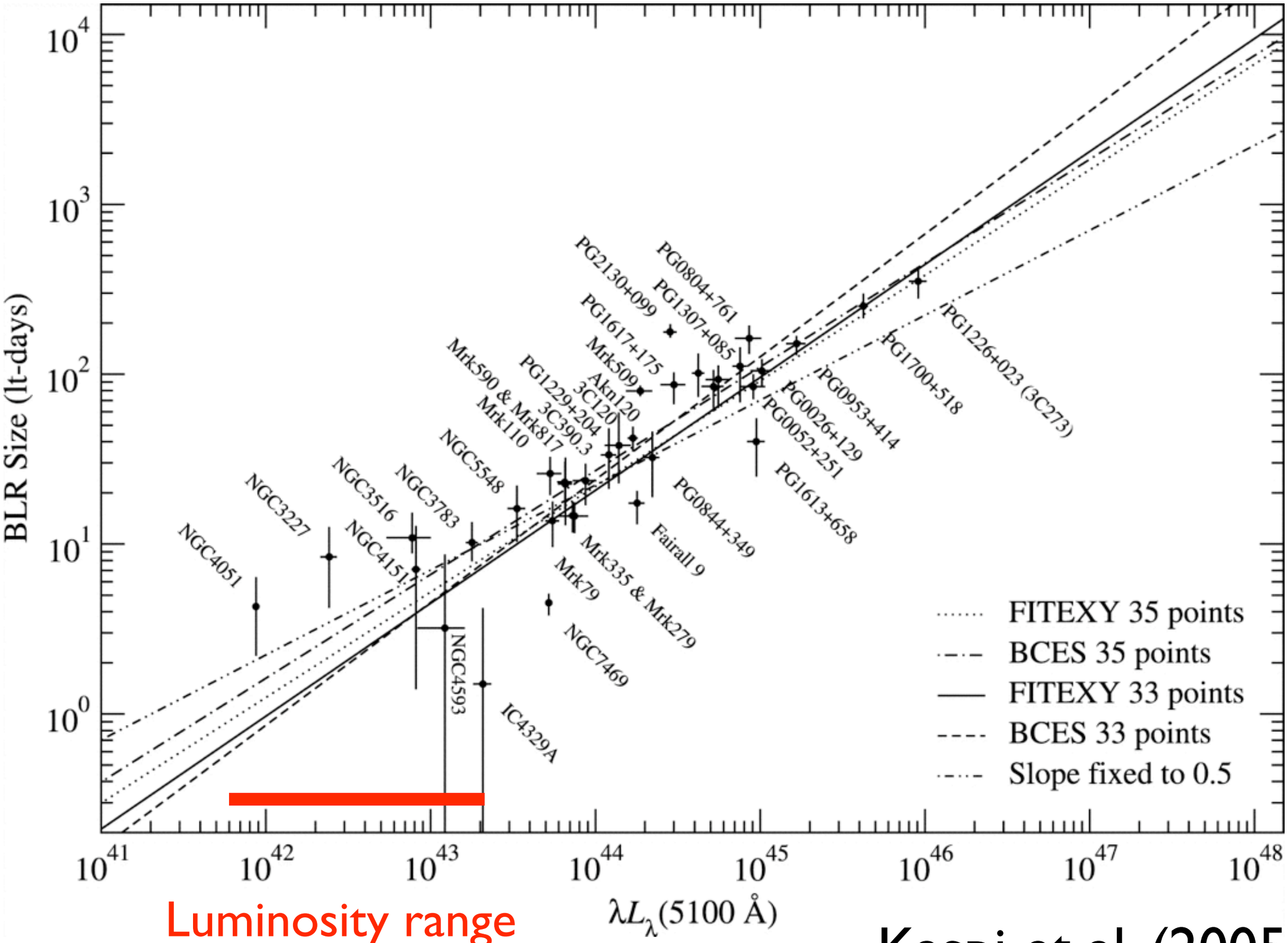


(Barth, Greene, & Ho 2005)

SDSS Seyfert 1s on the M-σ relation

(Barth, Greene, & Ho 2005)

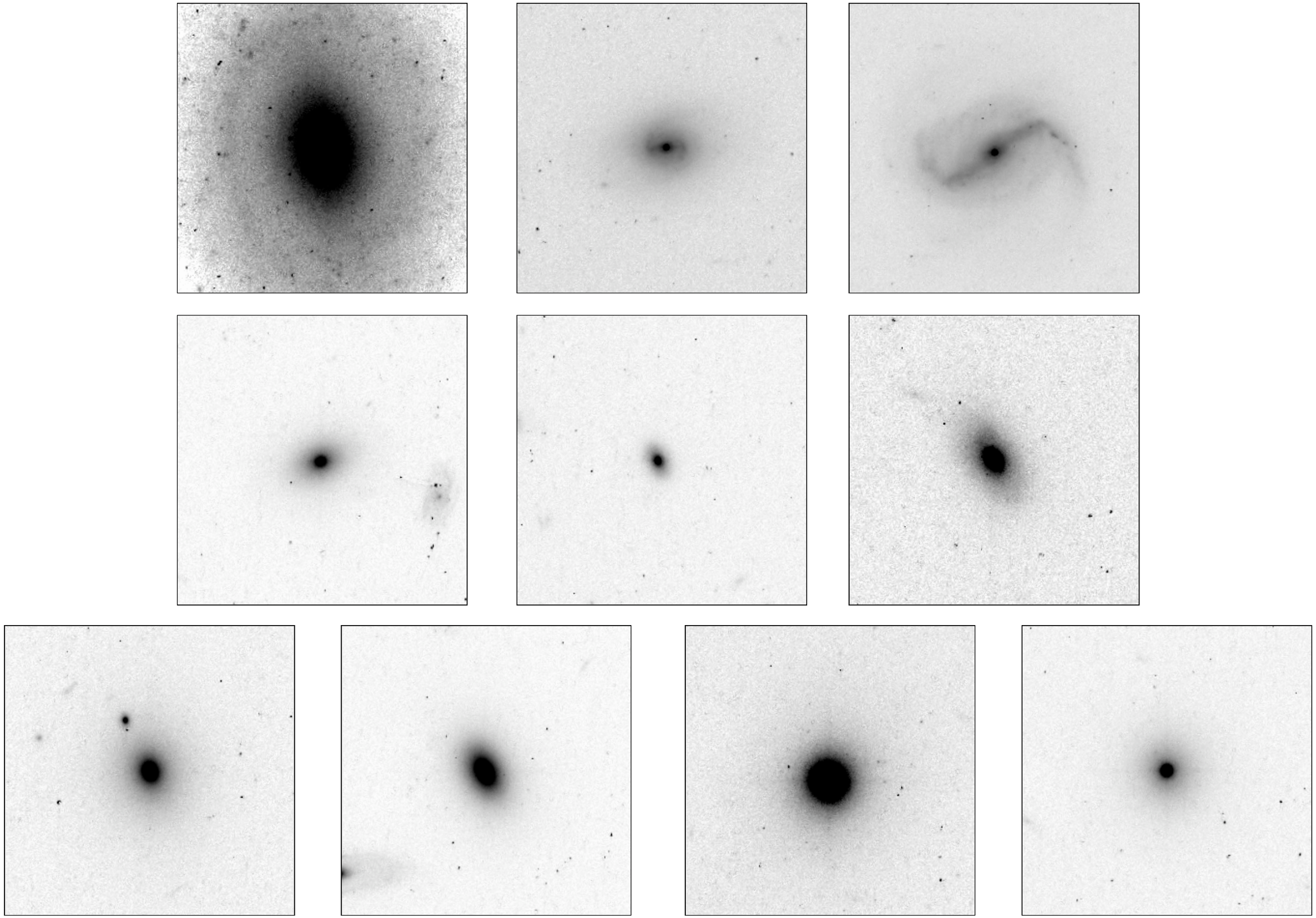




Luminosity range of the SDSS sample

Kaspi et al. (2005)

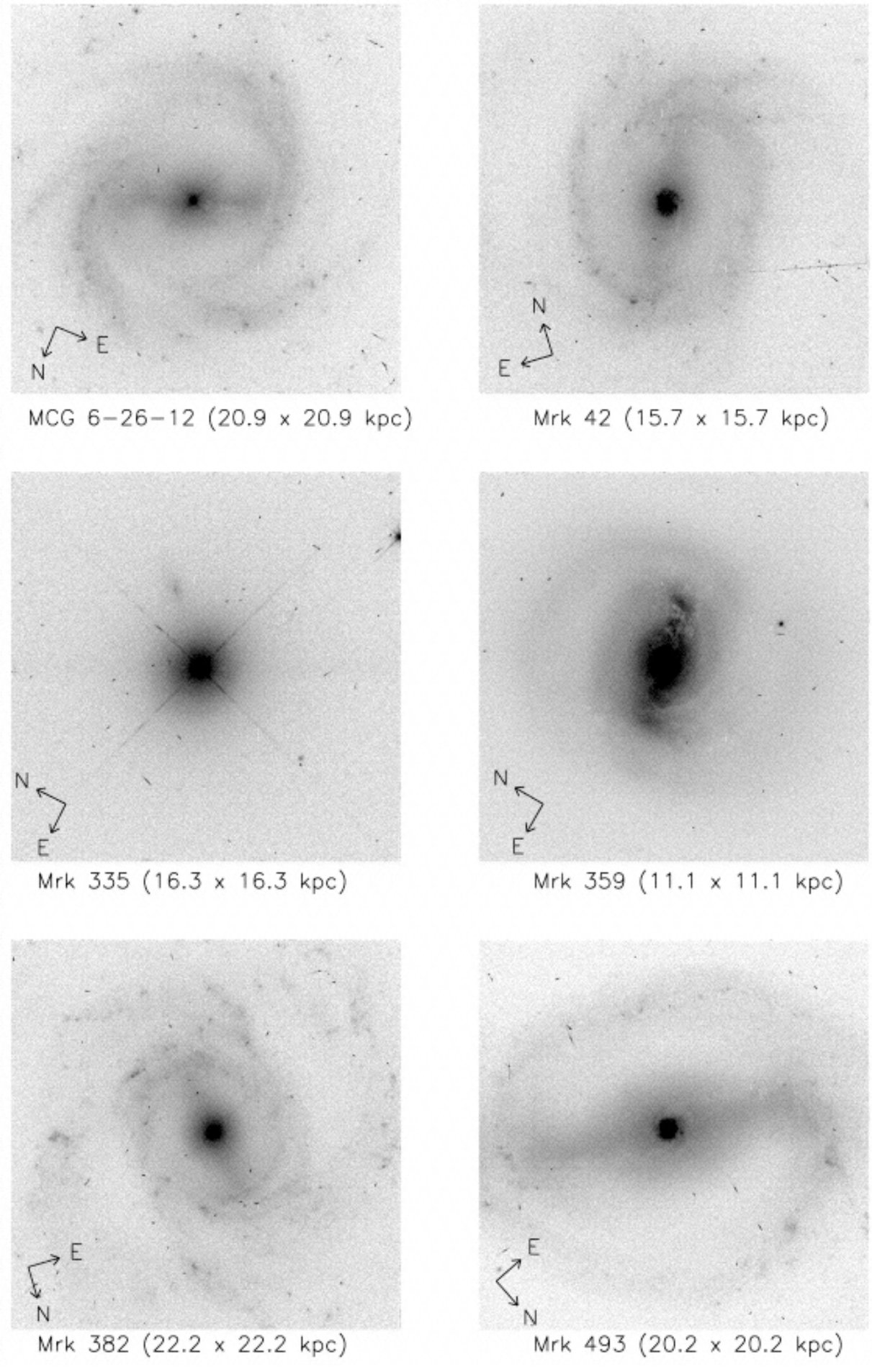
New HST ACS/WFC Images



Host galaxies of NLS1s

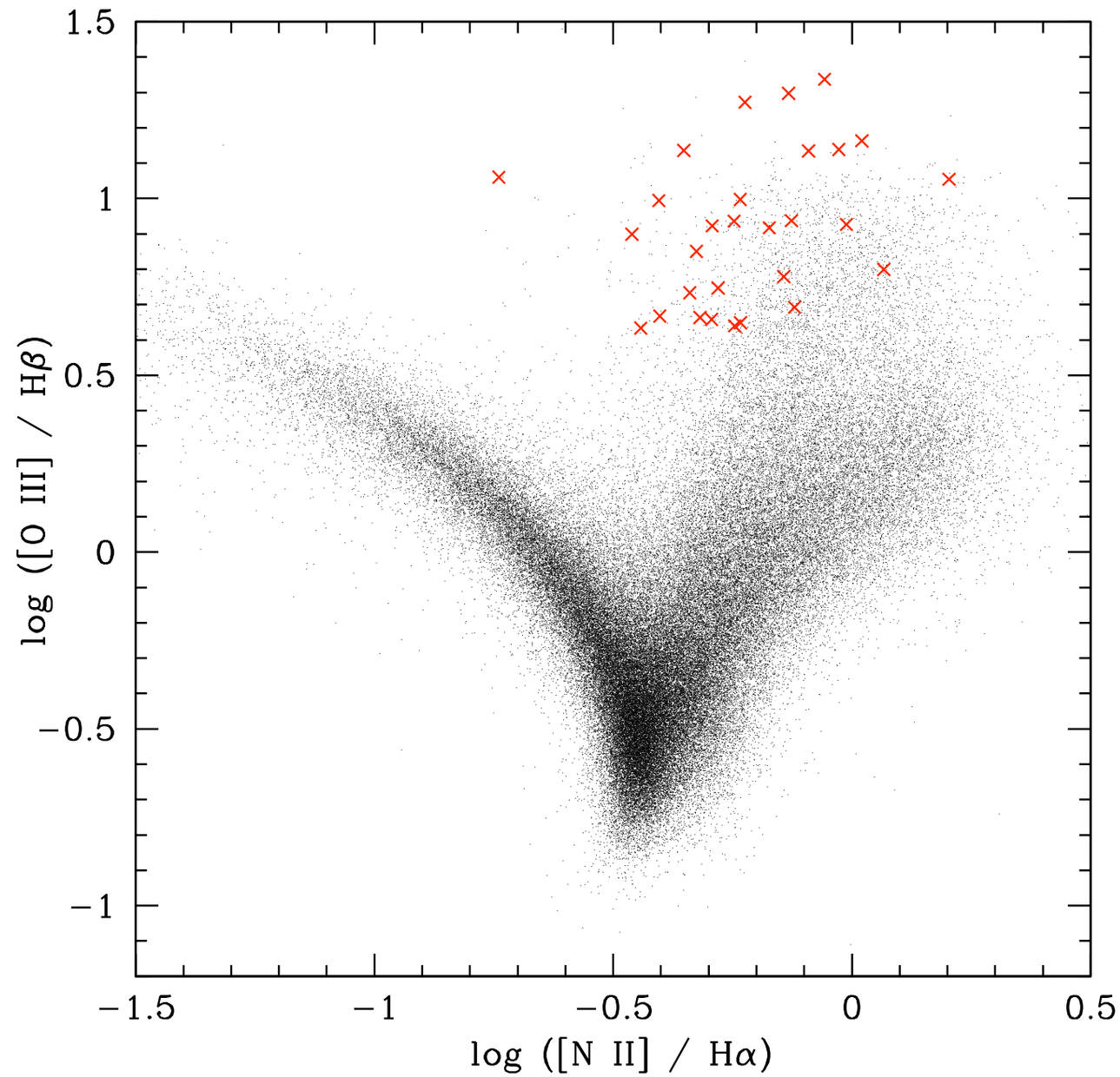
(Crenshaw, Kraemer, & Gabel 2003)

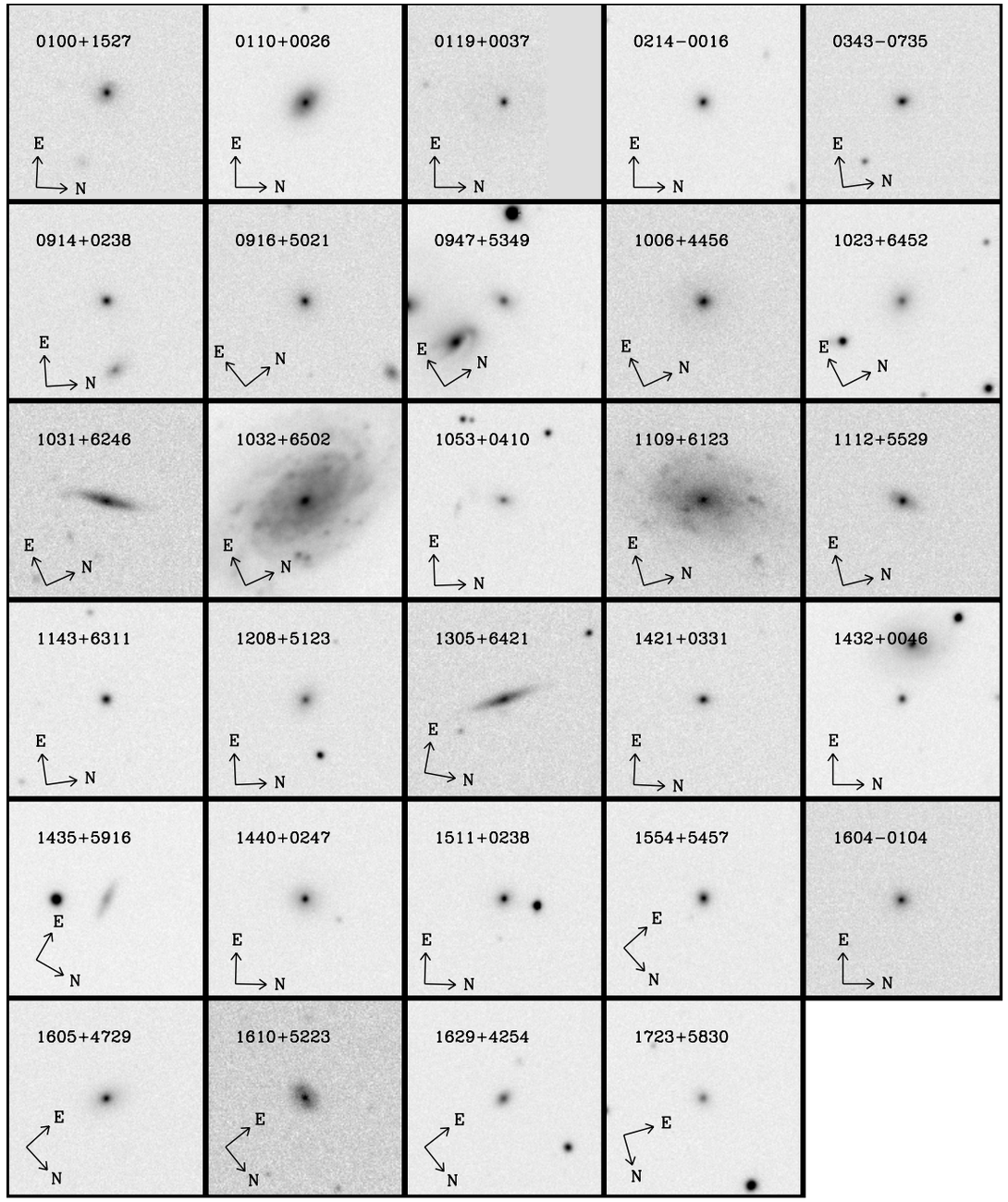
- SDSS low-mass Seyferts seem to be drawn from a different population of host galaxies than normal nearby NLS1s

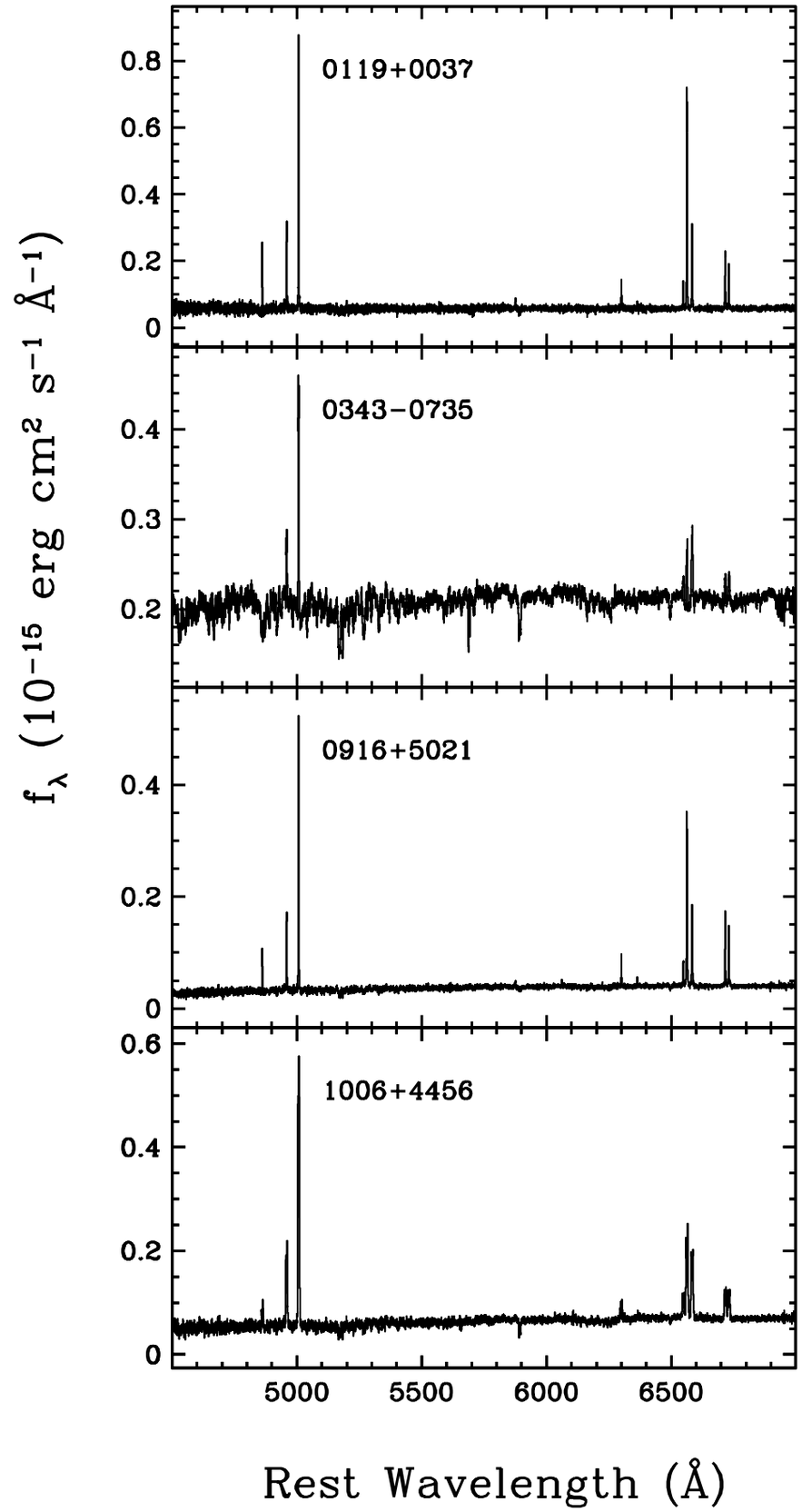


What are the smallest Seyfert 2 host galaxies?

- From SDSS AGN catalogs of Kauffmann et al. (2003), Hao et al. (2005), select Seyfert 2s with
  - High-excitation Seyfert emission lines with [O III] / Hβ > 3
  - σ <~ 70 km/s (unresolved by SDSS)
  - Mg > -19.5 mag
- New Keck observations of 29 galaxies to get velocity dispersions





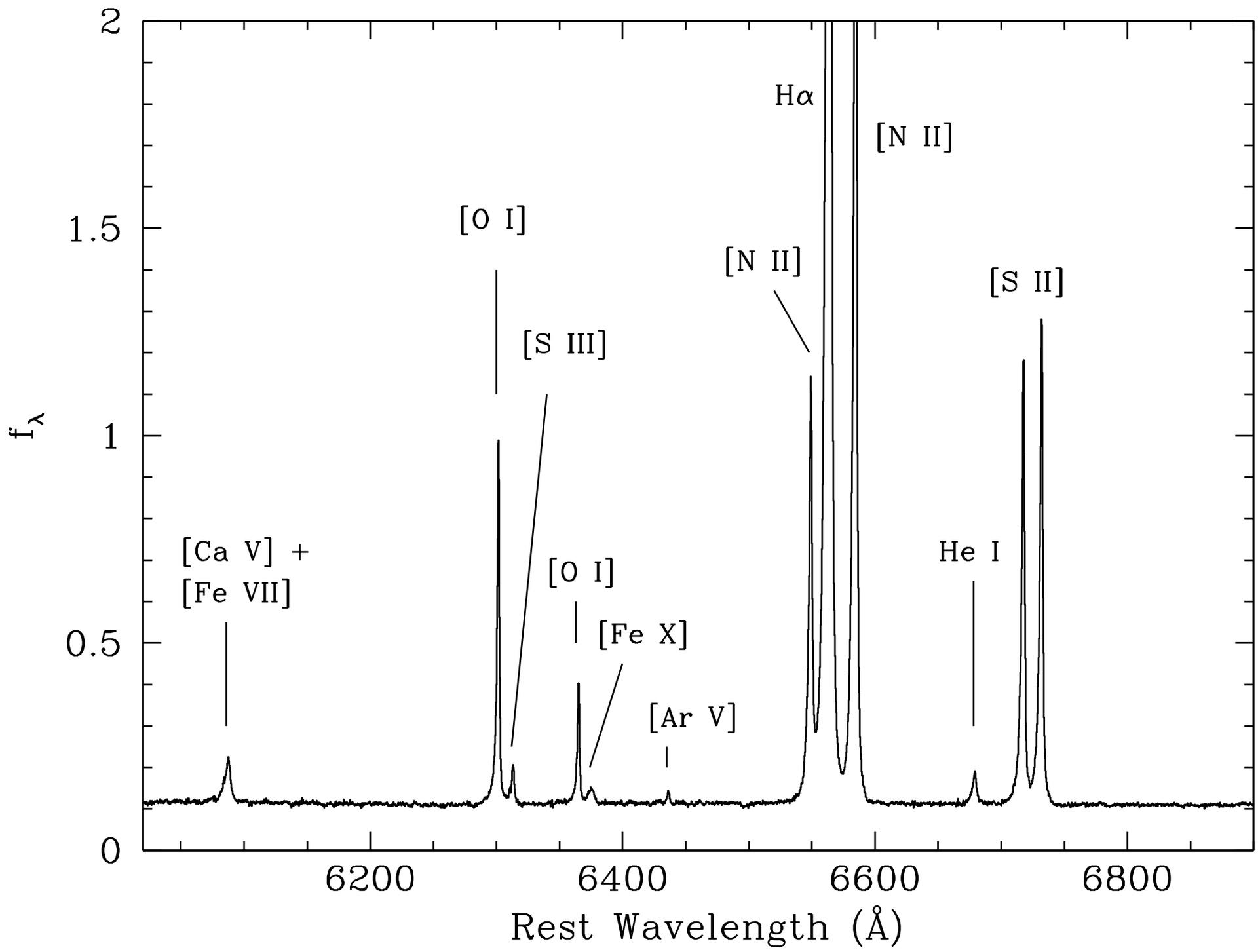


- Velocity dispersions for the Seyfert 2s range from 25 to 85 km/s
- 20 objects found to have σ < 70 km/s,
  - 13 have σ < 60 km/s

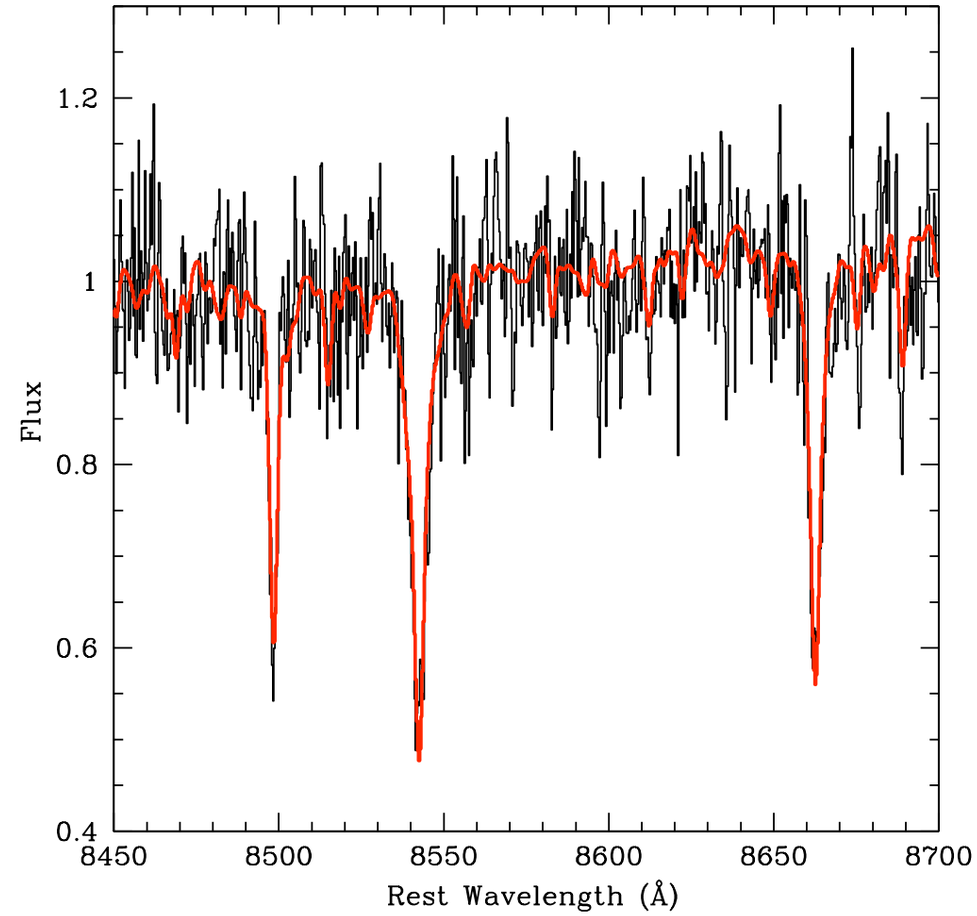
(Barth, Greene, & Ho, in prep.)

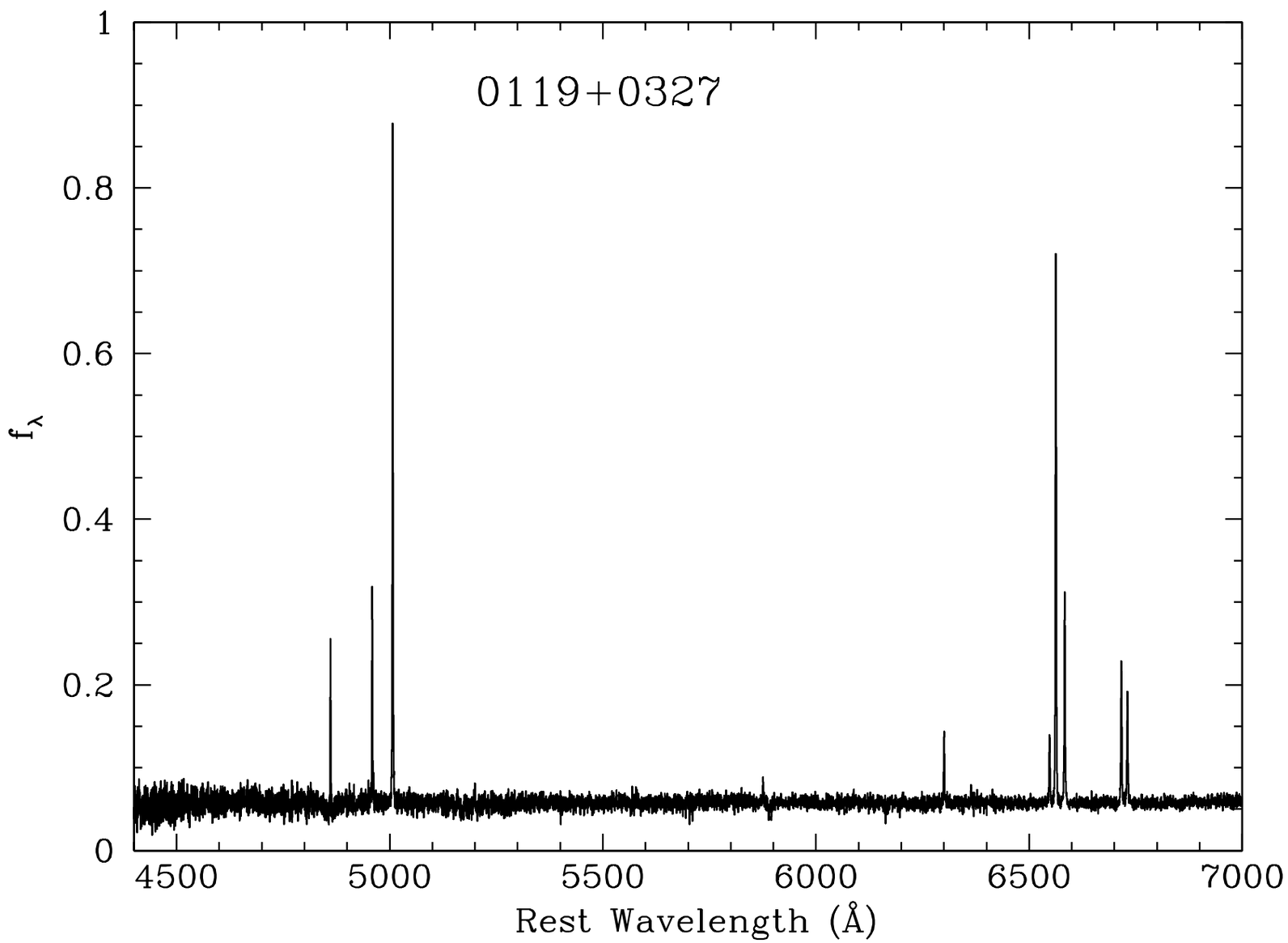
SDSS 1440+0247

- σ = 46 ± 6 km/s
- FWHM([O III]) = 92 km/s



The smallest velocity dispersion for an AGN host: SDSS 0119+0037

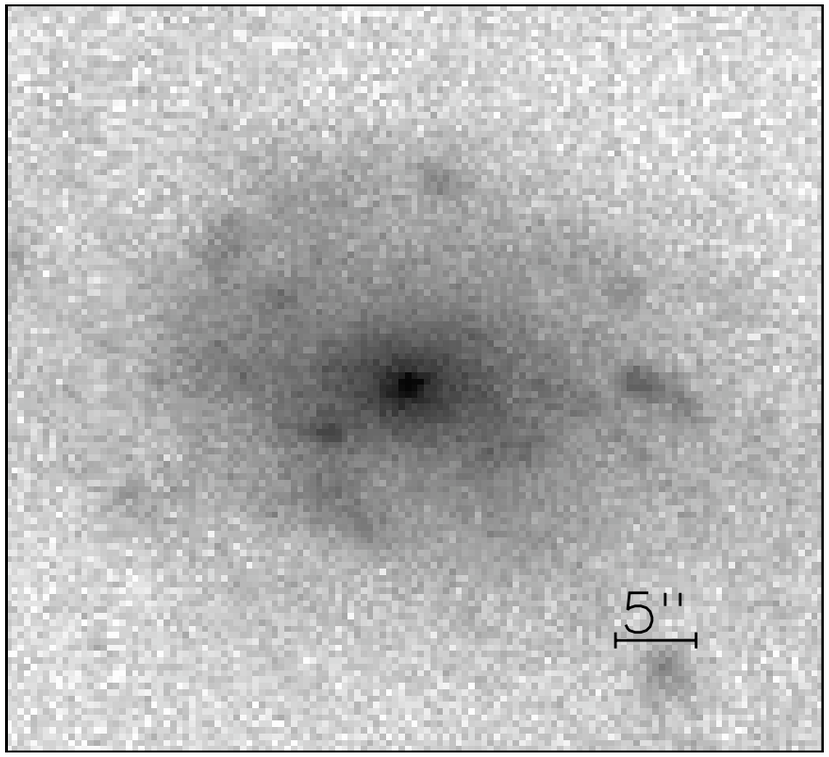


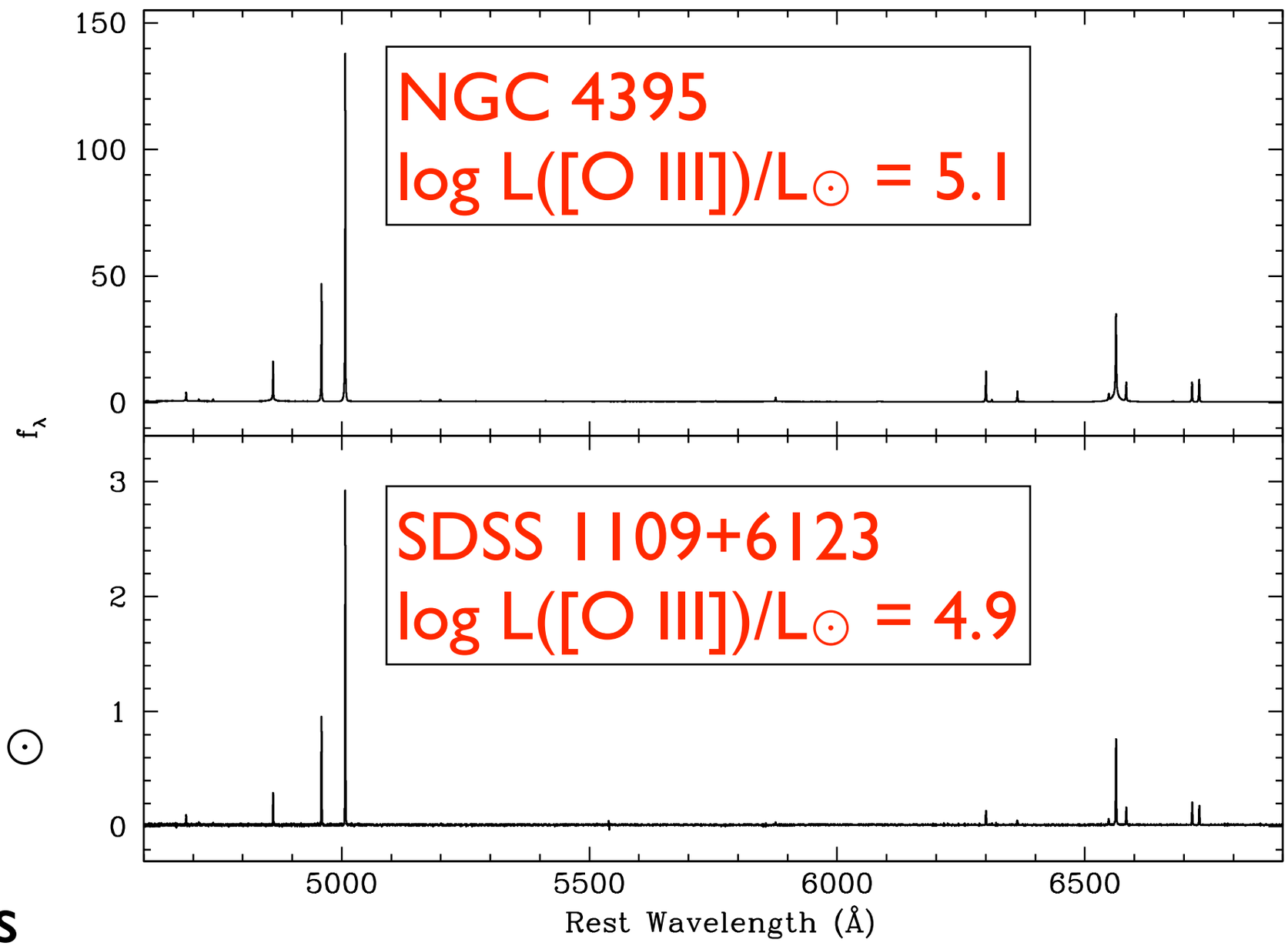


- σ = 25±6 km/s
- log $M_\star$=9.16

(Kauffmann et al. 2003)

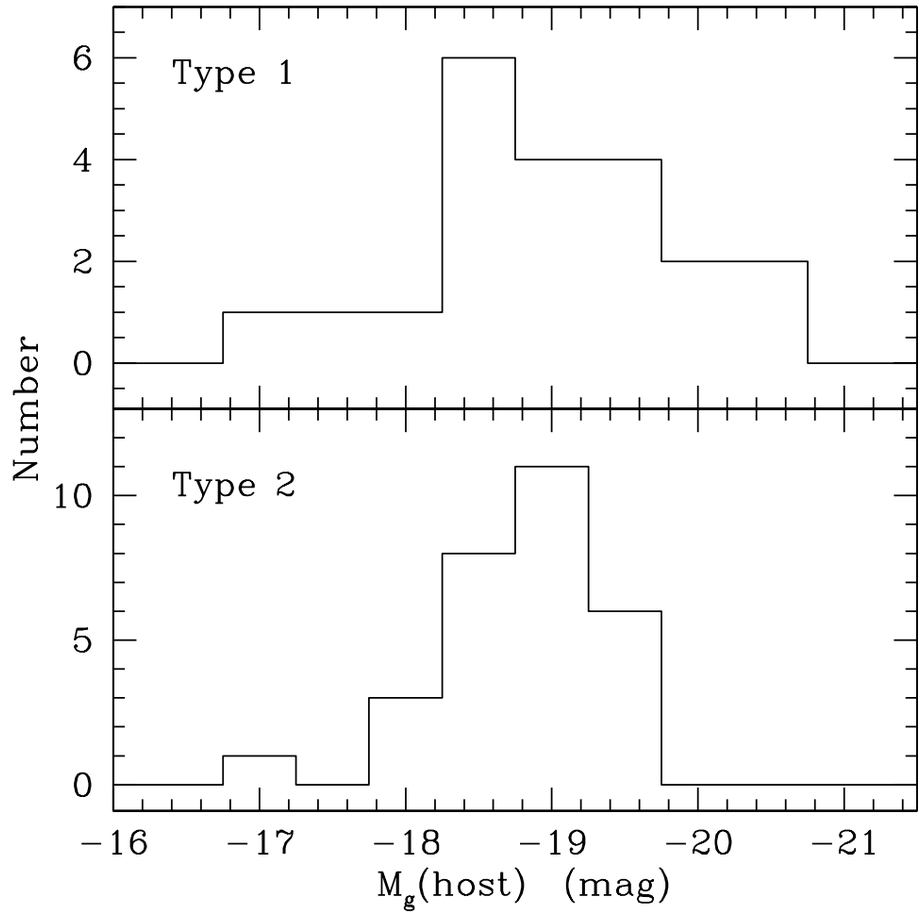
The first Type 2 analog of NGC 4395: SDSS 1109+6123

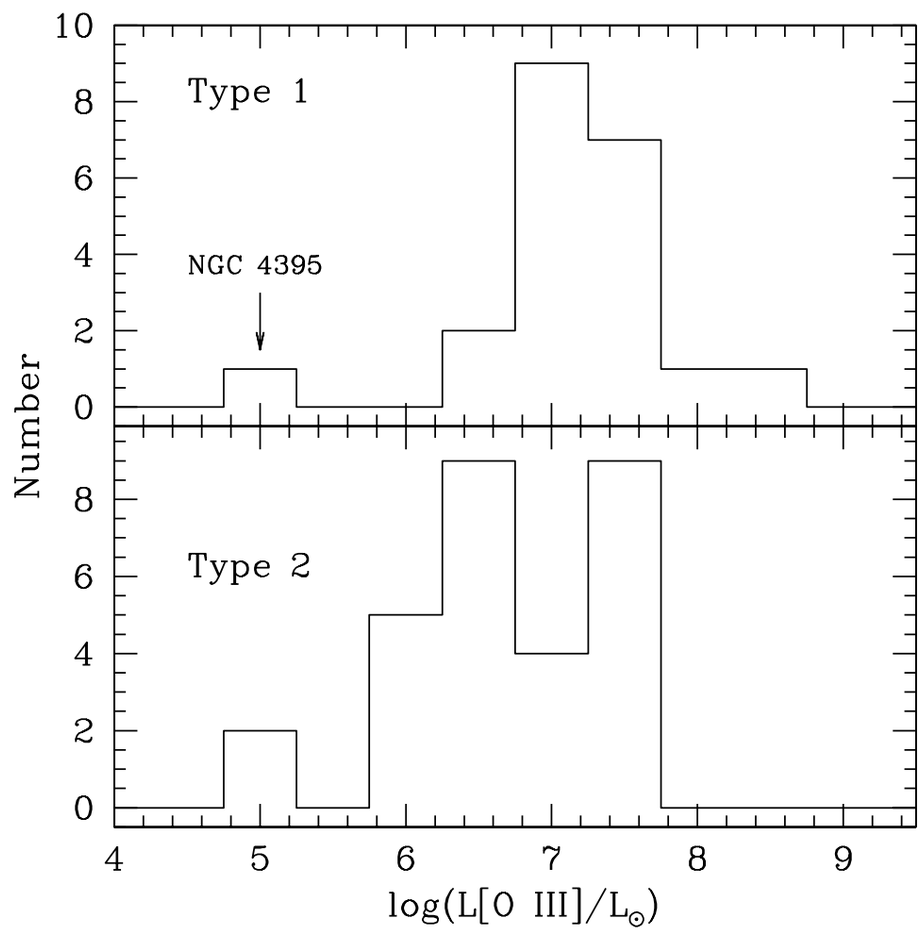


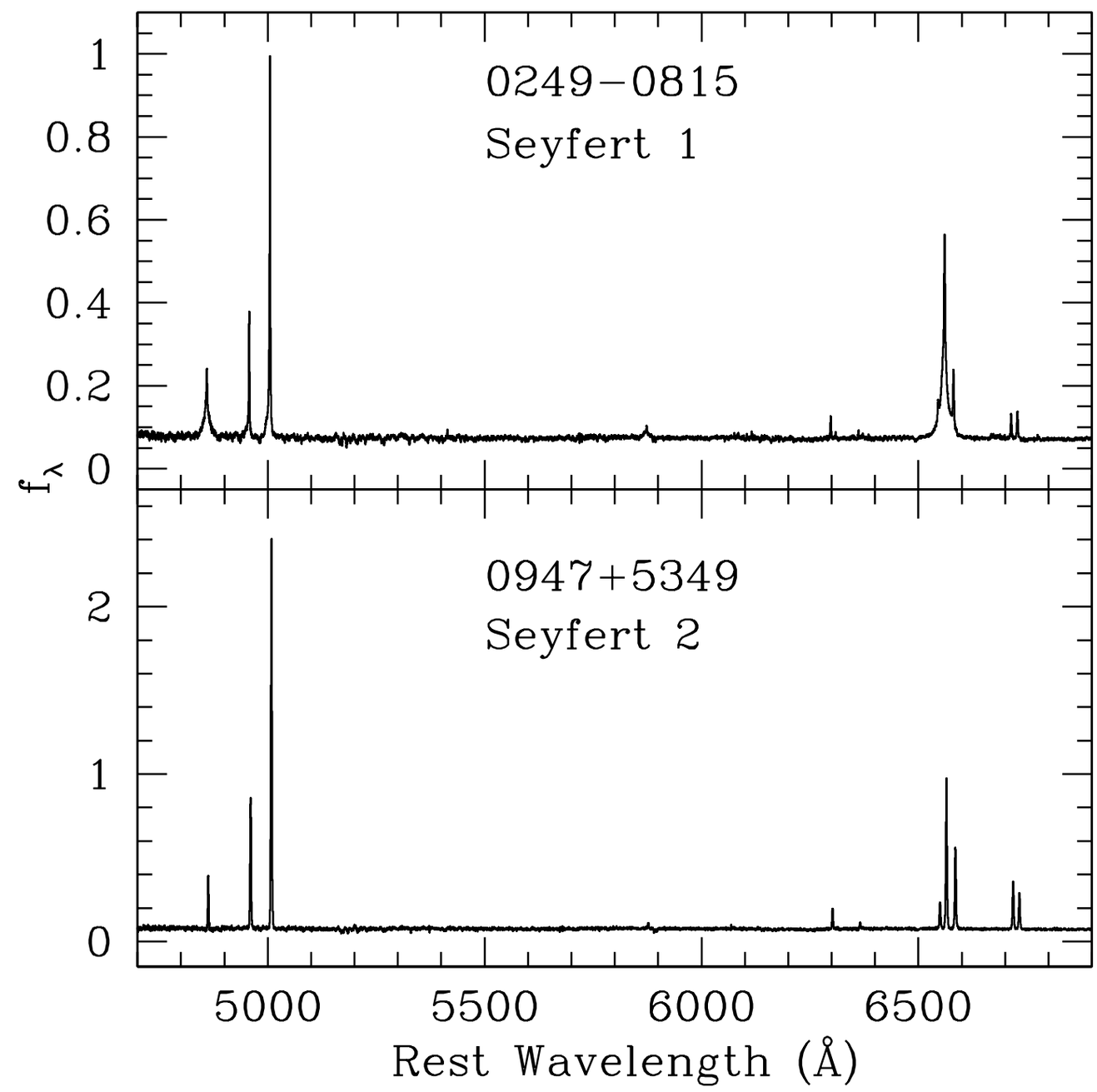


- $M_g = -16.8$ mag
- Stellar mass $10^{8.1}$ $M_\odot$
  (Kauffmann et al. 2003)
- σ([O III]) = 28 km/s

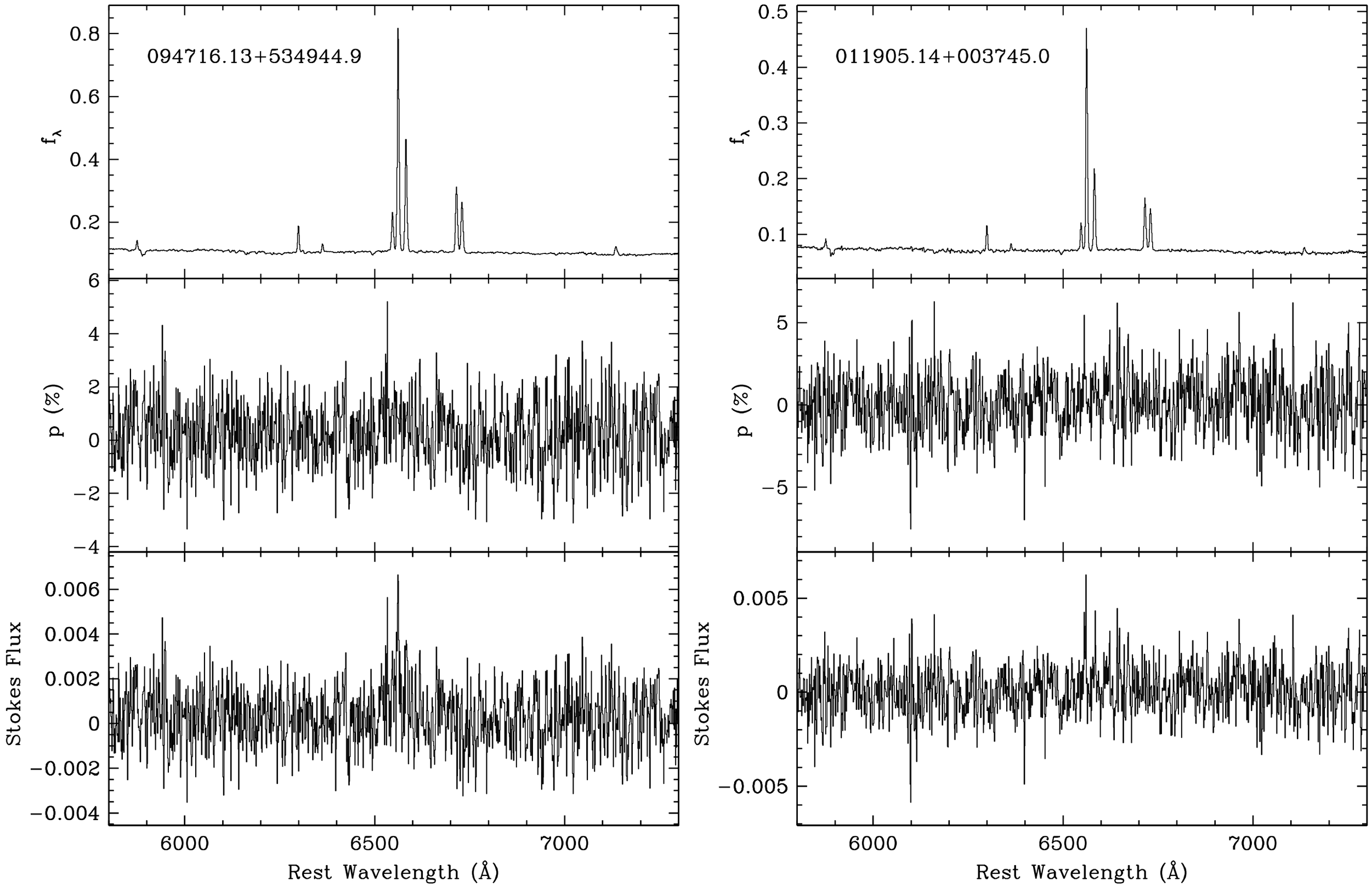
Type 1 and 2 "dwarf" Seyferts



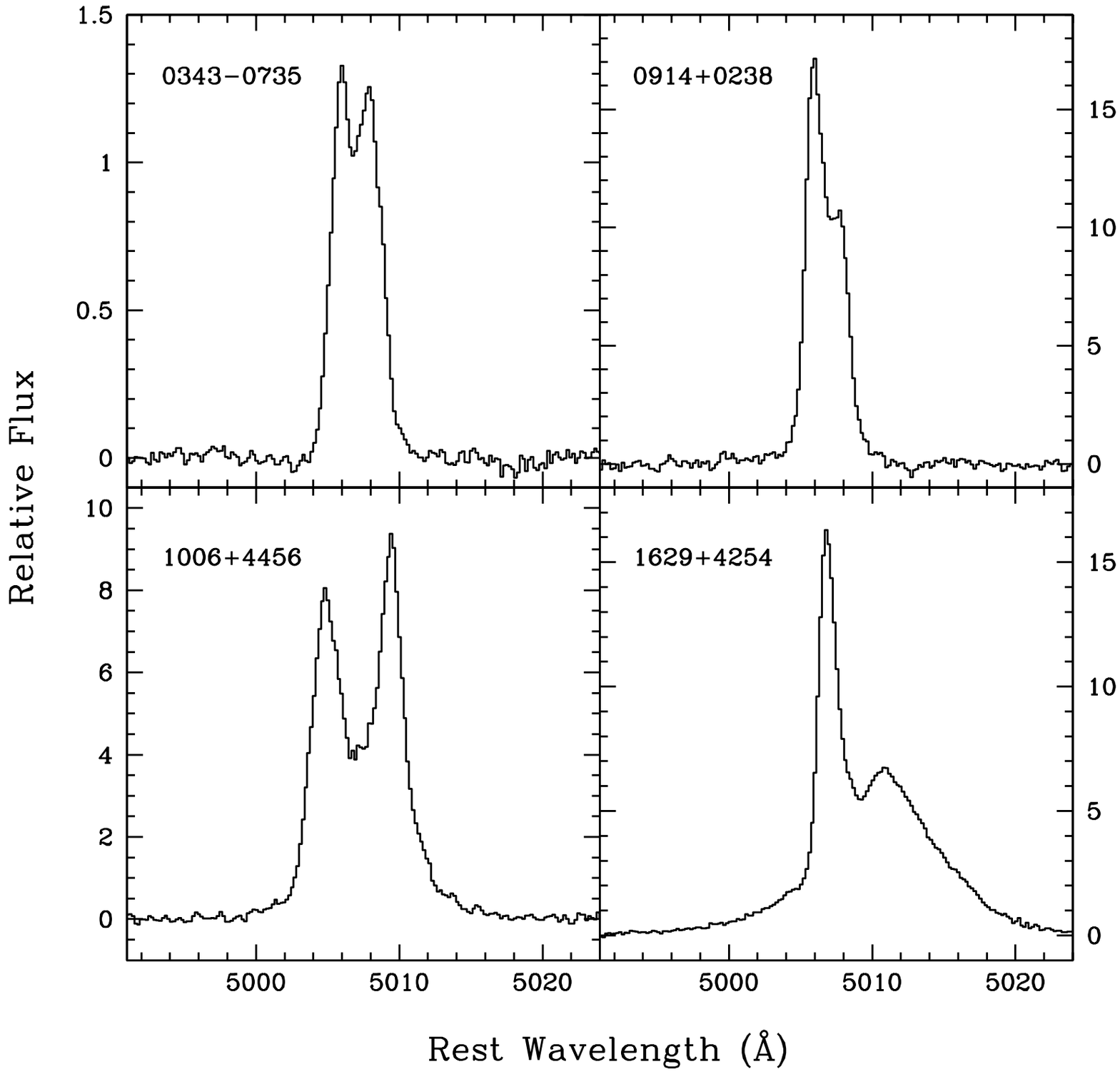




Spectropolarimetry



[O III] line profiles



Conclusions

- AGNs occur in host galaxies with velocity dispersions down to ~25 km/s
- Morphologies of low-mass AGN hosts include spirals and dwarf ellipticals
  - But Seyfert nuclei in NGC 4395-type host galaxies appear to be extremely rare!
- Type 1 AGNs are ~consistent with a simple extrapolation of the power-law M-σ relation to low velocity dispersions, *but*
  - there is *tentative* evidence for a flattening in slope below σ=60 km/s

Current & future work

- Optical variability & reverberation mapping
- XMM, Chandra, Spitzer observations
  - Spectral energy distribution, L_{bol}, black hole accretion rate
  - Hidden central engines in the smallest Seyfert 2s?
- HST imaging to get host galaxy morphologies, L_{bulge}
- Demographics:
  - Black hole "occupation fraction" in low-mass galaxies
  - Space density of black holes below 10^6 $M_\odot$