UNIVERSITÀ DEGLI STUDI FIRENZE

Active Galactic Nuclei

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Outline

- A brief introduction to Active Galactic Nuclei (or ... accreting supermassive black holes)
- Coevolution of black holes and host galaxies
- Open questions: seeking answers in near-UV spectroscopy

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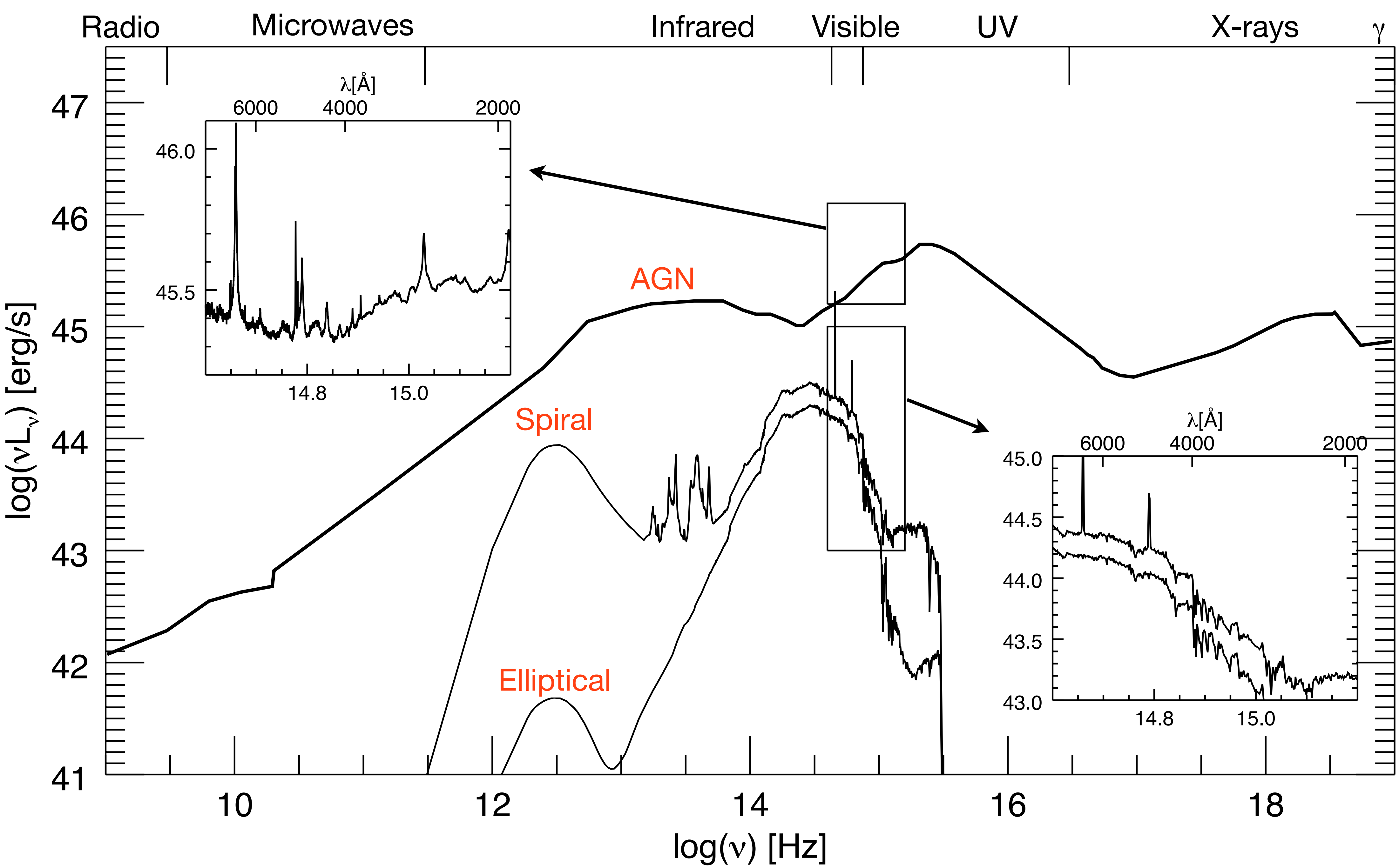
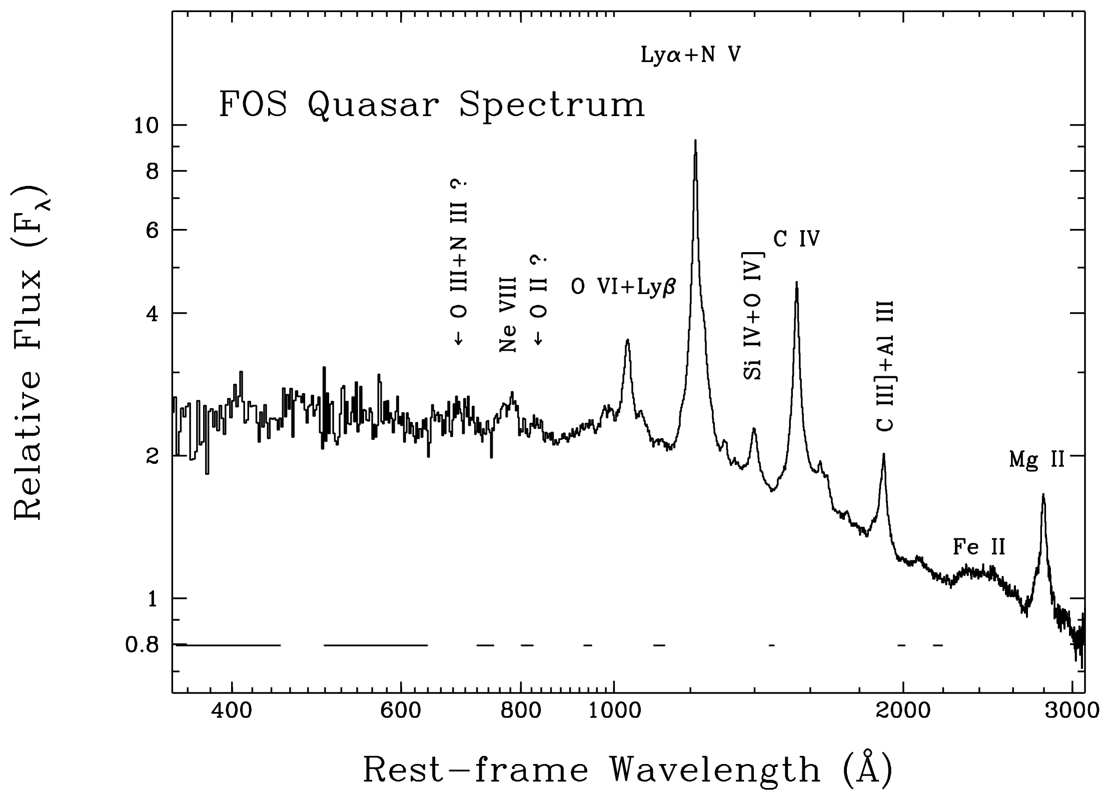
AGN in a nutshell

- An Active Galactic Nucleus (AGN) is a galaxy nucleus with indications *non-stellar* activity ($L \sim 10^{11}$-10^{15} $L_\odot$, non-stellar continuum, prominent emission lines, jets of relativistic material, strong and fast variability)
- Many observational classes: Quasars, Seyfert galaxies, radio gal., etc.

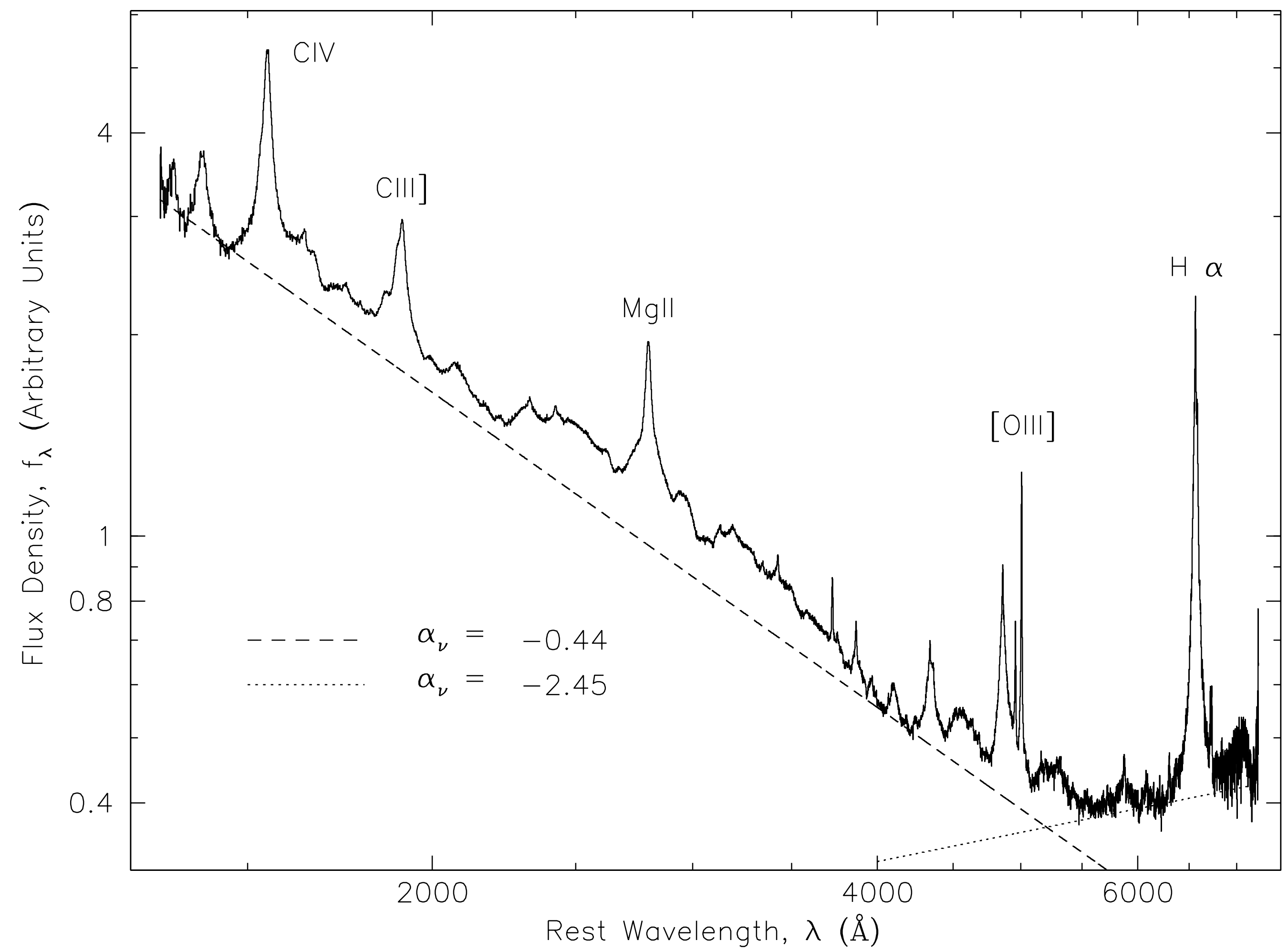


UV-Optical Spectra of Quasars

- Prominent broad (FWHM >1000 km/s, up to ~10000 km/s) emission lines
- Strong blue continuum



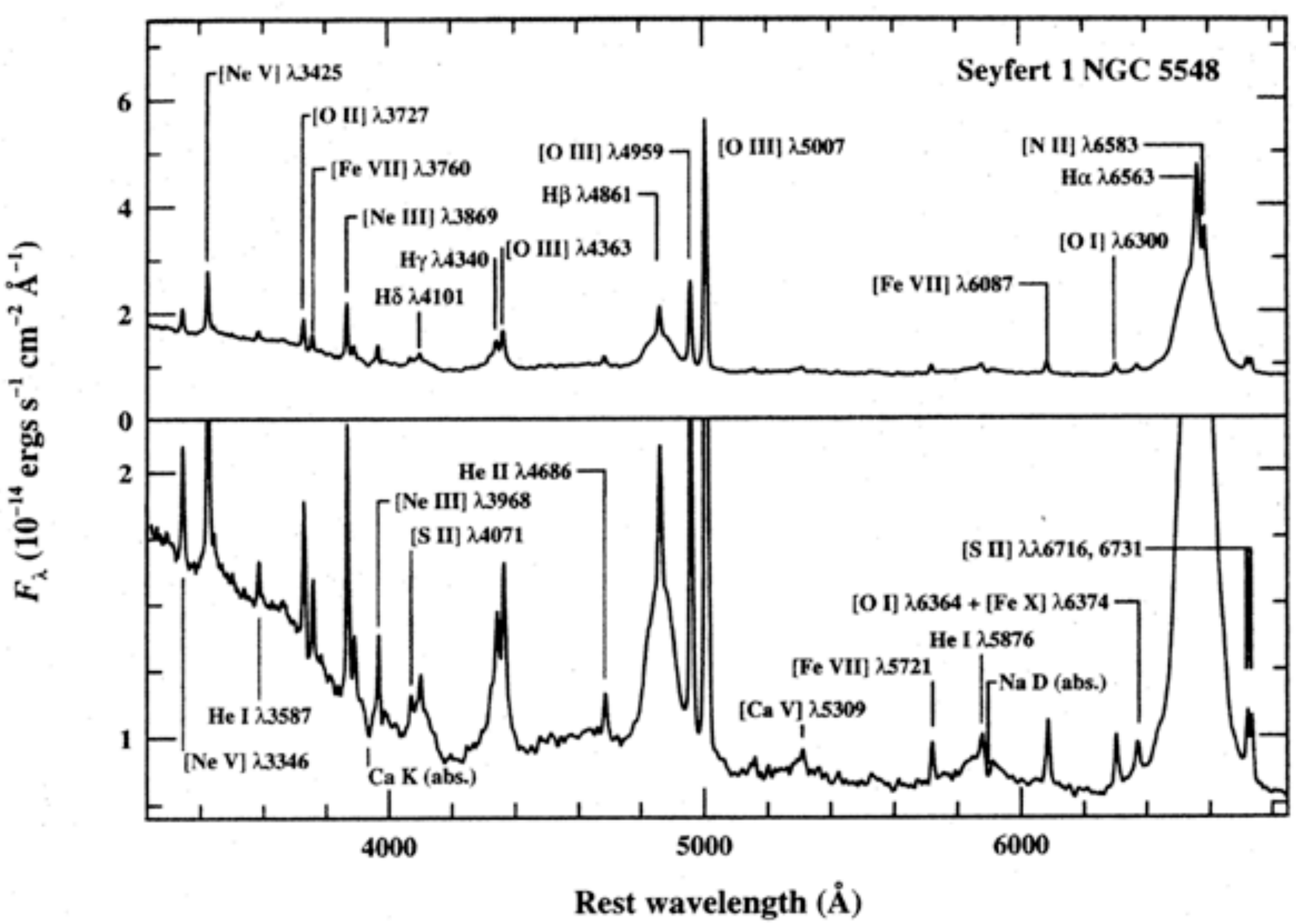
Composite HST Quasar spectrum (Zheng+1997)

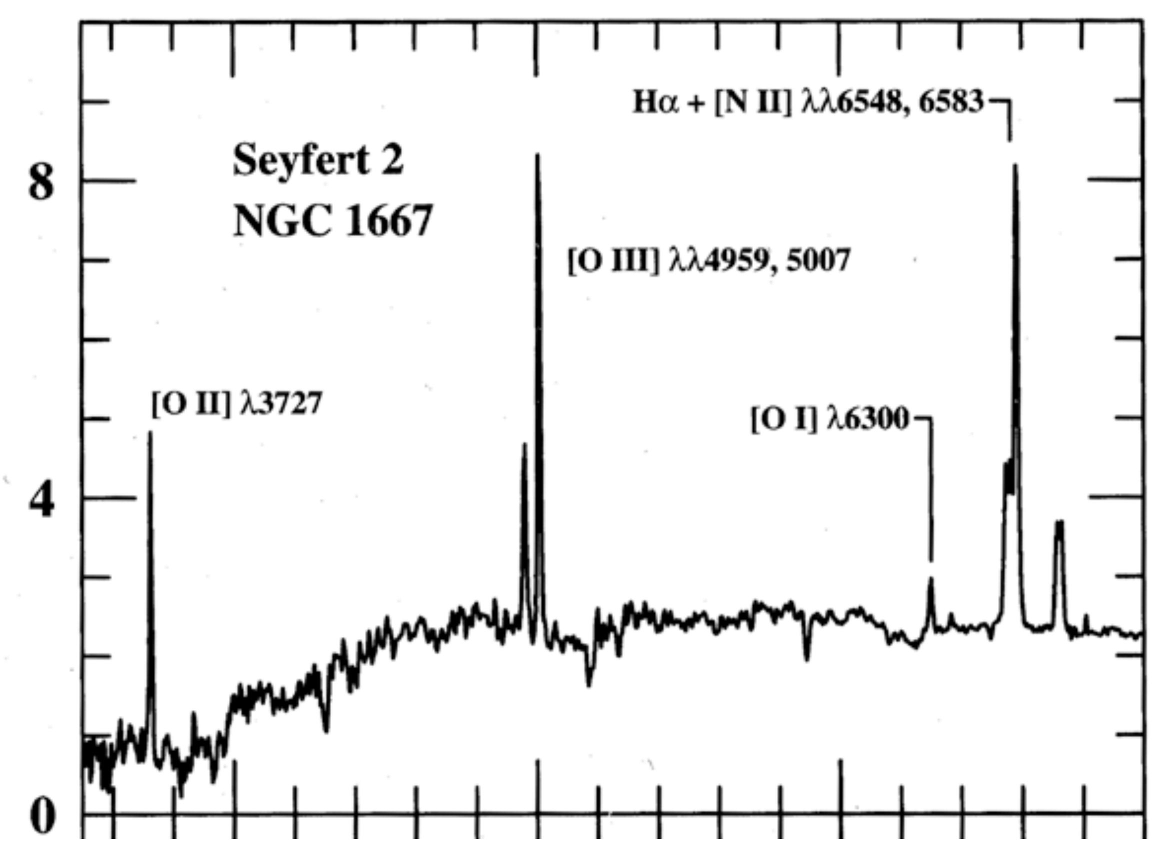


Composite SDSS Quasar spectrum (Vanden Berk+2001)

UV-Optical Spectra of Seyferts

- Broad (FWHM > 1000, 3000-10000 km/s) permitted (Hα, Hβ, MgII, CIV) lines
- Narrow (FWHM < 1000, ~500 km/s) permitted and forbidden lines ([OIII], [NII], etc.)
- Seyfert 1 galaxies: broad and narrow lines → in general type 1 objects
- Seyfert 2 galaxies: narrow lines only → in general type 2 objects

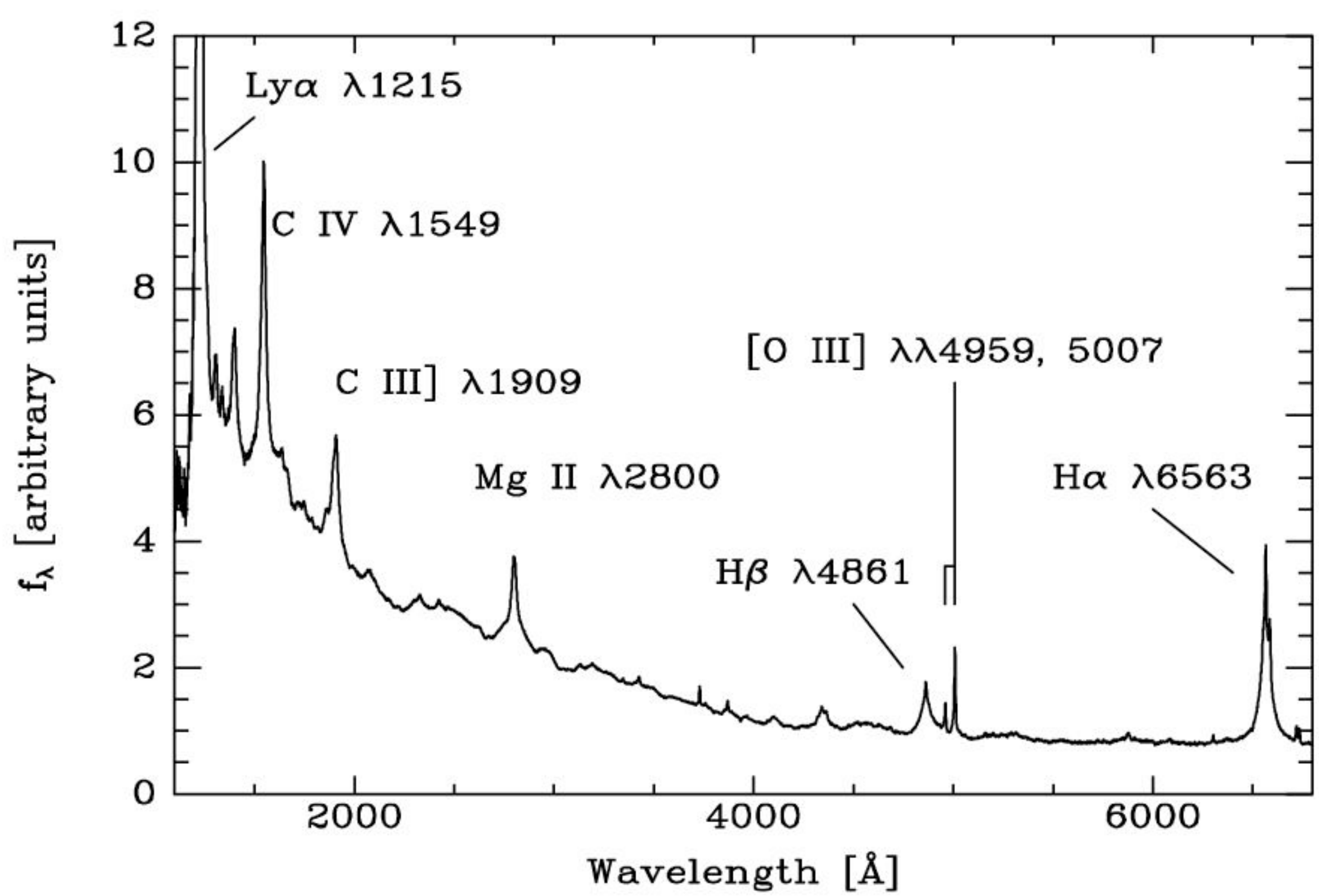




BLR and NLR

- Narrow emission lines from the Narrow Line Region (NLR)
  - low density (compared to critical density of forbidden lines, $N_c \sim 10^6$ cm^{-3}),
  - Doppler broadened but "small" velocity clouds (~500 km/s but typical velocities of host galaxies ~100-300 km/s)
  - galactic scales (~100 pc to kpc scales)

- Broad emission lines from Broad Line Region (BLR)
  - large densities (>> N_c, forbidden lines collisionally suppressed)
  - Doppler broadened by large velocities (~1000-10000 km/s)
  - very small scales (~light days to < pc)



Central engine: accreting BH

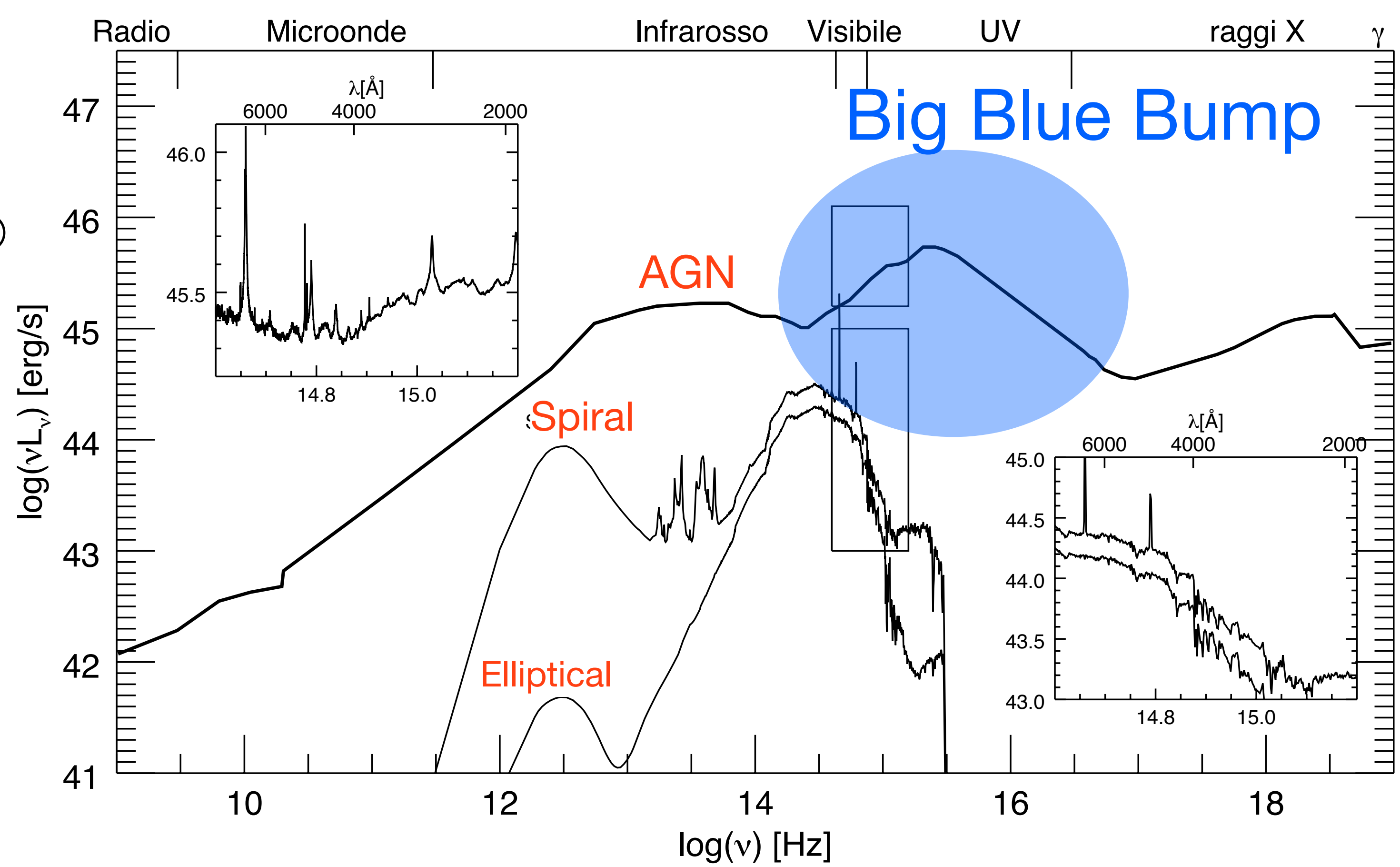
- Large luminosities from small volumes

$$L = \varepsilon \dot{M} c^2$$

- Require large efficiencies (>> 0.007 of nuclear reactions in stars)

Accretion onto supermassive black holes (Salpeter 1964, Zel'dovich 1964)

- small volumes (a few Schwarschild radii)
- large efficiencies (ε ~ 0.06-0.4 for non rotating - rotating BH)
- $L < L_{Edd}$ implies large M_{BH}, much larger than stellar BHs
  $L \sim 10^{12}\, L_\odot \rightarrow M_{BH} > 3\times10^7\, L_\odot$
- Emission is due to accretion disk providing plenty of ionizing photons
  (Big Blue Bump)
  harder spectrum than O stars

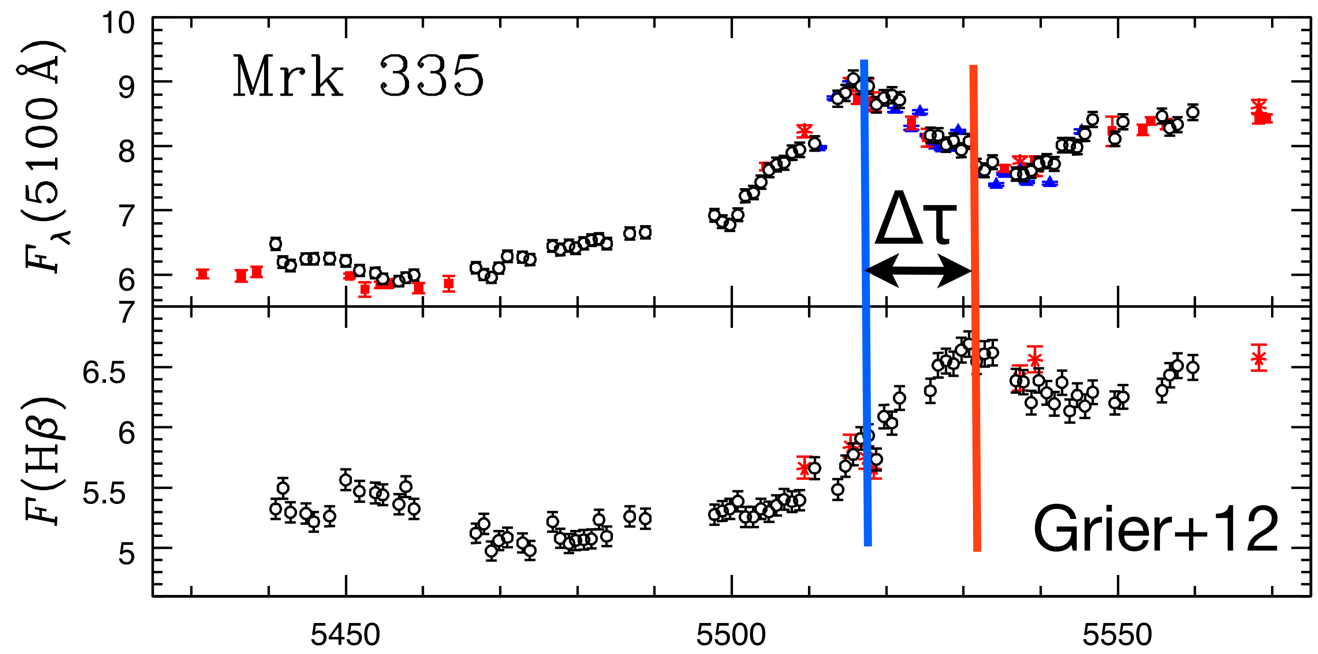


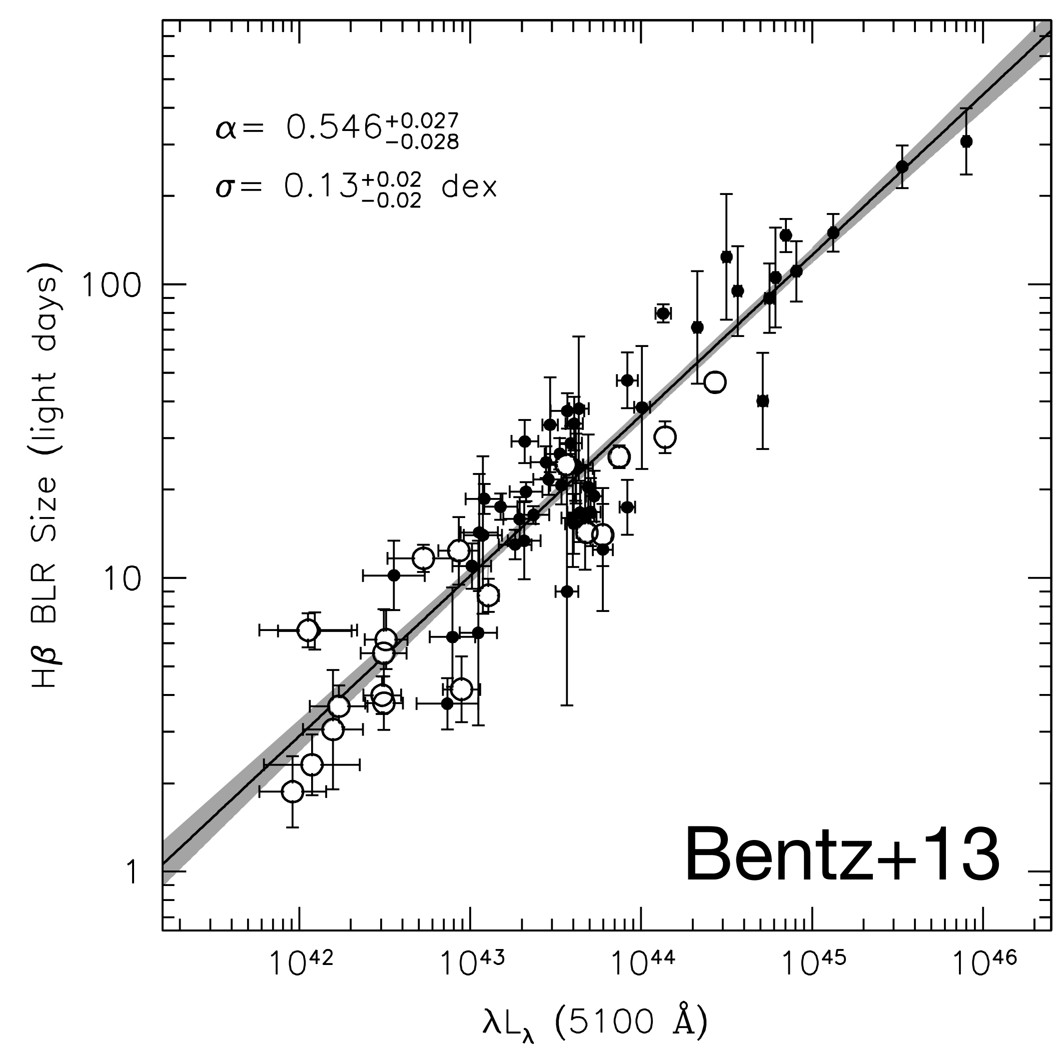
Reverberation mapping of BLR

- Light curves of continuum and broad emission lines are similar
- time lag (= light crossing time) implies small dimensions of BLR ($R_{BLR} = c\,\Delta\tau$)
- Combine line widths with time lags to estimate BH mass (e.g. Peterson et al.)

$$M_{BH} = f\,\frac{V^2 R}{G}$$

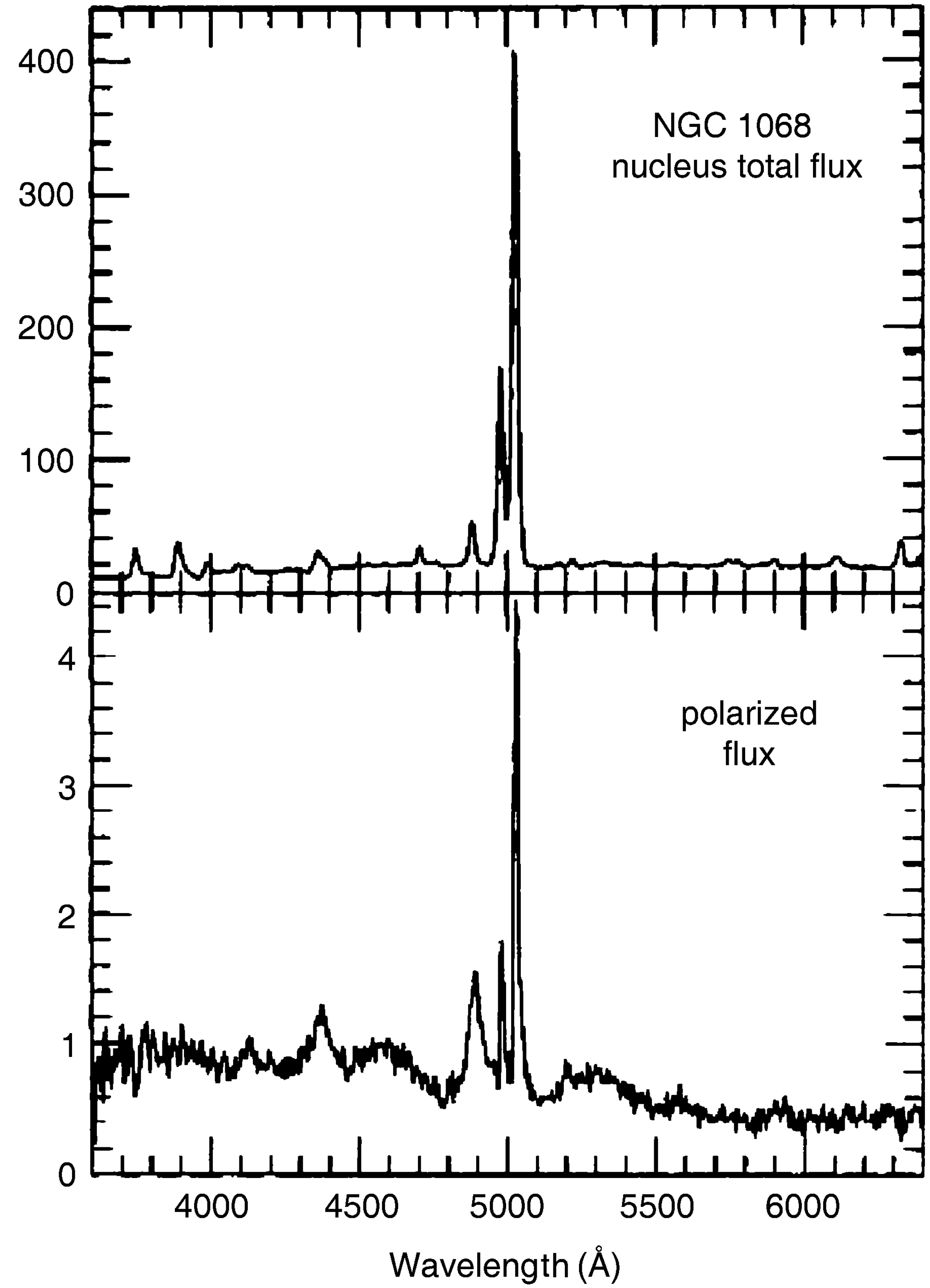
- $M_{BH} \sim 10^6\text{-}10^9\ M_\odot$ found
- Radius luminosity relation: $R_{BLR} \sim L_{AGN}$ (Kaspi+00,Bentz+13)
- BLR is photoionized from central continuum source
- Possible to measure BH masses from any type 1 spectrum (combine line width and L_{AGN})



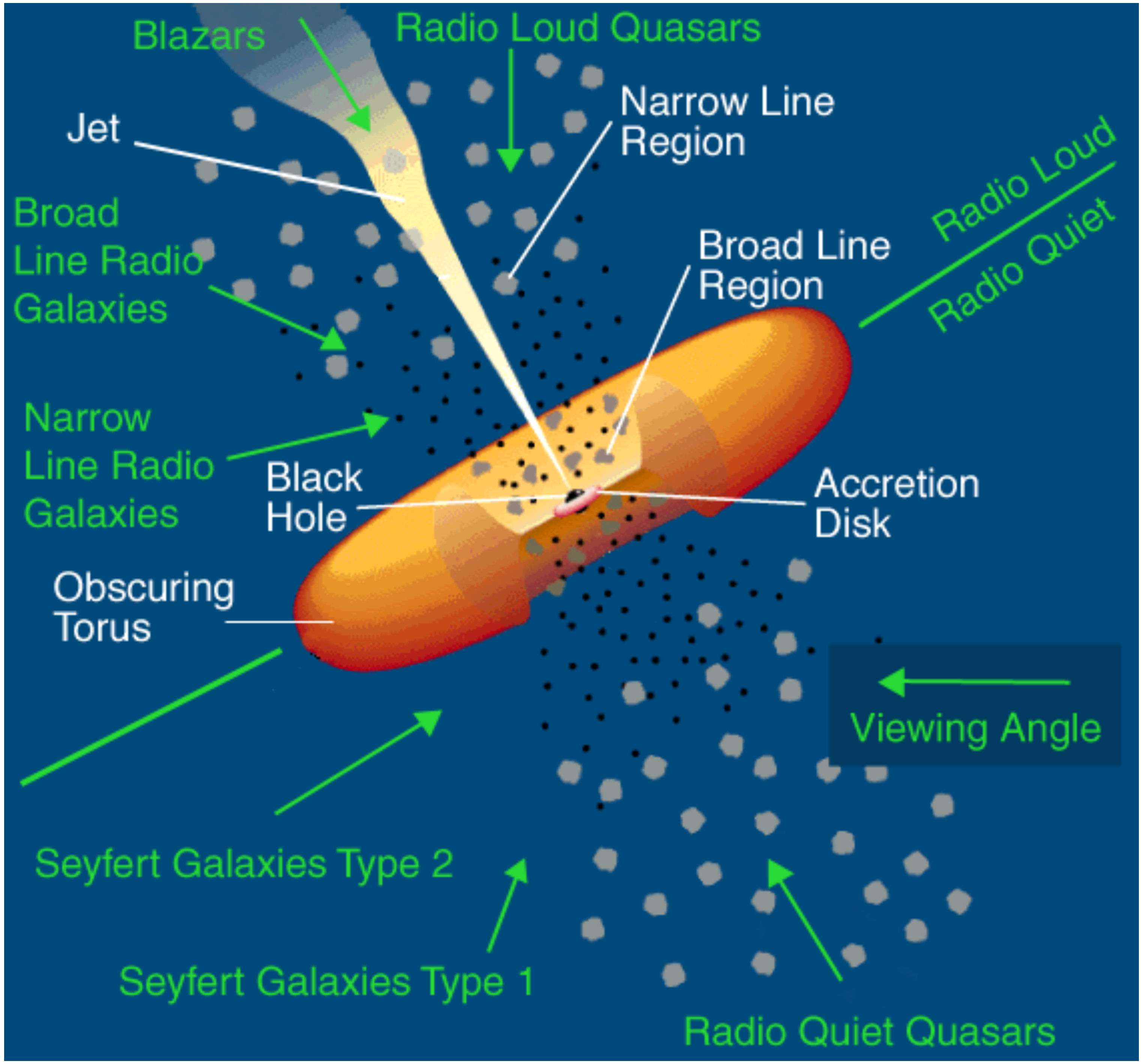


AGN unified model: orientation effect

- Broad polarized lines in archetypal Seyfert 2 (Antonucci & MIller 1985)
- Unified model: all sources intrinsically the same, but seen under different viewing angles



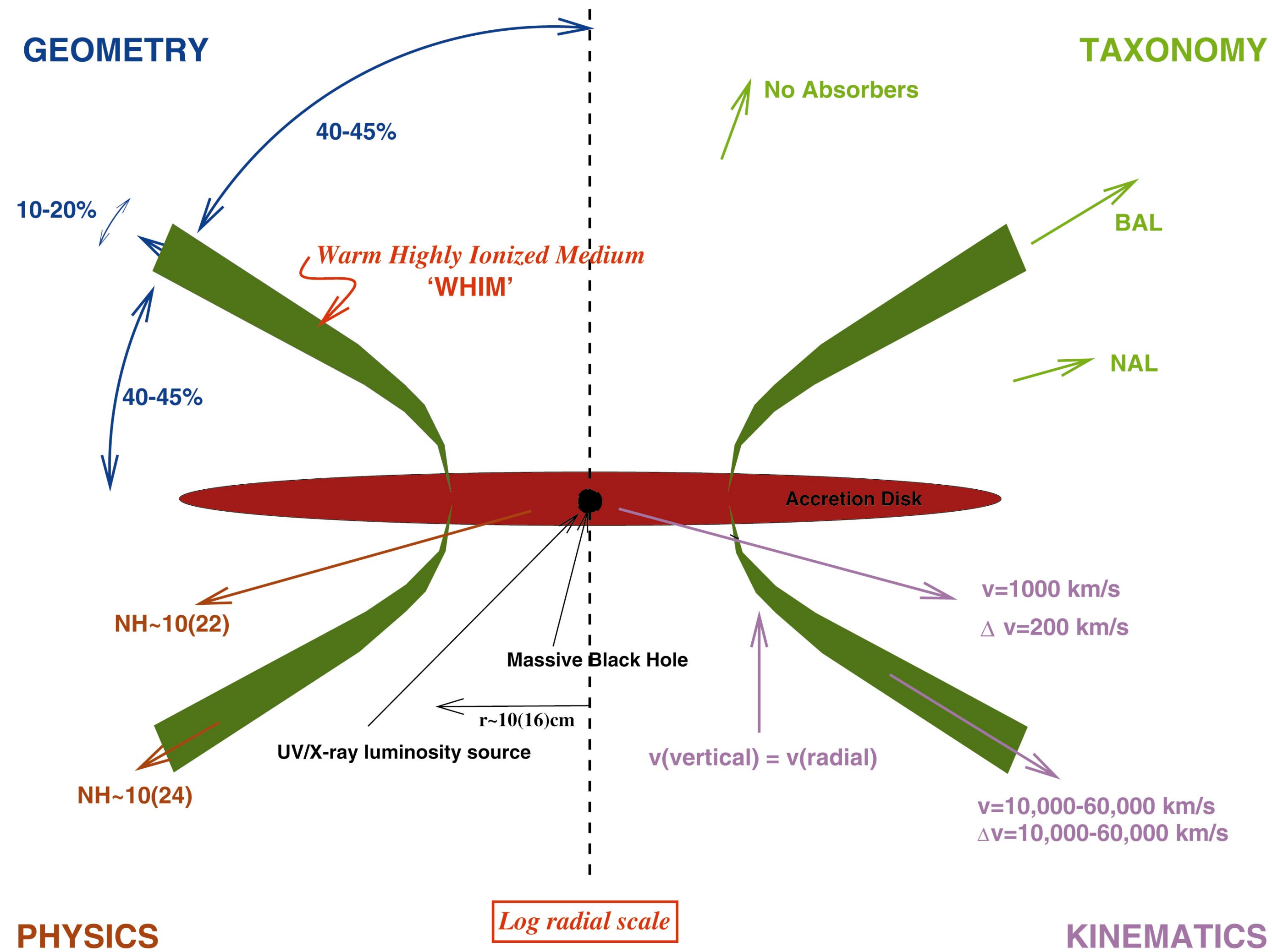
Antonucci & Miller 1985



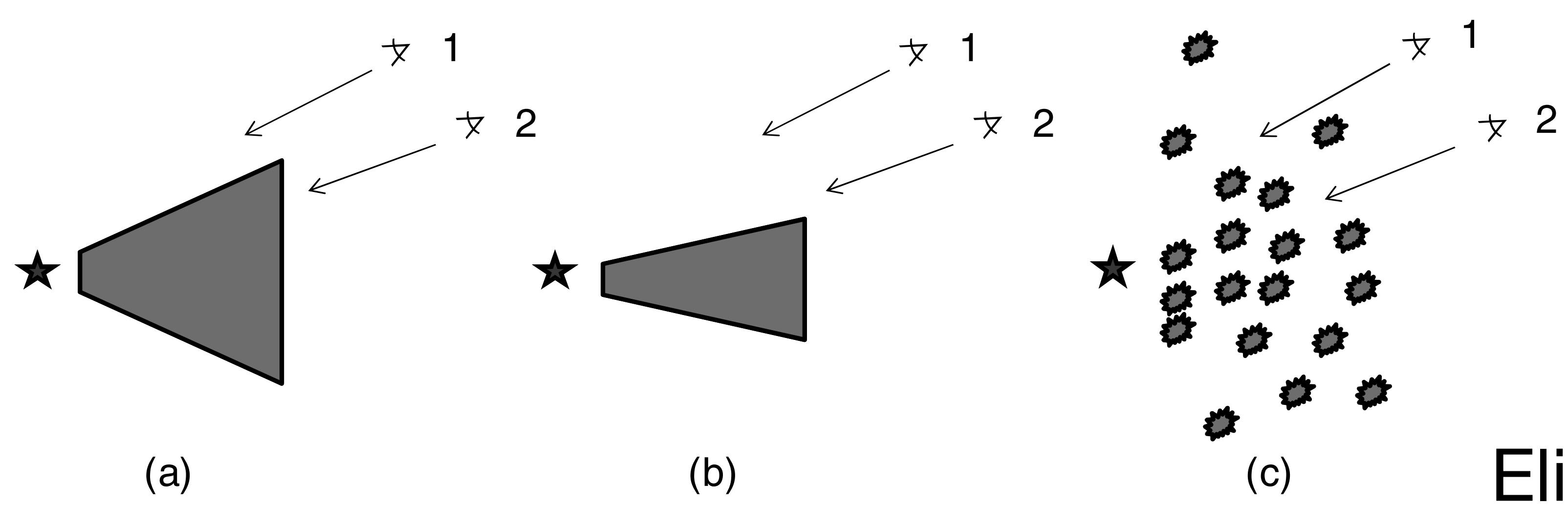
Urry & Padovani 1995

Beyond the unified model

- Torus is usually considered to be a homogeneous dusty medium but alternatives to better match observations have been proposed:
  - Disk - wind structure (Elvis 2000)
  - Toroidal obscuration made by dusty clouds (e.g. Elitzur 2012)



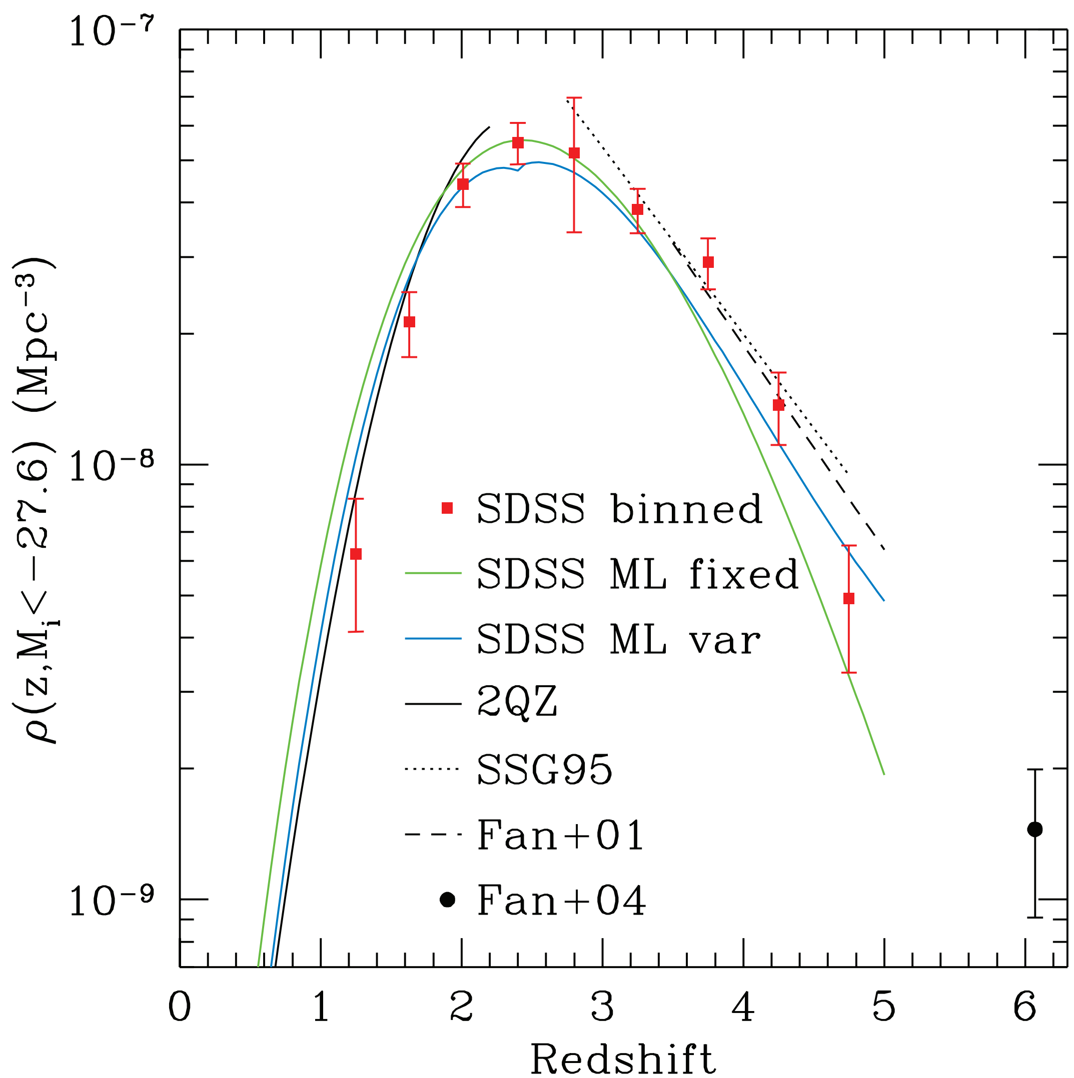
Elvis 2000



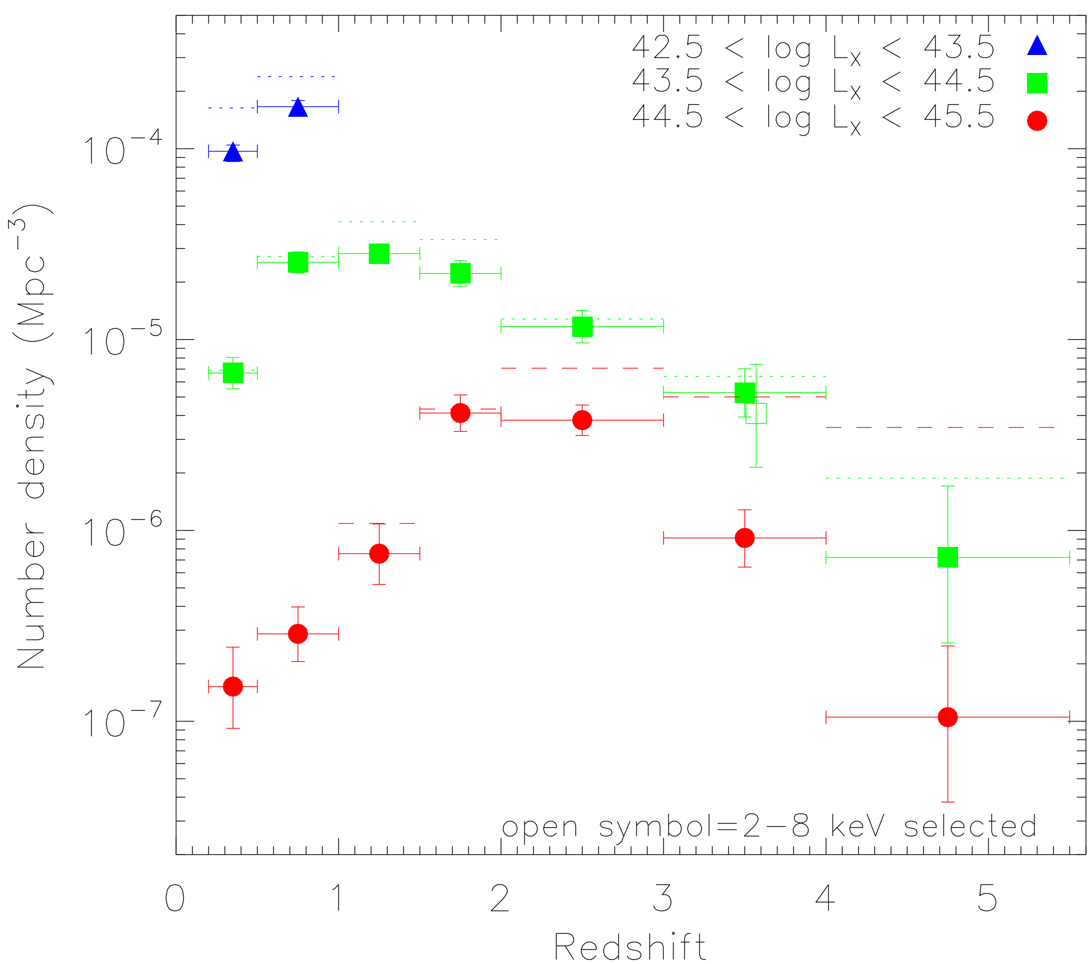
Elitzur 2012

Cosmological evolution of AGN

- Numerous ground based (optical, radio) and space based surveys (X-rays, MIR & FIR) in the last 30 years ...
- Quasar era: peak of quasar number density at z~2-3
- X-ray surveys: differential evolution with luminosity (downsizing)
- High luminosity, high mass BHs (~10^9 $M_\odot$) exist at very early epochs (< 1 Gyr from Big Bang): little time to grow them with accretion (e.g. Fan)



QSO: Richards+2006 (Boyle+2000)



Xrays: Silverman+2007 (Ueda+2003, Fiore+2004, La Franca+2005, Hasinger+2005)

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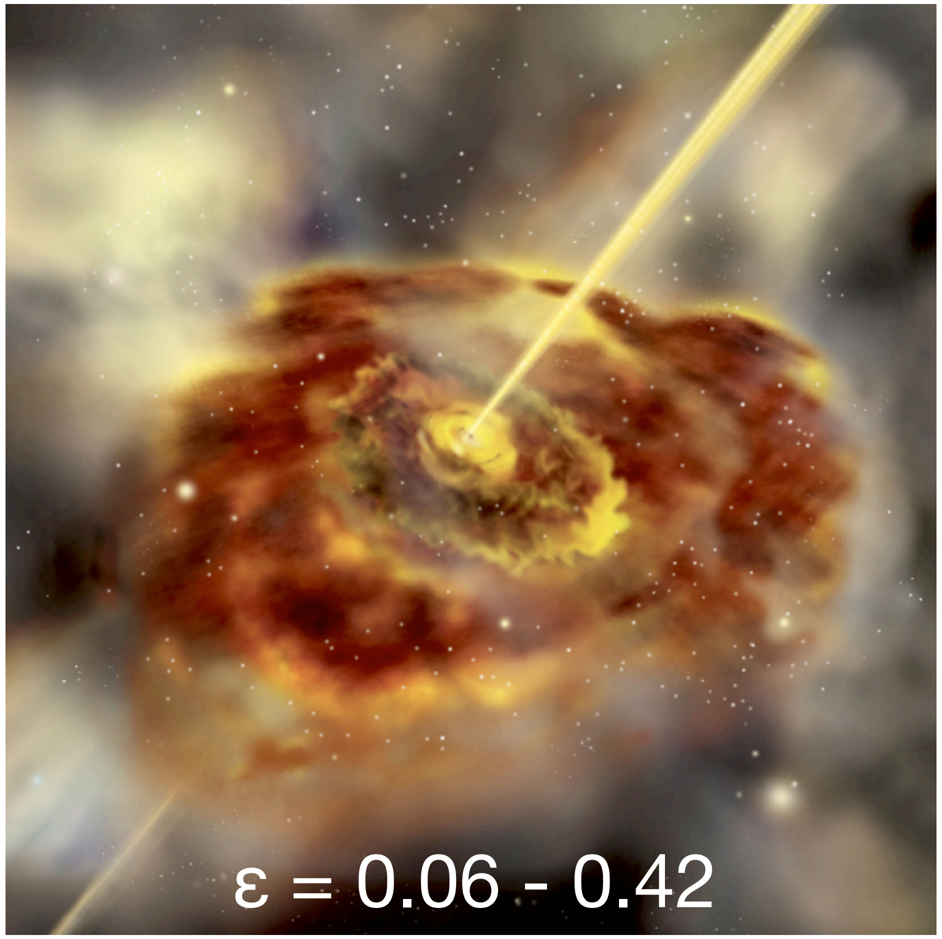
Supermassive Black Holes

- Supermassive black holes: 10^6-10^{10} $M_\odot$
- Active Galactic Nuclei are powered by accretion onto supermassive black holes (Salpeter 1964, Zel'dovich 1964)
- Fraction ε of accreted mass is "radiated" away, (1-ε) increases BH mass



$$L_{AGN} = \varepsilon \left(\frac{\Delta M_{acc}}{\Delta t_{AGN}} \right) c^2$$

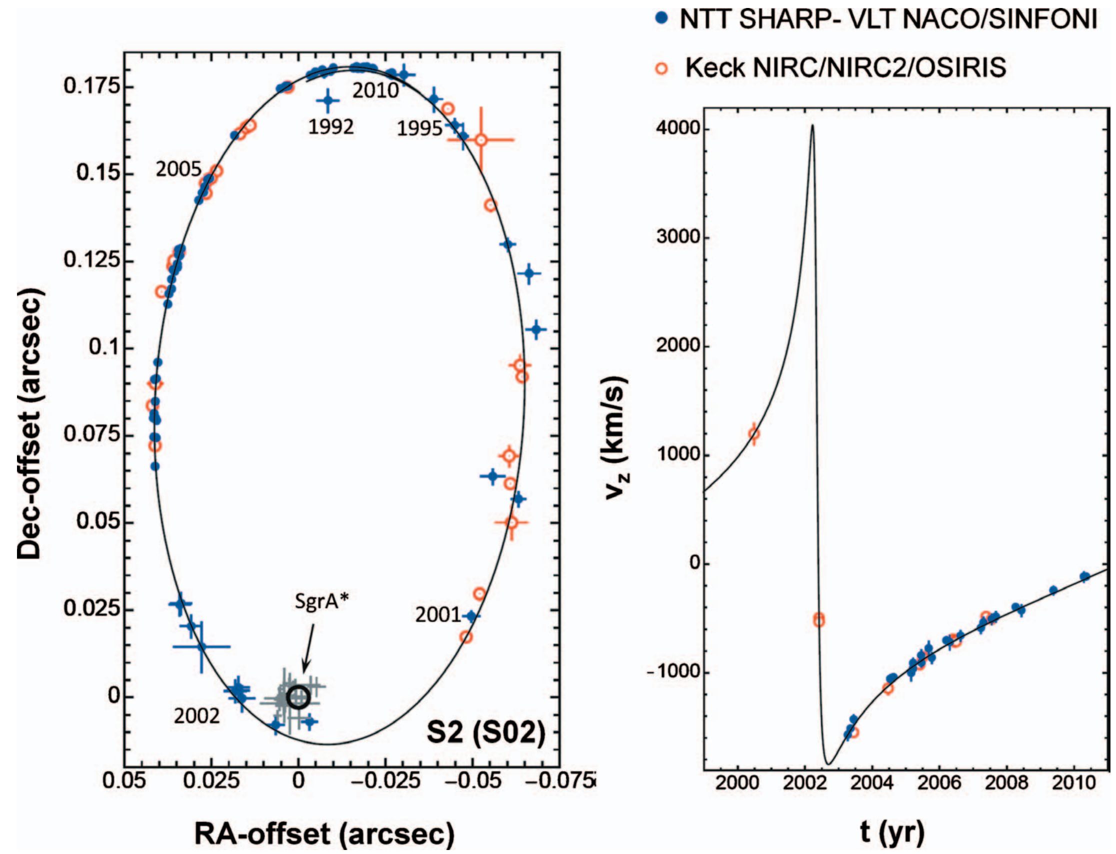
$$\Delta M_{BH} = \frac{1-\varepsilon}{\varepsilon\, c^2} L_{AGN} \Delta t_{AGN}$$

$$\Delta M_{BH} = 6.1 \times 10^6\, \mathrm{M}_\odot \left(\frac{L_{AGN}}{10^{12}\, \mathrm{L}_\odot} \right) \left(\frac{\Delta t_{AGN}}{10^7\, \mathrm{yr}} \right) \qquad \text{for } \varepsilon = 0.1$$

- Luminous AGN much more numerous in the past
- *We expect SMBH in the nuclei of quiescent (old) galaxies, as remnants of past AGN activity.*

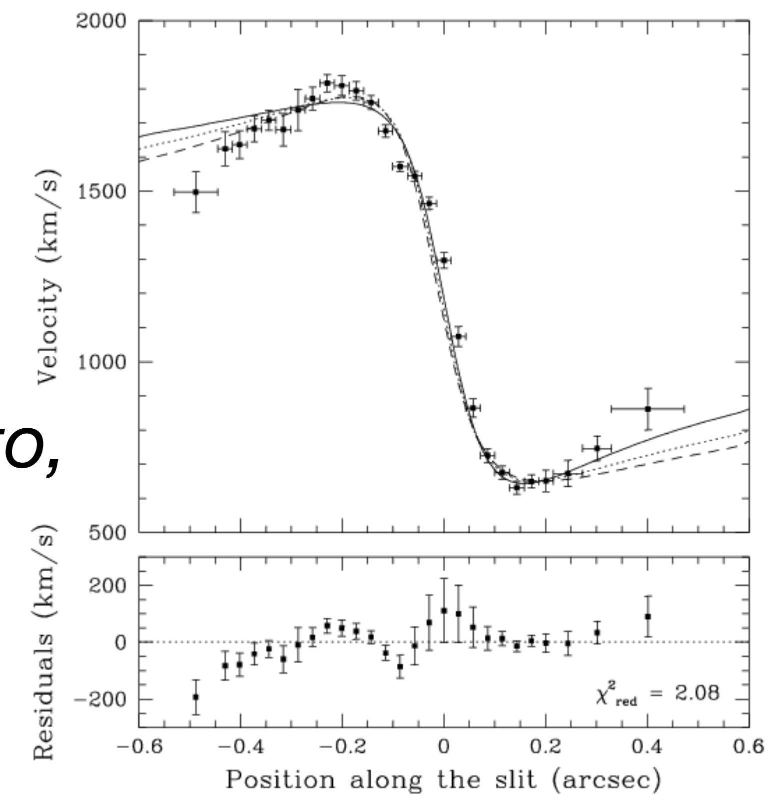
Supermassive Black Holes

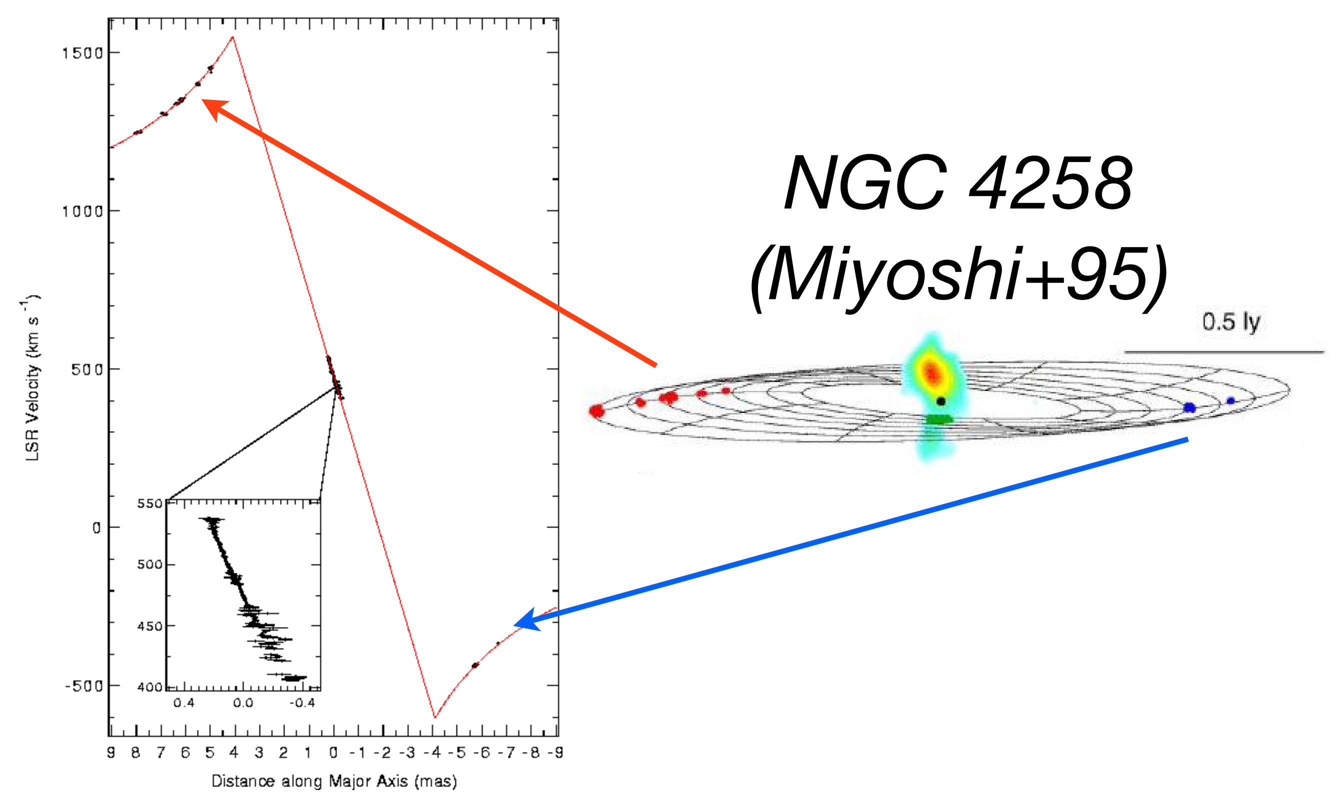
- *Supermassive BHs (M_{BH}~10^7-10^{10} $M_\odot$) detected in nuclei of nearby galaxies*
- Notable examples:
  - Galactic Center (Genzel+10)
  - NGC 4258, Circinus, other H_2O maser galaxies (Miyoshi+95,Greenhill+03,Kuo+11)
  - M31 (Kormendy & Richston 1995), M32 (van der Marel+97)
  - M87 (Macchetto, AM+97, Gebhardt & Thomas 2009)
  - Centaurus A (Marconi+01, Neumayer+07)



Galactic center (Gillessen+09)

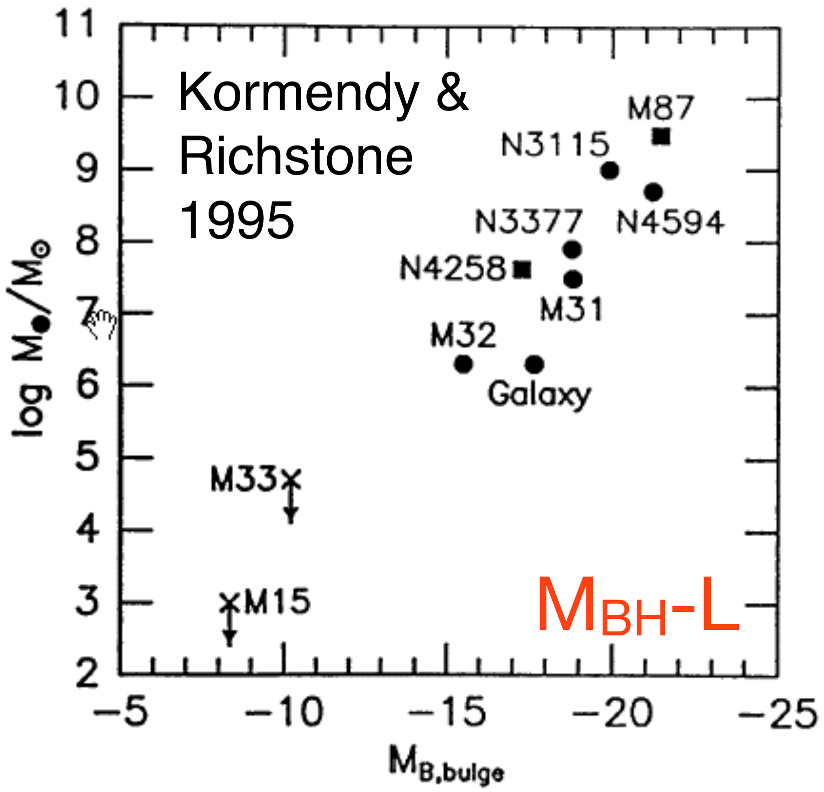
M87 (Macchetto, AM+97)





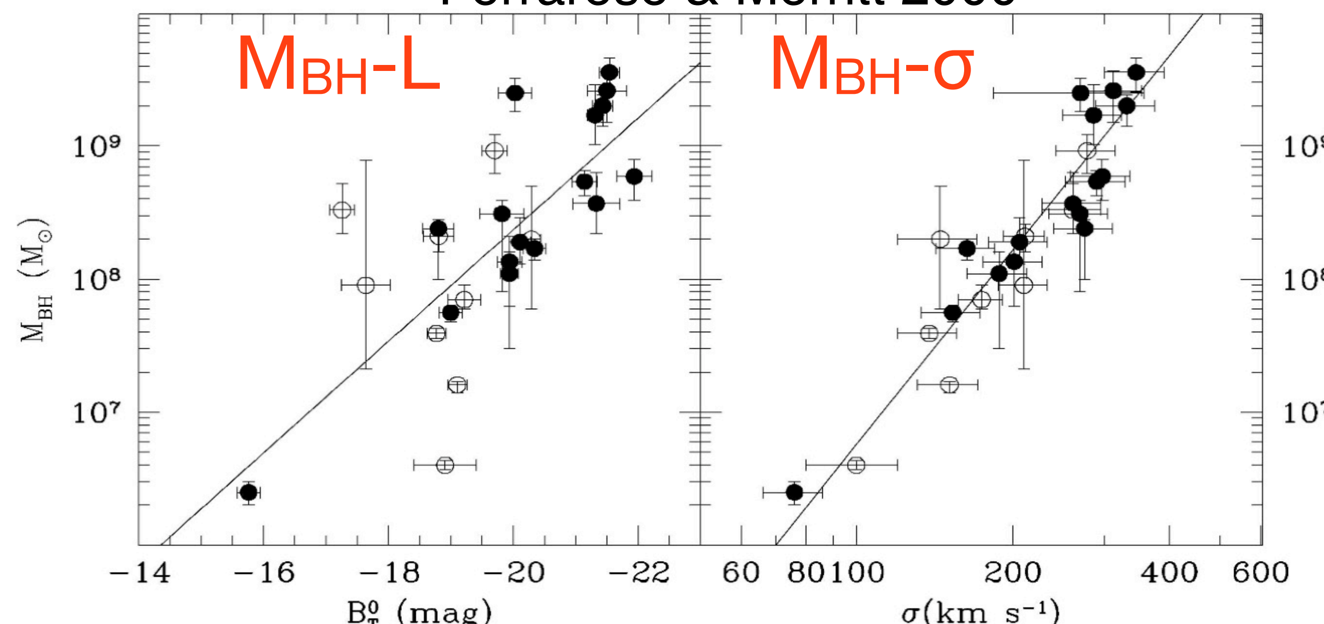
NGC 4258 (Miyoshi+95)

BHs and Relations with host galaxy

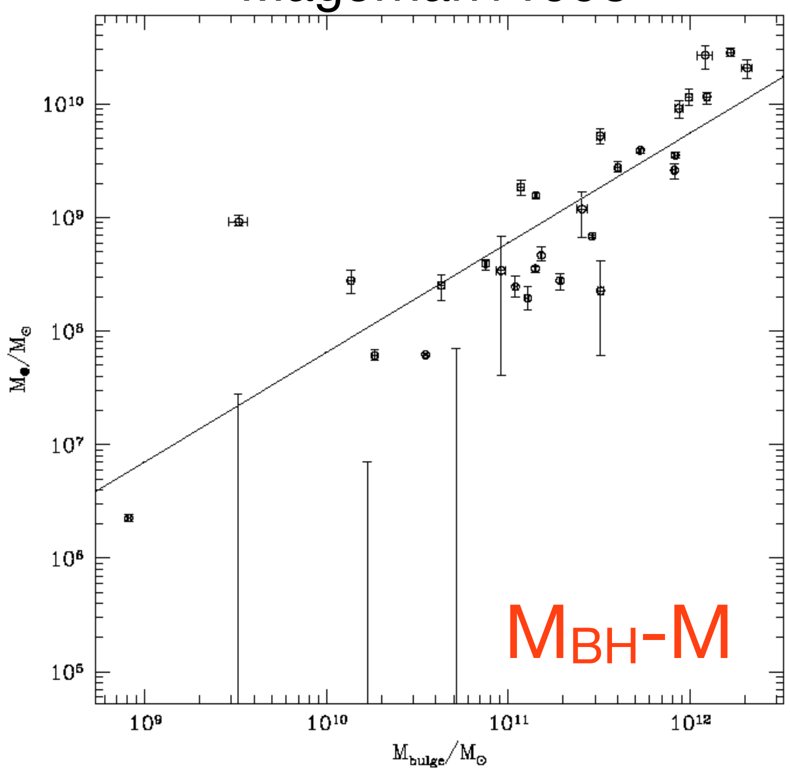


- BH detected in nearby **normal** galaxies!
- Correlations M_{BH} vs host spheroid (M, L, σ)
- *Consistent with zero intrinsic scatter?*
- *Great impact in literature!*

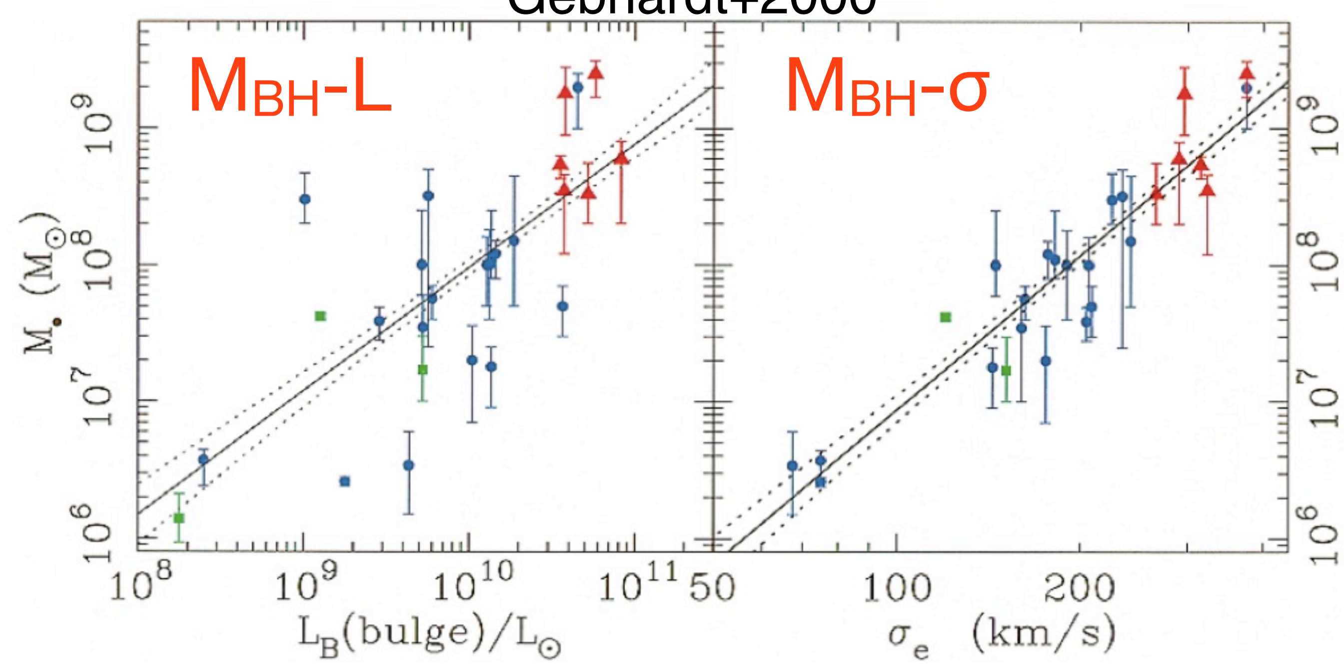
Ferrarese & Merritt 2000



Magorrian+1998

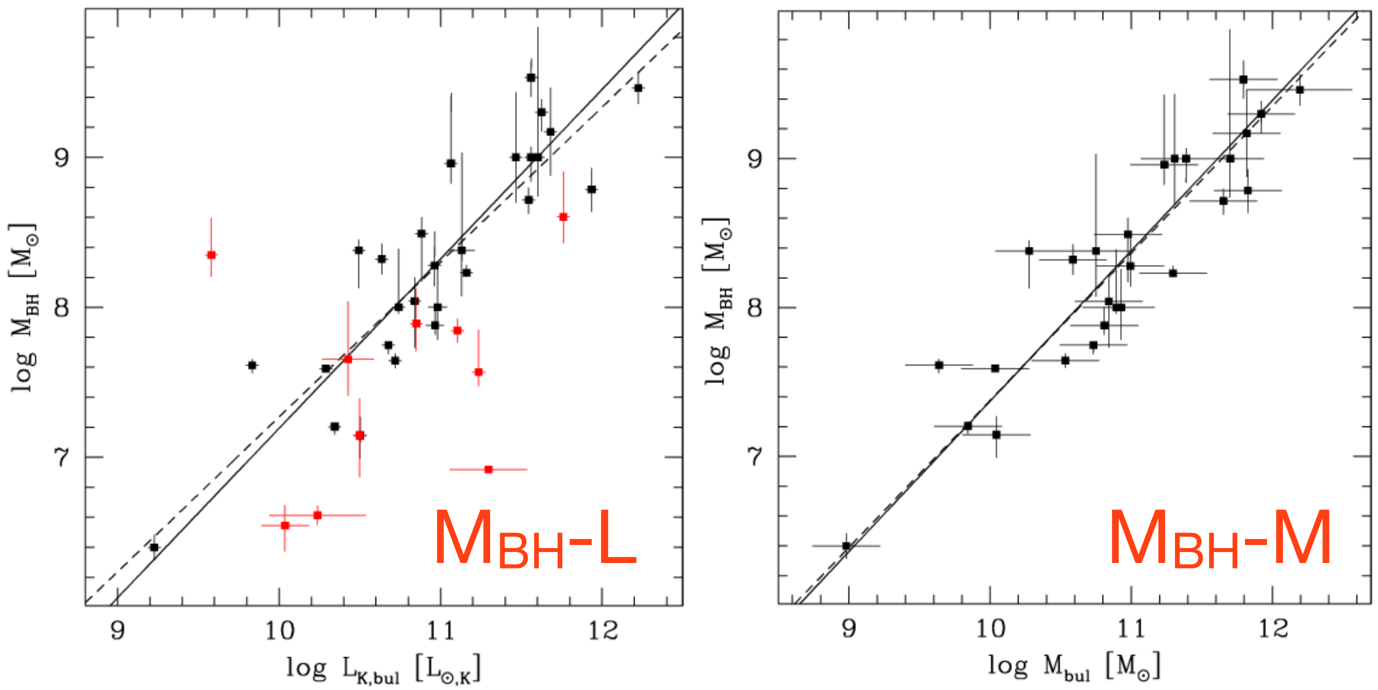


Gebhardt+2000



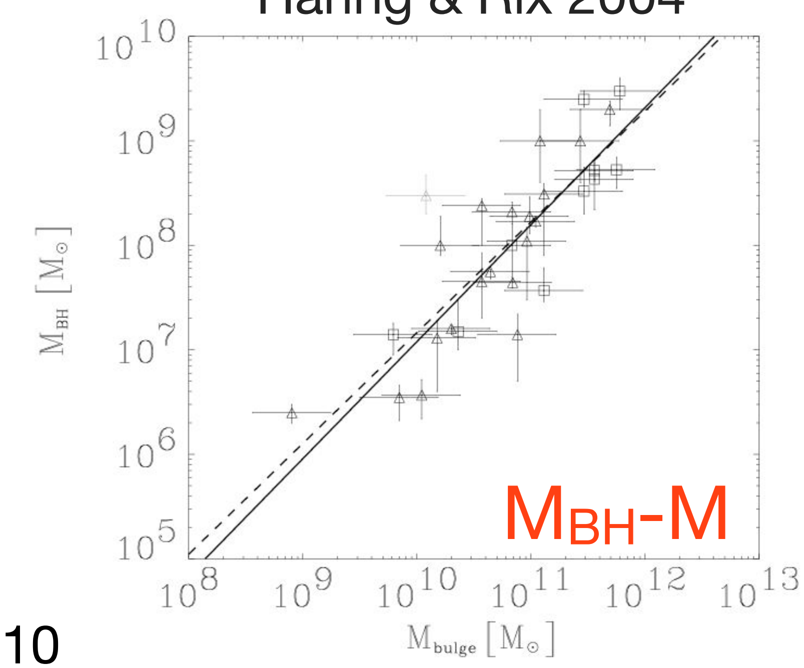
Relations with host galaxy (II)

Marconi & Hunt 2003

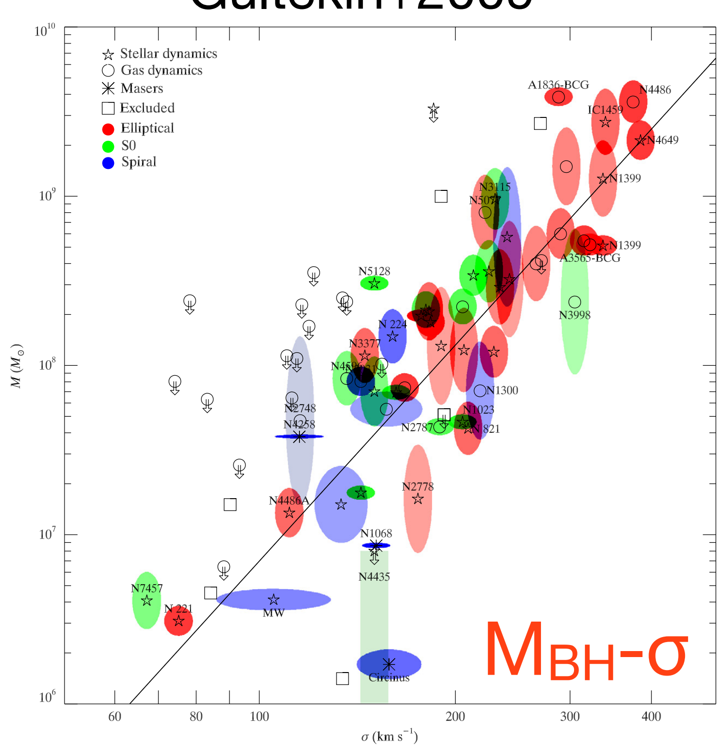


⭐ *More recent versions: more points, more colors,* ***more scatter!***

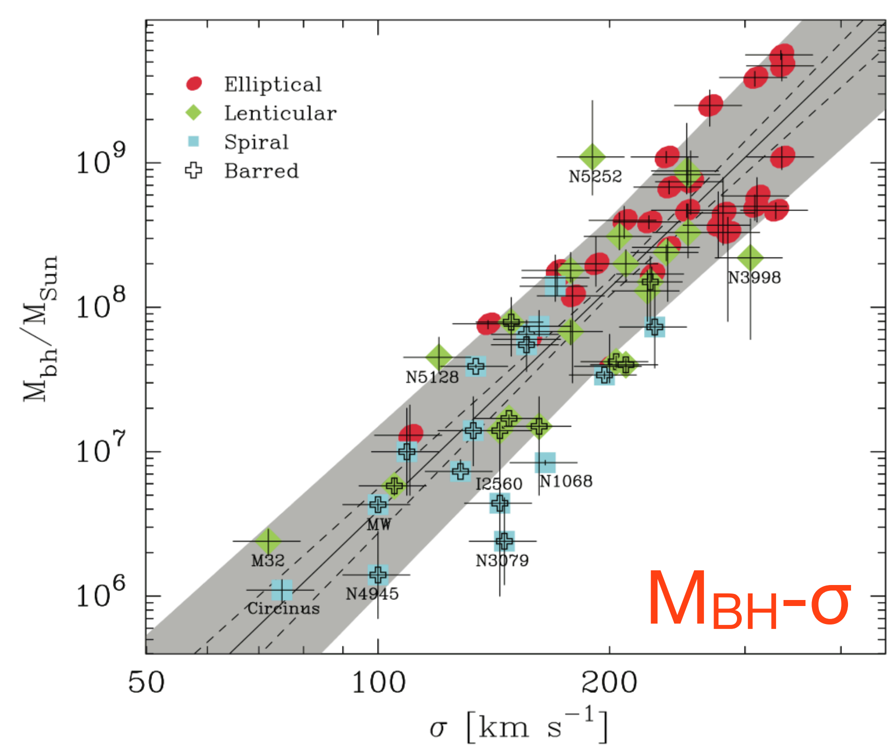
Häring & Rix 2004

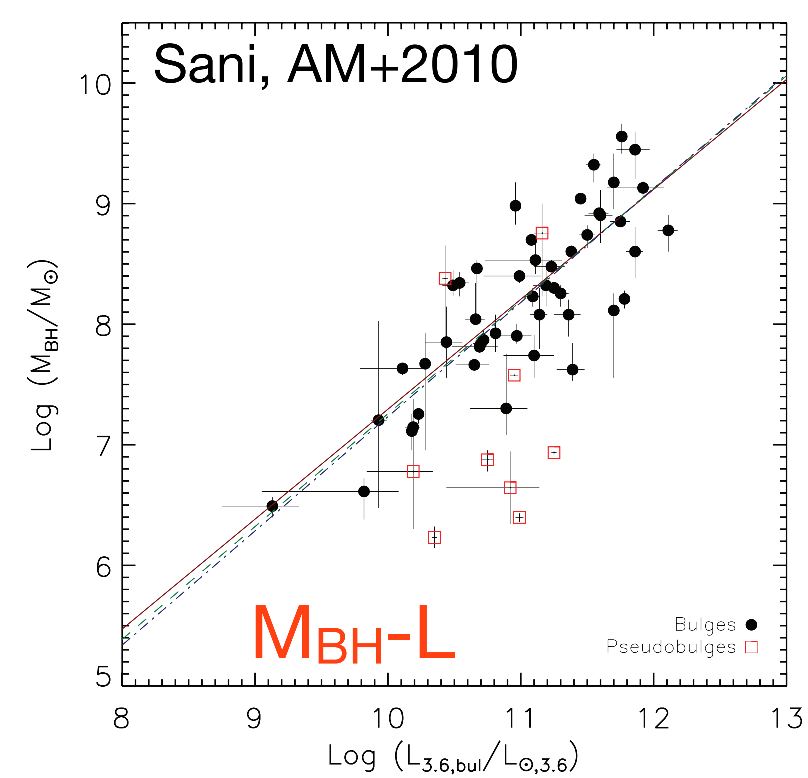


Gultekin+2009



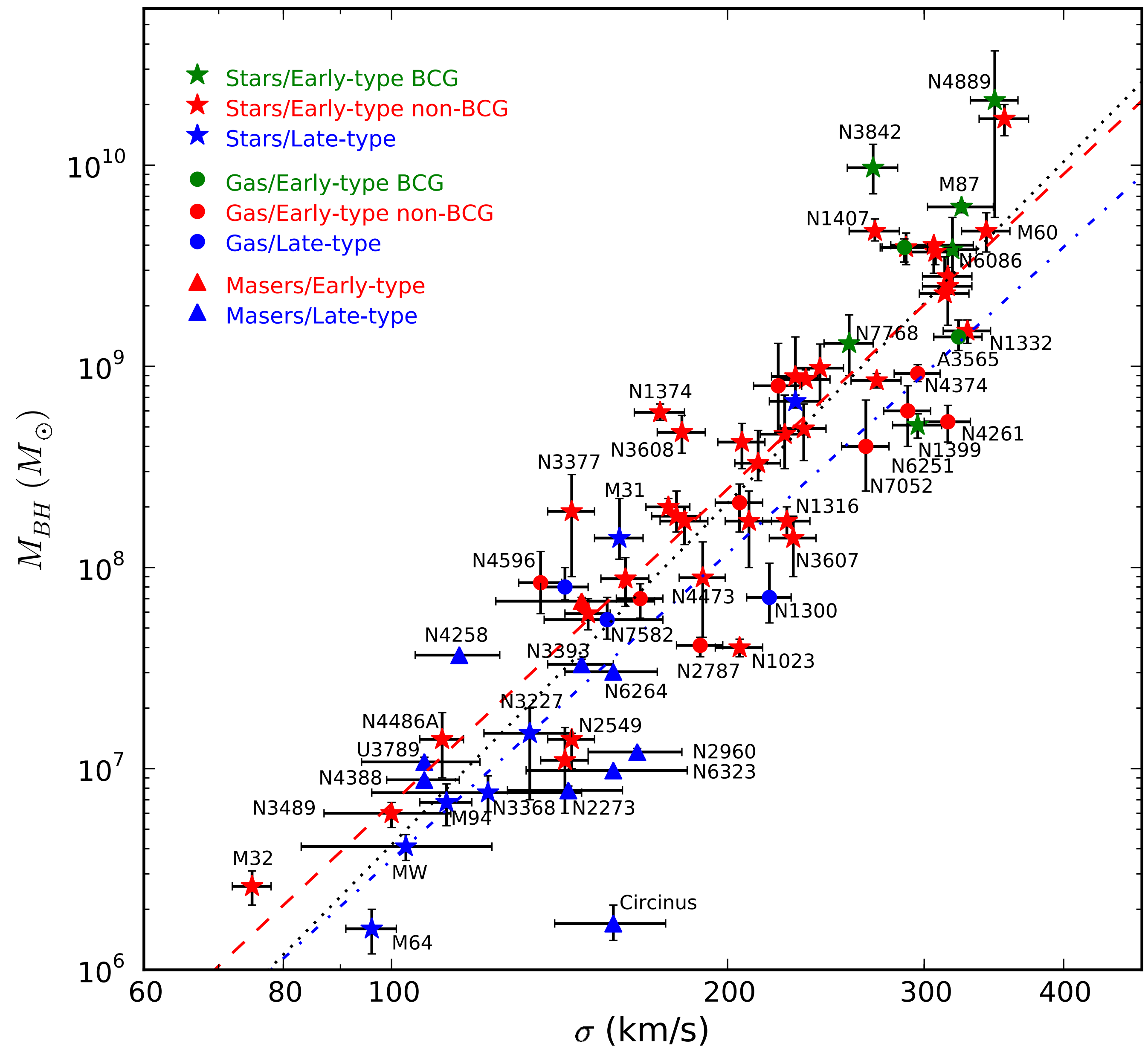
Graham+2010





Relations with host galaxy (III)

- BH gravitational influence over a volume ~10^{-7} that of host galaxy
- How can BH know about galaxy and vice-versa?
- AGN feedback: with massive BH ($M_{BH} > 10^7\ M_\odot$), AGN luminous enough ($L \sim L_{Edd}$) to affect host galaxy
- Gas is expelled quenching both BH accretion and star formation: situation in frozen when $M_{BH}/M_{gal} \sim 10^{-3}$
(but it is not so simple ...)



McConnell+2011

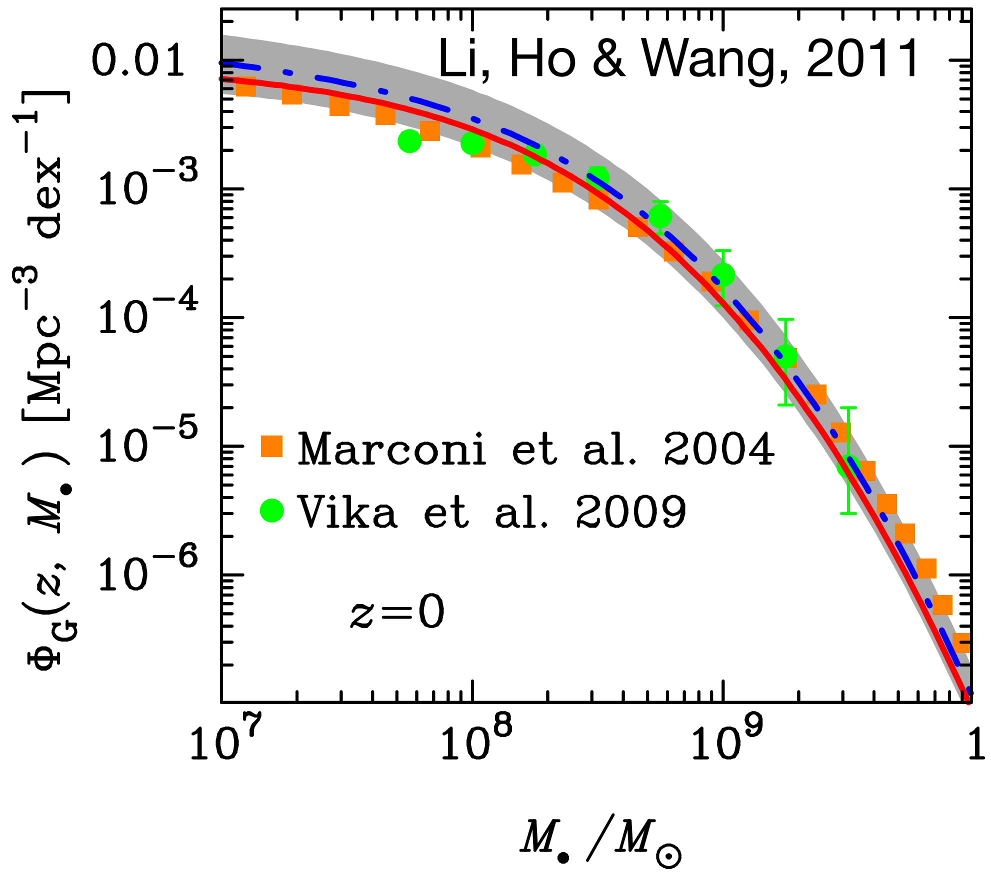
- *Co-evolution of BHs and host galaxies (see, eg, Kormendy & Ho 2013)*

Coevolution of BHs and galaxies

- If all galaxies host a BH and M_{BH}-galaxy relations apply to all galaxy can estimate demography of supermassive BHs in nearby galaxies from galaxy luminosity functions

$\rho_{BH} \simeq 3.5\text{-}5.5 \times 10^5\ M_\odot\ Mpc^{-3}$

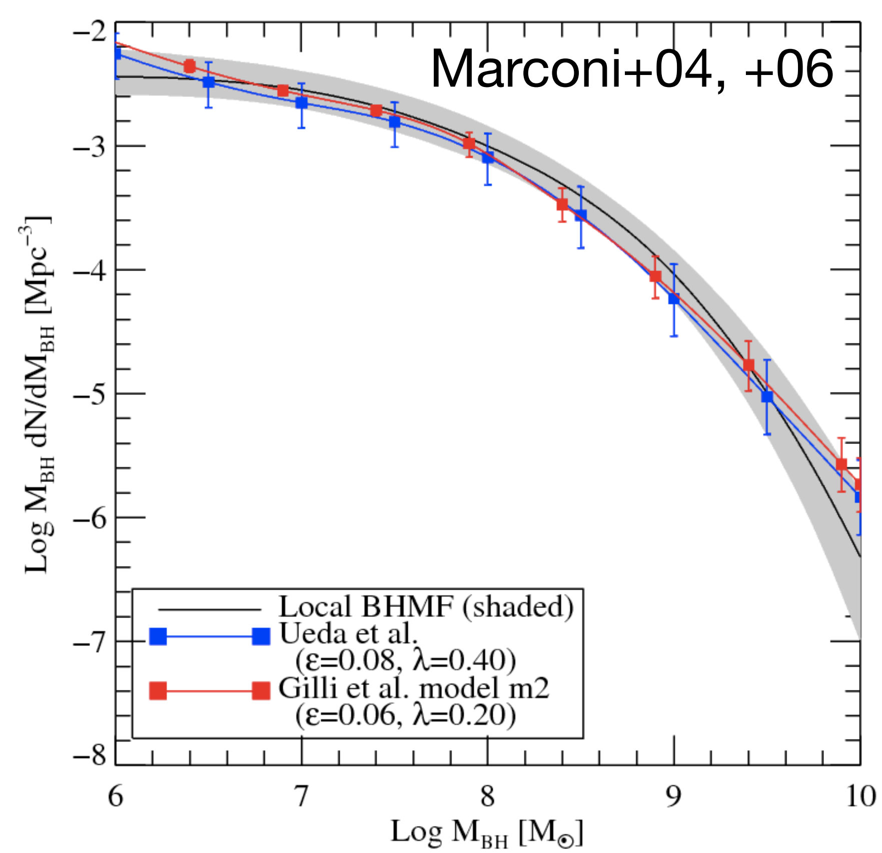
Salucci +99, Yu & Tremaine 02, Marconi +04, Shankar +04, Tamura+06, Tundo +07, Hopkins +07, Graham +07, Shankar +08, Vika+09 et many al.



- If AGN powered from BH accretion can estimate expected BH demography in local universe from past AGN activity (AGN luminosity function) (Sołtan's argument)
- *Successful comparison between local BH mass function and accreted mass function from AGN yelds*

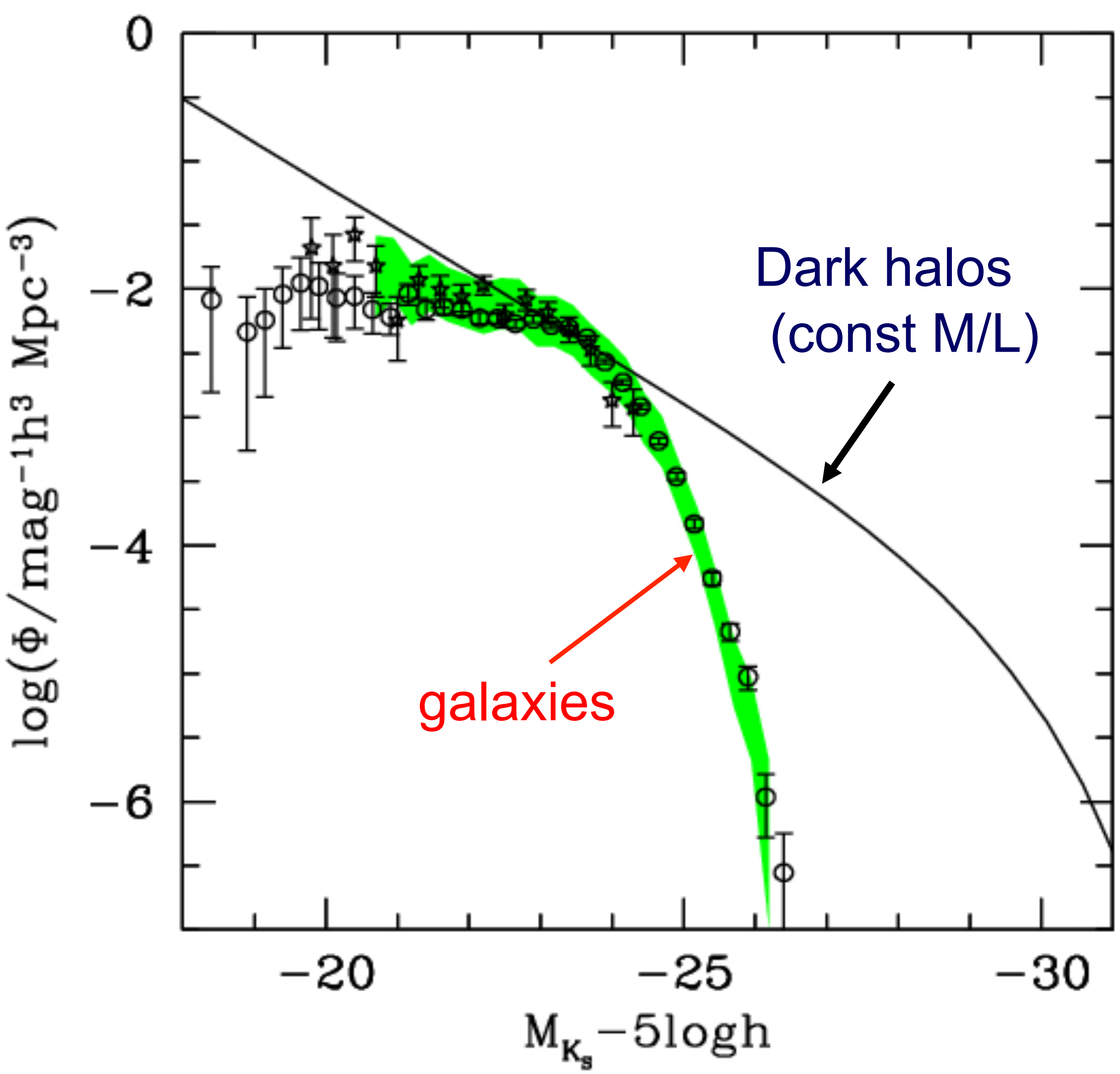
$L/L_{Edd} \sim 1$ and $\varepsilon \sim 0.1$

Yu & Tremaine 02, Marconi +04, Shankar+04, Merloni 04, Shankar +08, Merloni & Heinz 2009, Cao 10, Shankar+12, et many al.



AGN Feedback

- Feedback from accreting BHs can explain BH-galaxy relation but also can solve issue of “missing” high mass galaxies.



(Courtesy of C. Lacey)

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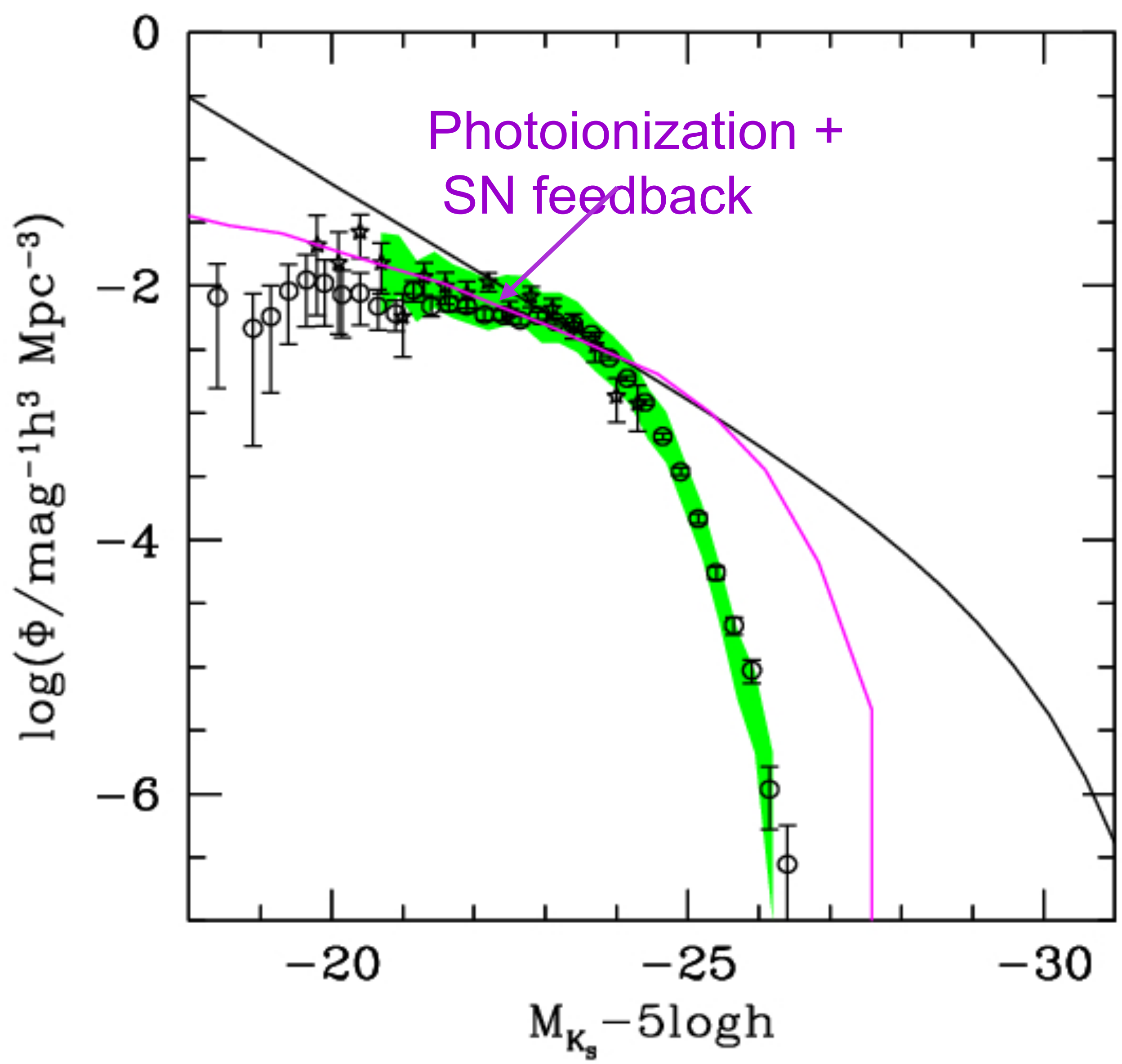

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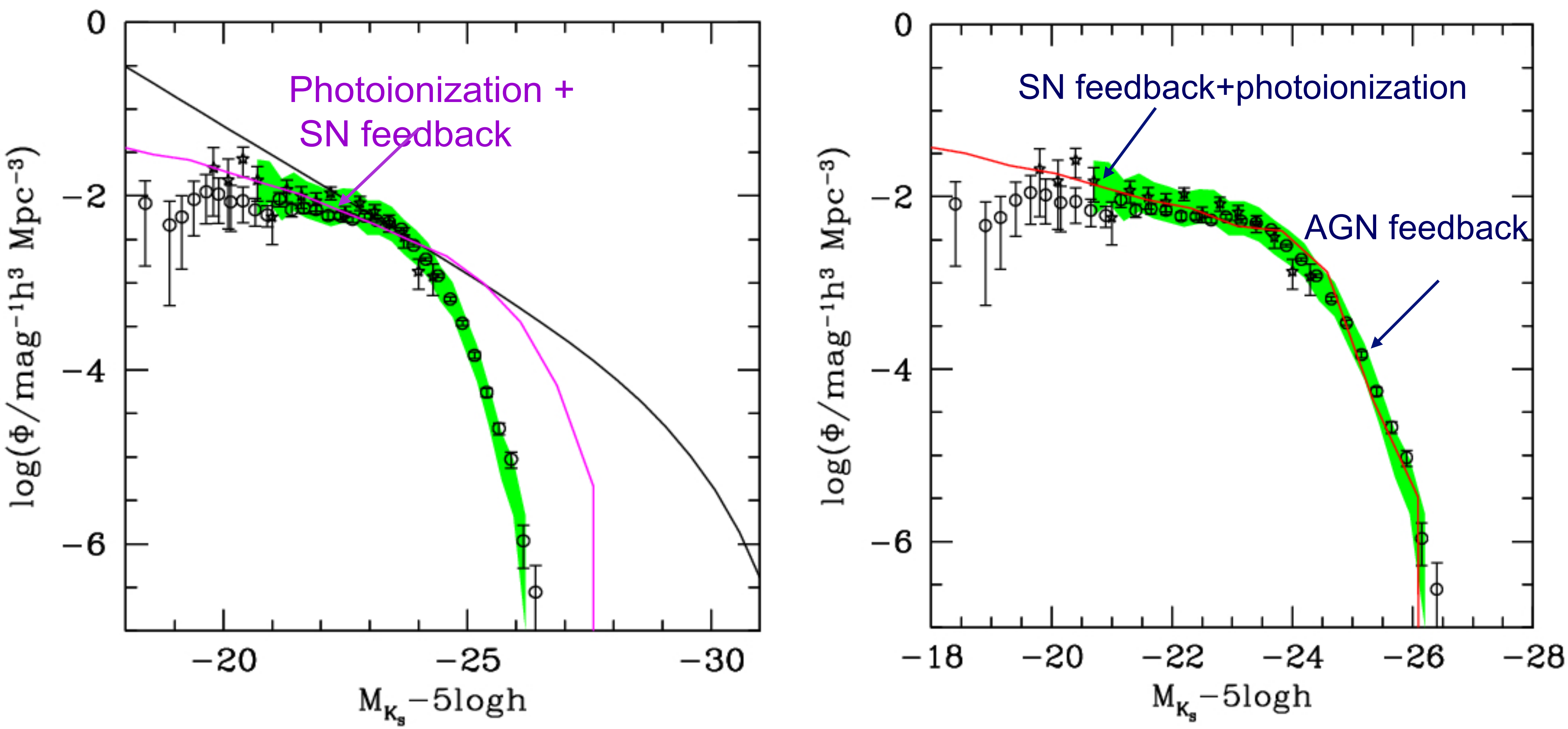
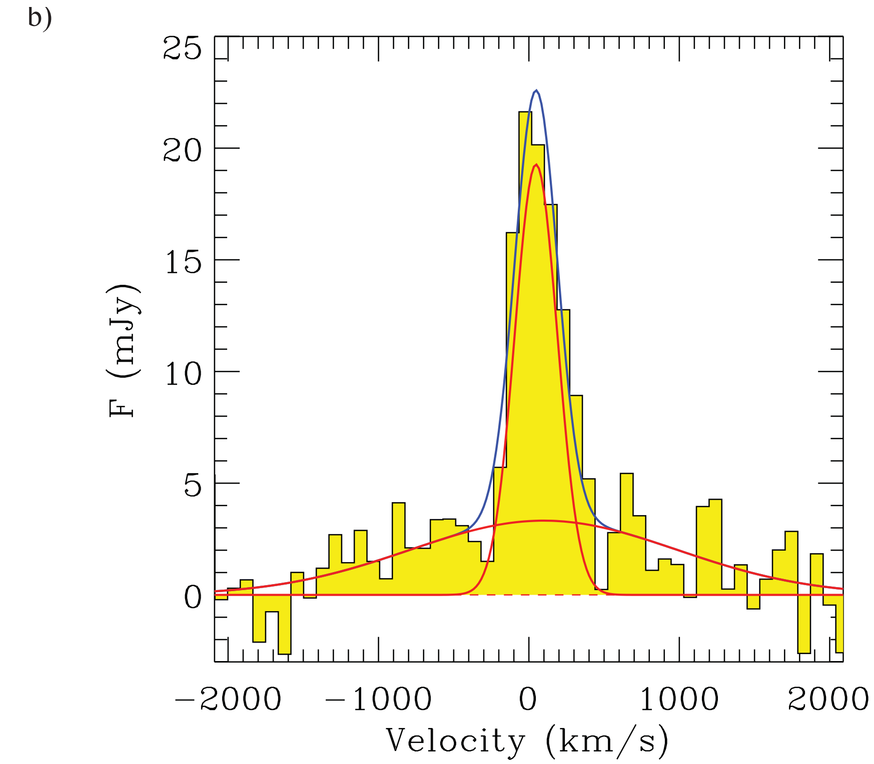


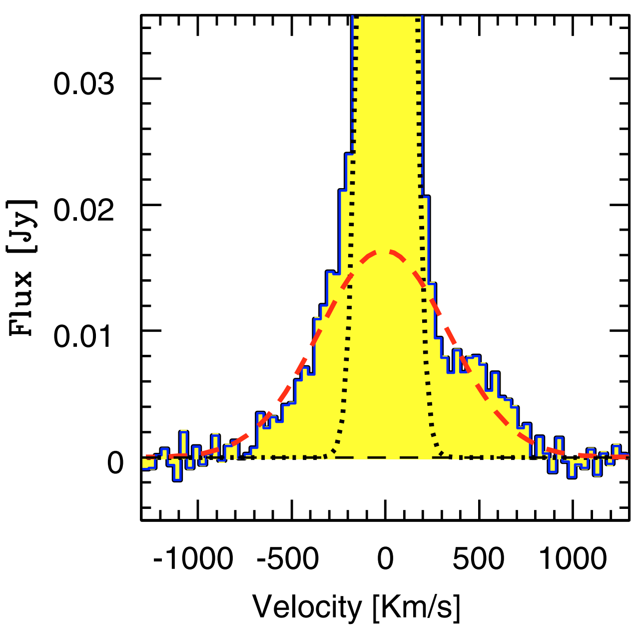
(Courtesy of C. Lacey)

AGN Feedback

- Feedback is starting to be observed in galaxies in the form of hot bubbles or outflows driven by an AGN
- molecular OH line with Herschel or CO (1-0) line
  - terminal velocities of *molecular gas* up to ~1000 km/s
  - outflow rates up to ~1000 $M_\odot$/yr, several time the SFR (~200 $M_\odot$/yr)
  - cold reservoir of gas in ULIRGs can be expelled in ~10^6-10^8 yr
  - energy of outflow is ~few % of L_{AGN}

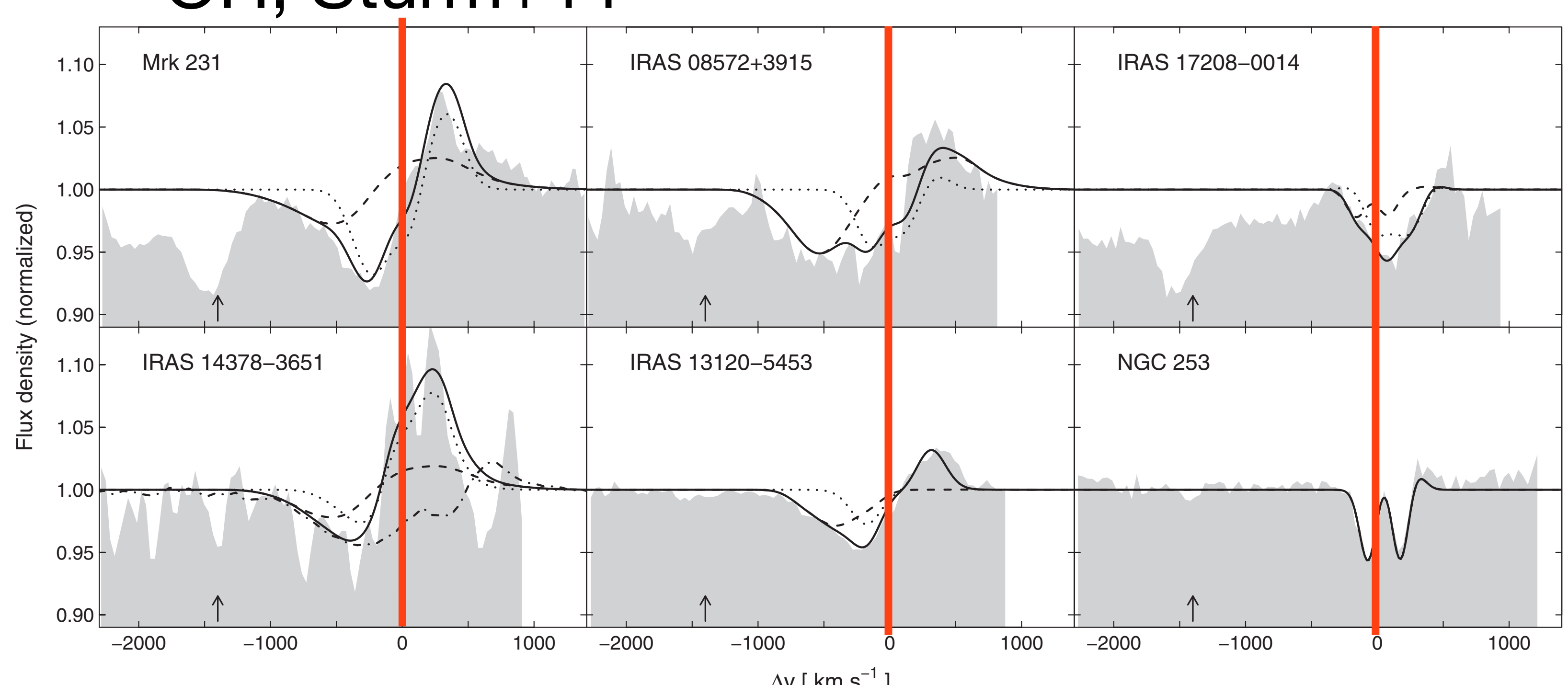


Maiolino+12 ([CII] 158 μm at z~6.4 obs. in submm)



CO, Feruglio+11

OH, Sturm+11



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Selected open questions

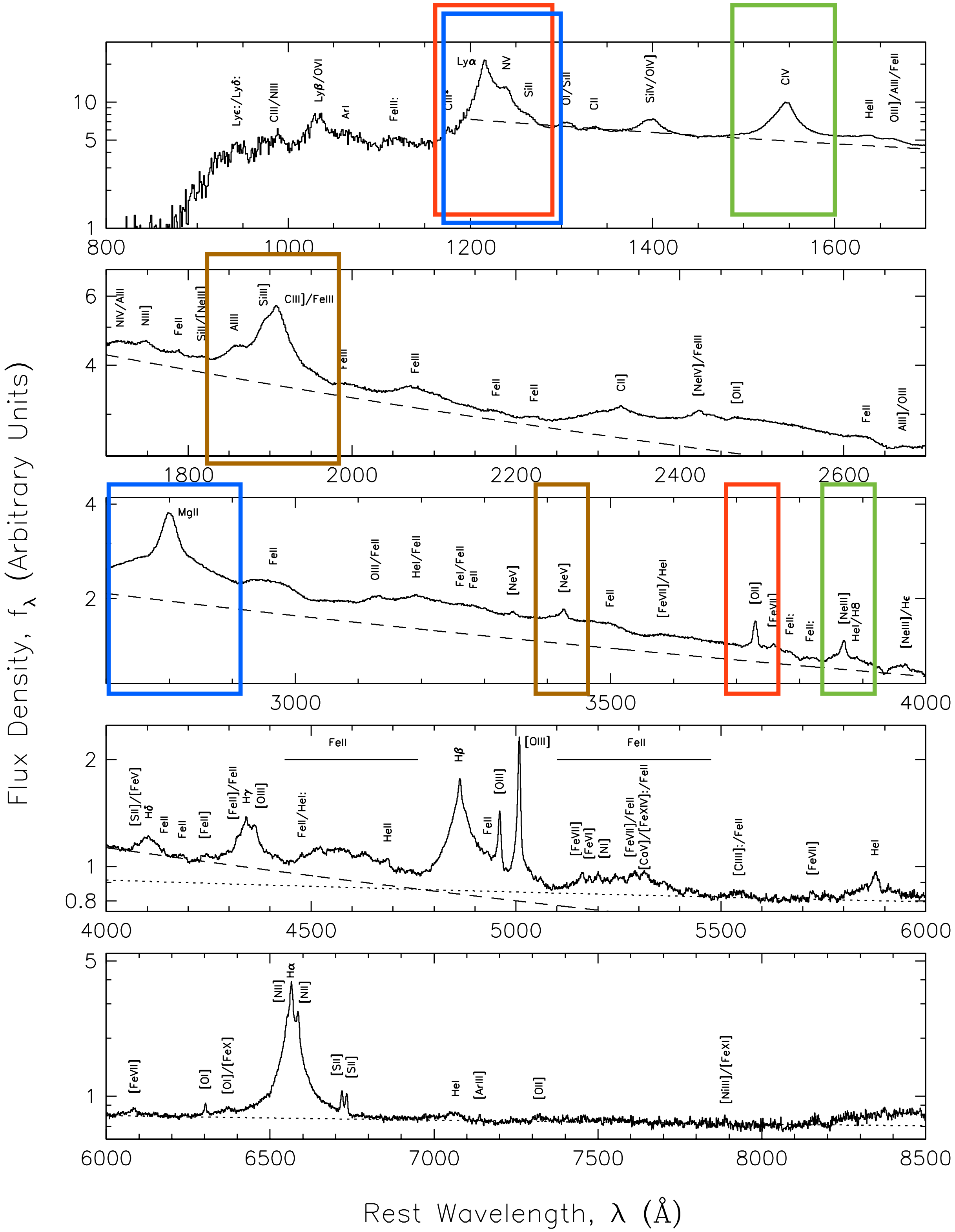
- How can we trace the cosmological growth of BHs?
  - importance of measuring BH masses at all redshifts; we can only use virial masses in type 1 AGN (with broad lines)
  - what is the origin of BLR, disk, wind or both?
  - what is the best estimator, Hβ, MgII, CIV? can high resolution help in disentangling narrow components & absorption lines affecting line widths measures?

- What is the relation between SF and AGN activity?

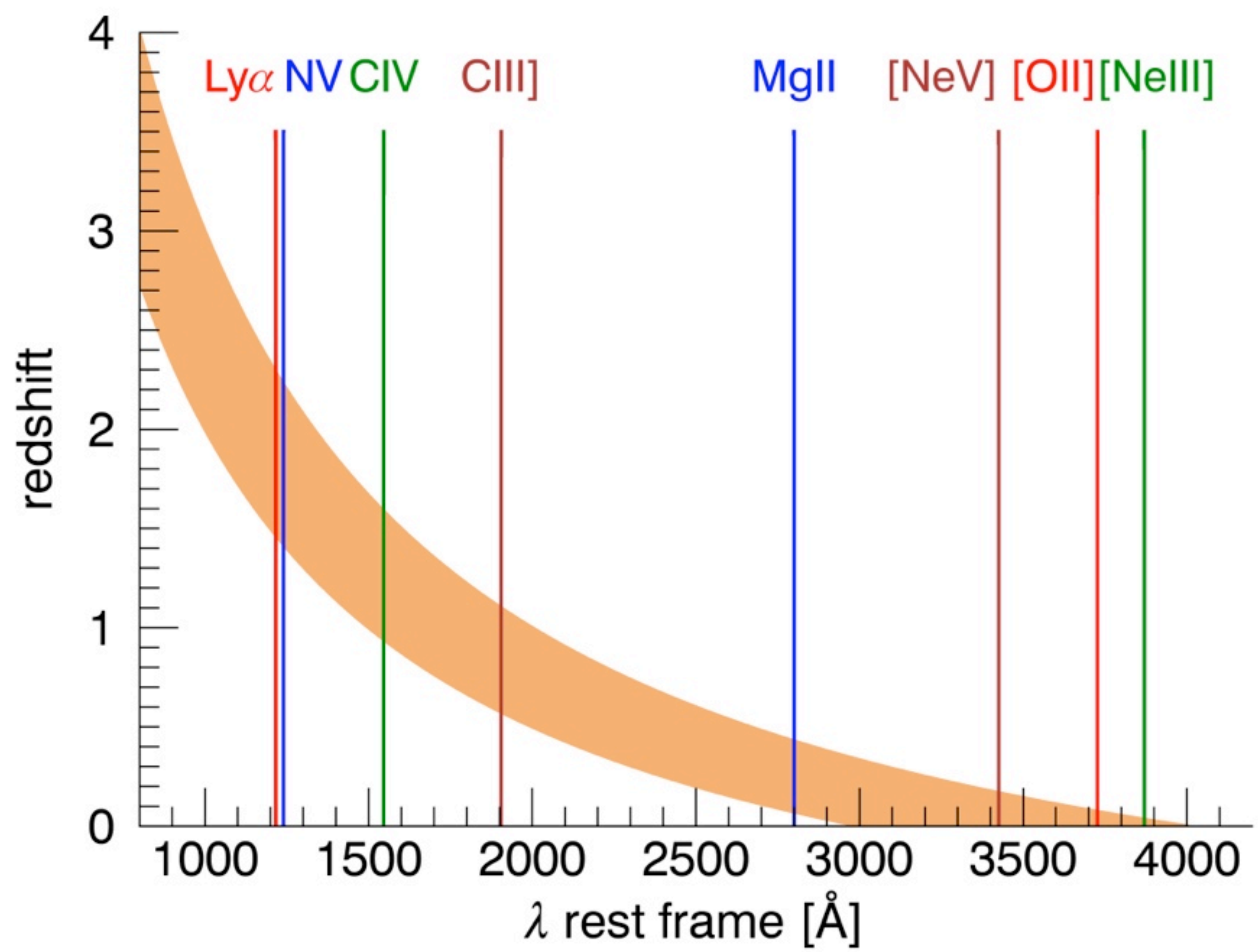
- Is it possible to trace fossils of SF in AGN?
  - what are the Metallicities of BLR and NLR?

- Is there AGN feedback? Can observed outflows account for it?
  - What can we learn from outflows in AGN host galaxies observing broad and narrow absorption lines?

CUBES spectral range



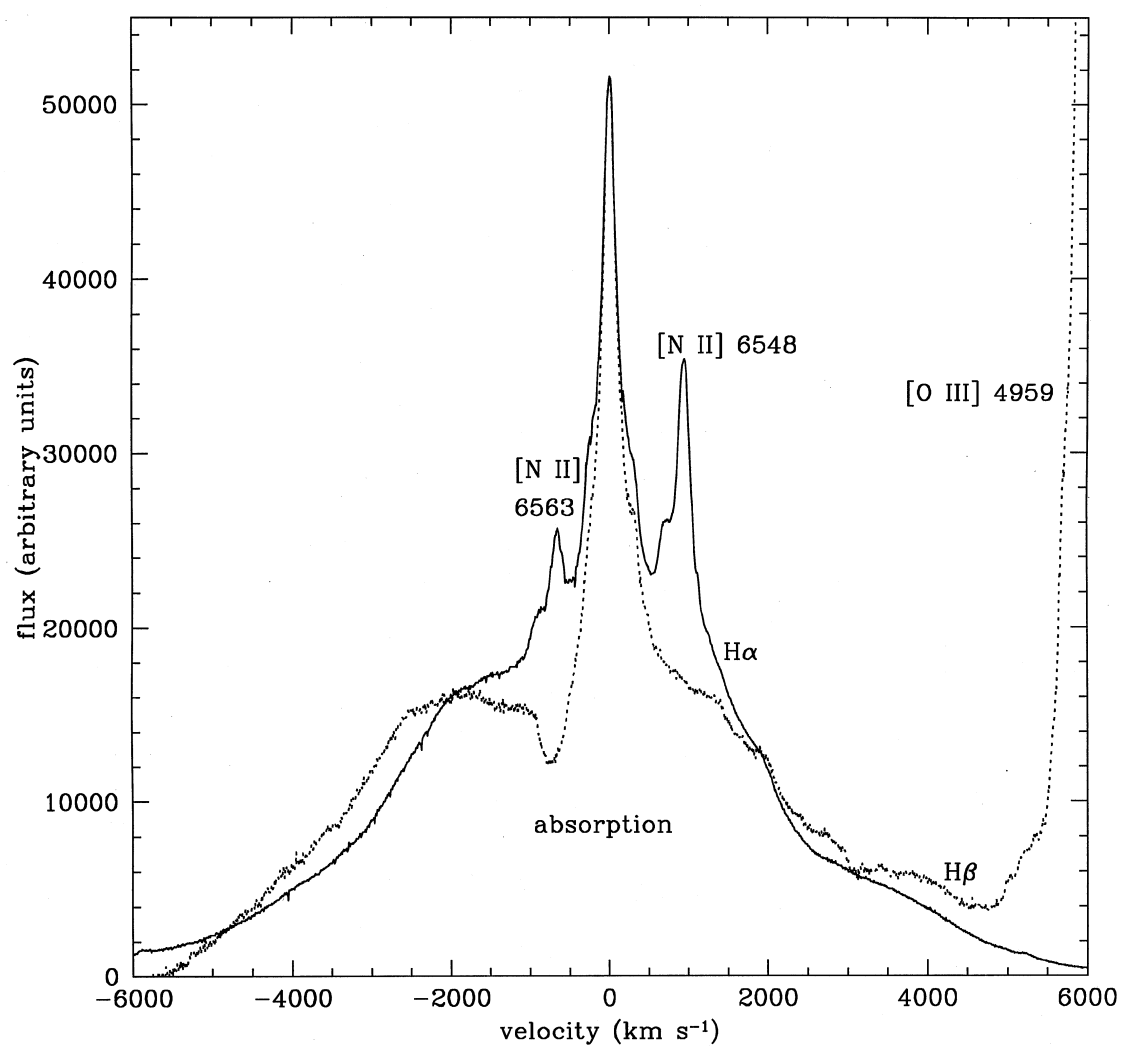
Vanden Berk+2001



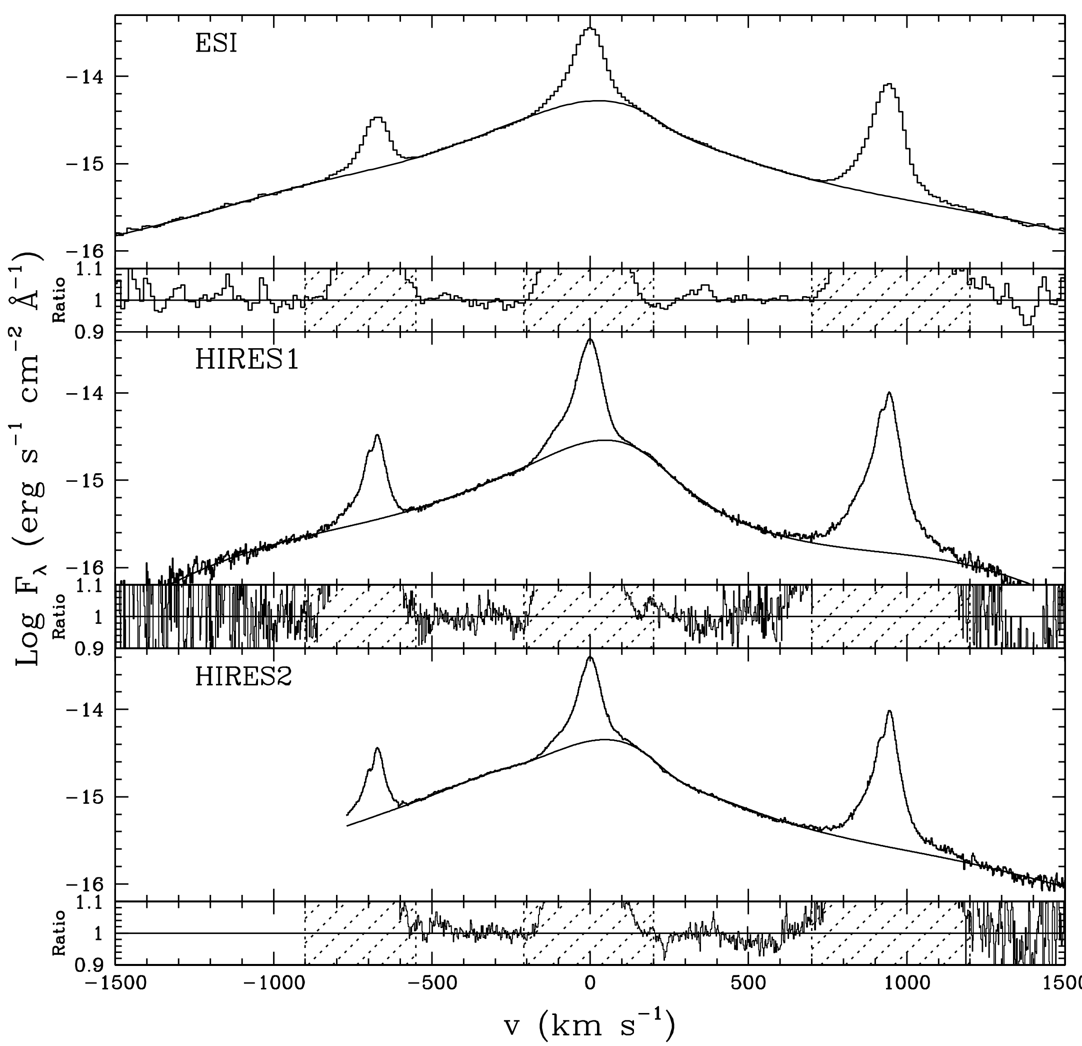
Permitted broad lines
→ BLR (BH scales)
Permitted & forbidden narrow lines
→ NLR (galactic scales)
Both in emission & absorption

Origin of BLR

- Continuous (wind) or clumpy medium (disk)?
- Smoothness of observed Hβ profiles suggests smooth medium (wind?) instead of clumpy one (disk?).
- Only a handful of sources observed so far but were the right sources and right emission lines observed?
- Compare CIV (wind?) vs Hβ (wind+disk?) vs MgII (disk?)



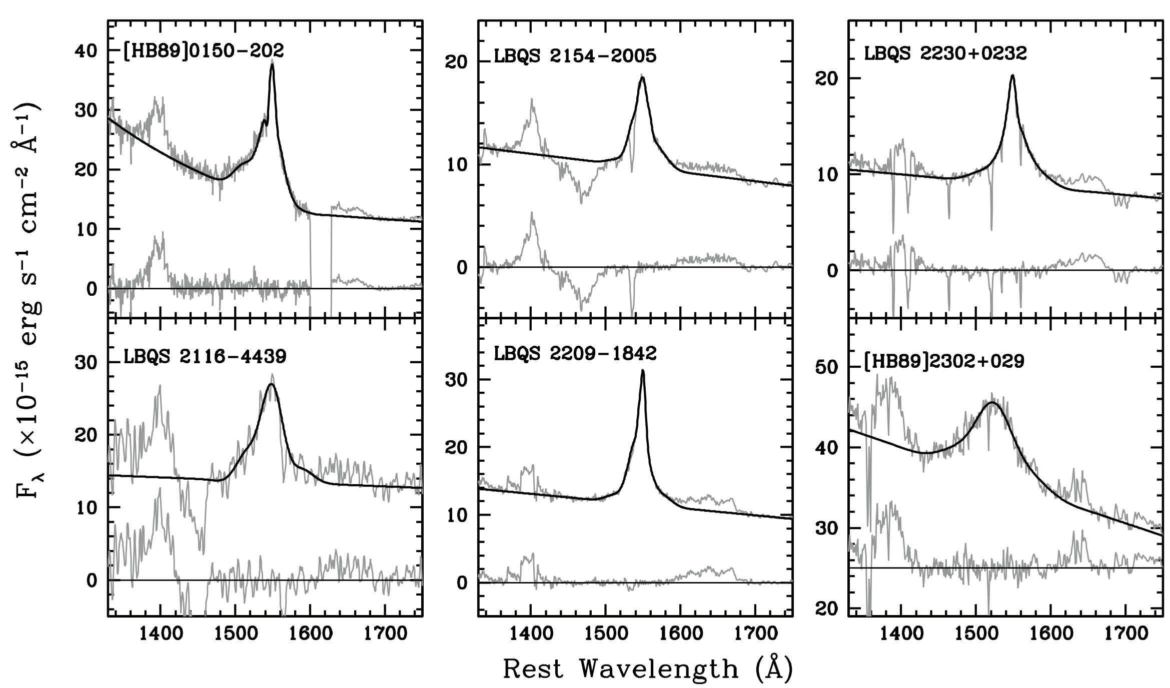
R~50000, Arav+1998



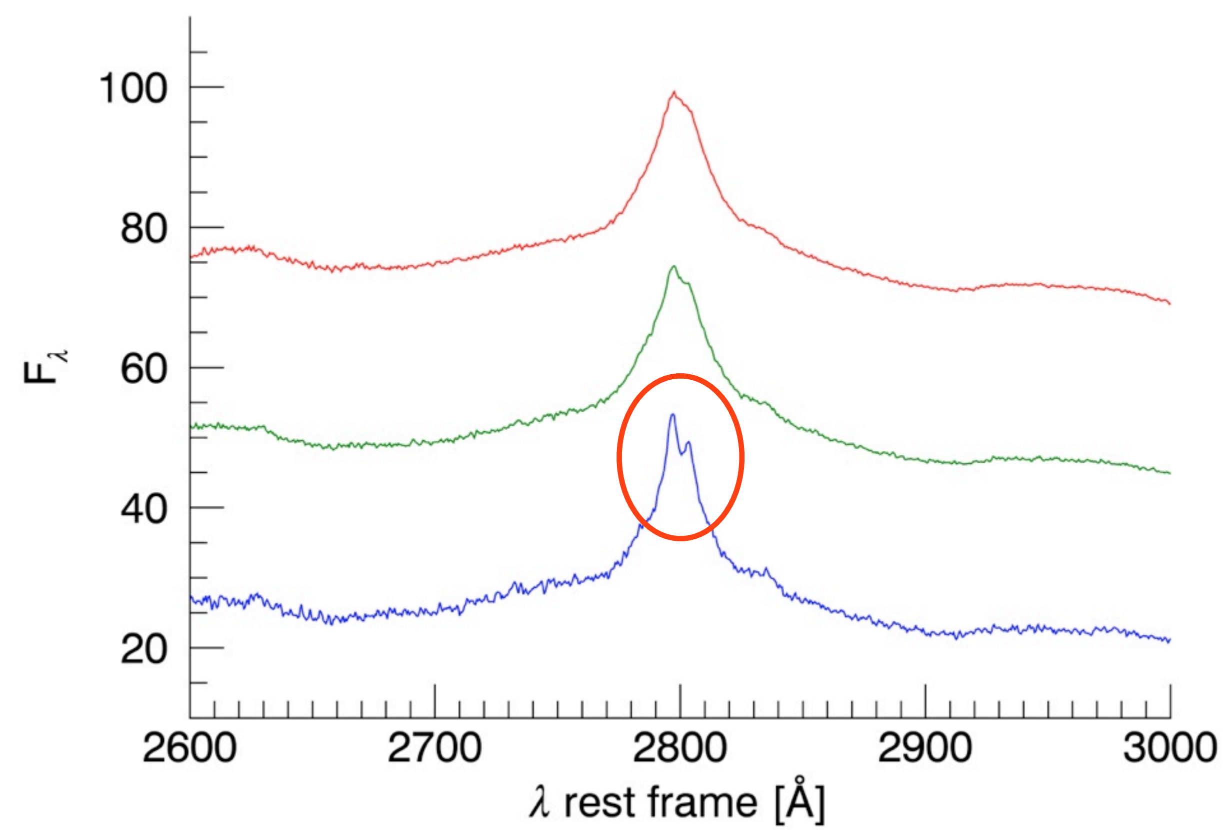
R~40000, Laor+2006

Virial BH masses

- BH masses usually estimated from Hβ, MgII and CIV
- Hβ and MgII believed to be better estimators (virialized), CIV believed to be bad estimator
- But CIV usually measured from low S/N spectra, possibly affected by absorption lines; also there is evidence for an intermediate/low velocity component which strongly FWHM estimates (Denney 2013a, 2013b)
- Can high resolution spectroscopy help in disentangling narrow from broad components?
- See also previous spectra ...



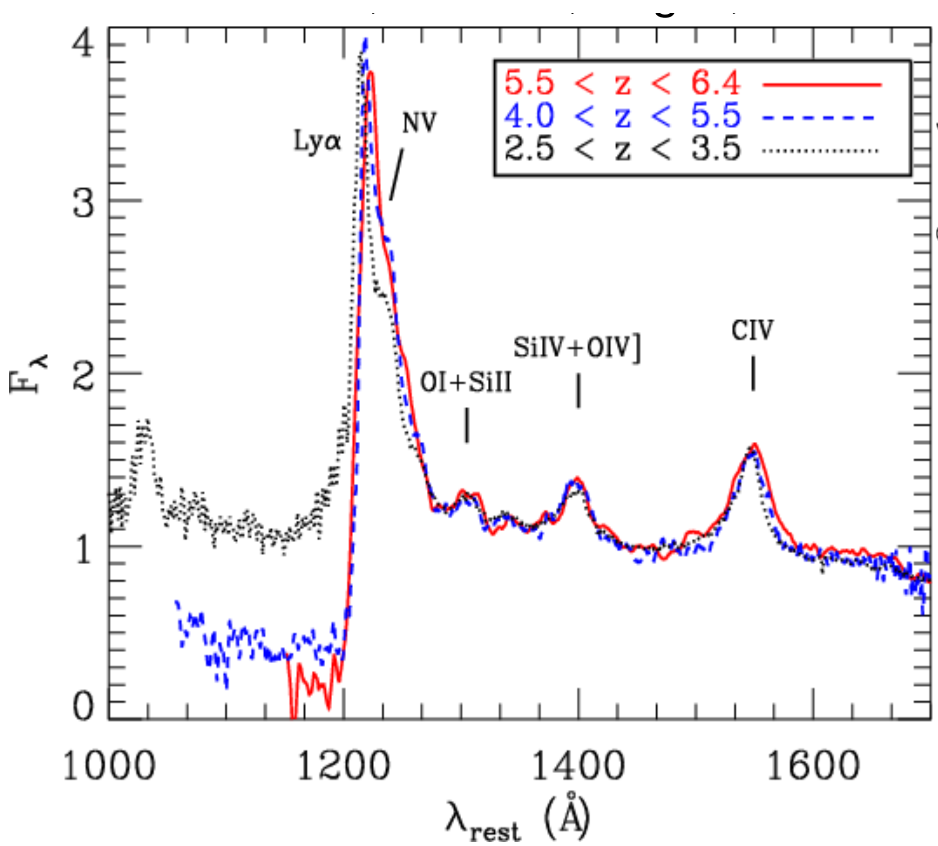
Denney 2013



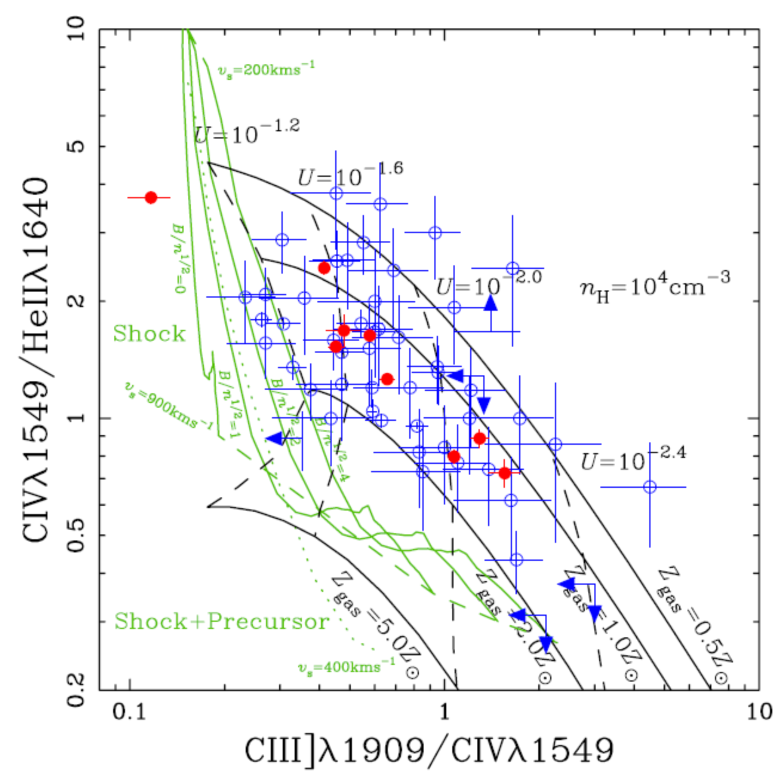
R~2000, Bisogni, AM+2014

BLR Metallicities vs Host Galaxy

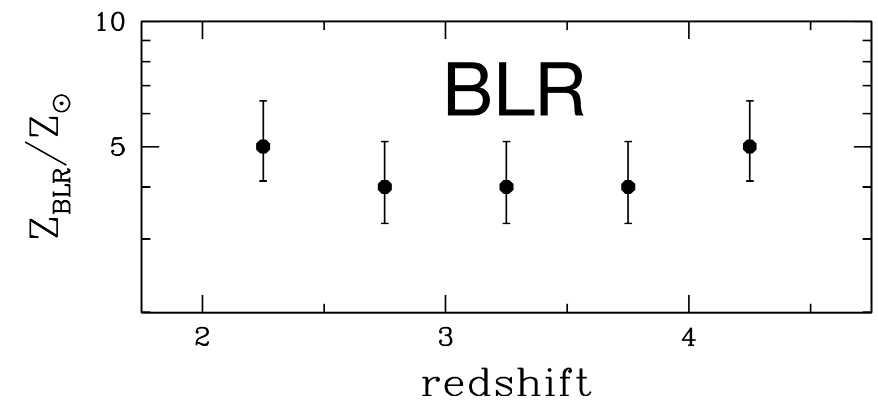
- Metallicity traces *integrated* star formation
- Attempts at measuring metallicities from broad lines; easy to measure up to high redshifts but *tiny* masses of gas probably non representative of the whole galaxy
- High resolution spectroscopy could allow to measure metallicities of narrow lines (galaxy wide) and compare with BLR (crucial to disentangle narrow and broad components)



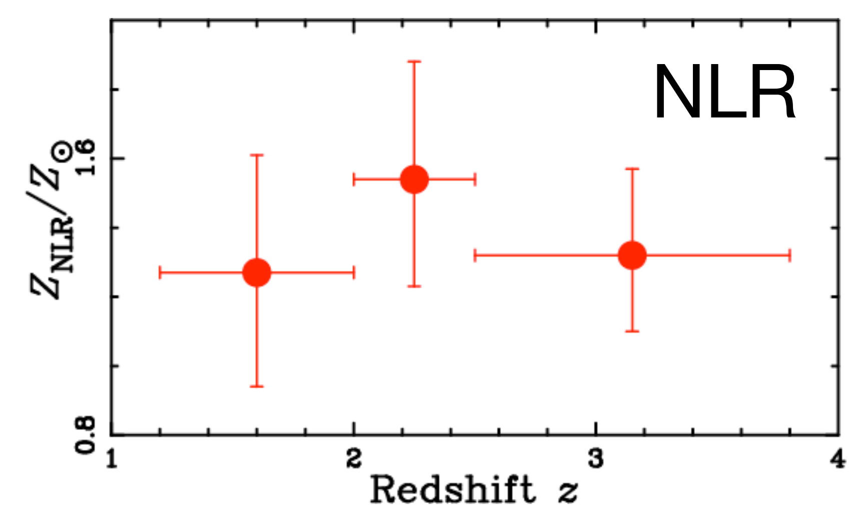
Similarity of BLR at all redshifts; Juarez+09



NLR Metallicity diagnostics (in radio galaxies); Matsuoka+09



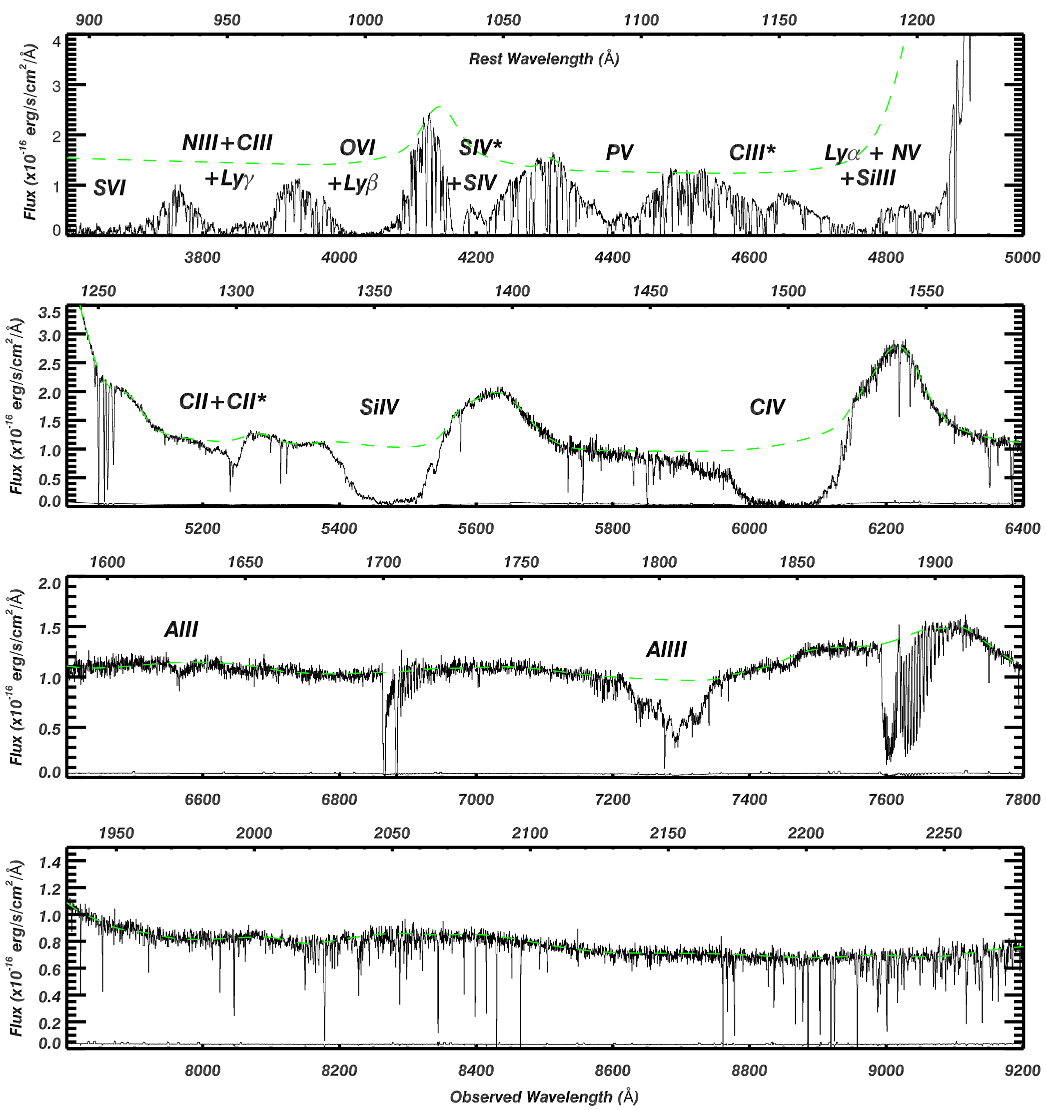
Nagao+06



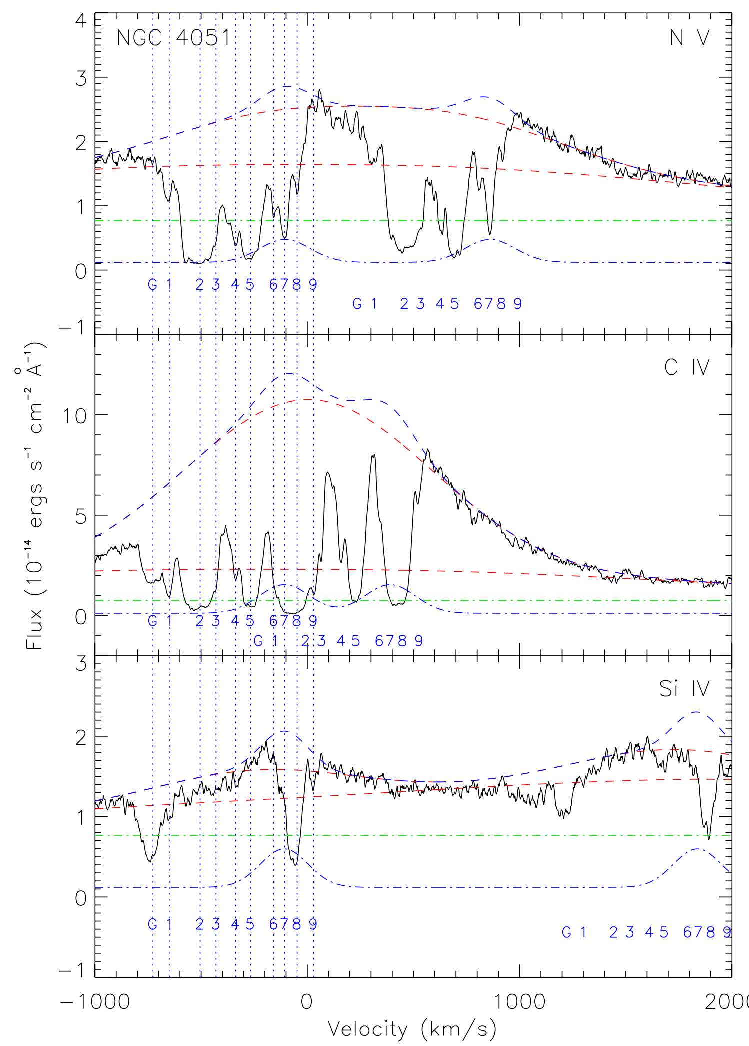
Matsuoka+09

Outflows & feedback

- Signatures of outflowing absorbers are common in AGN UV spectra
  - both broad (BAL) and narrow absorption lines trace gas on scales of 0.1-1000 pc
  - outflow rates can be 10-1000 times larger than accretion rates
  - kinetic luminosities ~few % of bolometric luminosity
  - can provide significant feedback in AGN



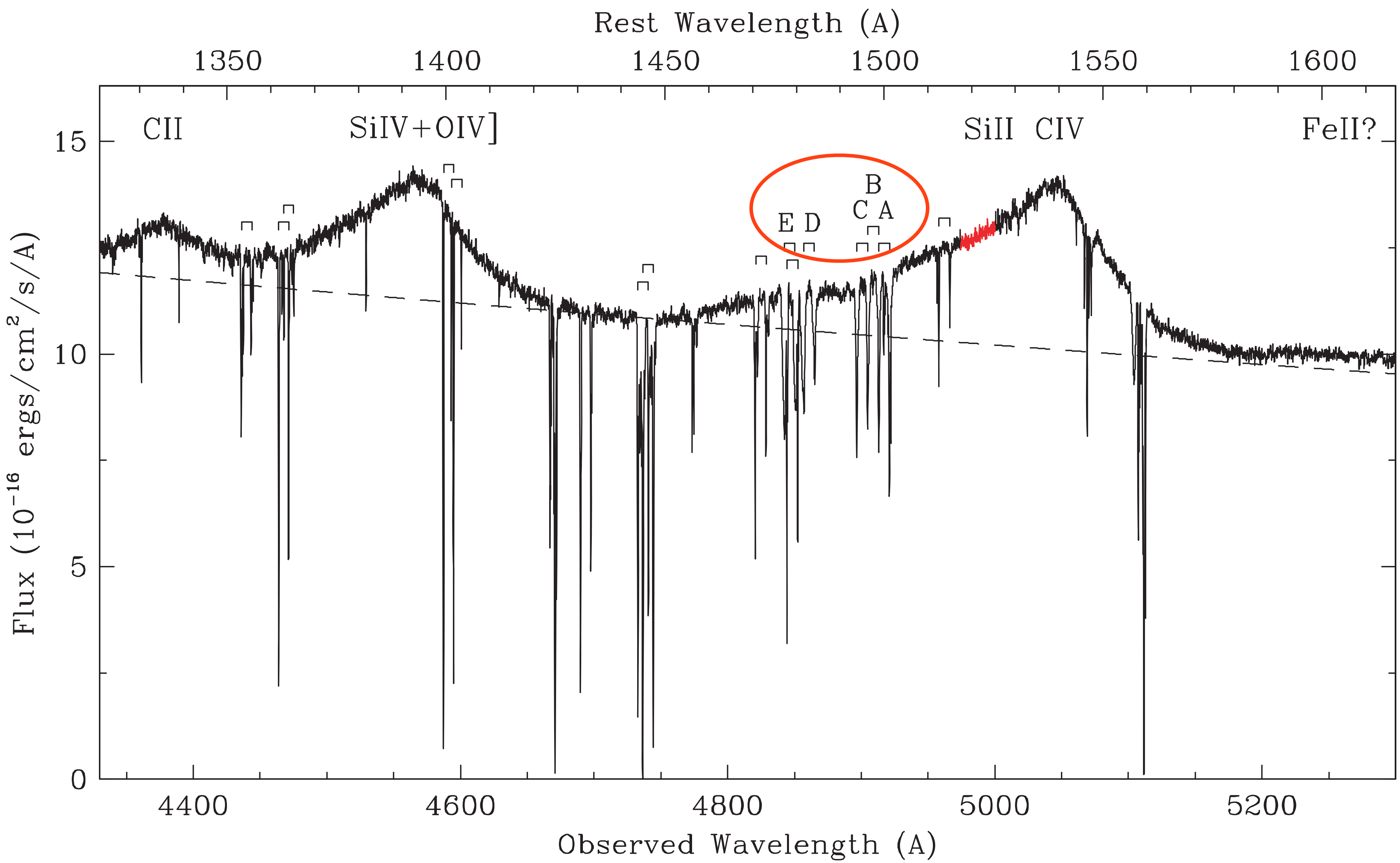
X-Shooter observations of BAL QSO; Borguet+13



COS spectra of NGC4051 (Sy1) R~16000; Kraemer+12

Outflows & feedback

- High velocity narrow absorption lines outflows in UV quasar spectra (eg Hamann+11); also useful to measure metallicities (~2 solar in this case).



Keck spectrum with R~100000; Hamann+11

Conclusions

- AGN (accreting BHs) are fundamental ingredients for galaxy evolution
- Current view: co-evolution of BHs and their host galaxies
- High resolution UV spectroscopy can in principle allow to:
  - probe the BLR structure and measure virial BH masses
  - estimate metallicities from broad and narrow lines
  - probe outflows and feedback from BLR to galactic scales