Science Drivers for Studies of Active Galactic Nuclei

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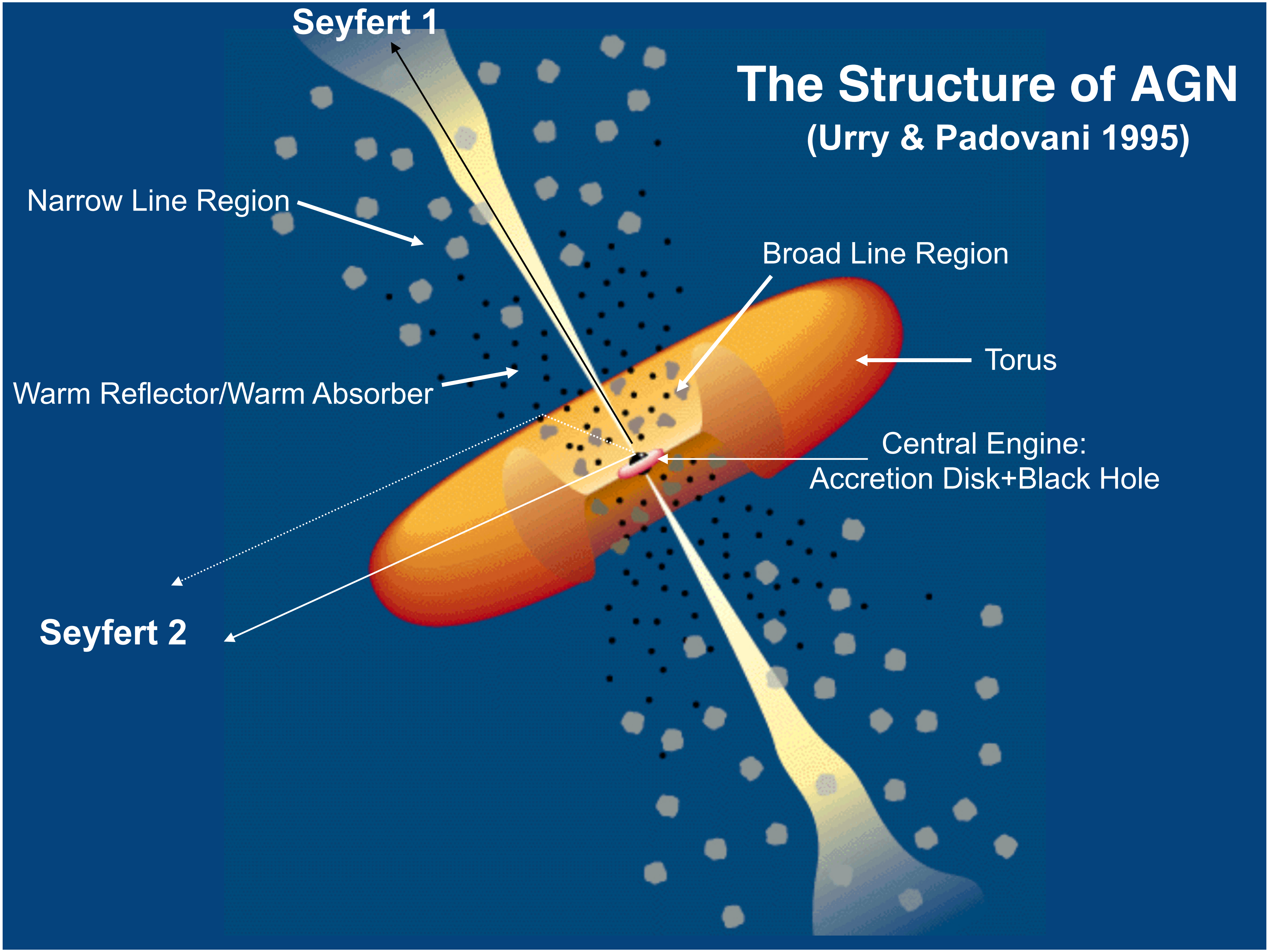
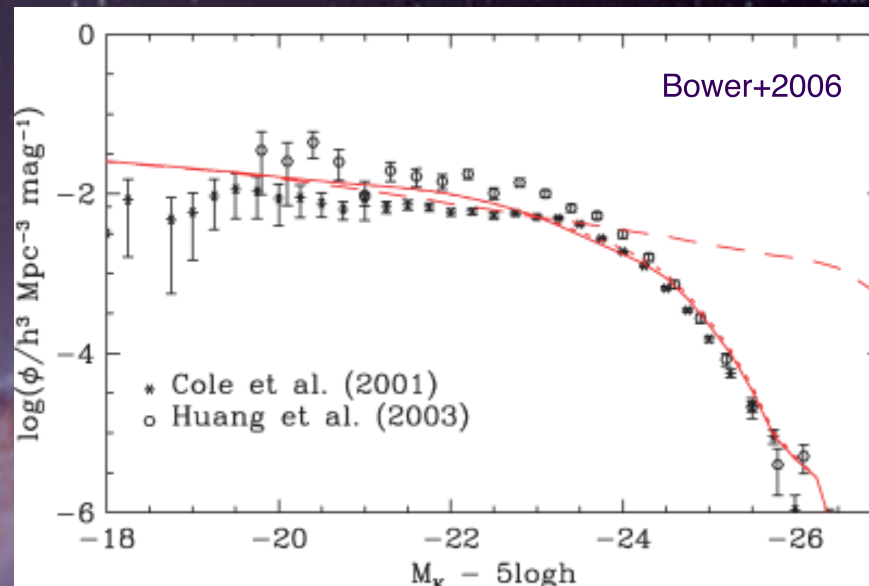
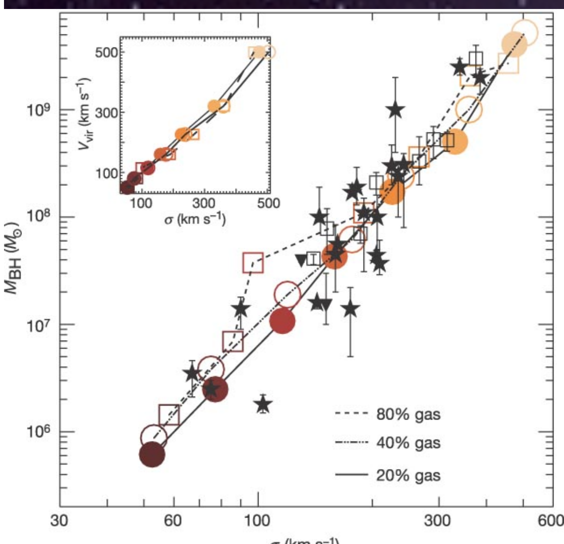

The Structure of AGN
(Urry & Padovani 1995)
Seyfert 1
Narrow Line Region
Broad Line Region
Torus
Warm Reflector/Warm Absorber
Central Engine:
Accretion Disk+Black Hole
Seyfert 2

Galaxy Evolution, AGN and Feedback

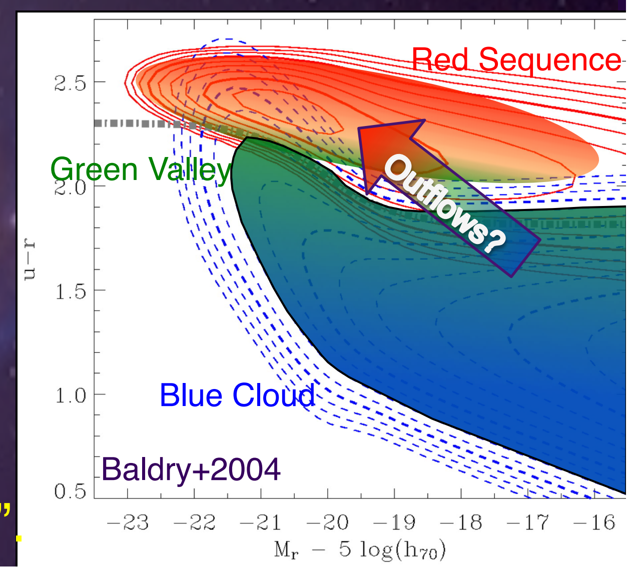
★ Downsizing: AGN feedback limits galaxy growth.



DiMatteo+2005



★ M_{BH}-σ : Feedback couples black hole growth to galaxy growth, leading to the correlation.



★ Color Evolution: Outflows can help AGN move from the “Blue Cloud” across the “Green Valley” and onto the “Red Sequence”.


The Black Hole

Black Holes in AGN

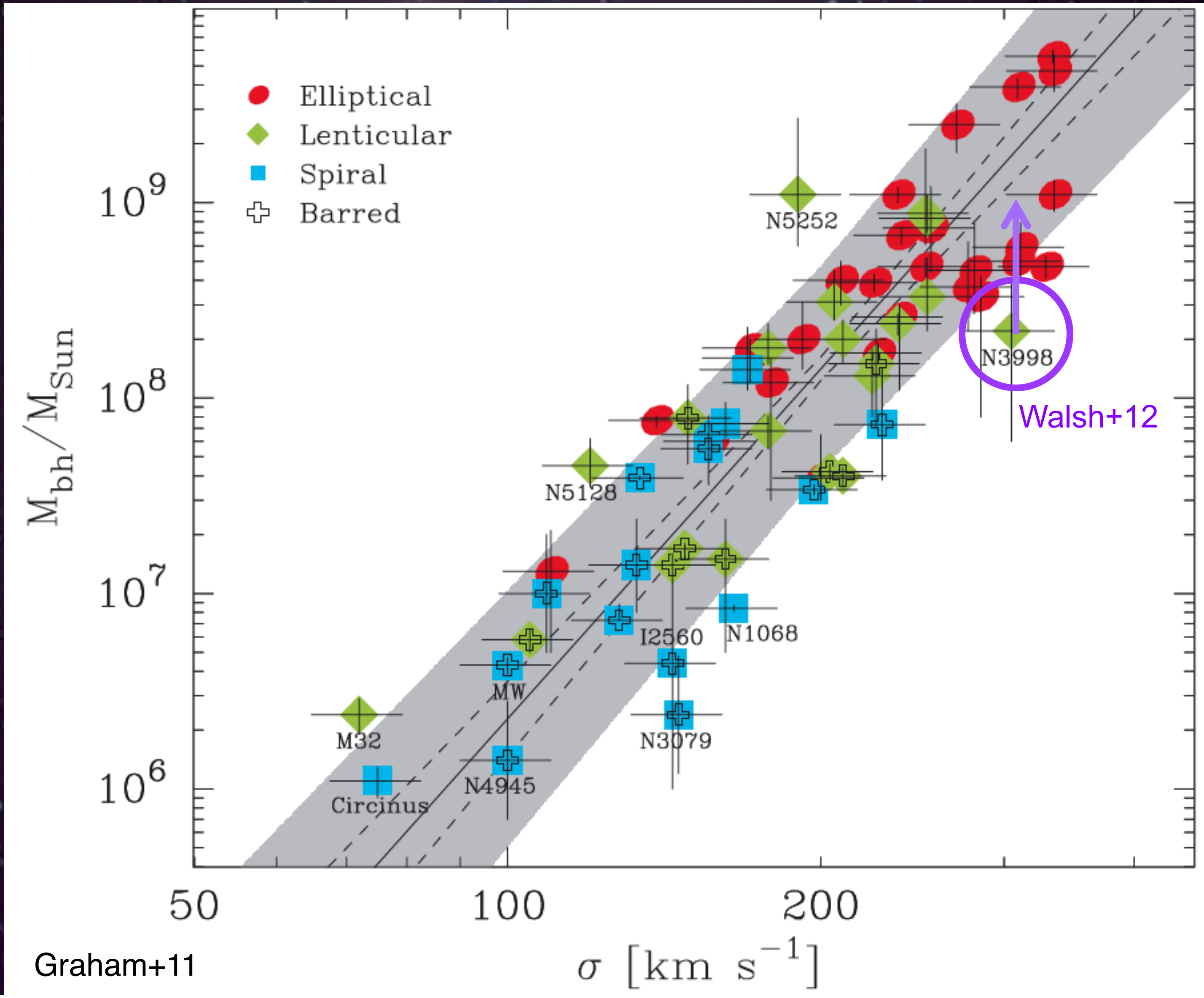
- ★ **Black hole masses in galaxies are correlated with the host galaxy's mass and luminosity [Magorrian+98; Ferrarese+00; Gebhart+00].**

- ★ **It is now routine to dynamically determine black hole masses.**

- ★ **Focus of current work is on:**
  - Understanding the extremes in the M_{BH} vs. σ relation
  - Comparing dynamical masses for different methods:
    - Emission-line gas disks
    - Stellar dynamics
    - Reverberation mapping (in AGN)

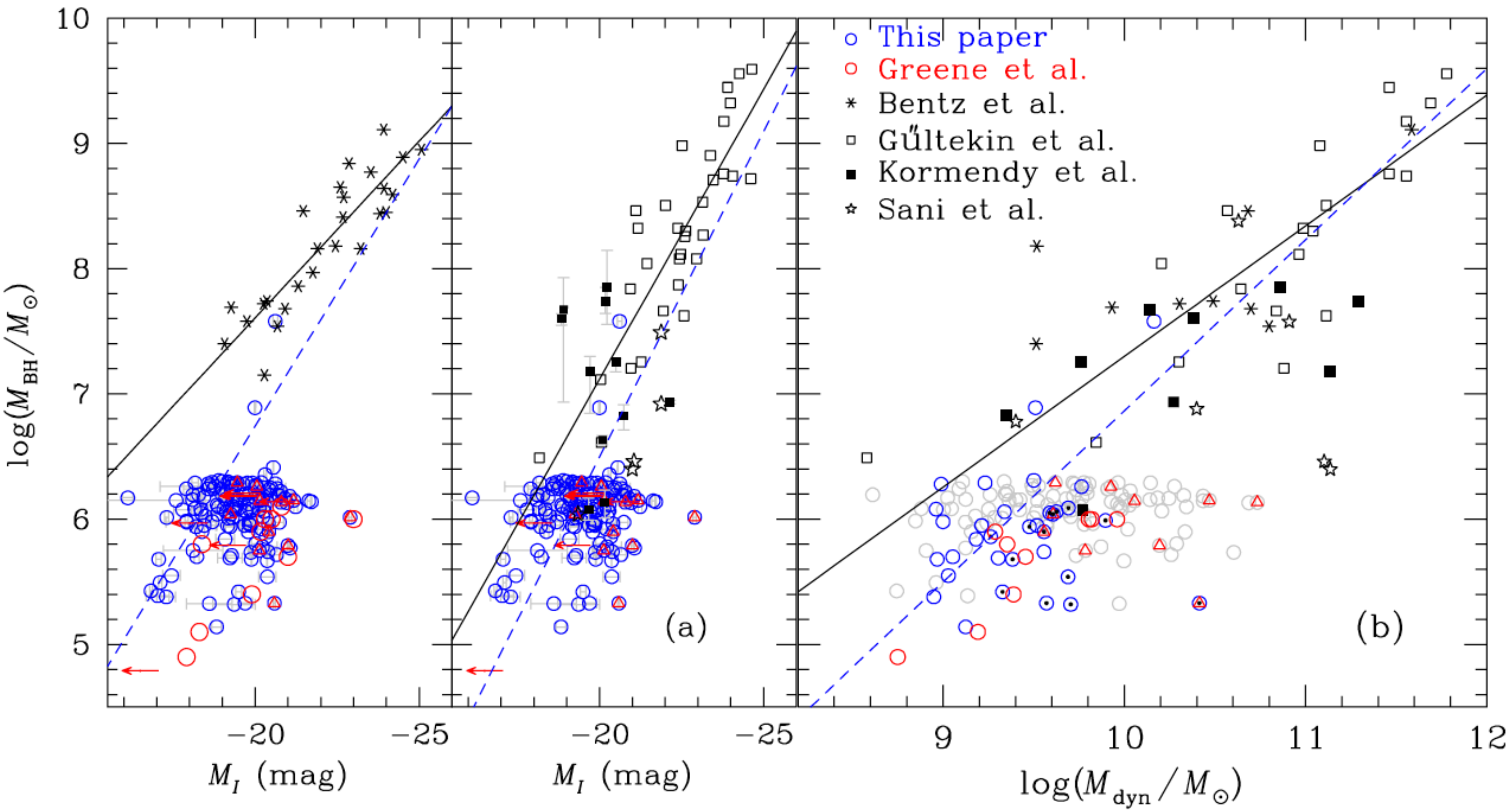
- ★ **Scaling laws for M_{BH} based on emission line widths (anchored by reverberation-mapping results) (e.g. Vestergaard & Peterson 2006) allow demographic studies.**

Black-Hole Mass vs. σ: High Masses



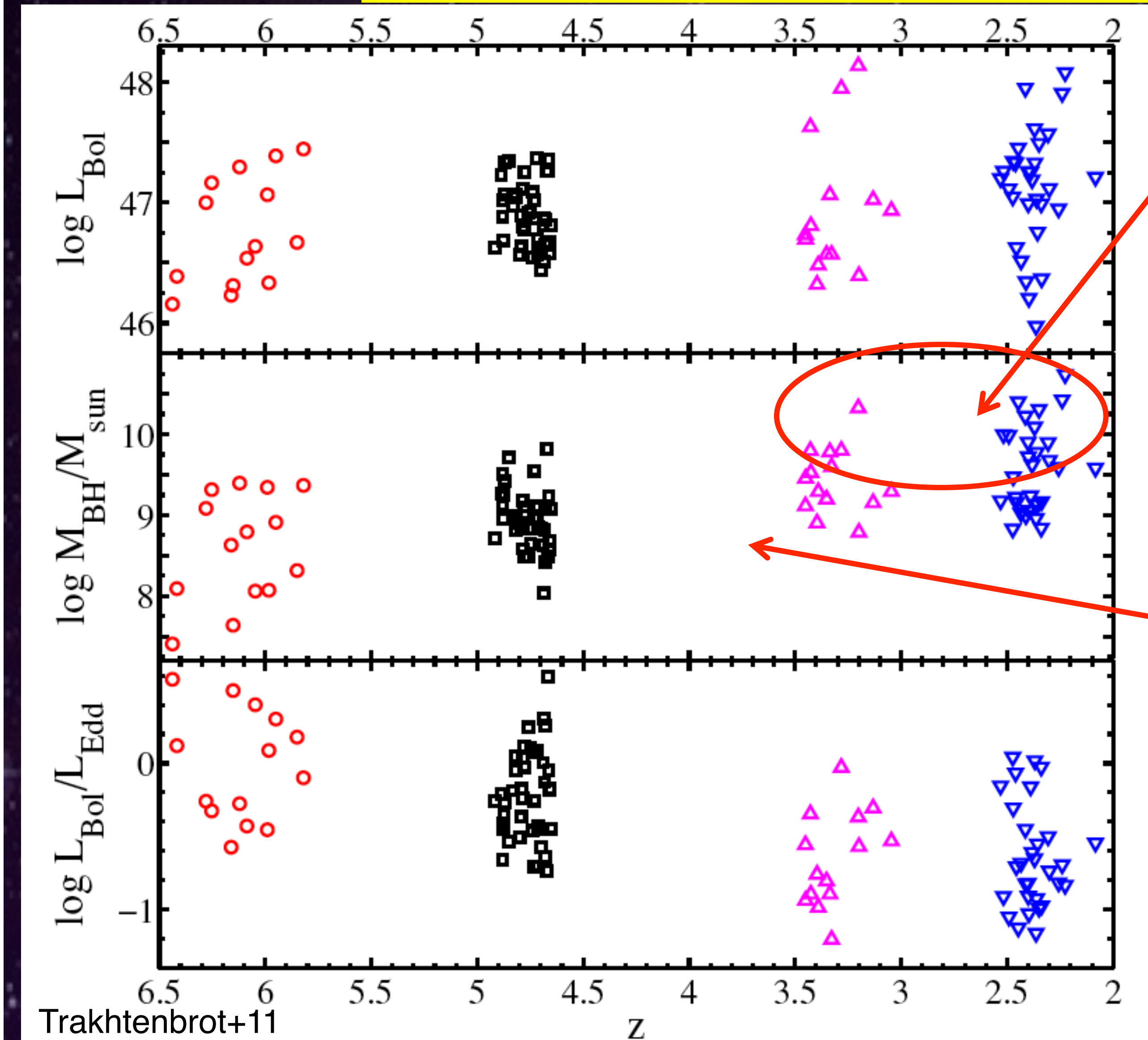
Graham+11

Black-Hole Mass vs. σ: Low Masses



Jiang, Greene & Ho 2011

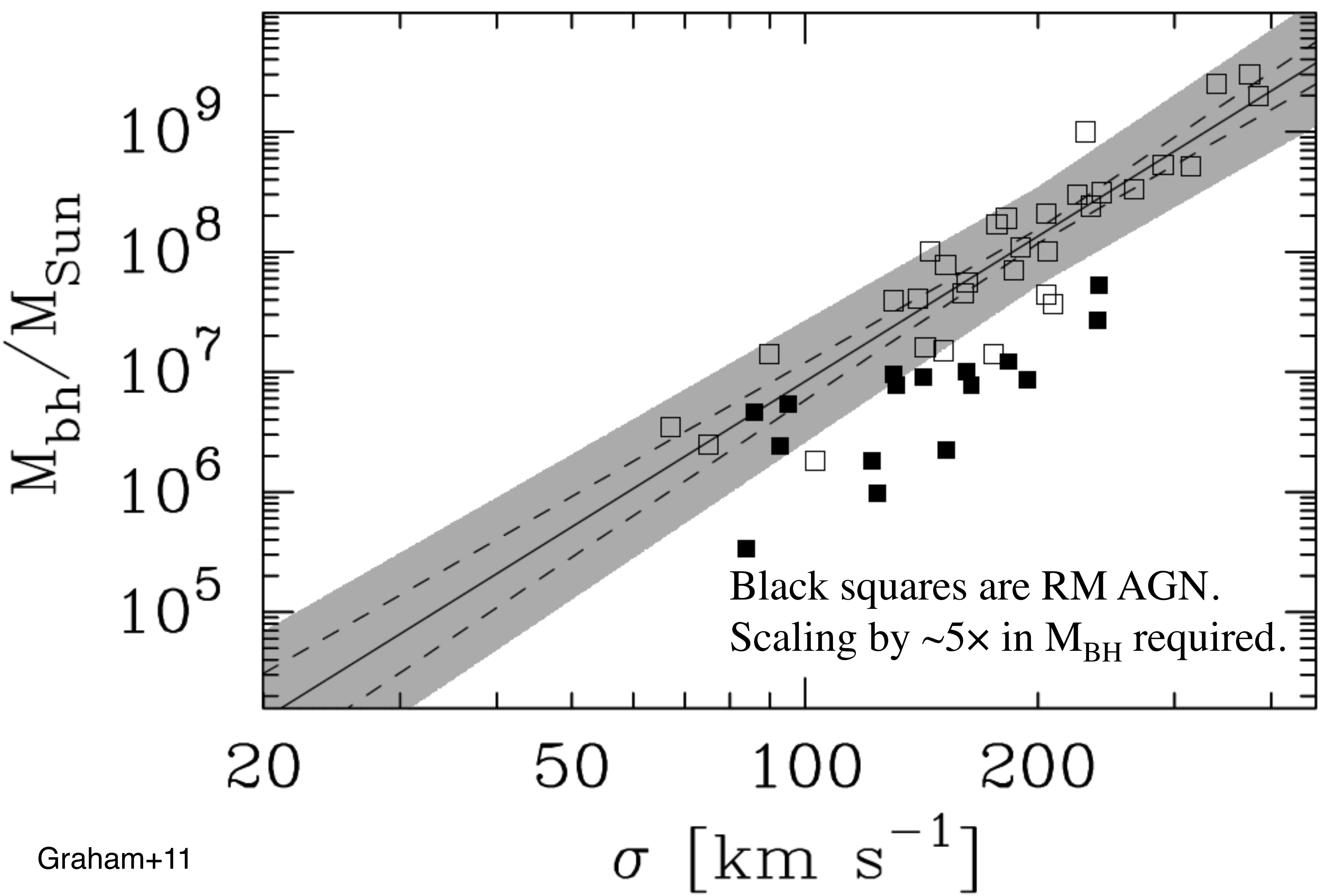
Quasar Demographics/Population Studies



But, where are the remnants of these 10^{10} M_{sun} BHs?

Black hole masses in QSOs are growing as the universe ages.

M_{BH} vs. σ including Reverberation-Mapped AGN



Graham+11

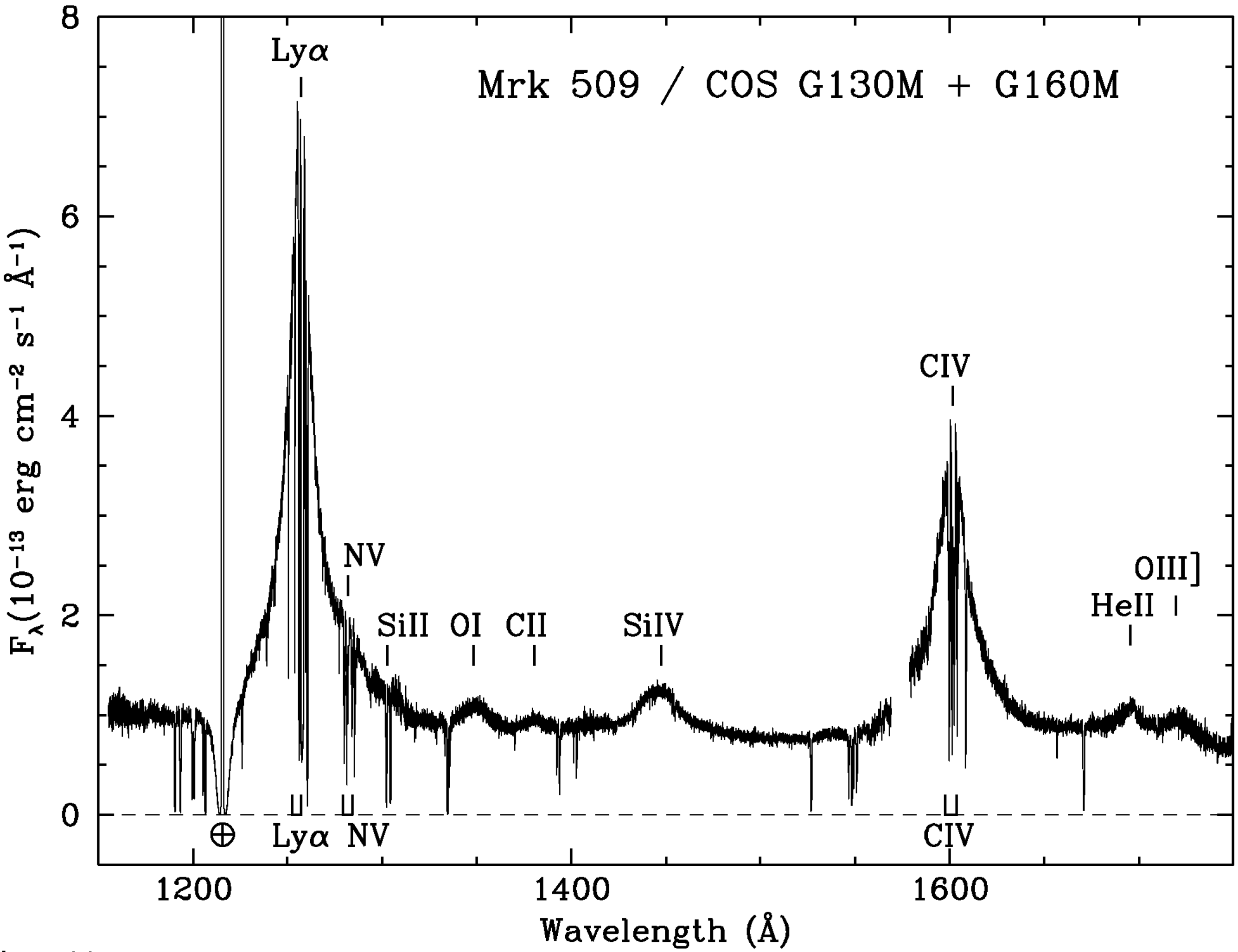
Future Directions for Black Holes in AGN

- ★ **Adaptive Optics with Integral Field Units on large ground-based telescopes will provide the most powerful approach for direct dynamical studies.**

- ★ **Reverberation mapping for AGN is improving for ground-based methods, but the UV provides the most direct probe of the inner broad-line region.**
  - Producing 2D reverberation maps requires long campaigns (100—200 days), frequent samples (once every day or so), and high precision and reproducibility (few percent or less).

The Broad Line Region

COS Spectrum of the Seyfert 1, Mrk 509



Kriss+11

What is the Broad Line Region?

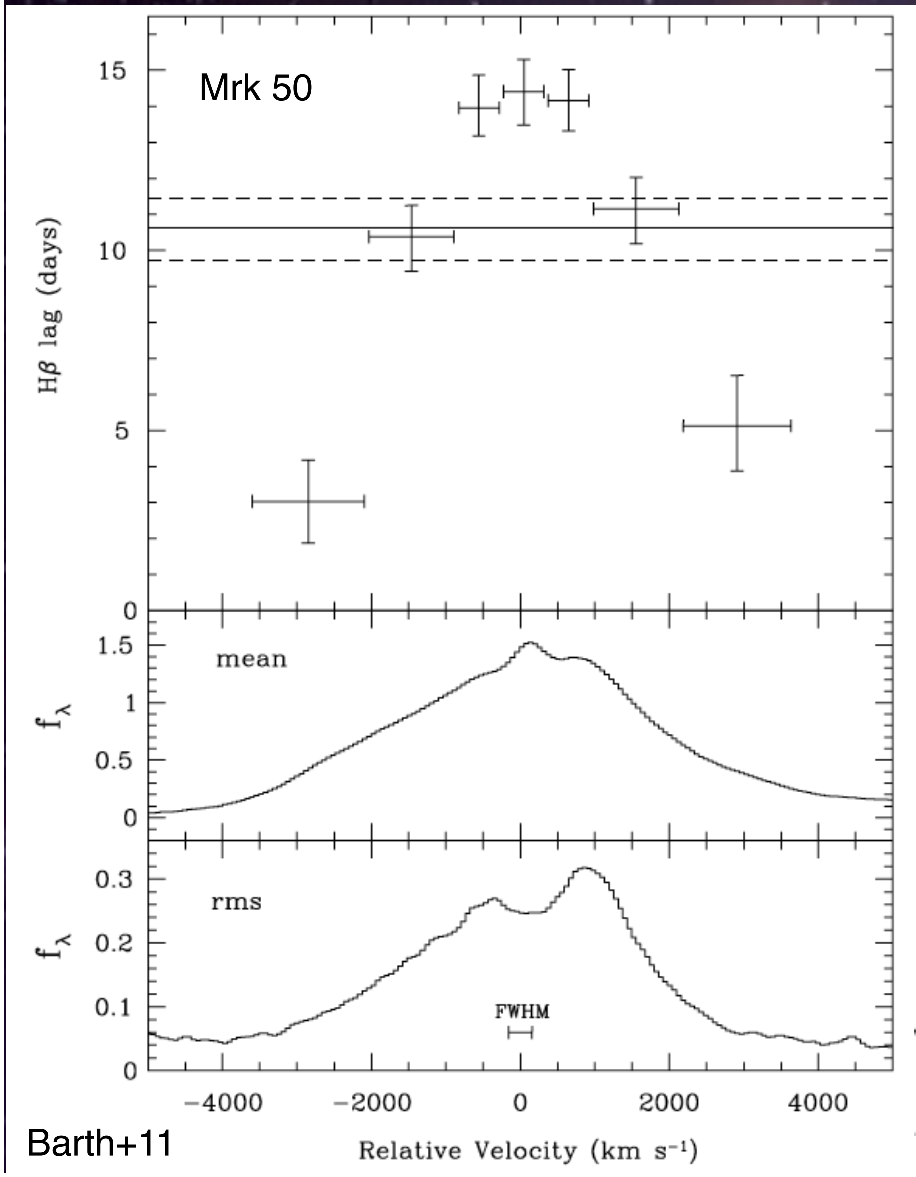
- ★ Photo-evaporated stars near the central engine?
  [Alexander & Netzer 1994, 1997]

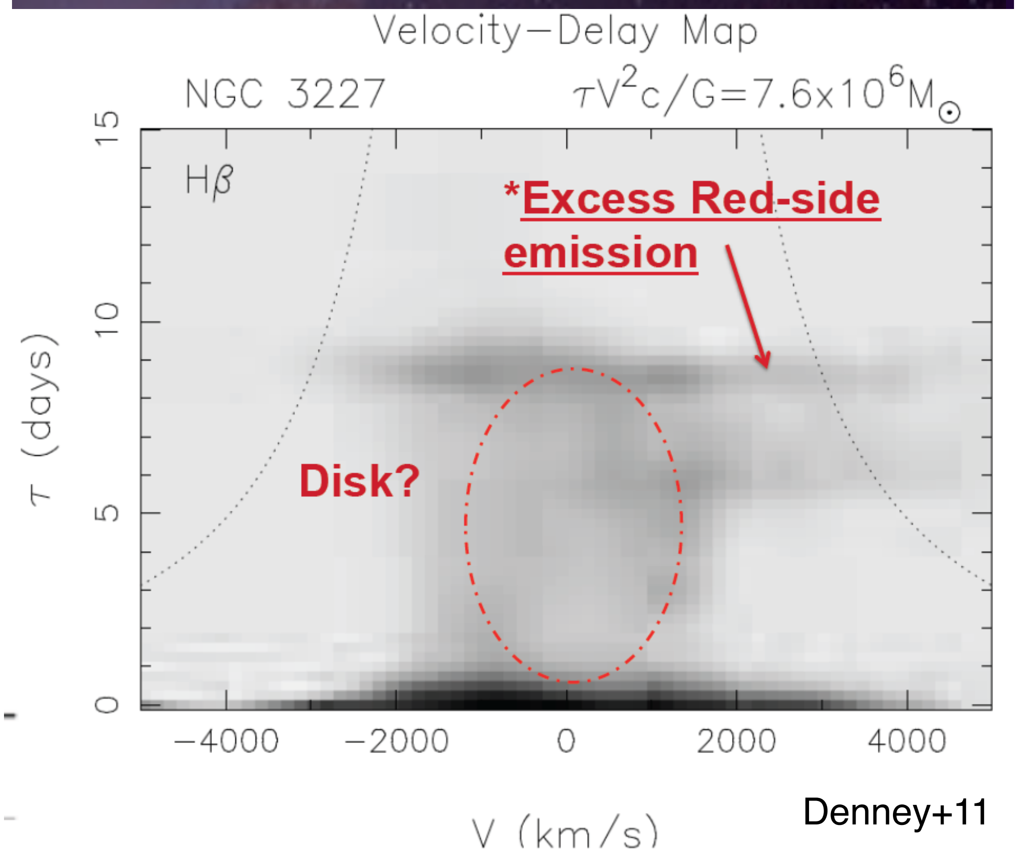
- ★ Developing consensus that the BLR arises at the base of an accretion-disk wind, but little hard observational evidence exists.

- ★ 1D reverberation mapping strongly suggests virialized motions, so the wind component is probably small.

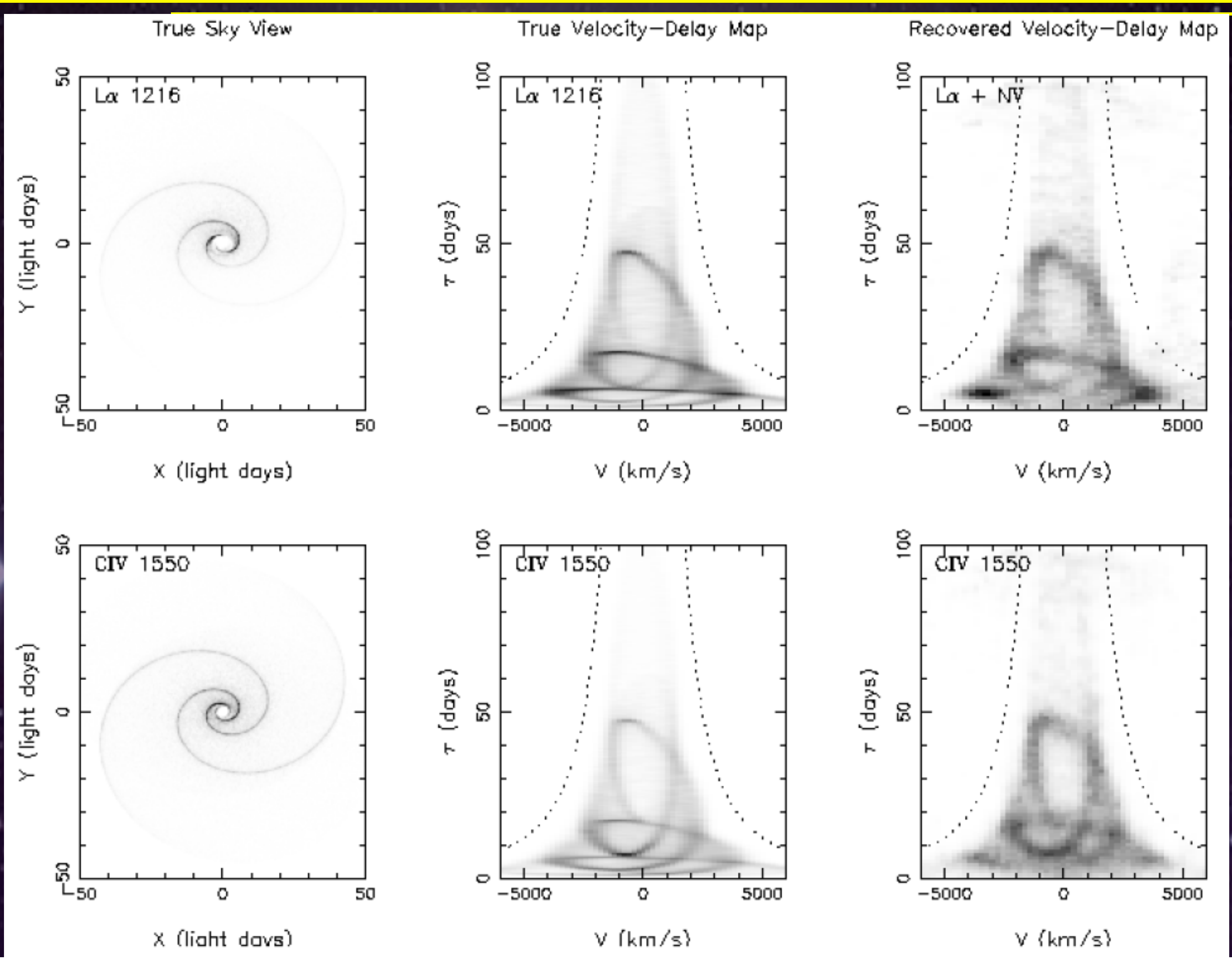
- ★ 2D reverberation mapping in the UV would provide needed observational verification of geometry and kinematics.

Velocity Resolved Reverberation





Hypothetical 2D Reverberation Map of NGC 5548 (Peterson et al. 2012)

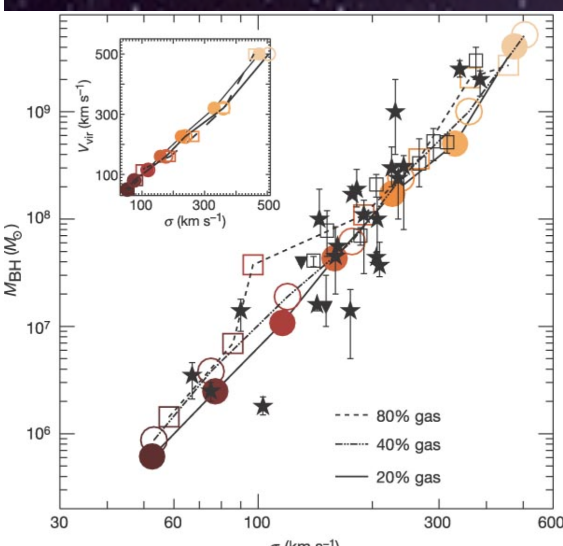


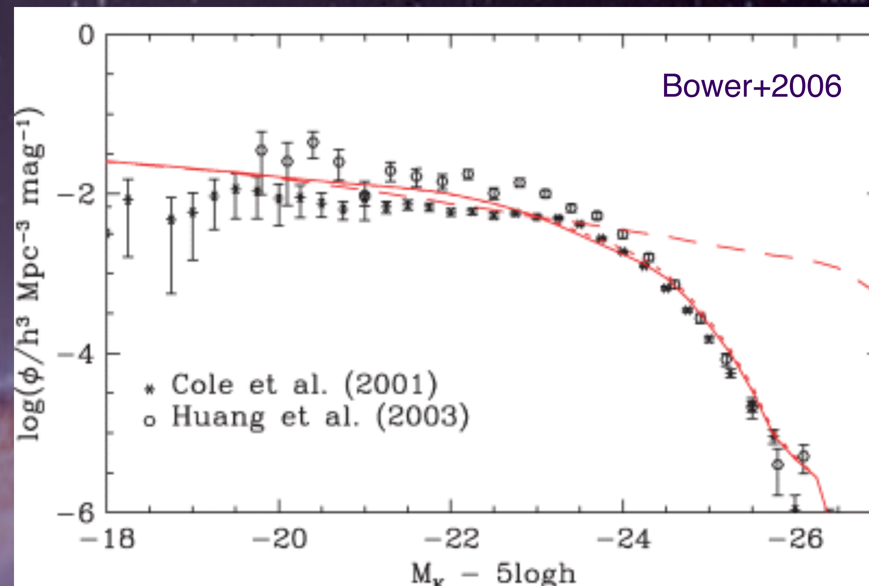

Outflows from AGN

Galaxy Evolution, AGN and Feedback

★ Downsizing: AGN feedback limits galaxy growth.

DiMatteo+2005





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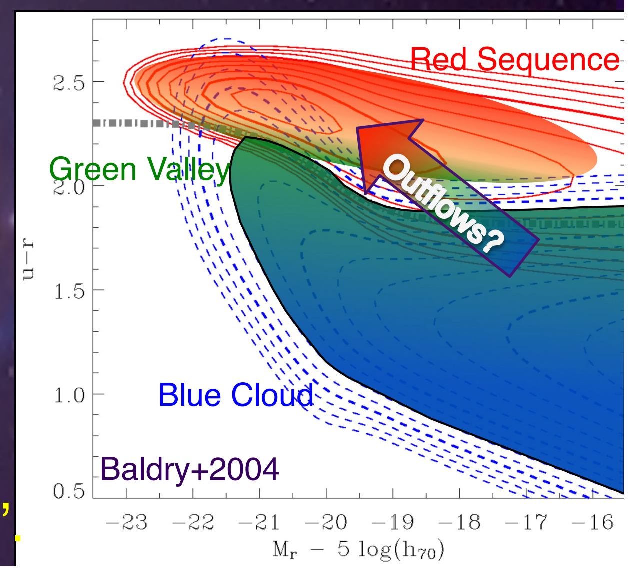
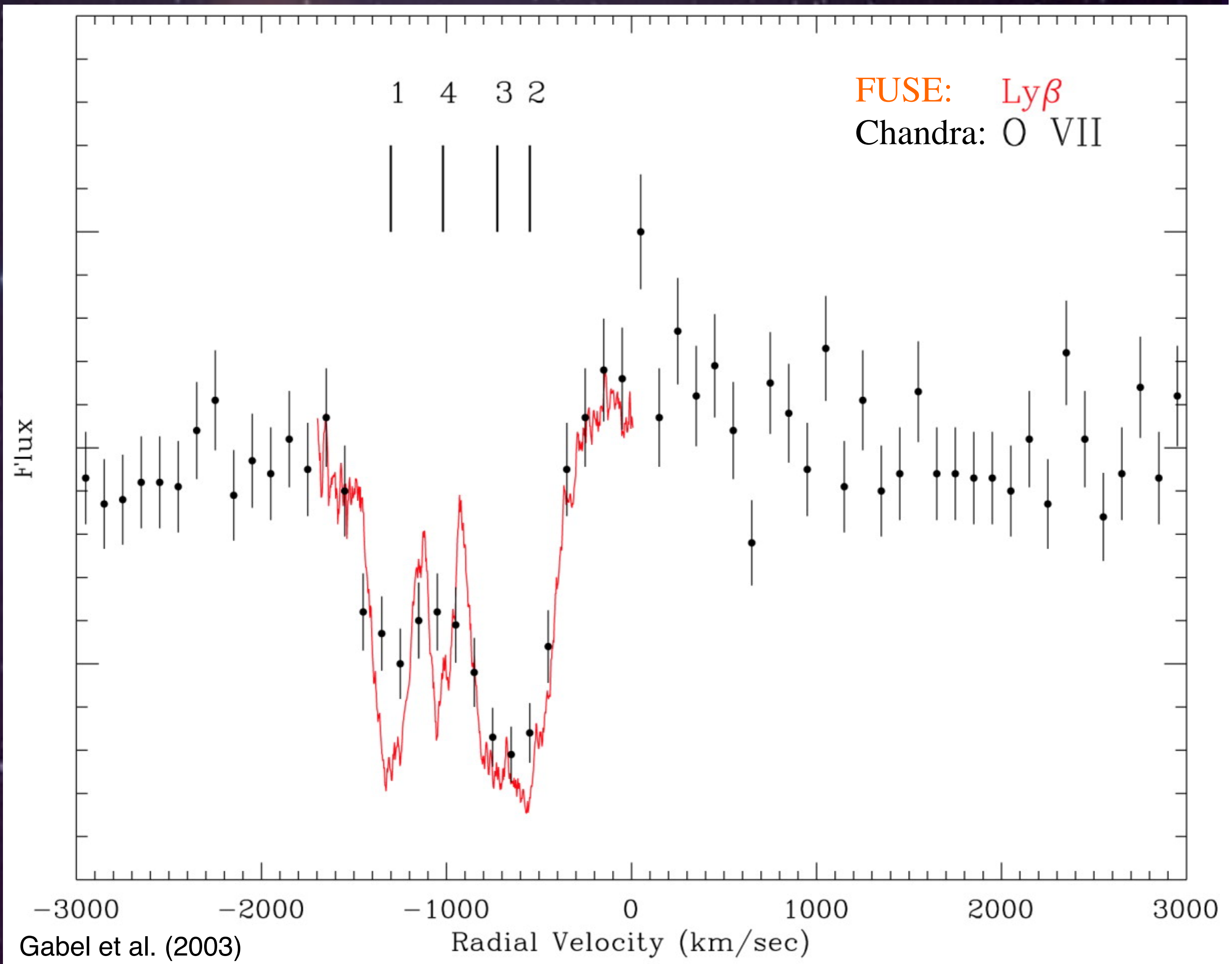


NGC 3783–UV vs. X-ray Absorption

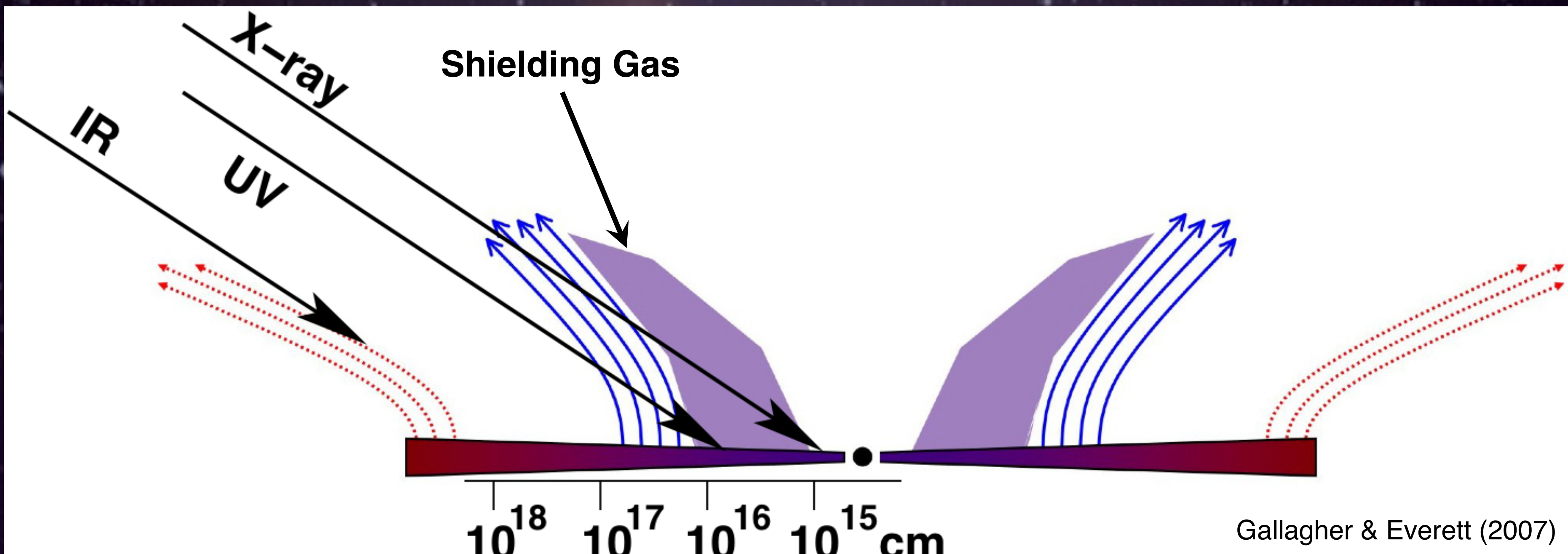
From Gabel et al. (2003):

★ The UV (Lyβ) and X-ray (OVII) absorption have similar kinematics.



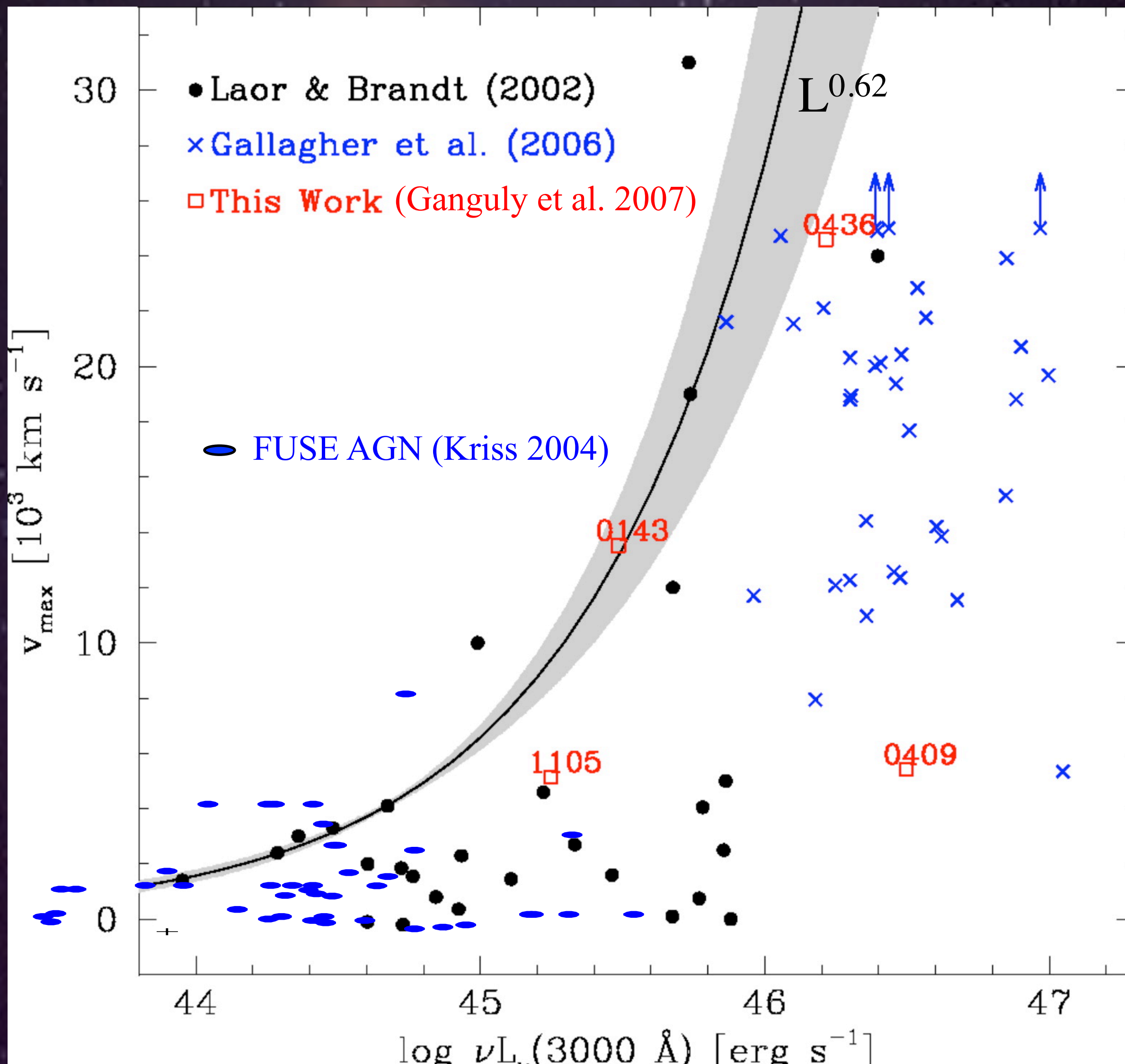
Gabel et al. (2003)

Disk-wind Model for BALQSOs



- ★ Wind terminal velocity depends on launch radius: $v_{term} \sim (M_{BH} / R_{launch})^{1/2}$
- ★ X-ray luminous ⇒ thinner shield ⇒ larger R_{launch} ⇒ lower v_{term}

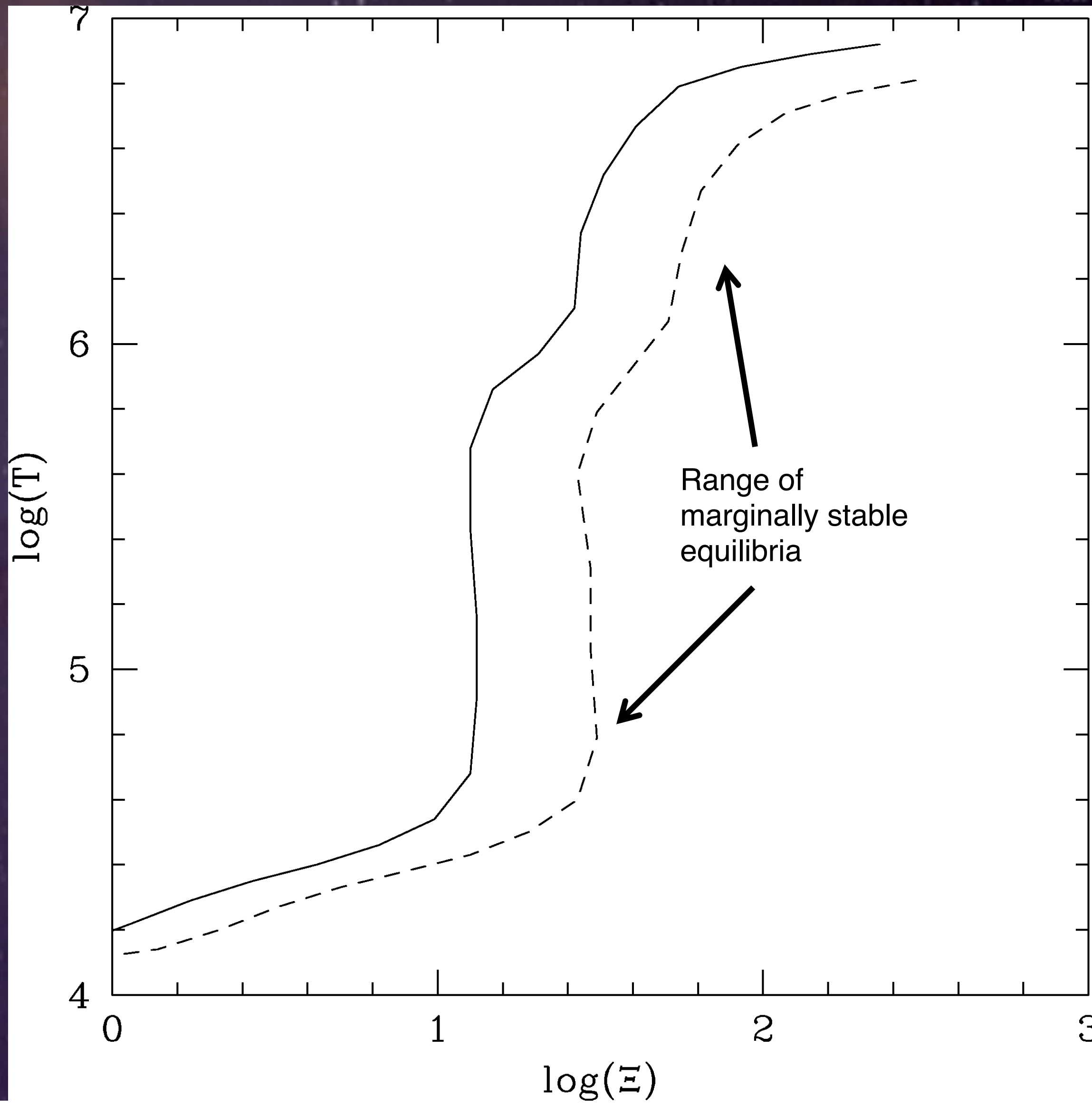
Outflow Velocity Depends on Luminosity



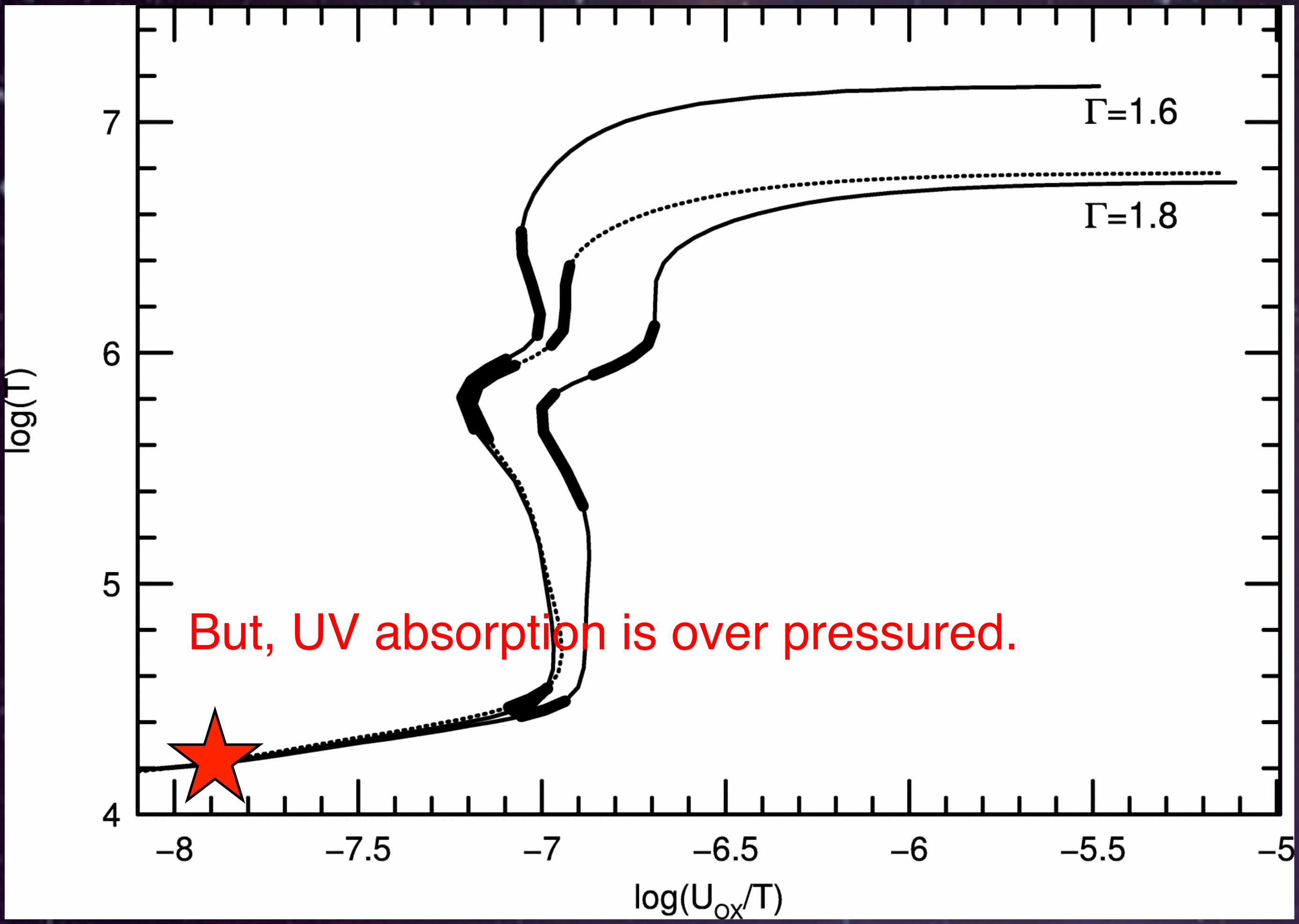
Thermally Driven Winds

From Krolik & Kriss (2001):

- ★Photoionized evaporation in the presence of a copious mass source locks the ratio of ionizing intensity to gas pressure (Ξ) at a critical value.
- ★Gas at a wide range of temperatures can coexist in pressure equilibrium.



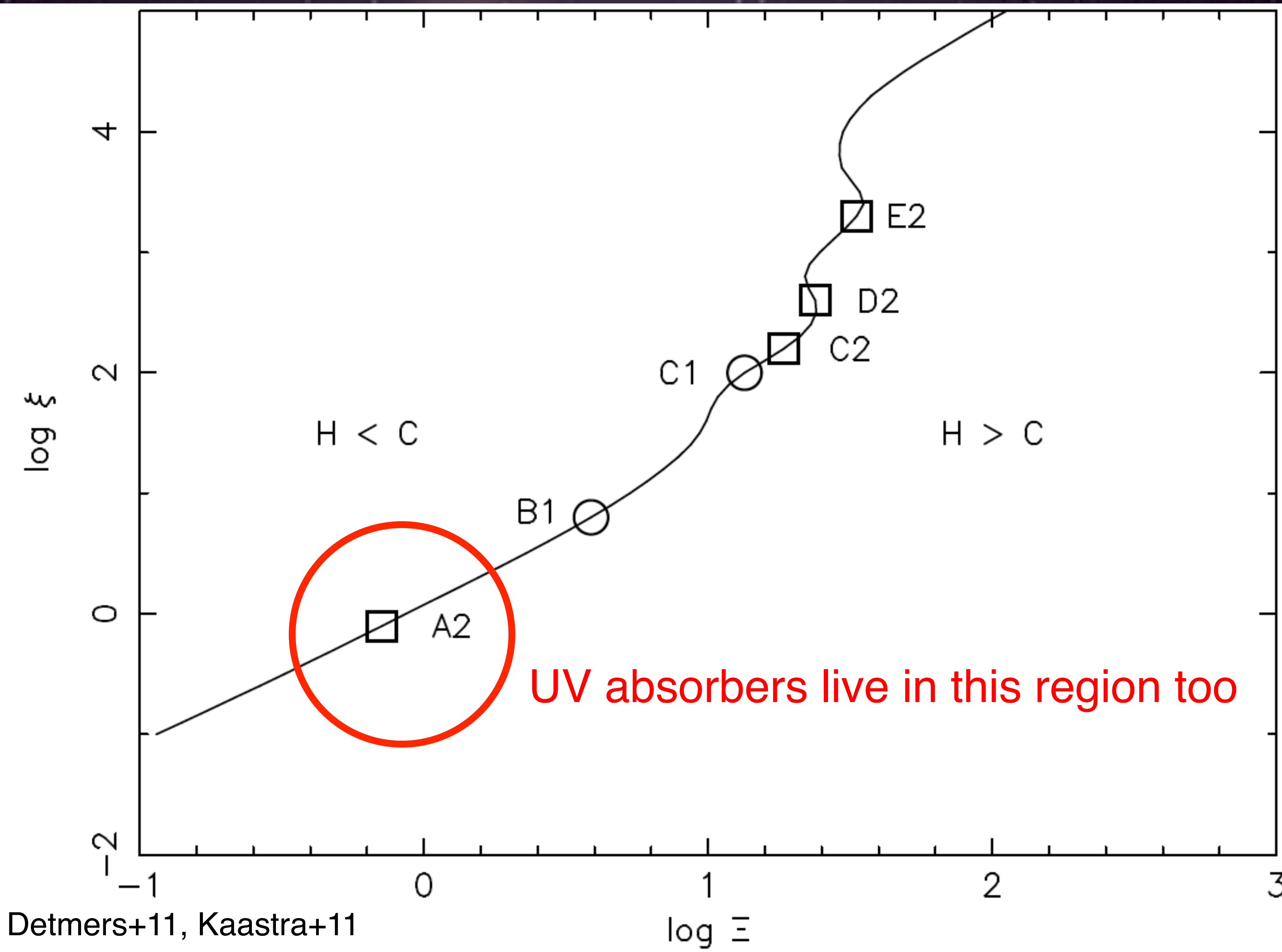
A Thermally Driven Wind in NGC 3783



Netzer et al. (2003)

The best-fitting set of models are all distributed along the vertical, marginally stable branch of the equilibrium curve, as suggested by Krolik & Kriss (2001).

No Pressure Equilibrium in Mrk 509



Detmers+11, Kaastra+11

Measuring the Impact of AGN Outflows

★ **Mechanically coupling 5% of the luminosity to the surrounding gas is the threshold for effective feedback (Dimatteo+2005).**

★ **The key quantities we need to measure are**

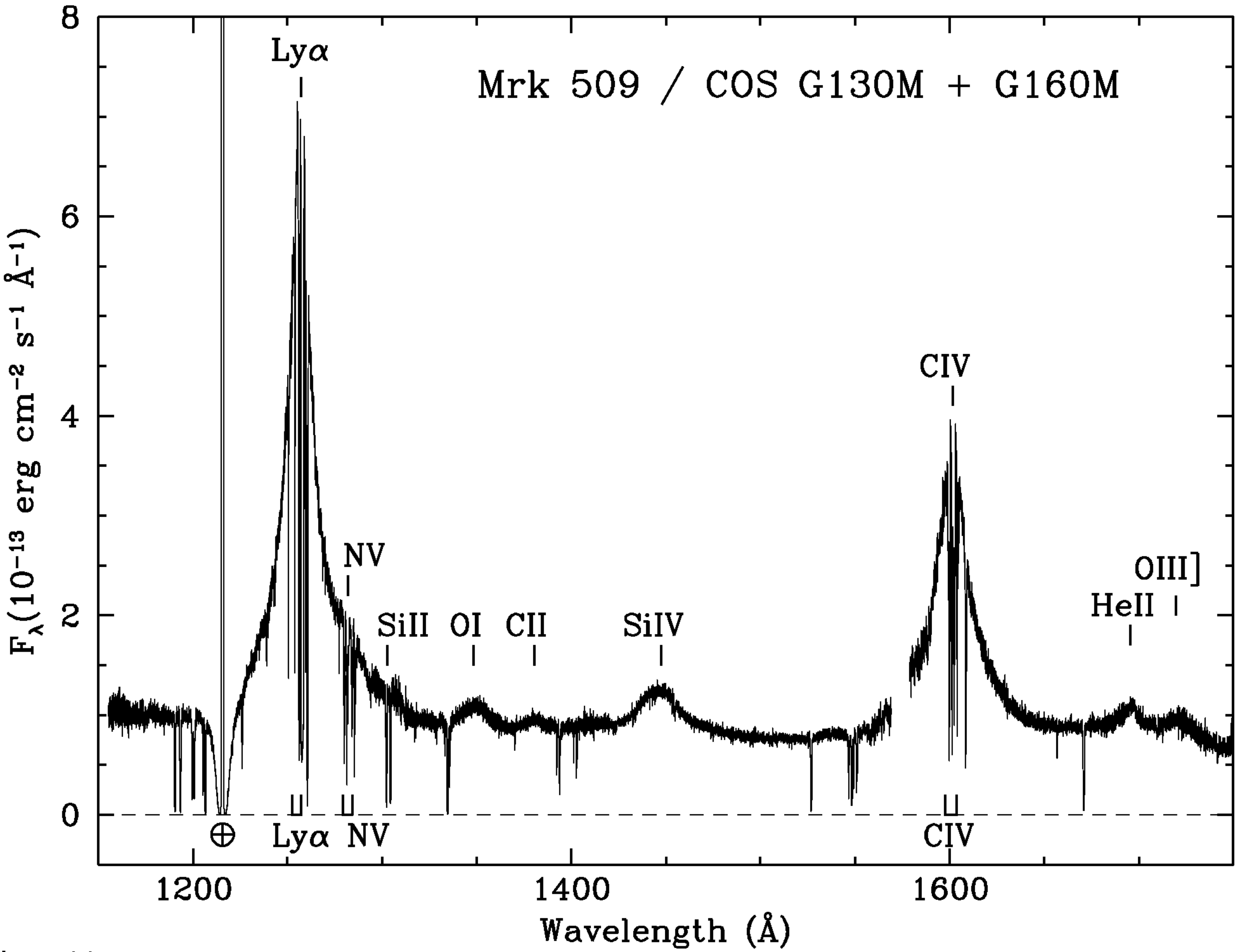
- The mass flux, $\dot{M}_{out} = 4\pi\ \Delta\Omega\ r\ N_H\ \mu m_p\ v_{out}$
- The kinetic luminosity, $L_k = ½\ \dot{M}_{out} v_{out}^2$

★ **The SED plus photoionization modeling gives us a density-dependent distance through the ionization parameter:**

$$\xi = \frac{L_{ion}}{n\ r^2}$$

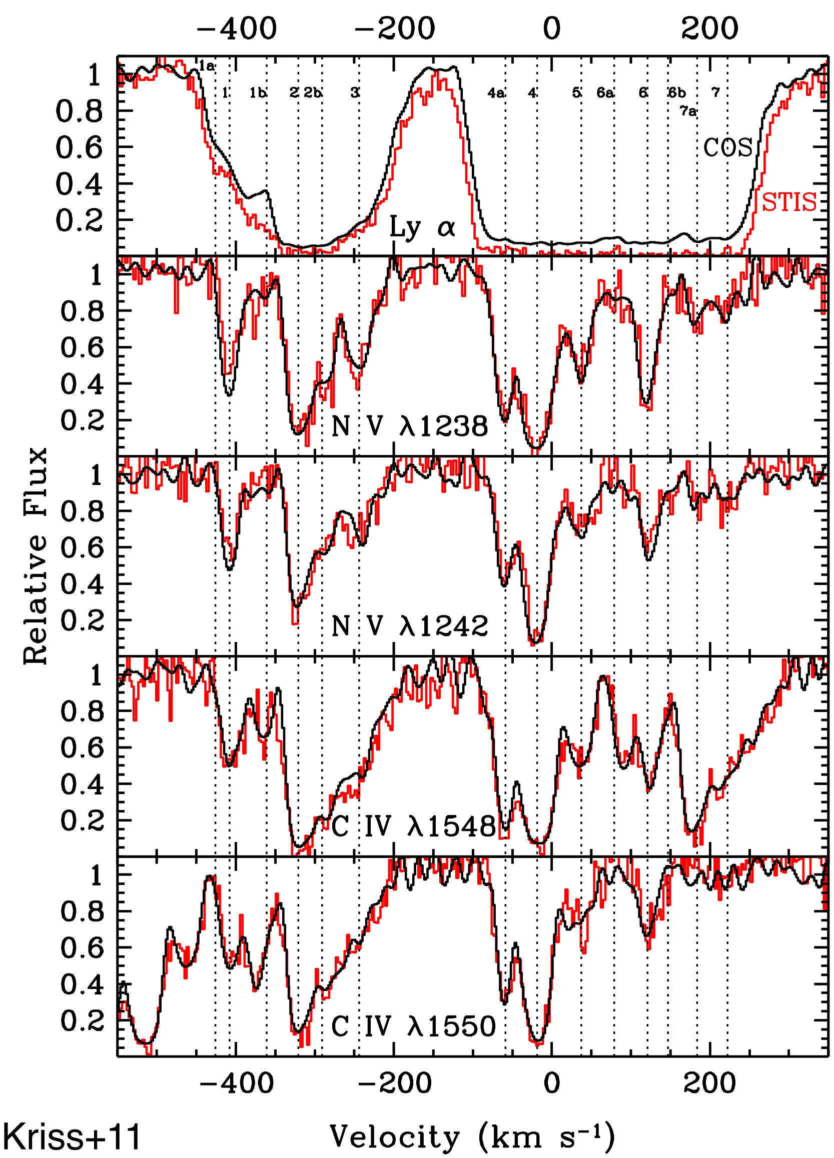
★ **Density measurements enable us to then determine the distance, r.**

COS Merged Spectrum (10 orbits) of Mrk 509



Kriss+11

Variability between COS & STIS

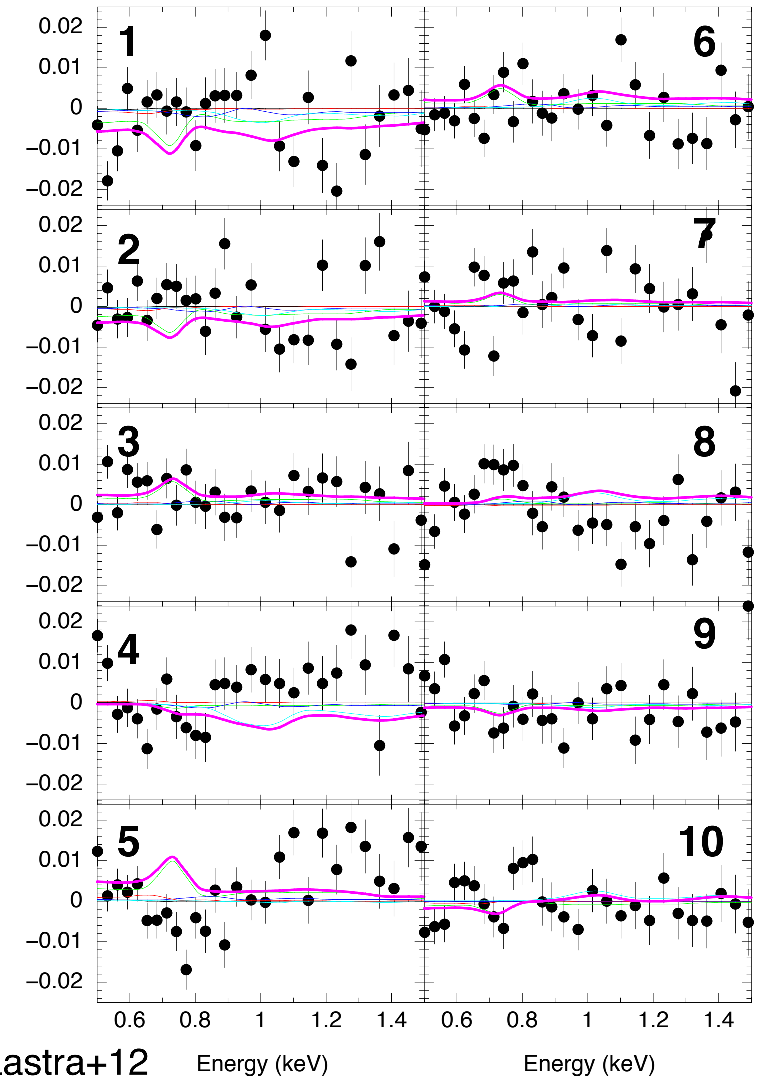


Kriss+11

- STIS spectrum from 2001 [Kraemer+03].
- COS spectrum from 2009 [Kriss+11].

- Variations in Component #1 of N V set a lower limit for the density of $n_e > 160\ cm^{-3}$.
- Given a photoionization model with log ξ = 0.67 (Kraemer+03), we get an upper limit on the distance of r < 250 pc.
- *Lack* of variability in Components 2–7 gives an *upper* limit on the density and a *lower* limit of r > 100–200 pc.

(Lack of) X-ray Absorption Variations in the Mrk 509 Campaign



Kaastra+12

- Data points show the XMM pn spectra for each observation divided by the stacked mean spectrum.
- Colored curves show the *instantaneous* change *expected* in each spectrum based on an ionization response to the changing flux.
- The lack of an instantaneous (or even slightly delayed response) implies densities lower than that required for a recombination time < 4 days.
- This implies distances r > 5 pc for the X-ray absorbing gas.

Implications for Feedback

- ★ **Most feedback models require a total energy input from the active nucleus of $\gtrsim$0.5—5% of L_{bol} to significantly influence the evolution of the host galaxy.**

- ★ **The density and distance limits for Component #1 allow us to evaluate the mass flux and kinetic luminosity:**

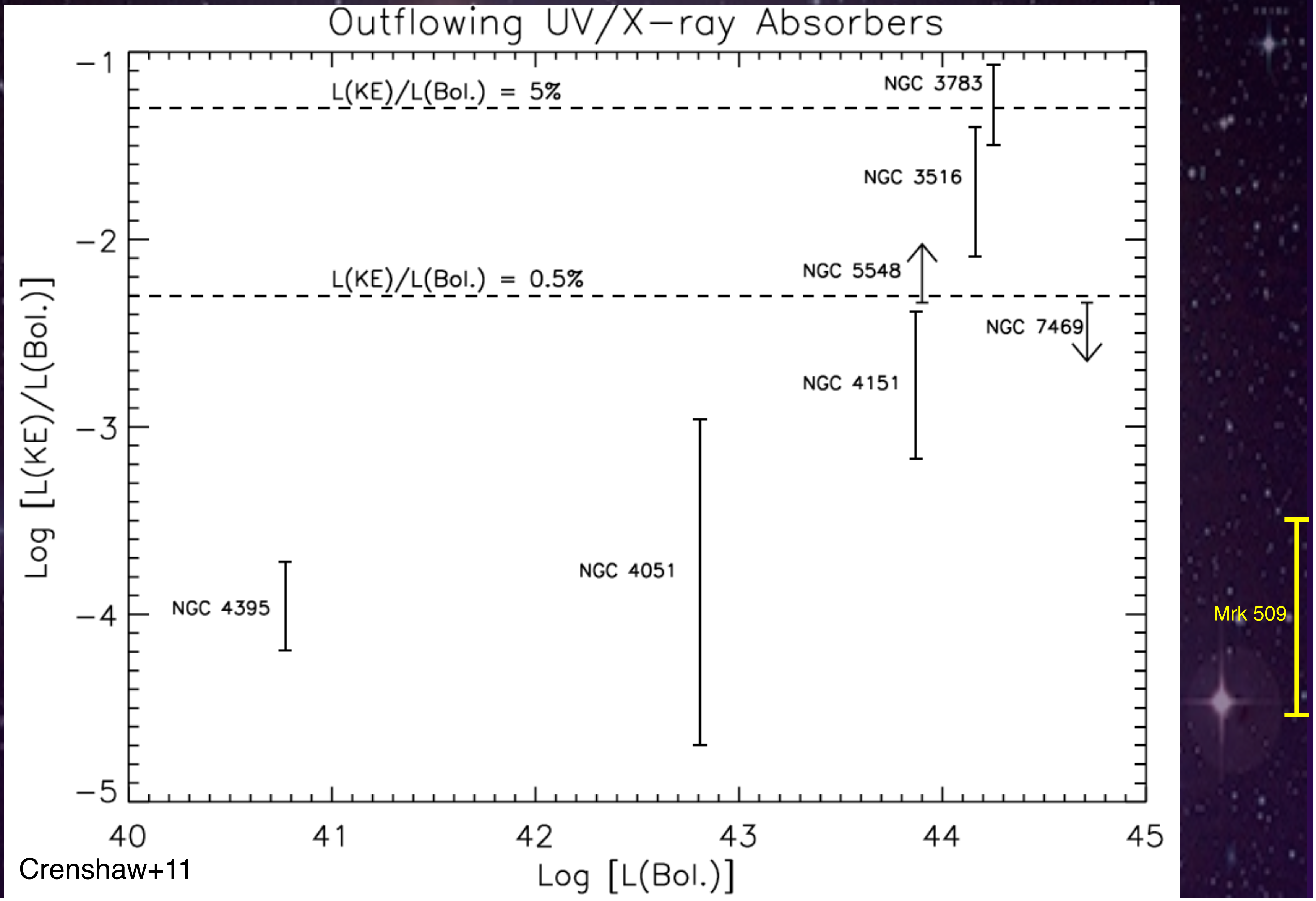
  - $\dot{M}_{out} = 4\pi\ \Delta\Omega\ r\ N_H\ \mu m_p\ v_{out} = 3\pi(r/250\ \mathrm{pc})(N_H/1.0\times10^{19}\ \mathrm{cm}^{-2})(v/400\ \mathrm{km\ s}^{-1})$
    $< 0.12\ M_\odot \mathrm{yr}^{-1}$

  - $L_k = ½\ \dot{M}_{out}\ v_{out}^2 < 6.4\times10^{39}\ \mathrm{erg\ s}^{-1}$

  - We measure $L_{bol} = 6.4\times10^{45}\ \mathrm{erg\ s}^{-1}$ (which requires $\dot{M}_{acc} \sim 1.1\ M_\odot \mathrm{yr}^{-1}$), so

  - $L_k/L_{bol} < 1\times10^{-6}$ (but increases to $\sim1\times10^{-4}$, for the X-ray absorbing gas).

Most Outflows are too Weak for Effective Feedback



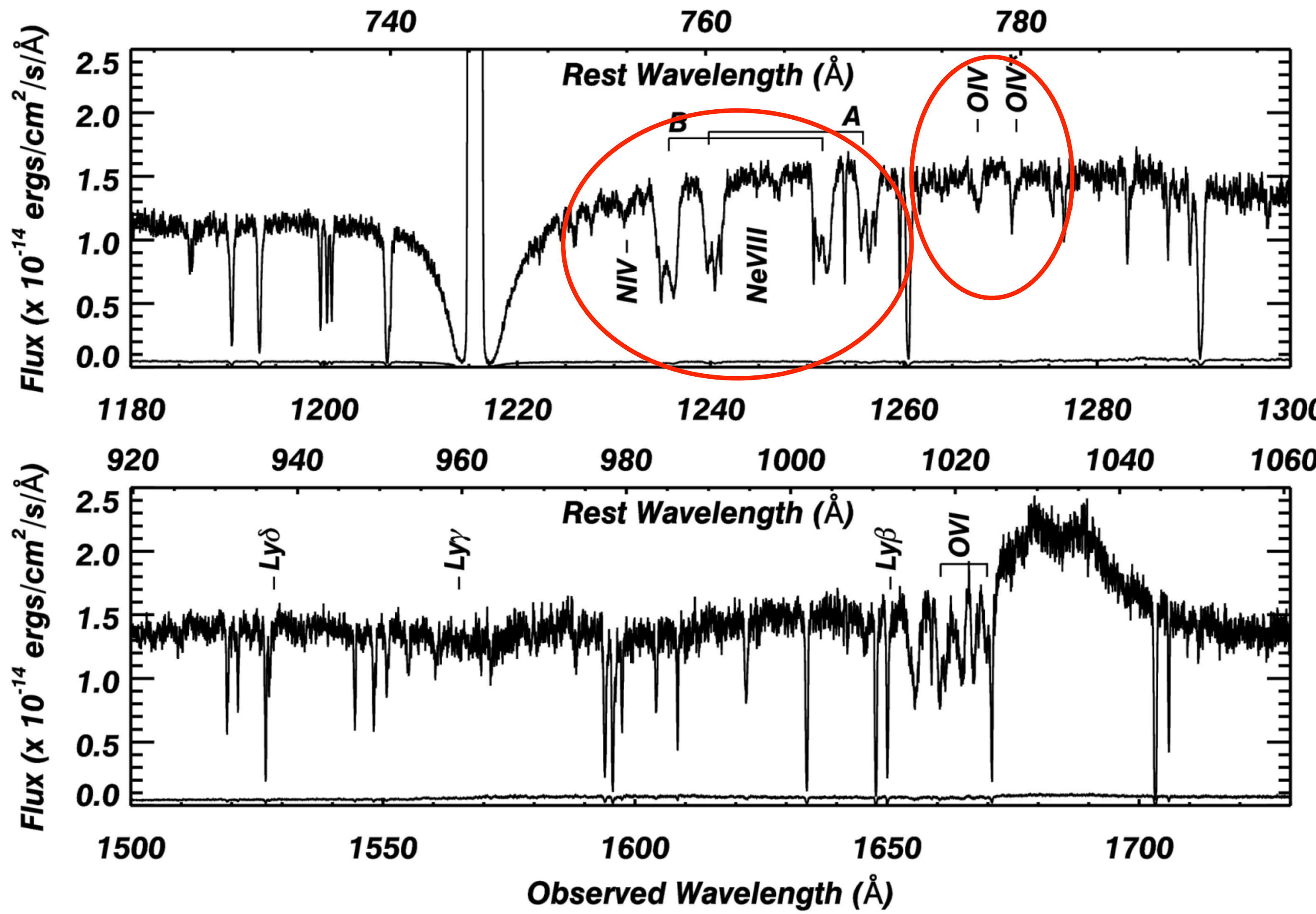
Crenshaw+11

Larger-Scale Outflows in QSOs

- **We have now measured outflow parameters for several QSOs with COS and found large, galaxy-scale outflows:**
- **IRAS** F04250-5718 **[Edmonds+11]**
  - Z = 0.104
  - >9 kpc distances
  - Kinetic luminosity of only 0.001% L_{bol}
- **IRAS** F22456-5125 **[Borguet+12]**
  - Z = 0.101
  - 10 kpc distances
  - Kinetic luminosity of only 0.01% L_{bol}
- **HE0238-1914 [Arav+12]**
  - Z = 0.61
  - 300—800 pc distances
  - Kinetic luminosity of 0.5—2.0% L_{bol}

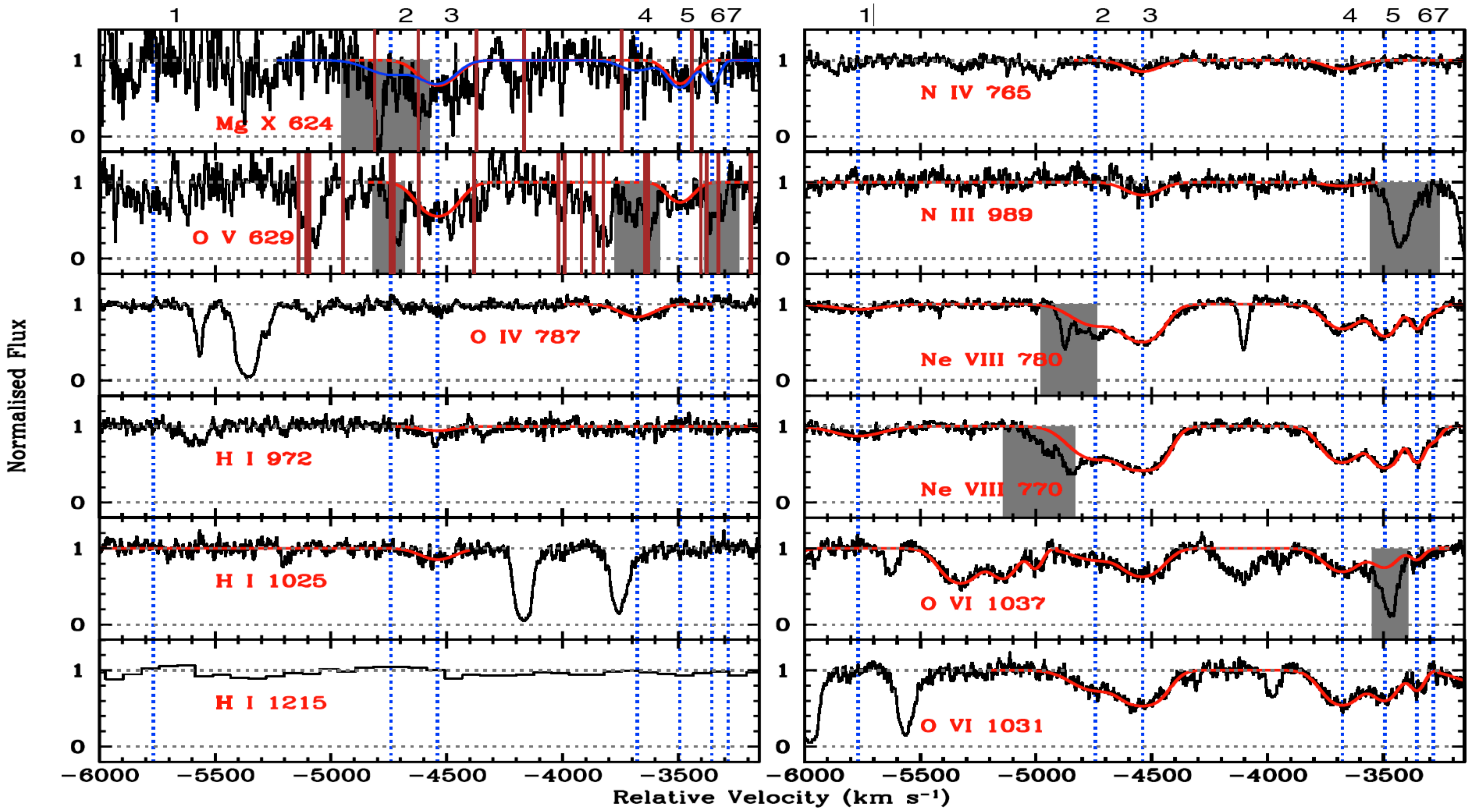
High-ionization components could carry 10—100x more energy.

COS Spectrum of HE 0238-1914



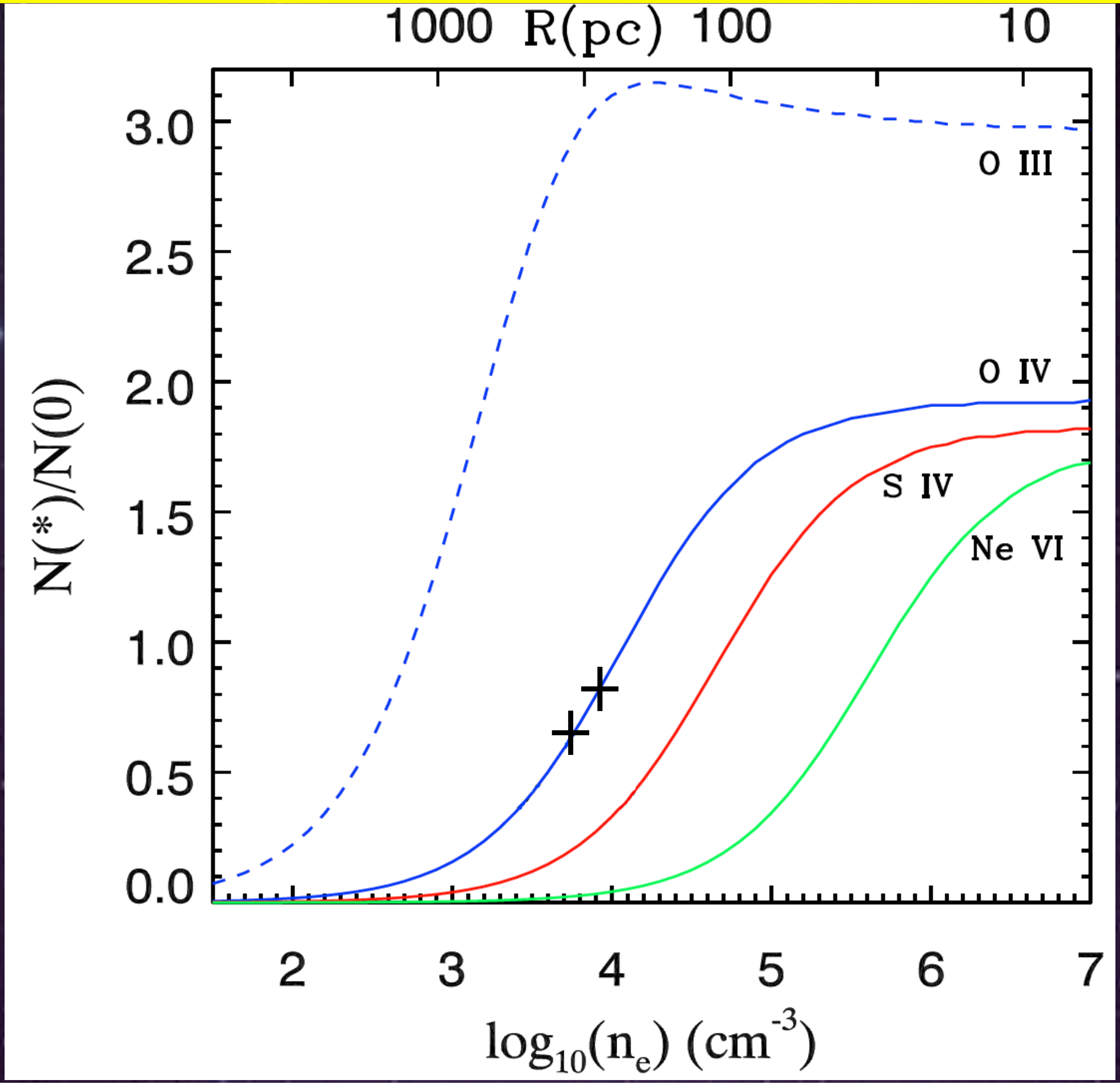
Arav et al. 2012

FUSE and COS Spectra of HE 0238-1914



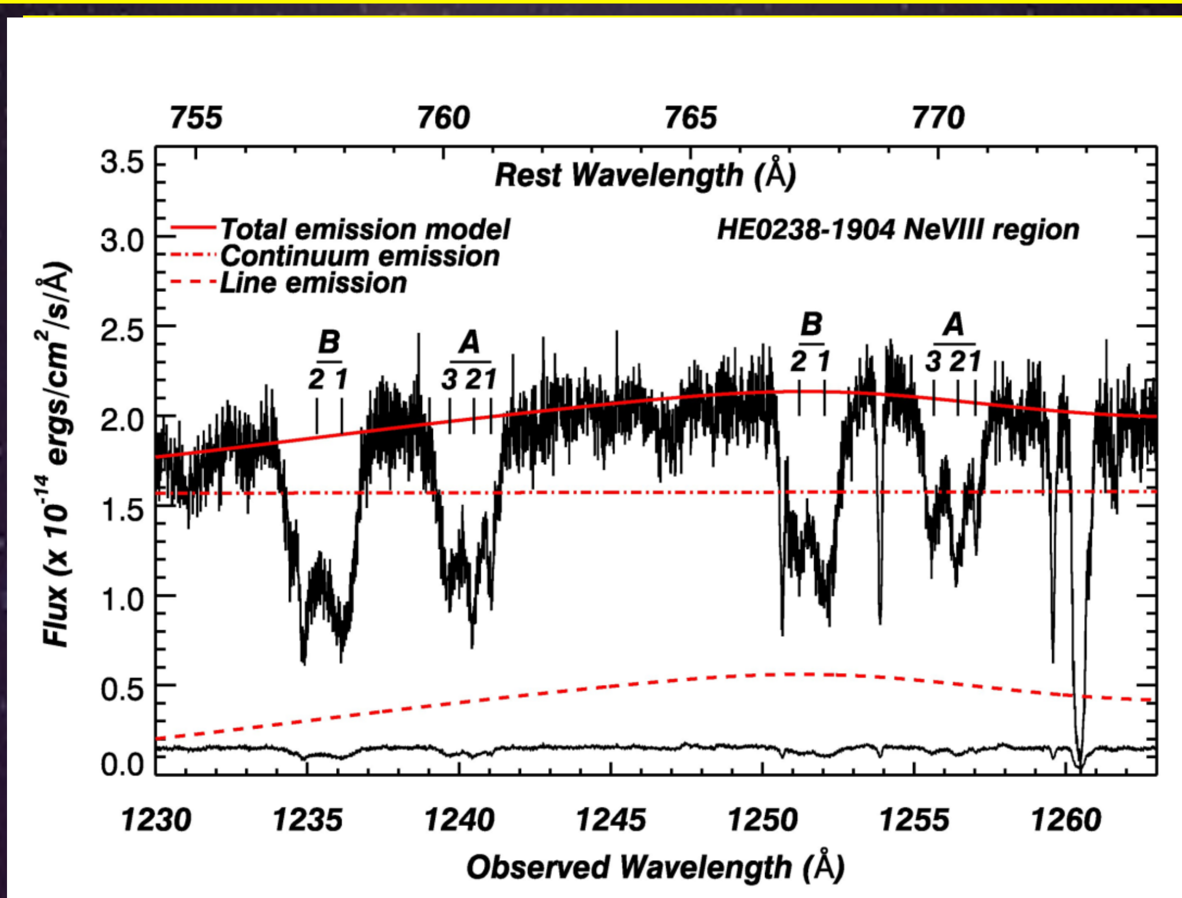
Arav et al. 2012

Density-sensitive, Excited-state Transitions Give Distances



Arav et al. 2012

Physical parameters of the outflow in HE0238-1914

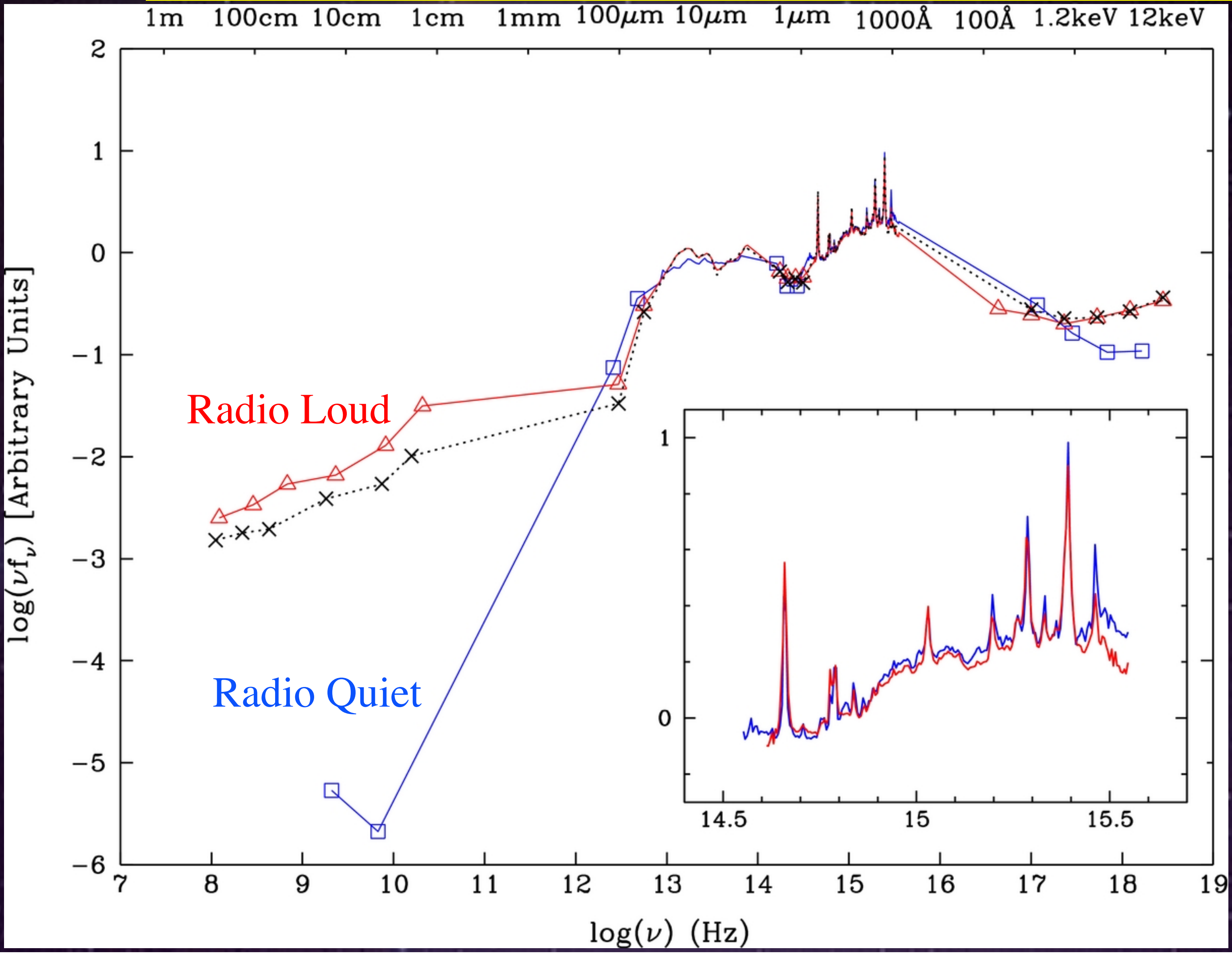


Arav et al. 2012

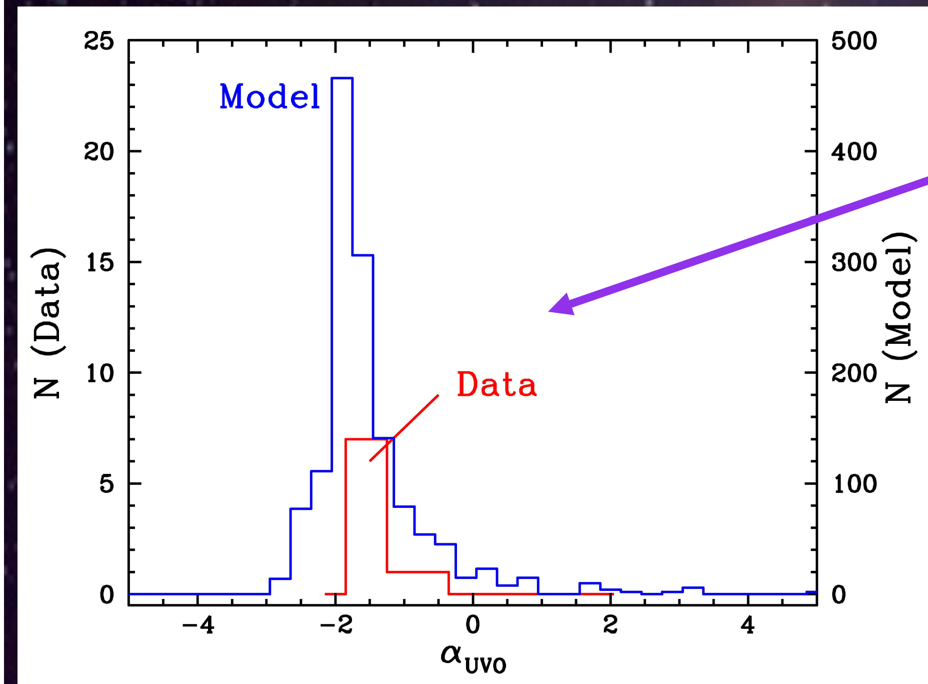
	Log (n_e)	R(pc)	M_{dot}	L_k 10^{44} erg/s	v km/s
A	3.8	800	100	4 (0.5%L_{BOL})	4000
B	3.9	300	250	20 (2%L_{BOL})	5000


The Accretion Disk

AGN Spectral Energy Distribution (Shang+11)

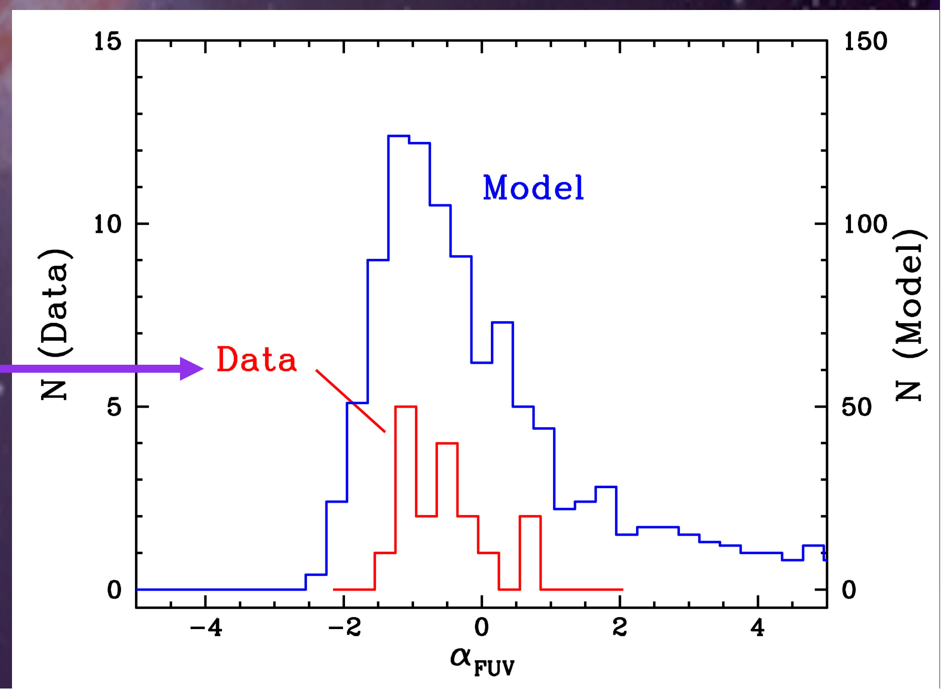


Spectral Shapes Match Predictions of non-LTE Thin Accretion Disks



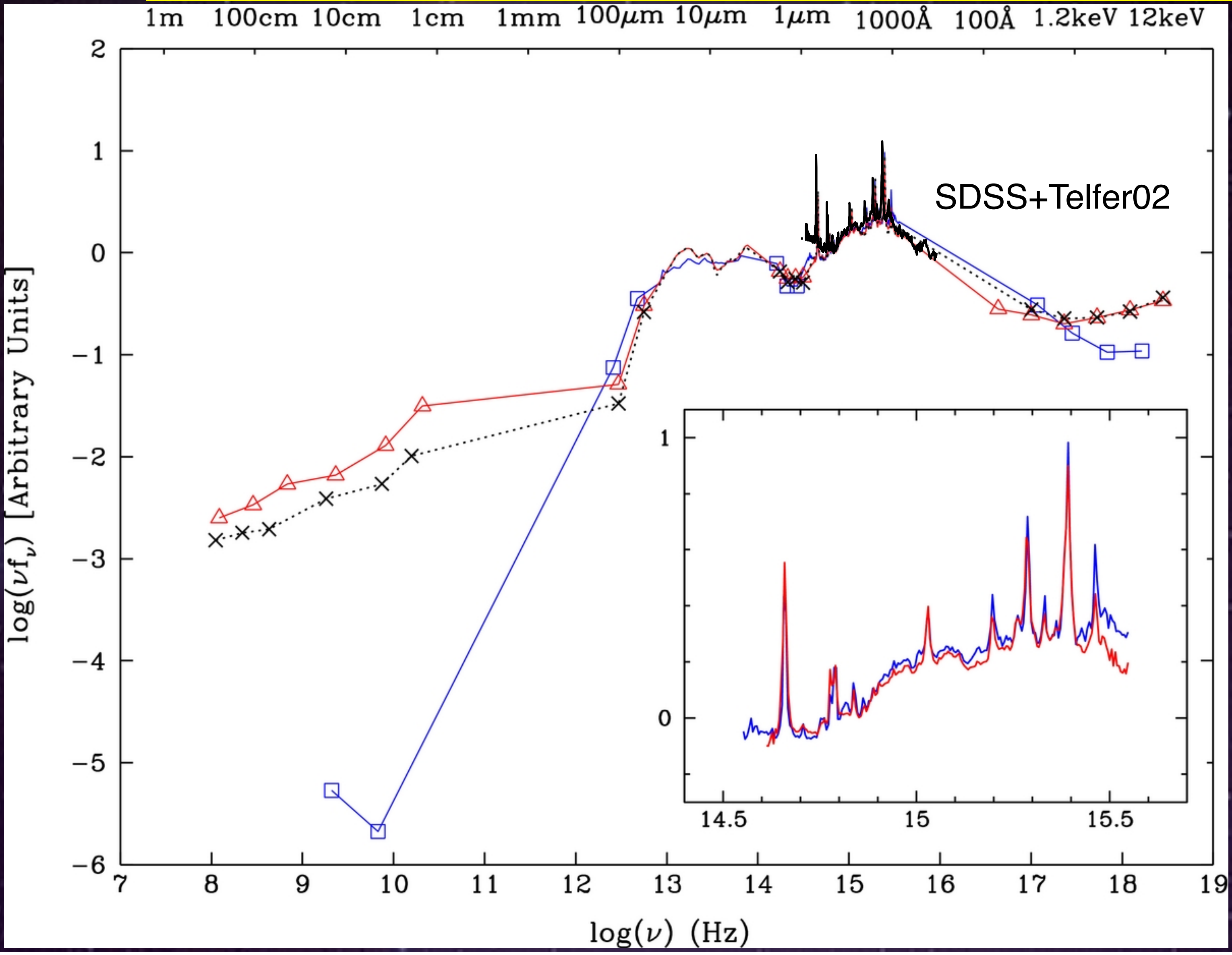
★ **UV/optical power law indices (λ=1200 – 5000 Å) show a narrow distribution consistent with accretion disk models.**

★ **The broad distribution of far-UV (900 – 1200 Å) power-law indices is also consistent with accretion disk models.**



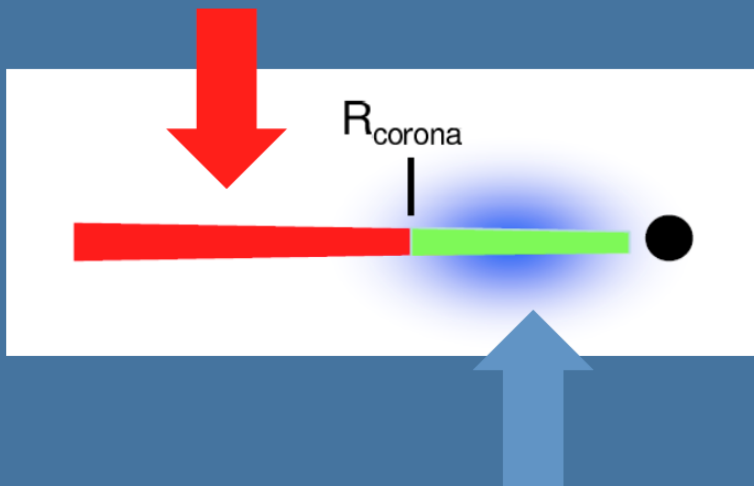
Shang et al. (2005)

AGN Spectral Energy Distribution (Shang+11)

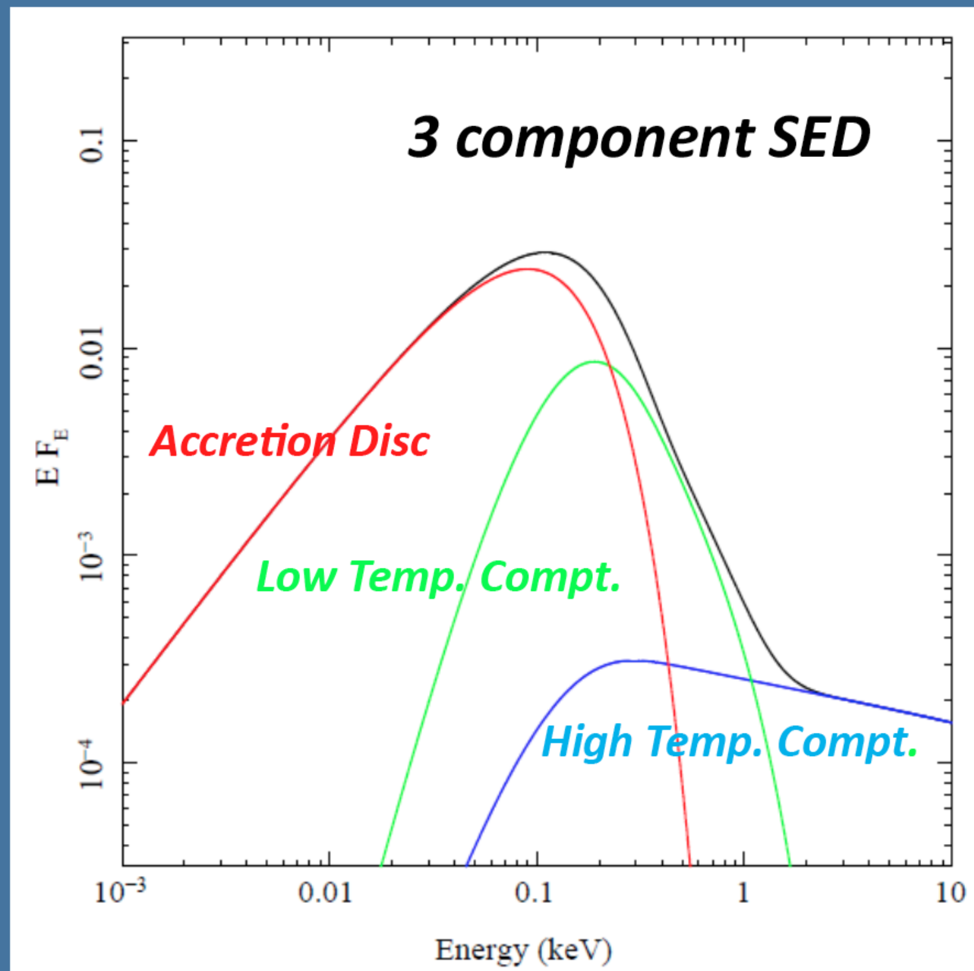


Broadband SED Model (Done et al. 2012)

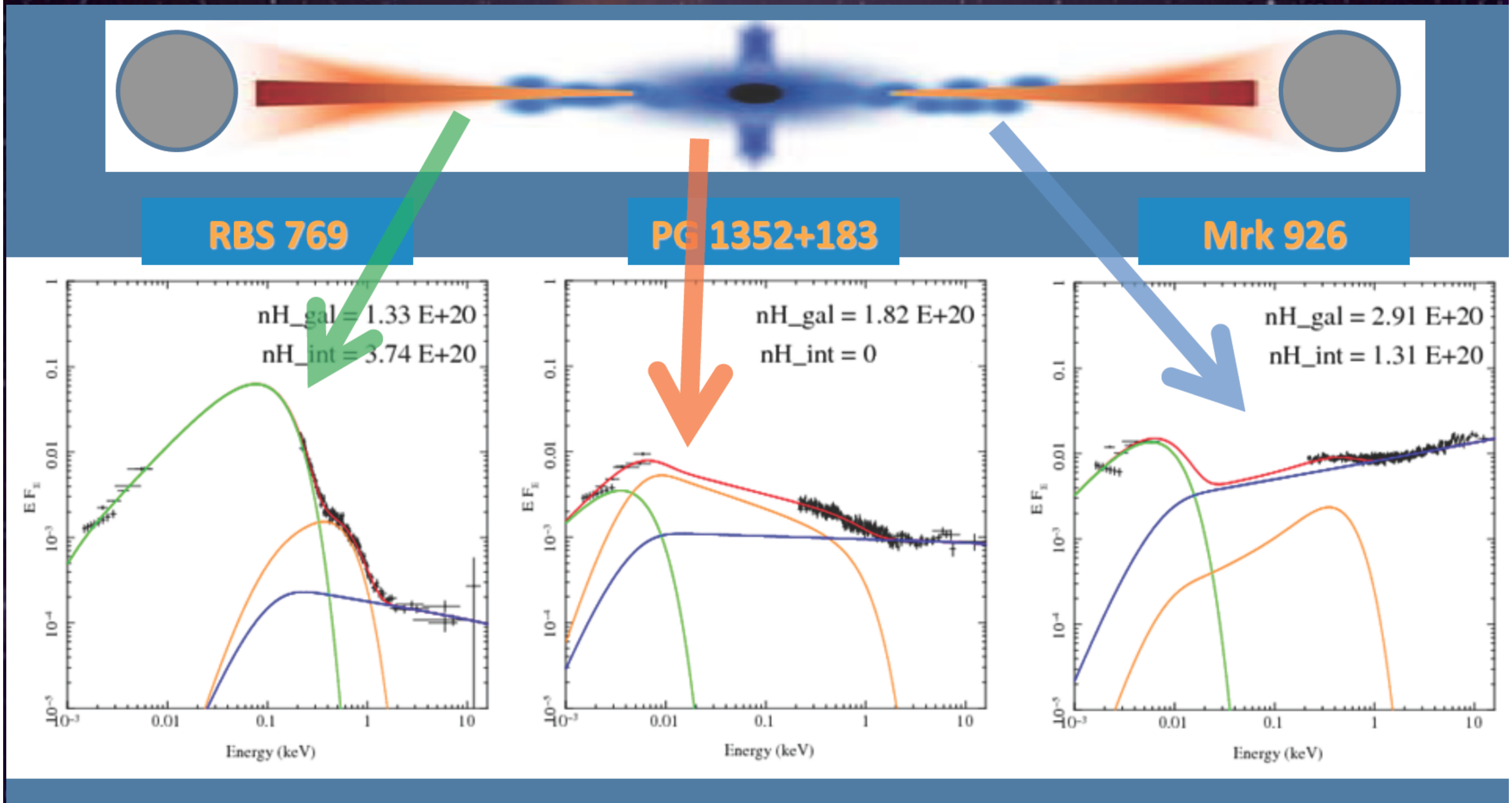
Above *R_corona* exists a standard multi temp. SS accretion disc



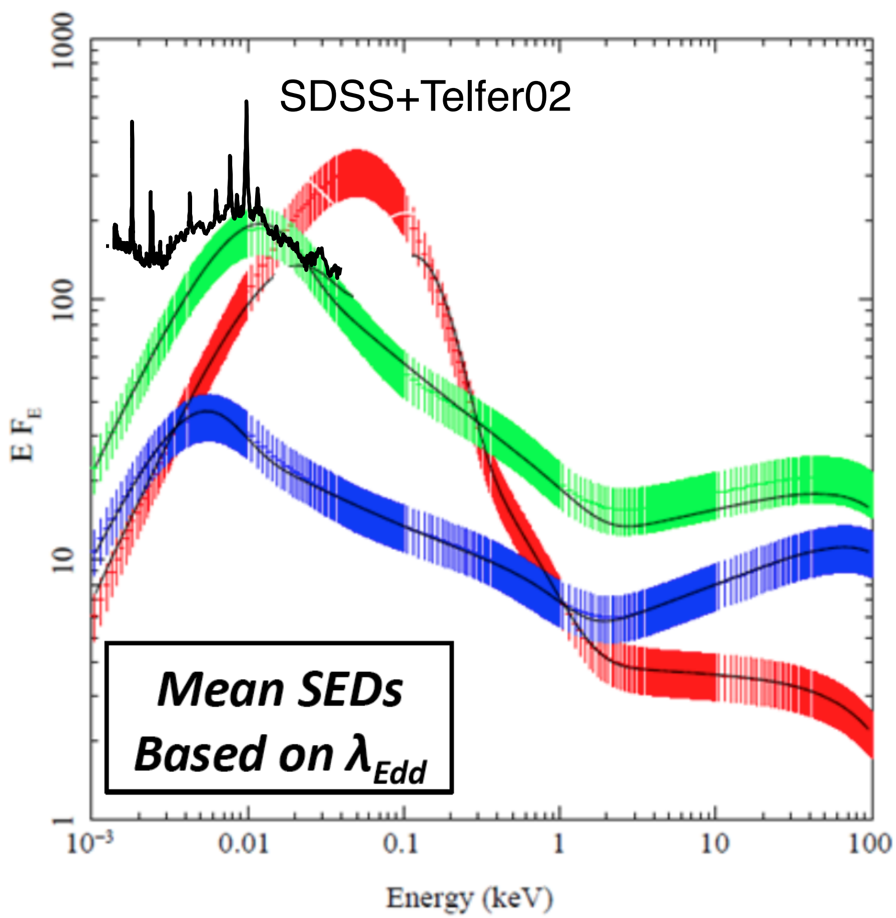
Below *R_corona*: disc photons are Compton up-scattered to higher energies by two hot electron populations (energy is conserved)

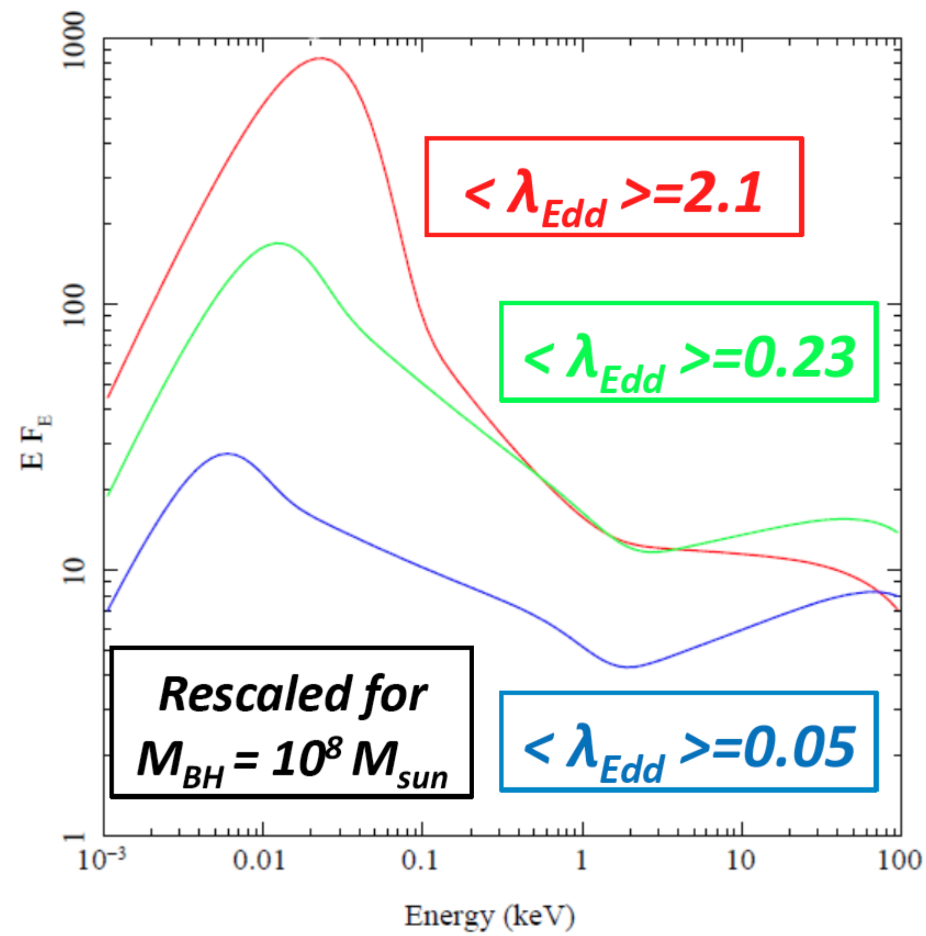


Fits to Three Example AGN (Jin, Ward & Done 2012)



Eddington Ratio is Best Indicator of the SED Shape (Jin, Ward & Done 2012)



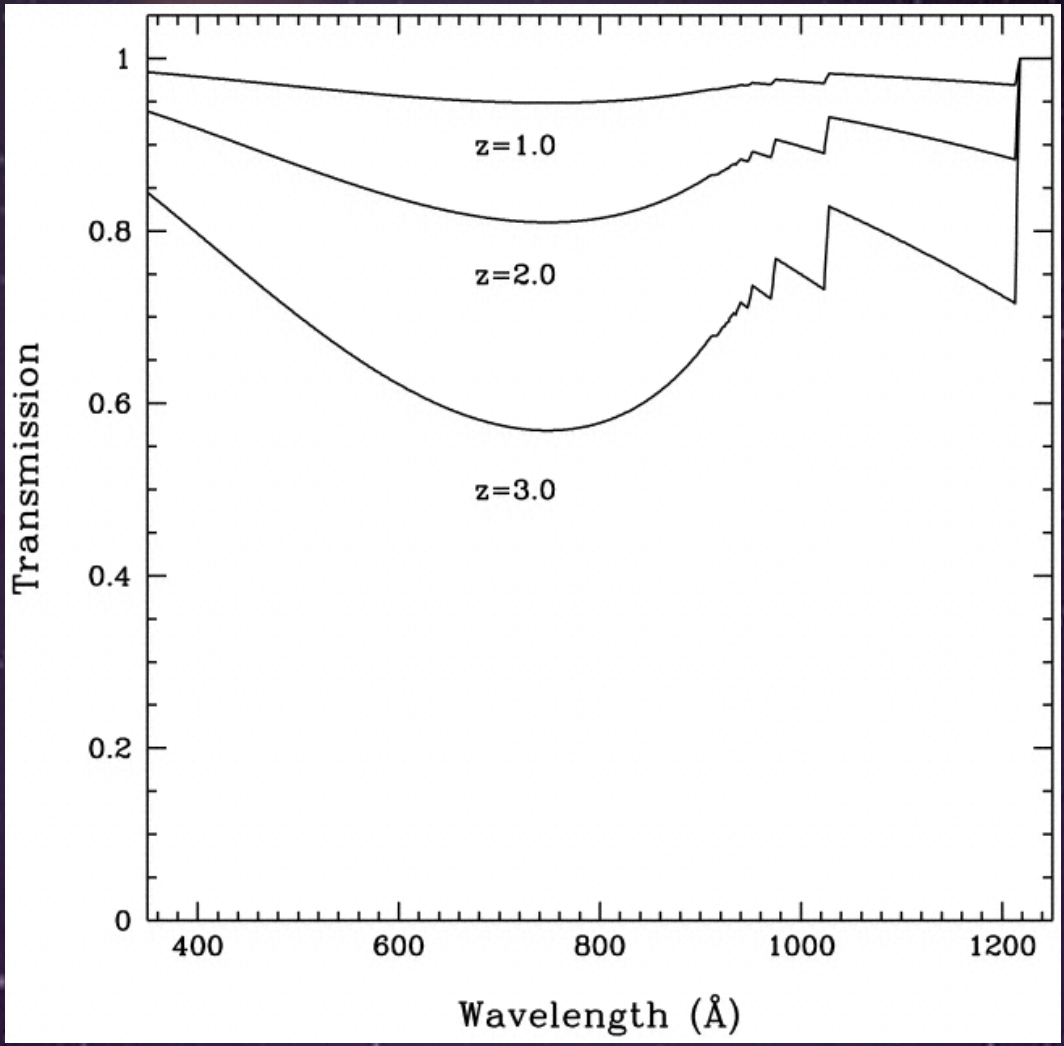


Future Directions for UV Observations

- The extreme UV (λ>912 Å) holds the most promise for understanding outflows and accretion in AGN.

- Moderate redshifts (z=0.5—2.0) are needed to access this band. Such surveys could probe the evolution of outflows with redshift.

Intervening Lyα Absorption in the IGM Has Minor Impact



Zheng et al. 1997

The Comptonized Tail of the Accretion Disk Spectrum

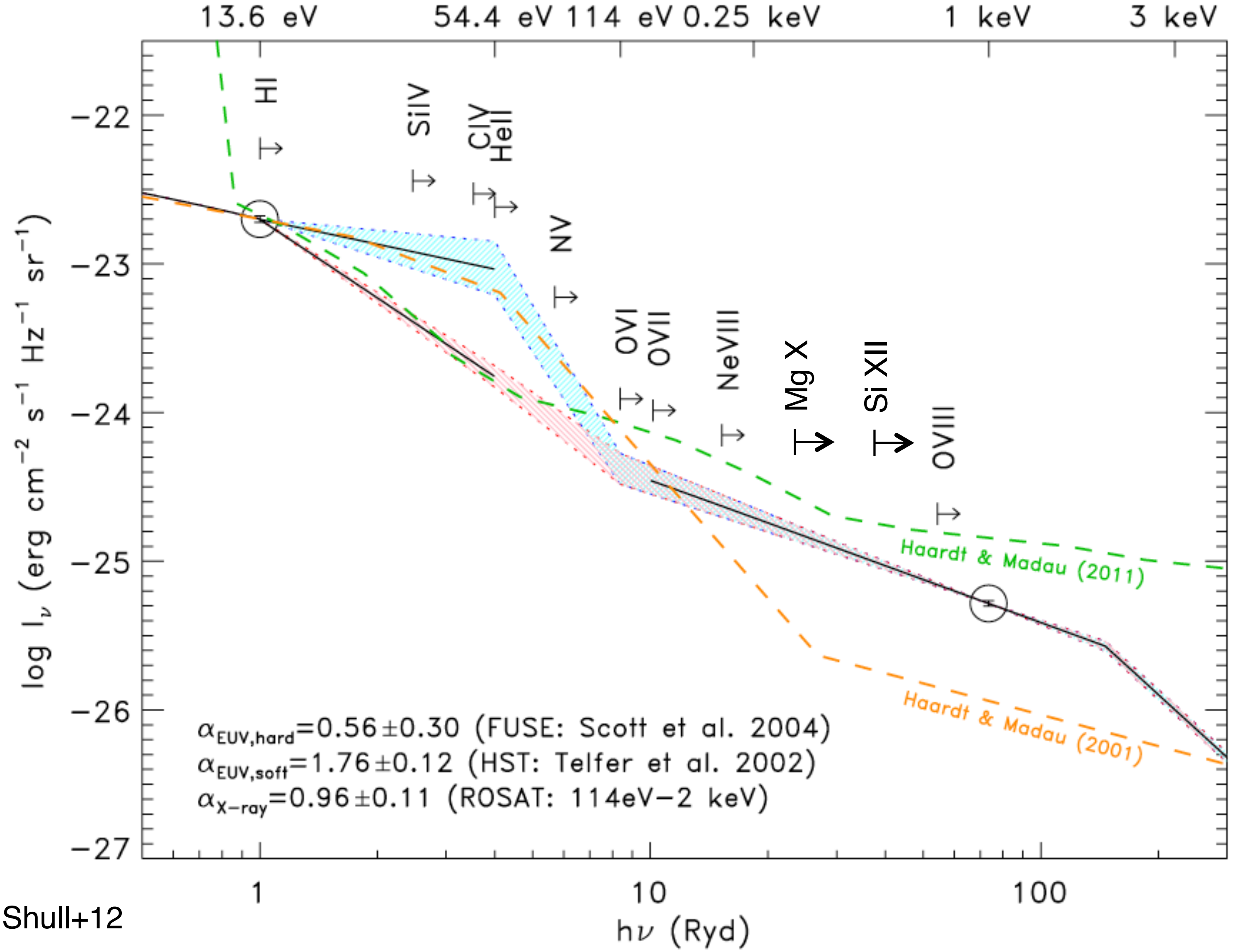
- ★ Sensitivity down to 1000 Å would allow direct observation of the continuum in a large sample of AGN at moderate redshift.
- ★ Existing ground-based observations (e.g., SDSS DR7) would give fundamental parameters such as M_{BH} and L_{Edd}.
- ★ Simultaneous ground-based observations would allow direct correlation of the soft seed photons from the disk with the Compton-scattered EUV.
- ★ Lags in the correlation would yield the geometry of the scattering region.

Observing Highly Ionized Outflows in the EUV

- ★ Observations of local AGN show that the bulk of the mass and kinetic energy in the outflows is in high-ionization gas seen in the X-ray.
- ★ At moderate redshifts (z~1) X-ray diagnostic lines such as O VII and O VIII are absorbed by the local ISM, and X-ray fluxes are too low for spectroscopy. This makes studying the evolution of outflows difficult.
- ★ High-ionization lines such as Ne VIII λλ770,780, Mg X λλ610,625 and Si XII λλ499,521 probe gas at ionization levels comparable to the O VII and O VIII features commonly seen in X-rays from local AGN.
- ★ Equally importantly, high-ionization excited-state transitions provide density diagnostics: O IV λλ608,610, O IV λλ788,790.

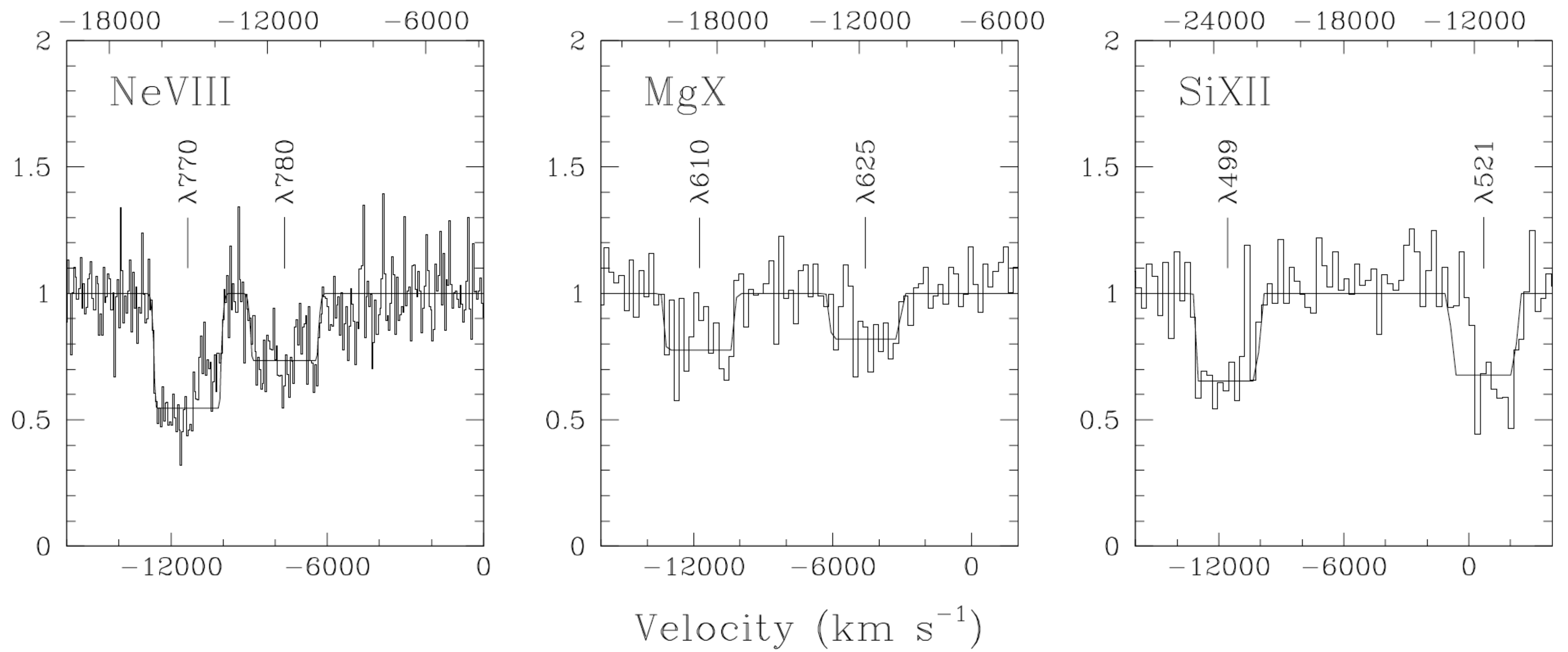
- ★ UV observations can achieve higher sensitivity and resolution.

EUV/Soft X-ray Composite Spectra of AGN



Shull+12

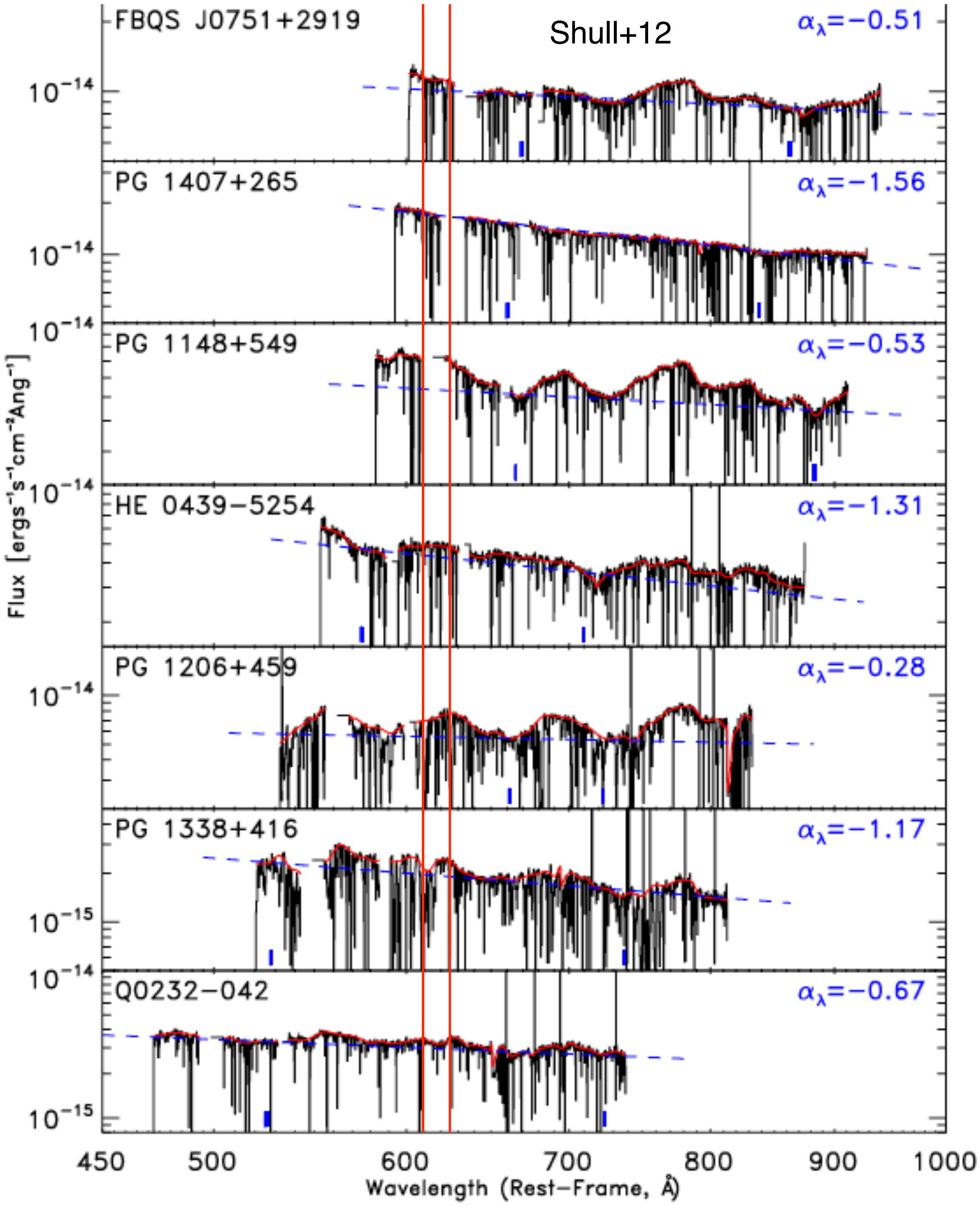
High Ionization Absorption in SBS 1542+541 (An FOS observation!)



Telfer et al. 1998

QSOs w/ z > 0.89 from Shull et al. (2012) ...

show no Mg X absorption.



Probing High Ionization Outflows in the EUV

- Probing AGN outflows requires R~15,000 and S/N~15 in the continuum.

- COS can reach flux levels of $F_\lambda > 1.5\times10^{-14}$ in ~5 orbits, or about 10^4 s. This is equivalent to i=15 for the SDSS composite QSO spectrum. However, only a handful of AGN at redshifts z >0.5 are this bright.

- At i<17, and predicted $F_\lambda > 1\times10^{-15}$, SDSS DR7 has over 250 AGN with 0.89 < z < 1.50 (to see Mg X at λ>1150 Å and Lyα at λ<3200 Å). This requires ~5 times the throughput of COS.

- Sensitivity to 1000 Å would allow observations of Mg X at z>0.61.

Far-UV Spectroscopy of Point Sources

- ★ A 4-m telescope can fit a standard Falcon 9 fairing. This gives 2.7x the throughput of HST.
- ★ For an exclusively spectroscopic mission, a light-weight mirror with 1” images optimized for point sources could be relatively inexpensive.
- ★ Improved detectors (e.g., photon-counting CCDs) could add another factor of 2x in throughput.
- ★ Improved mirror coatings could give LiF reflectivity or better down to 1000 Å.

- ★ Moderate redshift AGN would also serve to probe the IGM and the ISM.