Ultraviolet Observations of Active Galactic Nuclei and their Environs

Gerard Kriss
STScI

5/6/2013

Collaborators:
Nahum Arav (Virginia Tech), Anton Koekemoer (STScI),
Smita Mathur (Ohio State),
Jennifer E. Scott (Towson University)

Also see white paper “Synergistic Astrophysics in the Ultraviolet using Active Galactic Nuclei”, Kriss et al. 2012, arXiv1209.3196

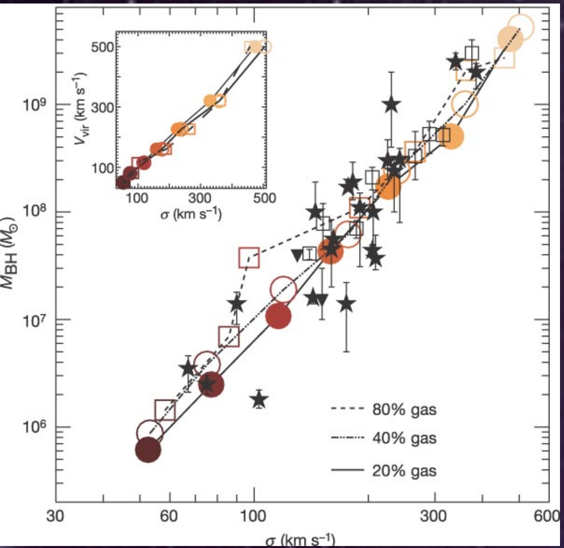
Observations of AGN Fulfill Multiple Scientific Objectives

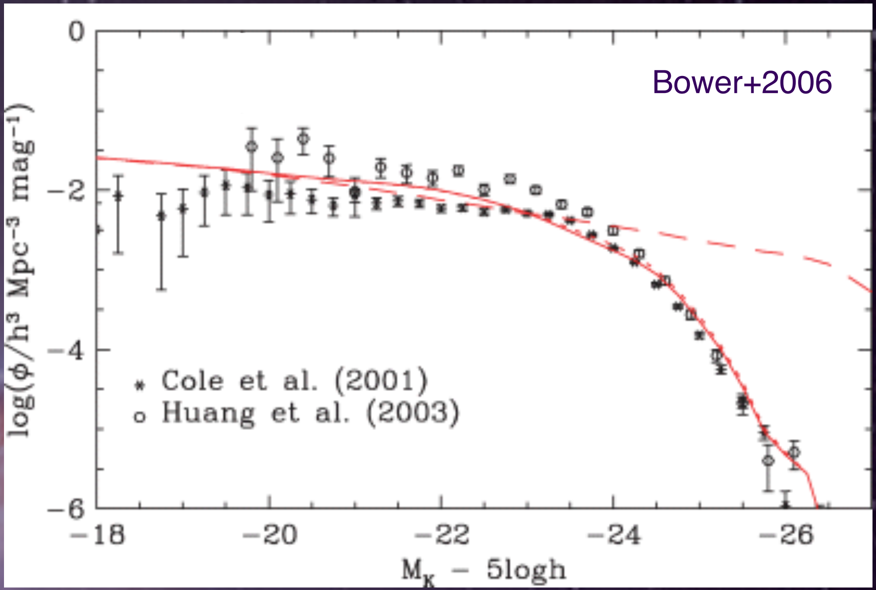
- **How do black holes accrete matter, grow through cosmic time and influence their host galaxies?**
- **AGN are ideal background light sources for studying the intergalactic medium (IGM), the circumgalactic medium (CGM), the interstellar medium (ISM), and galactic halos.**
- **Observations of well defined samples of AGN can be used to probe foreground gas while doing all of the following simultaneously:**
  - Reverberation mapping of the BLR in nearby AGN, and quantifying the kinetic luminosity of outflows seen in absorption.
  - Survey and quantify outflows in intermediate redshift AGN, ascertain the shape of the continuum in the extreme ultraviolet, and study radiation reprocessing near the black hole and accretion disk.
- **Observations of ~200 local AGN have defined a basic paradigm. We need greatly expanded samples with real measurements to test it.**

AGN and Feedback are Critical for Galaxy Evolution

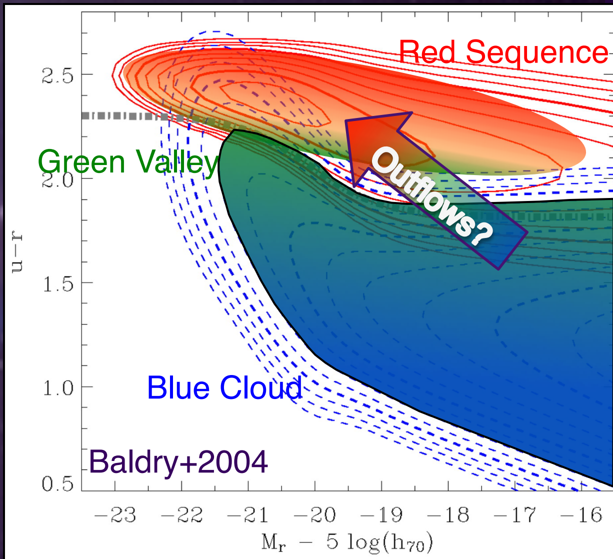
★ Downsizing: AGN feedback limits galaxy growth.

DiMatteo+2005





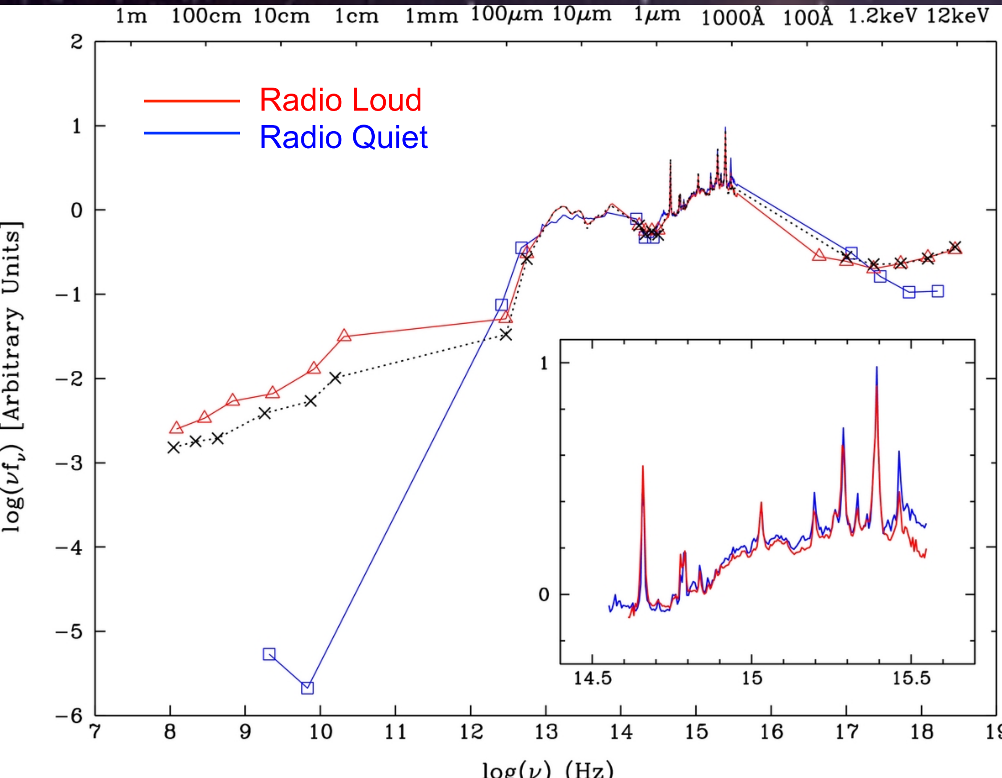
★ M_{BH}-σ : Feedback of ~5% of L_{edd} couples black hole growth to galaxy growth, leading to the correlation.



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

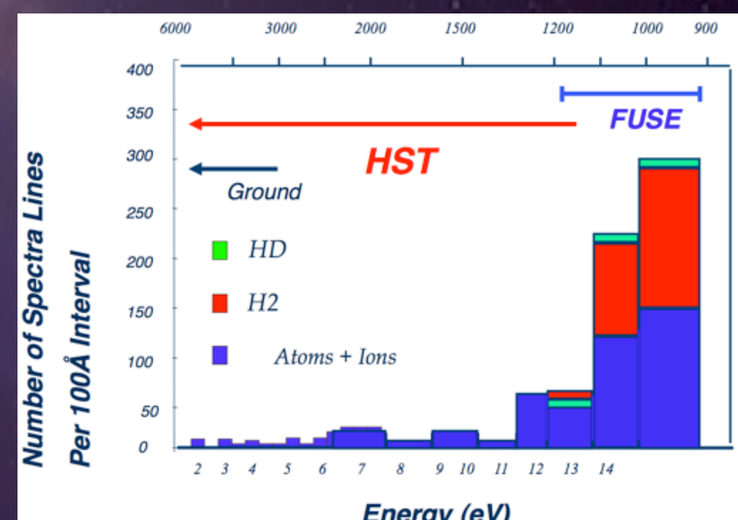
Why the Ultraviolet is important for AGN

AGN Energy Output Peaks in the Ultraviolet



Shang+11

Spectral diagnostics are abundant in the UV and EUV



(Courtesy E. Jenkins)

Science Challenges for Future Studies of AGN

★ **How do inflows feed accretion onto the black hole?**

★ **How do outflows influence the evolution of the host galaxy?**

- Both inflows and outflows may be related to the structure and dynamics of the broad-line region (BLR) in AGN.

★ **How does the accretion disk radiate the extracted gravitational energy of the inflowing matter?**

★ **What are the demographics of black holes in AGN?**

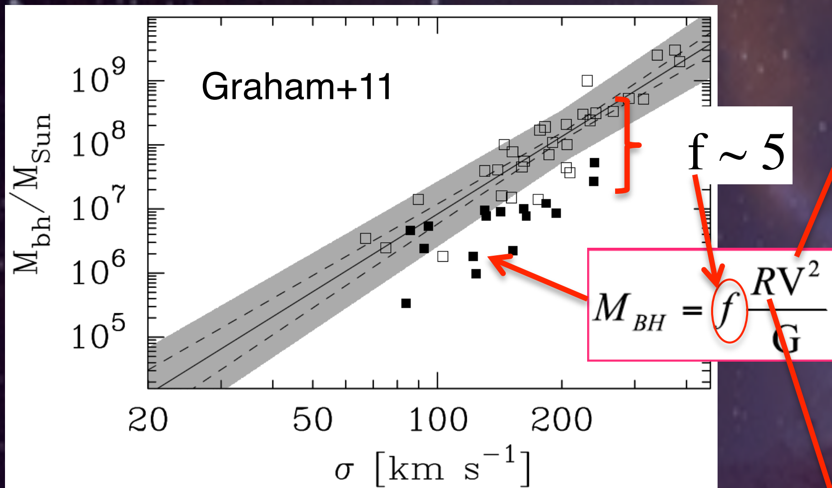
The Bottom Line

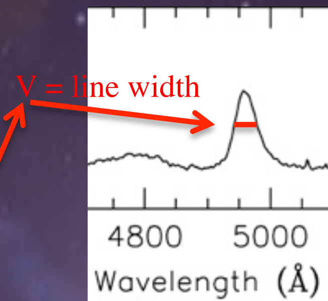
Fundamental progress requires an 8m-class observatory with

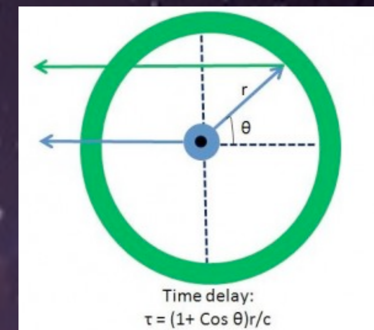
- High-resolution UV spectroscopy
- High spatial resolution integral-field spectroscopy

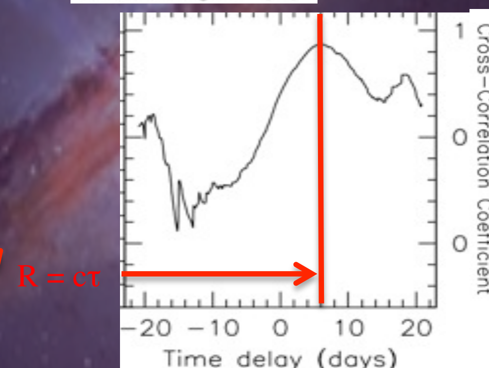
Black Hole Masses via 2D Reverberation Mapping

- All black-hole masses in AGN at z >~0.1 are based on scalings from 1D reverberation mapping of local AGN (~16 objects).
- Local AGN are placed on the M_{BH}/σ relation using empirical scale factor, f.



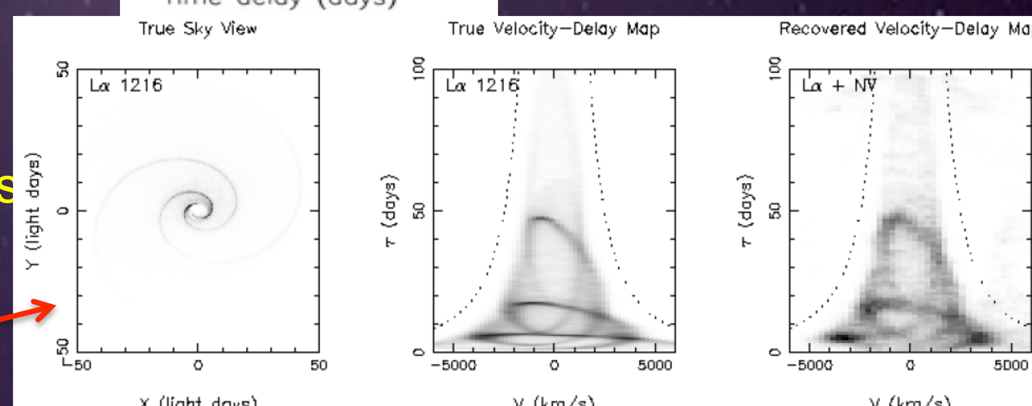




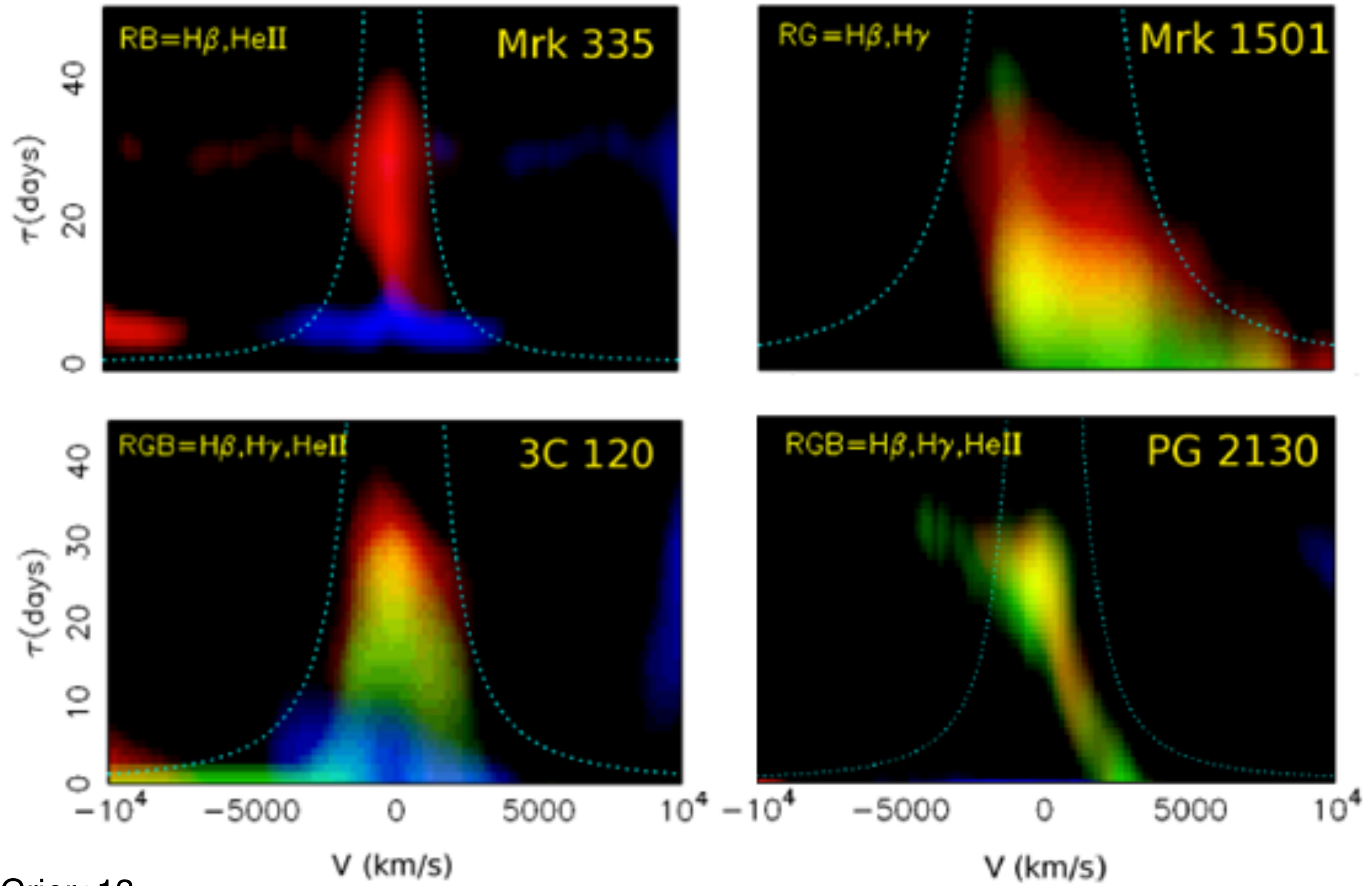


COS observations of NGC 5548 require 1 orbit per day for 150 days. The campaign is tolerant to several dropouts of 1-3 days.

- The scale factor, f, depends on the geometry and kinematics of the broad-line gas.
- Two-dimensional (i.e., velocity-dependent) reverberation mapping reveals the geometry and kinematics of the BLR, giving "f".
- Result from simulated 150-day campaign on NGC 5548.



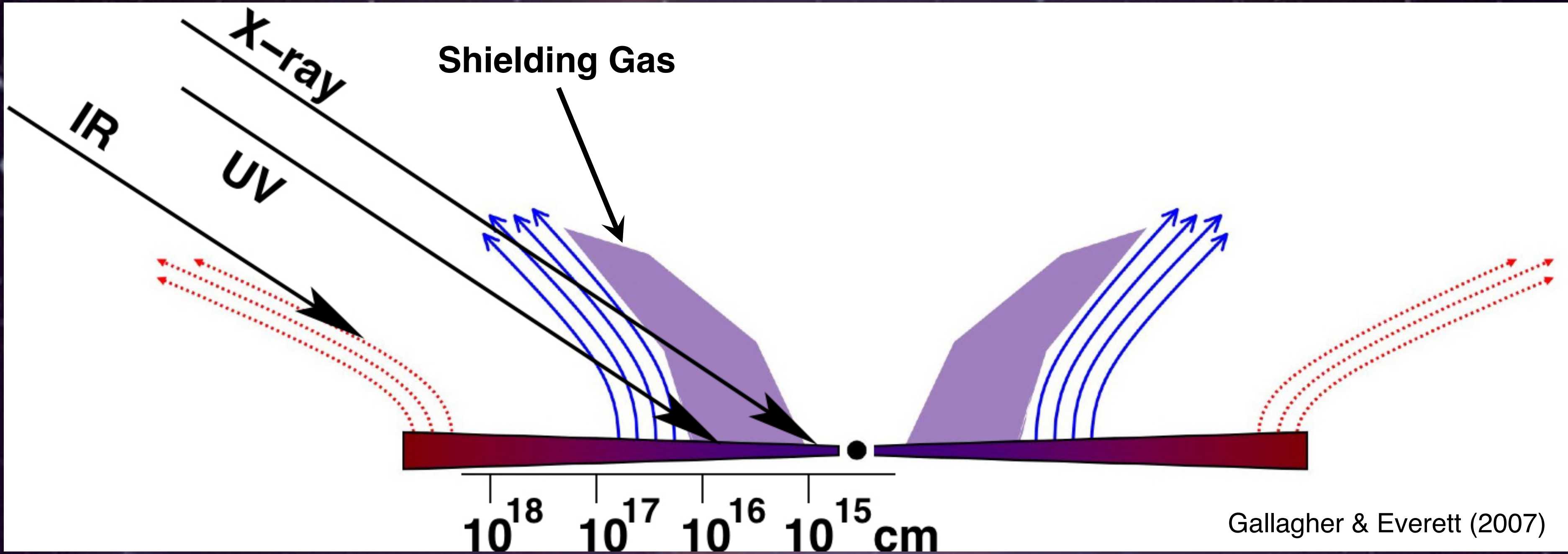
2D Ground-Based Reverberation Maps Show Infall



Grier+13

Would UV lines, Lyα and C IV, show the expected outflow if the BLR is also a wind from the accretion disk?

Disk-wind Model for Outflows in AGN



- ★ 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}

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**

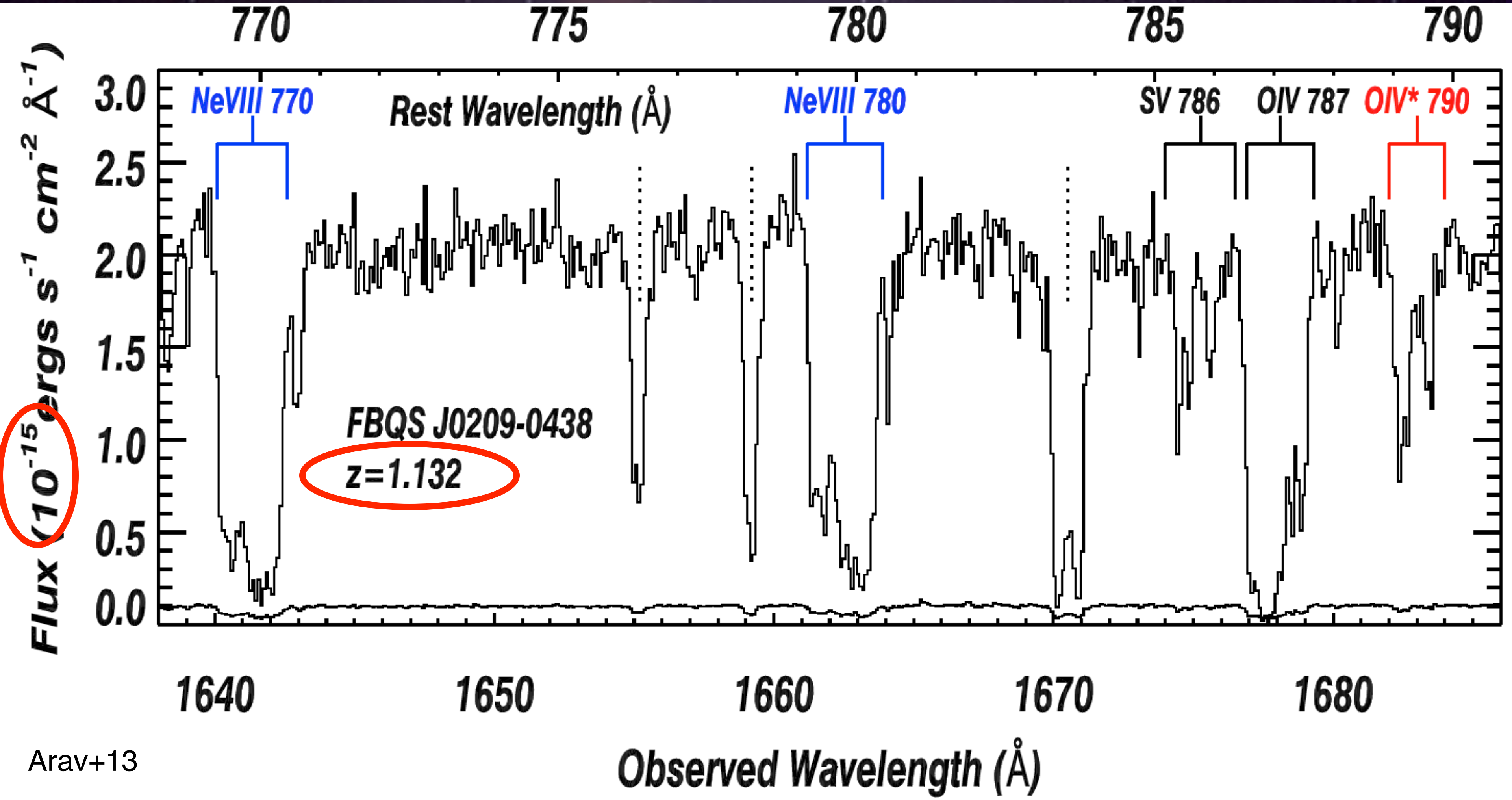
- The mass flux, $\dot{M}_{out} = 4\pi \, \Delta\Omega \, r \, N_H \, \mu m_p \, v_{out}$
- The kinetic luminosity, $L_k = ½ \, \dot{M}_{out} v_{out}^2$

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

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

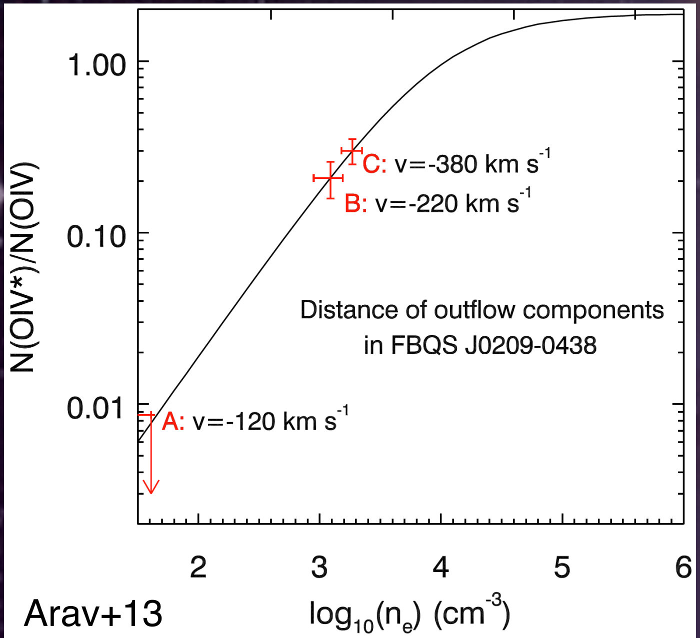
★ **Density measurements enable us to then determine the distance, r.**

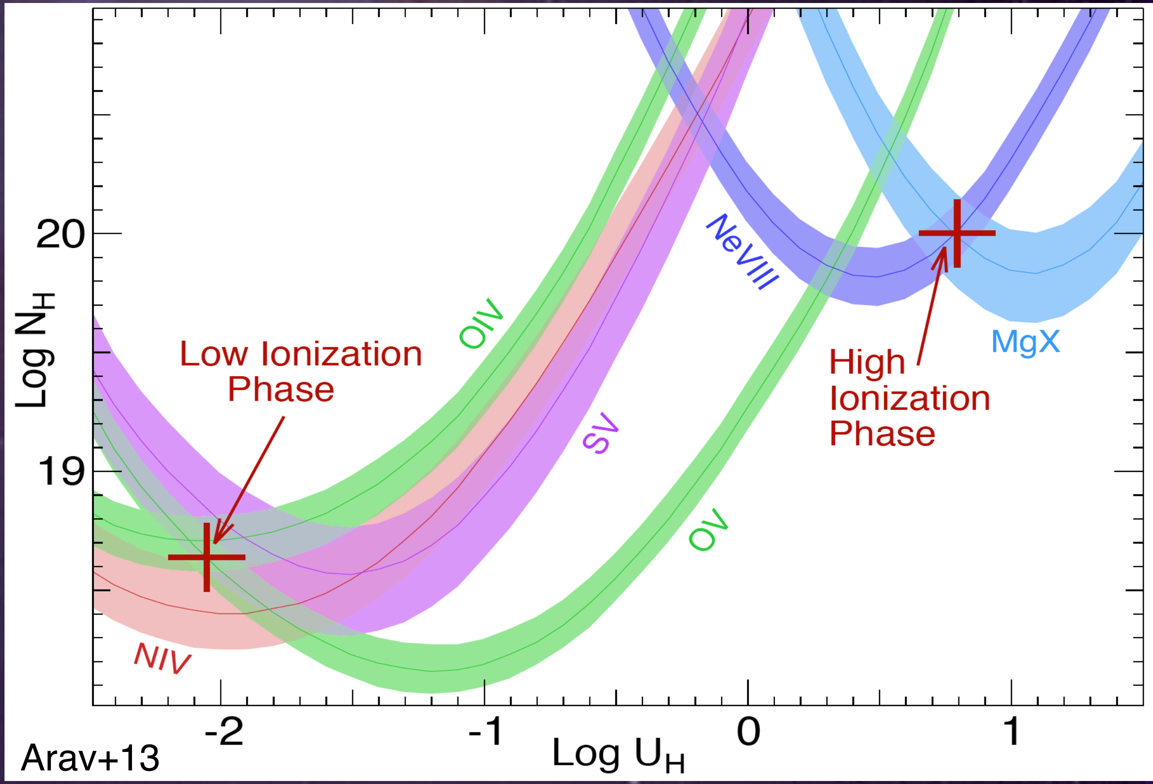
A high-ionization outflow in FBQS J0209-0438



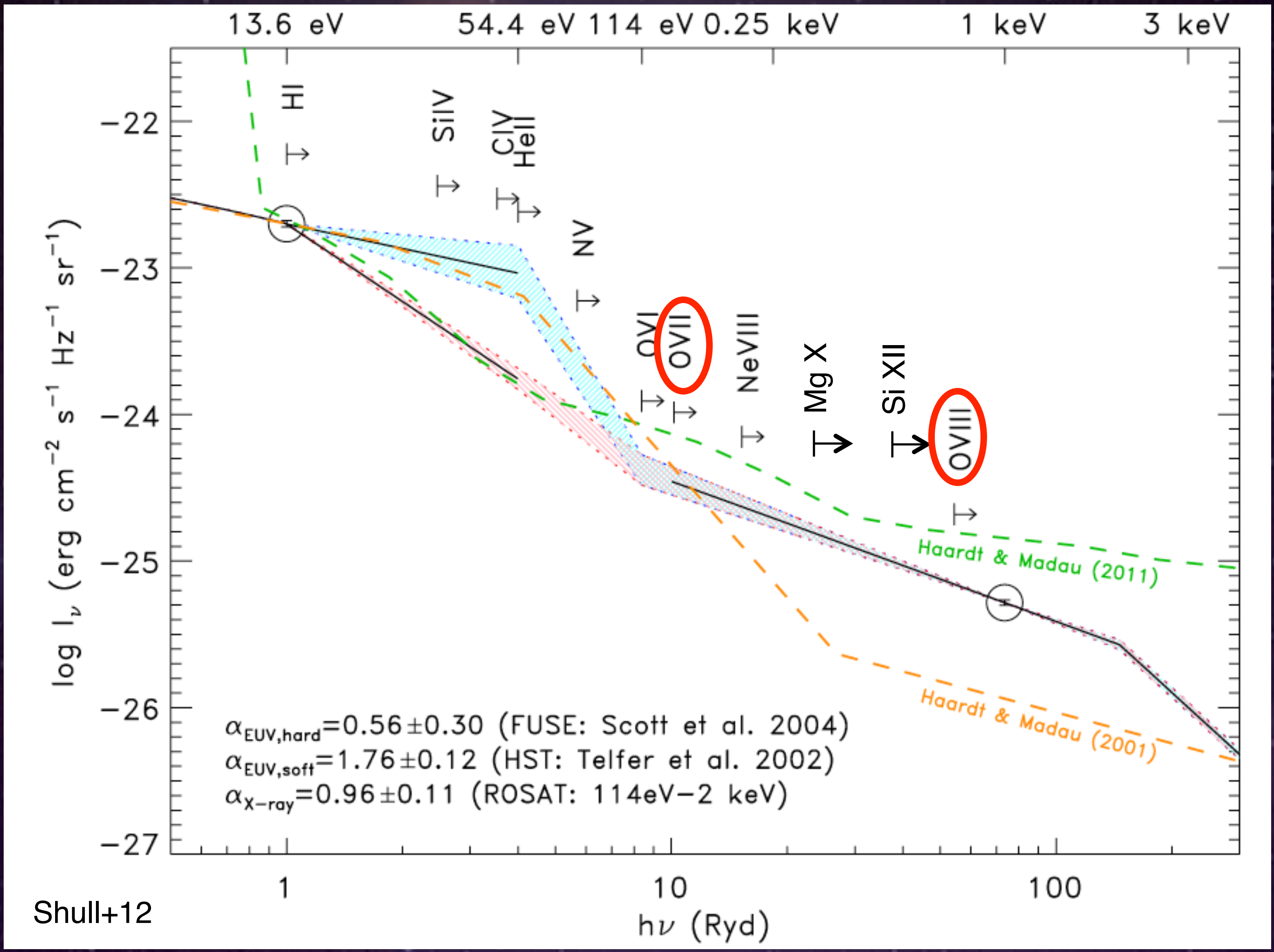
Arav+13

Physical parameters of the outflow in FBQS J0209-0438

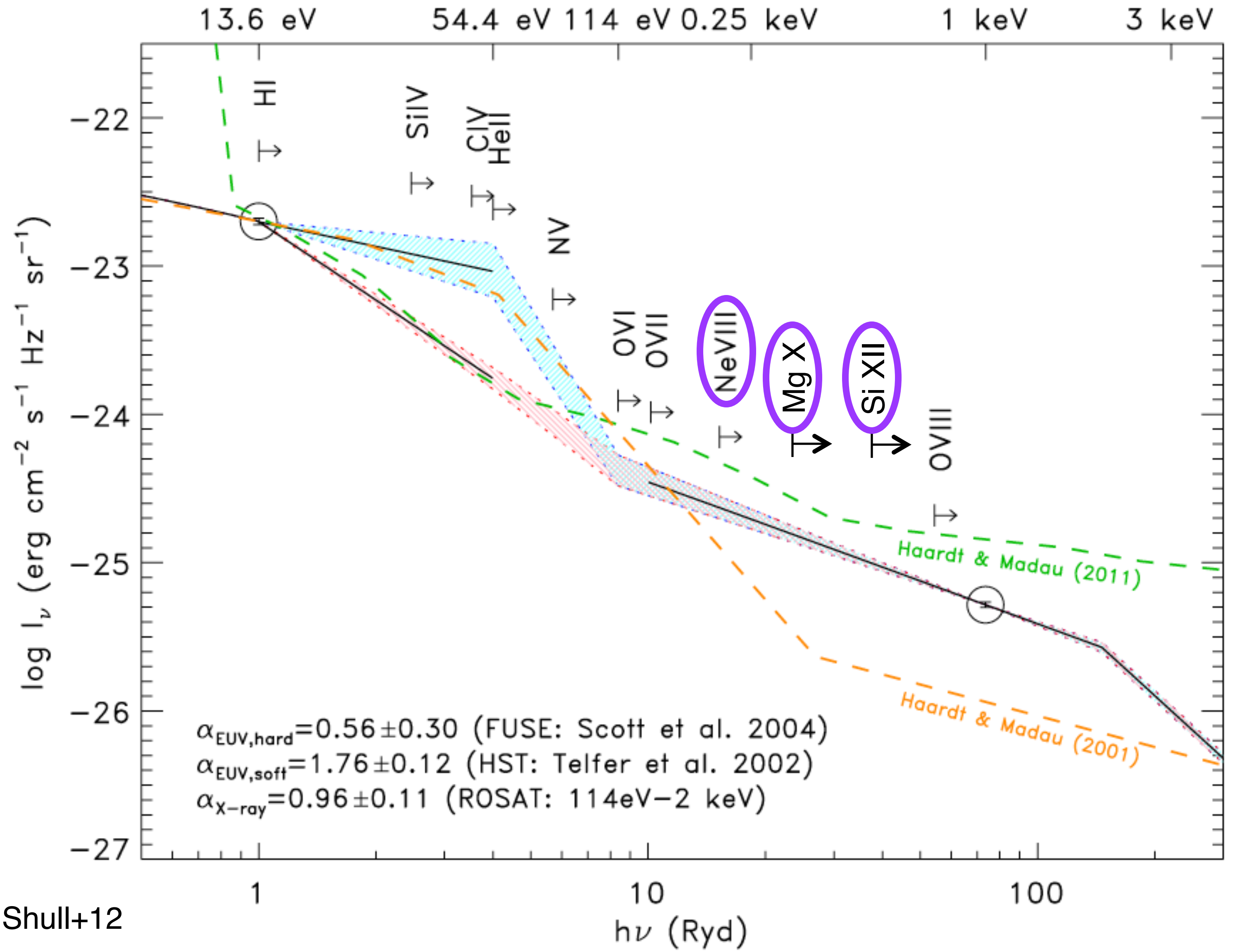




High Ionization EUV Lines in AGN Trace the Same Gas as X-ray Observations in Low-redshift AGN

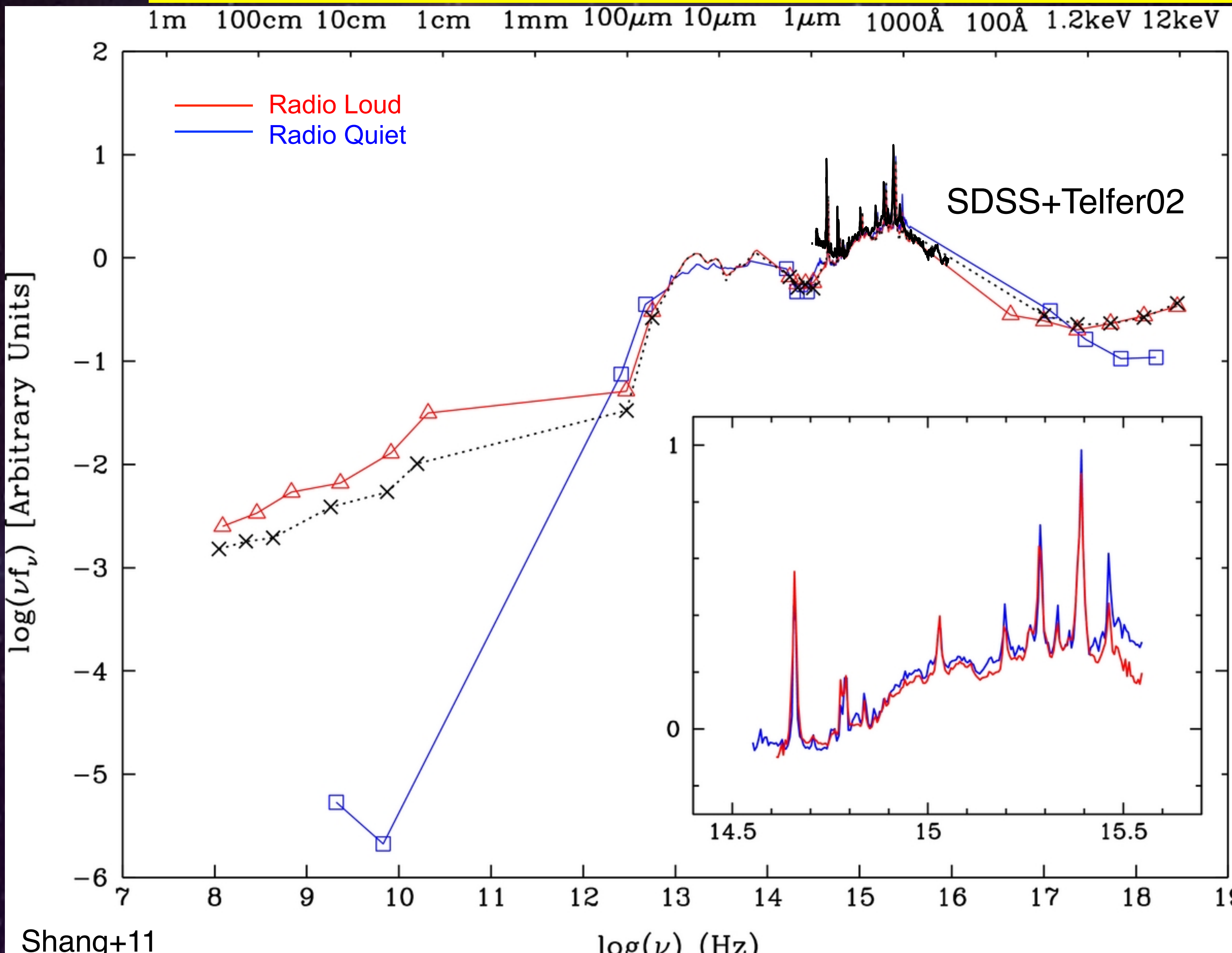


High Ionization EUV Lines in AGN Trace the Same Gas as X-ray Observations in Low-redshift AGN



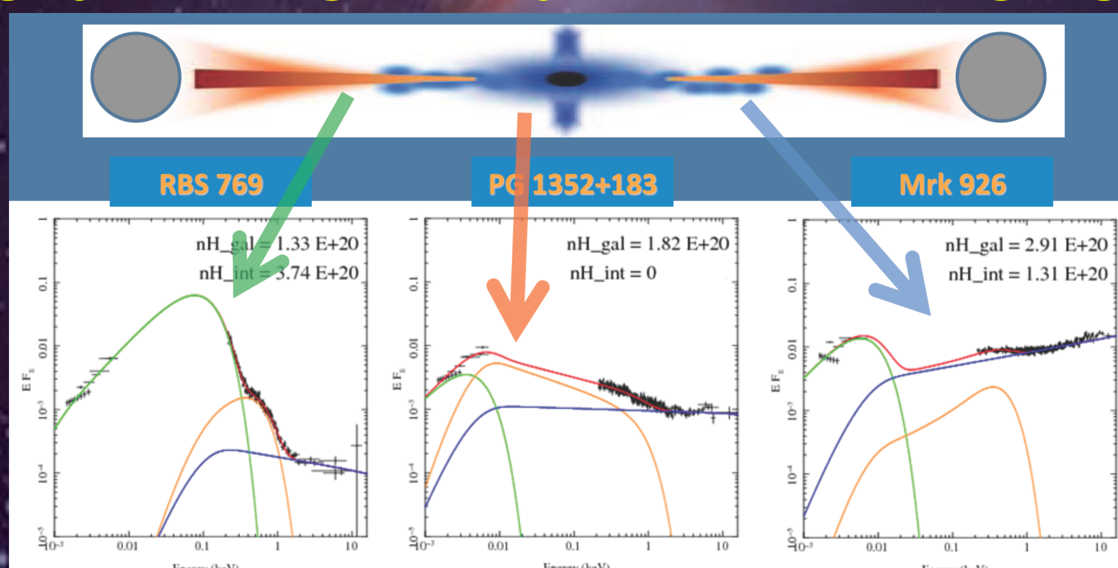
Shull+12

AGN Spectral Energy Distribution



The Physics of the Accretion Disk in the Extreme UV

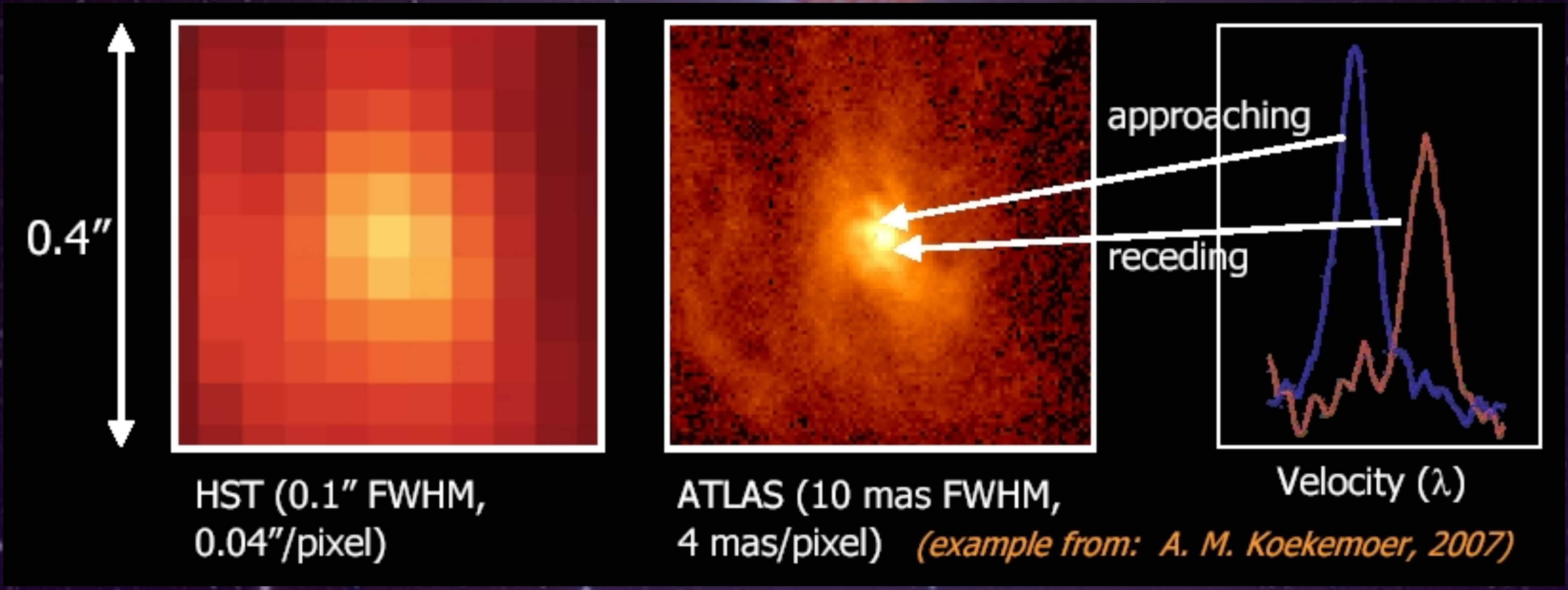
- Sensitivity down to 1000 Å would allow direct observation of the continuum in large numbers of AGN at redshifts from 0.5—3.0.
- Existing ground-based observations (e.g., SDSS DR7) would give fundamental parameters such as M_{BH} and L_{edd}.
- Simultaneous ground-based observations would allow direct correlation of the soft seed photons from the disk with the Compton-scattered EUV.
- Correlated lags yield the geometry of the scattering region.



Jin, Done & Ward 2012

Direct Black Hole Mass Measurements to Cosmological Distances

- Batcheldor & Koekemoer (2009) show that the resolution and low sky brightness afforded by the Lyα emission line in the UV is more efficient than 30-m ground-based telescopes in the IR.
- An 8-m space-based telescope can observe a disk with the Lyα surface brightness of M87 to a limiting redshift of z=1.5.



Far Ultraviolet Observations of AGN
Science Requirements

- **Spectroscopy with time resolution of 1000 s**
- **Field of View: arc seconds to arc minutes**
  - Point source observations can use a single aperture
  - Black-hole masses require integral field spectroscopy over 1” × 1”
  - Arc-minute fields could enable multi-object spectroscopy when probing galactic environs
- **Physical / angular resolution(s)**
  - Most targets are point sources, however,
  - Measuring black hole masses requires angular resolution of 10 mas @ 3000 Å.
- **Spectral resolution(s)**
  - Required: R=15,000 / Desired: R=40,000
  - Integral Field Unit required for black-hole mass measurements w/ R=1000
- **Wavelength band(s)**
  - Required: 1150—3200 Å / Desired: 912—3200 Å
- **Sensitivity**
  - Required: 1×10^{-15} erg cm^{-2} s^{-1} per resolution element in 2000 s at 1150 Å
  - Desired: 5×10^{-16} erg cm^{-2} s^{-1} per resolution element in 2000 s at 912 Å

The Path Forward: the Next 10 Years

★ **Hubble is all we have for 5—10 years**

- HST will obtain good spectra of a few dozen high-ionization outflows
- HST will characterize the continua of ~100 moderate redshift QSOs
- HST can do ~1 reverberation campaign per cycle.

  BONUS: Parallel imaging in adjacent fields gives HDF-like depths.

The Path Forward: Years 10—20

★ **Without Hubble, they don't look promising, but there is a path:**

- Use Explorers for technology development & special applications
  - Dedicated missions for monitoring/reverberation mapping
  - Improved mirror coatings for >80% reflectivity from 912—3200 Å
  - Improved UV detectors with >50% DQE
  - Develop high throughput UV Integral Field Spectrographs

- Make the 2nd NRO telescope a UV/Optical optimized observatory
  - Moderate resolution UV Spectroscopy (R~20,000)
  - Wide-field imaging
  - At least as good, if not better, than HST with improved technology

The Path Forward: Years 20—30

★ **Further progress requires a multi-purpose 8m+ UV/O observatory providing both diffraction-limited imaging and UV/O spectroscopy.**

- All AGN with i > 19 are accessible to high-resolution UV spectroscopy. (This is several thousand QSOs.)
- Density on the sky is sufficient for tomographic mapping of the environs of nearby galaxies, including all AGN at z < 0.03.
- IFU spectroscopy of outflows in emission will be possible, as well as absorption spectroscopy using background AGN.
- IFU spectroscopy will enable direct black-hole mass measurements to cosmological distances using Lyα emission in gaseous disks.

★ **The sky density of accessible AGN enables parallel spectroscopy when carrying out deep imaging surveys.**

★ **Well chosen samples of AGN simultaneously probe foreground gas in the IGM, CGM, the ISM and galactic halos.**

Anticipated Scientific Achievements

- ★ **The structure and kinematics of gas flows in AGN, from the scales that feed the accretion process to those that influence the host galaxy via massive outflows.**

- ★ **Understand the processes and structures that govern the radiative output of accretion disks.**

- ★ **Measure black hole masses directly, and calibrate secondary indicators.**
  - Demographic studies of QSO/Black Hole/Host evolution
  - Yield an alternative standard candle for cosmological studies (see abstract by Benz & Vestergaard).