Multiwavelength observation campaign of Mrk 509: UV spectra of the X-ray Outflow

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The Influence of AGN Outflows

- ★ **They may affect dispersal of heavy elements into the IGM and ICM.** [Cavaliere et al. 2002; Adelberger et al. 2003; Granato et al. 2004; Scannapieco & Oh 2004]
- ★ **They influence the ionization structure of the IGM.** [Kriss et al. 1997].
- ★ **They are intertwined with the evolution of the host galaxy.** [Silk & Rees 1998; Wyithe & Loeb 2003].
- ★ **We still aren't sure how the outflows are created, what structure they have, or how much mass and energy they carry.**
  - A key question: do the outflows escape the confines of the host galaxy?
- ★ **Crucial to understanding the workings of the central engine:**
  - Accretion process
  - Total energy budget
- ★ **Low-redshift AGN are the nearest and brightest.**
  - ➢ We can study these at the highest angular resolution and best S/N.

X-ray/UV Campaign on Mrk 509 (Fall 2009)

★ **XMM/Newton (Kaastra)**
- 10 x 60 ks at 4-day intervals

★ **INTEGRAL (Petrucci)**
- 10 x 120 ks, matched to XMM

★ **Swift (Kaastra)**
- Simultaneous continuum monitoring in UV and X-ray w/ XRT & UVOT
- 12 x 1 ks at 4-day intervals establishing baseline before XMM

★ **Chandra + HST (Kaastra)**
- 180 ks Chandra/LETGS: 10 & 12 Dec 2009.
- 10 orbits HST/COS: 5 on 10 Dec 2009, 5 on 11 Dec 2009.

Scientific Goals for the X-ray/UV Campaign on Mrk 509

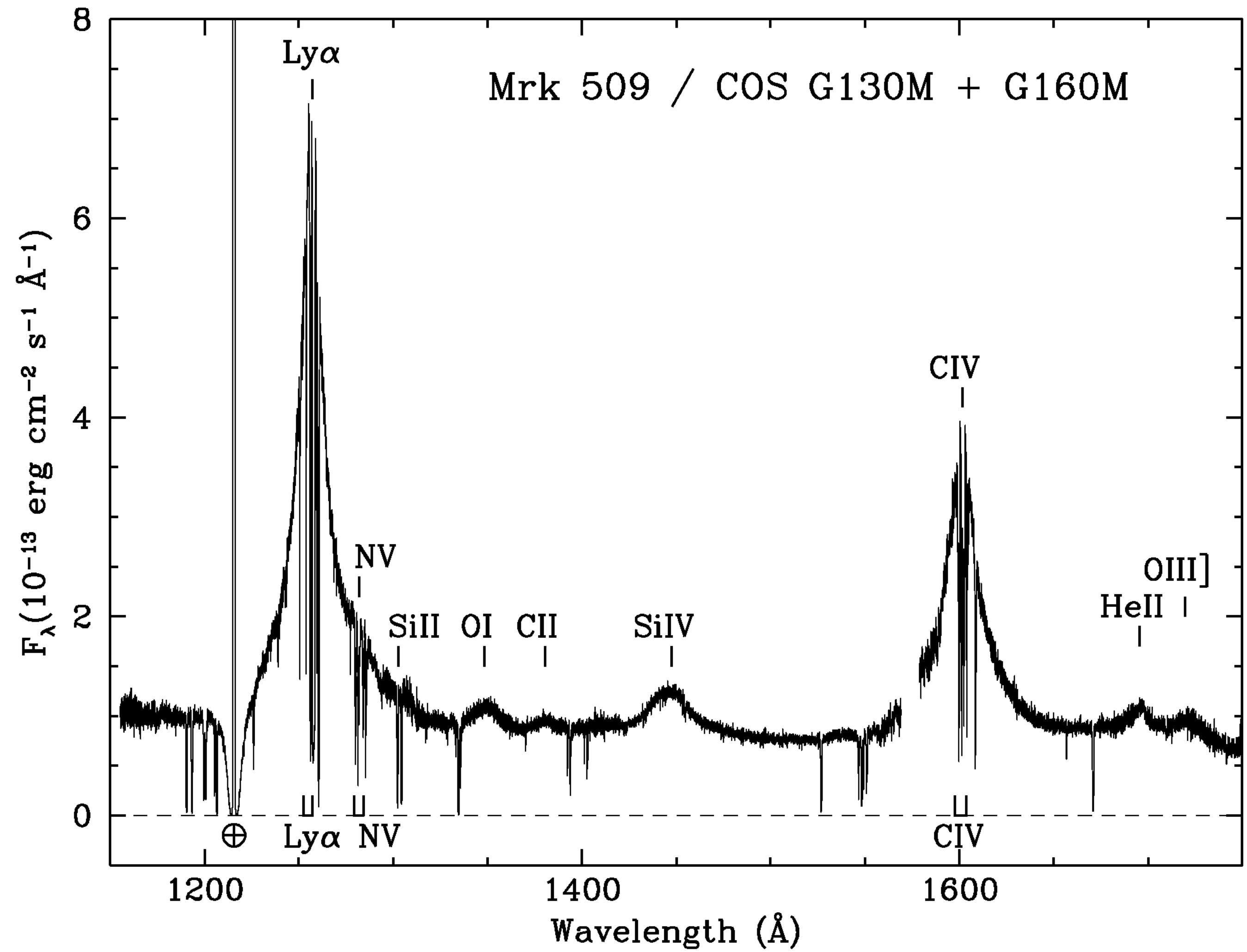
- ★ **Measure absorption in the outflowing gas.**
- ★ **Determine abundances of C, N, O, Ne, Si, S, and Fe over a broad range of ionization parameters.**

  ⇒ Contributions from various supernova types and intermediate mass stars to the chemical enrichment processes in galaxy cores.

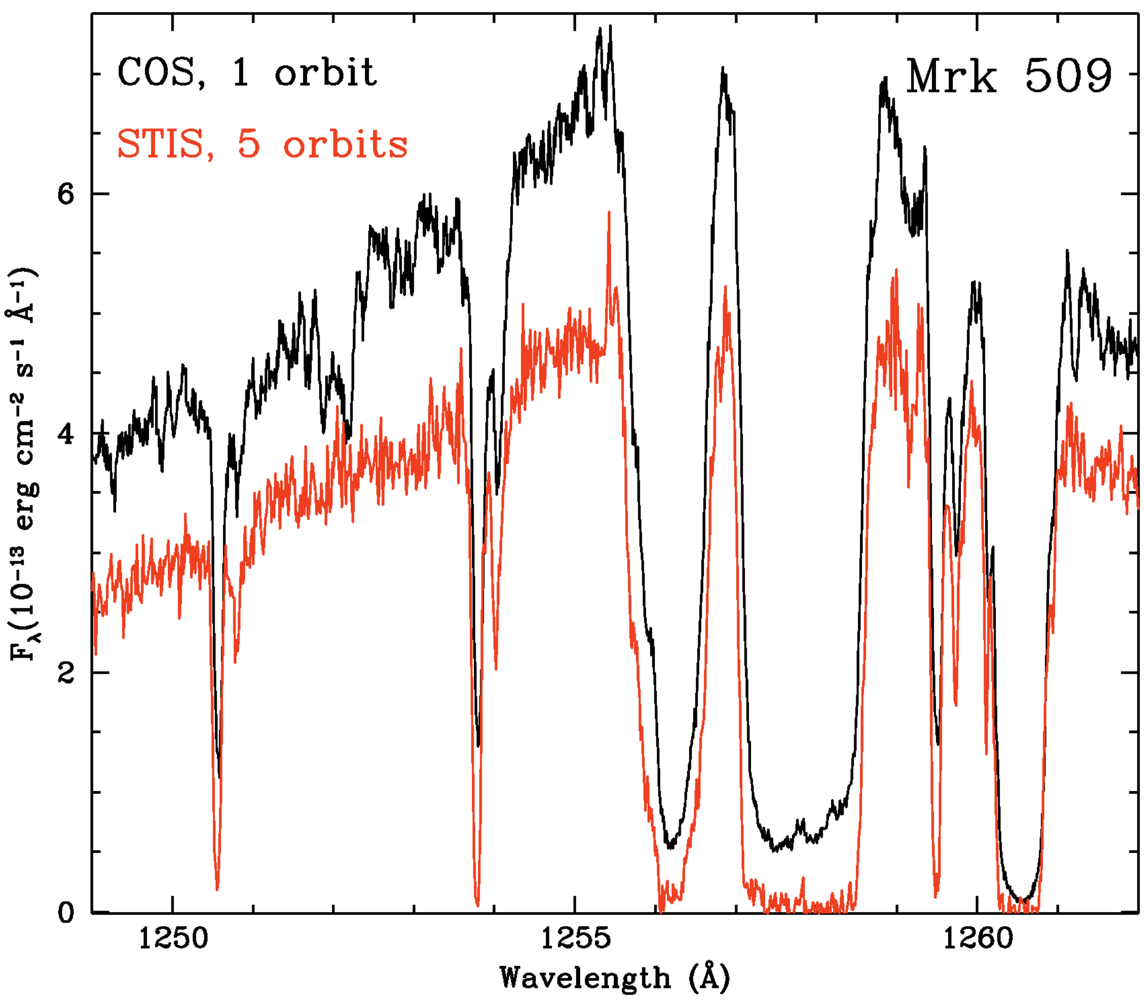
- ★ **In the UV, use velocity-resolved measurements of Li-like doublets to determine column density and covering factors for C and N in the outflowing gas.**
- ★ **With photoionization modeling, this gives CNO abundances.**

  ⇒ This provides an anchor for the X-ray measurements since historical (FUSE and HST) and current HST UV measurements can determine the total Hydrogen column density.

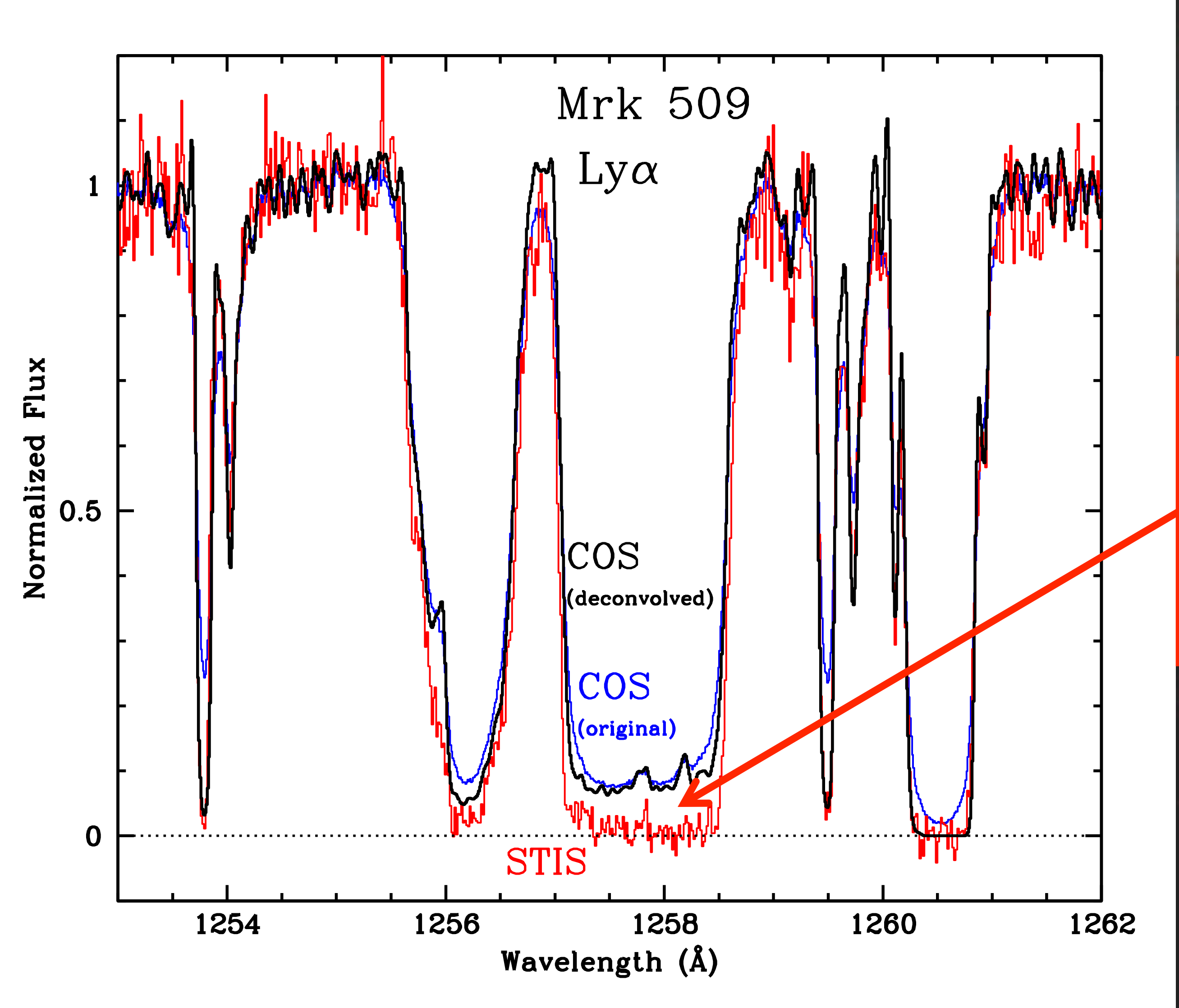
COS Merged Spectrum (10 orbits) of Mrk 509



Lyα Region of Mrk 509



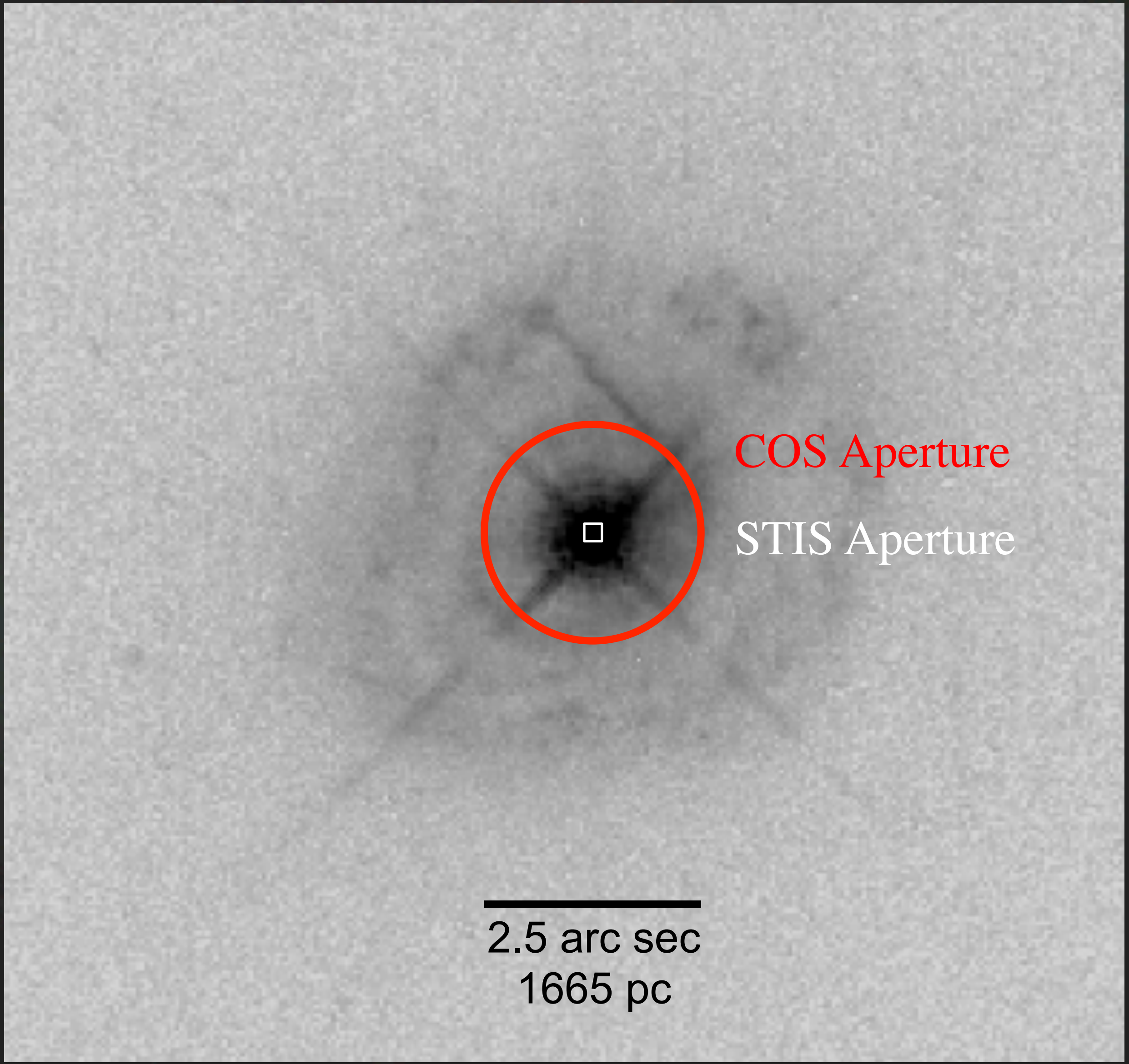
Deconvolved COS Spectrum Compared to STIS



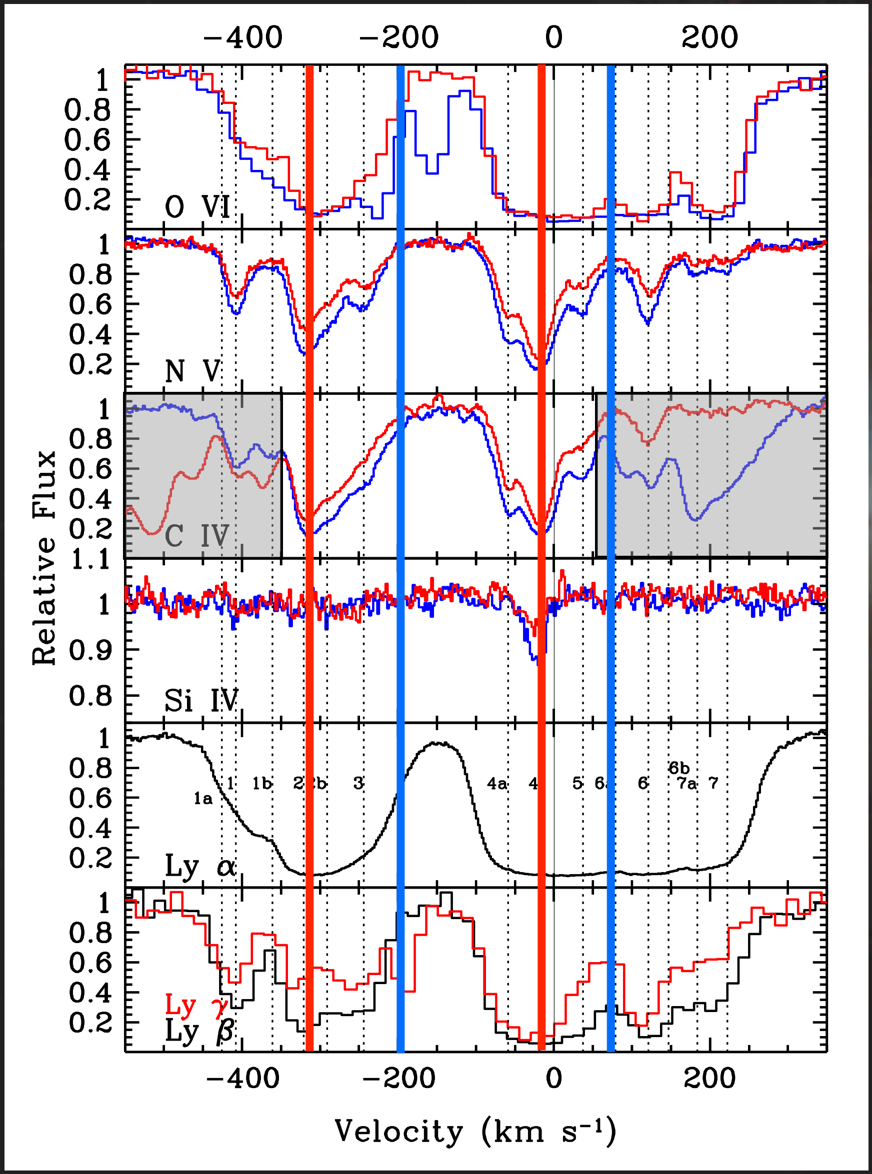
Red: STIS
Blue: Original COS
Black: Deconvolved COS

"Extra" light here is scattered light from a region <0.45" in diameter surrounding the nucleus.

HST WFPC2/F547M Image of Mrk 509

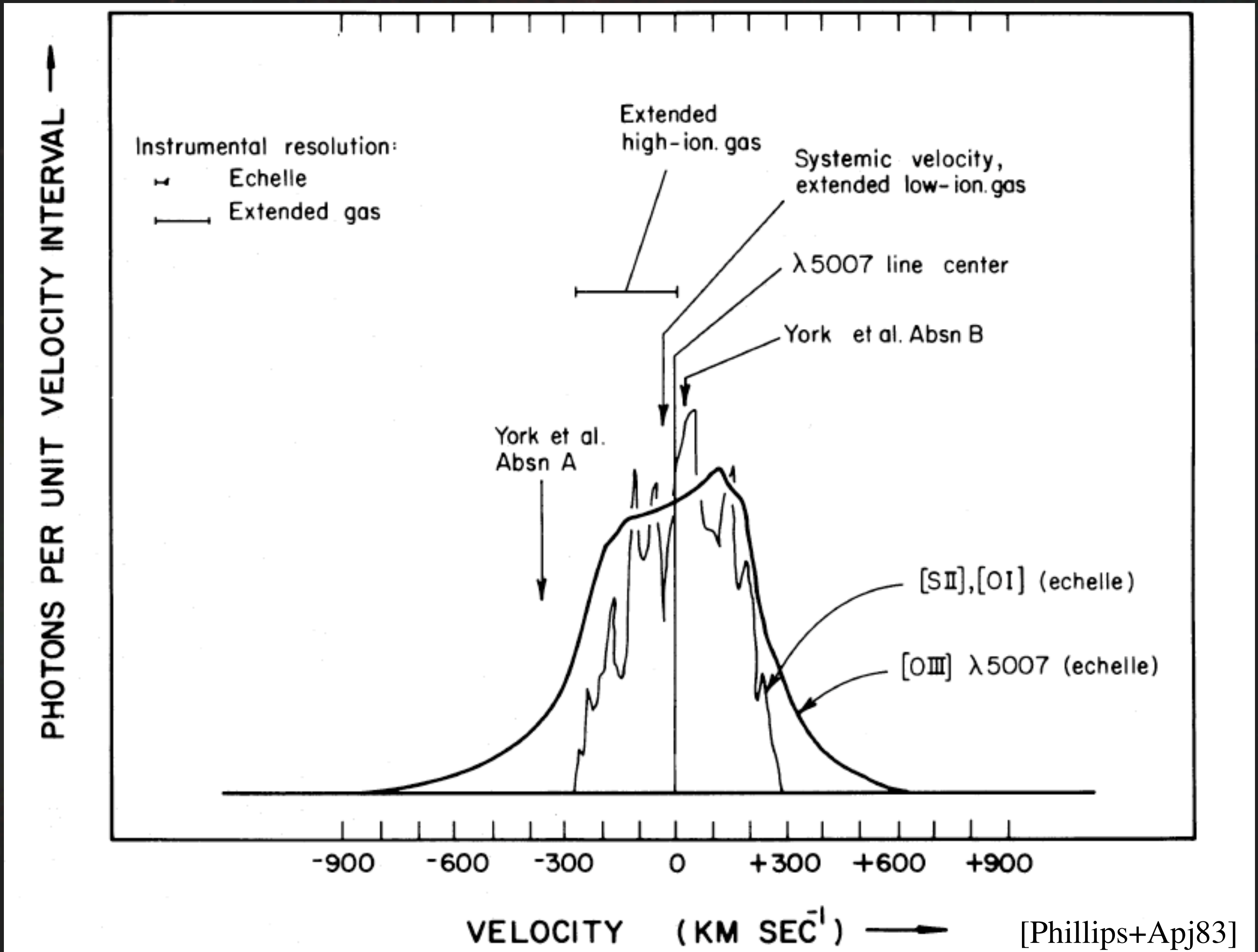


COS & FUSE UV Absorption lines in Mrk 509



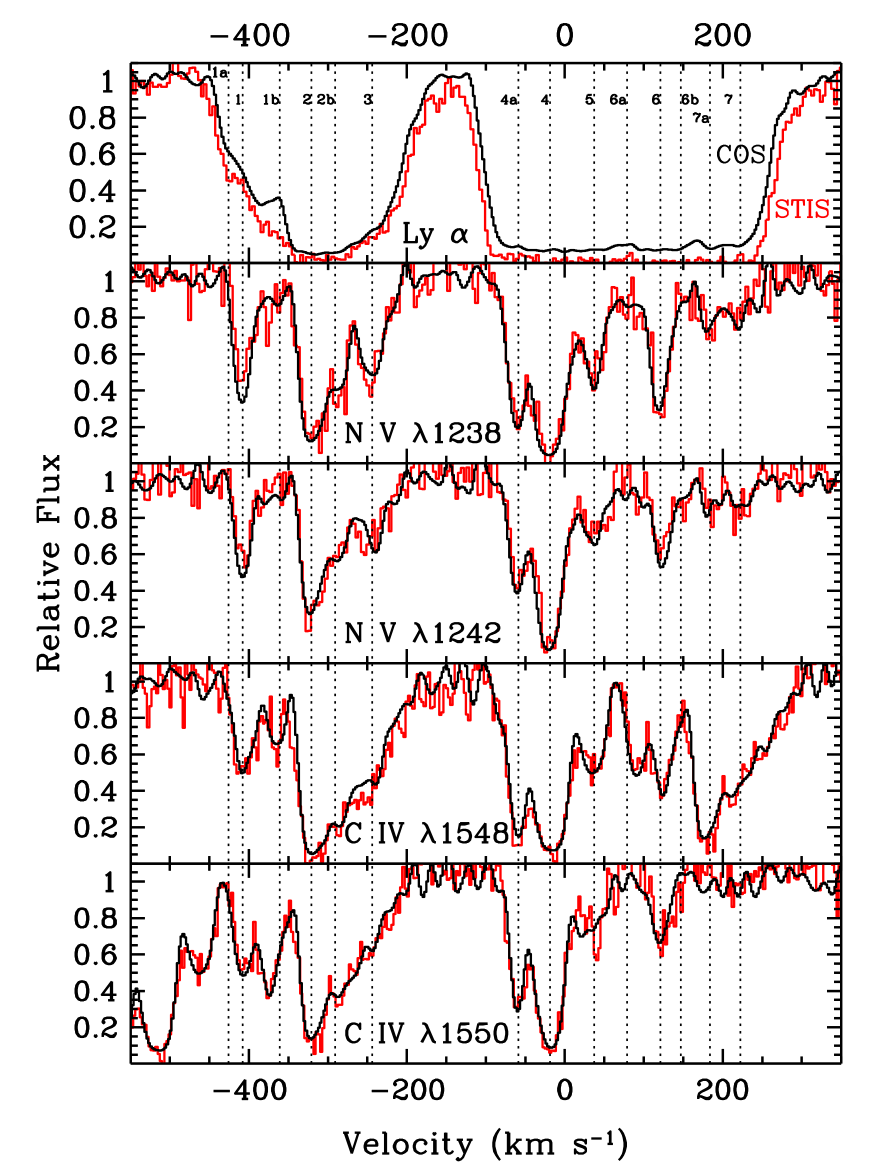
- O VI, Lyβ, and Lyγ from FUSE spectrum [Kriss+00]
- C IV doublet is split by only 500 km s^{-1}, so grey regions can't be used for optical-depth.
- Red lines mark the velocities of the components seen in the RGS spectrum.
- Blue lines mark the velocities of the components seen in the Chandra/LETGS spectrum.

[O III] Line profile in the Nucleus



[Phillips+Apj83]

Variability between the COS & STIS Spectra

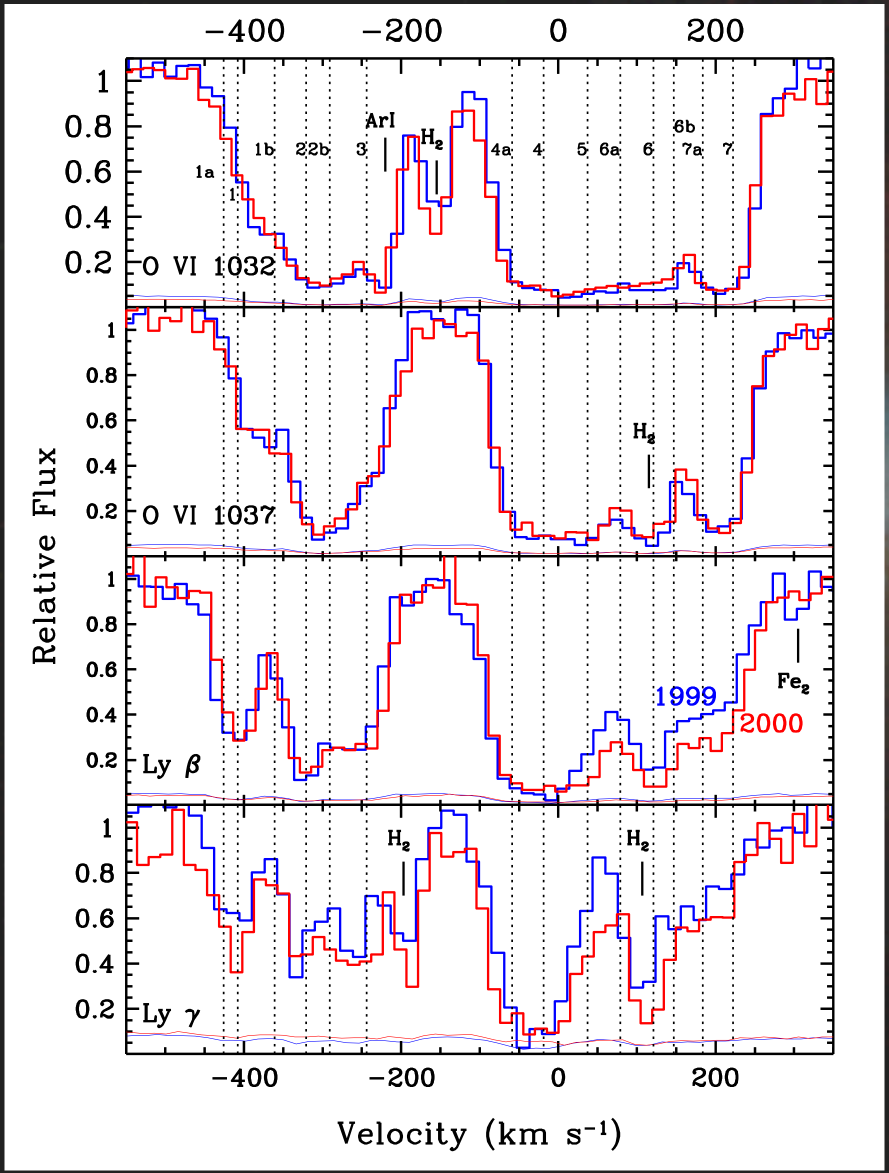


- STIS spectrum from 2001 [Kraemer+03].
- COS spectrum from 2009 [Kriss+11].

- 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 $\xi = 0.67$ (Kraemer+03), we get an upper limit on the distance of $r < 250$ pc.

Variability between the FUSE Spectra



- FUSE spectra from 1999-11-06 [Kriss+00] and 2000-09-05 [Kriss+11].
- Variations in Lyβ and Lyγ in Components 5 and 6 set a lower limit on the density in all of these components of $n_e > 6\ \mathrm{cm}^{-3}$.
- Given a photoionization model with $\log \xi = 0.71$(Kraemer+03), we get an upper limit on the distance of $r < 250$ pc.

Interpretation of the Absorption Components

- ★ **Components 1-3 are part of the AGN outflow, although the UV gas is lower ionization than the X-ray.**
- ★ **Similarly, Components 4a, 5-6 are associated with the lower-velocity portion of the X-ray outflow, but again, lower ionization than the X-ray gas.**
- ★ **Component 4 is the ISM+Halo of the host galaxy.**
- ★ **Component 7 at ~200 km s^{-1}, is infalling to Mrk 509. We suggest that it might be similar to an HVC.**
  - Thom et al. (2008) find that HVC Complex C in the Milky Way has log n ~ −2.5, dimensions 3x15 kpc, distance of 10 kpc, and a total mass of 8.2×10^6 *M*.
  - For Component 7 in Mrk 509, for solar abundances, the total hydrogen column is $\sim 4 \times 10^{18}$ cm^{-2}. If this is similar to Complex C, its size is 1.3 kpc, and its distance from the center of Mrk 509 is 19 kpc.

Implications for Feedback

★ **Most feedback models require a total energy input from the active nucleus of >~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:**

- $\dot{M} = C_f\, 4\pi\, r^2\, n\, v = 0.75\times(r/250\ \mathrm{pc})(n/160)(v/400\ \mathrm{km\ s^{-1}}) < 940\ M_\odot \mathrm{yr}^{-1}$
- $L_k = ½\, \dot{M}\, v^2 < 4.8\times10^{43}\ \mathrm{erg\ s^{-1}}$
- We measure $L_{bol} = 6.4\times10^{45}\ \mathrm{erg\ s^{-1}}$, so
- $L_k/L_{bol} < 0.018$

Summary

- ★ **Mrk 509 shows 14 intrinsic absorption components in the UV spectrum.**
- ★ **The absorbers are both blue shifted and redshifted.**
- ★ **At least 2 of these are kinematically associated with X-ray absorbers:**
  - One or more (Components #1, 1a, 2, 2a, 3) are associated with the blue-shifted outflow from the nucleus.
  - Another (Component #4) may be associated with the halo or ISM of the host galaxy.
- ★ **The UV absorbers have lower ionization and lower column density gas than that causing the X-ray absorption.**

  ⇒ UV-absorbing gas is due to higher density clumps embedded in an X-ray absorbing wind?
- ★ **Limits on the density and distance of the absorbers show that their kinetic luminosity is insufficient to cause significant feedback.**