Highlights on feedback from AGN: the HST view

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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.

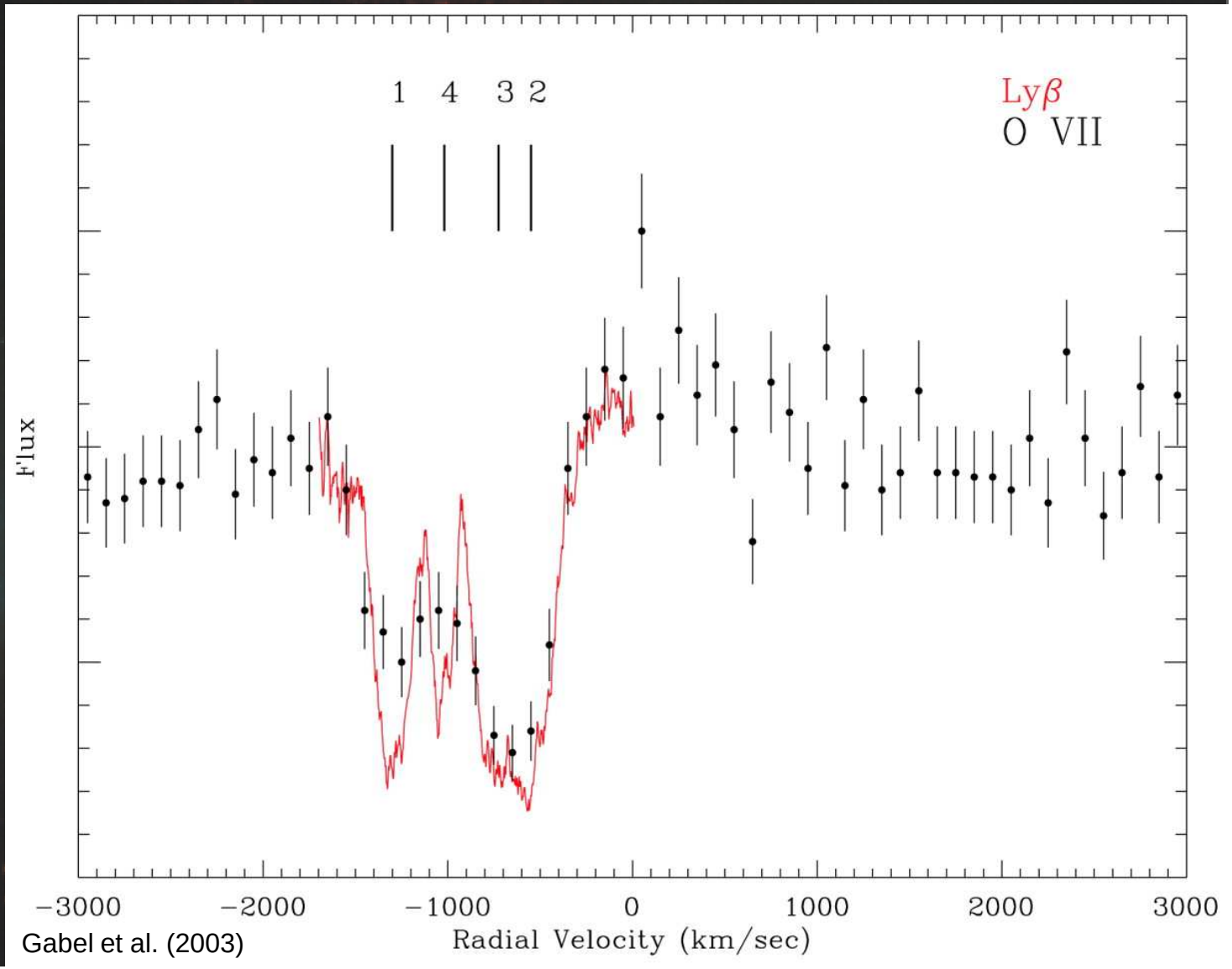
Key HST Contributions

- ★ The NGC 3783 monitoring campaign using HST, FUSE, and Chandra.
- ★ Imaging NLRs, outflow regions, and kinematics of those outflows. E.g., NGC 1068 and NGC 4151 by Kraemer, Crenshaw, and others.
- ★ High S/N, high resolution spectra of absorption troughs showing saturated doublets in detail to unravel covering fraction variations as a function of velocity.

NGC 3783–UV vs. X-ray Absorption

From Gabel et al. (2003):

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

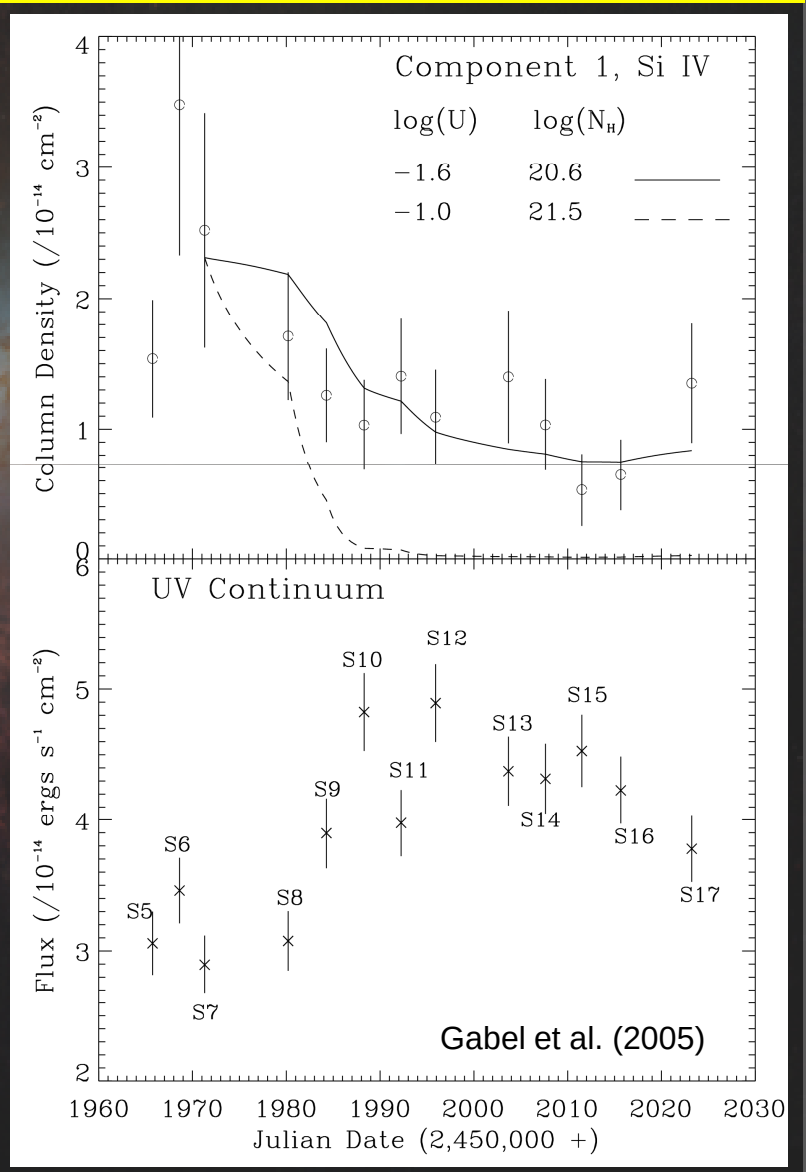


Gabel et al. (2003)

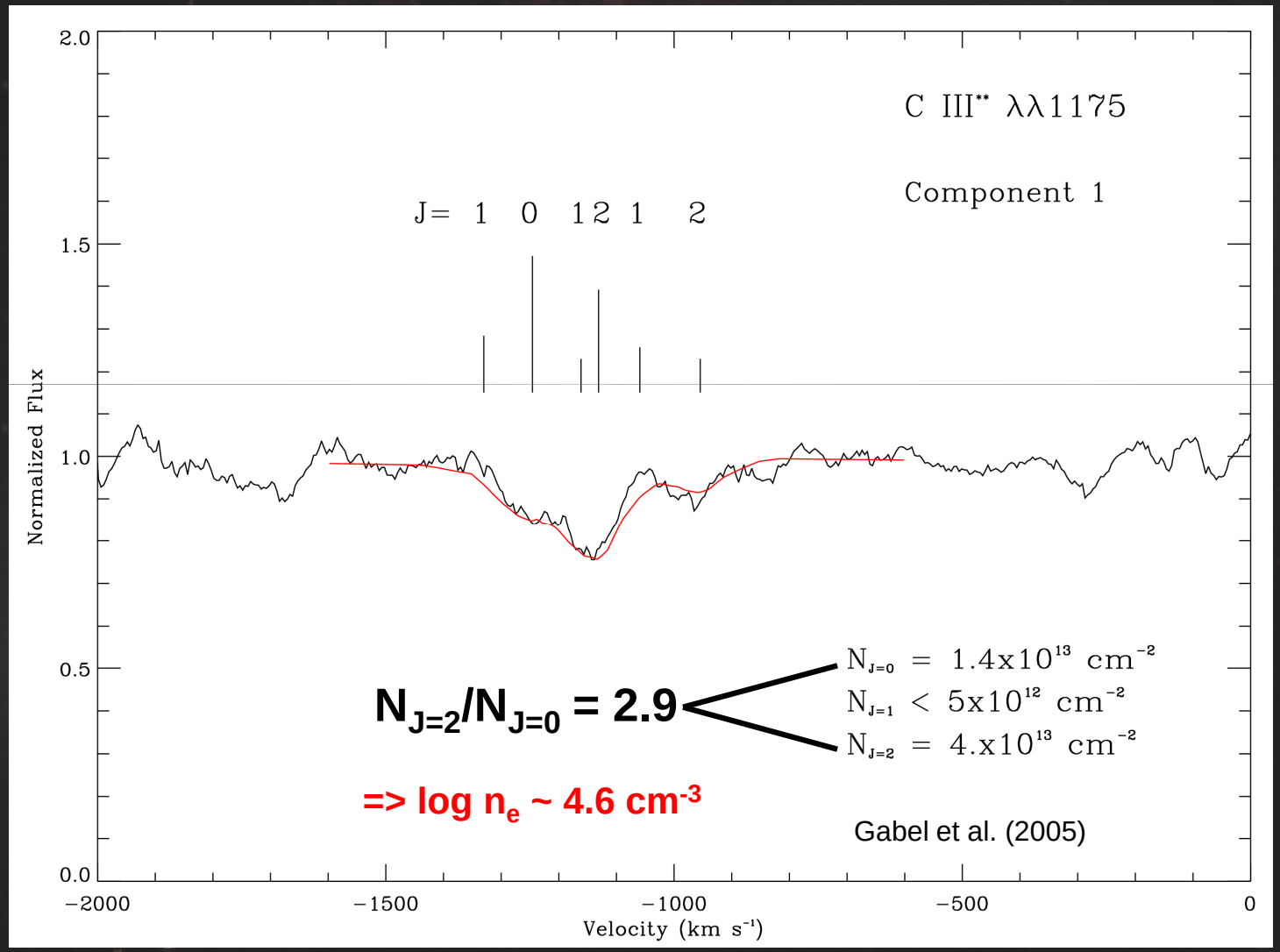
Ionization/Recombination Times ⇒ Density

From Gabel et al. (2005):

- ★ Modeling the response to flux variations gives the gas density.
- ★ Gas density + photoionization models give the distance of the gas.
- ★ For Component 1 in NGC 3783, the gas lies at a radial distance of ~25 pc.



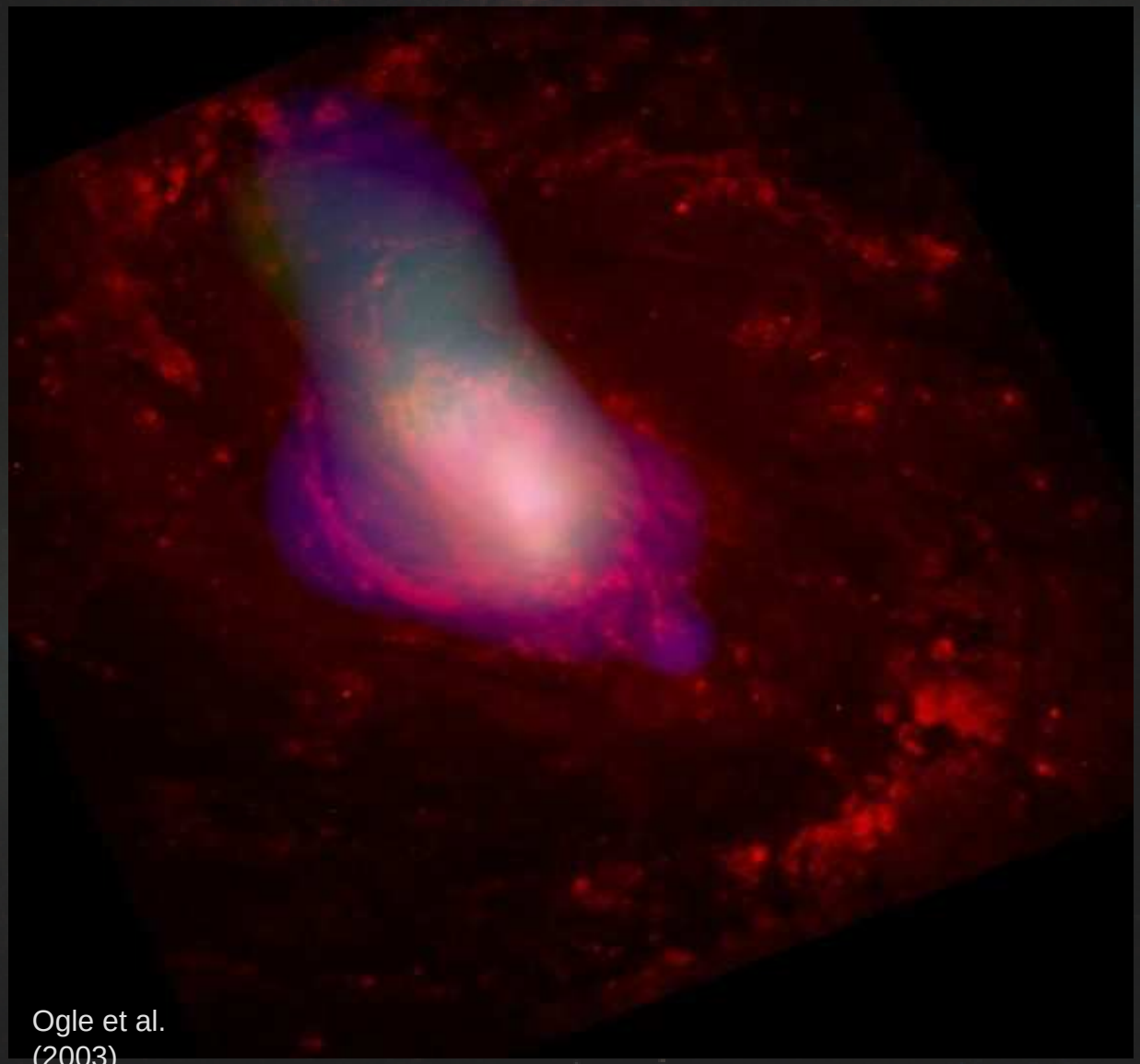
C III λ1176—a Density Diagnostic



Most AGN Outflows Arise near the NLR

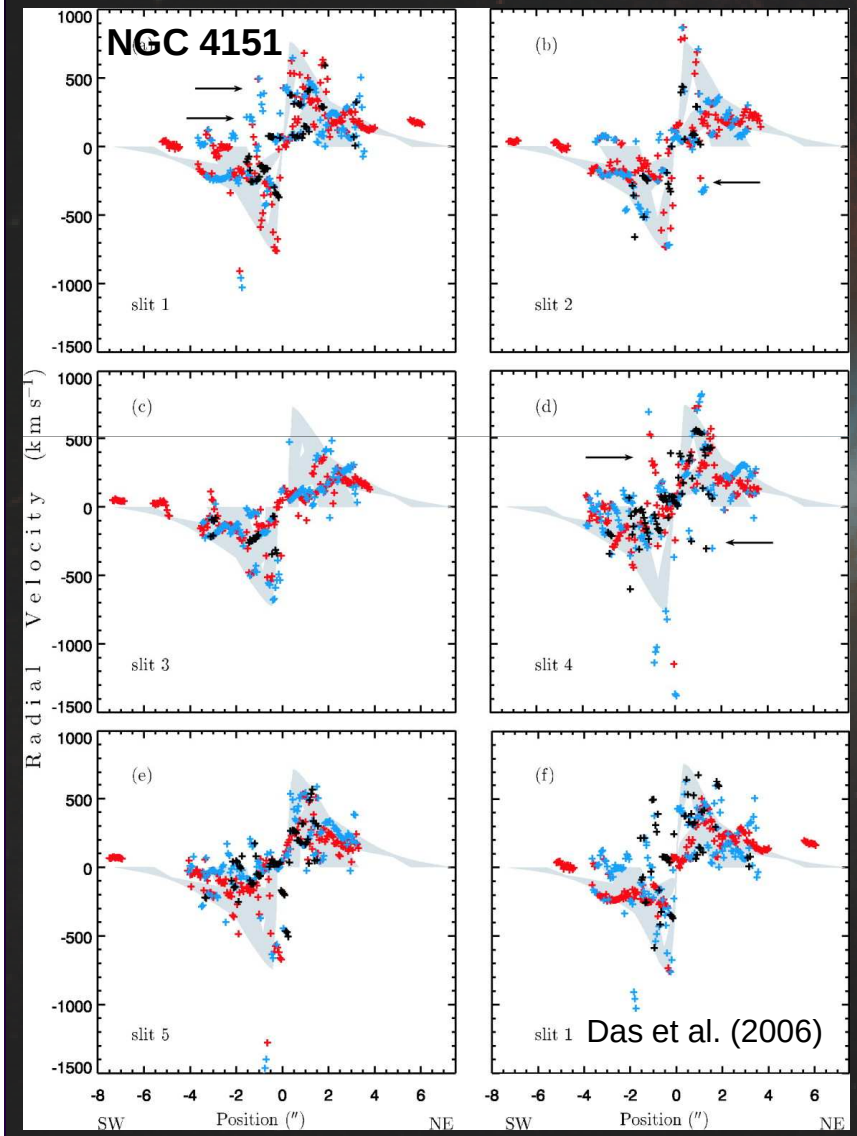
- **Two measures of density from the NGC 3783 campaign place the gas at tens of parsecs from the nucleus (Gabel et al. 2005).**
- **Monitoring of absorption variability in NGC 4151 also suggests distances of tens of parsecs (Kriss et al. 1997; Espey et al. 1998).**
- **Kinematics of the UV absorbers are similar to those of the NLR (Crenshaw & Kraemer 2005).**
- **But, does the gas escape?**
  - Velocities are high enough …
  - But entrainment, mass loading, and confinement can prevent it—
    - The extended NLR of NGC 4151 appears to be at a standstill at 290 pc (Crenshaw et al. 2000).

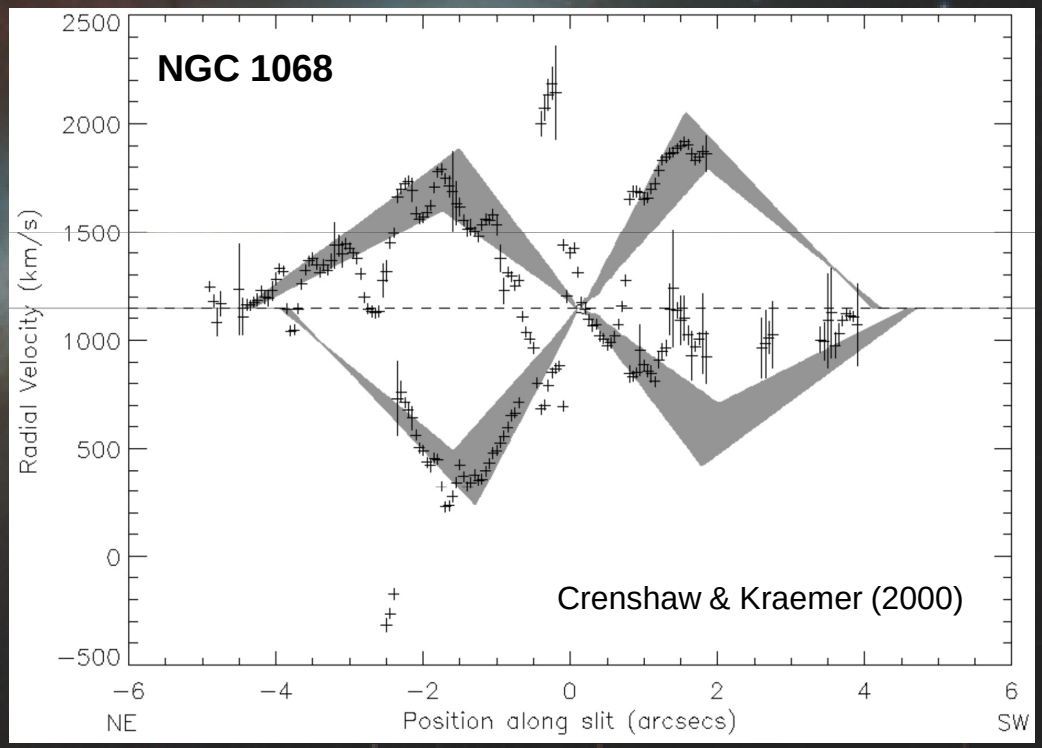
NGC 1068 CXO+HST



Ogle et al.
(2003)

Outflows in the NLRs of NGC 4151 & NGC 1068





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- ★ The NGC 3783 monitoring campaign using HST, FUSE, and Chandra.
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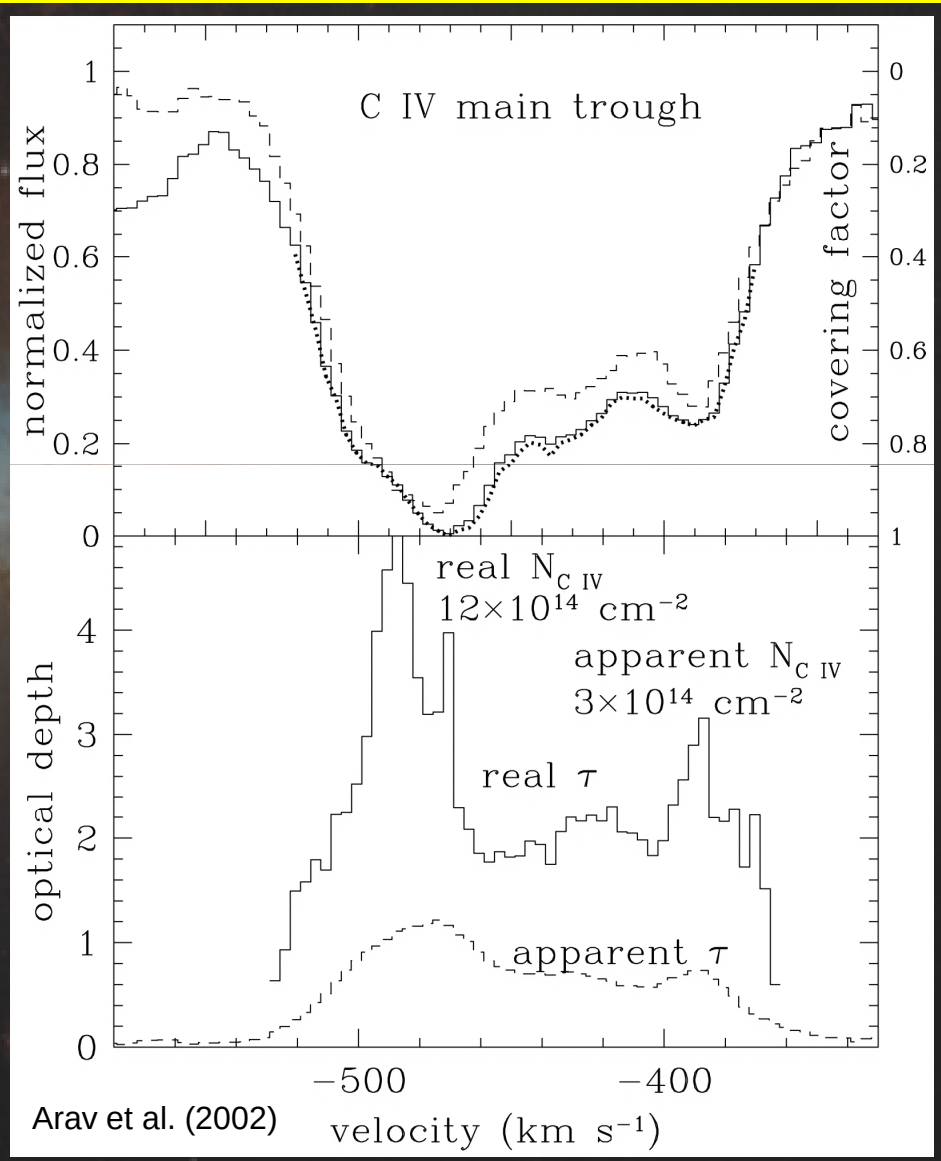
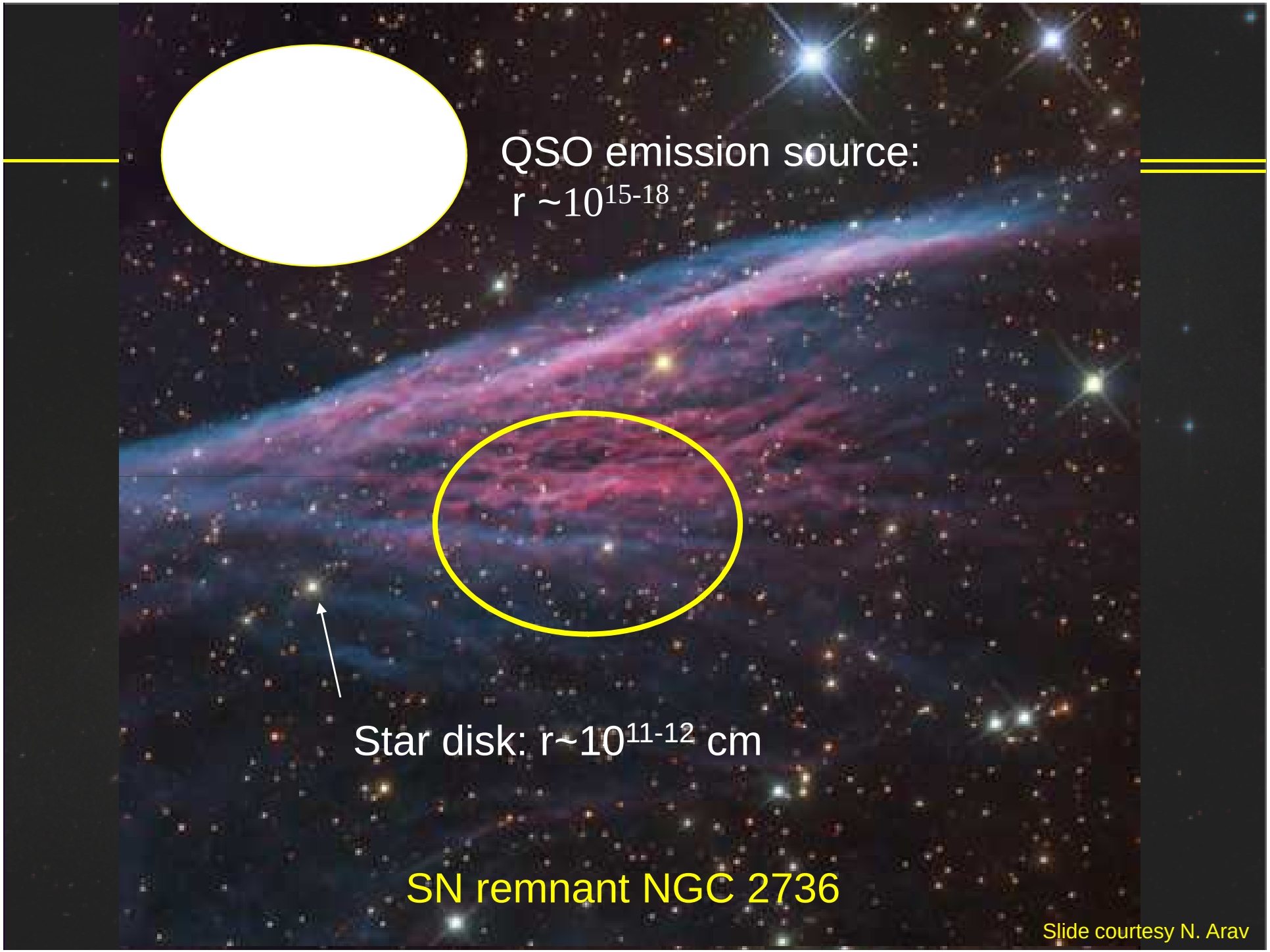
Saturated Absorption in NGC 5548

- Both lines in the C IV doublet have the same profile.
- Although the line troughs are not black, the doublet ratio implies saturation.
- The line profile shape is governed primarily by the variation of covering factor with velocity, not optical depth.



Arav et al. (2002)



Slide courtesy N. Arav

Capabilities of HST after SM4 relevant to AGN

- ★ COS provides high-resolution spectroscopy with an order of magnitude improvement in sensitivity over STIS.
- ★ The repair of STIS restores our ability to do high-spatial resolution spectroscopy.

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

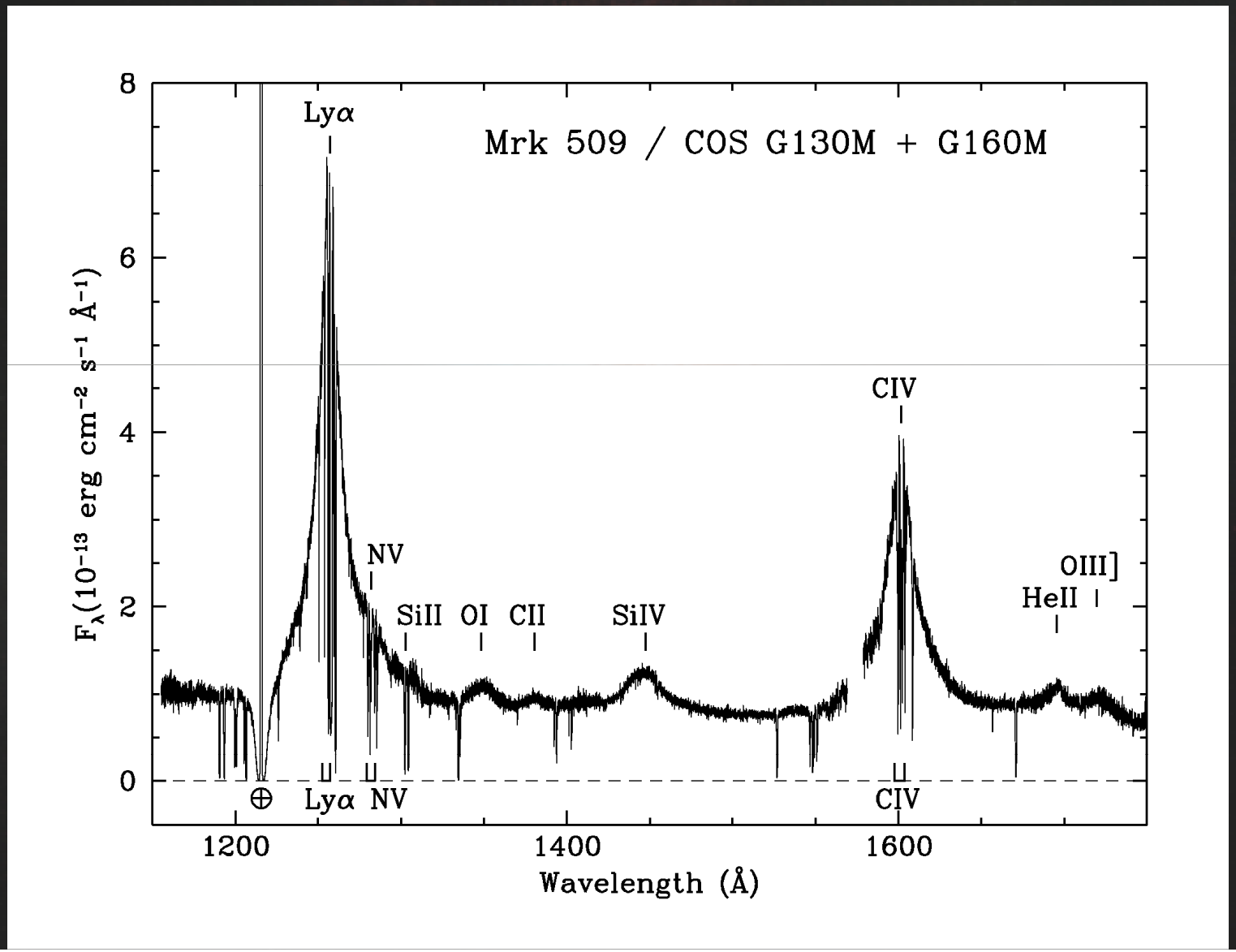
- **Measure absorption in the outflowing gas.**
- **Determine abundances of C, N, O, Ne, Si, S, and Fe over a broad range of ionization parameters.**

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

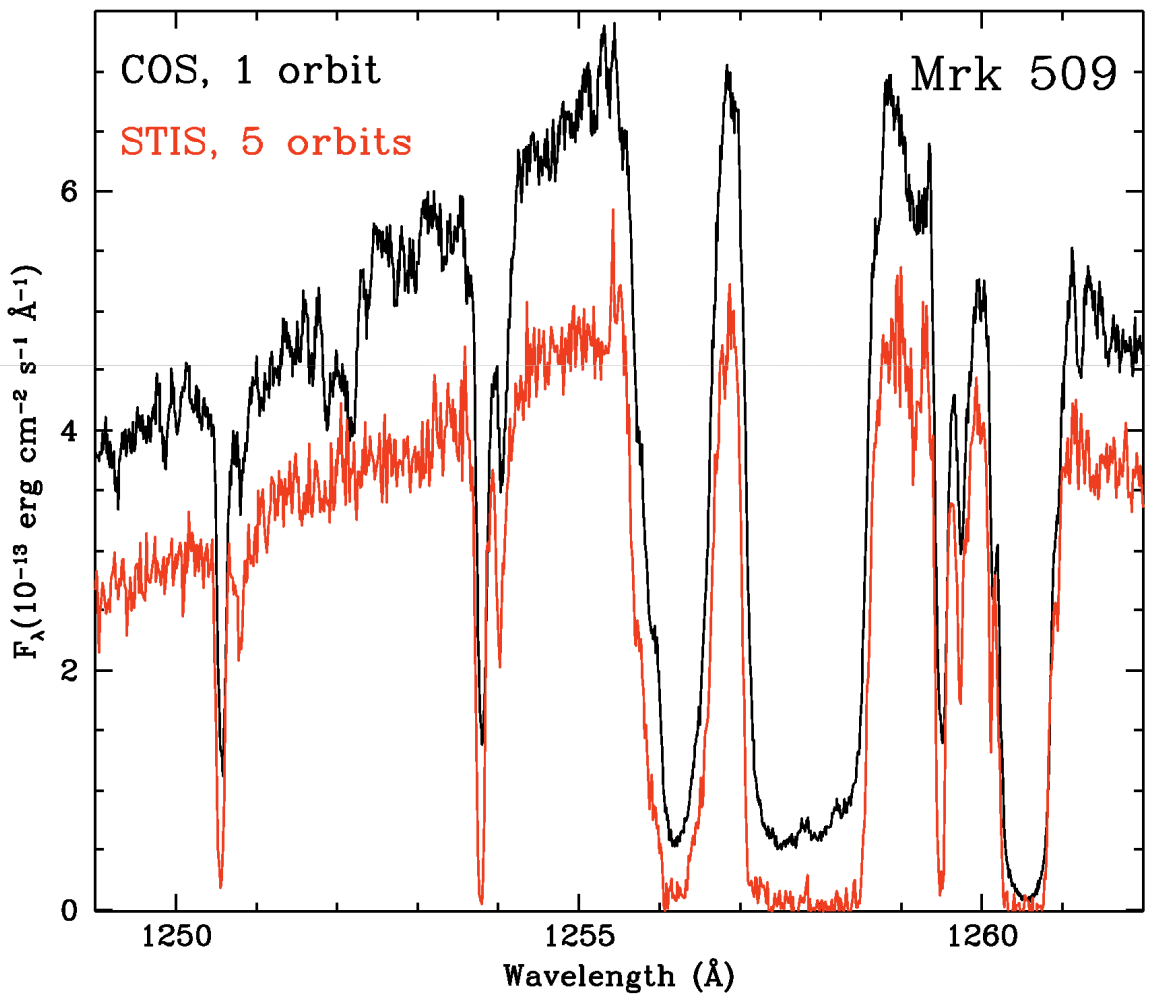
- **In the UV, use velocity-resolved measurements of Li-like doublets to determine column density and covering factors for C and N in the outflowing gas.**
- **With photoionization modeling, this gives CNO abundances.**

  ⇒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.

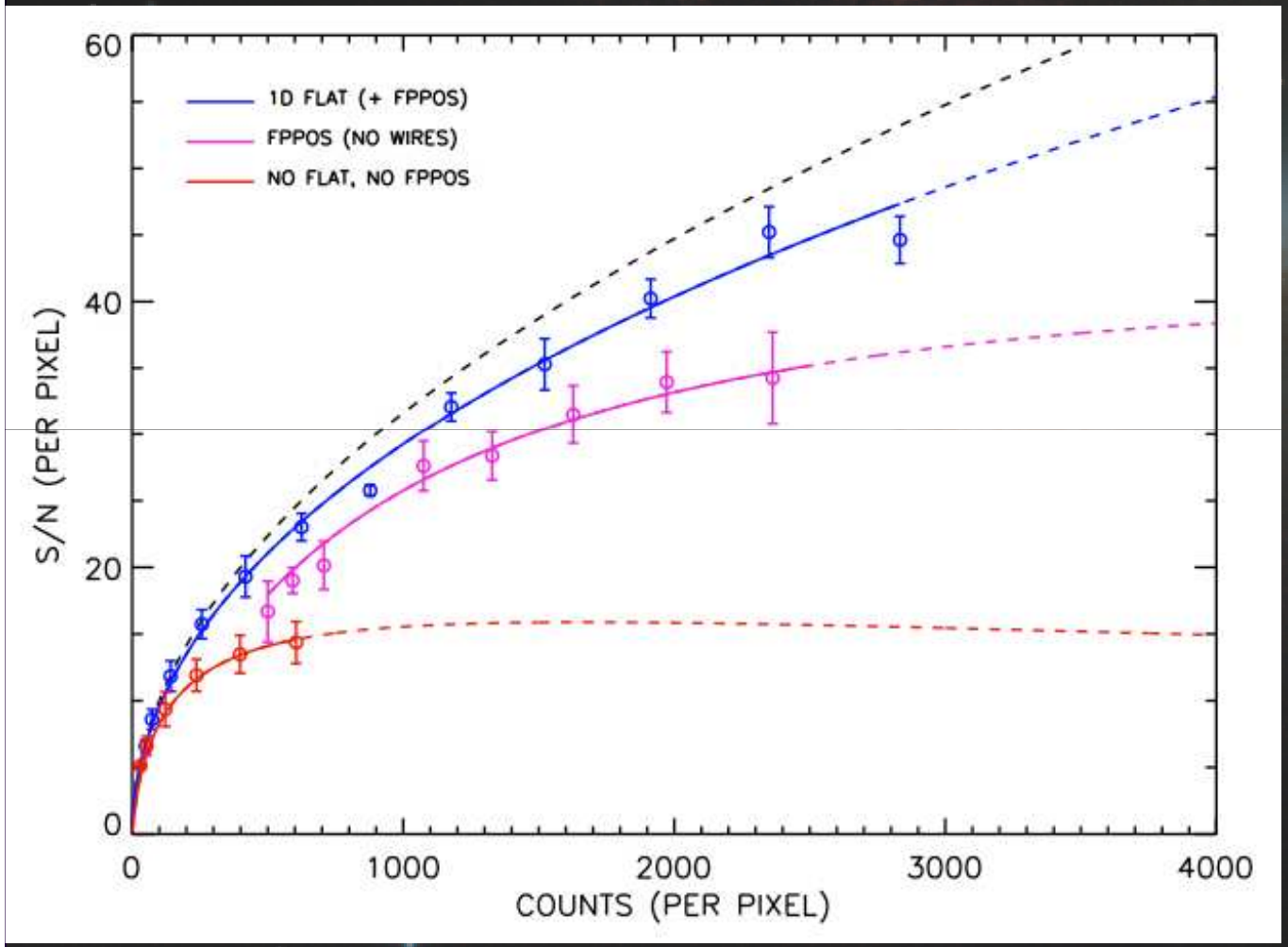
COS Merged Spectrum (10 orbits) of Mrk 509



Lyα Region of Mrk 509

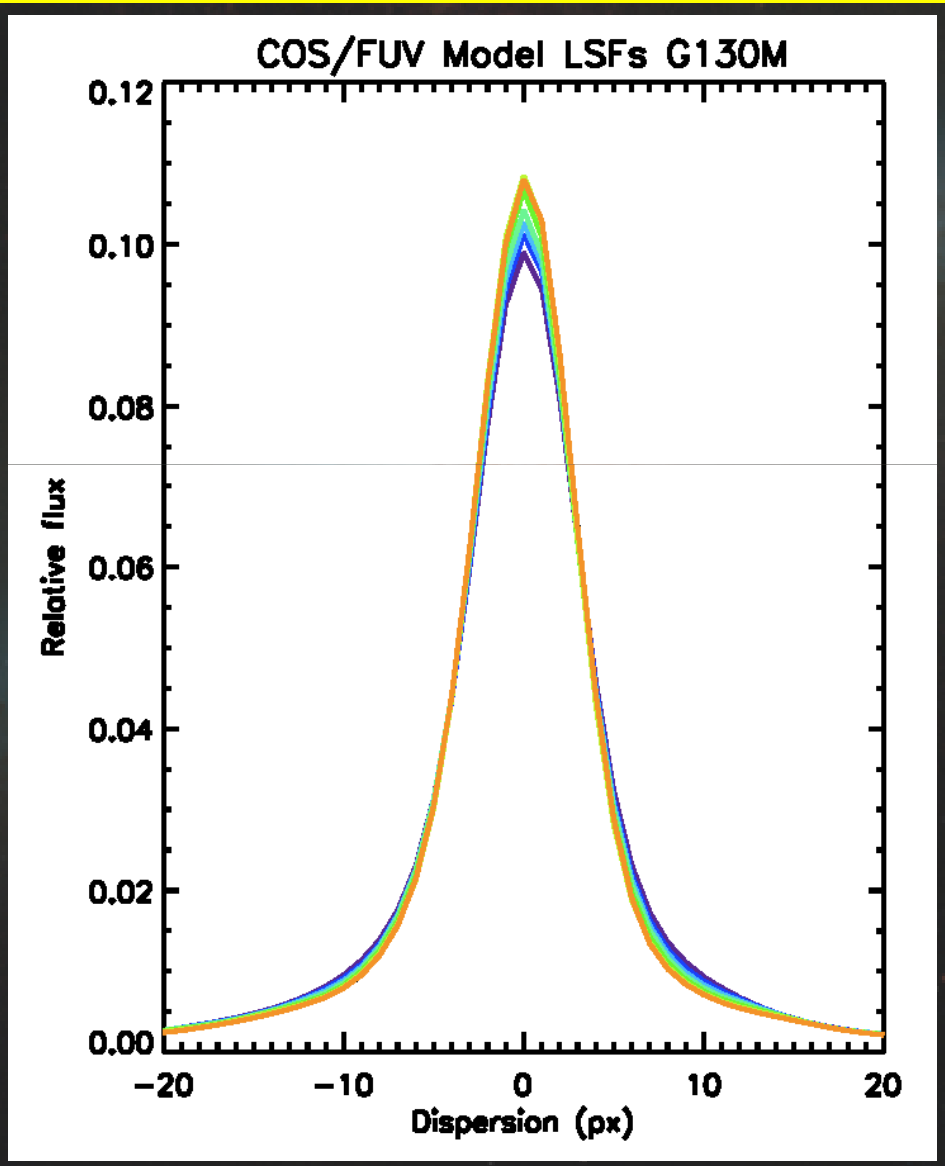


Signal-to-Noise Achieved in COS Data

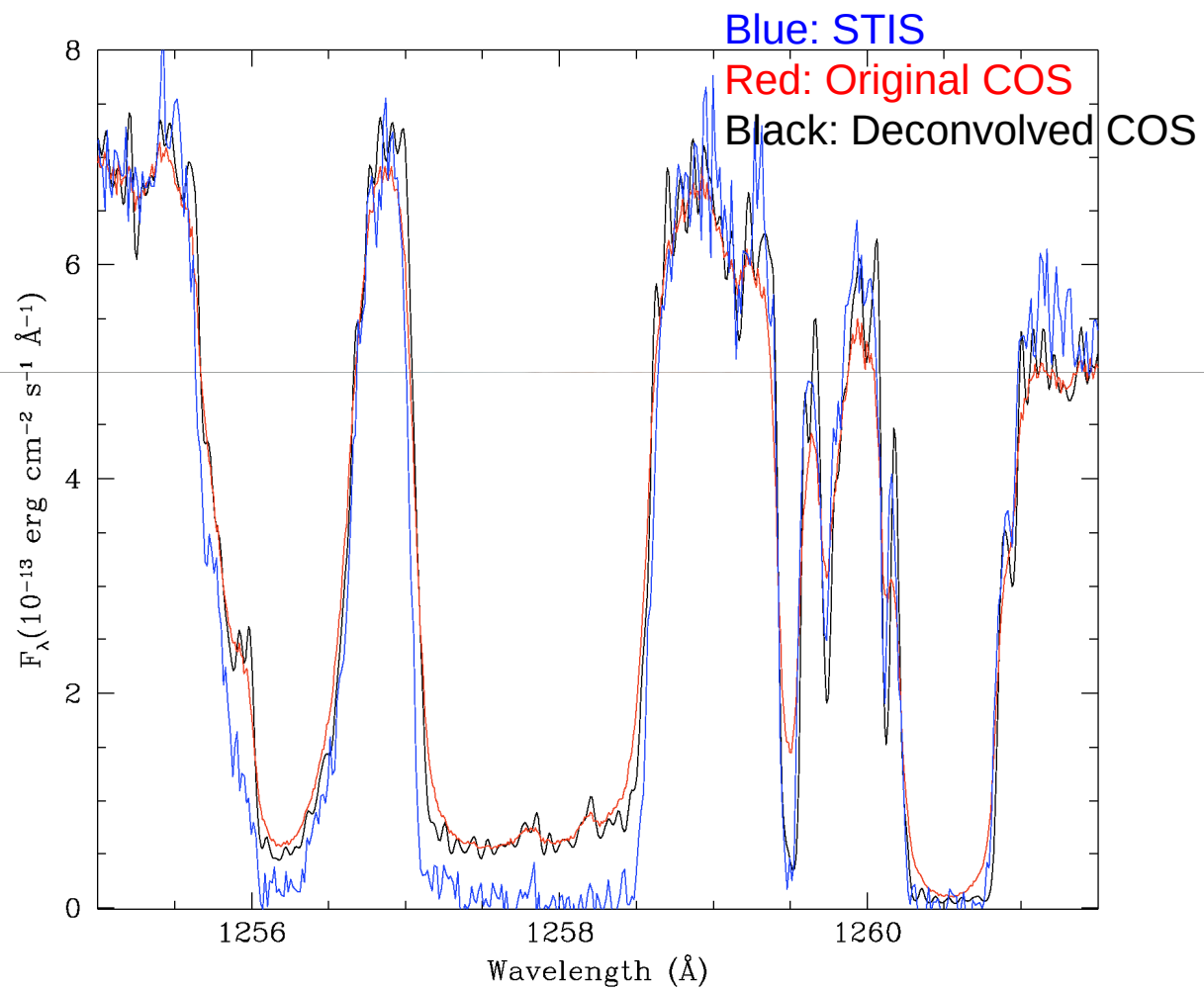


- Maximum S/N for single grating setting (~14 per pixel) reached at ~700 counts/pixel.
- Current CALCOS X1DSUM ignoring grid wires improves global S/N by smoothing FPN.
- Flat fielding increases S/N close to Poisson noise for single exposures. With 4 FP-POS steps, S/N=45 per pixel possible.

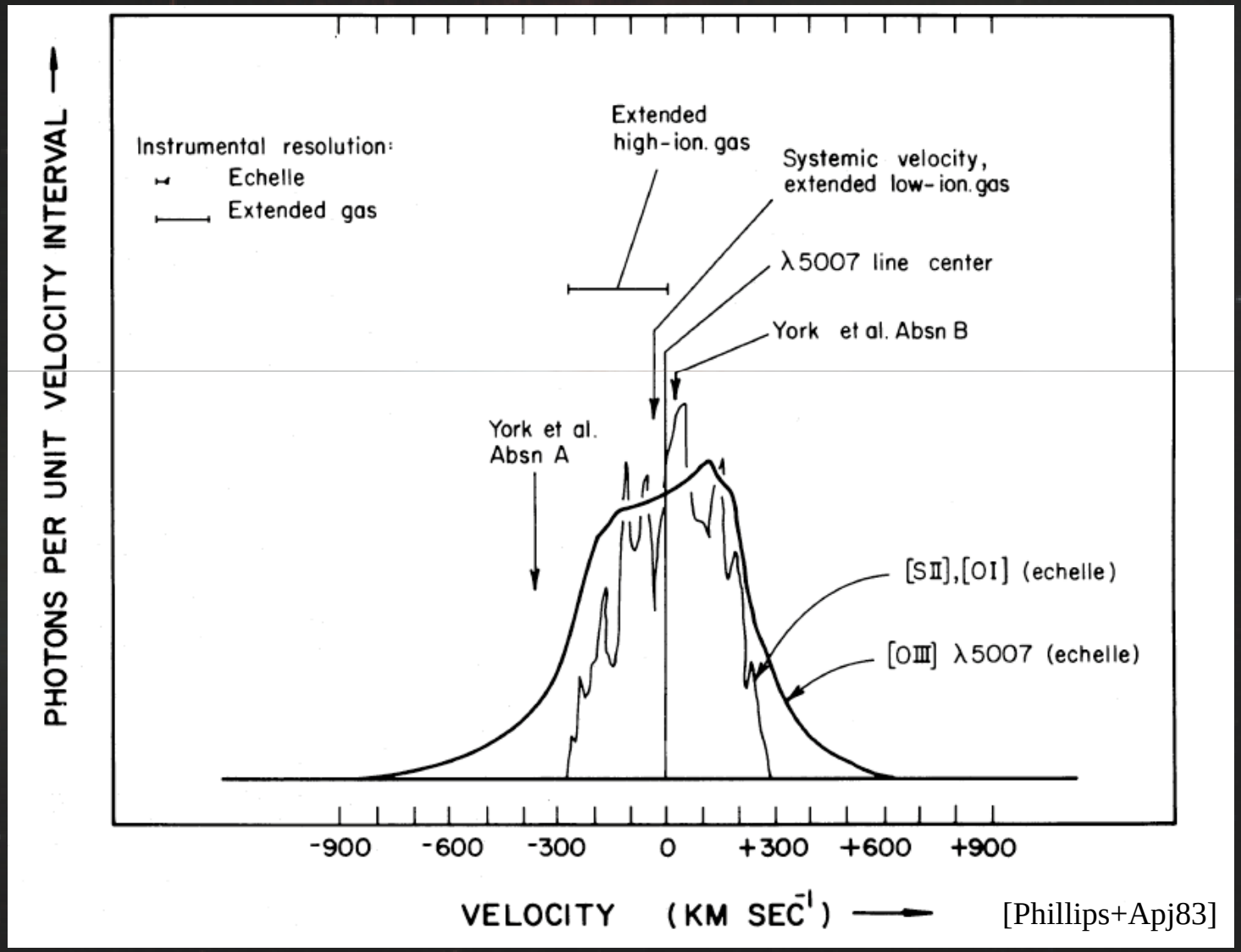
Broad Wings on the COS Line Spread Function



Deconvolved COS Spectrum Compared to STIS



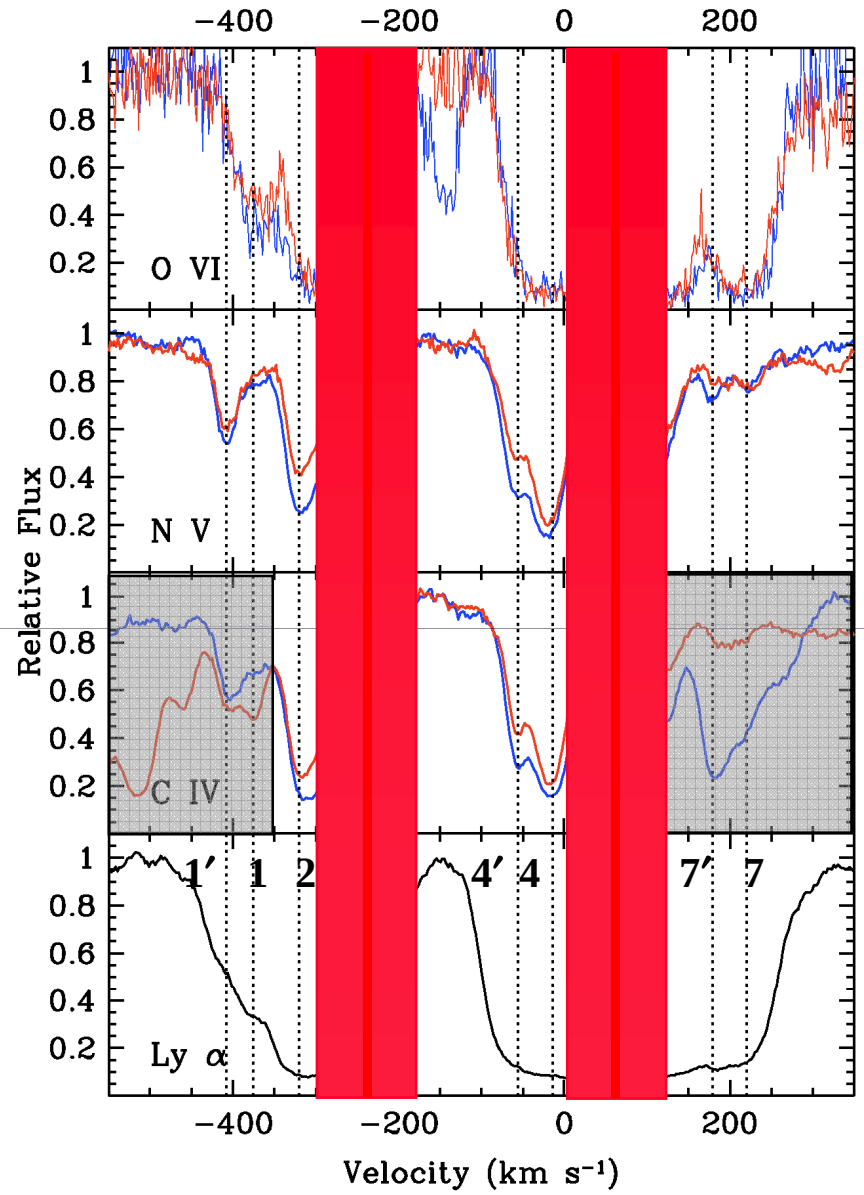
[O III] Line profile in the Nucleus



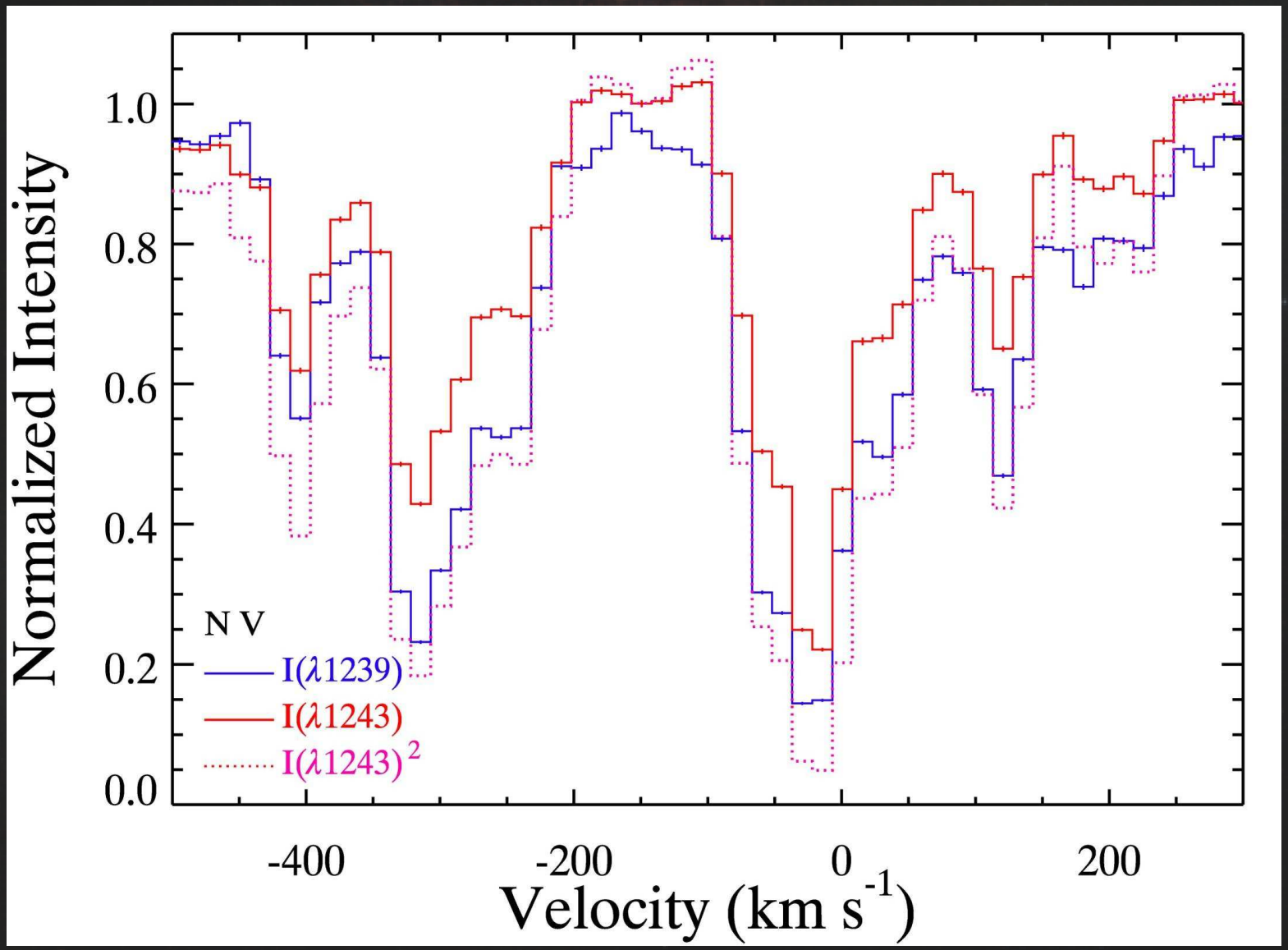
[Phillips+Apj83]

Absorption Lines in Mrk 509

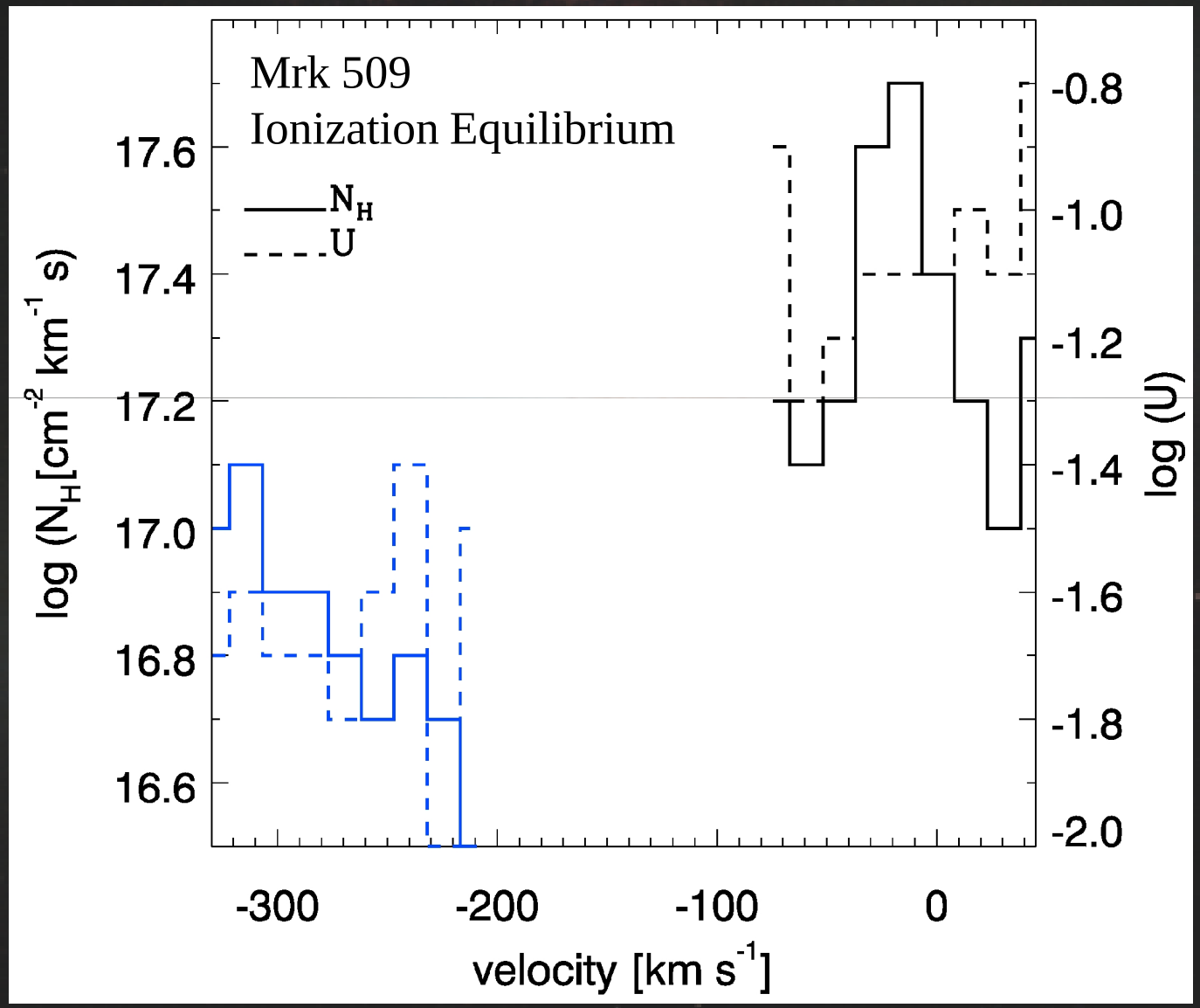
- O VI Spectrum from FUSE [Kriss+ 2000]
- C IV doublet is split by only 500 km s^{-1}, so grey regions can't be used for optical-depth.
- Red lines mark the velocities of the components seen in the RGS spectrum.



Optical Depth Analysis for NV Doublet in Mrk 509



Ionization Solutions for NV & CIV Doublets in Mrk 509



Summary

- ★ **Outflows are common in AGN. More than half show outflowing absorbing gas in both the UV and the X-ray.**
- ★ **Outflow velocities are typically hundreds to thousands of km/s.**
- ★ **Outflows typically show a broad range of temperatures and ionization parameters in the absorbing gas.**
  - **Most UV absorption is due to lower ionization, 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?
- ★ **Possible origins for the outflowing gas range from the accretion disk to the obscuring torus. There may well be two populations of absorbers:**
  - High-velocity, broad troughs may originate in a disk wind.
  - Lower velocity, associated absorbers may originate in a thermal wind from the torus.
- ★ **But, the outflows may rarely escape the confines of the host galaxy …**

Upcoming HST Observations

- **Cycle 17 – 11686, Arav et al. -- The Cosmological Impact of AGN Outflows: Measuring Absolute Abundances and Kinetic Luminosities**
  - 40 orbits, 6 objects
  - Measure CIII* λ1176 to determine densities ➔ distances
  - Measure Lyα, NV and CIV to compare to FUSE Lyβ and OVI for reliable N_H ➔ absolute abundances
- **Cycle 18 – Crenshaw et al. -- What are the Locations and Kinematics of Mass Outflows in AGN?**
  - 29 orbits, 11 objects
  - Track historical long-term variability of bright, well known AGN
  - Measure CIII* λ1176 to determine densities ➔ distances
  - WFC3 [O III] imaging and STIS long-slit G430M spectra of 9 objects to measure NLR kinematics and outflow velocities.