Outflow Distances from C III* UV Absorption:

Application to NGC 3783 and High-z QSOs

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Overview:

- Intrinsic Absorption in NGC 3783
  - *C III* λ1175 Absorption & Metastable Level Populations: Density Diagnostic*
  - *Photoionization Models:* N_H, U + n_e ⇒ *Distance*
  - *Detailed time-dependent behavior*

  [with Mike Crenshaw, Steve Kraemer, Ian George, Hagai Netzer, Fred Hamann, Gerry Kriss, Jane Turner, Shai Kaspi, Niel Brandt, Joe Shields, Smita Mathur, Mary Beth Kaiser, Brad Peterson, Joe Shields, Kirpal Nandra, Wei Zheng]

- Density Constraints in High-z QSO Outflows: Ground-Based Observations
  - *BALs in high-z QSOs from the SDSS: Distance constraints from limits on C III**
  - *High-resolution spectra: seeing through the forest*

[with Nahum Arav and Maxwell Moe]

Distance Scale of AGN Outflows

- Distance (*R*) is a key parameter in understanding outflows: *mass outflow rate, energetics & feedback mechanisms, input for dynamical models, etc*.

- Constraining *R*:

- number density of photoionized absorber from excited level absorption: $U = Q / 4 \pi c n_H R^2$

- variability timescale analysis with photoionization models

- limits from line-of-sight covering factors + emission region sizes

I. Intrinsic UV Absorption in NGC 3783

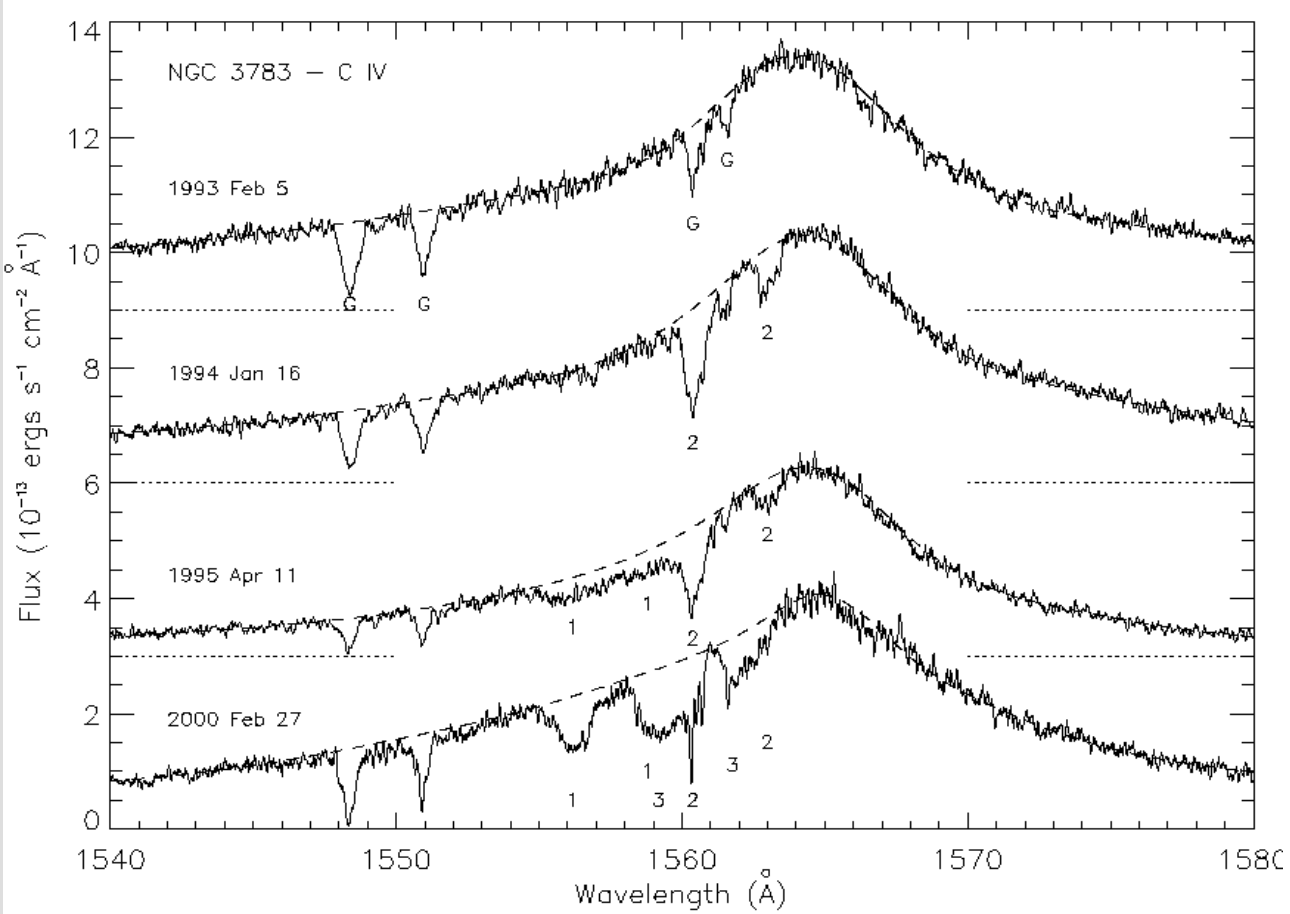
- 3 distinct kinematic components appeared in 3 *HST* observations, separated by 1-5 year timescales

  v ~ –1400 – –500 km s^{-1}; FWHM ~ 170 – 280 km s^{-1}

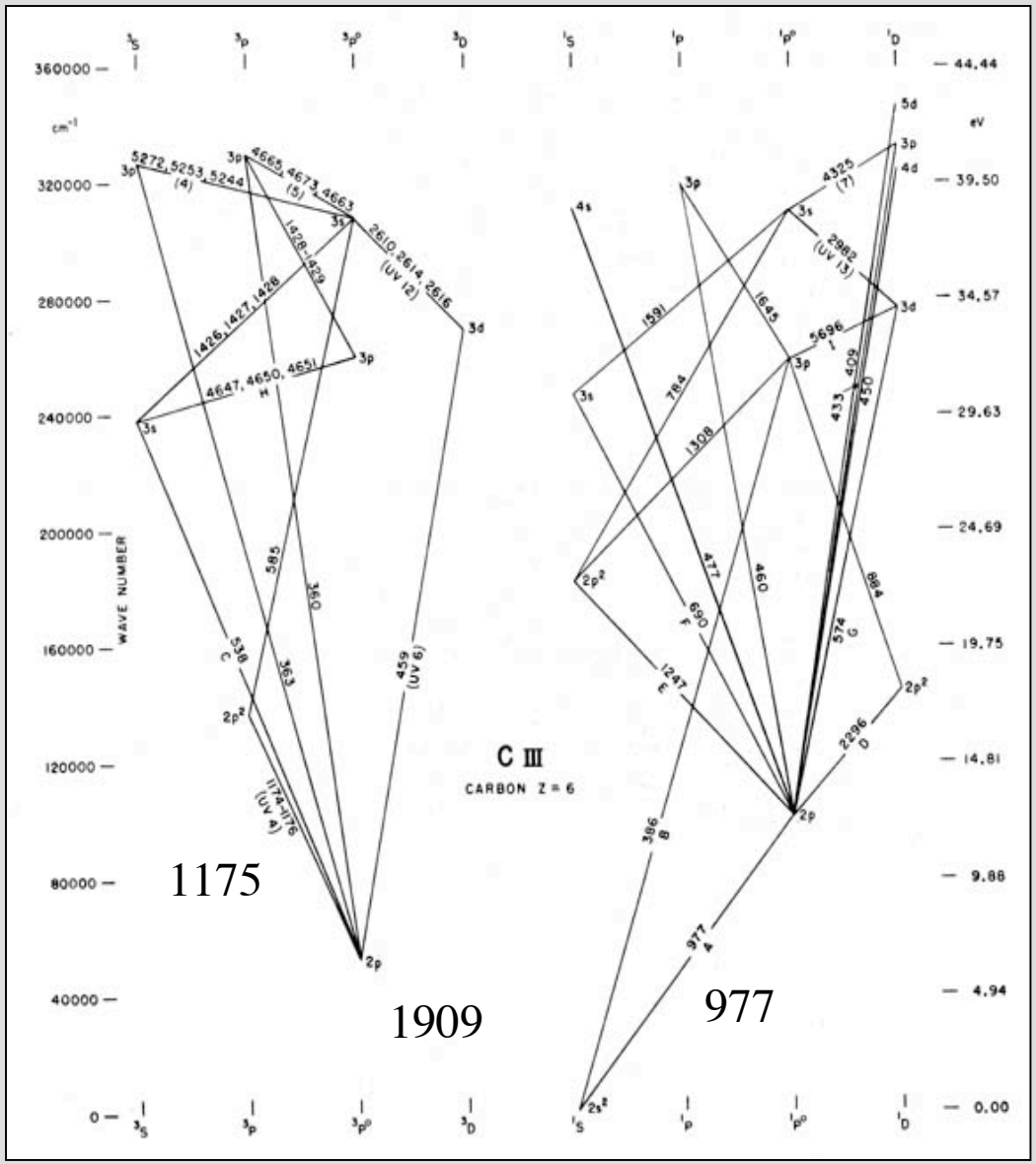
- Monitoring Campaign:

18 HST/STIS E140M (monthly and weekly timescales)

6 FUSE & CXO



$^3P^o_J$ Metastable Levels of C III



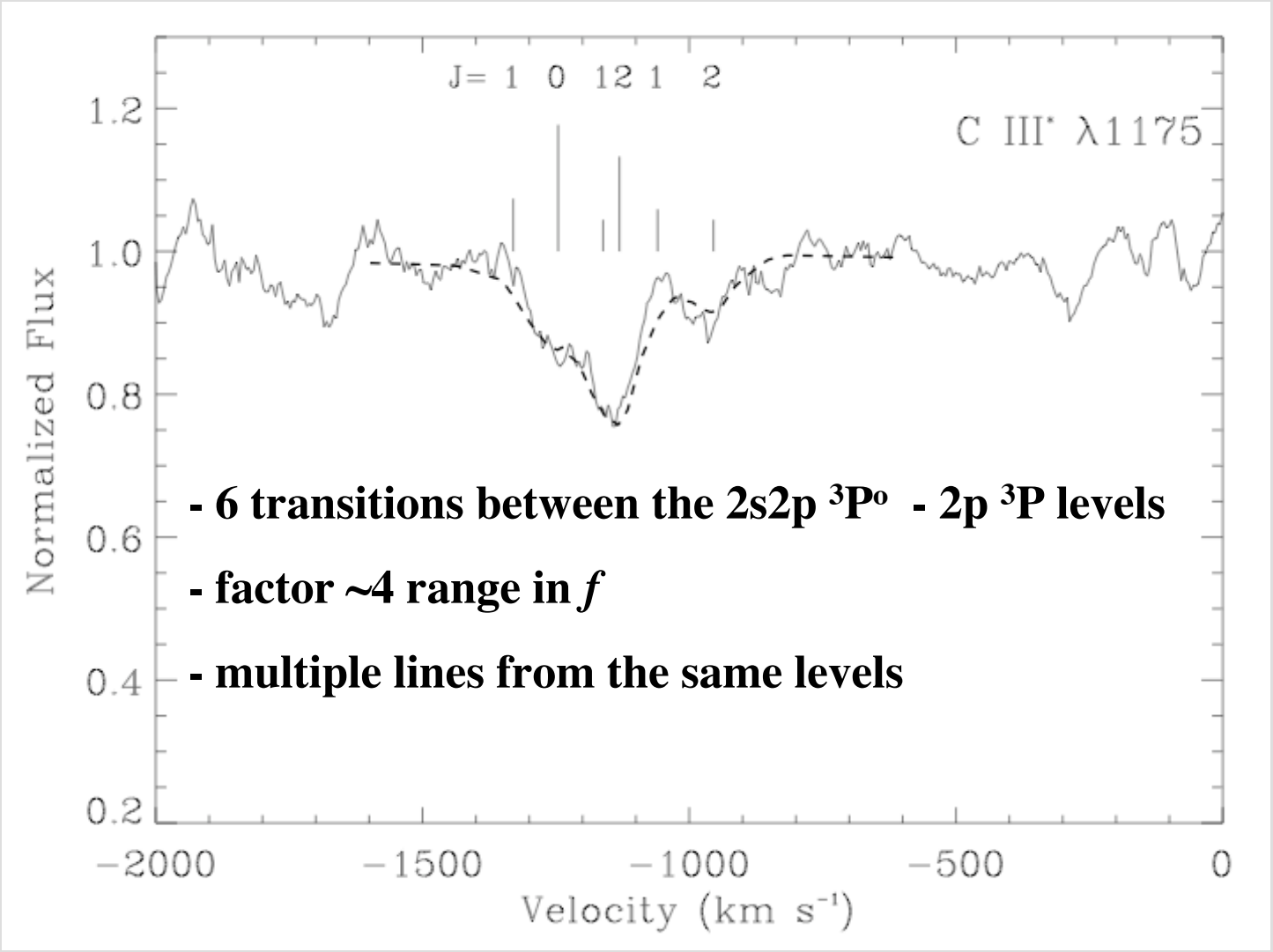
3 metastable levels in the lowest energy triplet term ($^3P^o$, 6 eV), with radiative transition probabilities:

$J = 0 \quad A_{ji} \sim 0$

$J = 1 \quad A_{ji} = 75\ s^{-1}$

$J = 2 \quad A_{ji} = 5 \times 10^{-3}\ s^{-1}$

C III* 1175 Absorption Complex



- 6 transitions between the 2s2p $^3P^o$ - 2p ^3P levels

- factor ~4 range in *f*

- multiple lines from the same levels

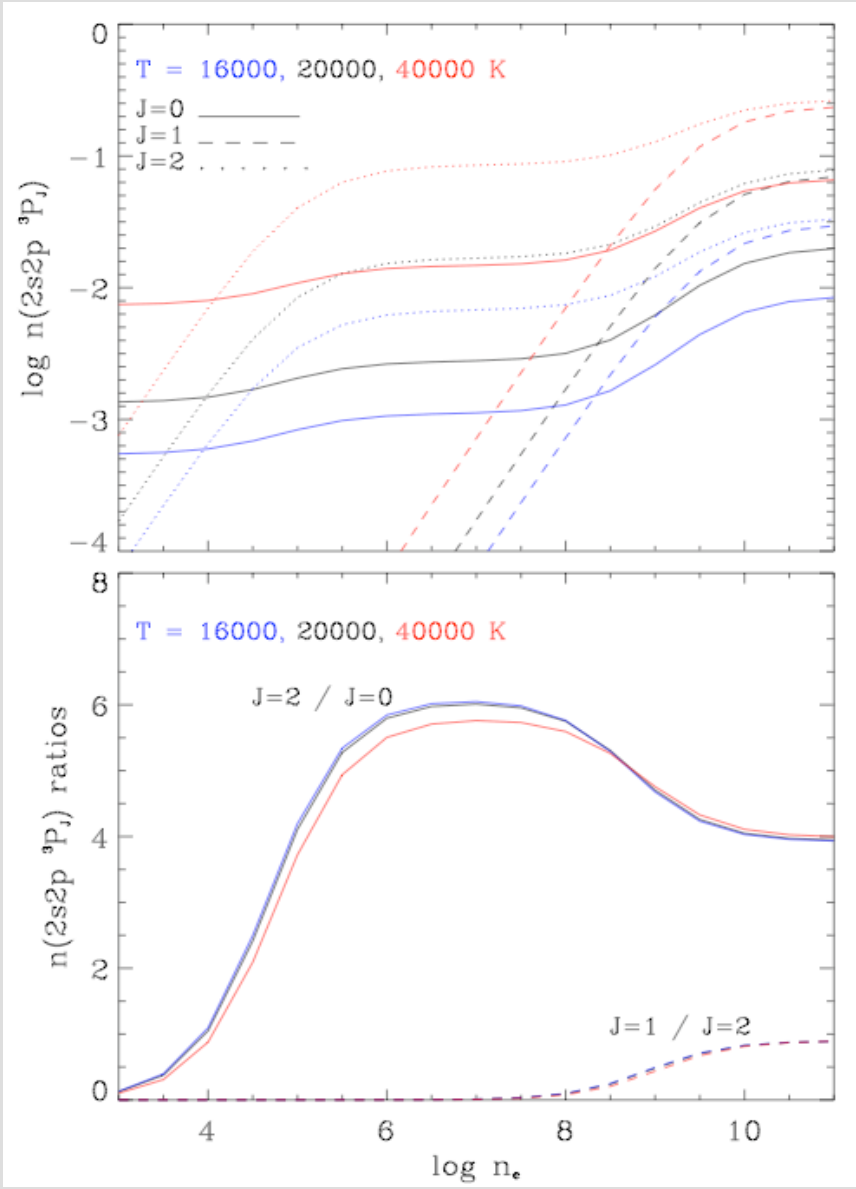
C III* Metastable Level Populations

- **Level populations exhibit strong density & temperature dependence**

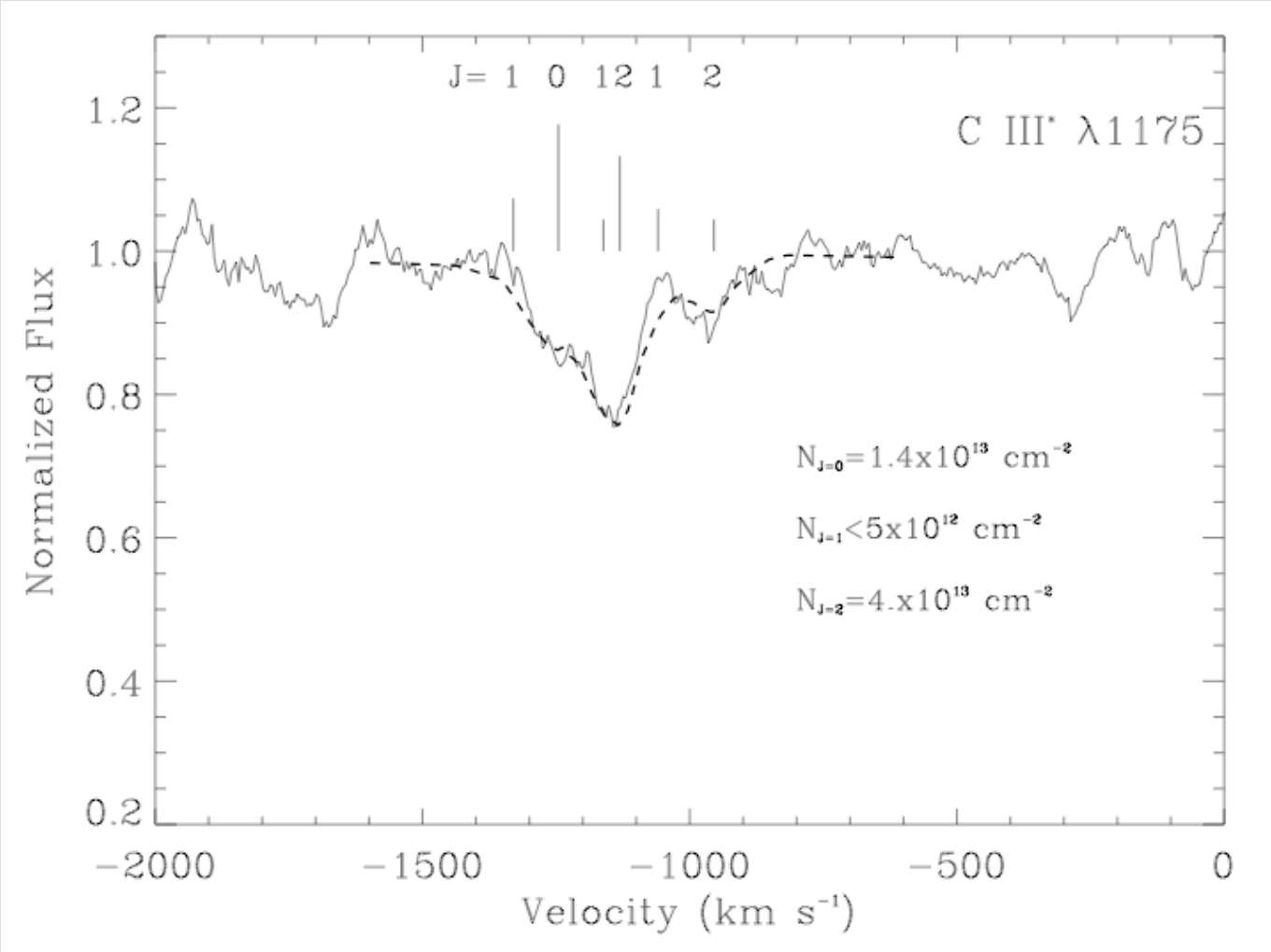
- **J=0,2 levels are populated at moderate densities; J=1 requires high density**

- ***Relative* level populations exhibit strong density dependence (independent of T)**

- **Resolved C III*1175 complex provides powerful density diagnostic**



C III* 1175 in Component 1 of NGC 3783



Density from J ratios

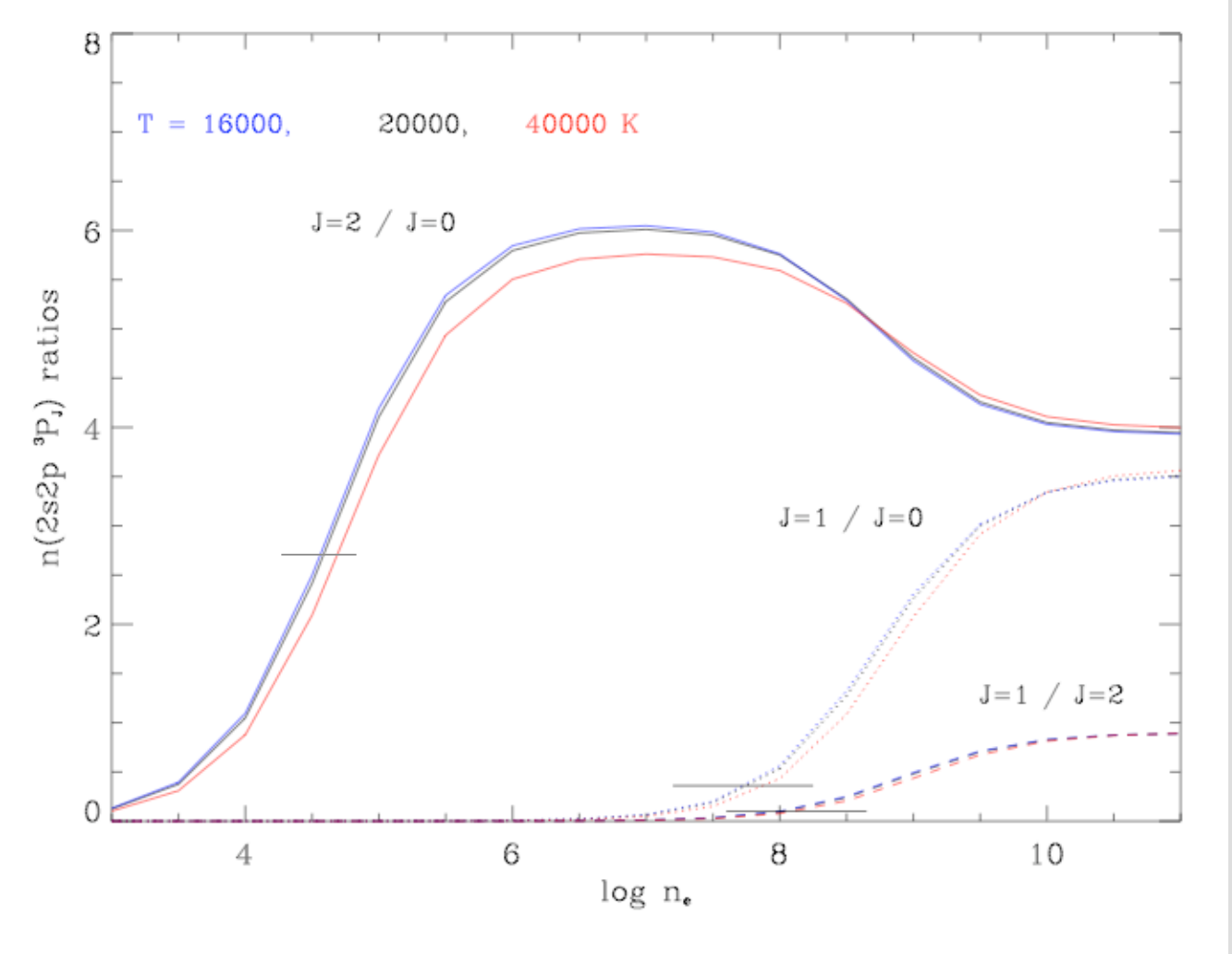
- J=2:J=0

$n_e=3x10^4 cm^{-3}$

$(+5/-1.5x10^4)$

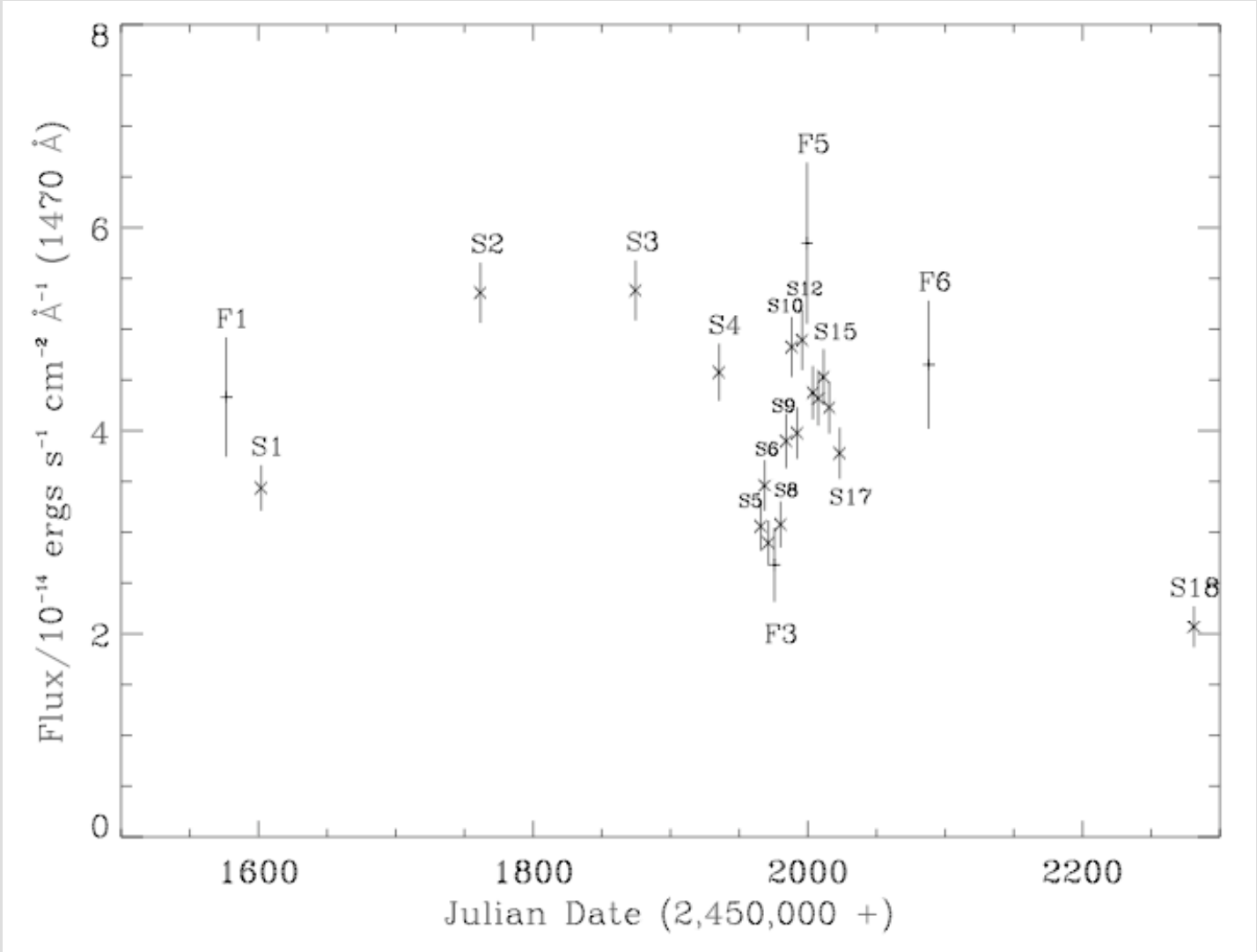
- J=1:J=0

$n_e<10^8\ cm^{-3}$



Variability Analysis & Photoionization Modeling

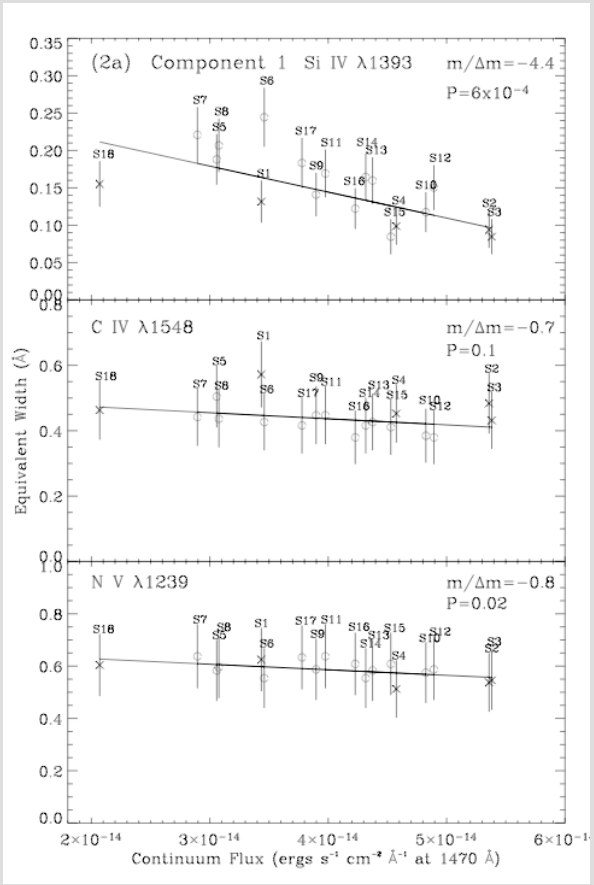
STIS UV Continuum Light Curve

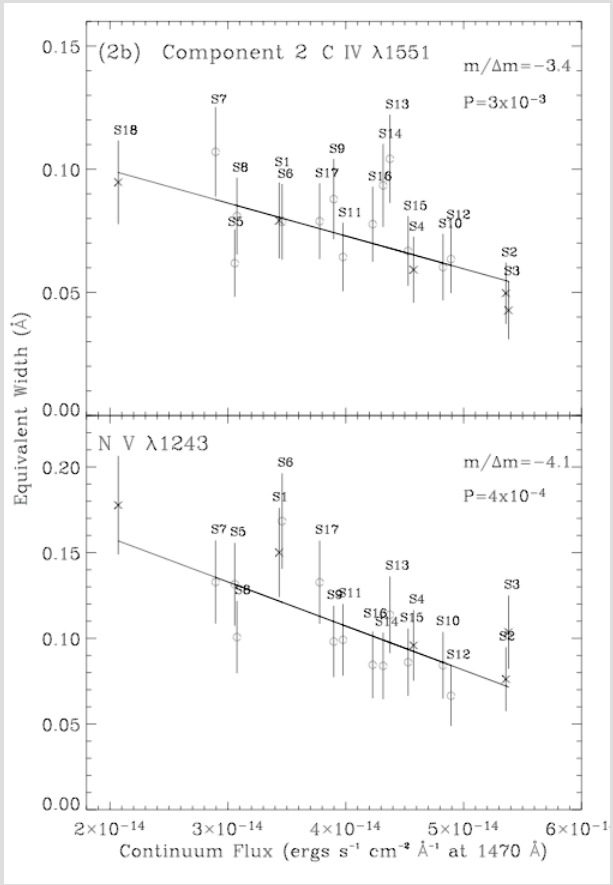


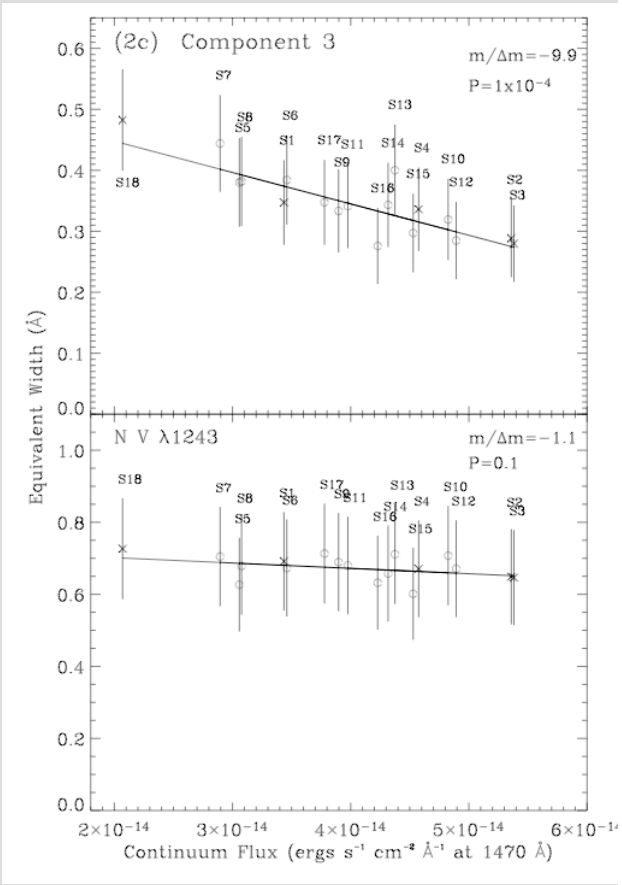
Equivalent Width Variability

-Lowest ionization species vary inversely with continuum flux in each component

-non-varying lines consistent with covering factor solutions showing saturation







Light Curve - Intensive Monitoring

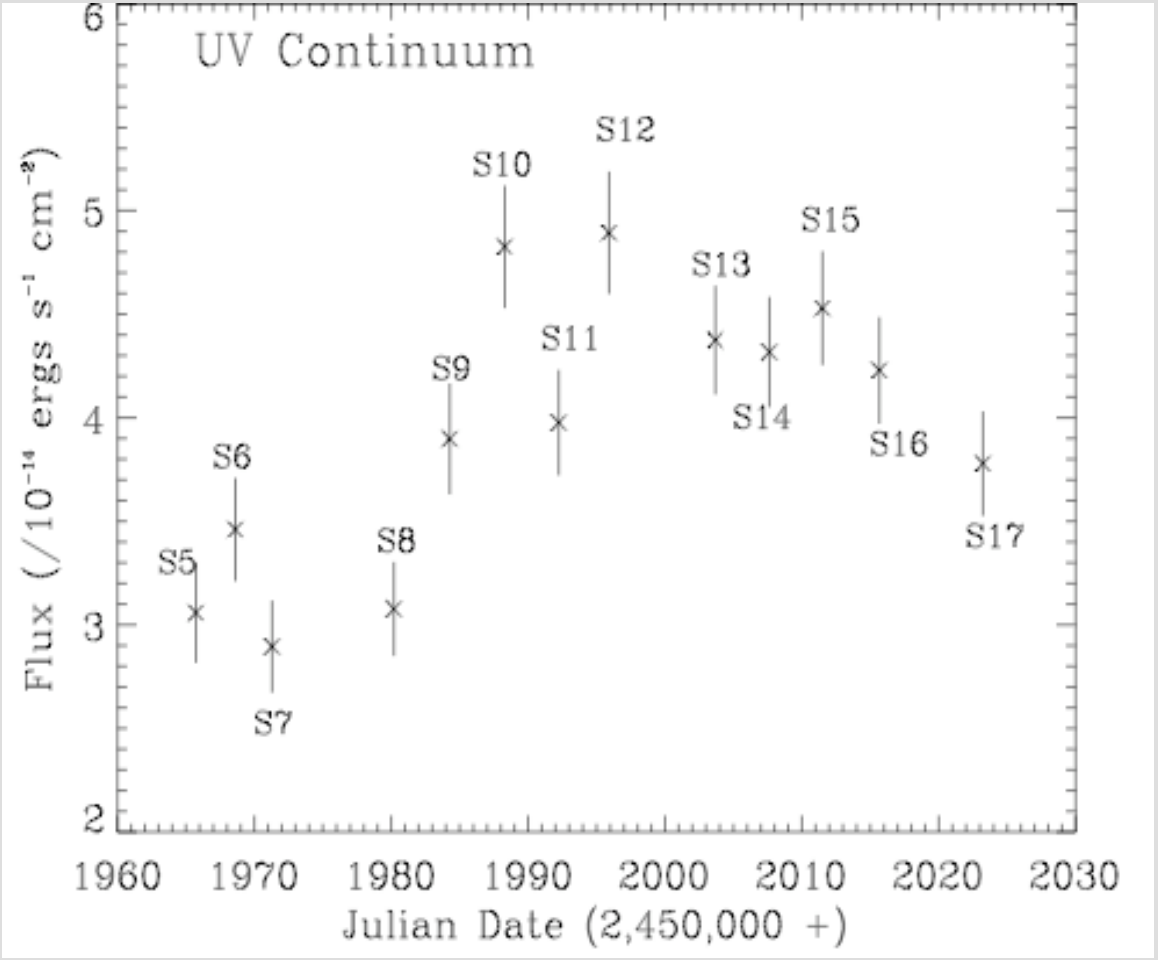
Mean low state:

STIS 5 - 8; FUSE 2 - 4

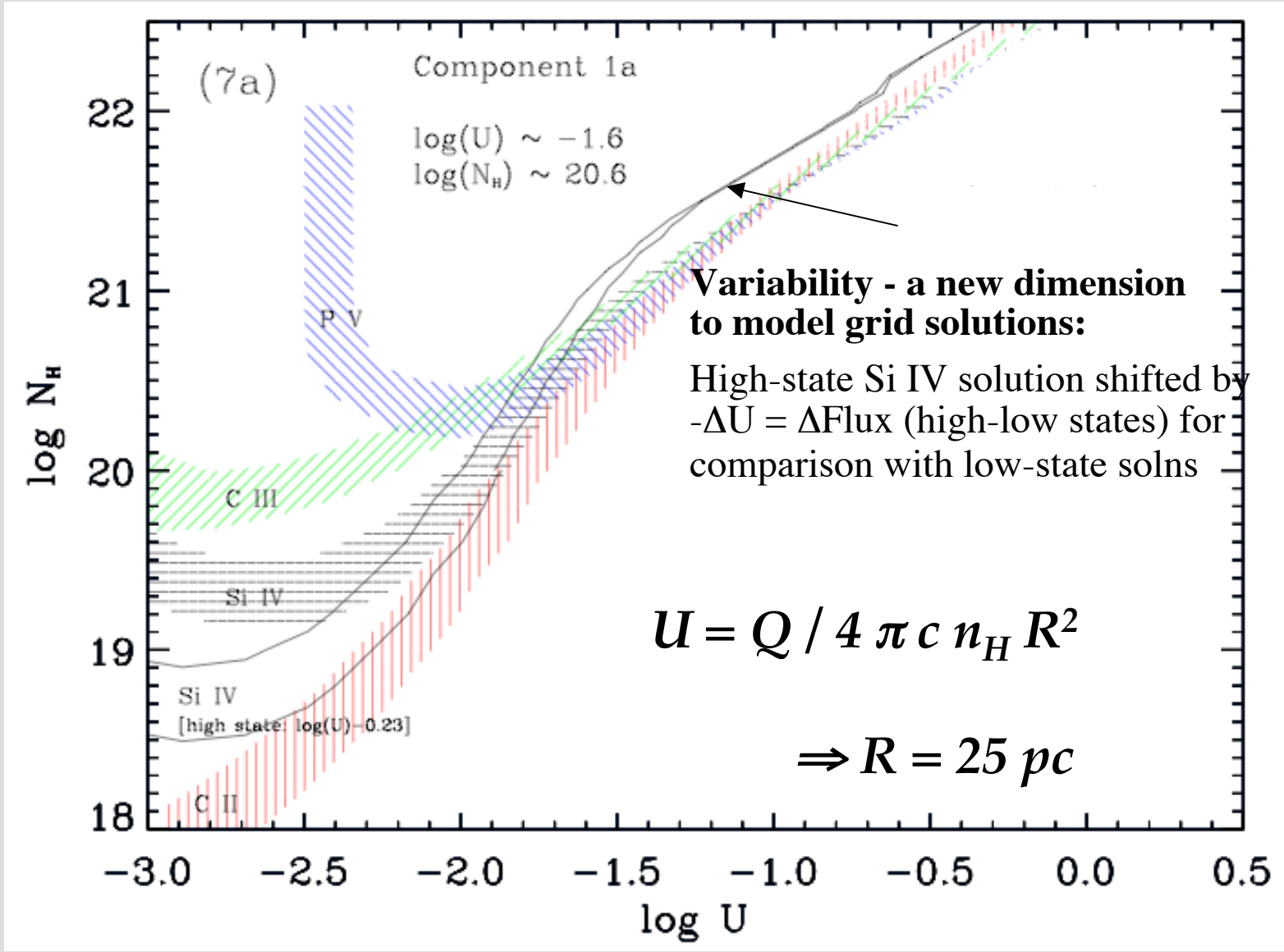
Mean high state:

S10, S12; F5

(F ~ 1.7x low state)



Photoionization Modeling Results



Variability - a new dimension to model grid solutions:

High-state Si IV solution shifted by -ΔU = ΔFlux (high-low states) for comparison with low-state solns

$$U = Q / 4 \pi c n_H R^2$$

$$\Rightarrow R = 25\ pc$$

Time-Dependent Photoionization

- With n_e , U-N_H determined, detailed time-dependent behavior of component 1 can be explored: equilibrium, variability timescales

- Response time for an ionic species depends on:
  - n_e
  - population relative to adjacent stages
  - magnitude of ionizing flux variation

- Solve the system of 1st order D Eqs:

$$\partial n_i / \partial t = -[p_i + n_e \alpha_{rec,\, i-1}\,]\, n_i + n_e\, n_{i+1}\, \alpha_{rec,\, i} + p_{i-1}\, n_{i-1}$$

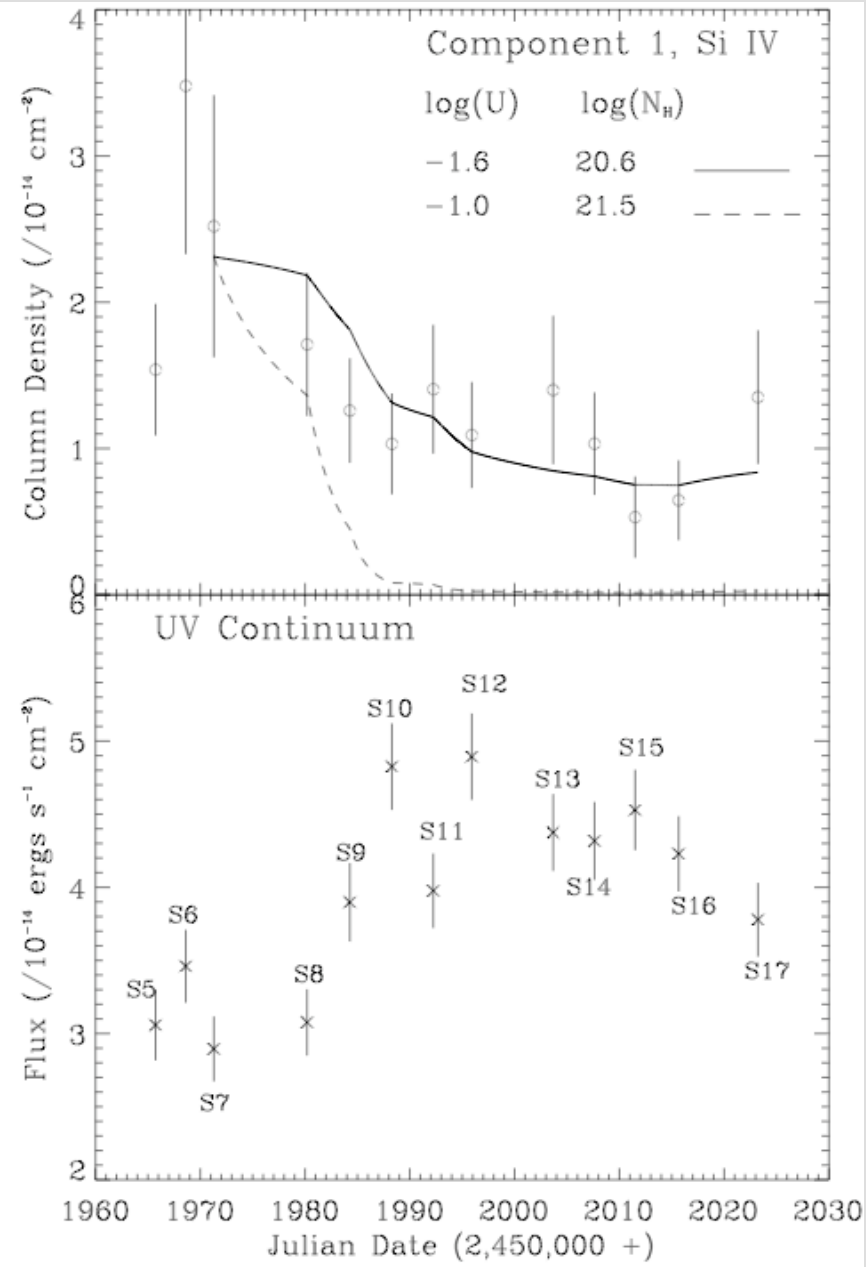
- Start with equilibrium model rates and ionic populations (from Cloudy) in low-state solution; track Si IV variations for observed flux variations during intensive STIS monitoring

Si IV Variability

- Are the equilibrium model solutions consistent with the CIII* density and observed variability?

  Yes

- High-ionization, non-equilibrium model overestimates the variability



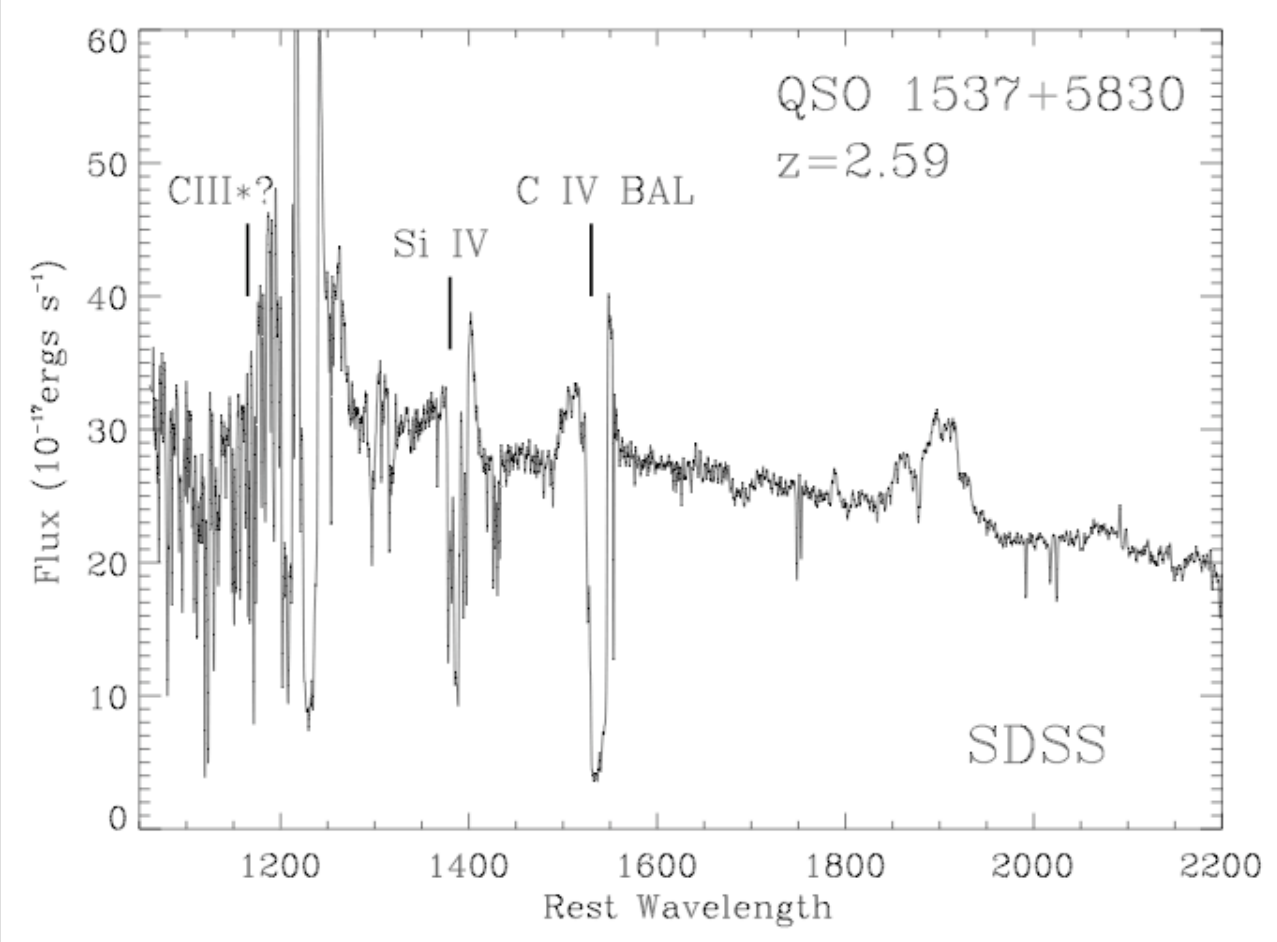
II. Constraints on n_e in high-z QSOs: SDSS

Sample selection:

- brightest QSOs in SDSS with C IV BALs

- Si IV absorption ⇒ large C^{+2} column

- z > 2.4 (C III* 1175 in SDSS bandpass)

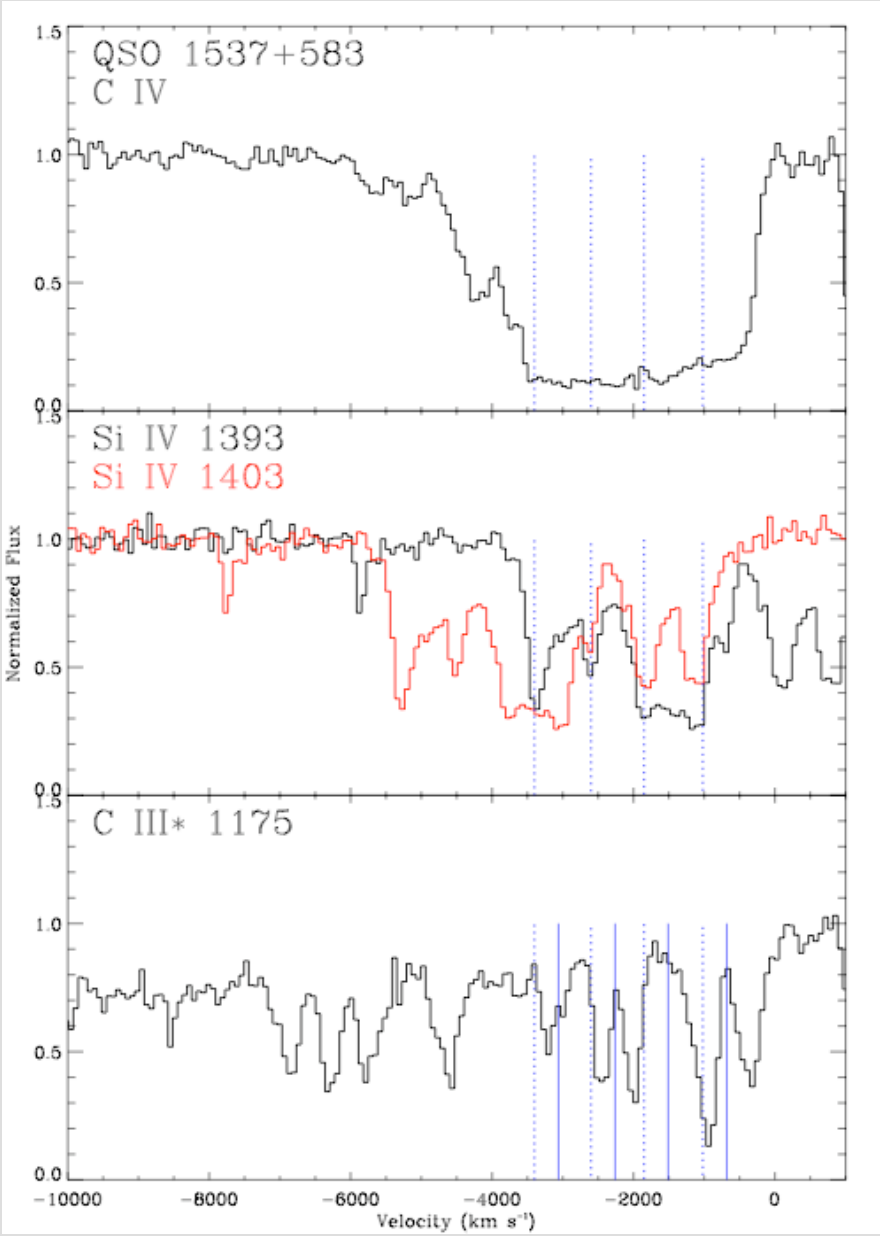


Example Target - SDSS QSO 1537+538

- C IV BAL

- Strong Si IV, narrow substructure
  -> large C III column density

- Upper limits on C III*1175 through gaps in the Lyα forest



Model C III* Absorption vs n_e

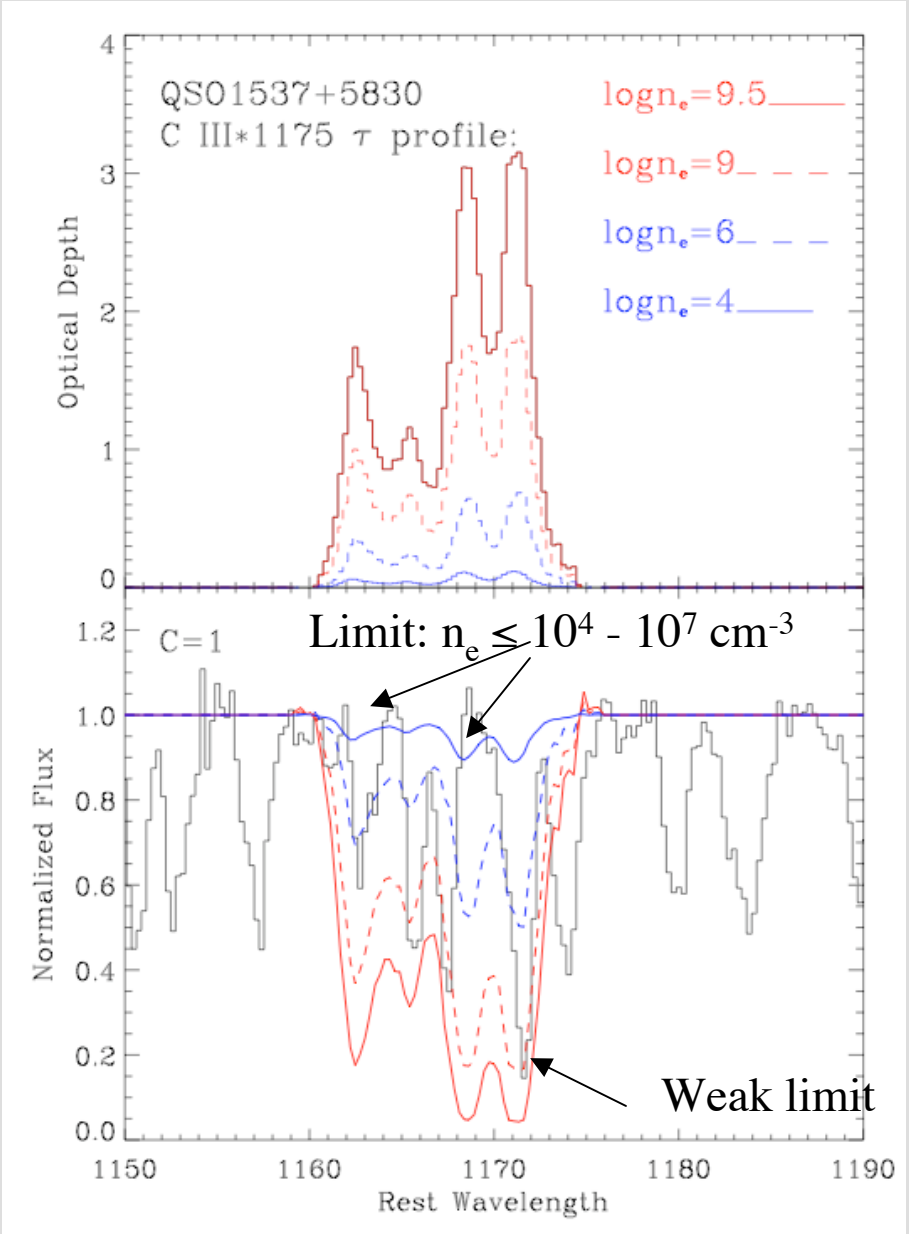
• adopt C IV profile as covering factor to measure Si IV column density

• at SDSS resolution, not sensitive to **relative** J level population rather **total** metastable population

• Limits from Photoionization Models: *Family of U,N_H solutions matching Si IV column density +upper limit on C II*

⇒ range of C III column densities

• upper limits on n_e from limits on C III* 1175 absorption



Separating C III* - Lyα forest at high-resolution: Precision Density Measurments

VLT/UVES spectrum of QSO J2233-606 vs model profiles at various densities

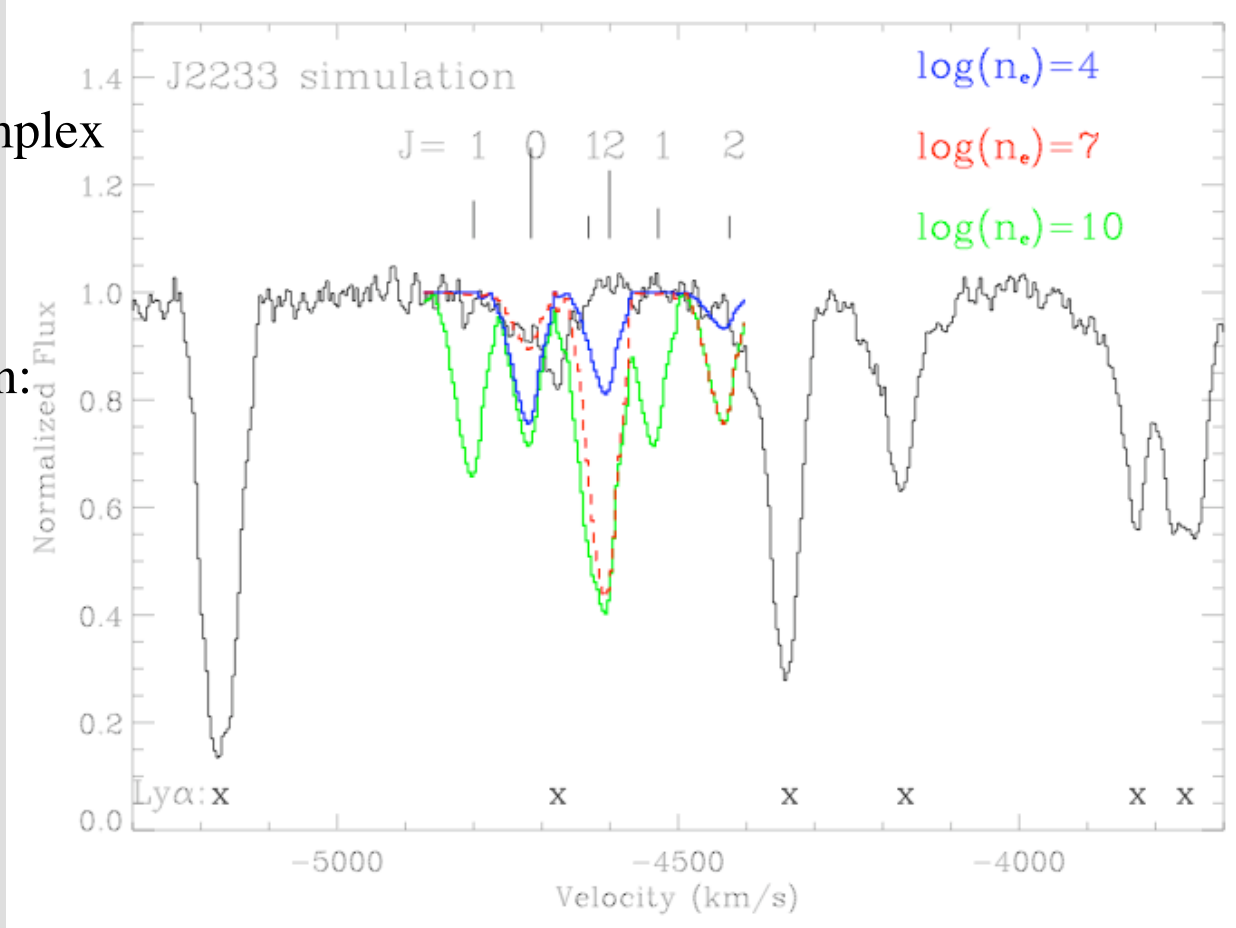
•Model profile: intrinsic C IV NAL observed in UVES spectrum

• Model C III* λ1175 complex for log(n_e)=4,7,10

• Result - at high resolution:

-C III λ1175 can be isolated*

-n_e measureable from individual line strengths



Summary

- Seyfert NGC 3783; tightly constrained UV absorber:
  - resolved C III*1175 complex & metastable level calculations:

    $n_e = 3 \times 10^4$ cm^{-3}
  - Photoionization models: log(U)= -1.6 , log(N_H)=20.6
    - U, n_e , luminosity -> $\underline{R = 25 \text{ pc}}$
  - detailed time-dependent behavior consistent with equilibrium models for derived density
- Constraints on high-z SDSS QSOs
  - C IV BALs, Si IV, z > 2.4 (C III* to λ > 4000Å): some useful upper limits on n_e
  - high-resolution optical spectra can isolate C III* from Lyα forest