WHY HIGH SPECTRAL RESOLUTION IS NEEDED FOR THE CONSTELLATION-X MISSION

Jeffrey L. Linsky

JILA/University of Colorado and NIST

Constellation-X Spectroscopy Workshop 2003

Columbia University

May 5, 2003

Collaborators

Tom Ayres	CASA/University of Colorado
Nick Gnedin	CASA/University of Colorado
Rachel Osten	National Radio Astronomy Observatory
Chris Reynolds	University of Maryland

Outline of the talk

- How useful is high resolution spectroscopy?
- What is the structure in the IGM?
- Characterizing warm absorber gas in AGN spectra
- Dynamics of stellar coronae
- What spectral resolution is needed for Con-X?

1 How useful is high resolution spectroscopy?

An important lesson learned from UV spectroscopy of plasmas with emission line spectra (temperatures from 10^3 to 10^7 K) is that high spectral resolution spectra is required to infer the information contained in the spectral lines:

- Separate line blends
- Correct for line saturation
- Determine line shapes and Doppler shifts
- Measure abundances accurately, etc.

Two examples:

(1) α TrA observed with STIS E230H: Separately measure the emission line strength, two interstellar absorption lines, and the shape of the wind absorption. (See Figure 1.)

(2) AD Leo observed with STIS E140M: Separate the Fe XXI 1354.08 Å line from the C I 1354.288 Å line ($\Delta v =$ 46 km/s), measure the Fe XXI line width and Doppler shift. (See Figure 2.)

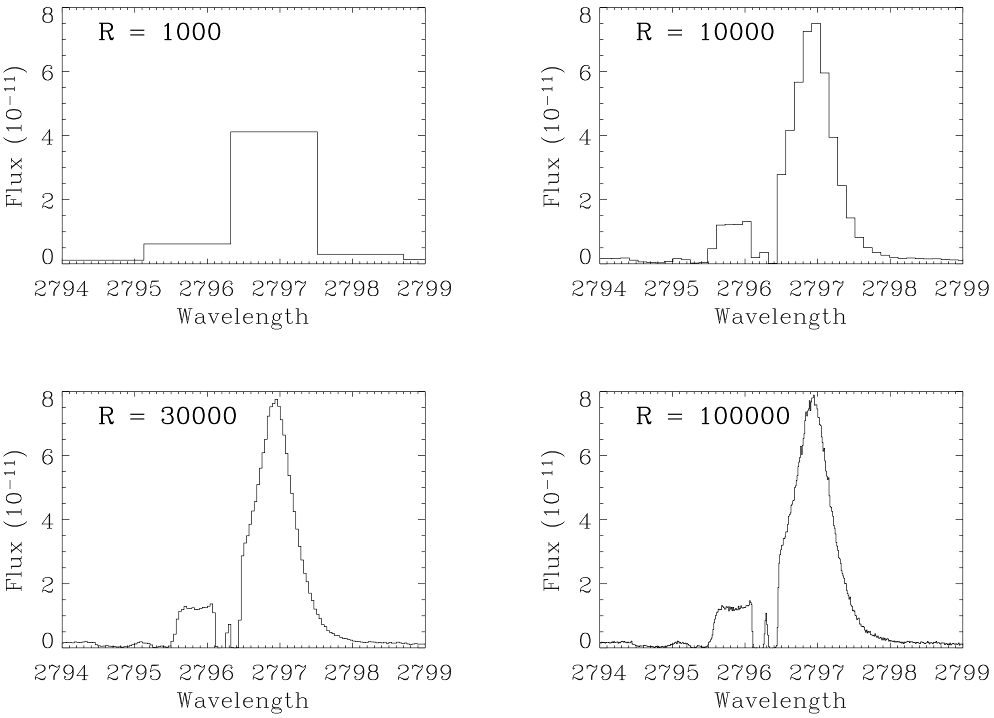


Figure 1: Spectrum of the Mg II $\lambda 2796$ Å line of the K4 II star α TrA obtained with the high resolution echelle mode of HST/STIS. The resolution is $\mathrm{R} = \lambda/\Delta\lambda = 100,000$ (3 km s^{-1}). The chromospheric emission line is altered by two narrow interstellar absorption lines near 2796.5 Å and a complex wind absorption feature on the blue side of the chromospheric emission line. As the resolution is degraded, the information content of the line profile disappears.

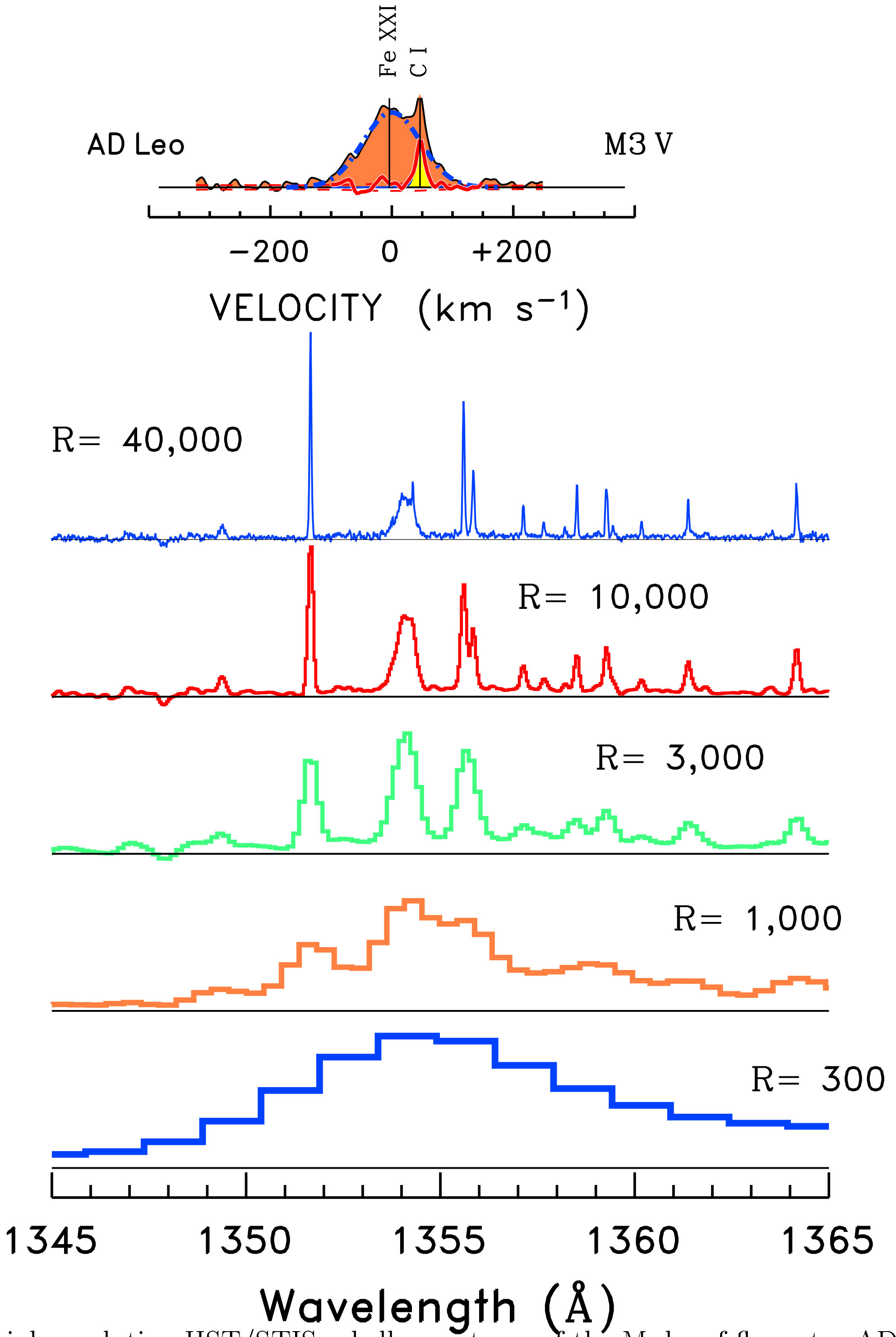


Figure 2: The high resolution HST/STIS echelle spectrum of the M dwarf flare star AD Leo. The Fe XXI line can be separated from the C I blending line at R = 40,000 and perhaps at R = 10,000, but not at lower resolution. At R = 1,000 it is not even clear that the Fe XXI line is present in the spectrum.

2 What is the structure of the IGM?

What resolution is needed to characterize the IGM (absorption line fluxes, components, and line widths)?

- Simulation for the O VIII Lyman-α line at 20.02 Å in the direction of PKS 2155-304. (see Figure 3).
- Continuum flux 0.0033 ph/cm^2/s/Å (Fang et al 2002, ApJ 572, L127).
- Simulation by Nick Gnedin assuming $A_{eff} = 3,000$ cm^2 and an integration time of 50 ks.
- Since the line is saturated, need R = 3,000 to measure the line column density.
- To measure the line width need R = 3,000.

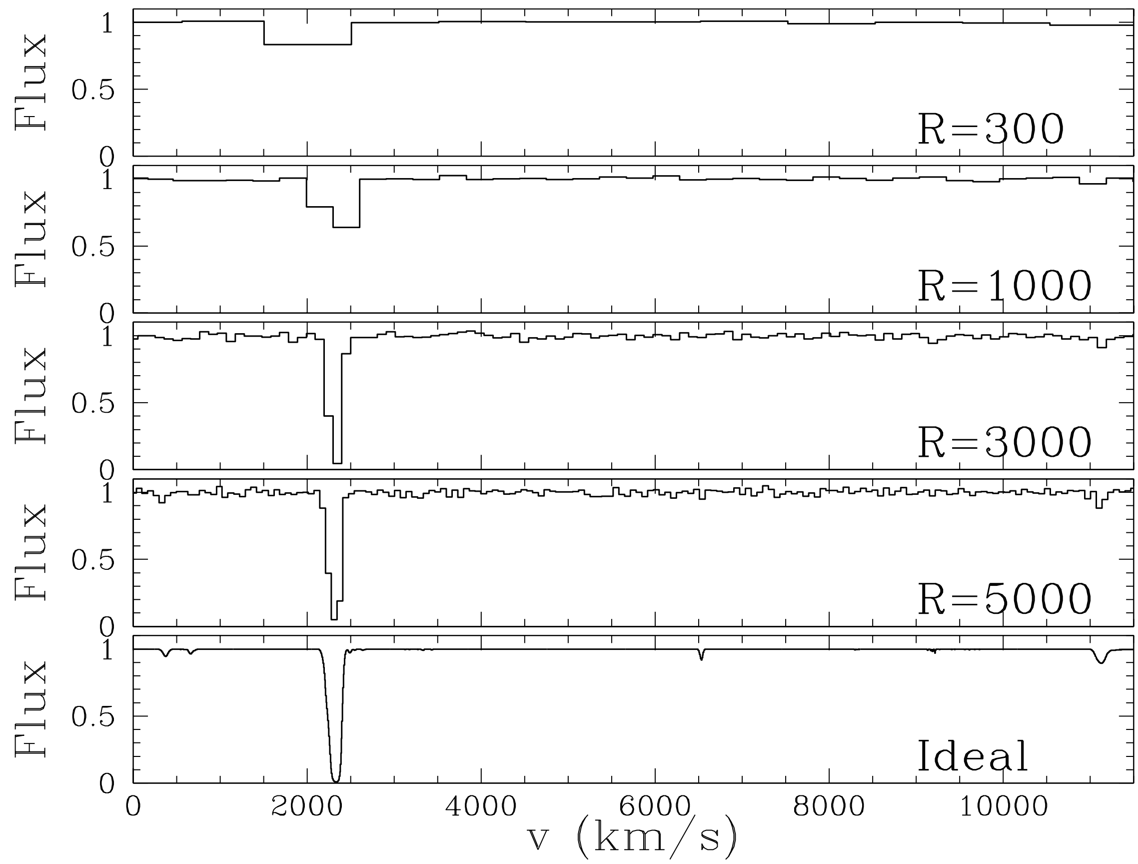


Figure 3: Simulation for the O VIII Lyman-α line at 20.02 Å in the direction of PKS 2155-304. Line saturation is evident for resolutions greater than 3,000. At lower resolution one would likely conclude that the line is optically thin.

3 Warm absorber gas in AGN spectra

Simulated spectrum of an AGN continuum and "warm absorber" gas computed by Chris Reynolds.

- Assume $A_{eff} = 3,000$ cm^2 and an integration time $t = 10^5$ seconds.
- Power law AGN continuum with a photon index of 2.
- Absorption by a large column density ($N_H = 10^{23}$ cm^{-2}) of highly ionized gas.
- Ionization parameter $L/nr^2 = 1,000$.
- We compute a rich absorption line spectrum that can be studied in high resolution data. (see Figures 4 and 5).

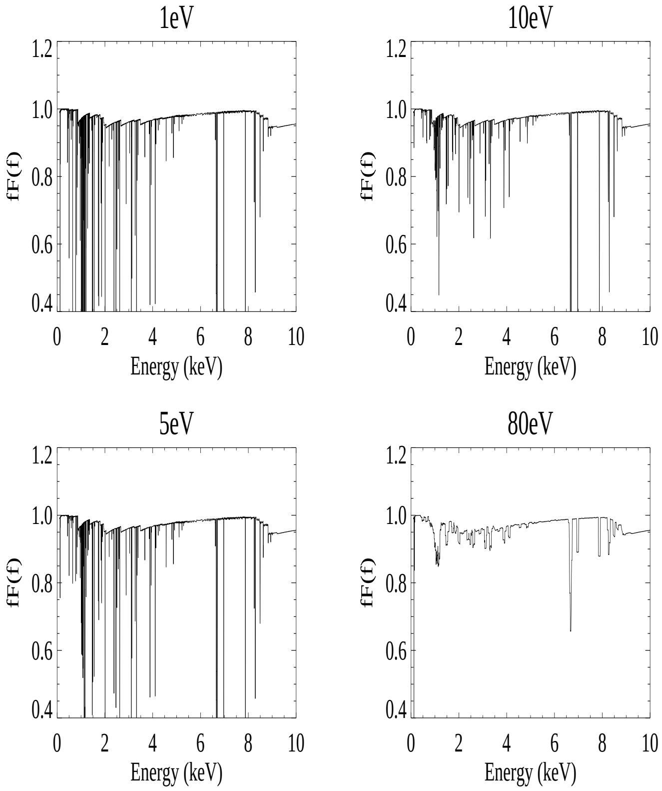


Figure 4: Simulated spectrum of an AGN continuum and "warm absorber" gas at different resolutions. Note that many lines do not appear to be saturated at low resolution.

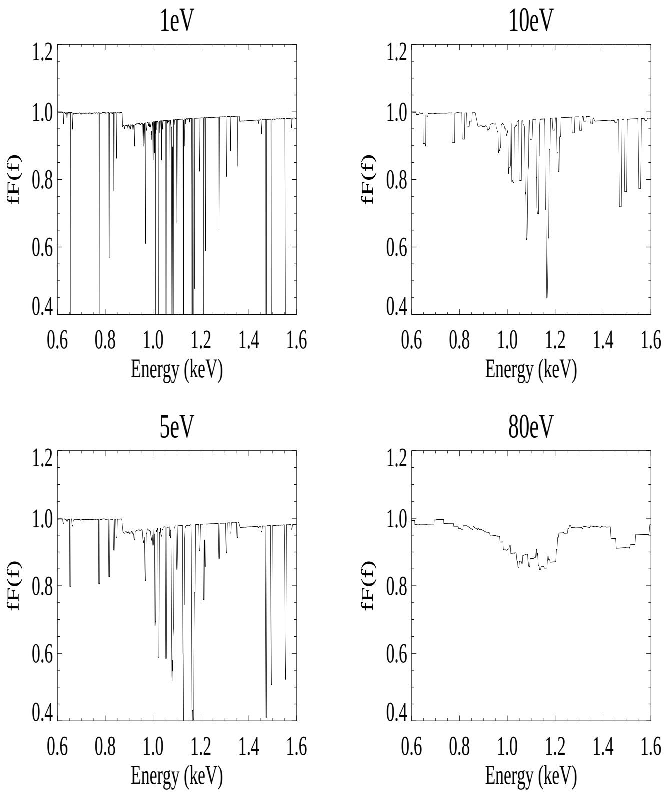


Figure 5: An expanded version of the AGN spectrum in the low energy range. Note that many lines do not appear to be saturated at low resolution. At 1 keV a resolution of at least 1,000 is required to determine whether lines are saturated.

What resolution is needed to diagnose the plasma?

- In the soft part of the spectrum (0.6–1.6 keV) the spectrum is very rich and many lines are saturated. A resolution of 1 eV ($R = E/\Delta E \approx 1,000$) is needed to separate the lines and measure the central line depths (essential for determining the column depths of saturated lines). (See Figure 4.)
- In the hard part of the spectrum (8.0–10.0 keV) the lines are widely separated and weak. A resolution of 10 eV ($R \approx 1,000$) is probably sufficient to measure the line column densities. (See Figure 5.)
- The 6.6 keV iron feature is saturated. To measure its column density accurately will require a resolution better than 5 eV ($R > 1,300$).

4 Dynamics of stellar coronae

What spectral resolution is needed to measure electron densities?

- The Ne IX triplet: 13.45 Å (r), 13.55 Å (i), 13.70 Å (f)
- The i/f ratio measures electron densities in the range 10^{11}–10^{13} cm^{-3}. (See Figures 6 and 7.)
- Simulations based on the APEC v. 1.2 code assuming the DEM of σ^2 CrB (an RS CVn binary system).
- At R = 300 it is not possible to measure n_e at any density even with infinite S/N.
- At R = 1,000 it is difficult to measure n_e at 10^{11} – 10^{12} cm^{-3}, but not at higher n_e even with very high S/N.
- At R = 3,000 one can accurately measure n_e.

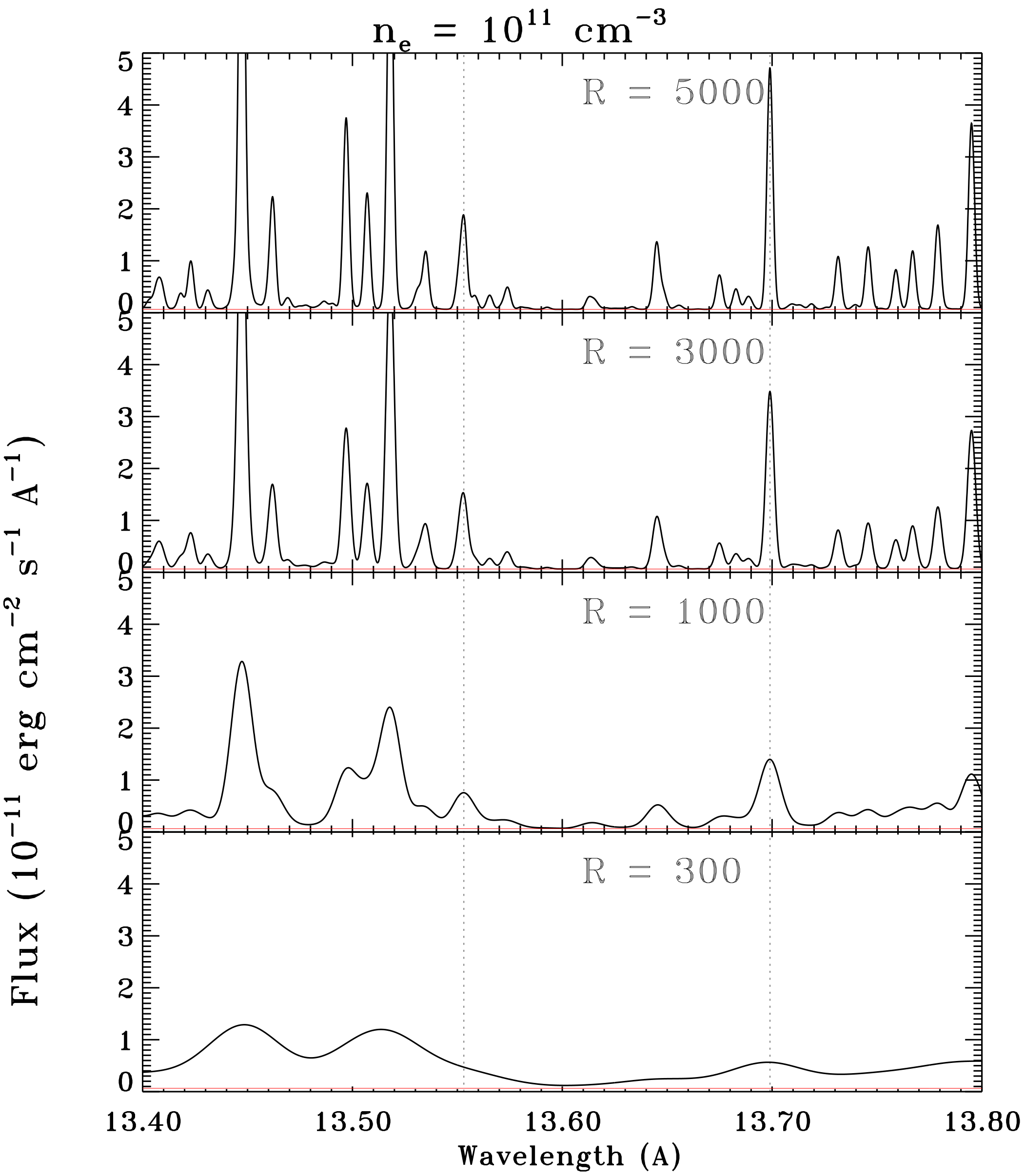


Figure 6: Computed spectrum of a stellar corona using the emission measure distribution for σ^2 CrB and an assumed electron density of 10^{11} cm^{-3}. The vertical dotted lines are for the intersystem (13.55 Å) and forbidden (13.70 Å) lines of Ne IX.

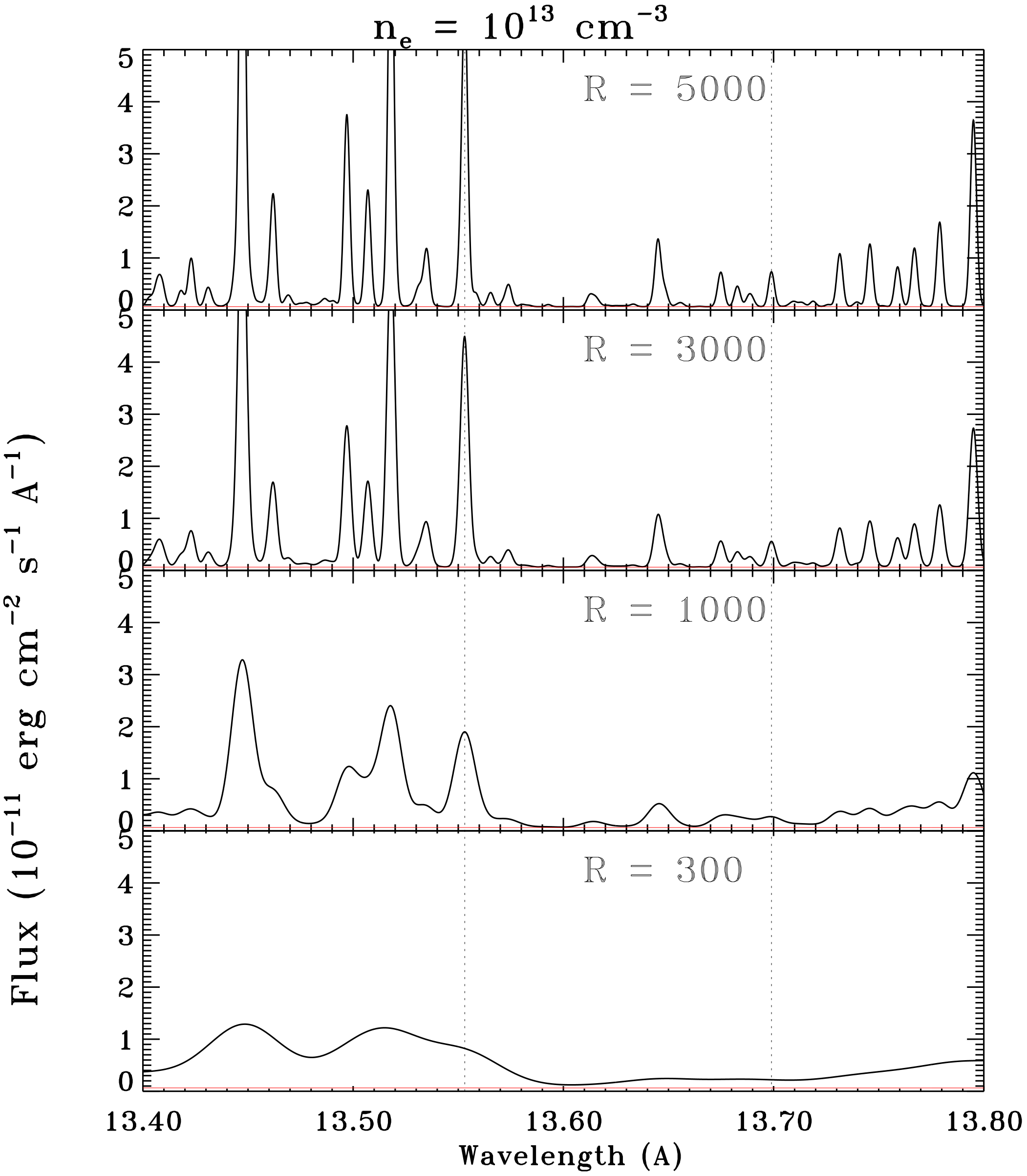


Figure 7: Same as Figure 6 except for an electron density of 10^{11} cm^{-3}.

What spectral resolution is needed to measure the continuum and to separate spectral lines?

- Simulation of the 11–12 Å spectrum of σ^2 CrB using its DEM and the APEC v. 1.2 code. (See Figure 8.)
- At R = 300 one cannot measure the continuum or separate spectral lines.
- At R = 1,000 and very high S/N one can measure the continuum and measure the flux of isolated lines.
- At R = 3,000 One can accurately measure the continuum and the fluxes of most spectral lines even with moderate S/N.

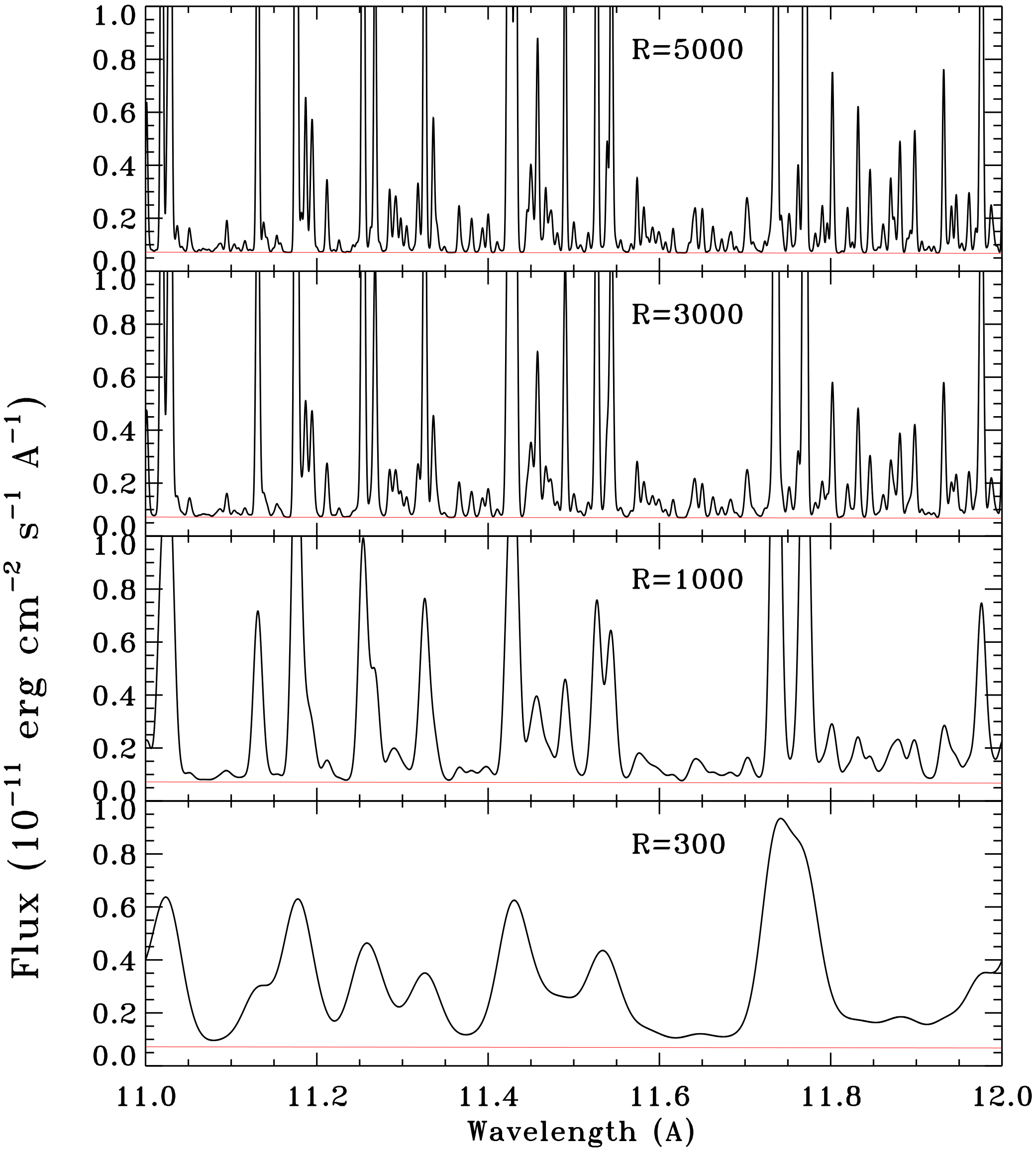


Figure 8: Simulation of the 11–12 Å spectrum of σ^2 CrB at different resolutions. The horizontal line just above zero flux is the computed continuum. At a resolution of 1,000 it is difficult to measure the continuum flux even with very high S/N. An accurate measurement of the continuum is essential for determining metal abundances relative to hydrogen.

What spectral resolution is needed to measure line widths, line asymmetries, and the continuum?

- Simulation for the Ne IX 13.45 Å line in AR Lac. Con-X should detect 300 counts in the line in 300 seconds. Intrinsic line width about 80 km/s.
- To measure the line width need R $\geq 3,000$.
- To identify two lines split by 180 km/s need R $\geq 3,000$.
- To identify a line asymmetry (a component 25% of the main peak separated by 90 km/s) need R $\geq 3,000$.
- To measure the continuum the resolution must be at least as good as the minimum line separation, R = 3,000–5,000.

What resolution is needed to measure thermal line widths?

For lines with 300 counts, the minimum resolution needed is $R = 1400\sqrt{(m/T_6)}$.

Ion	At. Weight	$\log T_{ion}$	Resolution
O VII	16	6.3	4,000
O VIII	16	6.7	2,500
Ne IX	20	6.6	3,200
Ne X	20	6.9	2,200
Mg XII	24	7.2	1,700
Si XIV	28	7.4	1,500
Fe XVII	56	6.7	4,700
Fe XXV	56	7.8	1,300

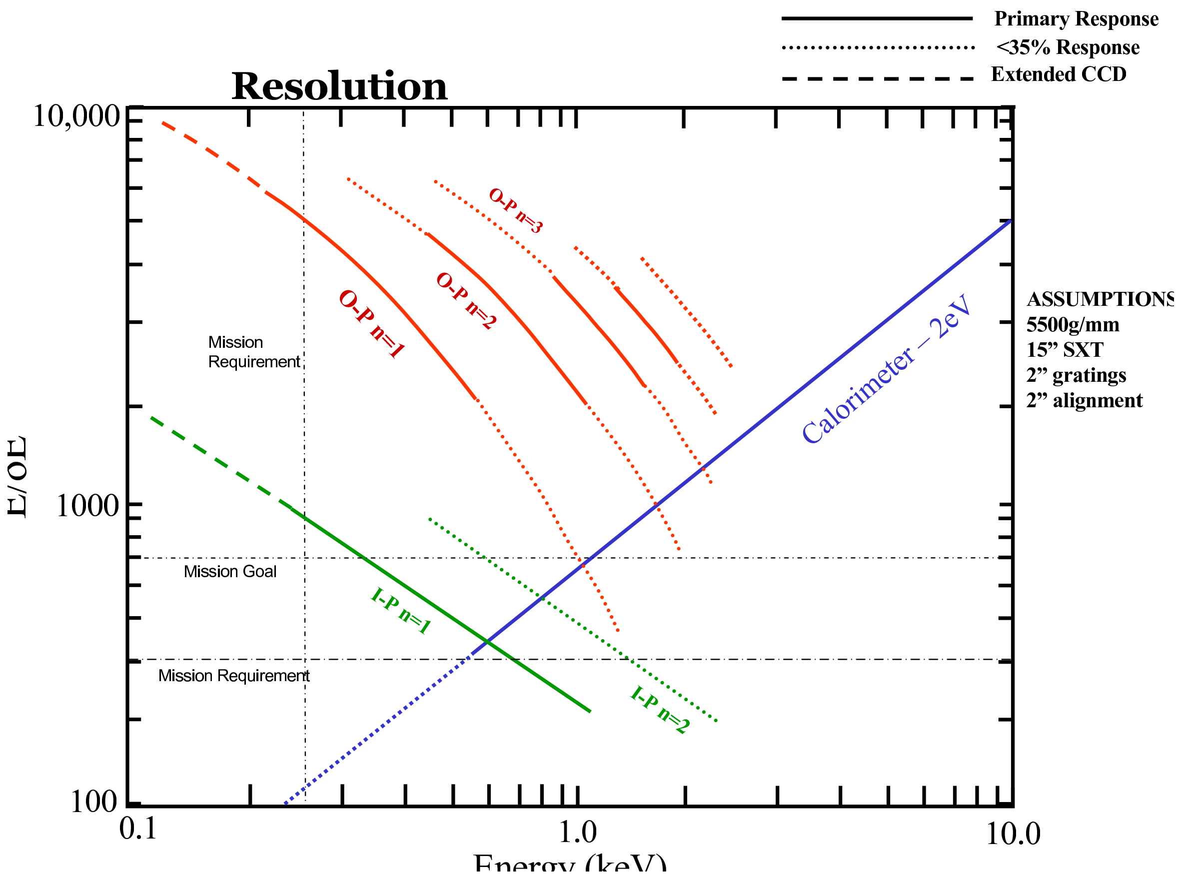
5 What spectral resolution is needed for Con-X?

Requirement: R = 1,500 (Will accomplish many of the science objectives)

Goal: R = 4,500 (Will accomplish all of the science objectives).

Is this feasible? Web Cash is developing off-plane radial groove reflection grating designs to accomplish the R = 4,500 goal.

The next 4 figures are taken from a presentation made by Webster Cash in September 19, 2002. They show that high spectral resolution with high throughput is possible with the off-plane radial groove reflection grating architecture. The Con-X project is presently funding this development work, and we look forward to a successful high resolution mission in the not too distant future.



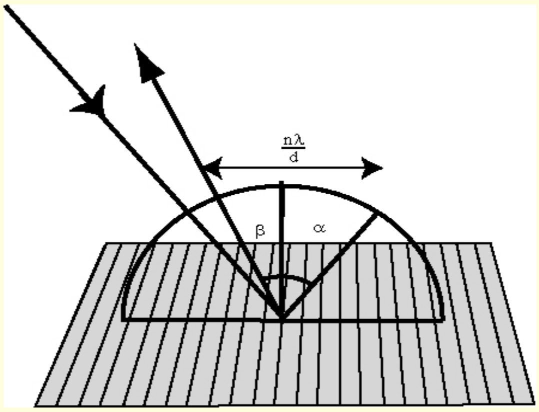
Primary Response
<35% Response
Extended CCD
Resolution
10,000
1000
100
0.1
1.0
10.0
Energy (keV)
E/δE
O-P n=1
O-P n=2
O-P n=3
I-P n=1
I-P n=2
Calorimeter – 2eV
Mission Requirement
Mission Goal
Mission Requirement
ASSUMPTIONS
5500g/mm
15" SXT
2" gratings
2" alignment

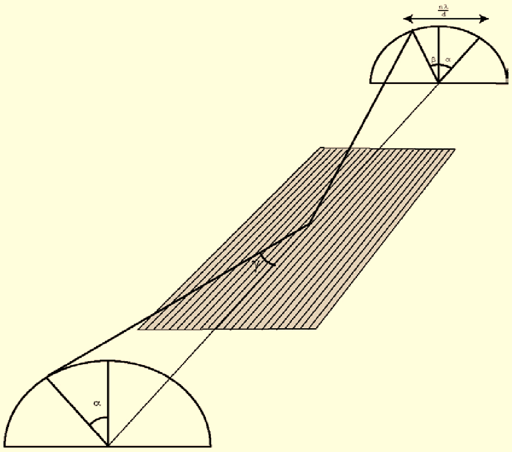
In-plane Mount

Off-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d}$$

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d\sin\gamma}$$





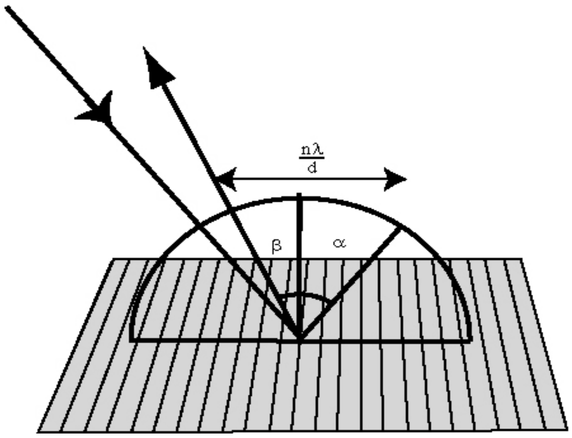
University of Colorado Constellation-X *September 19, 2002*

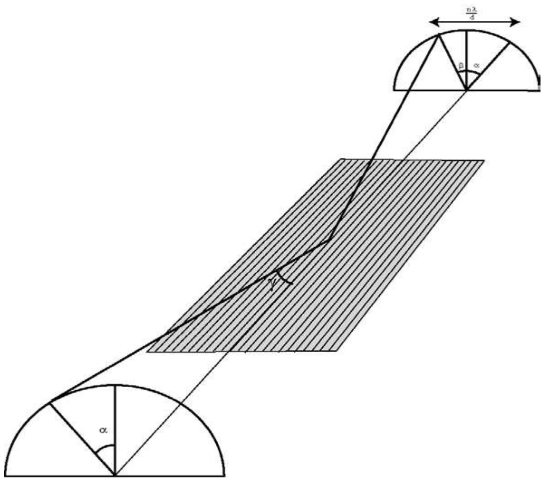
In-plane Mount

Off-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d}$$

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d\sin\gamma}$$





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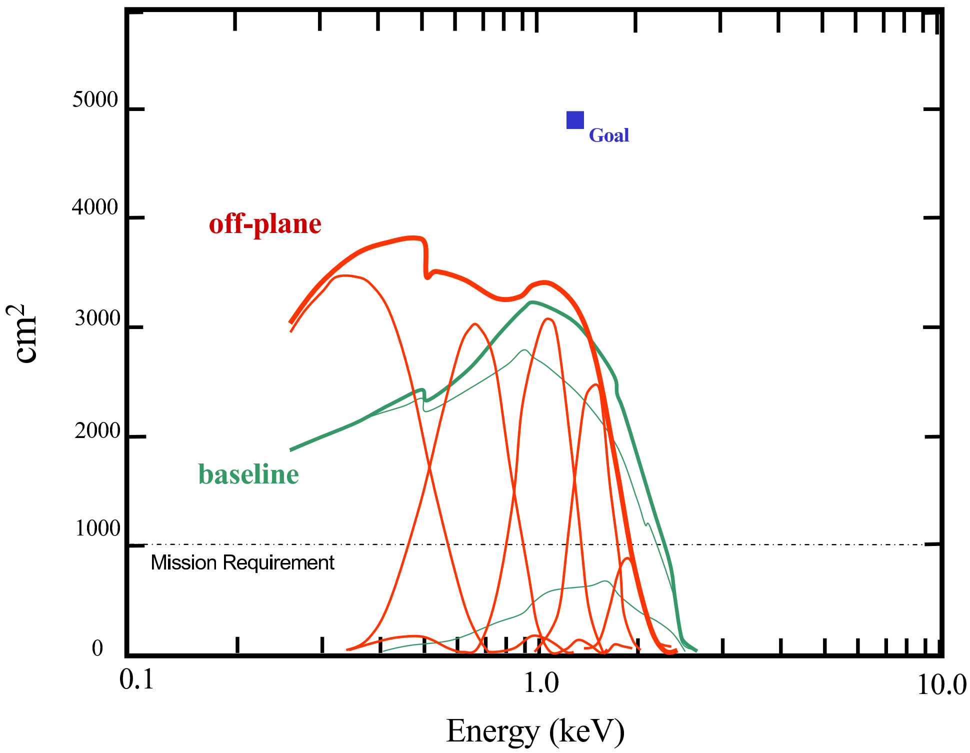
Effective Area



ASSUMPTIONS:

Coverage 40% of outer envelop

Off-Plane Groove Efficiency 80% of theoretical

85% Structure Transmission

CCD thin Al filter only