Recent Laboratory Astrophysics Work at the LLNL Electron Beam Ion Traps

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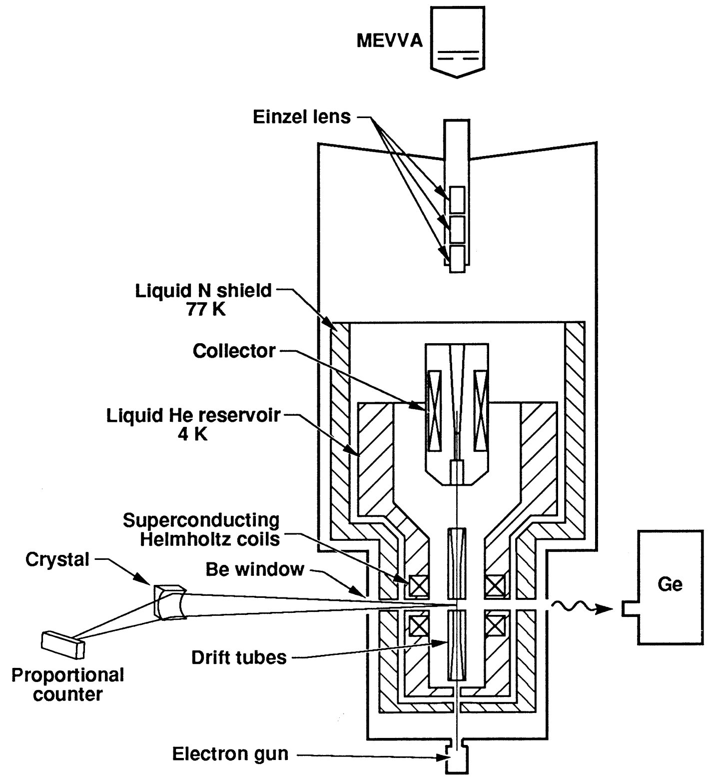
Outline

- Overview of LLNL EBIT.
- Cross sections of Ne-like Fe XVII lines.
- Cross sections of Fe XVIII-XXIV lines.
- Inner K-shell transitions of O III-VI.
- Wavelengths survey of high-n lines of Fe XVIII-XXIV.
- Wavelengths survey of $3 \rightarrow 2$ transitions of L-shell Ni.
- Future work.

the LLNL Electron Beam Ion Trap



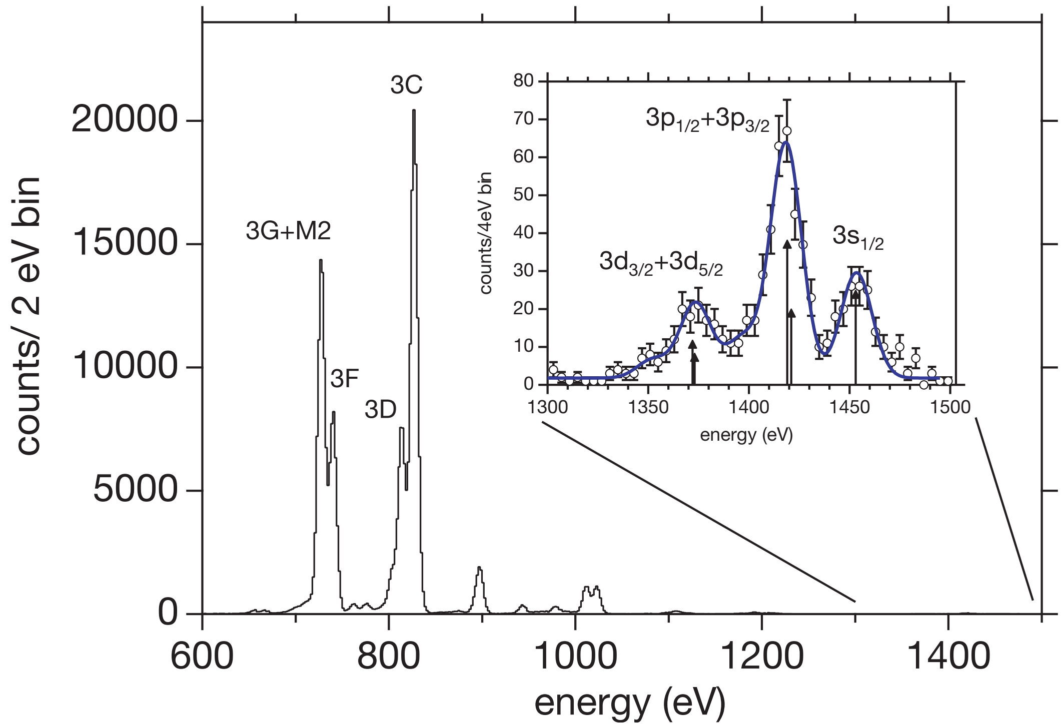
Available spectrometers:

crystal, grating, and X-ray microcalorimeter.

Cross Section Measurements Using the XRS

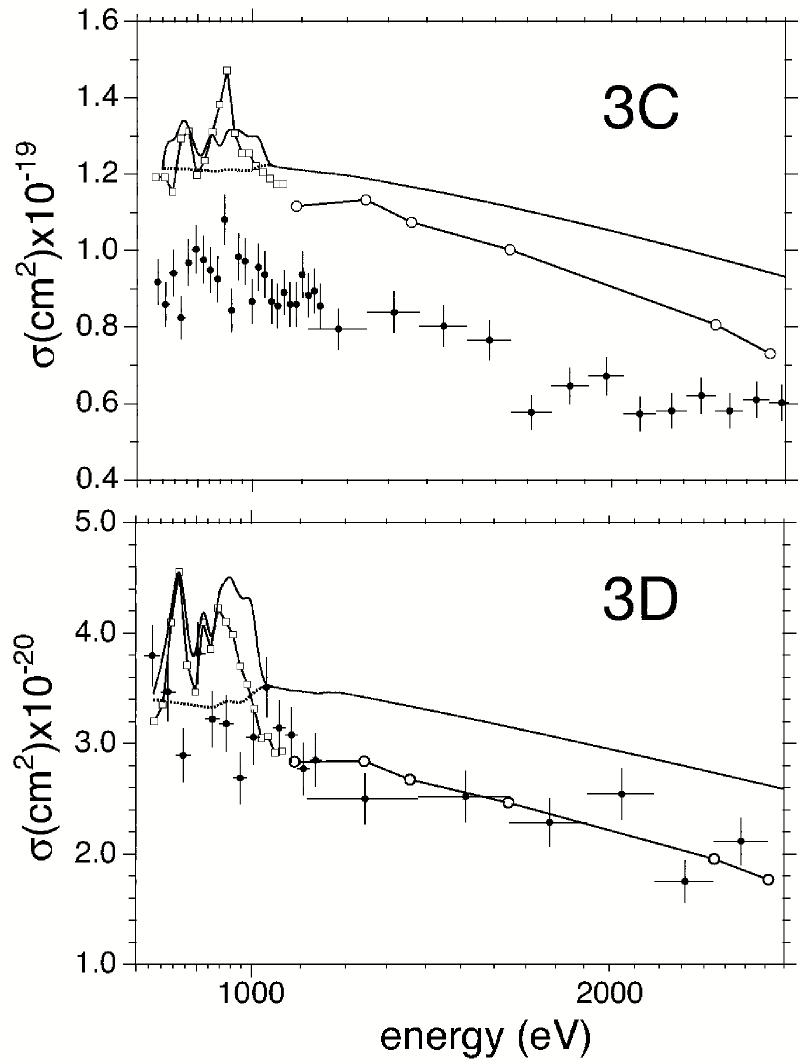
- High quantum efficiency.
- Large energy coverage.
- Long-time gain stability.
- Simultaneous monitoring of the collisional excitation and radiative recombination emission.
- $\sigma_{ex}(E) = K(E)\sigma_{rr}(E) \times \frac{I_{ex}}{I_{rr}}$.

Fe XVII Spectrum measured by Microcalorimeter

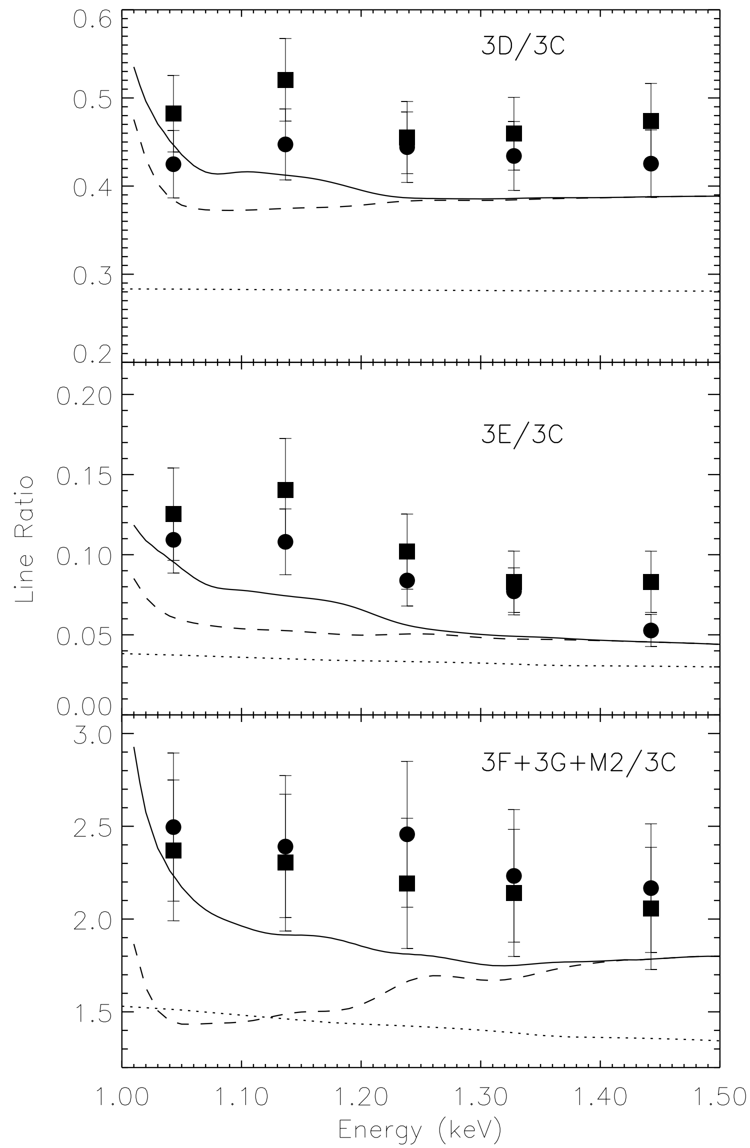


$E_b = 964$ eV. Brown et al. Phys. Rev. Lett. (submitted)

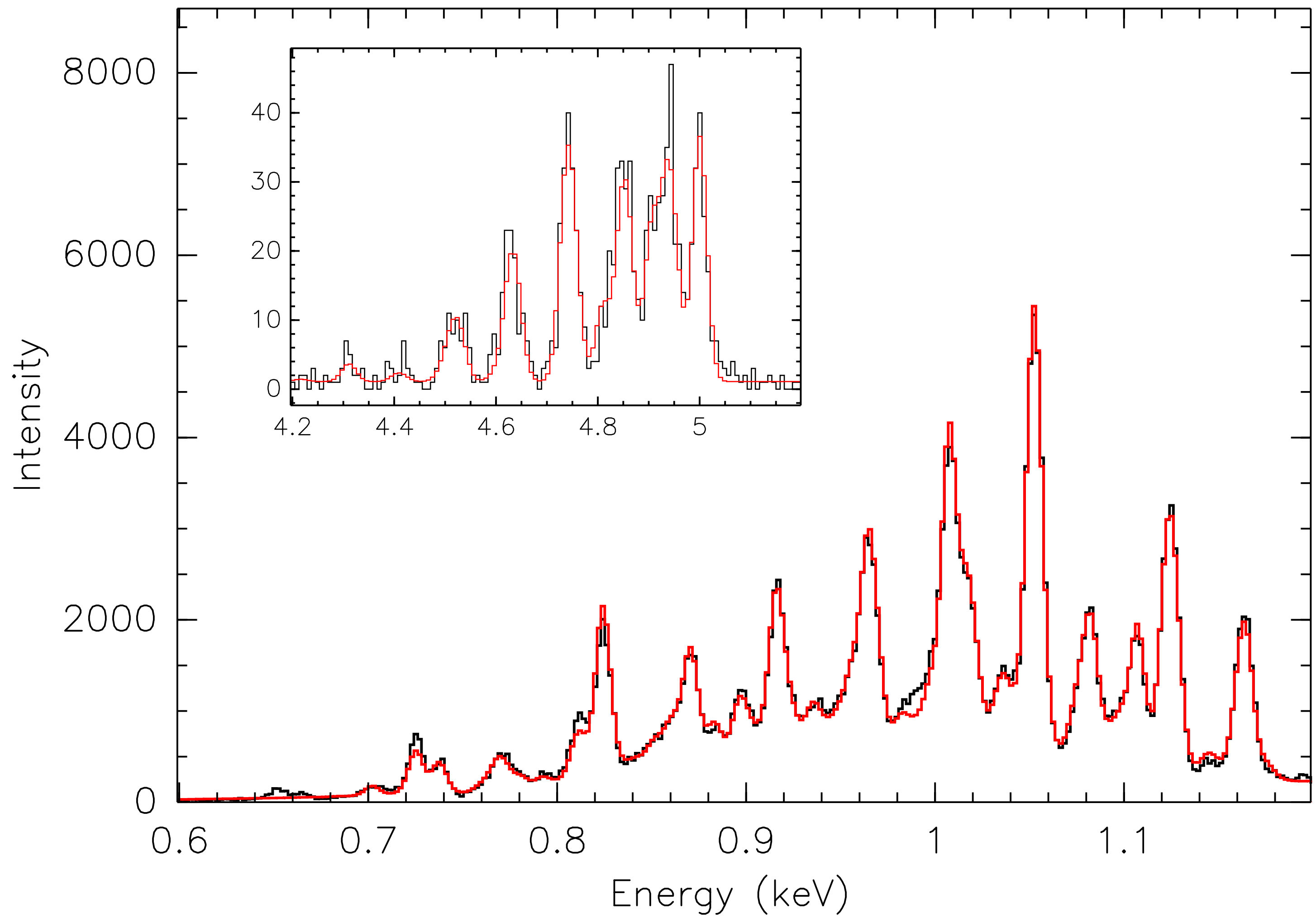
Comparison between Theories and Exp.



Line Ratios of Ne-like Ni XIX

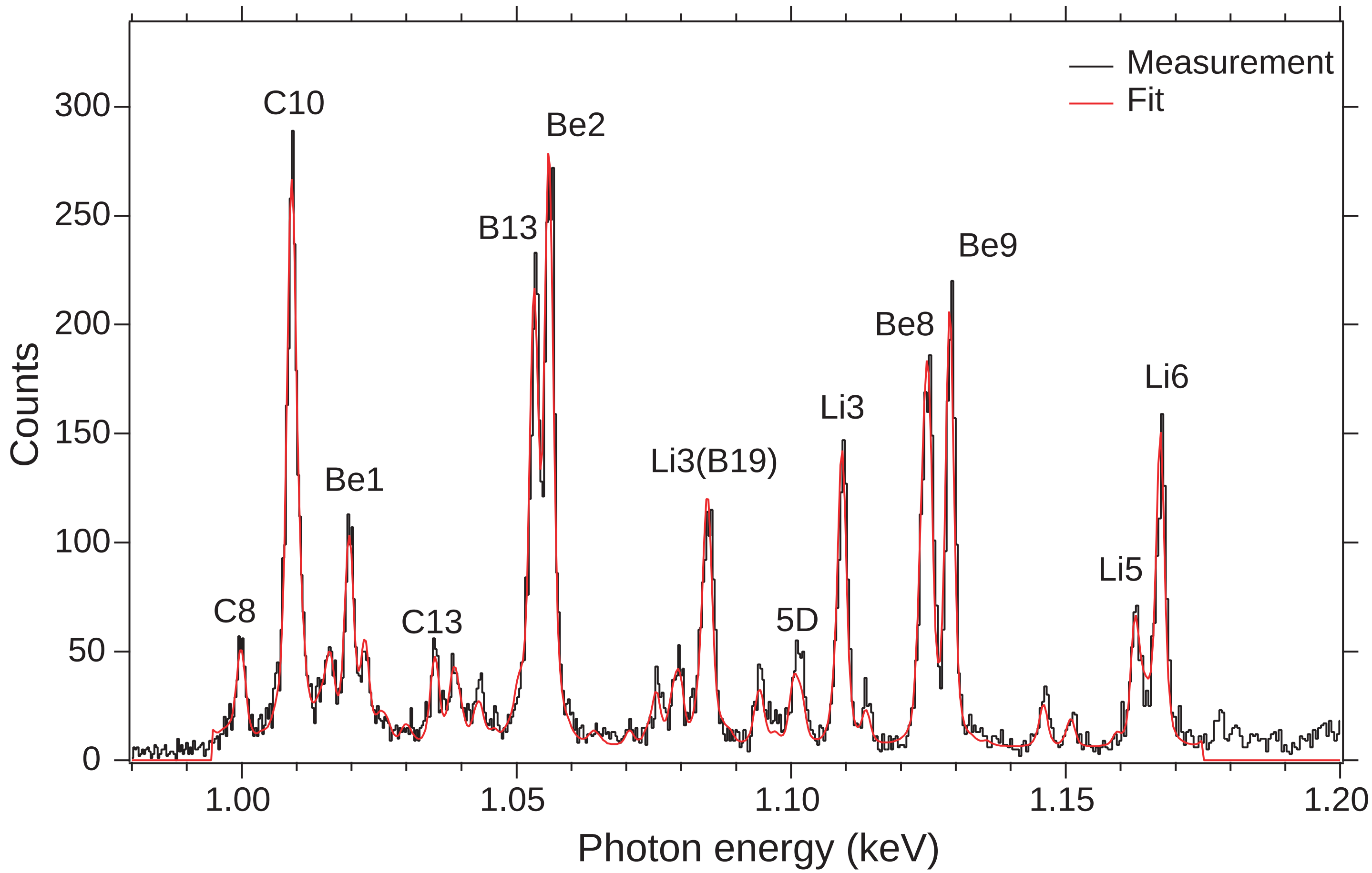


Cross Sections of Fe XVIII-XXIV Lines



$E_b = 2.9$ keV

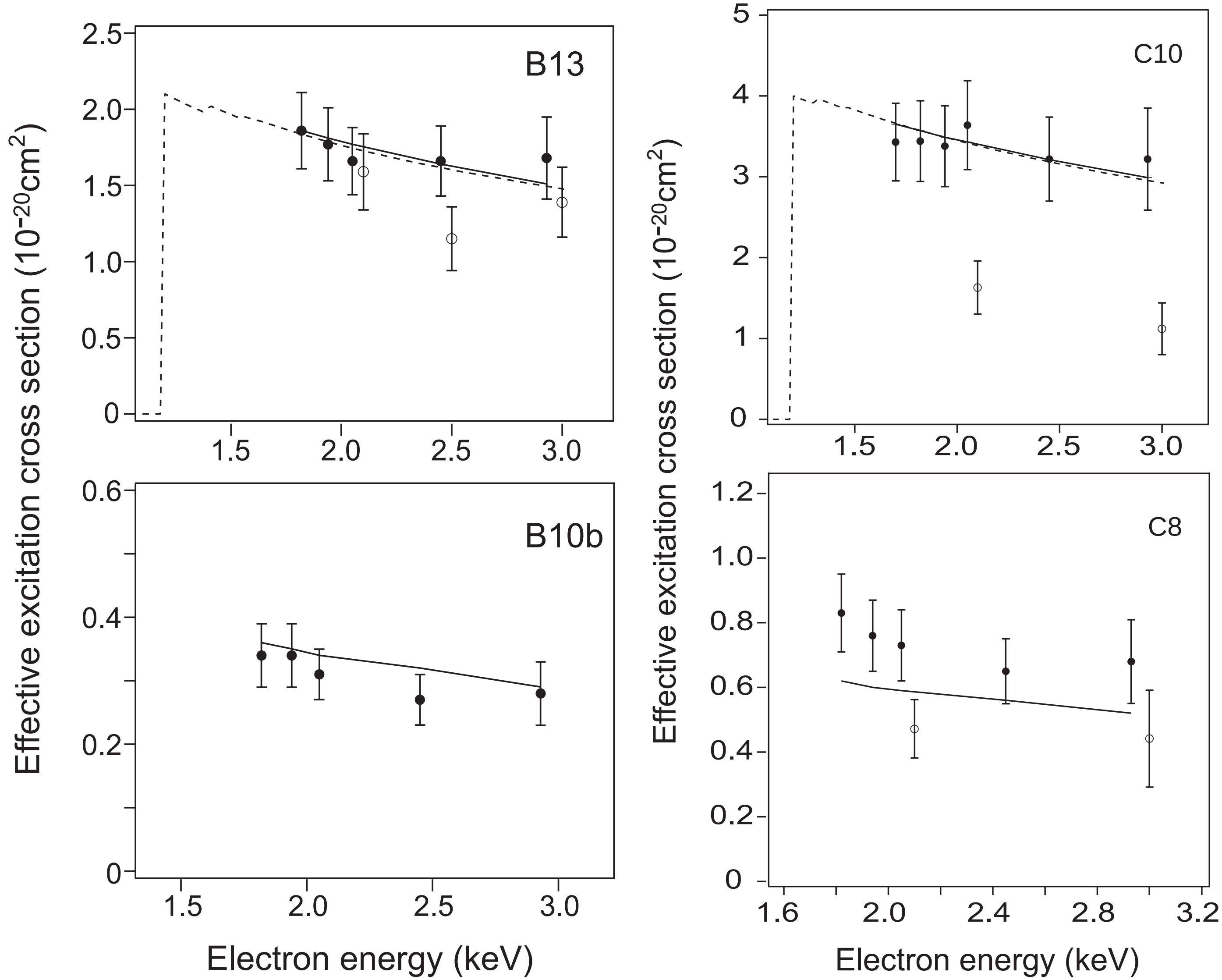
Supplement XRS with the Crystal Spectrometer



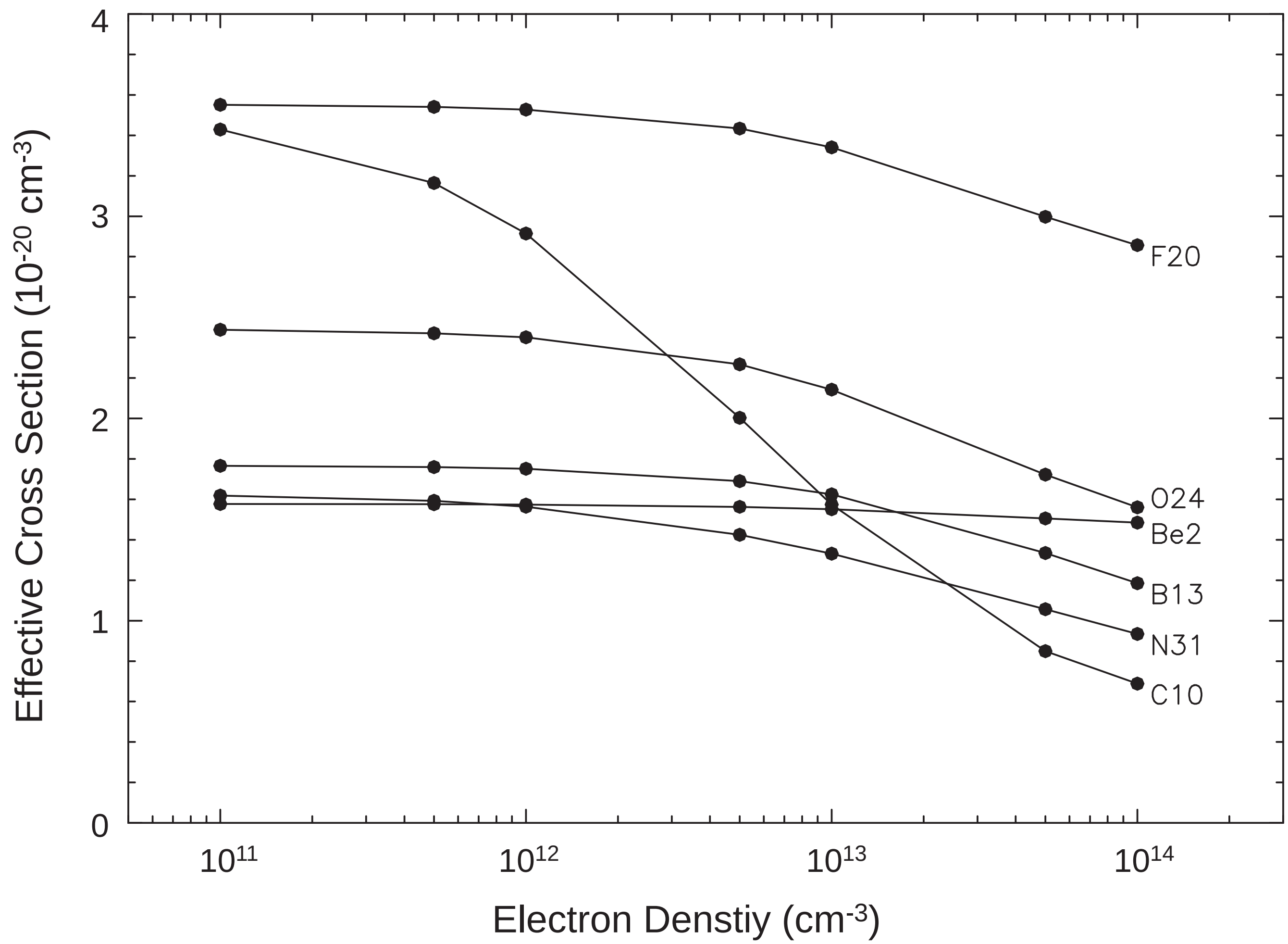
Global Analysis Method

1. Fit XRS RR spectra to derive relative ion abundances.
2. Fit crystal spectra, using the relative ion abundances derived from RR, and allow the cross sections of strong lines to vary, while keeping the those for weak lines fixed at the theoretical values.
3. Fit XRS excitation spectra, fixing the cross sections as derived from the crystal spectra, determine a new set of ion abundances.
4. The ion abundances derived in step 1 and 3 are compared, and the ratios for each charge state are used to normalize the cross section.
5. Ensures that the relative cross sections are determined from the high resolution crystal spectra, while the absolute normalizations are obtained from the fit to the XRS data

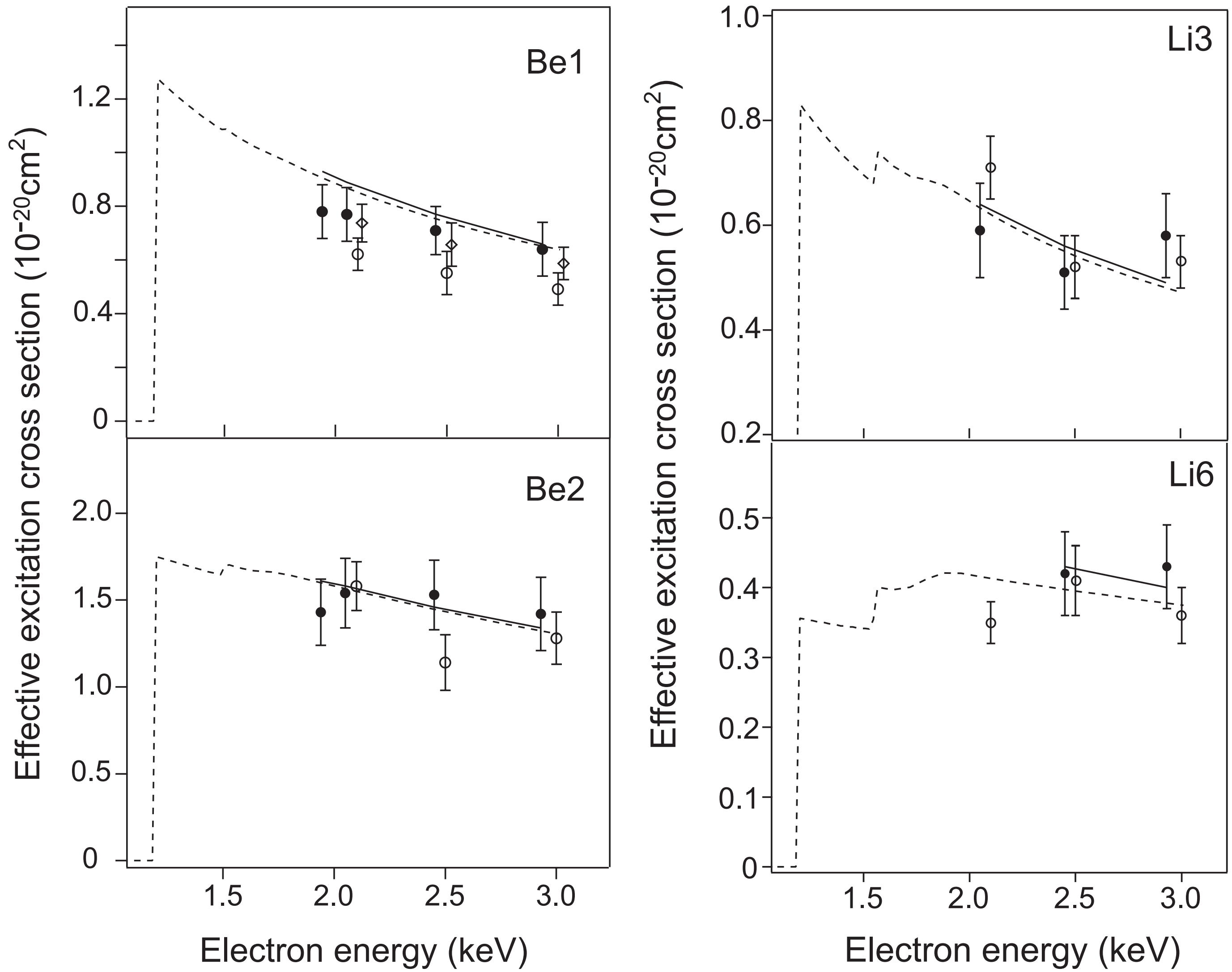
Examples of Measured Cross Sections



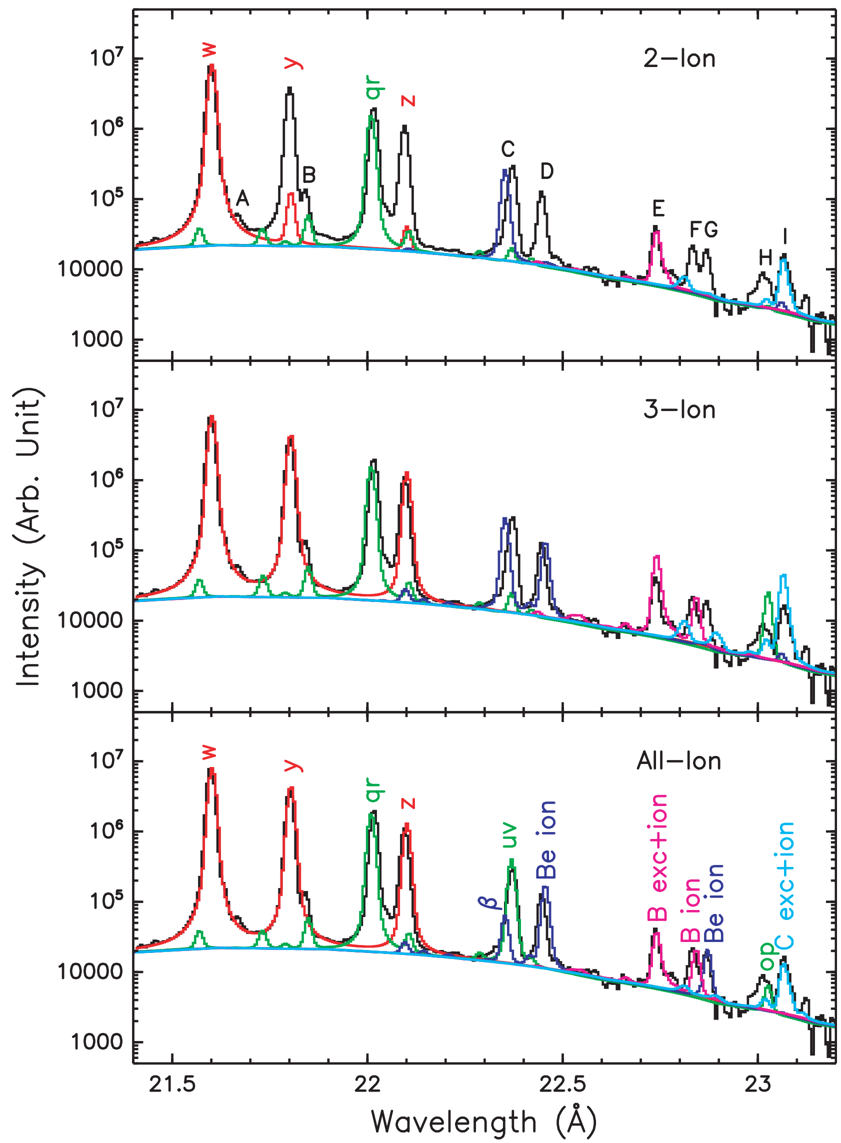
Density Sensitivity of C-like line C10



Examples of Measured Cross Sections



Inner K-shell Transitions of O III-VI



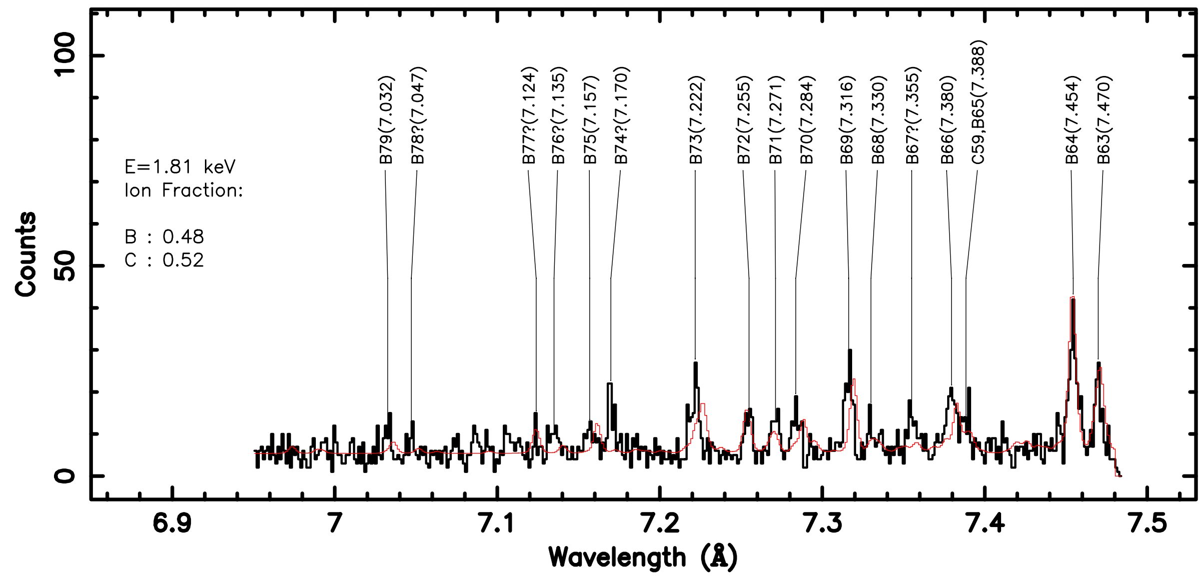
Measured Wavelengths for K-shell Transitions

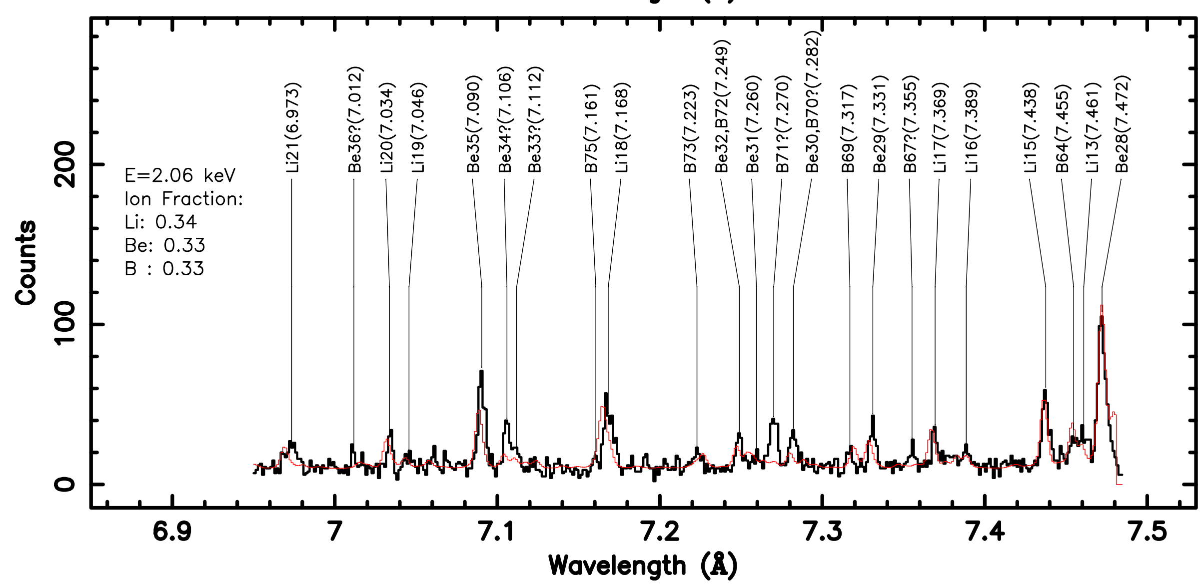
Ion	Lower(J)	Upper(J)	$\lambda_{\rm exp}$(Å)	Label	Index
O VI	$1s^2 2s(\frac{1}{2})$	$1s2s2p(\frac{1}{2},\frac{3}{2})$	22.374(8)	u,v	C
O VI	$1s^2 2p(\frac{1}{2},\frac{3}{2})$	$1s2s^2(\frac{1}{2})$	23.017(20)	o,p	H
O V	$1s^2 2s^2(0)$	$1s2s^2 2p(1)$	22.370(10)	β	C
O V	$1s^2 2s2p(0,1,2)$	$1s2s2p^2(0,1,2)$	22.449(8)		D
O V	$1s^2 2s2p(2)$	$1s2s2p^2(2)$	22.871(5)		G
O IV	$1s^2 2s^2 2p(\frac{1}{2},\frac{3}{2})$	$1s2s^2 2p^2(\frac{1}{2},\frac{3}{2})$	22.741(5)		E
O IV	$1s^2 2s2p^2(\frac{5}{2},\frac{3}{2})$	$1s2s2p^3(\frac{3}{2})$	22.836(5)		F
O III	$1s^2 2s^2 2p^2(1,2)$	$1s2s^2 2p^3(1)$	23.071(6)		I

Wavelengths of High-n Lines of Fe L-shell Ions

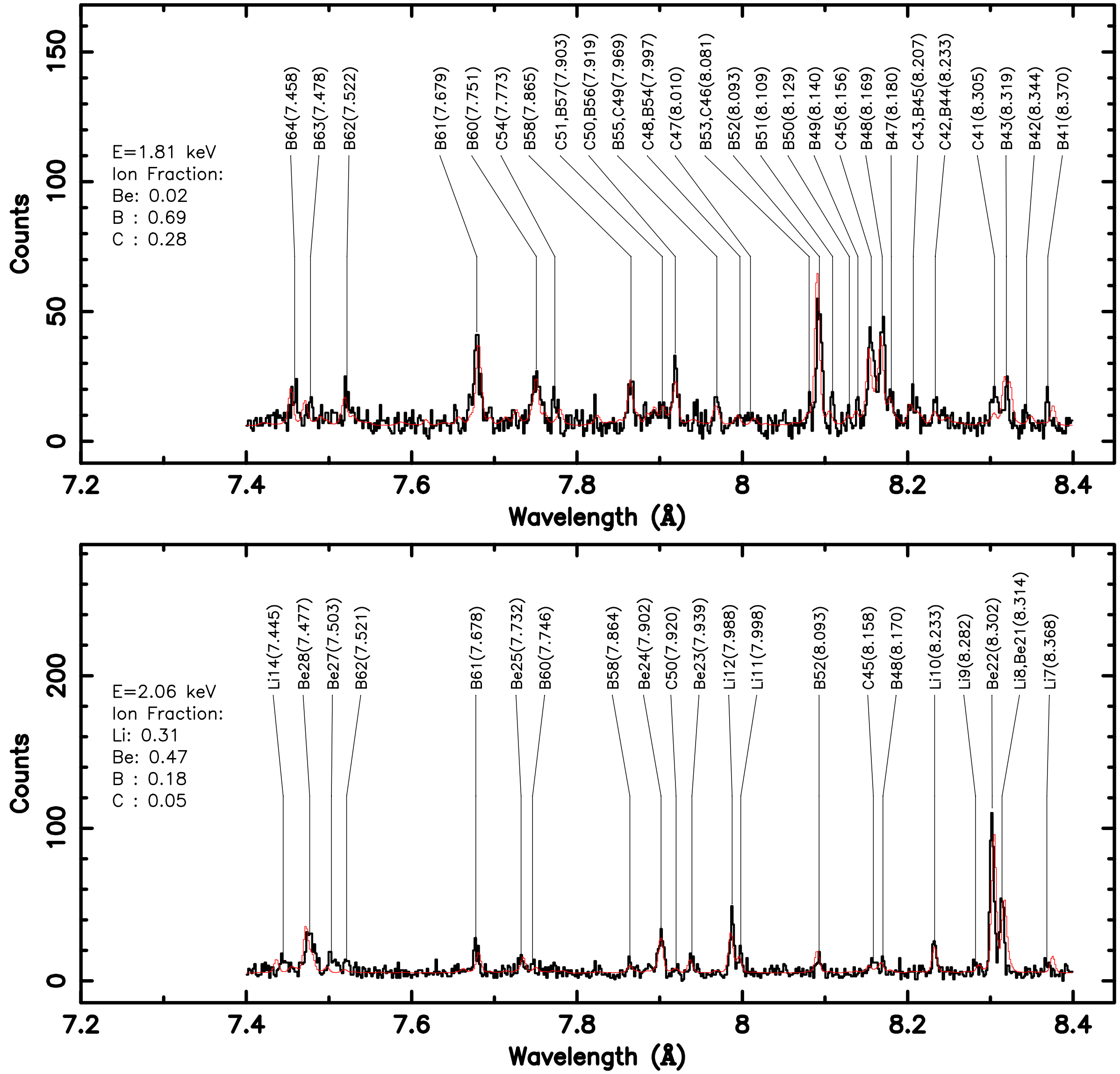
- For Fe L-shell lines between 10.6 and 18 Å, see Brown et al. ApJS, 140, 589, and ApJ, 502, 1015.
- Wavelengths of weaker, high-n transitions of Fe L-shell ions are important, e.g., for modeling the line blending in the Mg XI triplet region.
- Using crystal spectrometers, and with four crystal settings, we measured all significant Fe L-shell emissions between 7 and 11 Å, mostly, high-$n \rightarrow 2$ transitions, with $4 \geq n \leq 10$.
- Measurements were taking at different beam energies to select charge states.
- Compilation of the line list is in preparation (Chen et al., 2006).

Lines between 7.0 and 7.5 Å

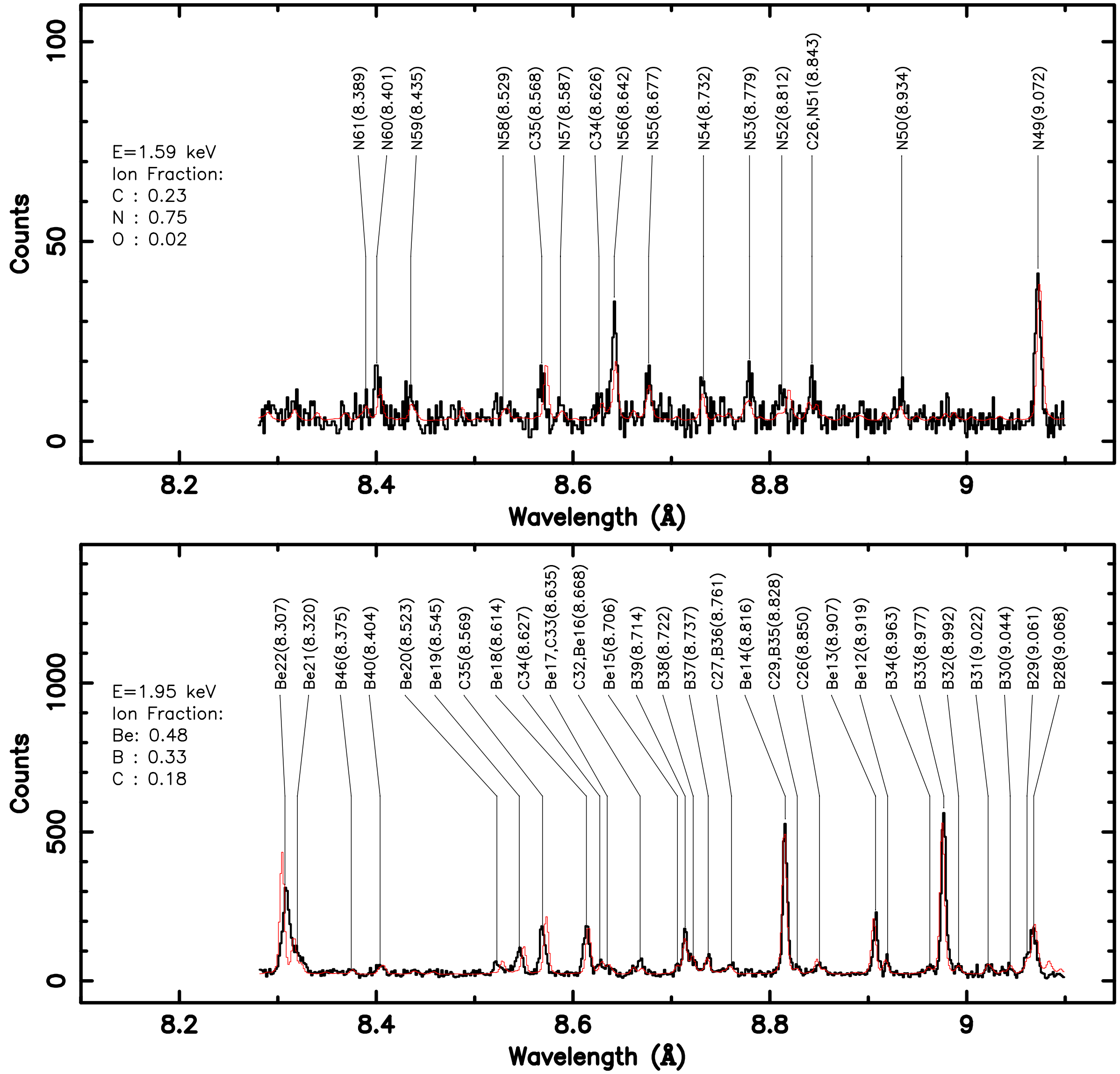




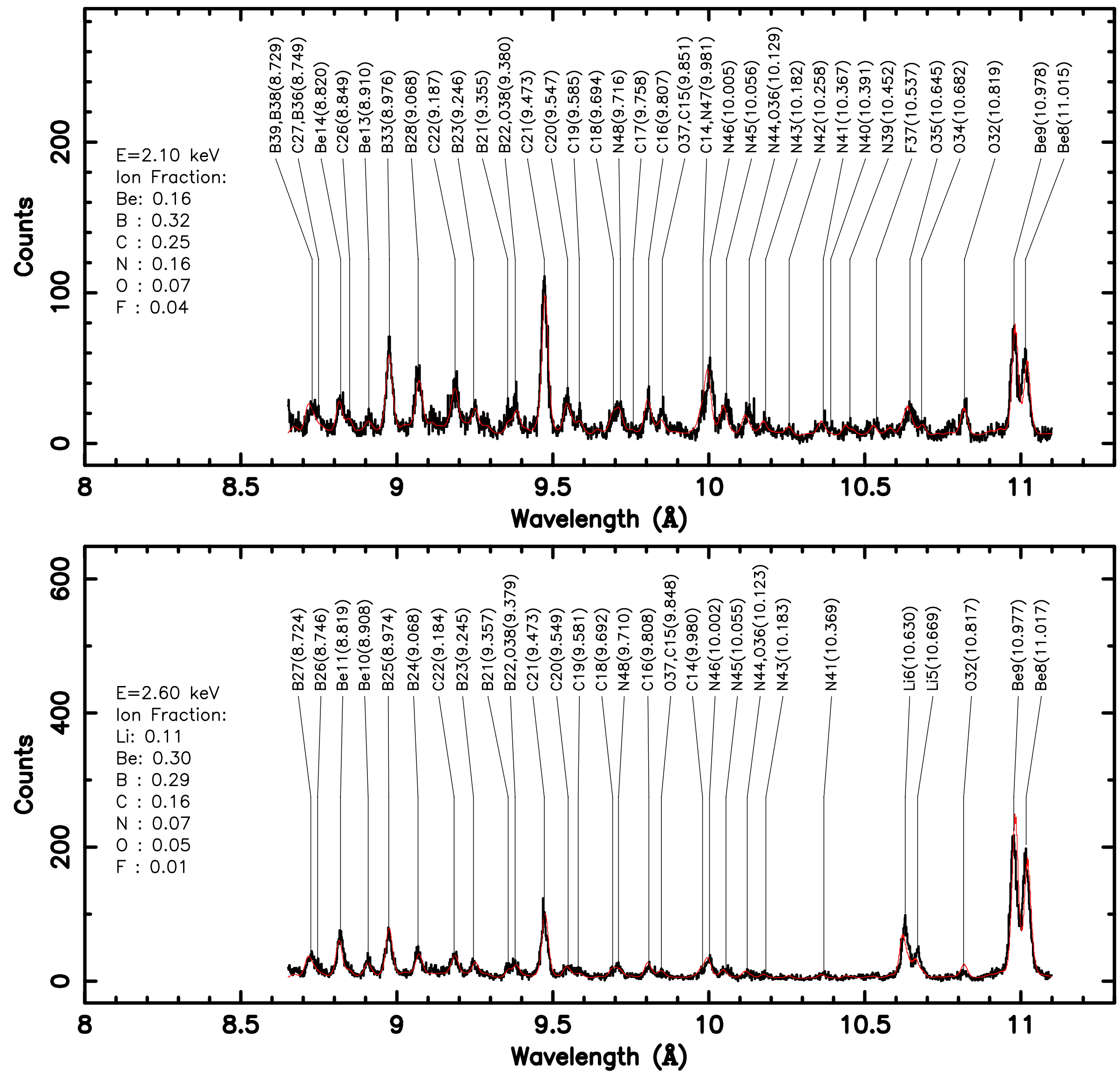
Lines between 7.4 and 8.4 Å



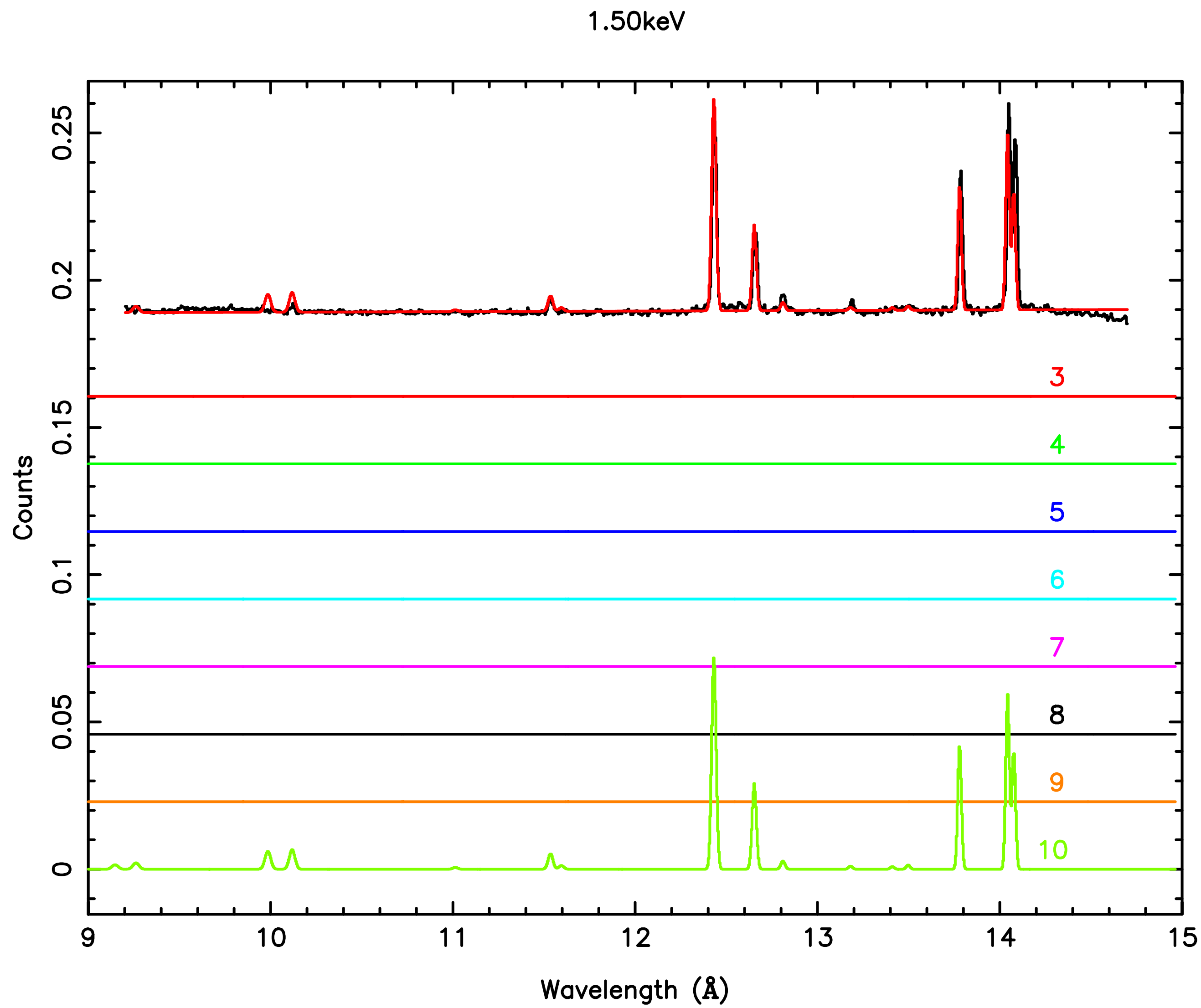
Lines between 8.3 and 9.0 Å



Lines between 8.7 and 11.0 Å



Wavelengths of Ni L-shell Lines



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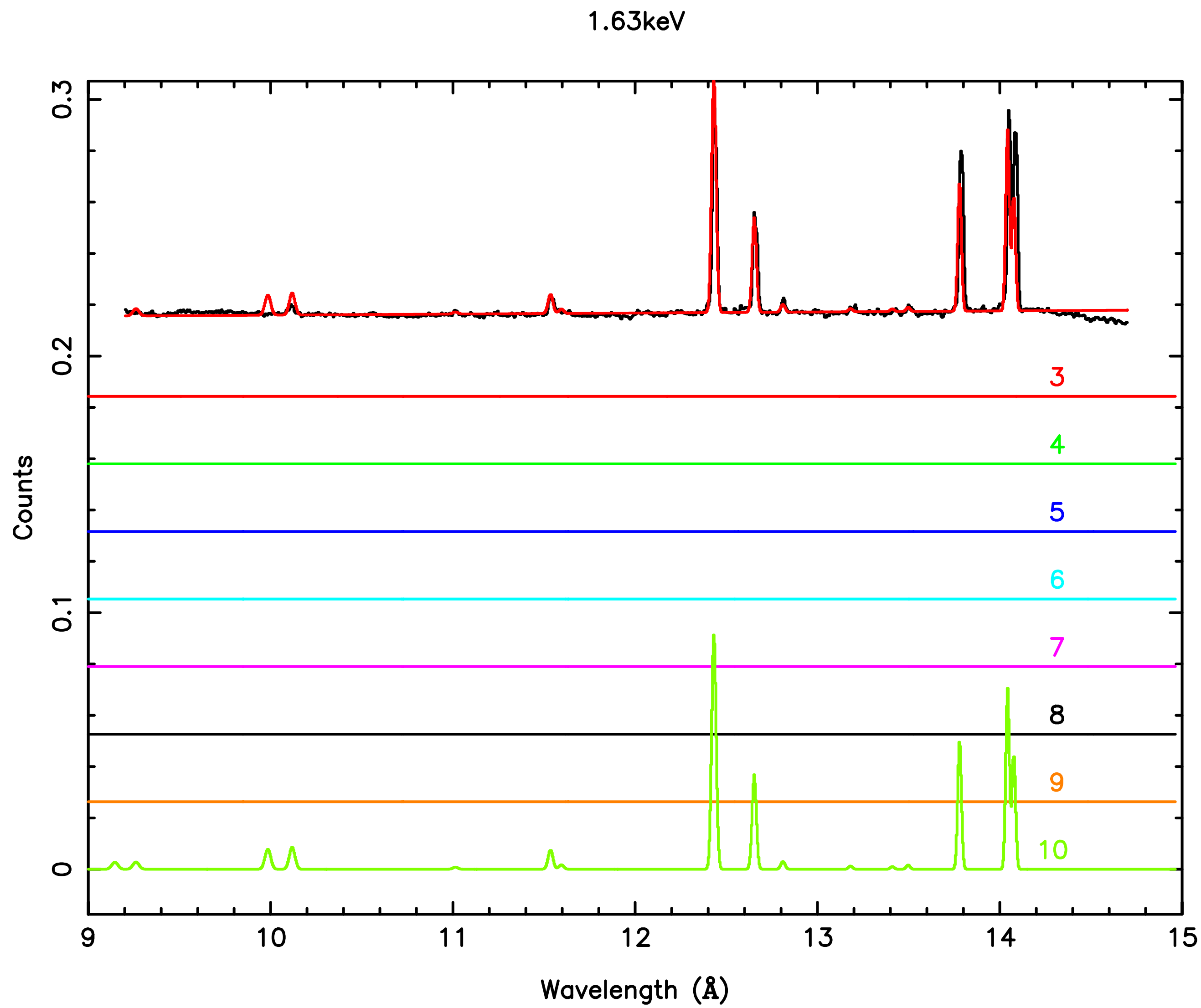

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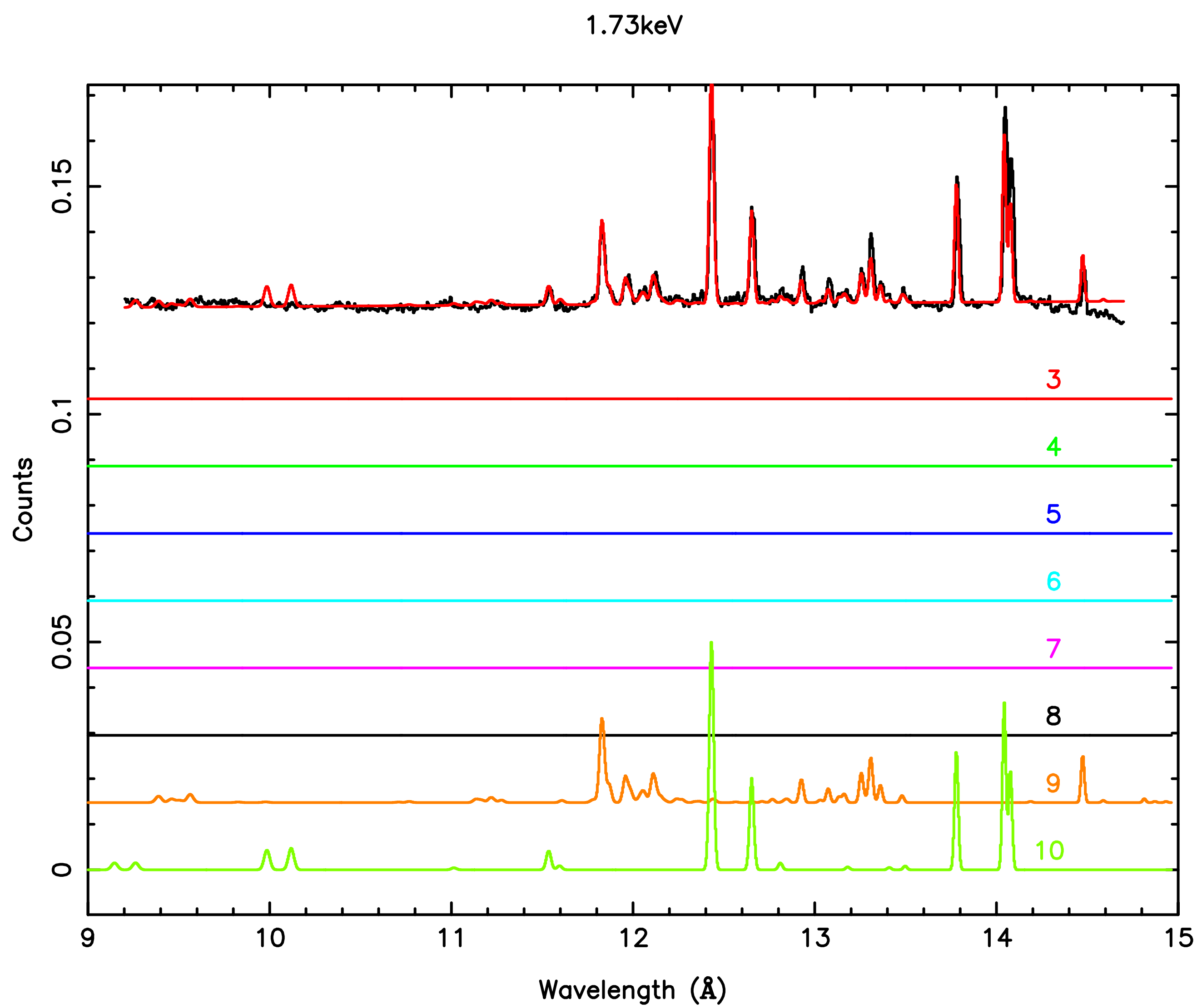

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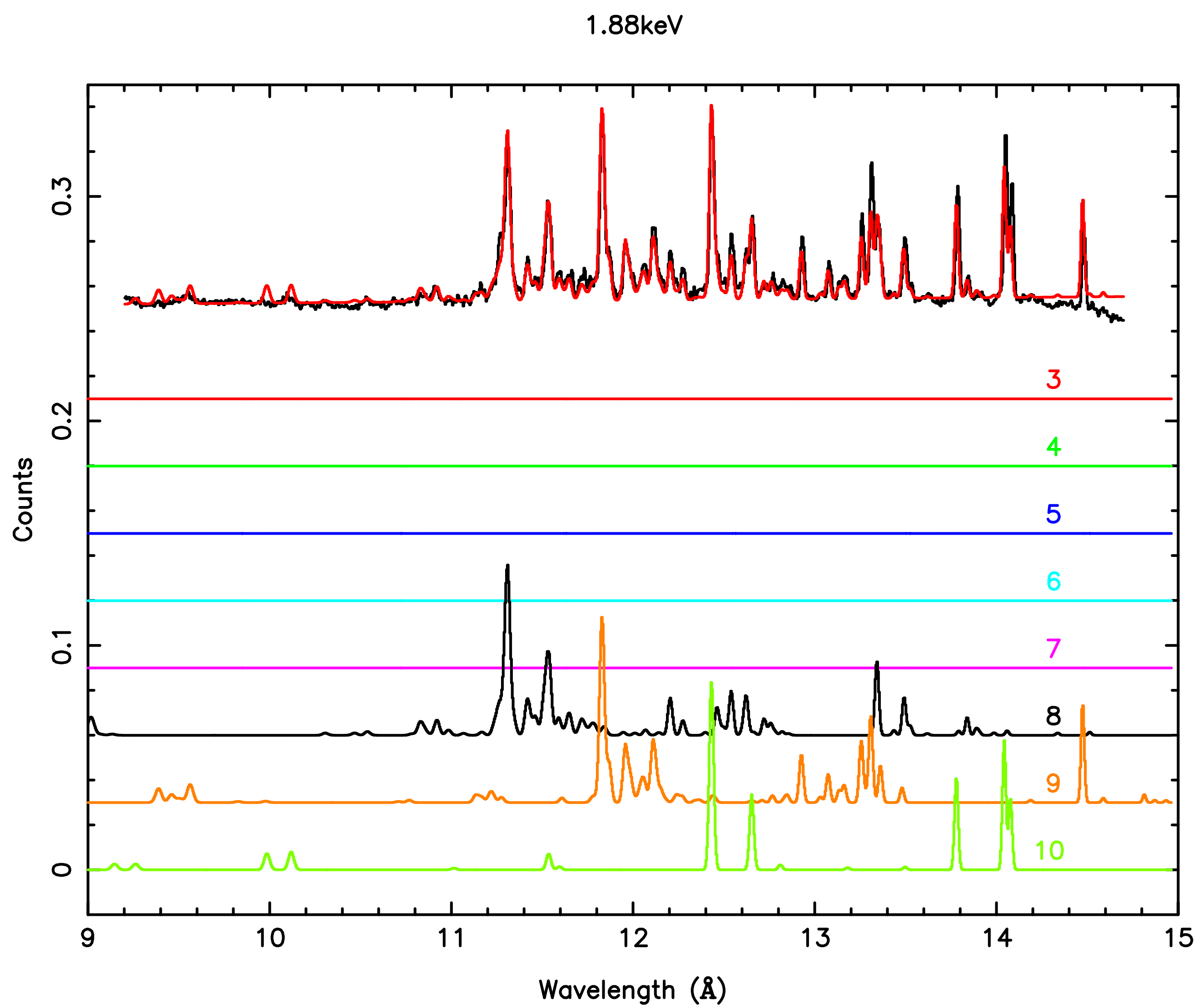
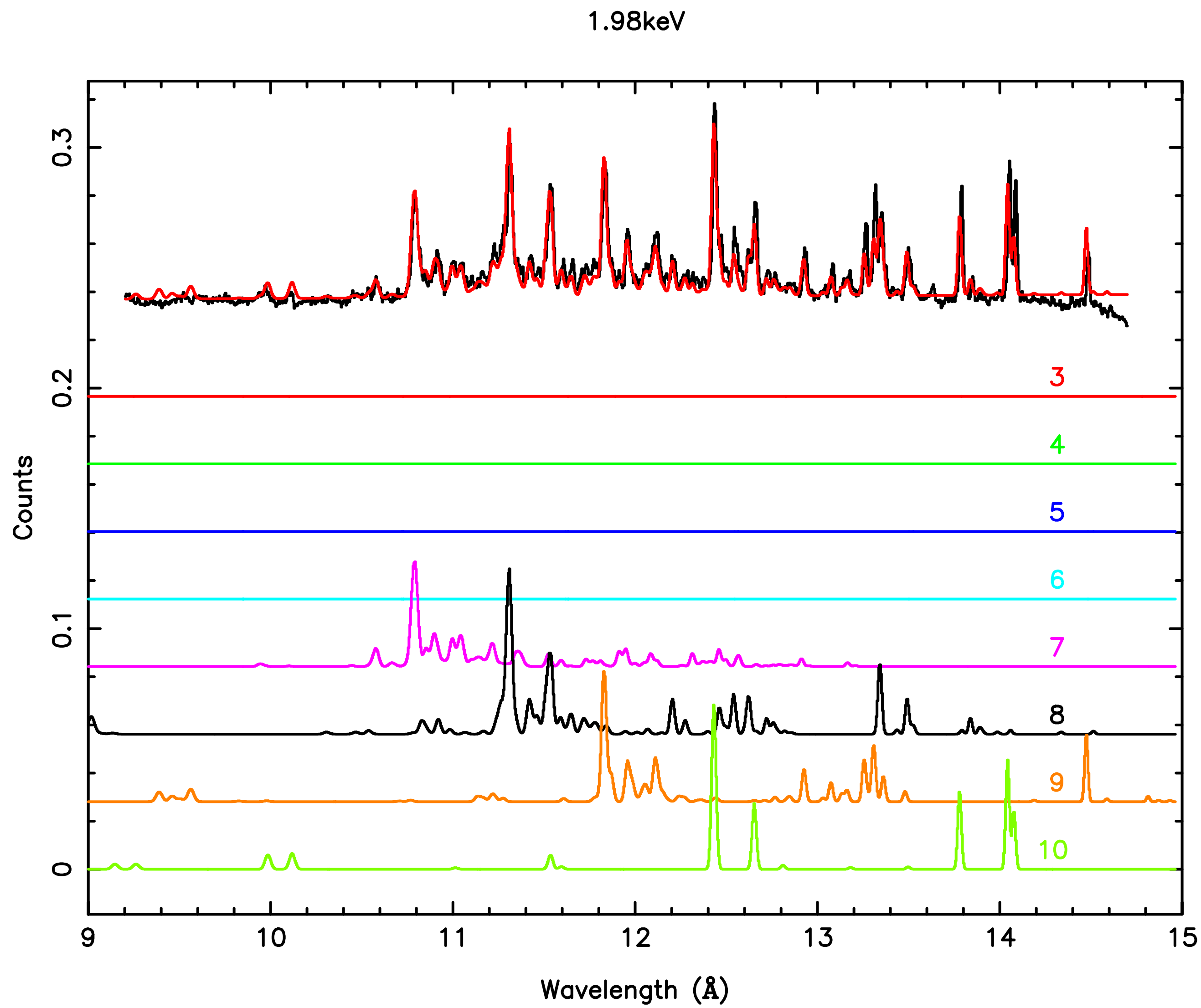
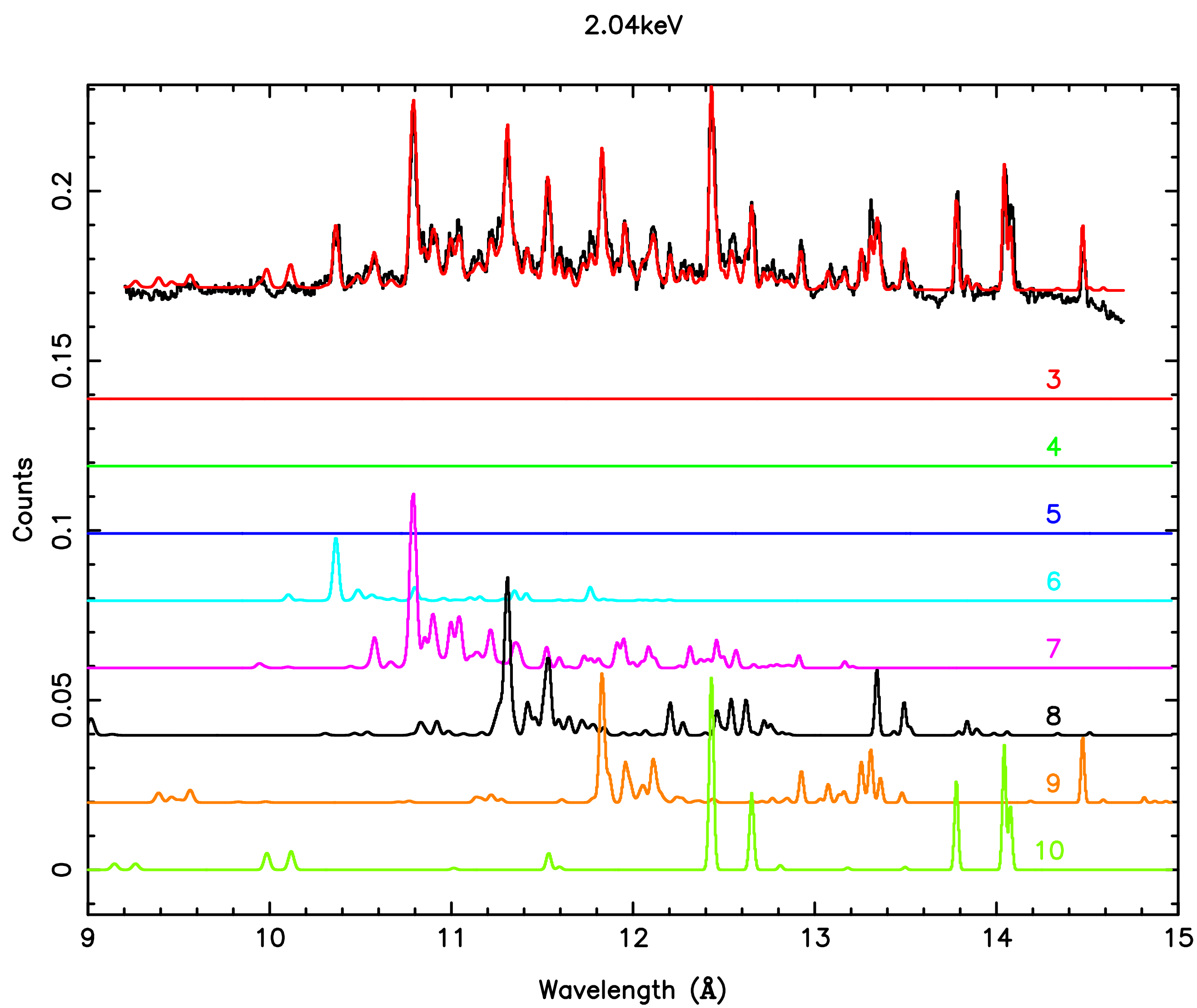


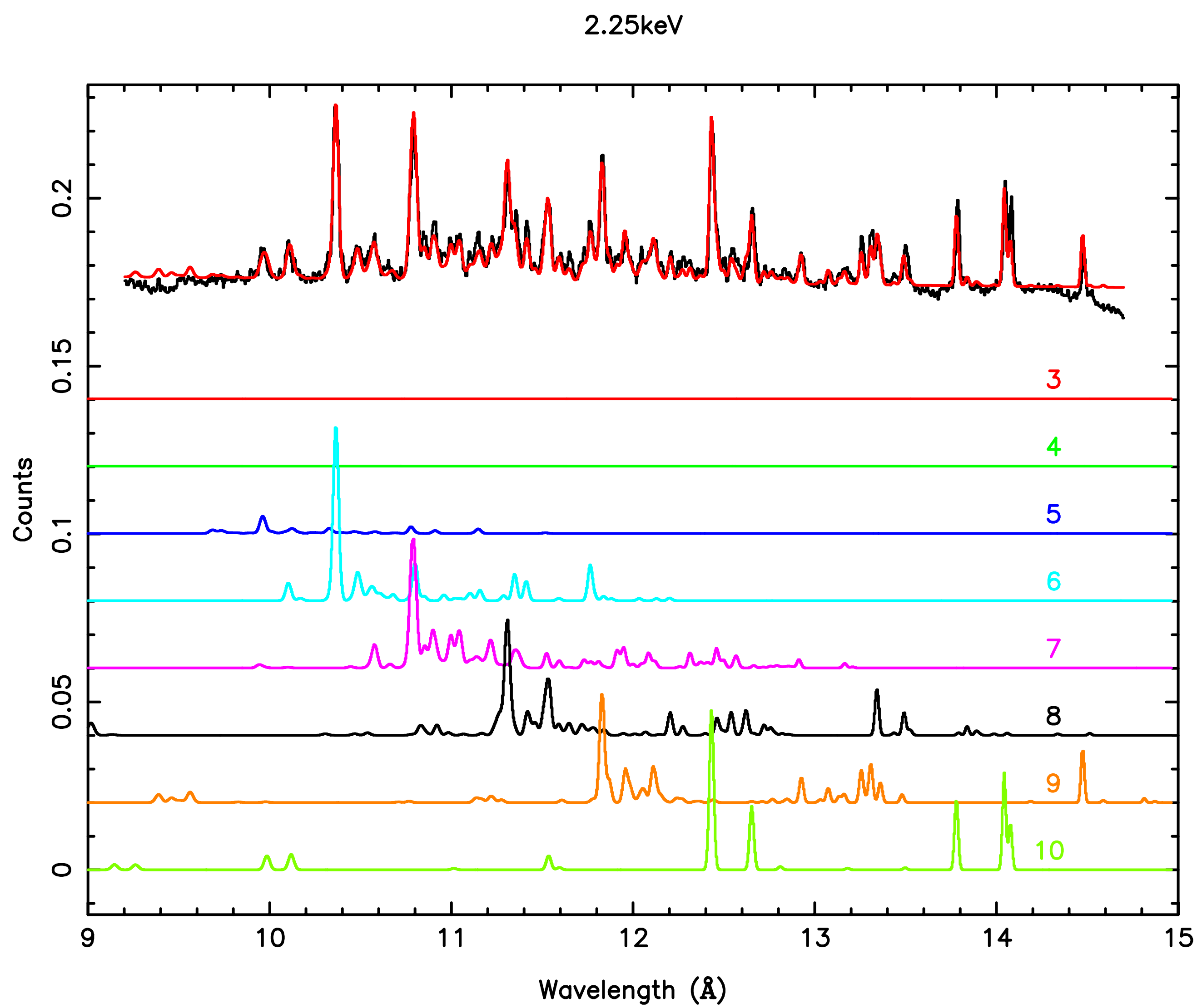
Wavelengths of Ni L-shell Lines



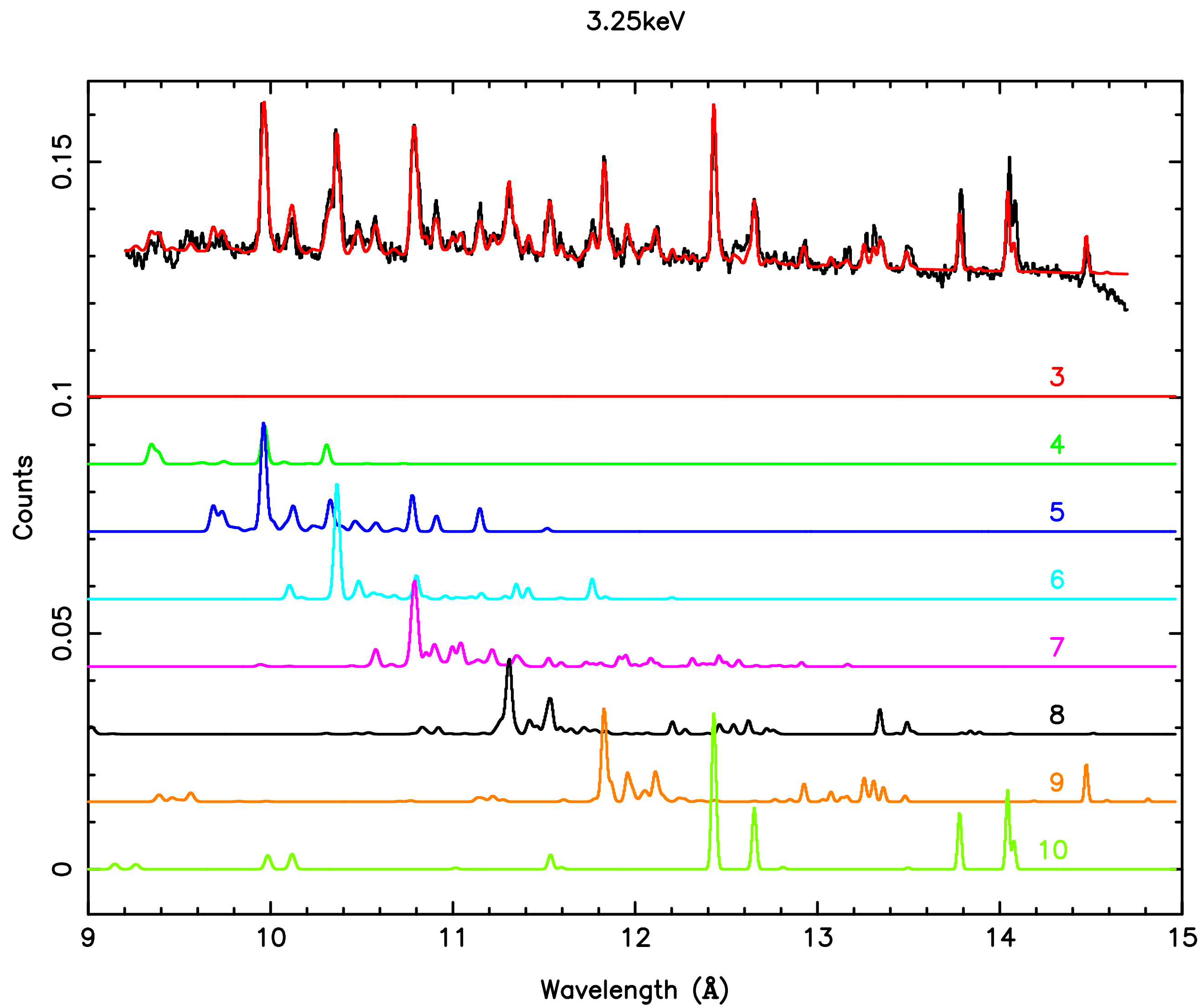
Wavelengths of Ni L-shell Lines



Wavelengths of Ni L-shell Lines



Wavelengths of Ni L-shell Lines



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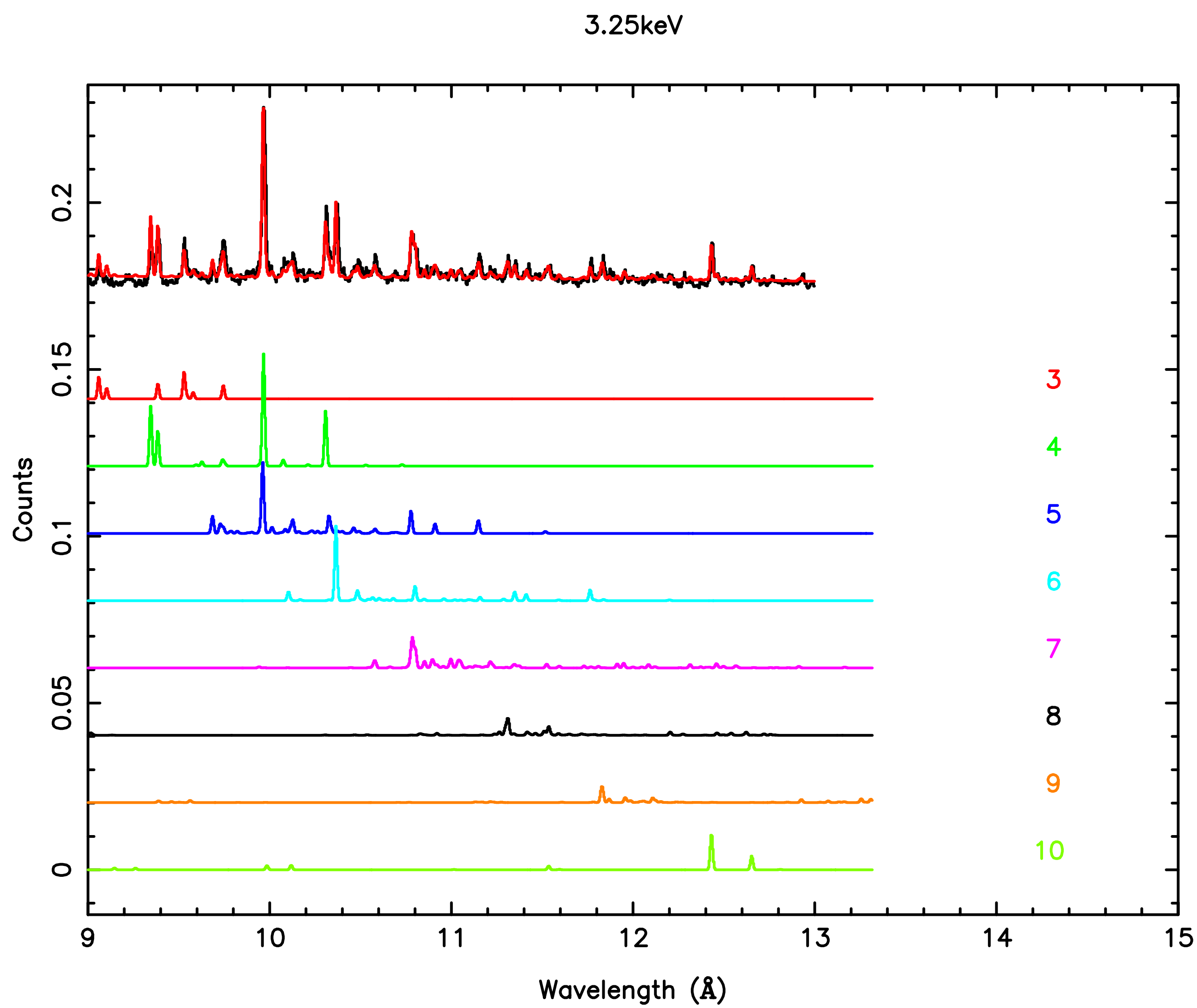

Future Work

- X-ray emission following Charge Exchange.
- Inner-shell transitions, K-shell lines of L-shell ions and L-shell lines of M-shell ions (Fe M-shell UTA).
- Life time measurement of M2 transitions in Ne-like ions, important for density diagnositcs.
- Ionization balance measurement of L-shell ions.
- Benchmark the recombination and resonance contributions to the $3s - 2p$ transitions in Fe XVII–XX.