The High Resolution X-ray Spectrum of Markarian 509

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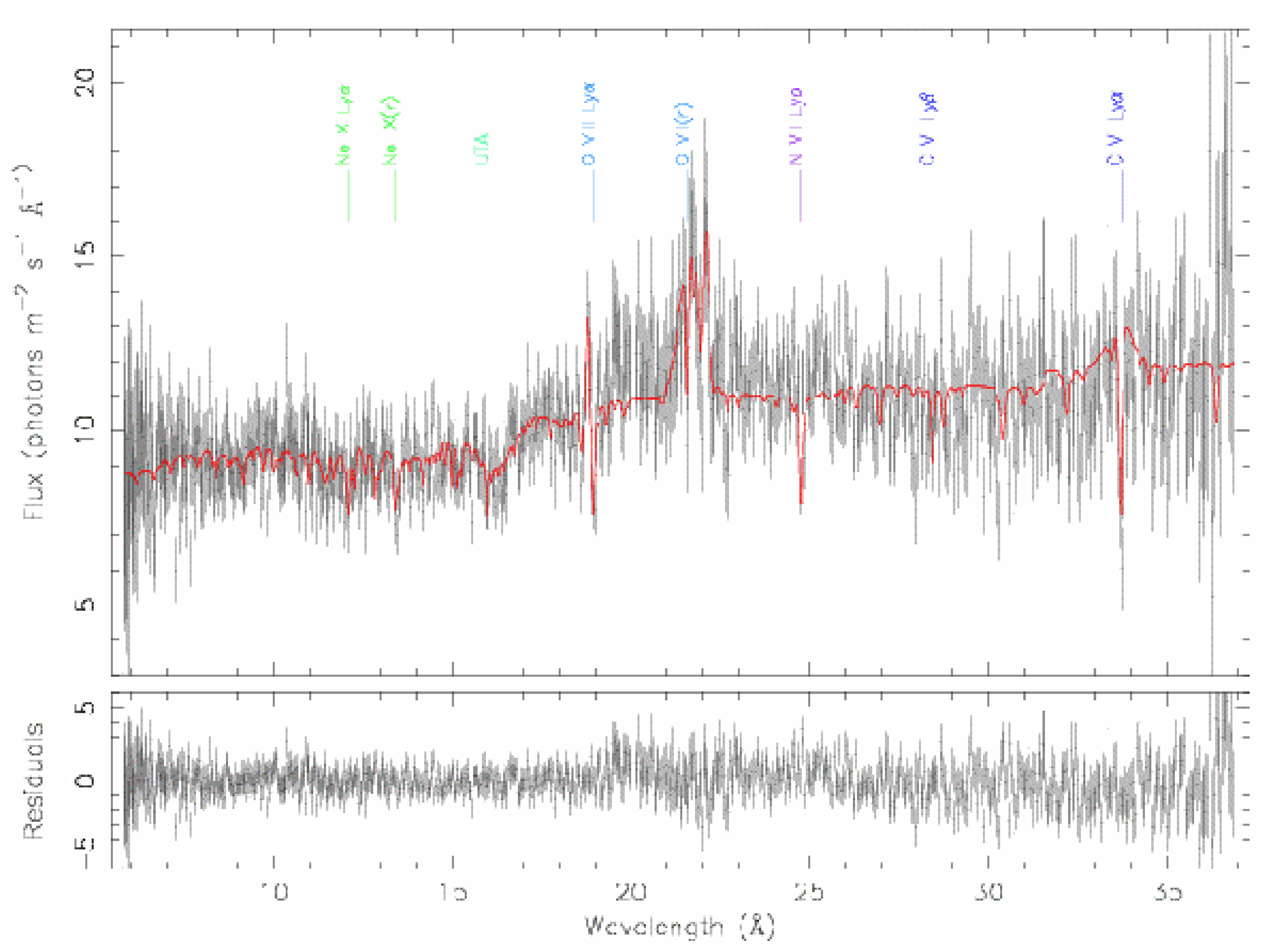

Fig.1. *XMM-Newton* RGS data, best fit and residuals for a model including a power-law, two broad and two narrow Gaussian emission lines, and three phases of photoionized gas.

1 ABSTRACT

We present a detailed analysis of the high resolution soft X-ray spectrum of the Seyfert 1 galaxy Markarian 509 taken with the *XMM-Newton* Reflection Grating Spectrometer. An underlying power-law continuum and three warm absorber phases provide a good fit to the data along with a number of broad and narrow emission lines. Each of our three warm absorber phases has a different ionization parameter and column density. All phases are blueshifted with respect to the systemic velocity with velocities ranging from -60kms^{-1} to -510kms^{-1}. The observed CVI and OVII broad emission features have an RMS velocity of 8000±3000kms^{-1} and a flow velocity of -140±2500kms^{-1}. We also observe OVII and OVIII narrow emission lines and a possible CVI radiative recombination continuum (RRC). Particular attention is paid to an unusually raised area in the spectrum between 19Å and 25Å.

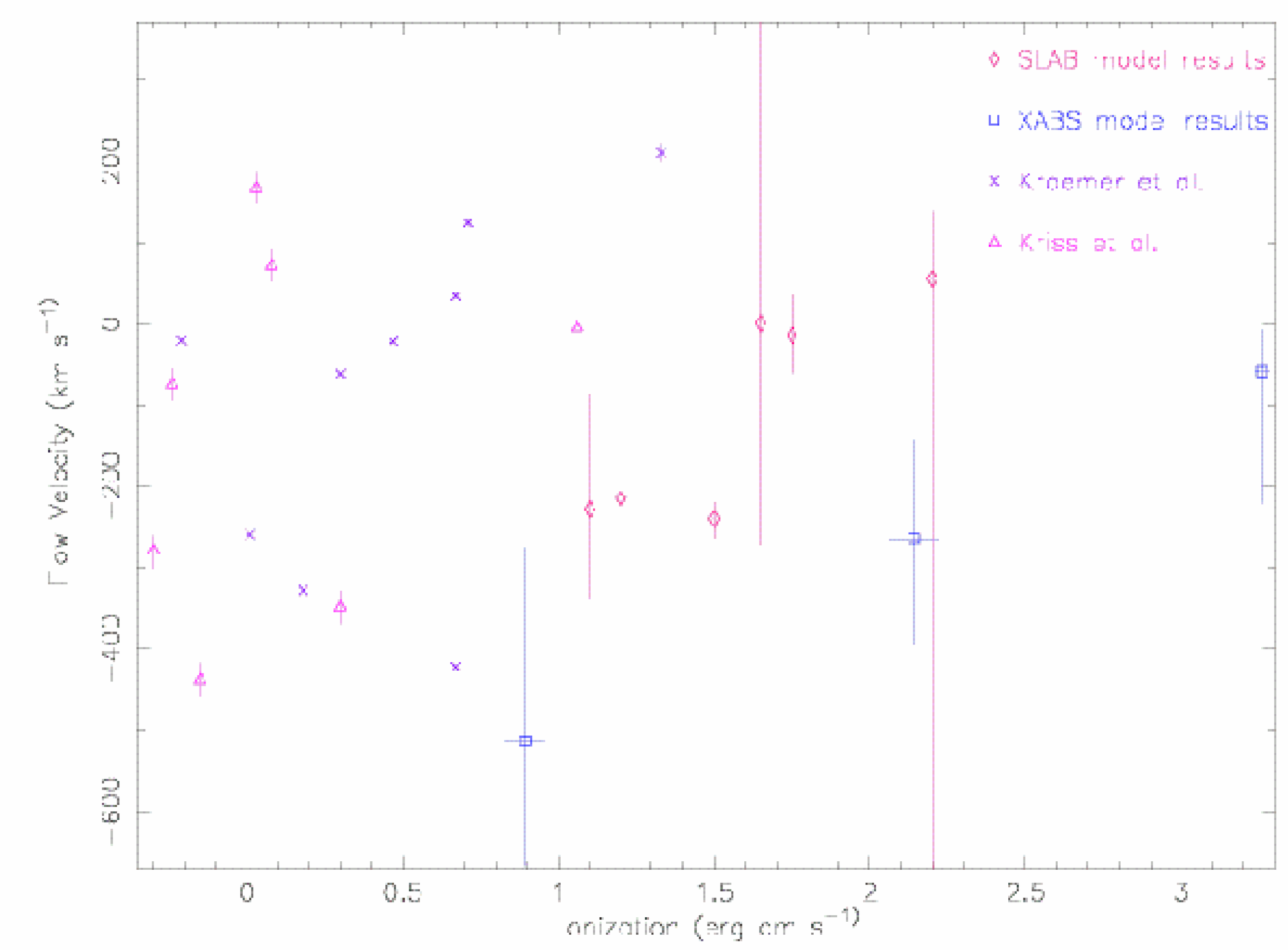

Fig. 2. The relationship between the ionization parameter at maximum abundance and flow velocity for the elements fitted with our models. Shown also are the UV results from Kraemer et al. (2003) and Kriss et al. (2000).

2 ABSORPTION

In the spectrum of Markarian 509 we find three separate phases. Phase 1 produces the low ionization, high outflow velocity, OVI and NVI absorption lines, and an Fe M-shell UTA feature. Phase 2 is the intermediate phase in both ionization and outflow velocity and produces the OVII, NVII, CVI, and NeIX absorption features. Phase 3 contributes the high ionization, low outflow velocity iron lines along with the NeX and OVIII absorption features, all shown in Fig. 3. It is interesting to note that in our X-ray phases the ionization increases with decreasing outflow velocity (Fig. 2); however this trend is not supported by previous UV results. The confidence intervals for our RMS velocities, outflowing velocities and ionization parameters have no overlap, so we are observing at least three phases in the gas. A continuous ionization distribution throughout the gas, though, cannot be excluded.

Using line ratios, ionization parameters and velocity profiles we have been able to characterise our Phase 1 as producing one of the UV phases identified by Kriss et al. (2000) and Kraemer et al. (2003).

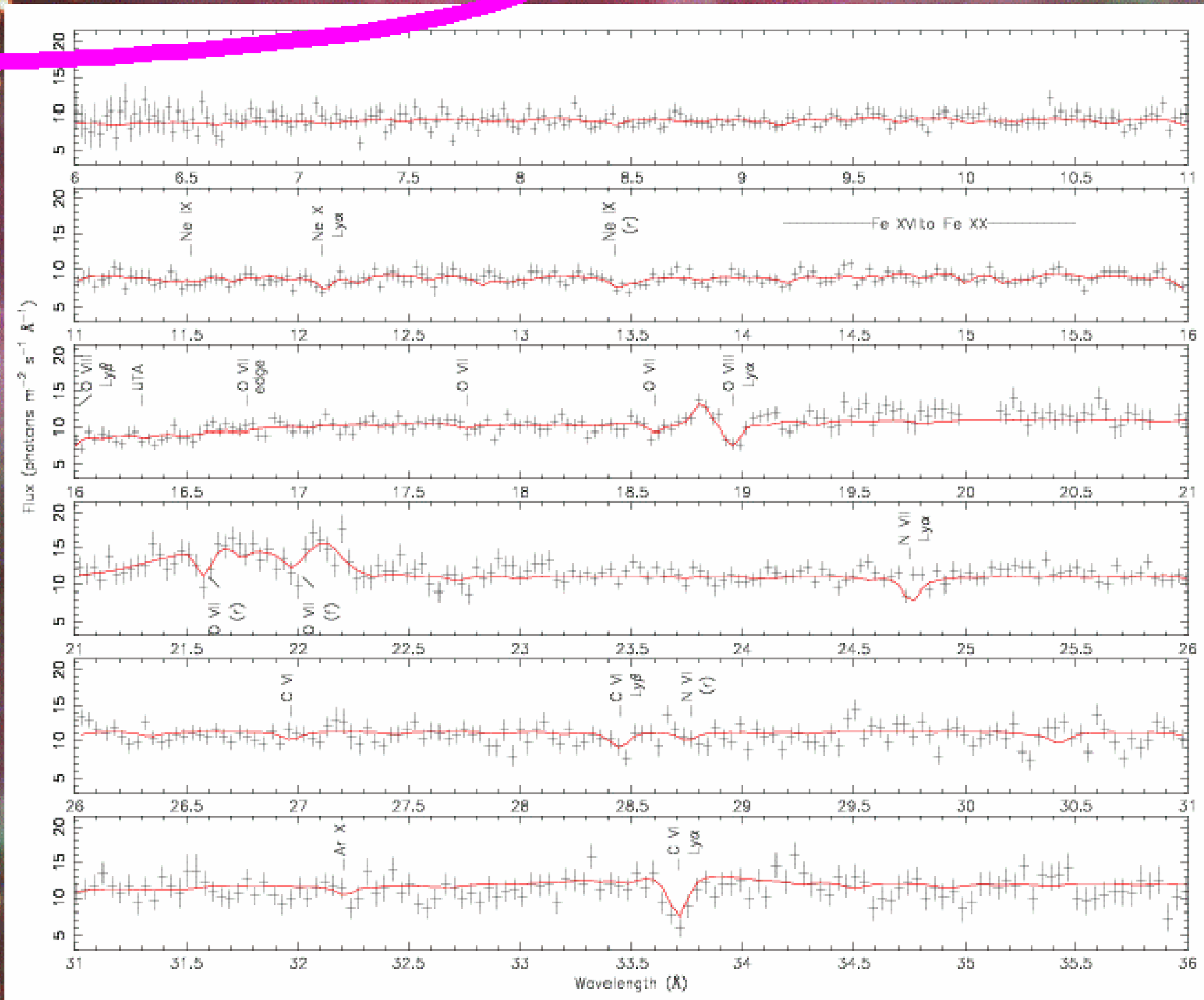

Fig. 3. A large scale view of the RGS Markarian 509 spectrum fitted with a power law, two broad (OVII and CVI) and two narrow (OVII(f) and OVIII) Gaussian emission lines and three XABS components.

3 EMISSION

We have included in our fits two broad emission lines due to OVII, 21.7Å, and CVI, 33.7Å (Fig. 1). The best fit to these lines gives a RMS velocity value of 8000±3000kms^{-1}. However, the OVII velocity values are unreliable due to the line being the sum of the three lines of the triplet. We also find a broad feature at 25.2Å, which we identify as a possible blueshifted CVI RRC. These values are in good agreement with the corresponding broad emission lines identified in the UV and optical spectra of Markarian 509. The velocity structure of the broad lines identified here indicates that they are not connected with the warm absorber but are instead produced in the broad line region (BLR), close to the centre of the AGN.

We also identify two narrow emission lines at 18.8Å (OVIII) and 22.1Å (OVII(f)), with flow velocities of -2400±400kms^{-1} and +360±350kms^{-1} respectively. There are large uncertainties in the velocity profiles of the narrow emission lines due to contamination of the lines. Both have been partially eaten away by absorption lines, altering their RMS and flow velocity values.

The warm absorber best fit parameters (with 2σ error bounds) for a model including a power law, two broad and two narrow Gaussian emission lines, and three phases of photoionized gas.

Phase	Flow Velocity km s^{-1}	RMS Velocity km s^{-1}	Ionization Parameter erg cm s^{-1}	Column Density 10^{21} cm^{-2}	Prominent Ions
Phase 1	-510 ± 200	0 + 20	0.89 ± 0.06	0.79 ± 0.04	OVI, NVI, FeIX-FeXIII
Phase 2	-260 ± 120	70 ± 30	2.14 ± 0.08	0.75 ± 0.13	OVII, NVII, CVI, NeIX
Phase 3	-60 ± 100	0 ± 20	3.26 ± 0.02	5.5 ± 0.3	OVIII, NeX, FeXVII-FeXX

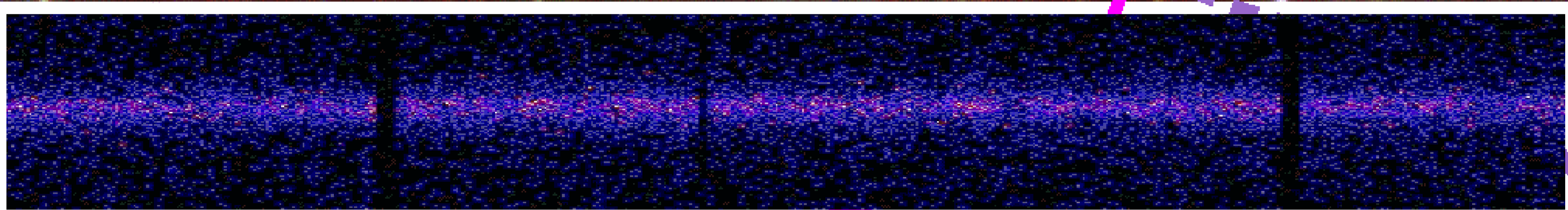

Fig. 4. Dispersed 1st order RGS1 spectrum. The dark lines are due to chip gaps in the instrument.

Best fit parameters for both the broad (top) and narrow (bottom) emission lines.

Wavelength Å	FWHM Å	Norm 10^{44} ph s^{-1}	RMS Velocity km s^{-1}	Flow Velocity km s^{-1}	Species
21.67 ± 0.06	0.63 ± 0.14	$1.1\times10^{7} \pm 1.8\times10^{6}$	8700 ± 2000		OVII triplet
25.23 ± 0.25	1.12 ± 0.65	$3.1\times10^{6} \pm 1.9\times10^{6}$	13000 ± 5000	-820 ± 2900	CVI RRC
33.72 ± 0.28	0.80 ± 0.45	$4.0\times10^{6} \pm 2.2\times10^{6}$	7100 ± 4100	-140 ± 2500	CVI
18.82 ± 0.03	0 ± 0.22	$1.1\times10^{6} \pm 4.2\times10^{5}$	0 + 3000	-2400 ± 400	OVIII
22.12 ± 0.03	0.13 ± 0.14	$2.4\times10^{6} \pm 6.2\times10^{5}$	1700 ± 1800	+360 ± 400	OVII (f)

4 CONCLUSION

In conclusion, we find evidence of broad line emission from carbon and oxygen. These broad lines account for the majority, but not all, of the raised sections in the spectrum. More investigation is required to fit the continuum shape more precisely. We also identify three phases of X-ray absorbing gas, each with different properties. The low ionization X-ray phase has also been found to account for a previously identified, high outflow velocity, UV absorbing phase: having similar ionization, elemental abundances and velocity structure.

REFERENCES

Kraemer S.B., Crenshaw D.M., Yaqoob T., et al., Jan. 2003, ApJ, 582, 125

Kriss G.A., Green R.F., Brotherton M., et al., Jul. 2000, ApJ, 538, L17