Determinate the relative abundances in the nucleus allows for the study of the enrichment processes in the host galaxy of Mrk 509. Furthermore, the relative abundances we measure can be compared with the (relative) abundances measured for active galactic nuclei (AGN) at high redshifts, to determine abundance evolution and thus the history of the enrichment processes prevalent at different epochs. At high redshifts super-solar abundances have been derived from the broad emission lines of quasar spectra [Hamann & Ferland (1992)]. However, these results are at odds with the fraction of old low mass stars observed in the eight brightest nearby galaxy clusters [van Dokkum & Conroy (2010)].

The main advantage of using X-ray absorption lines over the optically detected broad emission lines or UV detected narrow absorption lines, is that the ionisation structure of the absorber can be accurately determined. This is crucial in disentangling the effects on the plasma of the abundances from those of the ionisation structure. Unless the ionisation structure is well known, one can only use ions that have their peak ionic column density at the same ionisation parameter to determine the abundances. There are no hydrogen transition lines in the X-ray spectra: only continuum absorption is present. However, the continuum absorption is due to H is degenerate with the continuum model used, which is not a priori known. Therefore only relative abundances are determined. All the relative abundances are with respect to proto-solar ones [Lodders & Palme (2009)] and we measure the abundances of C, N, Mg, Si, S, Ca and Fe compared to O, sampling the elements that are created by different enrichment processes occurring in the host galaxy.

2 Results

The relative abundances versus oxygen, derived using different methods, and versus iron are given in Table 1, where we also list the proto-solar abundances [Lodders & Palme (2009)]. One method used was to assume that the warm absorber has six (three for LETGS) different ionisation components [Detmers et al. (2011), Ebere et al. (2011)], which were fit with the xabs model in SPEX [Kaastra, Meew & Nieuwenhuijen (1996)]. The xabs model gives the transmission of a photo-ionised layer, where the ionic column densities are determined from the total hydrogen column density, the abundances and the ionisation parameter. Alternatively we used the ionic column densities measured with the slab model to measure the absorption measure distribution (AMD) [Detmers et al. (2011)]. In this the method we do not a priori make an assumption about whether the ionisation structure is discrete or continuous. The difference in relative abundances as measured with the different methods gives a good indication about the uncertainties in the results due to the ionisation structure assumed. The S/O ratio is underdetermined as we only have one proto-solar abundance ratio; although both the CO and Fe/O ratio are consistent with proto-solar abundance ratios. For all the other elements the ratios compared to O and Fe are consistent with the proto-solar ratios.

Considering the small error bars on the determined relative abundances for the RGS data, we did try to determine the relative abundances for the slow and faster outflow components of the warm absorber observed in the X-ray spectra. However, the spectral resolution and quality of the RGS data is not enough to disentangle these velocity components. As a result the error bars are large, but the abundance ratios are consistent with the abundances given in Table 1.

3 Discussion

The relative abundances determined with the different methods agree with each other, as do the RGS and LETGS measured relative abundances. There is a significant difference occurs for the Ca/O abundance ratio. In the spectrum only Ca XIV is detected, and this is contaminated by absorption from Galactic N VII Lyα. Considering that the xabs component is more reliable in fitting weaker and blended features than the slab component, we prefer the xabs determined relative abundance for the Ca/O abundance ratio.

We compared our relative abundances with the absolute abundances measured in Mrk 279 [Arav et al. (2007)], the abundances measured near the Galactic Centre, the metallicity predicted from the mass-metallicity relationship [Tremonti et al. (2004)], the abundances measured for the hot interstellar medium in local galaxies, and the relative abundances derived for three clusters of galaxies. Considering the statistical and in some cases also systematic uncertainties, the different abundances derived for the different type of sources in the Galactic Centre, and in the case of the hot ISM and clusters of galaxies the range in abundances measured for the different sources studied, we conclude that the relative abundances of the warm absorber in Mrk 509 are consistent with those derived by the methods above. Table 2 gives the comparison between the measured relative abundances in Mrk 509 and three clusters of galaxies: Hydra A, Sérsic 159-3 and 2A 0335+096 [Simonescu et al. (2009), de Plaa et al. (2006), Werner et al. (2006)].

4 Conclusions

The relative abundances compared to oxygen of the warm absorber are consistent with the proto-solar abundance ratios, with the exception for S, which is slightly underdetermined compared to the other elements measured. We show that these relative abundances are consistent with the abundances measured in a large range of other environments, but that likely stellar winds and SN type II have been more important in enriching the nucleus of Mrk 509 than in the enrichment of the inner few arcseconds of clusters. A possible reason is that the fact that stellar winds might not as readily escape the potential of the galaxy. Mrk 509 is a very disturbed galaxy, which might recently have undergone a burst of star-formation, enhancing the number of supernova type II versus the number of supernova type Ia.

Figure 1: A comparison of the relative abundances (8=O/Fe, 10=Ne/Fe, 12=Mg/Fe, 14=Si/Fe, 16=SF/Fe, 20=Ca/Fe) measured in the warm absorber of Mrk 509 (open circles) and the clusters of galaxies Hydra A (small triangles; red squares) and 2A 0335+096 (dark blue triangles) [Simonescu et al. (2009), de Plaa et al. (2006), Werner et al. (2006)].