RELATIVE ABUNDANCES OF THE WARM ABSORBER IN Mrk 509

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Abstract

Determining the abundances in the nuclei of AGN allow us to investigate the enrichment processes in the host galaxy and has the advantage that it allows for the study of abundances for a large range in redshift, and thus determine the abundance evolution. Until recently broad emission lines were used, deriving high abundances at high redshifts and a slight increase of the abundance with redshift. However this method has to make some, likely incorrect, assumptions. Here we present the relative abundances determined from the X-ray observed narrow absorption lines of the warm absorber in the Seyfert 1 galaxy Mrk 509. Using the stacked 600 ks RGS and 180 ks LETGS spectra recently obtained, we derive C/O, N/O, Ne/O, Mg/O, Si/O, Ca/O and Fe/O abundances similar to the proto-solar nebula abundance ratios. The S/O ratio is smaller than the proto-solar ratio. Due to the excellent statistics and the use of updated atomic data, this is the first time that accurate and reliable abundances have been determined for the warm absorber, the ionised outflow observed in $\sim$50% of all Seyfert 1 galaxies.

1 Introduction

Determining 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 cluster galaxies [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 from 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, Ne, 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), Ebrero et al. (2011)], which were fit with the `xabs` model in `SPEX` [Kaastra, Mewe & Nieuwenhuijzen (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 the this 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 underabundant and the C/Fe ratio has a super proto-solar abundance ratio; although both the C/O 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 completely. As a result the error bars are large, but the abundance ratios are consistent with the abundances given in Table 1.

Table 1: Best fit abundances relative to oxygen compared to the proto-solar abundance ratio for the RGS spectrum (using the `xabs` and the AMD models) and the LETGS spectrum using the `xabs` and discrete AMD model. Also listed are the abundances relative to Fe and the proto-solar abundances.

ion	RGS: `xabs`	discrete AMD	continuous AMD	LETGS: `xabs`	discrete AMD[a]	recommended	ion		ion[b]	
C/O	1.19±0.08	1.00±0.07	1.01±0.03	1.2±0.3	1.00	1.19±0.08	C/Fe	1.40±0.1	C	8.46
N/O	0.98±0.08	0.80±0.05	0.80±0.03	0.5±0.2	0.80	0.98±0.08	N/Fe	1.15±0.06	N	7.90
O		1.00±0.05	1.00±0.05[c]		1.11		O/Fe	1.17±0.06	O	8.76
Ne/O	1.11±0.10	1.17±0.15	1.16±0.07	0.9±0.3	1.17	1.11±0.10	Ne/Fe	1.31±0.17	Ne	7.95
Mg/O	0.68±0.16	0.92±0.29	0.93±0.15	0.7±0.6	2.9±5.3	0.68±0.16	Mg/Fe	1.21±0.16	Mg	7.62
Si/O				1.3±0.6	1.2±1.5	1.3±0.6	Si/Fe	1.53±0.60	Si	7.61
S/O	0.57±0.14	0.68±0.24	0.69±0.09	0.4±0.4	1±1.10	0.89±0.25	S/Fe	0.95±0.15	S	7.26
Ca/O	0.89±0.25	3.34±0.75	3.81±0.86	2.7±1.6	5.1±4.7	0.57±0.14	Ca/Fe	1.05±0.26	Ca	6.41
Fe/O	0.85±0.06	0.81±0.05	0.79±0.08	1.1±0.2	0.81	0.85±0.06	Fe		Fe	7.54

[a] Values without error bars denote that they were kept froze to the best fit discrete AMD model of the RGS spectrum.

[b] Logarithmic proto-solar abundances of Lodders & Palme (2009), where H has a value of 12.

[c] Frozen to the value obtained for the discrete AMD model.

3 Discussion

The relative abundances determined with the different methods agree with each other, as do the RGS and LETGS measured relative abundances. The only significant difference occurs for the Ca/O abundance ratio. In the spectrum only Ca XIV is detected, and this line is contaminated by absorption from Galactic N VII Lyα absorption. 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.

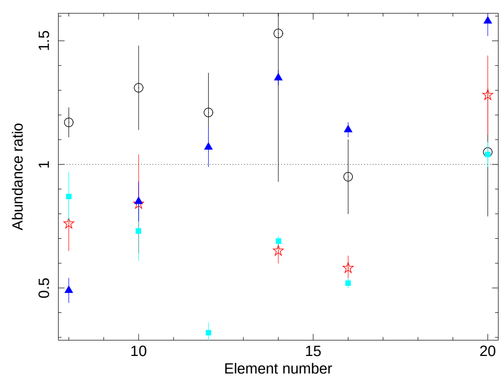
We compared our relative abundances with the absolute abundances measured in Mrk 279 [Arav et al. (2007)], the abundances measured near the Galactic Centre, the metallicity predicted from the mass-metallicity relationship [Tremonti et al. (2004)], the abundances measured for the hot interstellar medium 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 159-03 and 2A 0335+096 [Simionescu et al. (2009), de Plaa et al. (2006), Werner et al. (2006)].

Table 2: Comparison between the relative abundances in Mrk 509 with those derived for the cores of the cluster of galaxies: Hydra A, Sérsic 159-03 and 2A 0335+096 [Simionescu et al. (2009), de Plaa et al. (2006), Werner et al. (2006)].

	Mrk 509	Hydra A	Sérsic 159-03	2A 0335+096
O/Fe	1.17±0.06	0.76±0.11	0.87±0.10	0.49±0.05
Ne/Fe	1.31±0.17	0.84±0.20	0.73±0.12	0.85±0.08
Mg/Fe	1.21±0.16		0.32±0.04	1.07±0.08
Si/Fe	1.53±0.60	0.65±0.05	0.69±0.02	1.35±0.03
S/Fe	0.95±0.15	0.58±0.05	0.52±0.02	1.14±0.03
Ca/Fe	1.05±0.26	1.28±0.16	1.04±0.05	1.58±0.06

The best comparison can be made with clusters of galaxies, as a range of overlapping relative abundances are measured. In general we find that although each abundance ratio is within 3σ consistent with the range measured in the three clusters of galaxies, the O/Fe and Ne/Fe ratios are higher in Mrk 509 than in the clusters of galaxies. Note that the absolute abundances in clusters of galaxies will be lower, due to mixing with a large reservoir of primordial gas. The O/Fe and Ne/Fe ratios indicate that stellar winds and supernova type II have been more important in the recent history of Mrk 509 than in the enrichment of the inner few arcseconds of clusters. A possible reason is 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=S/Fe, 20=Ca/Fe) measured in the warm absorber of Mrk 509 (open circles) and the clusteres of galaxies Hydra A (red stars), Sérsic 159-03 (blue squares) and 2A 0335+096 (dark blue triangles) [Simionescu 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 underabundant 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 the cores of clusters of galaxies.

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