The RGS wavelength scale

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1 Introduction

It has been known since quite early in the XMM mission that the wavelengths of lines measured with the high-resolution RGS instrument have differed from the values expected from laboratory measurements by a typically few mÅ for a line width in first order of about 60mÅ. These conclusions have been based on empirical measurements of a few of the brightest narrow lines in bright coronal sources. The statistical errors, typically about 1mÅ for bright lines, are significantly smaller than the 7 or 8 mÅ systematic errors, which if brought under control, would allow the RGS to make important contributions to X-ray line databases. One possibility not yet excluded is that these shifts are not instrumental in origin but are from Doppler shifts resulting from bulk motion in the sources themselves. A proper statistical comparison of line models incorporating wavelength or velocity shifts is one of the motivations for the current reassessment of the RGS wavelength scale.

2 Data and data processing

The targets selected for this study are presented in Table 1. A total of four stars were chosen for the properties of their X-Ray spectra (e.g. strength of the lines). The analysis has been carried out on 66 spectra in total. Some of the properties of the observations are listed in Tables 2, 3, 5, 4. These stars were chosen among the most common calibrators.

The data analysed were downloaded from the XMM-Newton archive as ODFs. The appropriate CCF files were produced with SAS7.1 for each observation. Response matrices with a resolution of 20000 were generated with `rgsrmfgen`. The spectra were then fitted within XSPEC using a Skelta function with spectral lines between 6.1Å(SiXIV) and $\sim$ 37.7Å(SXII) were added. The position of the laboratory and observed lines were then compared, and the shift in wavelenght scale (Δ_λ) measured. Velocity shifts (Δ_v) were also measured with the same method. Details of the actual procedure as well as parts of the code used are given in Appendix.

Table 1: The sample. Columns are: name of target, coordinates and proper motion extracted from SIMBAD; number of RGS observations per target.

TARGET	RA(2000)	DEC(2000)	Proper motion		Number of observations
			μ_α (mas/yr)	μ_δ (mas/yr)	
AB Dor	$05^h28^m44.5^s$	-65°27'02.1"	32.14	150.97	28
Capella	$05^h16^m41.4^s$	+45°59'52.8"	75.52	-427.11	19
Procyon	$07^h39^m18.1^s$	+05°13'30.0"	-716.58	-1034.60	5
HR1099	$03^h36^m47.3^s$	+00°35'15.9"	-32.98	-163.45	14

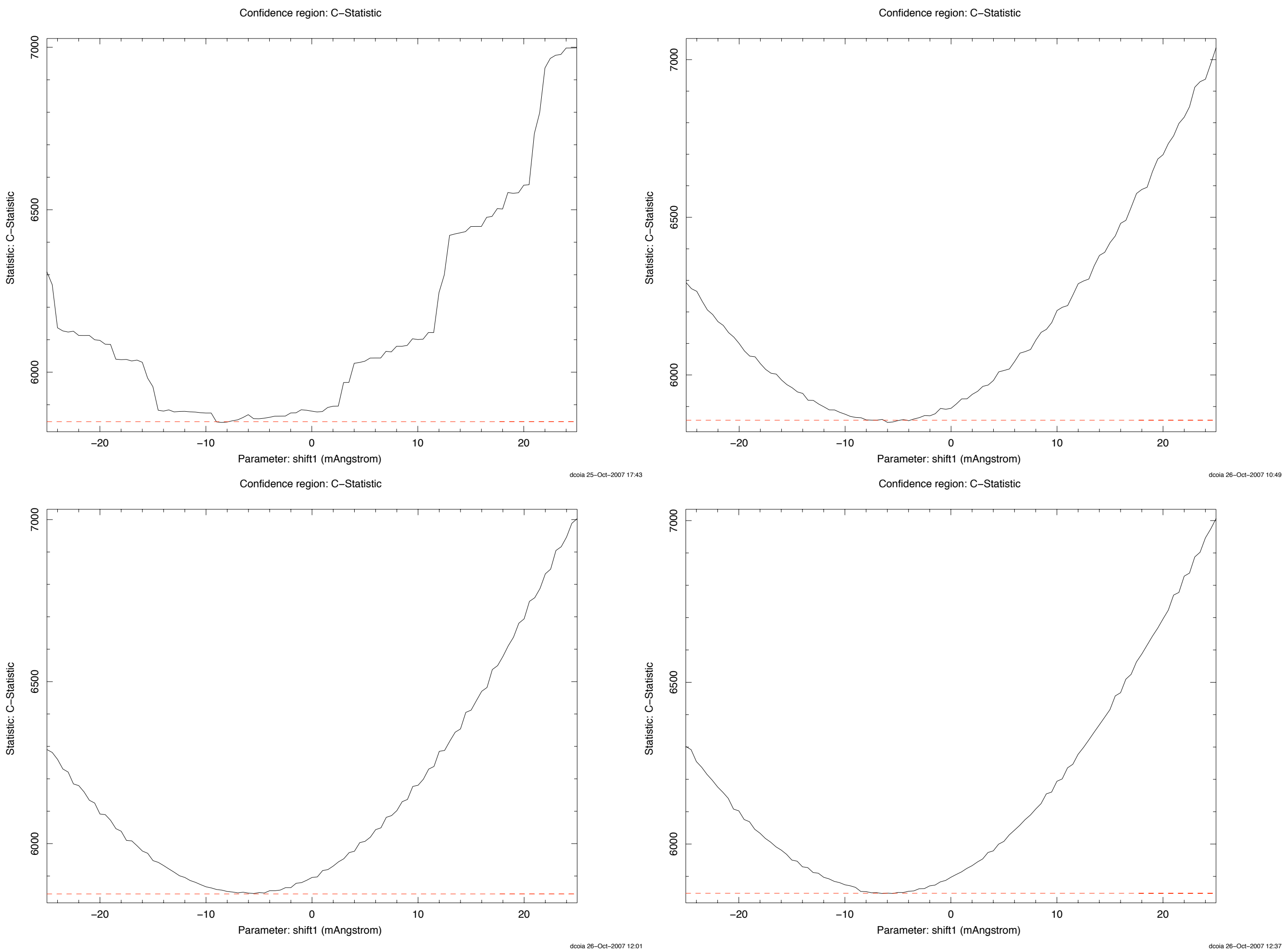

Figure 1: Example of C-statistic for the same observation but with resolution of response matrices of 4000, 20000, 30000, 40000 (up left to right bottom). The same parameters were used to produce all plots (Procyon, OBS ID: 0123940201).

2.1 High resolution response matrices

The need for response matrices with resolution higher than the default (4000) has arise early in the analysis. Fig. 1 shows the C-statistic produced for the analysis of the same observation using response matrices of resolution 4000, 20000, 30000, 40000. The goodness of the C-statistic increases significantly as to justify the need for response matrices of resolution higher than the default. The higher the resolution the better the C-statistic. Unfortunately, the generation of such matrices is prohibitive in term of disk space (several gigabytes) and processing time (days of grid time), both during the creation of the matrices and for the subsequent analysis, e.g. spectral fitting. It would neither be realistic nor feasible for ordinary observers to produce their own high resolution matrices but it would be appropriate for the SOC to accomplish this task.

A good compromise is the choice of a resolution of 20000, which will be adopted in the rest of this analysis.

3 Differences in methodology with previous studies

The methodology used in this work is not dissimilar to that described in Lorente, Pollock & Gabriel (2003). Main differences with that previous study are:

Table 2: Observations of AB Dor. Columns are: revolution; ID and date of observation; displacements in the dispersion and cross-dispersion directions and count rates for both RGS1 and RGS2.

AB Dor								
	OBS		RGS1			RGS2		
REV	ID	Date	$\Delta\beta$ (")	$\Delta\chi$ (")	count rate (s^{-1})	$\Delta\beta$ (")	$\Delta\chi$ (")	count rate (s^{-1})
0072	0123720201	2000-05-01	+1.2	-20.1	1.475 ± 0.006	+12.6	-9.1	1.474 ± 0.006
0091	0126130201	2000-06-07	-6.2	-18.1	1.059 ± 0.005	+5.1	-7.2	1.065 ± 0.004
0162	0123720301	2000-10-27	-0.7	+0.4	1.086 ± 0.004	+10.5	+11.3	1.396 ± 0.005
0185	0133120101	2000-12-11	+70.5	-14.1	1.271 ± 0.005	+81.8	-3.0	1.598 ± 0.006
0185	0133120701	2000-12-11	+70.6	-14.2	1.161 ± 0.012	+81.9	-3.1	1.455 ± 0.013
0185	0133120201	2000-12-12	+32.2	-83.9	1.259 ± 0.008	+43.8	-72.9	1.539 ± 0.009
0205	0134520301	2001-01-20	+8.4	-5.5	1.599 ± 0.008	+19.8	+5.3	2.044 ± 0.009
0266	0134520701	2001-05-22	-6.4	-16.8	1.101 ± 0.005	+4.9	-5.8	1.423 ± 0.006
0338	0134521301	2001-10-13	-0.5	+8.1	1.077 ± 0.006	+10.7	+19.0	1.375 ± 0.006
0375	0134521401	2001-12-26	+11.7	+1.3	1.153 ± 0.016	+23.0	+12.2	1.455 ± 0.018
0429	0134521501	2002-04-12	+1.5	-11.8	0.994 ± 0.005	+12.8	-0.9	1.248 ± 0.005
0462	0155150101	2002-06-18	+22.7	+7.3	2.154 ± 0.011	+34.0	+18.3	2.632 ± 0.012
0462	0134521601	2002-06-18	-2.4	-3.7	1.464 ± 0.007	+8.8	+7.1	1.788 ± 0.007
0532	0134521801	2002-11-05	-2.5	-7.5	1.378 ± 0.011	+8.8	+3.3	1.776 ± 0.012
0537	0134521701	2002-11-15	-2.5	-5.2	1.244 ± 0.009	+8.8	+5.6	1.609 ± 0.009
0546	0134522001	2002-12-03	+2.6	-3.7	1.471 ± 0.011	+14.0	+7.1	1.895 ± 0.012
0560	0134522101	2002-12-30	+0.9	-4.8	1.329 ± 0.005	+12.2	+6.0	1.736 ± 0.006
0572	0134522201	2003-01-23	+0.9	-6.0	0.993 ± 0.005	+12.3	+4.8	1.289 ± 0.005
0605	0134522301	2003-03-30	-1.2	-6.1	1.480 ± 0.006	+10.0	+4.8	1.944 ± 0.007
0636	0134522401	2003-05-31	-1.7	-1.9	1.121 ± 0.009	+9.5	+9.0	1.452 ± 0.010
0668	0160362501	2003-08-02	+1.0	-3.3	1.125 ± 0.045	+12.4	+7.6	1.450 ± 0.012
0668	0160362601	2003-08-02	+1.8	-4.9	0.941 ± 0.006	+13.1	+5.9	1.230 ± 0.007
0709	0160362701	2003-10-24	-0.5	-3.6	1.015 ± 0.006	+10.7	+7.3	1.253 ± 0.007
0732	0160362801	2003-12-08	+0.3	-6.2	1.344 ± 0.005	+11.7	+4.6	1.716 ± 0.006
0910	0160362901	2004-11-27	-111.8	-1.2	0.935 ± 0.005	-100.4	+9.3	1.158 ± 0.006
0981	0160363001	2005-04-18	-0.6	-6.2	1.069 ± 0.006	+10.6	+4.6	1.375 ± 0.006
1072	0160363201	2005-10-16	+0.3	-3.6	1.206 ± 0.006	+11.7	+7.2	1.570 ± 0.006
1292	0412580101	2006-12-31	+2.1	-4.2	1.369 ± 0.006	+13.4	+6.6	1.747 ± 0.007

- Fitting procedure is applied to the whole spectrum, instead of single lines. The spectrum is made up of a continuum and as many individual X-ray lines as necessary;
- The appropriate response matrices are used in conjunction with each individual spectrum;
- Proper statistical methods are implemented (e.g. C-statistic);
- **rgsproc** is run using SIMBAD J2000 coordinates and independently with SIMBAD J2000 proper motion corrected positions for each star. The effects of proper motion have in fact never been considered before and it is therefore mandatory to consider it to possibly improve the calibration of RGS;
- The sample presented here is much larger. It is comprised of four stars and 66 observations in total, while the sample presented in the previous study was comprised of three stars and 28 observations.

Table 3: Observations of Capella. The meaning of columns is as for Table 2.

Capella								
	OBS		RGS1			RGS2		
REV	ID	Date	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})
0043	0119700201	2000-03-03	-1.4	-96.1	2.990 ± 0.020	+10.1	-85.2	3.262 ± 0.021
0043	0119700301	2000-03-03	-1.3	-96.7	2.898 ± 0.011	+10.3	-85.7	3.304 ± 0.012
0043	0119700401	2000-03-04	-3.4	-98.1	2.945 ± 0.009	+8.1	-87.2	3.280 ± 0.009
0043	0119700601	2000-03-03	-1.2	-97.1	3.028 ± 0.009	+10.3	-86.2	3.360 ± 0.009
0043	0119700701	2000-03-05	-3.6	-98.3	2.953 ± 0.009	+8.0	-87.4	3.543 ± 0.009
0046	0120900201	2000-03-09	+3.4	+72.5	3.327 ± 0.010	+14.4	+83.5	3.818 ± 0.001
0053	0121500201	2000-03-24	+671.8	-29.8	1.894 ± 0.011	+682.6	-17.2	1.815 ± 0.011
0053	0121500301	2000-03-23	-332.7	-6.2	2.812 ± 0.013	-321.0	+3.8	2.581 ± 0.012
0053	0121500401	2000-03-24	+340.4	-19.4	2.857 ± 0.013	+351.5	-7.6	3.009 ± 0.013
0054	0121920101	2000-03-25	-0.6	+10.1	3.130 ± 0.008	+10.6	+21.0	3.428 ± 0.008
0232	0134720101	2001-03-15	+2.7	+15.8	2.322 ± 0.009	+14.0	+26.8	3.184 ± 0.011
0517	0134720401	2002-10-05	-0.2	-2.9	2.638 ± 0.009	+11.0	+7.9	3.476 ± 0.011
0790	0134720801	2004-04-01	-0.4	-3.1	2.589 ± 0.007	+10.8	+7.7	3.540 ± 0.049
0871	0134721501	2004-09-10	+0.6	-4.0	2.648 ± 0.006	+11.9	+6.8	3.662 ± 0.008
0971	0134721601	2005-03-28	-1.8	-4.9	3.443 ± 0.013	+9.4	+5.9	4.707 ± 0.015
0972	0134721701	2005-03-31	-1.0	-2.5	3.535 ± 0.015	+10.2	+8.3	4.824 ± 0.017
1149	0134722001	2006-03-20	-0.1	-4.9	2.082 ± 0.006	+11.2	+5.9	2.457 ± 0.007
1318	0134722101	2007-02-20	+3.9	-1.0	3.304 ± 0.008	+15.1	+9.8	4.507 ± 0.009
1412	0510780101	2007-08-27	-2.5	-8.3	3.937 ± 0.008	+8.8	+2.5	5.663 ± 0.010

Table 4: Observations of Procyon. The meaning of columns is as for Table 2.

Procyon								
	OBS		RGS1			RGS2		
REV	ID	Date	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})
0160	0123940101	2000-10-23	-0.8	-10.6	0.118 ± 0.002	+10.4	+0.3	0.099 ± 0.002
0160	0123940201	2000-10-24	-2.9	-9.1	0.114 ± 0.005	+8.3	+1.7	0.101 ± 0.005
1341	0415580101	2007-04-07	-16.6	+1.5	0.087 ± 0.002	-5.3	+12.4	0.081 ± 0.002
1341	0415580201	2007-04-08	-5.3	+5.7	0.096 ± 0.002	+5.9	+16.6	0.081 ± 0.002
1341	0415580301	2007-04-08	+5.1	+5.6	0.086 ± 0.004	+16.4	+16.6	0.072 ± 0.003

Table 5: Observations of HR1099. The meaning of columns is as for Table 2.

HR1099								
	OBS		RGS1			RGS2		
REV	ID	Date	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})	$\Delta\beta$ (“)	$\Delta\chi$ (“)	count rate (s^{-1})
0031	0116890801	2000-02-08	+0.0	-3.4	4.205 ± 0.020	+11.3	+7.5	4.250 ± 0.020
0031	0116890901	2000-02-08	+0.0	-3.6	3.619 ± 0.012	+11.4	+7.3	3.661 ± 0.012
0031	0116891101	2000-02-09	-6.1	-2.1	3.170 ± 0.018	+5.2	+8.7	3.149 ± 0.018
0036	0117890801	2000-02-18	-469.6	-4.0	1.856 ± 0.030	-457.8	+5.7	1.790 ± 0.029
0036	0117890901	2000-02-18	-469.5	-4.1	2.529 ± 0.009	-457.7	+5.6	2.358 ± 0.009
0132	0129350201	2000-08-28	-3.9	-14.1	3.635 ± 0.011	+7.4	-3.1	3.560 ± 0.011
0132	0129350301	2000-08-27	-3.9	-14.1	4.014 ± 0.017	+7.4	-3.1	3.941 ± 0.017
0214	0134540301	2001-02-07	+1.1	+6.9	1.858 ± 0.031	+12.4	+17.8	2.391 ± 0.033
0221	0134540101	2001-02-22	+2.7	+5.2	1.655 ± 0.006	+14.0	+16.2	2.186 ± 0.007
0310	0134540401	2001-08-18	-4.2	-13.4	1.579 ± 0.009	+7.1	-2.5	2.040 ± 0.010
0310	0134540501	2001-08-18	-6.0	-13.5	1.533 ± 0.018	+5.2	-2.6	1.988 ± 0.019
0495	0134540601	2002-08-22	+0.0	-6.2	1.469 ± 0.007	+11.4	+4.6	1.897 ± 0.008
0857	0134540801	2004-08-13	-0.0	-4.2	1.757 ± 0.006	+11.2	+6.7	2.293 ± 0.007
0942	0134540901	2005-01-29	-1.8	-5.4	3.024 ± 0.008	+9.4	+5.4	3.752 ± 0.008

4 Results

A wavelength shift is evident for both RGS1 and RGS2 (Fig. 2), but is much larger for the latter, with a ratio $\Delta_{\lambda,\mathrm{RGS2}}/\Delta_{\lambda,\mathrm{RGS1}} \sim 3$ for both orders. The shift is minimum for the second order for both RGSs.

The shift does not seem to be correlated with neither the cross-dispersion or the incidence angles (Fig. 3).

Figs. 4 and 5 illustrate the most important results of this analysis. The figures show that there is a linear relation between the wavelength shifts for RGS1 and RGS2 for all observations. However, the relation changes for first and second order. In first order it is found that $\Delta_{\lambda,\mathrm{RGS2}}[\mathrm{m\AA}] = (1.034 \pm 0.04) \times \Delta_{\lambda,\mathrm{RGS1}}[\mathrm{m\AA}] + (4.94 \pm 0.31)$. In second order the relation is $\Delta_{\lambda,\mathrm{RGS2}}[\mathrm{m\AA}] = (1.04 \pm 0.06) \times \Delta_{\lambda,\mathrm{RGS1}}[\mathrm{m\AA}] + (1.61 \pm 0.36)$. The comparison between first and second order wavelength shifts is in Figs. 6, 7.

A similar results is found for velocity shifts (Figs. 8, 9). The relation between RGS1 and RGS2 in first order is $\Delta_{\mathrm{v,RGS2}}[\mathrm{km\,s^{-1}}] = (1.06 \pm 0.04) \times \Delta_{\mathrm{v,RGS1}}[\mathrm{km\,s^{-1}}] + (-84.65 \pm 5.32)$ while in second order is $\Delta_{\lambda,\mathrm{RGS2}}[\mathrm{m\AA}] = (\pm) \times \Delta_{\lambda,\mathrm{RGS1}}[\mathrm{m\AA}] + (\pm)$. The comparison between first and second order velocity shifts is in Figs. 10, 11.

Figs. 6 (10) and 7 (11) compare the results of wavelength (velocity) shifts for a given RGS and both orders.
Tables 6 and 7 contain wavelength and velocity shifts as well as results from C-statistic for each observation.

5 Future Prospects

This study has established that the difference in wavelength measured by the two RGS instruments is

- $\Delta_\lambda(\mathrm{RGS2})[\mathrm{m\AA}] - \Delta_\lambda(\mathrm{RGS1})[\mathrm{m\AA}] = 4.94 \pm 0.31$

This should form the basis of a CCF release to align both instruments. The absolute shift should be checked against the position of the OVII absorption lines seen in the accumulated spectra of blazars. Further steps

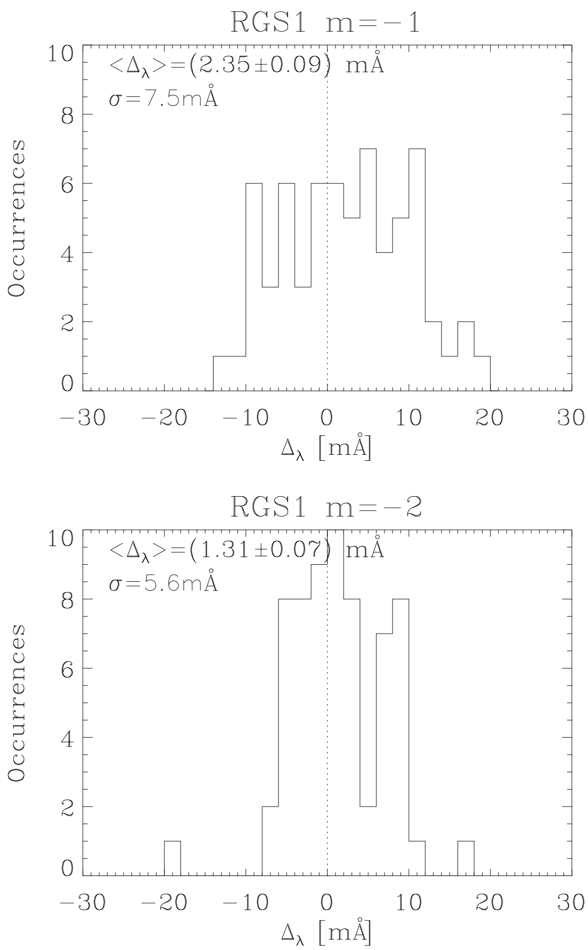

Figure 2: Distribution of first and second order wavelength shifts for RGS1 and RGS2. The mean wavelength shift is larger for RGS2.

will then include geometry adjustments to individual CCD positions and finally an investigation of the origin of the shifts seen in single observations.

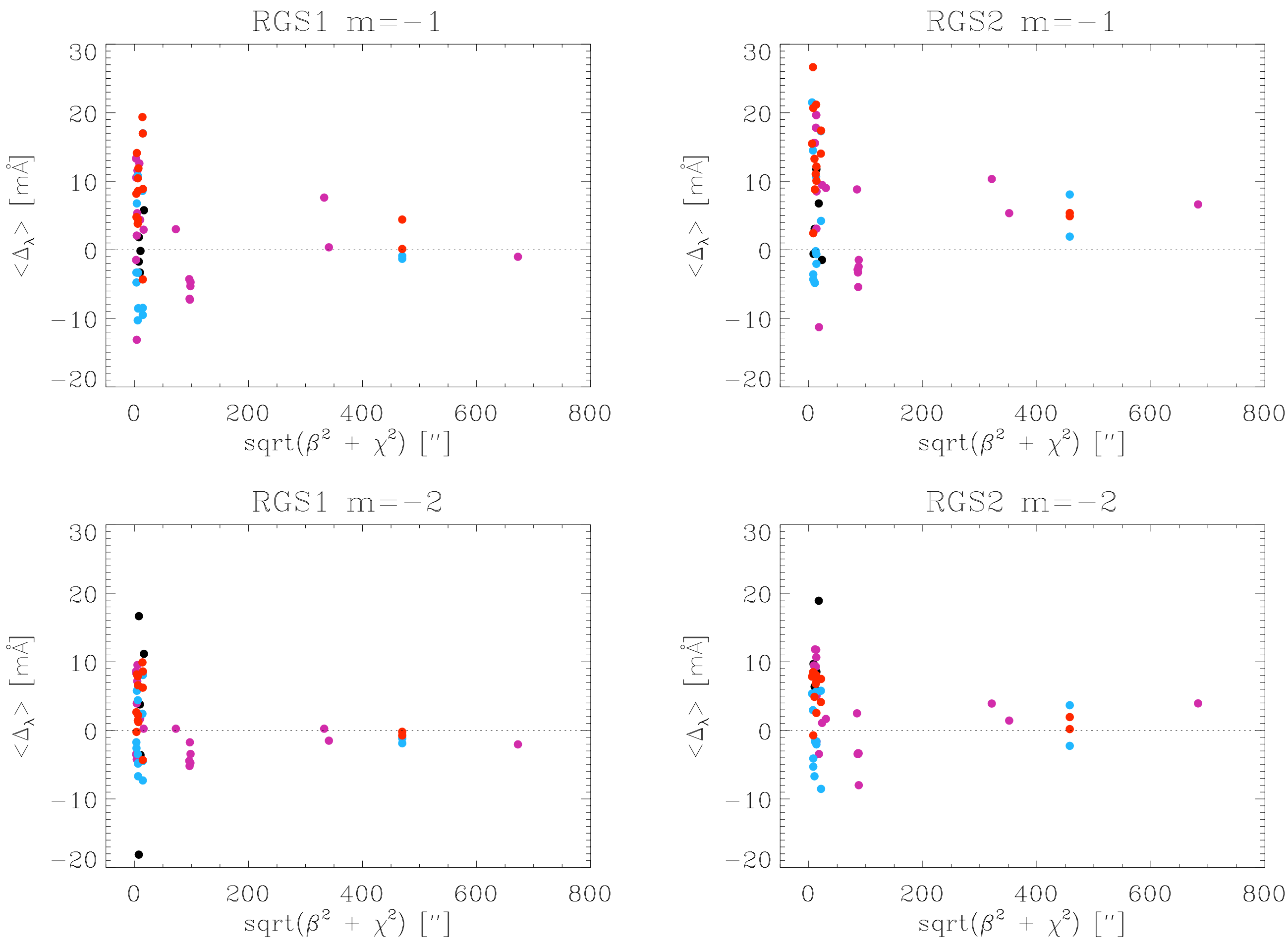

Figure 3: Mean shift in wavelength per observations for RGS1 and RGS2, first and second order, as a function of β and *chi*. The results from the different stars are black (Procyon), pink (Capella), blue (HR1099) and red (AB Dor). The same colours are used in the remaining figures.

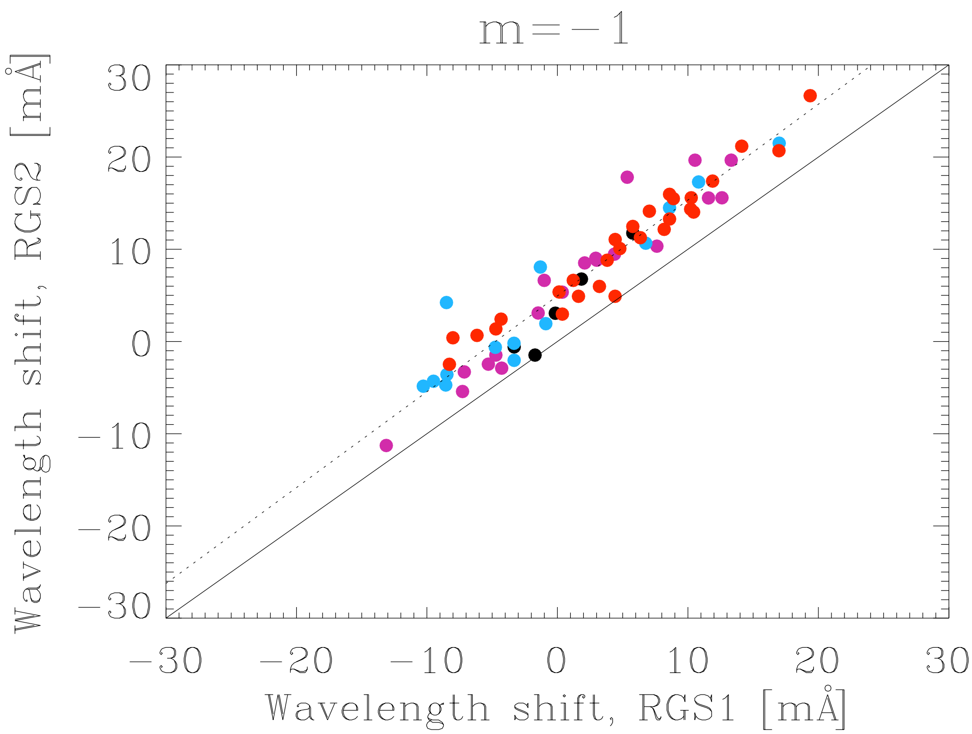

Figure 4: Wavelength shifts for RGS1 and RGS2, first order. The relation between RGS1 and RGS2 is $\Delta_{\lambda,\mathrm{RGS2}}[\mathrm{m\AA}] = (1.034 \pm 0.04) \times \Delta_{\lambda,\mathrm{RGS1}}[\mathrm{m\AA}] + (4.94 \pm 0.31)$.

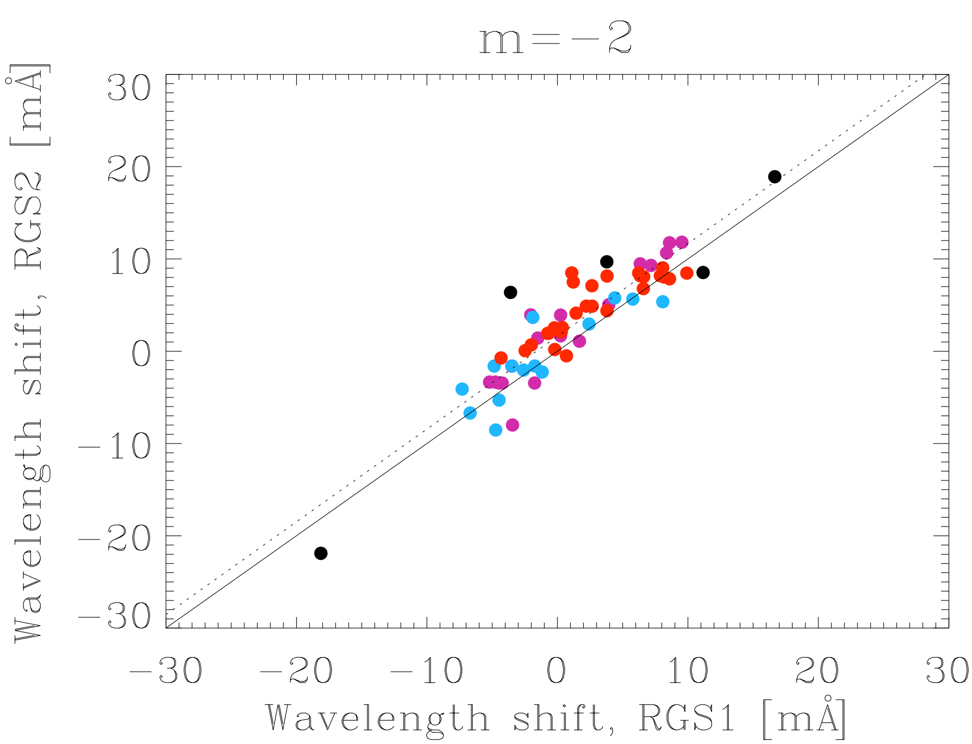

Figure 5: Wavelength shifts for RGS1 and RGS2, second order. The relation between RGS1 and RGS2 is $\Delta_{\lambda,\mathrm{RGS2}}[\mathrm{m\AA}] = (1.04 \pm 0.06) \times \Delta_{\lambda,\mathrm{RGS1}}[\mathrm{m\AA}] + (1.61 \pm 0.36)$.

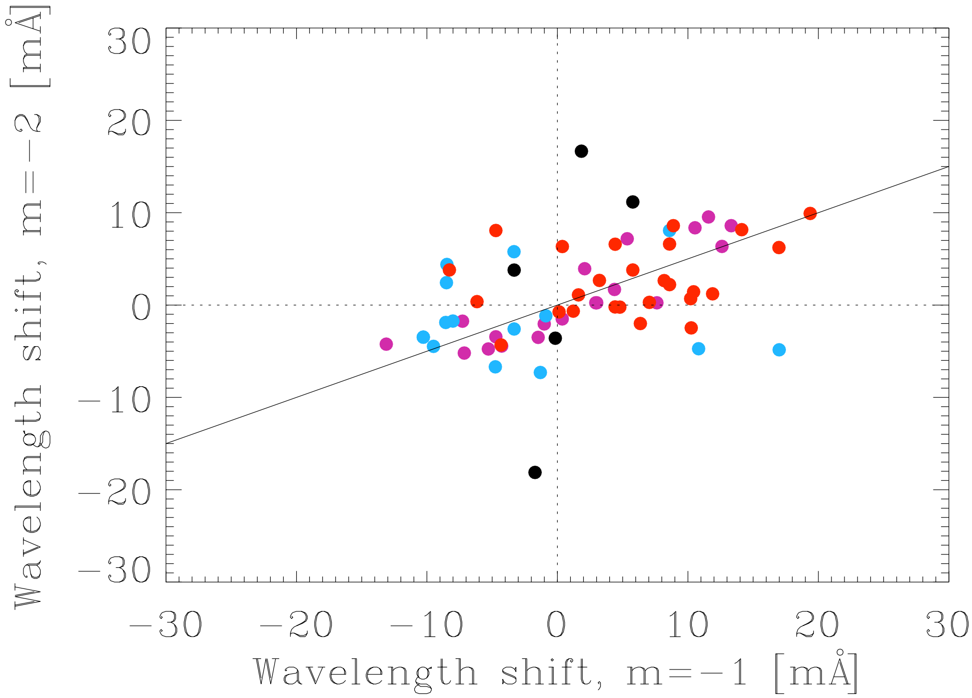

Figure 6: Wavelength shifts for RGS1 in first and second order. The solid line shows the slope expected for wavelength shift in first and second order.

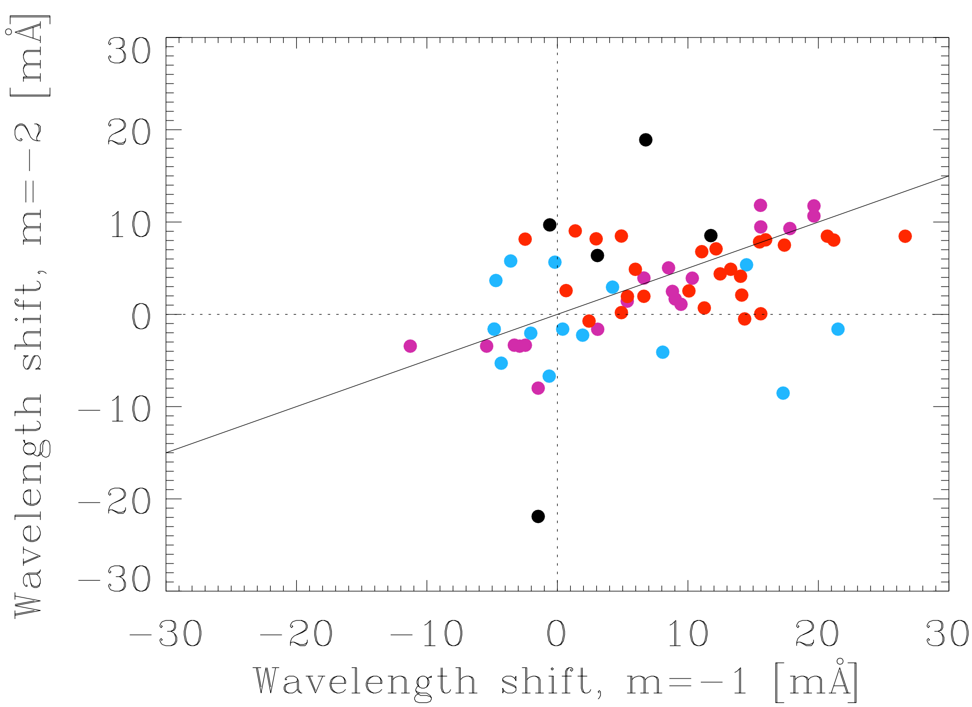

Figure 7: Wavelength shifts for RGS2 in first and second order. The solid line shows the slope expected for wavelength shift in first and second order.

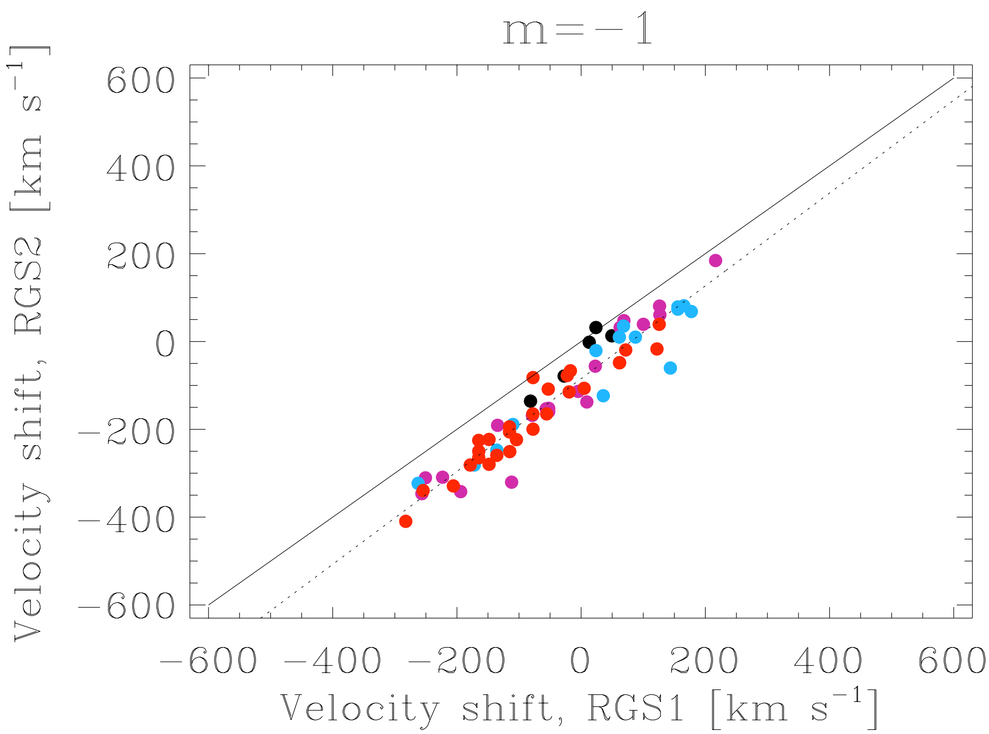

Figure 8: Velocity shifts measured for RGS1 and RGS2, first order. The relation between RGS1 and RGS2 is $\Delta_{\mathrm{v,RGS2}}[\mathrm{km\,s^{-1}}] = (1.06 \pm 0.04) \times \Delta_{\mathrm{v,RGS1}}[\mathrm{km\,s^{-1}}] + (-84.65 \pm 5.32)$.

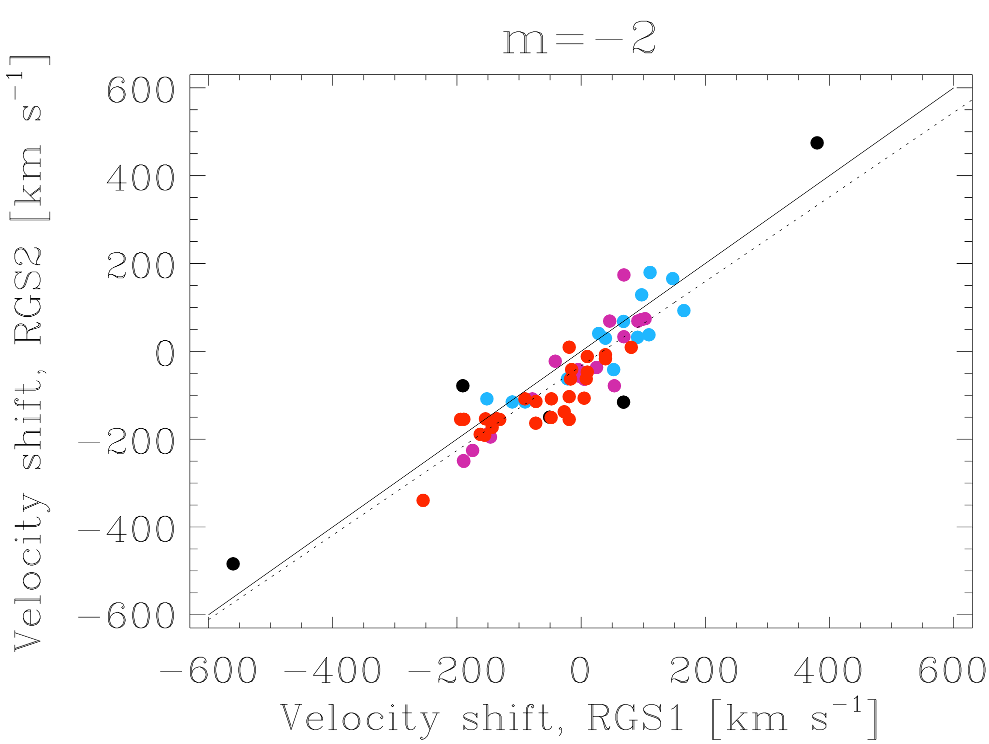

Figure 9: Velocity shifts measured for RGS1 and RGS2, second order. The relation between RGS1 and RGS2 is $\Delta_{\mathrm{v,RGS2}}[\mathrm{km\,s^{-1}}] = (\pm) \times \Delta_{\mathrm{v,RGS1}}[\mathrm{km\,s^{-1}}] + (\pm)$.

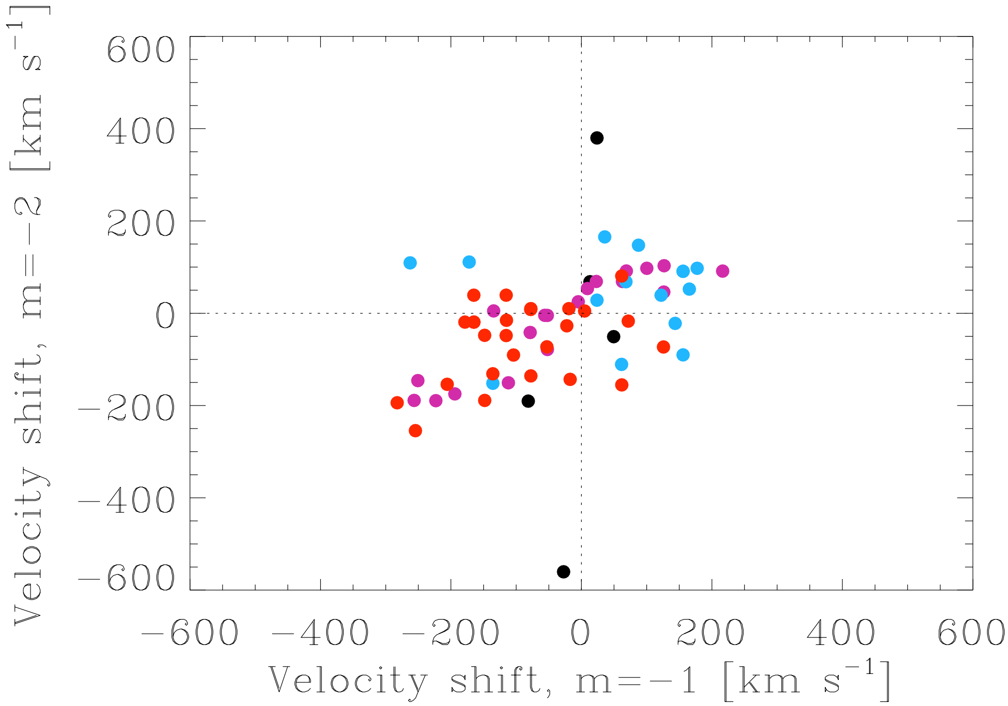

Figure 10: Velocity shifts for RGS1 in first order.

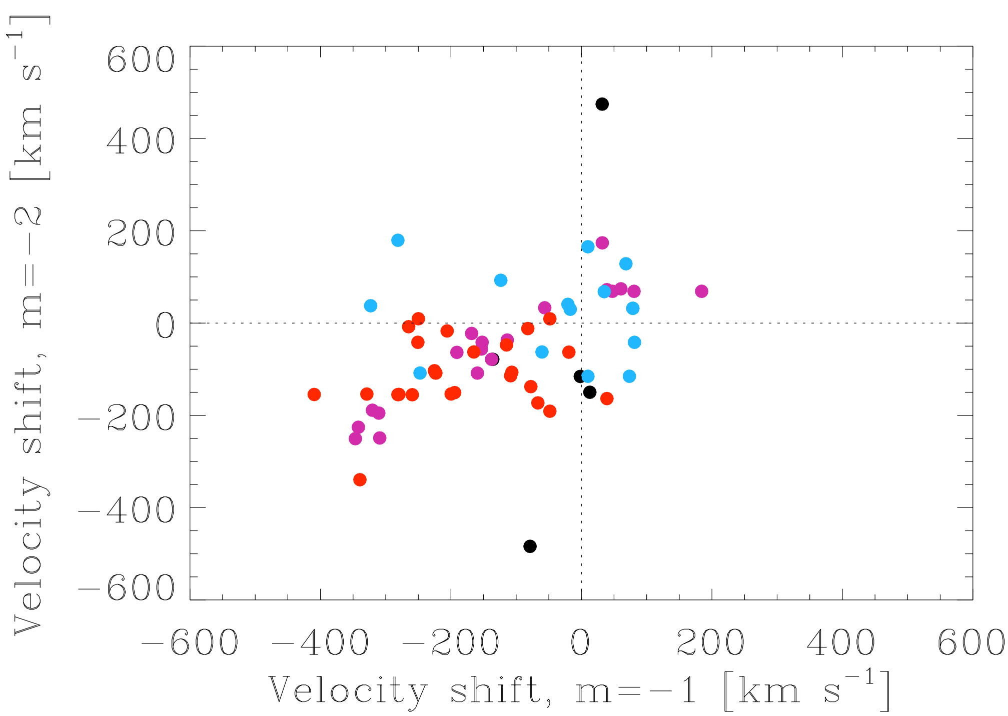

Figure 11: Velocity shifts for RGS2 in second order.

Table 6: C-statistic values and shifts, order 1.

OBS ID	Target	$C_{\Delta_\lambda=0,\Delta_v=0}$	$C_{\Delta_\lambda,\Delta_v=0}$	$C_{\Delta_\lambda=0,\Delta_v}$	$\Delta_{\lambda,RGS1}$	$\Delta_{v,RGS1}$	$\Delta_{\lambda,RGS2}$	$\Delta_{v,RGS2}$
0123940101	Procyon	5653.16	5655.54	5652.64	-0.161693	13.0580	3.06656	-1.75928
0123940201	Procyon	5702.44	5719.48	5696.58	-3.31508	49.4340	-0.586980	12.9351
0415580101	Procyon	5671.17	5632.48	5630.19	5.77819	-81.4908	11.7596	-135.765
0415580201	Procyon	4986.97	4976.86	4995.80	1.83909	-27.3518	6.77110	-78.7411
0415580301	Procyon	5673.78	5669.28	5672.20	-1.71621	23.8285	-1.47440	31.8067
0119700201	Capella	7301.77	7182.44	7187.07	-4.27156	68.8528	-2.88980	47.4475
0119700301	Capella	11393.8	10868.1	10868.5	-7.13769	126.754	-3.30129	60.5656
0119700401	Capella	14808.9	13889.4	13956.8	-5.29240	100.240	-2.45656	39.1151
0119700601	Capella	6357.70	6333.13	6332.33	-7.27221	126.291	-5.42269	80.6534
0119700701	Capella	6384.22	6378.28	6381.17	-4.71752	62.8617	-1.47380	31.9766
0120900201	Capella	16984.3	16385.6	16294.5	3.01259	-56.2343	8.81427	-153.178
0121500201	Capella	7986.07	7943.86	7935.36	-1.01115	9.18730	6.62770	-137.714
0121500301	Capella	10557.4	10204.6	10147.3	7.62450	-134.516	10.3357	-190.894
0121500401	Capella	9232.99	9156.75	9141.96	0.369580	-4.87698	5.35132	-113.636
0121920101	Capella	18888.6	17746.5	17699.1	4.37320	-78.5365	9.46888	-168.255
0134720101	Capella	10793.0	10466.5	10429.0	2.93947	-52.2456	9.02515	-152.179
0134720401	Capella	11085.7	10782.4	10796.9	-1.47558	22.8038	3.08679	-56.2343
0134720801	Capella	24158.8	20638.3	20062.7	10.5443	-193.979	19.6586	-341.876
0134721501	Capella	21437.7	20863.1	20660.8	2.08799	-52.1525	8.51681	-159.433
0134721601	Capella	14985.7	13854.5	13607.5	11.5781	-223.117	15.5638	-309.122
0134721701	Capella	12887.6	11663.8	11427.3	13.3186	-256.402	19.6612	-346.502
0134722001	Capella	15351.5	14266.2	13919.9	5.34998	-111.949	17.8134	-320.355
0134722101	Capella	26945.8	22713.3	23090.0	-13.1155	216.456	-11.2775	184.326
0510780101	Capella	34214.8	31245.4	30535.6	12.6098	-250.723	15.5833	-310.569
0123720201	AB Dor	5986.80	5936.74	5939.63	8.18210	-115.351	12.1589	-194.343
0126130201	AB Dor	6809.83	6720.99	6704.03	4.78386	-77.7403	10.0768	-164.891
0134520701	AB Dor	6379.51	6165.18	6149.36	8.59277	-148.317	13.2800	-223.094
0133120101	AB Dor	6494.86	6426.73	6425.05	0.126967	4.87703	5.36541	-106.639
0133120701	AB Dor	5531.59	5534.62	5529.55	4.41998	-77.4755	4.90284	-82.1825
0134520301	AB Dor	6648.71	6598.48	6590.26	-4.31886	61.8296	2.42207	-48.3328
0134521301	AB Dor	6723.25	6138.45	6112.92	16.9767	-254.433	20.6868	-339.489
0134521501	AB Dor	6613.60	6274.98	6265.69	10.4363	-164.868	14.0355	-225.237
0134521801	AB Dor	5885.09	5706.16	5697.17	11.8924	-178.591	17.3941	-281.289
0134522401	AB Dor	5898.42	5471.11	5449.52	19.3708	-282.404	26.6526	-409.538
0134522301	AB Dor	6721.03	6299.46	6214.91	8.88510	-148.238	15.4921	-279.652
0134522201	AB Dor	6525.02	6330.00	6277.10	4.42589	-77.4751	11.0605	-199.673
0155150101	AB Dor	5932.37	5671.74	5670.32	14.1248	-205.748	21.1786	-328.855
0160362501	AB Dor	5497.76	5475.26	5471.68	3.81412	-55.5053	8.81133	-164.864
0160363001	AB Dor	6912.63	6529.96	6469.92	10.2545	-164.910	15.5833	-264.819
0412580101	AB Dor	5893.60	5685.26	5689.97	-8.27860	125.756	-2.47313	39.1150
0134521601	AB Dor	6483.12	6187.64	6181.25	8.59258	-135.753	15.9575	-259.258
0160363201	AB Dor	7589.69	7392.37	7336.99	5.77790	-104.095	12.4759	-223.494
0160362701	AB Dor	5747.61	5677.47	5672.93	3.21922	-52.9437	5.97301	-108.426
0160362901	AB Dor	5609.87	5602.86	5593.81	0.377432	-17.2768	2.96829	-66.7351
0134521701	AB Dor	5810.57	5741.70	5715.98	6.35530	-115.320	11.2560	-205.813
0133120201	AB Dor	5744.53	5709.79	5707.15	1.61374	-22.3849	4.90272	-77.4719
0134521401	AB Dor	5733.89	5661.84	5662.44	10.2113	-164.865	14.3495	-249.885
0134522001	AB Dor	5286.17	5216.06	5220.70	-6.16302	71.7902	0.662181	-19.2413

OBS ID	Target	$C_{\Delta_\lambda=0,\Delta_v=0}$	$C_{\Delta_\lambda,\Delta_v=0}$	$C_{\Delta_\lambda=0,\Delta_v}$	$\Delta_{\lambda,RGS1}$	$\Delta_{v,RGS1}$	$\Delta_{\lambda,RGS2}$	$\Delta_{v,RGS2}$
0134522101	AB Dor	6368.28	6196.51	6195.91	-4.71780	61.8843	1.36591	-48.3321
0160362601	AB Dor	5798.69	5637.63	5618.96	7.04522	-114.906	14.1257	-250.688
0123720301	AB Dor	6397.80	6347.20	6331.54	1.21431	-19.1984	6.62693	-114.801
0160362801	AB Dor	6779.32	6519.31	6528.68	-8.00735	122.129	0.404785	-17.0685
0116890801	HR1099	21796.1	21712.8	21730.4	-3.31712	68.2543	-2.04324	35.0385
0116890901	HR1099	36282.3	36181.0	36170.4	-4.75757	87.4491	-0.631088	9.97394
0116891101	HR1099	17179.6	16956.1	16948.2	-8.55833	165.440	-4.71569	81.3738
0117890801	HR1099	5673.37	5664.08	5665.97	-0.888081	23.8298	1.93355	-20.7141
0117890901	HR1099	7087.95	6881.73	6888.01	-1.30892	35.7108	8.07208	-123.521
0129350201	HR1099	6836.68	6506.64	6493.90	-9.49813	177.414	-4.30855	68.2635
0129350301	HR1099	6234.75	6095.48	6079.57	-8.46985	155.776	-3.58097	73.6267
0134540101	HR1099	7277.78	6716.96	6710.04	10.8186	-172.062	17.2978	-281.293
0134540301	HR1099	5827.66	5809.97	5808.35	-8.50454	143.716	4.22467	-60.4284
0134540401	HR1099	5991.58	5725.54	5723.07	8.59257	-135.752	14.4939	-247.376
0134540501	HR1099	5384.95	5263.91	5262.78	16.9966	-262.515	21.5028	-323.033
0134540601	HR1099	6287.68	6148.31	6146.98	-3.32762	61.5591	-0.191964	9.97066
0134540801	HR1099	6897.49	6653.39	6639.59	6.77111	-109.843	10.6599	-188.943
0134540901	HR1099	6677.77	6171.77	6197.04	-10.2777	155.816	-4.84510	78.7775

Table 7: C-statistic values and shifts, order 2.

OBS ID	Target	$C_{\Delta_\lambda=0,\Delta_v=0}$	$C_{\Delta_\lambda,\Delta_v=0}$	$C_{\Delta_\lambda=0,\Delta_v}$	$\Delta_{\lambda,RGS1}$	$\Delta_{v,RGS1}$	$\Delta_{\lambda,RGS2}$	$\Delta_{v,RGS2}$
0123940101	Procyon	3276.13	3271.80	3264.86	-3.59102	68.2699	6.37568	-115.689
0123940201	Procyon	3362.34	3360.05	3361.02	3.78618	-50.7344	9.69105	-149.927
0415580101	Procyon	3941.76	3939.36	3938.48	11.1627	-190.474	8.53006	-78.5188
0415580201	Procyon	2526.58	2510.20	2509.96	16.6586	-560.353	18.9073	-483.903
0415580301	Procyon	4289.19	4277.56	4280.69	-18.1256	379.954	-21.9004	474.534
0119700201	Capella	4705.36	4614.31	4621.61	-4.44180	91.5752	-3.44650	68.8292
0119700301	Capella	5950.12	5797.80	5879.69	-5.19962	103.011	-3.34234	74.1713
0119700401	Capella	7028.07	6701.80	6720.56	-4.75550	97.4202	-3.34761	72.3458
0119700601	Capella	4417.79	4413.76	4412.84	-1.74541	45.9555	-3.44737	68.8147
0119700701	Capella	4056.31	3960.37	3957.20	-3.44008	68.8869	-7.99614	173.842
0120900201	Capella	6892.60	6920.74	6974.33	0.243001	-4.48949	2.48395	-56.2343
0121500201	Capella	5142.34	5092.16	5080.31	-2.04469	53.5013	3.93452	-78.5404
0121500301	Capella	6136.92	6071.90	6052.35	0.243012	5.02510	3.91589	-63.5391
0121500401	Capella	5498.08	5540.37	6384.07	-1.50279	24.8357	1.42914	-36.7606
0121920101	Capella	8263.25	8140.42	8196.38	1.68739	-41.6835	1.08751	-22.4960
0134720101	Capella	6397.10	6220.16	6274.18	0.242914	-4.72135	1.66640	-41.6849
0134720401	Capella	7449.87	7244.68	7210.26	-3.49768	68.8534	-1.61840	33.0713
0134720801	Capella	12143.1	12175.2	11563.1	8.36609	-174.767	10.6599	-225.762
0134721501	Capella	11850.3	11537.9	11522.3	3.93340	-78.5145	5.03379	-108.391
0134721601	Capella	8981.39	8483.65	8338.82	9.53962	-189.458	11.8102	-248.976
0134721701	Capella	7794.10	7175.73	7317.82	8.59258	-188.943	11.7508	-250.515
0134722001	Capella	9584.26	9065.24	8556.49	7.17621	-150.728	9.29690	-188.887
0160363001	AB Dor	4448.96	4402.26	4404.35	7.89053	-162.511	8.18250	-188.943
0412580101	AB Dor	3993.43	3925.25	3924.93	-2.47439	39.1141	0.0598262	-7.88455
0134521601	AB Dor	4713.53	4460.19	4442.34	3.80099	-73.0624	8.14559	-163.607
0160363201	AB Dor	4646.28	4503.21	4492.44	6.60932	-131.187	8.07193	-155.294
0123720301	AB Dor	4558.83	4298.63	4292.07	0.291349	-15.2705	2.08801	-41.6847
0160362801	AB Dor	4690.12	4656.52	4672.13	-0.659781	9.97507	1.95466	-47.3686
0116890801	HR1099	10417.1	10097.1	10109.8	-1.73471	39.1153	-1.60254	29.8489
0134540301	HR1099	4422.81	4395.93	4394.70	-4.73010	110.998	-8.53607	179.475
0134540401	HR1099	4423.20	4388.48	4399.31	2.42138	-21.9665	2.94563	-62.6704
0134540501	HR1099	4462.15	4447.24	4446.07	8.07317	-151.781	5.36372	-108.237
0134540601	HR1099	4519.70	4491.88	4404.44	-4.84486	109.192	-1.60449	37.5120
0134540801	HR1099	4983.92	4616.65	4687.51	5.77815	-110.845	5.65100	-115.324
0134540901	HR1099	4903.66	4576.29	4570.98	-3.47433	90.9105	-1.60283	32.0048

6 References

Lorente R., Pollock A.M.T., Gabriel C., 2003,
`http://xmm.vilspa.esa.es/docs/documents/CAL-TN-0041-1-0.ps.gz`

APPENDIX

The starting point of the analysis, following the creation of CCFs in SAS, is the automatic compilation of a FITS binary table (`RGS.2007CoronalSkeltaLineSurvey.fits`). This table contains, for each observation: revolution; OBSID; date at beginning and end of observation; RA, DEC and proper motion of instrument pointing; target; coordinates of target at J2000; proper motion of target; RA and DEC after proper motion correction; the angles β, χ and α; count rates derived from XSpec. It also includes columns that would be automatically filled during the analysis, such as C-statistic values, wavelength and velocity shifts. The table is internally available.

The table is then fed into a process of which `fitRGSCoronalSpectrum` is the main part. Part of the code is as follows.

```
proc fitRGSCoronalSpectrum {target obsid rgsidList {srcid 003} {order 1} path {modelFile ””} {shape SkeltaFunction}} {

global LineList SHAPE

set SHAPE $shape

switch $order 1 {set W1 6.; set W2 38.} 2 {set W1 6.; set W2 20.}
setLineVisibility $W1 $W2

data none
clearSpectrumList

model clear
set LineList [makeRGSCoronalSpectrum $target $SHAPE]

cd $path/$obsid}/RGS

set bkgid BGSPEC

foreach rgsid $rgsidList {
set label ${obsid}${rgsid}
addRGSXspecData $obsid $rgsid $order $srcid $bkgid $label $W1 $W2
}
}

if {$modelFile != ””} {
model clear
@${modelFile}
}

query no
fit 100; fit 10

return $LineList

}
```

The code above loads a specific spectrum with the corresponding background and response matrix, corresponding to the observation at the line currently loaded from the table.

It then reads in a list of ions to be put into a Skelta function that would be used for fitting the loaded spectrum. A Skelta function is a Delta function spectral line of known laboratory wavelength from which it can be shifted in wavelength of velocity.

The use of the Skelta function has three modes: 000, when both starting velocity and wavelength are set to 0. In this case the default matrix. The second mode (W00) is thawing the wavelength fixing the velocity parameter to 0, while the third mode (00V) is thawing the velocity fixing the wavelength parameter to 0.

The C-statistic derived from fitting the Skelta function to the actual data in the three modes is then included in the table.