An investigation into RGS-pn rectification

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1 Introduction

This document describes the investigation of a method designed to eliminate significant systematic model inconsistencies between RGS and EPIC spectra such as those, particularly below 0.5 keV, reported in recent editions of the XMM-Newton Cross-Calibration Status Document. It follows Action 2009-05-07/03 of the XMM-Newton Users Group: *"The Instrument Teams should establish a time epoch-dependent fudge function for the RGS effective area such that the joint analysis of RGS and EPIC data is possible. Results of this effort should be presented at the next UG meeting in 2010 with the aim to make it available to the general user after the review"* Results are presented through sets of wavelength-dependent RGS-pn Rectification Factors to be applied to RGS models only to bring them into statistical agreement with simultaneous EPIC-pn spectra.

The RGS-pn Rectification Factors have been implemented in SASv10.0 as a new RECTIFICATION extension in the RGS EFFAREACORR CCF, whose use is controlled through the optional parameter switch `withrectification` applied to `rgsproc` and `rgsrmfgen`. At present, these factors have been set to 1.

2 Data and Processing details

The observations used here are a subset of those included in the XMM-SOC XCal Archive. The XCal Archive is a database maintained by the XMM-SOC, containing observations of XMM-Newton and other X-ray missions used for calibration purposes (see, e.g. the presentation by M. Stuhlinger in the Users Group Meeting of June 2007). For each observation, the archive contains, among many other details: EPIC source and background extraction regions chosen to mitigate pile-up; a suitable model of the spectrum, including parameter constraints; and best-fit values of the model parameters. When new versions of software or calibration files become available, the full set of observations can be reprocessed in a relatively short time. Since all the previous results are stored, comparison can easily be made of different versions of calibration or software.

During the course of the work, new calibrations components for both RGS and EPIC-pn became available, allowing three different sets of calibrations to be compared:

- Version 1

  EPIC-pn and RGS data were processed with SASv9.1. The RGS contamination model used to compute the effective area in

  RGS[12]_EFFAREACORR_0005.CCF

  assumed a linear increase of the thickness of the contaminating Carbon layer with time.

- Version 2

  Recent measurements have shown that the thickness of RGS contamination is now increasing more slowly than predicted by the linear model and that an exponential form is better, as described in the recent CCF release note XMM-CCF-REL-262. With this improved contamination model incorporated into the effective in

  RGS[12]_EFFAREACORR_0006.CCF

  new RGS response matrices were generated with xmmsas_20100227_1801-10.0.0-Alpha. Otherwise, Version 1 EPIC-pn data were used. Therefore, Version 2 takes advantage of the most up-to-date knowledge of the RGS instrument.

- Version 3

  A new set of parameters describing EPIC-pn redistribution was delivered to the SOC on April 17 and subsequently made available for testing on April 22 via the new CCF named below which is not yet public. The new RGS and EPIC-pn CCFs

  RGS[12]_EFFAREACORR_0006.CCF

  EPN_REDIST_0011.CCF

  were used together to processes observations in the XCal Archive to give a Version 3 set of spectra and responses that take simultaneous advantage of the most up-to-date RGS calibration and a new trial EPIC-pn calibration [1]

In what follows, the results obtained from the latest Version 3 will be discussed in detail and compared with those from Versions 1 and 2.

[1] On April 27, notification from the EPIC-pn Instrument Team specified that some refinements in the new response matrix might still be necessary at high energies near 6 keV. Therefore, the results obtained with this version of the EPIC-pn redistribution should be taken as preliminary although the low energies relevant for the RGS-pn comparison are reliable.

3 The Sample

The initial sample consisted of the 148 observations available in the XCal archive. Of these, we have considered only continuum sources. Results were initially obtained for 76 observations, as shown in the list below, were the number of observations of each object is given in parenthesis:

- 3C 273 (22)
- PKS 2155-304 (14)
- PKS 0548-322 (1)
- H1426+428 (7)
- Mkn 501 (2)
- 1H 0414+009 (1)
- 1H 0707-495 (10)
- MS0737.9+7441 (2)
- Akn 120 (1)
- RX J1856.6-3754 (14)

Subsequently, a number of these observation were excluded from most further analysis: 1H 0707-495 due to the poor signal-to-noise ratio of its spectra - it is a factor ≈ 10 fainter than 3C 273; PKS 0548-322, Mkn 501, 1H 0414+009, MS0737.9+7441 and Akn 120 because the small number of observations of these targets precluded a detailed analysis of the dependencies with time or PN filter, for example; and the Isolated Neutron Star RX J1856.6-3754 because its extremely soft spectrum leads to significantly different rectification factors above 30 Å (i.e. below 0.4 keV) from those derived from the other sources. This final point is discussed further below.

The final sample was composed of 43 observations of the bright blazars 3C 273, PKS 2155-304 and H1426+428, all observed in EPIC-pn Small Window Mode. There are only 3 observations with the EPIC-pn Thick filter, all of PKS 2155-304.

Some observational details of the sample are given in Tables 1 and 2. Figure 1 show the distribution of the observations in time, and in PN count rate.

4 The Method

The RGS-pn Rectification function has been parametrized as step functions on 33 grid points in wavelength named R6...R38, that cover the range from 6 to 38 Å in 1 Å intervals, so that the factor R20 covers the range from 19.5 to 20.5 Å, for example. A multiplicative Xspec user model with 33 free parameters, called `rgsrectify`, was written to derive the factors.

Each observation was analysed with the following procedure:

- Start with the data and model in the XCal Archive.
  - chisq statistic.
  - spectra grouped to a minimum count of 25.
  - adopt XCal constraints regarding fixed and variable parameters.
- Get best fit and sigma of the XCal model parameters.
- Add to the fit the Xspec user model `rgsrectify`:
  - EPIC-pn rectification factors fixed at 1.
  - Factors in missing RGS chips fixed at 1.
  - Get best fit and sigma of the 33 rectification factors for RGS 1 and RGS 2.
- Collect auxiliary data to inform interpretation

Tables 3 and 4 show the results of the joint fit before and after applying the `rgsrectify` model. The first model parameter is in all cases the Hydrogen Column Density (in units of 10^{22} cm^2). For the `TBabs*bknpower` model, the other four parameters are the first power law index, the Energy break point (in keV), the second power law index, and the normalisation factor, and for the `TBabs(powerlaw+powerlaw)` model, the power law index and normalisation factors for the two components. The last column in the table shows the reduced χ^2 of the fit.

5 Results

Results obtained with the new preliminary EPIC-pn redistribution matrix and the new RGS contamination model are shown in Sections 5 (RGS 1), 6 (RGS 2) and 7 (comparison RGS 1-RGS 2).

- RGS 1
  - Average rectification factors derived from each of the three targets are very similar (Figures 2 and 3), except in the region 24-26 Å, where 3C 273 is $\approx 5\%$ higher.
  - Between 23 and 24 Å (in coincidence with the Oxygen edge) the rectification factors increase by a few percent. The effect is more marked in 3C 273 and nearly negligible in H1426+428.
  - There is a slight dependence on the EPIC-pn filter, with smaller rectification factors for the thicker filters becomes thicker. This result must be taken with caution, as there are only 4 observations taken with the EPIC-pn thick filter, all of the same target, and in a relatively small range of time (Figures 2 and 4).
  - There is not any clear evidence for a time dependence. The strong trend observed when applying the previous RGS contamination model (see below) does not appear now (Figures 2 and 5).

  Tables 5, 6 and 7 shows the average RGS 1 rectification factors derived by target, by filter, and by epoch. (missing values in the wavelength range of CCD7 have been set to zero).

  Figure 6 shows the evolution in time of the individual 33 RGS 1 rectification factors.

- RGS 2
  - Average rectification factors derived from each of the three targets are similar for PKS 2155-304 and H1426+428, although those of 3C 273 are systematically higher above 24 Å (Figures 7 and 8).
  - Again, above 24 Å in coincidence with the Oxygen edge, the rectification factors increase by a few percent, although this is less certain, as the edge falls on the inoperative CCD4.
  - There also is a slight dependence on the EPIC-pn filter, with rectification factors decreasing as the filter becomes thicker. This result must be taken with caution, as there are only 3 observations taken with the EPIC-pn thick filter, all of the same target over a relatively small range of time (Figures 7 and 9).

  - There is no clear evidence for time dependence, except for slightly lower values in the most recent observations. The strong trend observed when applying the previous RGS contamination model does not appear now (Figures 7 and 10).

  Tables 8, 9 and 10 shows the average RGS 1 rectification factors derived by target, by filter, and by epoch: missing values in the wavelength range of CCD4 have been set to zero.

  Figure 11 shows the evolution in time of the individual 33 RGS 2 rectification factors.

  Note that in this RGS the factor at 38 Å has been set to zero, as most of this bin is outside the covered spectral range.

- RGS 1 vs. RGS 2

  - Average factors for RGS 1 and RGS 2 are plotted in Figure 12 and listed in Table 11 (where missing values in the wavelength range of RGS 2 CCD4 have been set to zero). Except for a few cases (e.g. in the range of CCD7 of RGS 1, where there are few points), they agree well.
  - RGS 1 and RGS 2 average factors for each target are in good agreement (Figure 13).
  - RGS 1 and RGS 2 average factors for each filter are in good agreement (Figure 14).
  - RGS 1 and RGS 2 average factors for groups of 400 revolutions filter are in good agreement, except for the most recent data, for which RGS 2 factors are systematically lower (Figure 15).

6 Comparison with previous calibrations

Figure 16 compares the rectification factors obtained from previous calibrations. The largest difference, introduced by the use of the new EPIC-pn redistribution matrices, in seen longwards of 15 Å, and much more noticeably longwards of the O edge.

The difference in the use of the new RGS contamination model is shown more clearly in Figures 17 and 18, where the factors are shown in groups of 400 revolutions. The top panel shows that, with the old contamination model, there was strong time dependence, with the rectification factors becoming systematically larger for more recent observations. This dependence disappears with the new contamination model (middle and bottom panels), implying confirmation of its validity.

7 The case of RX J1856.6-3854

As mentioned above, the rectification factors obtained from the observations of the Isolated Neutron Star RX J1856.6-3754 differ systematically from those obtained from the three selected blazars. As shown in Figure 19, above 30 Å the factors are a 5-7 % higher.

This difference is clearly related to the very soft spectrum of this source, whose EPIC-pn spectrum has essentially no counts at energies above 1 keV.

Figures 20 and 21 show how the rectification factors for this source have changed as different calibrations have been applied. The difference with respect to the average blazar values has gone down from about 15-20 % to about 5-7 %.

8 Conclusions

In this report, we have summarized work carried out to evaluate the systematic discrepancies observed between RGS and EPIC-pn models below 0.5 keV, and derive appropriate rectification factors for possible use in the SAS.

We have presented in detail the results obtained using the most up-to-date EPIC-pn and RGS calibrations, from a sample of 43 observations of the three bright blazars 3C 273, PKS 2155-304 and H1426+428. The results, which were obtained for EPIC-pn observations in Small Window Mode, may be summarised as follows:

- RGS-pn rectification factors show no significant trends with target, EPIC-pn filter or time.
- Median factors between 7 and 37 Angstroms are 0.991 ± 0.021 for RGS1 and 0.983 ± 0.020 for RGS2.
- Median factors increase from short to long wavelength across the oxygen edge at 23.5 Angstroms:
  RGS1 from 0.972 ± 0.015 to 1.000 ± 0.014;
  RGS2 from 0.977 ± 0.010 to 1.006 ± 0.018.
- The most recent calibrations represent substantial changes with respect to those previously available. The time dependence of the rectification factors disappeared once the new public RGS contamination model was applied. The rectification factors longwards of the O-edge decreased substantially with the use of the new trial EPIC-pn redistribution matrix.

9 Appendix

The Appendix shows in detail the results for each of three blazars and for RX J1856.6-3745.

10 The Sample

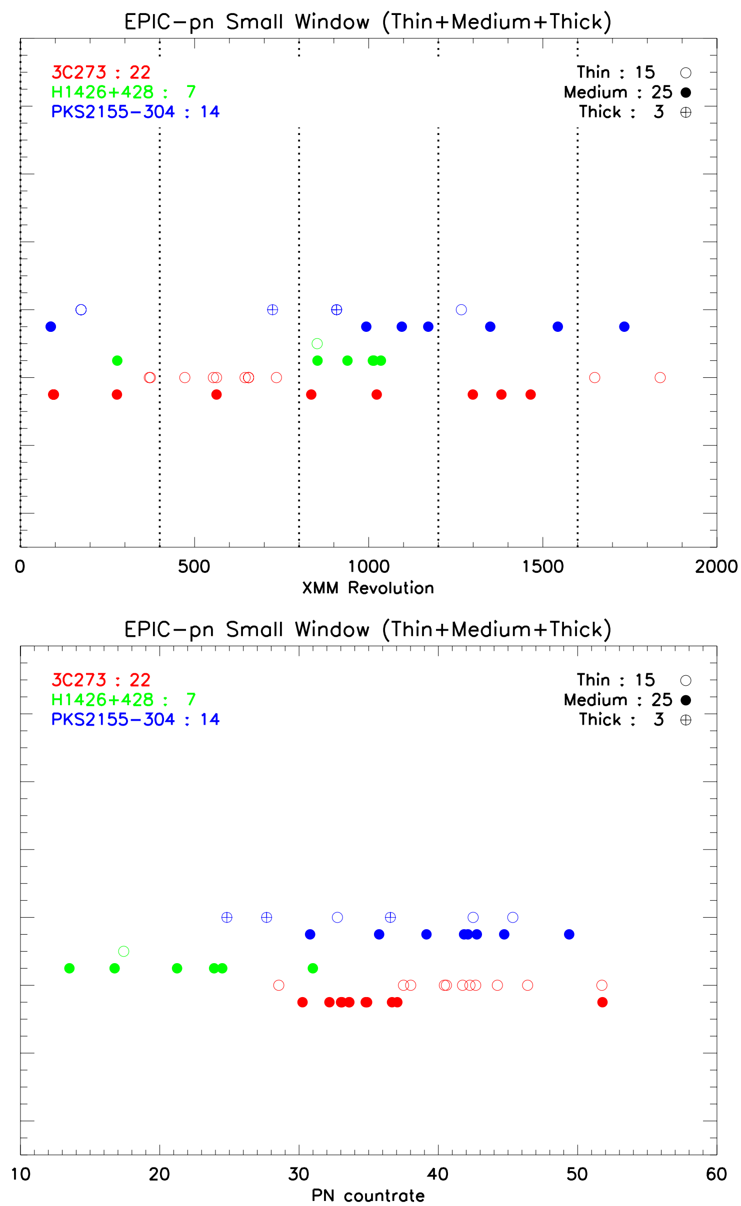


Figure 1: Distribution of the observations in the sample in time and in PN count rate. The vertical lines indicate the intervals chosen to group the observations for the subsequent time analysis.

Table 1: Sample: RGS details

Target	Revolution	Obsid	R1 ExpId	R1 Texp	R1 Rate	R1 Counts	R2 ExpId	R2 Texp	R2 Rate	R2 Counts
PKS2155-304	0087	0124930101	S006	26915	4.17	112271	S007	26156	3.96	103577
PKS2155-304	0087	0124930201	S004	36121	4.19	151391	S005	35100	3.92	137473
3C273	0094	0126700301	S004	58372	1.78	103852	S005	56594	1.68	94994
3C273	0095	0126700701	S004	19685	1.65	32507	S005	19277	1.59	30711
3C273	0095	0126700601	S004	25677	1.71	44022	S005	24867	1.62	40383
3C273	0096	0126700801	S004	45466	1.62	73625	S005	44308	1.55	68683
PKS2155-304	0174	0080940301	S004	48269	2.63	127109	S005	47018	2.75	129081
PKS2155-304	0174	0080940101	S004	55595	3.16	175573	S005	53884	3.35	180552
3C273	0277	0136550101	U002	44309	1.89	83738	U002	43054	2.09	89892
H1426+428	0278	0111850201	S004	44867	0.56	25301	S005	43258	0.63	27131
3C273	0370	0112770101	S004	2932	2.20	6439	S005	2804	2.43	6810
3C273	0373	0112770201	S004	4557	2.08	9491	S005	4337	2.30	9961
3C273	0472	0112770601	S004	2284	1.59	3633	S005	2151	1.81	3894
3C273	0554	0112770801	S004	4617	2.53	11680	S005	4617	2.76	12729
3C273	0563	0136550501	S004	8412	2.16	18145	S005	8412	2.36	19828
3C273	0563	0112770701	S004	4617	2.16	9965	S005	4617	2.39	11032
3C273	0645	0112771001	S004	5214	2.58	13450	S005	5214	2.82	14713
3C273	0655	0112770501	S004	7738	2.21	17125	S005	7742	2.47	19132
3C273	0655	0159960101	S001	57276	2.24	128023	S002	57276	2.48	142009
PKS2155-304	0724	0158960101	S004	26400	1.68	44442	S005	26399	1.75	46104
3C273	0735	0112771101	S004	8170	1.65	13463	S005	8170	1.82	14833
3C273	0835	0136550801	S004	17867	1.35	24113	S005	17830	1.49	26584
H1426+428	0852	0165770101	S004	58059	0.68	39370	S005	58049	0.76	43899
H1426+428	0853	0165770201	S004	61719	0.71	44062	S005	61713	0.80	49446
PKS2155-304	0908	0158961001	S004	27602	2.40	66248	S005	27603	2.52	69475
PKS2155-304	0908	0158960901	S004	27037	1.87	50601	S005	27021	1.95	52684
H1426+428	0939	0212090201	S004	28861	0.90	25976	S005	28842	1.01	29254
PKS2155-304	0993	0158961101	S004	13213	3.02	39969	S005	13208	3.20	42314
H1426+428	1012	0310190101	S004	35131	1.28	45073	S005	35118	1.44	50675
H1426+428	1015	0310190201	S004	29403	1.01	29762	S005	29401	1.15	33912
3C273	1023	0136551001	S004	27443	1.48	40717	S005	27443	1.62	44334
H1426+428	1035	0310190501	S004	36175	1.04	37578	S005	36170	1.16	42120
PKS2155-304	1095	0158961301	S004	50994	3.36	171109	S005	50979	3.52	179660
PKS2155-304	1171	0158961401	S004	61936	1.25	77261	S005	61924	1.34	83055
PKS2155-304	1266	0411780101	S004	29878	1.62	48343	S005	29848	1.74	51854
3C273	1299	0414190101	S004	64484	1.44	92716	S005	64461	1.64	105862
PKS2155-304	1349	0411780201	S004	47122	3.10	146075	S005	47101	3.26	153586
3C273	1381	0414190301	S004	31563	1.22	38533	S005	31561	1.40	44239
3C273	1465	0414190401	S004	35195	2.68	94415	S005	35250	2.90	102199
PKS2155-304	1543	0411780301	S004	60552	3.71	224721	S005	60671	3.87	234568
3C273	1649	0414190501	S004	37687	1.69	63796	S005	37728	1.85	69728
PKS2155-304	1734	0411780401	S004	52821	2.62	138145	S005	52857	2.68	141639
3C273	1837	0414190601	S004	31286	1.84	57612	S005	31335	2.04	63825

Table 2: Sample: PN details

Target	Revolution	Obsid	ExpId	pn Mode	pn Filter	pn Texp	pn Rate	pn Counts
PKS2155-304	0087	0124930101	S010	Small Window	Medium	19274	42	824190
PKS2155-304	0087	0124930201	S003	Small Window	Medium	25953	42	1093204
3C273	0094	0126700301	S003	Small Window	Medium	41800	34	1454023
3C273	0095	0126700701	S003	Small Window	Medium	14186	32	456542
3C273	0095	0126700601	S003	Small Window	Medium	18355	33	616489
3C273	0096	0126700801	S003	Small Window	Medium	32644	33	1079831
PKS2155-304	0174	0080940301	S003	Small Window	Thin	34634	45	1570456
PKS2155-304	0174	0080940101	S003	Small Window	Thin	39841	42	1693128
3C273	0277	0136550101	S003	Small Window	Medium	31692	34	1105542
H1426+428	0278	0111850201	S003	Small Window	Medium	32056	13	433240
3C273	0370	0112770101	S001	Small Window	Thin	2102	42	88856
3C273	0373	0112770201	S001	Small Window	Thin	3233	40	130741
3C273	0472	0112770601	S001	Small Window	Thin	1609	28	45942
3C273	0554	0112770801	S001	Small Window	Thin	3243	46	150521
3C273	0563	0136550501	S003	Small Window	Medium	5910	36	216761
3C273	0563	0112770701	S001	Small Window	Thin	3243	51	167819
3C273	0645	0112771001	S001	Small Window	Thin	3664	44	162096
3C273	0655	0112770501	S001	Small Window	Thin	5436	38	206682
3C273	0655	0159960101	S005	Small Window	Thin	40190	41	1677511
PKS2155-304	0724	0158960101	S001	Small Window	Thick	18537	24	460046
3C273	0735	0112771101	S001	Small Window	Thin	5739	42	244950
3C273	0835	0136550801	S019	Small Window	Medium	12524	33	413443
H1426+428	0852	0165770101	S001	Small Window	Thin	40783	17	710113
H1426+428	0853	0165770201	S001	Small Window	Medium	43370	16	726865
PKS2155-304	0908	0158961001	S013	Small Window	Thick	19413	36	709706
PKS2155-304	0908	0158960901	S001	Small Window	Thick	18991	27	525538
H1426+428	0939	0212090201	S001	Small Window	Medium	20276	21	430717
PKS2155-304	0993	0158961101	S001	Small Window	Medium	9338	39	365546
H1426+428	1012	0310190101	S003	Small Window	Medium	24691	30	765203
H1426+428	1015	0310190201	S003	Small Window	Medium	20715	24	507230
3C273	1023	0136551001	S003	Small Window	Medium	19272	37	714114
H1426+428	1035	0310190501	S003	Small Window	Medium	25425	23	607692
PKS2155-304	1095	0158961301	S001	Small Window	Medium	35824	44	1602348
PKS2155-304	1171	0158961401	S001	Small Window	Medium	43513	30	1339927
PKS2155-304	1266	0411780101	S001	Small Window	Thin	20868	32	683532
3C273	1299	0414190101	S003	Small Window	Medium	45315	30	1370739
PKS2155-304	1349	0411780201	S001	Small Window	Medium	33166	41	1387904
3C273	1381	0414190301	S003	Small Window	Medium	22175	33	745294
3C273	1465	0414190401	S003	Small Window	Medium	24723	51	1280245
PKS2155-304	1543	0411780301	S001	Small Window	Medium	42536	49	2100942
3C273	1649	0414190501	S003	Small Window	Thin	26484	37	993131
PKS2155-304	1734	0411780401	S001	Small Window	Medium	37186	35	1329354
3C273	1837	0414190601	S003	Small Window	Thin	21979	40	891853

Table 3: Joint Fit details

Target	Revolution	Obsid	XCAL Model	Model Parameters					Red. χ^2
PKS2155-304	0087	0124930101	TBabs*bknpower	0.012	2.556	2.008	2.681	0.040	1.64
PKS2155-304	0087	0124930201	TBabs*bknpower	0.012	2.519	2.120	2.594	0.040	1.77
3C273	0094	0126700301	TBabs(powerlaw+powerlaw)	0.018	1.613	0.018	3.217	0.003	1.33
3C273	0095	0126700701	TBabs(powerlaw+powerlaw)	0.018	1.600	0.016	3.326	0.003	1.23
3C273	0095	0126700601	TBabs(powerlaw+powerlaw)	0.018	1.582	0.016	3.219	0.003	1.27
3C273	0096	0126700801	TBabs(powerlaw+powerlaw)	0.018	1.574	0.016	3.290	0.003	1.23
PKS2155-304	0174	0080940301	TBabs*bknpower	0.012	2.700	1.373	2.859	0.027	2.06
PKS2155-304	0174	0080940101	TBabs*bknpower	0.012	2.614	1.304	2.795	0.034	2.23
3C273	0277	0136550101	TBabs(powerlaw+powerlaw)	0.018	1.550	0.018	3.053	0.008	1.24
H1426+428	0278	0111850201	TBabs*bknpower	0.014	2.055	0.533	1.800	0.007	1.11
3C273	0370	0112770101	TBabs(powerlaw+powerlaw)	0.018	1.604	0.024	2.899	0.007	1.16
3C273	0373	0112770201	TBabs(powerlaw+powerlaw)	0.018	1.615	0.026	3.127	0.004	1.24
3C273	0472	0112770601	TBabs(powerlaw+powerlaw)	0.018	1.697	0.020	3.196	0.003	1.11
3C273	0554	0112770801	TBabs(powerlaw+powerlaw)	0.018	1.724	0.027	3.026	0.007	1.18
3C273	0563	0136550501	TBabs(powerlaw+powerlaw)	0.018	1.719	0.022	3.169	0.006	1.09
3C273	0563	0112770701	TBabs(powerlaw+powerlaw)	0.018	1.694	0.020	2.943	0.008	1.35
3C273	0645	0112771001	TBabs(powerlaw+powerlaw)	0.018	1.717	0.029	3.208	0.006	1.31
3C273	0655	0112770501	TBabs(powerlaw+powerlaw)	0.018	1.775	0.026	2.956	0.005	1.30
3C273	0655	0159960101	TBabs(powerlaw+powerlaw)	0.018	1.750	0.026	2.976	0.005	1.35
PKS2155-304	0724	0158960101	TBabs*bknpower	0.012	2.796	1.431	2.898	0.017	1.23
3C273	0735	0112771101	TBabs(powerlaw+powerlaw)	0.018	1.662	0.019	3.210	0.004	1.22
3C273	0835	0136550801	TBabs(powerlaw+powerlaw)	0.018	1.707	0.017	3.345	0.002	1.13
H1426+428	0852	0165770101	TBabs*bknpower	0.014	1.925	1.404	2.183	0.010	1.11
H1426+428	0853	0165770201	TBabs*bknpower	0.014	1.946	1.451	2.199	0.011	1.17
PKS2155-304	0908	0158961001	TBabs*bknpower	0.012	2.641	1.073	2.884	0.027	1.49
PKS2155-304	0908	0158960901	TBabs*bknpower	0.012	2.756	1.077	3.001	0.019	1.36
H1426+428	0939	0212090201	TBabs*bknpower	0.014	1.961	1.452	2.238	0.014	1.13
PKS2155-304	0993	0158961101	TBabs*bknpower	0.012	2.584	1.405	2.625	0.034	1.35
H1426+428	1012	0310190101	TBabs*bknpower	0.014	1.905	1.528	2.026	0.019	1.11
H1426+428	1015	0310190201	TBabs*bknpower	0.014	1.969	1.542	2.174	0.015	1.18
3C273	1023	0136551001	TBabs(powerlaw+powerlaw)	0.018	1.538	0.016	3.030	0.005	1.20
H1426+428	1035	0310190501	TBabs*bknpower	0.014	2.037	1.430	2.300	0.015	1.16
PKS2155-304	1095	0158961301	TBabs*bknpower	0.012	2.647	2.094	2.683	0.037	2.27
PKS2155-304	1171	0158961401	TBabs*bknpower	0.012	2.901	0.412	2.580	0.011	1.45
PKS2155-304	1266	0411780101	TBabs*bknpower	0.012	2.847	0.434	2.528	0.015	1.19
3C273	1299	0414190101	TBabs(powerlaw+powerlaw)	0.018	1.394	0.020	3.135	0.003	1.40
PKS2155-304	1349	0411780201	TBabs*bknpower	0.012	2.866	0.406	2.671	0.029	1.97
3C273	1381	0414190301	TBabs(powerlaw+powerlaw)	0.018	1.550	0.017	3.159	0.002	1.23
3C273	1465	0414190401	TBabs(powerlaw+powerlaw)	0.018	1.579	0.032	3.147	0.007	1.36
PKS2155-304	1543	0411780301	TBabs*bknpower	0.012	2.575	1.519	2.669	0.044	2.13
3C273	1649	0414190501	TBabs(powerlaw+powerlaw)	0.018	1.475	0.021	3.114	0.005	1.34
PKS2155-304	1734	0411780401	TBabs*bknpower	0.012	2.787	1.500	2.889	0.029	1.89
3C273	1837	0414190601	TBabs(powerlaw+powerlaw)	0.018	1.473	0.022	2.971	0.007	1.30

Table 4: After-rectification Joint Fit details

Target	Revolution	Obsid	XCAL Model	Model Parameters					Red. χ^2
PKS2155-304	0087	0124930101	TBabs*bknpower	0.012	2.561	1.984	2.681	0.039	1.19
PKS2155-304	0087	0124930201	TBabs*bknpower	0.012	2.521	1.922	2.603	0.039	1.22
3C273	0094	0126700301	TBabs(powerlaw+powerlaw)	0.018	1.591	0.017	3.032	0.004	1.10
3C273	0095	0126700701	TBabs(powerlaw+powerlaw)	0.018	1.574	0.015	3.123	0.003	1.02
3C273	0095	0126700601	TBabs(powerlaw+powerlaw)	0.018	1.545	0.015	2.996	0.004	1.06
3C273	0096	0126700801	TBabs(powerlaw+powerlaw)	0.018	1.556	0.015	3.133	0.004	1.04
PKS2155-304	0174	0080940301	TBabs*bknpower	0.012	2.716	1.370	2.860	0.026	1.27
PKS2155-304	0174	0080940101	TBabs*bknpower	0.012	2.657	1.437	2.813	0.033	1.41
3C273	0277	0136550101	TBabs(powerlaw+powerlaw)	0.018	1.531	0.017	3.006	0.008	1.07
H1426+428	0278	0111850201	TBabs*bknpower	0.014	2.052	0.567	1.809	0.007	1.04
3C273	0370	0112770101	TBabs(powerlaw+powerlaw)	0.018	1.546	0.021	2.750	0.010	1.02
3C273	0373	0112770201	TBabs(powerlaw+powerlaw)	0.018	1.584	0.023	2.977	0.006	1.09
3C273	0472	0112770601	TBabs(powerlaw+powerlaw)	0.018	1.667	0.018	3.000	0.004	1.04
3C273	0554	0112770801	TBabs(powerlaw+powerlaw)	0.018	1.683	0.024	2.867	0.009	1.06
3C273	0563	0136550501	TBabs(powerlaw+powerlaw)	0.018	1.683	0.020	3.032	0.008	1.03
3C273	0563	0112770701	TBabs(powerlaw+powerlaw)	0.018	1.640	0.017	2.829	0.010	1.06
3C273	0645	0112771001	TBabs(powerlaw+powerlaw)	0.018	1.706	0.027	3.120	0.007	1.06
3C273	0655	0112770501	TBabs(powerlaw+powerlaw)	0.018	1.746	0.023	2.833	0.007	1.06
3C273	0655	0159960101	TBabs(powerlaw+powerlaw)	0.018	1.711	0.023	2.796	0.008	1.14
PKS2155-304	0724	0158960101	TBabs*bknpower	0.012	2.780	0.804	2.876	0.018	1.06
3C273	0735	0112771101	TBabs(powerlaw+powerlaw)	0.018	1.629	0.017	3.060	0.005	1.13
3C273	0835	0136550801	TBabs(powerlaw+powerlaw)	0.018	1.677	0.015	3.135	0.003	1.04
H1426+428	0852	0165770101	TBabs*bknpower	0.014	1.937	1.340	2.182	0.010	1.01
H1426+428	0853	0165770201	TBabs*bknpower	0.014	1.965	1.391	2.200	0.011	1.03
PKS2155-304	0908	0158961001	TBabs*bknpower	0.012	2.649	0.935	2.882	0.027	1.04
PKS2155-304	0908	0158960901	TBabs*bknpower	0.012	2.748	0.820	2.986	0.020	1.03
H1426+428	0939	0212090201	TBabs*bknpower	0.014	1.981	1.446	2.238	0.013	1.04
PKS2155-304	0993	0158961101	TBabs*bknpower	0.012	2.612	0.150	2.613	0.034	1.07
H1426+428	1012	0310190101	TBabs*bknpower	0.014	1.918	1.429	2.023	0.019	1.01
H1426+428	1015	0310190201	TBabs*bknpower	0.014	1.992	1.636	2.189	0.015	1.07
3C273	1023	0136551001	TBabs(powerlaw+powerlaw)	0.018	1.507	0.015	2.926	0.006	1.04
H1426+428	1035	0310190501	TBabs*bknpower	0.014	2.059	1.428	2.305	0.015	1.04
PKS2155-304	1095	0158961301	TBabs*bknpower	0.012	2.673	16.895	2.722	0.038	1.67
PKS2155-304	1171	0158961401	TBabs*bknpower	0.012	2.892	0.396	2.602	0.011	1.08
PKS2155-304	1266	0411780101	TBabs*bknpower	0.012	3.014	0.346	2.558	0.012	1.04
3C273	1299	0414190101	TBabs(powerlaw+powerlaw)	0.018	1.360	0.018	2.918	0.005	1.11
PKS2155-304	1349	0411780201	TBabs*bknpower	0.012	2.899	0.339	2.700	0.029	1.14
3C273	1381	0414190301	TBabs(powerlaw+powerlaw)	0.018	1.514	0.016	2.893	0.004	1.03
3C273	1465	0414190401	TBabs(powerlaw+powerlaw)	0.018	1.539	0.029	2.948	0.010	1.09
PKS2155-304	1543	0411780301	TBabs*bknpower	0.012	2.596	1.468	2.681	0.045	1.15
3C273	1649	0414190501	TBabs(powerlaw+powerlaw)	0.018	1.440	0.019	2.906	0.007	1.05
PKS2155-304	1734	0411780401	TBabs*bknpower	0.012	2.817	1.211	2.887	0.029	1.09
3C273	1837	0414190601	TBabs(powerlaw+powerlaw)	0.018	1.421	0.019	2.775	0.010	1.04

11 RGS 1

11.1 Summary of results

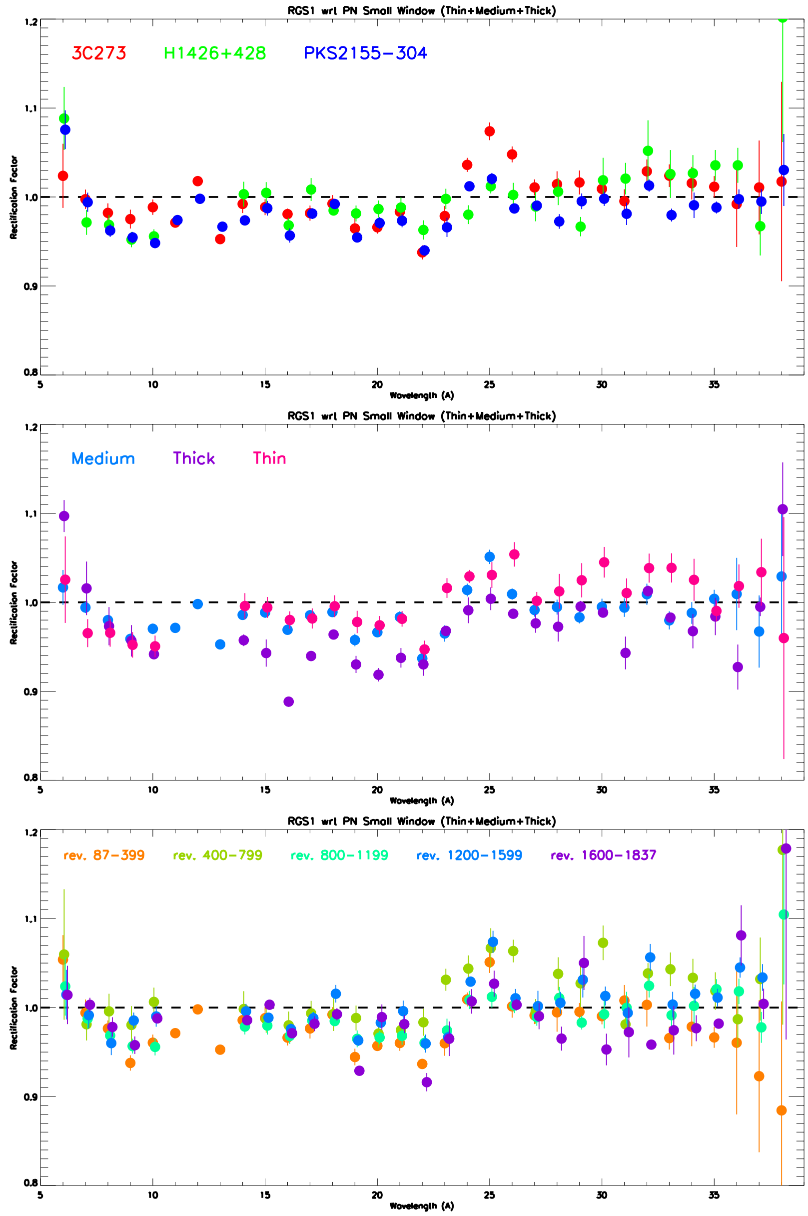


Figure 2: Summary of the results for RGS 1. From top to bottom, rectification factor by object, by filter, and by epoch.

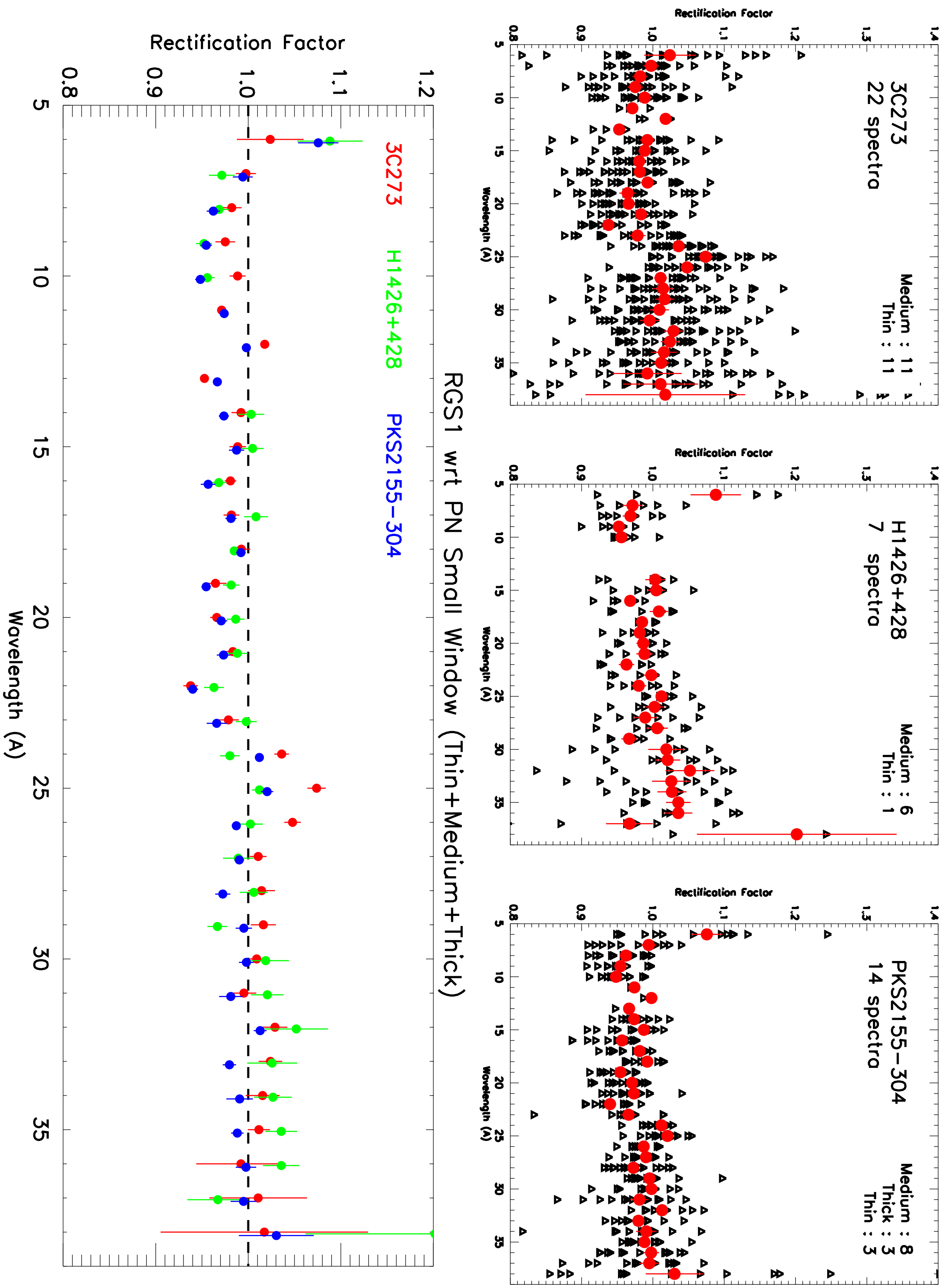


Figure 3: RGS 1 rectification factors for the selected objects. In the top panels black symbols represent individual observations, and red points the average. The bottom panel shows the average factors for all the objects.

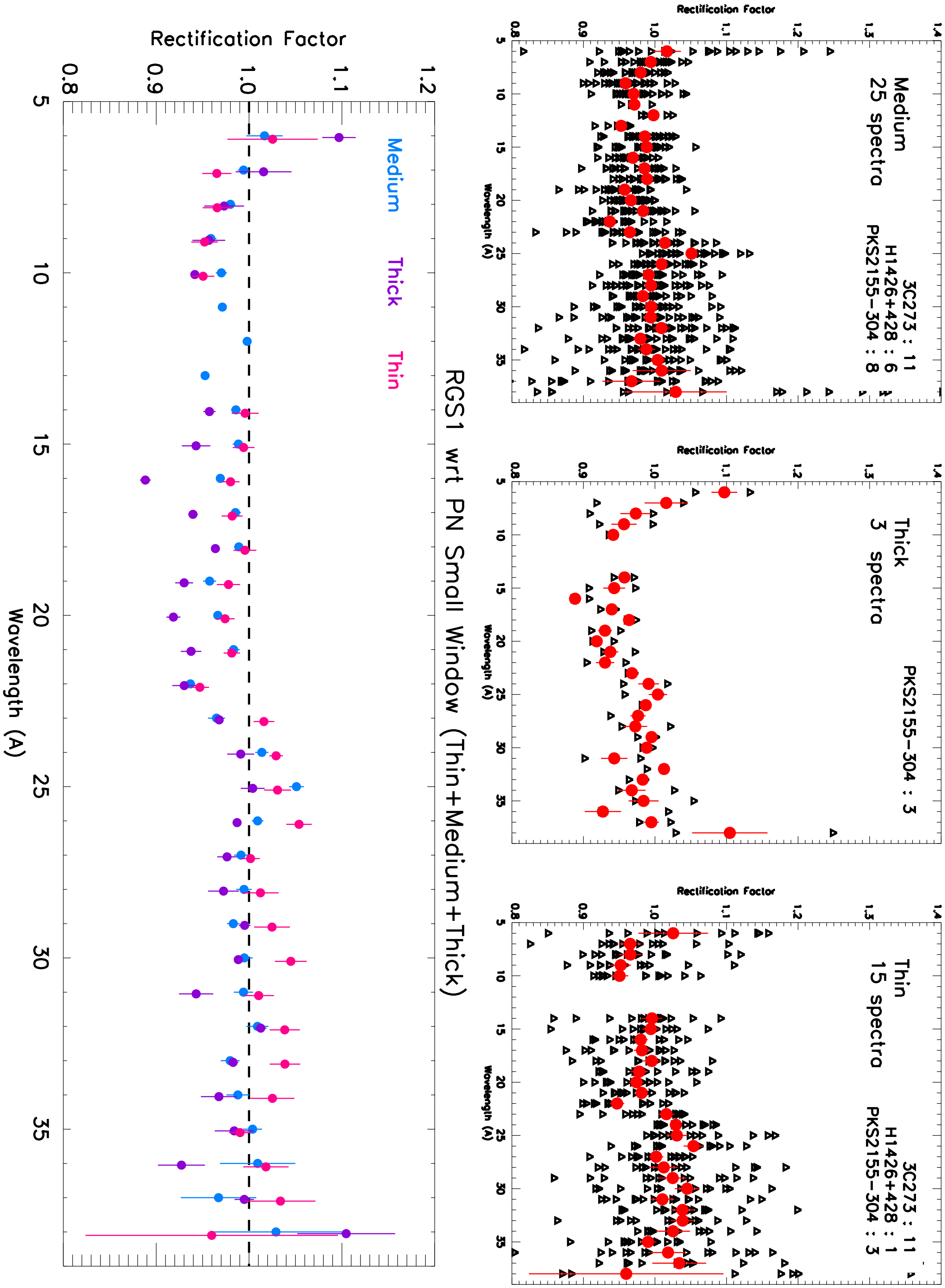


Figure 4: RGS 1 rectification factors according to the PN filter. In the top panels, black symbols represent individual observations, and red points the average. The bottom panel shows the average factors for the different filters.

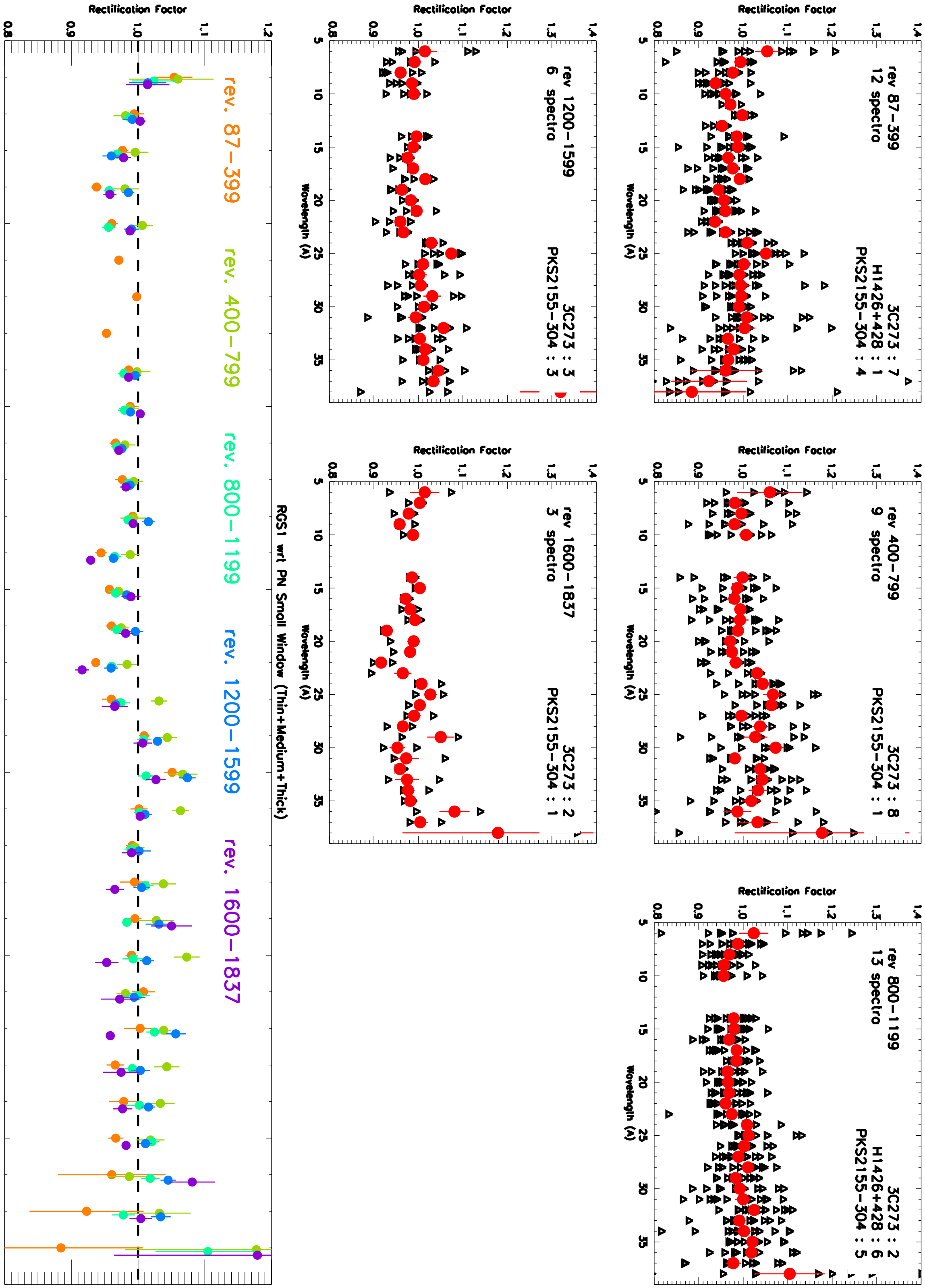
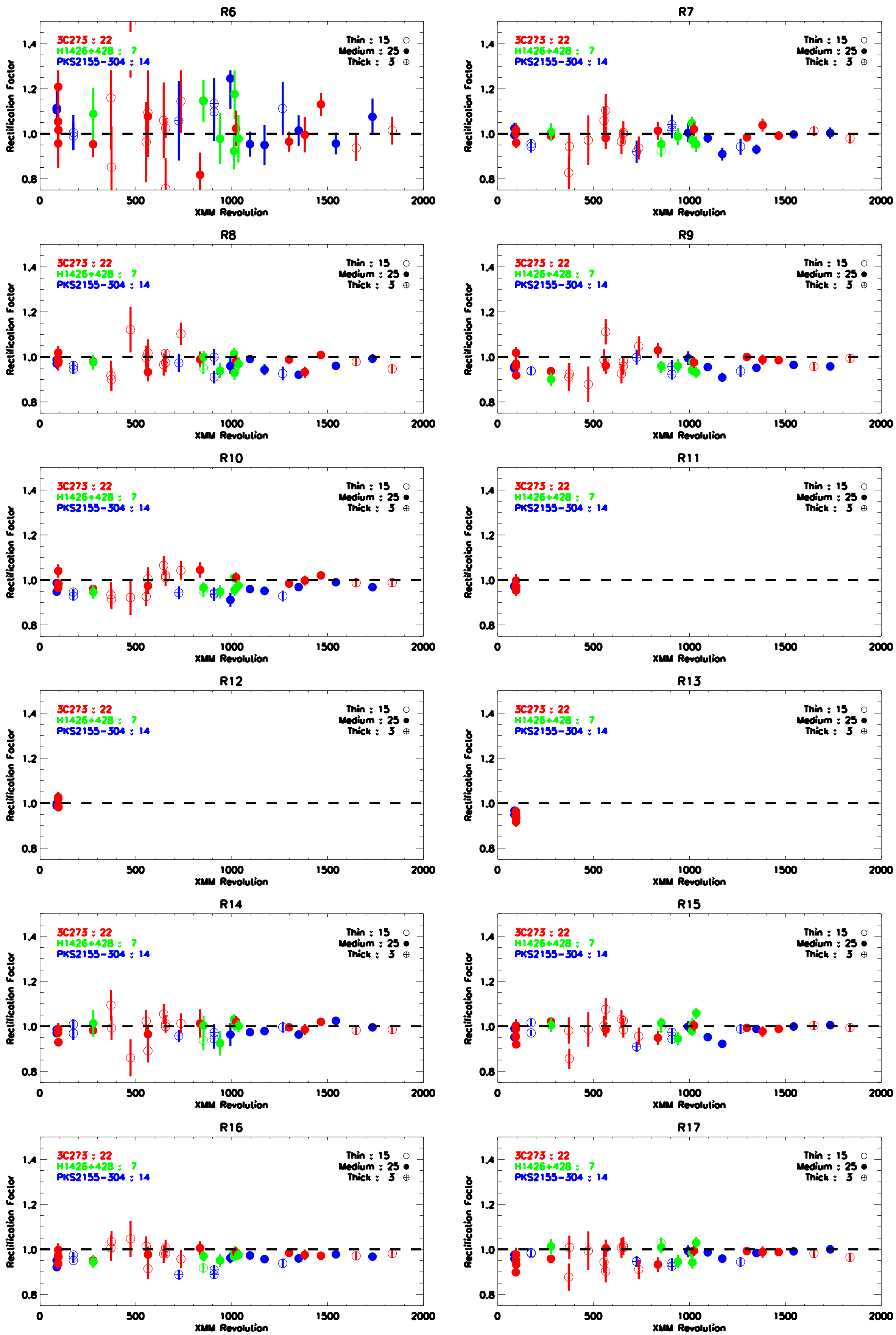
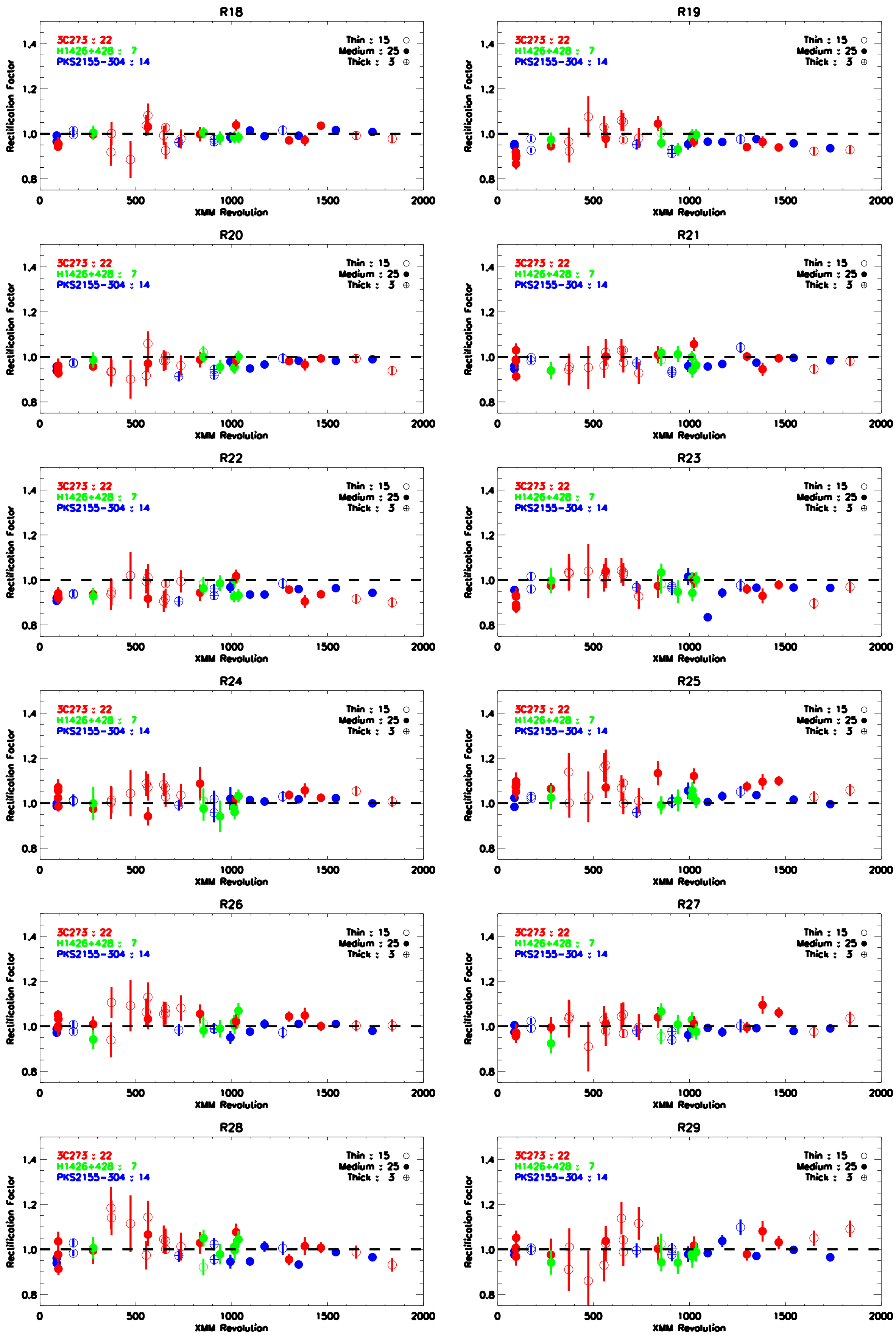


Figure 5: RGS 1 rectification factors according to the date of the observation, in groups of 400 revolutions. In the top panels, black symbols represent individual observations, and red points the average. The bottom panel shows the comparison of the different epochs.


R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
3C273 : 22
H1426+428 : 7
PKS2155-304 : 14
Thin : 15
Medium : 25
Thick : 3
Rectification Factor
XMM Revolution
0
500
1000
1500
2000
0.8
1.0
1.2
1.4


R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
3C273 : 22
H1426+428 : 7
PKS2155-304 : 14
Thin : 15
Medium : 25
Thick : 3
Rectification Factor
XMM Revolution

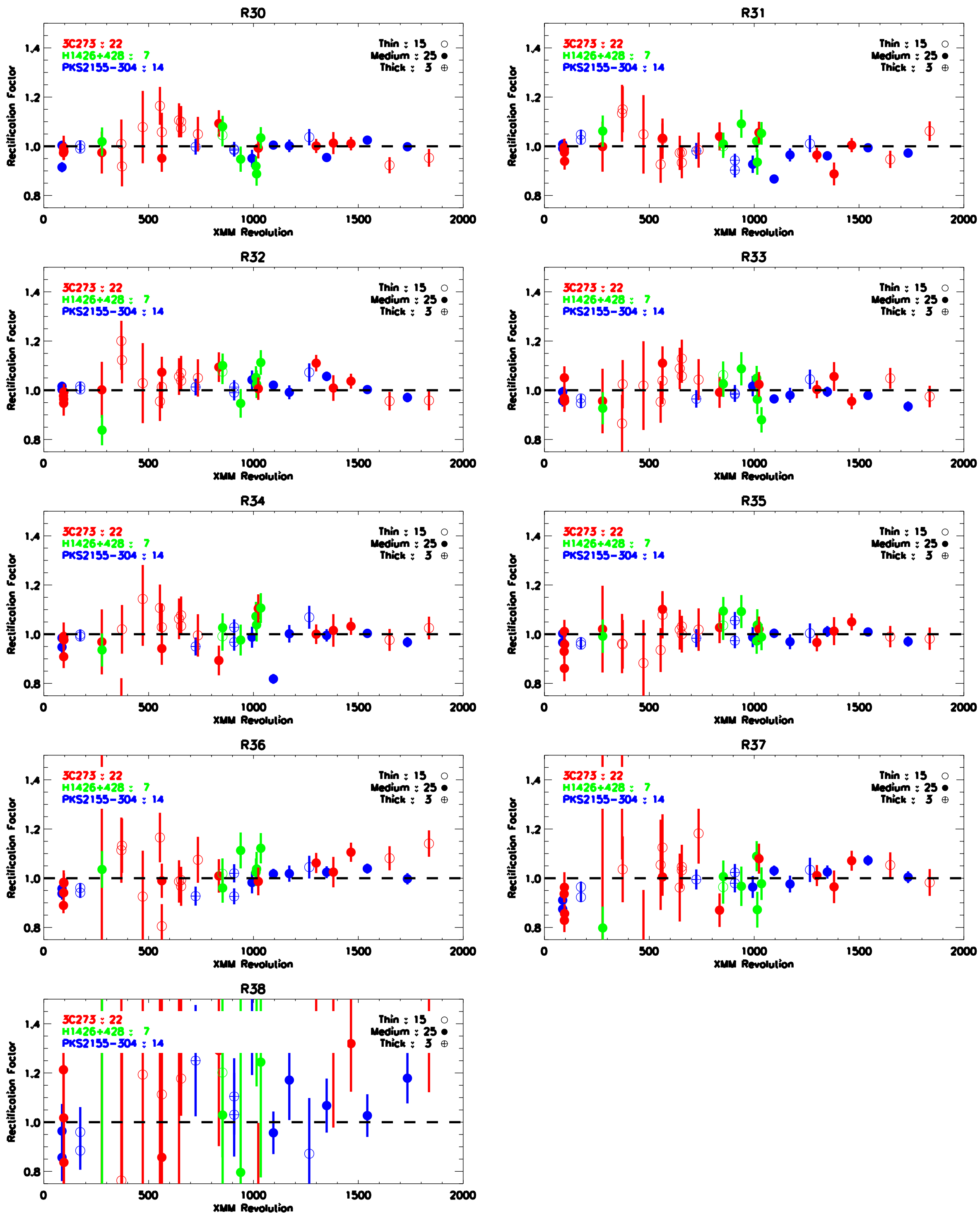


Figure 6: Time evolution of the individual RGS 1 rectification factors.

Table 5: RGS 1 Rectification Factors by Target

Wavelength	3C273	H1426+428	PKS2155-304
6	1.024±0.036	1.088±0.035	1.076±0.022
7	0.997±0.011	0.971±0.014	0.994±0.011
8	0.982±0.011	0.969±0.011	0.962±0.007
9	0.975±0.011	0.952±0.009	0.955±0.006
10	0.989±0.009	0.956±0.008	0.948±0.006
11	0.971±0.003	0.000±0.000	0.974±0.001
12	1.018±0.004	0.000±0.000	0.998±0.001
13	0.953±0.004	0.000±0.000	0.967±0.002
14	0.992±0.010	1.003±0.014	0.974±0.006
15	0.989±0.009	1.005±0.012	0.987±0.008
16	0.981±0.006	0.968±0.008	0.957±0.008
17	0.982±0.009	1.008±0.013	0.981±0.006
18	0.993±0.010	0.985±0.004	0.992±0.005
19	0.965±0.012	0.981±0.009	0.955±0.005
20	0.966±0.007	0.986±0.010	0.971±0.007
21	0.983±0.008	0.988±0.011	0.973±0.007
22	0.938±0.008	0.963±0.011	0.940±0.006
23	0.979±0.011	0.998±0.011	0.966±0.011
24	1.036±0.008	0.980±0.011	1.012±0.005
25	1.074±0.010	1.012±0.008	1.020±0.007
26	1.048±0.009	1.002±0.014	0.987±0.005
27	1.011±0.009	0.989±0.017	0.990±0.005
28	1.014±0.015	1.006±0.015	0.972±0.008
29	1.016±0.013	0.967±0.011	0.995±0.009
30	1.009±0.013	1.019±0.025	0.998±0.008
31	0.995±0.013	1.021±0.018	0.981±0.013
32	1.029±0.013	1.052±0.034	1.013±0.007
33	1.024±0.013	1.026±0.027	0.980±0.007
34	1.016±0.018	1.027±0.020	0.991±0.014
35	1.012±0.012	1.036±0.017	0.988±0.007
36	0.992±0.048	1.036±0.020	0.998±0.011
37	1.011±0.053	0.967±0.033	0.995±0.014
38	1.017±0.112	1.202±0.140	1.030±0.040

Table 6: RGS 1 Rectification Factors by Filter

Wavelength	Medium	Thick	Thin
6	1.017±0.020	1.097±0.018	1.025±0.049
7	0.994±0.006	1.016±0.030	0.965±0.016
8	0.980±0.005	0.973±0.021	0.966±0.016
9	0.959±0.006	0.957±0.018	0.952±0.014
10	0.970±0.006	0.942±0.001	0.951±0.012
11	0.971±0.003	0.000±0.000	0.000±0.000
12	0.998±0.003	0.000±0.000	0.000±0.000
13	0.953±0.003	0.000±0.000	0.000±0.000
14	0.986±0.005	0.957±0.007	0.996±0.015
15	0.989±0.006	0.943±0.015	0.994±0.012
16	0.969±0.004	0.888±0.006	0.980±0.010
17	0.985±0.006	0.940±0.005	0.982±0.011
18	0.989±0.005	0.964±0.003	0.996±0.012
19	0.958±0.007	0.930±0.010	0.978±0.013
20	0.966±0.004	0.919±0.008	0.974±0.010
21	0.983±0.007	0.938±0.011	0.981±0.009
22	0.937±0.005	0.930±0.013	0.947±0.010
23	0.965±0.009	0.968±0.002	1.016±0.011
24	1.014±0.007	0.991±0.015	1.029±0.007
25	1.051±0.008	1.004±0.013	1.031±0.015
26	1.009±0.006	0.987±0.002	1.054±0.014
27	0.991±0.007	0.976±0.011	1.002±0.010
28	0.995±0.008	0.972±0.017	1.012±0.020
29	0.983±0.007	0.995±0.006	1.025±0.019
30	0.995±0.009	0.988±0.003	1.045±0.017
31	0.994±0.010	0.943±0.018	1.010±0.016
32	1.009±0.012	1.013±0.006	1.038±0.016
33	0.980±0.010	0.983±0.006	1.039±0.016
34	0.988±0.012	0.968±0.019	1.025±0.024
35	1.004±0.010	0.984±0.021	0.990±0.012
36	1.009±0.041	0.927±0.025	1.018±0.024
37	0.967±0.041	0.995±0.010	1.034±0.038
38	1.029±0.071	1.105±0.053	0.960±0.136

Table 7: RGS 1 Rectification Factors by Range of Revolutions

Wavelength	87-399	400-799	800-1199	1200-1599	1600-1837
6	1.054±0.028	1.060±0.073	1.024±0.033	1.015±0.028	1.014±0.033
7	0.994±0.015	0.981±0.018	0.988±0.011	0.991±0.015	1.003±0.008
8	0.977±0.009	0.996±0.020	0.969±0.008	0.960±0.013	0.978±0.011
9	0.938±0.009	0.980±0.021	0.957±0.008	0.985±0.009	0.958±0.010
10	0.961±0.009	1.006±0.016	0.956±0.010	0.990±0.012	0.988±0.005
11	0.971±0.004	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
12	0.998±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
13	0.953±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
14	0.986±0.011	0.998±0.020	0.979±0.009	0.996±0.008	0.986±0.003
15	0.988±0.013	0.987±0.015	0.980±0.010	0.989±0.003	1.003±0.003
16	0.966±0.009	0.980±0.015	0.968±0.009	0.976±0.006	0.971±0.003
17	0.976±0.011	0.994±0.014	0.985±0.010	0.988±0.007	0.982±0.008
18	0.992±0.008	0.993±0.019	0.985±0.005	1.016±0.010	0.993±0.007
19	0.944±0.009	0.988±0.014	0.965±0.009	0.963±0.006	0.929±0.003
20	0.957±0.005	0.971±0.016	0.966±0.008	0.983±0.004	0.989±0.014
21	0.960±0.009	0.975±0.011	0.968±0.010	0.996±0.012	0.981±0.010
22	0.937±0.003	0.983±0.015	0.960±0.008	0.960±0.010	0.916±0.010
23	0.960±0.014	1.031±0.012	0.974±0.013	0.966±0.007	0.965±0.019
24	1.009±0.008	1.044±0.015	1.009±0.010	1.029±0.005	1.007±0.014
25	1.051±0.012	1.067±0.022	1.012±0.012	1.074±0.012	1.027±0.015
26	1.001±0.013	1.064±0.013	1.002±0.009	1.010±0.010	1.003±0.006
27	0.991±0.010	0.996±0.014	0.989±0.010	1.002±0.017	0.990±0.015
28	0.995±0.022	1.038±0.019	1.011±0.013	1.005±0.012	0.965±0.013
29	0.995±0.010	1.027±0.027	0.983±0.008	1.031±0.020	1.050±0.030
30	0.990±0.009	1.073±0.019	0.992±0.016	1.013±0.011	0.953±0.018
31	1.008±0.017	0.981±0.013	1.000±0.018	0.994±0.017	0.972±0.028
32	1.003±0.024	1.038±0.012	1.024±0.013	1.056±0.015	0.958±0.004
33	0.966±0.013	1.043±0.019	0.991±0.014	1.003±0.014	0.975±0.027
34	0.978±0.022	1.033±0.021	1.002±0.021	1.016±0.010	0.977±0.015
35	0.966±0.012	1.019±0.021	1.021±0.011	1.011±0.010	0.982±0.005
36	0.960±0.081	0.987±0.031	1.018±0.014	1.045±0.011	1.081±0.034
37	0.923±0.085	1.032±0.047	0.978±0.017	1.034±0.015	1.004±0.017
38	0.884±0.122	1.177±0.196	1.105±0.079	1.320±0.091	1.179±0.215

12 RGS 2

12.1 Summary of results

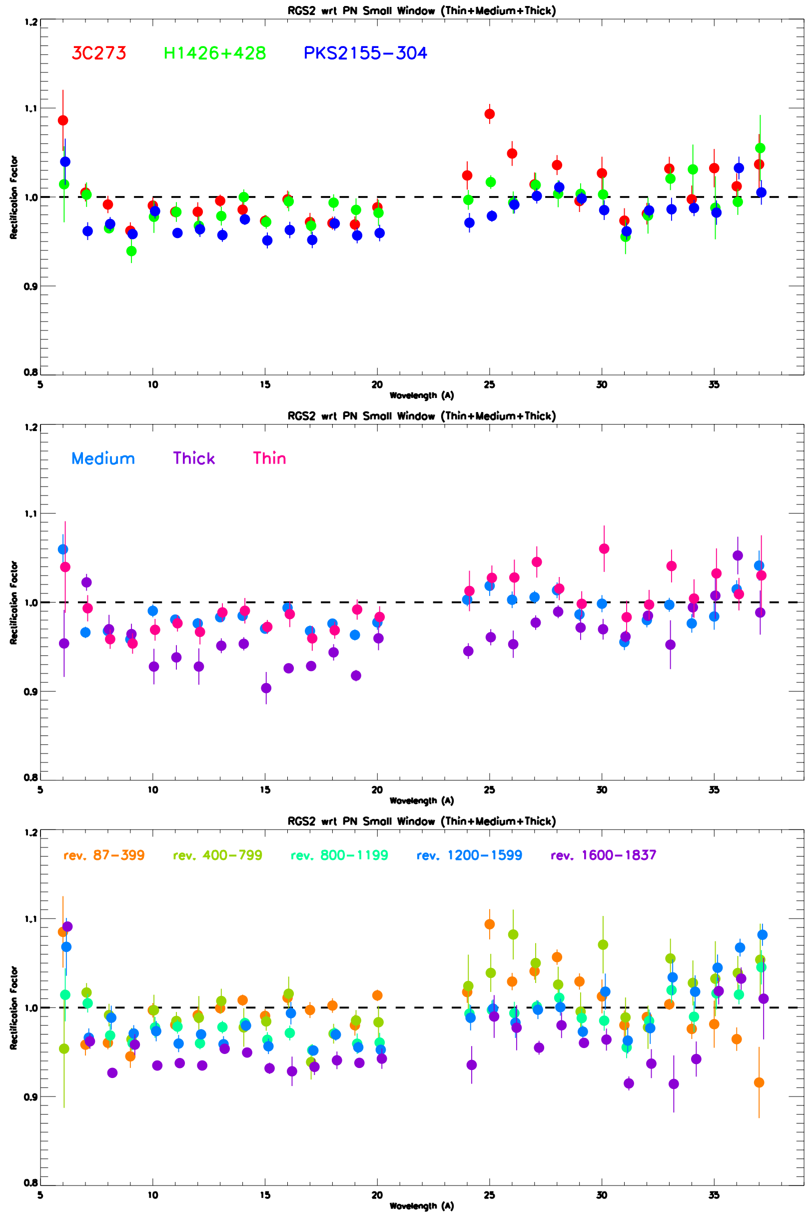


Figure 7: Summary of the results for RGS 2. From top to bottom, rectification factor by object, by filter, and by epoch.

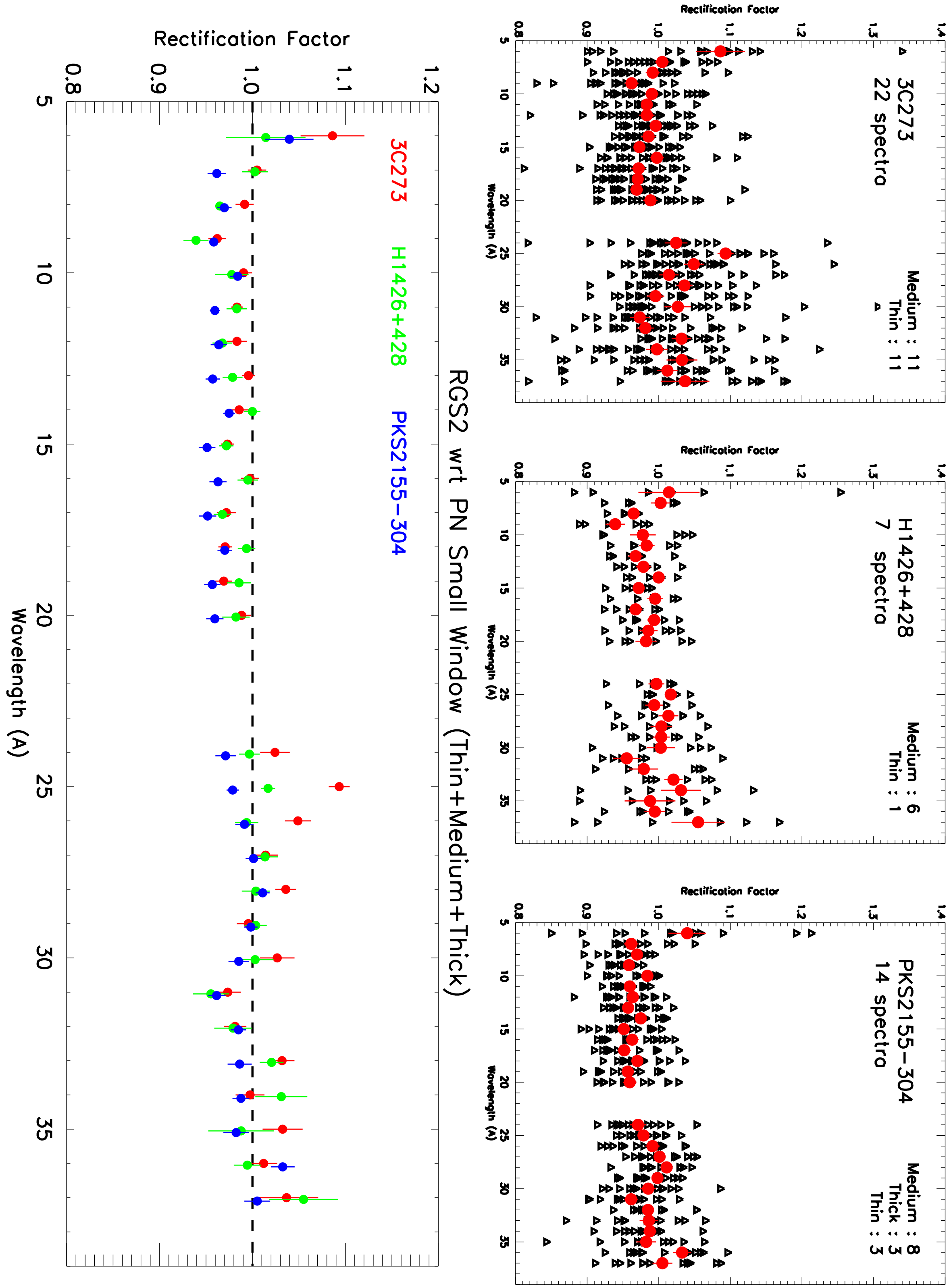


Figure 8: RGS 2 rectification factors for the selected objects. In the top panels, black symbols represent individual observations, and red points the average. The bottom panel shows the average factors for all the objects.

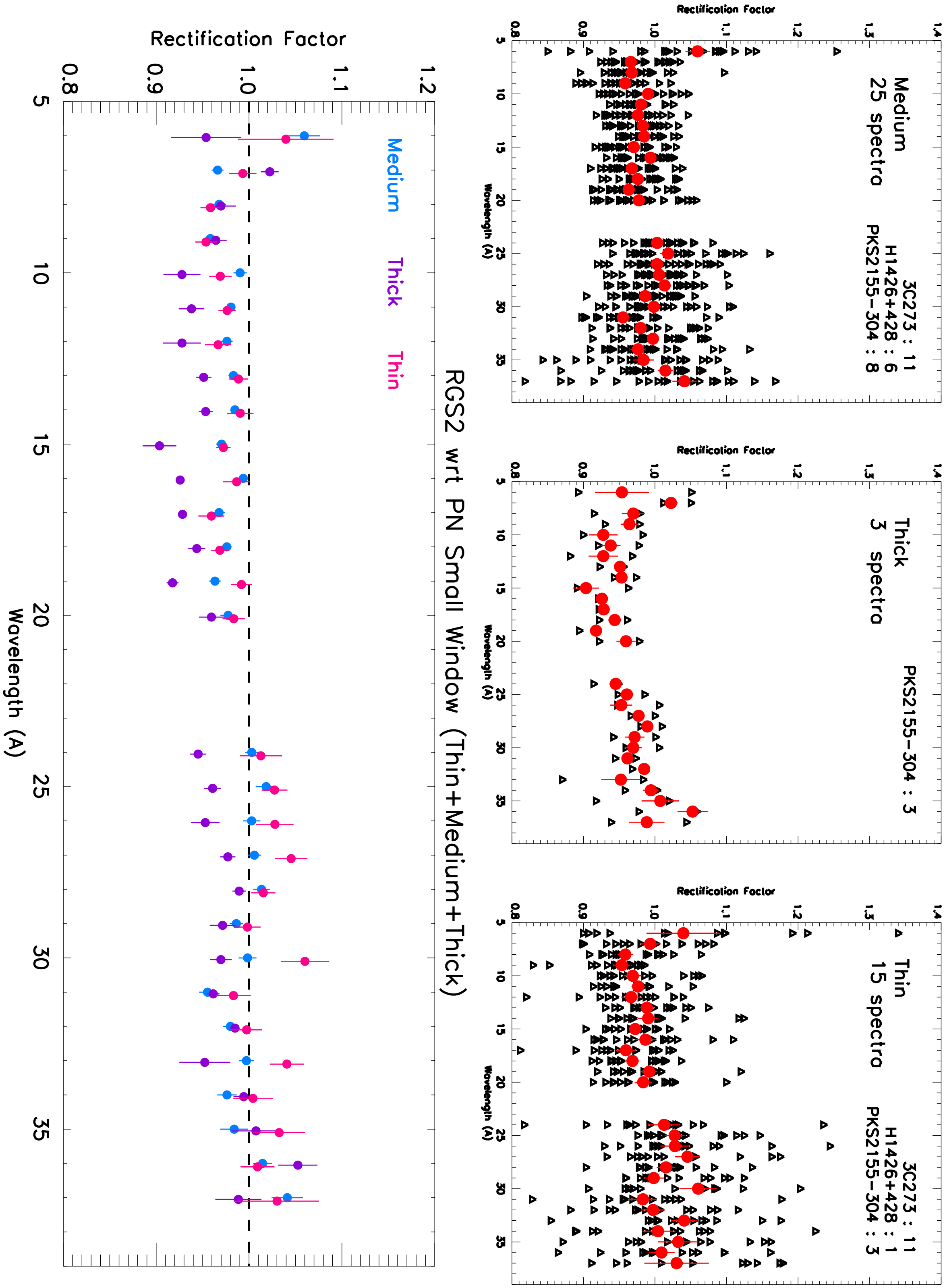


Figure 9: RGS 2 rectification factors according to the PN filter. In the top panels, black symbols represent individual observations, and red points the average. The bottom panel shows the average factors for the different filters.

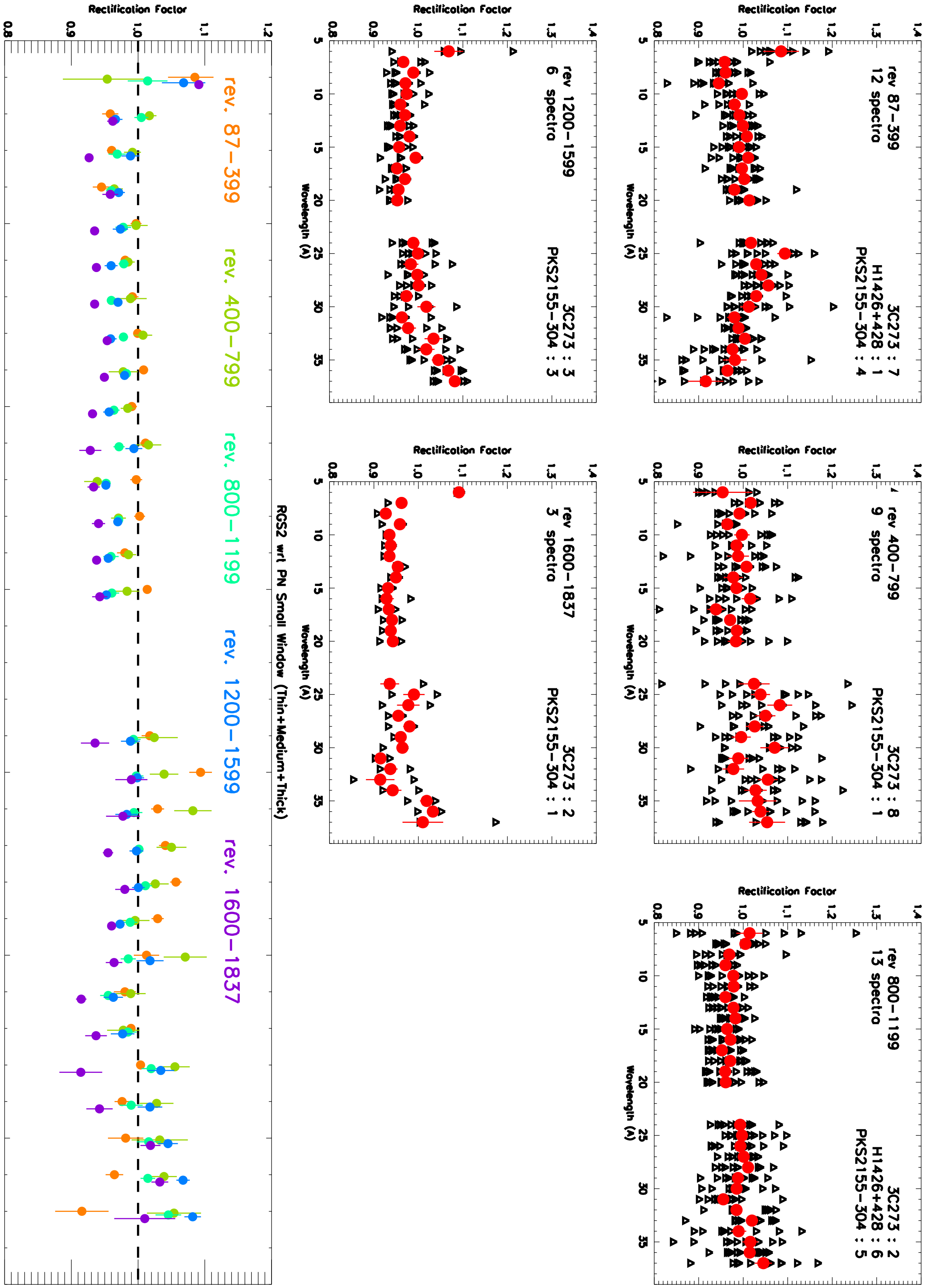
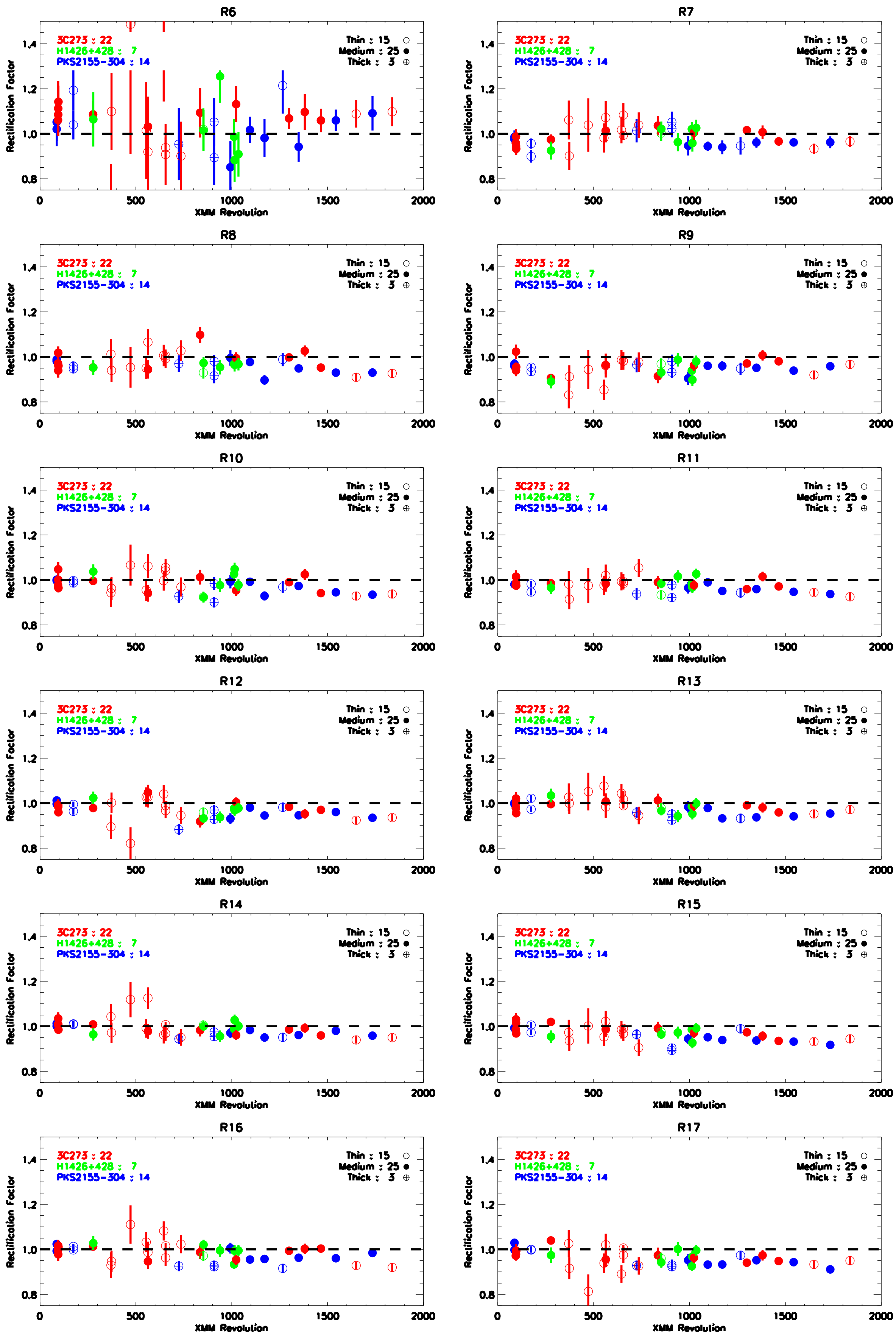
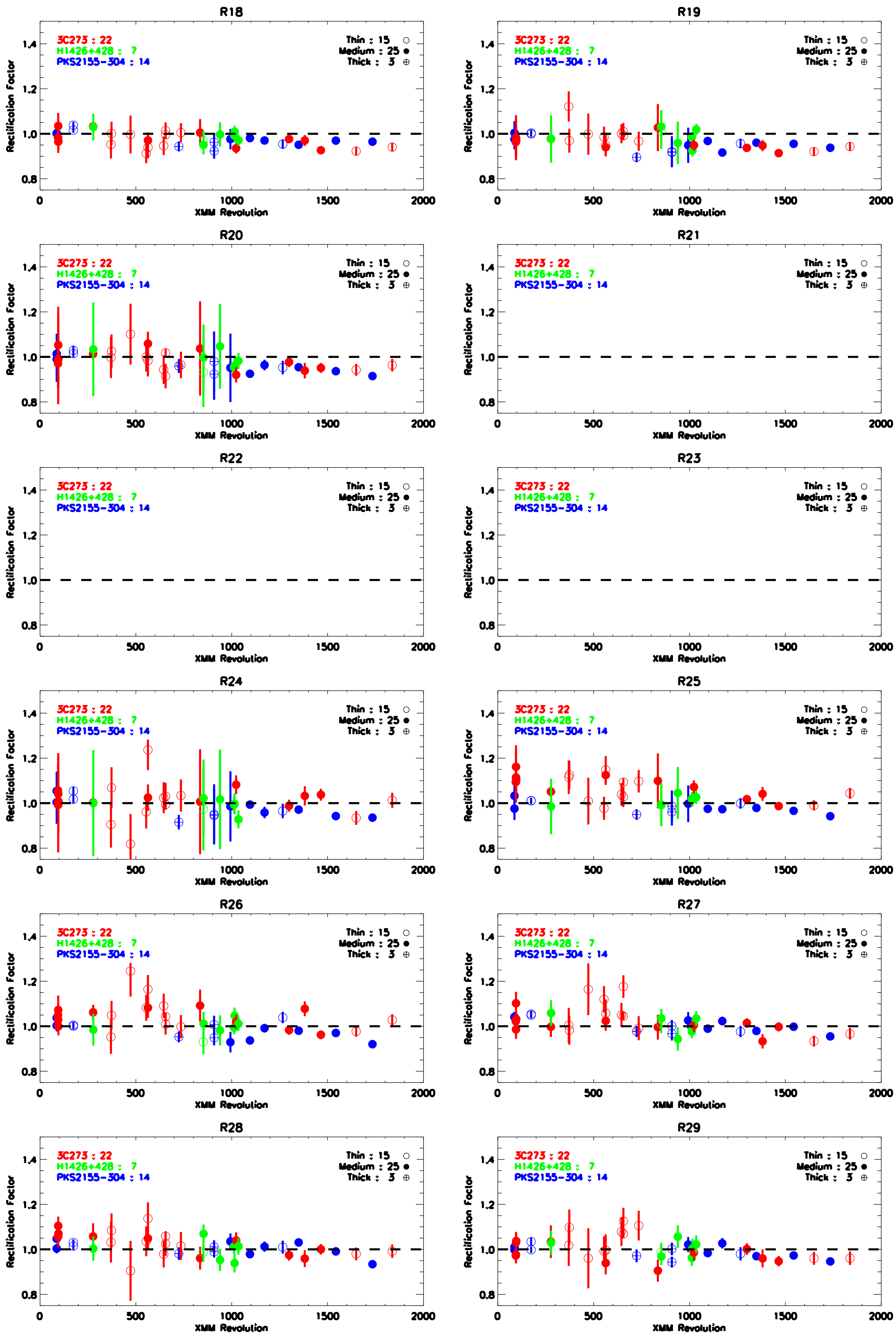


Figure 10: RGS 2 rectification factors according to the date of the observation, in groups of 400 revolutions. In the top panels, black symbols represent individual observations, and red points the average. The bottom panel shows the comparison of the different epochs.


R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
3C273 : 22
H1426+428 : 7
PKS2155-304 : 14
Thin : 15
Medium : 25
Thick : 3
Rectification Factor
XMM Revolution


R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
3C273 : 22
H1426+428 : 7
PKS2155-304 : 14
Thin : 15
Medium : 25
Thick : 3
Rectification Factor
XMM Revolution
0
500
1000
1500
2000
0.8
1.0
1.2
1.4

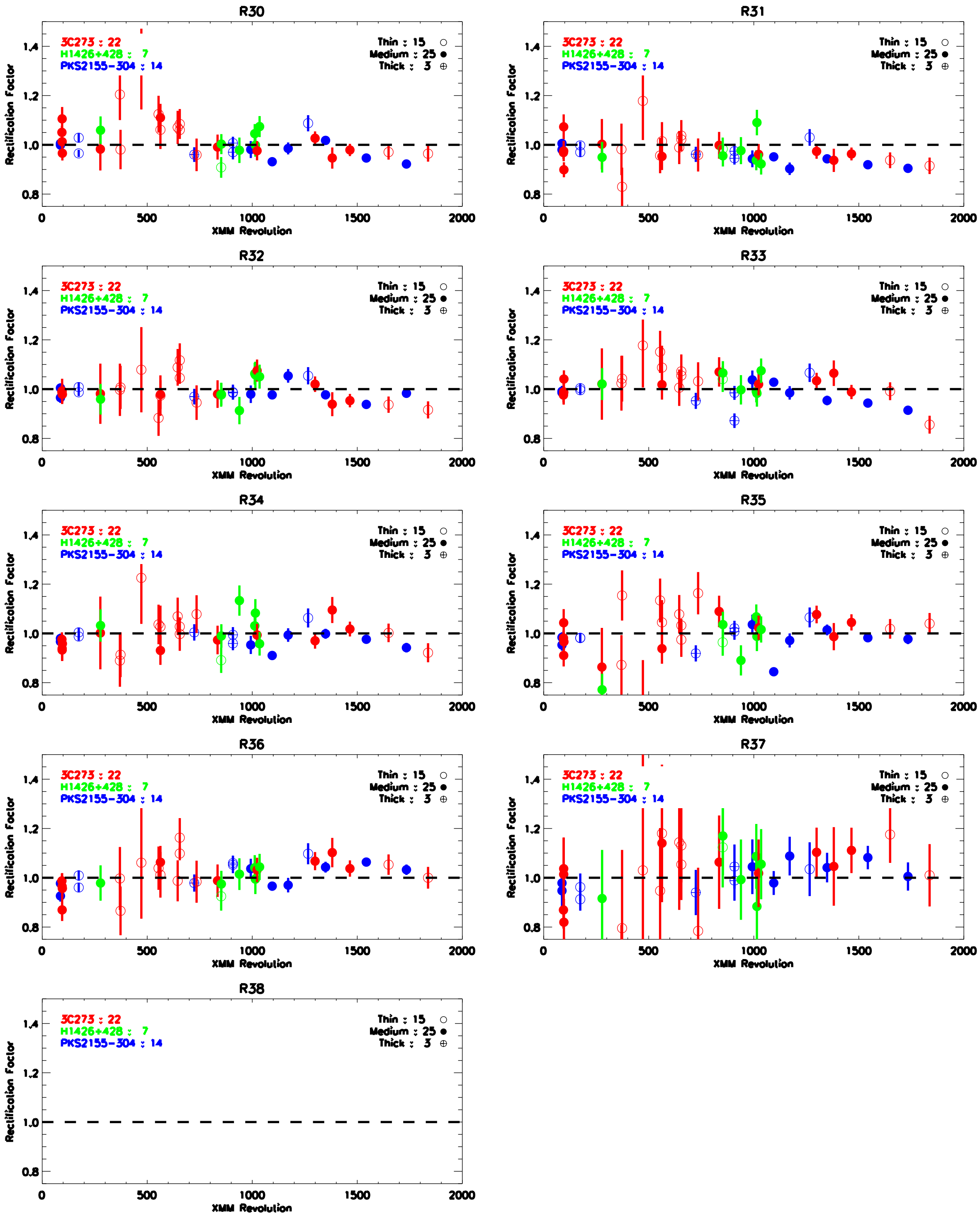


Figure 11: Time evolution of the individual RGS 2 rectification factors.

Table 8: RGS 2 Rectification Factors by Target

Wavelength	3C273	H1426+428	PKS2155-304
6	1.086±0.034	1.014±0.043	1.040±0.026
7	1.005±0.010	1.003±0.014	0.962±0.010
8	0.992±0.010	0.965±0.005	0.970±0.008
9	0.962±0.010	0.939±0.013	0.958±0.005
10	0.990±0.009	0.978±0.018	0.984±0.008
11	0.983±0.006	0.983±0.011	0.960±0.005
12	0.983±0.011	0.968±0.011	0.964±0.009
13	0.996±0.007	0.979±0.011	0.957±0.008
14	0.986±0.010	1.000±0.009	0.975±0.006
15	0.973±0.007	0.972±0.008	0.951±0.009
16	0.997±0.010	0.995±0.011	0.963±0.009
17	0.972±0.010	0.968±0.010	0.952±0.009
18	0.971±0.007	0.994±0.009	0.970±0.008
19	0.969±0.009	0.986±0.013	0.957±0.009
20	0.988±0.010	0.982±0.015	0.960±0.009
21	0.000±0.000	0.000±0.000	0.000±0.000
22	0.000±0.000	0.000±0.000	0.000±0.000
23	0.000±0.000	0.000±0.000	0.000±0.000
24	1.024±0.016	0.997±0.011	0.971±0.011
25	1.093±0.011	1.017±0.008	0.979±0.007
26	1.049±0.014	0.994±0.013	0.991±0.010
27	1.014±0.013	1.013±0.014	1.001±0.009
28	1.036±0.011	1.004±0.015	1.011±0.007
29	0.995±0.012	1.003±0.012	0.998±0.007
30	1.027±0.019	1.003±0.020	0.985±0.011
31	0.973±0.014	0.955±0.019	0.961±0.010
32	0.981±0.012	0.979±0.020	0.985±0.008
33	1.032±0.013	1.021±0.013	0.986±0.013
34	0.997±0.016	1.031±0.028	0.988±0.009
35	1.032±0.022	0.988±0.035	0.982±0.014
36	1.012±0.015	0.995±0.015	1.033±0.013
37	1.037±0.034	1.055±0.037	1.005±0.014
38	0.000±0.000	0.000±0.000	0.000±0.000

Table 9: RGS 2 Rectification Factors by Filter

Wavelength	Medium	Thick	Thin
6	1.060±0.017	0.954±0.038	1.040±0.051
7	0.966±0.006	1.022±0.009	0.993±0.015
8	0.968±0.008	0.970±0.016	0.959±0.011
9	0.958±0.006	0.964±0.012	0.954±0.011
10	0.990±0.007	0.928±0.020	0.969±0.012
11	0.981±0.004	0.938±0.014	0.976±0.009
12	0.976±0.006	0.928±0.020	0.967±0.014
13	0.983±0.005	0.951±0.008	0.989±0.010
14	0.985±0.005	0.953±0.007	0.990±0.014
15	0.970±0.006	0.904±0.018	0.972±0.008
16	0.994±0.005	0.926±0.002	0.987±0.015
17	0.968±0.006	0.928±0.002	0.959±0.014
18	0.976±0.005	0.944±0.009	0.969±0.010
19	0.963±0.006	0.918±0.006	0.992±0.011
20	0.977±0.008	0.960±0.013	0.984±0.012
21	0.000±0.000	0.000±0.000	0.000±0.000
22	0.000±0.000	0.000±0.000	0.000±0.000
23	0.000±0.000	0.000±0.000	0.000±0.000
24	1.003±0.007	0.945±0.009	1.013±0.023
25	1.018±0.011	0.961±0.009	1.027±0.014
26	1.003±0.009	0.953±0.015	1.028±0.020
27	1.006±0.007	0.977±0.008	1.045±0.018
28	1.013±0.009	0.989±0.007	1.015±0.013
29	0.986±0.007	0.972±0.014	0.998±0.014
30	0.998±0.010	0.970±0.012	1.060±0.026
31	0.955±0.009	0.961±0.007	0.983±0.019
32	0.980±0.008	0.985±0.005	0.997±0.017
33	0.997±0.008	0.952±0.027	1.041±0.018
34	0.976±0.010	0.994±0.011	1.004±0.022
35	0.984±0.015	1.007±0.026	1.032±0.028
36	1.015±0.010	1.053±0.021	1.009±0.018
37	1.041±0.017	0.988±0.025	1.030±0.045
38	0.000±0.000	0.000±0.000	0.000±0.000

Table 10: RGS 2 Rectification Factors by Range of Revolutions

Wavelength	87-399	400-799	800-1199	1200-1599	1600-1837
6	1.085±0.040	0.954±0.066	1.014±0.030	1.068±0.033	1.091±0.002
7	0.958±0.012	1.017±0.011	1.005±0.010	0.966±0.010	0.962±0.008
8	0.960±0.007	0.992±0.013	0.969±0.013	0.989±0.014	0.927±0.005
9	0.945±0.013	0.964±0.013	0.960±0.008	0.971±0.009	0.958±0.012
10	0.997±0.008	0.997±0.017	0.978±0.012	0.974±0.011	0.935±0.002
11	0.981±0.007	0.985±0.010	0.979±0.008	0.960±0.010	0.938±0.005
12	0.992±0.009	0.989±0.024	0.960±0.007	0.970±0.006	0.935±0.003
13	0.999±0.006	1.007±0.014	0.978±0.007	0.959±0.009	0.954±0.005
14	1.008±0.006	0.978±0.022	0.983±0.006	0.980±0.006	0.949±0.004
15	0.991±0.008	0.984±0.010	0.964±0.009	0.956±0.009	0.932±0.006
16	1.011±0.008	1.016±0.019	0.971±0.008	0.994±0.013	0.928±0.017
17	0.997±0.009	0.939±0.020	0.952±0.007	0.952±0.006	0.933±0.009
18	1.002±0.008	0.971±0.011	0.971±0.007	0.970±0.007	0.941±0.010
19	0.980±0.012	0.986±0.012	0.959±0.011	0.955±0.006	0.938±0.006
20	1.014±0.006	0.984±0.018	0.961±0.011	0.953±0.005	0.943±0.011
21	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
22	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
23	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
24	1.017±0.012	1.024±0.035	0.993±0.011	0.989±0.014	0.936±0.021
25	1.094±0.017	1.039±0.021	0.997±0.011	0.999±0.010	0.990±0.024
26	1.029±0.010	1.082±0.028	0.994±0.013	0.983±0.017	0.977±0.025
27	1.041±0.010	1.050±0.022	1.001±0.007	0.998±0.010	0.955±0.008
28	1.057±0.009	1.026±0.020	1.011±0.010	1.000±0.010	0.980±0.014
29	1.029±0.009	0.995±0.022	0.988±0.011	0.973±0.007	0.960±0.004
30	1.013±0.019	1.071±0.032	0.985±0.011	1.018±0.020	0.964±0.012
31	0.980±0.016	0.989±0.022	0.955±0.012	0.963±0.014	0.915±0.008
32	0.989±0.004	0.978±0.024	0.985±0.013	0.977±0.018	0.937±0.016
33	1.004±0.006	1.055±0.022	1.020±0.014	1.034±0.020	0.914±0.032
34	0.976±0.011	1.028±0.025	0.990±0.017	1.018±0.018	0.942±0.020
35	0.981±0.027	1.032±0.042	1.016±0.018	1.045±0.015	1.019±0.015
36	0.965±0.013	1.039±0.019	1.015±0.011	1.067±0.010	1.033±0.013
37	0.916±0.040	1.054±0.041	1.045±0.019	1.082±0.012	1.010±0.046
38	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000

13 Comparison RGS 1 – RGS 2

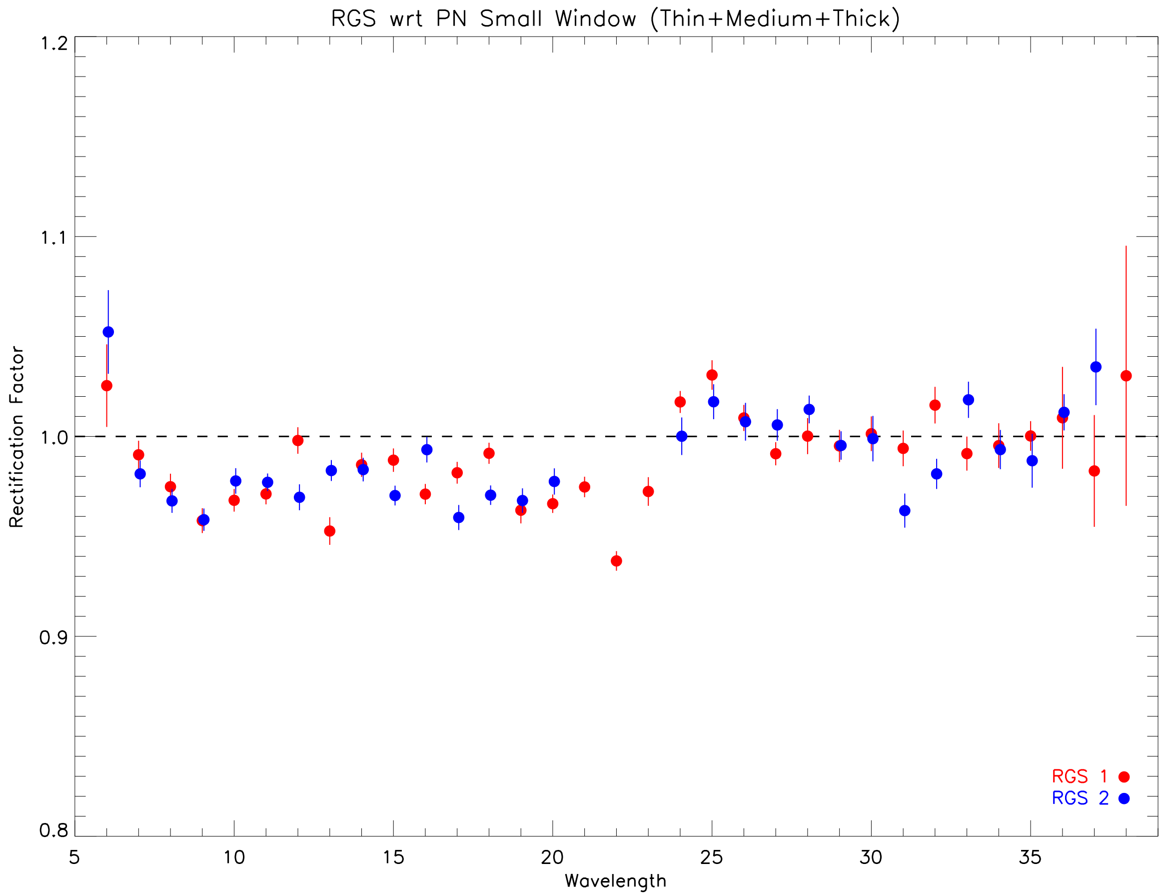


Figure 12: Average RGS 1 and RGS 2 rectification factors

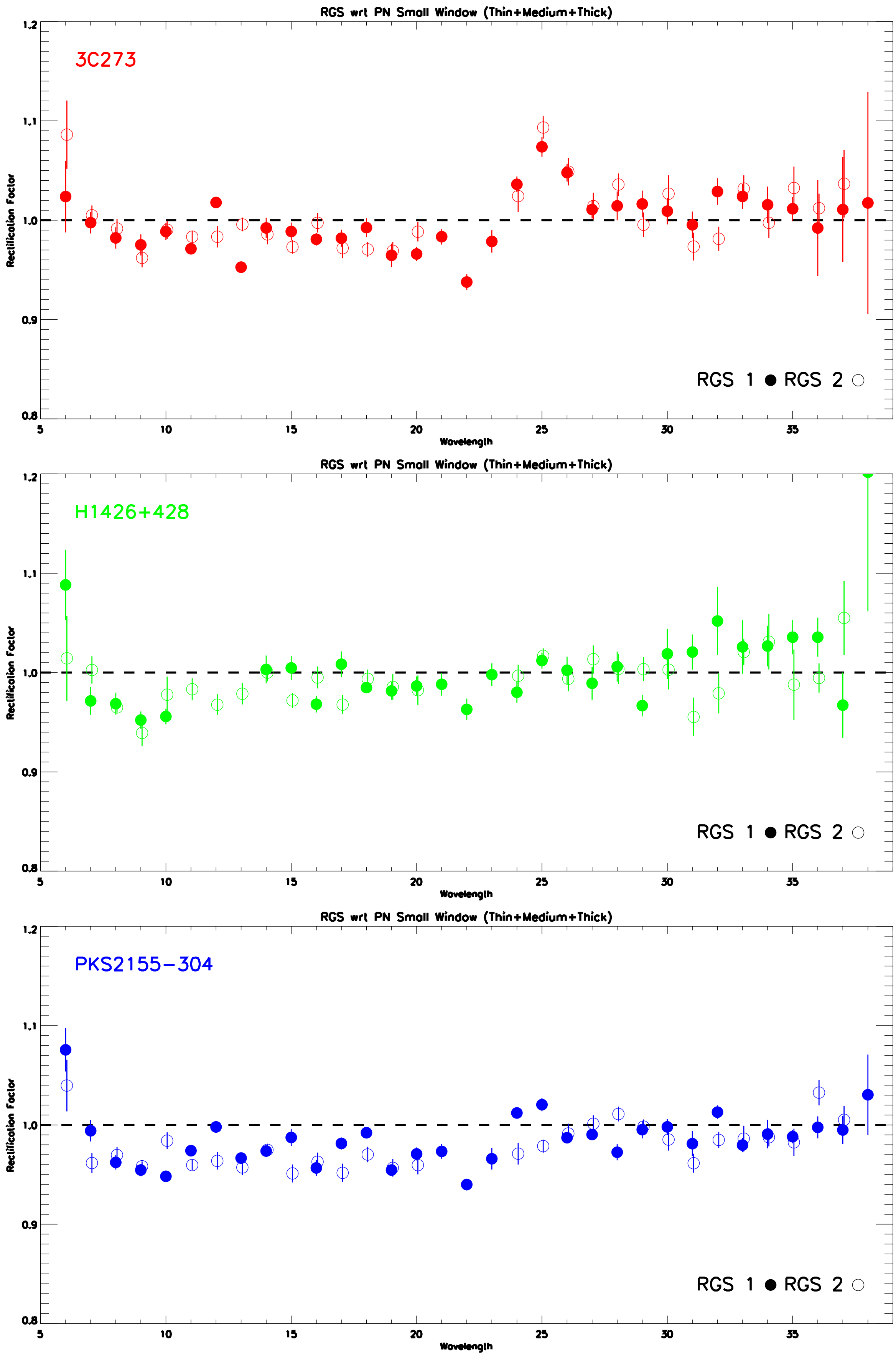


Figure 13: Comparison of the average RGS 1 and RGS 2 rectification factors for the selected targets.

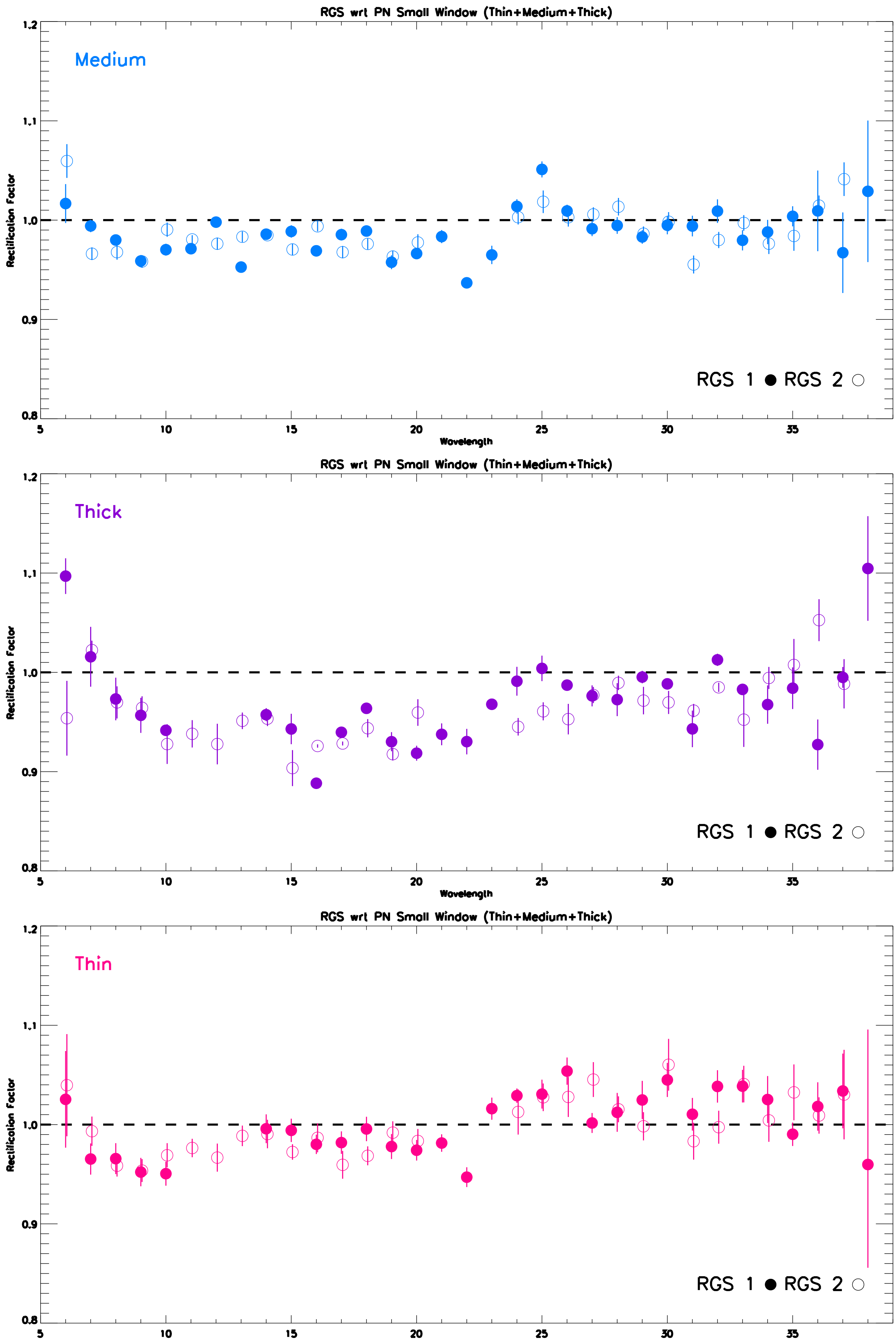


Figure 14: Comparison of the average RGS 1 and RGS 2 rectification factors according to the PN filter.

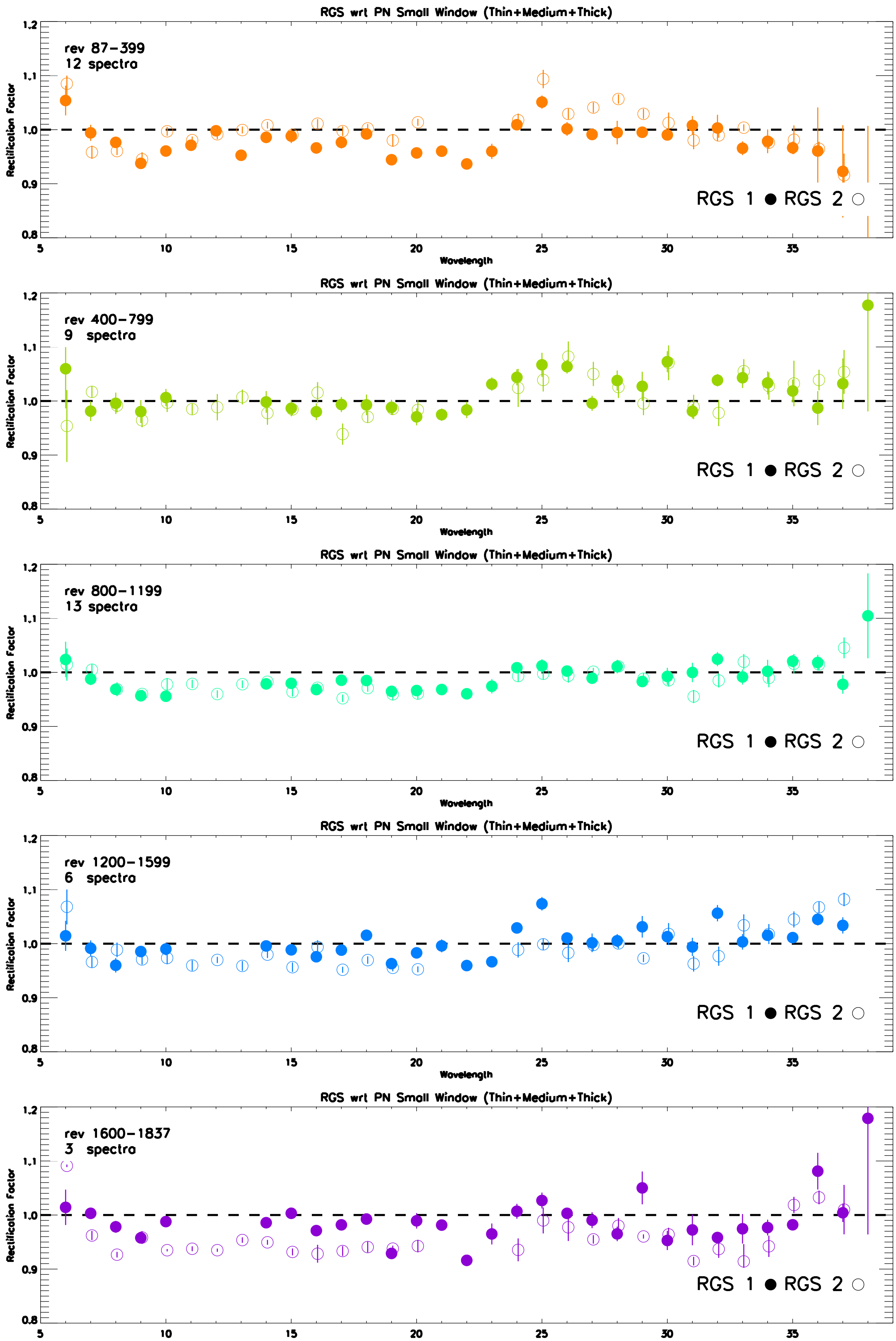


Figure 15: Comparison of the average RGS 1 and RGS 2 rectification factors according to the date of observation, in groups of 400 revolutions.

Table 11: Average Rectification Factors

Wavelength	RGS1	RGS2
6	1.025±0.021	1.052±0.021
7	0.991±0.007	0.981±0.007
8	0.975±0.007	0.968±0.006
9	0.958±0.006	0.958±0.006
10	0.968±0.006	0.978±0.006
11	0.971±0.005	0.977±0.004
12	0.998±0.007	0.970±0.006
13	0.953±0.007	0.983±0.005
14	0.986±0.006	0.983±0.006
15	0.988±0.006	0.970±0.005
16	0.971±0.005	0.993±0.006
17	0.982±0.005	0.959±0.006
18	0.992±0.005	0.971±0.005
19	0.963±0.007	0.968±0.006
20	0.966±0.005	0.977±0.007
21	0.975±0.005	0.000±0.000
22	0.938±0.005	0.000±0.000
23	0.972±0.007	0.000±0.000
24	1.017±0.006	1.000±0.009
25	1.031±0.007	1.017±0.009
26	1.009±0.007	1.007±0.009
27	0.991±0.006	1.006±0.008
28	1.000±0.009	1.013±0.007
29	0.995±0.008	0.995±0.007
30	1.001±0.009	0.999±0.011
31	0.994±0.009	0.963±0.009
32	1.016±0.009	0.981±0.008
33	0.991±0.009	1.018±0.009
34	0.995±0.011	0.993±0.010
35	1.000±0.007	0.988±0.013
36	1.009±0.025	1.012±0.009
37	0.983±0.028	1.035±0.019
38	1.030±0.065	0.000±0.000

14 Comparison with previous calibrations

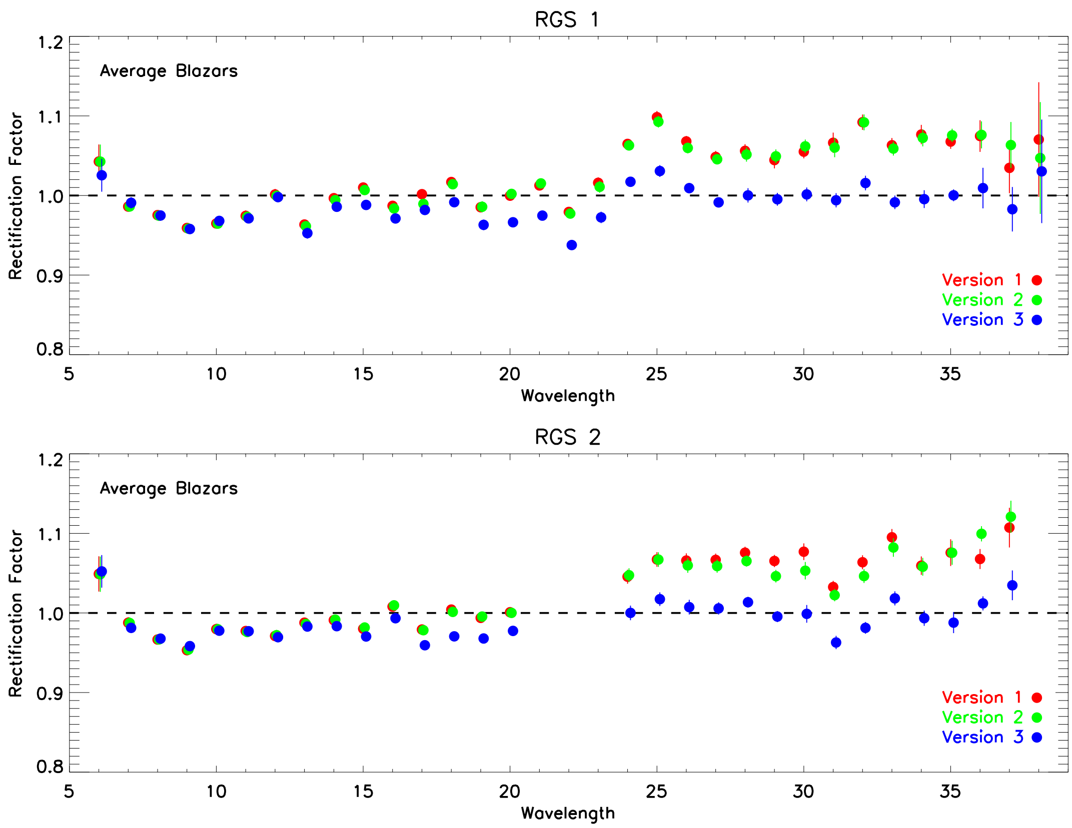


Figure 16: Comparison of the rectification factors obtained with the the different sets of calibrations.

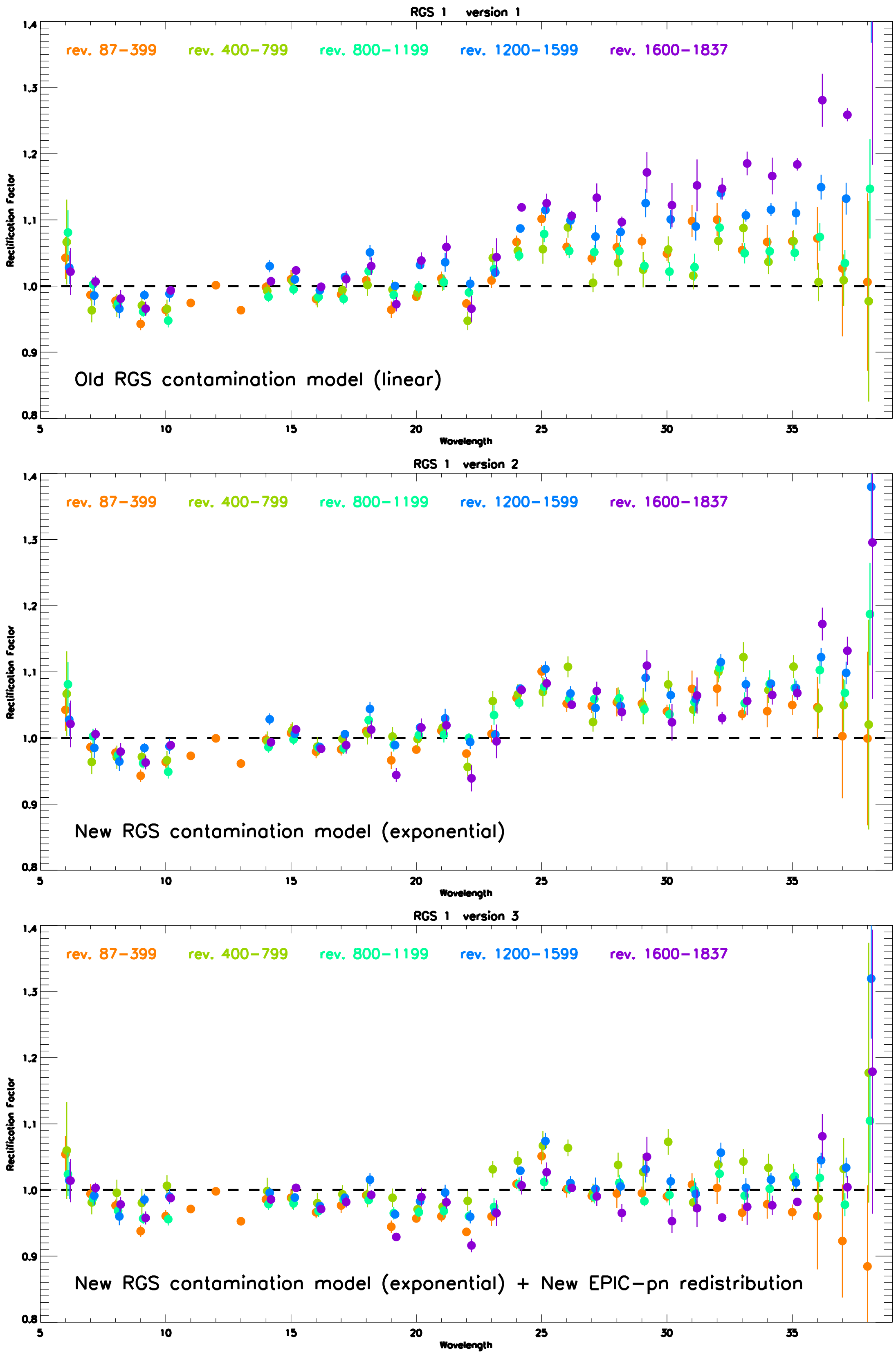


Figure 17: Dependence on time of the RGS 1 rectification factors obtained with the the different sets of calibrations.

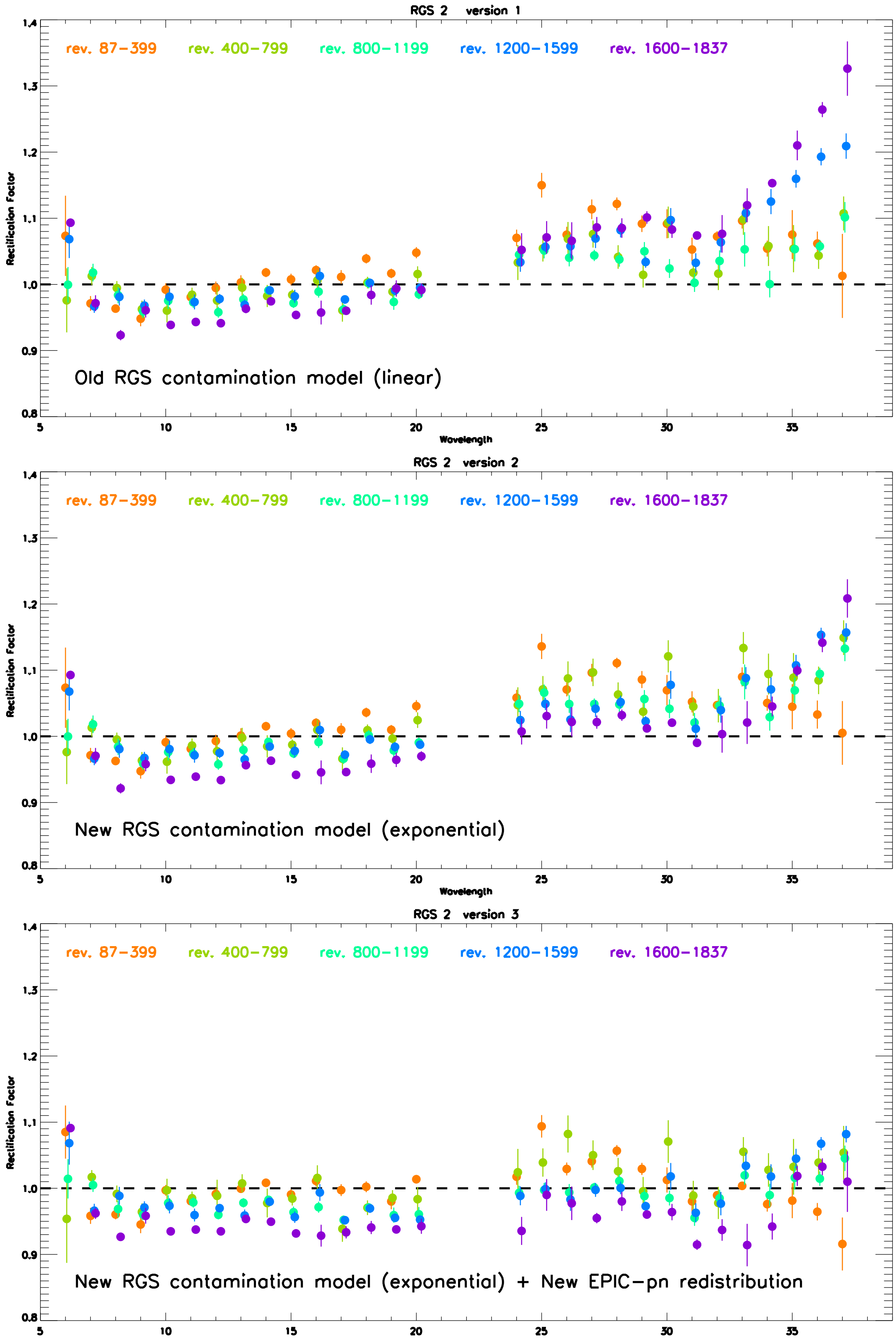


Figure 18: Same as previous figure, but for RGS 2.

15 The Isolated Neutron Star RX J1856.6-3754

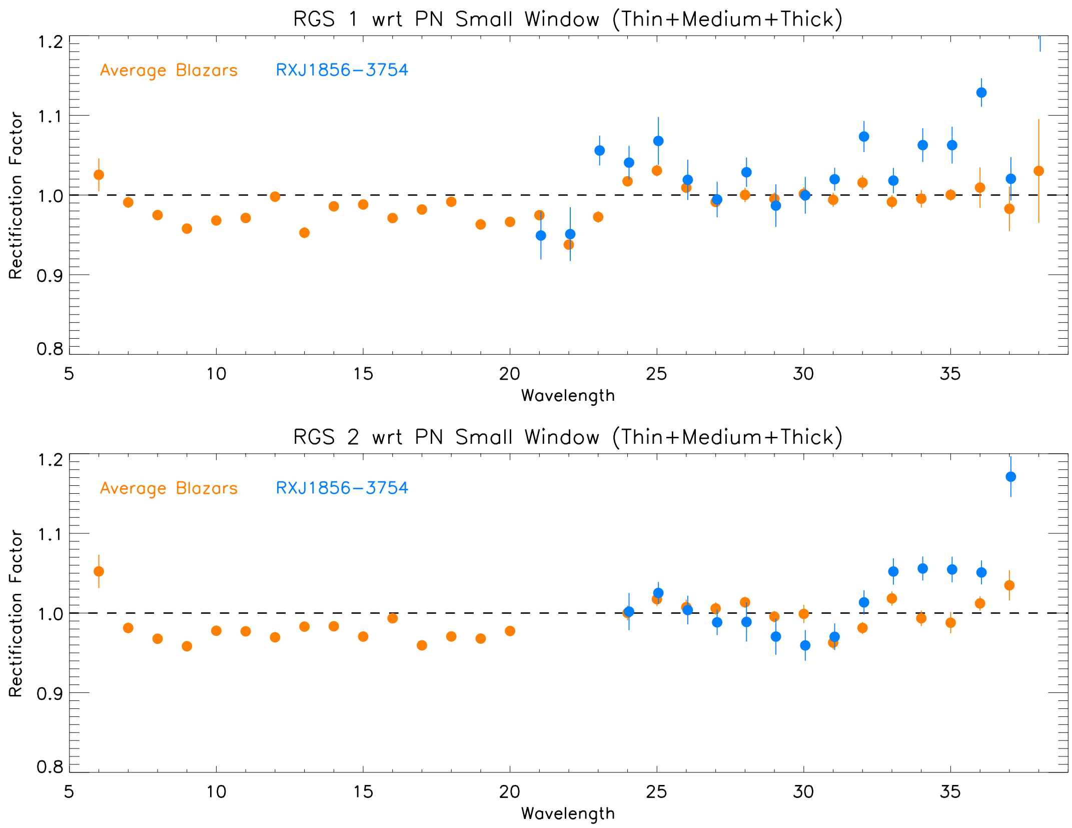


Figure 19: Average rectification factors obtained from the three blazars compared with those obtained from 14 observations the INS RXJ1856-3754.

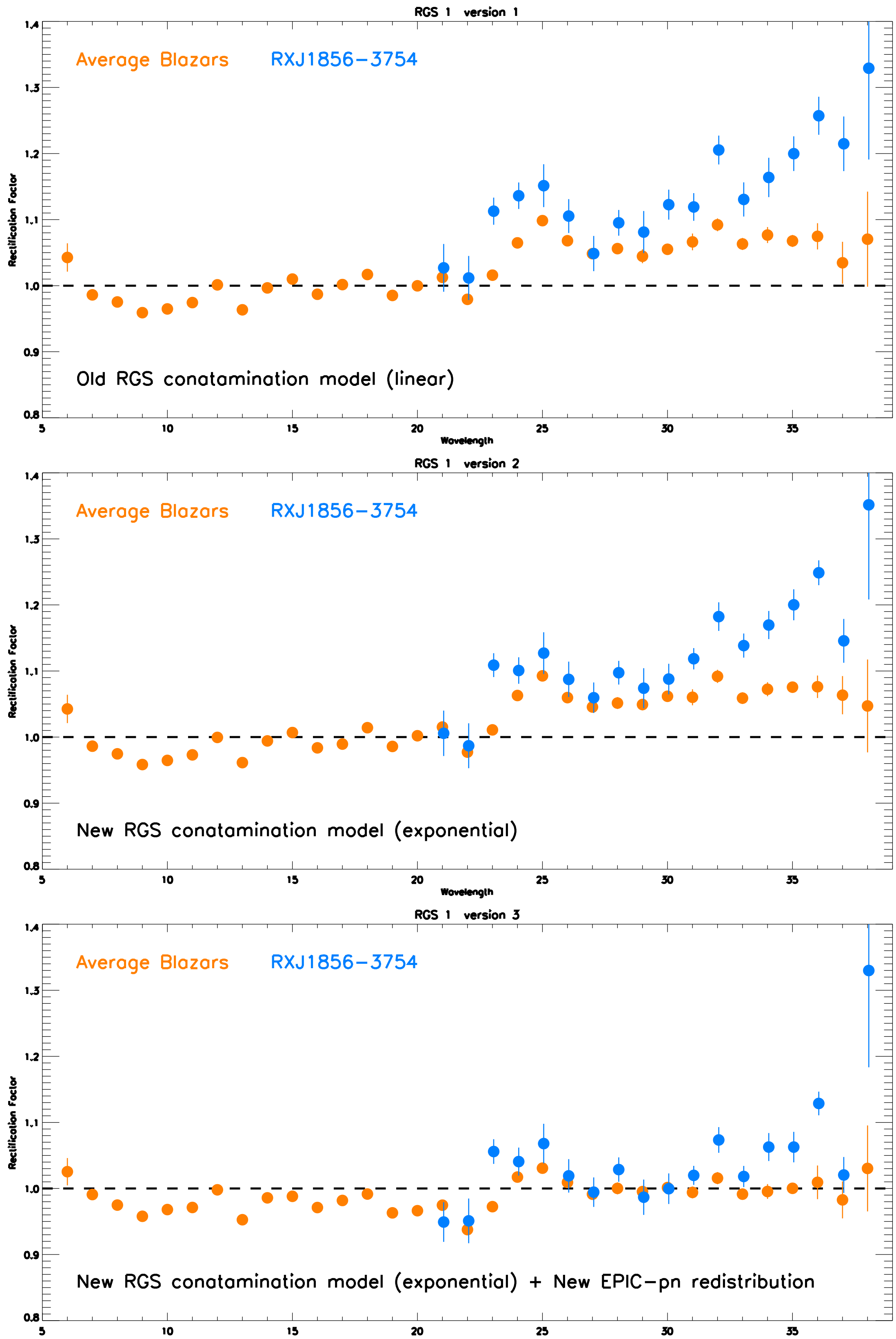


Figure 20: RGS 1 rectification factors obtained for RX J1856.6-3754 with the the different sets of calibrations.

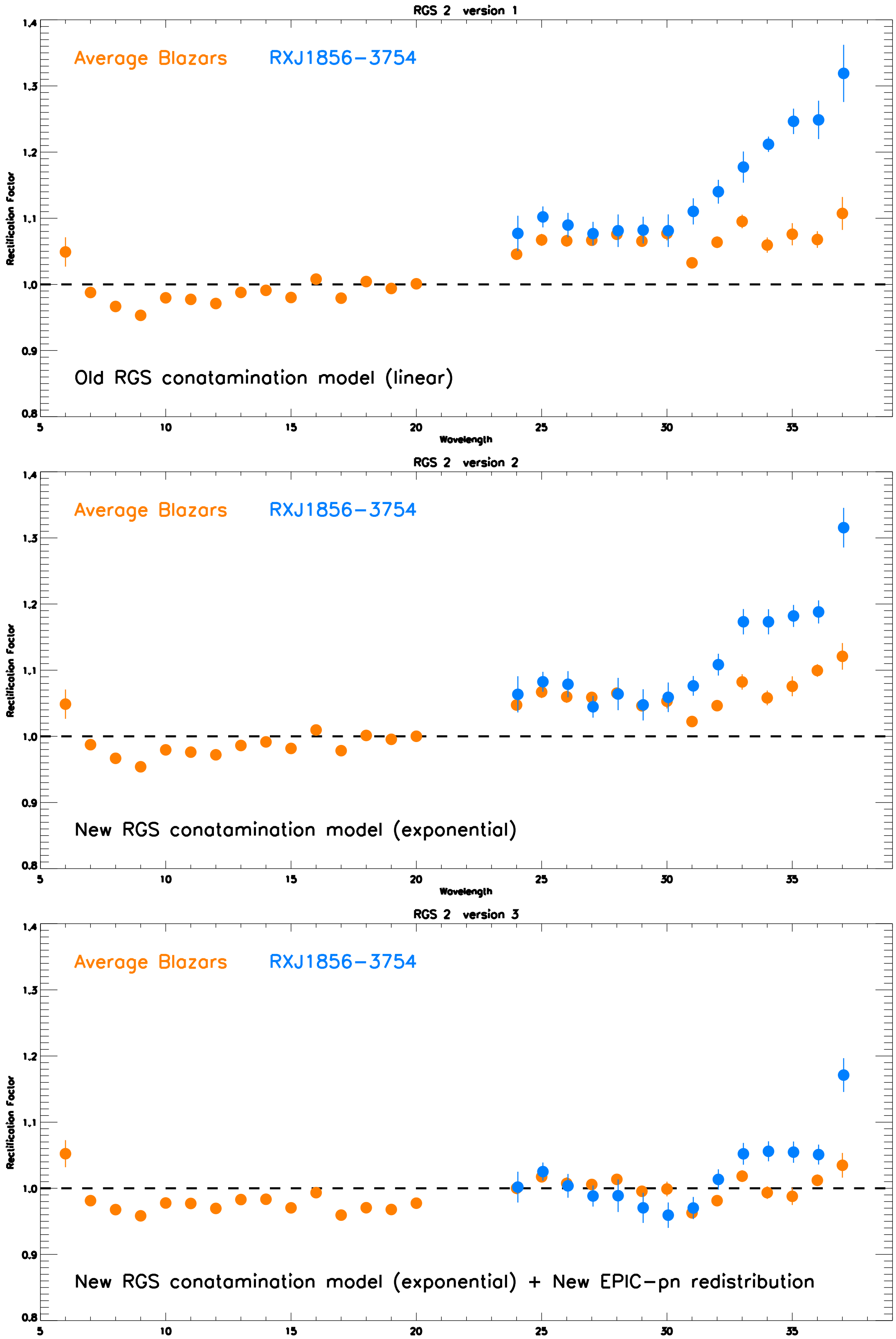


Figure 21: Same as previous figure, but for RGS 2.

16 Appendix

16.1 RGS 1

16.1.1 3C 273

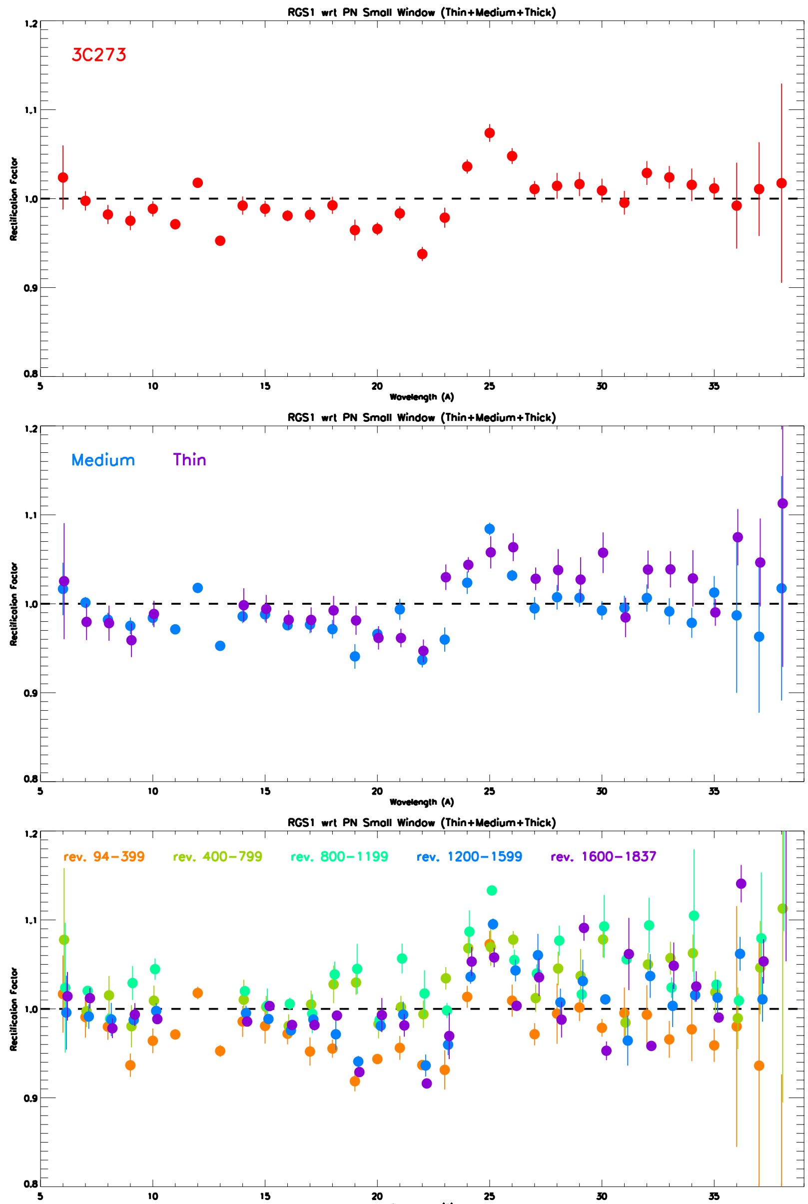


Figure 22: Summary of the results for 3C 273, RGS 1. From top to bottom, average rectification factor, by filter, and by epoch.

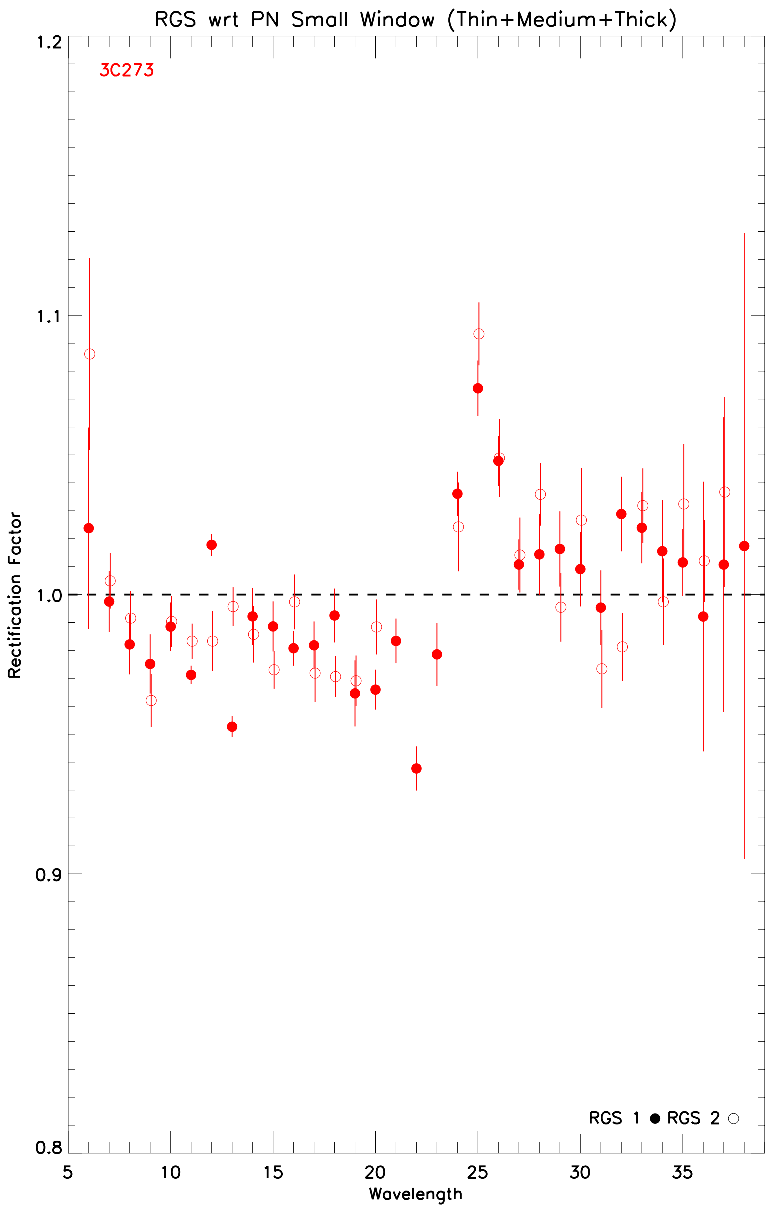


Figure 23: Comparison of the rectification factors for RGS 1 and RGS 2 for 3C 273.

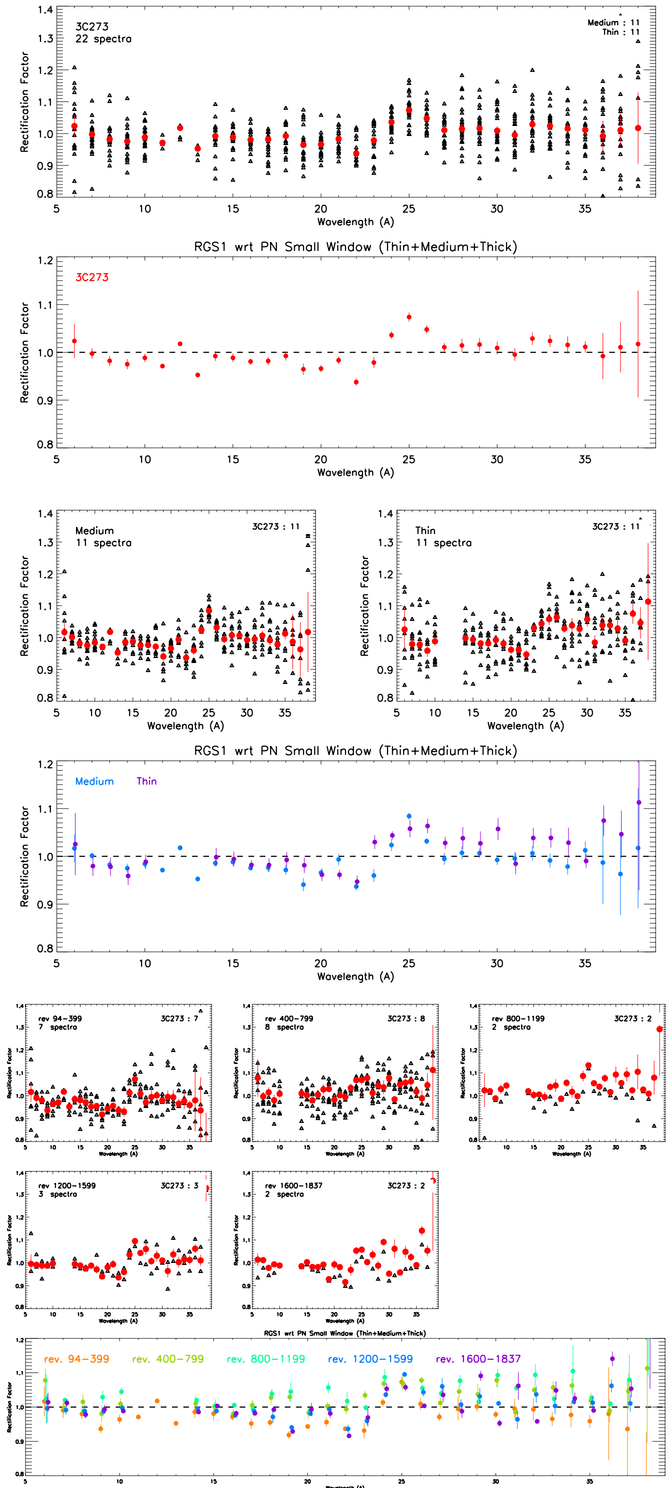


Figure 24: RGS 1 rectification factors for 3C 273. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

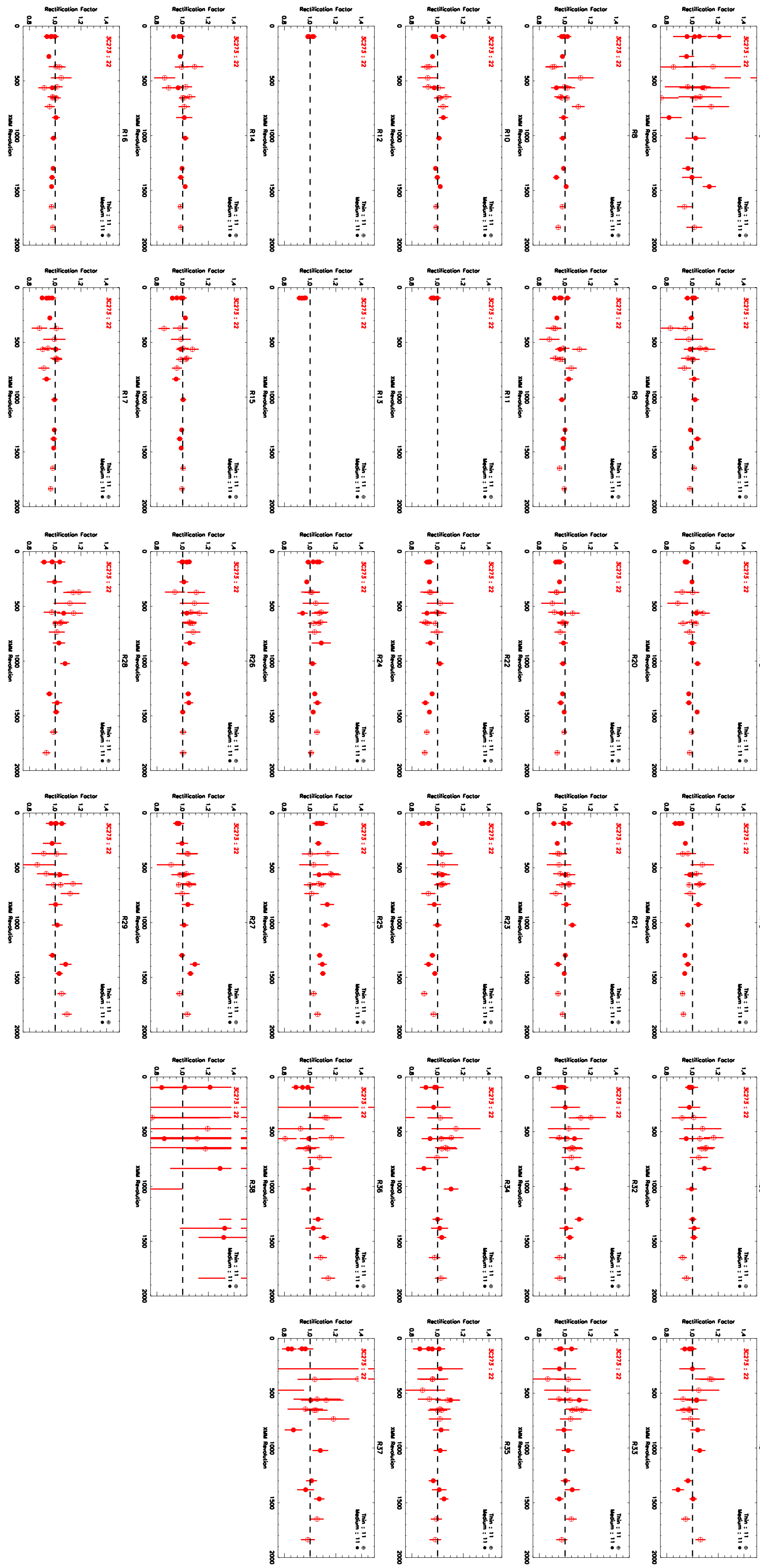


Figure 25: Time evolution of the RGS 1 rectification factors for 3C 273.

16.1.2 H1426+428

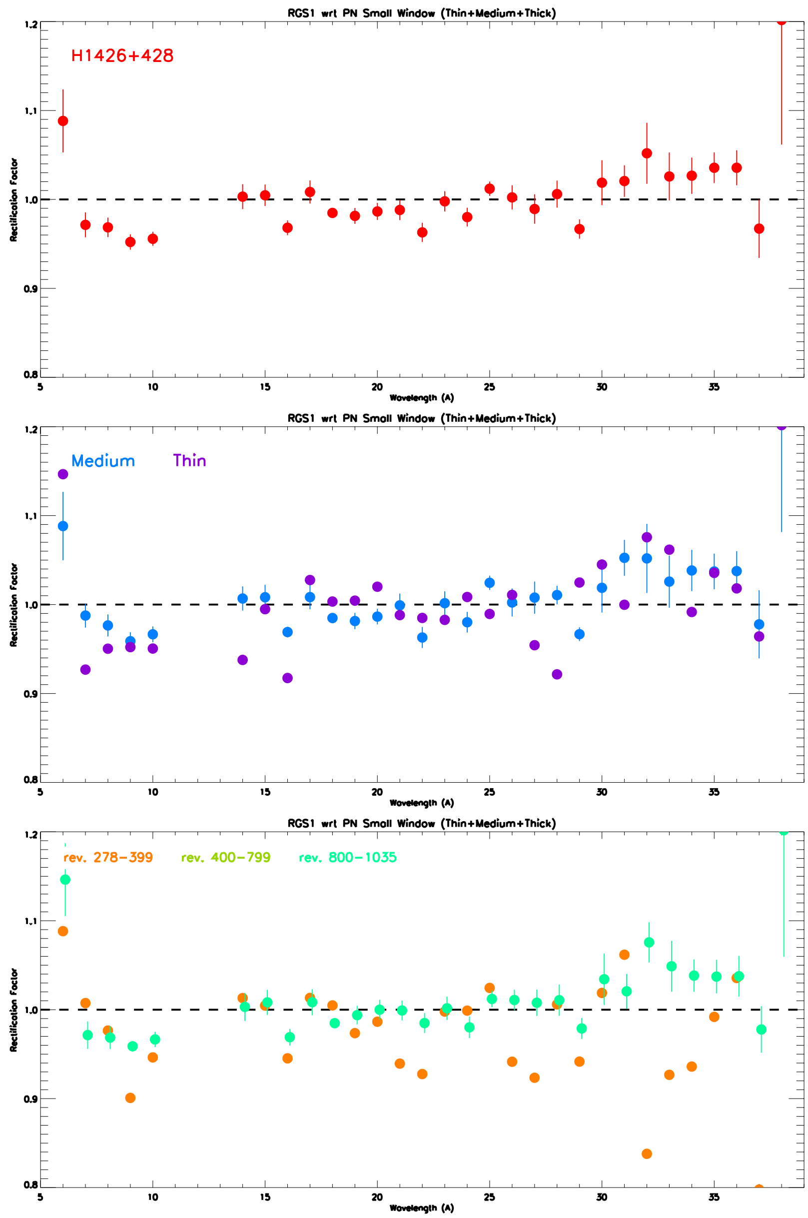


Figure 26: Summary of the results for H1426+428, RGS 1. From top to bottom, average rectification factor, by filter, and by epoch.

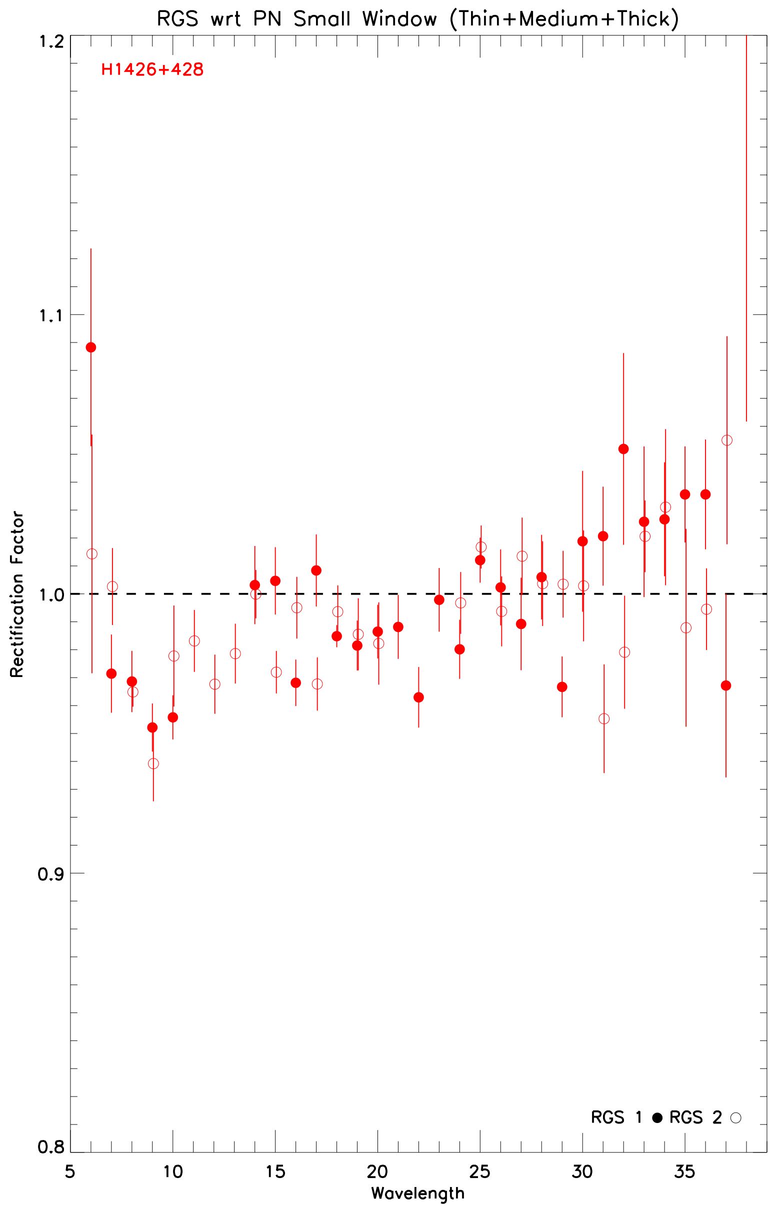


Figure 27: Comparison of the rectification factors for RGS 1 and RGS 2 for H1426+428.

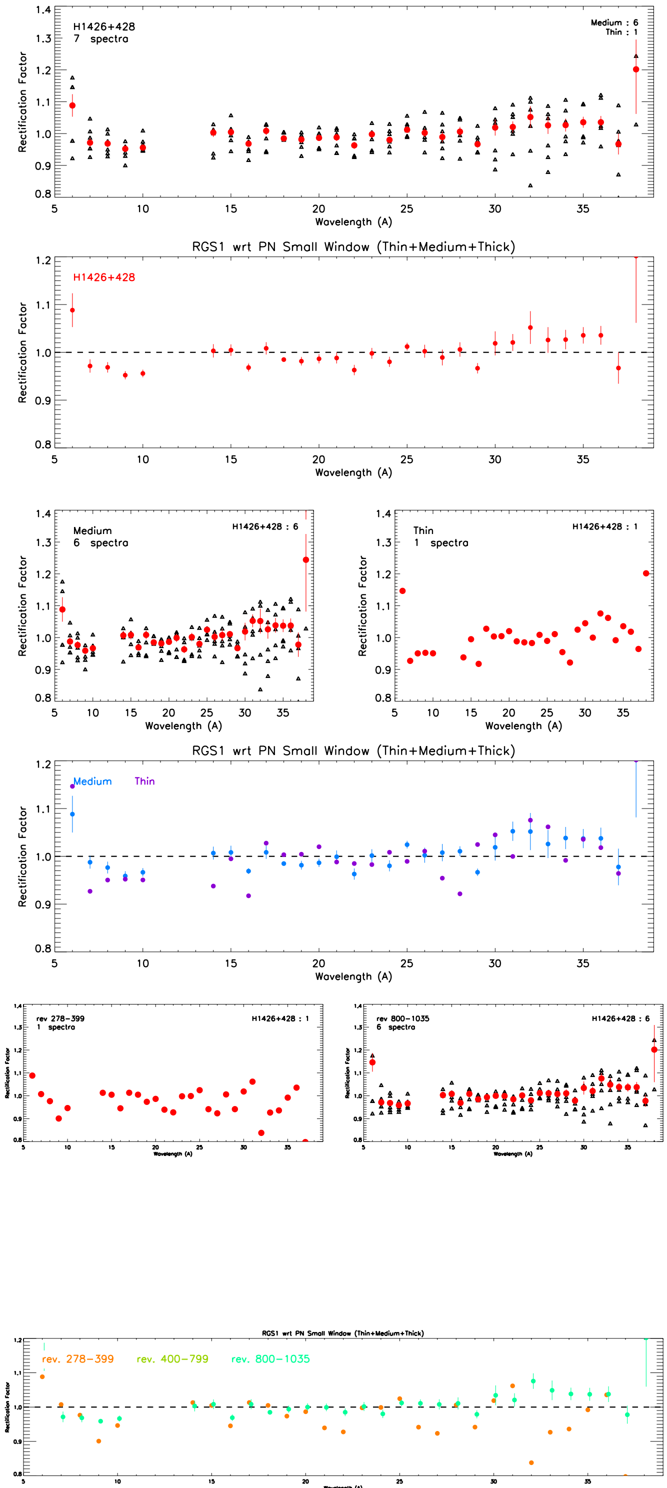


Figure 28: RGS 1 rectification factors for H1426+428. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

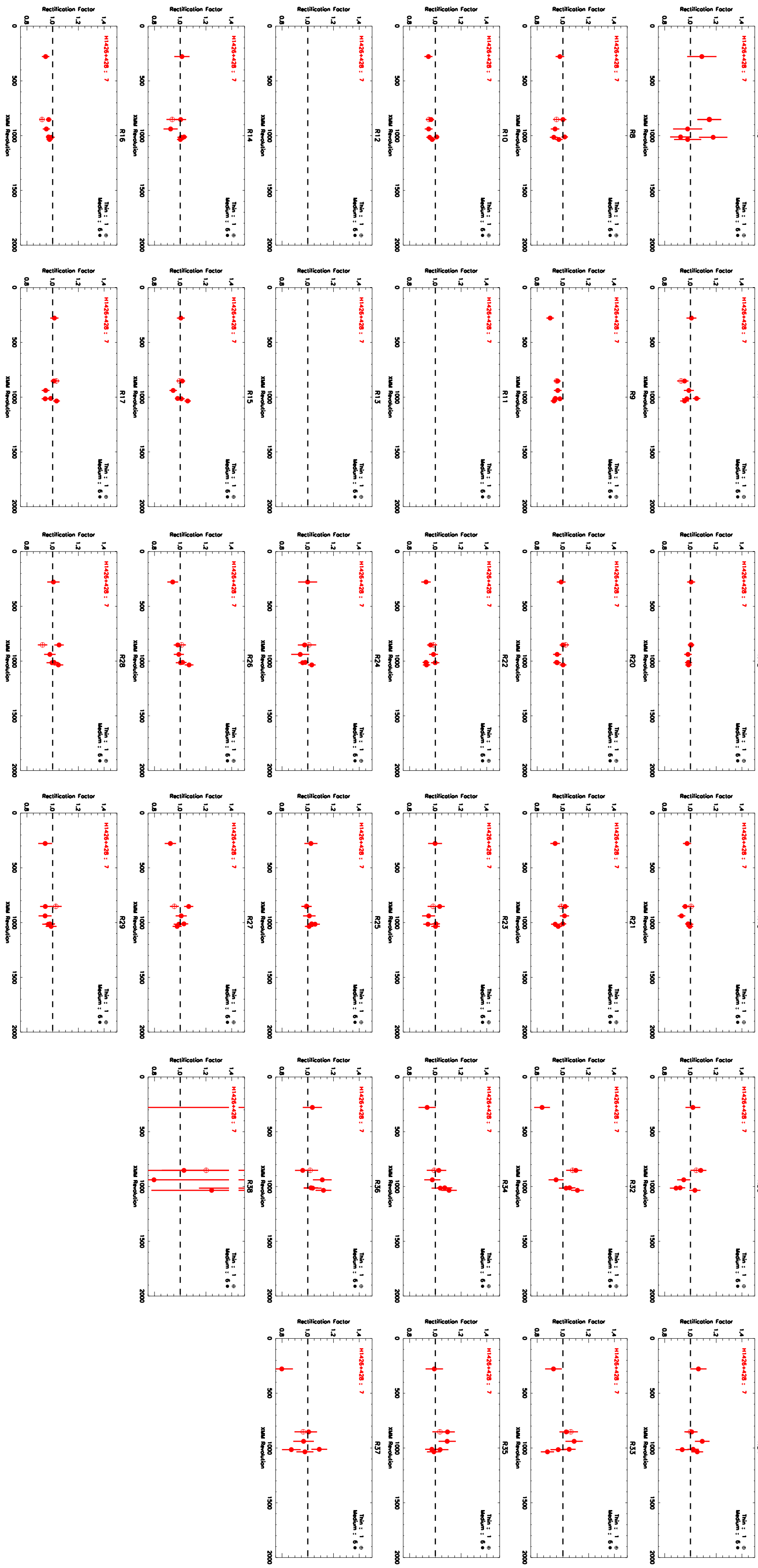


Figure 29: Time evolution of the RGS 1 rectification factors for H1426+428.

16.1.3 PKS 2155-304

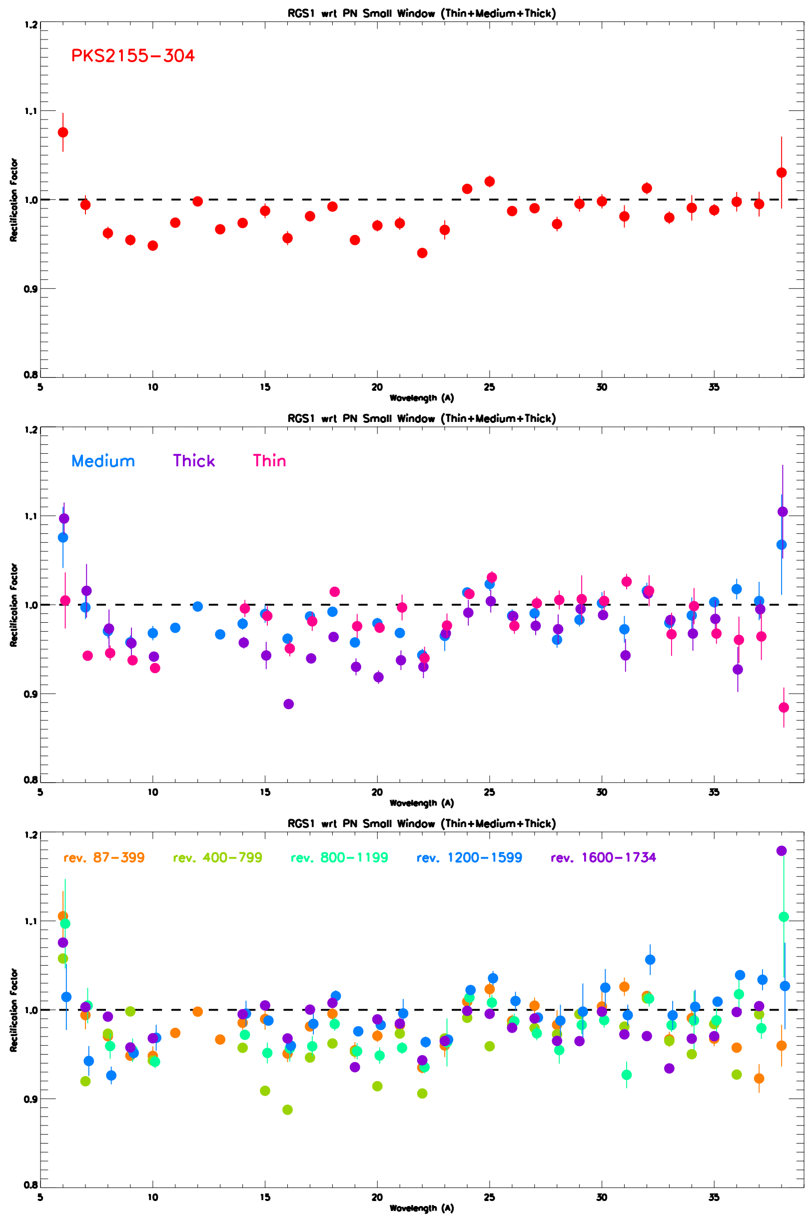


Figure 30: Summary of the results for PKS 2155-304, RGS 1. From top to bottom, average rectification factor, by filter, and by epoch.

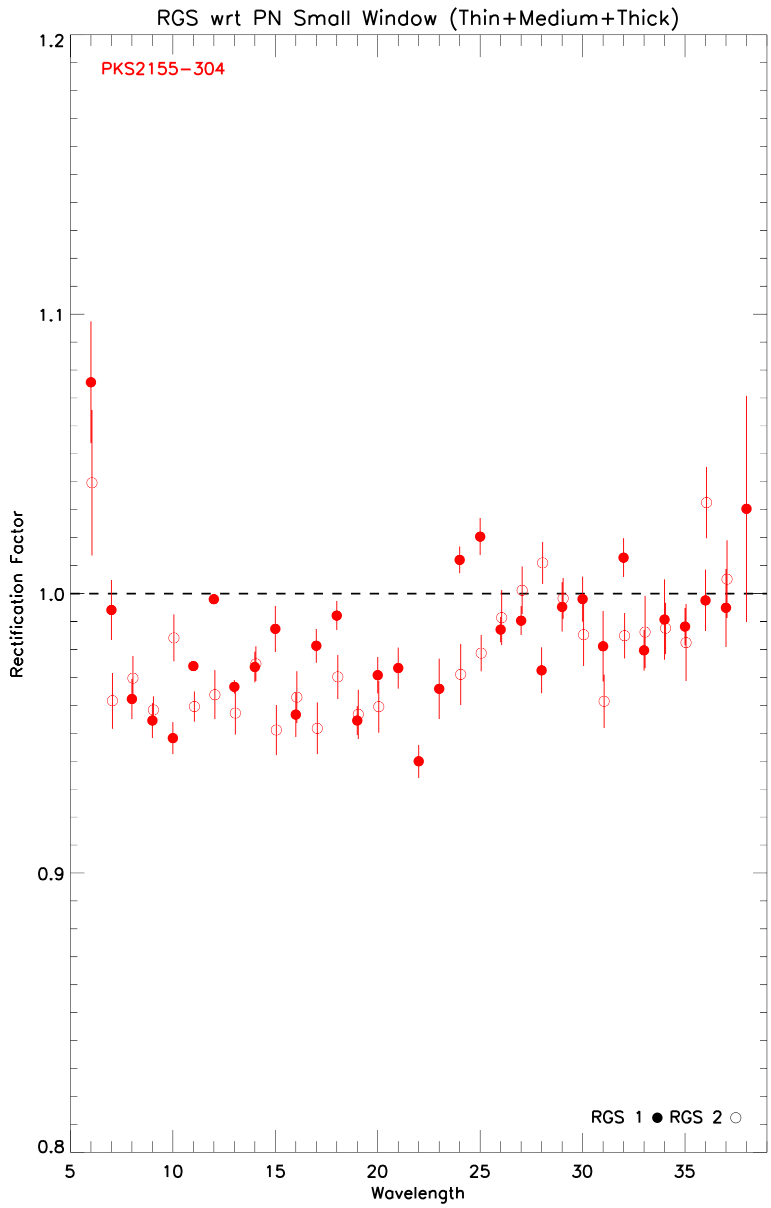


Figure 31: Comparison of the rectification factors for RGS 1 and RGS 2 for PKS 2155-304.

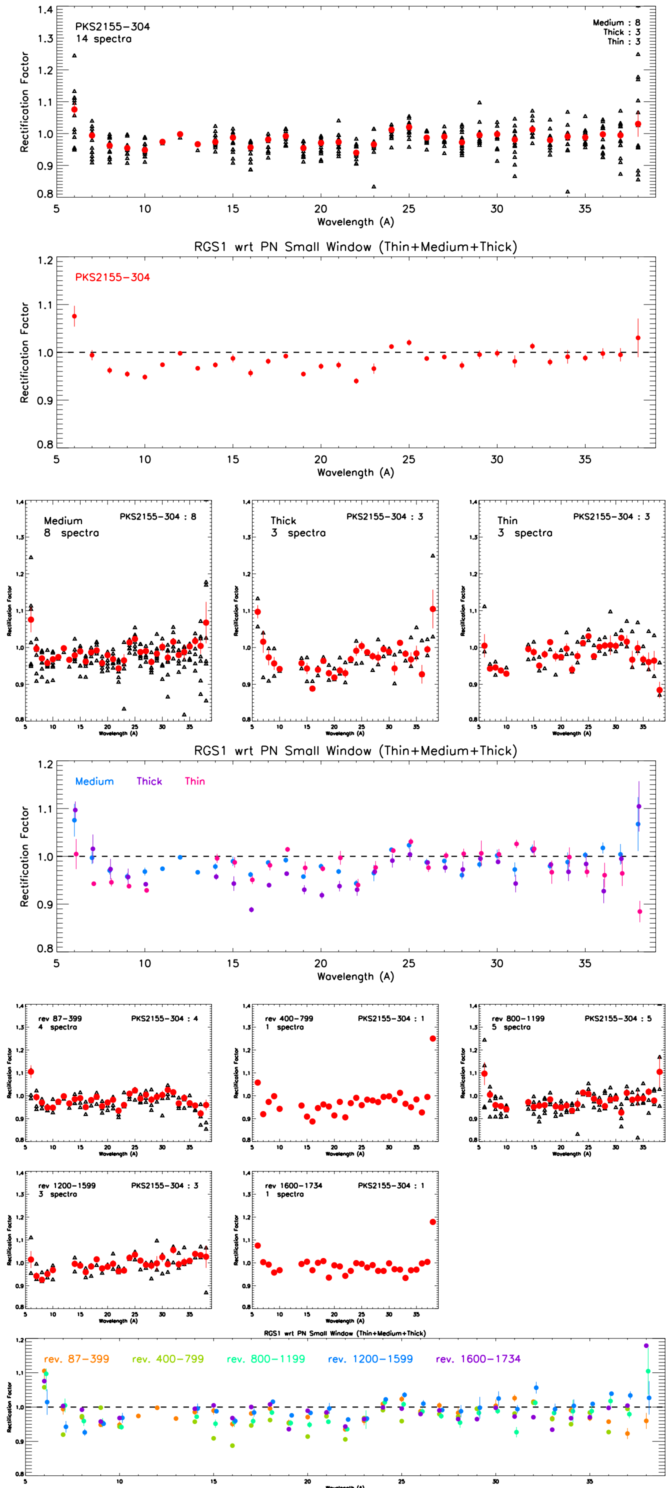


Figure 32: RGS 1 rectification factors for PKS 2155-304. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

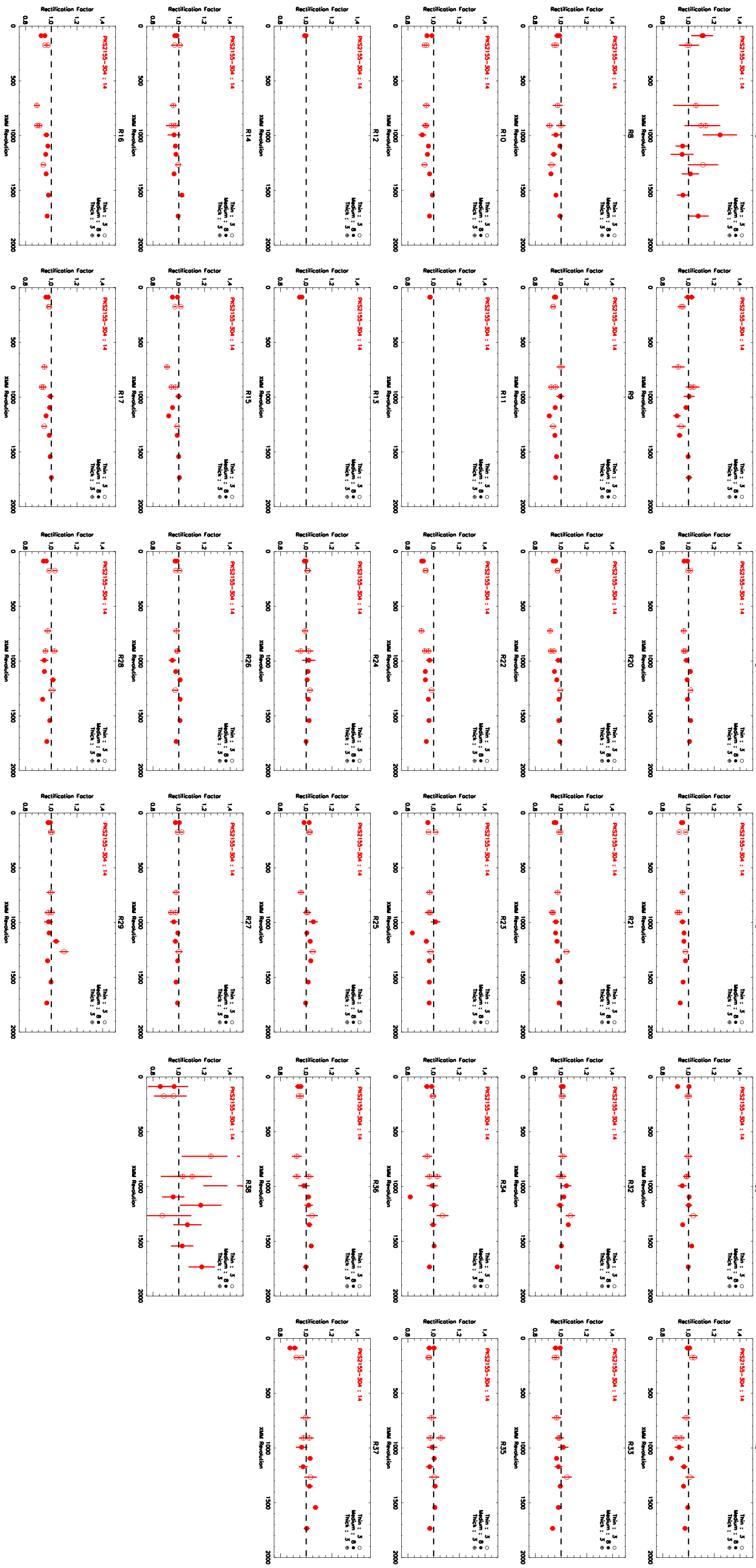


Figure 33: Time evolution of the RGS 1 rectification factors for PKS 2155-304.

16.1.4 RX J1856.6-3754

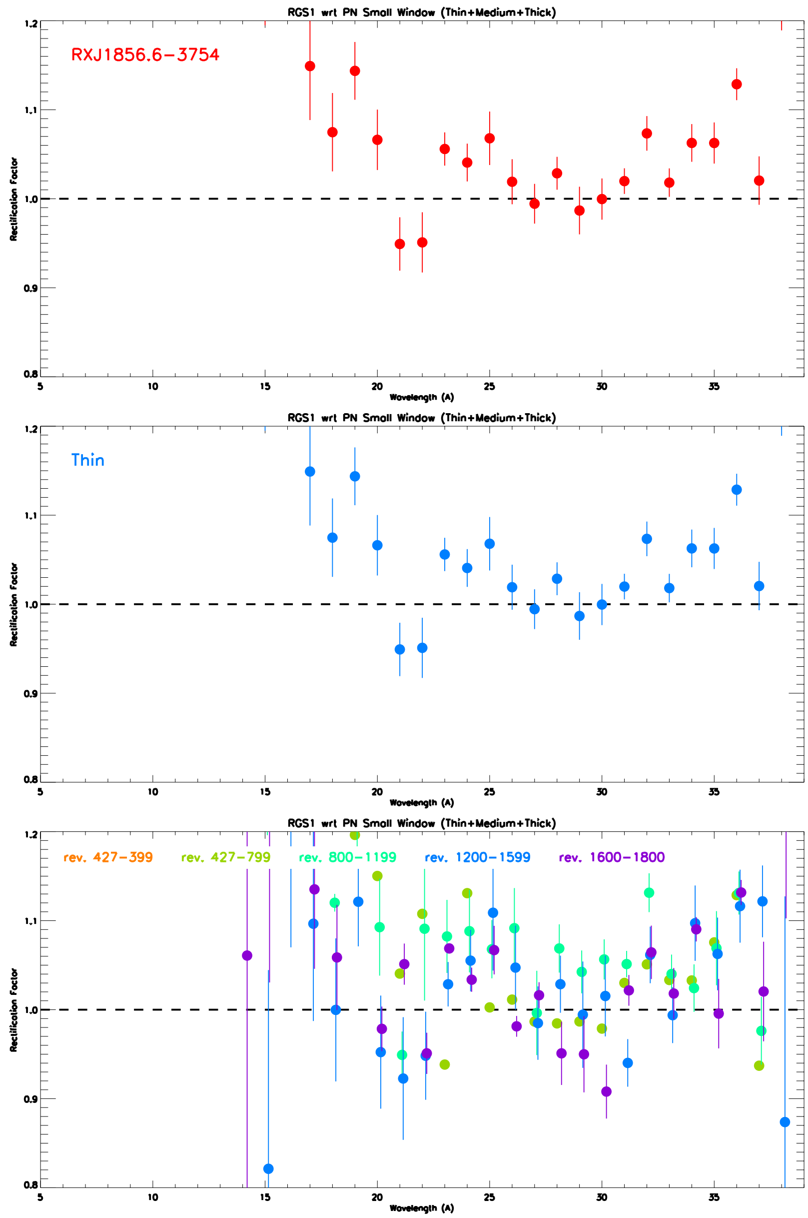


Figure 34: Summary of the results for RX J1856.6-3754, RGS 1. From top to bottom, average rectification factor, by filter, and by epoch.

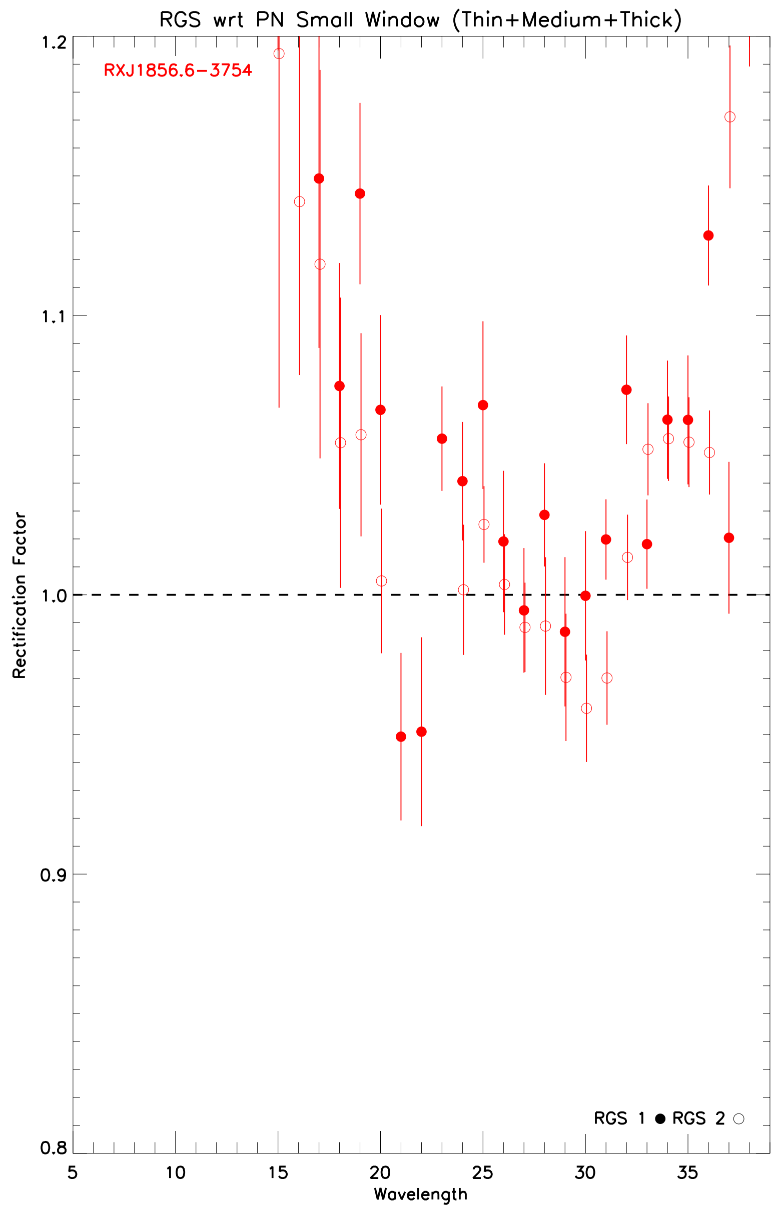


Figure 35: Comparison of the rectification factors for RGS 1 and RGS 2 for RX J1856.6-3754.

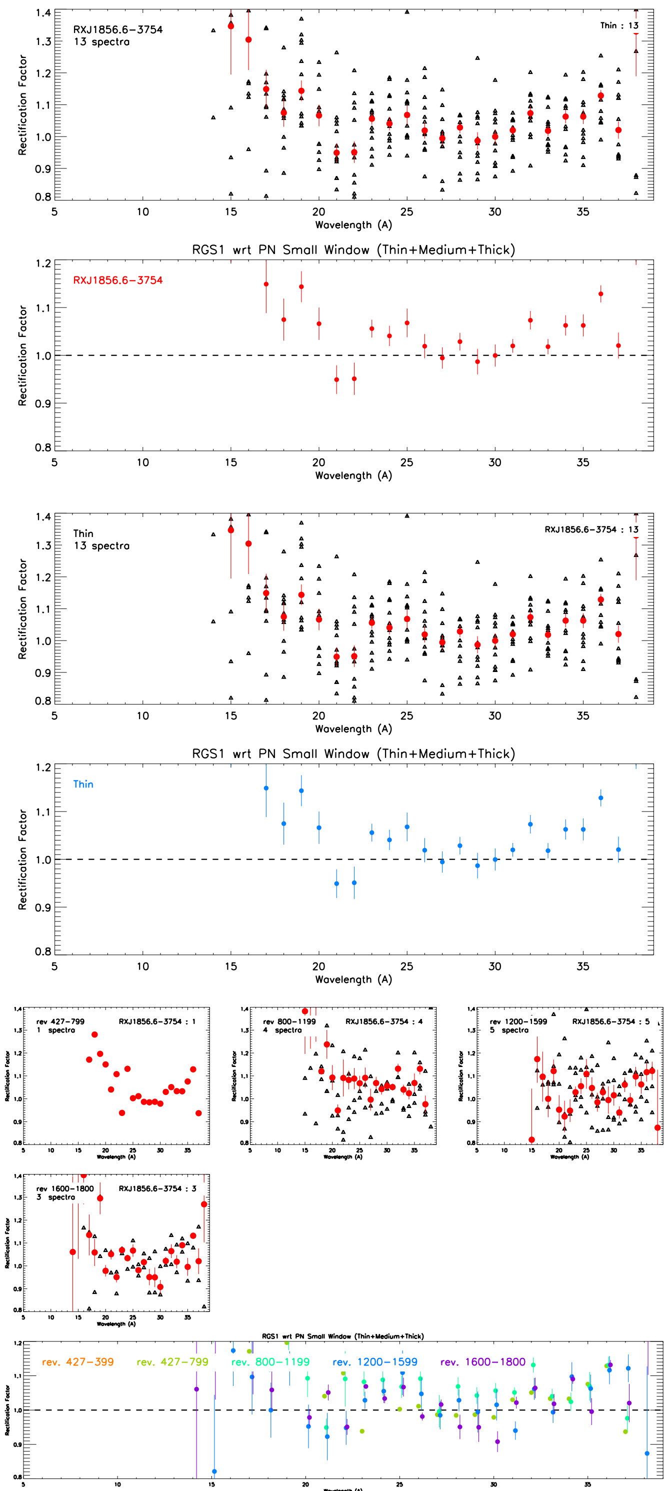


Figure 36: RGS 1 rectification factors for RX J1856.6-3754. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

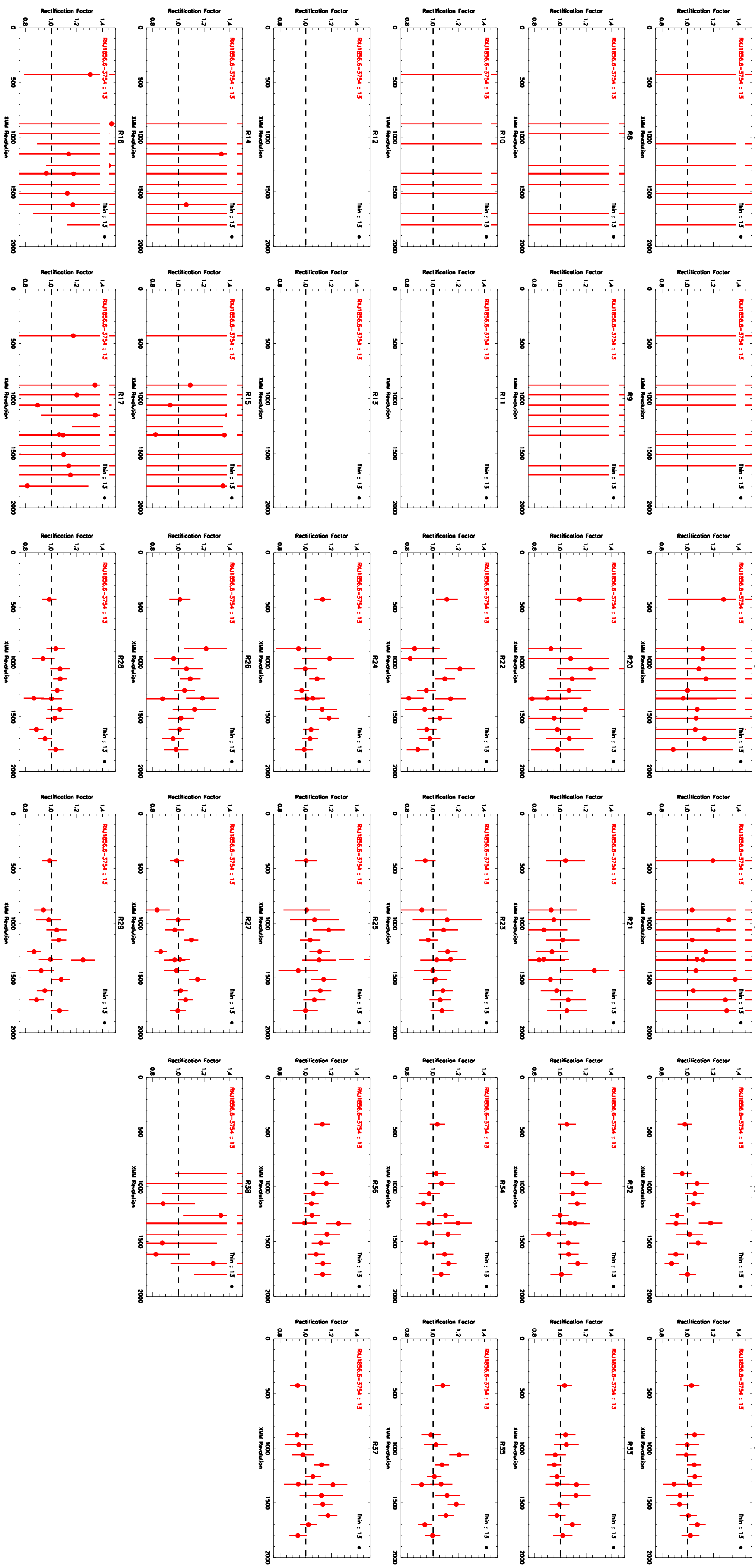


Figure 37: Time evolution of the RGS 1 rectification factors for RX J1856.6-3754.

16.2 RGS 2

16.2.1 3C 273

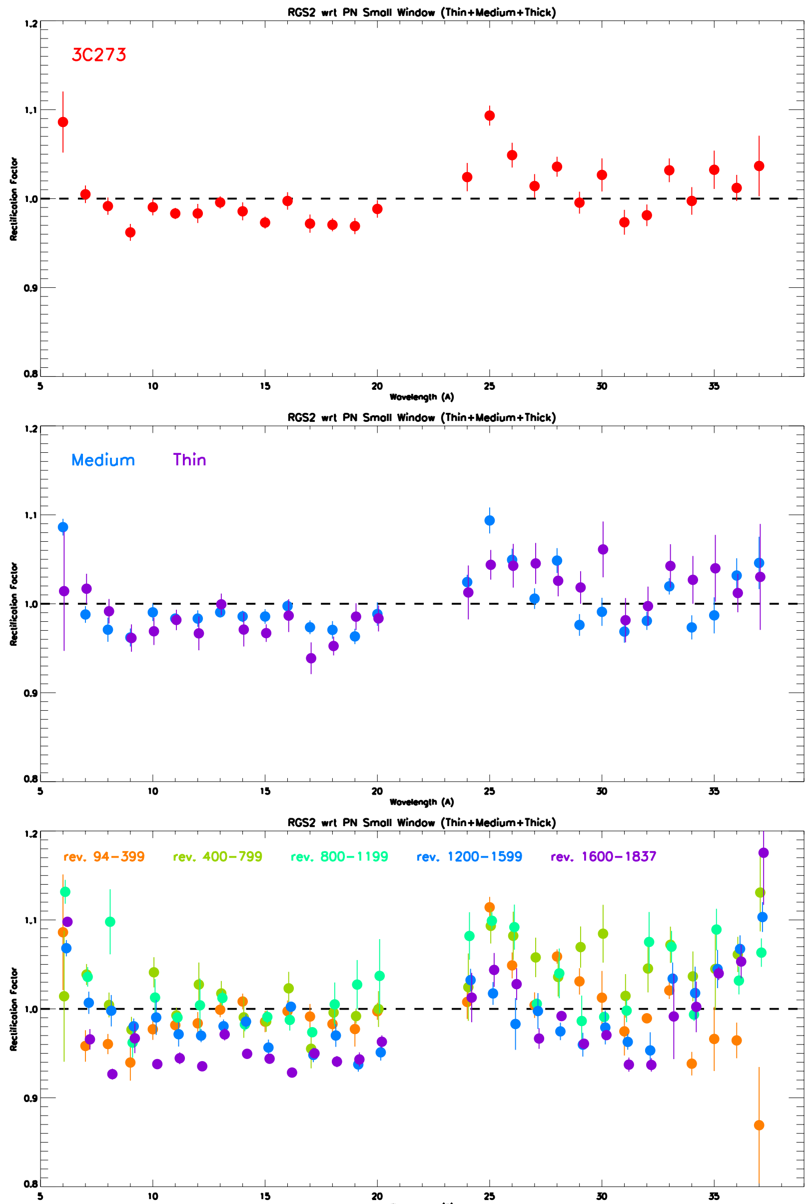


Figure 38: Summary of the results for 3C 273, RGS 2. From top to bottom, average rectification factor, by filter, and by epoch.

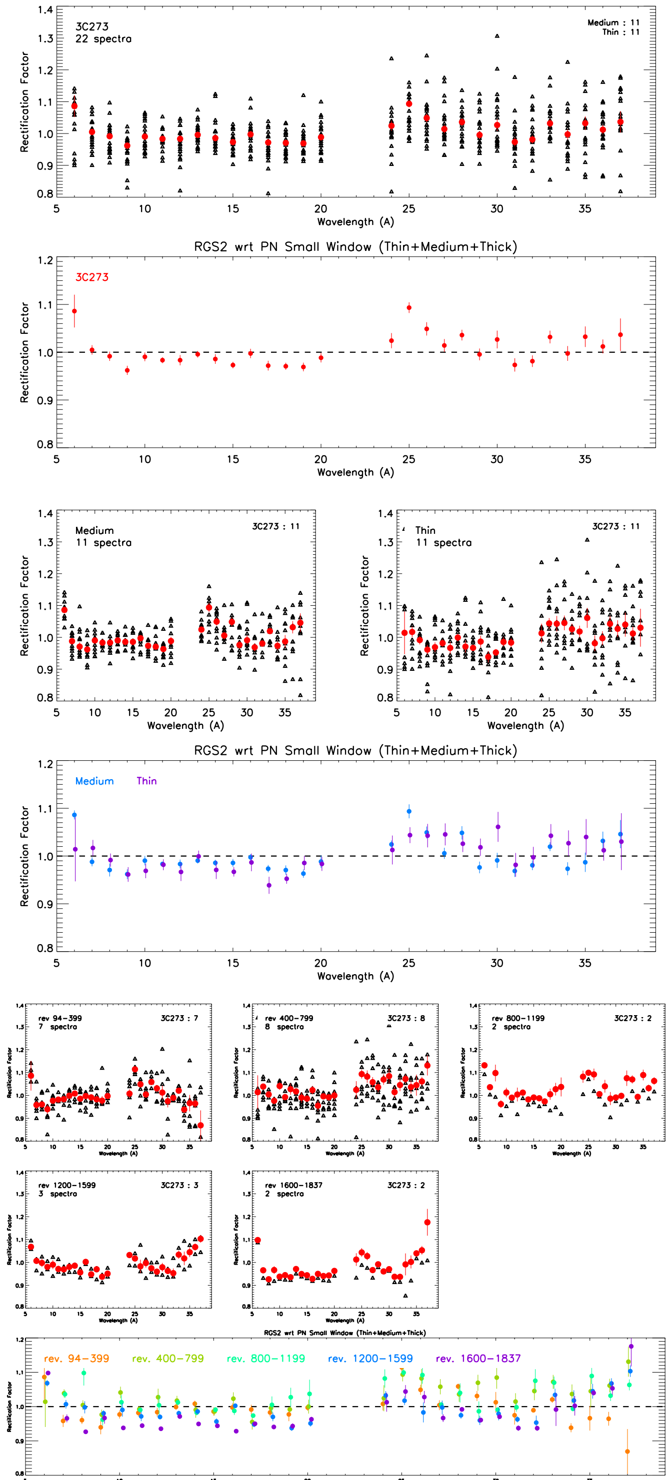


Figure 39: RGS 2 rectification factors for 3C 273. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

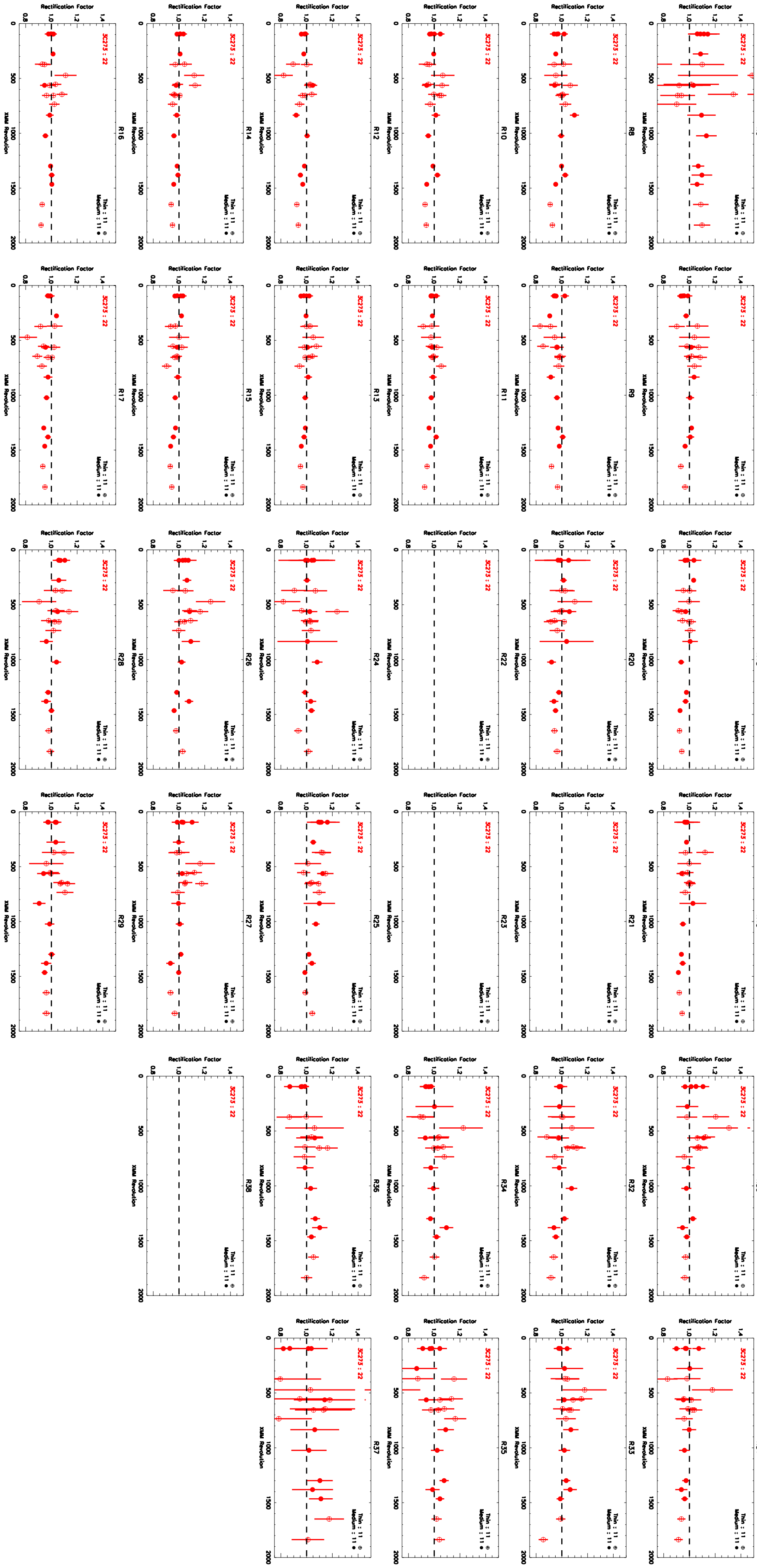


Figure 40: Time evolution of the RGS 2 rectification factors for 3C 273.

16.2.2 H1426+428

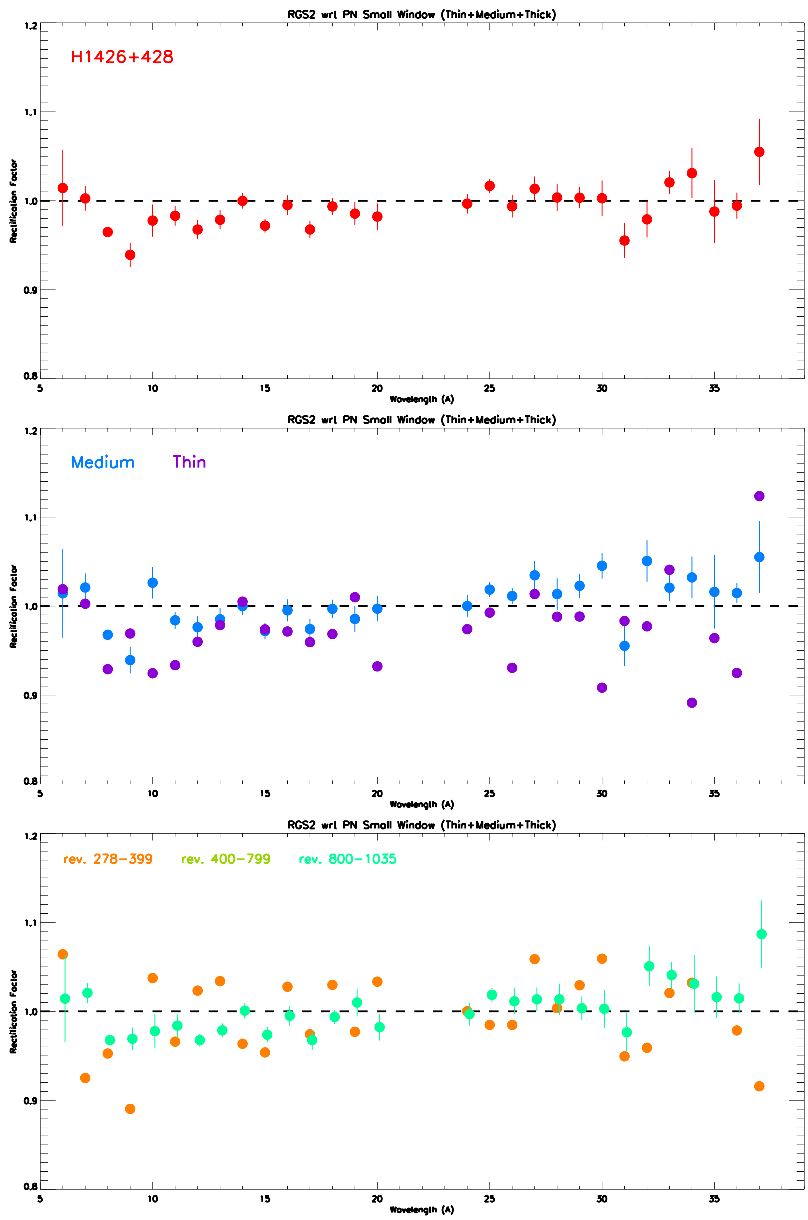


Figure 41: Summary of the results for H1426+428, RGS 2. From top to bottom, average rectification factor, by filter, and by epoch.

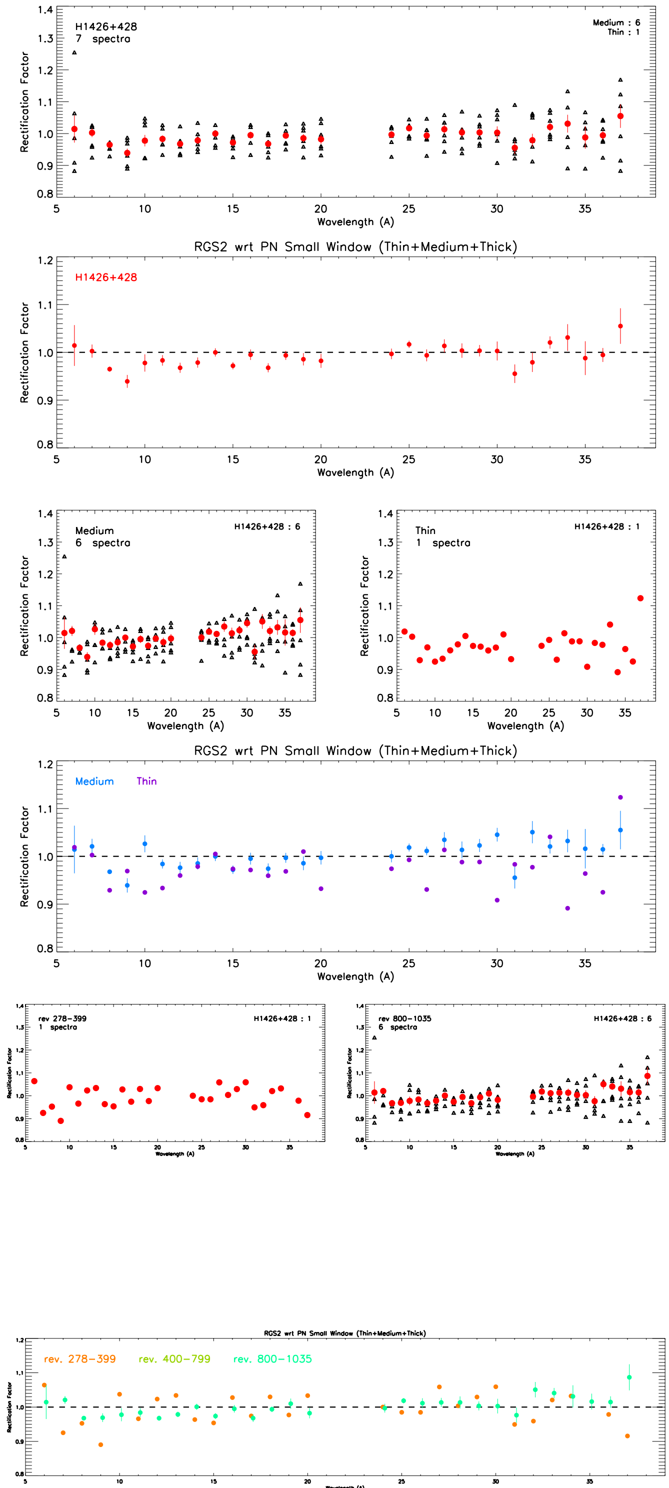


Figure 42: RGS 2 rectification factors for H1426+428. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

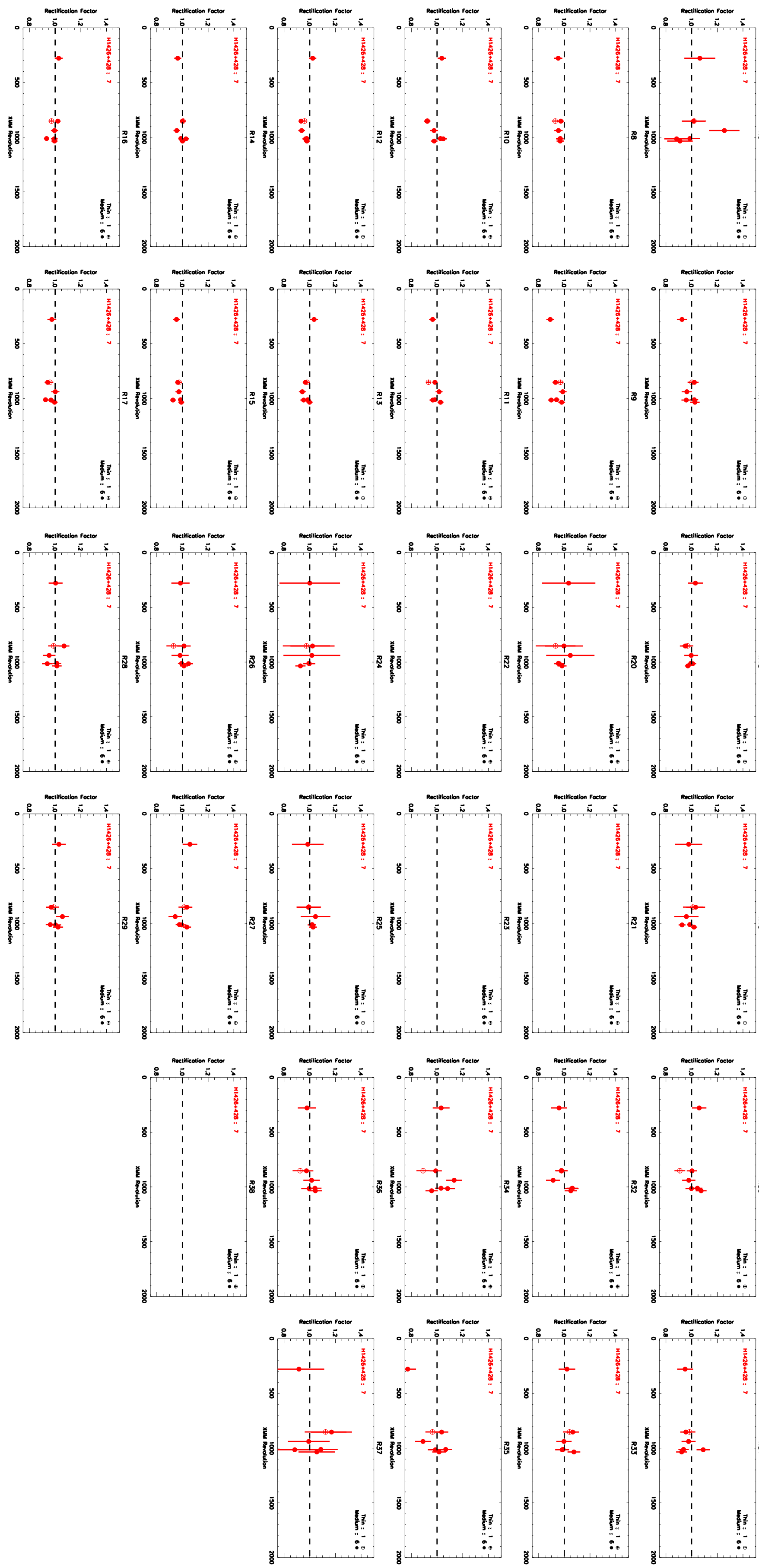


Figure 43: Time evolution of the RGS 2 rectification factors for H1426+428.

16.2.3 PKS 2155-304

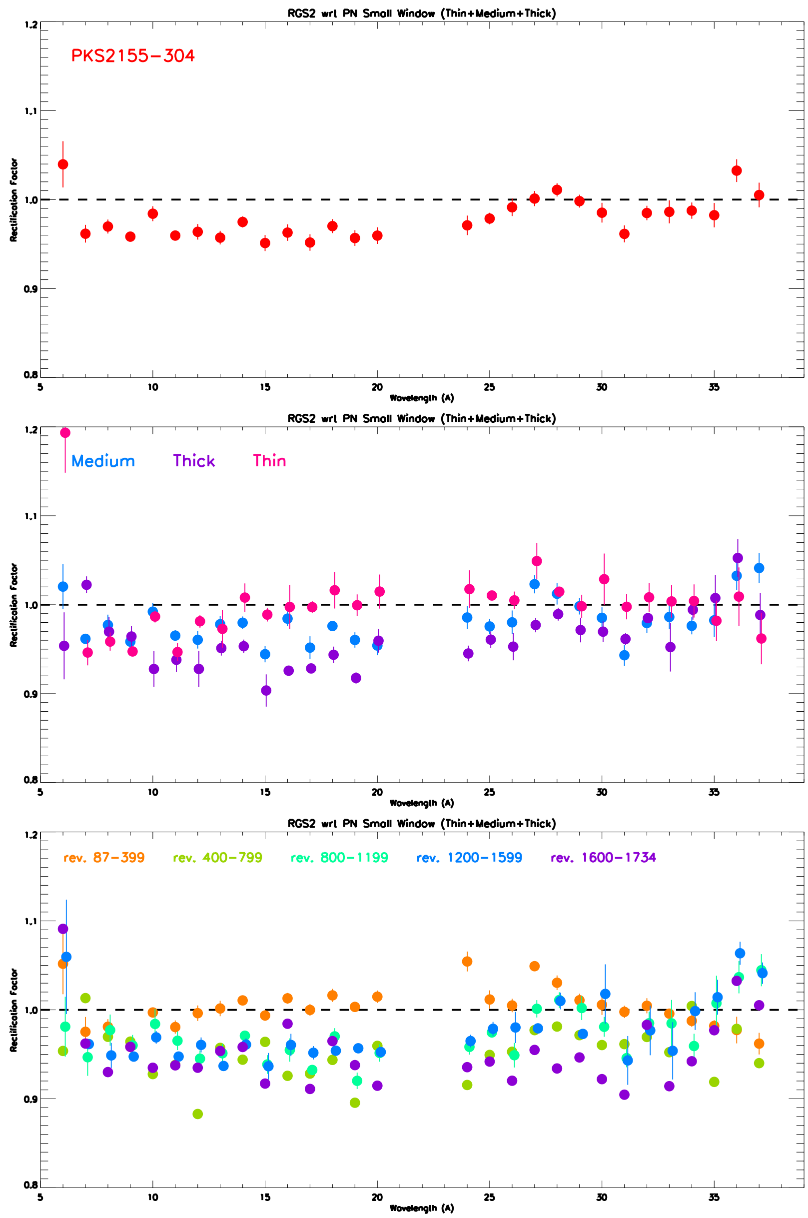


Figure 44: Summary of the results for PKS 2155-304, RGS 2. From top to bottom, average rectification factor, by filter, and by epoch.

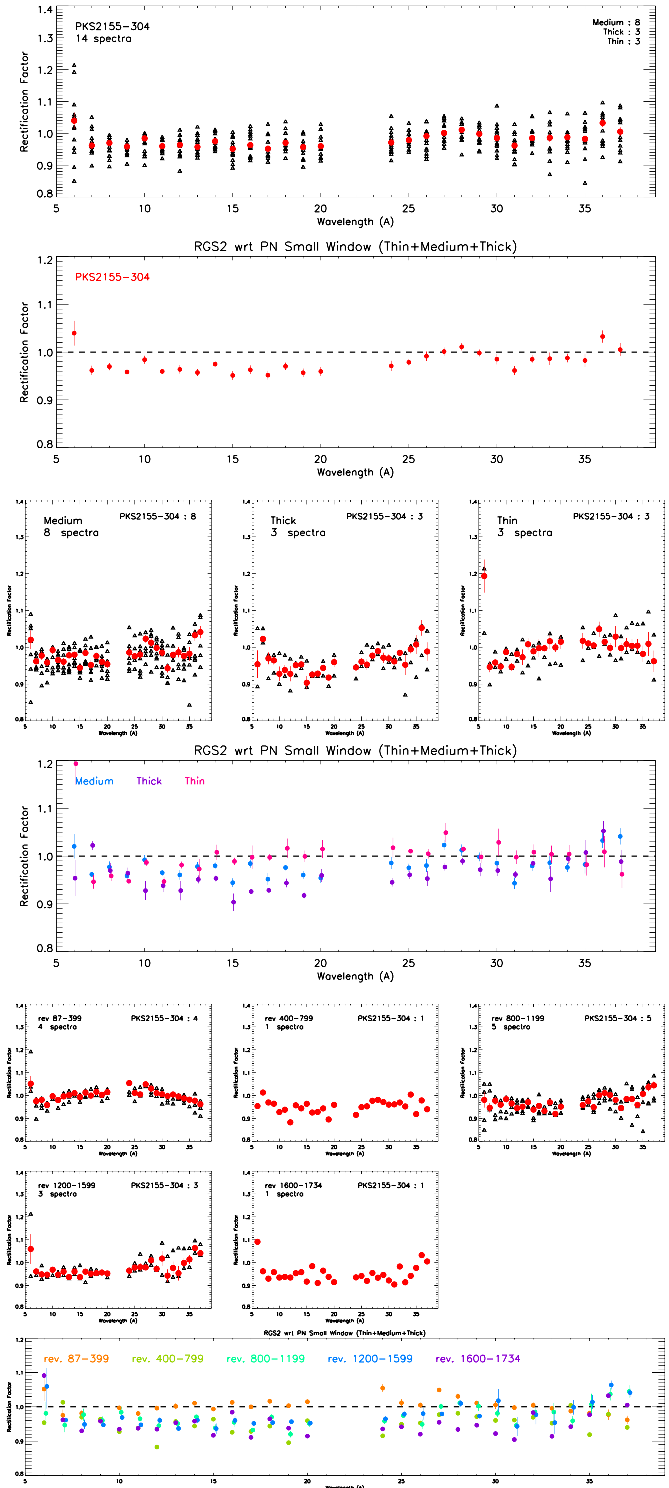


Figure 45: RGS 2 rectification factors for PKS 2155-304. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

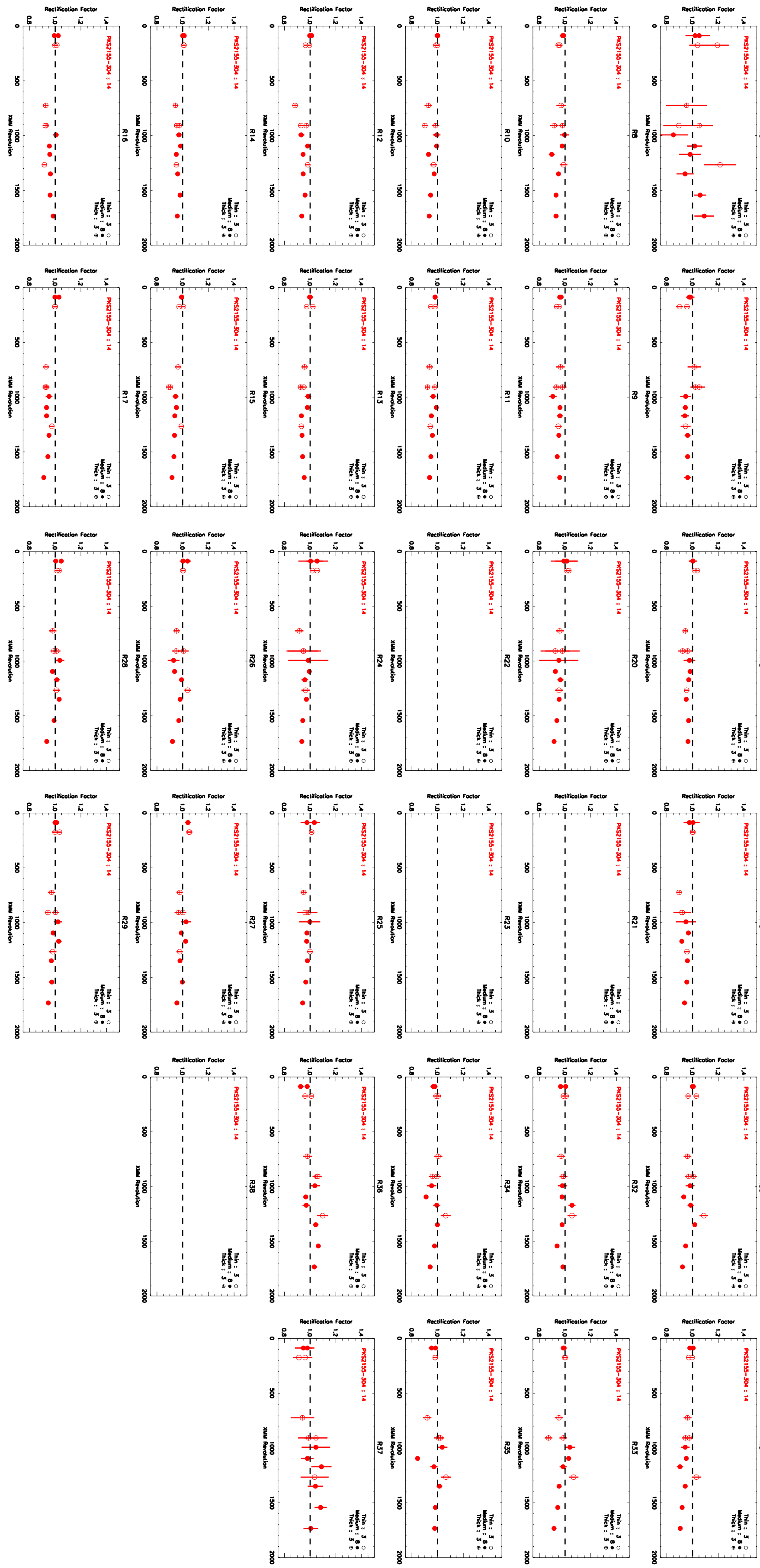


Figure 46: Time evolution of the RGS 2 rectification factors for PKS 2155-304.

16.2.4 RX J1856.6-3754

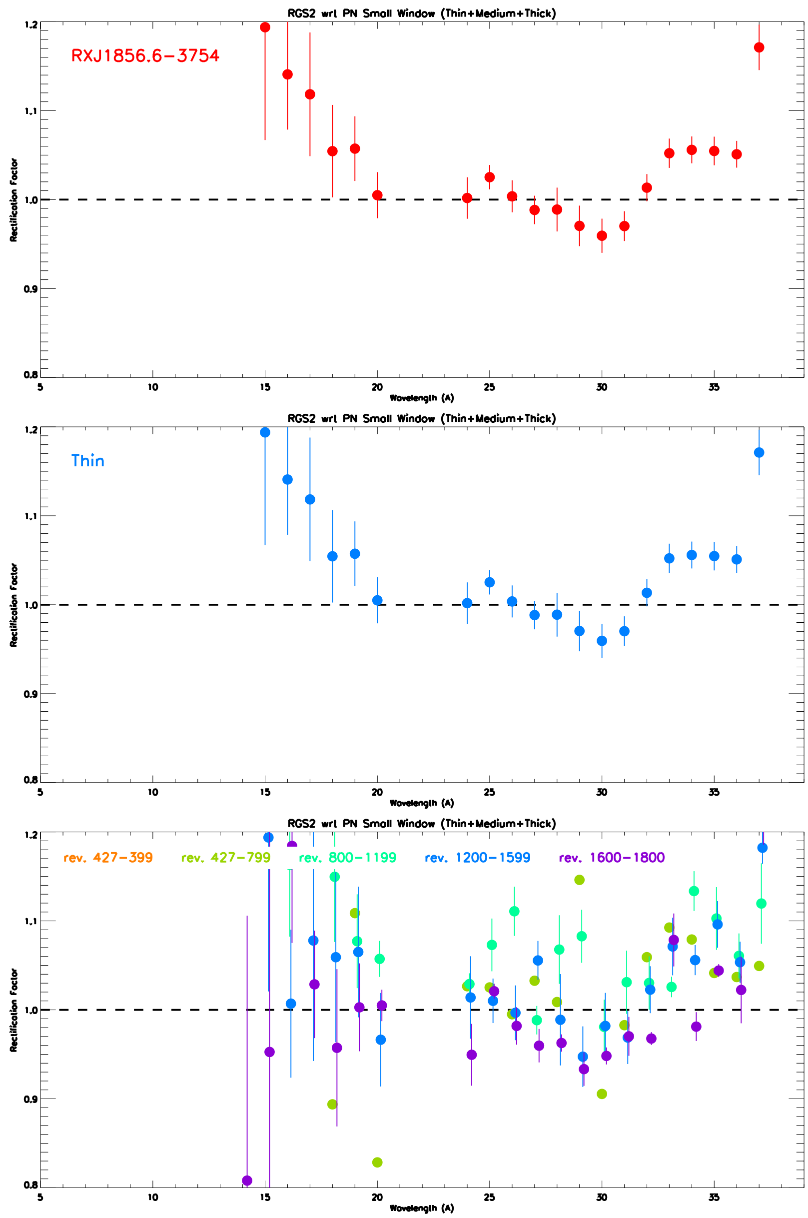


Figure 47: Summary of the results for RX J1856.6-3754, RGS 2. From top to bottom, average rectification factor, by filter, and by epoch.

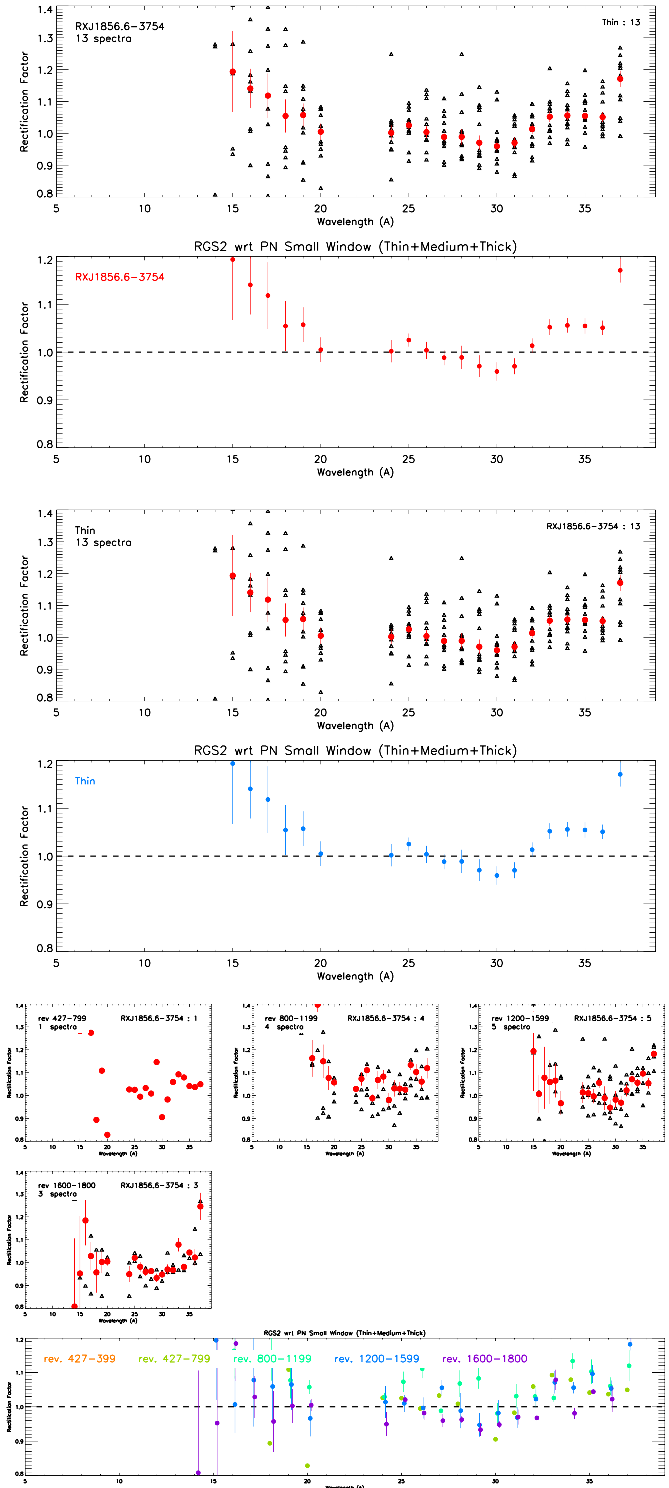


Figure 48: RGS 2 rectification factors for RX J1856.6-3754. In the top panels, black symbols represent individual observations, and red points the average and standard deviation. The bottom panel shows the average factor, and the factors by filter and by epoch

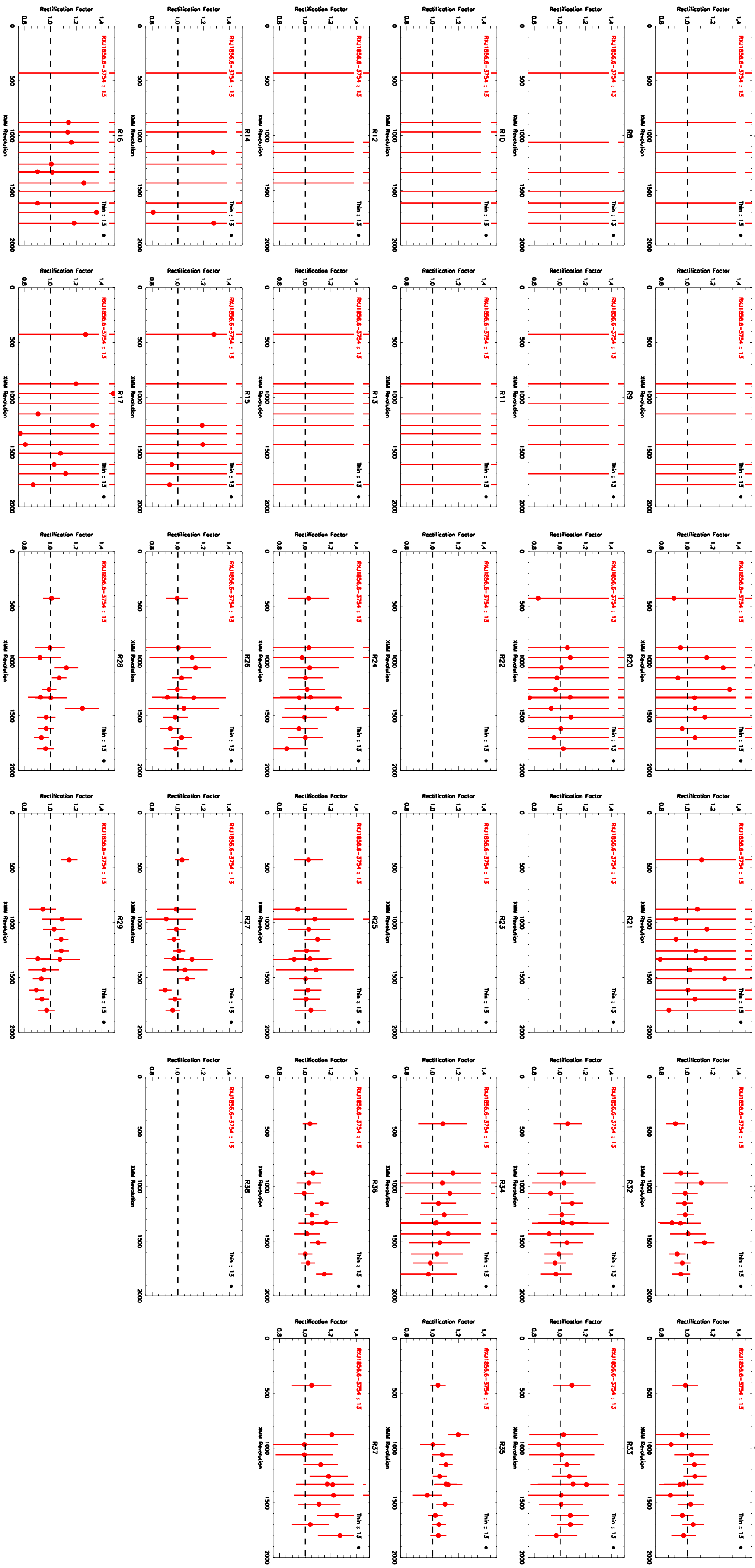


Figure 49: Time evolution of the RGS 2 rectification factors for RX J1856.6-3754.