A study of the C IV BALs in HiBALQSOs spectra

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BALQSOs absorption lines

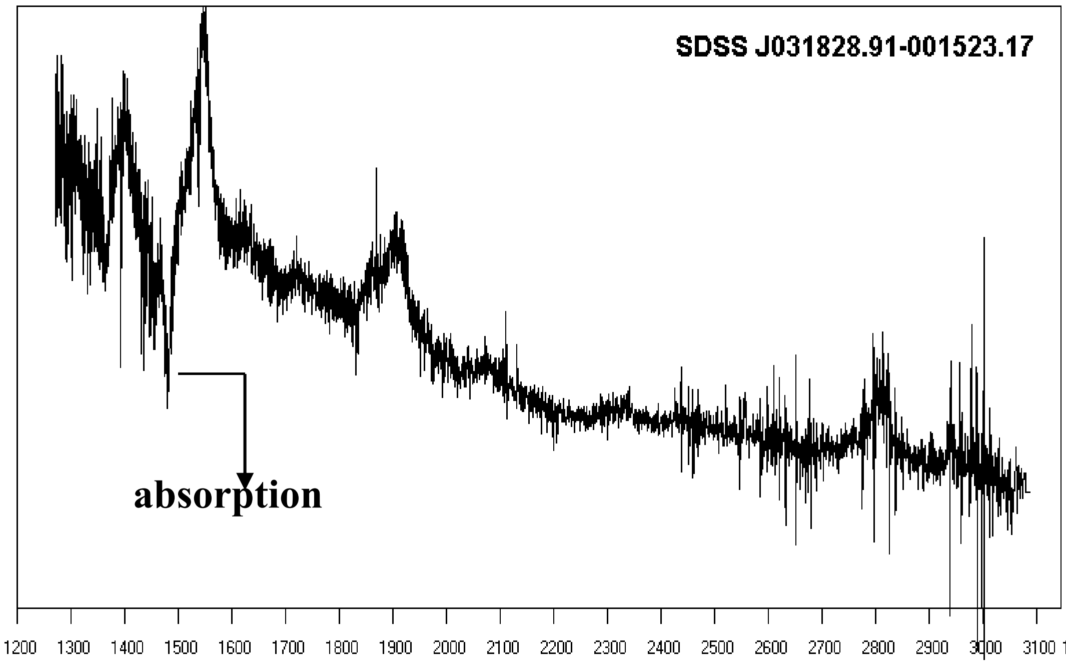
Approximately about **10% of all quasars present broad, blue shifted absorption lines.** The outflow velocity can reach up to **0.1 0.2 c**.

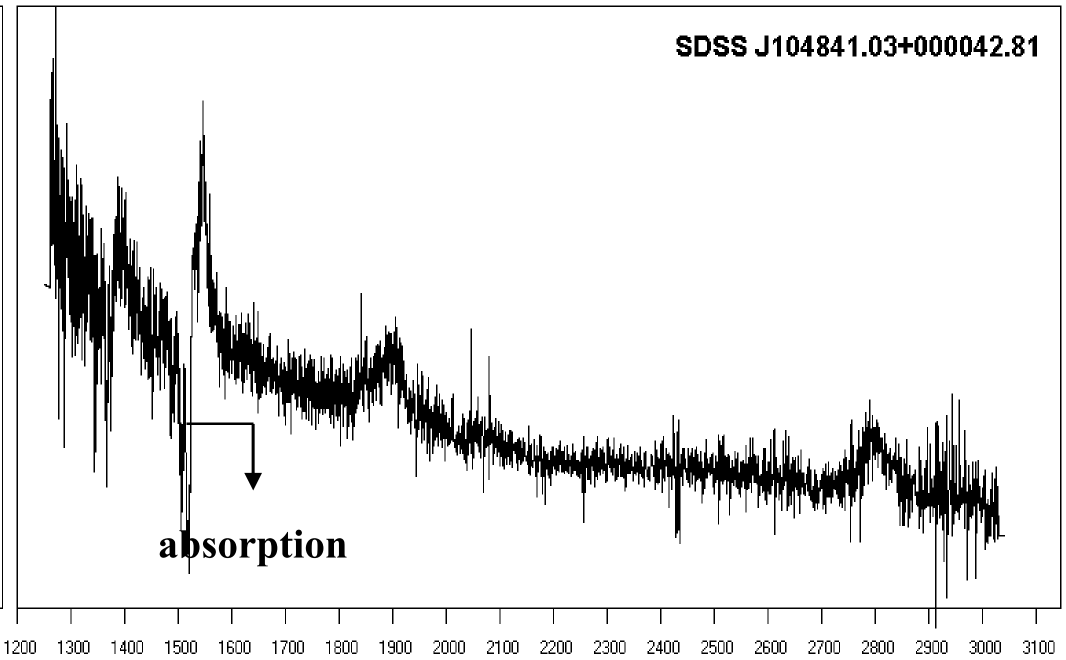
Usually, in their spectra we observe the lines of high ionization species as **C IV λ 1549 Å, Si IV λ 1397 Å, N V λ 1240 Å** and **Lya**.

Rarely some low ionization lines, such as **Mg II λ 2798 Å** and **Al III λ 1857 Å**, also exhibit broad absorption lines (see e.g. Hamann et al., 1993; Crenshaw et al., 2003).

Broad absorption lines can have **different shapes.**

Also different types of these objects may have **differences in their continua** (Reichard et al. 2003).



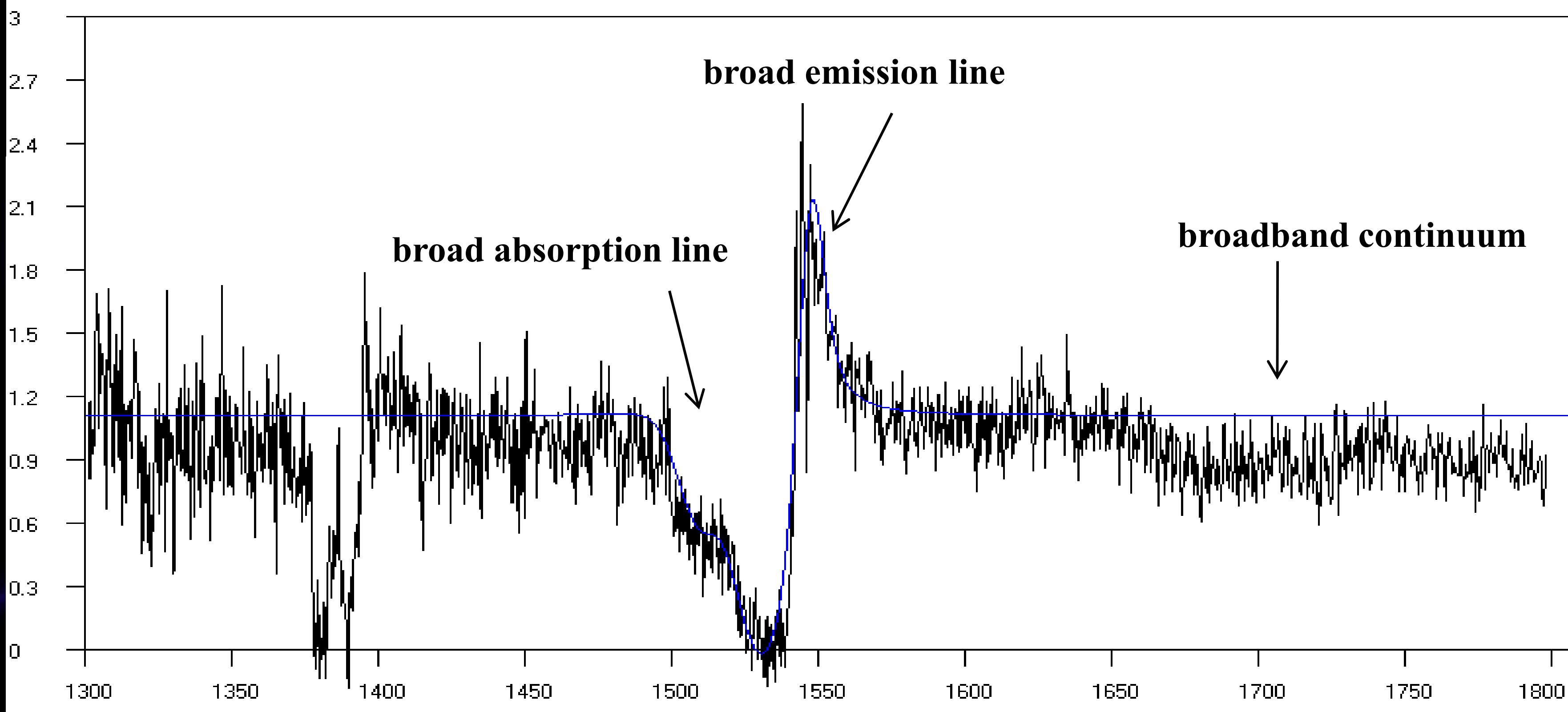


Some first propositions for BALQSOs

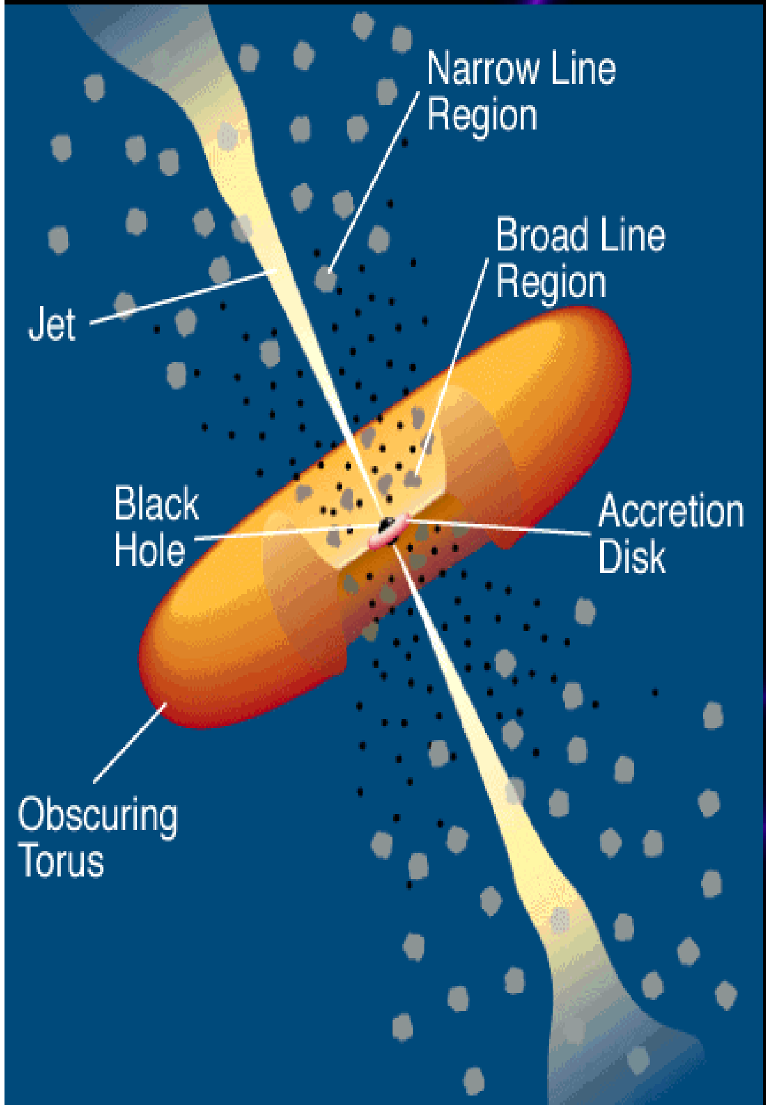
One proposed explanation of the Broad Absorption Line (BAL) phenomenon is that BALQSOs and non-BALQSOs are distinct populations of objects (Surdej & Hutsemekers 1987).

Similarly, some have argued that only low-ionization BALQSOs (LoBALs) are a different class of quasars (Boroson & Meyers 1992).

Others suggest that BALQSOs and non-BALQSOs are the same type of quasars but viewed from different orientations (Weymann et al. 1991; Ogle et al. 1999; Schmidt & Hines 1999) or at different stages in their life cycles (Becker et al. 2000).



The spectrum of a Broad Absorption Line Quasar (BALQSO) is usually interpreted as a combination of (i) a broadband continuum arising from the central engine, (ii) the broad emission lines coming from the Broad Emission Line Regions (BELR), emerging near the center of the QSO and (iii) the broad absorption lines that are superposed, originating in a separate outlying region – Broad Absorption Line Region (BALR). But, it is also possible, that emission and absorption occur in the same line-forming region (Branch et al., 2002).



An important question is: **Which are the physical connections between the BLR and BALR?** This is also important, since at least a part of the BLR seems to be originated from wind of accretion disk (see Murray and Chiang, 1998; Popović et al. 2004).

Another question is: **Where is the BALR placed with respect to the center of a BALQSO and the Broad Line Region?** To answer this question, one should investigate the kinematical properties of the emission and absorption lines.

Disk wind models (Murray and Chiang 1998, Proga et al. 2000, Williams et al. 1999) explain many properties of BAL quasars, but it is unclear if they can explain the full range of BAL profiles and column densities.

BALs are caused by outflowing gas intrinsic to the quasar and are not produced by galaxies along the line of sight (as is the case for most narrow-absorption systems).

Determining whether a quasar is a BALQSO is a complicated task. The standard method is to calculate the "balnicity" index (BI), defined by Weymann et al. (1991).

A BI of zero indicates that broad absorption is absent, while a positive BI indicates not only the presence of one or more broad absorption lines but also the amount of absorption.

The Balnicity Index (BI)

The BI is essentially a modified equivalent width expressed in velocity units and is defined as follows:

1. Absorption should appear between 3000 and 25000 km/s blueward of C IV emission redshift and

2. At this place and for at least 2000 km/s the absorption must fall at least 10% below the continuum.

BIs can range from 0 to 20000 km/s.

BI limits

• The 25000 km/s limit is chosen to avoid emission and absorption from Si IV.

•Absorption lines within 3000 km/s with width smaller than 2000 km/s are excluded to avoid contamination from absorption that might not be due to an outflow.

These lines are called "associated absorption lines" (Foltz et al. 1986).

Some of these associated systems are known to be intrinsic outflows, but others may simply be the result of absorption in the host galaxy or a nearby galaxy.

BALQSOs: those quasars with C IV absorption at least 2000 km/s broad, located between 3000 and 25000 km/s blueward of the emission (or Mg II absorption 1000 km/s broad between 0 and 25000 km/s blueward of the emission.

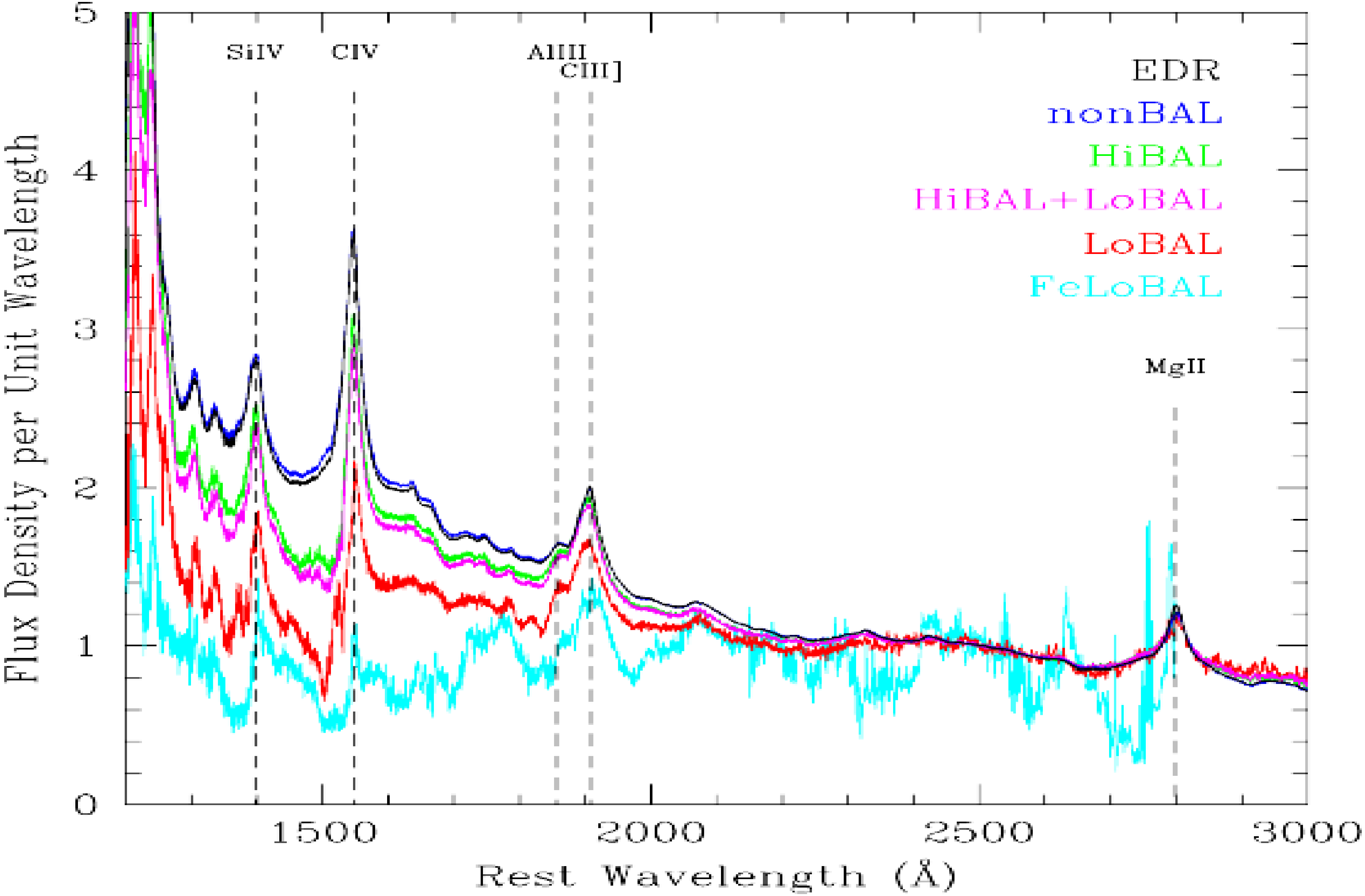
HiBAL: broad absorption trough just blueward of C IV emission lines.

LoBAL: broad absorption troughs just blueward of both the C IV and Mg II emission lines.

non-BAL: no broad absorption troughs just blueward of the C IV and Mg II emission lines.

FeLoBALs: BALQSOs with excited iron absorption features.

Composite spectra of all categories (Richards et al. 2001)

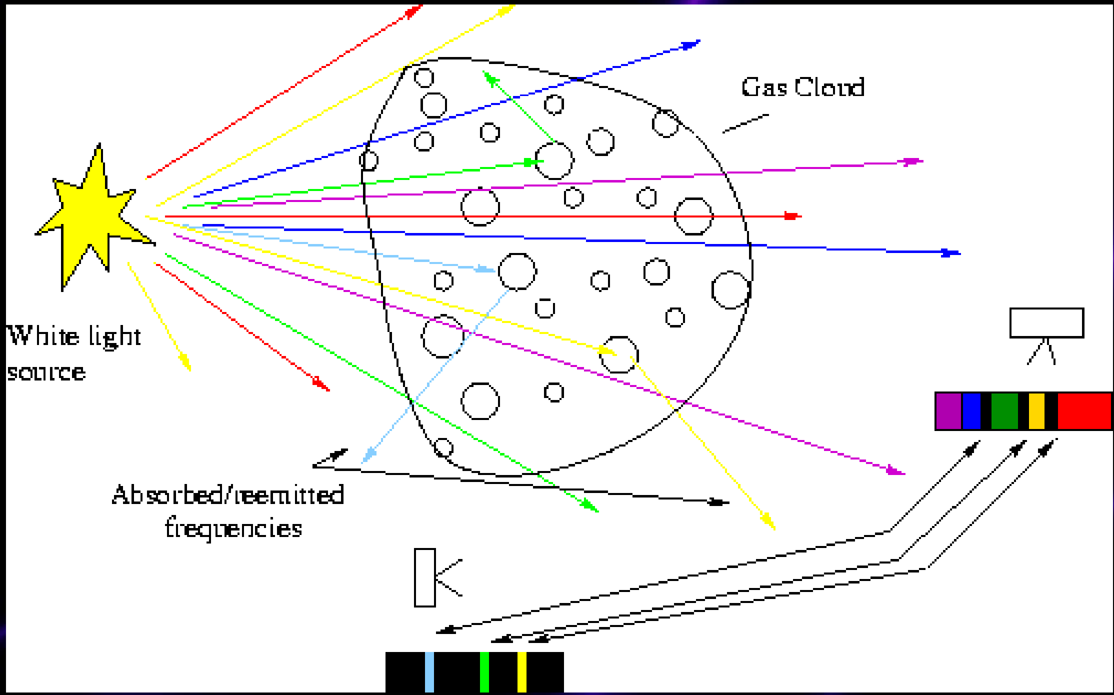


Very Complex Profiles of BALs

The problem

Most of BALs in QSOs present very complex profiles. This means that we cannot fit the observed profiles with a known physical distribution.

An idea about the BALs very complex profiles

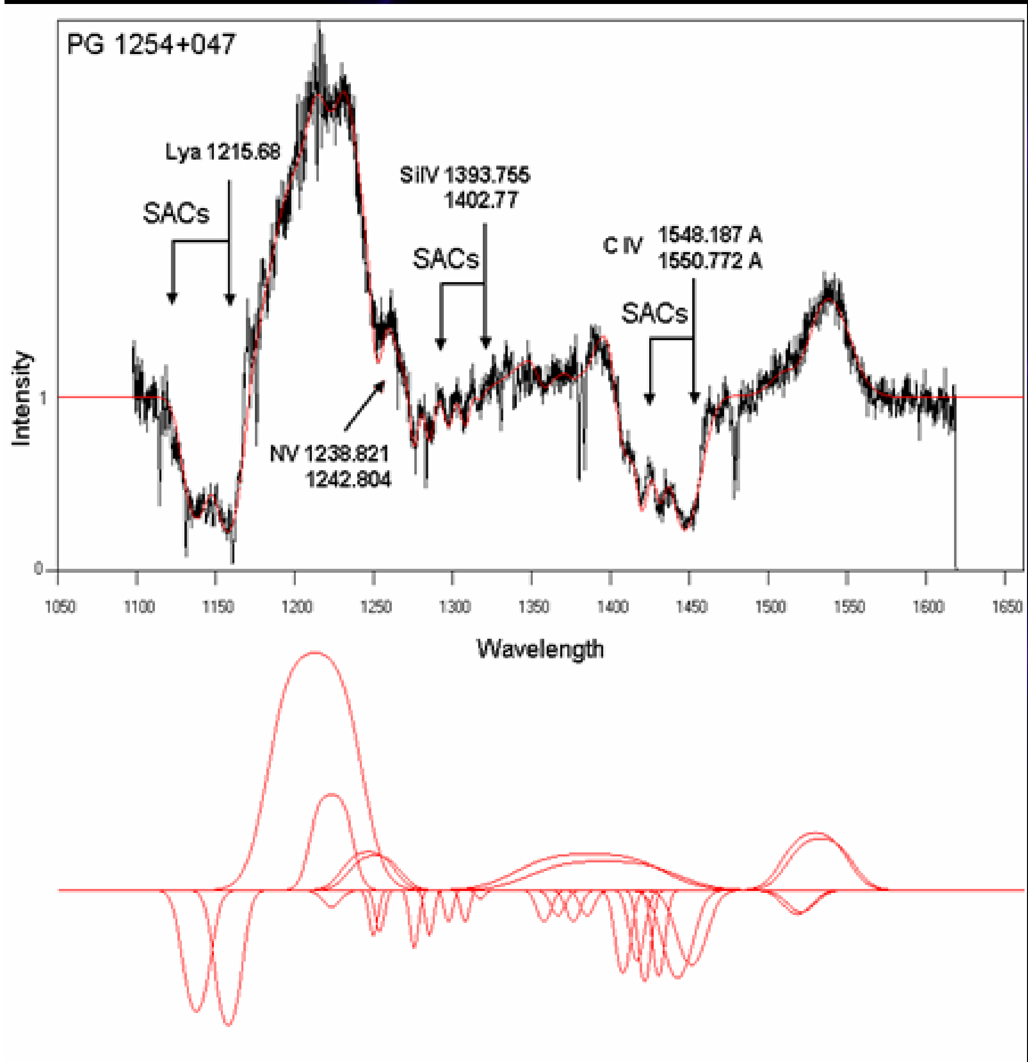


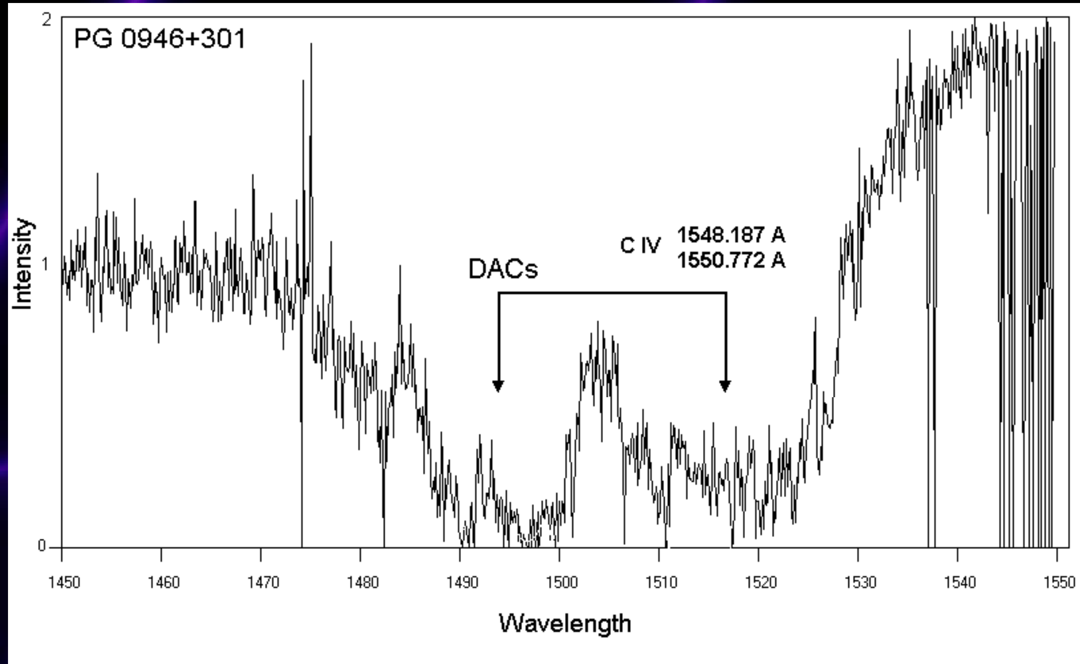
The dynamical systems of BLRs are not homogeneous but consist of a number of density regions or ion populations with different physical parameters

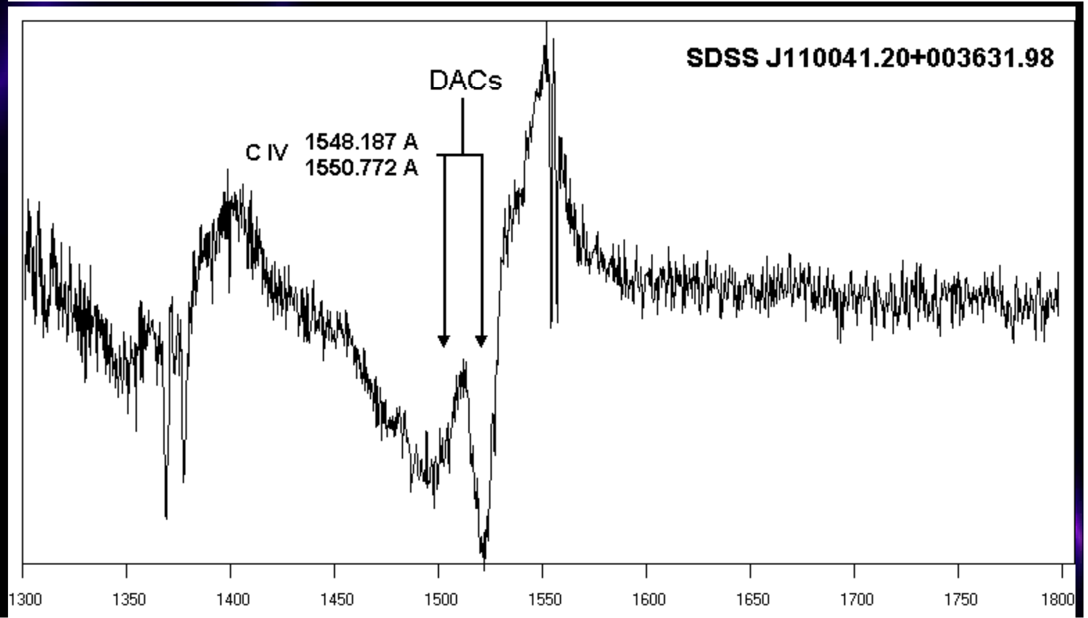
An idea about the BALs very complex profiles

Each one of these density regions gives us an independent classical absorption line.
If the regions that give rise to such lines move radially with small velocities and rotate with large velocities, or their ions present very quick random motions, then the produced lines have small shifts and large widths.
As a result they are blended among themselves and thus they are not discrete.

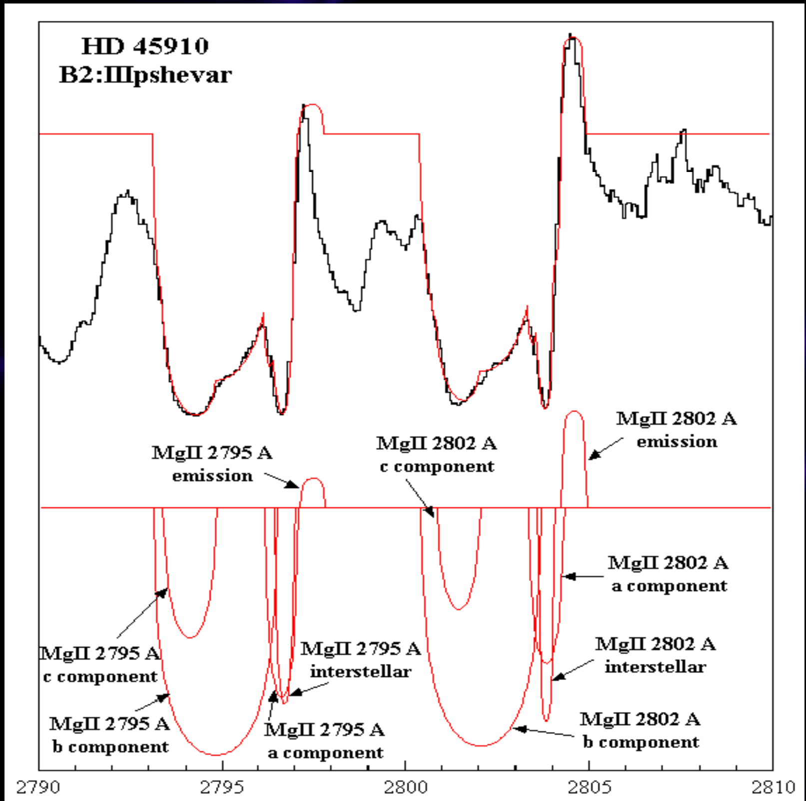
Some QSOs present complex profiles

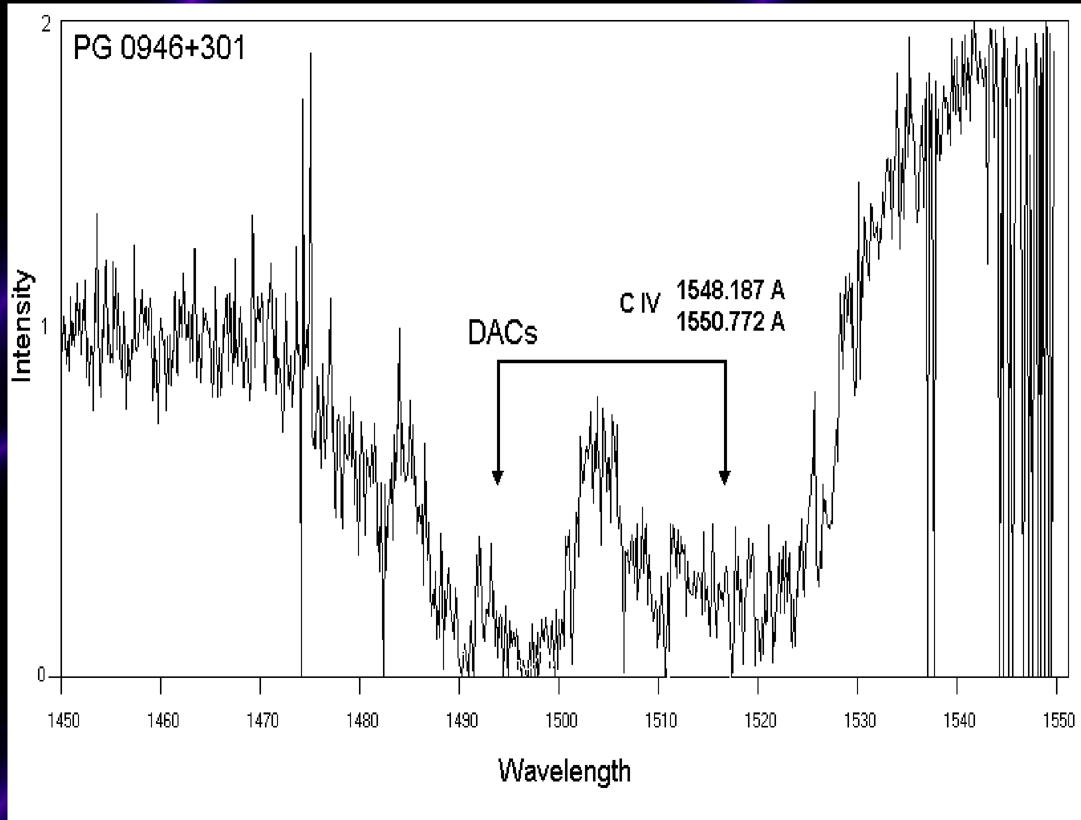






The complex line profiles in the spectra of Hot emission stars





A similar phenomenon can explain the very complex profiles of a great number of very broad lines in the spectra of hot emission stars

(Danezis et al. 2007, PASJ, 59, 827, Danezis et al. 2009, NewAR, 53, 214, Lyratzi et al. 2007, PASJ, 59, 357, Antoniou et al. 2009, CoAst, 159, 119)

The complex line profiles in the spectra of QSOs

In the spectra of QSOs, the system of Broad Absorption Lines and the "Associated" Absorption Lines that arise from the studied QSO (the most broad ones), create the proposed multi-structure phenomena.

Maybe, the BALs that we cannot fit with a classical distribution, as they have a very complex profile, are a combination of many absorption components that arise from a number of density regions or ion populations with different physical parameters.

The Method

Since we detected the multi-structure phenomena in QSOs, we use the **GR model (Gauss-Rotation model)**, in order to study the complex line shapes observed in BALQSOs. (Danezis et al., 2006, 2007, Lyratzi et al. 2009).

The proposed model is relatively simple, aiming to describe the regions where the spectral lines are created.

We assume that the BALR and BELR are composed of a number of successive independent absorbing/emitting density layers of matter (that are originated in a disk wind). The absorbing, or emitting, regions have three apparent velocities (projected on the line-of-sight of the observer):

(i) velocity of outflow

(ii) random velocity of ions in the BLR

(iii) possible rotational velocity.

These velocities can be calculated using the GR model.

Additionally with the GR model we can calculate :

1. The Full Width at Half Maximum (FWHM) of all the absorption components of the studied spectral lines
2. The optical depth of the independent regions of matter which produce all the absorption components of the studied spectral lines
3. The absorbed and the emitted energy of the independent regions of matter which produce all the absorption components of the studied spectral lines
4. The column density of the independent regions of matter which produce all the absorption components of the studied spectral lines.

Broadening Mechanisms

The relevant broadening mechanisms in the case of BALs is random motion of absorbing gas, but also, a part of rotation caused by massive black hole. In order to find the limits for rotational and random velocities, we fit the observed lines using two approaches:

(a) assuming that random motion is dominant, i.e. random velocity is maximal and rotational component is minimal (in this case we will say that it is GR approach),

(b) assuming that rotational component is dominant (so called RG approach).

After that we use F-test to conclude on which approach of the model is more appropriate to explain the complex absorption line profiles.

In our work, which is in progress, we study BALs of QSOs with different Balnicity Index, using the GR model.

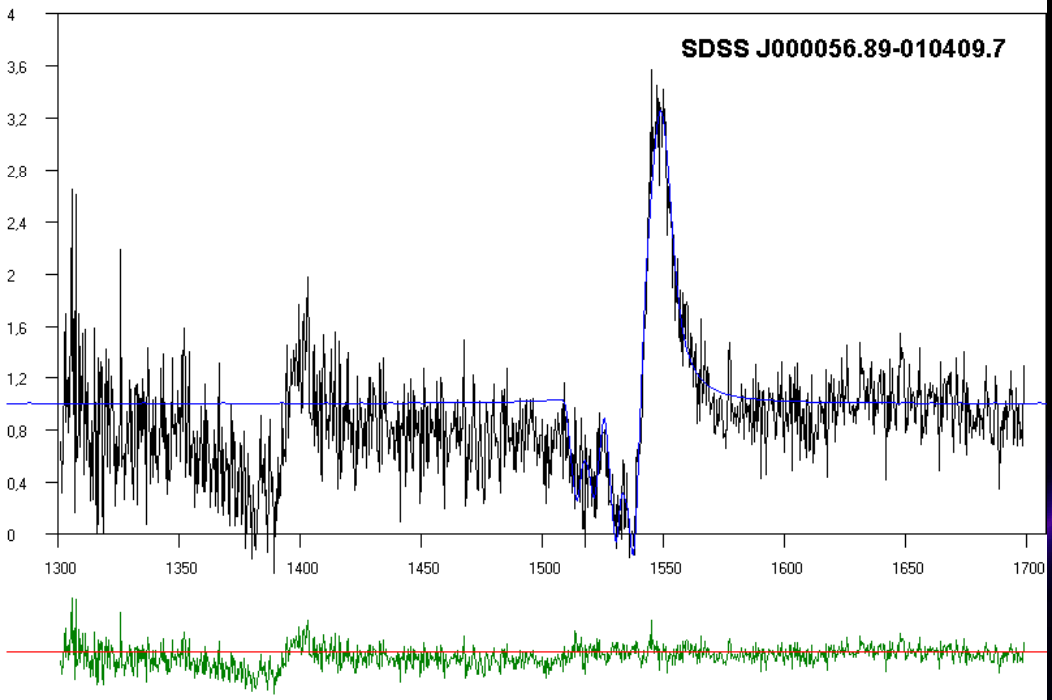
Here we present a part of this work, where we study BALs of C IV in the spectra of Hi BALQSOs.

Data

In order to study the C IV resonance lines ($\lambda\lambda$ 1548.187, 1550.772 Å) we apply the GR model to the spectra of 30 broad absorption line quasars (BALQSOs) taken from the Sloan Digital Sky Survey's Data Release 7. The SDSS imaging survey uses a wide-field multi-CCD camera (Gunn et al. 1998). The spectra cover the optical range 3800–9200 Å at a resolution of 1800–2100.

In the following Table, column 1 lists the name of the QSOs, using the SDSS format of J2000.0 right ascension (hhmmss.ss) and declination (±ddmmss.s), columns 2 lists the modified Julian date-plate-fiber, column 3 lists the redshift and column 4 lists the dates of observations.

Object Name (SDSS)	MJD-Plate-Fiber	Redshift	Date
J000056.89-010409.7	51791-0387-098	2,12325	4/9/2000 7:08
J001025.90+005447.6	51795-0389-332	2,84727	7/9/2000 6:08
J001438.28-010750.1	51795-0389-211	1,81564	7/9/2000 6:08
J001502.26+001212.4	51795-0389-465	2,85152	7/9/2000 6:08
J002127.88+010420.1	51900-0390-443	1,81965	7/12/2000 1:57
J003551.98+005726.4	51793-0392-449	1,90110	6/9/2000 8:20
J004041.39-005537.3	51794-0393-298	2,09094	7/9/2000 8:10
J004118.59+001742.4	51793-0392-631	1,76485	6/9/2000 8:20
J004323.43-001552.4	51794-0393-181	2,81671	7/9/2000 8:10
J004732.73+002111.3	51794-0393-588	2,87768	7/9/2000 8:10
J005355.15-000309.3	51783-0395-352	1,71893	27/8/2000 9:41
J005419.99+002727.9	51876-0394-514	2,51946	21/11/2000 2:17
J010241.04-004208.9	51816-0396-261	1,74475	29/9/2000 8:28
J010336.40-005508.7	51816-0396-297	2,44295	29/9/2000 8:28
J011227.60-011221.7	51794-0397-122	1,75767	7/9/2000 10:05
J015024.44+004432.99	51793-0402-485	2,00596	6/9/2000 10:06
J015048.83+004126.29	51793-0402-505	3,70225	6/9/2000 10:06
J021327.25-001446.92	51816-0405-197	2,39948	29/9/2000 9:57
J023252.80-001351.17	51820-0407-158	2,03289	3/10/2000 9:41
J023908.99-002121.42	51821-0408-179	3,74	4/10/2000 9:38
J025331.93+001624.79	51816-0410-391	1,8214	24/9/2000 11:26
J025747.75-000502.91	51816-0410-117	2,19139	24/9/2000 11:26
J031828.91-001523.17	51929-0413-170	1,98447	20/1/2001 4:23
J102517.58+003422.17	51941-0272-501	1,88842	1/2/2001 9:30
J104109.86+001051.76	51913-0274-482	2,25924	4/1/2001 11:00
J104152.62-001102.18	51913-0274-159	1,70876	4/1/2001 11:00
J104841.03+000042.81	51909-0276-310	2,03044	31/12/2000 11:08
J110041.20+003631.98	51908-0277-437	2,01143	30/12/2000 11:19
J110736.68+000329.60	51900-0278-271	1,74162	22/12/2000 12:12
J112602.81+003418.23	51614-0281-432	1,7819	11/3/2000 6:52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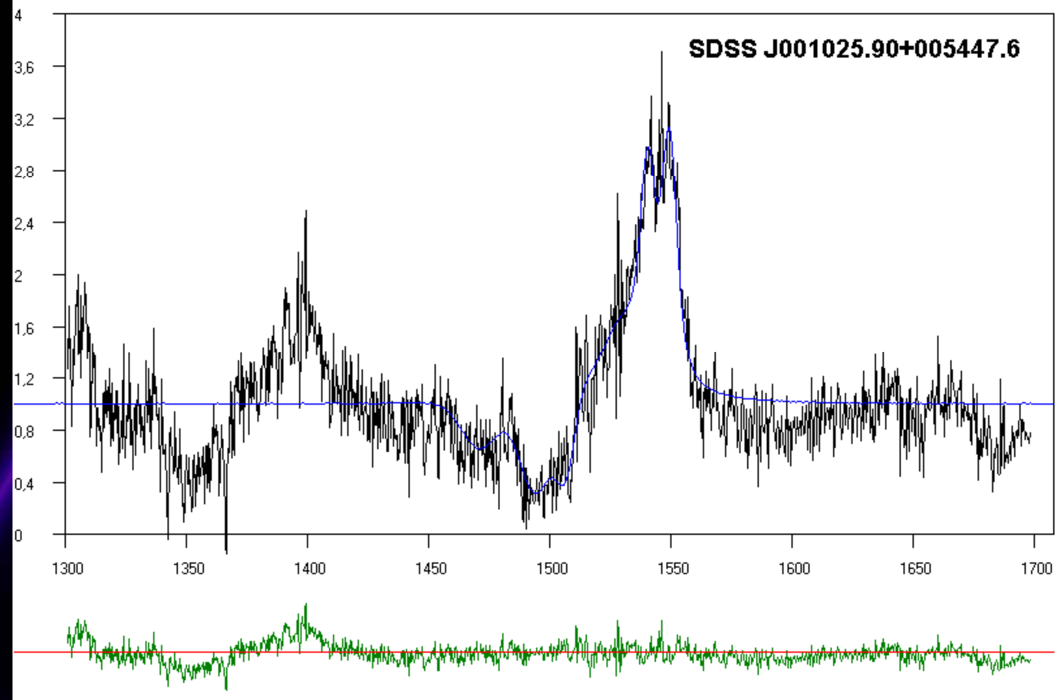
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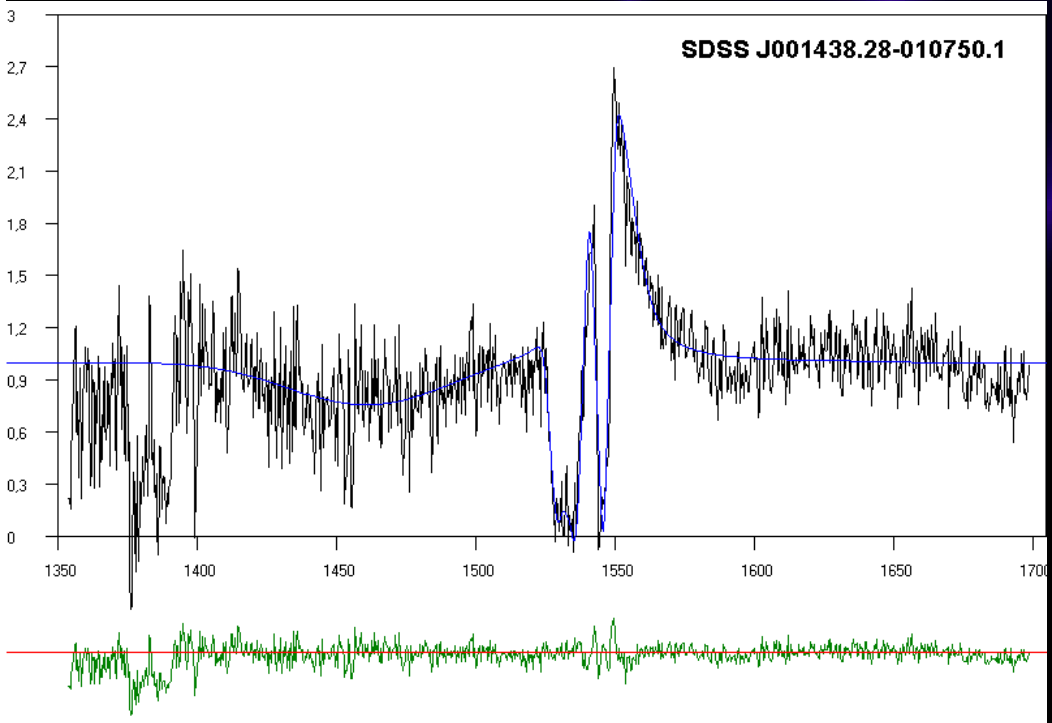
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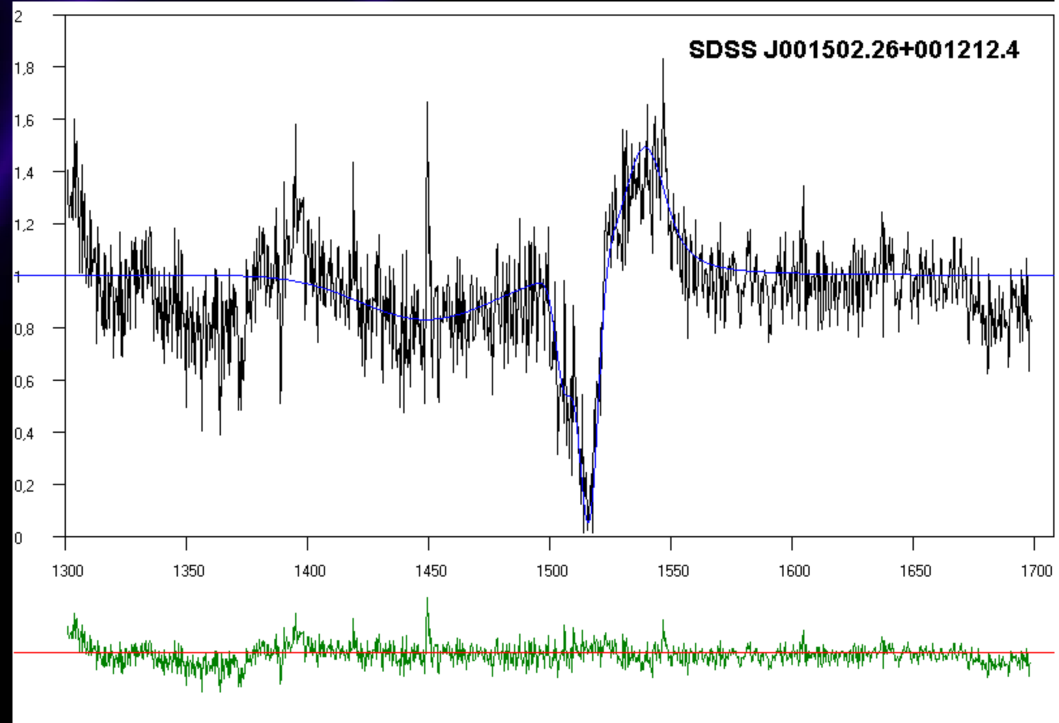
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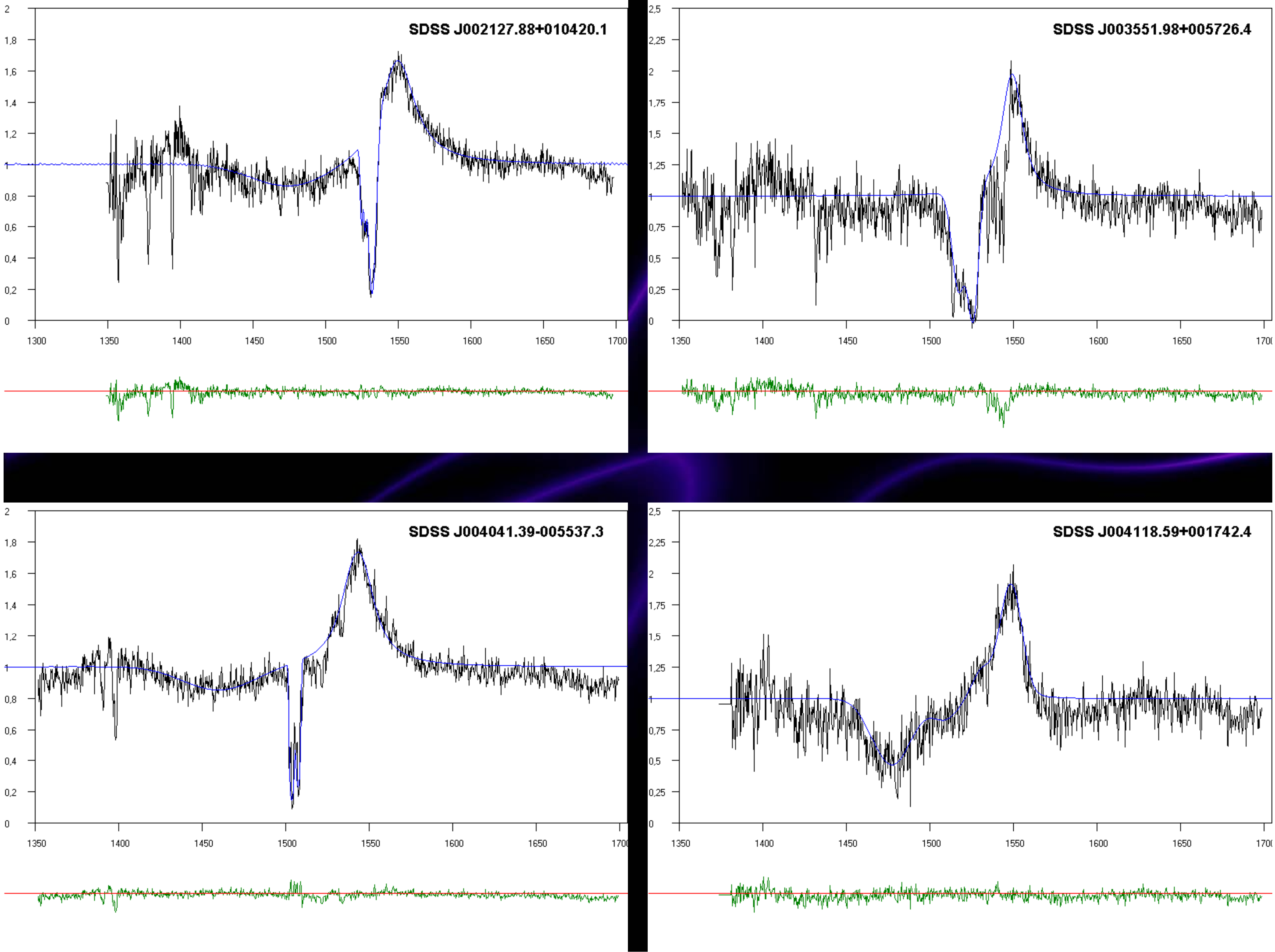
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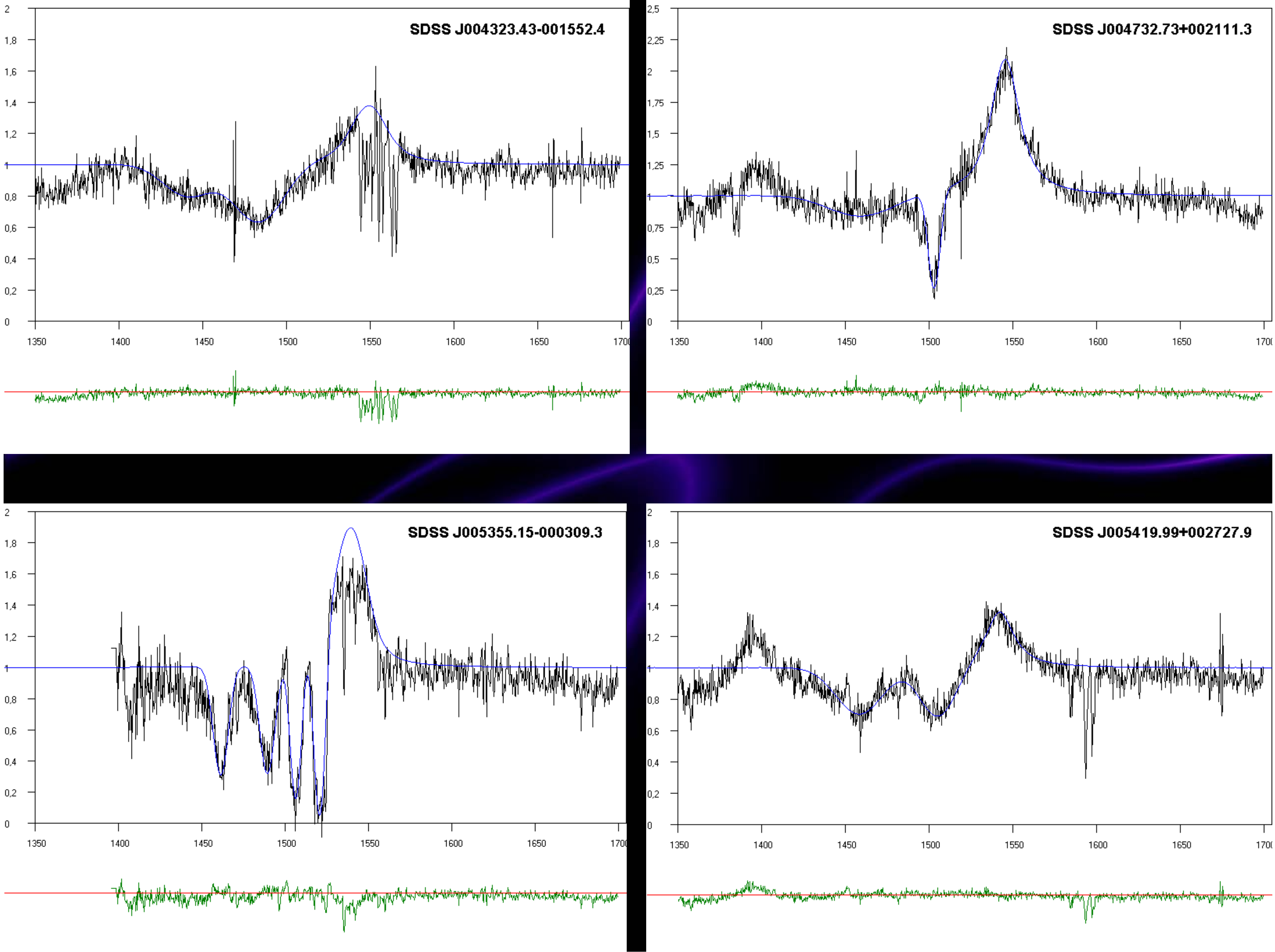
SDSS J004041.39-005537.3
SDSS J004118.59+001742.4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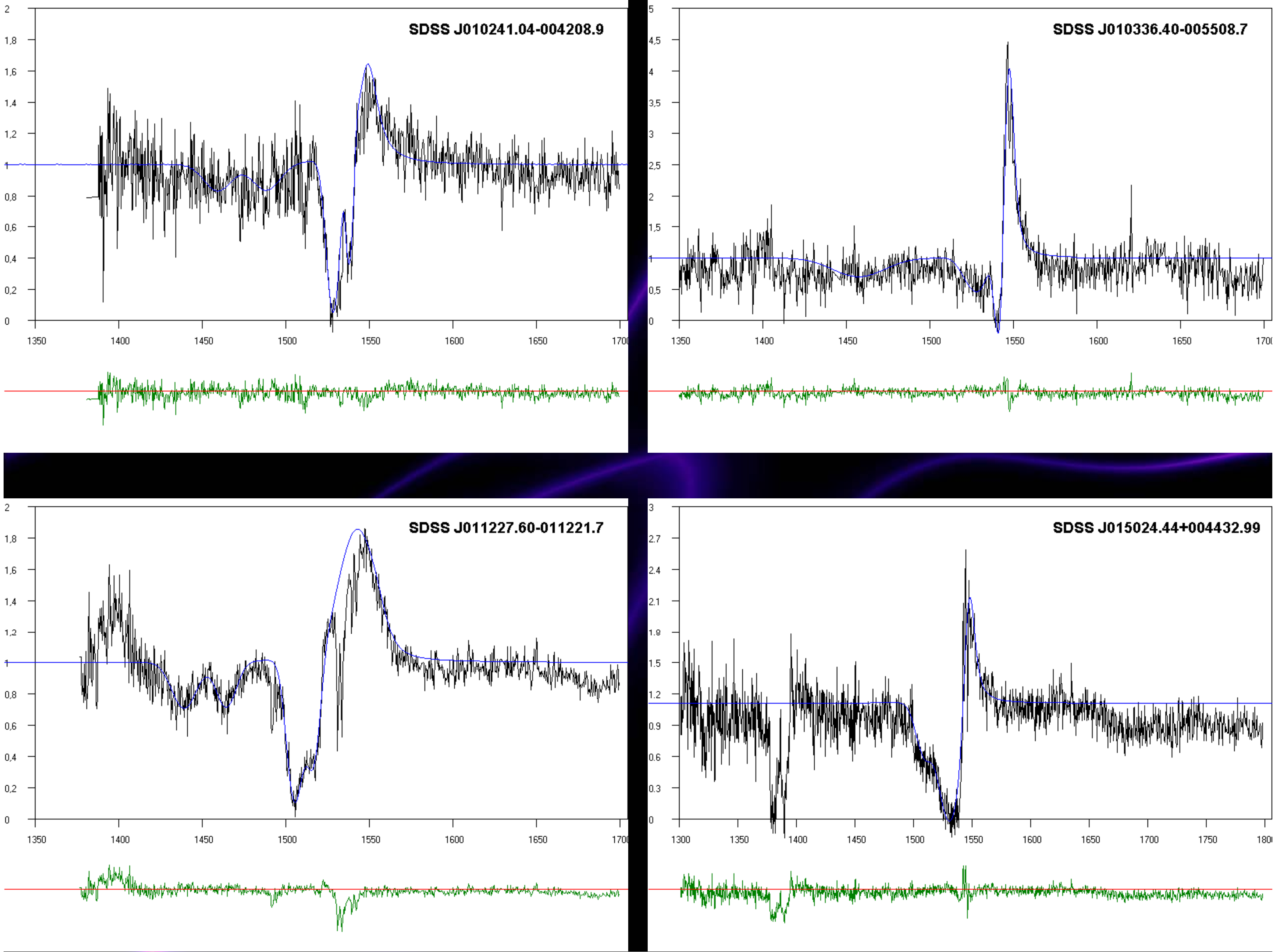

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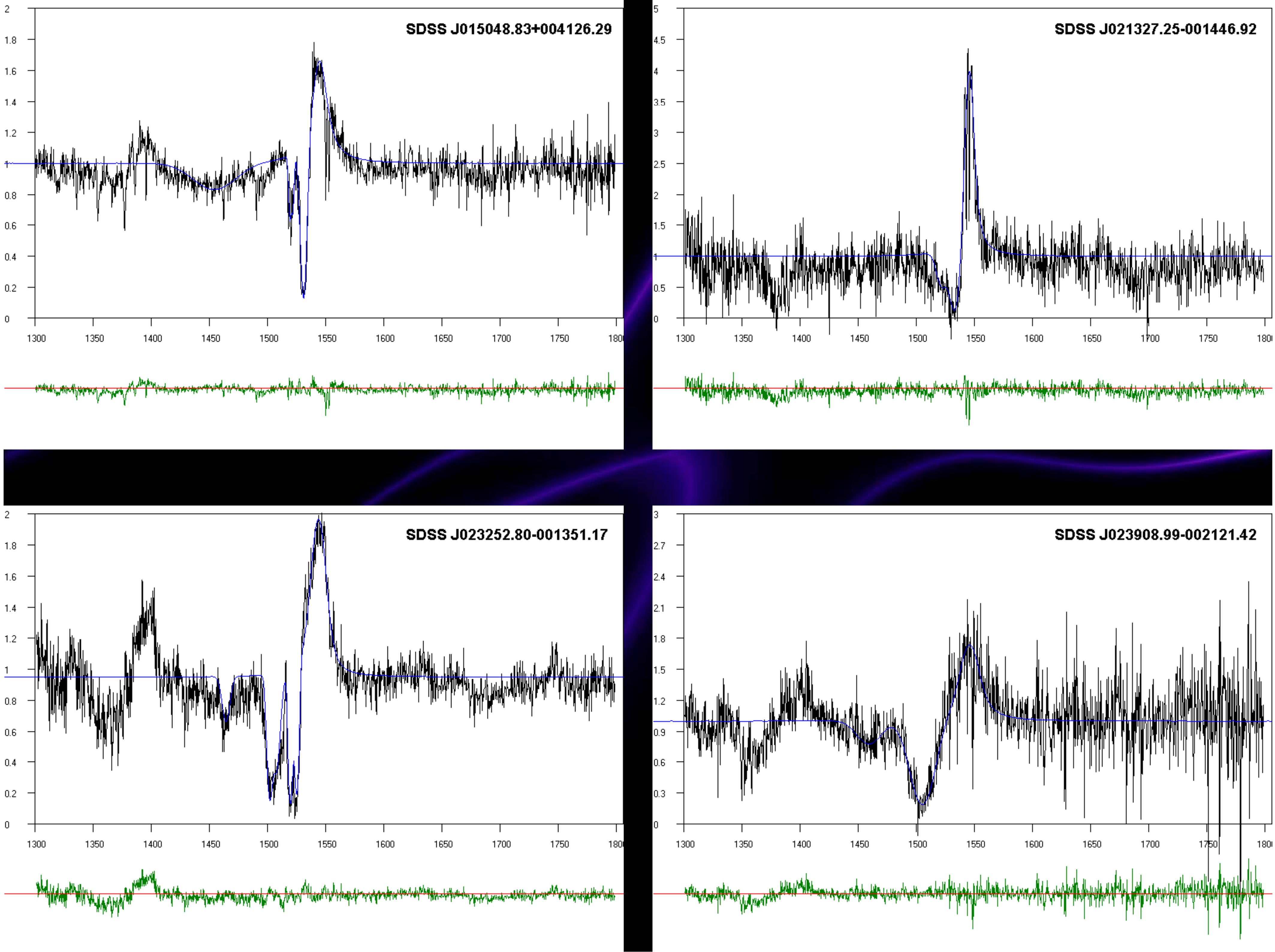
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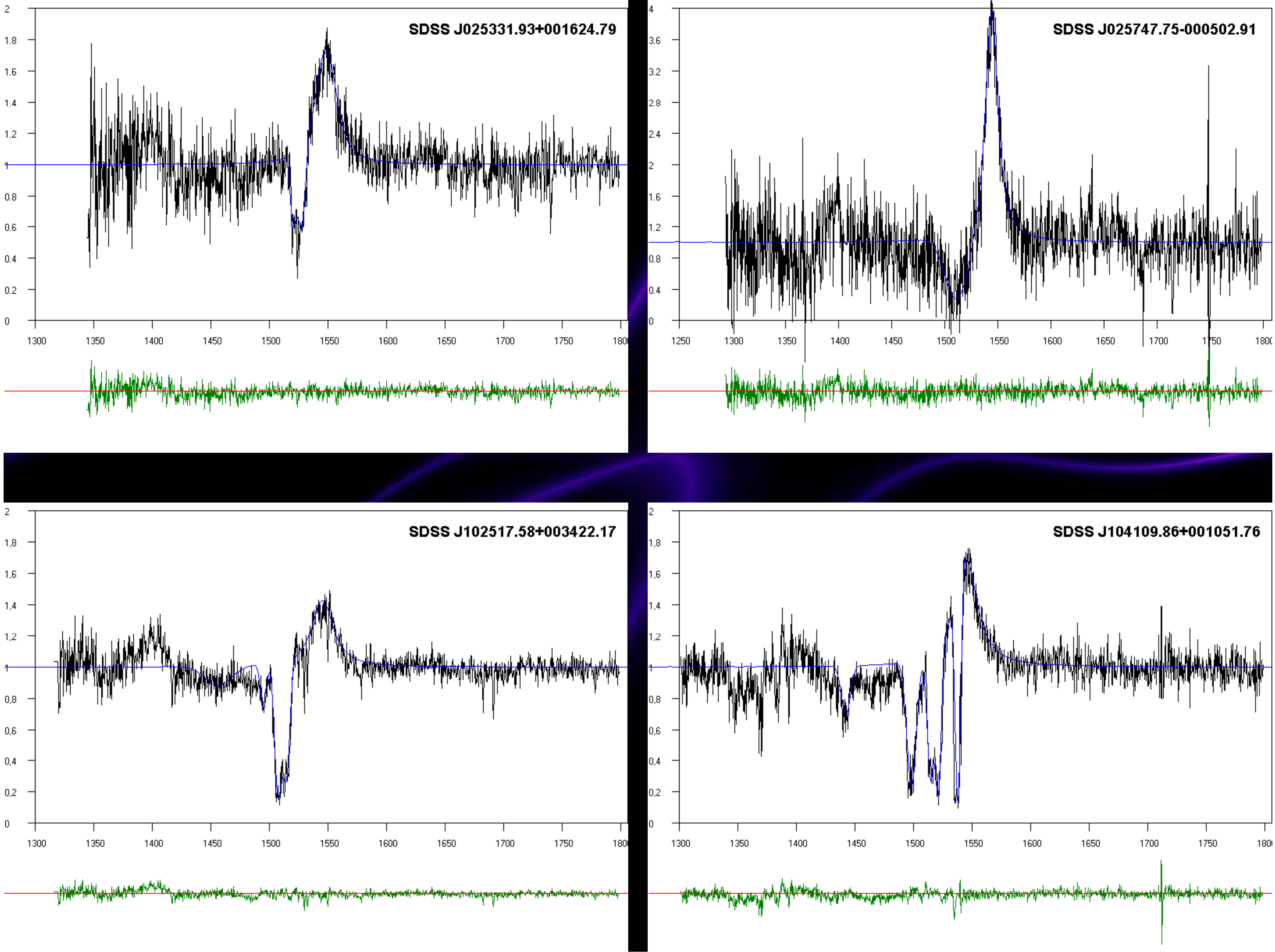
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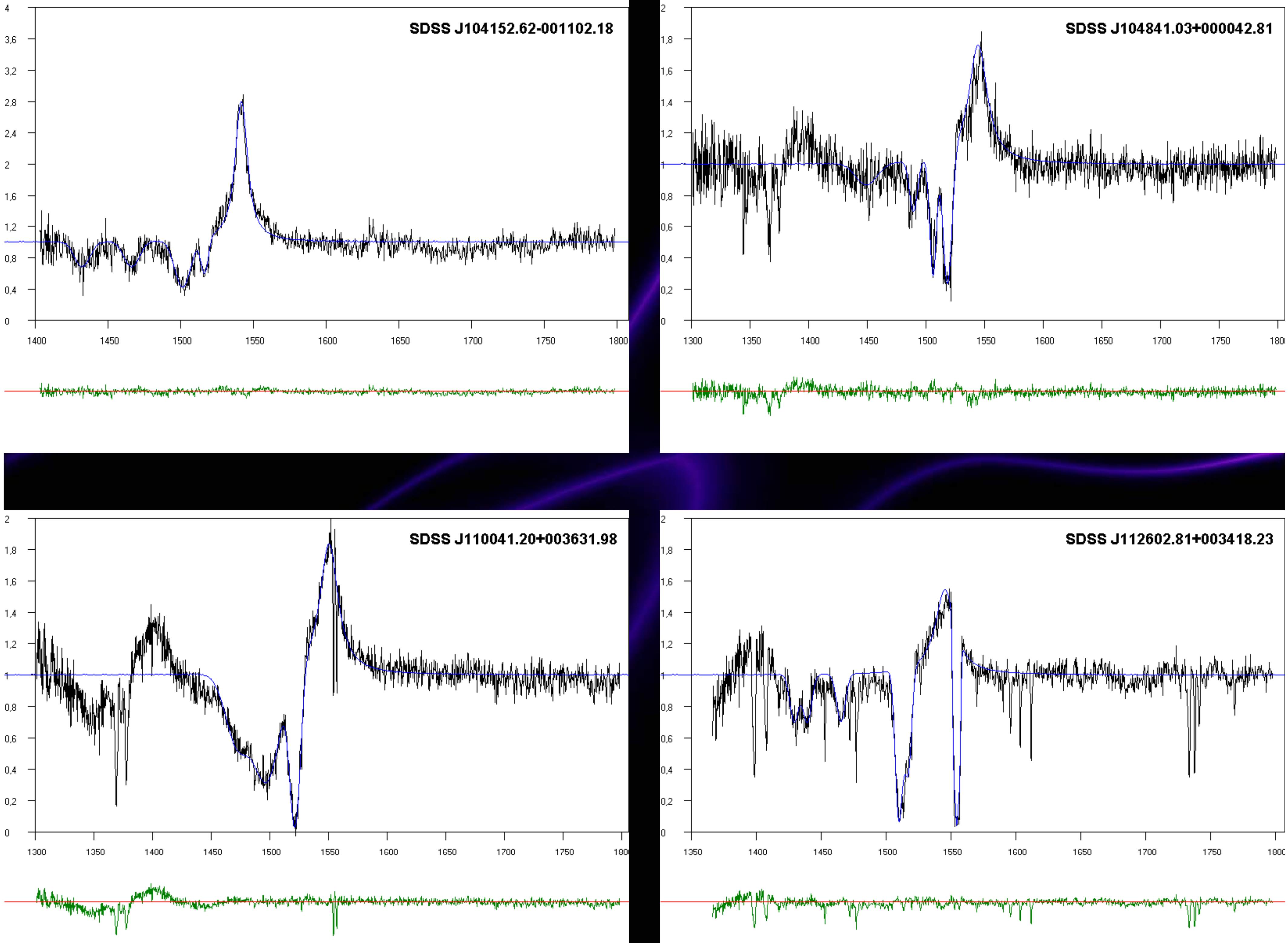
SDSS J104109.86+001051.76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SDSS J110041.20+003631.98
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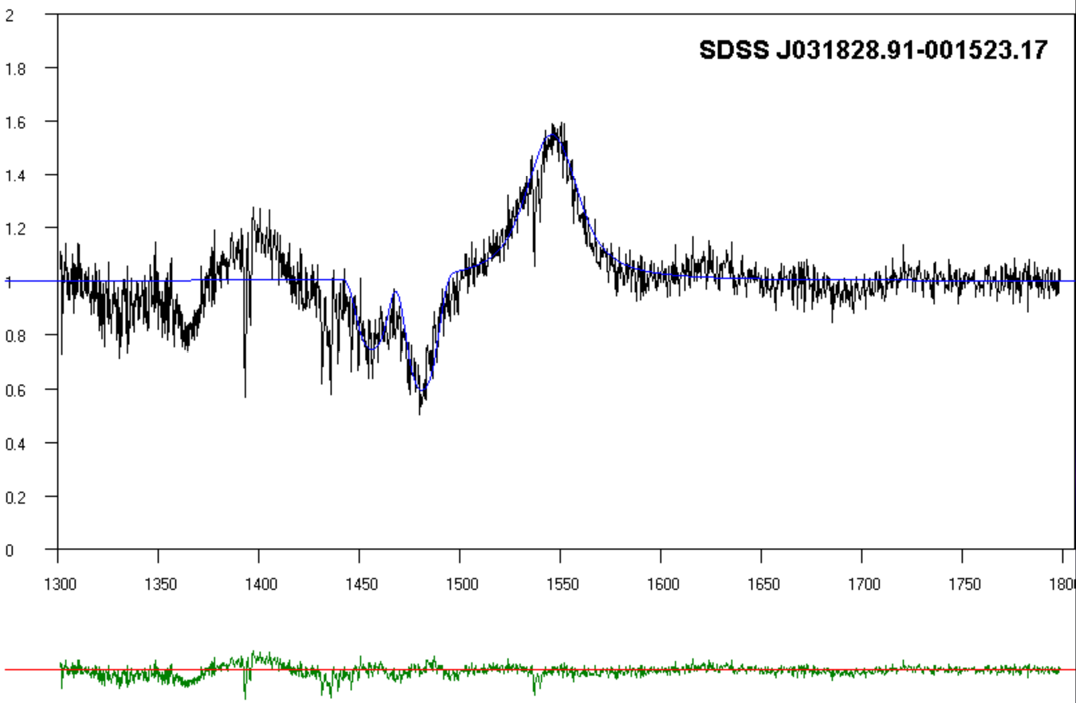
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0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
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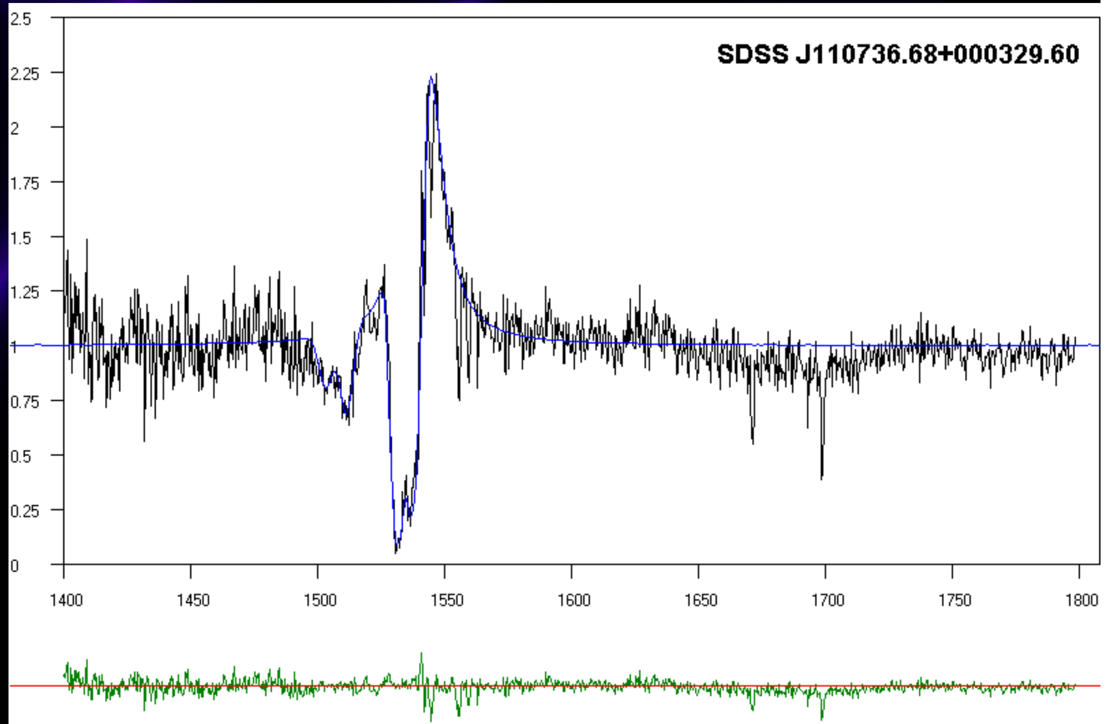
1650
1700
1750
1800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0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
1400
1450
1500
1550
1600
1650
1700
1750
1800

We studied all the absorption lines that follow the first **Balnicity Index criterion**, i.e. the lines that are located between 3000 and 25000 km/s blueward of the emission, meaning the lines that come from the studied BALQSOs.

Then, from all these lines we accepted as BALs only those that follow the rest **Balnicity Index criteria**, i.e. the absorption lines that are at least 2000 km/s broad and for which the absorption falls at least 10% below the continuum.

We found that 25 of the 30 quasars of our sample present Broad Absorption Lines.

In the following tables we give the calculated values of the kinematical parameters (V_{rad}, V_{rot}, V_{rand}), the Column Density of the absorption lines and the Absorbed Energy.

Kinematical Parameters (km/s)

Object Name (SDSS)	Vrad1	Vrad2	Vrad3	Vrad4	Vrad5	Vrot1	Vrot2	Vrot3	Vrot4	Vrot5	Vrand1	Vrand2	Vrand3	Vrand4	Vrand5
J001025.90+005447.6	-15092	-10642				600	600				1596	1368			
J001438.28-010750.1	-17026					100					6155				
J001502.26+001212.4	-19348					100					6155				
J002127.88+010420.1	-14624					100					6155				
J003551.98+005726.4				-6192					100					787	
J004041.39-005537.3	-17220					3000					4559				
J004118.59+001742.4	-13931		-7740			100		100			2508		1824		
J004323.43-001552.4	-20896	-12770				3000	3000				2736	2736			
J004732.73+002111.3	-17414					100					4332				
J005355.15-000309.3	-17026	-11609				100	100				912	912			
J005419.99+002727.9	-17607		-8513			3000		550			2280		2052		
J010241.04-004208.9	-17414	-11802			-4063	50	50			50	1824	1824			798
J010336.40-005508.7	-17800				-4063	100				100	3420				1596
J011227.60-011221.7	-21283	-16446	-8513	-6385		550	550	550	550		1596	1254	912	798	
J015024.44+004432.99			-7546		-3483			1500		2200			1368		1140
J015048.83+004126.29	-18381					50					4104				
J021327.25-001446.92				-5321	-3096				100	100				912	935
J023908.99-002121.42	-17414		-8513			30		30			2280		2280		
J025747.75-000502.91			-7352					100					2280		
J031828.91-001523.17	-17994	-13157				2000	2000				456	570			
J102517.58+003422.17	-17994					50					2508				
J104109.86+001051.76			-9867					100					798		
J104152.62-001102.18	-22637	-16059	-9287			50	50	50			1140	1140	1140		
J104841.03+000042.81	-19348					50					2052				
J110041.20+003631.98	-14704	-10061		-5417		50	70		50		2280	2280		912	
MEAN	-17757	-12818	-8416	-5829	-3676	1830	1538	550	550		2952	1510	1582	852	1117
STDEV	2171	2197	809	466	410	1088	1026	0	0		1704	676	565	60	302

Column Density (cm^{-2})

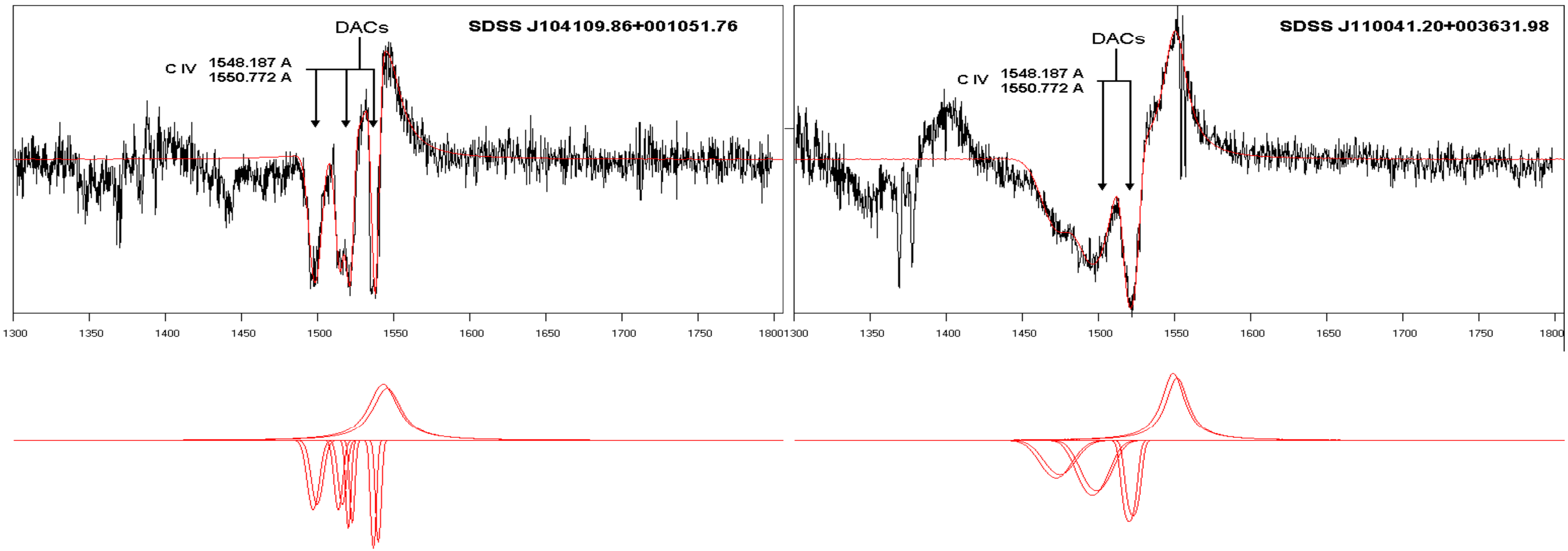
Object Name (SDSS)	λ 1548.187					λ 1550.772				
	CD1	CD2	CD3	CD4	CD5	CD1	CD2	CD3	CD4	CD5
J001025.90+005447.6	-2,38E+10	-4,26E+10				-1,93E+10	-3,52E+10			
J001438.28-010750.1	-6,26E+10					-5,07E+10				
J001502.26+001212.4	-4,25E+10					-3,43E+10				
J002127.88+010420.1	-3,84E+10					-3,09E+10				
J003551.98+005726.4				-2,81E+10					-2,27E+10	
J004041.39-005537.3	-3,03E+10					-2,44E+10				
J004118.59+001742.4	-5,56E+10		-1,26E+10			-4,56E+10		-1,02E+10		
J004323.43-001552.4	-2,65E+10	-4,94E+10				-2,14E+10	-4,02E+10			
J004732.73+002111.3	-2,99E+10					-2,41E+10				
J005355.15-000309.3	-2,76E+10	-2,76E+10				-2,28E+10	-2,28E+10			
J005419.99+002727.9	-3,47E+10		-2,77E+10			-2,82E+10		-2,25E+10		
J010241.04-004208.9	-1,26E+10	-1,26E+10			-3,51E+10	-1,02E+10	-1,02E+10			-2,96E+10
J010336.40-005508.7	-4,13E+10				-3,98E+10	-3,35E+10				-3,28E+10
J011227.60-011221.7	-1,96E+10	-1,56E+10	-3,83E+10	-2,60E+10		-1,59E+10	-1,27E+10	-3,21E+10	-2,15E+10	
J015024.44+004432.99			-3,51E+10		-8,81E+10			-3,20E+10		-8,15E+10
J015048.83+004126.29	-2,83E+10					-2,28E+10				
J021327.25-001446.92				-2,03E+10	-4,12E+10				-1,85E+10	-3,80E+10
J023908.99-002121.42	-2,17E+10		-7,67E+10			-1,76E+10		-7,04E+10		
J025747.75-000502.91			-7,23E+10					-6,63E+10		
J031828.91-001523.17	-1,43E+10	-2,37E+10				-1,30E+10	-2,16E+10			
J102517.58+003422.17	-1,22E+10					-9,85E+09				
J104109.86+001051.76			-2,81E+10					-2,34E+10		
J104152.62-001102.18	-1,52E+10	-1,52E+10	-2,72E+10			-1,23E+10	-1,23E+10	-2,48E+10		
J104841.03+000042.81	-1,14E+10					-9,19E+09				
J110041.20+003631.98	-4,14E+10	-6,17E+10		-3,82E+10		-3,77E+10	-5,65E+10		-3,52E+10	
MEAN	-2,95E+10	-3,10E+10	-3,97E+10	-2,81E+10	-5,11E+10	-2,42E+10	-2,64E+10	-3,52E+10	-2,45E+10	-4,55E+10
STDEV	1,39E+10	1,70E+10	2,13E+10	6,47E+09	2,15E+10	1,15E+10	1,52E+10	2,02E+10	6,40E+09	2,10E+10
MEAN of ALL	-3,59E+10					-3,12E+10				
STDEV of ALL	0,86E+10					0,82E+10				

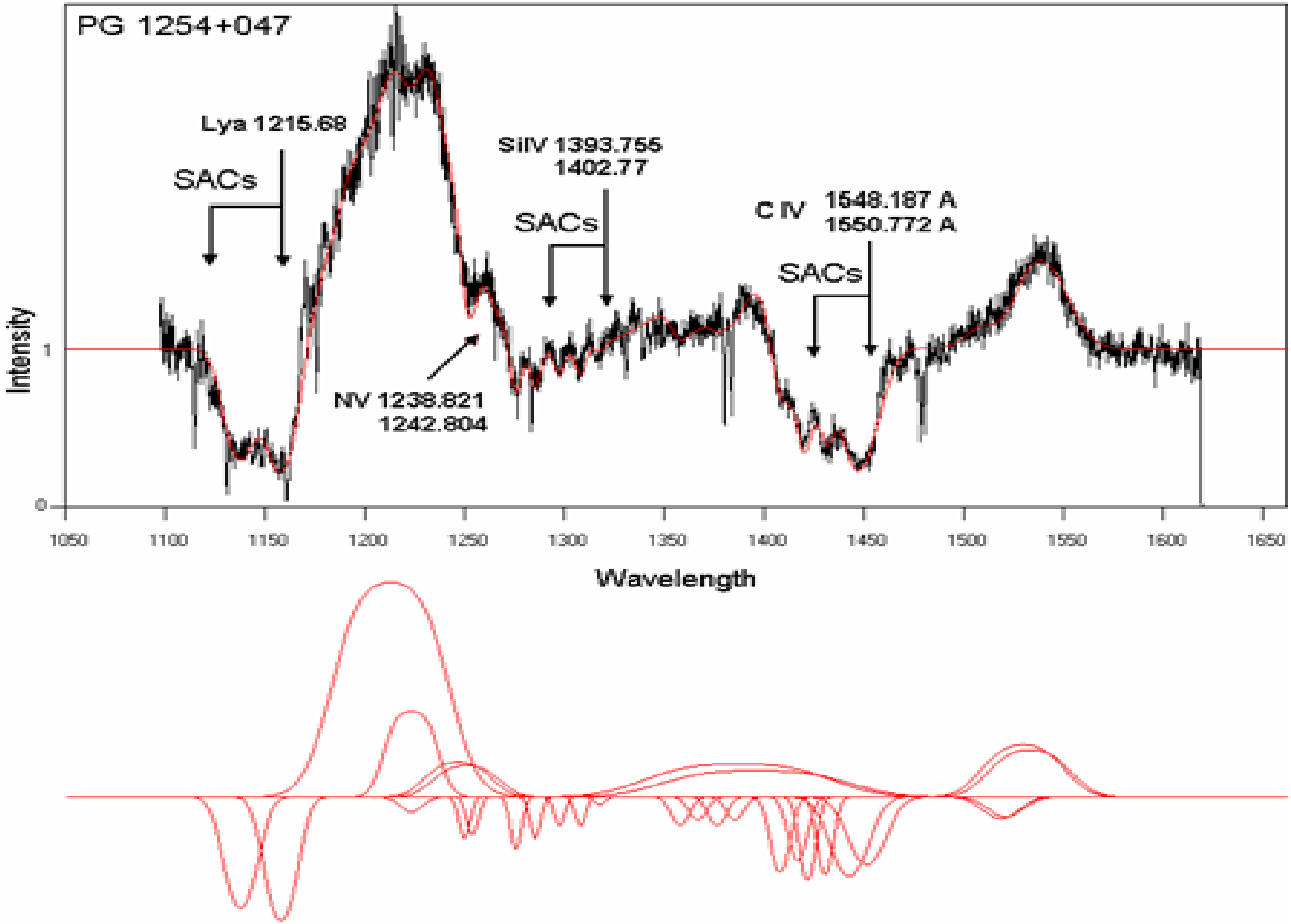
Absorbed Energy (eV)

Object Name (SDSS)	λ 1548.187					λ 1550.772				
	Ea1	Ea2	Ea3	Ea4	Ea5	Ea1	Ea2	Ea3	Ea4	Ea5
J001025.90+005447.6	-3,66	-6,55				-2,97	-5,41			
J001438.28-010750.1	-9,64					-7,79				
J001502.26+001212.4	-6,54					-5,26				
J002127.88+010420.1	-5,90					-4,75				
J003551.98+005726.4				-4,32					-3,49	
J004041.39-005537.3	-4,66					-3,75				
J004118.59+001742.4	-8,56		-1,94			-7,01		-1,56		
J004323.43-001552.4	-4,08	-7,60				-3,29	-6,18			
J004732.73+002111.3	-4,60					-3,70				
J005355.15-000309.3	-4,24	-4,24				-3,51	-3,51			
J005419.99+002727.9	-5,35		-4,26			-4,34		-3,45		
J010241.04-004208.9	-1,94	-1,94			-5,40	-1,56	-1,56			-4,54
J010336.40-005508.7	-6,36				-6,13	-5,15				-5,03
J011227.60-011221.7	-3,02	-2,40	-5,90	-4,00		-2,45	-1,94	-4,93	-3,30	
J015024.44+004432.99			-5,40		-13,55			-4,91		-12,53
J015048.83+004126.29	-4,36					-3,51				
J021327.25-001446.92				-3,12	-6,34				-2,84	-5,85
J023908.99-002121.42	-3,34		-11,81			-2,70		-10,82		
J025747.75-000502.91			-11,12					-10,18		
J031828.91-001523.17	-2,20	-3,64				-2,00	-3,32			
J102517.58+003422.17	-1,88					-1,51				
J104109.86+001051.76			-4,32					-3,59		
J104152.62-001102.18	-2,34	-2,34	-4,19			-1,90	-1,90	-3,81		
J104841.03+000042.81	-1,75					-1,41				
J110041.20+003631.98	-6,37	-9,50		-5,88		-5,79	-8,68		-5,41	
MEAN	-4,54	-4,78	-6,12	-4,33	-7,86	-3,72	-4,06	-5,41	-3,76	-6,99
STDEV	2,15	2,61	3,28	1,00	3,31	1,76	2,34	3,10	0,98	3,23
MEAN of ALL	-5,52					-4,79				
STDEV of ALL	1,32					1,26				

Remarks

1. The Hi BALQSOs complex profiles may be explained if we accept that the BLRs present a multi-structure, i.e. they are not homogeneous but they consist of a number of density regions or ion populations with different physical parameters.
2. The spectra of QSOs that present Broad Absorption Lines can be studied with the GR model.




PG 1254+047
Lya 1215.68
SACs
SiIV 1393.755
1402.77
SACs
C IV
1548.187 A
1550.772 A
SACs
NV 1238.821
1242.804
Intensity
1
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
Wavelength

Conclusions

From our study we conclude that:

1. **The C IV complex profiles of the studied BALQSOs are fitted with 1 to 5 absorption components.**
2. **For the absorption lines that follow the BI criteria we found that:**
   a) **The radial velocities lie between -3676 ± 410 km/s and -17757 ± 2171 km/s.**
   b) **The random velocities lie between 1117 ± 302 km/s and 2952 ± 1704 km/s.**
   c) **The column density of all the absorption components of both the two members of the doublet is almost the same with mean value $-3.35\times10^{-10} \pm 0.24\times10^{-10}$ cm^{-2}.**
   d) **The absorbed energy has the value of -5.52 ± 1.32 eV for the line at 1548.187 Å and -4.79 ± 1.26 eV for the line at 1550.772 Å.**

Thank you!!!