Studying the complex BAL profiles of C IV in 21 BALQSO spectra

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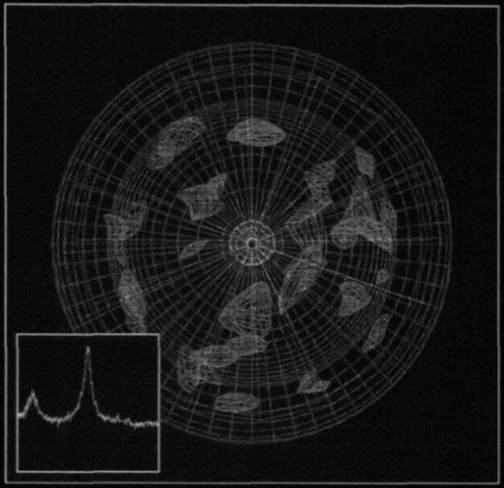
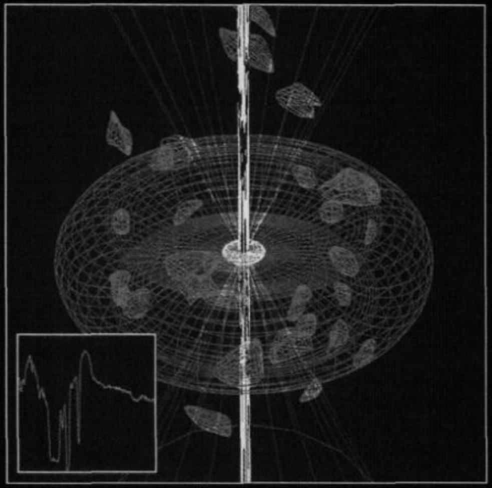
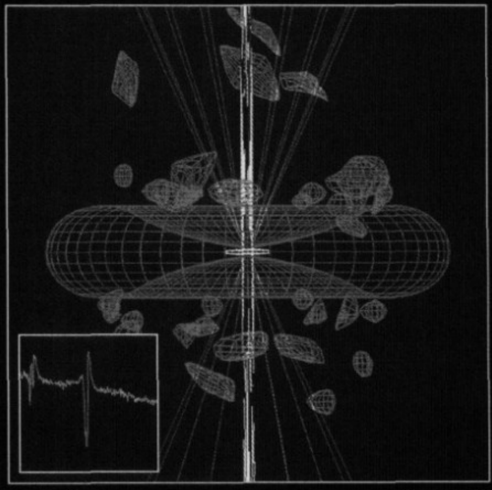




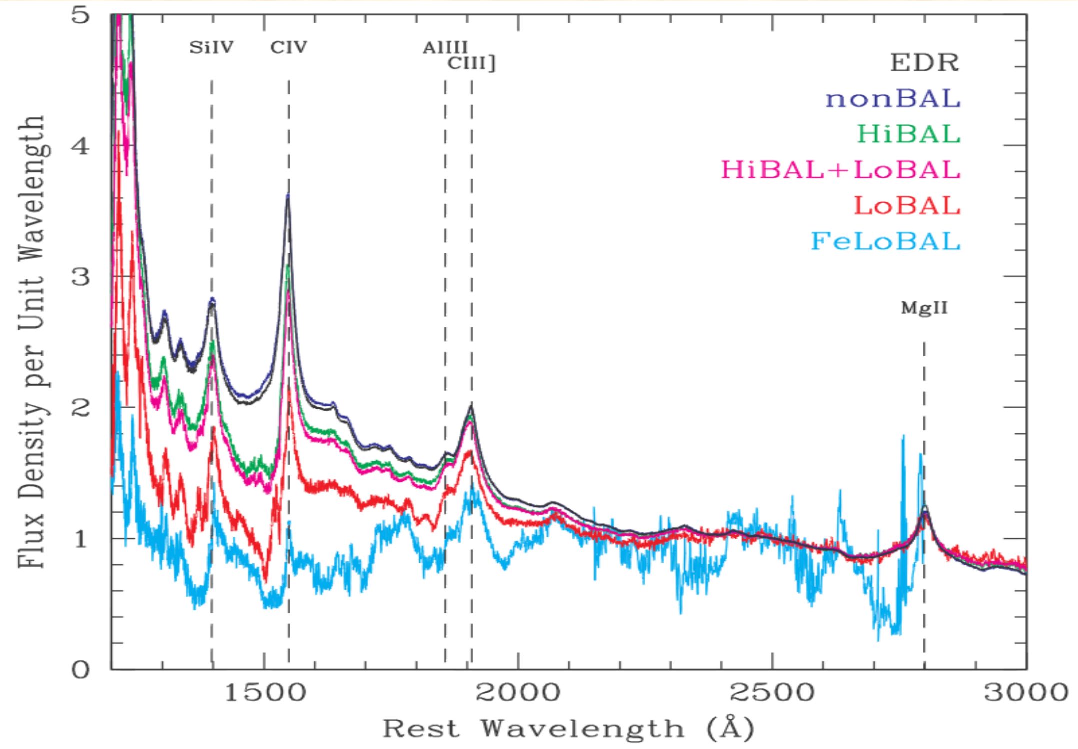


Spectral Classification of BALQSOs

- High-ionization BALs (HiBALs) contain strong, broad absorption high-ionization lines such as C IV, Si IV, N V

- Low ionization BALQSOs (LoBALs) contain HiBAL features but also have absorption from low-ionization lines such as Mg II.

- FeloBALQSOs LoBALs with excited-state Fe II or Fe III absorption

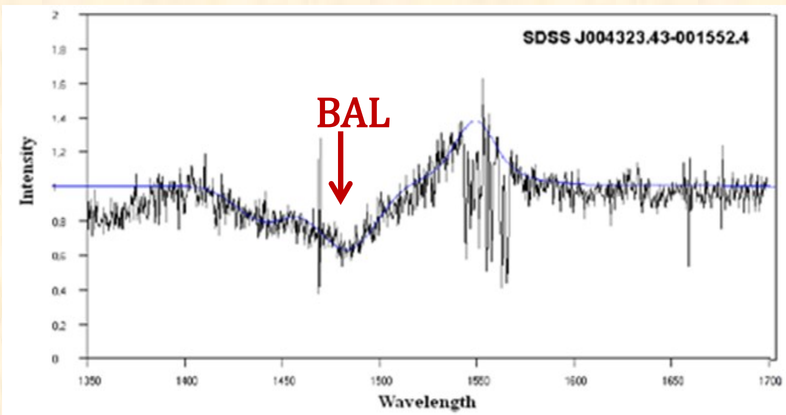


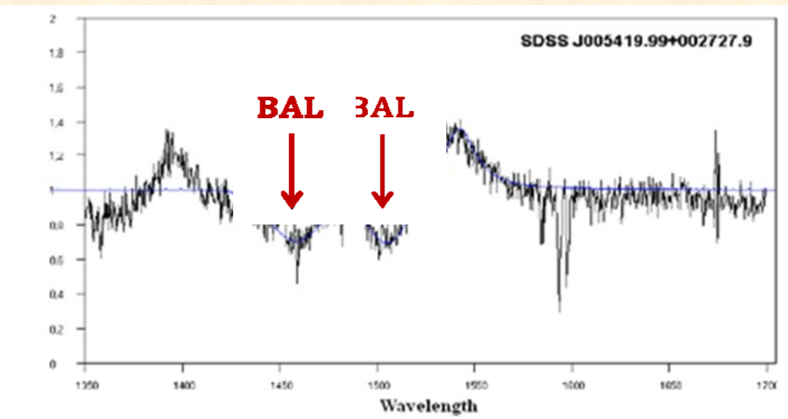
Reichard et al. 2003

HiBALQSO Absorption Lines

1st Subgroup

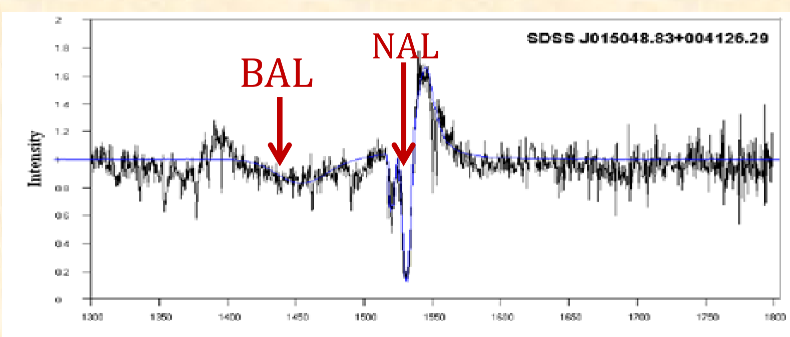
- Lines that show very broad and complex profiles. These profiles represent a number of lines of the same ion and the same wavelength shifted to different Δλ.
- This effect occurs because these lines are created in different clouds that move radially and rotate (around their axes)with different velocities (Danezis et al. 2007). Can't fit using classical distributions.

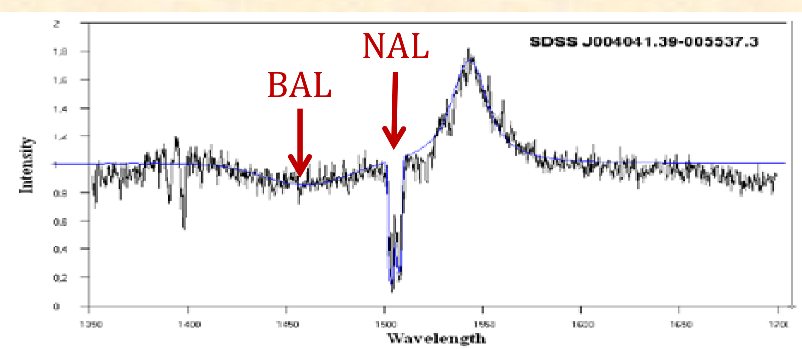




2nd Subgroup

- Spectral lines with simple profiles
- These lines can be fitted using classical distributions such as Gauss, Lorentz or Voigt

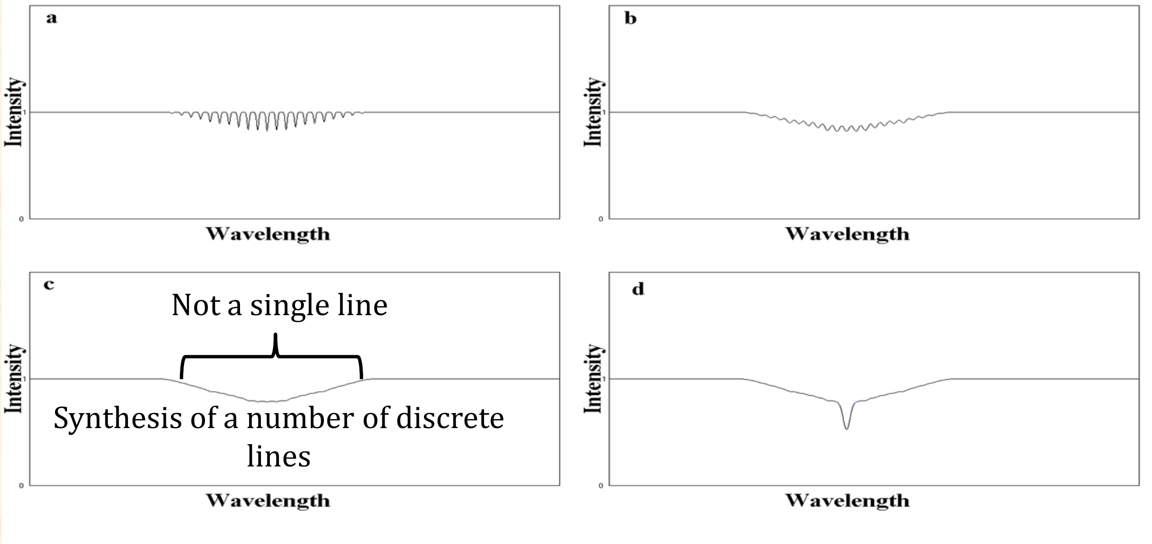




Problems in HiBALQSO Spectra - Interpretation

1. BALR's spectral line profiles appear to be rather complex in structure. This means that these spectral lines are not created in a single region but are the spectral synthesis of many discrete lines. These discrete lines are created in separate and independent regions (clouds) that have different spectral characteristics (Danezis 1984, 1986, Danezis et al. 1991, 2003 and Lyratzi & Danezis 2004, Boksenberg et al. 2003, Zheng et al. 2001, Dobrzycki et al. 2007).

Each plasma cloud produces a classical absorption line. If these clouds rotate around their axes, with large velocities and move radially with small velocities, then the produced spectral lines have large widths and small shifts. As a result, these lines are blended among themselves as well as with the main spectral line producing a complex profile (Danezis 1984, 1986, Danezis et al. 1991, 2003 and Lyratzi & Danezis 2004).



From (a) το (c) we can observe how a series of spectral lines can produce an apparent broad absorption line. This means that when the width of each narrow line increases (from a to c) then the result is a very broad absorption line. In (d) we can observe the combination of broad absorption line with a classical absorption line (Danezis et al. 2008).

• BALRs consist of a number of independent plasma clouds (Arav et al. 1997, Ferland 2004, Laor 2006, Laor et al. 2006).
• Each cloud produces a specific spectral profile (described by a mathematical distribution).
• No physical – mathematical model could fit the complex absorption line troughs.
• Radiative transfer equation not solved through a complex environment.

2. Known Mathematical distribution and their inability to fit the complex profiles

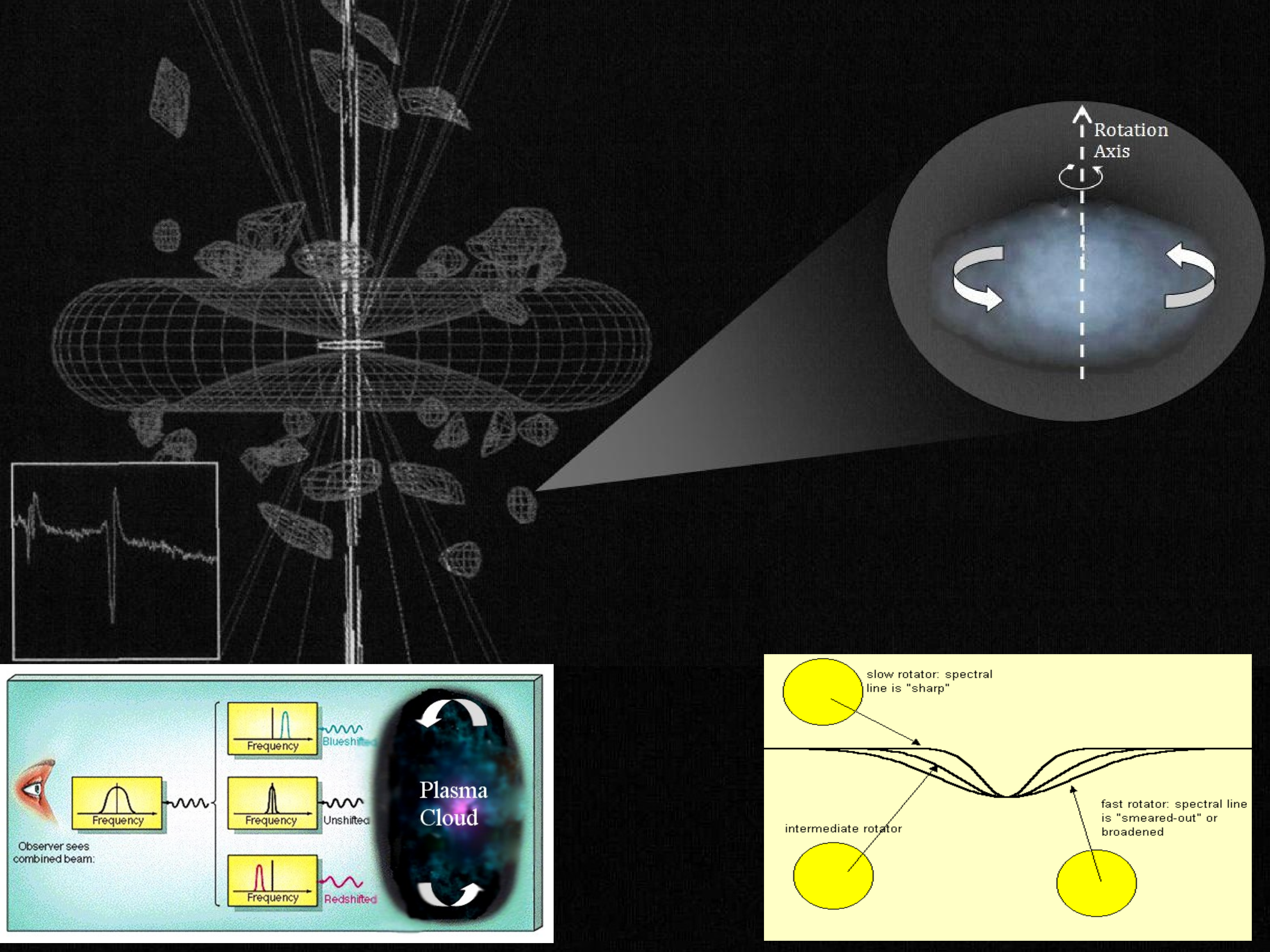
Gauss: Random Motions
Lorentz: Pressure
Voigt: Random Motions + Pressure

Inadequate to fit the complex profiles

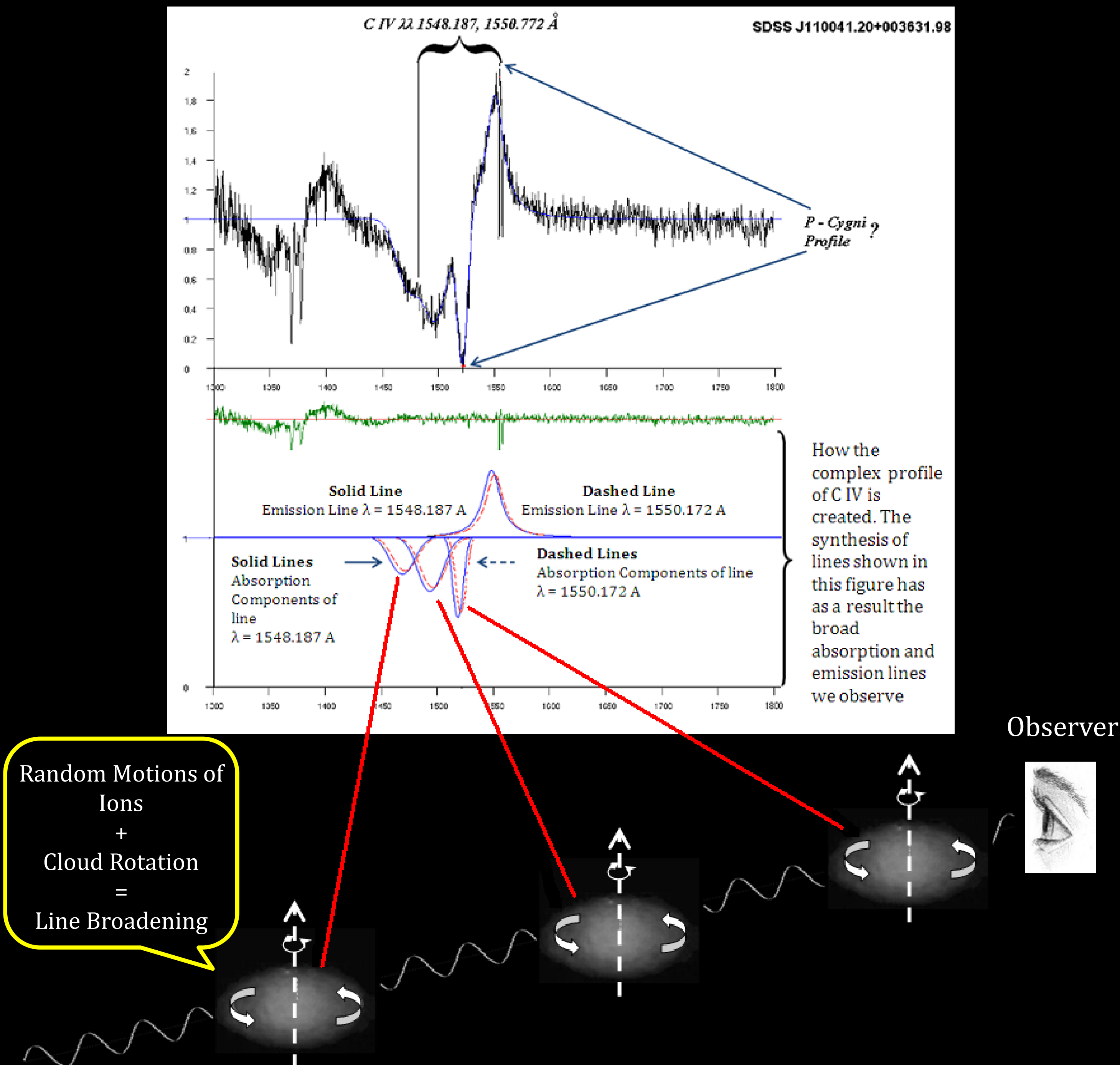
<u>However, the rotation of a plasma cloud around its own axis causes line broadening</u>

So we need:
• A mathematical distribution that can describe the rotation of a cloud around its axis.
• A mathematical distribution that can describe **simultaneously**

<u>the rotation of a plasma cloud + the thermal motion of the cloud's ions</u>



Rotation Axis
Frequency
Blueshi
Frequency
Unshifted
Frequency
Redshifted
Frequency
Observer sees combined beam:
Plasma Cloud
slow rotator: spectral line is "sharp"
intermediate rotator
fast rotator: spectral line is "smeared-out" or broadened


C IV λλ 1548.187, 1550.772 Å
SDSS J110041.20+003631.98
P - Cygni Profile ?
How the complex profile of C IV is created. The synthesis of lines shown in this figure has as a result the broad absorption and emission lines we observe
Solid Line
Emission Line λ = 1548.187 A
Dashed Line
Emission Line λ = 1550.172 A
Solid Lines
Absorption Components of line
λ = 1548.187 A
Dashed Lines
Absorption Components of line
λ = 1550.172 A
Observer
Random Motions of Ions
+
Cloud Rotation
=
Line Broadening

What do we need?

1. A physical model with a mathematical description that solves the radiative transfer equation through a complex environment.

2. The line function (that comes from the solution of radiative transfer equation) that can describe accurately each complex spectral line.

3. A physical and mathematical model that can describe the self - rotation of plasma clouds + the random motions of the ions.

4. As mentioned earlier, the complex absorption troughs do not represent a single spectral line but a synthesis of independent absorption lines originating from different plasma clouds. So the model should be able to describe not only the entire profile but also the profiles of the independent lines that compose the entire profile.

5. So the model should be able to calculate the physical parameters of each absorption component which means the physical parameters of each absorbing cloud.

6. The model must be self consistent and should include the geometry of the region that produces the spectral lines.

In our research we use the GR Model (Danezis et al. 2007, PASJ, 59, 827) for the following reasons:

1. In the context of GR Model, the radiative transfer equation for a complex atmosphere has been solved.

2. As a result we calculated the final line function via which we can fit not only the simple but the complex (absorption and emission) spectral lines as well.

3. GR model includes two new mathematical – physical distributions.

   - ***Rotation Distribution:***
     - *Describes the rotation of plasma clouds around their own axes*
     - *Line broadening due to cloud self rotation.*

   - ***Gauss – Rotation Distribution:***
     - *Describes the combination of Random Motion of Ions (inside plasma clouds) and the self – rotation of plasma clouds*
     - *Line broadening due to Random Motions of Ions + Self – Rotation of Clouds.*

4. GR Model includes the physical expression of mathematical distributions Gauss, Lorentz and Voigt.

Using the GR model

We can calculate some important parameters of the plasma clouds that construct the components of the observed spectral feature, such as:

Direct calculations

- The apparent rotational velocities of absorbing or emitting plasma clouds (V_{rot})
- The apparent radial velocities of absorbing or emitting plasma clouds (V_{rad})
- The Gaussian typical deviation of the ions' random motions (σ)
- The optical depth in the center of the absorption or emission components (ξ_i)

Indirect calculations

- The random velocities of the ions of plasma clouds (V_{random})
- The FWHM
- The absorbed or emitted energy (Ea, Ee)
- The column density (CD)

Data and Spectral Analysis

In this work we study the resonance lines of C IV λλ 1548.187, 1550.772 Å in the spectra of 21 HiBALQSOs.

The spectra were obtained from the SDSS DR7 database, they cover the spectral range 3800 – 9200 Å and the spectral analysis is 1800 - 2100.

Table 1

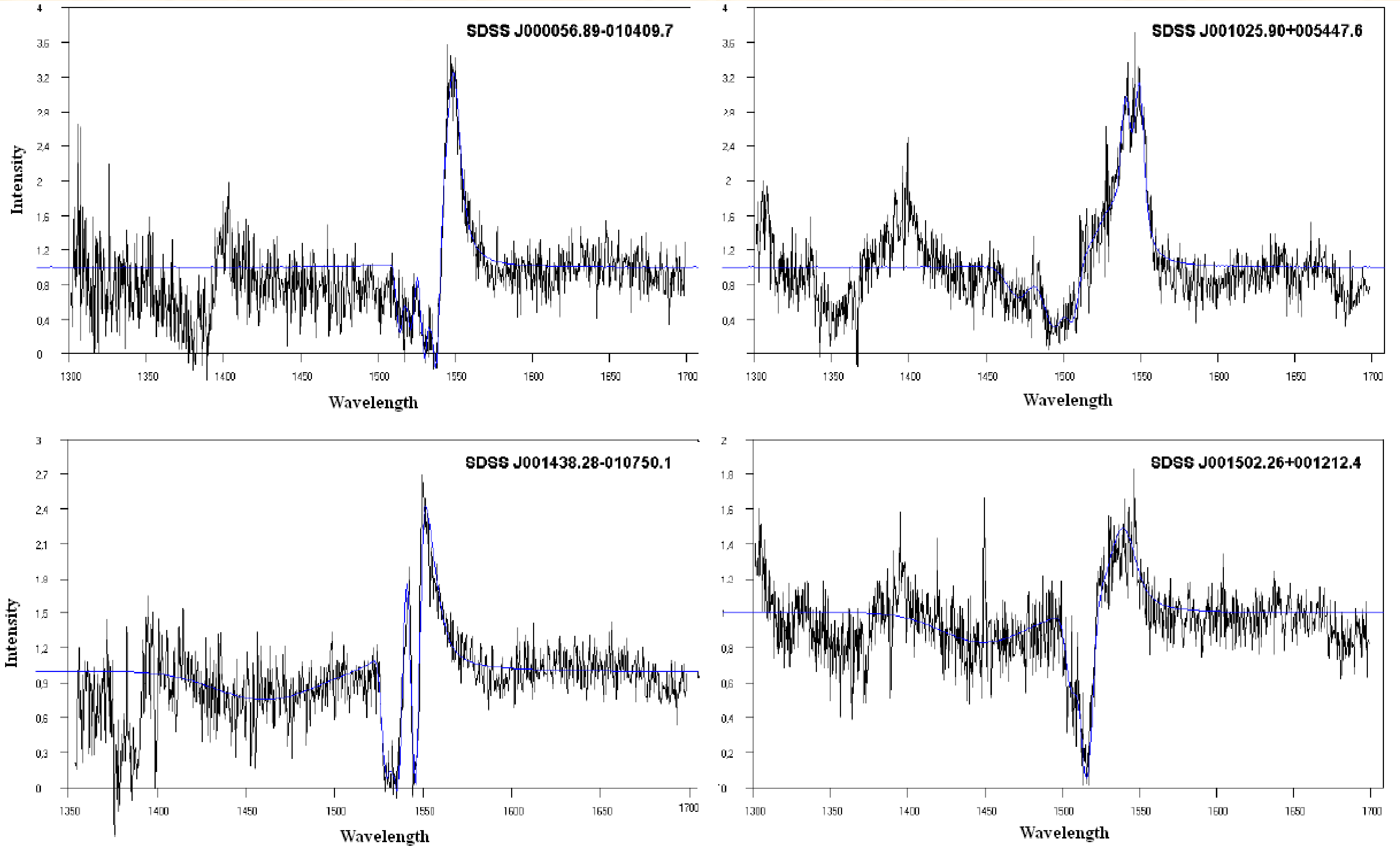
Object Name (SDSS)	MJD-Plate-Fiber	Redshift	Date
J004323.43-001552.4	51794-0393-181	2,81671	7/9/2000, 8:10
J104109.86+001051.76	51913-0274-482	2,25924	4/1/2001, 11:00
J001502.26+001212.4	51795-0389-465	2,85152	7/9/2000, 6:08
J104841.03+000042.81	51909-0276-310	2,03044	31/12/2000, 11:08
J015048.83+004126.29	51793-0402-505	3,70225	6/9/2000, 10:06
J102517.58+003422.17	51941-0272-501	1,88842	1/2/2001, 9:30
J031828.91-001523.17	51929-0413-170	1,98447	20/1/2001, 4:23
J010336.40-005508.7	51816-0396-297	2,44295	29/9/2000, 8:28
J005419.99+002727.9	51876-0394-514	2,51946	21/11/2000, 2:17
J004732.73+002111.3	51794-0393-588	2,87768	7/9/2000, 8:10
J023908.99-002121.42	51821-0408-179	3,74	4/10/2000, 9:38
J004041.39-005537.3	51794-0393-298	2,09094	7/9/2000, 8:10
J001438.28-010750.1	51795-0389-211	1,81564	7/9/2000, 6:08
J023252.80-001351.17	51820-0407-158	2,03289	3/10/2000, 9:41
J001025.90+005447.6	51795-0389-332	2,84727	7/9/2000, 6:08
J110041.20+003631.98	51908-0277-437	2,01143	30/12/2000, 11:19
J000056.89-010409.7	51791-0387-098	2,12325	4/9/2000, 7:08
J003551.98+005726.4	51793-0392-449	1,90110	6/9/2000, 8:20
J015024.44+004432.99	51793-0402-485	2,00596	6/9/2000, 10:06
J000103.85-104630.2	52143-650-133	2.081	28/2/2000 5:52
J000913.77-095754.5	52141-651-519	2.076	28/2/2000 5:52

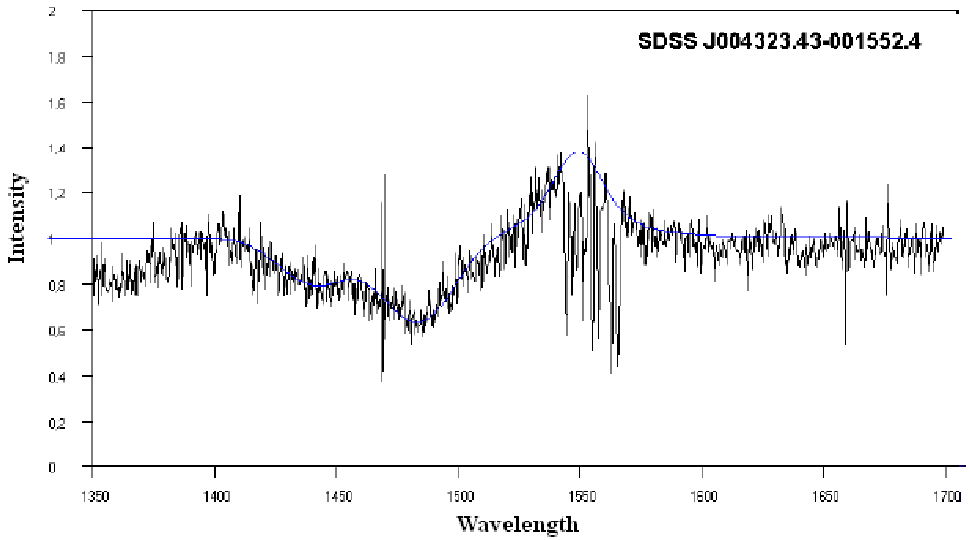
The 21 HiBALQSOs were sorted in descending order of the clouds radial velocities beginning with the QSO that had the cloud with the highest radial velocity

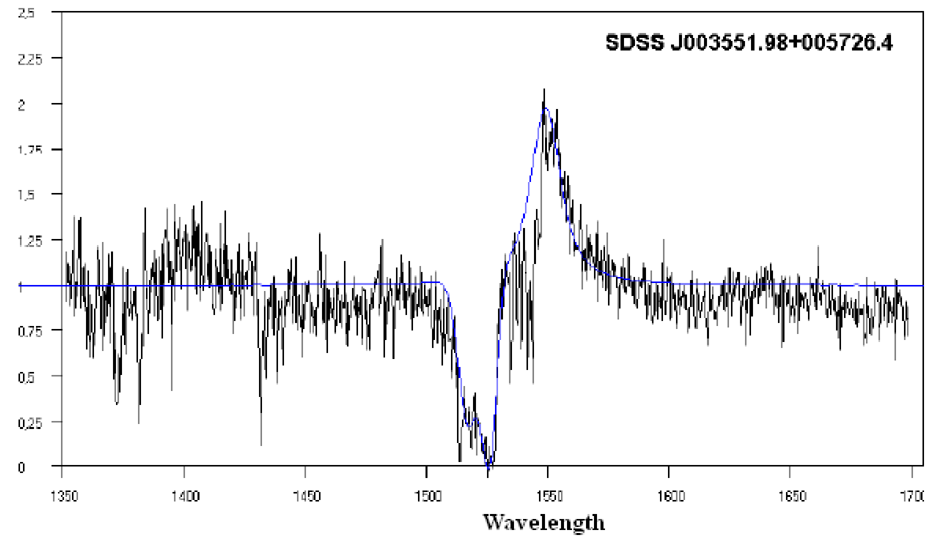
Studied Spectra and their Fit

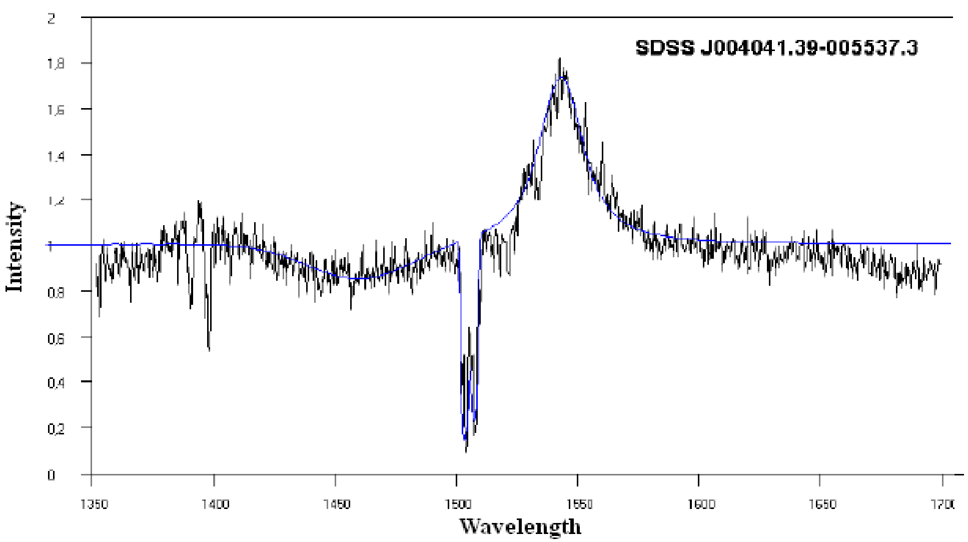
Black Line: Observed Spectra

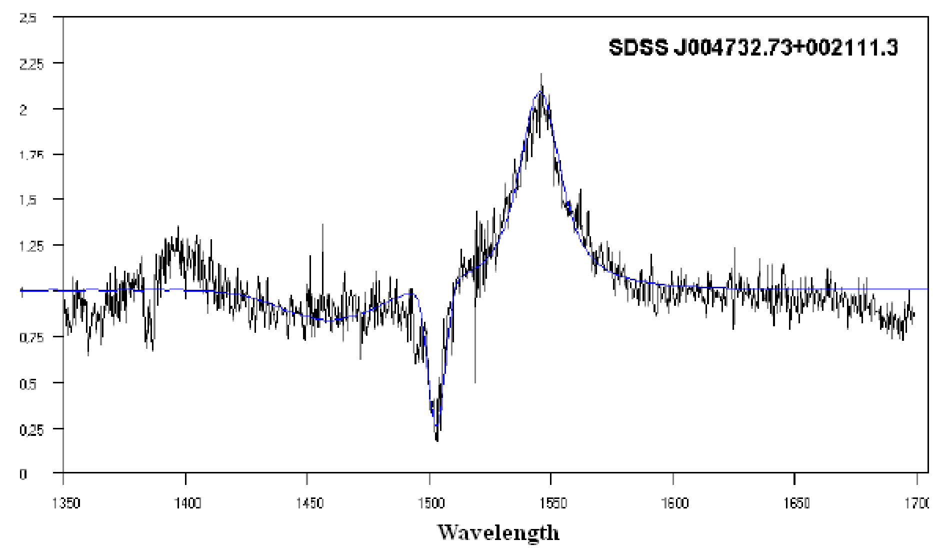
Blue Line: GR Model Fit




SDSS J004323.43-001552.4
Intensity
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1350
1400
1450
1500
1550
1600
1650
1700
Wavelength


SDSS J003551.98+005726.4
2,5
2,25
2
1,75
1,5
1,25
1
0,75
0,5
0,25
0
1350
1400
1450
1500
1550
1600
1650
Wavelength


SDSS J004041.39-005537.3
Intensity
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1350
1400
1450
1500
1550
1600
1650
Wavelength


SDSS J004732.73+002111.3
2,5
2,25
2
1,75
1,5
1,25
1
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0,25
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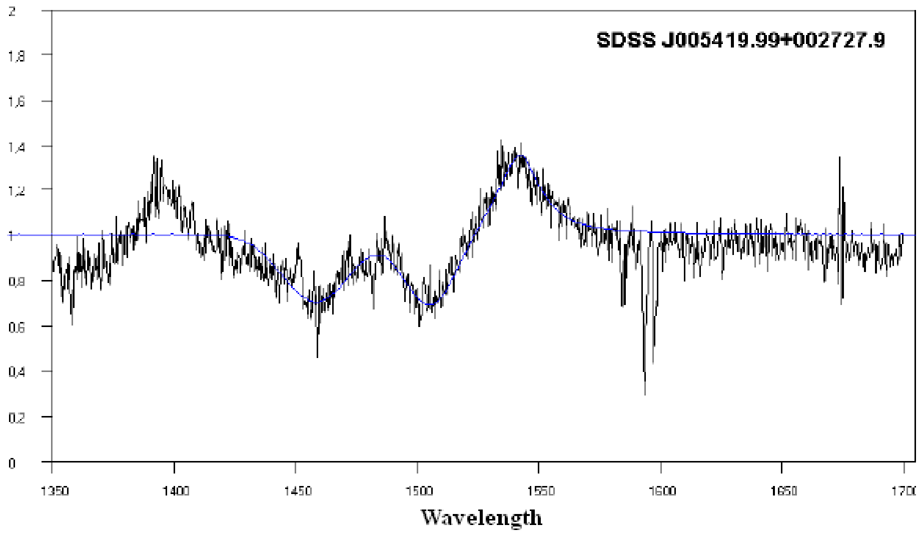
1350
1400
1450
1500
1550
1600
1650
Wavelength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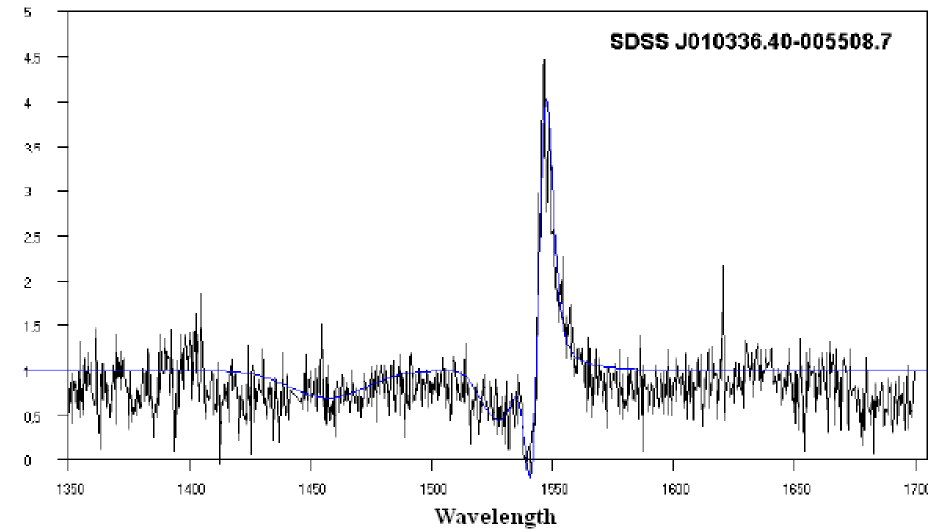
Wavelength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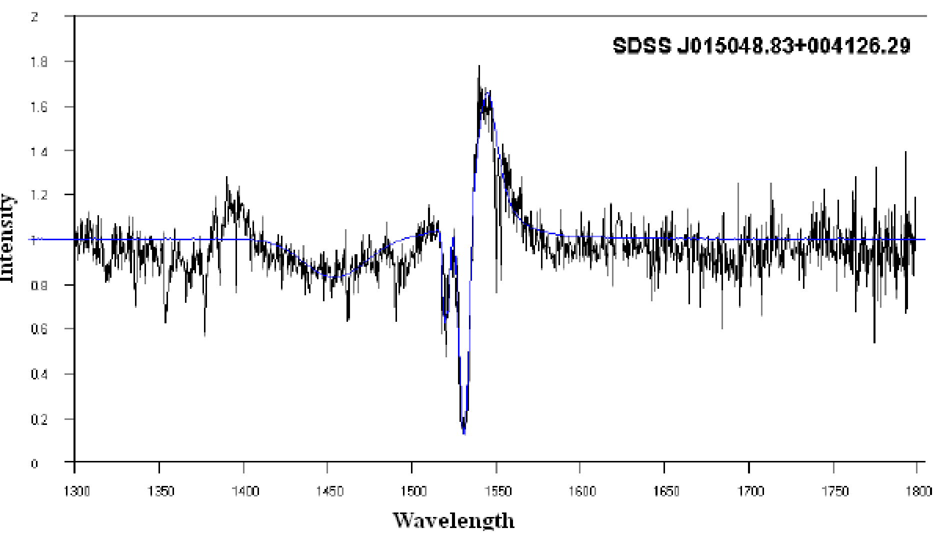
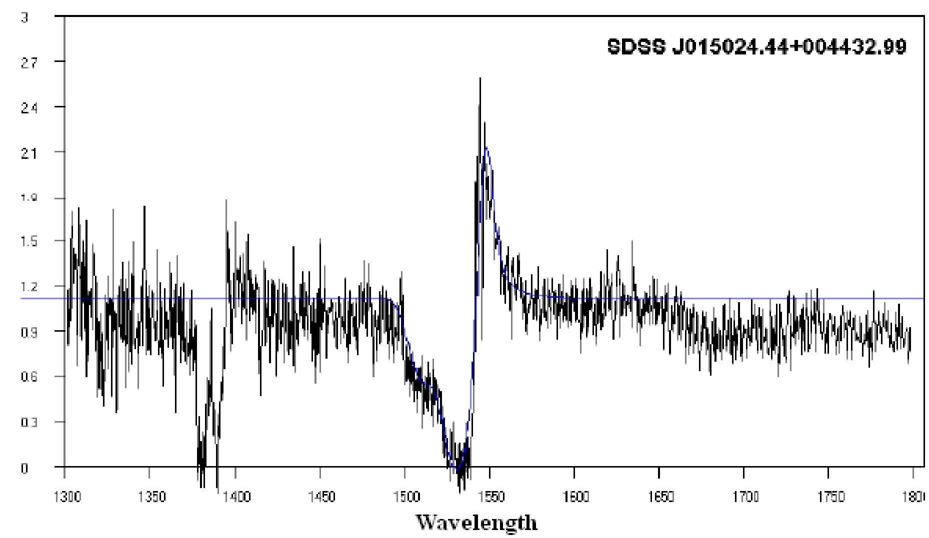
Wavelength


SDSS J015048.83+004126.29
Intensity
Wavelength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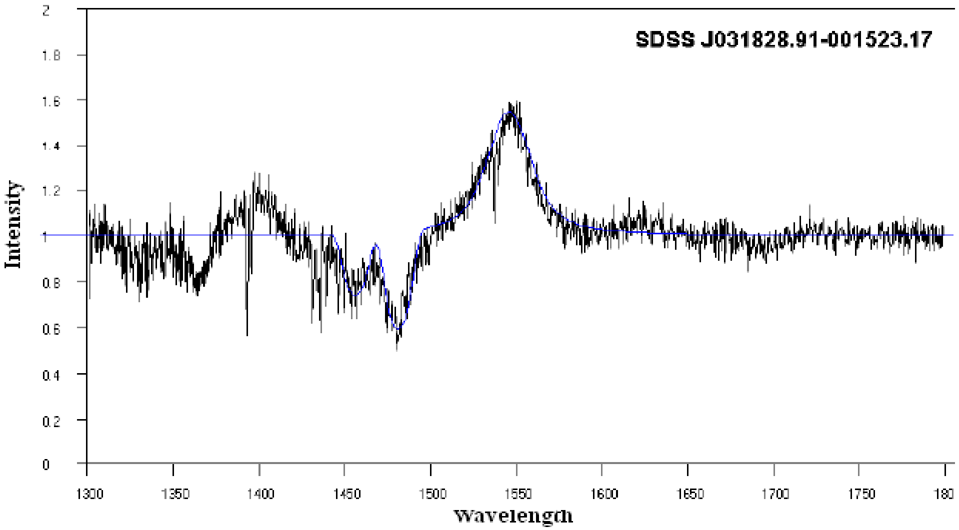
Wavelength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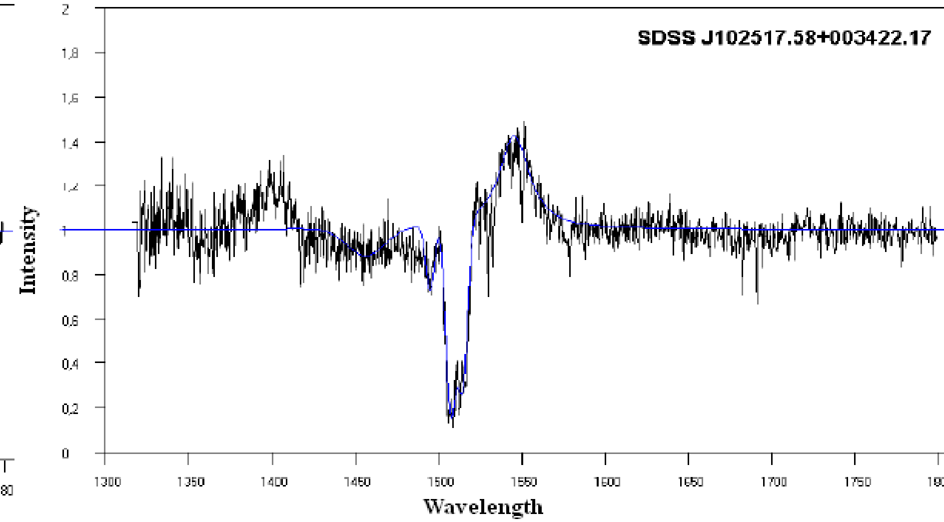
Intensity
Wavelength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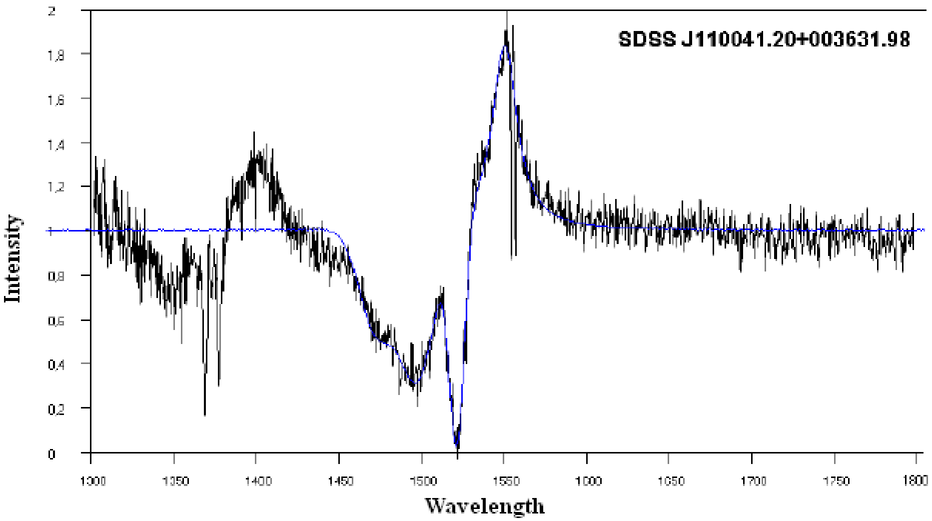
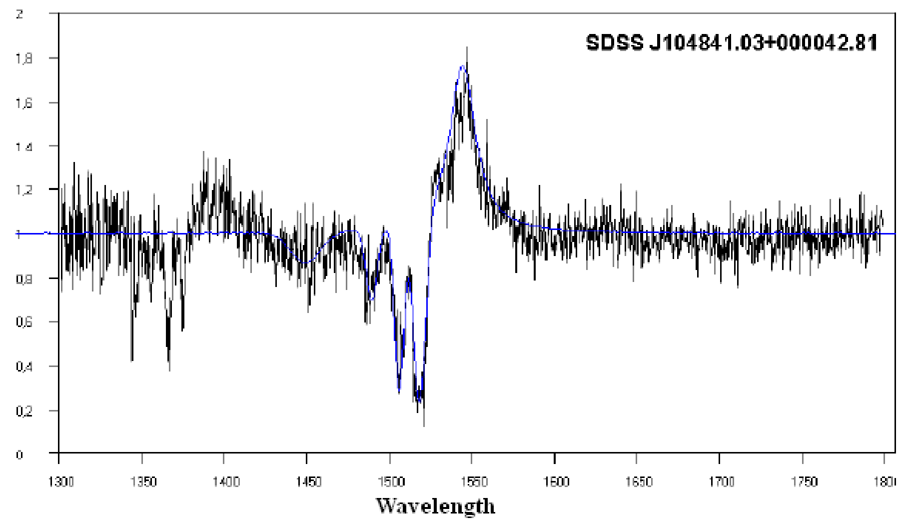
Intensity
Wavelength


SDSS J110041.20+003631.98
Intensity
Wavelength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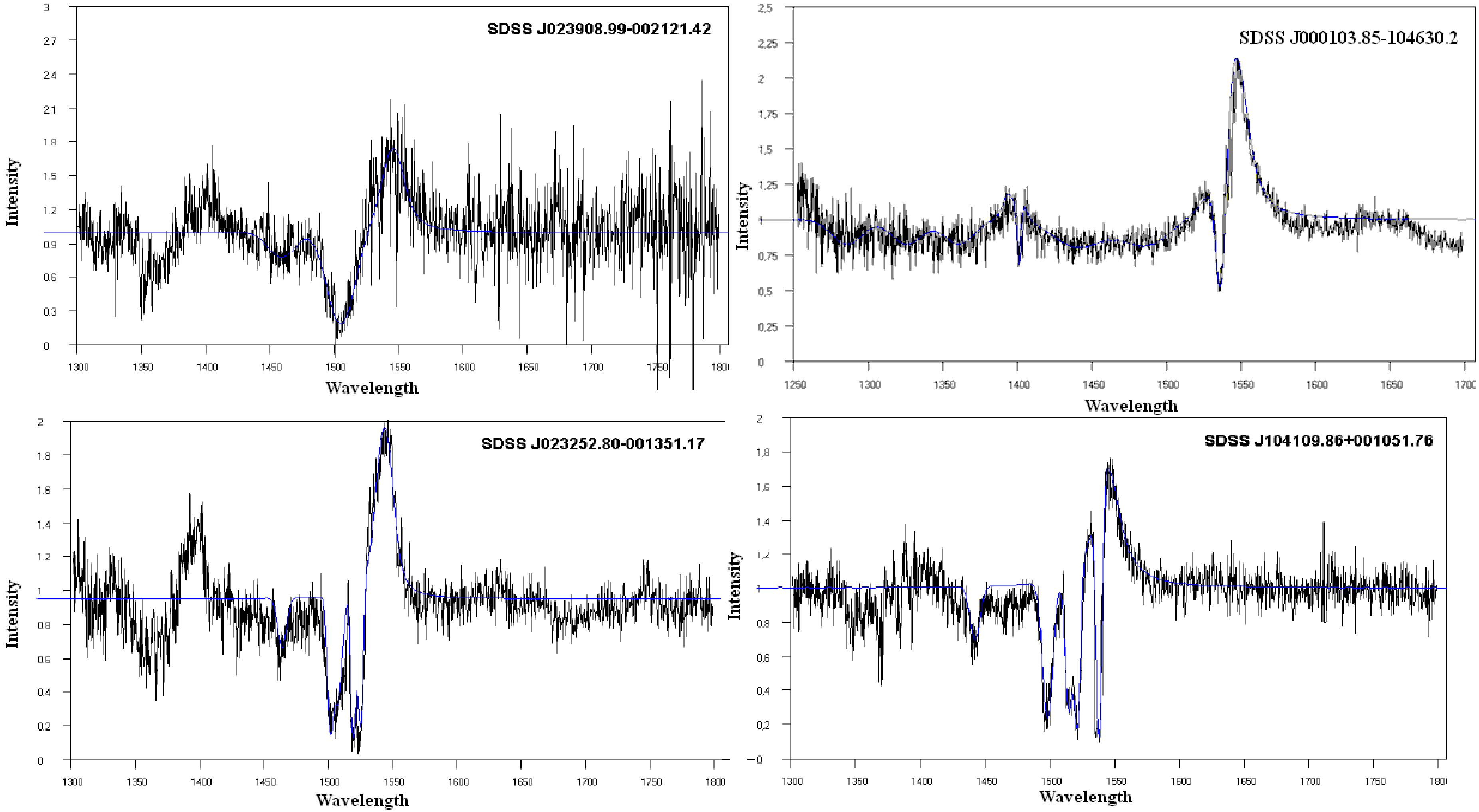
Wavelength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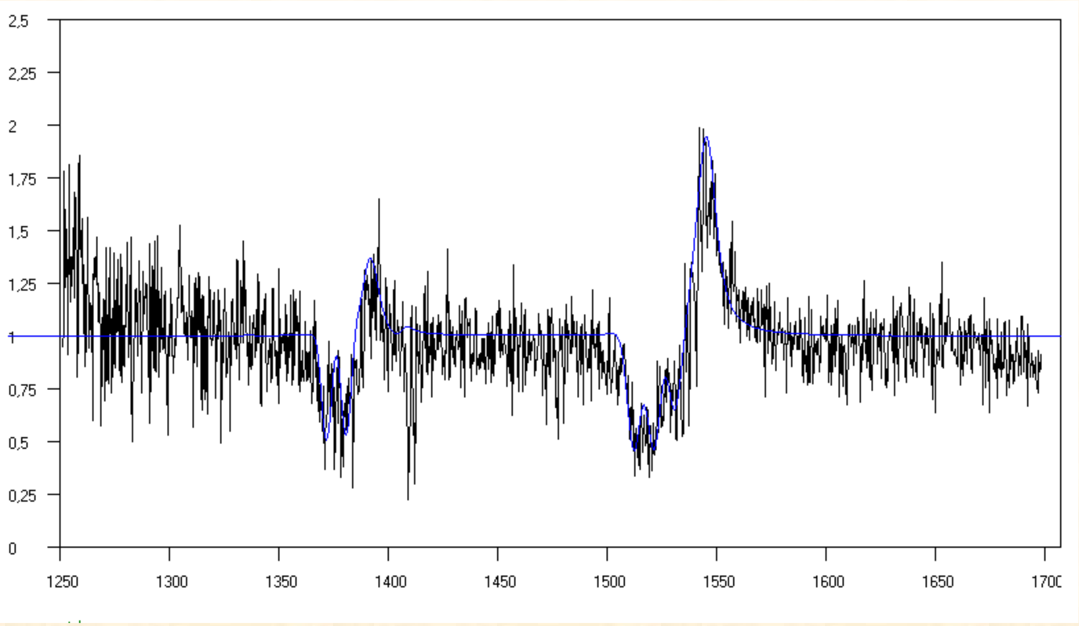
Intensity
Wavelength
SDSS J000103.85-104630.2
Intensity
Wavelength
SDSS J023252.80-001351.17
Intensity
Wavelength
SDSS J104109.86+001051.76
Intensity
Wavelength


2,5
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1,75
1,5
1,25
1
0,75
0,5
0,25
0
1250
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1350
1400
1450
1500
1550
1600
1650
1700

Conclusions

In our study of 21 BALQSOs we observed 5 different ranges of values of radial velocities. However, none of the 21 QSOS had 5 absorbing clouds. Our study showed that the BALRs, of our sample, show up to 4 absorbing clouds (or absorption components) in the line of sight. To be more specific, from the 21 QSOs,
1 has 4 absorbing clouds,
6 have 3 absorbing clouds,
11 have 2 clouds,
3 QSOs that have one absorbing cloud in the line of sight.

An Important Remark

C IV resonance lines arise from regions that have a specific ionization potential which is 64 eV.
So the random velocities of the ions should lie in a specific range of values.
As we know at the far left side of the C IV emission, the very broad absorption troughs are for sure C IV absorption components. Based on our study the mean random velocity of C IV ions should lie between 3800 km/s – 1200 km/s.
This means that all the absorption components that we can detect in the spectra of the 21 HiBALQSOs that have random velocities beneath the limit of 1200 km/s probably are not C IV absorption lines.

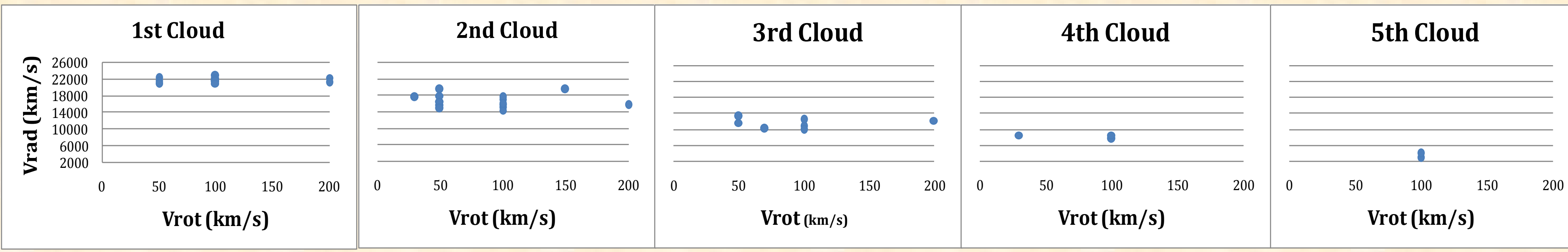
Based on the above, this may set a new Balnicity criterion.

So in the following analysis we did not include the spectral components with random velocities smaller than 1200 km/s.

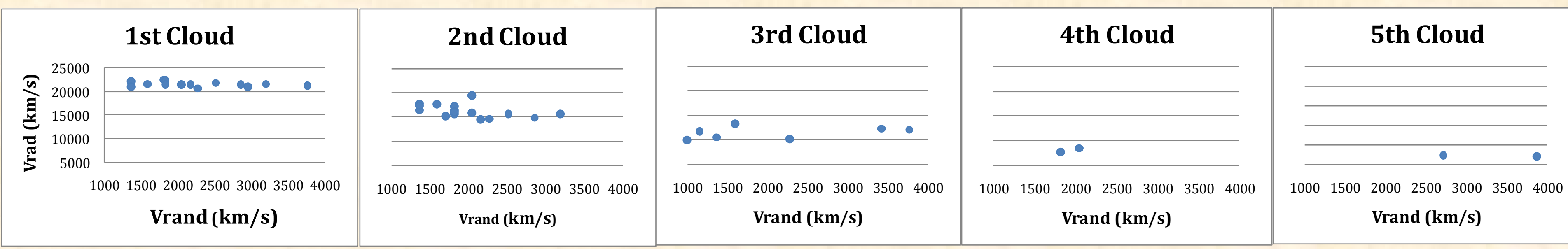
QSOs	1st Cloud	2nd Cloud	3rd Cloud	4th Cloud	5th Cloud
Object Name (SDSS)	**Vrad1**	**Vrad2**	**Vrad3**	**Vrad4**	**Vrad5**
J023252.80-001351.17	22618	16460			
J015024.44+004432.99	22269	15491		7552	2711
J031828.91-001523.17	22075	17815	13167		
J001502.26+001212.4	21881	15491			
J001025.90+005447.6	21688	15104	10650		
J003551.98+005726.4	21688	17040			
J015048.83+004126.29	21688	15491			
J004041.39-005537.3	21301	14910			
J004732.73+002111.3	21301	14329			
J005419.99+002727.9	21301	17428		8520	
J010336.40-005508.7	21301	15879			3873
J000103.85-104630.2	21107		12199		
J102517.58+003422.17	21300	15685			
J004323.43-001552.4	20913		12393		
J104109.86+001051.76	20913	16460		9876	
J110041.20+003631.98	20720	14717	10069		
J000056.89-010409.7				Rejected	Rejected
J001438.28-010750.1		19364			
J023908.99-002121.42		17427		8520	
J104841.03+000042.81		19364	11618		
J000913.77-095754.5				Rejected	Rejected

QSOs	1st Cloud	2nd Cloud	3rd Cloud	4th Cloud	5th Cloud
Object Name (SDSS)	**Vrot1**	**Vrot2**	**Vrot3**	**Vrot4**	**Vrot5**
J023252.80-001351.17	100	50			
J015024.44+004432.99	200	200		100	100
J031828.91-001523.17	50	50	50		
J001502.26+001212.4	100	100			
J001025.90+005447.6	100	100	100		
J003551.98+005726.4	100	100			
J015048.83+004126.29	100	100			
J004041.39-005537.3	100	100			
J004732.73+002111.3	100	100			
J005419.99+002727.9	100	100		100	
J010336.40-005508.7	100	100			100
J000103.85-104630.2	200		200		
J102517.58+003422.17	50	50			
J004323.43-001552.4	100		100		
J104109.86+001051.76	50	50		100	
J110041.20+003631.98	50	50	70		
J000056.89-010409.7				Rejected	Rejected
J001438.28-010750.1		150			
J023908.99-002121.42		30		30	
J104841.03+000042.81		50	50		
J000913.77-095754.5				Rejected	Rejected

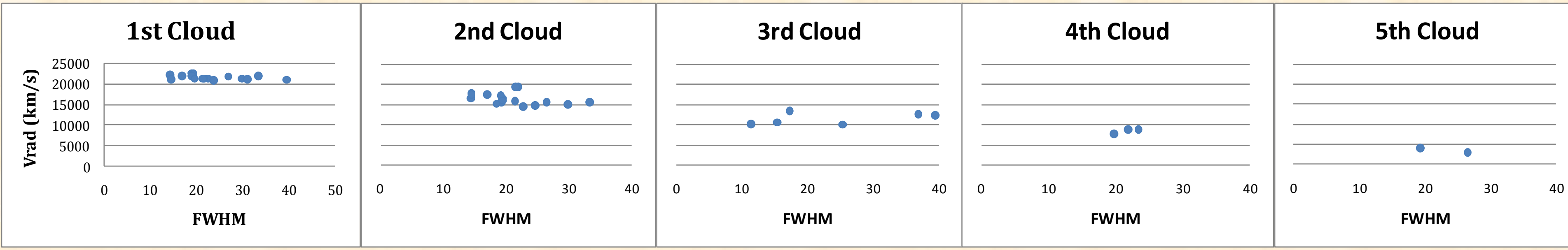
Diagrams showing the correlations between the calculated physical parameters



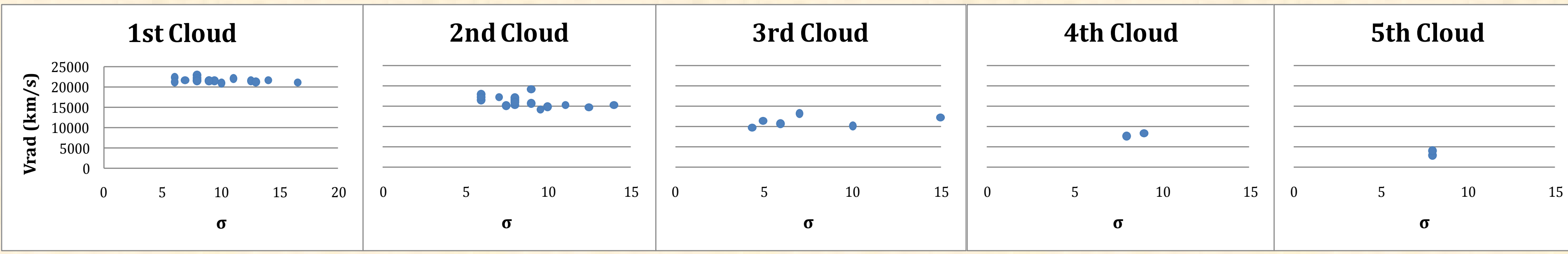
Mean radial velocity <Vrad> as a function of mean rotational velocity <Vrot> for every absorbing cloud.



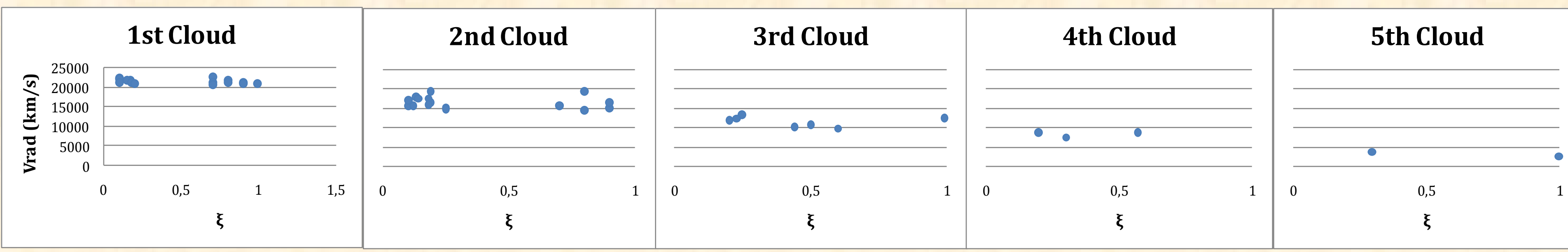
Mean radial velocity <Vrad> as a function of mean random velocity <Vrand> of the ions for every absorbing cloud.



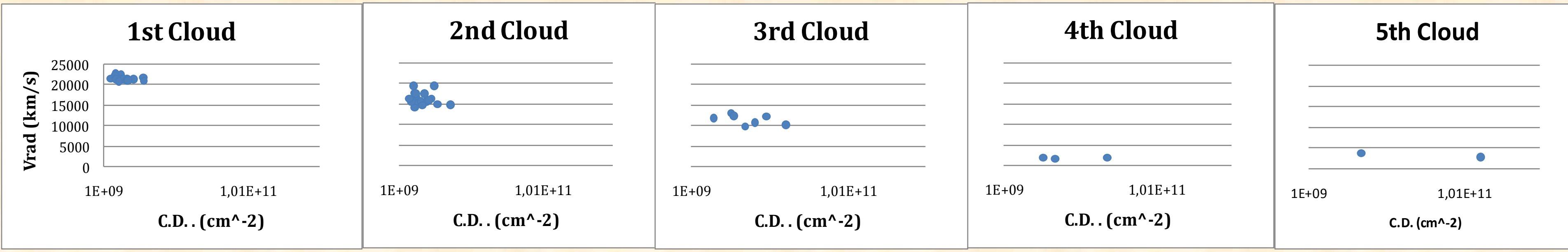
Mean Radial velocity <Vrad> as a function of FWHM for every absorbing cloud.



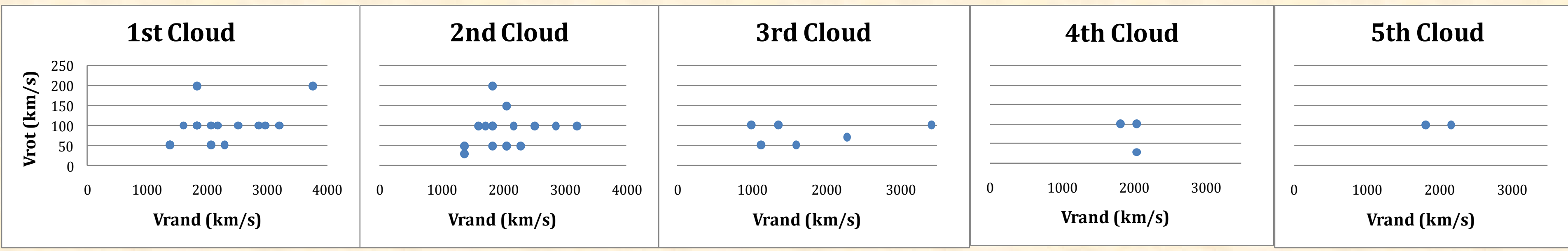
Mean Radial velocity <Vrad> as a function of Gaussian typical deviation <σ> for every absorbing cloud.



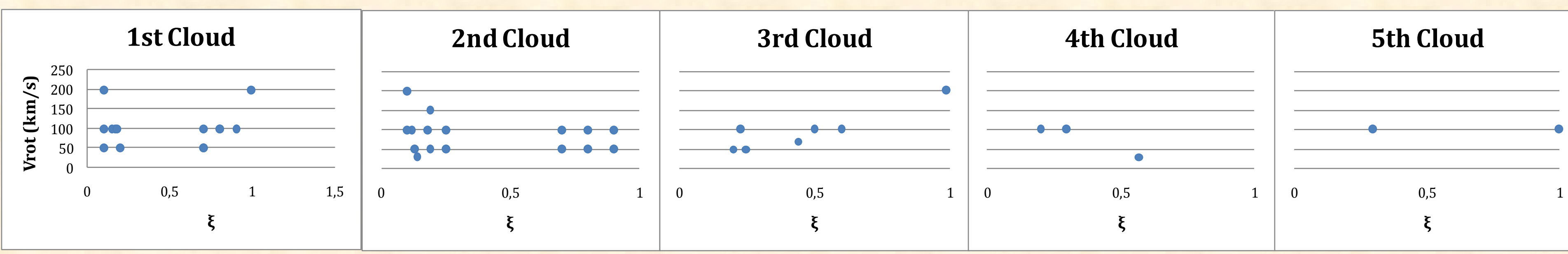
Mean Radial velocity <Vrad> as a function of mean optical depth <ξ> for every absorbing cloud.



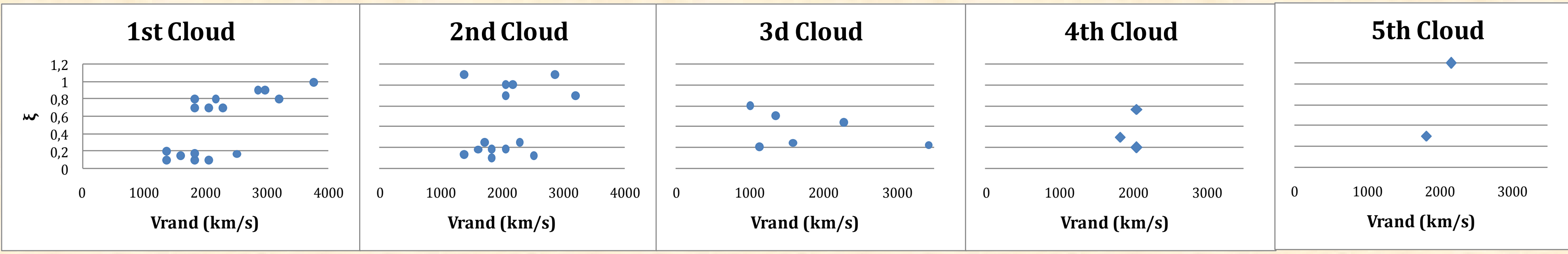
Mean Radial velocity <Vrad> as a function of mean column density <C.D.> for every absorbing cloud.



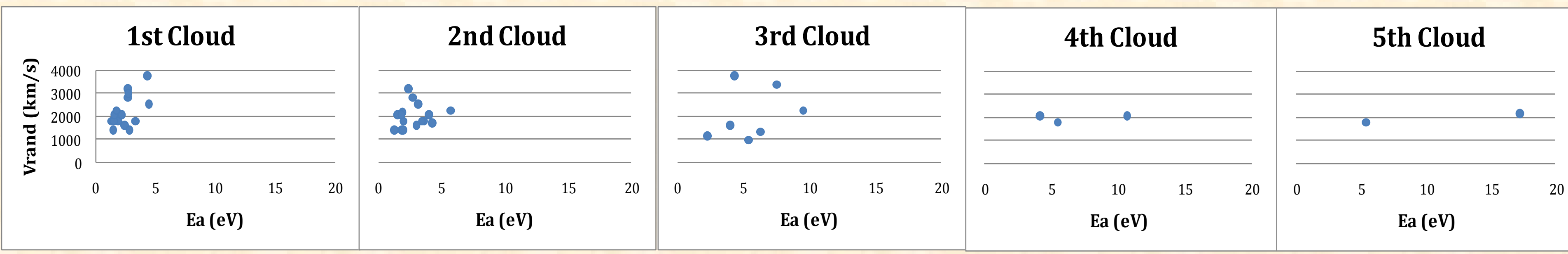
Mean Rotational velocity <Vrot> as a function of mean Random Velocity <Vrand> for every absorbing cloud.



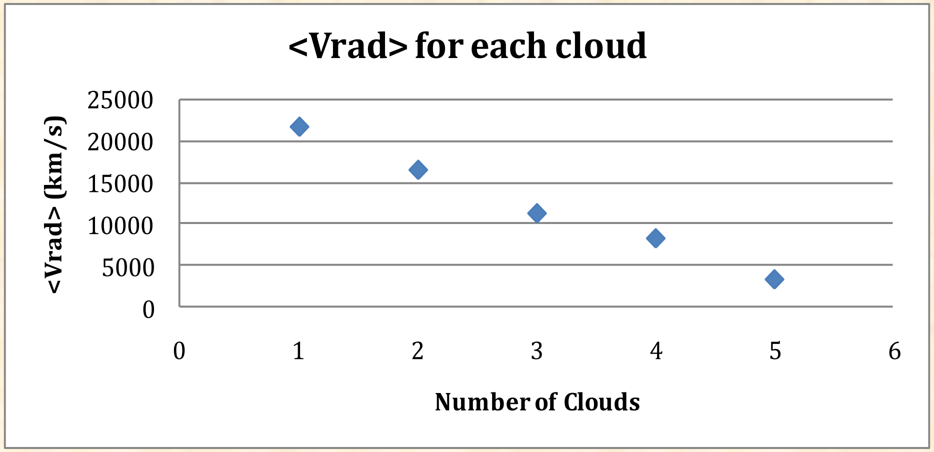
Mean Rotational velocity <Vrot> as a function of mean optical depth <ξ> for every absorbing cloud.

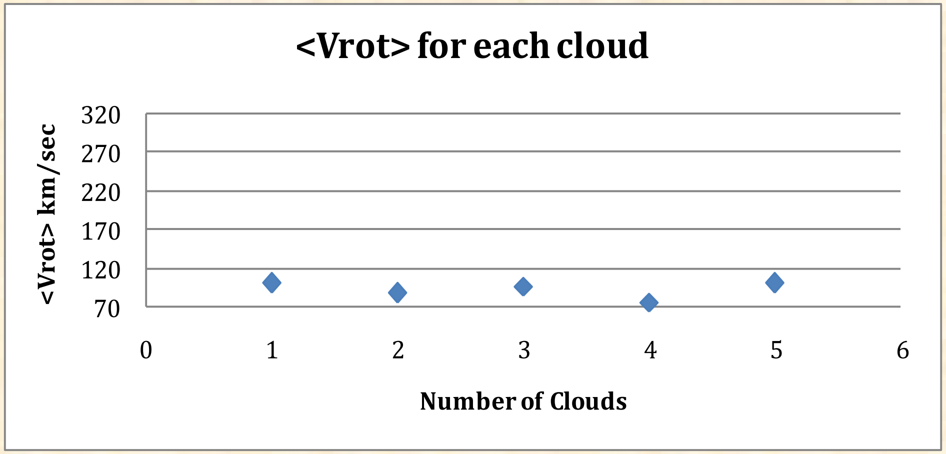


Mean optical dpeth <ξ> as a function of mean Random Velocity <Vrand> for every absorbing cloud.

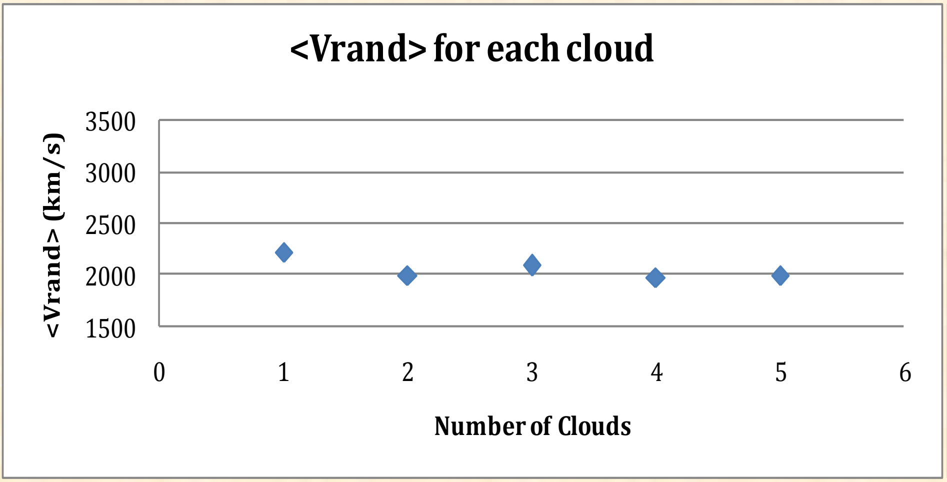


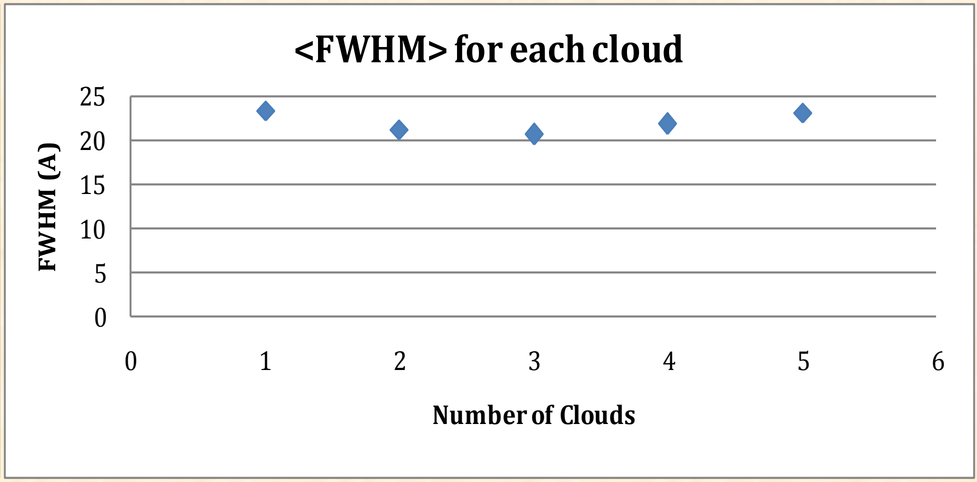
Mean Random Velocity <Vrand> as a function of mean Absorbed Energy <Eabs> for every absorbing cloud.



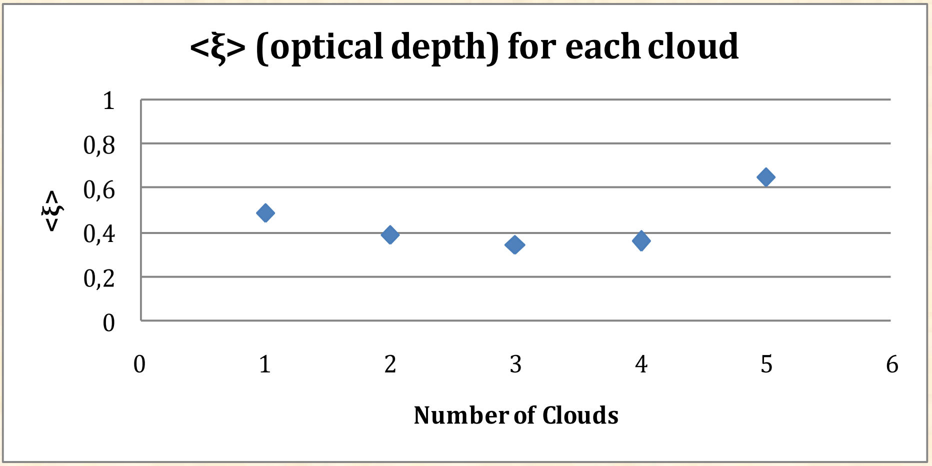


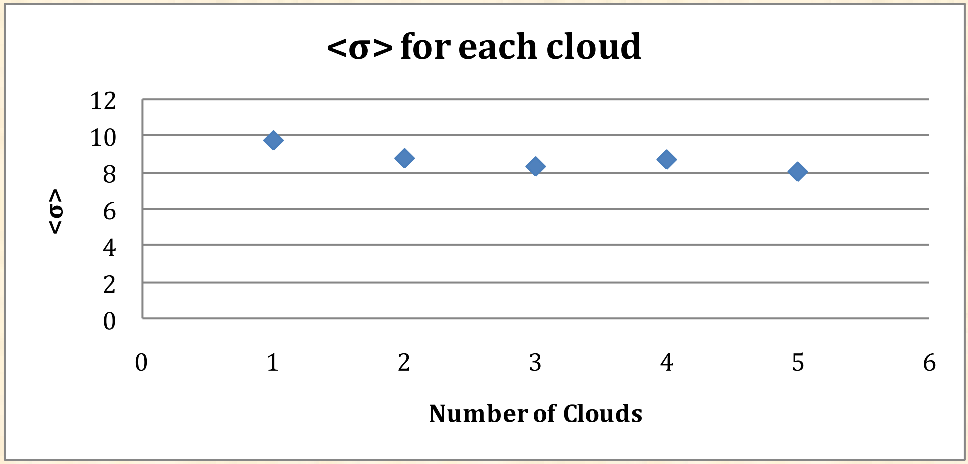
#	Radial Velocity			Rotational Velocity		
Clouds	U_{rad}^{min} (km/s)	U_{rad}^{max} (km/s)	$\langle U_{rad} \rangle$ (km/s)	U_{rot}^{min} (km/s)	U_{rot}^{max} (km/s)	$\langle U_{rot} \rangle$ (km/s)
1st	20982	22025	21504	55	145	100
2nd	14872	17888	16380	44	130	87
3rd	10529	12836	11683	38	151	95
4th	7661	9572	8617	48	118	82
5th	2470	4114	3292	100	100	100



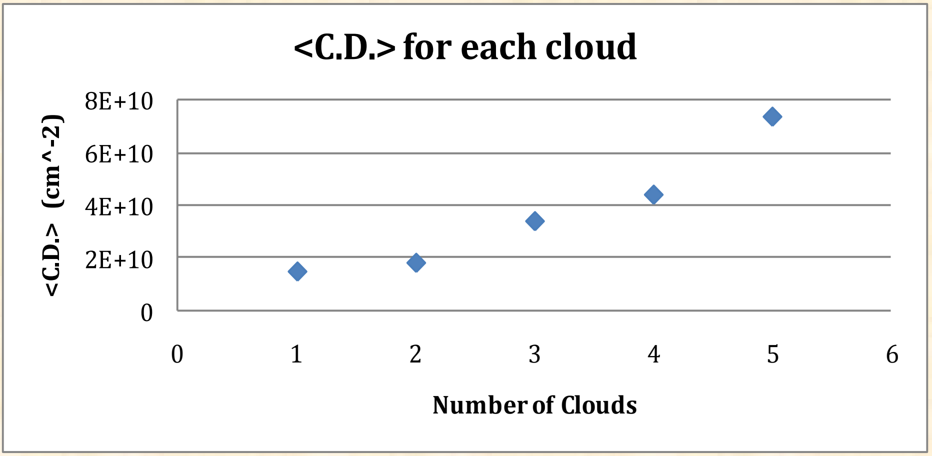


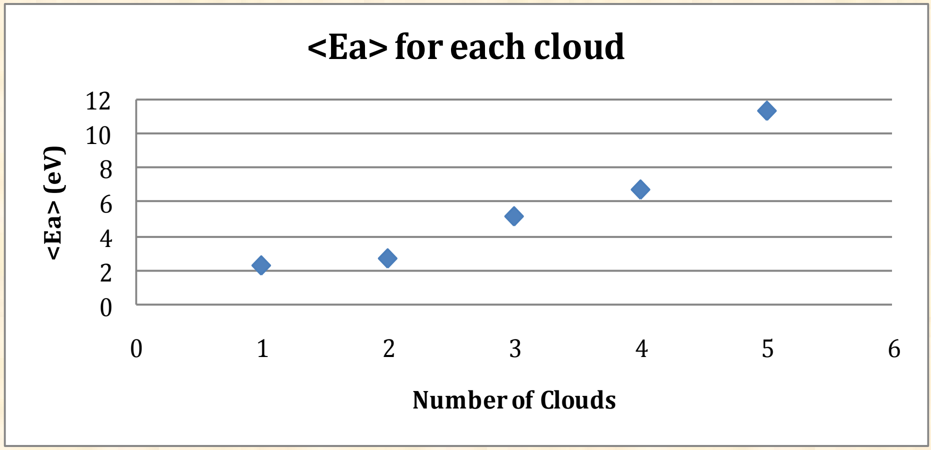
#	FWHM			Random Velocity (Ions)		
Clouds	$FWHM_{min}$ (Å)	$FWHM_{max}$ (Å)	$\langle FWHM \rangle$ (Å)	U_{rand}^{min} (km/s)	U_{rand}^{max} (km/s)	$\langle U_{rand} \rangle$ (km/s)
1st	16.24	30.41	23.33	1540	2894	2217
2nd	15.81	26.33	21.07	1487	2498	1992
3rd	12.91	35.98	24.45	1158	3364	2261
4th	13.88	24.52	19.20	1235	2232	1733
5th	18.01	27.93	22.97	1754	2238	1996





#	Optical Depth ξ			Gauss Standard Deviation (σ)		
Clouds	ξ_{min}	ξ_{max}	$\langle\xi\rangle$	σ_{min}	σ_{max}	$\langle\sigma\rangle$
1st	0.16	0.87	0.51	6.74	12.69	9.72
2nd	0.07	0.71	0.39	6.52	10.96	8.74
3rd	0.13	0.73	0.435	5.08	14.76	9.92
4th	0.22	0.62	0.42	5.41	9.78	7.6
5th	0.15	1.15	0.65	8	8	8





#	Column Density (C.D)			Absorbed Energy (E_{abs})		
Clouds	$C.D._{min}$ (cm^{-2})	$C.D._{max}$ (cm^{-2})	$\langle C.D \rangle$ (cm^{-2})	E_{abs}^{min} (eV)	E_{abs}^{max} (eV)	$\langle E_{abs} \rangle$ (eV)
1st	$8.6 \cdot 10^{9}$	$2.2 \cdot 10^{10}$	$1.5 \cdot 10^{10}$	1.49	3.41	2.45
2nd	$1 \cdot 10^{10}$	$2.5 \cdot 10^{10}$	$1.8 \cdot 10^{10}$	1.55	3.92	2.74
3rd	$2 \cdot 10^{10}$	$5.4 \cdot 10^{10}$	$3.7 \cdot 10^{10}$	3.08	8.32	5.70
4th	$2.3 \cdot 10^{10}$	$6.0 \cdot 10^{10}$	$4.2 \cdot 10^{10}$	3.57	9.28	6.42
5th	$1.9 \cdot 10^{10}$	$1.3 \cdot 10^{11}$	$7.4 \cdot 10^{10}$	2.97	19.75	11.36

Future Work

1.The study of a greater sample of BALQSOs

2.Calculation of all the previously mentioned physical parameters in the case of one more spectral line (Si IV, N V)

3. Finding out the narrow absorption lines and separating the QSO intrinsic absorption lines from the lines of the host galaxy or other galaxies in the line of sight.

4. Study the p – Cygni profiles (Weymann, Carswell and Smith 1981)in order to find out the mass loss.

5. Further study of Balnicity Index through the random velocities of the Clouds' Ions.

Thank you very much!