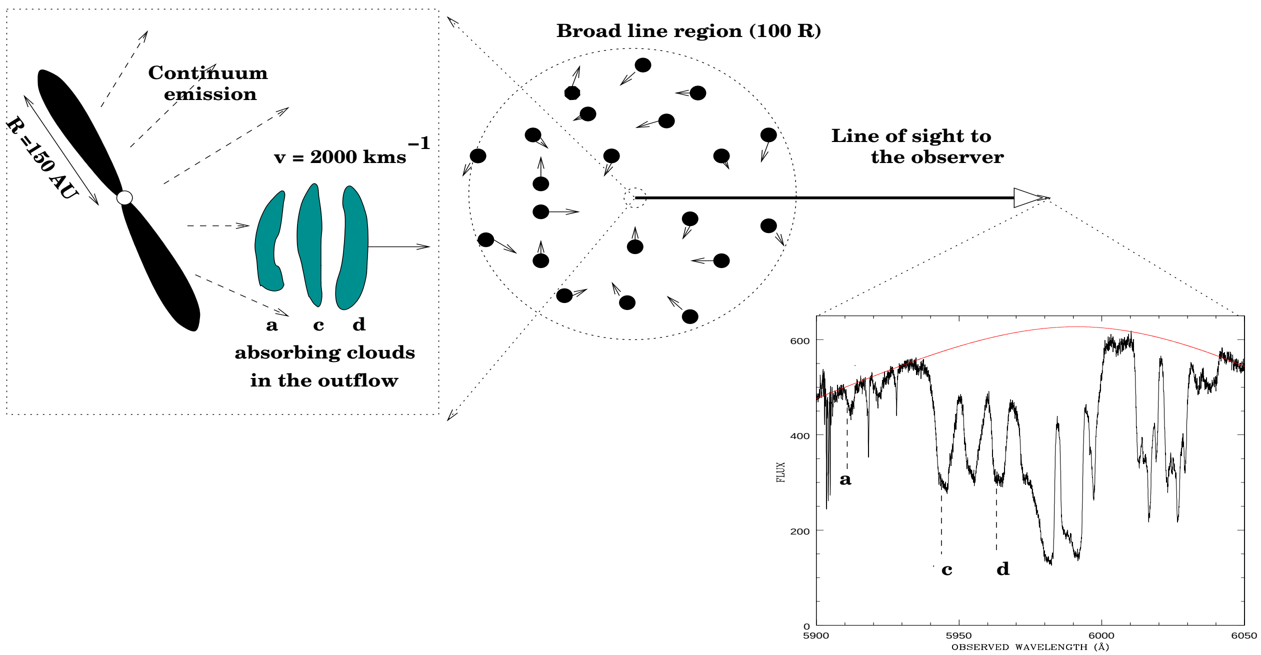
Winds from AGNs: A multiwavelength perspective



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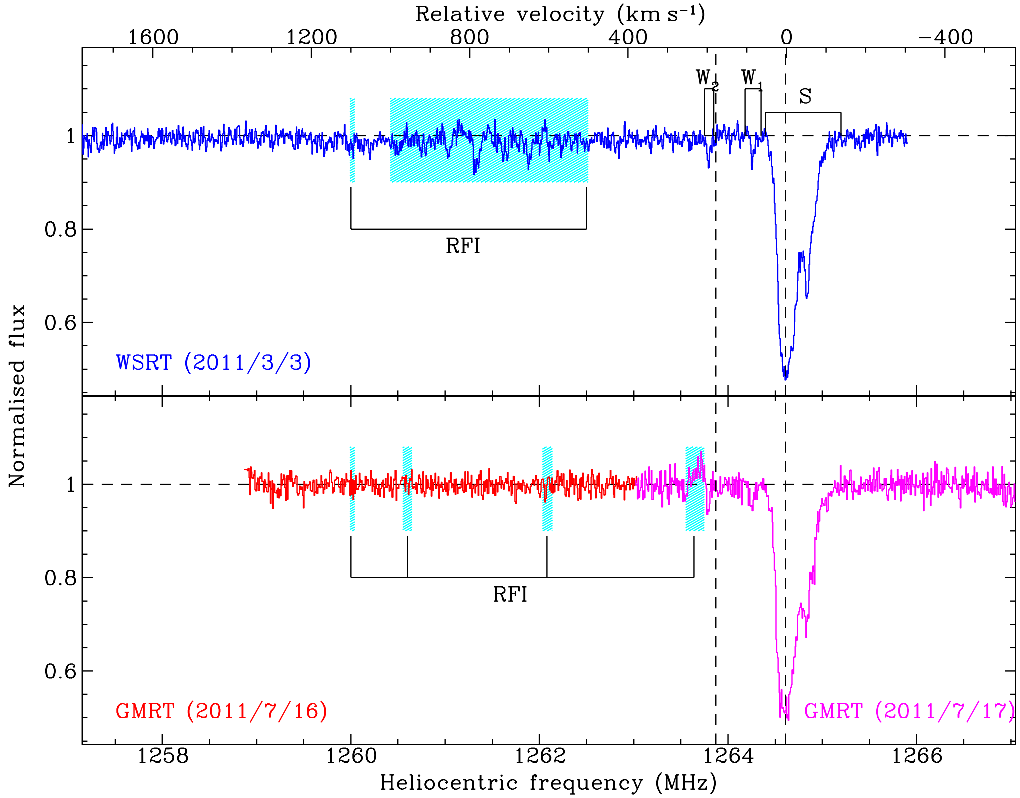
Why study AGN outflows?

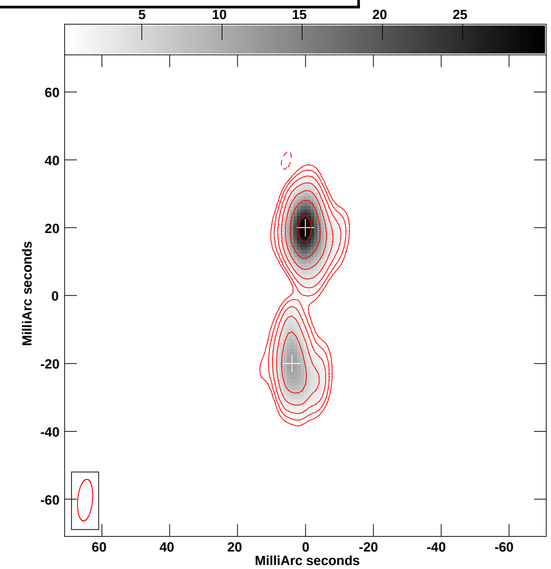
- **Kinematics, dynamics, nature and origin of the flow:**
  - Hydro dynamics, Radiation hydro-dynamics, MHD ?
  - Location, geometry, covering factor, stability and confinement.
- **Chemical enrichment**
  - Nature of star formation activities in the Galactic centre
  - Starburst - Black hole connection.
- **Feedback to the structure formation**
  - Birth of an AGN from the dusty central region.
  - Heating and enrichment of the IGM.
  - Heating of the intra-cluster medium.
  - Blackhole buldge relation.
  - High luminosity end of the galaxy luminosity function

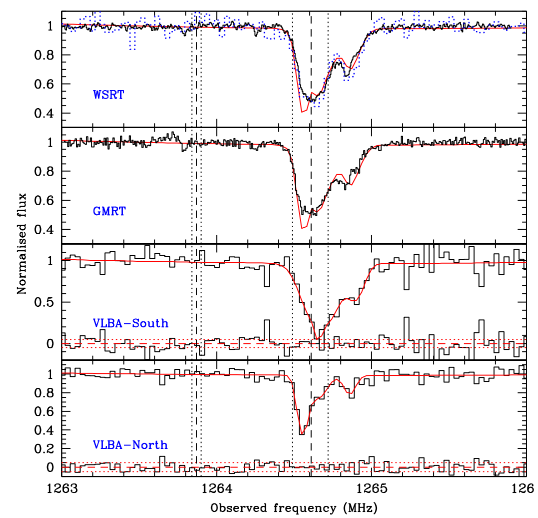
How does one study AGN outflows?

- **Optical-FUV regime:** *Detected as absorption in the AGN spectrum*
  - Broad absorption line QSOs - BAL QSOs
  - Narrow associated absorption systems - NALs
  - Diffuse Ly-α emission around QSOs
- **X-ray regime:**
  - Warm ionized absorbers: lines as well as edges
- **Radio regime:**
  - Large and small scale collimated jets
  - Associated broad H I absorption

Associated H I 21-cm absorption





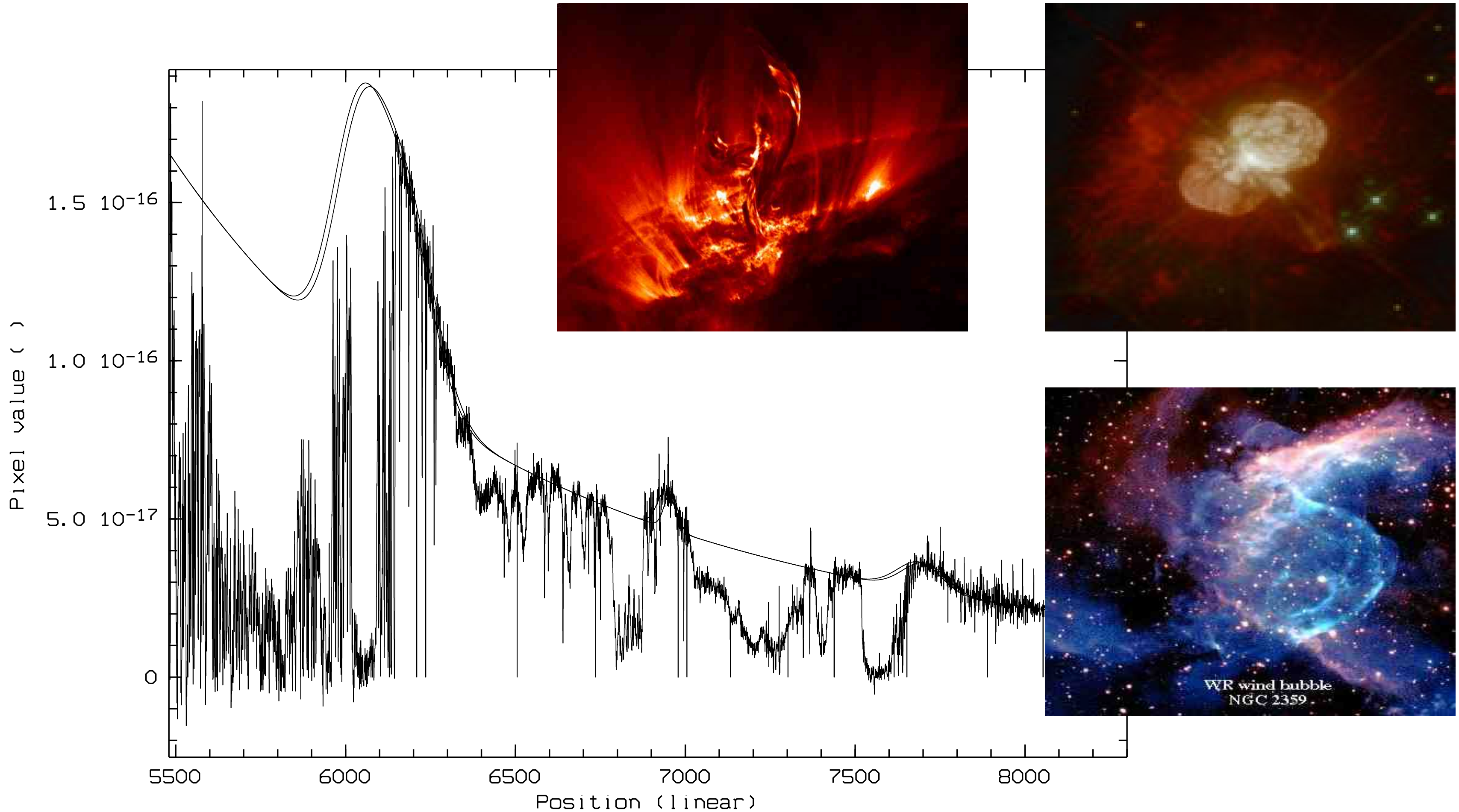


Srianand, Gupta, Momjian and Vivek, 2015, MNRAS, 451, 917

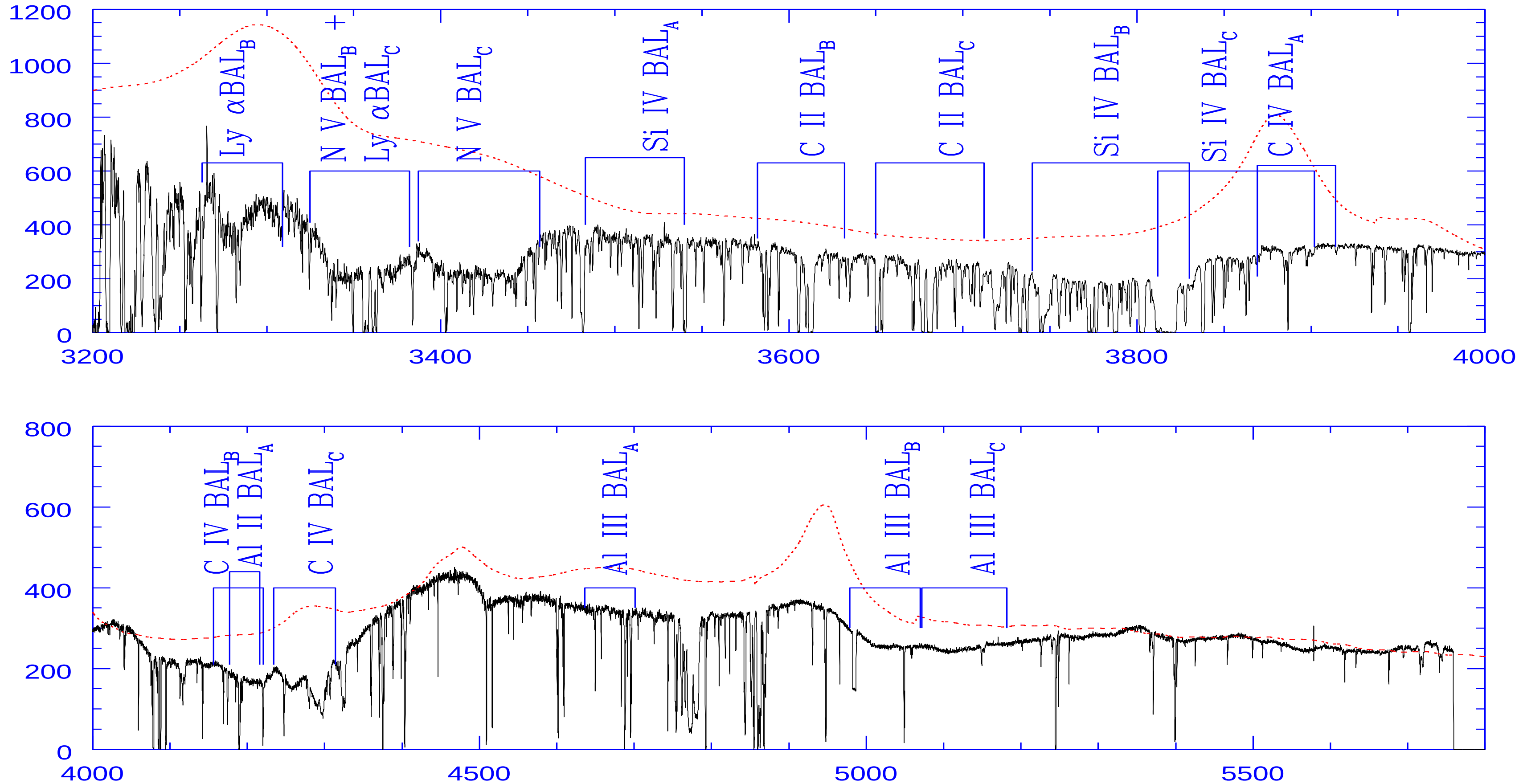
Associated H I 21-cm absorption

- Roughly 30-50% of radio-loud AGNs show H I absorption at the systemic redshift of the QSOs.
- Absorption detection rate is higher towards compact sources
- Absorption profile typically contains narrow as well as broad velocity components. About 5% of the systems show clear signatures of outflow upto few 1000 km s^{-1}
- Gas at the systemic redshift probably related to the circumnuclear regions, cold infall from the IGM or from merging, and cold outflows due to Jet-Cloud interactions.
- 21-cm absorption is sensitive to N(H I) and Spin-temperature $\mathrm{T_S}$. Therefore, this method is sensitive to cold gas in the outflow.
- Orientation and/or evolution

Broad absorption lines: Outflows



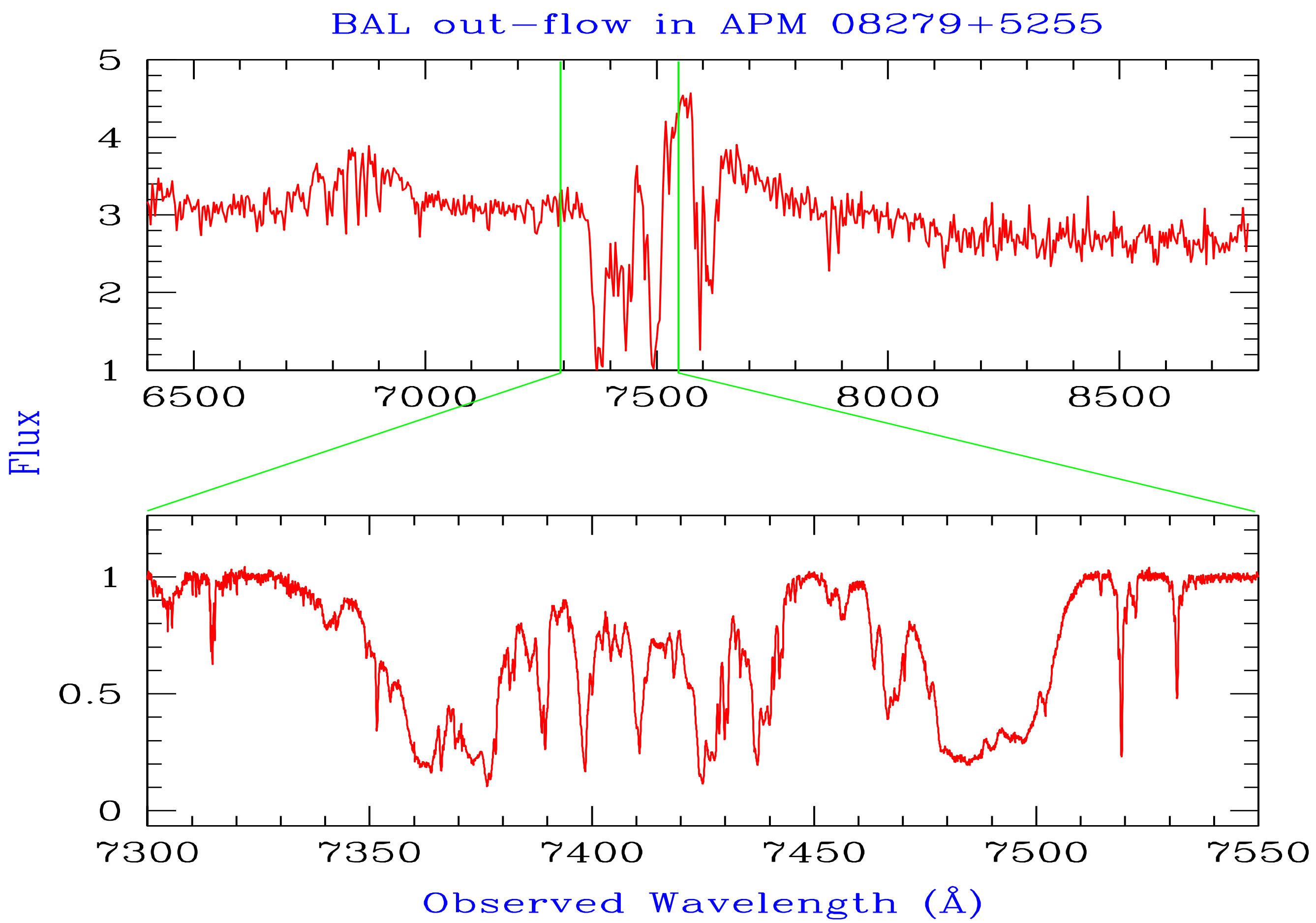
BALs: Very large ejection velocities



V_{eje} = **36000, 25300 and 22300 km s** ^{1}

Srianand & Petitjean, 2001,A&A 373, 816

BALs: Smooth or discrete



Srianand & Petitjean, 2000,A&A 357, 414

BALs: High ionization

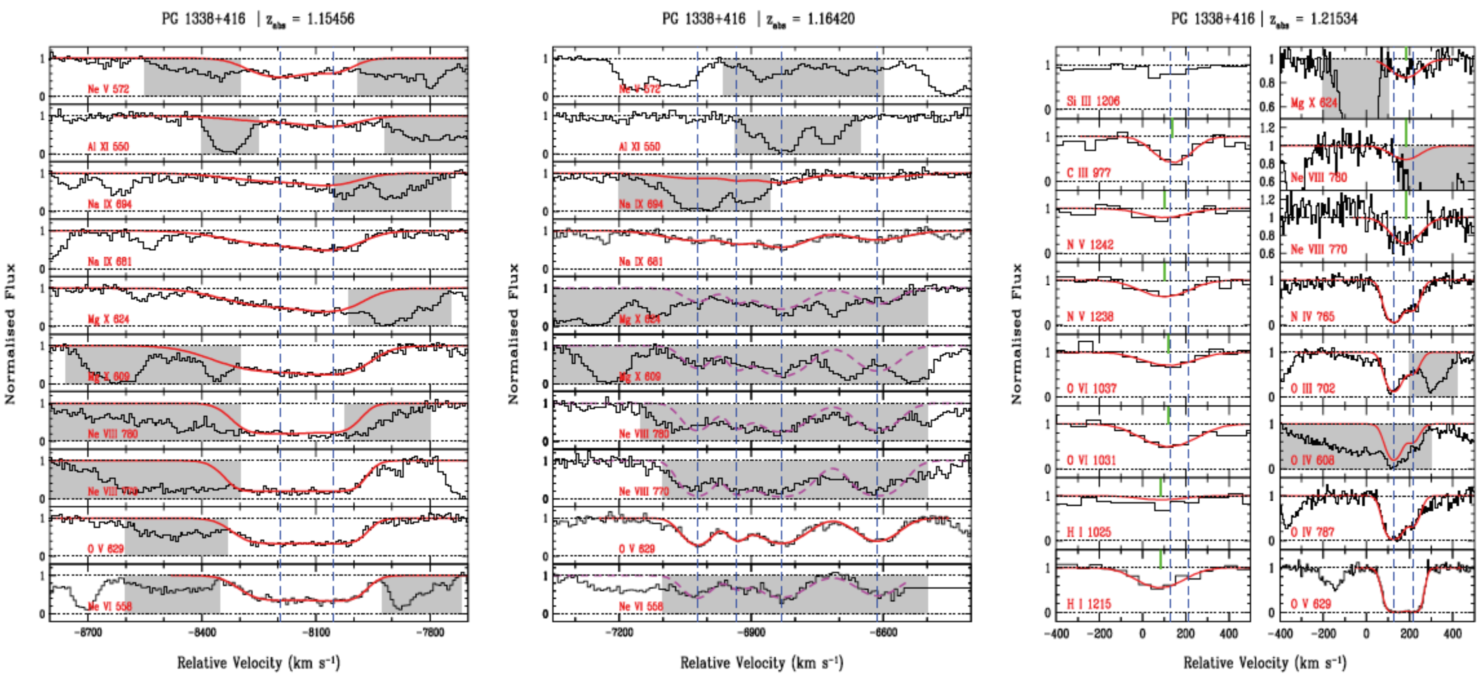
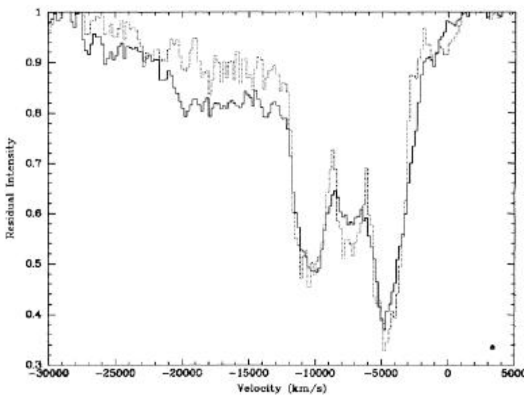
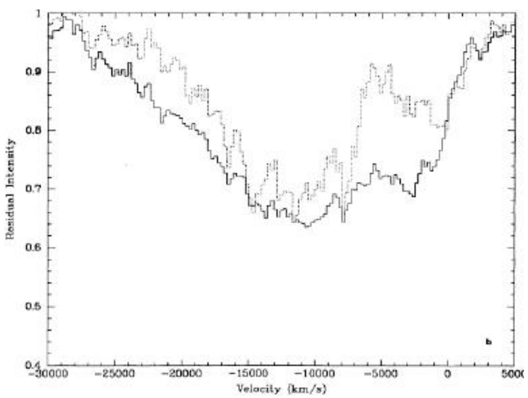


Figure 9. Velocity plot of the three associated Ne VIII systems detected towards PG 1338+416. The zero velocity corresponds to the emission redshift (z_{em} = 1.214) of the QSO. The smooth curves overplotted on top of the data show the best-fitting Voigt profiles after correcting for the partial coverage whenever needed. The shaded regions mark the contamination due to unrelated absorption to the system of interest. The vertical dashed lines mark the positions of individual Voigt profile components. Left: the system at z_{abs} = 1.154 56. Middle: the system at z_{abs} = 1.164 20. The smooth dashed curves represent not fit to the data, but the synthetic profiles corresponding to the maximum allowed column density assuming complete coverage (see the text). Right: the system at z_{abs} = 1.215 34. Apart from C III all other species plotted in the left-hand sub-panel are from FOS/G270H spectrum whereas C III is from FOS/G190H spectrum. All the species plotted in the right-hand sub-panel are from COS spectrum. Two components are clearly seen in O III, O IV, N IV and O V absorption (shown by two vertical dashed lines). In all other cases single component is needed as shown by (green) solid tick.

Muzahid, Srianand, Arav, Savage & Narayanan, 2013, MNRAS 431, 2885

BALs: Physics that drives the flow?

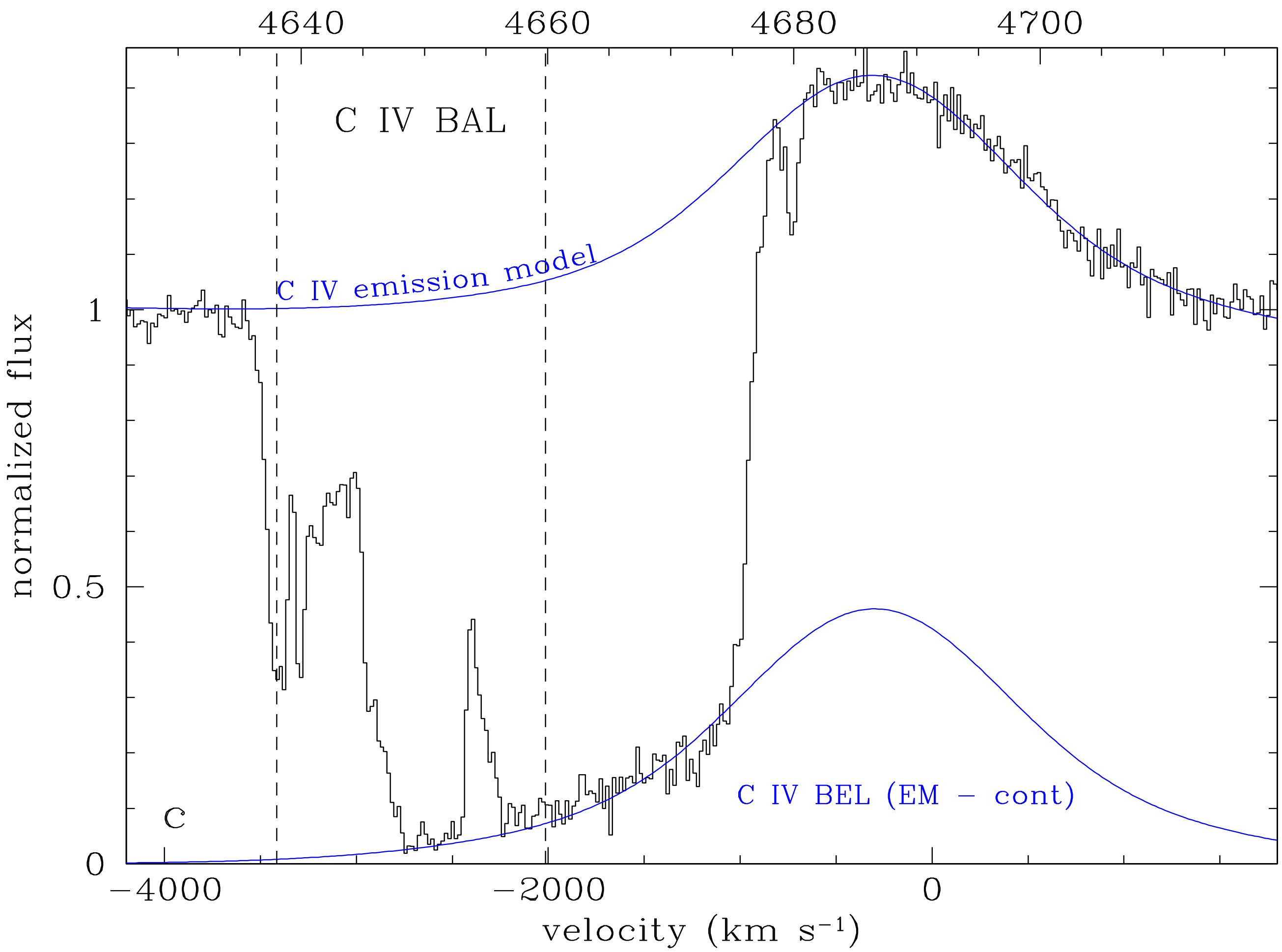




- What is driving the flow?
- Lyα - NV line locking seen in 20$-$30% cases.
- Much smoother profile in most cases.
- Line-driven acceleration may be important in 20-30% cases.
- However, acceleration is very rarely seen.
- Signatures of shocks are also difficult to detect

Arav, 1996, ApJ, 465, 617

BALs: Location?



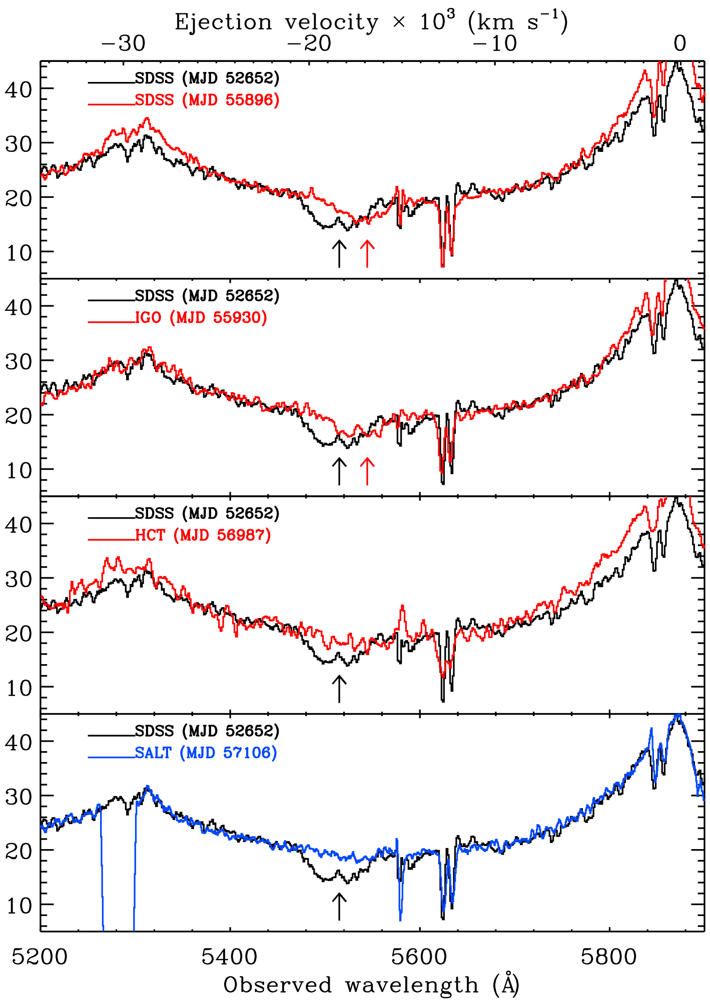
Most of the time covers the BLR?

Arav et al. 1999

BALs: X-ray observations

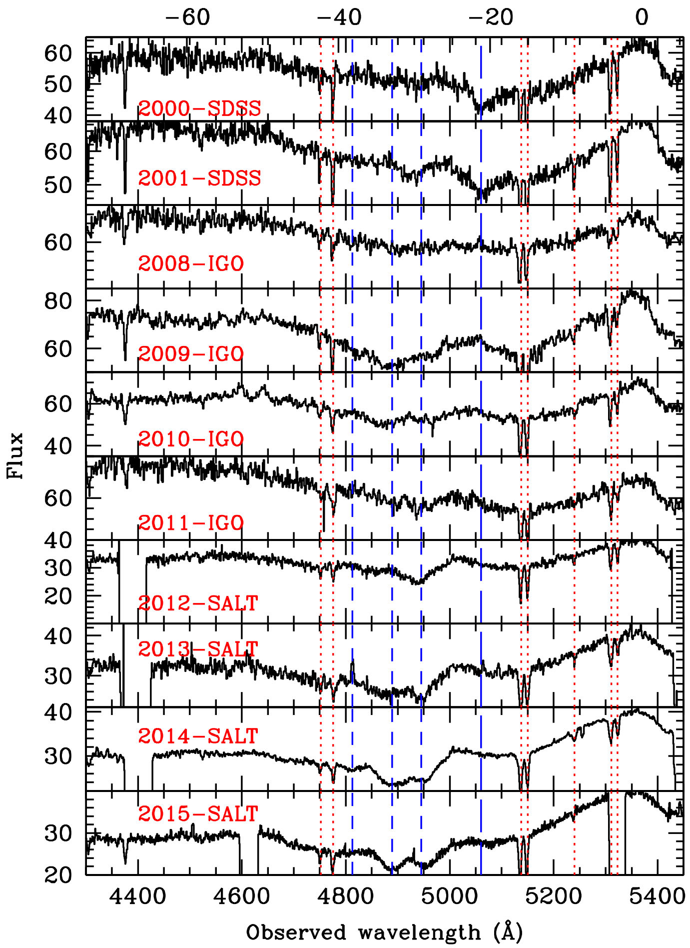
- Under-luminous in X-rays.
  - BAL QSOs are intrinsically X-ray weak.
  - BAL QSOs are highly absorbed: COLD X-ray absorbers, WARM absorbers (PHL 5200) , Compton/Thomson screen (PG 0946+301).
  - Unabsorbed emission lines of BAL and non-BAL QSOs are statistically identical. This implies the intrinsic spectrum of the central engine is more or less identical.

Disappeared BAL in X-ray loud QSO J0911+055



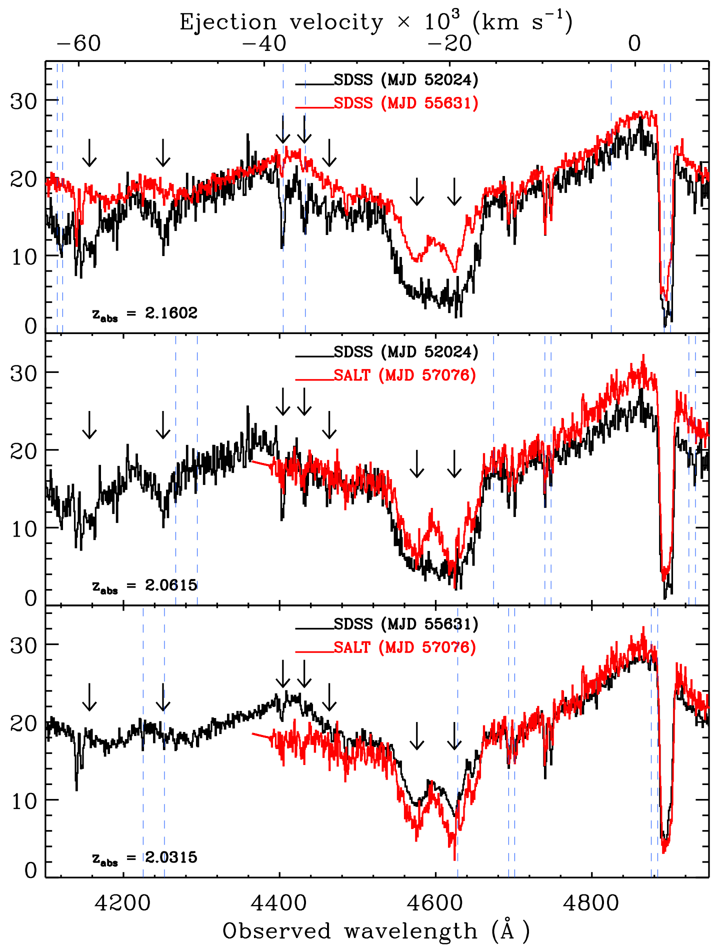
- X-ray loud BAL QSO with $z_{\rm em}$ = 2.793.
- Joshi et al. (2014) reported a possible deceleration of -2.0 ± 0.1 cm s^{-2} over the QSO rest frame time-scale of 2.34 yrs.
- Deceleration is explained by making outflow in a curved path. If so the absorption will disappear when the transverse displacement is larger than the size of the accretion disk + absorbing cloud.
- The absorption is now disappeard in the latest SALT spectrum. We are modelling the flow to extact accretion disk and absorbing gas parameters and say some thing about magnetic fields.
- Future proposal: Has X-ray flux increased with the disappearance of the absorption.

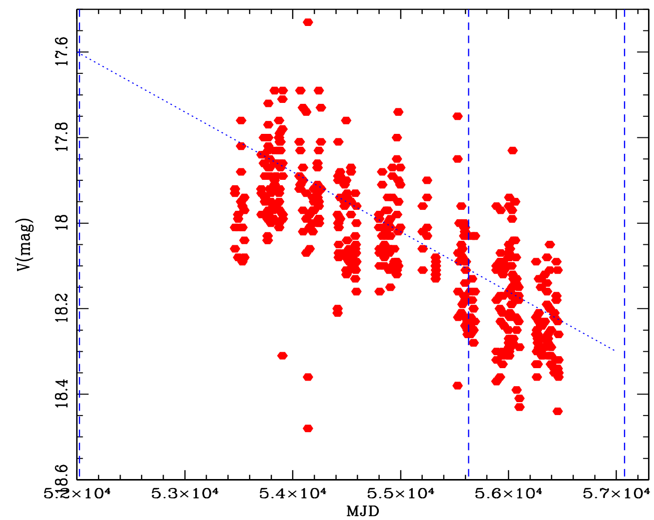
Recurring Mg II BAL absorption in J1333-0012



- Vivek et al. (2012) reported diappearing red and dynamically evolving blue component. Originally classified as Mg II BAL had become normal QSO again with out any absorption.
- This is the only known Mg II absorber that has shown such a large variability over time-scales of months to years.
- In the SALT spectrum the absorption reappears at the same wavelength as before. It has grown to a full strength and beginning to weaken. A future disappearence will confirm the recurring BAL.

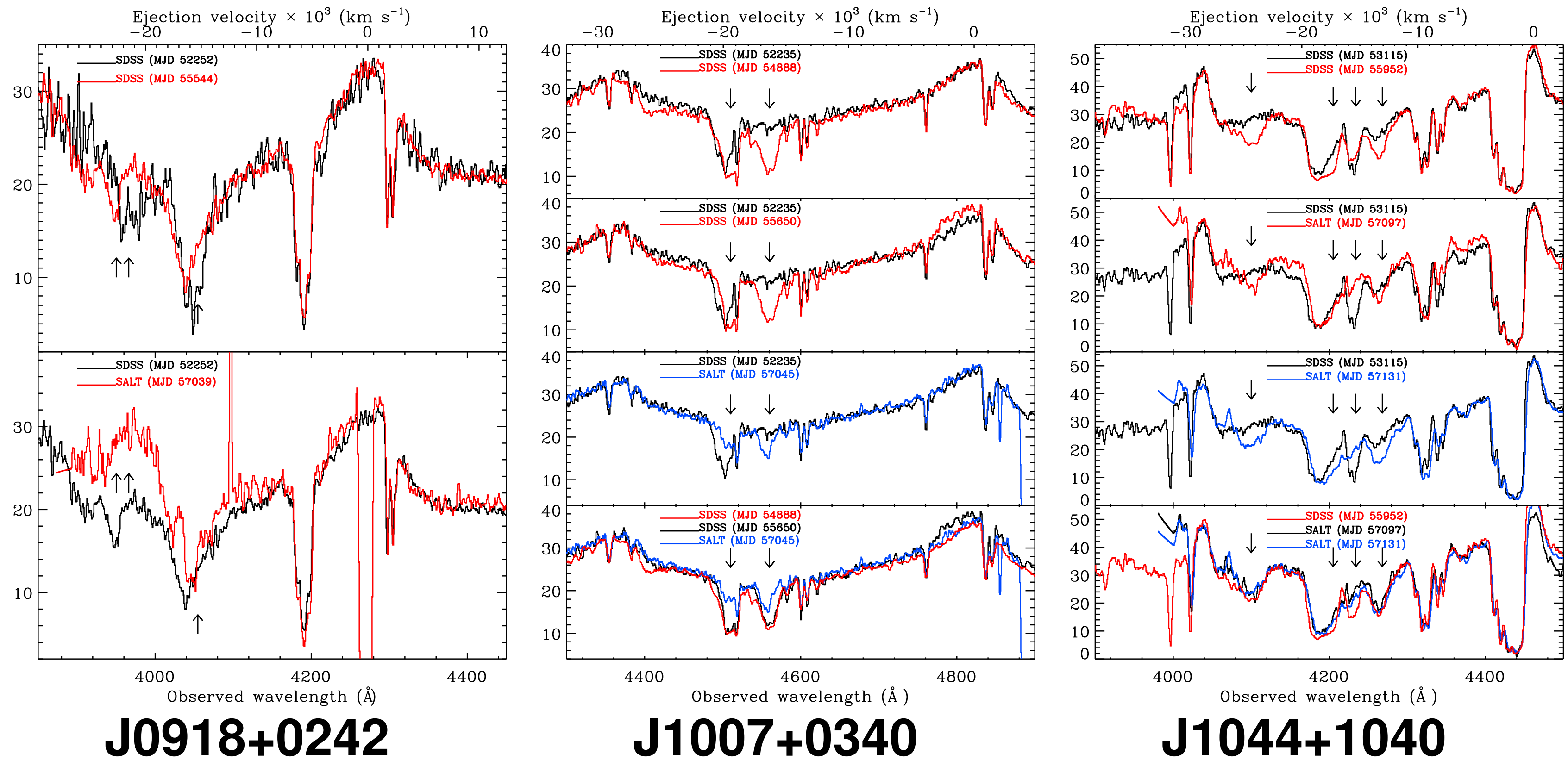
J1205+0134: Photoionization induced variability



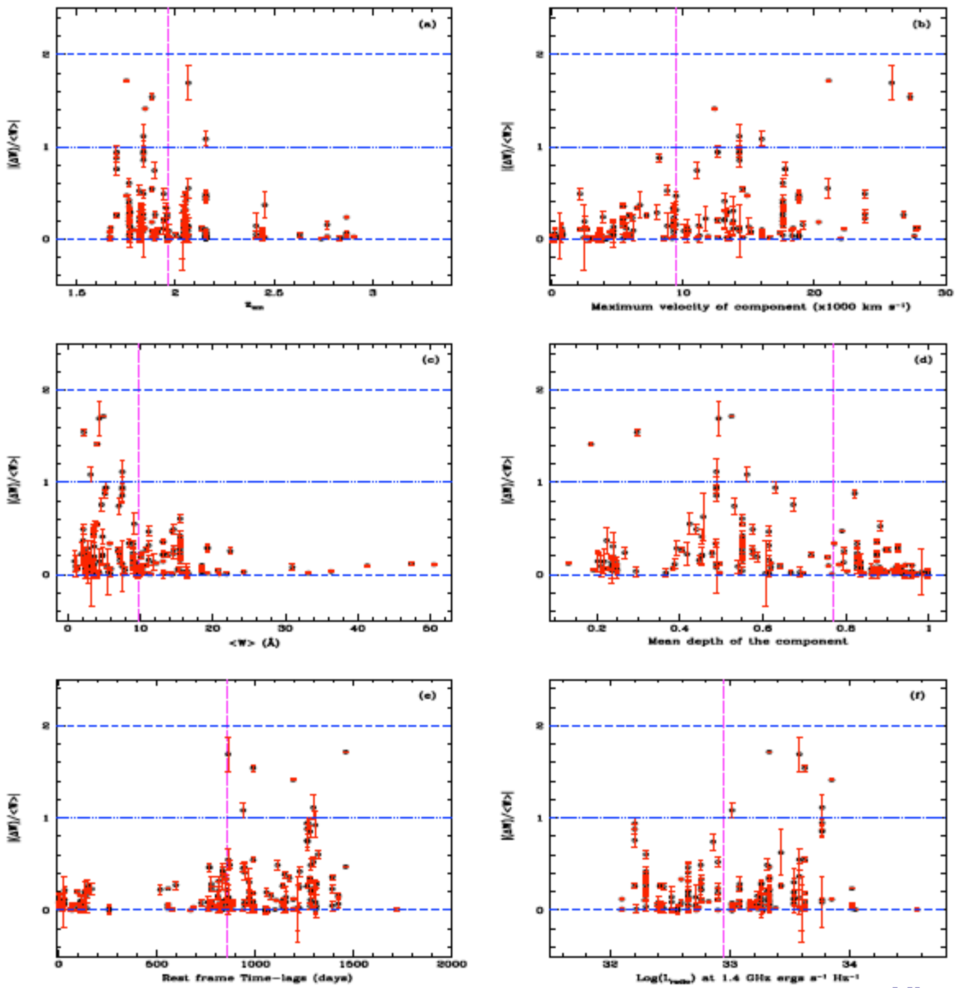


- An infalling gas with narrow absorption + broad outflowing gas + excess intervening C IV absorption seen.
- All the associated absorption + Emission lines show variability. Light curve also confirms continuum dimming.
- Variability time-scale = recombination time ==> density constraint; distance from ionization modelling and the gas carries enough mechanical luminosity to provide sufficient feedback.

Some more examples:



Variability and correlations



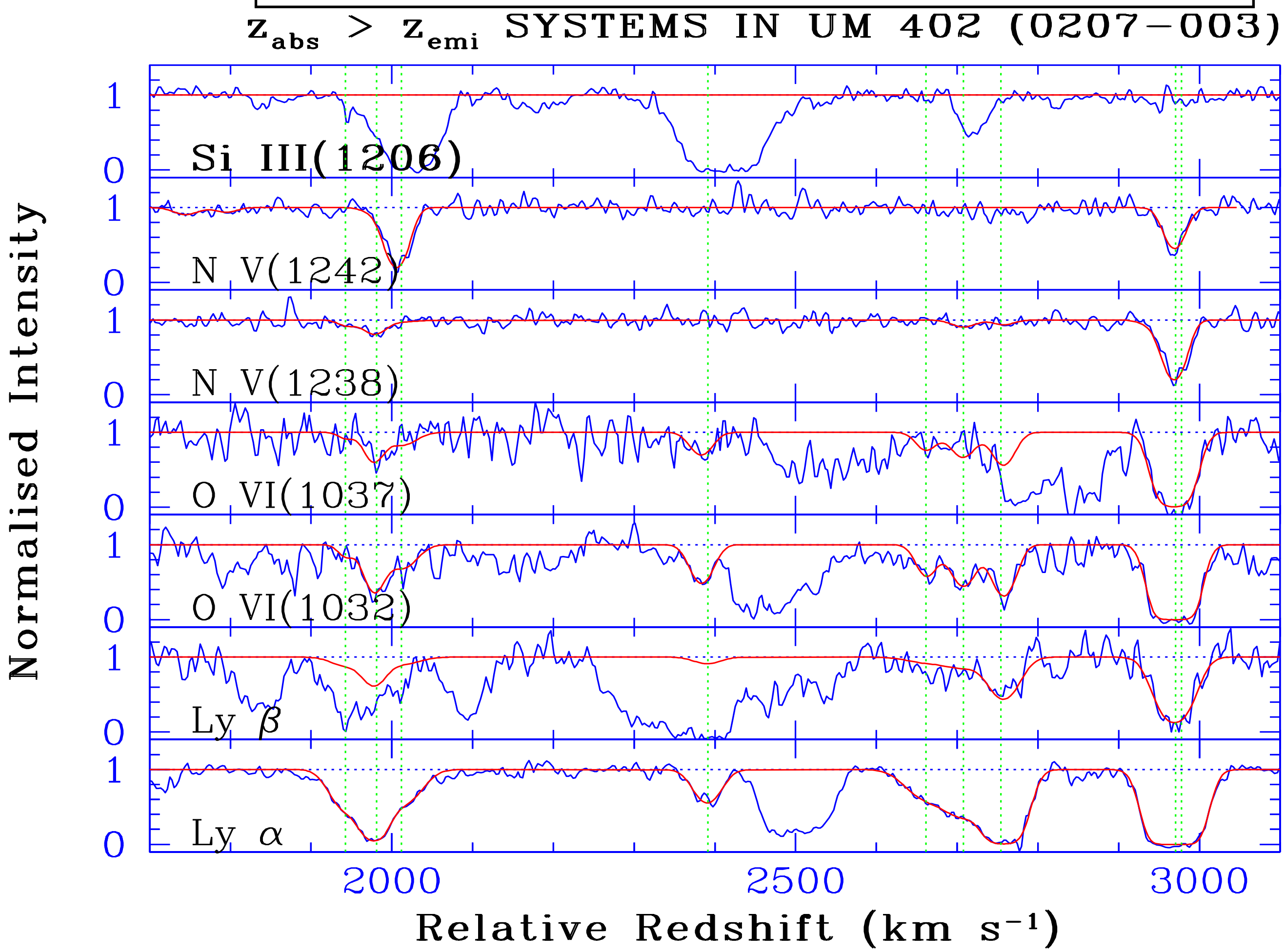
- Variability is high at high ejection velocities
- Variability (in particular transient absorption) frequenty occur over t>3 months
- Mainly weak components show strong variability (including transient)
- A weak tendency for radio brigh objects to show large line variability.
- Variability does not depend on AGN properties like BH mass, Eddington ratio etc...

Vivek, Srianand, Gupta, 2015, MNRAS, submitted

Properties of BAL QSOs:

- Absorption lines have large velocity width and they show large velocities with respect to QSOs.
- 10% of the radio selected QSOs show BAL absorption. Possibly smaller solid angle for the flow. However, high luminosity RL QSOs are usually don't show BALs.
- Nature of the flow: Smooth fluid (or) discrete clouds.
- Absorption is mainly dominated by high ionization species and low ionization BALs are rare.
- BALs are either X-ray weak/quiet or highly absorbed.
- $\sim$ 20% of the BAL flow may be driven by radiative pressure.
- BAL variabilities are not induced by ionization chages.
- Line of sight crossing is the possible reason for the variability.
- Location can be anywhere between close to the accretion disk to the ISM.
- Very high inferred metallicity.

Intrinsic absorption lines: NAL

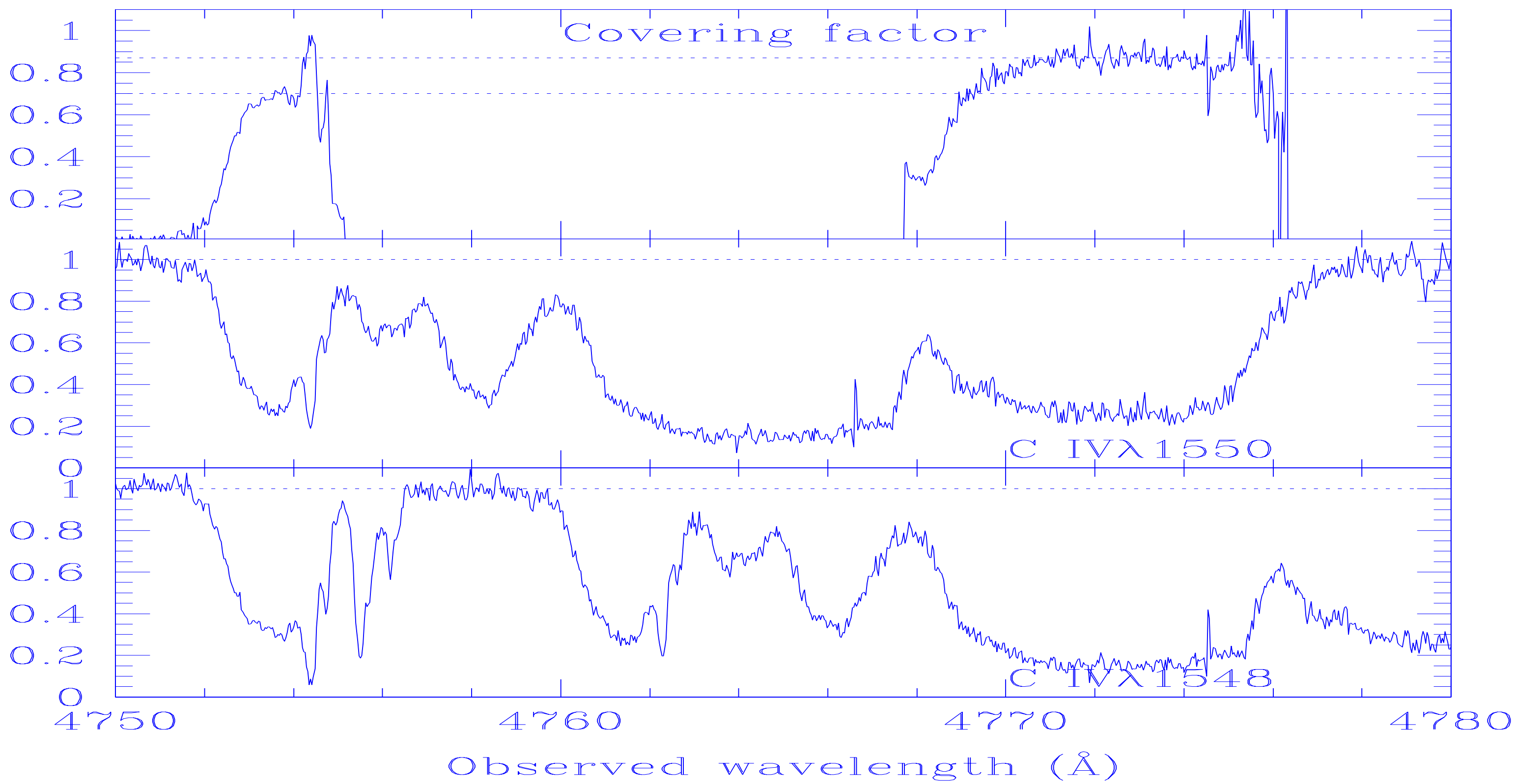


NAL:Partial coverage

- $I_\lambda = I_0(f_c \times e^{-\tau} + (1 - fc))$ **and** $R_\lambda = f_c \times e^{-\tau} + (1 - fc)$
- **For large τ,** $R_\lambda = (1 - fc)$
- $\tau \propto N\lambda f$
- **For doublets f_1 = 2 f_2; $\lambda_1 \simeq \lambda_2$ and N is same.**
- $f_c = \frac{1+R_2^2-2R_2}{1+R_1-2R_2}$

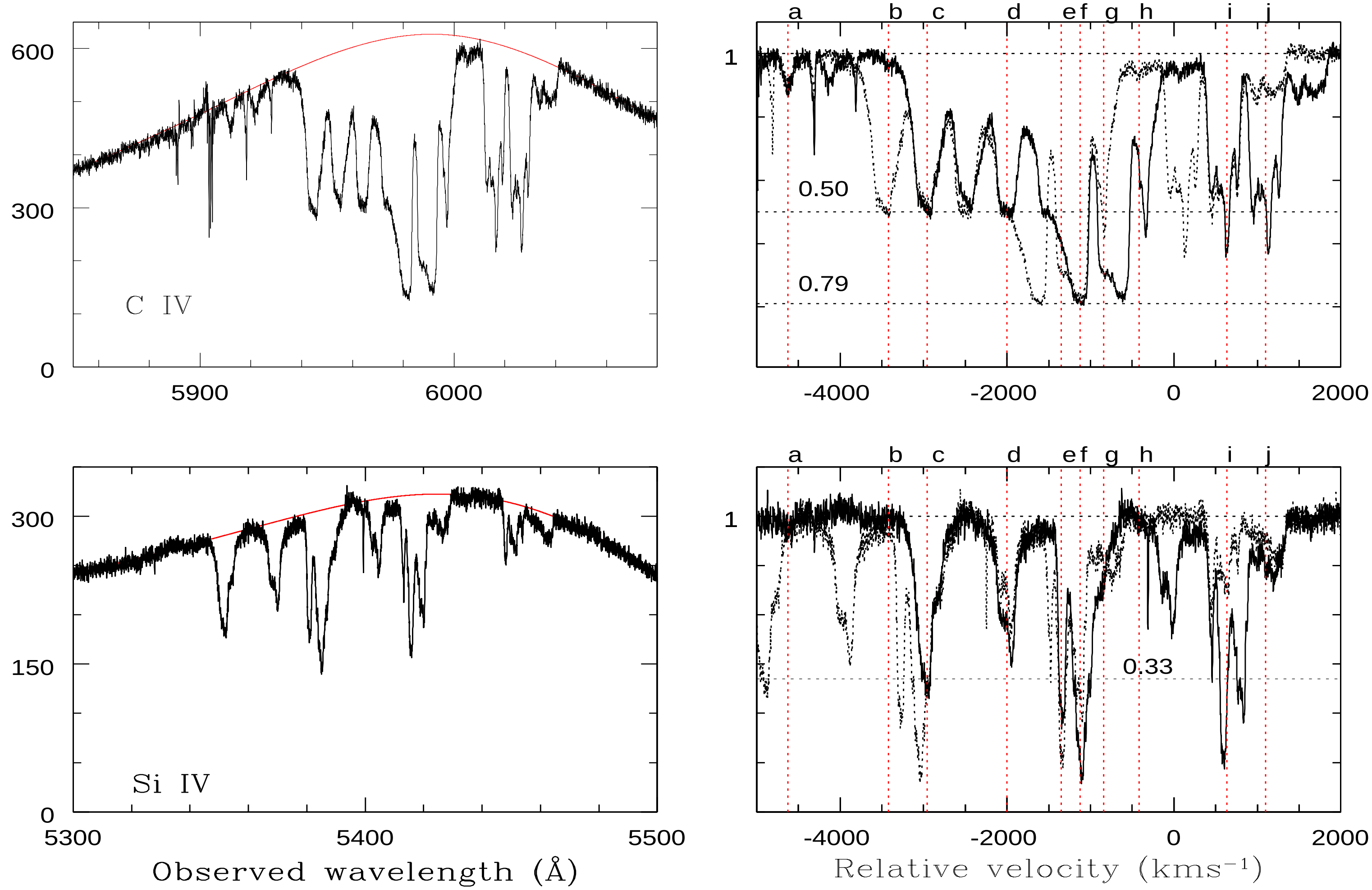
Srianand & Shankaranarayanan, 1999, ApJ, 518, 672

NAL:Partial coverage



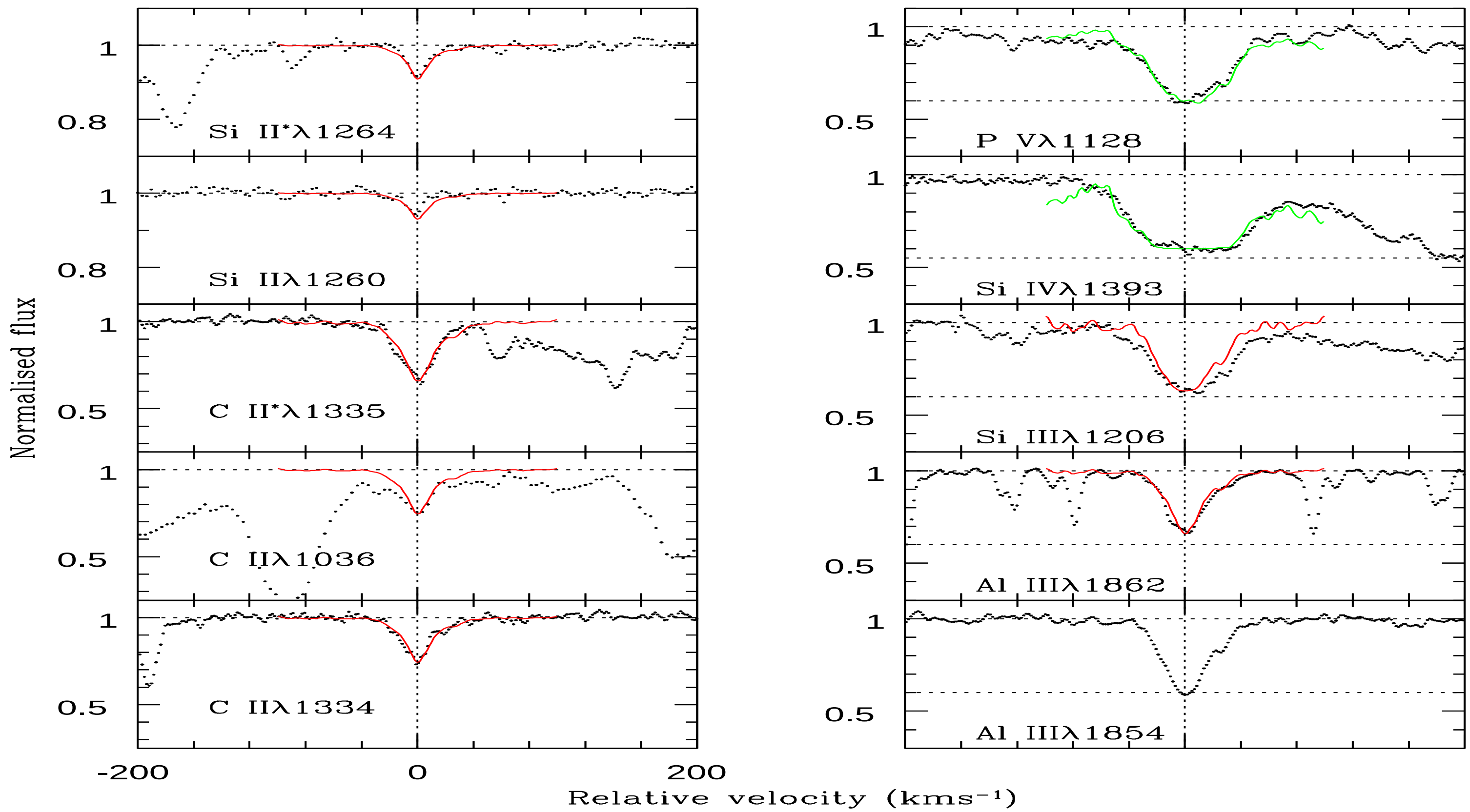
Srianand & Petitjean, 2001, A&A, 373, 816

NAL:Doublet line-locking



Srianand, Petitjean, Ledoux & Hazard, 2002, MNRAS, 336, 753

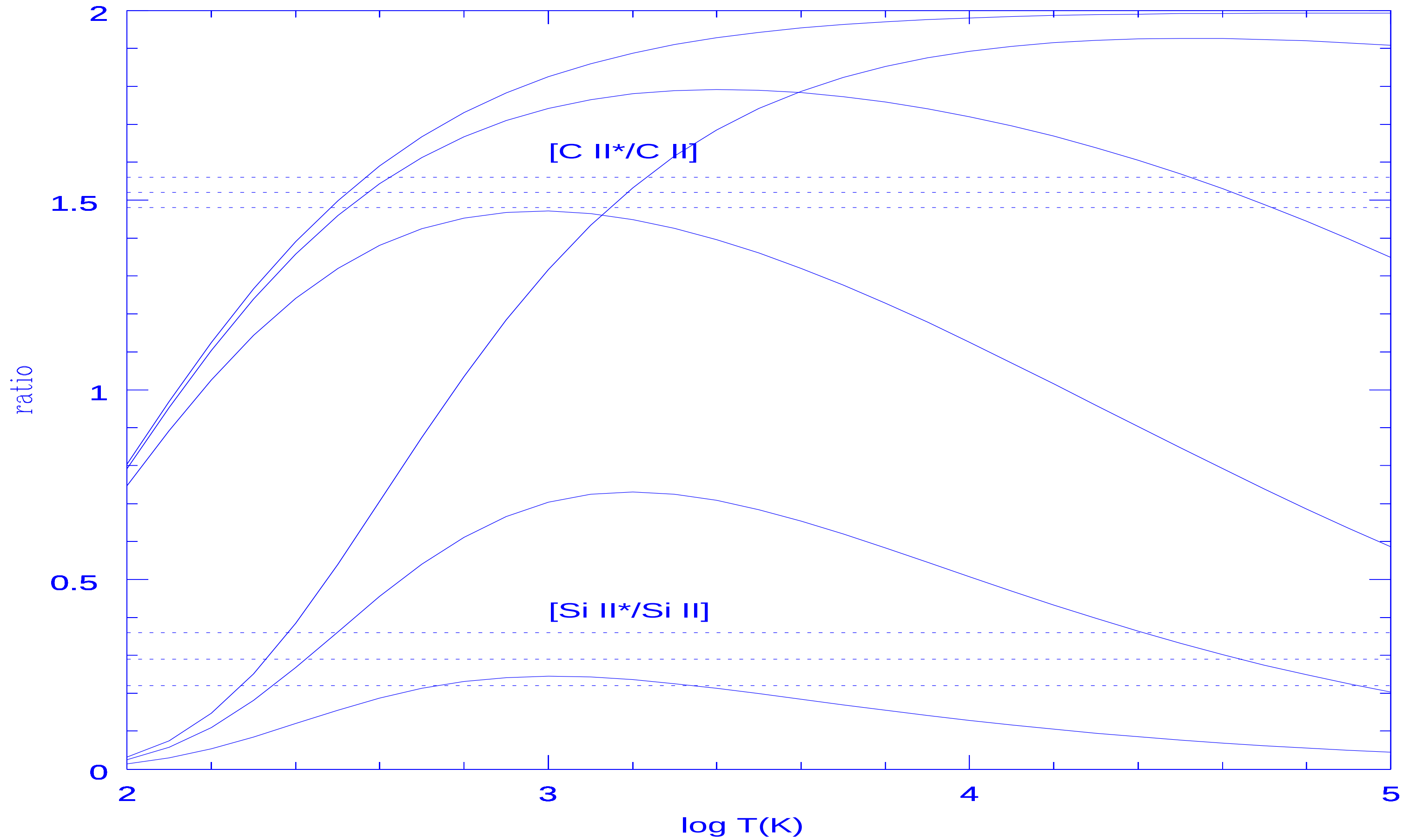
NAL: Excited fine-structure lines



NAL: Excited fine-structure lines

- **Local thermodynamic equilibrium (LTE):** $\frac{N_1}{N_2} = \frac{g_1}{g_2} exp(\frac{-h\nu}{kT})$
- $N_1 \sum Q^i_{12} n^i + N_1 B_{12} = N_2 A_{21} + N_2 B_{21} + N_2 \sum Q^i_{21} n^i$
- **The relative populations of fine-structure levels (or hyper-fine-structure levels) are sensitive tracers of density, temperature (pressure) and radiation field (mainly IR and mm wave....CMBR).**
- **There is no isolated two level system in the real universe. define UV pumping.**

NAL: Excited fine-structure lines



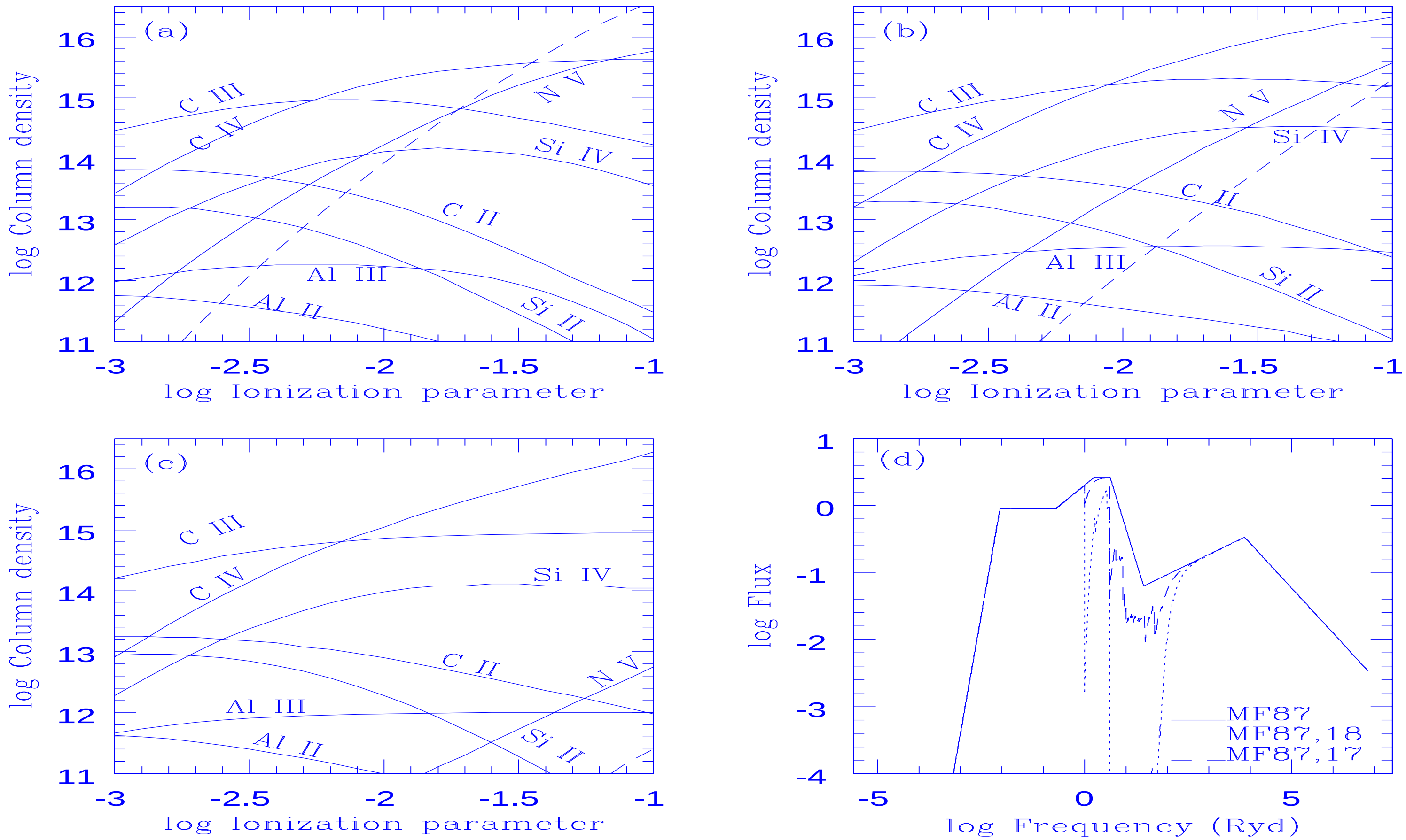
NAL: Time variability

- **If absorption variability follows the continuum variability then the relevant time-scale in the problem is the recombination time-scale (1/$n_e \alpha(T)$).**
- **If absorption lines do not respond to the variation in the continuum then upper limit on density can be obtained.**
- **Variability could also be caused by displacement and dynamical change in the line emitting region.**

NAL: Ionization corrections

- $n_{H\ I} \times (\frac{L}{4\pi r^2 h\nu c}) \times \kappa_\nu = n_e n_p \alpha = n_e^2 \alpha$
- $\frac{f}{1-f} = \frac{\alpha}{\kappa U}$
- **Here U is the ionization parameter, f is the fraction of hydrogen in neutral form, κ is no of photo-absorptions per sec per unit volume and α is the recombination rate.**
- α **depends on temperature. You need a separate eqn for thermal equilibrium (i,e total heating rate = total cooling rate).**
- **At a given temperature the ionization state of hydrogen can be uniquely determined by U. But there is a degeneracy between r and n_e.**

NAL: Ionization corrections



Properties of NAL:

- **50% of the seyferts (and about 20% of QSOs) narrow UV absorption due to outflowing gas.**
- **Presence of excited fine-structure lines.**
- **Partial coverage**
- **Very high degree of ionization**
- **Time variability: high densities**
- **Very large metallicity: Even at z $>$5 large metallicities are inferred. It appears that most of the enrichment has happened in about few 10^8 years.**

On Kinetic luminosity in the AGN outflow:

$$
\begin{aligned}
\dot{M}_{out} &= 4\pi r^2 \rho v_w C_\Omega \\
&= 4\pi \mu m_p C_\Omega (n_H r) r v_w \\
&= 4\pi \mu m_p C_\Omega N_H r v_w \\
\dot{E}_k &= 1/2 \dot{M}_{out} v_w^2 \\
&= 2\pi \mu m_p C_\Omega N_H r {v_w}^3
\end{aligned}
$$

v_w = Approximated to the outflow detection rate
r = Either from ionization parameter + fine-structure lines
v_w = Directly measurable but remember the thin-shell approximation
N_H = Total N(H), we need to know the ionization correction and/or metallicity.

The claim is, we do have sufficient $\dot{E}_k$ to provide necessary AGN feed back for galaxy formation models.