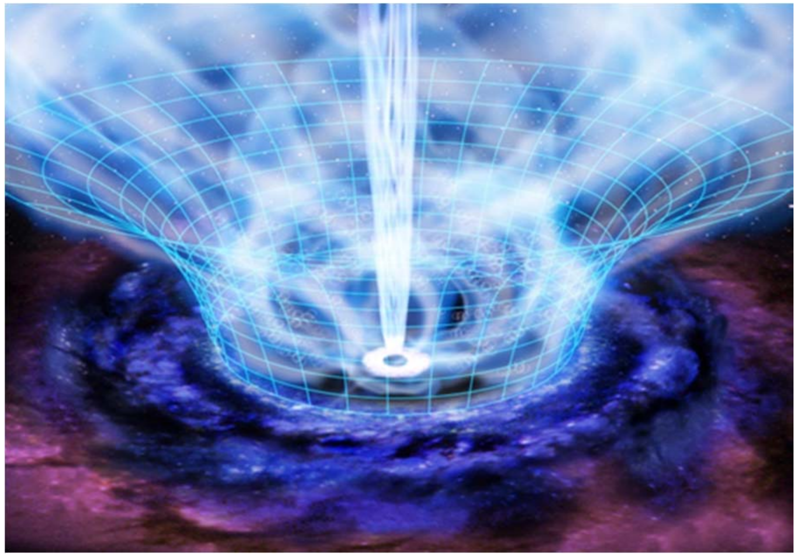
EWASS 2017 @ the Charles University in Prague

Physical Properties of Narrow and mini-Broad Absorption Line Systems



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OUTLINE

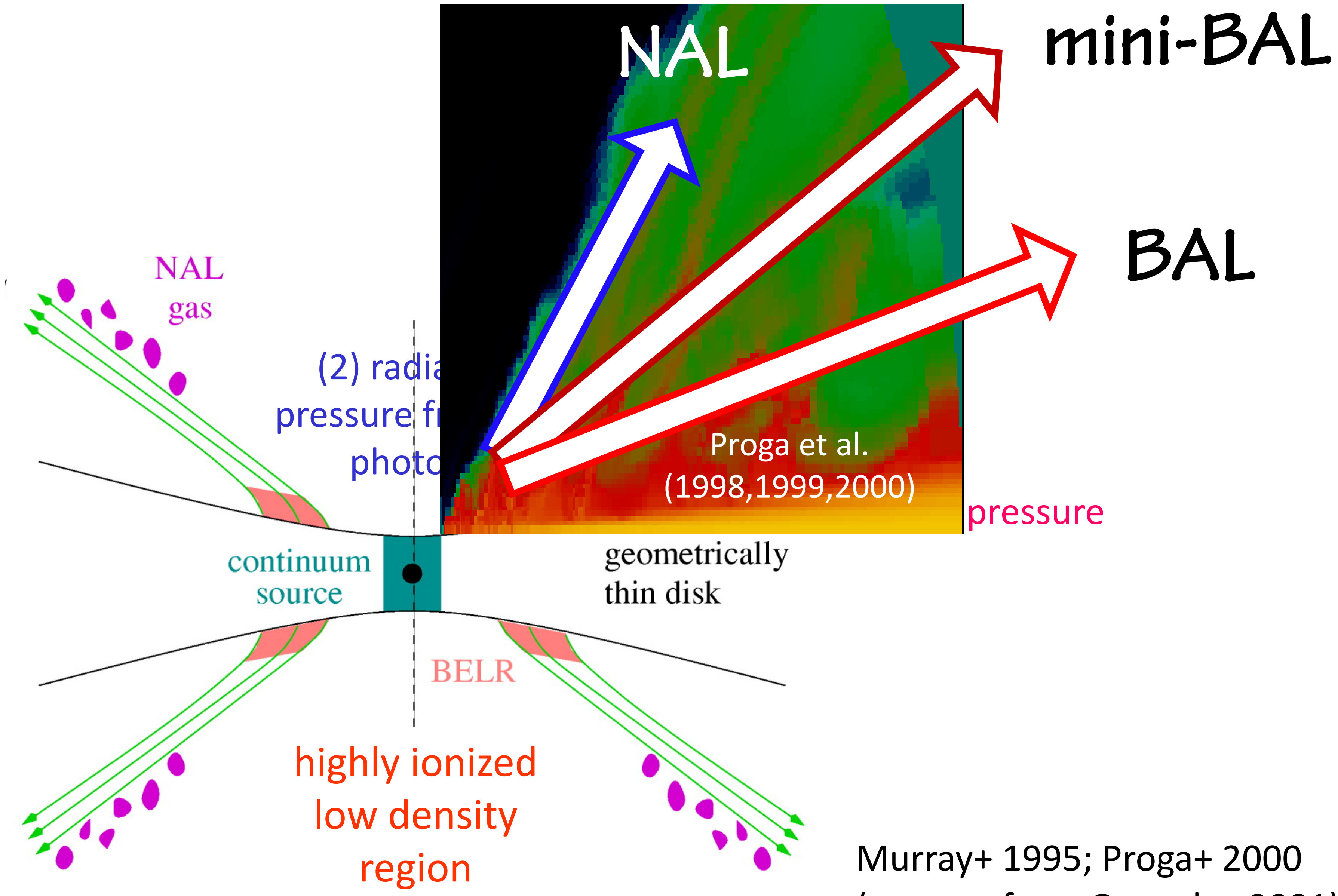
1. Background
    - The AGN accretion disk wind model
    - Classification of quasar absorption lines
    - intrinsic and intervening NALs

2. Physical properties of NALs and mini-BALs
    1) Statistical properties of intrinsic NALs
    2) Variability trends of intrinsic NALs and mini-BALs
    3) Internal structure of the outflow

3. Summary
    - Possible geometry of the AGN outflow

Background

Accretion Disk-Wind Model

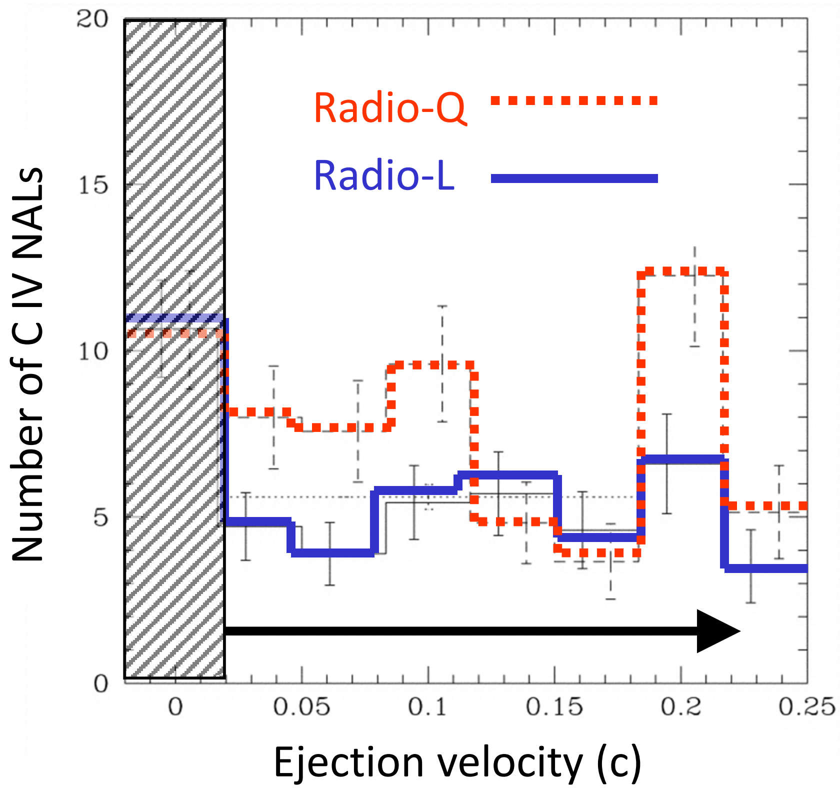


Murray+ 1995; Proga+ 2000
(cartoon from Ganguly+ 2001)

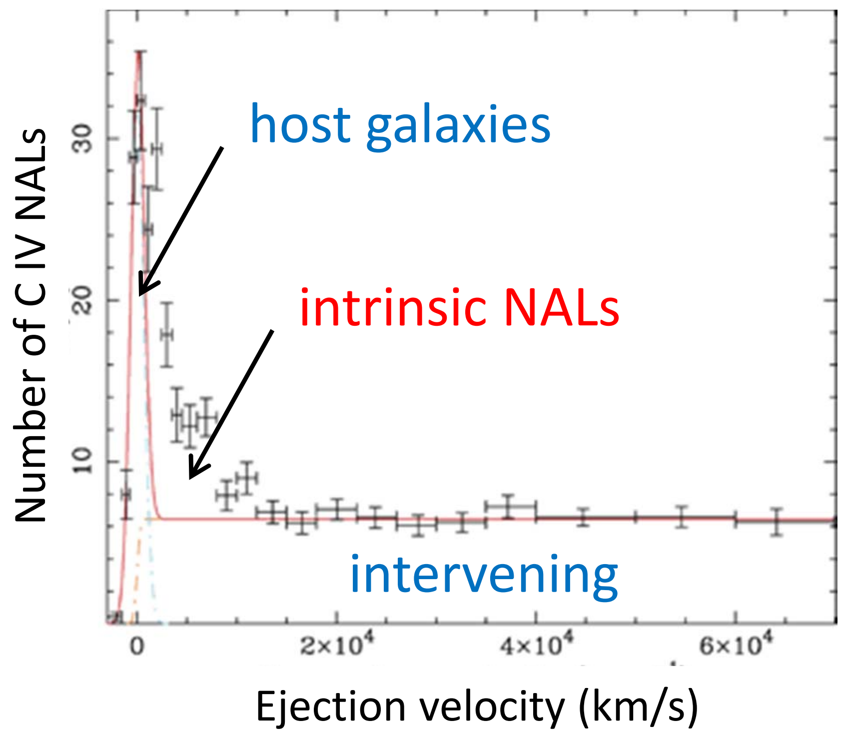
Contamination of intrinsic NALs

Some fraction of NALs are physically associated to background quasars because:

1) Number of C IV NALs changes on the properties of background quasars (Richards+ 1999; 2001) → intrinsic NAL contamination as high as 36%
2) Number excess of C IV NALs within 10,000 km/s of z_{em} of background quasars (~2200 SDSS quasars; Nestor+ 2008) → intrinsic NAL as high as 50%



Richards+ 1999

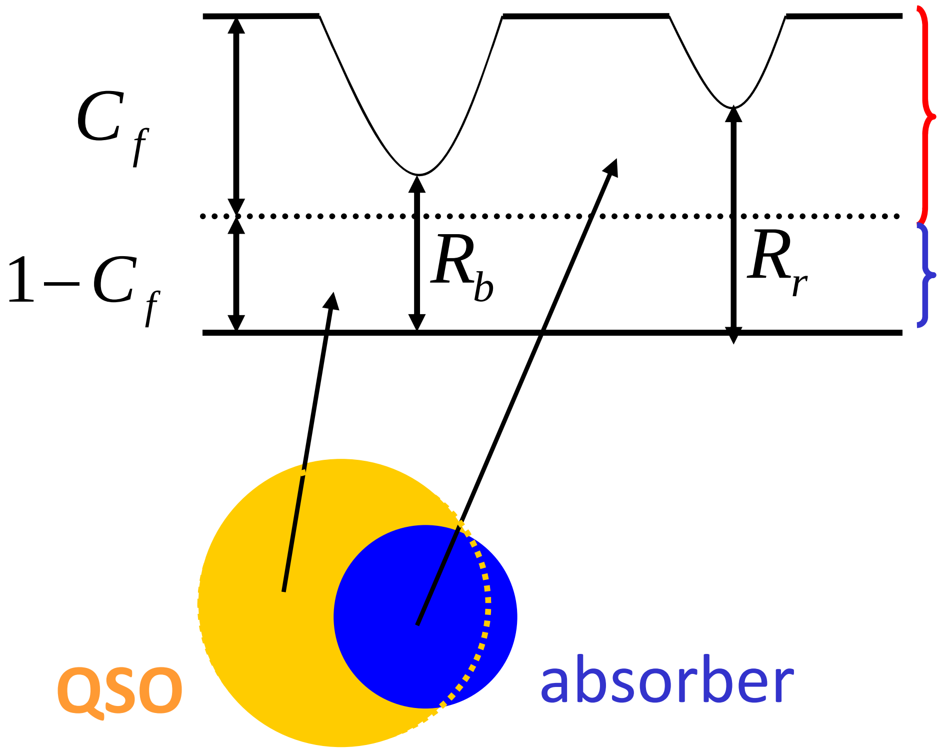


Nestor+ 2008

Physical Properties of NALs and mini-BALs

How to identify intrinsic absorption lines

Dilution of absorption troughs by unocculted light from the quasar continuum source makes the optical depth ratio of resonant UV doublets (e.g., C IV, N V) deviate from 2:1, as dictated by atomic physics (e.g., Wampler+ 1995).



$$R(\lambda) = \underline{C_f(\lambda)e^{-\tau(\lambda)}} + \underline{[1-C_f(\lambda)]}$$

$$\tau \propto Nf\lambda$$

$$\left(\frac{R_r - 1 + C_f}{C_f}\right)^{f_b\lambda_b / f_r\lambda_r} = \frac{R_b - 1 + C_f}{C_f}$$

$$C_f = \frac{[R_r(v) - 1]^2}{R_b(v) - 2R_r(v) + 1}$$

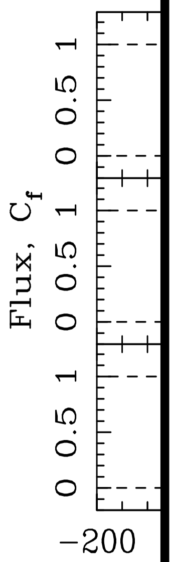
150 NAL systems in 37 Keck/HIRES quasar spectra

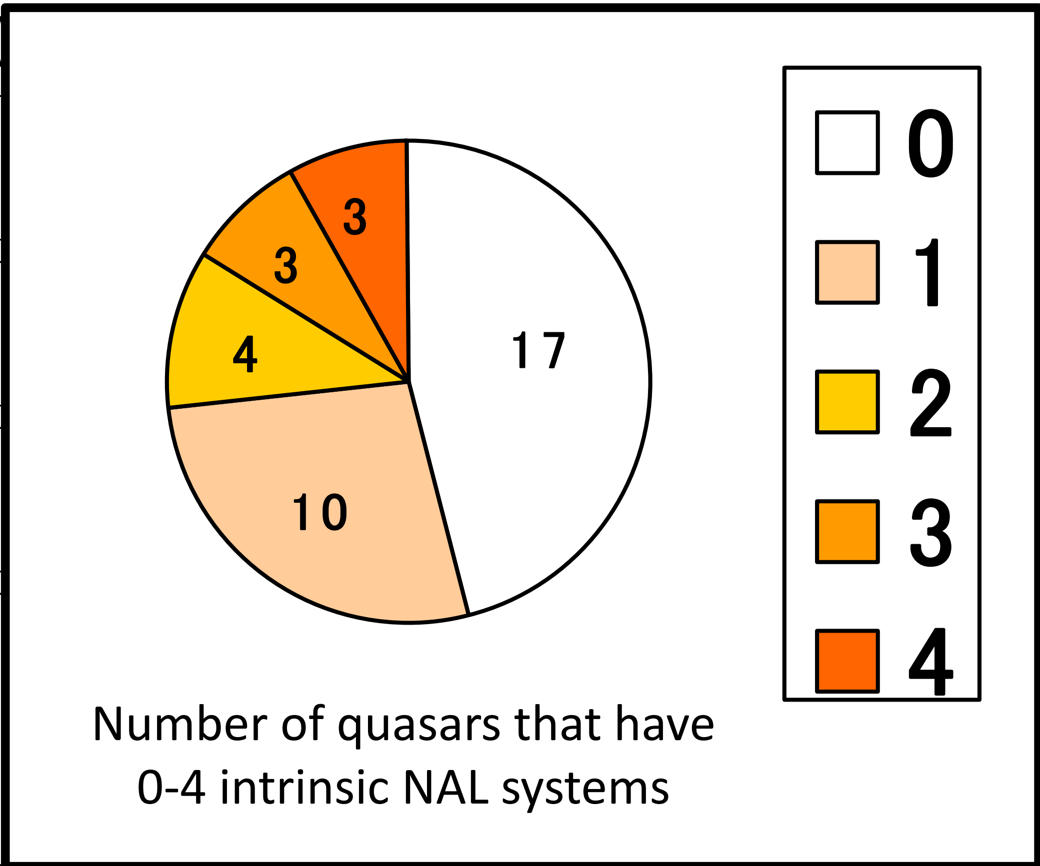
Class A

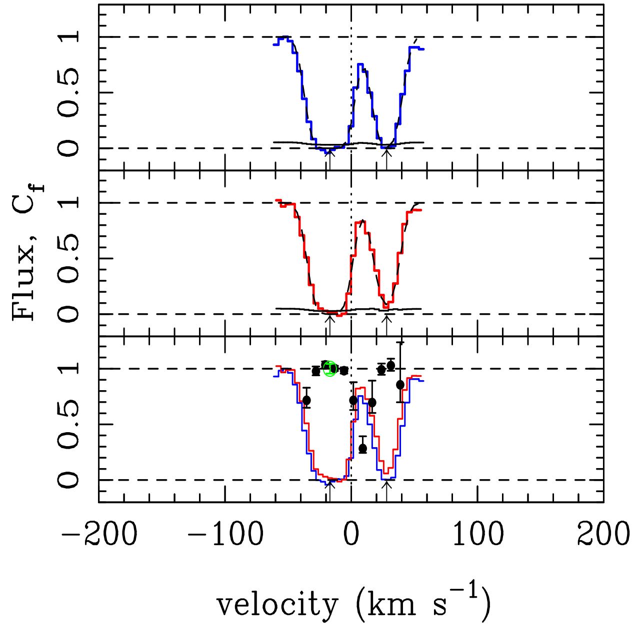
Class B

Class C

(intervening/unclassified)







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Intrinsic NALs

Intervening NALs

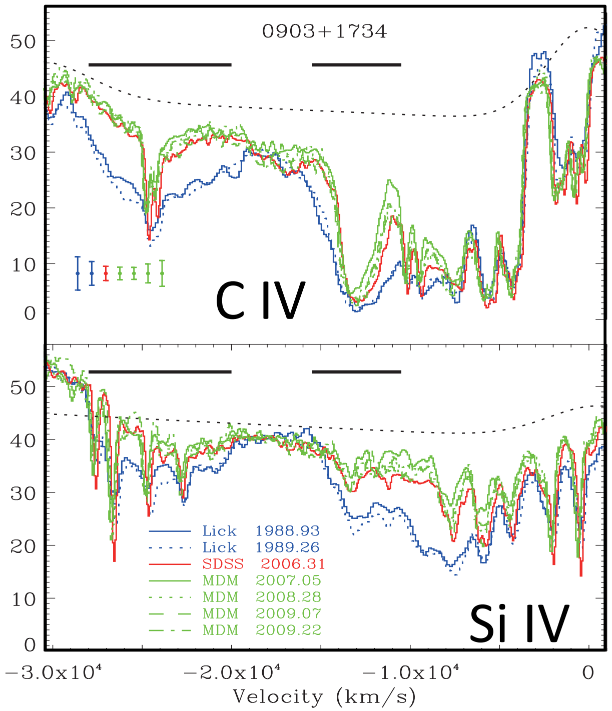
Misawa+ 2007

Variability in BALs, mini-BAL, and NAL

A significant fraction (**70-90%**) of BALs and mini-BALs are variable, while only **20%** of NALs show weak variability. The variability amplitude becomes larger in longer time intervals.

BAL

(Q0903+1734)

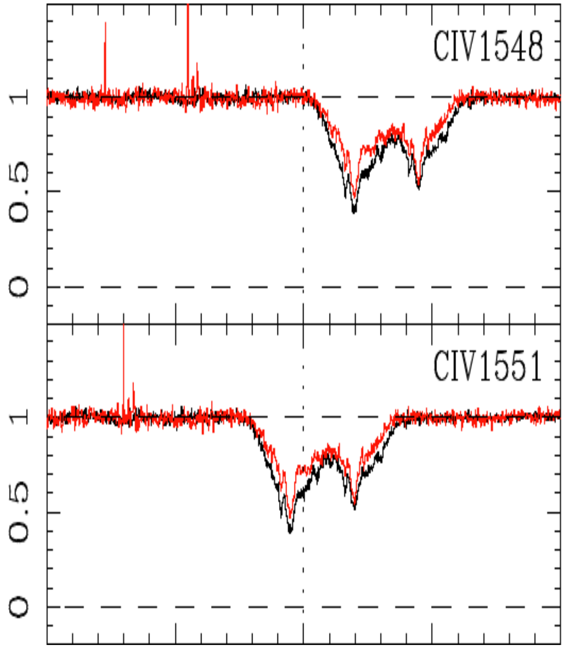


Capellupo+ 2012,13

variable

mini-BAL

(UM675)

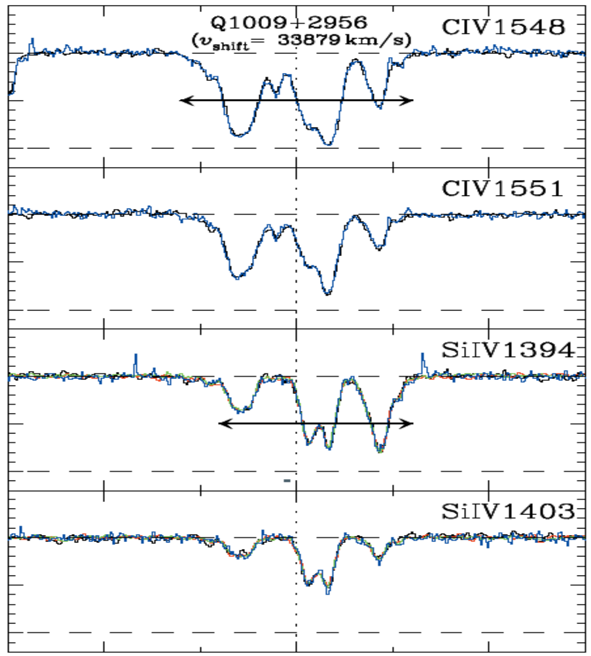


Misawa+ 2014

variable

NAL

(Q0904-1050)

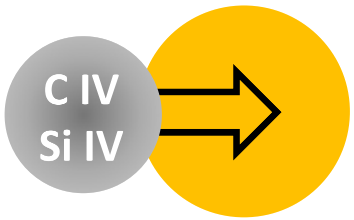


Misawa+ 2014

stable

Possible Origins of Variability

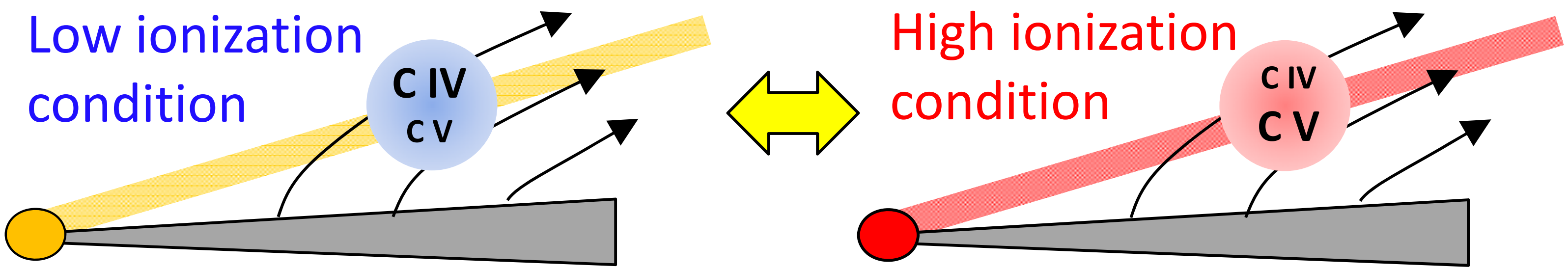
Gas motion across our sightline to the source 【Gas motion (**GM**) scenario】



Motion of the absorbing gas parcels across our line of sight change the covering factor (i.e., absorption profile and strength).

e.g., Hamann+ 1997, Gibson+ 2008

Change in ionization condition 【Variable Ionization State (**VIS**) scenario】

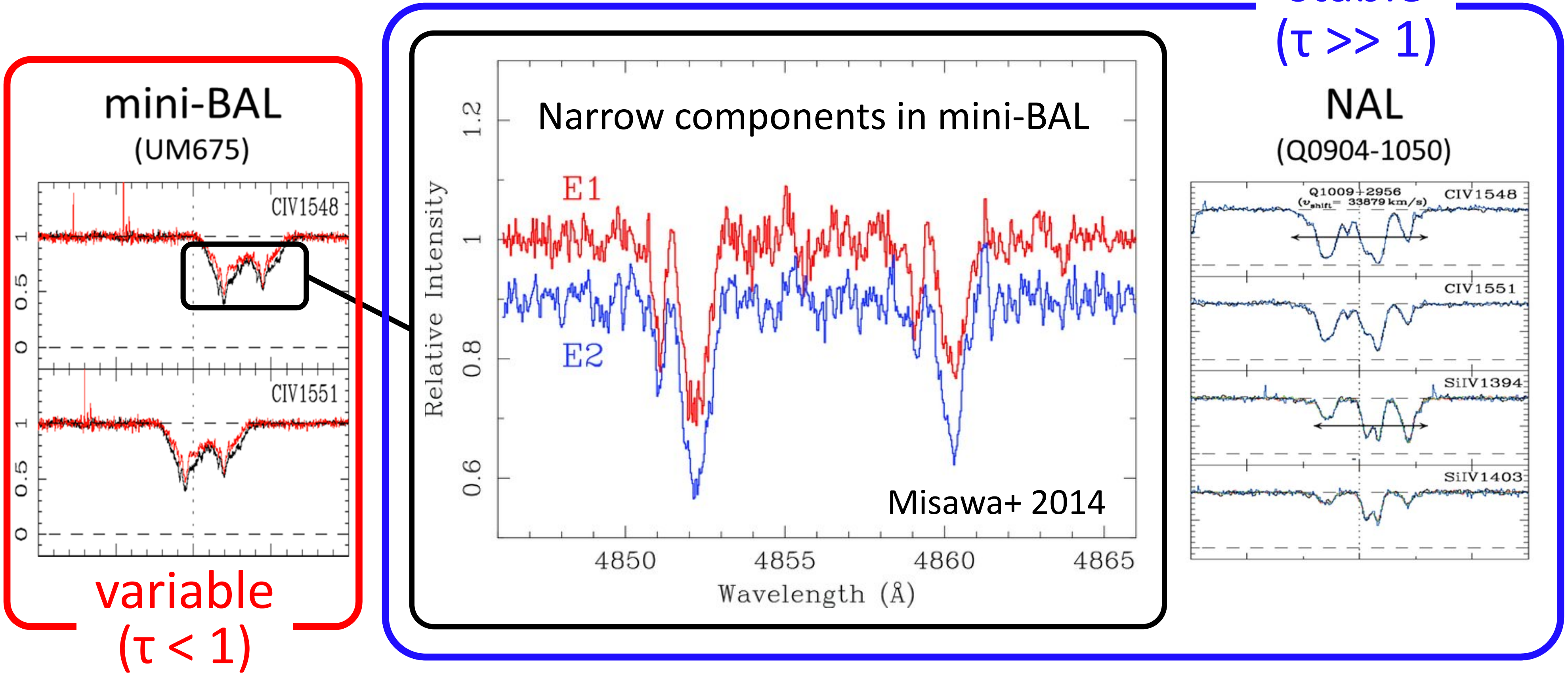


Changes in the ionization state of the absorber due to a variable ionizing continuum cause variability in absorption strength.

e.g., Hamann+ 2011, Trevese+ 2013

Narrow components in mini-BALs

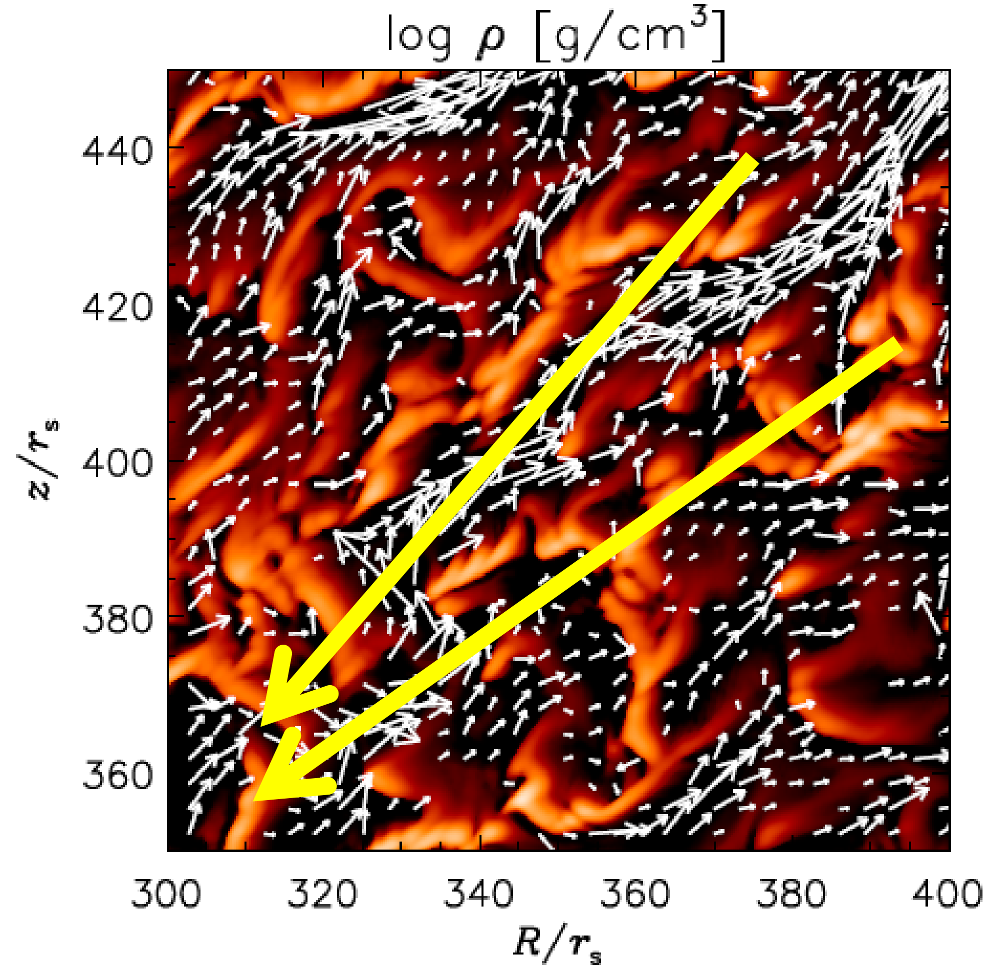
Narrow kinematic components are sometimes found near the centers of mini-BALs. Their strengths and profiles (after broader troughs are fitted out) are stable like NALs. Both of them could have a same origin.



- NALs and the narrow cores of mini-BALs arise in high-density clumpy clouds (τ>>1).
- The broader troughs of mini-BALs arise in diffusely distributed gas (τ<1), and it could be **a filamentary structure** above the main stream of the outflow.

Complex Internal Structure?

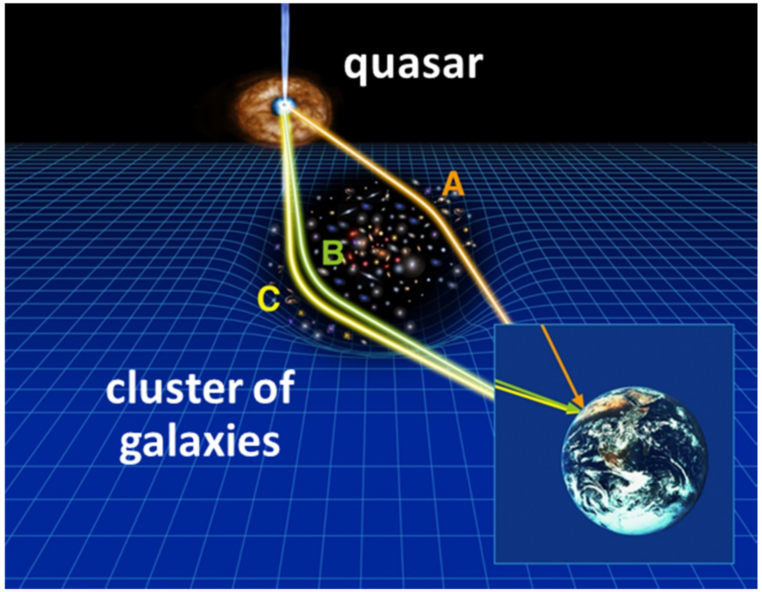
The outflow stream may have a complex internal structure that consist of a number of small clumpy clouds ($\leq 10^{-3}$ pc) with very high gas densities ($n_e \geq 10^7$ cm^{-3}) (e.g., Hamann+ 2013).

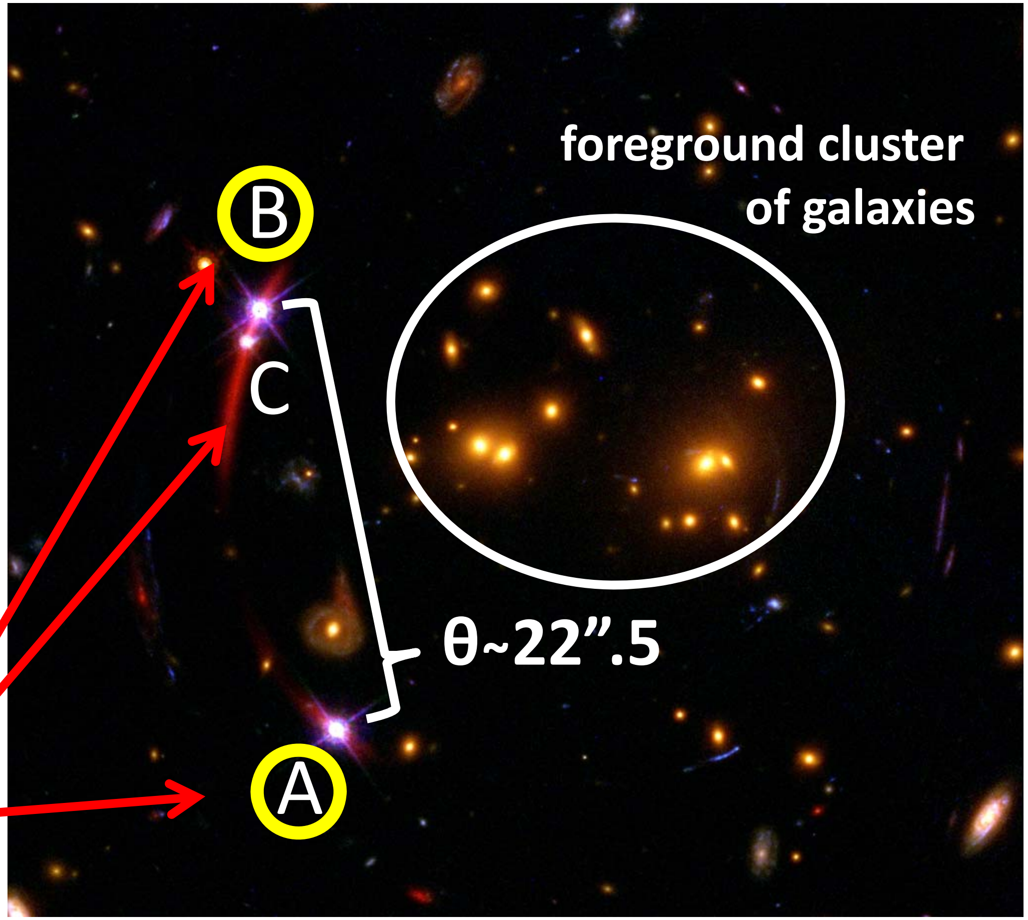


A radiation-MHD simulation (Takeuchi+ 2013).

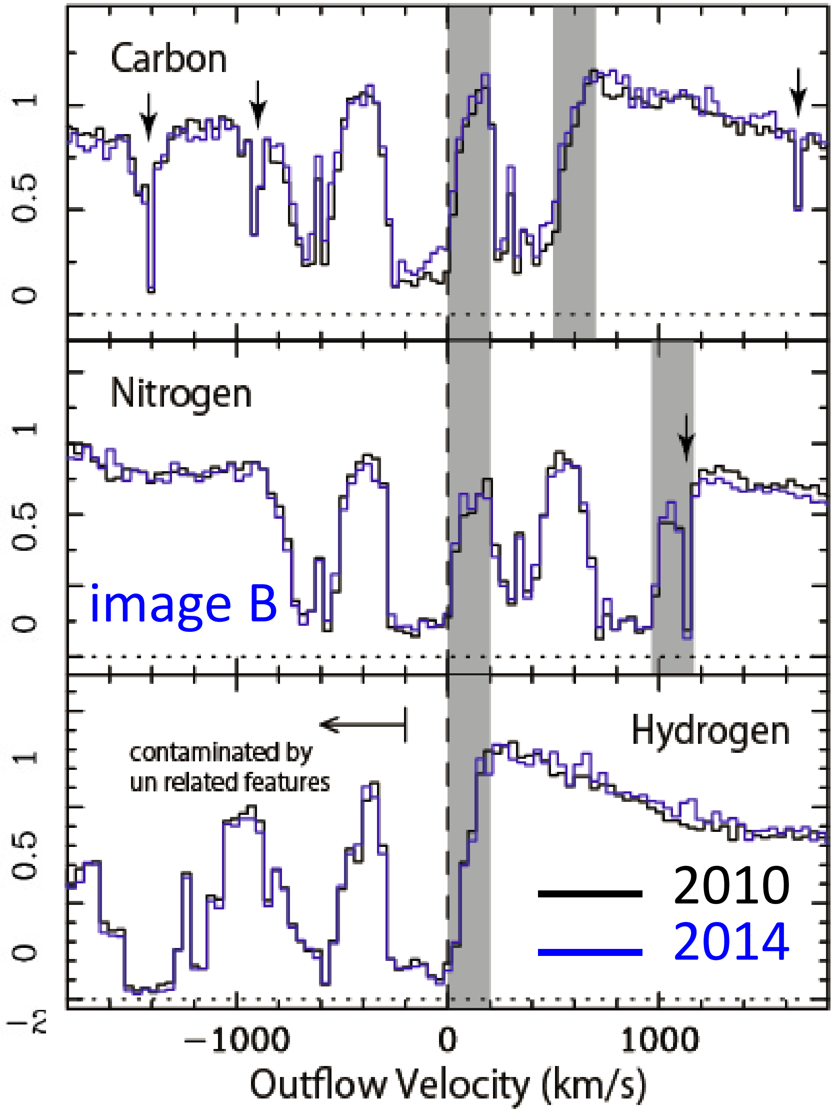
Multi-sightline observation

Using Subaru and VLT, we performed multi-sightline spectroscopy of a gravitationally lensed quasar SDSS J1029+2623 whose image separation (~22.5") is largest among those discovered so far.





Sightline difference in absorption lines



A clear difference in absorption profile between the images A and B in the shaded area (Misawa+ 2013). Possible scenarios include:

1. ~~time variability over time delay of images A and B (Δt_{obs} ~744d) (e.g., Chartas+ 2007)~~
2. difference in the absorption level along different sightlines (Chelouche 2003; Green 2006)

The difference in absorption profiles has almost unchanged, implying the difference is due to differences along the sightlines (Misawa+ 2014).

→ cloud size is **<10^{-3} pc**, if r~10pc

Possible geometry of the AGN outflow

Properties of BAL, mini-BAL, and intrinsic NAL

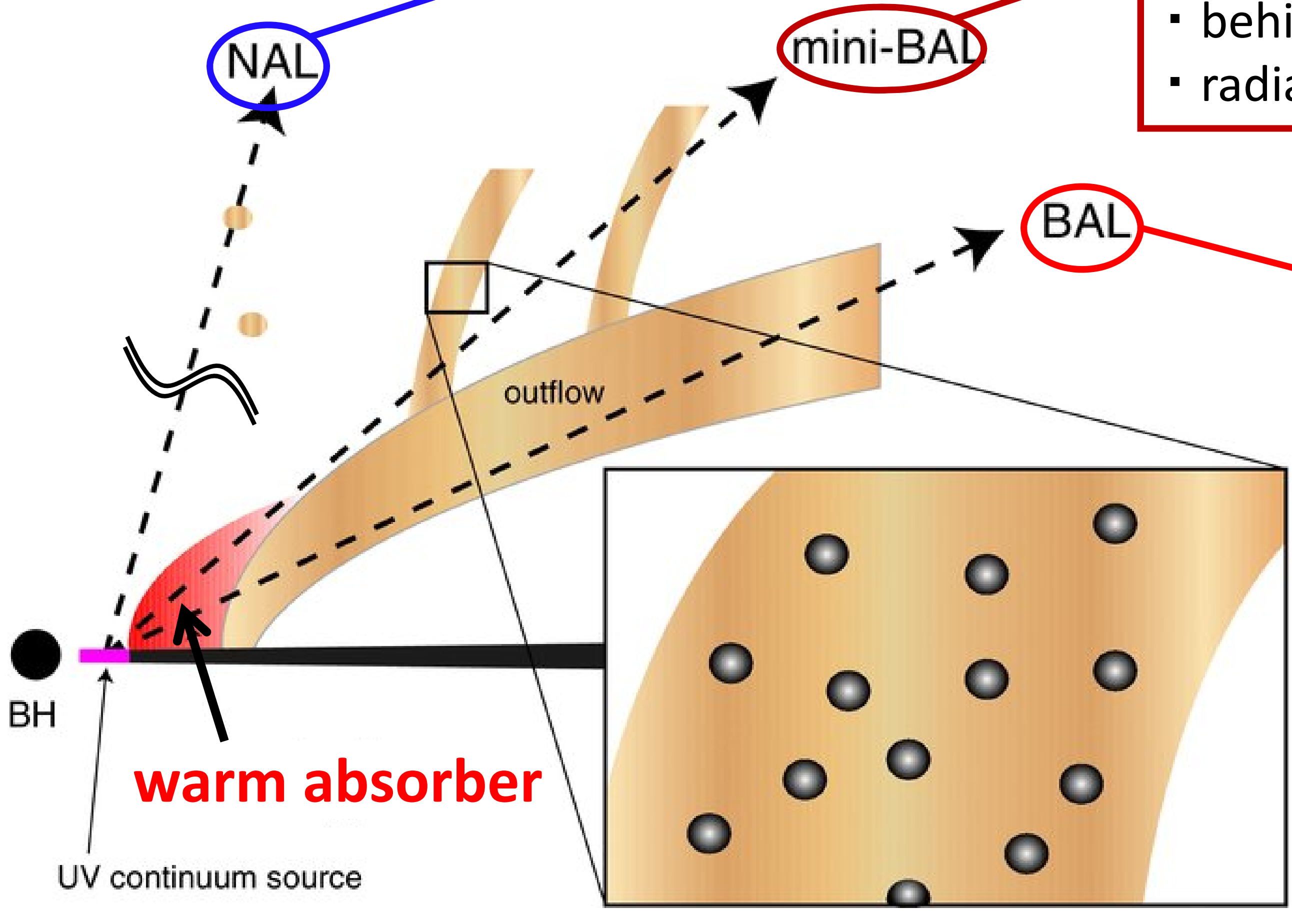
		BAL	mini-BAL	intrinsic NAL
FWHM [km/s]		> 2,000	500 - 2,000	< 500
Detection Rate [%]		~20	~5	**~50**
Variability	Strength	very often	**very often**	**rarely**
	Profile	Variable	**stable**	**stable**
Origin of variability		GM & VIS	**VIS** (broad)	**-**
Transverse cloud size [pc]		**< 10^{-3} (per cloud) at r ~10pc**		
Radial distance [pc]		< 100	< 100	> 100
Location		low latitude (main stream)	**intermediate (filament?)**	**high latitude**
Total column density* [cm^{-2}]		10^{23} - 10^{24}	intermediate	< 10^{22}

* from X-ray observations (e.g., Gallagher+ 2002, Giustini+ 2011, Misawa+ 2008)

Possible Geometry of the Outflow

- high-density clouds at **high latitude**
- coverage fraction is **~50%**
- rarely variable
- radial distance is **~100-1000pc**

- **filament** above main wind
- coverage fraction is **~5%**
- variable due to VIS
- behind warm absorber
- radial distance is **~pc**



- **main stream** of outflow
- coverage fraction is **~20%**
- variable due to GM & VIS
- behind warm absorber
- radial distance is **~pc**

A cartoon from Misawa+ 2014

SUMMARY

- BAL, mini-BAL, and intrinsic NAL are complementary to each other for a study of outflow wind because their locations in/around the outflow wind are different.
- Global coverage fractions (i.e., detection rate) of BAL, mini-BAL, and intrinsic NAL are ~20%, ~5%, and ~50%, respectively (i.e., total coverage fraction is ~75%).
- A significant fraction (~70-90%) of BALs and mini-BALs are variable in a few years, while NALs and the narrow components in mini-BALs are rarely variable.
- There are two possible origins of time variability: a) gas motion across our sightline and b) a change in ionization state of the absorber. The latter is more important for mini-BAL and NAL absorbers.
- Outflow wind in a gravitationally lensed quasar SDSS J1029+2623 have an internal structure with a scale of $<10^{-3}$ pc assuming its radial distance is ~10pc.
- Possible Geometry: mini-BALs originate in a filamentary structure rising from the main stream of the outflow (i.e., BAL absorber), while intrinsic NALs arise in a high-density clumpy clouds in the polar direction.