Intrinsic, Narrow N V Absorption Reveals a Clumpy Outflow in $z < 0.4$ Radio-Loud Quasars

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I. Introduction

- Quasar outflows are potentially important for tying observed parameters (e.g., emission line widths) to physical parameters (e.g., black hole mass) in models where the BLR is part of the outflow, for addressing the important physical processes of the accretion process, and for affecting the host galaxy evolution.
- Many statistical studies have gauged the incidence of different forms of intrinsic absorbers (e.g., BALs, mini-BALs, AALs). These fractions are often interpretted in terms of the geometry of the outflow and the orientation of the observer. Moreover, there are apparent differences between radio-quiet and radio-loud objects, possibly suggesting differences in the outflow geometry.
- In an accompanying poster (by Culliton), we examine the HST/COS archive in search of intrinsic, narrow N V absorption (Figure 1) in low-redshift quasars. Oddly, we discovered a dearth of absorbers in radio-loud objects. Here, we present a follow-up study to examine whether this dearth arose from an orientation bias in the HST archive, or whether radio-loud objects are more nefarious than heretofore supposed.
- We assembled a sample of 14 low-redshift radio-loud objects from SDSS with lobe-dominated FIRST morphologies, as noted by Jiang et al. (2007). Table 1 lists these objects, and the virial black hole mass and Eddington ratio estimates from Shen et al. (2011).

Figure 1: In Misawa et al. (2007), Wu et al. (2010), Ganguly et al. (2013), and Culliton et al. (2017, in prep), we have showed that N V is a more efficient ion for selecting truly intrinsic absorption. Shown above, the N V bus at Penn State is accepting passengers.

Table 1: Sample Properties

	Name SDSS J	z	$M_{\rm BH}$ (10^8 M$_\odot$)	$L/L_{\rm Edd}$	$R_{\rm core}$ (5 GHz)	i (°)	R^* (6 cm/ 2500 Å)
(1)	150455.56+564920.3	0.3589	7.3	0.09	<0.01	>66	260
(2)	092837.98+602521.0	0.2959	8.4	0.07	0.04	61	480
(3)	121613.62+524246.2	0.2698	1.6	0.12	<0.07	>58	29
(4)	235156.12-010913.3	0.1742	6.5	0.07	0.11	55	648
(5)	110436.33+212417.8	0.1879	3.7	0.06	0.26	49	63
(6)	110717.77+080438.2	0.2010	2.5	0.11	0.42	44	24
(7)	154007.84+141137.0	0.1202	2.9	0.03	0.57	39	34
(8)	074906.50+451033.8	0.1923	3.5	0.08	0.69	34	82
(9)	093200.07+553347.4	0.2665	3.7	0.09	0.81	27	10
(10)	142735.60+263214.5	0.3638	45.2	0.02	0.81	27	107
(11)	122011.88+020342.2	0.2404	7.3	0.13	0.86	23	141
(12)	114047.89+462204.8	0.1143	1.2	0.16	0.89	20	57
(13)	091401.75+050750.6	0.3017	22.8	0.02	0.91	18	78
(14)	141628.66+124213.5	0.3349	15.2	0.04	0.93	15	132

Key – **column 1**: Object number used also in Figures 2–5; **column 2**: Object SDSS name; **column 3**: Redshift; **column 4**: Viral estimate of black hole mass; **column 5**: Eddington ratio estimate; **column 6**: radio core fraction; **column 7**: estimated inclination; **column 8**: radio-loudness.

II. Orienting The Jet

- Figure 2 shows the FIRST images of the our sample ordered in radio core fraction (see below) from least (1) to most (14) core-dominated. The radio intensity is shown in red. The SDSS g-band image is overlayed in blue.
- The core fraction, defined as the ratio of the core emission to the total (core plus lobes) emission, provides a means of quantifying the orientation: $R_{\rm c} = \frac{F_{\rm core}}{F_{total}}$, where the F is the energy flux. We estimate inclination angles using the semi-empirical relationship reported by Marin & Antonucci (2016):

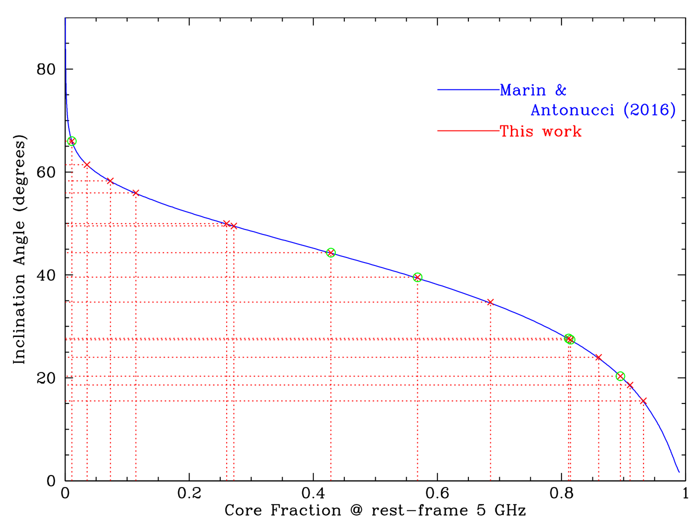

Figure 3: Empirical estimation of the inclinations of the 14 objects in our sample, based on the determination by Marin & Antonucci (2016). The blue curve is the $i(R)$ relation reported in that work. The specific objects in our sample are indicated with red dashed lines, vertical lines for the measured core fractions, and horizontal lines for the estimated inclination angles.

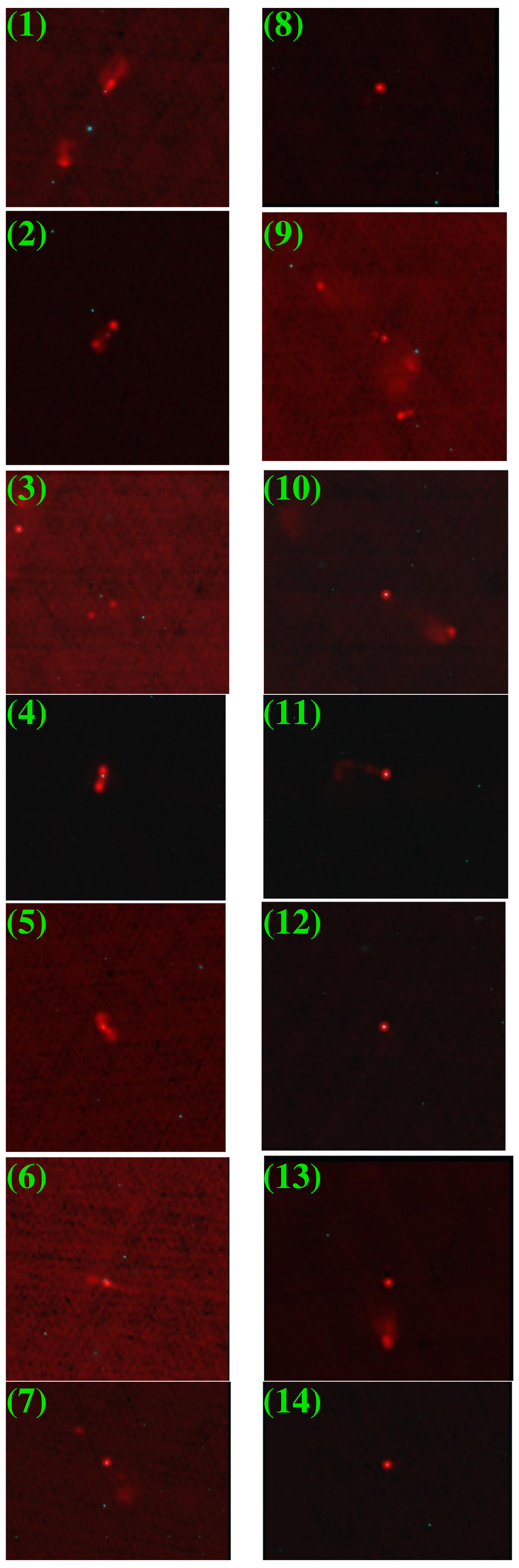

Figure 2: FIRST 1.4 GHz images (red) of the 14 objects in our sample. The ordinal number sequence the core fractions from least to most core-dominated, or from most edge-on to most face-on disks. The images are 8.′2 across. In blue, we overlay the SDSS g-band image to show the optical counterpart in the center.

III. Hubble Observes An Outflow?

- In previous efforts (Misawa et al. 2007, Wu et al. 2010, Ganguly et al. 2013, and Culliton et al. 2017, in prep), we have shown that the N V ion is an efficient means of separating truly-intrinsic absorption from absorption by structures not directly related to the outflow.
- For our low-redshift sample, we designed our HST/COS observations to cover both the N V $\lambda\lambda1238.821, 1242.804$ resonant UV doublet, and the H I $\lambda1215.670$ line.
- In Figure 4, we show this portion of the HST/COS spectra of each of the objects, ordered according the inclination with respect to the line of sight. When an outflow is detected in absorption, the H I is highlighted in red, and the N V absorption is highlighted in green.
- Objects 1, 6, 7, 9, 10 and 12 show N V absorption. These all show multiple kinematic components. Three (1, 6, 9) of them have a suffiently large velocity dispersion that components are blended to produce a line-locking effect.

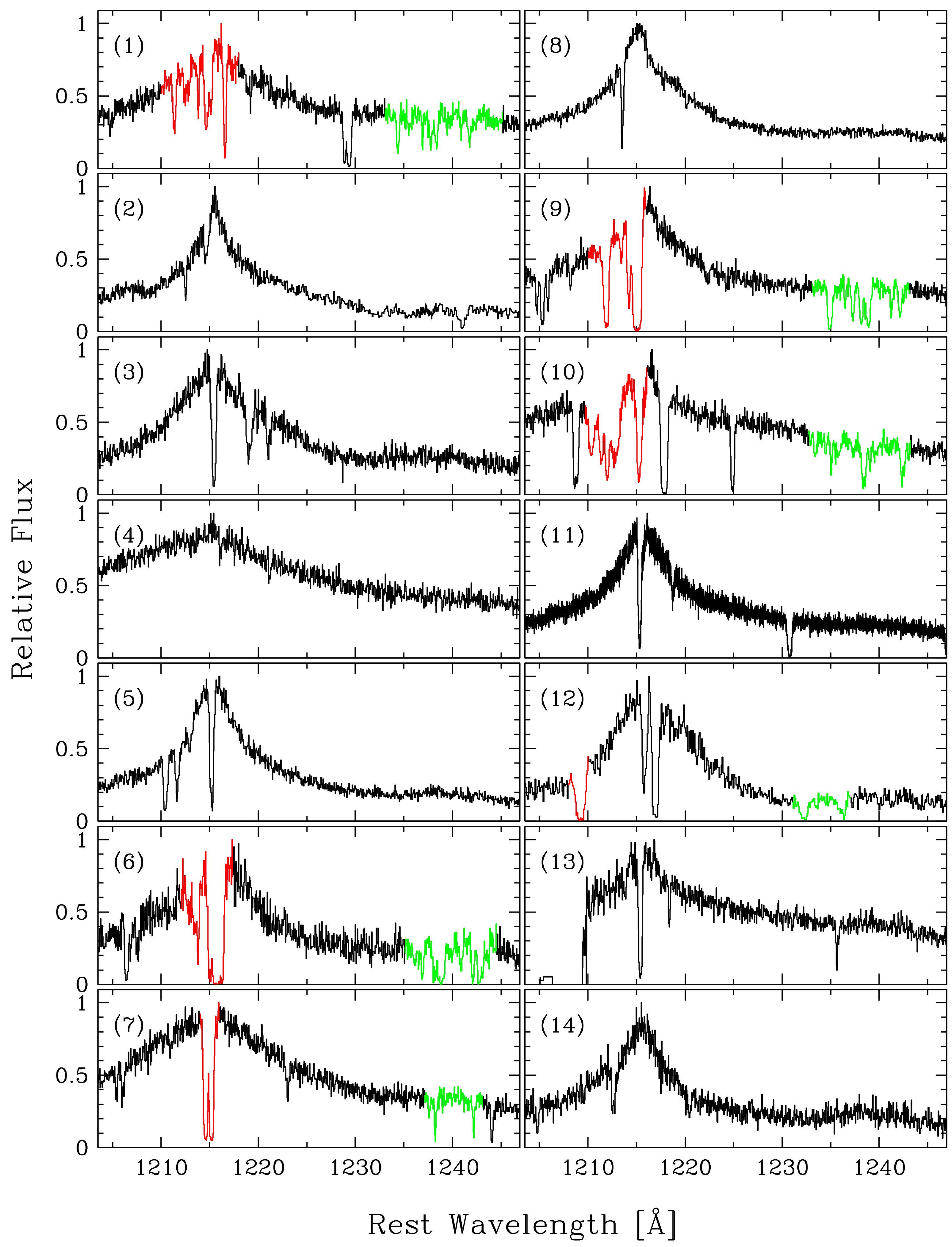

Figure 4: (above) HST/COS spectra of the 14 objects in our sample. In each panel, we show only the portion of the spectrum covering the Ly α and N V emission lines. When detected, H I absorption is highlighted in red and N V absorption is highlighted in green. The sequence of ordinal numbers progresses from least to most radio core dominated, corresponding to the Figure 2 and Table 1.

IV. Results

- We have examined the spectra of 14 radio-loud objects spanning a range of inclination angles, $15°$ up to $> 66°$, or 56% of the "sky" around the black hole. Our basic finding is that six (43%) show an outflow. If this translates to a covering factor, then the preceding fraction is diminished to 24%.
- The N V-bearing gas in these systems appear *not* to prefer more edge-on orientations.
- Could a varying outflow opening angle explain the range of inclinations where N V- bearing gas is observed and the mixture of sightlines where it and is not observed? Omitting objects #7, 10, 13, and 14, the sample spans only a factor of ~0.8 dex in black hole mass and ~0.4 dex in Eddington ratio. It is unclear whether such a narrow range of physical parameters could explain such a broad range of potential outflow opening angles ($> 46°$).
- This result is tantalizing as scenarios, such as depicted in Figure 5 would predict that there should be a continuous range of more edge-on inclinations the outflowing gas are detected in absorption. Alongside the discrete kinematics and other work (e.g., Misawa et al. 2014, 2016), this implies that the outflow is more clumpy.

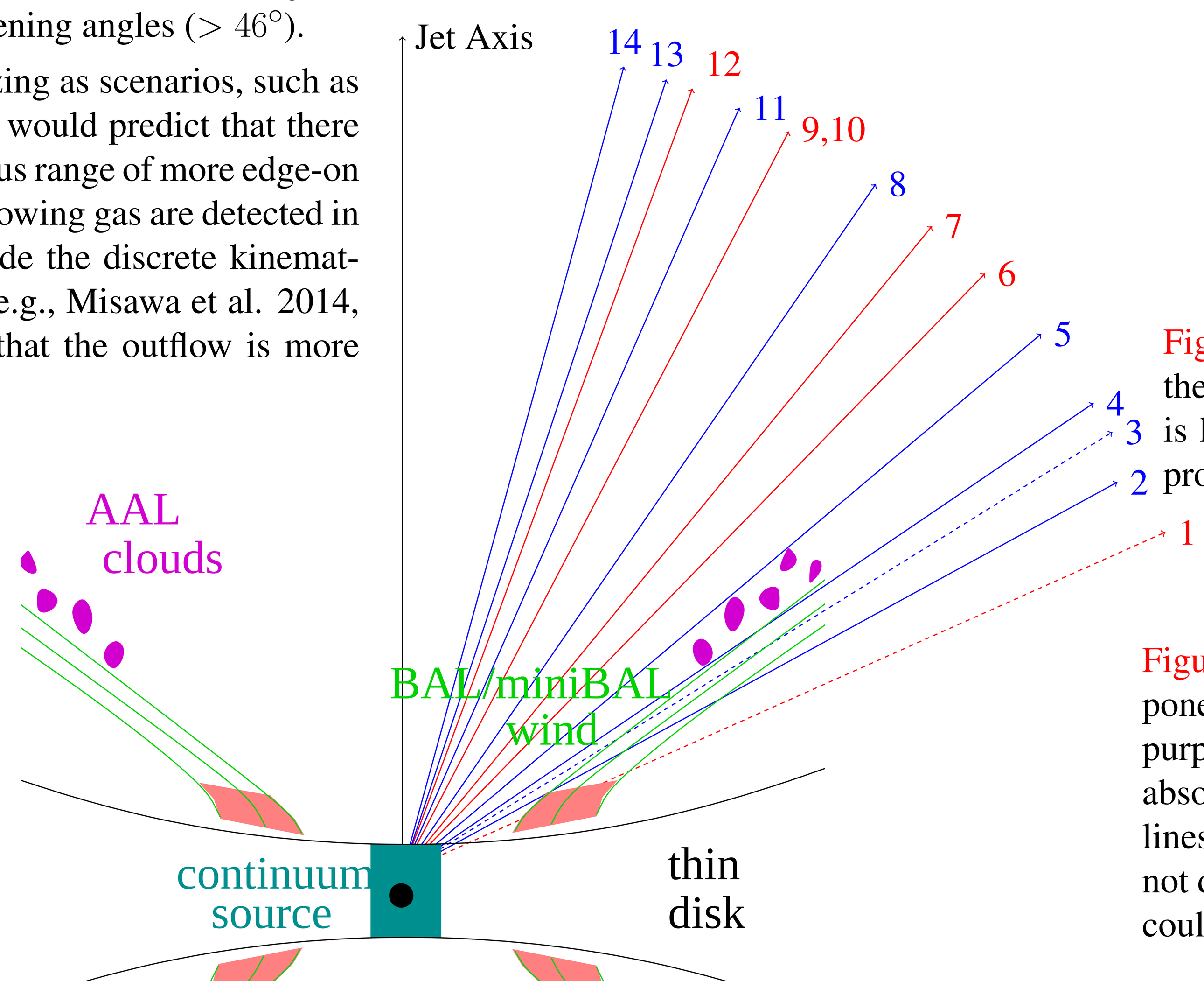

Figure 5: (left) A possible scenario of the structure of a quasar system with various structural components labelled (Ganguly et al. 2001). In particular, we depict the outflow as green streamlines, and purple clumps. In principle, sightlines that pass through these structures would show the outflow in absorption. On top of the schematic, we show the sightlines for the objects in our sample. Red sightlines indicate objects for which we see outflows. Blue sightlines indicate objects where an outflow is not detected. A dashed sightline indicates one in which the radio core is not detected. Such a sightline could be more inclined than shown.