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Mass flow rates in quasars

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Summary. Under the assumption that the broad emission line clouds in quasars are being driven outwards by radiative acceleration, one can use the Curtis Schmidt survey of Osmer and Smith to calculate the rate at which mass is being ejected from quasars. This is compared with the accretion rate derived from the luminosities of the quasars and the ratio of mass outflow to mass inflow is obtained. I find that typically ten percent of the mass which fuels a quasar is ejected in the form of broad line clouds, and I discuss this in the context of a simple accretion disc model with outflow.

Key words: quasars – emission line profiles – mass flow rates

1. Introduction

It is widely believed that the broad emission lines which are observed in the spectra of quasars arise from clouds within 10^{16} cm of the central black hole. These clouds have densities of $n_e = 10^{9\pm1}$ cm^{-3} and temperatures of about 10^4 K as can be inferred from photoionization models of the clouds and the strengths of the various emission lines (Davidson and Netzer, 1979). These clouds are required to have very large optical depths in the Lyman alpha line if the Lyα/Hβ ratio is to be explained without invoking unreasonable reddening by dust (Krolik and McKee, 1978). Although we understand the details of individual clouds reasonably well, we do not have a single convincing model for the motions of the clouds and how these give rise to the observed line profiles. The clouds may be moving radially towards or away from the quasar or they may be in orbit around it, and for each of these cases the emission line profile can be calculated on the assumption that the line broadening due to the motion of the clouds dominates the internal velocity dispersion of a single cloud. An alternative suggestion is that the emission lines do not come from clouds but directly from the surface of an accretion disc (Osterbrock, 1978; Collin-Souffrin, 1980). This model does not seem likely for quasars (Capriotti et al., 1980, hereafter referred to as CFB; Mathews, 1982) since it requires rather contrived inclination angles to explain the observed profiles, although Raine and Smith (1981) do manage to improve the fit by having a "scattering illuminated" disc. On the other hand the line profiles of many Seyfert galaxies can be fit quite succesfully by emission lines from a turbulent accretion disc (van Groningen, preprint) and one possible way of connecting these two prictures is if there is always some line emission from an accretion disc, but in the case of the quasars, the line emission from the disc is swamped by the emission from clouds.

CFB have shown that almost any type of radial motion, inwards or outwards, with optically thin or thick clouds being accelerated by radiation pressure, or with clouds moving ballistically, can give a good fit to the logarithmic line profiles which are observed. On account of this it is rather difficult to decide between the alternatives. In what follows I shall assume that the clouds are flowing radially outwards due to the radiative acceleration by the central continuum source, although a similar analysis would be applicable for a ballistic outflow model if the mean kinetic energy of the clouds was proportional to the continuum luminosity of the quasars.

2. The dynamical model

The model of Blumenthal and Mathews (1975, hereafter referred to as BM), which predicts that the line profile should have a logarithmic dependence on wavelength in good agreement with many observations, has been the subject of much discussion in the literature. One point of debate is whether or not the clouds are optically thin to the ionizing continuum radiation. BM assumed that the clouds were optically thin, however, Davidson (1976) argues that the clouds are probably optically thick to Lyman continuum photons due to the weakness of the Lyman continuum in OQ172. Weymann (1976) has shown that optically thick clouds can also be accelerated efficiently by radiation pressure: McKee and Tarter (1975) argue that if the clouds are optically thick they will be disrupted by internal radiation pressure, whereas Blumenthal and Mathews (1979) calculate that the clouds will be optically thick pancakes which are stable. Fortunately though, while this point is obviously very important for the understanding of the structure of the clouds, it is almost irrelevant for calculating mass flow rates from the line widths.

2.1. Line profiles

This section follows the work of BM and CFB closely. We consider a cloud to have two components, an ionized component of mass M_i and a neutral component which may or may not be present. The number of recombinations per second in the cloud is $\beta n_e M_i/m_p$

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where β is the recombination coefficient, n_e is the electron density in the ionized component and m_p is the mass of a proton. Therefore if the radiative acceleration acting on the cloud is much larger than gravity then the equation of motion for a cloud is

$$M_t u du = (\beta \phi n_e M_i h\upsilon_* / m_p c) dr, \tag{1}$$

where M_t is the total mass of a cloud ($M_t \geqq M_i$), u is the velocity of a cloud, ϕ is a factor to allow for absorption by hydrogen lines and heavy elements and $h\upsilon_*$ is the mean photon energy per photoionization. In a steady, radial outflow,

$$\dot{M}_{\rm out} = \Omega r^2 u N_c M_t, \tag{2}$$

where $\dot{M}_{\rm out}$ is the mass outflow rate, N_c is the number density of clouds and Ω is the solid angle into which the clouds are flowing. If there is an accretion disc present then Ω must be less than 4π, however, the accretion disc occupies a small solid angle as seen from the centre, so that Ω will be close to 4π. There is observational support for this from the fact that the emission lines are well fit by a logarithmic profile, which would not be true if Ω was small. The Lyman alpha emission from a single cloud is $\beta_l n_e h\upsilon_l M_i/m_p$ erg s^{-1} where $\beta_l n_e^2$ is the effective emissivity of a cloud in the Lyα line, and $h\upsilon_l$ is the energy of a Lyman alpha photon. The profile of the blue wing of the line is given by (BM)

$$L_\upsilon = \int_0^\infty dr \int_0^1 d\mu \delta \left[\upsilon - \upsilon_l \left(1 + \frac{u}{c} \mu \right) \right] \frac{\Omega}{2} r^2 N_c \frac{\beta_l n_e M_i h\upsilon_l}{m_p}, \tag{3}$$

where μ is the cosine of the angle which the velocity vector of a cloud makes with the line of sight. Using Eqs. (1) and (2), this can be written as

$$L_\upsilon = \frac{\dot{M}_{\rm out} c^2}{2\upsilon_*} \frac{\beta_l}{\beta\phi} \ln \left(\frac{u_{\rm max}}{c} \frac{\upsilon_l}{\upsilon - \upsilon_l} \right) \quad \text{erg s}^{-1}\ \text{Hz}^{-1} \tag{4}$$

(BM appear to lose a factor of two here).

Note that the factors of M_i and M_t have cancelled out, which shows that the same line profile results from optically thick or thin clouds, at least in the crude two component cloud model used here. CFB also came to this conclusion. The total luminosity of a line is

$$L_l = \dot{M}_{\rm out} c^2 \frac{\beta_l}{\beta\phi} \frac{\upsilon_l}{\upsilon_*} \frac{u_{\rm max}}{c} \tag{5}$$

and hence if we can measure the line width and line luminosity, and if we know β_l/β, and ϕ, then we can calculate the rate at which mass is flowing away from a quasar.

2.2. The ratio β_l/β and the value of ϕ

If the mass outflow rate is to be calculated from the observed line data, then we must know β_l/β, the effective fraction of recombinations which result in the emission of a Lyman alpha photon from the cloud. This is not a simple number to calculate since the optical depth of a cloud to Lyman alpha photons is very large and good models of line emission clouds require the use of large computer programs. Even then the models are rather idealized.

Some models have been calculated recently by Mathews et al. (1980), Canfield and Puetter (1980), and Kwan and Krolik (1979, 1981). Kwan and Krolik obtain a Lyα/Hβ ratio of 10.4 in their model 1 of a cloud which is optically thick in the Lyman continuum, which agrees with the observed ratio (Green et al., 1980). Their model predicts a Lyman alpha flux of 5.5 10^7 erg cm^{-2} s^{-1}, as a result of absorbing a Lyman continuum flux of 1.55 10^8 erg cm^{-2} s^{-1} and a Balmer continuum flux of 2.7 10^7 erg cm^{-2} s^{-1}. Therefore if we define υ_* in Eq. (1) to be the frequency of the Lyman edge ($h\upsilon_* = 13.6$ eV), then

$$\frac{\beta_l}{\beta} \frac{\upsilon_l}{\upsilon_*} = \frac{5.5\ 10^7}{1.55\ 10^8 + 2.7\ 10^7}. \tag{7}$$

Hence $\beta_l/\beta = 0.40$.

The basic model of the cloud assumes that the cloud is radiating isotropically and if this is not true then the effective value of β_l/β will be altered. For example, if a cloud radiates predominantly from its illuminated face then this will give a larger acceleration to the cloud and so will reduce β_l/β. This would show up as an asymmetry in the line profile, with the red wing being stronger than the blue wing (CFB and Ferland et al., 1979).

By putting the non isotropic corrections into β_l/β, we can always quote an 'equivalent isotropic radiator' value of β_l/β, and when numerical results are quoted I shall use $\beta_l/\beta = 0.40$.

Another source of uncertainty in the calculation is the value of ϕ, the ratio of the total momentum absorbed from the radiation field to the momentum absorbed due to hydrogen recombinations alone. ϕ will be greater than unity due to absorption in the hydrogen lines, and due to any absorption by heavy elements. The effect of Balmer line absorption is suppressed somewhat due to the optical depth of the lines, however, elements such as carbon, nitrogen and oxygen will also play a role. Unfortunately the current models of broad line clouds do not include the effects of heavy elements, so it is not possible to give accurate values for ϕ, but a range of 1–5 should include all likely possibilities, with a typical value around 2 to 3. We can see that heavy elements should not be much more important that hydrogen since the metal lines appear to be excited by collisional processes (Davidson and Netzer, 1979) and so the fraction of the line strength which comes from resonant absorption must be less than about half the total. Since the total emission in metal lines is comparable to the Lyα emission, resonant absorption by metals can be important, but will not make ϕ greater than a few.

3. The observational data

To calculate the ratio of mass outflow for a quasar we need to know the redshift, continuum flux and the Lyman alpha line flux and width. Data for seventy two quasars with the Lyman alpha line present in the spectrum were taken from the CTIO Curtis Schmidt survey of Osmer and Smith (1980).

The redshift, magnitude and Lyman alpha flux are given in Tables 1 and 2 of Osmer and Smith: the full width at zero intensity of the Lyman alpha line was measured directly from the published spectra of Fig. 2 of Osmer and Smith. The measurement of the line width is an important source of uncertainty in calculating the mass outflow rate. The red wing of Lyα is broadened by the presence of the NV 1240 line and there is absorption on the blue side due to Lyman alpha clouds at a smaller redshift than the quasar. These two effects tend to cancel out in measuring the line width, and in what follows I have assumed that the cancellation is exact, so that the measured width is taken to be the true width. The only way to test this assumption is to measure the line profile of Lyα using a resolution which is high enough to separate out the NV line and resolve the absorption lines that the basic underlying Lyα profile can be recovered.

High resolution observations of a sample of quasars by Wilkes (1982) indicate that the basic Lyα line is symmetric, contrary to

Table 1. Observational data and results. The number of each object is the one used by Osmer and Smith (1980)

No.	Object	F_ℓ 10^{-14}erg cm^{-2} s^{-1}	$\Delta\lambda$ Å	f_c 10^{-29}erg cm^{-2} s^{-1} Å^{-1}	$\dot{M}_{out}$ 10^{27} g s^{-1}	$\dot{M}_{in}$	R*
1	Q 1952-390	2.8	252	77	0.140	1.753	0.080
2	Q 2002-382	3.4	372	101	0.141	2.624	0.054
3	Q 2023-385	6.6	282	92	0.385	2.493	0.154
4	Q 2040-400	7.8	300	211	0.275	4.320	0.064
6	Q 2123-408	4.4	282	146	0.240	3.792	0.063
12	Q 2217-422	4.5	270	64	0.170	1.275	0.133
13	Q 2219-394	13.0	330	146	0.381	2.823	0.135
14	Q 2222-396	4.3	354	254	0.156	5.866	0.027
15	Q 2224-408	4.3	318	146	0.222	3.952	0.056
16	Q 2224-397	4.2	360	92	0.195	2.519	0.077
17	Q 2225-401	8.3	240	48	0.278	0.830	0.334
18	Q 2225-404	10.6	312	211	0.328	4.080	0.080
20	Q 2228-399	5.2	300	175	0.230	4.147	0.055
22	Q 2233-377	4.0	354	175	0.135	3.885	0.035
24	Q 2240-419	9.1	372	231	0.263	4.791	0.055
25	Q 2246-389	17.0	282	254	0.696	5.493	0.127
26	Q 2247-396	6.2	324	64	0.485	2.263	0.214
27	Q 2250-391	5.0	300	111	0.283	3.059	0.093
28	Q 2254-393	10.0	300	133	0.505	3.423	0.148
29	Q 2258-391	14.0	282	231	0.506	4.631	0.109
31	Q 2304-423	13.0	312	334	1.057	11.877	0.089
32	Q 2304-409	4.5	342	77	0.157	1.696	0.093
33	Q 2307-422	3.5	372	64	0.131	1.555	0.084
38	Q 2323-389	1.6	252	64	0.071	1.350	0.052
39	Q 2328-385	4.9	240	70	0.158	1.172	0.135
42	Q 2329-406	5.9	270	146	0.275	3.339	0.082
43	Q 2332-377	7.2	258	111	0.270	2.141	0.126
44	Q 2336-413	3.9	252	133	0.238	3.459	0.069
45	Q 2338-393	3.5	300	92	0.186	2.443	0.076
47	Q 2351-415	5.0	240	101	0.191	1.886	0.101
48	Q 2352-411	4.5	210	77	0.162	1.269	0.128
49	Q 2352-420	4.7	264	92	0.252	2.271	0.111
50	Q 2355-389	7.0	330	160	0.757	7.035	0.108
51	Q 2359-397	4.5	300	92	0.148	1.802	0.082
53	Q 0002-387	3.5	252	40	0.194	0.981	0.197
57	Q 0014-392	4.8	420	111	0.191	3.028	0.063
58	Q 0017-397	9.3	312	160	0.248	2.817	0.088
60	Q 0018-422	4.9	348	133	0.509	5.901	0.086
62	Q 0019-396	2.8	252	44	0.168	1.133	0.149
63	Q 0019-392	3.2	312	53	0.136	1.252	0.109
64	Q 0020-408	7.7	300	111	0.670	4.006	0.167
65	Q 0023-418	4.1	252	70	0.223	1.687	0.132
66	Q 0026-392	11.0	270	77	0.346	1.364	0.254
68	Q 0032-424	7.5	330	101	0.380	2.762	0.138
69	Q 0047-394	5.7	312	92	0.411	3.035	0.135
70	Q 0049-402	5.0	192	92	0.334	2.130	0.157
71	Q 0049-393	8.3	240	252	1.234	11.149	0.111
72	Q 0052-410	9.0	318	211	0.294	4.272	0.069
74	Q 0103-395	7.9	264	222	0.517	3.090	0.167
75	Q 0105-391	9.1	294	211	0.493	5.596	0.088
76	Q 0105-409	3.2	222	40	0.194	0.960	0.202
77	Q 0108-376	7.7	300	160	0.191	2.619	0.073
79	Q 0113-406	3.5	234	146	0.195	3.412	0.057
80	Q 0113-392	8.5	210	121	0.428	2.486	0.172
81	Q 0117-380	3.8	228	101	0.161	1.953	0.082
82	Q 0117-400	5.4	330	64	0.179	1.335	0.134
84	Q 0119-403	5.2	294	84	0.282	2.228	0.126
85	Q 0122-380	12.0	270	766	0.579	17.908	0.032
86	Q 0123-396	2.9	162	48	0.250	1.179	0.212
88	Q 0128-411	4.2	270	121	0.277	3.457	0.080
91	Q 0132-399	7.4	342	133	0.292	3.180	0.092
92	Q 0132-409	6.9	378	64	0.341	1.869	0.182
95	Q 0205-379	15.0	330	402	0.849	11.795	0.072
97	Q 0209-418	2.2	210	92	0.092	1.680	0.055
100	Q 0231-410	4.8	240	40	0.313	1.055	0.297
102	Q 0239-420	3.4	240	133	0.222	3.495	0.063
105	Q 0254-404	8.6	264	402	0.502	10.445	0.048
107	Q 0319-409	5.3	240	111	0.369	3.028	0.122
112	Q 0338-394	8.8	240	160	0.903	5.580	0.162
119	Q 0451-418	7.8	240	192	0.382	4.214	0.091
120	Q 0452-398	6.0	288	77	0.213	1.533	0.139
125	Q 0545-417	7.5	252	121	0.344	2.629	0.131

some earlier claims, and her data lend support to the idea that the directly measured line width is a reasonable measure of the true width. Osmer and Smith give the continuum flux density of each quasar at a rest frame wavelength of 1475 Å (f_{1475}), and in calculating the total continuum flux (F_c) from f_{1475} (as given in Table 1 of Osmer and Smith as an equivalent magnitude), I have adopted the spectrum used by Kwan and Krolik (1981) for consistency with using their value of β_l/β. Thus

$$\begin{aligned} f_\upsilon &\propto \upsilon^{-0.5} \qquad && \upsilon < \upsilon_L \\ f_\upsilon &\propto \upsilon^{-2} && \upsilon_L < \upsilon < \upsilon_x \\ f_\upsilon &\propto \upsilon^{-0.5} && \upsilon_x < \upsilon < \upsilon_c , \end{aligned} \tag{9}$$

where υ_L is the frequency of the Lyman limit, $h\upsilon_x = 100$ eV, and there is a cut off above $h\upsilon_c = 12$ keV. This spectrum gives $F_c = 1.08\ 10^{15} f_{1475}/(1+z)$ erg cm^{-2} s^{-1}, where the factor of the $1+z$ allows for the compression of bandwidth in the observer's frame compared with the rest frame of the quasar. It is a simple matter to allow for different continuum spectra by normalizing the model spectra to have the same flux density at 1475 Å in the quasar's rest frame. To convert line and continuum fluxes to luminosities I have taken a $q_0 = 0$ Friedmann model, therefore

$$L = 4\pi F\left(\frac{cz}{H_0}\left(1+\frac{z}{2}\right)\right)^2 , \tag{10}$$

where L is either a line or continuum luminosity. For numerical results $H_0 = 50$ km s^{-1} Mpc^{-1} was used, although it should be

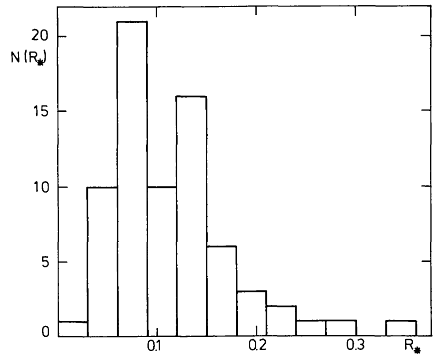

Fig. 1. Histogram of the number of objects in each R_* bin

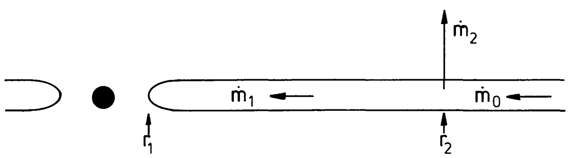

Fig. 2. The simple accretion disc with outflow

noted that the final ratio of mass flow rates is independent of both H_0 and q_0.

Finally we wish to relate the luminosities to mass flow rates. One can relate the total continuum luminosity, L_c to the mass accretion rate $\dot{M}_{\rm in}$ by

$$L_c = \eta \dot{M}_{\rm in} c^2 , \tag{11}$$

where all of our ignorance of the correct physics is contained in the efficiency η. Typical values for η are 5% for an accretion disc around a Schwarzschild black hole and 43% for an accretion disc around a maximally rotating Kerr hole. When numerical results are quoted I shall take $\eta = 0.1$. The mass outflow rate is related to the line luminosity by Eq. (5) where $u_{\max}/c = \Delta\lambda/2\lambda$, and $\Delta\lambda$ is the full width at zero intensity of the line. Note that the width and the wavelength of the line must be referred to the same frame of reference.

4. Results

Rather than concentrate on the actual mass flow rates, we shall work with a quantity $R = \dot{M}_{\rm out}/\dot{M}_{\rm in}$ which is connected to the ratio of mass outflow to inflow, although it is not actually equal to it (see Sect. 5). This has the advantage that the scaling of the mass flow rates with quantities such as the mass of the quasars are cancelled out in R if the scaling is the same for $\dot{M}_{\rm out}$ and $\dot{M}_{\rm in}$. The values of R given in Table 1 are calculated assuming that the model parameters are as indicated previously, and these R values are denoted as R_*. In general R is given by

$$R = R_* \left(\frac{\eta}{0.1}\right) \left(\frac{\beta_l/\beta}{0.4}\right)^{-1} \phi^{-1} S^{-1}, \tag{12}$$

where S is a factor allowing for a different continuum spectrum from that of Eqs. (9), and is equal to the new luminosity divided by the luminosity used in this paper, with equal flux densities at a rest frame wavelength of 1475 Å. In principle, each quasar should have its own value of S calculated from its measured spectrum, however, for the present sample, the spectrum is only known over a narrow optical band, so this correction is not possible. Future observations over a wider range of the spectrum can remove this added source of uncertainty. The observational data, calculated mass flow rates and values of R_* for each quasar in the sample, are given in Table 1, and a histogram of R_* values is given in Fig. 1. The mean value of R_* is 0.11, with a standard deviation of 0.06, and the maximum R_* value is 0.33. The reduction in the number of quasars with $R_* < 0.06$ compared with the peak at approximately 0.08 is unlikely to be due to a selection effect such as the line merging into the continuum, as the spectra of all the quasars in the sample have a very strong Lyman alpha line.

5. Interpretation

The parameter $\dot{M}_{\rm in}$ which is used in defining R, is essentially just a re-expression of the continuum luminosity, and is not necessarily a true inflow rate. In fact there is no unique inflow rate as Fig. 2 shows. This shows a simplified model of an accretion disc with outflow. $\dot{m}_0$ g s^{-1} are flowing inwards from infinity and at a radius r_2, $\dot{m}_2$ g s^{-1} are ejected from the disc leaving $\dot{m}_1$ g s^{-1} to fall towards the black hole, the disc stopping at r_1, approximately the last stable orbit. The luminosity which we observe has terms $GM\dot{m}_1/2r_1$ from the gas which stays in the disc and $GM\dot{m}_2/2r_2$ from the gas which only gets down to r_2 (relativistic corrections are ignored), where M is the mass of the black hole. The outflowing gas absorbs some radiation from the disc to provide it with the energy to escape to infinity and this subtracts an amount

$$\left(\frac{1}{2}\frac{GM}{r_2} + \frac{1}{2}u_\infty^2\right)\dot{m}_2$$

from the luminosity where u_∞ is the terminal velocity of the outflowing gas. Hence

$$L_c = \frac{1}{2}\frac{GM\dot{m}_1}{r_1} - \frac{1}{2}u_\infty^2 \dot{m}_2 . \tag{13}$$

Now $L_c = \eta \dot{M}_{\rm in} c^2$ by definition, and $\dot{M}_{\rm out} = \dot{m}_2$ as there is no ambiguity about the outflow, so we find that

$$\frac{4\eta}{R} + \frac{2u_\infty^2}{c^2} = \frac{\dot{m}_1}{\dot{m}_2}\frac{r_s}{r_1} , \tag{14}$$

where r_s is the Schwarzschild radius of the black hole. This equation relates the 'true' ratio of outflow to inflow, $\dot{m}_2/\dot{m}_1$, to R. In all cases the term in u_∞ is small, so we have

$$\frac{\dot{m}_2}{\dot{m}_1} = \frac{R}{4\eta}\frac{r_s}{r_1}$$

and the mean value is

$$\left(\frac{\dot{m}_2}{\dot{m}_1}\right)_{\rm mean} = 0.27 \left(\frac{\beta_l/\beta}{0.4}\right)^{-1} \phi^{-1} S^{-1} \left(\frac{r_s}{r_1}\right).$$

For a non rotating black hole $r_1 = 3r_s$ and $(\dot{m}_2/\dot{m}_1)_{\rm mean} = 0.09$: for a maximally rotating black hole $r_1 = 1/2 r_s$ and $(\dot{m}_2/\dot{m}_1)_{\rm mean} = 0.54$. Therefore we see that a typical value of $\dot{m}_2/\dot{m}_1$ is about 0.1 and that in some extreme cases (large R, small r_1) it may be possible for more than half of the gas which is accreted from infinity to be ejected as clouds before falling into the black hole. While there is no problem with ejecting a large fraction of gas on gross energetic grounds it does mean that it must be ejected at a large distance from the black hole, since only ten percent or less of the continuum radiation is absorbed by the clouds, and so is available to accelerate them (Baldwin, 1979). Thus r_2 is given approximately by $L_l = GM\dot{m}_2/r_2$ which using the mean values of the present data gives $r_2 = 300\,r_s$. This is the result one would intuitively expect, since it is not likely that the cloud velocities, as measured by the line width, can be much less than the escape velocity of the region of the disc from where the clouds are emitted.

One point which has been glossed over until now is that the broad line clouds do not necessarily make up all of the matter which is flowing away from a quasar. In some quasars we know that there are radio jets which are believed to be relativistic plasma ejected from the nucleus. Unfortunately it is very difficult to make estimates of the mass flux in the jet since there is no direct way of measuring the velocity of the gas in the jet. Blandford and Icke (1978) estimate that $6\,M_\odot$/yr ($4\ 10^{26}\ \mathrm{g\,s^{-1}}$) are ejected into the jet of the radio galaxy 3C 31 and a figure of a few solar masses per year seems to be a typical figure when estimates can be made. This is the same order of magnitude as the mass ejected as broad line clouds, however, most quasars do not show much radio emission (Murdock and Crawford, 1977) and so it is probably correct to neglect this in a statistical study such as this.

A more serious problem is that there will be a hot intercloud medium which is in pressure equilibrium with the clouds and is presumably flowing along with them. This will provide a further outflow of gas which is again difficult to estimate since we need to know the physical properties of this hot wind to estimate this. Usually there is no observational evidence of the hot wind, but the broad absorption troughs which are seen in a few quasars (Perry et al., 1978; Drew and Giddings, 1982) may be manifestations of this wind. A better theoretical understanding of the formation of the clouds would be useful here, since the clouds presumably condense out of a hot wind (possibly from an accretion disc as suggested in this section), but very little is known about exactly how much condenses into clouds.

Due to the large uncertainties in estimating the added contributions to the total outflow, I shall only quote outflow rates for the broad line cloud component. One should be aware though that the extra contributions do exist.

6. Conclusion

For the chosen sample of seventy two quasars, we have shown that typically ten percent of the accreted mass which powers the quasars is ejected to form the broad line clouds. While the present calculation has been based on a modified version of the Blumenthal and Mathews (1975) model, other models of cloud motion should give similar results (CFB), so the values of R_* discussed in this paper are unlikely to be in error by more than a factor of two. In the future, with better models of the kinematics and radiation of the clouds and better observations, it will be possible to reduce the uncertainties due to β_l/β, ϕ, S, and η, and it may even possible to use the ratio of outflow to inflow to determine whether the clouds are truely moving outwards or are actually falling in towards the quasar. If the clouds are falling into the black hole and are the fuel for the quasar then the 'outflow rate' and inflow rate must be equal, at least in a time averaged sense. The mean value of $R = 0.11$ found here is suggestive that this is not the case, but at this stage it is not possible for the inflow model to be excluded.

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