An Overview of Dynamical Models for Outflows in BAL QSOs and Seyferts

Martijn de Kool

JILA, University of Colorado, Boulder

Abstract. In this paper I will review the dynamical models that attempt to explain the outflows in QSOs and Seyfert galaxies that are responsible for the blueshifted absorption lines observed in some of these objects.

Most models face the difficulty that the absorbing gas appears to consist of very small, low filling factor clouds, that are likely to be hydrodynamically unstable, and require an intercloud medium at high pressure to keep them confined. Two types of intercloud medium have been proposed: hot gas and magnetic field. Hot gas confinement leads to many apparent physical contradictions, and until these are resolved can not be considered a serious candidate. Magnetic confinement seems more promising, but needs more study to assess its viability. A third possibility that should be seriously considered in the light of the confinement problem is that some of the arguments leading to the conclusion that a small filling factor is required is wrong. As an example, Murray et al. showed that a model that allows the ionization parameter of the absorbing gas to be much higher than generally thought can avoid the confinement problem.

Three types of acceleration mechanisms have been considered for for wind-like outflows in AGN: hot gas or cosmic ray pressure-driven winds, winds driven by radiation pressure and centrifugally-driven magnetic disk winds. The first two have been shown to be able to produce absorption lines similar to the observed ones, with line radiation pressure requiring the smallest leaps of faith. The formation of absorption lines in magnetic winds is still unexplored.

1. Introduction

The existence of broad absorption line quasars and blueshifted absorption lines in Seyferts provides clear evidence that high speed outflows of gas are common in AGNs. The basic questions one would like to have answered by a theoretical model for these outflows are:

- What is the origin of the gas flowing out?
- What is its geometry?
- What force accelerates it?
• What determines its ionization state?

While answering these questions, a good model should satisfy these observational constraints:

• it should produce lines similar to the observed ones. Significant column densities (10^{15} to 10^{18} cm^{-2}) of both high ionization potential ions (O VI, N V, C IV, etc.) and low ionization potential ions (O III, Si IV) should be produced.

• material has to be accelerated up to at least 30,000 km sec^{-1} in QSOs and 5,000 km sec^{-1} in Seyferts

• the ionization parameter should not vary drastically for gas with different speeds along the line-of-sight

• the outflow should not produce emission at speeds higher than observed in the emission lines, which presumably implies it has a covering factor of less than 20% (Hamann, Korista & Morris 1993)

• the geometry should be such that high speed BAL material occurs outside the Lyα broad emission line region, since Lyα is seen to be heavily absorbed by high speed material containing N V ions.

• it should explain why there is such a wide range in absorption line morphology (Turnshek 1988)

• it should be consistent with the lack of variability in the structure of the absorption lines in BAL QSOs over timescales of 10 years (Barlow 1994)

In this paper I will give a critical review of the theoretical models that have been proposed so far, and discuss to what extent they fulfill the criteria above.

2. The State of the Absorbing Gas and the Confinement Problem

The fact that the strongest absorption lines formed in the outflow are of species like C IV, O VI, O III, Si IV and N V suggest that if the absorbing gas is irradiated by a “standard” AGN spectrum (e.g., Mathews & Ferland 1987) the ionization parameter \( U \) (density of photons below the Lyman limit divided by the hydrogen density) is of the order \( U \sim 0.1 \). This leads immediately to an estimate of the density of the absorbing gas of

\[
n_{\text{abs}} \sim 10^{10} L_{46} R_{17}^{-2} U_{-1} \text{ cm}^{-3}
\]

with \( L_{46} \) the luminosity of the central engine in units of 10^{46} ergs/sec, \( R_{17} \) the size of the region in which the absorption lines are formed in units of 10^{17} cm, and \( U_{-1} \) the ionization parameter normalized to 0.1. Estimates of the total column density of the absorbing gas are difficult to obtain due to saturation of the lines, but are typically in the range \( N_{\text{abs}} \sim 10^{21} - 10^{23} \text{ cm} \), so that the total thickness of the absorbing layer is

\[
D_{\text{abs}} \sim \frac{N_{\text{abs}}}{n_{\text{abs}}} \sim 10^{13} N_{23} L_{46}^{-1} R_{17}^{-2} U_{-1} \text{ cm} .
\]
From the fact that both the continuum and the broad emission lines are seen to be absorbed, we know that the absorbing region lies outside or is cospatial with the BEL region, we have \( R_{\text{abs}} \sim R_{\text{BEL}} \sim 10^{17}\text{cm} \). Thus, comparing the size of the absorbing region with the thickness of the absorbing layer we arrive at a very small filling factor for the absorbing gas,

\[
f_{\text{abs}} \sim \frac{D_{\text{abs}}}{R_{\text{abs}}} \sim 10^{-4} N_{23} L_{46}^{-1} R_{17} U_{-1}
\]

(3)

If we require additionally that the flow gives rise to the smooth absorption troughs observed in some BAL QSOs that extend over hundreds to thousands of thermal line widths, it is clear that we will need hundreds to thousands of clouds in our line of sight, implying very small sizes (\( \sim 10^{10} \text{ cm} \)) for individual clouds.

What are the consequences of this low filling factor? It is clear that there has to be a confining medium around the clouds to keep them from expanding and becoming too highly ionized, since the sound crossing time of the clouds is very short. There are two obvious choices for this confining medium: hot gas or magnetic field.

### 2.1. Hot Gas Confinement

Confinement by hot gas would be the simplest explanation, but it leads to a large number of problems (Weymann, Turnshek & Christiansen 1985; Begelman, de Kool & Sikora 1991). If there is any velocity difference in the outflow between the clouds and the hot gas, the timescale for destruction of the clouds by hydrodynamical instabilities such as Kelvin-Helmholtz or Rayleigh-Taylor is very short compared to the acceleration time. The flow could consist of a true two-phase medium in which cool clouds could continuously reform, but unless the densities are higher than we infer, the timescale to cool down from the hot phase is longer than the crossing time of the absorbing region.

Because of the very low filling factor of the cool clouds, the mass of gas in the hot phase will be larger than in the clouds unless it has a very high temperature, \( \sim 10^9 \text{ K} \). If the temperature of the hot phase would be around the Compton temperature of the AGN radiation field, the mass loss in the hot phase would be uncomfortably large, of the order of tens of solar masses per year. However, gas at a temperature of \( \sim 10^9 \text{ K} \) is not able to confine the small clouds thought to exist in the absorbing region, because the mean free path of the hot particles is longer than the size of the clouds.

Finally, there is a problem with the fact that the ionization parameter of the absorbing clouds is observed to remain approximately constant as they are accelerated (e.g., Turnshek 1988). Any hot gas flowing out with the clouds will cool down quickly due to adiabatic expansion losses, causing the confining pressure to drop much too rapidly to keep \( U \) approximately constant. Thus, any hot gas confinement model has to have some way to release a lot of energy into the hot gas as it is being accelerated.

### 2.2. Magnetic Confinement

Confinement by magnetic field avoids several of the problems associated with hot gas. If the clouds travel along magnetic field lines, hydromagnetic instabil-
ities are likely to be much less severe, and the drag forces could be very small, although these effects have not been studied in much detail yet. A magnetic field could provide confinement in the direction perpendicular to the field, but other processes have to be invoked for confinement along the field. One advantage is that the cloud can expand only in one dimension, so that it will take a much longer time for the density to drop than in the case of spherical expansion. Confinement along the field could possibly be provided by ram pressure or radiation pressure from the central source, since the development of the Rayleigh-Taylor instability normally associated with this process will be suppressed by the magnetic field. There is in fact some indication that the clouds are being pushed, since the small size of the clouds is consistent with the scaleheight in the cool gas assuming that they experience an "artificial gravity" equal to their mean acceleration $v_{BAL}^2/R_{BAL}$ (de Kool & Begelman 1995). Another possibility is that the flow is self-confining in the direction along the flow, i.e., it consists of very thin flow tubes with a very low filling factor and small size perpendicular to the field, that are completely filled with cool material. Such a picture would fulfill all the constraints derived above.

Simple magnetic field models (such as completely radial or azimuthal field lines) also cannot reproduce a confining pressure that is approximately constant as the clouds are accelerated, since the field strength drops too rapidly. More complicated field geometries are clearly required.

3. Acceleration Mechanisms

3.1. Pressure-Driven Winds

The large drag forces that the absorbing clouds experience when they move relative to any confining gas led Weymann et al. (1985) to the conclusion that the clouds are likely to be dragged along in an accelerating confining medium rather than being accelerated themselves. The low density and high pressure in the confining gas make it a good candidate for a pressure driven wind. Pressure driven winds typically reach end speeds of a few times the sound speed in the wind, so the high velocity observed in BAL QSO outflows requires either an extremely hot wind ($T > 10^9$ K), or a wind driven by non-thermal particles such as cosmic rays.

Two models have been proposed along these lines. The first was by Weymann, Scott, Schiano & Christiansen (1982), which attempted to explain the broad emission line region as a hot outflow with embedded clouds, driven by relativistic electrons diffusing out of the central engine. The second model (Begelman et al. 1991) was specifically aimed at explaining the broad absorption lines. Here the primary cosmic rays were highly relativistic neutrons that are produced in the central engine, that can travel out to parsec scale before they decay to protons and couple locally to the magnetic field. Because the neutrons decay over a wide range of radii, there is a steady energy injection into the wind as it is being accelerated, compensating for the adiabatic losses that would otherwise make the confining pressure drop too fast. This model can produce BALs with characteristics similar to the observed ones, but it does require significant fine tuning of the parameters. Note that cosmic rays have very long mean free paths, and will penetrate the BAL clouds easily, so that the cosmic ray pressure itself.
can not provide confinement. Thus, dissipation of cosmic ray energy into the thermal intercloud gas (to equipartition) seems to be required anyway.

The origin of the clouds in these models is not clear. For stability reasons, it would be preferable if large velocity differences between the clouds and the confining medium would never develop, and from this point of view it is most attractive to inject the clouds at the base of the wind and let the ensemble accelerate together. On the other hand, there are many BAL profiles in which the absorption sets in sharply at some high velocity, which would be hard to understand in a radial outflow picture. An alternative injection mechanism is that the wind is accelerated on smaller scales, and hits some large (molecular?) cloud at high speed, ripping off material from the surface. In this picture, we would only see a BAL if we are looking through the wake of such a cloud. It is doubtful however that the clouds of cold material could survive long enough to be accelerated to velocities as high as observed, because (at least simple) estimates of the hydrodynamical destruction time are much shorter than the acceleration time. Numerical models along these lines (Schiano, Christiansen & Knerr 1995) have not been conclusive.

Observationally, we do not have much direct evidence for the existence of a very hot wind in BAL QSOs. Stocke, Morris, Weymann & Foltz (1992) have argued that the radio emission from radioquiet BAL QSOs and Seyferts is consistent with a hot wind model, and exhibits the proper scaling of outflow speed with luminosity.

3.2. Centrifugally-Driven Magnetic Disk Winds

The studies of this outflow mechanism have so far been restricted to the formation of broad emission lines (Emmering, Blandford & Shlosman 1992; Bottorff, Korista, Shlosman & Blandford 1997) or dusty winds at large disk radii that could form the obscuring torus in Seyfert 2 galaxies (Königl & Kartje 1994). Clearly it is also a good candidate for the origin of blueshifted absorption lines, but there are as yet no models exploring the formation of absorption lines in such flows in detail.

All these models are based on the basic self-similar outflow model proposed by Blandford & Payne (1982). It should be kept in mind that this model is highly simplified to make it mathematically tractable. There are no reasons why the flow should be self-similar, since self-similarity is only obtained for a special set of boundary conditions that is not preferred over others.

In this model (see Figure 1) cool clouds of gas emerge from the surface of the disk threaded by magnetic field lines that are anchored in disk. If the angle between the field line and the disk is small enough, the cloud will move outward but is forced to corotate with the point in the disk where the field line is anchored, making it rotate faster than local Keplerian speed. This causes a centrifugal force on the cloud, that tends to move it to even larger radii. The speeds attained scale with the Keplerian speed at the field line footprint, and with the ratio of magnetic flux to mass flux on the surface of the disk. For reasonable values, outflow speeds of the order 3 times the Keplerian speed are reached. Comparing the properties of BELs formed in such a wind with the observations, Emmering et al. (1992) invoked an extra source of electron scattering for the line photons in order to obtain cuspy line profiles while keeping

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the extent of base of the outflow below two decades in radius on the surface of the disk. The extra electron scattering also appears to be necessary to explain the fact that the high velocity wings of the line do not vary as much in response to the continuum as the core does (Ferland, Korista & Peterson 1991).

Even the simple self-similar model has about ten parameters that have to be specified to obtain the exact flow geometry (Bottorff et al. 1997). In the light of this, it may not be surprising that this model is able to fit the BEL profiles of many sources quite well. A more rigorous test of this model was recently performed by Bottorff et al. who showed that for NGC 5548, a self-similar hydromagnetic wind model for which the ten flow parameters have been obtained by fitting the observed BEL profile can reproduce the response of the line profile to continuum variability quite accurately (see also these proceedings). Since the time variability data have not been used to determine the flow parameters, this is a truly independent test that provides significant support for this model of BEL formation.

To what extent this type of outflow can also be responsible for BALs is not clear. There may be a problem in obtaining high enough speeds, since BAL speeds are typically several times higher than BEL speeds. Also the basic geometry of the self-similar model is not favorable to explain the fact that high velocity BAL material is obscuring low velocity material, since in these models the high velocities occur on much smaller scale than the low velocities, typically scaling with $v \propto r^{-1/2}$. Thus the high velocity material with BAL-like speeds
would typically be expected to be 10–100 times closer in than the material with
typical broad emission line speeds. For Seyferts however, which show absorption
lines that typically have speeds similar to the broad emission line width, this
seems a more promising model. A theoretical problem may be the neglect of the
effects of radiation pressure on the clouds, which should be important unless the
clouds are very optically thick.

3.3. Outflows Driven by Radiation Pressure on Dust

One suggestion about the nature of BAL QSOs is that they are QSOs near the
end of their forming stage, that are blowing out the remaining circumnuclear gas
after the central engine has turned on (e.g., Voit, Weymann & Korista 1993).
An important driving force for this outflow would be radiation pressure on dust.
This model is not very popular, because the argument that the upper limit on
the covering factor of the BAL region is about equal to the observed fraction of
BAL QSOs to non-BAL QSOs suggests that all QSOs must have BAL regions.
However, the point about the likely importance of radiation pressure on dust is
a very good one.

Scoville & Norman (1995, see also these proceedings) have worked out a
model in which BAL material derives from the stellar winds of cool giants, that
is accelerated outward by radiation pressure acting on the dust in the wind.
The high outflow speeds of ~ 30,000 km sec⁻¹ are a natural consequence of this
model, given that the dust opacity is relatively well known, and the starting
radius of the outflow must be approximately equal to the radius (~ 1 pc) where
the equilibrium temperature of the dust is equal to the evaporation temperature
of ~ 1,800 K. A weak point in this model appears to be the confinement of the
cool gas in the wind trails from the giants, which is due to the trails being
compressed between the radiation pressure from the inside, and the ram pressure
due to the non-comoving surrounding medium from the outside, which would
appear to be very unstable. From an observational point of view, there is the
problem that many high-ionization BAL QSOs show no signs of dust absorption
in their UV spectra (e.g., Weymann et al. 1991; Korista et al. 1992).

3.4. Line Radiation Pressure-Driven Winds

There are several compelling arguments that acceleration by UV line photons
plays an important role in BAL QSOs. It has the advantage over the other
models that the source of the acceleration is directly observed. Making a simple
estimate of the total momentum in the outflow:

$$\dot{M}v_{\text{wind}} \sim 10^{33} f_{-1} N_{23} R_{17} v_9^2 \text{ g cm s}^{-2}$$

with \( f_{-1} \) the covering fraction of the BAL outflow in units of 0.1, \( N_{23} \) the column
density of the BAL region in units of \( 10^{23} \text{ cm}^{-2} \), \( R_{17} \) its size in units of \( 10^{17} \)
cm, and \( v_9 \) the wind speed in units of \( 10^4 \text{ km s}^{-1} \), and comparing this to the
momentum absorbed from the radiation field in the BAL troughs:

$$\frac{\Delta L}{c} \sim \frac{f_{\text{cov}} N_{\text{line}} W_{\lambda} L}{c} \sim 10^{34} L_{46} f_{-1} N_{1} v_9 \text{ g cm s}^{-2}$$

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where $N_1$ is the number of important driving lines divided by 10, and $W_\lambda/\lambda \sim v_{\text{wind}}/c$, we find that line radiation pressure must play an important role. Furthermore, there is some direct evidence for the dynamical importance of line radiation by the occurrence of line locking in some Si IV profiles (Turnshek 1988) and extra acceleration of the flow at velocities where the Ly$\alpha$ broad emission line overlaps with the N V absorption, resulting in a steeper velocity gradient and a reduced optical depth in the BAL profiles of other species (Arav & Begelman 1994). The standard problems associated with small clouds and low filling factors (drag, hydrodynamical destruction, confinement with constant $U$) also plague this model, but recent studies of the instabilities occurring in line-driven winds from O-stars may provide some solutions to these problems (e.g., Owocki 1994, and the contribution by Feldmeier & Norman in these proceedings).

Early Models. Because of the similarity of many BAL profiles with stellar P-Cygni profiles of hot stars with fast winds driven by line radiation, this model was in fact among the first to be considered for BAL QSOs. In analogy with hot stars, Drew & Boksenberg (1984) constructed spherically-symmetric wind models with a filling factor of 1. They were not very successful in reproducing the observed profiles because of the very reasons that led to the constraints on the filling factor above: unrealistically high mass loss rates are necessary to keep the density high enough, and thus the ionization parameter sufficiently low to avoid heating the gas to too high temperatures, and it was very difficult to keep the ionization parameter approximately constant as the flow is accelerated. Also the model could not account for the absence of emission at high velocities, a consequence of the spherical symmetry that was assumed.

An early radiatively-driven disk wind model for the broad emission line region was proposed by Shlosman, Vitello & Shaviv (1985). In this model the wind is not driven radially outward, but vertically up from the UV-emitting part of the accretion disk. While it is still in the shadow of the atmosphere of the inner disk the wind is in a single, cool phase. As it gets exposed to the full hard AGN continuum above the atmosphere it becomes thermally unstable and turns into a two-phase state, with cool clouds embedded in a hot gas. This effectively launches clouds with a velocity perpendicular to the disk, and it is assumed that after this radiation pressure is no longer important. In this model, we would expect to see broad absorption lines under most viewing angles, with the highest velocities occurring when we are observing the disk face-on, in contrast to most other disk wind models where the wind is visible only if our line of sight is close to the disk plane.

Line-Driven Wind Models with Low Filling Factor. More recently, Arav, Li & Begelman (1994) reinvestigated the possibility of line radiation pressure driven winds in BAL QSOs. They decided to neglect all the problems associated with low filling factors, and just assumed that the absorbing clouds are infinitely small, and embedded in a massless confining medium that exerts no drag forces, and has the correct run of confining pressure with radius to be consistent with observations. Once these assumptions are made, the classic CAK theory for line driven winds (Castor, Abbott & Klein 1975) can be applied to derive the properties of the wind. This theory is remarkably successful and correctly predicts the important driving lines, and the final velocity if it is assumed that the
Figure 2. The radiatively accelerated and magnetically confined disk wind model of de Kool & Begelman (1995). The radiation from the central source compresses the magnetic field until its pressure is comparable to the radiation pressure, thus providing a roughly constant ionization parameter.

flow starts at radii comparable to the broad emission line region, and is exposed to the optical to X-ray continuum produced close to the center of an AGN. They also pointed out that if the confining pressure varies with radius in such a way that the ionization parameter is approximately constant, the gradient of this pressure should play a non-negligible role in the acceleration, and a model taking this into account was presented.

A possible candidate for the massless confining medium with just the right properties was suggested by de Kool & Begelman (1995). Their model is a hybrid between the radiation pressure and magnetic disk wind models, that is based on the simple estimate that line radiation pressure will accelerate clouds much faster than the magnetic centrifugal effect (if they are not too optically thick). Just as in the model of Emmering et al. (1992), cool matter emerges from the disk threaded by magnetic field. As it is exposed to the central continuum, the matter is heated and expands until it is in pressure equilibrium with the magnetic field around it. Line radiation pressure then accelerates the clouds, dragging the magnetic field along with it (see Figure 2). The radiation pressure alone would accelerate the flow in a very thin wedge over the surface of the disk. However, all of the magnetic flux emerging from the inner parts of the disk is forced into this wedge, and if it becomes too thin large magnetic pressure gradients develop that will widen the outflow wedge again. Thus an equilibrium configuration will develop in which the magnetic pressure gradients balance the radiation pressure, which is only possible if the magnetic pressure is a significant fraction of the radiation pressure. This is just what is required to obtain an ionization parameter in the clouds that is self-regulating and approximately constant.

The Disk Wind Model of Murray et al. The most recent example of a radiatively-driven disk wind model is the one by Murray, Chiang, Grossman & Voit (1995).
Figure 3. A schematic representation of the disk wind model by Murray, Chiang, Grossman & Voit (1995). The material labelled “hitchhiking gas” is what screens the disk wind from the hard X-rays from the central source.

This differs radically from all the other ones, since it assumes that the filling factor of the absorbing material is unity. In order to avoid the earlier arguments against this, the authors argue that the ionization parameter of the BAL gas is about three orders of magnitude higher than previously assumed. This is possible if one assumes that the ionizing spectrum irradiating the BAL gas is not the full central continuum, but rather one that has already passed through a high column density highly ionized absorber (Figure 3). This would absorb the far UV and the soft X-rays out of the spectrum, and there would not be enough hard photons left to ionize the observed BAL species like C IV completely away. A very strong point of this model is that indeed all BAL QSOs appear to have strong absorption in their soft X-ray spectra, since ROSAT observations have shown them to be very weak soft X-ray emitters (Green & Mathur 1996). In the one case where a column density could be determined (PHL 5200, Mathur, Elvis & Singh 1995) a value consistent with the ones needed to keep the ionization low was found. In subsequent papers (Chiang & Murray 1996; Murray & Chiang 1997) it is argued that the emission lines formed at the base of the disk wind can also account for the reverberation mapping results and broad emission line profiles from Seyfert galaxies (see also these proceedings).

This is a very attractive picture because it avoids all the problems associated with clouds. However, a few problems with this model have not been satisfactorily resolved. The first one is that the model requires that the BALs are formed at very small radii $\sim 10^{16}$ cm. The reason for this is that the highly ionized wind is not as easily accelerated because of the low abundance of the ions that drive the wind. To obtain speeds as high as observed in BAL QSOs, it is necessary to start the flow very close in. Since the evidence that the BEL region lies inside or is cospatial with the BAL region is incontrovertible, this also implies that the BEL region in QSOs has a much much smaller size than commonly accepted. With these small scales, the crossing time of the BAL region is only a month or so, and it is difficult to understand that the highly complex kinematical structures that BALs often exhibit do not appear to vary on timescales of 10 years (Barlow 1994). Even if the absorption components we see are not actual cloud complexes being accelerated but rather standing flow patterns, it would be likely that they are anchored to certain positions on the disk, and the short rotation period of the disk would be likely to cause changes on the observed timescale. Any structure in the wind that is due to the line
driving instability is not likely to be axisymmetric, and the analogy with O-star winds suggest that such structures would be seen to move in a few dynamical times (Owocki 1994; Braun & Milgrom 1990).

It is not clear if the full range of ions observed to show BAL profiles can be explained by the very high ionization parameters required by this model. As an example, the ionization model presented by Murray et al. would have difficulties explaining the presence of broad absorption lines from ions with ionization potentials like O III or lower. It would also be interesting to explore the consequences of the small broad emission line region in more detail, to see if the proper line ratios can be obtained, and if the density limits obtained from semi-forbidden lines are not violated.

The origin and dynamics of the highly ionized absorber assumed to exist between the hard continuum source and the wind needs to be worked out in more detail. Murray et al. argue that it is a “failed wind” which attempts to start from the disk at radii interior to the real wind, which becomes too highly ionized to achieve escape speed but which could still get far enough above the disk surface to shield the outer wind. Their derivation of the dynamics is very approximative, and a more rigorous calculation (which would involve some fairly complicated 2-D radiation hydrodynamics) would lend more credibility to this model.

4. Conclusions

It is clear that the problem of the origin of the blueshifted UV absorption lines in AGN is far from being solved. Looking back at the the basic questions posed in the introduction, it appears that there are clear favorites for the accelerating force (radiative acceleration by UV line photons) and geometry (disk-like, compare the great similarities between Figures 1, 2 and 3), but the origin of the BAL material and the regulation mechanism for the ionization parameter are still very uncertain. One of the outstanding problems is the lack of variability in the kinematic structures in the BAL QSO line profiles, which is beginning to be an embarrassment even for the models operating on parsec scale, since small velocity shifts in the components could have been easily detected. No model has as yet attempted to explain the highly irregular structure of the absorption line profiles, with both very smooth broad and some quite narrow (~ a few hundred km sec⁻¹) components.

It seems likely that most of the processes that play a role in the formation of the absorption lines have been recognized. It now remains to look at them in much more detail to see if the primitive models that have been proposed so far can really fit all the observational constraints.

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References

Discussion

Brad Peterson: Suppose that broad emission line clouds are not confined and can freely expand (e.g., expanding atmospheres of stars). The clouds, driven outward by radiation pressure, expand and become optically thin, producing the optically thin component of the broad-line emission. These clouds will continue to expand, and will heat up to the Compton temperature (higher in Seyferts than in QSOs because of the flatter $\alpha_{ox}$); in Seyferts, you get a highly ionized warm absorber, and in QSOs you get high velocities, but lower ionization levels like BAL clouds. What are the major failings of this very simple model?

Martijn de Kool: I think that the Compton temperature in QSOs would still be much too high to be consistent with the ionization state of the BAL gas.