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Dynamics of Clouds in the Broad Line Region

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A physical understanding of the dynamics in the broad line region is essential for an explanation of the narrowness of the permitted lines in Narrow-Line Seyfert 1 galaxies. We have looked at the stability of orbits in the presence of radiation pressure. We find that for strong radiative support, circular orbits are unstable, and an inward perturbation pushes the cloud on an eccentric orbit which produces a narrow line profile. We have also looked at the hydrodynamic stability of clouds using axisymmetric simulations. A purely azimuthal magnetic field leads to quick cloud destruction via Mathew's pancake mechanism. An additional poloidal component may inhibit this particular mechanism.

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1. Introduction

Narrow-Line Seyfert 1 (NLS1) galaxies have been so named because of the unusual narrowness of their broad permitted emission lines [7]. This immediately begs the question why the broad lines are so small. Any possible answer must address the dynamics of the line emitting objects, which are traditionally called clouds. The simplest assumption is certainly that all broad line regions are essentially identical regarding dynamics. This assumption has also the advantage that physical details may be ignored to some extent. The only variable that is now left to make the line width smaller in some objects is the orientation to the line of sight. This does of course imply that the broad line region does not look identical in all directions, which is perhaps most easily realised by a disky configuration. Indeed, there is observational evidence in this direction (compare [3]). In such a scenario, NLS1s would be the ones seen pole on. Todd Boroson has discussed the effect of orientation at this meeting [2], concluding that a given Active Galactic Nucleus (AGN) would appear to be about twice as bright, and having half the line width when seen pole-on as compared to an edge-on view (if Seyfert 1 galaxies could be seen edge-on). He further concludes that this effect may explain some, but not all of the difference that NLS1s exhibit. This would imply that NLS1s are intrinsically different from other AGN. In fact, when the usual dynamical measurement of the central black hole masses is applied, they turn out to have intrinsically small supermassive black holes (SMBHs) and high Eddington ratios [2]. As intrinsic cloud dynamical difference, Marconi et al. have observationally identified the varying degree to which radiation pressure contributes to the force budget of the clouds in the broad line region [4]. We have recently investigated the physical basis of this picture. The problem is complex and simplifications have to be made. In the following, we report two approaches. First, we address the stability of cloud orbits in the presence of radiative, centrifugal and gravitational forces. The result is that from a certain level of radiative support, circular orbits are no longer stable. Instead, such systems have to have the clouds on elliptical orbits, where the slow outer parts dominate the emission, and thus produce narrow lines [3]. The second investigation is on the hydrodynamic stability. Here, we confirm the quick destruction of BLR-clouds by hydrodynamic instabilities, but also find hints that a complex magnetic field structure might make the clouds more stable.

2. Orbits in the presence of the radiative force

2.1 Isotropic illumination

We have calculated the effective potential for a featureless, spherical cloud of constant mass [3]. As usual [6], the cloud is assumed to react to the ambient pressure which is assumed to be a function of radius. The cloud's cross section therefore increases with radius, which may lead to an instable situation, in which the cloud experiences a negative restoring force for an arbitrarily small perturbation of its orbit. This leads to ejection or transition to an eccentric orbit, if the perturbation was applied inwards. For reasonable power law indices of the pressure profile ($1 < s < 3$), we find a critical equilibrium circular velocity of about 80 per cent of the Kepler velocity (the equilibrium velocity is lower than the Kepler velocity because of the additional radiative support). Figure 1 summarises these findings.

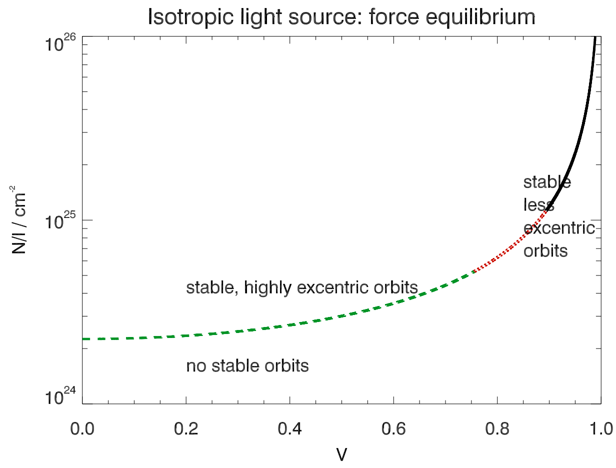

Figure 1: Dynamical equilibrium column density over luminosity in Eddington units against rotation velocity in Kepler units for an isotropic light source. The green, dashed part of the line corresponds to a maximum of the effective potential for reasonable choices of the parameter s ($s > 1$) that characterises the pressure profile. Stable orbits are still found in this case, but are highly eccentric, and are found above the green line. The red, dotted part corresponds to a stable minimum for certain values of s. The solid, black region is always a minimum of the effective potential, provided $s < 3$, and therefore allows for orbits with low eccentricity, which scatter around the line.

2.2 Anisotropic illumination

The primary light source is the accretion disk and therefore thought to be anisotropic. We model the luminosity as a Lambertian surface with a $\cos(\theta)$ luminosity dependence [3]. In such a setting, BLR clouds cannot orbit in the equatorial plane, because they would not intercept any light in this case. For orbits inclined to the equatorial plane, the radiative force changes along the orbit. The total force is therefore no longer conservative, and the angular momentum is the only constant of the motion. We have numerically integrated some example orbits. The solutions are precessing ellipses, with higher eccentricity for increasing radiative support, very similar to the isotropically illuminated case. The emission of strongly radiatively supported clouds is dominated by the slow outer parts of the orbit, where the clouds are also the biggest. We find that very sub-Keplerian line profiles are possible.

3. Hydrodynamic cloud stability

This is an unsolved issue for many decades. In the seventies, quasar clouds have been assumed to be accelerated to their high observed velocities by the radiation pressure [1]. Subsequent theoretical investigations have revealed that the clouds are vulnerable to a number of hydrodynamic instabilities, most important perhaps being ram pressure and radiative shear. Another important problem is the *pancake*-mechanism identified in 1982 by W. Mathews [5]: Radiation pressure is not able to build up a stable radial (with regard to the SMBH) force equilibrium. The result is that the cloud is compressed and spreads out sideways like a pancake. The sideways flow cannot be stabilised and the clouds are doomed to disperse. We have followed this scenario with hydrodynamic

PoS(NLS1)014

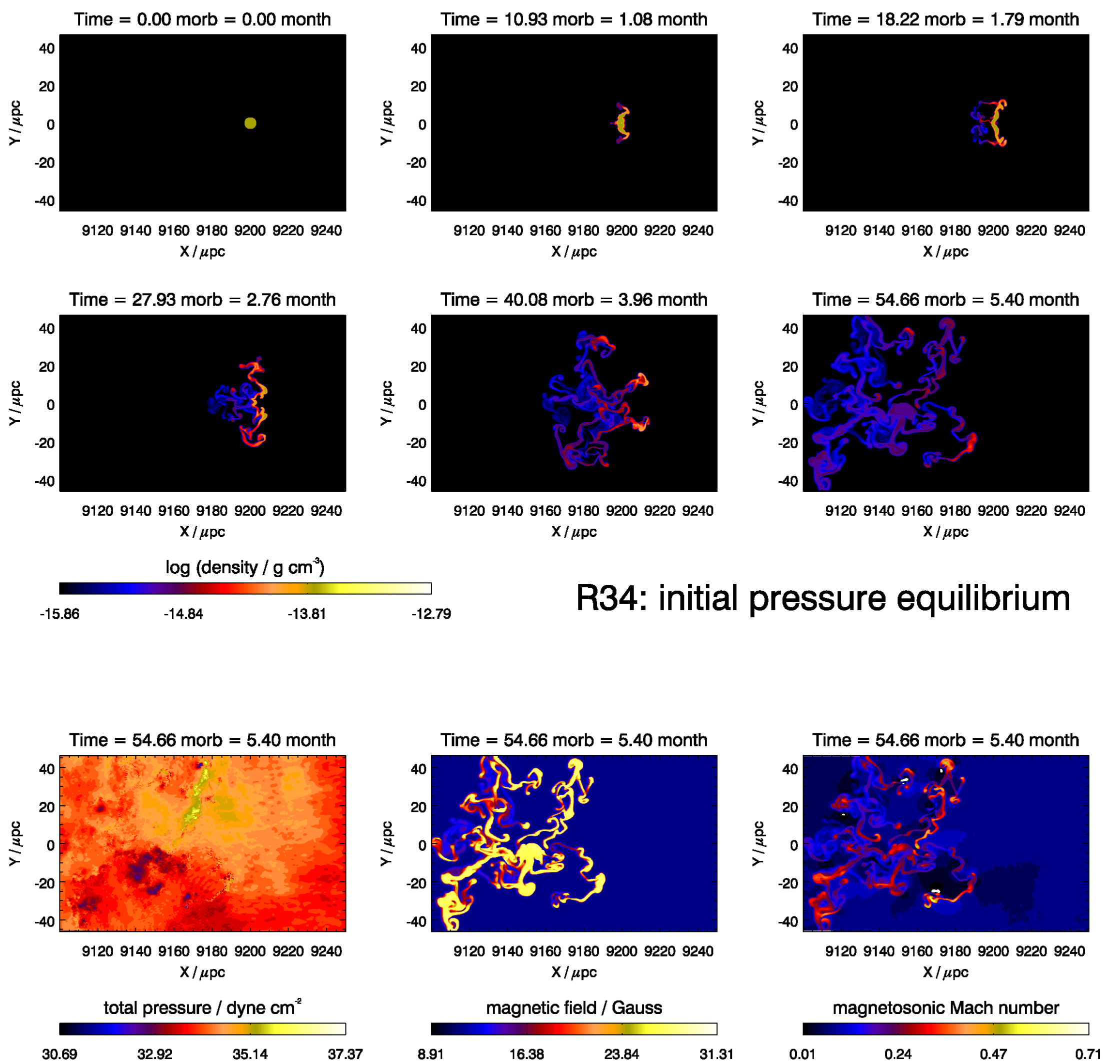

Figure 2: Magnetohydrodynamic simulation of a spherical cloud in 2D axisymmetry with azimuthal magnetic field. The top six images show the logarithm of the density for different snapshot times, indicated in milli orbits (morb) and months on the individual images. The bottom three images show for the final snapshot from left to right: Total pressure, magnetic field strength and magnetosonic Mach number for the velocity component in the meridional plane. In the cold cloud gas, the magnetosonic speed is almost the same as the Alfvén speed.

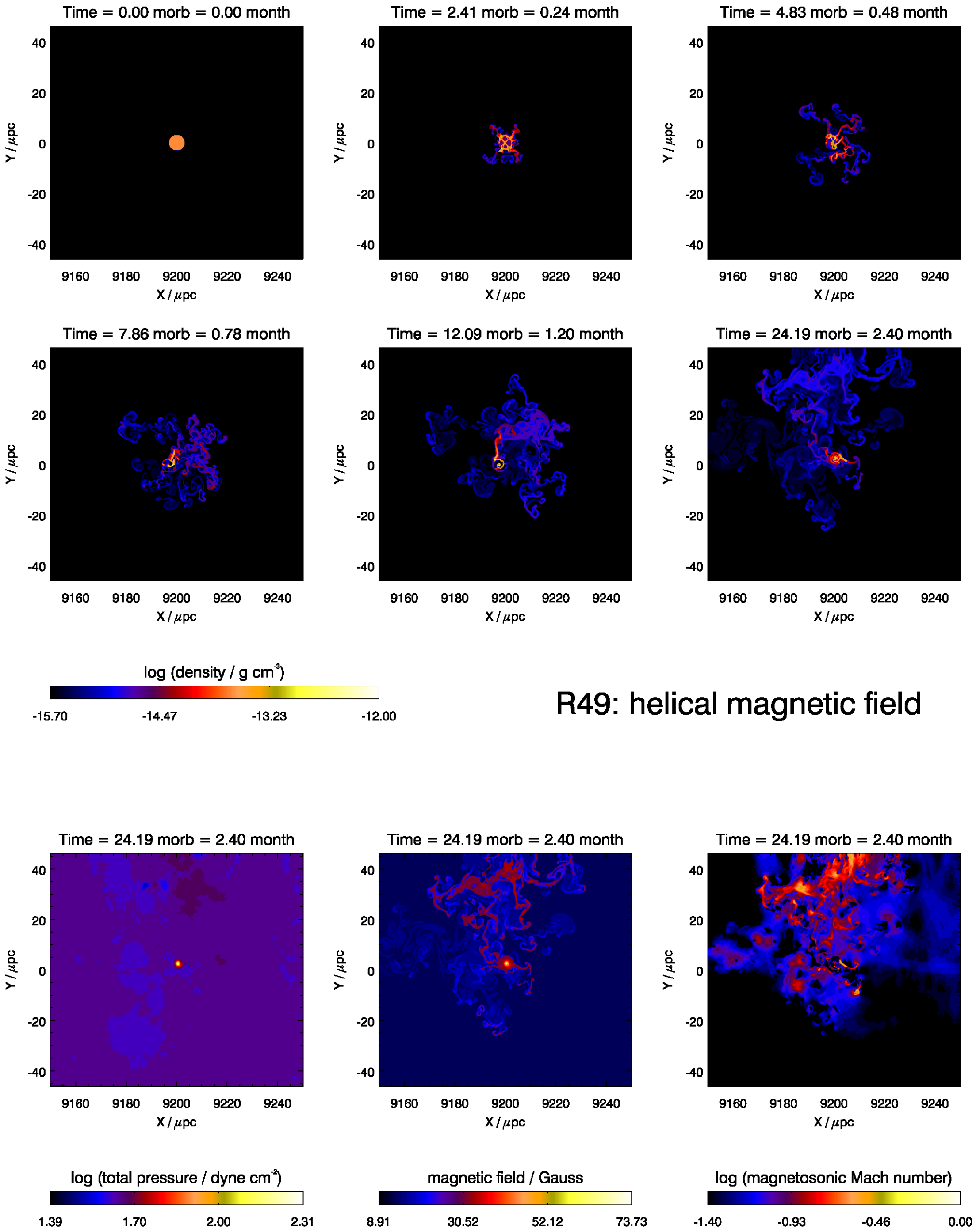

Figure 3: Same as Figure 2 for an initially helical magnetic field configuration, except the plots on the bottom left and bottom right have a logarithmic scaling.

simulations. Without explicit internal pressure source, a non-rotating cloud is simply ablated near its rim and collapses radially. Subsequently, it re-expands in a clumpy and filamentary way [8]. We have also realised internal pressure support by an azimuthal magnetic field in a 2D axisymmetric simulation (Figure 2). The cloud is set up in stable circular rotation according to the calculation above. The cloud behaves essentially like Mathews's quasar pancakes: It is compressed radially, expands sideways and is then dispersed due to the Kelvin-Helmholtz instability. It is advected towards the SMBH at the end of the simulation due to the loss of rotational support because of mixing and drag of the ambient gas.

We have also used helical magnetic fields as initial configuration (Figure 3). The additional magnetic tension force now resists compression and sideways expansion, and the cloud keeps a spherical core. The cloud still looses mass along filaments. The asymmetry in this simulation is caused by strong reflections at the grid boundaries.

4. Summary

If orientation is indeed not the only factor necessary to explain the small line widths in NLS1s, then their BLR dynamics has to be intrinsically different. We may have found a physical basis that could explain this difference, namely that for strong radiation pressure support, circular orbits are no longer possible, and the orbits become highly eccentric with the emission being dominated by the slow outer parts of the cloud orbits. Hydrodynamic stability is still an issue and the clouds may well be short-lived. Purely azimuthal as well as purely helical magnetic fields are certainly a simplification. Within these limits, we confirm the destructive pancake mechanism for purely azimuthally magnetised clouds, and stability against this mechanism for the helical case.

References

[1] G. R. Blumenthal, W. G. Mathews, *Theoretical emission line profiles in QSOs and Seyfert galaxies*, ApJ, 198, 517 (1975).

[2] T. Boroson: *NLS1 properties and demographics*. In: *Proceedings of the Workshop Narrow-Line Seyfert 1 Galaxies and Their Place in the Universe*, PoS(NLS1)003 (2011).

[3] M. Krause, A. Burkert, M. Schartmann, *Stability of cloud orbits in the broad-line region of active galactic nuclei*, MNRAS, 411, 550 (2011).

[4] A. Marconi, D. J. Axon, R. Maiolino, T. Nagao, G. Pastorini, P. Pietrini, A. Robinson, & G. Torricelli, *The Effect of Radiation Pressure on Virial Black Hole Mass Estimates and the Case of Narrow-Line Seyfert 1 Galaxies*, ApJ, 678, 693 (2008).

[5] W. G. Mathews, *Quasar pancakes*, ApJ, 252, 39 (1982)

[6] H. Netzer, P. Marziani, *The Effect of Radiation Pressure on Emission-line Profiles and Black Hole Mass Determination in Active Galactic Nuclei*, ApJ 724, 318 (2010).

[7] R. W. Pogge: *A quarter century of Narrow-Line Seyfert 1s*. In: *Proceedings of the Workshop Narrow-Line Seyfert 1 Galaxies and Their Place in the Universe*, PoS(NLS1)002 (2011).

[8] M. Schartmann, M. Krause, A. Burkert, *Radiation feedback on dusty clouds during Seyfert activity*, MNRAS (in press).