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ORIGIN AND DYNAMICS OF EMISSION LINE CLOUDS IN COOLING FLOW ENVIRONMENTS

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The interstellar environment of central dominant (cd) cluster galaxies is unique among ISM's in external galaxies as it is pervaded by hot, high pressure gas accreted from the surrounding intracluster medium. Typical average temperatures and pressures are $T \sim 310^7$ K and $P/k \sim 10^6$ K cm^{-3}. Central peaks in the x-ray surface brightness distribution, and inwardly decreasing temperature profiles suggest that a massive, subsonic, cooling inflow is centered on the cd galaxy.

One of the intriguing aspects of the x-ray observations is that they cannot be fit by homogeneous steady-state cooling flow models. To date, the only models successful in explaining the observations in detail are those where the accretion rate decreases approximately linearly in radius – mass appears to be dropping out of the flow and forming (mostly low mass) stars. This scenario is independently supported by soft x-ray line measurements and by the existence of extended emission line regions of $T \sim 10^4$ K gas.

When first proposed, the mass deposition hypothesis seemed to be on a firm theoretical footing via the mechanism of thermal instability – comoving perturbations in pressure equilibrium exhibit the same kind of rapid growth as in static atmospheres (Mathews and Bregman 1978). However recent work has pointed out two important mitigating factors – conduction and, particularly, buoyancy. Since the ICM is stably stratified in a background gravitational field, linear perturbations are not in fact comoving but tend to oscillate buoyantly. This oscillatory behaviour dominates over cooling for the conditions appropriate to cooling flows – very modest growth rates are therefore inferred (Malagoli, Bodo, and Rosner 1987; Balbus 1988; Balbus and Soker 1989).

However, this is still not the final word on linear perturbations. Buoyancy forces can be supported if there are non-isotropic stresses. In particular, I have reconsidered Eulerian perturbations including the effects of magnetic fields self-consistently by perturbing the full MHD equations with gravity, thermal conduction, and radiative cooling (Loewenstein 1989a). The results are that there are comoving, thermally ustable modes for a finite region in wave number space in regions where (for a radial background magnetic field)

$$\lambda_B{}^2 + \frac{v_A{}^2}{c^2}\lambda_g{}^2 > \frac{\lambda_F{}^2}{(2-\alpha)}.$$

Here λ_g is the pressure scale height, λ_B is the coherence length of the magnetic field, λ_F a local conduction length, α the slope of the cooling function, c the local adiabatic sound speed, and v_A the local Alfvèn speed.

The relevance of all this linear analysis can be questioned since there are reasons to believe that the ICM is fundamentally inhomogeneous due to the effects of continued subcluster merging, galactic halo stripping, and possibly radio source-cooling flow interaction and central galaxy motion. A phenomenological, multiphase, comoving flow model can reproduce the x-ray observations in a self-consistent way (Thomas, Fabian, and Nulsen 1987). Hydrodynamic calculations of finite perturbations have been performed by David, Bregman, and Seab (1988), by Loewenstein (1989b), and by Hattori and Habe (1989). Only the latter work is two-dimensional and illustrates the importance of lateral flows and the formation of vortex-like structures, although at the price of somewhat unrealistic background models. The former work has the most careful treatment of cooling and ionization; however, their choice of plane parallel symmetry precludes buoyancy. In Loewenstein (1989b), I found the same kind of thermal-convective oscillations that occur for infinitesimal perturbations to occur in finite, isolated inhomogeneities as long as the density contrast is less than about 10. An additional mechanism must be included to induce "cooling out" – the coupling of inhomogeneities to the background flow via drag. This introduces a maximum length scale for thermally unstable perturbations of about 1 pc.

It also introduces an apparent paradox – in order to cool out, perturbations must be co-moving and yet the emission lines presumed to be their descendants have observed velocity widths of several hundred km s^{-1}. Since cooling flows are presumed to be nearly hydrostatic, these velocities are relative to a high pressure background so that severe survivability problems are created as a result of various shear instabilities. The parameter space (in the mass-temperature plane) of Jeans-stable clouds that can be stably accelerated is probably unrealistically small (Loewenstein and Fabian 1989). We have therefore suggested that clouds are born co-moving in a turbulent ICM – the allowed parameter space can now be opened up to a more acceptable range. Large-scale motions can be driven in the central parts of cooling flows by a number of mechanisms including the motion of the central and other galaxies, and the dissipation of advected, focussed rotational and magnetic energy. In addition to the velocity width paradox, two other paradoxes (Heckman *et al.* 1989) can be solved if the ICM is turbulent. Firstly, the heating source for the emission line regions has always been puzzling – line luminosities are extremely high for a given (optical or radio) galaxy luminosity compared to those in non-cooling flow galaxies, therefore a mechanism peculiar to cooling flows must be at work. However most, if not all, previously suggested heating mechanisms either fail to provide enough ionization or give the wrong line ratios, or both. The kinetic energy in the turbulence provides a natural energy source if it can be efficiently converted to cloud heat – we suggest this can be done via magneto-hydrodynamic waves through plasma slip. Secondly, while the x-ray observations indicate extended mass deposition, the optical line emission is more centrally concentrated. Since many of the turbulence-inducing mechanisms are strongest in the central regions of the ICM, so is the method of heating. In other words material is dropping out everywhere but only being lit up in the center.

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