ARE COOLING FLOWS GOVERNING E-GALAXY EVOLUTION?

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Gas accretion of intra cluster gas into the potential well of giant elliptical or cD galaxies can provide the material for both nuclear non–thermal activity and continuous, probably low mass, star formation (Fabian *et al.* 1982, Valentijn and Bijleveld 1983). In a few dozen cases it has been observed in the nearby universe that the hydrostatic equilibrium of X-ray emitting gaseous atmospheres around cD galaxies is disturbed by the thermal bremsstrahlung cooling in the central high density area, leading to an inflow of gas into the centrally located gE or cD galaxy ("cooling flows", Jones and Forman 1984). This thermal instability is different from those studied in models of early galaxy formation (Gunn and Gott 1972, Rees and Ostriker 1972) only because of the assumed self–gravitation of the collapsing gas in the galaxy formation scenarios. If however, during early galaxy formation the collapsing gas is accreted by a pre–existing dark potential well, then the processes of early galaxy formation and the observed present epoch cooling flows are likely to be intimately related to each other. The cooling accretion flows could then lead to the original formation of the visible object, and subsequently govern its evolution through the fuelling of star formation and nuclear non–thermal activity.

INPUT PARAMETERS

The velocity dispersions, σ, in the central (<10 kpc) regions of cD's (Tonry 1985) suggest a stellar mass profile $M_*(< R) = \epsilon\, 2\, 10^{10}\, R_{kpc}\, \sigma^2_{300\, km\, sec^{-1}}\, (M_\odot)$, with ϵ a factor $\sim$ 5 representing the softness of the potential well. Dressler's (1979) measurements of the A2029 cD and the analysis of the confinement of X-ray haloes around cD galaxies, however, suggest a total (stellar + dark matter) mass profile $M_{*+d}(< R) = \epsilon\, 17\, 10^{10}\, R_{kpc}\, T_{3\, 10^7 K}\, (M_\odot)$. The dark component thus suggested has $M_{*+d}/M_* = 8$ and a scale size of $\sim 250\, kpc$. We assume that this dark component is pre-existent at $z > 6$ and that it will dominate the potential well throughout the galaxy formation/evolution epochs without evolving significantly itself. The central gas densities in the atmospheres of cD galaxies are observed to be about a factor 100 higher than that of the overall intra cluster gas, which in turn is supposed to accrete its contents from the supercluster pervading medium with an average enhancement of a factor 10 in density (Gunn and Gott, 1972). In a first order approach we can thus couple the central gas density in a cD type potential to that of the supercluster pervading gas by simply taking $\rho_{cen} = 1000 \rho_{sc}$. Radio observations of head tails in

T. de Zeeuw (ed.), Structure and Dynamics of Elliptical Galaxies, 433–434.

the Coma and the Hercules superclusters indicate $\rho_{sc} = 4\,10^{-6}\,cm^{-3}$, which is low enough to follow the Hubble flow. Thus we can parametrize the supercluster gas evolution as $\rho_{sc} = 2\,10^{-6}\,(1+z)^3\,cm^{-3}$ and $T_{sc} = 5\,10^6\,(1+z)^2 K$.

RESULTS

In order to start the accretion (and thus the galaxy formation) process, the temperature of the surrounding gas should be low enough to be bound by the dark component. Using the input parameters the required mass to initiate binding and form a gaseous halo is $M_{req}(< R) = \epsilon\ 1.5\,10^{10}\,R_{kpc}\,(1+z)^2\,(M_\odot)$. When comparing with M_{*+d} this shows that the heaviest systems will start halo formation at z=3.9, while systems with a present halo temperature of $3\,10^7 K$ would start binding a halo at $z = 2.4$. Note, that this turn–on redshift is nowhere pre–programmed in the model since the dark component is assumed to exist from $z = 6$ onwards.

Using the input parameters, the bremsstrahlung cooling time in the centers of the gaseous haloes is $4.6\,10^9\,(1+z)^{-2}$ year. Thus, in all Friedmann cosmologies the cooling time is always short enough to switch on cooling flows immediately after the atmospheres have been formed at $z \leq 4$. However, for $z < 1$ the cooling time approaches or exceeds the object lifetime, especially in $\Omega \geq 1$ cosmologies. This implies that for $z < 1$ the rate of accretion flows becomes critically dependent on other parameters and as $z \rightarrow 0$ both the rate of occurrence of cooling flows and the mass inflow rate in lasting flows decreases. Thus, in an $\Omega = 1$ cosmology, the flows can start at $z < 4$ and will be able to fuel nuclear activity and star formation. At later epochs galaxies are expected to become less active, which seems in agreement with the observed evolution of nuclear activity and optical color indices. For $\Omega = 2$ the turn–on redshift is at $z \sim 3$ which seems not in agreement with the apparent turn–on epoch of quasars. For $\Omega = 0$ cosmologies the predicted effects of cooling flows are not consistent with the observed cosmological evolution, since the cooling times are then always much shorter than the object lifetimes.

The total mass inflow rate can be estimated by assuming total dissipation of energy of the accreted gas, *i.e.* the maximum the galaxy can eat. Over the *total* volume involved this is $\dot{M}_{tot} = 570\,M_d^2\,\rho_{sc}^o\,T_{sc}^{o\;-3/2}\,(M_\odot/year)$, with ρ_{sc}^o and T_{sc}^o the $z = 0$ values of ρ_{sc} and T_{sc}. There is no significant z–dependence in the *total* mass inflow rate and in a $\Omega = 1$ cosmology at most $\sim 6\,10^{12} M_\odot$ of gaseous material can be deposited into the galaxy. The *central* mass inflow rate can be evaluated from the z-evolution of the size of the cooling region and is $\dot{M}_{central} = 2.6\,(1+z)^5\,M_\odot/year$ and is a strong function of z. Both the cosmological enhancement factor of quasars and the evolution of the power of radio sources have been observed to follow a $(1+z)^5$ law, which appears to be consistent with a cooling accretion model as the source of their activity in a $\Omega = 1$, $H_0 = 50$ universe.

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