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MERGERS, COOLING FLOWS AND EVAPORATION

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1. Abstract

Mergers (the capture of cold gas, especially) can have a profound influence on the hot coronal gas of early-type galaxies and clusters, potentially inducing symptoms hitherto attributed to a cooling flow, if thermal conduction is operative in the coronal plasma. Heat can be conducted from the hot phase into the cold phase, simultanteously ionizing the cold gas to make optical filaments, while locally cooling the coronal gas to mimic a cooling-flow. If there is heat conduction, though, there is no standard cooling-flow since radiative losses are balanced by conduction and not mass deposition.

Amongst the strongest observational support for the existence of cooling-flows is the presence of intermediate temperature gas with X-ray emission-line strengths in agreement with cooling-flow models. Here, X-ray line strengths are calculated for this alternative model, in which mergers are responsible for the observed optical and X-ray properties.

Since gas around 10^4K is thermally stable, the cold cloud need not necessarily evaporate and hydrostatic solutions exist. Good agreement with the X-ray data is obtained. The relative strengths of intermediate temperature X-ray emission lines are in significantly *better* agreement with a simple conduction model than with published cooling-flow models. The good agreement of the conduction model with optical, infra-red and X-ray data indicates that significantly more theoretical effort into this type of solution would be profitable.

2. What can a merger do to pre-existing coronal gas?

Although optical emission filaments typically represent a trifling amount of mass, energetically they can be very important and can have radiated energy fluxes in excess of the X-ray excess. Sparks, Macchetto and Golombek (1989) favoured an accretion or merger origin for the optical emission filaments and dust-lane in NGC 4696 and showed that a conduction model, where the accreted cold gas is heated by the hot coronal plasma, works very well on energetic grounds. Sparks and Macchetto (1990) also showed that a conduction model correctly predicts optical line emission surface brightness *vs.* radius in M87. By contrast the cooling-flow model consistently fails to account for both the strength of optical line emission and the run of emission-line surface brightness with radius. Other reasons for inferring an accretion origin for cooler gas in general are reviewed by Macchetto and Sparks (1991).

If 10^4K is chosen as the cloud boundary, then clouds are highly radiative and do not need to evaporate. Models of static conduction interfaces can be constructed, with a wide range of conductive heat flux, q_0, across the inner boundary. The solution to the static, plane-parallel, isobaric heat-flow problem is:

$$q^2 = q_0^2 + 2\alpha g(y) \qquad (1)$$

where $y = (T/10^7\mathrm{K})^{7/2}$, $g(y) = \int_{y_0}^{y} \Lambda_{23} dy'/y'^{2/7}$, a dimensionless function derived from the cooling function, Λ, q is the normalized heat flux, and $\alpha \propto n_0^2 T_0^2$. The solution expressed in this way contains the information needed to confront observations. It is a 'phase-space' solution with temperature gradient expressed as a function of temperature and changes in q indicative of radiative losses. The total emission from the cloud is the direct conductive heat input plus photons from the interface that travel inwards.

Using John Raymond's optically thin hot plasma emission code, this solution was used to calculate X–ray line fluxes for the example of M87, with parameters for the models obtained from optical observations of the filaments and X–ray observations of the corona. The resultant line ratios are given in the table, the conduction models representing extremes of entirely radiative and entirely conductive powering of the filaments. Observations are from Canizares *et al.* (1982) and the cooling-flow model from Stewart *et al.* (1984). Clearly the conduction models provide a statistically better fit. The absolute levels are also in good agreement with observation.

Table 1: Observed and Model X–Ray Line Ratios for M87

Line	Observed	$q_0 = 0$	$q_0 = 60$	Saturated limit	Cooling flow
OVIII Lyα	16.3 ± 5.4	23.1	21.2	19.2	9.5
OVIII Lyβ	< 2.3	4.0	3.8	3.6	
Blend 1	5.4 ± 1.0	3.9	3.9	3.8	4.2
Blend 1.5	< 1.5	1.1	1.1	1.0	
Blend 2	5.1 ± 1.1	5.3	5.2	5.1	5.4
Blend 3	4.3 ± 1.1	3.7	3.8	3.8	4.6
Blend 4	2.5 ± 1.1	3.3	3.4	3.7	4.8
Blend 5	3.2 ± 0.6	3.6	3.8	3.9	5.7
Blend 6	2.0 ± 1.0	1.7	1.7	1.8	1.3
FeXVII	2.5 ± 1.1	4.0	3.6	3.0	0.8
Continuum	100.0	100.0	100.0	100.0	
Reduced χ^2		0.89	0.75	0.76	3.28

3. Summary

Simple theoretical models of thermal interaction between hot and cold gas phases have been explored. Standard evaporation concepts have been questioned and solutions derived in the hydrostatic case, see Sparks (1992) for details. Detailed comparison of a simple conduction theory using reasonable, observationally derived parameters, with observations of M87 gives good agreement with the intermediate temperature X–ray properties, better in fact than the published 'cooling-flow' analysis of this galaxy. Observational results at X–ray, optical and infra-red wavelengths are readily understood within the framework of this description, including the strengths and ratios of X–ray lines, the strength of optical line emission, the spatial distribution of optical line emission and the presence of dust and infra-red emission associated with the optical filaments. Hence, it is possible that incorporation of heat conduction may provide the key to understanding inter-relationships between the different gaseous phases that have been observed in different wavelength regimes. Rather than treating systems as self-contained 'closed-boxes', it may be necessary to consider the environment in much more detail.