Continuing formation of the central star cluster in M87

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The rising velocity dispersion of the stars in the neighbourhood of the central luminosity spike observed[1–3] in the elliptical radio galaxy M87 was originally considered to be evidence for the presence of a massive black hole[4] ($M \sim 5\times10^9 M_\odot$). A later spectrum[3] taken in good seeing, however, shows that most of the light in the spike is due to stars, which restricts any black hole model; the luminosity spike may be a star cluster formed from gas infalling from the outer regions of M87[5,6]. Our analysis[7] of Einstein Observatory X-ray data on M87 revealed a cooling inflow of gas occurring at the rate required to build such a cluster. We show here that the back-reaction on the flow of the nuclear luminosity is small unless M87 was much brighter in the past and we suggest that massive central star clusters may be common in the central galaxies in many clusters and, on a smaller scale, in many elliptical galaxies.

X-ray continuum[5,8] and emission line[5,9,10] measurements of the temperature of the gas in M87 have established the presence of a temperature gradient which implies that the gas is cooling and accreting onto the galaxy[11–14]. We have combined these spectral and imaging[15] data to determine in detail the gas temperature and density profiles and thence the mass flow rate, $\dot{M}$, at each radius[7]. $\dot{M}$ drops from 10 $M_\odot\,yr^{-1}$ beyond about 50 kpc to $\sim1\,M_\odot\,yr^{-1}$ at 750 pc, or 10 arc s, from the nucleus. At this inner radius, which is determined by the quality of the data, the gas temperature, T, is $\sim10^7$ K. It must fall steeply at some point within this region, liberating an X-ray luminosity $\sim5/2\,\dot{M}/\mu m_H\,kT$, where μm_H is the mean mass per particle. We have identified this luminosity with the 2–3 arc s extended X-ray source[16] that coincides with the central luminosity spike. Gas is thus cooling and collapsing there at a rate of $\sim1\,M_\odot\,yr^{-1}$ and we presume that most of it forms stars. Up to $\sim10^{10}\,M_\odot$ is added over the age of the galaxy if the flow is steady. The high pressure in a cooling flow ($\sim10^6\,cm^{-3}$ K) leads to the formation of low mass stars[17,18] and we therefore expect the star cluster so formed to have a large ratio of mass to luminosity ($M/L > 10$). The optical colours[1] are consistent with the models of Sarazin and O'Connell[18].

The optical jet in M87 is evidence for activity in the nucleus and we therefore consider the possible influence of nuclear luminosity on the cooling flow. The flow itself would provide sufficient matter to power even a bright quasar if it were accreted by a compact object. The ionization equilibrium of gas in a cooling flow was calculated numerically by iterating the effects of photo-absorption and collisional ionization due to X-rays from the gas as well as from a nuclear X-ray source ΔL. The important bound–bound, bound–free and free–free radiative processes above 10^6 K of H, C, N, O, S, Si and Fe were included in the calculations. The density and temperature of successive radial shells of gas were interpolated from our solution[7] and extrapolated into the centre assuming constant pressure and $\dot{M}$. The results below are quoted for a radius of 190 pc, which is within the core of M87.

Departures from collisional equilibrium alone are small (less than a factor of 2) for the dominant ions of C, N, O and Fe provided that the $\Delta L_{41} < 10$, where $\Delta L = \Delta L_{41}\times10^{41}\,erg\,s^{-1}$ in the 0.5–4.5 keV range (an energy index of 0.75 was used). Radiation pressure is negligible in any reasonable distribution of mass in the core of M87 provided that $\Delta L_{41} < 10^5$. The local heating rate due to photoabsorption and to Compton interactions is found to exceed the local cooling rate in our calculations when $\Delta L_{41} > 10^2$. The cooling flow should be strongly disrupted above that luminosity. The observations[17] indicate $\Delta L_{41} < 4$, which means that the core of M87 must brighten considerably before the cooling flow is stopped. (Increasing $\dot{M}$ does, of course, increase the limits on ΔL.) The smooth X-ray surface brightness profile is observational evidence that the flow has lasted for times comparable with a typical cooling time of $\lesssim10^9$ yr.

Cooling flows are relatively common in clusters surrounding a single cD galaxy[19,20] and we may expect that some of the inferred 5–500 $M_\odot\,yr^{-1}$ of accreting gas forms central star clusters in them. We have re-analysed the X-ray surface brightness profile[21] of NGC1275 in the Perseus cluster to determine $\dot{M}(r)$ within a reasonable gravitational potential. Once again, we find that $\dot{M}$ increases with radius, r, up to 400 $M_\odot\,yr^{-1}$ at 100 kpc and that $\sim40\,M_\odot\,yr^{-1}$ passes into the inner 10 kpc (our best resolution) of the galaxy. It appears that the stars form over a large range of radii, comparable with the extent of the optical filaments[22], and by analogy with M87, it is likely that NGC1275 contains a large star cluster in its core. Scaled-down versions of the flows in M87 and NGC1275 may occur in many elliptical galaxies[23] and could also take place in the bulges of spiral galaxies. The centre of M31 may possibly contain a cluster of low mass stars (ref. 24; but see 25). The evolution of the densest core of a large central star cluster may in turn be related to the nuclear activity seen in many galaxies. Gravitational accretion by any central mass takes place from a hot (10^6–10^7 K) medium.

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1. Young *et al.* *Astrophys. J.* **221,** 721–730 (1978).
2. de Vaucouleurs, G. & Nieto, J.-L. *Astrophys. J.* **230.** 697 (1979).
3. Dressler, A. *Astrophys. J. Lett.* **240,** L11–L16 (1980).
4. Sargent *et al.* *Astrophys. J.* **221,** 731–744 (1978).
5. Lea, S. M., Mushotzky, R. F. & Holt, S. S. *Astrophys. J.* **262,** 24–32 (1982).
6. Okazaki, A. T. & Inagaki, S. *Publs astr. Soc. Japan* (submitted).
7. Stewart, G. C., Canizares, C. R., Fabian, A. C. & Nulsen, P. E. J. *Astrophys. J.* (in the press).
8. Fabricant, D. & Gorenstein, P. *Astrophys. J.* **267,** 535–546 (1983).
9. Canizares *et al.* *Astrophys. J. Lett.* **234,** L33–L38 (1979).
10. Canizares, C. R., Clark, G. W., Jernigan, J. G. & Markert, T. H. *Astrophys. J. Lett.* **262,** L33–43 (1982).
11. Cowie, L. L. & Binney, J. *Astrophys. J.* **215,** 723–732 (1977).
12. Fabian, A. C. & Nulsen, P. E. J. *Mon. Not. R. astr. Soc.* **180,** 479–484 (1977).
13. Matthews, W. G. & Bregman, J. N. *Astrophys. J.* **224,** 308–319 (1978).
14. Binney, J. & Cowie, L. L. *Astrophys. J.* **247,** 464–472 (1981).
15. Fabricant, D., Lecar, M. & Gorenstein, P. *Astrophys. J.* **241,** 552–560 (1978).
16. Schreier, E. J., Gorenstein, P. & Feigelson, E. D. *Astrophys. J.* **261,** 42–50 (1982).
17. Fabian, A. C., Nulsen, P. E. J. & Canizares, C. R. *Mon. Not. R. astr. Soc.* **201,** 933–938 (1982).
18. Sarazin, C. L. & O'Connell, R. W. *Astrophys. J.* **268,** 552–560 (1983).
19. Stewart, G. C., Fabian, A. C., Jones, C. & Forman, W. *Astrophys. J.* (submitted).
20. Stewart, G. C., Canizares, C. R. & Fabian, A. C. *Astrophys. J.* **272,** 449–455 (1983).
21. Fabian, A. C., Hu, E. M., Cowie, L. L. & Grindlay, J. *Astrophys. J.* **248,** 47–54 (1981).
22. Lynds, R. *Astrophys. J. Lett.* **159,** L151–L154 (1970).
23. Nulsen *et al.* *Mon. Not. R. astr. Soc.* (in the press).
24. Faber, S. M. & French, H. B. *Astrophys. J.* **235,** 405–412 (1980).
25. Persson *et al.* *Astrophys. J.* **240,** 779 (1980).

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