Windows on Galaxies

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PROCEEDINGS

Windows on Galaxies

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The sixth workshop of the Advanced School of Astronomy examined at galaxies through all available wavelength windows. Over the last twenty years, new wavelength windows have been opened in astronomy which have created many new possibilities for the observation of the properties of galaxies. The outcome of the meeting clearly stated that the approach towards the study of galaxies should be *panchromatic*.
Each window, from radio to gamma-rays, shows different components, and a synthesis of this knowledge presents astronomers with a comprehensive physical image of these astronomical systems: star formation, evolution of galaxies, molecular contents, gas flows, interstellar matter and properties of galaxies in the several wavelength fields are discussed in this volume.

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PROCEEDINGS OF THE SIXTH WORKSHOP OF THE
ADVANCED SCHOOL OF ASTRONOMY OF THE
ETTORE MAJORANA CENTRE FOR SCIENTIFIC CULTURE,
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THE INFLUENCE OF CENTRAL STELLAR DENSITY AND EXTERNAL PRESSURE ON GAS FLOWS IN ELLIPTICALS

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In a recent paper (D'Ercole *et al.* 1989) we have presented a set of hydrodynamical models describing the evolution of the X-ray gas in elliptical galaxies. As usual, the gas is shed by the evolving stars at a rate $\alpha_*(t)$ and heated to X-ray temperatures ($T \sim 10^7$ K) by type I supernovae occurring at the rate $R_{\rm SN}(t)$. Unlike previous time dependent models (Loewenstein and Mathews 1987), we assume that $R_{\rm SN}$ decreases with time slightly faster than α_*; in this way the global supernova heating – hereafter SN luminosity $L_{\rm SN}$ – is initially sufficient to extract from the galaxy the gas lost by the stars, a supersonic wind is established which slowly evolves into a subsonic outflow. Later, an inflow can eventually be established, similar to that of ordinary cooling-flow models (e.g. Sarazin and White 1988). Contrary to the cooling flow approximation, this kind of models permits to account for the large scatter in X-ray luminosity $L_{\rm X}$ for given optical luminosity $L_{\rm B}$, as well as to avoid an excessive concentration of matter in the center of the galaxy (D'Ercole *et al.* 1989; Ciotti *et al.* 1989; Renzini, this volume). Here we present additional models addressing two specific questions: 1) the effects of the density distribution near the center of the model galaxies, and 2) the effects of the external pressure due to the intracluster gas.

In order to investigate the effects on the flows due to different stellar distributions, we constructed two model galaxies, the "King Model" (KM) and the "de Vaucouleurs Model" (dVM); both these models have $L_{\rm B} = 5 \times 10^{10}\ L_\odot$ and a ratio of dark matter halo to stars $R = 9$. A complete discussion about the construction of the model galaxies is given elsewhere (Ciotti *et al.* 1989); here we want to stress that the KM and the dVM are "dynamically" equivalent, i.e. they have the same $L_{\rm SN}$ and the same $L^-_{\rm grav}$, which is the power required to steadily extract from the galaxy the gas lost by the stars. By no means these two galaxies are observationally equivalent, differing in central velocity dispersion, effective radius, and, especially,

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Figure 1. The X-ray luminosity evolution of King and de Vaucouleurs model galaxies is shown by the solid lines labelled 1 and 2ab respectively. Lines 2a and 2b refer to a core radius of respectively 100 and 200 pc in the de Vaucouleurs density profile. $L_{\rm SN}$ *and* $L^{-}_{\rm grav}$ *are given respectively by the dotted and dashed lines.*

in central density. Indeed, as it is well known the dVM is highly peaked at the center, and a truncation is required to avoid an unphysical central singularity. We have then truncated at either 100 or 200 pc from the center, and inside this radius a constant stellar density has been assumed. In practice, this was obtained by alternatively placing the first mesh of the grid at the mentioned distances. For both models we assumed $R_{\rm SN} \propto t^{-1.5}$ and a present value of $R_{\rm SN}$ a factor 2/3 lower than that given by Tammann (1982). Fig. 1 shows the evolution of the X-ray luminosities of the models together with $L_{\rm SN}$ and $L^{-}_{\rm grav}$. We note that the overall evolution of $L_{\rm X}$ is very similar in both models. The main qualitative difference

Figure 2. The evolution of the mass of gas lost by the galaxy (dashed lines), accreted onto the center (solid), and instantaneously present inside the galaxy (dotted) for the King and the equivalent *de Vaucouleurs model.*

Figure 3. The evolution of the X-ray luminosities for a $R = 9$ de Vaucouleurs model with an external pressure $P_{\rm ext} = 2 \times 10^3$ cm^{-3} K (1a) is compared to that of a model without external pressure (2). The effect of reducing the dark to bright matter ratio R to 4.5 (with the the same $P_{\rm ext} = 2 \times 10^3$ cm^{-3} K) is also shown (1b). The evolution of the power required to steadly extract the gas from the galaxy ($L^{-}_{\rm grav}$) is shown for the $R = 9$ case.

between the KM and the dVM consists in a different behavior of the fluid velocity near the center. In the KM the velocity is everywhere positive during the outflow phase, while the stagnation radius moves quickly outward ($r_s \sim 10$ kpc) at the transition to the inflow phase. On the contrary, in the dVM the core and the outer regions of the galaxy appear to be less tightly coupled: near the center a *mini-inflow* is present since the beginning, even when the rest of the galaxy is still supporting a supersonic wind. This is due to the very high central star density in the dVM: in the central region the density of the gas lost by the stars is high enough for the whole local SN heating to be efficiently radiated away.

Fig. 1 also shows the $L_{\rm X}$ evolution of the dVM truncated at $r = 200$ pc, which therefore has a lower central density. In this case the mini-inflow is less extended, the overall outflow phase has a somewhat longer duration, and the transition to the major inflow phase is delayed. This difference indicates that even the central fine structure of the galaxy can have an influence on the evolution of the global flow, a point subject to potential observational tests. The difference between KM and dVM galaxies is reflected in the amount of gas which is collected at the center during the gas flows. Fig. 2 shows that in the KM galaxy cooled material starts to accumulate only following the transition to the inflow phase at $t = 6$ Gyr, while a small amount of material soon starts to accumulate at the center of the dVM galaxy. This corresponds to the early mini-inflow phase, while the transition to the major inflow phase takes place at $t = 10$ Gyr.

The previous results are obtained for model galaxies which are assumed to be isolated, in an originally empty space. In reality, galaxies interact with the intracluster gas, thus experiencing either confinement or ram-pressure stripping. In our one-dimensional treatment, we modeled this situation in the simplest possible

way: as a pressure exerted on the galaxy by an initially hydrostatic atmosphere surrounding the galaxy itself.

The results shown in Fig. 3 refer to a de Vaucouleurs model with the same L_B but a lower L^-_{grav} with respect to the previous dVM. This was achieved by reducing the central velocity dispersion. As a consequence this model is still supporting a wind after 15 Gyr. Now, by applying an external pressure $P_{ext} = 2 \times 10^3$ cm^{-3} K an inflow is induced at $t = 6$ Gyr from the beginning. Moreover, by halving the dark matter content of the model one recovers a configuration which is still in the outflow phase at $t = 15$ Gyr, in spite of the confining pressure. It is therefore worth noting that such a pressure does not necessarily *suffocate* the outflow phase, that can be the prevalent phase among X-ray ellipticals (D'Ercole *et al.* 1989).

In conclusion, our numerical experiments indicate that both the environment, and the central fine structure of the galaxies can add further varieties to the behavior of gas flows in elliptical galaxies, and then to their X-ray properties.

References

Ciotti, L., D'Ercole, A., Pellegrini, S., and Renzini, A. 1989, in preparation.

D'Ercole, A., Renzini, A., Ciotti, L., and Pellegrini, S. 1989, *Ap. J. Lett.*, **341**, L9.

Loewenstein, M., and Mathews, W.G. 1987, *Ap. J.* **319**, 614.

Sarazin, C.L., and White, R.E. 1988, *Ap. J.*, **331**, 102.

Tammann, G. 1982, in *Supernovae: A Survey of Current Research*, ed. M. Rees and R. Stoneham (Dordrecht: Reidel), p. 371.

DISCUSSION

Hensler: (i) What is your initial condition for the density and to what amount does it predetermine your results? (ii) The differences of your results depending on grid spacing, especially in the case of large gradients of the potential might reveal that your numerical code is too diffusive. Did you perform tests with different grid spacings and/or apply even smaller intervals of the mesh points?

D'Ercole: The initial gas density is supposed to be zero. In other words, like in many other models (e.g. Larson, Arimoto, etc.), we assume that an early wind is established by type II supernovae, but we do not model this early phase. We believe that our results are not very sensitive to this initial condition, unless the gas density in the galaxy was always very high. Note that initially in our models $L_{SN} \gg L^-_{grav}$. About the second question, of course we did check for the results to be independent of the adopted grid spacing, in particular for the KM galaxies! But, as you know, no core radius is present in a pure $r^{1/4}$-law, and the results do indeed depend on where we decide to truncate it. But this corresponds to different physical (not just numerical) conditions, i.e. to galaxies with different central density.