Constraining feedback in galaxy formation: using galaxy and AGN surveys to shed light on "gastrophysics"

Pierluigi Monaco

Dipartimento di Astronomia and INAF-Osservatorio Astronomico di Trieste, via Tiepolo 11, 34143 Trieste

Abstract. We present some results of the new MORGANA model for the rise of galaxies and active nuclei, and show that the improved physical motivation of the description of star formation and feedback allows to get hints on the physical processes at play. We propose that the high level of turbulence in star-forming bulges is at the base of the observed downsizing of AGNs. In this framework it is also possible to reproduce the recently obtained evidence that most low-redshift accretion is powered by relatively massive, slowly accreting black holes. Besides, we notice that many galaxy formation models (including MORGANA) fail to reproduce a basic observable, namely the number density of $10^{11} \, M_\odot$ galaxies at $z \sim 1$, as traced by the GOODS-MUSIC sample. This points to a possibly missing ingredient in the modeling of stellar feedback.

1. Introduction

Understanding the properties of galaxy and AGN populations is one of the major challenges of modern cosmology. However, our poor understanding of the astrophysical processes that drive the formation of stars in galaxies has forced cosmologists to use simple phenomenological recipes to describe these processes. This is true both for semi-analytic codes and N-body simulations, for which star formation and feedback are "sub-grid physics". As a consequence, once agreement between model predictions and data is achieved, it is not straightforward to get hints on the physical processes that have shaped galaxies.

Besides, more and more information is being gathered on how feedback from newly formed stars at high redshift regulates star formation by observing single galaxies or their surrounding intergalactic medium (see Steidel, these proceedings). Most importantly, IFU observations of high-redshift galaxies (Genzel et al. 2006; Swinbank, these proceedings) are revealing unexpected details that give important and new clues on the processes at play.

To bridge these sets of data we need a galaxy formation model based on a more realistic and sophisticated description of feedback and able to produce predictions for large galaxy datasets. To this aim we have developed the galaxy formation code MORGANA (MOdel for the Rise of Galaxies aNd Active nuclei).

2. Kinetic feedback in star-forming bulges

The MORGANA code is described in full detail in Monaco, Fontanot & Taffoni (2006). We show here an example of its ability to obtain insight on stellar feed-
back by comparing model predictions on the evolution of the AGN population to observational data.

Feedback from star formation is implemented using the results of the multiphase model of Monaco (2004). According to this model, the way feedback works depends sensitively on the surface density and geometry of the system. In thin and moderately dense systems like spiral discs, the superbubbles originated by multiple SN explosions blow out of the system very soon, thus injecting most of their thermal and kinetic energy to the external halo, while in denser and/or thicker systems like star-forming spheroids, the energy gets trapped in the interstellar medium. A consequence of this is a higher level of turbulence is expected in the cold gas of a star-forming spheroid. Assuming that the energy injected by SNe is balanced by the loss due to the decay of turbulence, the velocity dispersion of cold clouds $\sigma_{\text{cold}}$ should scale as:

$$\sigma_{\text{cold}} = \sigma_0 \left( \frac{t_s}{1 \text{ Gyr}} \right)^{-1/3} \text{ km s}^{-1}$$

(1)

The increase of turbulence in star-forming galaxies has been measured, for instance, by Dib, Bell & Burkert (2006). Moreover, star-forming discs at high redshift are observed to be denser and with a much higher degree of turbulence (Genzel et al. 2006). A high level of turbulence increases the probability that some clouds have high enough kinetic energy to be ejected out of the galaxy. As a consequence, gas will be easily evacuated from small, gas-rich bulges.
In Fontanot et al. (2006b) we show that kinetic feedback is a very good candidate to be the main physical cause of the observed downsizing of AGNs. The left panel of figure 1 shows the predicted number density of AGNs in bins of bolometric luminosity as a function of redshift; the lines show models with increasing values of $\sigma_0$ (equation 1). The effect of kinetic feedback is that of suppressing accretion onto black holes (by ejecting gas out of the galaxy) in small, gas-rich bulges at high redshift, thus moving the peak of low level activity to lower redshift, while the brighter quasars, associated to more massive bulges, are hardly influenced. This also implies that the low-level activity that gives rise to the bulk of the hard X-ray background is due to relatively large black holes hosted in middle-sized bulges. This prediction is indeed in line with the recent findings of Ballo et al. (2006) who, analyzing a sample of X-ray active galaxies at $0.4 < z < 1$ in the GOODS fields, computed bolometric luminosities from optical (nuclear) and X-ray data, and inferred black hole masses from bulge masses. The agreement between model predictions and data, shown in figure 1, gives support to this scenario. However, a closer look to the figure reveals that the agreement gets worse when the smaller black holes are concerned. Is there a problem with small bulges/black holes?

3. Something missing?

Despite the deep differences in the implementation, several galaxy formation models are now giving consistent results. It is then very interesting to examine those cases where the results are consistently discrepant with observations. One result in this sense has recently been obtained with the GOODS-MUSIC sample (Grazian et al. 2006), which exploits the imaging performed with HST/ACS in the optical, VLT in the U and NIR and Spitzer/IRAC in the MIR to give robust estimates of photometric redshifts (trained on a large basis of available spectroscopic redshifts) and stellar masses for a large sample of galaxies with $K_s < 23.5$. Figure 2, left panel, shows the stellar mass function of Fontana et al. (2006), compared to morgana and to the models of Bower et al. (2006), Menci et al. (2006) and the N-body+hydro codes of Nagamine et al. (2005a,b). While the build-up of massive galaxies is roughly followed, all models consistently overpredict at $z \sim 1$ the number of galaxies with stellar masses $\sim 10^{10} M_\odot$.

More than a simple disagreement by a modest factor of two, this discrepancy points to a significantly different evolution of the stellar mass function in the reality and in the model: the real stellar mass function evolves first in the low-mass tail, while, as shown in the right panel of figure 2, the model mass function is remarkably constant in the same mass range. If we now define “downsizing” as the tendency of smaller galaxies to increase significantly in number at low redshift, at variance with the relatively stable number density of the more massive galaxies, then this discrepancy points to an insufficient degree of downsizing in the models.

MORGANA has been written in order to easily introduce new physical processes. We have exploited this feature to insert many recipes to suppress the number of such objects, without success. As AGN feedback is unlikely to be in play in these small galaxies, which were shown above to host slowly accreting black holes, this discrepancy strongly hints that there is some form of feedback
that we still do not understand. A deeper study of “gastrophysics” is needed to make sense of this basic observation.

Acknowledgments. This work has been developed in collaboration with Fabio Fontanot, Giuliano Taffoni, Stefano Cristiani, Paolo Tozzi, Laura Silva, Lucia Ballo, Andrea Grazian, Adriano Fontana and the GOODS teams of Trieste and Roma.

References

Ballo, L., Cristiani, S., Fasano, G., et al., 2006, submitted to ApJ
Barger, A.J., Cowie, L.L., Mushotzky, R.F., Yang, Y., Wang, W.-H., Steffen, A.T., Capak, P., 2005, AJ, 129, 578
Bower, R.C., Benson, A.J., Malbon, R., et al. 2006, MNRAS, 370, 645
Dib, S., Bell, E., Burkert, A., 2006, ApJ, 638, 797
Fan, X., Strauss, M.A., Schneider, D.P., et al. 2003, AJ, 125, 1649
Fontana, A., Salimbeni, S., Grazian, A., et al., 2006, A&A, in press (astro-ph/0609068)
Fontanot, F., Cristiani, S., Monaco, P. et al., 2006a, A&A, in press (astro-ph/0608664)
Fontanot, F., Monaco, P., Cristiani, S., Tozzi, P., 2006b, MNRAS, in press
Genzel, R., Tacconi, L., Eisenhauer, F., et al., 2006, Nature, 442, 786
Grazian, A., Fontana, A., de Santis, C., et al., 2006, A&A, 449, 951
La Franca, F., Fiore, F., Comastri, A., et al., 2005, ApJ, 635, 864
Menci, N., Fontana, A., Giallongo, E., Grazian, A., Salimbeni, S. 2006, ApJ, 647, 753
Monaco, P., 2004, MNRAS, 352, 181
Monaco, P., Fontanot, F., Taffoni, G., 2006, MNRAS, accepted (astro-ph/0610805)
Nagamine K., Cen, R., Hernquist, L., Ostriker, J. P., Springel, V. 2005a, ApJ, 618, 23
Nagamine K., Cen, R., Hernquist, L., Ostriker, J. P., Springel, V. 2005b, ApJ, 627, 608
Ueda Y., Akiyama M., Ohta K., Miyaji T., 2003, ApJ, 598, 886