The Massive Nearby SBNGs: Young Galaxies in Formation

Roger Coziol  
Laboratório Nacional de Astrofísica, Itajubá, Brasil

Thierry Contini  
School of Physics & Astronomy, Tel-Aviv University, Israel

Emmanuel Davoust  
UMR 5572, Observatoire Midi-Pyrénées, Toulouse, France

Suzanne Considère  
UPRES-A 6091, Observatoire de Besançon, France

Abstract.  
We discuss the implications of the recent discovery that Starburst Nucleus Galaxies (SBNGs) have lower oxygen abundances than “normal galaxies” of the same morphological type. Our interpretation of this result is that SBNGs are young galaxies, still in the process of formation. We consider several alternatives, but none of them provides a viable explanation. This new result has important consequences for our understanding of galaxy evolution, as it confirms the scenario of hierarchical formation of galaxies, and explains recent observations of the Hubble Space Telescope.

1. Introduction

The current paradigm about starbursts is that they are sporadic events that can occur at any time in the evolution of a galaxy, generally triggered by galaxy interactions (Heckman 1997). One of the reasons for this assumption is probably that starbursts are often seen in gravitationally interacting galaxies, and this paradigm has been reinforced in the last decade by the discovery that ultraluminous infrared galaxies are generally violently interacting.

In a recent paper (Coziol et al. 1997a), we gathered published and unpublished data on several large samples of Starburst Nucleus Galaxies (SBNGs) to show that they have lower oxygen abundance than normal galaxies of the same morphological type, and that early-type SBNGs are even more deficient in oxygen than late-type ones.

The simplest interpretation of this result is that SBNGs are young galaxies, which are still in the process of formation. The fact that early-type galaxies are less abundant in oxygen than late-type ones can be readily understood in
the frame of the theory of hierarchical formation of galaxies. In this scenario of
galaxy evolution (Tinsley & Larson 1979; Struck-Marcell 1981), ellipticals and
bulges of spirals are formed by mergers of stellar and gaseous systems, while
disks form by the collapse of the gas left from the successive mergers.

2. Alternative interpretations of the low oxygen abundances

Is our interpretation of SBNGs as young galaxies inescapable, or are there viable
alternative explanations for the low values of the oxygen abundances measured
in SBNGs? We review here four possible hypotheses.

- The first alternative that comes to mind for explaining that a galaxy has an
  unusually low oxygen abundance is rejuvenation by accretion of unprocessed gas
during gravitational interaction with another galaxy. But most of the galaxies
in our samples are isolated (Coziol et al. 1995; Contini 1996), and so are most
HII galaxies (Telles & Terlevich 1995).

We have examined several samples of interacting galaxies to see if there is
a relation between interaction and oxygen abundance. If one removes all the
Markarian galaxies from the sample of interacting galaxies of Keel et al. (1985),
the remaining galaxies have solar abundances on the average. Therefore, in-
teractions do not necessarily imply low metallicities. The interacting galaxies
of Bushouse (1986) do have low abundances, but these galaxies are also IRAS
sources. They are thus probably of the SBNG type, because ~85% of the
SBNGs are IRAS sources (Coziol et al. 1995). This suggests that we should
distinguish two types of interacting galaxies at the present epoch, metal poor
ones, which are young galaxies still in formation (~1/4 of the SBNGs and HII
galaxies show signs of interaction), and metal rich ones, which are old and well
evolved galaxies.

In fact, we should expect to find few interacting galaxies among the SBNGs,
if the latter are the outcome of multiple mergers of small mass galaxies that took
place 2 or 3 Gyr ago. Obviously, the remnant of a merger must be a relatively
massive and isolated galaxy.

The unprocessed gas could also come from intergalactic space or a massive
halo. The presence of a bar is then required to provide the gravitational torque
for funneling the gas toward the center. But this would only work for part of
the sample, since not all our galaxies are barred. And this mechanism leads to
a paradox, since it seems to be less efficient in late-type galaxies, where bars
are more frequent. One would also have to explain why gas is accreted in some
galaxies (the SBNGs) and not in others (the normal ones).

- Another possibility is winds from massive stars and supernova explosions;
  they could have swept away the enriched gas formed in the nuclear regions of
SGNGs. One then expects the radial oxygen abundance gradients in SBNGs to
be flat, or very low. But recent high signal-to-noise spectroscopic observations
of 24 galaxies from the sample of Contini et al. (1998) reveal that the abundance
gradients in barred SBNGs are not unusual (Considère et al., in preparation).
Furthermore, De Young & Heckman (1994) find that gaseous outflows tend to
destroy low mass galaxies, but probably play no role in the evolution of massive
ones. Also, why would stellar winds be stronger in early-type galaxies (which
show lower abundances) than in late-type ones?
One could also try to explain our results by advocating a different source of ionization for the gas in the nuclear regions. Our estimates of the oxygen abundances rest on the assumption that the observed emission lines are produced by OB stars which excite the interstellar gas. If this assumption is incorrect, for example if the source of ionization of the gas is nonthermal, such as a hidden AGN or shock heating, then of course the lower abundances are not real. The only peculiar characteristic of our SBNGs is a high $[\text{N}\,\text{ii}]\lambda 6584/\text{H}\alpha$ ratio (see also Coziol et al. 1997b), which could indeed point to non-thermal processes. We have shown elsewhere (Coziol et al. 1997a; Contini et al. 1998) that this excess emission of nitrogen in our sample is not the sign of AGN activity. We believe that the relative excess of $[\text{N}\,\text{ii}]$ corresponds to an overabundance of nitrogen which is produced by the evolution of intermediate mass stars formed during a sequence of bursts over the last 2-3 Gyr (Carlos Reyes & Coziol, in preparation).

Finally, our abundance estimates could also be incorrect if dust removes atomic coolants from the gas phase. Calculations by Shields & Kennicutt (1995) indicate that dust can have an appreciable influence on the optical spectrum in environments with high (above solar) metallicity. The predicted line ratios of $[\text{N}\,\text{ii}]/\text{H}\alpha$ agree reasonably well with our high-abundance nuclei ($[\text{O}\,\text{iii}]/\text{H}\beta \leq 0.5$) and those near the limit with LINERs; but this is probably a coincidence, because the predicted ratio $[\text{S}\,\text{ii}]/\text{H}\alpha$ does not match our data (see Fig. 1 of Contini et al. 1998). A clear correlation between reddening and oxygen abundance in the sample of Markarian barred galaxies (Considère et al., in preparation) provides further evidence against this possibility which would predict the opposite correlation.

3. Consequences of our discovery

We believe that the low oxygen abundances of SBNGs imply that they are young galaxies, still in the process of formation. This result has deep implications for the models of galaxy formation and evolution, and may provide a significant contribution to our understanding of recent Hubble Space Telescope and other observations of galaxies at high ($z > 2$) and intermediate ($z \simeq 0.5-2$) redshifts. We review below some of the consequences of our result.

3.1. The hierarchical formation of galaxies

The theory that is compatible with all our observations is that of hierarchical formation of galaxies by Tinsley & Larson (1979), modified by Struck-Marcell (1981) to include the effect of gas accretion. This theory explains the luminosity-metallicity ($L-Z$) relation, and is the only one that predicts a difference in oxygen abundance between early- and late-type SBNGs.

It is already well known that ellipticals and dwarf spheroidals trace a $L-Z$ relation that spans 13 magnitudes in $M_B$ and a factor of 200 in abundances (Faber 1973; Brodie & Huchra 1991; Bender et al. 1993). Zaritsky et al. (1994) have shown that the spiral and irregular galaxies follow a similar relationship, which spans over 10 magnitudes in luminosity and a factor of over 100 in metallicity. They noted, however, that the $L-Z$ relation should be steeper for the giant spirals. They could not come up with a mechanism that could produce it.
Figure 1. The model of hierarchical formation of galaxies applied to the SBNGs. The solid line is the empirical $L$-$Z$ relation for the elliptical and dwarf spheroidal galaxies (Brodie & Huchra 1991). The dashed line corresponds to the Tinsley & Larson (1979) merger model. The dotted lines correspond to the Struck-Marcell (1981) accretion model after 3, 5, 7 and 9 mergers. A mass-luminosity ratio of $\sim 6$ was used (Faber & Gallagher 1979).

We find that the late-type SBNGs show the same behavior as the giant spirals in the $L$-$Z$ diagram (Fig. 1), and it therefore seems to us that the mechanism that explains the difference between the early- and late-type SBNGs should also explain the position of the giant spirals in the $L$-$Z$ diagram.

According to Tinsley & Larson (1979), the spheroidal bulges of spirals and S0 galaxies are built in the same way as ellipticals, by successive mergers of small masses of gas and stellar systems, each one producing a burst of star formation. After each generation of bursts, more stars of a given metallicity are created and the metallicities of the galaxies increase following a $L$ – $Z$ relation. In a slightly different scenario, a galaxy will acquire a disk if, after the violent merger phase producing the bulge, residual outlying gas or gas-rich small subsystems keep being accreted. Following Struck-Marcell (1981), accretion of more gas than stars will result in a steepening of the mass-luminosity relation, explaining the difference between early- and late-type galaxies. The results of applying Struck-Marcell’s models to the SBNGs are shown in Fig. 1.
3.2. The origin of SBNGs

The massive nuclear starbursts observed today occur in galaxies that merged at an intermediate redshift, i.e. more recently than normal galaxies. If this is the case, there should be a population of merging galaxies observable at intermediate redshifts. These galaxies should be small-mass, irregular, gas rich, and metal poor systems, probably similar to the nearby HII galaxies. This description is consistent with the recent observations of the Hubble Space Telescope which show a substantial increase in the proportion of galaxies with irregular morphology and high star formation rates at moderately large redshift (Madau 1998; Fioc & Rocca Volmerange 1998; Brinchmann et al. 1998; Lilly et al. 1998).

But why can galaxy formation occur so late in some cases? This is a question for cosmologists, but we can volunteer an explanation: that the rate of evolution is linked to the local, rather than global, density of matter in the Universe. According to this assumption, massive structures such as groups and clusters of galaxies should be more evolved than field galaxies from the point of view of stellar populations and metallicity.

References

Bender, R., Burstein, D., Faber, & S. 1992, ApJ, 399, 462
Brinchmann, J., Abraham, R., Schade D., et al. 1998, ApJ, in press (astro-ph/9712060)
Brodie, J.P. & Huchra, J.P. 1991, ApJ, 379, 157
Bushouse, H.A. 1986, AJ, 91, 255
Contini, T. 1996, Ph.D. Thesis, Université Paul Sabatier, Toulouse, France
Contini, T., Considère, S., & Davoust, E. 1998, A&AS, in press (astro-ph/9712024)
Coziol, R. 1996, A&A, 309, 345
Coziol, R., Barth, C.S., & Demers S. 1995, MNRAS, 276, 1245
Coziol, R., Contini, T., Davoust, E., & Considère, S. 1997a, ApJ, 481, L67
Coziol, R., Demers, S., Barneoud, R., & Peña, M. 1997b, AJ, 113, 1548
De Young, D.S. & Heckman, T.M. 1994, ApJ, 431, 598
Faber, S.M. 1973, ApJ, 170, 423
Faber, S.M. & Gallagher, J.S. 1979, ARAA, 17, 135
Fioc, M. & Rocca-Volmerange, B. 1998, MNRAS, submitted (astro-ph/9709064)
Heckman, T.M. 1997, Proceedings of the conference “Origins”, ed C. Woodward & J.M. Shull (astro-ph/9708263)
Keel, W.C., Kennicutt, R.C., Hummel, E., & van der Hulst, J.M. 1985, AJ, 90, 708
Lilly, S.J., Schade, D., Ellis, R.S., et al. 1998, (astro-ph/9712061)
Madau, P. 1998, in The Hubble Deep Field, ed. M. Livio, S.M. Fall, & P. Madau, STScI Symposium series (astro-ph/9709147)
Shields, J.C. & Kennicutt, R.C. 1995, ApJ, 454, 807
Struck-Marcell, C. 1981, MNRAS, 197, 487
Telles, E. & Terlevich, R. 1995, MNRAS, 275, 1
Tinsley, B.M. & Larson, R.B. 1979, MNRAS, 186, 503
Zaritsky, D., Kennicutt, R.C., & Huchra, J.P. 1994, ApJ, 420, 87