Young Giant Elliptical Galaxies: where are they?

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Abstract.

Recent work have raised the intriguing possibility that the activity seen in most active galactic nuclei (AGN) is powered solely by young stars and supernova remnants in a burst of star formation at the time when the metal rich core of the spheroid of a normal, albeit young galaxy, was formed. The predicted emitted multifrequency spectrum, line width, variability and luminosity function of the young cores of ellipticals, are indistiguishable from those observed in Quasars. Only a small fraction (~5 %) of the total mass of elliptical galaxies, the core mass, is needed to explain the observed luminosities and luminosity function of Quasars at $z \gtrsim 2.0$.

Key words: Young galaxies - Elliptical galaxies - Active Galactic Nuclei

1. Introduction

There are several lines of evidence suggesting that giant elliptical galaxies are among the oldest stellar systems: their colours and line strengths similar to those of galactic giants, the continuity of the colours and stellar absorption line strengths with those of galactic globular clusters and their high metallicity coupled with a very low content of cold gas and dust (Faber 1977). Recent work based on the extremely small scatter in the colour-magnitude or colour-diameter relations for the Coma and Virgo clusters (Bower *et al.* 1992), provides direct evidence that cluster ellipticals have probably completed star formation by redshift $z > 2$. If this is true, a first rank elliptical with $M = 5 \times 10^{12}\,M_\odot$forming in about $2Gyr$ will have an *average* star formation rate $2500\,M_\odot yr^{-1}$, thus reaching absolute magnitudes of -27 in the blue band (H_0=50 $\mathrm{km\,s^{-1}\,Mpc^{-1}}$, q_0=0.5 and Λ=0, are used throughout this paper). If there is a peak in the star formation rate as suggested by dissipative galaxy formation models (Larson 1974,Carlberg1984), the maximum luminosity could be much higher. A short peak in the star formation rate can be also triggered by tidal encounters or mergers. Thus, it is possible that during a short period, first rank ellipticals may have reached absolute magnitudes $\sim -28, -29$ comparable with that of the most luminous Quasars. A similar result is obtained by considering the luminosity in massive stars needed to produce by redshift 2 the metals we observe today in first rank ellipticals (Cowie 1988).

Where are these bright blue galaxies?

In this paper I explore the possibility that many (most?) of the high redshift blue emission line objects discovered in wide field optical surveys and classified as Quasars due to the presence of broad emission lines in their spectrum, are in fact young ellipticals forming their metal rich core.

2. The Starburst model for AGN

The possibility that a starburst can power the most extreme forms of activity that are seen in Quasars and luminous Seyfert nuclei has been proposed several times in the past (Shklovskii, 1960; Field, 1964; Mc Crea, 1976), but was abandoned because it failed to explain satisfactorily the observed variability of luminous Quasars, their

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radio emission, unresolved images, the presence of broad permitted and narrow forbidden emission lines and their intensity ratios.

More recently Terlevich and Melnick (1985; hereafter TM85) started a systematic study of Starburst in high metallicity environment. In this model (Terlevich *et al.* 1987), nuclear activity is the *direct* consequence of the evolution of a massive young cluster of coeval stars in the high metal abundance environment of the nuclear region of early type galaxies (Pagel and Edmunds 1981; Díaz *et al.* 1985).

The phenomenology of narrow line AGN (Seyfert 2 and LINERS) and its relation to nuclear starbursts has been analyzed by TM85 who further predicted an evolutionary sequence which follows the evolution of a coeval nuclear cluster. For luminous objects the nuclear emission line regions evolve from normal HII regions to type 2 Seyferts and later to LINERS with transitions after about 3 Myrs and 5 Myrs, respectively. The subsequent evolution of these young clusters into the supernova phase and the development of the broad line region (BLR), has been described by Terlevich *et al.* (1987) and Terlevich (1989,1990a,b). During this supernova or Quasar phase, most of the bolometric luminosity is emitted by the young stars, while the broad permitted emission lines and their variability are due to supernova (SN) and supernova remnant (SNR) activity (Terlevich and Melnick 1985, 1988; Terlevich 1989; Filippenko 1989;Terlevich 1990b; Terlevich *et al.* 1992).Heckman (1991) and Filippenko (1992) excellent reviews of the Starburst model for AGN provide also good discussions of some potential problems. Terlevich (1992) addressed some of the problems raised by Heckman (1991).

3. The evolution of nuclear star clusters

The early evolution of a massive metal rich star cluster presents four different phases. The appearance of the first extreme Wolf-Rayet or WARMERS (TM85) marks the beginning of the Seyfert phase and the end of the HII region phase. The explosion of the first SN of type Ib corresponds to the onset of non-thermal radio emission while the first explosions of type II SN lead to the formation of the BLR.

Phase 1. (From 0 to 3 Myr). During this phase the photoionization is dominated by hot main sequence stars and the nuclear spectrum is typical of a low excitation, high metallicity, HII region. Computations of the ionizing continuum and emission-line spectra are given by García Vargas and Díaz (1992).

Phase 2. (From 3 to 4 Myr). The most massive stars in the cluster ($M \geq 40\text{-}60\,M_\odot$) become extreme WC or WO Wolf-Rayet stars and reach the *warmer* phase.

A key aspect is that stellar mass loss rates increases with increasing metal abundance in massive stars. Thus, very massive stars formed in metal rich environments end their lives as bare C-O cores with effective teperatures reaching $T_{eff} \sim 2 \times 10^5$K and luminosities reaching 4×10^6 $L_\odot$. Models show that after 3 Myr, the ionizing continuum of a young cluster is nearly a power law of index $\alpha \sim -1.5$ (where $f_\nu \alpha \nu^\alpha$), with an exponential cutoff at about 30 Ryd (TM85, Cid Fernandez *et al.* 1992). The emission line spectrum of the ionized surrounding gas is that of type 2 Seyferts. Furthermore, the "blue featureless continuum" and the associated big UV bump observed in most Seyferts may be the reddened spectrum of the ionizing cluster (Terlevich 1990a, Cid Fernandez and Terlevich 1992). Strong support for this interpretation comes from the discovery that the strength of infrared CaII triplet absorption lines in Seyfert 2 nuclei with weak or absent optical stellar absortion lines, is as strong as, or stronger than, those in normal galactic nuclei, as is expected from a young cluster containing red supergiants (Terlevich *et al.* 1990).

Large amounts of dust are synthesized just before the Wolf-Rayet stage of the most massive stars, so we expect to see an extremely reddened high excitation Seyfert type 2 nucleus at this stage.

Phase 3. (From 4 to 8 Myr). The first SNIb with massive progenitors ($M \geq 40\, M_\odot$) appear in the cluster and with them copious amounts of non-thermal radio emission from the SNR. These SN are optically dim (due to the lack of an extended envelope to thermalize the energy) and probably very luminous in radio frequencies (Weiler and Sramek, 1988). During this phase, the ionization sources are main sequence hot stars, *warmers*, and SN; the emitted spectrum resembles that of a Seyfert 2 (or a LINER for the less luminous objects).

Due either to dynamical friction or initial conditions, the most massive stars in nearby young clusters and giant HII regions populate the inner core of the cluster (Terlevich 1987), while the less massive stars tend to live in a more extended region. The collective action of stellar winds and SN explosions from these very massive stars creates a hot cavity in the interstellar medium (ISM). This hot "superbubble" will expand along the steepest density gradient (along the poles in the case of a disk). Material flowing along this axis, "superwinds", will give rise to elongated, mildly collimated radio structures (Heckman, Armus and Miley 1990). The combined ejecta of several SN may in some cases reach the outer parts and shock the ISM at large distances from the nucleus. Ionizing radiation will also escape along this tunnel and photoionize the shocked ISM at large distances from the nuclei giving rise to optical filaments correlated in position with the radio ejecta. Ionization cones, such as those seen by Tadhunter and Tsvetanov (1989) and Pogge (1988a,b), should be relatively common in this phase.

Phase 4. (from 8 to 60 Myr). This is the type II SN phase. The remnants of the metal rich massive stars ($M \sim 8 - 25\ M_\odot$) are presumably very luminous at radio, IR, optical, UV and X-ray wavelengths because their kinetic energy is rapidly thermalized by dense circumstellar material around the metal rich progenitor red giant stars. These remnants *are* the BLR.

The BLR is fully developed during this phase and the optical spectrum is dominated by broad and variable permitted lines. Most of the ionization comes from the strong UV and X-ray emission from the high velocity SNR shocks. Variability is due to SN flashes, to cooling instabilities in the expanding SNR shells and to the luminosity curve of the remnants. Most of the initial dust is evaporated by the first few SN.

Recent observations show that the spectrum of at least some luminous SN exploding in HII regions have a striking resemblance to that of the BLR of Seyfert galaxies (Filippenko 1989) and, conversely, that the flares of some Seyfert galaxies have the luminosity, life-time and spectral signatures of type II SN (Terlevich and Melnick, 1988). The fundamental difference between "Seyfert-like" and normal

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type II SN can be understood if the former are associated with shocks that, after leaving the envelope of the star, expand into a region of ***high circumstellar gas densities.*** Theoretical computations of the evolution of SNR in dense environments show that after sweeping up a small amount of gas these remnants become radiative and deposit most of their energy in very short time scales thus reaching very high luminosities. Because of the large shock velocities, most of the energy is radiated in the extreme UV and X-ray region of the spectrum (*e.g.* Shull, 1980; Terlevich *et al.* 1992).

4. Properties of the young cores in elliptical galaxies

There is mounting observational evidence that large spheroid formation is more or less complete by z=2 to 2.5 (Cowie, 1988 and references therein). I will assume that giant elliptical galaxies formed their metal rich cores in a core crossing time at the epoch of formation of the large spheroids, $2 < z_{form} \lesssim 10$. The size of the core of bright elliptical galaxies with $M_B = -23$ is $r_{c,app} = 1000$ pc while an elliptical with luminosity L* has $r_{c,app} \sim 200$pc (Kormendy, 1987). The core contains 1/20 of the total mass of the elliptical galaxy and its crossing time is, even for the largest galaxies, less than 2.5×10^7 years. A typical L* elliptical has a core crossing time of about 1.4×10^6 years (Terlevich, 1992). This time scale is smaller than the life time of the most massive stars, thus, star formation can be synchronized over the whole core. Clusters of about this size, and decoupled either photometrically or kinematically, have recently been found in many nearby elliptical galaxies (Franx and Illingworth, 1988; Bender, 1988).

The luminosity function of the population of young cores will be that of present day old cores shifted to higher luminosities by the change in the M/L ratio of the stellar population and with a co-moving volume density weighted by the short life-time of the event. The luminosity function of elliptical galaxies (Tammann *et al.* , 1979) has a maximum value of about $2 \times 10^{-4} Mpc^{-3} mag^{-1}$ for low luminosity ellipticals and the absolute blue magnitude corresponding to L^* is M_B = -21.0. The reduction of the co-moving density associated with the short life-time of the young core can be estimated from the ratio of the age of the universe at z=2 (about 2.4×10^9 years) to the total lifetime of the burst at the end of the type II SN phase, 6×10^7 years. Thus for young cores the maximum density will be at $z = 2$, $(1/40) \times 2 \times 10^{-4} Mpc^{-3} mag^{-1} = 5 \times 10^{-6} Mpc^{-3} mag^{-1}$, very similar to the maximum density of Quasars at the same redshift (Boyle, 1991; Terlevich, 1992). The luminosity function of present day cores is that of present day ellipticals shifted to lower luminosities by the ratio of core luminosity to total galactic luminosity, $2.5 log(1/20) = 3.25$ mag. The typical L_B/M ratio for a young stellar cluster with type II SN activity is about 50 (Terlevich 1990).The present value of L_B/M for cores in a luminous elliptical is 1/20. Thus, the blue luminosity of young cores will be about 7.5 mag brighter than that of old ones. For a typical L^* elliptical, the young core will have $M_B = -25.2$ and $R_{eff} = 200$pc and, at a redshift of 2, its effective radius will be 0.05 arcsec with apparent blue magnitude, including K correction, of $B = 20.0$. Its density will be about $3 \times 10^{-6} Mpc^{-3} mag^{-1}$. For a bright elliptical, $M_B = -23$, the young core will have $M_B = -27.2$ and $R_{eff} =$

1000pc and, at a redshift of 2, its effective radius will be 0.25 arcsec with apparent blue magnitude, including K correction, of $B = 18.0$. Its density will be about $4 \times 10^{-8} Mpc^{-3} mag^{-1}$. The predicted parameters of young cores are in very good agreement with the observed ones for Quasars (Terlevich, 1992). The young cores of the brightest ellipticals will reach $M_B = -28.5$, similar to the most luminous Quasars.

5. Discussion

The possibility that the bulk of the stellar population we see today in the cores of elliptical galaxies was generated in a burst of star formation is supported by the short crossing time of the core. Also, dissipational galaxy formation models suggest that, at the end of the formation of a luminous elliptical, a short lived peak in the star formation occurs (Larson, 1974; Carlberg, 1984) in the central parts of the galaxy. This peak in the star formation rate should not be an exclusive property of dissipational models of galaxy formation. It can be generated in almost any galaxy formation scenario by the late infall of enriched gas into the central regions of the elliptical. There the metal rich gas can sit until star formation is triggered either by tidal interactions or by the generation of a bar instability when the gas density reaches some critical value (Efstathiou and Silk, 1983).

The predicted young core luminosity function is an excellent match to the observed luminosity function for Quasars in the redshift range from 2.0 to 2.9 (Boyle, 1991; Terlevich 1992; Terlevich and Boyle, in preparation). Thus, *the young cores of ellipticals containing only 5 % of the total galactic mass are capable of producing the luminosity of even the most luminous Quasars.* The upper limit on the size of the active region is compatible with their lack of resolution. The emitted multifrequecy spectrum is very similar to the average AGN spectrum (Terlevich 1990)

The suggestion is that perhaps most of the high redshift emission line objects found in optical surveys and classified as Quasars due to the presence of broad emission lines in their spectrum, are in fact young spheroids forming their metal rich core.

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