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Nuclear Activity and Supernova Occurrence

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Abstract. It is argued that the occurrence of nuclear activity and supernovae in E and S0 galaxies are correlated and a result of accretion of gas by the galaxy.

Key words: nuclear activity—extragalactic radio sources—supernovae

1. Introduction

We shall argue that there is a correlation between the occurrence of nuclear activity and supernovae (SN); both occur only in those E and S0 galaxies which accrete matter from outside and form stars. In the next section we review the arguments in favour of the hypothesis that SN I come from short-lived stars (Oemler & Tinsley 1979) and show that contrary to the general belief the colour observations of ellipticals do not rule out this hypothesis. It is our contention that a typical isolated E/S0 galaxy, which is gas-free and does not form stars will not produce SN. Indeed, we introduce the concept of a *supernovic* elliptical. An elliptical which can produce SN is called here supernovic (just as a nation which produced heroes is called a heroic nation). Of course some supernovic E/S0s may be more supernova-prone than the others, but a non-supernovic E/S0 galaxy will not produce a SN at all.

A supernovic elliptical may accrete gas from its own halo (*e.g.* M 86) or from the intergalactic or intracluster medium (N 1275 = Perseus A, M 87) or from a neighbouring galaxy (N 3226). Alternatively or simultaneously an elliptical may swallow gas clouds or gas-rich dwarf galaxies (N 1316 = Fornax A).

Nuclear activity of E/S0 galaxies is interpreted in terms of a central engine (*e.g.* a black hole) which uses gas as fuel and converts energy from a passive into an active form (*e.g.* Rees 1977). Now since a typical galaxy is gas free, a central engine in such a galaxy—if it existed—would lie idle for want of fuel. However if an E/S0 accretes gas from outside, in course of time this gas would find its way to the nuclear regions and give rise to nuclear activity (Shklovskiǐ 1963). Thus the presence of gas and dust, star formation, occurrence of SN, and nuclear activity in E/S0 galaxies are all interrelated and a consequence of accretion of gas by the galaxy.

2. Progenitors of SN I

The occurrence of SN I in E/S0 galaxies has been interpreted to mean that SN I progenitors are low-mass stars. In recent times this picture has come under severe strain. Oemler & Tinsley (1979) have argued, on the basis of SN I rates in I0 and spiral galaxies and other evidence, that SN I come from stars in the mass range 4–7 $M_\odot$. Recent theoretical work supports this view; the most plausible models for SN I are the carbon deflagration models, in which a star of mass $(6 \pm 2) < M/M_\odot < (8 \pm 2)$ loses its hydrogen envelope, by being in a binary or otherwise, and explodes as SN I (Nomoto 1981). This picture is consistent with the absence of a hot neutron star in the remnants of historical SN I, Tycho and Kepler, and with the recent estimates of pulsar and stellar birthrates (Kochhar 1981).

The fact that E/S0 galaxies have produced only SN I means that stars more massive than $7 M_\odot$ do not form in them. It seems that as one moves along the Hubble sequence and towards a decreasing bulge-to-disc ratio, the IMF becomes shallower. This has an interesting consequence. If very many massive stars form, the associated energetics will heat and disperse the interstellar gas with the result that the next phase of star formation would be delayed (Seiden & Gerola 1982). By the time the next phase of star formation takes place, the earlier stars would have completed their evolution, returning most of the gas back to the interstellar medium. Thus a shallow IMF will ensure a perennial availability of gas. On the other hand, if IMF is steep, all the available gas will be used up in the formation of long-lived stars.

If SN I come from short-lived stars, the E/S0 galaxies that produce SN should be bluer than the ones which do not. Sandage & Visvanathan (1978a, b) give corrected photoelectric colours for a sample of 354 unambiguous E/S0s out of which 12 have produced SN. For these 12 galaxies one obtains $\langle (u-V)_{0.5}^{\mathrm{KEM}} \rangle = 2.32 \pm 0.08$ which is not significantly different from the value 2.33 ± 0.09 for the whole sample. Before one jumps from this to the conclusion that the supernovic E/S0s are not bluer than the nonsupernovic ones, one must examine the various corrections that have gone into obtaining these numbers from the raw data.

Since an error of 10 per cent in the distance translates into an error of 0.5 mag in $(u-V)^{\mathrm{KEM}}$ colours through the colour–magnitude (C–M) relation, it is advisable to confine one's attention to a single cluster while comparing the supernovic and the nonsupernovic E/S0s. The well-studied Virgo I cluster of galaxies—usually referred to as the Virgo cluster—is a small, irregular, dynamically unevolved, spiral-rich cluster containing 205 Shapley–Ames galaxies of which 19 per cent are elliptical. It contains eight supernovic E/S0s making it an obvious choice for a study of the difference between the supernovic and nonsupernovic E/S0s. Six of the eight supernovic E/S0s are 0.06 ± 0.01 mag bluer than the general sample taken from Visvanathan & Sandage (1977). (See Fig. 1.) Kochhar & Prabhu (1984) point out that the colours of the E/S0s should be seen in the light of their metallicities. Fig. 2 shows a plot of Mg index versus absolute magnitude (Mg–M) for 54 E/S0s for which data are available in the literature. Significantly, all the supernovic E/S0 have higher line-strength than expected from the mean Mg–M relationship. (The only exception is the interacting dwarf elliptical N 3226.) In particular the supernovic Virgo galaxies N 4374, 4486 and 4621, which are on an average 0.027 mag bluer in $(u-V)$, have 0.019 mag excess line-strength. If their colours were to reflect this excess metallicity, these galaxies should have been 0.1 mag redder than expected from the mean C–M relation. In other words, these supernovic E/S0 are 0.13 mag bluer than they would have been if star formation had not occurred in them. Their excess metallicity may itself have resulted from such recurrent bursts of star formation.

Thus the spread in the C–M relation is not all intrinsic and is in part due to star

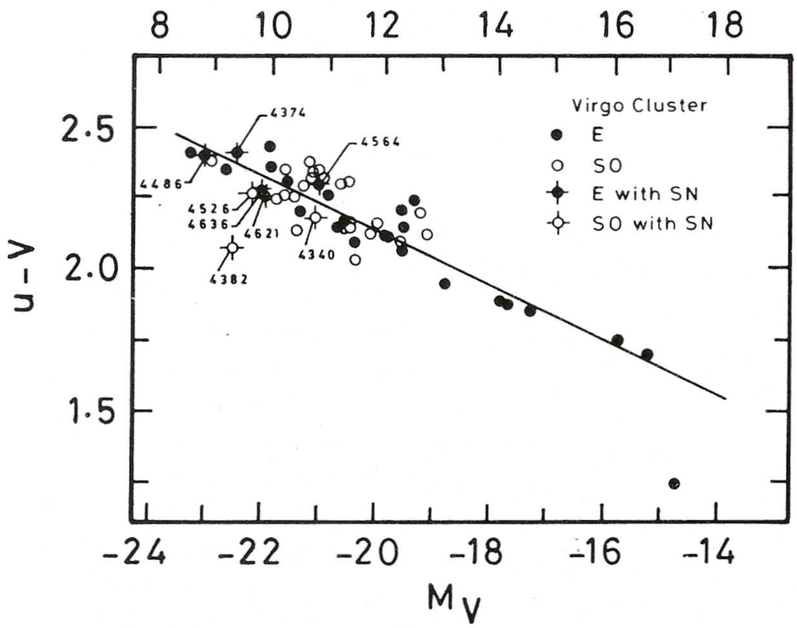

Figure 1. The colour–magnitude diagram of Virgo E/S0 galaxies. Supernovic ones are marked.

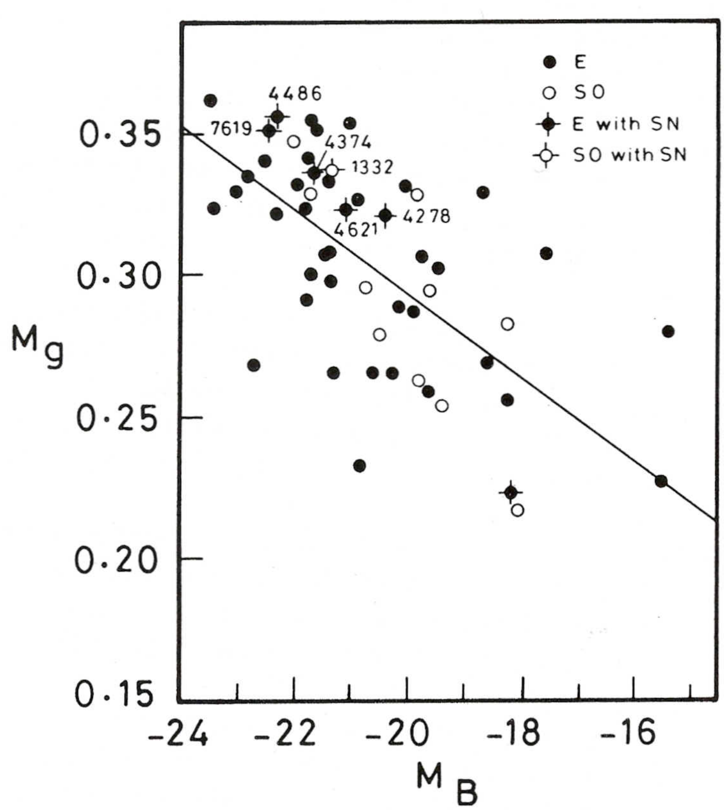

Figure 2. The Mg-index–absolute magnitude diagram for E/S0 galaxies. Supernovic ones are marked.

formation in some of the galaxies. However, the star formation is not so extensive as to make a galaxy bluer than the scatter. But these galaxies are metal-richer than normal.

3. Galactic ecology

If an elliptical accretes matter, it may show up as neutral hydrogen and/or dust. Hummel (1980) has convincingly shown that elliptical galaxies with detected H I are much more likely to contain nuclear emission-line regions and nuclear continuum radio emission than ellipticals without detected H I, suggesting that the accreted gas fuels the central source. Shostak *et al.* (1983) find that the H I detection rate in radio galaxies is consistent with the presence of thin H I discs of galactic dimensions in all radio galaxies. In the case of 8 radio ellipticals with dust lanes, radio axis is perpendicular to the dust lane (Kotanyi & Ekers 1979) again highlighting the connection between accretion and radio activity. Out of these 8 galaxies, N 1316 has had two SN and N 4374 one.

The suggestion that it is gas accreted by an E/S0 galaxy from outside which fuels the nuclear activity finds support from observations of radio spirals. Nuclear sources in barred spirals are on an average brighter than those in non-barred spirals, and nuclear sources in double galaxies are brighter than in isolated galaxies (Hummel 1980). Whereas in the case of paired galaxies the supply of gas to the central regions is ensured by tidal interaction, the centres of barred spirals receive their fuel supplies as a result of the interaction of the bar with the gas in the disc.

The environments of an E/S0 galaxy play the same role as the disc of a barred spiral, that is, they ensure the central regions of fuel supply. Thus an elliptical galaxy is more likely to be a radio source if it is in a Zwicky cluster, and is still more likely to be a radio source if it is in a group within a cluster (Dressel 1981).

The Virgo cluster shows a two-component X-ray spectrum; the cluster is permeated by a hot ($\sim 10^8$ K) intracluster gas in which are embedded galaxies with individual cool ($\sim 10^7$ K) atmospheres (Forman *et al.* 1981). The non-thermal activity in the central regions of N 4486 (M 87) is explained in terms of accretion from its massive halo (Mathews 1978). We hold this accretion responsible for the SN also (A similar case is that of the powerful X-ray and radio source N 1275 = Per A [Fabian & Nulsen 1977], which has also produced a SN). X-ray haloes have been detected around M 84 and M 86 (Forman *et al.* 1981). It is reasonable to suppose that other ellipticals in the Virgo cluster too would have similar haloes, confined by the hot intracluster gas (Fabian, Schwartz & Forman 1980). The presence of individual gas reservoirs around ellipticals from which they can accrete gas explains why Virgo ellipticals are predominantly supernovic and radio active.

The hot gas (10^8 K) in the compact, dynamically evolved, spiral-poor Coma cluster is associated with the cluster as a whole and not with any individual galaxy. It approximates an isothermal gas sphere and shows no sign of radiatively regulated accretion (Forman *et al.* 1981). There are indications that SN rate in Coma is about a factor of 3 lower than in Virgo (Barbon 1978).

Coma cluster is fairly uniform in galaxy type and shows a central maximum density with a symmetrical decrease towards the boundaries. If all galaxies were equally likely to produce SN, we should expect the supernovic ellipticals to have the same distribution as the galaxies in general. This, however, is not the case. All supernovic E/S0 in Coma are confined to a plane (Barbon 1978). Presumably, some gas in Coma has settled down in a disc and is accreted by the galaxies there, giving rise to supernovic activity. Of the seven SN in the central regions of Coma, two have occurred in I0 galaxies, four in E/S0 galaxies and only one in an Sb galaxy (Thomson 1981). At the centre of the cluster and the disc lies the giant elliptical radio galaxy N 4874 which has produced two SN.

Further support for the accretion hypothesis comes from Caldwell & Oemler (1981), who find that the spiral-rich outer regions of rich clusters of galaxies have higher SN rate in the E/S0 galaxies as compared to the spiral-poor and gas-poor central regions of such clusters. They also find that the E/S0 galaxies in the outer regions of rich clusters are bluer than the ones in the inner regions suggesting that recent star formation is more active in the E/S0 galaxies embedded in gas-rich outer regions of the rich clusters.

4. Conclusions

We have argued in favour of the assertion that all SN I come from short-lived stars. We have, however, suggested that a typical, isolated E/S0 galaxy will not produce SN. Only if an E/S0 galaxy accretes matter from outside and forms stars will it produce SN. Thus not all E/S0 galaxies are *supernovic.*

We have discussed some aspects of what may be termed *galactic ecology*, that is, the role of environment in determining the properties of an E/S0 galaxy. We have argued that occurrence of supernovae and nuclear activity in elliptical and lenticular galaxies are interrelated and a consequence of accretion of gas and resultant star formation.

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