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Serendipitous discovery of a tidal tail in NGC632[1]

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Nulla a che vedere con il vuoto angoscioso della pagina bianca, per la snervante attesa che una parola si accenda nell'oscurità del tuo cielo, come lo scoppio di una supernova.

Paolo Maurensig, Venere Lesa

Abstract. While searching for a light echo of the Ia SN1998es type in NGC632, we discovered a very faint tidal tail, which extends for at least 50 kpc from the galaxy nucleus. This finding, together with the presence of a strong nuclear starburst, the boxy shape of the isophotes and their twisting, strongly suggests that what we see in NGC632 is the result of a galaxy merger. NGC632 was previously classified as an S0, while the deep VLT imaging discussed in this paper shows very clearly the presence of spiral arms, on top of which rather blue knots appear to be projected. They are possible sites of star formation, probably triggered by the galaxy merger. Further observations needed to clarify the open questions are outlined.

Keywords. NGC632, starburst, tidal tails.

1. Introduction. In the last few years the study of light echoes in Supernovae (SNe) has become rather fashionable, since they provide a potential tool to perform a detailed tomography of the SN environment (see, for example, Sugerman & Crotts 2002) and, in turn, can provide important insights into the progenitor's nature, a matter which is still under debate.

Due to the typical number density of dust particles which are responsible for the light scattering, the echoes are expected to have an integrated

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brightness about ten magnitudes fainter than the SN at maximum. For this reason, a SN Ia in the Virgo cluster is supposed to produce, if any, an echo at a magnitude V~21.0. As a simple consequence, it is much easier to observe such a phenomenon in an Ia than in any other SN type, due to its high intrinsic luminosity. As a matter of fact, only four cases are known: the SNe Ia 1991T (Schmidt et al. 1992, Sparks et al. 1999) and 1998bu (Cappellaro et al. 2000), and the II SN1987A (Xu et al. 1994) and 1993J types (Sugerman & Crotts 2002). As expected, the light echo detections for the two core-collapse events occurred in nearby galaxies: LMC (d=50 Kpc) and M81 (d=3.6 Mpc), respectively.

While a dusty environment is expected to result from explosions arising in massive and short-lived progenitors, this is in principle not the case for the kind of stars which are commonly supposed to generate Ia events, i.e. old population and low mass stars. This is why the detection of substantial dust in the immediate surroundings of thermonuclear SNe, or at least in a fraction of them, would indicate a different scenario.

Actually, several authors have pointed out that the observed characteristics of Ia's, such as intrinsic luminosity, color, decline rate, expansion velocity and so on, appear to be related to the morphological type of the host galaxy (van den Bergh & Pazder 1992; Hamuy et al. 1996, 2000; Howell 2001). Since these objects represent a fundamental tool in Cosmology (see for instance Leibundgut 2000), it is clear that a full understanding of the underlying physics is mandatory in order to exclude possible biases in the determination of cosmological parameters like Ω and Λ. In this framework, disentangling between possible Ia sub-classes is a fundamental step.

In this respect, an important year in the SN history is 1991, when two extreme objects were discovered, i.e. SN1991T (Filippenko et al. 1992a) and SN1991bg (Filippenko et al 1992b). The former was an intrinsically blue, slow declining and spectroscopically peculiar event, while the latter was intrinsically red, fast declining and also showing some spectral peculiarities.

From that time on, several other objects sharing the characteristics of one or the other event were discovered, indicating that these deviations from the *standard* Ia were not so rare. Of course, one of the most important issues generated by the discovery of such theme variations concerned the explosion mechanism. The growing evidence produced by the observations in the last ten years has clearly demonstrated that subluminous events (1991bg-like) are preferentially found in early type galaxies (E/S0), while the superluminous ones (1991T-like) tend to occur in spirals (Sbc or later). This has an immediate consequence on the progenitors, in the sense that subluminous events appear to arise from an old population, while super-luminous ones would rather occur in star-forming environments and would thus be associated with a younger population. This important topic has been recently discussed in a work by Howell (2001), to which the reader is referred for a more detailed review.

What is important to emphasize here is that 1991T-like events tend to be associated with young environments and are, therefore, the most promising candidates for the study of light echoes. Or, in turn, if light echoes are detected around such kind of SNe, this would strengthen their association with sites of relatively recent star formation.

The first case of light echo in an Ia (1991T) seems to confirm this hypothesis, in the sense that the SN was overluminous and the host galaxy (NGC4527) is an Sbc and a *liner* too. Slightly less convincing is the other known case (1998bu), since the galaxy (NGC3368) is both an Sbc and a *liner*, but the SN is neither overluminous nor spectroscopically peculiar. The only characteristic in common with SN1991T is its decline rate Δm_{15}, which is lower than average, even though not so extreme as in the case of 1991T. Nevertheless, the HST observations by Garnavich et al. (2001) show that some significant amount of dust must be present within 10pc from the SN.

Of course, no statistically significant conclusion can be drawn from such a small sample, which definitely needs to be enlarged. For this reason, during the past years, we have been looking for new cases, the most promising of which is represented by SN1998es in NGC632. This SN, in fact, was classified as a 1991T-like by Jha et al. (1998) who also noticed that the parent galaxy was classified as an S0, hosting a nuclear star-burst (Pogge & Eskridge 1993). Moreover, the SN was reported to be projected very close to a star-forming region and an Echelle spectrum obtained with FEROS at La Silla (Patat et al. in preparation) showed very strong NaID lines at the SN rest frame velocity. The latter indicates the presence of significant absorbing material in front of the SN.

All these facts were pointing towards the possible appearance of a light echo. If this were of the same nature as those seen in 1991T and 1998bu, due to the higher distance of NGC632 (d=42.2 Mpc, H_0=75 km s^{-1} Mpc^{-1}), it would be expected to have a magnitude V~24. Due to the relative faintness of the target, the observations were carried out with one of the 8.2m ESO VLTs equipped with FORS2.

In the following we report about the results from these observations which, if on the one hand did not lead to light echo detection, on the other they brought to our attention the existence of a very faint filament, extending for at least 160,000 light years from the nucleus of NGC632 in the SW direction. While the implications on the SN environment will be discussed in a forthcoming paper, we will focus on a preliminary analysis of the tidal tail and the inner morphology of NGC632 in connection with its star-burst nature.

2. Observations and Data Reduction. NGC632 was observed in B and V Bessel filters on September 25, 2001 with FORS2 mounted at the Cassegrain focus of the ESO 8.2m

UT3-Yepun[2] telescope, located at Cerro Paranal, Chile. FORS2 is equipped with a 2048x2048 pixel (px) TK2048EB4-1 backside thinned CCD. When, as in our case, the standard resolution collimator is used, a projected scale of 0″.2 per pixel (24 μm x 24 μm) is obtained, which corresponds to a field of view of 6'.8 x 6'.8. To allow for a proper removal of cosmic-ray hits, three images of 300 sec and 600 sec each were obtained in each passband; an image quality of about 0″.62 and 0″.75 in B and V raw frames was achieved respectively.

The images were bias and flat-field corrected by the FORS pipeline, while frame registration and stacking were performed using IRAF[3]. The final image quality achieved in both B and V stacked images is about 0″.64 and 0″.78, while the limiting magnitude for unresolved objects (5σ peak level) is about 27.0 and 25.0 in B and V, respectively.

Photometric calibration (zero points and color terms) was achieved through the observation of standard fields (Landolt 1992).

The sky background was computed using the mode of the pixel intensity distribution, using areas of the images free from extended objects. Due to the FORS2 field of view, which is much larger than the actual extension of NGC632, it was possible to select large regions where the intensity distribution was dominated by background emission.

In this kind of studies, the so-called *unsharp masking* is widely used (see, for example, Peng et al. 2002). The application of this technique has the effect of revealing fine structures overimposed on smooth backgrounds, which would otherwise be hardly detectable.

Since NGC632 has structures with extremely different scales (see next section) and intensities, we adopted another procedure, which is basically a differential compression of the image dynamics in order to bring highly differently exposed regions to a similar contrast range.

We achieved this by using the radial profile of the diffuse component of the galaxy by means of the median value calculation within elliptical coronae centered on the galaxy nucleus. For the position angle and ellipticity we adopted the values deduced by Chitre & Joshi (1999) from the isophotes' fitting. Using this profile we then constructed a bi-dimensional function having the same average isophotal properties of the galaxy. Finally, we divided the original image by this function scaled by a suitable constant and thus applied a differential compression factor, which in the end brings all regions to a similar dynamical range.

This process, of course, does not conserve the flux and is not suitable for photometry, but allows one to display on a single plot features which originally had a very large intensity range (see Figure 5).

In fact, as we will see in the next section, NGC632 has a strongly peaked diffuse component, on top of which stellar-like knots, spiral arms and other diffuse structures with complex morphology are overimposed.

3. Results. The images were reduced and analyzed immediately after the observations to detect the light echo and follow it up with spectroscopy. A careful inspection of the SN location, though, did not show any trace of a point source down to B=25.5, i.e. 1.5 magnitudes fainter than a 1991T-like echo. Nevertheless, a re-analysis of the data that was carried out about one year later, revealed the presence of two very faint tidal tails, one of which clearly extending beyond the FORS2 image. This is clearly shown in Figure 1, where we set the image cuts to rather extreme values in order to show the faint structures. The longer tail, coming out in the SE direction, has a typical intensity of about 20 counts above the sky background in B, which turns into a surface brightness of about 27 mag arcsec^{-2}. At the NGC632distance this implies a projected length of at least 50 kpc, which is enormous, being comparable to the distance from the

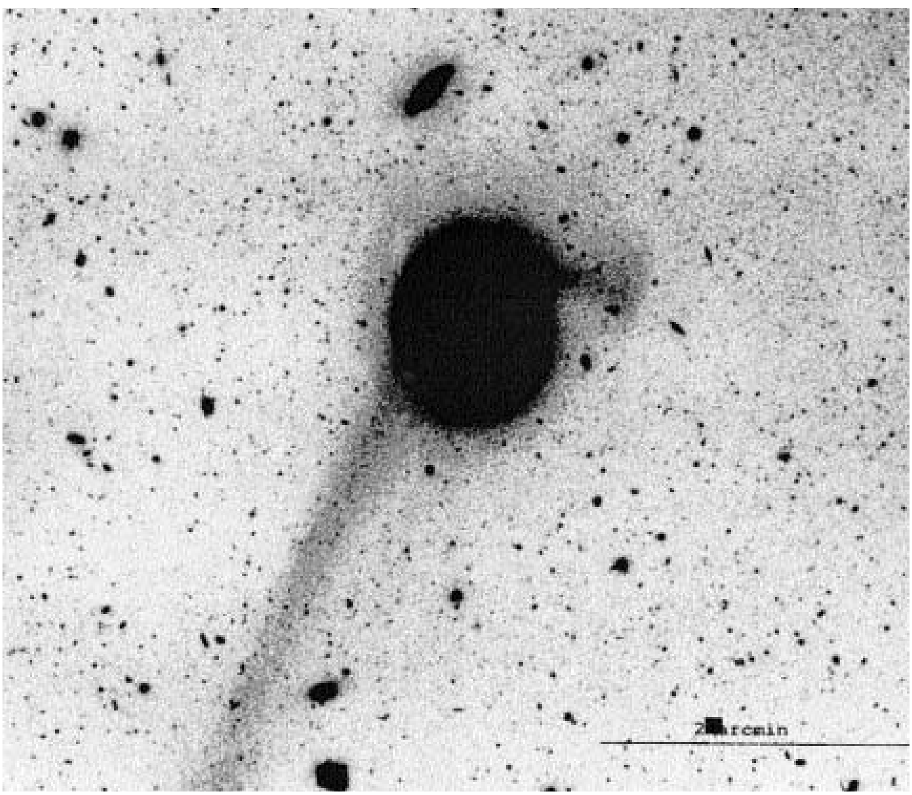

Figure 1. VLT+FORS2 B image of NGC632 obtained by stacking 3 frames of 600 seconds each. The field of view is 7'x7'; North is up and East to the left. The original images were obtained on September 25, 2001 with a seeing of 0".6. To enhance the tidal tail structure, the combined image was binned 2x2. At the distance of NGC632, 1' corresponds to about 12.3 kpc.

Large Magellanic Cloud. The other tail is brighter but much shorter and shows a widening at its end.

Another fact which is clearly displayed in Figure 1 is the slight deformation of the galaxy in the SW direction, which becomes more evident in Figure 2, where we present a contour plot for the B band. There are several interesting facts that emerge from this Figure. The first is the clear detection of a well-defined spiral structure, within 20″ from the nucleus. In this respect, we noticed that the existence of a rudimentary spiral structure was pointed out by Chitre & Joshi (1999). The second aspect concerns the shape of the isophotes, which tend to twist counterclockwise and to become more and more box-shaped. Chitre & Joshi (1999) found a similar result, even though their data had a much smaller signal-to-noise ratio and a lower spatial resolution which

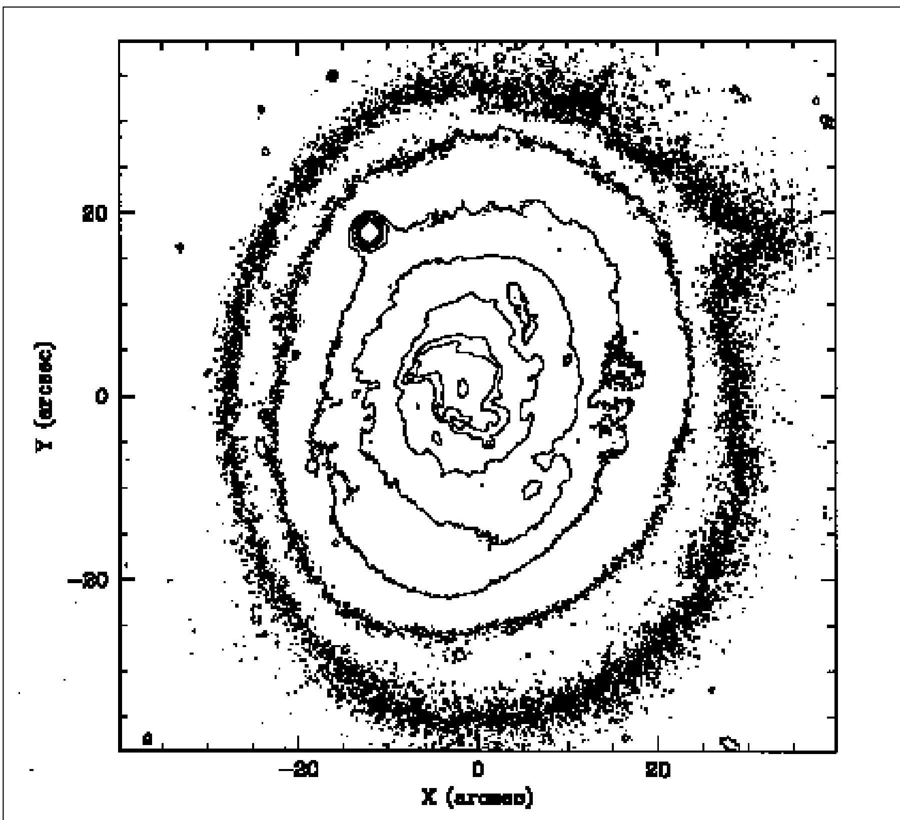

Figure 2. B contour plot of NGC632. The saturated part of the nucleus is indicated by the inner contour, while the outer contour is at a 3σ level on the sky background.

made the conclusion rather questionable (see their Fig. 1h). They interpreted these two findings as a possible indication for a merger and our detection of a tidal tail seems indeed to agree with their suggestion.

Finally, the isophotes, especially in the outer parts, are distorted in the SW direction and this breaks the symmetry around the nucleus, which roughly holds up to a semi-minor axis of about 17″. At larger distances a clear deformation is seen and the joining of the smaller tidal tail with the galaxy appears at about 30″ NW of the nucleus.

Probably, the complex structure of this galaxy is better shown in Figure 3, where we applied to our B stack the dynamics compression technique described in the Introduction. The spiral structure appears very clearly and it is not confined to the inner regions only. Close to the nucleus

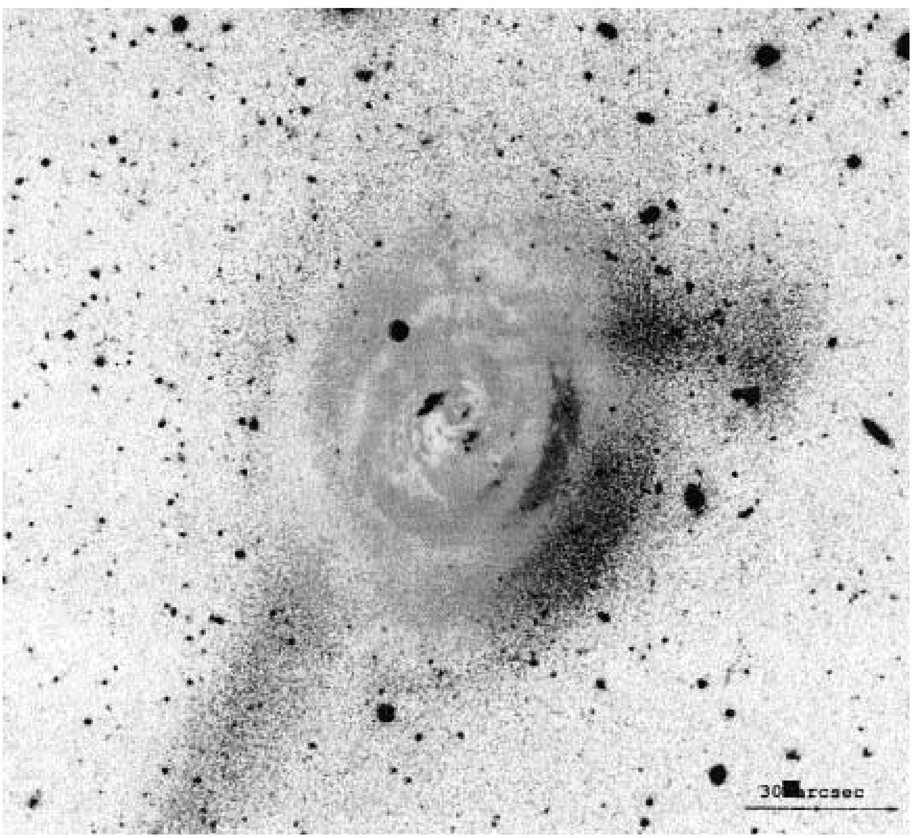

Figure 3. NGC632 after the application of dynamic compression (see the Introduction).

several bright point sources are visible on top of the spiral arms; in particular, there is a short filament, slightly off-centered with respect to the nucleus, which points towards the starting point of the upper tidal tail.

Even though the noise produced by the high level of the diffuse galactic component tends to mask it, one can follow this tail until it almost reaches the spiral structure. Besides the spiral arms visible in the inner region, we notice the presence of an almost symmetric elliptical ring with a semi-minor axis of about 19″, which causes a kink in the radial profile (see also Figure 5). The NW symmetry breaking is evident in Figure 3: it starts with an enhancement of the intensity in this elliptical ring and is followed by the appearance of a diffuse and extended component, which

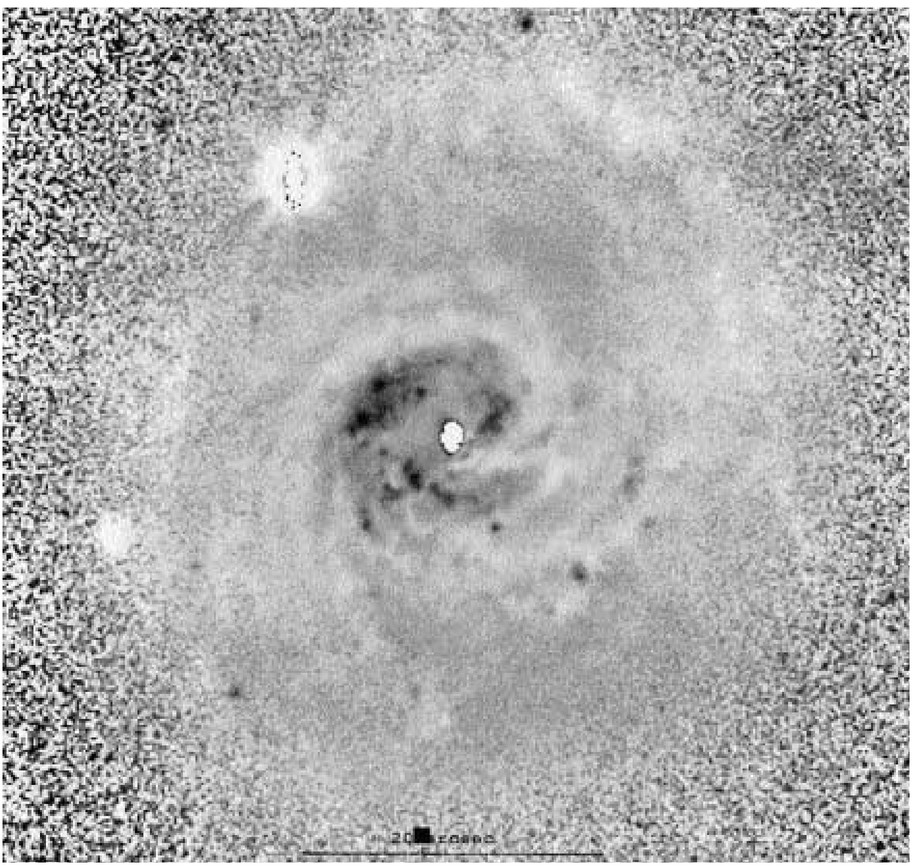

Figure 4. (B-V) color image of NGC632 computed from the two B and V stacks. The greyscale is linear and displays the color range 0.1-1.1 (black-white). The white region in the center is the saturated part of the nucleus.

seems to join clockwise the SE tidal tail at its origin. Another relevant aspect in Figure 3 is the presence of semi-stellar objects on top of the diffuse component in the outer regions of the galaxy. These are probably star clusters, which certainly deserve a multicolor study.

Even though a complete set of deeper UBVRI images would be necessary to analyze the stellar population present in the galaxy, some interesting results can be obtained already from the inspection of the (B–V) color image (see Figure 4). Several unresolved, very blue objects with $0.1 \leq$ (B–V) ≤ 0.4 are detected on top of the inner spiral structure, while the diffuse component appears to have a typical (B–V)~0.7. For comparison, the color of the nuclear region is (B–V)=0.38 (Chitre & Joshi 1999), consistent with the estimate we get from a few unsaturated pixels in our images. NGC632 is known to show Hα emission both in the nucleus and in the clumpy circumnuclear region (Balzano 1983) and this has been interpreted as a sign of starburst activity (Pogge & Eskridge 1993). For this reason, we tend to believe that the blue spots we see in the inner region are sites of recent star formation. Besides these knots and the diffuse component, Figure 4 shows some redder filaments with a typical (B–V)=0.95, which are probably due to the presence of dust.

From what we have been discussing so far, it is clear that we are dealing with two kinds of components, i.e. a very faint spiral structure and an underlying diffuse and smooth component. To get the approximate properties of the latter, we computed its radial profile within elliptical coronae, assuming the position angle and ellipticity given by Chitre & Joshi (1999), i.e. 163° and 0.26 respectively. The result is shown in Figure 5, where we plotted the radial surface brightness profiles of the diffused component as a function of the isophotes semi-minor axis for B and V passbands (upper panels).

Due to the large number of pixels included in the elliptical coronae at large radii, it is possible to follow the profile with a reasonable accuracy out to at least 50″ which, at the distance of NGC632, correspond to about 10.4 kpc. In these outer regions, the surface brightness is about 27.7 and 27.2 mag arcsec^{-2} in B and V, respectively.

With the exception of the inner 5″ (~1 kpc), which are dominated by the peaked nucleus, both profiles show an exponential decrease out to 35″ (~7 kpc), where they tend to bend. The very low signal to noise, however, does not make it possible to establish whether this is due to the onset of an additional component following a different law. Here we only note that the exponential disk we see in the inner part of NGC632 is typical of spiral galaxies.

One remarkable feature displayed by both B and V profiles is the appearance of a kink at about 17″ (3.5 kpc), which corresponds to the elliptical ring we have mentioned before.

Finally, in the lower panel of Figure 5, we have shown the (B–V) color

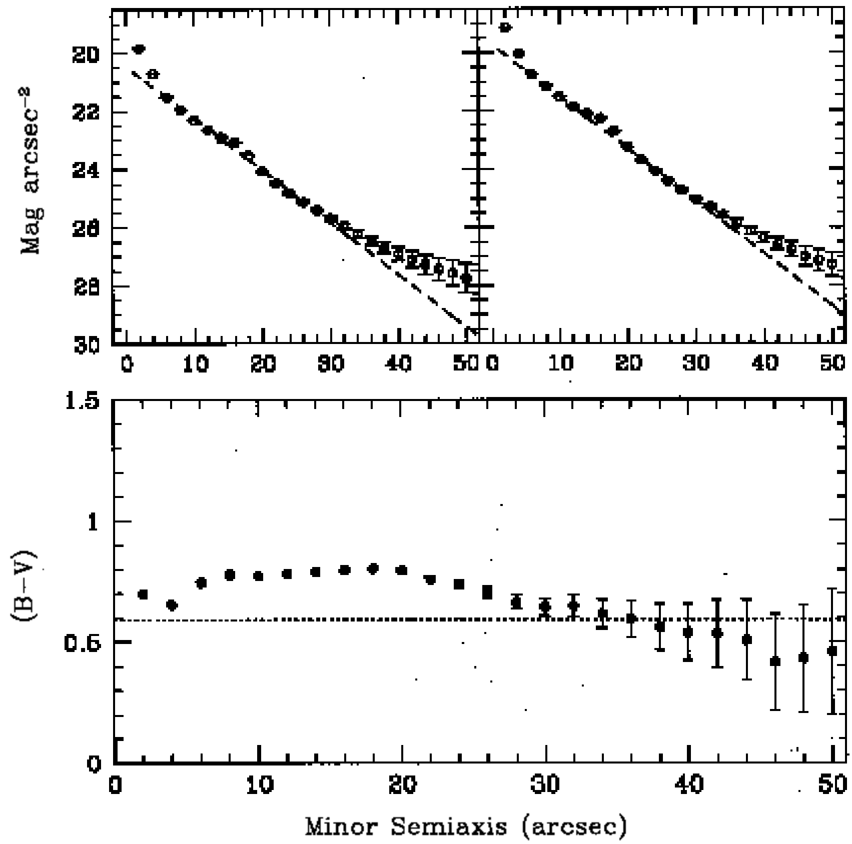

Figure 5. Upper panel: surface brightness radial profile for the diffuse component in B (left) and V (right). The dashed lines trace a fitting with an exponential law. Lower panel: (B–V) profile of the diffuse component. The dotted line is placed at the average value.

profile for the diffused component, which appears to be roughly constant, at a value of (B–V)=0.7.

This integrated color is consistent with a population of stars whose turn-off mass is of the order of 0.8 solar masses and an age of some Gyr (Bressan, Chiosi & Fagotto 1994).

On average, the color within 20″ from the nucleus is 0.1 mag redder than in the outer regions, even though the large error bars do not allow a firm conclusion.

4. Discussion and conclusions. NGC632 is classified as E1 in the Markarian catalogue (Mrk 1002) and as S0 by Balzano (1983), while we have shown that there are indeed traces of spiral arms, even though they are masked by the dominant diffuse component.

Traditionally, S0 galaxies have been interpreted as fossile disk systems, with a small amount of gas and are therefore considered as *dead* from the point of view of star formation. This scenario has started to change, since more and more evidence of star forming activity is being gathered. The case of NGC632 is emblematic: the nucleus shows a strong HII region spectrum (Balzano 1983) and probably hosts a nuclear starburst with considerable circumnuclear star formation (Pogge & Eskridge 1993). Of course, one of the main issues here is how such a dead galaxy can generate massive stars, given the fact that a very small amount of gas is supposed to be left.

Possible explanations have been provided. For example, Larson & Tinsley (1978) have first proposed that tidal forces in interacting galaxies could trigger such events, while Bournaud & Combes (2002, and references therein) have shown that in the presence of bar-like structures, gravitational torques can drive the gas leftovers into the central regions and give similar results.

In particular, the most active starbursts are found almost exclusively in on-going mergers (Hibbard 1997 and references therein), a fact that clearly establishes the link between the two phenomena.

In the case of NGC632, Chitre & Joshi (1999) have already pointed out that the cause of the observed star-forming activity was probably the remote merging of a gaseous disk into the main galaxy. Our tidal tail detection gives a definite support to this hypothesis and strengthens the idea that mergers are responsible for starbursts even in the cases where direct evidence of close galaxy encounters (v.g. strong asymmetries, tidal tails and double nuclei) has been totally spoiled. A deep survey of S0 starburst galaxies carried out with an 8m-class telescope could probably demonstrate whether this is the case or not.

Since our data were obtained for a completely different purpose, we are certainly not in the conditions of fully solving the case of NGC632. There is in fact a number of fundamental points which need to be addressed.

First of all, a full set of UBVRI very deep imaging is required to properly study the stellar and globular cluster populations both in the galaxy and in the tails, solving the age-metallicity degeneracy. This requires several hours of integration time per filter even with an 8m-class telescope in order to get a sufficient signal-to-noise ratio in the outer parts of the galaxy and in the tidal tail. The latter needs also to be imaged at larger distances, to get its full extension.

Another important piece of information would be given by deep Hα imaging, which will allow one to detect all emitting regions to be studied later on with spectroscopy. We suspect that the blue knots we detected in the inner part of the galaxy are circum-nuclear regions of active star formation. High-resolution spectroscopy of those clumps would unveil their nature, provide fundamental hints on their chemical composition and physical conditions. Finally, a kinematical map of the inner regions would provide us with a fundamental tool for the reconstruction of the merging-event dynamics.

Nowadays hierarchical clustering of galaxies is reckoned as one of the fundamental large-scale processes in Astrophysics. Therefore, the study of cases where this mechanism is still at work is of great relevance for understanding Universe evolution.

Notes

[1] Based on observations collected at ESO-Paranal.
[2] Yepun in the Mapuche word for Sirius.
[3] IRAF is distributed by National Optical Astronomy Observatories, which is operated by the Association of Universities Inc. (AURA) under cooperative agreement with the National Science Foundation, U.S.A.

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