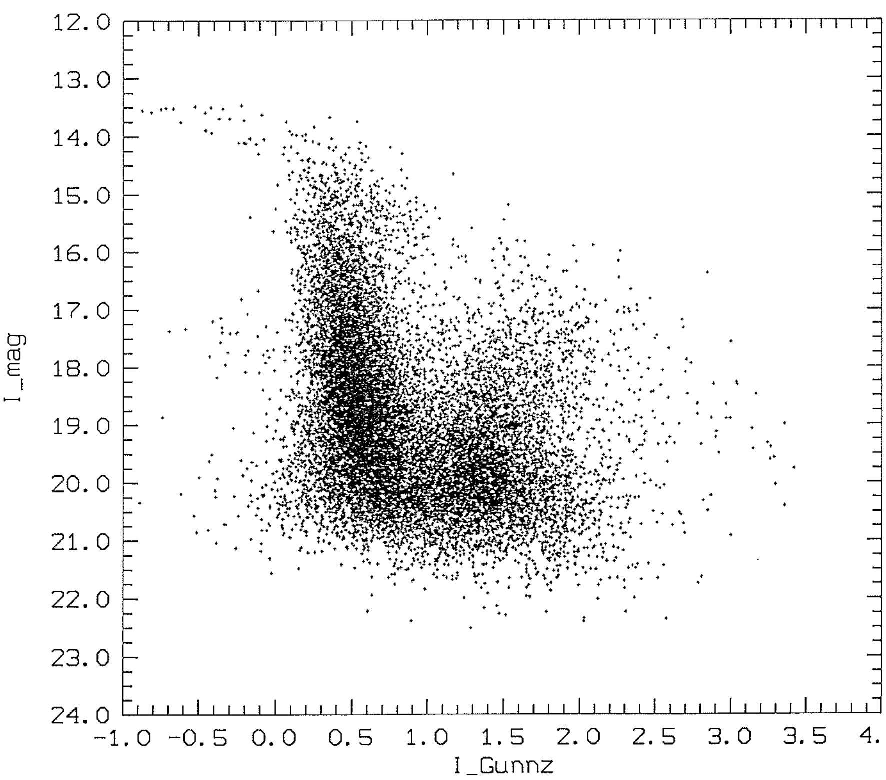

Figure 3: *Colour-magnitude diagram for the field near Liller 1, of size ~ 10′×8′ containing 20,000 stars.*

metallicity effects are seen also in these near-infrared bands, which otherwise are little affected by blanketing in less metal-rich clusters.

Another important result can be seen in Figure 3 where we show the CMD for the whole field of size ~ 10′×8′ containing about 20,000 stars, which is provided by the present equipment. In addition to the strong main sequence, the bulge field GB and HB are observed. Note the similarity of the latter component, in terms of values and morphology, to Liller 1. We conclude from this similarity that Liller 1 is located at the distance of the bulge bulk stellar population (close to the Galactic centre) and present similar metallicity. An interesting future project would be high-resolution spectroscopy of giant members for better metallicity determination of stars in the inner bulge. As such stars have I ≈ 18 magnitudes, one clearly will need telescope apertures such as that of the VLT. New, direct image observations in the cores of these clusters are also planned with the WFPCII of Space Telescope.

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Fine Structure in the Early-Type Components in Mixed Pairs of Galaxies

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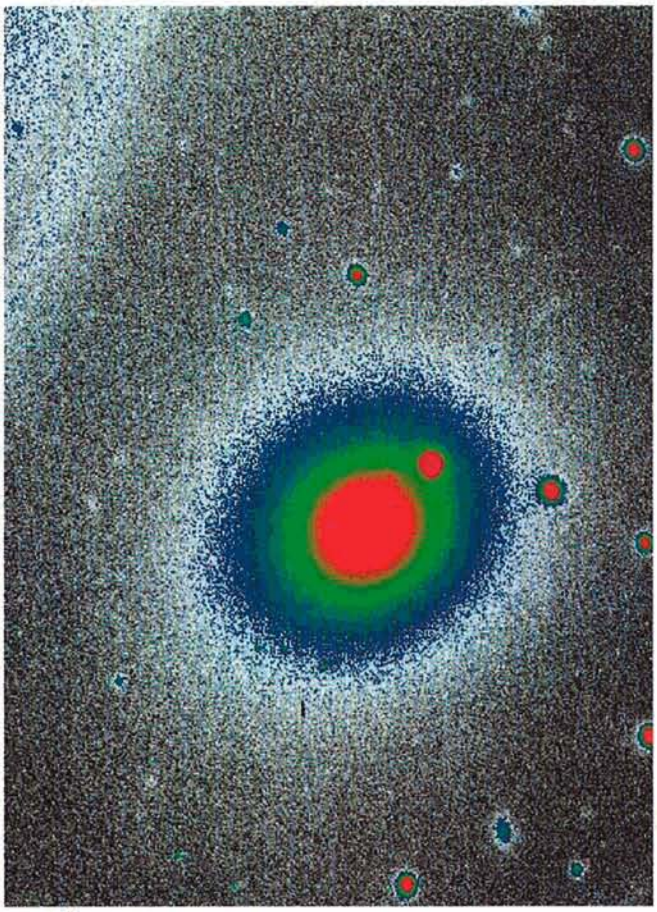
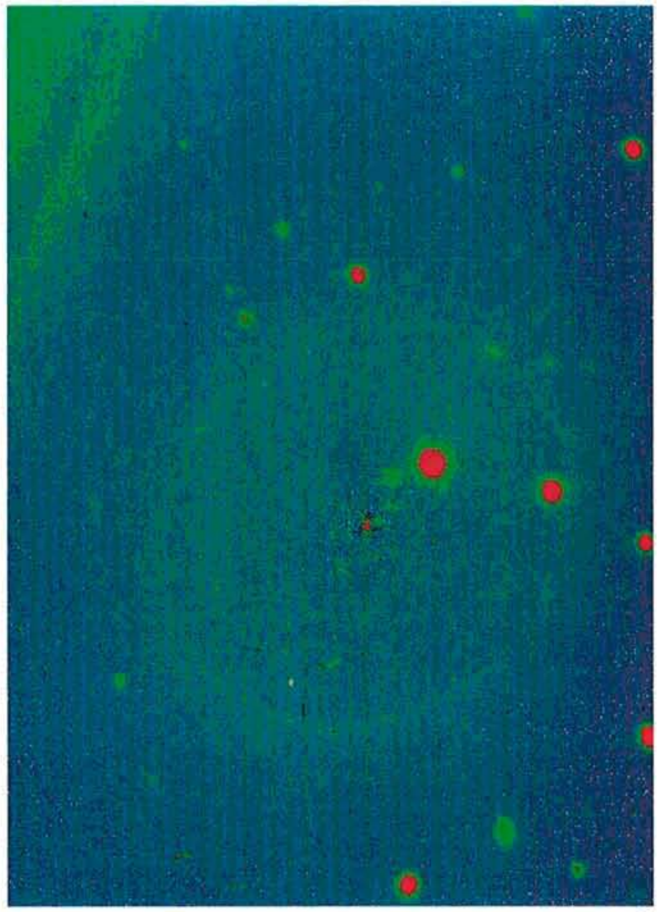
Elliptical galaxies were once viewed as the simplest of the forms assumed by stellar aggregates in the universe. Many observational discoveries in the past 15 years have altered this simple viewpoint. Both kinematic and morphological complexities are rapidly becoming the rule rather than the exception when ellipticals are studied closely. We describe here a new observational study of fine structure in elliptical members of binary galaxy systems. The structure is not always obvious in raw images because the smooth contribution from the stellar component is so strong. We consider techniques for enhancing these clues into the structure and evolutionary history of elliptical galaxies.

I. Introduction

One of the competing explanations for the origin of (many or all) elliptical galaxies views them as merger products. Fine structure, such as the shells, ripples and X-structure observed in many ellipticals, is considered by some as evidence for merging/accretion events. An objective definition of what constitutes a merger product must await a better understanding of the phenomenon and its frequency of occurrence. Even allowing for a large uncertainty in the numbers, it seems that a link exists between observed fine structure and other suspected signatures of past interaction, such as kinematically decoupled cores, unusual UBV colours and X-ray emission.

We are interested in the structure of E/S0 galaxies that are paired with spiral galaxies in so-called mixed morphology pairs. The existence of physical pairs of mixed type was questioned until recent optical and FIR studies showed that considerable numbers must exist. We are interested in comparing the properties of galaxies in such pairs with isolated galaxies of similar morphological type. We are searching for evidence that the morphology difference of galaxies in mixed pairs might be due to secular evolutionary effects related to periodic encounters with the close companion. If many of the structural peculiarities now





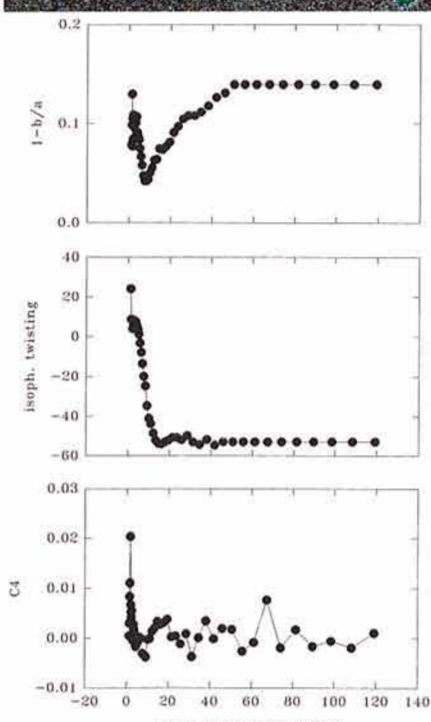


Figure 1: *(Upper left) Original image of E506-01 (B_T = 13.28). This galaxy (with cz = 3275 km s^{-1}) is paired with the spiral E506-02. (Upper right) E506-01 with model subtraction. No substructure is observed. (Left) Radial variation of ellipticity, twisting and isophotal shape derived from the model used in the above subtraction.*

found in ellipticals can be ascribed to interaction, then we might expect an even greater frequency of occurrence in binary systems. The problem is, of course, detecting and enhancing such fine structure.

We adopt a modelling technique in order to study the fine structure in the early-type components of mixed pairs. A galaxy is modelled using the photometric and geometrical information obtained from an isophotal fitting algorithm. We find that the frequency of occurrence of shells and X-structure appears to be lower than that found in a sample of relatively isolated ellipticals (Schweizer 1992). A true deficit may imply that pairs undergo fewer low mass accretion events or that fine structure is destroyed rather than created by interaction.

II. The Sample

Our primary sample of mixed pairs was selected from the southern sky using criteria similar to those employed in compiling the CPG (Karachentsev 1972; Sulentic 1989). The original sample was extracted from the Lauberts and Valentijn (1989) catalogue. The working sample includes pairs of galaxies that are isolated and that show a maximum component size ratio of four to one. The IRAS detected members of the southern sample with known redshift have also been observed in CO with SEST (Combes et al. 1993). The enhanced FIR and CO emission detected in that sample gives us confidence that we are dealing with physical binaries and multiplets. We have recently supplemented our southern sample with 168 northern mixed pairs that were imaged at KPNO by N. Sharp and JWS.

We have imaged 16 of the southern mixed pairs (and 3 early-type pairs) with the 90-cm ESO-Dutch telescope at La Silla (Chile) through B, V and R Bessel filters. We used a 512×512 CCD (# 33) with 27 μm pixels and a scale of 0.44 arcsec px^{-1}. Typical exposure times were 10 min in R, 20 min in V and 45 min in B. A set of standard stars was observed for photometric calibration. Combined with a previous sample (Rampazzo & Sulentic 1992) observed with the 2.2-m ESO telescope we now have imaging data for a total of 41 pairs which include 45 early-type galaxies. The 2.2-m sample was taken from a mixed pair catalogue compiled by one of us from visual inspection of the ESO/SERC sky survey. Only three of the pairs

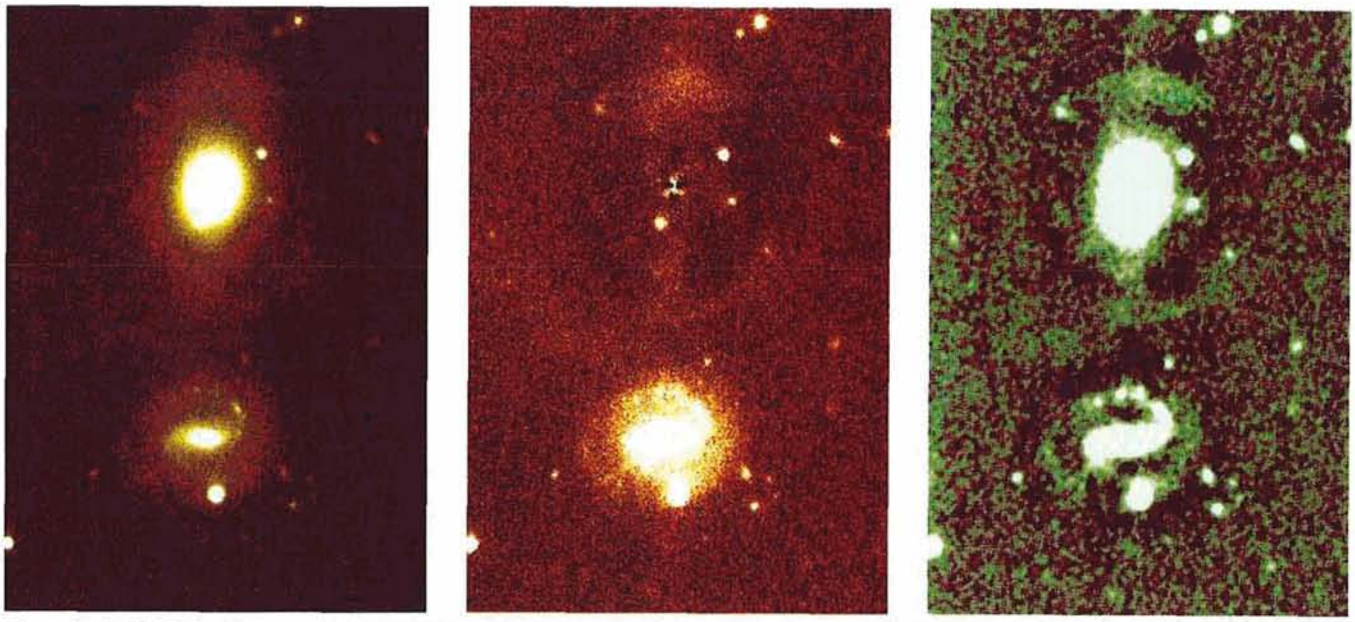


Figure 2: *(Left) Original image of AM 2312-511. (Middle) The pair after model subtraction. (Right) The pair after subtraction from the original image of a 69×69 pixel low pass model (with 5×5 pixel boxcar smoothing).*

with known redshift are above 10,000 kms^{-1}. A complete photometric analysis is in progress but we want to report here on the search for substructure in the early-type components.

III. Fine Structure Detection

Fine structure near the centre of an elliptical galaxy is usually many orders of magnitude less intense than the stellar component. The essential secret to revealing and enhancing it involves an understanding of the spatial frequency distribution in an image. If we were to take the 2D Fourier Transform of an image, we could represent the spatial frequency content of an image by its power spectrum. White noise dominates at the highest frequencies while galaxy structure and large scale background variations dominate the low and intermediate frequencies. Flat fielding will remove most of the instrumentally induced background variations. Removal of the low spatial frequency galaxy component in the Fourier domain would involve filtering or weighting the power spectrum so that the low frequencies are removed or underrepresented. Retransformation into real space will yield an image displaying only higher spatial frequency structure (if it is present). Filtering in the Fourier (linear spatial frequency) domain is not a trivial task however. Modification of the power spectrum usually results in the introduction of unwanted artifact that greatly complicates interpretation of the data. It is almost always preferable to use filter or modelling tools in the non-linear real space domain rather than in the Fourier

TABLE 1. *Early-type member of pairs showing structures*

Ident.	Other ident.	Type	B_T	1	2	3	4	5	Notes
AM2312-511		E	15.7	•				•	
AM2353-192	E471-471	E	14.69		•			•	Tidal
	E471-470	S0	15.16		•				origin
AM0106-285	E412-07	E	13.5	•					
		SB0/a	14.3	•					
	E541-240	S0	15.18				•	•?	One
	E541-241	S0	17.02						distorted
AM1754-634	E102-20	E	13.2				•		Small central
									disk
AM1806-852	E010-01	E	13.37				•	•	
AM2019-442	E285-04	E/S0	14.42				•	•	
AM2144-551		E/S0	14.5		•		•		Uncertain
AM2154-382		SB0/a	15.1	•			•	•	
	E511-31	E/S0	14.26				•?	•	Uncertain
	E187-23	S0	12.92				•	•	
AM1440-241	E512-18	E/S0	12.96		•		•		S0+Spiral
	E386-04	E/S0	13.74	•			•		
	E360-11	S0	15.31	•	•		•		
	E556-13	E/S0	13.7			•			
	E556-14	S0	14.49						Bar?
	E436-18	S0	15.12	•			•		Small galaxies
									superimposed
	E566-08	E/S0	15.56		•				Spiral?
	E365-29	E	14.79		•		•	•	
	E123-11	E	13.74		•				Spiral-like
									or jet-like
AM1325-292	E444-45	E	13.29		•		•	•	Tidal Origin
AM2319-234		E	–	•				•	Tidal Origin?
	E605-05	–	14.36		•		•	•	Multiple object
AM0012-235		E	≈17					•	Comp.
									pseudo-spiral
AM1945-541	E185-21	E	–	•?				•?	
AM1840-622	E140-44	E	12.69		•				Uncertain
	E545-40	E/S0	13.83		•				
AM2016-330	E400-07	E	15.03		•?				Contamination
									by a star
AM0051-473	E195-11	E	15.27		•		•		Triplet
AM2225-250	E533-31	E	12.96		•		•		
AM2233-613	E147-03	E	15.27					•	
AM0054-634	E079-131	E/S0	15.05		•			•	*Triplet*

Note: Morphological types are determined from inspection of the CCD frame. Columns are: (1) Ripples, Shells, (2) Tail-Plumes, Jets, (3) X-Structure, (4) Dust, (5) Asymmetries

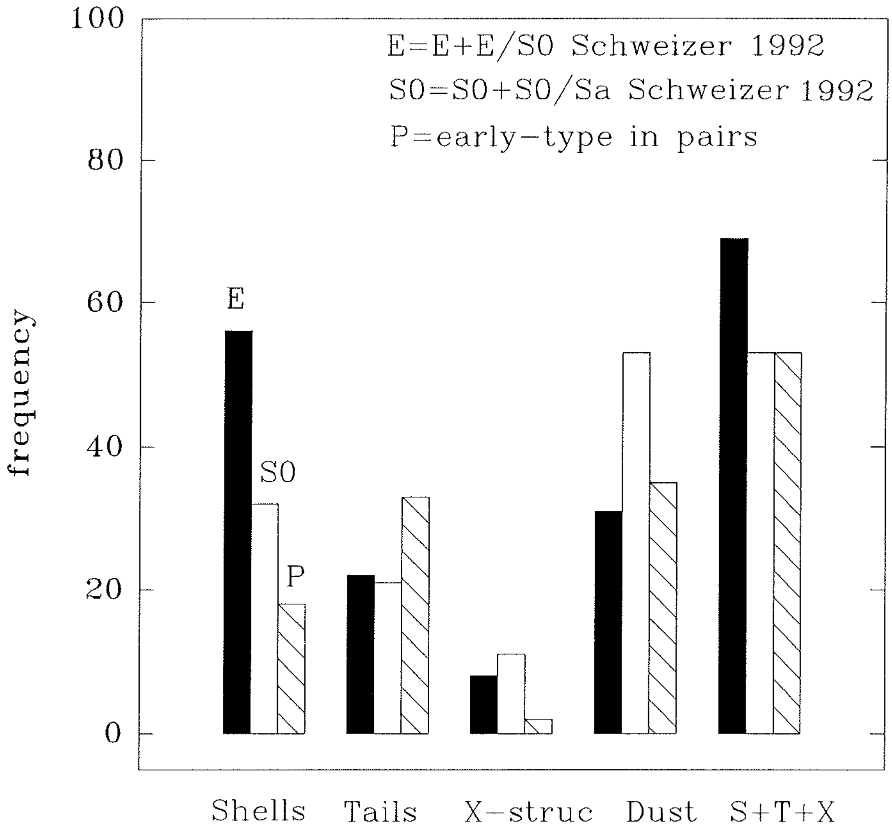


Figure 3: *Detection frequencies for various kinds of fine structure detected in the early-type components of binary galaxies. Results for the Schweizer (1992) sample are presented for comparison.*

domain. This is not intended to suggest that Fourier analysis of galaxy structure is a waste of time. It is just not the easiest approach for the tasks described here.

A median filter is the first tool that one considers when attempting spatial frequency filtering in real space (see Sulentic et al. 1985). One simply chooses a median kernel at least two times larger than the largest feature one wants to preserve. One creates a low pass model with this filter (which "sees" only the extended structure). Subtraction of the low pass model from the original image yields an image with the residual high frequency structure. This approach is infinitely preferable to a mean or gaussian filter in the presence of data with a large dynamic range. For instance, a suitably chosen median filter will not even "see" stellar features in the image while other filters will smear them out. However, even the median filter is not very good in the presence of complex structure such as we are finding in the central regions of galaxies. In the case of ellipticals we can now make use of the generally smooth and axisymmetric stellar distribution and use a modelling approach. This technique has been widely used for enhancing shell structure and for detecting internal dustlanes (see for instance Prieur 1989, Capaccioli et al. 1988, Forbes & Thomson 1992). It usually produces results that are superior to those obtained from filtering.

We used the IRAF reduction package at both Brera Observatory and the University of Alabama to carry out our analysis. Our modelling procedure is based on a method developed by Jedrzejewski (1987) and implemented in STSDAS. After the subtraction of foreground stars by means of squared masks (formed of pixels not considered by the computing algorithm), each isophote of the galaxy under study is fitted by a mean ellipse and parametrized using values of position angle, ellipticity and coordinates of the centre. The deviation from a pure ellipse expressed in terms of a Fourier series is also given. The fourth cosine term in the Fourier series expansion is a particularly useful measure of the deviation from ellipticity, measuring the degree of diskiness or boxiness of the isophotes. The entire galaxy is parameterized in luminosity and geometrical parameters between a minimum (usually 1.5 pixels) and maximum radius. The latter is big enough to include the complete visual extension of the main body of the object. The programme usually starts with some default radius (typically 10 pixels) and increases with a geometrical progression as far out as possible. It then restarts from the initial point and goes down to the centre of the galaxy. We adopted a variation step in the radius equal to 10 %. Each parameter is allowed to vary during the fitting, permitting us to map any small variations and to build up a reliable synthetic model of the object. This model is produced using a bilinear interpolation of the fitted isophotes.

The luminosity of the internal structures is in many cases very low, at most a few per cent compared to the intensity of the galaxy's main body. Still it is possible for the resultant synthetic image to be influenced by their presence. Actually it is known that the fine structures can significantly modify the model isophotes (see Forbes & Thomson, 1992). The subtraction of such a *false* model from the original image may then erase the faint details that we are searching for. In order to avoid this problem we tried to optimize our internal feature enhancement by including luminosity clipping in the modelling procedure. In this way the fitting algorithm can be modified and a percentage up to 40 % of the brightest pixels can be removed from the elliptical annulus to be fitted. This permits us to exclude from the list of examined pixels the ones eventually associated with the superimposed faint details.

Figure 1 shows an example of an image where no hidden structure was found in the residuals after model subtraction. The result was complete removal of the early-type galaxy from the image. This shows that the technique, when correctly applied, does not produce serious artifact. On the other side, Figure 2 shows an example where features are immediately visible. In this case the applied technique can be tested in order to verify that it preserves and enhances this structure. This example shows shell structure which is fairly frequently found in the outskirts of galaxies. Shell features have been interpreted as interaction generated phenomena both with and without an actual merger. In Figure 2 we show one of the pairs studied by Rampazzo and Sulentic. The three panels show: (1) the raw image, (2) enhancement by model subtraction and (3) enhancement by subtraction of a 69×69 pixel low pass median filtred image from the original. The latter frame has been smoothed with a 5×5 boxfilter. Both methods produce a useful enhancement in this case. The model approach further tests if structure exists in the central region by removing the entire starlight component.

Next we focus on possible features near the centres of our target galaxies. The limited number of data points in the ellipse fitting can create a spurious model near the centre. We must be alert

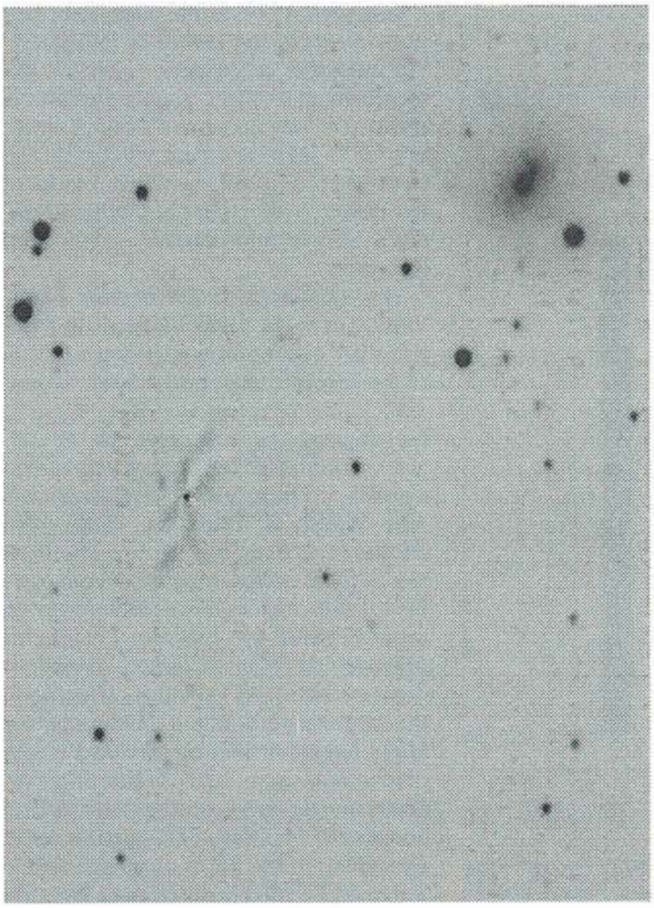


Figure 4: *An example of X-structure found at the centre of E556-13, the early-type component of a non-hierarchical mixed pair. Note the two typical brightness enhancements at the opposite ends of the X-structure also visible in IC 4767.*

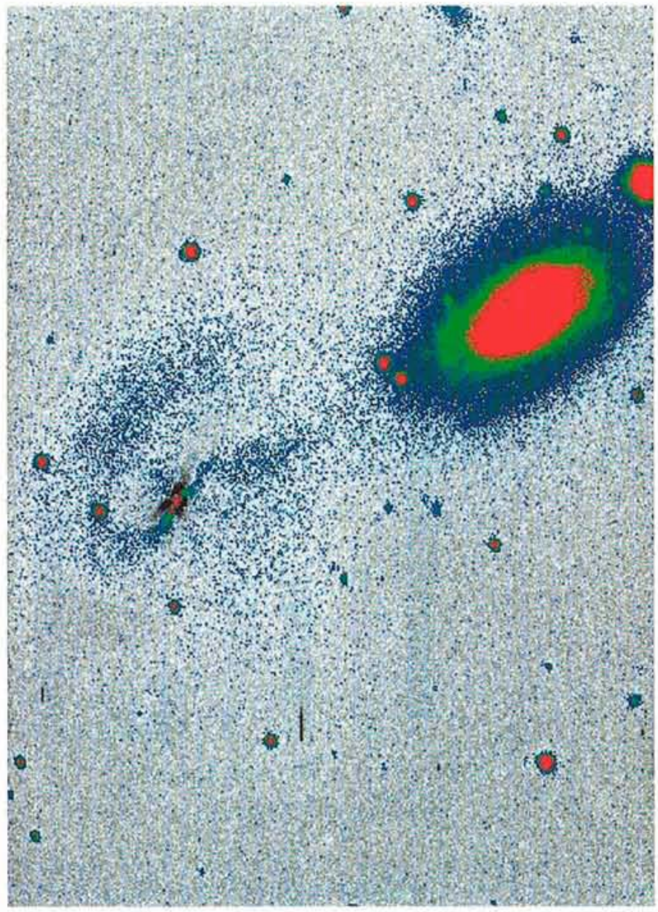


Figure 5: *Fine structure in E123-11. The structure is reminiscent of incipient spiral arms. It appears very sharp at the centre and then widens and becomes more diffuse towards the outskirts.*

to the possibility of false structure related to artifact produced by the model subtraction. The average apparent magnitude of the detected objects was $B_T = 14.5$. Table 1 and Figure 3 summarize the results of our structural analysis. X-structure is one of the less frequently observed forms of fine structure. IC 4767 is the prototype of this structural class (Whitmore & Bell 1988). Figure 4 shows the clear presence of X-structure in the centre of the early type galaxy E556-13. It is the only example in our sample. X-structure has been attributed to a phase mixed population of stars (Binney & Petrou 1985) and can apparently also be created by internal phenomena (see Merrit & Hernquist 1991). Related to X-structure we notice an isophotal boxy structure.

Figure 5 shows an example of an early-type galaxy with incipient spiral or jet-like structure. This is visible in all the photometric bands we studied. Most of the "tail" features appear more indicative of ongoing tidal interaction than as remnants of a past merger event (as in NGC 7252). Two cases, E605-05 and E113-42, show tails more suggestive of a merger in progress (they are imaged in Rampazzo & Sulentic 1992). We observed both of these "E+S" examples because the tail features suggested the presence of a spiral member on the ESO sky survey. E605-05, in particular, appears to be a triplet or compact group in the process of coalescence.

Considering all fine structure (shells, tails, jets, X-structure, dust lanes and patches) we find a detection percentage (see Fig. 3) that is similar to the one found for a sample of isolated galaxies (Schweizer 1992). Our result must be considered preliminary until we have controlled it with a well matched isolated sample. Our sample is fainter on average than the isolated sample we are comparing ourselves with, so we cannot rule out the possibility that we have missed fine structure in some of the fainter galaxies. Our results suggest that early-type galaxies in pairs show no more fine structure than field objects. We think that our percentage is an upper limit considering the subjectivity existing in the classification/identification of various and faint features. It should also be taken into account that the percentage is clearly augmented by tail features that are a direct result of tidal effects rather than merger/accretion events. If we consider features like shells/ripples ($\approx$ 20 %) or X-structure (2 %), we actually find a deficit compared to the Schweizer sample, on average, *by a factor of three.*

We believe that correction for the effect of our fainter sample is unlikely to reverse this deficit. This is all the more surprising because the frequency of other features agrees very well with independent samples and environments. For instance, we find evidence for internal dust lanes in 37 % of our sample which is consistent both with Schweizer (1992) and Ebneter et al. (1988). We would like to make a few preliminary inferences. If shells/ripples are created by interaction with a companion as suggested by Thomson & Wright (1990), we would expect to find an increase of such features in an interacting sample. Since we do not, we are forced to reject this hypothesis. One way out would be to argue that interaction would destroy fine structure after a relatively short period of time. The same argument is valid also in the case of X-structure, the lack of an interaction related excess may indicate that such features are due to internal processes.

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Contribution of the ESO Adaptive Optics Programme to Astronomy: a First Review

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Since 1988, the *Messenger* has kept its readers informed [1] of the steady progress being made in the ESO adaptive optics (AO) programme. The latest developments have been described in detail [2]. We simply recall here the main features. ComeOnPlus [3] is an adaptive system installed at the f/8.09 Cassegrain focus of the 3.6-m telescope at La Silla. It differs from the early prototype ComeOn in many ways: the deformable mirror has 52 actuators (instead of 19); a broader temporal bandpass (30 Hz) is available; modal control, which optimizes the efficiency of AO for a given observation, is implemented, and a user-friendly interface (ADONIS) using artificial intelligence to optimize the use of the system in real time is in preparation. The mechanical structure has been redesigned for high rigidity, and the optical train allows the installation of new elements, possibly provided by visitors, such as a coronograph, single-mode optical fiber pick-up, and in the future, spectroscopic capability or polarimetry.

In parallel, an agreement has been concluded between the Max-Planck-Institut für Extraterrestrische Physik in Garching and the Observatoire de Paris to install and operate a copy of the Sharp Infrared camera used at the NTT. This new camera, called Sharp II, is now on loan to ESO for Periods 52 and 53. ESO is planning to buy an upgraded version of the camera, with some new features, namely a Fabry-Perot spectrometer (resolution ca. 3,000), additional image scales and filters. This upgraded version will then permanently enhance the AO system.

Originally designed as a prototype system to evaluate the value of AO for the VLT, the first version of Come On was soon being used to obtain astronomical data, but was far from being user-friendly. Nevertheless the remarkable results obtained during technical runs in 1992 and 1993 and the unique availability of such a dedicated system on a large telescope encouraged ESO to take the risk of offering this "non-ESO standard" instrument to a broad community. To do so, a new staff member (M. Faucherre) was recruited and trained at La Silla to maintain, improve and operate the system, allowing visiting astronomers to use this new facility without special competence in exploiting adaptive optics. For the past eight months the ComeOnPlus/Sharp II configuration has been offered to visitors (see announcements for Periods 52 and 53), and the requests for observing time have steadily grown in number.

As a consequence, observing programmes of great diversity have benefited from 40 observing nights in Periods 51 and 52, broadly covering the fields of planetary, galactic, stellar and extragalactic astronomy. They all aim to exploit the near diffraction limited and high sensitivity imaging capability of AO, sometimes coupled to other functions such as coronography or spectrography. We present here some recent results in advance of forthcoming publications. They provide a good overview of the variety of fields currently covered by the astronomers using the AO system and demonstrate the worldwide leadership obtained in Europe, as no other group to date is able to present such applications of adaptive optics to frontier astronomical problems.

Solar System

The minor planets Ceres [4] and Pallas [5] were observed successfully. The axis of rotation of Ceres was determined, as well as the value of the ground thermal properties. Titan [5] was imaged in the 1.19–2.14 μm band (Fig. 1), a wavelength where the stratospheric haze is transparent and the low altitude clouds or even the ground may be observed. The ultimate purpose is to characterize the nature of Titan's ground and to test the current hypothesis of a global ocean. The tentative image obtained during Period 51 needs confirmation, and these infrared studies will complement Hubble Telescope observations in order to prepare for the Huyghens descent probe of the Cassini mission, planned to reach Titan in 2004. Examined in this band, Titan exhibits bright areas departing from circular symmetry. These may be caused by al-