Fig. 2: *Aerial view of Cerro Paranal. The elevation is close to 2,700 m and the coast is only at 15 km distance. The white spot at the right hand of the summit is a shelter used by the two persons who monitor the site. The ridge is facing the prevailing wind direction and is about 400 m long.*

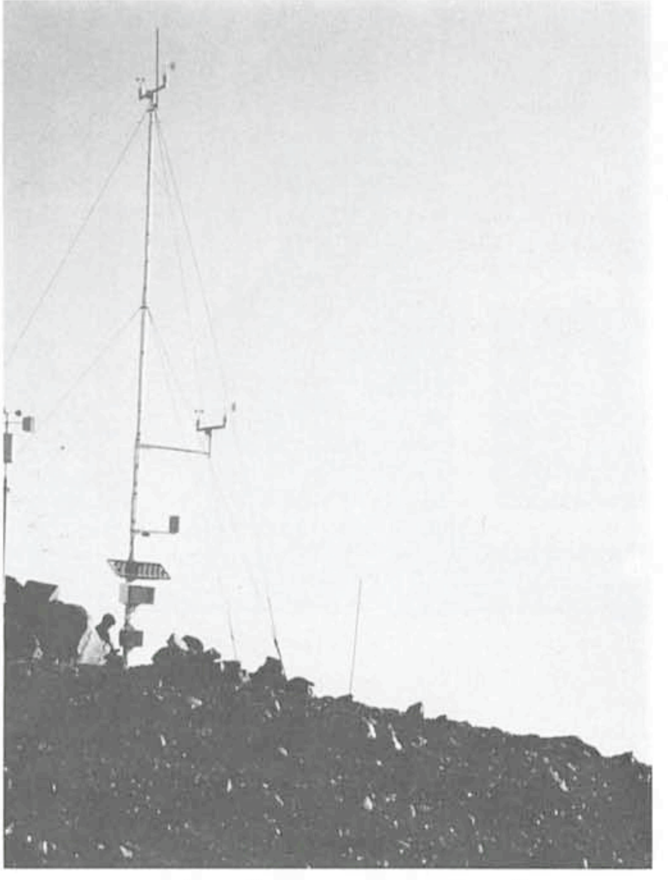

Fig. 3: *A new automatic meteorologic station at Cerro Paranal. Another station is installed at La Silla on a 30 m high mast. A third one will be installed on a high elevation site.*

high elevation site in December. They will provide easy processable data that will complement the data collected since September 1983. A tethered balloon will also permit to measure the turbulence as well as other meteorologic parameters, between 0 and 800 m above sites. This equipment is easily transportable and should permit a preliminary investigation of the local contribution to seeing. More permanent equipment, such as fast thermal sensors, acoustic radars and seeing monitors, is planned for 1985 at Paranal (and La Silla in view of an absolute calibration with existing telescopes).

The importance of seeing for the new large telescope projects as well as the perspective for improving the image quality through adaptive correction have raised up considerable efforts by several groups to better understand the causes of seeing deterioration, and possibly find cures. Despite the difficulty of comparing quantitatively results obtained by different methods at different places, it is hoped that within 2 to 3 years an agreement could be reached on a few vital questions such as "what makes a site really good?", or "how important is it to set a telescope at a high site?". Those questions are indeed of paramount importance for the ESO VLT.

Blue Compact Galaxies: Infants of the Universe?

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1. What is a Blue Compact Galaxy?

Shortly after the completion of the 48" Palomar Observatory Schmidt telescope in the beginning of the 1950s, a great number of stellar objects with fuzzy images were discovered on photographic plates obtained with the instrument. Subsequent spectroscopic observations revealed that these so-called "stars" actually were of extragalactic nature. In the 1960s Fritz Zwicky established this new fascinating type of objects as a separate morphological type, the "compact galaxies", CGs, defining them by their stellar appearance and by demanding that their surface luminosity should be brighter than 20^{m}arcsec^{-2}. Examples of three such cases, which we are presently investigating, are given in Fig. 1.

Historically it is interesting to note that while Zwicky thought that many compact galaxies represented one of the final stages in the life of a galaxy, closely related to what he called "OBJECT HADES", supposed to be "ultimate objects of greatest compactness", most work today is done on compact galaxies that have properties more typical of newly formed galaxies.

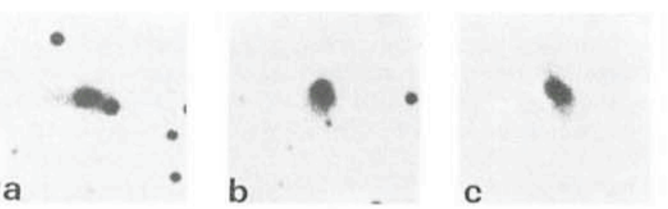

Fig. 1: *Three blue compact galaxies as seen on the ESO Quick Blue Survey plates obtained with the ESO 1 m Schmidt telescope: (a) ESO 338-IG04, (b) ESO 400-G43, (c) ESO 480-IG12 (1 arcmin = 17 mm). Top is north, east is to the left.*

At an early stage Zwicky realized that CGs as a group contained such diverse creatures as giant H II regions, quasars, and stripped-off dwarf ellipticals. This heterogeneous nature of the CGs is reflected in a colour-colour diagram, where they disperse rather much, as is shown in Fig. 2. Here we have plotted positions of 52 CGs in the southern hemisphere, all observed by the Uppsala group. The majority are gathered within the rectangular box where "normal galaxies" are found. However, some of these galaxies show colours that are unusually blue (up and towards the left in the diagram). By far the bluest in our sample is ESO 338–IG04 (B–V = −0.08, U–B = −0.62, extinction corrected). In fact, this object proves to be one of the bluest galaxies ever found.

Two decades ago little was known about these extreme cases. Therefore, a new branch of extragalactic astronomy was developed: the study of blue compact galaxies (BCGs). The blue light is a consequence of the high proportion of young stars in the galaxies, and in some cases no old stars at all can be definitely detected. Among other properties of the BCGs are their richness in gas and their strong deficiency of elements heavier than helium, when compared to galactic H II regions. Therefore, a fundamental question is whether these galaxies are truly young. Alternatively, they may be old galaxies which occasionally go through short bursts of intense star formation. Such a situation is predicted by the stochastic star formation theory (Gerola et al., 1980, *Astrophysical Journal* **242,** 517), provided that the galaxies are sufficiently small. Indeed, the BCGs typically have small sizes. We shall discuss these intricate processes of star formation further in section 4.

In Uppsala, we are now in the process of studying a sample of the bluest compacts by means of observations in the wavelength region from the ultraviolet to the infrared. Besides the already mentioned photometry, we have, for a large sample, obtained spectra of the central regions, mainly by use of the Image Dissector Scanner at La Silla. These show emission-lines and resemble spectra of H II regions superposed on an underlying stellar population. The availability of CCD detectors during the last years has brought new insights into the mystery of BCGs and has revealed peculiarities within these objects that we never would have been able to discover through traditional observational methods. Parallel to the observations we are also developing synthetic models of colour evolution of galaxies as a function of time, based on evolutionary tracks of stars of low metallicity. The purpose is to compare our observed colours with those obtained from the models and thus be able to determine the age of the observed BCGs (for at least the ongoing burst) and to derive information about their stellar mass function. These models will be further discussed below.

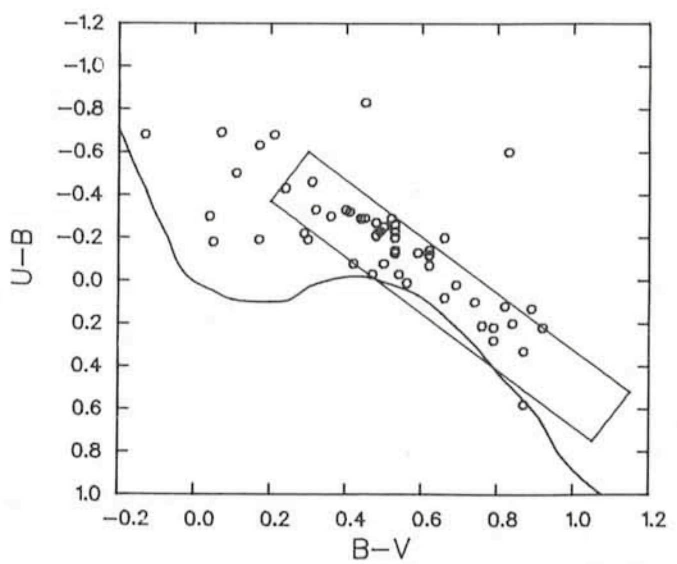

Fig. 2: *U-B/B-V diagram (Johnson system) for a sample of compact galaxies observed with the ESO 1 m telescope at La Silla, by the Uppsala group. Except for a few cases, the aperture covers most of the galaxy. No corrections for galactic extinction have been applied. For comparison, the positions of normal galaxies (box) and galactic main-sequence stars (curve) have been indicated.*

The Proceedings of the IAU Colloquium No. 79 on

"Very Large Telescopes, their Instrumentation and Programs"

which took place in Garching from April 9 to 12, 1984, have now been published. They may be ordered from ESO-Garching.

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2. Breaking Through the Compact Crust . . .

The compact appearance of a BCG is mainly a consequence of its relatively small apparent dimensions and its high surface brightness, which produce overexposed images on the photographic survey plates. Using larger instruments one can resolve the images of these objects and begin to see some very interesting structures.

Fig. 3a shows the appearance of ESO 338–IG04 (see also Fig. 1a) on a short-exposed photographic plate that registers the blue light of the galaxy. The knots surrounding the central "blob" may be giant H II regions or star clusters. A much larger dynamical range is available if one uses a CCD camera as in Fig. 3b and c. The first image (Fig. 3b) shows the result of a division between two CCD frames, one obtained through a broadband filter centred on Hα and the other through an infrared filter centred on ~ 8000 Å (Fig. 3c). Since the "Hα-image" contains light from both gas and stars, while the infrared image is entirely dominated by starlight, the resulting image will show, mainly through the strength of Hα as compared to the stellar continuum, regions where the gaseous emission, and thus probably also the star-forming activity, is most intense. As we can see, a very interesting structure appears, consisting of three hot spots of star formation enclosing the centre. We also see a structure reminding of a spiral arm, stretching out towards the east. It is tempting to interpret the observations in terms of a collapsing agglomeration of H I clouds which are being shocked on their way towards the gravitational centre, thereby triggering the spectacular burst of star formation we are now witnessing. This is what a young galaxy should look like!

The infrared image, however, looks strikingly different with its regular isophotes, more reminding of an old galaxy. It also has a luminosity profile which is typical of old stellar systems. We expect that the time it would take for a galaxy to obtain such a relaxed structure would be of the order of a few 10^8 years.

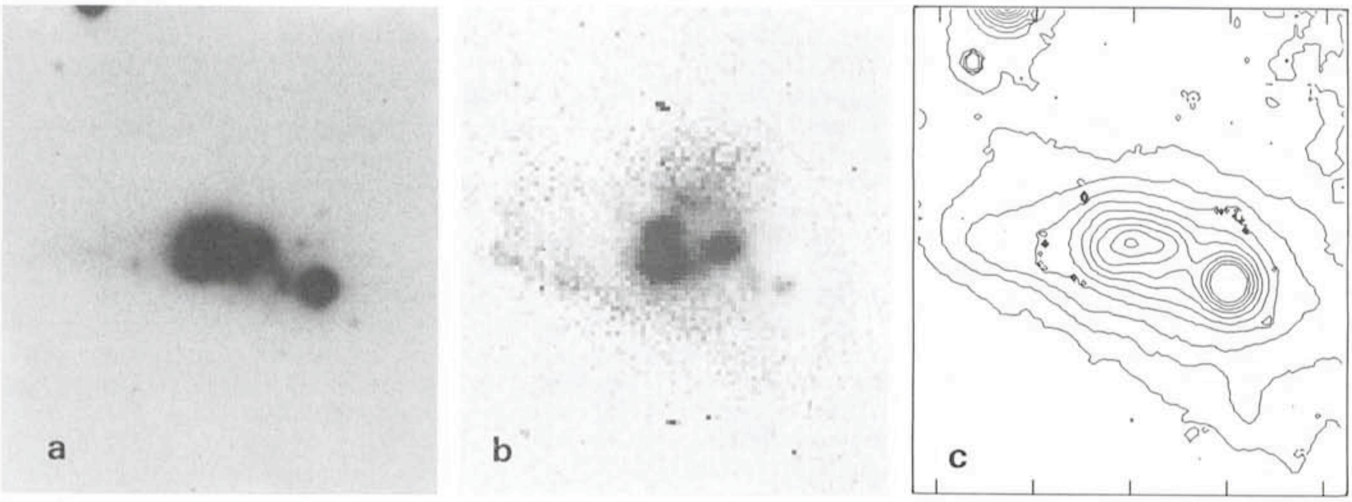

Fig. 3: *Prime focus images of ESO 338-IG04 obtained with the ESO 3.6 m telescope. Top is north, east is to the left. Scale: 0.9" mm⁻¹. A bright star is superposed on the south-west part of the galaxy. (a) Baked IIIa-J +GG385 filter. Exposure time: 20 minutes. This blue image shows the distribution of the youngest stars in the galaxy. (b) CCD exposure through a broadband ($\Delta\lambda = 120$ Å) filter centred on Hα, divided by the following infrared image. This image shows regions where the equivalent width of Hα is large. These regions are likely to contain the hottest stars. (c) Infrared CCD image obtained through a Gunn I filter centred on ~8000 Å.*

The conclusion we draw from these observations is that the burst we now observe in ESO 338-IG04 is probably not the first one to appear in the history of the galaxy.

3. . . . Heading for the Nebulous Core . . .

If we equip our telescope with a good spectrograph and turn it towards the centre of ESO 338-IG04, we obtain the result shown in Fig. 4. This spectrum is quite typical of BCGs. It is dominated by strong emission lines, emitted by a hot gas of low density, which is mixed with, and ionized by, young massive stars. Although we cannot see much of the spectrum of the stars themselves in the optical region, spectra in the ultraviolet wavelength region obtained with the IUE satellite confirm the presence of hot OB stars. From the relative intensities of the emission lines we may calculate the density, electron temperature and the chemical abundances of the interstellar medium in the object. In ESO 338-IG04, as well as in other BCGs, the abundances are found to be low. If we start from the assumption that the galaxies are old, the low abundances can be explained if the mean gas-consumption rate has been lower than in the solar neighbourhood, or if the

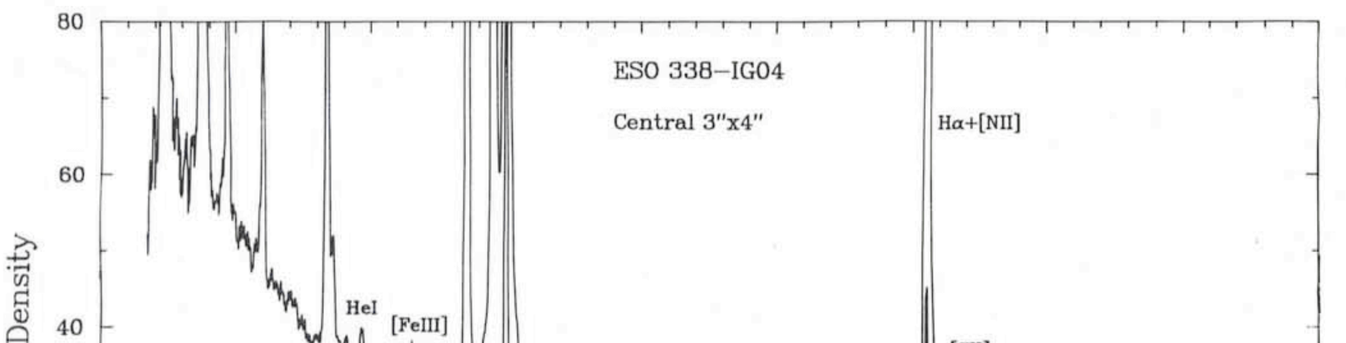

Fig. 4: *Spectrum of the central 3" x 4" (pos. angle = 270°) obtained at the ESO 3.6 m telescope equipped with a Boller and Chivens spectrograph and an Image Dissector Scanner. Two versions of the same spectrum are shown. The lower one has been scaled down by a factor of 10. Flux density unit = 1.0×10^{-19} Wm⁻²Å⁻¹ for the high amplitude spectrum.*

interstellar gas is steadily being replenished by unprocessed gas, being accreted from the halo. In any case the ongoing burst should be shortlived, in accordance with the stochastic star formation theory.

Alternatively we can speculate over the age of the objects; are they truly young systems? The abundances of the heavy elements should then be biased towards those synthesized in the most massive stars, since they are the first ones to exhaust their nuclear fuel and enrich the interstellar medium through supernovae outbursts. Some support for such a case was found from the C/O abundance in ESO 388-IG04, derived tentatively from an IUE spectrum. On the other hand, Silk (1983, *Mon. Not. Royal Astron. Soc.* **205,** 705) and other workers have found reasons to believe that the mass function for stars in a low-abundant medium is weighted towards the more massive ones. This should produce a similar result and is in line with other results presented below.

Of particular interest is the helium content of the interstellar medium. Like the heavy elements, helium is produced through thermonuclear reactions in the stars. But it is also thought to have been produced within the first minutes following the Big Bang. A good value of the primordial helium content may be determined from analysis of spectra of low-abundant BCGs, since the amount of helium produced in stars is small enough not to influence significantly the determination of the primordial value. This is of course of great interest, since the value is tied to the fundamental cosmological parameters, e.g. the baryon density. The value obtained for ESO 338-IG04, after a careful error analysis, is N(He)/N(H) = 7.4 ± 0.4 %, which is unusually low but still rather typical of BCGs. It indicates that the density of baryons alone is not sufficient to halt the present expansion of the universe. Thus, unless neutrinos or other non-baryonic matter strongly dominate the mass in the universe, we are destined to be travellers with one-way tickets in a forever expanding universe.

4. Colourful Models of Galaxy Evolution

One way of testing the assumption that these galaxies are young is by synthesizing their colour evolution as a function of time, and compare the predicted colours with the observed ones. This is accomplished by utilizing evolutionary tracks of stars. Since we know that BCGs in general have low abundances, we can use metal deficient stars to construct as realistic models as possible. The accuracy of the model results are dependent on our knowledge of how stars of different mass, effective temperature and luminosity evolve as a function of time and metallicity. Present theory of stellar evolution provides us with a fairly detailed description of the life-cycle of a star, at least during most of their lifetimes. Unfortunately the red supergiant phase for stars of low abundances is not very well known.

More important for the model result is the chosen form of the initial mass function (IMF), i.e. the amount of stars formed as a function of their mass, and the star formation rate. The most commonly used form of the IMF is the power law function introduced by Salpeter 1955 (*Astrophysical Journal* **121,** 161) where the slope has the value of $\alpha = 2.35$. Another widely used form of the IMF is the Miller-Scalo mass function, which encounters changes in the slope at 1 and 10 solar masses. In order to illustrate the power of the models, we calculated the evolution of a burst of star formation using two contrasting IMFs, the Miller-Scalo function and a comparatively flat IMF ($\alpha = 1.5$ over the whole mass range). Fig. 5 shows the result. The mass range was 0.5–100 solar masses and the star formation rate was assumed to be constant for 20×10^6 years and was then halted completely.

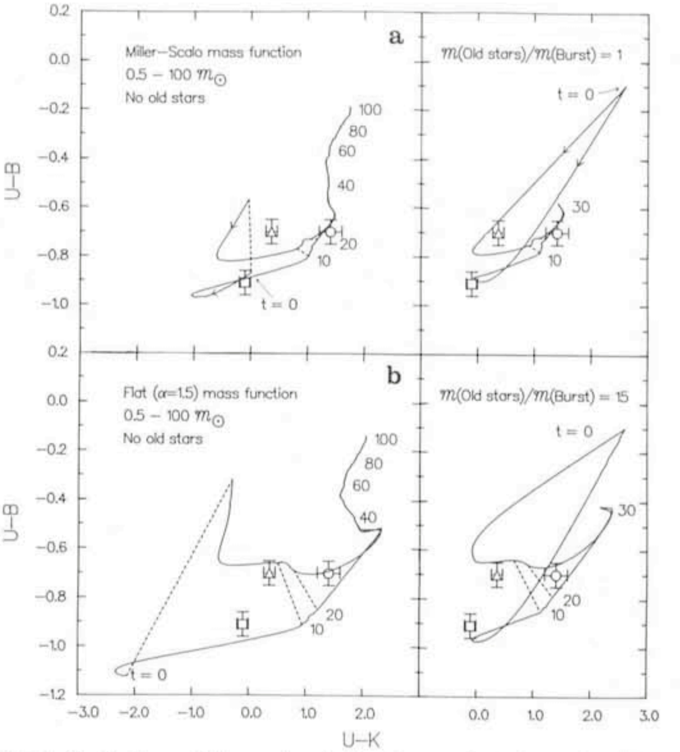

Fig. 5: *Synthetic evolutionary tracks for a burst of star formation. The positions of the three BCGs shown in Fig. 1 are indicated with a square (ESO 338-IG04), a triangle (ESO 480-IG12) and a circle (ESO 400-G43). Bars are mean errors. The U and B magnitudes were obtained with the ESO 1 m telescope, as was the K magnitude for ESO 400-G43. The K magnitude for ESO 480-IG12 was obtained with the ESO 3.6 m telescope while that of ESO 338-IG04 was taken from Gondhalekar et al. (1984,* Mon. Not. R. Astron. Soc. ***209,** 59). The duration of the burst is 20×10^6 years. The time in 10^6 years is indicated along the evolutionary tracks. The left side of the diagrams shows cases where the galaxy contains no old stars, while on the right old stars have been added. Two tracks are displayed in each diagram, the lower one holds for the pure stellar population in the galaxy, while the upper one includes also the effect of gaseous emission. Two forms of the initial mass function (IMF) were chosen, the Miller-Scalo mass function (a) and a considerably flatter mass function, having an exponent of $\alpha = 1.5$ (b). Evidently the flatter IMF fits better to the observations. A more careful check can be made by comparing other colour indices and the predicted line intensities, obtained from the model, with the observed ones.*

For each IMF, two cases are shown, one which encounters its first burst of star formation, and one with a burst superposed on an underlying older stellar population. Plotted are also positions of three BCGs observed by the Uppsala group. Note that the abscissa gives the broadband colour U–K. This we regard as a more decisive choice when compared to the traditionally more used UBV colours. We see that, in general, model and theory coincide very well, especially for the flat mass function. Our model can also provide us with predicted values of fluxes of the gaseous emission lines. They may be used in order to narrow the range of the free parameters in the models. As regards the youth hypothesis, we see that one cannot rule out the possibility that a large proportion of the mass of the galaxy may be in the form of old stars. Even if we include other colour indices, or predicted emission line fluxes, in the comparison, this frustrating situation does not change much. Today our observations and our models are too crude to permit us to make a conclusive distinction between a young stellar population and a mixed one.

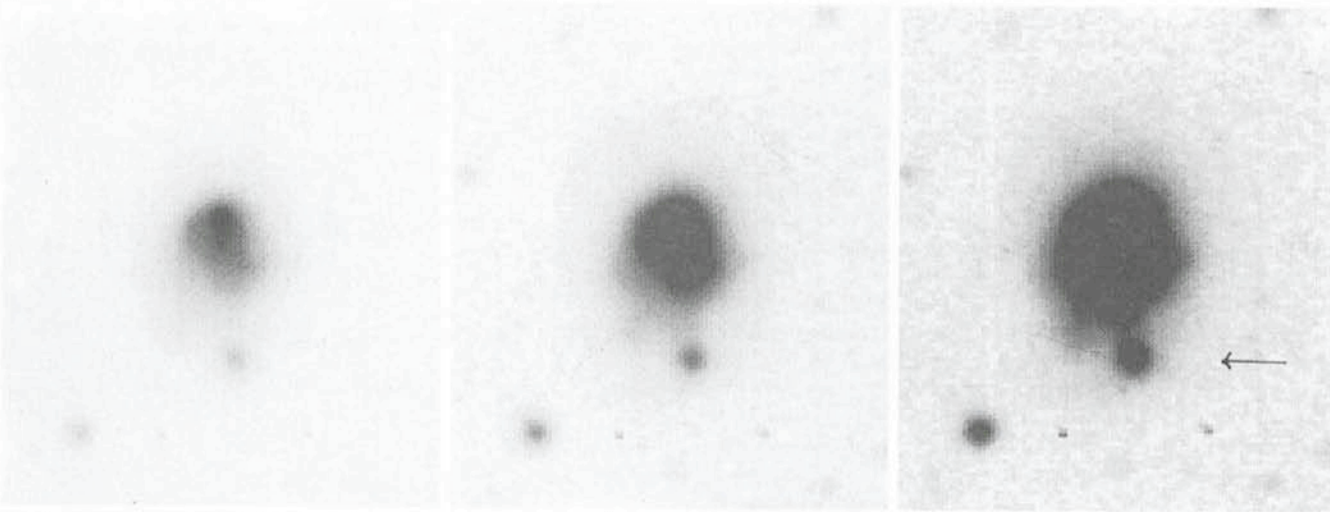

Fig. 6: *CCD image of ESO 400-G43 obtained with the ESO 3.6 m telescope, showing the galaxy as seen in the visual wavelength region. Three different representations of the same exposure are shown in order to let the structural details appear more clearly. The compact object indicated by the arrow is part of the galaxy and shows strong emission lines.*

5. Epilogue

From the preceding discussion we understand that much is still to be learnt about blue compact galaxies. Are they young or are they galaxies that have experienced several bursts of star formation? The answer at this stage has to be yes and no, a diplomatic but still logical answer since we cannot rule out any of these two possibilities. One way of getting ahead is by combining credible spectral synthesis models with carefully planned observations within a broad wavelength region. Results from such work will also be valuable when studying how the IMF and the chemical abundances are related and how they vary across the face of a galaxy. We are now extending our models by implementing spectra of metal-poor stars to the models already presented. More observations in different colours with a CCD camera attached to a large telescope would give us valuable information about the substructure within the objects. Is it complex like in the case of ESO 338-IG04? Do all BCGs have a relaxed structure in the infrared? We note that CCD observations of ESO 400-G43 (Fig. 6) show a smooth (although not symmetrical) structure surrounding the compact core also in the visual. And what is the nature of the peculiar emission-line object situated immediately south of the main body (arrow)? We are facing an exciting future in the exotic work of BCGs!

A Complete Optical Survey of Candidate Quasars Down to B = 22.0 with the ESO 3.6 m Telescope

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The study of the number-magnitude relationship of quasars, together with the statistical analysis of redshift and luminosity distributions of complete samples of quasars at different limiting magnitudes, provides the best tool to investigate the problem of the cosmological evolution of such objects. A summary of the present knowledge on the optical number counts of quasars can be found in recent reviews (see, for example, Woltjer and Setti 1982; Véron 1983). Moreover, after the Einstein X-Ray Observatory provided definitive evidence that quasars are strong X-ray emitters (Tananbaum et al. 1979; Zamorani et al. 1981), the observed optical number counts of quasars have often been used to estimate the overall contribution of this population to the soft X-ray background (Setti and Woltjer 1982; Zamorani 1982). One of the most important sources of uncertainty in this estimate is represented by the still relatively poor knowledge of the detailed behaviour of the number counts relationship for faint ($B > 19.5$) quasars. In fact, it has been shown that, given the observed flattening at faint magnitudes of the number-magnitude relationship, most of the quasars' contribution to the X-ray background is expected from objects in the magnitude range 20–22 (Bonoli et al. 1980).

Two main methods have been successfully applied to the optical selection of quasars:

(1) The ultraviolet excess (UVX) method (see, for example, Braccesi et al. 1980), based on the observational evidence that almost all the known quasars with $z < 2.2$ show $U\text{-}B < -0.40$. Since high galactic latitude stars with this colour are rare objects, especially at faint magnitudes, this method provides quite complete and reasonably uncontaminated samples of candidate quasars with $z < 2.2$.

(2) The search for emission-line objects and/or objects with blue continuum on deep "grism" plates. This method is highly efficient in finding high redshift quasars, and, in fact, almost all the radio quiet quasars with redshift larger than 3 have been found by this technique. However, its level of completeness