Observations of the Shell Galaxy NGC 3923 with EFOSC

J.-L. PRIEUR, Observatoire du Pic-du-Midi et de Toulouse, France

NGC 3923 was observed at the 3.6-m ESO telescope in March 1985 with EFOSC, the ESO Faint Object Spectrograph and Camera (Dekker and D'Odorico, 1985). The results of these observations and other observations made at CFHT and AAT are described in more detail in Prieur (1987). NGC 3923 is an elliptical galaxy which exhibits peculiar arc-like structures or "shells" aligned with the major axis. They were first discovered by Malin (1977). Malin developed new techniques of photographic processing which are very efficient for detecting faint outer extensions around galaxies ("contrast enhancement") or inner structures superimposed over a bright background ("unsharp masking"). At present such shells have been seen around more than 140 elliptical galaxies. NGC 3923 appears as the richest system among the shell galaxy catalogue of Malin and Carter (1983). As an aligned system, it could be representative of the class of "aligned" systems which represent about 35 % of shell galaxies (Wilkinson et al., 1988). As it seems that at least 17 % of isolated elliptical galaxies are shell galaxies (Malin and Carter, 1983), the understanding of the origin of these structures is important for our knowledge of ellipticals and galaxies in general.

Quinn (1984) proposed a model to account for the properties of the shells. In his model, shells are the remnant of the merging of a small galaxy within a large elliptical. In phase space the location of the infalling stars wraps around the origin with time. Shells are density waves formed by stars near the apocentre. Another model was proposed by Williams and Christiansen (1985). The origin of the shells is internal to the elliptical galaxy. Stars form within an expanding blast wave of matter ejected from an active nucleus in an early phase of the history of the galaxy. But according to the authors themselves such a model cannot account for the large number of shells observed around NGC 3923.

Sandro D'Odorico included the observations of NGC 3923 in a technical run of EFOSC in March 1985 as a way to test the photometric accuracy and the speed of the instrument. EFOSC was used in direct imaging mode as an F/2.5 focal reducer with a B filter. The detector was a thinned, back-illuminated RCA CCD with 320×512, 30μm pixels. The resulting field was 3.′6 × 5.′7 with a scale of 0.″67/pixel (seeing ≈ 1.″9).

A series of 5 pictures were taken with the same orientation, moving the telescope slightly between each exposure. Each image was corrected following the usual procedure by subtracting a bias model and dividing by a mean flat field. The cosmetic defects of the chip (mainly a bad column and some "hot spots") were removed by interpolation on the surrounding pixels. We noted a slight light concentration in the centre of the frames (Cf. Fig. 1). We used these pictures for determining shell profiles and worked on thin slices. Since shells are thin we could interpolate the value of this light gradient in the profiles (in the same way that we computed the residuals of the background of the galaxy). Comparing the results from ESO frames with AAT images we could verify that there was a good agreement. Therefore for our purpose, this light gradient did not affect our measurements. The actual shift of each image was determined by measuring the centres of unsaturated stars. Then the images were shifted back and added. The result was checked by comparing the F.W.H.M. of some stars before and after the operation. One of the major advantages of this

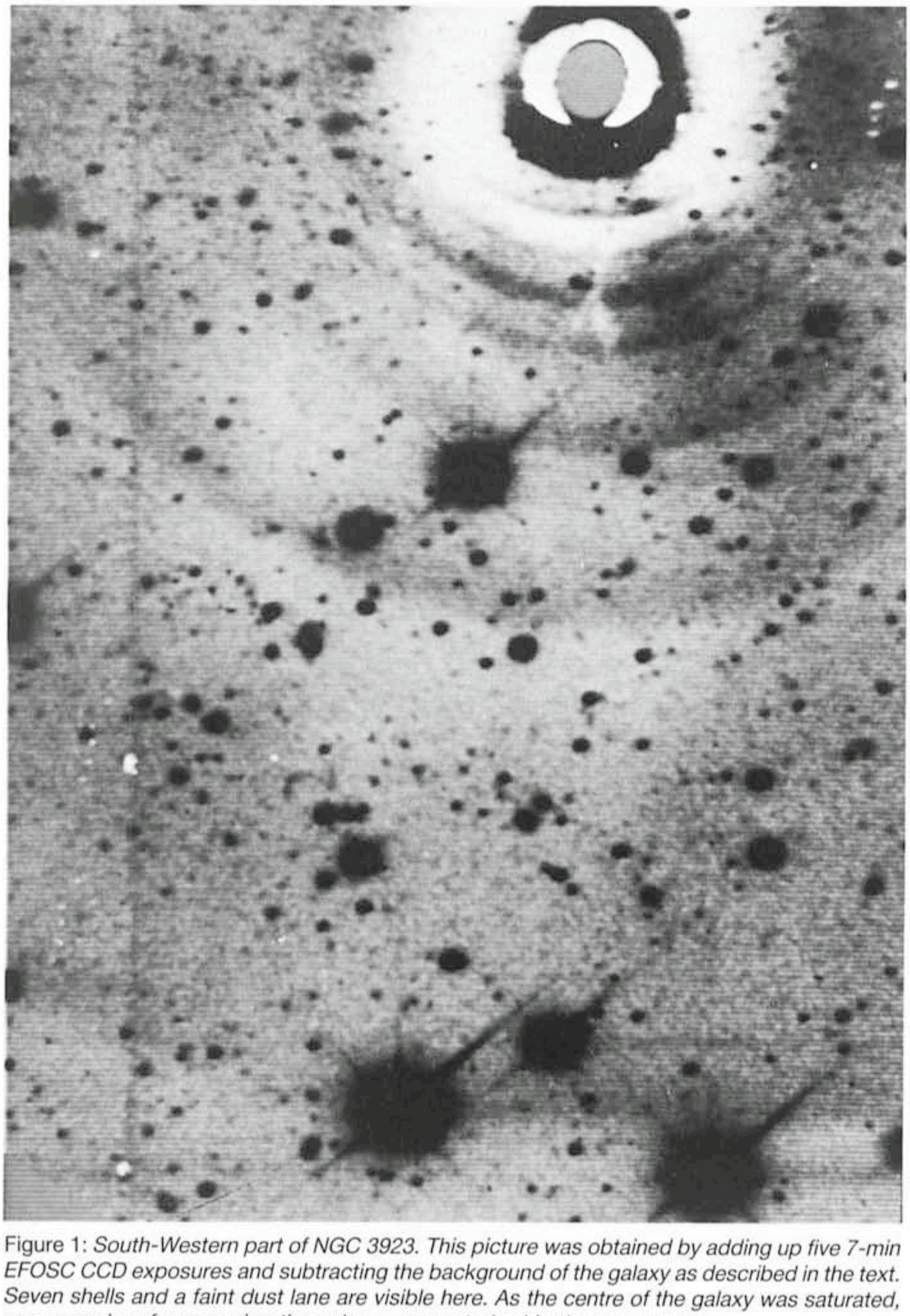

Figure 1: *South-Western part of NGC 3923. This picture was obtained by adding up five 7-min EFOSC CCD exposures and subtracting the background of the galaxy as described in the text. Seven shells and a faint dust lane are visible here. As the centre of the galaxy was saturated, our procedure for removing the galaxy was perturbed in the very centre.*

technique is to increase the intensity range of the images avoiding the problem of electronic saturation of long exposures.

Shells around NGC 3923 are faint and it is difficult to distinguish them from the bright background of the galaxy. Except for the outer shells the galaxy background had to be removed for our study, as we did to compute the shell colours in a previous paper (Fort et al. 1986). A luminosity profile of NGC 3923 was computed and used to construct a model for the galaxy, assuming a simple geometry of concentric ellipses. This background was subtracted and shells appeared clearly as shown in Figure 1. Following Malin (1977) we also used unsharp masking filtering which was effective for the inner shells.

The Shells Around NGC 3923

NGC 3923 seems a normal elliptical with no unusual features apart from the shells. Our estimate of the central M/L ratio, $M/L = 13. \pm 2.$ ($h = 0.75$), is compatible with most elliptical galaxies.

The galaxy is surrounded by about 22 shells aligned with the major axis. The dynamical range in radius is very large with a distance of about 100 kpc for the outermost shell and about 1.7 kpc for the innermost shell ($h = 0.75$). They are regularly spaced in the outer parts, but not in the inner parts where some can be associated in pairs of the same distance. The interleaving of the outer shells gives strong support to Quinn's model with wrapping in phase space. In the centre the system is as regular. This needs to be investigated with numerical simulations.

The shells have a roughly constant ellipticity, $E = 1. \pm 0.4$, and a roughly constant angular extent of about 60°. Dupraz and Combes (1986) suggested that the shape of the shells could be related to the equipotentials of the main galaxy. A brief study of the shape of current models of ellipticals shows that the shells have ellipticities of the same magnitude as the expected ellipticities for the equipotentials. But the uncertainties are rather large and the graphs do not show any obvious relationship. The shape of shells has still to be studied in theory.

New shells were found in the outer parts and very close to the centre of the galaxy (less than 2 kpc). To account for the presence of shells very close to the centre a dissipative process has to be invoked. This argument gives support to current models with a progressive launching of stars from an infalling galaxy which is slowed by dynamical friction.

Profiles were computed for 19 shells. Shells do not appear as "plateaus" as predicted by Hernquist and Quinn (1987c). But we think this is linked to the fact that these authors did not use an angularly limited shell for the projection onto the line of sight. We used a simple 3-dimensional model with a gaussian radial distribution and limited angular extent, and obtained good agreement with the observed profiles. The shell thickness parameter appears to be roughly constant for the inner shells $r_g = 0.17\ kpc \pm 0.11$.

The total luminosity of the shells is about 5 % of the luminosity of NGC 3923. In the merging scenario the number of stars actually in the shells is only a fraction of the total number of orbiting stars. Therefore the luminosity of the infalling companion is expected to represent more than 5 % of the total luminosity of NGC 3923.

The outermost shells are much brighter than the inner ones and contribute a large part of the total luminosity. Shell 1-N is three times as bright as the sum of the 17 inner shells. Therefore it seems that the infalling galaxy lost most of its stars in the first few oscillations. The remaining core was slowed down by dynamical friction and progressively disrupted but at a slower rate. Because of this loss of energy caused by dynamical friction, it sank deeper and deeper into the potential well, eventually forming shells at less than 2 kpc from the centre. From the total luminosity of the shells and the study of Dupraz et al. (1987) it seems that in such a scenario dynamical friction alone cannot account for the observed distribution of the shell distances and luminosities. But it is likely to reduce significantly the previous estimates of the mass of dark matter needed to account for the shell radial distribution.

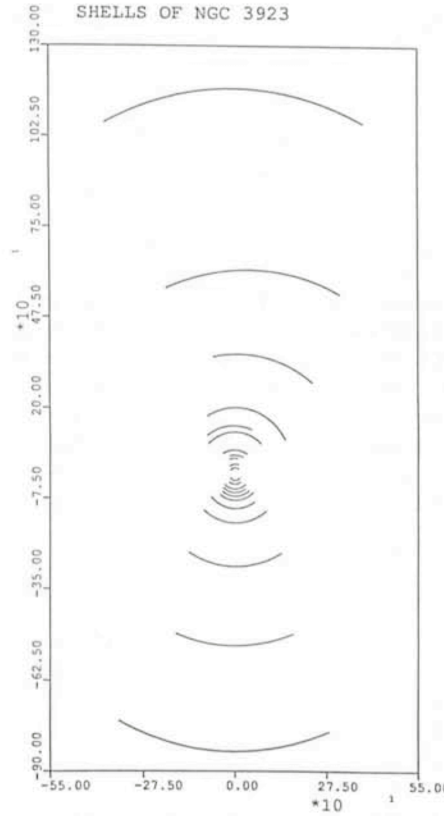

Figure 2: *Schematic diagram of the shells around NGC 3923. This diagram was obtained with observations from CFHT, AAT, and ESO.*

The Discovery of a Dust Lane Aligned with the Major Axis of the Galaxy

On the ESO CCD images a dust lane aligned with the major axis is visible in the South Western part of the galaxy, from about 30 arcseconds from the centre to about 80 arcseconds. The inner limit is probably underestimated since the galaxy background is very bright in the inner regions. This dust lane is rather faint and is best visible on processed images (Fig. 1). It is likely to go through the centre and also be present on the North Eastern side but unfortunately we do not have very deep exposures for the North Eastern side.

Preferred planes in different models of ellipticals have been studied in detail by many authors (see for example Habe and Ikeuchi [1985]) who have shown that only the equatorial plane of the potential is stable in a prolate potential or in an oblate potential. Dust lanes aligned with the major axis of bi-axial galaxies are stable only in oblate galaxies. Thus if this dust lane is in a stable configuration, NGC 3923 is not prolate. Such an observation seems to disagree with the conclusions of Dupraz and Combes that NGC 3923 was the archetype of prolate systems (Dupraz and Combes 1985, 1986). Of course, we must be careful in our interpretation of these observations since the possibility of an unstable configuration of the dust lane cannot be excluded.

In triaxial systems dust lanes in stable configuration can be observed aligned with either the longest or the shortest axis. Therefore NGC 3923 could also be a triaxial system.

Tumbling prolate systems could also have a dust lane aligned with the major axis but only at large distances from the centre where the orbital time is large compared to the tumbling period (Tohline and Durisen 1982). In that case the dust lane would only "feel" a smoothed potential which is oblate for a prolate galaxy tumbling around its minor axis. There are two objections to this hypothesis. First the outer shells would also feel an oblate potential and their geometry would be affected. It is shown by Dupraz et al. (1986) that outer shells are randomly distributed in angle in a tumbling bar with aligned inner shells since in the inner parts the orbital time is smaller than the tumbling period, and the inner shells can feel a prolate potential. Secondly the dust lane is too close to the centre of the galaxy to feel a "smoothed" potential when all the shells feel a prolate potential.

Conclusions

The complementary observations made at ESO brought a decisive contribution to the comprehensive study of NGC 3923 which is about to be published (Prieur 1987). With other observations from AAT and CFHT they allowed us to obtain accurate positions of faint shells around the galaxy, and measure physical parameters which can be directly compared to theoretical models and numerical simulations. It was found that models published until now do not fully account for the properties that we have observed. Among the current models the merging model seems to be the more likely to be able to solve the problem. The main theoretical problem is the modelling of dynamical friction in the centre of the galaxy (which is far from being negligible as some authors thought). This study provides new parameters which had never been measured and which go further than what numerical simulations or theoretical studies have been able to predict until now. We hope that this work will stimulate new theoretical developments on this field.

These observations with EFOSC as a focal reducer demonstrate that this instrument can also be a very efficient and powerful tool for photometry of extended objects. The decisive data used in this paper came from only a few 7-minute exposures!

Acknowledgements

I am very grateful to Sandro D'Odorico for obtaining the CCD pictures of NGC 3923.

References

Dekker, H., D'Odorico, S., 1985, *ESO Operating Manual* No. 4.
Dupraz, C., Combes, F., 1985, in "New Aspects of Galaxy Photometry". Ed. J.-L. Nieto, *Lectures Notes Phys.* (Springer Heidelberg Berlin).
Dupraz, C., Combes, F., 1986, *A & A* **166,** 53.
Dupraz, C., Combes, F., Gerhard, O.E., 1987, *A & A* preprint.
Dupraz, C. Combes, F., Prieur, J.-L., 1986, "Structure and Dynamics of Elliptical Galaxies", IAU Symp. no. 127, Ed. T. De Zeeuw (Dortrecht Reidel), in press.
Fort, B., Carter, D., Prieur, J.-L., Meatheringham, S.J., Vigroux, L., 1986, *Ap. J.* **306,** 110.
Habe, A., Ikeuchi, S., 1985, *Ap. J.* **289,** 540.
Hernquist, L., Quinn, P.J., 1987a, *Ap. J.* **312,** 1.
Hernquist, L., Quinn, P.J., 1987b, preprint.
Malin, D.F., 1977, *A.A.S. Photo-Bulletin* **16,** 10.
Malin, D.F., Carter, D., 1983, *Ap. J.* **274,** 534.
Prieur, J.-L., 1987, *Ap. J.* submitted.
Quinn, P.J., 1984, *Ap. J.* **279,** 596.
Tohline, J.E., Durisen, R.H., 1982, *Ap. J.* **257,** 94.
Wilkinson, A., Carter, D., Malin, D.F., Prieur, J.-L., Sparks, B., 1988, in preparation.
Williams, R.E., and Christiansen, W.A., 1985, *Ap. J.,* **291,** 80.

Visiting Astronomers

(October 1, 1987–April 1, 1988)

Observing time has now been allocated for Period 40 (October 1, 1987–April 1, 1988). As usual, the demand for telescope time was much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6-m Telescope

October 1987: Moorwood/Oliva, Danziger/Moorwood/Oliva, Bergvall/Johansson, Moeller/Kjaergaard Rasmussen, Pickles/van der Kruit, Soucail/Fort/Mathez/Mellier/D'Odorico, Mellier/Soucail/Fort/Mathez, Bergeron/Boissé, Maccagni/Vettolani, Danziger/Gilmozzi, Benvenuti/Porceddu.

November 1987: Benvenuti/Porceddu, Kudritzki/Humphreys/Groth/Butler/Steenbock/Gehren/Fitzpatrick, Wolf/Stahl/Davidson/Humphreys, Reitermann/Bascheck/Scholz/Krautter/Wolf, Richtler, Surdej/Courvoisier/Magain/Swings, Butcher/Mighell/Buonanno, Ellis/Couch/D'Odorico, Schwarz/Larsson, Chincarini/Manoussoyanaki, Breysacher/Azzopardi/Lequeux/Meysonnier/Rebeirot/Westerlund, di Serego Alighieri.

December 1987: Westerlund/Azzopardi/Rebeirot/Breysacher, Azzopardi/Lequeux/Westerlund, Pottasch/Pecker/Karoji/Sahu, Zadrozny/Leggett/Perrier, Kern/Merkle/Lacombe/Léna, Nesci/Perola, Westerlund/Lundgren/Edvardsson, Kunth/Schild/Arnault, Melnick, Cristiani/Barbieri/Clowes/Iovino/Nota, Melnick, Wampler, Reimers/Schröder/Toussaint.

January 1988: Reimers/Schröder/Toussaint, Becker/Appenzeller/Wilson/Schulte-Ladbeck, Koornneef/Israel, Bouvier/Bertout, Giraud, Bignami/Caraveo/Vigroux, Renzini/D'Odorico/Greggio/Bragaglia/Federici, Östreicher/Ruder/Seifert/Wunner, Mathys/Maeder, de Loore/David/Hensberge/Verschueren/Blaauw.

February 1988: de Loore/David/Hensberge/Verschueren/Blaauw, Rosa, Danziger/Cristiani/Guzzo, Meylan/Djorgovski, Röser/Meisenheimer/Perley, Trinchieri/di Serego Alighieri, Bianchi/Grewing/Bässgen M., François/Matteucci.

March 1988: François/Matteucci, Kudritzki/Méndez/Husfeld, Ruiz/Maza/Méndez, Jakobsen/Perryman, Pottasch/Manchado/Mampaso, Jarvis/Martinet, Le Bertre/Epchtein, Dennefeld/Bottinelli/Gouguenheim/Martin, Krautter/Mundt/Hessman/Ray, Israel/van Dishoeck.

2.2-m Telescope

October 1987: MPI time, Schwarz.

November 1987: Schwarz, Landi Degl'Innocenti/Landolfi/Pasquini, Bues/Pragal, Gouiffes/Cristiani, Surdej/Courvoisier/Kellermann/Kühr/Magain/Swings/Refsdal, Cayrel/Tarrab, Butcher/Mighell/Buonanno, Christensen/Sommer-Larsen/Hawkins, Westerlund/Azzopardi/Rebeirot/Breysacher.

December 1987: Gouiffes/Cristiani, Fusi Pecci/Buonanno/Corsi/Greggio/Renzini/Sweigart, Fusi Pecci/Buonanno/Corsi/Ferraro/Bragaglia, Meylan/Djorgovski, Paresce/Burrows/Viotti/Lamers, Weigelt/Baier/Fleischmann.

January 1988: Lyngå/Johansson, Le Bertre/Epchtein, Courvoisier/Bouchet/Robson, Tanzi/Bouchet/Falomo/Maraschi/Treves, Pakull/Stasinska/Testor/Motch/Heydari-Malayeri, Wouterloot/Brand/Stirpe, Reipurth/Zinnecker, Rodríguez Espinosa/Stanga, MPI time.

February 1988: MPI time, Schwarz/Larsson.

March 1988: Schwarz/Larsson, Schwarz/Aspin/Magalhaes/Schulte-Ladbeck, Durret/Boisson/Bergeron, Krautter, Galletta/Bettoni, Ulrich/Pierre, Tosi/Focardi/Gregio, Piotto/Capaccioli, Capaccioli/Held/Nieto, Aurière/Koch-Miramond/Cordoni, Ögelman/Aurière/Alpar, Gouiffes/Cristiani.

1.5-m Spectrographic Telescope

October 1987: Lortet/Testor, Danziger/Fosbury/Lucy/Wampler, Schwarz, Johansson/Bergvall, Dettmar/Barteldrees, Maccagni/Vettolani, Herczeg/Drechsel.

November 1987: Herczeg/Drechsel, Pasquini/Schmitt, Bues/Müller/Rupprecht, Bertola/Buson, Sauvageot/Dennefeld, Balkowski/Maurogordato/Proust/Talavera, Danziger/Fosbury/Lucy/Wampler.

December 1987: Danziger/Fosbury/Lucy/Wampler, Courvoisier/Bouchet, Pottasch/Pecker/Karoji/Sahu, Mantegazza, Lundgren, Rafanelli/Marziani, Divan/Prévot-Burnichon, Danziger/Fosbury/Lucy/Wampler.

January 1988: Danziger/Fosbury/Lucy/Wampler, Tanzi/Bouchet/Falomo/Maraschi/Treves, Bica/Alloin, de Ruiter/Lub, Alloin/Baribaud/Pelat/Phillips, Tarrab, Thé/Westerlund/Vardya, Danziger/Fosbury/Lucy/Wampler.

February 1988: Möllenhoff/Bender/Madejsky, Arsenault/Durand, Duerbeck, Danziger/Fosbury/Lucy/Wampler, Gerbaldi/Faraggiana/Castelli.

March 1988: Gerbaldi/Faraggiana/Castelli, Friedjung/Bianchini/Sabbadin, Alloin/