Mem. S.A.It. Suppl. Vol. 25, 41


**Memorie** della
**Supplementi**

# Multi-wavelength structural decomposition of nearby galaxies

M. Vika[1], S. Bamford[2], B. Häußler[2], and A. Rojas[1]

[1] Carnegie Mellon University in Qatar, Education City, PO Box 24866, Doha, Qatar
e-mail: mvika@qatar.cmu.edu
[2] School of Physics and Astronomy, The University of Nottingham, University Park, Nottingham, NG7 2RD, UK

**Abstract.** We present a modified version of the two-dimensional galaxy fitting software, GALFIT. Our new technique, named GALFITM, extends GALFIT's current single-band fitting process and enables a galaxy to be fit using images at many different wavelengths simultaneously. Each profile parameter may vary as a function of wavelength, with a user-definable degree of smoothness, from constant to fully free. I verify the advantages of our technique by applying it to a sample of 4026 galaxies with *ugriz* imaging data, comprising the original SDSS imaging for 163 low redshift galaxies and 3863 artificially redshifted images of the same galaxies. Our technique enables physical parameters of galaxy components to be robustly measured at lower signal-to-noise and resolution than would otherwise be possible.

**Key words.** galaxies: structure – galaxies: photometry – methods: data analysis – techniques: image processing

## 1. Introduction

Fitting an analytic function to the two-dimensional surface brightness profile of a galaxy provides a powerful method of quantifying its internal structure. The resulting parameters reveal the size, shape and luminosity of the galaxy and its separate structural components (e.g., disk and bulge). Current galaxy fitting techniques typically consider only a single image at a time. However, variations in stellar populations between and within galaxy structures indicate that their observed properties depend on wavelength. Correctly studying the physical properties of galaxy components requires that these wavelength variations are accounted for. Current multi-wavelength studies require significant compromises: either the fits to each band must be done independently, or one band must be favoured for determining structural parameters, which are then imposed on fits to the other bands.

In this proceeding we will demonstrate a new technique developed as part of the MegaMorph project. We investigate ways of improving our ability to extract physically meaningful structural information from galaxy images (Bamford et al. 2011) by testing the performance of GALFITM for fitting single-Sérsic profiles to galaxy images with a wide range of resolution and signal-to-noise. This is achieved by analysing Sloan Digital Sky Survey (SDSS; Abazajian et al. 2009) images of nearby galaxies, as well as versions of these images that have been convolved and resampled to simu-

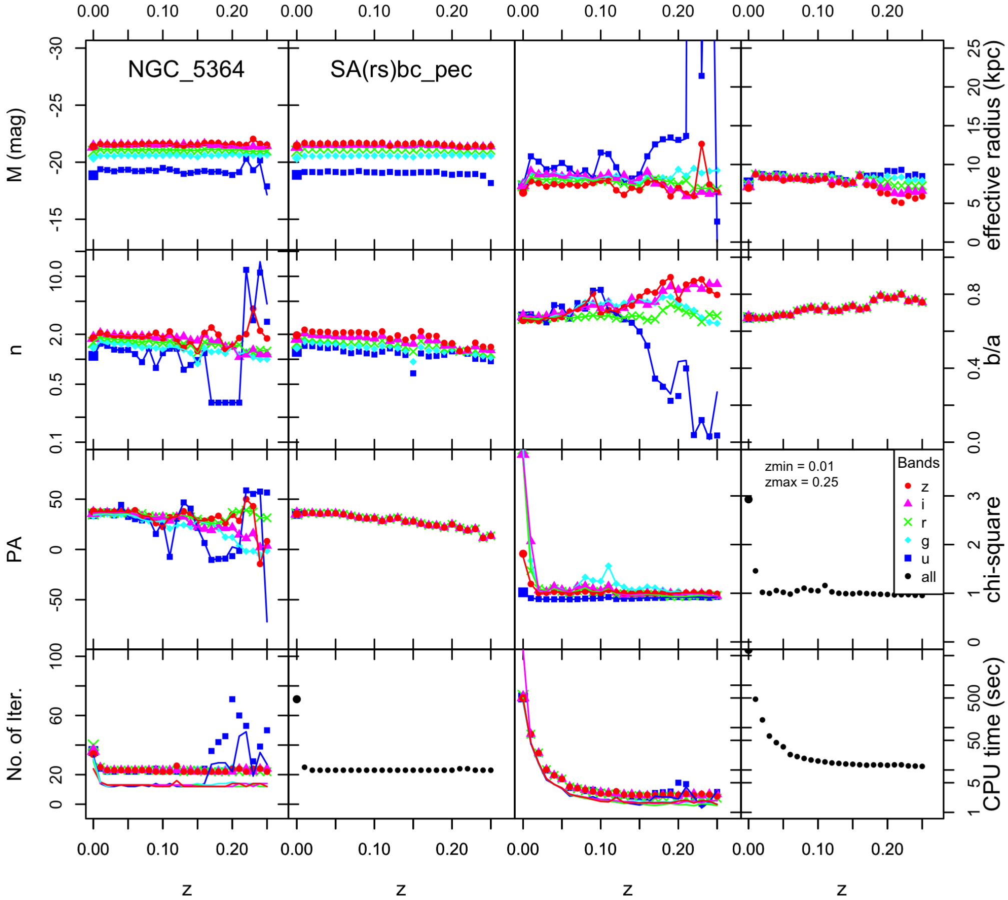


**Fig. 1.** A series of plots presenting the variation of recovered parameters as a function of redshift for galaxy NGC5364. First and third columns show the results of single-band fits (points:GALFITM, lines:GALFIT) while the second and the fourth columns show results of our multi-band fits. The points at redshift zero in each panel give the values for the original galaxy image, while the rest of the points represent the artificially redshifted images.

late their appearance at a range of higher redshifts.

## 2. GALFITM

We have adapted GALFIT (Peng et al. 2002, 2010) version 3.0.2 for the requirements of this project. To differentiate our modified version from the single-band version we refer to it as GALFITM. The code will be publicly released in the near future.

The standard version of GALFIT accepts only a single image with which constrains the model fit. It was therefore necessary to make a number of significant modifications to enable the use of multiple images. However, most of the original code is used unmodified, and our new version is backward compatible when used with one image (Vika et al. in prep.). The most important new feature of GALFITM is the ability to accept an arbitrary number of images at different wavelengths. To these images GALFITM fits a single, wavelength-dependent, model. Each Sérsic model has a number of free parameters, e.g. centre position ($x_c$, $y_c$), magnitude ($m$), effective radius ($r_e$), Sérsic index

($n$), axial ratio ($b/a$) and position angle ($\theta$). To extend these component functions to multi-wavelength, their free parameters are replaced with functions of wavelength. These are chosen to be Chebyshev polynomials. In the fitting algorithm, the standard parameters are thus replaced by the coefficients of these polynomials.

The implementation of this technique has been achieved in a general manner, so all of the standard GALFIT component functions are available, and all of the standard parameters of those functions are treated identically. For full details please refer to Bamford et al (in prep.).

## 3. Fitting

Our primary aim in this proceeding is to evaluate the benefits of modelling galaxy structure by simultaneously fitting imaging data at a variety of wavelengths. For this purpose we select 163 galaxies which are located within the footprint of the SDSS and *ugriz* images are available. Also, we wish to assess the accuracy and reliability of galaxy profile fitting over wide ranges of spatial resolution and signal-to-noise, and, in particular, compare the performance of single- and multi-band fitting techniques. For this purpose we constructed a sample of artificially redshifted images with the use of FERENGI (Barden et al. 2008).

We obtain the structural parameters of our galaxies by fitting two-dimensional elliptical single-Sérsic models using both GALFIT and GALFITM. We run three types of fit, each of which is performed on the $u$, $g$, $r$, $i$, $z$ band images for all of our original and redshifted galaxies. The first run fits each band individually with GALFIT (single-band fitting), the second repeats the same fits using GALFITM (again single-band fitting), and the third run fits each galaxy with GALFITM using all the five bands simultaneously (multi-band fitting).

In the multi-band fitting we choose to allow magnitudes to vary completely freely between bands. In practice, this means that we set the wavelength dependence of magnitude to be described by a 4th order polynomial, i.e. with as many coefficients as the number of bands. We allow full freedom as we wish to avoid any potential biases on the recovered magnitudes, and hence colours, which may result from assuming a lower-order polynomial dependence.

For effective radius and Sérsic index we elect to allow linear variations with wavelength. In contrast to magnitude, we expect physical variations in these parameters to be smaller and smoother, particularly when compared to their measurement uncertainties and overt the limited optical wavelength range considered in this paper ($\sim$ 350–900 nm). Finally, we assume that the shapes of our galaxies do not change within the range of wavelength defined by SDSS bands, so we specify the galaxy center, the axis ratio and the position angle to be constant with wavelength. These parameters are still free to vary during the fit, just without any variation with wavelength.

In all the three runs we use the same initial parameters for galaxy center ($x_c, y_c$), magnitude ($m$), effective radius ($r_e$), Sérsic index ($n$), axis ratio ($b/a$), position angle ($\theta$) and sky background value (although different values are used for each galaxy image, as described below). First, we fit the sample of original galaxy images. Once we have established accurate fits for the original images, we repeat the same three runs of the fitting process on the artificially redshifted images.

For each galaxy we visually inspect all recovered parameters for both original and artificial images. In Figure 1 we present a summary of the results for one example galaxy. In this figure, the first and the third columns show the results of the single-band fits (points: GALFITM, lines: GALFIT) while the second and the fourth columns show the results of the multi-bands fits. The first row of panels shows the absolute magnitude ($M$) and effective radius, where the fit was successful, both for original and artificially-redshifted images. The second row shows the Sérsic index and axis ratio, while the third row shows presents the position angle and the minimised chi-square. Finally, the last row shows the number of iterations needed to fit each galaxy and the cpu time taken by the fitting process. In these figures, absolute magnitude and effective radius are determined assuming distances simply derived from the observed redshift and adopted cosmology.

Figure 1 presents the recovered structural parameters for the galaxy NGC5364. The first thing to mention is that, ignoring *u*-band for a moment we note that the results for the single-band approach agree very well between GALFIT (lines in columns 1 and 3) and GALFITM (points in columns 1 and 3). The results for single- and multi-band techniques also generally agree for low redshift recovered parameters. If we now focus on the *u*-band, the lowest signal-to-noise band, we see that for the single-band methods first *n* begins to show an increasing scatter, then *PA* and $b/a$, and finally *M* and $r_e$. Other bands start to show significant increases in scatter for higher redshifts, particularly for *n*. In contrast, the multi-band fitting results remain consistent for all bands to higher redshifts. Significantly increased scatter does not set in for any parameters until $z \gtrsim 0.16$.

The more reliable behaviour of our multi-band method is a result of their structural parameters being constrained by more data, with many of the values required to display a degree of consistency between bands. Remember that there is no restriction on the variation of magnitude with wavelength, hence the improvement of the values in this parameter are the indirect result of the linear constraints imposed on the other parameters. The behaviours seen in Figure 1 are typical for many of the galaxies in our sample.

## 4. Conclusions

By comparing single- and multi-band fitting we found that for low signal-to-noise bands (*u* and *z*) there is a clear reduction of both the systematic and statistical uncertainties for fainter galaxies. Another important advantage of multi- versus single-band fitting is that the multi-band approach increases the number of galaxies that are successfully fitted (For more details see Häußler et al. in prep.). These improvements are noticeable for low quality data, but in all the tests we performed multi-band fitting is found to improve upon, or at least do no worse than, single-band results in terms of accuracy and robustness.

*Acknowledgements.* This publication was made possible by NPRP grant # 08-643-1-112 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors. BH and MV are supported by this NPRP grant. SPB gratefully acknowledges an STFC Advanced Fellowship. We would like to thank Carnegie Mellon University in Qatar and The University of Nottingham for their hospitality. Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/.

## References

Abazajian K. N., et al., 2009, ApJS, 182, 543

Bamford S. P. , Häußler B., Rojas A. & Borch A., 2011, Astronomical Data Analysis Software and Systems XX, 442, 479

Bamford S. P., et al., in prep.

Barden M., Jahnke K. & Häußler, B., 2008, ApJS, 175,105

Häussler B., et al., 2013, MNRAS, 430, 330

Peng C.Y., Ho, L.C., Impey C.D. & Rix H.-W., 2002, AJ, 124, 266

Peng C.Y., Ho, L.C., Impey C.D. & Rix H.-W., 2010, AJ, 139, 2097

Vika M., et al., in prep.