MEGAMORPH

– advanced galaxy decomposition for large multi-wavelength surveys

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Find more information, and get the software, at:
www.nottingham.ac.uk/astronomy/megamorph

Motivation

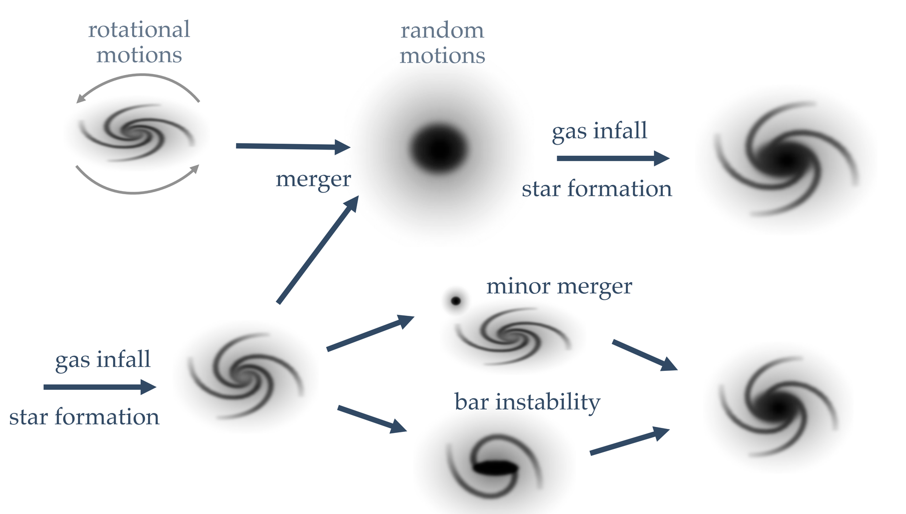
The distinct stellar **structural components** of galaxies – bulges, disks, bars and finer features – retain detailed 'memories' of their assembly and star-formation histories. This valuable information is greatly degraded when the components are averaged over, for example through the use of aperture photometry, as typical in the analysis of large surveys. Classifying galaxies by morphological type (or proxies, such as concentration or colour) allows one to consider subsets of similar objects, but does not overcome the key averaging issue.

Quantifying the spatial, kinematic and spectral energy distributions of the separate structural components in the Milky Way and other individual nearby galaxies, has proved essential to our knowledge of the basic physics governing the formation and evolution of these systems. Accessing similar information for very **large samples of galaxies**, covering wide ranges of mass and environment, will similarly allow us to differentiate between the various plausible mechanisms that may operate on the galaxy population.

Current extragalactic surveys already produce well-resolved images for hundreds of thousands of galaxies in a variety of wavebands. The areal coverage, depth and spatial resolution of imaging surveys is rapidly increasing. At the same time resolved galaxy images are being obtained over wider wavelength ranges and with finer wavelength sampling. There is a need to make optimal use of these **multi-wavelength datasets** in order to address key questions of galaxy evolution.

Two distinct galaxy components

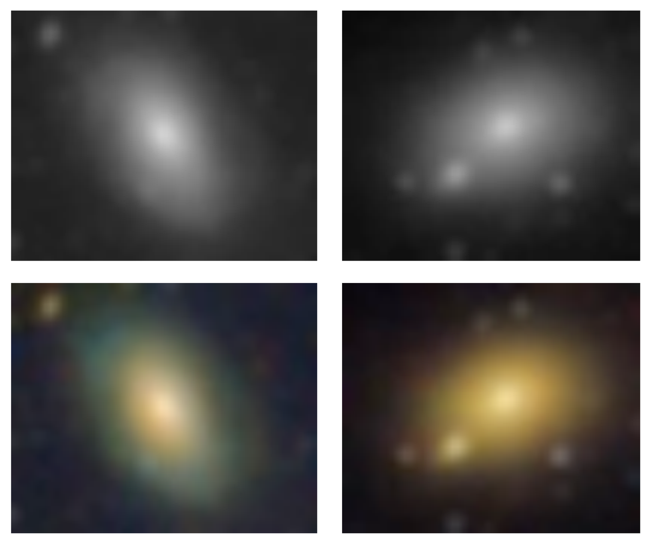
Models of galaxy formation draw fundamental distinctions between disk and spheroidal galaxy components. Stellar disks form directly from cooling gas, while spheroids are typically formed by merging or disturbing previously formed stellar disks. They therefore represent distinct periods in a galaxy's history and possess contrasting stellar populations.



The value of colour information

Spheroid and disk components generally possess different colours. This provides extremely useful information when separating their contributions to galaxy images, but this is neglected by conventional approaches to galaxy decomposition.

In a single-band image it is difficult to determine whether each galaxy would be best fit by a single component or a combination of bulge and disk, never mind their relative sizes and shapes. When colour information is added, it becomes much more apparent when a galaxy is a bulge-disk system.



Fit robustness and model selection

A significant fraction of galaxy bulge-disk decompositions fail to produce physically meaningful models (commonly ~25%, even on good data). A important cause of this is the presence of unmodelled features: bars, spiral arms, star-formation regions, nuclear sources, unmasked neighbouring galaxies, foreground stars, etc. Somehow accounting for the expected presence of these varied features could greatly improve the robustness of galaxy decomposition.

Our solutions

We have adapted GALFIT3 and GALAPAGOS to fit arbitrary sets of pixel-registered multi-band images in a very flexible manner.

GALFITM also adds options of including a non-parametric component or performing a more rigorous exploration of parameter space.

GALAPAGOS-2 allows one to apply GALFITM to perform single-Sérsic and bulge-disk fits to large surveys in an automated manner.

Built on tried and tested software

GALAPAGOS by Marco Barden, et al.

SExtractor by Emmanuel Bertin

GALFIT by Chien Peng

MultiNest by Farhan Feroz & Mike Hobson

A single wavelength-dependent model

Our approach is to replace each standard parameter of a GALFIT model with a function of wavelength with user-selectable smoothness. We choose to use a series of Chebyshev polynomials for convenience.

$$f(\lambda) = \sum_{i=0}^{m} c_i T_i(\lambda)$$

where $T_i(\lambda)$ is the ith Chebyshev polynomial: $T_0(\lambda) = 1$, $T_1(\lambda) = x$, $T_{n+1}(\lambda) = 2x\,T_n(\lambda) - T_{n-1}(\lambda)$

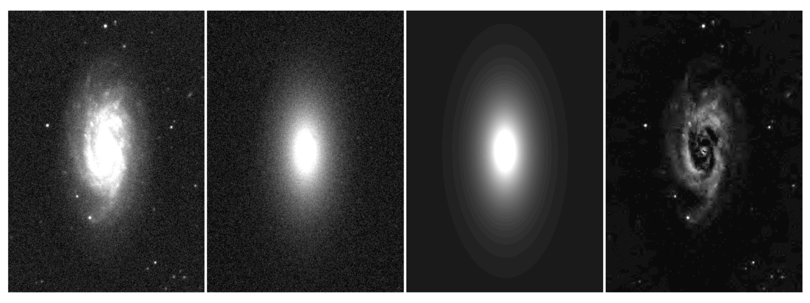
The fit is then performed to find the optimal coefficients, c_i. The order, m, of the polynomial may be selected for each parameter. Choosing m equal to the number of bands gives full freedom, while $m = 0$ requires the parameter value to be identical in every band. Intermediate values control the smoothness with which each parameter may vary with wavelength.

$$I(r) = I_e \exp(-b_n [(r/r_e)^{1/n} - 1])$$

$I_e(\lambda)$ $r_e(\lambda)$ $n(\lambda)$

Adding a non-parametric component

We have implemented a method to account for the presence of galaxy features which cannot be fit by simple parametric models. A "non-parametric" image of these features is gradually constructed by wavelet filtering the residuals periodically during the usual fitting process. The non-parametric image is subtracted from the original data and the parametric model is fit to this. The resulting parametric model tends to be a better representation of the smooth stellar components. The colours of the non-parametric image may be constrained to be homogeneous, which may help to isolate coherent features.

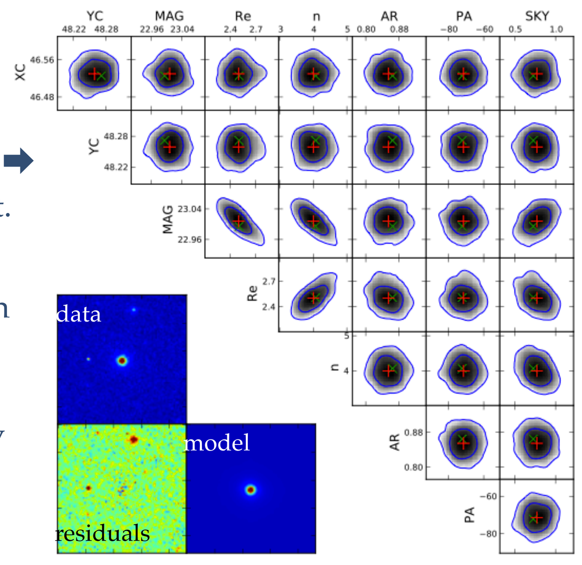


Thoroughly sampling parameter space

We have implemented the MultiNest sampling algorithm (Feroz et al. 2009, MNRAS, 398, 1601) as an alternative to the Levenberg-Marquardt downhill method. Although costly in terms of CPU time, this enables one to more reliably find the global maximum likelihood solution, determine accurate confidence intervals. We are also exploring the use of the resulting Bayesian Evidence, and other methods, to select the appropriate model.

Example parameter confidence regions for a single-Sérsic fit.

One can see the covariances between the magnitude, effective radius, Sérsic index and sky level.



Demonstrations and tests

We have evaluated the performance of our developments on a variety of real and simulated data. These consistently show the advantages of our multi-band approach.

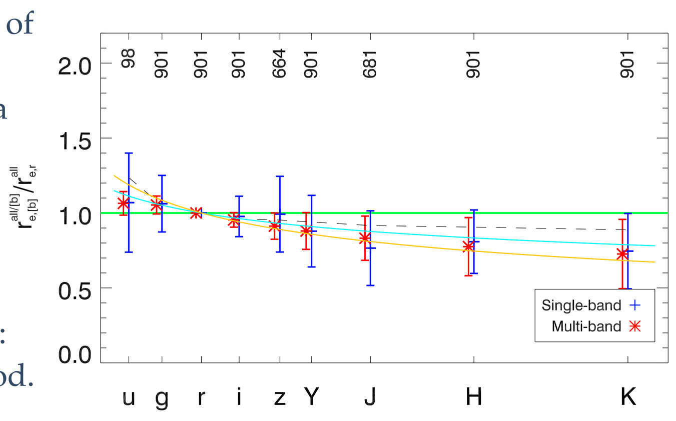
GAMA data and simulations

Häußler et al. 2013, MNRAS, 430, 330; Häußler et al. in prep.

We have fit tens of thousands of galaxies using *ugrizYJHK* data from the GAMA survey, plus data simulated to have the same parameter distributions.

We directly compare the accuracy of our recovered parameters for the simulated data, while for real data we show a decrease in the scatter between wavebands.

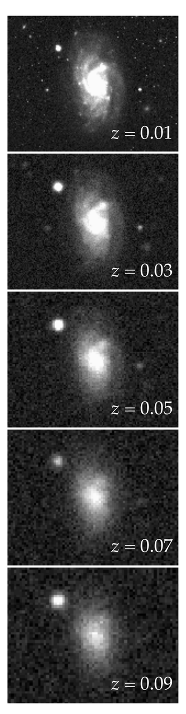
An example for single-Sérsic effective radius. Points show the median, error bars the rms scatter: consistently smaller for our method.



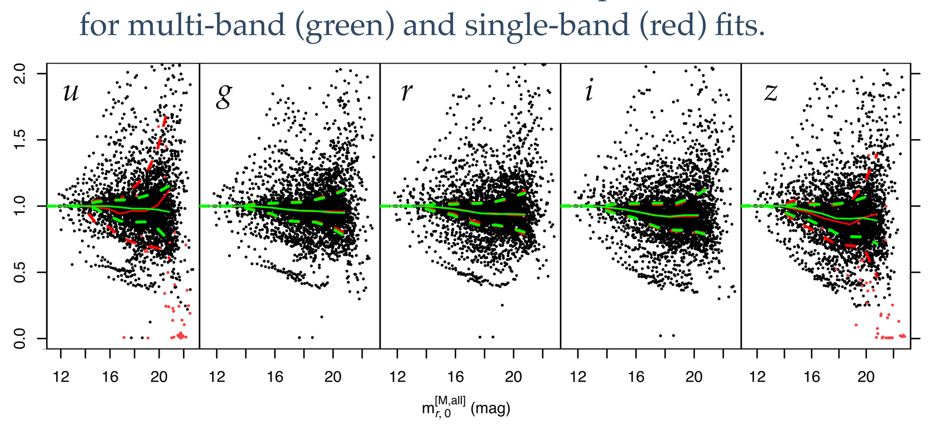
Artificially redshifted nearby galaxies

Vika et al. 2013, MNRAS, 435, 623; Vika et al. in prep.

We have created mock SDSS *ugriz* images of ~150 NGC galaxies, as they would appear at redshifts of 0.01, 0.02, ..., 0.25; using FERENGI (Barden et al. 2008, ApJS, 175, 105). These have been fit using both a conventional single-band approach and using the MegaMorph multi-band technique. The latter results in more accurate recovered parameters, especially for low-S/N bands.

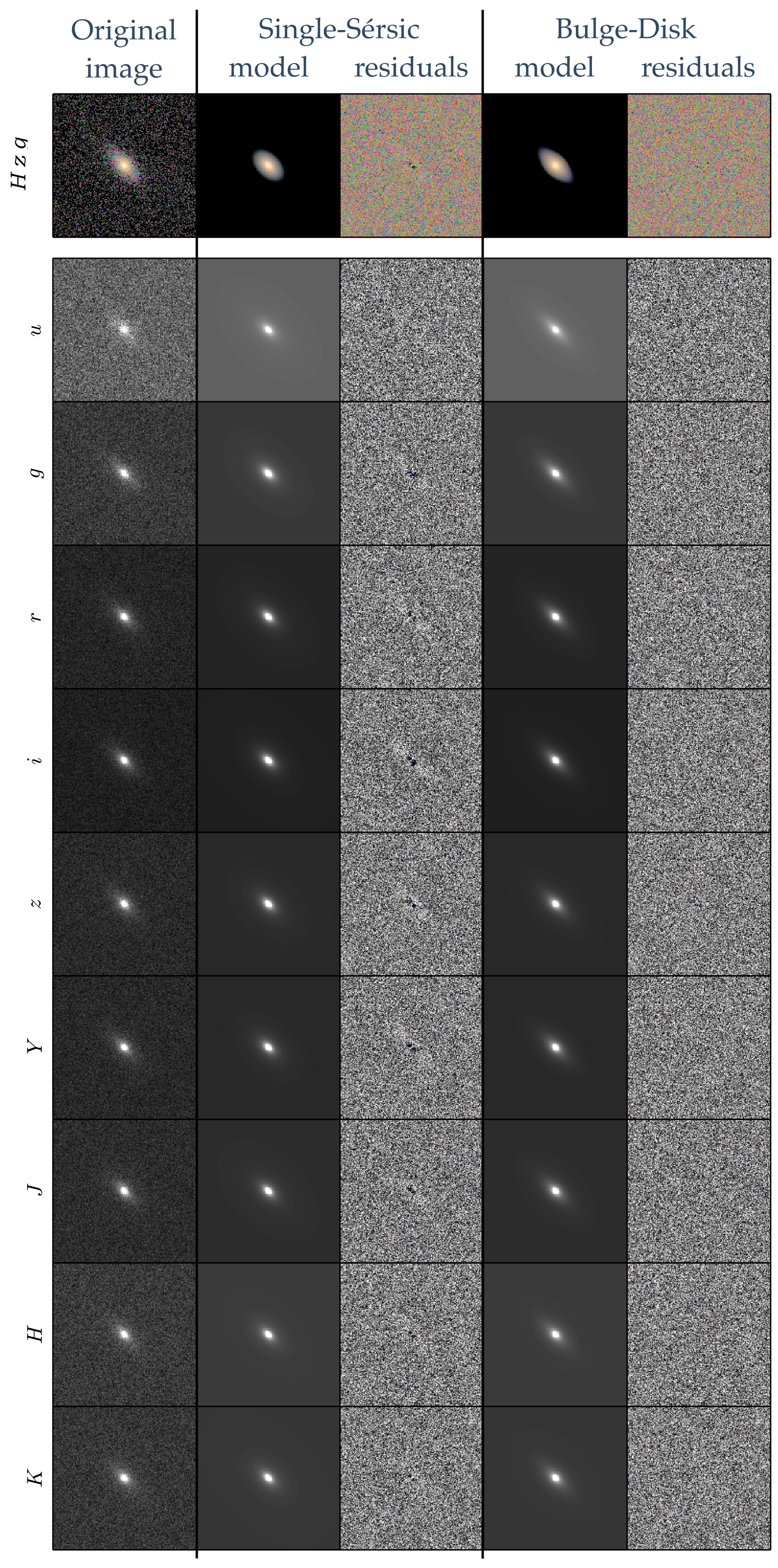


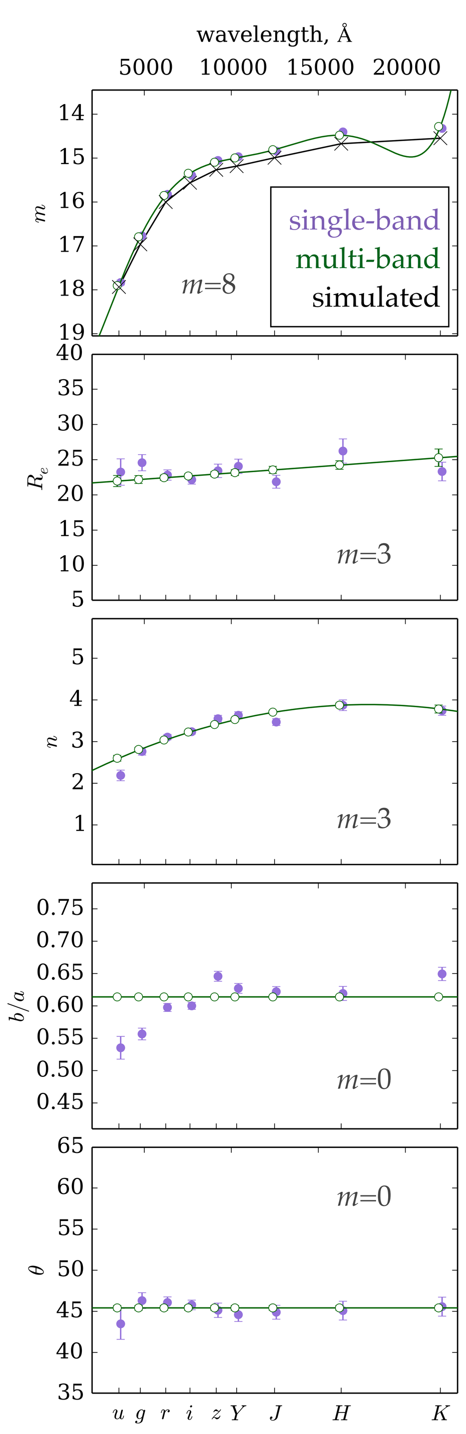
Ratio of recovered effective radius in artificially-redshifted images versus measured value at z=0.01, versus apparent magnitude. Points show multi-band measurements; lines show medians (solid) and 16th–84th percentiles (dashed) for multi-band (green) and single-band (red) fits.



Illustrative simulations

Bamford et al. in prep.

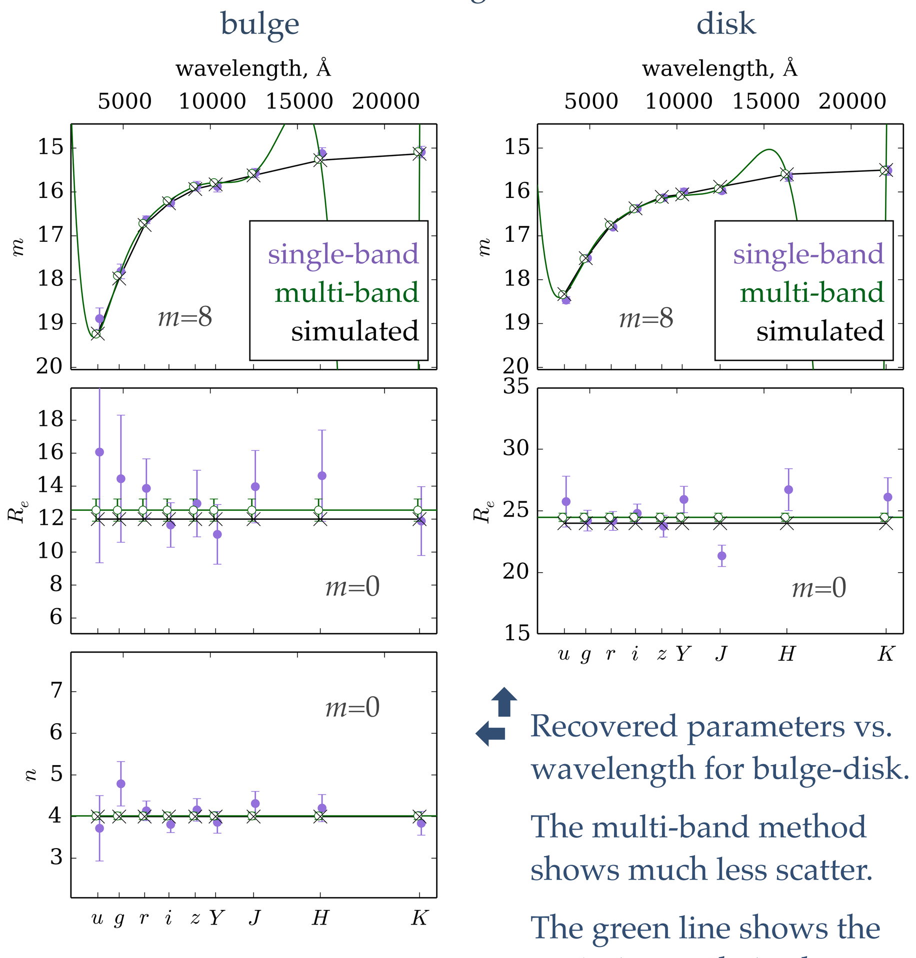




Recovered parameters vs. wavelength for single-Sérsic.

The multi-band method displays less scatter.

Idealised simulations for a typical r~16 bulge-disk galaxy in a *ugrizYJHK* GAMA-like dataset, fitted with multi-band models using GALFITM.



Recovered parameters vs. wavelength for bulge-disk.

The multi-band method shows much less scatter.

The green line shows the underlying Chebyshev polynomial. When this is given a lot of freedom, it tends to oscillate, but only the values at the band wavelengths matter.

See related talks on Friday afternoon...

Boris Häußler – Examining the morphological properties of GAMA galaxies using MegaMorph

Marina Vika – Separating early-type (Sa/S0/E) galaxies in large surveys

Steven Bamford – Measuring messy galaxies using a non-parametric component

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