The Colour-Magnitude Relation for Elliptical Galaxies

Laboratory hand-in exercise for the course *Galaxies*
at Stockholm observatory, autumn 2003

1. Introduction

In this exercise, a HST/WFPC2 image of the core of the galaxy cluster Cl0016+16 will be used to derive a relationship between colour and magnitude for early-type galaxies.

The CCD image is 730x750 pixels in size, with each pixel representing 0.1 arcsec. The field size corresponds to about 500 kpc in diameter for a Hubble constant of 50 km/sec/Mpc. This is a true colour representation of the cluster made by combining frames taken with V (visual, around 5500 Å) and I (near-infrared, centered at 8100 Å) filters. The total magnitude of each galaxy is calculated by integrating the light in the galaxy out to a radius where the brightness of the galaxy falls below the noise in the background sky. A small correction is then applied for the light which would lie outside of this radius. In contrast, the colour of the galaxy is measured within a small aperture (after subtracting the background light from the sky) fixed on the image of the galaxy on the I frame and then in the same aperture on the V frame. The ratio of the fluxes in these two images gives the colour of the galaxy.

2. Running the program

By following the link marked "Analyze Cl0016+16" from the main homepage of this exercise, the image of Cl0016+16 plus a separate window containing a diagram of I versus (V-I) should appear (try changing the size of the window if the axes do not appear automatically). By clicking the cursor on one of the galaxies, the program will present the coordinates, magnitude, colour and observational error of your chosen target. Its colour and magnitude will also be plotted in the (I,V-I) diagram of the associated window. Please note that some of the galaxies in the frame are too faint for the program to center on.

3. Analysis

By selecting appropriate objects from the image of Cl0016+16, you can investigate the structure of the cluster's colour-magnitude (C-M) diagram as a function of galaxy morphology and hence the colour-magnitude relation of early-type galaxies. The aim is to populate the C-M diagram sufficiently to tackle the problems listed below.

As you select your galaxies, you should transfer their magnitudes, colours and observational uncertainties to a text file for later use. Also make a note about their morphologies - a crude estimate, i.e. late-type (spiral and irregular galaxies) or early-type (E or S0), will be sufficient. A convenient way of doing this may be to save late-type and early-type data to different files.

4. Problems

1. How faint do you feel you can reliably classify the galaxies into early- or late-type?

2. Notice the way in which the structure builds up in the C-M diagram as you select more galaxies. Can you identify any structure in the plot? What do such structures say about the properties of the galaxies in this distant cluster?

3. Estimate what proportion of galaxies in Cl0016+16 are early-type galaxies. What is a good way of defining this number: in terms of galaxies brighter than a given magnitude, or the fraction of the total number of galaxies in the cluster, or as a fraction of the galaxies within some area of the cluster? How did you go about measuring this?

4. Having completed your catalogue of galaxies in Cl0016+16, you should derive a C-M relation for the early-type cluster members (the population corresponding to the strong ridge-feature which should be apparent in you colour-magnitude diagram).

Use Matlab or some similar software to analyze the data files you have created. Select a magnitude limit for your analysis, taking both the observational errors on the colours measured from the CCD frame and your estimate of the limit of your ability to distinguish early- and late-type galaxies into account. Then, remove all galaxies fainter than this limit from your catalog. Next, use your morphological classifications to remove all remaining late-type galaxies. Fit a linear relation to the early-type C-M relation. Plot the fit together and the data used.

5. Now, compare the predicted colour of a galaxy with an apparent magnitude of I=21 from your linear fit to the C-M relation with that observed for a galaxy with this luminosity in the local Universe. By simply considering the shifts in the filter passbands for observations of galaxies at high redshift, an early-type galaxy with an apparent magnitude of I=21 in Cl0016+16 should have a colour of (V-I)=2.68±0.03. What is the difference between this colour and that derived from your fit? Are your observations bluer or redder than the prediction and what might be the cause of this? Remember that you are observing the galaxies in Cl0016+16 at high redshift and hence seeing them as they appeared at substantially earlier epochs, due to the finite travel time for light, and that younger stellar populations tend to be bluer (as they contain more young, massive blue stars).

6. The rate of change of (V-I) colour with age can be estimated from theoretical models of the evolution of simple stellar populations. These indicate that the (V-I) colour of a galaxy (a significant time after the formation of the stars) should become redder at a rate of d(V-I)/dt = 0.05 magnitudes per Gyr. Taking the colour difference which you derived above and this rate of change of colour, estimate the how much younger the stars in Cl0016+16 appear to be compared to those in local Universe. This represents the lookback time to the galaxy cluster. What is your best estimate of the error in this measurement?

7. Finally, use your fit to the C-M relation to determine the magnitude of a galaxy which has an apparent colour of (V-I)=2.4. The equivalent rest-frame colour in a local cluster, corrected for the evolutionary effects discussed above, corresponds to an absolute magnitude of -21.3 ± 0.1 in the I-band. Estimate the distance to Cl0016+16, using the apparent and absolute magnitudes of the galaxy. Suggest any shortcomings of using the Colour-Magnitude relationship as a distance indicator.

5. Report

Your results should be presented in a written report containing an abstract, a short introduction, detailed solutions to all the problems posed and plots of your data set and the C-M relation derived.

This is a modified version of an exercise originally designed by Dr. Ian Smail, Department of Physics, University of Durham. The modified version was made by Erik Zackrisson (Department of Astronomy and Space Physics, Uppsala University). Current version valid for course on Galaxies at Stockholm Observatory, Stockholm University, autumn 2003, teacher: Göran Östlin.

Assistant for this exercise at Stockholm Observatory, autumn 2003: Magnus Gålfalk.

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