UNIVERSITY OF SURREY

Module PHY3054
Research Techniques in Astronomy

FHEQ Level 6

Coursework

Deadline:
Tuesday 24 November 2020 @ 4pm

Instructions

Write a Python code and a report for each of the three problems in the assignment. The suggested length of the report is 4-6 pages, and should not exceed 8 pages. Both a LaTeX and Word template are provided on SurreyLearn. The first half of the report should focus on problems 1 and 2, and the second half should focus on problem 3. The report should include, for each problem:

1. A description of the problem
2. A description of the results obtained
3. All necessary figures.

The format for the report is pdf, and the code format is an executable python file (.py extension). The report and the codes should be submitted to the modules page on SurreyLearn. All data can be found in the 'Coursework data' section of the course material page on SurreyLearn.

IMPORTANT: Any code that generates an error will be given zero marks. You must provide an executable version of your code (i.e. a .py file). Please verify that the codes are written for python 3, and run on the lab computers without errors, especially if you have written it on your own computer.

Marking scheme

Marks will be assigned in the following way:

- Problem 1: Total = 50 marks. Code = 25 marks. Report = 25 marks.
- Problem 2: Total = 50 marks. Code = 25 marks. Report = 25 marks.
- Problem 3: Total = 100 marks. Code = 50 marks. Report = 50 marks.

Coding marks will be assigned based on both the accuracy of the output (80%), as well as your code's efficiency and readability (20%, see rubric on SurreyLearn).

A rubric for the report is available on SurreyLearn for your guidance.

This assignment contributes 50% to the total module mark.

1 Problem 1

Python programming and visualisation [Code: 25 marks, report: 25 marks]

Write a Python function that can return each of the first three spherical Bessel functions $J_n(x)$: [10 marks]

$$\begin{aligned} J_0(x) &= \frac{\sin(x)}{x} && (1) \\ J_1(x) &= \frac{\sin(x)}{x^2} - \frac{\cos(x)}{x} && (2) \\ J_2(x) &= \left(\frac{3}{x^2} - 1\right)\frac{\sin(x)}{x} - \frac{3\cos(x)}{x^2}\,. && (3) \end{aligned}$$

The function should take as arguments a `NumPy` array x and the order n, and should return an array of the designated order n spherical Bessel function. Make sure that your functions behave properly at $x = 0$.

Plot the three Bessel functions for $0 \leq x \leq 20$ on the same graph, using different colours and linestyles. [15 marks]

Your report should include a discussion on the importance and use of the Bessel functions, as well as presenting the results from your code.

2 Problem 2

Python programming and DS9 - The Andromeda galaxy [Code: 25 marks, report: 25 marks]

Andromeda is a spiral galaxy, similar in mass and luminosity to our own Galaxy. The rotation speed of its stellar disk reaches a maximum velocity in the outskirts ($R \sim 20$ kpc) of $V = 226$ kms^{-1}. This rotation can be linked to the enclosed mass ($M(< R)$) at a given radius (R) with the following equation:

$$V = \sqrt{\frac{GM(< R)}{R}} \tag{4}$$

where G is Newton's gravitational constant. Using this equation, calculate the mass enclosed within the extent of Andromeda's disk ($R = 20$ kpc), making sensible assumptions about the shape of the *total* potential. Convert this into an average density in g cm^{-3}, and print this value to the screen. [5 marks]

The critical density of the Universe is the density required for a flat cosmology, and can be written as:

$$\rho_c = \frac{3H_0^2}{8\pi G} \tag{5}$$

Given $H_0 = 70$ kms^{-1}Mpc^{-1}, calculate the critical density of the Universe in g cm^{-3}, print this to screen, and print the ratio between the density of Andromeda and the critical density. [5 marks]

Finally, three FITS images of Andromeda - taken in different filters - are provided on SurreyLearn. These are named:

- AndromedaRed.fits
- AndromedaBlue.fits
- AndromedaGreen.fits

Using DS9, combine these 3 files into an RGB composite file. Alter the scale settings to make the image as clear and realistic as possible. Save this image in a format that preserves your chosen scalings. Finally, there are two satellite galaxies in the image. Highlight these with regions, and save these regions to a file. An image with these regions should be included in your report [15 marks]

Your report should include a discussion of Andromeda, for example, a brief description of historic and modern observations; or a discussion of the satellites you have highlighted.

3 Problem 3

Identifying solar system objects in Yale La Silla-QUEST data [Code: 50 marks, report: 50 marks]

In this problem, we will reduce raw images from the Yale La Silla-QUEST Kuiper Belt survey to identify Neptune and its moons from a series of images. The data were provided by Professor Marla Geha at Yale University, as part of the Yale Astronomy research techniques course. The data files required for this assignment can be found in the QUESTdata folder on SurreyLearn. Within this folder are three sub-folders containing the science images, as well as the dark images, and the sky flats necessary to calibrate the 3 science images.

Write a python code that will calibrate the 3 science images by applying bias, dark and flat corrections to each, and then shift them to a common pixel frame. Examine the 3 calibrated images in DS9, and identify the positions of Neptune and any other moving objects in each frame. Note their positions in pixel and coordinate space for each image. You should upload your final reduced images with regions files for your moving objects with your coursework submission.

In your report you should explain each stage of the reduction. You should also include your final reduced images, with the moons you have found highlighted. You may include any other images that you think clarify the steps you have followed for your data reduction.

To reduce and analyse the data, it is recommended that you follow these steps:

1. *Examine the data in DS9.* [Code: 5 marks]

   - Identify the bias overscan region in this image and determine its pixel range.
   - Examine the dark frames, which have already been bias corrected.
   - Examine the flat frames. These are sky flats. Describe what you see in these images in your report.
   - Examine the raw science files. Note any features in the images that are features of the telescope/CCD and not the science image.

2. *Calibrate the science images* [Code: 30 marks]

   - Read in all images, plus their headers, to python. Determine the exposure times for science, dark and flat images. Which dark field belongs to the science observation, and which to the flat observations?
   - Bias correct the flat field and science images using the overscan region. This is done by determining the mean flux value for each row in the overscan. Subtract this value from every pixel in the same row of each image separately.
   - Subtract the dark field from each image in turn. Select the correct dark image for the flats and science images.
   - Create your master flat by combining the bias and dark subtracted flat fields. Normalise this master flat, and plot the pixel values as a histogram to demonstrate this has been done. You should also provide the master flat with your report (if your code automatically generates and saves your master flat to a file, it does not need to be included).
   - Flat field each science image. Examine these corrected images in python or DS9 to ensure that the features associated with the telescope/CCD have been removed.

- Remove the bias overscan region from each of your science images by subtracting these pixels from the images.
- Sky-subtract your science images following the procedure outlined in your notes.
- Write science images to FITS files, including the original header with the data.

3. *Find Neptune and its moons* [Code: 15 marks]

   - Each science frame is slightly offset from one other. Using DS9, measure the pixel shifts of the 2nd and 3rd image with respect to the first image, by comparing the pixel positions of at least 4 unsaturated stars in each images. Then, shift the images to a common scale. Write these shifted images to FITS files, with their original headers.
   - Load the final 3 images into different frames in DS9. Blink between the three images to identify the position of Neptune (the brightest object) in each field. Identify 3 other moving objects within the field, and make a note of their positions (these objects will be *much* fainter than Neptune). Create a DS9 region file for each frame that will annotate your final images with the positions of the moving objects you identify, and submit this with your report.