Part 1  **STRUCTURE**
1.1  Introduction
1.2  Experimental strand
1.3  Computing strand
1.4  Timetable
1.5  Assessment scheme
1.6  Safety Rules

Part 2  **ADVICE AND GUIDANCE**
2.1  Revision of error analysis formulae  *(available online)*
2.2  Writing laboratory reports  *(see also your Semester 1 Lab manual)*
2.3  Glossary of astrophysical terms  *(available online)*

Part 3  **EXPERIMENTAL SCRIPTS**  *(available online; print as needed)*
A. The Moons of Uranus  (3 weeks)
B. Stellar astrophysics  (2 weeks)
C. The Hubble Redshift–Distance Relation  (2 weeks)

This manual is available online for printing. The lab scripts and parts of the advice and guidance are available online only. Online material can be accessed from within Blackboard (see the PHY-10023 module, Electricity and Stellar Structure) or by pointing your browser directly to

[http://www.astro.keele.ac.uk/~rdj/astrolab.html](http://www.astro.keele.ac.uk/~rdj/astrolab.html)
ASTROPHYSICS LABORATORY: Astrophysical Methods and Skills

PART 1: Structure

1.1 Introduction

The Physics and Astrophysics Lab components of your modules are different in structure and style to the lecture components. The lectures provide an education in the knowledge required to become a Physicist, while the labs are primarily concerned with educating the student in the skills required to be a Physicist. These skills can only be acquired by practice and experience over a period of time. Whereas the lecture material can be assessed by an examination at the end of the course the labs are wholly examined by continuous assessment, throughout the two semesters. In the first semester, the Physics and Astrophysics labs follow an identical program, covering basic experimental methods and skills common to both disciplines. In the second semester the Physics and Astrophysics labs follow different programs of work, specialising in the different needs of the two disciplines.

There are two strands to the Lab structure, corresponding to two basic skills a modern experimental Physicist needs to master. These are (i) both the practical abilities to perform experiments and the intellectual ability to analyse and assess the results of experiments; and (ii) basic computational skills. In Section 1.5 the mark scheme for each of the component parts of the second-semester Astro Lab is given. Briefly, a mark is given based on continuous assessment of your lab book (weight 30%), on the assessment of two word-processed lab reports (combined weight 60%), and on the satisfactory completion of a set of computer programming exercises (weight 10%). The total Labs mark will contribute 20% of the final overall mark in your second-semester lecture modules. A minimum total mark of 40% in the Labs component is required to pass a module.

This manual is predominantly concerned with the second semester strand (i), which is discussed in the next section. However, please read this manual in conjunction with information given in the semester one Physics laboratory manual. This is still relevant in semester two, particularly those parts concerning the treatment and analysis of experimental uncertainties and the construction of laboratory reports. Bring both of these manuals to laboratory sessions.

1.2 The Experimental Strand

In this strand you must perform at least two laboratory experiments during semester 2 and submit two word-processed laboratory reports. Students who achieve this minimum requirement should be capable of achieving (at most) about 70% of the experimental marks available. To gain full marks a third experiment should be completed. Equal assessment weighting is given to each of the laboratory reports (which will be returned to you with a mark out of 30) and to your in-lab performance and lab-book contents for the three experiments, which will normally be conducted over the course of 8 weeks (you will receive a mark of 0, 1, 2, 3, or 4 each week; see below).

These labs take place in PC Lab LJ1.27 on the first floor of Lennard-Jones, where a set of computer-based experiments are available. The main aim of these experiments is to allow you to practise and develop skills acquired during semester one, especially the treatment of errors, fitting of models and consideration of the significance of results. These skills will now be applied in an astrophysical context; you will learn some interesting astrophysics along the way and the experiments will introduce basic astronomical units and measurements (e.g. the magnitude brightness scale). You will find some of this unfamiliar and it is recommended that you read relevant sections of introductory astronomy texts. The experiments require you to think about your data, results and methods perhaps more deeply than you have so far. It is often the case that there are clear distinctions between systematic and statistical errors which you should appreciate. Each experimental script has a series of questions, which you must attempt to answer in your laboratory notebook.
At the end of each laboratory session you will hand in your laboratory notebook, which will be assessed each week as described below. The laboratory notebook is an extremely important document. In it you must record what, why and how you do things, record all relevant numbers and measurements (with their uncertainties), record your calculations, explain the nature of any graphs, pictures or spreadsheet printouts which are firmly and permanently attached therein (for instance with glue or staples). Include sufficient detail so that you, or a demonstrator, can follow exactly what you have done and so that you will later be able to write a laboratory report based on its contents. You should also answer questions (where they are asked in the scripts) in your notebook.

An important point to note is that you don't get marks for getting the "right answer" in these experiments; you get marks for good experimental practice. Even if your results seem totally different to the accepted textbook results, as long as you've used good experimental practice and attempt to identify the reasons behind discrepancies you'll get good marks. A second important point: ask questions of the staff, post-graduate demonstrators and technicians if you need help. Asking questions or seeking help will not count against you for any mark you receive. However, failing to ask for help when you need it will almost certainly mean that you won't achieve as much as you could.

The marking scheme for the lab book is a simple scale from 0 to 4. You will receive a mark every week based on the following criteria compared against the milestones and questions set out in the experimental scripts.

0 Absent from the laboratory or did not hand in a laboratory notebook. It is your responsibility to make sure you hand in your notebook to a demonstrator or member of staff before you leave the laboratory. If you turn up for laboratory late (after 2:30pm) or do not bring a laboratory notebook (where you have been allowed to take it out of the laboratory, for instance in the week before a laboratory report is due) you will also not be eligible for marks. Note that lost lab-book marks will not be recoverable at a later date unless any absence is for good reason (and documented), as defined in the student handbook.

1 A poor attempt. Either substantially incomplete or incorrect in many places. Poor treatment of uncertainties, little genuine attempt to answer questions posed in the experimental script, data and results poorly organised, presented, and described in the laboratory notebook.

2 A middling attempt. Some milestones complete; some treatment of uncertainties and systematic errors; discussions or answers for some of the questions posed by the experimental script; decent attempt to clearly organise and explain data and results recorded in the laboratory notebook.

3 A good attempt. Nearly complete milestones; reasonable treatment of uncertainties and systematic errors; discussion or answers to relevant questions posed by the experimental script; good organisation and clear presentation of data and results in the laboratory notebook.

4 An excellent attempt. All milestones complete; a good and thorough consideration of uncertainties and systematic errors; all data and results clearly presented and well organised in the laboratory notebook; thoughtful discussion and good answers for most or all of the questions posed by the experimental scripts.

During this semester you must write two word-processed laboratory reports. The deadlines for these reports are the ends of week 6 and week 9 respectively. The basic structure of the reports should be the same as that for your Physics lab reports; more details and guidance are given below in Section 2.2 of this document. The lab scripts contain instructions about specific items to include and questions to address in your written reports (as well as in your lab books). Ask
the Lab instructor if you are unsure about any expectations about any aspect of the reports. You should also re-read the general advice about reports in the Lecture Notes in Part II of your first-semester Physics Lab manual.

A note on timekeeping and expectations

The experimental laboratory sessions will start at 2:05 pm sharp and will finish at 5pm. An attendance register will be kept. You are expected to work hard during this time. Apart from preparing the laboratory reports, you are not expected to do work on these labs outside these hours. The experiments you do should take two or three weeks each if you work well. Only performing two experiments would be sufficient to pass the module but could not qualify for a mark of >70% in the lab-book component (see below).

1.3 Computing Strand

The introduction to programming part of the course occurs at the end of semester two, during weeks 9 through 12. It is taught by a series of "exercises" using PYTHON and is intended to educate you in the elements of programming and encourage you to think how to apply computer programmes to solve problems in Physics. These labs take place in the large PC facility on the ground floor of the Lennard-Jones building.

1.4 Timetable

The timetable is very simple: you have one compulsory session every Thursday afternoon from 14:00–17:00. During the first eight weeks you will perform the astrophysics experiments in Lennard-Jones LJ1.27. During weeks 9-12 you will do the computing exercises in the Lennard-Jones ground-floor PC facility.
1.5 Assessment Scheme

<table>
<thead>
<tr>
<th>Experimental Strand</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Book</td>
<td>30%</td>
</tr>
<tr>
<td>weekly; 2–3 experiments</td>
<td></td>
</tr>
<tr>
<td>Reports</td>
<td>30%</td>
</tr>
<tr>
<td>report #1</td>
<td></td>
</tr>
<tr>
<td>report #2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computational Strand</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises in Python programming for science</td>
<td>10%</td>
</tr>
</tbody>
</table>

**Total second-semester lab mark** ................................................................. 100%

*The total lab mark contributes 20% to the overall grades achieved in your lecture modules.*

*A minimum total lab mark of 40% is required to pass a module*
1.6 Safety Rules (for laboratories in the Lennard-Jones building)

General Safety in the Department

Your attention is drawn to the formal statement on safety policy issued by the University. A copy of this statement is displayed on the special Safety Notice Board and in the University Safety Handbook (with the black and yellow cover) which you have been given by the University.

In keeping with the overall University policy and with the requirements of the Health and Safety at Work legislation, we have established a "Workplace Safety Committee" to cover the activities of the Department. The constitution and terms of reference of this Committee are displayed on the Safety Notice Board, together with copies of the minutes of recent meetings. The Committee welcomes observations or suggestions concerning health and safety within the department.

Responsibilities of Individuals

Under the Health and Safety at Work Act, the university must provide a safe working place to ensure that students, staff and other persons are not exposed to risks to their health and safety. It is the responsibility of each individual to protect themselves, and others, from hazards resulting from their work or behaviour.

Safety Rules and Procedures - Undergraduates

There are a series of rules and safety procedures applicable to everyone working in the department which are designed to decrease the risk of personal injury and/or damage to equipment and buildings. The rules which are applicable to undergraduates working in the undergraduate laboratories are summarised below.

1. General Rules

No-one may work alone in any section of the department except at the most elementary and routine tasks.

All undergraduates working in one of the laboratories, other than in their timetabled session, must obtain permission from a member of the permanent staff AND must report to them or their nominee when they arrive and before they depart.

Suitable clothing including footwear must be worn at all times in laboratories and workshops. Where appropriate special protective clothing should be worn and is available on request.

2. Safety Procedures

Long Term Experiments

Temporary "circuits" using electrical power, water or gas must not be left turned on unattended.
Before any experiment is left running unattended in a teaching lab, e.g. overnight or over lunch, permission of the permanent member of staff must be obtained and suitable notices displayed.

**Chemicals**

Before using any chemical, read and fully understand the relevant hazard assessment form (COSHH assessment). Ensure that fresh antidote is available when toxic material is to be used.

**Radiation**

All intense radiation is potentially dangerous and particular care is needed for non-visible radiation. Special rules apply to the use of (a) x-ray generators, (b) lasers and (c) observing the sun. Radiation film badges are available from the Departmental Radiation Protection Advisor.

**Accidents and Incidents**

All accidents including chemical spillage's must be recorded in the "accident book" as soon as possible. This "Accident Book" is kept in room LJ.0.13 as is the departmental "Incident book". This "Incident book" is intended to record the circumstances of any occurrence which is judged by those involved to have caused some danger, even though no personal injuries were sustained (e.g. falling objects, collapse of some structure, spillage of acid etc.).

**Visitors**

Members of the department are reminded that as individuals they may be held legally responsible for the safety of any personal visitors invited into the laboratories.

3. **Emergency Procedures**

**Electric Shock**

All undergraduates are expected to be familiar with the details given on the notices, displayed in all laboratories on "Treatment for electric shock".

**Fire Alarm**

On hearing alarm bells:

i. Switch off the power supply to your own experiment at wall sockets (if you are still nearby).

ii. Leave the building by the nearest exit and report to assembly point

4. **Summoning the Emergency Services**

In order to summon the emergency services dial **9-999 (FIRE AND AMBULANCE)** giving the necessary information and then dial **888** to inform the university 24 hour reception on where to direct the emergency services upon their arrival. The internal telephone number of the university **HEALTH CENTRE** is **33189**.
PART 2: Advice and Guidance

2.1 Revision of error analysis formulae: online

2.2 Writing Laboratory Reports

This section re-iterates what is required to write a good laboratory report. It should be read in conjunction with the notes given on this subject in the first-semester manual.

The abstract should be a concise summary of what is in the report. It should say what the experiment was, what the main results were (any numerical results should have uncertainties associated with them) and what main conclusions were inferred from these. There is obviously some judgement involved in deciding what main means. It is not appropriate to include detailed descriptions of your methods, intermediate results, equations (unless the purpose of the experiment was to derive or test such a particular equation), or numerical results without error bars.

The Introduction should set out the context of the experiment, how it relates to Physics/Astrophysics as a whole and what questions or theories your experiment sets out to answer or test.

The Experimental Methods section should discuss all the work that leads to the results presented later on—starting with the “raw” measurements you make and going through your manipulations of these to obtain key, derived quantities. The level of detail is a matter of judgement; you need to balance conciseness with clarity and completeness. Do not omit important information. Make sure that you discuss uncertainties in measurements and how these were estimated but you might stop short of describing a telescope simulator or detailed spreadsheet command syntax.

The Results section should be a piece of prose that links together the results of your measurements and quantities that were derived from them. This has to be done in a coherent, logical way. You will need to refer to properly labelled and captioned Figures (or diagrams or graphs) and Tables and probably to numbered equations. All of these things must be presented in a clear, logical and easy-to-find order within the report. You will need to explain uncertainties in derived quantities, i.e., tell how you have propagated raw measurement errors through any calculations to obtain the derived quantities.

Your results need to be discussed. By this I mean you have to say what your results mean, what you can deduce from them and why they may be either inaccurate or imprecise because of shortcomings in your methods, or limitations in the data you have to work with. Results should be compared with accepted values and you should properly reference where these came from. Are there discrepancies? If so, why? Use the questions in the lab scripts as a guide to what you should be discussing. This discussion could be a separate section, or appear at the end of the results section, or begin a discussion and conclusions section. If you can think of improvements in your methods then this is also where they should appear.

Conclusions should be concise, accurate and correctly (i.e., logically) argued on the basis of the evidence at hand.

You should include a Bibliography which gives the details of any literature sources you have cited in the text of your report.
In your written reports…

**DO NOT**

- Fail to label Figures, Equations and Tables or fail to give them adequate captions if it is not blindingly obvious what they are.
- Waffle anywhere, but especially in the abstract and conclusions.
- Quote numerical results without uncertainties.
- Use different numbers of decimal places in results and their uncertainties.
- Fail to say where uncertainties come from in numerical results or in points on graphs.
- Quote "accepted values" without a reference.
- Neglect to comment on poor fits to data, large goodness of fit (chi-squared) values or clearly discrepant results.
- Miss out important details of methods and techniques.
- Present your results as a list of numbers.
- Use "data" as a singular noun; it is plural!
- Cite Wikipedia (or any similar such resource) as a primary reference for anything.

**DO**

- Remember that you are being marked on the quality of the science in your report, not solely on its presentation. Bad science and bad logic will lead to poor marks.

### 2.3 Glossary of astrophysical terms: online

**PART 3: Experimental Scripts**

All lab scripts are available online, through Blackboard (module PHY-10023) or from http://www.astro.keele.ac.uk/~rdj/astrolab.html