The TRUMP Astrophysics Project: resources for physics teaching

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1. Introduction

Comets and quasars, black holes and the big bang, pulsars and planets all feature in the media and excite people to find out more – astronomy might be described as the popular face of modern science. In the UK, recent changes in Advanced Level (A-level) physics courses mean that many students have the option of studying astrophysics to a depth beyond the merely descriptive. This option is proving popular with teachers and students, but presents particular challenges shared by few other areas of A-level physics courses.

1.1. *Astrophysics within A-level physics*

A-level courses are taken by students who choose to stay in education beyond the age of sixteen. Students typically study three subjects at A-level over the course of two years. A-level is approximately equivalent to 12th grade and the first year of a bachelors degree in the USA. Students are awarded grades for their A-level work which depend on their performance in external examinations and on evidence of experimental skills collected by their teachers. The examinations are set, and the grades awarded, by independent examination boards which specify the content on which students are to be examined and the skills for which teachers are required to provide evidence. For many students, A-levels are a preparation for more advanced study at university.

Fifty percent of the content of all A-level physics syllabuses is now defined nationally (School Curriculum and Assessment Authority, 1994), whereas previously the examinations boards had a greater degree of autonomy. Current syllabuses have been discussed and summarized by Avison, 1994; most consist of a compulsory element, with a menu of optional topics of which students must study (and be examined on) a specified number. (The numbers of options vary between boards, but typically students study three from a menu of six.) The range of optional topics includes medical physics, particle physics, electronics, materials, environmental physics – and astrophysics.

Table 1. Areas of astrophysics in A-level physics syllabus

Making observations	Observational properties	Stars	Galaxies and Cosmology
Lenses and mirrors Telescopes Fibre optics Diffraction and Atmospheric effects Satellites Radar Detectors	Electromagnetic radiation Line spectra Doppler shift Black body radiation Luminosity, flux and magnitude Stellar classification HR diagrams	Formation and evolution Gravitation Nuclear reactions Energy transfer Binary objects	Models of the universe Structure and scale of solar system, universe Hubble expansion Big Bang Open and closed universe

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Before embarking on A-level work, students in England and Wales will have studied a range of subjects up to the age of 16 as required by the National Curriculum, which includes physics, chemistry and biology and some aspects of astronomy mainly of the what goes around what variety. The content of astrophysical options at A-level builds on this and is relatively sophisticated in terms of astronomical knowledge and of relevant physical principles. Table 1 lists some of the items in the syllabuses. The approach is generally quantitative; students are expected to use algebra, graphs and trigonometry, for example, but not calculus or much in the way of statistical techniques.

1.2. *The need for resource materials*

Students and teachers are very enthusiastic about including astrophysics in A- level work, but teachers, in particular, have some concerns. First, while most teachers of A-level physics are physics graduates, few have studied astrophysics and so lack the specialist knowledge needed to teach the topic with confidence. Second, there is a concern about what students actually do in class, since astrophysics does not seem readily to lend itself to the laboratory practical activities that are an integral part of much A-level physics work: few teachers wish to resort to lecturing their students, preferring to engage them in more active learning. Furthermore, some examination boards require that experimental skills be developed and assessed within each optional topic.

Teachers also have a concern about the financial and time demands of teaching astrophysics within A-level. Some schools and colleges are very well equipped (with telescopes and computers for example) and there are teachers with exceptional enthusiasm and expertise who involve their students in astronomical observations and visits outside normal school hours. But such institutions and teachers are unusual; the majority of schools and colleges operate on restricted budgets, and few teachers are able to spend significant extra time on an area that represents a relatively small fraction of their overall teaching commitment.

Despite the recent proliferation of astronomical material on CD-ROM, the Internet, and so on, as well as in books, there is little that meets the particular needs of A-level physics teachers and students: there is little between professional texts (which are too advanced) and popular materials which, while attractive and stimulating, do not address the underlying physical principles required for A-level study. The TRUMP Astrophysics project set out to address two distinct needs. First, the need of teachers to become familiar with aspects of modern astrophysics, and second, the need for activities in which, during normal class time and with easily- obtainable equipment, students are actively involved in learning astrophysics.

1.3. *The TRUMP Astrophysics project*

The Teaching Resources Unit for Modern Physics (TRUMP) is a collaboration between school teachers and academic experts whose aim is to support the teaching of modern physics in A-level courses. The forerunner to TRUMP was the Particle Physics Project which was instrumental in introducing particle physics into A-level courses (Swinbank, 1992) and which developed a resource package to support teachers and students in this exciting but unfamiliar area (Particle Physics Project, 1992).

Following the introduction of astrophysical options into A-level courses, the project team identified a need for a similar resource package devoted to astrophysics which would set out to address the particular needs of A-level physics teachers and students noted above.

A grant from the UK Particle Physics and Astronomy Research Council (PPARC) under the Public Understanding of Science and Technology (PUST) scheme has enabled us to develop one section of our planned resource package as a pilot. The pilot materials (which relate to observational properties of astronomical objects) are being evaluated by teachers during 1996 September and October. Additional funding from the UK Institute of Physics, PPARC, and industrial and charitable sponsorship, will enable us to develop materials relating to telescopes and instruments, stellar evolution, planets, galaxies and cosmology, and hence to complete the package.

One of the main strengths of the TRUMP project, which we would commend to others seeking to develop curriculum resources, is the range of experience within the team. The combination of practising school teachers and academic experts ensures that the materials are both scientifically rigorous and appropriate for use with students. Most of the TRUMP Astrophysics team work as consultants to the project in addition to their full-time jobs, so they necessarily bring a high level of enthusiasm and commitment which is another of the projects great strengths.

2. Designing an effective resource package

To meet the needs of the intended users discussed above, the TRUMP team believe that an A-level astrophysics resource package should aim to (a) help teachers to become familiar with the areas of astrophysics included in their syllabuses (b) support appropriate student activities and (c) be readily accessible to all teachers and institutions. A resource package was therefore designed with these aims in mind.

2.1. *The structure of the TRUMP Astrophysics package*

The TRUMP package has three main components: Study Notes and Teaching Notes (bound together in a Teachers Guide booklet) and a bank of loose-leaf Student Sheets. The Study Notes relate to the first aim. They are similar in style to Open University texts (Jones 1996) and are written so that teachers may study areas of astrophysics relevant to their syllabus prior to teaching it. Teachers can use the notes at times most convenient to them, and are free to skip parts that may already be familiar and to spend longer on aspects which are new. Teachers therefore have the flexibility to organise their study to suit their own particular circumstances, which many find preferable to attending in-service courses demanding full-time commitment at times that are not always convenient.

The second aim is addressed by the Teaching Notes and Student Sheets. The Teaching Notes are designed to help teachers plan a teaching programme appropriate to their particular students and examination syllabus. They suggest approaches to teaching, referring to the Study Notes and syllabus documents published by the examination boards and drawing attention to areas that may need particularly careful handling, and give details of a variety of student activities. The Teaching Notes also refer to some other resources that are appropriate for A-level physics. Many of the student activities are supported by Student Sheets - photocopy masters which may be reproduced for class use within the purchasing institution. All the materials are paper-based, so the package can be bought at relatively low cost and used without recourse to specialist equipment, thus addressing the third aim.

2.2. *Student activities in the TRUMP resource package*

While there are many observational and classroom resources in astronomy that have been described in this symposium and elsewhere, few meet the particular needs of A-level physics students in the majority of schools and colleges. Some exercises involve students only in the fairly passive receipt of images and information, many require telescopes and/or computing equipment, some can only be carried out at night and may require observations over an extended period, and (most important of all) the majority involve no thinking about physics. Activities appropriate for A-level physics students are therefore an important component of the TRUMP Astrophysics package.

In their A-level physics courses, students are required to develop experimental skills which include handling and interpretation of experimental data as well as using apparatus to make observations or measurements. While there may be few opportunities for students to carry out hands-on laboratory work in astrophysics, students can develop relevant skills using data obtained elsewhere and if the data are authentic and recent, students can gain an insight into current research in astrophysics. The TRUMP package therefore includes several data-related activities, using examples chosen carefully so that they relate to physics studied at A-level and can be tackled using appropriate mathematics.

In addition to experimental skills, the TRUMP activities help students to develop more general skills which include study skills, working with others and communication. This is not only a valuable part of students general education, but can also help them to transfer relevant skills (mathematical skills, in particular) from one context to another and so make their learning of astrophysics more effective. Following a recent review of qualifications for 16-19-year-olds in England and Wales (Dearing 1996) development of such 'key skills'will soon be a central feature of all A-level work.

Related to the development of study skills, many teachers encourage A-level students to take some responsibility for their own learning. The Student Sheets in the TRUMP package are therefore written so that they can be used by students working fairly independently: they contain guidance on ways of working as well as posing questions and problems for students to tackle. Where Student Sheets pose direct questions, answers and notes are provided - these are printed separately, though, as some teachers prefer to withhold them.

Finally, for reasons noted previously, the activities in the TRUMP package have been devised so as not to require specialised or expensive equipment, or extensive work away from school or outside normal class time. Table 2 lists the student activities developed for the pilot section of the resource package. Three examples are discussed further below.

2.2.1. *Broadband spectra*

In this activity a discussion of images and graphs over a wide range of wavelengths first gives students an opportunity to review their knowledge of the electromagnetic spectrum. Teachers then introduce the physics of black-body radiation, including Stefan's and Wien's Laws - the Study Notes and Teaching Notes discuss some conceptual difficulties and suggest some approaches to teaching. Students then return to the broad-band spectra provided on the Student Sheet, and are asked to decide which objects appear black-body-like over part or all of their spectra: some of the spectra provided resemble that of a black body (the microwave background spectrum from COBE is included), while others (for example the Crab Nebula) do not. They then estimate the temperatures of the black bodies' using Wien's Law with wavelengths or frequencies read from the graphs. Students thus have an opportunity to apply an important piece of basic physics in an astronomical context, at the same time learning that while many astronomical objects have black-body-like spectra, many do not, and that astronomical black-body temperatures range from 2.7 to many millions of kelvin. The activity also gives students practice in interpreting graphical information.

Table 2. Student activities in the TRUMP package

Activity	In this activity students will ...
Developing a summary	... devise summaries of key terms
Observing the night sky	... observe the colour and brightness of objects in the night sky
Comparing lab. light sources	... observe and discuss factors affecting the apparent brightness of lamps
Questions on luminosity	... use the inverse-square law in calculations relating flux, luminosity and distance
Questions on magnitudes	... use the magnitude scale in calculations involving distance and magnitude
3D model	... make and discuss a scale model of Cassiopeia
Cepheids(1)	... use Hubble data to estimate the distance to M100
Broadband spectra(1)	... discuss and interpret broadband spectra
Line spectra	... read a contemporary account of spectral classification and identify some line spectra
Oil-spot photometer(2)	... use simple apparatus to estimate the Sun's luminosity
HR diagrams(1)	... plot and interpret Hertzsprung-Russell diagrams

(1) Discussed below

(2) Reproduced from an Open University course (Jones, 1996)

2.2.2. *Cepheids*

This is a fairly open-ended problem-solving activity, intended to introduce students to the idea of a standard candle and to reinforce their understanding of brightness and distance. After reading some introductory information about standard candle techniques and about Cepheid variable stars, students encounter a variety of data including some Hubble measurements of Cepheids in the galaxy M100 and a graph of the general period-luminosity relation for Cepheids. They are invited to work in small groups, first to decide how best to use the data, then to estimate the distance to M100 and finally to present their result in a brief report. There are several ways in which the data can be used, so students have to think and understand rather than merely carry out a learned procedure. They have to apply graphical and numerical skills (including the use of logs), and to communicate their findings to others using skills of communication and presentation.

2.2.3. *HR diagrams*

Students are provided with luminosities, temperatures, magnitudes and colours of about a hundred bright and nearby stars and produce a Hertzsprung-Russell diagram using the data (the Teaching Notes suggest various ways in which this might be done). Students then work in small groups to tackle a variety of questions and exercises relating to the HR diagram: these include discussions of the quantities plotted and conventions for labelling the axes; identification of the main sequence, red giant and white dwarf regions; calculations using Stefan's Law to relate the luminosities of stars to their size and temperature; using a cluster HR diagram to estimate distance. From the start of this extended series of activities, students are invited to devise their own written account of the HR diagram for their own future use – they are asked to consider what information they should record and how this might be done most effectively. These linked activities therefore enable students to use skills of communication and presentation, to plot and interpret graphs, and to carry out calculations, while at the same time reviewing key areas of physics (Stefan's Law; brightness and distance) – all based around the HR diagram which is central to stellar astronomy and astrophysics.

3. Summary: key features of the TRUMP project

The TRUMP Astrophysics project provides one model for the development of effective curriculum resources. Key features, which could be transferred to other projects, include:

- active involvement of practising high-school teachers and academic experts
- low-cost materials that require no expensive or specialised equipment
- independent-learning materials for teachers' own professional development
- student activities that use suitable data and images to enable the learning of physical principles and the development of skills.

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