S384 Module Guide

This item contains selected online content. It is for use alongside, not as a replacement for the module website, which is the primary study format and contains activities and resources that cannot be replicated in the printed versions.

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1 Introduction

Welcome to the world of stellar and exoplanetary astrophysics, to the study of stars and of the planets they host.

Stars play an essential role in shaping the Universe. The continuing cycle of star formation, evolution and stellar death creates and destroys cosmic environments, which at the same time are beautiful and hostile, fertile and destructive. Stars also interact with their environments; they radiate energy, heat interstellar matter and shed processed material. Therefore, over time, stars alter the chemical composition of the Universe they inhabit. The study of stars dates back thousands of years to the very beginnings of science and has evolved rapidly in the last century. While stellar astrophysics is in a mature phase, the continuing development of larger and more sensitive instruments is revealing stars in ever greater detail. The closer we look, the more surprises we find; it is as if the study of stars is never-ending.

A remarkable series of discoveries from the late twentieth and early twenty-first centuries showed that many, if not most, stars host planets; it is now known for certain that the Sun is not the only star with a planetary system. The rapid advance of exoplanetary research has demonstrated that planets around stars other than the Sun are not only common but come in more diverse configurations than the planets in our Solar System, which has challenged theories of planet formation. The search for exoplanets is ongoing and is driven, in part, by the enticing prospect of discovering Earth-like habitable worlds around nearby stars.

This guide will help you to navigate S384 *Astrophysics of stars and exoplanets*. It explains what S384 is about, how the module is organised, how to study the module, including the prior knowledge required, and how the module is assessed.

Note

It is important that you read through this guide fully and thoroughly to give you the best possible chance of a satisfying study experience and successfully completing the module.

2 Module overview

During S384, you will learn to quantitatively describe the physics of stars and exoplanets. You will be introduced to the physical concepts underpinning our understanding of these objects and the astronomical techniques used to explore them. Building on these foundations, you will be given a flavour of cutting-edge findings in selected areas of the discipline, and the opportunity to experience authentic research with your own observational data.

S384 has four main, interlinked learning components: two module textbooks, an observational astronomy project and online case studies.

Two module textbooks

The astrophysical foundations of the discipline are conveyed in two self-contained module textbooks.

Exoplanets This book introduces you to the fast-moving field of the astrophysics of planets orbiting stars other than the Sun. In this presentation, the book will be supplied in two parts (Chapters 1–3 and Chapters 4–6).

Stars This book outlines the processes that lead to the formation of stars, the energy sources that fuel them, their structure and behaviour over the course of their lifetimes, and what happens when their fuel runs out.

Each book begins with a short introduction, followed by a ‘Chapter 0’ to outline assumed prior knowledge, and six main chapters on selected topics from exoplanetary and stellar astrophysics. Each main chapter corresponds to one study week and contains practice and consolidation examples and exercises with solutions.

Observational astronomy project

The observational astronomy project on exoplanets will allow you to put into practice what you have learnt in the first few chapters of the *Exoplanets* book. You will obtain and analyse your own transit light curve with one of the OpenScience Observatories’ telescopes in Tenerife: the COmpletely Autonomous Service Telescope (COAST) or the Physics Innovations Robotic Telescope Explorer (PIRATE). The project takes six weeks in total to plan, prepare for, carry out and analyse. Two more weeks are allocated for you to collate your results and communicate your findings via a report.

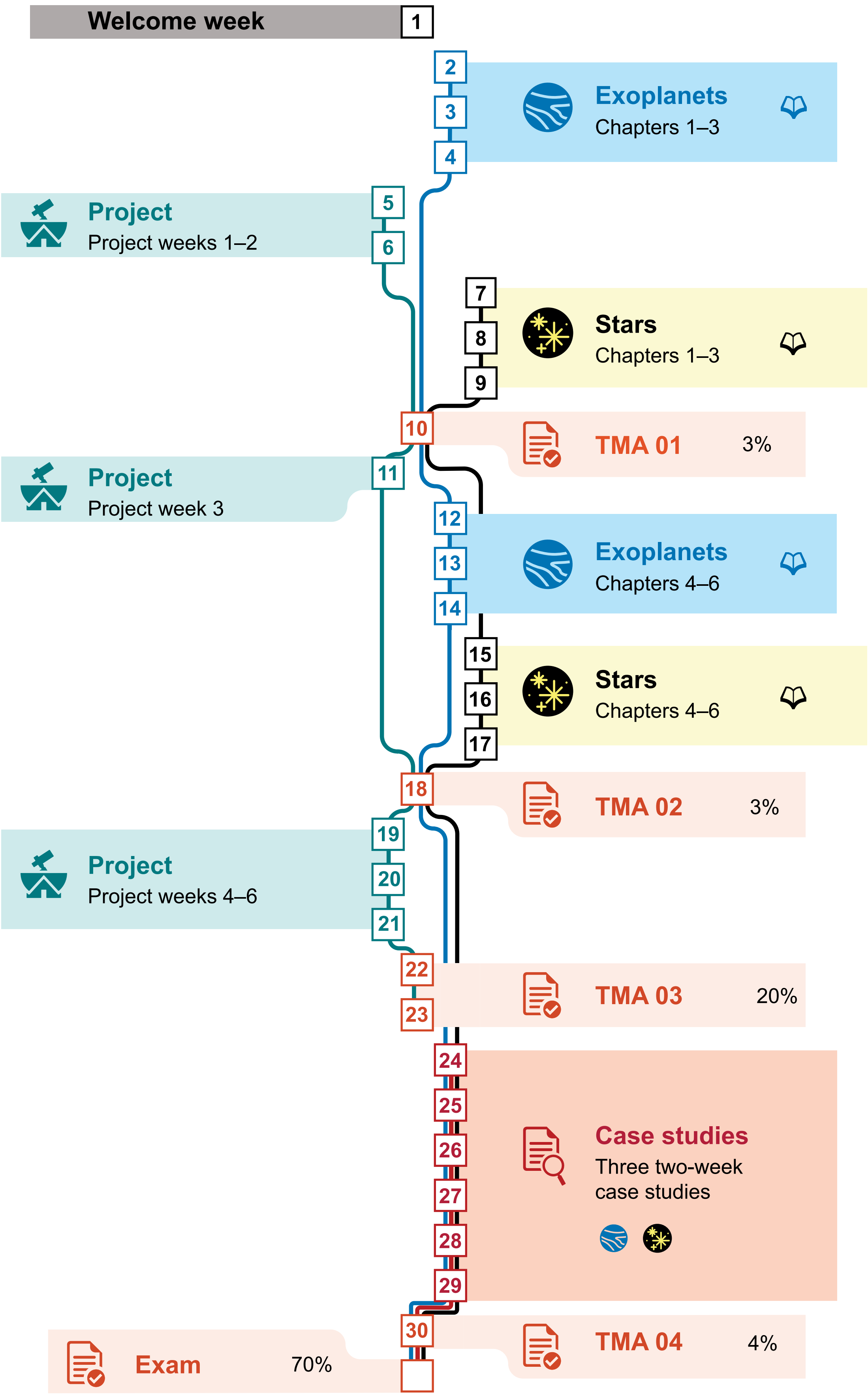
Online case studies

The final learning component of this module comprises three case studies, extending over two study weeks each. The case studies discuss topics that have seen recent scientific progress, and give you further opportunities to use some of the research tools of professional astronomy.

2.1 S384 module map

The research of stars and exoplanets occurs hand in hand, and this is reflected in the way the module is structured. It is essential that you check the S384 study planner each week and follow the suggested study order to help you prepare for the four tutor-marked assignments (TMAs) and the end-of-module exam.

The structure of S384 is illustrated in the module map that follows. The numbers in squares represent study week numbers.


Welcome week
1
2
3
4
Exoplanets
Chapters 1–3
5
6
Project
Project weeks 1–2
7
8
9
Stars
Chapters 1–3
10
TMA 01
3%
11
Project
Project week 3
12
13
14
Exoplanets
Chapters 4–6
15
16
17
Stars
Chapters 4–6
18
TMA 02
3%
19
20
21
Project
Project weeks 4–6
22
23
TMA 03
20%
24
25
26
27
28
29
Case studies
Three two-week case studies
30
TMA 04
4%
Exam
70%

Notes

The observational astronomy project amounts to six weeks of study time (plus a two-week revision and assessment period), but this project work is spread over a three-month period to allow the telescopes to acquire sufficient data.

Always check the S384 study planner – it provides clear guidance on how to navigate the module and which resources to study in each week.

A number of thematic Forums will be used to facilitate discussions between you and your peers. Module-team members, including tutors, may also respond to the queries and issues raised there, or use the forum for announcements and clarifications. You will also have a dedicated tutor-group forum, and a forum for your project group.

2.2 The astrophysics and skills developed in S384

The next five sections give an overview of the astrophysics you will meet and the astrophysical skills you will develop during the different elements of S384.

2.2.1 Module textbook *Exoplanets*

This book comprises six main chapters on the astrophysics of exoplanets.

- Chapter 1 introduces the most common exoplanet detection techniques.
- Chapter 2 focuses on the radial-velocity curves of exoplanet host stars, obtained via spectroscopy, and what they tell us about star–exoplanet systems.
- Chapter 3 deals with the light curves of exoplanet host stars, obtained via photometry, and what physical parameters can be derived from them.
- Chapter 4 introduces transit spectroscopy and what may be determined about the atmospheric structure and chemistry of exoplanets by examining the spectrum of a star while a planet transits in front of it.
- Chapter 5 discusses the influence of the star's and planet's rotation on the stellar spectrum and the light curve.
- Finally, Chapter 6 considers the challenges connected with reconciling the observed sample of exoplanets with the current theories of planet formation.

2.2.2 Module textbook *Stars*

This book comprises six main chapters on the astrophysics of stars.

- Chapter 1 looks at the contraction of gas clouds that leads to the formation of protostars.
- Chapter 2 presents the behaviour and evolution of protostars formed in this way until their arrival on the main sequence, and considers some bulk properties of stellar structure.
- Chapter 3 considers the lower limit to the mass of a star and introduces the rules of quantum mechanics that determine the physics of nuclear fusion.
- Chapter 4 looks at the various nucleosynthesis reactions that occur within stars throughout their lifetimes.

- Chapter 5 considers how both the internal structures of stars and their external properties evolve as these nuclear reactions proceed.
- Finally, Chapter 6 presents the end points of stellar evolution and looks at the exotic states of matter involved.

2.2.3 Observational astronomy project

The observational astronomy project commences after you have studied Chapter 3 of *Exoplanets* on transit light curves.

- Project weeks 1 and 2 (studied in Weeks 5 and 6) are for planning and preparing a monitoring campaign of stars expected to display an exoplanet transit. This planning exercise will be conducted collaboratively with a small team of your peers and will lead to the addition of selected targets to an automated scheduler for PIRATE and COAST. At this point the teamwork ends, and all activities during Project weeks 3–6 should be completed individually.

  PIRATE and COAST will work through their scheduled observing queue autonomously over the following few weeks while you continue studying the module textbooks. You do not have to operate or monitor the telescopes during this time, and you will not have to spend evenings or nights collecting data.
- In Project week 3 (studied in Week 11) you will download an astronomical data-analysis package called ‘HOlomon Photometric Software’ (or ‘HOPS’), and practise its use. This software is tailor-made to extract exoplanet light curves from astronomical image data.
- In Project weeks 4–6 (studied in Weeks 19–21), once the S384 observing campaign is completed, you can download the newly acquired data and process them using HOPS. You will delve into astronomical research literature and databases to review and interpret the new transit light curve, and you will write up your results in a report.

2.2.4 Case studies

The case studies follow on from the two module textbooks and observational astronomy project.

- Case study 1: *Stars and planets as parts of interacting populations* deals with open questions regarding stellar populations that don’t exist near the Sun. You will learn about how stars and planets interact with each other to determine their respective fates, the measurement of stellar parameters, and how to identify stars of scientific interest. You will also gain experience with extracting data from key astronomical databases, obtain insights into how time on scientific facilities is requested and allocated, and what kind of considerations are needed when writing a proposal for an experiment.
- Case study 2: *Doppler imaging* explains the technique of Doppler imaging and shows what stellar physics this can probe. This case study also gives you experience in identifying suitable targets for study with current and future telescope facilities.
- Case study 3: *Transiting exoplanet demographics in the JWST era* discusses our latest understanding of the transiting exoplanet population in light of recent and planned observations from *JWST*. You will learn about what makes *JWST* such an effective tool, some of the unexpected things it has already discovered in the atmosphere of hot Jupiter WASP-39b, and explore how we eventually hope to investigate temperate and potentially habitable worlds. You will use a publicly

available planetary simulation tool, the Planetary Spectrum Generator, to explore the technique of transit spectroscopy further and see how different gases in a planet's atmosphere change the observed spectrum.

2.2.5 Employability

The skills you will develop in this module provide a foundation from which you can progress to more advanced applications in astrophysics. The observational astronomy project and the case studies will give you a flavour of authentic astrophysics research. The transferable skills you will gain are equally important for tasks in many types of analytical work and employment. You can log the skills you learn and track your progress towards your study goals using the OU's FutureYOU tool. For more information on the opportunities and skills provided by studying physics and astrophysics, visit the Science skills and careers website. For further guidance, you can contact Careers and Employability Services, including booking an individual careers consultation.

3 Module learning outcomes

The module is designed to develop your knowledge and understanding of the discipline, and to develop skills expected from an astrophysics graduate. The module assessment allows you to demonstrate that you have met the following formal learning outcomes.

Knowledge and understanding

When you complete this module, you will have knowledge and understanding of:

- the fundamental concepts, principles and terminology of hydrodynamics, thermodynamics, plasma physics, quantum physics, nuclear physics and particle physics that are of relevance to stellar and exoplanetary astrophysics (KU1)
- the behaviour and properties of stars in different evolutionary stages and environments, from their formation to death, and the physical processes that sustain their energy output and drive each stage of their evolution (KU2)
- the methods used in the detection and characterisation of exoplanets, their overall properties, and the astrophysics of their atmospheres that are revealed by the known population (KU3).

Cognitive skills

When you complete this module you will be able to:

- devise and sustain arguments on the basis of conceptual understanding of stellar and exoplanetary astrophysics (CS1)
- critically analyse and synthesise scientific information and data presented in a variety of ways including texts, tables, graphs, diagrams, equations and mathematical derivations (CS2)
- apply the methods and techniques of the discipline, including calculus and physics, to solve problems in familiar and unfamiliar contexts of stellar and exoplanetary astrophysics (CS3).

Key skills

When you complete this module, you will be able to:

- communicate scientific information, arguments and ideas in stellar and exoplanetary astrophysics accurately and effectively using written and numerical descriptions (KS1)
- evaluate and synthesise information from a variety of sources and media, including material not specifically written for an undergraduate audience (KS2).

Practical and professional skills

When you complete this module you will be able to:

- reflect critically on feedback and achievements in order to identify goals that will continue to develop your personal and professional skills (PPS1)
- plan and organise tasks effectively in order to meet deadlines and identified goals (PPS2)

- collaboratively plan observations, analyse astronomical data and communicate their outcomes accurately and effectively (PPS3).

4 Studying S384

4.1 Required knowledge

S384 is an Open University (OU) Level 3 module and is designed to follow the suite of Level 2 modules in the OU's Physical Sciences curriculum. In particular, you are ready to study S384 if you have successfully completed SXPS288 *Remote experiments in physics and space*, MST224 *Mathematical methods*, and either S217 *Physics: from classical to quantum* or the combination of S284 *Astronomy* and S283 *Planetary science and the search for life*.

While it would be desirable to have studied both S284 and S217, if you are on one of our standard BSc pathways you are unlikely to have done so. It is therefore likely that you have to catch up on selected physics or astronomy concepts before starting with new material in the S384 module textbooks. If you have arrived here without having successfully completed all of the expected Level 2 modules (i.e. either SXPS288, MST224 and S217, or SXPS288, MST224, S284 and S283), then it is *essential* that you establish whether your background and experience is sufficient to continue with S384. To this end we produced an 'Are you ready for S384?' quiz to help you decide whether you already have the *recommended* background knowledge and experience to start this module or whether you need some extra preparation. Should your answers signal that you have significant knowledge and skills gaps, please discuss your options with your tutor or the Student Support Team via StudentHome straight away.

You can find support and revision material on the Preparation for Stage 3 astrophysics and cosmology modules website to help you catch up on the essential mathematics, physics and astronomy concepts that S384 will build on.

S384 has two module textbooks that both start with a 'Chapter 0' to outline and summarise some of the assumed prior knowledge in stellar or exoplanetary astronomy. It is recommended that you engage with *Stars* Chapter 0 and *Exoplanets* Chapter 0 now.

4.2 Module-directed and student-directed study

The module is structured so that, on average, a little more than half of the study time is taken up by module-directed learning. This is time you will spend to work through the core material the module team has prepared for you, such as the textbooks and all of the exercises they contain, the project instructions, and the case-study descriptions and instructions.

The remaining study time is to be dedicated to consolidation, revision, practice and enrichment activities that you select yourself, depending on what is the most effective way for you to fully digest the new material you have studied. This could include reading selected paragraphs of the module books again and repeating certain exercises, but also working through additional practice questions, self-assessment quizzes and general enrichment material. It is essential that you spend this student-directed learning time wisely and consider it an integral part of your study commitment.

The distinction between module-directed and self-directed study is somewhat blurred in the project and case studies, as many of the module-directed instructions in these components introduce open-ended activities where you need to decide yourself how far you wish to follow through. Some of the activities that use external tools such as software or web interfaces will take different students different amounts of time depending on their learning style, approach and experience with computer tools. The student-directed time therefore includes a generous element for the completion of these activities, with ample time if required.

4.3 Tuition

Throughout your module studies, you will get help and support from your assigned module tutor, who will:

- mark your TMAs and provide detailed feedback for you to improve your future work
- guide you to additional learning resources
- provide individual guidance, whether for general study skills or specific module content
- facilitate online discussions between your fellow students in the dedicated module and tutor-group forums
- run online tutorials throughout the module. (Where possible, recordings of online tutorials will be made available to you. While these tutorials won't be compulsory to complete the module, you're strongly encouraged to take part.)

During the observational astronomy project, further help will be available from a project support scientist with experience of the data-analysis software you will be using.

4.4 Software requirements

For the observational astronomy project, you will need to install the astronomical image analysis software HOPS. The HOPS installer, in turn, requires Python to be installed, which works best if it is done via Anaconda™ Distribution. (You may have met Anaconda already if you used the resources of Python for Physical Sciences – see in particular Section 3 of 'Python – Getting started'.)

Detailed instructions on how to install Anaconda and HOPS are given in Week 11 (Project week 3). You are welcome to attempt this installation earlier, but please note that the project support scientist who can advise on any installation problems is only available from Week 11 onwards.

In the project, you will also be asked to manipulate data and generate graphs. These tasks can be achieved with spreadsheet software such as Microsoft Excel. You are expected to be fluent in using spreadsheet software; the module does not provide specific support for learning how to use spreadsheets, but the page on Software and tools for Physical Sciences (part of the Physics, astronomy and planetary science study site) provides some useful resources that should help you get up to speed.

As an alternative to spreadsheets, you are also welcome to use your own Python scripts, for example in the form of Jupyter Notebooks, which can be run using the Anaconda installation. This approach might be suitable if you are already familiar with Jupyter Notebooks from modules such as SXPS288, S385 or SM380, but please note that we are not able to provide expert support for any Python issues you may experience.

For the teamworking phase of the project, you would benefit from using an online, shared spreadsheet via Microsoft Office 365. As a registered OU student, you have been allocated a free Microsoft Office 365 account. The Help Centre web page explains how to activate and access it. Note that if you already have Microsoft Office 365 from a private or company account, you have to sign out before accessing the OU Microsoft Office 365 account. There is no obligation to use Microsoft Office 365, but please note that without it, the project activities with a shared spreadsheet will be a little more cumbersome.

4.5 Collaborative work

Collaborative work on this module should be conducted within the University's systems. You should use the discussion forums and tools that are suggested in the module materials. Avoid using third-party tools or products, such as social media platforms, for collaborative tasks.

The OU Social Media Policy covers behaviour on all forms of social media.

4.6 Getting help

If you need help with studying the module, you can contact your tutor or ask a question on the module forums. For more general help, queries and advice, you can contact your Student Support Team via the information available on the Contact the OU website.

5 Assessment

S384 has a number of assessments that are designed to serve a dual purpose.

1. Assessments give you the opportunity to demonstrate how well you have achieved the module learning outcomes. These so-called summative assessment elements determine your module result.
2. Perhaps most importantly, assessments allow you to check that your understanding and skills develop as intended as you progress through the module. This form of assessment is called formative.

S384 deploys both summative and formative assessments.

Purely formative elements

Many weeks include a brief self-assessment quiz to help you identify any gaps in your learning. If any gaps become apparent, you are strongly encouraged to revisit the module material that the quiz in question relates to.

Formative and summative elements

In TMAs 01, 02 and 04, you will practise exam-style questions. Your tutor will provide detailed feedback on your answers to help further improve or consolidate your knowledge and understanding, the skills you will develop in the module, and your confidence in preparation for the exam. The bulk of the questions in these TMAs will be purely formative, but there is also a reflective question that will be graded and counts towards your module result. For TMAs 01 and 02, this summative component will contribute 3% to the final module mark, rising to 4% for TMA 04. You are strongly encouraged to engage fully and in a timely way with all parts of all of the TMAs, as doing so will improve your learning and significantly increase your chances for success in the module.

Purely summative elements

TMA 03 assesses your work on the observational astronomy and data-analysis project and contributes 20% to the overall module mark.

The open-book remote exam at the end of the module assesses the knowledge, understanding and skills you have acquired during the whole of the module, excluding the project phase. The exam contributes 70% to the overall module mark.

5.1 Assessment weightings

Table 1 summarises the different assessment elements and their weighting in the final module result.

Table 1 S384 assessment elements

Assessment element	Summative component	Coverage	Weighting
TMA 01	small summative component	*Exoplanets* Chapters 1–3 *Stars* Chapters 1–3 Project teamwork	3%

TMA 02	small summative component	*Exoplanets* Chapters 4–6 *Stars* Chapters 4–6 Project preparation	3%
TMA 03	all of the TMA is summative	Project	20%
TMA 04	small summative component	Case studies	4%
Open-book remote exam	all summative	*Exoplanets* *Stars* Case studies	70%

5.2 Open-book remote exam

During the open-book remote exam you will work through a set of problems and questions that test your understanding of the subject of this module and your problem-solving skills. Once you start the exam, you have a limited number of hours to work on it before the answers have to be submitted through a dedicated online portal.

Note

While working on the exam, you have access to all module resources and any other external resources, including the internet. However, you will not be able to look up any material of substance – there simply will not be enough time!

The exam is not designed to test your look-up skills or ability to quote from internet pages. Instead, we are testing your conceptual understanding of the astrophysics of stars and exoplanets, and your ability to express these concepts quantitatively in mathematical form, apply them to unfamiliar situations and solve problems in this context. The only way to do this successfully is to come to the exam well-prepared, having done plenty of revision and practice.

General information on remote exams is available in the Exam arrangements handbook.

5.3 Submitting assessments

For information about special circumstances relating to TMA submission, please see the Assessment Policies.

Information on how to scan, photograph or otherwise capture your answers and submit them is given on the Student guidance for preparing and submitting TMAs page of the Mathematics and statistics website.

Plagiarism

Each assessment includes a plagiarism warning. Make sure you read and understand this warning.

Please note that you are required to complete all assessment elements individually and without help from others, even for the observational astronomy project despite the group work at the beginning of the project.

6 Accessibility

Please see the S384 Accessibility Guide for detailed descriptions of the accessibility provisions in this module.

The OU Library also provides accessibility support, which can be sought by contacting the Library Helpdesk.

7 Next steps

This guide has provided an overview of the most important elements of S384. You may wish to refer back to it during the module if you are ever unclear about the purpose of any of the module elements and how they relate to the overall module structure.

Before you set off on your journey into the world of stellar and exoplanetary astrophysics, which can be both awe-inspiring and daunting, we again strongly recommend that you first engage thoroughly with the preparation and diagnostic material compiled on the S384 study planner under the heading of Week 1. Only with a proper foundation in physics and mathematics will you be able to access the deeper understanding of the inner workings of stars and exoplanets, and if you do, we hope that you will draw much enjoyment and satisfaction from it.

Good luck with your studies and research in astrophysics!

8 Contributors

Authors

John Barnes

John is a research fellow based at the OU's Walton Hall campus. He specialises in the use of spectroscopic techniques to study the astrophysics of stars and exoplanets. His primary interests are in stellar activity research and the detection and characterisation of exoplanetary systems.

Jo Barstow

Jo is an astronomer and planetary scientist based at the OU's Walton Hall campus. She specialises in modelling and analysis of planetary atmospheres, both inside and outside the Solar System. Her research mostly relies on data from the *Hubble Space Telescope* and *James Webb Space Telescope*.

Mariangela Bonavita

Mariangela is an astronomer based in Edinburgh. Her research focuses mainly on the detection and characterisation of young giant planets and brown dwarfs using direct imaging. She has developed several widely used tools for the statistical analysis of exoplanet search surveys. Mariangela is also a member of several consortia behind recently implemented and upcoming planet finders, such as SPHERE at the Very Large Telescope in Chile and the European Space Agency's PLATO mission.

Ulrich Kolb

Ulrich is an astronomer based at the OU's Walton Hall campus. His research interests are in stellar populations, binary and multiple stars, exoplanets and time-domain studies using robotic optical telescopes. He is also involved in astronomy educational research and is the academic lead of the OpenScience Observatories.

Iain McDonald

Iain is a Scottish astrophysicist whose research interests include the late stages of stellar evolution; metal-poor stellar populations; the discovery, characterisation and evolution of exoplanets; and the creation of interstellar dust. Over nearly 20 years of research and undergraduate and postgraduate teaching, he has used a large proportion of the theoretical principles and observational techniques discussed in this module. He also publishes in human population genetics.

Andrew Norton

Andrew is an astronomer based at the OU in Milton Keynes and is a former vice president of the Royal Astronomical Society. He began his research career working on interacting compact binary stars, but currently focuses on time-domain astrophysics from large-scale photometric surveys, including variable stars and their investigation using citizen science projects. He has an Erdös–Bacon–Sabbath number of 13.

Staff tutor

Becca Whitehead

Becca has a research background in experimental ultra-low temperature physics and has taught a variety of physics and astronomy modules with the OU. As a staff tutor she is responsible for associate lecturers, supports students and helps to develop online teaching resources. She is Senior Fellow of the Higher Education Academy.

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1.1