Institute of Astronomy
University of Cambridge

**Natural Sciences Tripos**

**Part II Astrophysics**

**COURSE GUIDE**
**2022-2023**

# Contents

Welcome to the Institute of Astronomy and to Part II Astrophysics. We hope you will enjoy this course and the friendly and relaxed working environment offered by the Institute of Astronomy.

Those enrolling for Part II Astrophysics in 2022 may either graduate in 2023 or, subject to satisfactory performance – a II.1 or higher in Part II Astrophysics – proceed to Part III. All students proceeding to Part III Astrophysics are required to complete a computational project, either as assessed work for Part II Astrophysics or as additional work over the summer before starting the Part III course. It is presumed that most of you will have studied Physics A, Physics B and Mathematics in Part IB of the Natural Sciences Tripos or have taken Part IB of the Mathematical Tripos. If not, the course coordinator will advise if extra preliminary reading is required.

The following sections provide information on the course and the department. We have not included sections describing general undergraduate life and facilities in Cambridge, because you have been here for two years and know almost all of it already. If you do need any further information at any stage, then please contact the IoA Undergraduate Office, who will either deal with your query directly or consult or put you in touch with a relevant staff member.

## Aims and Objectives

The University's stated aims are "to foster and develop academic excellence across a wide range of subjects and at all levels of study". Furthermore, the University aims "to provide an education of the highest calibre at both undergraduate and postgraduate level, and so produce graduates of the calibre sought by industry, the professions, and the public service, as well as providing academic teachers and researchers for the future".

In addition, the specific aims of the Institute of Astronomy are:

- to encourage and pursue research of the highest quality in astronomy and maintain Cambridge's position as one of the world's leading centres in the field;
- to continue to attract outstanding students from all backgrounds;
- to provide an intellectually stimulating environment in which students can have the opportunity to develop their skills and enthusiasms to the best of their potential;
- and to maintain the highest academic standards in undergraduate and graduate teaching and to develop new areas of teaching and research in response to the advance of scholarship.

The Part II Astrophysics course is part of the Natural Sciences Tripos and the topics covered follow on from several in the first two years of the Mathematical Tripos and the Physics part of the Natural Sciences Tripos.

The syllabus includes eight examinable lecture courses split between the Michaelmas and Lent terms. These lecture courses come in two flavours, those which teach the fundamental physics underlying the rest of the course:

- Relativity,
- Principles of Quantum Mechanics,
- Statistical Physics
- Astrophysical Fluid Dynamics

And those which apply these concepts to particular astronomical subject areas:

- Topics in Astrophysics,
- Introduction to Cosmology,
- Stellar Dynamics and Structure of Galaxies
- Structure and Evolution of Stars.
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In the Michaelmas term, there is also a non-examinable course giving a general introduction to Astrophysics.

Four of the examinable lecture courses are unique to Astrophysics. The rest are courses shared with Part II Mathematics or Physics. Michaelmas Term includes courses in Quantum Mechanics (in the Maths Department), Structure and Evolution of Stars, Stellar Dynamics and Structure of Galaxies and Relativity (in the Physics department). In the Lent Term there are four courses, Astrophysical Fluid Dynamics (shared with Physics), Introduction to Cosmology, Topics in Astrophysics, and Statistical Physics (in the Maths Department). Topics in Astrophysics plays the dual role of familiarising students with a range of exciting topics in contemporary astrophysics and developing abilities in physical reasoning and order of magnitude estimates in an astronomical context.

In addition to the lectures, students must choose between two options:

i. The Extended Essay - Students choosing this option will select a topic from a list of approved titles provided during the Michaelmas Term and must submit their work early in the Easter Term. They will receive two separate supervisions on structuring the essays and feedback on scientific writing.

ii. The CATAM computational projects - Students choosing this option will complete projects offered by Part II of the Mathematics Tripos.

After completing the year's work students should have:

1. Obtained an introduction from the course as a whole to astronomy, astrophysics and cosmology, emphasising the very wide range of applicability of concepts from many areas in physics;
2. Obtained experience of independent investigation, either through reading for and preparing the essay or through completion of the computational projects;
3. Developed their appreciation of general reasoning in the physical sciences; and
4. Developed transferable skills

**Preparation for Part II**

In order that all students are well equipped for the course, we strongly recommend that students entering from Part IB Physics should complete two computational CATAM projects, which will be marked for feedback at the beginning of Michaelmas Term. Full details of these assignments are emailed to students early in the summer.

**Supervisions**

The Department organises supervisions on behalf of the Colleges and students are told who their supervisors are within about two weeks of the start of Full Term. There are normally 4 supervisions in groups of two for each course. It is usual for the lecturers in each topic to supervise two pairs of students on their course. Supervisions may be held in the Meeting Room (Observatory Building, room 1) which may be booked for this purpose, or in offices elsewhere as appropriate. If there are any problems with supervision arrangements, please see the Course Coordinator at the earliest opportunity.

**Telescopes**

There is no practical element to the course. However, students are encouraged to get involved in the IoA's flourishing Public Outreach Programme. Students may also join the Cambridge University Astronomy Society through which they can gain access to various telescopes on the IoA site.

## Feedback and Consultation Mechanisms

During the first two weeks of Michaelmas Term, students will be invited to elect one representative from their Part II Astrophysics cohort to attend Teaching Committee meetings. Normally, these meetings are held at 2pm on the fourth Thursday of each Full Term.

**Questionnaires**

Students are invited to complete feedback questionnaires for each lecture course. These are relayed to the lecturer. In addition, at the end of the year there is a general feedback questionnaire on the course as a whole and a feedback meeting with the Course Coordinator and Chair of the Teaching Committee, which takes place at the end of Lent Term. These outcomes are considered by the Astrophysics Teaching Committee. However, if something needs changing, it is then too late to be of use to you, so we encourage you to tell us about it over coffee, through the IoA Undergraduate Office, or any member of the staff.

## Key Contacts

| Role | Contact | Phone | Office | Email |
|---|---|---|---|---|
| **Course Coordinator** | Ian Parry | 37092 | Hoyle Rm 22 | irp@ast.cam.ac.uk |
| **CATAM Advisor at IoA** | Paul Hewett | 37507 | Hoyle Rm 19 | phewett@ast.cam.ac.uk |
| **Course Administrator** | Mahsa Zohhadi | 37552 | Hoyle Rm 06 | undergraduate.admin@ast.cam.ac.uk |
| **Teaching Committee Chair** | Cathie Clarke | 39087 | Hoyle Rm 10 | cclarke@ast.cam.ac.uk |
| **Joint Directors** | Cathie Clarke | 39087 | Hoyle Rm 10 | cclarke@ast.cam.ac.uk |
| | Mark Wyatt | 37517 | Hoyle Rm 38 | wyatt@ast.cam.ac.uk |
| **Director's PA** | Susan Hatley | 37521 | Hoyle Rm 48 | hodpa@ast.cam.ac.uk |
| **IoA Librarian** | Mark Hurn | 37537 | Obs Library Office | hurnm@ast.cam.ac.uk |
| **Public Astronomer** | Matt Bothwell | 39279 | Hoyle Rm 59 | bothwell@ast.cam.ac.uk |
| **IT Helpdesk** | | 66666 | Hoyle Rm 42 | helpdesk@ast.cam.ac.uk<br>http://helpdesk.ast.cam.ac.uk |

The Course Administrator oversees the day-to-day administration and is normally the first point of contact for anything related to the course.

**Several course-related items are notified directly by email so you should check your email frequently.** Please ensure that the IoA Undergraduate Office has your up-to-date email address and the contact details of your Director of Studies. The Part II Noticeboard outside Hoyle Room 6 should also be checked frequently. In addition, it is advisable to give the Course Administrator contact details for your Director of Studies.

## General Information

It is hoped that as a Part II Astrophysics student, you will feel part of the Institute of Astronomy and will participate in some of the activities that maintain its friendly and interactive atmosphere.

**Access**

As a Part II student, you will have access to the IoA, DAMPT and Cavendish Buildings. Please ensure you find time to report to Reception on Tuesday 4th October, as your University card will need to be programmed to grant you access to both the Hoyle and Obs. Buildings. Your card will automatically be updated to give you access to the DAMPT and Cavendish Buildings.

**Coffee**

The IoA staff have coffee (and tea) in the Hoyle building foyer from about 11 am. There is no charge for coffee for Part II Astrophysics students.

**Journal Club and Social**

There will be a series of sessions for Part II and Part III students which are designed to build confidence in giving presentations and will also allow socialising between the two-year groups. The sessions are run by enthusiastic PhD students who will offer friendly advice on preparing and giving scientific talks (lecturers do not attend). Further details of these events are to be confirmed.

**Public Outreach**

The IoA runs an extremely successful programme of Public Outreach on Wednesday evenings. Student participation is welcome. More information will be provided during an introductory session (**12:30 Wednesday 5th October 2022**), which will be delivered by our Public Astronomer, Matthew Bothwell.

**Food**

There are several possibilities for lunchtime food provision. Snacks can be obtained on site from the vending machine located in the Hoyle building. Off-site there are several possibilities for canteen style food (CMS, Cavendish Laboratory and Churchill College) and a full range of meals at the Hauser Forum as well. There is also a bread and cheese lunch held on Wednesdays at 12:30pm, which precedes the Seminar.

**Computing**

Undergraduate computing facilities are provided by the University Computing Service and the Colleges. Part II Astrophysics students may use the CATAM Public Workstation Facility, details of which are provided in the CATAM handbook.

**Library**

The Institute of Astronomy library holds 8,000 books and 11,000 volumes of astronomical periodicals. Undergraduate students are encouraged to use the library facilities. There is a selection of the recommended textbooks for the courses in the library area on the first floor of the Hoyle building, and a complete set in Library room B in the Observatory building. All books must be used within the confines of the library and returned to the correct location on the shelves after use. If you need any help, ask the Librarian, Mark Hurn, who has an office in the library area in the Observatory building.

College libraries should also have copies of the recommended textbooks.

**Photocopying**

There is a photocopier in the reprographic room (opposite the vending machine), another is located to the right of the stairs to the Lecture Theatre in the Hoyle building and there is one in the main library in the Observatory building. Course-related copying is free of charge. For private copying there is a charge of 3p per A4 sheet.

**Summer Projects**

A summer placement undertaking astronomical research may be of interest, particularly for those considering a PhD in Astrophysics. The Institute of Astronomy has only a very modest summer student programme and the few positions available are deliberately targeted at students who are not familiar with the Institute.

It is in your own interests to broaden your experience of research beyond the Institute and obtaining a position elsewhere can be rewarding and benefit future applications for PhD places. Unfortunately, there is no central clearing system for summer positions, and it is a case of making enquiries to individual departments/observatories. Many departments in the UK do have positions and those with larger astronomy groups, e.g., Durham, Edinburgh, Oxford, Manchester, are particularly worth investigating. Further afield, several observatories and European groups offer places, e.g., Anglo-Australian Observatory, Australia and Lund Observatory, Sweden.

Some departments/observatories offer funded placements but within the UK it may well be worth making an application for a RAS bursary in collaboration with your target institution/supervisor but you will need to be organised and contact departments in January.

**Useful Links**

**Raven:** The University of Cambridge web authentication server.
You will need your Raven password to log in to the Teaching Information System (q.v.), and to access material (such as past examination papers) on the teaching website from outside the cam.ac.uk domain.

- If you use the Hermes mailstore, you can get your Raven password here.
- If you have lost your Raven password, or you don't use Hermes, contact the University's IT Support Portal.
- If you have a Raven password and your login is rejected by the teaching system, contact the IoA Undergraduate Office, providing your CRSID and we will enable your account.

**CamCORS:** The Cambridge Colleges Online Reporting System
Supervisors use this to report to Directors of Studies and Tutors on the progress of their supervisees, and to claim from the colleges for the supervisions provided. If colleges choose to release the information, students can view their supervision reports here directly.

**CamSIS**: The Student Information System
Students use this to enter for exams, and (when the results are uploaded) to check their Tripos results.

**Moodle**: The University's Virtual Learning Environment used by many departments at the University. Students will be enrolled on to the Part II/MAST Astrophysics Moodle site by the Undergraduate Office at the beginning of the Michaelmas Term. All Part II Astrophysics lecture courses will also have their own site on Moodle. A recording of the lecture material delivered on any given day is expected to be available via the Moodle site within 48 working hours.

**The University's Timetable Tool:** This allows you to create your own timetable of lectures and add to your own electronic calendar.

**The Cambridge University Reporter**: The University's journal of official business and the primary means through which official information and governance-related matters are conveyed by the University to its members and the wider community.

# Wellbeing

### Pastoral Support

Students sometimes encounter personal difficulties during Part III that are not to do with the course itself (for example, there may be financial difficulties or family illness). If such problems arise, you are strongly advised to discuss the situation with your College Tutor as soon as possible. Colleges are used to dealing with such problems, and are experienced in offering advice, help and support. For more on the role of Colleges, click here.

There are also many central University resources available to students.

### Medical Problems and Disabilities

Students with medical problems or disabilities are strongly advised to discuss such problems with their College, who will offer advice and support for medical problems and disabilities.

For more information, please visit the University Disability Resource Centre.

### Mitigating Circumstances

Candidates who are seriously hindered in preparing for, or sitting, their examinations should contact their College Tutor at the earliest possible opportunity. The Tutor will advise on what further action is needed (e.g. securing medical or other evidence) and, in cases of illness or other grave cause, the Tutor can make an application on the candidate’s behalf to the University for an Examination Allowance.

### Special Examination Arrangements

Any student who believes there are circumstances that require special treatment by the examiners must ensure that this information is communicated to the IoA Undergraduate Office by their College at the earliest opportunity and well before the project presentations, for further information, click here.

## Lecture Timetable

| Michaelmas Term 2022 | Lent 2023 |
|---|---|
| Prof. D. B. Skinner*<br>Classical Dynamics<br>M.W.F. 09:00 CMS MR9 | Prof. G. Efstathiou<br>Introduction to Cosmology<br>M. F 10:00 W.12:00 HLT |
| Dr A. Fialkov<br>Relativity<br>M. W. F. 10:15 Pippard, Cavendish Lab | Dr. C. E. Thomas<br>Statistical Physics<br>Tu. Th. 10:00 CMS MR2 [M] |
| Dr. E. Pajer<br>Principles of Quantum Mechanics<br>M. W. F. 12:00 CMS MR2 [M] | Prof. C. Reynolds<br>Astrophysical Fluid Dynamics<br>Tu. Th. 11:30 W. 10:00 HLT |
| Prof. C. Clarke<br>Stellar Dynamics and Structure of Galaxies<br>M. 13:30 Tu. Th. 09:00 HLT | Prof. M. Wyatt and Dr O. Shorttle<br>Topics in Astrophysics<br>Tu. Th. 12:30 W. 11:00 HLT |
| Prof. C. Mackay<br>Introduction to Astrophysics<br>Tu. Th. 10:00 F. 13:30 HLT | |
| Prof. M. Pettini<br>Structure and Evolution of Stars<br>Tu. Th. 12:00 W. 14:30 HLT | |

*[M] indicates that the course is owned by the Maths department.*
** Classical Dynamics, Prof. D. B. Skinner, M. W. F. 09:00 CMS MR9 - non-examinable*

## Talks

There are a number of seminars of astronomical interest within various Cambridge departments. Students are encouraged to attend seminars, although the large number of possibilities implies that students need to be selective in those they attend. The Institute of Astronomy has two regular series of talks, one being the Wednesday lunchtime talks at 12:30 and which usually combines 2 half-hour talks on specialised research topics.

The second series is the Colloquia on Thursdays at 15:30 during Michaelmas Full Term. The Colloquia are hour-long talks that generally contain a larger review element, as well as presenting latest scientific results. All IoA students are strongly encouraged to attend the Colloquia weekly. The schedule of talks for the forthcoming week can be found on the IoA website.

Commitments to lecture courses mean that it is essential to be selective about which talks to attend. However, in addition to the benefits of attending a talk containing relevant subject matter, critical assessment of a number of talks offers the opportunity to gain direct experience of what does and does not work when presenting material to a non-specialist audience. Such experience is likely to be of direct benefit when preparing the project oral presentation to the Examiners in the Easter Term.

For full details of the all the Talks and Seminars on offer at the University, click here.

# Lecture Courses

## Introduction to Astrophysics (non-examinable)

***Michaelmas Term, 24 Lectures*** **– Professor C. Mackay**

1. **Basics:** Scale and content of Universe: Sizes and masses. Magnitudes, HR diagram, Distance determination, The Sun as a typical star, overview of stellar lifecycles, Newtonian mechanics, orbits, tides, blackbodies, continuum radiation mechanisms, spectra and line radiation. [4]
2. **Telescopes, instruments, and observational techniques:** E-M radiation, gamma-rays, X-rays, UV, visible, IR, mm, radio, transparency of the atmosphere, Major space-based and ground-based facilities, S/N calculations. [2]
3. **White dwarfs and neutron stars:** WD origin, structure, neutron star origin, structure, discovery of pulsars, observed properties, evolution, beaming, magnetic fields, magnetic dipoles, pulse timing, the utility of pulsaras, gravitational waves. [3]
4. **Close Binary Stars:** Observations, visual binaries, spectroscopic binaries, eclipsing binaries, masses and radii, consequences of a supernova, equipotentials, mass transfer, accretion discs, magnetic stars, evolution in binary systems, cataclysmic variables, the variety of binary systems, stellar mass black holes. [3]
5. **Supernovae and Hypernovae:** Types, energetics, rates, light curves, spectra, pre-cursors, remnants, radio-active decay, Gamma Ray Bursts (GRBs), discovery, searches, observations, long and short duration GRBs, collapsar-hypernova model, merging of neutron stars and black holes, fireball-shock model, beaming. QSOs as a probe of the intergalactic medium. [3]
6. **Active Galactic Nuclei:** Discovery, observations, classification, energetics, standard model, host galaxies, reverberation mapping, jets, superluminal motion, unified models, QSO population evolution, black holes in non-AGN galaxies. [3]
7. **Galaxies and Clusters of Galaxies:** Structure and content, galaxies within them, hot X-ray gas, magnetic fields, dark matter, virial mass, tidal stripping, S-Z effect, cooling flows. [2]
8. **Gravitational Lenses:** Basic physics, Young diagrams, Einstein rings, critical surface mass density, strong lensing by galaxy clusters, caustics and critical lines, cluster masses, weak lensing, determining the hubble constant, micro-lensing, constraints on halo objects. [2]
9. **Exoplanets:** Discovery methods, statistics of known exoplanets, pulsar planets, hot jupiters, transits, planet formation, dust, proto-planetary discs, Hill radius, future observations, life. [2]

**Recommended Reading**


– Shu, F.H., *The Physical Universe*, chaps. 5-10, University Science Books, California, (1982).
– Accretion Power in Astrophysics (Cambridge Astrophysics) Hardcover – 17 Jan. 2002 by Juhan Frank, Andrew King, Derek Raine. CUP
– † Carroll, B.W. & Ostlie, D.A. An Introduction to Modern Astrophysics (Addison-Wesley) 2017.

# Stellar Dynamics and Structure of Galaxies

***Michaelmas Term*, 24 Lectures – Professor C. Clarke**

1. Introduction to gravitating systems in the Universe. [1]
2. Orbits in a given potential. Particle orbit in Newtonian gravity; energy, angular momentum. Radial force law - general orbit is in a plane; equations of motion in cylindrical polars. Inverse square law; bound and unbound orbits, Kepler's laws; escape velocity; binary stars; reduced mass. General orbit under radial force law; radial and azimuthal periods; precession. [4]
3. Derivation of potential from density distribution. Poisson's equation. Description of structure of galaxies. Gravitational potential for spherical systems: homogeneous sphere, modified Hubble profile, power law. Circular orbits; rotation law $V_c(R)$; escape velocities $V_{esc}(R)$. [2]
4. Nearly circular orbits. Radial perturbations; epicyclic frequency; stability; apsidal precession. Application to pseudo-black hole potential $\Phi = -GM/(r-r_s)$. Vertical perturbations in axisymmetric potential; vertical oscillation frequency; nodal precession. [2]
5. Axisymmetric density distribution. General axisymmetric solution of $\nabla^2\Phi = 0$. Potential due to ring of matter; series solution; 18-year eclipse cycle. Potential due to thin disc; rotation curves of Mestel's disc; exponential disc. Rotation curve of the galaxy; Oort's constants. Rotation curves of spiral galaxies; need for dark matter. [5]
6. Collisionless systems. Relaxation time. Estimates for stellar and galaxy clusters. Gravitational drag. The stellar distribution function; collisionless Boltzmann equation. The Jeans equations as moments of the Boltzmann equation. Analogy with fluid equations. Application to mass in the solar neighbourhood (Oort limit). [4]
7. Jeans Theorem. Application to simple systems in which the distribution function depends only on energy. Useful approximate galactic potentials; polytrope, Plummer's model, isothermal sphere. [3]
8. Globular cluster evolution. Models of globular clusters. King models. *Models with anisotropic velocity distributions.* Observational tests. [3]

**The topics starred in the schedules will be lectured, but questions will not be set on them in examinations.*

**Recommended Reading**


– Goldstein *Classical Mechanics*, Addison-Wesley (2nd edition 1980).
– † Binney, J. & Tremaine, S.D. *Galactic Dynamics*, Princeton University Press (2008).
– Landau & Lifshitz *Mechanics*, Pergamon (3rd edition 1976, reprinted 1994).
– † Binney, J. & Merrifield, M. *Galactic Astronomy*, Princeton University Press (1998).
– Sparke, L.D. & Gallagher, J.S. *Galaxies in the Universe - An Introduction* CUP (2000) (ISBN 0-521-59740-4)

## Principles of Quantum Mechanics

***Michaelmas Term,* 24 Lectures – Dr E. Pajer**

*Further information about this course is available on the Department of Mathematics course pages. Examples papers are available on the DAMTP Examples page.*

1. **Dirac formalism:** Bra and ket notation, operators and observables, probability amplitudes, expectation values, complete commuting sets of operators, unitary operators. Schrodinger equation, wave functions in position and momentum space. [3]
2. **Time evolution operator:** Schrodinger & Heisenberg pictures, Heisenberg equations of motion. [2]
3. **Harmonic oscillator:** Analysis using annihilation, creation and number operators. Significance for normal modes in physical examples. [2]
4. **Multiparticle systems:** Composite systems and tensor products, wave functions for multiparticle systems. Symmetry or antisymmetry of states for identical particles, Bose and Fermi statistics, Pauli exclusion principle. [3]
5. **Perturbation theory:** Time-independent theory; second order without degeneracy, first order with degeneracy. [2]
6. **Angular momentum:** Analysis of states ljm> from commutation relations. Addition of angular momenta, calculation of Clebsch-Gordan coefficients. Spin, Pauli matrices, singlet and triplet combinations for two spin half states. [4]
7. **Translations and rotations:** Unitary operators corresponding to spatial translations, momenta as generators, conservation of momentum and translational invariance. Corresponding discussion for rotations. Reactions, parity, intrinsic parity. [3]
8. **Time-dependent perturbation theory:** Interaction picture. First-order transition probability, the golden rule for transition rates. Application to atomic transitions, selection rules based on angular momentum and parity, absorption, stimulated and spontaneous emission of photons. [3]
9. **Quantum basics:** Quantum data, qubits, no cloning theorem. Entanglement, pure and mixed states, density matrix. Classical determinism versus quantum probability, Bell inequality for singlet two-electron state, GHZ state. [2]

**Recommended Reading**


- E. Merzbacher Quantum Mechanics, 3rd edition. Wiley 1998
- B.H. Bransden and C.J. Joachain Quantum Mechanics, 2nd edition. Pearson
- J. Binney and D. Skinner The Physics of Quantum Mechanics. Cappella Archive, 3rd edition
- P.A.M. Dirac The Principles of Quantum Mechanics. Oxford University Press 1967, reprinted 2003
- S. Weinberg Lectures on Quantum Mechanics. CUP, 2nd ed., 2015
- J.J. Sakurai and J.J. Napolitano Modern Quantum Mechanics. CUP 2017

## Structure and Evolution of Stars

***Michaelmas Term,* 24 Lectures – Professor Max Pettini**

1. **Basic Concepts and Observational Properties:** Course overview; Mass, Temperature, Luminosity Gravity, composition, Age; Photometry and stellar colours; Spectra and spectral lines;
2. **Distance:** parallax, apparent and absolute magnitudes; Masses from binary stars;
3. **Temperature:** black-body radiation, Wien's Law; The Hertzsprung-Russell Diagram and spectral classification
4. **Stellar Structure:** Timescales; dynamical, thermal nuclear. Energy generation, thermonuclear reactions. Energy transport; opacity, radiative and convective transport. Equations of stellar structure. Hydrostatic equilibrium, Virial Theorem, Pressure. Stellar properties as a function of mass, homology. Degeneracy: Chandrasekar limit.
5. **Stellar Evolution and the Hertzsprung-Russell diagram:** Pre-main sequence evolution, Hayashi and Henyey tracks. Post-main sequence evolution: massive stars, supernovae, neutron stars, black holes. Post-main sequence evolution: low-mass stars, planetary nebulae, white dwarfs, Type Ia supernovae. Initial mass function
6. **Observational Tests and Constraints:** The mass-luminosity relationship. Stellar abundances. The most massive stars and stellar winds. Supernovae

**Recommended Reading**

- Prialnik, D., An Introduction to the Theory of Stellar Structure and Evolution, Cambridge University Press, 2000, 2nd Edition 2010
- Lamers, H J G L M and Levesque E M, Understanding Stellar Evolution, IOP Publishing, 2017
- Guidry, M, Stars and Stellar Processes, Cambridge University Press, 2019
- LeBlanc, F, An Introduction to Stellar Astrophysics, Wiley, 2010

## Relativity

***Michaelmas term,* 24 Lectures – Dr A. Fialkov**

1. **Introduction:** problems with Newtonian gravity, the equivalence principle, gravity as spacetime curvature.
2. **Foundations of special relativity:** Inertial frames, spacetime geometry, Lorentz transformations, length contraction and time dilation, Minkowski line element, particle worldlines and proper time, Doppler effect, addition of velocities, acceleration and event horizons in special relativity.
3. **Manifolds, coordinates and tensors:** Concept of a manifold, curves and surfaces, coordinate transformations, Riemannian geometry, intrinsic and extrinsic geometry, the metric tensor, lengths and volumes, local Cartesian coordinates, pseudo- Riemannian geometry, scalar fields, vectors and dual vectors, tensor fields, tensor algebra, covariant differentiation and the metric connection, intrinsic derivative, parallel transport, geodesics.
4. **Minkowski space and particle dynamics:** Cartesian inertial coordinates, Lorentz transformations, 4-tensors and inertial bases, 4-vectors and the lightcone, 4-velocity, 4-acceleration, 4-momentum of massive and massless particles, relativistic mechanics, arbitrary coordinate systems.
5. **Electromagnetism:** Lorentz force, the current 4-vector, the electromagnetic field tensor and field equations, the electromagnetic 4-potential.
6. **Spacetime curvature:** Locally-inertial coordinates, weak gravitational fields, intrinsic curvature, the curvature tensor, the Ricci tensor, parallel transport, geodesic deviation and tidal effects, physical laws in curved spacetime.
7. **Gravitational field equations:** the energy-momentum tensor, perfect fluids, relativistic fluid dynamics, the Einstein equations, the weak field limit, the cosmological constant.
8. **Schwarzschild spacetime:** static isotropic metrics, solution of empty-space field equations, Birkhoff’s theorem, gravitational redshift, trajectories of massive particles and photons. Singularities, radially-infalling particles, event horizons, Eddington- Finkelstein coordinates, gravitational collapse, tidal forces.
9. **Experimental tests of general relativity:** precession of planetary orbits, the bending of light.
10. **Friedmann–Robertson–Walker spacetime:** the cosmological principle, comoving coordinates, the maximally-symmetric 3-space, the FRW metric, geodesics, cosmological redshift, the cosmological field equations.
11. **Linearised gravity and gravitational waves:** weak field metric, linearised field equations, Lorenz gauge, wave solutions of linearised field equations.*

**The topics starred in the schedules may be lectured, but questions will not be set on them in examinations.*

# Introduction to Cosmology

***Lent Term,* 24 Lectures – Professor G. Efstathiou**

1. **Is cosmology science?:** Causal structure of space-time: our past light cone. Technology horizon, particle horizon and the `size' of the Universe. Importance of symmetry principles in cosmology. Big problems in cosmology. [1]
2. **The background cosmology:** Symmetric spaces. The Friedmann-Robertson-Walker metric. Energy Momentum Tensor for Perfect Fluid. Friedman equations and geometry of the Universe. Cosmological redshift. Newtonian cosmology. Cosmological constant. de-Sitter space and time-slicing. Horizons. Distances and age of the Universe.[6]
3. **Thermal history:** The cosmic microwave background (CMB) radiation. Thermal equilibrium: bosons and fermions. Particle content at early times. Neutrinos and neutrino decoupling. Big-bang nucleosynthesis. Relic particles. Dark matter. Baryon asymmetry. Recombination. [5]
4. **Fluctuations:** Newtonian perturbation theory. Fluctuations in the CMB – Silk Damping. Inflation and the origin of fluctuations. Gravitational waves and tests of inflation. What can we learn from the CMB? The LCDM model. The multiverse. Unanswered questions. [5]
5. **Observational Probes:** Standard candles – Type 1a supernovae. Standard ruler – Baryon Acoustic Oscillations. Inverse distance ladder and $H_{0.}$ Forward distance ladder and $H_{0.}$ Gravitational lensing. Redshift space distortions. Is LCDM consistent with observations? [4]
6. **Non-linear evolution of structure:** Spherical collapse model. The mass function. Galaxy formation. [4]

# Statistical Physics

**Lent Term, 24 Lectures – Dr C.E. Thomas**

Further information about this course is available on the Department of Mathematics course pages.
Examples papers are available on the DAMTP Examples page.

1. **Fundamentals of statistical mechanics:** Microcanonical ensemble. Entropy, temperature and pressure. Laws of thermodynamics. Example of paramagnetism. Boltzmann distribution and canonical ensemble. Partition function. Free energy. Specific heats. Chemical potential. Grand Canonical Ensemble. [5]
2. **Classical gases:** Density of states and the classical limit. Ideal gas. Maxwell distribution. Equipartition of energy. Diatomic gas. Interacting gases. Virial expansion. Van der Waals equation of state. Basic kinetic theory. [3]
3. **Quantum gases:** Density of states. Planck distribution and black body radiation. Debye model of phonons in solids. Bose-Einstein distribution. Ideal Bose gas and Bose-Einstein condensation. Fermi-Dirac distribution. Ideal Fermi gas. Pauli paramagnetism. [8]
4. **Thermodynamics:** Thermodynamic temperature scale. Heat and work. Carnot cycle. Applications of laws of thermodynamics. Thermodynamic potentials. Maxwell relations. [4]
5. **Phase transitions:** Liquid-gas transitions. Critical point and critical exponents. Ising model. Mean field theory. First and second order phase transitions. Symmetries and order parameters. [4]

**Recommended Reading**


- F. Mandl *Statistical Physics*. Wiley 1988
- R.K. Pathria *Statistical Mechanics, 2nd ed.* Butterworth-Heinemann 1996
- L.D. Landau and E.M. Lifshitz *Statistical Physics, Part 1 (Course of Theoretical Physics volume 5).*
- Butterworth-Heinemann 1996
- M. Kardar *Statistical Physics of Particles.* CUP 2007. (See also course 8.333, MIT OpenCourseWare https://ocw.mit/edu)
- F. Reif *Fundamentals of Thermal and Statistical Physics.* McGraw-Hill 1965
- A.B. Pippard *Elements of Classical Thermodynamics.* Cambridge University Press, 1957
- K. Huang *Introduction to Statistical Physics.* Taylor and Francis 2001

# Astrophysical Fluid Dynamics

***Lent Term,* 24 Lectures – Professor C. Reynolds**

Fluids are ubiquitous in the Universe on all scales. As well as obvious fluids, (e.g. the gas that is in stars or clouds in the interstellar medium) a variety of other systems are amenable to a fluid dynamical description - including the dust that makes up the rings of Saturn and even the orbits of stars in the galactic potential. Although some of the techniques of conventional (terrestrial) fluid dynamics are relevant to astrophysical fluids, there are some important differences: astronomical objects are often self-gravitating or else may be accelerated by powerful gravitational fields to highly supersonic velocities. In the latter case, the flows are highly compressible and strong shock fronts are often observed (for example, the spiral shocks that are so prominent in the gas of galaxies like the Milky Way).

In this course, we consider a wide range of topical issues in astronomy, such as the propagation of supernova shock waves through the interstellar medium, the internal structure of stars and the variety of instabilities that affect interstellar/intergalactic gas. These include, perhaps most importantly, the Jeans instability whose action is responsible for the formation of every star and galaxy in the Universe. We also deal with exotic astronomical environments, such as the orbiting discs of gas which feed black holes.

1. **Introduction:** The concept of a fluid. Collisional and collisionless fluids. Kinematics. Conservation of mass. Pressure. (Inviscid) momentum equation for a fluid under gravity. Stress tensor and the concept of ram pressure. [2]
2. **Basic Concepts of Gravity:** Poisson's equation. Gravitational potential. The Virial Theorem. [1]
3. **Equation of State:** Barotropic relation between pressure and density. Energy equation. Hydrostatic equilibrium. Examples: hydrostatic atmosphere under uniform gravity; self-gravitating isothermal slab; self-gravitating polytropes as simple models of stars, mass-radius relation. [4]
4. **Sound Waves:** Sound speed: adiabatic and isothermal case. Sound waves in a stratified atmosphere. [1]
5. **Supersonic Flows:** Rankine-Hugoniot conditions for adiabatic and isothermal shocks. Application to blast waves and supernova remnants. [3]
6. **Bernoulli's Equation and its Applicability:** De Laval nozzle and its relevance to astrophysical jets. Bondi accretion, stellar winds and mass loss. [2]
7. **Fluid Instabilities.** Convective instability, Schwarzschild criterion. Jeans instability. Rayleigh-Taylor and Kelvin-Helmholtz instability. Thermal instability, Field criterion. [3]
8. **Viscous Flows:** Linear shear flow. Navier-Stokes equation. Vorticity and energy dissipation in viscous flows. Accretion discs. Steady thin discs. [3]
9. **Magnetohydrodynamics:** The ideal MHD equations. Alfven waves. [3]
10. **Computational Astrophysical Fluid Dynamics** [2]

**Recommended Reading**

- Clarke, C.J. & Carswell, R.F. Principles of Astrophysical Fluid Dynamics, Cambridge University Press (2014)  Landau & Lifshitz, Fluid Mechanics, Pergamon Press (1987)

**Further Suggestions**

- Acheson, D. Elementary Fluid Dynamics Oxford University Press (1990)
- Batchelor, G.K. An Introduction to Fluid Dynamics, Cambridge University Press (1967, reprinted 2000) Lamb, H. Hydrodynamics, Cambridge University Press (6th ed 1932, reprinted 1993

## Topics in Astrophysics

***Lent Term,*** 24 Lectures – Professor M. Wyatt, Dr O. Shorttle and IoA/Physics staff

Most of your Part II Astrophysics courses follow a strictly disciplinary approach: teaching specific physics to tackle specific astrophysical problems. Yet, much research is inherently interdisciplinary, motivated primarily by outstanding questions about the Universe and then adopting whatever mix of methods, observational and theoretical, are required to address these questions. In Topics the aim is to develop your familiarity with this more research-oriented, question-first, approach to astrophysics, by exploring interdisciplinary astrophysics via two different, but complementary approaches: applying *specific physical concepts* to diverse astrophysical phenomena; and, applying diverse physical concepts to a *specific research theme*, 'planet formation'.

First, we will investigate how specific *physical concepts* can be applied to understand a wide diversity of astrophysical phenomena. This approach is explored in lectures 1-12, where you will gain expertise in the physics of tides and the description of populations of astrophysical objects as distributions. The lectures then illustrate how this Newtonian dynamics and tidal theory can be applied to a host of astronomical objects from quasars and super massive black holes, to stellar clusters, asteroids and moons. This exemplifies how mastery of specific physical concepts can open up a diverse range of astrophysical processes to investigation.

Second, we focus on a specific *research theme*, 'planet formation', and bring a range of physics to bear on this rich problem in planetary and exoplanetary science. In lectures 13-24 we begin by reviewing key results in planetary and exoplanetary science and primary questions and challenges these pose for the field of planet formation. Then we move through the key processes from protoplanetary disk to planet accretion, seeing how these are all linked in understanding 'planet formation'. This half of the course emphasises how by being question-led in research we often need to reach to a host of methods in physics to address that motivating problem.

To further your understanding of astrophysics as a research discipline, the core lectures from these two halves of the course are interspersed with `Guest Lectures', in which a number of staff in astronomy departments across Cambridge will provide a perspective on their cutting-edge research.

1. Timescales and Distributions [3]
2. Tides and Dynamics [6]
3. Guest lectures [3]
4. Lessons from the solar system [2]
5. Exoplanet demographics [2]
6. Protoplanetary disks and planetary accretion [6]
7. Guest lectures [2]

*The scheduling of lecture topics may deviate slightly (e.g., depending on the availability of the guest lecturers).*

**Recommended Reading:**

There are no textbooks to support the course. However, for students who are interested in learning more about some of the topics covered, the following books (in addition to those supporting other Part II Astro. courses) are recommended:

- P. Armitage, The Astrophysics of Planet Formation, Cambridge University Press, 2010.
- D Catling & J Kasting, Atmospheric evolution on inhabited and lifeless worlds, CUP, 2017
- Frank, J., King, A., Raine, D., Accretion Power in Astrophysics, Cambridge University Press, 2002.
- F. Mellia High Energy Astrophysics, Princeton University Press, 2009.
- D Turcotte, Geodynamics, CUP, 2018
- D. Ward-Thompson & A. Whitworth, An Introduction to Star Formation, Cambridge University Press, 2011.
-

# Part II Coursework

**The Extended Essay**
Students may choose to undertake an extended essay, for which the maximum credit awarded is the equivalent to that for a course of 24 lectures.

The purpose of the essay is to bring students to a closer awareness of the current frontiers of astronomical research, by reading and assimilating research literature addressing problems that have not been completely solved in some limited area of endeavour. The essay should be at the forefront of research and not be merely a summary of the literature (or lecture notes) and the ideas they contain but should be organized in such a way as to address specifically some issue or issues which the candidate considers to be particularly interesting and important. A critical approach should be adopted, and students should not refrain from making their own judgements on the validity or plausibility of the arguments discussed. Back-of-the-envelope calculations and general physical arguments should be made to support those judgements, whenever that is possible.

It is important to realize that marks are awarded by the Examiners not merely for a well written review which shows that the candidate has understood the issues in question, but also for originality of presentation providing a demonstration that those issues have been thoroughly digested. More credit will be given for an essay containing a thorough, well-reasoned discussion of a relatively small area of the subject than a superficial review of a wide area. Nevertheless, candidates are advised to set their discussion into a wider context, briefly explaining its relevance to other issues. The Examiners will award marks for an up-to-date essay which demonstrates a good physical understanding of the material. In order to prepare for this, students will receive two separate supervisions on structuring the essays and feedback on scientific writing.

You may choose whatever format and style of writing you prefer although, you should be aware that an overly sensational or journalistic style may not suit the subject matter. The length of the essay will be **not more than 5,000 words** (exclusive of tables, figures, footnotes, appendices, and bibliography). Note that figure captions and table captions do not count towards the total word count.

Whist handwritten essays are permitted, those that are deemed by the Examiners to be 'not sufficiently legible' may need to be resubmitted in typescript.

**Plagiarism**
It is a fundamental tenet of scientific writing that due acknowledgment is given to the work and ideas of others that form the basis of, or are incorporated in, the essay. You must always acknowledge the source of an idea or material you use with a specific reference. Plagiarism, including the use of another individual's ideas, data or text, is regarded as an extremely serious disciplinary offence by the University. Please ensure you read the University's guidelines on plagiarism.

**Key Dates**
A list of the essay topics will be posted on the Course Moodle site and on the Part II noticeboard outside the IoA Undergraduate Office by the middle of the Michaelmas Term. The Course Administrator will have further details from the essay supervisors giving brief descriptions for each of them. Students are strongly encouraged to consult the advisor who has been assigned to the essay of

choice and should be aware that some advisors may be difficult to contact for extended periods over the Easter break, so starting work on the essay no later than the start of the Lent Term is advisable.

Students choosing the extended essay **must** then notify the IoA Undergraduate Office of their chosen essay topic by **Friday 17th March 2023** (the last day of the Full Lent Term) at the latest.

An electronic PDF copy of the final project essay must be uploaded to the Part II Astrophysics Moodle site by **12:00 BST Thursday 4th May 2023** (the tenth day of the Full Easter Term) at the latest. After which, the submission point will close.

**Late Submissions**

Late submissions are very strongly discouraged because you will be left with insufficient time to properly revise for the written examinations. In circumstances in which it is unavoidable you **must** contact the IoA Undergraduate Office **at least 1 week in advance of the deadline** to seek permission. Late submissions must then be submitted to the IoA Undergraduate Office **via your college Tutor** with an accompanying letter of explanation from the Tutor.

***Please note all students entering Part III Astrophysics are required to have completed a CATAM project. As such, those choosing to complete the Extended Essay in Part II, will be required to complete a CATAM project in the long vacation prior to the Michaelmas term of Part III.***

**Computational Projects**

Students may, as an alternative to the essay, complete computational projects selected from those offered in Part II of the Mathematical Tripos. The maximum credit for the projects is 16 units, which is equivalent to that for a course of 24 lectures. This will generally involve two, or at most three, projects. Fewer units may be offered for proportionally less credit. If more than 16 units are submitted (e.g., if your choice of projects does not fit in the 16-unit total), your credit will be scaled to bring the number of units back to 16.

A full description of the projects on offer, and the number of units ascribed to them, can be found in the Part II Computational Project Manual. You will also find the required form of the reports and the assessment procedure. For Part II Astrophysics students, there are two major differences from those taking Part II Mathematics:

1. **Maximum credit can be obtained by submitting projects amounting to 16 units**, and this credit is equivalent to a 24-lecture course (rather than as stated in CATAM sections 1.1 & 2.1.1).
2. While the marking scheme is the same, **the scaling of the marks will be carried out to reflect the fact that 16 units corresponds to a 24-lecture course**. (The comments regarding the marking for Mathematics students in the third paragraph of CATAM section 2.1 are not relevant.)

All other aspects are as described in the Part II Computational Projects Manual.

Please read the advice in the CATAM Project Handbook Introduction and read the FAQs concerning Part II CATAM projects before submitting a question to the helpline. One Computational Projects lecture is given at the beginning of Michaelmas Term by the various assessors who introduce their projects and answer questions on them. There will also be updates made to via the CATAM News. Further help is available from Professor Paul Hewett at the Institute of Astronomy.

Students who intend to submit the computational project reports must then notify the IoA Undergraduate Office by **Friday 17th March 2023** (the last day of the Full Lent Term) at the latest.

You will be required to submit electronical copies of both your Final Reports and your Program Source files to the CATAM Moodle site by 16:00, **Wednesday 3rd May 2023** at the latest.

**Late Submissions**

If an extension is likely to be needed, a letter of application and explanation is required from your Director of Studies. The application should be sent to the CATAM Director by the submission date as detailed above.

- Applications must demonstrate that there has been an unexpected development in the student's circumstances.
- Extensions are not normally granted past the Friday of submission week.

**Examinations**

Specific information regarding the examinations will be given in notices posted on the Part II noticeboard outside Hoyle Room 6 and in The Reporter.

The Teaching Committee have recommended to Examiners that, in addition to a numerical mark, extra credit should be available for the completeness and quality of each answer. An alpha quality mark signifies an answer of high quality which is substantially complete. A beta quality mark usually signifies at least half marks. It must be understood that Examiners have discretion in the implementation of these recommendations.

**Calculators**

The use of electronic calculators will **NOT be permitted** in any papers borrowed for the Mathematical Tripos.

In the examinations candidates will not be required to quote elaborate formulae from memory as an approved formula booklet will be provided. It is the responsibility of each student to equip themselves with a suitable calculator (see following notice). A few spare calculators are provided in the examination rooms but only to students whose own calculator has malfunctioned.

The use of electronic calculators will **NOT be permitted** in any papers borrowed from the Mathematical Tripos.

The following calculators marked in the approved manner are permitted for use in any papers borrowed from Part II Physics examinations:

- CASIO fx 991 (any version)
- CASIO fx 115 (any version)
- CASIO fx 570 (any version)

**It is the responsibility of each student to equip themselves with a suitable calculator as described.**
Each such calculator permitted in an examination must be marked by the Department in the approved fashion so that they are clearly identified as being permitted during the examination. No other calculator may be brought into the examination.

**Sale of Approved Calculators**
Approved calculators, marked in the approved fashion, will be on sale from the Department of Physics, Bragg Building (Natural Sciences Tripos). Approved calculators bought elsewhere will need to have the approved marking applied by the Department.

**The form of the examination**
There will be four papers in total of three hours each. Each of these four papers consists of a question from each of the eight courses, which carry equal total exam credit.

Candidates may attempt **not more than six questions** on each paper and have free choice of these.

Each question will consist of a Part (i) and a Part (ii). Part (i) will be designed to be very straightforward and to take about half as long to answer as Part (ii). In a given question, Part (i) and Part (ii) may or may not be directly related and will be given separate quality marks.

- Previous examination papers can be found here.
- External Examiner's Report is here.
- Formulae sheet (provided for all examinations)

The examiners may, at their discretion, further examine a candidate viva voce.

**Examination Results**
Examinations are a University matter and covered by strict regulations. Whether you have a complaint or not, **you should not, under any circumstances, seek to discuss your examination result with your examiners.** The University has a standard procedure for dealing with complaints about examination results.

The various steps in the procedure are **time-limited** and you should therefore immediately discuss the matter with your College Tutor, who will advise you further. You should note that any investigation by the University will usually confine itself to seeing that the examiners acted correctly (for example that all the marks you received were entered into the mark book) and not try to second-guess the examiners by remarking your papers.

**Criteria for Marking Pt II Astrophysics Examination Papers**
The Institute of Astronomy Teaching Committee recommends that the NST Part II Astrophysics examiners mark the written examinations and assess their contribution to the overall degree class according to the following criteria. An explanation of the marking scheme can be found here.

**First class marks**
A candidate placed in the first class will be able to demonstrate a full command and a secure understanding of the examinable material. Scripts will contain substantially correct solutions to most of the quantitative parts of a question, showing a good grasp of mathematical skills. For the essay and questions of an essay nature, first class marks will be awarded for work which is excellent, both in range and in depth of knowledge and in the argument and analysis that it brings to bear.

**Upper Second class marks, II.1**
A candidate placed in the upper second class will be able to demonstrate a good command and some understanding of the examinable material. Scripts will contain solutions to most of the quantitative parts of a question, thereby demonstrating the basic skills involved. For the essay and questions of an

essay nature, II.1 marks will be awarded for work that demonstrates knowledge, but which does not provide as impressive a display of understanding, argument and analysis as those in the first class.

**Lower Second class marks, II.2**

A candidate placed in the lower second class will be able to demonstrate some command of the examinable material but with limited understanding. Candidates should demonstrate the ability to make good attempts at the straightforward parts of questions but limited ability to tackle any of the more challenging topics. Answers to questions of a mathematical nature will show an indication of what is required but fail to proceed sufficiently far into the later parts to demonstrate the skills involved. Essays in this class may often read like prepared material rote learnt for the occasion and fail to be impressive in the range of relevant knowledge and depth of understanding, being superficial in scope or lacking clarity of structure.

**Third class mark**

A candidate placed in the third class will be able to demonstrate some knowledge but have a poor command of the skills expected and very limited understanding of the examinable material. Essays in this class may be unduly brief, lacking in examples or failing to adhere to the rubric, by, for example, answering intelligently, but on material unrelated to the question, or containing some relevant material presented without clear structure or reasoned explanation.

**Ordinary/Fail**

A fail mark will be given when a candidate demonstrates little or no knowledge of the material and little or no ability to begin to tackle questions of a mathematical nature. Essays in this class will demonstrate unsatisfactory command of material through a lack of knowledge and an inability to demonstrate any appreciable understanding. It is likely that such answers will be very brief and incomplete, or rambling and irrelevant.

# Transferable Skills

All students in the University are encouraged to engage in personal development planning. The Astrophysics courses are designed to provide all students with opportunities to develop a wide range of transferable skills. The University also offers plenty of opportunities to acquire skills outside the curriculum particularly in College-based activities and in numerous specialist interest clubs and societies. Students also have access to the University of Cambridge Training system, which hosts a wide range of courses run by participating University training providers.

The Institute of Astronomy has identified the following set of skills and attributes which all undergraduates can reasonably expect to acquire during their university career. These skills enhance students' academic performance, can be used beyond university, and are valued by employers.

This following sets out the ways in which transferable skills are acquired through the teaching programme offered by the Institute. The Part II and Part III Astrophysics courses overlap with courses provided by the Departments of Physics and Applied Mathematics and Theoretical Physics and so the transferable skills policy statements of those departments are also relevant.

**Intellectual Skills**

The most important intellectual skills which our students learn are abilities at quantitative and qualitative reasoning in the exact physical sciences and the application of this understanding to problem-solving. Examples include development of models of phenomena, mathematical analysis of models, appropriate approximation, and statistical analysis. These skills are developed both the IoA through lectures, examples classes, seminars, projects and examinations and your College through supervisions involving discussion, reasoning, problem solving, and critical analysis.

**Communication Skills**

All students develop their communication skills as part of the teaching and assessment programme. In Part II essays and Part III projects credit is given for the quality of the student's communication skills. The principal elements of the training involve the following:

i. **Writing**
   - Department: Guidance notes provided by the Department on the preparation and presentation of Part II essays. Individual guidance by supervisors of Part III research projects, encouraging a critical attitude and an innovative approach to problem solving.
   - College: Supervisions involving the discussion and written solution of problems.

ii. **Oral**
   - Department: Oral presentations of project work in Part III (also including software presentation packages and visual aids).
   - College: Supervisions involving oral explanations and discussion with supervisors and other students.

iii. **Non-verbal (development of an argument using mathematical concepts or symbolic language)**
   - Department: Computational projects, essays, and examples sheets.
   - College: Supervisions involving problem solving.

**Organisational and Interpersonal Skills**

Students develop self-discipline in the management of a complex work programme of lectures, supervisions, examples classes, projects, literature reviews and examinations with strict deadlines.
Interpersonal skills and self-expression are developed through constant interaction with peers,

supervisors, lecturers and working within a research group as part of a Part III project.

- Department: Provision of a framework within which the students carry out their work programme with clear deadlines. Advice on organising the programme of work in the Course Guide.
- College and University societies: Oversight of the students' programmes is maintained by Directors of Study and Tutors. Advice on organisation of the work programme through supervisions. Living, working, and socialising in a diverse community and taking positions of responsibility are important contributors.

**Research Skills**

Students develop information-acquisition skills from the selection and use of appropriate textbooks to the sourcing and assimilation of scientific literature particularly for essays and projects.

- Department: Development of all aspects of research skills involving the application of understanding of concepts to new problems by use of the library, electronic and Internet resources to supplement information given in lectures and supervisions, critical analysis of published papers in preparation for a Part II essay and the Part III research project. Appreciating how to access the experience and knowledge of expert scientists.

**Numeracy and Computing**

Success in Astrophysics is dependent on a high level of numeracy and computing skills, all of which are highly transferable to other spheres.

- Department: In earlier years of the Natural Sciences Tripos students will have followed courses in mathematics. All Astrophysics courses contain mathematical elements. Lectures and examples classes are provided in mathematical methods and statistical Astrophysics, daily use of mathematics and computational methods for study and problem solving and data analysis in essays and projects. CATAM courses are specifically focussed on programming skills, many at a very advanced level.
- College: Supervisions in all courses. Computing resources for the above such as e-mail and Internet access. Word processing is used for all aspects of written communication.

**Foreign Language Skills**

Students have access to the University's Language Centre and extensive opportunities for self-teaching in foreign languages.

# Appendix 1

**NST Part II Astrophysics: Guide to Class Boundary Construction**

1. The examiners mark the examination questions numerically with a quality mark α or β if a certain standard is reached. The examiners are free to choose this standard depending on the question but normally a numerical mark on part (i) of 5–7 is awarded a β while 8–10 is awarded an α. On part (ii) 10–14 is normally awarded two βs and 15–20 two αs.

   Candidate's total numerical marks (awarded on examination questions and project work/essay) and quality marks (numbers of αs plus half the number of βs) are used to produce a plot of total marks versus quality marks. Also plotted as reference are the class boundaries for (at least) the previous two years.

2. The quality marks and total marks per candidate are compared to at least the previous two years to gain an insight into whether the examination is easier or more difficult. In the last two years the examinations have been conducted online (open book in 2019-2020, closed book in 2020-2021). The most appropriate previous years will be chosen as reference to reflect the exam condition in 2021-2022. If the class lines for the reference years indicate a very different result for the ensemble, then this suggests that the examination may have been too hard or too easy. The locations of the highest and lowest performing candidates can also give insight into the relative difficulty of the examination.

3. The dividing lines between firsts and upper-seconds, upper-seconds and lower-seconds and lower-seconds and thirds are adjusted in the light of these considerations. The dividing lines may be moved slightly upward or downward depending on whether the exam is judged harder or easier than in previous years. It is undesirable for the dividing lines to separate strongly clustered candidates on the total marks versus quality marks plot.

4. At the discretion of the examiners, in some years candidates just below a boundary may be invited for a viva.

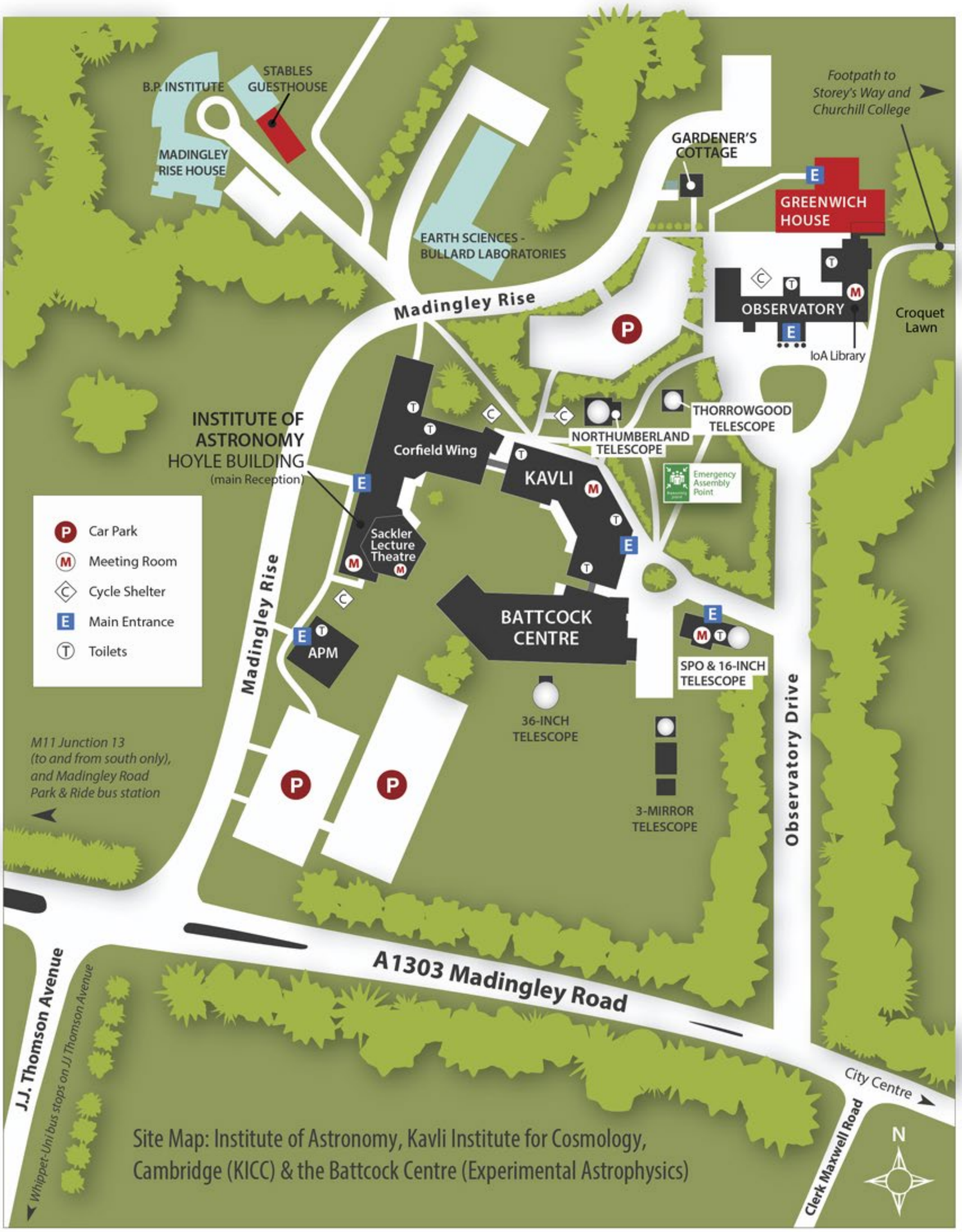
5. The examiners now consider scenarios in which any candidate may have been disadvantaged by typographical errors or other issues arising in the examination. If necessary, the locations of candidates including and excluding marks from the disputed question, or even papers, are considered and the examiners look to see if any candidate moves across class boundaries. The candidates' identities are then revealed.

6. The vivas are conducted by the Senior Examiner and the External Examiner. Candidates receive a viva mark, in addition to their regular marks. If the viva mark is sufficiently good, then a candidate may go up a class. Candidates cannot be disadvantaged by the viva. It has been decided that there will be no viva option this academic year.

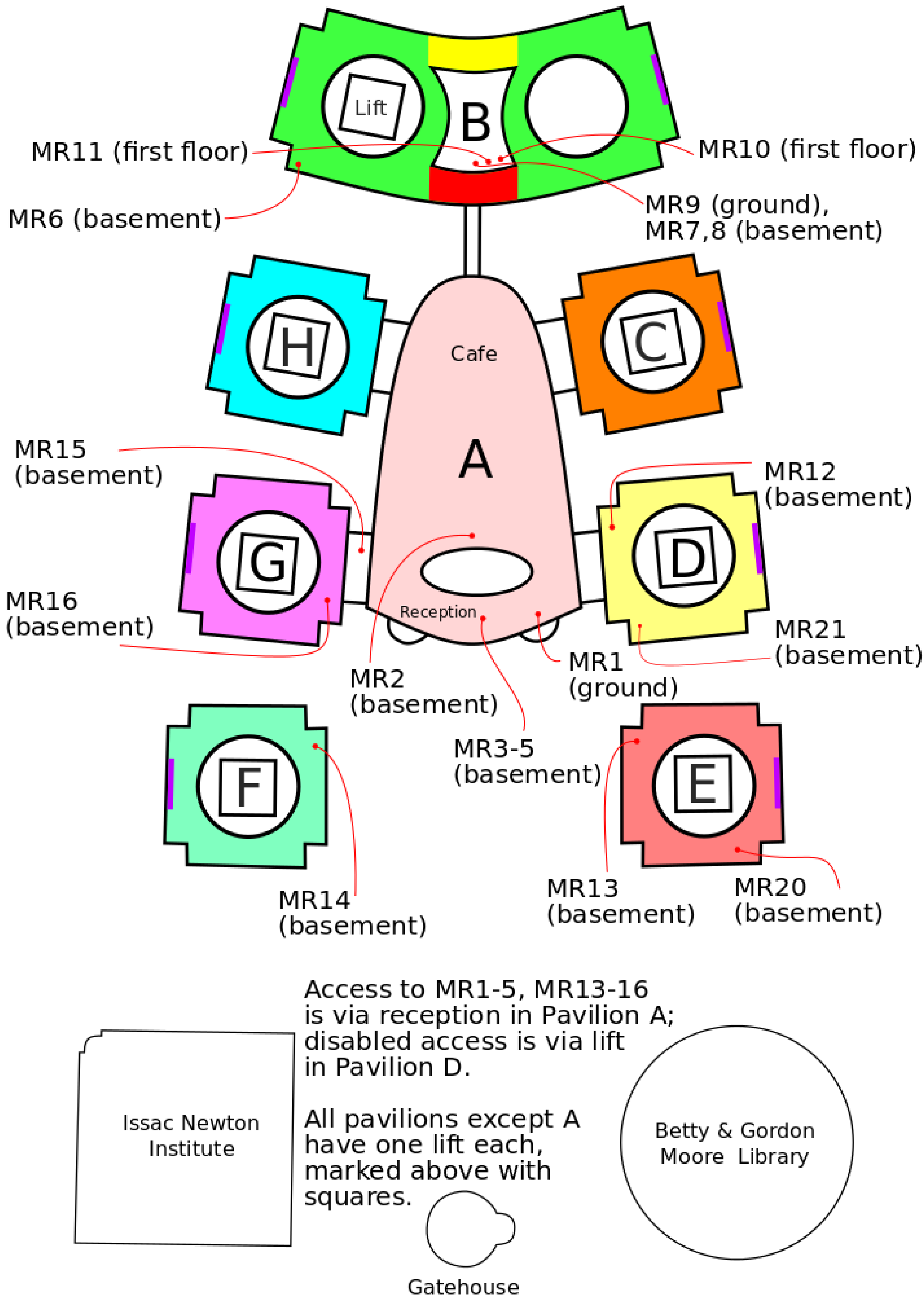
7. NST marks are assigned based on distances of the (total mark, quality mark) points from the class boundaries, with the first/upper-second boundary corresponding to an NST mark of 70, the upper-second/lower-second boundary to a mark of 60, the lower-second/third boundary to a mark of 50 28 and the third/fail boundary to a mark of 40. 8. Final NST Marks and Classes having been agreed, the Class List is produced and signed by the examiners.

Mark Wyatt (Senior Examiner 2017)
Martin Haehnelt (Senior Examiner 2022)

## Welcome to the Institute of Astronomy




© IoA 2016 - MAP NOT TO SCALE


Lift
B
MR11 (first floor)
MR10 (first floor)
MR6 (basement)
MR9 (ground),
MR7,8 (basement)
H
C
Cafe
A
MR15
(basement)
MR12
(basement)
G
D
MR16
(basement)
Reception
MR21
(basement)
MR1
(ground)
MR2
(basement)
MR3-5
(basement)
F
E
MR14
(basement)
MR13
(basement)
MR20
(basement)
Access to MR1-5, MR13-16
is via reception in Pavilion A;
disabled access is via lift
in Pavilion D.
All pavilions except A
have one lift each,
marked above with
squares.
Issac Newton
Institute
Betty & Gordon
Moore Library
Gatehouse

UNIVERSITY OF CAMBRIDGE

**INSTITUTE OF ASTRONOMY**

# Safety Manual

**Action if you discover a fire**

**Operate alarm**
using nearest break-glass unit

**Call Fire Brigade:** dial 1999

**Tackle fire** with hand-held extinguishers
**if safe to do so** without personal risk
or
**Evacuate building** by nearest exit

Do not stop to collect belongings
Do not re-enter building

**Action when fire alarm sounds**

Leave by nearest available exit
Assemble on Thorrowgood Lawn
(between Observatory and SPO buildings)

**University Security Control Centre**

24 hour number 31818
Emergency number 101

**Accidents**

For Ambulance dial 1999

**First Aiders**

Cormac O'Connell 07801707058 or 37505
Monica Gamboa 37548
Mark Hurn (Library Office)37537
Debbie Peterson (H6) 66643

Updated: September 2021