CAREERS THROUGH MATHS: ASTRONOMER

JOB DESCRIPTION

An astronomer is a scientist who studies the universe, seeking to understand the physical nature of celestial objects and the processes that govern them. In the UK, the role is predominantly research-focused, with most professional astronomers employed by universities, research institutes, or government-funded facilities. A typical day involves a blend of independent research, collaborative meetings, and writing proposals or papers. For instance, an astronomer at the University of Cambridge's Institute of Astronomy might spend their morning analysing data from the European Space Agency's Gaia mission to map the Milky Way, followed by an afternoon developing complex computer simulations of galaxy formation, and concluding with writing a research paper for a journal like *Monthly Notices of the Royal Astronomical Society*.

The work environment is primarily office and laboratory-based, centred around high-performance computing clusters, with occasional travel to international observatories or conferences. Key duties include applying for observing time on world-class facilities like the James Clerk Maxwell Telescope in Hawaii (operated by the UK-led East Asian Observatory) or the Square Kilometre Array (SKA) organisation, whose global headquarters are at Jodrell Bank, Cheshire. They are also responsible for reducing and calibrating raw observational data, a meticulous process that turns detector readings into usable scientific measurements.

Mathematics is the fundamental language of astronomy. It is central to every aspect of the role, from formulating physical theories to interpreting observational data. An astronomer doesn't just use maths; they think in mathematical terms. For example, to determine the mass of a black hole in a binary system, an astronomer must apply Kepler's laws and Newtonian mechanics to the orbital motion of its companion star. Similarly, analysing the light spectrum from a distant galaxy to measure its composition and velocity requires a deep understanding of atomic physics and statistical methods to extract meaningful signals from noisy data. This rigorous, maths-driven approach allows UK astronomers to contribute to global discoveries, from characterising exoplanets with the UK-led SuperWASP project to testing fundamental physics with pulsar timing.

HOW MATHEMATICS IS USED

- **Calculus (Differential and Integral):** This is the primary tool for modelling continuous change and dynamic systems in the cosmos. Astronomers use differential equations to describe how physical quantities evolve over time, such as the rate of stellar fusion or the expansion of the universe. For example, integrating the luminosity of a star over its surface area is necessary to calculate its total energy output. In a UK context, researchers at the University of Edinburgh use calculus-intensive magnetohydrodynamics (MHD) simulations to model the behaviour of plasma in the solar corona, helping to predict space weather that can affect satellite communications and power grids in Britain.

- **Linear Algebra:** This is indispensable for handling and transforming large, multi-dimensional datasets. Modern astronomical instruments produce data in the form of vast matrices, such as the pixel arrays from a charge-coupled device (CCD) camera on the Isaac Newton Telescope in La Palma. Techniques like matrix inversion and eigenvalue decomposition are used for image processing, coordinate transformations, and principal component analysis to identify patterns in data. For instance, when analysing the cosmic microwave background data from the Planck satellite (a mission with major UK involvement), linear algebra is used to separate the faint cosmological signal from foreground emissions from our own galaxy.

- **Statistics and Probability:** Given that astronomers often work with faint signals and uncertain measurements, statistical analysis is crucial. They use probability distributions to quantify errors in measurements, such as the position or brightness of a star. Hypothesis testing, like the chi-squared test, is used to compare theoretical models with observational data. A key application in the UK is the search for exoplanets via the transit method with instruments like the Next-Generation Transit Survey (NGTS) in Chile. Astronomers must use sophisticated statistical models to distinguish the tiny, periodic dip in a star's brightness caused by a planet from random noise, calculating the false-alarm probability to confirm a discovery.

- **Fourier Analysis:** This mathematical technique is used to decompose complex signals into their constituent frequencies. It is essential in radio astronomy, a field where the UK has a world-leading presence through institutions like Jodrell Bank. Pulsars, for example, are neutron stars that emit regular pulses of radio waves. Fourier analysis is used to find the precise rotation period of a pulsar from its time-series data. Similarly, in asteroseismology, astronomers study the internal structure of stars by analysing the Fourier spectrum of their brightness oscillations, a technique used by researchers at the University of Birmingham.

- **Numerical Analysis and Mathematical Modelling:** Since many problems in astrophysics cannot be solved with pen and paper alone, astronomers rely on numerical methods to find approximate solutions. This involves developing complex computational models to simulate physical phenomena. UK astronomers at Durham University's Institute for Computational Cosmology (ICC) run some of the world's most detailed simulations of the universe's formation (such as the EAGLE project). These models use numerical techniques to solve the equations of gravity, gas dynamics, and dark matter evolution on supercomputers, requiring a deep understanding of algorithms, discretisation, and error analysis.

KEY SKILLS & TOOLS

Skill/Tool	Application
Python with Scientific Libraries (NumPy, SciPy, Astropy)	The dominant programming language in UK astronomy. Used for virtually all data analysis, from basic script writing to automate file handling to performing complex mathematical operations. For example, using NumPy arrays for efficient matrix algebra on image data from the UKIRT Infrared Deep Sky Survey, or

	employing the Astropy library to perform standard coordinate conversions and cosmological calculations.
Specialised Data Analysis Software (SAOImage DS9, TOPCAT)	Used for visualising and interactively analysing astronomical data. An astronomer at the University of Oxford might use DS9 to examine multi-wavelength images of a galaxy cluster, applying mathematical filters to enhance specific features. TOPCAT is used for statistical analysis of large catalogues, such as cross-matching stellar positions from the Gaia mission with other surveys to calculate proper motions and distances.
High-Performance Computing (HPC) Clusters	Access to national facilities like the DiRAC (Distributed Research utilising Advanced Computing) service is critical. Astronomers use these to run resource-intensive numerical simulations, such as modelling black hole mergers (relevant to the UK's involvement in the LIGO-Virgo collaboration) or large-scale cosmological simulations, which require parallel processing and advanced algorithm design.
Programming Languages (C++, Fortran)	Used for developing the core computational code of large-scale simulations and for writing performance-critical sections of data reduction pipelines. The high-speed rendering engines for visualisations at the ICC or the data processing software for the SKA are often written in C++ for computational efficiency in solving complex mathematical models.
Telescopes and Instrumentation (e.g., SKA Pathfinders)	While astronomers rarely operate telescopes directly, they must understand the mathematical principles of their instruments. For radio telescopes like the e-MERLIN array at Jodrell Bank, this includes understanding interferometry, which uses the Fourier transform to synthesise a large aperture from multiple smaller dishes, a direct application of mathematical theory to engineering.
LaTeX and Presentation Software	Essential for communicating complex mathematical findings. Research papers, which are dense with equations, derivations, and data plots, are almost exclusively written in LaTeX. Results are also presented to peers at conferences (e.g., the UK National Astronomy Meeting) and to the public, requiring the clear visualisation of mathematical concepts and statistical results.
Statistical Inference and Error Analysis	A fundamental skill rather than a single tool. Astronomers must constantly apply rigorous statistical methods to quantify uncertainties in their measurements. This includes using

	techniques like Markov chain Monte Carlo (MCMC) sampling to find the best-fitting parameters and their confidence intervals for a model of, for example, an exoplanet's atmosphere.

Typical Pathway: The pathway begins with strong GCSEs and A-levels, specifically in Mathematics and Physics, often with Further Mathematics being highly advantageous. The next step is a three-year BSc (or four-year MSci) undergraduate degree in Physics with Astronomy, Astrophysics, or a related field from a university like St Andrews, Cardiff, or University College London. This is followed by a four-year, fully-funded PhD in a specialised area of astronomy, typically at a different UK university or research institute like the Science and Technology Facilities Council's (STFC) UK Astronomy Technology Centre. Post-PhD, astronomers typically undertake several short-term (2-3 year) postdoctoral research fellowships at institutions in the UK and abroad to build their publication record. Career progression then leads to a permanent lectureship or senior fellowship at a university, or a research scientist position at a government facility like RAL Space. While there is no specific chartered status for astronomers, many are members of the Royal Astronomical Society.

Industry Demand: The demand for professional astronomy research posts in the UK is highly competitive, with a steady number of positions tied to STFC and university funding. However, the advanced quantitative and computational skills developed are in very high demand in the wider UK economy. According to the Office for National Statistics, roles requiring sophisticated data analysis skills are among the fastest-growing. Astronomers are increasingly recruited into UK-based industries such as data science, quantitative finance, software engineering, and defence and security, where their ability to model complex systems and extract insights from large datasets is highly valued.

Real-World Impact: The work of UK astronomers has a profound impact beyond pure research. Technology developed for astronomy, such as the charge-coupled device (invented at AT&T Bell Labs but perfected for astronomy), has found widespread commercial application. The UK astronomy sector also inspires the next generation of scientists and engineers, contributing to the national STEM skills base. Furthermore, UK involvement in major international projects like the Square Kilometre Array drives innovation in Big Data, high-performance computing, and software engineering, creating spin-off technologies and high-skilled jobs within the UK, while solidifying the country's position as a global leader in scientific discovery.