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Out into Space

We live in a time full of remarkable astronomical discoveries. Scarcely a week goes by without media reports of some interesting new celestial object, be it an Earth-like planet orbiting a nearby star, an object of unknown origin arriving in the solar system or, as discussed in this book, the most distant known galaxy seen as it would have appeared when its light first set out for Earth billions of years ago. The universe fascinates many of us, and increasingly so as the pace of discovery accelerates. Unlike some other scientific disciplines, which require the understanding of difficult concepts with unfamiliar terminologies, astronomy has the advantage that everyone can understand the fascination of exploring outer space and discovering what's out there. Who hasn't, at one time or another, pondered such fundamental questions as, are we alone in the universe? Where did the world around us and the worlds beyond us come from? What does the future hold for the universe and our place within it? And what can we learn from gazing billions of years into its past?

My fascination with astronomy dates from childhood. When I was 6 years old, I visited the public library in the small coastal town of Colwyn Bay in North Wales, where I was born and grew up. One day I found a book in the children's section that set me on a career path of five decades as a professional astronomer. Exactly why I picked up this book is unclear to me now. It was a little blue book entitled *Out into Space*, with no striking illustrations on its cover or inside. It describes the fictional adventures of a young brother and sister who go to stay with their eccentric Uncle Richard (!), an astronomer with a telescope in his back garden. To this day I remember the chapter in which Uncle Richard persuades his niece and nephew to get up at six in the morning to observe the planet Mercury through his telescope. Gazing at Mercury, the children are fascinated to observe it as a small pinkish crescent, and they are struck by how remote it seems.

The book was written by (later Sir) Patrick Moore (1923–2012), Britain's most famous amateur astronomer and presenter of the BBC's *The Sky at Night*—a monthly documentary programme on astronomy. He presented the programme from 1957 until a posthumous broadcast in 2013, making it the longest-running series with the same host in television history. I was a guest on this programme twice in the 1990s, and, during my first appearance, I mentioned how Moore's little blue book had ignited my youthful interest in astronomy. To my surprise and delight, he subsequently sent me a signed version. It appears to have been his personal copy (this time with an illustrated cover). Rereading the book more than six decades after that trip to the library, I find it still evokes the childhood wonder of exploring the universe (see plate 1).

Moore's book set me on a course of reading everything I could find about astronomy. Public interest in the subject certainly grew after Soviet cosmonaut Yuri Gagarin became the first human to ride a rocket into outer space and make one full orbit of the Earth in 1961. I was in year six of primary school (the British equivalent of the American fifth grade) at the time, and I was asked by my teacher to describe the importance of this achievement to the class. By this time most of my classmates knew that I wanted to become an astronomer. The next logical step was to get hold of a telescope. Here I got a bit of help from the father of a friend. He generously gave me a small 4-inch reflecting mirror, which I then began to figure out how to fashion into a telescope. Acting on the advice of an older cousin, I managed to find a cardboard tube of approximately the right dimensions in a carpet shop and varnished it with a paint brush. With an eyepiece from a pair of marine binoculars that my seafaring father had acquired during his career as a captain in the British Merchant Navy, I now had the optical components. Then came the challenge of cutting the carboard tube to the right length, while keeping the mirror and eyepiece installed and pointing at the moon. This was more than a little nerve-wracking lest I cut the tube too short, in which case the telescope would never be in focus!

Finally I was ready to set up an observation station in the back garden. Even though I had a reasonably good idea of what to expect after all my reading, I was still unprepared for my first clear sight of the magnified night sky. I was immediately struck by the various colours of bright stars (indicative of their different temperatures), and, on subsequent nights, I followed the orbits of Jupiter's four largest moons and inspected craters and mountains on our own moon. These were exciting times for a young boy. I found I couldn't wait for it to get dark: there was so much to explore. But Wales is famous for its rainy climate, and, regardless, it is often overcast. The uncooperative weather, along with the interfering glare of nearby street lights and the limitations of my primitive telescope, which could not track the movement of stars across the sky, led to much frustration.

Today, youngsters with a keen interest in astronomy are likely to have more opportunities for encouragement and practical support. Numerous sites on the internet provide information about purchasing small telescopes and offer advice about assembling them; mobile-phone applications make it possible to view the night sky's appearance at any time and place across the globe. Local astronomical societies host viewing nights and offer talks and even workshops with both professional and experienced amateur astronomers.

North Wales in the early 1960s offered no such opportunities. My high school had no scientific societies, and even my parents, who generally kept close track of my educational progress and stressed the importance of academic success, rarely came outside to share my enthusiasm. Books from the public library and Patrick Moore's television programme were my only sources of information. Fortunately, Colwyn Bay's library had an excellent collection of quite advanced astronomy books, although my junior member's ticket wouldn't let me borrow books from the adult section. I had to be resourceful. From careful observations over several visits, I identified a librarian who appeared not to be aware of the difference between books in the children's and adults' sections. One afternoon I waited patiently until it was her turn at the desk and promptly presented her with a selection of astronomy books from the adult section to check out. This strategy worked well until one memorable day when, just as I marched up to the librarian in question, she was relieved of duty and replaced by another, who told me smugly, "You can't take out these books from the adult section on a junior ticket!" Despite that momentary setback, I eventually managed to extract and read most of the astronomy books in the adult section. Years later, I learned that the Colwyn Bay library had been established in 1904 with a benefaction of several thousand pounds from Andrew Carnegie, the wealthy Scottish American industrialist and philanthropist who played a major role in the development of Californian astronomy.[1]

Having exhausted the local library's resources, I began to look elsewhere for guidance and advice on how to develop my interest in astronomy. At about the age of 15, I joined the British Astronomical Association (BAA), which held regular meetings and organised amateur activities that involved coordinated telescope observations of the sun, planets, variable stars, comets, and so on. Unfortunately, all these events were based in or around London. It was impractical to hope to get involved at a distance of nearly 250 miles away in the wilds of North Wales. I did send for, and received, a BAA brochure entitled "Astronomy as a Career" (price 1 shilling) but found it painted a gloomy picture, warning of years of study and many hurdles to overcome before I could "enter the holy of holies: the dome of a large telescope for a night's observations."[2] Although I later found out that some of this advice was true (I didn't get to use one of the world's largest telescopes until more than a decade later), these were hardly words to encourage and inspire a 15-year-old.

The BAA brochure did offer me some practical and, as it turned out, highly useful advice. Mixed in with the "holy of holies" verbiage was the hard-headed admonition that modern astronomy is a rigorous and

1. *Colwyn Bay: Its Origin and Growth*, Norman Tucker (Colwyn Bay Borough Council 1953), p214.

2. *Astronomy as a Career*, E. A. Beet and R. H. Garstang (British Astronomical Association 1962), p5.

challenging *physical science*. To become a professional astronomer, a fascination with discovering the night sky, rewarding and exciting though that activity can be, is insufficient. A thorough grasp of mathematics and physics is essential. Indeed, in my career, I have met more than a few professional astronomers who are completely unfamiliar with the constellations, unable to name any bright star (other than the sun!), and generally content just to grapple with equations and program supercomputers.

In this regard I was fortunate in high school to have a dedicated physics teacher, Mr. E.O.P. Williams, who introduced me to the magic of applying the laws of physics across a wide range of everyday life. I was captivated by how familiar words such as "force," "energy," and "power" acquired tangible physical meaning, and by how physical laws could be used to predict the behaviour of objects in the real world. However, the headmaster of my high school was quite concerned when I told him I wanted to become an astronomer. A strict Welshman, unpopular even with his staff and willing to use corporal punishment on his students (including me), he tried to discourage me. He claimed he knew someone working at the Royal Greenwich Observatory who was "going nowhere fast." On the home front, my mother nurtured hopes that I would become a medical doctor or banker. Fortunately, she eventually recognised my unwavering determination and came around to accept that I was going to be an astronomer.

Teenage life was not, of course, all about academic study and preparations for a future career. The year was 1966, and a cultural revolution was under way in Britain, led by the Beatles and Rolling Stones, whose influence on music, fashion, and acceptable behaviour permeated every facet of adolescent life. Like teenage boys throughout Britain and the United States, my school friends and I formed a rock band called The Omegas and had some fun times performing at local venues. Not surprisingly, my burgeoning distaste for authority led to much friction with the headmaster, who had made known to all pupils his aversion to long hair. The school rule was that a boy's hair should not touch his collar. To this day I recall encountering the headmaster in the school corridor and rapidly assuming a posture with head bent forward and collar rolled back to be compliant. In my final 2 years of high school, known in Britain as the sixth form, students were usually appointed as "prefects," a supposed distinction that gave them authority to maintain order amongst the younger boys. My fellow Omegas and I unilaterally declined this responsibility, in conformity with our rebellion against any level of authority! One of my friends, who was skilled at restoring old automobiles, bought an enormous Mark 7 Jaguar for five pounds, in which he and I regularly skipped classes, driving out of the school car park at high speed in this huge green car. Of course, our "bunking" eventually got noticed and led to the inevitable showdown with the headmaster.

This new-found liberation notwithstanding, when the time came to apply to university, my career ambitions severely limited my options. In 1960s Britain, the procedure for college-bound students was to prioritise six university choices on an application form submitted to a centralised admissions authority. My applications listed just three, the only institutions in the United Kingdom at that time to offer astronomy as an undergraduate major. I simply left the other boxes of the application form blank. Although I was warned that this was a risky strategy, it certainly indicated I knew what I wanted to study. University College London (UCL) was the most appealing choice and ranked number one, and I was fortunate to be admitted as a first-year student in October 1968.

Life in London had many attractions, one of which was the opportunity to meet and interact with the professional astronomical community in the nation's capital. Undergraduates in UCL's astronomy programme were encouraged to attend monthly meetings of the Royal Astronomical Society (RAS), where professional astronomers gathered once a month in Burlington House, Piccadilly. However, this was "Swinging London" in the late 1960s at the height of the era of hippies, psychedelic drugs, and rock music. Whereas some university lecturers had adapted to teaching long-haired students, my reaction to seeing professional astronomers at RAS meetings for the first time was that they looked astonishingly dull and old-fashioned. Their tweed suits, ties, and, to my mind, excessively formal and humourless demeanour did nothing to enliven the atmosphere in meetings that I found to be unbearably stuffy. Did I really want to spend my life working with these people?

Inevitably, almost all participants were male, and their talks mostly revolved around the life cycle of stars or, more appealing to me, theories of cosmology—the nature and evolution of the universe on large scales. If, occasionally, someone presented results based on actual observations with a telescope, it was usually on what I considered to be a mundane topic, such as the varying light output of an individual star. Young as I was, I began to sense a disconnect in Britain's professional community between the theorists, aspiring to address the big astrophysical questions, and the observers, who, it seemed to me, were content to study minutiae.

While I pondered my future prospects, I was learning the techniques of observing. UCL has a well-equipped teaching observatory at Mill Hill, a leafy North London suburb, where we undertook observational projects once a week (plate 2). Although the London skies were as cloudy as the Welsh ones much of the time, we students could still undertake "cloudy night experiments" based on analyses of photographic plates previously taken by cameras attached to the Mill Hill telescopes. But when the weather was clear, taking and analysing my own photographs was inspirational! The largest telescope available for students was—and still is—the Radcliffe 24-inch (60 cm) refractor. I used it to photograph our Milky Way galaxy's nearest large neighbour, the Andromeda spiral (Messier 31), and to study the outermost layers of the sun during a partial solar eclipse (plate 2). Undertaking observations at Mill Hill was addictive. Although cosmology continued to have its attractions, I had no doubt that my future lay with observational astronomy.

I began my undergraduate studies at a time when astronomers were beginning to exploit wavelengths beyond the familiar optical region, which had been the sole province of telescopes back to Galileo. In 1800 William Herschel, one of Britain's most famous astronomers, discovered in a laboratory experiment that there were invisible "calorific rays" that could be reflected and refracted just like optical light. This *infrared* radiation has a wavelength longer than that of visible light and is emitted from objects cooler than the sun. Around the same time, Johann Ritter, a German chemist, conducted experiments with chemicals that reacted to sunlight and found "chemical rays" that extended to shorter wavelengths, which we now know as the *ultraviolet*. These pioneering experiments eventually led to the far-reaching discovery that celestial objects radiate across a much wider range of wavelengths than the narrow band accessible to our human eyes, from X-rays at the shortest wavelengths to radio waves at the longest.

In the 1960s, radio astronomy had emerged as a particularly active research field in the United Kingdom, as the immensely successful deployment of radar in wartime was adapted to peaceful uses, including studies of the cosmos. Radio telescopes had been built at Jodrell Bank, near Manchester, and at Cambridge University. I certainly heard a lot about their observations as an undergraduate, including the discovery of pulsars by Antony Hewish (1924–2021) and his graduate student Jocelyn Bell. Pulsars, the remnants of massive collapsed stars, are rapidly rotating compact objects that emit regular pulses of radio waves from their magnetic poles, rather like a celestial lighthouse. However, unlike optical and radio studies, making successful observations across much of the electromagnetic spectrum necessitates getting above the Earth's atmosphere since, fortunately for the human race, harmful X-rays and ultraviolet rays are absorbed by it. The same is largely true of the more benign infrared radiation. The 1960s saw the launch of modest telescopes aboard both high-altitude balloons and rockets to explore the sky at these new wavelengths for the first time. Perhaps because I was so inspired by the use of the optical facilities at Mill Hill, it never occurred to me to move into these new areas. There was enough excitement with traditional optical astronomy.

In my final undergraduate year, astronomy students had to produce a short dissertation on a research topic of their own choice, the idea being to give students a feel for what it is like to conduct original research. For my topic I chose quasar absorption lines, which offered an ingenious new means of studying the universe by analysing the nature of light emanating from its most distant objects. I was intrigued by the idea that one could study phenomena at enormous distances, well beyond the confines of our own Milky Way galaxy, in what astronomers called the "extragalactic universe."

This investigation opened up a whole new world for me. Quasars—short for quasi-stellar objects, or QSOs—were discovered in the early 1960s. Their large recessional velocities indicated they were being seen at enormous distances (more on this in chapters 2 and 3). Although their precise nature remained a mystery for many years, we now know that these exotic objects are spectacularly luminous galaxies whose nuclei harbour massive black holes. With masses often a billion times or more that of the sun, these heavyweight black holes are capable of accreting large amounts of gaseous matter from the rest of the galaxy through their dominant gravitational influence. As this gas spirals inwards, it releases copious amounts of radiation, which can be used to probe the nature of the *intergalactic medium*—the tenuous clouds of hydrogen gas and other material that fill the cosmos between galaxies.

How does this work? As the light from a distant quasar makes its way to a telescope, it intercepts clouds of intergalactic hydrogen. Although these clouds do not emit their own light and are, therefore, from the astronomer's perspective "dark," they are capable of absorbing portions of the quasar light at a particular wavelength through atomic interactions with the light particles (photons). A spectrum of the quasar reveals these absorption signals as cosmic "fingerprints" that contain valuable information about the properties of these clouds, including their chemical composition and distribution in space. Through this type of detective work, remote and otherwise inscrutable tracts of the universe become accessible to analysis. One can think of the quasar in some sense as a distant car headlight that is bright enough to reveal otherwise invisible wisps of mist rolling along the road towards you.

Atomic spectroscopy was taught at UCL by a talented and disarmingly modest assistant professor (a "lecturer," in UK academic parlance) named Bill Somerville. In his precise and soft-spoken accent (a curious blend of Scottish and Irish), he explained the mathematics of this phenomenally powerful tool of the astronomer. In an instrument called a spectrograph, through the application of a prism or diffraction grating, the light from a celestial object can be dispersed into its constituent wavelengths. This "spectrum" has a much higher fidelity than the colours visible in a rainbow and can reveal a wealth of information about the chemical and physical make-up of stars, galaxies, and the intergalactic medium. My introduction to spectroscopy's potential for probing the far reaches of the universe left an impression not unlike my earliest stargazing experiences, except here, I realised, was a tool far more formidable and sophisticated than the primitive backyard telescope that first introduced me to the night sky.

I spent nearly all my spare time poring over the latest astronomical journals in the polished wood surroundings of UCL's main library, immersing myself in this fascinating new topic. The key question for astronomers, and the topic of my project, was, exactly where was this absorption in the quasar light occurring? Was it happening in the gaseous clouds in the immediate vicinity of quasars or in the vast intergalactic spaces in between galaxies? Today we know that the answer is the latter, but that was far from clear at the time. Some astronomers even questioned whether quasars were truly energy-emitting sources at great distances; conceivably, they argued, quasars were nearby sources expelled at high velocity from our own Milky Way.

I was discovering a fascinating topic at the frontier of knowledge. None of my UCL lecturers seemed familiar with my topic of research, and yet the pace of discovery was rapid; every new issue of the *Astrophysical Journal*, a premier research publication in astrophysics, contained articles with new data. Significantly, the progress was almost entirely observational. Without exception, the quasar spectra came from telescopes in the United States, most notably from the renowned instrument where quasars were first discovered—the 200-inch Hale Telescope on Mount Palomar near San Diego, California. Although I found some theoretical papers on the topic authored by UK astronomers, they were primarily concerned with interpreting the data taken by their American counterparts This dichotomy between British and American astronomers reflected the simple fact that without access to their own large telescope, British astronomers could not lead observational campaigns at the frontier of knowledge such as those that inspired my undergraduate dissertation on quasar absorption lines.

How could this situation, so detrimental to British astronomy, have arisen? The story dates back to the late 1920s, when the giant 200-inch telescope at Palomar was conceived by the visionary solar astronomer and indefatigable fundraiser George Ellery Hale, whose role in establishing Southern California's Mount Wilson Observatory and co-founding the California Institute of Technology in the early part of the twentieth century would greatly influence the course of American science. Following its completion in 1948, the Hale Telescope (named for its originator) reigned as the world's largest and most powerful optical telescope for the next four decades. It is no exaggeration to say it dominated the field of observational astronomy (chapter 3).

In 1946, in recognition of the 300th anniversary of Isaac Newton's birth, the Royal Society of London announced plans to fund a 98-inch telescope, a facility that would have seven times the *light-gathering power* of Britain's largest telescope at the time. This term refers to an optical telescope's capacity for collecting photons. The larger the area of the telescope's primary mirror, the more photons it is capable of accumulating. The hope was that this Isaac Newton Telescope (INT) would go some way towards rectifying the depressing fact that, as far as optical astronomy was concerned, US astronomers were making nearly all the observational discoveries. Indeed, I later discovered many of those "US astronomers," including the ones pioneering the study of quasar spectroscopy, were like myself born and educated in Britain. They had emigrated to the United States when they realised there were no professional prospects for them in their native country.

It was agreed that the INT would be operated and maintained by staff at the Royal Greenwich Observatory (RGO). Astonishingly, by the late 1950s, more than 10 years after it was first envisioned, there had been little progress in constructing the telescope, other than acquiring a free mirror blank (i.e., unpolished glass) originally intended for a telescope in Michigan that was never built. Following the appointment in 1956 of a new energetic Astronomer Royal, Sir Richard van der Riet Woolley (1906–1986), construction eventually progressed. However, soon after, the bewildering and fateful decision was made to locate the new telescope alongside the RGO, which had recently been moved from London to Herstmonceux Castle in Sussex (plate 3). Apparently the proximity of RGO staff to the telescope was a more important consideration than avoiding the infamous English weather. Although some had argued that Sussex was the sunniest part of England, they failed to notice that sea mist regularly rolled in from the coast at night. These problems immediately became apparent upon the telescope's completion in 1965 and its subsequent opening in a ceremony with Queen Elizabeth II. Plans to have Her Majesty view the planet Saturn and its regal rings on that occasion had to be scrapped because it was raining. This did not augur well for the revival of British observational astronomy!

As a result of its poor location, the INT at Herstmonceux was not a great success. Indeed, I wasn't even aware of its existence until the early 1970s, by which time there were serious discussions about moving it. Ultimately, under pressure from the British astronomical community, and in a remarkable admission of failure, the INT was disassembled, transported across the sea, and then reassembled, "brick by brick," as it were, on the island of La Palma in the Canaries in 1979. In the early 1980s I was appointed to commission two new instruments on the relocated telescope (see chapter 5).

Such was the state of UK observational astronomy after I graduated from UCL and began a PhD in astrophysics at Oxford in 1971. My UCL research project had definitely fired up my enthusiasm for observations of distant extragalactic sources, but where would I get the relevant data to continue such studies? Oxford's only extragalactic astronomer, John Peach, was no longer taking graduate students for exactly this reason. Instead, for my PhD thesis work, I was redirected to a project researching the atmospheres of the sun and a bright star, Arcturus, that was within reach of the smaller telescopes to which Oxford had access. Britain was continuing to produce talented astronomers and theoretical research was progressing well, but, for the foreseeable future, those seeking observational data for world-class projects would have to emigrate to the United States. There was, seemingly, nowhere else for them to go.

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Numbers in *italics* refer to pages with illustrations.