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Introduction: the development of astronomy in Europe

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The tradition of astronomy in Europe has been unbroken from the Neolithic and Bronze Age menhir monuments of north-western Europe to its large telescopes and space-probes. While astronomy still retains practical features, in most part it now concentrates on discovering new science. Recent advances include the discovery of previously unsuspected properties of neutrinos, confirmation of the theory of general relativity near black holes and the successful development of a coherent theory of the origin of the Universe in the Big Bang. These discoveries suggest that 19/20ths of the density of the Universe is of unknown form. There is more to do!

The Sun rises over the Heel Stone of the megalithic monument of Stonehenge in Wiltshire in England at midsummer sunrise, and the pattern of stones is so sophisticated that, through alignment with the motions of the Sun and Moon, it could in principle be used to predict eclipses. The Temple Wood stone circle in Argyllshire in Scotland shows alignments on significant lunar phenomena and appears to be a lunar observatory. Lines of stones and le Grand Menhir Brisé on the Champs de Menhirs at Carnac in Brittany have similar features. The Newgrange barrow in Ireland has a curious 'roof box' that admits the rays of the rising Sun at the midwinter solstice into the grave passage.

These monumental structures on the north-western fringe of the continent, the oldest of which date from about 2700BC, are the earliest astronomical observatories in Europe. The methods that they used to view the motions of the Moon and Sun were simple, being based on sighting lines through arrangements and alignments of standing stones, and features on the horizons around them.[1]

Although simple, the works remain magnificent and impressive to this day, especially considering the building technology of the time. What they imply is

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that there was a coherent culture across the region at that time, connected by organizational ability, common technology and intellectual knowledge, which included astronomical observation and possibly even prediction. Presumably these astronomical activities were used to signify important human events, some perhaps of practical benefit (such as timing the planting of crops at the right seasons, or even, it has been suggested, the seasonal properties of the tides), others of ritual significance.

At the time that the menhir culture was fading, on the opposite side of Europe Greek philosophers were beginning to develop what we now identify as Ptolemaic and Aristotlean cosmology. This describes the theory of the cosmos as the philosophers saw it (we still see the cosmos in this way, although we believe it to be fundamentally different from our perception). The Universe was viewed as centred on the Earth, which was orbited by the Sun, Moon, planets and stars. The stars provided an unchanging backdrop for the mutable world below. With the aid of the parallel development of mathematical knowledge, applied to this model, it became possible to predict the motions of the planets into the future.

Considering the psychology of the situation, it is hardly surprising that such predictions about so magnificent a system that was centred on ourselves led to the rise of astrology – a belief that it is possible to describe and predict the effects of the motions of celestial bodies on human life.

Knowledge about the positions of the Sun, the Moon and the planets passed from the Greek world to the Islamic. In the Middle Ages, it returned to Europe, in elaborated form and oriented strongly towards astrology. Astrology's beliefs and practices remain embedded in European languages. The word *consideration* is from thinking 'about the stars' and what will happen. A *disaster* (*un désastre*) is etymologically a 'bad event originating in the stars'. *Desire* (*le desir*) is also provoked 'from the stars', and lovers can be *star-struck*, or like Romeo and Juliet, come to a tragic end through astrological effects, as Shakespeare describes:

> From forth the fatal loins of these two foes
> A pair of star-cross'd lovers take their life;
> Whose misadventured piteous overthrows
> Do with their death bury their parents' strife.[2]

Influenza is a disease 'flowing' from occult power, such as the influence of a comet; but celestial influence can also be benevolent or enchanting, as shown in the words of John Milton (seventeenth century).

> … the grey
> Dawn and the Pleiades before him danc'd
> Shedding sweet influence.[3]

> Ladies, whose bright eies
> Rain influence and judge the Prise.[4]

Astrological effects are associated with the weather and the human mood. *La canicule* is a time of intense hot weather (a heat wave), as in France in 1992, the 'dog days'. Originally the dog days seasonally correspond, in the eastern Mediterranean regions, to the hottest part of the year when the Dog Star, Sirius (alpha Canis Majoris), first appears in the night sky. People of a *mercurial* temperament are 'under the influence of Mercury'. Warlike or *martial* people are 'affected by Mars' and *jovial* people 'affected by Jupiter or Jove'. Saturn makes people depressed or *saturnine* and the Sun causes a *sunny* disposition but the influence of the Moon may cause aberrant behaviour in *lunatics (les lunatiques)*.

In a degenerate form, belief in the effect of astronomical events on human life persists to the present time, even flourishes, in Europe. Newspapers offer alleged predictions about human relationships through horoscopes and, particularly in France, almanacs are for sale which purport to identify times for successful gardening activity through the phases of the Moon. Astrology has degenerated into fortune telling, superstition and trivial tricks, and astrologers have become ridiculous.

> While geomancers see in the east arise
> Their Great Fortune, ere the dawn be come,
> By a path which not long dark before it lies[5]

Swift is more ironic, of course:

> Among the ancients, fortune telling by the stars was a very beggardly trade. The professors lay upon straw, and their cabins were covered with the same materials: Whence every one who followed that mystery was called *A straw lodger* or a lodger in straw; but in the new-fangled way of spelling, *Astrologer*.[6]

As well as associations between astrology and everyday life, the practicalities of early astronomy also survive in European language, particularly through the practice of navigation. The word *star* (Anglo-Saxon *steorra*, German *stern*, Dutch *ster*) is close to the word *steer*, meaning 'direct a boat or other craft' (German *steuren*, Dutch *besturen*). *Starboard* (*steuerbord* in German, *stuurboord* in Dutch) and *stern* are nautical terms for the parts of the ship from which early sailors steered (the right-hand side and the rear, respectively). Greek sailors navigated the Aegean and the Mediterranean seas by the constellation of the Great Bear towards the north celestial pole, and the Greek *arktos*, meaning 'bear', provides the word *Arctic* for the far north and *Antarctic* for its opposite.

This tradition of the practicality of astronomy in Europe continues to this day, as the article on 'Space weather' by Alexi Glover and her collaborators shows. Astronomers are deploying space satellites and observatories to observe the behaviour of the Sun and its effect on the magnetic environment of the Earth, to protect satellite systems, aircraft crew and terrestrial electricity networks. The understanding of solar weather events is still, often, empirical.

However, modern astronomy has also developed into a basic understanding of the nature and science of astronomical phenomena themselves. The trigger for the change in style of astronomy was the appearance of the New Star discovered by Tycho Brahe in 1572. Using the sixteenth century's equivalents of Bronze Age menhirs, namely sighting instruments that he had himself caused to be constructed, Tycho measured the position of the New Star accurately enough to show that it was beyond the orbit of the Moon and planets. Although the New Star dramatically changed (it had been invisible, rose suddenly in brightness to be visible to the naked eye and then faded away over about a year) it was among the stars. Contrary to Aristotle's philosophy as John Donne's simile expressed in 1610, there were intrinsic changes that had to be explained.

> New starres, and old doe vanish from our eyes:
> As though heav'n suffered earthquakes, peace or war[7]

In fact, the changes in the New Star, what we would now term a supernova, was a dramatic stage in the life history of a star – the final flames. We now understand the evolution of stars very accurately, as shown in Gisella Clementi and Raffaele Gratton's article on 'The oldest stars and the age of the universe'. In their article they tell how the accuracy of the theory of stellar evolution is so secure that, in 2000, it forced a successful search for new properties of the elementary particles known as neutrinos. These properties departed from the so-called Standard Model of particle physics and necessitated new science.

Galileo confirmed the modern approach to the nature of astronomical objects when he deployed the telescope on the sky for the first time, in 1609–10. He saw mountains on the Moon, reminiscent of those on the Earth. He saw masses of stars in clusters, and resolved the Milky Way into individually invisible faint stars. He not only made it possible to see where things were more accurately, but also to see what they were made of. Galileo saw that Jupiter had moons, circling it as the Moon circles our own world. It was a miniature solar system, built on the model proposed by Nicholas Copernicus in 1543. Just as the planets, in the Copernican philosophy, orbit the Sun, so four large moons orbit the planet Jupiter. The Earth and the solar system were not unique!. In Thérèse Encrenaz's article on the 'Origin of the planets and the solar system', she identifies again this similarity to postulate a common process for the origin of the solar system and, on a smaller scale, the Jovian system. Galileo's discovery also implied that there are planets orbiting other suns, or stars, in the universe, as plausibly inferred (in an earlier scientific context) by Greek philosophy, for example Epicurus (third century BC):

> There are infinite worlds both like and unlike this world of ours. For the atoms being infinite in number, as was already proved, are borne on far out into space.

> For those atoms which are of such a nature that a world could be created by them or made by them, have not been used up either in one world or a limited number of worlds … So that there nowhere exists an obstacle to the infinite number of worlds.[8]

The solar system itself remained the only planetary system known until the discovery of the first extra-solar planetary system by astronomers Michel Mayor and Didier Queloz of the Geneva Observatory in 1995. Jean Schneider's article 'New worlds outside the solar system' shows how astronomers have proved the existence so far of over 70 planetary systems in orbit around other stars.

Since Galileo, astronomers have sought better and better telescopes to enable them to see more. It is only in the last 50 years that it has been possible to visit other worlds to examine them *in situ*. American astronauts have stood on one world, exploring the Moon (in the words of the space treaties of the United Nations) as representatives of all mankind. The space probes of several nations, often in international consortia, such as the European Space Agency (ESA), have acted as proxy explorers of the nine planets and more than 60 moons of the solar system. They show amazing individuality, as distinctively different as the faces in a crowd of Olympic Games spectators. Thérèse Encrenaz describes not only how the planets of the solar system formed but also how they evolved to their present variety.

European Review previously carried an article by Giacomo Cavallo[9] on the European space programme and its astronomical missions. In this issue, Graham Smith describes the advances in radio telescopes, and Catherine Cesarsky and Richard West the advances in optical and infrared telescopes that Europe expects in the future. Some may belittle their articles with the opinion that they merely describe new 'toys', likening astronomers to children who have never grown up. What these authors are actually doing is describing the strategy to use, on a time-scale of decades, the foreseeable developments in technology and engineering to advance astronomical science by similar leaps and bounds to the less consciously planned advances of Tycho and Galileo. Multidisciplinary fields of engineering and science have never been more explicitly harnessed into an alliance for common purpose.

> Look in the giant mirror
> And you look into a well,
> The depth of which is Time,
> The gage of which is Light …
>
> The speed of light is known,
> But not the speed of thought
> Crossing the Milky Way
> On rapid wings of prayer[10]

Projects to develop and build such instruments, not only take decades to carry through, they are literally global in scale. Graham-Smith relates how radio telescopes have been linked across Europe and, indeed, across the world, to create the largest scientific instrument of the present time. He illustrates their astonishing ability to discern detail in distant galaxies.

The most amazing future astronomical project, in my opinion, is the space mission LISA, which is intended in the period 2010–15 to measure the disturbances in space and time caused by gravitational waves. Predicted by Einstein's theory of General Relativity, the effects of gravitational waves have been detected through their indirect effects on a particular double star, but never detected directly. LISA is a joint mission of ESA and NASA and will certainly detect gravitational waves if they exist and are made by double stars in general. For LISA, astronomers, scientists and engineers will construct an interferometer made of three spacecraft orbiting in the solar system at separations of 5 million km.[11] It will be the largest scientific instrument ever made, indeed by far the largest human construct.

Through equivalent instrumental advances in their own time, Tycho's and Galileo's scientific advances caused turbulence in science as the Ptolemaic and Aristotelian philosophical systems crumbled. John Donne's contemporary reaction of 1610 was:

> And new Philosophy calls all in doubt,
> The Element of fire is quite put out;
> The Sun is lost, and th' Earth, and no man's wit
> Can well direct him where to looke for it.
> And freely men confesse that this world's spent,
> When in the Planets, and the Firmament
> They seeke so many new; they see that this
> Is crumbled out againe to his atomies,
> 'Tis all in peeces, all cohaerence gone;
> All just supply, and all Relation.[12]

However, the measurements of the positions of the planets by Tycho, and the empirical laws of planetary motion discovered by his pupil Johannes Kepler, were combined together into a discovery that brought back some security. In a single unifying theory, the 'universal' Theory of Gravitation, Isaac Newton postulated that masses attracted each other across a distance, the force between them inversely proportional to the square of the distance by which they were separated. Kepler's Laws were shown to be a consequence of this and other simple physical principles. The law of gravitation applied to the planets, but also 'universally' to our Moon, the moons of the other planets, comets, our world, and ourselves. This was philosophically and scientifically illuminating to Alexander Pope (1688–1744).

> Nature and Nature's laws lay hid in night:
> God said, Let Newton be! and all was light[13]

The success of Newton's law of gravitation in describing the motions of the planets, as expounded by Voltaire, led in the mid-eighteenth century French Enlightenment to a boost for materialism and a deterministic perspective on life. Confidence in Newtonian physics was a factor that led Buffon, Diderot, d'Alembert, Rousseau, Helvétius, d'Holbach, Condillac, Quesnay, Turgot and Hume to the belief that scientific methods could be applied, not just to astronomy, but to medicine, economics, psychology, law, sociology and practical technological enterprises. According to Paul d'Holbach (1770), 'In short, Nature is but an immense chain of causes and effects, which unceasingly flow from each other.'[14] The idea could be pushed to an unsustainable extreme. In the epilogue of *War and Peace*, Tolstoy suggested that the historical and economic events that he had just described could, in principle, have been predicted if economics and history had been brought to the same state of sophistication as astronomy. When the Great Comet of 1811 first came into view it was hailed by Napoleon as his guiding star and controller of his destiny. In *War and Peace*, the comet in the sky in 1812 over Moscow is a symbol of the optimism for Russia of Napoleon's retreat. It also contrasts human understanding of the regularity of events in the heavens and ignorance of the reasons behind the events of the world. In Tolstoy's opinion an aspiration of sociology or history was that, one day, it would find its Newton.

> As with astronomy the difficulty of recognising the motion of the earth lay in abandoning the immediate sensation of the earth's fixity and of the motion of the planets, so in history the difficulty of recognising the subjection of personality to the laws of space, time, and cause lies in renouncing the direct feeling of the independence of one's own personality. But as in astronomy the new view said: 'It is true that we do not feel the movement of the earth, but by admitting its immobility we arrive at absurdity, while by admitting its motion (which we do not feel) we arrive at laws,' so also in history the new view says: 'It is true that we are not conscious of our dependence, but by admitting our free will we arrive at absurdity, while by admitting our dependence on the external world, on time, and on cause, we arrive at laws.'[15]

In modern times, however, quantum mechanics has shown the inherent uncertainty in nature at the microscopic level. The theory of chaos shows how prediction of larger complex systems is uncertain because the points from which the prediction starts cannot be formulated precisely. Even the solar system as described by Newton's laws is chaotic, because the interactions between the planets add complexity to the simple case that Newton was so successful in describing. For example, the climate of the Earth depends (among other things) on the non-circularity of the Earth's orbit, on the tilt of the Earth's axis, and so on. These quantities change in time due to the interaction of the Moon and the planet Jupiter with the Earth. They could, in principle, be calculated by Newtonian theory, but because the precise positions of the planets at the present time are uncertain on the scale of metres, centimetres or millimetres, it is impossible to track these changes back with enough certainty to correlate them with geological records of climate change.

Jules Poincaré (1854–1912) recounted these limitations. 'If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment. But even if it were the case that the natural laws had no longer any secret for us, we could still only know the initial situation approximately… it may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible …' If Newtonian physics cannot, in fact, describe everything about nine real planets, however successful it is in describing two idealized bodies, then we see why Tolstoy's wish for the development of the theory of history is not likely to be soon fulfilled.[16]

Even more fundamental, Newton's formulation of the law of gravitation is not the last word on the subject – no scientific law has permanent status. Einstein's theories of relativity presented not only a new attitude to science and the nature of space and time, they also showed how intense gravity affected space and time to such an extent that it closed off some regions of space into black holes. General Relativity is so modern a theory that we may forget that it is nearly a century old as shown by Thomas Hardy's poem of 1928:

> And now comes Einstein with a notion -
>   Not yet quite clear
>   To many here -
> That there's no time, no space, no motion,
>   Nor rathe nor late,
>   Nor square nor straight,
> But just a sort of bending-ocean …[17]

Phil Charles' article on 'Black holes in stars and galaxies' shows how the concept of black holes is even older than General Relativity, having been envisaged by John Michell in 1783 and Pierre-Simon Laplace in 1795. He describes how astronomers have successfully searched for the real solutions behind this apparently most theoretical of problems. The effects of General Relativity have been clearly identified in the radiation emitted by black holes in the most powerful X-ray emitting galaxies.

The menhirs, Tycho's sighting instruments, Galileo's telescope, its modern successors and the space probes of this century all developed and changed Europe's world picture. In this century, the largest-scale achievement is the intellectual construct of the Big Bang cosmology. According to present-day astronomers, the Universe is the result of an explosion known as the Big Bang. The Big Bang occurred some 15 000 million years ago, and created an intense fireball. The fireball pervaded, and still pervades, the whole of space. We on Earth view the relic of the fireball of the explosion from within. It has been diluted by the expansion of the Universe and fills a much larger volume than before. The relic of it now takes the form of weak microwave radiation, rather than the energetic gamma radiation of its first fiery seconds. The radiation can be perceived by radio astronomers as a 'thin echo', in Primo Levi's words in the extract below, of the Big Bang.

All matter was created in the Big Bang, by the fierce energies of the explosion. The matter of the present Universe is also a relic of the Big Bang. This is a perception that we all share, because the Big Bang was the origin, not only of the stars and galaxies, but also of our world and of everything in it, including ourselves. Indeed the very hydrogen atoms in our bodies are relics of the Big Bang. In principle, one could tag a given hydrogen atom in one's finger and follow its history back through geological time, back out into interstellar space before the formation of the solar system and back to the Big Bang.

> Fellow human beings, to whom a year is a long time,
> A century a venerable goal,
> Struggling for your bread,
> Tired, fretful, tricked, sick, lost:
> Listen and may it be mockery and consolation.
> Twenty billion years before now,
> Brilliant, soaring in space and time,
> There was a ball of flame, solitary, eternal,
> Our common father and our executioner.
> It exploded, and every change began.
> Even now the thin echo of this one reverse catastrophe
> Resounds from the farthest reaches.
> From that one spasm everything was born:
> The same abyss that enfolds and challenges us,
> The same time that spawns and defeats us,
> Everything anyone has ever thought,
> The eyes of a woman we have loved,
> Suns by the thousands
> And this hand that writes.[18]

Andrew Liddle's article shows that the Big Bang theory has developed into the status of a *standard model*, a benchmark to which scientists reference other theories, say of the evolution of large-scale structure in the Universe (galaxies and clusters of galaxies). But not all has been made clear and there still remain prospects for discovery. It appears that only 5% of the density of the Universe is in the forms that we readily perceive as stars and galaxies. Most of the density of the Universe is in a dark form whose existence we can infer indirectly but cannot see, and whose fundamental nature is a mystery. About the nature of 95% of the Universe, we can only say that it seems to be made of two unknown forms, one being some kind of dark matter and the other some kind of dark energy. Bob Kirschner dryly remarked at an invited discourse on this topic at the International Astronomical Union's meeting in Manchester in 1999 that science still has some details to fill in! Searches for dark matter in the form of elementary particles, known as WIMPs, are presently under way in tunnels and mines under the Italian Alps and the northern English moors, and elsewhere.

As the history of astronomy and the present collection of articles show, the Universe is a set of naturally occurring experiments in extreme conditions of density, temperature and pressure, which cannot be replicated in the laboratory. The study of these experiments offers new insights into science. New scientific laws, new forms of matter, new ways of thinking about the extremes of space and time are the outcome of the study of these natural experiments.

> To see a World in a Grain of Sand,
> And a Heaven in a Wild Flower,
> Hold Infinity in the palm of your hand,
> And Eternity in an hour.[19]

New knowledge does not come easily. We have to struggle to overcome the limitations of our small scale and our confinement to a small and rather limited place in the Universe, extremely distant from the objects studied in astronomy. To the extent that we have succeeded in understanding our position in the Universe, this has been possible through technology and engineering, and above all understanding and imagination. Bound together in a common pursuit, diversified in our approach, united in our aim, the scientists of Europe and the entire world have been pushing back the frontiers and opening up new land. There still remains unseen land beyond the horizon.

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