Astronomy in History

The Uses of Astronomy

Astronomy is generally reckoned to be the oldest of the sciences. Most ancient civilisations practised something that we would recognise as astronomy; the first applications of mathematics to the understanding of the natural world involved astronomy; the mediaeval university syllabus included astronomy (the *trivium* of grammar, rhetoric and logic was followed by the more advanced *quadrivium* of arithmetic, astronomy, geometry and music). Astronomy also played a very large part in the foundation of "modern science" in the 17th century – the so-called "Scientific Revolution" is often considered to have begun with the publication of Copernicus' *De Revolutionibus* in 1543. Why is this? Why did such an apparently abstract discipline – the study of the night sky – play such an important role in ancient societies?

There are two – perhaps three – principal reasons for the importance of astronomy in pre-modern eras. All require a certain level of observational precision and mathematical sophistication: this is why astronomy quickly became recognisable as a science, whereas other equally important disciplines – such as engineering and medicine – remained more in the nature of "crafts".

Calendrics

Knowing the time of year is key to a successful agrarian society: you need to know when to plant crops, when to expect rains or river floods, how long the stored grain has to last, and so on. The time of year can be estimated quite accurately from natural phenomena such as the return of migratory animals, but one might reasonably suspect that a certain amount of prestige would be acquired by anyone who could predict such events *in advance*. A regular, calculable, observable phenomenon would be very useful for this purpose – and the night sky offers precisely that. In an era before street lighting, the phases of the Moon and the shifting positions of the naked-eye planets (most of which are very bright compared to most stars) would be very dramatic. The regularity of these motions is clear enough to be perceptible, but complicated enough to require careful study to be useful: for example, the year does not contain an exact number of full moons, so a lunar calendar quickly gets out of step with the seasons. Therefore there is an incentive to keep good records, and to develop mathematical models of the motion of those celestial bodies which are seen to move (this is the origin of the Greek term *planetes*, "wanderer", which gives us our word "planet").

Navigation

The positions of celestial bodies can provide useful markers for navigation. The height of the Sun at noon can easily be used to calculate latitude, and the constellations can provide the same service at night (though the use of the Pole Star to determine north is only temporary, because of precession). Navigation was not a major use of astronomy for most ancient societies – most sea-faring was done within sight of land. However, with the advent of transatlantic voyages in the 16th century navigation became a preoccupation of many European governments, and considerable effort was put into developing the necessary techniques and instrumentation (leading eventually to the development of the sextant, which remained an important nautical instrument up to modern times). The most challenging problem for astronomical observations is the determination of longitude; the development of practical methods of longitude determination took up a great deal of astronomical manpower in the 17th and 18th centuries, but the problem was eventually solved by the development of reliable chronometers.

Astrology/Religion

To anyone living near the sea, it is obvious that the phases of the Moon are linked with the height of the tide. The changing day length over the seasons is equally obviously linked to the position of sunrise and sunset. We accept these relations as causal – the Earth-Sun-Moon geometry *does* affect the height of tides; the angle of the Sun *does* determine the warmth of the season, and its declination *does* determine the length of the day. It is not surprising that ancient peoples were prepared to accept other associations as causal, and to assume that the motion of the planets might affect human actions as well as natural phenomena. Thus astrology was, from earliest times to the 17th century, a major driver for astronomical observations (Tycho Brahe is remembered as the pre-eminent naked-eye astronomer and the man who bequeathed Kepler the data he needed to construct his three laws; but Tycho also cast horoscopes). This can be clearly seen in the nature of the observations that were made: the European tradition viewed the heavens as basically unchanging and focused on the motions of the planets, whereas the Chinese thought transient celestial phenomena were astrologically important; therefore we have superb records of comets and supernovae from the Chinese records, but very little from the Europeans.

Even when astrology became detached from mainstream religion, astronomical observations were still of importance for the timing of religious festivals. This ties in with the calendric function of astronomy: lunar calendars require intercalation of additional months if they are to remain in step with the seasons, and even purely solar calendars require the occasional extra day to account for the fact that the year is not precisely 365 days.

Thus, from very early times there were incentives to observe the night sky and to attempt to predict the motions of celestial bodies. Since the making of precise, testable predictions is now regarded as one of the hallmarks of science, astronomy was "scientific" from its earliest days. However, note that most of the early incentives for studying astronomy relate primarily to the motion of the "planets" (in this sense including the Sun and Moon); the stars are simply useful signposts to assist in defining the locations of the planets. This is reflected in the history of astronomy: despite the name, which means "star-watching", the *stars* do not really attract much attention until the 19th century.

Note that none of these early motivations for the study of astronomy has really persisted to the present time. Our current standards for time measurement and navigation do not rely on astronomy, and of all the major religions only Islam still ties its calendar directly to astronomical observations (of the "new moon", which in Islam means the first visible crescent, rather than the astronomical meaning of lunar conjunction, which produces no visible Moon at all). The modern reasons for studying astronomy can be divided into two (overlapping) categories:

Astronomy as a laboratory for extreme physics

From the birth of modern science to the present day, astronomy has provided insights into physics which, because of the extreme conditions required, were not (at the time) deducible from conventional experimental physics. Some examples of this include

- evidence for the "universality" of Newton's laws of motion and of gravity, as set out in the *Principia* (the same laws can describe falling bodies on Earth and the motion of the planets as codified by Kepler);
- the finite speed of light, as deduced by Römer from the timing of the occultations of Jupiter's moons;
- evidence in favour of General Relativity, initially from the advance of the perihelion of Mercury (a "postdiction", in that this was a known problem before 1915, but persuasive because GR could account for the discrepancy with good quantitative precision) and the observation of gravitational bending of starlight by Eddington in 1919; in more modern epochs by studies of binary pulsars (which won Hulse and Taylor a Nobel Prize in 1993);
- evidence for non-zero neutrino masses (from the solar neutrino deficit; the best current upper limit on what those masses actually are is also astronomical, deduced from the WMAP studies of the cosmic microwave background).

This motivation has decreased somewhat in modern times, because modern experimental techniques can often probe extreme conditions in the laboratory. The most notable exception is the increasingly tight linkage between theoretical particle physics and theoretical cosmology, caused by the fact that energy scales in the very early universe exceed any that could be produced in terrestrial accelerators.

Addressing Big Questions

The primary motivation for modern astronomy is undoubtedly human curiosity. Astronomy addresses the "big questions" (Where do we come from? How did the world begin?) which have always attracted the attention of humanity, albeit usually in the guise of religion. This is the motivation usually expressed by students wishing to study astronomy at university, and probably also explains the success of popular expositions of astronomy, and particularly cosmology – e.g. Hawking's *A Brief History of Time* and Bill Bryson's *A Short History of Nearly Everything*. (Similar "big questions" (What is the world made of? Why do things behave in the way that they do?) are also the primary rationale behind the study of particle physics – but particle physics is more abstruse and more difficult to explain than astronomy, and hence does not usually manage to resonate with non-scientists as astronomy does. However, the new discipline of "particle cosmology" is challenging this, with books such as Brian Greene's *The Elegant Universe* achieving popular success.) In terms of popular support, it surely helps that astronomy produces arresting visual imagery – consider the number of HST images that make their way on to the front pages of newspapers, despite their lack of obvious relevance to the lives of the papers' readers – but this is clearly not a dominant motivation in the persistence of the subject as a scientific discipline!

Thus, the history of astronomy spans not only a vast amount of time, but also a vast change in the attitudes of practitioners and the general public. Initially, astronomy was very much an applied science, in the service of religion and the calendar; later, it became an inspiration and a test-bed for the application of mathematical techniques to natural phenomena, and subsequently for the development of empirically supported "laws of nature" which gave birth to modern science; finally, it has become established as a "pure", curiosity-driven, science aiming to shed light on fundamental questions about humanity and the universe. A study of the history of astronomy therefore touches on many aspects of history, culture, society and philosophy, as well as documenting our progress in understanding the cosmos. Some (by no means all) of these issues will be considered in this course; for more details on any given aspect, consult the extensive specialist literature.

A Timeline for the History of Astronomy

In this course, we shall take a thematic (albeit broadly chronological) approach to the history of astronomy, as summarised in the course outline. This has the disadvantage that it may sometimes obscure the overall picture of what is happening at any given time. Therefore, we start the course with a brief chronological account of the history of astronomy, together with relevant events in the wider history of science and in the socio-political context. This timeline focuses primarily on Western Europe and the Near East, because this is the tradition that ultimately led to modern astronomy; it should be noted that from ~1000 BC much excellent observational work was carried out in China and neighbours (Japan, Korea, Vietnam, Cambodia). This is of particular interest because, owing to a different astrological system, the Chinese recorded transient phenomena ignored by Western observers; the Chinese records are thus our main source for information on phenomena such as supernovae and comets. However, the Chinese do not seem to have attempted any model building along the lines of the Greek philosophers.

Date	**Astronomy**	**Other Sciences**	**Social/Political**
3500 – 2000 BC	Astronomically aligned monuments, e.g. Stonehenge, Newgrange. Early calendars, e.g. Egyptian		Nothing known of the society which built megalithic monuments. Egyptians developed both a lunisolar religious calendar and a 365-day civil calendar.
2000 – 1000 BC	Babylonians begin to keep astronomical records (along with others) for the purpose of interpreting omens	[Maths] Babylonians develop sexagesimal place-value notation for numbers	Complex bureaucratic civilisations of Near East well established.
~700 BC	Systematic Babylonian record-keeping.		Babylon part of Assyrian empire
~500 BC	Babylonians identify Metonic (lunisolar) cycle	Pythagoras (580-500) and his school work on various aspects of maths, astronomy & music	Babylon now under Persian rule.

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~400 BC	Greeks begin to develop models of Earth and sky (spherical Earth, lunar phases, geocentric system of circular motion)		Greek city-states
340-323 BC	Aristotle (384-322): distinction between "terrestrial" and "celestial" phenomena; crystal spheres; Earth as natural centre of universe.	Aristotle works extensively in various sciences, developing highly respected body of work.	Reign of Alexander the Great Conquest of both Greece and Persia, hence contact between Greek model-builders and Babylonian record-keepers established.
323 BC – AD 0	*Hellenistic astronomy*: Aristarchus (310-230), distance of Moon and Sun, heliocentric model; Eratosthenes (276-195), size of Earth; Apollonius (262-190), eccentric orbits, epicycles; Hipparchos (167-126), star catalogue, precession, improved models for Sun and Moon.	[Maths] Euclid (330-260) develops formal geometry; Apollonius works on conic sections. [Physics and Maths] Archimedes (287-212) almost invents integral calculus, invents various machines for deterring Romans, discovers his Principle.	Alexandrian empire fragments after his death. Ptolemy grabs Egypt. Alexandria develops as centre of scientific learning. Rise of Rome.
c. AD 100 – 170	*Ptolemy*: "Almagest" (originally *Megale syntaxis*): grand synthesis of geocentric system.		Roman empire at peak. Hadrian's wall built.
AD200-600	Little progress. Romans enthusiastic users of technology, but not innovative in science. Western Empire falls, ~440 AD; Eastern empire persists until sack of Constantinople, 1453, but has strongly mystical/religious focus. After fall of Western empire Europe fragments into various warring kingdoms. The "Dark Ages."		
AD600 – 1200	Islamic scholars translate and thus preserve much Greek science, refine and develop Ptolemaic models, improve instrumentation (astrolabe). Tables of planetary positions, especially Toledo Tables by Ibn al-Zarqâla (1029-87).	[Maths] Islamic scholars import "Arabic" numbers from India, develop trigonometry (including spherical trig) and make advances in maths generally (cf. *algebra*, *algorithm*). Also Islamic work on optics, medicine and chemistry.	Mohammed 570-632. Meteoric rise of Islam. Islamic respect for scholarship contrasts strongly with mediaeval Europe, but Moorish occupation of Spain provides invaluable bridge between cultures.

Date	Astronomy	Other Sciences	Social/Political
AD1200 – 1500	Aristotelian/Ptolemaic astronomy taught in universities, and textbooks written. Alfonsine Tables of planetary positions (1252). More developments in instrumentation: cross-staff, quadrant. Regiomontanus (1436-76): systematic programme of observations and printing of crucial works (interrupted by his early death; pupil Walther continued observations until 1504).	Thomas Aquinas (1225-74) unites Aristotle and church learning (bad move). Roger Bacon (~1220-94) stresses importance of experiment in science (good move). Early clocks (often “astronomical” with lunar phases etc.).	Greater stability in Europe, and rise of merchant class. More education; (re-)invention of printing improves dissemination of knowledge. Fall of Constantinople (1453) ends Eastern Empire. Contact with New World (1492) emphasises importance of navigation.
AD1500 – 1600	Copernicus (1473-1543) writes *De Revolutionibus* (1543): reintroduction of heliocentric cosmology. Tycho Brahe (1546-1601): observations of unprecedented accuracy. Demonstrates that comet of 1577 and “Tycho’s supernova” of 1572 are **not** sublunar (and that Aristotle’s spheres cannot be real). Attempts to measure parallax of Mars; fails, but leaves vital set of observations for Kepler.	[Chemistry] Paracelsus (1493-1541) revives study of chemistry in Europe. [Maths] Development of algebra – beginning of shift from geometric methods to algebraic. Decimal notation developed. [Physics] Gilbert, *De Magnete* (1600)	Reformation and rise of various Protestant denominations reduces authority of Catholic church. Increasing levels of education and intellectual independence.
AD1600 – 1700	1602 Tycho’s star catalogue 1604 “Kepler’s supernova” Galileo begins telescopic observations, 1608 1609 *Astronomia Nova* (Kepler’s first two laws)	Many foundations of modern science laid, e.g. gas laws (Boyle, Hooke), mechanics (Galileo, Hooke, Newton), calculus (Newton and Leibniz). Rise of **empirical** scientific work and **predictive** mathematical models. Concept of universal natural laws.	Union of the Crowns of Scotland and England, 1603.

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AD1600 – 1700 , continued	1610 Galileo, Sidereus Nuncius Galileo discovers satellites of Jupiter. 1611 Kepler improves telescope design 1613 Galileo writes letters on sunspots 1619 Kepler's third law 1632 Galileo, Dialogue of the Two Chief World Systems 1639 Huygens interprets Saturn's rings 1667 Paris Observatory 1675 Greenwich Observatory. Römer recognises finite speed of light 1677-8 Halley catalogues southern stars from St Helena 1687 Newton, *Principia* 1695 Halley recognises periodicity of "Halley's comet"	1614 John Napier invents logarithms 1644 Descartes, Principles of Philosophy 1662 Royal Society founded 1665 *Phil Trans* started 1666 Académie des Sciences founded 1672 Newton uses prism to decompose white light	Unpopularity of later Stuart kings results in English civil war (1642) and establishment of Commonwealth. Beginning of the end for absolute monarchies and rise of recognisable modern states. Increasing long-distance travel: importance of navigation. Access to southern hemisphere.
AD 1700 – 1800	Rapid development of astronomical instrumentation: achromatic lenses, reflecting telescopes, improved eyepieces. Numerous star catalogues. First studies of "nebulae" by Herschel and Messier. First attempts to understand the Galaxy. Many detailed Newtonian calculations of planetary and lunar orbits.	Emergence of modern chemistry (Priestley, Lavoisier, Dalton). Advances in Newtonian mechanics by Laplace, Lagrange, etc. – mostly driven by astronomical calculations.	Much social upheaval (Jacobite rebellions in Scotland, 1715, 1745; American independence, 1776; French Revolution, 1789).

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AD 1700 – 1800, continued	1729 Bradley, stellar aberration 1750 Wright, early speculations on structure of Galaxy 1758 Dolland, achromatic lens 1759 Halley's comet duly returns 1761 Transit of Venus 1767 Michell recognises existence of binary stars and stellar clusters 1781 Messier's catalogue of "things that aren't comets" 1781 Herschel discovers Uranus 1783 Goodricke, Algol 1796 Laplace, nebular hypothesis	Longitude problem solved by development of reliable chronometers (Harrison H4, 1761). Hutton's *Theory of the Earth* (1788) introduces "uniformitarianism" in geology and a very great age for the Earth ("no vestige of a beginning, no prospect of an end.") First systematic studies of heat and electricity.	Beginnings of industrial revolution: steam power, iron working, canals. Heavy industry and urbanisation.
AD 1800 – 1900	Major technological developments in telescope making (Fraunhofer); introduction of spectroscopy and photography (birth of modern observational astronomy) 1801 Piazzi discovers Ceres 1802 Olbers discovers Pallas 1803 Herschel confirms binary stars 1804 Juno and Vesta discovered	"Classical physics" perfected: wave theory of light (Young, 1801; Fresnel, 1830); thermodynamics (Carnot, Meyer, Joule, Kelvin, Helmholtz, Maxwell, etc.); classical electrodynamics (Oersted, Faraday, Ampère, Maxwell, Hertz, etc.).	Continuing advance of industrialisation and development of new technologies. Strong emphasis on science and engineering to support this.

Date	Astronomy	Other Sciences	Social/Political
AD 1800 – 1900, continued	1814-15 Fraunhofer maps solar spectrum 1838 Bessel makes first reliable parallax measurement, of 61 Cygni (nearly simultaneously, Struve and Henderson measure less accurate parallaxes for Vega and α Cen respectively). 1842 Solar corona and prominences observed during eclipse 1844 Bessel announces Sirius and Procyon are binary 1846 Neptune discovered 1857 Maxwell analyses dynamics of Saturn's rings 1868 Secchi develops first stellar classification system 1872 Draper photographs spectrum of Vega 1880 Silver on glass technology introduced 1898 Crossley reflector at Lick Observatory becomes first modern research reflecting telescope	Lyell, *Principles of Geology*, (1830) establishes modern geology Darwin's *Origin of Species* (1859) [from astronomical perspective this puts real pressure on theories of Sun's energy source] 1859 Kirchhoff and Bunsen establish rules for spectral line production. 1895 Röntgen, X-rays 1896 Becquerel, radioactivity 1897 Thomson, electron	Technologies that impact on astronomy include precision engineering (cf. Bessel's "twice-built telescope"), spectroscopy and photography.
AD 1900 - 1950	The advances in physics plus improved instrumentation led to the development of modern astrophysics (requiring quantum mechanics) and cosmology (requiring general relativity) 1905 Hertzsprung, giant stars 1906 Kapteyn's Galaxy	Dramatic shift from view of classical physics as "finished article": 1900 Planck's quantised theory of blackbody radiation 1905 Einstein's "annus mirabilis": special relativity, quantum theory of photo-electric effect, Brownian motion and existence of atoms	Two world wars; emergence of USA and (post 1945) USSR as superpowers.

Date	Astronomy	Other Sciences	Social/Political
AD 1900 - 1950	1908 Mt Wilson 60-inch 1912 Leavitt's period-luminosity relation for Cepheids 1913 Russell draws first modern style HR diagram 1914 Slipher, redshifted nebulae; Shapley, Cepheids as pulsating variables 1917 Mt Wilson 100-inch 1918-24 HD catalogue 1919 Eddington measures bending of starlight 1920 Saha, ionisation in stellar atmospheres 1922 Friedman, expansion 1923 Hubble finds Cepheid in M31, establishes existence of external galaxies 1924 Cecelia Payne, solar composition; Eddington, mass-luminosity relation 1926 Eddington, Internal Constitution of the Stars 1929 Hubble, redshift-distance relation 1931 Chandrasekhar, theory of white dwarfs 1932 Jansky, radio astronomy 1934 Baade and Zwicky, theory of neutron stars 1939 Bethe, theory of hydrogen fusion	~1910 Rutherford's experiments in Manchester establish nuclear atom 1913 Bohr's semi-classical model of the hydrogen atom 1915 Einstein's theory of general relativity 1920-27 Initial development of quantum mechanics (Schrödinger equation) 1932 Chadwick, neutron	From an astronomical viewpoint, the big shift is from private to Government funding of astronomical research (and indeed scientific research generally) – previously Government funding had been restricted to particular aspects, e.g. Greenwich Observatory and Astronomer Royal (mostly for navigation and timekeeping).

Date	Astronomy	Other Sciences	Social/Political
	1944 Baade, stellar populations 1946 V2 rockets used for astronomy 1948 Palomar Observatory (200-inch, 48-in Schmidt) 1948 Birth of modern cosmology: αβγ paper on hot dense early universe, Bondi, Gold and Hoyle on Steady State		Development of radar in WWII paves way for radio astronomy

From 1950 to the present day the line between "astronomy" and "history of astronomy" becomes increasingly blurred, and the rapid pace of change makes developing a timeline increasingly difficult. The difference between astronomy in 1900 (still very primitive) and 1950 (recognisably modern, with most lines of enquiry already established, and only the advent of space-borne instrumentation still to come) is very striking: although we started by saying that astronomy is the oldest science, this dramatic shift means that in some senses it is also one of the youngest – very little of the theory learned in undergraduate astrophysics is more than a century old (in contrast to, say, physics, where much of 19th century classical physics is still used despite the huge 20th century change in its theoretical underpinnings).

Exercises

1. Imagine you have been commissioned to write a review of the state of the art in astronomy, perhaps for some funding agency which is considering supporting astronomical projects. You should briefly explain what the current state of knowledge is, what the major discoveries of the last 10 or (if considering a date before 1900) 20 years have been, and what the main unanswered questions seem to be. **Try to maintain the perspective of a contemporary observer** – in other words, don't assume that it was obvious in 1920 that hydrogen fusion was the main stellar energy source (it wasn't!).

   Dates to consider:

   1820; 1850; 1900; 1930; 1950

   Note: this exercise is intended in part as a preparation for the assessed *News and Views* article. One of the primary requirements for a successful *N&V* article is the ability to assess the current state of the field.