The New Cosmos

2nd Revised and Enlarged Edition

Translated by R. C. Smith
based on the translation by
W. H. McCrea of the 1st Edition

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The photo on the cover shows the Crab nebula.

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From the Author's Preface to the First Edition

This book may serve to present the modern view of the universe to a large number of readers whose over-full professional commitments leave them no time for the study of larger monographs . . . Such a book should not be too compendious. Accordingly, the author has been at pains to allow the leading ideas of the various domains of astronomical investigation to stand out plainly in their scientific and historical settings; the introductory chapters of the three parts of the book, in the framework of historical surveys, should assist the general review. With that in mind, the title was chosen following Alexander von Humboldt's well known book "*Kosmos, Entwurf einer physischen Weltbeschreibung*" (1827–1859). On the other hand, particular results—which admittedly first lend color to the picture—are often simply stated without attempting any thorough justification.

The reader seeking further information will find guidance in the Bibliography. This makes no pretensions to completeness or historical balance. References in the text or in captions for the figures, by quoting authors and years, make it possible for the reader to trace the relevant publications through the standard abstracting journals.

I wish to thank my colleagues V. Weidemann, E. Richter and B. Baschek for their critical reading of the book and for much helpful counsel, and H. Holweger for his tireless collaboration with the proofs. Similarly, my thanks are due to Miss Antje Wagner for the careful preparation of the typescript.

April 1966 ALBRECHT UNSÖLD

Kiel
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Translator's Foreword to the First Edition

Many graduates in mathematics and physics turn to research in optical or radio astronomy, in astrophysics, in space science, or in cosmology. Professor Unsöld has provided the concise but comprehensive introduction to modern astronomy that all such students need at the outset of their work. Scientists in other fields who follow current advances in astronomy will find in it a compact work of reference to provide the background for their reading. Professor Unsöld has had in mind the widest possible circle of readers who for any reason want to know what modern astronomy is about and how it works. It is a privilege to help to extend this circle of readers to include those who prefer to read the book in English.

I have sought to put the work into serviceable English while losing as little as possible of the force and economy of Professor Unsöld's own masterly writing. It has not been my concern to create any illusion that the work was originally written in English.

I thank Professor Unsöld for reading my translation and for all the helpful comments which have, indeed, convinced me that he could himself have written his book in English better than anyone else. He has also supplied corrections of a few minor errors in the German text. I am grateful to Dr John Hazlehurst for preparing all the diagrams and their legends for the English edition. I thank Miss Shirley Ansell for taking infinite trouble with the typescript and the proofs.

Winter 1968

WILLIAM H. MCCREA

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Author's Preface to the Second Edition

The development of astronomy in the last ten years has been nothing short of explosive. This second edition of The New Cosmos, considerably revised and enlarged, tries to share this development with its readers. Let us mention a few key words: from moon landings, planetary probes, and continental drift through pulsars, X-ray and γ-ray sources, interstellar molecules, quasars, and the structure and evolution of stars and stellar systems right up to cosmological models.

As before, the most important task of this book is to give a not too difficult introduction to present-day astronomy and astrophysics, both to the student of astronomy and to the specialist from a neighboring discipline. We therefore draw to the attention of the reader, as an essential part of our description, the numerous illustrations—many of them new—and their detailed captions. As far as possible we link a description of important observations with basic features of the theory. On the other hand, when it comes to detail we often content ourselves with a brief description, leaving the detailed explanation to the specialist literature. The transition to the specialist literature should be eased by the Bibliography at the end of the book. Important new investigations are noted in the text by their year, not so much for historical reasons as to enable the original work to be found in the Astronomy and Astrophysics Abstracts (1969 on).

The amateur astronomer should not let himself be frightened by a few formulas. Rather, it is best for him in the meantime to accept their numerical results in good faith and to pursue his reading in the spirit of "divine curiosity" so prized by Einstein.

My colleagues V. Weidemann, H. Holweger, D. Reimers, and T. Gehren have upheld me in the friendliest way by reading the manuscript, by a variety of helpful advice, and by reading the proofs. Mrs G. Mangelsen and Mrs G. Hebeler have helped untiringly with the production of the manuscript. To all these are due my heartiest thanks.

August 1974

ALBRECHT UNSÖLD

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Translator's Foreword to the Second Edition

This second edition of The New Cosmos is a worthy successor to the now well-known first edition. Professor Unsöld has taken the opportunity not only to bring his book up to date but also to expand on some topics which previously received only a brief mention. The task of translation has been greatly lightened by the high quality of the book.

Like Professor McCrea, whose excellent translation of the first edition I have used where possible, I have tried mainly to produce a faithful translation in clear English. Despite that, there are inevitable differences in style between the two translations, and I can only hope that these are not too glaringly obvious.

I am grateful to Professor Unsöld for patiently answering my queries and for his percipient comments on my translation. I also wish to thank Drs Brian and Deborah Charlesworth for comments on Section 31. I am grateful to Ms Esther Salve, to Ms Elizabeth Barnes, and in particular to Mrs Hazel Freeman for producing the typescript.

July 1977 ROBERT C. SMITH

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I. Classical Astronomy

1. Stars and Men: Observing and Thinking

Historical introduction to classical astronomy

Through all the ages the stars have run their courses uninfluenced by man. So the starry heavens have ever symbolized the "Other"—Nature, Deity—the antithesis of the "Self" with its world of inner consciousness, desires, and activities. The history of astronomy forms one of the most stirring chapters in the history of the human spirit. All along the emergence of new modes of thought has interlocked with the discovery of new phenomena, often made with the use of new-fashioned instruments.

Here we cannot recount the great contributions of the peoples of the ancient orient, the Sumerians, Babylonians, Assyrians and Egyptians. Also we must forbear to describe what was in its own way the highly developed astronomy of the peoples of the far east, the Chinese, Japanese, and Indians.

The concept of the cosmos and of its investigation in our sense of the word goes back to the Greeks. Discarding all notions of magic and aided by an immensely serviceable language, they set about constructing forms of thought that made it possible step by step to "understand" the cosmical manifestations.

How daring were the ideas of the Presocratics! Six centuries before Christ, Thales of Miletus was already clear about the Earth being round, he knew that the Moon is illumined by the Sun, and he had predicted the solar eclipse of the year 585 B.C. Is it not just as important, however, that he sought to refer the entire universe to a single basic principle, namely "water?"

The little that we know about Pythagoras (mid-sixth century B.C.) and his school has an astonishingly modern ring. Here already is talk of the sphericity of the Earth, Moon, and Sun, of the rotation of the Earth and of the revolution of at least the two inferior planets Mercury and Venus round the Sun.

Because after the dissolution of the Greek states science had found a new home in Alexandria, there the quantitative investigation of the heavens based upon systematic measurements made rapid advances. Rather than dwell here upon the numerical results, it is of particular interest to note how the great Greek astronomers above all dared to apply *geo*metrical laws to the cosmos. Aristarchus of Samos, who lived in the first half of the third century B.C., sought to compare quantitatively the Sun-Earth and Moon-Earth distances as well as the diameters of these three heavenly bodies. His starting point was that at the Moon's first and third quarters the Sun-Moon-Earth triangle is right-angled at the Moon. Following this first measurement in outer space, Aristarchus was the first to teach the heliocentric world-system. He appreciated its portentous consequence that the distances of the fixed stars must be stupendously greater than the distance of the Sun from the Earth. How far he was ahead of his time is best shown by the fact that the succeeding generation proceeded to forget this great discovery of his. Soon after these notable achievements of Aristarchus, Eratosthenes carried out between Alexandria and Syene the first measurement of a degree of arc on the Earth's surface. He compared the difference in latitude between the two places with their separation along a well-used caravan route, and he inferred thus early fairly exact values of the circumference and diameter of the Earth. The greatest observer of antiquity was Hipparchus (about 150 B.C.), whose star catalog was scarcely surpassed in accuracy even in the sixteenth century. Even though his equipment naturally did not suffice for him significantly to improve the determination of the fundamental parameters of the planetary system, he nevertheless succeeded in making the important discovery of precession, that is, of the advance of the equinoxes and so of the difference between the tropical and sidereal year.

Within the compass of Greek astronomy, the theory of planetary motion, which we must now discuss, had to remain a problem in geometry and kinematics. Gradual improvement of observations on the one hand, and the development of new mathematical approaches on the other hand, provided the material from which Philolaus, Eudoxus, Heracleides, Apollonius, and others strove to construct a representation of planetary motions by means of ever more complicated interlacings of circular motions. It was much later that the astronomy and planetary theory of antiquity first attained its definitive form through Claudius Ptolemy who about 150 A.D. in Alexandria wrote the thirteen books of his Handbook of Astronomy (Math-

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ematics) *Μαθηματικῆσ Συντάξεωσ βιβλία ιγ*. The "Syntax" later earned the nickname *μεγίστη* (greatest), from which the arabic title *Almagest* ultimately emerged. Although the contents of the Almagest rested extensively upon the observations and investigations of Hipparchus, Ptolemy did nevertheless contribute something new, especially to the theory of planetary motion. Here we need give only a brief sketch of Ptolemy's geocentric world system: The Earth rests at the center of the cosmos. The motions of the Moon and the Sun around the sky may be fairly well represented simply by circular paths. Ptolemy described the motions of the planets using the theory of epicycles. A planet moves round a circle, the so-called epicycle, the immaterial center of which moves around the Earth in a second circle, the deferent. Here we need not go into the elaboration of the system using further circles, some of them eccentric, and so on. In Section 6 we shall consider the connexion between this system and the heliocentric world system of Copernicus, and the way they differ. In its intellectual attitude, the Almagest shows clearly the influence of Aristotelian philosophy, or rather of *Aristotelianism*. Its scheme of thought, which had developed from the tools of vital investigations into what eventually became the dogmas of a rigid doctrine, contributed not a little to the astonishing historical durability of the Ptolemaic system.

We cannot here trace in detail the way in which, after the decline of the Academy at Alexandria, first the nestorian Christians in Syria and then the Arabs in Baghdad took over and extended the work of Ptolemy.

Translations and commentaries upon the Almagest formed the essential sources for the first western textbook of astronomy, the *Tractatus de Sphaera* of Johannes de Sacrobosco, an Englishman by birth who taught in the University of Paris until his death in 1256. The *Sphaera* was time and again reissued and commented upon; it was the text for academic instruction even to the time of Galileo.

Suddenly an altogether new spirit in thought and life showed itself in the fifteenth century, first in Italy, and soon afterwards in the north. Today for the first time we are beginning to appreciate the penetrating meditations of Cardinal Nicolaus Cusanus (1401–1464). It is of the greatest interest to see how with Cusanus ideas about the infinity of the universe and about the quantitative investigation of nature sprang from religious and theological reflections. Toward the end of the century (1492) came the discovery of America by Christopher Columbus, who expressed the new feeling about the world in his classic remark, "il mondo e poco." A few years later Nicholas Copernicus (1473–1543) initiated the heliocentric world-system.

Part of the intellectual background of the new thinking came from the fact that after the sack of Constantinople by the Turks in 1453 many learned works of antiquity were made available in the west by Byzantine scholars. Certain very fragmentary traditions about the heliocentric systems of the ancients had obviously made a deep impression upon Copernicus. Furthermore, we notice a trend away from the rigid doctrine of Aristotle toward the much more vital mode of thought of the Pythagoreans and the Platonists. The "platonic" concept is that the advance of knowledge consists in a progressive adjustment of our inner world of ideas and thought-forms to the ever more fully investigated external world of phenomena. It has been shared by all the important investigators in modern times from Cusanus through Kepler to Niels Bohr. Finally, with the rise of industry, the question was no longer, "What does Aristotle say about so and so?" but, "How does one do so and so?"

About 1510 Copernicus sent to several notable astronomers in the form of a letter a communication, first rediscovered in 1877, *Nicolai Copernici de hypothesibus motuum caelestium a se constitutis commentariolus,* which already contained most of the results of his masterpiece, *De revolutionibus orbium coelestium libri VI,* first published in Nuremberg in 1543, the year of Copernicus's death.

Throughout his life Copernicus held to the idea of the perfection of circular motion that was inescapable throughout ancient and mediaeval times, and he never contemplated any other motions.

Following the traditions of the Pythagoreans and Platonists, Johannes Kepler (1571–1630) was the first to succeed in attaining a more general standpoint in "mathematico-physical aesthetics." Starting from the observations of Tycho Brahe (1546–1601), which far excelled all earlier ones in accuracy, he discovered his three laws of planetary motion (see Section 3). Kepler found the first two as a result of an incredibly burdensome trigonometric computation, using Tycho's observations of Mars, in his *Astronomia nova, seu physica coelestis tradita commentariis de motibus stellae Martis ex observationibus G. V. Tychonis Brahe* (Prague, 1609). The third of Kepler's laws was announced in the *Harmonices mundi libri V* (1619). Kepler's fundamental work on optics, his astronomical telescope, his Rudolphine Tables (1627), and much else, can be only barely mentioned here.

About the same time in Italy, Galileo Galilei (1564–1642) directed the telescope, which he had constructed in 1609, on the heavens and discovered in rapid succession: the maria, the craters, and other mountain-formations on the Moon, the many stars in the Pleiades and the Hyades, the four moons of Jupiter and their free revolution round the planet, the first indication of Saturn's rings and sunspots. Galileo's *Sidereus nuncius* (1610), in which he described his discoveries with the telescope, the *Dialogo delli due massimi sistemi del mondo, Tolemaico e Copernicano* (1632), and the book he produced after his condemnation by the Inquisition, the *Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica ed ai movimenti locali* (1638), with its beginning of theoretical mechanics, are all masterpieces not only scientifically but also artistically in the way they are presented. The observations with the telescope, the observations of the supernovae of 1572 by Tycho Brahe and of 1604 by Kepler and Galileo, and finally the appearance of several comets, all promoted what was perhaps the most important perception of the times. Contrary to the Aristotelian view, it was that there is no basic difference between celestial and terrestrial matter, and that the same physical laws hold good in the realm of astronomy as in the realm of terrestrial physics. The Greeks had perceived this already so far as geometry was concerned. Recalling the case of Copernicus makes the difficulty of the concept evident. But it was this that gave wings to the enormous upsurge of natural science at the beginning of the seventeenth century. Also W. Gilbert's investigations of magnetism and electricity, Otto von Guericke's experiments with the air pump and the electrical machine, and much else sprang from the transformation of the astronomical outlook.

We cannot here pay tribute to the many observers and theorists who built up the new astronomy among whom such notabilities as Hevelius, Huygens, and Halley were outstanding.

A whole new epoch of natural philosophy began with Isaac Newton (1642–1727). His masterpiece, *Philosophiae naturalis principia mathematica* (1687), with the help of his newly created infinitesmal calculus (fluxions), placed theoretical mechanics for the first time upon a sure foundation. In combination with his law of gravitation, it accounted for Kepler's laws, and at a single stroke it founded the whole of terrestrial and celestial mechanics.

In the domain of optics, Newton invented the reflecting telescope and discussed the interference phenomena of "Newton's rings." Almost by the way, Newton developed the basic ideas for many branches of theoretical physics.

We may compare with him only the "princeps mathematicorum" Carl Friedrich Gauss (1777–1855) to whom astronomy owes the theory of determination of orbits, important contributions to celestial mechanics and advanced geodesy, as well as the method of least squares. Never has any other mathematician combined sure judgment in opening up new fields of investigation with such preeminent skill in solving special problems.

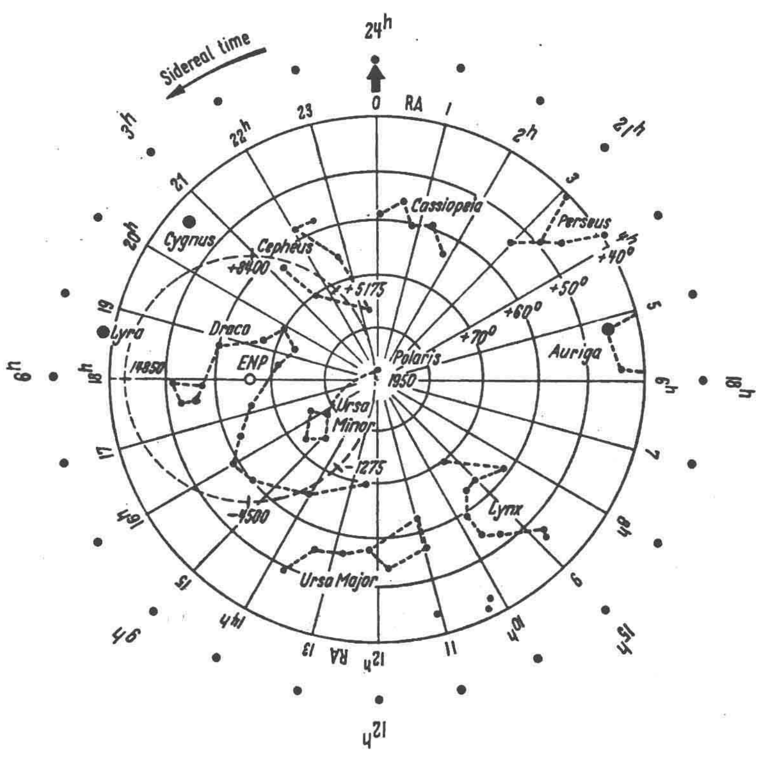
Again this is not the place to commemorate the great workers in celestial mechanics from Euler through Lagrange and Laplace to Henri Poincaré. Also we shall be able to mention the great observers like F. W. Herschel and J. F. W. Herschel, F. W. Bessel, F. G. W. Struve, and O. W. Struve only in connexion with their discoveries. As the conclusion of this review let a single historic date be recorded—that of the measurement of the first trigonometric stellar parallaxes and so of the distances of stars by F. W. Bessel (61 Cygni), F. G. W. Struve (Vega) and T. Henderson (α Centauri) in the year 1838. This conspicuous achievement of the technique of astronomical measurement forms basically the starting point for the modern advance into cosmic space.

(We shall preface Part II with some historical remarks on astrophysics and Part III with some on galactic research as well as cosmogony and cosmology.)

2. Celestial Sphere: Astronomical Coordinates: Geographic Latitude and Longitude

Man's imagination has from ancient times made star pictures out of easily recognizable groupings of stars (Figure 2.1). In the northern sky we easily recognize the Great Bear (Plough). We find the Polestar if we produce the line joining the two brightest stars of the Great Bear by about five times its length. The Polestar is the brightest star in the Little Bear; if we extend the line past it to about the same distance on the other side, we come to the "W" of Cassiopeia. With the help of a celestial globe or a star map, other

Figure 2.1. Circumpolar stars for a place of geographical latitude $\varphi = +50°$ (for example, approximately Frankfurt or Winnipeg). The coordinates are right ascension RA and declination (+ 40° to + 90°). The hour hand turning with the stars (see above), whose extension passes through the first point of Aries, shows *sidereal time* on the outer dial. *Precession:* the celestial pole turns about the pole of the ecliptic ENP once in 25,800 years. The position of the celestial north pole is denoted for various past and future dates.



constellations are easily found. In 1603, J. Bayer in his *Uranometria nova* denoted the stars in each constellation in a generally decreasing order of brightness as α, β, γ,. . . . Nowadays these Greek letters are supplemented by the numbering introduced by the first Astronomer Royal, J. Flamsteed, in his *Historia Coelestis Britannica* (1725). The Latin names of the constellations are usually abbreviated to three letters.

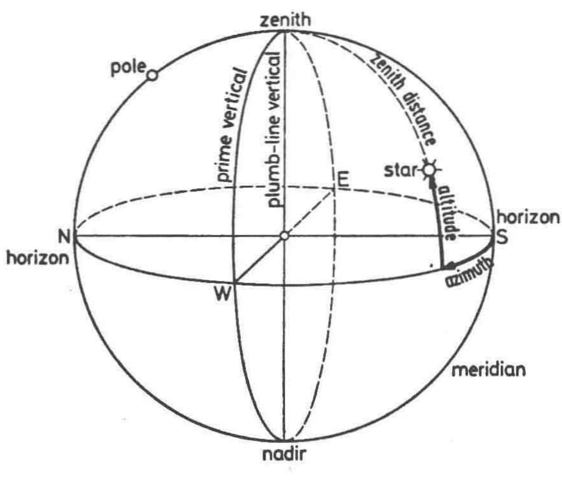
As an example, the second brightest star in the Great Bear (Ursa Major) is known as β U Ma or 48 U Ma (read as 48 Ursae Majoris).

The *celestial sphere* is, mathematically speaking, the infinitely distant sphere upon which we see the stars to be projected. On this sphere we distinguish (Figure 2.2):

(1) The *horizon* with the directions north, west, south, east.
(2) Vertically above us the *zenith* and below us the *nadir*.
(3) The *meridian* through the celestial pole, the zenith, the south point, the nadir, and the north point.
(4) The *prime vertical* through the zenith, the west point, and the east point, at right angles to the horizon and to the meridian.

In the coordinate system so determined we describe the instantaneous position of a star by specifying two angles (Figure 2.2): (1) The *azimuth* is reckoned along the horizon from 0° to 180° (W or E) and is measured either from the south point or the north point. (2) The *altitude* = 90° − *zenith distance*.

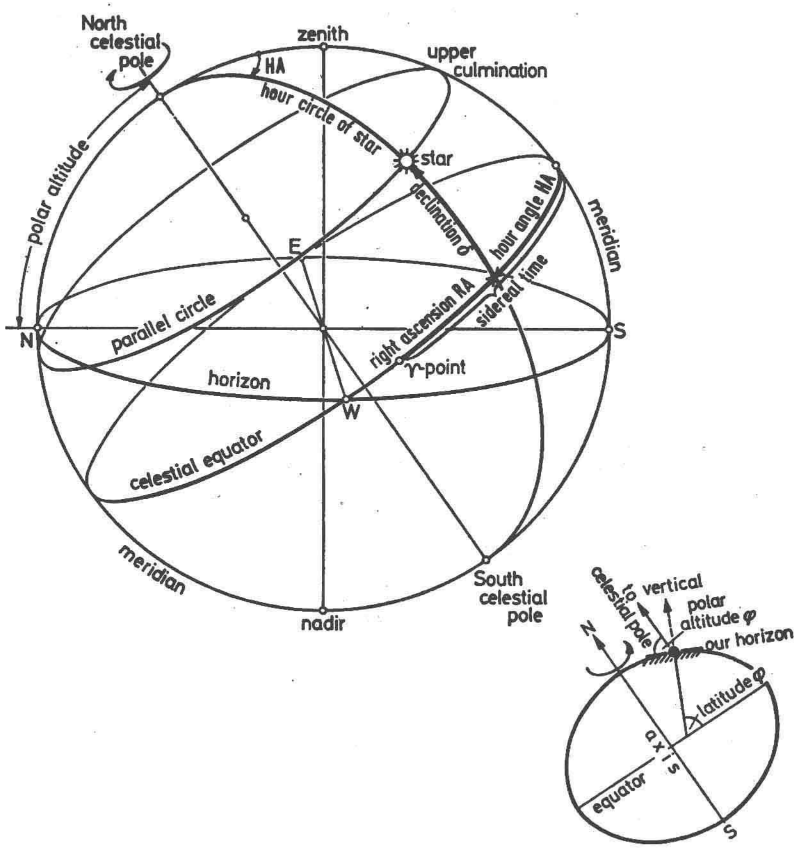
Figure 2.2 Celestial sphere. Horizon with north, south, east and west points. The (celestial) meridian passes through the north point, the (celestial) pole, the zenith, the south point and the nadir. Coordinates are altitude and azimuth.



The celestial sphere with all the stars appears to rotate each day around the *axis* of the heavens, through the north pole and south pole of the sky. The *celestial equator* is in the plane perpendicular to this axis. At a particular instant we describe the *place* (position) *of a star* upon the celestial sphere (Figure 2.3), thought of as infinitely remote, by the *declination* δ, reckoned positive from the equator toward the north pole and negative toward the south pole, and the *hour angle* HA, reckoned from the meridian in the sense of the daily motion, that is, westward from the meridian.

In the course of a day, a star traverses a *parallel circle* on the sphere; it reaches its greatest altitude on the meridian at *upper culmination* and its least altitude at *lower culmination*.

Figure 2.3. Celestial coordinates. Right ascension RA and declination δ. Hour angle HA = sidereal time minus right ascension RA. Lower right: the Earth (flattening exaggerated). Polar altitude = geographical latitude φ.



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