Angular Measure

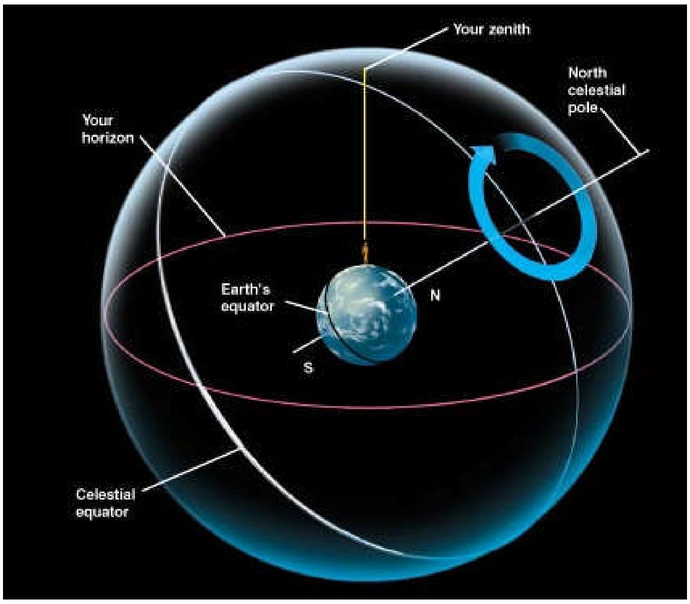
Size and scale are often specified by measuring lengths and angles. The concept of length measurement is fairly intuitive to most of us. The concept of *angular measurement* may be less familiar, but it too can become second nature if you remember a few simple facts.

- A full circle contains 360 *degrees* (360°). Thus, the half-circle that stretches from horizon to horizon, passing directly overhead and spanning the portion of the sky visible to one person at any one time, contains 180°.
- Each 1° increment can be further subdivided into fractions of a degree, called *arc minutes.* There are 60 arc minutes (written 60´) in one degree. (The term "arc" is used to distinguish this angular unit from the unit of time.) Both the Sun and the Moon project an angular size of 30 arc minutes on the sky. Your little finger, held at arm's length, does about the same, covering about a 40' slice of the 180° horizon-to-horizon arc.
- An arc minute can be divided into 60 *arc seconds* (60´´). Put another way, an arc minute is 1/60 of a degree, and an arc second is $1/60 \times 1/60 = 1/3600$ of a degree. An arc second is an extremely small unit of angular measure—it is the angular size of a centimeter-sized object (a dime, say) at a distance of about two kilometers (a little over a mile).

Don't be confused by the units used to measure angles. Arc minutes and arc seconds have nothing to do with the measurement of time, and degrees have nothing to do with temperature. Degrees, arc minutes, and arc seconds are simply ways to measure the size and position of objects in the universe. The angular size of an object depends both on its actual size and on its distance from us. For example, the Moon, at its present distance from Earth, has an angular diameter of 0.5°, or 30´. If the Moon were twice as far away, it would appear half as big—15´ across—even though its actual size would be the same. Thus, *angular size by itself is not enough to determine the actual diameter of an object—the distance must also be known.*

Celestial Coordinates

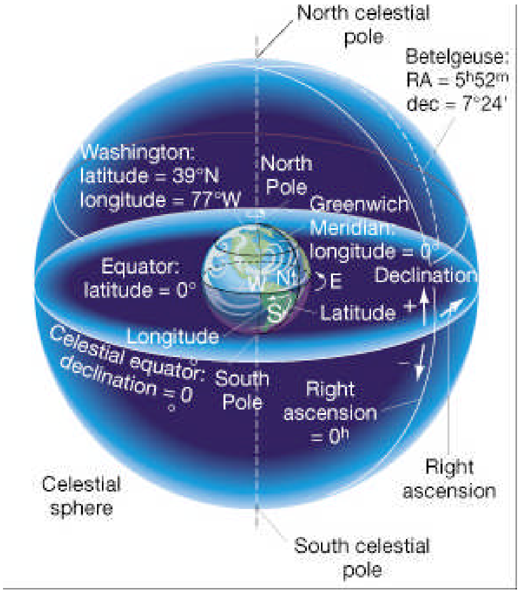
The Celestial Sphere - The (imaginary) celestial sphere around the Earth, on which objects in the sky can turn. In reality, it is the Earth that turns around the axis, creating the illusion that the sky revolves around us. The Earth in this picture has been tilted so that your location is at the top and the North Pole is where the little N is.



The simplest method of locating stars in the sky is to specify their constellation and then rank the stars in it in order of brightness. The brightest star is denoted by the Greek letter α (alpha), the second brightest by β (beta), and so on. Thus, the two brightest stars in the constellation Orion—Betelgeuse and Rigel—are also known as α Orionis and β Orionis, respectively.

For more precise measurements, astronomers find it helpful to lay down a system of *celestial coordinates* on the sky. If we think of the stars as being attached to the celestial sphere centered on Earth, then the familiar system of latitude and longitude on Earth's surface extends naturally to cover the sky. The celestial analogs of latitude and longitude on Earth's surface are called *declination* and right *ascension*, respectively.

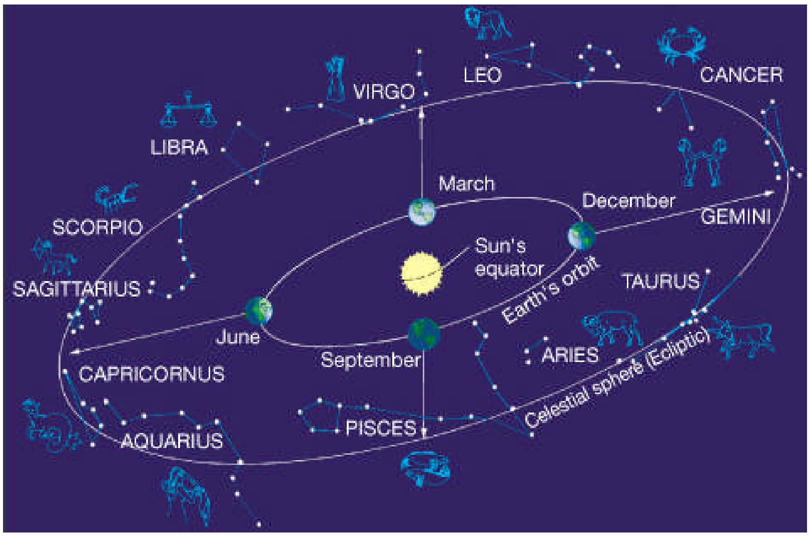
- Declination (dec) is measured in degrees (°) north or south of the celestial equator, just as latitude is measured in degrees north or south of Earth's equator. Thus, the celestial equator is at a declination of 0°, the north celestial pole is at +90°, and the south celestial pole is at -90° (the minus sign here just means "south of the celestial equator").
- Right ascension (RA) is measured in units called *hours, minutes*, and *seconds*, and it increases in the eastward direction. The angular units used to measure right ascension are constructed to parallel the units of time, in order to assist astronomical observation. The two sets of units are connected by the rotation of Earth (or of the celestial sphere). In 24 hours, Earth rotates once on its axis, or through 360°. Thus, in a time period of one hour, Earth rotates through 360°/24 = 15°, or 1^h. In one minute of time, Earth rotates through an angle of 1^m = 15°/60 = 0.25°, or 15 arc minutes (15´). In one second of time, Earth rotates through an angle of 1^s = 15´/60 = 15 arc seconds (15´´). The choice of zero right ascension is conventionally taken to be the position of the Sun in the sky *at the instant of the vernal equinox.*



Right ascension and declination specify locations on the sky in much the same way as longitude and latitude allow us to locate a point on Earth's surface. For example, to find Washington on Earth, look 77° west of the Greenwich Meridian (the line on Earth's surface with a longitude of zero) and 39° north of the equator. Similarly, to locate the star Betelgeuse on the celestial sphere, look $5^h52^m0^s$ east of the vernal equinox (the line on the sky with a right ascension of zero) and 7°24′ north of the celestial equator. The star Rigel, also mentioned earlier, lies at $5^h13^m36^s$ (RA), -8°13´ (dec). Right ascension and declination are fixed on the celestial sphere. Although the stars appear to move across the sky because of Earth's rotation, their celestial coordinates remain *constant*.

Earth's Orbital Motion

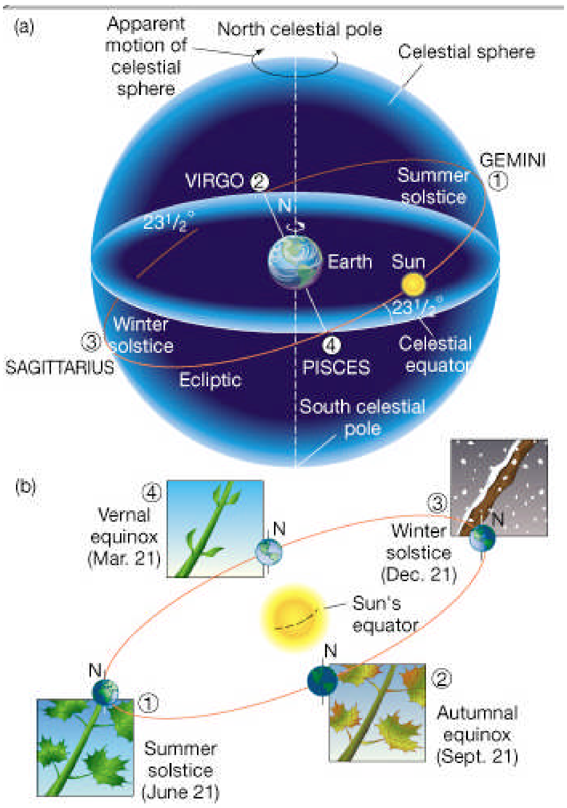
The Earth is revolving around the Sun. Because of this motion, the Sun appears (to an observer on Earth) to move relative to the background stars over the course of a year. This apparent motion of the Sun on the sky traces out a path on the celestial sphere known as the **ecliptic.**



The 12 constellations through which the Sun passes as it moves along the ecliptic—that is, the constellations we would see looking in the direction of the Sun, if they weren't overwhelmed by the Sun's light are collectively known as the **zodiac**.

The ecliptic forms a great circle on the celestial sphere, inclined at an angle of 23.5° to the celestial equator. In reality the plane of the ecliptic is *the plane of Earth's orbit around the Sun.* Its tilt is a consequence of the *inclination* of our planet's rotation axis to its orbital plane.

The time required for Earth to complete exactly one orbit around the Sun, relative to the stars, is called a **sidereal year**. One sidereal year is 365.256 mean solar days long.

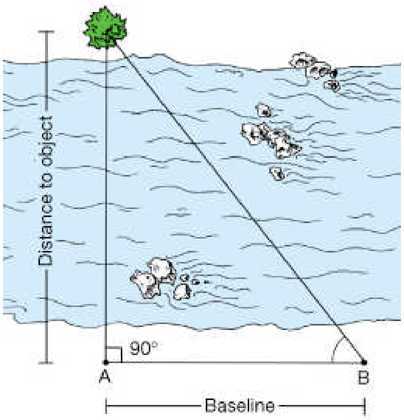


Seasons

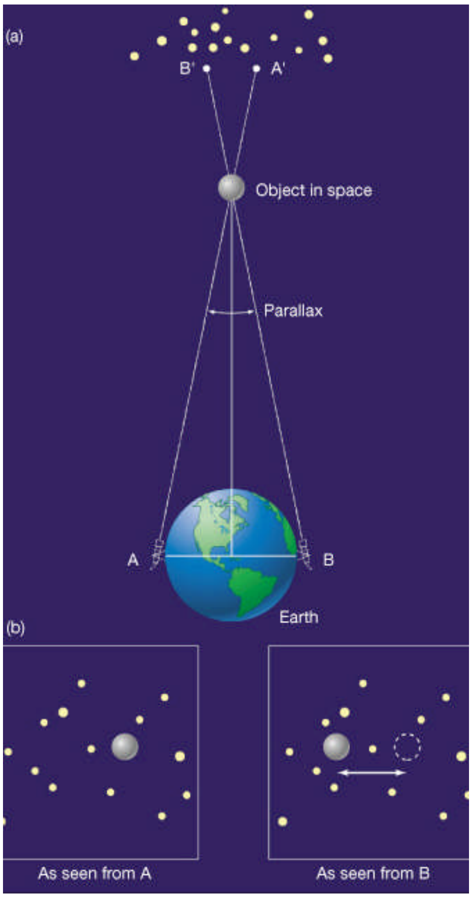
(a) The apparent path of the Sun on the celestial sphere and (b) its actual relation to Earth's rotation and revolution. The seasons result from the changing height of the Sun above the horizon. At the summer solstice (the points marked 1), the Sun is highest in the sky, as seen from the Northern Hemisphere, and the days are longest. In the "celestial sphere" figure (part a), the Sun is at its northernmost point on its path around the ecliptic; in reality

(b) the summer solstice corresponds to the point on Earth's orbit where our planet's North Pole points most nearly toward the Sun. The reverse is true at the winter solstice (point 3). At the vernal and autumnal equinoxes, day and night are of equal length. These are the times when, as seen from Earth (a), the Sun crosses the celestial equator. They correspond to the points in Earth's orbit when our planet's axis is perpendicular to the line joining Earth and Sun (b).

The Measurement of Distance and Parallax



Triangulation Surveyors often use simple geometry and trigonometry to estimate the distance to a faraway object. By measuring the angles at A and B and the length of the baseline, the distance can be calculated without the need for direct measurement.



Parallax

(a) This imaginary triangle extends from Earth to a nearby object in space (such as a planet). The group of stars at the top represents a background field of very distant stars.

(b) Hypothetical photographs of the same star field showing the nearby object's apparent displacement, or shift, relative to the distant, undisplaced stars.

This apparent displacement of a foreground object relative to the background as the observer's location changes is known as **parallax**.

The amount of parallax is thus inversely proportional to an object's distance. Small parallax implies large distance, and large parallax implies small distance. Knowing the amount of parallax (as an angle) and the length of the baseline, we can easily derive the distance through triangulation.