9.8 APPENDIX H: INTRODUCTION TO CELESTIAL COORDINATE SYSTEMS

Introduction to celestial coordinate systems

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AstroCue: planning and logging astronomical observations via computational astronomy, open data, and public APIs

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9.8.1 CELESTIAL COORDINATE SYSTEMS

To calculate the positions of astronomical objects in the sky from different positions on Earth at different times, AstroCue needed to implement various computational astronomy algorithms and work in multiple coordinate systems.

The two different celestial coordinate systems supported by AstroCue were:

1. Equatorial
2. Horizontal

9.8.2 EQUATORIAL COORDINATE SYSTEM

Much like positions on the surface of the Earth are uniquely identified and located using lines of longitude and latitude, the mapping of stars and deep sky objects is achieved using a similar system.

It appears, from Earth, that astronomical objects (excluding the Moon, planets, and artificial satellites) are stationary relative to one another. The distances to and between them are so incomprehensibly large that just by looking, we cannot discern any movement or relative distances. By extension, one can then imagine a model in which all distant objects seem to be *projected* onto the inside of a large sphere within which the Earth exists – this is concept is called the **celestial sphere**:

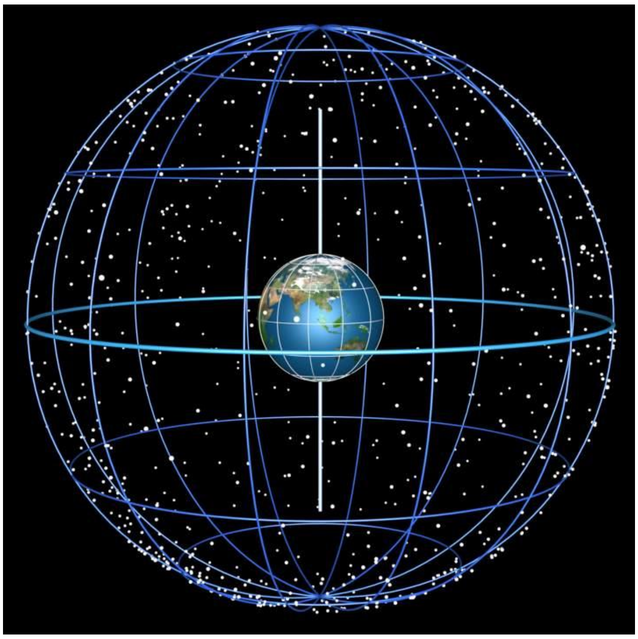

Figure 44: The 'celestial sphere' with stars (Perkic, n.d.)

As can be seen in the above diagram, the Earth's equator is then projected onto this sphere, and we can draw gridlines on the inside of it, just as we can draw longitude and latitude lines on the outside of Earth. The projected equator divides the celestial sphere into northern and southern hemispheres.

Now, units are required – how do we define a specific point in the sky? Right ascension (α/RA) and Declination (δ/Dec) are the units of the equatorial system.

- RA can be thought of as the celestial longitude – ranging from $0°$ to $360°$ starting from the vernal equinox in March.
- Dec is the celestial latitude, ranging from $-90°$ (south celestial pole) to $90°$ (north celestial pole).

However, RA is usually measured in terms of hours/minutes/seconds of Earth's rotation, so for example, $107.145°$ would be represented as $07^h08^m35^s$ (Meeus, 1998, p. 8). Similarly, Dec is represented in degrees/arcminutes/arcseconds, so -33.6019 would be $-33°36'07''$. These all signify the same values but are just representational differences.

A combination of RA and Dec can allow you to describe any position on the celestial sphere, and every catalogued astronomical object has its location given in these coordinates.

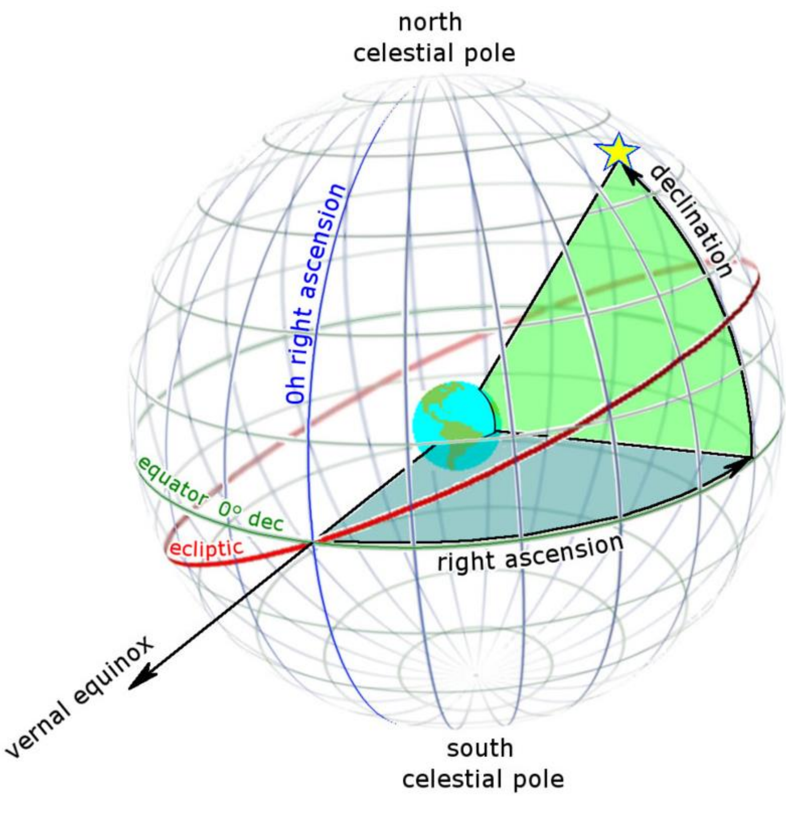

Figure 45: RA and Dec allow location of objects in the celestial sphere (Sky & Telescope, 2019).

However, despite these coordinates being 'fixed', they slowly become more and more inaccurate over time. Why is that? It all comes down to the fact that Earth's movement isn't quite as simple as it first seems. While everyone is aware that Earth spins on its axis, many are unaware that it also slowly 'wobbles' around its axis in a process called '**axial precession**'; caused by tidal forces between the Earth-Moon-Sun system. The completion of a full cycle of precession takes around 26,000 years (Meeus, 1998, p. 131).

Due to this slow drift, the equatorial coordinates of an astronomical object (α, δ) are inherently relative to the instant in which they were measured. The increase in inaccuracy is gradual, but nonetheless present, and needs to be considered in high precision calculations.

However, for the purpose of AstroCue, this inaccuracy doesn't hinder the results in any meaningful way and can be safely ignored. If needed, it can be accounted for algorithmically (Meeus, 1998, p. 132).

To make this measurement relativity clear, equatorial coordinates are often prefixed or suffixed with their 'epoch', or the year in which they were taken. I.e., it is common to see measurements such as:

$$\alpha_{1950} = 07^h 08^m 35^s \textbf{ or } \alpha_{2000} = 07^h 11^m 06^s$$

with the latter clearly being more accurate today if taken at face value without any adjustments.

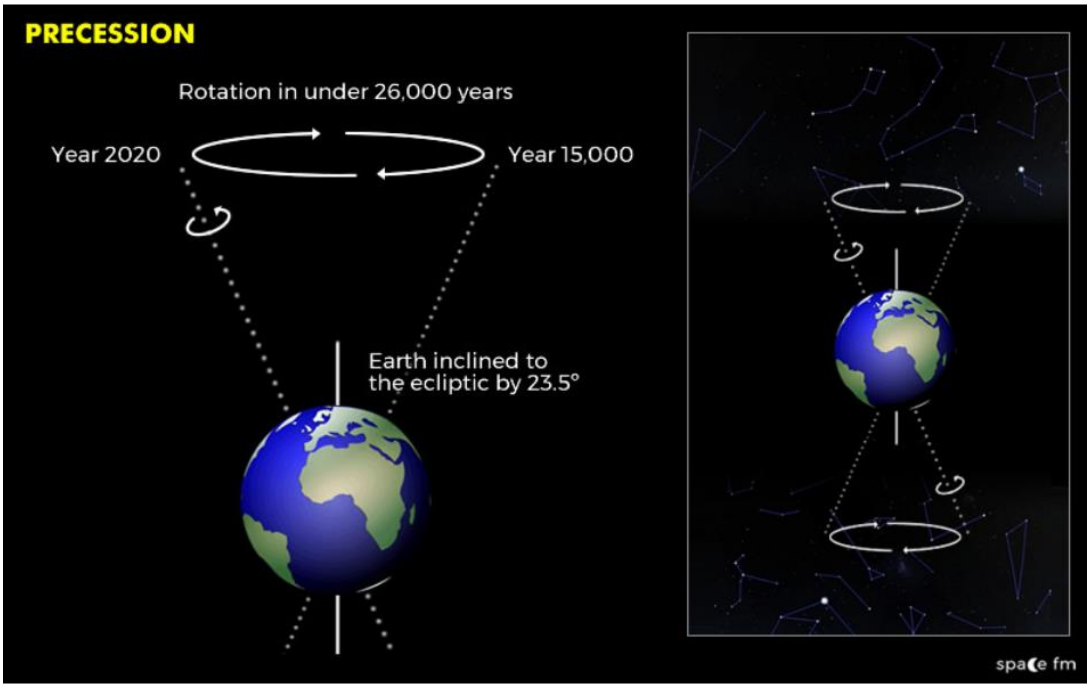

Figure 46: Earth's Precession (space.fm, n.d.).

9.8.3 HORIZONTAL COORDINATE SYSTEM

While the equatorial system is great for positions of objects on the fixed celestial sphere – it isn't particularly useful to observers looking to find objects from locations on Earth. For this purpose, the horizontal coordinate system exists.

The horizontal coordinate system uses an observer's local horizon as the zero point for both of its units, which are altitude and azimuth. Imagine you, the observer, are in a flat field that extends out to the observable horizon all around you, and you are facing South.

Azimuth is measured from $0°$ to $360°$ moving westwards from South (or North in some examples – if you pick one and stick to it for consistency, your calculations will be correct. Astronomers typically measures from the South, however) (Meeus, 1998, pp. 91-92).

Altitude, on the other hand, is measured from $0°$ at the horizon, to $90°$ directly above your head (called the zenith). It then holds that any altitude $< 0°$ is below the horizon.

A combination of altitude and azimuth (alt/az) allows an observer, from any position, to locate an object relative to themselves and their local horizon.

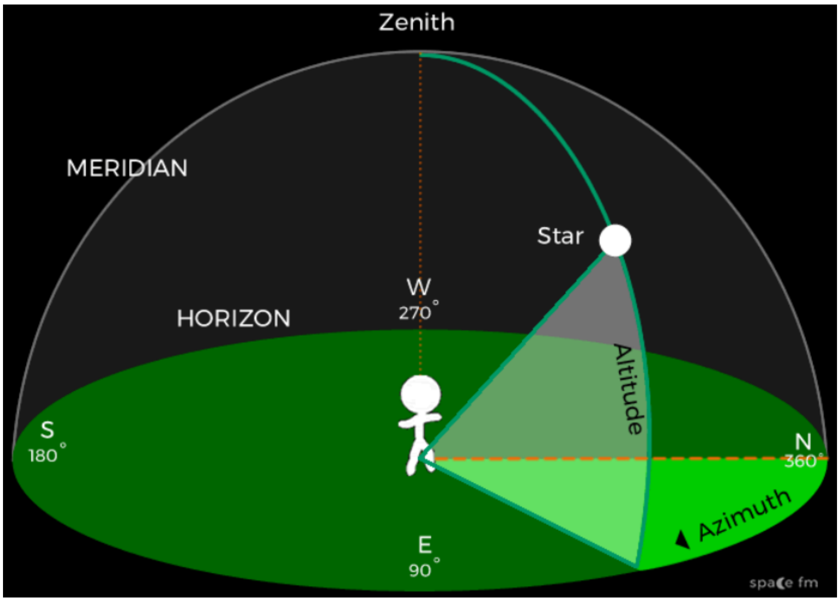

Figure 47: Horizontal coordinate system (space.fm, n.d.).

AstroCue leans on the fact that there are calculations that can transform equatorial coordinates into horizontal coordinates once an observer's longitude, latitude and local time are known.