Astronomy Primer

# Introduction

This document will describe the fundamental concepts needed to successfully perform astronomical calculations.

# Time Frames

Most astronomical calculations are a function of time. For this reason, it is convenient to have a uniformly ticking time scale to use. The most commonly used civil calendar is the Gregorian calendar, which has a few features making it discontinuous and non-uniform. For example, the month of December has 30 days whereas March has 31, so adding a month to a date means something slightly different depending on the starting month. Adding to this, February has either 28 or 29 days, depending on the year. So not all years have the same duration.

Similarly, wall clock times are subject to changing time zones (e.g. during daylight savings time, which may start and end at different times depending on the year and the location), and additionally leap seconds are implemented at irregular intervals. For these reasons, wall clock time and the Gregorian calendar do not work well as inputs to mathematical equations and algorithms. They do however offer a natural and relatable starting point.

Astronomers have introduced several uniformly ticking time scales over the last centuries, with the common goal of making calculations more practical. They will then take common civil dates and times, calculate which time point they correspond to on the uniform scale they prefer, and then use that for calculations. To better understand this solution, it can be helpful to first understand the problem in greater detail. The following section will discuss some highlights from the history of time keeping.

## Time Keeping throughout History

We have very little evidence of how humans kept track of the passing of days and years in pre-historic times (obviously, pre-historic means there are no written records to consult.) They will certainly have been aware of the passing of seasons, simply by observing their surroundings, and it is widely believed that they may have noticed the rise of certain stars or constellations[[1]](#footnote-1) at the beginning of each season. This would allow them to plan for things like hunting of migrating herd animals, and later as agriculture gained popularity, sowing, planting and harvesting.

There is also archaeological evidence of ancient cultures tracking the movement of the Sun (and/or the Moon, depending on the culture) during the year, by aligning buildings and structures to coincide with certain points in the yearly cycle of the Sun (e.g. summer and winter solstice). This is not surprising, as it is the Sun which gives rise to the changing seasons.

Early examples of the dating of events typically enumerated years and days since a given ruler came to power. In Roman culture, during the reign of Julius Caesar, this was formalized to simply giving a year, which would increase monotonously no matter the current ruler. The calendar thus introduced is called the Julian calendar, and consisted of 365 days per year, with leap years every 4th year. In practice, after the death of Julius Caesar the leap years were applied incorrectly for a while and were subsequently cleaned up later.

Initially the year was divided into 10 months, which is where the names for October, November and December (literally meaning the 8th, the 9th and the 10th) come from. However, some rulers added a couple of extra months to honour themselves or another popular ruler, which is where July (after Julius Caesar) and August (after Augustus) got their names. Additionally the lengths of each month have been adjusted a few times (e.g. July and august should of course be the longest months, so days were taken from elsewhere.)

While the Julian calendar did a decent job of following the seasons for several centuries, it was eventually evident that it was falling out of sync with the seasonal year. Thus, pope Gregory XIII decreed a new calendar, taking effect in October 1582. That the calendar was introduced by a religious authority (the Catholic Church) is unsurprising, as their religious holidays are aligned with both seasons and the movements of the Moon (in terms of week days, which are believed to originate as ¼ lunar cycles). To bring the religious holidays back into alignment with nature, Julian Thursday 4 October 1582 was immediately followed by Gregorian Friday 15 October 1582.

Of course, this new calendar was not adopted everywhere at the same time. Some countries only made the transition very recently, like Turkey in 1926, and Saudi Arabia in 2016. It is therefore very important to consider the origin of a historical document when interpreting any dates mentioned in the document.

To avoid ambiguity, some use a “proleptic Gregorian calendar” which basically pretends that the Gregorian calendar was in use as far back as whichever phenomenon is being described. Such a proleptic approach resolves one issue, which is the missing dates as communities transitioned from Julian to Gregorian. However, it does not resolve the more annoying issue of uneven year length due to the irregular introduction of leap days, so the Gregorian calendar is not the steady astronomical time scale we would want.

Even in pre-historic times, it must have been commonplace to reckon the passage of the day by the position of the Sun. The Sun roughly aligns with due south at midday, which is halfway between sunrise and sunset. There is plenty of archaeological evidence for more deliberate time keeping using sundials and water clocks. Each of these come with their own set of challenges, as the length of daylight and night-time varies considerably throughout the year, especially at latitudes far from the equator.

The division of days into what we now call hours, started by dividing the daylight period into even parts, sometimes 10 but often 12, and the same for the night-time. This causes night hours and day hours to differ but was common practice for many centuries. It was only with mechanical clocks that day and night hours began to be counted in equal length. This of course introduced the now familiar notion that sunrise and sunset happens at different times of day during different parts of the year.

With the mechanical clocks came the further subdivisions of hours into minutes, and later minutes into seconds. Minute literally means little, and second refers to the fact that it is the second subdivision (where minutes are the first subdivision) of an hour. The terms were probably adopted from the sexagesimal measure of angles, where it had been in use long before clocks were introduced.

Due to the apparent daily motion of the Sun, it is not daylight everywhere at the same time. Local solar noon appears to shift by roughly 1 hour for every 15 degrees of geographic longitude. Today we attribute this to the daily rotation of Earth, where 360 degrees divided by 24 hours equals 15 degrees per hour. Up until large railroad networks were established, each town typically had their own local time, often displayed prominently and rung out by the local churches and based on local solar noon where the Sun passes due south.

As communication and transport of goods and people between far flung regions became more common, it made sense to standardize on a more structured approach to clock time. There were even safety concerns, as some trains using the same set of tracks had collided due to scheduling misunderstandings. Time zones were allocated in hourly sections, where the region 7.5 degrees east and west of each 15 degrees of longitude would have the same local time. In this way it was predictable what the local time in each place would be, and differences were always a whole hour apart.

Of course, local circumstances meant that the exact borders of a time zone would be adjusted based on convenience where a region (e.g. a country) reaching slightly into an adjacent time zone would typically adopt the main time zone in the whole region. Today, time zones are reckoned as offsets from UTC (Coordinated Universal Time, the acronym is from French), which is the standard time at the 0 degree meridian. Some localities have changed which time zone they adhere to over time, and there are a few odd local time zones with non-integer hour offsets. This again means that when interpreting a time of day given in a historical document, great care must be taken to examine the history of the local time zone.

Adding to this, many regions switch to a different time zone offset during summertime, to have the long daylight hours align better with typical working hours. This is called daylight savings time, and different regions change time zone offset at different times of the year. Some places are now discussing whether they should abandon this scheme entirely, and the EU (European Union) has recently voted yes to do exactly that. It is currently in debate within the member nations, whether and when to move forward with abolishing daylight savings. Furthermore, there is debate over which zone offset to keep permanently, the one used during wintertime (which has solar noon at 12:00) or the one currently used during summertime, which would be offset from the Sun by one hour.

## Modern Timekeeping

With increasingly accurate clocks, small variations in the astronomical cycles become apparent.

# Coordinate Systems

In astronomy, one of the main goals is to be able to describe the location of various objects, and how those locations change over time. In this context, a coordinate system is simply a framework which allows us to describe locations of objects using numbers. This allows the construction of functions which take time as a parameter and provide the location of an object at the given time.

Early astronomers found it relatively easy to describe the direction in which an object could be observed but struggled to determine the distances to objects. This poses a challenge when trying to define coordinates for a given object. With only a direction, the object could potentially be located anywhere along the line of sight of that direction.

Of course, if the object is very close it will appear to change position as an observer moves perpendicular to the line of sight, an effect known as parallax. Since this effect was not observed, astronomical objects were known to be further than some minimum distance. But it was not known how much further, and whether different objects were at about the same distance or at vastly different distances.

If parallax was observed, it could be used to compute the distance to the object. On the other hand, without an observable parallax it can be assumed that all objects are at infinity, when it comes to direction calculations. The distance can simply be ignored, and calculations can be performed on just the direction in which the object is observed.

The practical way of achieving this is by use of spherical coordinates. One example is the use of latitude and longitude on Earth. If Earth were 2 or 100 times as large (equally in all directions), the latitude and longitude coordinates of a point on the surface would remain the same. Likewise, astronomical objects can be considered to be located on a sphere centred on Earth, with a radius so large that Earth is essentially point sized in comparison.

Mapping objects to this so-called celestial sphere is called positional astronomy or spherical astronomy. Note that this has nothing to do with the shape of the Earth, the term simply refers to the shape of the coordinate system used to describe the directions in which objects are observed.

1. A more appropriate term is ‘asterism’, which specifically refers to the “stick-figures” many cultures associate with groups of bright stars. Scientifically “constellation” refers to one of the 88 standard asterisms adopted by the IAU, along with their boundaries which allow astronomers to refer to the general region of the sky covered by a constellation. These in turn are the basis for naming bright stars in the sky. [↑](#footnote-ref-1)