DJORGOVSKI: The last part of today's lecture-- we'll talk now about coordinate systems in the sky, and the way we account for time. This won't take very long. We need to have some kind of coordinates. So what astronomers have done is they've projected Earth's coordinate systems onto the sky, and as Earth rotates, so will the sky. And so when you anchor it not to the point above the earth, but certain part in the celestial sphere, then you have celestial equivalent of equatorial system, and that's what it's called.

Now, Earth's equator projects the celestial equator, so that's an easy way to account for latitude-- or declination, as astronomers call it. And you have a choice where to start accounting for the other coordinate, the equivalent of longitude-- which we call right ascension. And the choice was made that this will be a position of Sun at the moment of the spring equinox.

Now since you're at Caltech, you all know what causes seasons-- Earth's axis is tilted relative to the planet ecliptic-- and what the equinoxes or solstices mean, right? Yes? OK, good. Likewise, you know how Sun moves on a sphere, because the tilt of the axis-- it's not always around the equator. It goes above and below, and it's always on the ecliptic. And so it inspires this sinusoidal motion throughout the year. Summer solstice is with the highest, and winter is the opposite. Equinox is when it's exactly-- when equator and ecliptic cross each other.

There is a simpler coordinate system, which is for any given point, which is the elevation angle or the distance from the zenith, and direction relative to the south, the Alt-Azimuth system. That's relevant for telescopes, and so their proper trig formulae to convert from one the other.

I have to mention two others, which are ecliptic and galactic. Just like we projected the terrestrial equator to the sky, and that became celestial equator defined equatorial system, you can take the plane of the ecliptic projected on sky that defines ecliptic equator. Or it can take plane of the Milky Way, and that defines galactic equator. And that actually can see on the sky. Here is the picture of the sky in mid to far infrared in galactic coordinates. So the horizontal reddish streak is the plane of the Milky Way marked by hot dust, and the fuzzy blue thing is actually another great circle, tilted relative to the galactic plane, and that's the ecliptic. Anybody care to guess why it's fuzzy? Why's it there to begin with, if ecliptic is simply just plane of Earth's orbit?

STUDENT: [INAUDIBLE]

DJORGOVSKI: That's correct. It is the result of dust that's been heated by sunlight and emits in infrared. And because dust is a little fluffier than just planetary orbits, so does this.

Couple other concepts, and then we'll be done. So we account for time through the earth's rotation. And so you can count day from say noon to noon, midnight to midnight. So it's defined relative to the sun. But during the year, Earth makes one extra turn because it went around the sun. And so relative to the stars, there is one more day in a year. So those are two different time systems. There is synodic-- relative to Sun. That's what you usually think of as time. And there's sidereal, which has one extra day per year. And that one is relevant for astronomical observations, because who cares how Earth turns? It's what happens in celestial sphere.

Now universal time, or Greenwich time, is local synodic time defined through the Greenwich Meridian. We are now seven hours behind it-- eight when it's not daylight savings time. Every once in a while, there is a need to tweak it up because Earth's rotation slows down, and it slows down because of tidal interaction with the Moon. And so that's why they add leap seconds. That's where they come from.

Two last things. First of all, this tilt of Earth's axis is not always constant. It tends to wobble around, and this period of that wobble is 26,000 years. So Polaris is polar star now, but at some point Vega will be polar star. And so you have to always define which equatorial system do you mean? Today? In year 2000? In year 1950? And so they're all sharply defined coordinate systems astronomers refer to. Axes also wobbles and jiggers, and those are much smaller effects, but still they can be measured.

One interesting consequence of this instability of Earth's tilt and orbit is that it leads to the ice ages. This was first proposed by an astronomer named Milankovitch, and he figured out how the shape of Earth's orbit might change in time, due to the perturbations by Jupiter and instability of this angular momentum vector, and so on. And so it's procession and eccentricity and so on, and you can match that to the fossil record of ice ages, it matches very well. So major climate cycles on planet Earth are due to this dynamical interaction of Earth's rotation with its rotation around the sun and some perturbation by other planets.