ASTR 400/700: Stellar Astrophysics

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The Celestial Sphere
Chapter 1.3
Our lack of depth perception when we look into space creates the illusion that Earth is surrounded by a celestial sphere. In reality, stars that appear very close together in our sky may actually lie at very different distances from Earth. Remember that we are on the INSIDE of the sphere (on Earth) looking out!
Points on the Celestial Sphere

- North and south celestial poles
- Celestial equator

**REMEMBER:** These are points /lines on the *celestial sphere* and NOT on the Earth

- From now on:
  equator = celestial equator
The Dome of the Local Sky

- Zenith
- Nadir
- Horizon
- Meridian
**Horizon coordinate system**
- Coordinates are measured with respect to horizon
- Change with time and depend on observer

- **Azimuth:**
  - 0 to 360 degrees around horizon from north towards east
  - $0^\circ = \text{North}$, $90^\circ = \text{East}$, $180^\circ = \text{South}$, $270^\circ = \text{West}$

- **Altitude:**
  - 0 to 90 degrees up from horizon
  - $0^\circ = \text{Horizon}$, $90^\circ = \text{Zenith}$
Ecliptic Plane

Plane containing the Sun and planets
Ecliptic is tilted 23.5° with respect to the Equator

Eclipses can only occur when the moon crosses this plane
• Ecliptic:
  – The Sun's apparent annual path among the constellations

• Zodiac Constellations
  – The constellations on the celestial sphere through which the ecliptic passes
  – Origin of Astrology (Zodiac Sign)
Cardinal Points on the Ecliptic

• Vernal Equinox
  • Sun rises due East and sets due West
  • Length of day = length of night = 12 hours

• Summer Solstice
  • Sun is highest in the sky (this is why it’s so hot during summer)

• Autumnal Equinox

• Winter Solstice
  • Sun is lowest in the sky (this is why it’s so cold during winter)
Equatorial coordinate system
Equatorial coordinate system
- coordinates fixed on the celestial sphere
- time and observer independent

• declination (dec)
  - Analogous to latitude, but on the celestial sphere; it is the angular north-south distance between the celestial equator and a location on the celestial sphere.
  - Measured in degrees:
    » 0 ° to 90 ° – north from celestial equator
    » 0 ° to -90 ° – south from celestial equator

• right ascension (RA)
  - Analogous to longitude, but on the celestial sphere; it is the angular east-west distance between the vernal equinox and a location on the celestial sphere.
  - Measured in units of time: hours, minutes, seconds
    » 0 h – 24 h from Vernal Equinox towards east
    » Ex. Sirius has RA = 6 h 45 m OR 06:45
RA and Dec of the Cardinal Points on the Ecliptic

Vernal Equinox
- Sun appears on March 21
- RA = 0h Dec = 0°

Summer Solstice
- Sun appears on June 21
- RA = 6h Dec = 23.5°

Autumnal Equinox
- Sun appears on Sept. 21
- RA = 12h Dec = 0°

Winter Solstice
- Sun appears on Dec. 21
- RA = 18h Dec = -23.5°
RA and Dec of the Cardinal Points on the Ecliptic

Vernal Equinox
Sun appears on March 21
RA = 0h  Dec = 0°

Summer Solstice
Sun appears on June 21
RA = 6h  Dec = 23.5°

Autumnal Equinox
Sun appears on Sept. 21
RA = 12h  Dec = 0°

Winter Solstice
Sun appears on Dec. 21
RA = 18h  Dec = -23.5°
Sidereal Time

Sidereal time

1) Time measured according to the position of stars in the sky rather than the position of the Sun in the sky.

2) How long ago the vernal equinox has transited

3) *It’s the Right Ascension of ANY transiting star.*
Precession

• Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.
  — Polaris won’t always be the North Star.
  — Positions of equinoxes shift around orbit; for example, the spring equinox, once in Aries, is now in Pisces!

Earth’s axis precesses like the axis of a spinning top.
Julian Date

- Because of precession, we need a reference date (epoch) from which to measure stellar motions.

- We use the Julian Calendar (days since noon, January 1, 4713 BC).

- The Julian Date on January 1, 2000 was 2,451,545.

- Various other versions: Modified Julian Date (MJD), Heliocentric Julian Date (HJD), Barycentric Julian Date (BJD).
Julian Date

Approximate expressions for the changes in the coordinates relative to J2000.0 are

\[
\Delta \alpha = M + N \sin \alpha \tan \delta \\
\Delta \delta = N \cos \alpha,
\]

(1.2)

(1.3)

where \( M \) and \( N \) are given by

\[
M = 1.2812323T + 0.0003879T^2 + 0.0000101T^3 \\
N = 0.5567530T - 0.000185T^2 - 0.0000116T^3
\]

and \( T \) is defined as

\[
T = (t - 2000.0)/100
\]

(1.4)

where \( t \) is the current date, specified in fractions of a year.
Stellar Parallax

Chapter 3.1
Angular Measurements

• Full circle = 360°
• $1^\circ = 60'$ (arcminutes)
• $1' = 60''$ (arcseconds)
Angular Size

\[ \text{angular size} = \text{physical size} \times \frac{360 \text{ degrees}}{2\pi \times \text{distance}} \]

An object’s angular size appears smaller if it is farther away.
Parallax is the apparent shift in position of a nearby object against a background of more distant objects.
Apparent positions of the nearest stars shift by about an arcsecond as Earth orbits the Sun. Angle depends on distance.
Every January, we see this.

Every July, we see this.

As Earth orbits the Sun...

... the position of a nearby star appears to shift against the background of more distant stars.

Not to scale

1 AU
Parallax and Distance

\[ p = \text{parallax angle} \]

\[ d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}} \]

\[ d \text{ (in light-years)} = 3.26 \frac{1}{p \text{ (in arcseconds)}} \]

One parsec is the distance at which the mean radius of the Earth's orbit subtends an angle of one second of arc.
Parallax ain’t easy

• Parallax shifts are fractions of an arc second
  – ground based limits: $P > 0.05 \text{ arcsec.} \ (d < 20 \text{ pc})$
  – space based limits: $P > 0.002 \text{ arcsec.} \ (d < 500 \text{ pc})$

• Beyond about 500 pc must use indirect methods
• Find and calibrate “standard candles”

Definition: Objects of known luminosity (e.g. sun-like stars)
Proxima Centauri

Nearest star to the Solar System and Sun

Robert Innis – discovered Proxima in 1915

Observed parallax shift on the sky over a six month time interval is

\[ \text{Angle} = 1.5377 \text{ arc seconds} = 0.00042714 \text{ degrees} = 2 \times P \]

Proper motion over 25 years

\[ \text{Angle of parallax} = P = \frac{1.5377}{2} = 0.76885 \text{ arc seconds} \]

Distance to Proxima = \( \frac{1}{P} = \frac{1}{0.76885} = 1.301 \) parsecs
# First parallax numbers (1837)

<table>
<thead>
<tr>
<th>Star</th>
<th>Parallax (arcsec)</th>
<th>Distance (pc)</th>
<th>Spectral type</th>
<th>Apparent magnitude</th>
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<tbody>
<tr>
<td>α Cen A</td>
<td>0.750</td>
<td>1.3</td>
<td>G2</td>
<td>-0.01</td>
</tr>
<tr>
<td>Vega</td>
<td>0.123</td>
<td>8.1</td>
<td>A0</td>
<td>0.04</td>
</tr>
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<td>61 Cyg</td>
<td>0.292</td>
<td>3.4</td>
<td>K5</td>
<td>5.22</td>
</tr>
</tbody>
</table>

(Sun-like star)