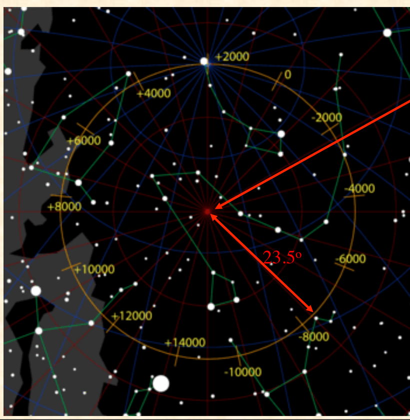
- LAST TIME: Finish Basic Motions & Cycles
  - time & calendars; precession, nutation
- TODAY: Cataloging Stellar Properties. I.
  - Position (RA and Dec)
  - Parallax and Proper Motion
  - Apparent Brightness and Luminosity
  - Colors and Temperature
- FRIDAY: Cataloging Stellar Properties. II.
  - Apparent and True Brightness; Magnitude Scale
  - Color
  - Some examples

## Longer Term Variations of the Sky

- Precession
  - our coordinate grid tied to our angular momentum vector
  - rotation axis tipped 23.5° compared to ecliptic pole
  - rapid rotation should keep this fixed in space (gyroscope)
  - gravitational perturbations from Sun, Moon, and planets causes precession of the axis direction (but not angle; to 1st order)
  - north celestial pole traces out 47° circle on sky
  - entire sky rotates around grid with ~26,000 year cycle
  - vernal equinox moves 50”/year in ecliptic longitude
  - correlation with climatic cycles?
- Nutation
  - relative position of Sun and Moon; angle of axis wobbles
  - ~18.6 year cycle is largest; less than 1 arc minute
  - but the motion is more complex than that




What is this point?

The Earth’s axis moves in space with a period of about 25 750 years, a phenomenon known as precession. Hence the celestial equator and poles also move. The positions of the stars therefore slowly change with time. Catalogues of stars customarily give the date, or epoch, for which the stellar positions that they list are valid. To obtain the position at some other date, the effects of precession must be added to the catalogue positions

$\Delta\delta \sim \cos(\alpha)$ :
$$\delta_T = \delta_E + (\theta \sin \varepsilon \cos \alpha_E)T \qquad (5.1.4)$$

$\Delta\alpha \sim \alpha$ & $\delta$ :
$$\alpha_T = \alpha_E + [\theta(\cos \varepsilon + \sin \varepsilon \sin \alpha_E \tan \delta_E)]\, T \qquad (5.1.5)$$

where $\alpha_T$ and $\delta_T$ are the right ascension and declination of the object at an interval $T$ after the epoch $E$, $\alpha_E, \delta_E$ are the coordinates at the epoch and $\theta$ is the precession constant

$$\theta = 50.40'' \text{ yr}^{-1}. \qquad (5.1.6)$$

$\varepsilon$ is the angle between the equator and the ecliptic—more commonly known as the obliquity of the ecliptic

$$\varepsilon = 23^\circ\ 27'\ 8''. \qquad (5.1.7)$$

Commonly used epochs are the beginnings of the years 1900, 1950, 2000 etc. Other effects upon the position, such as nutation, proper motion etc, may also need to be taken into account in determining an up-to-date position for an object.

## Other Things That Affect RA & Dec

- Diurnal Parallax: Moon 57’; Sun 8.8”
- Refraction affects altitude (dec) measurements
  - up to 34 arc-min at horizon (angular size of Sun!)
  - so we can see “below the horizon”
  - generally function of “zenith distance” or “air mass”
- Atmospheric Turbulence
- “Aberration” due to Earth’s motion
  - time of flight through telescope
  - no affect when looking in direction of motion
  - maximum effect 90° from direction of motion
  - orbital velocity 30 km/s --> +/-20.5” / year
  - rotational velocity 0.5 km/s --> +/-0.3”/day

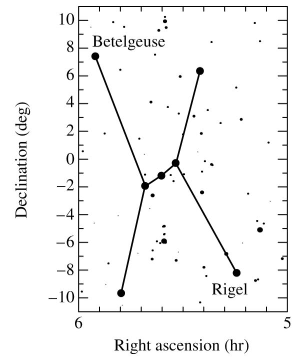
## Measuring Fundamental Parameters

1. Unique Identification
2. Position “on” the sky
3. Change in Position
   - parallax---> distance
   - proper motion --> transverse velocity
4. Apparent Brightness; Apparent Magnitude
5. Luminosity; Absolute Magnitude
6. Color
7. Effective Temperature

## 1. Some Famous Catalogs

- A "catalog" is a table of stellar parameters
- An "atlas" is a map of the sky
- Ptolemy's Almagest (1025 stars) from Hipparchos'
- BD, CD ~million stars (1800's)
- HD (225,000 stars) catalog ~1920 (spectral types)
- Palomar Sky Survey (photographic atlas)
- SAO catalog (1960's)
- Yale "Bright Star Catalog"
- Hubble Guide Star Catalogs (500 million stars!)
- USNO B1.0 (1,024,618,261stars, by my count ;-)
- Hipparcos and Tycho Catalogs
- Next: SIM (NASA) ~ ?? ; Gaia (ESA) ~2014
- Note: SIMBAD isn't really a catalog

## 2. Position




- Right Ascension and Declination. But how do you determine this from an image?
- Sounds easy enough. Just point your telescope and take a picture! Right?
- What (if anything) can we do with a catalog of stellar positions?

## Position: Practical Limitations

- There are >40,000 square degrees on the sky!
- 1 degree = 3600 arc-seconds. Want maximum magnification, but size of detector is limited, so you need LOTS of images.
- How do you determine RA & Dec from an image?
  - there's no "grid" painted on the sky!
  - limited pointing accuracy of telescope (and you don't want to do them one at a time if you can avoid it)
  - bootstrap; do brightest stars first
  - fundamental catalog FK6 has 4150 primary positions

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- Other practical problems to overcome:
  - all the stuff we talked about before
  - atmospheric "seeing" blurs position
  - detector itself can alter positions
- We need extremely accurate positions of lots of faint guide stars to control the Hubble Space Telescope, so we made heroic ground-based efforts (in the late 70's and early 80's) to get accurate positions
- Space-based surveys (e.g. Hipparcos) yield even more accurate positions of bright stars
- Radio VLBI yields the best positions (so accurate they need their own coordinate system)

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- It's not all bad:
  - Can centroid star image very precisely, but the less "seeing" and other distortions, the better
  - All stars in a single field ~ equally affected by dominant perturbations (aberration, refraction, precession, nutation)
  - Satellites can survey entire sky in 6 months
  - We now have large detector arrays with small pixels
  - Tremendous advances in computational power

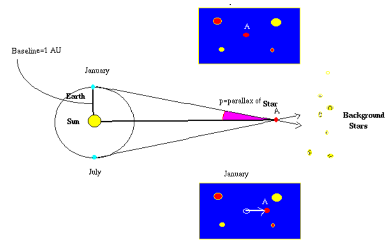
## Other Coordinate Systems

- Ecliptic (geocentric)
  - 0 latitude: ecliptic plane [β : -90° to +90°]
  - 0 longitude: toward Vernal Equinox [$0^h$, 0°]
  - [λ: 0° to 360° counterclockwise (eastward)]
  - heliocentric: need distance to object
- Galactic (geocentric)
  - 0 latitude: galactic plane [*b* : -90° to +90°]
  - 0 longitude: direction galactic center [$17^h45.7^m$ , -29°]
  - [*l*: 0° to 360° counterclockwise (eastward)]

# 3. Change in Position

- Once we've mastered measuring positions, we just keep doing it and build up a database of position v. time
- Nearby stars show more *parallax*, which is periodic
- Fast moving, nearby stars show more *proper motion*
  - space motion: proper motion + radial velocity
  - nearby stars, stars flung from clusters, pulsars blasted out by SN explosions, Pop II stars passing through the disk all have high proper motions
- Other things we can derive: binary star orbits, wobbles due to planets, cluster dynamics, etc.

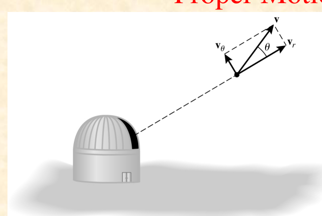
# Parallax




- notice that for small angles, tan p ~ p
- 1 parsec = distance to an object with a parallax of 1 arc-sec
- parallaxes are referenced to a baseline of 2 A.U., but you can observe with a smaller baseline
- nearest star has a parallax of less than 1 arc-sec (d > 1 pc)

- Before Hipparcos
  - Gliese (Wooley) catalog of all stars within 25 pc
  - "volume-limited" sample
  - mostly M stars
  - had some glaring errors
- Hipparcos
  - goal 100,000 stars to better than 0.002 arc-sec
  - achieved >100,000 at ~ 0.001 arc-sec
  - 0.001" -> 1000 pc
  - brighter stars out to this distance
  - fainter stars only to ~100 pc

# Proper Motion




- $\Delta\theta$ usually given as $\mu$ :

$\mu = \{(\mu_\alpha \cos\delta)^2 + (\mu_\delta)^2\}^{1/2}$

units: arc-sec/year

- Note that: $v_t = \mu d$
- Barnard's Star: 10.3 ″/y

- component of true velocity vector projected onto the "plane" of the sky
- transverse velocity not measured directly; only change of angular position with time (i.e. angular velocity)
- to get true space velocity, also need radial velocity and distance