Coordinates and Motions
ASTR 2110
Sarazin
Homework #1

Due Monday, September 4
Credit reduced to 50% if turned in late
For people without texts, last two problems and a useful table are on the back.

Scan of text

I put a scan of the Preface and Chapt. 1 on the class webpage, under Reading, and on the Resource/Reading section of Collab
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Astronomical Images vs. Earth Maps

- **Earth Maps**
  - Standard orientation is North = up, South = down, East = right, West = left
  - Looking *down* on Earth from space
Earth Maps
Astronomical Images vs. Earth Maps

• Earth Maps
  – Standard orientation is North = up, South = down, East = right, West = left
  – Looking down on Earth from space

• Astronomical Images
  – Standard orientation is North = up, South = down, East = left, West = right
  – Looking up at sky from Earth
Astronomical Images
Astronomical Images vs. Earth Maps

- **Earth Maps**
  - Standard orientation is North = up, South = down, East = right, West = left
  - Looking down on Earth from space

- **Astronomical Images**
  - Standard orientation is North = up, South = down, East = left, West = right
  - Looking up at sky from Earth
  - RA increases West to East
    - right to left
    - opposite of graphs, x increases to the right
Time

- Solar Time
  - “Day” = time for Sun to return to same position
- Sidereal Time (ST)
  - “Day” = time for stars to return to same position
  - Actual rotation period of Earth
  - ST = 0ʰ when Vernal Equinox is overhead
Solar day is longer than one Earth rotation period

Because the Earth is moving in its orbit, solar day is about 4 minutes longer than sidereal day. 4 minutes per day = one extra sidereal day per year.
Relation of ST and Solar Time

Ignore complications: Earth’s orbit not circular, time zones, daylight savings, . . .

One extra sidereal day / year

\[ 1 \text{ day / year} = \frac{(24 \text{ h / day}) \times (60 \text{ m / h})}{365.2425 \text{ days}} \approx 4 \text{ minutes / day} \]

At Vernal Equinox, Solar Time = 12\(^{h}\), ST = 0\(^{h}\)

Agree on Autumnal Equinox

\[ \text{ST} \approx \text{Solar Time} + (4 \text{ min/day}) \times (# \text{ of days after Sept. 21}) \]
HA = ST - RA
Example

Deneb: When is it overhead at midnight?

R.A. = 20^h 41^m

Overhead ⇒ H.A. = 0^h
HA = ST - RA
Example

Deneb: When is it overhead at midnight?

R.A. = 20^h 41^m
Overhead ⇒ H.A. = 0^h
H.A. = S.T. − R.A.
0^h = S.T. − 20^h 41^m ⇒ S.T. = 20^h 41^m
Midnight ⇒ Solar Time = 0^h

S.T. ≈ Solar Time + \left(\frac{4 \text{ min}}{\text{day}}\right)D

D = # of days after Sept. 21

D \approx \frac{20^h 41^m}{4\text{min/day}} = \frac{1241\text{min}}{4\text{min/day}} = 310 \text{ d} = (365 − 55)\text{d}

≈ August 1
Calendars

Complicated by fact that year is not even number of days

Gregorian Calendar:
   Uses leap years to account for this

What is time between two events?
   Complicated by unequal months, leap years, time zones, daylight savings, . . .

Julian Date:
   Gives time as number of days or fraction since noon (UT) on January 1, 4713 BC

Current Julian date $\approx 2457994$
Motions of the Planets
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Motion of the Planets

Key intellectual question for 2000 years
Led to development of physics, calculus, and modern science
Motion of the Planets

Each day, Sun, Moon, stars, planets rise and set (Earth’s rotation)

From night to night, stars keep same positions relative to one another (constellations fixed)

Sun, Moon move west to east among stars (orbits)

Most of the time, planets also move west to east among stars

Name “planet” means wanderer

Ancients knew of 5 planets: Mercury, Venus, Mars, Jupiter, Saturn
Retrograde Motion

Planets mainly move west to east among stars ("prograde" motion)
Occasionally, planets stop, and move backwards (east to west)

Retrograde Motion

About once a year (~4 months – 2 years)
Retrograde Motion
Mars in 2005
Retrograde Motion

loop

wiggle or z
Inferior and Superior Planets

Inferior Planets:
- Mercury, Venus
  - Always near Sun on Sky
  - Only seen at dawn and dusk
Mercury, Venus, and rising Sun
Inferior and Superior Planets

Inferior Planets:
- Mercury, Venus
- Always near Sun on Sky
- Only seen at dawn and dusk

Superior Planets
- Mars, Jupiter, Saturn (Uranus, Neptune)
- Can be near or far from Sun
- Can be seen any time of day
Saturn and full Moon
Conjunction, Opposition, Greatest Elongation
Inferior and Superior Planets

Inferior Planets:
- Mercury, Venus
- Always near Sun on Sky
- Only seen at dawn and dusk
- Retrograde motion when very close to Sun on sky
  (Every other time)

Superior Planets
- Mars, Jupiter, Saturn (Uranus, Neptune)
- Can be near or far from Sun
- Can be seen any time of day
- Retrograde motion when opposite Sun on sky
Early Greeks knew

- Earth, Moon, Sun are spheres
  - "Earth is round"

- Size of Earth, Moon, Sun
  - Earth is bigger than Moon, but Sun is much bigger than Earth
  - Sun is bigger than the planets

- Distance to Moon and Sun
  - Sun is much further away
  - Basic size of Solar System

All ~2500 year ago!
Structure of Solar System

What is center of Solar System?

• Aristarchus:
  – Sun is largest object in Solar System
  – Sun center of Solar System
  – Earth orbits around Sun

Correct explanation ~1600 years before Copernicus!
What is center of Solar System?

- Aristotle (also Plato, Eudoxus, others)
  - Earth is center of Solar System
  - Main argument was lack of observable parallax from Earth
Hipparchos, ca 150 BC

Isle of Rhodes
Parallax

If Earth travels around Sun, we view stars from different angles.
The stars will appear to shift back and forth every year.
Parallax
Parallax

If Earth travels around Sun, we view stars from different angles.
The stars will appear to shift back and forth every year.
Effect decreases with increasing distance.
Parallax

Hipparchus found NO measurable shift for stars each year

Aristarchus: Earth orbits around Sun, but stars are VERY far away, so parallax too small to measure
  Correct explanation, but required that stars be > 1000 times further away than planets (actually millions of times further)

Aristotle, Hipparchus: Earth is center of Solar System, Sun orbits Earth
  Stars could not be so far away
Hipparchus (160-127 BCE): Greatest of the Ancient Astronomers

- Invented magnitudes for star brightness
- Determined accurate sizes and distances for Sun and Moon
- Determined accurate length of year
- Very good orbit for Moon and Sun
- Refined eclipse predictions (within 1 hour)
- Compiled star catalogue
Hipparchus (cont.)

• Found Sun didn’t move at a constant speed
• Discovered precession of Earth’s axis
Ptolemy (100-170 AD)
Ptolemy (Cladius Ptolemaeus)

- Compiled previous measurements by Hipparchus and others (most original sources lost)
- Made improved measurements
- Systemized the constellations
- Measured distance to Moon to 3% using parallax
- Constructed first complete theory of motion of planets
- Compiled all in series of 13 volumes: “The Almagest” (from Al Magisti, Arabic for The Greatest). Main source of information about Greek astronomy
Ptolemy’s Theory of Planetary Motions

Starting points
1. Earth is center of Universe
   Geocentric theory
   No measurable parallax
   Hipparchus, Aristotle
2. Orbits are circles
   Most perfect plane figure
   Plato, Aristotle
Problem: No retrograde motion
No inferior and superior planets
Ptolemy’s Theory

1. Orbits are Epicycles
   circles within circles
   Sun and Moon do not have epicycles
Ptolemy: how epicycles produce retrograde motion
Ptolemy’s Theory

1. Orbits are Epicycles
   circles within circles
   Sun and Moon do not have epicycles

2. Earth is off set from center
   only one retrograde motion period per orbit
Ptolemy’s Epicycles
Ptolemy’s Theory

1. Orbits are Epicycles
   circles within circles
   Sun and Moon do not have epicycles
2. Earth is off set from center
   only one retrograde motion per orbit
3. Epicycles of inferior planets tied to Sun
   Mercury, Venus
   center of epicycle point to Sun
Inferior Planets

Venus
Earth
Sun
Ptolemy’s Geocentric Universe
Ptolemy Theory

• Negatives
  – **Wrong!**
  – Very complex, epicycles within epicycles, offsets, …
  – Required complex tables
  – Did not predict planetary motions correctly for long times, had to be “corrected” by adding more epicycles
  – Not a physical, scientific theory (descriptive)
Ptolemy Theory

• Positives
  – Survived for ~1300 years!
  – Worked OK, given enough effort
Time Flies When You’re Having Fun . . .

1300 year pass
- Ptolemy’s work spreads through Roman Empire
- Western Roman Empire falls
- “Dark Ages” in Europe, much of science lost
- Arab astronomers translate Almagest into Arabic, make new observations, update theory
- Muslim invaders in Europe (e.g., Spain) carry Greek books back to Europe, Almagest
Alphonsine Tables

Last hurrah of Ptolemy
- King Alphonse X, Toledo, Spain, ~1270 AD
- Collects astronomers, mainly from Moorish Spain
- Translate Almagest
- Updates Ptolemy’s theory, tables
- Very complex, ~130 epicycles

“If the Lord Almighty had consulted me before embarking on creation thus, I should have recommended something simpler.” - King Alphonse X
Funny, I didn’t see that coming

... 

Ptolemy’s geocentric universe becomes part of Catholic doctrine!!