

Astro Notes

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1 Class overview

Office hours tues and thurs 11-12 astro 237

ta office hours

wed 3:30-5:30 astro 2367

hw due wed

hw posted week before

- solar system
- stellar evo
- compact objects
- galaxy quasi darkmatter
- cosmic web
- big bang

course goals

- apply pys to universe
- understand foundations of modern astro, astrophys, and cosmology
- conceptual understanding of the uni based on physical principles

2 Early Astronomy

2.0.1 Greek

- Aristotle
 - earth is spherical
 - partial lunar eclipses
 - some stars visible from southern locations but not northern and vice versa

- had ideas regarding perfect geo influenced by Pythagoras and Plato
- Aristarchus (310-230 BC):
 - unprecedented heliocentric framework
 - trig distances earth-moon-sun system
 - angular diameters $\theta_{sun} \approx \theta_{moon} \therefore \frac{A}{C} = \frac{D_{moon}}{D_{moon}}$
 - diameters from lunar eclipses $D_{moon} < D_{earth}$
- Eratosthenes (176-195 BC):
 - Determined radius of spherical earth R_E
 - Sun at zenith at noon on summer solstice at Aswan
 - But further north in Alexandria, Egypt, the sun is south of the zenith by angle α
- Hipparchus (190-120 BC):
 - Discover precession of the equinoxes from examination of star catalogs over centuries
 - established the magnitude system
- Copernicus (1473-1543):
 - heliocentric
 - earth rotates
 - still assumed uniform circular celestial motion
 - inferior planets: orbit smaller than earths
 - superior planets: orbits larger than earths

2.1 Emergence of modern Astro

Inferior planets

- $B/C = \sin \theta_E$
- $B=C \sin \theta_E$
- C is AU
- Early astronomers didnt know C, so they could only infer ratios of B/C.
Ie. Orbital radii measured in AU

Superior Planets

- Measure time between opposition and eastern quadrature
- want angle θ between opp and east quad

- $\theta = (\omega_E - \omega_p)$ and $C/B = \cos\theta$
- measure τ and synodic period, calculate sidereal period and ω_p ; know ω_E and infer C/B

Galilean Revolution

- Galileo Galilei (1564 -1642)
 - improved and used a basic refracting telescoping
- def publication of early results 1610 "*starry messenger*"
 - Moon is cratered; not a perfect Sphere
 - milkyway is made out of stars
 - Jupiter has moons (or as he thought, stars)
 - measured phases of Venus

Phases of Venus

- direct confrontation with Ptolemaic geocentric models
- in Ptolemaic models you only see crescent phases

Tycho Brahe (1546-1601)

- Denmark, later Prague
- Given island by king Fredrick (and staff)
- made a accurate and vast database of celestial motion
- had a lead nose?
- Threw giant ragers
- supernova named after him

Johannes Kepler (1571–1630, Prague)

- 'Inherited' (maybe stole) Brahe's data
- also has a SN
- Kepler fit a new empirical model of heliocentric orbits, abandoning perfect circles
 - "*It was as if I awoke from sleep and saw a new light*" (Kepler, New astronomy)

Kepler's Laws

First law

- The planets travel on elliptical orbits with the sun at one focus
- Semimajor axis, half the major axis
- eccentricity: how elliptical (stretched) an orbit is - distance between foci divided by major axis.

second law

- A line drawn from the sun to a planet sweeps out equal areas in equal time intervals'
- perihelion: orbital point closet to the sun
- aphelion: furthest orbital point from the sun

third law

Def: *The square of the sidereal orbital periods of the planets are prop to the cubes of the Semimajor axis of their orbits*

$$p^2 = Ka^3$$

P = planets sidereal period
a= length of semimajor axis
K = constant

Consequences of heliocentric model

- retrograde motion of outer planets
- positions of outer and inner planets wrt sun
- annual parallax
- aberration of starlight
- Coriolis effect

Parallax

- annual parallax: change in the apparent position when seen from two diff locations due to earth revolving around the sun. First measured by Bessel in 1838

Aberration of starlight

- deflection of apparent stellar positions in the direction of the observers motion
- analog: running throw rain and getting wet in the front and not in the back
- detected (Picard, 1680); explained (Bradley, 1729)

- telescope is moving along orbital vector around the sun; translation along orbit cannot exceed transit time of light through telescope

Coriolis effect: evidence of earth rotation

- coriolis acceleration is perp to the direction of motion

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$$a_{cor}^{\vec{}} = s\vec{v} \times \vec{\omega}$$

- can be deduced from a pendulum
- and in hurricanes!

3 Orbital Mechanics I

3.1 Newtonian mechanics

Parametric vectors

Displacement $\vec{r}(t) = x(t)\hat{i}y(t)\hat{j} + z(t)\hat{k}$

distance: $r(t) = |\vec{r}(t)| = \sqrt{\vec{r} \cdot \vec{r}}$

3.2 Newtons laws

First law

- Isaac newton(1642-1727)
- an objects' velocity remains constant unless a net outside force acts upon it
- $\vec{v}(t) = \vec{v}_0 = const$

second law

- $\vec{F} = m\vec{a}(t)$
- $\vec{F} = \frac{d\vec{p}(t)}{dt}$
- $d\vec{v}/dt = \vec{f}/m$
- force changes velocity
- used a lot in computational math

third law

- forces come in pairs, equal in magnitude, and opposite in direction

Newtonian gravity

- a force, grav, exists between any two objects having mass m and M , proportional to the product of their masses mM and inversely proportional to the square of the separation distance r of their centers
- for coordinates centered on M :
- $\vec{F} = -G \frac{Mm}{|\vec{r}|^2} \hat{r}$

3.3 Displacement vector and polar coordinates

- cartesian coordinates are often written as (x,y,z) in a coordinate system centered on mass M
- Axis orientations are chosen so that the planet orbits in the x - y plane
- Displacement $\vec{r}(t) = x(t)\hat{i} + y(t)\hat{j}$

velocity vector and polar coordinates

- unit vectors in polar coordinates vary with $\theta(t)$

$$\frac{d\hat{r}(t)}{dt} = \frac{d\hat{r}(t)}{d\theta} \frac{d\theta(t)}{dt} = \frac{d\theta(t)}{dt} \hat{\theta}(t)$$

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$$\vec{v}(t) = v_r \hat{r} + v_t \hat{\theta}$$

- two velocity components in polar coords

3.4 Kepler laws: angular momentum

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3.5 keplers 2nd law = const, angular momentum

- $d\vec{L}/dt = 0$

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$$\vec{L} = \vec{R} \times \vec{p} = \vec{r} \times m\vec{v} = \text{const}$$

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$$\Rightarrow |\vec{v}| = L = mrv_1$$

3.6 Keplers Laws

3.6.1 Keplers First Law

- $\frac{d\vec{v}}{dt} = -\frac{GM}{r^2}\hat{r}$

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$$\frac{L}{GMm} \frac{d\vec{v}}{dt} = \frac{d\hat{\theta}}{dt}$$

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$$\frac{L}{GMm} \vec{v} = \hat{\theta} + e\hat{j}$$

- take dot product of both sides with unit vector $\hat{\theta}$, *using*

- $\hat{j} \cdot \hat{\theta} = \cos \theta$

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4 Glossary

Synodic period

- time elapsed between success conjunctions or oppositions
- this is the period we observe from earth, which is moving

Sidereal Period

- elapsed time of full orbit relative to the fixed stars (inertial ref frame)
- This is the one we will want to put in keplers laws