Please hand in problem sets

on desk

PUT YOUR **NAME** ON THE P.S. !

---

new problem set available later today

sections start Monday!

CB Starbucks hrs Monday 10 - 11:45

OBSERVATIONS

CLASSIFACATION

INTERPRETION

inner planets (small, rocky)

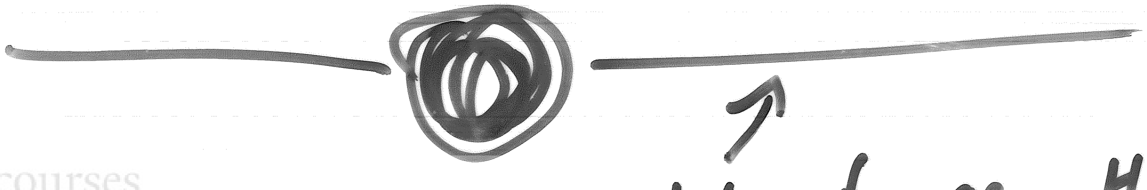
vs. outer planets (large, rocks + ice + gas)

circular, co-planar

Theory of Planetary Formation

---

planets form from a disk of material around sun



lots of gas H, He

some "ice" C, N, O

a little heavier elements Si, Fe

in disk things gradually
stick together

→ "planetesimals"

these stick together

→ one big object in
each region (distance
from star)

(makes a circular
co-planar orbit)

inner solar system:
ice, gas planetesimals
evaporates
planets are only rocky

outer solar system
ice is frozen
planets have rocks & ice

⇒ more massive
↳ hold onto gas as well

PREDICTION:

planetary systems should have inner rocky planets outer gas ~~tie~~ planets

dividing line is determined by temperature, hence by luminosity of star

Open Yale courses

OBSERVING EXOPLANETS

stars move too

$$V_* M_* = V_p M_p$$ (momentum)

$$D_* M_* = D_p M_p$$ (center of mass)

$$D_{TOT} = D_* + D_p$$
$$V_{TOT} = V_* + V_p$$
$$M_{TOT} = M_* + M_p$$

$$\text{maximum}(D_{TOT}) = a$$
(a ← semi-major axis)

<u>for nearly circular orbits</u>

$$D_{TOT} \sim a$$

$$\text{velocity} = \frac{\text{distance}}{\text{time}} = \frac{2\pi a}{P}$$

$$\boxed{V = \frac{2\pi a}{P}}$$

V_*, $a = D_*$

V_p, $a = D_p = D_{TOT}$

$V_{TOT} = V_p$

---

how fast is the earth?

$$V = \frac{2\pi a}{P} = \frac{2\pi \text{ A.U.}}{yr}$$

$$V = \frac{2\pi \; 1.5\times10^{11}}{3\times10^{7}} = 3\times10^{4} \text{ m/s}$$
$$= 30 \text{ km/s}$$

for Jupiter: $15 \text{ km/s} = 1.5\times10^{4} \text{ m/s}$

---

how fast is solar motion induced by Jupiter?

$$V_J M_J = V_\odot M_\odot$$

$$V_\odot = V_J \cdot \frac{M_J}{M_\odot} = 1.5\times10^{4} \; \frac{2\times10^{27}}{2\times10^{30}}$$

$= 1.5 \times 10^1 = 15$ m/sec.

DETECTABLE

---

solar motion due to Earth

$$M_E V_E = M_\odot V_\odot$$

$$V_\odot = \frac{V_E M_E}{M_\odot} = \frac{3 \times 10^4 \cdot 3 \times 10^{24}}{2 \times 10^{30}}$$

$$= \frac{10^1 \times 10^4 \times 10^{24}}{10^{30}}$$

$$= 10^{-1} = 1/10 \text{ m/s}$$

$$= 10 \text{ cm/s}$$

NOT DETECTABLE
(YET)

Doppler Shift

light is characterized by wavelength λ

ultra violet

$\lambda \sim 4 \times 10^{-7}$ m blue

5×10^{-7} m green

7×10^{-7} m red

longer Infra-red

⋮

radio

really short: X-rays & gamma-rays

"electro-magnetic radiation"

observed wavelength CHANGES depending on relative motion of source & observer motion toward: λ shorter

motion away: λ longer

"blueshift" "redshift"

$$\frac{\Delta\lambda}{\lambda_0} = \frac{V_R}{c}$$

radial velocity

+ve going away

-ve going toward

0 going sideways

rest wavelength

speed of light 3×10^8 m/s

~~chang~~ change in wavelength

$$\lambda_{obs} = \lambda_0 + \Delta\lambda$$

how fast to make a red light green

green 5×10^{-7} m

red 7×10^{-7} m

$$\Delta\lambda = (7-5) \times 10^{-7} = 2 \times 10^{-7}\,m$$

λ_0 red

λ_{obs} green

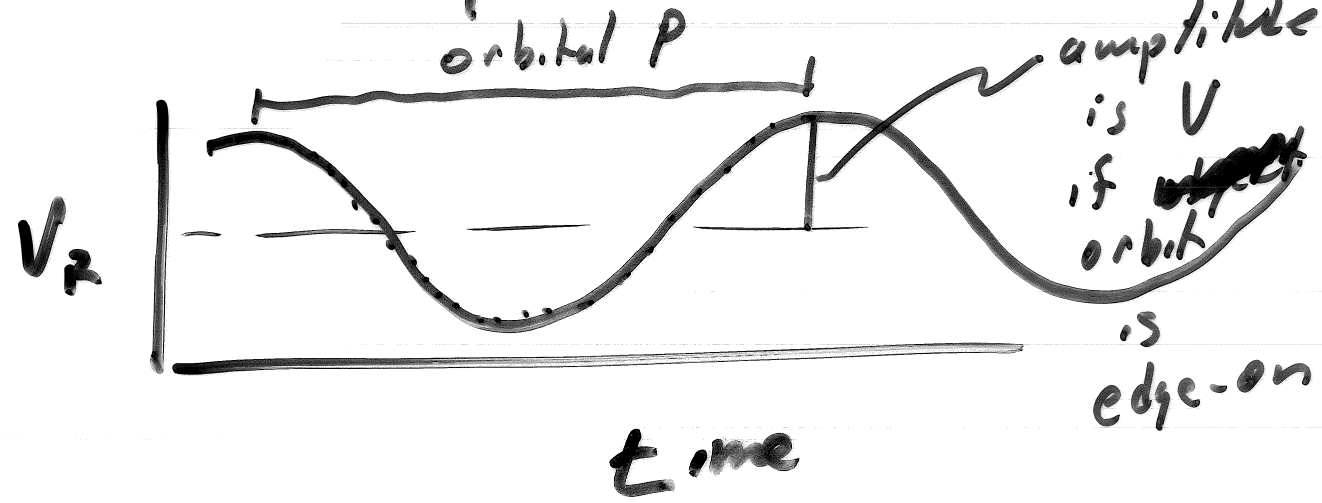
$$\lambda_{obs} = \lambda_0 + \Delta\lambda \quad \rightarrow -2 \times 10^{-7}\,m$$

$$\frac{\Delta\lambda}{\lambda_0} = \frac{-2 \times 10^{-7}}{5 \times 10^{-7}} = \frac{-2}{5} = \frac{V_R}{c}$$

$$\frac{-2}{5} c = V_R$$

Open Yale courses

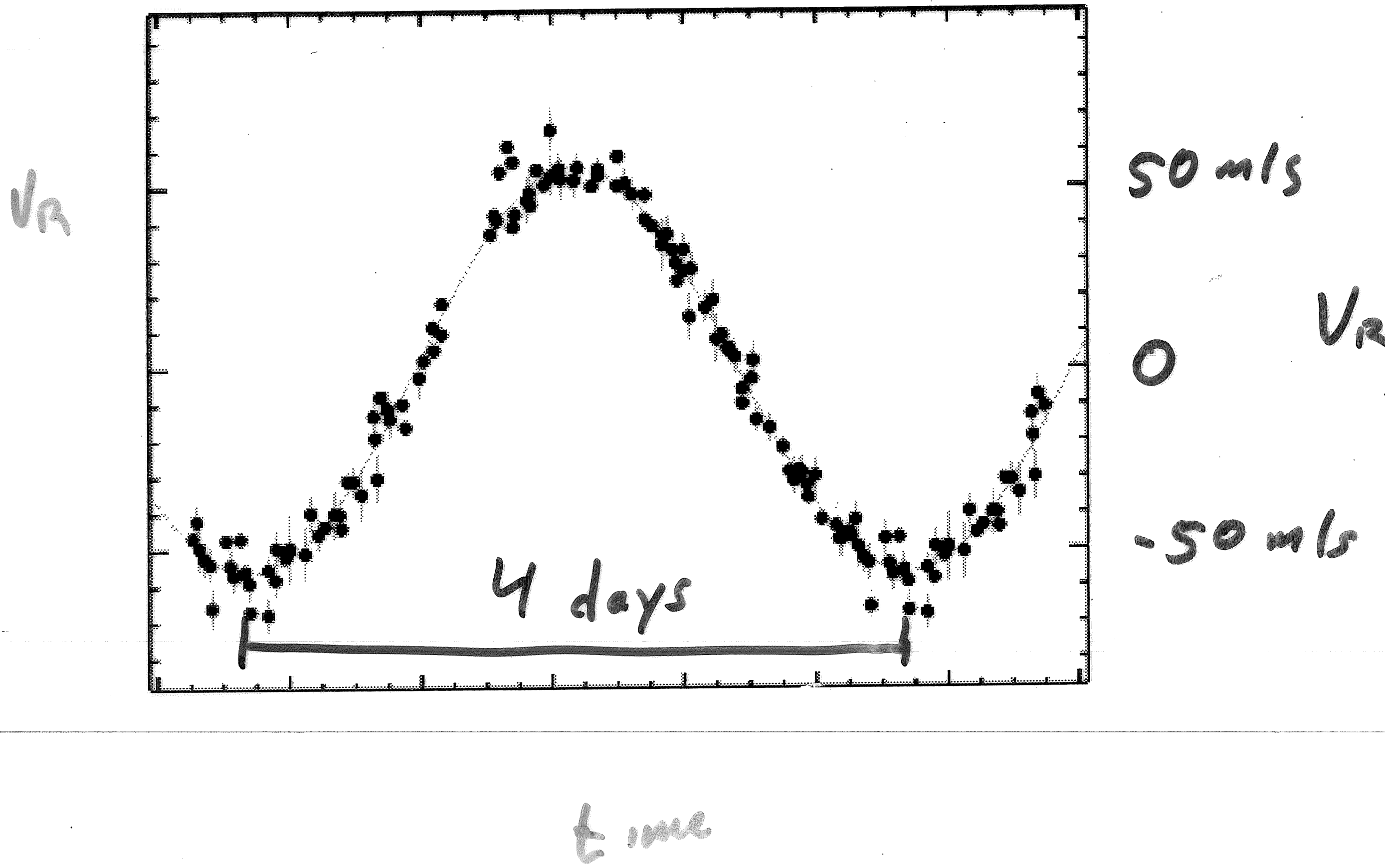
looking at star in orbit



for circular orbits

→ sine wave

51 Pegasus "solar analog"



Problem #1 x-axis

$P = 4$ days

Problem #2 y-axis

$V_* = 50$ m/s

what is semi-major axis of planet

$$P = \frac{4}{365.24} = \frac{1}{100} = 10^{-2} \text{ in years}$$

$$M = 1 M_\odot$$

$$a^3 = P^2 M^1 = (10^{-2})^2 = 10^{-4}$$

$$a = (100 \times 10^{-6})^{1/3} = 5 \times 10^{-2} \text{ AU}$$

$$= 5 \times 10^{-2} \; 1.5 \times 10^{11} \text{ m} = 7 \times 10^{9} \text{ m}$$

$$V = \frac{2\pi a}{P} = \frac{2 \times \pi \times 7 \times 10^9}{10^{-2} \times 3 \times 10^7}$$

$$= 15 \times \frac{10^9}{10^5} = 15 \times 10^4 = 1.5 \times 10^5$$

150 km/s

$\downarrow$

$V_{TOT} \sim V_P$

$$M_p V_p = M_* V_*$$

$$M_p \, 15 \times 10^4 = 2 \times 10^{30} \; 5 \times 10^1$$

$$M_p = 2 \times 10^{30} \times \frac{5 \times 10^{1}}{15 \times 10^{4}}$$

$$= \frac{1}{3} \times \underbrace{10^{-3} M_\odot}_{M_{Jupiter}}$$

$$= \frac{1}{3} M_{jupiter}$$

$>$ Mass of Saturn

---

very close planet
quite massive

IMPOSSIBLE

soon dozens more like it

"Hot Jupiters"