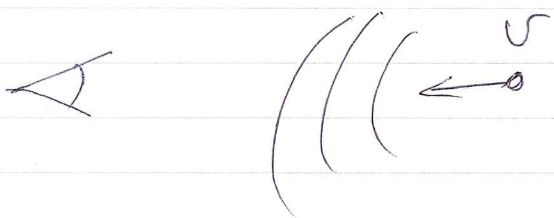
lecture 11

Exoplanets search

Note same methods can be used for binary stars search as well.
~~But for planets it~~

For planets search it is hard to do visual, since planets are dim (we see reflected light) and they are near superbright light source (star) which out shine them.

Doppler effect (1842)



towards observer

$$f_{obs} = f_{rest}\left(1 \pm \frac{v}{c}\right)$$

f_{rest} ↑ source — $-$ ↑ away from observer

for the $\oplus$: $f_{obs} > f_{source} \Rightarrow \lambda_{obs} < \lambda_{source}$
$\Longrightarrow$ blue shift

So if we have an orbit like

we can detect the motion ~~to~~ by observing Doppler effect

1st order

Bad angle motion in plane $\perp$ to line of sight no Doppler effect

So what kind of speeds we are talking:

recall
$$\begin{cases} v_a^2 = \dfrac{GM_T}{a}\,\dfrac{1-e}{1+e} & \text{apoapsis} \\[2ex] v_p^2 = \dfrac{GM_T}{a}\,\dfrac{1+e}{1-e} & \text{periapsis} \end{cases}$$

speed of vector connecting 2 bodies.

$$\vec{v}_1 = \vec{v}\,\frac{\mu}{m_1} \qquad \vec{v}_1 - \vec{v}_2 = \vec{v}$$

$$\vec{v}_2 = -\vec{v}\,\frac{\mu}{m_2} \qquad \Rightarrow$$

$$m_1 = m_{planet} \ll m_2 = m_{star}$$

$$\Rightarrow \mu \approx m_1$$

$$\Rightarrow \quad v_1 \approx v$$

$$v_2 = v_{star} = \frac{m_{planet}}{m_{star}}\,v$$

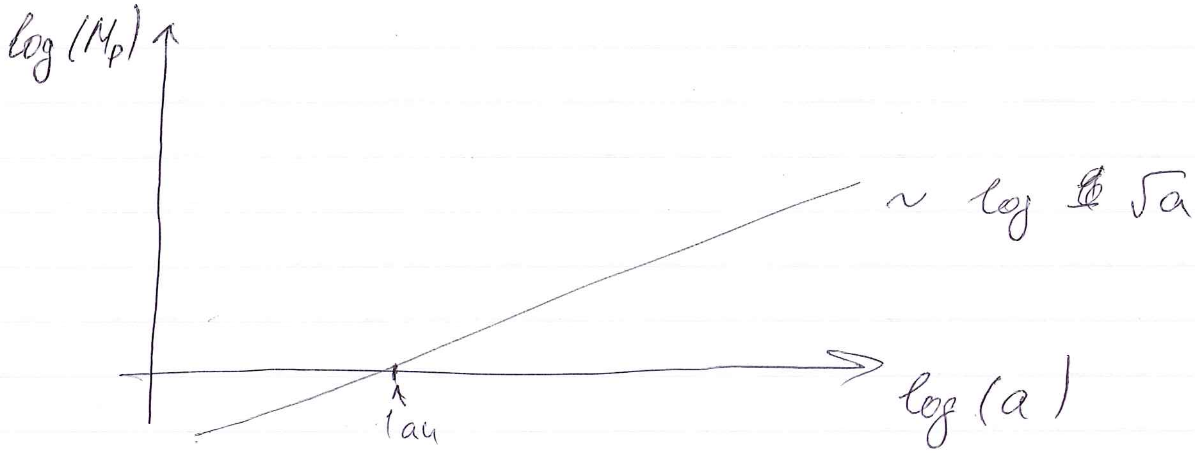
$$v_{p\,star} = \cancel{\frac{m_{planet}}{m_{star}}\,\frac{G\,M_{total}}{a}\,\frac{1+e}{1-e}} \quad \cancel{\approx M_{star}}$$

$$= \cancel{\frac{G\,M_{planet}}{a}\,\frac{1+e}{1-e}}$$

$$= \frac{m_p}{M_s}\sqrt{\frac{GM_T}{a}}\sqrt{\frac{1+e}{1-e}} = /\ M_T \approx M_s\ /$$

$$= m_p\sqrt{\frac{G}{a M_s}}\sqrt{\frac{1+e}{1-e}}$$

$$\Rightarrow \quad m_p = v_{p\,star} \sqrt{\frac{a\, m_s}{G}} \sqrt{\frac{1-e}{1+e}}$$



First discovery in 1989 by this method

for current sensitivity

$v \approx 60$ cm/s

the smallest mass we can detect at 1au around sun like star

$e = 0$

$$\boxed{m_p} = 0.6 \sqrt{\frac{1au \cdot 2 \cdot 10^{30} kg}{6.67 \cdot 10^{-11}}} =$$

$$= 0.6 \cdot \sqrt{\frac{1.5 \cdot 10^{11} \cdot 2 \cdot 10^{30}}{6.67 \cdot 10^{-11}}} \approx$$

$$\approx 0.6 \sqrt{\frac{3}{6.67} 10^{52}} = 4 \cdot 10^{25} \text{ kg}$$

$$= / M_E \approx 6 \cdot 10^{24} / = \boxed{6.7 \cdot M_E}$$

Note $M_{Jupiter} \approx 316 M_E$

So to detect Earth like planet we need to move speed sensitivity to $\frac{0.6 m/s}{6.7} \approx 9 \frac{cm}{s}$

See Astrocomb!

Problems with radial velocity method.

$v_{obs} = v_{star} \cdot \sin(i)$

so we always see this combo

So we always know mass ~~x~~ times unknown factor $\sin(i)$

'e' is also unknown.

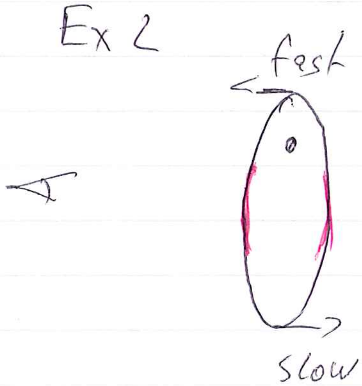
But if we can track $v_{obs}(t)$ we can learn something

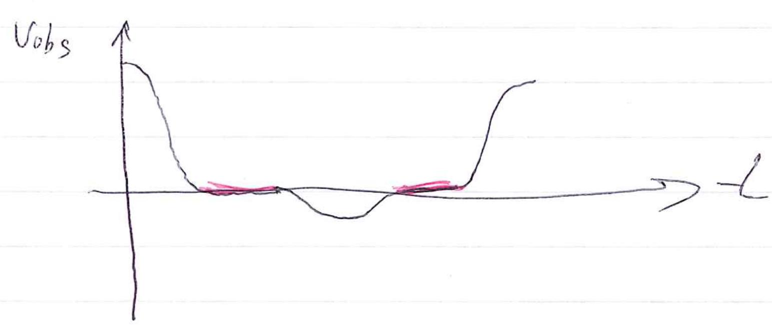
Ex 1 Circular orbit

$\theta = \omega t$

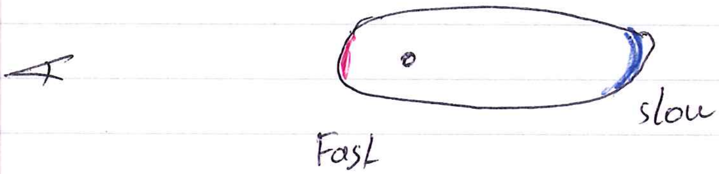
$v_{obs} = v \cdot \sin\theta = v \cdot \sin(\omega t)$

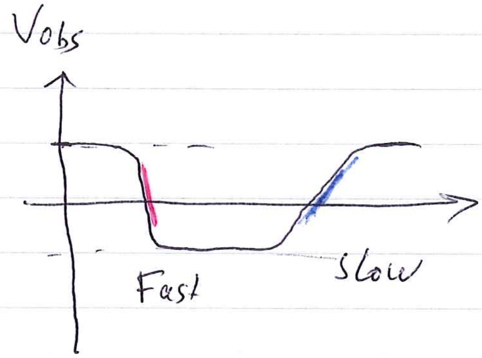
Ex 2



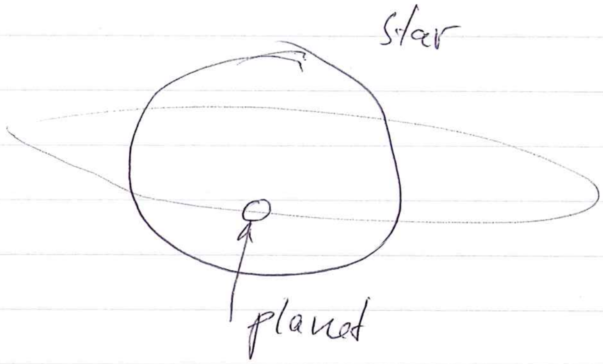


Ex 3

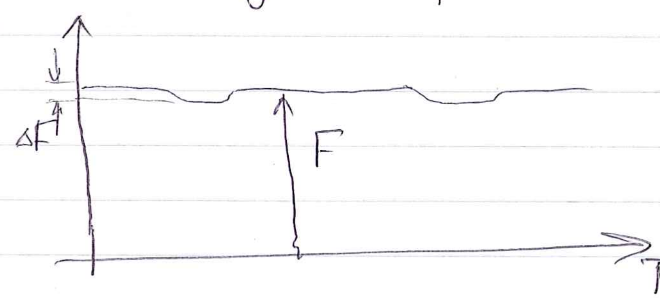




Other method: transits



So we should see periodic change in flux.



Let's estimate Earth transit across Sun disk.

$R_\odot = 7 \cdot 10^8$ m $\qquad A_\odot = \pi R_\odot^2$

$R_\oplus = 6.4 \cdot 10^6$ m $\qquad A_\oplus = \pi R_\oplus^2$

$$\frac{\Delta F}{F} = \frac{\pi R_\oplus^2}{\pi R_\odot^2} = \frac{(6.4 \cdot 10^6)^2}{(7 \cdot 10^8)^2} = 8 \cdot 10^{-5}$$

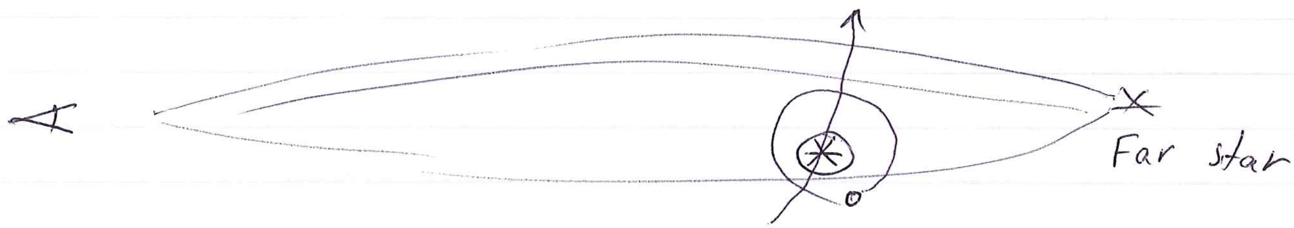
No way to do it on Earth due to atmospheric disturbances.

The method also favors giant planets search.

Direct observation
with telescopes.

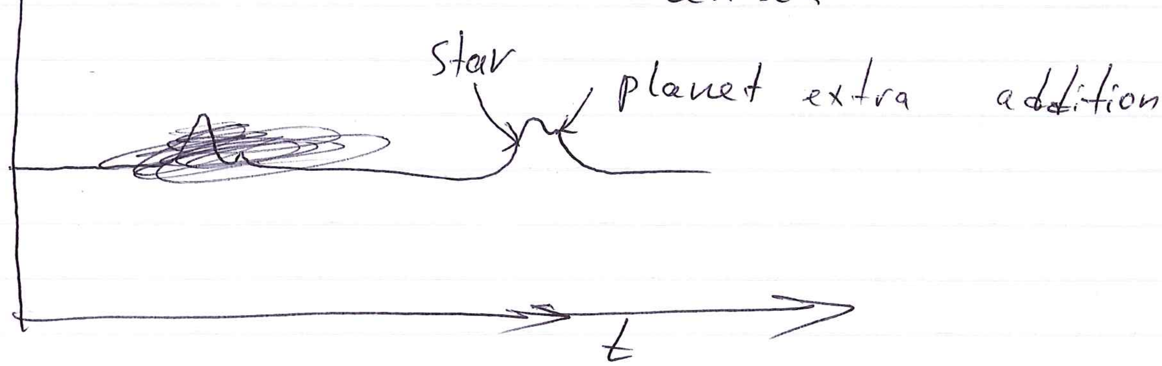
About 50
~~Only~~ star systems by 2015

There is Also gravitational lensing



Masses behave like lenses

Far star flux



Overall by Febrary 2015 about 1889 exoplanets are known.