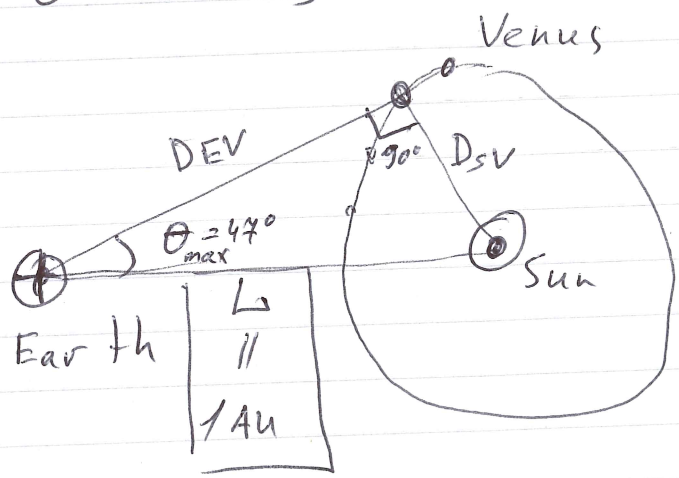
Lecture 2

* Stellarium demo to show planets motion

* Did Greeks knew distances to known planets?

Yes! for inner planets, but relative to $\oplus \leftrightarrow \odot$ distances

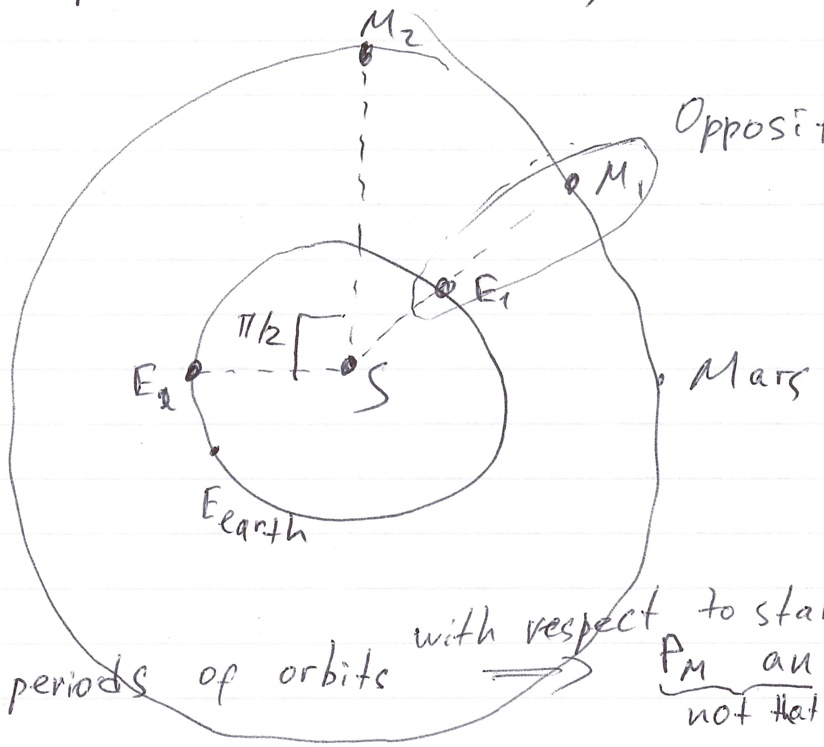
Idea:



$$\cancel{D_{EV}} \quad D_{SV} = L \cdot \sin\theta_{max} =$$

$$= 0.73 \text{ AU}$$

Outer planets are tricky but doable too!



*Measure periods of orbits $\xrightarrow{\text{with respect to stars}}$ $\underbrace{P_M}_{\text{not that easy}}$ and P_E easy

** Wait for opposition, then wait for anoter one, lets call this time S (synodic)

Time S is the same to make 2π arc with respect to another planet

~~Mot~~ Assuming circular orbits with respect to stars each planet makes arc $= \frac{2\pi}{P} \cdot t$

so $$\frac{2\pi}{P_E} S - \frac{2\pi}{P_M} S = 2\pi$$

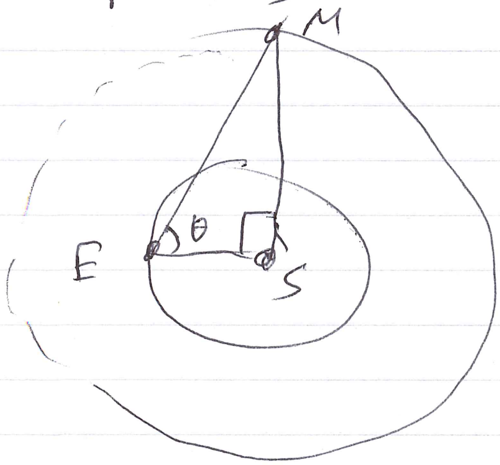
$$\Rightarrow \boxed{\frac{1}{S} = \frac{1}{P_E} - \frac{1}{P_M}}$$

flip sign if planets is an inner one

Mars is just an example true for any ~~oth~~ planet

Now we have P_M and P_E

So if we wait time $t_{\pi/2}$ nessesary to have arc difference of $\pi/2$ aften an opposition we will get $\pi/2$ angle betwen a planet → sun directions.



Measure θ and we will know distance to Mars

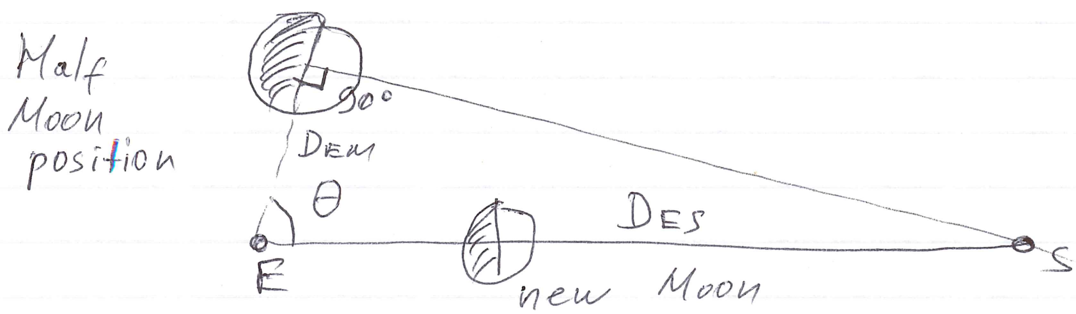
$$\frac{\pi}{2} = \frac{2\pi}{P_E} t_{\pi/2} - \frac{2\pi}{P_M} t_{\pi/2}$$

$$\frac{\pi}{2} = 2\pi \frac{1}{S} t_{\pi/2}$$

$$\Rightarrow \boxed{t_{\pi/2} = \frac{S}{4}}$$

$$\boxed{D_{SM} = 1au \cdot \tan\theta}$$

How to measure distance to the moon?
Idea from Aristarchus (310 – 230 BC)
who by the way suggested (Helio / sun)centric model



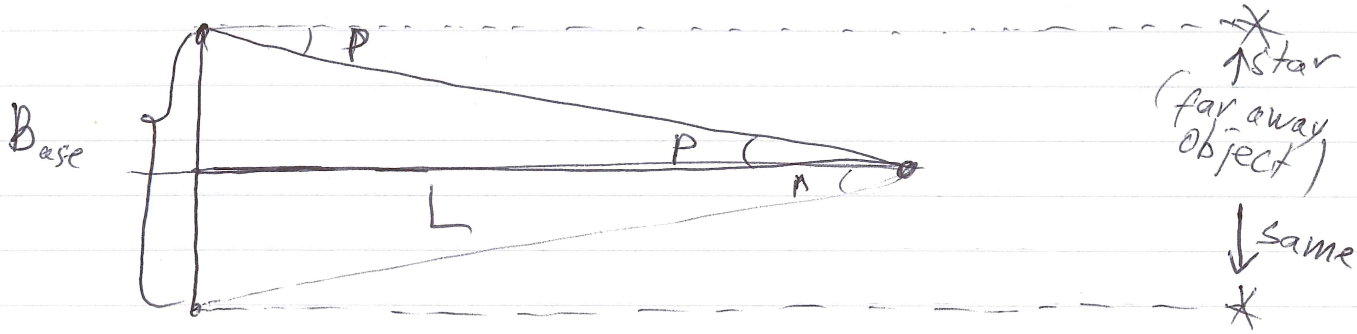
$$\frac{D_{EM}}{D_{ES}} = \cancel{D_E} \cos\theta$$

$$\Rightarrow \quad D_{EM} = \cos\theta \cdot \underline{1au}$$

~~Aristart~~
Aristarchus estimate of $\theta \simeq 87^\circ$
modern day values $= 89^\circ 50'$
$\cos\theta = 0.003$

There is still a problem:
<u>what is 1 au?</u>

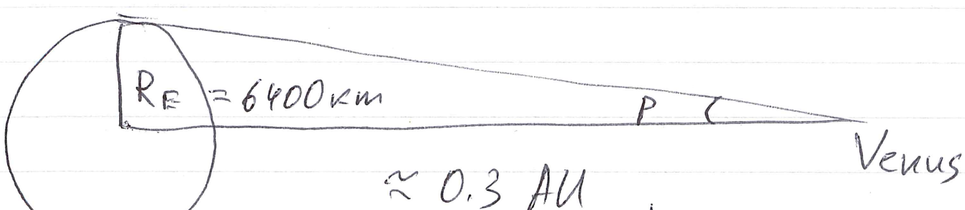
How can we measure distance to the far object



$$L = \frac{B}{2} \cdot \frac{1}{\tan p} = |p \ll 1| = \frac{B}{2p}$$

So why 1 au is hard?

the largest Base on Earth is its diameter



modern data

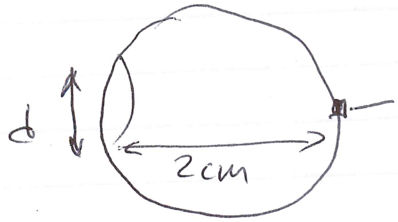
$$\boxed{1\ AU = 1.5 \cdot 10^{11}\ m}$$

$$P = \frac{6400\,km}{0.3 \cdot 1.5 \cdot 10^{11}} \approx = 1.4 \cdot 10^{-4}\ rad \cdot \frac{180^\circ}{\pi} \cdot \frac{60'}{1^\circ} =$$

$$= 0.49'$$ ↑ arc. minutes

1' is it small or big?

Eye



Physiological limit

'pixel' size of the rods and cones $\approx 2\,\mu m$

$$\theta_{min} = \frac{2\mu m}{2cm} = \frac{2\cdot 10^{-6}}{2\cdot 10^{-2}} \approx 10^{-4}\ rad$$

$$\approx 0.34'$$

Best possible condition

There is also diffraction limit (wave optics)

$$\theta_{min} = 1.22\frac{\lambda}{d} = 1.22\,\frac{500\,nm}{5\,mm} = 1.22\cdot\frac{500\cdot 10^{-9}}{5\cdot 10^{-3}} =$$

$$= 1.22\cdot 10^{-4} = 0.4'$$

Amasingly close to physiological limit

All of above is for the best possible conditions.

So when Tycho Brahe reported 4' resolution, it was impesively good.

But not enough to measure distance to Venus, even with $1 R_E$ base (unavailable at that time 1546-160