Johannes Kepler, 1571-1630 (compare Tycho 1546-1601, Galileo 1564-1642)

Kepler son of mercenary and innkeeper's daughter, attended school irregularly
Early training at monastery school at Maulbronn near Heidelberg, and mystical/spiritual disposition – search for god in perfection of mathematics

Combined both Platonist and Aristotelian sides
Platonist: search for beauty & spiritual fulfillment through mathematics & perfection
Aristotelian: study nature, observe carefully to obtain spiritual fulfillment

+ 1 new aspect! Kepler asks one question neither Plato nor Aristotle think of: *why* do planets move the way they do – what is the cause? Carl Sagan: "Before Kepler…science lacked the slightest notion of underlying physical law."

Early career, after Maulbronn, university at Tübingen under Mästlin, the man whose observations of the comet of 1577 had influenced Tycho, open to Copernicanism (note most of Germany is protestant at this time, so these ideas could be discussed openly). Kepler became Copernican also, but was obsessed with mathematics of celestial motions, felt structure of cosmos, e.g. distance between planets, could not be accident but must be part of god's design. After Tübingen he's sent to teach math at Graz (catholic Austria), and during class supposedly realizes that the radii of the planets orbits are very close to those of a set of nested platonic solids. He's excited because he thinks he has explained why there are 6 planets, and why they are spaced the way they are, all by geometry. (He also asks himself a 3rd question early on: why do the planets have the speeds they are observed to had; no answer yet.)

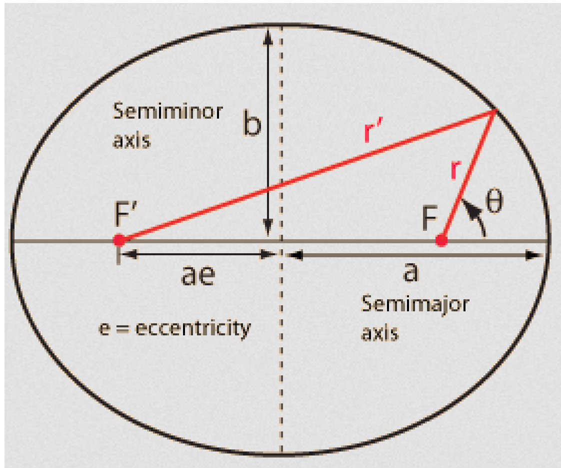
But upon closer inspection, the radii of the spheres enclosing the solids don't fit the orbits perfectly; Kepler suspects the data are flawed, and seeks out Tycho, the precision of whose data is legendary. Tycho invites him to come to Prague, convenient since Graz is in turmoil.

Tycho gives Kepler problem of the orbit of Mars – hardest to fit into a circular orbit in Tychonic scheme. Kepler begins thinking (as a Copernican), in 2 ways:

a) Accurate mathematical description of Mars' orbit
b) Physically, what caused Mars to move as it did? (!)

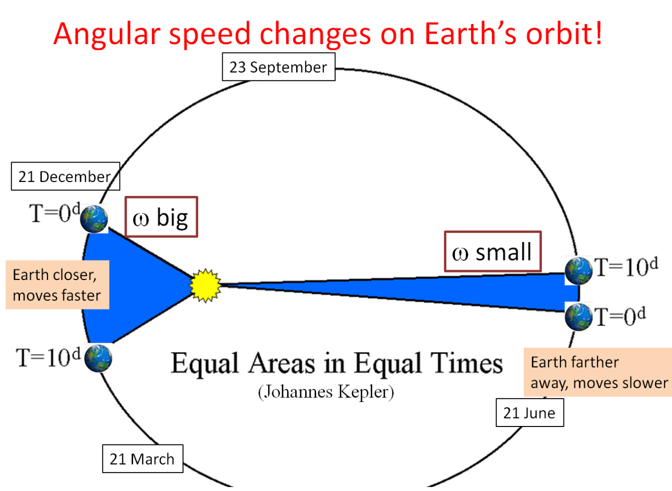
Mars problem could be solved by moving Sun away from center of circle, then it would sometimes be slower and further away. Didn't quite work with highly accurate data of Tycho, so he realized he needed a new orbit shape; eventually tried ellipse & it worked (after correcting an initial error)

Kepler's 1st law: planets move around the sun in elliptical orbits, with the sun at one focus.



Recent publication of *de Magnete* (Gilbert, 1600) led K to think about Sun exuding magnetic force that pushed planets around in their orbits. Force should get weaker farther away from Sun (like magnet), so planets further from sun on their elliptical orbits would be slower. He guessed "law of equal areas and equal times":

Kepler's 2nd law: as planet moves around its orbit, it sweeps out equal areas in equal times.



1st and 2nd laws published in 1609 in *The New Astronomy: based on causes, or celestial physics.* Gregory: "the marriage of physics and astronomy".

Jupiter and Saturn conjunction

1618 publishes *The Harmony of the World*, about harmonies in mathematics, music, astronomy, and nature. Note Kepler, who famously said that "God is geometry itself", never abandoned his picture of the nested platonic solids, despite the fact that he knew the construction could not explain the planets' spacing after all (nor, it turns out, their number). This happens often in science, that scientists, who are human, manage to live with and accommodate this kind of cognitive dissonance until someone else insists that the two things are blatantly contradictory.

Answer to question 3 about planetary velocities: the third law, in *The Harmony of the World*.

Kepler's 3rd Law. the period and average radius of the planets' orbits are related to each other by $T^2 \propto R^3$

Final question: *why* Kepler's 2nd law: equal areas in equal times? Note that when Earth closer to sun, it goes faster. Let's get quantitative: 147.1 million kilometers at perihelion (closest to sun), 152.1 million kilometers at aphelion (farthest away). Speeds are 109,033 km/h at perihelion, 105,448 km/h at aphelion. Now notice something: if distance gets bigger, speed gets smaller and vice versa. Just for fun, let's multiply distance R and speed v together. At aphelion, $Rv= (1.521 \times 10^8)(1.0545\times 10^5)=1.60389 \times 10^{13}$. At perihelion $(1.471\times 10^8)(1.0903\times 10^5)=1.60383 \times 10^{13}$. Whoa! They are the same. The product of the speed and the distance *does not change* as the Earth goes around the sun. This is a special case of something called *angular momentum conservation* in physics,

$$m\, v\, R = \text{const.}$$

and it's the same thing as what happens to a figure skater when he/she pulls in his or her arms in a spin – he/she speeds up! In our case here the mass m of the Earth didn't change between perihelion and aphelion, so we left it out.

Definitions: $p=mv$ the *momentum* of a body

$L = m\, v\, R = p\, R$ the *angular momentum* of a body

Q: have we fully explained *why* Kepler's 2nd law works? Not really, just given a clue to what might be going on.