

MASS OF A BLACK HOLE:

(A bit of history and simple arithmetic!)



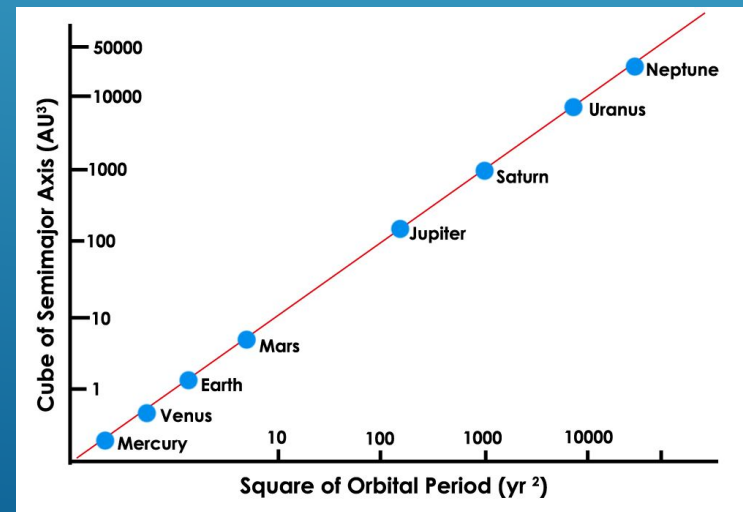
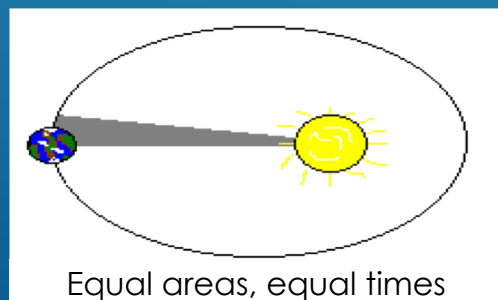
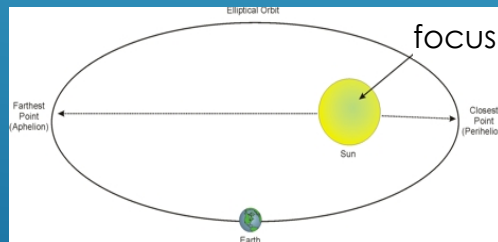
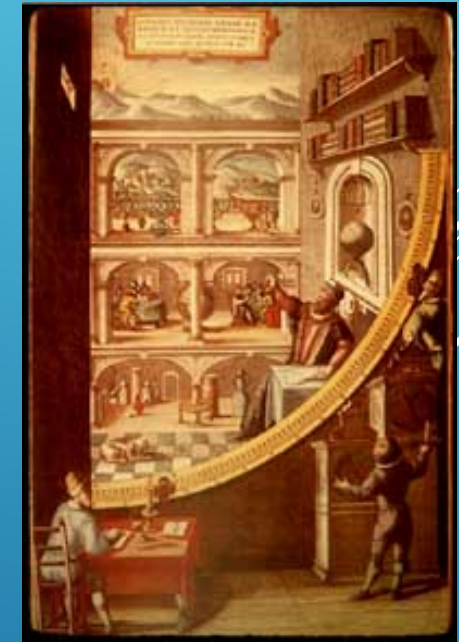
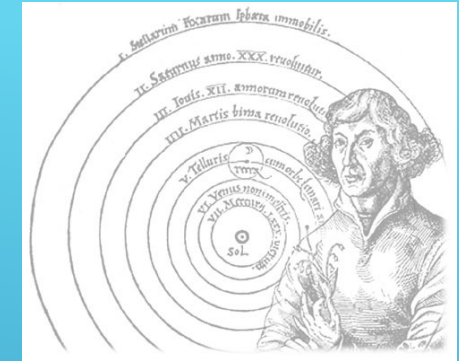
SAGITTARIUS A*

Mick de Pomerai

- **Myth: Nicolaus Copernicus** (1473 -1543), Polish monk, simply “thought up” a heliocentric model of the Solar System...

- **Mania:** ideas pursued by **Tycho Brahe** (1546-1601), Danish nobleman, measured positions of planets & stars to ± 2 minutes of arc at Uraniborg - huge tables of data but ?? how to interpret...

- **Math: Johannes Kepler** (1571-1630), German mathematician, Copernican enthusiast, analysed Brahe’s data => published *Harmonices Mundi* 1618, introducing model of *elliptical* orbits.



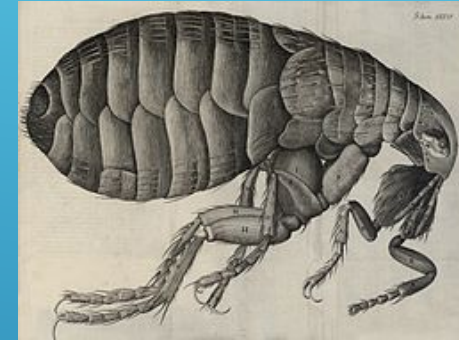
$$T^2 \propto r^3$$

- **Mad Genius?:** 1687 - **Isaac Newton** (1642-1726): publishes Theory of Gravitation as part of the *Principia* (Fluxions, blah blah)...



- $F = - \frac{GMm}{r^2}$ (applies to ellipses where r is *semi-major axis*)

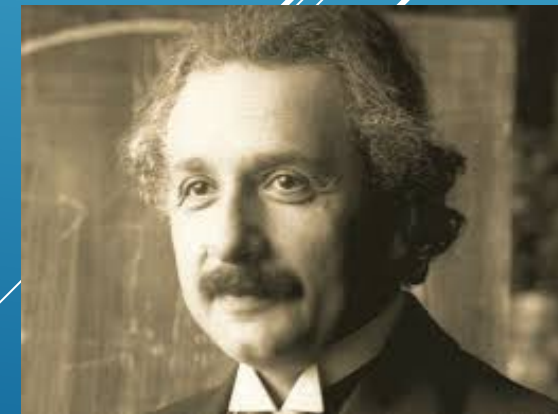
- **Misrepresented:** **Robert Hooke's** work on circular motion tells us: $F = - m\omega^2 r$ where $\omega = 2\pi/T$ and T is the orbital period. Combines to give:



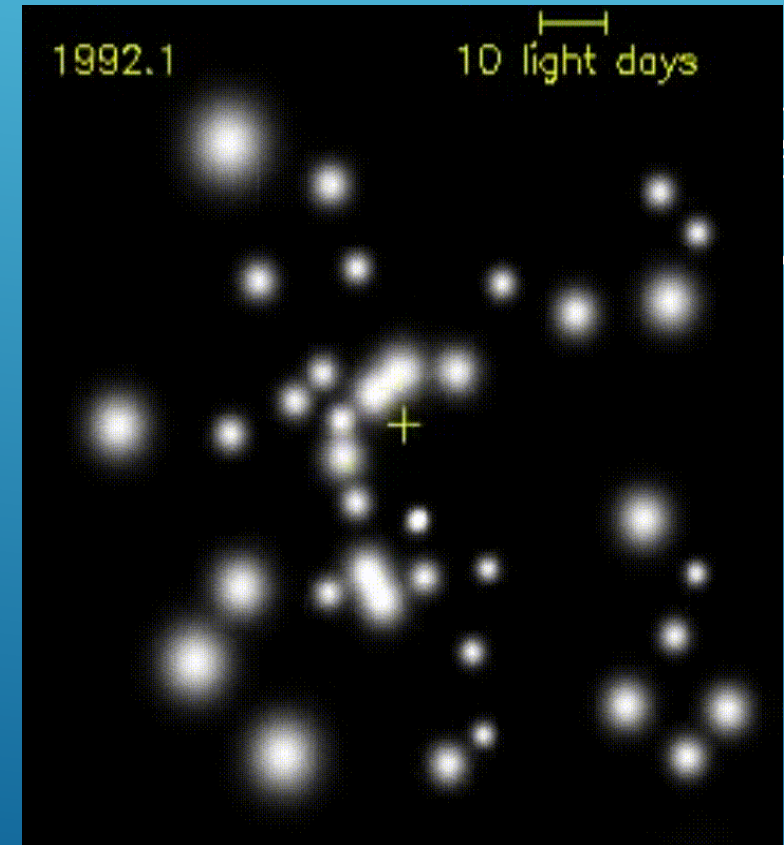
- ▶ $r^3 = \frac{GMT^2}{4\pi^2}$ i.e. Kepler's 3rd Law with bells & whistles!

Fast forward to the 20th Century...

- **Masterful:** 1915 – **Albert Einstein** (1879 -1955): General Theory of Relativity, which predicts **Black Holes**... objects so dense that their escape velocity exceeds the speed of light, c .

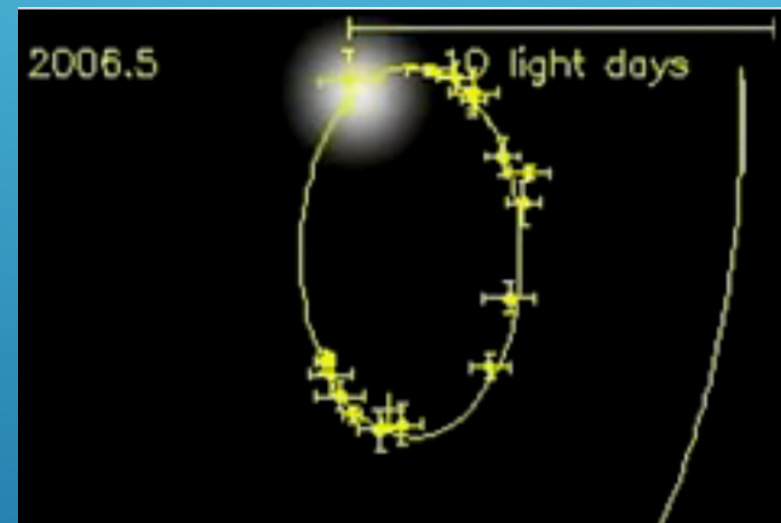
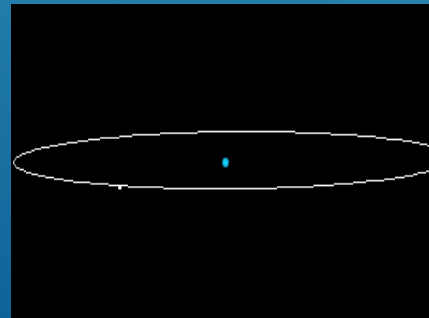


- 1930: discovery that much radio “static” originates from an object in constellation Sagittarius, later termed A*.
- Problem: Sagittarius A* appears to be near centre of our galaxy, optically obscured by interstellar gas & dust
- 1990s to early 2000s – *infra-red* observations with the Keck telescope, Hawaii, & the VLT at Paranal, Chile.
- Revealed orbits of stars near the galactic centre – but *no object seen at the common focus of their ellipses...*
- Explanation? **A supermassive Black Hole** (producing radio “static” as material spirals into it).
- But **how massive?** You work it out (data on next slide)



- Estimate orbital period, T , in years (decimal) and semi-major axis, r , in light-days.
- Convert T into seconds ($1 \text{ y} = 3.1 \times 10^7 \text{ s}$) and r into metres ($c = 3.0 \times 10^8 \text{ ms}^{-1}$ and $1 \text{ day} = 8.6 \times 10^4 \text{ s}$)
- Use $r^3 = GMT^2 / 4\pi^2$ to find M ($G = 6.7 \times 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2}$).
- To give a sensible answer, we can convert M (in kg) to something more meaningful – say, a multiple of our Sun’s mass ($2.0 \times 10^{30} \text{ kg}$)...
- As a physicist(!) I have to consider likely *sources of error* – can you see an obvious one, and figure out how its magnitude might be estimated?

(click for help)



Have Fun!