Are We Alone in the Universe?

Professor John Lattanzio
Monash Centre for Astrophysics
Monash University
Australia

Thanks!

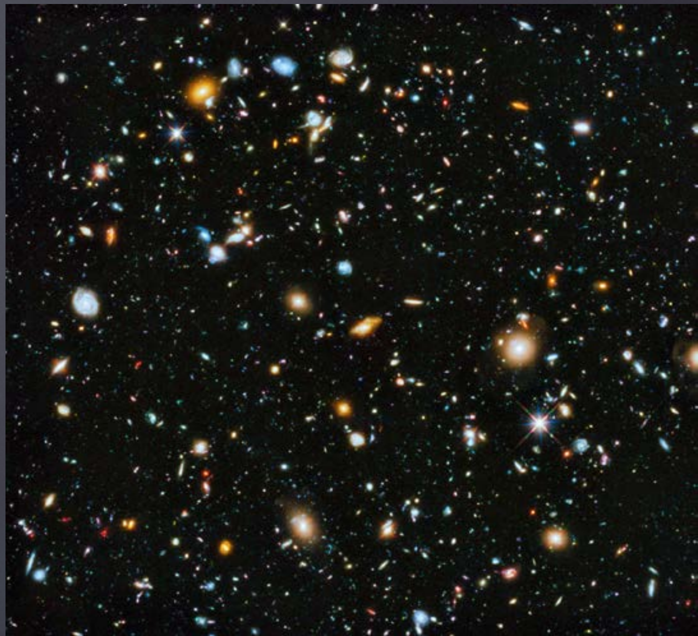
1) Honors Carolina
2) Morehead-Cain Scholars Program
3) UNC Department of Physics and Astronomy

for inviting me to serve as the 2018 Morehead-Cain Alumni Visiting Distinguished Honors Professor

I: LIFE ON EARTH: COULD IT HAPPEN ELSEWHERE?

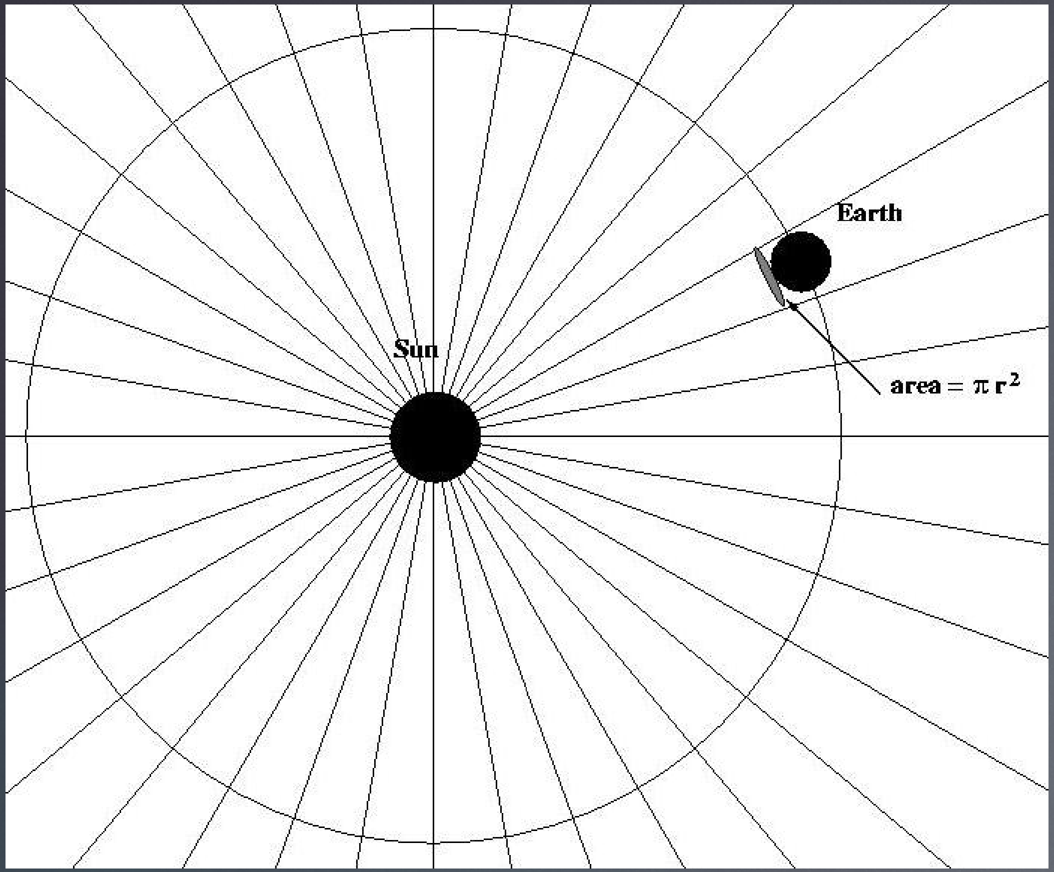
II: MAKING ALIENS

III: TALKING WITH ALIENS



Kardashev Civilization Types

- **Type I:**
  - Can utilize all energy available on its home planet
  - Approximate this as all the solar energy arriving on the Earth



Earth's radius = r_E = 6400 km
Earth's orbit = d_E =1.5 x 10^{11} m
Solar energy output = L = 4 x 10^{26} W
So Earth receives Power = ?

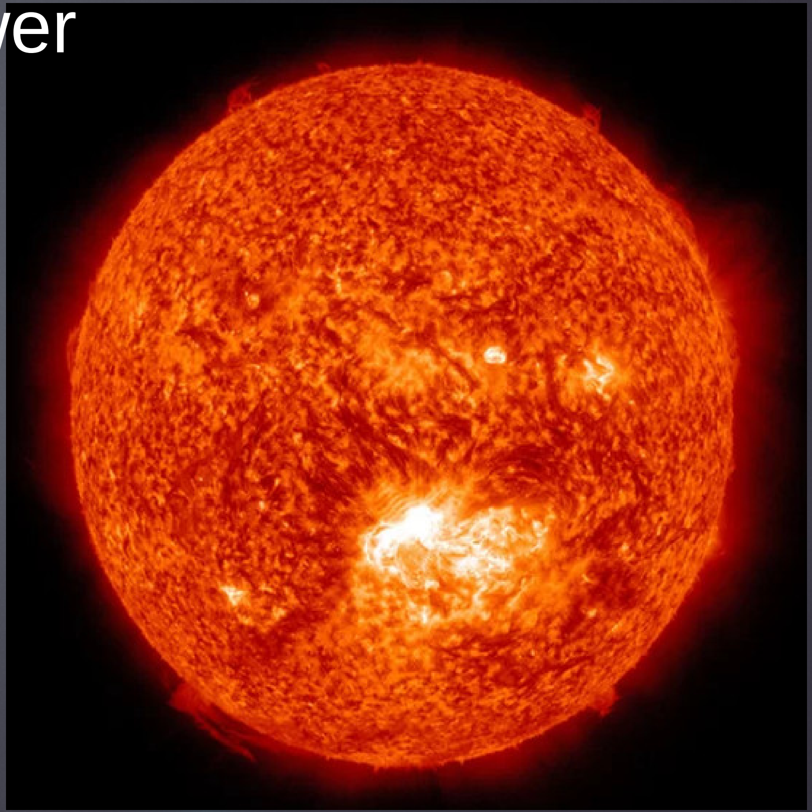
$$P = L\left(\frac{\pi r_E^2}{4\pi d_E^2}\right)$$

Hence P ≃ 2 x 10^{17} W

Hence we take the power usage of a Type I Civilization as about 10^{17}W.
Note that it depends on the central star. So an approximate value is OK for now.

Kardashev Civilization Types

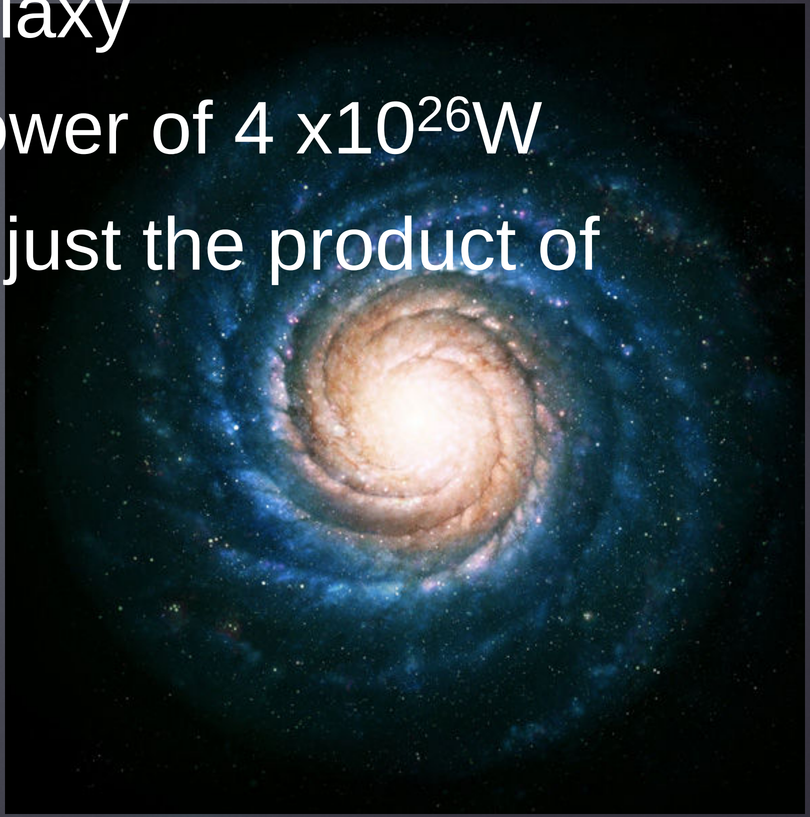
- **Type II:**
  - Can utilize all energy available from its home star
  - If we take the Sun as typical then the power of a Type II Civilization is about 10^{26}W



Kardashev Civilization Types

- **Type III:**
  - Can utilize all energy available from its home galaxy
  - So if there are about 3 $x10^{11}$ stars per Galaxy
  - And each is like the Sun and emitting a power of 4 $x10^{26}$W

…then the power of a Type III Civilization is just the product of these two or about 10^{38}W



Kardashev Civilization Types

- **Type I:**
  - Can utilize all energy available on its home planet: $P = 10^{17}$ W
- **Type II:**
  - Can utilize all energy available from its home star: $P = 10^{26}$ W
- **Type III:**
  - Can utilize all energy available form home Galaxy: $P = 10^{38}$ W

Kardashev Civilization Types

- Carl Sagan noticed that there are about 10 orders of magnitude between each of these levels
- So he devised a formula that links them…
- He approximated the values of the three civilization types as 10^{16}, 10^{26} and 10^{36} W
- So the formula that fits them together is:

$$K = \frac{\log_{10} P - 6}{10}$$

- Where K is the Karadashev Civilization number

Kardashev Civilization Types

- **We currently uses about P = 10^{13} W on the Earth**
- **So our K value is**

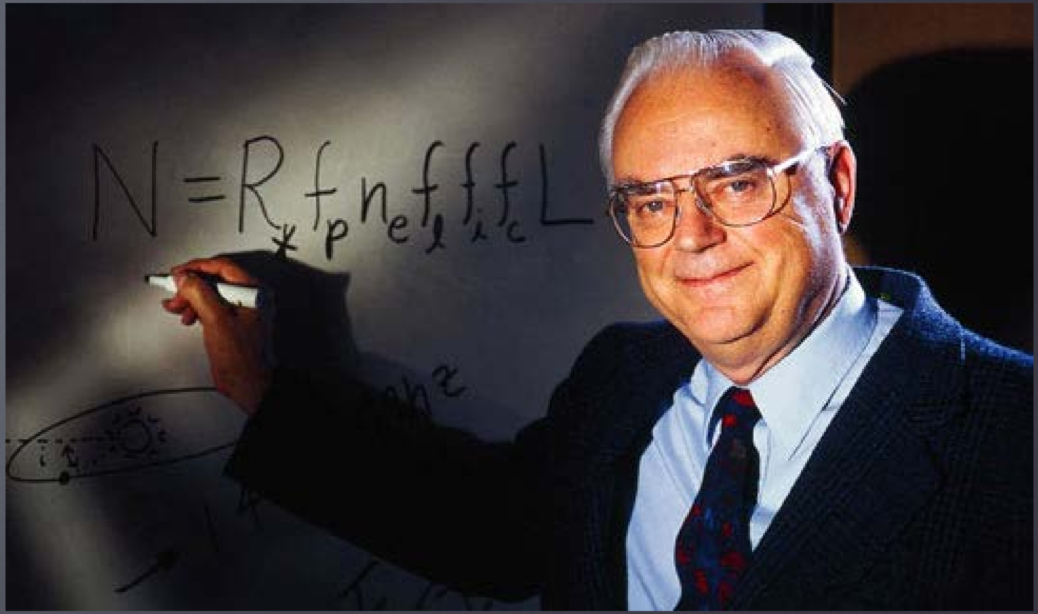
$$K = \frac{\log_{10} 10^{13} - 6}{10} = 0.7$$

How Many Civilizations are there?

The Drake Equation

- Let's see how many communicating civilizations are likely to be out there…
- Famously done by Frank Drake in 1961

- Not reliable…
- But informative
- Can guide our thinking
- Be careful not to be constrained by it!



Let N = number of communicating civilizations in the galaxy

N = number of suitable planets in the galaxy
× chance of a communicating civilization arising on a suitable planet

$N = N_{astro} \times f_{bio}$

N_{astro} = number of suitable planets in the galaxy
= number of stars in the galaxy
× fraction that are suitable for life (Sun-like)
× number of planets per suitable star
× fraction of suitable (Earth-like) planets per system
$= N_{\star} \times f_s \times N_p \times f_e$

f_{bio} = chance of a communicating civilization arising on a suitable planet
= chance of life developing
x chance it becomes intelligent
x chance it develops a communication technology
$= f_L \times f_i \times f_c$

Let N = number of communicating civilizations in the galaxy

N = number of suitable planets in the galaxy

× chance of a communicating civilization arising on a suitable planet

$$N = N_{astro} \times f_{bio}$$

$$= (N_{\star} \times f_s \times N_p \times f_e) \times (f_L \times f_i \times f_c)$$

But: this is the total number.
We want to know how many are around at any given time (e.g. now)

If they survive a year before being wiped out, then there is no chance of us communicating with them!
If they live for the life of the galaxy then we can communicate with them at any time…

So we need to include the lifetime of a communicating civilization.

Let N = number of communicating civilizations in the galaxy right now

N = number of communicating civilization in the galaxy × survival fraction

N = number of communicating civilization in the galaxy × $\frac{\text{lifetime of civilization}}{\text{age of galaxy}}$

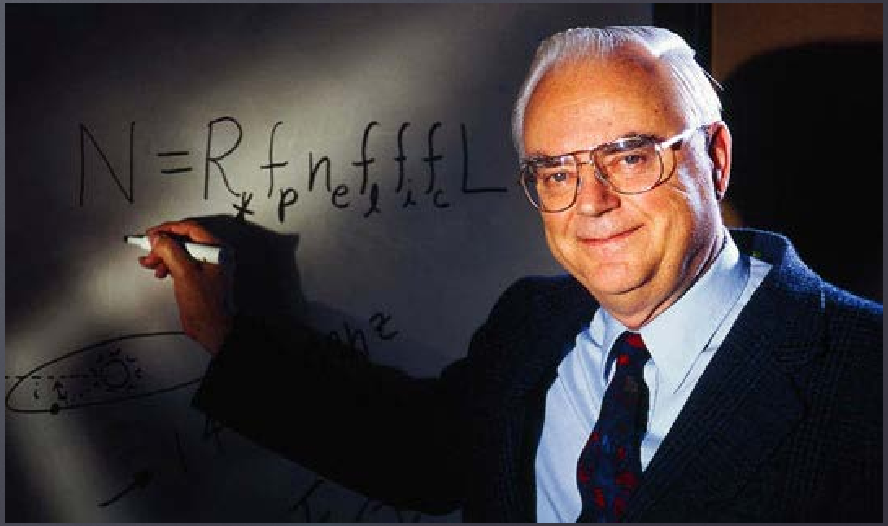
$N = N_{astro} \times f_{bio}$

$= (N_\star \times f_s \times N_p \times f_e) \times (f_L \times f_i \times f_c) \times L/L_{MW}$

Note that $N_\star / L_{MW}$ = rate of star formation = $R_\star$

So we often see the equation written with $R_\star$...

There are many different, equivalent forms...



Estimates

$$N = (N_\star \times f_s \times N_p \times f_e) \times (f_L \times f_i \times f_c) \times L_c/L_{MW}$$

Term	Meaning	Optimistic Value	Pessimistic Value	"Best" Value
$N_\star$	Number of stars in the Galaxy	3×10^{11}	3×10^{11}	3×10^{11}
f_s	Fraction of suitable (Sun-like) stars	0.2	0.2	0.2
N_p	Number of planets per suitable star	10	3	5
f_e	Fraction of suitable (Earth-like) planets	0.3	0.01	0.2
f_L	Fraction where life begin	1	1×10^{-6}	0.5
f_i	Fraction that develop intelligence	1	1×10^{-6}	0.5
f_c	Fraction that develop communicating technology	1	0.001	0.5
L	Lifetime of civilization	10^{10} y	100 y	10^5 y
L_{MW}	Age of Milky Way	10^{10} y	10^{10} y	10^{10} y
N	Number of communication civilizations in the Galaxy now	$\mathbf{1.8 \times 10^{11} \approx 10^{11}}$ **≈ L (years)**	$\mathbf{1.8 \times 10^{-14} \approx 0}$ **≈ L (years)**	$\mathbf{7.5 \times 10^4}$ **≈ L (years)**

$$N \approx L$$

..when L is measured in years

Frank Drake's Number Plate...

L measured in years….

BUT: note the huge uncertainties!

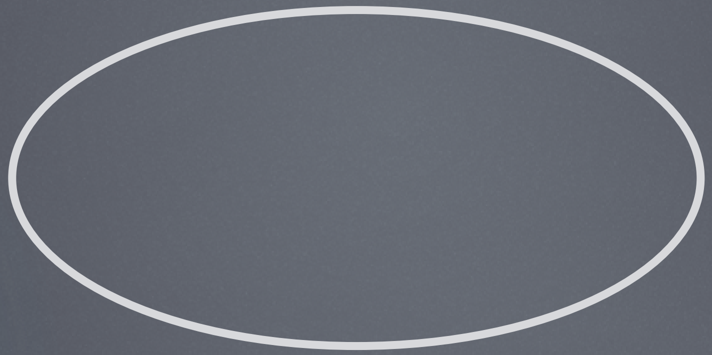
Gravity

- We are all familiar with gravity
- Gravitational force between two objects of masses M_1 and M_2 separated by a distance r is:

$$F = \frac{G M_1 M_2}{r^2}$$

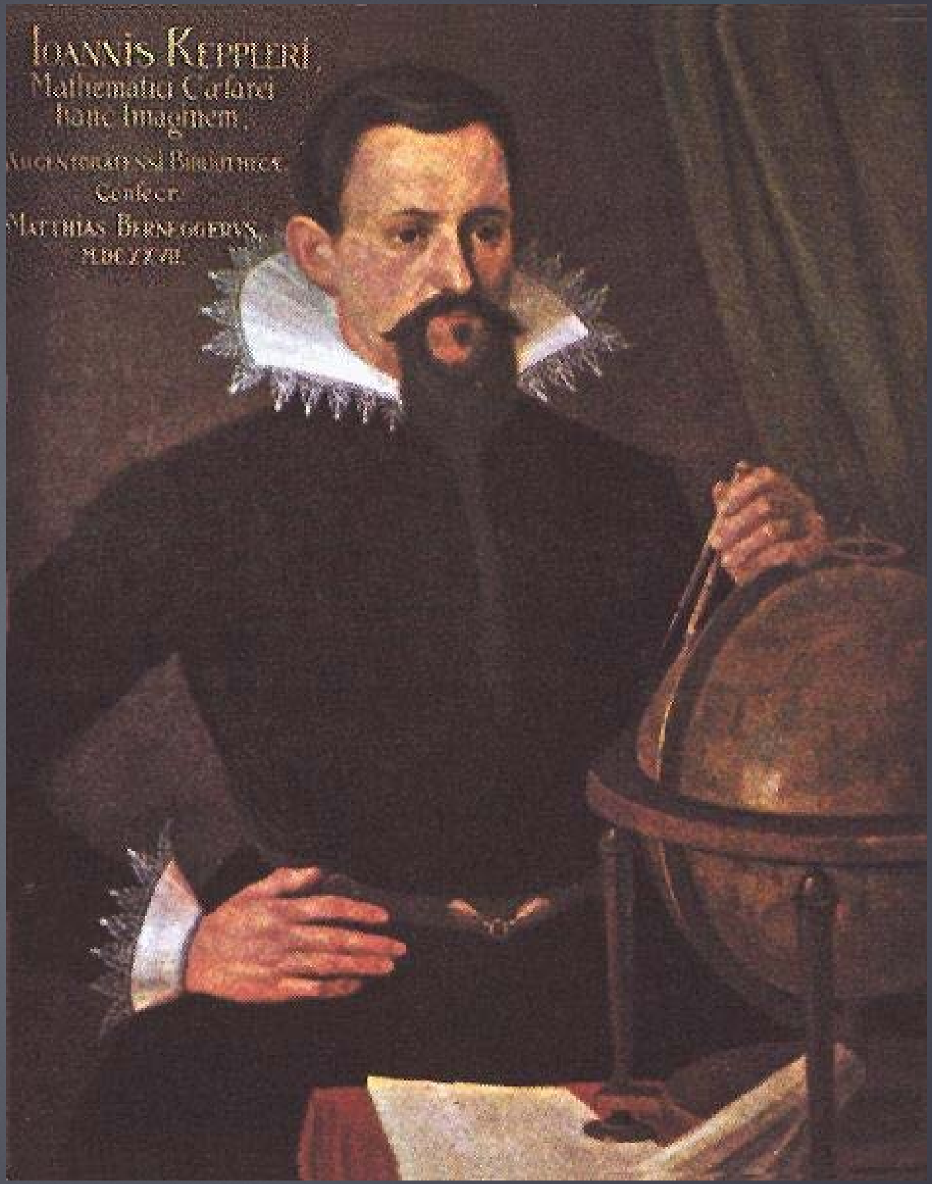
Orbits

- Copernican revolution: Sun at centre of solar system
- Kepler observed carefully and found that the orbits were ***ellipses*** and not circles



Kepler’s Laws

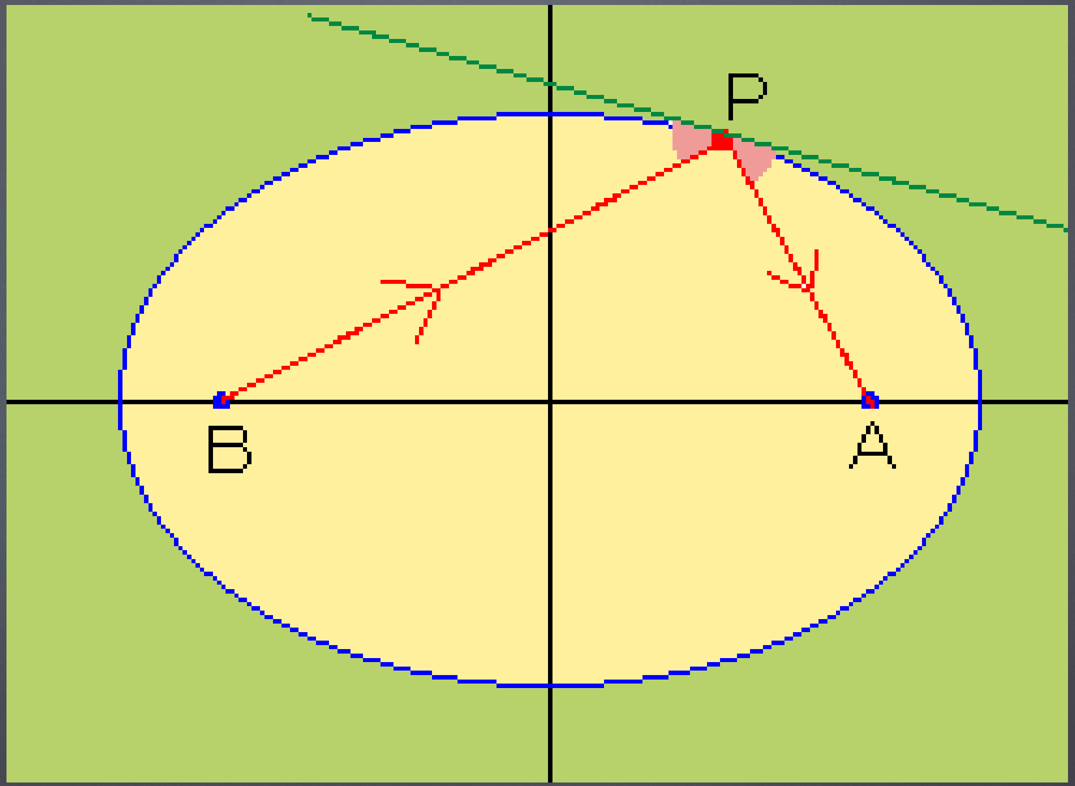
- Kepler studied the solar system
- Plotted orbits very accurately
- This led to the formulation of three laws



Johannes Kepler: 1571-1630

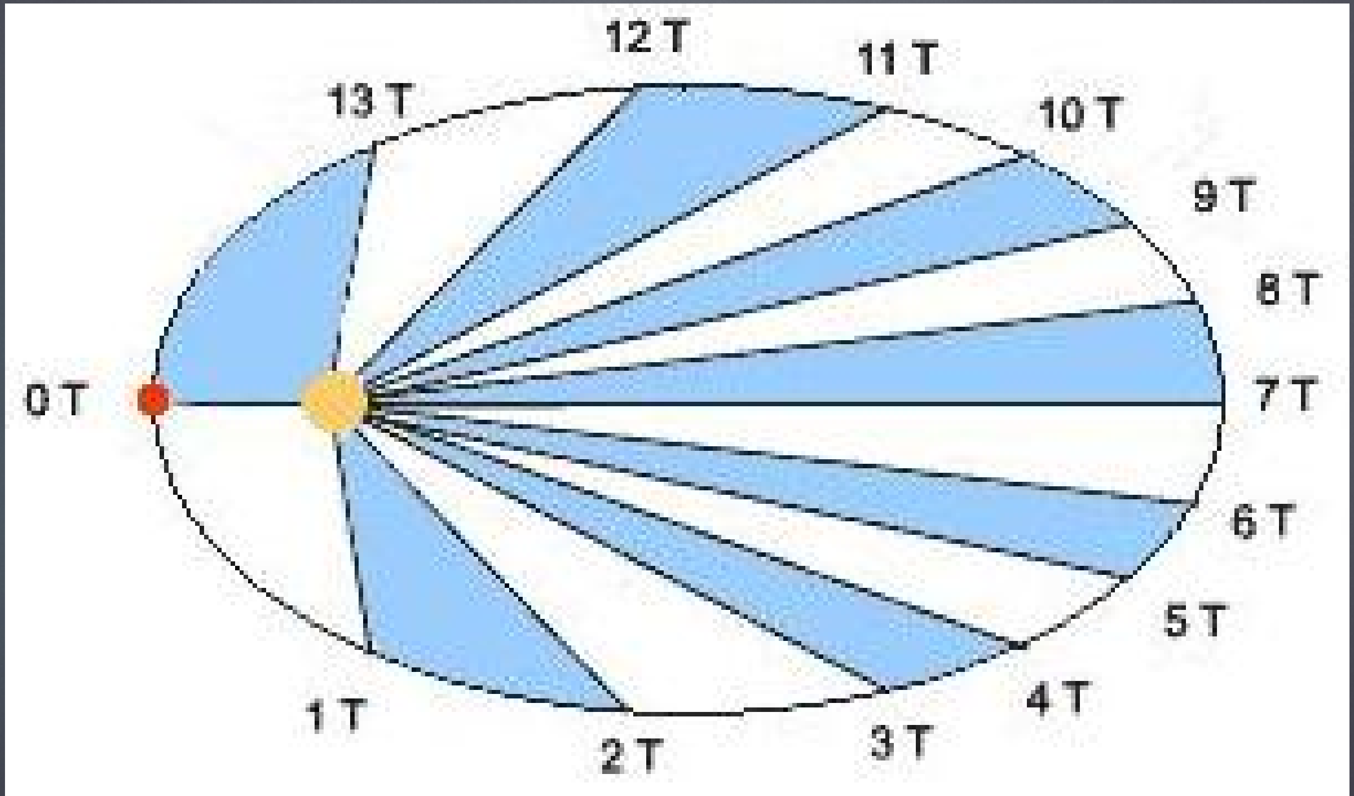
Kepler’s Laws

- Law I: Each planet moves in an orbit that is an ellipse, with the Sun at one of the foci (the other is empty)



Kepler's Laws

- Law II: The speed of the moving planet changes with distance from the Sun, so that the radius vector sweeps out equal areas in equal intervals of time



Kepler's Laws

- Law III: The squares of the periods of revolution are equal to the cube of their mean distances from the Sun

$$P^2 = a^3$$

- P = orbital period (in years)
- a = average distance from Sun (in au)
- eg for Earth P=1 year and a=1au: $1^2 = 1^3$
- eg for Mars P=1.88y and a=1.52au

  $P^2 = 1.88^2 = 3.53$ $a^3 = 1.52^3 = 3.51$

Kepler v Newton

- Kepler's work was *empirical:*

  "Relying on or derived from observation or experiment"

He thought these laws were all independent!

Newton showed that they were all the result of a

single law of gravity

- A slight modification to Law I:

  The Sun actually moves about its "centre-of-mass" rather than being stationary at one focus

Launch point A
High launch speed
Unbound orbits
Low launch speed
Earth's center
Inside Earth
Bound orbits
Circular orbit
Escape velocity

Escape velocity

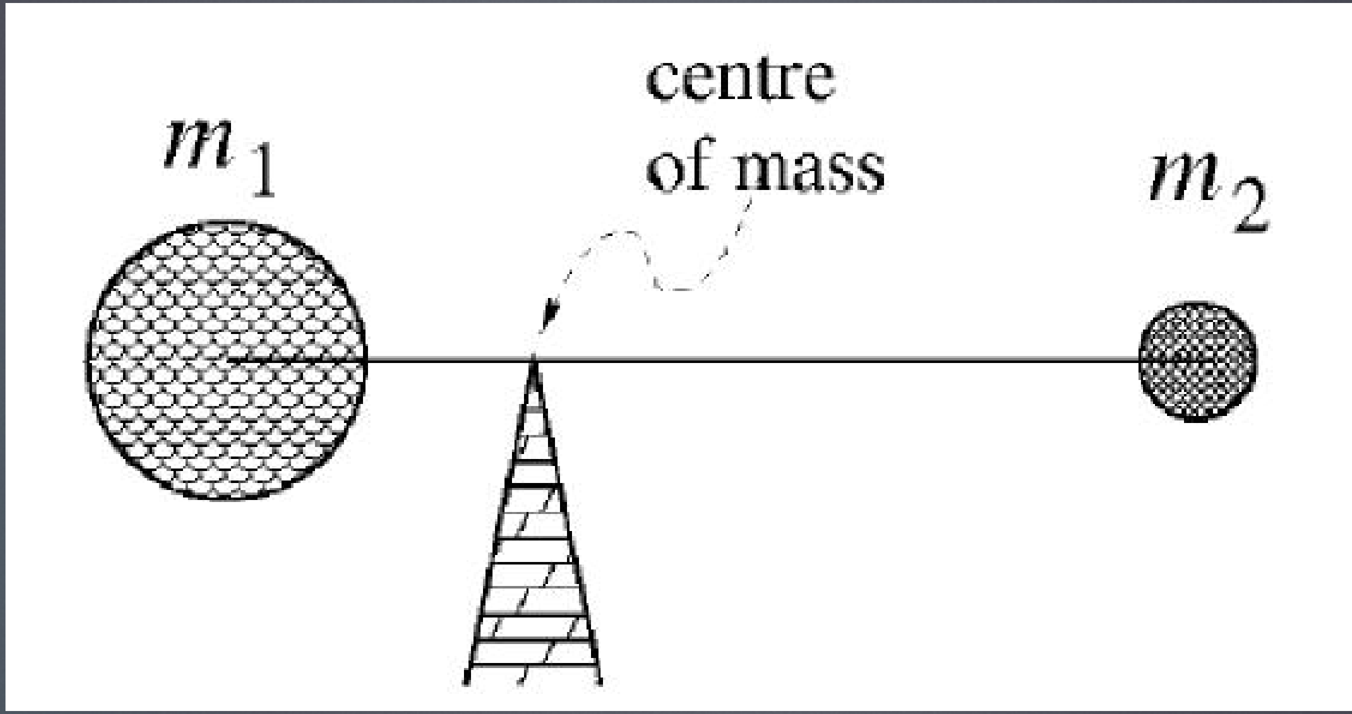
- To escape the gravity of the Earth an object must have sufficient kinetic energy.
- The Earth pulls with a gravitational potential energy (on the surface) given by

$$\mathrm{PE} = \frac{G M_E m}{r_E}$$

where M_E is the mass of the Earth, m is the mass of the object trying to leave the Earth, and r_E is the radius of the Earth.

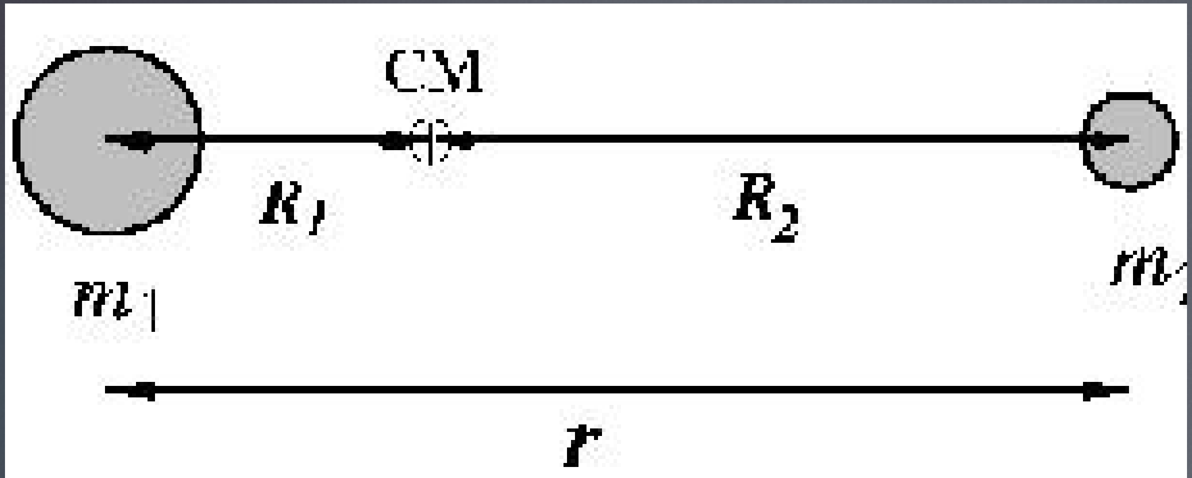
- The kinetic energy of a mass m moving with speed v is $KE = \frac{1}{2} m v^2$
- To escape the Earth we need KE > PE
- Show that this corresponds to a speed of about 11 km/sec

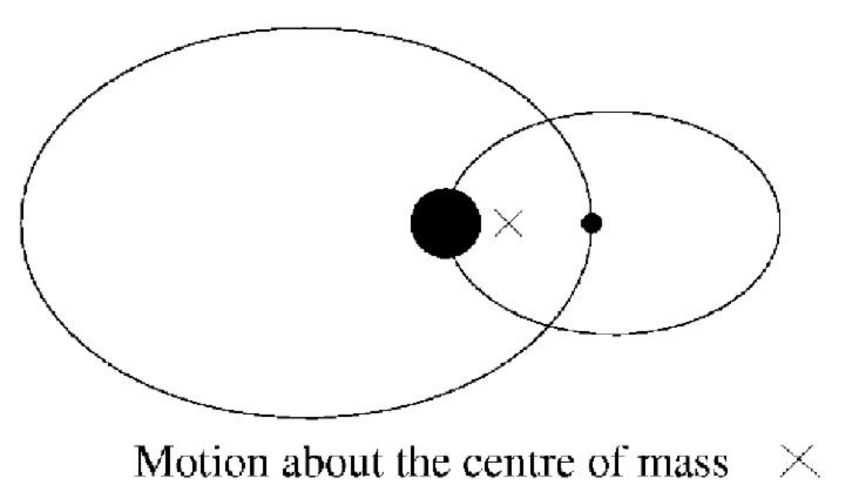
Centre of Mass



Centre of mass

- We determine the position of the centre of mass this way:





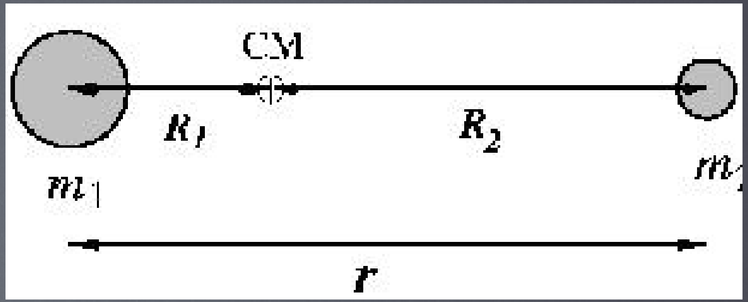
$$m_1 R_1 = m_2 R_2$$

Separation is $r = R_1 + R_2$

Example

- Where is Centre of mass of Earth-Sun system?

Sun



Earth

$m_1R_1 = m_2R_2$

$$\frac{R_1}{R_2} = \frac{m_2}{m_1} = \frac{5.98\text{x}10^{27}}{1.99\text{x}10^{33}} = 3.00\text{x } 10^{-6}$$

Separation is $r = 1\text{au} = R_1 + R_2$ So $R_2 = r - R_1$

Example

$$\frac{R_1}{R_2} = \frac{R_I}{r - R_1} = 3 \times 10^{-6}$$

$$R_1 = (r - R_1) \times 3 \times 10^{-6}$$

Now r is just 1au = 1.5 x 10^{11} m

Hence I leave it for you to show that R1 is about 450km

That is about 0.00064 of the Sun's radius!

So the centre of mass is well inside the Sun!!!

Binary Stars

- We saw that in the solar system the planetary orbits obeyed

$$P^2 = a^3$$

where P is in years and a is in au

- This particularly simple form comes from the fact that the mass of the planet is negligible compared to the Sun
- For binary stars the law is a bit more complicated.
- For two stars of masses m_1 and m_2 separated by a distance a we get

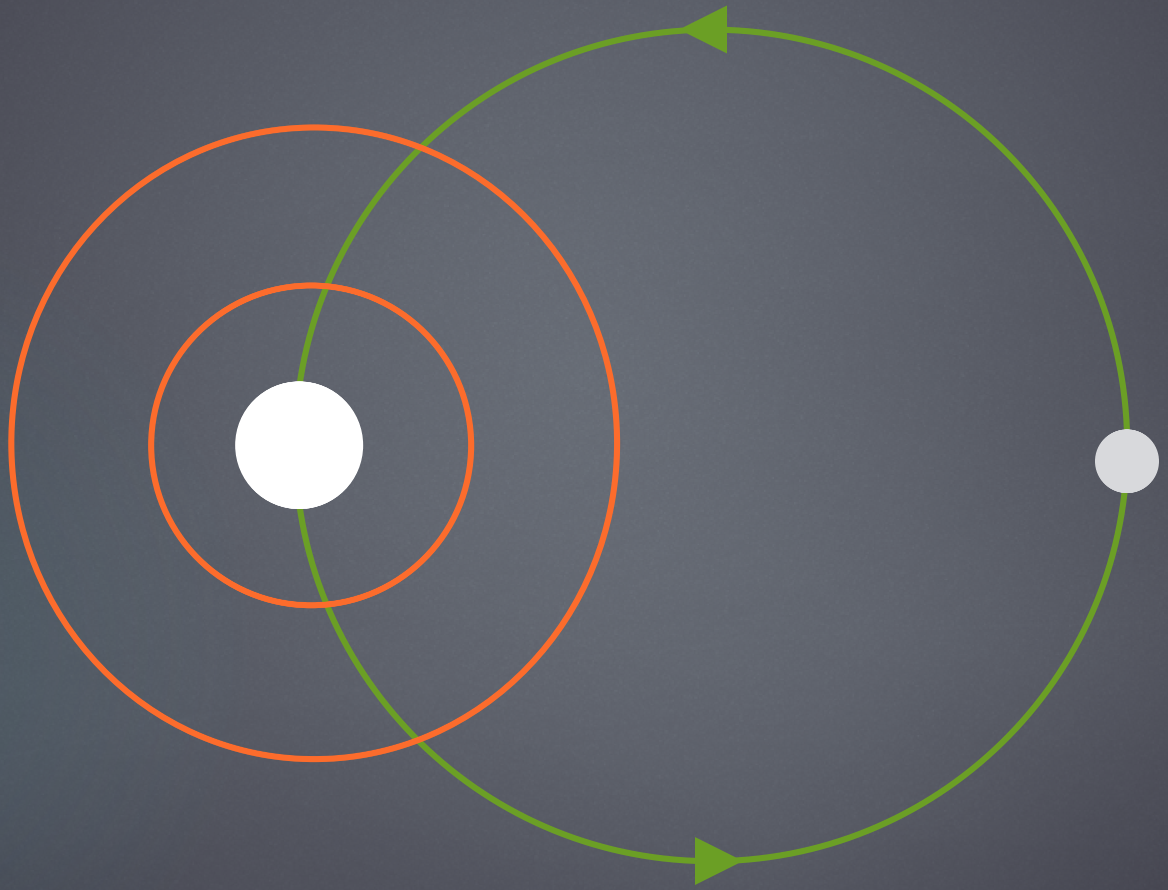
$$P^2 = \left(\frac{4\pi^2}{G(m_1 + m_2)}\right) a^3$$

- Here P is in seconds, m is in grams, a is in cm

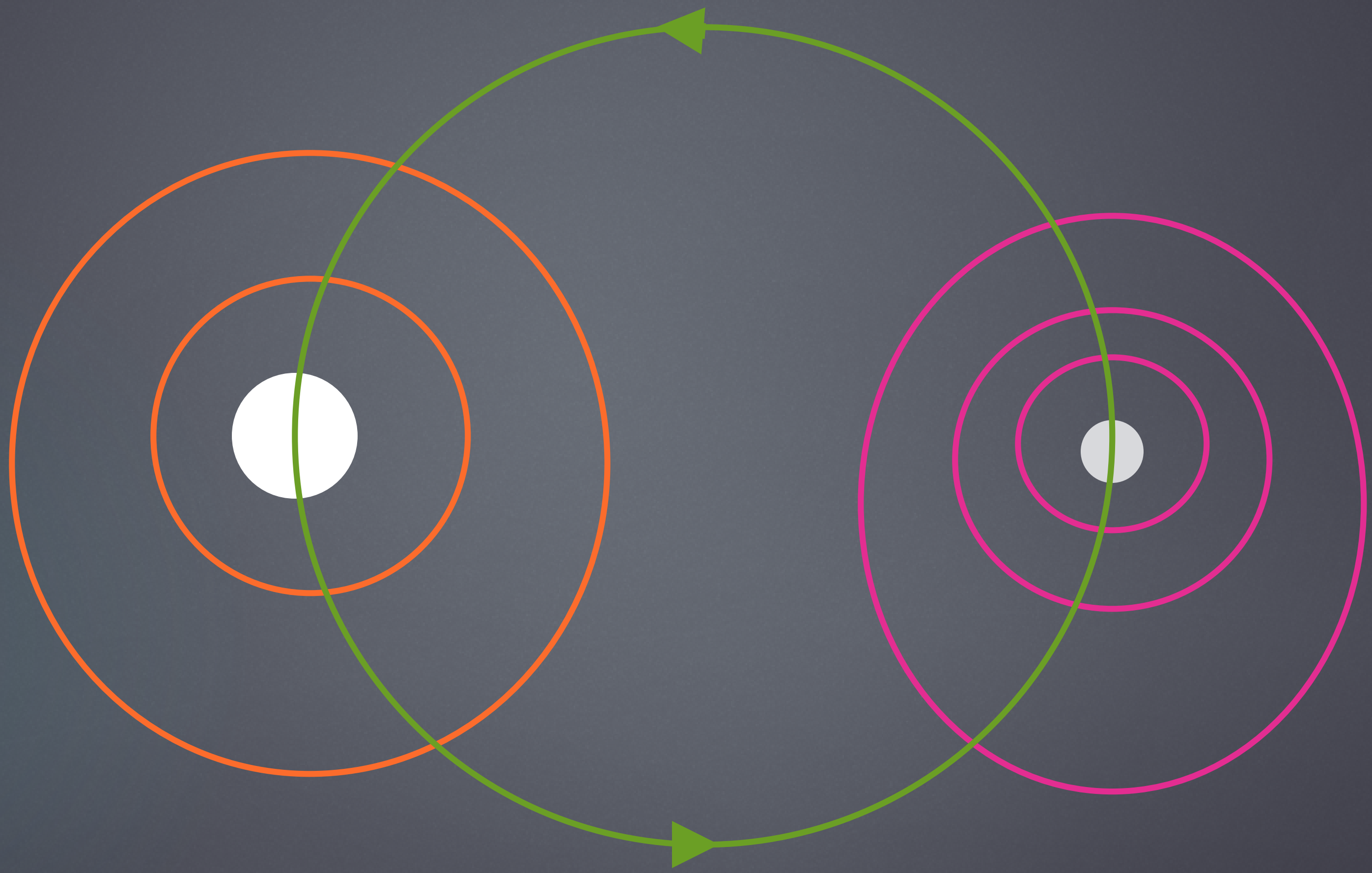
But most stars are binaries

- So much for orbits around single stars
- But most stars are found in binaries
- Can planets exist around stars in binary systems?
- What sort of things are possible?
- Depends on formation mechanism
- But can still look at resulting orbits
- Three cases

1: planets around one star



2: planets around both stars



3: planets around the binary system