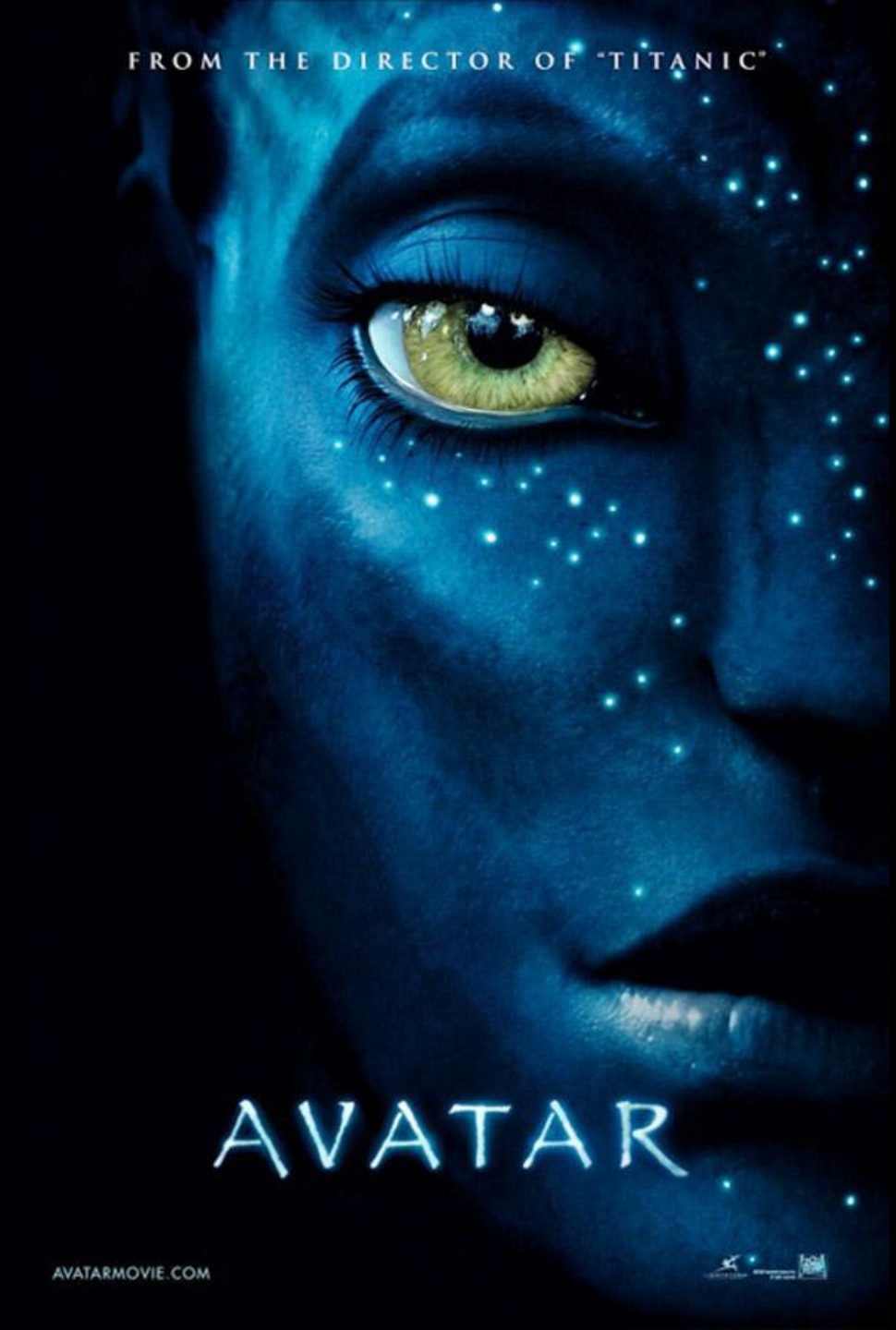
PiTP

Lectures on Quantum Phenomena

How science is <u>really</u> done

A tantalising tale of
duels, harems, heroines,
and… a cold case of murder

Prof. Jaymie Matthews
UBC Physics & Astronomy



Now at a theatre near you

AVOGADRO

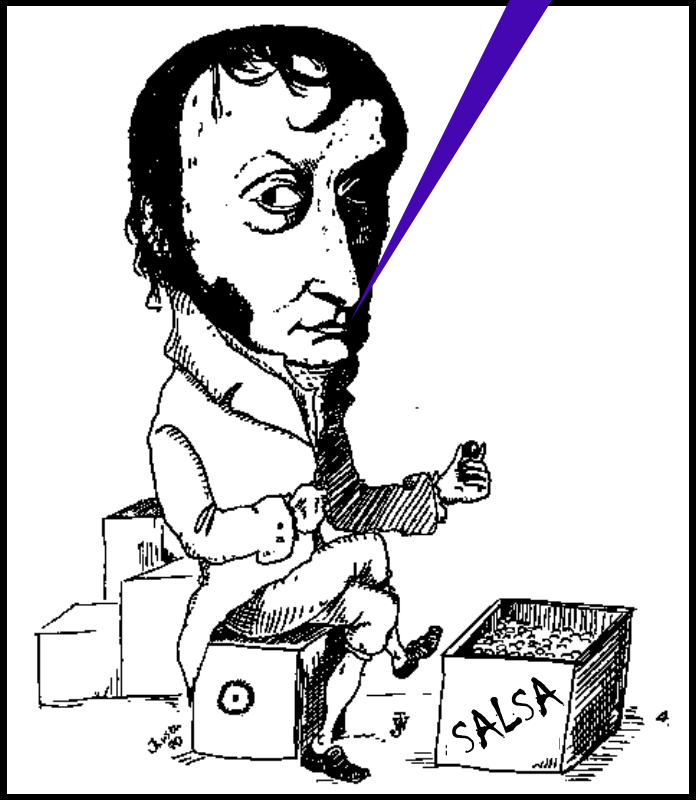
Coming soon

$N_A = 6.023 \times 10^{23}$

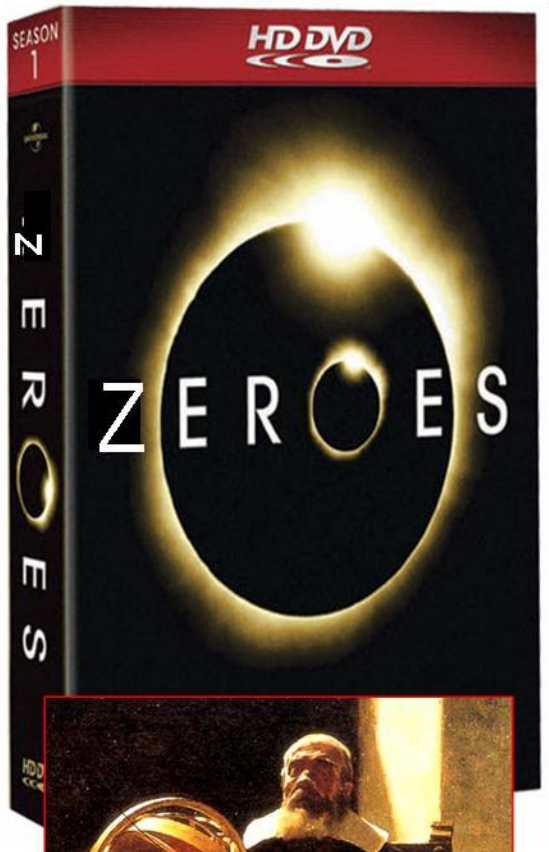
Good to the last molecule

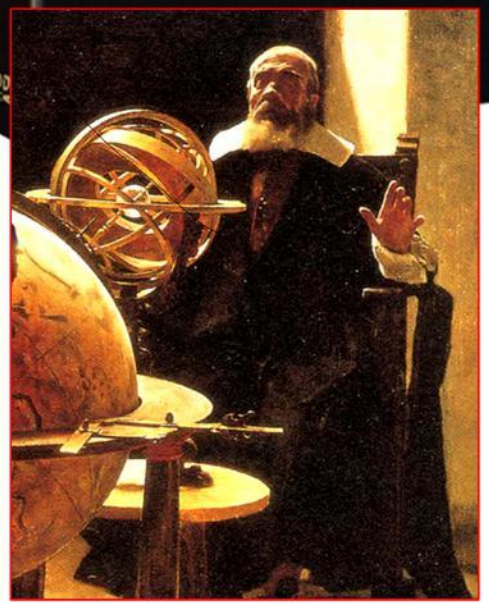
Good to the last molecule

Great for an astro party



Galileos gone WILD





PAPAL ADVISORY
EXPLICIT SCIENCE

A Physics Trivial Pursuit question?

What's the connection between *gravity* and *life insurance*?

A Physics Trivial Pursuit question?

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What's the connection between *gravity* and *life insurance*?

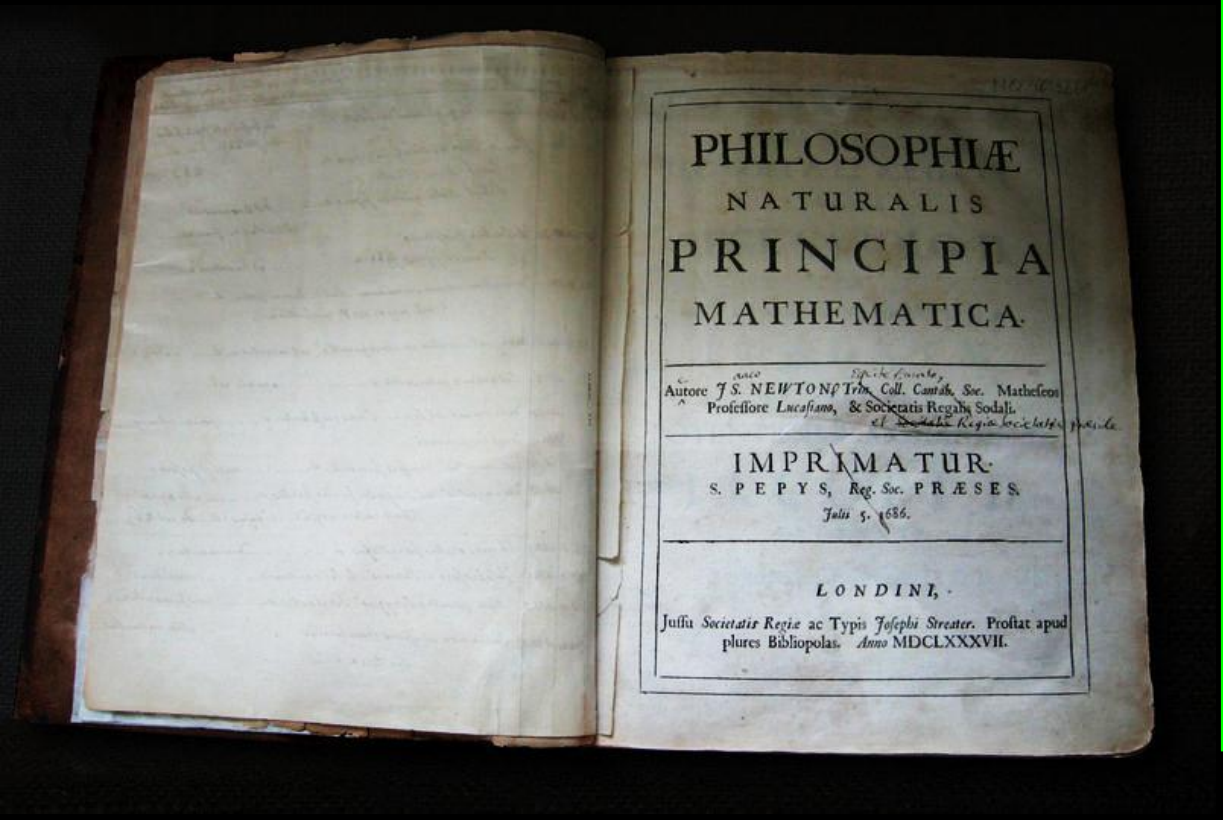
A Physics Trivial Pursuit question?

What's the connection between *gravity* and *life insurance*?

The laws of motion and gravity

My story begins with this man

Sir Isaac Newton (1643 – 1727)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S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

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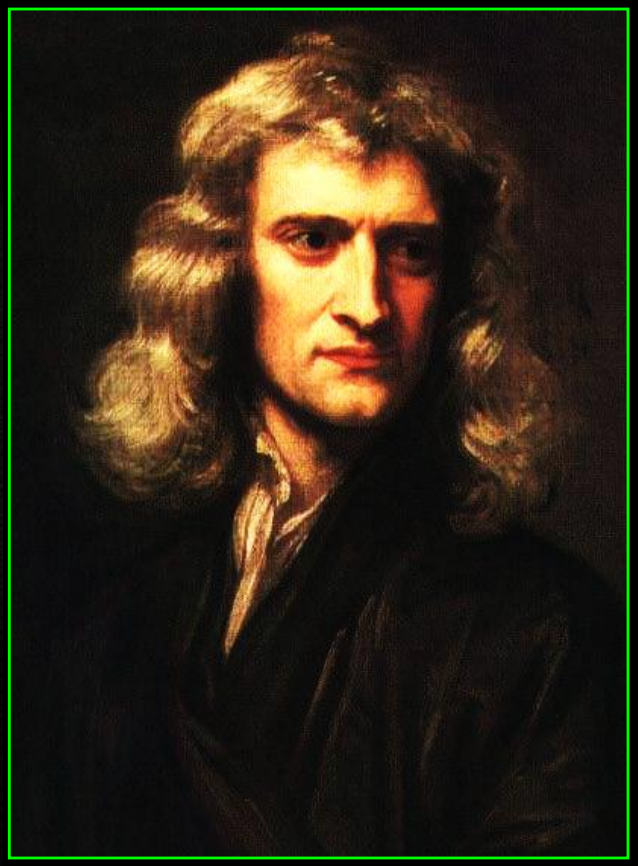


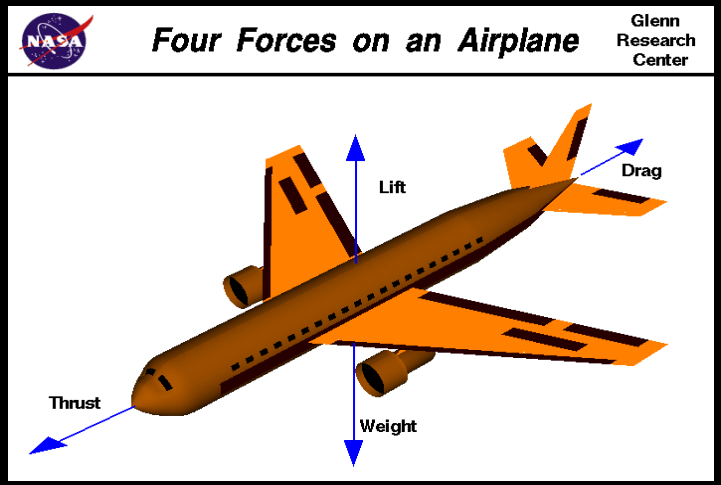
The laws of motion and gravity

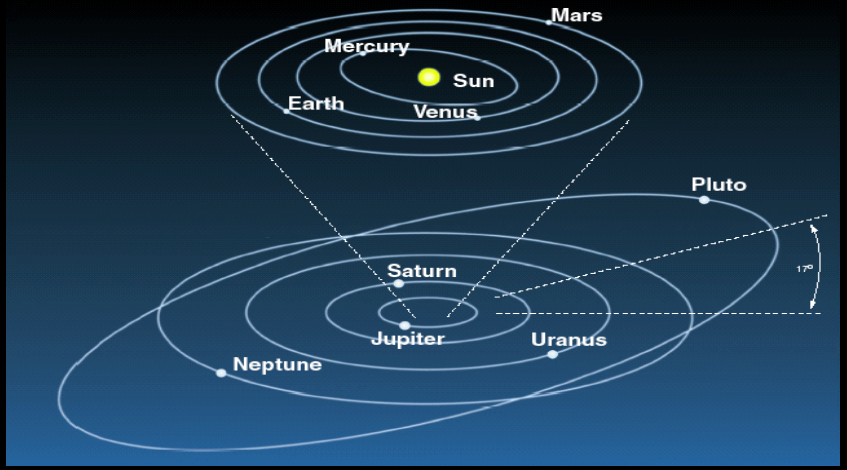
Newton's Laws of motion

- ✓ **First Law**
  Every body continues at rest or in motion in a straight line unless acted upon by an outside force

- ✓ **Second Law**
  The acceleration of a body is proportional to the force acting on it (in the direction that the force is acting)

- ✓ **Third Law**
  For every action, there is an equal and opposite reaction

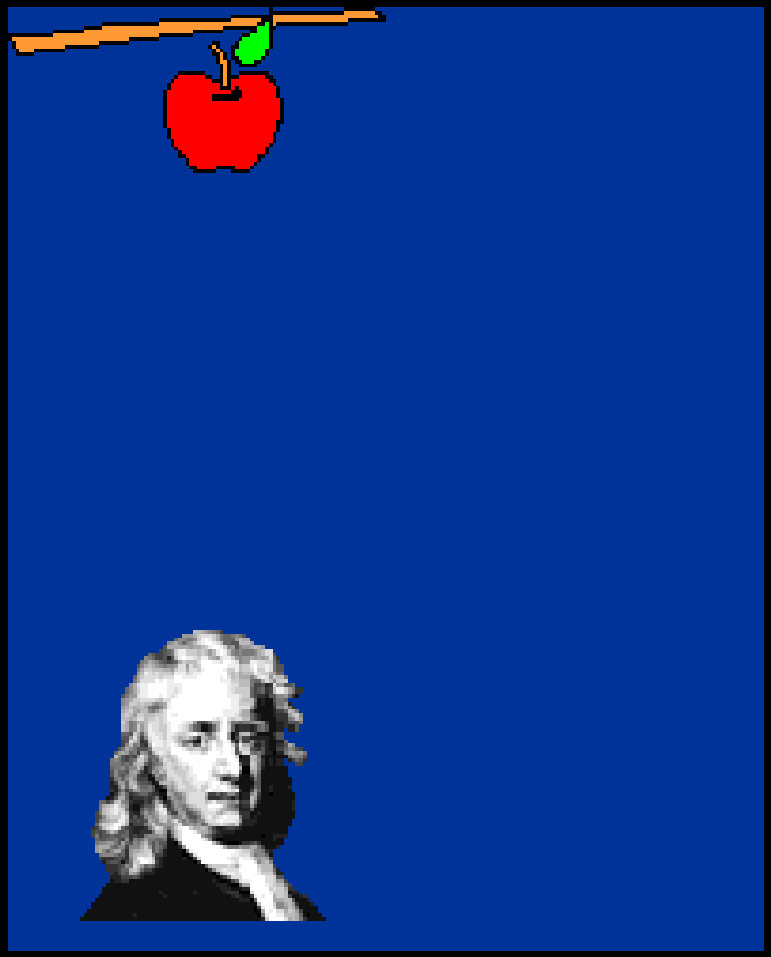




Gravitational Force

Universal law of gravitation

It's the popular notion that Newton "discovered" gravity and the story is that he did so when struck on the head by an apple while sleeping under a tree



Gravitational Force

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This is a direct descendant of the apple tree that was below Newton's room at Cambridge University

Gravitational Force

Scientific history in our backyard

In 1968, to commemorate the opening of the TRIUMF lab, cuttings from Newton's apple tree were planted on the south campus of UBC

This is a direct descendant of the apple tree that was below Newton's room at Cambridge University

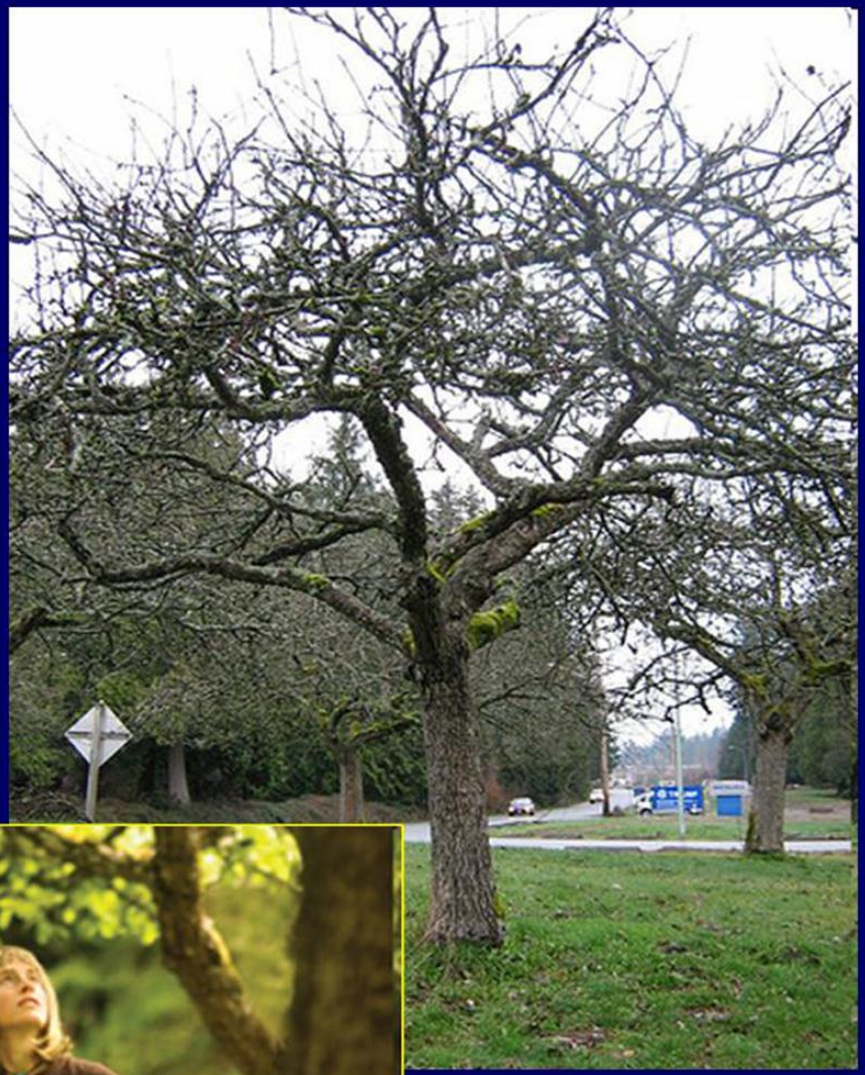
Gravitational Force

Scientific history in our backyard

In 1968, to commemorate the opening of the TRIUMF lab, cuttings from Newton's apple tree were planted on the south campus of UBC

This is a direct descendant of the apple tree that was below Newton's room at Cambridge University

Those six trees bear fruit every year. If you nap under one, you may discover the next big thing in science

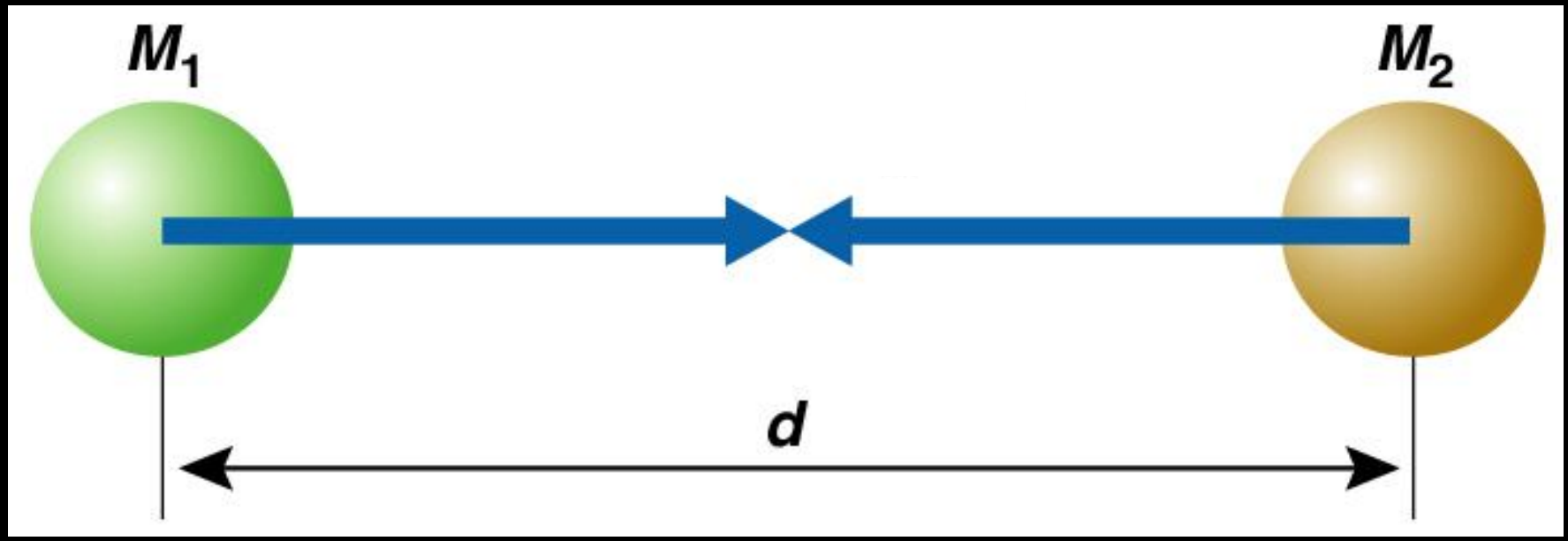


Cambridge
England

Vancouver
Canada

Gravitational Force

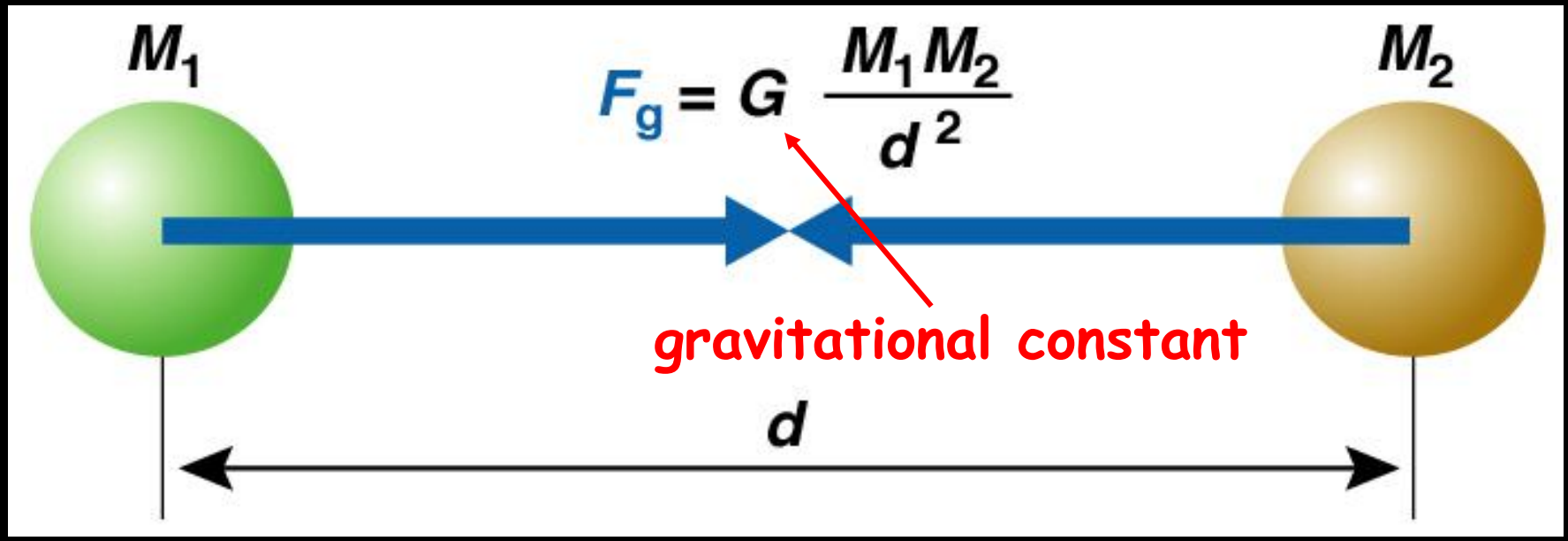
Universal law of gravitation



Between every two objects there is an attractive force which is directly proportional to the masses of the objects and inversely proportional to the square of the distance between the centres of the objects

Gravitational Force

Universal law of gravitation



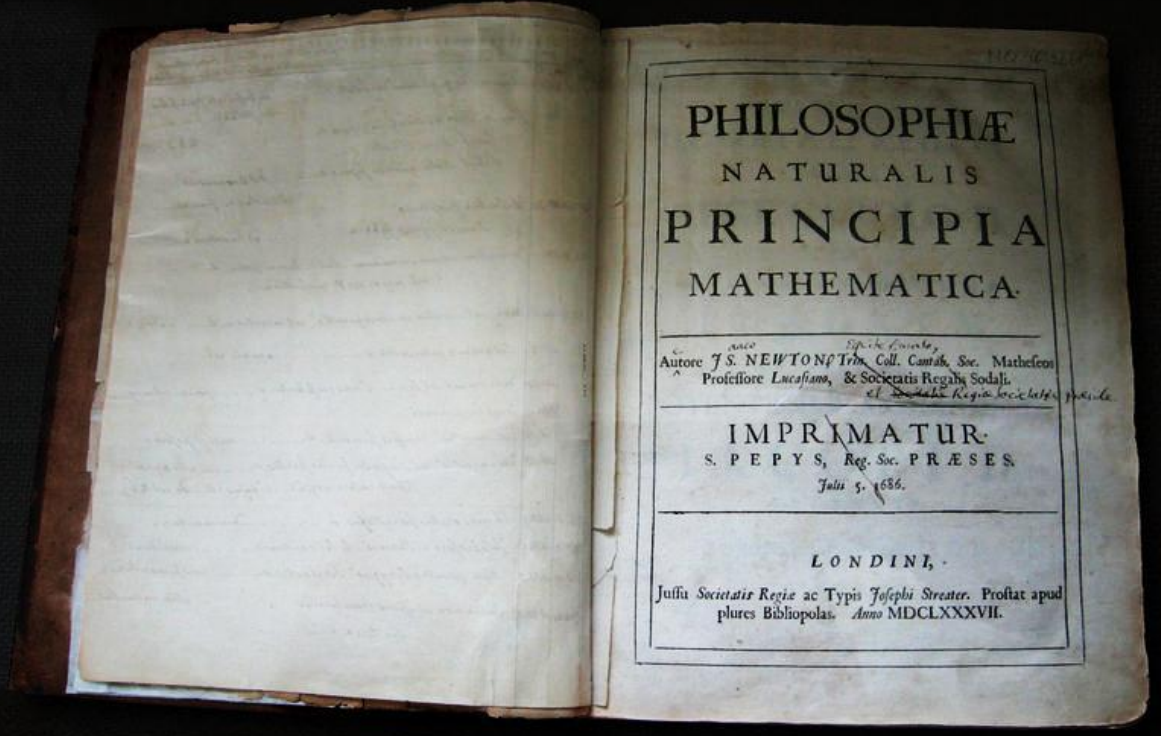
$$F_g = G \frac{M_1 M_2}{d^2}$$

gravitational constant

$G = 6.67 \times 10^{-11}\ N\ m^2 / kg^2$

Principia

The rule book for that law



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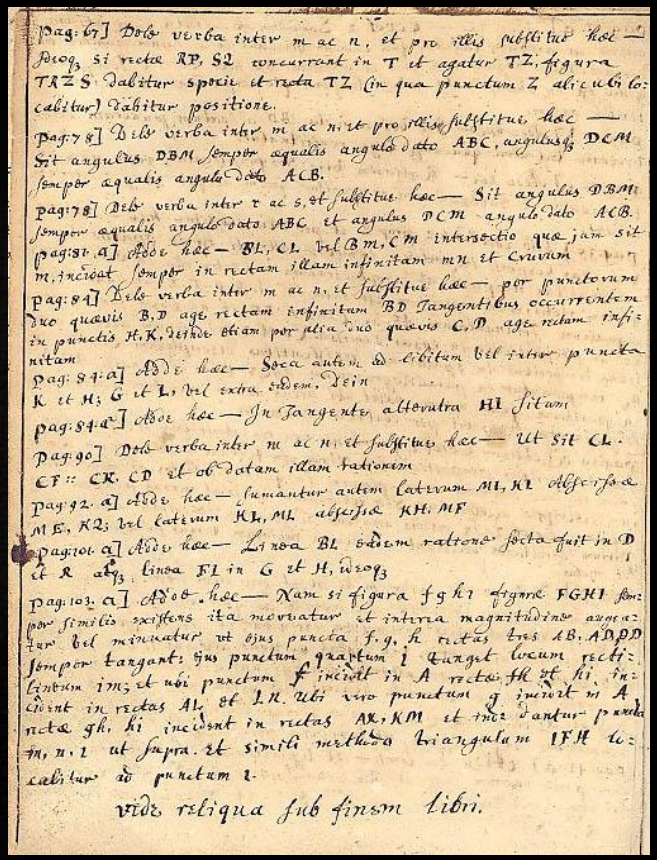


[pag: 67] Dele verba inter m ac n, et pro illis substitue hoc — Recq si rectæ RP, SQ concurrant in T et agatur TZ, figura TRZS dabitur specie et recta TZ (in qua punctum Z alicubi locabitur) dabitur positione.

pag: 78] Dele verba inter m ac n, et pro illis substitue hoc — Sit angulus DBM semper æqualis angulo dato ABC, angulusq; DCM semper æqualis angulo dato ACB.

pag: 78] Dele verba inter r ac s, et substitue hoc — Sit angulus DBM semper æqualis angulo dato ABC et angulus DCM angulo dato ACB.

pag: 81. a] Adde hoc — BL, CL vel BM, CM intersectio quæ jam sit m, incidat semper in rectam illam infinitam MN et eruium

pag: 84] Dele verba inter m ac n, et substitue hæc — per punctorum duo quævis B, D age rectam infinitam BD Tangentibus occurrentem in punctis H, K, deinde etiam per alia duo quævis C, D age rectam infinitam

pag: 84. a] Adde hæc — Sæca autem ad libitum vel inter puncta K et H; G et L, vel extra eadem. Dein

pag: 84. a] Adde hæc — In Tangente alterutra HI sitam

pag: 90] Dele verba inter m ac n, et substitue hæc — Ut sit CL. CF :: CK. CD et ob datam illam rationem

pag: 92. a] Adde hæc — sumantur autem latera MI, KI abscissæ ME, KQ; vel latera KH, MI abscissæ KH. MF

pag: 101. a] Adde hæc — Linea BL eadem ratione facta fuit in D et R adq; linea FL in G et H, itaq;

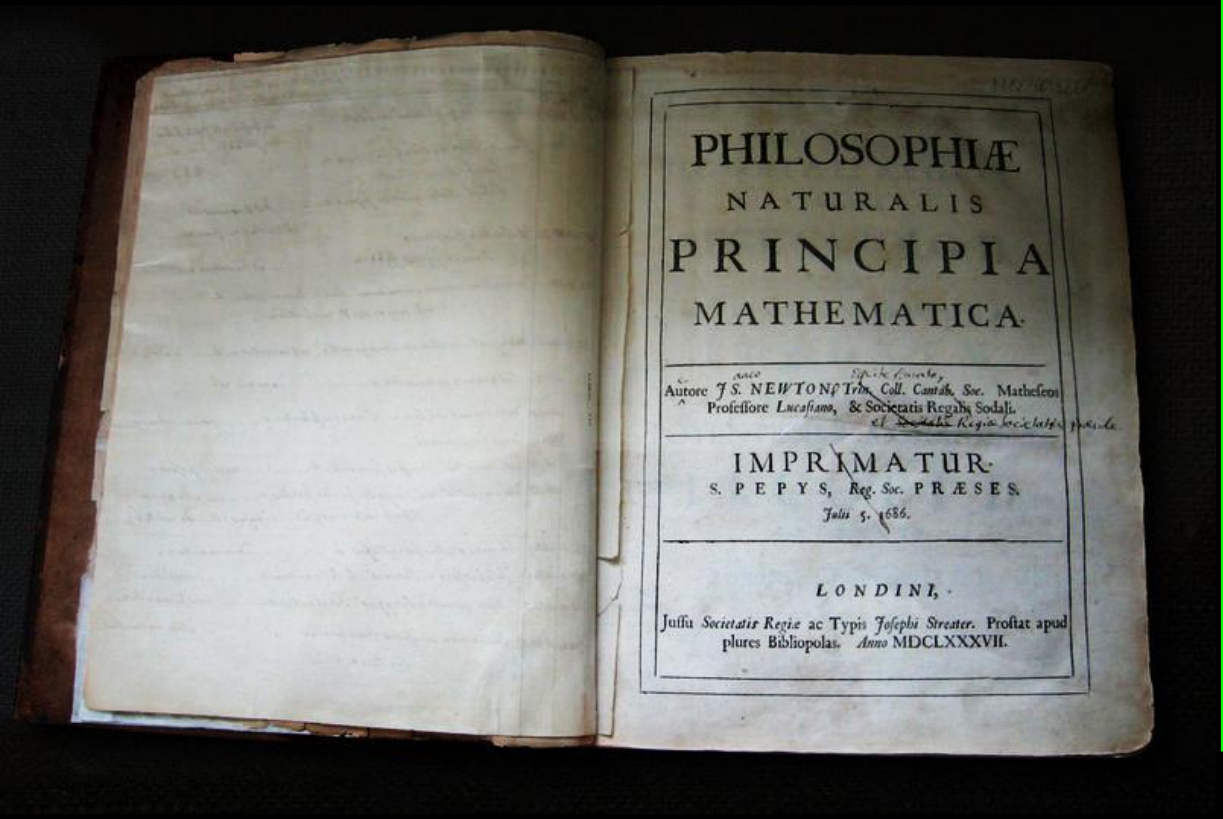
pag: 103. a] Adde hæc — Nam si figura fghi figuræ FGHI similis existens ita mutatur et interea magnitudine augeatur vel minuatur ut ejus puncta f, g, h rectas tres AB, ADPD semper tangant; ejus punctum quodlibet i tanget locum rectilineum im; et ubi punctum f incidit in A rectæ fh et hi incident in rectas AL et LN. Ubi vero punctum g incidit in A rectæ gh, hi incident in rectas AK, KM et inde dantur puncta n, n, I ut supra. et simili methodo triangulum IFH tota describitur ad punctum I.

Vide reliqua sub finem libri.

The laws of motion and gravity

My story began with this man …

Sir Isaac Newton (1643 – 1727)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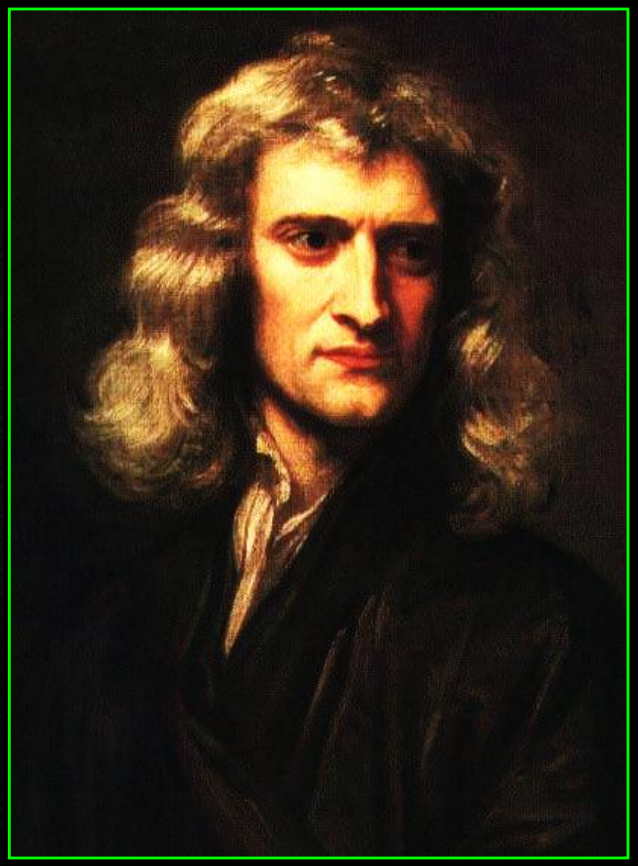


The laws of motion and gravity

… but the hero of my tale is this man

Sir Edmond Halley (1656 – 1743)

The laws of motion and gravity

He's known people by most for this

Sir Edmond Halley (1656 – 1743)

Halley's Comet
(as seen in 1986)

The laws of motion and gravity

… but not for the right reason

Sir Edmond Halley (1656 – 1743)

Halley didn't discover this comet.
but he proposed that comets.
that had been seen every 76 years.
in history were the same comet.

He predicted that comet's return.

Halley's Comet
(as seen in 1986)

The laws of motion and gravity

A legacy of cleverness in the sky

Sir Edmond Halley (1656 – 1743)

Halley didn't discover this comet
but he proposed that comets
that had been seen every 76 years
in history were the same comet.

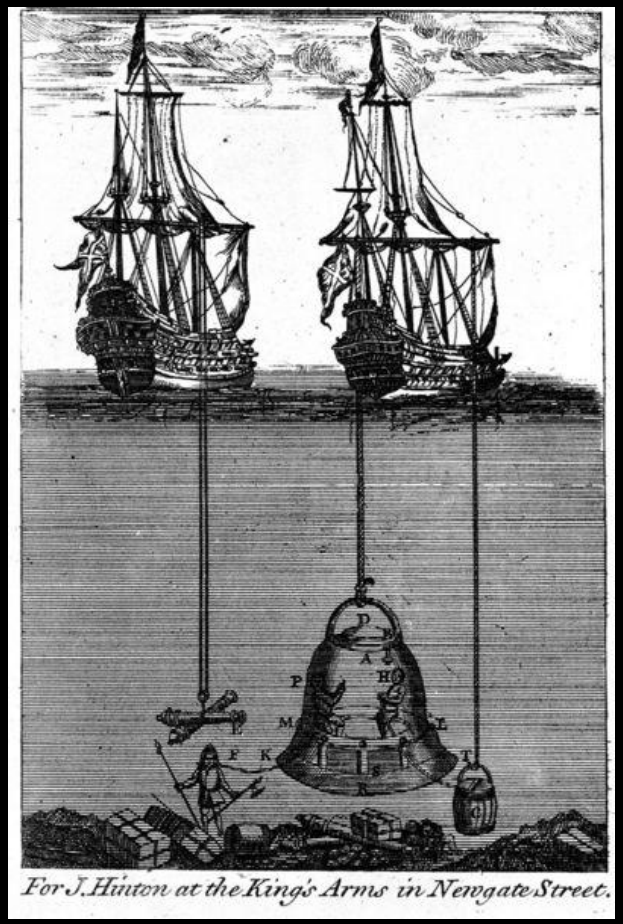
He predicted that comet's return.

After it was seen in the sky
when and where he predicted
(but after his death)
the comet was named after him.

A scientist adventurer

Getting underneath the surface of a problem

Sir Edmond Halley (1656 – 1743)



also designed,
built and tested
in 1690
the forerunner
of the modern
diving bell

He and five friends used it to stay for 90 minutes beneath the River Thames at a depth of 60 feet

A scientist adventurer

Wandering around the globe

Sir Edmond Halley (1656 – 1743) also commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole

A scientist adventurer

Wandering around the globe

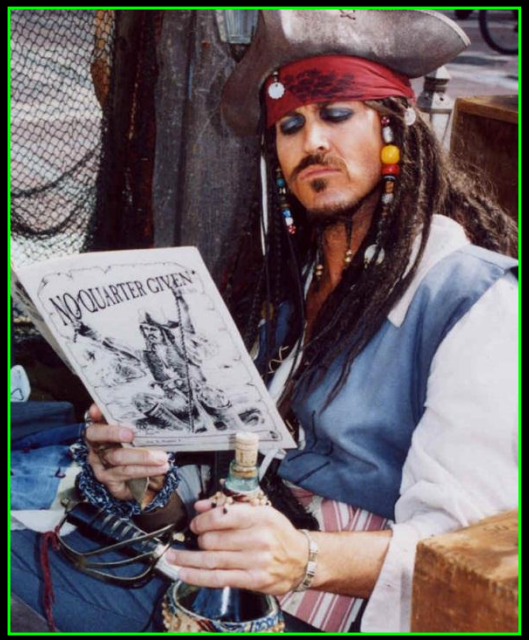
Sir Edmond Halley (1656 – 1743) also commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole

While sailing the ocean Halley learned to "curse like a sea dog"

A scientist adventurer

Wandering around the globe

Sir Edmond Halley (1656 – 1743) also commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole



While sailing the ocean Halley learned to "curse like a sea dog"

A scientist adventurer

Wandering around the globe

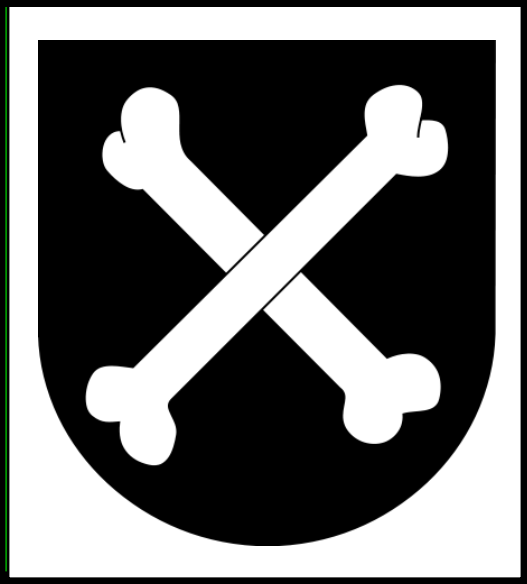
Sir Edmond Halley (1656 – 1743) also commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole

Pirate Captain Jack Sparrow's family crest

A scientist adventurer

Wandering around the globe

Sir Edmond Halley (1656 – 1743) also commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole

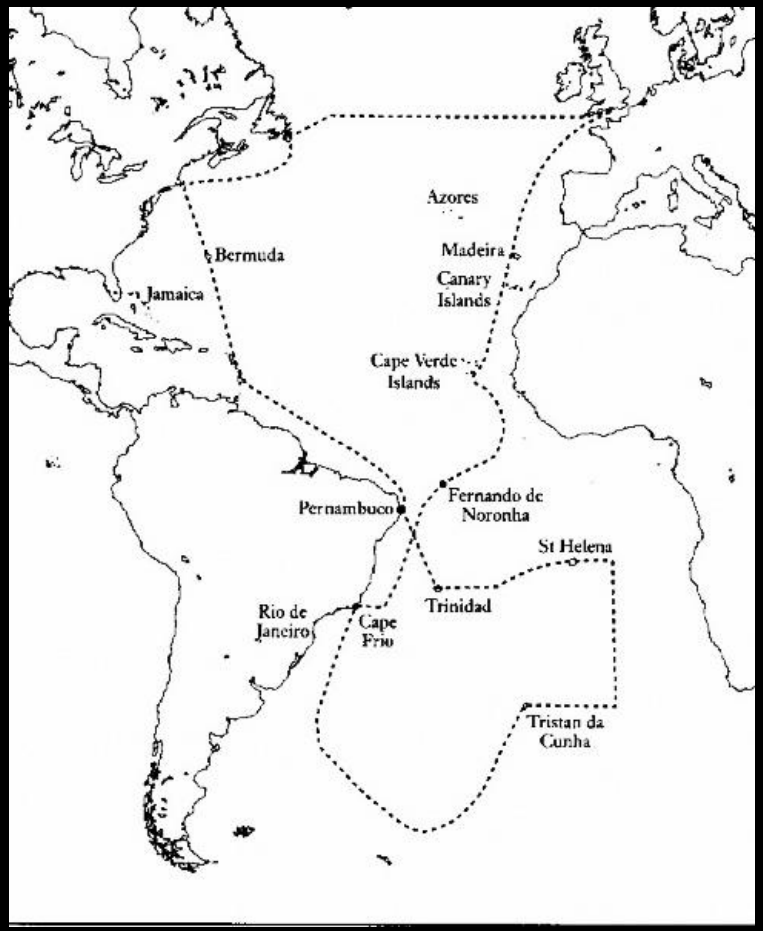


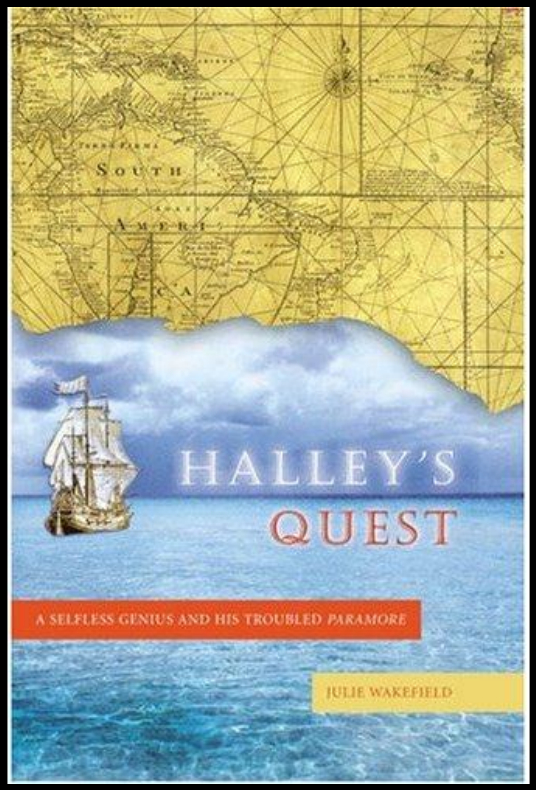
Physics Captain Isaac Newton's family crest

A scientist adventurer

Wandering around the globe

Sir Edmond Halley (1656 – 1743)



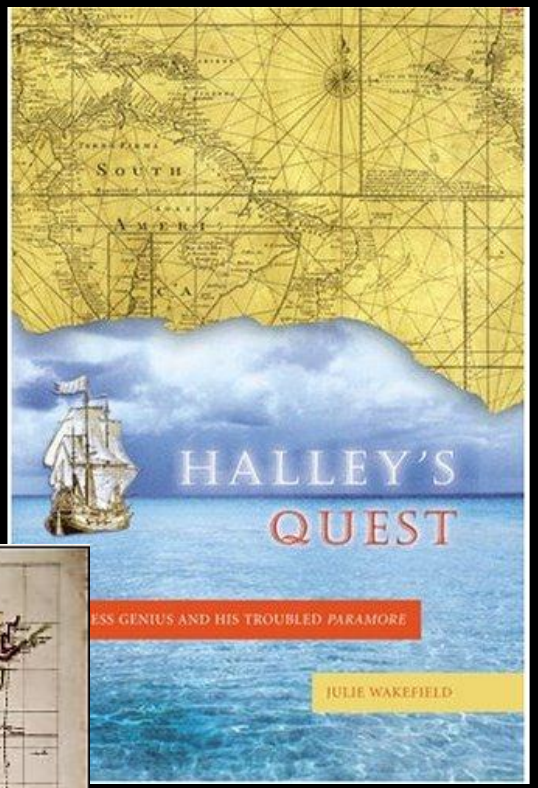


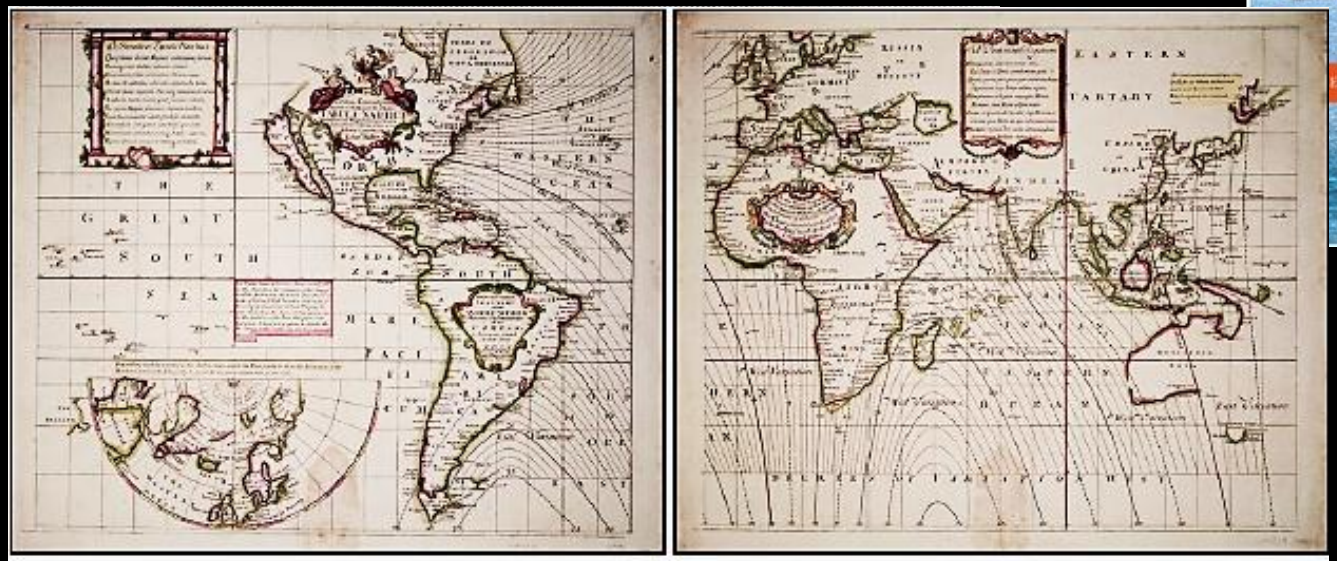
commanded the *Paramour* to chart the wander of the Earth's north magnetic pole

A scientist adventurer

Wandering around the globe

Sir Edmond Halley (1656 – 1743) commanded the sailing ship *Paramour* to chart the wander of the Earth's north magnetic pole

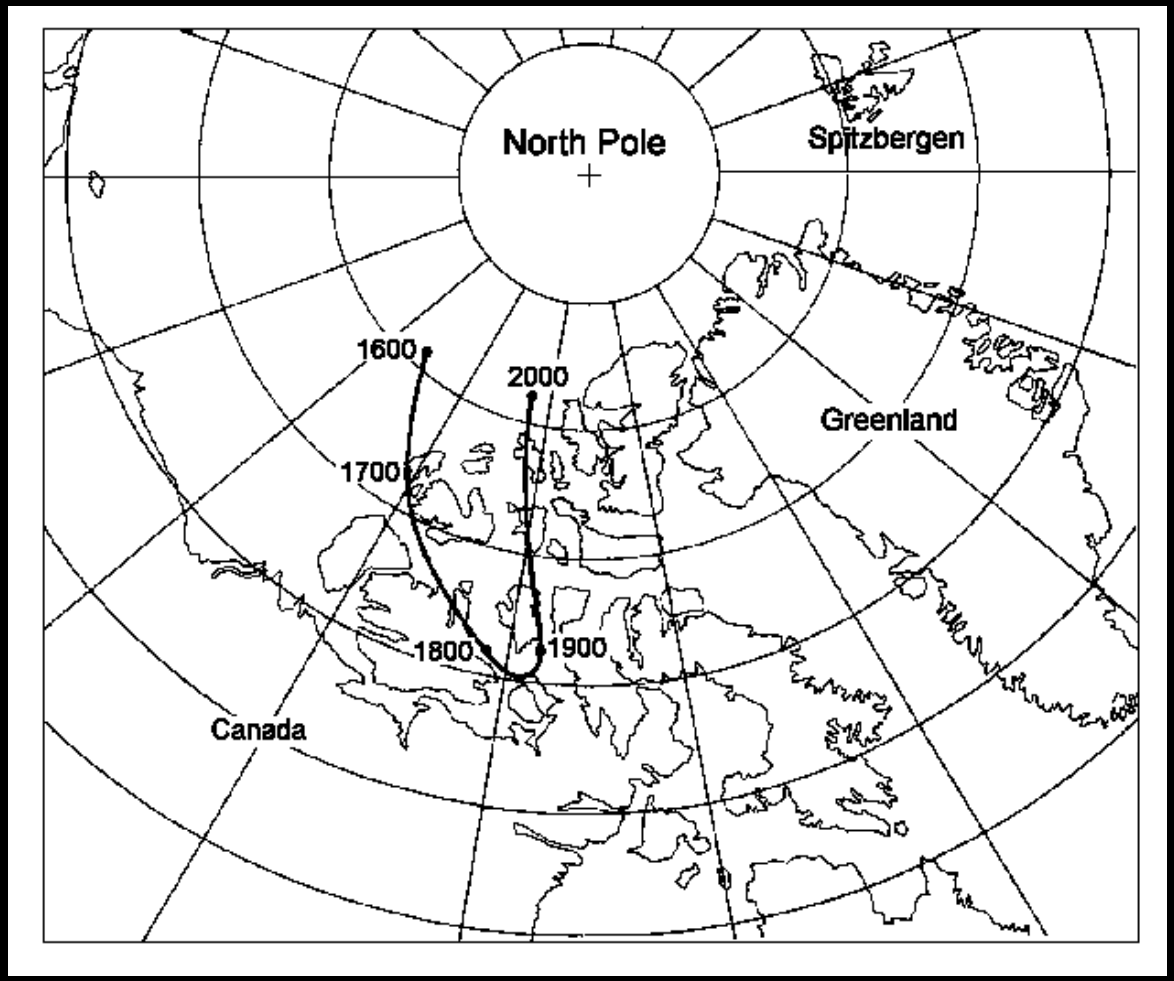


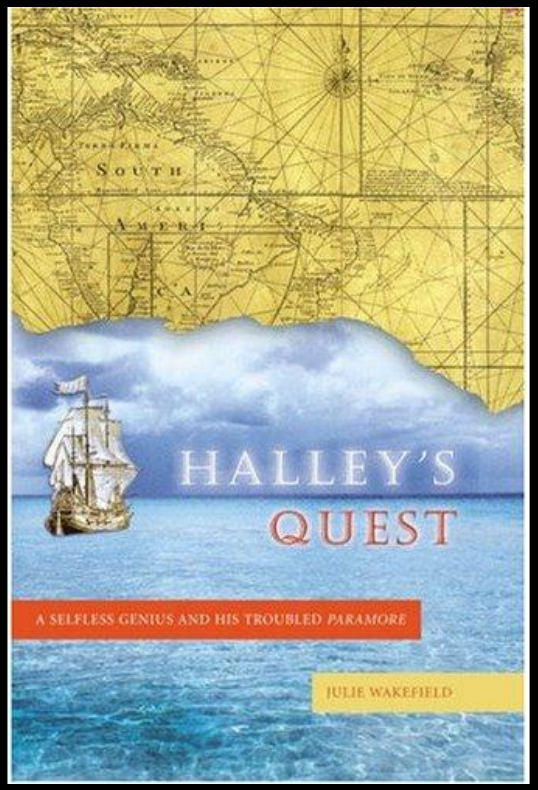


Edmund Halley's 1701 map of the known magnetic variations of the world.

A scientist adventurer

Wandering around the globe





A scientist adventurer

When Halley wasn't wandering, he was …

A scientist's inspiration

"Hooke"d on a problem

Halley, architect *Christopher Wren* and physicist *Robert Hooke*

debated in January 1684 and Hooke claimed to have derived *Kepler's Laws of planetary motion*

Kepler's Three Laws

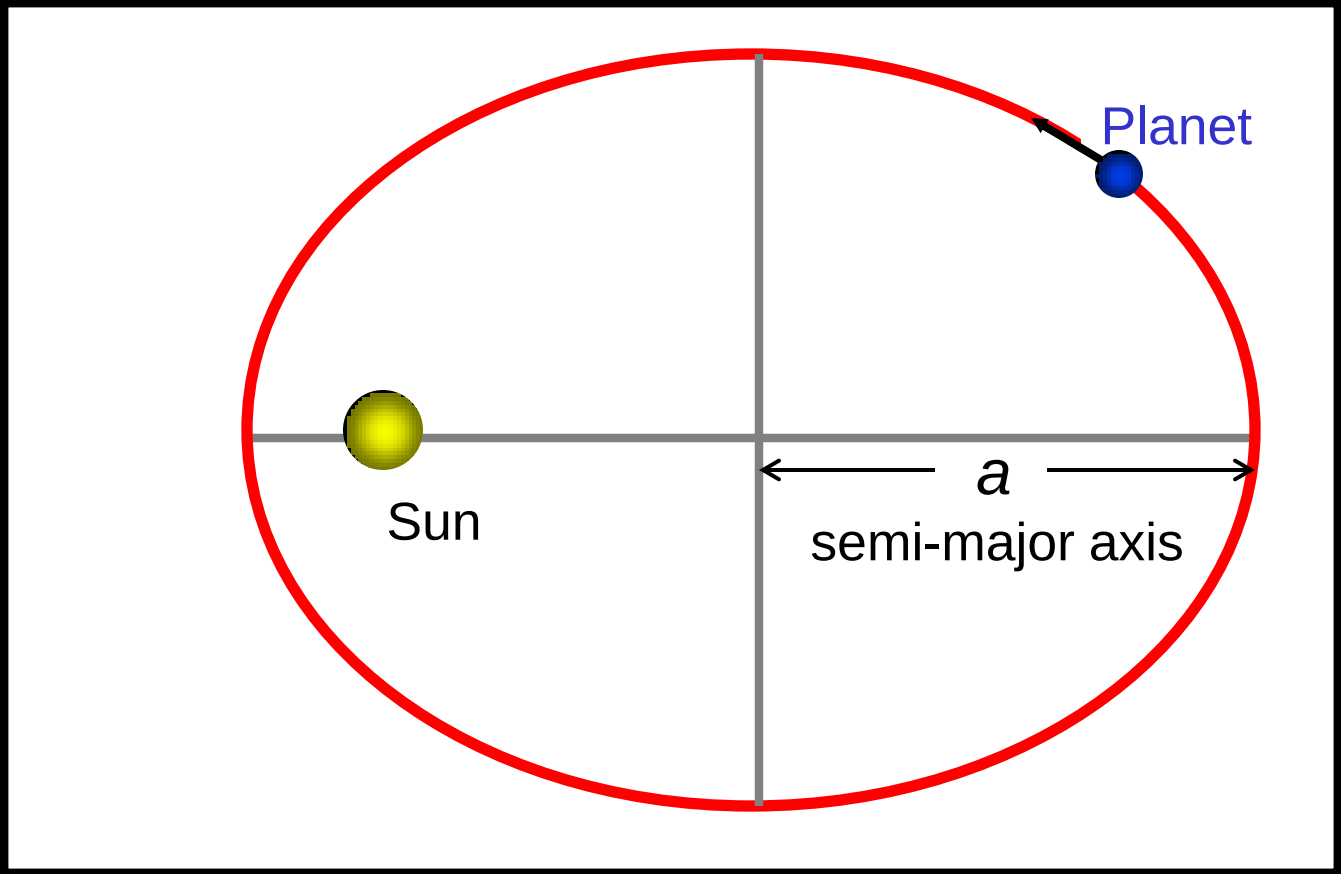
Principles of planetary motion

Johannes Kepler,
a German mathematician,
took two decades
to correctly interpret
Danish astronomer
Tycho Brahe's
measurements of
the positions of
the planet Mars in the sky

His *three laws of planetary motion*
are still used today

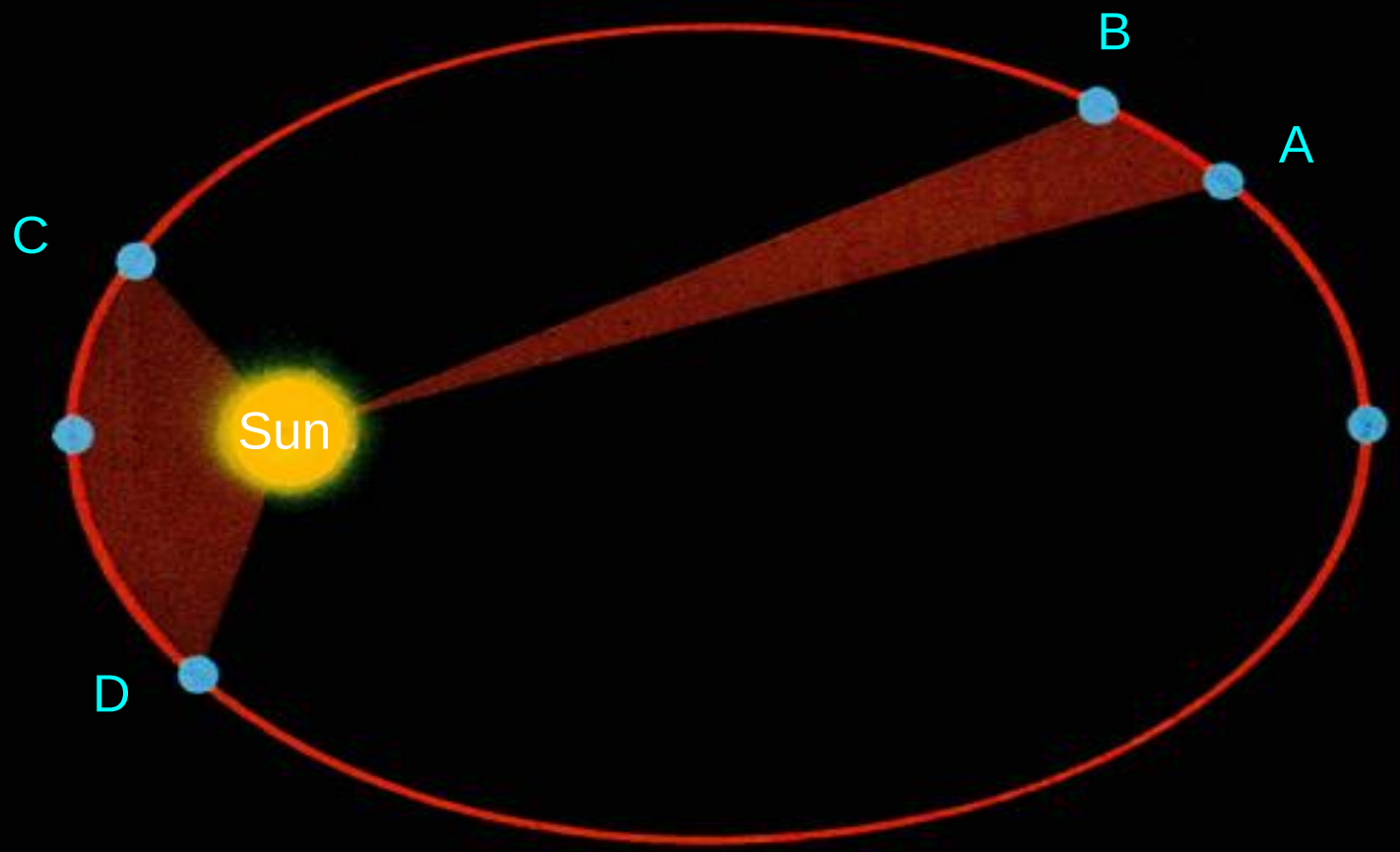
Kepler's First Law

Planets' orbits are ellipses with the Sun at one focus



Kepler's Second Law

A line joining the planet and the Sun sweeps out equal areas in equal times



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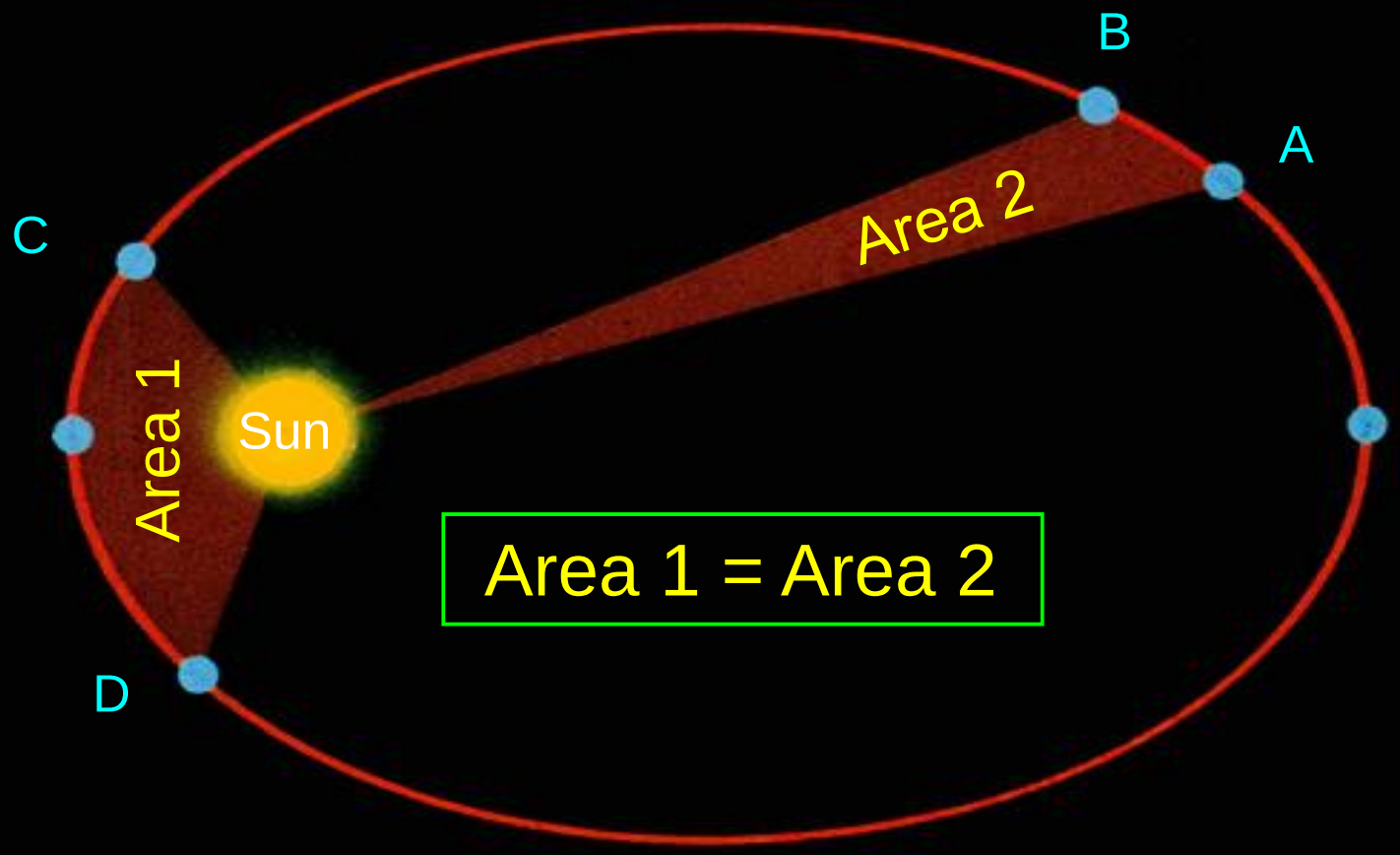

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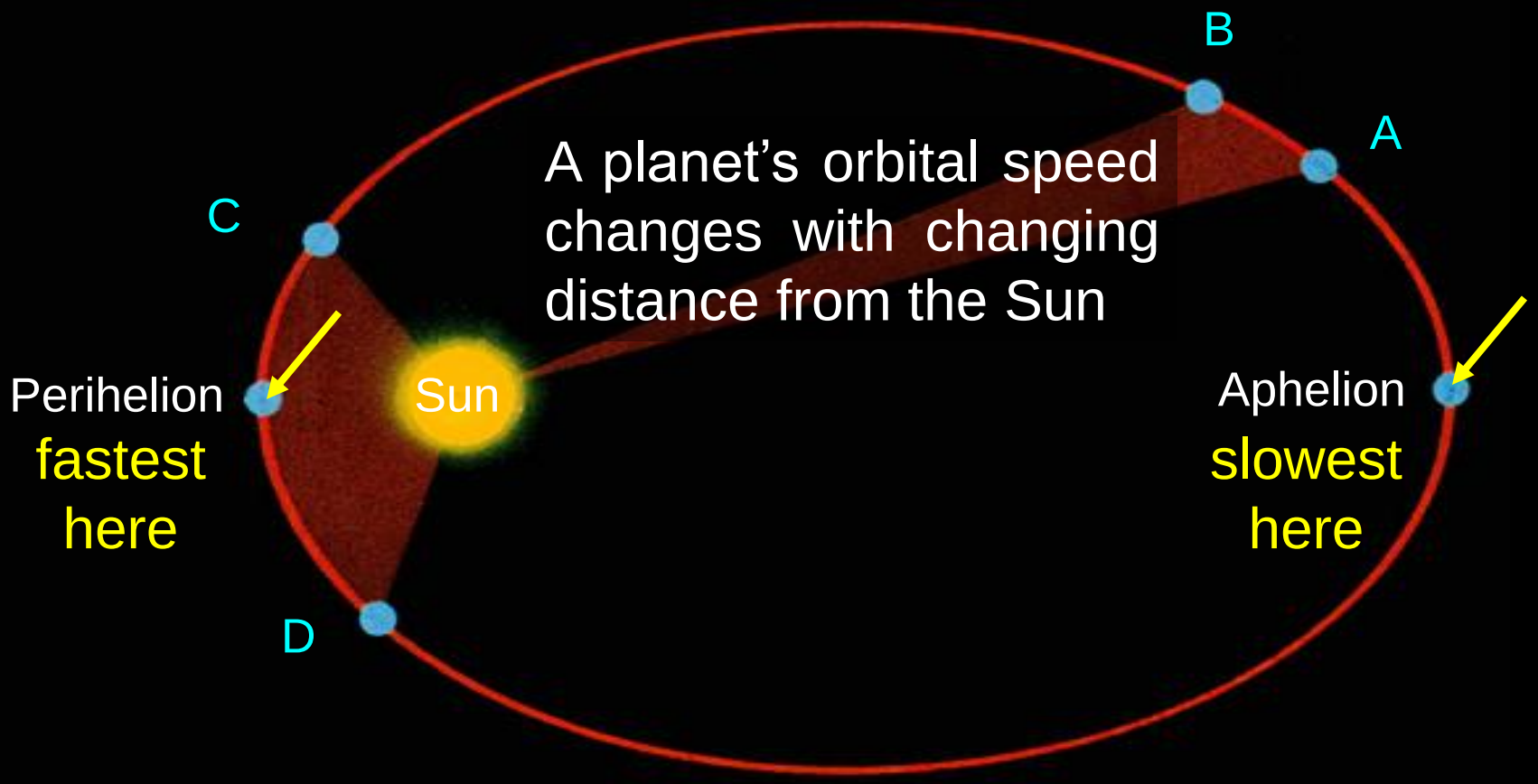


Kepler's Third Law

The (orbital period)^2 is proportional to (semi-major axis)^3

The planets Kepler knew

	semi-major axis *a* (AU)	period P (years)	a^3	P^2
Mercury	***0.39***	***0.24***	***0.0593***	***0.0576***
Venus	***0.72***	***0.62***	***0.3732***	***0.3844***
Earth	***1.00***	***1.00***	***1.000***	***1.000***
Mars	***1.52***	***1.88***	***3.5118***	***3.5344***
Jupiter	***5.20***	***11.86***	***140.61***	***140.66***
Saturn	***9.54***	***29.4***	***868.25***	***867.89***

Kepler's Third Law

The (orbital period)^2 is proportional to (semi-major axis)^3

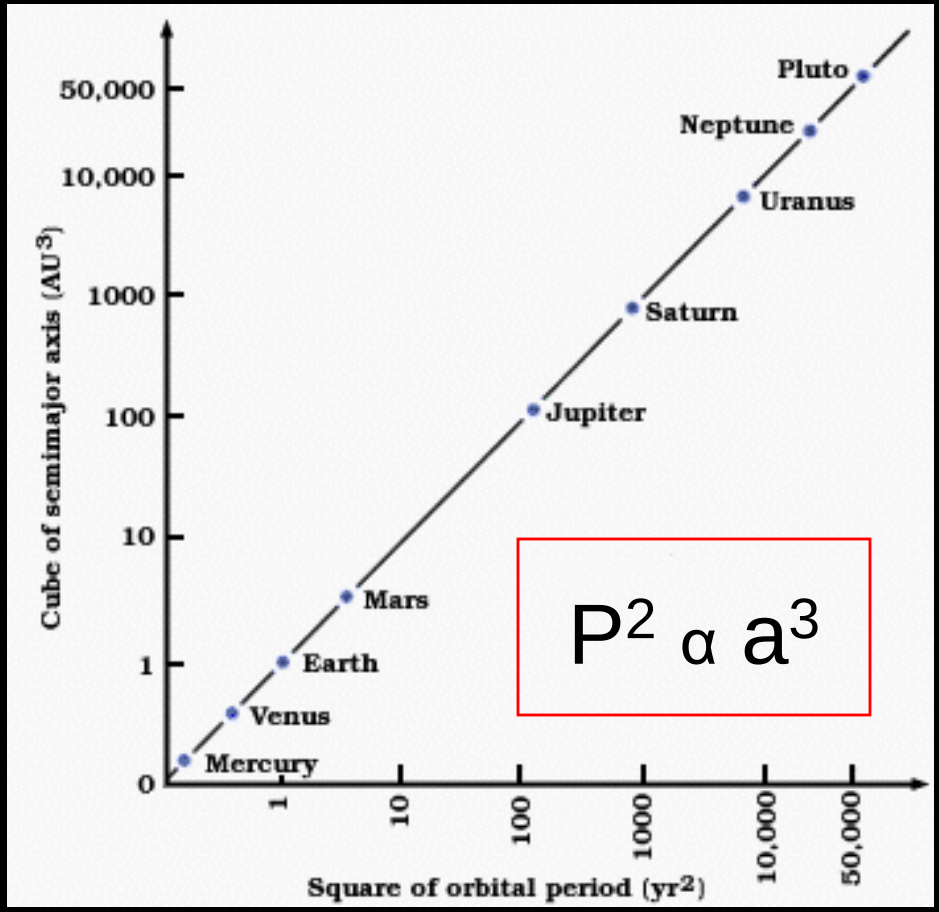
The planets we now know

	semi-major axis *a* (AU)	period P (years)	a^3	P^2
Mercury	***0.39***	***0.24***	***0.0593***	***0.0576***
Venus	***0.72***	***0.62***	***0.3732***	***0.3844***
Earth	***1.00***	***1.00***	***1.000***	***1.000***
Mars	***1.52***	***1.88***	***3.5118***	***3.5344***
Not a planet *Asteroid belt*	***2.77***	***4.60***	***21.254***	***21.160***
Jupiter	***5.20***	***11.86***	***140.61***	***140.66***
Saturn	***9.54***	***29.4***	***868.25***	***867.89***
Uranus	***19.19***	***84.07***	***7,066***	***7,068***
Neptune	***30.06***	***164.80***	***27,162***	***27,159***
Not a planet *Pluto*	***39.60***	***248.60***	***62,099***	***61,802***

Kepler's Third Law

The (orbital period)^2 is proportional to (semi-major axis)^3

If you know the orbital period of a planet in the Solar System you can use Kepler's 3rd Law to determine its distance from the Sun relative to Earth's distance (1 AU)



A scientist's inspiration

"Hooke"d on a problem

Halley, architect *Christopher Wren* and physicist *Robert Hooke*

talked in January 1684 and Hooke claimed to have derived Kepler's Laws of planetary motion

A scientist's inspiration

"Hooke"d on a problem

Hooke could not produce his general derivation and *Halley* was suspicious of the claim

This spurred him to raise the problem in August 1684 with his friend *Newton* who was inspired by Halley's interest and enthusiasm

A scientist's inspiration

"Hooke"d on a problem

Hooke could not produce his general derivation and *Halley* was suspicious of the claim

This spurred him to raise the problem in August 1684 with his friend *Newton* who was inspired by Halley's interest and enthusiasm

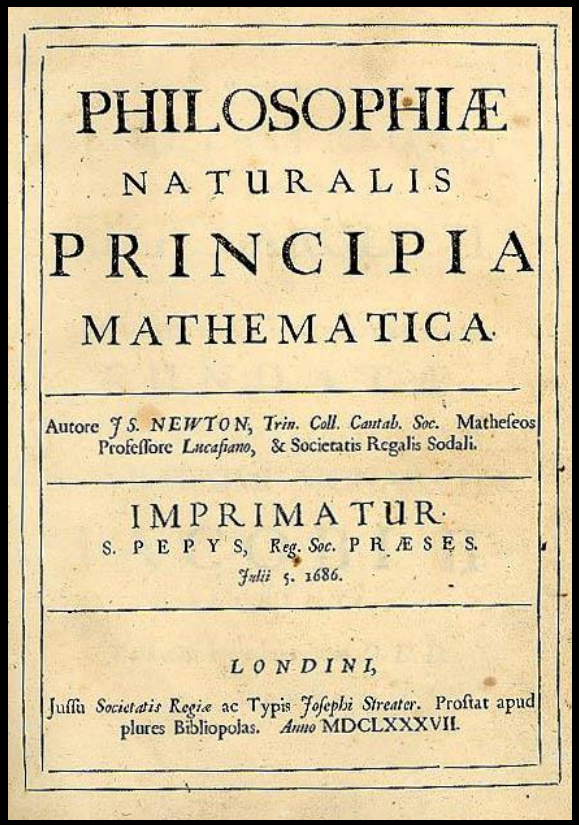
In November 1684, *Newton* presented *Halley* with a 9-page manuscript "*De moto corporum in gyrum*" ("Of the motions of a body in orbit") – Kepler's laws derived with an inverse-square force

A scientist's inspiration

"Hooke"d on a problem

Halley was impressed and pleaded with *Newton* to present more such work to the Royal Society

Newton was consumed by this and spent the next two years writing what would become *Philosophiæ Naturalis Principia Mathematica*



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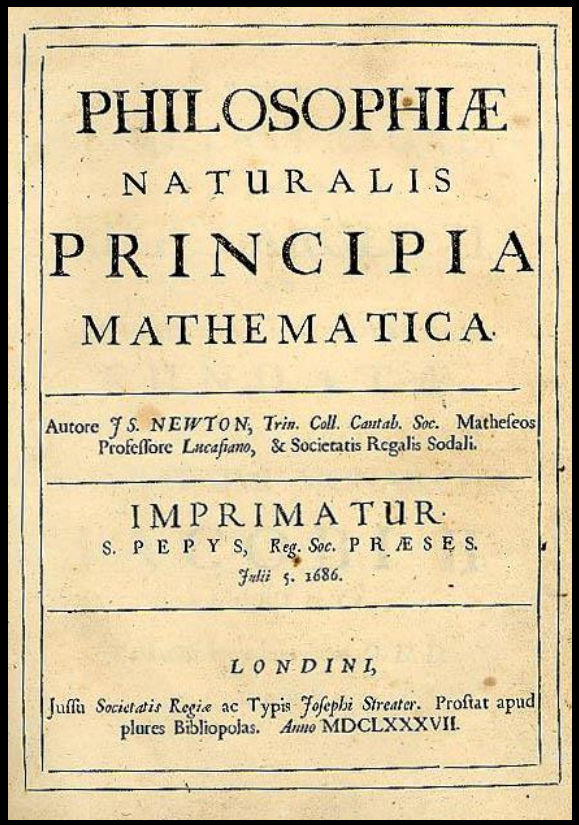
Halley was impressed and pleaded with *Newton* to present more such work to the Royal Society

Newton was consumed by this and spent the next two years writing what would become *Philosophiæ Naturalis Principia Mathematica*


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore *J. S. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

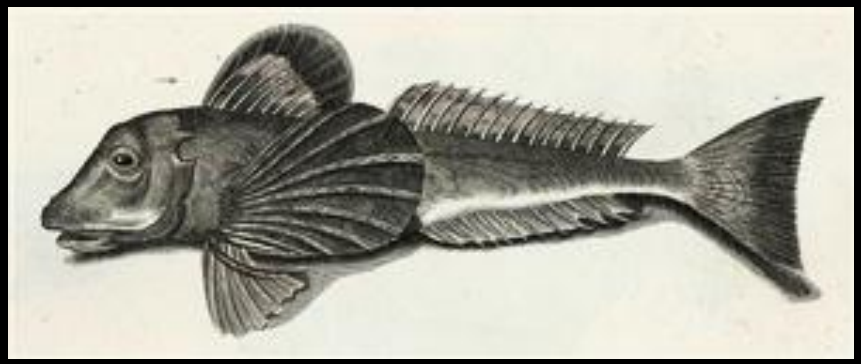
IMPRIMATUR
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

But this is NOT the end of the story

A scientist's nightmare

Hooked on a fish



This is a red gurnard as depicted in *Francis Willughby's* *De Historia Piscium* ("The History of Fishes")

A scientist's nightmare

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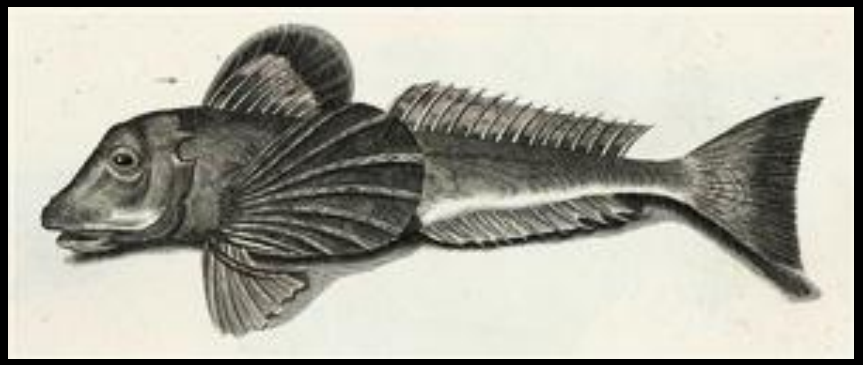

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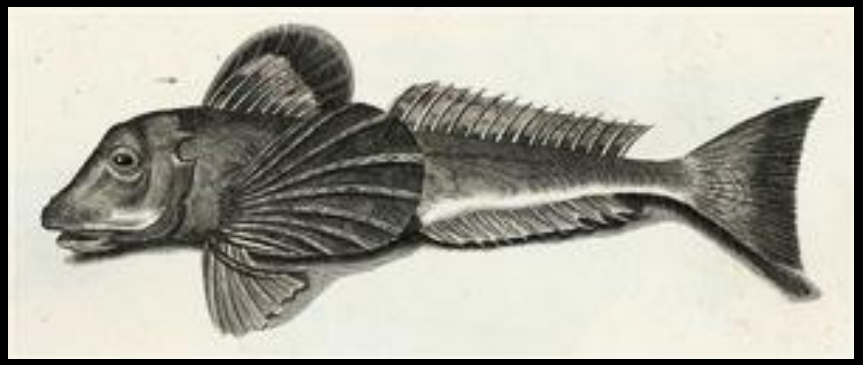
The Royal Society consumed almost their entire budget in 1686 to publish "The History of Fishes" which was a commercial disaster

They had no money left to publish *Principia*

A scientist's saviour

Off the hook



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They had no money left to publish *Principia*

Halley stepped in and underwrote the publication of the first edition

5 July 1687

What about my original question?

What's the connection between *gravity* and *life insurance*?

insurance salesman

The Halley connection

Halley was a very clever scientist !!!

Sir Edmond Halley
was the 'inventor' of *life insurance*

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Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.
1	1000	8	680	15	628	22	586	29	539	36	481
2	855	9	670	16	622	23	579	30	531	37	472
3	798	10	661	17	616	24	573	31	523	38	463
4	760	11	653	18	610	25	567	32	515	39	454
5	732	12	646	19	604	26	560	33	507	40	445
6	710	13	640	20	598	27	553	34	499	41	436
7	692	14	634	21	592	28	546	35	490	42	427
Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.
43	417	50	346	57	272	64	202	71	131	78	58
44	407	51	335	58	262	65	192	72	120	79	49
45	397	52	324	59	252	66	182	73	109	80	41
46	387	53	313	60	242	67	172	74	98	81	34
47	377	54	302	61	232	68	162	75	88	82	28
48	367	55	292	62	222	69	152	76	78	83	23
49	357	56	282	63	212	70	142	77	68	84	20

Age.	Persons.
7	5547
14	4584
21	4270
28	3964
35	3604
42	3178
49	2709
56	2194
63	1694
70	1204
77	692
84	253
100	107
	34000

Sum Total.

The first actuarial table

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From "An estimate of the degrees of the mortality of mankind, drawn from curious tables of the births and funerals at the city of Breslaw; with an attempt to ascertain the price of annuities upon lives" (1693)

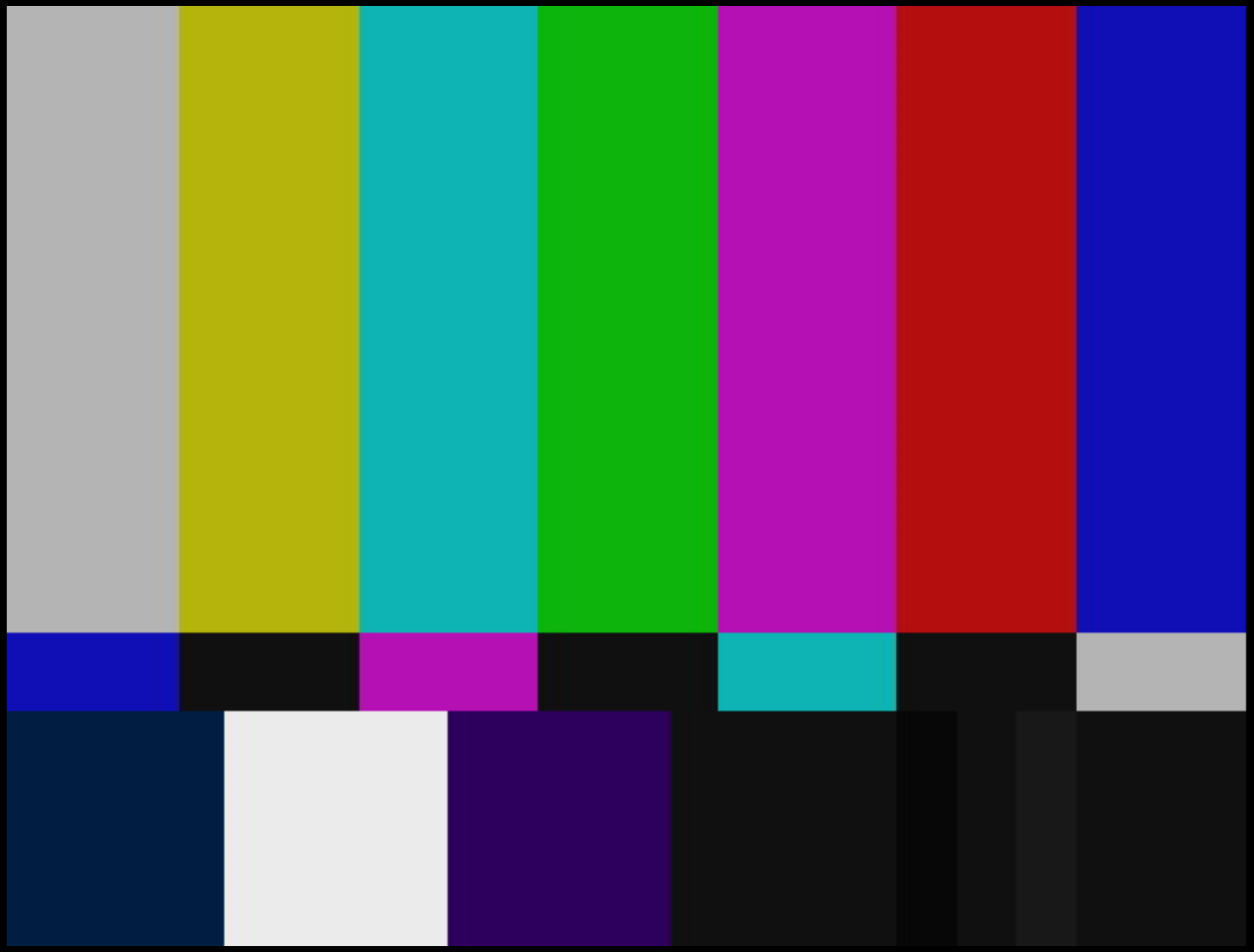
The first actuarial table

A Physics Trivial Pursuit question?

Q. What's the connection between *gravity* and *life insurance*?

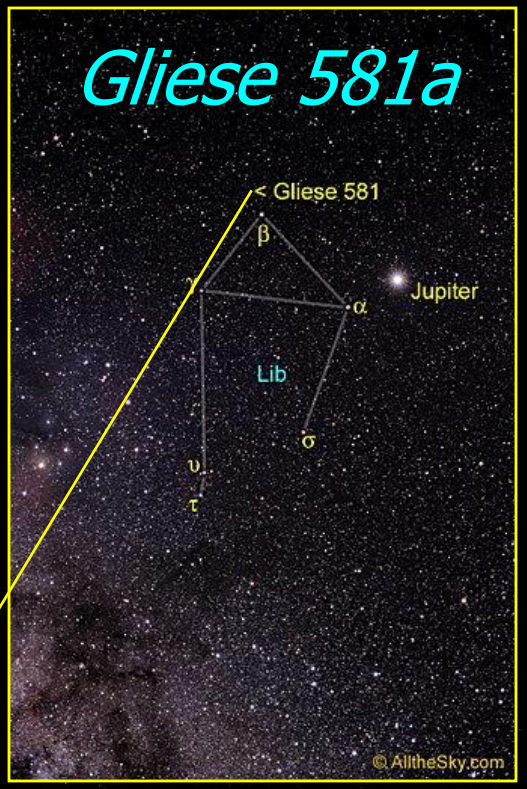
A. Halley, friend and funder of Newton, and a clever scientist in his own right

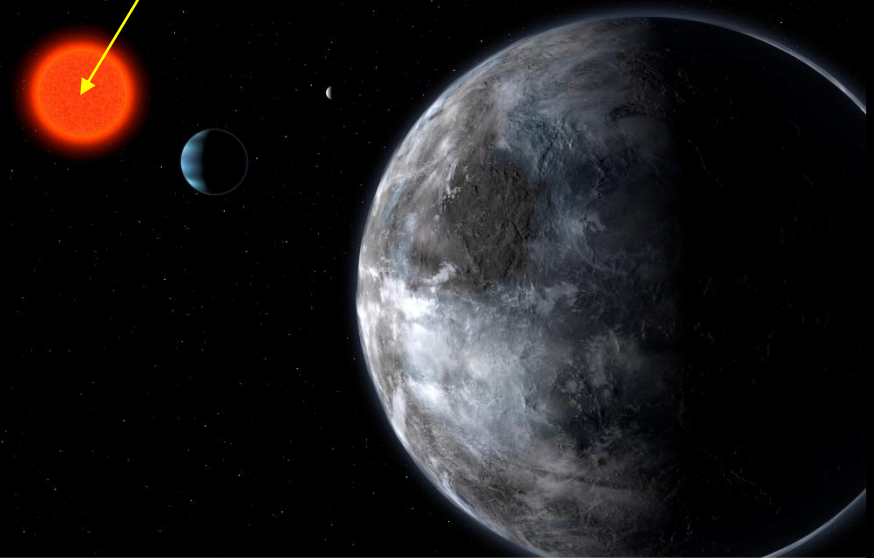
Back to our regular programming



A habitable world?

- ✓ *Swiss astronomers discovered three planets around a dim red dwarf*
  - ➢ *one of these planets may be in the habitable zone*





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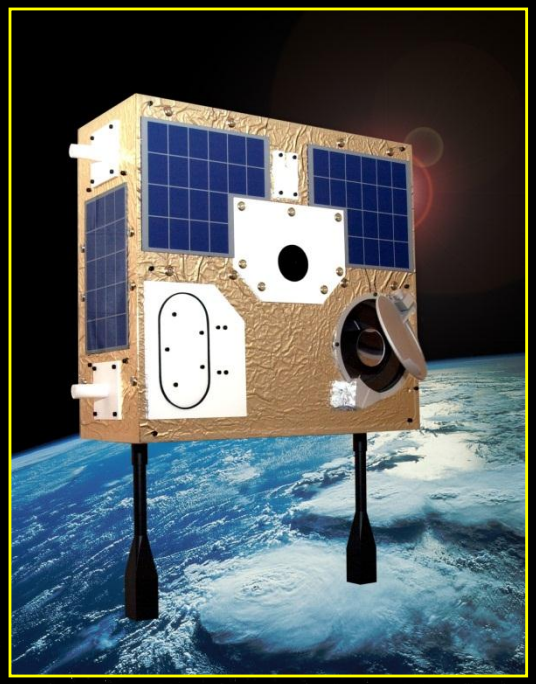

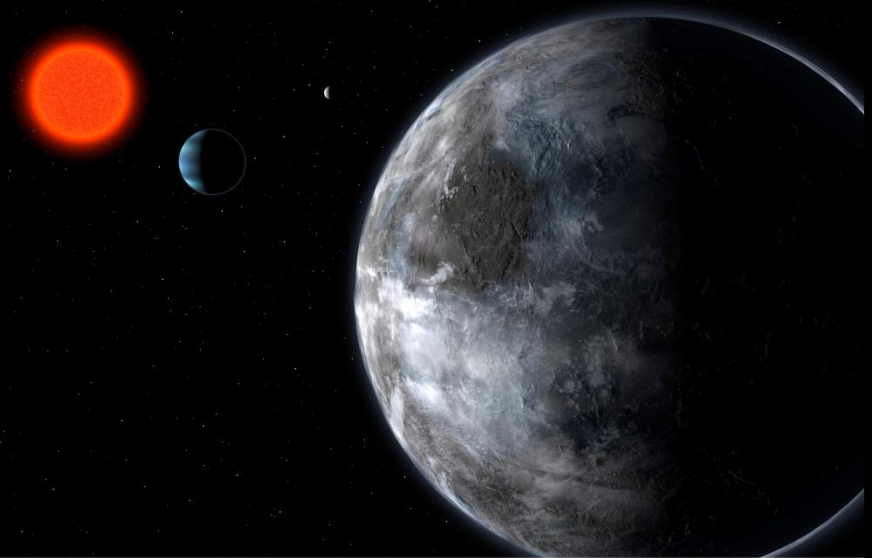

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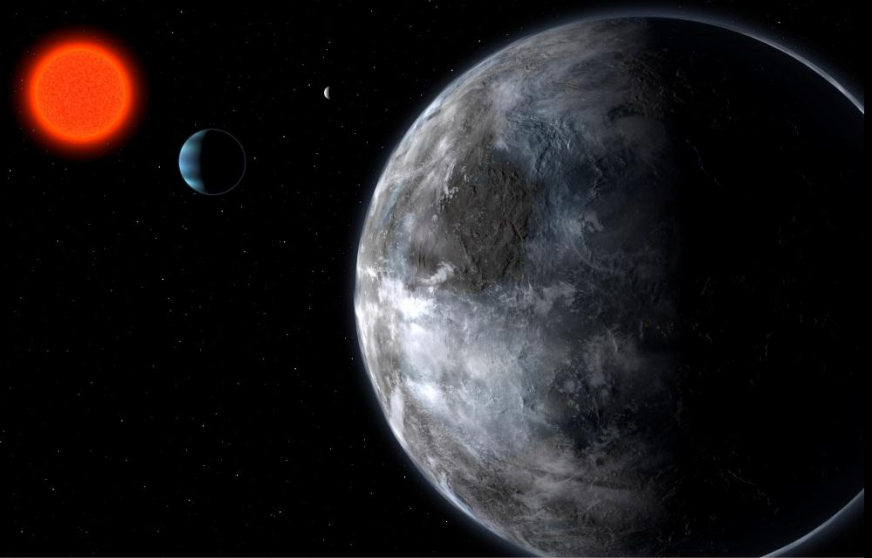

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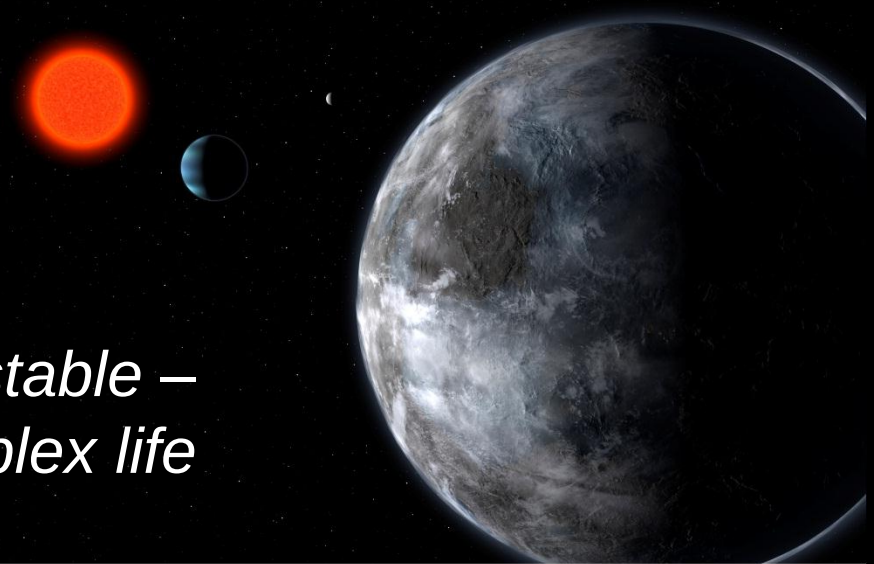
- ✓ *"Boring" is good for life*
  The red dwarf star is old and stable – conditions favourable for complex life



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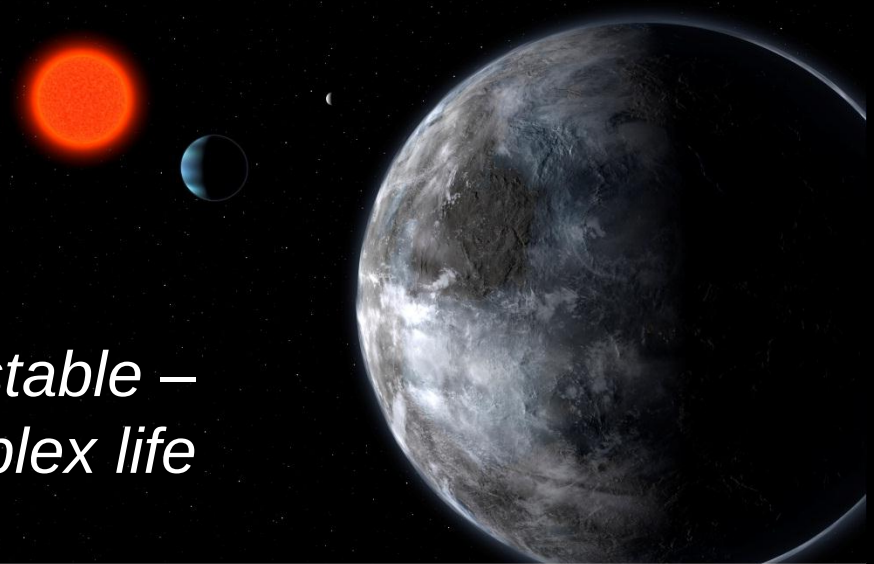
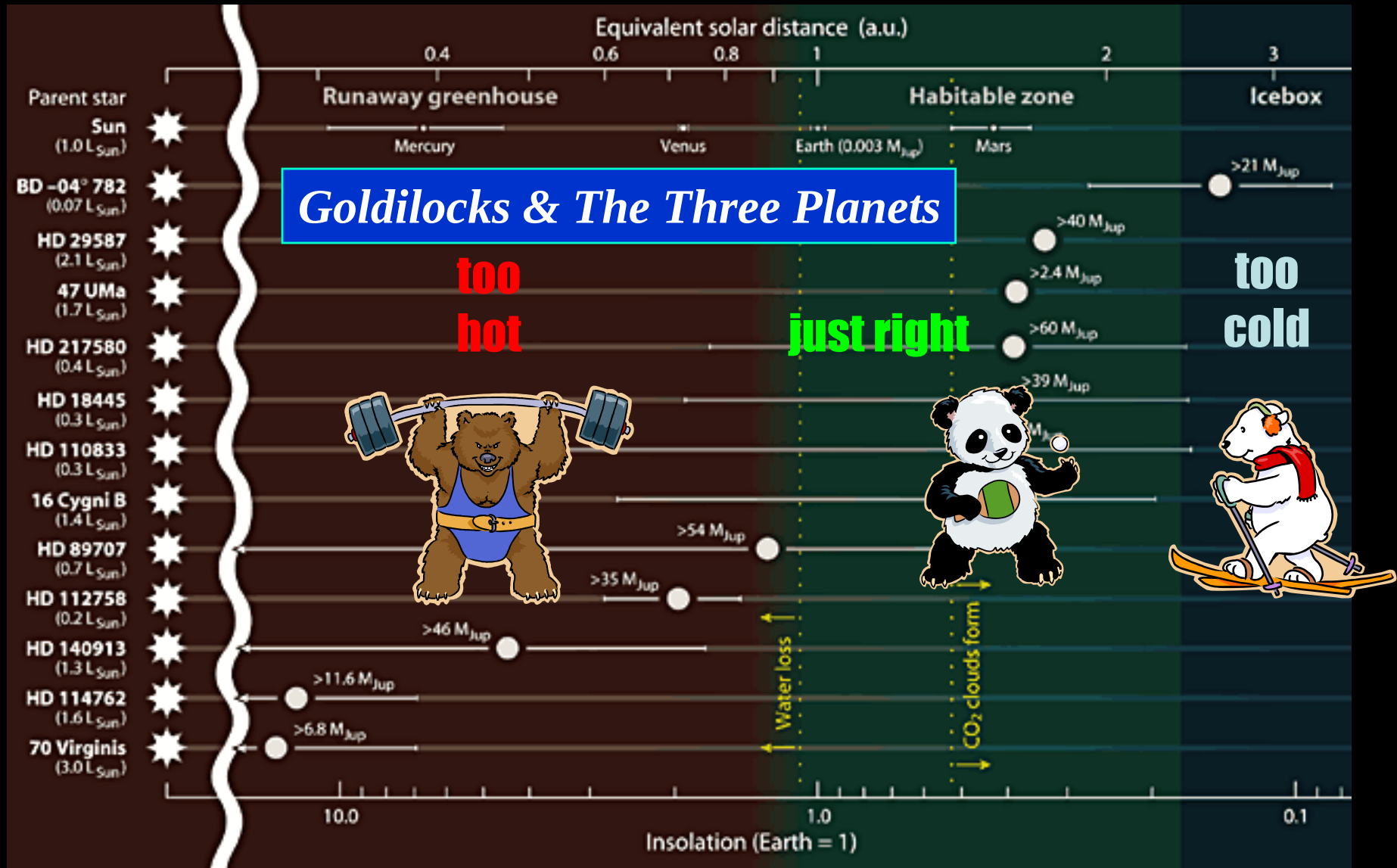
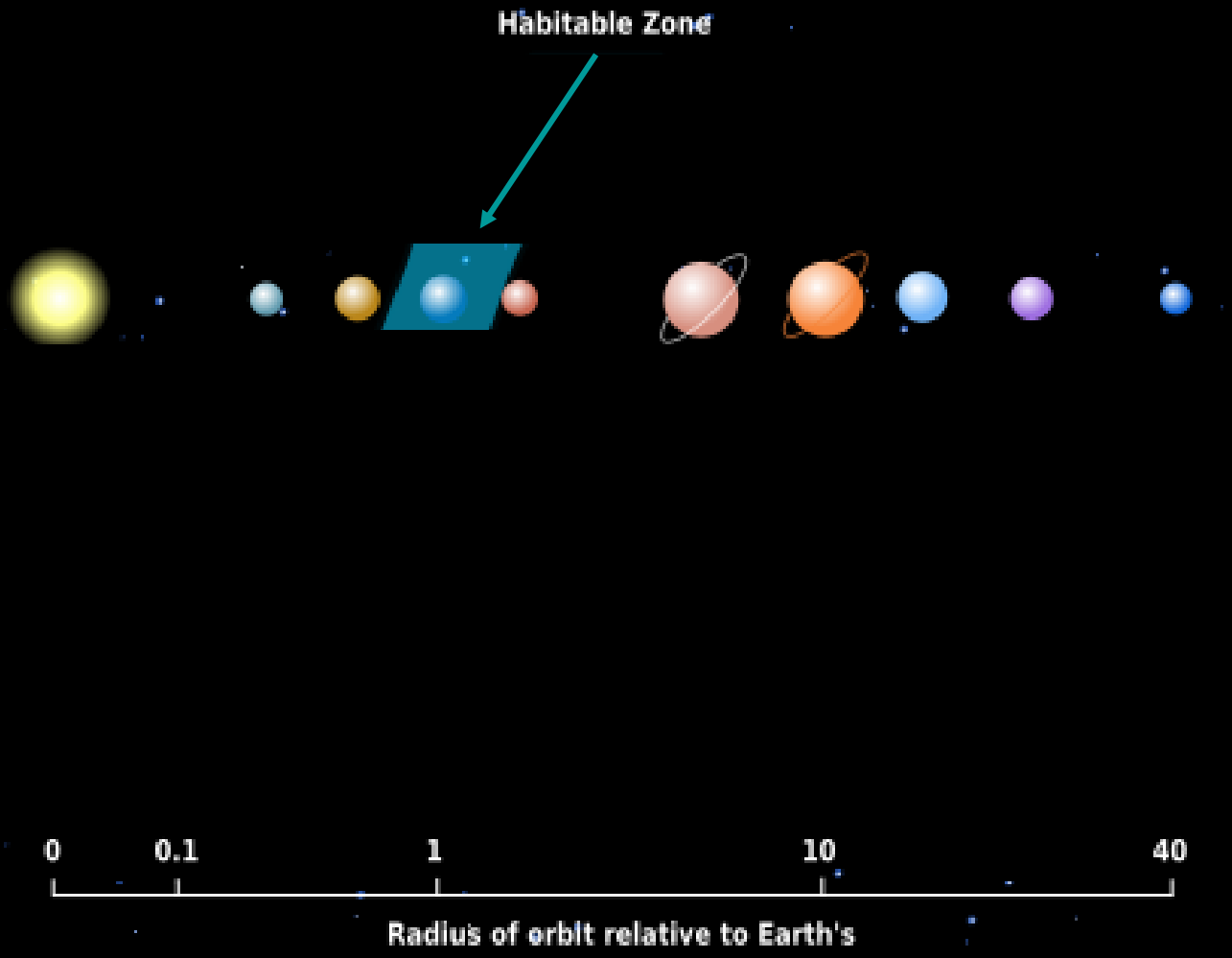


Habitable exoplanets?

The question of life out there: A fairy tale?

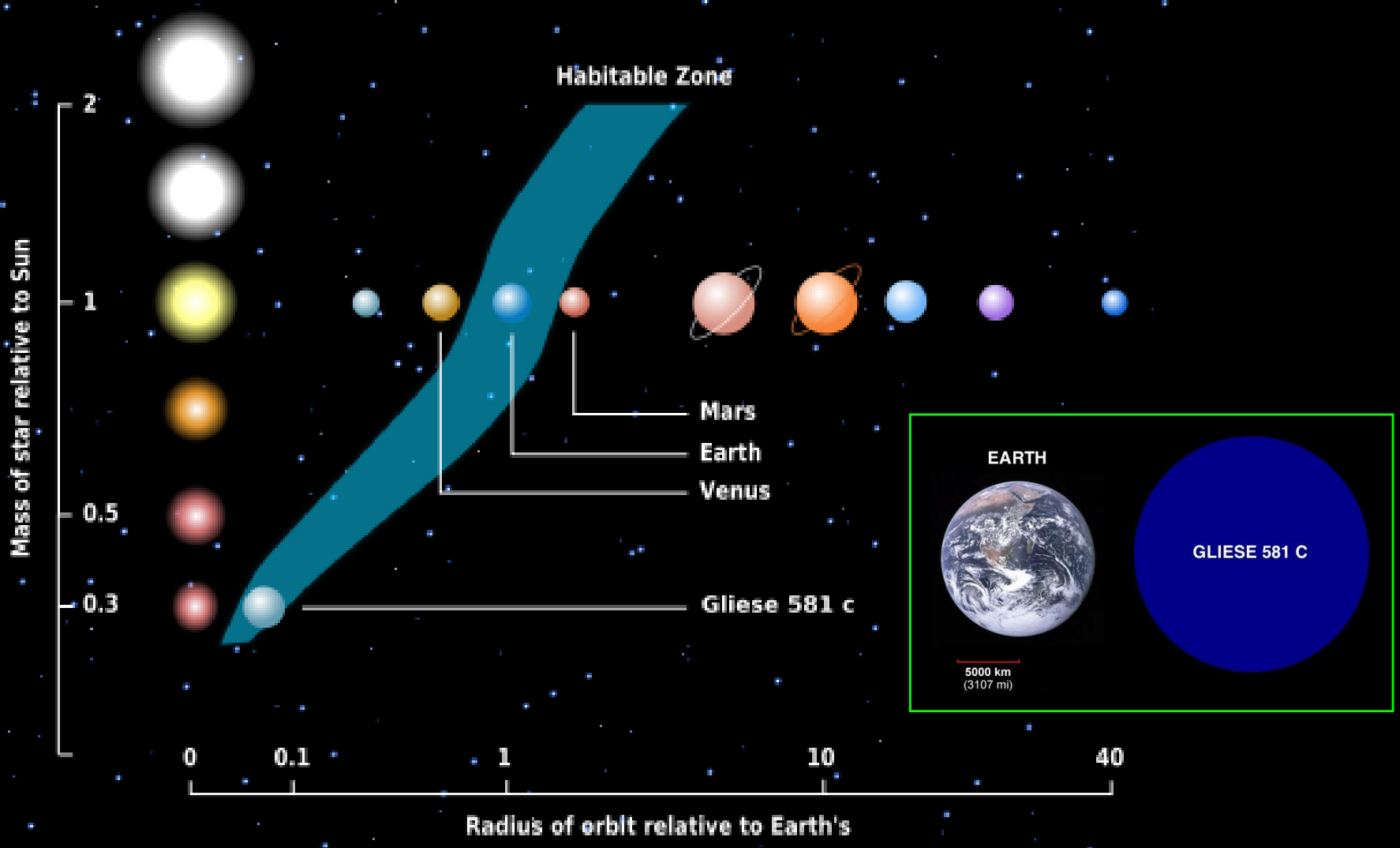


Habitable exoplanets?

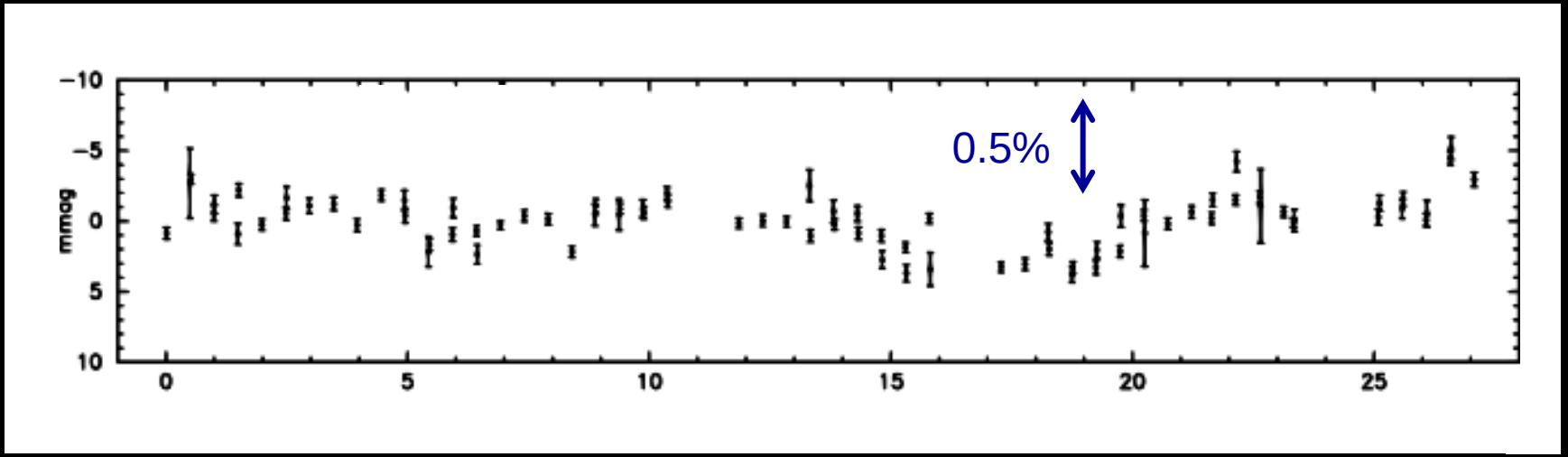


Habitable exoplanets?

Gliese 581c

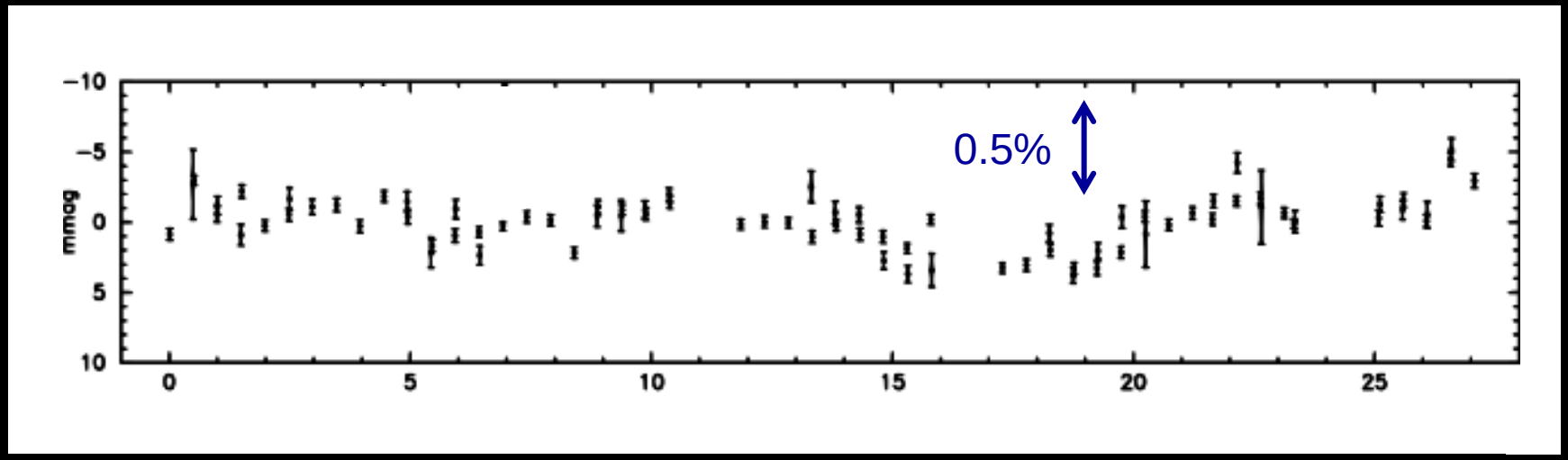


Gliese 581a: A boring red dwarf

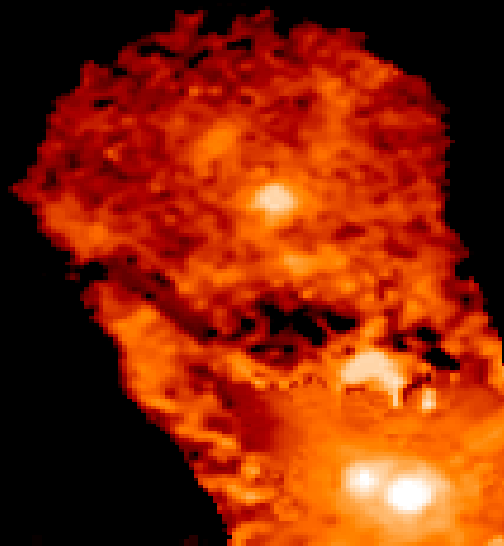


- ✓ *light from star steady over 2 months < 0.5%*
  - ➢ *our Sun is stable at this level*

Gliese 581a: A boring red dwarf



- ✓ *light from star steady over 2 months < 0.5%*
  - ➢ *our Sun is stable at this level*
- ✓ *no violent flares*



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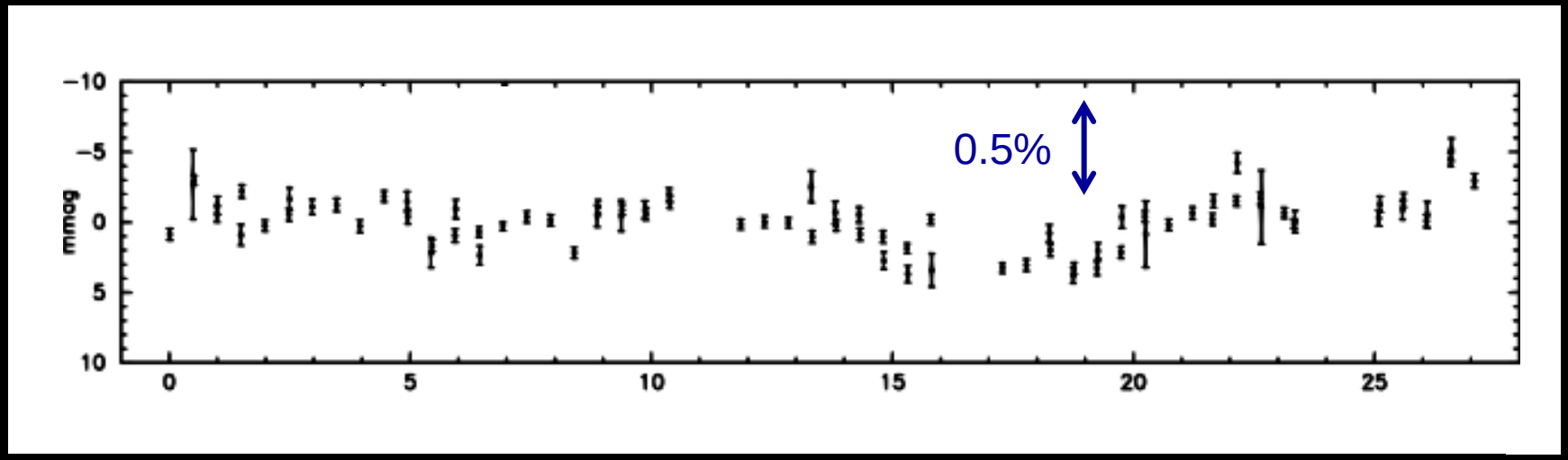


- ✓ *light from star steady over 2 months < 0.5%*
  - ➢ *our Sun is stable at this level*
- ✓ *no violent flares*
- ✓ *old star, age > 3 billion years*
  - ➢ *enough time for complex life to evolve*

Exoplanets and climate change

Gliese 581c

climate change models

von Bloh et al. 2007
Potsdam Institute for Climate Change Research

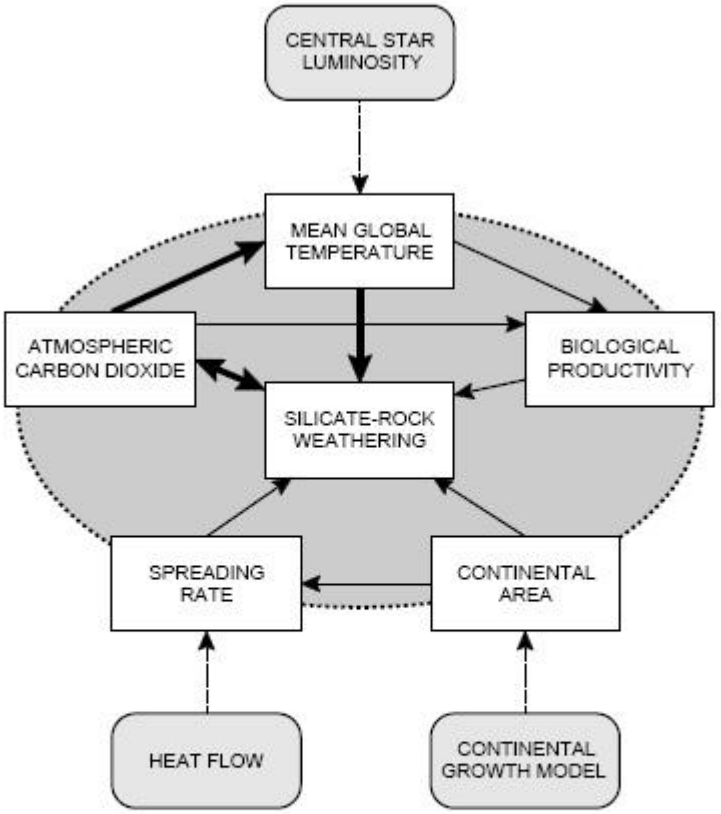
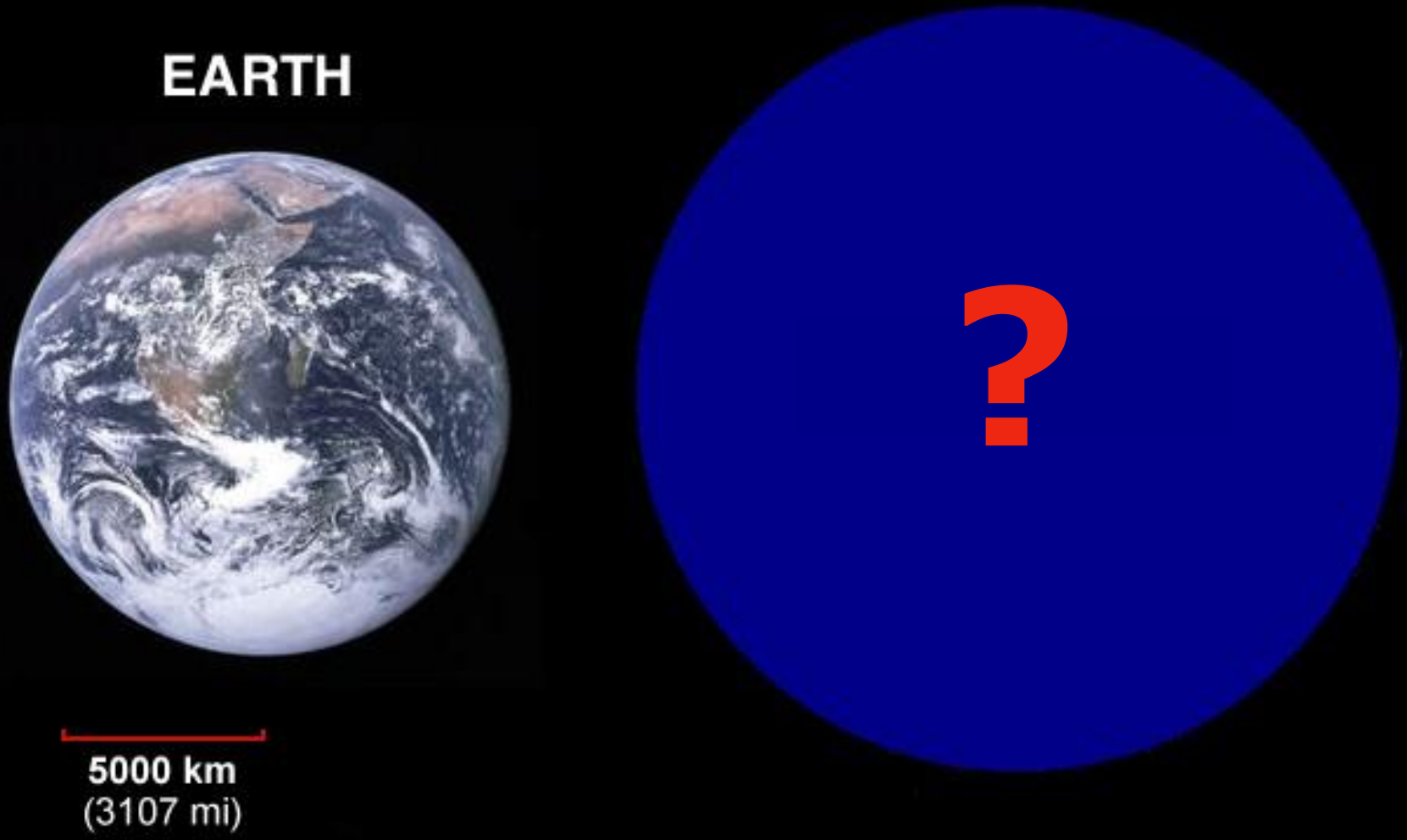


Fig. 1. Earth system box model. The arrows indicate the different forcing and feedback mechanisms. The bold arrows indicate the negative feedback stabilising the planetary climate.

Travelling on the MOST transit system

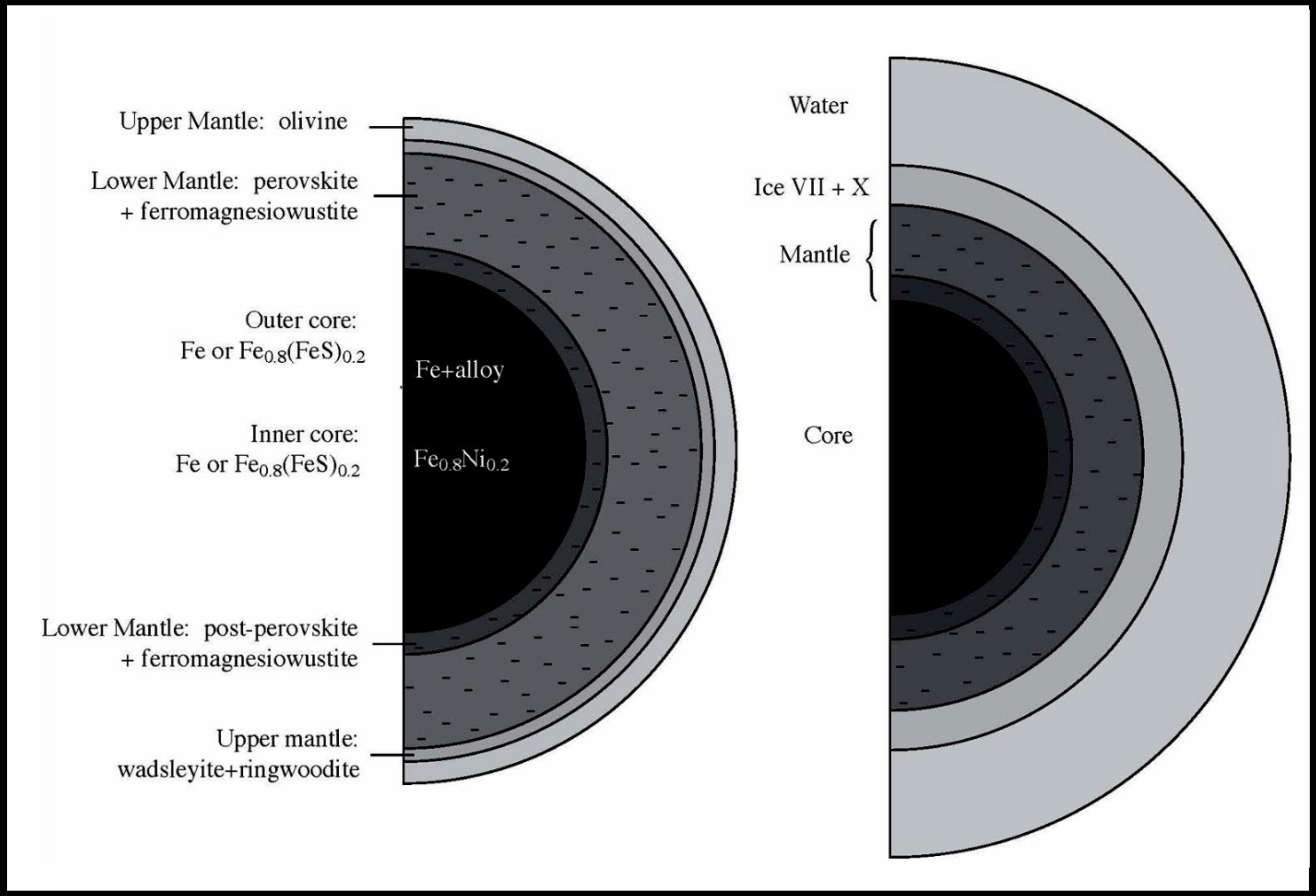
Gliese 581c

Gliese 581c



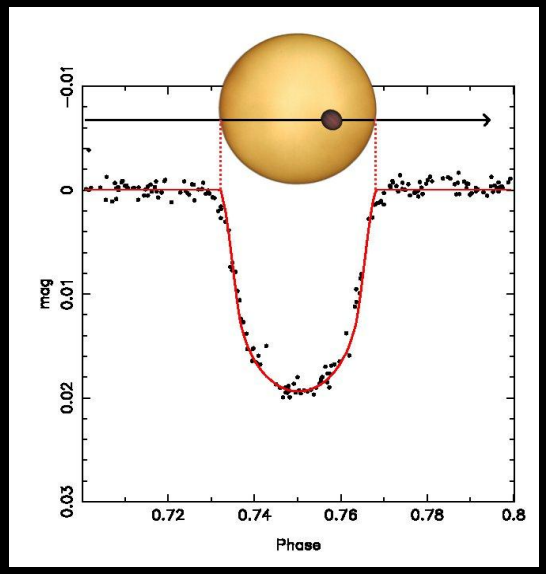
superEarth models

Earth-like *Ocean Planet*



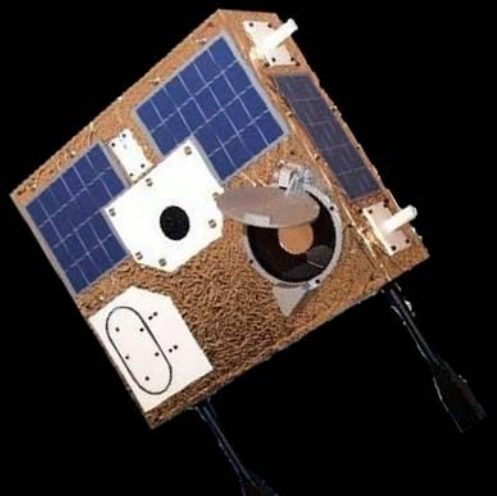
Valencia, Thomsen & Sasselov 2007

superEarth transits



Planet Transit Depths

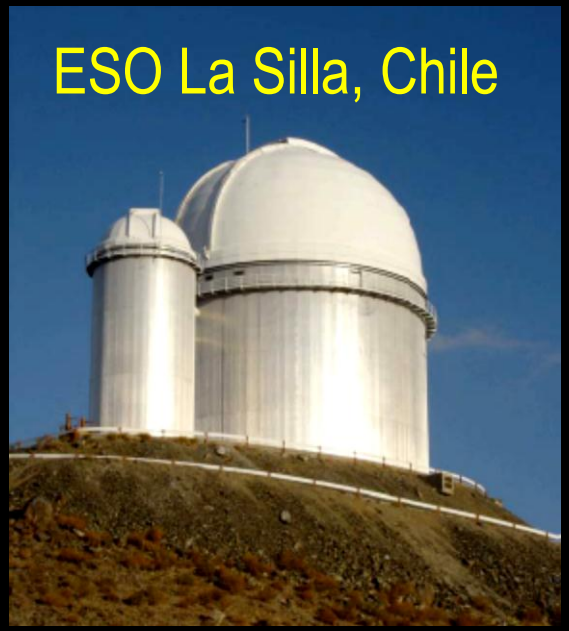
- ✓ superEarth model: *455 ppm*
- ✓ 20% ocean planet: *540 ppm*
- ✓ 40% ocean planet: *600 ppm*
- ✓ superMercury model: *380 ppm*



MOST will be able to tell the difference!

superEarth transits

- ✓ Geneva team (Major, Queloz, Lovis, Udry et al.)
  → *HARPS spectrograph radial velocity survey*



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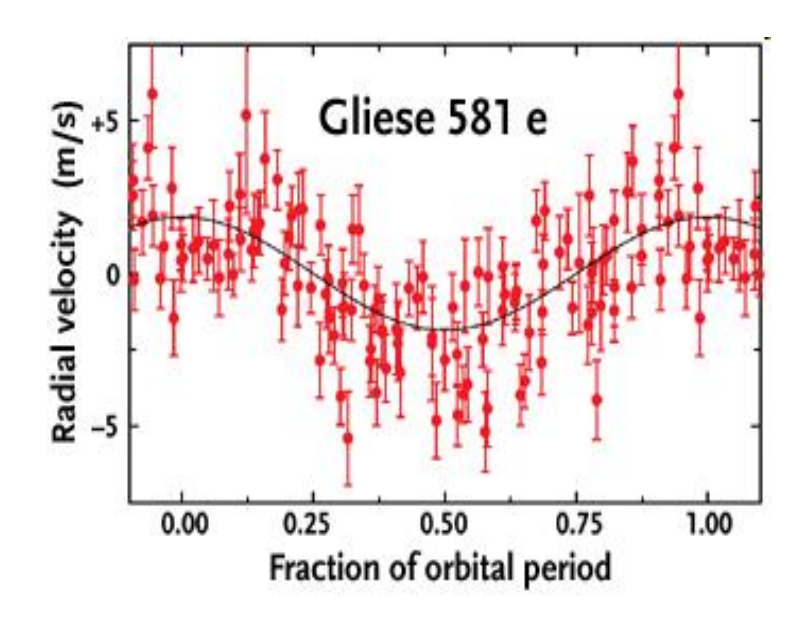
- ✓ MOST monitoring those in its CVZ



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HARPS
New Earth Facility
William Herschel Telescope

Harvard CfA
with Obs. Geneve