COSMOS

The infographic book of space

Stuart Lowe & Chris North

Cosmos

The infographic book of space

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Contents

Introduction

Space and astronomy are subjects that can really grab the imagination - something they did to both of us at an early age. Many of the detailed explanations may seem complex, and sometimes rather subtle, but the basic ideas are familiar to us all at some level. The scales and distances can be so vast as to be all but unimaginable, and simply writing out huge numbers is not always helpful.

In this book we've tried to display the processes and concepts in a visual way, allowing the ideas to be easily viewed without hiding the details. Where possible we show the data to scale. For example, in 'Journey to the Moon' the Earth, Moon and the size of the Moon's orbit are all to scale. However, given the vast range of sizes and ideas in astronomy, that isn't always achievable within the confines of the page. So there are instances where we have used logarithmic scaling or, in the most extreme cases, abstracted the scale entirely.

We've ranged from human exploration of the Earth and Moon, to the way galaxies are scattered throughout the cosmos over scales of billions of light years; from the building of telescopes to observe the heavens, to humanity's attempts to contact alien civilisations. Whatever your knowledge of space and astronomy, there's bound to be something to interest you.

The graphics are based on as up-to-date knowledge and research as possible. Most of the data sets are valid up to the end of 2014. As is the nature of a field of active research, new discoveries are made and our knowledge moves on so some aspects could very well be out-of-date by the time of printing. We'll keep track of updates, as well as provide interactive versions of some infographics, at cosmos-book.github.io.

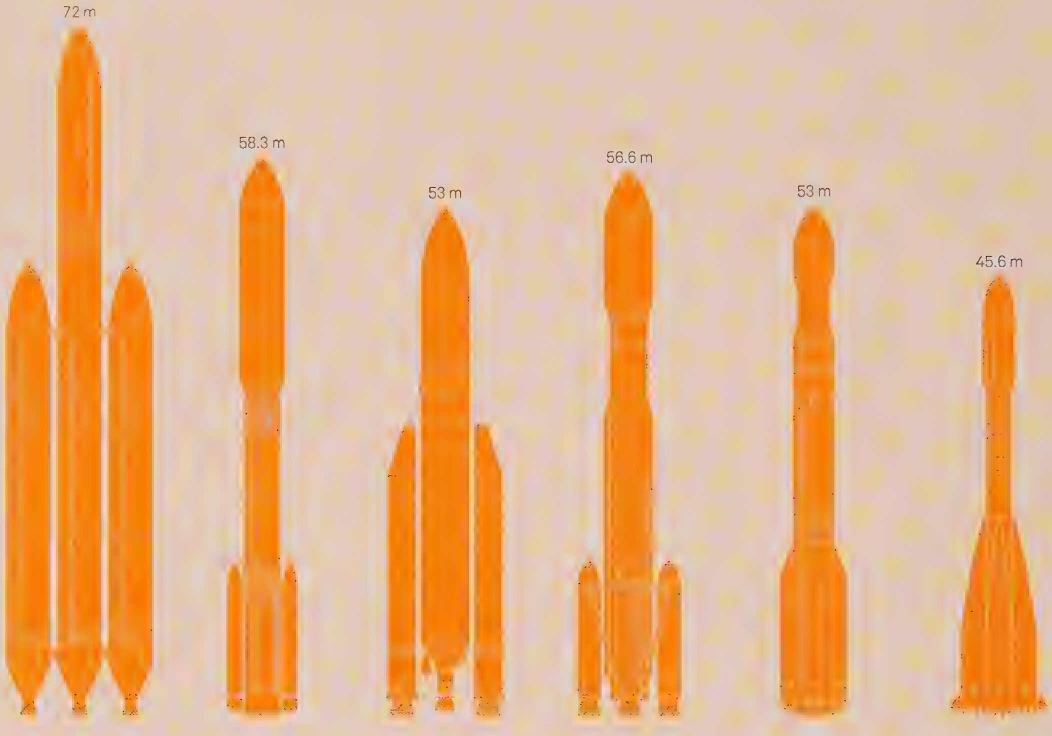
While both of us are astronomers, our professional research has been focussed on relatively narrow fields, so some areas of the book were relatively new to us when we started. We have, however, both hugely enjoyed public communication of astronomy, from podcasts and websites, to radio and TV programmes. This outreach work spans fields spread across almost all of astronomy, but despite this experience we have both learned an awful lot compiling this book. We hope you enjoy reading it as much as we enjoyed writing it!

Stuart Lowe & Chris North
March 2015

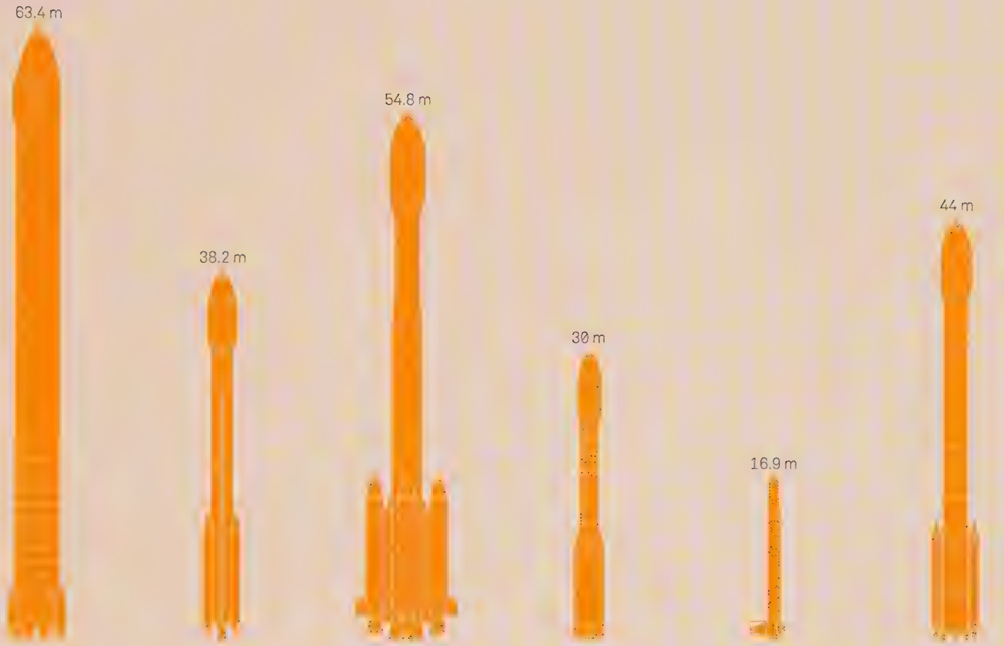
One / Space exploration

Launch vehicles

If you want to launch something into space you have a range of options, from government space agencies to private companies. The cost depends on how much you want to send up, how far up you want to send it, and how much risk you are willing to take.



Name	Delta IV Heavy	Atlas V	Ariane 5	H-IIB	Proton-M	Soyuz-U
Launch site	NASA / Kennedy Space Center, California	NASA / Kennedy Space Center, California	ESA / Guiana Space Centre, French Guiana	JAXA / Tanegashima Space Center, Japan	Roscosmos / Plesetsk Cosmo-drome, Russia	Roscosmos / Plesetsk Cosmo-drome & Guiana SC
First launch	2004	2002	1996	2009	1999	1973
Launch cost, £	200 million	150 million	100 million	80 million	60 million	60 million
Success rate	95%	98%	96%	95%	88%	98%
Mass to Low-Earth Orbit, tonnes	28.8	18.5	21	16.5	21.6	6.9
Mass beyond Low-Earth Orbit, tonnes	14	8.7	10	8	6.2	2.9
Payload diameter, metres	5	3.5	5.5	5	4	3

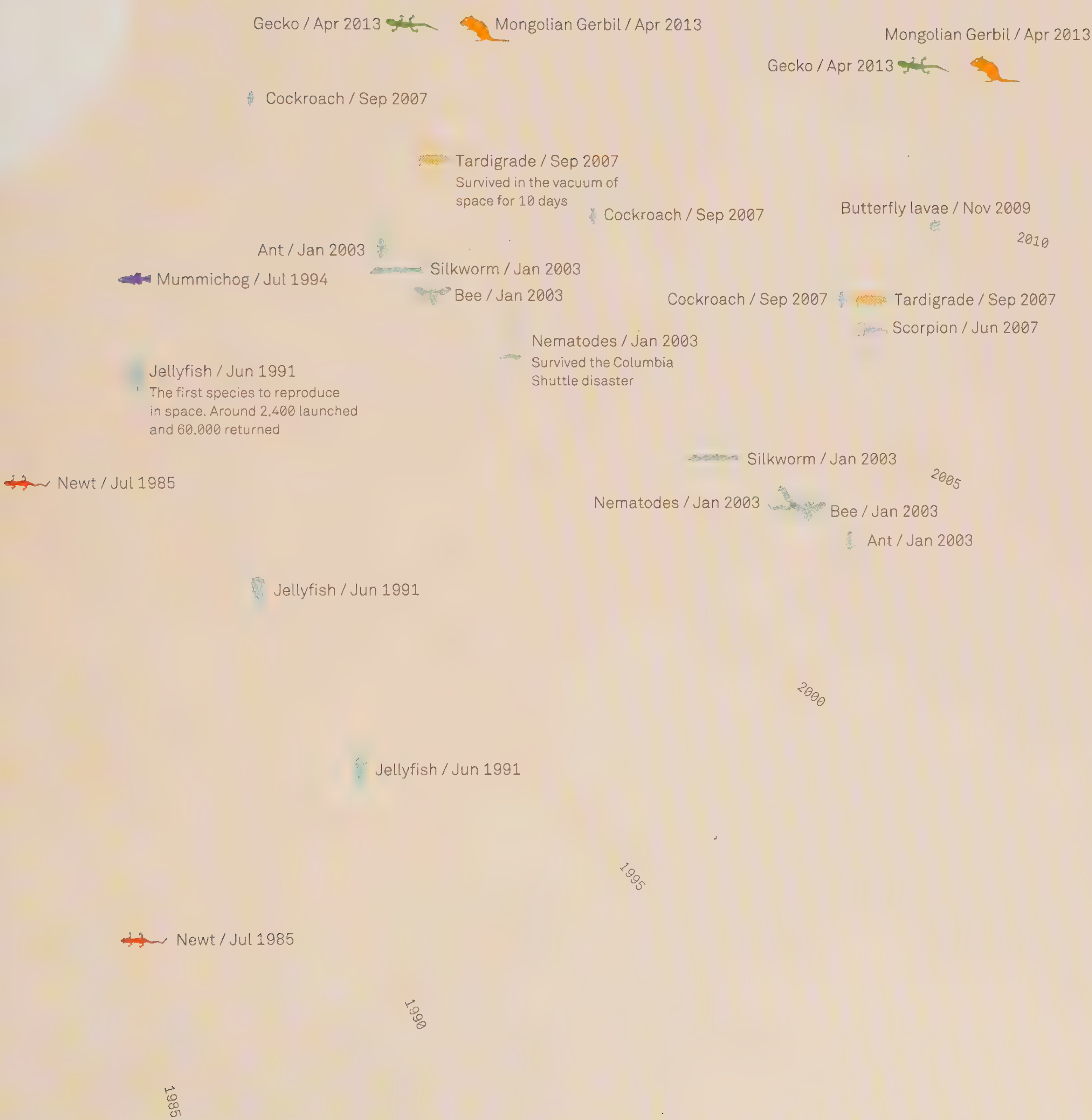


Name	Falcon 9	Delta II	Long March 3B	Vega	Pegasus	PSLV
Launch site	NASA / Kennedy Space Center, California	NASA / Kennedy Space Center, California	CNSA / Xichang Satellite Launch Center, China	ESA / Guiana Space Centre, French Guiana	Orbital / Carrier Aircraft	ISRO / Satish Dhawan Space Centre, India
First launch	2013	1990	1996	2012	1990	1993
Launch cost, £	40 million	30 million	30 million	23 million	15 million	11.4 million
Success rate	97%	99%	75%	98%	92%	96%
Mass to Low-Earth Orbit, tonnes	13.2	5	11.5	1.4	0.4	3.8
Mass beyond Low-Earth Orbit, tonnes	4.9	1.8	5.5	0	0	1.3
Payload diameter, metres	3.5	3	3.5	3	1.2	3.2

One small step for...

Humans are not the only, or even the first, species to venture into space. The first recorded space flight was in 1947. Those pioneering astronauts were fruit flies and they returned alive. In 1949 they were followed by the first monkeys in space although it wasn't until 1959 that 'Able' and 'Baker' became the first monkeys to survive spaceflight. In 1951 mice were the first mammals to survive actual space-flight conditions. Close behind, dogs made their first successful trips to space in 1951 and made their first orbital flight in 1957. In March 1961, mice (together with frogs, guinea pigs, and insects) beat humans by a few weeks to be the first animals to successfully orbit the Earth.

In September 1968, three months before *Apollo 8*, *Zond 5* took the first earthlings around the Moon and returned them safely to Earth. The crew included a tortoise, wine flies and meal worms.


Gecko / Apr 2013
Mongolian Gerbil / Apr 2013
Mongolian Gerbil / Apr 2013
Gecko / Apr 2013
Cockroach / Sep 2007
Tardigrade / Sep 2007
Survived in the vacuum of space for 10 days
Cockroach / Sep 2007
Butterfly lavae / Nov 2009
2010
Ant / Jan 2003
Mummichog / Jul 1994
Silkworm / Jan 2003
Bee / Jan 2003
Cockroach / Sep 2007
Tardigrade / Sep 2007
Scorpion / Jun 2007
Nematodes / Jan 2003
Survived the Columbia Shuttle disaster
Jellyfish / Jun 1991
The first species to reproduce in space. Around 2,400 launched and 60,000 returned
Silkworm / Jan 2003
Newt / Jul 1985
2005
Nematodes / Jan 2003
Bee / Jan 2003
Ant / Jan 2003
Jellyfish / Jun 1991
2000
Jellyfish / Jun 1991
1995
Newt / Jul 1985
1990
1985

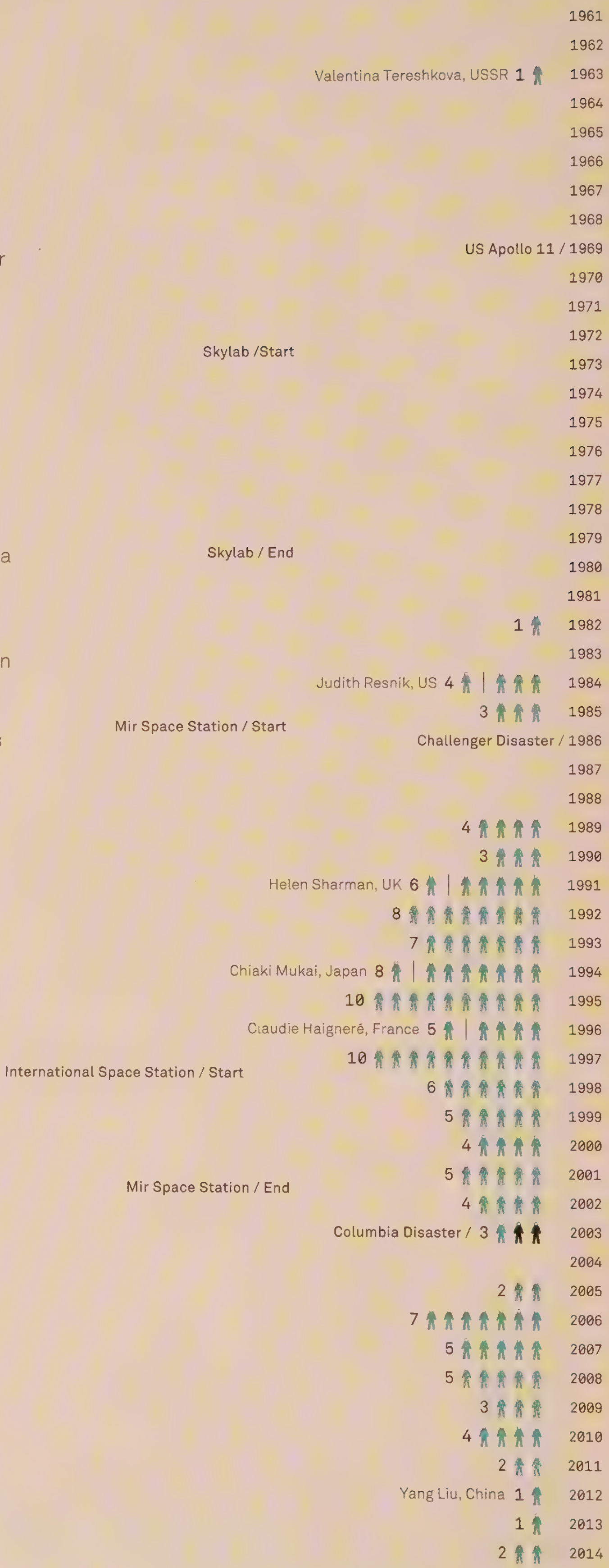
Human spaceflight

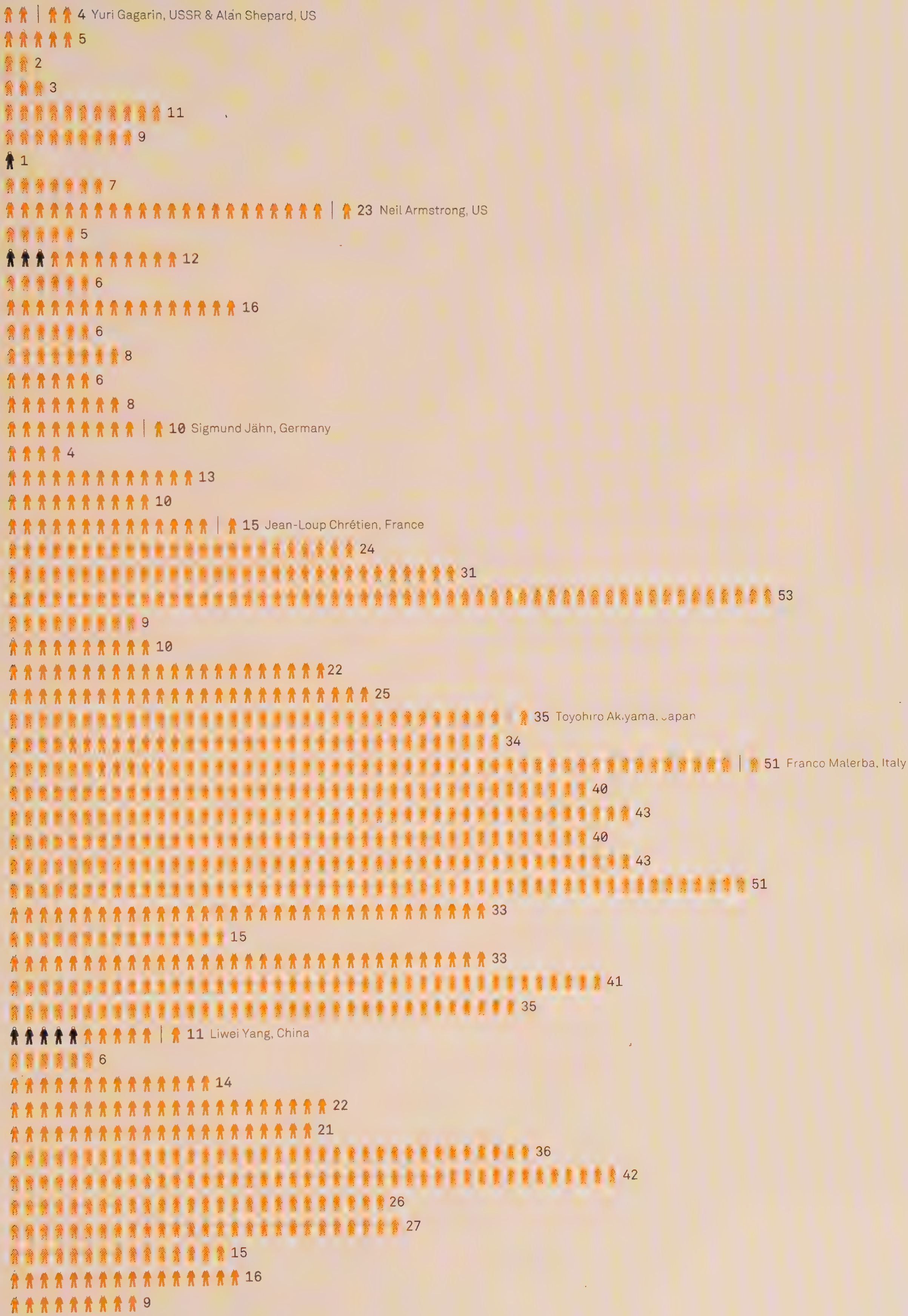
Humans first reached space (defined as 100 kilometres above the surface) in 1961 with the flight of cosmonaut Yuri Gagarin (USSR). The first woman – Valentina Tereshkova (USSR) – followed in 1963. Far from peaking at the time of Apollo, the number of people in space gradually grew during the 1980s and 1990s with the Mir Space Station and Shuttle programmes. Since 31 October 2000 humanity has had a continuous presence in space in the form of the permanently staffed International Space Station.

Thankfully, considering the dangers involved, there have been relatively few deaths in space. In 1967 Vladimir Komarov (USSR) died on impact after a parachute failure during re-entry. Georgi Dobrovolski (USSR), Viktor Patsayev (USSR) and Vladislav Volkov (USSR) all died in 1971 after they undocked from the *Salyut 1* space station to return to Earth. The Space Shuttle Challenger exploded on launch in 1986 killing Greg Jarvis (US), Christa McAuliffe (US), Ronald McNair (US), Ellison Onizuka (US), Judith Resnik (US), Michael Smith (US) and Dick Scobee (US). In 2003 the Space Shuttle Columbia broke up on re-entry, due to a damaged heat tile, killing Michael Anderson (US), David Brown (US), Kalpana Chawla (US), Laurel Clark (US), Rick Husband (US), William McCool (US), and Ilan Ramon (Israel). Both Shuttle accidents resulted in pauses on human spaceflight as the accidents were investigated.

Female Male Fatality

Name, country , notable firsts by country




4 Yuri Gagarin, USSR & Alan Shepard, US
5
2
3
11
9
1
7
23 Neil Armstrong, US
5
12
6
16
6
8
6
8
10 Sigmund Jähn, Germany
4
13
10
15 Jean-Loup Chrétien, France
24
31
53
9
10
22
25
35 Toyohiro Akiyama, Japan
34
51 Franco Malerba, Italy
40
43
40
43
51
33
15
33
41
35
11 Liwei Yang, China
6
14
22
21
36
42
26
27
15
16
9

Travels in time and space

In the 20th Century space travel left the realms of science fiction. These days it is almost routine, even if currently confined to a Low-Earth Orbit. Astronauts regularly spend many months at a time in orbit. At orbital velocity, they circle our planet 16 times a day and cover huge distances.

One interesting feature of travelling at orbital speeds is that time runs slightly slower than it does for those of us on the ground. The result is that astronauts are ever so slightly younger than they'd be if they stayed at home. This effect is tiny (25 milliseconds at most) but is comparable to the gap between the world's top six fastest 100-metre runners.

A **Neil Alden Armstrong, US** / First flight 1966 / Days in space 8.58 / First person to walk on the Moon.

B **Edward Michael Fincke, US** / First flight 2004 / Days in space 381.63 / American with most time in space – 381.63 days.

C **Yuri Alekseyevich Gagarin, USSR** / First flight 1961 / Days in space 0.08 / The first person in space – 1961.

D **Sergei Konstantinovich Krikalyov, USSR** / First flight 1988 / Days in space 803.4 / Has spent the most time in space – 803.4.

E **Valeri Vladimirovich Polyakov, USSR** / First flight 1988 / Days in space 678.69 / Longest single flight at 437.75 days.

F **Charles Simonyi, Hungary** / First flight 2007 / Days in space 26.6 / The space tourist with the most time in space.

G **Anatoli Yakovlevich Soloviyov, USSR** / First flight 1988 / Days in space 651 / Has spent the most time on space walks – 68 hours 44 minutes.

H **Dennis Tito, US** / First flight 2001 / Days in space 7.92 / First space tourist.

I **Koichi Wakata, Japan** / First flight 1996 / Days in space 238.24 / International astronaut with the most time in space – 238.24 days.

J **Peggy Annette Whitson, US** / First flight 2002 / Days in space 376.72 / Woman with the most time in space – 376.72 days.

K **Liwei Yang, China** / First flight 2003 / Days in space 0.89 / First Chinese taikonaut.

- US Astronauts
- Russian Cosmonauts
- Chinese Taikonauts
- International Astronauts
- Space Tourists


A
B
D
E
F
G
H
10 days
100 days
1.000

In TV and movies, people who find themselves suddenly exposed to the vacuum of space often explode or instantly freeze to death. Neither of these scenarios will occur and death won't be instantaneous. We have some idea what will happen based on tests of animals (including humans) as well as accidents that occurred in pressure chambers on the ground and during space-flight.

You will not freeze to death / You will not immediately freeze. Space is a fairly good insulator so there is no conduction/convection. In sunlight, in orbit around Earth, you may radiate energy slightly quicker than you would at room temperature. You will cool slowly.

Blood will not boil / Unless you go into deep shock, the pressure will stay high enough that it won't boil.

Sunburn / If you have no protection, UV radiation from the Sun will give you very bad sunburn.

Partial exposure / If only part of your body is exposed, your chances are better. In 1960 Joe Kittinger Jr exposed his right hand to low pressure on a high-altitude balloon flight. It swelled to twice its size but returned to normal within a few hours.

Sound / After the initial loss of air you won't be able to hear anything.

Abdominal distress / Expansion of gases in your stomach may cause pain. The advice is to pass any excess gas.

A punctured spacecraft / If your spacecraft is ten cubic metres in volume and gets a one square centimetre puncture, it'll take about six minutes for the pressure to drop to half an atmosphere where critical hypoxia starts.

From the moment of the explosive decompression you'll have about 60 – 90 seconds to get back into a pressurised atmosphere if you are to survive. The clock is ticking...

Within five to eleven seconds you will start to lose consciousness so make it count. However, being more active uses up oxygen more quickly.

Around ten seconds you will start to experience 'the bends'.

Approaching 14 seconds, with the reduction in pressure, the boiling point of water drops and the water in your mouth will evaporate. If you are still conscious you'll feel a tingling sensation. Gas and water vapour continue to flow out of your mouth and nose reducing their temperature to near freezing.

By 15 seconds the oxygen-deprived blood will reach the brain. You will now be unconscious so your survival will depend on others helping you.

Water in your soft tissues evaporates causing you to swell to twice your size. If you survive this you should return to normal. Well-fitted elastic garments can help counter some of this swelling. There will probably be bruising but the skin is strong enough not to break so you won't burst.

The nitrogen in the blood forms bubbles due to the low pressure.

After a minute the pressure in the veins exceeds the pressure in the arteries and blood circulation is effectively stopped.

If re-compression occurs within 60 – 90 seconds, survival is possible. However, if heart action has stopped then death is inevitable. The damage to your lungs will be mild to moderate if re-compression occurs within 90 seconds.

Beyond 90 seconds lung damage will become severe with major haemorrhaging and serious brain-damage occurring.

Launch sites

Rockets travel very fast, but they don't necessarily go upwards very far. After all, most satellites are only at altitudes of a few hundred kilometres, but they are travelling at over 20,000 kilometres per hour around the Earth. They also can't change direction very easily, so it's important that they are launched in the correct direction.

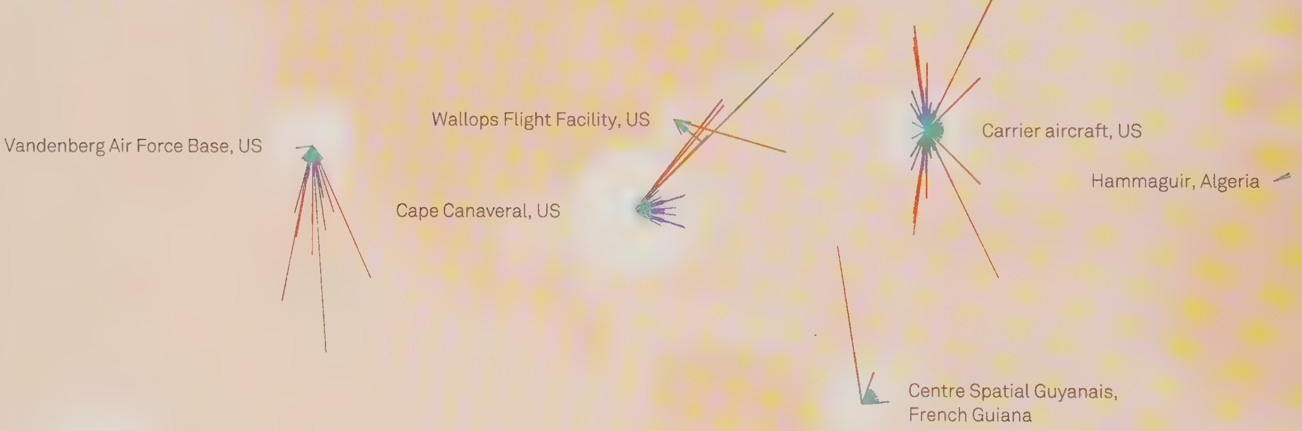
The Earth's equator is spinning at over 1,600 kilometres per hour in an easterly direction. Many launch sites are close to the equator, using this 'free' speed boost to reduce the amount of fuel required to reach equatorial orbits. To avoid the risk of damage to people or property, most launches take place over the sea.

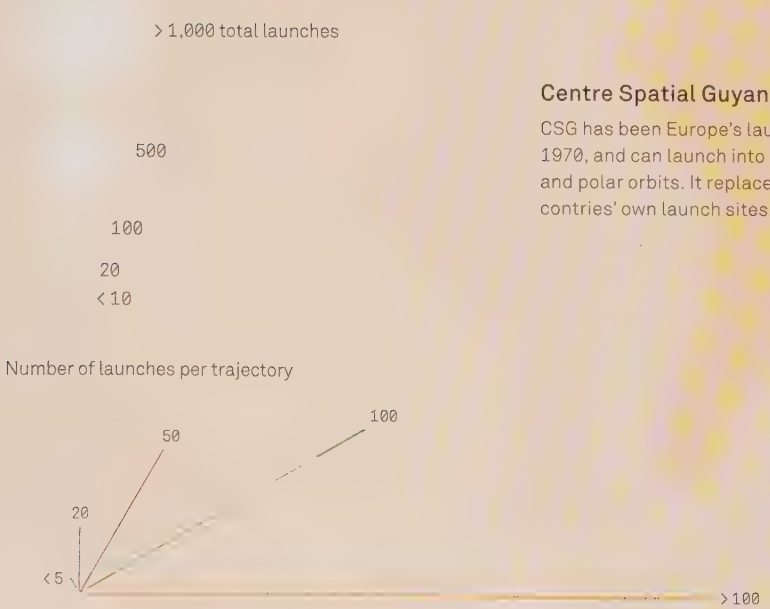
United States

Cape Canaveral, home to the Kennedy Space Center, is arguably the most famous launch site in the world. While this makes it ideal for reaching the International Space Stations's orbit, it can't be used for polar orbits. Those are achieved from Vandenberg Air Force Base, in California. The US also operates a number of other launch sites around the world.

Carrier aircraft, US

Orbital Science's Pegasus rocket is suspended below a carrier aircraft, and can be used to launch small payloads in almost any direction.



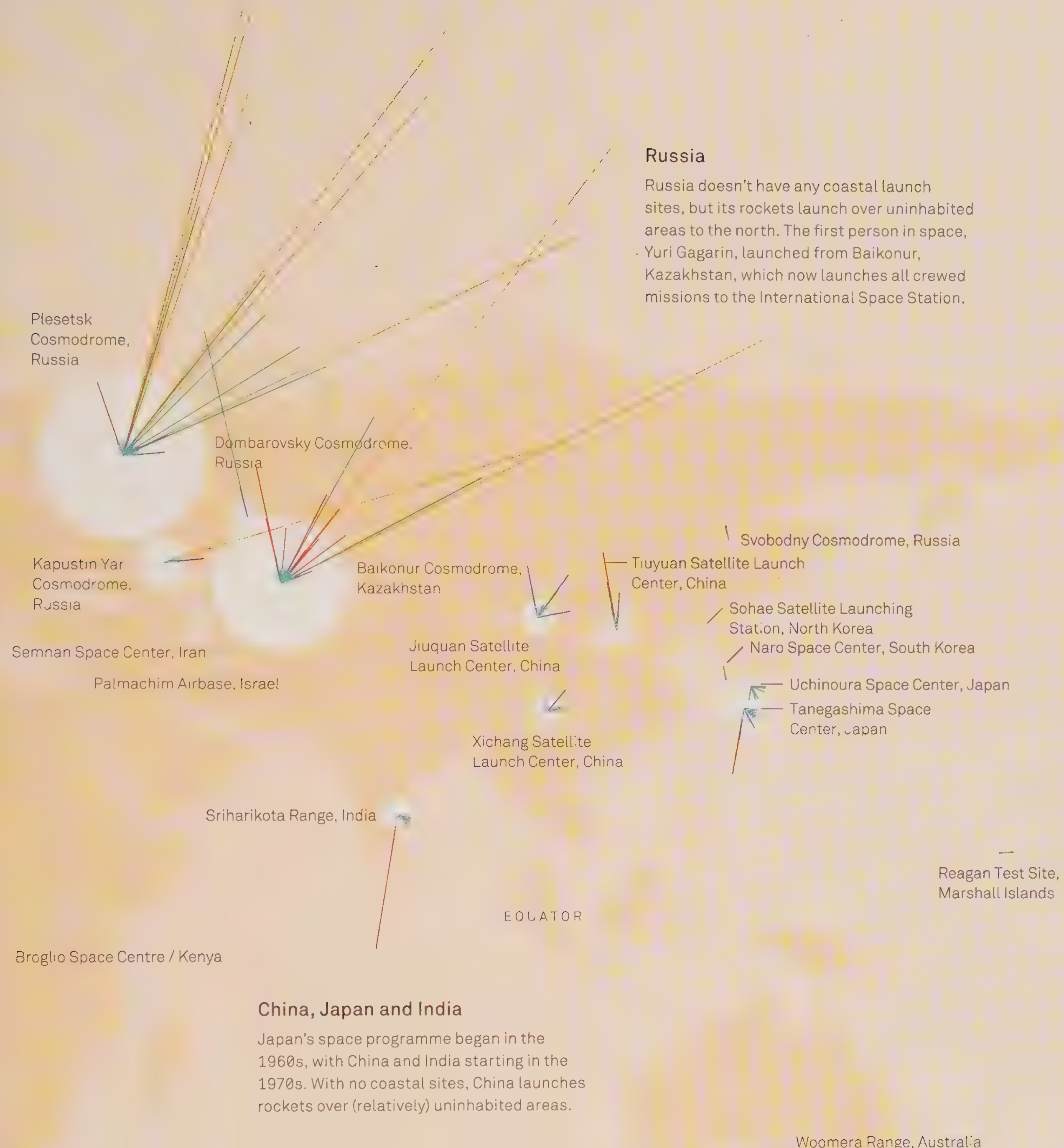


Centre Spatial Guyanais

CSG has been Europe's launch site since 1970, and can launch into both equatorial and polar orbits. It replaced many European contries' own launch sites.

Russia

Russia doesn't have any coastal launch sites, but its rockets launch over uninhabited areas to the north. The first person in space, Yuri Gagarin, launched from Baikonur, Kazakhstan, which now launches all crewed missions to the International Space Station.



China, Japan and India

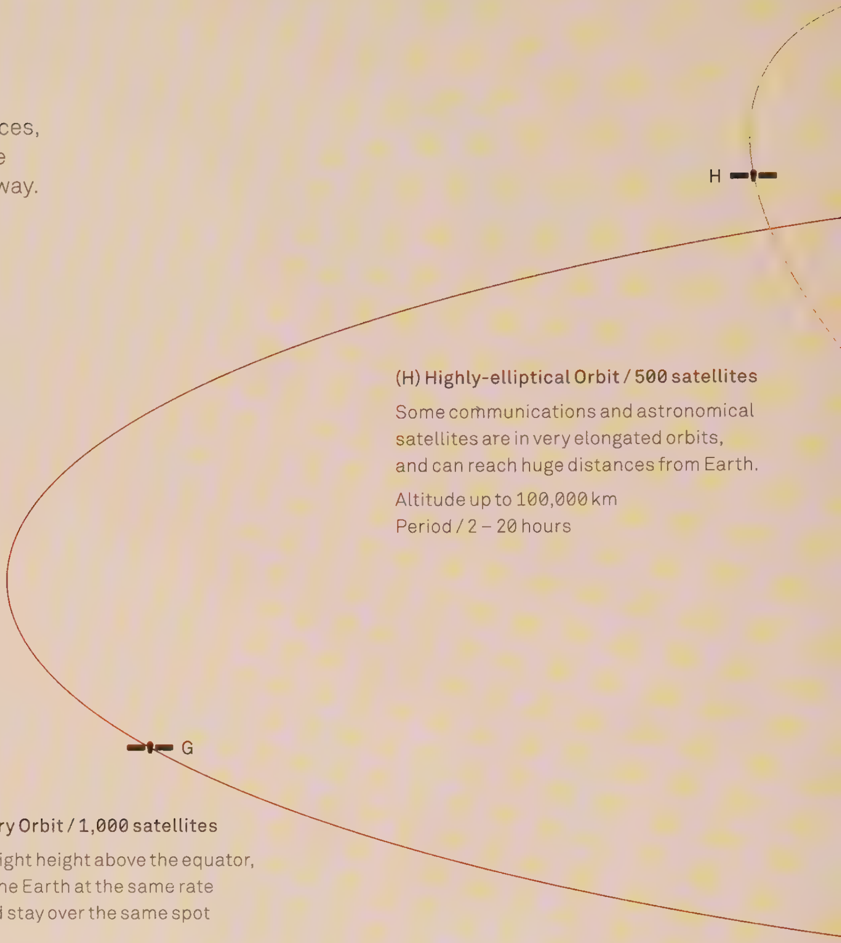
Japan's space programme began in the 1960s, with China and India starting in the 1970s. With no coastal sites, China launches rockets over (relatively) uninhabited areas.

Woomera

From 1969 – 1971, the UK used Woomera Range in Australia to launch Black Arrow rocket. There were only two successful launches before the project was cancelled, making the UK the only nation to have started and then cancelled a spaceflight programme.

Orbits

Satellites orbit the Earth at a range of distances, from just a few hundred kilometres above the surface to tens of thousands of kilometres away.



(H) Highly-elliptical Orbit / 500 satellites

Some communications and astronomical satellites are in very elongated orbits, and can reach huge distances from Earth.

Altitude up to 100,000 km
Period / 2 – 20 hours

< Sun / 149,600,000 km away

(G) Geostationary Orbit / 1,000 satellites

If they're at the right height above the equator, satellites orbit the Earth at the same rate as it rotates, and stay over the same spot on the surface.

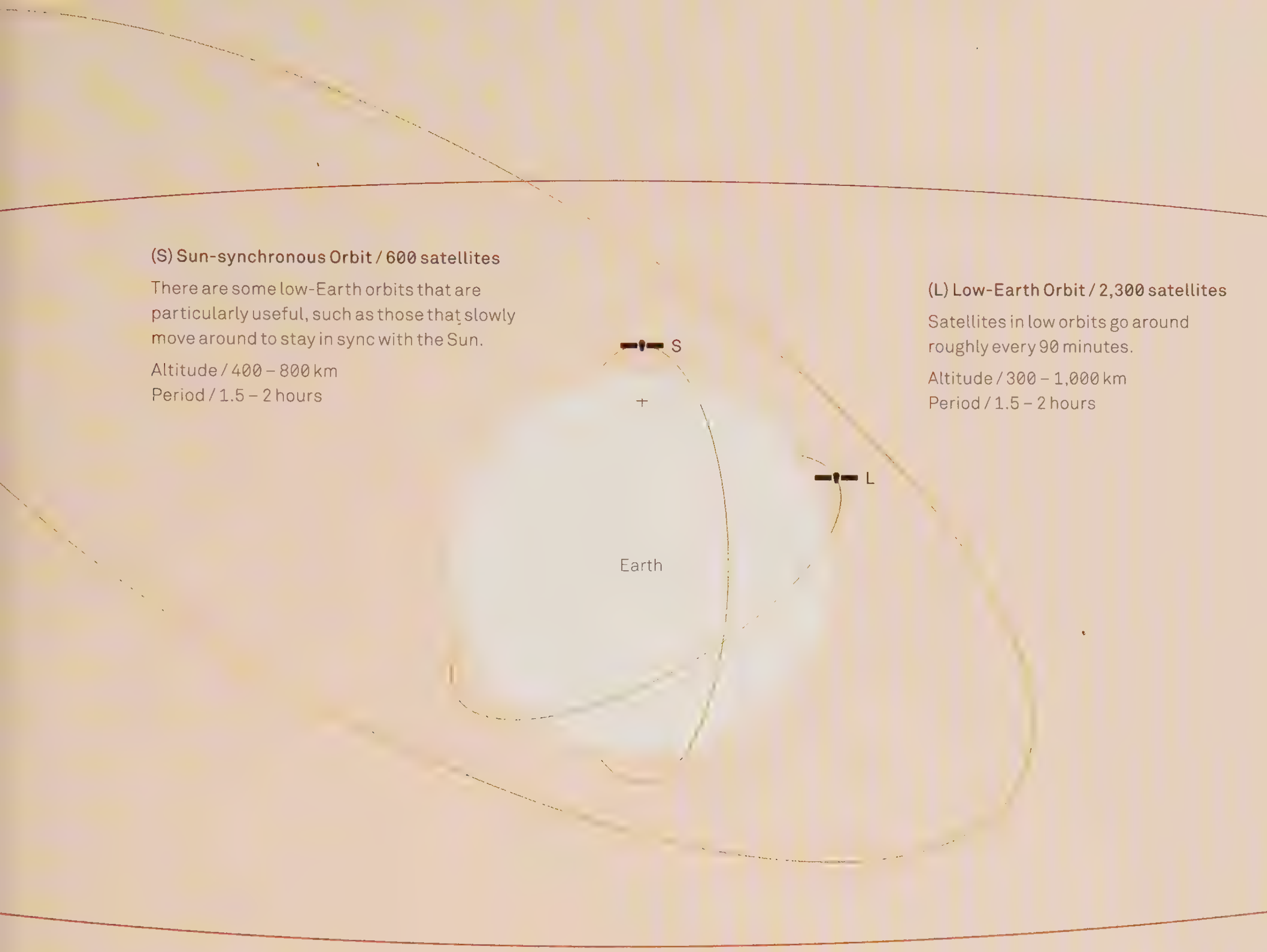
Altitude / 36,000 km
Period / 23 hours 56 minutes

Some astronomy satellites go much further from Earth. Those observing the Sun often travel to the Lagrangian point one (L1), a gravitational sweetspot 1.5 million kilometres towards the Sun. Spacecraft observing the distant cosmos often travel to L2, which is a similar distance in the opposite direction. A few leave Earth orbit and trail either ahead or behind as they orbit the Sun, gradually drifting further away over time.

< Sun / 149,600,000 km away

Sun-Earth L1 / 3 satellites

Altitude / 1,500,000 km
Period / 365.25 days


(S) Sun-synchronous Orbit / 600 satellites
There are some low-Earth orbits that are particularly useful, such as those that slowly move around to stay in sync with the Sun.
Altitude / 400 – 800 km
Period / 1.5 – 2 hours
S
(L) Low-Earth Orbit / 2,300 satellites
Satellites in low orbits go around roughly every 90 minutes.
Altitude / 300 – 1,000 km
Period / 1.5 – 2 hours
L
Earth


Earth-leading Orbit / 1 satellite
Period / < 365.25 days
Earth's orbit
Geostationary Orbit
Earth
Moon's orbit
Altitude / 380,000 km
Sun-Earth L2 / 1 satellite
Altitude / 1,500,000 km
Period / 365.25 days
Earth-trailing Orbit / 3 satellites
Period / > 365.25 days

Space junk

Each day tens of tonnes of rock fall from space. Since 1957 this natural shower of meteors has been joined by bits of rocket, dead satellites and even entire space stations. Not all of these fall to Earth though and some are left in orbit. Far from harmless, our space age littering has left a dangerous legacy as we surround our planet with debris travelling at speeds of up to 28,000 kilometres per hour.

Country of origin / Payloads x10 / Rocket bodies & debris x10 / **Total**

The most immediate threat from space junk is to the lives of astronauts aboard the International Space Station and the Tiangong Space Station. These 'hypervelocity impacts' are a very real problem. In June 2014 a 10-centimetre puncture hole was found on the ISS, extremely close to coolant tubes in a photovoltaic radiator.

To tackle the issue, the world's major space agencies set up the Inter-Agency Space Debris Coordination in 1993. As part of this, NASA and the US Department of Defense track objects larger than ten centimetres in Low-Earth Orbit and objects larger than one metre in Geosynchronous Orbit.

Space stations

Getting to space is one thing. Staying there is much harder. You need supplies of oxygen to breathe, food to eat and you need to be able to deal with the waste products.

The first space station was Russia's *Salyut 1* launched in 1971 with three compartments. The US put their first space station – Skylab – in orbit in 1973. It was visited by three crews and eventually came down over Australia in 1979.

During the 1970s, the Russians sent a series of replacement Salyuts into orbit *(Salyuts 3 – 7)*. This set the stage for the much more ambitious Mir space station launched in 1986. Mir was continuously occupied for ten years, providing insight into the effects on the body of long-term human spaceflight.

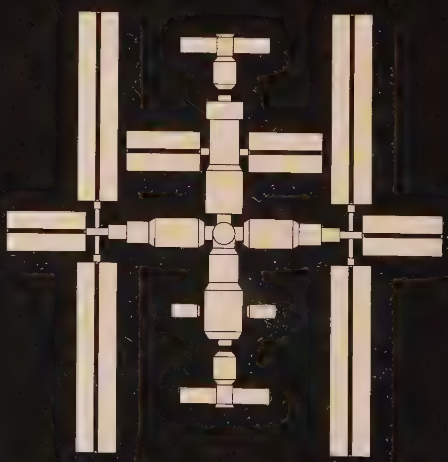
In 1998, 16 nations started to construct the largest station yet: the International Space Station. It used a modular system that allowed different parts to be made by different countries and connected together. It now consists of 14 pressurised modules covering a range of purposes. It has been continuously crewed since 2000. The Chinese launched the *Tiangong-1* space station in 2011 and plan to launch a larger station in the 2020s.

Tiangong-1, Chinese
Operational lifetime / 2011 – 2020 estimate
Length / 10.4 m

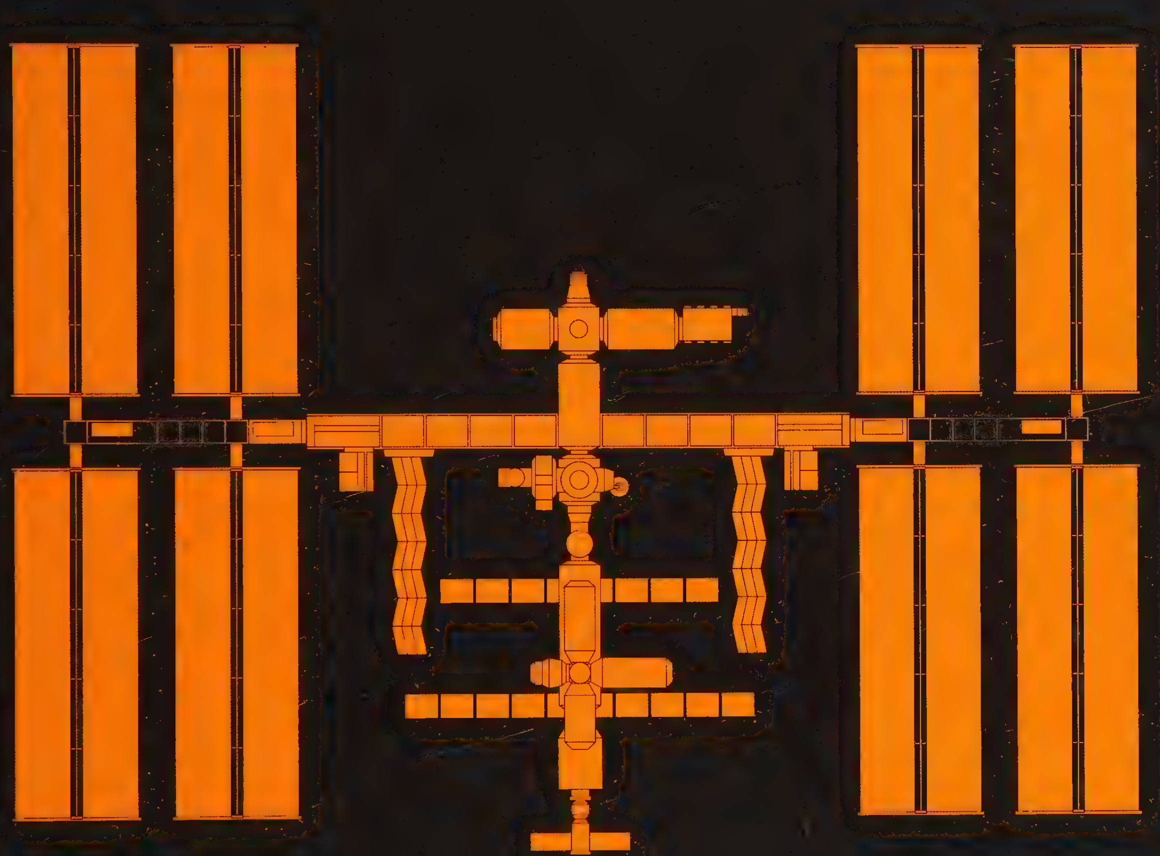
Salyut (1, 3 – 7) / Soyuz capsule, Russia
Operational lifetime / 1971 – 1991
Length / 15.8 m

Mir space station, Russia
Operational lifetime / 1986 – 2001
Length / 31 m

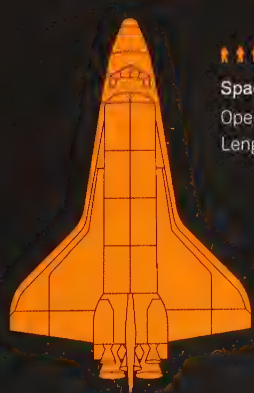
Skylab, NASA
Operational lifetime / 1973 – 1979
Length / 26.3 m



Chinese space station (planned)
Operational lifetime / 2023 –
Length / 20 m



International Space Station (ISS)
Operational lifetime / 1998 – 2024 estimate
Length / 109 m



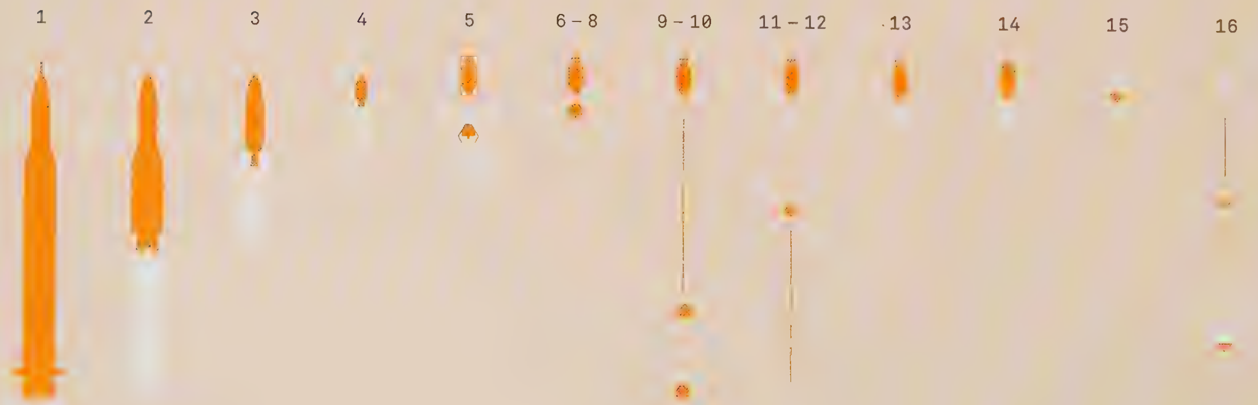
Space Shuttle (retired)
Operational lifetime / 1981 – 2011
Length / 37 m

Journey to the Moon

On 16 July 1969, a Saturn V rocket launched from Kennedy Space Center bound for the Moon. The crew of three would traverse the 380,000 kilometres between the Earth and Moon over the next three days.

Once in lunar orbit, Neil Armstrong and Edwin 'Buzz' Aldrin left Michael Collins and took the Eagle Lunar Module down to the surface. The final moments of descent required their piloting expertise as they had to avoid a boulder field. They landed with only 25 seconds of fuel remaining.

After stepping out onto the Moon at 02:56 UTC on 21 July, Aldrin and Armstrong performed various tests, collected soil samples, took many photographs and spoke to President Nixon. They returned to the Lunar Module about two-and-a-half-hours later. Following several hours of rest, they prepared for lift-off at 17:54 UTC. They rejoined Michael Collins in orbit and then started the journey back to Earth.



*All times in UTC (Coordinated universal time)

On the Moon

On 20 July 1969 at 20:18 UTC, the *Apollo 11* Lunar Module (LM) touched down on the surface of the Moon. They had only 45 seconds of fuel left in the tank.

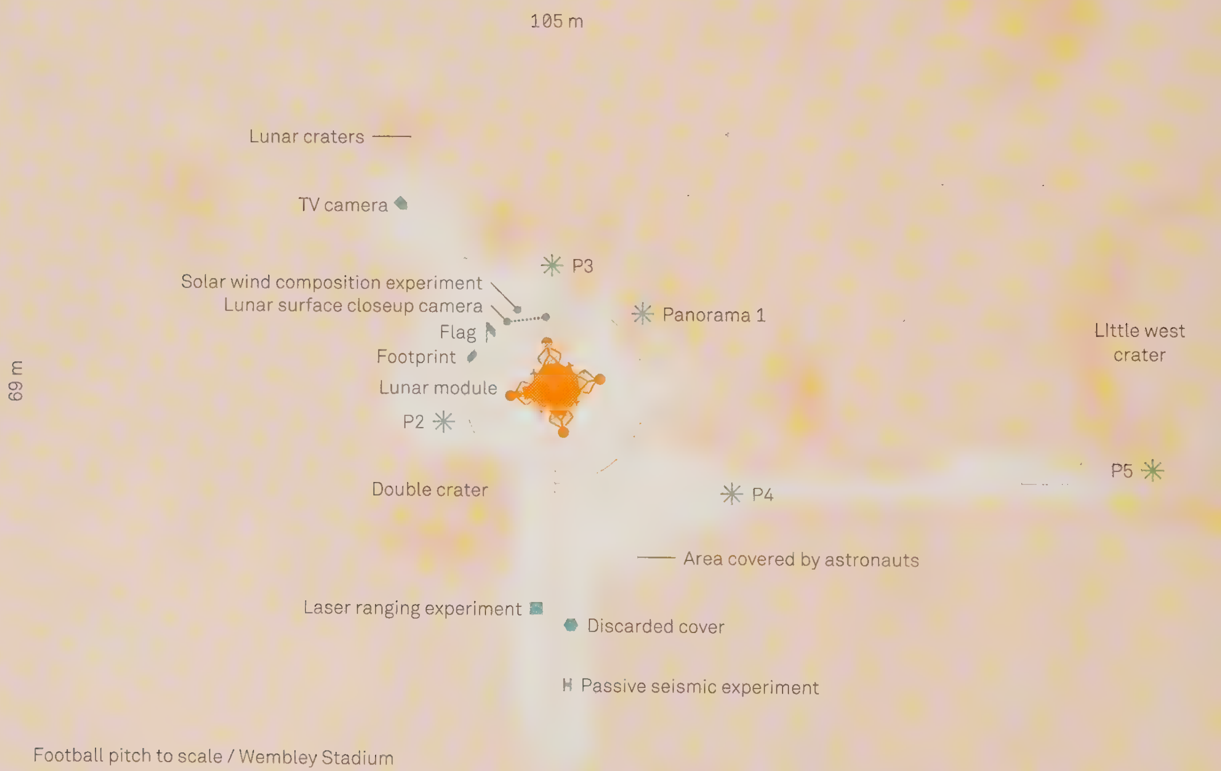
Astronauts Neil Armstrong and Buzz Aldrin spent two hours preparing the LM so it would be ready to take off when necessary. They then had a meal break and prepared for their walk outside. About six and a half hours after landing, Neil Armstrong stepped out of the hatch to the top of the ladder. He swung out a black and white TV camera to film the event and descended the ladder. On the surface he said his famous lines and was then joined by Buzz Aldrin.

They placed a TV camera some distance from the LM, planted a US flag and talked to the US President. After some experimentation with the best method of moving around, they explored the local area, took photographs, set up a few experiments, and collected rock samples to bring back. In total they brought back around 20 kilogram of lunar material.

After a relatively brief 21.6 hours on the lunar surface, the first visitors from planet Earth launched themselves back into orbit. Five more Apollo missions followed.

Apollo 11 landing site

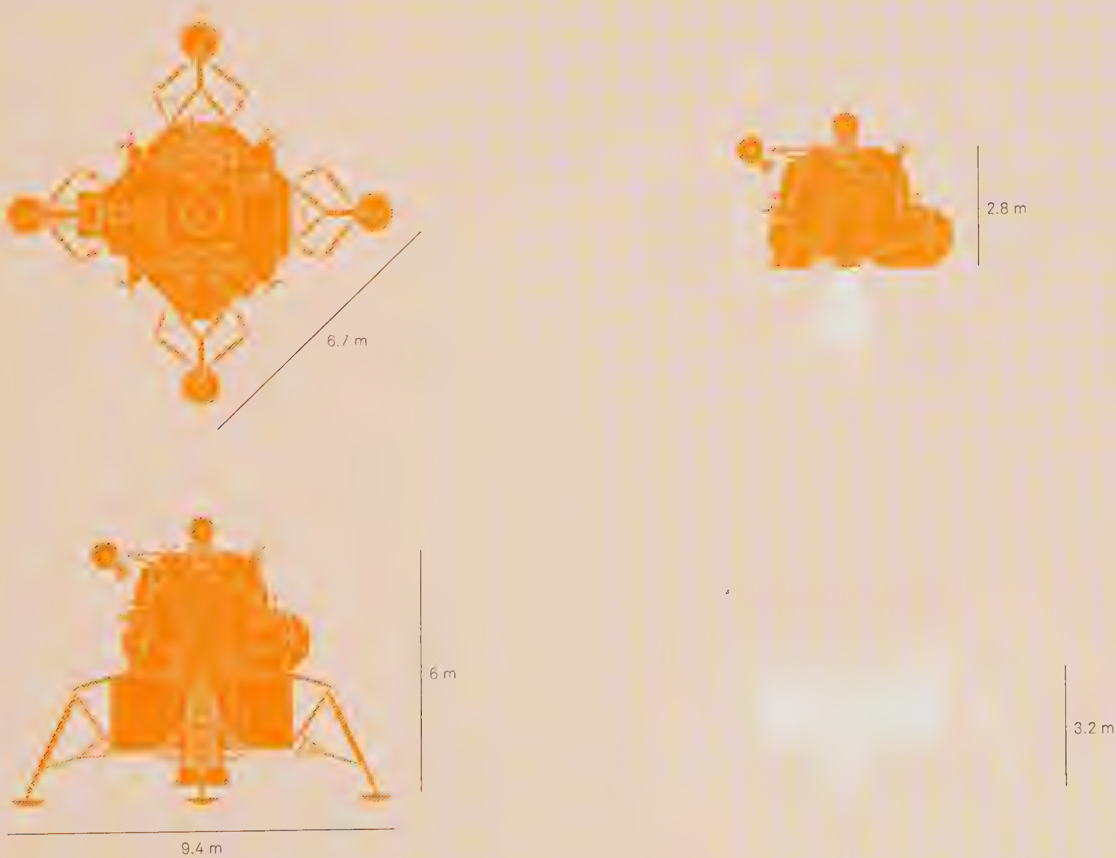
0.67409 degrees north / 23.47298 degrees east



Equipment left on the Moon by Apollo 11

LM descent stage
Gold olive branch
Apollo 1 patch
Cosmonaut medals
Moon memorial disk
TV camera
TV subsystem
TV wide-angle lens
TV day lens
TV cable assembly (30.5 m)
Polarizing filter
S-band antenna
S-band antenna cable
Flag kit
Experimental central station
Passive seismic experiment
Laser range reflector
Portable Life Support System
Oxygen filter
Remote control unit
Urine collection assemblies
Defecation collection device
Overshoes
Bags
Gas connector covers
Waist tether
Life line
Conveyor assembly
Food assembly (4 man days)
SRC/OPS adapter
Canister, ECS LIOR
Containers
Pallet assembly x2
Primary structure assembly
Hammer
Large sample scoop
Extension handle
Tongs
Gnomon (excluding mount)
Ascent stage

Apollo 11 Lunar Module



Missions to the Moon

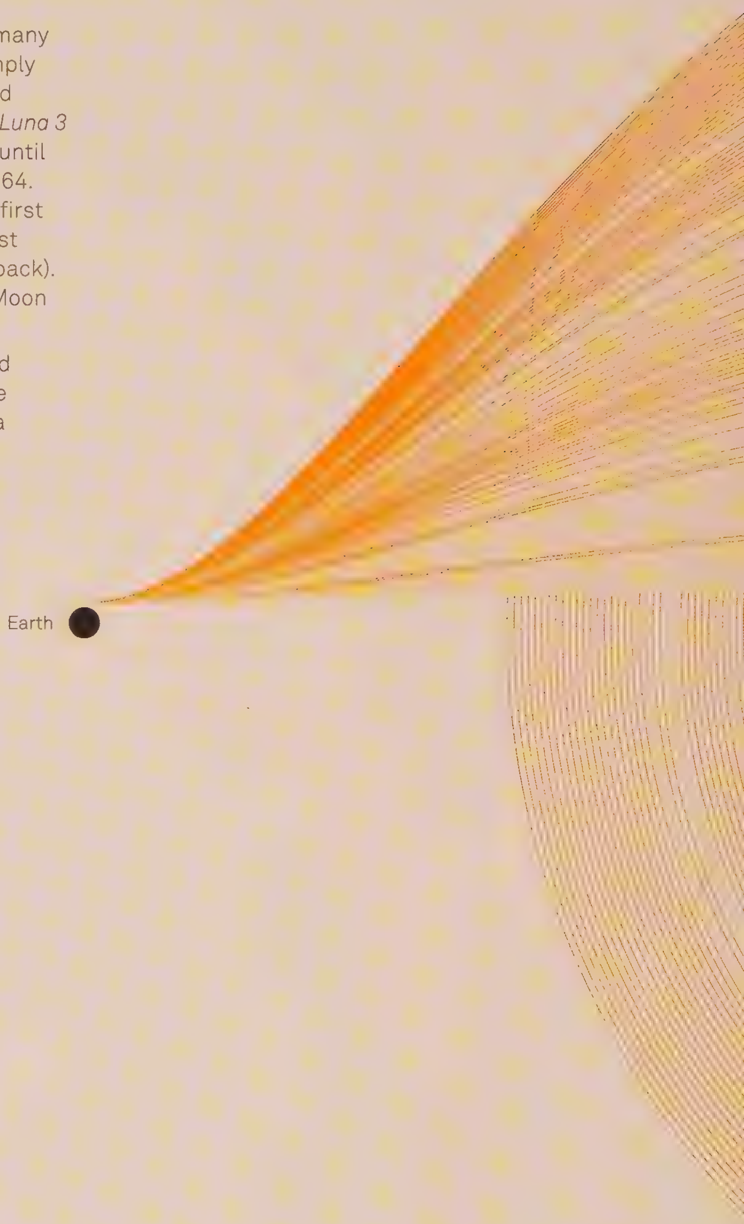
For millennia humans have looked at the Moon. Some have dreamed of visiting our celestial neighbour. In the 20th Century those dreams were finally turned into reality as both the USSR and US built rockets that were capable of reaching across the void.

The early missions were fraught with difficultly and many exploded at launch or shortly afterwards. Others simply failed to move to the correct orbit. The first confirmed success was the USSR's *Luna 2* in 1959, followed by *Luna 3* a few weeks later. There followed a string of failures until the first successful American mission *Ranger 7* in 1964. Over the next five years, reliability improved and the first humans orbited the Moon during Christmas 1968 (just three months after *Zond 5* took a tortoise there and back). Overall, the US took 12 people to the surface of the Moon and back.

After the Apollo missions, interest in the Moon waned for many years. The Millennium saw a renewed space race including missions from Europe, India and China that all explored the Moon.

— Successful missions
Failed missions

A / **Able I** 1958
B / **Luna 2** 1959
C / **Ranger 7** 1964
D / **Luna 9** 1966
E / **Apollo 8** 1968
F / **Apollo 11** 1969
G / **Apollo 13** 1970 (partial failure)
H / **Luna 17** 1970
I / **Apollo 17** 1972
J / **Luna 21** 1973
K / **Luna 24** 1976
L / **Hiten** 1990
M / **SMART-1** 2003
N / **Chandrayaan-1** 2008
O / **Chang'e 3** 2013




Moon
A
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C
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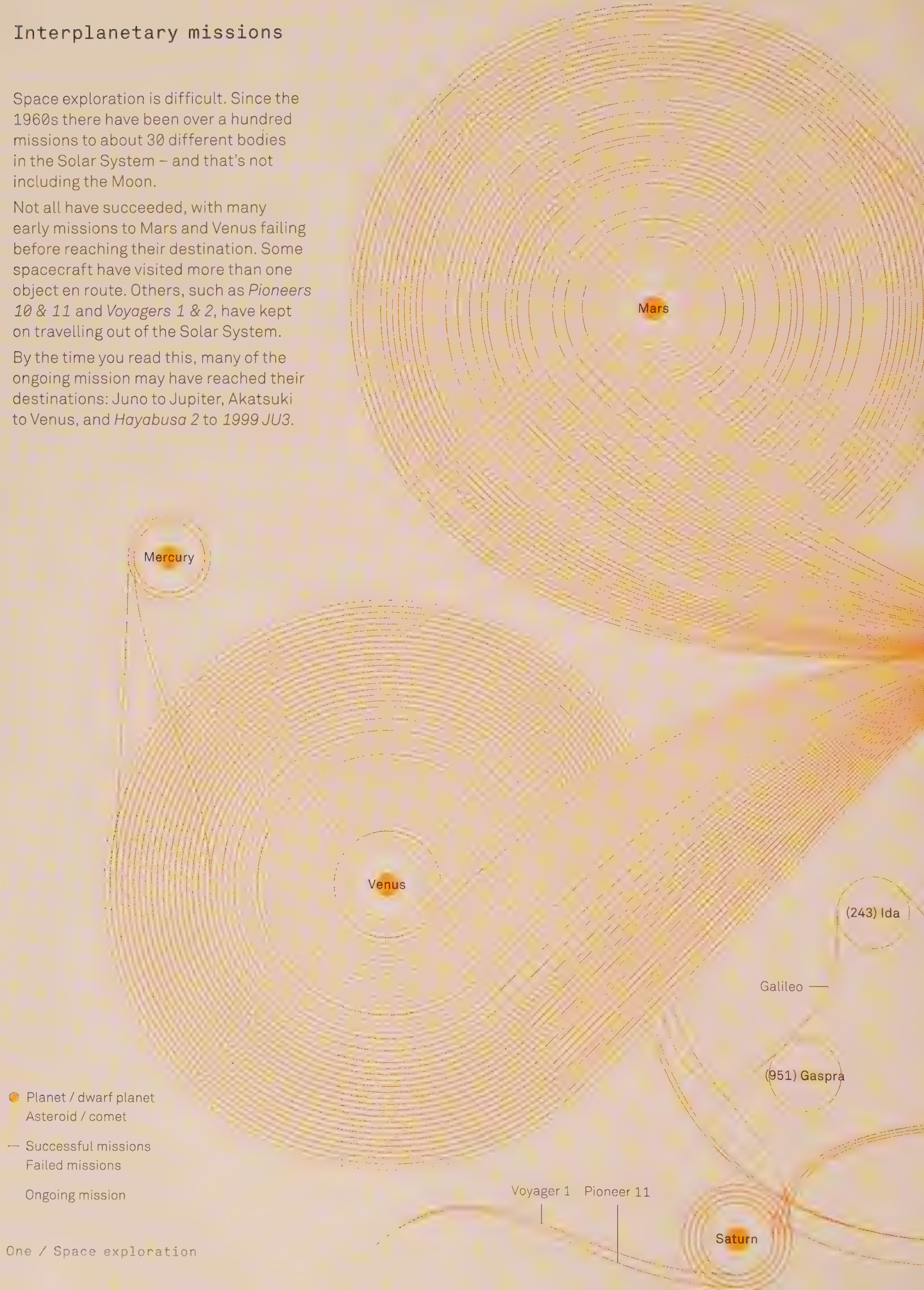
Interplanetary missions

Space exploration is difficult. Since the 1960s there have been over a hundred missions to about 30 different bodies in the Solar System – and that's not including the Moon.

Not all have succeeded, with many early missions to Mars and Venus failing before reaching their destination. Some spacecraft have visited more than one object en route. Others, such as *Pioneers 10 & 11* and *Voyagers 1 & 2*, have kept on travelling out of the Solar System.

By the time you read this, many of the ongoing mission may have reached their destinations: Juno to Jupiter, Akatsuki to Venus, and *Hayabusa 2* to *1999 JU3*.




Ceres
67P/Churyumov-Gerasimenko
Dawn
Rosetta
(21) Lutetia
Vesta
Deep Impact
103P/Hartley
(2867) Šteins
9P/Tempel
Stardust
(162173) 1999 JU3
Hayabusa 2
81P/Wild
(25143) Itokawa
Stardust NExT
Hayabusa
(5535) Annefrank
(433) Eros
CONTOUR
Earth
2P/Encke
73P/Schwassmann-Wachmann
21P/Giacobini-Zinner
1P/Halley
ICE
Chang'e 2
Giotto
(4179) Toutatis
Deep Space 1
26P/Grigg-Skjellerup
(9969) Braille
Pluto
(132524) APL
19P/Borrelly
New Horizons
Pioneer 10
Voyager 2
Jupiter
Uranus
Vega 1 & 2
Neptune

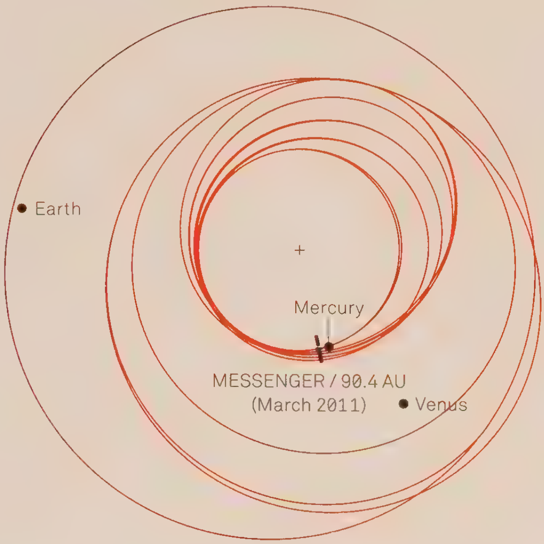
MESSENGER / 90.4 Astronomical Units

NASA's MESSENGER mission launched in 2004 on a trip to the innermost planet, Mercury. Getting so close to the Sun and into an orbit around Mercury requires a large loss of speed. A long trip with visits to Earth, Venus and Mercury was needed to use their gravity to slow the probe down.

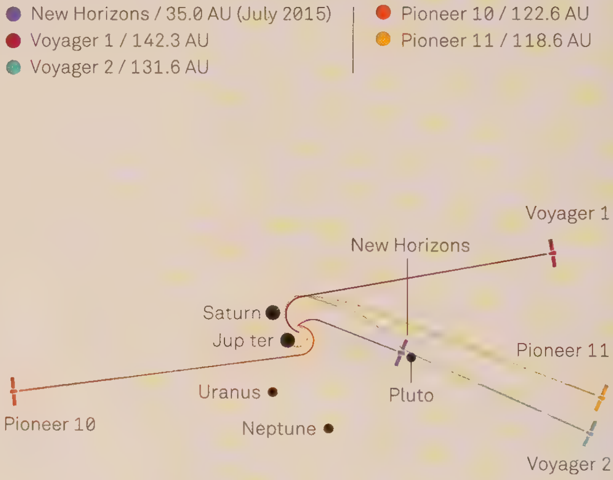
Voyagers, Pioneers and New Horizons

NASA's *Pioneers 10 & 11* launched in 1972 and 1973 were the first missions to visit Jupiter. In 1977 NASA launched *Voyagers 1 & 2* to visit Jupiter and Saturn as they were favourably aligned. *Voyager 2* carried on to be the only probe to visit Uranus and Neptune. In 2006 New Horizons became the first probe designed to visit Pluto and reached it in July 2015.

MESSENGER / plan

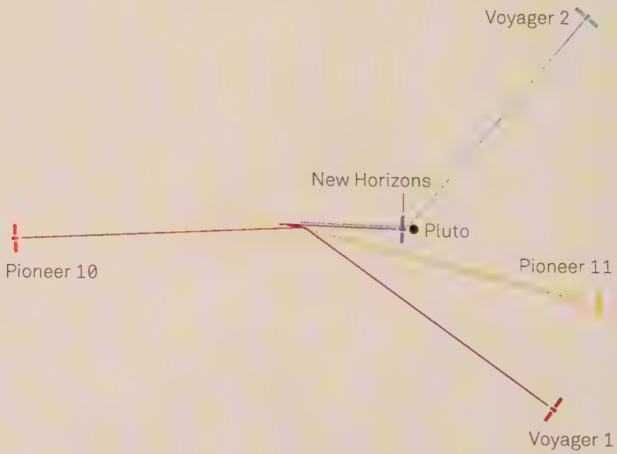


Voyagers, Pioneers and New Horizons / plan



MESSENGER / elevation

Voyagers, Pioneers and New Horizons / elevation



1 Astronomical Unit (AU) = 149.6 million km (distance from the Earth to the Sun)

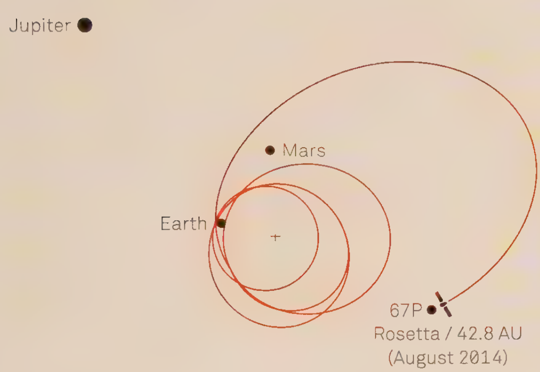
Rosetta / 42.8 Astronomical Units

ESA's Rosetta mission launched in 2004 and spent 10 years chasing down comet *67P/Churyumov–Gerasimenko*. On the way it visited Mars, Jupiter and two asteroids. In late 2014 Rosetta became the first spacecraft to orbit a comet nucleus and also the first to land a probe on a comet surface successfully.

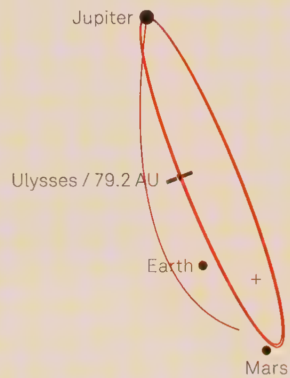
Ulysses / 79.2 Astronomical Units

This NASA/ESA probe launched in 1990 on a mission to observe the Sun from a range of angles. To reach an orbit that took it up and over the poles of the Sun required using the gravity of the planet Jupiter to hurl it out of the plane of the Solar System.

Rosetta / plan

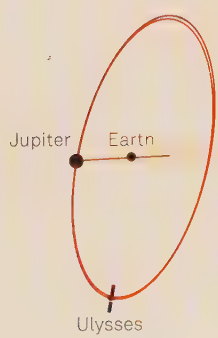


Ulysses / plan



Rosetta / elevation

Ulysses / elevation



Planetary rovers

By 1970 the race to the Moon was over. Now it was time to explore the surface. The Soviet Union leapt into the lead with robotic roving, sending two Lunokhod rovers to the Moon. *Lunokhod 2's* distance record was held for decades.

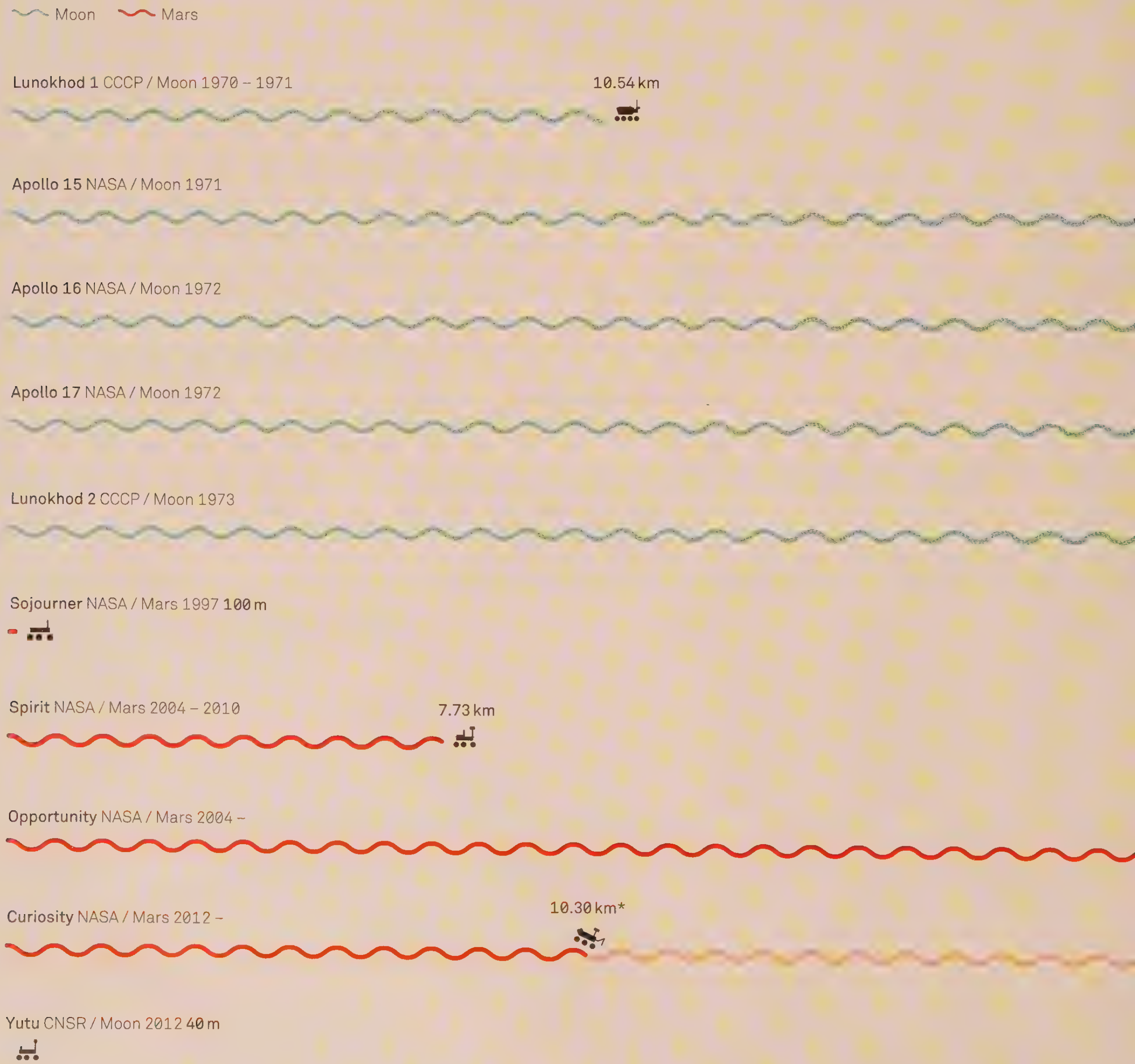
NASA equipped the later Apollo astronauts with lunar rovers, lightweight buggies that allowed them to travel much futher and faster than the earlier pioneers.

NASA's first robotic rover – the teatray-sized rover Sojourner – went to the red planet. Despite only travelling around 100 metres, and straying no more than 12 metres from the main lander, it led the way for the next generation.

Spirit and Opportunity landed on Mars in 2004, with an intended mission duration of 90 days. Both far exceeded the expectations of their human masters. Spirit got stuck in soft sand in 2009 and succumbed to the cold Martian winter in 2010.

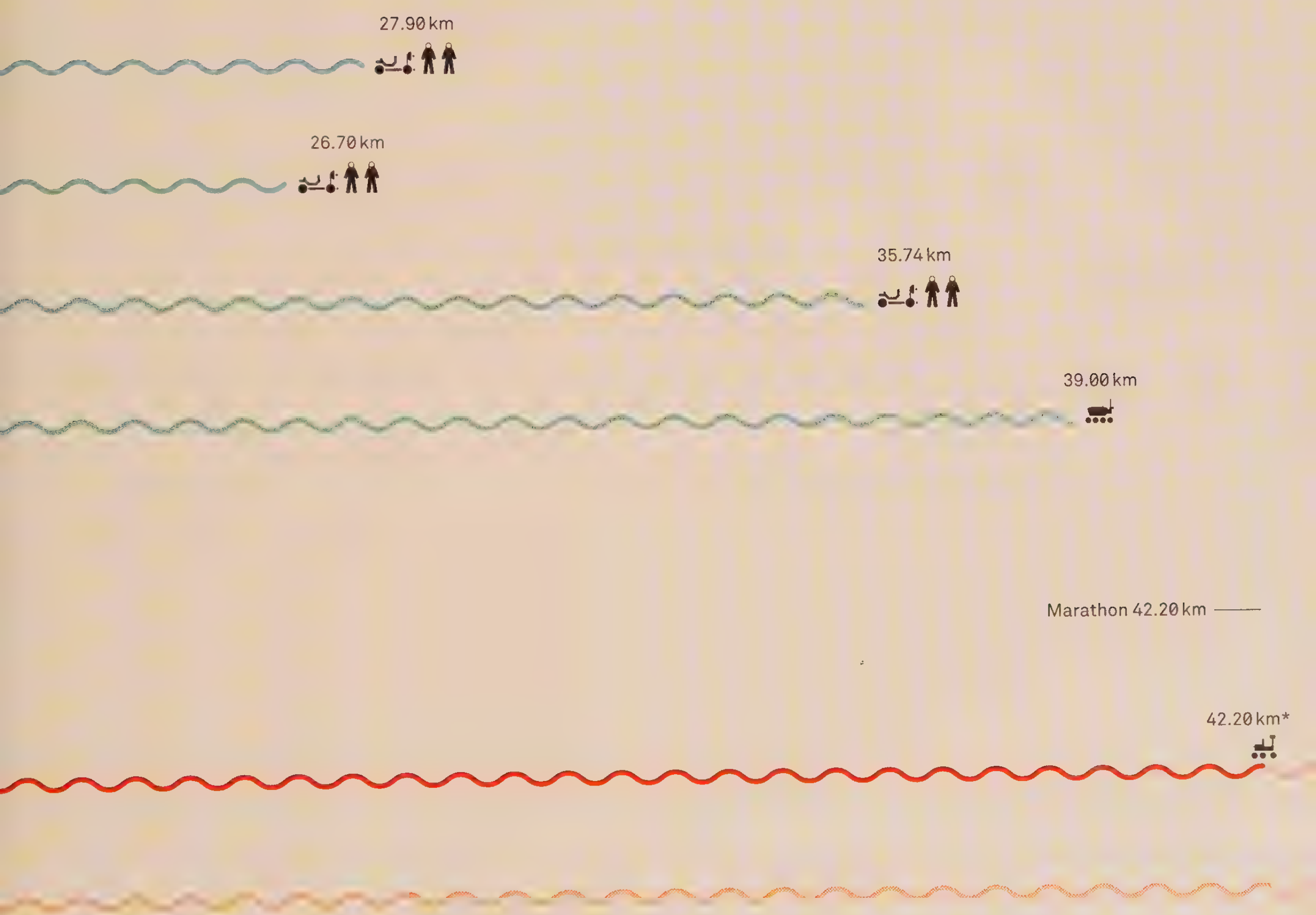
Opportunity was still going a decade after landing, and broke the distance record for extra-terrestrial roving in 2014. These rovers confirmed that billions of years ago Mars was a much warmer, wetter world.

The most advanced rover to date is Curiosity, a car-sized rover which landed in 2012. With ten scientific instruments



on board, including a laser, it has shown that Mars was once capable of supporting life. The question of whether there ever was life there, however, will be left to future explorers, be they robotic or human, to answer.

In 2013, China successfully landed Chang'e 3 on the Moon and with it the Yutu rover. Yutu circled the lander and traversed a further 40 metres before a mechanical failure prevented it from roving, though it continued to send panoramic photos for months afterwards.



* Distance travelled as of March 2015

Two / Solar System

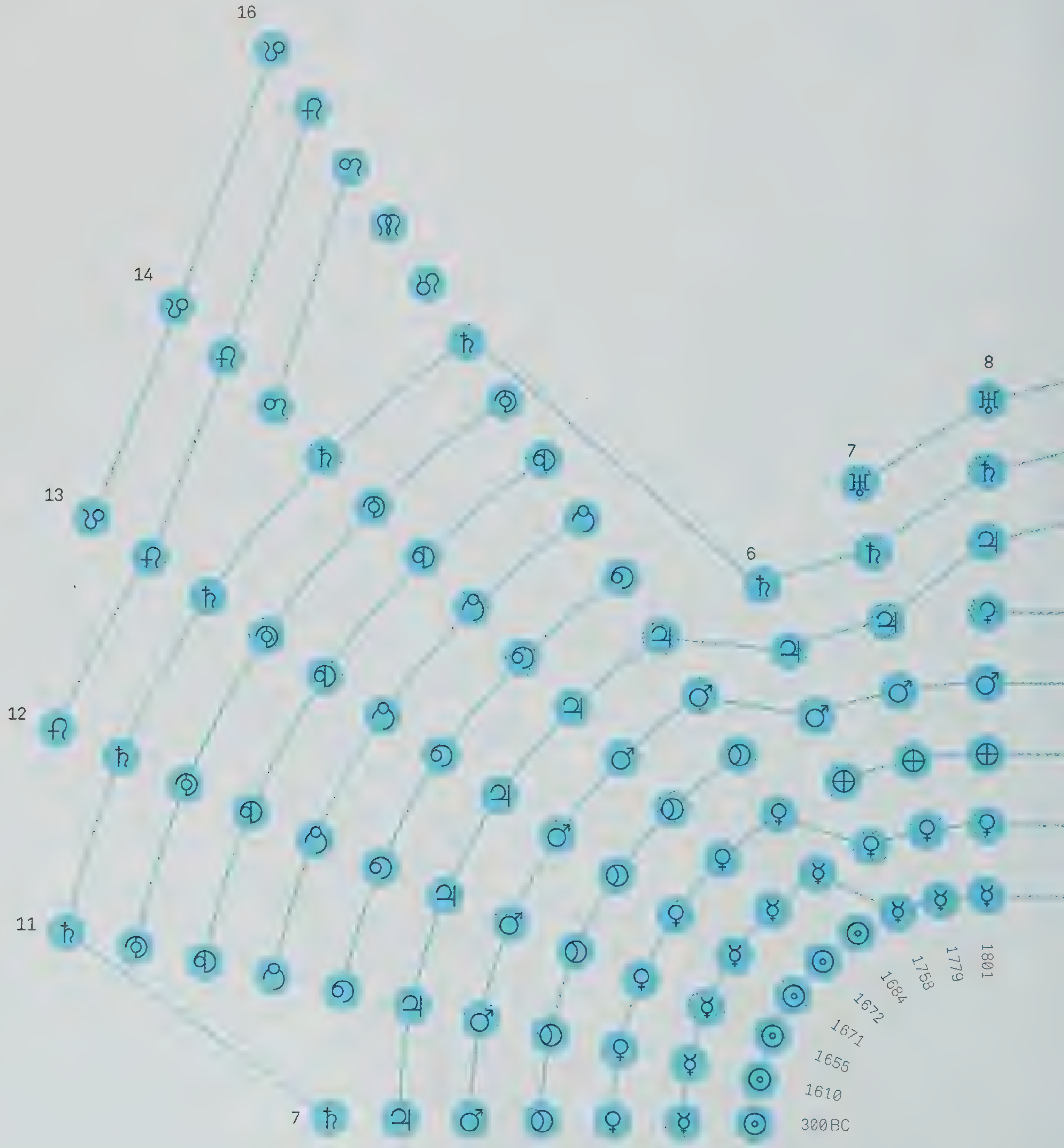
How many planets?

Planet comes from the ancient Greek meaning 'wanderer' and included any celestial object that appeared to move compared to the stars. For millenia the planets were known to be Mercury, Venus, Mars, Jupiter, Saturn, Sun, and Moon. That all changed in the 17th Century when the discovery of objects near Jupiter and Saturn swelled the ranks to 16.

As our understanding of the Solar System improved and, with observations showing comets to be celestial, the definition of what was a planet started to change for the first time. A planet became an object that orbited the Sun with a nearly circular path. The Sun was no longer a planet. The Earth was. The Moon, along with the satellites of Jupiter and Saturn, moved into a new class of moons.

Under the new definition, the discovery of Uranus became the first new planet since antiquity. In the early 19th Century numbers swelled once more when Neptune was discovered, along with Ceres, Pallas, Juno, Vesta, Hencke, taking the total to 13. In 1847, these small planets orbiting between Mars and Jupiter were reclassified as asteroids dropping the number of major planets back down to eight for the third time.

In 1930, the discovery of Pluto took us back to nine. In the 21st Century, Haumea, Eris, and Makemake were found and led to a redefinition of what makes a planet and created a new class of dwarf planet. Our Solar System now contains eight planets, five dwarf planets, 182 moons, and over 650,000 asteroids. For now...



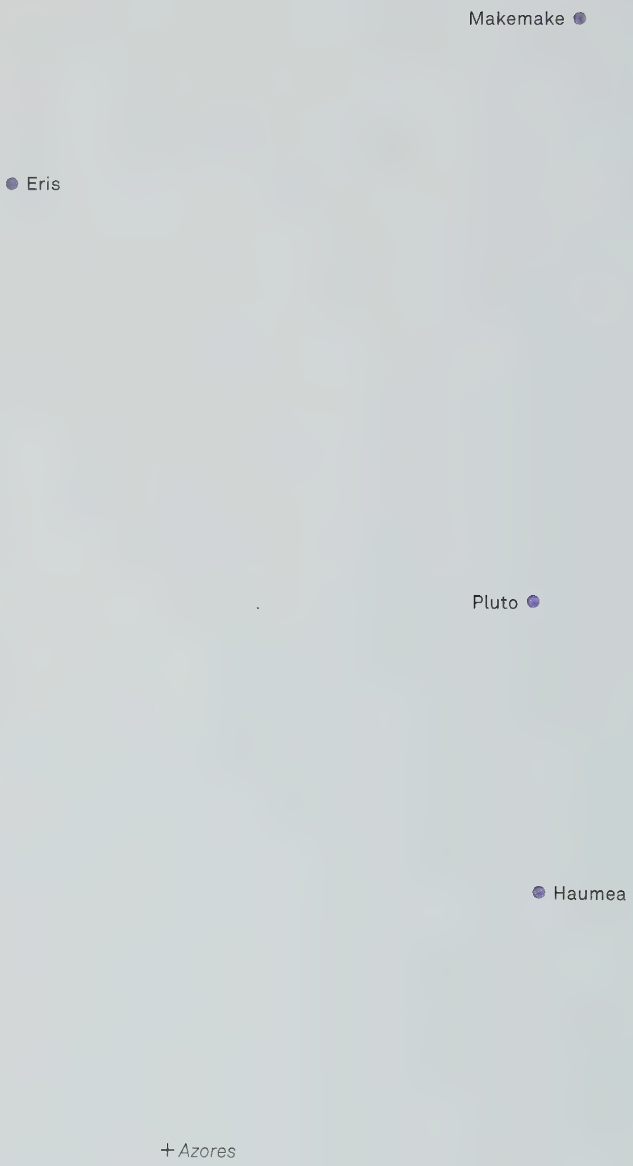
Planet classification change over time

- Planet
- Dwarf planet

- Astraea
- Callisto
- Ceres
- Dione
- Earth
- Eris
- Europa
- Ganymede
- Haumea
- Iapetus
- Io
- Juno
- Jupiter
- Makemake
- Mars
- Mercury
- Moon
- Neptune
- Pallas
- Pluto
- Rhea
- Saturn
- Sun
- Tethys
- Titan
- Uranus
- Venus
- Vesta

Scale model Solar System

Imagining the distances to the planets can be tricky, not least because they're so vast relative to their size. If the Sun were moved to Paris and shrunk to about the height of the Eiffel Tower, Mercury would skirt the outer suburbs of Paris. Meanwhile, the Earth would be nearly 40 kilometres away, and the size of an African elephant. While Jupiter would stay largely within France, Saturn's orbit would run through Brussels and London, and Uranus would pass through Munich and Liverpool. The outermost-planet, Neptune, could be found near Copenhagen, while the Kuiper Belt objects would be holidaying in Morocco or the Azores.



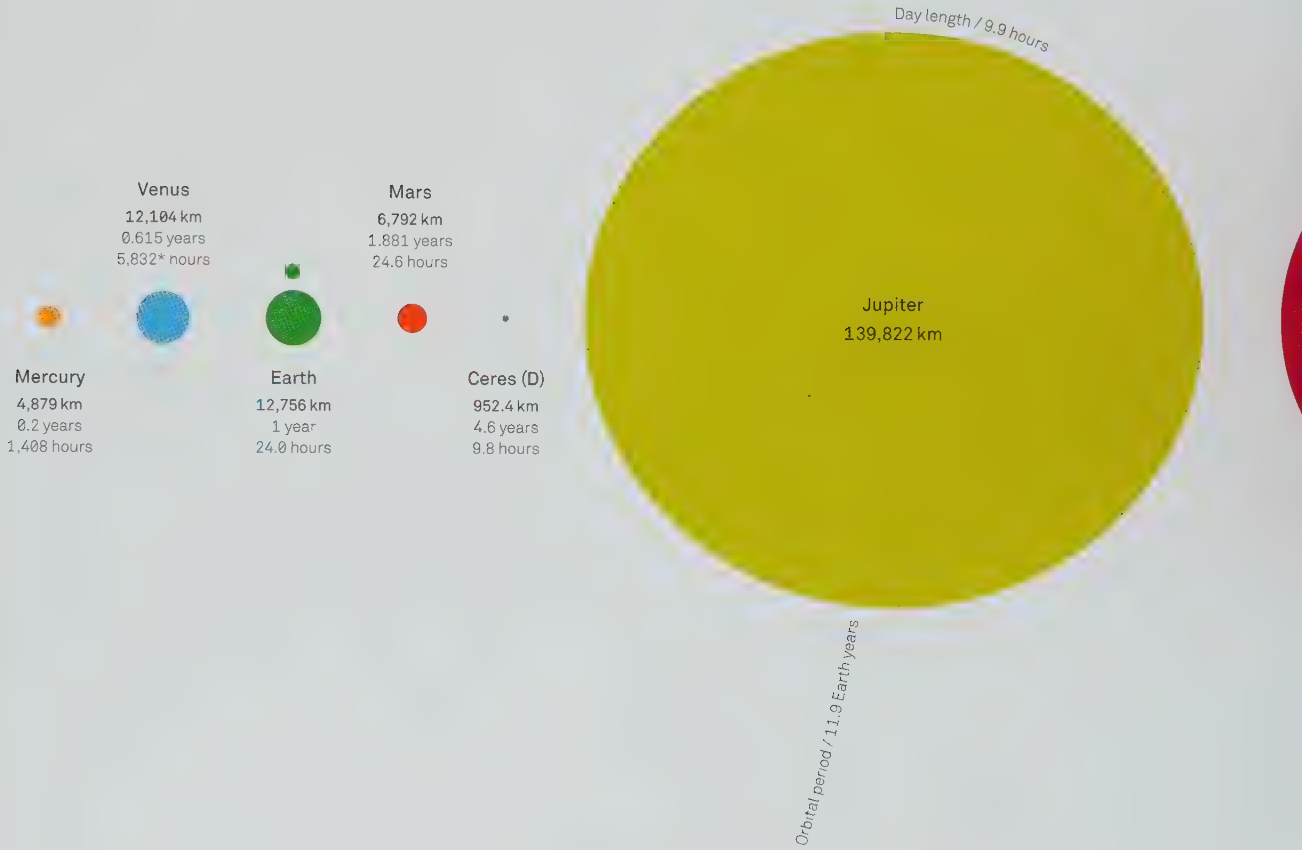

Oslo
Stockholm
Sandefiord
Aberdeen
Kalmar
Edinburgh
Copenhagen
Klaipėda
Newcastle
Belfast
Uranus
Leeds
Dublin
Liverpool
Hanover
Warsaw
Cardiff
London
Brussels
Rouen
Caen
Mars
Paris
Ceres
Jupiter
Munich
Vienna
Bratislava
Le Mans
Nantes
Saturn
Lyon
Milan
Zagreb
Belgrade
Genoa
Zadar
Bilbao
Rome
Barcelona
Vila Real
Madrid
Neptune
Naples
Taranto
Alicante
Algiers
Tunis
Sousse
Rabat
Fes

The family of planets

The constituents of our Solar System vary hugely in size from small asteroids only kilometres across to the gigantic Jupiter, nearly 140,000 kilometres in diameter.

The eight planets fall into three main categories. The four nearest the Sun are comprised mostly of rock. The two largest planets, Jupiter and Saturn, are the gas giants, made almost entirely of hydrogen and helium. The two most distant planets, the ice giants Uranus and Neptune, have larger solid cores and methane clouds in their atmospheres. Most of the dwarf planets lie in the Kuiper Belt, and are the largest examples of a collection of icy bodies that orbit out beyond Neptune. At such great distances these are hard to observe, and there are almost certainly many objects in the Kuiper Belt which are still to be discovered.

Many of the Solar System's smaller objects orbit in the asteroid belt, between Mars and Jupiter. The largest of these by far is Ceres, though there are dozens more that measure hundreds of kilometres in diameter. The four biggest objects in the asteroid belt make uphalf its total mass.



Planet name (D = dwarf planet)
Diameter
Orbital period, Earth years
Day length

* Venus spins around its own axis in the opposite sense to the other planets. Uranus and Pluto's rotation axes put them on their 'sides'.

Moons

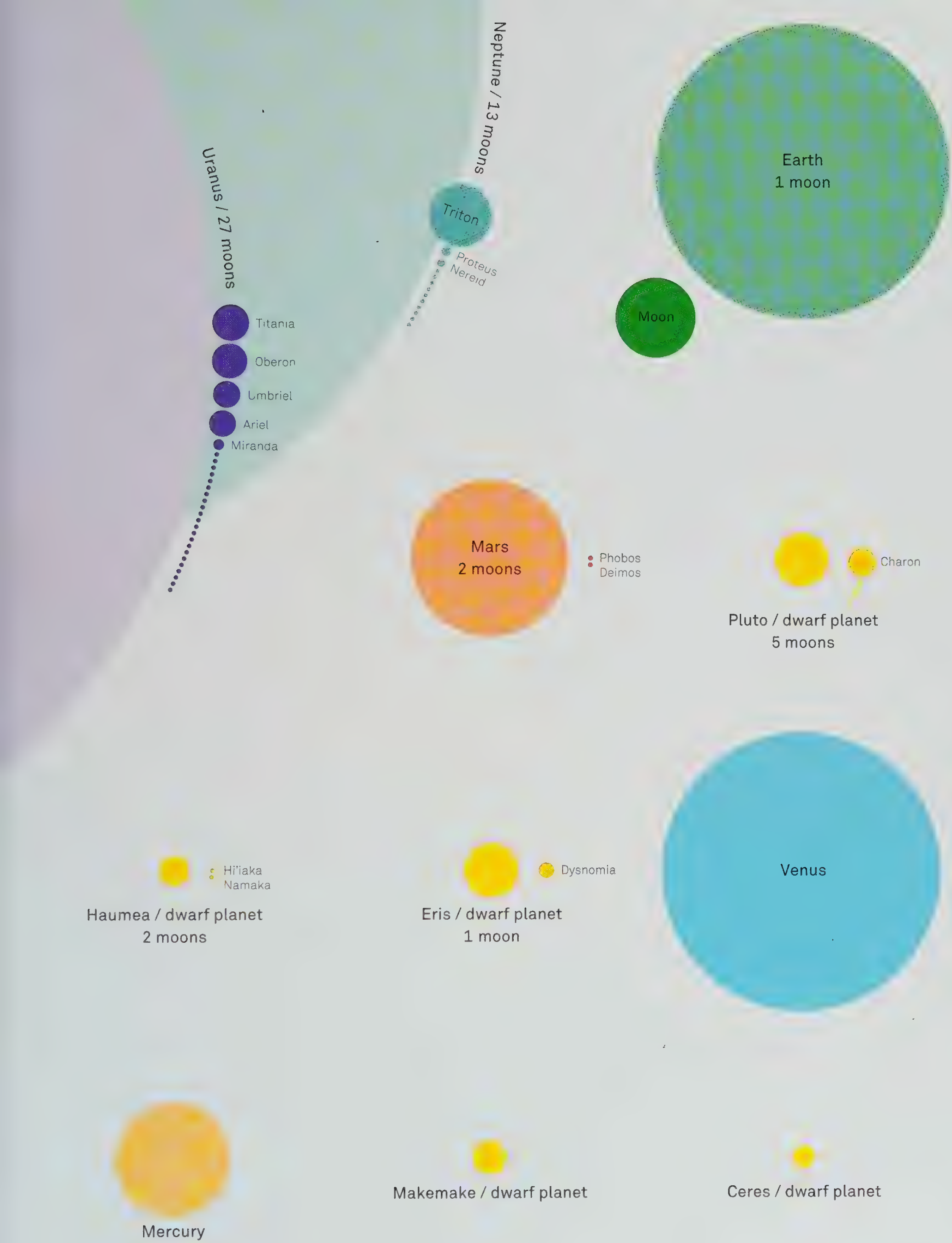
Today we think of a moon as a celestial body that orbits a planet. The most obvious example is our nearest neighbour – the Moon – which orbits Earth. It wasn't until January 1610 that we first found moons around another planet when Galileo turned his telescope towards Jupiter. The first of Saturn's moons was discovered in 1655. Uranus' first moons were seen in 1851 – 70 years after the planet itself was discovered. We had to wait until as late as 1877 before Mars' two tiny moons were finally identified.

The 20th and 21st Centuries saw a huge increase in the number of known moons thanks, in part, to advances in telescope resolution but mostly from the fleet of spacecraft we've sent out to visit the planets.

We now know of moons around Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, Eris and Haumea.

Naming

Historically, moons were often named by their discoverer but, since 1975, the International Astronomical Union has overseen the naming process. There are now several naming conventions depending on the parent body. The two moons of Mars are named after the sons of Ares (the Greek equivalent of Mars). Moons of Jupiter are named after the lovers or descendents of Jupiter (Zeus). Saturn's moons are named after giants or their descendents (currently from Greek, Norse, Gallic and Inuit mythologies). The moons of Uranus are named after characters in Shakespearean plays. Neptune's moons are named after Greek sea gods and Pluto's moons all have connections to Hades.


Neptune / 13 moons
Triton
Proteus
Nereid
Uranus / 27 moons
Titania
Oberon
Umbriel
Ariel
Miranda
Earth
1 moon
Moon
Mars
2 moons
Phobos
Deimos
Charon
Pluto / dwarf planet
5 moons
Hi'iaka
Namaka
Haumea / dwarf planet
2 moons
Dysnomia
Eris / dwarf planet
1 moon
Venus
Mercury
Makemake / dwarf planet
Ceres / dwarf planet

Eclipses

If you've ever had the opportunity to see a total solar eclipse you will know how special they are. Solar eclipses occur when the Moon passes between us and the disk of the Sun. Lunar eclipses happen when the Earth passes between the Moon and the Sun. But the Moon orbits the Earth every four weeks so why don't eclipses happen every fortnight?

The Moon's orbit is slightly tilted relative the Earth's so most of the time the Moon will appear to pass above or below the Sun and above or below the Earth's shadow.

Because its orbit is not circular, sometimes the Moon appears smaller and doesn't fully block the Sun. These solar eclipses are called 'annular eclipses' because a ring, or annulus, of sunlight remains visible.

The complicated movement of the Moon leads to many cycles in the frequency of eclipses. Amongst these are the 'semester' (177.2 days, or just under 6 months), the lunar year (354.4 days), and the 'saros' (6,585.32 days or just over 18 years).


Moon
Penumbra
Sun
A
Earth
B
Umbra
Penumbra
A / Solar eclipse
B / Lunar eclipse


New Moon
Full Moon
New Moon
Not to scale
July
August
September
October
November
December
1998
2002
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046

Solar System top ten

Mountains

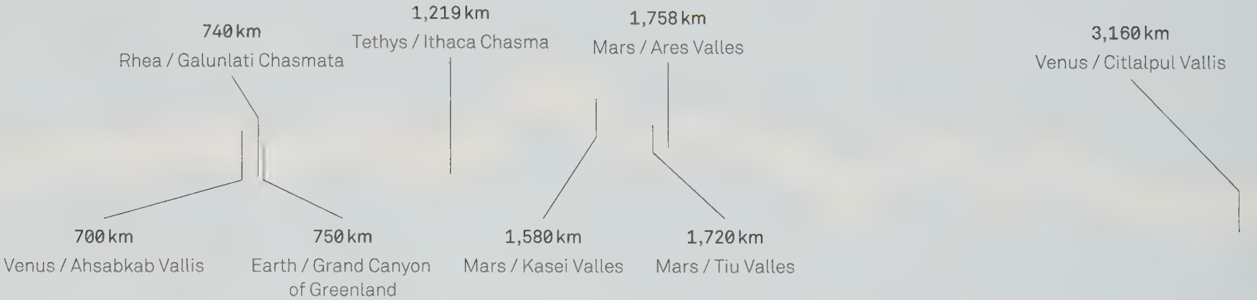
Heights of mountains in the Solar System from base to peak. The largest is Vesta's South Pole Mountain discovered in 2011 by the DAWN spacecraft.

Lakes

The largest known lake – Kraken Mare – was found by the Cassini spacecraft in 2007 and is composed of liquid hydrocarbons.

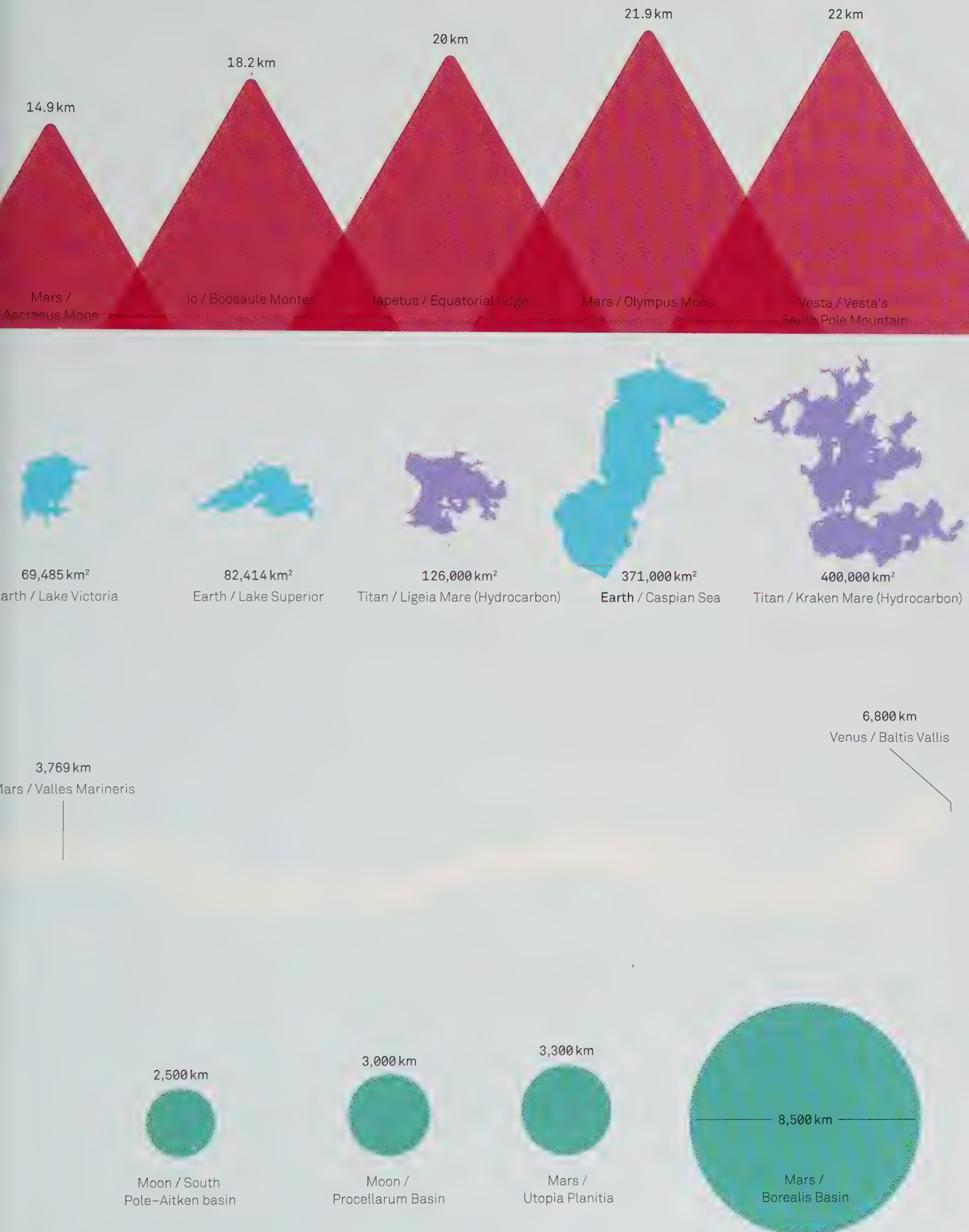
Canyons, outflow channels and chasmata

The longest channel in the Solar System – Baltis Vallis – was discovered by the *Venera 15 &16* spacecraft. It probably once held a river of lava.



Craters

Borealis Basin covers almost the entire northern hemisphere of Mars. Its origin is uncertain but is thought to be the result of an impact at some point in Mars' past.



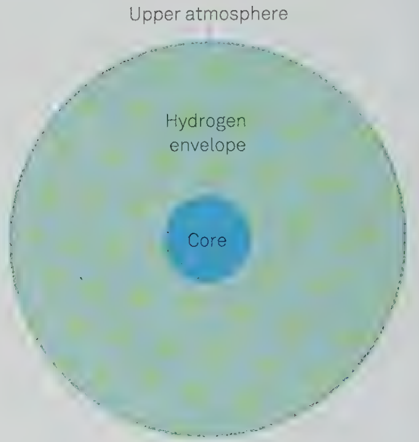
14.9 km
Mars / Ascraeus Mons
18.2 km
Io / Boösaule Montes
20 km
Iapetus / Equatorial ridge
21.9 km
Mars / Olympus Mons
22 km
Vesta / Vesta's South Pole Mountain
69,485 km²
arth / Lake Victoria
82,414 km²
Earth / Lake Superior
126,000 km²
Titan / Ligeia Mare (Hydrocarbon)
371,000 km²
Earth / Caspian Sea
400,000 km²
Titan / Kraken Mare (Hydrocarbon)
3,769 km
lars / Valles Marineris
6,800 km
Venus / Baltis Vallis
2,500 km
Moon / South Pole-Aitken basin
3,000 km
Moon / Procellarum Basin
3,300 km
Mars / Utopia Planitia
8,500 km
Mars / Borealis Basin

Structure of planets and moons

We know about the interior of the Earth thanks to seismology. Experiments left by lunar missions have used moon-quakes to understand the interior of the Moon. For the other bodies in the Solar System it's much harder to tell. Flybys of spacecraft, combined with physical models, can be used to estimate the interior structure.

The strong magnetic fields of Jupiter and Saturn mean they must have a conductive interior, probably made of 'metallic hydrogen'. Whether they have solid cores at their centres is much less clear. Uranus and Neptune are thought to have icy, rocky cores surrounded by a thick layer of ices, predominently water and methane.

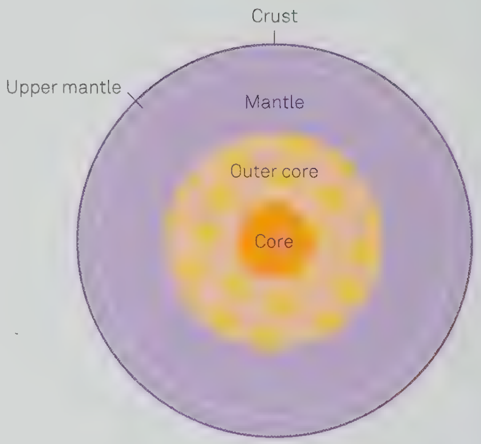
Many moons in the outer Solar System are now thought to have sub-surface oceans of liquid water, due to internal heating caused by tides from their parent planets. This makes these mini-worlds just as exciting and mysterious as the planets they orbit.



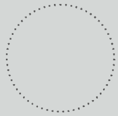
Jupiter

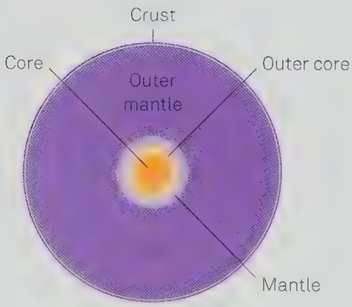

Earth to scale

- Water
- Ices
- Rock / ice
- Methane
- Metallic hydrogen
- Atmosphere
- Molten rock
- Rock
- Molten iron
- Solid iron
- Solid iron (FeS-rich)

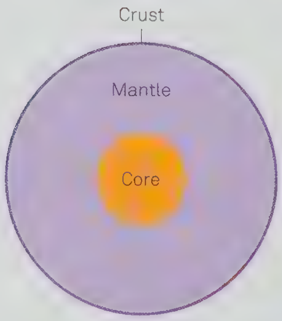


Earth

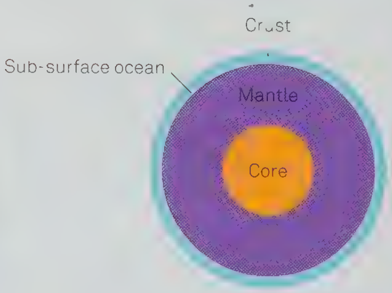

Moon to scale



Moon



Io



Europa

Upper atmosphere
Hydrogen envelope
Core
Saturn
Envelope
Mantle
Core
Uranus
Envelope
Mantle
Core
Neptune
Crust
Upper mantle
Mantle
Core
Venus
Crust
Mantle
Core
Mars
Crust
Mantle
Middle Core
Core
Outer Core
Mercury
Ice
Sub-surface ocean (several layers)
Mantle
Core
Ganymede
Ice
Mantle
Core
Sub-surface ocean
Callisto
Crust
Mantle
Core
Titan

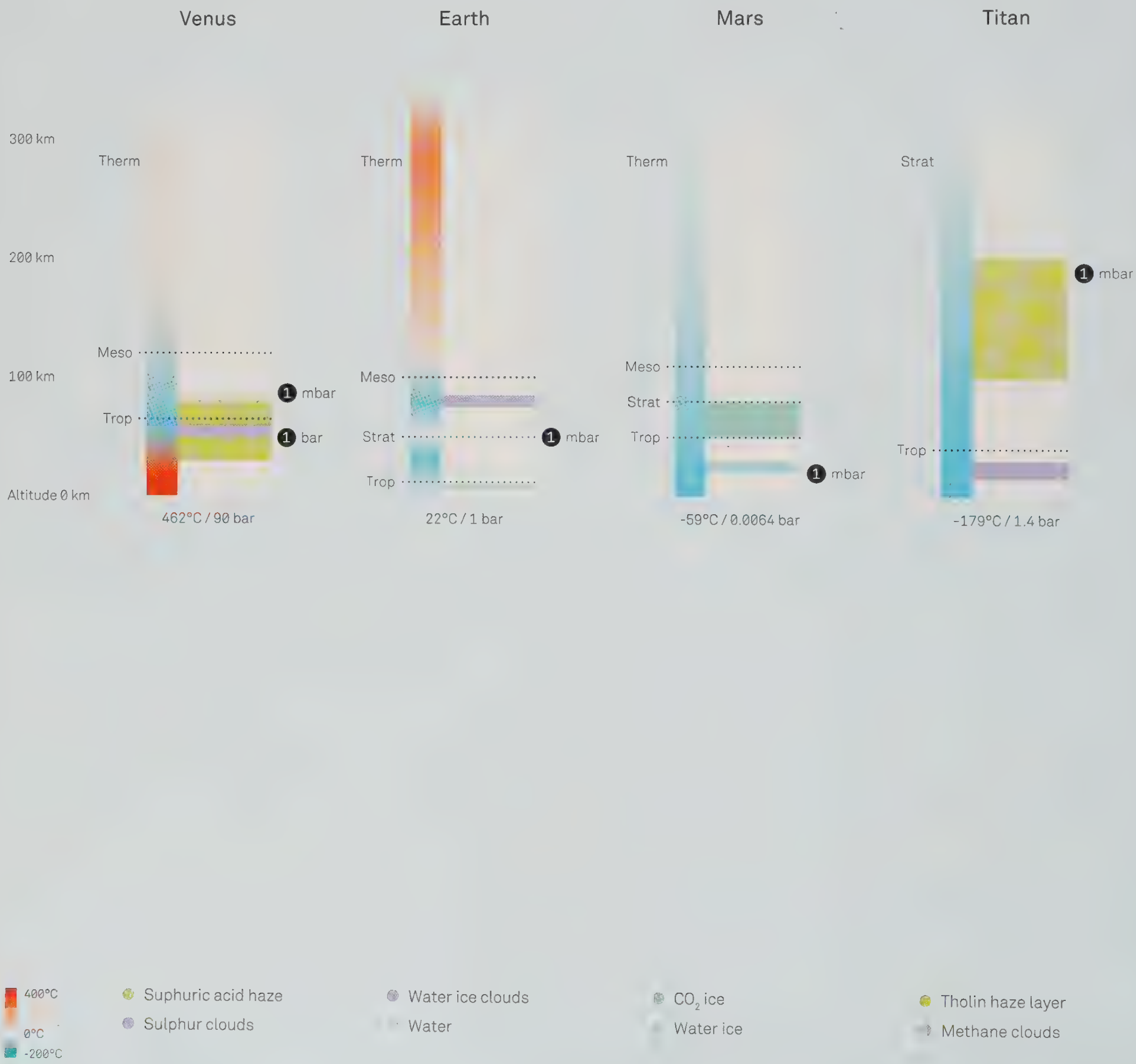
Planetary atmospheres

The Earth's atmosphere is a thin protective layer which cushions us from the harshness of outer space. The coldest place in the atmosphere is the tropopause, where the thin air is insulated from the ground heat. This region is also protected from sunlight, which heats the upper layers of the atmosphere.

Venus' crushing pressures and scorching temperatures make its surface uninhabitable. At an altitude of around 50 kilometres, however, the temperature and pressure are not dissimilar to Earth's surface.

Were it not for the howling winds, sulphuric acid rain and the long drop it could be quite cosy! Mars has a much thinner atmosphere, and is much colder. It has clouds of water ice, but also carbon dioxide (CO_2) ice.

Titan is Saturn's largest moon, and the only other object besides Earth with liquid on its surface. Its atmosphere is thicker than Earth's, but is far too cold for liquid water to exist anywhere. Instead, Titan has a hydrocarbon cycle, with clouds, lakes, rivers and even rain made from methane and ethane.



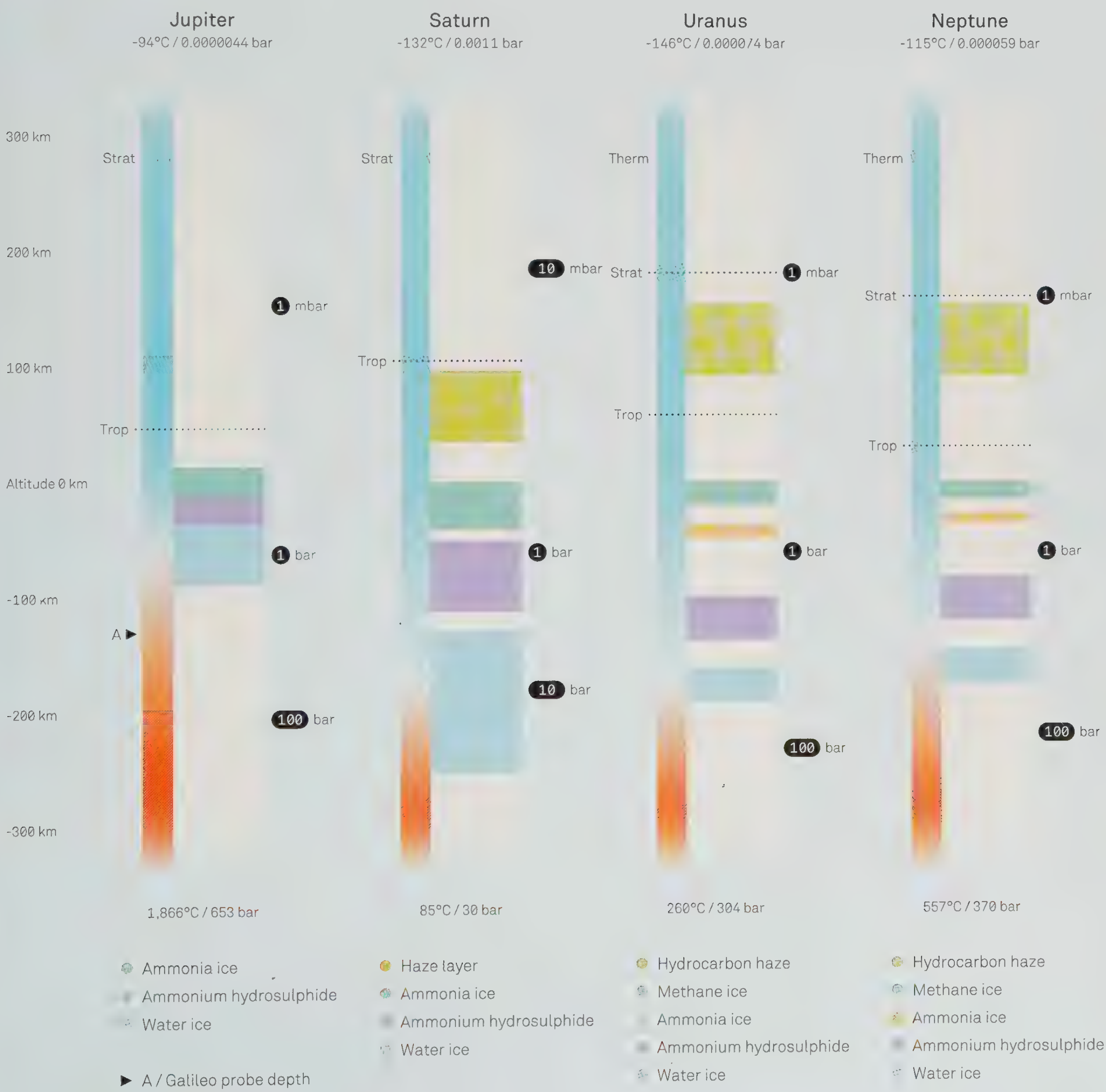
Thermosphere, Mesosphere, Troposphere and Stratosphere

With no known surfaces on the outer planets, altitude is normally given relative to the point at which atmospheric pressure is one bar, the same as on Earth's surface.

Jupiter's striped appearance is thanks to white clouds of ammonia ice above brownish hues of ammonia hydrosulphide, below which are thought to lie water ice clouds. In 1995 the Galileo spacecraft dropped a probe into Jupiter's atmosphere which sampled the composition down to depths of over 100 kilometres and measured wind speeds over 500 kilometres per hour.

Saturn's atmosphere is similar to Jupiter's, but due to the lower gravity is more expanded in altitude. A haze layer of hydrocarbons obscures the lower structures from view, giving it a much plainer appearance than Jupiter.

Uranus and Neptune have thick layers of methane which give them their blue hue. Neptune has the strongest winds ever measured in the Solar System, at more than 1,000 kilometres per hour.



Lords of the rings

Saturn is famous for its marvellous ring system, but it is not alone. The other outer planets all have their own ring systems, albeit not as bright or as expansive as Saturn's. Their origin is unknown, thought to be either the result of moons that were ripped apart, or possibly material that was never able to form a moon in the first place.

Neptune

Neptune's rings were first discovered in the 1980s, and confirmed by the *Voyager 2* spacecraft in 1989. They are named after astronomers who helped discover Neptune. Like the other planets' ring systems, they are associated with the smaller moons.

Uranus

Uranus' rings were first discovered in 1977, when they were seen to ever-so-slightly block the light of a background star. Rather than names, the rings have numbers and Greek letters.

Jupiter

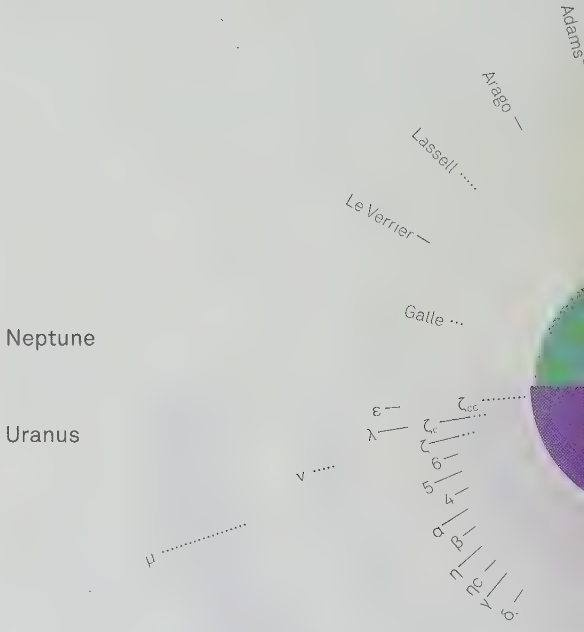
Jupiter's rings are very faint and weren't discovered until the *Voyager 1* spacecraft passed by in 1979. They are the result of the bombardment of the inner satellites by small meteorites.

Saturn

The main rings of Saturn are labelled with letters in the order of discovery, while the gaps and divisions between them are named after notable people in the history of Saturn observations. Despite spanning hundreds of thousands of kilometres, Saturn's rings are incredibly thin, with the main rings just tens of metres thick.

Observations by the Voyager and Cassini spacecraft showed that the divisions are caused by Saturn's smaller moons. The outer-most 'E Ring' is thought to be created by particles spewing from the south pole of Enceladus.

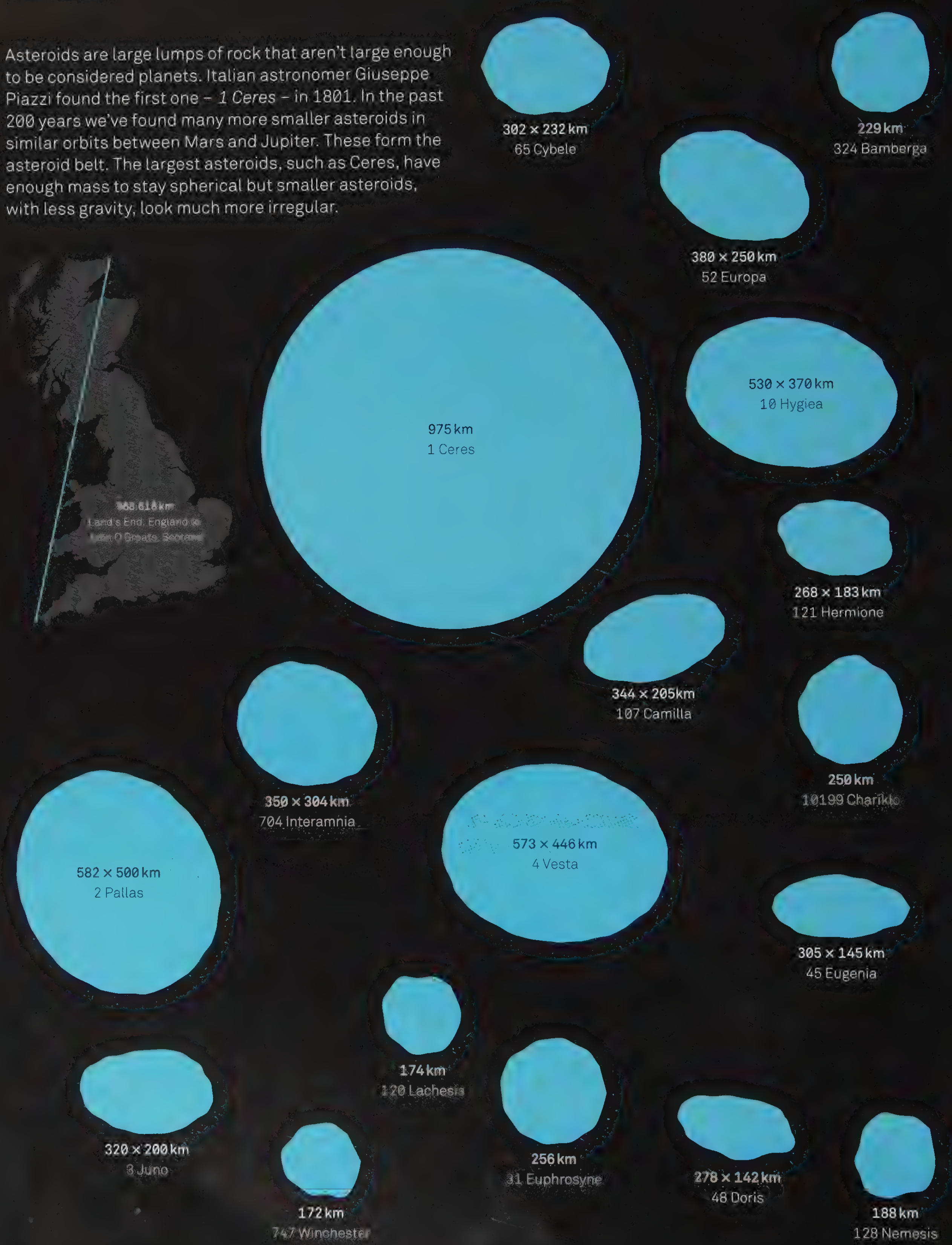
······ Ring width



Halo Ring 1979 J1R
Main Ring 1979 J2R
Amalthea Gossamer Ring
Thebe Gossamer Ring
Jupiter
Saturn
D Ring
Columba Gap
Maxwell Gap
Bond Gap
Dawes Gap
C Ring
B Ring
Cassini Division
Keeler Gap
Roche Division
A Ring
F Ring
Janus/Epimetheus Ring
G Ring
E Ring

Asteroids

Asteroids are large lumps of rock that aren't large enough to be considered planets. Italian astronomer Giuseppe Piazzi found the first one – *1 Ceres* – in 1801. In the past 200 years we've found many more smaller asteroids in similar orbits between Mars and Jupiter. These form the asteroid belt. The largest asteroids, such as Ceres, have enough mass to stay spherical but smaller asteroids, with less gravity, look much more irregular.




195 km
702 Alauda
140 km
209 Dido
233 × 193 km
29 Amphitrite
191 km
372 Palma
161 km
790 Pretoria
357 × 212 km
15 Eunomia
235 × 124 km
22 Kalliope
240 × 145 km
16 Psyche
213 × 160 km
41 Daphne
255 × 193 km
88 Thisbe
205 × 170 km
6 Hebe
222 × 130 km
9 Metis
384 × 232 km
87 Sylvia
212 km
423 Diotima
208 km
13 Egeria
171 km
153 Hilda
222 km
532 Herculina
60 × 19 km
243 Ida
225 km
451 Patientia
216 km
375 Ursula
225 × 173 km
94 Aurora
370 × 195 km
624 Hektor
121 × 101 km
21 Lutetia
240 × 200 km
7 Iris
18.2 × 10.5 km
951 Gaspra
187 km
154 Bertha
225 × 195 km
19 Fortuna
357 × 231 km
511 Davida
198 km
24 Themis
52 km
253 Mathilde

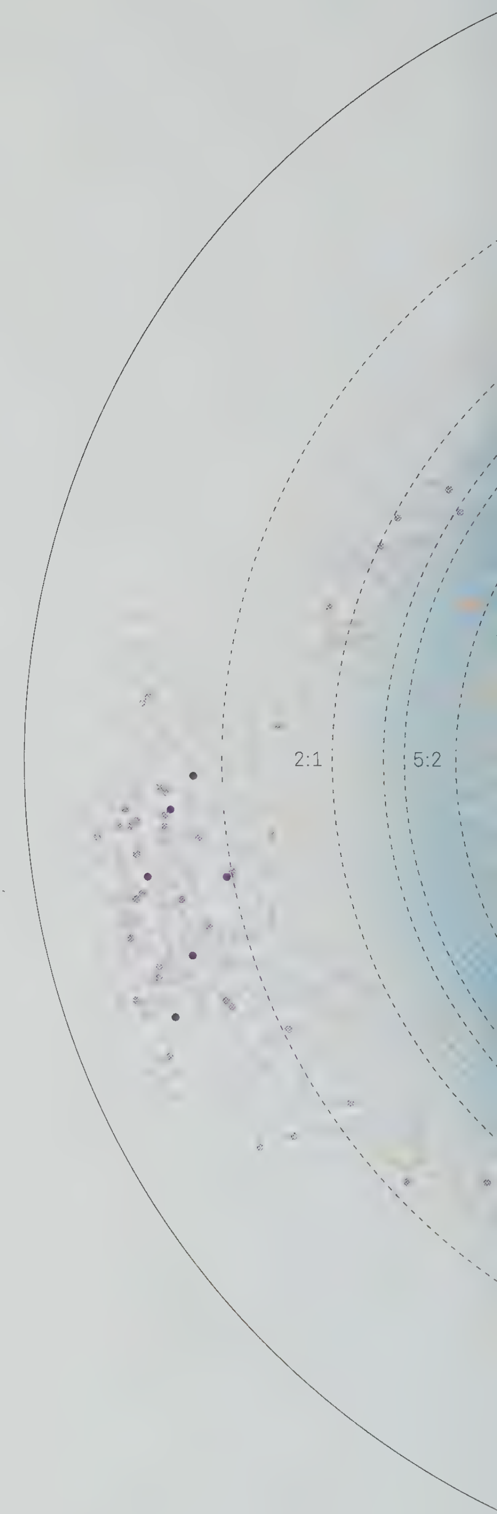
Locations of asteroids

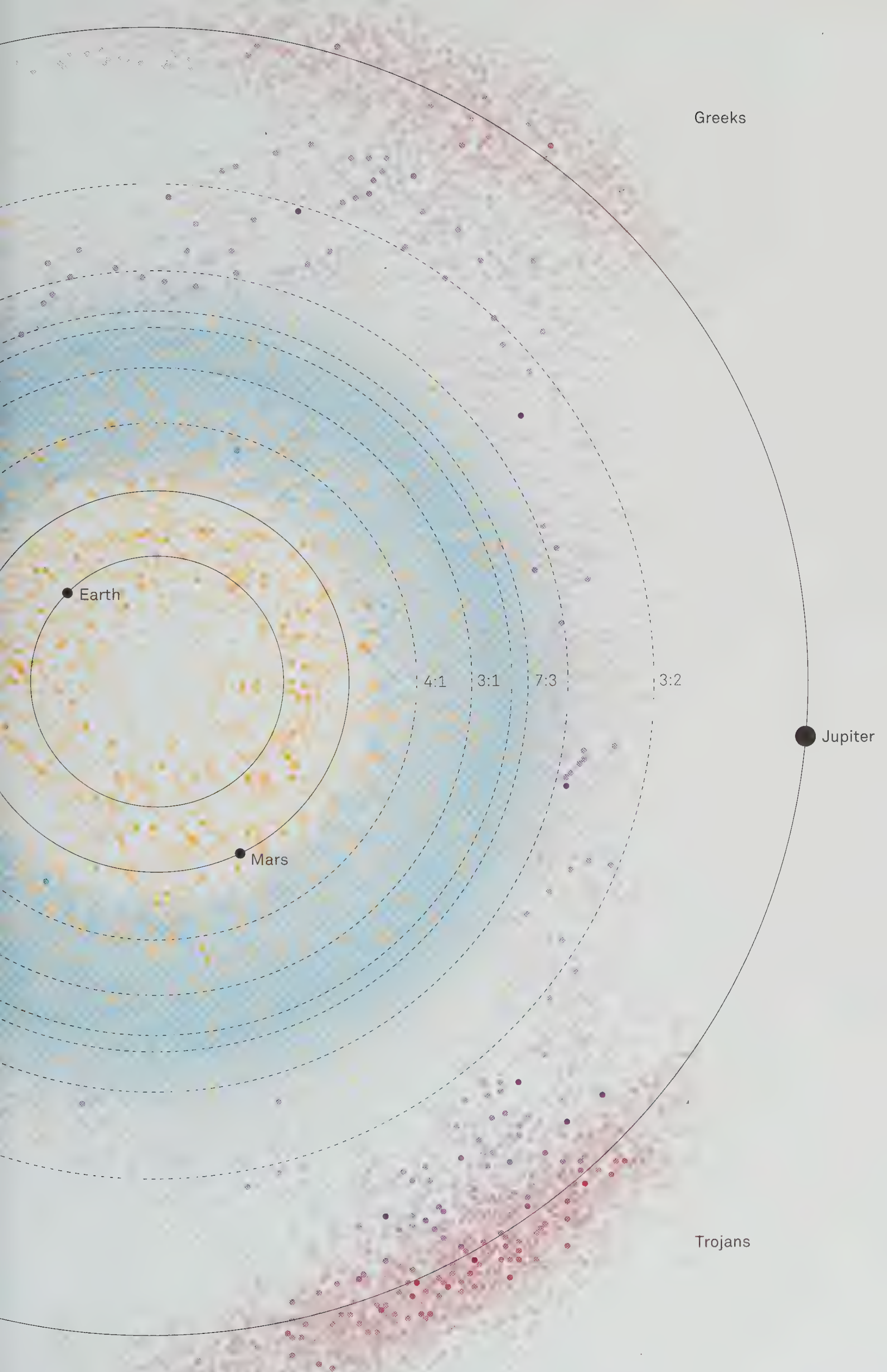
The vast majority of asteroids lie in the asteroid belt between the orbits of Mars and Jupiter, but not all asteroids stay there, and some stray into the inner Solar System. Those that get close to Earth's orbit, sometimes even crossing it, are called Near-Earth Asteroids. It is these that pose the greatest danger to us, as one day they could hit the Earth.

Jupiter's gravitational pull has a strong influence on the orbits of asteroids, and they don't like being in sync with the giant planet. There are very few with orbits longer than half that of Jupiter (a 2:1 resonance), or shorter than a quarter of that of Jupiter (a 4:1 resonance). Those within the 4:1 resonance are in the 'Hungaria' group.

Asteroids beyond the main belt can be trapped in gravitational sweet spots called 'Trojan points', so called because these asteroids are named after participants in the Greek-Trojan war. These asteroids stay about 60 degrees ahead or behind Jupiter in its orbit. The Hilda family of asteroids orbit the Sun three times for every two orbits that Jupiter makes (a 3:2 resonance).

1 90 / Main belt asteroids
1 09 / Trojans & Greeks
1 04 / Hildas
1 03 / Near Earth Asteroids




Greeks
Earth
4:1
3:1
7:3
3:2
Jupiter
Mars
Trojans

Names of asteroids

Themes have been established for naming the features, moons and rings of the major bodies in the Solar System. However, if you discover an asteroid you have the option to suggest any name you like for it. The main rule is that the name must be unique. Of 18,977 named asteroids, catalogued by the Minor Planet Center, 13,290 have citations describing who or what the asteroid is named for.

The names come from all over the world and cover a range of sources. As might be expected, many are named after scientists and astronomers (or their friends and families). There are also the names of mountains, villages, mythological characters, famous authors, and even the cast of Monty Python. Some asteroid names fall into multiple categories.

Entertainment

13070 Seanconnery / Sean Connery (1930) British actor known from the James Bond films.

13681 Monty Python / Monty Python's Flying Circus.

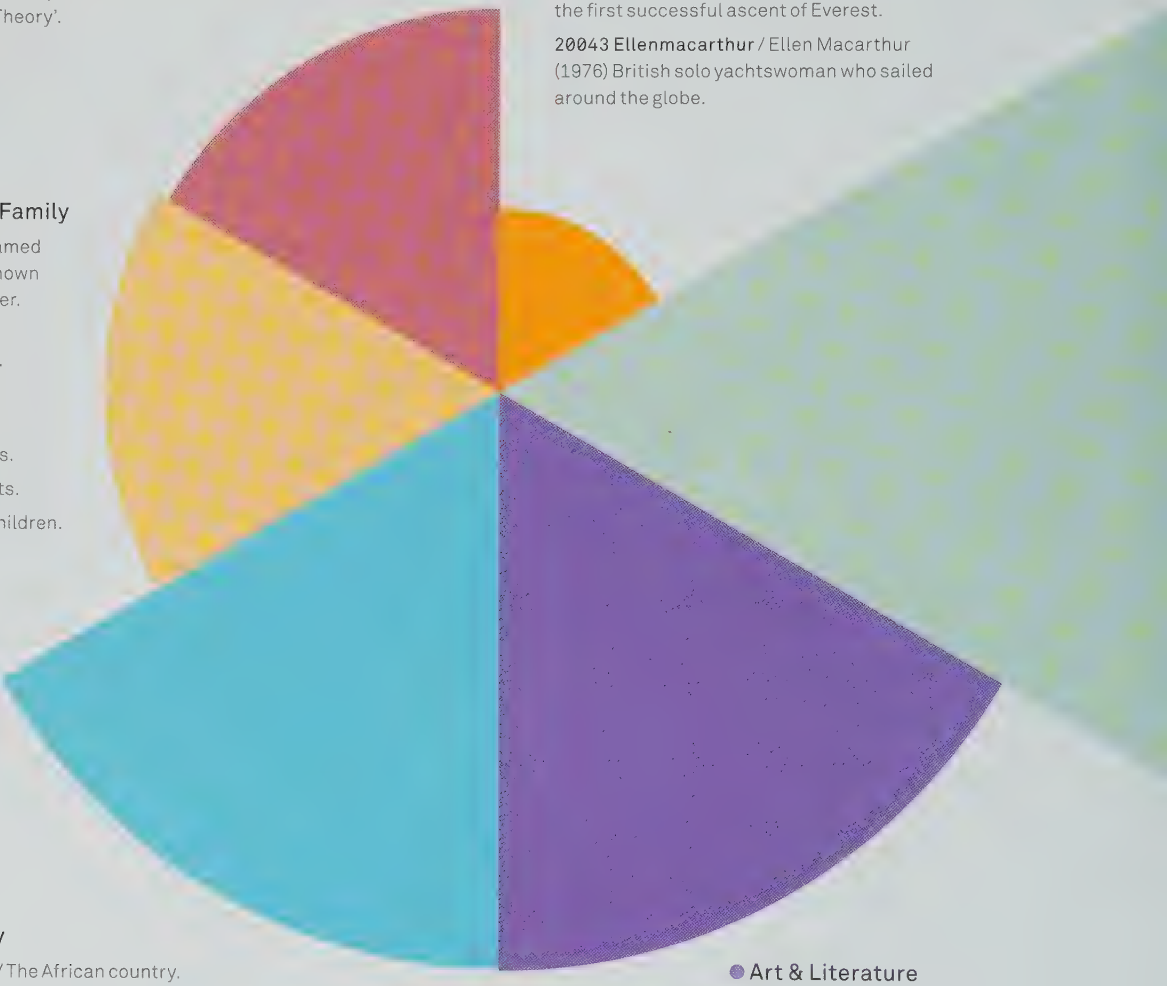
246247 Sheldoncooper / Character on the TV series 'The Big Bang Theory'.

Sport & Leisure

230975 Rogerfederer / Roger Federer (1981) Swiss tennis player.

6481 Tenzing / Tenzing Norgay (1914-1986) Nepalese climber who made the first successful ascent of Everest.

20043 Ellenmacarthur / Ellen Macarthur (1976) British solo yachtswoman who sailed around the globe.



Friends & Family

Of asteroids named after people known to the discoverer.

19% are sons and daughters.

18% are wives and husbands.

16% are friends.

16% are parents.

5% are grandchildren.

Geography

1718 Namibia / The African country.

10958 Mont Blanc / The highest mountain in Europe.

19620 Auckland / The largest city in New Zealand.

Art & Literature

4444 Escher / Maurits C. Escher (1898-1972) Dutch graphic artist.

10185 Gaudi / Antoni Gaudi (1852-1926) Spanish architect.

39427 Charlottebronte / Charlotte Bronte (1816-1855) British novelist and poet.

Science & Nature

1991 Darwin / Charles Darwin (1809 – 1882) English naturalist.

7672 Hawking / Stephen Hawking (1942) Theoretical physicist famous for his work on black holes.

25275 Jocelynbell / Jocelyn Bell (1943) British astrophysicist who discovered pulsars.

91006 Fleming / Alexander Fleming (1881-1955) British biologist & pharmacologist who discovered penicillin.

The birth years of people with asteroids named after them.

There was a sudden increase from 1984 due to US science fairs in the 2000s naming asteroids after the winners.

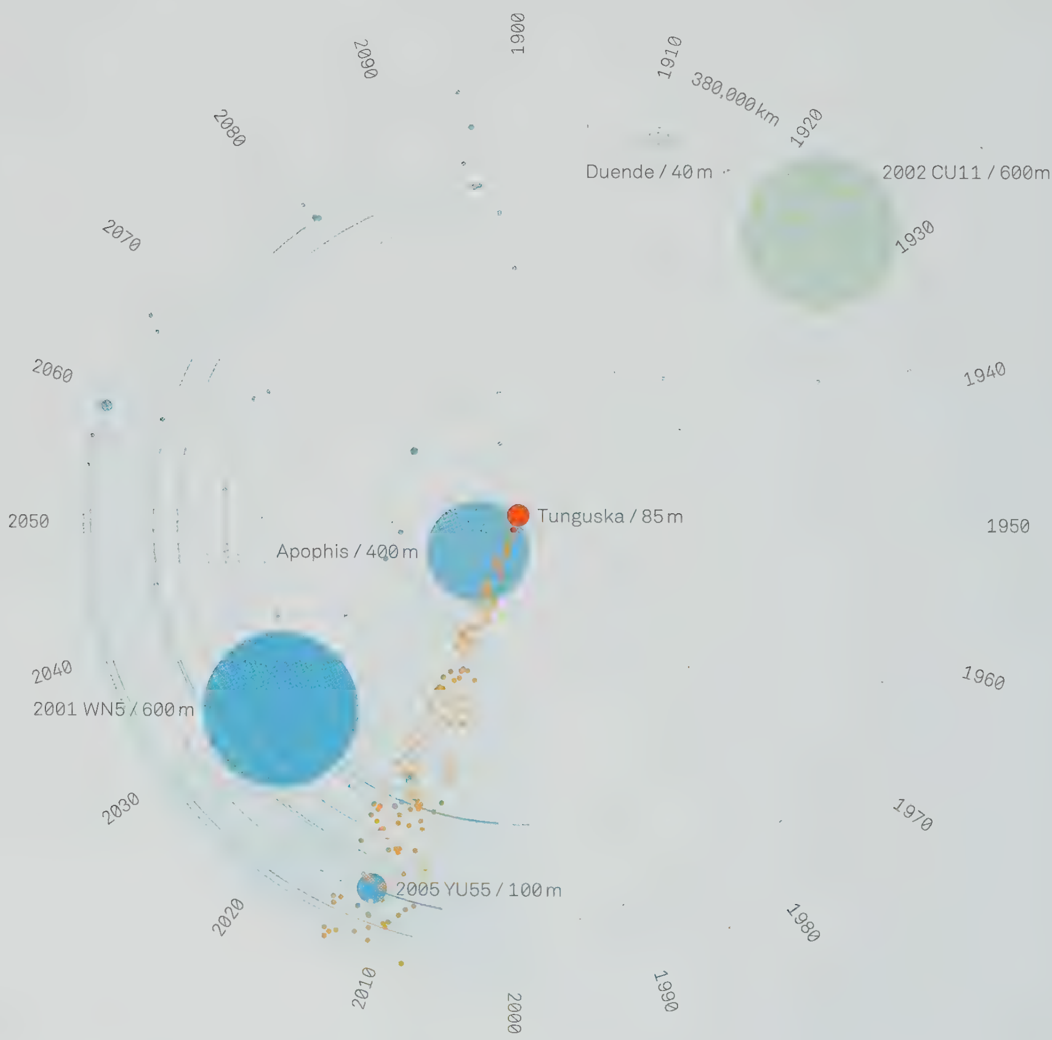
We discover tens of thousands of asteroids every year, most of which are very small and stay far from Earth. But every now and then we get a wake-up call, and find a large asteroid that is due to get a bit too close for comfort.

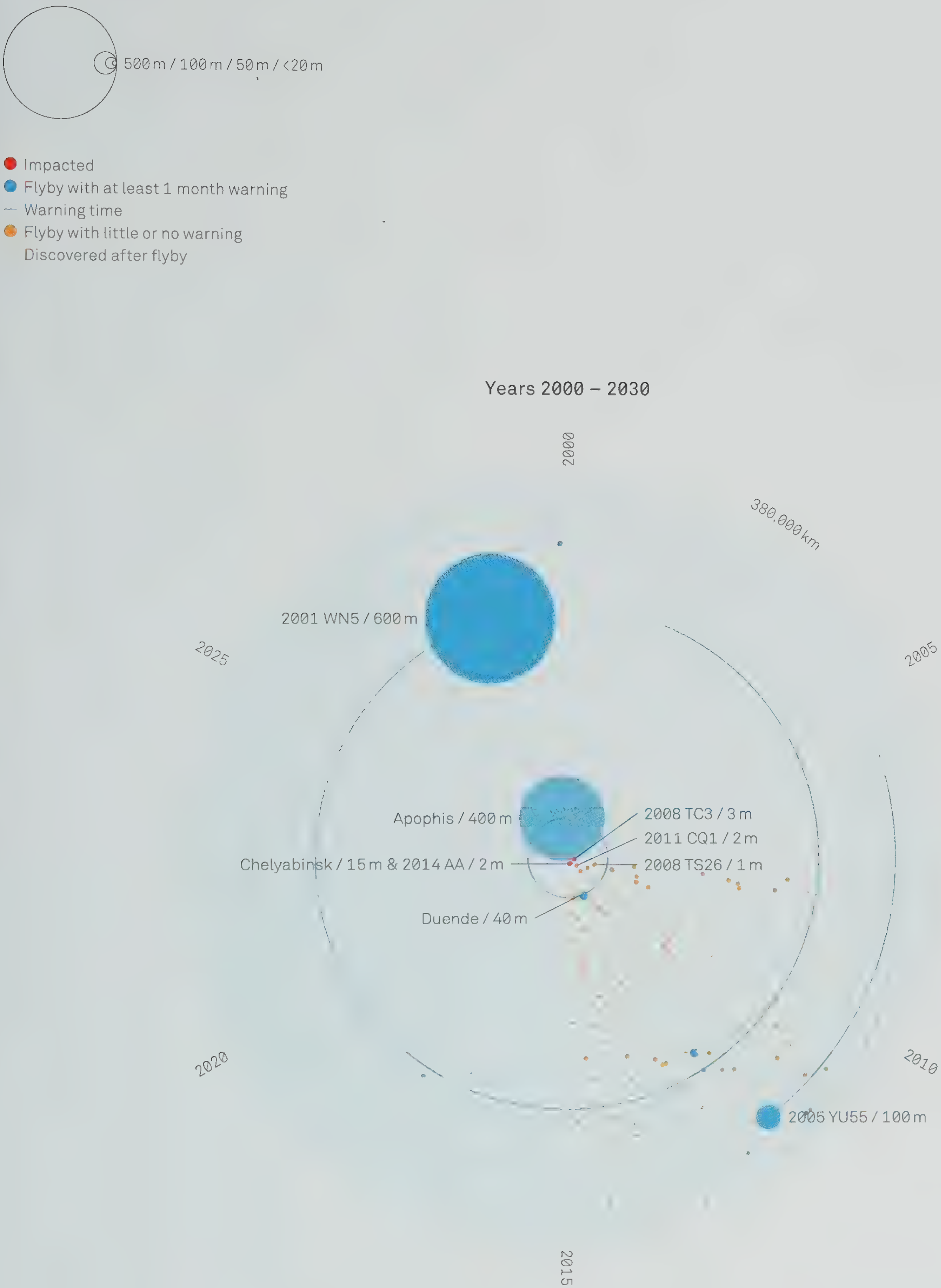
In 2029, the asteroid Apophis will pass within about 40,000 kilometres of Earth. That's really not very far astronomically speaking – only around one-tenth of the distance to the Moon. If it got just a little closer there would be huge devastation.

But then there are those asteroids we don't see coming. In 1908 an asteroid impacted in Tunguska, Russia, flattening trees over a huge area. We're on the lookout for these objects now, and though we have discovered hundreds in recent years, we still don't catch them all.

In February 2013 the world was taken by surprise when an asteroid 10 – 20 metres across entered the atmosphere with no warning and exploded over Chelyabinsk, Russia, injuring over 1,000 people. How many more are we missing?

Years 1900 – 2100





500 m / 100 m / 50 m / <20 m
Impacted
Flyby with at least 1 month warning
Warning time
Flyby with little or no warning
Discovered after flyby
Years 2000 – 2030
2000
2005
2010
2015
2020
2025
380,000 km
2001 WN5 / 600 m
Apophis / 400 m
2008 TC3 / 3 m
2011 CQ1 / 2 m
Chelyabinsk / 15 m & 2014 AA / 2 m
2008 TS26 / 1 m
Duende / 40 m
2005 YU55 / 100 m

Classifications of meteorites

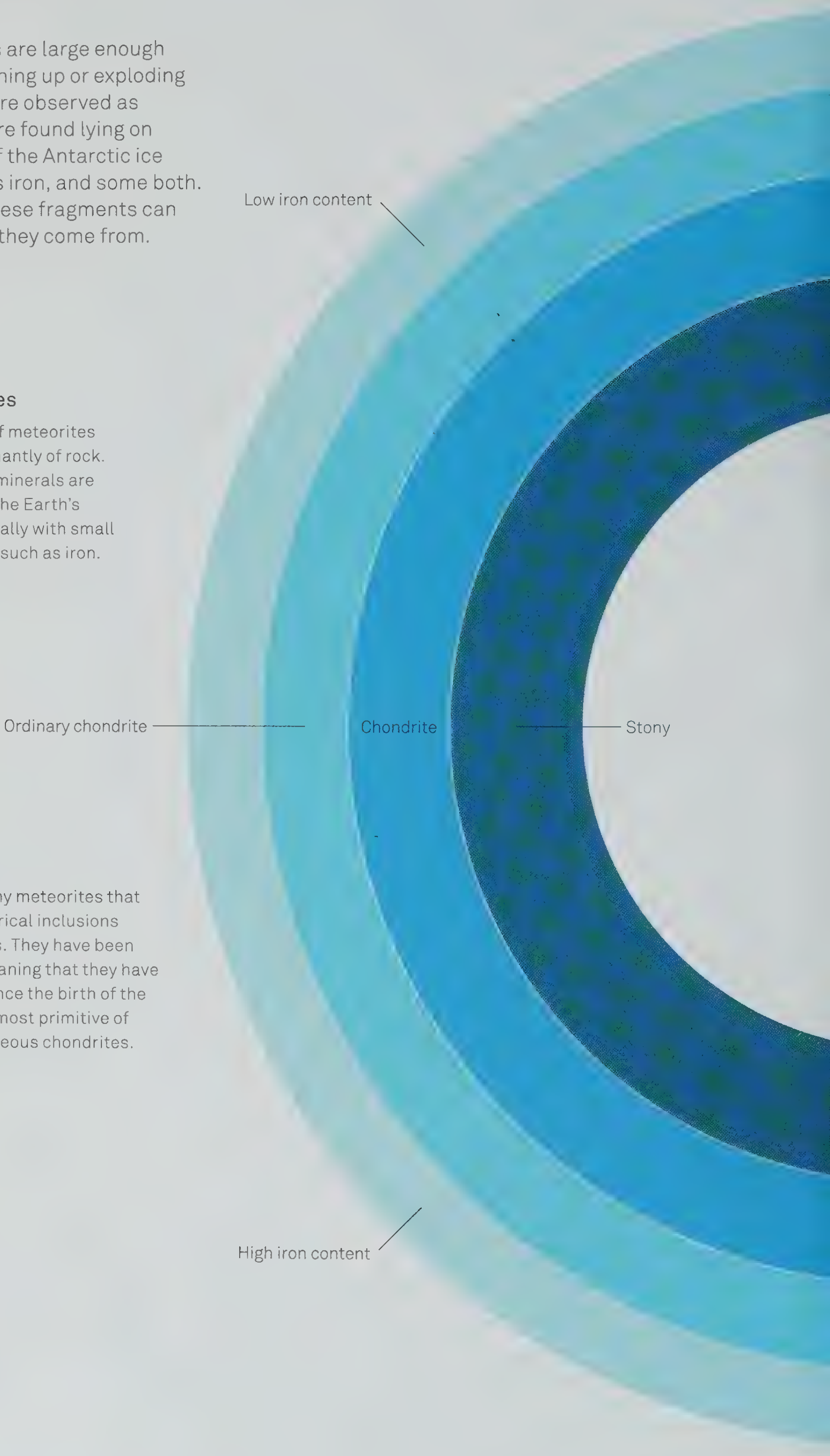
Now and again small pieces of debris are large enough to make it down to Earth without burning up or exploding in the atmosphere. A small fraction are observed as they fall from the sky, though most are found lying on the ground, most commonly on top of the Antarctic ice sheet. Some are made of rock, others iron, and some both. Studying the chemical make-up of these fragments can sometimes even tell us which object they come from.

Stony meteorites

The vast majority of meteorites are made predominantly of rock. The materials and minerals are similar to those in the Earth's crust, though normally with small amounts of metals such as iron.

Chondrites

Chondrites are stony meteorites that contain small spherical inclusions of specific minerals. They have been heated slightly, meaning that they have not been altered since the birth of the Solar System. The most primitive of these are carbonaceous chondrites.



Iron meteorites

Iron meteorites are made of iron and nickel, and are the result of high-energy impacts that melted the original object.

Stony iron meteorites

Stony iron meteorites are a roughly equal mixture of rock and metal.

Achondrites

Achondrites are stony meteorites that have been heated at some point in their past. These include meteorites from the Moon and Mars, but the largest group are thought to originate from Vesta.

A comet

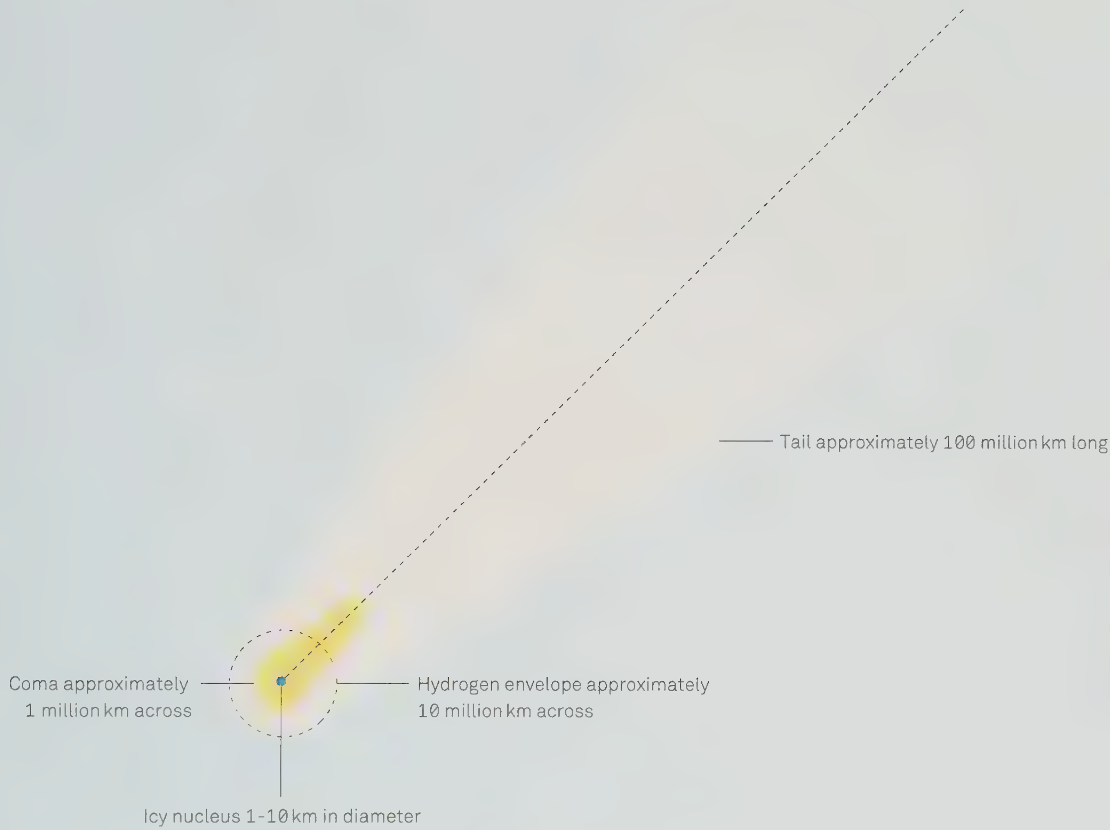
Thought to be omens by the ancients, we now know that comets are small icy and rocky bodies that orbit the Sun on elongated orbits. Although famous for their tails, they spend most of their time in the outer Solar System where it is cold and their tails are inactive. As they fall inwards towards the Sun the temperature rises. Their outer layers start to sublimate away from their central nuclei and form expansive tails. Comets actually have two tails; a dust tail and an ion tail.

As of 2015, six comets have been visited by spacecraft. In 2014 ESA's Rosetta spacecraft visited comet *67P/Churyumov-Gerasimenko*. It dropped the Philae lander which completed the first ever soft landing on a comet.

1986
Comet: 1P/Halley, Spacecraft: Giotto / Size: 14.9 km

2001
19P/Borrelly, Deep space 1 / 8 km

2004
81P/Wild, Stardust / 4 km



2005
9P/Tempel, Deep impact / 7.6 km

2010
103P/Hartley, Epoxi / 1.6 km

2014
67P/Churyumov-Gerasimenko, Rosetta / 4.3 km

Comets

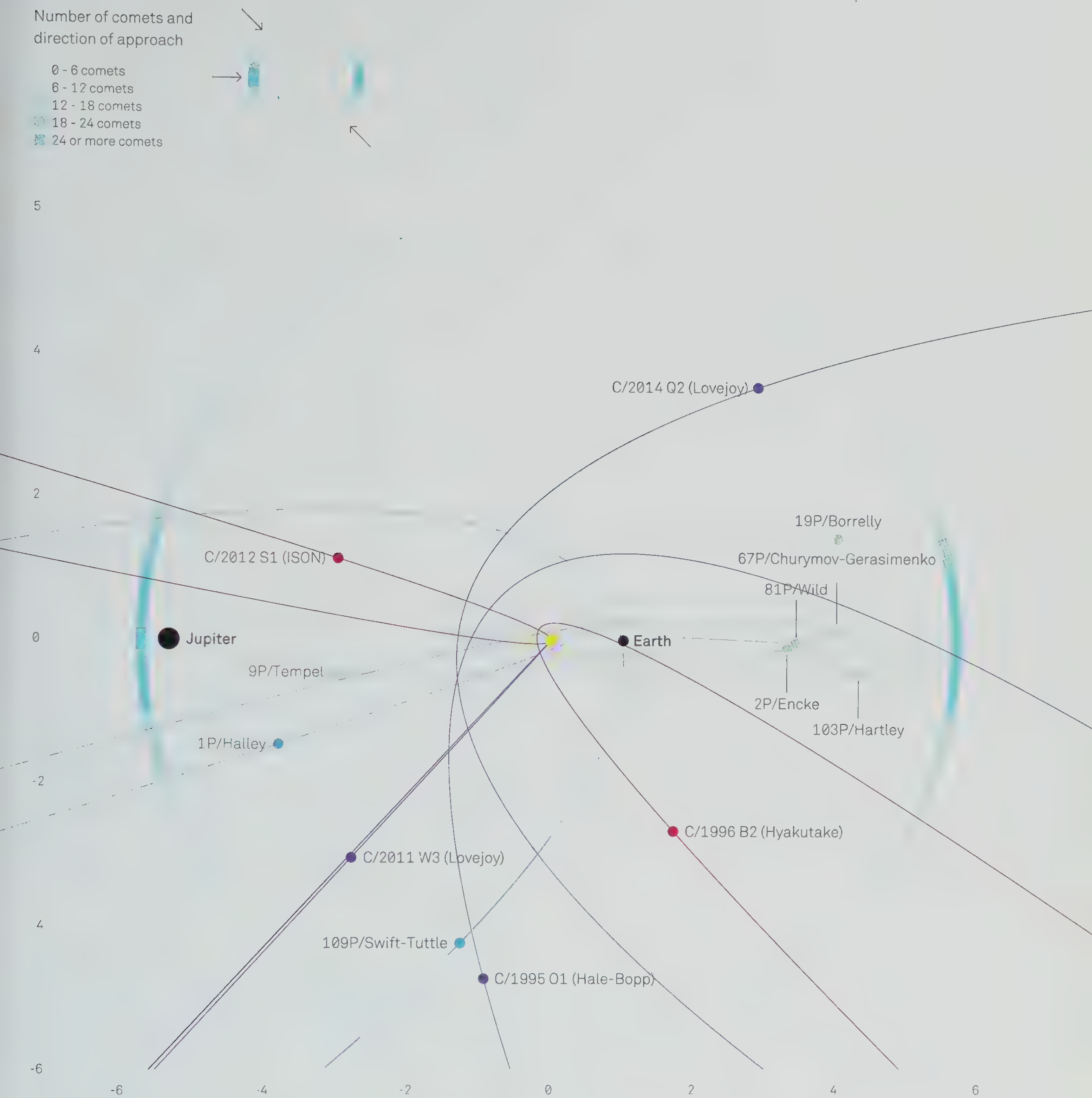
We only generally see comets when they come into the inner Solar System. But they originate much further out. Comets are split into several main groups depending on their orbits.

Short period comets

The short period comets have orbital periods less than 200 years, with most staying within the Kuiper Belt. Some, such as Halley's Comet (*1P/Halley*) come in at relatively high angles, and are though to have originated in the Oort cloud.

Jupiter family comets

The Jupiter family comets are short-period comets with orbits less than 20 years long, and which tend to orbit in the same plane as the planets. They are thought to have formed in the Kuiper Belt, but been sent inwards after coming too close to the giant planets. They are now on orbits that take them about as far out as Jupiter's orbit.



Long period comets

The long period coments have orbits over 200 years long, typically taking thousands of years. These originated in the Oort Cloud, but have been scattered in towards the inner Solar System. 'Sungrazing comets' are those which get very close to the Sun, such as *C/2011 W3 (Lovejoy)*. Most are thought to be fragments of a larger comet that broke up thousands of years ago when it got too close to the Sun.

Non-periodic comets

The Non-periodic comets are on such long orbits that it's not clear whether they will ever return to the inner Solar System or, if they do, not for millions of years. They may escape the Sun's gravity entirely. Comet *C/2012 S1 (ISON)* made its first visit to the inner Solar System in late 2013. It was a sungrazing comet that got so close to the Sun that it was ripped apart, leaving behind a cloud of gas and dust.

Comet hunters

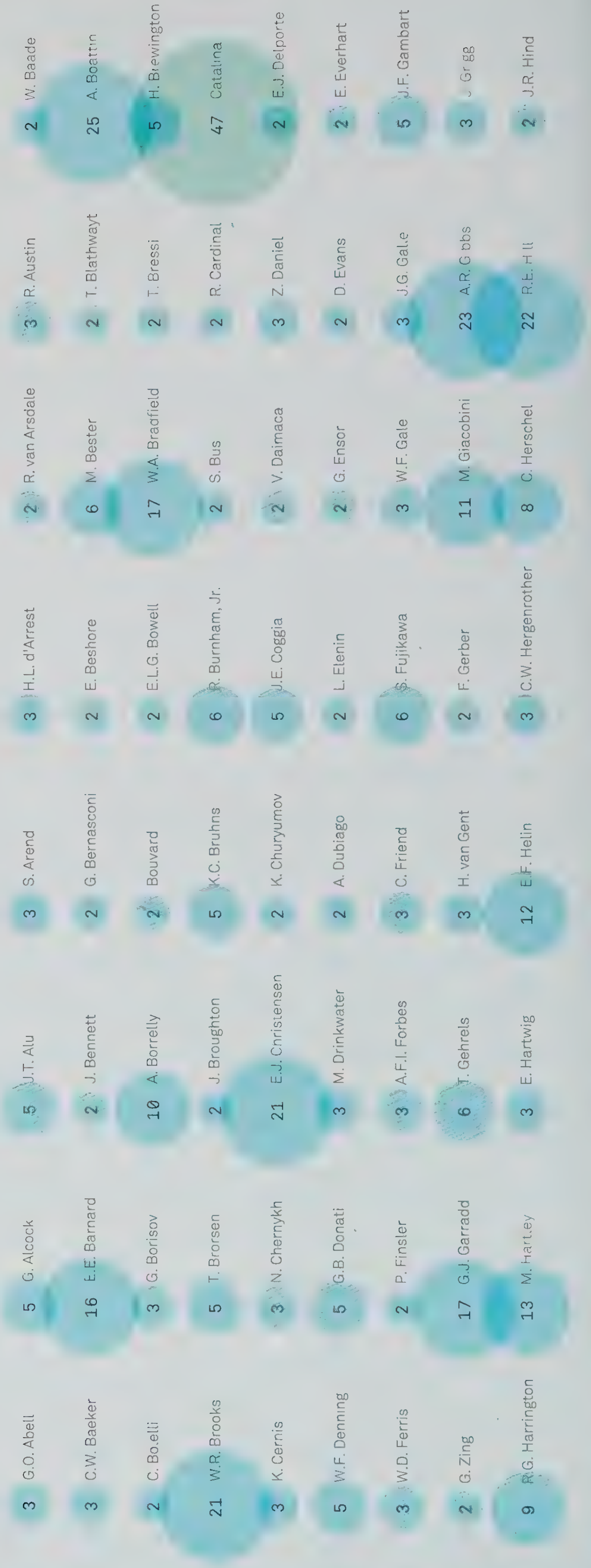
Comets – from the Greek 'kometes' meaning 'long-haired' – have been known since antiquity. For centuries it had been argued that they were anything from refracted light, to atmospheric vapours, to chains of stars. We now know that they orbit the Sun and many are periodic in nature.

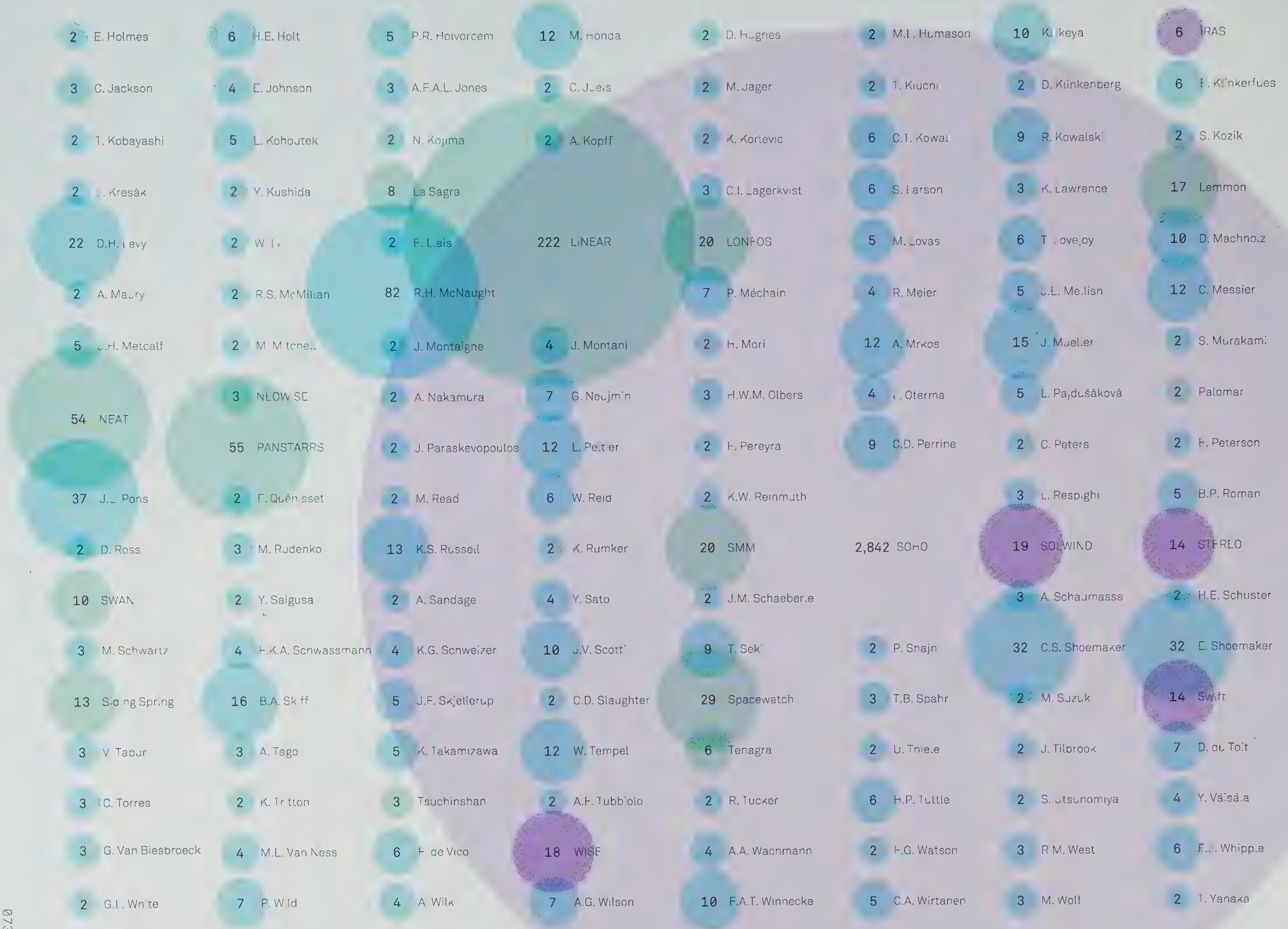
The invention of telescopes spurred a spate of comet discoveries. One of the earliest comet discoverers was Caroline Herschel who found a remarkable eight comets. Jean-Louis Pons set a long-held record for the most comets found by one person with 37. This was nearly equalled in the 1980/90s by Caroline and Eugene Shoemaker who co-discovered the famous *Shoemaker-Levy 9* which hit Jupiter in 1994. In the 21st Century, Robert H. McNaught has smashed the record with 82 comets to his name.

The 21st Century has seen the rise of ground and space-based projects which have often found comets as a by-product of their main observations. Most notable are discoveries on a mission by the ESA/NASA SOHO satellite designed to monitor the Sun: over 2,800 comets have been found, thanks to amateur and professional comet hunters combing images from the spacecraft. Perhaps the most prolific amateur is British astronomer Mike Oates who has found 144 comets this way.

Method of discovery and total number to date

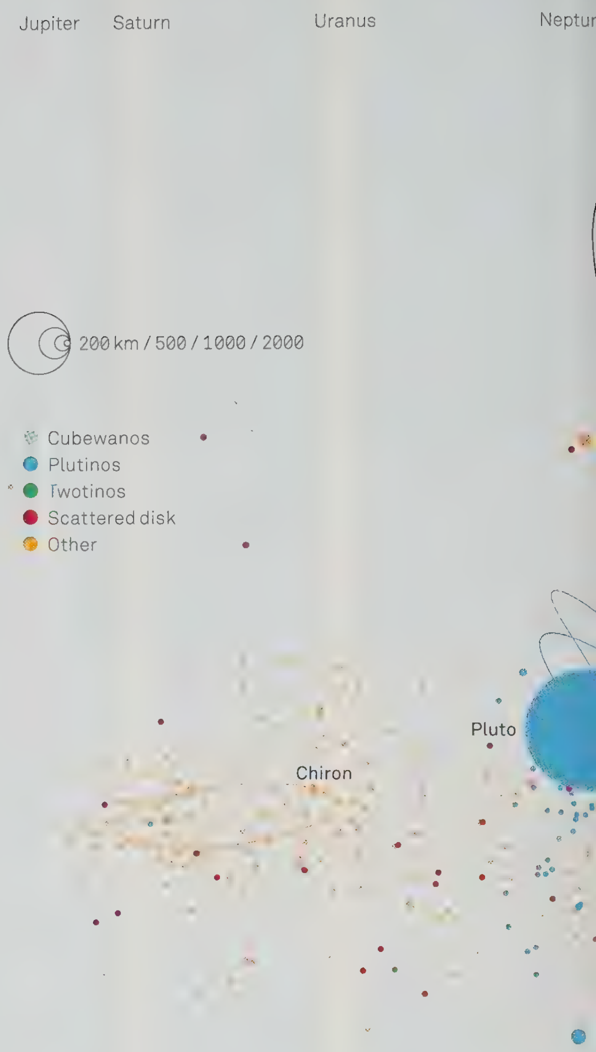
- Human
- Robotic survey
- Spacecraft




2 E. Holmes
3 C. Jackson
2 T. Kobayashi
2 L. Kresák
22 D.H. Levy
2 A. Maury
5 J.H. Metcalf
54 NEAT
37 J.L. Pons
2 D. Ross
10 SWAN
3 M. Schwartz
13 Siding Spring
3 V. Tabur
3 C. Torres
3 G. Van Biesbroeck
2 G.I. White
6 H.E. Holt
4 E. Johnson
5 L. Kohoutek
2 Y. Kushida
2 W. Li
2 R.S. McMillan
2 M. Mitchell
3 NEOWISE
55 PANSTARRS
2 F. Quénisset
3 M. Rudenko
2 Y. Saigusa
4 F.K.A. Schwassmann
16 B.A. Skiff
3 A. Tago
2 K. Tritton
4 M.L. Van Ness
7 P. Wild
5 P.R. Holvorcem
3 A.F.A.L. Jones
2 N. Kojima
8 La Sagra
2 F. Lais
82 R.H. McNaught
2 J. Montaigne
2 A. Nakamura
2 J. Paraskevopoulos
2 M. Read
13 K.S. Russell
2 A. Sandage
4 K.G. Schweizer
5 J.F. Skjellerup
5 K. Takamizawa
3 Tsuchinshan
6 F. de Vico
4 A. Wilk
12 M. Honda
2 C. Juels
2 A. Kopff
222 LINEAR
4 J. Montani
7 G. Neujmin
12 L. Peltier
6 W. Reid
2 K. Rumker
4 Y. Sato
10 J.V. Scotti
2 C.D. Slaughter
12 W. Tempel
2 A.F. Tubbiolo
18 WISE
7 A.G. Wilson
2 D. Hughes
2 M. Jager
2 K. Kortevic
3 C.I. Lagerkvist
20 LONEOS
7 P. Méchain
2 H. Mori
3 H.W.M. Olbers
2 F. Pereyra
2 K.W. Reinmuth
20 SMM
2 J.M. Schaeberle
9 T. Seki
29 Spacewatch
6 Tenagra
2 R. Tucker
4 A.A. Wachmann
10 F.A.T. Winnecke
2 M.L. Humason
2 T. Kiuchi
6 C.T. Kowal
6 S. Larson
5 M. Lovas
4 R. Meier
12 A. Mrkos
4 L. Oterma
9 C.D. Perrine
2,842 SOHO
2 P. Shajn
3 T.B. Spahr
2 U. Thiele
6 H.P. Tuttle
2 F.G. Watson
5 C.A. Wirtanen
10 K. Ikeya
2 D. Klinkenberg
9 R. Kowalski
3 K. Lawrence
6 T. Lovejoy
5 J.L. Mellish
15 J. Mueller
5 L. Pajdušáková
2 C. Peters
3 L. Respighi
19 SOLWIND
3 A. Schaumasse
32 C.S. Shoemaker
2 M. Suzuki
2 J. Tilbrook
2 S. Utsunomiya
3 R.M. West
3 M. Wolf
6 IRAS
6 E. Klinkerfues
2 S. Kozik
17 Lemmon
10 D. Machholz
12 C. Messier
2 S. Murakami
2 Palomar
2 F. Peterson
5 B.P. Roman
14 STEREO
2 H.E. Schuster
32 E. Shoemaker
14 Swift
7 D. du Toit
4 Y. Väisälä
6 F.L. Whipple
2 T. Yanaka

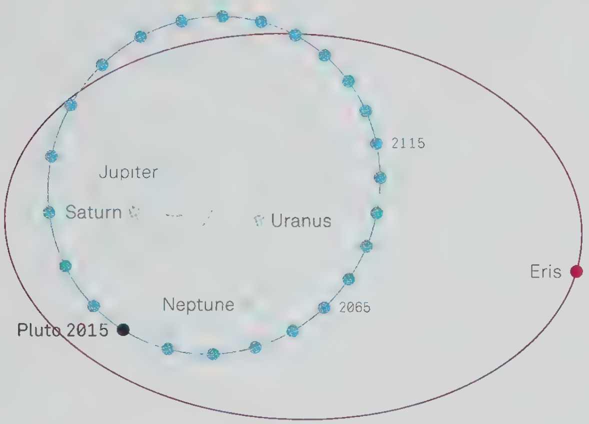
Kuiper belt

In 1992 astronomers discovered a small object out beyond the orbit of Neptune. Called 1992 QB1, it is now one of around 1,000 known objects that join Pluto out in the Kuiper Belt. The discovery of Eris in 2005 led to the realisation that Pluto is not the only large object in the outer Solar System. Most move in ellipses rather than circles, changing their distance from the Sun as they orbit.

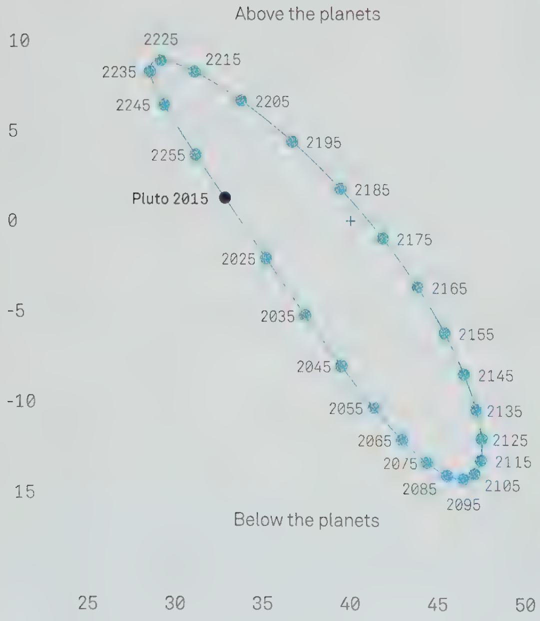


Pluto / plan

Objects in the Kuiper Belt often have orbits tilted relative to the eight main planets, so they move up and down as well as towards and away from the Sun.



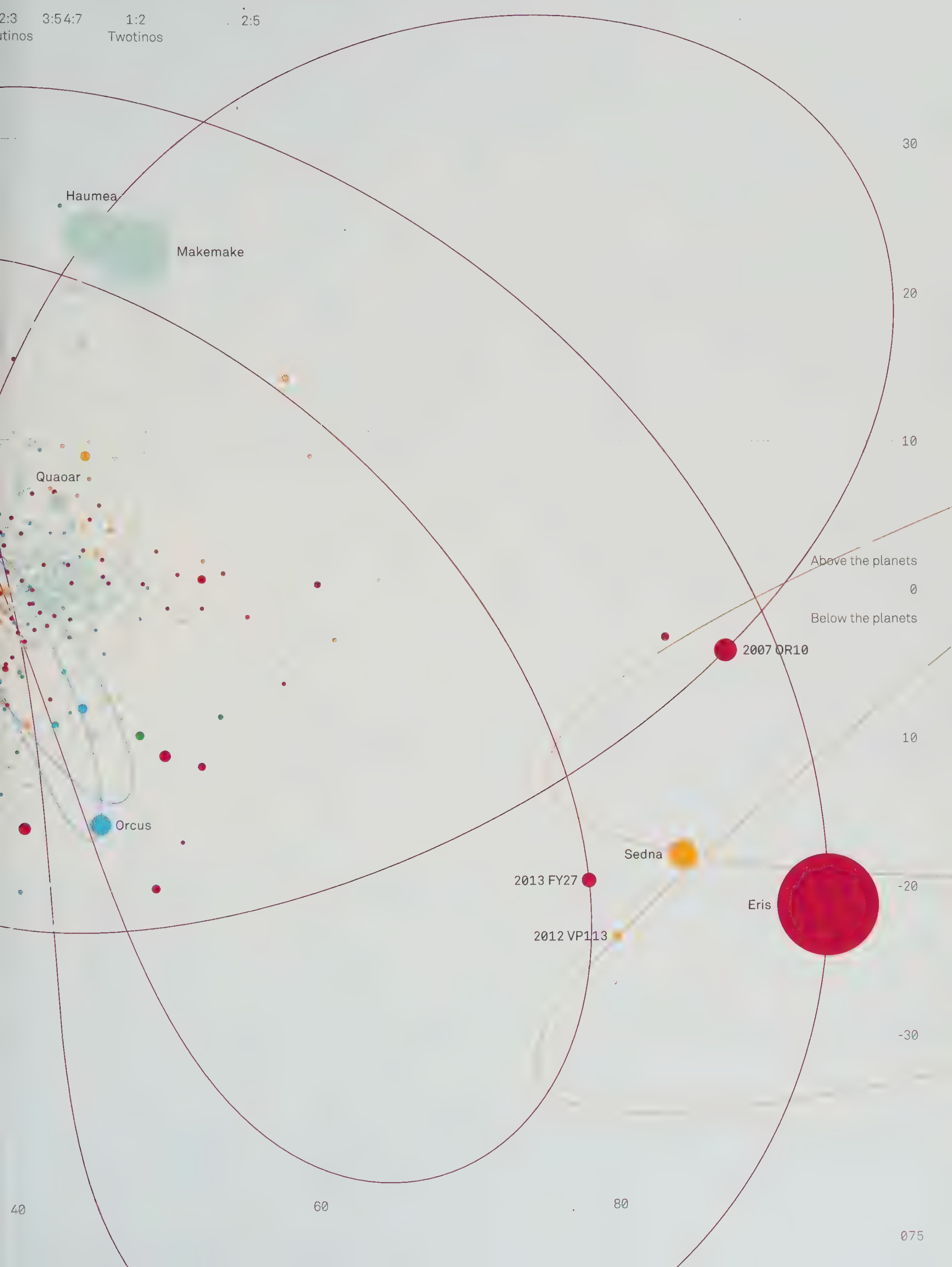
Pluto / elevation



Most objects in the Kuiper Belt orbit just beyond Neptune and don't cross its orbit (unlike Pluto). These are called 'Cubewanos' after the first discovered object, *1992 QB1*.

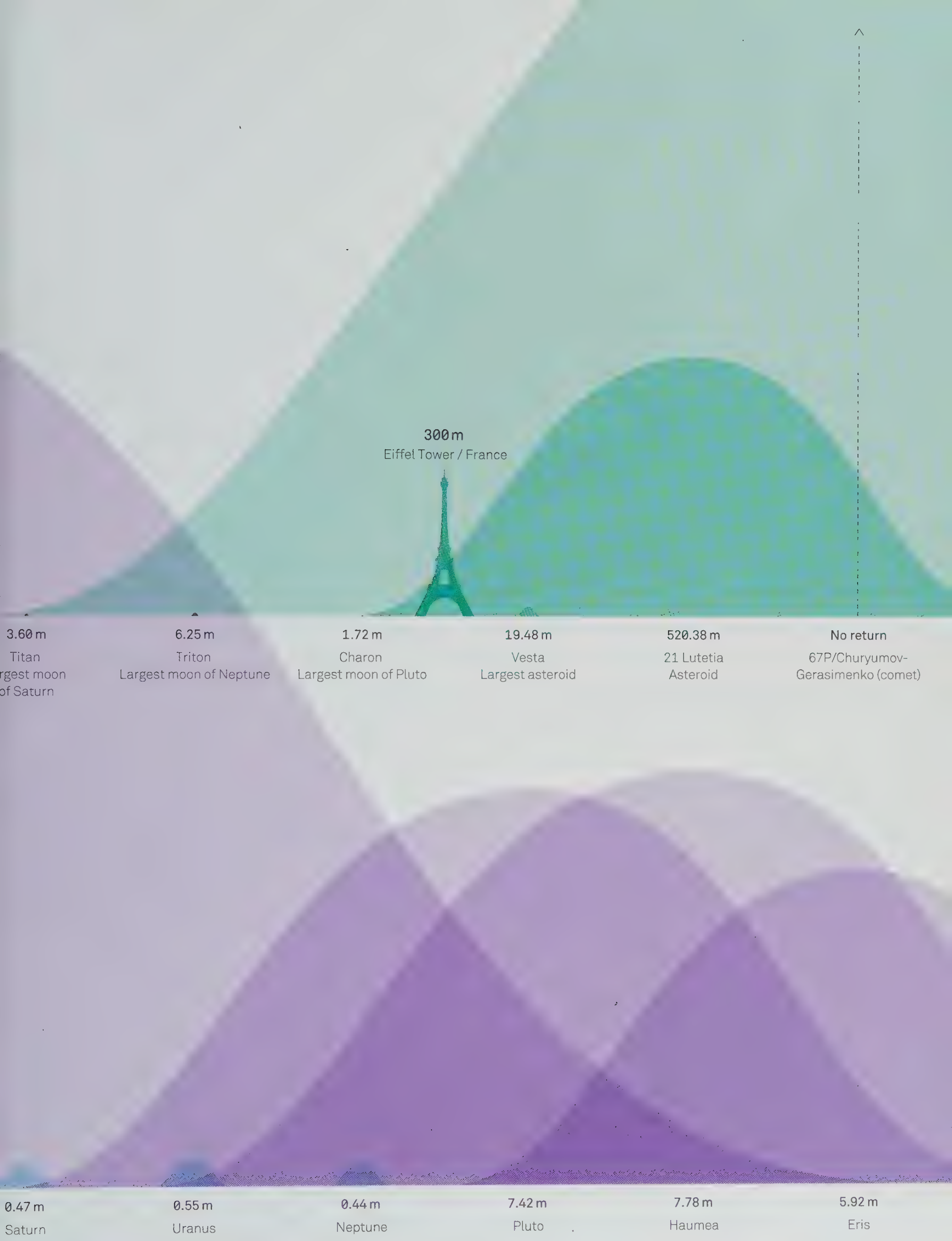
There are groups of objects that have orbits that resonate with Neptune's. Like Pluto, 'Plutinos' orbit the Sun twice for every three times Neptune orbits. 'Twotinos' orbit once for every two Neptune orbits.

Some bodies have very wild orbits, thought to be as a result of the gravitational pull of the outer planets, particularly Jupiter and Neptune. These make up the Scattered Disk.


2:3
tinos
3:5 4:7
1:2
Twotinos
2:5
Haumea
Makemake
Quaoar
Orcus
30
20
10
Above the planets
0
Below the planets
2007 OR10
10
Sedna
2013 FY27
Eris
2012 VP113
-20
-30
40
60
80

The high jump

If you can jump half a metre high on the Earth, how high could you jump on the Moon, Jupiter, or an asteroid? That depends on the mass and size of the object. If it's too small and light you'll never come back down.

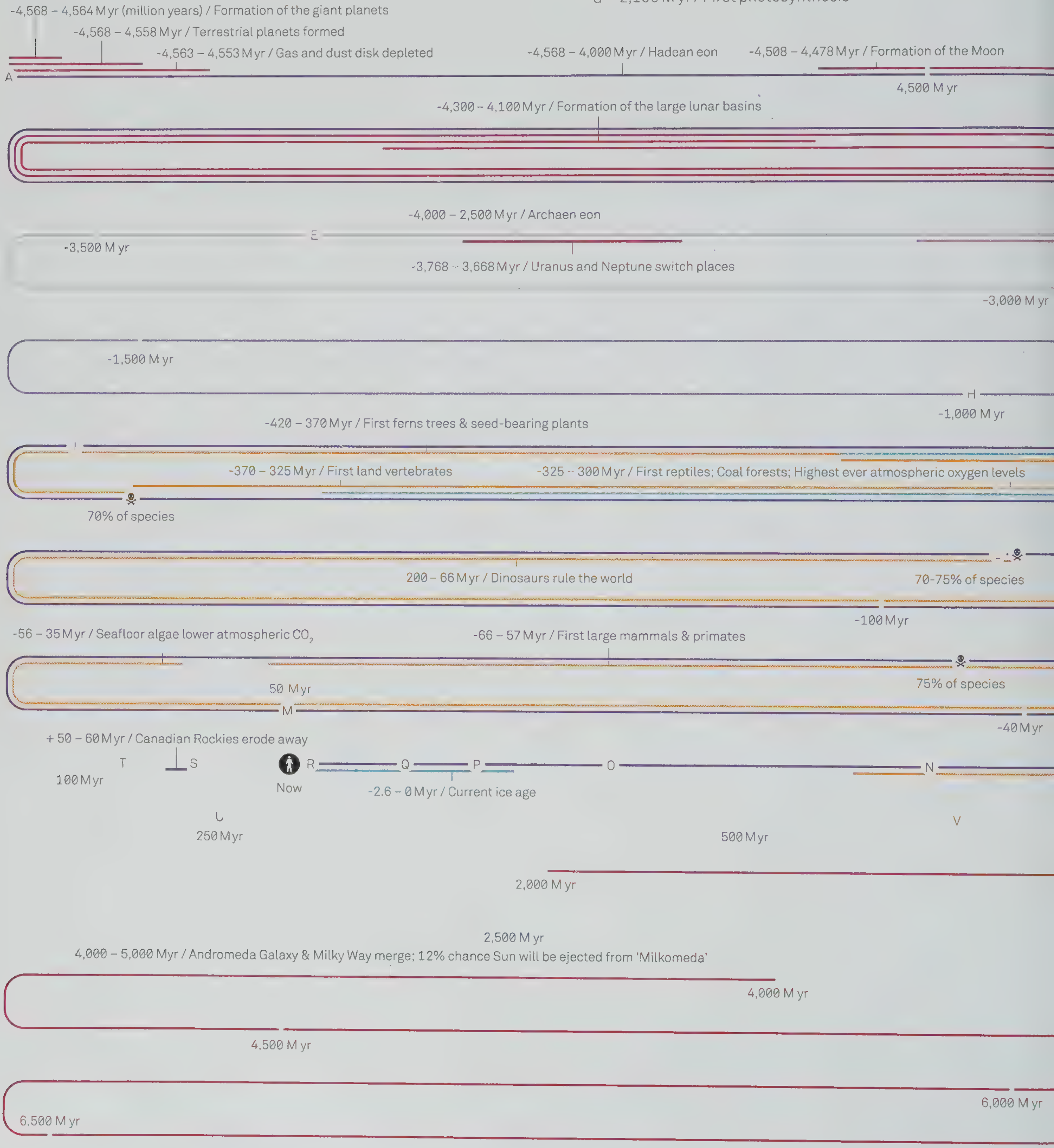

300 m
Eiffel Tower / France
3.60 m
Titan
rgest moon
of Saturn
6.25 m
Triton
Largest moon of Neptune
1.72 m
Charon
Largest moon of Pluto
19.48 m
Vesta
Largest asteroid
520.38 m
21 Lutetia
Asteroid
No return
67P/Churyumov-
Gerasimenko (comet)
0.47 m
Saturn
0.55 m
Uranus
0.44 m
Neptune
7.42 m
Pluto
7.78 m
Haumea
5.92 m
Eris

Timeline of the Solar System

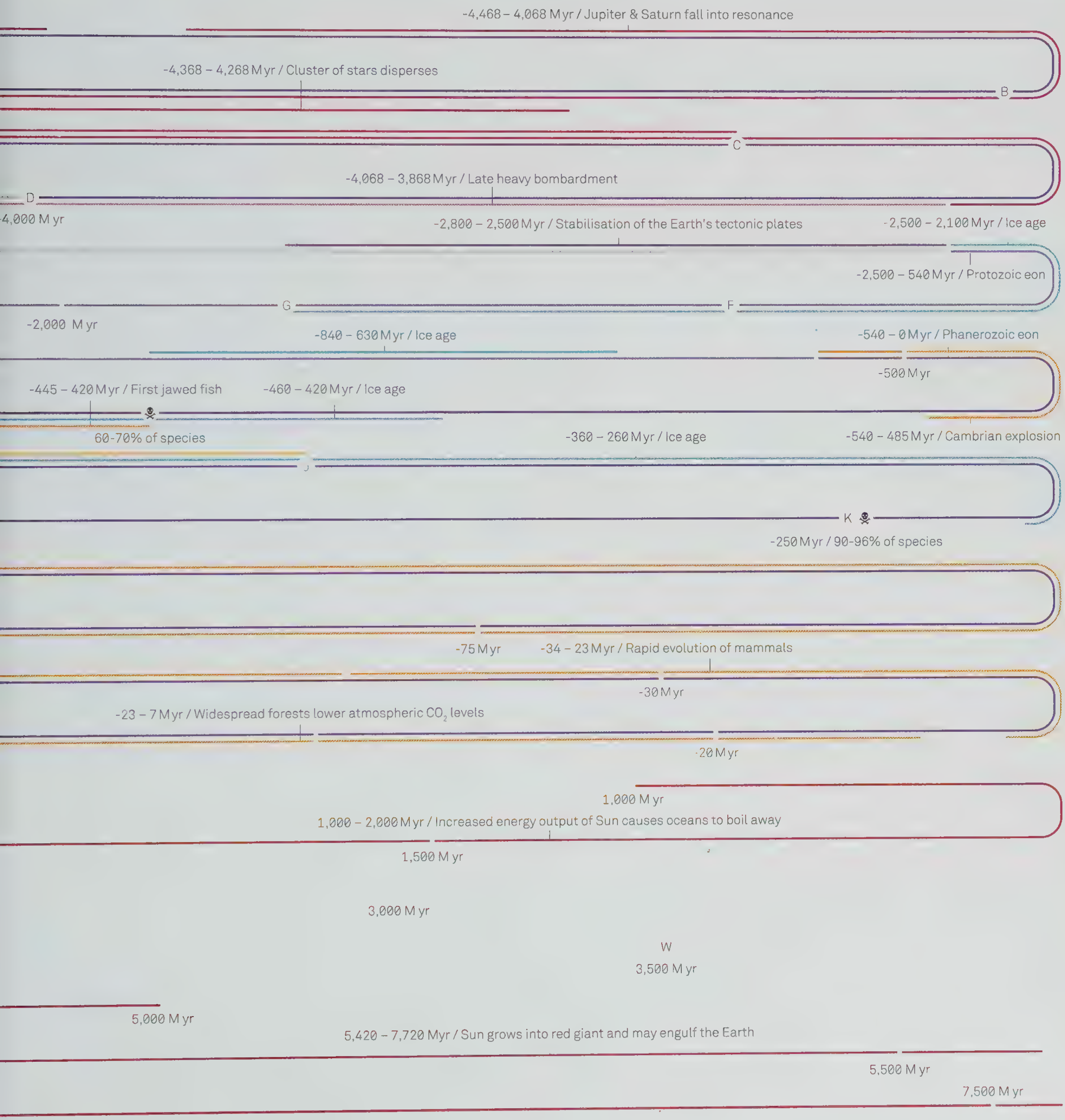
We know the age of the Solar System fairly precisely thanks to evidence from meteorites, which contain the first material to solidify. A lot has happened since then...

A -4,568 M yr / Formation of asteroids and comets
B -4,400 M yr / Formation of Saturn's rings
-4,400 M yr / Oldest minerals on Earth
C -4,100 M yr / Possible primordial life
D -4,000 M yr / Oldest rocks on Earth
E -3,600 M yr / First simple single-celled life & microfossils
F -2,300 M yr / Appearance of oxygen in Earth's atmosphere
G -2,100 M yr / First photosynthesis

Ice age | Astronomy | Geology | Life | Extinction event

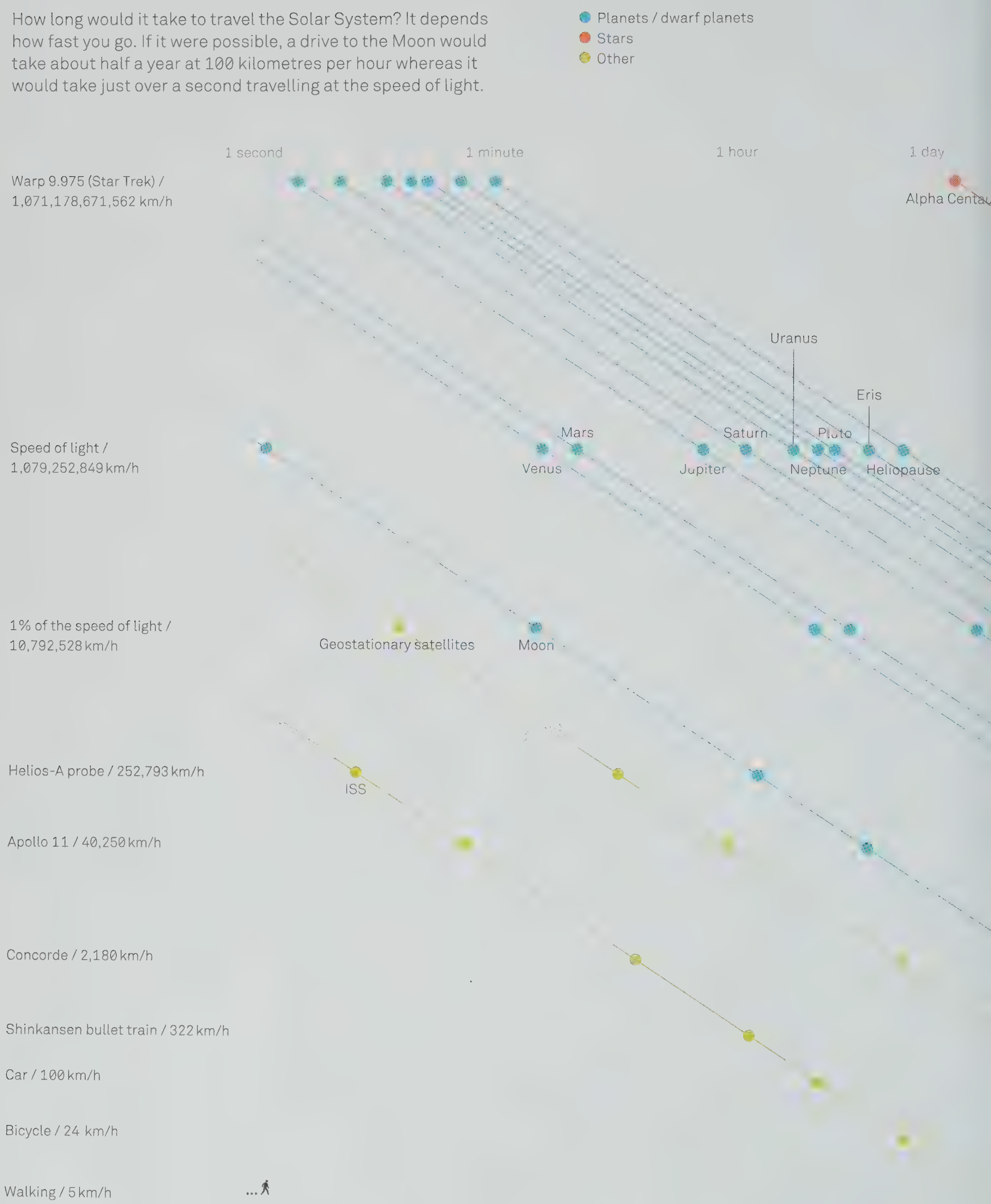


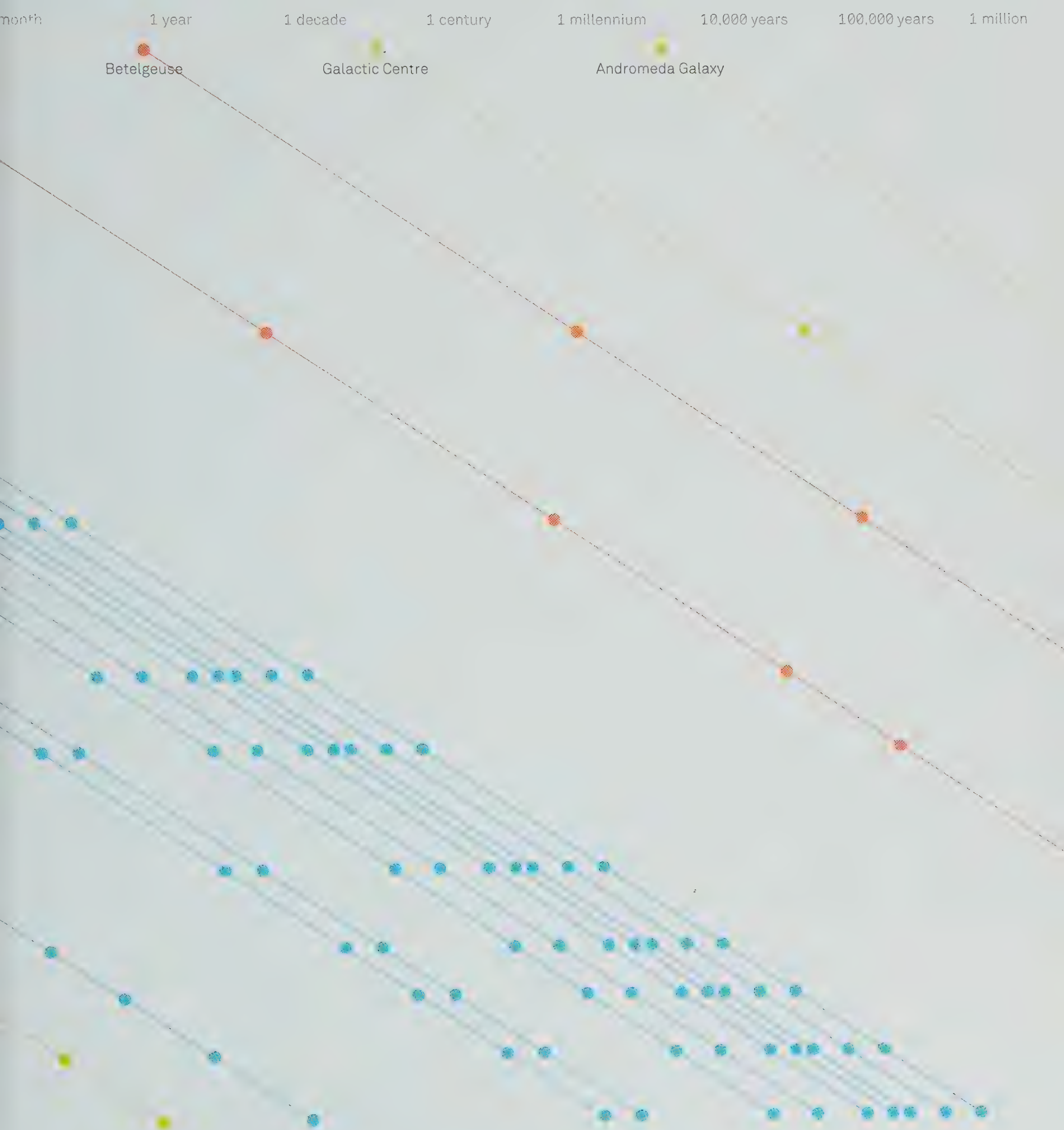
H -1,000 M yr / First simple multi-celled fossils
I -465 M yr / First green plants and fungi
J -300 M yr / Pangea supercontinent forms
K -250 M yr / First dinosaurs, crocodiles & mammals
L -200 M yr / Pangea breaks into Gondwana & Laurasia
M -50 M yr / Beginning of formation of Himalayas
N -8 M yr / Evolutionary split from gorillas
O -4 M yr / Evolutionary split from chimpanzees
P -2.3 M yr / First hominids
Q -1.4 M yr / First appearance of Homo erectus
R -0.2 M yr / First appearance of Homo sapiens
S 50 M yr / Phobos crashes into Mars or breaks up into a ring
T 80 M yr / Big Island of Hawaii will sink beneath the ocean
U 250 M yr / Another supercontinent forms
V 600 M yr / Moon too far for total solar eclipses to occur
W 3,500 M yr / Earth's atmosphere more like Venus' is now



Travel times

How long would it take to travel the Solar System? It depends how fast you go. If it were possible, a drive to the Moon would take about half a year at 100 kilometres per hour whereas it would take just over a second travelling at the speed of light.

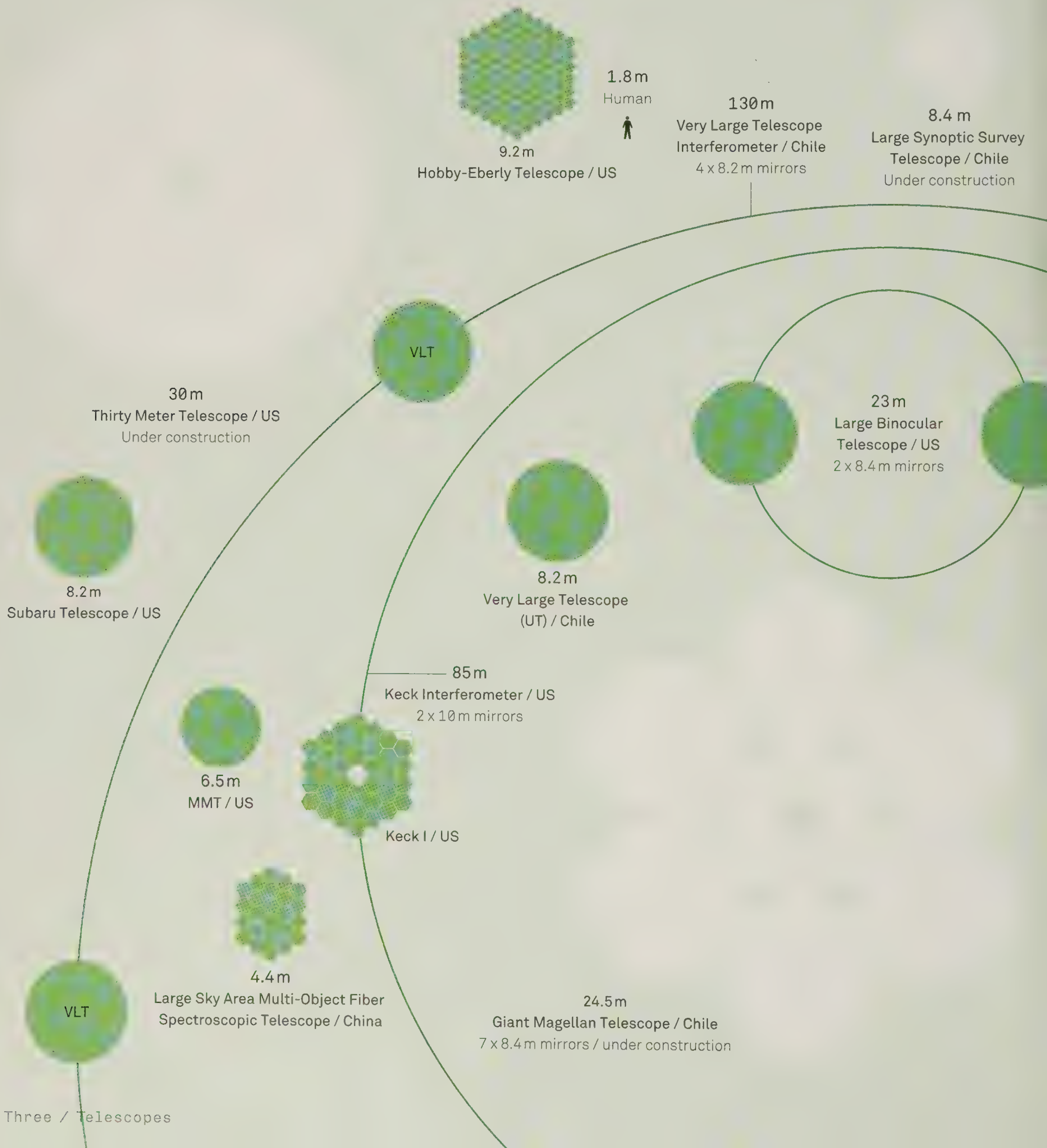


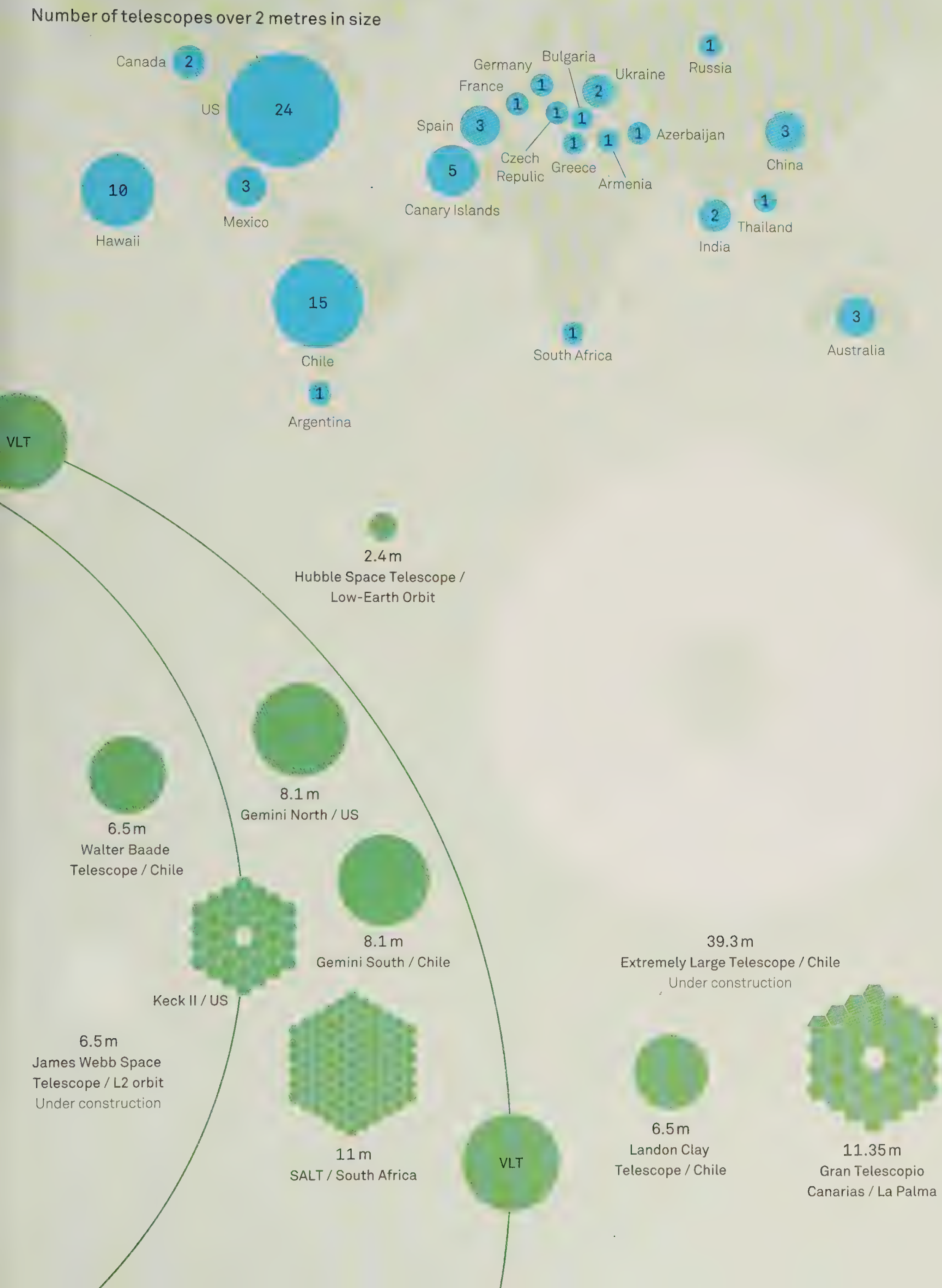

month
1 year
1 decade
1 century
1 millennium
10,000 years
100,000 years
1 million
Betelgeuse
Galactic Centre
Andromeda Galaxy

Three / Telescopes

Optical telescopes / size matters

There are two things that every telescope does, whatever it looks like. Firstly, it collects the light that falls through the main aperture, whether that is through a lens or a mirror. Secondly, it focuses that light onto a camera, film, eyepiece, or some other sort of detector. There are many ways of doing this, which often involve additional lenses or mirrors, and result in telescopes with a wide range of appearances, but those two principal jobs of a telescope haven't changed since the first one was used in the early 17th Century. Much of the development in these instruments over the last four centuries has revolved around making the main mirror or lens bigger.




Number of telescopes over 2 metres in size
Canada 2
US 24
Mexico 3
Hawaii 10
Chile 15
Argentina 1
Germany 1
France 1
Spain 3
Canary Islands 5
Bulgaria 1
Czech Repulic 1
Greece 1
Ukraine 2
Armenia 1
Azerbaijan 1
Russia 1
China 3
India 2
Thailand 1
South Africa 1
Australia 3
VLT
2.4 m
Hubble Space Telescope / Low-Earth Orbit
8.1 m
Gemini North / US
6.5 m
Walter Baade Telescope / Chile
8.1 m
Gemini South / Chile
Keck II / US
6.5 m
James Webb Space Telescope / L2 orbit
Under construction
11 m
SALT / South Africa
VLT
39.3 m
Extremely Large Telescope / Chile
Under construction
6.5 m
Landon Clay Telescope / Chile
11.35 m
Gran Telescopio Canarias / La Palma

Atmospheric windows

We think of the night sky as being full of stars, but our eyes show us only a tiny part of the full spectrum of light available. Using telescopes to view longer and shorter wavelengths we can see a huge range of objects and astrophysical phenomena. The Earth's atmosphere blocks much of that light, leaving wavelength windows that can be observed from the ground. To get the best view, telescopes have to be situated at the tops of mountains, flown on board aeroplanes, dangled from high-altitude balloons, or even launched into space.

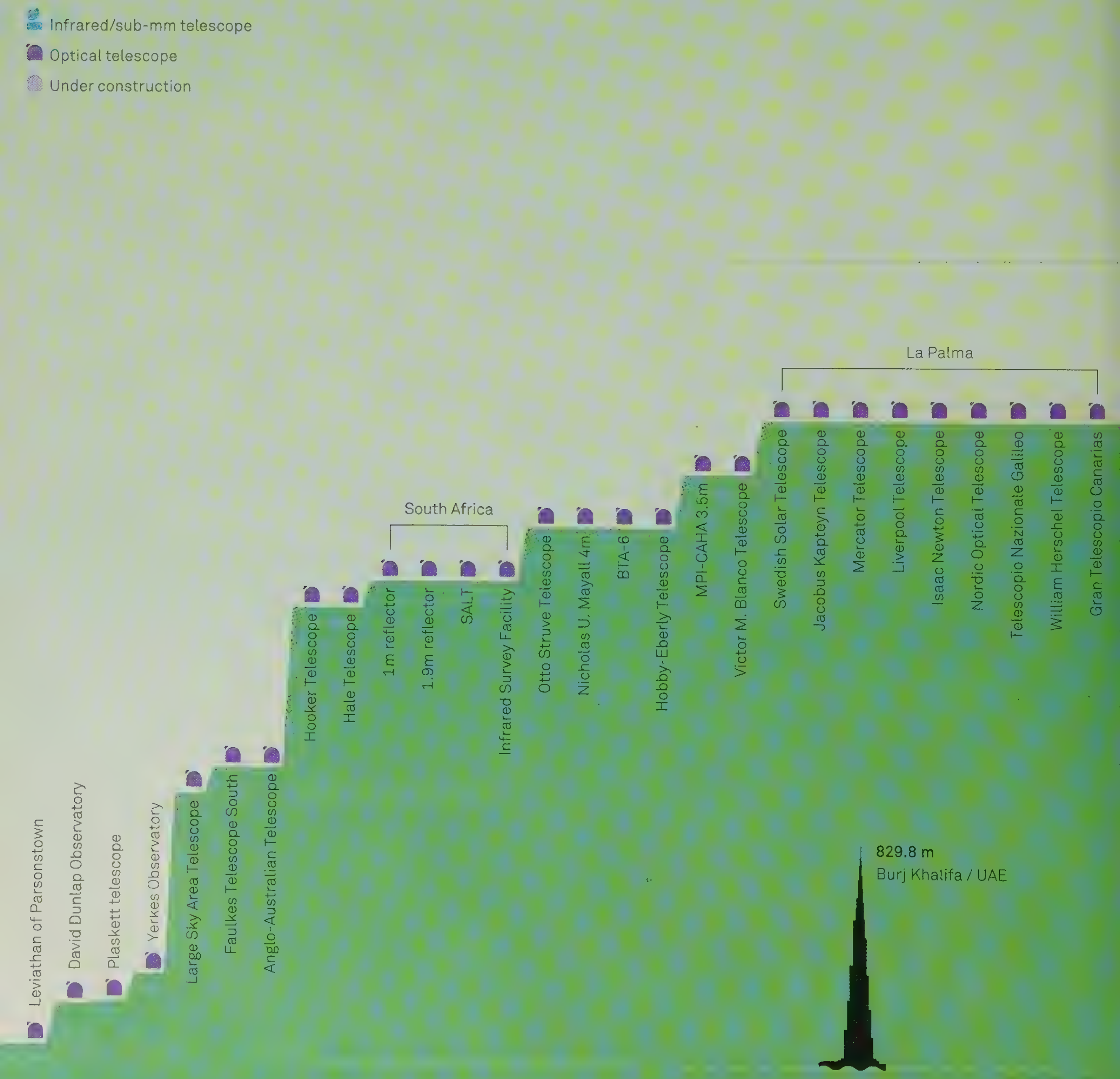

30 µm
7 µm
800 nm
400 nm
10 nm
0.1 nm
0.001 nm
Mid-IR
Hot dust
Near-IR
Cool Stars
Visible
Stars
UV
Hot, young stars
X-ray
Hot gas around binary stars, black holes and supernovae
Gamma-ray
Supernovae, hypernovae
JWST (planned)
Spitzer
Hubble
Chandra
Fermi
SOFIA
Keck

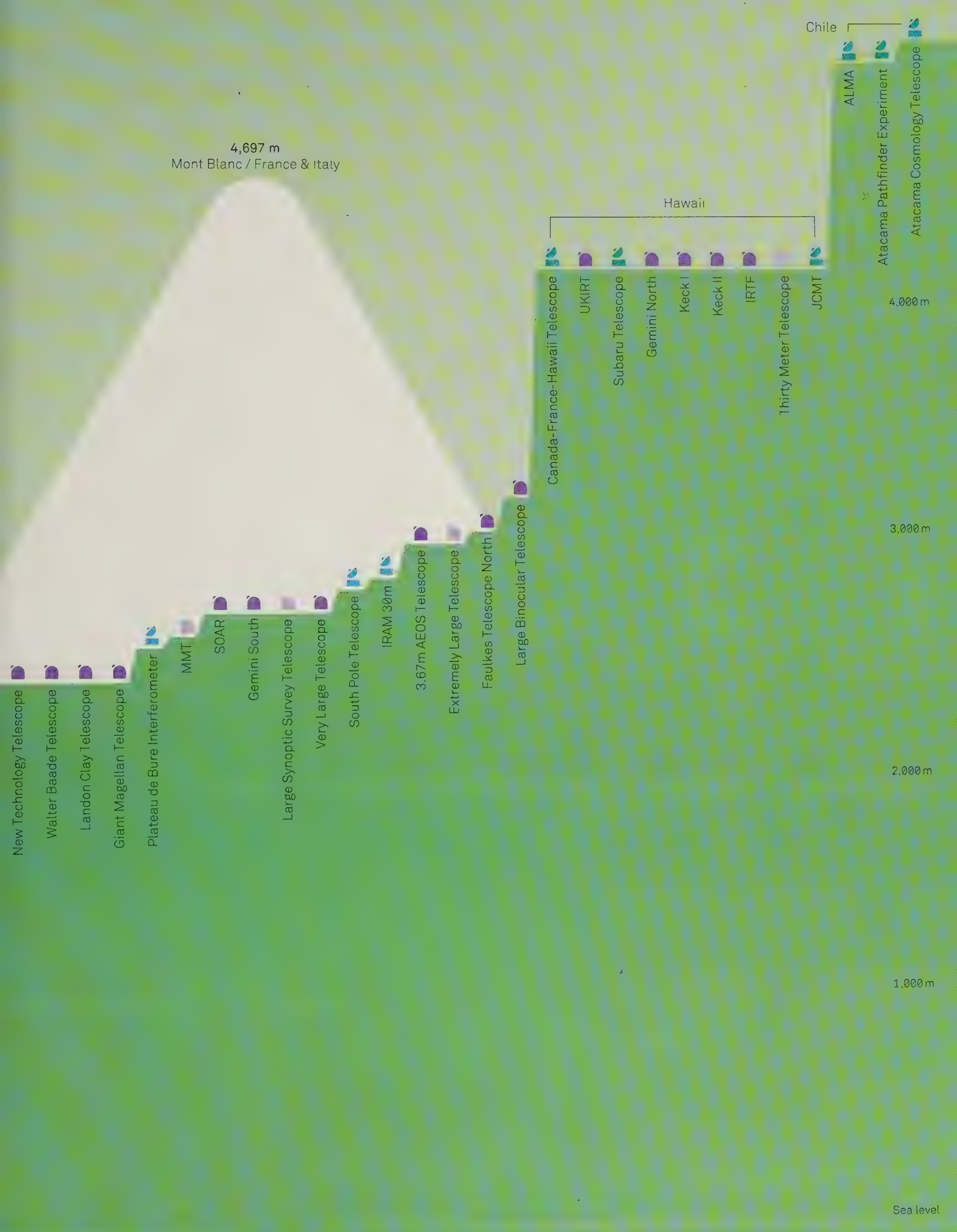
The sky's the limit

No optical telescope, however large it is, can observe through clouds. For this reason, most large telescopes are built as high as possible – above the clouds. Even so, the biggest obstacle a telescope faces is still the Earth's own atmosphere. Most of the best locations are on top of mountains, hence the mountain-top observatories in Europe and the USA. In the second half of the 20th Century, more remote sites became heavily used such as the Canary Islands, Mauna Kea on Hawaii, and the Andes mountain range in Chile.

There is still some air even at altitudes above 4,000 metres, so many of the largest telescopes employ techniques such as adaptive optics to reach the finest possible resolutions.

At longer wavelengths, the water vapour in the atmosphere is the biggest problem, and so it is important to find a very high, dry site. The best such example is the Atacama Desert in Chile, home to a number of optical telescopes and the ALMA telescope array. Coming a close second is the South Pole, which is very dry and also, thanks to a thick layer of ice, at relatively high altitude.




4,697 m
Mont Blanc / France & Italy
Chile
Hawaii
New Technology Telescope
Walter Baade Telescope
Landon Clay Telescope
Giant Magellan Telescope
Plateau de Bure Interferometer
MMT
SOAR
Gemini South
Large Synoptic Survey Telescope
Very Large Telescope
South Pole Telescope
IRAM 30m
3.67m AEOS Telescope
Extremely Large Telescope
Faulkes Telescope North
Large Binocular Telescope
Canada-France-Hawaii Telescope
UKIRT
Subaru Telescope
Gemini North
Keck I
Keck II
IRTF
Thirty Meter Telescope
JCMT
ALMA
Atacama Pathfinder Experiment
Atacama Cosmology Telescope
4,000 m
3,000 m
2,000 m
1,000 m
Sea level

The sky's not the limit

Sitting atop mountains is not the only way of getting above the limiting effects of our atmosphere. To get higher, telescopes have been placed in aeroplanes and hung from high altitude balloons. Even these measures do not completely mitigate the atmospheric effects. The only way to do that is to get into space. Although more expensive to build, and with few opportunities to fix them if they break, humanity now has a fleet of telescopes in orbit.

193,000,000 km
Spitzer Space Telescope /
Earth-trailing Heliocentric Orbit
1,500,000 km
Herschel Space
Observatory / L2
71,000 km
ISO / Highly elliptical
Earth Orbit
1,500,000 km
James Webb Space
Telescope / L2 (planned)
100,000 km
1,000,000 km
10,000,000 km
100,000,000 km
1,500,000 km
Planck / L2
133,000 km
Chandra X-ray Telescope /
Highly-elliptical Earth Orbit
1,500,000 km
WMAP / L2

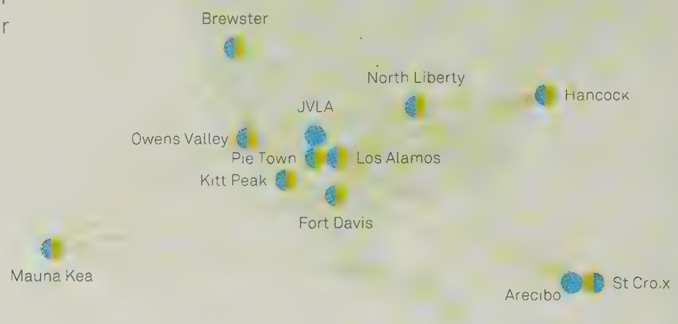
Radio telescopes / bigger and bigger

The light we see with our eyes is only a tiny fraction of the radiation that is available for study. In the early 20th Century astronomers started building telescopes that collect radio waves.

Some are not too unlike optical telescopes, comprising a large dish, acting as the mirror. As with optical telescopes, a larger mirror allows fainter objects to be observed in greater detail, and so there has always been a desire for larger radio telescopes. To achieve even finer detail, many dishes can be joined together to act as one giant telescope.

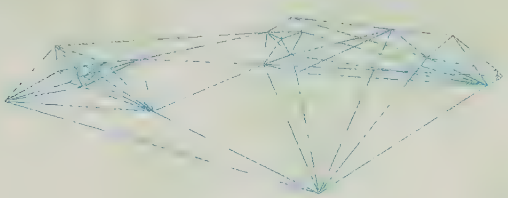
VLBA

Run by the US National Radio Astronomy Observatory, this spans the United States.



Global VLBI

To get the best resolution, VLBA, EVN, and space-based telescopes occasionally team up to act as one telescope three times the size of the Earth.



Sizes of telescopes

A larger telescope means more detail can be seen. China are building the world's most sensitive radio telescope – Five Hundred Meter Aperture Spherical Telescope (FAST).

e-MERLIN

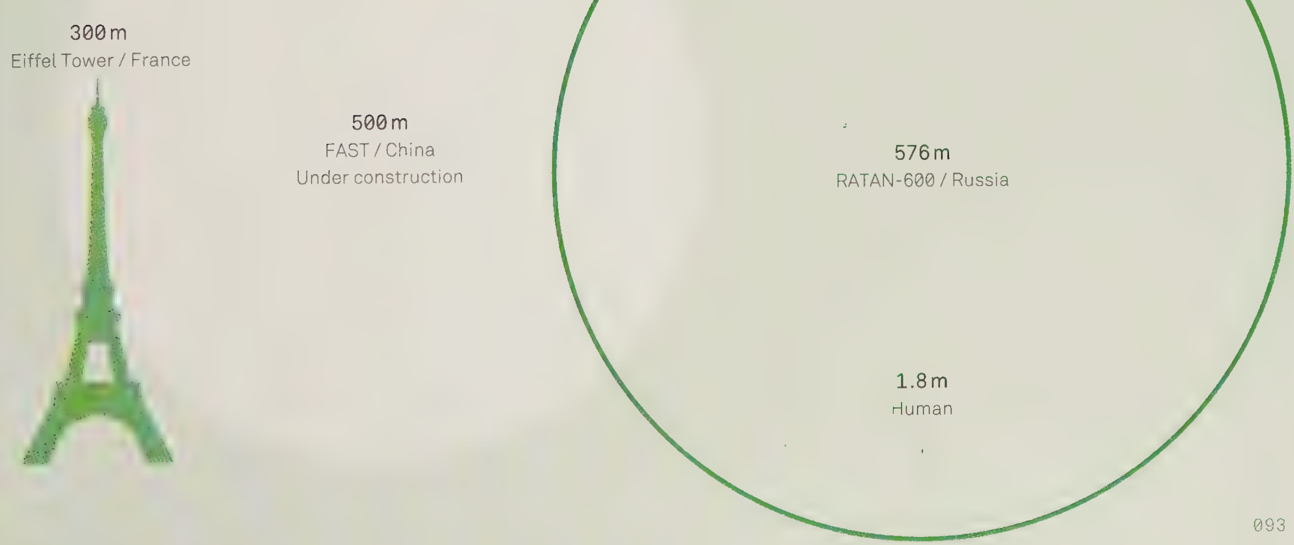
The UK's network spans from Cheshire to Cambridge and the Welsh borders. Its images have a similar resolution to those of the Hubble Space Telescope.

EVN

The European VLBI Network is operated from Dwingeloo, Netherlands, and includes telescopes as far away as South Africa and China.

Australian network

Covering Australia and New Zealand, parts of this relatively new network will make up the future Square Kilometre Array.



Telescope chronology

To get the best images astronomers seek ever-larger telescopes. During the 19th Century the largest was the Leviathan of Parsonstown in Ireland where the spiral arms of the Andromeda Galaxy were first seen. The 20th Century saw much larger telescopes built in the continental US and later Hawaii and Chile.

The first radio telescopes were in the 1930s but it wasn't until the start of the space race that the first large radio telescopes were constructed. Since the 1980s, radio astronomers have linked vast networks of telescopes together to create a telescope larger than our planet.

Telescope operational period 1840 –


space-VLBI / Low-Earth Orbit
VLBA / North America
e-MERLIN / UK
Jansky Very Large Array / US
Giant Metrewave Radio Telescope / India
ALMA / Chile
RATAN-600 / Russia
Arecibo / Puerto Rico
Robert C. Byrd Telescope / US
Effelsberg / Germany
300 Foot Telescope / US
Lovell Telescope / UK
Parkes / Australia
Extremely Large Telescope / Chile
Thirty Meter Telescope / US
JCMT / US
Gran Telescopio Canarias / La Palma
SALT / South Africa
Keck I / US
Reber's radio telescope / US
Large Synoptic Survey Telescope / Chile
Subaru Telescope / US
Very Large Telescope / Chile
Gemini North / US
James Webb Space Telescope / L2
William Herschel Telescope / La Palma
Anglo-Australian Telescope / Australia
UKIRT / US
Canada-France-Hawaii Telescope / US
New Technology Telescope / Chile
ESO 3.6 m Telescope / Chile
Herschel Space Observatory / L2
Isaac Newton Telescope / La Palma
Hubble Space Telescope / Low-Earth Orbit
Faulkes Telescope North / US
Faulkes Telescope South / Australia
Planck / L2
WMAP / L2
Spitzer Space Telescope / Earth-trailing Heliocentric Orbit
IRAS / Sun-synchronous Earth Orbit
ISO / Highly-elliptical Earth Orbit
COBE / Sun-synchronous Earth Orbit
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020

Megapixels

Over recent decades digital imaging technology has advanced at an incredible rate, and astronomy has been at the forefront of the development. The detectors are similar in design to those in standard smart phones and digital cameras, but much more sensitive. The standard unit of measurement for a camera is a megapixel (one million pixels).

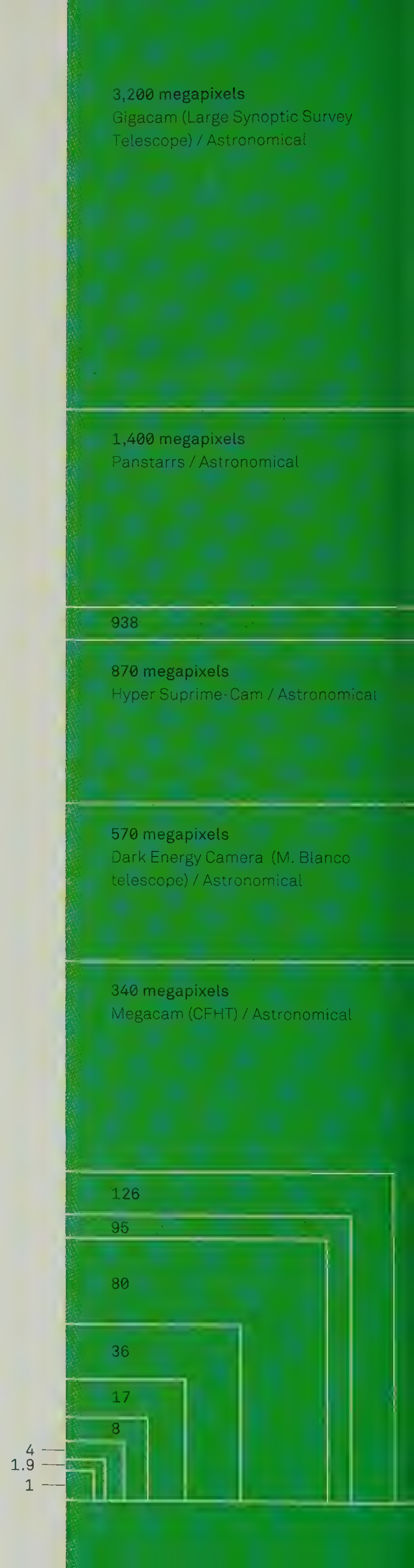
While early astronomical cameras were very modest, recent developments have allowed cameras to be built with billions of pixels. Most of these are on ground-based telescopes, with the exception of the 938-million-pixel camera on board the Gaia spacecraft. In general, interplanetary spacecraft have much smaller cameras because they were designed and built long before they arrive at their destinations but also because they have limited bandwidth to send images back to Earth.

20 megapixels
35mm film (equivalent)
Non-astronomical

13 megapixels
Canon EOS 5D DSLR
Non-astronomical

8 megapixels
iPhone 6
Non-astronomical

1 megapixel
Early digital Camera
Non-astronomical



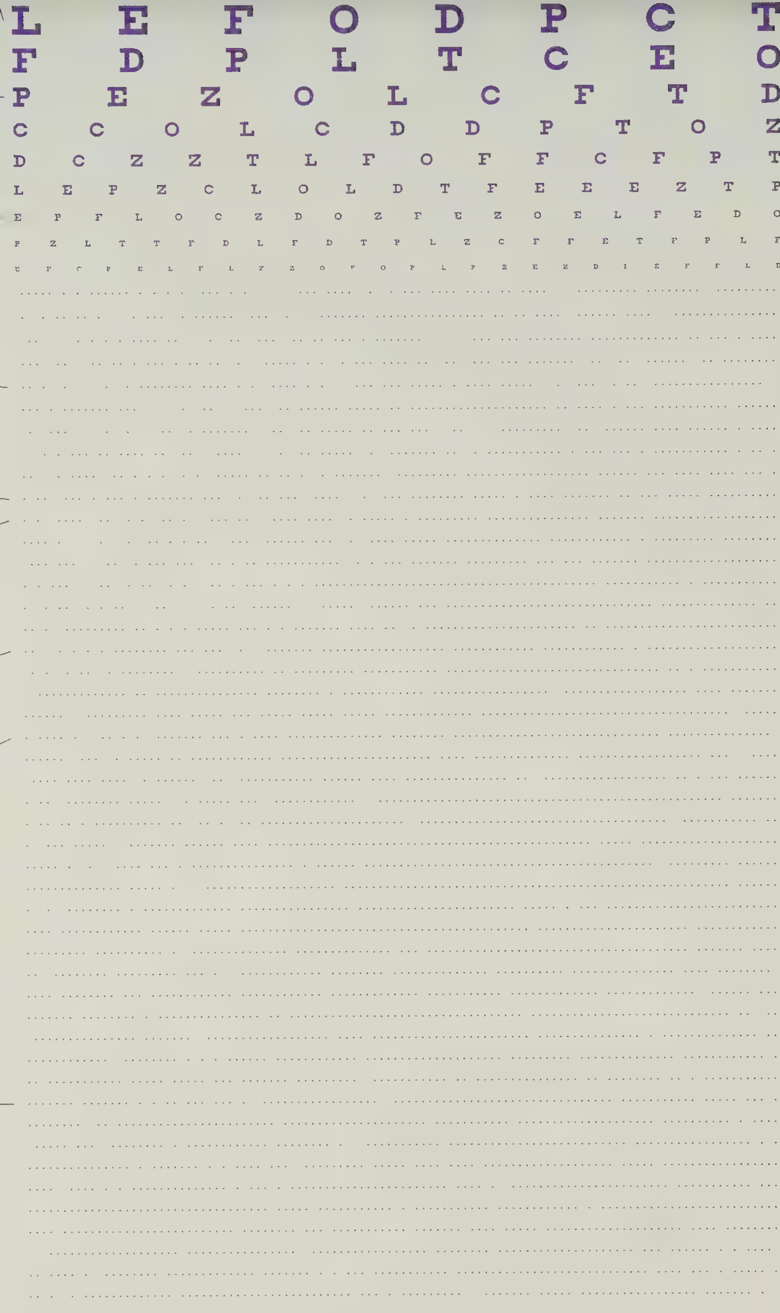
938 megapixels Gaia spacecraft / Astronomical
126 megapixels SDSS / Astronomical
95 megapixels Kepler space observatory / Spacecraft
80 megapixels Suprime-cam (Subaru) / Astronomical
36 megapixels LMI (Discovery Channel Telescope) / Astronomical
17 megapixels WFC3 (Hubble) / Astronomical
8 megapixels WFC (INT) / Astronomical
4 megapixels OSIRIS (Rosetta) / Spacecraft
1.9 megapixels MastCam & MAHLI (Curiosity) / Spacecraft
1 megapixel LORRI (New Horizons), MDIS (Messenger) & ISS (Cassini) / Spacecraft

Resolution

The unaided human eye can see objects down to about the size of the tip of a pin held at arm's length. That is equivalent to just being able to make out something 111 kilometres across on the surface of the Moon.

Larger telescopes can see finer detail and this has led to huge advances in astronomy. For optical and infrared telescopes the Earth's atmosphere is often the limiting factor because the turbulent air constantly distorts the light we see on the ground. For radio telescopes there is no such obstacle.

We can use an eye-chart to show the relative detail seen by different instruments, along with the equivalent size of objects they could discern at the distance of the Moon.



Row 11 / 25 arcseconds
Angular size of Mars (closest).
Smallest feature on the Moon **46** km

Row 13 / 18 arcseconds
Herschel infrared satellite.
Smallest feature on the Moon **33** km

Row 15 / 9.5 arcseconds
Angular size of Venus (furthest).
Smallest feature on the Moon **18** km

Row 20 / 3.5 arcseconds
Angular size of Mars (furthest).
Smallest feature on the Moon **6.4** km

Row 22 / 2 arcseconds
Angular size of Neptune.
Smallest feature on the Moon **3.7** km

Row 24 / 1.2 arcseconds
90 mm (3.5 inch) backyard telescope.
Smallest feature on the Moon **2.2** km

Row 25 / 1 arcsecond
Blurring effect of the atmosphere at dark sites. Smallest feature on the Moon **1.8** km

Row 27 / 0.7 arcseconds
Cassini division in Saturn's rings.
Smallest feature on the Moon **1.3** km

Row 28 / 0.5 arcseconds
Keck telescope.
Smallest feature on the Moon **920** m

Row 29 / 0.4 arcseconds
Blurring effect of the atmosphere at dark, high altitude sites.
Smallest feature on the Moon **735** m

Row 33 / 0.16 arcseconds
JWST – infrared satellite.
Smallest feature on the Moon **295** m

Row 35 / 0.1 arcseconds
Angular size of Pluto.
Smallest feature on the Moon **184** m

Row 38 / 0.05 arcseconds
Hubble Space Telescope and the angular size of Betelgeuse.
Smallest feature on the Moon **92** m

Row 39 / 0.04 arcseconds
e-MERLIN – radio interferometer.
Smallest feature on the Moon **74** m

Row 45 / 0.01 arcseconds
Keck telescope theoretical resolution.
Smallest feature on the Moon **18** m

Row 55 / 0.001 arcseconds
VLTI – optical interferometer.
Smallest feature on the Moon **1.8** m
(e.g. a human)

Row 63 / 0.0015 arcseconds
EVN radio interferometer.
Smallest feature on the Moon **0.3** m

Four / The Sun

The Sun

The Sun is the nearest star to Earth. It is a huge ball of plasma with thermonuclear reactions in its core. The light and heat it generates sustains almost all life on our planet. It is about 4.567 billion years old and is half way through its life.

Total light output

383,000,000,000,000,000,000,000,000 watts
(383 million billion billion watts)

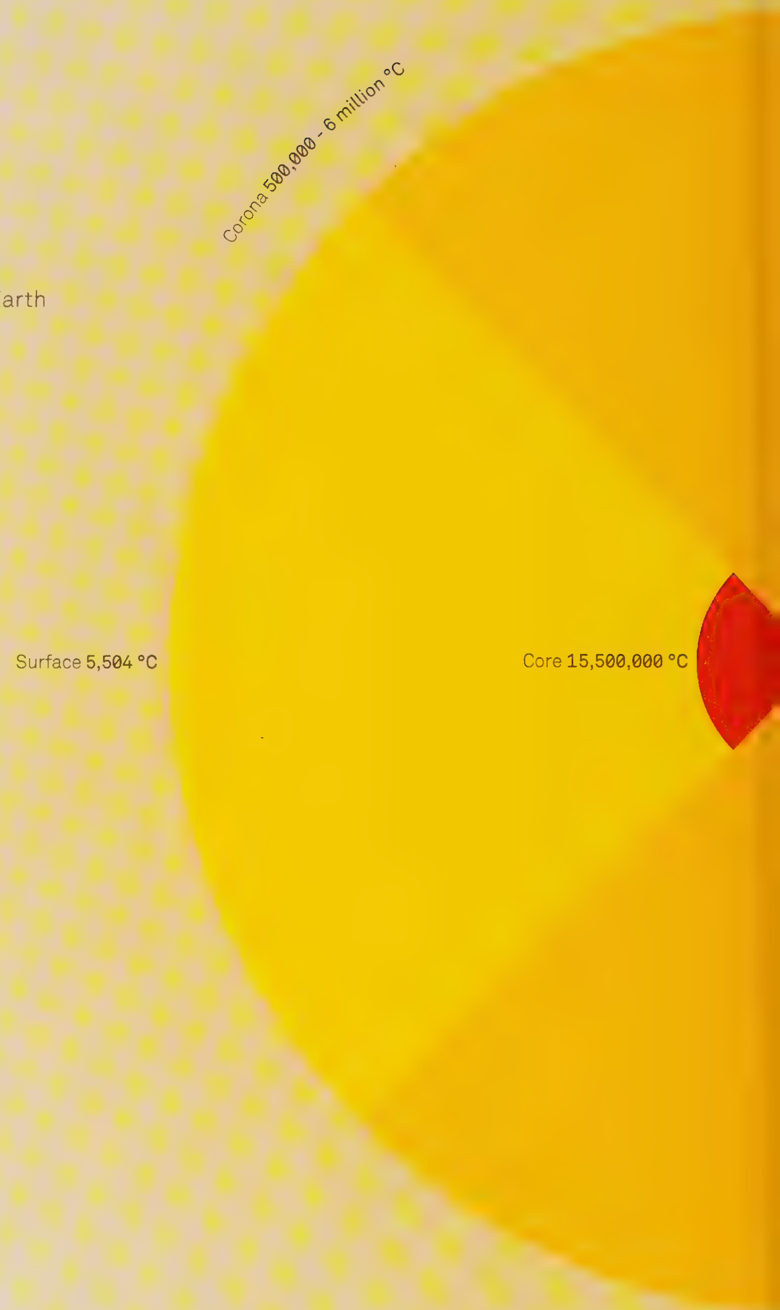
Mass

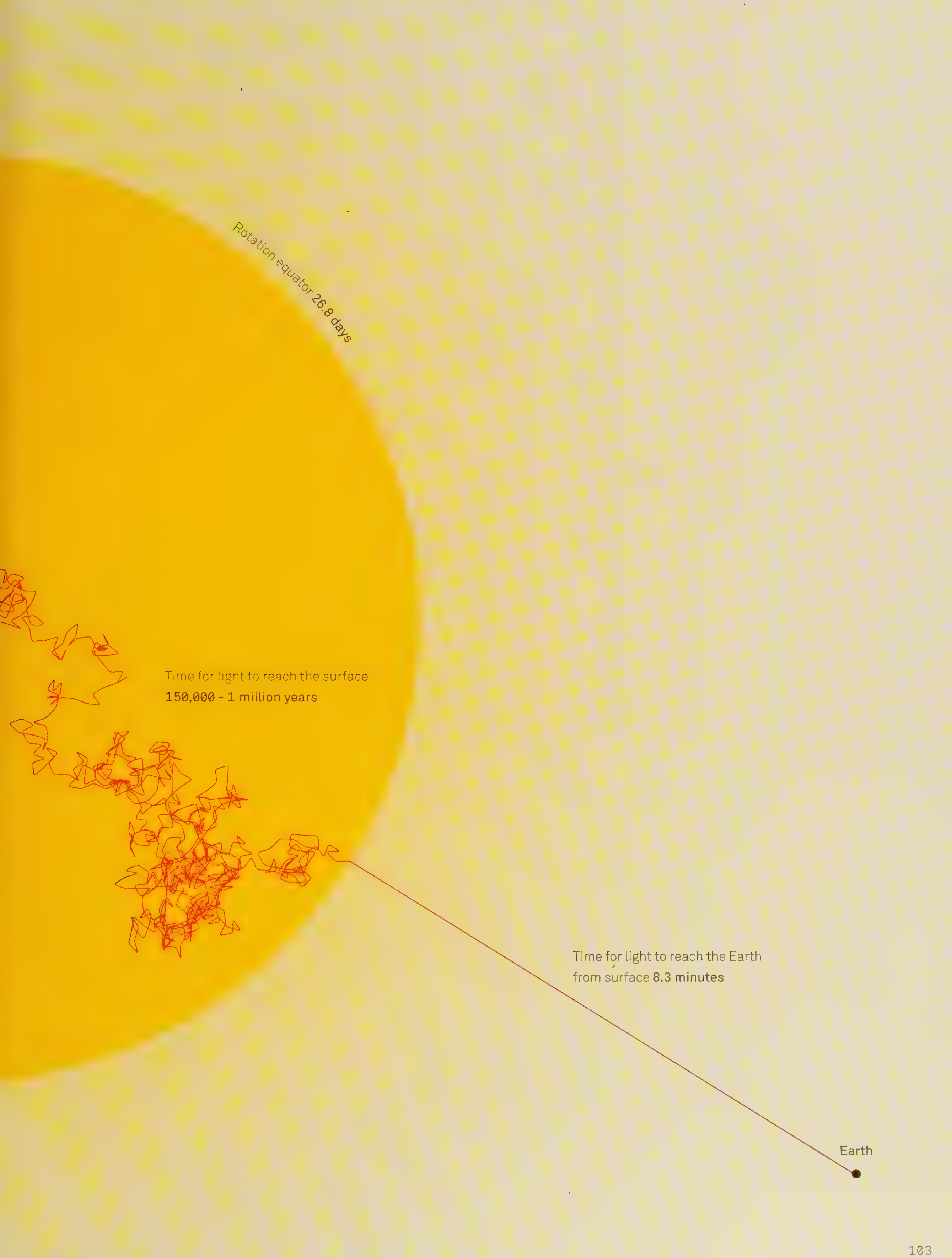
1,989,000,000,000,000,000,000,000,000,000 kg
(1,989 billion billion billion kg) = 330,000 times Earth

Mass loss

620,000,000,000 kg/s (620 billion kg)

Rotation at poles 36 days




Rotation equator 26.8 days
Time for light to reach the surface
150,000 - 1 million years
Time for light to reach the Earth
from surface 8.3 minutes
Earth

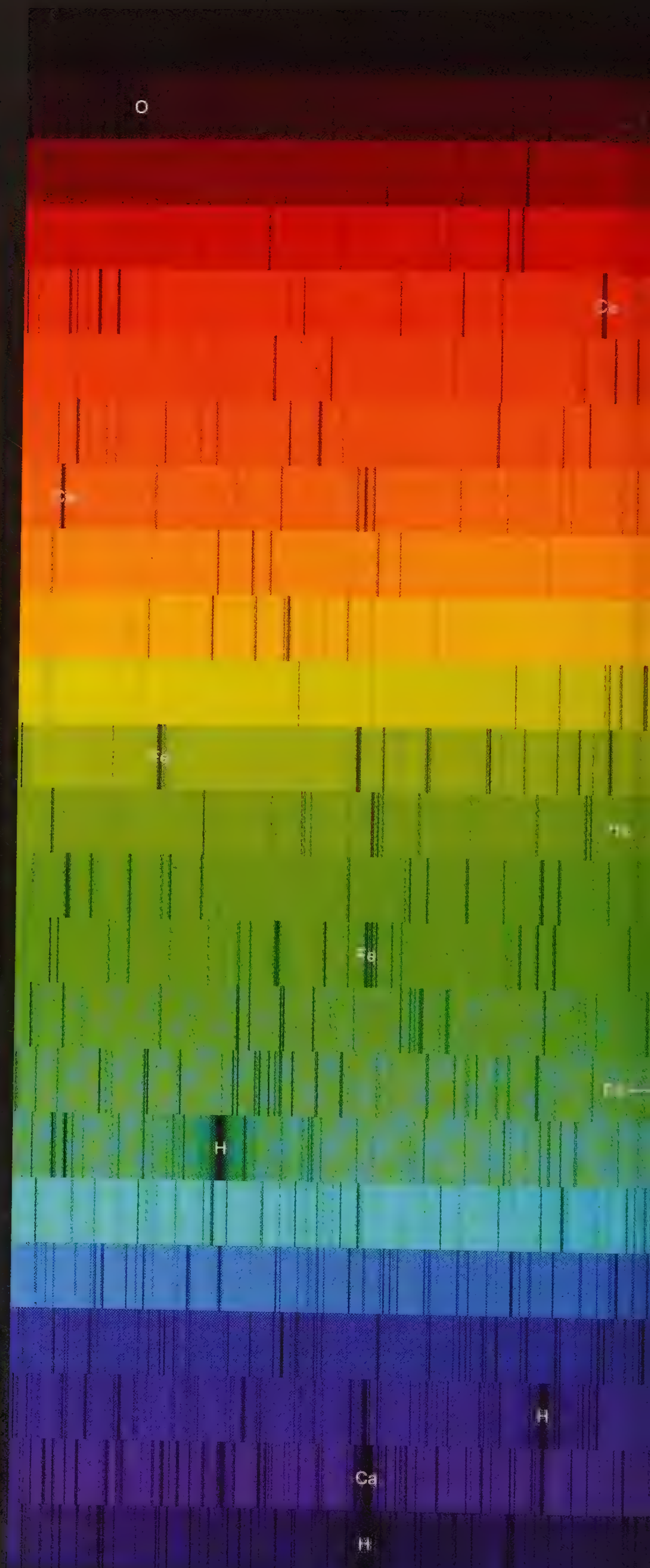
Spectrum of the Sun

The Sun's light can be split up into a spectrum of colours, most often seen as a rainbow. In the 19th Century, astronomers studying this rainbow realised that it contained dark bands. In 1860 Gustav Kirchoff and Robert Bunsen discovered that each chemical element produces its own particular set of bands at specific colours – a spectral fingerprint.

While analysing the spectrum of the Sun in 1868, astronomers Jules Janssen and Norman Lockyear identified a previously unknown element. It took until 1895 before Per Teodor Cleve and Nils Abraham Langlet finally discovered the new element on Earth. It was named helium after Helios, the Greek god of the Sun. Helium is now known to be the second most abundant element in the Sun, and the Universe as a whole.

As well as hydrogen and helium, the Sun's spectrum shows the presence of a wide range of elements – as well as oxygen in the Earth's atmosphere. The observed elements are in the Sun's upper atmosphere, and were mostly formed by a previous generation of stars.

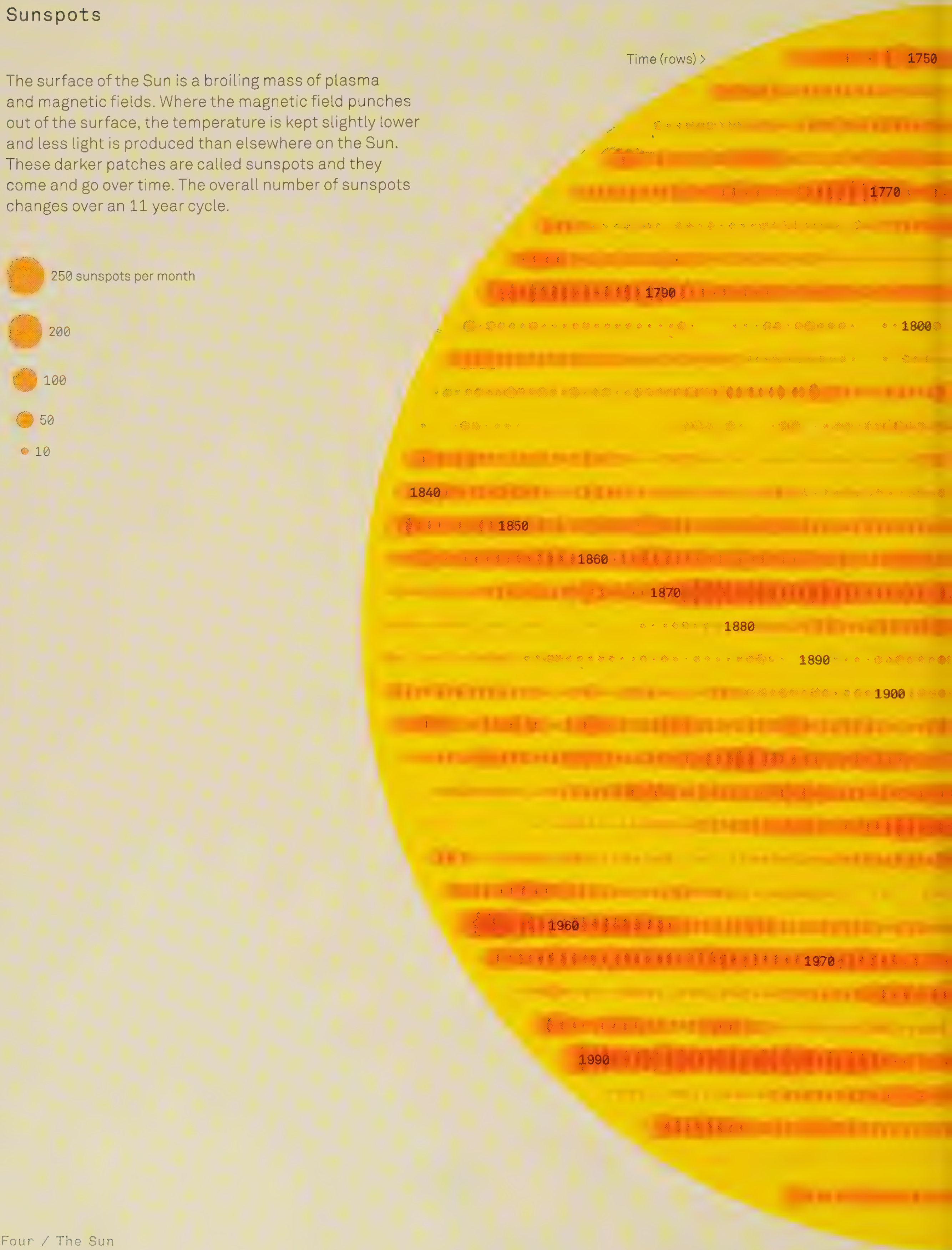
Ba / Barium
Ca / Calcium
Cr / Chromium
Fe / Iron
H / Hydrogen
He / Helium
Hg / Mercury
Mg / Magnesium
Na / Sodium
O / Oxygen (in Earth's atmosphere)
Sr / Strontium
Ti / Titanium




H
Ca
Ba
Na
Na
Fe
Mg
Fe Mg
Fe/Ca
Fe
Fe
Fe
Fe
Fe

Sunspots

The surface of the Sun is a broiling mass of plasma and magnetic fields. Where the magnetic field punches out of the surface, the temperature is kept slightly lower and less light is produced than elsewhere on the Sun. These darker patches are called sunspots and they come and go over time. The overall number of sunspots changes over an 11 year cycle.



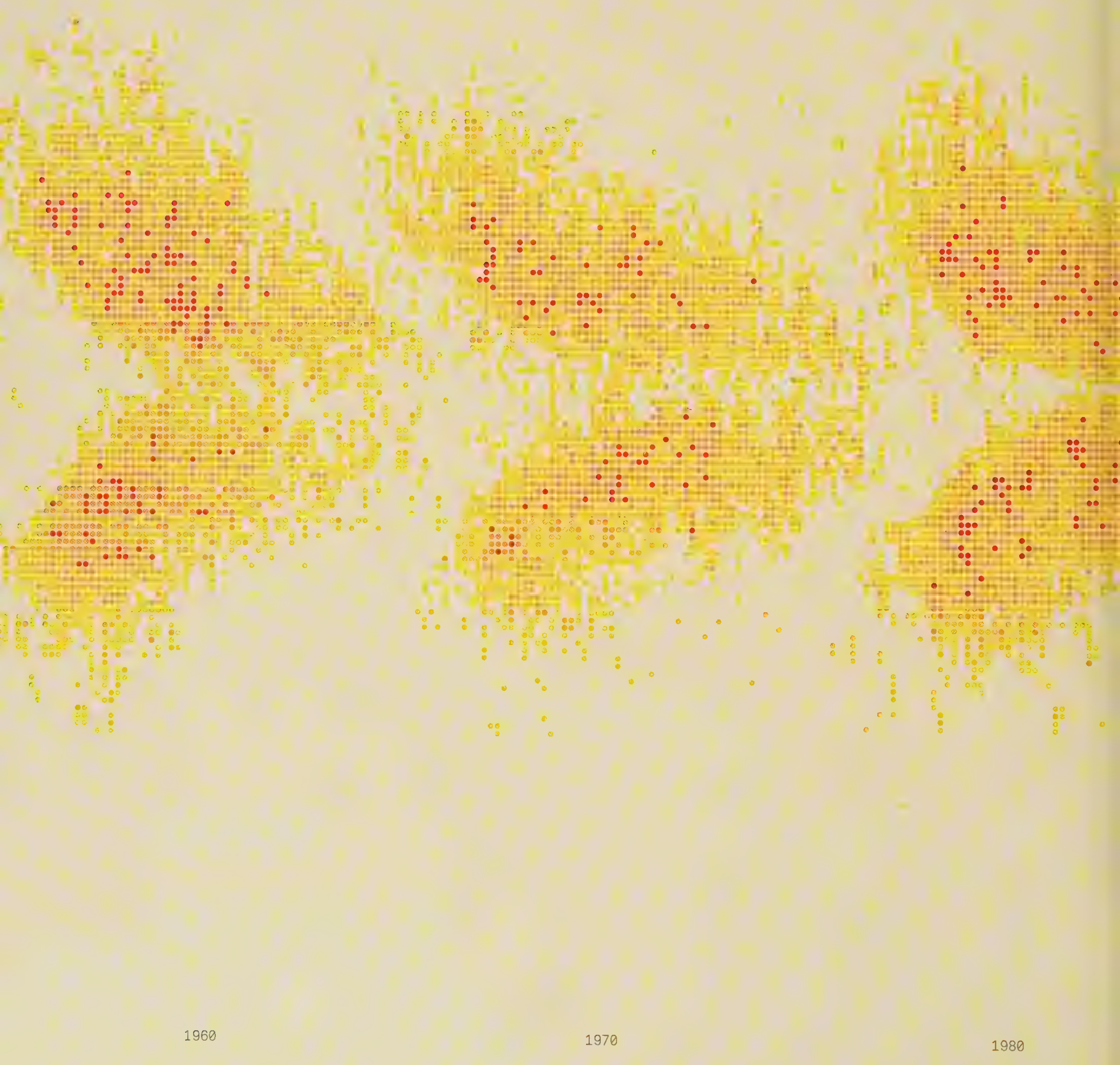

1760
1780
1810
1820
1830
1920
1930
1940
1950
1980
2000

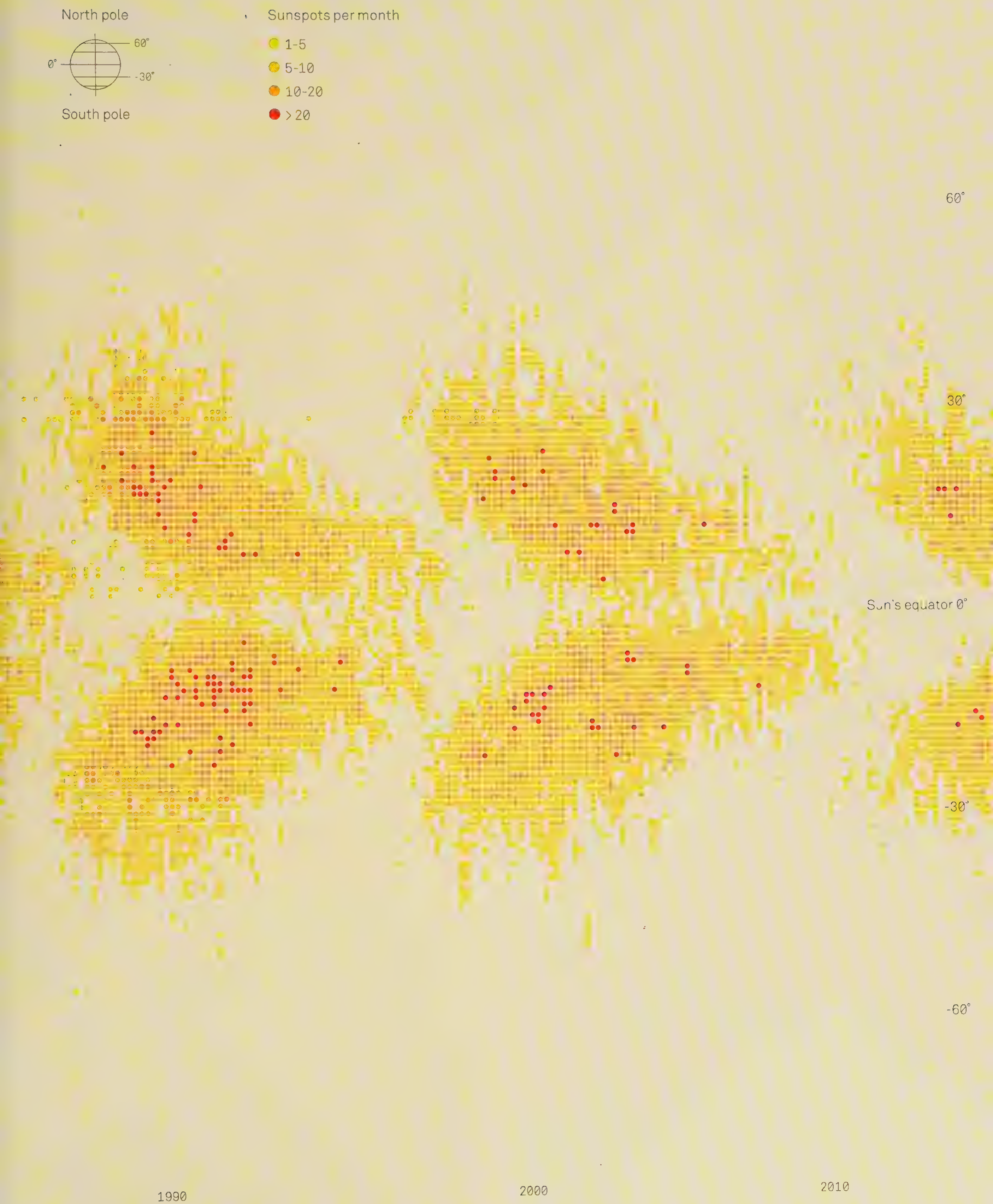
Butterfly diagram

Sunspots don't appear just anywhere on the surface of the Sun. Over the period of approximately 11 years they form gradually closer and closer to the Sun's equator. There is a clear link with the cycle of solar activity, which also takes around 11 years.

In the early 20th Century it was discovered that sunspots are magnetic phenomena, and they highlight where the Sun's magnetic field is breaking through its surface. Sunspots in alternating cycles have magnetic fields with opposite polarity. This showed that the Sun's magnetic field actually fluctuates over a period of 22 years.

This link between sunspots and the magnetic field, combined with historical data, means that the behaviour of the magnetic cycle can be inferred for hundreds of years.




North pole
60°
0°
-30°
South pole
Sunspots per month
1-5
5-10
10-20
> 20
60°
30°
Sun's equator 0°
-30°
-60°
1990
2000
2010

Solar flares

Since the late 1970s satellites have been recording explosive solar flares from the surface of the Sun. These flares are measured and put into several classes – A, B, C, M, or X – where each class is 10 times stronger than the one before. Within each class, the numbers 1 – 9 are used e.g. an M5 flare is five times more powerful than an M1.

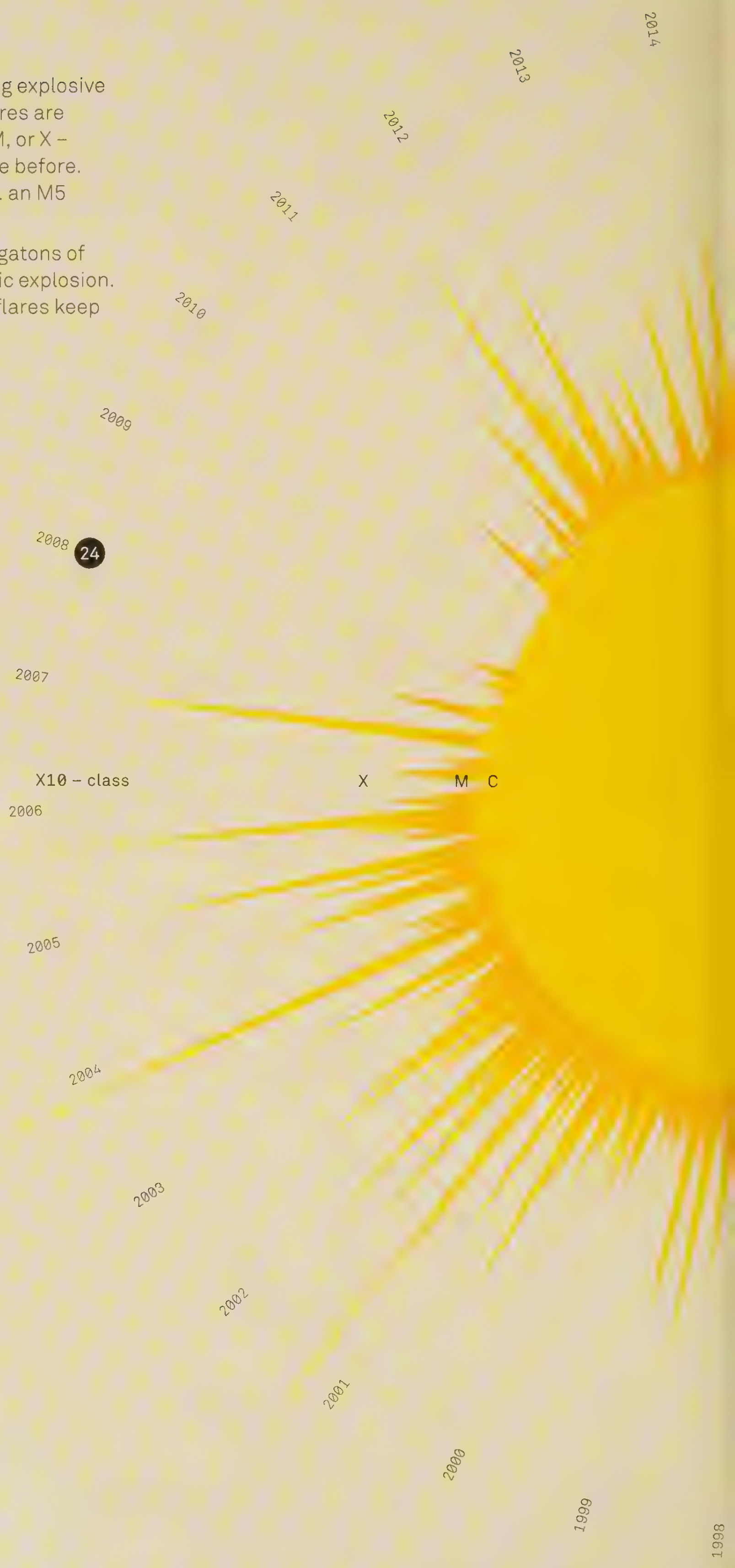
An X1 flare is equivalent to around 200 million megatons of TNT or a million times as much energy as a volcanic explosion. There is currently no class above X so the largest flares keep the 'X' designation but increase the number.

C – class
Don't noticeably affect us.

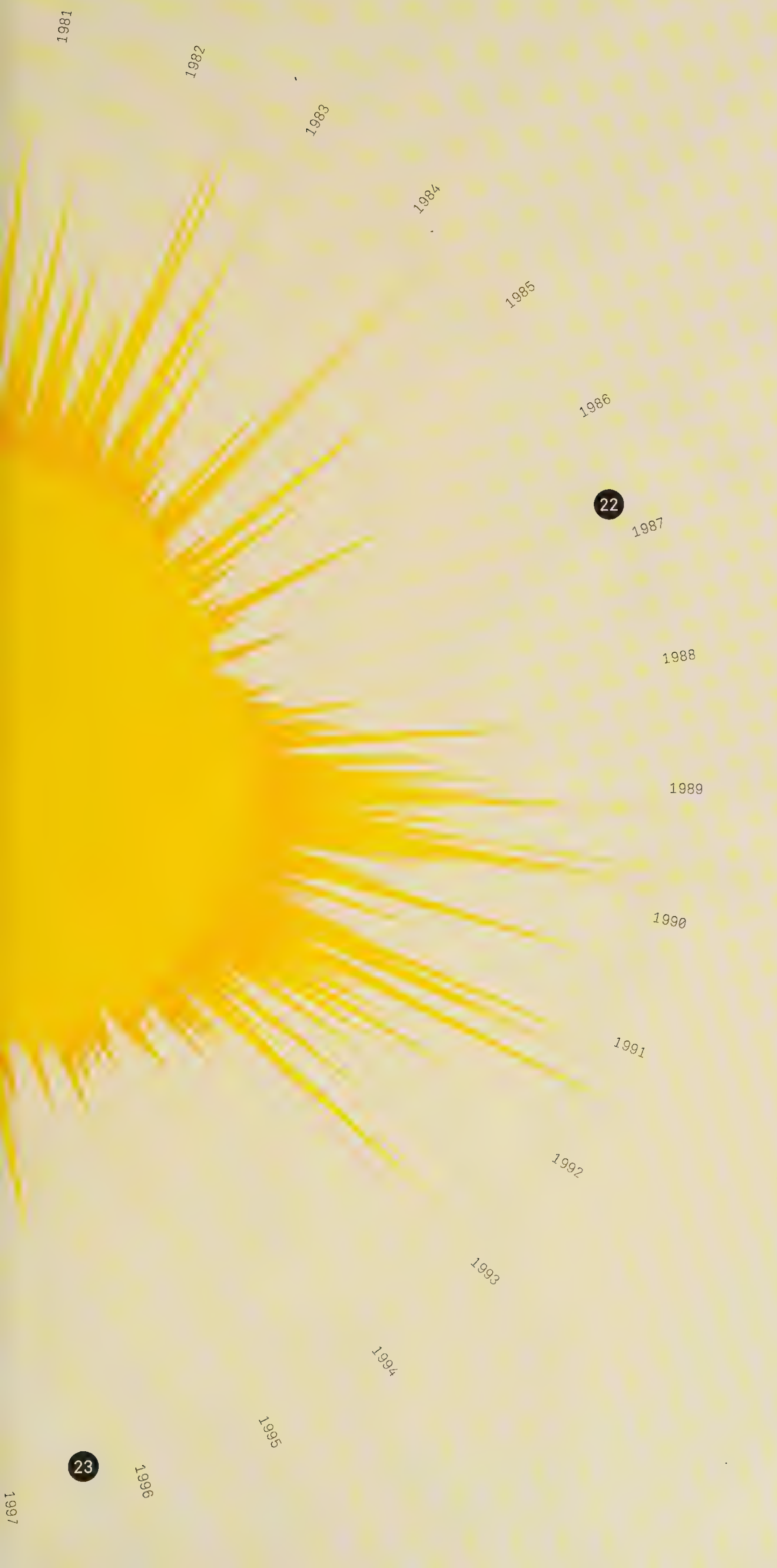
M – class
Can cause radio blackouts near the poles and radiation storms that can affect astronauts.

X – class
Can knock out satellites, increase the radiation doses of airline passengers, and create blackouts in electricity grids on the ground.

Solar cycles
24 / Started January 2008
23 / May 1996 – January 2008
22 / September 1986 – May 1996



Halloween Storm
The largest solar flare was on 4 November 2003. It was X28


1981
1982
1983
1984
1985
1986
22
1987
1988
1989
1990
1991
1992
1993
1994
1995
23
1996
1997

Dance of the Sun

We often think of the Sun as the centre of the Solar System but it isn't, not quite. The gravity of its many planetary partners leads it in complicated loops around the dance floor of the Solar System.

2038
+ 1978
2004
4
2040
1980
2016
2006
1992
2042
18
1982
+ 1990
+ 2000
+ 2010
+ 2030
+ 2040

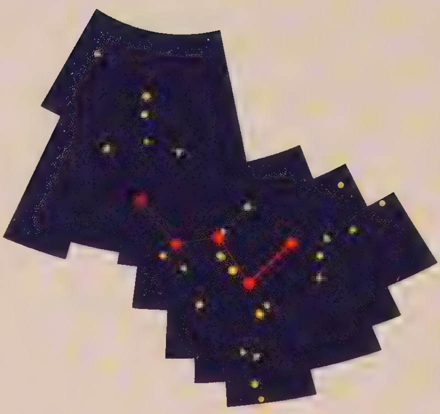
Five / Stars

Northern constellations

To ancient mariners and nomadic peoples, the night sky was a vital tool for navigation. It provided a point of reference for the time of year and latitude on the Earth when the Sun had set. Over the years people linked nearby stars to form patterns. These patterns are called constellations and neighbouring constellations are usually linked together in mythological stories. Today these stories are entertaining but they also help us remember the patterns that could be vital for planting crops, finding our way home, or even across an ocean.

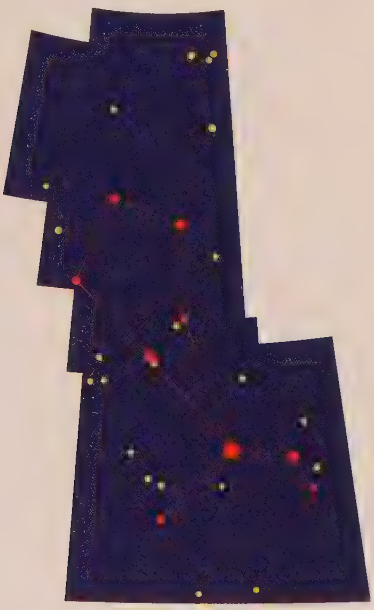
Many constellations have origins in ancient mythology. For instance, the hero Perseus is riding Pegasus (The Winged Horse) – to save Princess Andromeda, daughter of Queen Cassiopeia. Others are named after animals, such as Leo the Lion and Camelopardalis the giraffe (or the camel-leopard!).

One of the most famous northern constellations is Ursa Major (The Great Bear). This contains the famous asterism The Plough, or Big Dipper, as the tail and back of the bear.

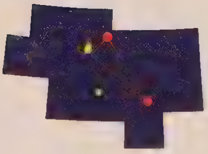


Cassiopeia / 598 sq deg

Andromeda / 722 sq deg

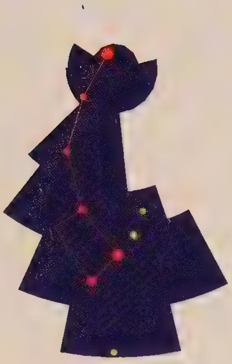


Boötes / 907 sq deg

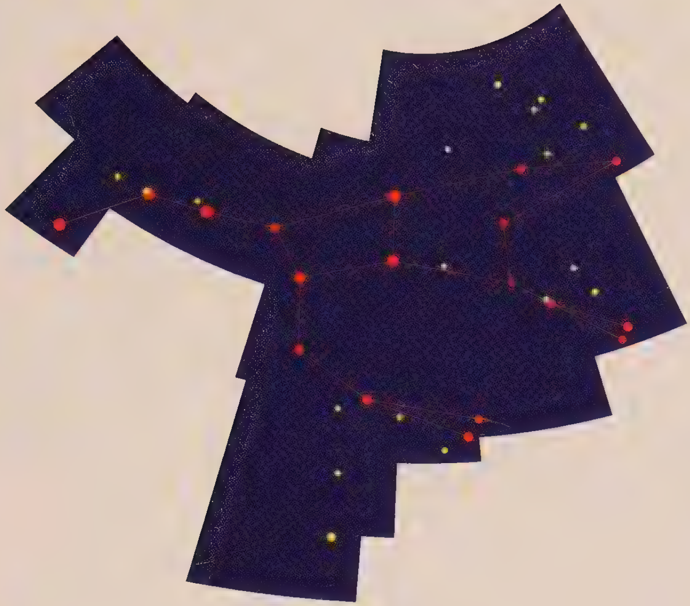


Triangulum / 132 sq deg

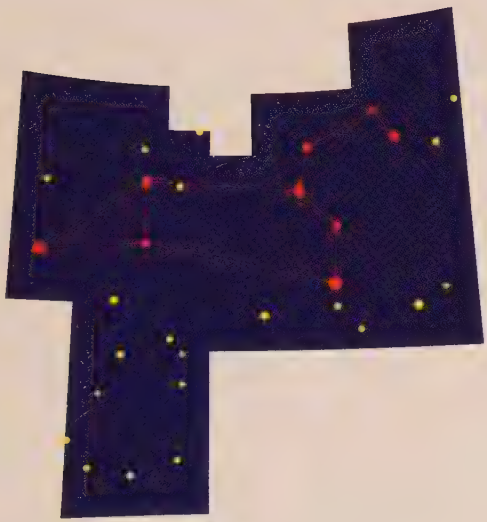
Camelopardalis / 757 sq deg



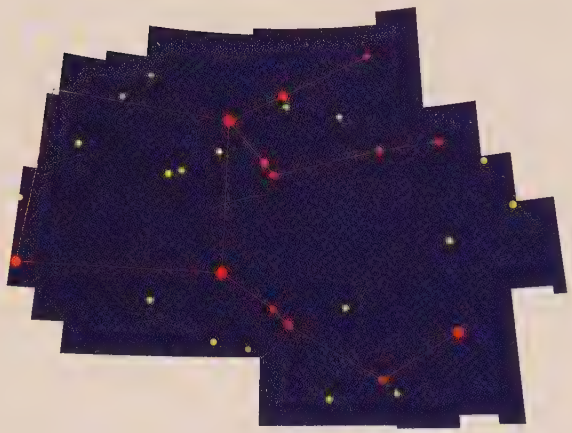
Ursa Minor / 256 sq deg



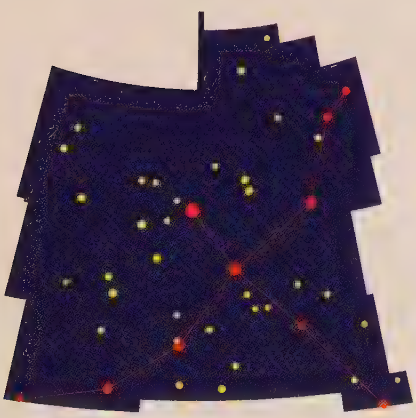
Ursa Major / 1,280 sq deg



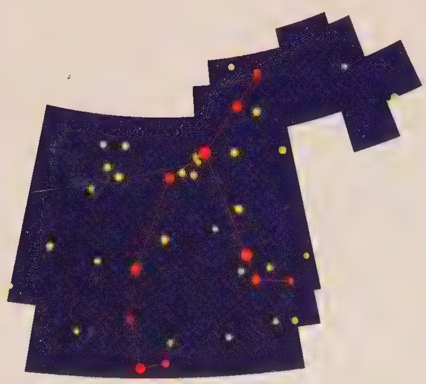
Leo / 947 sq deg



Pegasus / 1,121 sq deg



Cygnus / 804 sq deg

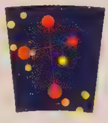


Perseus / 615 sq deg

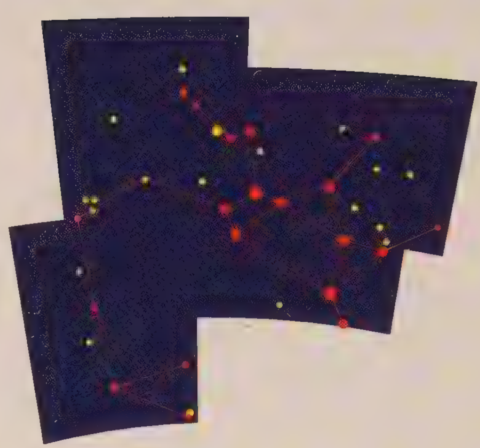
Southern constellations

The northern skies contain many well known constellations but the southern skies contain the largest and smallest constellations by area; Hydra (Female Water Snake) and Crux (The Southern Cross).

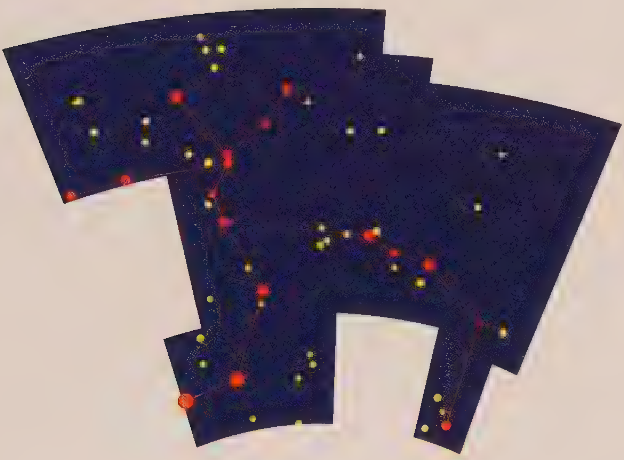
The names of the southern constellations often have more contemporary origins than their northern counterparts e.g. Norma (The Set Square, or Ruler), Dorado (Dolphinfish or Swordfish), and Pyxis (The Mariner's Compass).



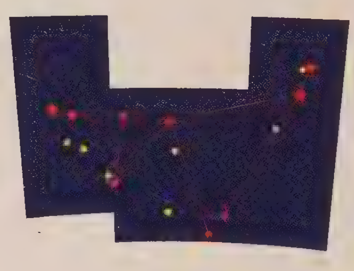
Crux / 68 sq deg



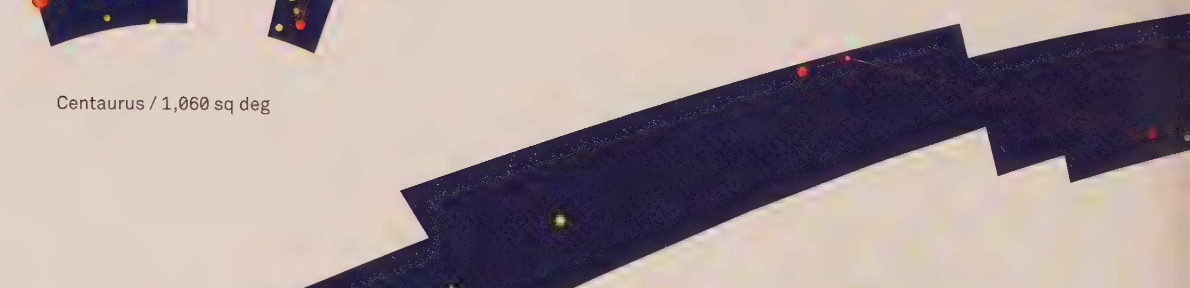
Sagittarius / 867 sq deg

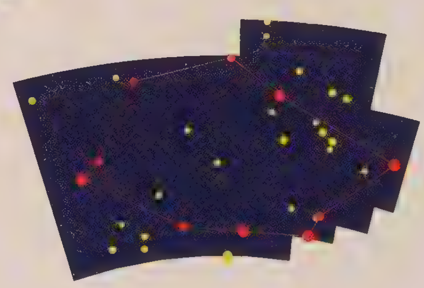


Centaurus / 1,060 sq deg

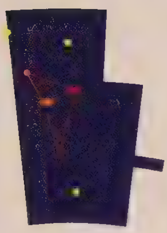


Capricornus / 414 sq deg

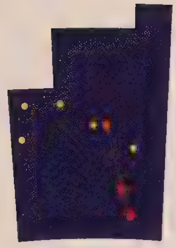




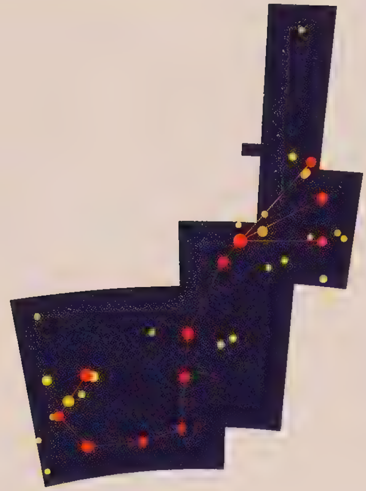
Vela / 500 sq deg



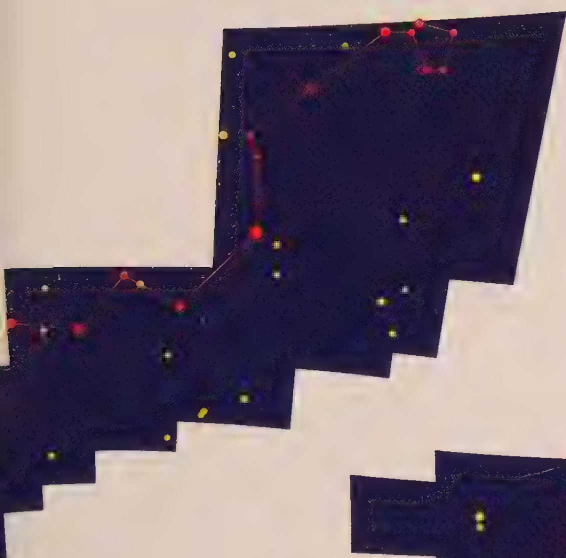
Norma / 165 sq deg



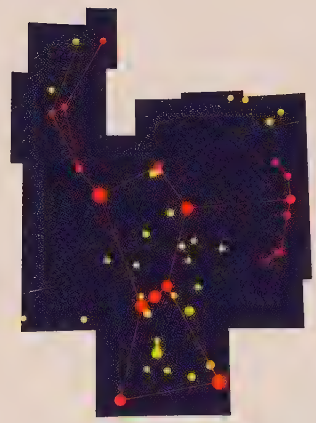
Pyxis / 221 sq deg



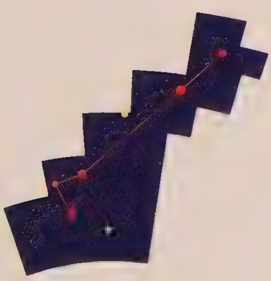
Scorpius / 497 sq deg



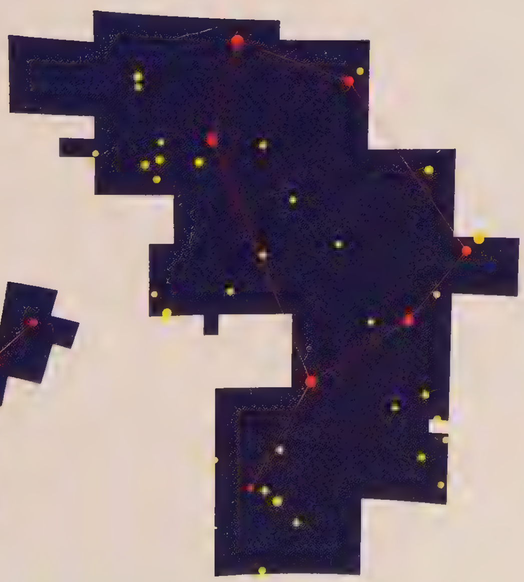
Hydra / 1,303 sq deg



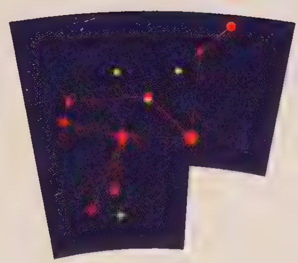
Orion / 594 sq deg



Dorado / 179 sq deg



Ophiuchus / 948 sq deg



Grus / 366 sq deg

3D Orion

Looking at the night sky it is natural to think of it as a tremendous crystal sphere with all the stars placed as points of lights on it. This was how many of the ancients imagined things to be. In reality, all the stars are at different, albeit enormous, distances. Space is 3D and we only see a 2D representation of it.

The familiar constellation of Orion, the Hunter, looks very different when viewed from a different direction. We see that the close grouping is lost when seen from other angles. Even the three stars of the belt turn out to contain an interloper in the form of the central star Alnilam which is a much brighter star but twice as far from Earth.

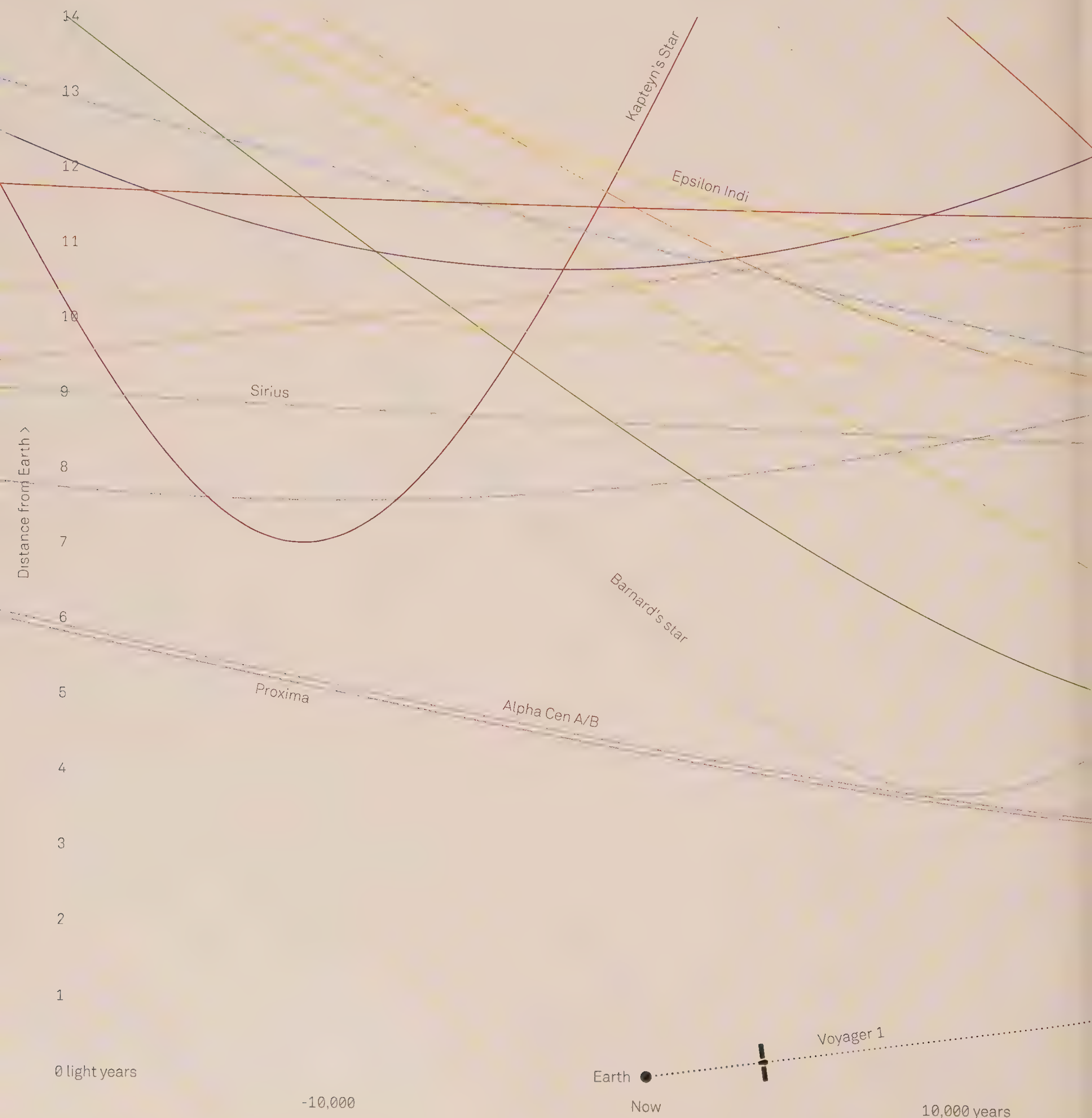
The position of Orion on the sky makes it visible to all cultures around the world. To the Greeks, Orion was a mighty Hunter. He was accompanied by his dogs (Canis Major and Canis Minor) as he fought Taurus (The Bull). In African bush stories, the three stars of Orion's belt are zebra being hunted by the bright star Aldebaran. In Australian aboriginal astronomy the belt is known as Djulpan (Three Brothers in a Canoe) and warns of the Monsoon season.

Orion / 594 sq deg

Nearest stars

Which are the closest stars to Earth? Aside from the Sun, our nearest neighbours are the Alpha Centauri triple star system about 4.3 light years away (40.7 trillion kilometres). The system contains two closely orbiting stars *Alpha Centauri A* and *B* orbited by Proxima Centauri. Stars are not static though and their positions change over time.

Barnard's star is moving towards us relatively quickly and will pass within four light years around 10,000 years from now. In approximately 35,000 years time the star *Ross 248* will be the closest star at around three light years. In roughly 40,000 years time, the *Voyager 1* spacecraft will be as close as 1.6 light years to the star *Gliese 445*.

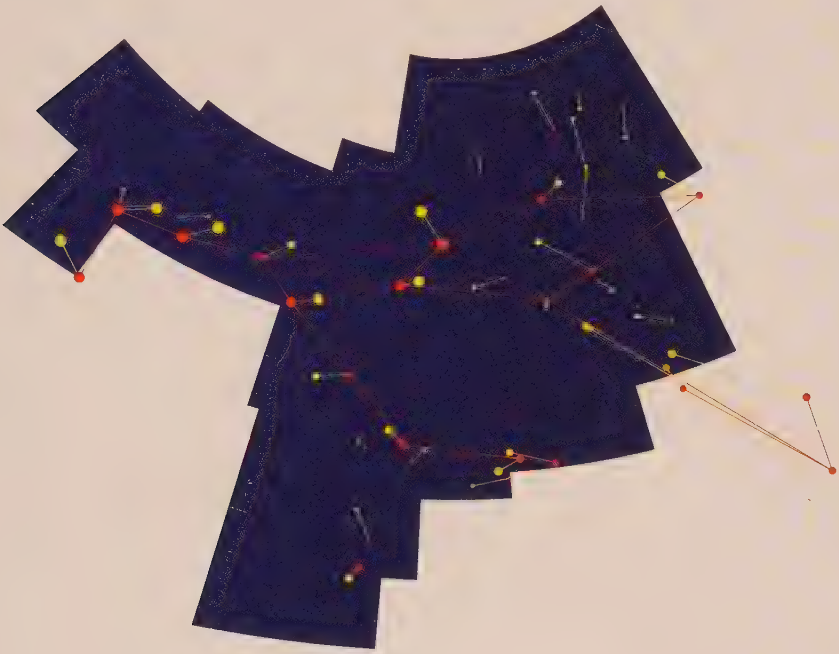


HD 217987
Gliese 65A/B
Epsilon Eridani
Procyon
Wolf 359
61 Cygni
Ross 154
Ross 128
Lalande 21185
Gliese 445
Ross 248
20,000
30,000
40,000

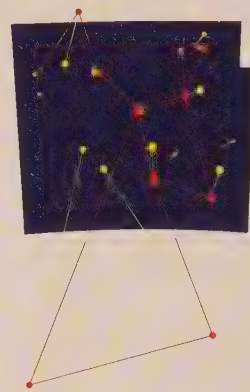
Proper motions

Throughout history astronomers have referred to the 'fixed stars' but, in reality, the stars are not static. Most stars are moving at different speeds and in different directions, though some move together through space. Given the huge distances involved, even at tens of kilometres per second, their motions are imperceptable to our eyes. With careful observations this 'proper motion' across the sky can be measured and, by making calculations, we can see what the sky will look like far off into the future. The patterns in the sky will look different to our descendants.

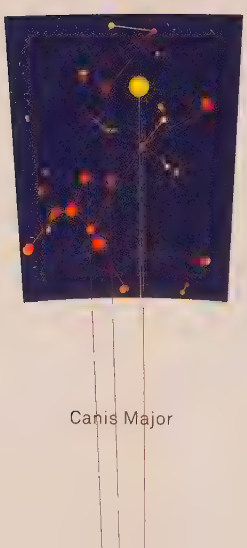
In 100,000 years from now the constellation of Leo will have lost its couchant pose, while the Gemini twins will have been decapitated! Cassiopeia will no longer be the familiar 'W' shape and Canis Major will have lost the 'Dog Star' – Sirius – from its collar. Although five of the bright stars in 'The Plough' – part of Ursa Major – are moving together through space, the bear will end up with a kink in its tail. The constellation of Orion will have adjusted his sword and shield but one of his shoulders – Betelgeuse – may also have ended its life in a supernova explosion.



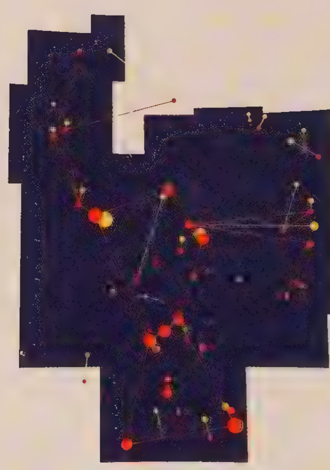
Ursa Major



Lepus



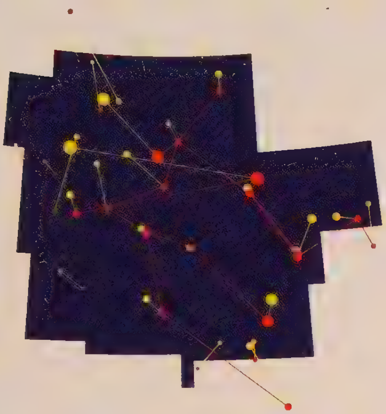
Canis Major



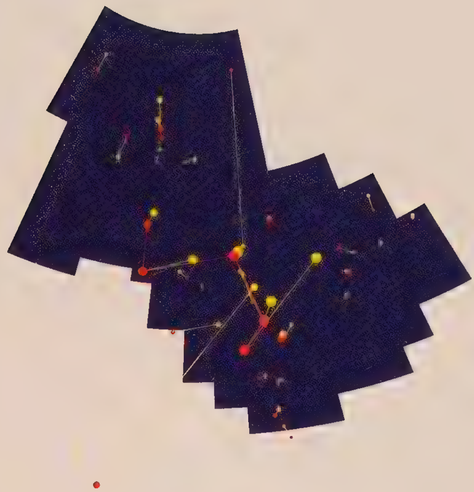
Orion

Position A, present day

Position B, 100,000 years in the future

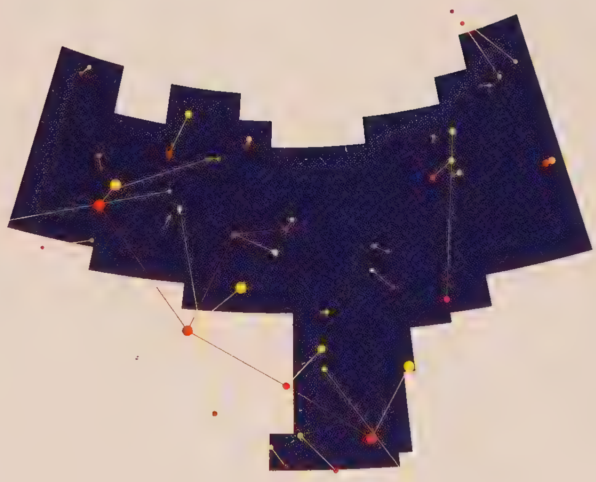


Gemini



Cassiopeia

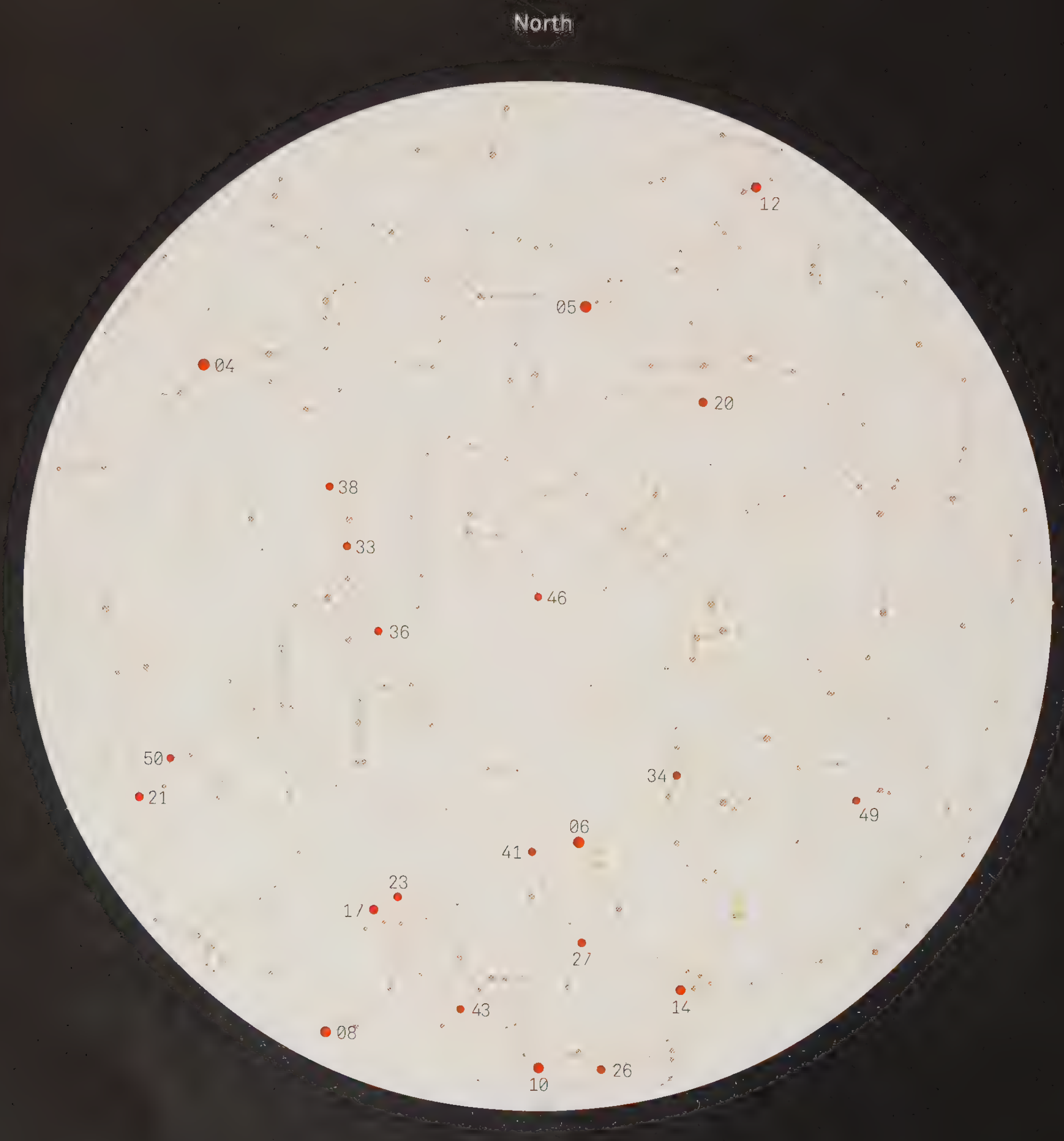
Leo



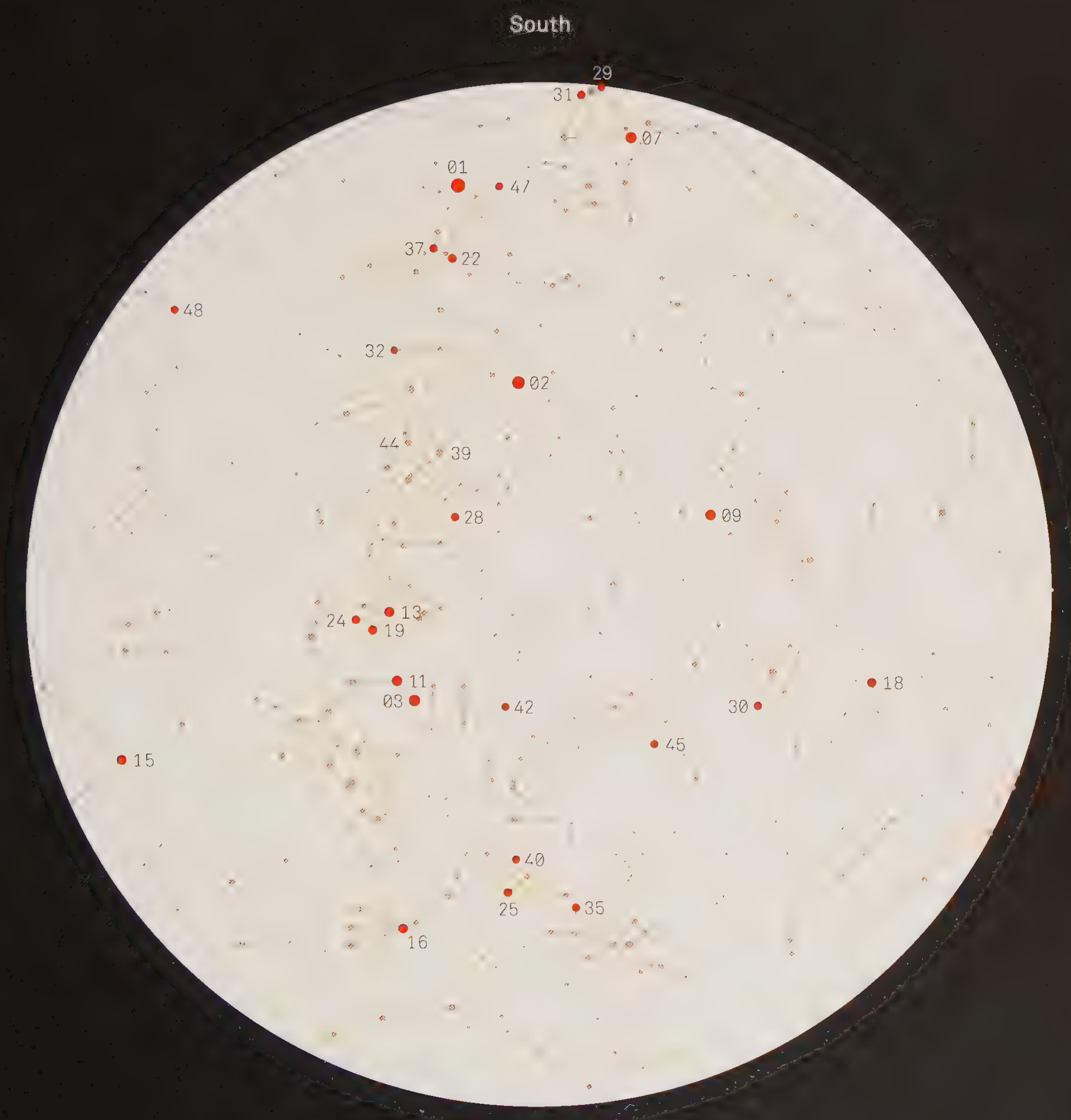
Andromeda

Brightest stars

When you look up into the night sky you see that some stars are brighter than others. The brightest star in the sky is Sirius, the Dog Star, which is actually a binary star system consisting of *Sirius A* and *Sirius B*. The next brightest star is Canopus which is roughly half as bright. Surprisingly, for many, the North Star (Polaris) is far down the list; its importance stems from its position near the pole rather than its brightness. The brightness we see from Earth is actually a combination of a star's true brightness and how close it is. A relatively faint star can appear brighter than others if it is much closer. For example, Canopus is actually 600 times brighter than Sirius, but nearly 40 times further away and so actually appears slightly fainter.



01 / Sirius
02 / Canopus
03 / Alpha Centauri
04 / Arcturus
05 / Vega
06 / Capella
07 / Rigel
08 / Procyon
09 / Achernar
10 / Betelgeuse
11 / Hadar
12 / Altair
13 / Acrux
14 / Aldebaran
15 / Spica
16 / Antares
17 / Pollux
18 / Fomalhaut
19 / Becrux
20 / Deneb
21 / Regulus
22 / Adhara
23 / Castor
24 / Gacrux
25 / Shaula
26 / Bellatrix
27 / Alnath
28 / Miaplacidus
29 / Alnilam
30 / Alnair
31 / Alnitak
32 / Gamma Velorum
33 / Alioth
34 / Mirfak
35 / Epsilon Sagittarii
36 / Dubhe
37 / Wezen
38 / Alkaid
39 / Avior
40 / Theta Scorpii
41 / Menkalinan
42 / Atria
43 / Alhena
44 / Delta Velorum
45 / Peacock
46 / Polaris
47 / Mirzam
48 / Alphard
49 / Hamal
50 / Algieba



Giant stars

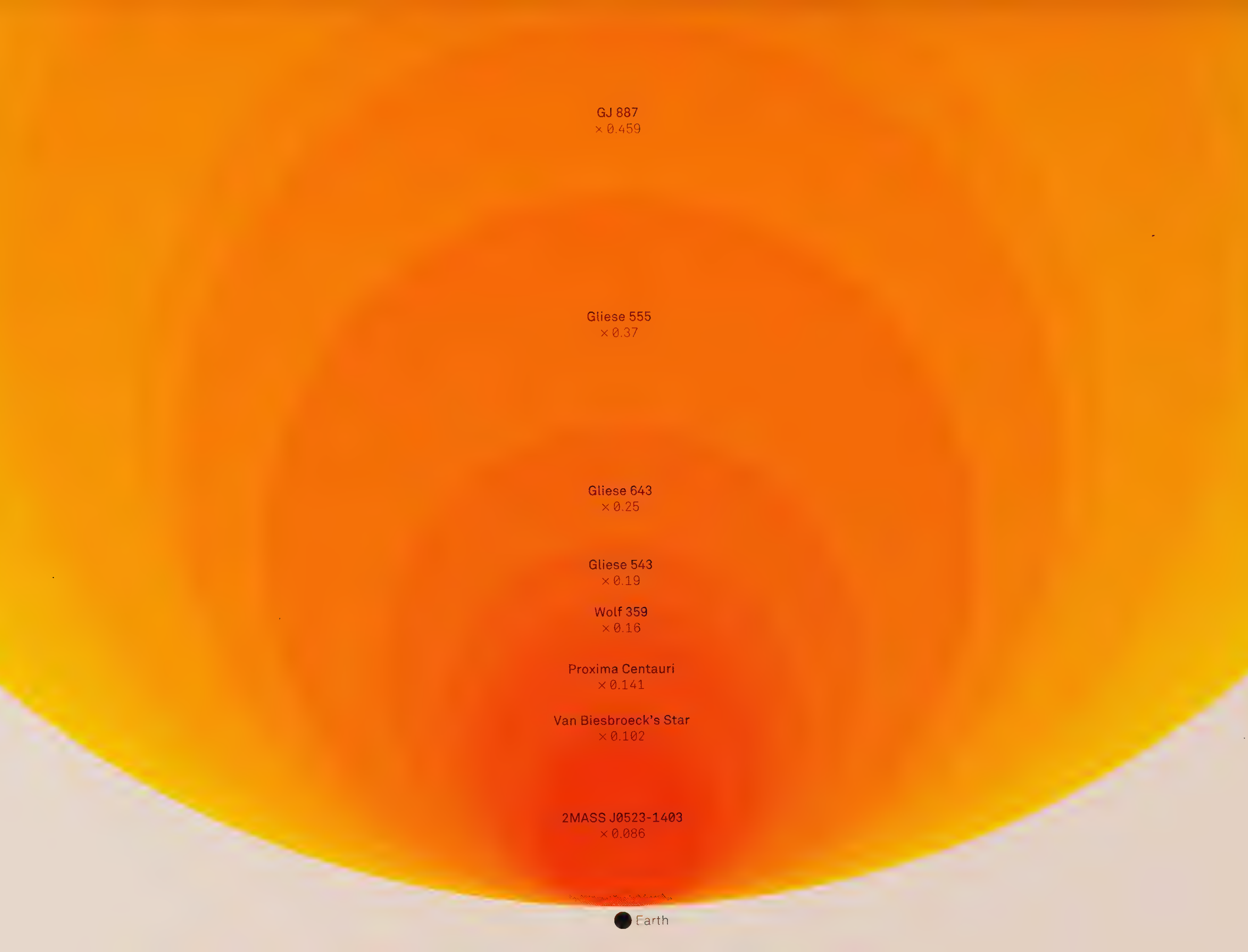
Our local star, the Sun, is roughly 1.4 million kilometres across. That is large – over 100 times the diameter of the Earth – but is tiny compared to many others. One of the contenders for largest known star is *UY Scuti*, which is found in the southern constellation of Scutum. At an estimated 1,700 times the size of the Sun, it would stretch beyond the orbit of Jupiter if it is placed at the centre of the Solar System.


Canopus
× 65
Aldebaran
× 44
Arcturus
× 25
Delta Boötis
× 10 the Sun
Sun

Dwarf stars

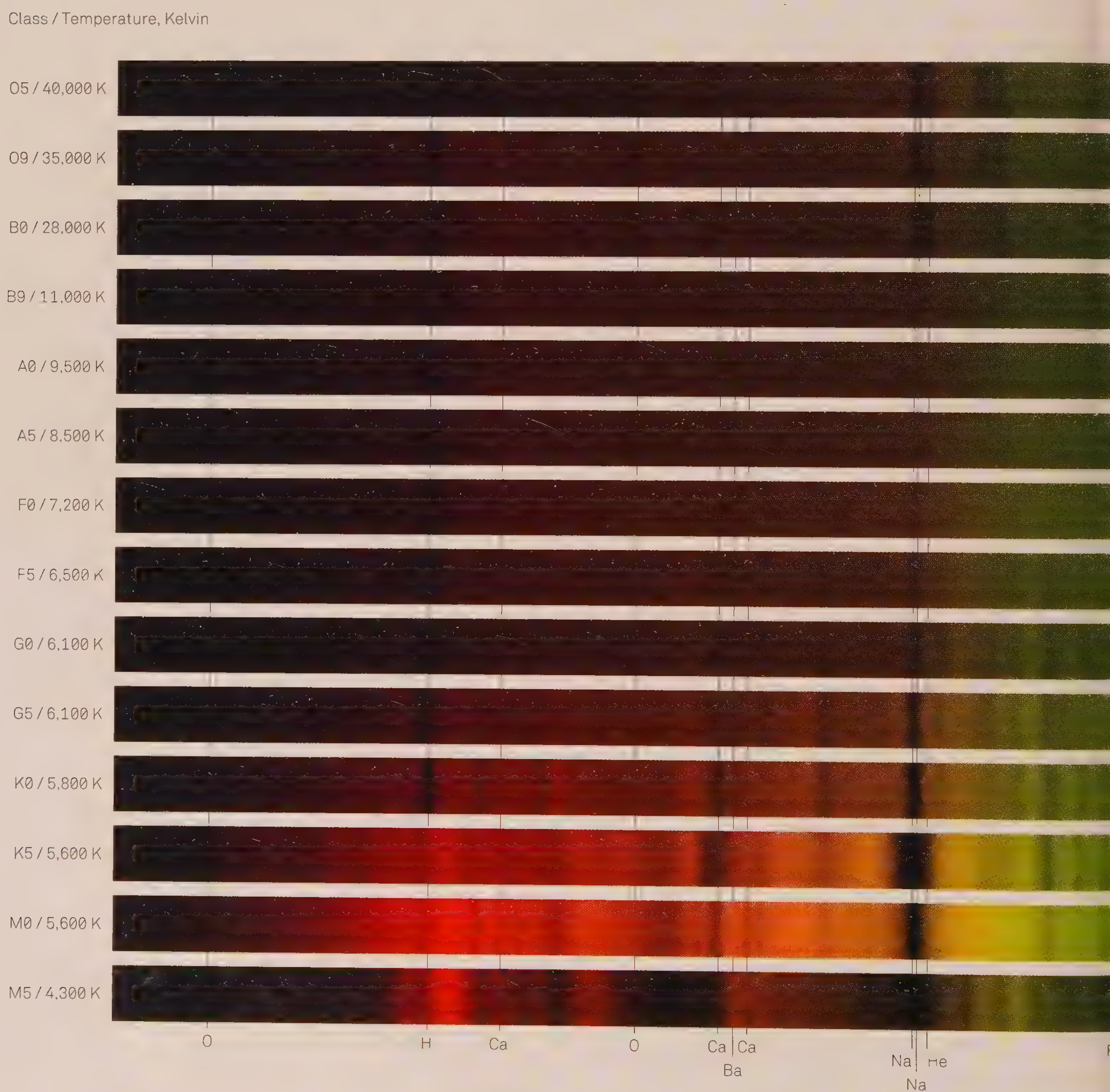
Just now small can a star be? A star is usually defined as a ball of plasma, held together by its own gravity, and shining due to thermonuclear fusion occuring at its core. For the fusion to occur, the core needs to be extremely hot and dense. We think there needs to be at least 7% of the mass of the Sun for there to be enough gravity to make athe conditions right.

The smallest star currently known is only 8.6% the diameter of the Sun, one eight-thousandth as bright, and has a temperature of only 2,100 Kelvin. It is known by the rather cumbersome designation *2MASS J0523-1403*.


GJ 887
× 0.459
Gliese 555
× 0.37
Gliese 643
× 0.25
Gliese 543
× 0.19
Wolf 359
× 0.16
Proxima Centauri
× 0.141
Van Biesbroeck's Star
× 0.102
2MASS J0523-1403
× 0.086
Earth

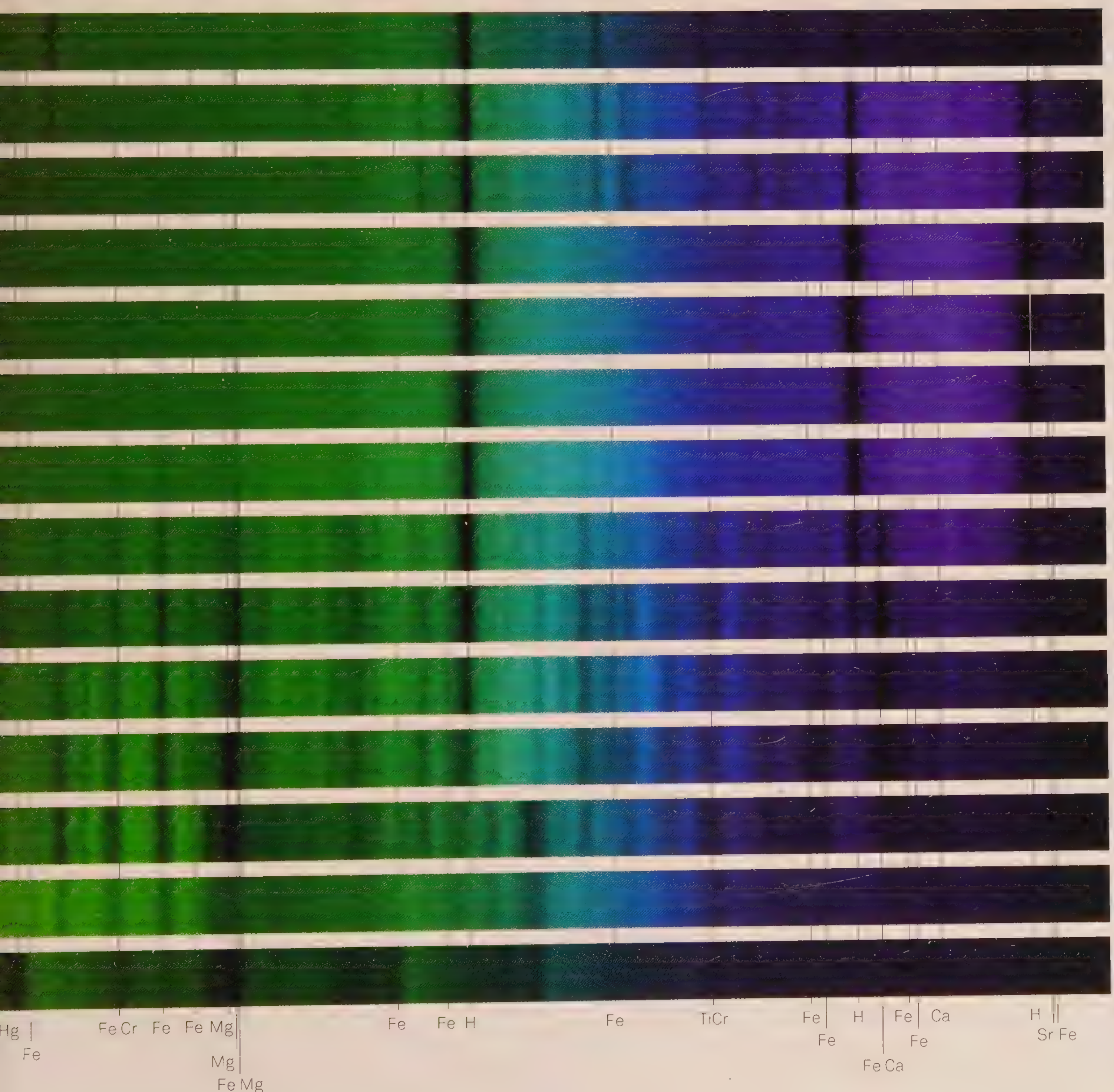
Stellar classifications

In the late 19th and early 20th Century astronomers classified stars into types based on the patterns of dark lines seen in their spectra. The modern classifications were devised by Annie Jump Cannon in 1901, and are given the letters: O, B, A, F, G, K, M. The ordering of the classifications depends on the relative strengths of the various lines, which are caused by the abundance of elements in the star's atmosphere. To remember them, astronomers use the mnemonic 'Oh, Be A Fine Girl/Guy, Kiss Me'. It was only later that it was realised that the order also depends on the surface temperature of the star. The cooler stars have more absorption lines because their cooler atmospheres allow simple molecules to form.



O / Oxygen in Earth's atmosphere
H / Hydrogen
Ca / Calcium
Ba / Barium
Na / Sodium
He / Helium

Fe / Iron
Mg / Magnesium
Hg / Mercury
Cr / Chromium
Ti / Titanium
Sr / Strontium



Brightness and colour

In the early 20th Century, Ejnar Hertzsprung and Henry Russell compared the true brightness of stars with their colour. The colour of a star depends on its surface temperature, with hotter stars appearing blue and cooler stars appearing red. By plotting these two properties on a diagram they found that the stars split up into different groups based on how large they were and where they were in their lives. We can make a modern version of a Hertzsprung-Russell diagram using up-to-date measurements for thousands of stars.

Running diagonally across the diagram is the 'Main Sequence' where most stars spend the majority of their lives. Where they are on this sequence depends on their mass at birth. As they age stars expand. This makes them cooler but also brighter, so they move towards the giant and supergiant areas. Just before the very end of their lives, the temperature suddenly increases moving them to the left. After it dies a star will slowly cool and fade as a white dwarf, a neutron star, or maybe even a black hole.

The Sun's journey

A 0 - Sun begins its life.

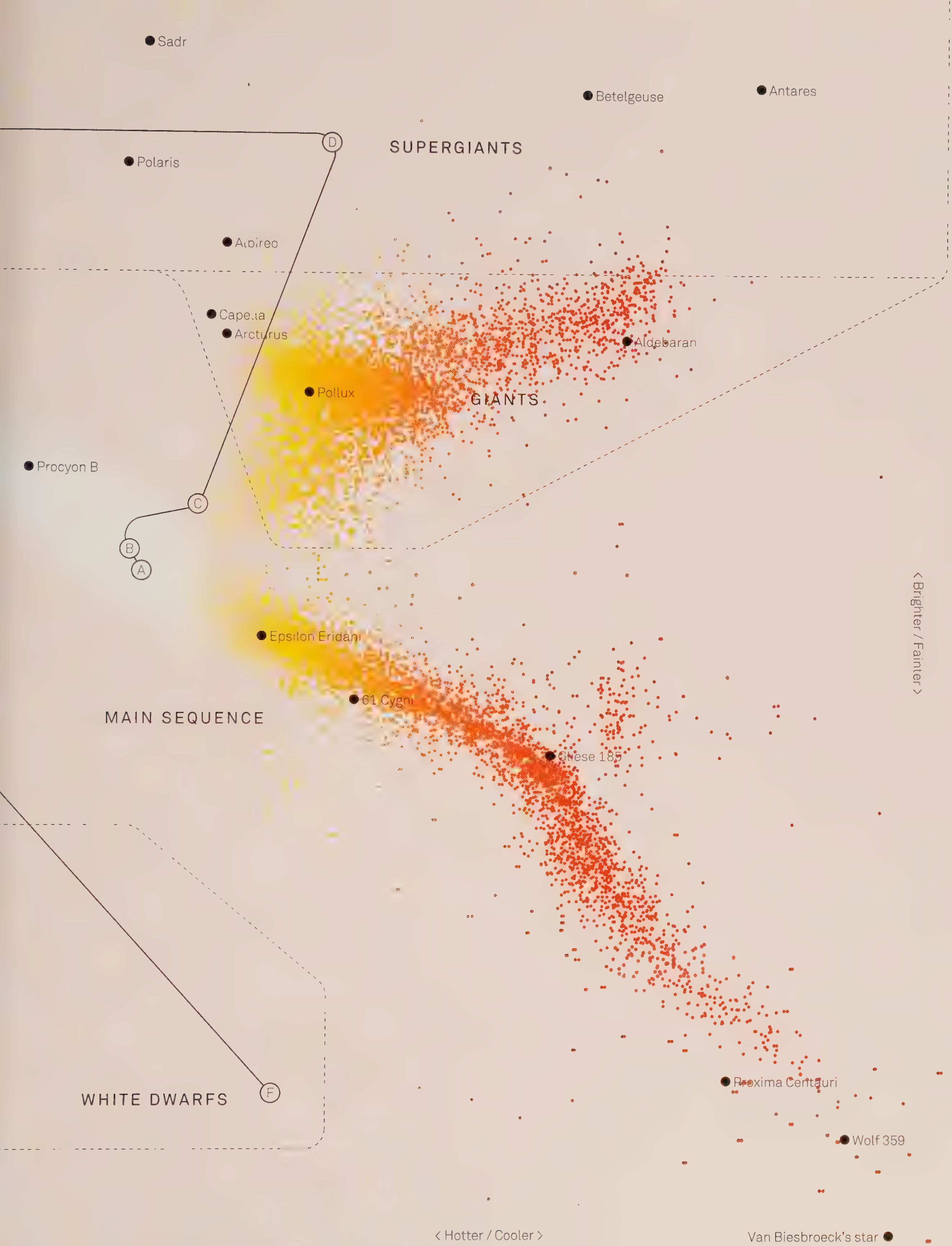
B 4.5 billion years – The Sun now. Over billions of years the Sun will get slightly brighter and hotter.

C 9.5 billion years – The Sun is expanding into a red giant. It is 2.3 times bigger and 3.2 times brighter.

D 10.3 billion years – The Sun is now 210 times bigger, about 4,200 times brighter, and nearly half its current temperature.

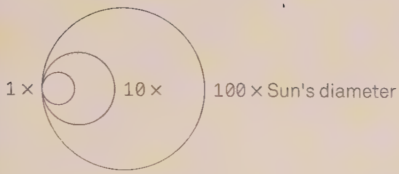
E 10.3 billion years – Having run out of fuel, the Sun has thrown off its outer layers. Just over half of the current mass remains and it has collapsed to about 20% of the original size. Its temperature is around 100,000 Kelvin and it is 3,000 times brighter than it is now.

F 12 billion years – The remnant of the Sun is 0.003% of its current brightness and only about 1.5 times the size of the Earth.


Sadr
Betelgeuse
Antares
SUPERGIANTS
D
Polaris
Albireo
Capella
Arcturus
Pollux
Aldebaran
GIANTS
Procyon B
C
B
A
Epsilon Eridani
61 Cygni
MAIN SEQUENCE
Gliese 185
< Brighter / Fainter >
Proxima Centauri
WHITE DWARFS
F
Wolf 359
< Hotter / Cooler >
Van Biesbroeck's star

Life cycle of stars

The life of a star is determined by how much mass it has when it is born. The more massive it is at birth, the more quickly it burns through its fuel supplies. Big stars live fast and die young. Through nuclear fusion, stars convert their huge supplies of hydrogen into progressively heavier elements. It is actually the radiation and energy from these nuclear reactions that keeps a star from collapsing under its own gravity. Once the fuel is depleted the star can no longer support itself and explodes off its outer layers while the inner parts collapse. This marks the death of the star. The end product will depend on the star's mass when it dies.



Stars more massive than around 25 times the Sun's mass collapse too rapidly to form a neutron star, instead they form a black hole.

When stars more than eight times the mass of the Sun end their lives in a supernova, their inner layers collapse to form a neutron star, which has a mass similar to the Sun but a diameter of only around 20 km.

Stars like the Sun shed their outer layers when they die, leaving their cores as white dwarfs.

Supernovae

When stars much more massive than our Sun reach the end of their lives they catastrophically explode as supernovae. These explosions can, briefly, outshine an entire galaxy. We estimate that about two or three occur each century in a galaxy the size of the Milky Way.

All supernovae we've found in the past 130 years have occurred in external galaxies and almost all were too faint to be seen by the unaided eye. The brightest supernova in living memory is *SN 1987A* which was seen in 1987 in the Large Magellanic Cloud.

These days we group supernovae into four main types – Ia, Ib, Ic and II – based on the elements observed in the spectra of their light. Although there are four types, there are two main causes.

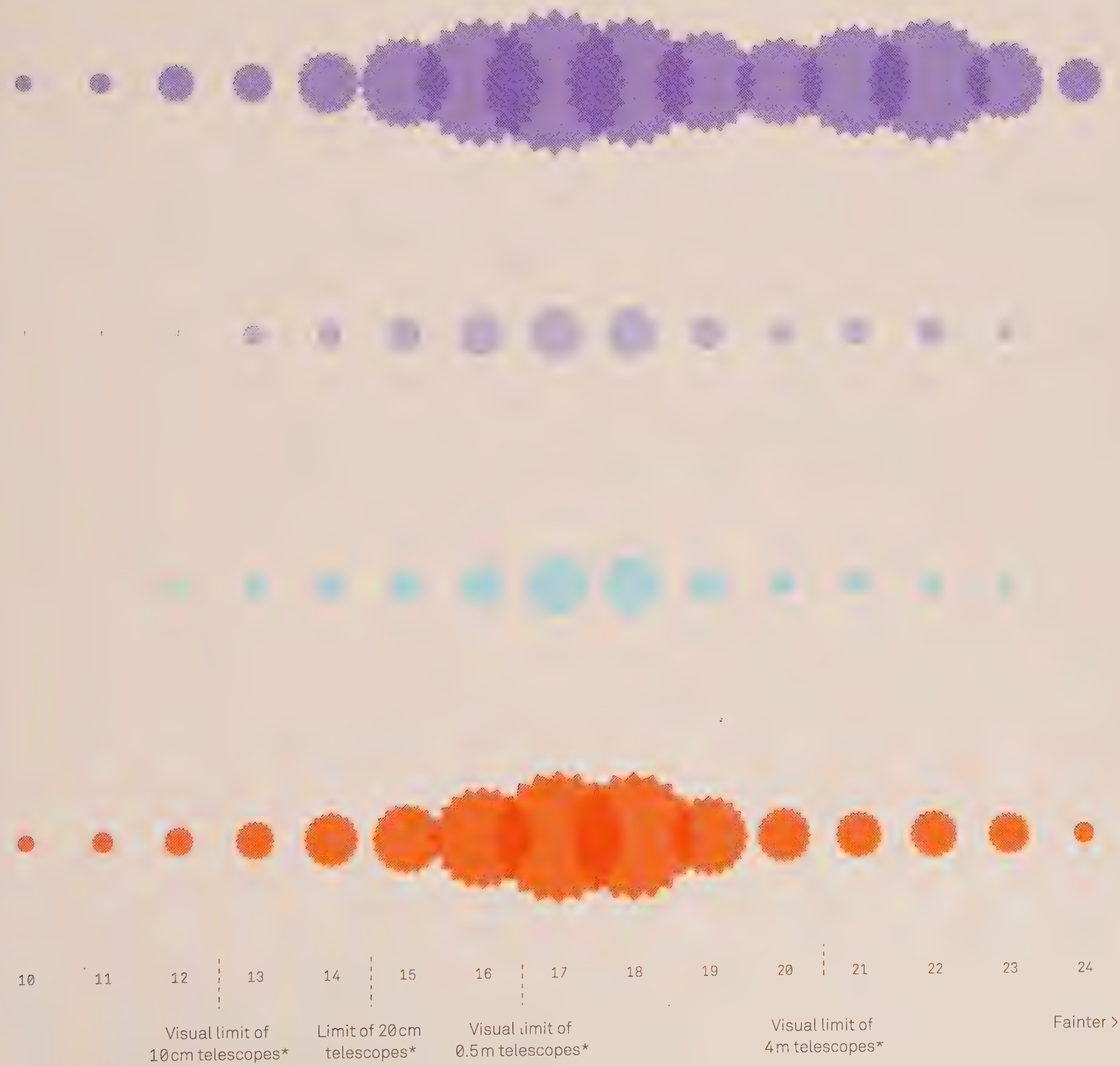
Type Ia supernovae occur when a companion star spills matter onto a white dwarf until it eventually reaches a critical mass and explodes.

Type Ib, Ic and II supernovae occur when the nuclear fusion in very massive stars is no longer able to counteract gravity

*Approximate

and the core collapses into either a neutron star or black hole. The type Ib and Ic are from stars that have lost most of their outer hydrogen layers through stellar winds in the final stages of their lives.

Over the past 130 years we've found more Type Ia supernovae than any other type and they make up the majority of the faintest supernovae. This is partly because these tend to be the brightest supernovae so we can detect them out to further distances.



Pulsars

In 1967 Cambridge University student Jocelyn Bell noticed 'a bit of scruff' in the data from her radio telescope. It was a regularly pulsating burst of radio waves and she realised it was extra-terrestrial in origin. She named it *'LGM 1'* – short for *'Little Green Man 1'* – and *LGM 2 & 3* were found a little later. After discussion with others she realised she had discovered a type of dead star that had been predicted but never seen.

A star much more massive than the Sun ends its life as a supernova. While the outer parts explode, the inner parts collapse to a tiny remnant with a mass slightly more than the Sun compressed to the size of a city. During the collapse the star spins faster, the magnetic field gets concentrated, and the density becomes so high that protons and electrons are forced together into neutrons. The result is a neutron star and the surface can be spinning as fast as 15% of the speed of light.

Often, neutron stars emit beams of radio waves from each magnetic pole. If the rotation and magnetic axes differ, the beams sweep around the sky just like the beams from a

Crab

One cubic centimetre of the Crab pulsar's magnetic field is equivalent to the output of a nuclear power plant. A cubic meter contains more energy than the total output of humanity.

J0737-3039A/B

In 2004 two pulsars were found orbiting each other. By carefully monitoring changes in their behaviour, astronomers have been able to test General Relativity to 99.995% accuracy.

lighthouse. If the beams sweep past the Earth we see a flash of radio waves each time and we call it a pulsating neutron star or pulsar.

Comparing the rotation time with how fast a pulsar is slowing produces interesting results. Younger pulsars are found towards the top left and pulsars with companions are found in the lower left. As a pulsar ages it slows and the rate of slow-down reduces too; the pulsar moves down and to the right. At some point it crosses the 'pulsar death line' where the beams seem to switch off.

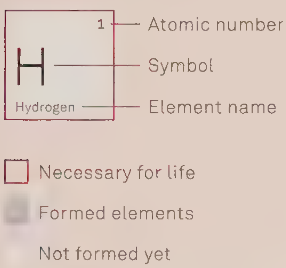
We are stardust

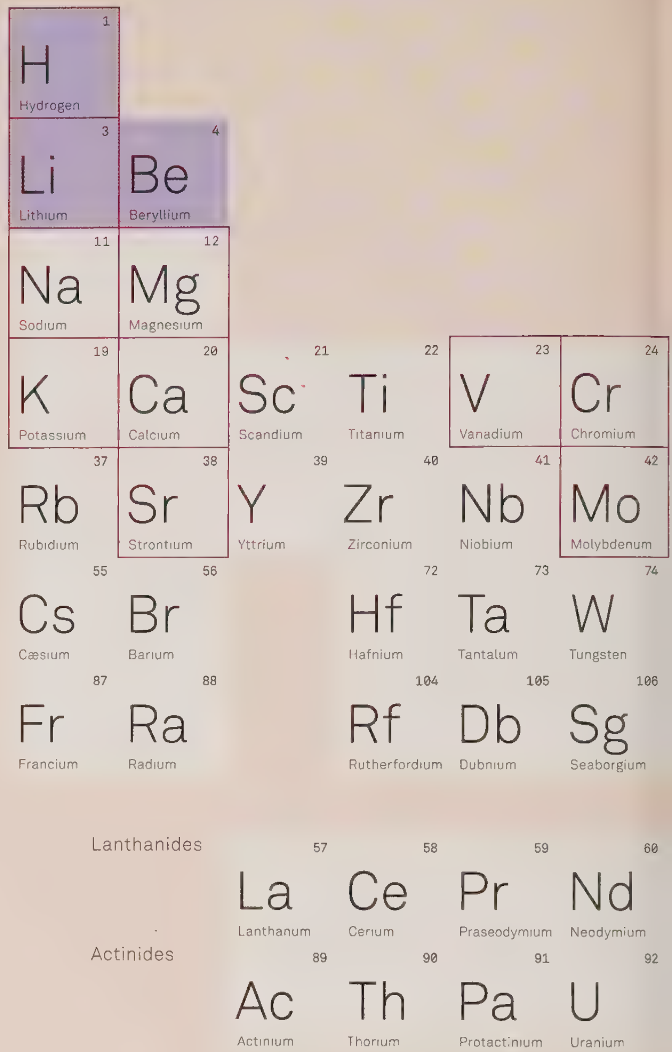
Life is complex, relying on chemical reactions between a huge variety of atoms and molecules. The basis for all life on Earth is DNA, which is made of hydrogen, carbon, nitrogen, oxygen and phosphorus. But where do all these chemical elements come from? Most of the heavier elements are formed during supernovae, including some of the elements that are crucial to life as we know it. This material goes into the formation of new stars and planets.

In the beginning

In the beginning*, the Universe was a sea of the two lightest elements, hydrogen and helium, with very small amounts of lithium, boron and beryllium formed from subsequent reactions.

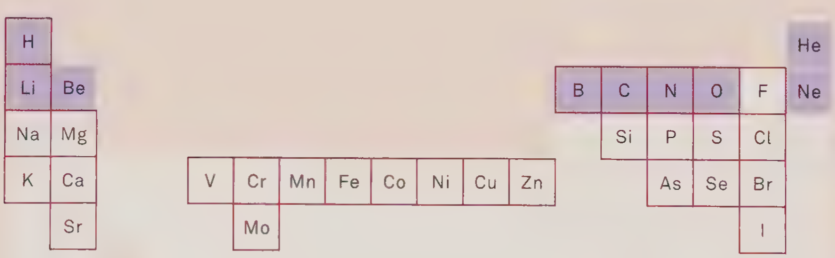
* Not quite the beginning; the first stable atoms didn't form until about 380,000 years after the Big Bang.





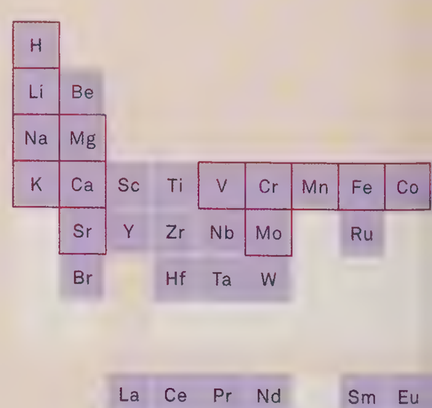
The hearts of stars

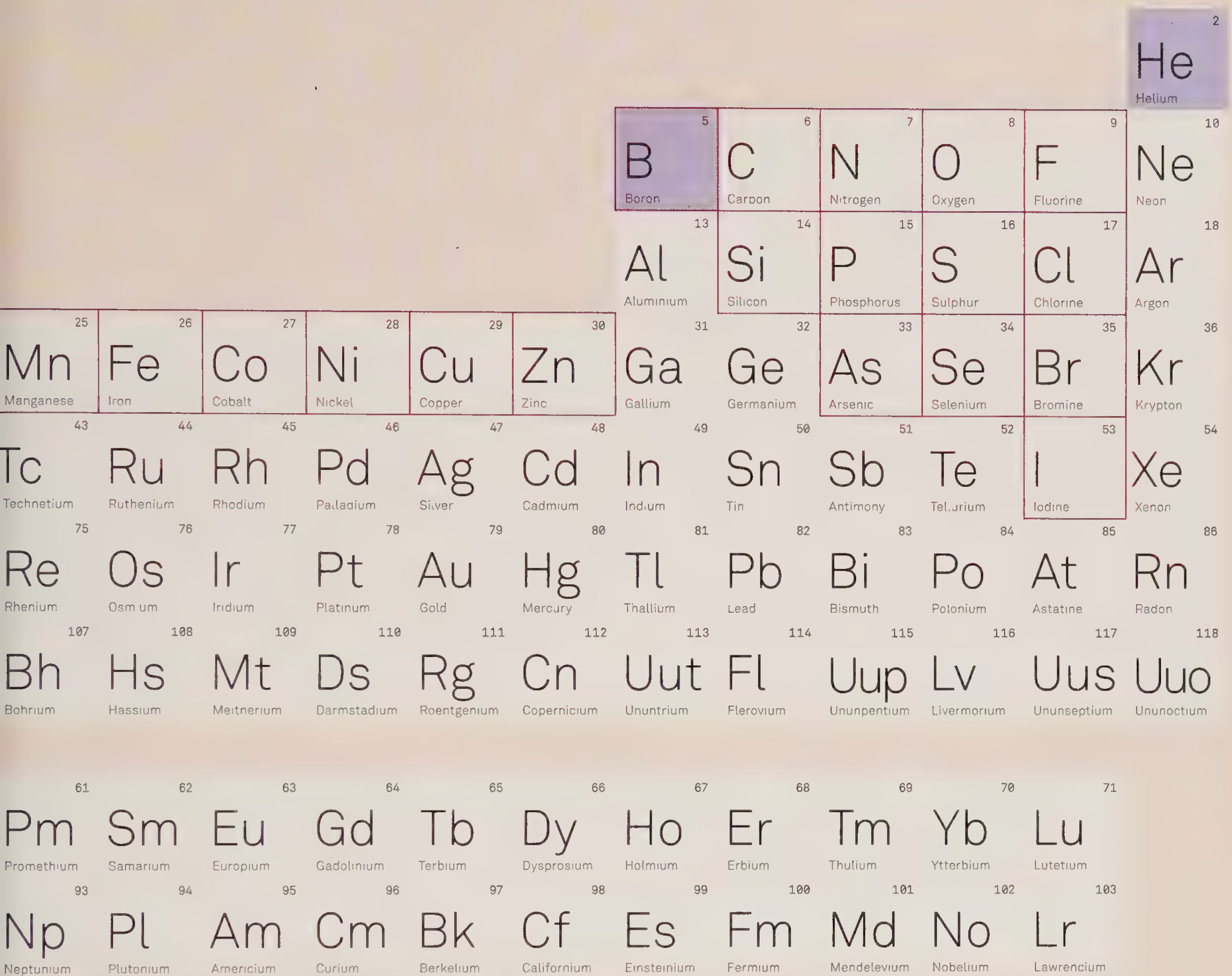
Stars like the Sun can form carbon, nitrogen, oxygen, neon, and silicon towards the end of their lives.



Stellar monsters

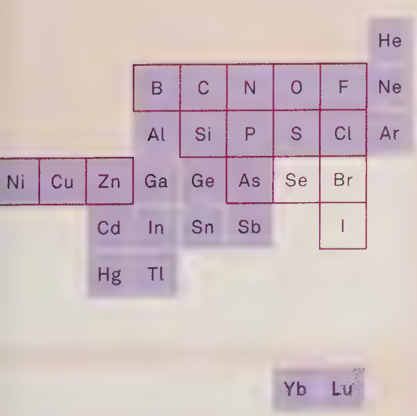
The energetic processes within the cores of massive stars produce elements that fill in half of the rest of the periodic table. Aluminium, silicon, and oxygen are the three most common elements found in the Earth's crust.

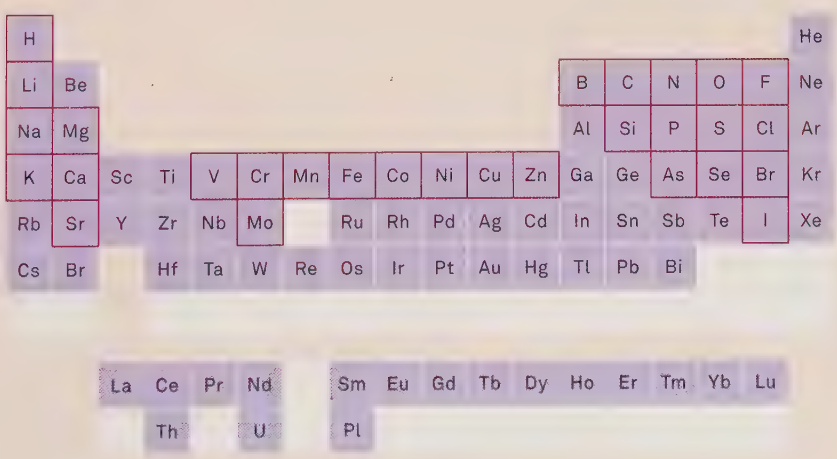




Ashes to ashes

Most of the heavier elements are formed during supernovae, the final death throws of the most massive stars. The material created in these explosions includes some of the elements that are crucial to life as we know it.

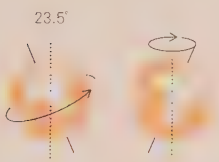




The north end of the Earth's axis of rotation points towards Polaris (or a point close to it), which is sometimes called the North or Pole Star. There's nothing particularly special about Polaris, though. This alignment of the North Celestial Pole with Polaris is just a coincidence, and hasn't always been the case. The Earth's axis is tilted by about 23.5 degrees relative to its orbit around the Sun. Over a period of tens of thousands of years this axis wobbles, changing position in the sky above the poles.

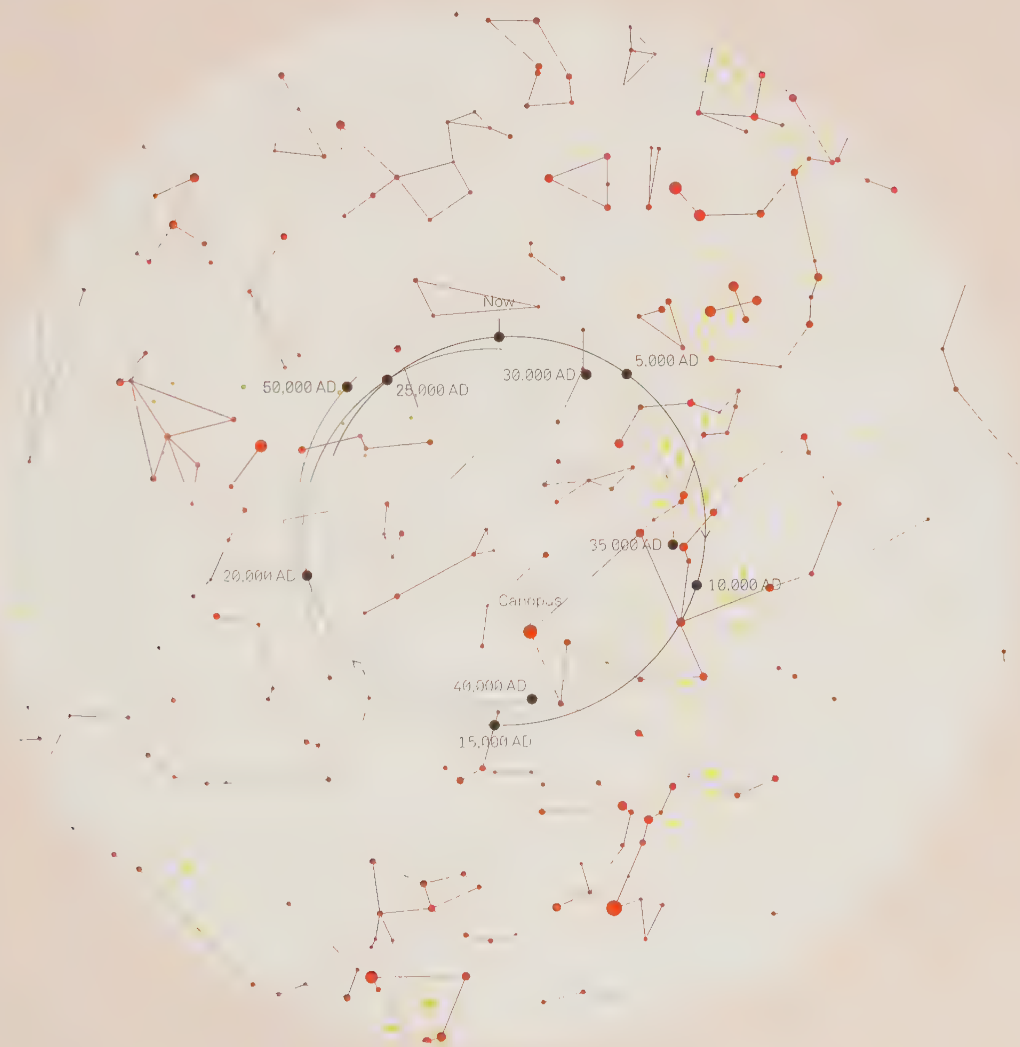
North Celestial Pole

When the pyramids were being built, the North Celestial Pole was close to the star Thuban, in Draco, and in 14,000 years hence the very bright star Vega will be the pole star.



South Celestial Pole

There isn't currently a bright star near the South Celestial Pole, but it is pointed to by the Southern Cross. In a thousand years that won't be the case, and in 14,000 years the pole will be about ten degrees from the second brightest star in the sky, Canopus.



Six / Galaxies

From the outside, our galaxy – the Milky Way – would look like two fried eggs placed back-to-back. We are in the white of the egg, roughly two-thirds of the way from the centre, so we see a band circling us. We can lay out the sky, as you would a globe, with the band of the Milky Way as the 'equator' line across the middle of the page and the centre of our galaxy at the centre of the map.

The left and right edges of the page join up. Looking at the 'equator' line means looking into the disk so we mostly see the local stars, dust and nebulae. Moving up or down from the 'equator' is to look up or down out of the disk giving a less obstructed view to the things beyond.

As well as stars, many other types of objects are visible in the sky, from clusters of stars which formed together, to galaxies both near and far.

Andromeda Galaxy

A similar galaxy to our own Milky Way. At a distance of 2.5 million light years, it is the most distant object visible to the naked eye.

The Pleiades

An 'open cluster' of a few hundred stars. They formed together from the same cloud of gas and dust around 100 million years ago, and will gradually disperse over time.

- Star
- Group of stars
- Open cluster
- Globular cluster
- Nebula
- Supernova remnant
- Galaxy
- Spiral galaxy
- Barred galaxy
- Lenticular galaxy
- Elliptical galaxy

North Celestial Pole

Galactic Centre

South Celestial Pole

3C 273

In the 1950s radio astronomers found hundreds of very bright objects all over the sky. Many of these were identified as distant galaxies with supermassive black holes at their centres. These objects are now called quasars.

Centaurus A

Looks like an unassuming galaxy in visible light but has two huge lobes spurting out in opposite directions from the supermassive black hole at its heart.

Vela Supernova Remnant

The remains of a massive star that exploded over 11,000 years ago in the direction of the constellation Vela. The centre contains a neutron star.

Omega Centauri

The largest globular cluster in our galaxy. This roughly spherical ball of stars formed together several billion years ago, and they are bound together by gravity.

Orion Nebula

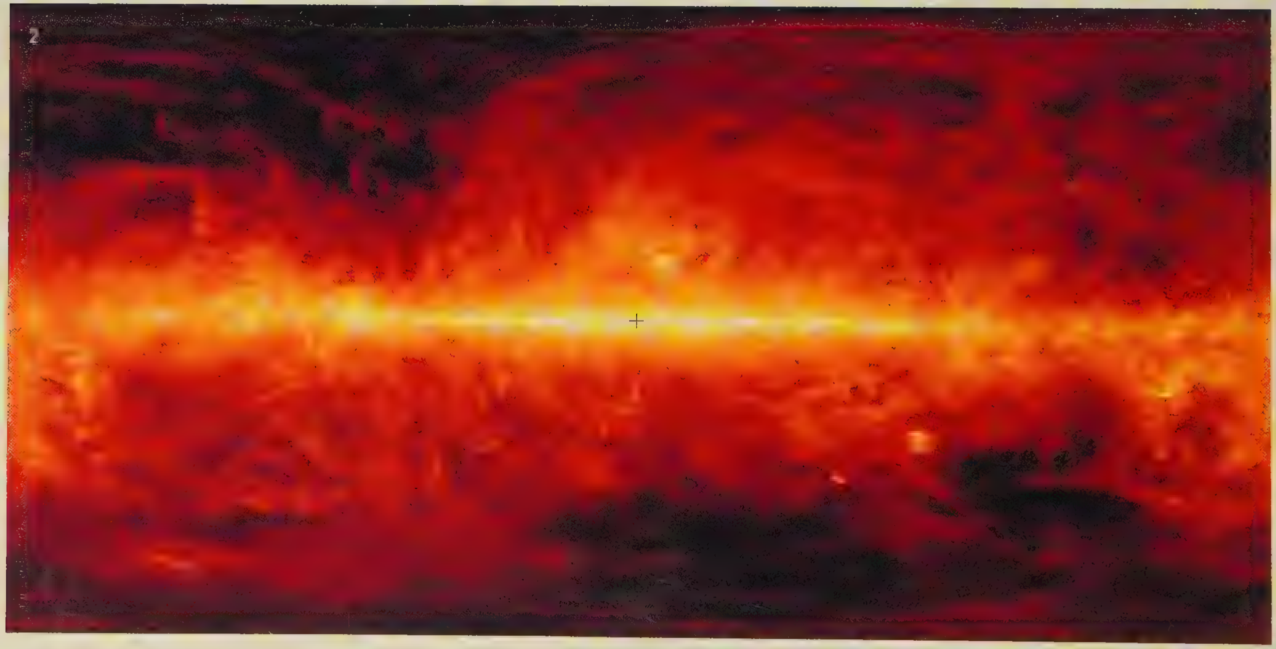
Stars form from clouds of gas and dust called nebula. The brightest of these, as seen from Earth, is the Orion Nebula which lies around 1,500 light years away.

Large and Small Magellanic Clouds

Small galaxies which are orbiting our own Milky Way. They are visible to the naked eye from the southern hemisphere.

The invisible galaxy

What we can see with our eyes is only part of the picture. Our first glimpses beyond the visible were with radio telescopes. These showed some of the same familiar features such as the band of the Milky Way but also strange new objects. With space telescopes we can now see across almost the entire electromagnetic spectrum.



1 / Gamma-ray

The Fermi Gamma-ray Space Telescope allows us to study subatomic particles at energies much greater than in ground-based particle accelerators. It lets us see the effects of black holes and other highly energetic events in the Universe.

2 / Infrared

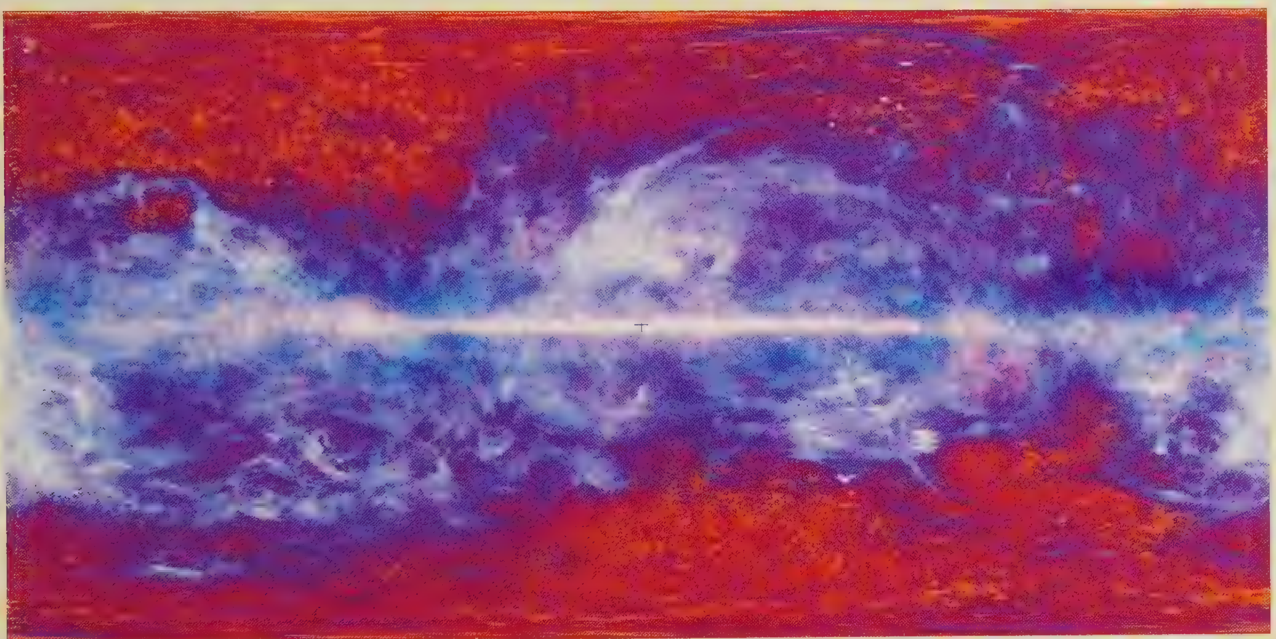
The infrared Astronomical Satellite (IRAS) was a joint satellite of the US, UK and the Netherlands. Infrared light is particularly useful in detecting wisps of warm dust called galactic cirrus.

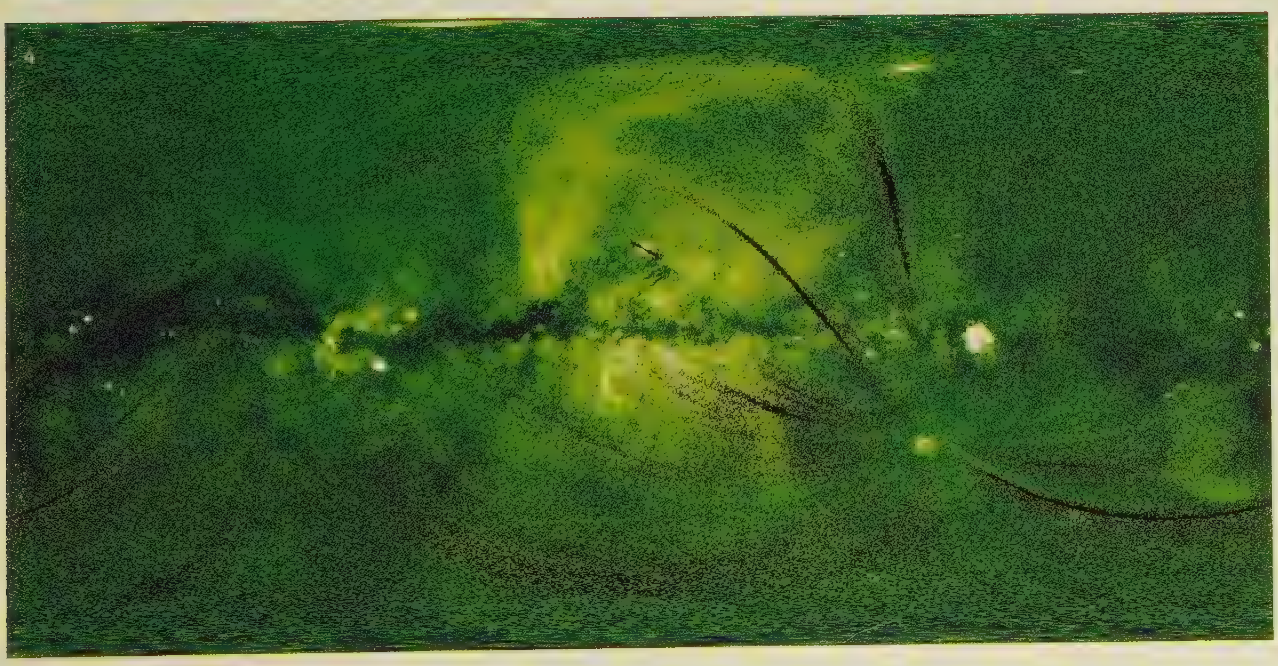
3 / Microwave

The Planck satellite was a European Space Agency mission launched in 2009. It shows gas and dust in our galaxy but also, high above and below the plane, sees the earliest light in the Universe that set off just 380,000 years after the big bang.

4 / X-ray

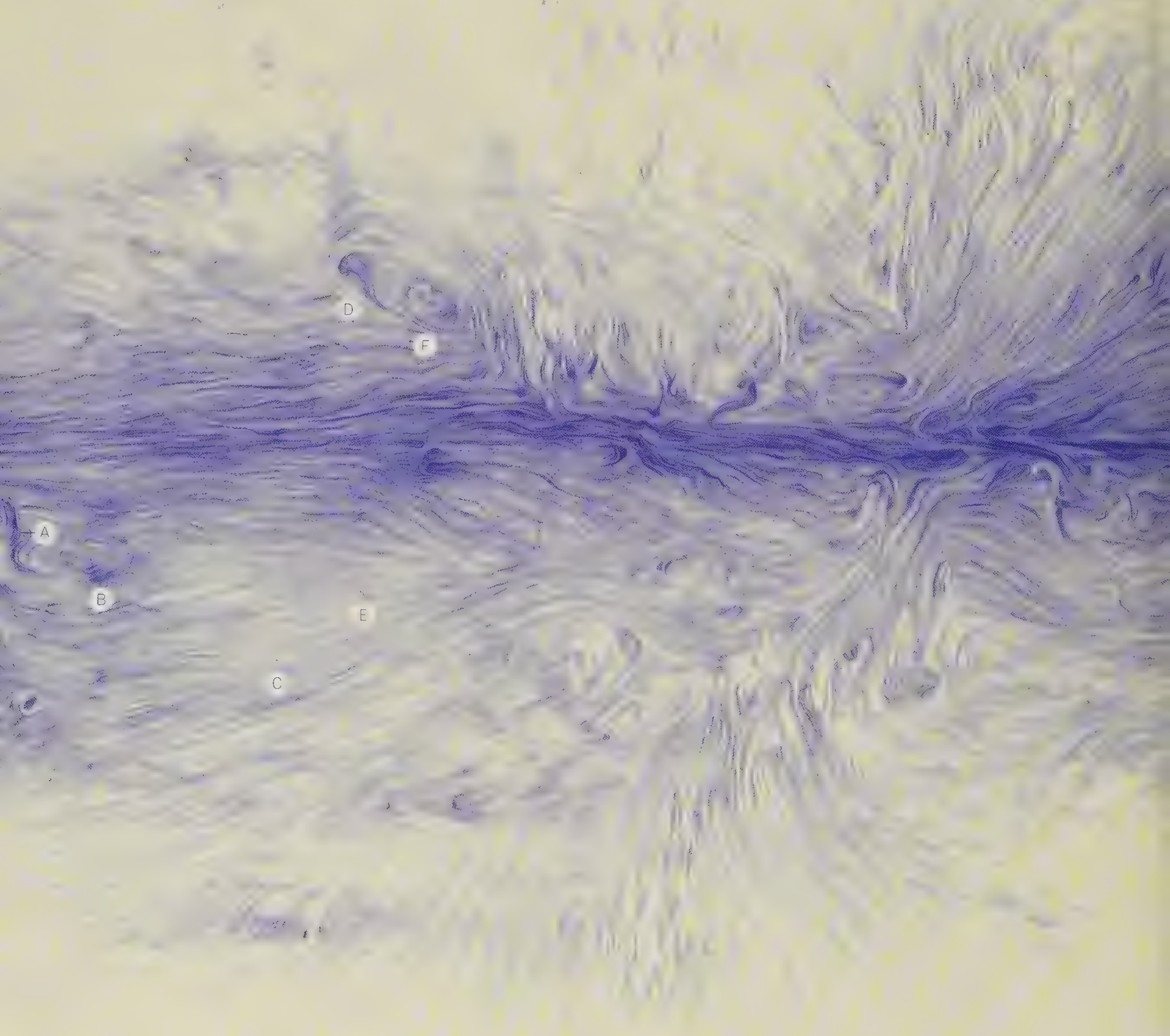
ROSAT was a joint German, US and UK X-ray satellite. X-rays are produced by matter heated to millions of degrees. They can come from cosmic explosions and high-speed matter. The black stripes are not real features; they are patches missed due to problems on the satellite.





Polarisation of the Galaxy

The Milky Way has a magnetic field generated by the motion of charged particles. While we can't see this magnetic field directly, we can see its side-effects, such as the alignment of tiny grains of cosmic dust. ESA's Planck satellite showed this pattern of alignment over the entire sky, revealing intricate structures both within the Milky Way and in nearby galaxies. The patterns highlight some of the nearby regions where stars and dust are forming, creating distortions and turbulence in the field.

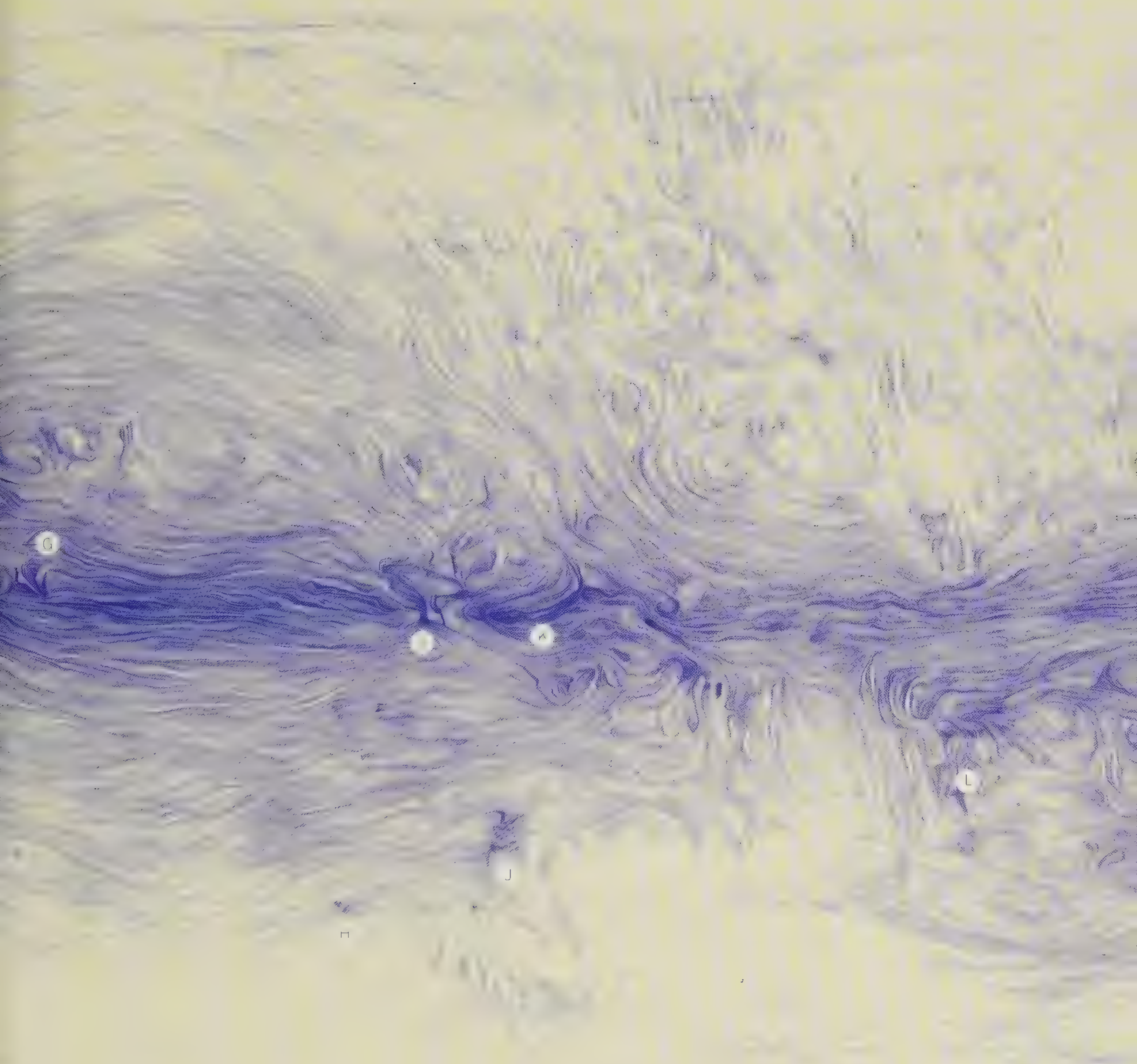


A / Taurus molecular cloud
B / Perseus molecular cloud
C / Triangulum Galaxy

D / Polaris flare
E / Andromeda Galaxy
F / Cepheus flare

G / Rho Ophiuchi
H / Small Magellanic Cloud
I / Carina Nebula

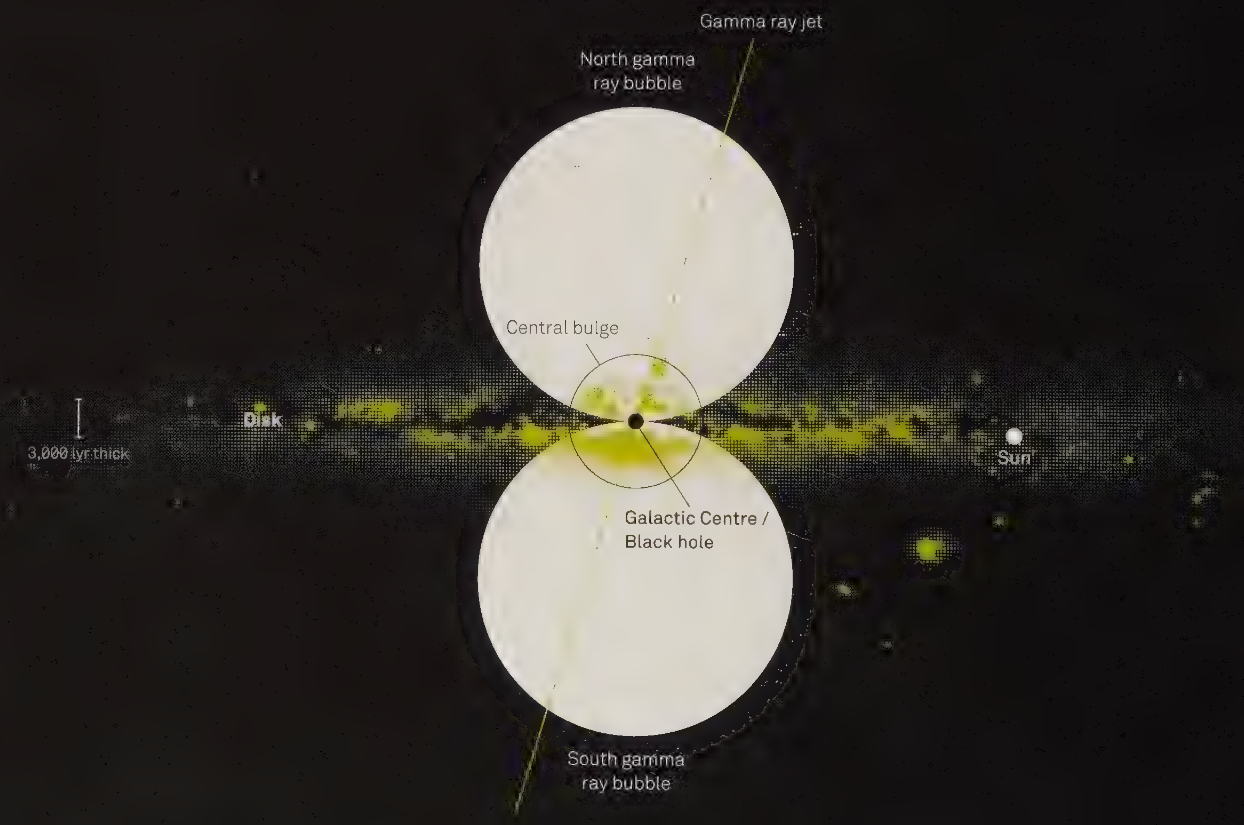
J / Large Magellanic Cloud
K / Vela molecular ridge
L / Orion molecular cloud


G
K
L
J

Structure of the Milky Way

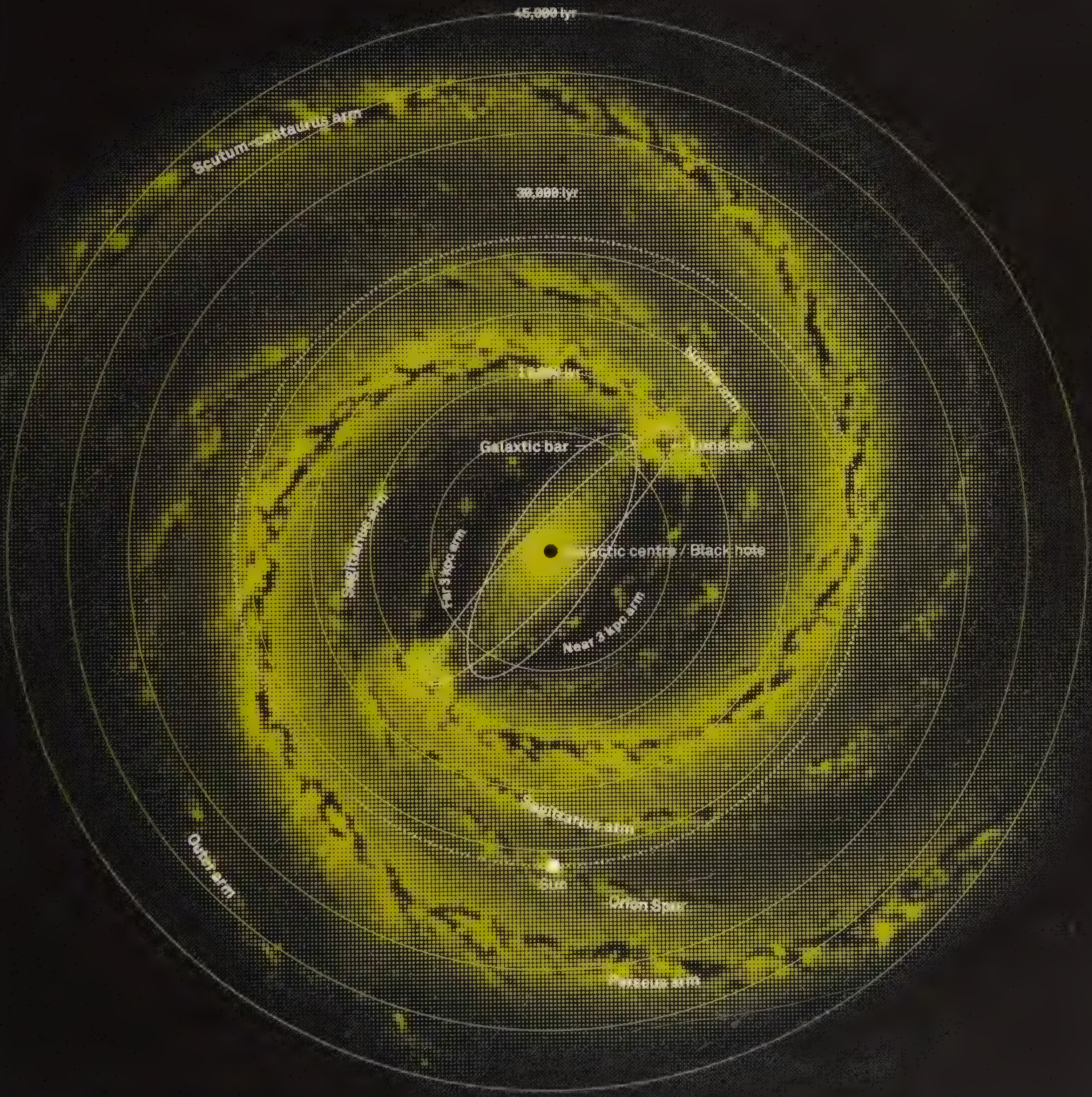
Most of the stars we see are within a few thousand light years of the Sun, and so relatively local on the scale of the Galaxy. Early observations showed that our galaxy is a disc shape, around 100,000 light years wide and just a few thousand light years thick. Observations in the 1980s showed that some older stars are in a thicker disk around 30,000 light years thick. Around the disk is a roughly spherical 'halo' of stars. These stars are amongst the oldest in the galaxy, and the halo contains a number of ancient globular clusters.

By mapping the galaxy at radio and infrared wavelengths, it is possible to see through much of the obscuring dust and build a map of the 3D structure. We now know that there are two main spiral arms that extend from the ends of a 30,000-light-year-long bar in the centre. These spiral arms aren't fixed structures, but show where there is a higher density of stars. They move independently of the stars, much as a traffic jam moves backwards along a motorway while the cars move forwards.



In 2010, NASA's Fermi satellite found evidence that there are bubbles of hot gas blowing from the centre of the Milky Way. These may be from the explosions of massive stars, or possibly linked to the central supermassive black hole in the Galactic Centre.

100,000 light years across



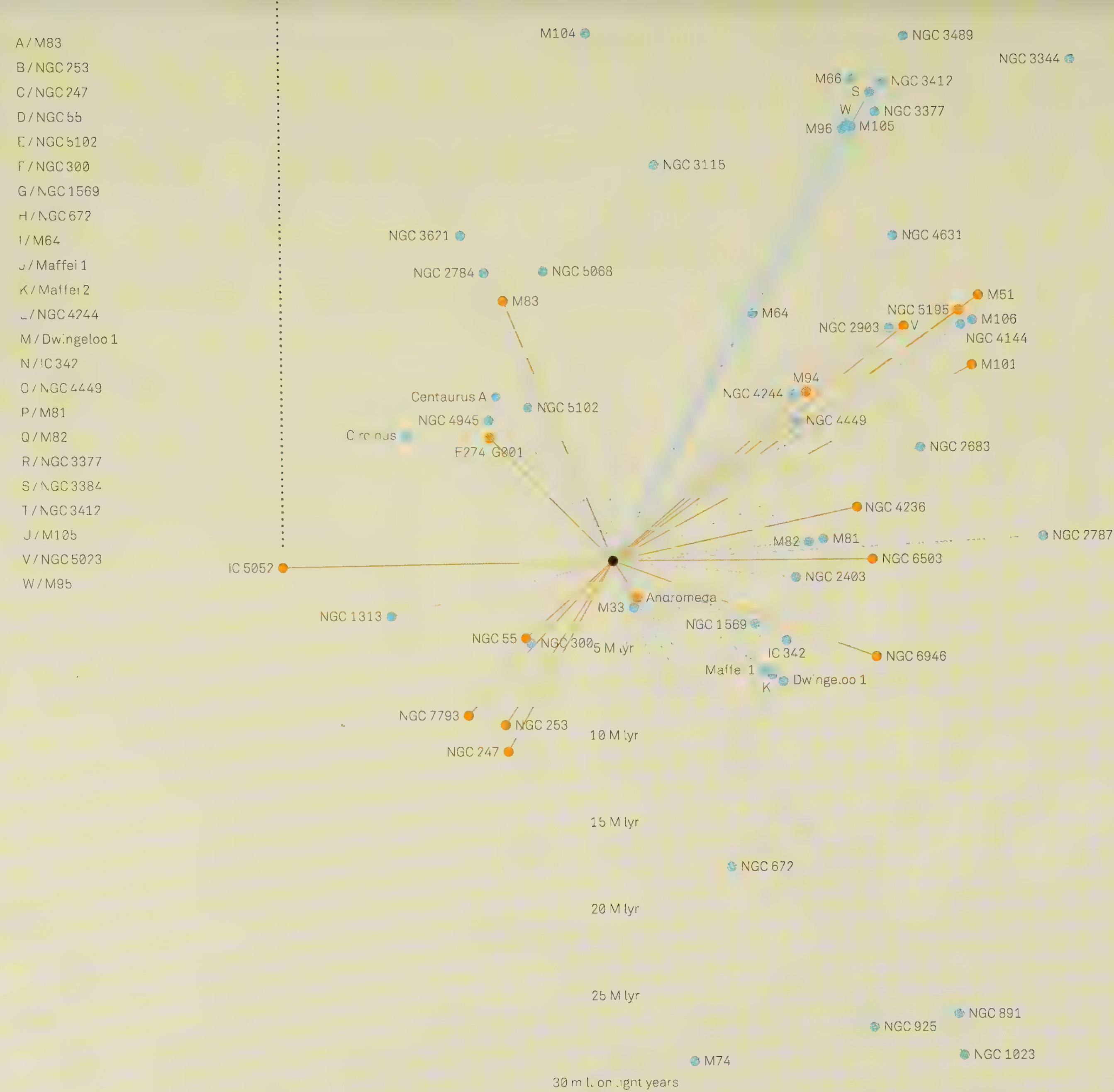
The Sun is located around 28,000 light years from the centre in the 'Orion Spur', sat between the two major spiral arms, and just below the centre of the disk.

The local sheet of galaxies

The Milky Way is just one of many galaxies. The closest galaxies to us are the dwarf irregular galaxies of the Large & Small Magellanic Clouds and the Sagittarius Dwarf Galaxy. The nearest large galaxy is the Andromeda Galaxy which is about 2.5 million light years away.

The Local Group consists of the Milky Way, Andromeda, and around 50 dwarf galaxies within about five million light years. Beyond the Local Group, within about 25 million light years, there are another 40 – 50 large, bright galaxies. Many of these form the Local Sheet; a thin, pancake-like cluster of galaxies inclined at eight degrees to the Local Supercluster (100,000 galaxies in a region 500 million light years across).

In the direction of Leo there is a small group of galaxies known as the *M96 Group*. This is physically separate from the Local Group but is part of the same Local Supercluster.



A / M83
B / NGC 253
C / NGC 247
D / NGC 55
E / NGC 5102
F / NGC 300
G / NGC 1569
H / NGC 672
I / M64
J / Maffei 1
K / Maffei 2
L / NGC 4244
M / Dwingeloo 1
N / IC 342
O / NGC 4449
P / M81
Q / M82
R / NGC 3377
S / NGC 3384
T / NGC 3412
U / M105
V / NGC 5023
W / M95
M104
NGC 3489
NGC 3344
M66
NGC 3412
S
W
NGC 3377
M96
M105
NGC 3115
NGC 3621
NGC 4631
NGC 2784
NGC 5068
M83
M51
M64
NGC 5195
M106
NGC 2903
V
NGC 4144
M101
M94
NGC 4244
Centaurus A
NGC 5102
NGC 4945
NGC 4449
Circinus
F274 G001
NGC 2683
NGC 4236
M82
M81
NGC 2787
IC 5052
NGC 6503
NGC 2403
Andromeda
M33
NGC 1313
NGC 1569
NGC 55
NGC 300
5 M lyr
IC 342
NGC 6946
Maffei 1
K
Dwingeloo 1
NGC 7793
NGC 253
NGC 247
10 M lyr
15 M lyr
NGC 672
20 M lyr
25 M lyr
NGC 891
NGC 925
NGC 1023
M74
30 million light years

The 30,000 nearest galaxies

When we look out into the Universe we see that galaxies are not evenly spread. When they formed, from the primordial soup of gas, the force of gravity started to pull them together. They can be found inhabiting huge clusters and are strung out in long streams across the sky. Our own galaxy is being pulled toward a nearby cluster, which is itself being slowly drawn towards a much more distant supercluster dubbed *The Great Attractor.*

Galaxy type
- Spiral
- Elliptical
- Other

Distance
near – far

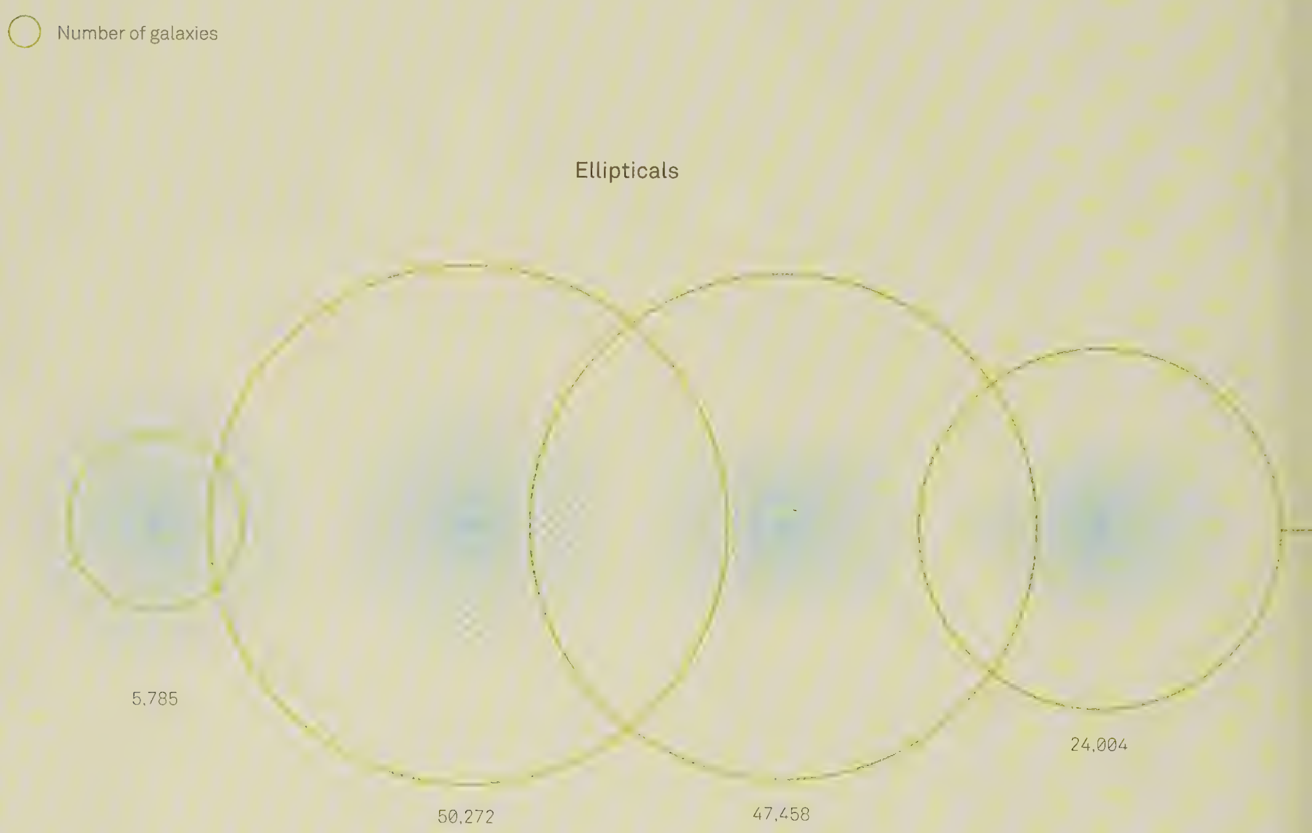
A / Perseus-Pisces Supercluster
B / Shapley Supercluster
C / Virgo Supercluster
D / The Great Attractor
E / Coma Supercluster

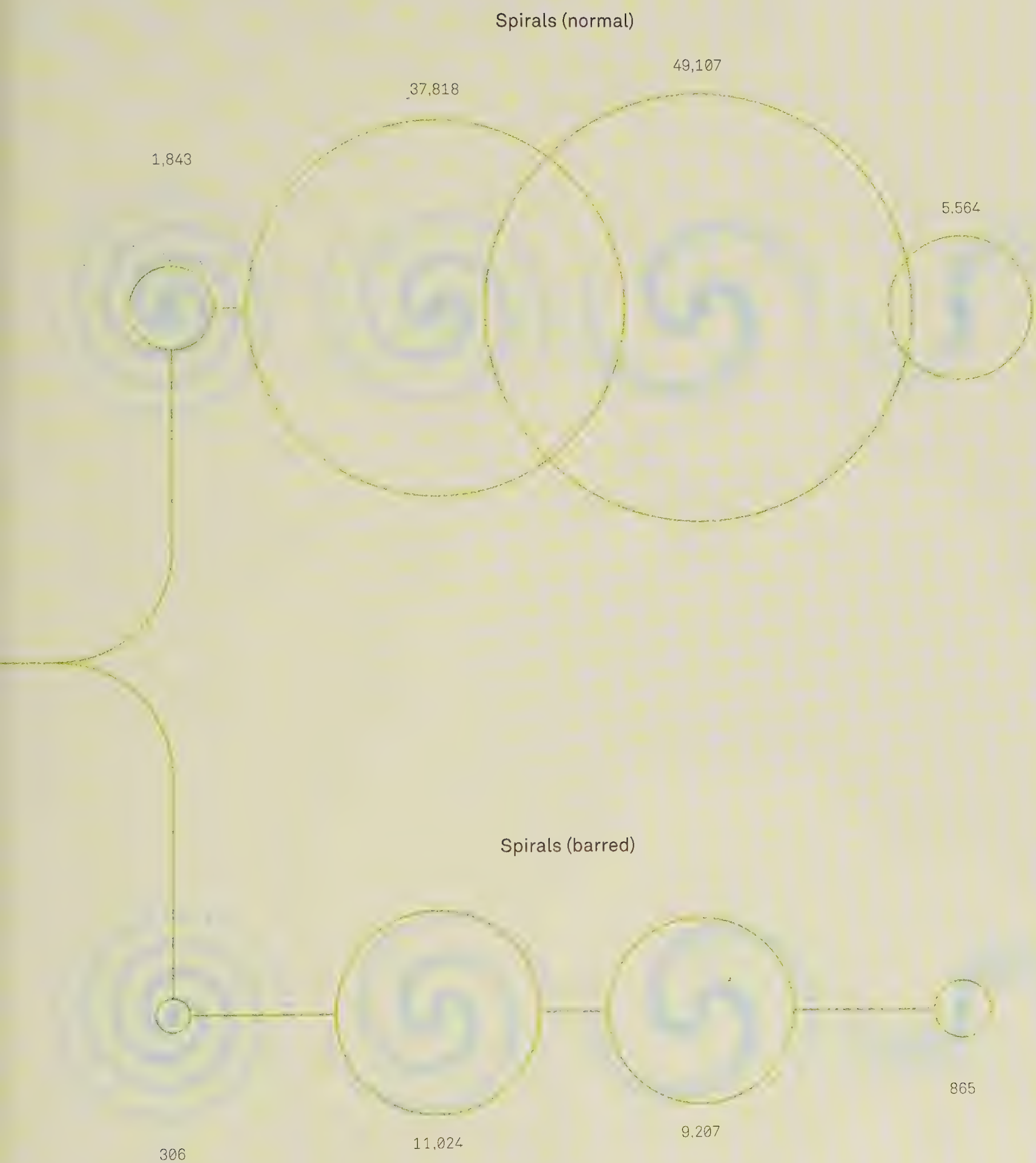
The galactic zoo

In 1926 astronomer Edwin Hubble proposed a method to classify the shapes of galaxies. This has become known as the Hubble Sequence or, more commonly, the Hubble Tuning Fork. It has ball-shaped galaxies on one end and spiral galaxies on the other. The fork-shape arises due to splitting spiral galaxies into groups with or without bars in their centres.

Classifying galaxies based on what they look like takes time and is a surprisingly difficult task for computers.

In 2007, with hundreds of thousands of galaxies found in the Sloan Digital Sky Survey, astronomers had to find a new way to process the data. They launched a website named galaxyzoo.org that asked members of the public to classify galaxies. The site turned out to be incredibly successful and, by 2010, nearly 84,000 members of the public had provided over 16 million detailed classifications of over 300,000 galaxies. Between them they compiled the largest and most reliable database of galaxy shapes yet.

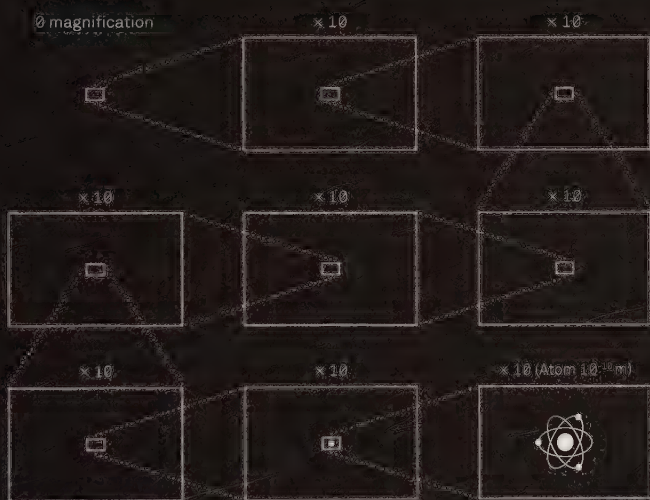



Spirals (normal)
1,843
37,818
49,107
5.564
Spirals (barred)
306
11,024
9.207
865

Seven / Cosmology

Empty space

Space is empty. Really empty. The average density is one hydrogen atom per cubic metre.


0 magnification
× 10
× 10
× 10
× 10
× 10
× 10
× 10
× 10 (Atom 10^{-10} m)

Models of the Universe

The Universe is everything there is. Our understanding of what that means, and our place in it, has changed considerably over the past few thousand years.

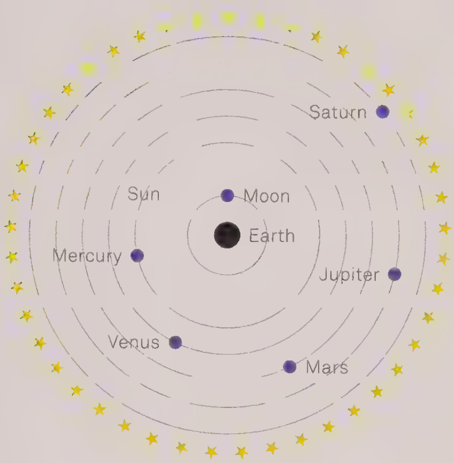
Many, but not all, early ideas put the Earth at the centre. Around the Earth were the planets on rotating spheres and beyond those the 'fixed' stars. Some argued the stars were distant versions of our own Sun with their own planetary systems.

The Platonic universe had the Earth at the centre with the planets orbiting in rotating spheres. It was clear though that this didn't explain the observed motions of the planets and so Ptolemy added eccentric circles and epicycles: the planets orbited points which, in turn, orbited a point offset from the Earth.

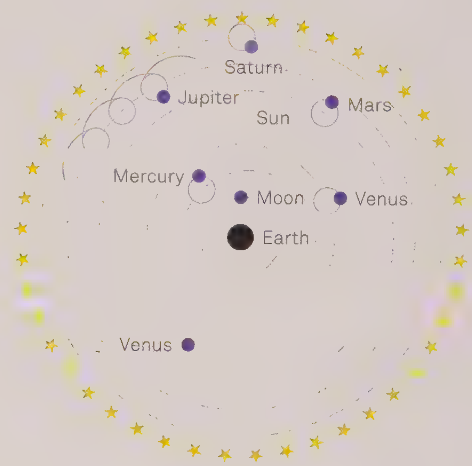
In medieval times, models of the Universe were still influenced by Plato but included current religious teachings and even novel shapes such as Hildegaard of Bingen's cosmic egg.

By the 16th Century mathematics and observation started to play a larger role. Copernicus found that

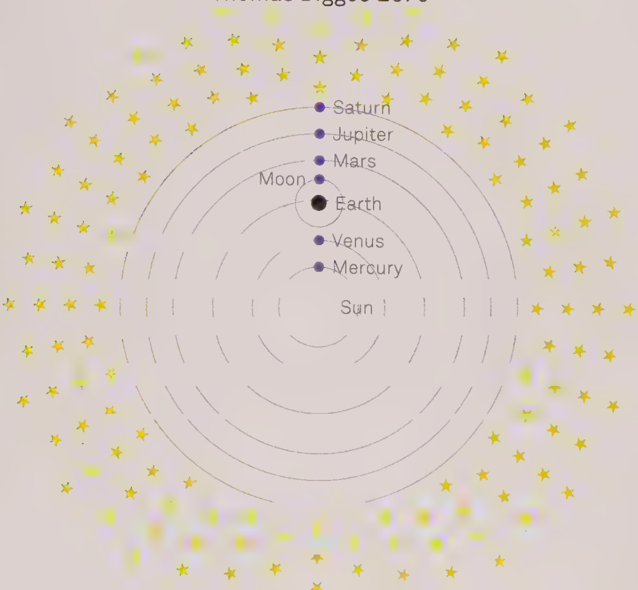
Plato 427-347 BCE



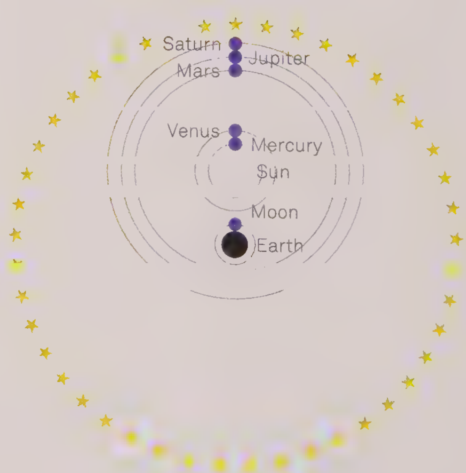
Ptolemy 2nd Century BCE



Thomas Digges 1576



Tycho Brahe 1583



calculations were easier if the Sun was placed at the centre with the planets on perfect, circular orbits.

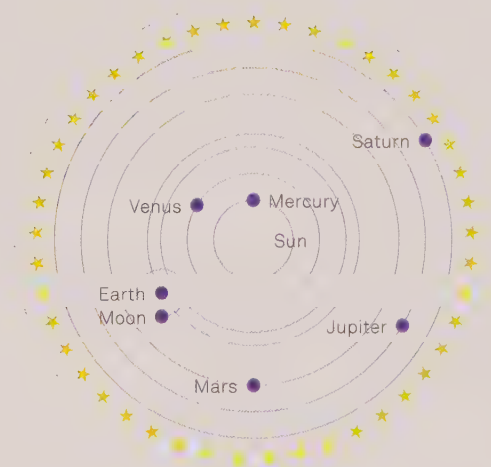
Thomas Digges modified this view by dispersing the stars evenly throughout a much larger universe. Danish astronomer Tycho Brahe used his observations to promote an Earth-centred universe but with a compromise: he had the Sun orbiting the Earth and all the other planets orbiting the Sun. Kepler brought back Copernicus's Sun-centred universe but with the planets orbiting on ellipses.

As the Enlightenment continued, observations and theory advanced. Thomas Wright and Immanuel Kant argued that the existence of the band of the Milky Way meant that stars must be distributed in some kind of disk around us. It was even suggested that our Milky Way was one of 'many islands' in the Universe.

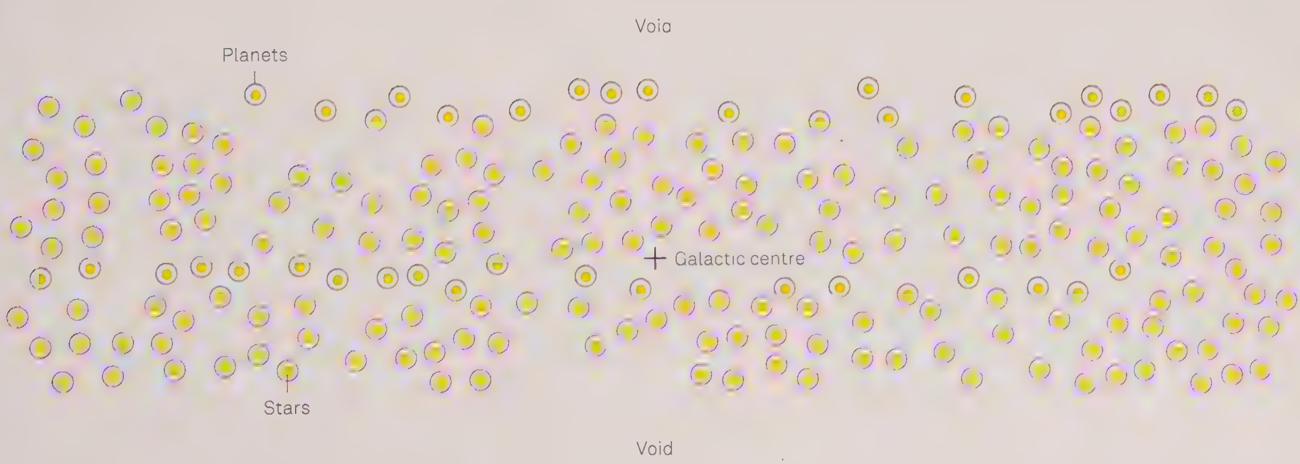
Today our observations are far superior to those of our ancestors but, as has often been the case, they hint that our current model isn't quite the whole picture.

Hildegaard of Bingen 1142

Nicolaus Copernicus 1543

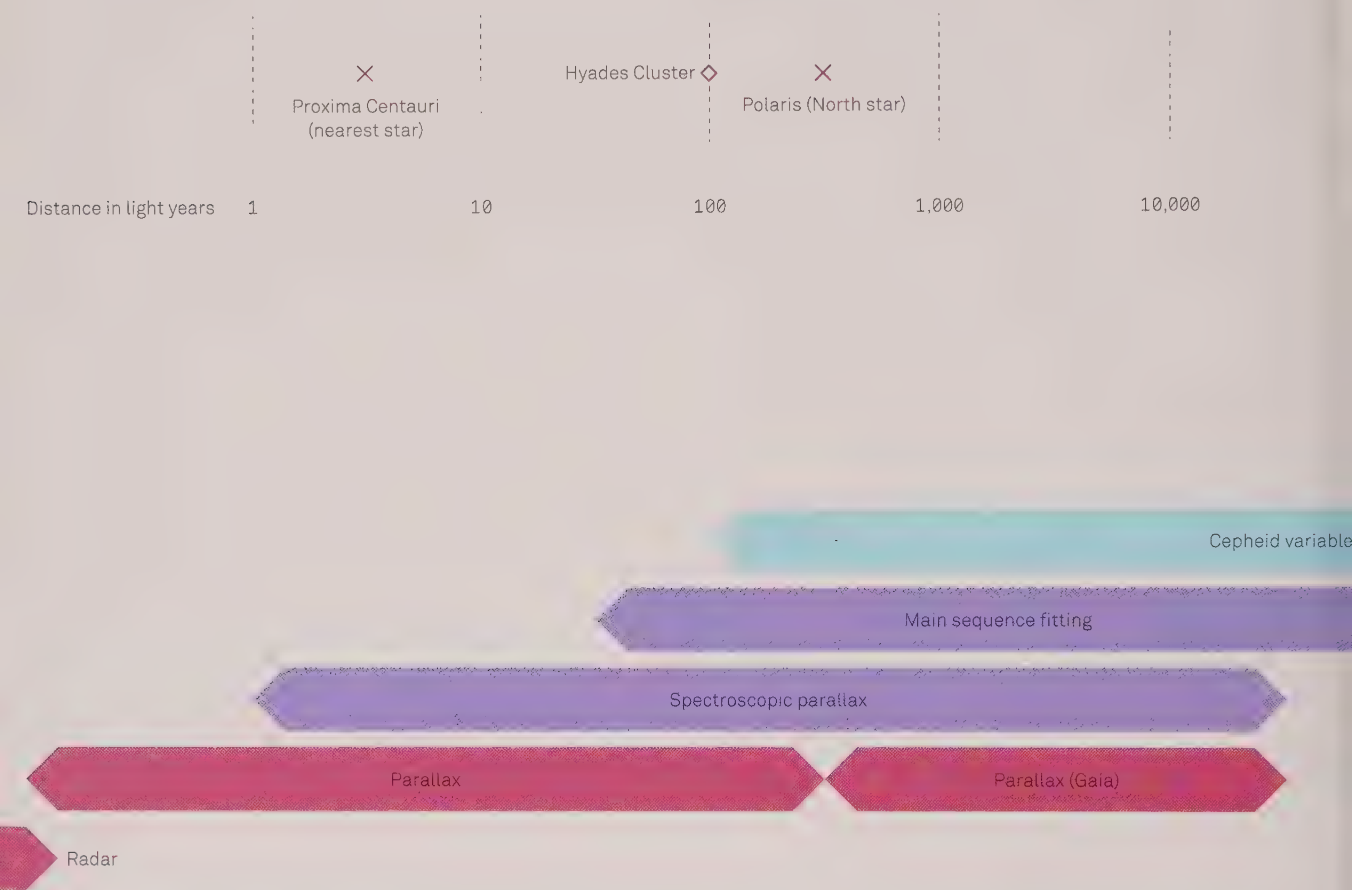


Thomas Wright 1750



The cosmological distance ladder

Measuring distances in the Universe isn't easy when you are confined to planet Earth. We can measure the distances to nearby objects using simple geometry but as we look out further into the Universe we have to use different methods. Many methods rely on finding a 'standard candle' – something for which we know the intrinsic brightness – and then finding its distance from its apparent brightness. Each method works over different ranges of distance so if we find enough overlapping methods we can connect them together to create what is called the cosmological distance ladder. ESA's Gaia satellite is currently measuring parallaxes out to much greater distances.



Radar

For nearby objects within our Solar System we can use radar to directly measure the distance. Radar measurements of the planet Venus helped define the scale of the Earth's orbit.

Parallax

If you hold up a finger in front of you and look at it with one eye at a time you see that it appears to move compared to distant objects. We can use exactly the same technique by measuring a star's position from different sides of the Earth's orbit. A bigger change in position means the star is closer.

Spectroscopic parallax

If a star is bright enough it is possible to measure its spectrum of light. Identifying dark absorption lines in this spectrum lets you work out what the intrinsic brightness of the star should be and from that work out the distance.

Main sequence fitting

We measure the apparent brightness and colour of all stars in a cluster which we assume formed at the same time and the same distance from Earth. Plotting these values on an H-R diagram we can see a group called the 'main sequence'. By calculating how much fainter or brighter this 'main sequence' is than that of another cluster, we can find the relative distances.

Cepheid variables

These variable stars brighten and fade as they expand and contract. The time it takes to pulse is directly linked to the star's true brightness. Measuring the period the true brightness can be found and comparing this to the apparent brightness gives us the distance.

Tully-Fisher

In 1977, astronomers Brent Tully and J.R. Fisher noticed that the rotation velocity of spiral galaxies was related to their intrinsic brightness. By measuring the velocity through the Doppler Effect, it is then possible to determine the distance.

Supernovae

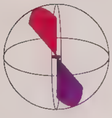
A Type Ia supernova occurs when a white dwarf reaches a critical mass (1.44 solar masses) and explodes. As the explosion occurs at a set mass, the true brightness of the explosion will always be the same. By measuring the apparent brightness and knowing the true brightness, the distance of the supernovae can be found.

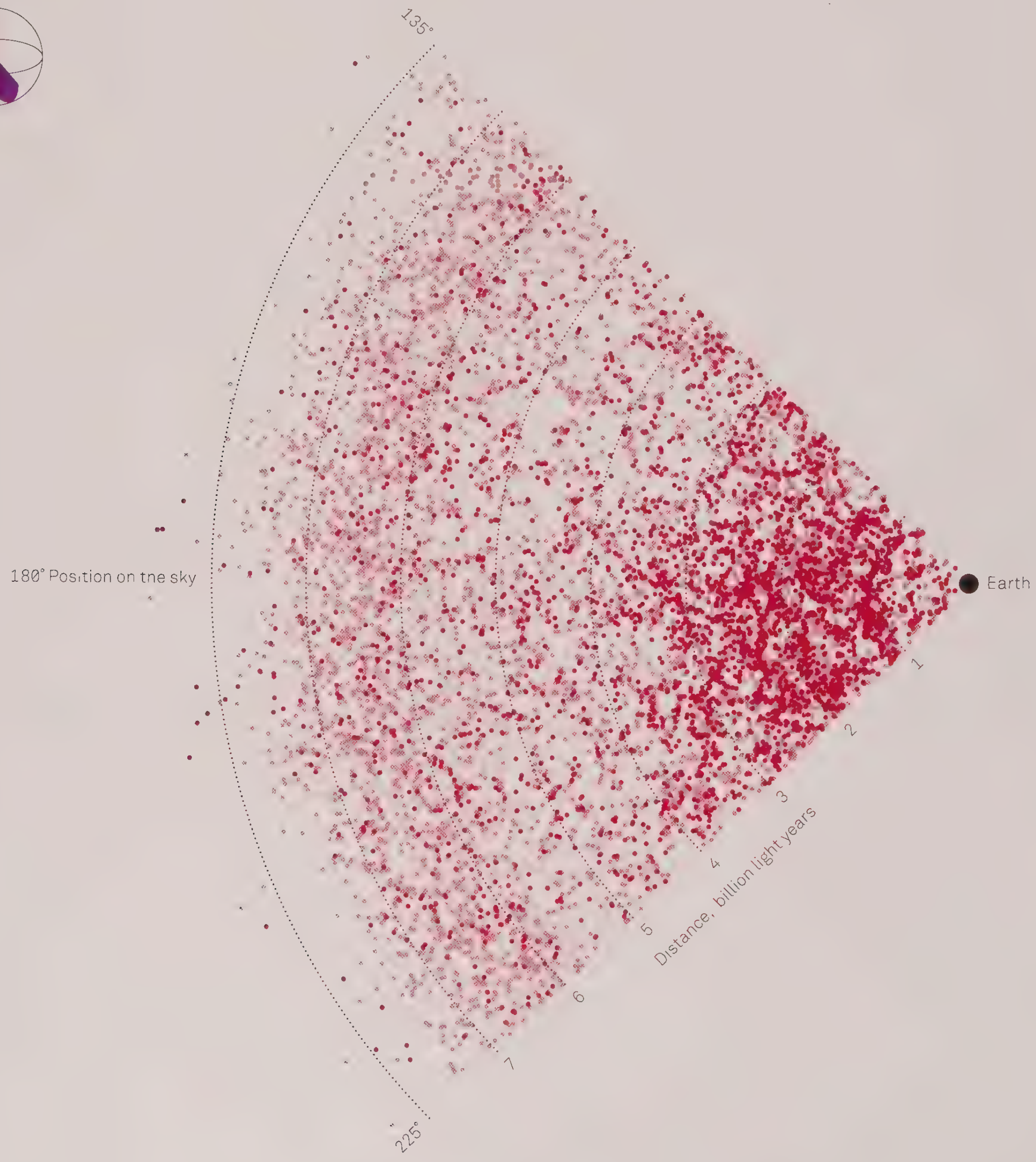
Redshift

The Universe is expanding and that means the light from distant galaxies is stretched (redshifted) as it travels towards us. How much the light is stretched depends on how far away the galaxy is from us and this can be found by measuring its spectrum.

Measuring distances to galaxies takes a lot of time, particularly when those galaxies are incredibly faint and distant. The Sloan Digital Sky Survey uses a dedicated telescope to do just that, and measures the distances to millions of galaxies, reaching out billions of light years. By looking at a narrow slice through space, away from contamination from our own Milky Way, the cosmic web of galaxy clusters becomes apparent, even when only showing the brightest galaxies.

Galaxies are seen to lie along long filaments, stretching billions of light years. Between the filaments are huge voids, with very few galaxies. This pattern continues out to huge distances, though the galaxies get harder to see.





Earth
1
2
3
4
5
6
7
Distance, billion light years
45°
0° Position on the sky
315°

What is the Universe made of?

When we look at the night sky we primarily see stars, but in fact they're only a tiny fraction of the Universe. In terms of mass they're outnumbered 10:1 by interstellar gas, dust and subatomic particles, which are largely invisible to the optical telescopes.

Even with all this, normal matter is outweighed 5:1 by 'dark matter'. This elusive component of the Universe doesn't emit, absorb or scatter light, but does have a gravitational pull.

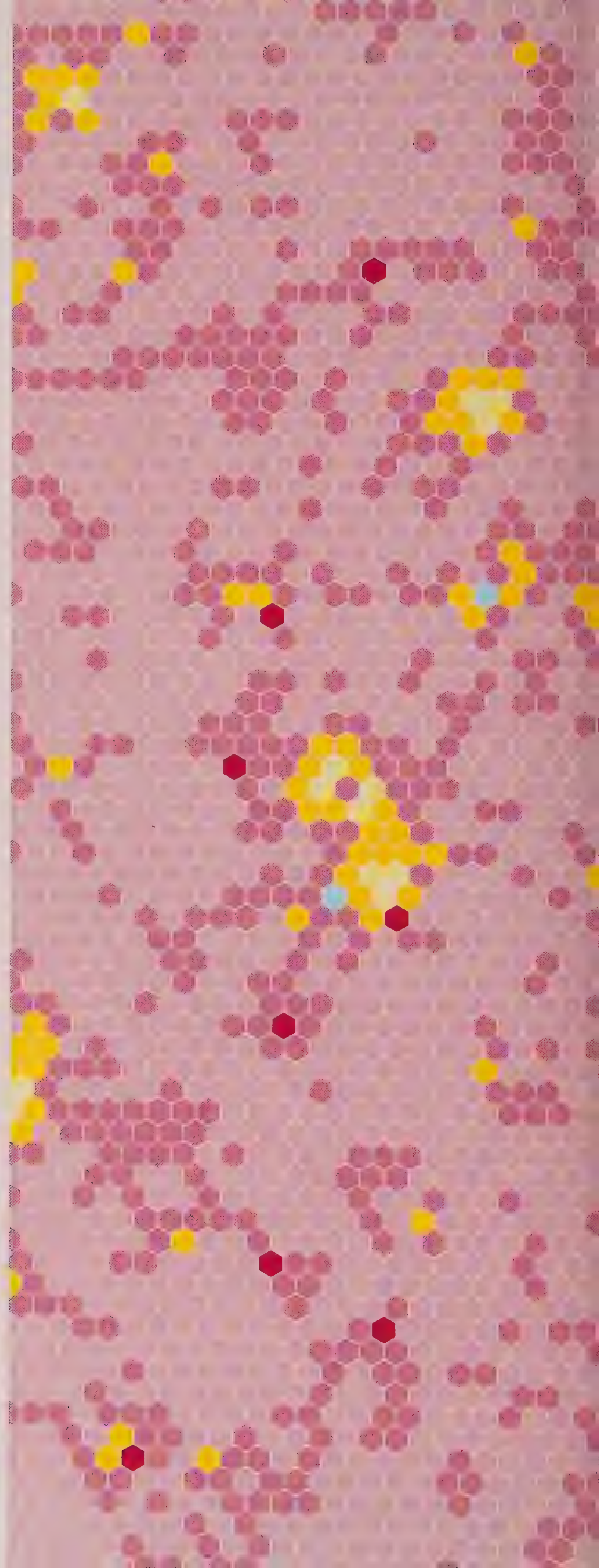
That still accounts for only about one third of the Universe. The majority of the energy in the Universe is due to the truly mysterious 'dark energy', which acts to push apart clusters of galaxies and accelerate the expansion of the Universe as a whole.

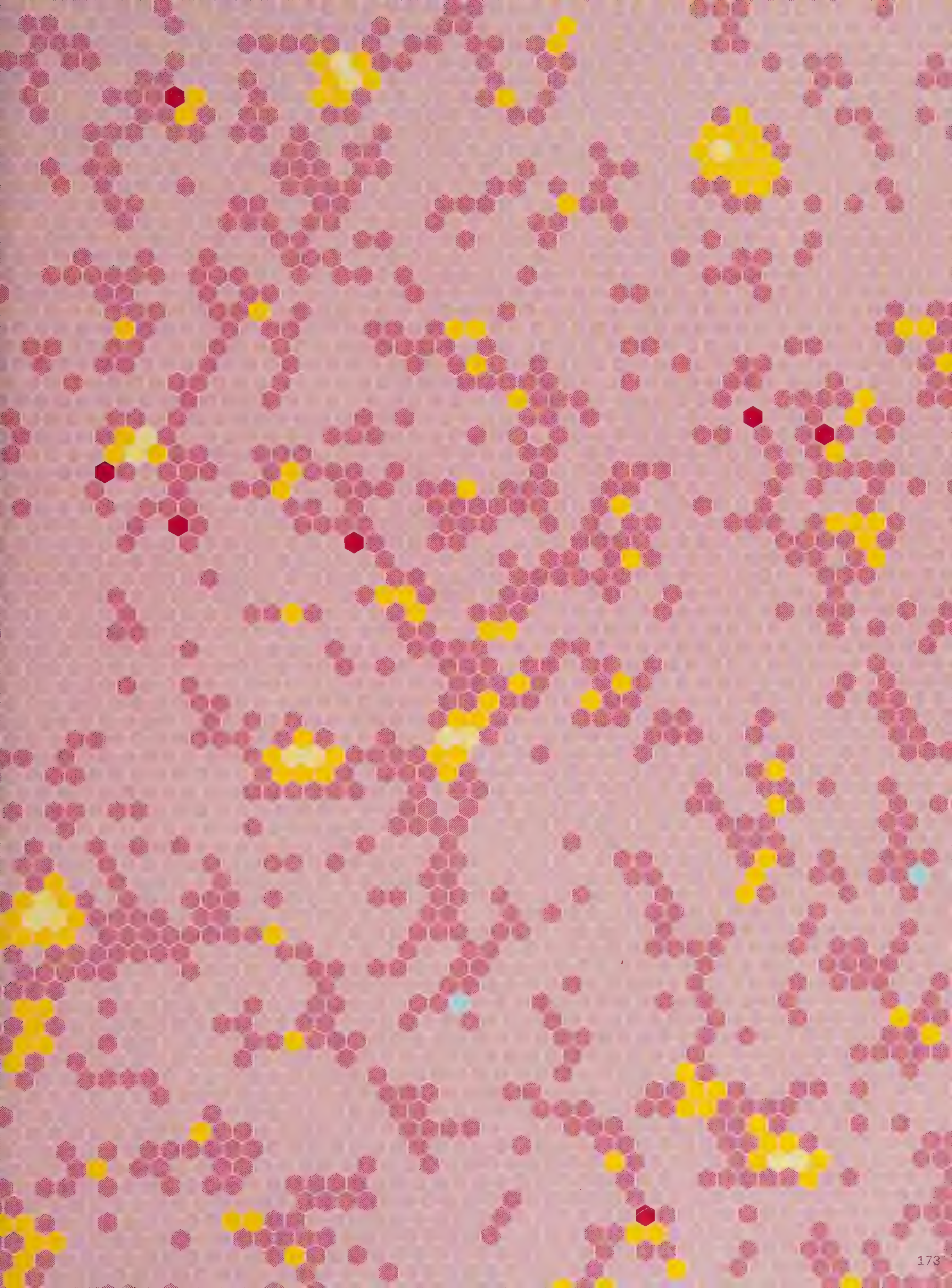
Dark energy 68.3%

Dark matter 26.8%

Normal matter 4.9%

- Stars 0.5%
- Gas 4%
- Neutrinos 0.3%
- Dust < 0.1%



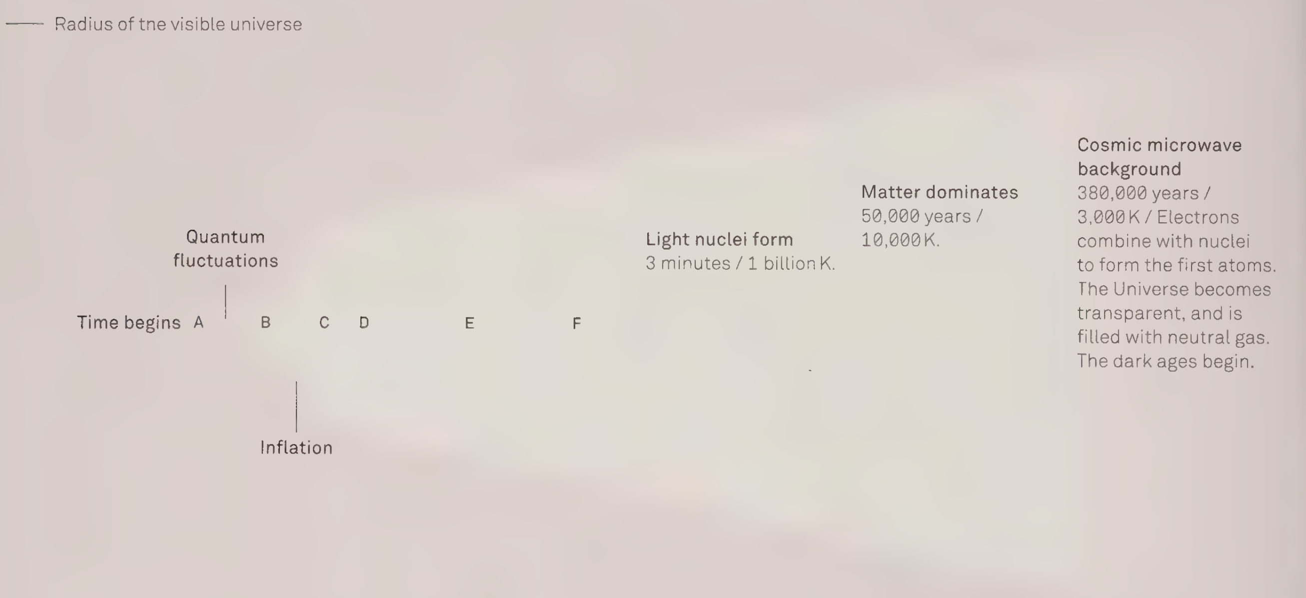


Evolution of the Universe

We can't describe the conditions right at the start of the Universe using current theories of physics, but we can get pretty close. Despite the huge temperatures involved, our current understanding allows us to understand the processes that took place within the first fraction of a second.

As the Universe expanded it cooled, and the constituents of the matter we're made of all formed within the first three minutes. It was too hot for atoms to exist until 380,000 years later, and the Universe was initially opaque to light. It is thought that the first stars formed a few hundred million years later, and that the galaxies built up over the next billion years. We think that the largest structures in the Universe – superclusters of galaxies – are due to tiny quantum fluctuations that originated in the first tiny fraction of a second after the Big Bang – the one period which we truly don't understand.

By the 1990s we thought we knew the future fate of the Universe. Then, in 1998, observations of distant supernovae showed that around 4 billion years ago something unexpected had happened. The expansion of space seems to have begun to accelerate, pushed apart by a mysterious 'dark energy'. The expansion seems to be real but nobody knows what this dark energy is.



A **Planck Epoch - unknown physics!**
10^{-43} seconds / 10^{32} Kelvin / Quantum gravity produces quantum fluctuations.

B **Start of inflation**
10^{-36} s / 10^{28} K / Quantum fluctuations blown up to macroscopic scale.

C **End of inflation**
10^{-32} s / 10^{27} K / Universe is almost completely uniform. Radiation dominates the Universe.

D **Subatomic particles form**
10^{-10} s / 10^{15} K / Formation of quarks, electrons and neutrinos at the end.

E **Protons form**
10^{-6} s / 1 trillion K / Formation of protons and neutrons.

F **Anihilation of antimatter**
1 s / 10 billion K / Most of the matter in the Universe is dark matter.

First stars
500 million years / 30 K / First stars form, reionising most of the gas in the Universe.

First galaxies
1 billion years / 15 K / First galaxies grow by merging together.

Galaxies merge
3 billion years / 7 K / Star formation is at its peak.

Milky Way forms
5 billion years / 6 K.

Dark energy dominates
10 billion years / 4 K / The expansion starts to accelerate.

Now
13.8 billion years / 2.7 K.

Powers of ten

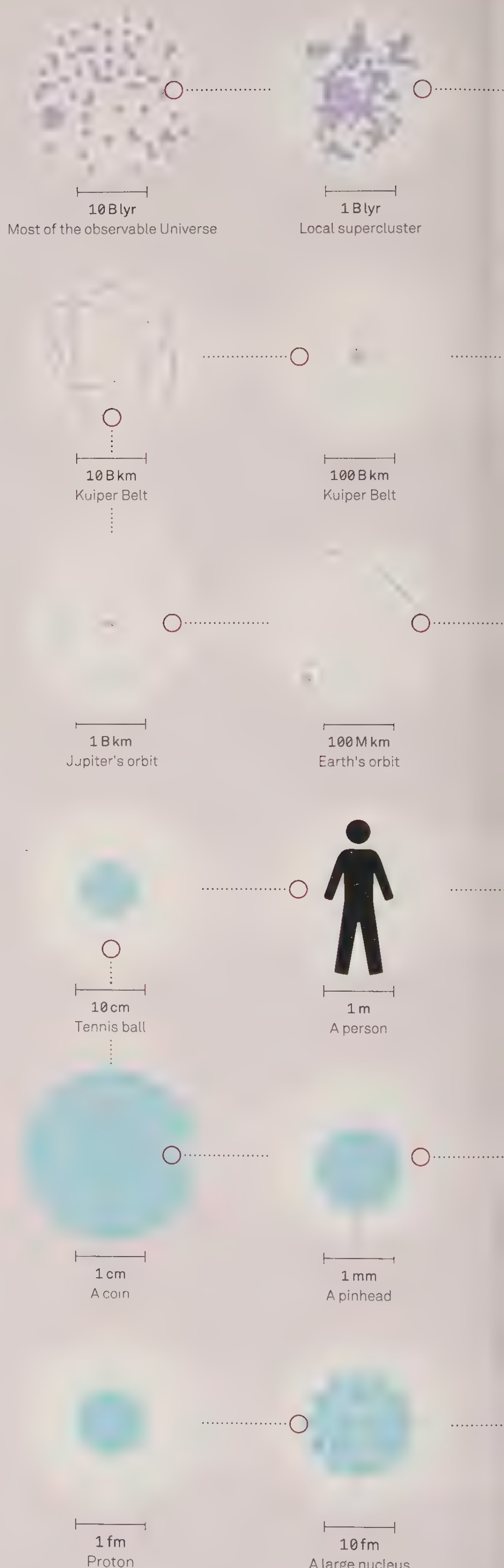
From the tiniest sub-atomic particles to the entire observable Universe, the scale of the Universe is truly vast.

As an attempt to get some understanding of the range let's start at the unbelievably tiny scale of a proton. We can zoom out by a factor of 10 and see the nucleus of an atom. Zooming out by a factor of 100,000 we get to the size of a water molecule and another factor of ten takes us to a DNA strand. Stepping up our zoom by a further 10,000 takes us to the width of a human hair and the scales we encounter every day.

Astronomy deals with enormous scales, often so vast as to be unimaginable. Even on local scales, the Moon is 380,000 kilometres away, which is a huge distance by human standards. The standard unit of length in astronomy is the light year, which is approximately 10 million million kilometres. Using these terms the scales are still huge – the Andromeda Galaxy, the Milky Way's nearest large neighbour, is over two million light years away.

The Universe seen on these large scales is just as empty as the Universe seen on the smallest scales. However you look at it, space really is empty!

B lyr / billion light years
M lyr / million light years
k lyr / thousand light years
T km / trillion kilometres
B km / billion kilometres
M km / million kilometres
km / kilometre
m / metre
cm / centimetre
mm / millimetre
μm / millionth of a metre
nm / billionth of a metre
pm / trillionth of a metre
fm / quadrillionth of a metre



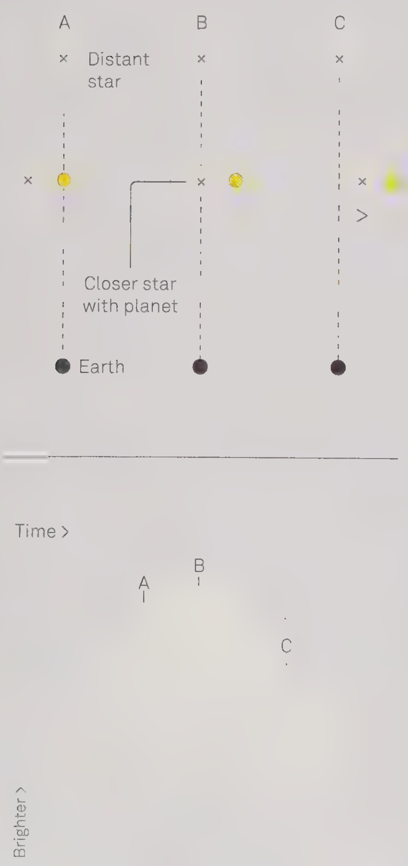

100 M lyr
Local cluster
10 M lyr
Local group
1 M lyr
Nearby galaxies
100 k lyr
The Milky Way
10 k lyr
Spiral arm
1 T km
Comet orbits
1 lyr
The Oort Cloud
10 lyr
Closest stars
100 lyr
Near by stars
1 k lyr
Stars & nebulae
10 M km
Earth & Moon orbits
1 M km
Earth & Moon
100,000 km
Geostationary Orbit
10,000 km
The Earth
1,000 km
North-west Europe
10 m
A house
100 m
A football pitch
1 km
A village
10 km
A city
100 km
Part of UK & France
100 μm
Human hair
10 μm
Red blood cell
1 μm
Large virus
100 nm
A smoke particle
10 nm
DNA strand
100 fm
A nucleus
1 pm
A nucleus
10 pm
A nucleus
100 pm
An atom
1 nm
Water molecule

Eight / Other worlds

An exoplanet is one that orbits a star other than the Sun. We've long suspected that other planetary systems existed but it wasn't until the 1990s that techniques first let us confirm them. How do you find one? There are several methods...

Blips (microlensing)

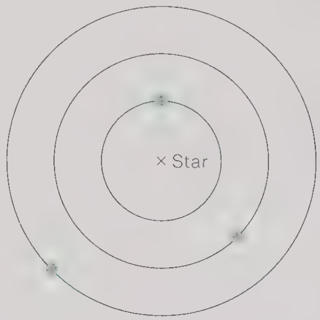
There is a small chance that, from our viewpoint on Earth, one star will happen to pass in front of another. When this happens, the gravity of the closer star bends the light from the more distant star around it and increases its brightness. If the closer star has a planet, that can also magnify the background star causing an extra blip in the brightness. This method can detect small planets but, unfortunately, the blips are one-off events that only last a few weeks so follow-up can be difficult.



A / Small bending of light due to planet
B / Small bending of light due to star

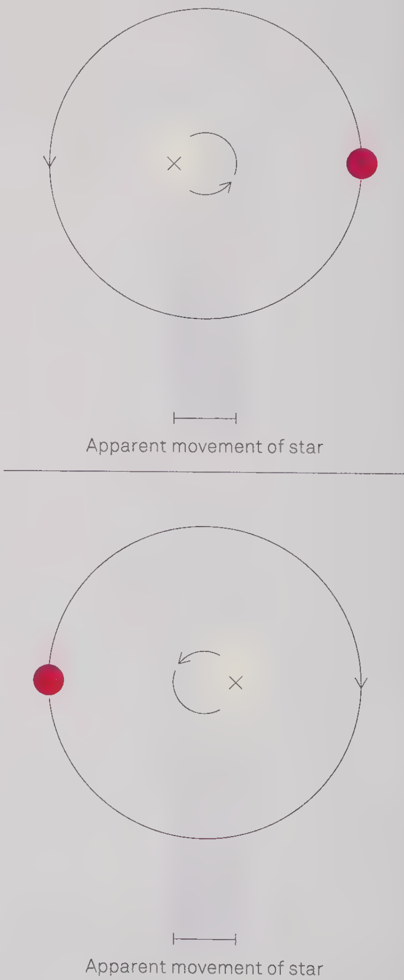
Pictures (direct imaging)

Seeing planets around stars is hard because a star is incredibly bright compared to a planet. It is like trying to see a fly next to a stadium floodlight. To give ourselves more of a chance we can change to infrared light where the planet will be brighter. For example, the Sun is about a billion times brighter than Jupiter in visible light but only 100 times brighter in infrared. To help even more we can try to block the light from the parent star. It is easier to find warmer planets further from their star with this method.



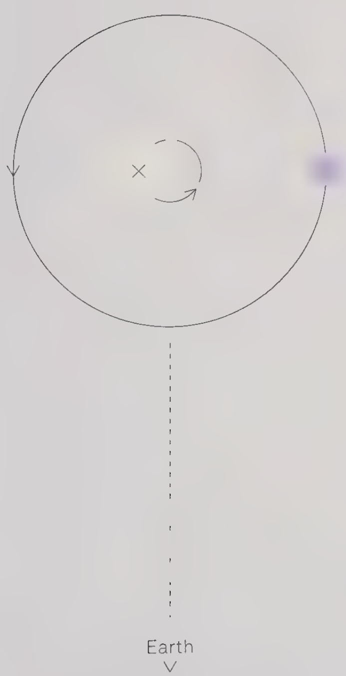
Side-to-side (astrometry)

We usually think of a planet orbiting a star but things are actually more subtle. Both the star and planet orbit their common centre of mass. If you make very accurate measurements of the position of the star over time, you can see it move around its orbit. The effect is larger when the planets are in larger orbits. This method is incredibly difficult because the movement of the star is so tiny. Nevertheless, the European Space Agency's Gaia spacecraft is expected to find many planets this way.



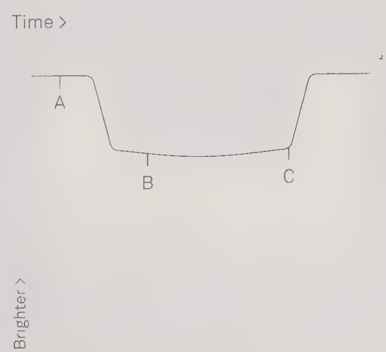
Ticks (pulsar timing)

The first confirmed exoplanets were found around a type of star known as a pulsar which emits beams of radiation much like a lighthouse. The flashes from a pulsar act as a very precise clock. Extremely accurate measurements will show changes in that clock due to the pulsar orbiting a common centre of mass. The planets found by this method were surprising as they would not have been expected to survive the explosion that created the pulsar.



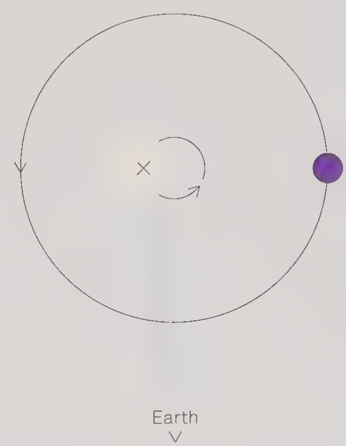
Winks (transit)

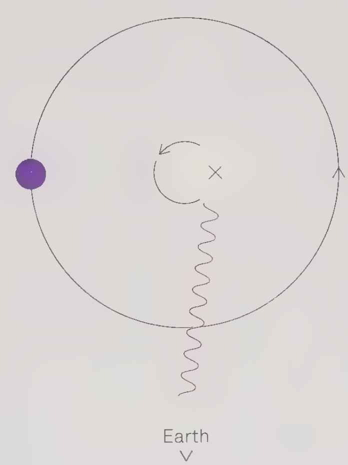
If the plane of the orbit of a planet happens to be aligned with the Earth, the planet will pass between its parent star and us. As it transits its star, it blocks out a small amount of its light. The amount of dimming depends on the size of the planet; a larger planet blocks more of the light. This dimming repeats every time the planet orbits the star so the time between each dip gives the period of the orbit.



Wobbles (radial velocity)

As the star orbits, it moves slightly towards or away from us. As it moves towards us, the Doppler Effect slightly shifts its light to bluer colours. As it moves away from us the light becomes slightly redder. By measuring the spectrum of the star this movement can be measured and any planets inferred. With this technique it is easier to spot larger planets because they cause larger wobbles. It is also easier to find planets on smaller orbits because they cause a faster wobble.

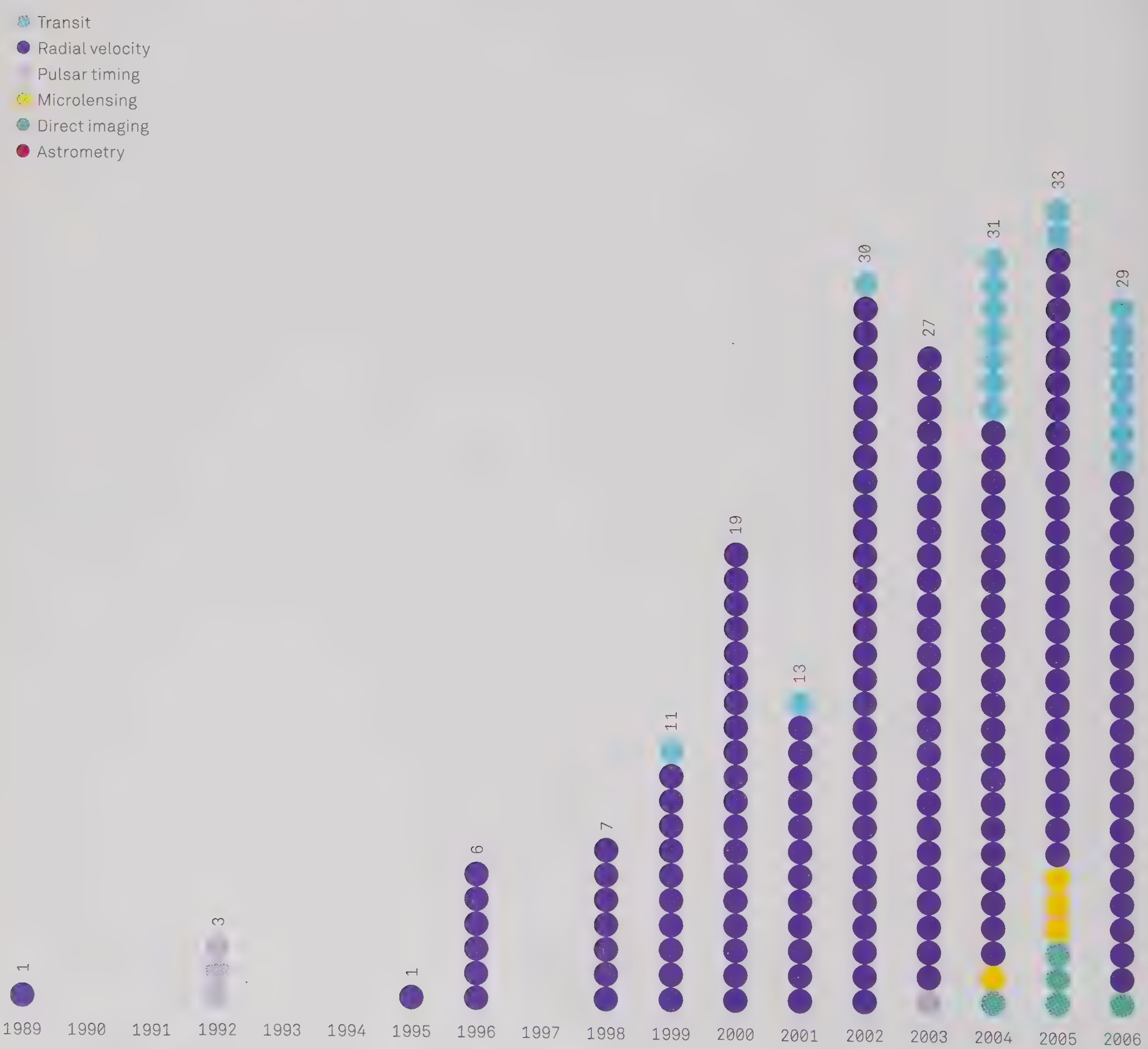


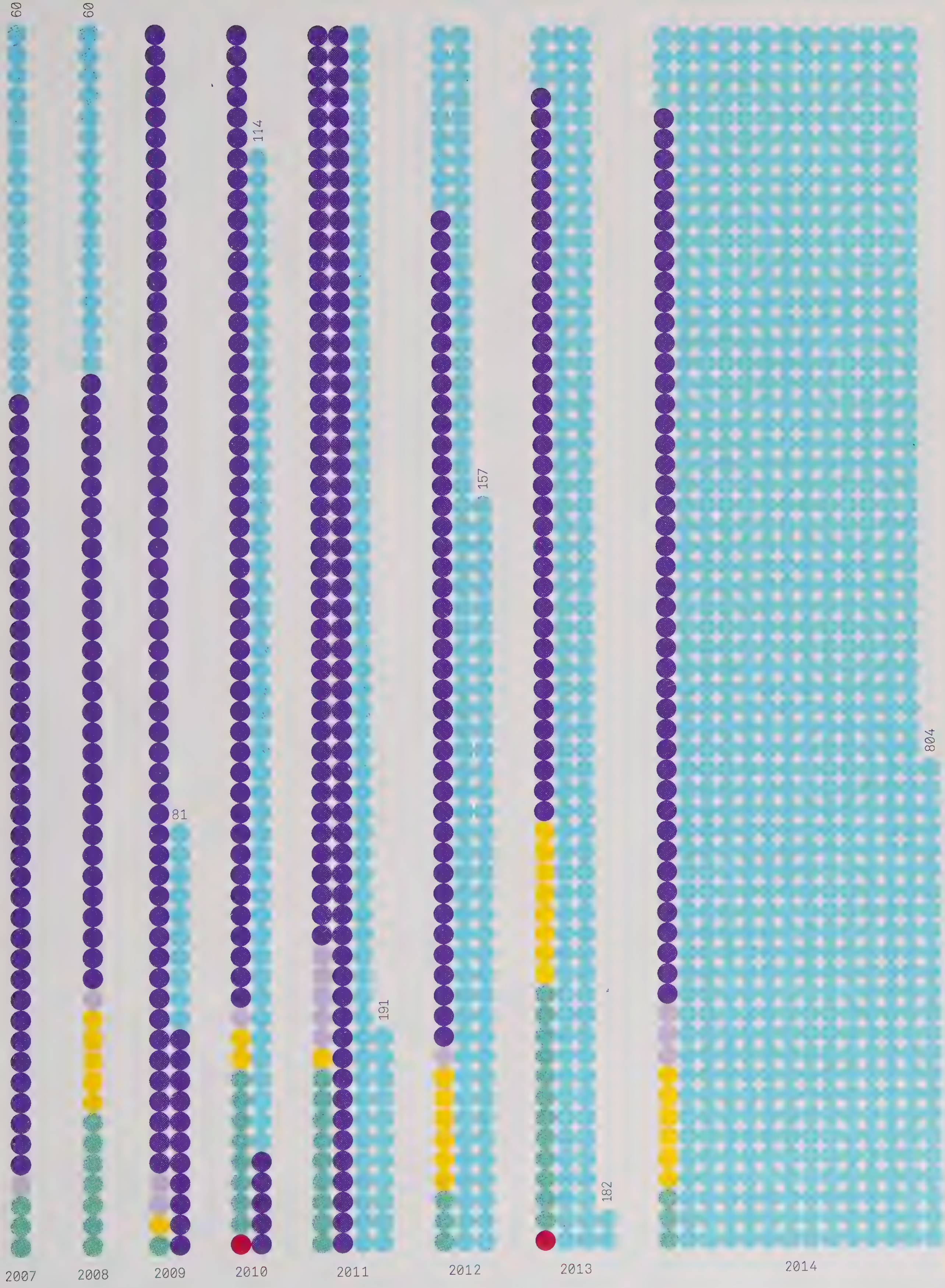


Exoplanet discoveries

The first planet around a star other than the Sun was detected in 1989. That detection was tentative and it wasn't until 1992 that three more were found around the unlikely body of a pulsating neutron star. In 1995, *51 Peg b* was found, around a Sun-like star, and it opened the door for many more in the years that followed.

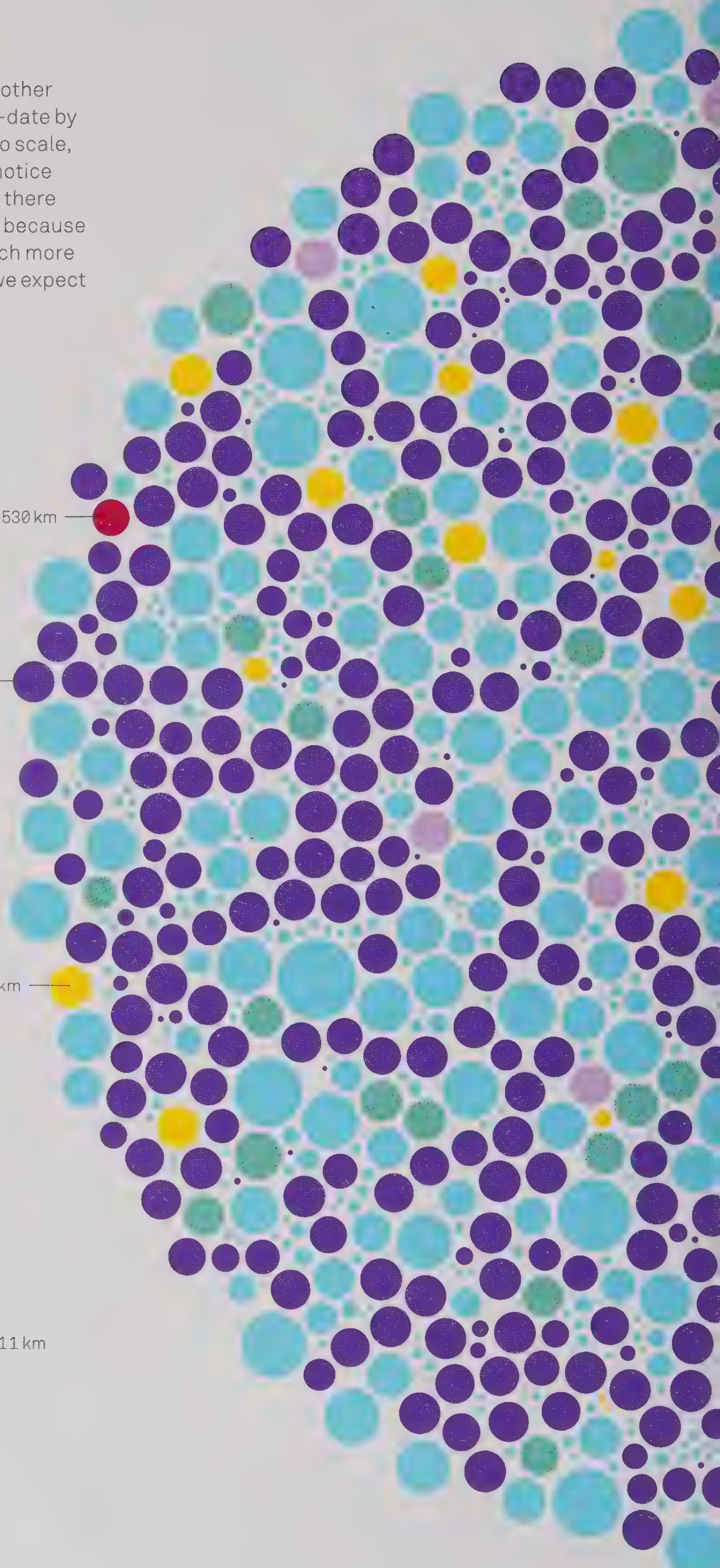
In 2009, NASA's Kepler spacecraft launched with a mission to find planets via the transit method: looking for planets obscuring the light from their host stars as they orbit. The mission has proved hugely successful having found over half of the confirmed exoplanets currently known. The mission continues to find planets and, as it is due to operate well into 2016, should find many more.



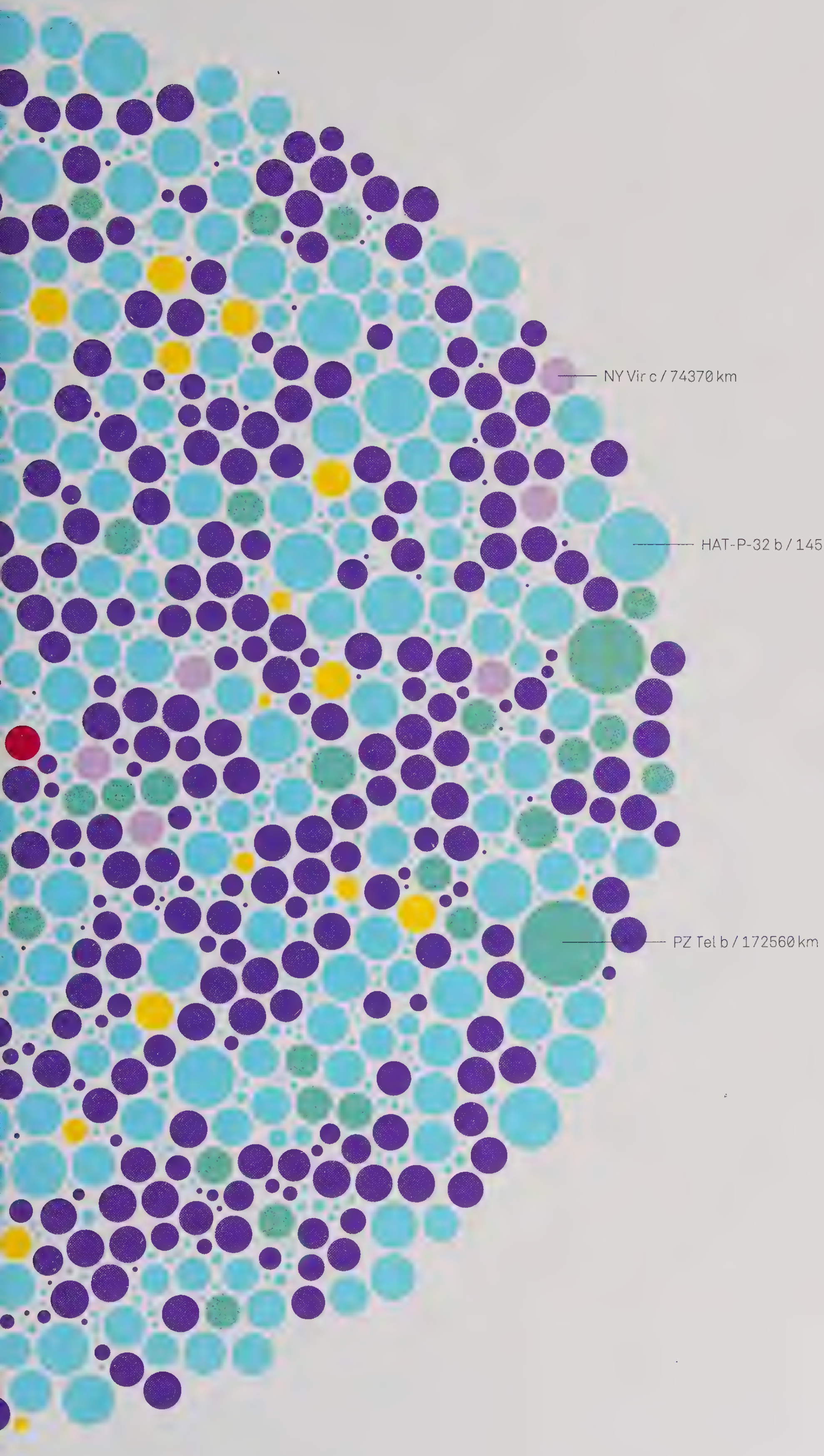

60
60
114
81
191
157
182
804
2007
2008
2009
2010
2011
2012
2013
2014

All known exoplanets

There are now over 1,800 confirmed planets orbiting other stars. The number is growing rapidly so will be out-of-date by the time you read this. If we place them all together, to scale, we get an idea what that looks like. The first thing to notice is the number of large planets. This is partly because there really are lots of planets bigger than Jupiter, but also because our planet-hunting techniques find large planets much more easily. As our instruments and techniques improve, we expect to be able to find many more Earth-sized planets.



Solar System



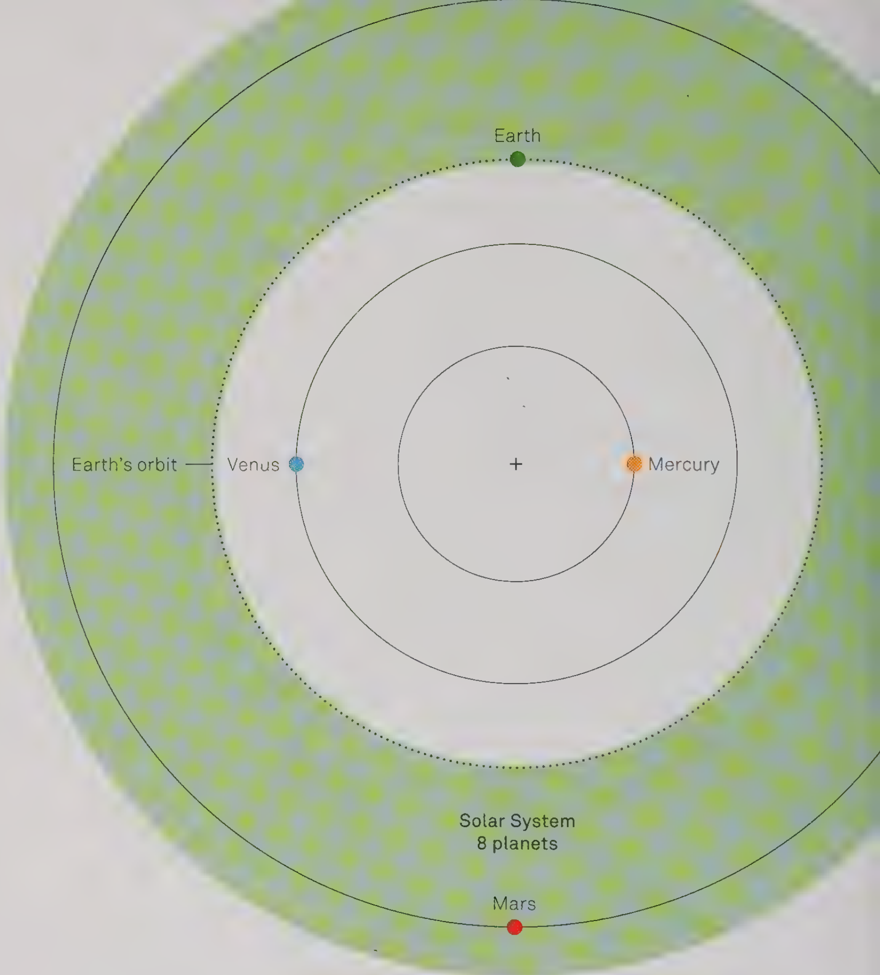
NY Vir c / 74370 km
HAT-P-32 b / 145240 km
PZ Tel b / 172560 km

Planetary systems

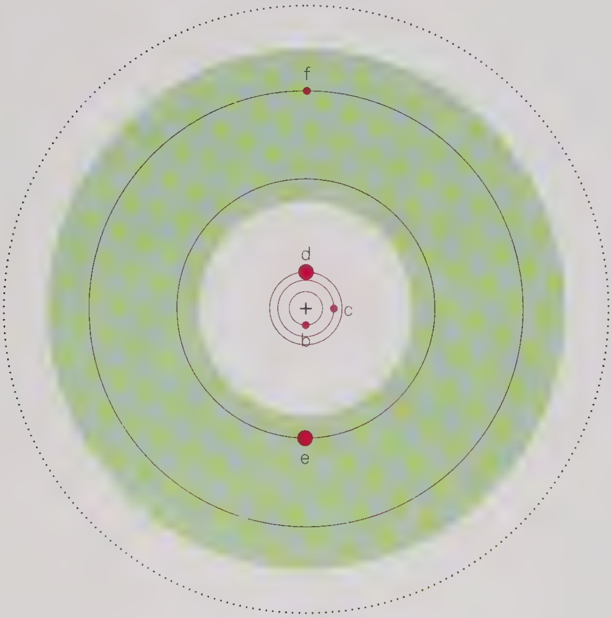
We now know of over 1,180 planetary systems. Many are very unlike our Solar System having super-Jupiters close in to their parent star. Being so close to their stars those planets will be intensely hot and inhospitable.

The main question we'd like to answer is 'are there any that we (or alien life) could live on?'. Our first requirement for a hospitable planet is for it to be at a suitable distance from its star that it isn't too hot or too cold and water can exist as a liquid. This livable range is known as the Habitable Zone.
Any closer the water will boil off.
Any further it turns to ice and makes it hard for life. In recent years we have found several solar systems that appear to have planets sitting in this zone. So far, these have tended to be around smaller, cooler stars than our Sun.

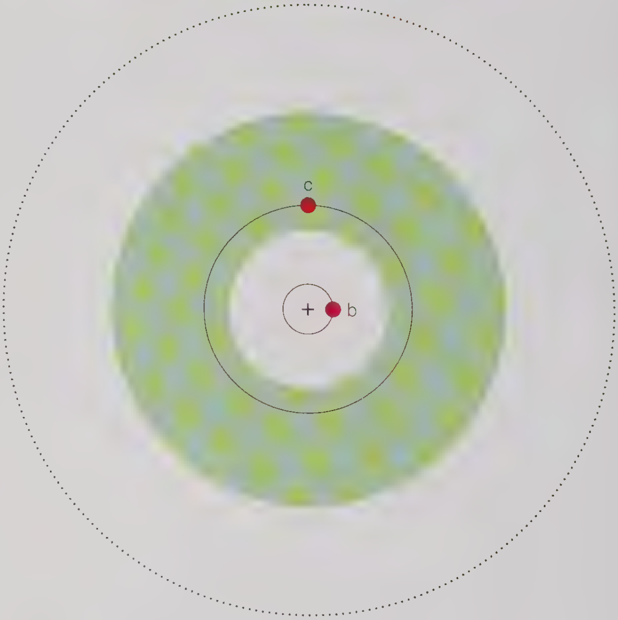
Habitable zone
Size of Earth's orbit



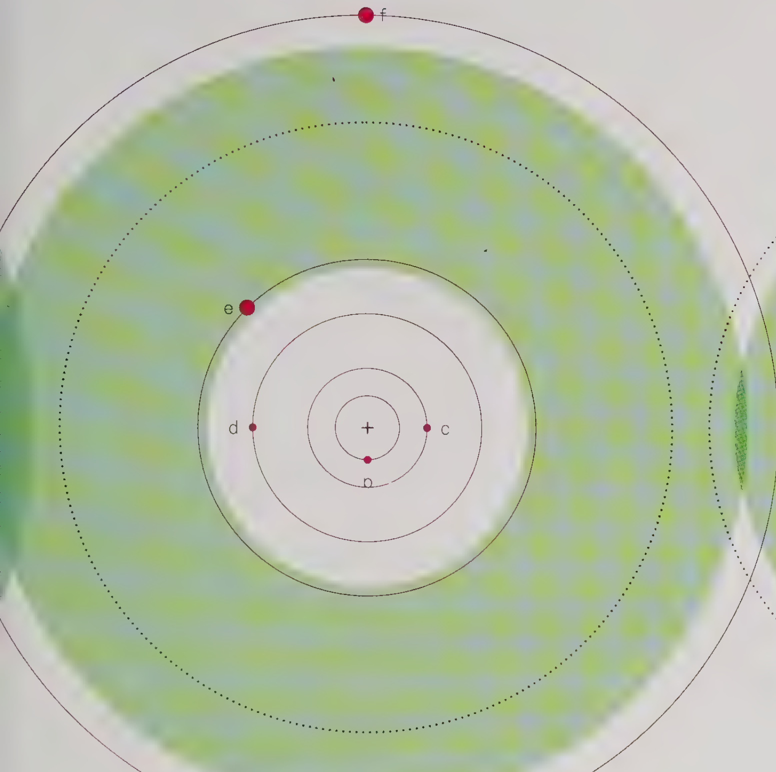
Solar System
8 planets



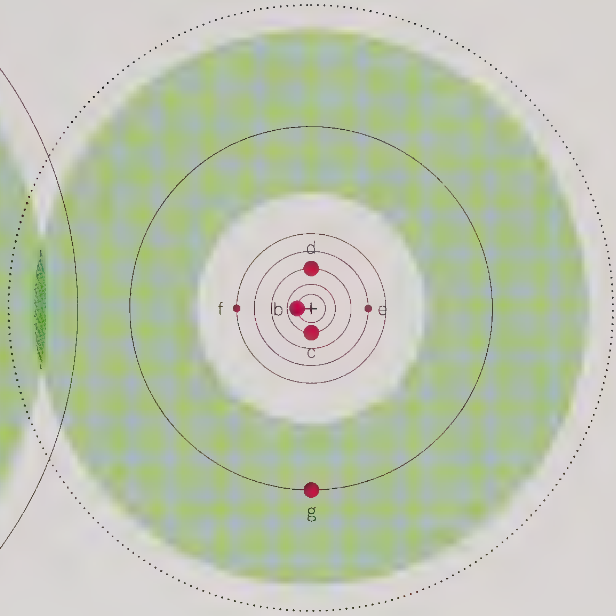
Kepler-62
5 planets



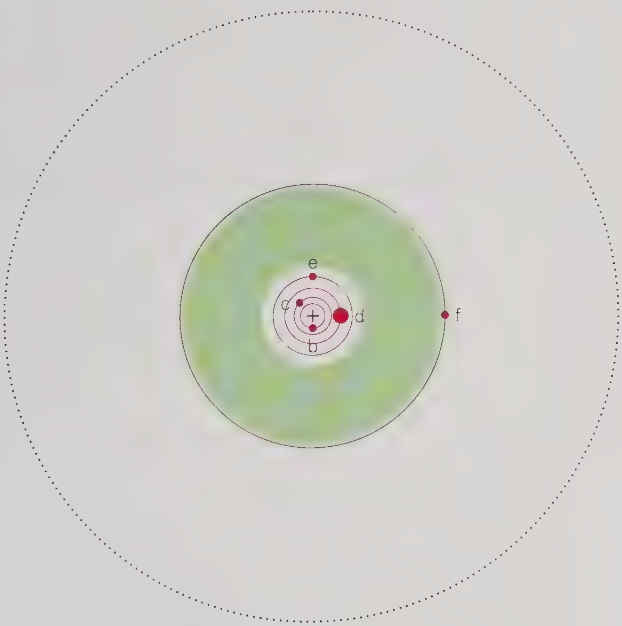
Kepler-283
2 planets



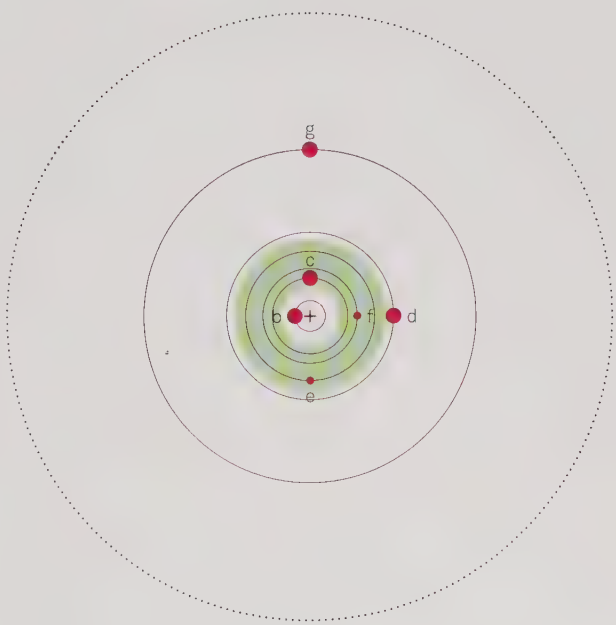
Tau Ceti
5 planets



HD 40307
6 planets



Kepler-186
5 planets



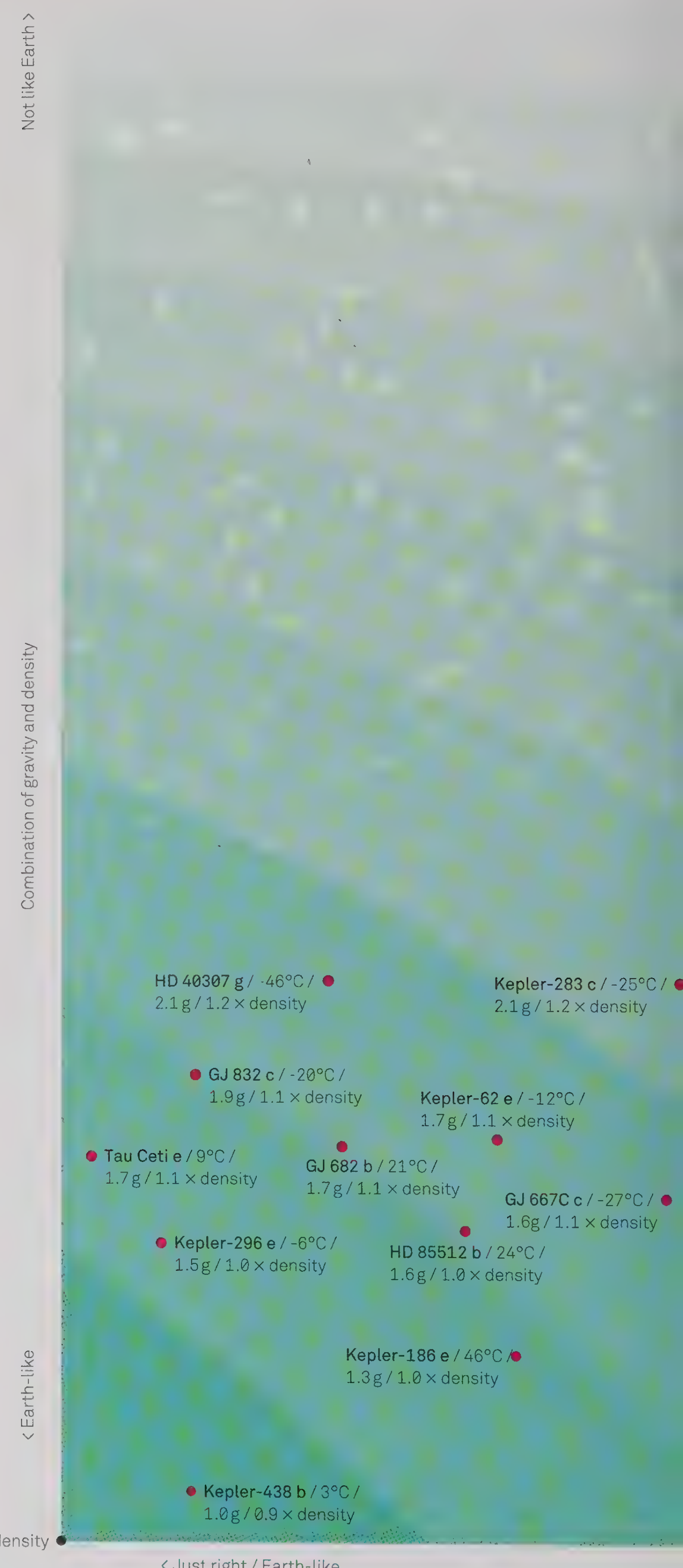
GJ 667C
6 planets

Earth-like

Planets in the *Habitable Zone* have survivable surface temperatures but that doesn't mean they are identical to the Earth. They could easily be much more massive – like Jupiter – or tiny like Ceres. For humans it will also need easily accessible water, about the right gravity and probably a solid surface. We don't have an answer to the water question at the moment but, for many exoplanets, we can calculate an approximate surface temperature, surface gravity, and if it is rocky or gassy. We can use those numbers to get a rough idea as to how Earth-like planets might be. We've certainly come a long way over the past 25 years.

- Solar System object
- Exoplanet

- Earth diameter
- 3 × Earth diameter
- 10 × Earth diameter
- 30 × Earth diameter



Temperature

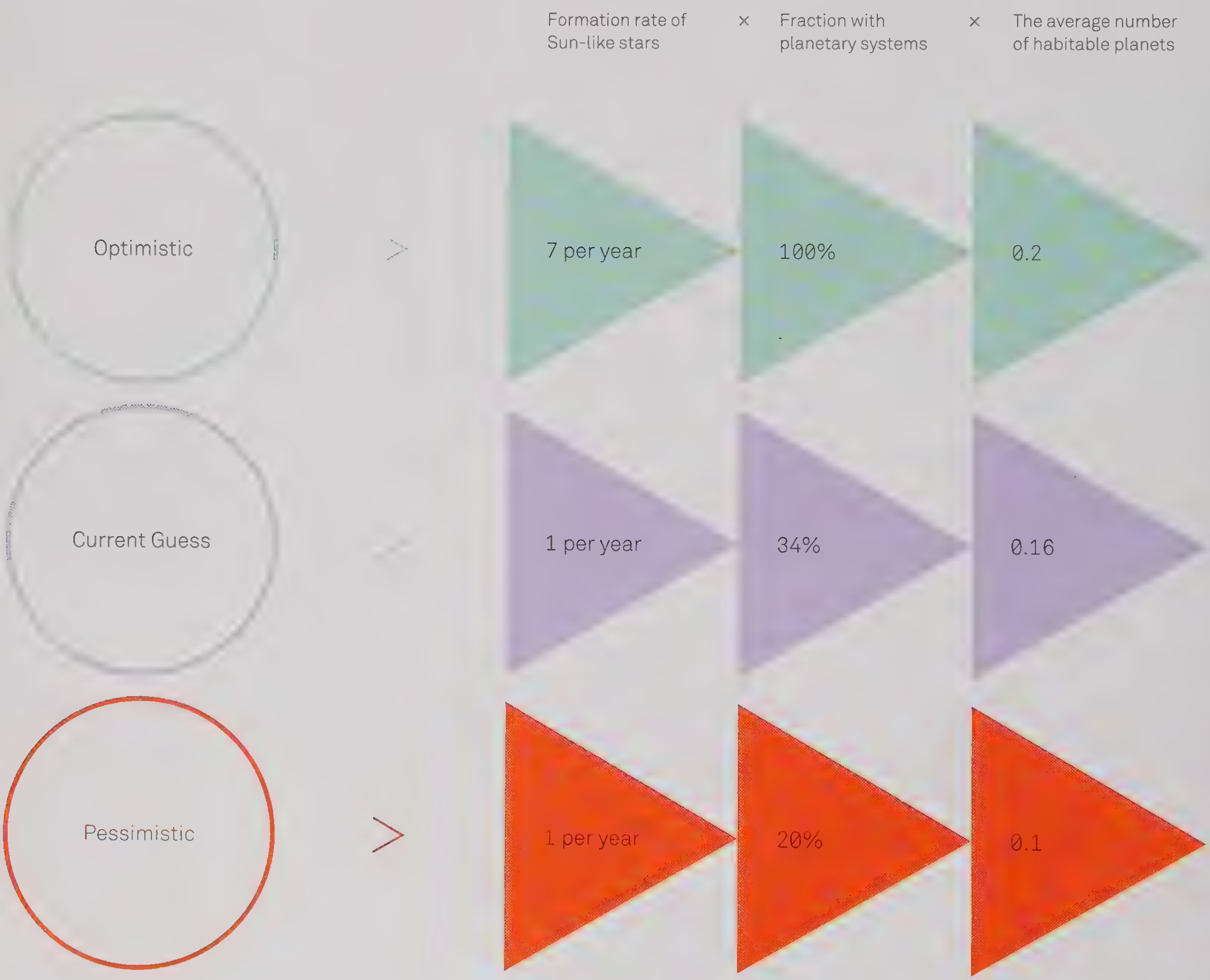
Too hot or too cold / Not like Earth >

Are we alone?

As of yet, we have not found life elsewhere in the Universe. That doesn't mean that we are alone in the cosmos; space is big and we've only just started searching.

In 1961, radio astronomer Frank Drake put forward an equation to estimate the number of intelligent civilisations that we could communicate with in the Galaxy. The equation is a way to help us think about what is needed for life to exist. It starts out by working out the chances of the right kind of star and planet for life to get started on. It then attempts to estimate the chances of life developing to the point where it decides to let others know of its existence. Over the years since the equation was proposed, we've been able to get better estimates for some of the numbers. However, the number with the largest uncertainty is the length of time a civilisation exists for.

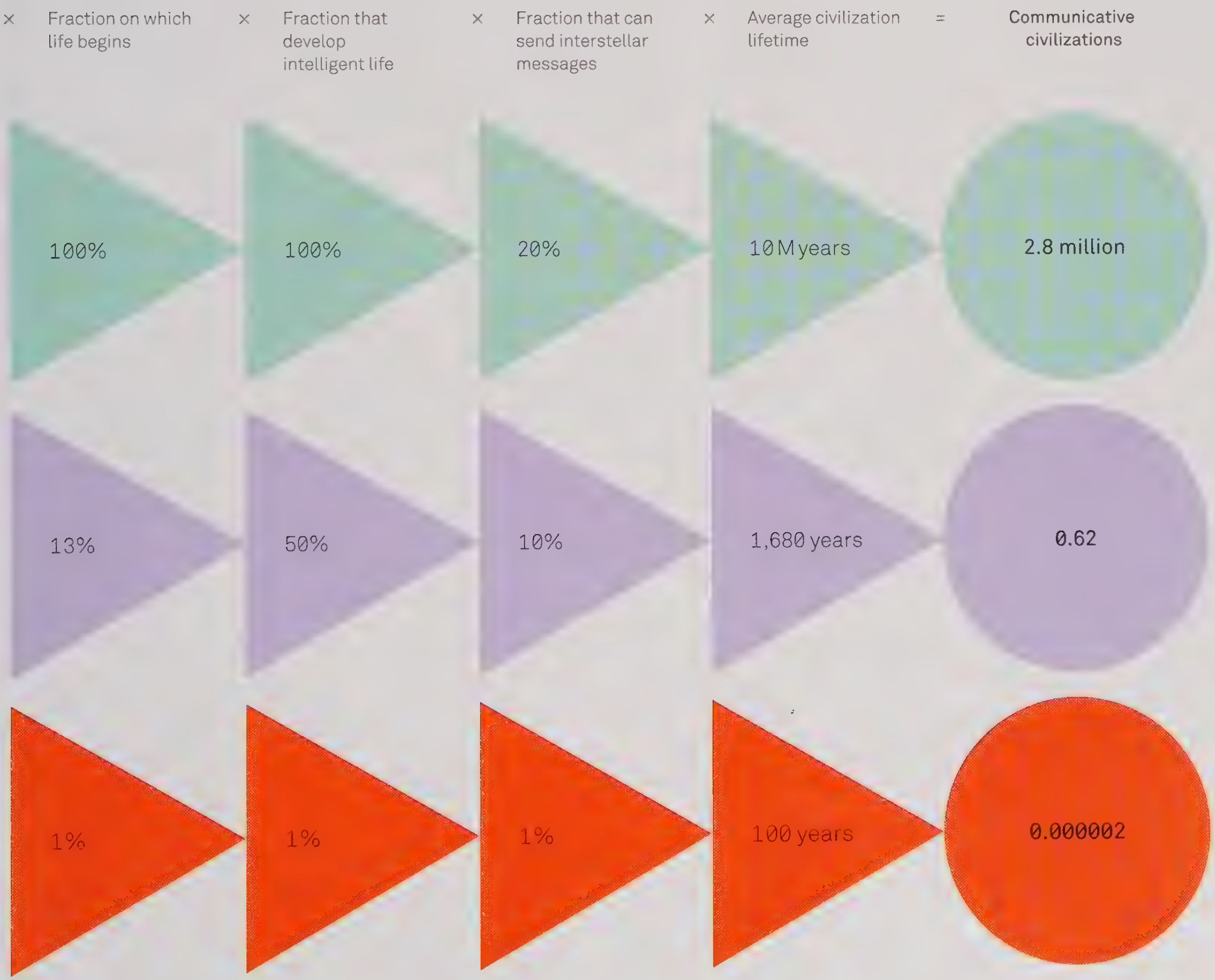
We've only been in the communicative state for under a century. How long can we exist without destroying ourselves?



Limitations

The equation makes a few assumptions, not least that a solar-type star and a planet are required for life. This could be too restrictive. In recent years we've found life existing around hydrothermal vents at the bottom of the oceans. These vents provide energy and nutrients to support life that may be entirely independent of the Sun. Similar processes could exist on the moons Enceladus and Europa, with energy provided from tidal interactions with their parent planets.

Does life even need a planet or moon? Experiments have shown that microscopic tardigrades are able to survive in a huge range of temperatures, high doses of radiation, and even the vacuum of space. Basic life can cope with much more extreme environments than we had previously assumed.

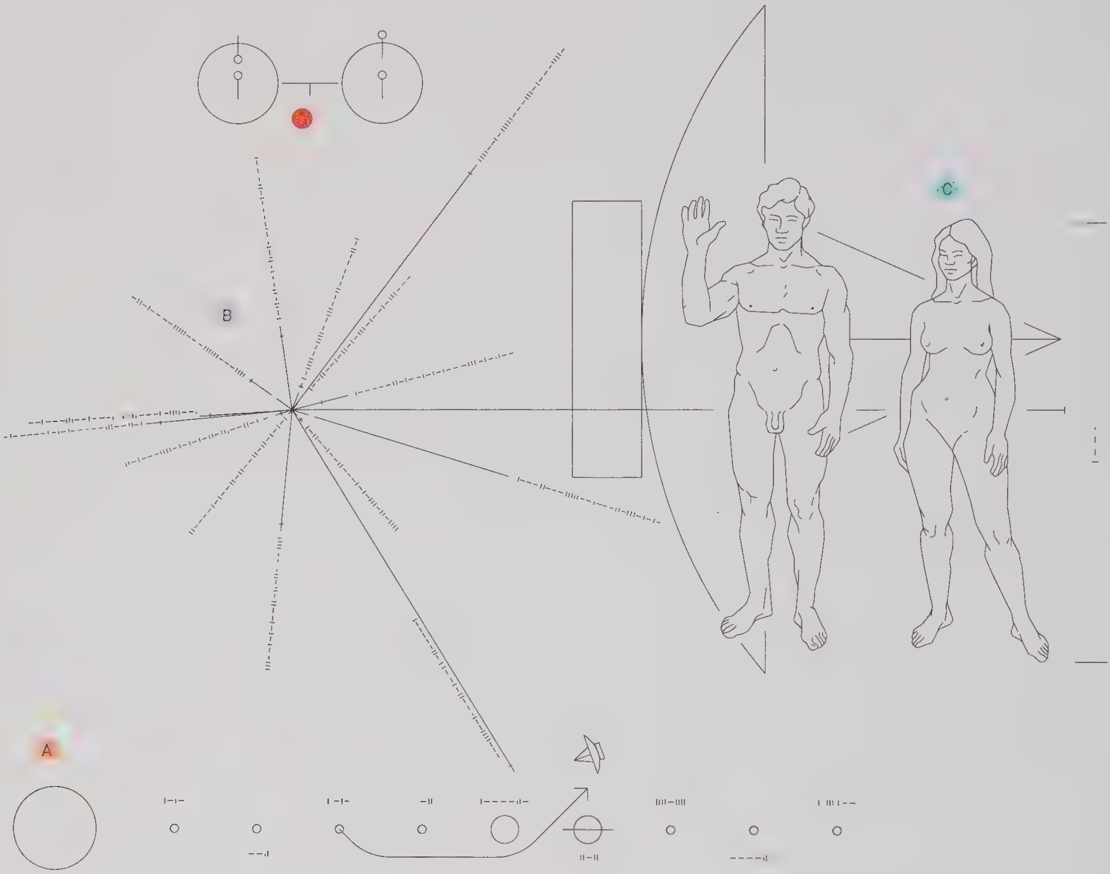


When we launched spacecraft that would eventually leave the Solar System, we included messages to any extra-terrestrials that found them. The two Pioneer spacecraft *(Pioneers 10 & 11)* included gold-anodized aluminium plaques with artwork by Linda Salzman Sagan, Carl Sagan, and Frank Drake.

The two Voyager probes *(Voyagers 1 & 2)* took golden records. None of our probes will reach close to other star systems for many tens of thousands of years. Will ET be able to decipher the messages? Can you?

Pioneer plaque

Width 229 mm × Height 152 mm



A Solar System

A representation of the Solar System with a curved line for the path of the spacecraft. The 'arrowhead' on the trajectory has been controversial as it is symbol from our hunter-gatherer past and may not be recognised. The objects depicted may be confusing given that their positions are not to scale and they aren't all the largest objects.

B Pulsar Map

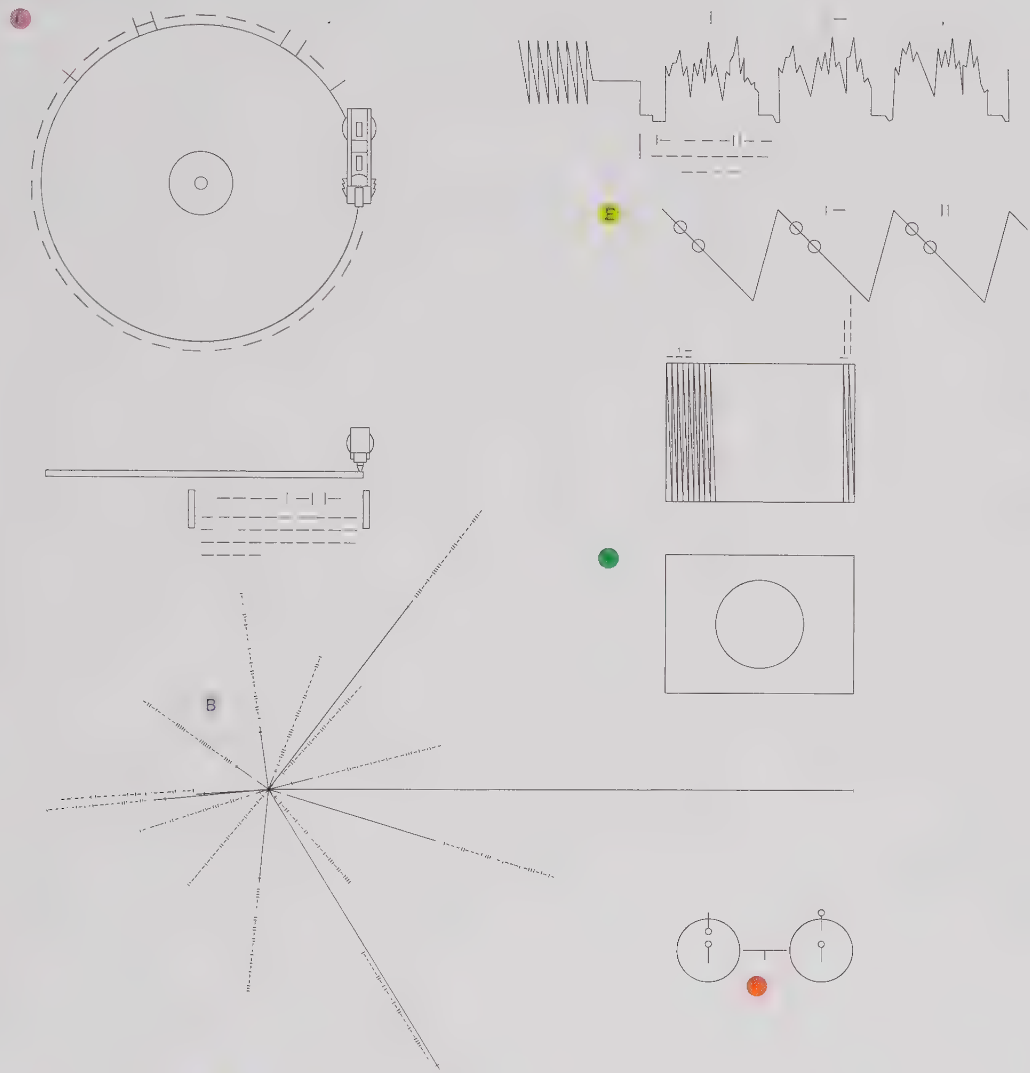
This shows the positions of 14 pulsars relative to the Sun with the lengths of the lines being the relative distances. The symbols along the lines are a binary representation of each pulsar's rotation frequency relative to the hydrogen atom at the time of launch. The horizontal line towards the right shows the position of the centre of the Galaxy.

C Woman and Man

Representations of humanity and the spacecraft on the same scale. The depictions of humans may be harder to decipher for extra-terrestrials.

Voyager golden record

Diameter 305 mm (12 inch)



Playing instructions

A plan and side view of the golden record with the enclosed stylus in position. Around the record is a representation, in binary, of the playing speed compared to the time associated with a hydrogen atom.

Video signal

These illustrations show the mechanics of recreating the video signal. The first part shows the waveform generated by playing the record.
The rectangles represent the way to build up an image with binary code so that there are 512 vertical lines. The bottom rectangle shows a circle which is the first image that will be shown if ET gets it to work.

Content

The video contains 116 images as well as various sounds of Earth including music by Bach and Chuck Berry.

Hydrogen Atom

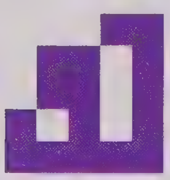
This shows an energy transition of the hydrogen atom: the most common element in the Universe. It is associated with a frequency (1420.406 MHz) and a wavelength (21 cm) to provide scale for other parts of the image.

In 1974, radio astronomers at the Arecibo radio telescope transmitted an image in the direction of globular star cluster *M13*. The cluster, containing around 300,000 stars, is 25,000 light years away in the direction of Hercules.

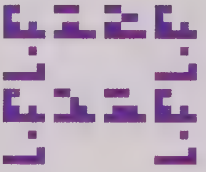
The transmission switched between two slightly different frequencies, near 2,380 MHz, to create a binary code. In total, 1,679 binary digits were sent; a number chosen because it is the product of two prime numbers. The hope was that extra-terrestrials would recognise that property of this number and would then arrange the message in a 23 × 73 pixel image. Even if ET work out how to display the image, they would still have to work out what it means. We just don't know how difficult that might be for them. It certainly isn't easy for humans to work out and it is *our* message.

Unfortunately, the cluster will move over the next 25,000 years so the message will miss any civilisations living there. We certainly shouldn't expect a reply anytime soon.

The numbers one to ten in a binary representation.

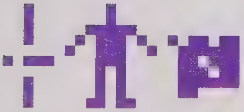


A binary representation of the atomic numbers of the elements making up DNA: hydrogen, carbon, nitrogen, oxygen and phospherous.



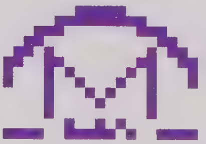
Formulas representing the chemical building blocks of DNA.

An image of DNA double helix with the number of nucleotides in the human genome encoded in binary in the middle.

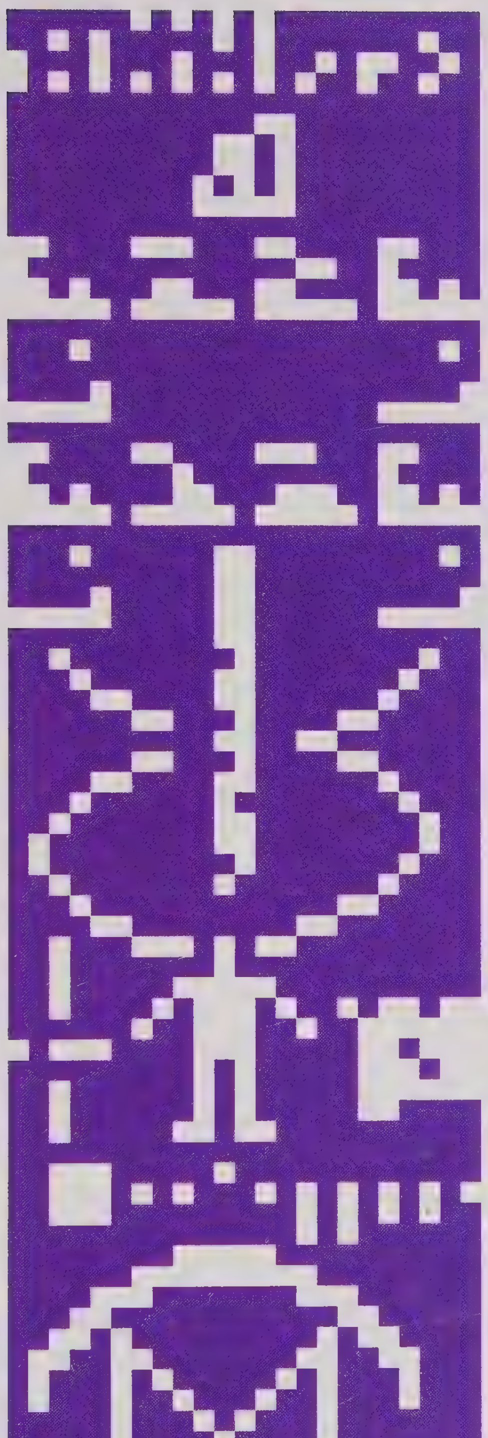


A picture of a human connected to the DNA strands. The number of humans (4 Bn at the time of the message) is included on the right.

The solar system showing the location of Earth raised and centred on the human.

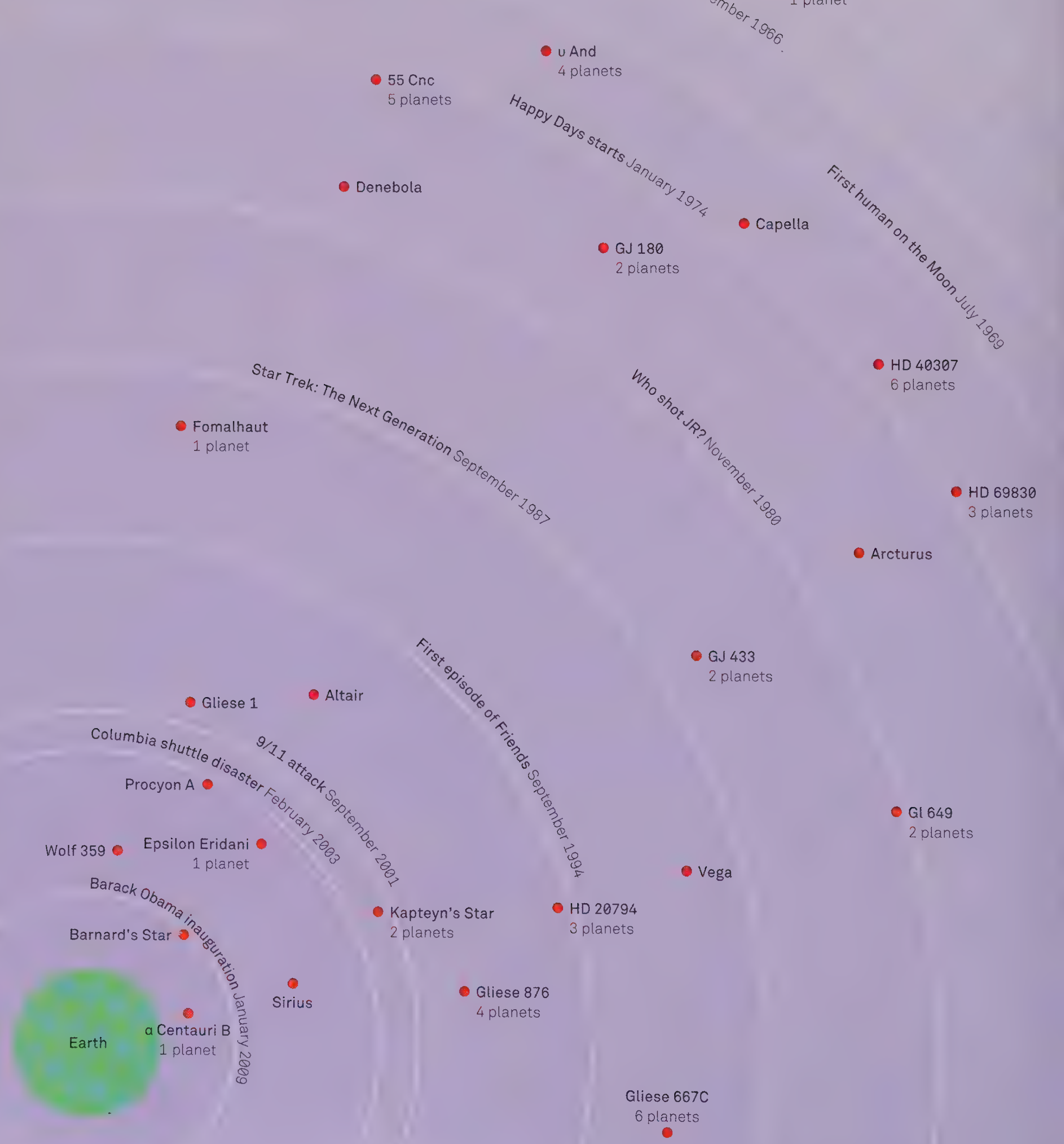


A picture of the Arecibo dish in Puerto Rico with the size of the antenna in binary.



Light spheres

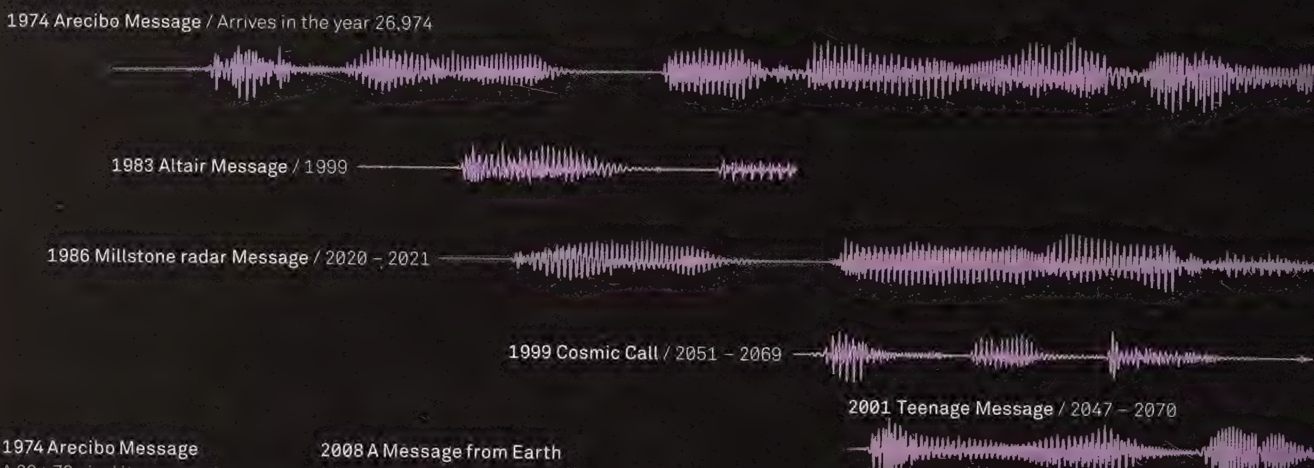
A fraction of the signal from all our TV and radio broadcasts leaks out into space. Unimpeded, these signals head off at the speed of light in an expanding sphere around us. In theory, alien civilisations with sensitive radio telescopes could pick up our broadcasts and listen in. Avid alien fans' knowledge of our history would be behind by a number of years determined by how far away they are.




Regulus
End of World War II August 1945
First BBC radio broadcast November 1922
δ Velorum
BD-061339
3 planets
Coronation of Queen Elizabeth II June 1953
HD 1461
2 planets
Orson Welles' 'The War Of The Worlds' broadcast October 1938
70 Virgo
1 planet
Aldebaran
HD 39194
3 planets
GJ 676A
4 planets
Mizar
BBC Empire Service starts December 1932
β Pictoris
1 planet
μ Ara
4 planets
JFK assassination / First episode of Doctor Who November 1963
Outbreak of World War II September 1939
Merak
51 Pegasus
1 planet
Hamal
1 planet

Messaging extra-terrestrial intelligence

Whereas the search for extra-terrestrial intelligence (SETI) is the passive activity of listening for messages from alien life, messaging extra-terrestrial intelligence (METI) is the opposite; telling the Universe at large 'We are here! You are not alone!'. Aside from the weak and incidental transmissions of our TV and radio broadcasts, over the years there have been several deliberate attempts to send messages to specific targets. These have come from academic and commercial sources. Our first contact messages have certainly varied hugely in content.



1974 Arecibo Message
A 23 x 73 pixel image sent towards globular cluster *M13* (arrives 26,974) (1,679 bits)

1983 Altair Message
(possibly apocryphal) Japanese astronomers sent thirteen 71 x 71 pixel images towards the star Altair (arrived in 1999)

1986 Millstone radar Message
(possibly apocryphal) audio message sent to Epsilon Eridani, Tau Ceti and two other stars (2020 / 2021)

1999 Cosmic Call a short 'encyclopedia' written in a special language was sent to four Sun-like stars (arrives 2051 / 2057 / 2067 / 2069) (370,967 bits)

2001 Teen Age Message
a 14 minute theremin concert as well as sounds, images and text selected by teenagers from around Russia sent to six Sun-like stars (arrives 2047 / 2057 / 2057 / 2059 / 2059 / 2070) (648,220 bits)

2003 Cosmic Call 2 another selection of text, images, music and video sent to five Sun-like stars (arrives 2036 / 2040 / 2044 / 2044 / 2049)

2005 Craigslist 130,000 postings from craigslist.org were sent into open space (no arrival time)

2008 A Message from Earth
501 messages from the social networking site Bebo sent towards *Gliese 581c* (arrives 2028)

2008 Across the Universe
NASA transmit The Beatles' Across the Universe towards Polaris (arrives 2439)

2008 Doritos advert A Doritos advert was sent towards the star *47 UMa* (arrives 2050)

2009 Hello from Earth 25,880 text messages were sent towards *Gliese 581d* (arrives 2029)

2009 RuBisCo The genetic code for a protein that used to perform photosynthesis sent to the stars Teegarden's star, *GJ 83.1*, and *Kappa1 Ceti* (arrives 2021 / 2024 / 2039)

2012 Wow! Reply 20,000 tweets from viewers of National Geographic sent to the stars *rho Cnc*, *37 Gem*, and *HIP 34511* (arrives 2052 / 2068 / 2163)

2013 Lone Signal A series of 144 character messages from the general public sent towards the star *Gliese 526* (arrives 2031)

To send or not to send?

That is a question with no global consensus. Some, including the likes of Steven Hawking, worry that this could encourage advanced, hostile, aliens to visit us with ill intent. Perhaps these civilisations would find us anyway so this concern may be moot. Others have called for a moratorium on further messages until we've discussed the implications globally. Alternatively, making first contact with alien life would be an historic and inspiring event that would answer the fundamental question of 'Are we alone?'.

Nine / Miscellaneous

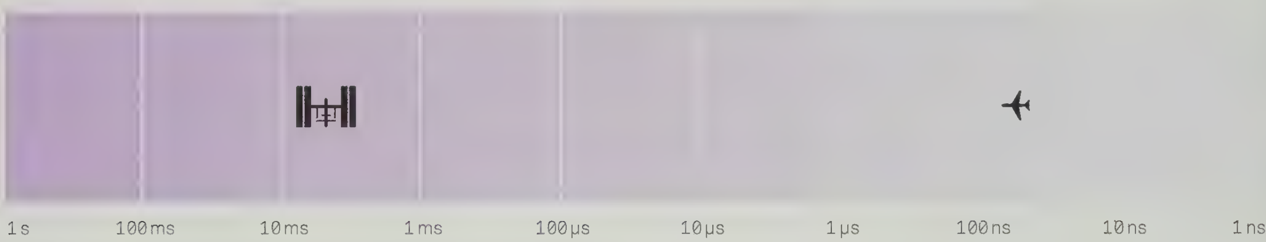
In 1905 Albert Einstein published his Special Theory of Relativity, which showed that measurements of time and distance change for observers moving at speed.

He followed it up in 1915 with his General Theory of Relativity, which showed the effect of gravity on light. These effects are not normally noticeable on human scales, but there are situations where they become important.

Time dilation

How old are you, exactly? Einstein showed that time is not a constant. Time runs more slowly for people who are moving very fast, or who are in a gravitational field, though the differences are very small. In 1971 Joseph Hafele and Richard Keating took atomic clocks on commercial round-the-world plane journeys in opposite directions.

Younger due to speed



6 months on the ISS

Speed / 25,500 km/h
Orbit height / 410 km
Duration / 6 months

Plane (Eastwards)

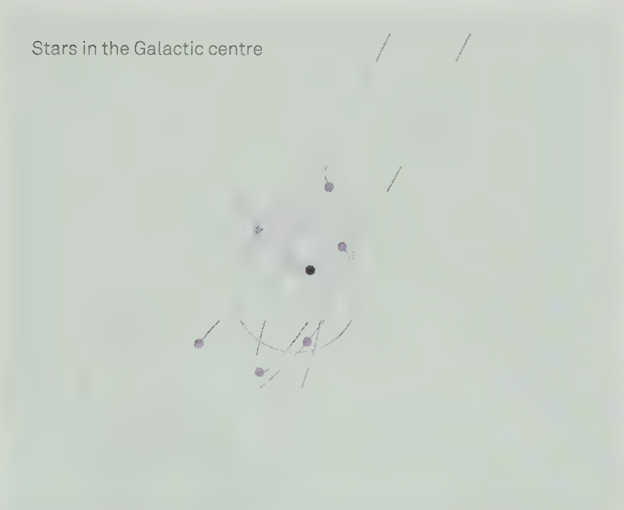
Speed / 700 km/h
Altitude / 10 km
Duration / 1.7 days

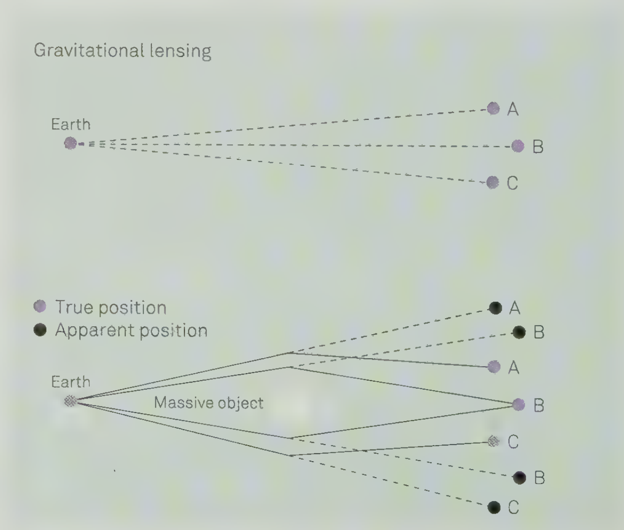
Black holes

The General Theory of Relativity predicts that black holes should exist. While we have never seen any directly, there is very good evidence for them. The motions of stars near the Galactic Centre must be around an object four million times the mass of the Sun, but which is completely invisible.

Gravitational lensing

Einstein's gravitation theories also predicted that massive objects distort the fabric of space, and that light passing near such objects would be bent. That can either make background objects appear to be in different places or, if the object is massive enough, create multiple images.

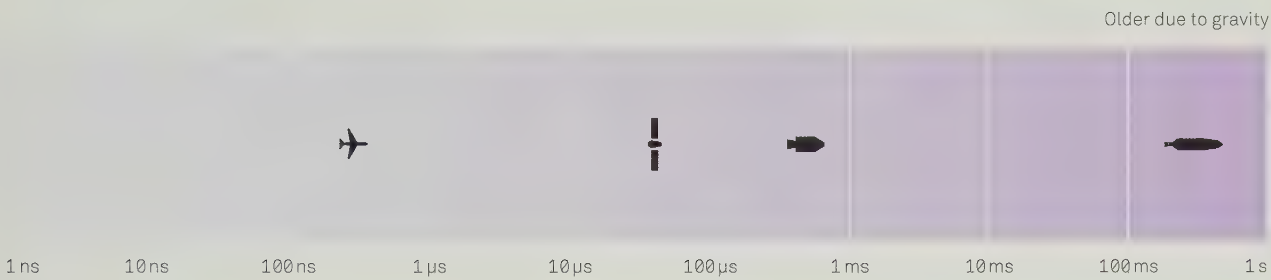




They showed that the effect is real, with the difference being because the Earth's surface is moving at 1,600 kilometres per hour at the equator. Satellite navigation systems rely on very precise timings, and the tiny difference would result in positions being wrong by over 100 metres per day if not accounted for.

Twin paradox

The differences are more noticeable when considering future interplanetary travel. At one tenth of the speed of light an explorer could travel to Neptune and back in less than four days, and would return 25 minutes younger than if they had stayed on Earth.



Plane (Westwards)
Speed / 700 km/h
Altitude / 10 km
Duration / 2 days

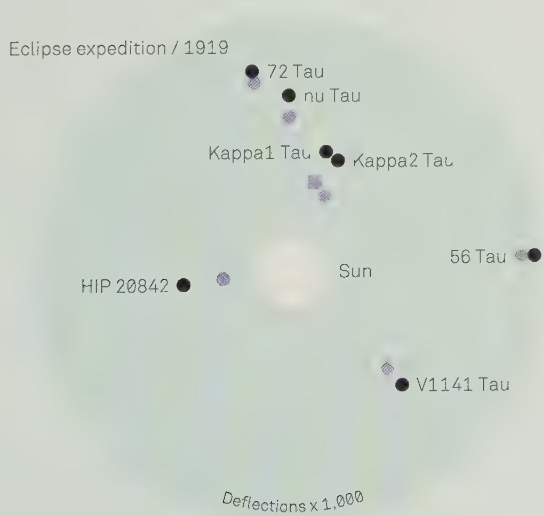
GPS satellite after 1 day
Speed / 14,000 km/h
Orbit height / 20,000 km
Duration / 1 day

Apollo 11 trip
Speed / 4,000 km/h
Distance from Earth / 380,000 km
Duration / 8 days

Return trip to Mars
Speed / 50,000 km/h
Distance from Earth / 78.4 M km
Duration / 3.4 years (2 yr on Mars)

In 1919, Arthur Eddington observed stars during a solar eclipse and found them to be in slightly different locations than normal. Although the apparent bending of the light was a tiny effect, this was the first observational proof of Einstein's theory.

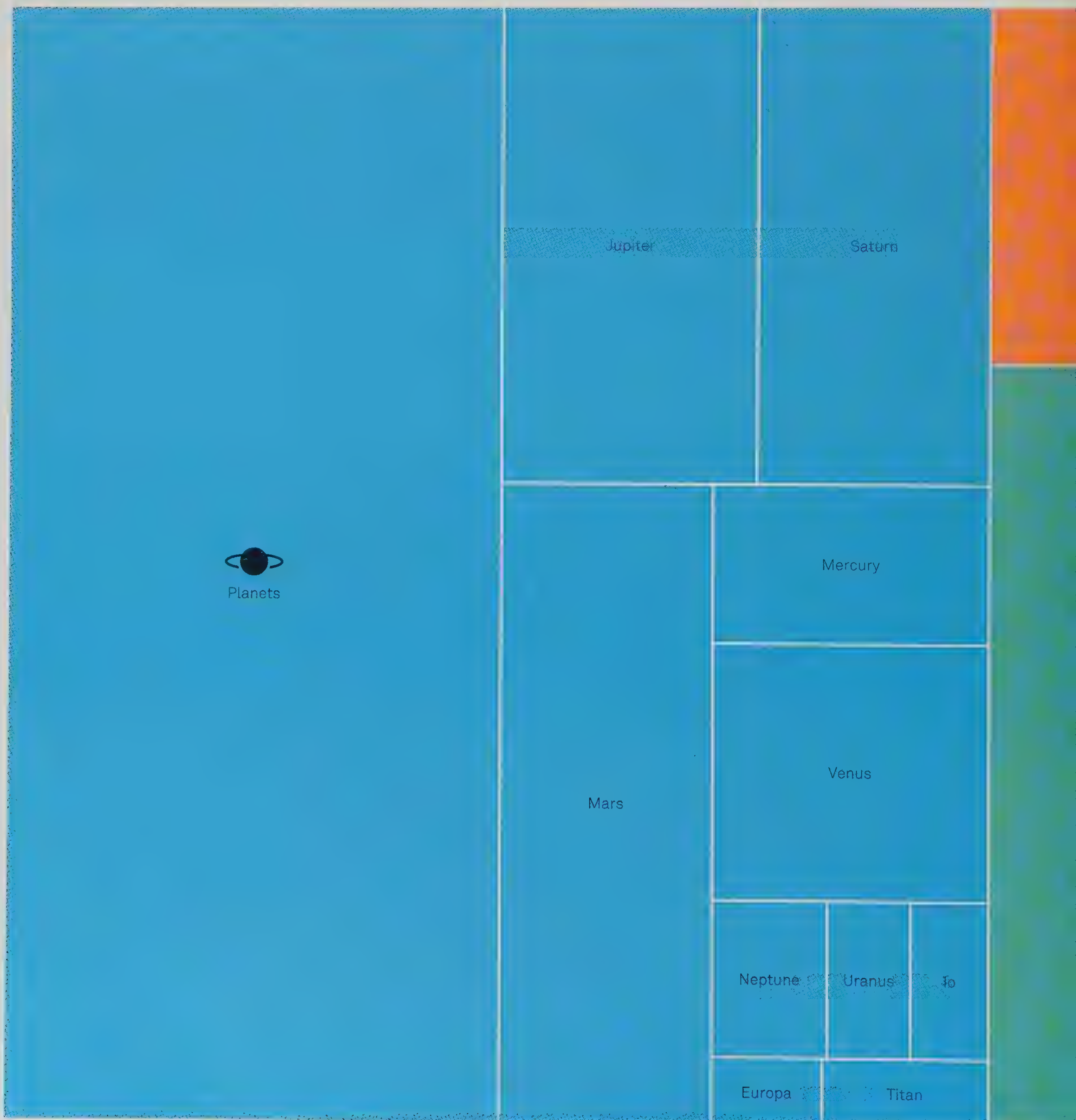
Massive clusters of galaxies act like gravitational lenses, magnifying and distorting the light from more distant objects. The background objects appear as arcs in the images, allowing us to study some of the most distant galaxies in the Universe.



Pictures of the day

The Astronomy Picture of the Day (APOD) website has been online since 16 June 1995. Every day it shows a different image of space along with a brief explanation. We've broken down the type of objects that have been included in APOD over its 20 year history.

These days APOD also appears on social media. Recent analysis has shown that the most popular types of APOD images shared by Google Plus users are of planets and moons. Skyscapes are the most popular amongst Facebook and Twitter users.




Stars and clusters
Eagle Nebula
Melotte 1
Interplanetary bodies and dwarf planets
Pluto
Comet Hale-Bopp
Comet Hyakutake
Nebulae
Lagoon Nebula
Trifid Nebula
Orion Nebula
Galaxies
Andromeda Galaxy
Cigar Galaxy
Bode's Galaxy
Triangulum Galaxy
Sky phenomenon
Orion
Solar Eclipse
Cosmology

Water worlds

The Earth is the only body in the Solar System with liquid water on its surface, but it's not the only place where we find water. In most cases, such as on Mars, this water is in the form of ice, either on the surface or within the rock layers just beneath the surface. The sub-surface ice does melt for short periods when heated by sunlight, causing rivulets to run down crater walls before evaporating in the low atmospheric pressure.

But there is water elsewhere in the Solar System, in the most unlikely of places. Jupiter's moon Europa has a thick layer of ice covering its surface, as do many moons in the outer Solar System. The surface is constantly being replaced, and we know that beneath it lies an ocean of water. This ocean is prevented from freezing by internal heat generated by tides caused by Jupiter. Europa may contain more water than all the Earth's oceans put together.

Saturn's moon Enceladus also has liquid water beneath its surface. This water has been observed escaping from the moon's south pole in salty geysers. We now think that that many of the larger moons in the outer Solar System have sub-surface oceans, though their depths – and volumes – are far from certain.

Earth / diameter 12,742 km


Europa / diameter 3,122 km
3 billion km³ Ice crust
with sub-surface ocean
1.4 billion km³
Ice, water and vapour
7.5 million km³ Ice with
water vapour geysers
Enceladus / diameter 504 km
5,000 km³ Ice at poles and
subsurface permafrost
Mars / diameter 6,779 km

Density

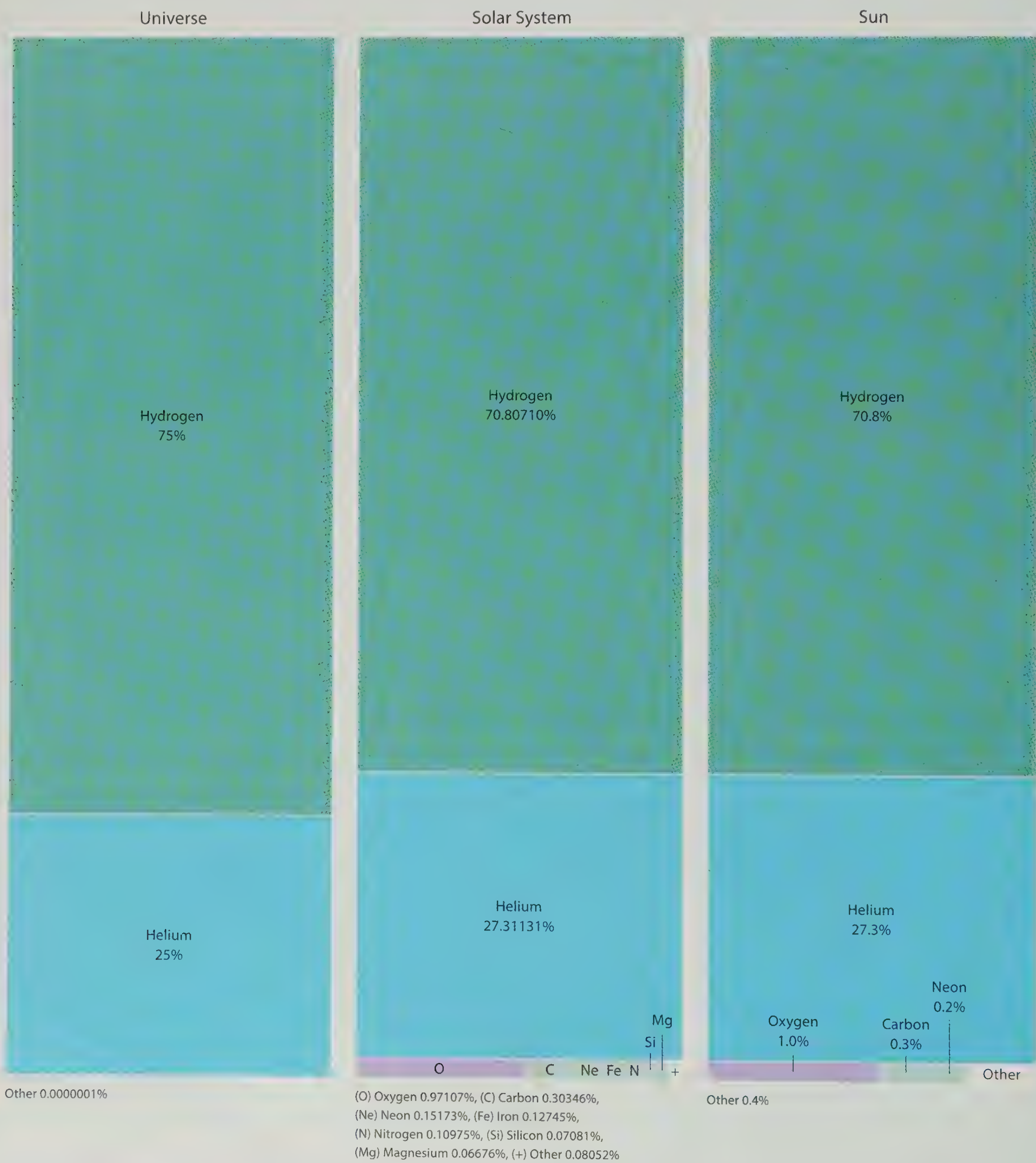
Space is very empty. The density of the gas between the stars is a thousand million millionth (quadrillionth) the density of air. But the objects in space can be very dense indeed. The centre of the Sun is 50 times denser than rock, and neutron stars are almost unimaginably dense. Since densities are hard to imagine, we can compare how much standard volumes of a substance would weigh. The standard volume used here is a bucket.


Earth (core)
Comet
Sun
Sun (core)
White dwarf
Neutron star
Black hole

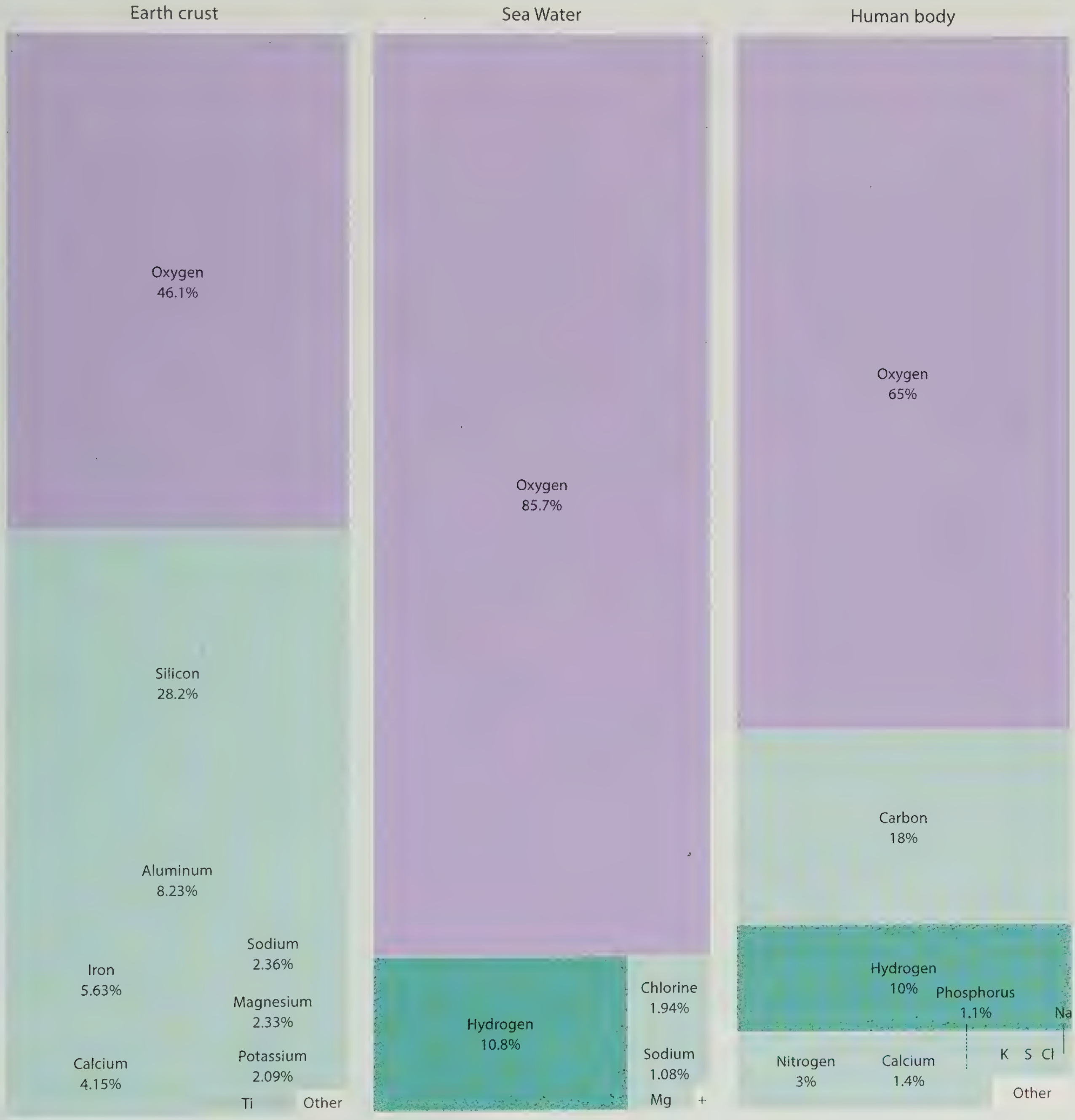
Building blocks

The Universe is composed almost completely of hydrogen and helium, formed within the first few minutes after the Big Bang. Successive generations of stars have created heavier elements, though only in relatively small amounts, and these are present in the Sun and Solar System.

As the planets were forming, the lighter elements were pushed outwards, leaving elements such as oxygen, carbon and silicon to form the inner planets. Heavy elements such as iron have sunk into the Earth's core, leaving a crust made primarily of silicon and oxygen.



The oceans are thought to have been created by impacts from asteroids and comets, returning some lighter elements to the Earth's surface. We are made of the same elements as our planet, just in slightly different proportions. Our DNA is made of carbon, oxygen, nitrogen, hydrogen and phosphorus, while calcium is the key to strong bones. Apart from hydrogen, all these elements were formed in stars – we really are stardust!



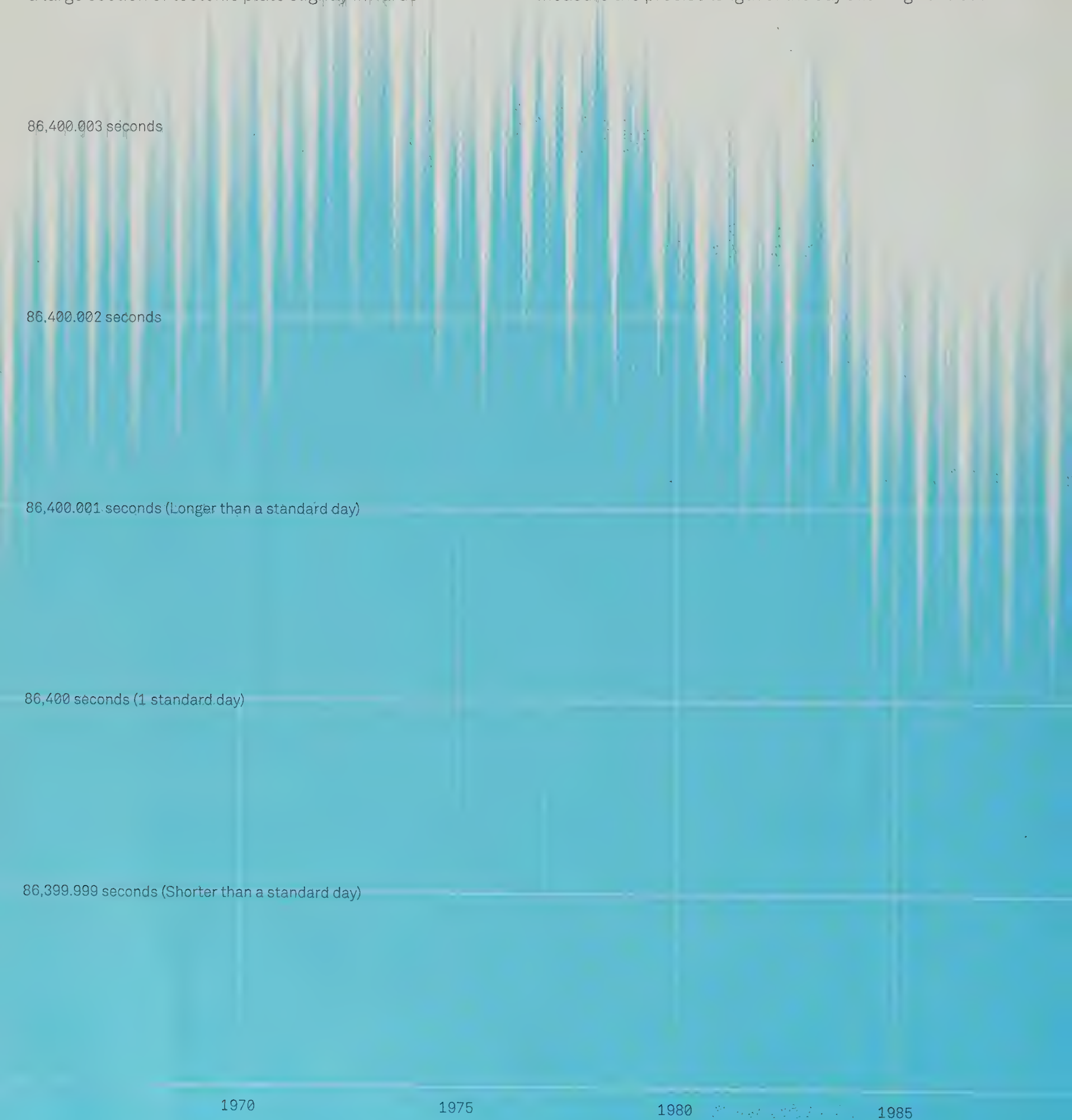
(Ti) Titanium 0.565%, Other 0.345%

(Mg) Magnesium 0.129%, (+) Other 0.351%

(K) Potassium 0.25%, (S) Sulphur 0.25%, (Cl) Chlorine 0.15%, (Na) Sodium 0.15%, Other 0.7%

How long is a day?

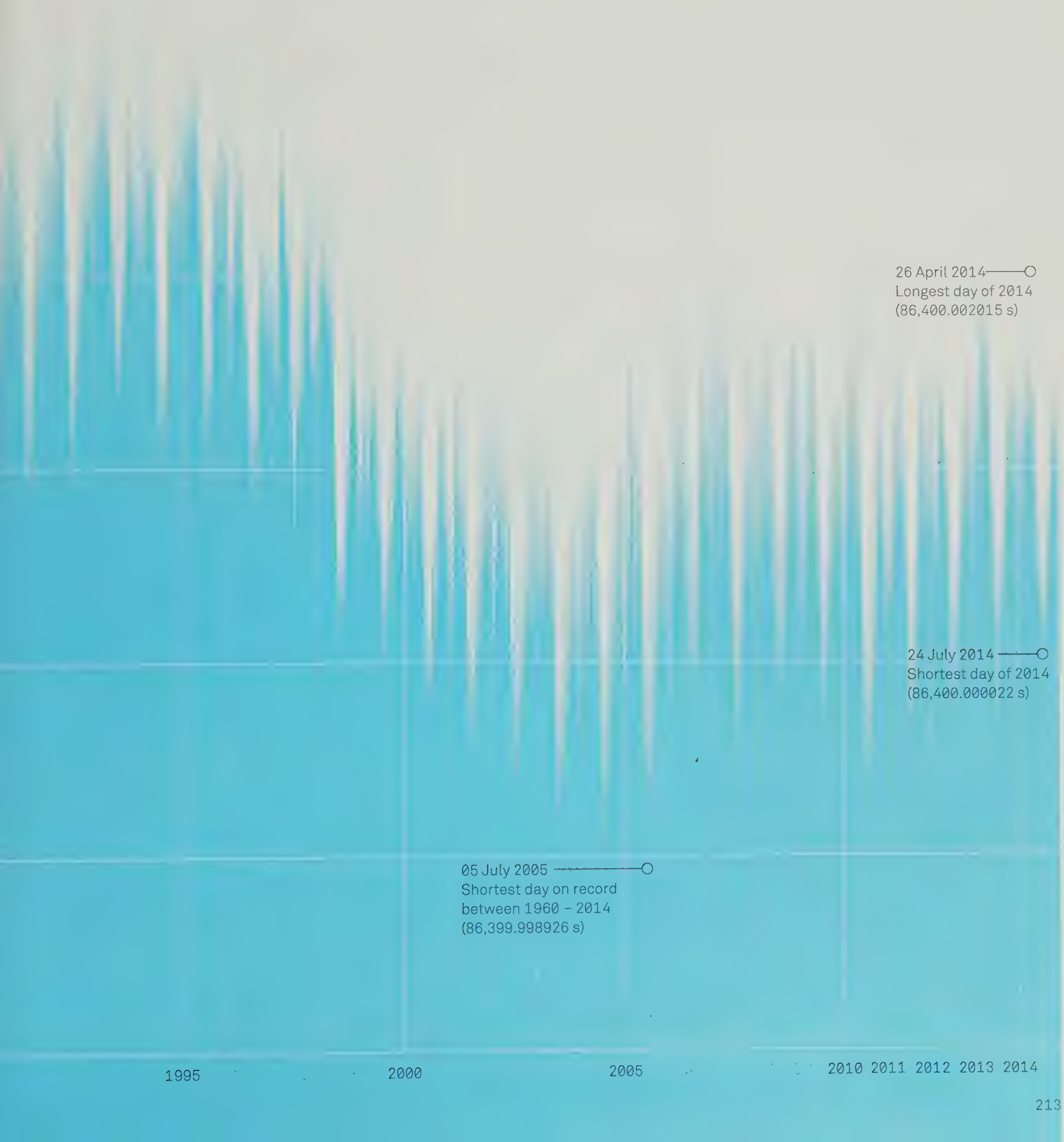
Did it feel like a long day today? It probably was. A standard day is defined as the time for one rotation of the planet and is taken as 86,400 seconds. However, the Earth's spin is not constant; sometimes it can be slightly faster and at other times slower. For example, the 2004 Indonesian earthquake brought a large section of tectonic plate slightly inwards and shortened the day by 2.7 microseconds. Conversely, the tides caused by the Moon are slightly slowing the Earth and increase the day by about 15 – 20 microseconds per year. The Earth Orientation Centre of the International Earth Rotation and Reference Systems Service (IERS) uses atomic clocks and radio observations of distant quasars to measure the precise length of the day allowing us to see how



it changes over time. Changes over decades are thought to be due to processes within the Earth's core. Changes on timescales less than two years are largely down to our atmosphere affecting the rotation of the planet.

The longest day on record was on the 12 April 1972 and lasted 4.36 milliseconds longer than the standard day. With the day being a millisecond or so longer than our definition, this slowly adds up over time.

After a few hundred days, the day will be wrong by as much as a second. To keep atomic time matched to the Earth, we occasionally add leap seconds. The IERS have added 25 leap seconds since 1972.



Identified flying objects

We've all seen things in the sky that seemed strange at first glance. Simple things such as Venus, the International Space Station, and Chinese lanterns can all seem quite mysterious if you aren't used to them. People sometimes contact local observatories, university astronomy departments, or even the police to find out what they are looking at. Usually, a few questions, a bit of deduction and a process of elimination will provide a likely explanation for these unknown aerial objects. The truth is out there. It just might be an uplit seagul.


Yes
Meteor shower
No
Did it land?
Yes
Did aliens come out of it?
No
Meteor
Yes
Have you been drinking?
No
Meteorite
Yes
You're drunk
No
Really?
Yes
Plane
No
Chinese lantern
Yes
ISS
No
Was it small and moving in a very straight line?
Yes
Satellite
No
Was it large and fuzzy?
Yes
Cloud
No
Bird(s)
Yes
Moon
No
Is it about 22 degrees from the Sun?
Yes
Sundog or halo
No
Does it look like an 'upside-down rainbow'?
No
Yes
Circumzenuthal arc
Yes
A bright star
No
Is it very bright?
Yes
Venus
No
Mercury/Mars
Yes
Noctilucent clouds
No
Magellanic clouds
Yes
Comet
No
Does it seem to move if you move?
Yes
Streetlight
No
Is it flashing just above the horizon?
Yes
Star near the horizon
No
Does it look slightly red?
Yes
Mars
No
Saturn/Jupiter or a star

Messier catalogue

Charles Messier was a French astronomer who moved to Paris when he was 14 years old. He wanted to find new comets but would often re-discover other fuzzy objects in the sky such as nebulae and star clusters.

To stop himself wasting time on these objects he created a catalogue of their positions. His catalogue – a simple list of things he didn't want to observe – has become one of his lasting legacies.

- Group of stars
- Open cluster
- Globular cluster
- Nebula
- Supernova remnant
- Galaxy
- Spiral galaxy
- Barred galaxy
- Elliptical galaxy
- Interacting galaxy


1
11
21
31
41
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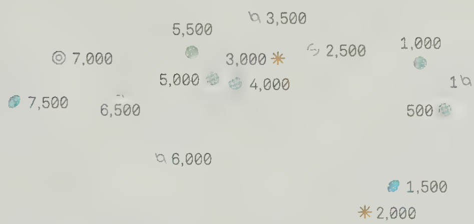
91
101

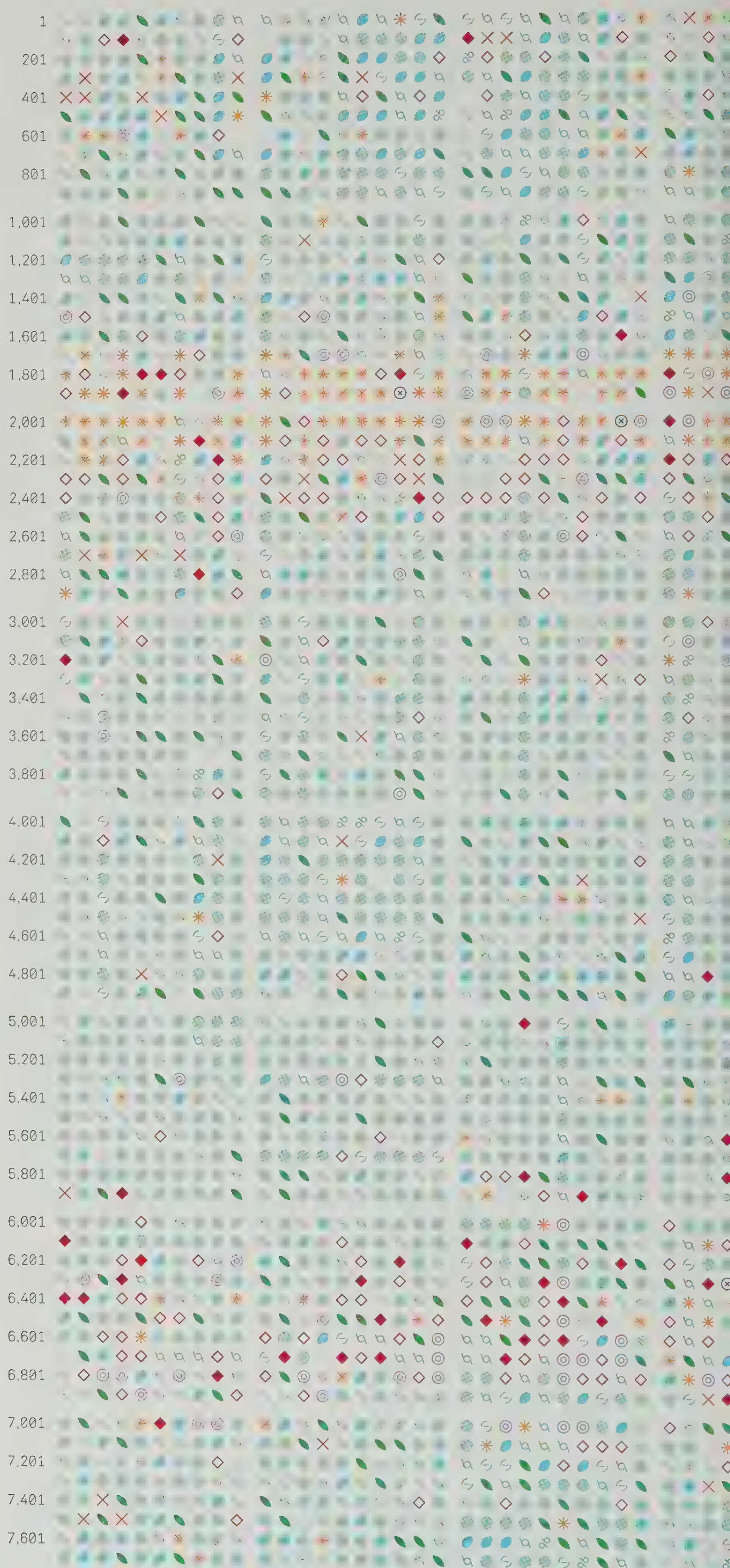
New General Catalogue

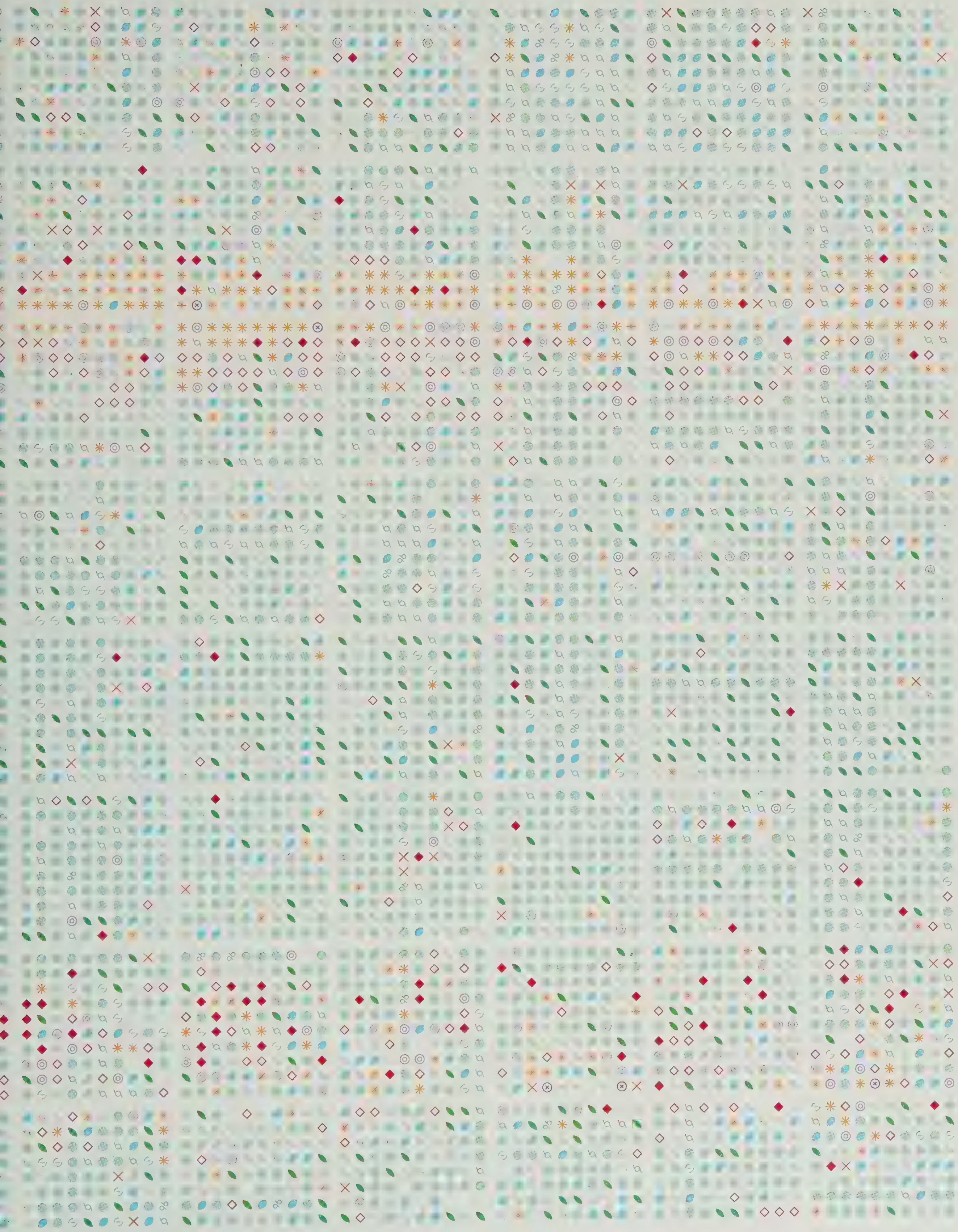
In the late 19th Century, the Royal Astronomical Society asked John Dreyer to compile a New General Catalogue (NGC) of nebulae and clusters. This was a large catalogue curated from previous catalogues and observations of astronomers from many different countries using many different telescopes.

The catalogue was arranged by angle on the sky so nearby catalogue entries can usually be observed at a similar time of night. In the regions *NGC 1700 – NGC 2500* and *NGC 6300 – NGC 7100* the catalogue cuts along the plane of the Galaxy so these parts show far more star clusters and nebulae than others. Since publication, nearly 60 of the objects have been found not to exist; they have either been lost or were mistakes.



Star
Group of stars
Open cluster
Globular cluster
Nebula
Supernova remnant
Galaxy
Spiral galaxy
Barred galaxy
Lenticular galaxy
Elliptical galaxy
Interacting galaxy
Lost / Doesn't exist (gap)





Unsung heroes of astronomy

Few astronomers become well known for their discoveries. Here are a selection who have increased our knowledge of the Universe but remain relatively unknown.

Aristarchus of Samos
310 – 230 BCE

Greek astronomer who first proposed the Sun as the centre of the Solar System. He also suggested that the stars were other suns. He attempted to measure the relative distances of the Moon and Sun.

Thomas Harriot
1560 – 1621

English astronomer who was the first person to observe the Moon through a telescope.

Maria Margarethe Kirch
1670 – 1720

German astronomer who studied the Aurora Borealis (northern lights), planetary conjunctions and created calendars. She was the first woman to discover a comet although the credit was taken by her husband.

Caroline Herschel
1750 – 1848

She was the first woman credited with the discovery of a comet in her own right. Discovered eight comets. In 1787 she was paid a salary by King George III to work as an astronomical assistant.

John Goodricke
1764 – 1786

Dutch-English amateur astronomer proposed the concept of an eclipsing binary star to explain his observations of the star Algol.

Urbain Le Verrier
1811 – 1877

He studied perturbations in the orbit of Uranus. Using mathematics he determined that these were due to an unknown body and sent his predictions of its location to Johann Galle at the Berlin Observatory. Galle found the planet Neptune within an hour of starting to look.

Angelo Secchi
1818 – 1878

Italian astronomer who invented the heliospectrograph for studying the spectrum of light from the Sun. He proved that prominences observed during eclipses were part of the Sun. He also discovered three comets and was the first to describe 'channels' (canali) on Mars.

Williamina Fleming
1857 – 1911

Scottish-American astronomer who discovered about 40% of the novae that were then known.

Annie Jump Cannon
1863 – 1941

American astronomer who created a classification scheme for stars that split them into the classes O, B, A, F, G, K, and M.

Annie Scott Dill Maunder
1868 – 1947

Irish astronomer who worked at the Royal Observatory Greenwich observing the Sun. She was an expert in eclipse photography. Together with her husband she discovered the minimum in sunspot numbers now known as the 'Maunder Minimum'.

Henrietta Swan Leavitt
1868 – 1921

American astronomer who discovered Cepheid variable stars which provided a standard candle to measure the Universe.

Georges Lemaître
1894 – 1966

Belgian cosmologist and priest who proposed the expansion of the Universe, first estimated the Hubble constant, and proposed that the Universe began with an explosion at a point in time.

Fritz Zwicky
1898 – 1974

Swiss astronomer who made contributions to many areas of astronomy. He found 123 supernovae and even helped coin the word for them. He predicted the existence of gravitational lenses due to galaxy clusters 42 years before the first one was found. He was also the first person to observe the effects of dark matter.

Celia Payne-Gaposchkin
1900 – 1979

As a 25 year old student, Payne's doctoral dissertation argued that the majority of the Sun, stars and the Universe was composed of hydrogen. Although initially dismissed, she was later shown to be correct.

Ruby Payne-Scott
1912 – 1981

Australian astronomer who was the first female radio astronomer. She extensively studied the Sun and discovered various types of radio burst. She played a large part in the first-ever radio interferometer.

Grote Reber
1911 – 2002

American who built the first parabolic dish radio telescope. He conducted the first radio sky map identifying the galaxy and also discovering objects such as Cassiopeia A and Cynus A.

Nancy Grace Roman
1925 –

American astronomer who became NASA's first Chief of Astronomy. She oversaw the launch of three solar observatories and three astronomical satellites. She was involved in the early planning and design for the Hubble Space Telescope.

Beatrice Tinsley
1941 – 1981

A New Zealand astronomer who studied stars and galaxies. She completed her PhD at the University of Texas in only two years and her thesis was the basis for much of the subsequent study of the evolution of galaxies. During her career she worked on a huge range of topics.

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The Universe is everything there is. Our understanding of what that means, and our position in it, has changed considerably over the past few thousand years. Incredible leaps in the technology available to us means that finally we are able to get a true glimpse of its astounding complexity, mindboggling scale and, more than anything, its breathtaking beauty. It contains stars 1,700 times larger than our Sun, thousands of galaxies and innumerable displays of nature on its grandest scale. In this huge expanse of dark matter anything is possible: intrepid robotic explorers trundle along in the exploration of Mars, there are lakes of lava and lakes of hydrocarbon, perhaps even planets that could support other civilisations.

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