Tweeting the Universe

Tiny explanations of very big ideas

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First published in 2011
by Faber and Faber Limited
Bloomsbury House, 74–77 Great Russell Street,
London, WC1B 3DA
This paperback edition first published in 2013

Typeset by Faber and Faber Limited
Printed and bound by CPI Group (UK) Ltd, Croydon CR0 4YY

A CIP record for this book
is available from the British Library

ISBN 978–0–571–29570–8

2 4 6 8 10 9 7 5 3 1

The Sky

1. What causes a rainbow?

1665. Plague in London. To northeast, Cambridge closes. Newton, 22, unknown, treks home. Secluded for 18 months, he changes face of science.

During his 'miraculous year', when he explains gravity, Newton wonders: Why are stars seen through telescopes fringed in rainbow colours?

Telescope uses lenses – glass discs whose thickness varies. Newton uses a simpler version: triangular wedge whose thickness varies (prism).

Newton places prism in the path of white sunlight coming through a slit in curtains at Woolsthorpe. Projected on darkened wall, he sees . . .

. . . fanned out into a 'spectrum', all colours of rainbow – red (r), orange (o), yellow (y), green (g), blue (b), indigo (i), violet (v).

(Not many people know this … Roy. G. Biv is actually a character in *The Information*, the comic novel by British novelist Martin Amis.)

Newton places a second prism (the other way up) in the path of the spectrum and the colours miraculously recombine into white light.

Newton concludes, correctly, that white light coming from the Sun is in fact made of all the colours of the rainbow woven together.

What glass in a prism in fact does is bend different colours by different amounts, fanning out white light into its constituent colours.

Light is a wave (too small to see) & different colours are different sizes (wavelengths). Red light is about 2x wavelength of blue.

A rainbow is created by rain droplets, acting like myriad tiny prisms and splitting white sunlight into its constituent colours.

Back surface of droplet acts like tiny mirror. Light can re-emerge after 1 reflection or 2: so often 2 rainbows, 2nd with colours reversed.

The angle between the incoming and outgoing light ray is 42° (the 'rainbow angle'). For the secondary bow the angle is 51°.

A rainbow is in fact a circle. However, because the horizon gets in the way, we see only part of the circle – a semicircular bow.

Newton overcame problem of rainbow colours fringing stars by replacing lenses with mirrors. Invented 'reflecting' telescope. That's genius!

2. Why is the sky blue?

Since air is patently transparent, this is far from obvious!

Explanation of why sky is blue was found in late 19th century by English physicist Lord Rayleigh (winner of 1904 Nobel Prize for physics).

Key fact 1: light is a wave like a ripple spreading on a pond. This is far from apparent since size of wave (wavelength) too small to see.

Key fact 2: White sunlight, as Newton discovered, is made of all colours of the rainbow, from blue (smallest wavelength) to red (longest).

Key fact 3: Molecules of oxygen/nitrogen in the air just happen to be of a size that deflects (scatters) blue light far more than red.

Consequence: as white sunlight comes down through air, blue light is preferentially removed (scattered). Creates diffuse blue background.

As Sun sets on horizon, it turns red since light must travel through more atmosphere, subtracting 100% of the blue light, leaving only red.

If the particle size in atmosphere changes, so too can sky colour. Sky goes red if there are pollutants or dust from volcanic eruption.

If particle size is just right, you can even get a blue moon. One possible origin of the phrase ‘once in a blue moon’, meaning ‘rarely’.

Sky on Mars can be pink or yellow since colour depends only on size of particles hoisted into the thin atmosphere by dust storms.

High up in Earth’s atmosphere, there are few air molecules to scatter sunlight. The sky, instead of blue, is therefore inky black.

3. Why is the rising Full Moon so large?

Quick answer: it isn't. Yes, the Moon does indeed appear huge when low on the horizon (as does the Sun). But it's just an optical illusion.

Here's how to prove it. Hold a small coin at arm's length. Compare the relative size of the rising Moon to the size of the coin. Then . . .

. . . repeat the same thing with the Moon high in sky. You'll find that the Moon's size is exactly the same. It's called the Moon illusion.

The same is true for the rising or setting Sun. But, since you usually don't stare at Sun, you notice the effect principally with Full Moon.

BTW: same effect seen with the constellations. The Plough seen just above distant buildings looks much larger than it does high in the sky.

So what causes effect? No one knows. May be related to our perception of the sky (incorrectly) as slightly flattened, not 100% spherical.

The Moon illusion is much less impressive from the middle of an ocean. Seems to imply trees/buildings on horizon are important ingredient.

Most probable reason Moon appears large is because it's in the same field of view as distant objects whose true size we know all too well.

If the Moon illusion is trick of mind, it should be absent if you fool your mind into seeing familiar things like trees as unfamiliar . . .

Bend over and look at rising Moon between your legs. Everything is upside down & unfamiliar and, hey presto, the Moon illusion almost gone.

In reality, the Moon on horizon is slightly 'smaller' than Moon above your head. Think about it: it is further away by one Earth radius.

Also, not every Full Moon has same size in sky. This is because Moon's orbit is elliptical, causing the Earth–Moon distance to vary a lot.

Thing to remember: Moon is actually a very small object in the sky. Artists always make it bigger than it should be in paintings/drawings.

4. What causes the phases of the Moon?

Appearance of Moon constantly changing: thin crescent, half-lit, gibbous, full etc. Time for complete cycle approx. 29.5 days (lunar month).

Key fact: unlike Sun, Moon doesn't emit its own light. Instead, Moon is visible only when illuminated by Sun – when it reflects sunlight.

The 'phases' are caused by changing illumination by the Sun: sometimes a lot of the Moon's surface is illuminated, sometimes only a little.

Like Earth, Moon has bright day side (facing Sun) & dark night side. Always half lit; no permanent dark side of the Moon (sorry Pink Floyd).

When the Moon and Sun are in about the same direction, the Moon is lit from behind. From Earth, we see its dark side. This is a New Moon.

About a week later, Moon has completed first 25% of orbit (First Quarter). Sun now illuminates Moon from the west. We see half-lit Moon.

After another week, the Moon is in the opposite direction to Sun. From Earth, we see its illuminated side. This is a Full Moon.

Finally, after completing 75% of its orbit (Last Quarter), Moon is illuminated from the east. West-facing hemisphere of Moon is now dark.

Memory aid: First Quarter Moon visible only during first half of night; Last Quarter Moon can be seen only during last half of night.

The Full Moon is opposite the Sun, so it rises around sunset, and sets around sunrise. This means it can be seen all night long.

Average lunar cycle lasts 29 days, 12 hours, 44 minutes, 2.9 seconds. This lunar month is still the basis of Jewish/Islamic calendars.

Earth also goes through phases, as seen from Moon. During New Moon, astronaut on Moon would see Full Earth, and vice versa.

5. What is a lunar eclipse?

A lunar eclipse occurs when the Earth blots out sunlight falling on Moon. Impressive phenomenon, mainly because of spooky red colour.

For lunar eclipses the Earth must be between the Sun and the Moon. So they can take place only at the time of a Full Moon.

Moon's orbit slightly tilted from Earth's equator. Full Moon tends to pass slightly above or below Earth's 'shadow' so no lunar eclipse.

During total lunar eclipse, Full Moon first enters outer, 'penumbral' shadow of Earth: only part of sunlight is blocked. Moon looks 'murky'.

Then, Moon enters central, 'umbral' shadow. A small bite is taken out of Moon, which grows larger & larger. Eventually, Moon fully eclipsed.

Surprisingly, Moon doesn't disappear altogether even if no direct sunlight falling on surface. Instead, glows with dark orange-red colour.

The eclipsed Moon's red colour comes from sunlight passing through Earth's atmosphere. Air molecules 'scatter' some light into the shadow.

To understand: imagine you're on the Moon during total lunar eclipse. You are in Earth's shadow, so Sun is blocked by Earth and invisible.

But Earth's atmosphere glows as red ring around dark planet, just as evening sky glows red after sunset. Result: Moon gets faint red hue.

During lunar eclipse, Full Moon first gets dim, then dark & red. Many more stars become visible. Total phase may take up to 1 hour, 40 min.

Some lunar eclipses are only partial (part of Moon passes through umbral shadow), or just penumbral (almost invisible).

Next total lunar eclipses: 10 Dec 2011 (Asia, Australia), 15 Apr 2014 (Americas, Australia), 8 Oct 2014 (N. America, East Asia, Australia).

6. What is a total solar eclipse?

A total solar eclipse is without doubt the most spectacular natural phenomenon you will ever witness. Don't die without seeing one.

Solar eclipse occurs when the Moon passes in front of the Sun. Since Moon must be between Earth & Sun, can take place only during New Moon.

Not every New Moon produces a solar eclipse. In most cases, New Moon passes above or below Sun because Moon's orbit is slightly tilted.

During eclipse, lunar shadow crosses Earth, tracing narrow zone of 'totality'. To see totality, you need to be at right place, right time.

During partial phase, Moon covers ever larger part of Sun's disc. Eventually, temperature drops, light gets eerie, animals become alarmed.

In final minutes, shadow races over ground to observer, planets come out in day, last sunlight glows like gem on circular 'diamond ring'.

Then darkness sets in, bright stars appear. Moon is like black hole in the sky, surrounded by glow of Sun's outer atmosphere, or 'corona'.

Totality lasts only a few minutes. Very powerful emotional event (some people cry!). Spell is broken by first sunlight at end of totality.

Total solar eclipse is result of cosmic coincidence. Sun is 400 x Moon size, but also 400 x further away, so they appear same size in sky.

Sometimes Moon further from Earth than average. Smaller apparent size means can't cover all Sun. Rather than total, 'annular' solar eclipse.

Next total solar eclipses: 13 Nov 2012 (N. Australia, Pacific), 20 Mar 2015 (N. Atlantic, Svalbard), 9 Mar 2016 (Indonesia, Pacific).

7. Why are summers warm and winters cold?

Earth's orbit isn't a perfect circle. It's slightly squashed ('ellipse'), so distance from Sun varies. However, nothing to do with seasons!

If it was, every place on Earth would have same seasons. Instead, it's summer in northern hemisphere when winter in south; & vice versa.

Seasons in fact caused by tilt of Earth's rotational axis. Like a globe in a classroom, the Earth is tilted 23.5 degrees from vertical.

In June, Earth's northern hemisphere is tilted towards Sun; southern hemisphere away. Six months later (December) it's the other way round.

In summer, days are longer than nights. Also, Sun climbs higher in sky, heating ground more efficiently. Net result: higher temperatures.

In winter, nights are longer than days. Sun stays low above horizon and doesn't have enough strength to substantially warm Earth's surface.

In northern hemisphere, most sunlight on 21 June – midsummer's day (summer solstice); least on 21 Dec – midwinter's day (winter solstice).

Since the ocean and atmosphere respond slowly to varying sunlight, the warmest/coldest months are actually after summer/winter solstice.

Around 20 March & 22 September, Sun exactly above Earth's equator. Spring/autumn equinox. Day and night same length everywhere.

Every planet with an axial tilt has seasons. Martian seasons are like ours (similar tilt), but they last longer (longer orbital period).

However, varying distance from Sun plays greater role on Mars since it has much more elliptical orbit than Earth. Seasons more extreme.

8. What is a constellation?

Tens of thousands of years ago, people looked up at the night sky and imagined patterns in the randomly scattered stars.

Some star groupings appeared to resemble animals such as bulls, dogs, bears and snakes. Thus were born the constellations.

Later, other star groups were named after gods and figures of myth. The Roman polymath, Ptolemy (AD 90–168), listed 48 constellations.

Most famous include: Ursa Major (Plough), Orion, Leo (Lion), Cygnus (Swan), Taurus (Bull), Cassiopeia, Gemini (Twins), Hercules.

In late 16th century, Dutch sailors mapped southern skies & added new constellations like Tucana (Toucan) & Apus (Bird of Paradise).

Later, new inconspicuous constellations were added to the northern hemisphere such as Vulpecula (Little Fox) & Lacerta (Lizard).

Since 1930, there have been 88 recognised constellations. Every location in the night sky is assigned to one or other constellation.

The stars in a constellation can be at vastly different distances and are usually not related, so constellations are apparent groupings.

A nearby star & an ultra-distant galaxy can belong to the same constellation – as long as they are neighbours in the sky.

Even as seen from Earth, the constellations change appearance over time very slowly, thanks to the proper motion of stars in the sky.

Some constellations are always visible; others never (except to people on the equator). Most can only be seen during a particular season.

Incas and Aboriginals also recognised 'dark cloud constellations': dark dust clouds in the Milky Way that resemble animals, like the Jaguar.

9. What is the zodiac?

Sun, Moon and planets move against the background of fixed stars. In other words they travel from one constellation to another.

In Sun's case, background constellations can't be seen of course. Nevertheless, path of Sun can still be deduced from observations.

Turns out Sun, Moon and planets are not free to wander anywhere in the sky. They never, for instance, show up in the Plough, or Orion.

Instead, motions of Sun, Moon and planets are always confined to band of 12 constellations circling sky: the constellations of the zodiac.

Zodiac constellations are best known: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, Pisces.

Though name 'zodiac' related to 'zoo', not all of its constellations are animals. Many are human. And Libra (Scales) isn't even alive.

The yearly path of the Sun through the zodiac (which reflects Earth's orbital motion) is actually a circle on the sky called the ecliptic.

Long ago, ecliptic was divided in 12 equal parts (zodiacal signs), more or less corresponding to constellations (which have unequal sizes).

Astrology (superstition) claims a person's character depends on position of Sun, Moon and planets in these zodiacal signs at time of birth.

In fact, due to slow wobble of Earth's axis, signs and constellations no longer match; shift is about one constellation in 2100 years.

Also, ecliptic (Sun's path) crosses non-zodiacal constellation of Ophiuchus (Serpent Bearer), which doesn't play role in astrology.

The zodiac contains some bright stars: Aldebaran (Taurus), Castor and Pollux (Gemini), Regulus (Leo), Spica (Virgo), Antares (Scorpio).

This means frequent beautiful 'conjunctions' of Moon and/or planets with one of these stars. Sometimes stars are even occulted by Moon.

10. What is the Milky Way?

Milky Way is faint band of light spanning the night sky. Can be seen only from dark places (outside cities), on clear, moonless nights.

According to Greek mythology, it was mother's milk spilled by goddess Hera when she breastfed Herakles. Romans called it Via Lactea.

In Norse mythology, ghostly Milky Way (Vintergatan, or Winter Street) was path along which dead souls travelled to Valhalla (afterlife).

Galileo Galilei (1564–1642) was first to study Milky Way with telescope. Surprised to find it consists of countless faint stars.

William Herschel (1738–1822) and Jacobus Kapteyn (1851–1922) tried to deduce extent and 3D shape of Milky Way by counting stars.

We now know the Milky Way is a giant, flattened disc of stars, with spiral arms. Sun is in outer regions of disc, close to central plane.

So why do we see Milky Way as band of light circling the sky? Analogy: living in suburb of giant city, where all buildings are transparent . . .

City is pretty flat, so most light you see during night is in (horizontal) band around you, with concentration in direction of city centre.

Looking up or down, you only see few lights (tall buildings, subway stations). Likewise, Milky Way is projection of flat disc of stars.

Size estimates of Herschel and Kapteyn much too small. Also, they thought Sun near centre of Milky Way. Hoodwinked by light-absorbing dust.

It's like being in city's suburb on very foggy night: you only see lights out to certain distance, and you seem to be at the centre.

Real size, spiral structure and dynamics of Milky Way could be measured only after advent of radio astronomy (1950s): not hampered by dust.

11. What are shooting stars?

Watch the night sky 15 minutes and you'll see something move across the stars. If it blinks and has a red light, it's probably an aircraft.

Bright orange/slow motion? Thai-style sky lantern, often in groups. Steady motion, visible for minutes? Artificial Earth-orbiting satellite.

As bright as planet Venus? Probably International Space Station (ISS). Follow @twisst for personalised, location-based alerts on Twitter.

But a star-like object that streaks across sky & is visible for just one or two seconds is almost certainly a meteor – 'shooting star'.

Not related to real stars at all. As meteor name implies (think meteorology), they arise high in Earth's atmosphere, at ~80 km up.

Their cause? Grain of sand/small pebble from space entering atmosphere (at 11 km/s or so). Heated to incandescence by friction with air.

The larger the pebble the brighter the meteor. The brightest ones are called fireballs. Can leave a faint trail lasting tens of seconds.

If large enough, burnt remnant can reach ground as a ‘meteorite’. Hard to find unless falls on snow (Antarctica) or desert sand (Sahara).

Meteors often connected to comets, which lose dust as they orbit Sun. If Earth moves through dust, more meteors than usual: meteor shower.

Meteors in shower appear to originate in one region in sky: the radiant. Similar perspective effect occurs if you drive through snow storm.

Showers occur yearly around same date. Famous: Perseids, around 12/13 Aug. Named because radiant is in constellation Perseus.

Others: Quadrantids (4 Jan), Lyrids (22 Apr), Draconids (9 Oct), Orionids (22 Oct), Taurids (6 Nov), Leonids (17 Nov), Geminids (14 Dec).

12. How many stars can I see?

It depends. On a crystal-clear, moonless night, far from city lights, a few thousand stars are visible to the unaided eye.

From a big city, only the very brightest stars can be seen. Fainter ones are washed out by light pollution, a curse to (amateur) astronomy.

Greek astronomers ranked stars according to brightness (magnitude). Brightest stars: magnitude 1; faintest visible with naked eye: mag 6.

Magnitude scale still in use, but made more precise. Difference in mag of 5 corresponds to factor 100 in brightness (1 mag to factor 2.512).

Also, brightest stars turn out to be brighter than mag 1. And stellar brightness can be measured with precision of 0.01 mag.

Betelgeuse: mag 0.50, Vega: mag 0.03, Sirius (brightest star in the sky): mag -1.46. Negative numbers imply greater brightness (Sun: -26.8).

Only 50 stars are brighter than mag 2 (visible from city); 500 brighter than mag 4; 5000 brighter than mag 6 (limit naked-eye visibility).

Using a telescope greatly increases the number of stars you can see. Small amateur telescope reveals stars as faint as mag 10: 340,000.

Hubble Space Telescope has revealed stars of mag 30 – few billion times as faint as your eye can see.

'Apparent brightness' depends on distance. Betelgeuse appears fainter than nearby Sirius, though in reality it pumps out much more light.

'Absolute brightness' is measure of true luminosity of star. Defined as apparent brightness if object were at 10 parsecs (32.6 light years).

Absolute brightness of Betelgeuse is mag -5.1. Of Sirius: mag +1.43. So Betelgeuse is few hundred times more luminous than Sirius.