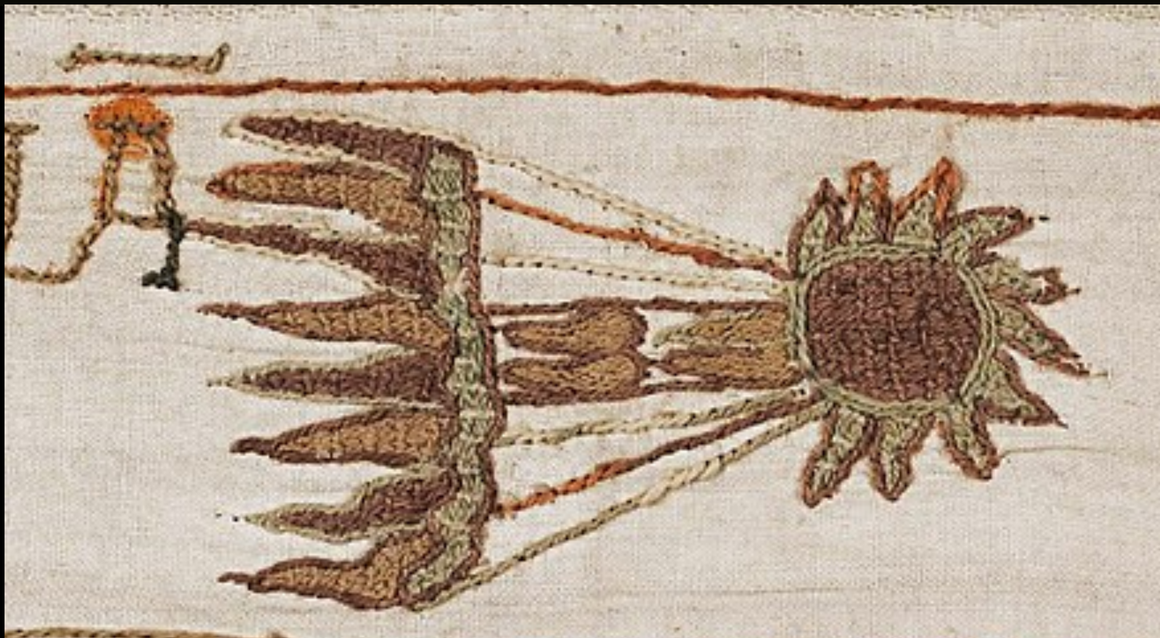
ASTB03 Lecture 13 Newton and followers

- Confirmation of Newtonian mechanics: comet Halley
- Newtonian Mechanics as a predictive science.
- Non-scientific life of ‘the last magician’
- Hallmarks of Scientific Method and Science

- Light and its spectrum – the emergence of astronomical spectroscopy

- LECTURE 14 = midterm

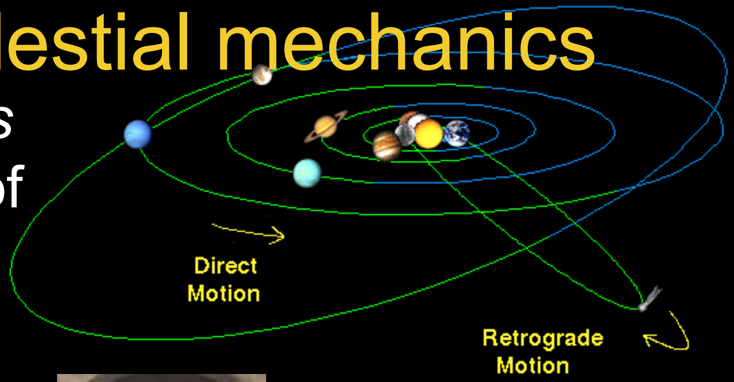
COMETS were feared. Bayeux tapestry from around 1066 with a bright comet that later became known as Halley's comet



battle of Hastings (1066)

1/P Halley in 1986:

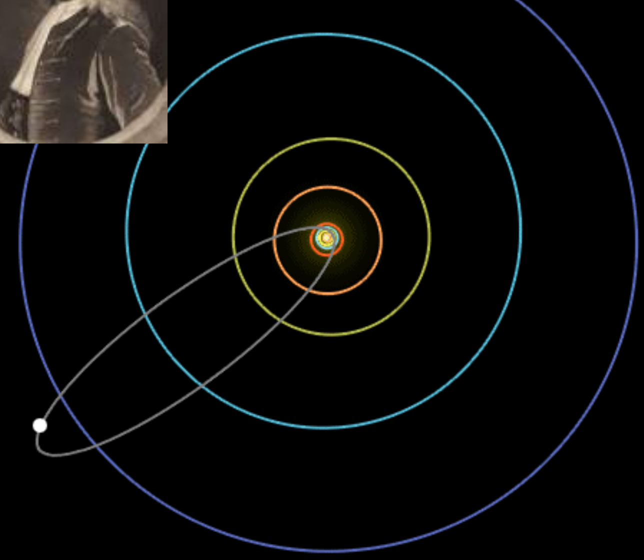
1P/Halley (Halley's comet) was a crucial confirmation of Newtonian celestial mechanics



Edmond Halley after computing *elements* (parameters such as *a,e,i* etc.) of orbits of 24 historical comets from observations, proposed that the comets previously observed by P. Apianus, J. Kepler and himself in 1682, every ~76 years, were one and the same object.
He predicted the return for 1758.

Halley died in 1742.

The comet was spotted in 1758, went through perihelion in 1759, and later was named after Halley.



Newtonian Mechanics became a predictive science.

a=17.8 AU, e = 0.967
P = 75.3 yr (currently)

TODAY WE KNOW THIS:

- Nucleus of comet Halley: an orbiting iceberg 15 km x 8 km x 8 km, losing ~6 m layer of silicate rocks and ice (H_2O and some CO, mostly) in every apparition
- The sand and stones remain in orbit, and cause Eta Aquarid meteor shower every May, and Orionid shower every October (e.g., 20 & 21 Oct. 2022)

photo: Giotto mission of ESA made this photo during a flyby in 1986

Life after science

Newton’s dog overturned a candle, causing a fire that destroyed much of his alchemical lab.

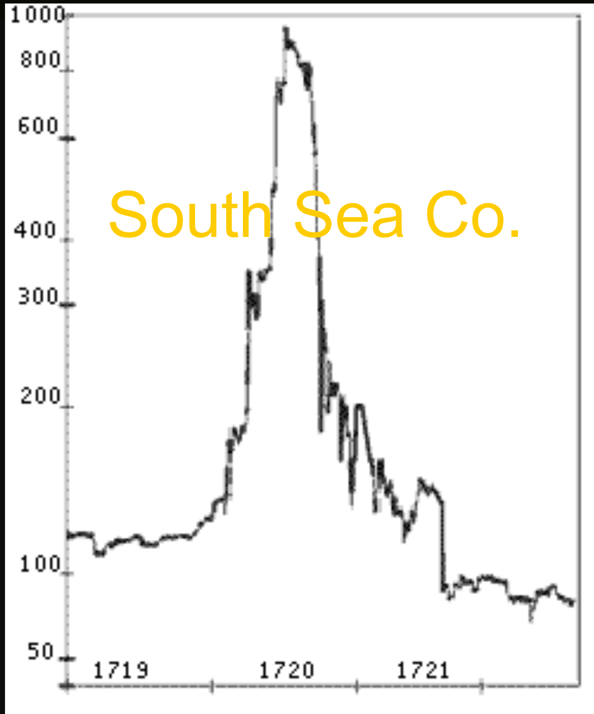
He moved to London and became a parliamentarian (never opening his mouth in Parliament, except on one occasion when he asked to close the window).

Then he became the Warden of Royal Mint (much like a central bank president, or Federal Reserve Board chairman today).

Newton was uncovering the coin forgeries with vehemence bordering on obsession (e.g., walking the streets in disguise).

He became rich.

But...



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Newton invested in South Sea Co. stock – using official Royal Mint account and perhaps money partially belonging to English taxpayers. A market bubble in the 1720 caused him to first sell the stock he owned for 7000 pounds after it has appreciated 2x. But the stock kept going up. Swept by euphoria, he bought it again at a much higher price, using all his(?) money. The bubble burst, but this time Newton held on to the stock. It is estimated that he lost most of his wealth, an equivalent of dozens of $millions today.

"I can calculate the motion of planets but not the madness of people"
Isaac Newton said, forbidding to utter words "South Sea" in his presence.

Literature on Newton and Halley

- A recommended book, 130 pages, if you want to learn more about Newton:

  Rob Iliffe, *Newton. A very short introduction,* (Oxford U. Press 2007).

UofT library makes the book available electronically. For your convenience, here is an alternative place

https://planets.utsc.utoronto.ca/~pawel/ASTB03/newton.pdf

- [BTW, If you want to read complete Principia (1687) in English with commentary of Steven Hawking, find his book "On the shoulders of giants".]

- Correspondence of E. Halley and other documents can be found at
- https://planets.utsc.utoronto.ca/~pawel/ASTB03/halley.pdf

(copy and paste URLs into browser if the links above do not work)

Newtonian dynamics as the first major unifying theory

Simple, i.e. with minimum number of principles, explaining very wide range of phenomena from oscillations of pendulum to orbits of planets.

Example: universal gravity

Unification and the economy of principles are important features of modern science that we call Scientific Method.

But principles can be simple & wrong at the same time. So more requirements are necessary.

Scientific method, whose origins can be traced to hellenistic period of Greece, became a norm in 17. century, the times of Galileo and Newton. It tells us how to build good scientific explanations.

Good scientific theories, those which provide new insight into Nature, are those that can make a broad range of *predictions that can & should be confirmed against observations.* *This is a requirement of scientific method.*

If a given doctrine cannot develop verifiable predictions and therefore, in principle, cannot be tested and falsified, then all you can do is to believe it, and it is not science.

If a theory is scientific, it cannot be proven once and for all, only supported empirically, leaving a possibility of future contradiction with empirical data.

A theory about Nature that is very well supported by evidence is called a natural law.

Newton's mechanics is exceptionally good science, verified successfully in countless experiments and practical life (such as engineering devices, vehicles). It has some limitations of applicability but we address circumstances not covered by classical Newtonian physics (such as very large speeds or gravity fields distorting geometry of space-time near a black hole, or extremely small objects) in newer, more general theories called Special and General Relativity, and Quantum Mechanics/Quantum Field Theory.

This does not make Newtonian physics 'wrong'. Quantum Mechanics is useless when you want to predict the trajectory of a planet or artificial satellite, for instance.

Incidentally, even if physicists ever find the sought-after Theory of Everything (unifying all interactions), it will have zero importance for biology, chemistry, or for building bridges.

Scientific method & the principle of economy of thought in Newton’s *Principia* (on p. 402):

“Hypoth. I. Causas rerum naturalium non plures admitti debere, quam que et ver sint et earum Phenomenis explicandis sufficiunt”

“Hypoth. I. That no more causes of natural things ought to be admitted than those which are both true and sufficient for explaining their phenomena”

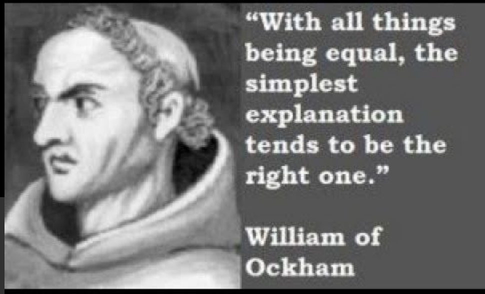
Good scientific theories strive to be economic about the number of basic principles, parameters and concepts: the fewer, the more elegant and better they are.

A single principle of universal gravitation, of biological evolution, or of quark structure of normal matter, can explain a very wide range of phenomena in physical and biological worlds. (*“Natura enim simplex est & rerum causis superfluis non luxuriat”*; *for Nature is simple and does not luxuriate in superfluous causes of things*”)

William of Occam (or Ockham) (1285-1347), a Franciscan.

Ockham’s razor: *do not make assumptions unnecessarily, cut the number & complexity of explanations to a minimum.*

It is incorporated as a guiding principle into science.




"OCCAM'S RAZOR?"
ARE YOU THREATENING ME??!!

Scientific method

Further hallmarks of the scientific method:

- openness through publication
- verifiability & repeatability by other scientists
- confronting theory with empirical studies (experiments or observations) is essential, pure theory usually degenerates into nonsense
- extraordinary claims require extraordinary evidence

Thus the scientific research sharply differs from:
business, military, politics, religion, occult, and pseudo-science (e.g., astrology)

Q: Should this list include the study of UFOs?

How science works and develops has been described by two 20th century philosophers of science, Karl Popper and Thomas Kuhn.

Science as an evolving process

According to Popper, science develops smoothly toward a better agreement with reality.

Kuhn disagreed, stressing that development of science is not logical, gradual and predictive. Rather, a given set of theories, a worldview, which we call *paradigm* can hold for a long time in science community, even though evidence against it accumulates (and is ignored). Then a scientific revolution happens, starting from most scientists disbelieving, ridiculing & not understanding the new paradigm, but later converting to it and saying that it is obvious and the previous was wrong/ridiculous. We saw this in Copernican Revolution but it happens repeatedly in all sciences.

Scientists are social creatures and most like to be in the “mainstream” science. Private donors before the 20th century and government funding agencies afterwards also influenced the development of science, mostly but not always in a helpful way.

But science can be objective and correct when done right. You will see it as you study the development of Astronomy. It is definitely not just a social construct.

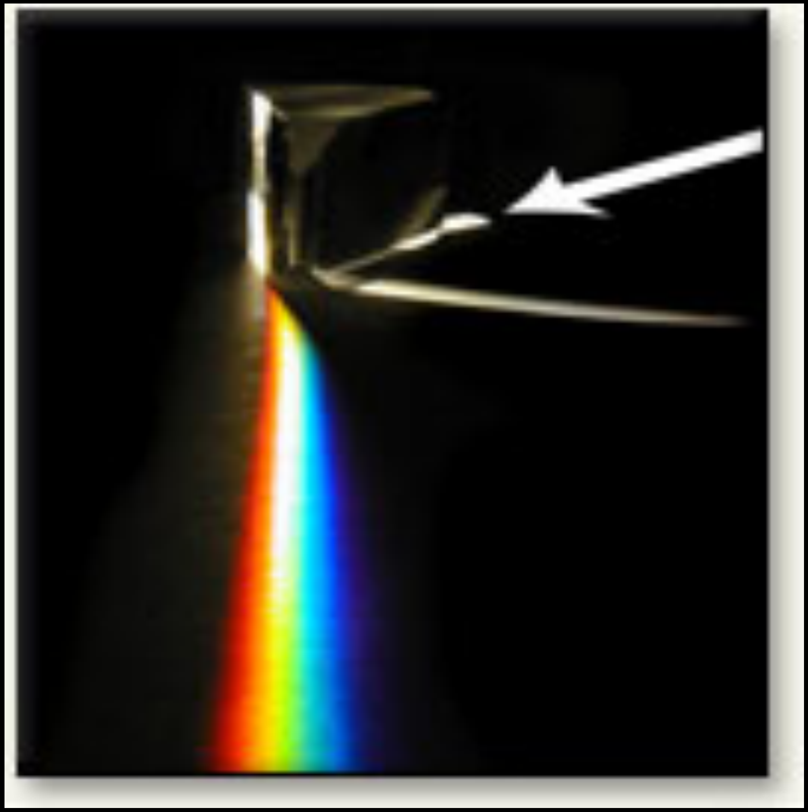
The ancient paradigm of ideal 5th element *ether*, or the native creation myths, fail to provide unifying, empirically supported answers.

Optics of Newton & later.

- Light and its spectrum
- Great new tool for Astronomy.

Light

Sunlight was decomposed into colorful bands by English philosopher Roger Bacon (1214-1294).
He used a glass of water, not a prism.
Prism is much better for splitting light, but the phenomenon is the same.

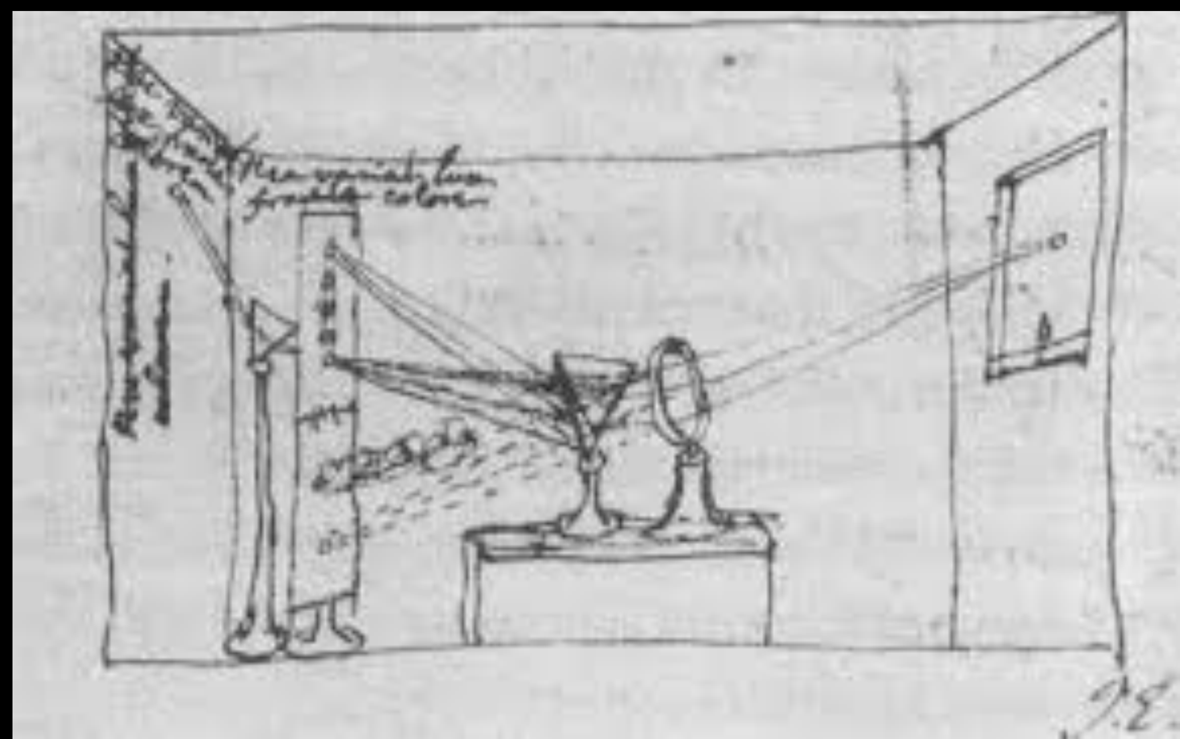


Light

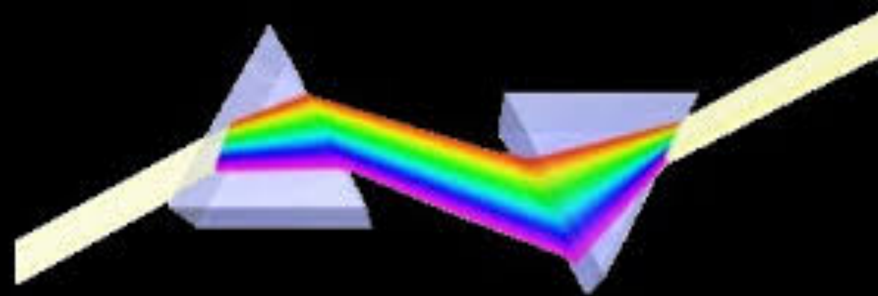
Sunlight was decomposed into spectrum by Newton between 1666 and 1672. It is a composite of “colors” – each color cannot be split further.

Newton claimed 7 rainbow colors. But that # was arbitrary.

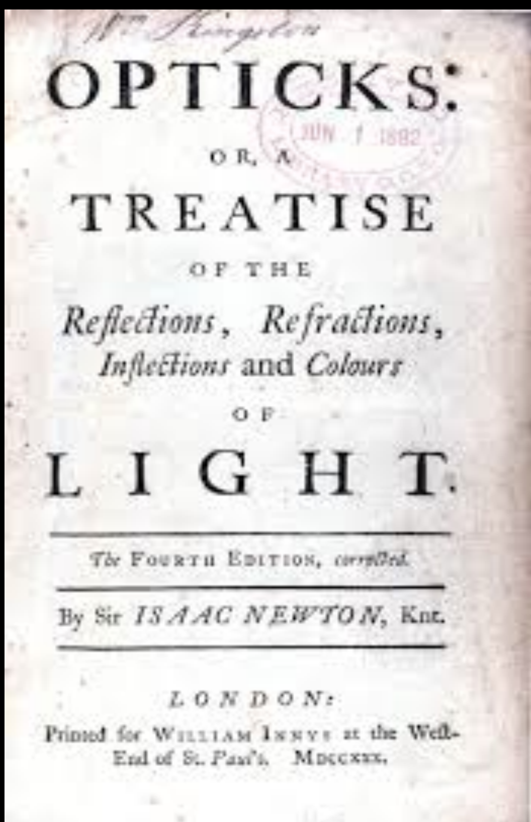
In fact, not arbitrary but motivated by the fact that 7 is a magic number!



Light



Sunlight was decomposed into colorful spectrum ***and*** recombined back to white light, which proves the composite theory of light.



OPTICKS:

OR, A

TREATISE

OF THE

Reflections, Refractions, Inflections and *Colours*

OF

LIGHT.

The FOURTH EDITION, corrected.

By Sir ISAAC NEWTON, Knt.

LONDON:

Printed for WILLIAM INNYS at the West-End of St. Paul's. MDCCXXX.

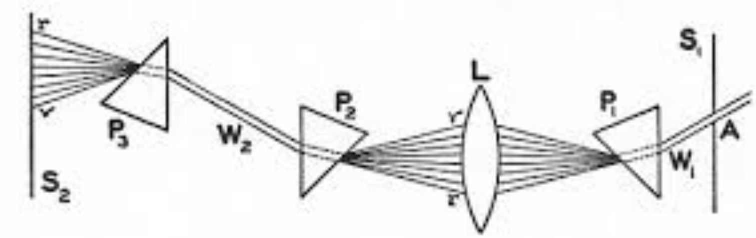
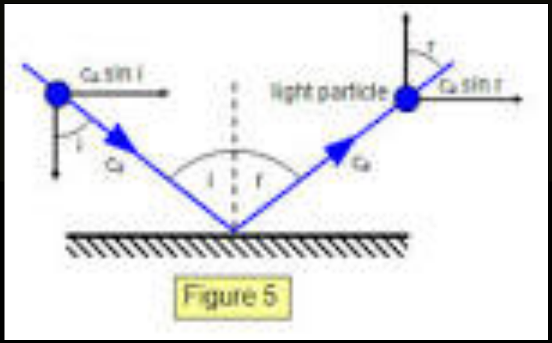


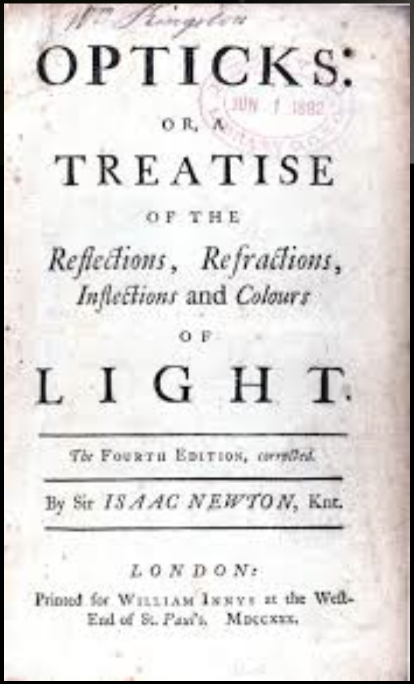
FIG. 8. NEWTON'S EXPERIMENT ON COLOR MIXTURE (1704)

W_1 is a beam of white light which passes through the aperture, A, in the shutter, S_1, and, being refracted by the prism, P_1, has its color dispersed as a spectrum, vr, upon the lens, L. The lens brings the colors together again on the prism, P_2, which, reversing the refraction at P_1, recombines the colors into a beam of white light, W_2, which is like the original W_1. The white light of W_2 can again be refracted and dispersed by the prism, P_3, so that the spectrum, rv, is thrown on the screen, S_2.

"Dark Side of the Moon" Pink Floyd album ~1972.
Two mistakes: a misleading title and a wrong cover Illustration (shown here) !

Light: particles or waves?





There is an analogy between light rays and elastic particles, for instance both bounce off a mirror/wall at the incidence angle. Thus Newton theorized that light is made of weightless material particles (corpuscules), not waves. Waves, according to Newton, don't behave like that. Particulate theory of light wasn't new. Pierre Gassendi (1592-1655) proposed it earlier.

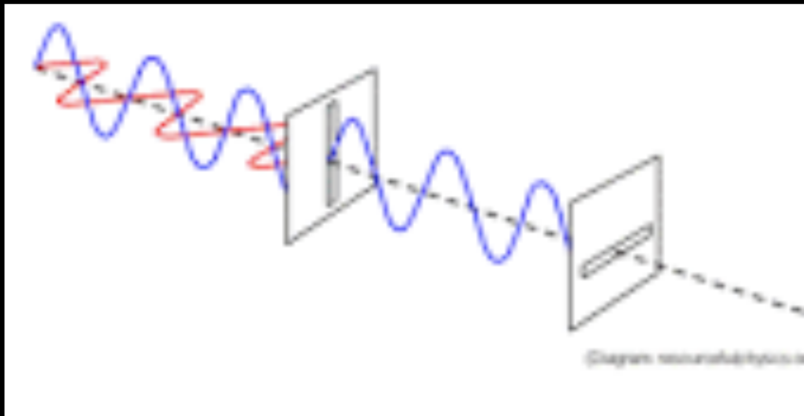
The wave vs. corpuscular (particle) nature of light was the first battleground between Newton and Hooke. The latter had much practical experience with optics. Hooke discovered the *diffraction of light* – and because the light did not behave like particles in diffraction, he favored a wave theory of light, as did Christian Huygens (1629-1695) in the Netherlands.

Light = corpuscules, a bad theory?

Isaac Newton's theory of light did not explain a lot of what was known in the 17th and 18th centuries. Newton was aware of the shortcomings of pure particle-based theory of light, so he added the part where particles are sent in pulses (in 'waves'). Despite the shortcomings, Newton's theory of light became accepted at least for a full century after Newton, so great were his reputation & authority. They created an unnecessary delay in the study of optical phenomena.

Robert Hooke, on the other hand, proposed that light waves are transverse vibrations of some substance (ether?), and this view survived until the 19th century. This basically correct theory could not, at first, explain the phenomenon of polarization. Polarization was discovered around 1670. Fortunately, Newton's ideas on the nature of light were not all wrong!

Newton suggested that light particles have "sides". Indeed, light *waves* have "sides": Electric field of light wave is a sum of two independently oscillating, mutually perpendicular waves.



Light – Astronomy's messenger

Before the the late 18th century, stars were just points of light. Copernicus argued that the "fixed stars" are extremely far away, since he didn't see the parallax motion of stars on the sky. Nothing certain was known about their nature, parameters or distance.

Below we'll see how this started to change quickly, especially when a spectroscope was constructed. Newton's prismatic experiment was then done on starlight, not only on sunlight.

But that story began not in astronomical observatories but in chemistry labs.

Early spectroscopy in the laboratory

Spectroscopy as a physical science was founded in 1752, when the Scottish natural philosopher
Thomas Melvyll (1726-1753)
noticed that a flame in which a salt or metal was burned gave out a spectrum which only contained bright lines. The pattern of lines depended on the substance burned.
Melvyll proposed to identify substances in chemical labs by spectroscopy.

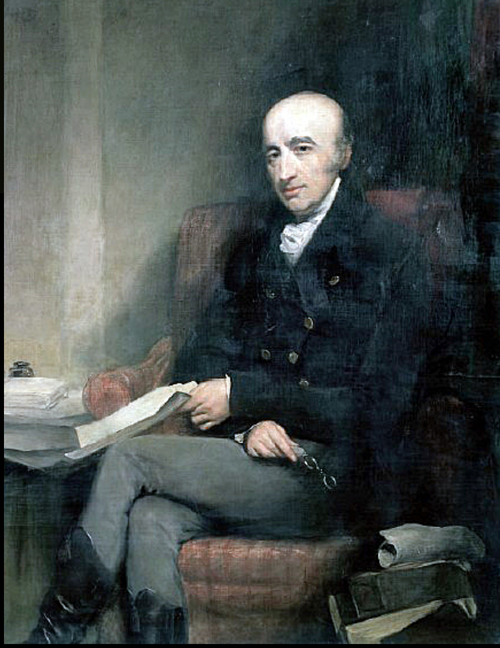
A widened range of wavelengths

Two discoveries, which later gave rise to the infrared and ultraviolet astronomy, took place around the turn of 18th and 19th c.

Frederic William Herschel (1738-1822). We will talk about his career in L15. He became interested in astronomy in his 30s. After constructing his first large telescope in 1774, he spent nine years carrying out thorough sky surveys, where his purpose was the investigation of double stars.
He pioneered the use of astronomical spectrometry as a diagnostic tool, using prisms and thermometers to measure the wavelength distribution of stellar spectra. He's found invisible light beyond the red end of Newton's spectrum: the infrared light (IR).

Later, J.W. Ritter tested the effect of solar spectrum on various chemicals. Silver chloride was blackened by the part of spectrum located beyond the violet end. He thus discovered the UV (ultraviolet).

Spectroscopy's beginnings



William Hyde Wollaston (1766-1828)

Medical doctor educated in Cambridge, then chemist (discovered palladium Pd & rhodium Rh), and metallurgist. In 1802 Wallaston repeated Newton's prism experiment but saw that the spectrum is not continuous. There was a pattern of dark lines in sun's spectrum. Wollaston thought that colors of any light in general are separated by black gaps but did not realize that the lines come from the sun's atmosphere. He thought colors of light are naturally separated like this.

12 years later, in 1814 the same observation of lines in the solar spectrum was made by Joseph Fraunhofer (1787-1823) in Germany. He compared it with other light sources…

Spectroscopy

A spectroscope was constructed by a Bavarian named Joseph Fraunhofer, in 1814. He later started a firm producing very good telescopes as well.

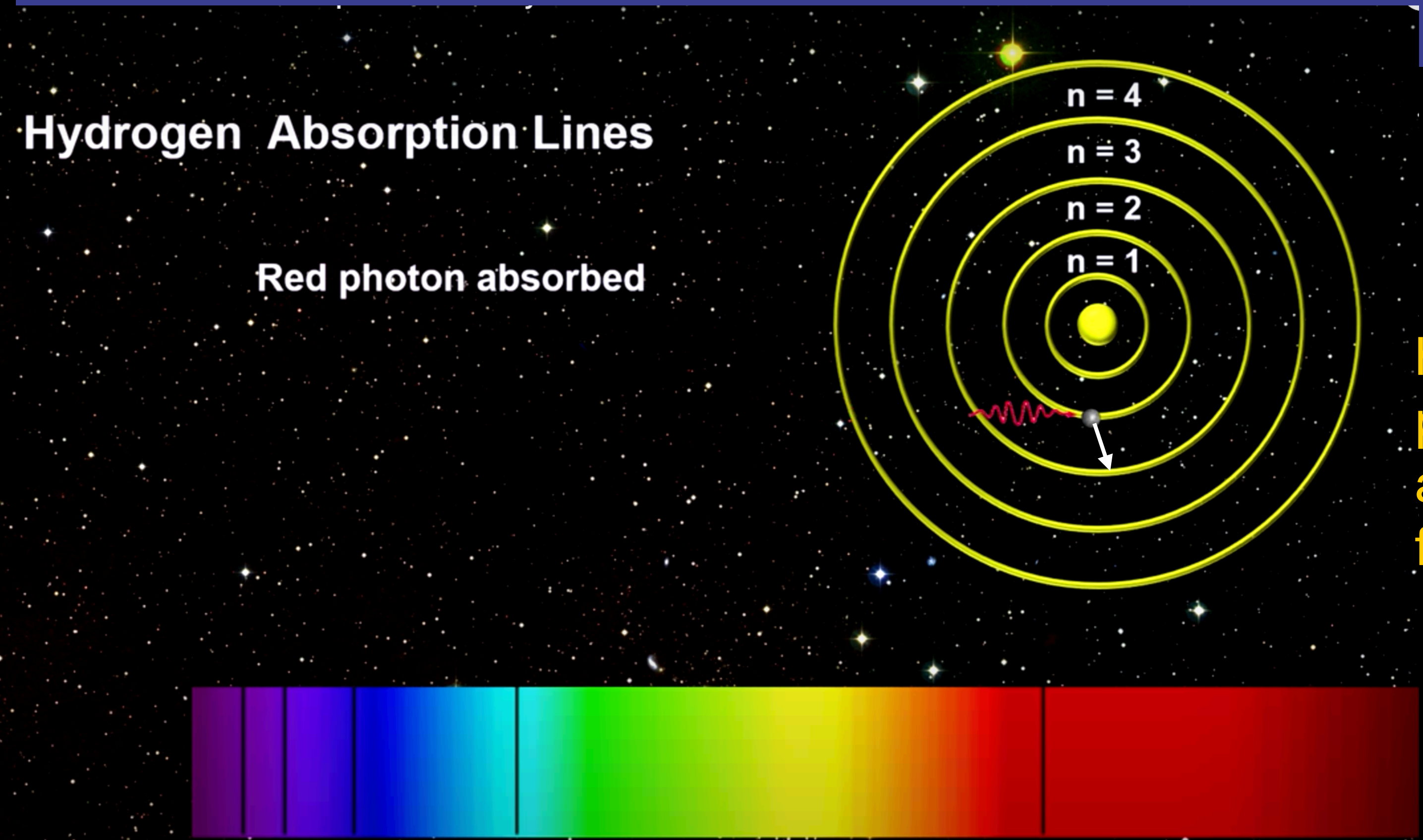
Fraunhofer realized that the line spectrum is the property of the sun, not of light itself. He measured 574 dark lines. We now measure millions of them.

He also used a telescope to gather more light from stars, and fed it to the spectroscope. The result was interesting: The lines were there, but at different positions and in different configurations than in the solar spectrum, depending on a star.

Fraunhofer and spectroscopy

- Video https://www.youtube.com/watch?v=cgV2OnKdzHk

When Fraunhofer lines were discovered, there was no connection yet between the bright lines of Melvyll and the dark lines in the stellar spectra.



how modern physics explains absorption line formation

Spectroscopy – the Great Moment in Astronomy

The connection was established in 1829, when Jean Bernard Leon Foucault (1819-1868) noticed that a dark line in the sun's spectrum, designated as D by Fraunhofer, appeared DARKER when the sunlight is first put through an electric arc, but BRIGHT in the spectrum of the electric arc itself. He understood the relationship between emission and absorption spectra.

Spectral lines correspond to the same wavelengths in both types of spectra. Emission lines are produced when the emitter (sodium in Foucault's arc experiment) is hot, absorption lines are produced when a continuum light (one with all possible wavelengths) is filtered by some object that selectively absorbs the special wavelengths, because it is colder than the source of continuum.

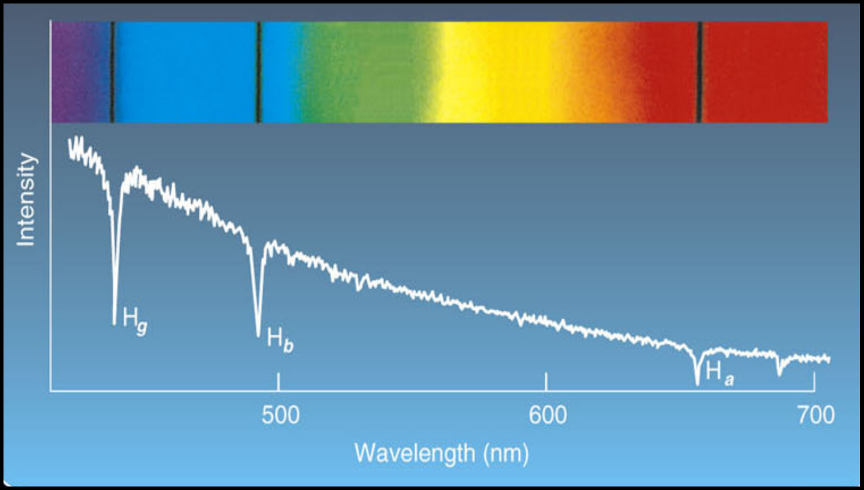
https://www.youtube.com/watch?v=I4yg4HTm3uk

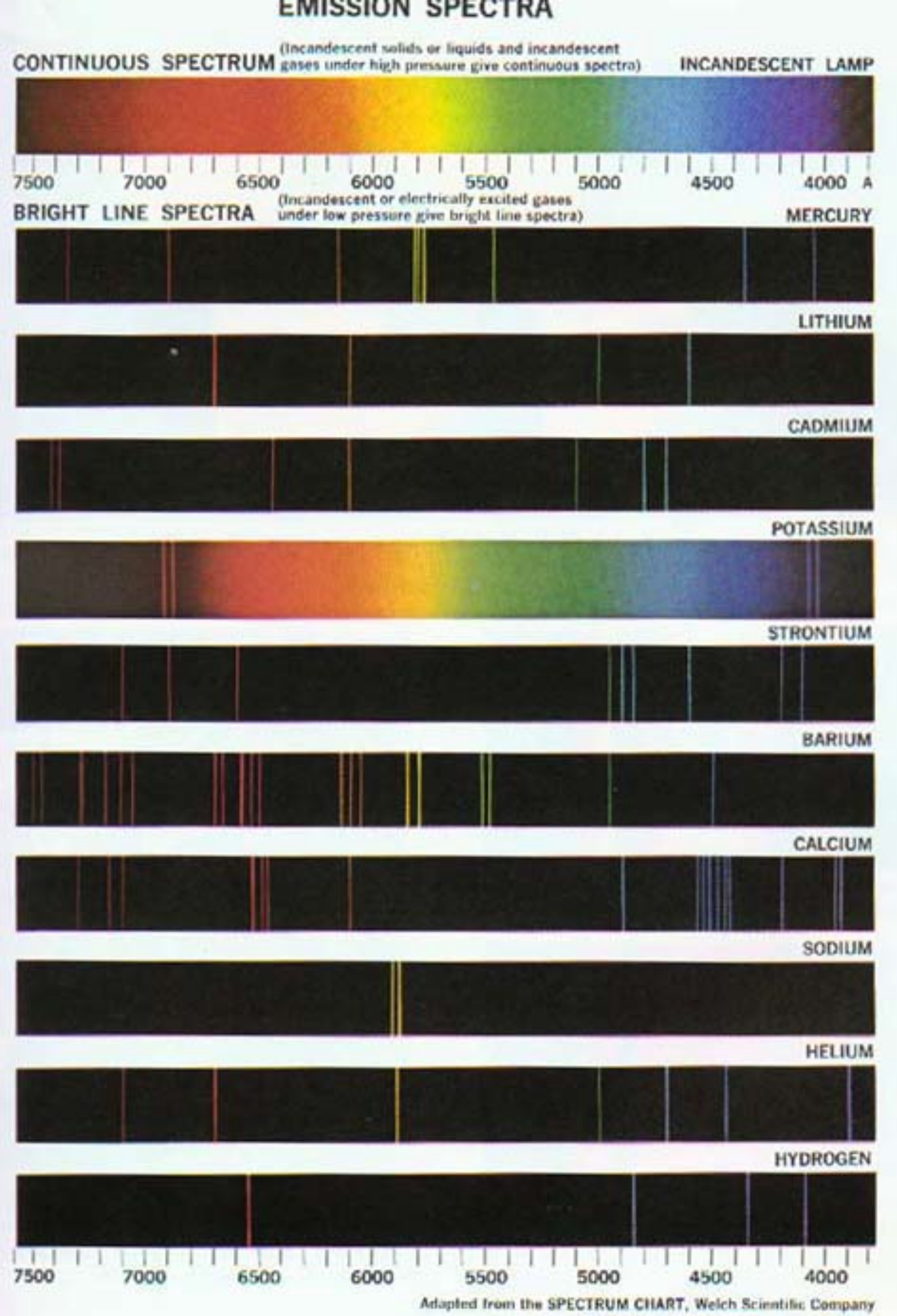
a 50-sec video about spectra

Emission spectra
(much later)

In 1823 John Herschel (son of F. William Herschel) was one of those who proposed to use spectroscopy to identify elements in stars.

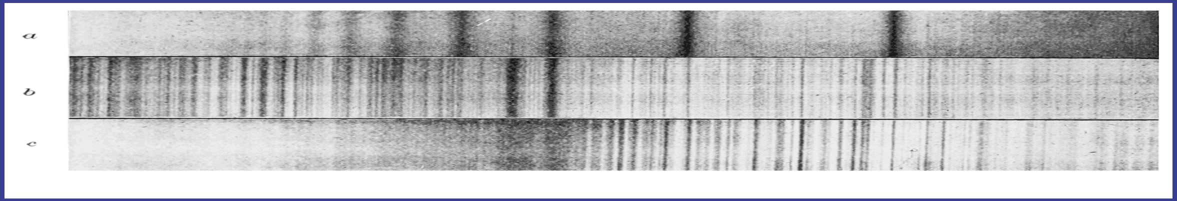
In 1855 David Alter described the spectrum of hydrogen.

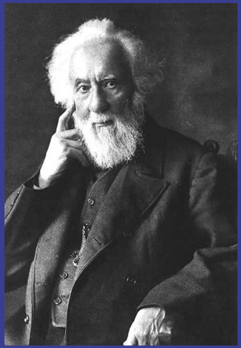




Spectroscopy

R. W. Bunsen (1811-99), G.R. Kirchhoff (1824-87) and H.E.R. Roscoe (1833-1915) were some of the most famous spectroscopists (the first two discovered new elements Cesium and Rubidium with that technique).





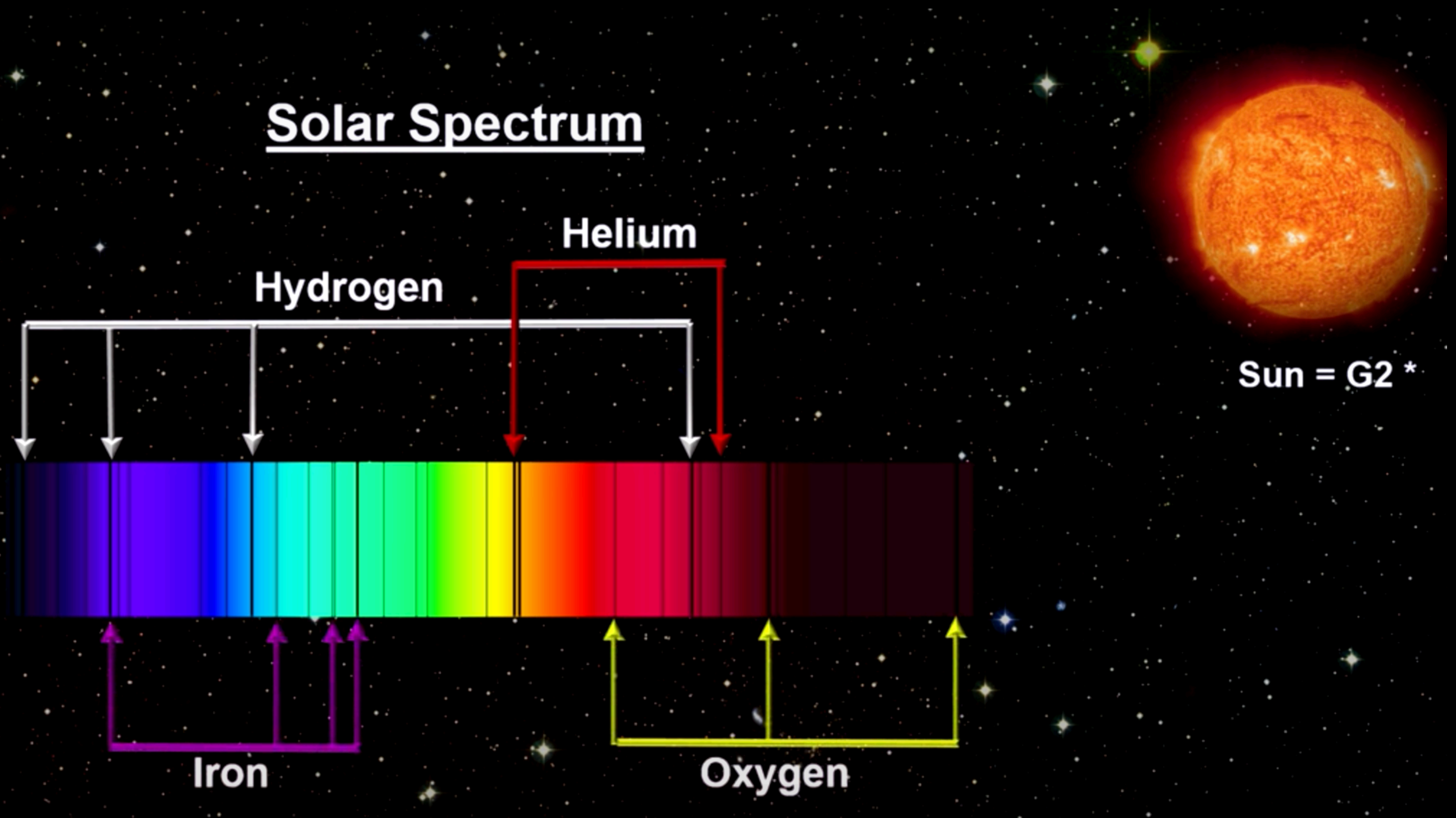
spectroscope & W. Huggins

Meanwhile, in the sky….

William Huggins (1824-1910),
Pierre Janssen (1824-1907),
and Norman Lockyer (1836-1920) started measuring the amounts of various elements in the stars.

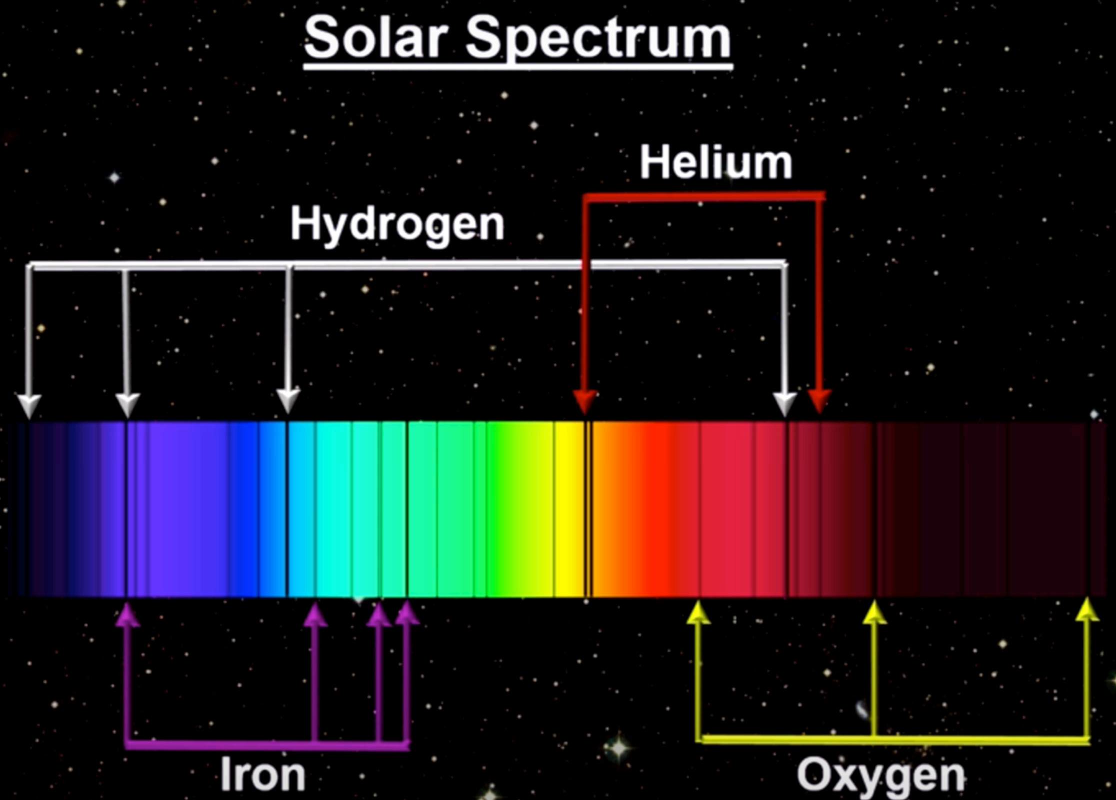
Stars were later divided into spectral classes: O B A F G K M R N, starting from the hottest & ending with those much cooler than the sun on the surface.

Suns spectral lines are due to many elements



* The number represents the temperature range within the spectral class (0-hottest to 9-coolest)

Abundance ratios can be derived from spectrum although that wasn't easy until late 19th c.

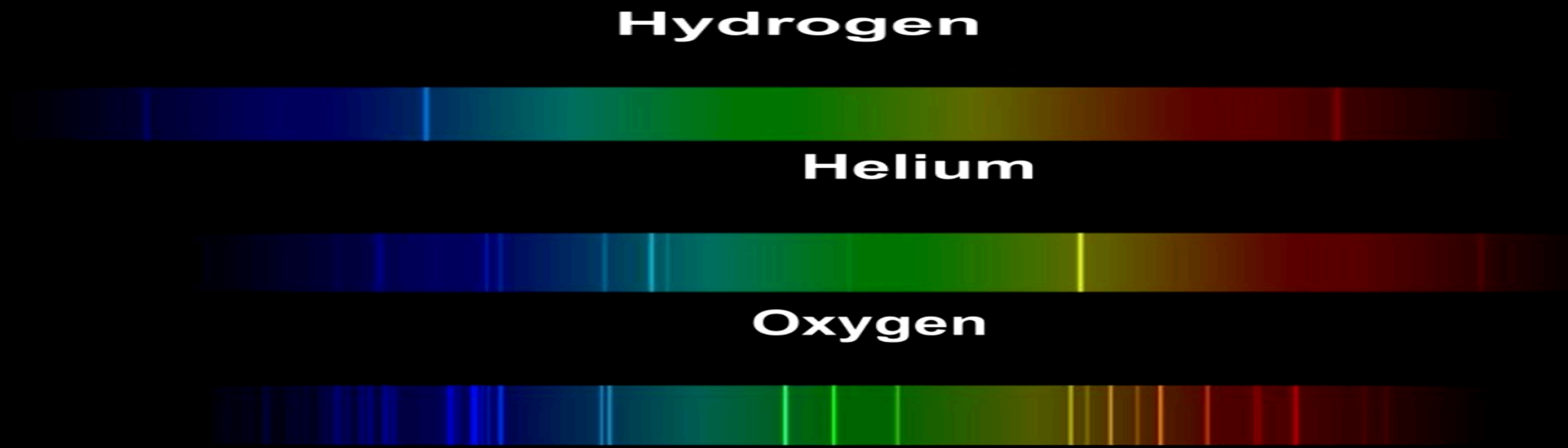


Sun = G2 *

Solar Content

Element	% total mass
Hydrogen	71.0
Helium	27.1
Oxygen	0.97
Carbon	0.40
Nitrogen	0.096
Silicon	0.099
Magnesium	0.076
Neon	0.058
Iron	0.014
Sulfur	0.040

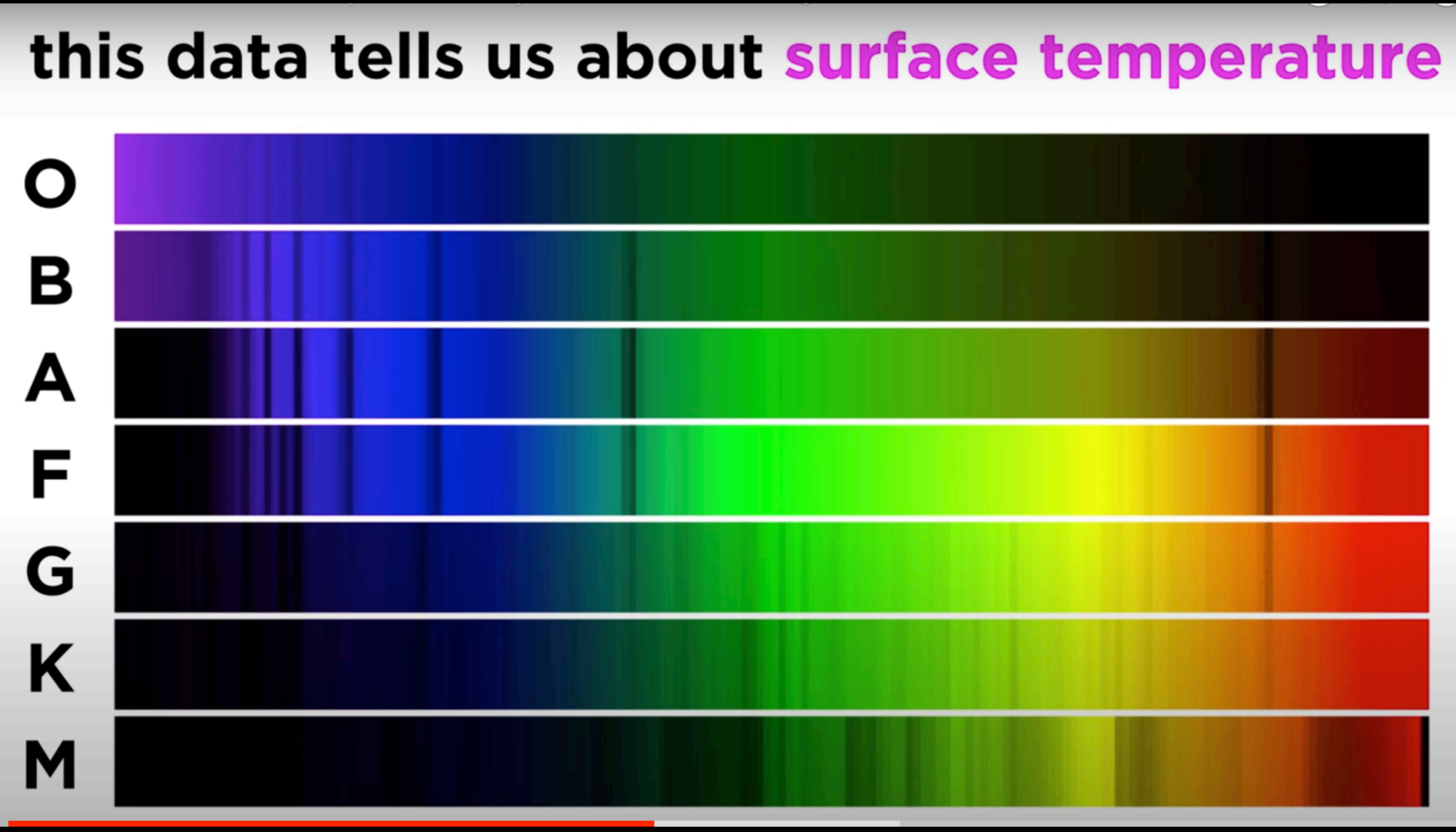
* The number represents the temperature range within the spectral class (0-hottest to 9-coolest)



Classification	Temperature (K)	Examples
O	> 30,000	Monocerotis
B	10,000 to 30,000	Rigel & Spica
A	7,500 to 10,000	Vega, Sirius B & Altair
F	6,000 to 7,500	Polaris
G	5,000 to 6,000	Alpha Centauri A & Capella
K	3,500 to 5,000	Arcturus & Aldebaran
M	< 3,500	Betelgeuse, Mira & Barnard's Star

Spectra of different stars form a sequence, which tells us not only about the chemical composition.

The peak of the spectrum is at wavelength that is inversely proportional to temperature.if the star's surface



surface temperature

25,000 K — 3,500 K

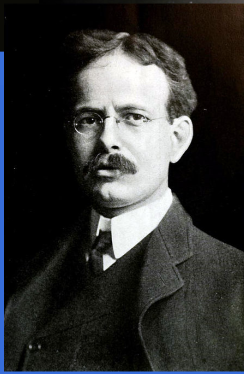
O B A F G K M

Oh, be a fine girl, kiss me!

Oh, be a fine guy, kiss me!

early type solar late type

Spectroscopy – early ideas about stellar evolution

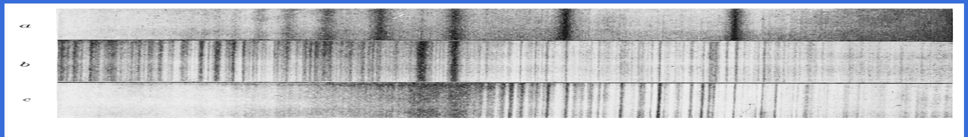


Huggins is mentioned in an interesting 1902 review of astronomy and astrophysics by George Ellery Hale, director of Yerkes, Mt. Wilson and Palomar observatories in the US (astrophysics is part of astronomy that partly stems from application of spectroscopy to the celestial objects)

http://en.wikisource.org/wiki/Popular_Science_Monthly/Volume_60/February_1902/Stellar_Evolution_in_the_Light_of_Recent_Research

"Sir William Huggins concludes from his spectroscopic studies that the highest stage of stellar temperature is reached in stars like Vega, while stars like Arcturus and the Sun have passed the stage of highest temperature and are already well advanced in their decline." (incorrect conclusion)

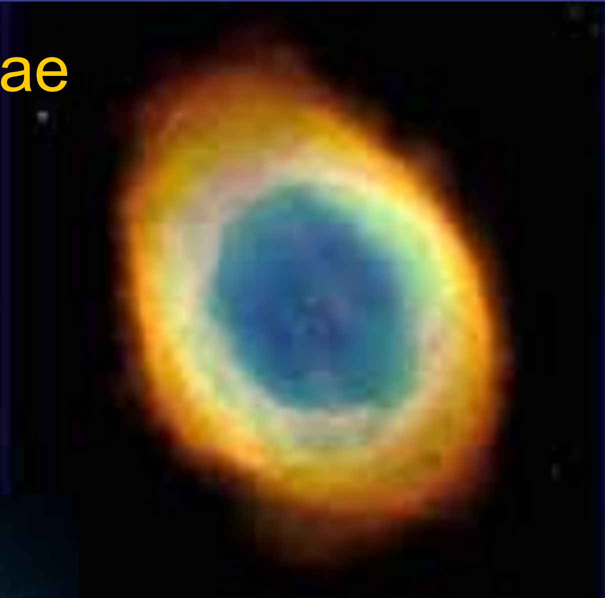
In 1902 there still was no understanding of stellar evolution! Astronomers assumed wrongly that the stars with hot surfaces are an early evolutionary stage, and that they later cool down to acquire a spectrum like the sun.
In reality, the O,B,A,F,G,K,M spectral classes contain completely different stars! (different mass at birth).



Spectroscopy – one of many Great Moments

William Huggins resolved the problem of the nature of **“planetary nebulae”** (Q: are they a gaseous nebula or star cluster? Through 19th century telescopes it wasn’t easy to see)

Planetary nebulae



← NGC 6543 in constellation of Draco
(Hubble Space Telescope mosaic)

Spectroscopy – its one of many Great Moments

Observing NGC 6543 from his home observatory in London, William Huggins proves that planetary nebulae are gaseous:

*On the evening of August 29, **1864**, I directed the spectroscope for the first time to a planetary nebula in Draco. I looked into the spectroscope. No spectrum such as I had expected! A single bright line only! At first I suspected some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. After passing through the two prisms it remained concentrated into a single bright line, having a width corresponding to the width of the slit, and occupying in the instrument a position at that part of the spectrum to which its light belongs in refrangibility. A little closer looking showed two other bright lines on the side towards the blue, all three lines being separated by intervals relatively dark. The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read: **Not an aggregation of stars, but a luminous gas.”***

Spectroscopy and the cosmic matter

https://www.youtube.com/watch?v=n_KyYFYNvpI - Video about the basics of astrophysical spectroscopy

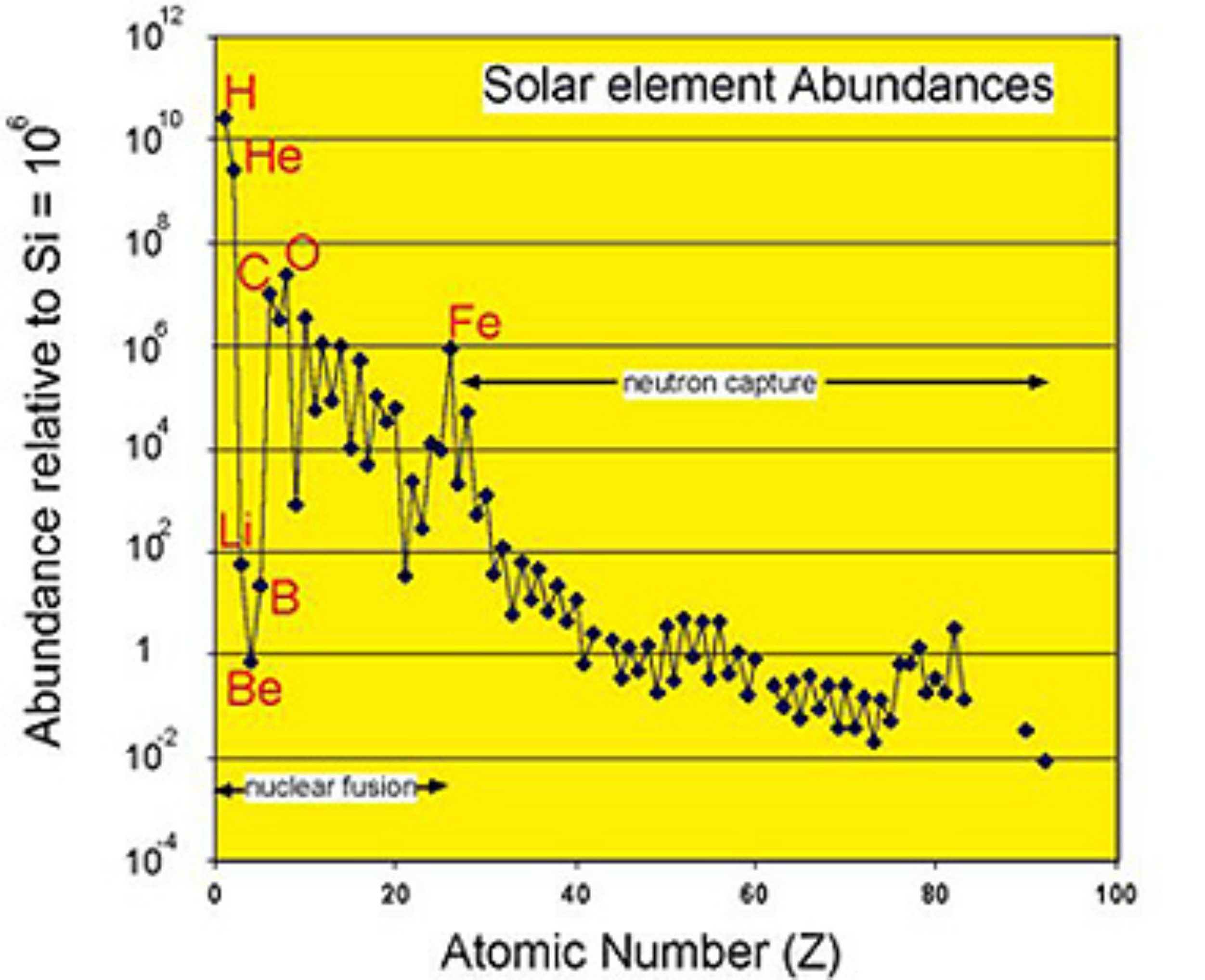
1878- Pierre Janssen and Norman Lockyer discovered Helium – a new and mysterious element not know on earth then:
https://www.youtube.com/watch?v=UrMQ38EJjjM&spfreload=10

Helium was a notable but short-lived exception. Helium is simply very rare on Earth (it escaped into space early in the history of our atmosphere; it was later discovered on Earth in 1895). Otherwise the rule is:

Every element we see in cosmos, we also find on Earth!

Spectroscopy and the elemental abundance

Gradually, astrophysicists learned the art of very precise, remote, chemical abundance measurements (first, in the sun). This diagram shows the number of atoms of each element, when # of silicon atoms = 1 million. Atomic number shows how massive each atom is.



Spectroscopy and the chemistry of Universe

We now know that the *whole universe is built from elements like those on Earth*, in not too different proportions (not exactly the same, with variations, but similar in the general pattern!)

One extreme example are very distant objects called quasars, which contain a supermassive black hole and a disk of gas around it. Most quasars lived just 1 or 2 Gyr after Big Bang so they are seen 10+ billion light years away from us, near the "edge of the observable Universe".

Somewhat unexpectedly, the gas in the vicinity of the black hole emits spectrum indicating roughly the same abundance pattern as in the sun, or sometimes a few times larger contents of heavy elements. BTW, elements heavier than helium are "metals" to astronomers.

Another example: The abundance pattern of rock-forming elements in the dust shed by asteroids and comets in extrasolar planetary systems is also similar to the solar one.

- The rest of the slides (below) present more in-depth information on Doppler effect and astronomical spectroscopy.
- The detailed historical information is not obligatory for exams, except the understanding of in what time periods something important for spectroscopy happened.

You just have to understand that relative motion of source or detector, or expansion of the space itself, affect the frequency and wavelength of light (speed of light in vacuum is constant). We call it Doppler effect. Measuring the shifts of spectral lines shows the motion of the light source w.r.t. the detector.

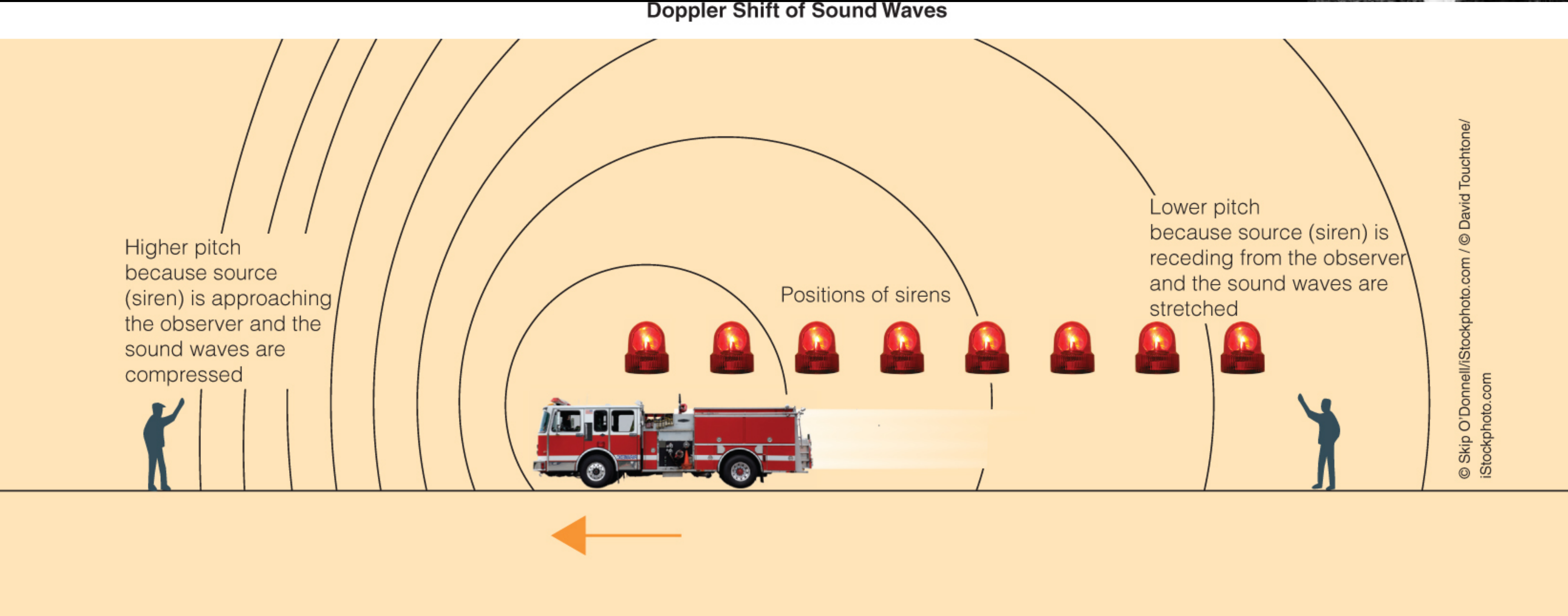
Doppler effect & how the spectrum reveals the radial velocity of the source object

- The Doppler effect is an observed change in the wavelength of radiation caused by relative motion of a source and observer. The effect is very small.
  - Astronomers use it to measure the speed of blobs of gas in the Sun's atmosphere toward or away from Earth, as well as speeds of entire stars, galaxies and far-away quasars.
  - There is also the so-called *Doppler broadening* of spectral emission/absorption lines, whenever the emitting/absorbing gas is not cold. Moving atoms emit/absorb at a slightly different wavelength than the resting atoms. Atoms move at speeds ~ soundspeed ~ $T^{1/2}$.
  - Line broadening thus measures the temperature T of emitting or absorbing gas (sometimes also micro-turbulence of gas).

The Doppler Effect (1839) –
Refresher about waves from moving objects

Christian Doppler

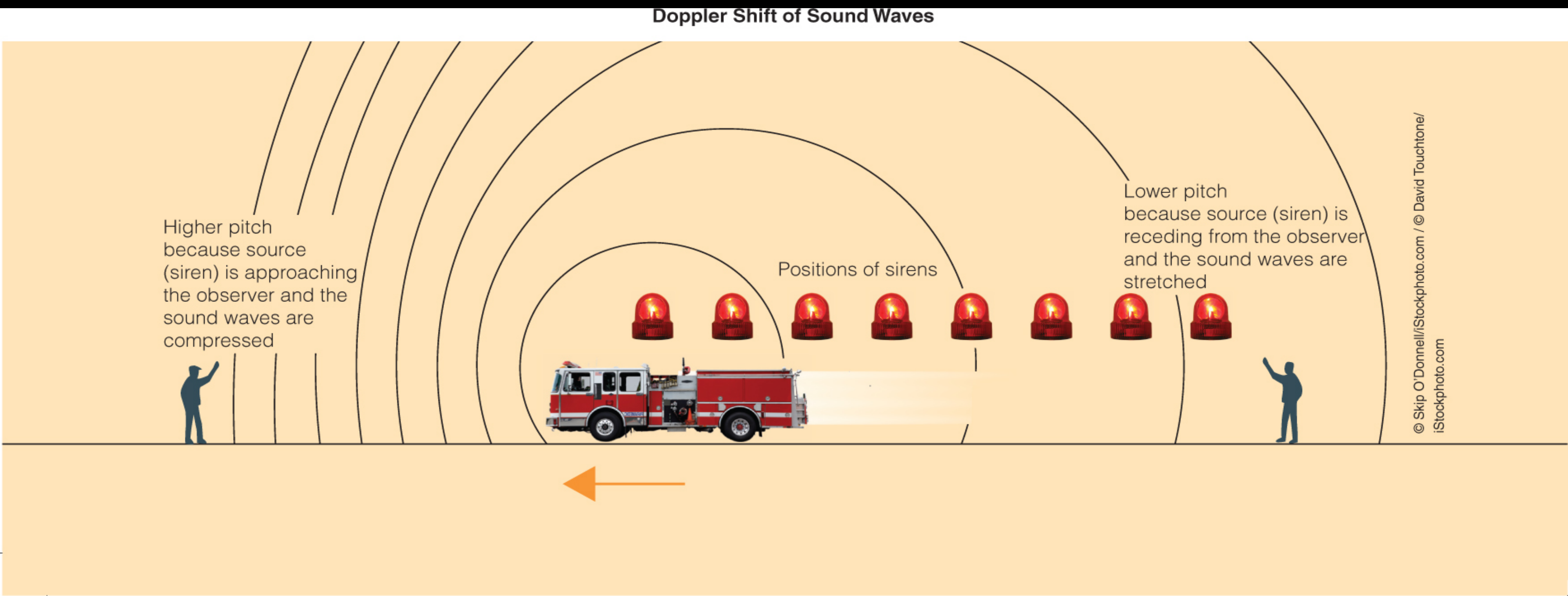
- The pitch of a sound is determined by its wavelength.
  - Sounds with long wavelengths have low pitch
  - Sounds with short wavelengths have higher pitch



The Doppler Effect for sound

Sound is shifted to shorter wavelengths and higher pitch while the source is approaching.

- The sound is shifted to longer wavelengths and lower pitch after source passes by & is receding.

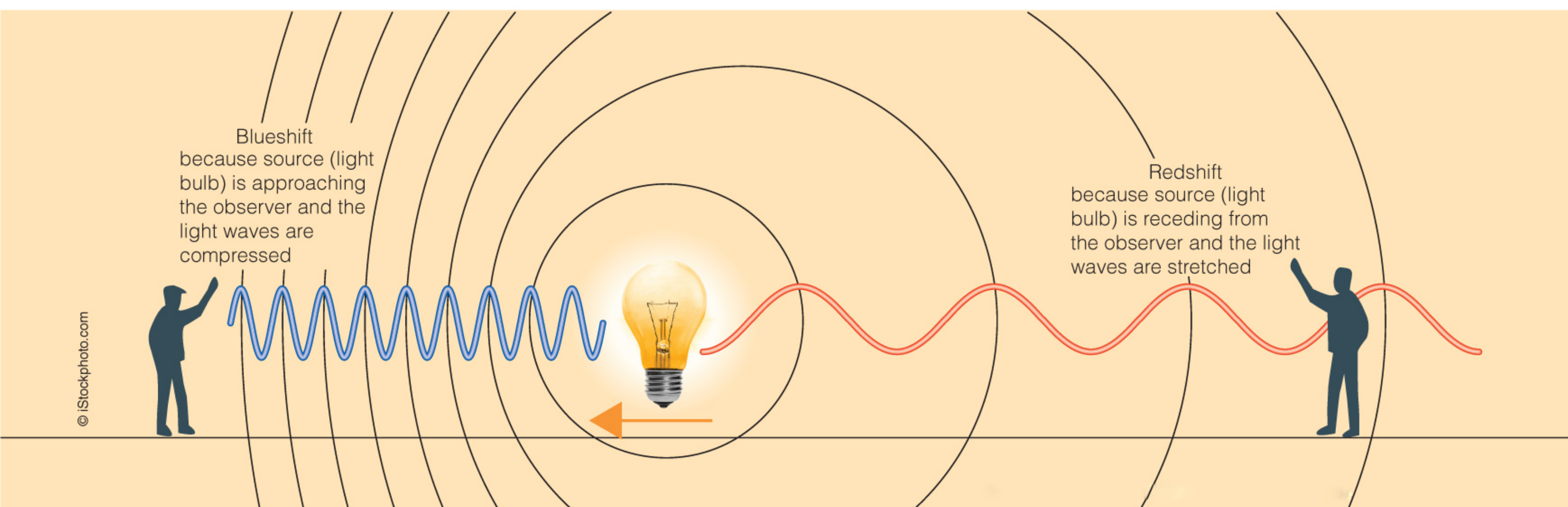


The Doppler Effect of light

Imagine a light source emitting waves continuously as it approaches you. The light will have a shorter wavelength, making it slightly bluer. This is called a blueshift.

A light source moving away from you has a longer wavelength and is slightly redder. This is a redshift.

Doppler Shift of Light Waves



The Doppler Effect

- The terms redshift and blueshift denote direction of chnge but not any specific range of wavelengths. The light does not actually have to be red or blue.
- The terms apply equally to wavelengths in the radio, X-ray, or gamma-ray parts of the spectrum.

- Also, note that these shifts are often much too small to change the color of a star noticeably.
  - However, they are easily detected by changes in the positions of features in a star's spectrum such as spectral lines.
  - And in case of very distant object the change of color may indeed be noticeable

The stellar atmosphere

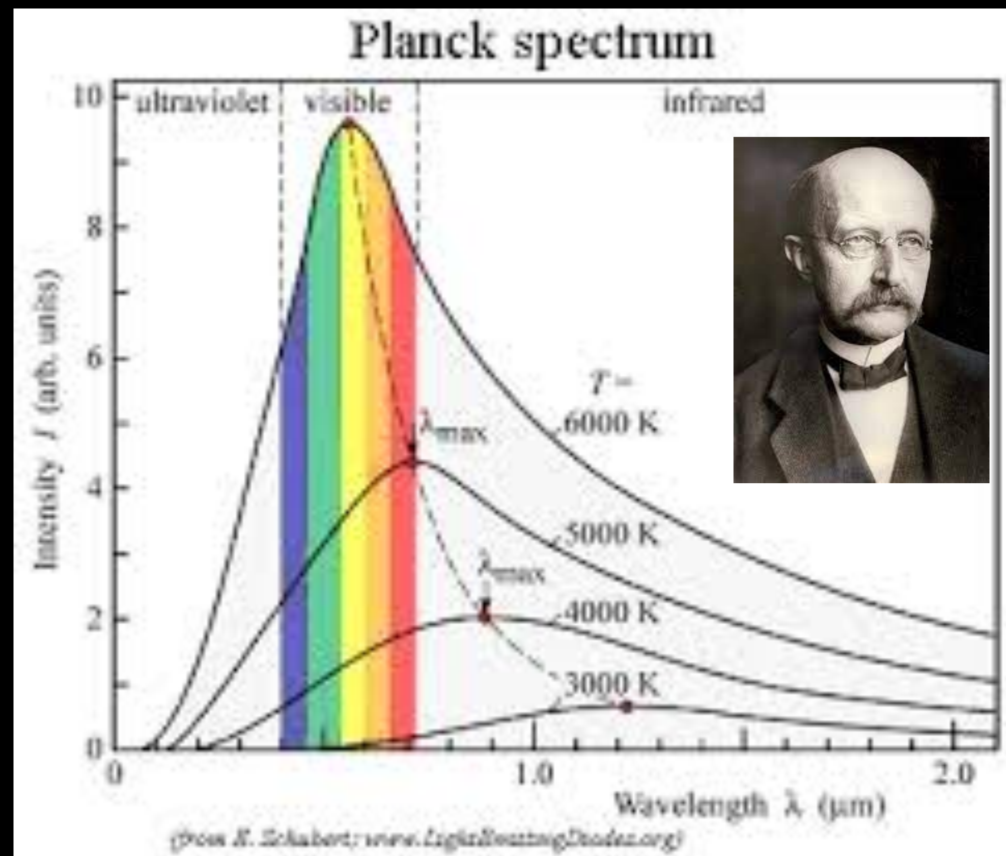
- The spectrum of a star shows you a lot about many aspects of a star, including the:
  - Star's temperature via the so-called Wien's law ($T \sim 1/\lambda$, where T is temperature and λ the wavelength at the peak power emitted in the stellar spectrum, cf. below) and the features seen by a spectroscopist in the spectrum
  - Composition of the gases in the stellar photosphere and atmosphere, and
  - Motions of those gases inside stellar atmosphere – microscopic via Doppler broadening of lines, macroscopic because of active layer called chromosphere
  - Motion of the star as a whole. This gives us an important way of estimating large distances to distant objects

Spectroscopy as an astro**physics** problem

The real understanding of all details of the spectra and all their uses had to wait until the late 19th and 20th century

After Wien & Kirchhoff understood some aspects of the spectrum of an ideally emitting body (so-called continuum spectrum of black body), Max Planck explained the shape of the spectrum

Wilhelm Wien & Gustaf Kirchhoff



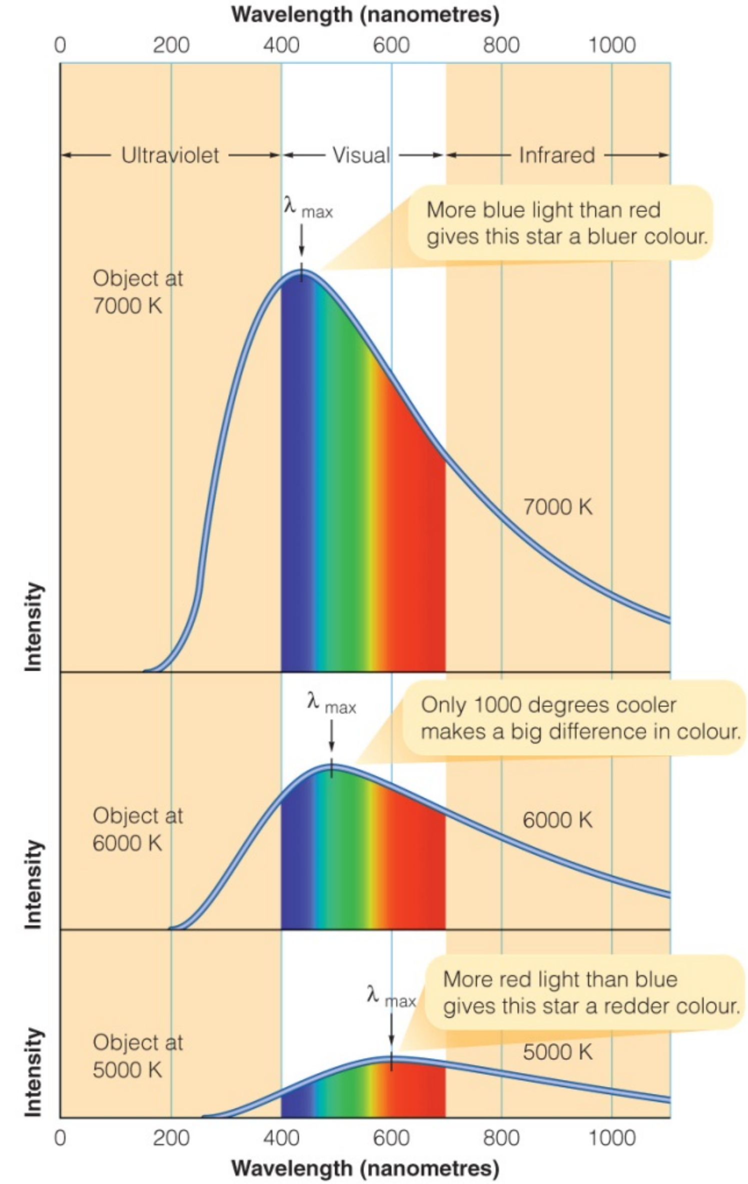
Effects of increasing temperature T of hot perfectly emitting body:

more energy leaves the body per unit time (emitted power grows)

peak of intensity vs. wavelength shifts to shorter wavelength.

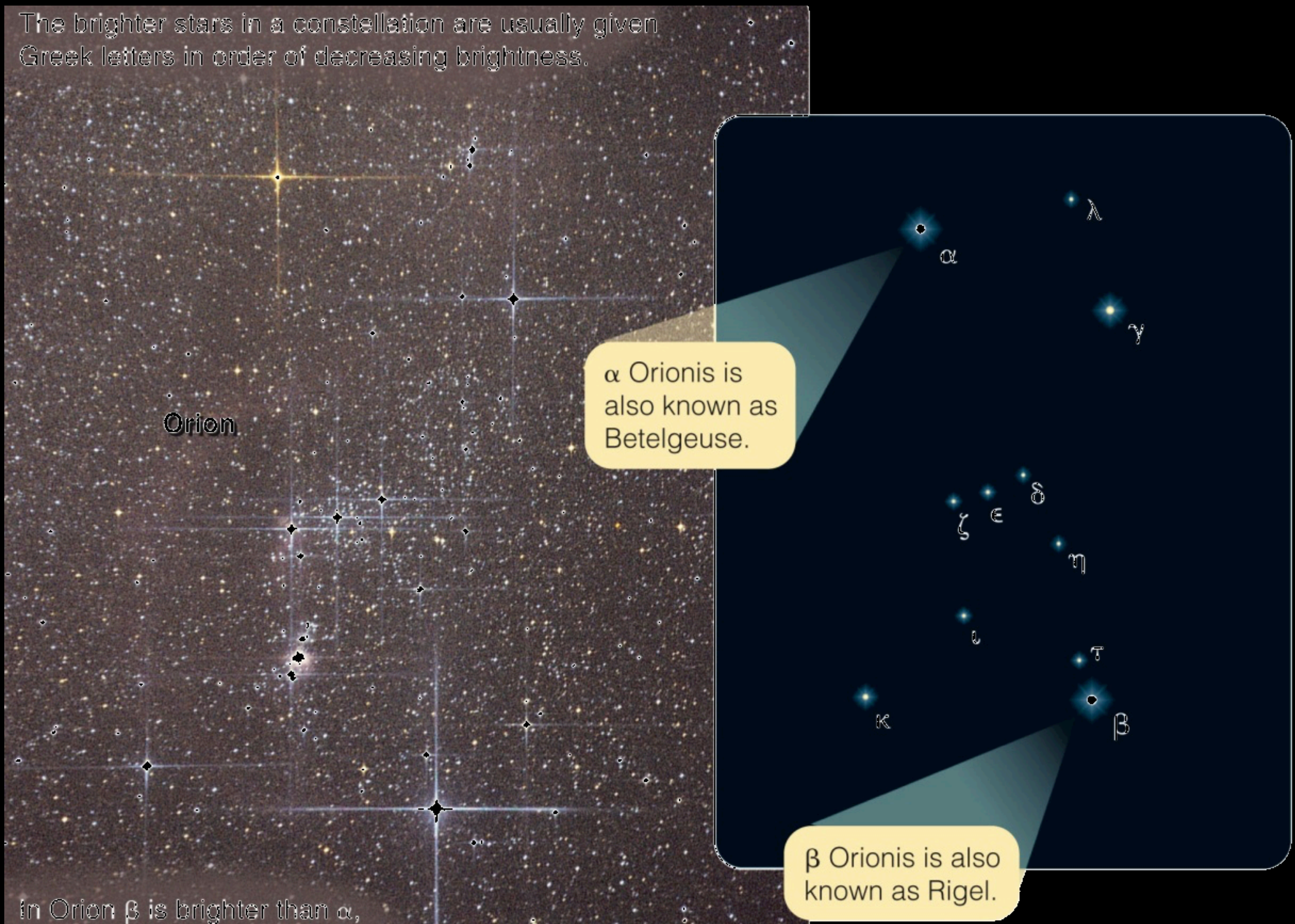
color of the body changes towards blue (more intense blue then red waves).
This explains colors of stars (but not planets - why?)

Figure 5.2
These graphs of blackbody radiation from three objects at different temperatures demonstrate that a hot object radiates more total energy (Stefan–Boltzmann law) and that the wavelength of maximum intensity is shorter for hotter objects (Wien's law). The hotter object here will look blue to your eyes, while the cooler object will look red.



Temperature, Heat, and Blackbody Radiation

Spectroscopy explains why two famous Orion stars, Betelgeuse and Rigel, have such different colors (yellow and blue)



Temperature, Heat, and Blackbody Radiation

- According to Wilhelm Wien's 1893 law (*wavelength of maximum intensity in the spectrum is inversely proportional to the temperature of the source of light*)
- Betelgeuse is cooler than the Sun, so it looks red.
- Rigel, though, is hotter than the Sun and looks blue.
- A star with the same temperature as the Sun would appear yellowish.

- Notice that cool objects may emit little visible radiation but are still producing blackbody radiation.
  - For example, the human body has a temperature of 310 K (37 C) and emits blackbody radiation mostly in the infrared part of the spectrum.

The photosphere (surface of last scattering) of the sun

- When you measure the amount of light of each wavelength coming from the photosphere (surface) of the sun and plot a curve as shown, then using Wien's law you find that the average temperature of the surface of our sun – the photosphere – is 5780 K (Kelvins)

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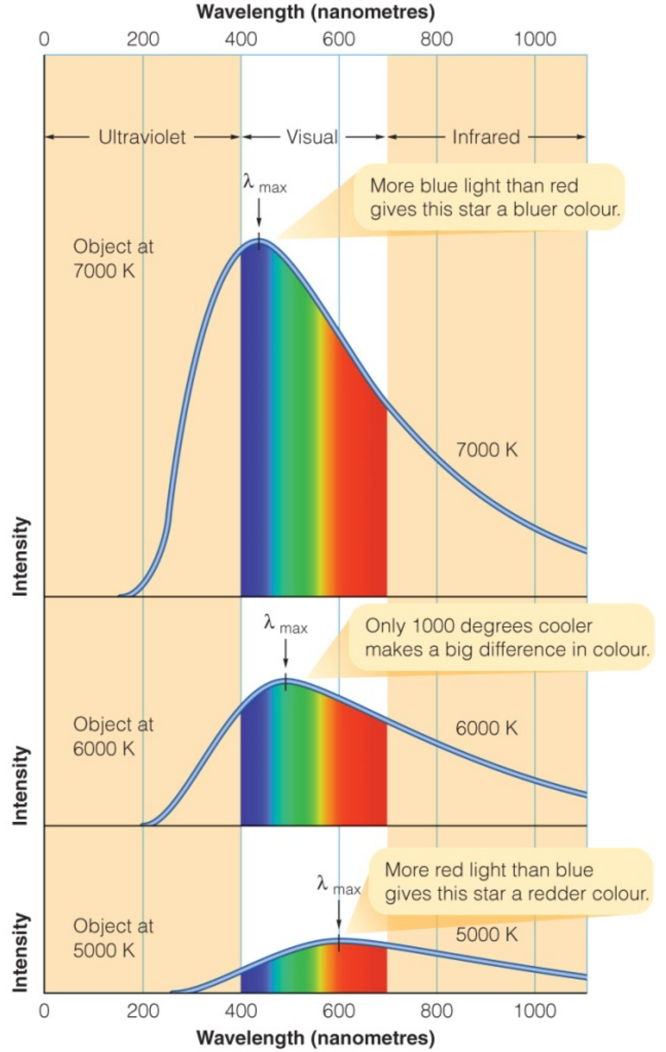

Formation of Spectra

- The emitted photons coming from a hot cloud of hydrogen gas have the same wavelengths as the photons absorbed by hydrogen atoms in the Sun's atmosphere, unless changed by the Doppler effect (motion)

- http://www.google.ca/sky/ - will show you the infrared and mm-wavelength (zoom-able) picture of the whole sky. The IR-bright Band (seen as sinusoidal curve in the particular sky projection) is the Milky Way.

Videos to widen your horizons on radiation and astronomical spectroscopy (non-required material)

- https://www.youtube.com/watch?v=sVev5RsKXog - 1/3
- https://www.youtube.com/watch?v=lsxvnVPLR1A&spfreload=10 - 2/3
- https://www.youtube.com/watch?v=Bx0SMevn-0c&spfreload=10 - 3/3