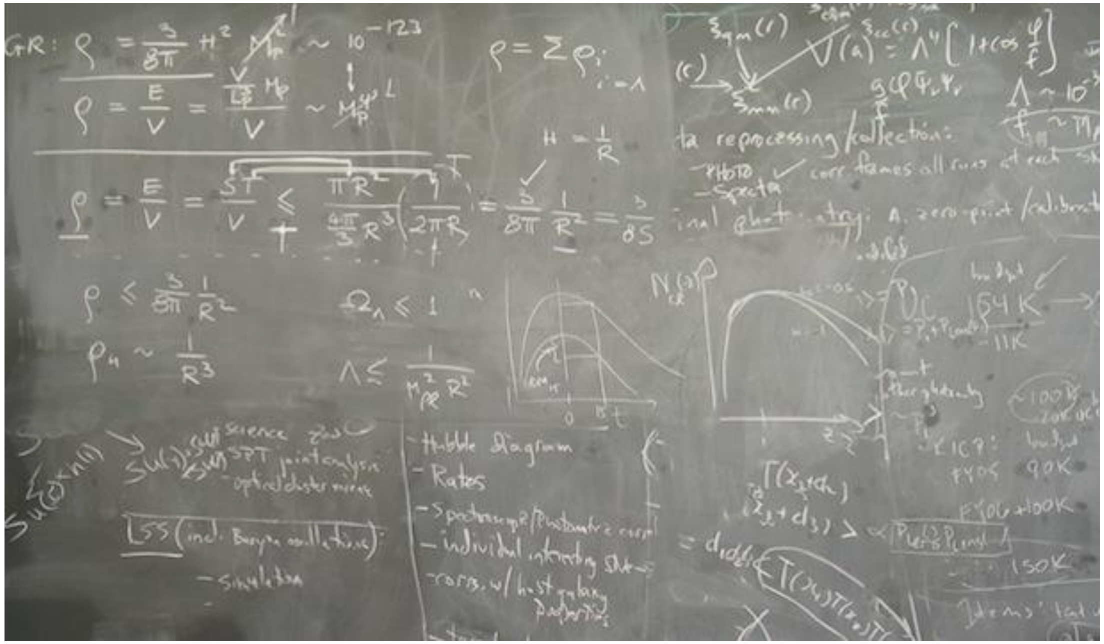
History of Science

(Wissenschaftsgeschichte)



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Department Chemical Engineering (CIW)
Institute for Optical Technologies (IOT)
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To My Person

Thomas Jüstel (born: May 1968), German, married

CV

- **University Bochum 1987 - 1994** *Coordination/Bioinorganic Chemistry*
- **Max-Planck Institute Mülheim 1995** *Electrochemistry*
- **Philips Research Aachen 1995 - 2004** *Solid State Chemistry, Luminescence*
- **Münster University of Applied Sciences**
  since 2004 **Head of RG Tailored Optical Materials**
  since 2013 **Dean of department chemical engineer.**

Teaching

- **Inorganic Chemistry**
  - **Main group and solid state chemistry**
  - **Coordination chemistry**
  - **Bioinorganic chemistry**
- **Material Science**
  - **Optical materials**
  - **Luminescent materials**
  - **Material characterisation**
- **Incoherent Light Sources**

Literature (Selection)

- N. Kopernikus, De revolutionibus orbium coelestium, Nuremberg 1543
- G. Galilei, Siderius Nuncius, Venedig 1610
- J. Kepler, Tabulae Rudolphinae, 1627
- I. Newton, Philosophiae Naturalis Principia Mathematica, Cambridge 1687
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- L. Pauling, General Chemistry, San Francisco and London 1953
- E. Schrödinger, Die Natur und die Griechen, Wien 1955
- M.E. Weeks, Discovery of the Elements, J. Chem. Educ., Easton PA 1956
- J.D. Watson, Die Doppelhelix, Hamburg 1969
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- D. Schwanitz, Bildung, München 1999
- R. Porter, Die Kunst des Heilens, Heidelberg and Berlin 2003
- J. Hamel, Meilensteine der Astronomie, Kosmos, Stuttgart 2006
- F. Krafft, Die bedeutendsten Astronomen, Wiesbaden 2007
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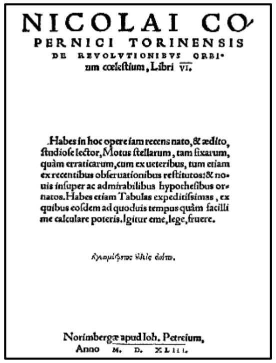
- David Wallace-Wells, Die unbewohnbare Erde, München 2019
- Peter Frankopan, The Earth Transformed: An Untold History, London 2023


NICOLAI CO
PERNICI TORINENSIS
DE REVOLVTIONIBVS ORBI-
um cœlestium, Libri VI.

Habes in hoc opere iam recens nato, & ædito, studiose lector, Motus stellarum, tam fixarum, quàm erraticarum, cum ex ueteribus, tum etiam ex recentibus obseruationibus restitutos: & nouis insuper ac admirabilibus hypothesibus ornatos. Habes etiam Tabulas expeditissimas, ex quibus eosdem ad quoduis tempus quàm facillime calculare poteris. Igitur eme, lege, fruere.

Norimbergæ apud Ioh. Petreium,
Anno M. D. XLIII.

Contents

Galileo Galilei

“Mathematics is the alphabet with which God has written the universe”

Lucius Aenaeus Seneca

“How many discoveries are reserved for the ages to come when our memory shall be no more, for this world of ours contains matter for investigation for all generations”

The Big Picture
- Science and Human Society Development -

The impact of Earth‘s Climate on the evolution of human species/societies

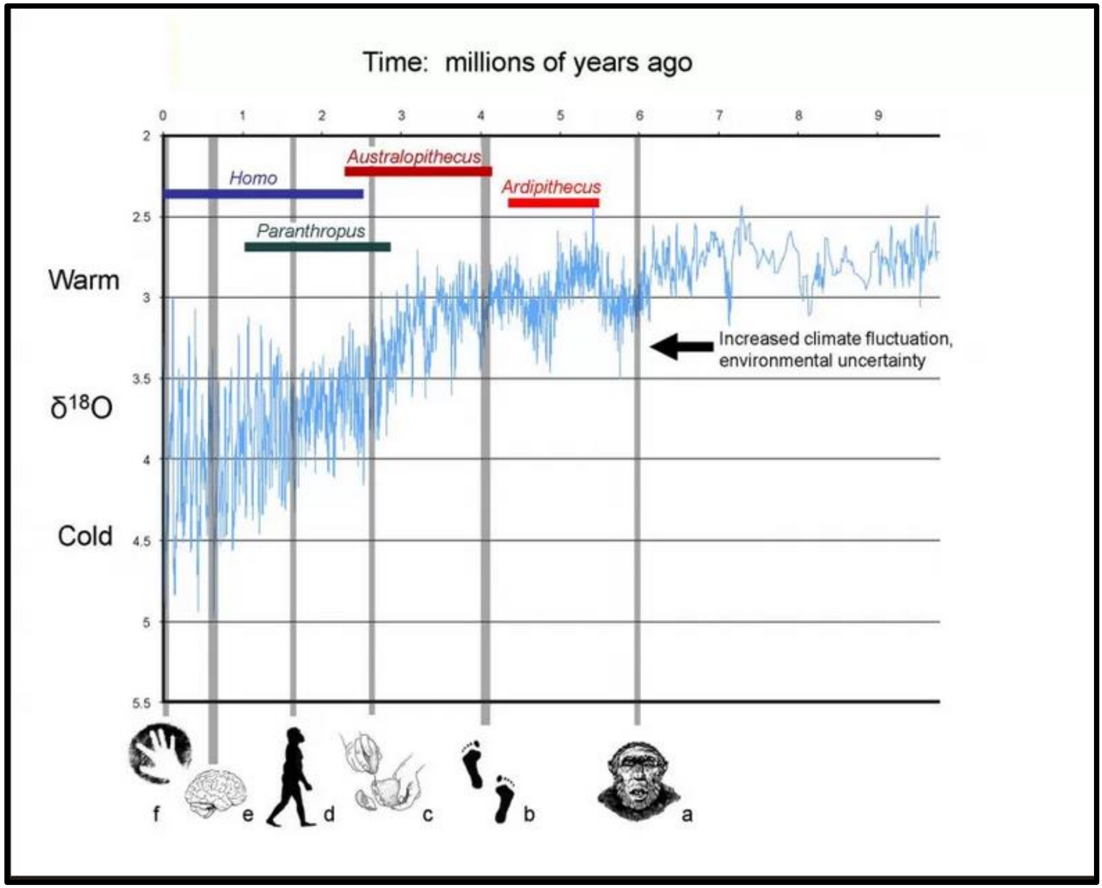
6 Mio. years ago
Increase in climate fluctuations
(Antarctica isolated)

4 Mio. years ago
Appearance of Australopthicus

2.5 Mio. years ago
Appearance of Homo

1.0 Mio. years ago
Appearance of Homo erectus

0.4 Mio. years ago
Appearance of Homo heidelbergensis



The Big Picture
- Science and Human Society Development -

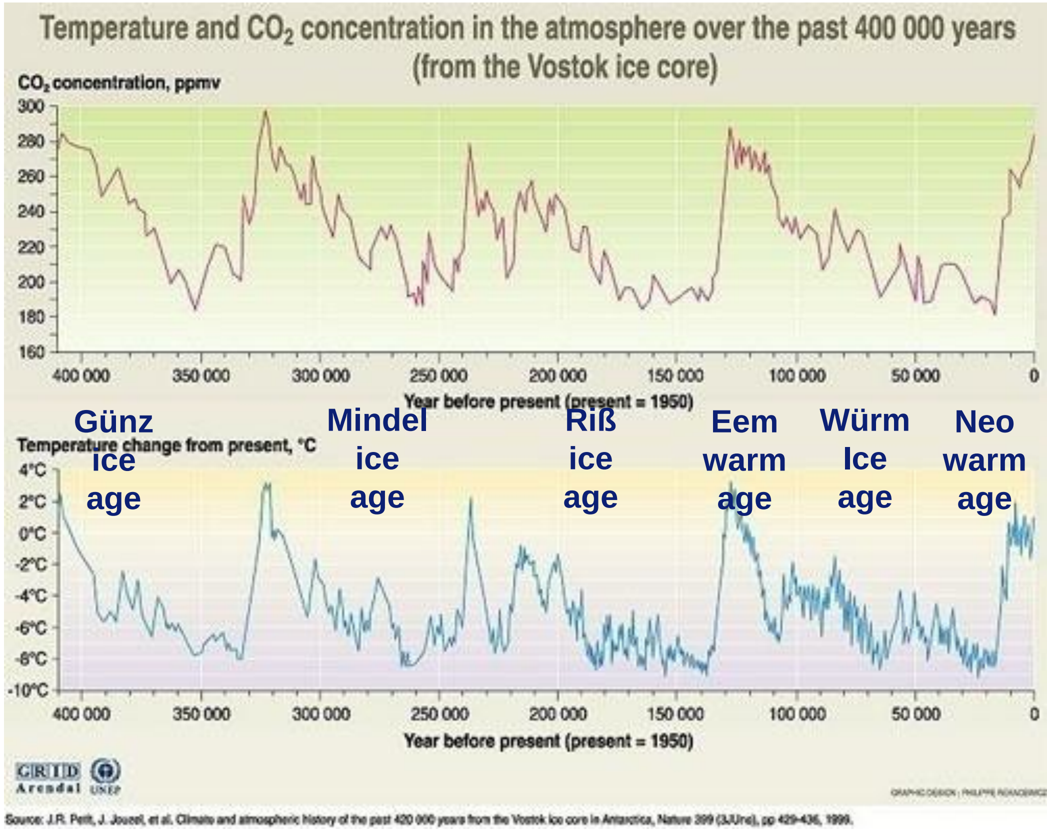
The impact of Earth's Climate on the evolution of human species/societies

400,000 years ago
Use of fire and torches by Home erectus

195,000 years ago
Appearance of Homo sapiens

125,000 years ago
Development of religious actions

50,000 years ago
Migration of Homo sapiens from Africa to Europe, Asia, and America



10,000 years ago
Domestication of animals and wheat
First major settlements
Large communities in Mesopotamia, Egypt, India, and China

The Big Picture
- Science and Human Society Development -

The impact of Earth's Climate on the evolution of human species/societies

11,000 years ago — **Begin of the Holozan (neo-warm age)**

8,000 - 4,000 years ago — **Holozanic optimum (neolithic age)**

3,000 years ago — **Ancient pessimum**

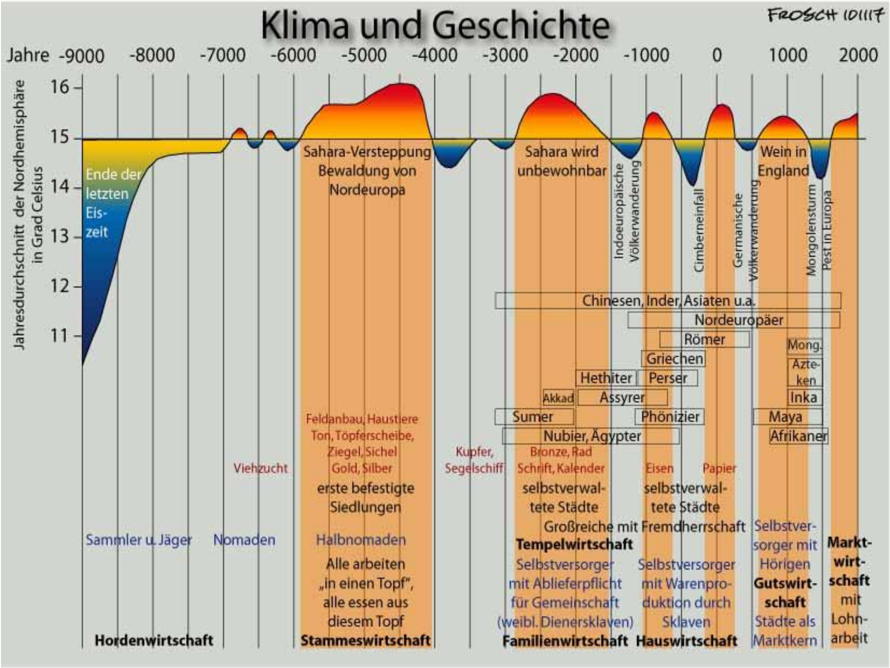
2,000 years ago — **Romain optimum**
→ Empire flowers

1,500 years ago — **Medievel pessimum**
→ Mass exodus

800 years ago — **Medievel optimum**

600 - 150 years ago — **„Little ice age"**

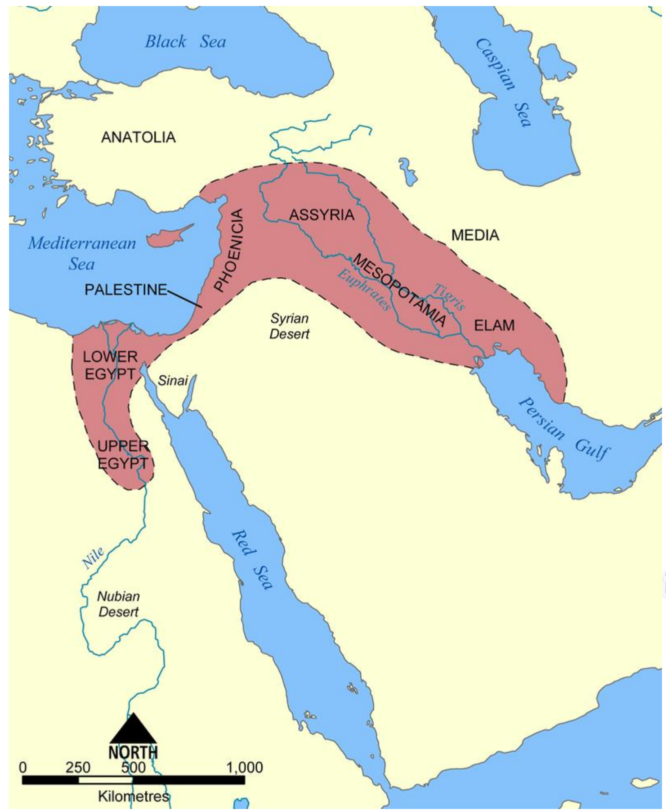
Today — **Modern optimum**

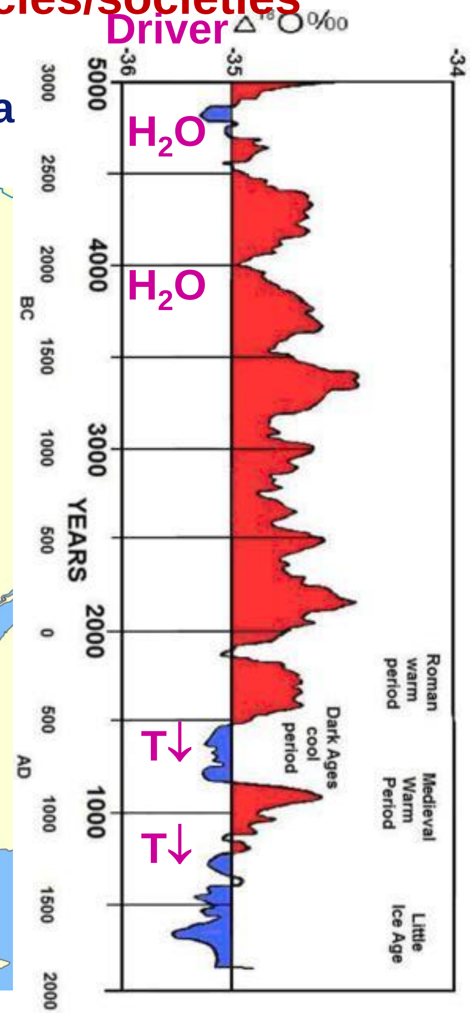


The Big Picture
- Science and Human Society Development -

The impact of Earth's Climate on the evolution of human species/societies

4,000 – 1,000 BC	**Mesopotamia: Sumer, Akkadia, Assyria, Babylonia**
3,000 – 1,000 BC	**Egypts**
2,200 – 1,000 BC	**Hittites, Minoans, Mycenaeans**
1,000 – 700 BC	**Greek dark age**
700 – 146 BC	**Greek optimum**
150 BC - 400 AD	**Romain optimum**
400 – 1,200 AD	**Arabia & Persia**
1,200 – 1,900 AD	**„European age"**
1,900 – 2,000 AD	**„US Century"**
since ~ 2,000 AD	**Southeast Asia**

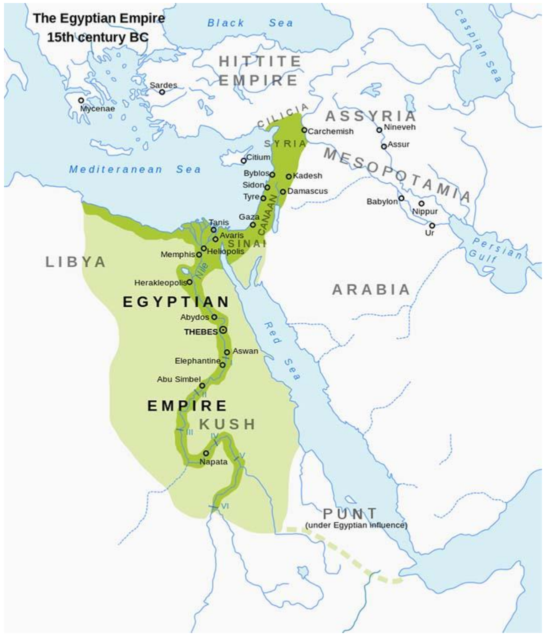




The Big Picture
- Science and Human Society Development -

Climate change and resource mismanagement played a key role in the collapse of human societies

- ~1200 BC Hittites, Anatolia
- 30 BC Egypt, Ptolemaic epoch Volcanic activity, Nile level
- 476 AD Western Romain Empire, Europe
- ~1000 AD Maya, Central America
- ~1700 AD Rapa Nui, Easter Island



The Big Picture
- Science and Human Society Development -

Technology ages are determined by new materials, regions (Silicon Valley, Argentina, Cyprus) & empires are dependent on materials → Hittites vs. Egypts

Years BC -10000 -8000 -6000 -4000 -2000 0 2000 3000 **Years AD**

Stone Age

Copper Age

Stone drill apparatus (reconstruction)

Bronze Age

Dagger, 2500 BC

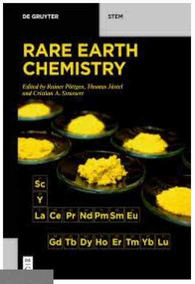
Iron Age

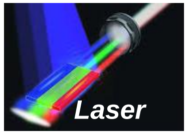
Nebra sky disk, 4000 BC

Greek & Romain Empire

Glass age

Silicon, plastics, rare earth, and crystal age





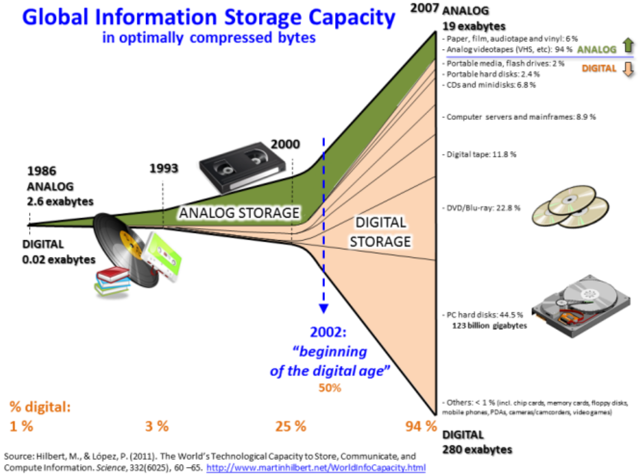
Transistors

21st century: RE based materials drive technological developments → magnets, phosphors

The Big Picture
- Science and Human Society Development -

Evolution of human society - Discoveries & inventions for knowledge managemt.

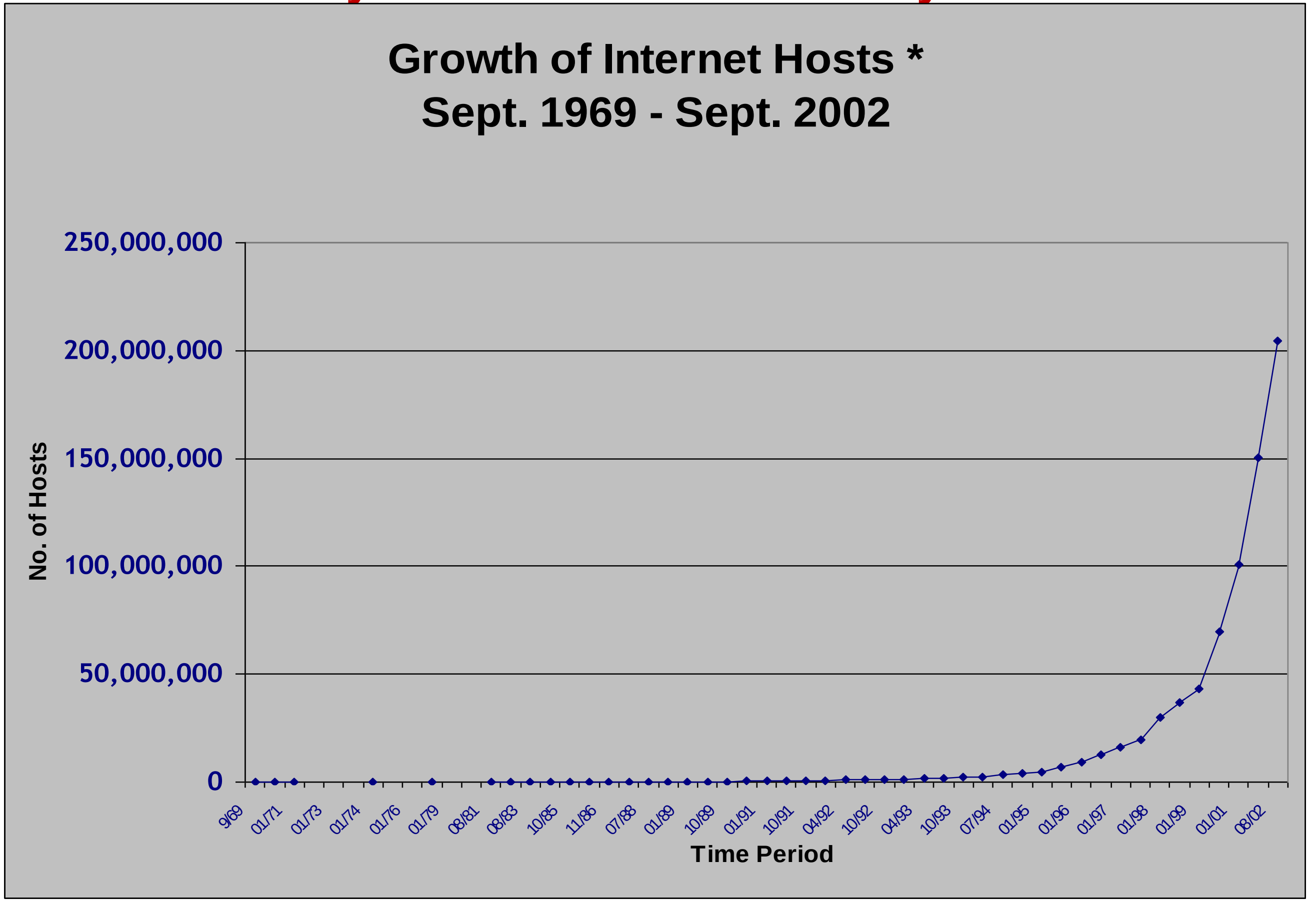
- 1015 Ibn Al Haythem (965 – 1040) “Book of Optics“
- 1455 The Gutenberg Bible: First book printed with movable metal types
- 1815 Fresnel and the wave nature of light
- 1865 Maxwell and electromagnetic waves
- 1915 General relativity – light in space and time
- 1945 Z4 von Konrad Zuse (2200 Relais)
- 1965 Cosmic microwave background
  Optical fibre technology
- 1989 Birth year of the WWW
- 2002 Beginning of the digital age
- 2007 ~ 300 exabyte stored
- 2010 50 Gbps transmitter (by four laser)
- 2014 Data transfer rate > 100 Gbps
- 2015 International Year of Light (IYL), > 1 ZB
- 2018 4-5 ZB stored, 294 bill. mails and 230 mill. tweets/day
- 2020 ~ 44 ZB stored
- 2030 Internet ~ 21% of projected electricity demand (Ref.: Nature 561 (2018) 163)



INTERNATIONAL YEAR OF LIGHT 2015

The Big Picture
- Science and Human Society Development -

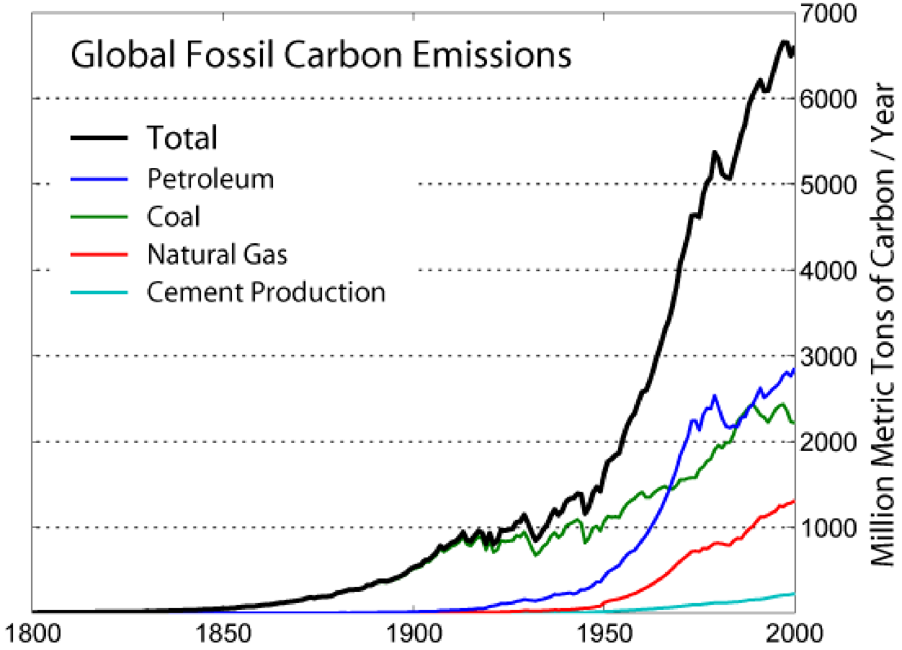
Evolution of human society - Growth of Connectivity

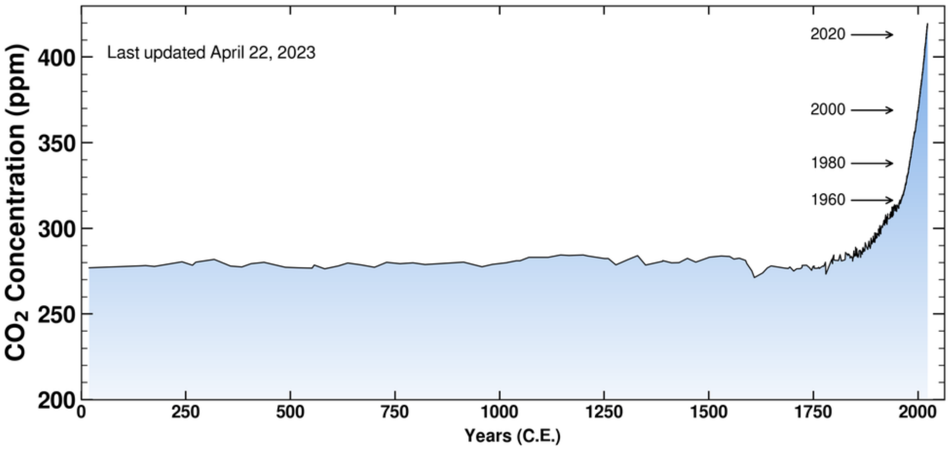


The Internet was not known as "The Internet" until January 1984, at which time there were 1000 hosts that were all converted over to using TCP/IP

The Big Picture
- Science and Human Society Development -

Impact of technology on ecology, e.g. on global carbon emission & atmospheric CO_2 concentration



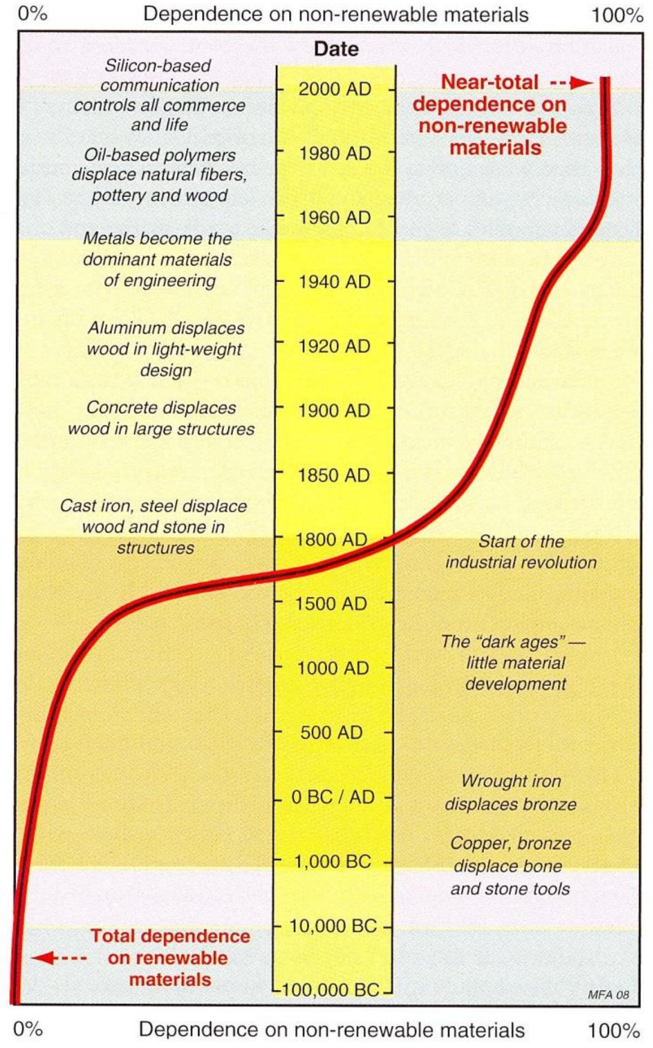


Source: http://gyandotcom.files.wordpress.com/2008/07/global-carbon-emission.png?w=555&h=402

The Big Picture
- Science and Human Society Development -

Global dependence on raw materials (non-renewable)

- Until about the year 1000 BC
  → only regenerative materials
  used Recycling rate almost 100%
- 1000 BC - 1000 AD
  → weak increase in the use of
  non-regenerative materials
- after 1000 AD (especially after 1500 AD)
  → strong increase in the use of
  non-regenerative materials
- since about 1960
  → de facto 100% dependence on non-
  regenerable materials recycling rate < 10%



Source: M.F. Ashby, Materials and the Environment, Elsevier (Butterworth-Heinemann), 2009, p. 8

The Big Picture
- Large Scale Problems of the 21st Century -

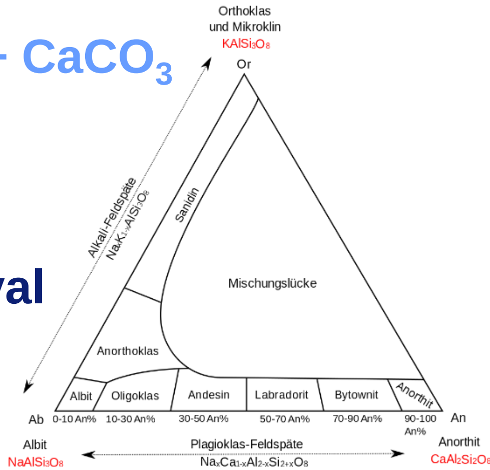
Modified statements of James Martin, Oxford

- GLOBAL WARMING Global warming will lead to severe climate change. Unless stopped, it will upset the basic control mechanisms of planet Earth.
- EXCESSIVE POPULATION GROWTH World population may grow to 10 billion people, with a growing demand for consumer goods and carbon-based energy, far exceeding what the planet can handle.
- WATER SHORTAGES Rivers and aquifers are drying up. Many farmers will not have the water essential for food growing. There will be wars over water.
- DESTRUCTION OF LIFE IN THE OCEANS Only 10% of edible fish remain in the oceans, and this percentage is rapidly declining. In 2050 oceans will contain more plastics than fish.
- MASS FAMINE IN ILL-ORGANIZED COUNTRIES Farm productivity is declining. Grain will rise in cost. This will harm the poorest countries.
- THE SPREAD OF DESERTS Soil is being eroded. Deserts are spreading in areas that used to have good soil and grassland.
- PANDEMICS AIDS is continuing to spread. Other infectious pandemics could spread at unstoppable rates, as they have in the past, but now with the capability to kill enormous numbers of people.
- EXTREME POVERTY 2 to 3 billion people live in conditions of extreme poverty, with lack of sanitation. The difference between rich and poor is becoming ever more extreme.
- GROWTH OF SHANTYCITIES Shantytowns (shanty cities) with extreme violence and poverty are growing in many parts of the world. Youth there have no hope.
- UNSTOPPABLE GLOBAL MIGRATION North-South divide and urban-rural gap

The Big Picture
- Large Scale Problems of the 21st Century -

According to National Academy of Engineering, USA

- Global economy without CO_2 release
  - PV modules with higher efficiency (concentrator, CIGS & perovskite cells)
  - Photocatalytic H_2O splitting, H_2 storage and conversion to gas/liquid fuels
  - Nuclear fusion: ITER (EU), NIF (US: National Ignition Facility)
- CO_2 sequestration
  - by geochemistry:
    albite, anorthite, orthoclase → caolin clay + quartz + $CaCO_3$
  - by underground / underwater storage
- Urban infrastructure with higher efficiency
  - Efficient energy, traffic, and data transfer systems
  - Efficient water supply and trash & waste water removal
  - Local energy and food production (urban farming
- Access to clean and safe drinking water
  - Reduction of pathogenes (microorganisms)
  - Removal of salt, microplastics, nanoplastics, uranium, and arsenate
  - Removal of NO_3^-, NO_2^-, and organic microimpurities, e.g. pharmaceuticals



The Big Picture
- Large Scale Problems of the 21st Century -

The 17 Sustainable Development Goals (SDGs) published by United Nations (UN)

The Big Picture
- Science and Human Society Development -

It all started with the Greek (written texts)!

The ancient Greeks are seen, in the west, as our intellectual forefathers. From Greece philosophy, drama, western artistic, aesthetics, geometry and so on was born

Theology was never an important aspect of Greek thought and orthodoxy was practically anathema

Ancient Greek society did not have a permanent priestly class that imposed dogma

Greek Gods & Goddesses were neither omnipotent nor omniscient

600 BC: Thales "Life is based on water"   Today: Biology = "Aquatic Chemistry"

$\Rightarrow$ Life on Earth depends on Solar light & Water

The Big Picture
- Science and Human Society Development -

Major Greek Philosophers

Socrates (470 – 399 BC) dialectic approach

Plato (427 – 347 BC) formation of the Academia at the garden of Akademos, Athens → Academia
Differs between ideas and phenomenon

Aristotle (384 – 322 BC) "Universals are abstractions from particulars and we have only knowledge of a scientific fact if we can prove that it could not be otherwise"
Reason rather observation at the center of scientific effort, since observation never shows the whole truth
Strong impact on medieval philosophy
Taught "Astronomy" and "Physics"

Euklid (365 – 300 BC) development of formal geometry, book "The Elements"

Religion, Philosophy, and Science
- Three Ways of Learning -

- **Religion:** Determines the nature of reality by **accepting** an existing explanation on faith
- **Philosophy:** Determines the nature of reality by **thinking** about it
- **Science:** Determines the nature of reality by **testing** it

These three ways can be reduced to

Believing **Thinking** **Testing/Verifying**

Science is the only systematic way to study the world/universe we live in

Religion, Philosophy, and Science
- Three Ways of Learning -

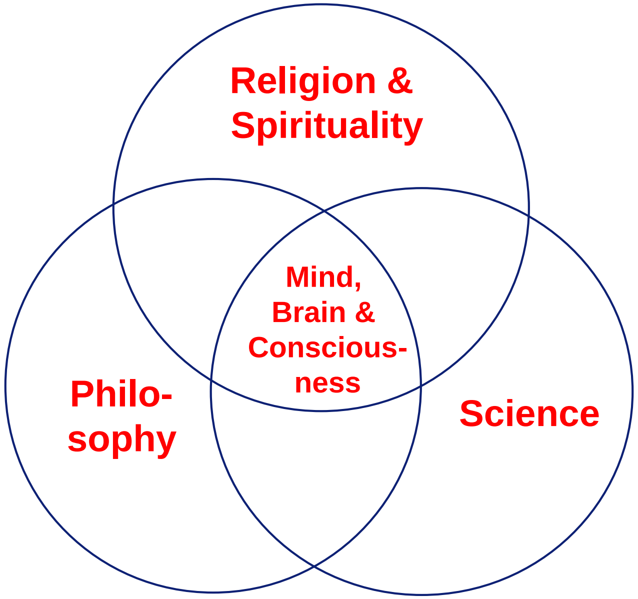
All three ways contributes to the development of human society

Species: (evolution) — **Brain development**

Individual: (education) — **Mind development**

Social: (organization) — **Interaction development**

The Unification of Philosophy, Religion, and Science



Individual → family → group → community → state → planetary society (globalization)

Religion, Philosophy, and Science
- Three Ways of Learning -

The scientific method - basis

Application of the principles of rigorous arguments as developed in mathematics and in logic

Deduction of sound conclusions from a set of generally accepted postulates
⇒ Mathematics: basic postulates are so-called axioms
⇒ Other sciences: principles and laws are not known, i.e. have to be discovered

Induction: Process of discovering these laws

1st Step	**Finding some facts by observation and experiment**
2nd Step	**Classification and correlation of many facts by a statement (law)**

Example:	**The law of definite proportions of chemical compounds**

Religion, Philosophy, and Science
- Three Ways of Learning -

The scientific method - properties

Objectivity
Scientific knowledge is independently formulated of religion, race, sex, space and time. Thus it is accessible to anybody who adopted the scientific language.

Systematicity
A scientific theory is the attempt to explain as much phenomena as possible by a scientific law that is as simple as possible.

Experiment
A scientific law is generally accepted if is able to predict phenomena, which can be confirmed by observation or experiments.

Religion, Philosophy, and Science
- Three Ways of Learning -

Middle ages

→ Studium general "*studia generalia*"
Higher faculties: Law, medicine, and theology
Basic faculties: Seven liberal arts "artes liberales"

Trivium	Quadrivium
Dialectic	Arithmetic
Grammar	Geometry
Rhetoric	Music
	Astronomy

ut omnes unum sint
„That all may be one"
„Das alle eins seien"

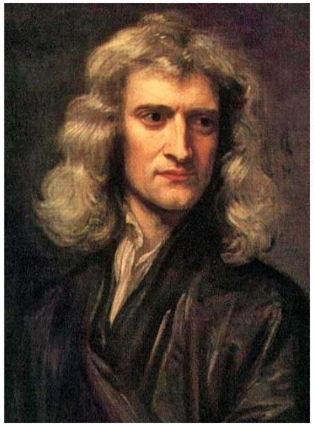
Plato: "Wie die Augen für die Astronomie ausgebildet sind, so sind die Ohren für den Fluss der Harmonien (Musik) ausgebildet"
Immanuel Kant: "Zwei Dinge erfüllen das Gemüt mit Bewunderung und Ehrfucht: Der bestirnte Himmel über mir und das moralische Gesetz in mir"

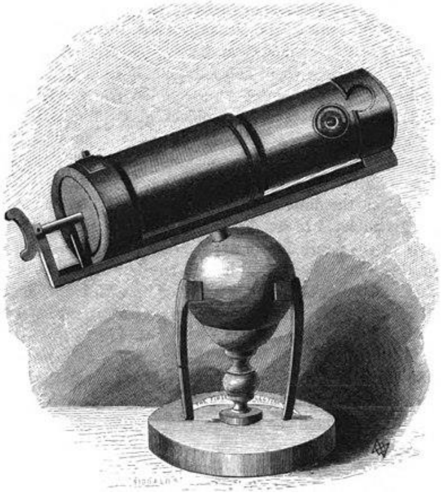
Religion, Philosophy, and Science
- Three Ways of Learning -

Age of enlightenment: 17th and 18th century

→ The emergence of experimentation in natural philosophy based on mathematics (Newton, Descartes, Leibniz, Pascal)
→ The struggle over adequate, reliable, and verifiable descriptions of faith, planetary motion, tides, gravity, material, and light

Sir Isaac Newton was central to this development even though he was not only interested in physics but also in
- alchemy
- astronomy
- christianity
- mathematics
- and unitarism





Newton wrote in 1713: “The cosmos could not have arisen without the design and dominion of an intelligent and powerful being”

The Basis of Science: Astronomy!

Observations in prehistoric times - The way to astronomy "study of celestial objects"

- Rising and setting of the Sun, the Moon, and stars
- Constellations
- Annual motion of the Sun
- Motion of planets through zodiac
- Phases of the Moon
- Eclipses

From Early Religions to Modern Astrophysics

Astronomy
Today: Study of the universe

Astrophysics
Study of the physical laws governing objects of the universe

Universe
Totality of

Space and Time spacetime

Matter and Energy $E = mc^2$

Dark matter and dark energy

From Early Religions to Modern Astrophysics

Astronomy is the first science of human society

Why?

a) Records of lunar phases in cave paintings & bone carvings ~ 30000 BC

b) About 3000 stars are visible at the night sky (in ancient times…)

Stars are randomly distributed but human brain tends to find patterns (constellations) and interpretations

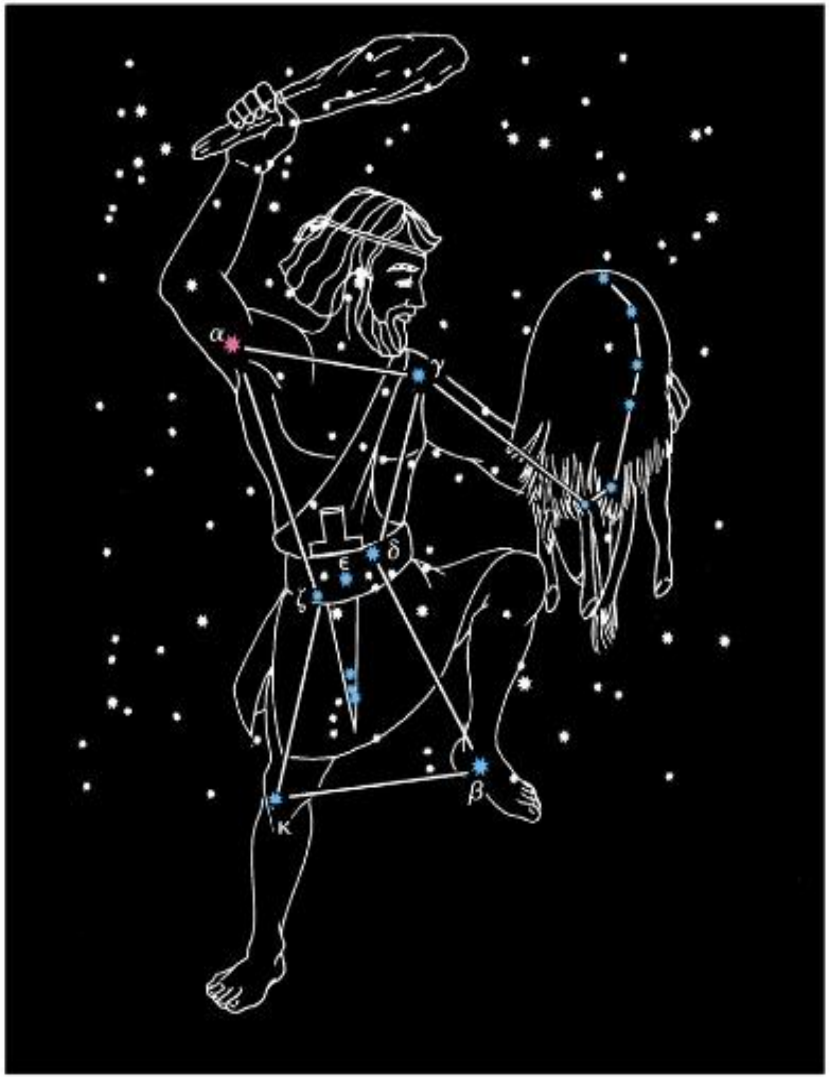
What shape do you see?

From Early Religions to Modern Astrophysics

Stars are grouped into constellations (88 officially recognized)

Figures having meaning to those doing the grouping

⇒ Basic of astrology (interpretation)



Some famous constellations

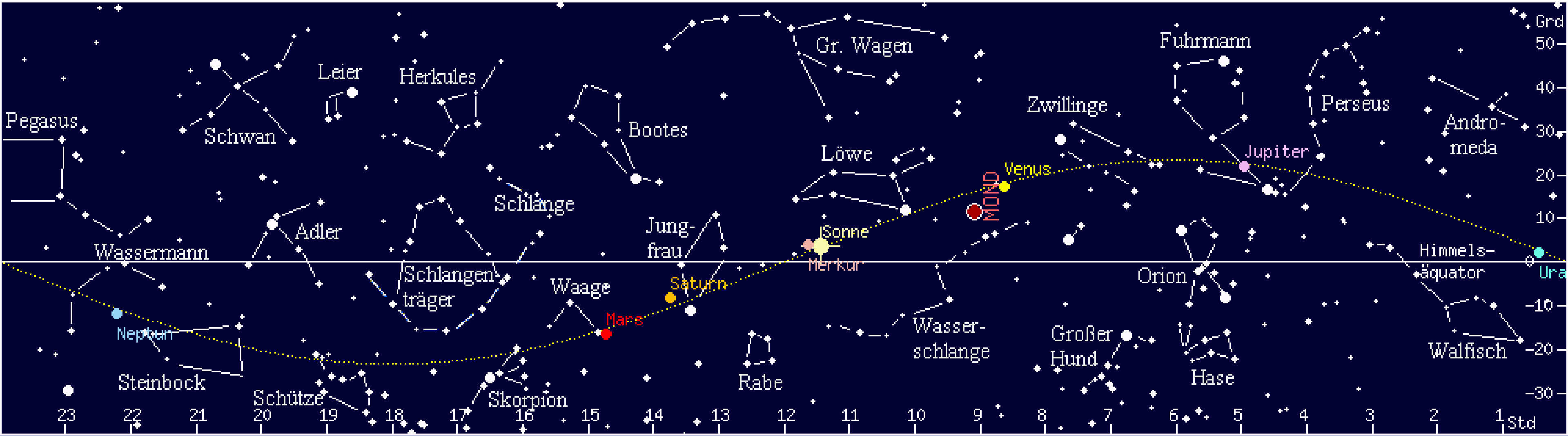
• Aquarius	water bearer
• Canis major	big dog
• Cassiopeia	queen of Ethiopia
• Crux	southern cross
• Cygnus	swan
• Lyra	lyre or harp
• Orion	Orion, the hunter
• Sagittarius	archer

From Early Religions to Modern Astrophysics

The ecliptic is the plane of Earth's orbit around the sun

⇒ The sun apparently moves within a year through certain constellations "The Zodiac": Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, and Pisces → 12

⇒ The moon and the planets (wanderers), i.e. Mercury, Venus, Mars, Jupiter, and Saturn can be found on or close to the ecliptic



From Early Religions to Modern Astrophysics

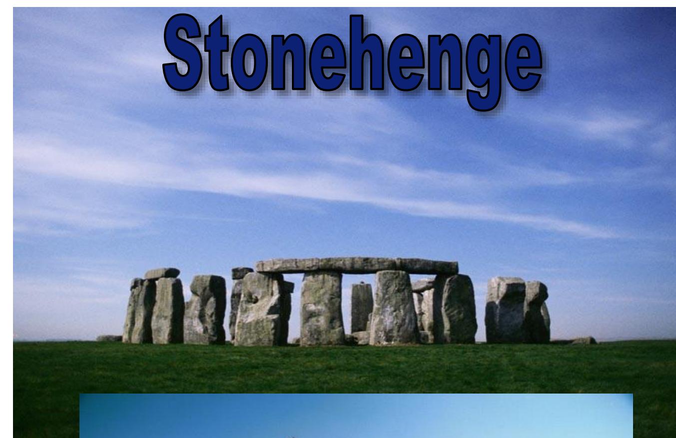
Modern Europeans made a lot astronomic discoveries, but were neither the only nor the first ones, who studied the sky in detail

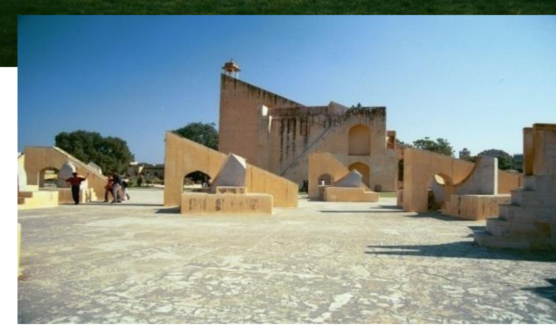
Development of Astronomy was driven by early religions all over the world, e.g. by the

- Babylonians
- The Maya
- The Chinese
- Hindus
- The Celtics
- The Indians of North America
- Egypts
- Greeks


El Caracol (Mexico - Mayan)


Su Song Star Map

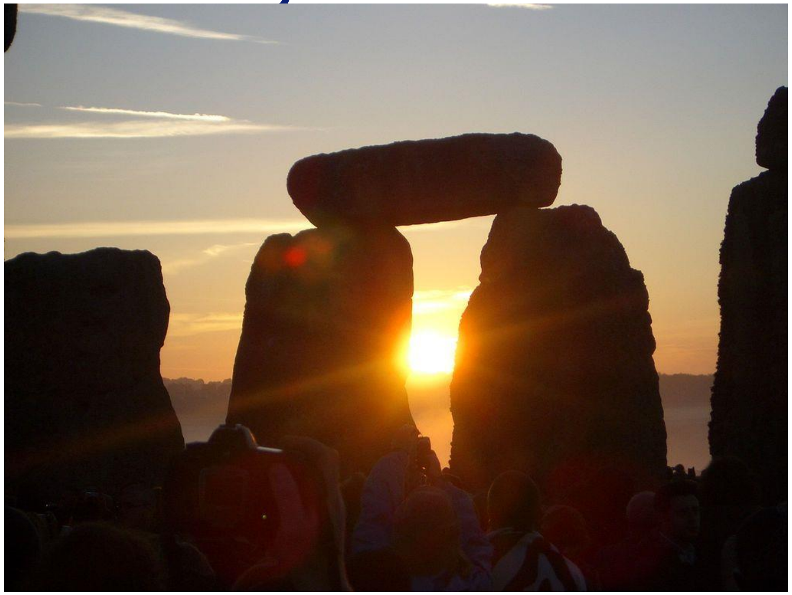

Stonehenge

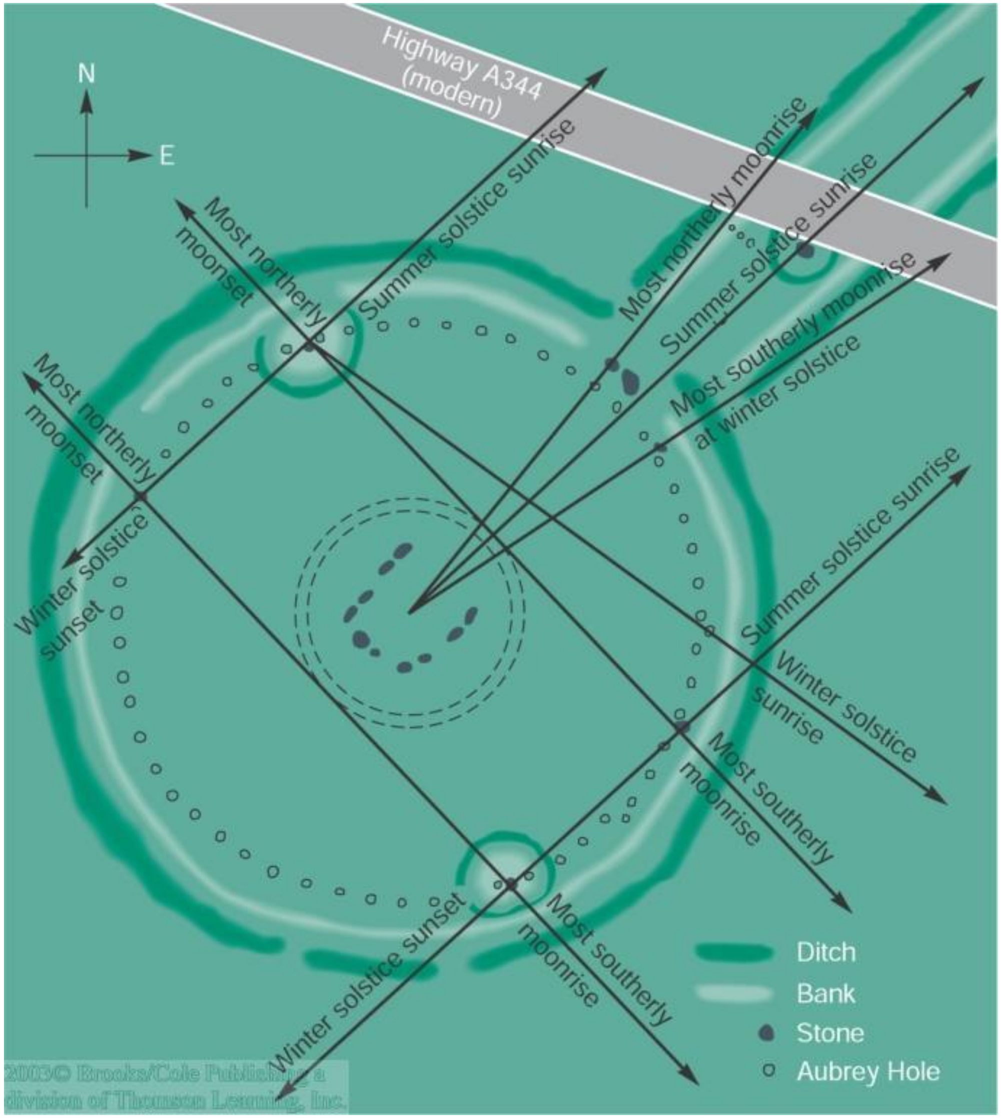

Jantar – Mantar (Delhi, India)

From Early Religions to Modern Astrophysics

Stonehenge, South England

- Constructed 3000 - 1800 BC
- Alignments with locations of sunset, sunrise, moonset and moonrise at summer and winter solstices
- Probably used as calendar





From Early Religions to Modern Astrophysics

Why was astronomy so important to ancient people?

- Time keeping and calendar development

- Religious significance

- Navigation and orientation

- Curiosity
  After people had taken care of their mere survival needs, some of them had time to study subjects they were curious about, e.g.
  - Solar and moon cycle/phases/eclipses
  - Movement of planets
  - Events: Shooting stars, comets, (super)novae, impacts, …

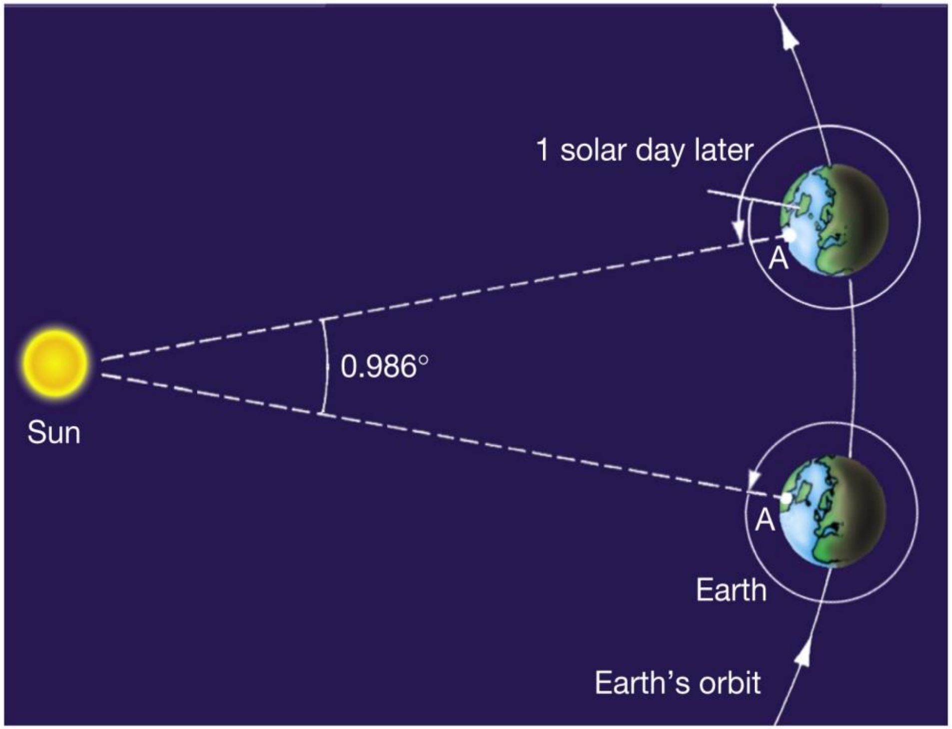
Astronomical Time Keeping

Time keeping based on the sun cycle

What is a day?
Sun overhead to sun overhead, is diurnal motion
solar (synod) day = 24:00:00 h

Stars aren't in quite the same place 24 hours later, due to Earth's revolution around sun
Once they are, a
sidereal day = 23:56:54 h
has passed by

Δt = 3 min 6 s
Δangle = 360/365.25 = 0.986°



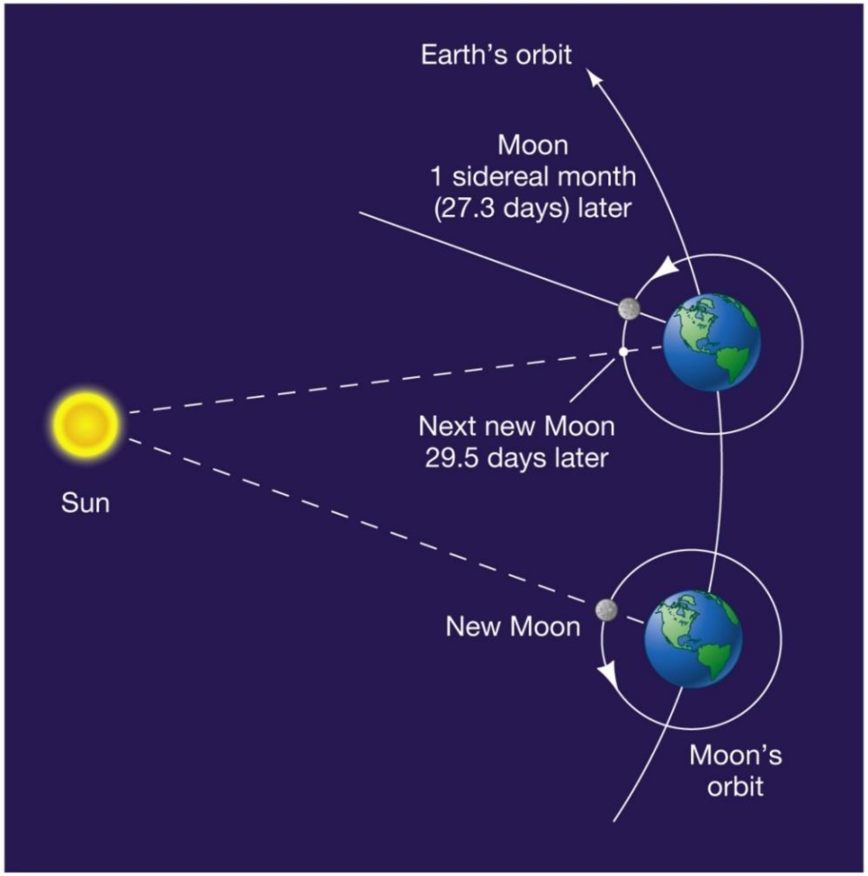
Astronomical Time Keeping

Time keeping based on the moon cycle

From new moon to next new moon
1 synod month "1 moon day"
= 29.5 days

Until the moon is in the same position relative to the stars
1 sidereal month
= 27.3 days

2.2 days/27.3 days * 365.25 days
= 29.5 days



Astronomical Time Keeping

Question?

What is Pink Floyd referring to when they titled their million seller album "The Dark Side of the Moon" released in 1973?

Answer

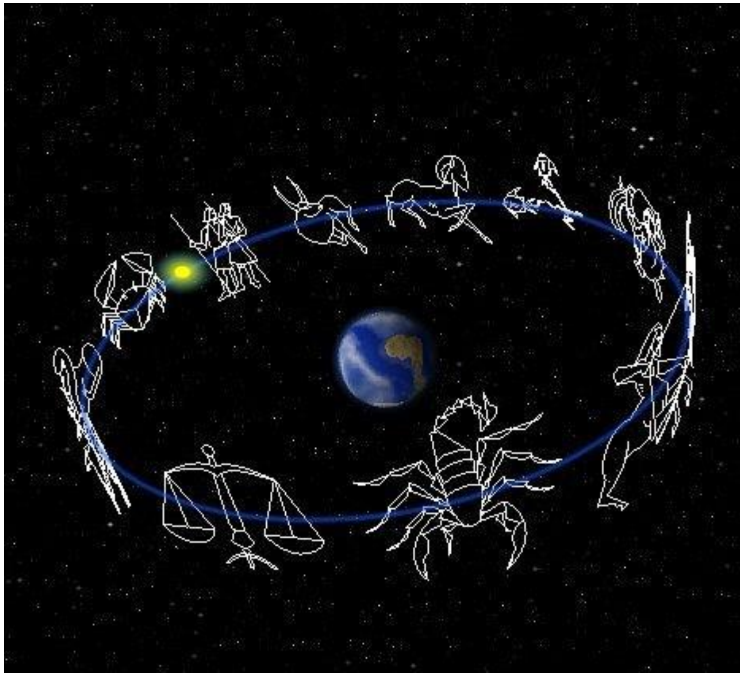
Bound rotation of the moon, i.e. 1 moon day is equal to 1 moon year

→ Origin of misleading conclusions

Astronomical Time Keeping

Calendar development

- **First calendar by the Chinese about 5000 years ago (Lunisolar)**
- **Established the length of a year by apparent motion of the sun through constellations., i.e. the Zodiac**



Astronomical Time Keeping

Calendar development

→ **Relevant for agricultural societies for calculation of the period of seeding, flowering, harvesting, and religious holidays**

Earth orbits the sun within1 year = 365.24220 days (tropical year)

Egypt	**1 year = 365 days = 12 month a 30 days + 5 leap days Sirius (brightest star at night sky) rise delays after 1460 = 365 x 4 years the Sirius rise is on time again**
Romains (46 BC)	**Julian calendar: An extra day every 4 years leap years 1 year = 365.25 days**
Middle Europe (October 4th, 1582)	**Gregorian calendar: Added 11 days and new rule for leap days no leap year if J/100 is integer and J/400 is non-integer 1 year = 365.2425 days ⇒ Deviation = 0.0003 days/year or 1 day in 3300 years**

Astronomical Time Keeping

Calendar development

Astronomical calendar (Julian dating) introduced by Joseph Justus Scaliger 1592 AD

Day 0:

January 1st, 4713 BC, 12.00 h UT (universal time = Greenwich time)

Greenwich: Royal British observatory in London with Prime Meridian, i.e. Longitude 0°

Example:

January 1st, 2002 AD, 12.00 h UT Begin of JD 2,452,276

Astronomical Time Keeping

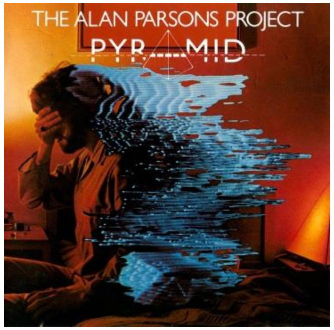
Problems

- The solar day is not constant: Increase of 1 s in 60,000 years, due to tidal resistance → the moon moves away from Earth
- The tropical year is not constant: Slow increase due to a distant increase caused by the mass loss of the sun (mass deficit by nuclear fusion and solar wind) → Kepler's laws 17th century
- Earth orbit is disturbed by adjacent planets, in particular by Venus, Mars and Jupiter
- Earthquakes results in millisecond irregularities of Earth rotation

20th century solution: Time keeping based on an atomic process:

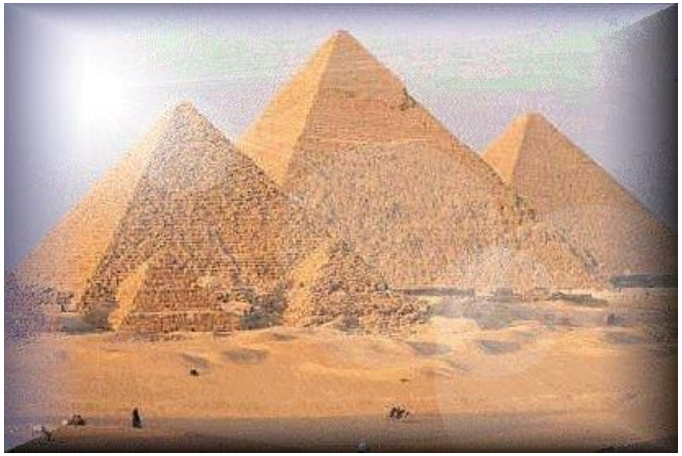
1 s is defined as the duration of 9,192,631,770 periods of the radiation, which corresponds to the transition between the two hyper-fine structure levels of the ground state of the element ^{133}Cs ($^2S_{1/2}$ ~ 0.3 cm^{-1})

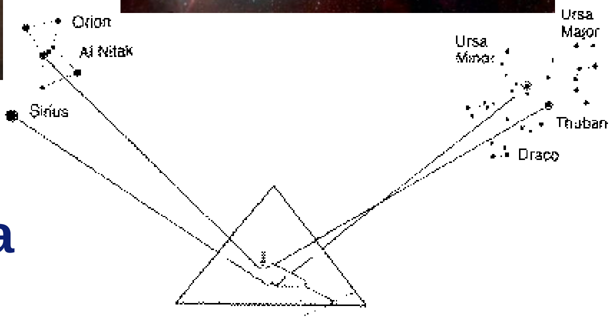
Religious Significance

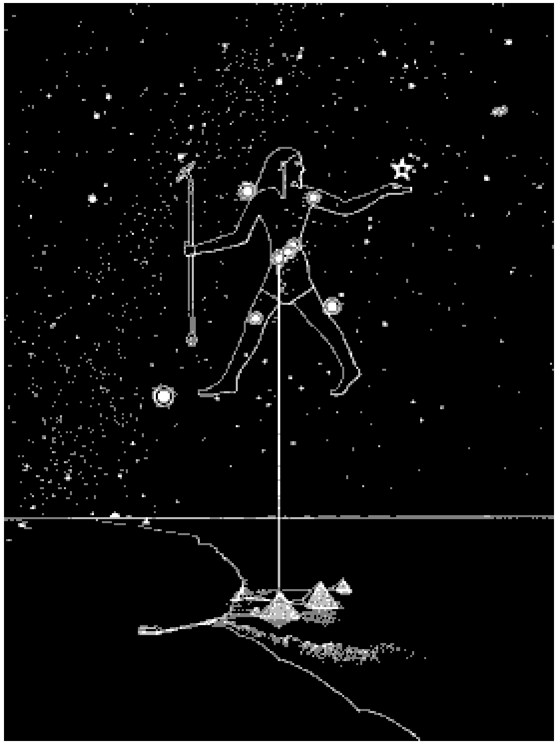


Ancient Egyptians about 4000 Years Ago

Used certain stars or constellations to align their pyramids, e.g. Sirius, Orion belt stars, Ursa major and minor, and milky way!







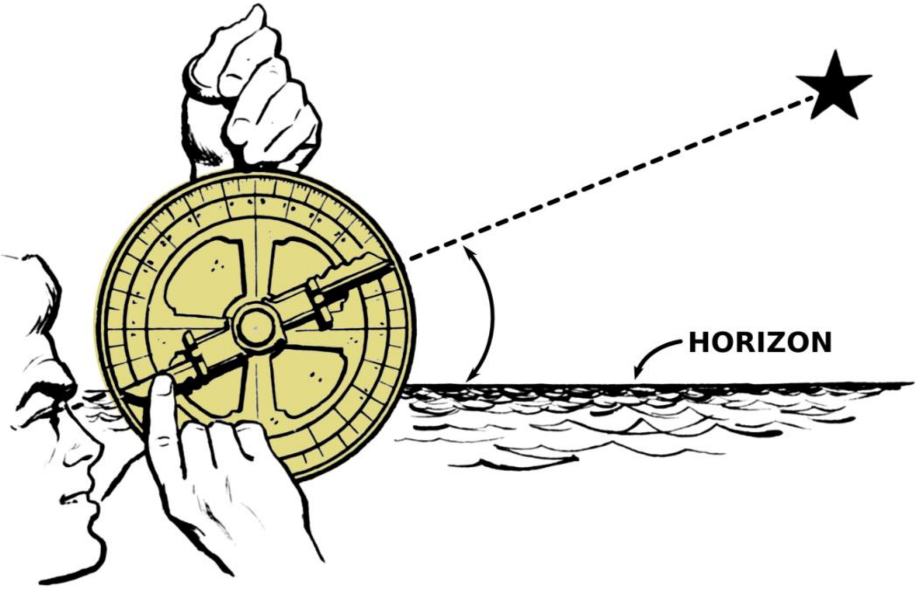
Orion belt stars are Alnitak + Alnilam + Mintaka

Link between astronomy & religion (pharao)

Navigation and Orientation

Determination of the latitude

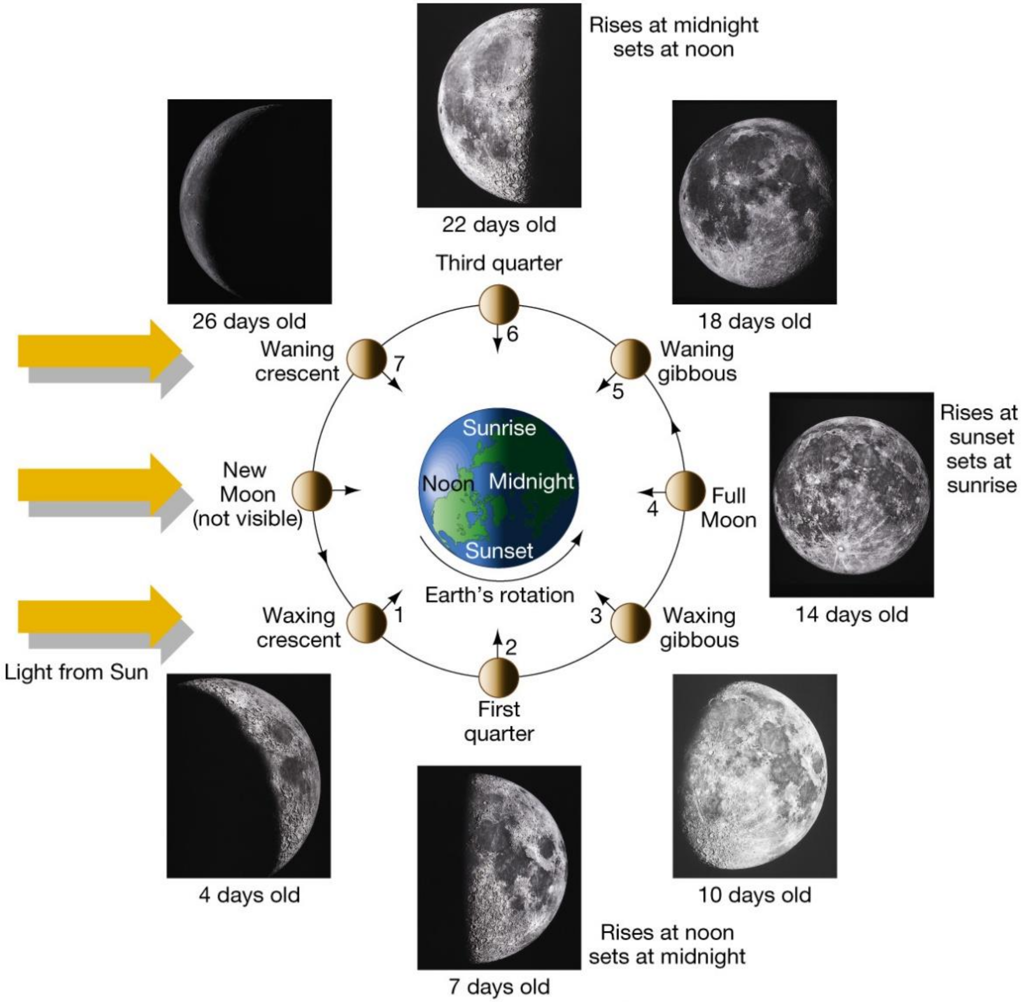
- An astrolab is a simple instrument used to find a locations latitude by observing a known star
- Since Polaris does not move over night it is a reference star
- Determination of the longitude requires a reference time and line as well as an accurate (fob) watch → 18th century → British empire



Observation of the Moon Phases

Some ancient observations

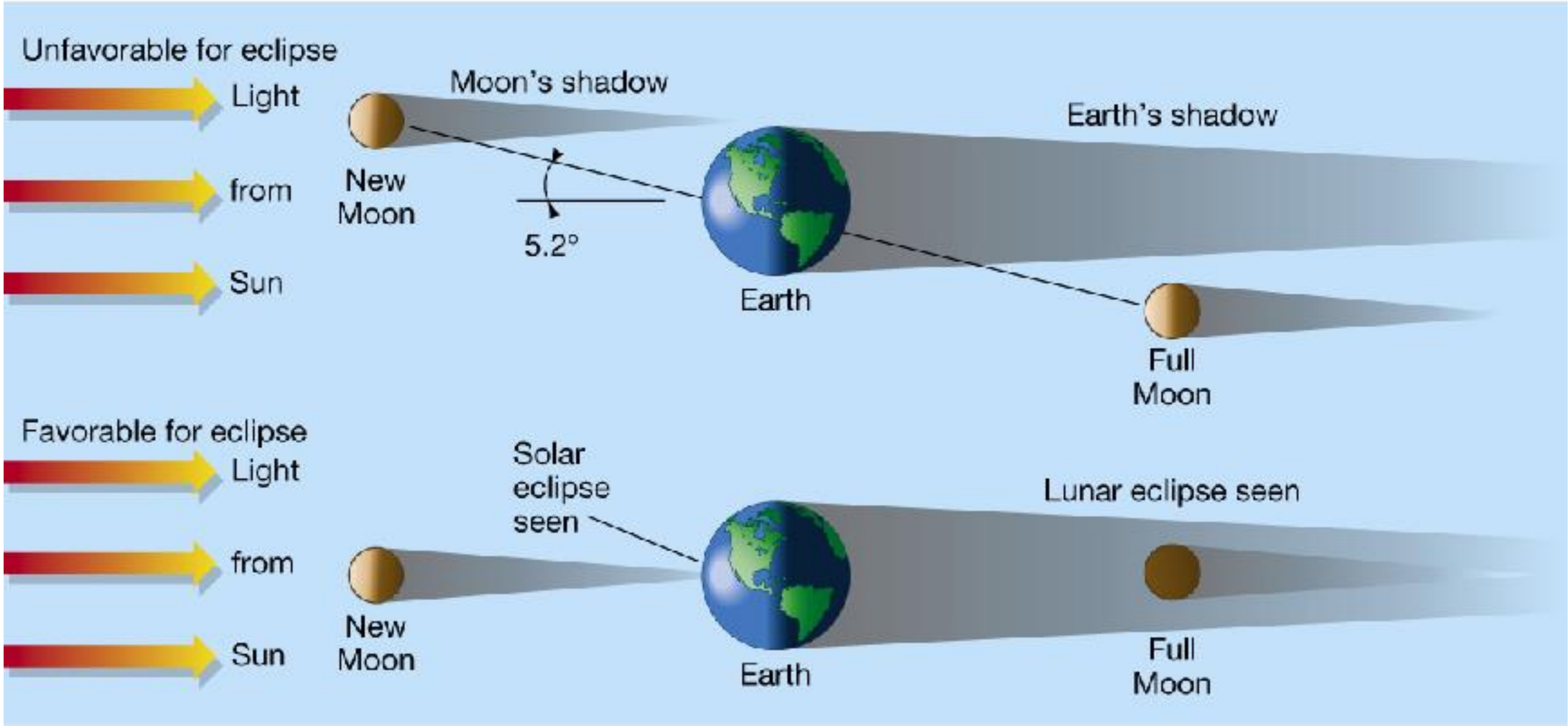
- Regular phases
- Tidal effects related to moon phases
- Eclipses of moon and sun appear regularly
  $\Rightarrow$ Saros cycle ~ 18 years
- First documented total eclipse of the sun observed 1825 BC by Chinese astronomers



Observation of the Moon Phases

Requirements for eclipses

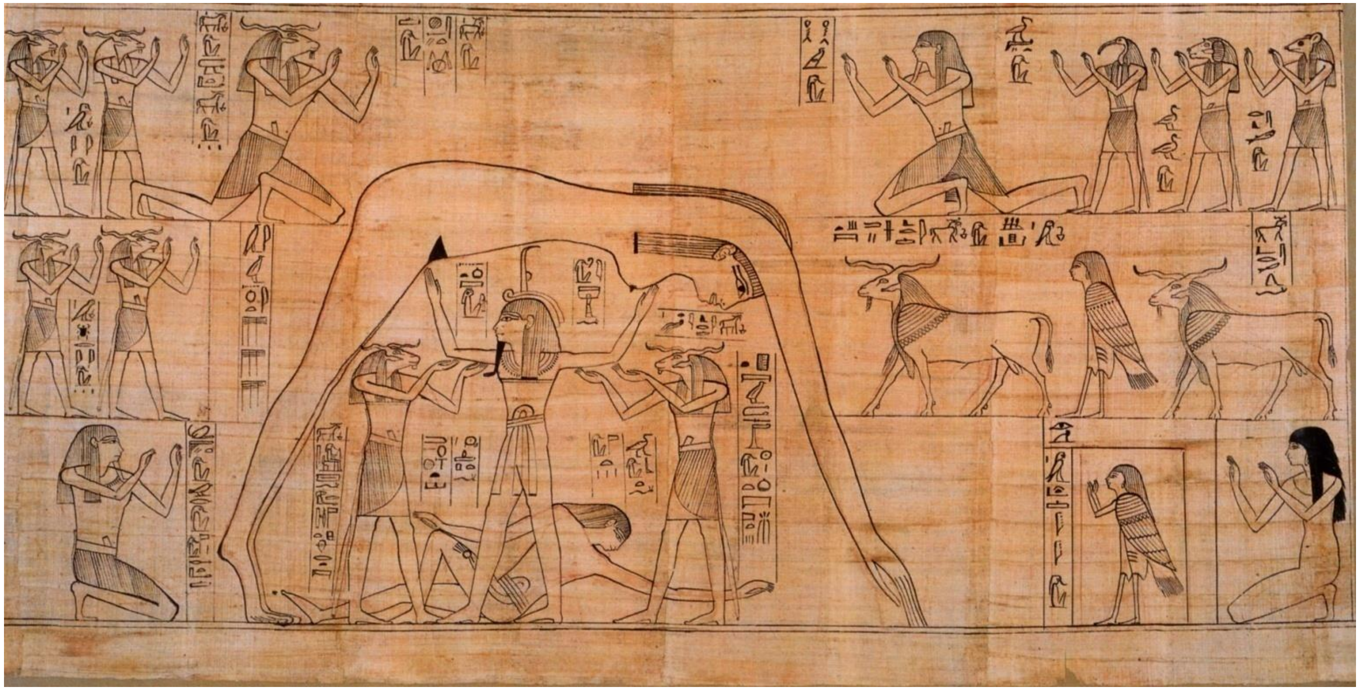
- New moon (solar) or full moon (lunar)
- Line of nodes of the two orbits points to the sun

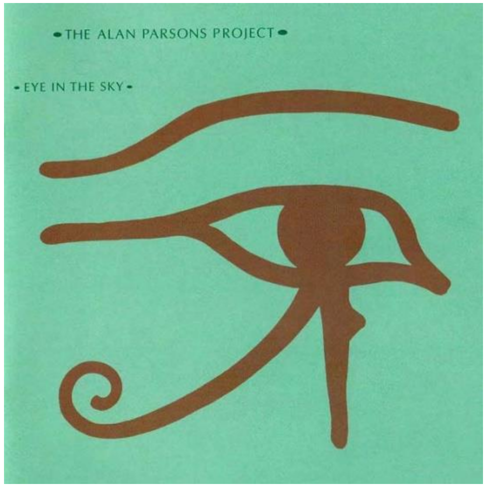


Observation of Eclipses

Egyptian mythology

- Nut (god of sky) and Geb (god of earth) are separated from each other
- The Horus eye - Link to the god of moon Thot
- Link between astronomy and religion

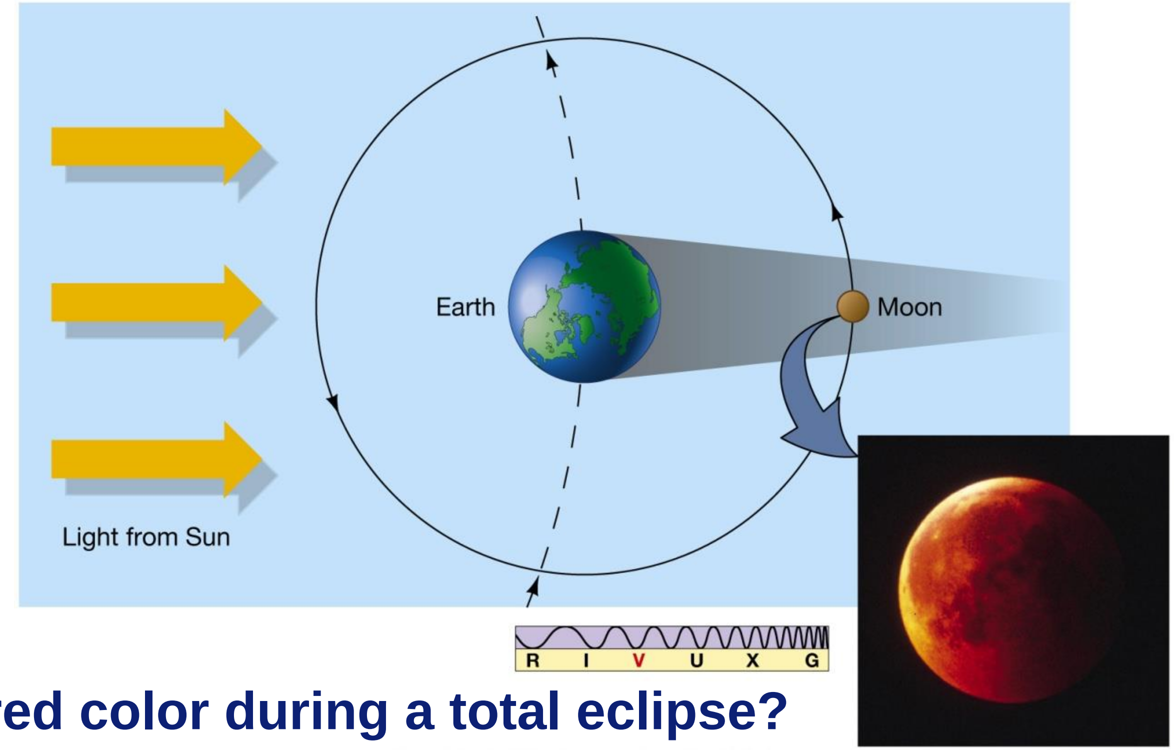




Total Eclipse of the Moon

Requirements

- Earth is between Moon and Sun
- Partial eclipse if only part of Moon is in Earth's shadow

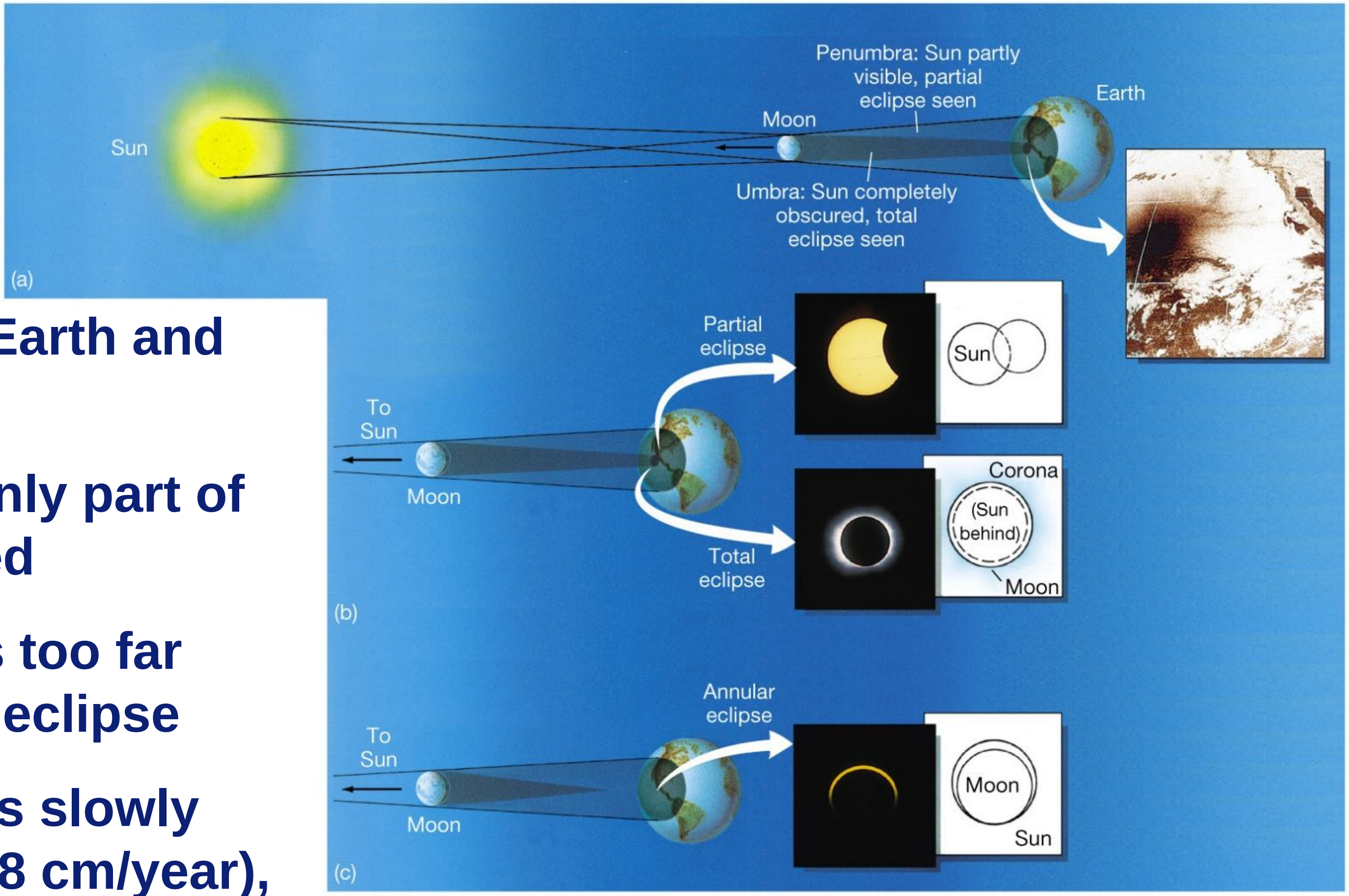


Question?

Why appear the moon in red color during a total eclipse?

Total Eclipse of the Sun

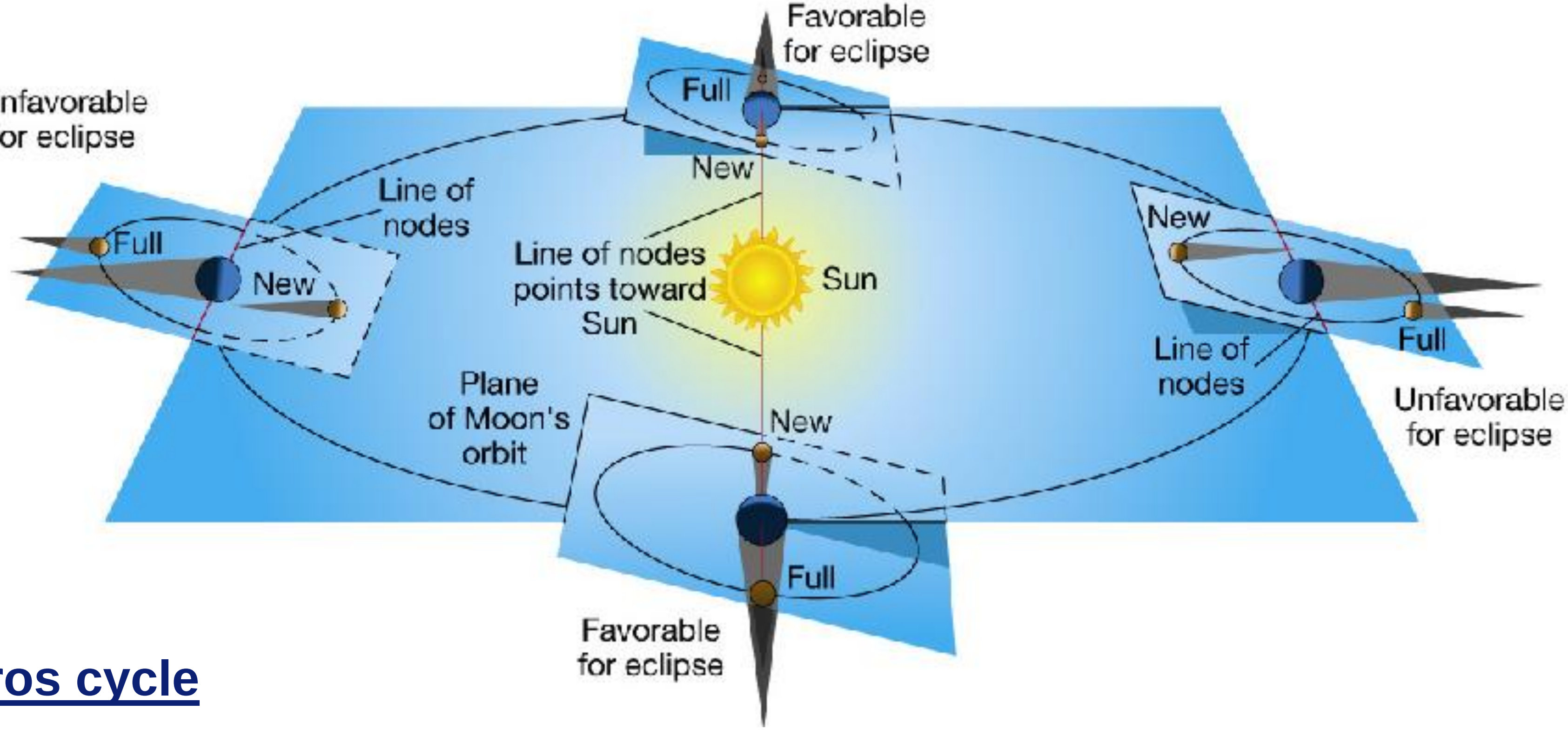
Requirements



- Moon is between Earth and Sun (New moon)
- Partial eclipse if only part of the Sun is shadowed
- Annular if moon is too far from Earth for total eclipse
- Since moon moves slowly away from Earth (3.8 cm/year), total eclipses will not occur anymore in a few million years

Total Eclipse of the Sun

Eclipses don't occur every month because Earth's and Moon's orbits are not in the same plane (angle to the ecliptic ~ 5°)



Saros cycle

Synod month 29.5 days * 223
Sidereal month 27.2 days * 242

= 6585.3 days = 18 years and 10.3 days or 11.3 days

Total Eclipse of the Sun

History of observation of eclipses

1875 BC	First documentation of a total eclipse by the Chinese
June 15th, 763 BC	Total eclipse observed by the Assyris
May 28th, 585 BC	Predicted by Thales of Milet
May 3rd, 1715	Calculation of the pathway of the shadow during a total eclipse of the sun by Edmond Halley
May 29th, 1919	Proof of gravitatic refraction of light as predicted by the general theory of relativity of Albert Einstein
August 11th, 1999	Total eclipse of the sun in Middle Europe
April 08th, 2024	Total eclipse of the sun in the US
September 3rd, 2081	Next total eclipse of the sun visible in Germany
December 11th, 2117	Next Venus transit

Greek Astronomy

Transition from Myths → Philosophy → Empirical sciences

500 BC — **Pythagoras**
Earth is a sphere that spins around its own axis once a day
Concludes that the morning star (Phosphoros) is equal to the evening star (Hesperos) ⇒ Named it Venus

480 BC — **Oinopides**
Determination of the inclination of the ecliptic (~23.5°)

400 BC — **Philolaus from Kroton**
Interpretation of the movement of the planets
Central fire, which is orbited by sun, earth, moon, and the planety in concentric circles

350 BC — **Aristotle (teacher of Alexander the Great)**
Causa movens (impetus of movements), Causa materialis, Causa formalis, and Causa finalis (sense) are responsible for all kind of things, states and processes

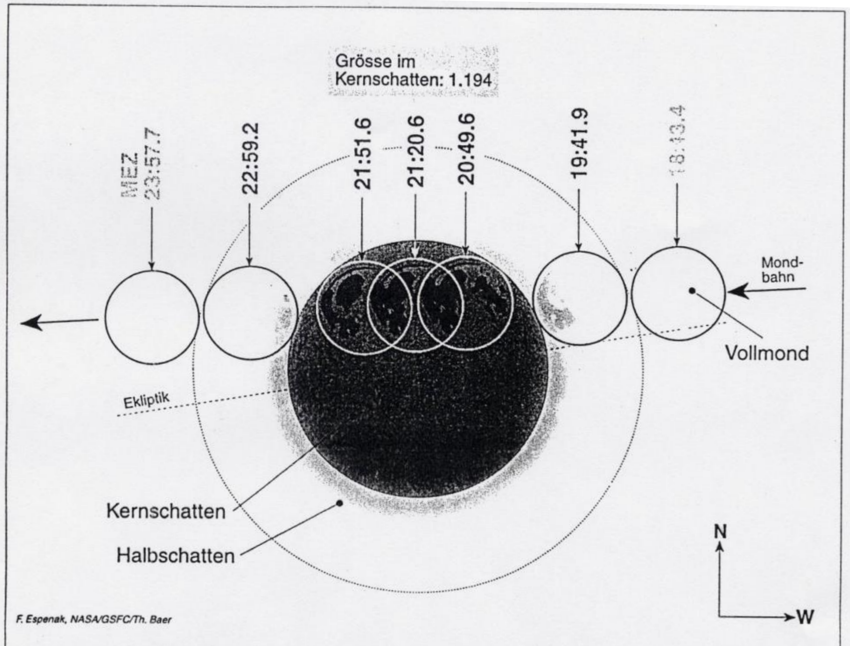
Greek Astronomy

Observation of total eclipse of the moon by Aristotle

- Earth's shadow is circular → Earth is a sphere
- Moon's diameter ~ 0.5°
- Moon moves with 0.5°/h
- Duration of totality of a eclipse ≈ 2 h
- Earth's shadow diameter ≈ 3 times the diameter of the moon (Today: 12756 km vs. 3475 km ≈ 3.67)

Totale Mondfinsternis vom 9. Januar 2001

Die obige Sequenz zeigt den Verlauf der Mondfinsternis am 9. Januar 2001 in Abständen von 10 Minuten. Der Kernschatten ist so gezeichnet, wie ihn ein Beobachter bezüglich des Horizontes sieht. Die Horizonthöhen gelten für 11° Ost und 50° Nord.



Totale Mondfinsternis vom 9. Januar 2001

Vollständig sichtbar in ganz Asien, Europa, Grönland und Afrika. Teilweise kann die Finsternis in Australien und Indonesien (morgens bei Monduntergang), sowie in Nord- und Südamerika (abends) beobachtet werden.

Greek Astronomy

Transition from Myths → Philosophy → Empirical sciences

265 BC	Aristarchos of Samos (310 – 230 BC) Heliocentric model of the universe (stars are very far) Determination of the moon diameter
220 BC	Eratosthenes (276 – 194 BC) Determination of Earth circumference (result 39,690 km)
150 BC	Hipparchos (190 – 120 BC) Apparent speed of the sun is not constant (→ Kepler) Discovery of precession of the axis of Earth
145 AD	Ptolemy (85 – 165 AD) Geocentric model of the universe by using mathematics Epycicle theory Stars at the outermost sphere Summary of the whole astronmical konwledge → Syntaxis (827 AD translated by the Arabs: Almagest)

Greek Astronomy

Determination of Earth‘s diameter by Eratosthenes

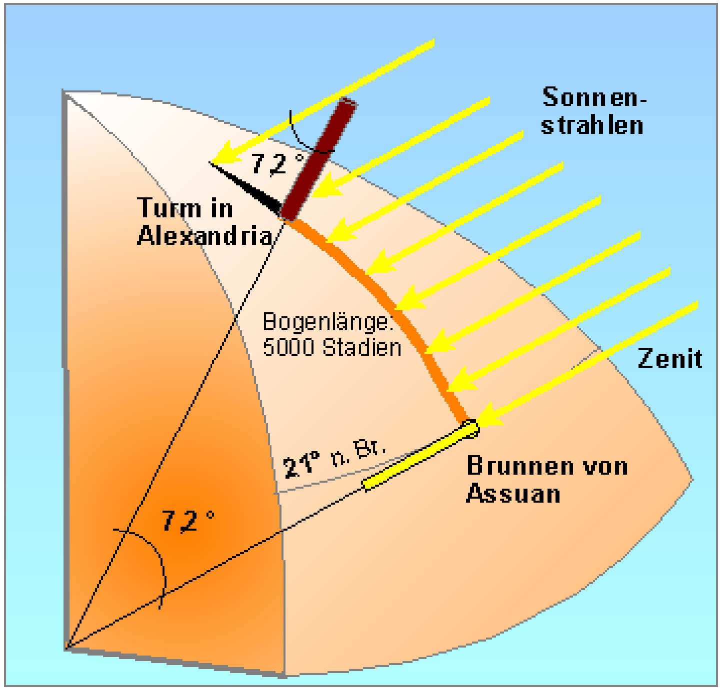
At June 21st, i.e. sun at the tropic of cancer (23.5° North)

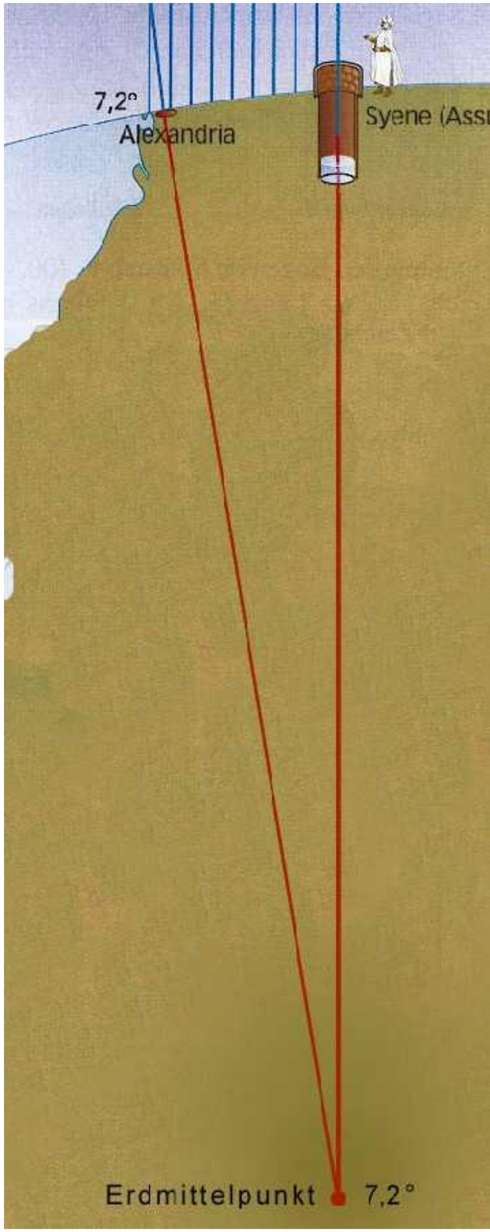
Distance Alexandria-Assuan = 794 km (5000 stadiums)

Measured angle of the sunrays to a tower in Alexandria is 7.2°

Earth is a sphere = 360°

Circumference = 360°/7.2°*5000 stadiums = 250,000 stadiums = 39,690 km



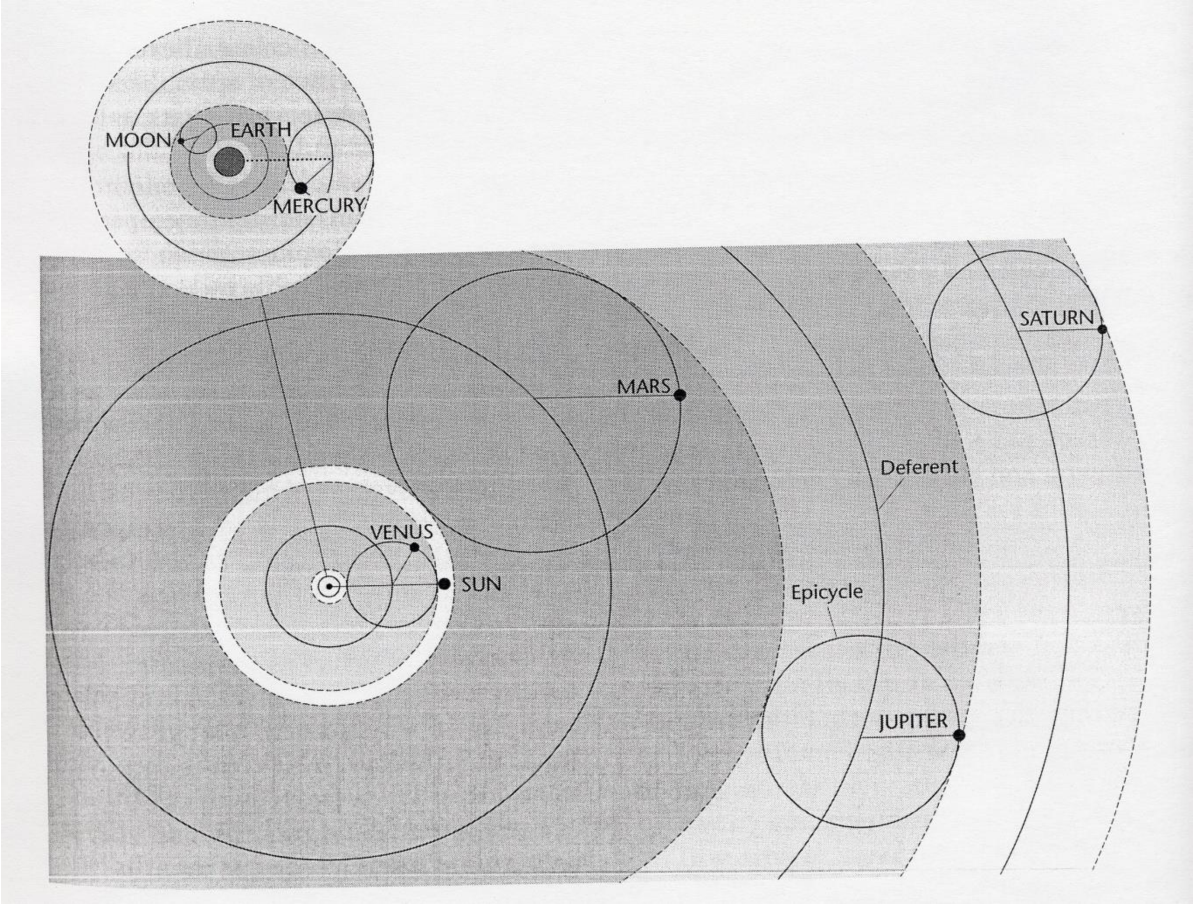


Equatorial:	40,075 km
Polar:	40,008 km

Greek Astronomy

Summary of their discoveries

- Size of the Earth
- Size of the Moon
- Distance to the Moon
- Distance to the Sun
- Size of the Sun

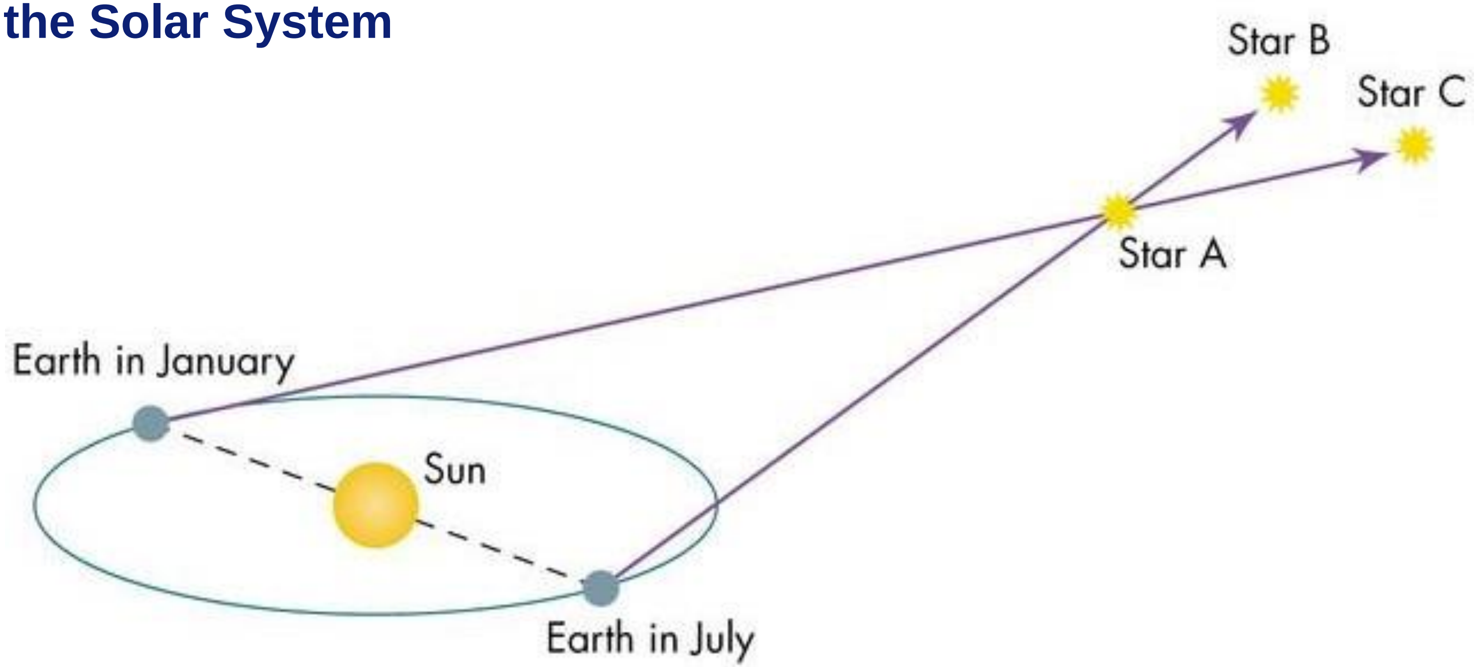


Most Greeks preferred the geocentric model of the universe, which was modified by Ptolemy for optimisation

Greek Astronomy

Argument for the geocentric model

Motion of the Earth around the Sun causes stellar parallax
Because the stars are so remote, this is too small to be seen by the naked eye
Thus the ancient Greeks incorrectly deduced that the Sun could not be the center of the Solar System



Or: Stars must be extremely remote, which was not imaginary those days!

Greek Astronomy

Some problems of the geocentric model of the universe

1. Mercury and Venus are always close to the sun (never in opposition)

2. Length of summer is longer than the length of winter

3. Movements and loops of the planets

Origin: Wrong assumptions

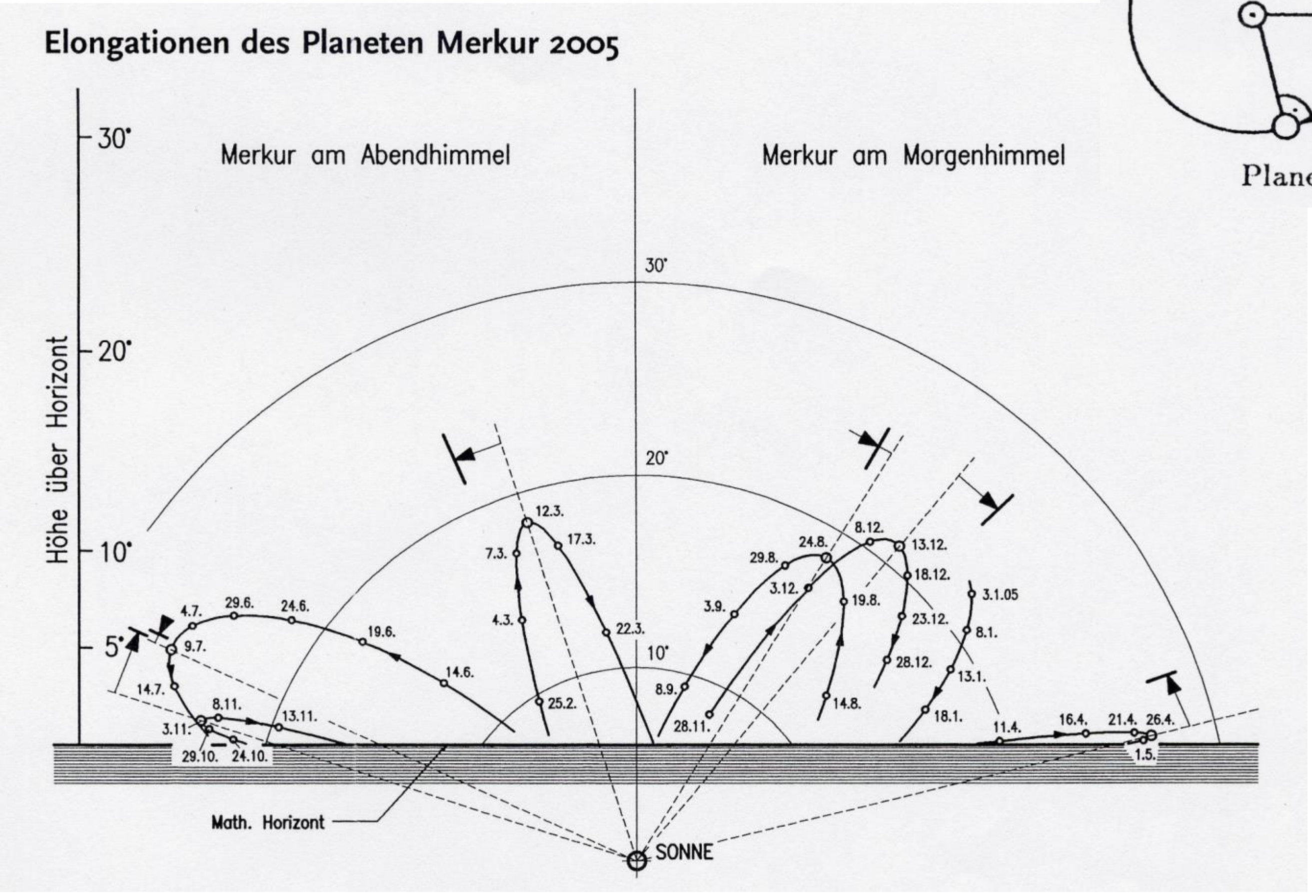
1. Geocentric model

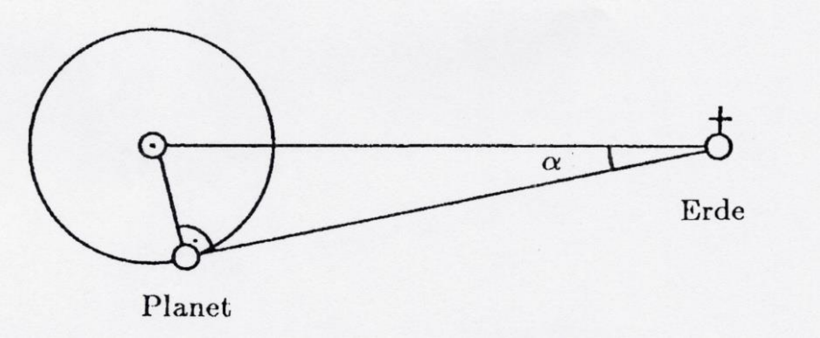
2. Circular orbits

3. Uniform movements

Greek Astronomy

1. Mercury and Venus are always close to the sun



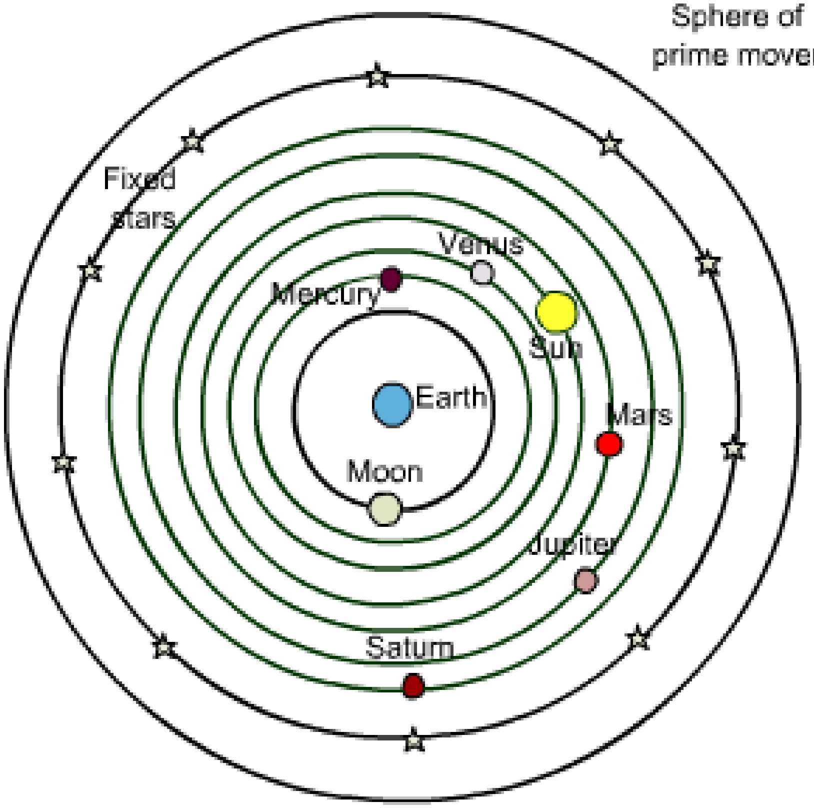


Greek Astronomy

1. Mercury and Venus are always close to the sun

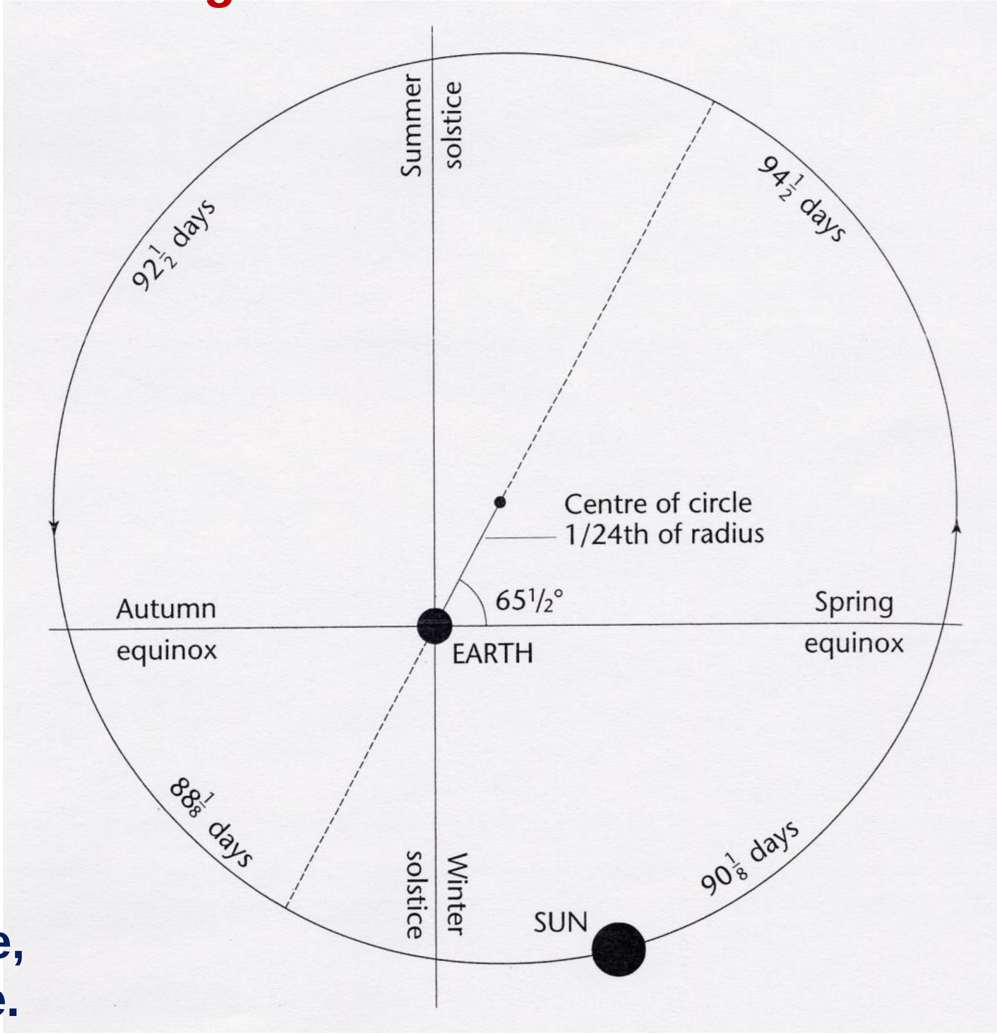
Solution

Mercury & Venus orbits around Earth inside the orbit of the sun



Greek Astronomy

2. Length of summer is longer than the length of winter



Solution

Earth is not in the centre of the circle, but in an eccentric position 1/24 of the radius of the centre of the circular orbit

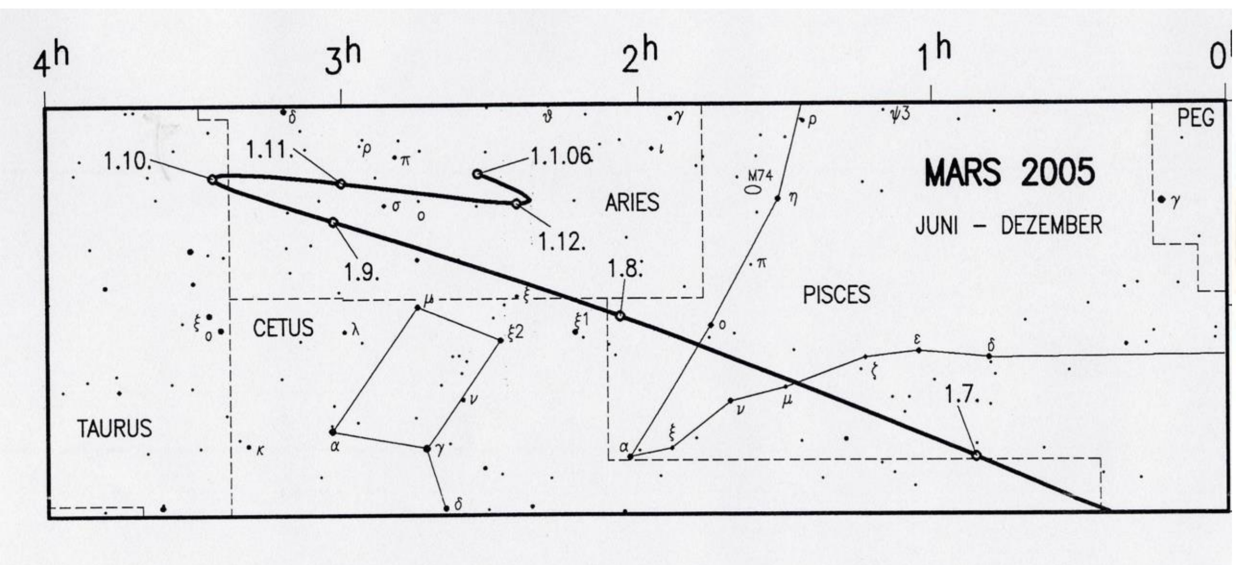
Spring	**94.5 days**
Summer	**92.5 days**
	187.0 days
Autumn	**88 1/8 days**
Winter	**90 1/8 days**
	178.25 days

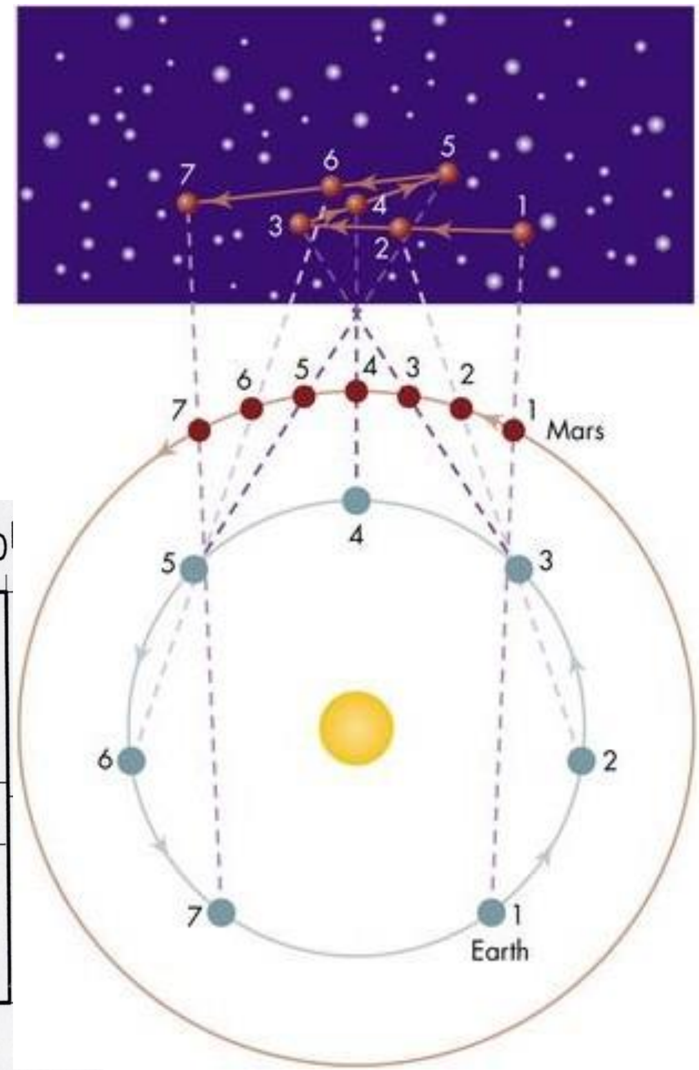
Situtation for the Northern hemisphere, Opposite for the Southern hemisphere.

Greek Astronomy

3. Movements and loops of the planets

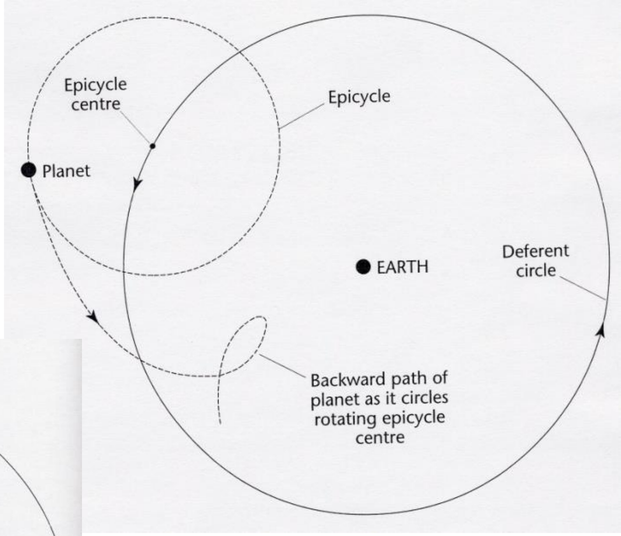
External planets show retrograde and backward movements, particularly visible for the Mars orbit





Greek Astronomy

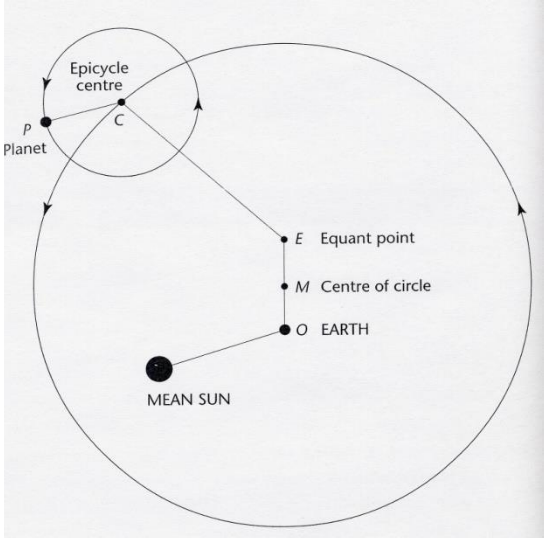
3. Movements and loops of the external planets



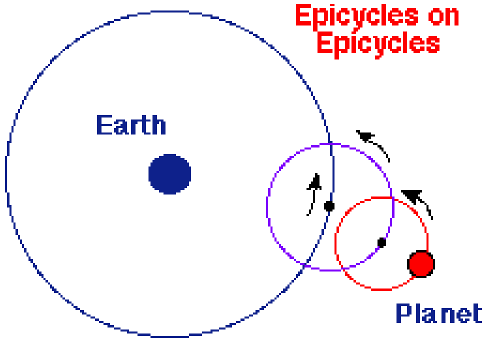
Solution

1. Approximation
   Epicycles

2. Approximation
   Epicycles + Eccentric position



3. Appoximation
   Epicycles on epicycles

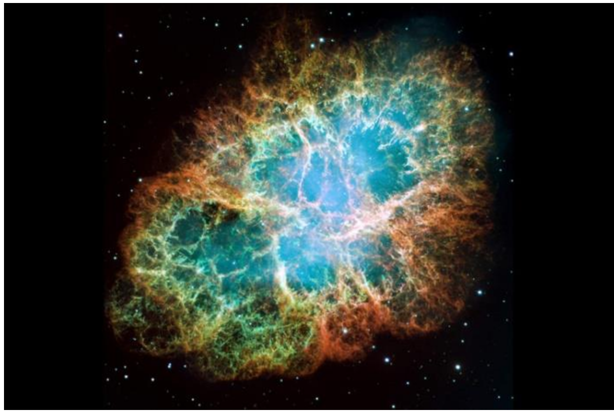


Geocentric model became more and more complicated!

Science and models
- The simple explanation tends to be the right explanation
- Refined model appear to solve problems, but ....

Medieval Age Astronomy

Dominated by the geocentric model of Ptolemy and the Almagest, which was translated from Arabic into Latin at 1175 AD



1054 Supernova (Crab nebula)
Documented by the Chinese, not in Europe!
Catholic church: The sky is perfect, eternal, and unchangeable

- 1500 System of Ptolemy was taught by the Arabs
Al Battani 858 - 928
Al Sufi 903 - 986
Alfons X of Kastilia 1226 - 1284 ⇒ Alfons tables (1st printed edition 1483)

1492 Christopher Columbus (Genova, ~1451 - 1506) → Discovery of America

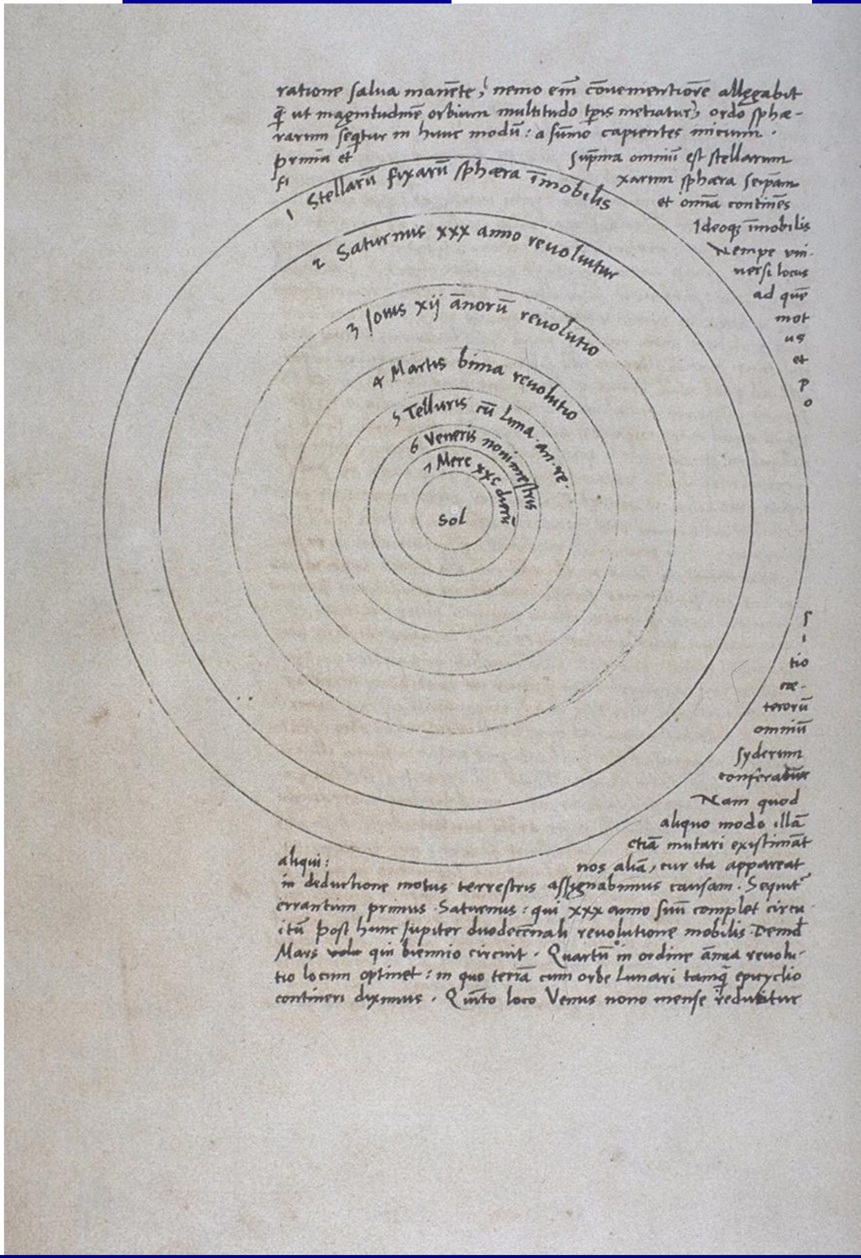
1543 Nikolaus Copernikus (February 19th, 1473 – 1543)
Published „De revolutionibus orbium coelestium" a heliocentric model of the universe mainly consistent to that of Aristarchos of Samos

The Heliocentric Model

Goal of Nikolaus Copernicus

To reduce the confusion of the medieval astronomy and to deliver an alternative to the complicates geocentric model of Ptolemy

Published in 1543, Nuremberg
“*De revolutionibus orbium coelestium*”



The Heliocentric Model

Explains the seasons and the movements of the planets

The ecliptic is the plane of Earth's path around Sun; at 23.5° to celestial equator

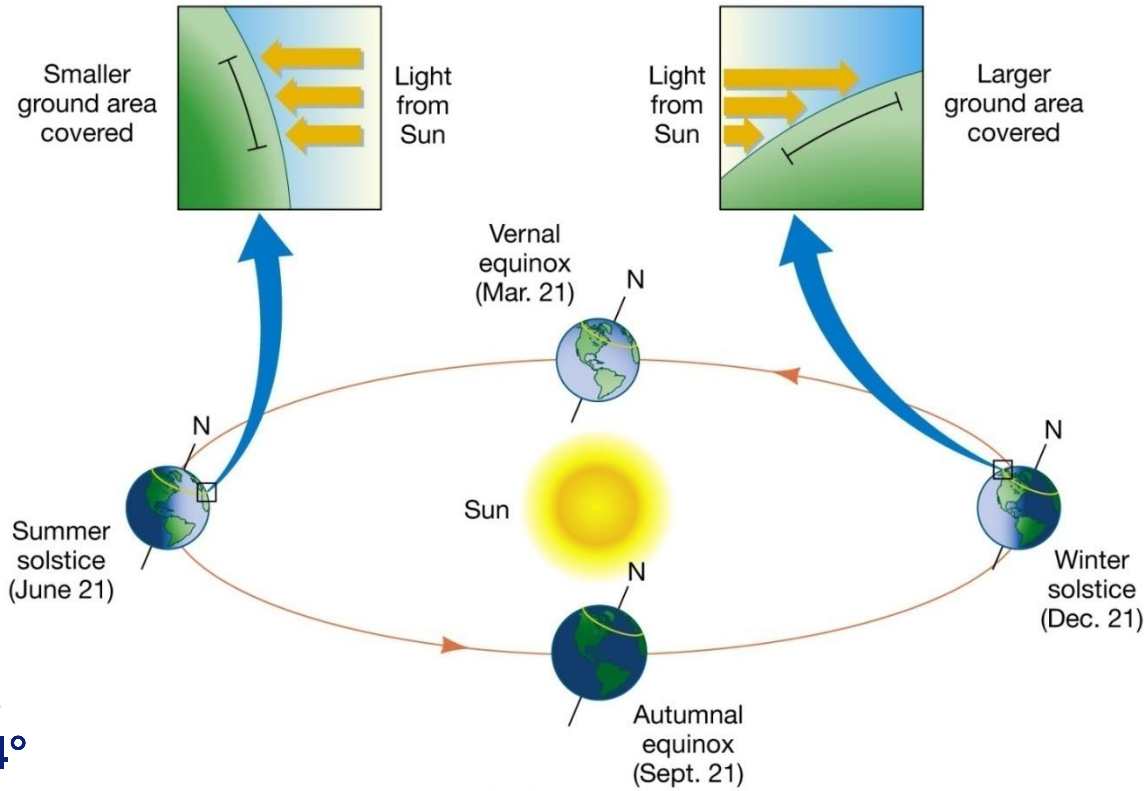
Northernmost point is summer Solstice (June 21st)

Southernmost point is winter solstice (December 21st)

Points where path crosses celestial equator are vernal and autumnal equinoxes

Time from one vernal equinox to next one is a tropical year

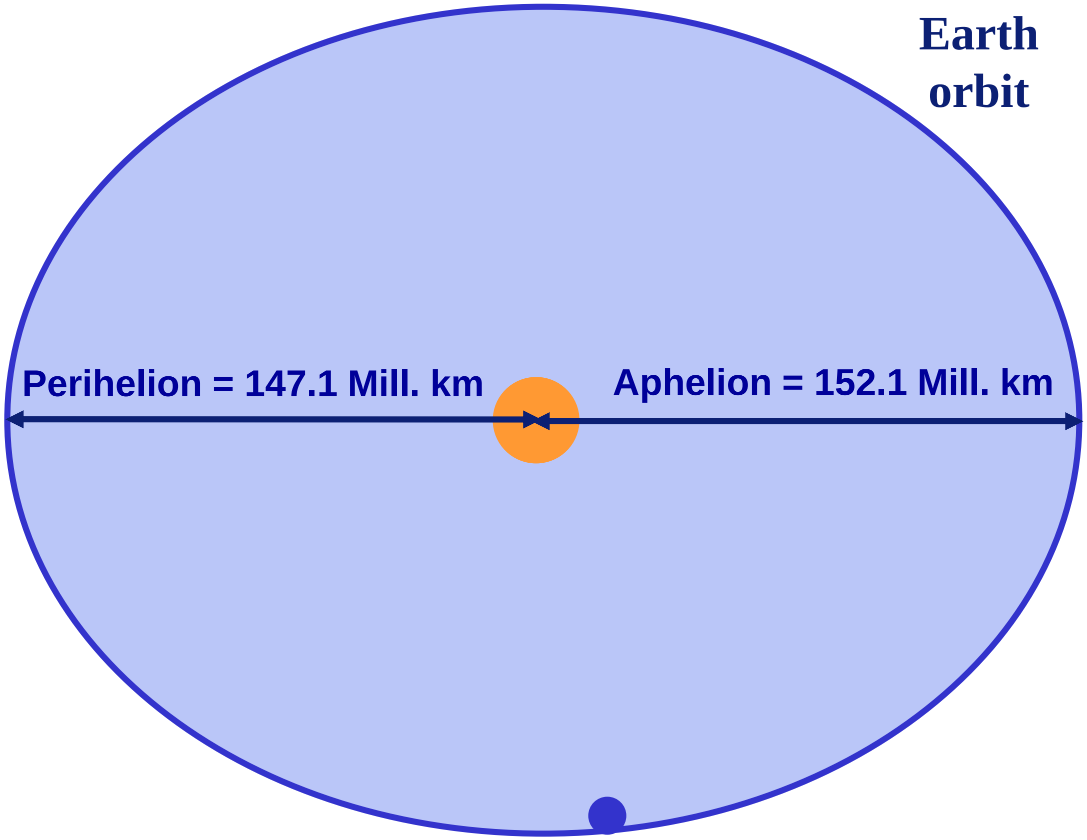
The inclination of the Earth axis changes between 21.8° and 24.4° with a period of 40,000 years



Earth's Orbital Motion

The orbit of the Earth is much more complicated as you might think...

- Its elliptic (numerical excentricity = 0.016708617)
- The eccentricity changes in a period of 96,000 years, i.e. the orbit pulsates
- Present Earth's orbit: Aphel at July 3rd Perihel at January 3rd ⇒ winter of northern hemisphere is milder and winter of southern hemisphere is stronger (Antarctica shows lowest temperatures)
- Perihelion rotation

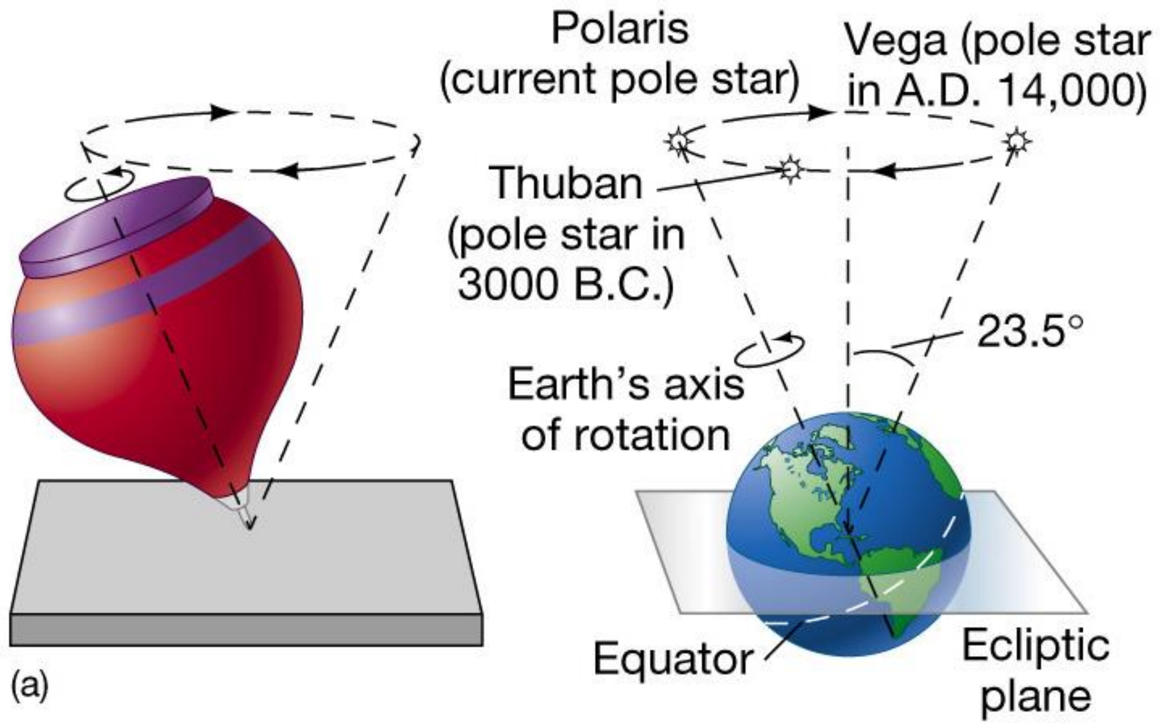


Earth's Orbital Motion

The orbit of the Earth is much more complicated as you might think...

- **Earth axis show precession, i.e. rotation around the normal of the ecliptic**
- **Period: 25,784 years**
  ⇒ The zodiac moves by one constellation in about 2,150 years

  ⇒ In 13,000 years Orion will be a summer instead of a winter constellation
- **In addition: Nutation with a period of 18.6 years**

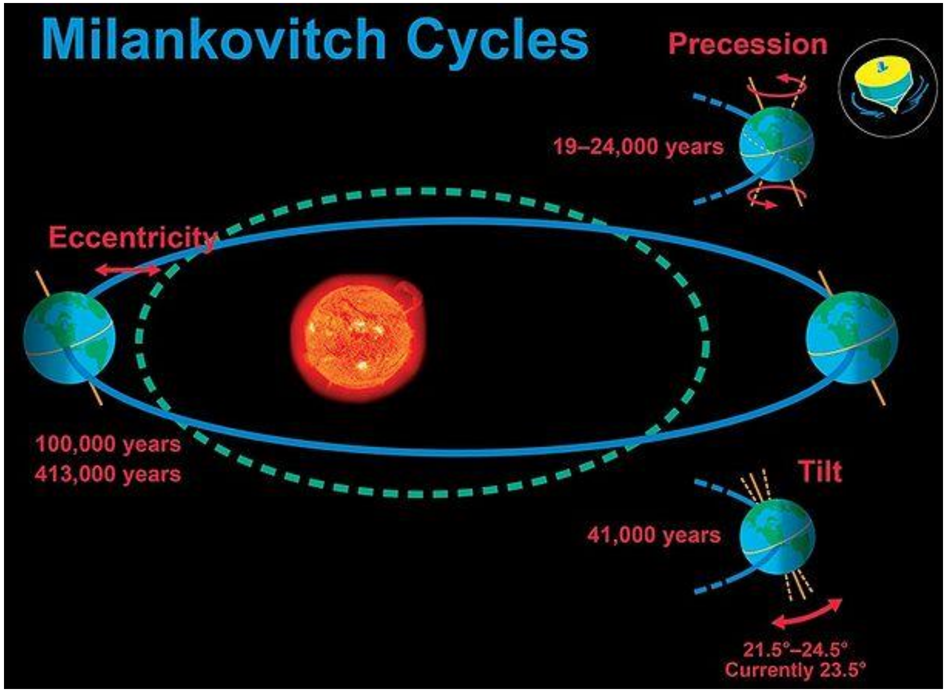


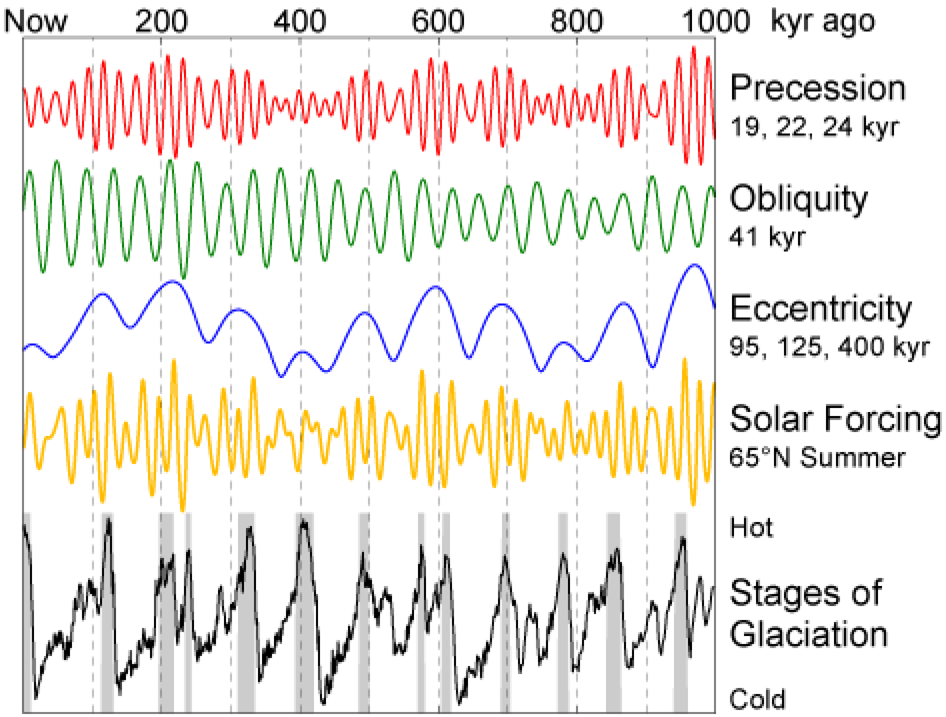
Milankovic-cycles: Explains ice and warm periods throughout the last 500,000 years as proven by ice drill cores from Antarctica

Milankovic Cycles

Theory first published in 1920 by Milutan Milankovic (1879 – 1958)

Describes the collective effect of all orbital parameters on Earth‘s climate





Modern Age Astronomy

New observations and theories

1572/73 Tycho Brahe (1546 - 1601)

Observes a supernova for 485 days

Contributes to the star catalogue „Uranometria“, which comprises 2000 stars and its positions

Determines Mars orbit with an accuracy of 2‘

1600 Giordano Bruno (1548 - 1600) death sentenced in Rome

"Innumerable suns exist; innumerable earths revolve around these suns in a manner similar to the way the seven planets revolve around our sun. Living beings inhabit these worlds."

1608 Hans Lippershey (~1570 - 1619)

Invented first telescope (refractor type based on two lenses, which are called objective and ocular)

Modern Age Astronomy

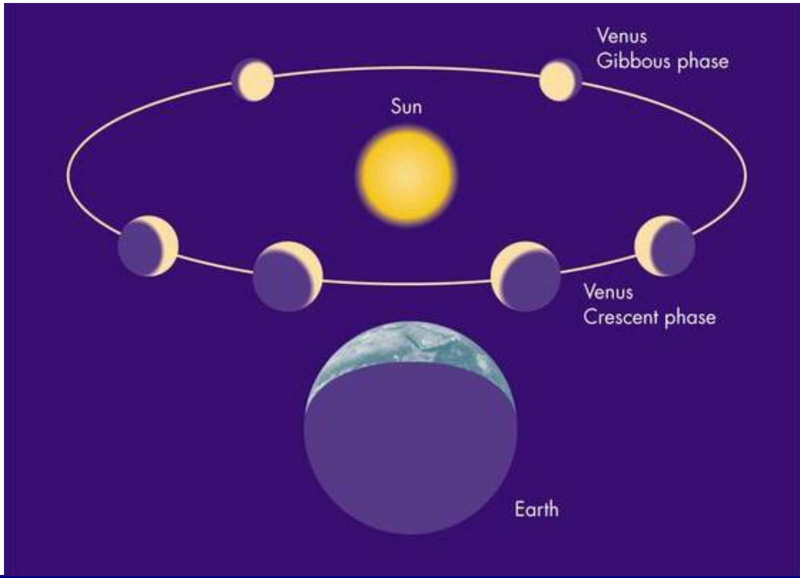
New observations and theories

1609/10 Galileo Galilei (1564 – 1642)

Defends heliocentric model of Copernicus (inquisition),
Constructs own telescope 1609
Discovers sun spots, phases of the Venus, mountains on the moon, and the large Jupiter moons, i.e. Ganymed, Io, Europa, and Kallisto
Movements of the moons obeys Kepler's laws
Contributions to the laws of mechanics

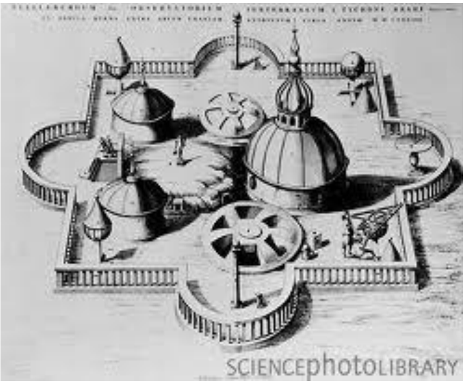
1609/18 Johannes Kepler (1571 – 1630)

Derived the so-called Kepler's laws from Mars data of Danish astronomer Tycho Brahe elliptical orbits and non-uniform movements
Heliocentric universe with elliptic orbits of the planets

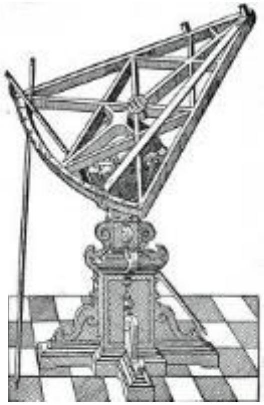


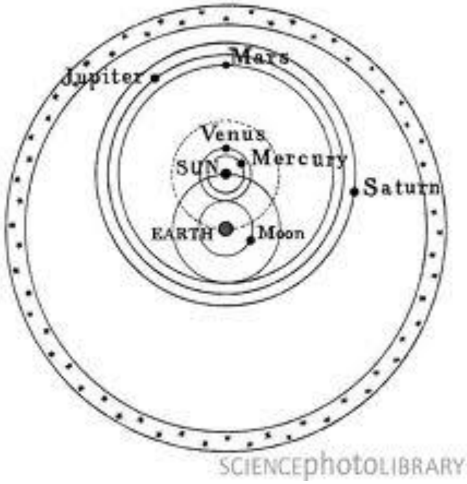
Tycho Brahe (1546 - 1601)

Constructed the observatory of Uraniborg (Greek word Urania: Muse of astronomy and goddess of the heavens)

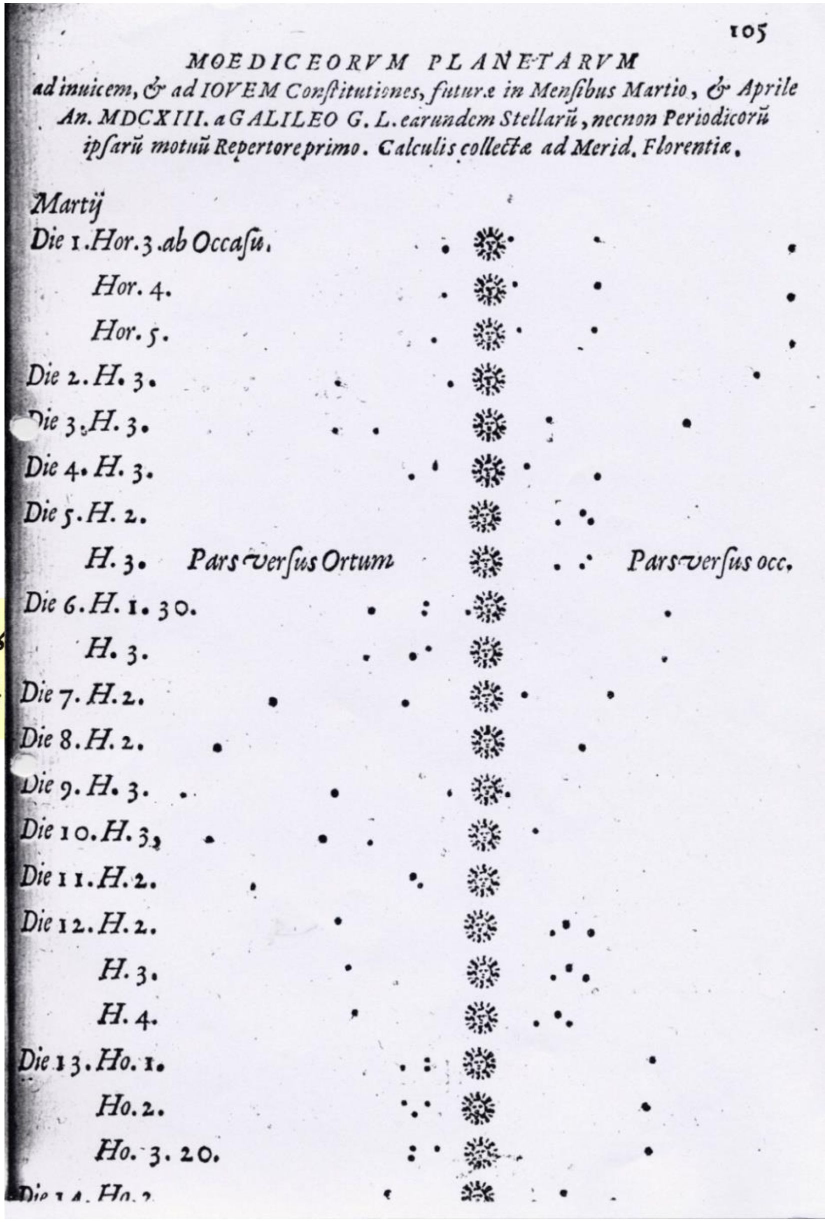


- Urania was lavishly equipped with scientific instruments of an accuracy never seen before, e.g. a two-man operated sextant which could measure angles within 1 arc minute
- Observed the conjunction of Jupiter & Saturn in 1563 and revealed inaccuracy of existing tables, i.e. 13th century Alphonsine tables were out by a month and Prutenic tables (based on Copernican model) were out by 2 days
- Successfully proved that comets were not meteorological using parallax, moreover proved comets move between planets and thus Aristotelian spheres did not exist in 1577
- The Tychonic system proposed the Sun and Moon go around the earth, while all the other planets go around the sun.



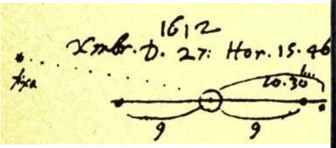


Galileo Galilei (1564 - 1642)

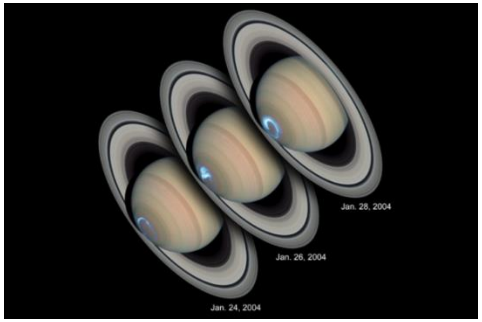


Introduced the telescope as a powerful tool in astronomy

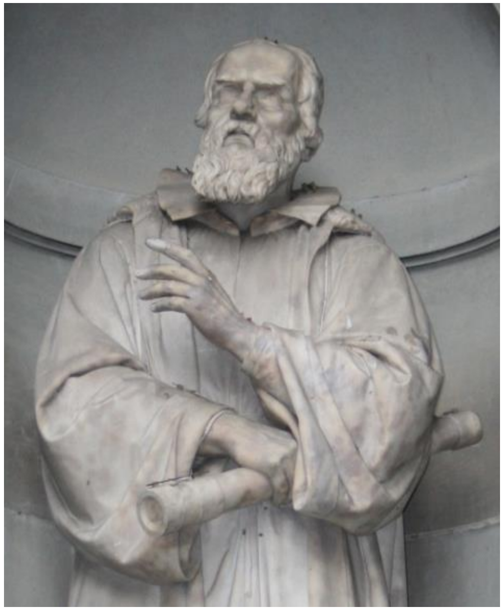
- Resolves milky way into stars
- Observed movements of the Jupiter moons → Kepler's laws
- Discovered ring of Saturn



- He was also the first one who observed Neptune close to Jupiter, but thought it was a star (December 28th, 1612)



Galileo Galilei (1564 - 1642)

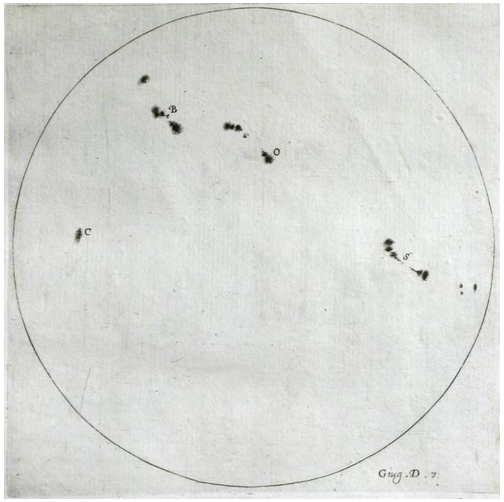


Discovered sunspots

- Sunspots were "discovered" on the Sun within months of the first use of the telescope for observing celestial objects in 1609

- However, spots on the Sun were previously noted by Chinese observers as early as 28 BC.

- Today: Sunspots linked to other scientific areas
  - Plasma physics
  - Solar physics
  - Climatology and metereology
  - History



Kepler's Laws

Mars orbit

Numerical eccentricity e ~ 0.093

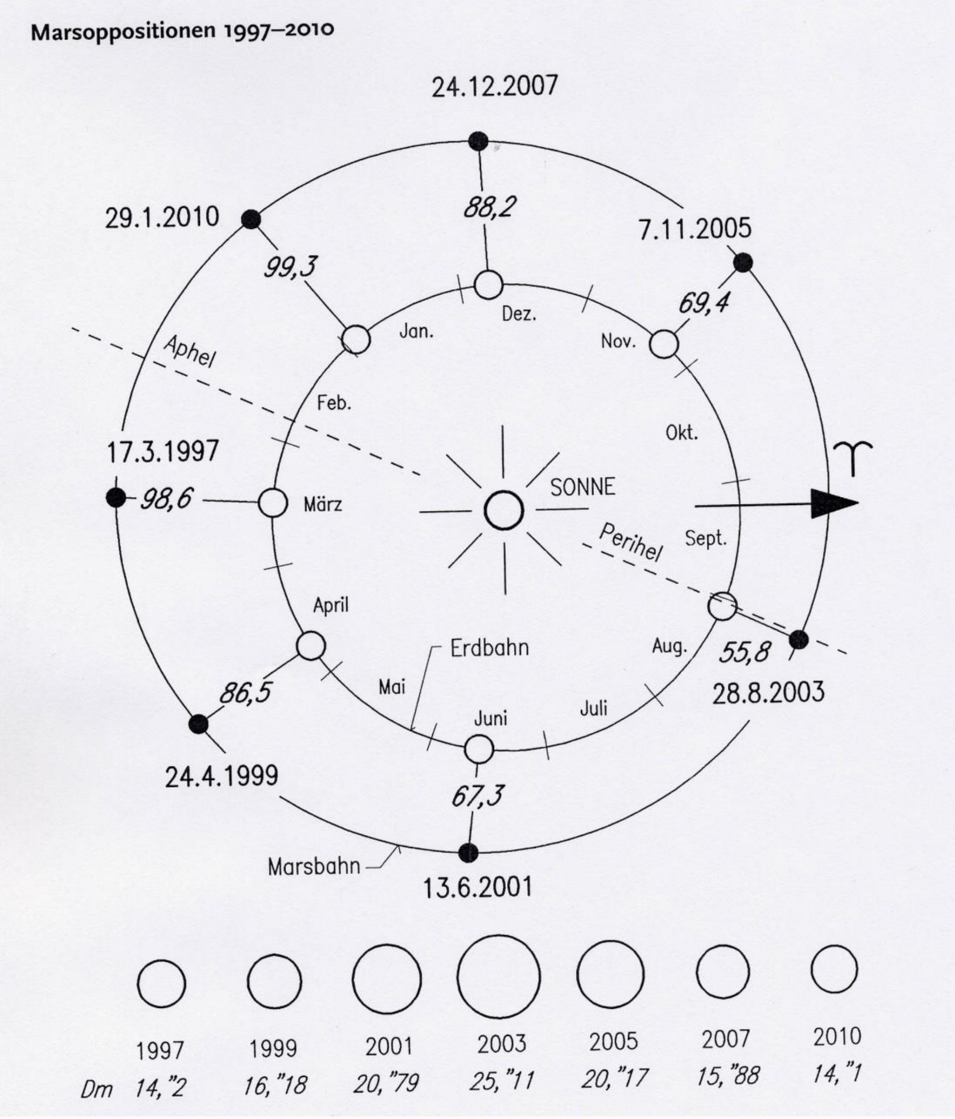
⇒ Distance to the sun

Aphelion	**249.2 Mill. km**
Perihilion	**206.7 Mill. km**

For comparison

Planet	Eccentricity e
Mercury	0.206
Venus	0.0068
Jupiter	0.048
Saturn	0.055
Uranus	0.047
Neptun	0.010

Mercury is difficult to observe!

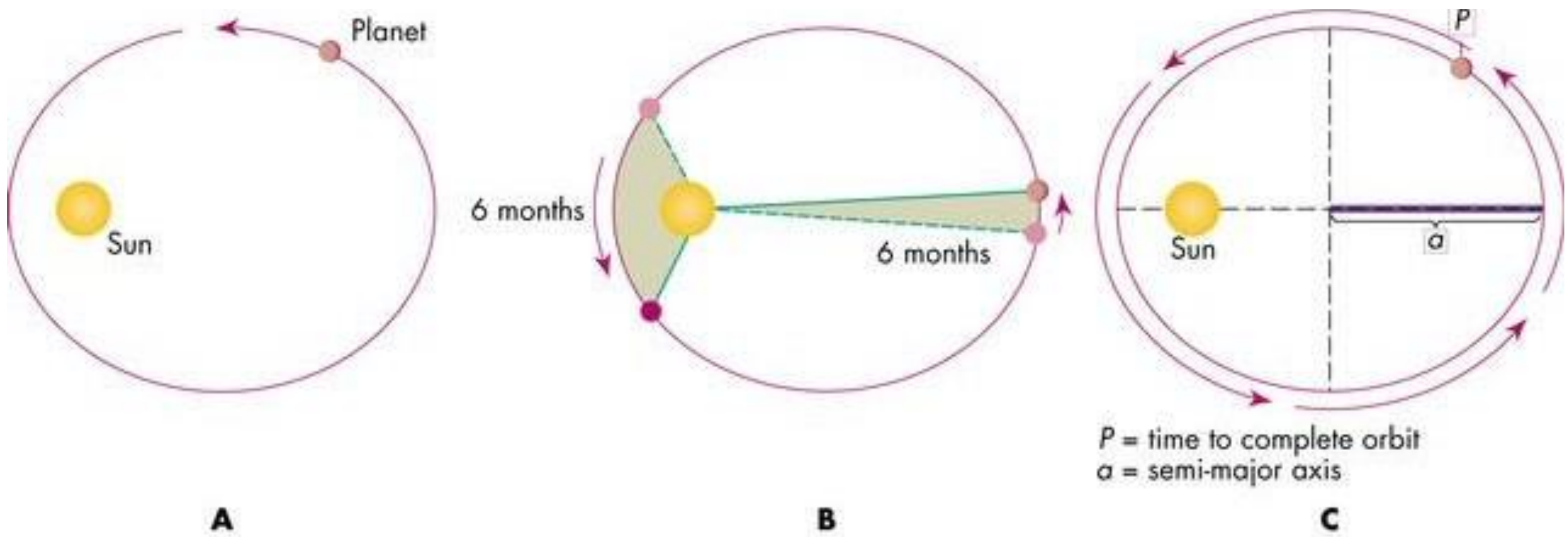


Kepler's Laws

a. Planets on elliptical orbits, while the sun is located at one focus of the ellipse

b. A planet moves so that a line from it to the Sun sweeps out equal areas in equal times. Thus the planet moves fastest when nearest to the Sun (constant integrals)

c. P^2/a^3 = constant with a = distance and P = period of revolution



Isaac Newton (1642 – 1727)

The 3 Newton laws of mechanics (1687)

1. Law of inertia (a body remains in rest or in uniform movement if no force is acting on it)
2. $F = dp/dt$ (any force causes a change in momentum in the direction of the force)
3. $F_{ij} = - F_{ji}$ (actio = reactio)

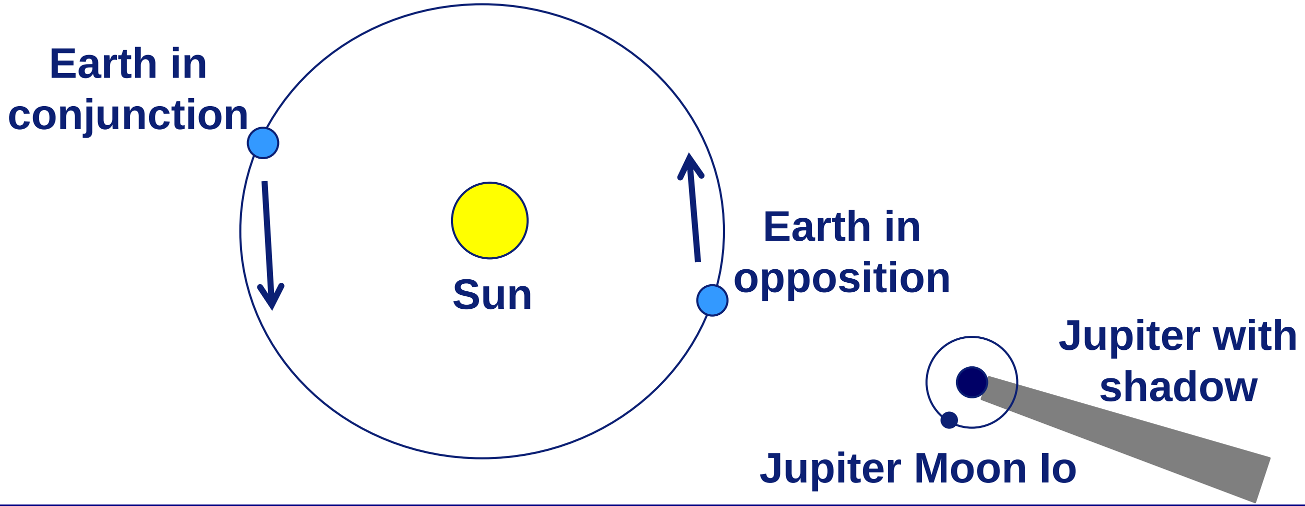
Revolution in science

- Mechanical view of the world/universe
- The empirically derived Kepler laws are exactly in line with Newton's mechanic
- Newton laws are universal
- Orbit of Halley comet (period 76 years) could be calculated

Discovery of the Properties of Light

Speed of light is fast but limited (c ~ 300,000 km/s)

Determination of c by the observation of the revolution of Io around Jupiter (Ole Rømer and G.D. Cassini 1675 AD) ⇒ P ~ 1.769 days
Determination of the time between the appearance of the moon and the re-entry into the shadow of Jupiter right after Earth was in opposition or after Earth was in conjunction
→ Difference ~ 20 min → c = 2.14 x 10^8 m/s (today: 2.998 x 10^8 m/s)

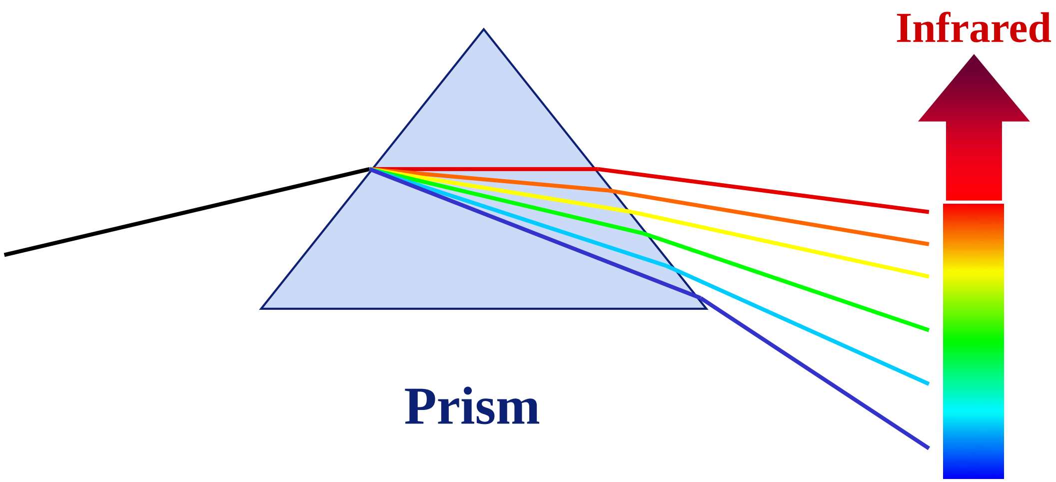


Discovery of the Properties of Light

Discovery of IR radiation

Wilhelm Herschel 1800

by its effect on a Hg thermometer



Wilhelm (William) Herschel (1738 – 1822)

His major discoveries

1779	Discovered double stars
1781	Discovered Uranus
	Irregularities in Uranus's orbit together with law of gravity leads to discovery of Neptune (1846 by Johann Gottfried Galle)
1783	Determined movements of stars
1784	Nature of the polar caps of Mars
1786	Published a nebula and star cluster catalogue
1787	Discovery of two Uranus moons
1789	Construction of a Newton Telescope with 48 inch mirror
1796/99	Brightness catalogue: Begin of astrometric photometry

Discovery of the Electromagnetic Spectrum

Discovery of UV radiation

Johann W. Ritter 1801 — **Discovered UV Radiation by the effect of dispersed solar light on $AgNO_3 \rightarrow Ag$ (black)**

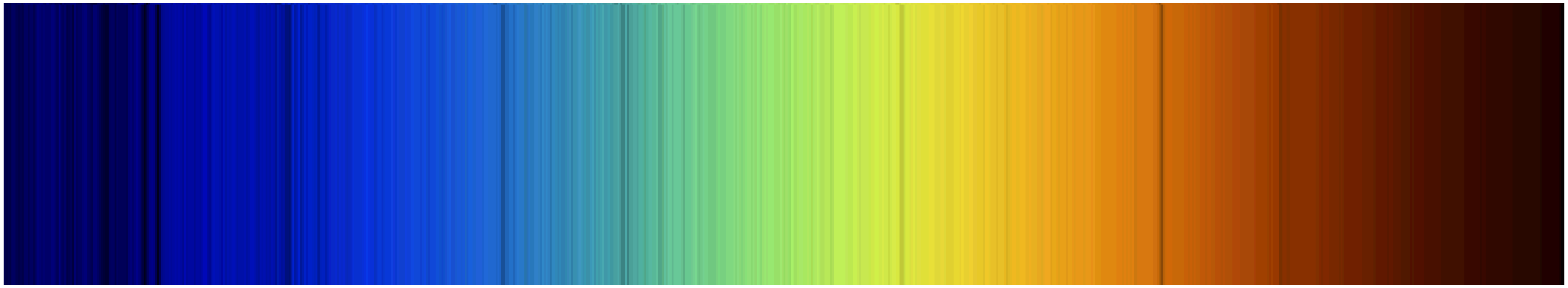
What kinds of astronomical objects typically emit what kinds of radiation?

Type of Radiation	Typical Sources
Gamma-rays	Disks around black holes, Gamma-ray bursts from supernovae
X-rays	Gas in clusters of galaxies, supernova remnants, stellar coronae, active galactic nuclei (AGN)
Ultraviolet	Supernova remnants, very hot stars
Visible	Galaxies, stars, planets, some moons
Infrared	Cool clouds of dust and gas (galactic disk), some planets
Radio waves	Radio wave emission is produced by electrons moving in magnetic fields, jets from interacting binaries & AGN

Discovery of the Properties of Light

Absorption lines in the solar spectrum

Discovered by Joseph Fraunhofer 1814 → Fraunhofer-Lines



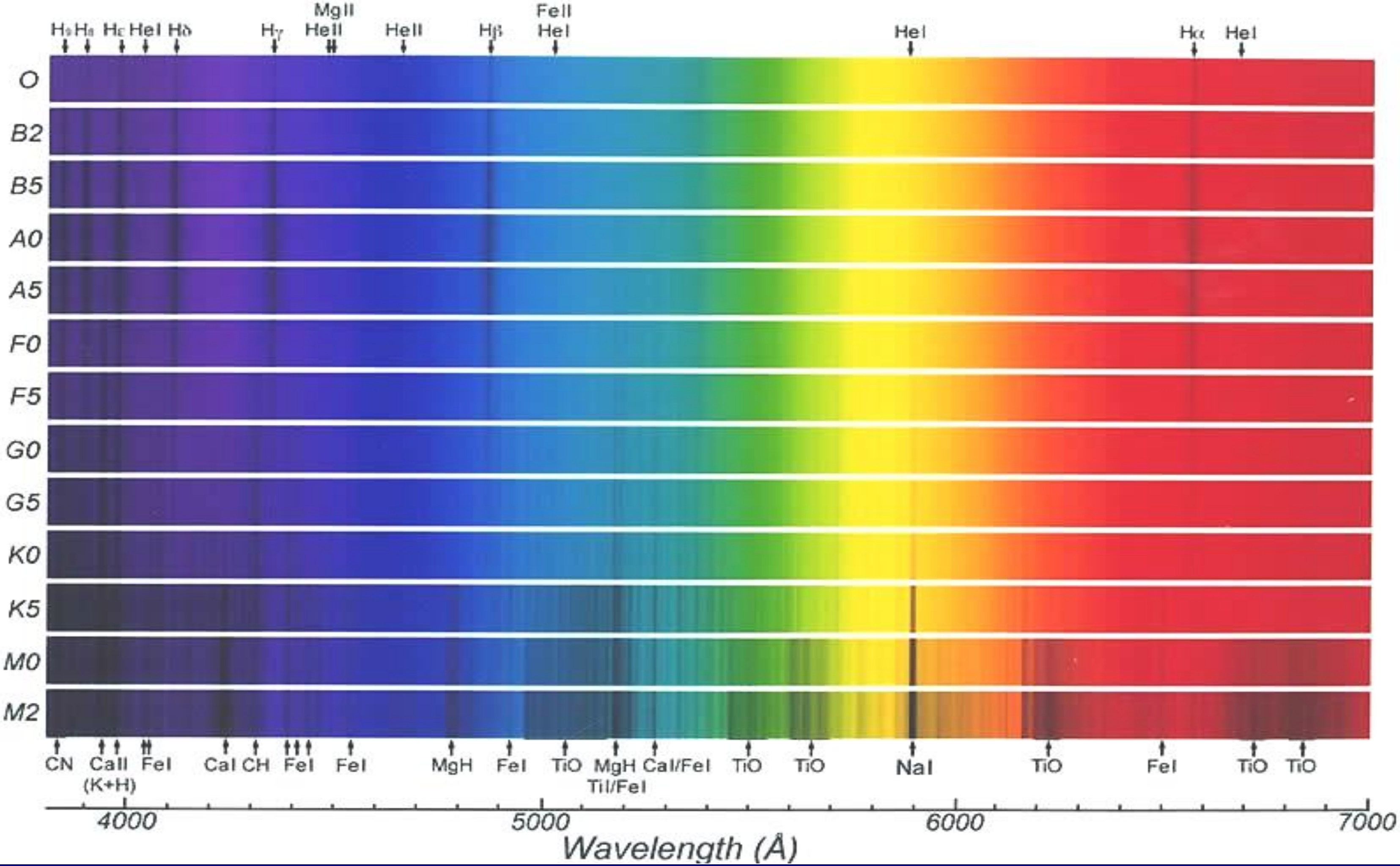
K H	G	F	b E	D	C	B	A
CaII	CH(methin)	HI	MgI FeII	NaI	HI	$O_2|_{terr}$	$O_2|_{terr}$

Fraunhofer listed 567 absorption lines
Today: ~100,000 lines of the solar spectrum are known

Spectra analysis by Gustav Robert Kirchhoff and Wilhelm Bunsen (1859)
They show, that the D-Lines at 589.0 and 589.6 nm are caused by Sodium (Na)
Birth of astrophysics: Physical status of astronomical objects can be examined

Discovery of the Properties of Light

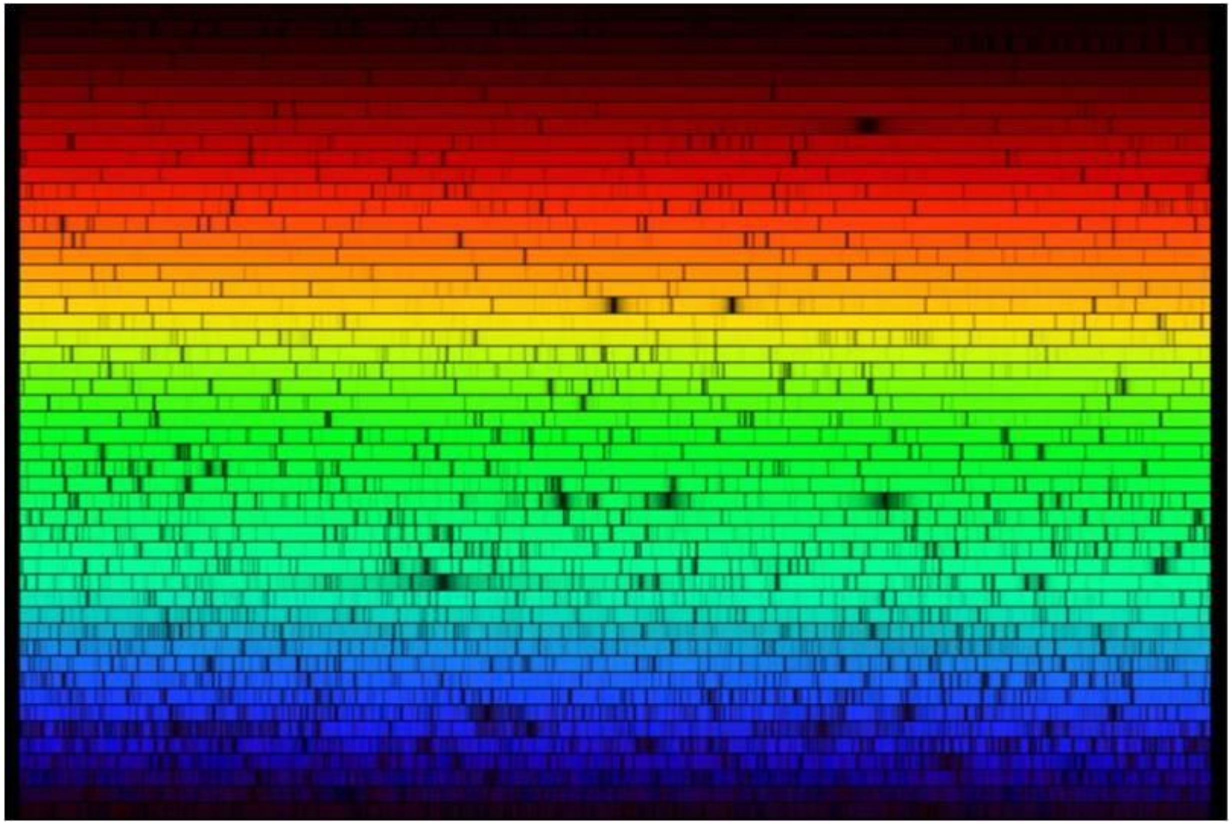
Spectra of stars $\Rightarrow$ Classification by temperature and composition



Discovery of the Properties of Light

The solar spectrum

- Comprises lines of almost all elements of the periodic table
- Helium was detected by the presence of its absorption lines (1859)



Spectroscopy allows the analysis of remote (astronomic) objects:

- Chemical composition
- Relative speed
- Rotation period
- Gravity field
- Magnetic field

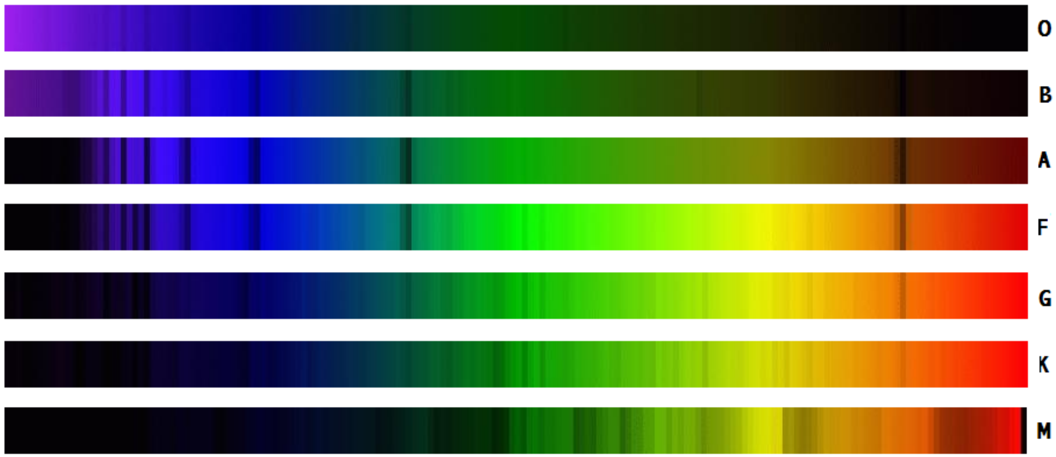
Impact on analytical chemistry

Discovery of the Properties of Light

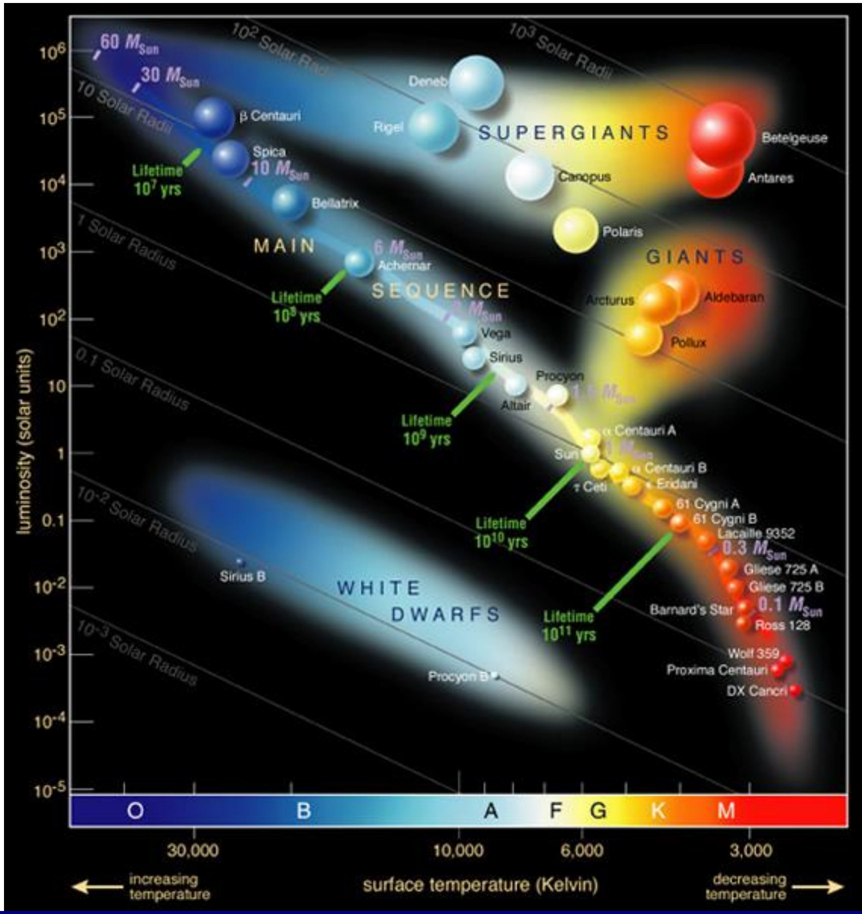
Classification of stars by Ejnar Hertzsprung (1873 - 1961) and Henri Norris Russell (1877 - 1957)

<u>Hertzsprung-Russel-Diagram</u>

It's a brightness (luminosity) over surface temperature diagram



Die effektive Temoeratur nimmt bei den Spektralklassen von O über B, A, F, G, K nach M ab.

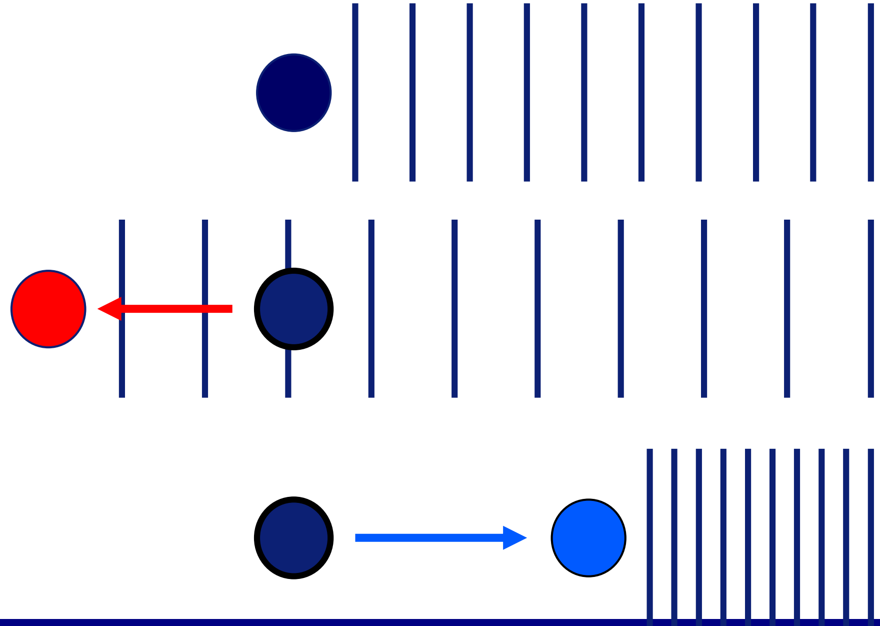


Discovery of the Properties of Light

Doppler effect (Christian Doppler 1803 - 1853)

Non-relativistic: $\Delta\lambda/\lambda_0 = v/c$
Relativistic: $\Delta\lambda/\lambda_0 = (1+v/c)^{1/2}/(1-v/c)^{1/2}$

Resting source:	$v = 0$	Wavelength not changed	
Vanishing source	$v > 0$	Wavelength enlarges	→ „Red shift“
Approaching source	$v < 0$	Wavelength declines	→ „Blue shift“



Discovery of the Properties of Light

Doppler effect

a) Red shift from spectra

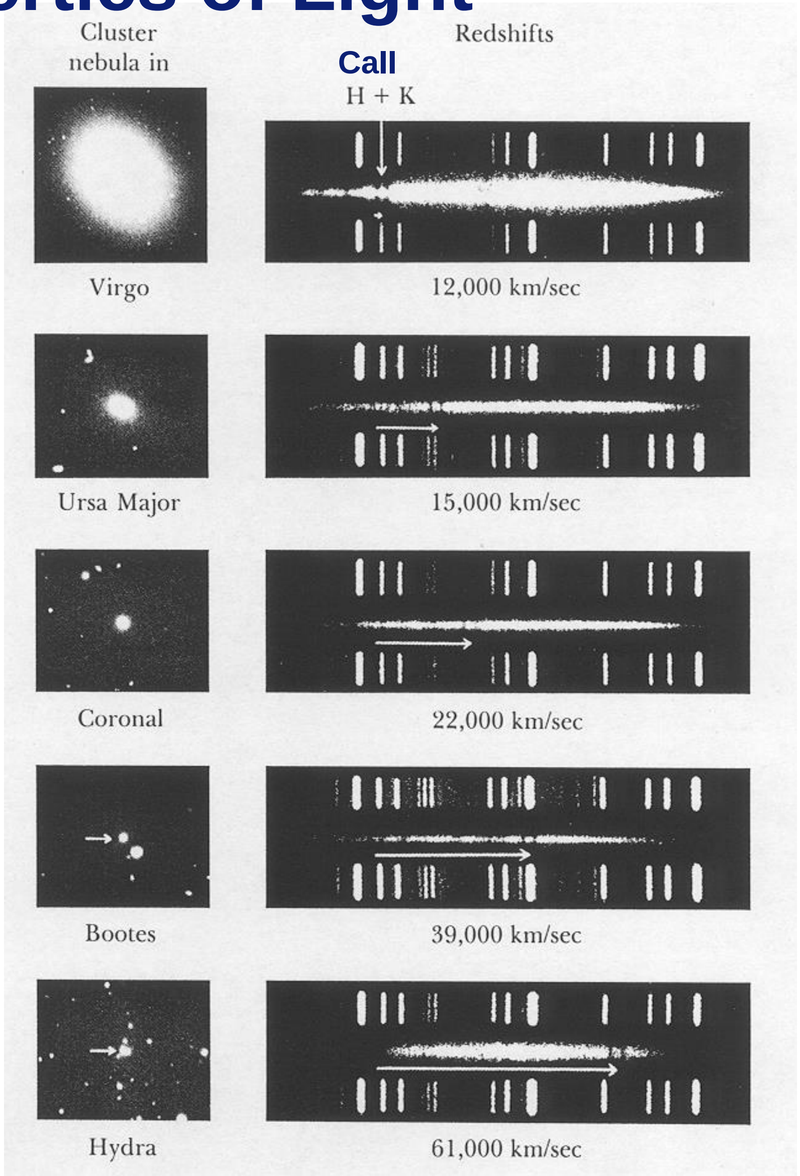
→ Radial speed v

b) Call (Ca^+)-dublett shows broadening due to scattering at interstellar/galactic dust/particles

→ Distance d

<u>Assumption</u>

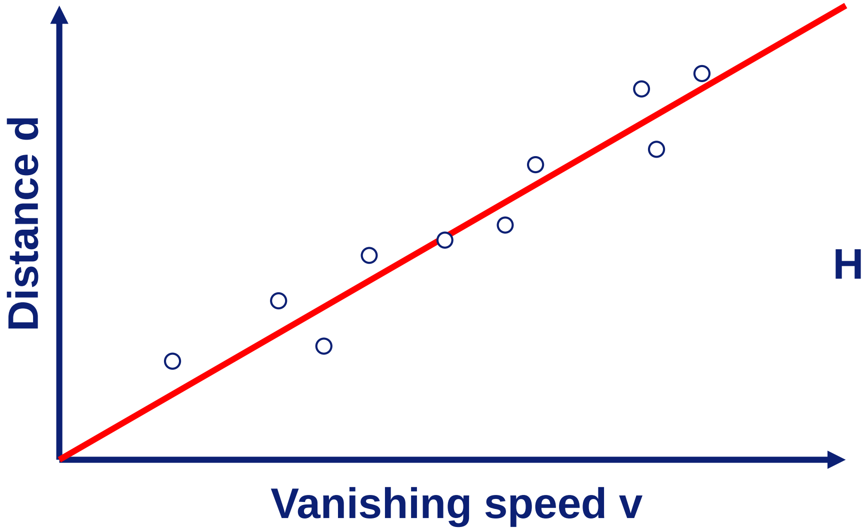
Interstellar scattering and extinction is homogeneous throughout whole universe



Discovery of the Properties of Light

The Doppler effect was used to proof cosmological expansion

Edwin Powell Hubble (1889 - 1953) et al. discovered (~ 1930), that remote galaxies show red-shifted spectra, while the distance is proportional to the observed red shift (radial speed)



d = H x v
H = 74.3 ± 2.1 km/sMpc
(Hubble constant)

Recent observations of remote galaxies showed that the expansion of the universe even accelerates → caused by dark energy (Nobel prize physics 2011)

Discovery of the Cosmic Architecture

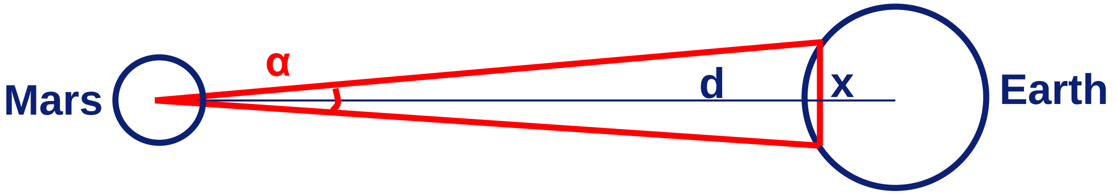
Distances in the "Universe"

Ancient Greeks: Distances in the solar system

- Earth - Sun ~ 30 x Earth - Moon by Aristarchos of Samos (250 BC)

Trigonometric determination of the distance to Mars

- At Mars opposition by Cassini in 1672 ⇒ Mars parallax
- Simultaneous determination of the Mars position from France and French Guayana (South America)

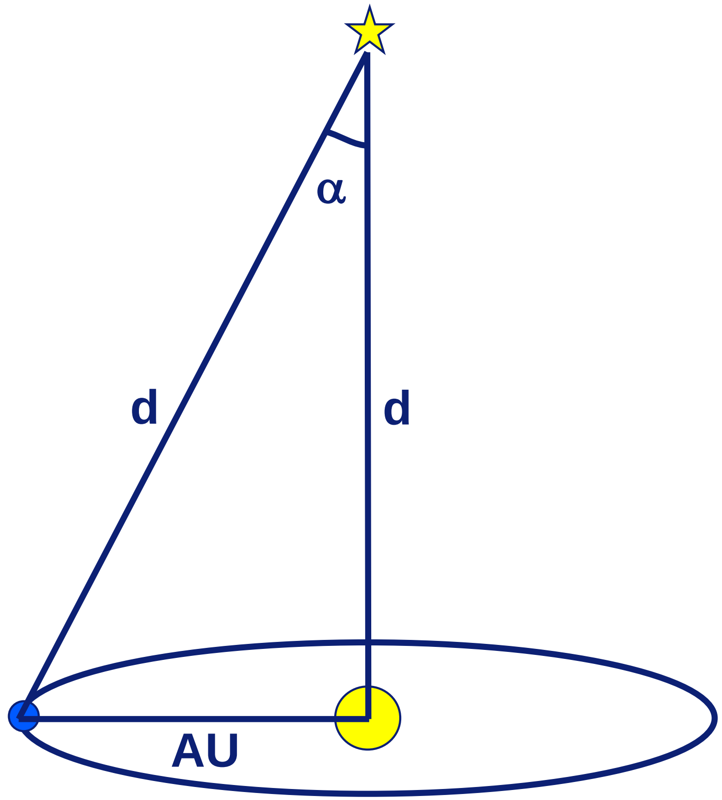


- $\sin \alpha = x/d = 6000$ km/d   Measurement: $\alpha = 21''$ $d = 6 \times 10^7$ km $= 0.4$ AU
- All other distances can be derived from Kepler's 3rd law:
  - $a^3_{Mars}/P^2_{Mars} = a^3_{Earth}/P^2_{Earth} = \text{const.}$ and $d = a_{Mars}(t_x) - a_{Earth}(t_x)$
  - 3 Equations and 3 unknown variables: a_{Mars}, a_{Earth}, const ($GM_{sun}/4\pi^2$)
  - → For all other planets: $a^3/P^2 = \text{const}$

Discovery of the Cosmic Architecture

Distances to the stars

Basis for the triangulation is the orbit of the Earth around the Sun



Base distance 1 AU = 1.496 x 10^8 km
AU = Astronomical Unit

Parallax (angle)
for α = 1" i.e. 2π / (360x60x60) = 1/206265
is d = AE/α = 3.094 x 10^{13} km

The corresponding distance d to 1" is thus 3.094 x 10^{13} km and is called the parallax second (parsec pc)

Star	Parallax
Sirius (α Canis Maioris)	0.379"
Deneb (α Cygni)	0.001"

Discovery of the Cosmic Architecture

History of the determination of star parallaxes

- Ancient Greeks and medieval age astronomers could not find any star parallaxes ⇒ conclusion: Earth does not move
- Tycho Brahe (~1600) tried to determine the parallaxes of stars (he did not use a telescope!)
- Bradley showed 1750, that star parallaxes are smaller than 1''
  (resolution of telescopes is limited to about 1'' due to the fluctuations of air at sea level)
- Struve determined 1838 for the first time the parallax of a star, namely for α Lyrae (Vega)
  p = 0.12'' → distance = 8 parsec (~ 26 ly)

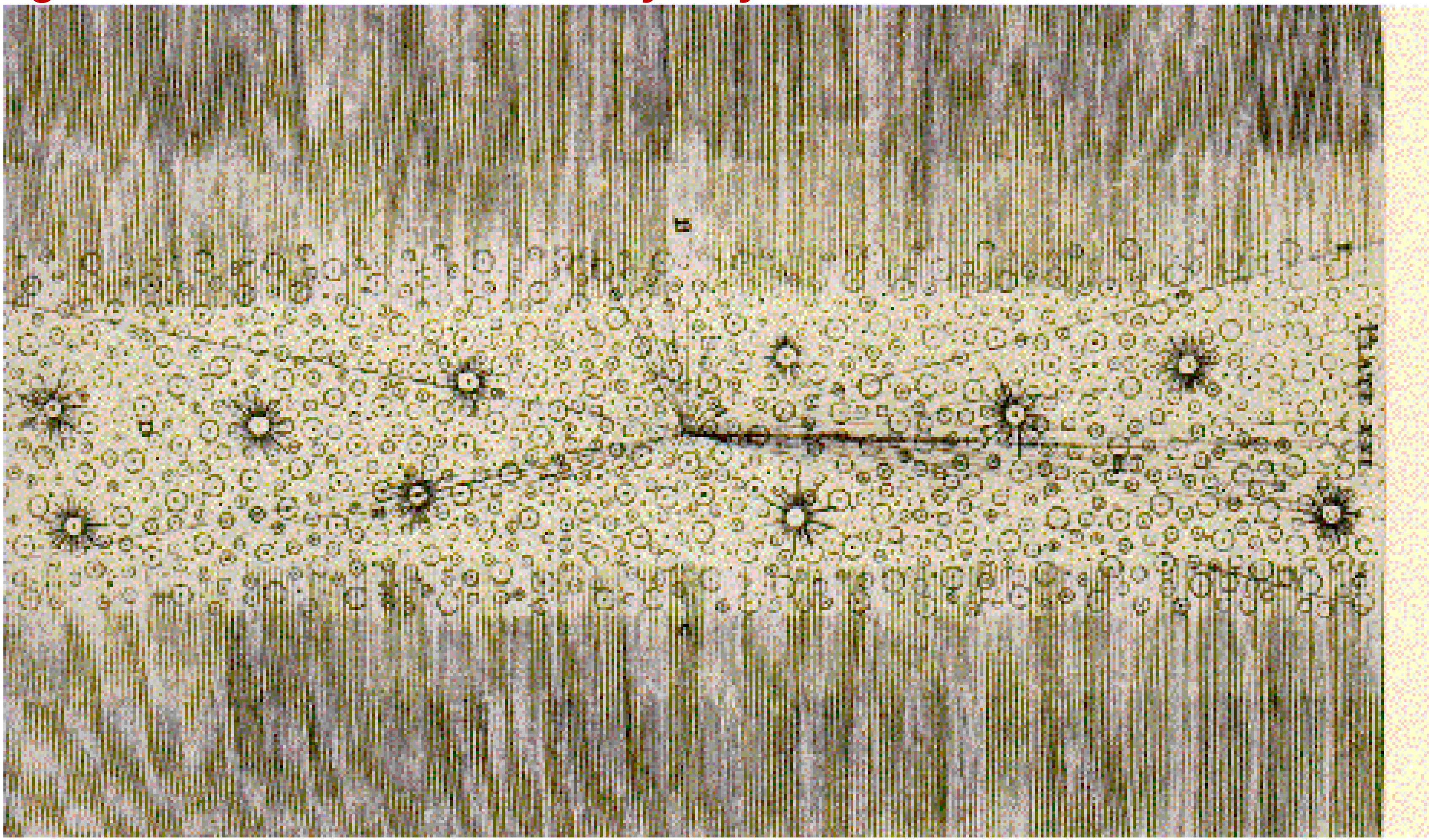
Discovery of the Cosmic Architecture

History of the determination of star parallaxes

- **The closest star "α Centauri" (triple system) has a parallax of about 0.75" (d = 1.3 parsec = 4.3 ly)**
- **Diameter of the milky way ~ 30 kpc**
- **Distance to closest adjacent galaxies ~ 1 Mpc**
- **Distance to quasars and remote galaxies ~ 1 Gpc**
- **1995 Satellite Hipparcos determined parallaxes of about 100,000 stars (up to a distance of d = 150 pc)**
- **Satellite GAIA measures star parallaxes of about 100 million stars to determine the 3D structure of the milky way**

Discovery of the Cosmic Architecture

The end of the Heliocentric universe ⇒ The Sun is an arbitrary star amongst million others of the milky way

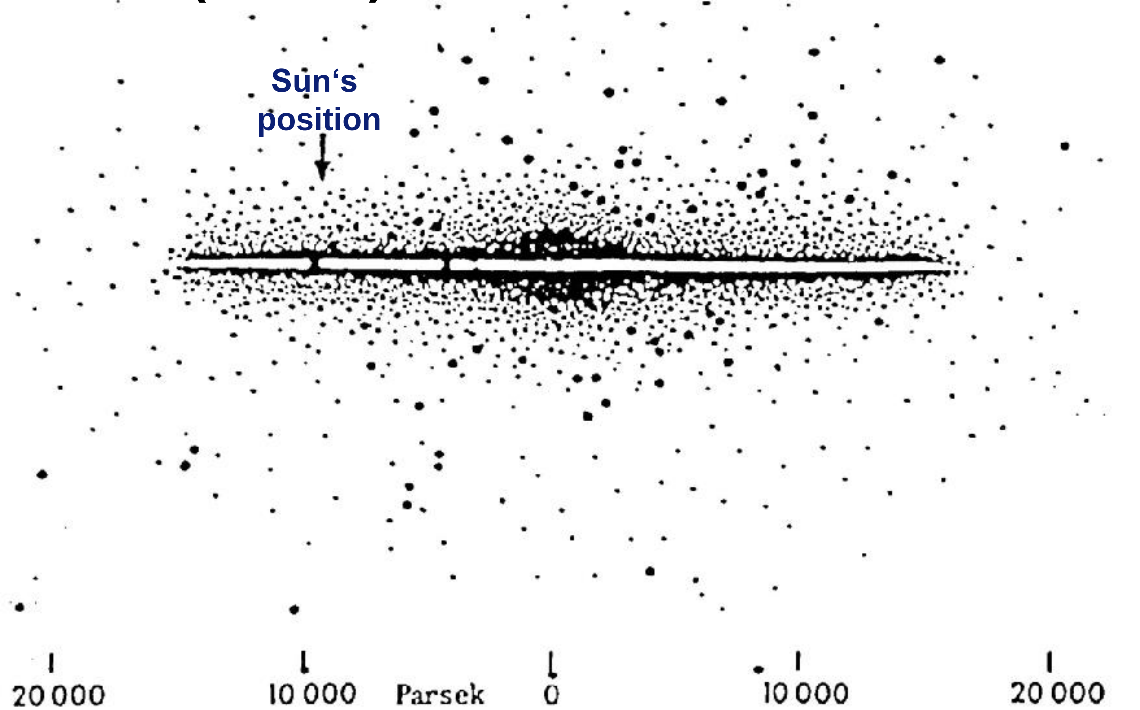


Holzschnitt von Thomas Wright (1750) zur Illustration der Milchstrassenstruktur

Discovery of the Cosmic Architecture

Galactocentric universe

Globular star cluster M3 (top) and M10 (bottom)

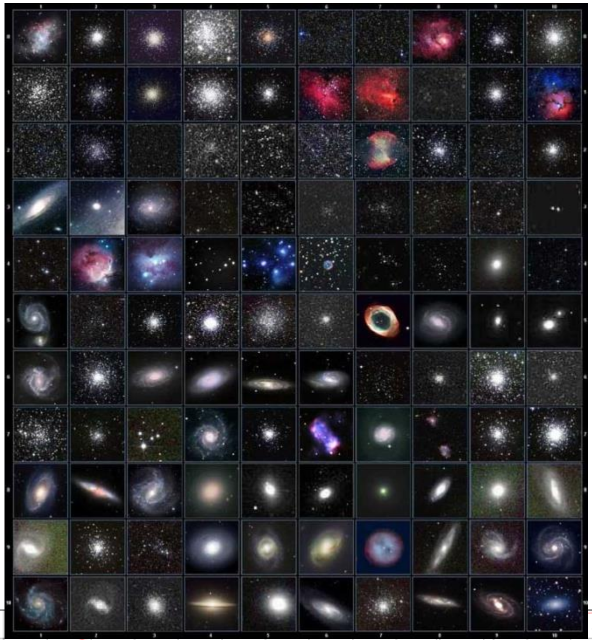


Harlow Shapley 1920: Sun is about 10 kpc away from the centre of the spherical distribution globular star clusters (= centre of the milky way)

Discovery of the Cosmic Architecture

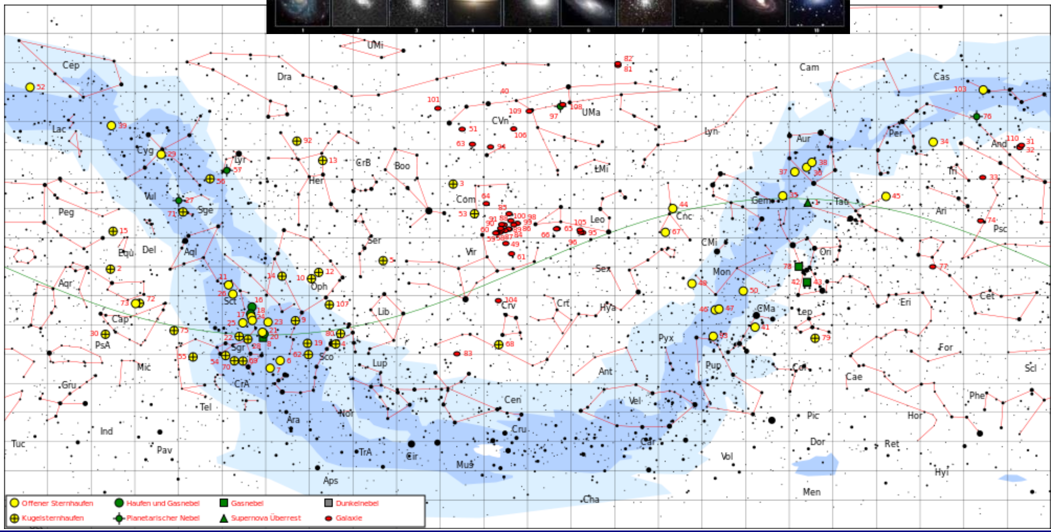
The Messier Objects

Charles Messier (1764 – 1782)
First catalogue of non-stellar objects
Today 110 objects: M1 – M110



Classes of "nebulae"

- galaxies
- globular clusters
- open clusters
- emission nebulae (luminescent objects!)
- reflection nebulae
- dark (absorption) nebulae
- planetary nebulae (ring shape)
- supernova remnants



Discovery of the Cosmic Architecture

Galactocentric universe

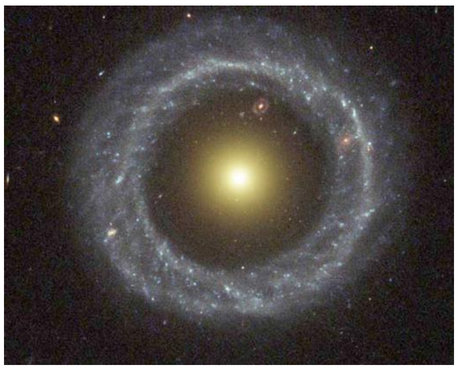
Is the milky way the centre of the universe? No!
Are nebula (spiral nebula) other "milky ways"? Yes!

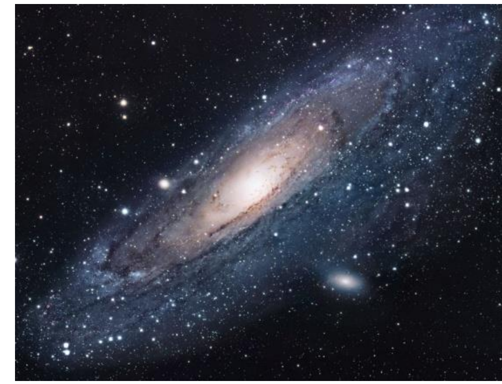
Messier-Object M51 "Whirlpool galaxy": William Parsons (Lord Rosse) discovered 1845 the spiral structure of a nebula (left sketch by Parsons, middle first photograph, right recent photograph)

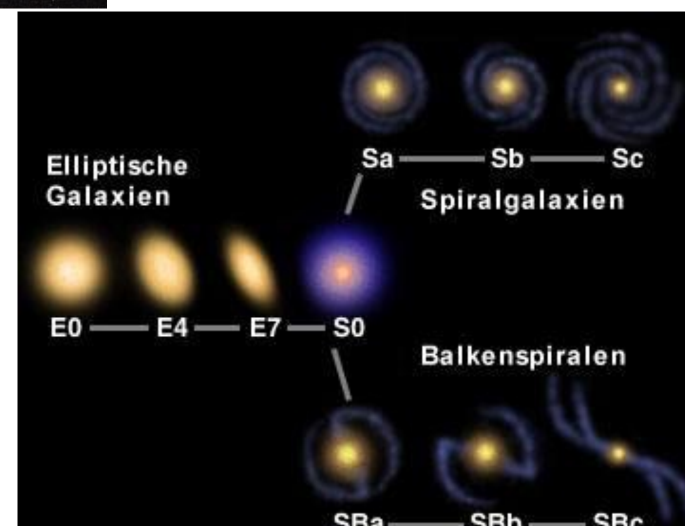
Discovery of the Cosmic Architecture

Modern model: The universe is “isotropic” and expands

20th century: The universe comprises billions of galaxies like our milky way



Edwin Hubble sorted them by the shape (~1930)

The Cosmic Architecture - The Earth

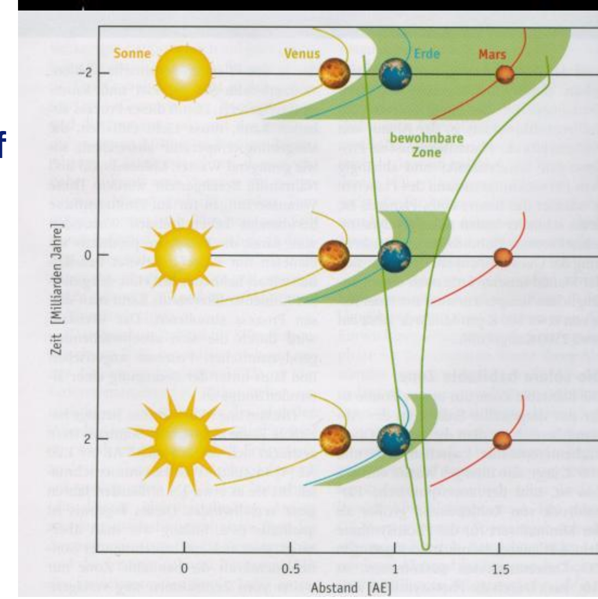
Earth diameter = 12,756 km

- First accurate measurement of Earth’s size made in 200 BC by Eratosthenes in Egypt

- Earth is an ‘oblate spheroid’ slightly flattened at the poles due to its rotation

Photo taken by the crew of Apollo 17 while travelling between the Earth and the Moon, December 1972

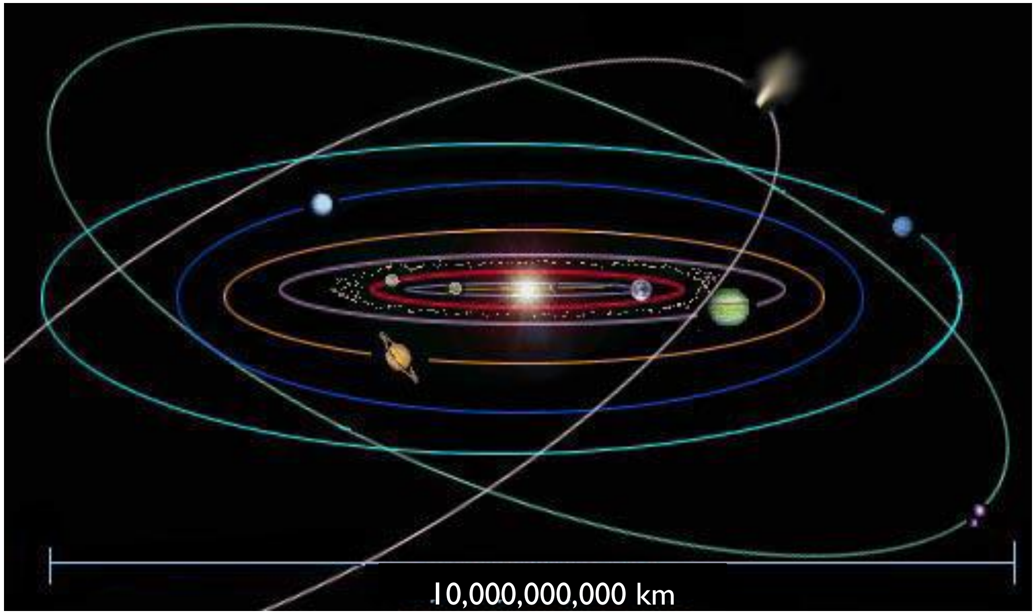
Shift of the habitable zone over lifetime of the Sun

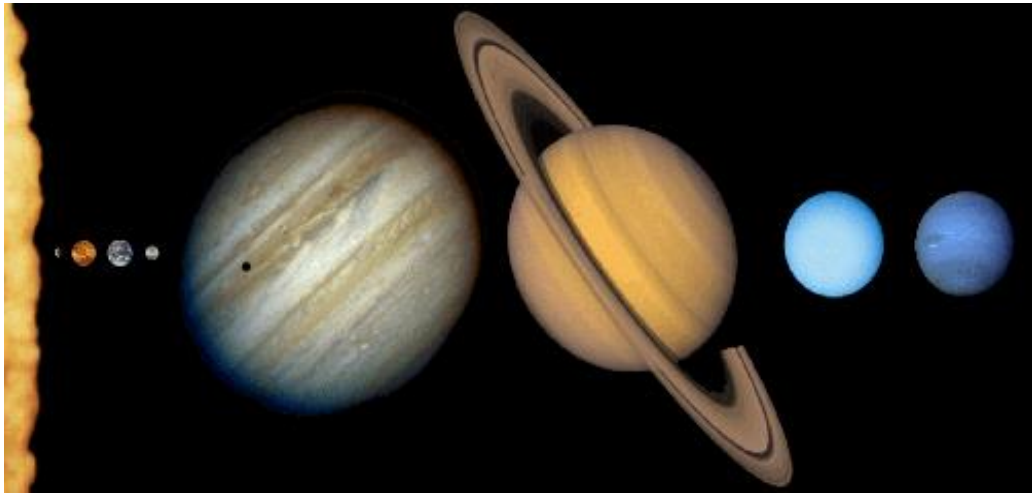


Astronomic length units

1. Astronomical unit = $149.6 \cdot 10^6$ km (not constant over time …..)
2. Light year (ly) = $9.46 \cdot 10^{12}$ km
3. Parsec (pc) = $3.094 \cdot 10^{13}$ km = 3.26 ly (not constant over time)

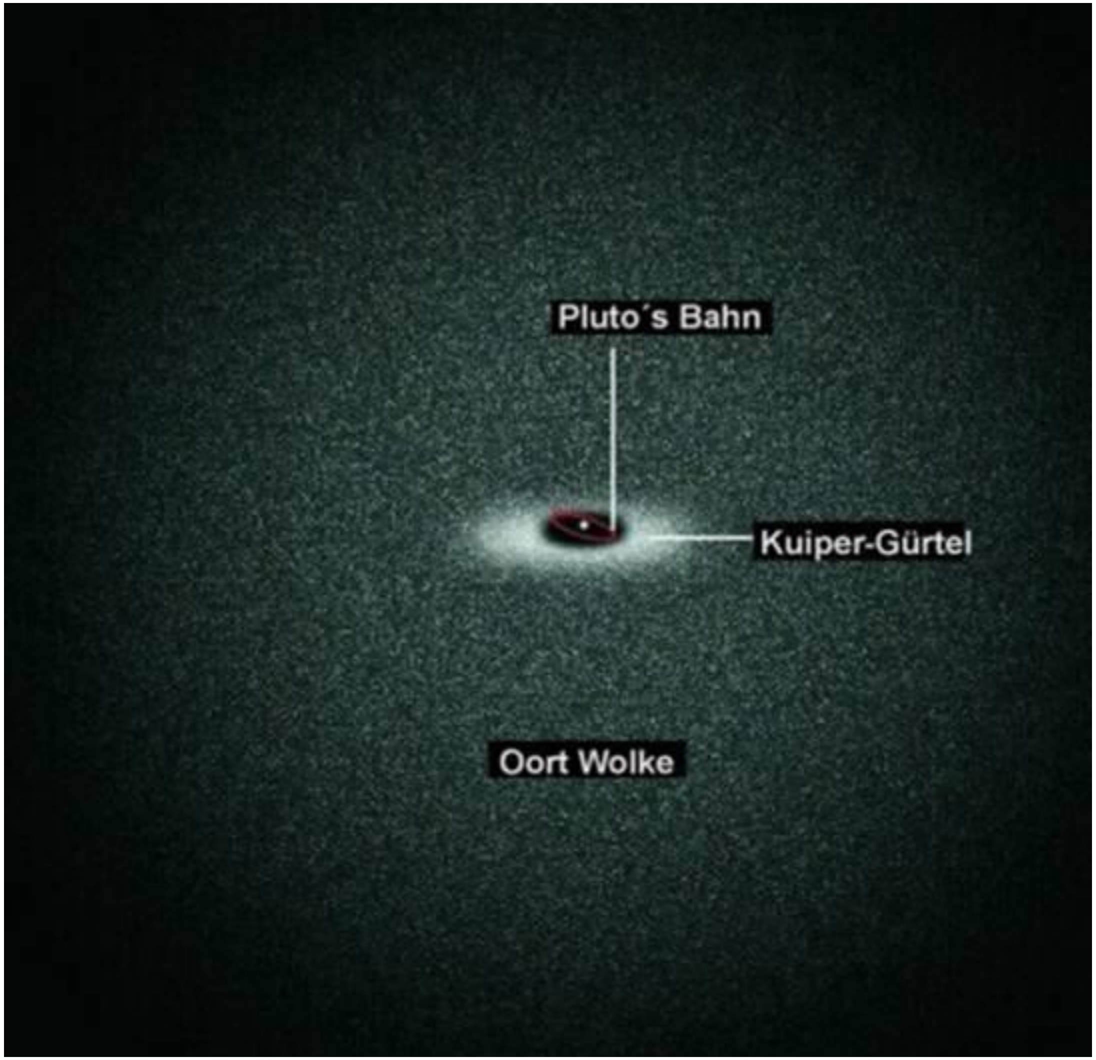
The Cosmic Architecture - The Solar System





- Average Earth - Moon distance is 384,400 km
  ~ 1.3 light seconds
- It takes about 8 minutes for light from the sun to reach Earth = 8 light minutes
- It takes about 8 hours for light to cross the whole solar system, i.e. to pass the Neptune orbit ~ 9,000,000,000 km
- The eight planets in our solar system scaled to size

The Cosmic Architecture - The Outer Solar System



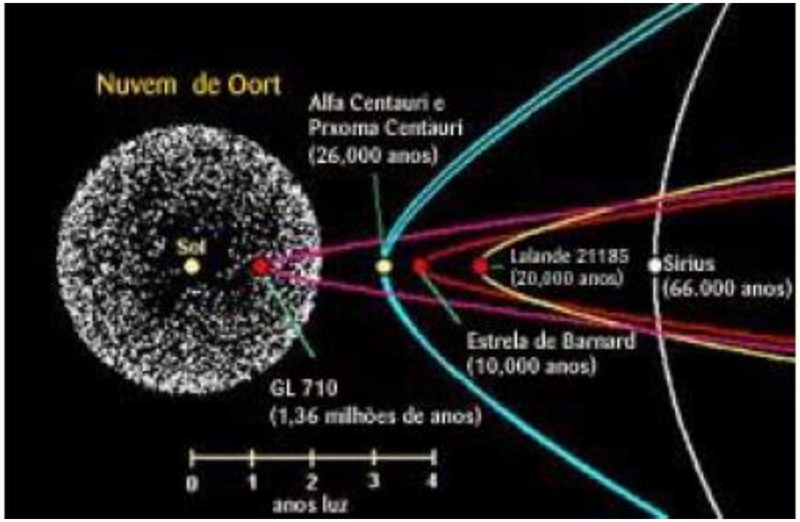
Pluto is an object of the Kuiper belt – a dwarf planet

Jan Hendrik Oort (1900 – 1992) claimed the solar system is surrounded by a cloud of objects (10^{11} – 10^{12}), which is the source of long-period comets

The Cosmic Architecture - Oort Cloud and Impacts

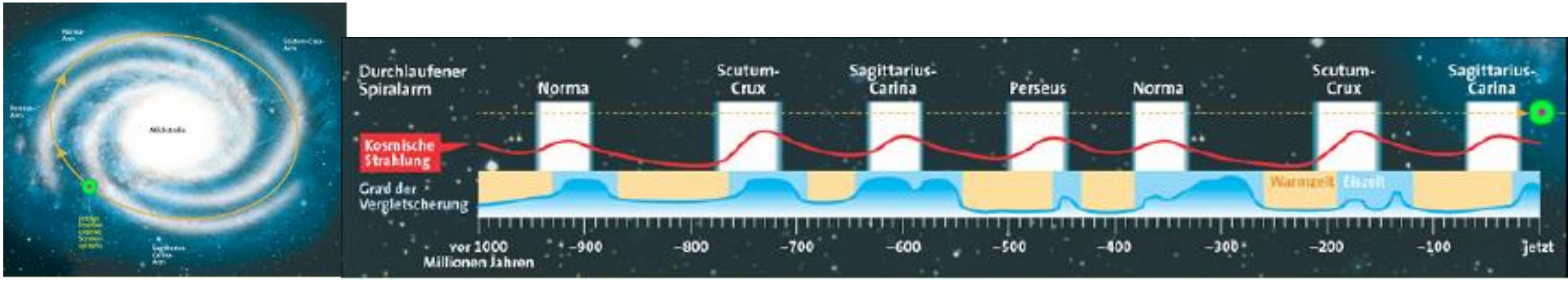
Close encounters with other stars results in forces on momentum transfer to Oort objects

$\Rightarrow$ **Novel comets**



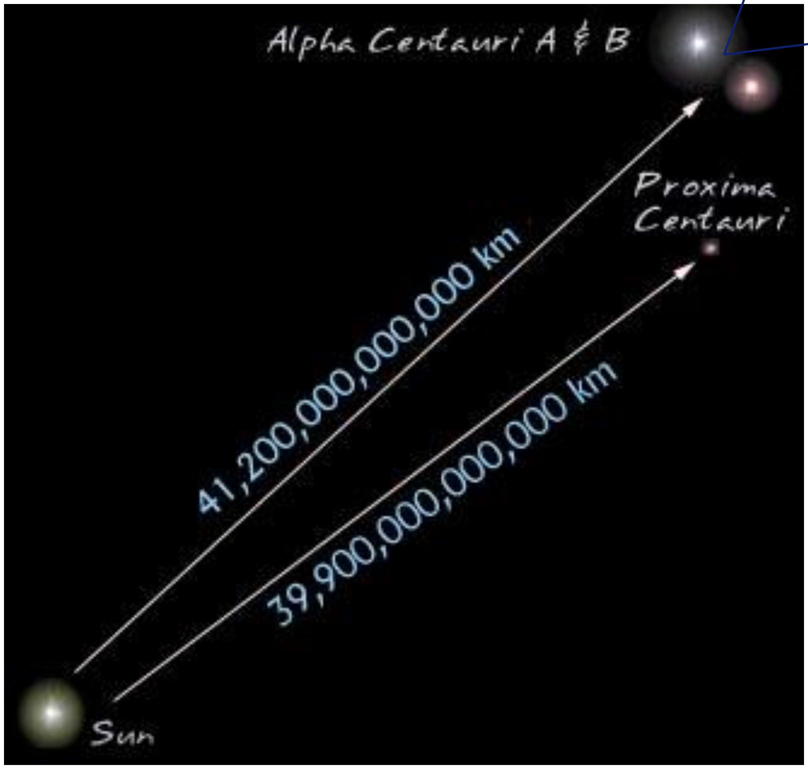
Travel through the milky way

- **Modulation of frequency of supernova explosions nearby**
- **Modulation of the intensity of cosmic radiation**



The Cosmic Architecture - The Next Nearest Star

Proxima Centauri is 4.22 ly from the Sun.
Alpha Centauri A & B are 4.35 ly from the Sun.

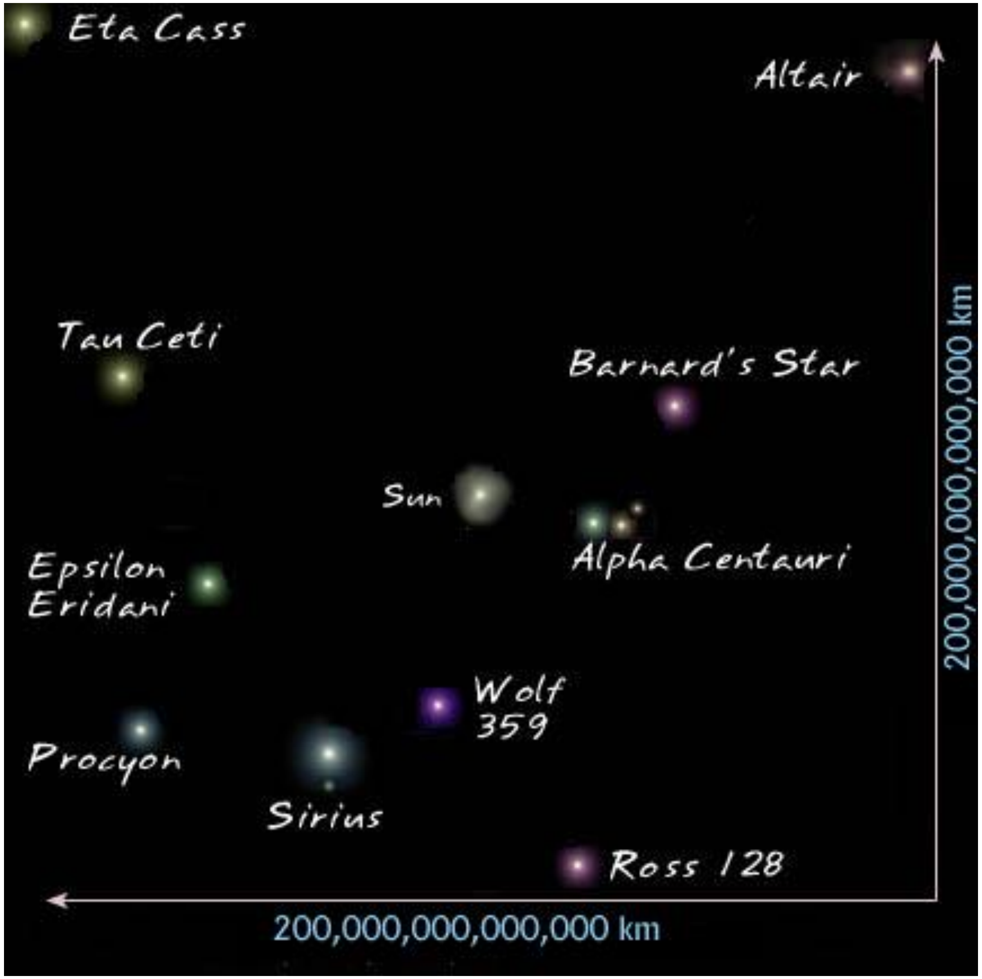


The nearest star, Proxima Centauri

Most stars are actually part of binaries or ternaries, rather than single like our Sun

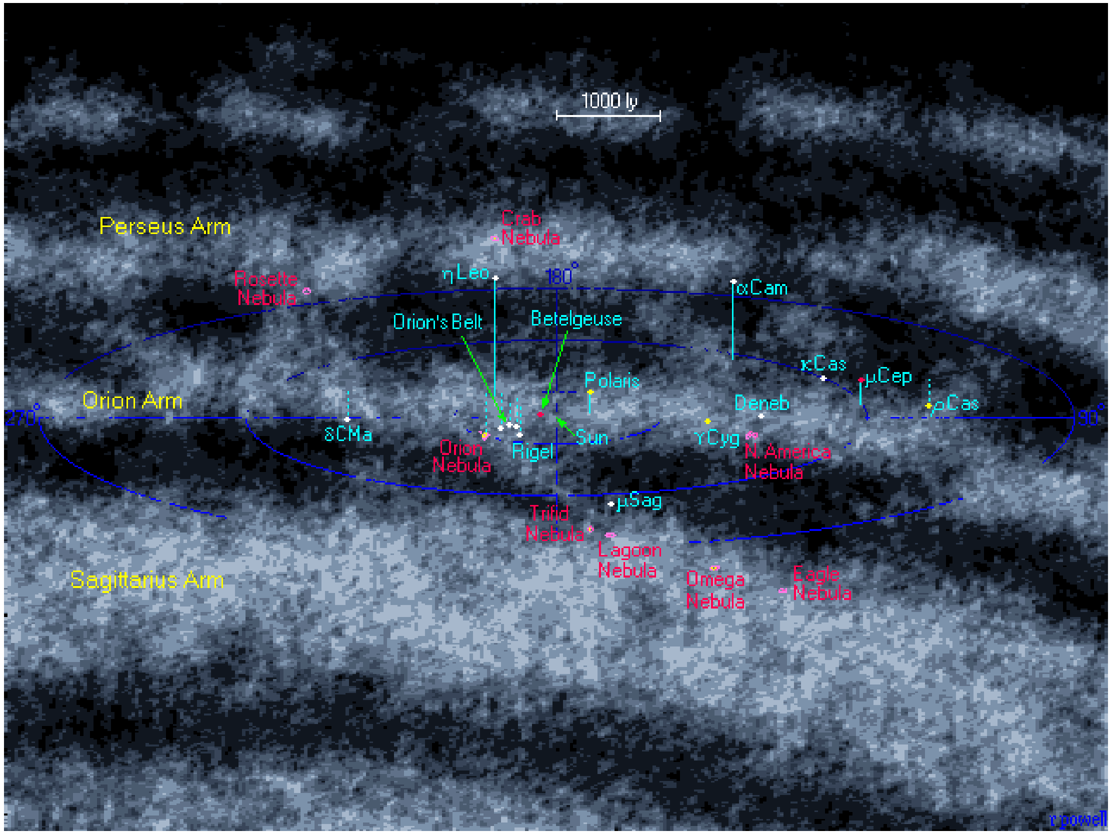
The Cosmic Architecture - The Solar Neighbourhood

- Sirius, Procyon, and Altair are all very bright stars easily visible to the naked eye
- 30 stars within 20 ly
- Different types of stars have different intrinsic brightness, so one cannot simply assume that bright stars are nearby while fainter ones are further away
- Epsilon Eridani has at least one planet (Jupiter- type, 3.2 AU)



2D representation of some stars near to the Sun, positioned in correct orientation with respect to the Sun, if image is taken as an 'overhead' view

The Cosmic Architecture - The Orion Arm

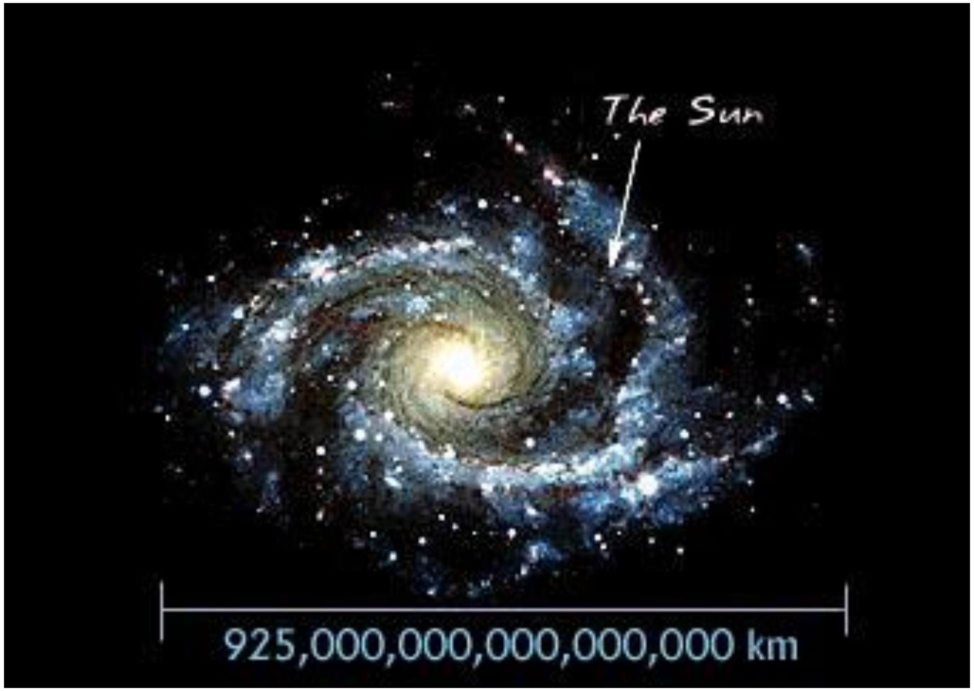


There are 133 stars visible with the naked eye within 50 ly of the Sun
Total about 2000 stars within this volume of space, 120,000 stars within 326 ly of the sun

- Our corner of the Milky Way
- Our spiral arm is named the ‘Orion Arm’ for the Orion star cluster (visible in the constellation Orion)
- The Sun is about 8.5 kpc from the Galactic Centre – about 2/3 of the way out from the centre to edge of the Milky Way

The Cosmic Architecture - The Milky Way Galaxy

- **Diameter ~ 100,000 ly**
- **Stars are closer together the closer you get to the Galactic centre.**
- **The centre "Sagittarius A" comprises a huge black hole with M_{Sun} ~ 4 million**

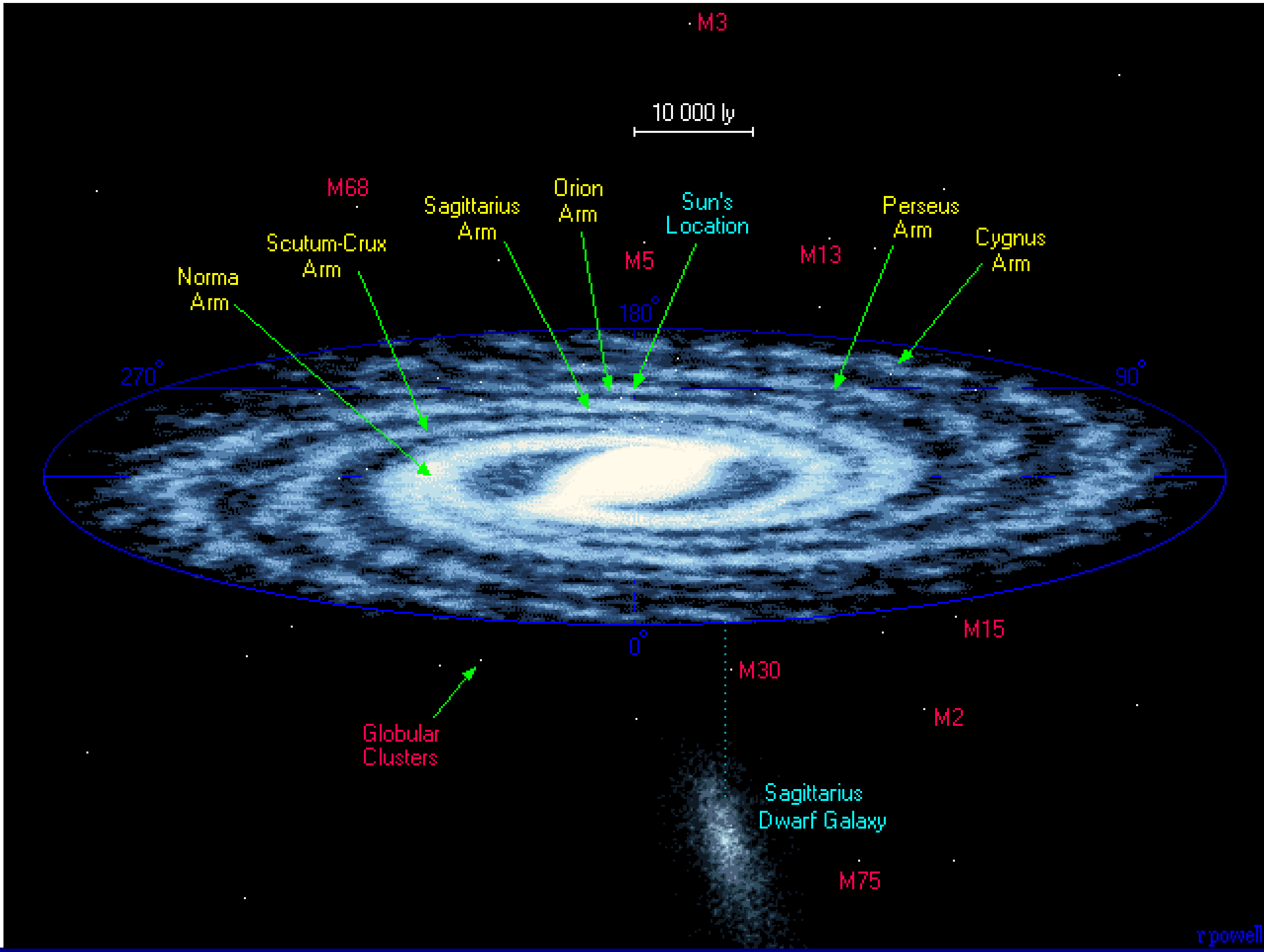


A calculated picture of our galaxy

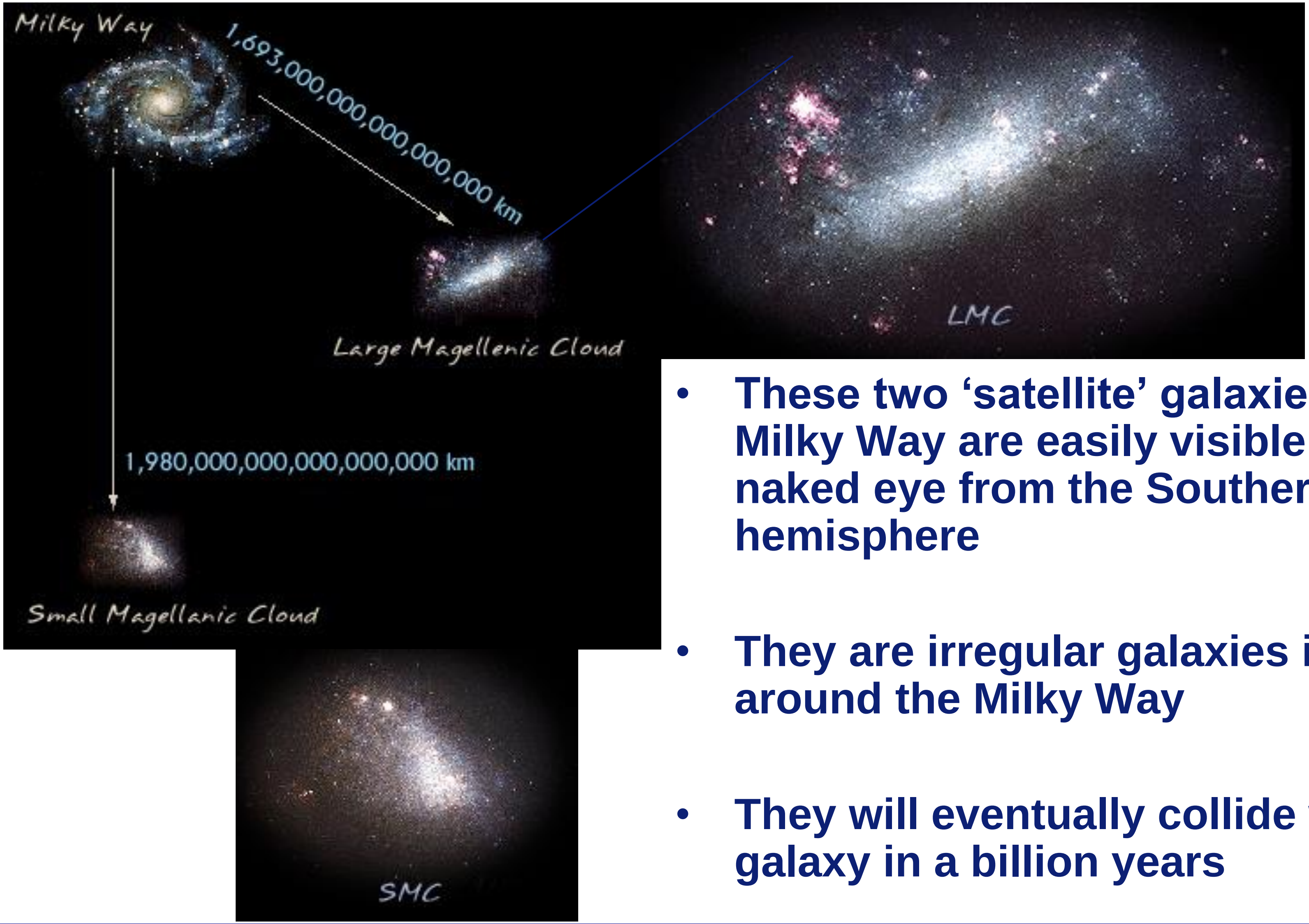
The Cosmic Architecture - The Milky Way Galaxy

The structure of the milky way

- This is an accurate representation of what our Galaxy looks like if we were able to see it from intergalactic space
- A “barred spiral” galaxy
- Diameter ~100,000 ly = 30 kpc



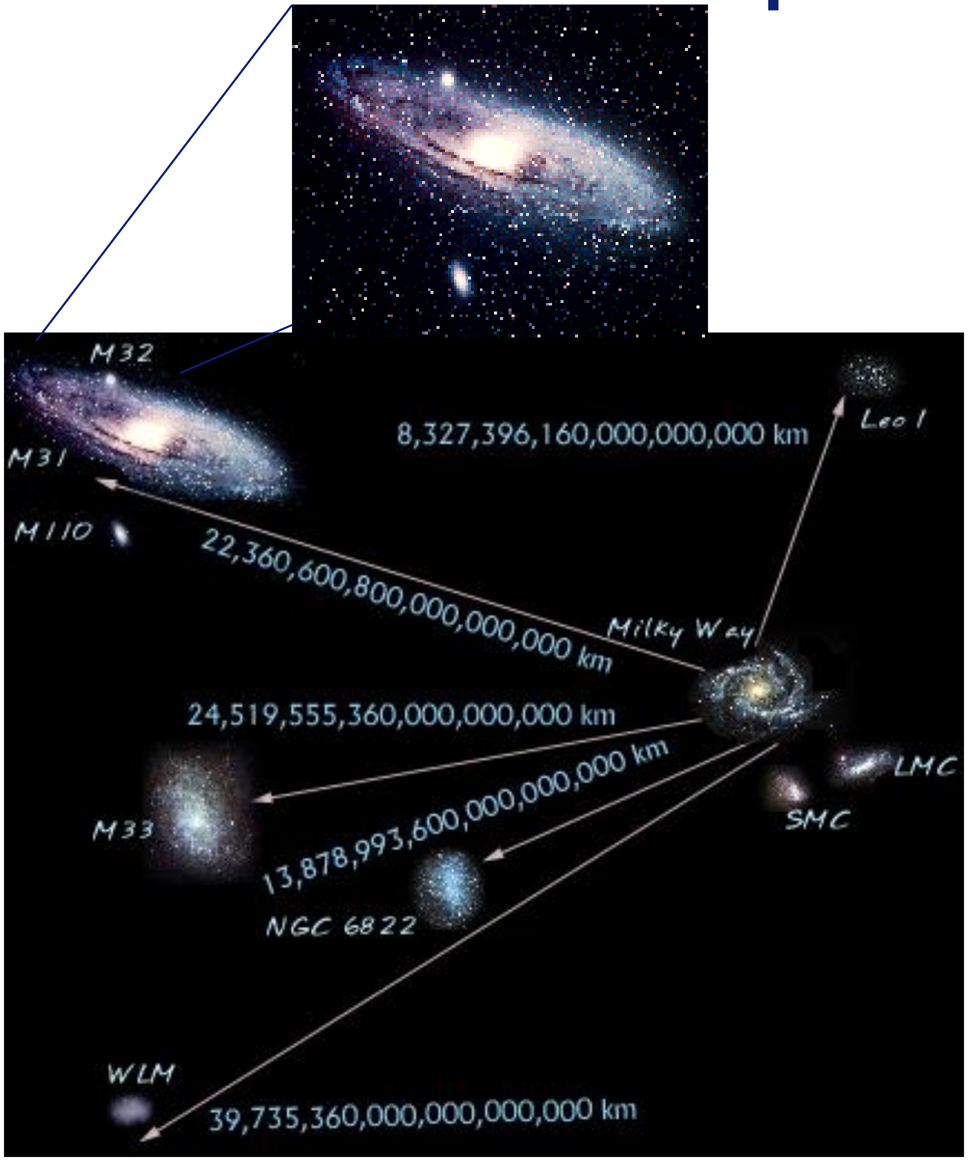
The Cosmic Architecture - The Nearest Galaxies



- These two ‘satellite’ galaxies of the Milky Way are easily visible with the naked eye from the Southern hemisphere
- They are irregular galaxies in orbit around the Milky Way
- They will eventually collide with our galaxy in a billion years

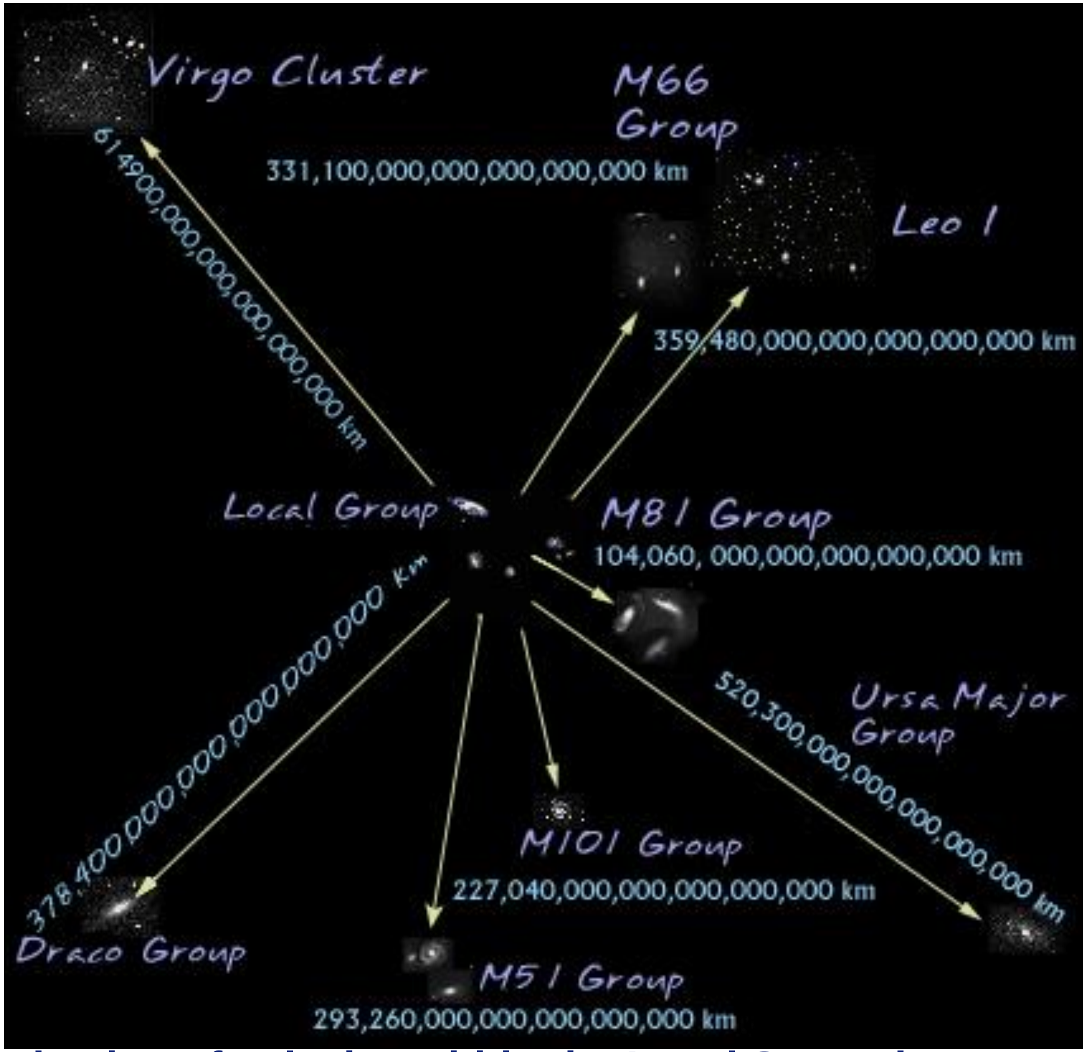
The Cosmic Architecture - The Local Group

- This composite image of the local group shows the galaxies in a ~correct orientation
- There are at least 40 galaxies in the local group, within an area of ~ 5 million ly
- The Milky Way is one of the 3 largest; most of the others are ‘dwarf’ galaxies
- In order of size: Andromeda, Milky Way, Triangulum (M33) – all spiral galaxies!



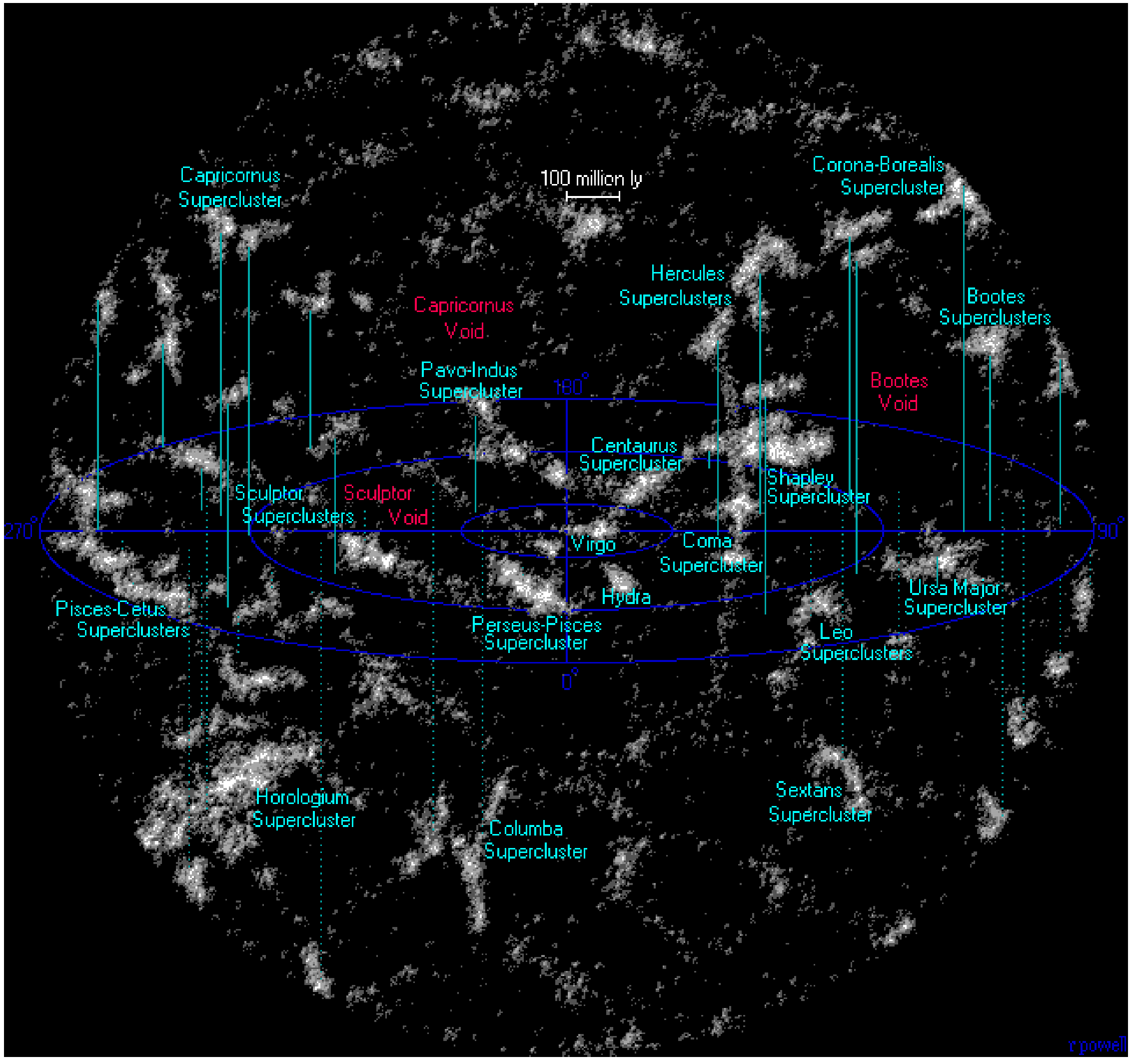
The Cosmic Architecture - The Local Supercluster

- Called the 'Virgo Supercluster' after the largest nearby cluster
- Covers ~100 million ly, contains ~28000 galaxies
- Galaxies tend to cluster in groups. About 75% of all galaxies are in clusters



This selection of galaxies within the Local Supercluster are pictured approximately correctly with respect to each other

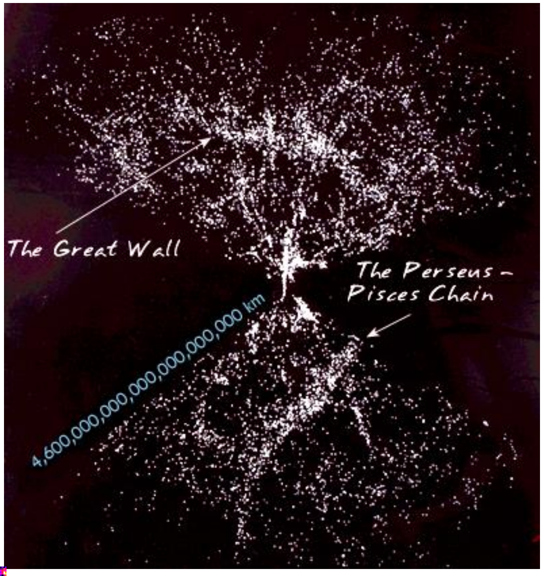
The Cosmic Architecture – Superclusters around Virgo Cluster

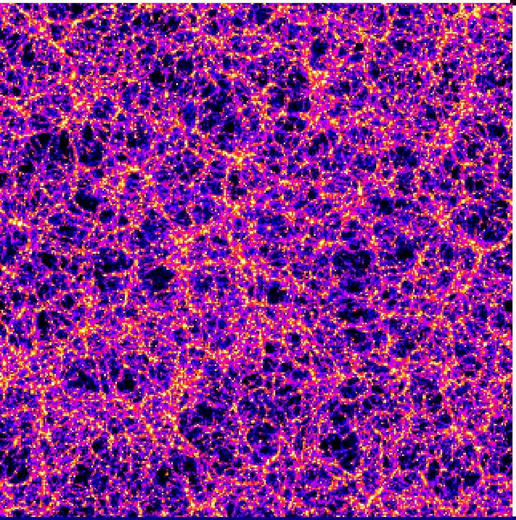


- Galaxies & galaxy clusters collect into vast clusters and sheets & walls of galaxies interspersed with large voids
- This map shows about 7% of the diameter of the entire visible Universe
- Cluster formation is caused by dark matter

The Cosmic Architecture – Sheets and Voids

The great wall is one of the largest known structure of the Universe

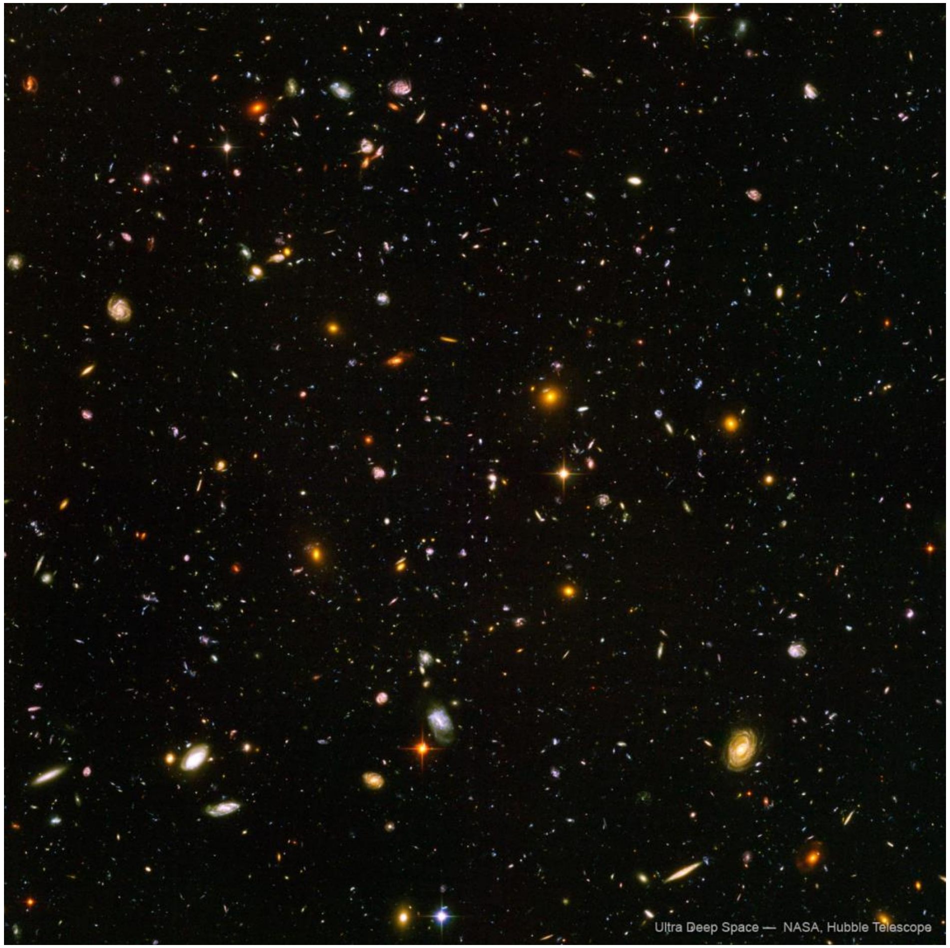




Calculated model of the whole Universe "brain type structure"

- Each of the 9325 points in this map is a galaxy
- The Universe has a 'bubbly' structure – sheets & filaments of galaxies in a web punctuated by voids
- Typical diameter of a void ~ 25 Mpc and fill about 90% of total space
- The 'great wall' is a sheet of galaxies measuring 200 x 70 Mpc, 100 Mpc away from us

The Cosmic Architecture - Most Remote Objects

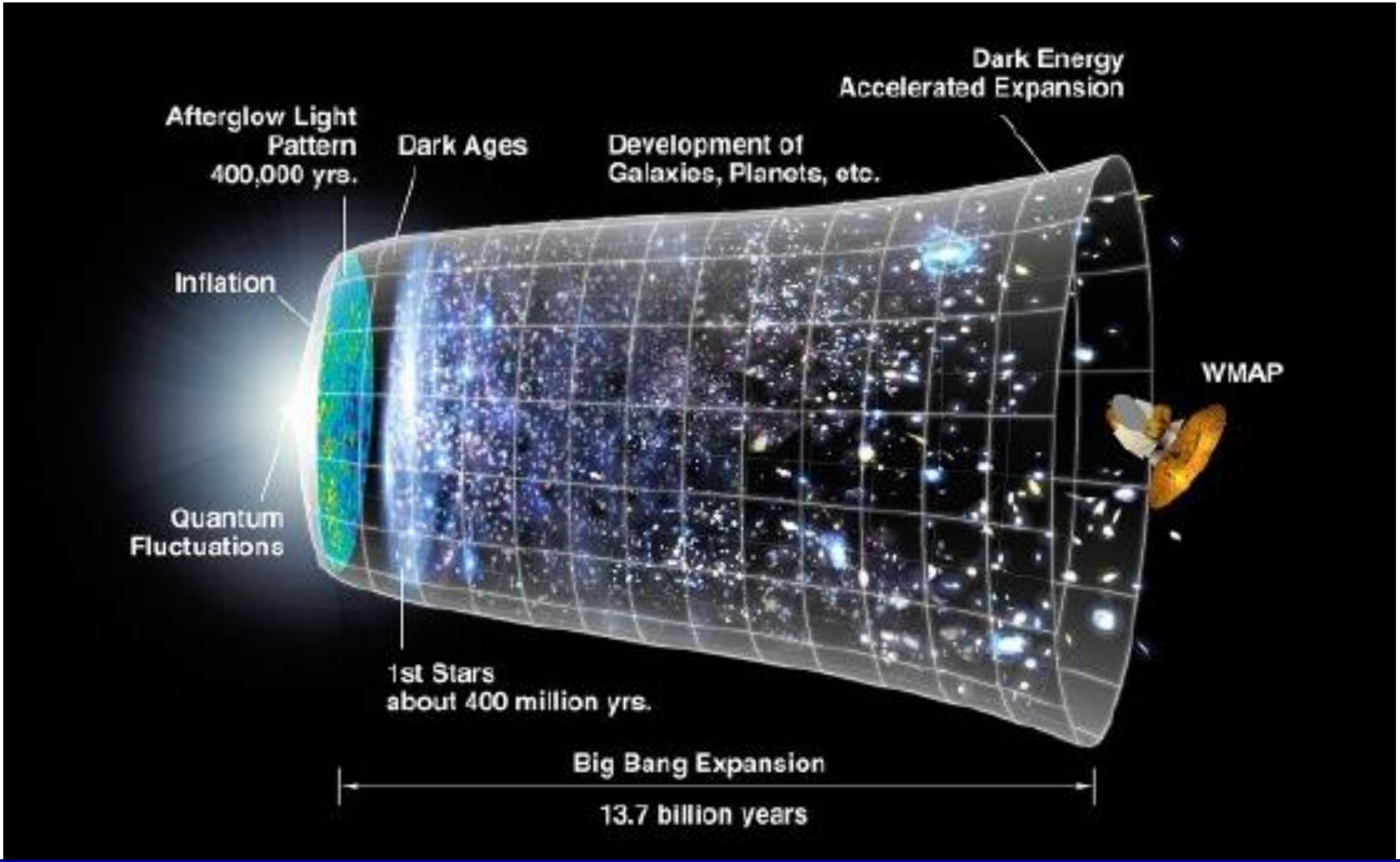


Hubble Deep Field taken from the Hubble space telescope showing 2.5“ x 2.5“ ($3x10^{-8}$ of the sky)
~ 3000 Objects, but only ~20 stars!
Some objects (quasars) are up to 12 bill. ly away

- The visible Universe has a radius of ~13.8 billion years, because the Universe is ~ 13.8 billion years old (time since the Big Bang occurred)
- The Universe shows accelerated expansion
- The Universe contains about 10 million galaxy superclusters ~ $2 \cdot 10^{22}$ = 20 billion trillion stars ”33 mmol”

The Cosmic Architecture - Space-Time Diagram

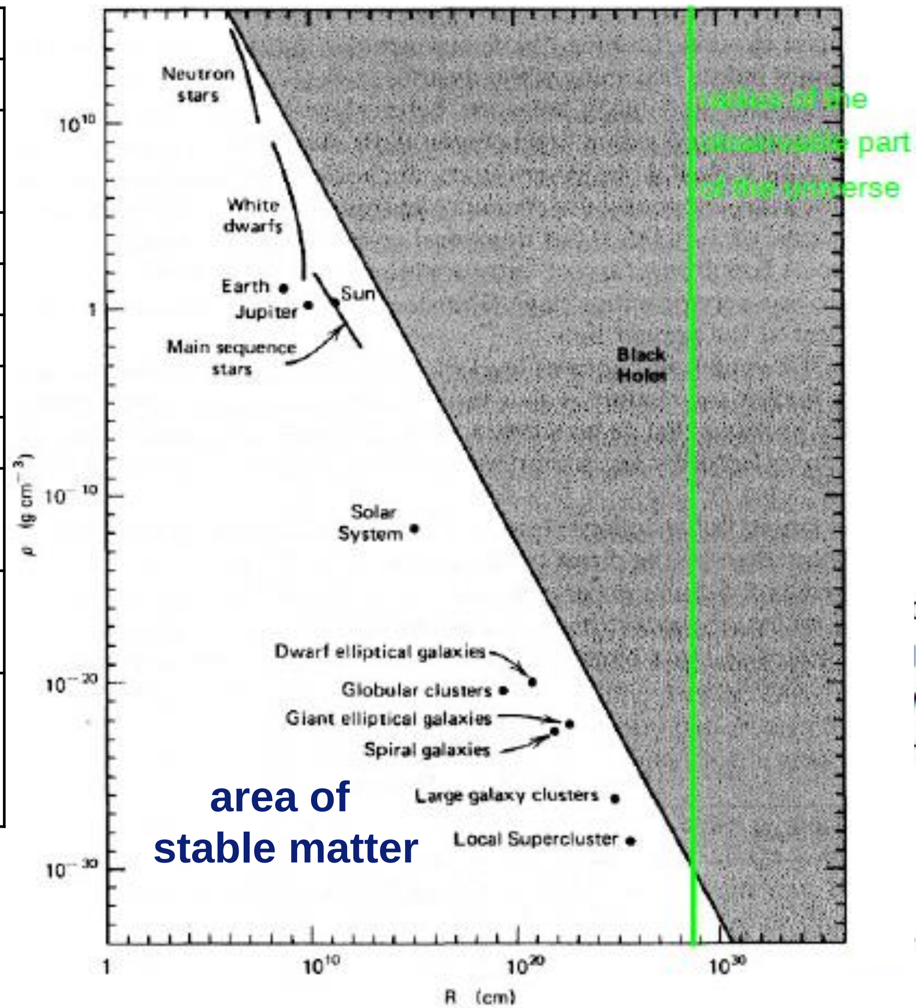
The most recent model of the Universe



The Cosmic Architecture - Density-Radius Diagram

The most recent model of the Universe

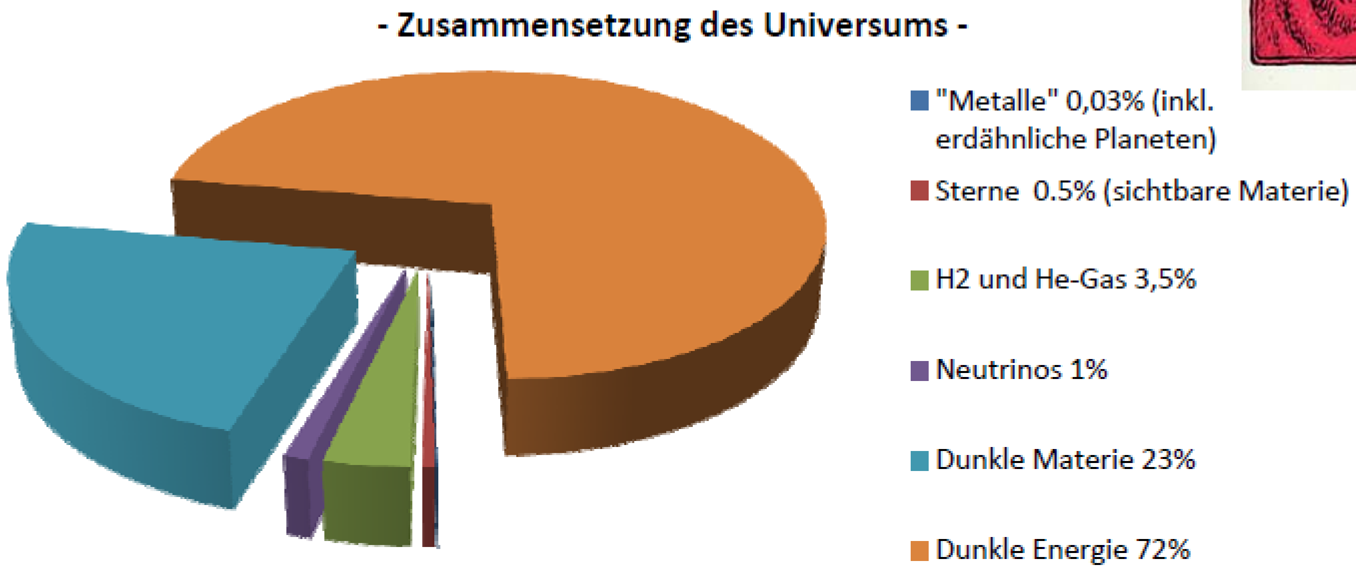
Substance/Object	Density [g/cm³]
Solar system	10^{-12}
Hydrogen at standard conditions	$8.4 \cdot 10^{-5}$
Saturn	0.69
Jupiter	1.33
Earth	5.52
Iridium	22.65
Sun at the centre	134
White dwarfs (e.g. Sirius B)	10^3 - 10^9
Neutron stars (e.g. Cygnus A)	10^{10} – 10^{14}
Black hole (within Schwarzschild radius)	10^{16}



The Cosmic Architecture - Composition of Matter

Baryonic matter (atoms) contributes solely to 4% to the composition of the universe

Astronomers define all elements that are heavier than He as metals. These metals are extremely rare, since more than 99% of the atoms are He or H!



The Cosmic Architecture - Origin of the Elements

Groups

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Periods
1 H																	2 He	1
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	2
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	3
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	4
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	5
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	6
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og	7

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	6
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	7

Synthesis within 15 min after the Big Bang

Stellar synthesis

Stellar formation by the s(slow)-Process (neutron capture and ß-decay)

Formation by the r(rapid)-Process during Supernova explosions of Type II

The Fate of the Universe

Depends on the evolution of spacetime and on stability of matter

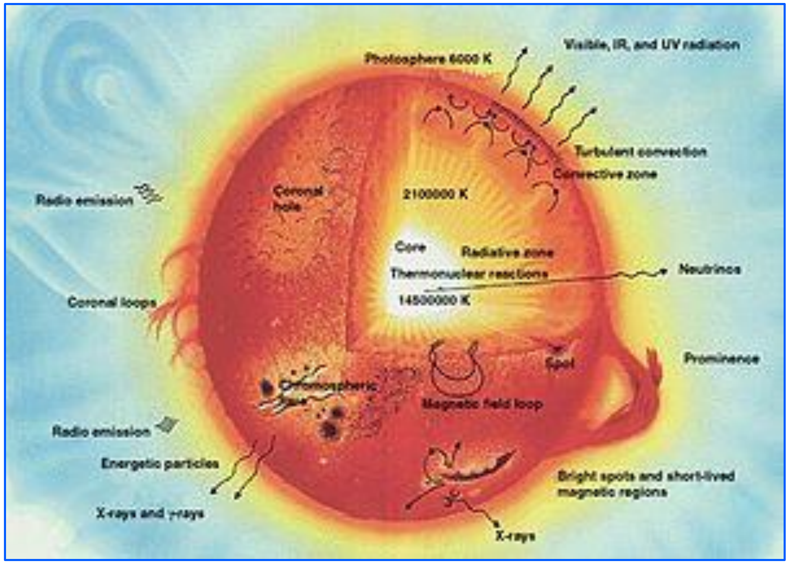
What is the origin of gravity? What is the effect on cosmic architecture?

What is the energy source of the sun and the stars?

Are and if why are the elements (the nuclei) stable?

Why does the universe not collapse by gravity of (dark) matter?

What is the nature of dark matter and energy?



<u>Some answers are given by</u>

- **Theory of relativity (special and general)**
- **Quantum electro dynamics**
- **Quantum chromo dynamics**

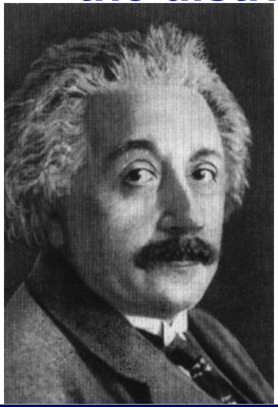
Albert Einstein (1879 – 1955)

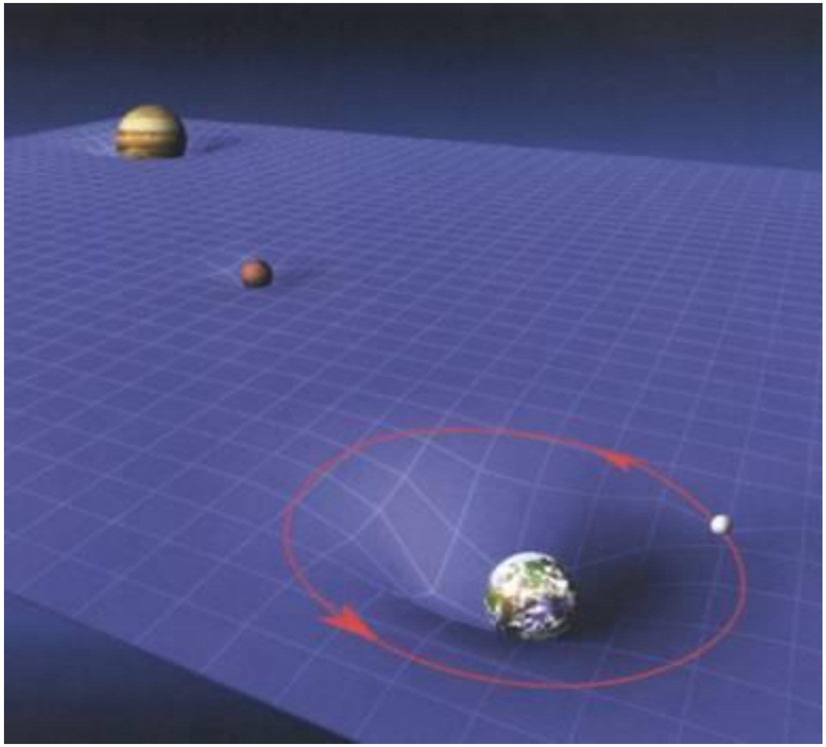
Special Theory of Relativity (1905)

- Speed of light c is constant and an absolute upper limit
- Time and length scale depend on motion → flat spacetime
- Energy is equal to matter: $E = mc^2$

General Theory of Relativity (1917)

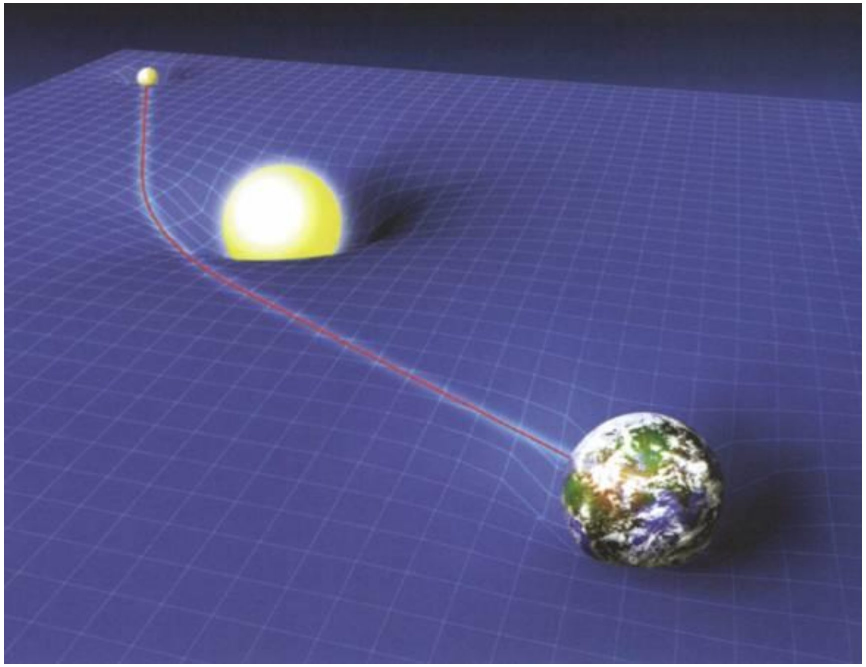
- Spacetime is not flat, but curved
- Gravitation is a consequence of the curvature of the spacetime
- Spacetime topology is determined by the distribution of matter and energy



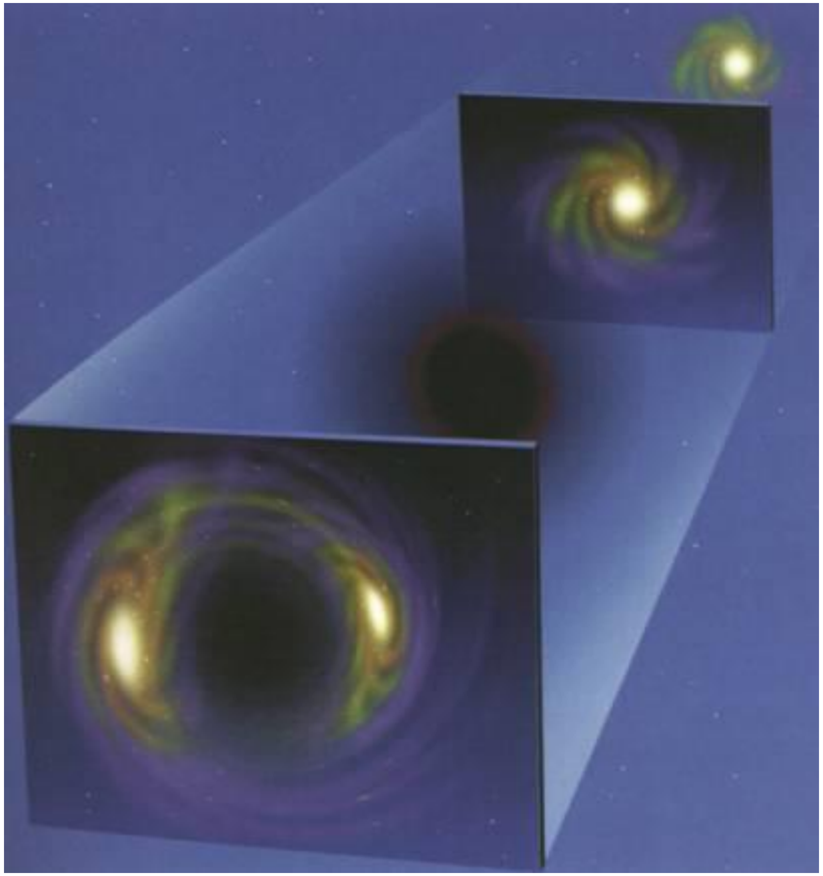


Part of our solar system
(Jupiter – Mars – Earth)

Gravity Refraction of Light by Matter



Proof: Arthur Stanley Eddington (May 29th, 1919)



Recent application: Detection of dark matter and black holes between us and remote galaxies or quasars

The Fate of the Universe

Age and lifetime of the sun

- Lifetime and stability of the Sun became a problem in 18th century, as Charles Darwin estimated the erosion process of the South England chalk cliffs to last for 300 Mill. years
- Lord Kelvin doubted Darwins results

  ⇒ he assumed that gravitational energy during the contraction process as proposed by Helmholtz is the origin of solar energy

  ⇒ age of sun < 100 Mill. years
- Ernest Rutherford proposed 1904 radioactive decay as the energy source of the Sun and of geothermal processes

All these mechanism are not sufficiently efficient to explain the stable energy production of the Sun over 4.6 Bill. years

Energy Production of Stars - The Sun (Mass M)

Arthur Eddington (1920) - Fusion of Hydrogen is the source of energy

- **Radiant power (Luminosity L)** $L = 3.86 \cdot 10^{26}$ W
- **Hard coal ball with the mass of the Sun:** $\tau_{Coal} = 10000$ years
- **Potential energy (gravity field)** $E_G = - E_{pot}(R) \cong G \cdot M^2/R$

  $\tau_{HK} = ½\ E_G/L \cong 3 \cdot 10^7$ years

- **Nuclear fusion: About 0.8% of matter is converted into energy**

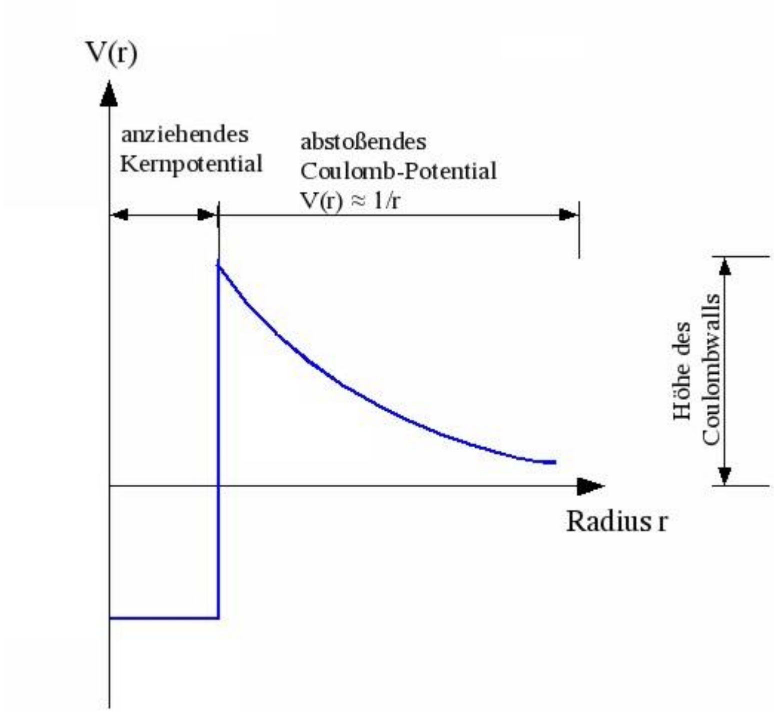
  $E_N = 0.008\ Mc^2$

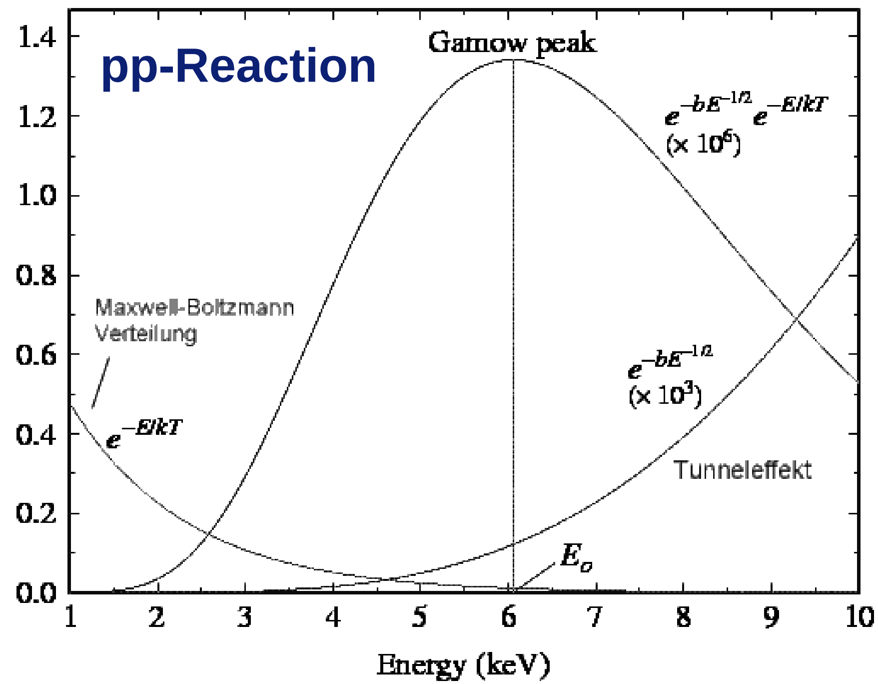
  $\tau_N = E_N/L \cong 10^{11}$ years

Energy Production of Stars - Nuclear Fusion

Principle

- $p^+ + p^+ \rightarrow He^{2+}$
- Problem: Electrostatic repulsion between protons
- Coulomb potential can be overcome by the tunnel effect
- Reaction rate ~ Maxwell-Boltzmann-Distribution * tunnel probability



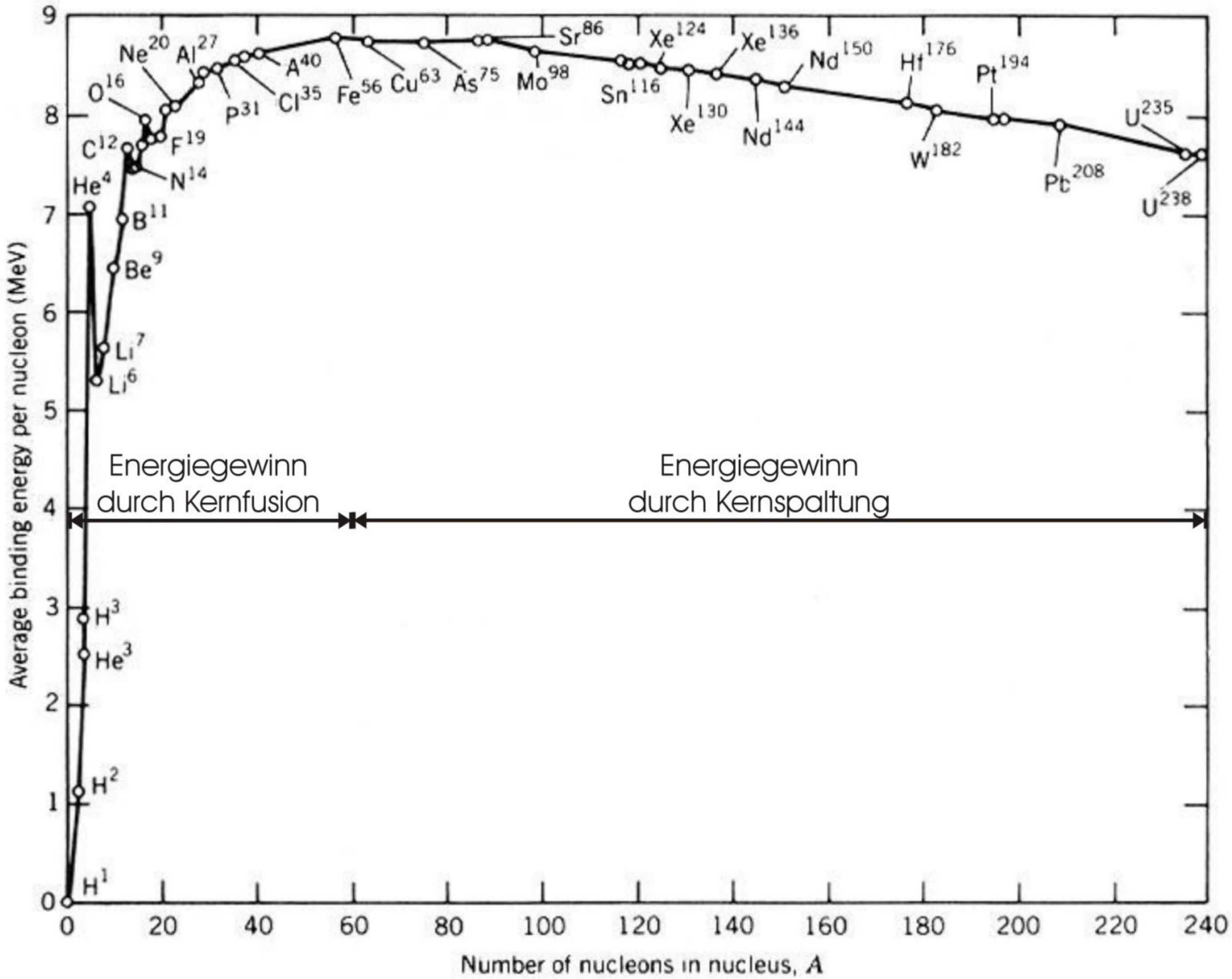


Energy Production of Stars - Nuclear Fusion

Mass Defect

- Mass of a nucleus is generally smaller than the sum of the masses of N Neutrons and Z Protons
- Albert Einstein 1905: Mass is equivalent to energy $\Rightarrow$ $E = mc^2$
- Nuclear binding energy: $E = B(Z,N) = [Zm_p + Nm_n – m(Z,N)]c^2$
- Maximum of the binding energy per Nucleon is achieved for the nuclid ^{56}Fe
- Formation of heavier isotopes than ^{56}Fe consumes energy: Fission

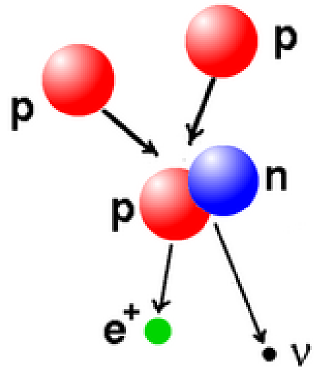
Energy Production of Stars - Nuclear Fusion



Energy Production of Stars - Nuclear Fusion

Proton-Proton Reaction (Overall Reaction)

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+} + 2\nu_{e} + 2\gamma + 26.2\ \text{MeV}$$

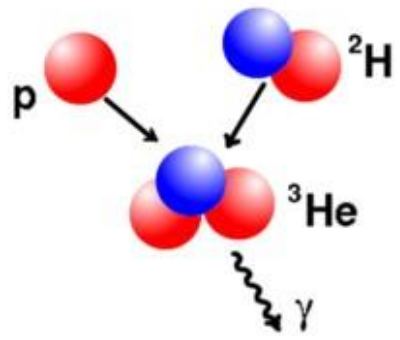


Start reactions

$$p + p \rightarrow {}^{2}_{1}H + e^{+} + \nu_{e} + 1.19\ \text{MeV}$$

$${}^{2}_{1}H + p \rightarrow {}^{3}_{2}He + \gamma + 5.49\ \text{MeV}$$

$$\mathbf{p} \rightarrow \mathbf{n} + \mathbf{e}^{+} + \boldsymbol{\nu}_{\mathbf{e}}$$



Energy Production of Stars - Nuclear Fusion

3 Posssible Subsequent Reactions

– **PP-Reaction I:**

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2p + 12{,}89\,MeV$$

– **PP-Reaction II:**

$$^{3}_{2}He + ^{4}_{2}He \rightarrow ^{7}_{4}Be + \gamma + 1{,}59\,MeV$$

$$^{7}_{4}Be + e^{-} \rightarrow ^{7}_{3}Li + \nu_e$$

$$^{7}_{3}Li + p \rightarrow 2\,^{4}_{2}He + 17{,}35\,MeV$$

– **PP-Reaction III:**

$$^{3}_{2}He + ^{4}_{2}He \rightarrow ^{7}_{4}Be + \gamma + 1{,}59\,MeV$$

$$^{7}_{4}Be + p \rightarrow ^{8}_{5}B + \gamma + 0{,}14\,MeV$$

$$^{8}_{5}B \rightarrow ^{8}_{4}Be + e^{+} + \nu_e$$

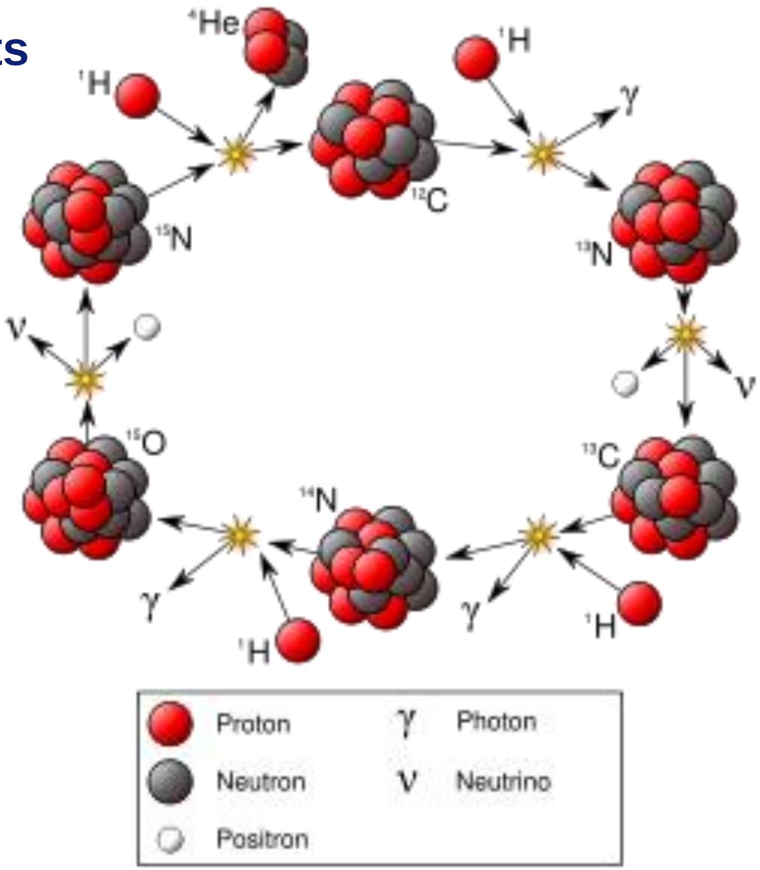
$$^{8}_{4}Be \rightarrow 2\,^{4}_{2}He$$

Energy Production of Stars - Nuclear Fusion

CNO-Cycle: Hans Albrecht Bethe (1906 - 2005) and Carl Friedrich von Weizsäcker (1912 - 2007) published in 1938

Carbon, Nitrogen, and Oxygen act as catalysts for the fusion of Hydrogen to Helium

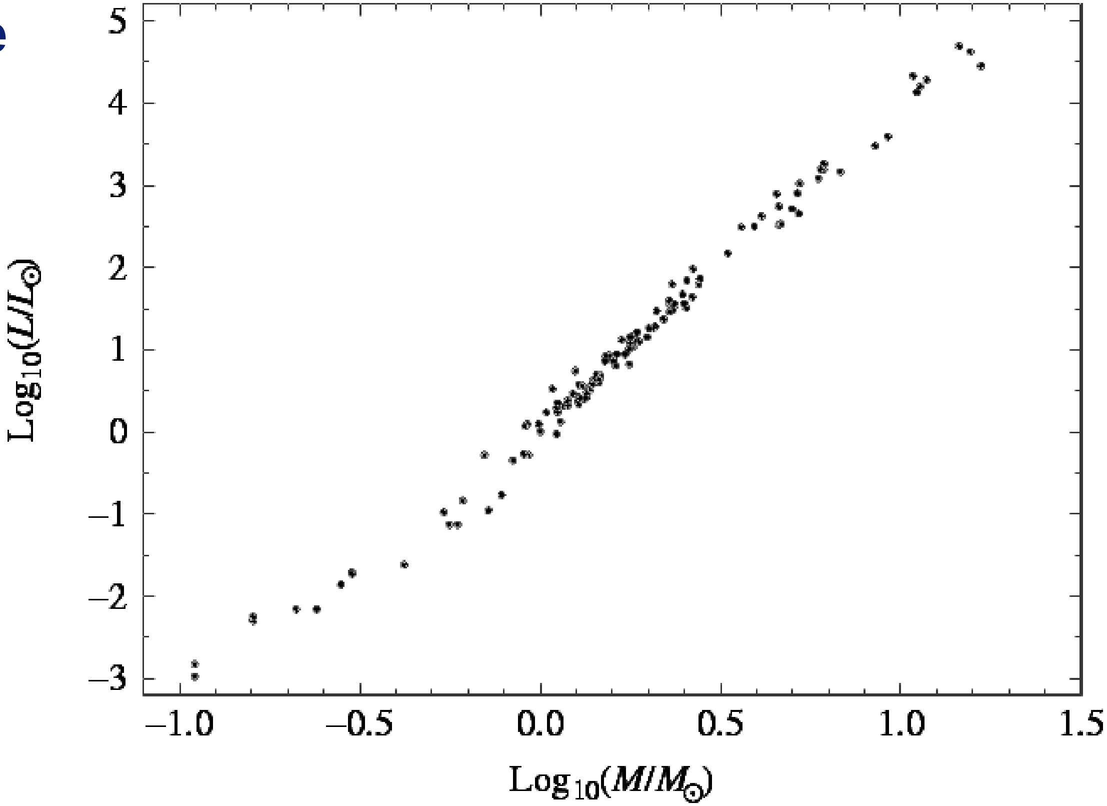
- $^{12}C + ^{1}H \rightarrow ^{13}N + \gamma + 1.95$ MeV
  $1.3 \cdot 10^{7}$ years
- $^{13}N \rightarrow ^{13}C + e^{+} + \nu_e + 1.37$ MeV
  7 minutes
- $^{13}C + ^{1}H \rightarrow ^{14}N + \gamma + 7.54$ MeV
  $2.7 \cdot 10^{6}$ years
- $^{14}N + ^{1}H \rightarrow ^{15}O + \gamma + 7.35$ MeV
  $3.2 \cdot 10^{8}$ years
- $^{15}O \rightarrow ^{15}N + e^{+} + \nu_e + 1.86$ MeV
  82 seconds
- $^{15}N + ^{1}H \rightarrow ^{12}C + ^{4}He + 4.96$ MeV
  $1.12 \cdot 10^{5}$ years



Energy Production of Stars - Nuclear Fusion

Lifetime of Stars

- **Luminance-Mass-Relation** $L \sim M^{7/2}$
- **Massive stars radiate more intense (are brighter) as light stars, i.e. they have a larger energy consumption and thus a shorter lifetime**

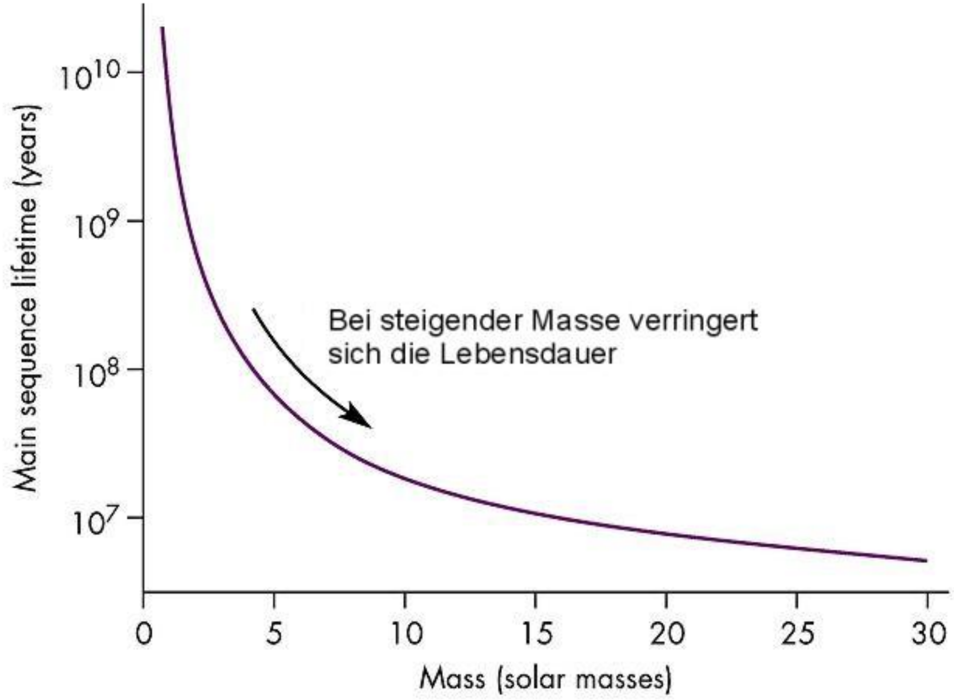


Energy Production of Stars - Nuclear Fusion

Temperature-Mass-Relation

$$T \sim \left(\frac{M}{M_*}\right)^{2/3}$$

→ Temperature increases with mass



Lifetime-Mass-Relation

$$t_{mainsequence} = 10^{10} / \left(\frac{M}{M_*}\right)^{5/2}$$

→ Lifetime decreases with increasing mass

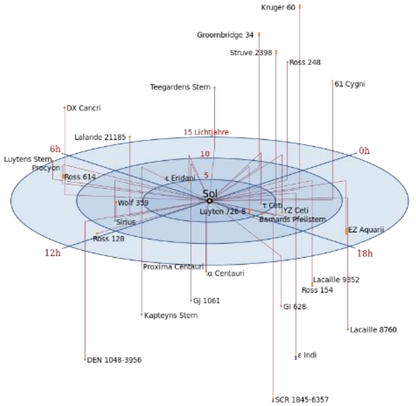
Energy Production of Stars - Nuclear Fusion

Main Sequence Stars

Spectral type	Mass [sun = 1]	Luminosity [sun = 1]	Time on main sequence
O5	40	$405 \cdot 10^3$	$1 \cdot 10^6$ years
B0	15	$13 \cdot 10^3$	$11 \cdot 10^6$ years
A0	3.5	80	$440 \cdot 10^6$ years
F0	1.7	6.4	$3 \cdot 10^9$ years
G0	1.1	1.4	$8 \cdot 10^9$ years
K0	0.8	0.46	$17 \cdot 10^9$ years
M0	0.5	0.08	$56 \cdot 10^9$ years
M5	0.1	0.000138	$4 \cdot 10^{12}$ years

Our nearest neighbor Proxima Centauri (distance: 4.247 ly) is an M5 star, i.e. it will live for more than a trillion years …

Source of ímage: ESA/Hubble



Life of Stars - Birth

General Process

- A gas cloud collapses due to its own gravity or external gravity waves (e.g. a nearby supernova)
  - Contraction → density increases
  - Release of gravitation energy → temperature increase

- Hydrogen fusion solely occurrs in the centre of the new star
  → T-Tauri stars

- Objects with less than 0.07 Sun mass does not reach a sufficiently high core temperature to ignite Hydrogen fusion
  → Brown dwarf

Life of Stars - Development

- Once 10% of the Hydrogen are consumed, the phase of Hydrogen fusion will end
- Speed of development depends on initial mass
- Star collapses → Potential energy converted into thermal energy in gravity field →Requirement for Helium fusion fulfilled (→ star leaves main sequence → Red giants)
- Very massive stars also induce carbon and silicon fusion

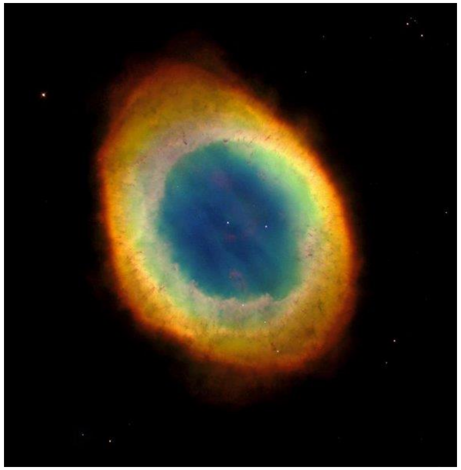
Evolutionary stages of a 25 solar mass star (a blue giant)

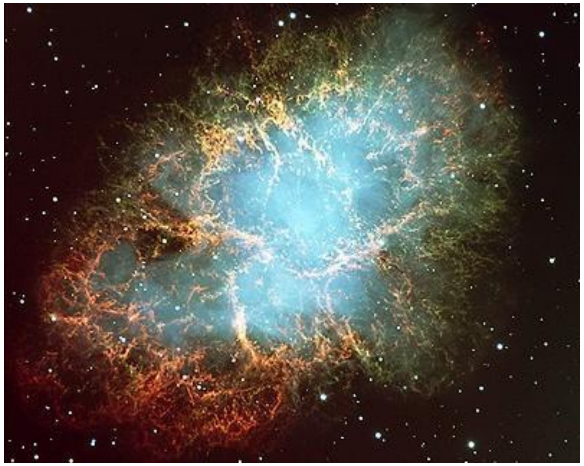
Stage	Temperature [K]	Density [kg/m³]	Duration of stage
Hydrogen burning	$4{\cdot}10^7$	$5{\cdot}10^3$	$7{\cdot}10^6$ years
Helium burning	$2{\cdot}10^8$	$7{\cdot}10^5$	$7{\cdot}10^5$ years
Carbon burning	$6{\cdot}10^8$	$2{\cdot}10^8$	600 years
Neon burning	$1.2{\cdot}10^9$	$4{\cdot}10^9$	1 year
Oxygen burning	$1.5{\cdot}10^9$	$1{\cdot}10^{10}$	6 months
Silicon burning	$2.7.10^9$	$3{\cdot}10^{10}$	1 day
Core collapse	$5.4{\cdot}10^9$	$3{\cdot}10^{12}$	0.25 seconds
Core bounce	$2.3{\cdot}10^{10}$	$4{\cdot}10^{15}$	milliseconds
Explosive	about 10^9	varies	10 seconds

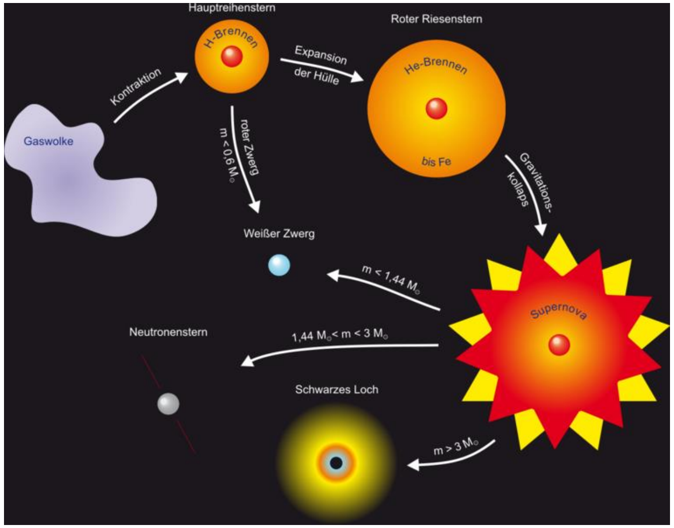
Life of Stars - End of Life

- Due to temperature and radiant power increase the star expands to form a red giant
- External shell will be repelled

  formation of a planetary nebula, while the mass of the remaining core determines the final state
- < 1.38 Sun mass → Collapse yielding a White Dwarf
- > 1.38 Sun mass → Supernova explosion
  - Remaining core < 3 Sun mass → Neutron star (pulsar)
  - Remaining core > 3 Sun mass → Black hole







Life of Stars - End of Life

Historical supernovae (SN) explosions with visibility by the naked eye

Year SN	m_{max}	visible [months]	Type	Remnant	D(ly)	R(ly)
185	-8.0	8	Ia	RCW86	9100	56
386	+1.5	3	-	-	-	-
393	-1.0	8	II/Ib	RXJ1713.8-3946	3000	30
1006	-7.5	21	Ia	PKS1451-41	7200	32
1054	-6.0	22	II	Crab nebula	6500	6.6
1181	-1.0	6	-	3C 38	> 8000	-
1572	-4.0	16	Ia	Tycho	11500	14
1604	-2.5	12	Ia	Kepler	20000	9

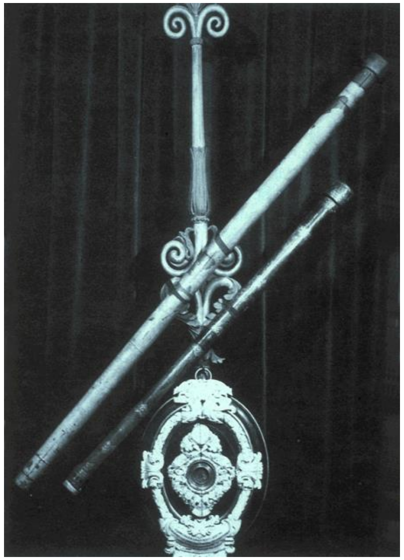
Type Ia: Thermonuclear explosion of a white C-O-dwarf (no H lines)
Type Ib: Core collapse of massive stars (no H lines, but Si lines)
Type II: Rapid collapse & violent explosion of massive stars (H lines)

Progress in Observation Techniques

Major inventions in astronomy/astrophysics research

- Telescopes + interferometry + adaptive optics
- Photography
- Spectroscopy
- Novel detection ranges
  - Radio astronomy
  - IR and Microwave astronomy
  - x- and gamma-ray astronomy
- Space probes and space telescopes

Progress in Observation Techniques

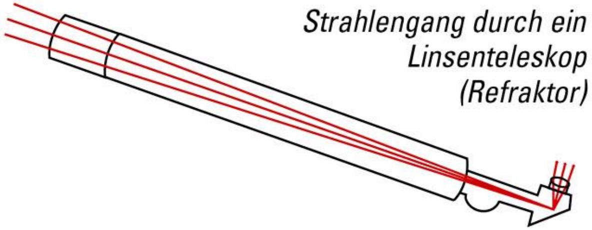


Telescopes (since 1608)

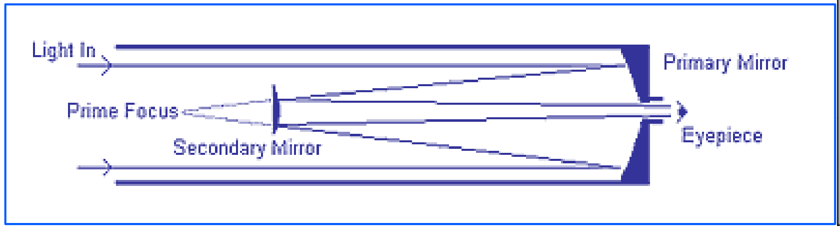
Inventor: Hans Lippershey (~1570 - 1619, a dutch optician)

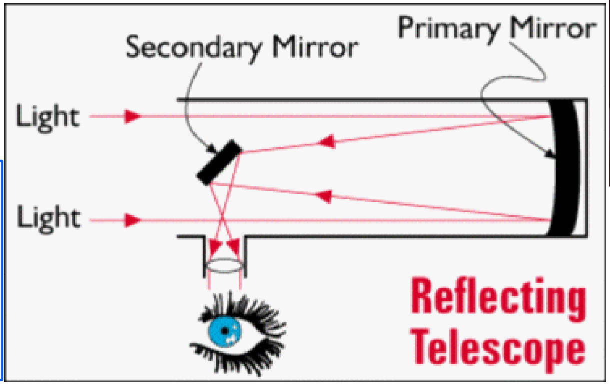
Main types

- **Refractors** - **Galileo type**



- **Reflectors** - **Newton type**
  - **Cassegrain type**
  - **Schmidt type**
  - **Dobson type**

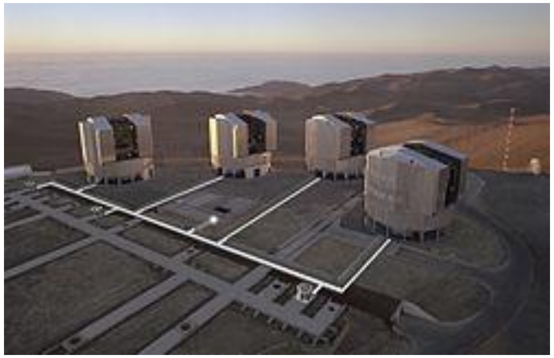


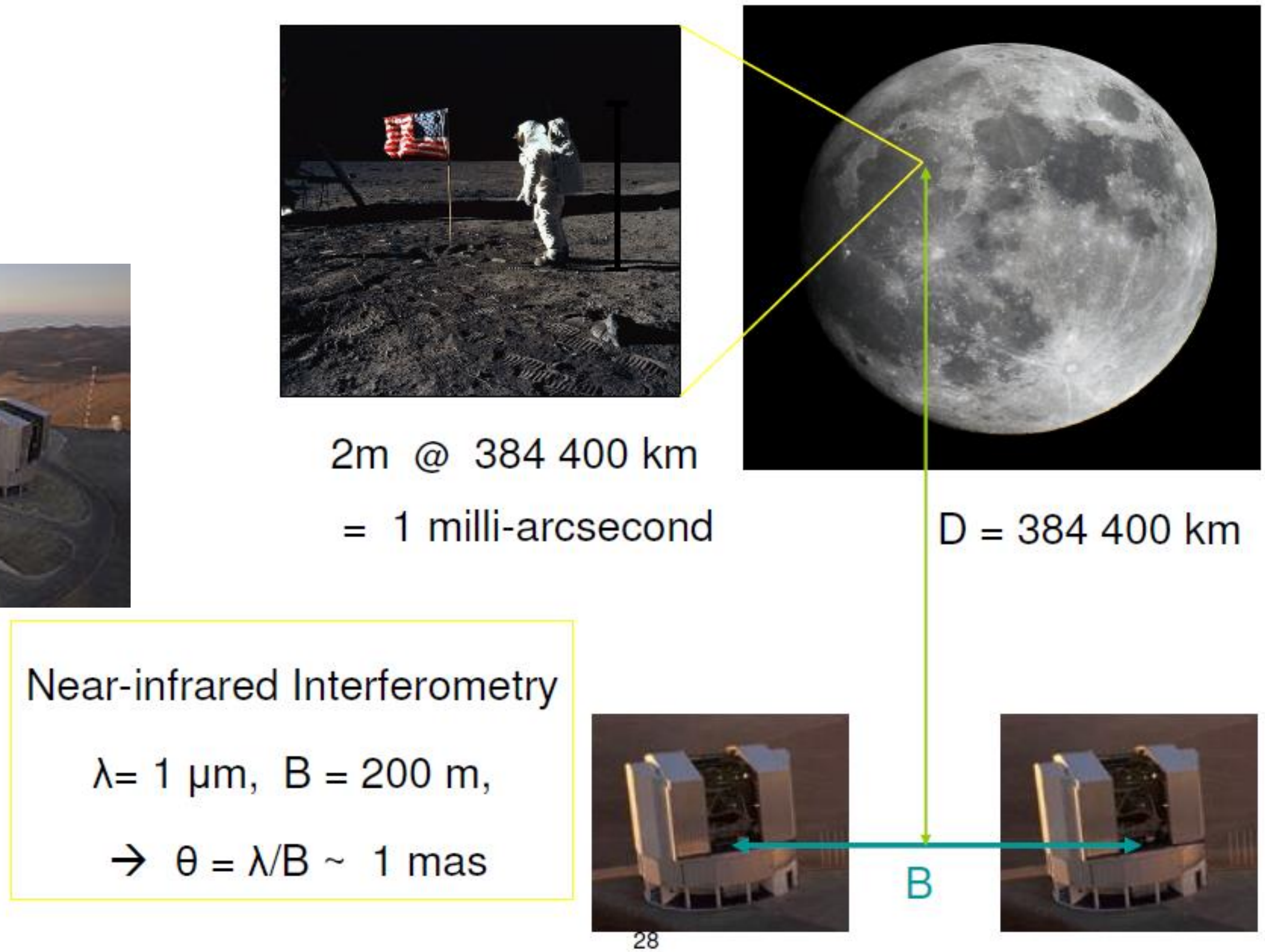


Progress in Observation Techniques

Intereferometry with the VLT from ESO (Paranal, Chile)

Apollo landers are visible from Earth!





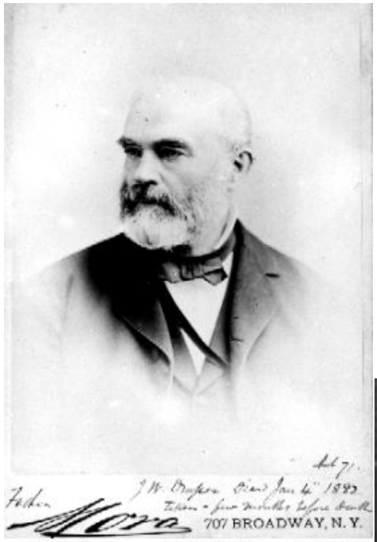
First Astronomical Photographs

John William Draper (1811 - 1882)

- 1st daguerrotype (silvered copper plate) of the Moon by the American physiologist and chemist in 1840, 20 minute exposure (later destroyed by fire).

- The first star was not recorded until the night of July 16-17, 1850, when William Cranch Bond , director of Harvard College Observatory, and J.A. Whipple, a photographer associated with Massachusetts General Hospital, took a daguerrotype of Vega.

- At right is an 1852 daguerrotype of the Moon taken by Whipple



John William Draper (1811-1882) SI neg. #72-11302

First Astronomical Photographs

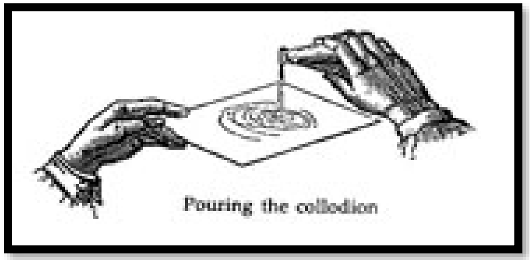
Need for Faster Process

- Astronomers needed a method to produce better quality images in less time
- In 1851, Frederick Scott-Archer (1813 - 1857) published an article describing the wet collodion process, although Gustave le Gray (1820 - 1884) and Robert J. Bingham (1824 - 1870) earlier had suggested and experimented with the technique
- Higher sensitivity than the early daguerrotypes, but it needed to be used as soon as it was made

First Astronomical Photographs

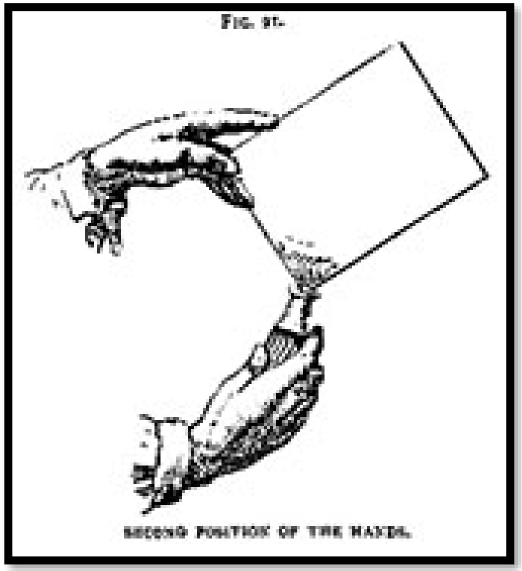
Wet Collodion Process - Chemistry

- Sulfuric acid and potassium nitrate were reacted on a small quantity of cotton to create guncotton (nitrocellulose)



- This guncotton was dissolved in alcohol and ether with iodides and bromides of cadmium, potassium, and ammonium

- The resulting colloid was spread on glass plates and evaporated to leave a thin film of nitrocellulose impregnated with bromides and iodides

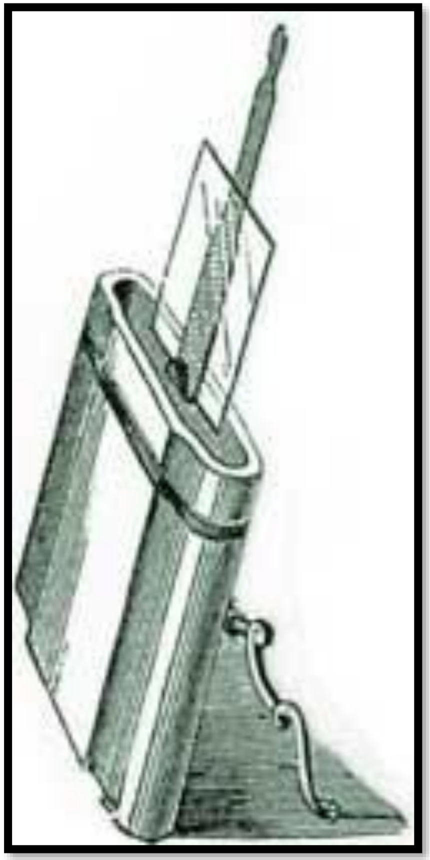


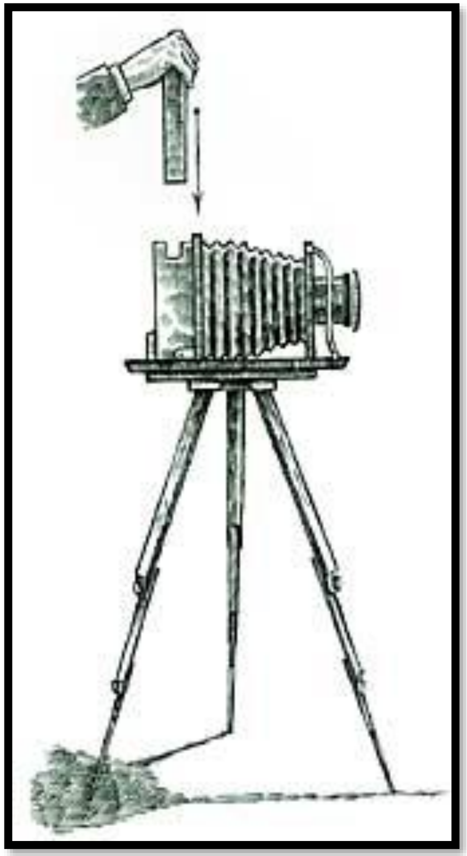
First Astronomical Photographs

Wet Collodion Process - Chemistry

- Once the plates were dry, they were dipped into a $AgNO_3$ solution, in which the iodides and bromides react to AgBr and AgI

- This silver halide coating was sensitive to light, but the plate had to be used immediately, or else the silver salts will degrade by light
  $2\ AgX \rightarrow 2\ Ag^0\ (black) + X_2$



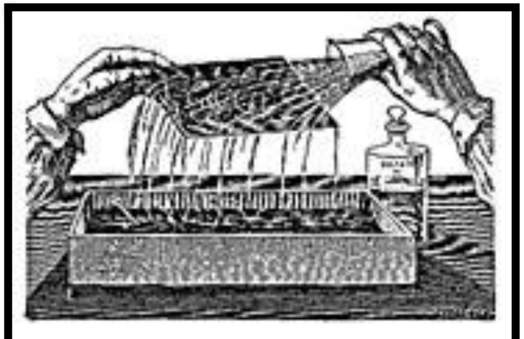


First Astronomical Photographs

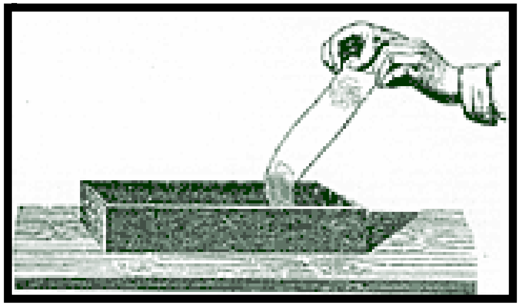
Wet Collodion Process - Chemistry

After the image was taken, the plate was developed in a bath of iron sulfate, acetic acid, and alcohol which turned the exposed silver halide grains into metallic silver Ag

Sodium thiosulfate was used as a fixer to remove the remaining (unexposed) silver halide grains. The plate was then washed to remove the chemicals a coat of varnish was applied to protect the image



Developing the plate

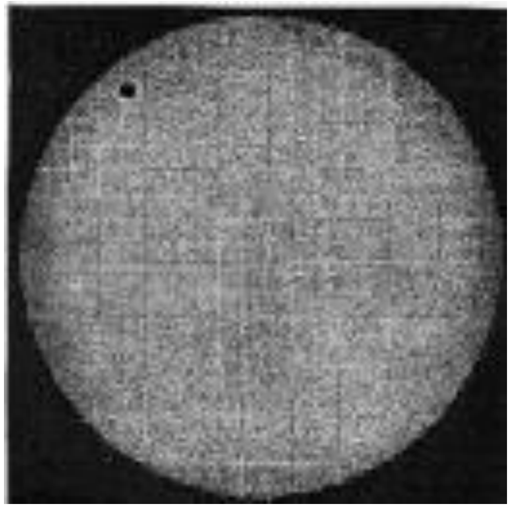


picture credits: PBS and http://www.collodion.org/

First Astronomical Photographs

Some examples

- Mizar and Alcor were photographed in March 1857 at Harvard College Observatory on wet collodion
- The 1874 transit of Venus was also widely photographed on collodion plates as well as on daguerrotypes
- The collodion plate at right was taken in Japan by Jules Janssen (1824 - 1907), later director of the Meudon Observatory



Last Venus transits	06. Dec 1631, 04. Dec 1639, 06. Jun 1761, 03. Jun 1769, 09. Dec 1874, 06. Dec 1882, 08. Jun 2004, 05. Jun 2012
Next Venus transits	10. Dec 2117, 08. Dec 2125

Technological Breakthroughs in 1870ties

Richard Maddox

1871, Richard Leach Maddox (1816 - 1902) - the first positive dry emulsion for physical development, using gelatin (a transparent animal protein)

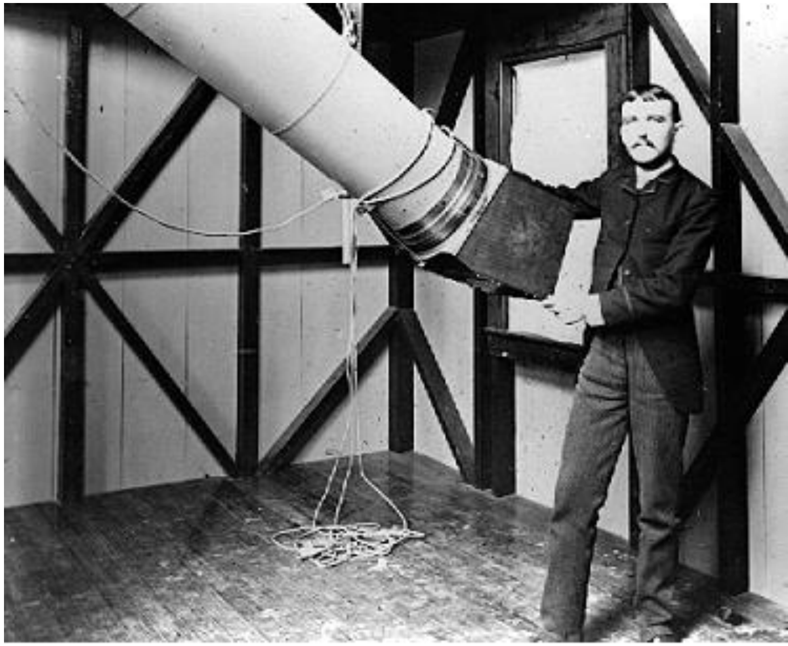
1874, J. Johnston and W.B. Bolton made the first negative emulsion for chemical development

1878, Charles Bennett had discovered a method by which he could increase the speed (sensitivity to light) of gelatin-silver bromide emulsions by aging them at 32 °C in a neutral medium.

1879, George Eastman (1854 - 1932) invented a machine to coat plates with emulsion, so that the plates could be produced in mass numbers, rather quickly and cheaply

Astronomy Advances

- With silver bromide AgBr dry emulsion plates, the first good photographs of Jupiter and Saturn were made in 1879 - 1886, and of comets in 1881 (Tebbutt's comet)
- A 51 minute exposure of the Orion Nebula was taken in September 1880 by Henry Draper (1837 - 1882)
- 1882, Draper took 137 minute exposure which revealed the entire nebula and the faintest stars in it
- 1872, the first spectrum of a star, viz. Vega, was taken by Henry Draper



Henry Draper (1837-1882) SI neg. 48,235

Astronomy Advances - Orion Nebula

1880 photograph

1882 photograph

Astronomy Advances

Julius Scheiner

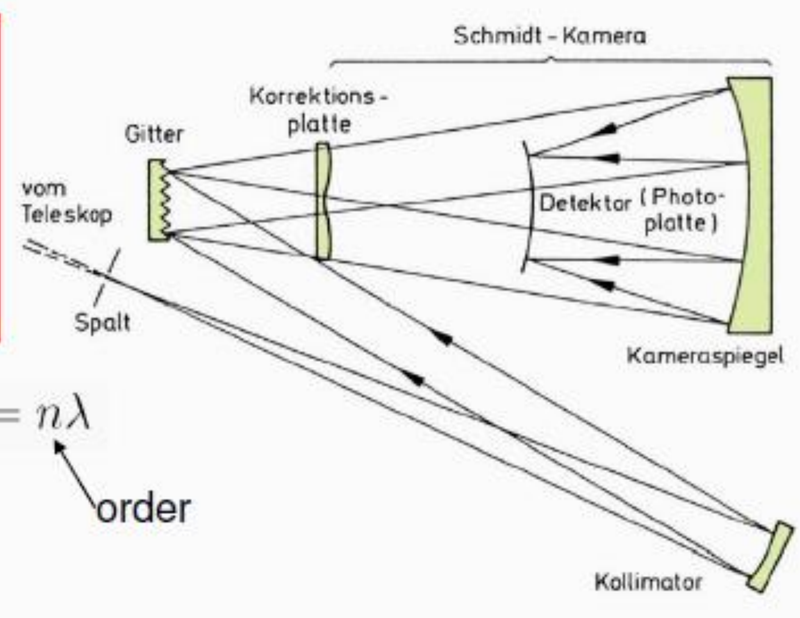
- **1882 Sir William Huggins (who was the first to show that stellar spectral lines could be identified with terrestrial elements, in 1864) took the first spectrum of a nebula (the Orion Nebula)**
- **1899 the first spectrum of a "spiral nebula" - 7½ hour exposure -taken by Julius Scheiner (1858 - 1913) with the Große Refractor of the Astrophysical Institute of Potsdam Observatory**
- **1882 - 1886: The first sky surveys were done at Harvard, each photograph covering a 15°x15° area of the sky and reaching stars as faint 8th magnitude**

Astronomy Advances

Spectroscopy requires a dispersive element ⇒ prisms or gratings

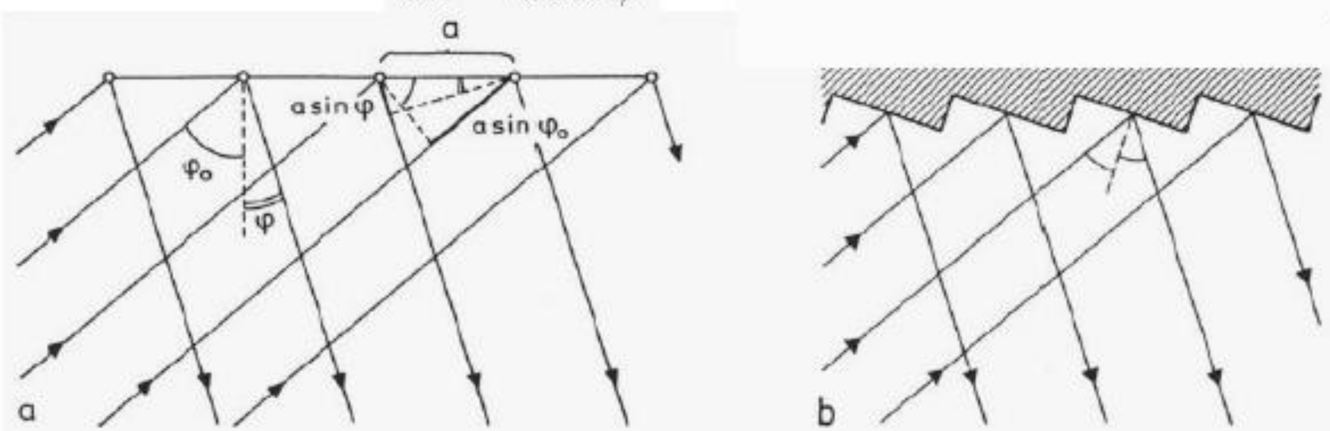
<u>Components of a simple spectrograph:</u>

- entrance aperture (slit, fiber)
- collimator (→ creates parallel beam)
- dispersing element (prisma, grating)
- camera (of Schmidt or other type)
- detector (now generally CCDs)



Grating equation: $a(\sin\phi - \sin\phi_0) = n\lambda$ ← order

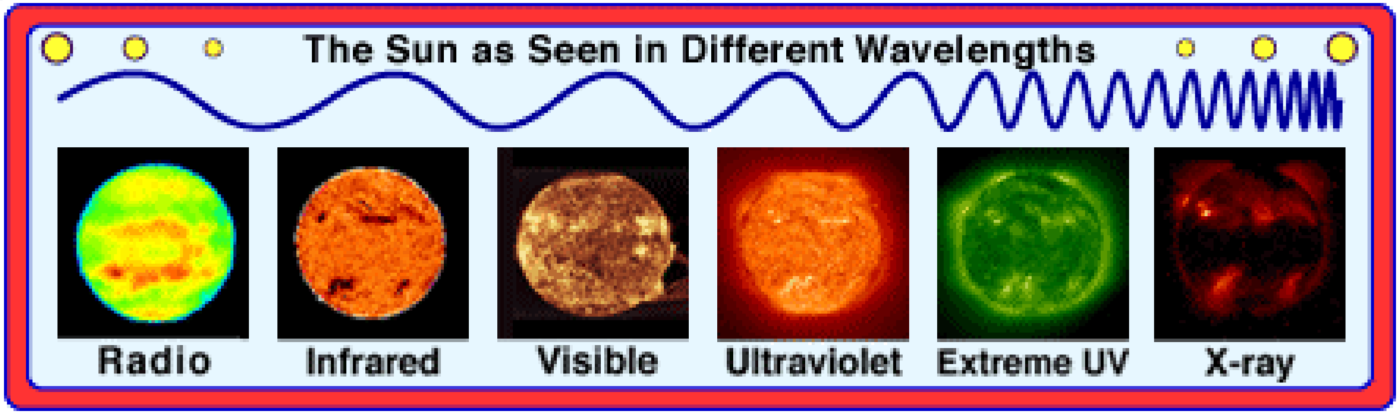
Angular dispersion: $\frac{d\phi}{d\lambda} = \frac{n}{a\cos\phi}$



Novel Detection Ranges

Multiwavelength Astronomy

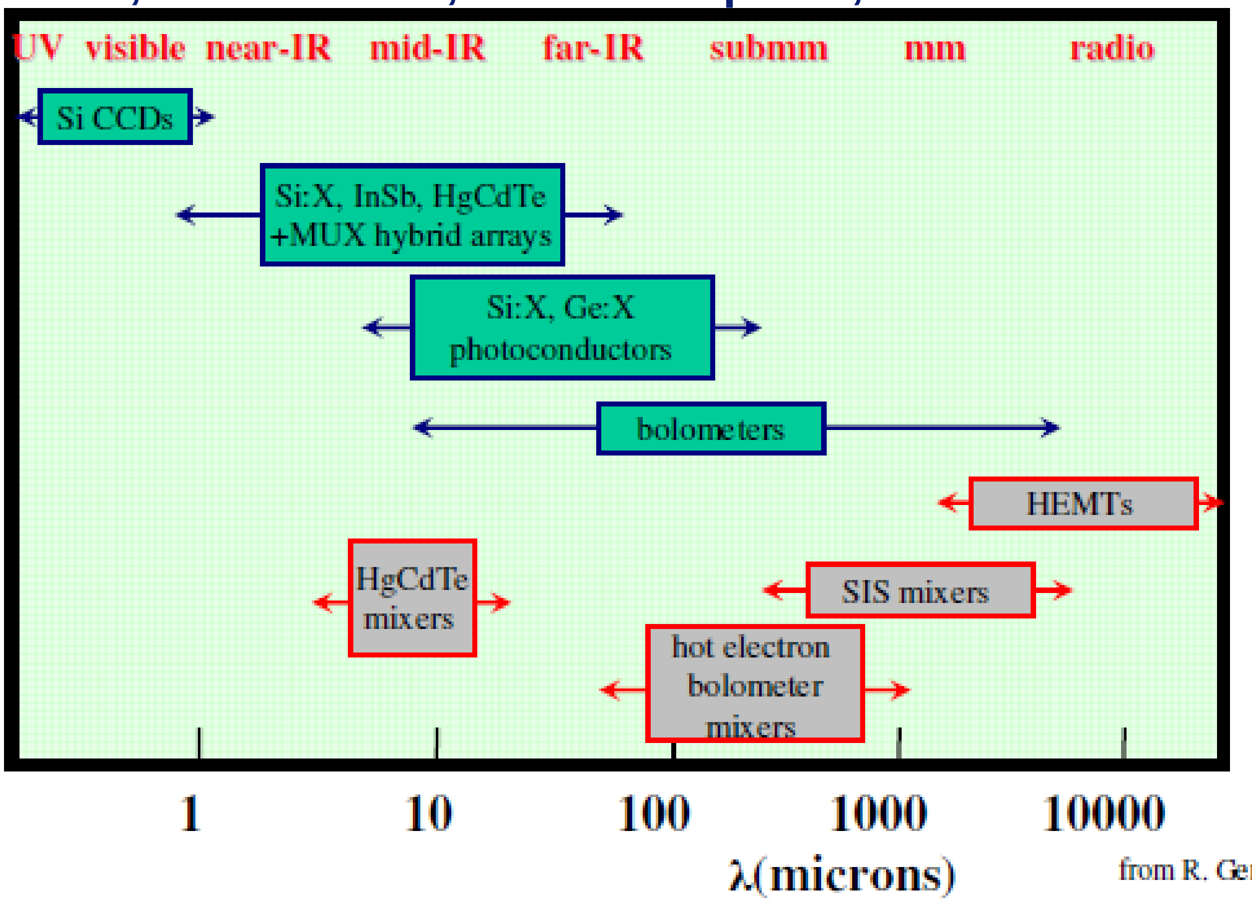
- What determines the type of electromagnetic radiation emitted by an astronomical object? Temperature!
- To observe at different wavelengths of light is to look at different temperatures & energies, which gives us different types of information about an object
- Most objects radiate over a range of wavelengths but generally they have a characteristic frequency/temperature where they radiate most strongly
- Living things radiate most strongly in the IR due to body heat



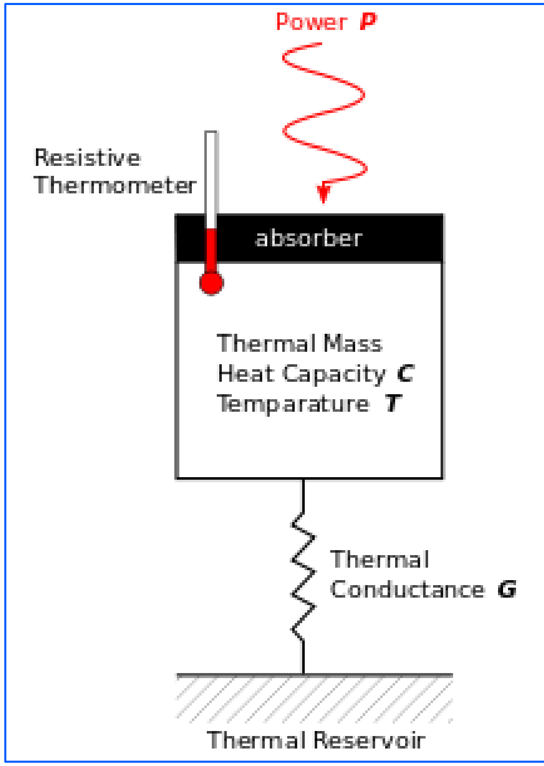
Novel Detection Ranges

Detectors for Multiwavelength Astronomy

CCDs, Photodiodes, Photomultipliers, and bolometers

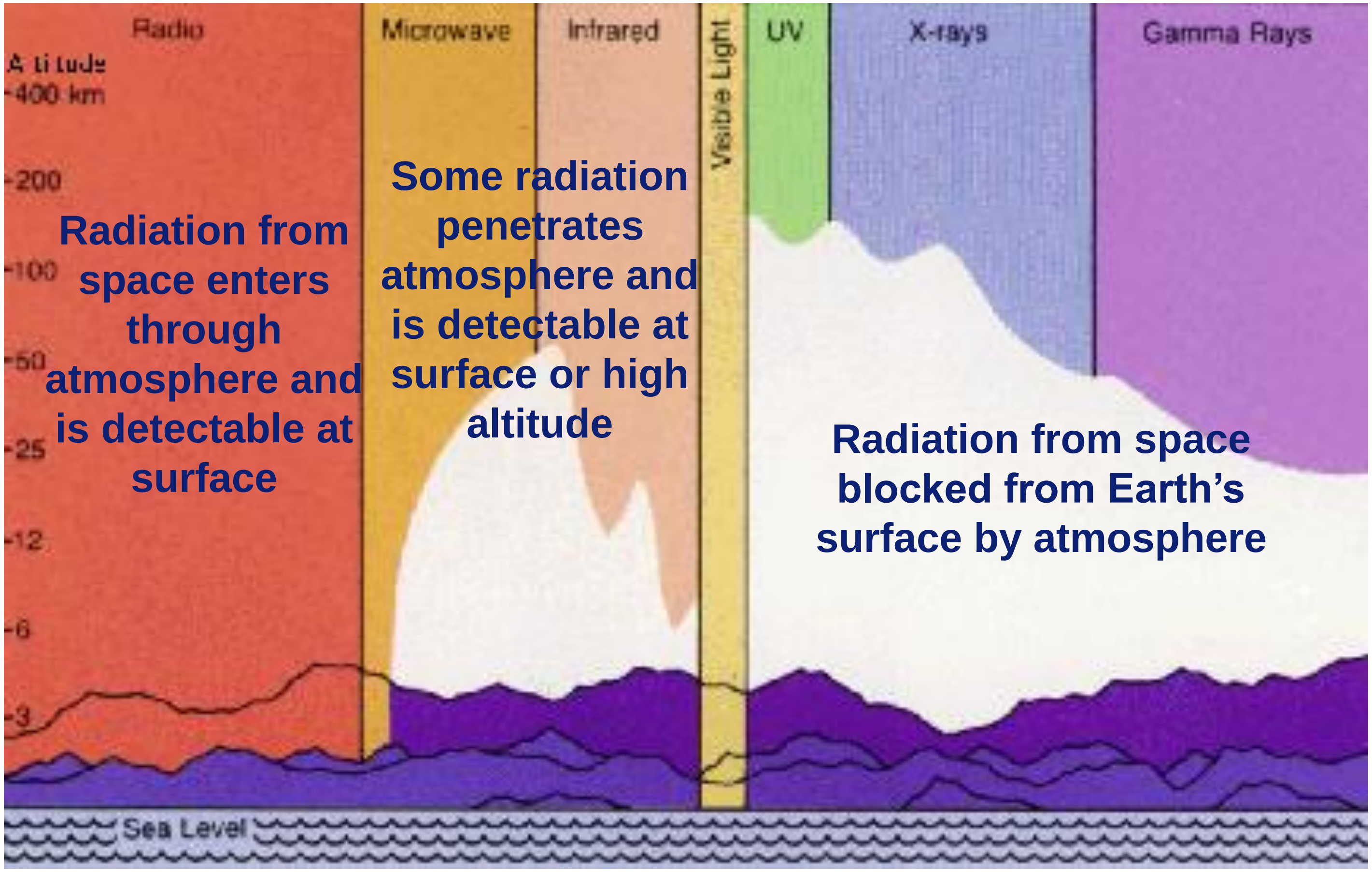


from R. Genzel



Novel Detection Ranges

Radiation from Space down to the Earth’s Surface

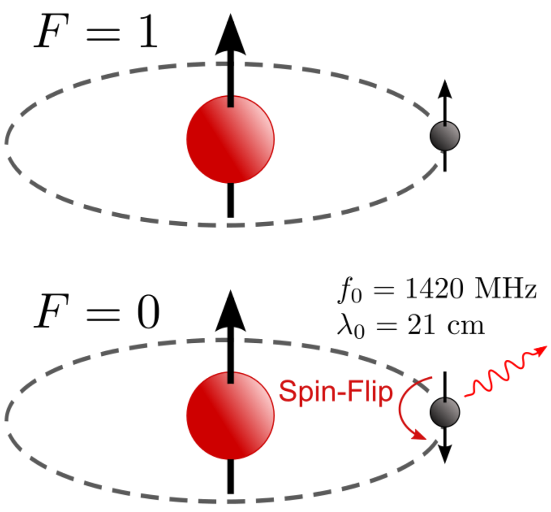


Ground-based telescopes → Access to visible light and radiowaves
Space-based telescoped → Access to μ-wave, IR, x-rays, and γ-rays

Radio Astronomy - Beginnings

First Discoveries in the 20th Century

- In the 50ties and 60ties, Radio telescopes first discovered the "signature" line of Hydrogen HI (H^0) at 21 cm wavelength (1420.4058 MHz) between stars
  - The hydrogen gas was found (in abundance) in the "empty" space between stars
  - Note: Domestic microwave furnaces use a radiation of ~ 12 cm wavelength (2.45 GHz) to cook food



- This gas was "dark" in the optical range but "bright" in the radio waves regime

Source: Wikipedia

Radio Astronomy - Telescopes

The world's largest telescope

Size: >100 m, Location: Green Bank, West Virginia, USA

Radio Telescopes - Principle

Collection Mode

- Radio Telescopes – Similar in many ways to optical telescopes
- Focus configurations:
  - Prime focus – radio receiver at the prime focus
  - Cassegrain – secondary convex reflector at prime focus
- How do you make a radio telescope (almost) the size of the Earth??
  - Answer: VLBA

Telescopes of the Very Long Baseline Array (VLBA)

St. Croix


Hancock


North Liberty


Fort Davis


Los Alamos


Pie Town


Kitt Peak


Owens Valley


Brewster

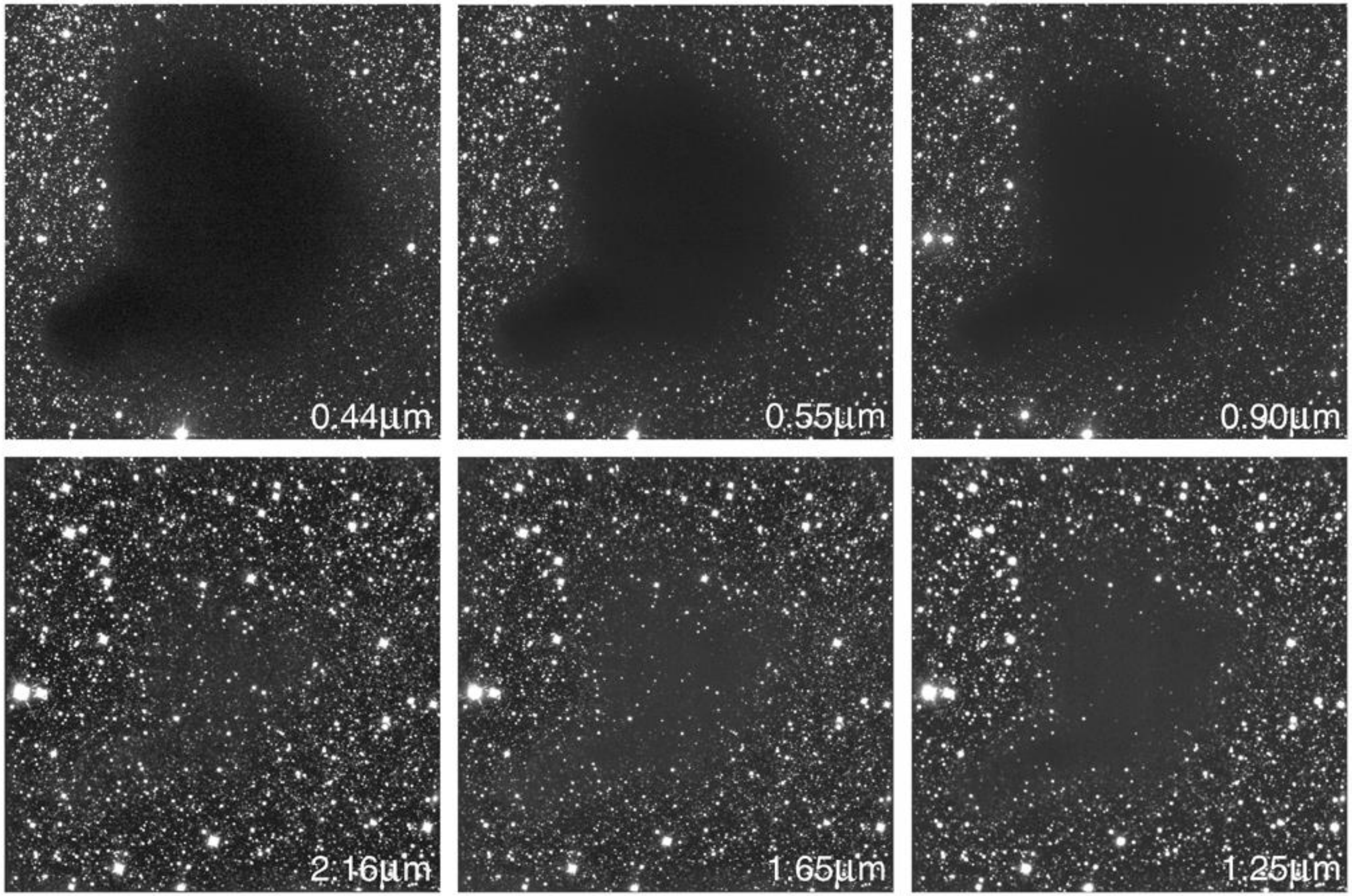
Mauna Kea

Some Chem. Compounds in Space - Astrochemistry

(Popular) Name	Chemical formula	Wavelength λ [cm]	Frequency υ [MHz]	Found in
Sulphur Monoxide	SO	8.28	36.202	Orion
Methanol	CH_3OH	8.29	36.169	Sagittarius
Formaldehyde	H_2CO	6.83	4.388	Sagittarius
Carbon Oxide Sulfide	OCS	8.22	36.488	Taurus
Silicon Monoxide	SiO	7.05	42.519	Sagittarius (Variable supergiant)
Silicon Tetracarbide	SiC_4	6.98	42.944	Taurus
Ammonia	NH_3	16.65	18.017	Giant molecular cloud

Today: More than 100 different molecules found in space, amongst them amino acids and other small biomolecules

IR-Astronomy - Examination of Hidden Objects

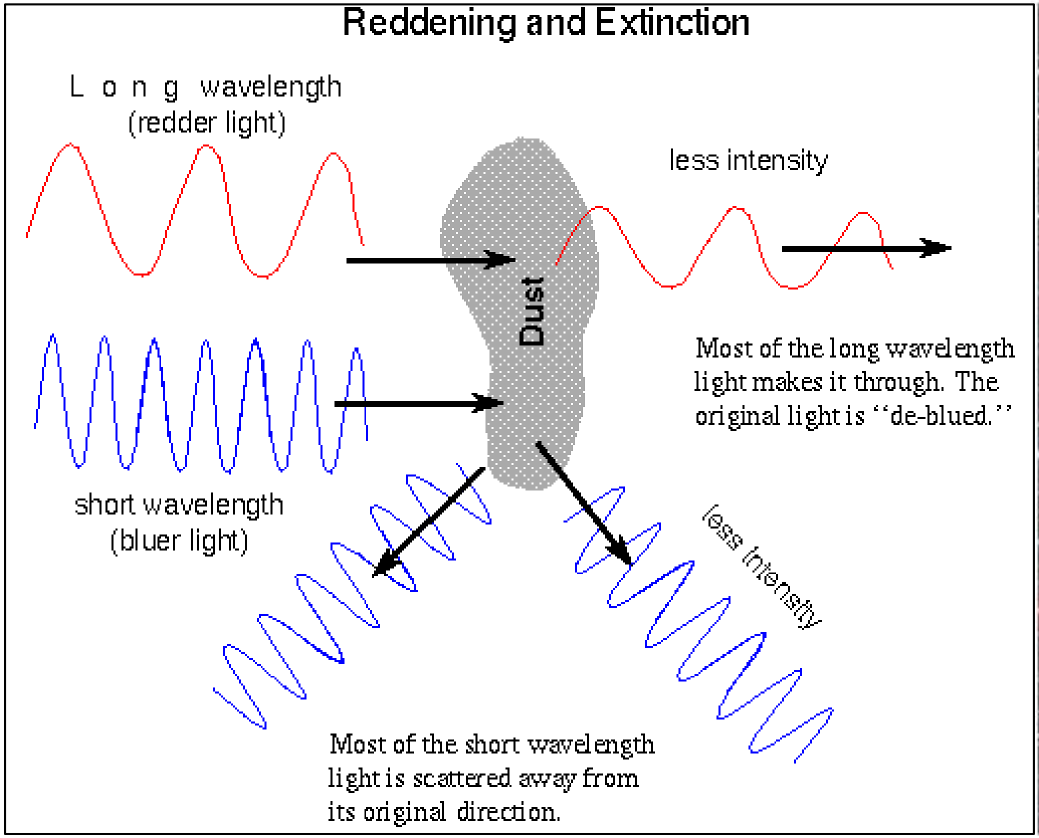


The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)

http://www.eso.org/public/outreach/press-rel/pr-1999/phot-29-99.html

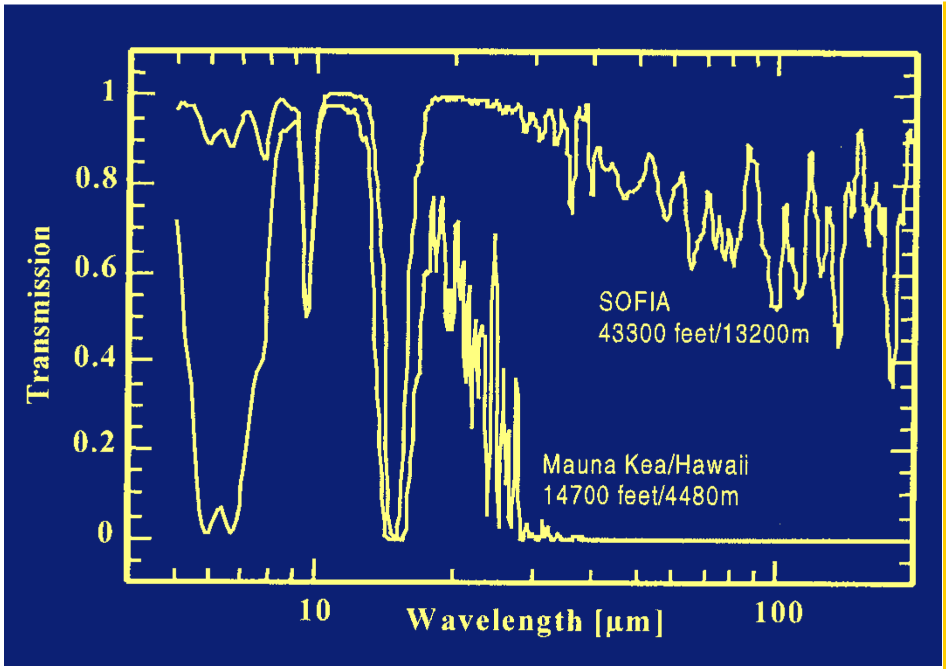
IR-Astronomy - Interstellar Extinction

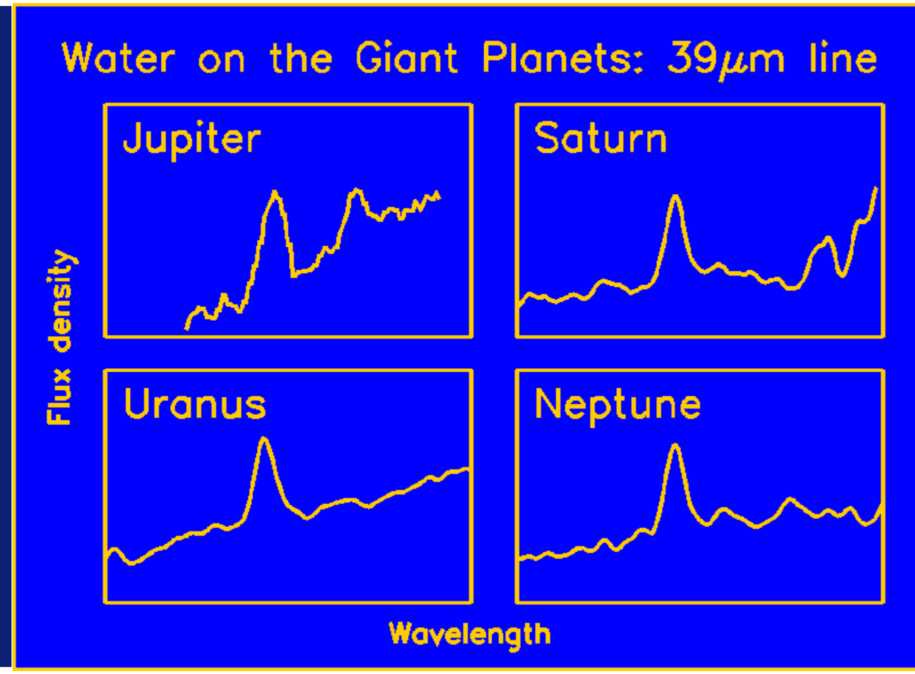


Dust acts as a radiation filter, i.e. it is transparent for deep red and NIR, but not for green/blue light or UV radiation

→ Inspired development of fog lamp for automotive + up-converter

IR-Astronomy - Impact of Water





IR-Astronomy requires water free optical pathway: Satellites, SOFIA

Water is found in almost any corner of the universe → Astrobiology

Microwave/IR Imaging Campaigns (Satellites)

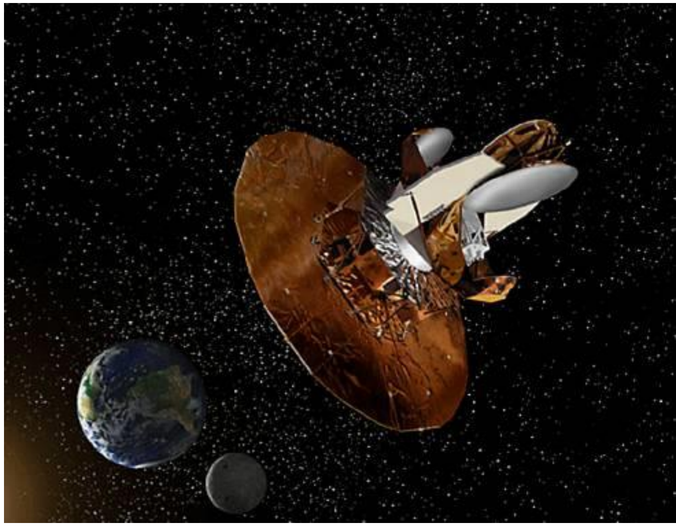
History

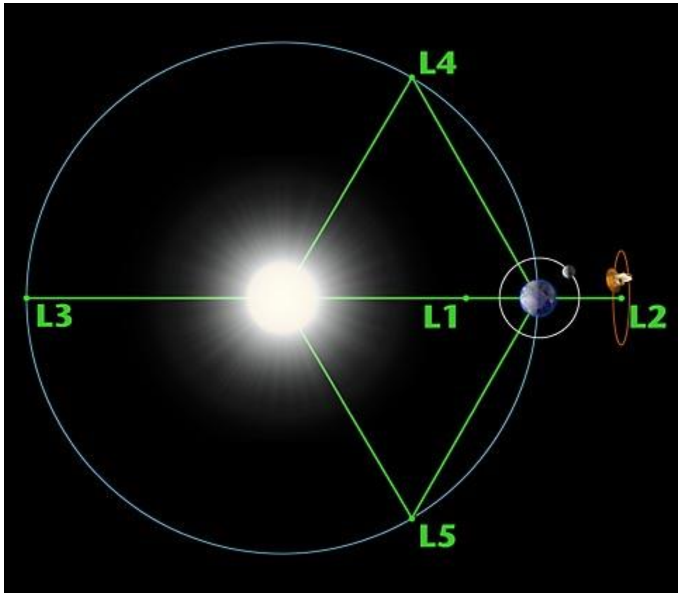
COBE
(= Cosmic Background Explorer)
NASA, 1989 - 1993

WMAP
(= Wilkinson Microwave Anisotropy Probe)
NASA, 2001 - 2010
Position: Lagrange Point L2

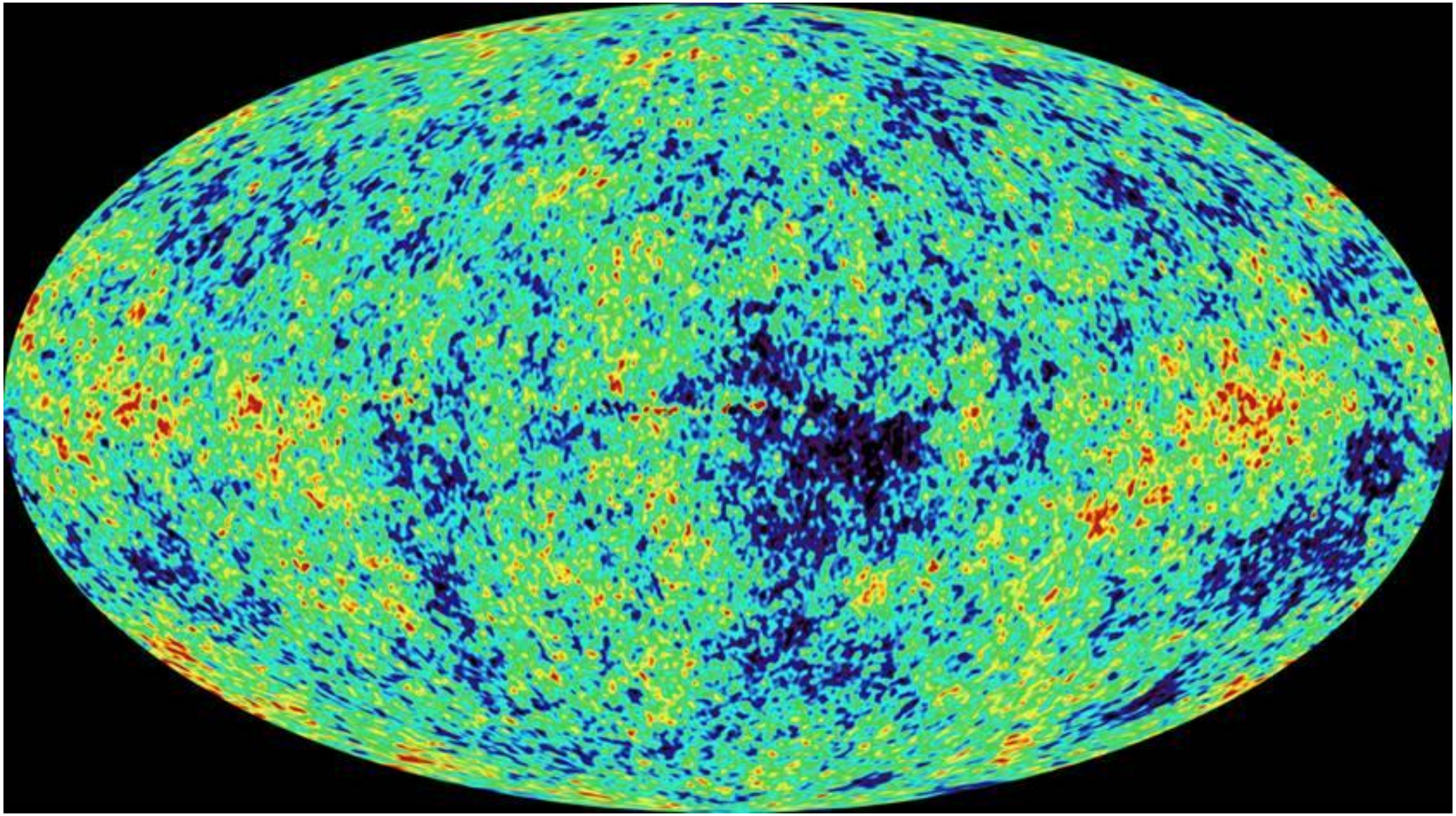
PLANCK
ESA, 2009 - 2011/2012

JWST (= James Webb Space Telescope)
NASA, 2021 – 2031
Position: Lagrange Point L2





Microwave Image of the Big Bang



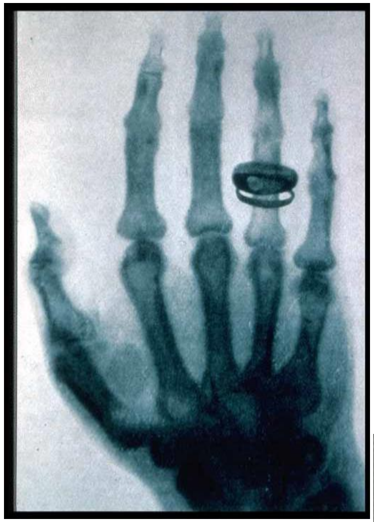
Cosmic Microwave Background (CMB) ~ 2.726 K

Fluctuations smaller than 1/100000!

CMB stems from 380,000 years after the big bang (universe became transparent)

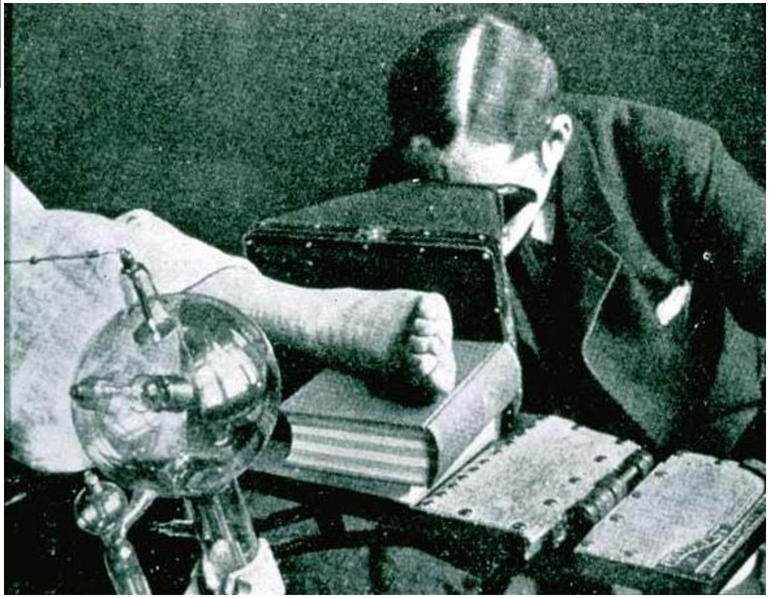
X-Ray Astronomy

Inspired by the discovery of x-rays (detection by scintillators)

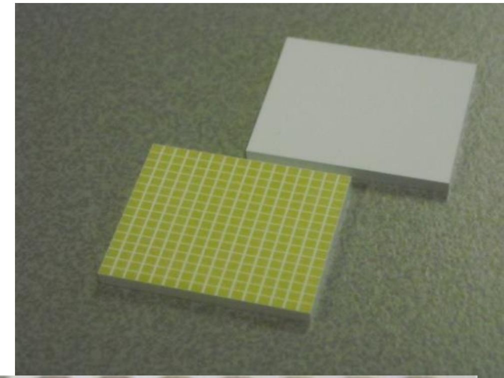


Wilhelm Conrad Röntgen, December 1895. The X-ray of Mrs. Röntgen's hand that began the world-wide "x-ray craze"

Dr. Rome Wagner and his assistant at demonstration of X-ray medical imaging

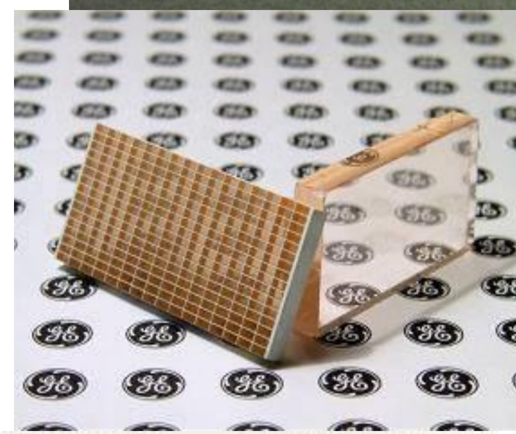


X-Ray Astronomy



Types of scintillators

- **Single crystals, e.g. Lu_2SiO_5:Ce**
- **Ceramics, e .g. $(Y,Gd)_2O_3$:Eu, Gd_2O_2S:Pr**

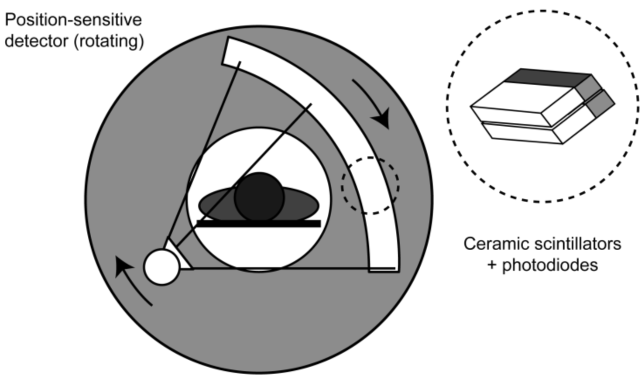


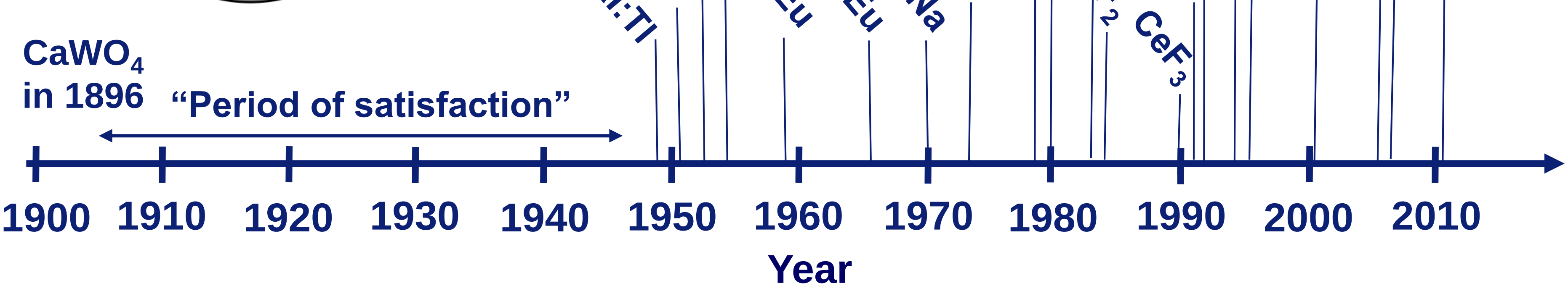
X-Ray Astronomy

Working principle and history of scintillators

1. Absorption of x-rays (or γ-rays or high energy particles)
2. Emission of visible light (x-ray luminescence)

Application areas: x-ray films, CT, PET, SPECT, …..



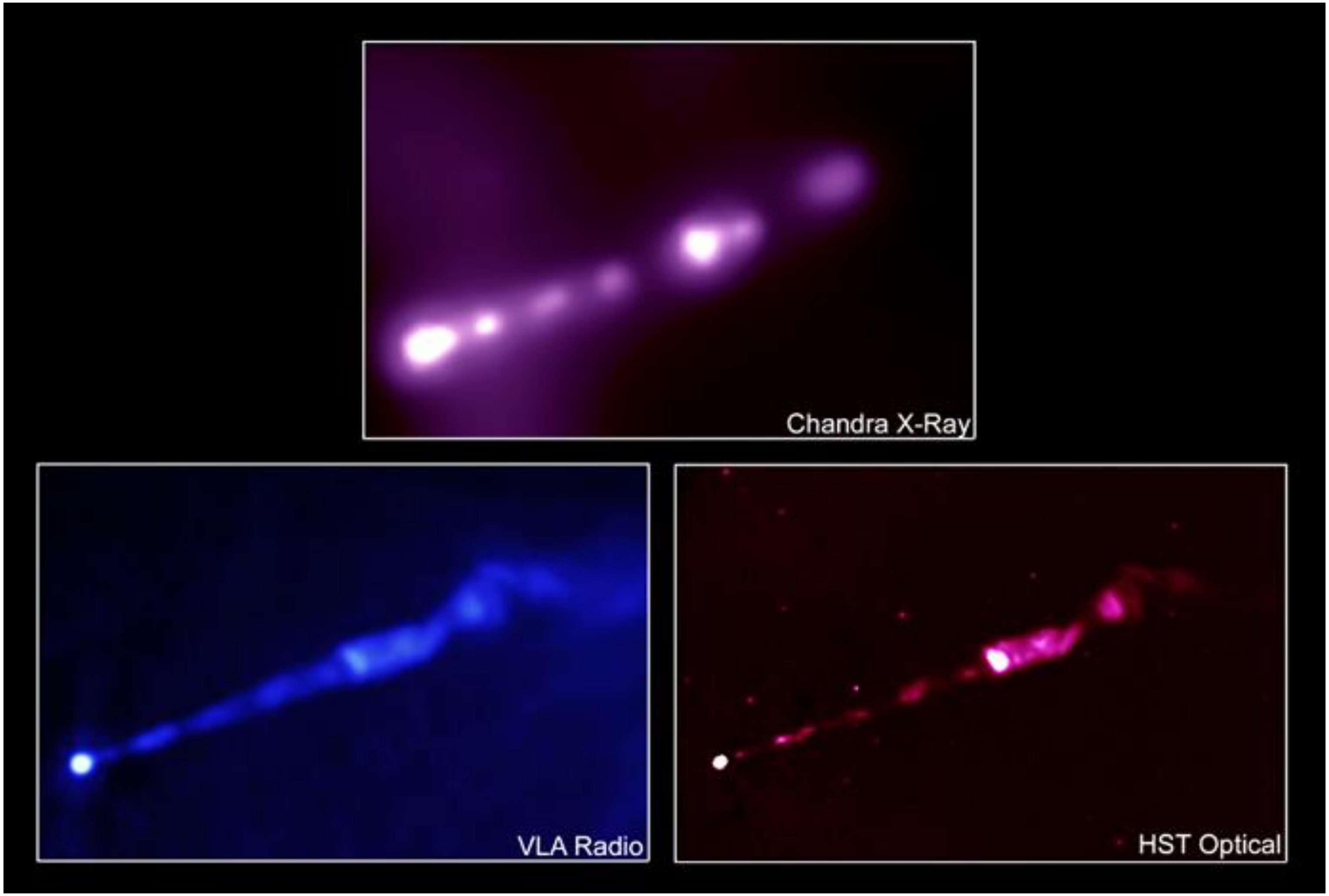


X-Ray Astronomy

High-Energy Satellites

X-Ray Astronomy

M87 galaxy's jet in the X-ray, radio and optical range



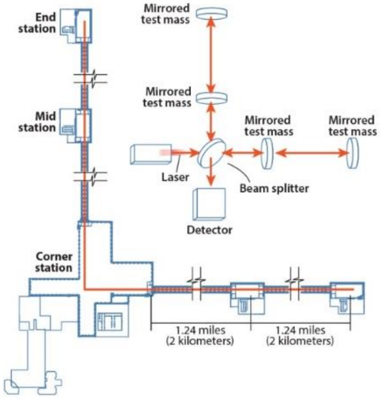
Gravitational Waves Astronomy

Detectors: LIGO and (Advanced) VIRGO

1916 Prediction of Gravitational Waves
by Albert Einstein (1879 - 1955)

2015 Sept 14th GW150914
Oct 12th LVT151012
Dec 26th GW151226

2017 Nobel Price for Physics awarded to
Rainer Weiss, Kip Thorne, and Barry Barish



2017 Jan 4th GW170104 Black hole merger
Jun 8th GW170608
Aug 14th GW170814
Aug 17th GW170817 First neutron star merger

>2030 Laser Interferometer Space Antenna (LISA): Three spacecraft, in a triangular stable orbit

First Image of a Black Hole

2019: Publication of image of 6.5 Billion Sun Mass Black Hole in M87

- Event Horizon Telescope (EHT) = Global network of radio telescopes for Very-Long-Baseline-Interferometry (VLBI)
  - ALMA Atacama Large Millimeter submillimeter Array
  - APEX Atacama Pathfinder EXperiment
  - 30-M IRAM 30-M Telescope
  - JCMT James Clark Maxwell Telescope
  - LMT Large Millimeter Telescope
  - SMA SubMillimeter Telescope
  - SPT South Pole Telescope
  - GLT GreenLand Telescope

- Image size: $42 \cdot 10^{-6}$ arc seconds (distance to M87 ~ 55 Mill. ly)
- 3300 Tbyte data on 1000 hard disc drives

Astronomy and Astrophysics in History of Science

Practical applications

- Time keeping (pulsar time), calendar, navigation (sextant, GPS), CCD

Contribution to other sciences

- Interaction with other basic sciences, e.g. elementary particle physics
- Origin of many branches of modern physics
  - Newton mechanics
  - Photonics: Speed of light (Ole Rømer), refraction, etc.
  - Atom physics (spectroscopy) and theory of relativity
  - Plasma physics

Contribution to our cultural development

- Satisfaction of curiosity
- Aesthetics of the night sky
- SETI and life on other (exo)planets (→ Exobiology)
- Origin of the cosmos and life (→ Religion)
- Model of the Universe and our role in Universe (→ Philosophy)

Astronomy and Astrophysics in History of Science

Development of the model of the universe (world)

Age	Universe (world) diameter
10,000 years BC	The valley you lived in
1,000 years BC	Your kingdom
300 years BC	The Mediterranean empires (Egyptians, Greeks, Romains)
100 years AD	The Earth + Celestial Sphere
400 years ago	The Solar System
100 years	The Milky Way
75 years ago	The "Modern" Universe (Radius: 2 Billion light years)
Today	An infinite universe (Radius of visible part: ~15 Billion light years)

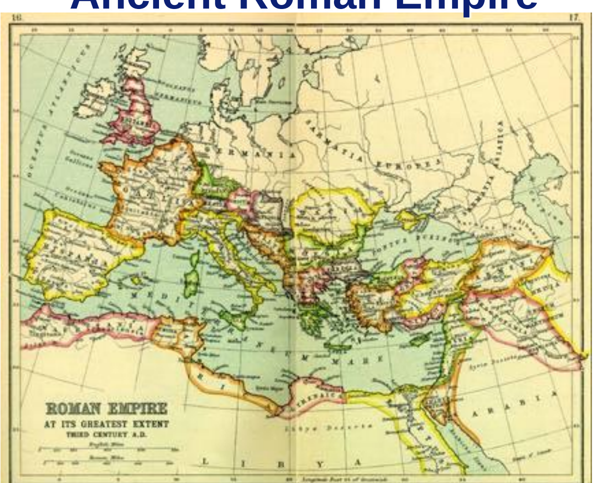
Astronomy and Astrophysics in History of Science

Transfer of astronomical knowledge

Ancient Babylon

Ancient Egypt

Ancient Roman Empire



Ancient Greece

Astronomy and Astrophysics in History of Science

Contribution to the technology development

- Mechanics
- Optics & Spectroscopy
- Photography
- Semiconductors
- X-Ray Detectors

Remaining questions

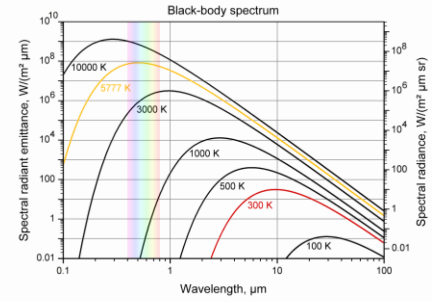
- Nature of dark matter and energy
- Is there anybody out there?
- Origin and the fate of the universe

21st century

Astronomy
- Search for extrasolar planets
- Astrochemistry and exobiology
- Dark matter and dark energy

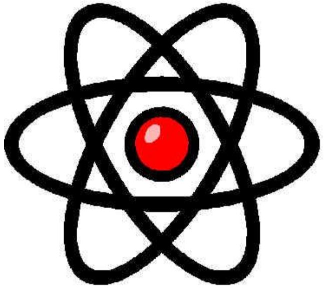
Physics
- High energy particle interactions
- Great unified theory (GUT)
- String theory & quantum gravitation

How Quantisation Developed



Some Historical Milestones

1900	Planck	Introduction of a new constant h (Planck constant) Explanation of the spectrum of thermal radiation	
1905	Einstein	Introduction of the light quantum (photon) Explanation of the photoeffect	$E_\gamma = h\,\nu$
1907	Einstein	Vibration quanta (phonon) Explanation of the specific heat of solids	$E_{vib} = h\,\omega$
1913	Bohr	Introduction of angular momentum quantum Explanation of the Hydrogen spectrum	$\hbar = h / (2\pi)$
1924	de Broglie	Postulation of Wave-Particle-Dualism Prediction of materia waves	$p = \hbar\,k$
1925	Schrödinger	Wave quantum mechanics	
	Heisenberg	Matrix quantum mechanics	
	Pauli	Pauli‘s exclusion principle (fermions)	



Physics of the Electron

19th Century: Physics was governed by the development of electromagnetism and its application areas (the electronic age)
⇒ Maxwell, Ampere, Ohm, Tesla, Volta, Watt, Edison, ….

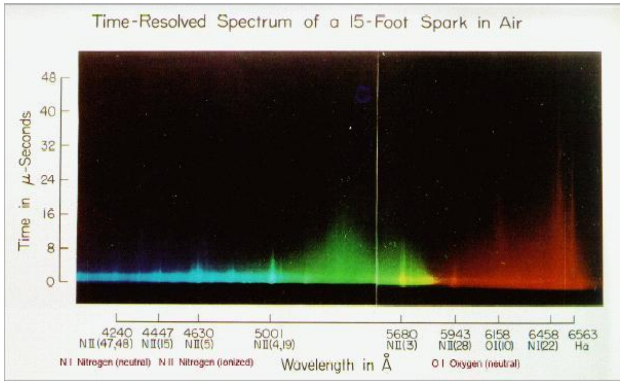
Remaining issues

- **How can all electrons in one atom stay together with their repulsive interaction?**
- **Only apparent solution was for electrons to move in some “non-uniform”, i.e. not straight line way**
- **Non-uniform motion of charge (by “classical physics”) produces radiation (light or heat), so eventually the atom will “run out of energy” and be unstable**

Atomic Structure before Bohr

Discoveries since 1800

- Regularities of element properties → periodic table
- Spectra revealed "something was moving inside the atom"
- Atoms could break up by "ionization" upon emission of electrons:



$A \rightarrow A^+ + e^-$

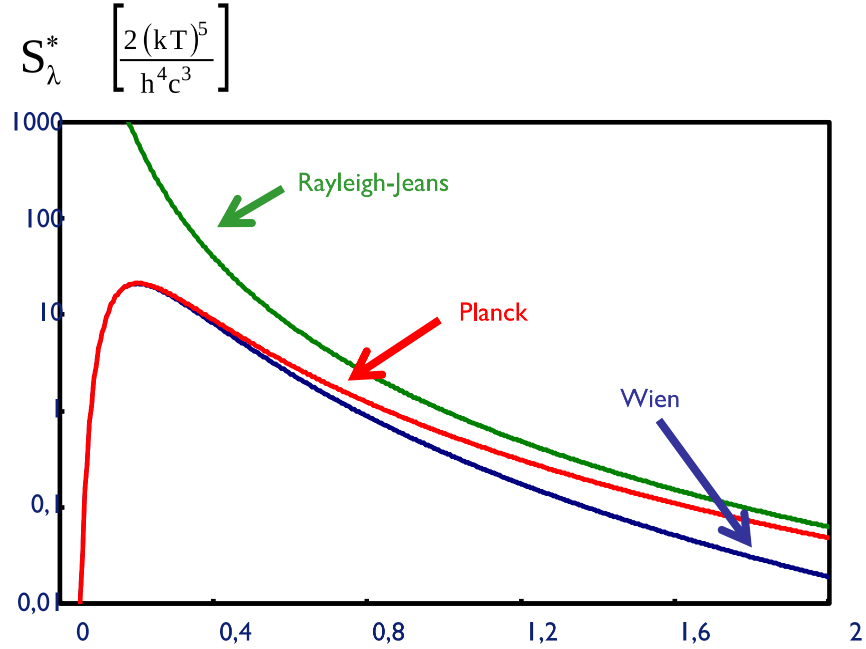
$A^+ + e^- \rightarrow A^* \rightarrow A + h\nu$ (gas discharge → lighting)

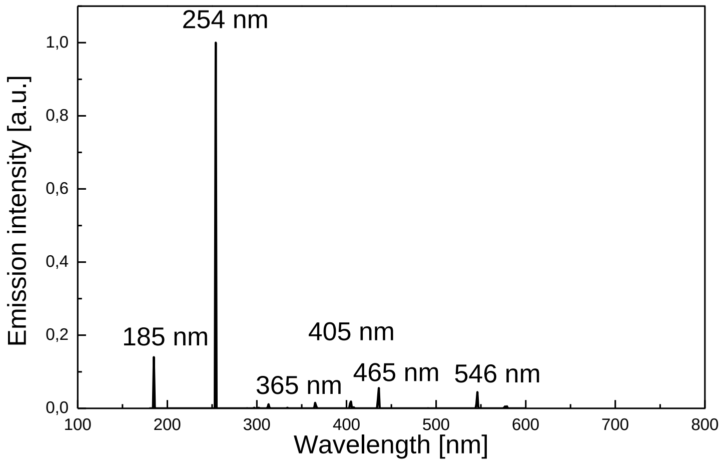
- Some atoms could break up by radioactive disintegration
- Element conversion (nuclear fusion and fission)

Atomic Structure before Bohr

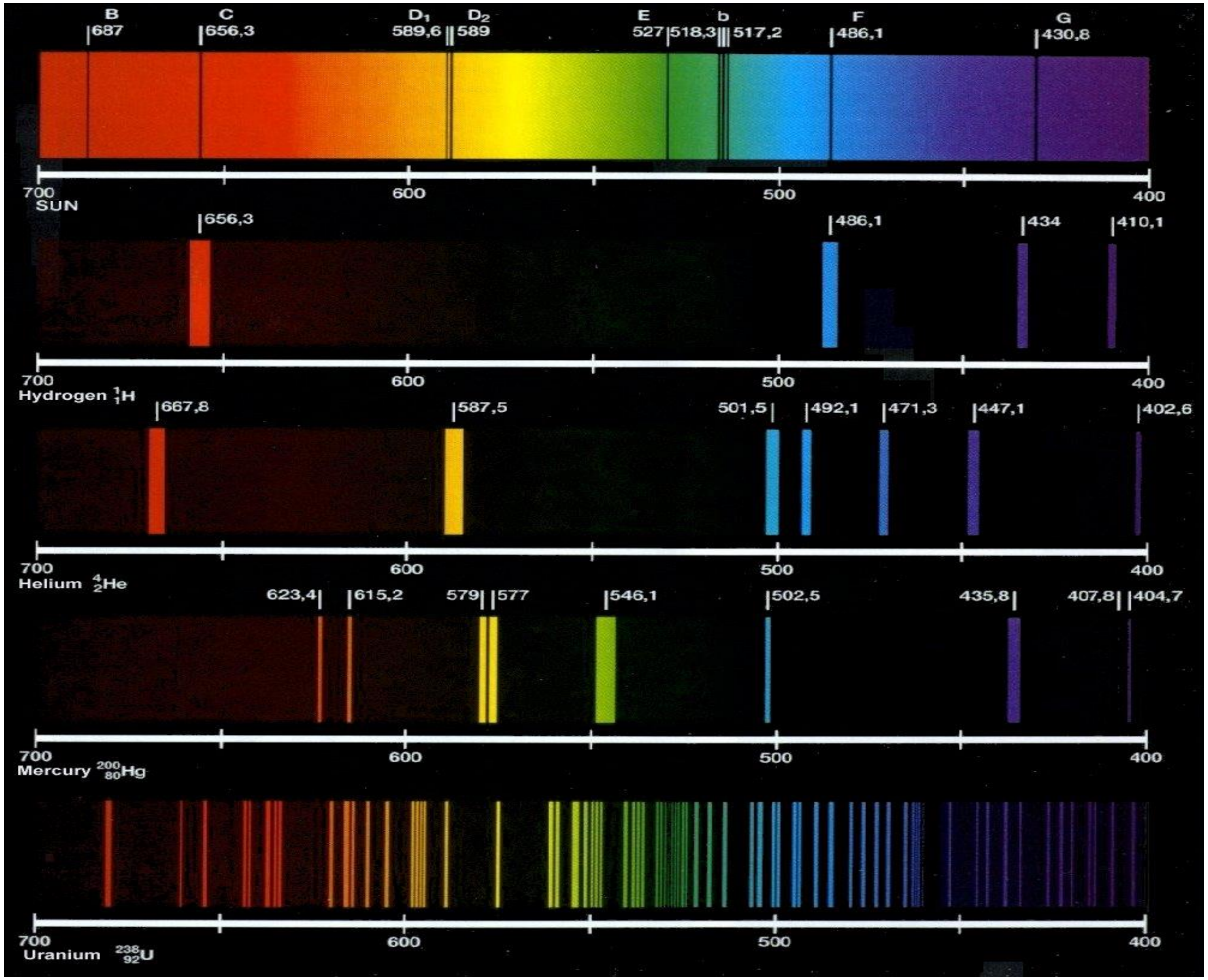
Discoveries since 1800

- **Black Body Radiation (Rayleigh-Jeans, Wien, Planck)**
- **Specific heat of solids at low temperature**
- **Line spectra of atoms and some molecules**
- **Luminescence processes**





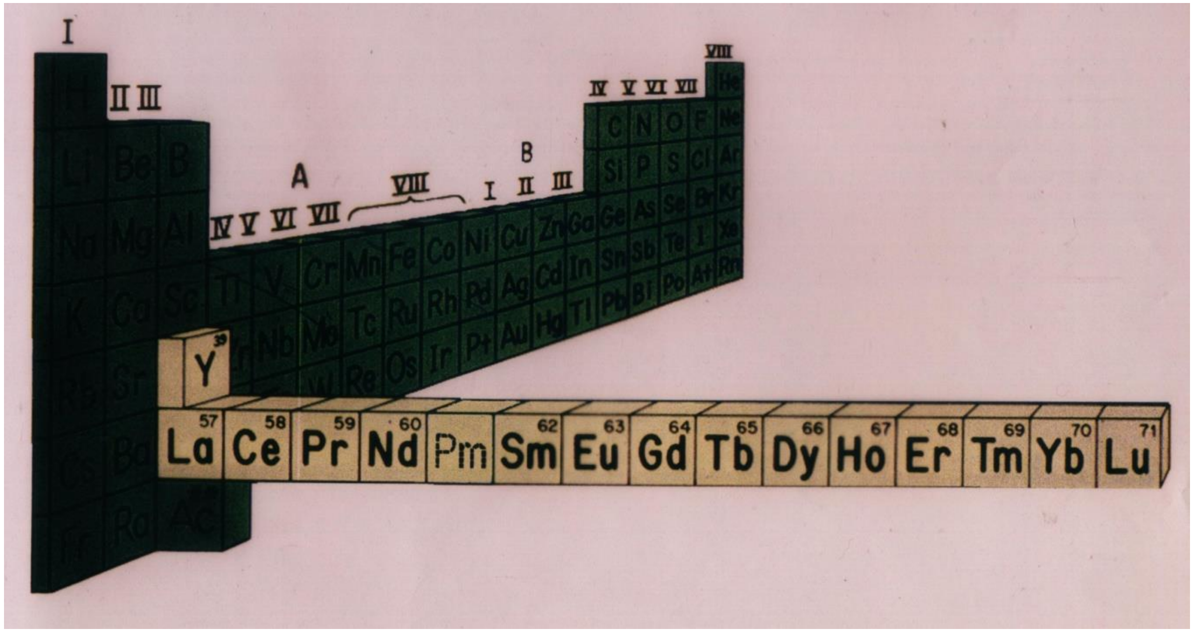
Absorption and Emission Spectra

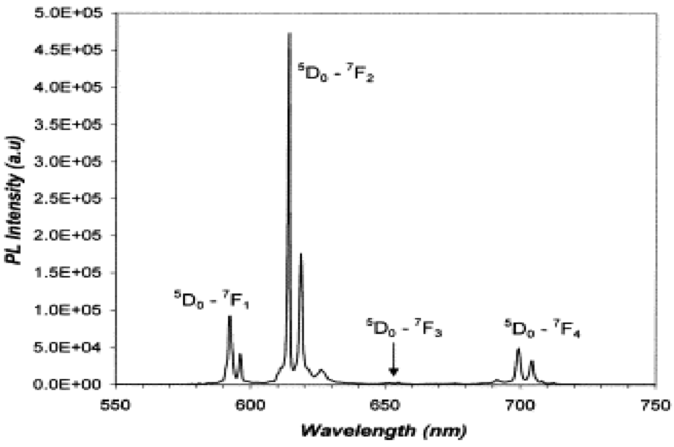


Rare Earth Ions - Quasi Atomic Energy Levels

Lanthanides ("to lie hidden" λανθανειν)

1908	**Bequerel**	**Sharp lines in optical spectra of Ln ions**
1937	**Van Vleck**	**The puzzle of rare earth**
1960's	**Judd, Wybourne, Dieke, Carnall**	**Theory for energy level structure and probabilities of 4f-4f transitions**





Rare Earth Ions - Quasi Atomic Energy Levels

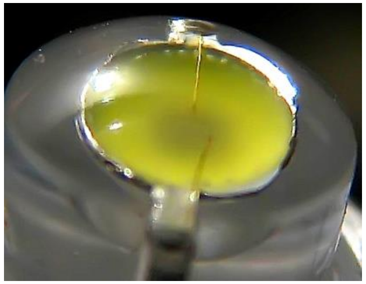
Lanthanides
(a better name would be "to be oustanding" επιφανης - epifanides)

Their technical use began in the 1960ties due to

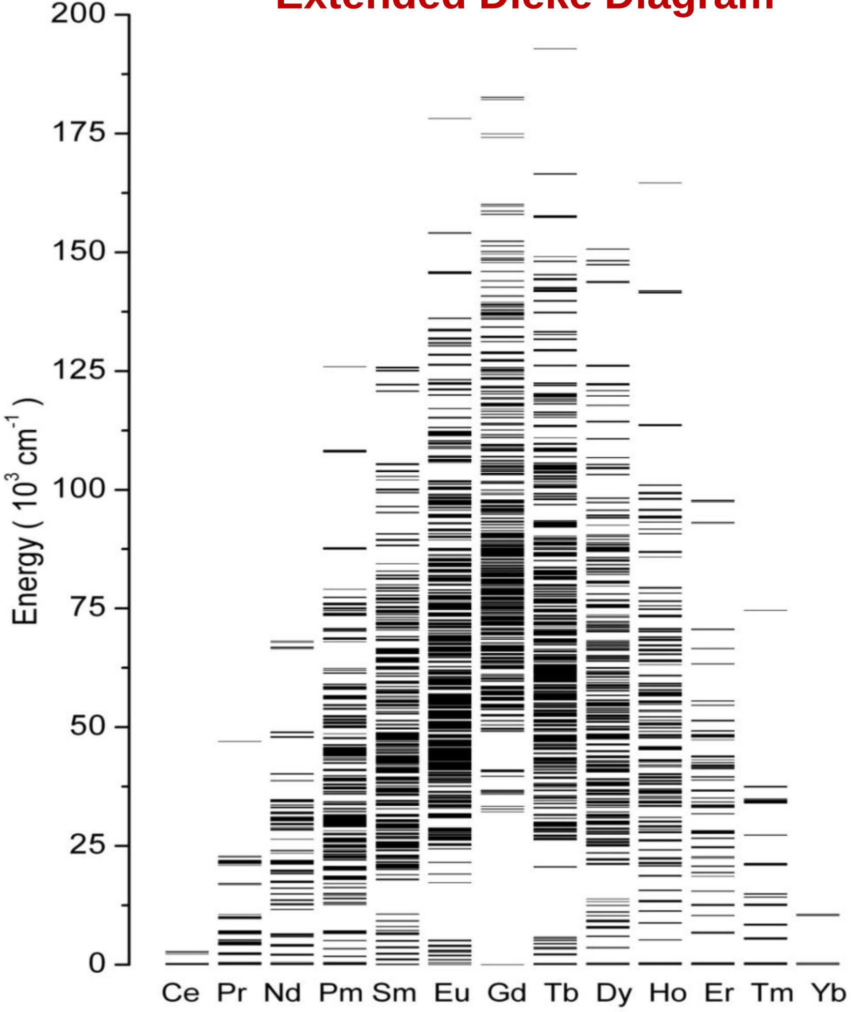
Unique optical spectra (Dieke diagram)

Unique magnetic properties

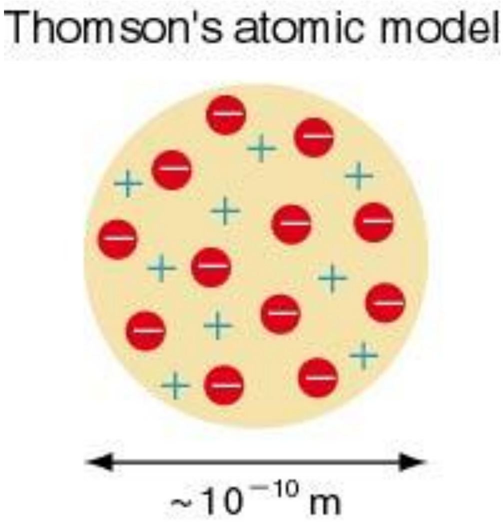
Development of
- **Discharge lamps**
- **Colour TVs**
- **LEDs**
- **Scintillators**
- **Magnets**
- **.....**



Extended Dieke Diagram



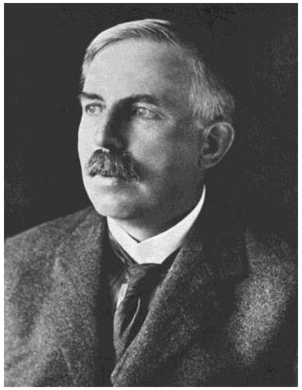
Models of Atoms



Joseph John Thomson (1856 - 1940)

- **Cambridge, England**
- **“Plum pudding model”**
- **Accounts for charge neutrality**
- **Does not account for radiation loss problem**

Rutherford's Scattering Experiment (actually done by Marsden and Geiger)



Ernest Rutherford (1871 - 1937)

Manchester and Cambridge England

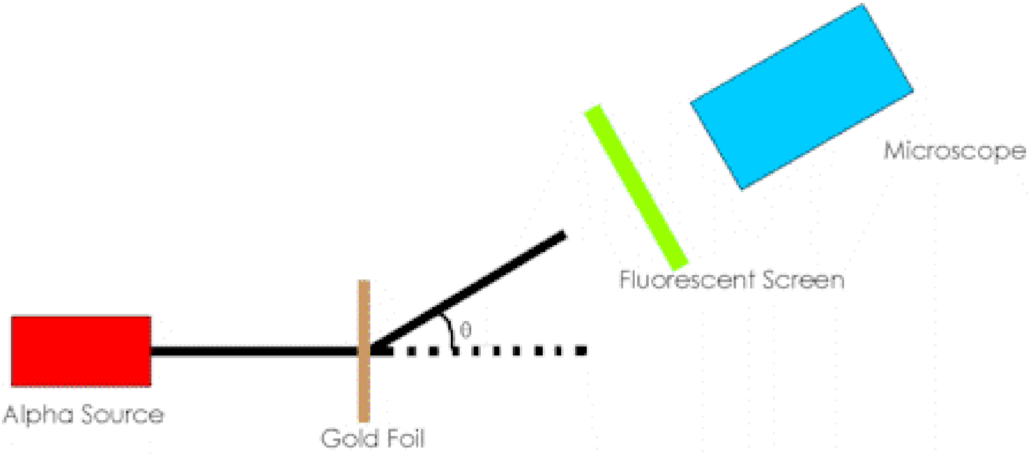


Fig. (D) Scattering of α rays by an atom

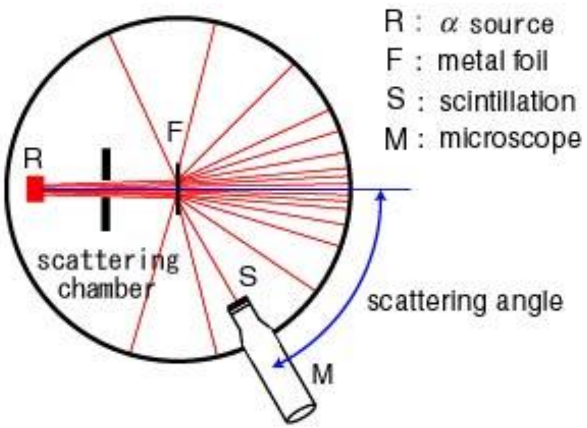
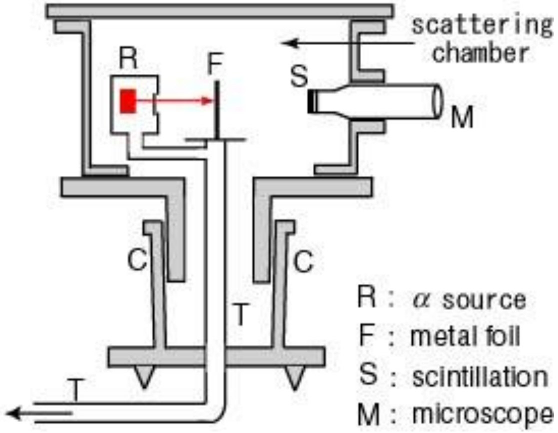
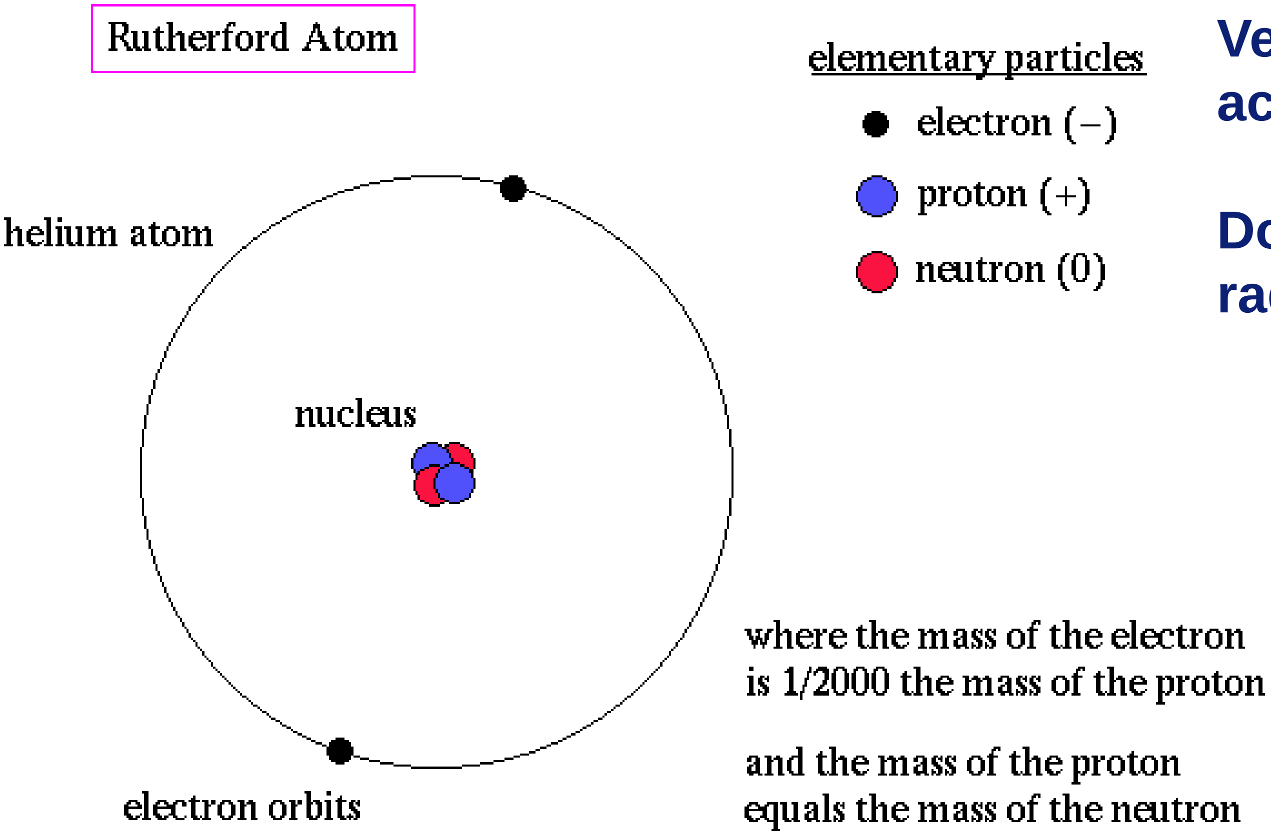


Fig. (E) Setting of the experiment



Rutherford's Atom



Very heavy nucleus accounts for scattering

Does not account for radiation loss problem

Bohr's Atom

Niels Bohr (1885 - 1962)

- Copenhagen, Manchester, and Cambridge
- Post-doctoral fellow with J.J. Thomson and then with Ernest Rutherford
- Son of famous physiologist
- Studied philosophy with Harald Høffding
- Attacked the problem of the frequency and speed of orbital motion of Rutherford's electrons

Bohr's Atom

Niels Bohr

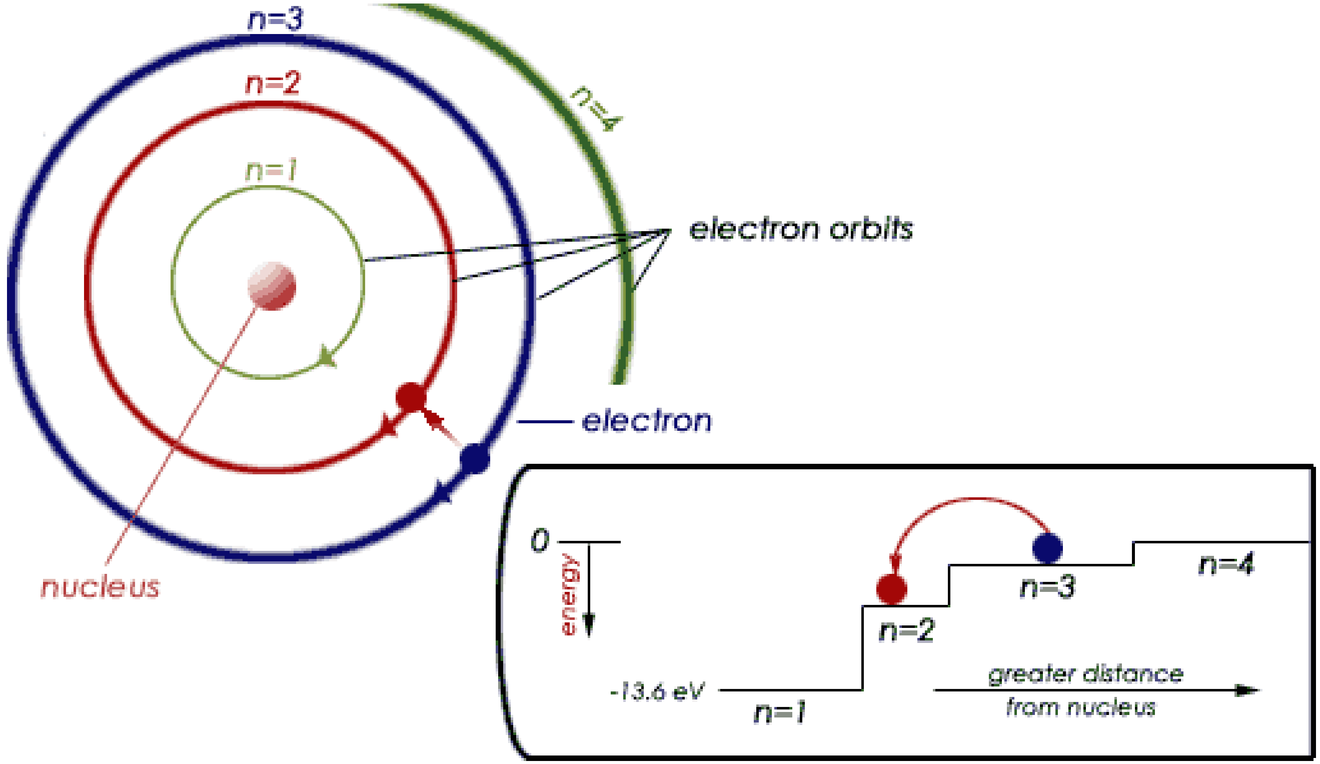
"We shall introduce a hypothesis, from which we can determine the quantities in question. This hypothesis is: that there for any stable ring (any ring occurring in the natural atoms) will be a definite ratio between the kinetic energy of the electron and the time of rotation.
This hypothesis, for which there will be given no attempt at a mechanical foundation (as it seems hopeless), is chose as the only one which seems to offer a possibility of an explanation of the whole group of experimental results which gather about and seems to confirm conceptions of the mechanisms of the radiation as the ones proposed by Planck and Einstein"

→ Dispair!

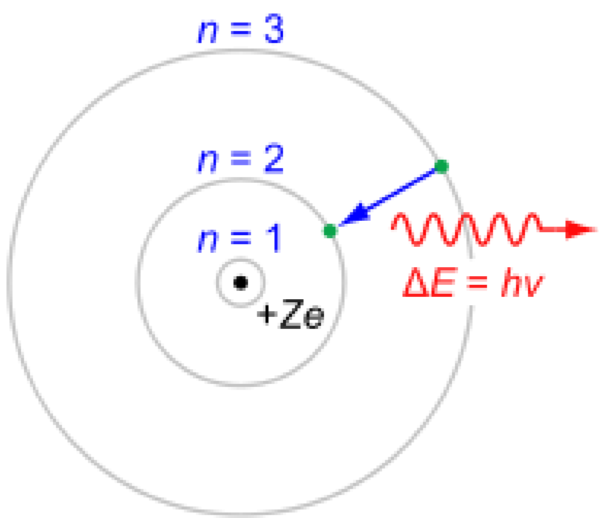
Bohr's Atom

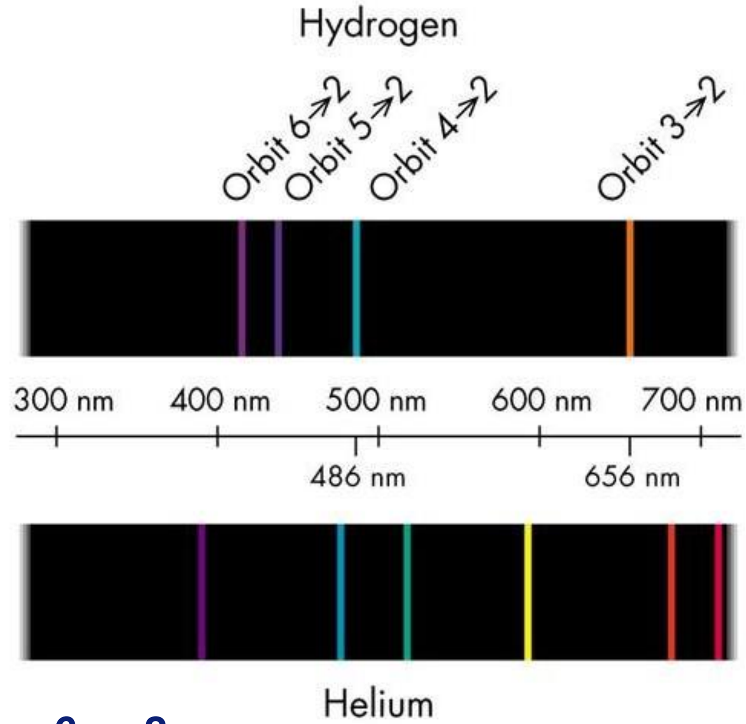
Niels Bohr 1913

Model of the Hydrogen atom to explain stability of electron orbiting the nucleus (without emitting radiation)



Balmer Spectrum for Hydrogen (Johan Balmer 1885)





Transition of n	**3 → 2**	**4 → 2**	**5 → 2**	**6 → 2**
Name	**H-α**	**H-β**	**H-γ**	**H-δ**
Wavelength (nm)	**656.3**	**486.1**	**434.1**	**410.2**
Color	**Red**	**Blue-green**	**Violet**	**Violet**

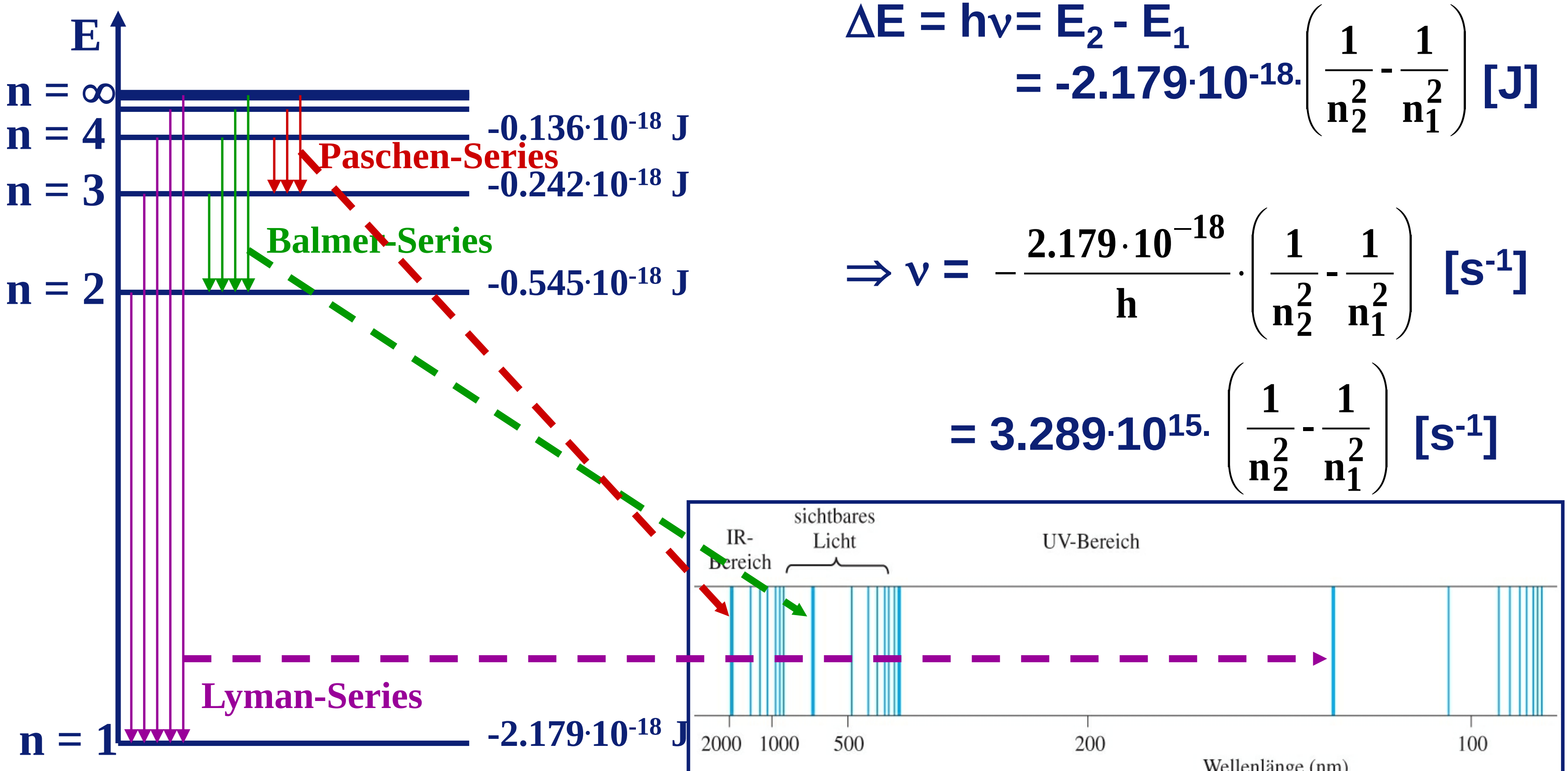
→ Balmer-Series

Bohr’s Atom and Spectroscopy

$$\Delta E = h\nu = E_2 - E_1 = -2.179\cdot 10^{-18}\cdot\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)\ [J]$$

$$\Rightarrow \nu = -\frac{2.179\cdot 10^{-18}}{h}\cdot\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)\ [s^{-1}]$$

$$= 3.289\cdot 10^{15}\cdot\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)\ [s^{-1}]$$



Aus "Allgemeine und Anorganische Chemie" (Binnewies, Jäckel, Willner, Rayner-Canham), erschienen bei Spektrum Akademischer Verlag, Heidelberg; © 2004 Elsevier GmbH München. Abbildung02-12.jpg

Bohr Model work for all atoms with one electron: H, He^+, Li^{2+}, Be^{3+}, ...

Models of Atoms

"Models" in Science

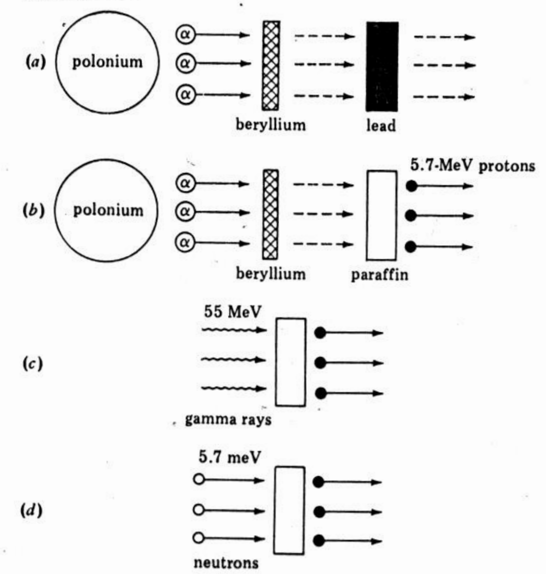
- Visual, mathematical, topological
- Often anthropomorphic
- Macroscopic vs. microscopic
- Model has some, but not all, homologies to nature
- Model can suggest further experiments (heuristic quality)
- A model is not the reality, just a simplification of the real world

Models of Atoms

Summary of major observations towards the modern atom model

- Quantum character of matter (discrete energy levels)
- Particles (atoms and electrons) can behave as wave or particle depending on the type of experiment (Wave-Particle Dualism)
- Atoms are made of electrons and a positively charged nucleus
- Neutron discovered by Chadwick (1932)
- Heisenberg formalizes neutron and proton model of nucleus

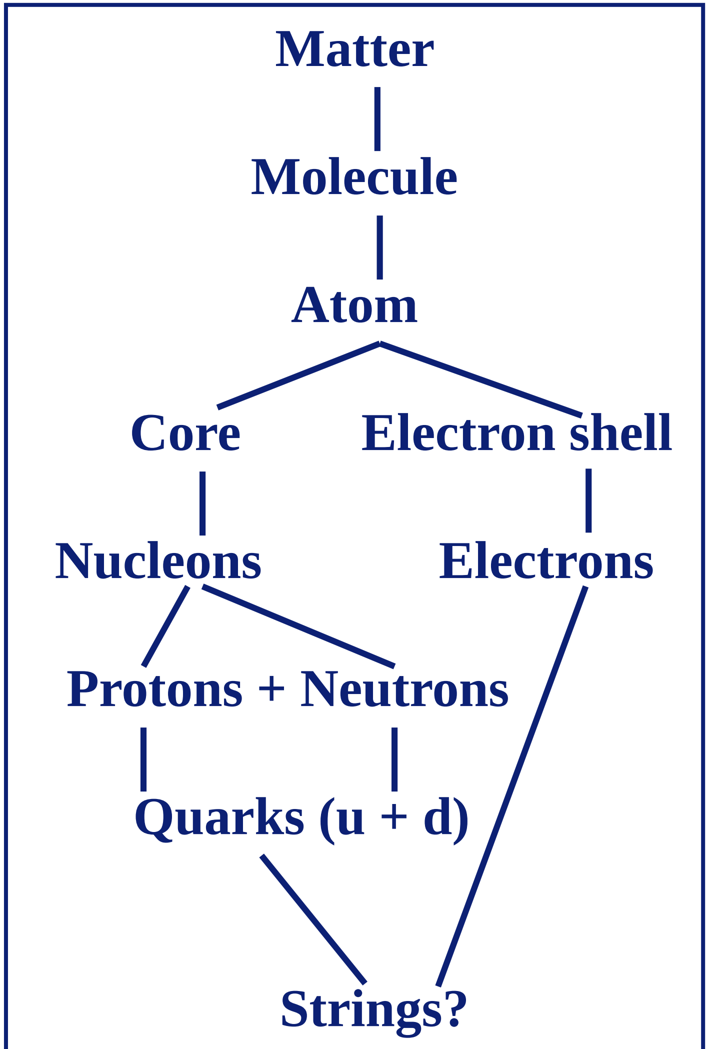
FIGURE 11.1 (a) Alpha particles incident on a beryllium foil cause the emission of a very penetrating radiation. (b) Protons of up to 5.7 MeV are ejected when the radiation strikes a paraffin slab. (c) If the radiation consists of gamma rays, their energies must be at least 55 MeV. (d) If the radiation consists of neutral particles of approximately proton mass, their energies need not exceed 5.7 MeV.

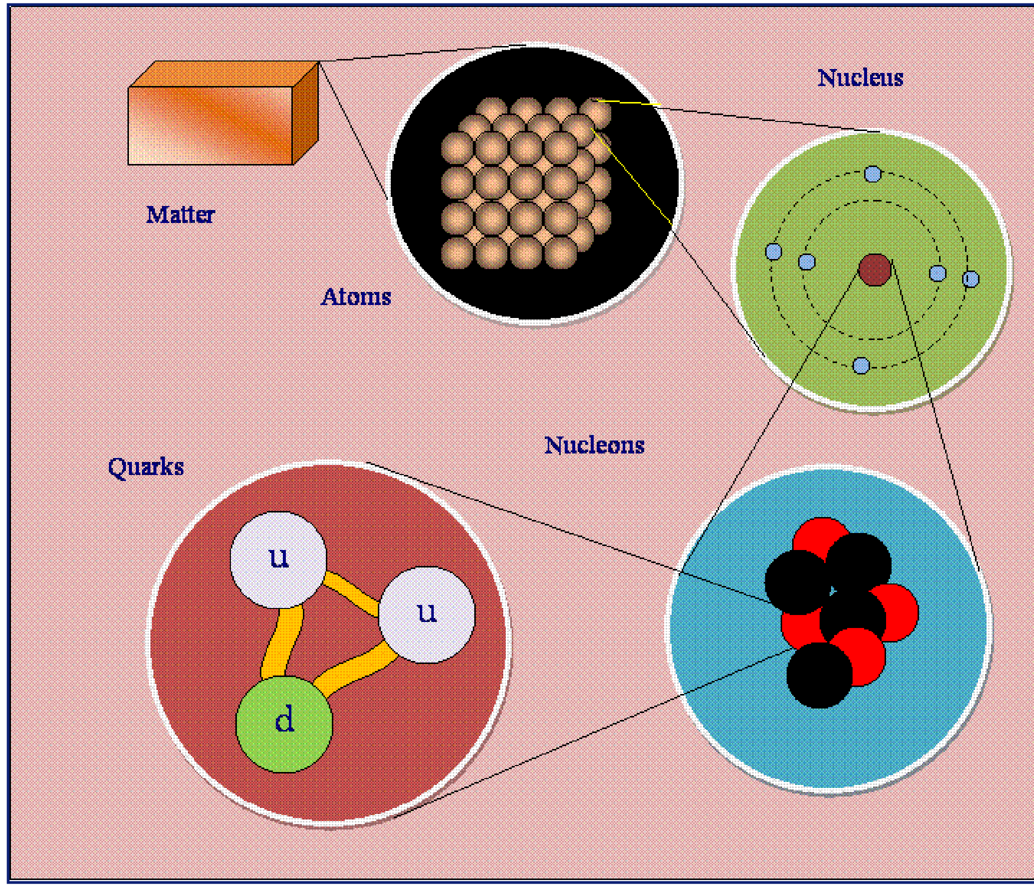


Atom → Electrons + nucleus

Nucleus → Protons and neutrons

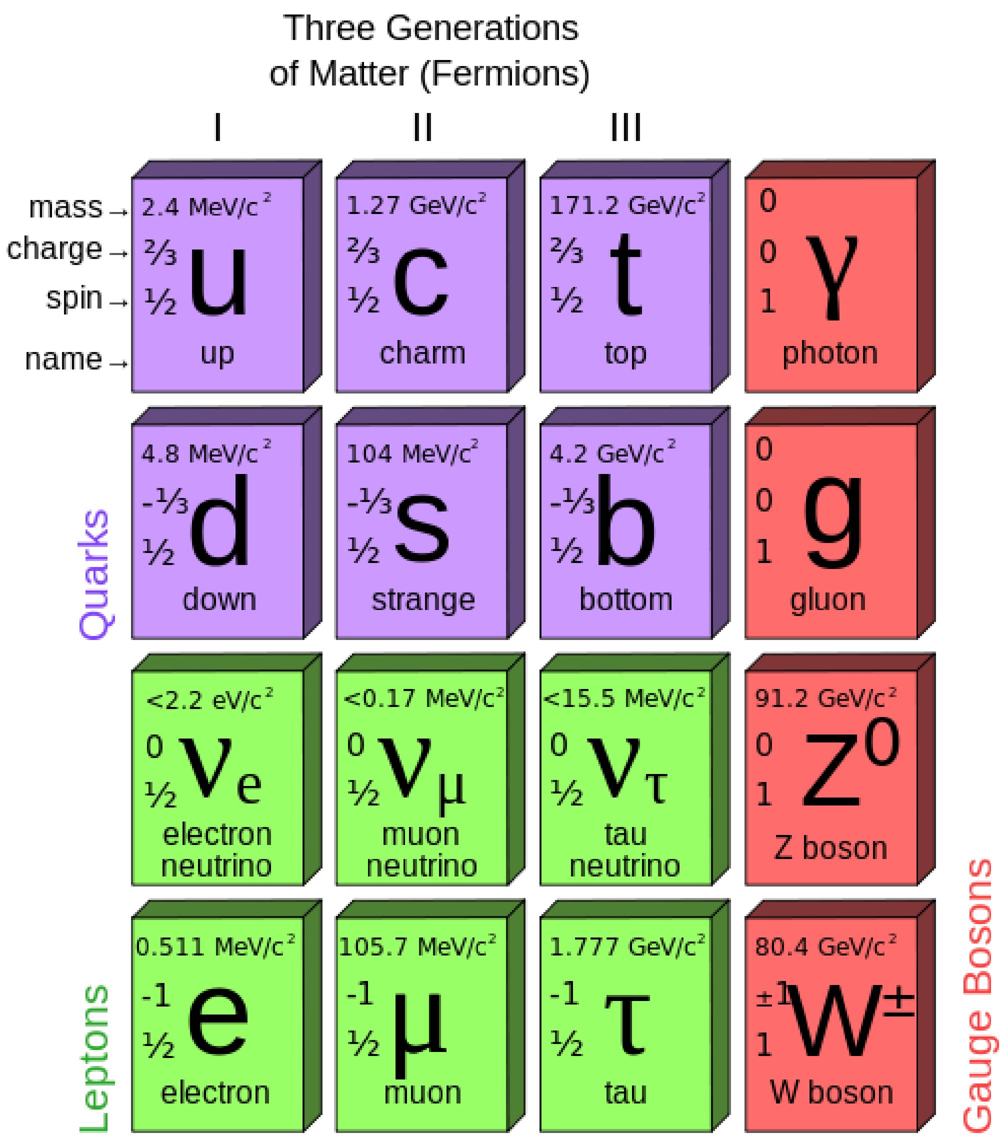
The Standard Model of Matter





- All quarks are trapped in nucleons
- Up-Quark (u) Q = +2/3
- Down-Quark (d) Q = -1/3

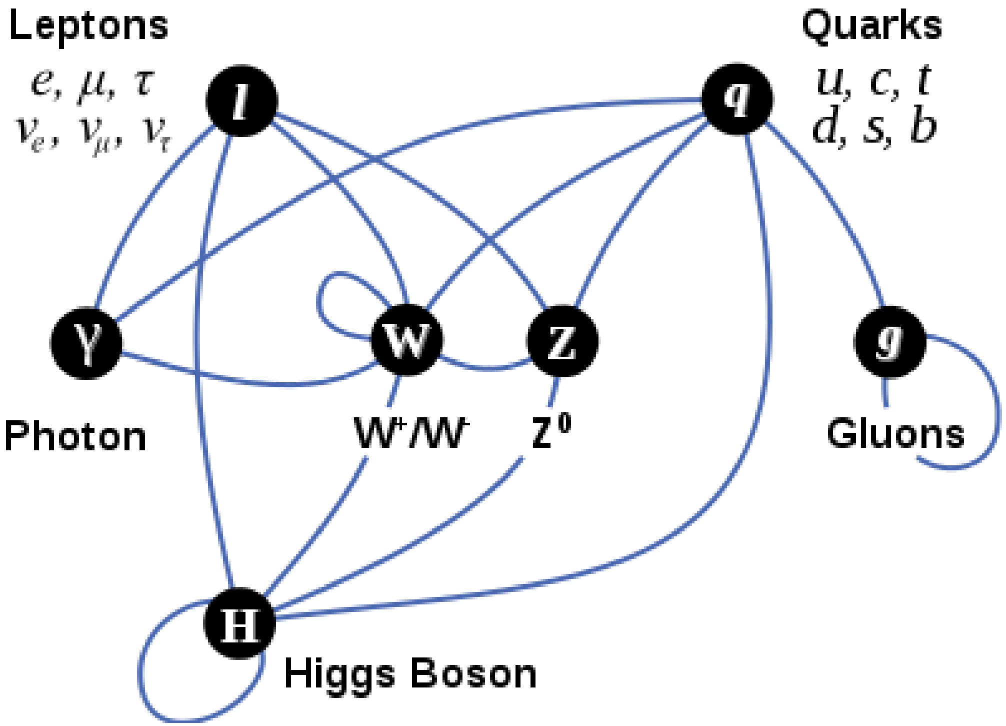
The Standard Model of Matter



The Standard Model of Matter, with the gauge bosons in the rightmost column

Source: http://en.wikipedia.org

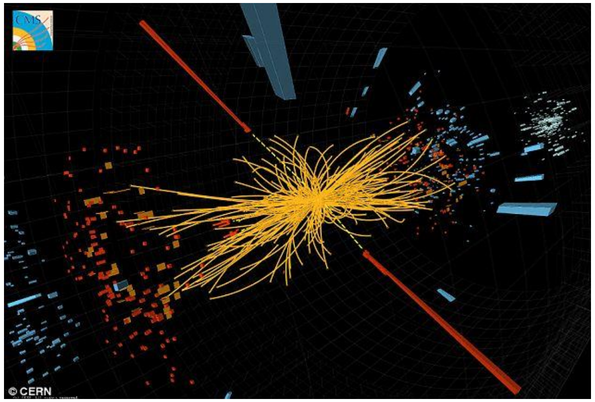
The Standard Model of Matter



Summary of interactions between particles described by the Standard Model.

Source: http://en.wikipedia.org

The missing link, the H-Boson was discovered in 2012 (Nobel Prize Physics 2013)



A typical 'candidate event' for the Higgs boson, including two high-energy photons whose energy (depicted by red towers) is measured by CMS. The yellow lines are the measured tracks of other particles produced in the collision (Source: CERN)

The Road to Nuclear Fission and Fusion

Nuclear Fission - Some Historical Milestones

1780	M.H. Klaproth	Discovery of uranium
1896	A. Becquerel	Discovery of radioactivity
1919	E. Rutherford	Disintegration of nitrogen by α-particle bombardment
1931	Cockcroft/Walton	First artificial splitting of a nucleus
1934	E. Fermi	Neutrons can split atoms
1939	Hahn/Strassman	Split of the uranium atom (Germany) Start of the Manhattan project (US)
1942	Lawrence/Fermi	Uranium enrichment, first controlled fission

The Road to Nuclear Fission and Fusion

Historical Year 1931

- **First artificial splitting of a nucleus**
- **First transmutation using artificially accelerated particles (protons)**
- **First experimental verification of *E = mc²***

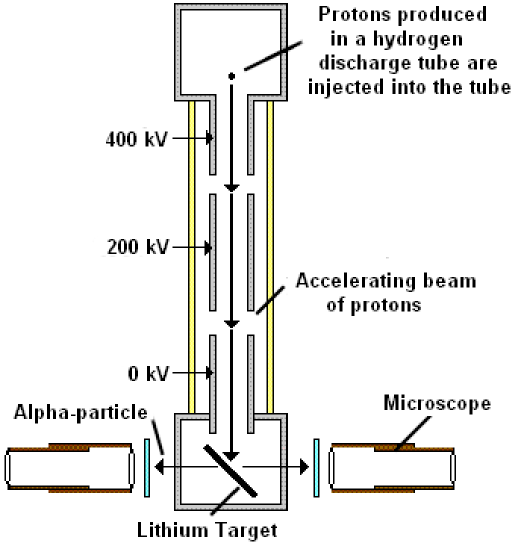
John Cockcroft **Ernest Walton**

Nobel Prize 1951

$$^{1}_{1}\mathrm{H} + ^{7}_{3}\mathrm{Li} \rightarrow ^{4}_{2}\mathrm{He} + ^{4}_{2}\mathrm{He} + \mathrm{Energy}$$

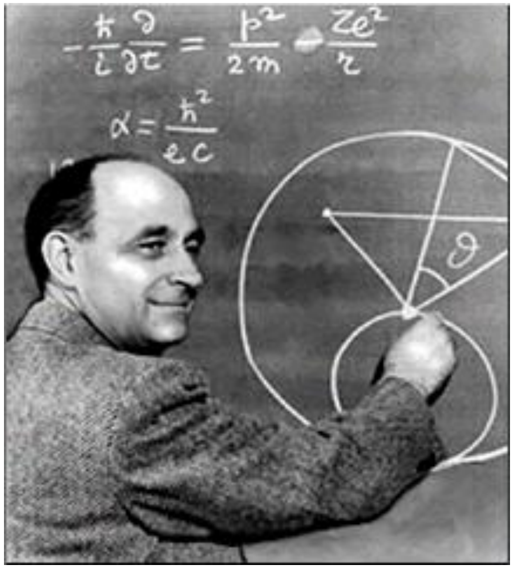
1 MeV **17.3 MeV**

Proton + Lithium → 2 alpha particles + Energy



The Road to Nuclear Fission and Fusion

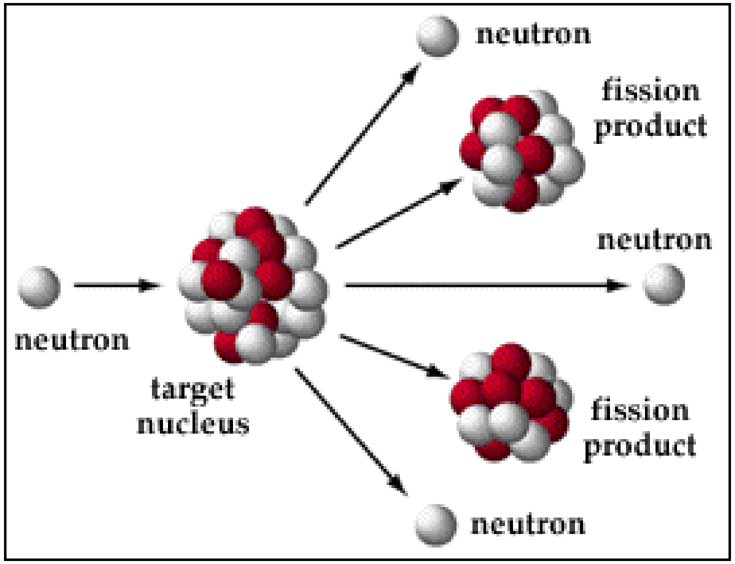
Enrico Fermi (1901 - 1954)



- Firing free neutrons at elements caused them to become radioactive and to emit β-particles

- He discovered that the fission reaction might release free neutrons which could cause further fission reactions

- A chain reaction could occur releasing a great deal of energy in a short time, a nuclear explosion.



The Road to Nuclear Fission and Fusion

Crisis Year 1939 (September 1st: Beginning of World War II)

- Discovery of induced nuclear fission by three groups:
  - Otto Hahn, Lise Meitner, and Fritz Strassman in Berlin
  - Frederic Joliot and Irene Curie in Paris
  - Enrico Fermi in Rome

- Hahn (chemist), Meitner (physicist), and Strassman (analytical chemist) used H_2S to precipitate the radioactive products from Uranium cleavage. The half-life measurements indicated to them that not one but many elements were produced.

- All three groups thought the reactions to be (in short notation):

$$^{238}U\ (n, \gamma)\ ^{239}U^{92}\ (, \beta)\ ^{239}E^{93}\ (, \beta)\ ^{239}E^{94}$$

The Road to Nuclear Fission and Fusion

Discovery of induced nuclear fission

The Official History of the Manhattan Project:

Dr. Lise Meitner brought the discovery of neutron induced fission to Copenhagen as she, a non-Aryan, exiled from Germany in 1938.

She told F. Strassman, who told N. Bohr and Bohr told E. Fermi

Fermi also found out that only ^{235}U underwent fission, for example:

$$^{235}U + n \rightarrow \; ^{142}Cs + \, ^{90}Rb + 4\, n$$

Neutrons are released and can undergo further nuclear reactions

The Road to Nuclear Fission and Fusion

Uniting Political and Nuclear Power (1939)

F.D. Roosevelt

Sir:
Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:
. . . . . (middle part omitted) . . . .
I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institute in Berlin where some of the American work on uranium is now being repeated.
Yours very truly,

The Road to Nuclear Fission and Fusion

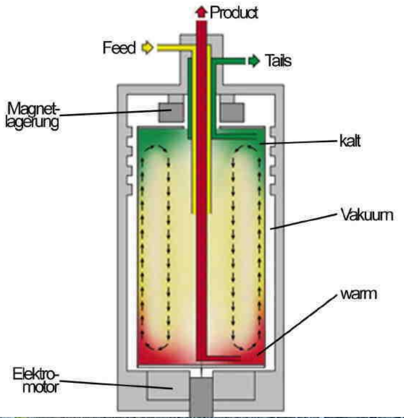
World War II year 1942: Uranium enrichment

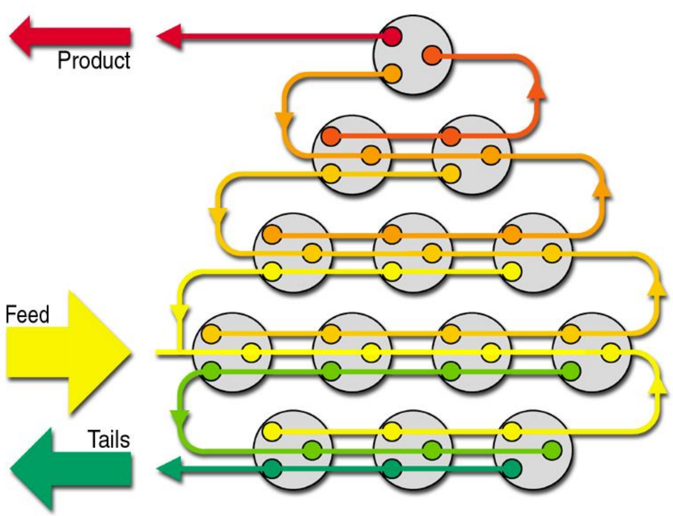
- **Niels Bohr was the first to establish that the U-235 isotope readily underwent fission, but the U-235 isotope is "diluted" in natural uranium by 140 atoms of U-238**
- **Enrichment was a way to increase the proportion of U-235 and aid in the chain reaction.**

  99.275% U-238

  0.720% U-235

  0.005% U-234
- **Uranium enrichment is a matter of global politics until today**





The Road to Nuclear Fission and Fusion

World War II year 1942: First fission nuclear reactor

Fermi's group assembled natural uranium into an atomic pile to test the feasibility of a sustained chain fission reaction.

Key elements:
Fuel (UO_2 pellets), neutron moderator, control rod, neutron detector, and radioactivity detector

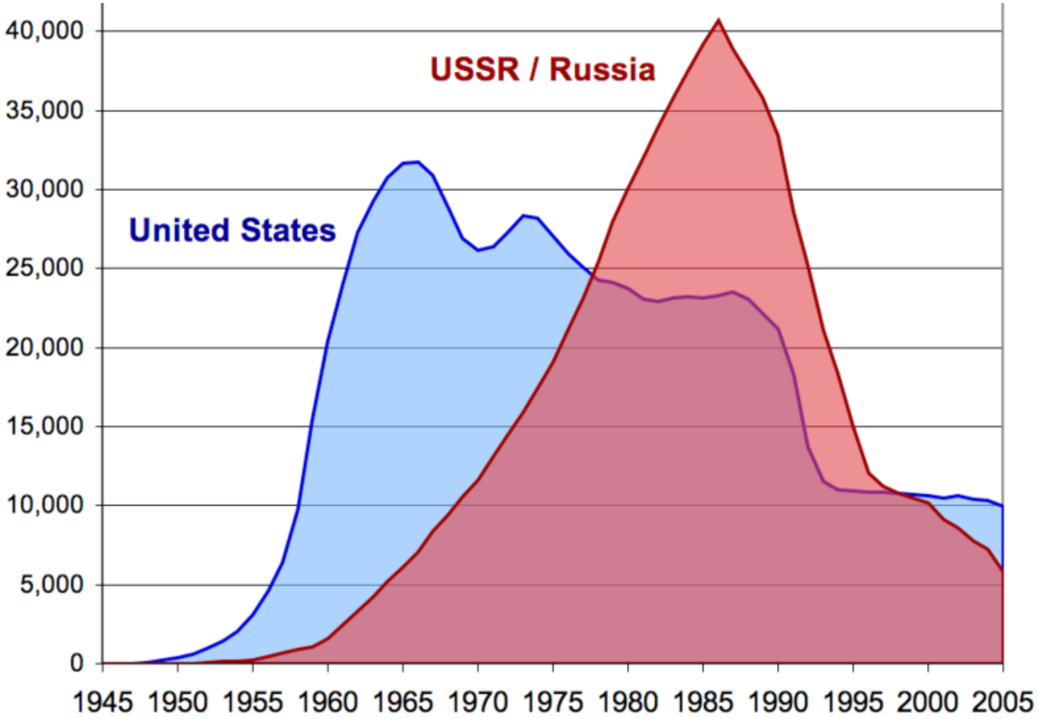
December 2nd, 1942, Fermi achieved sustained chain reaction, and the first fission reactor provided data for future design of nuclear reactors.

Today, more than 400 power nuclear reactors provided energy world wide, more than 100 of them in the US

The Road to Nuclear Fission and Fusion

World War II year 1945: Show-up of nuclear weapons

July 16th	Almogordo, NM	First atomic bomb test
August 6th	Hiroshima, Japan	First use in war
August 9th	Nagasaki, Japan	End of World War II



The Road to Nuclear Fission and Fusion

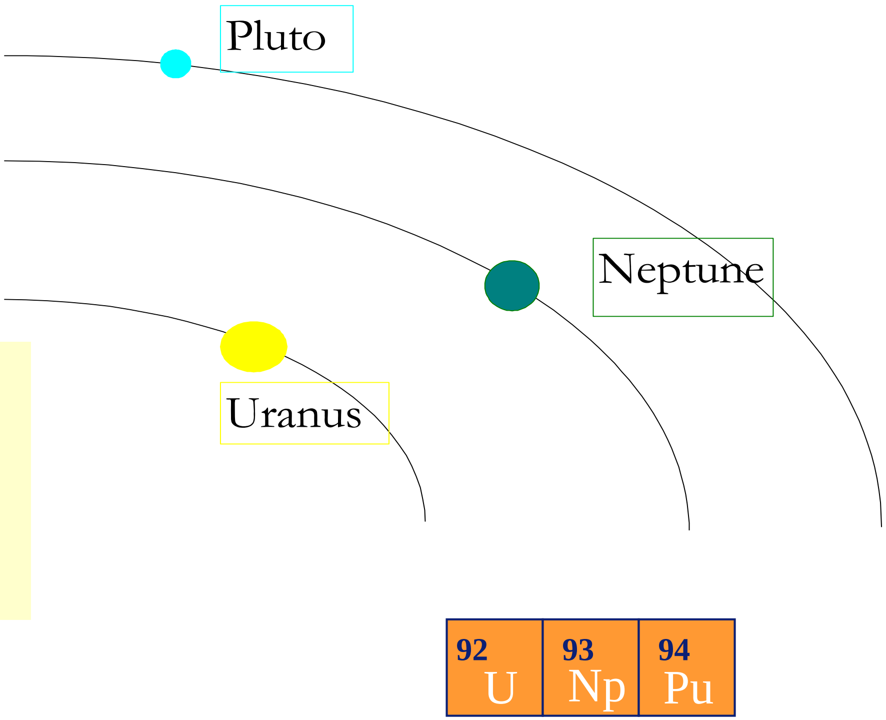
1959: First Commercial Power Plant

- Cost of $18 million in Morris, Illinois
- 200 MW Duel Cycle Boiling Water Reactor
- Designed and operated by General Electric until 1979 when it was shut down

The Road to Nuclear Fission and Fusion

The Synthesis of Plutonium

as a more efficient nuclear fuel



Short notations

$^{238}U\ (n, \gamma)\ ^{239}U\ (, \beta)\ ^{239}Np\ (, \beta)\ ^{239}Pu$

or

$^{238}U\ (n, 2\beta)\ ^{239}Pu$

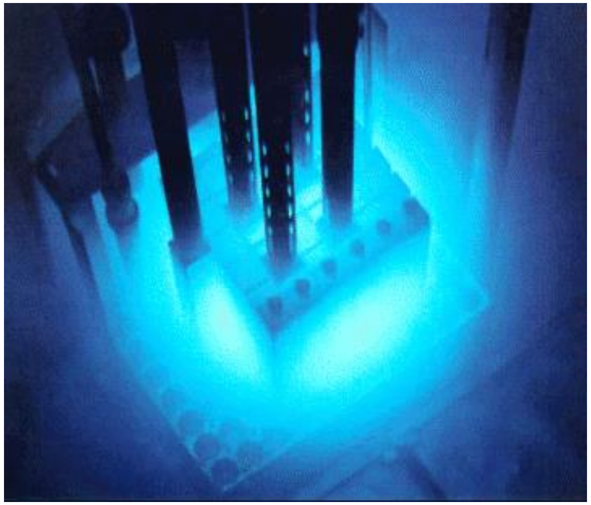
Fast neutrons provided the reactions:

$$^{238}U + n \rightarrow {}^{239}U + \gamma$$

$$^{239}U \rightarrow {}^{239}Np + \beta \quad (t_{1/2}\ 23.5\ min)$$

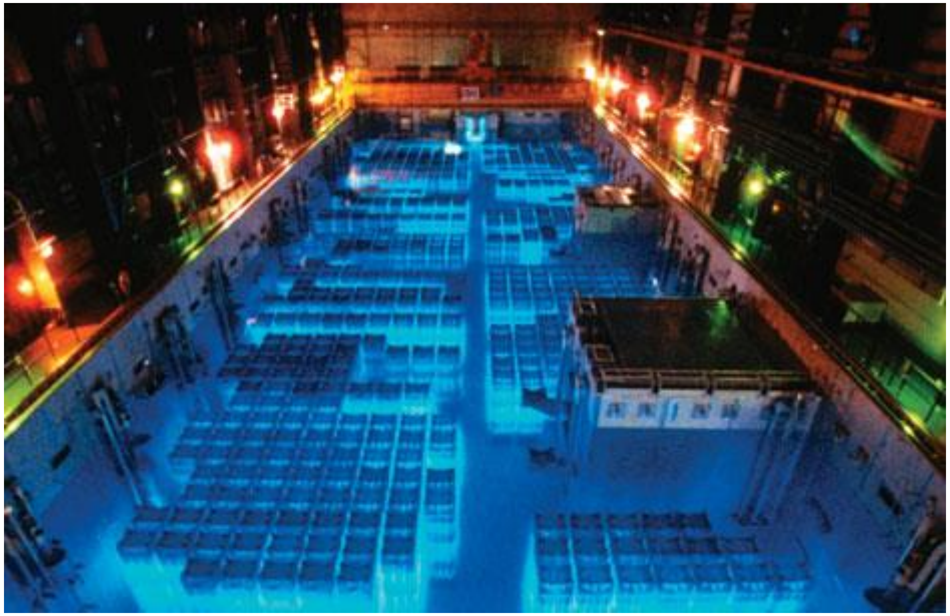
$$^{239}Np \rightarrow {}^{239}Pu + \beta \quad (t_{1/2}\ 2.35\ d)$$

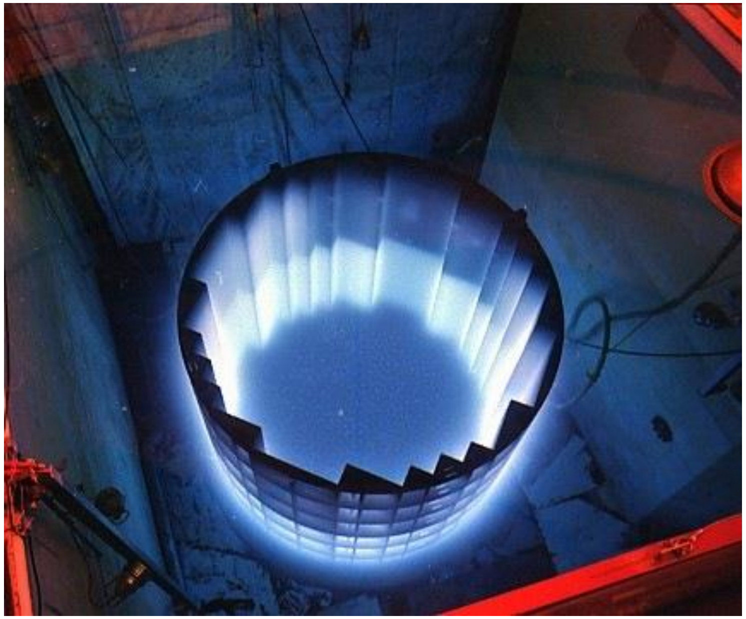
The Road to Nuclear Fission and Fusion



Problem: Used fuel rods

Present solutions:
- Final long-term storage
- Re-processing (La Hague, France)
- Transmutation?

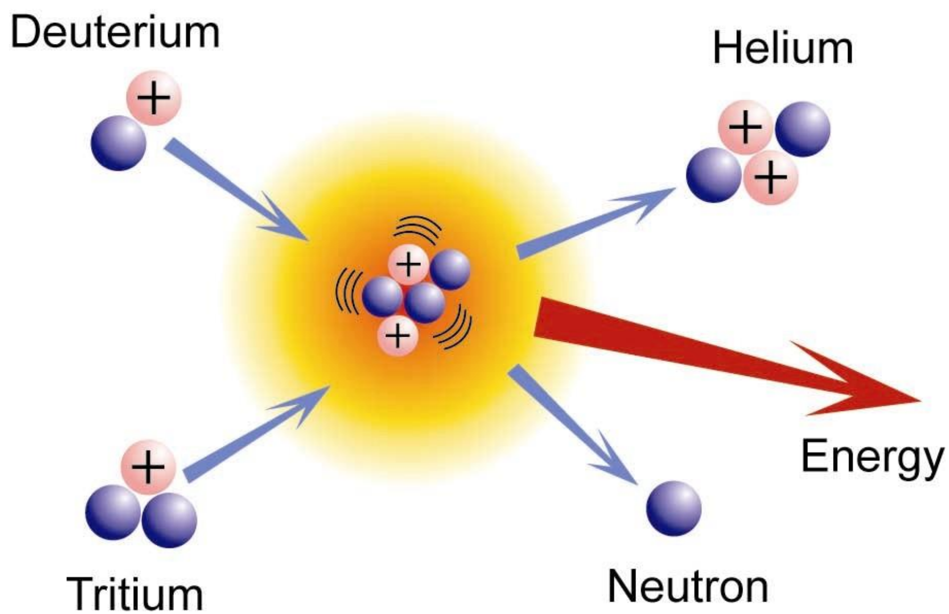




The Road to Nuclear Fission and Fusion

Nuclear fusion

- Two lighter nuclei combine to form a heavier nucleus
- Process that powers the heat generation of stars
- Original source of almost all of earths energy



Nuclear Energy

Solar Energy → **Light + Wind**

Geothermal Energy → **Hot Water (Vapour)**

Source: Joint European Torus (JET)

The Road to Nuclear Fission and Fusion

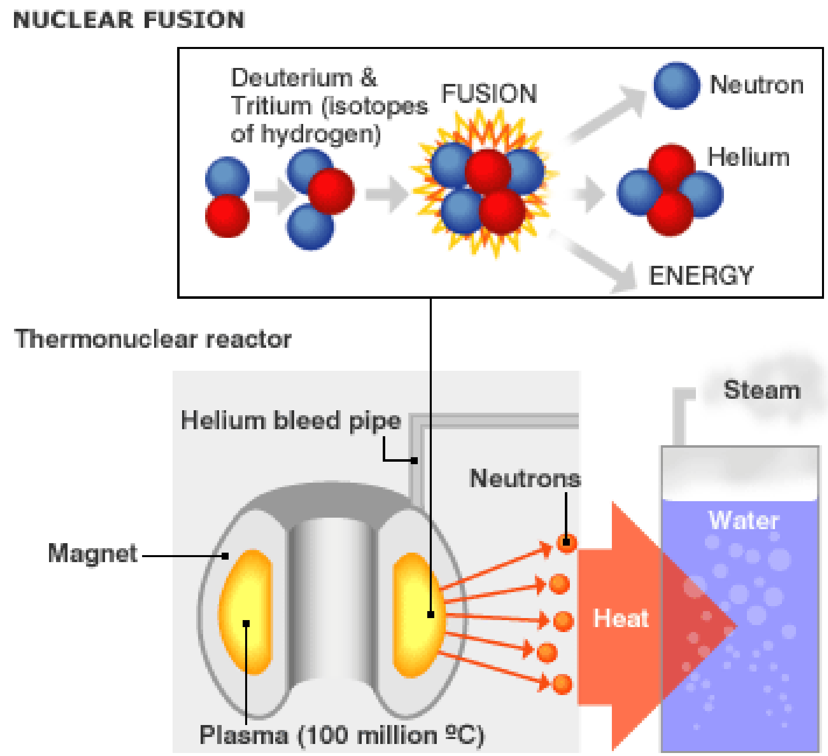
How fusion works

- **Most suitable reaction involves:**
  - **Deuterium (D)**
  - **Tritium (T)**

    (isotopes of Hydrogen)

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

- **Temperatures of > 10 million degree Celsius**
- **Plasma: State in which electrons have been completely removed from atomic nuclei**



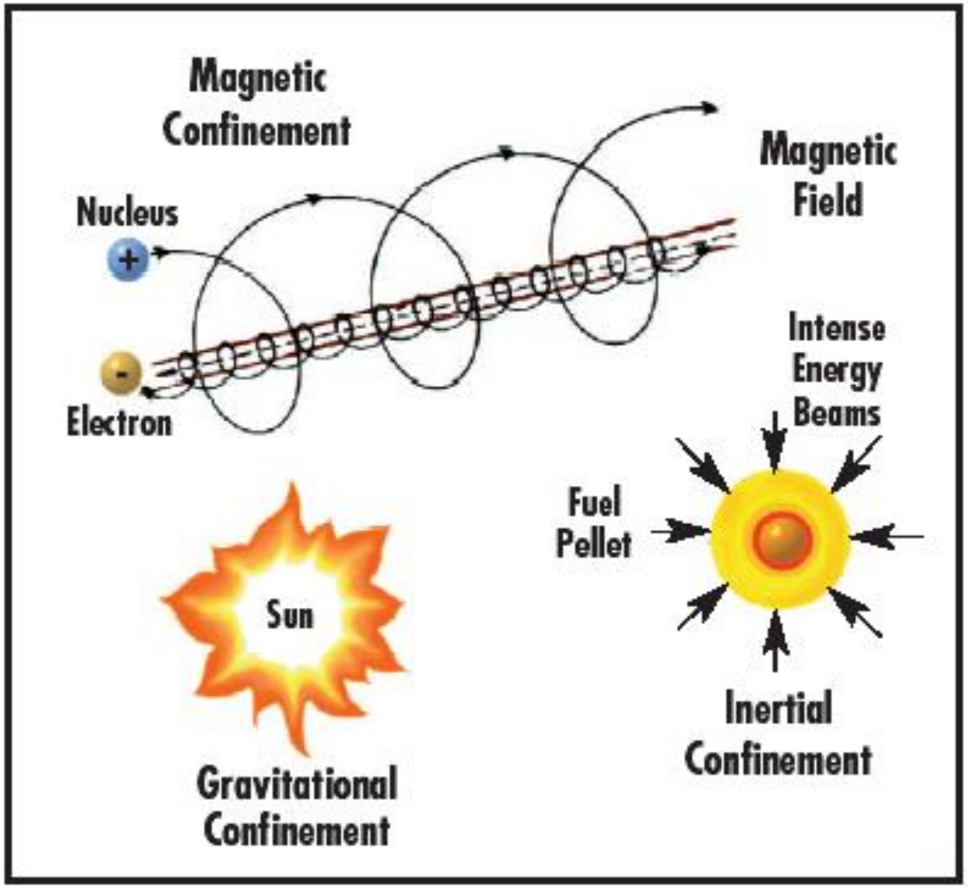
Source: Joint European Torus (JET)

The Road to Nuclear Fission and Fusion

Means of Initiating Nuclear Fusion

- Gravitation fields (Stars)
- Electromagnetic fields (Magnets)
- Photon fields (Laser)
- Cold Fusion? Myon catalyzed:

$^{2}D\mu^{3}T \rightarrow {}^{4}He + n + \mu + 17.6\ MeV$

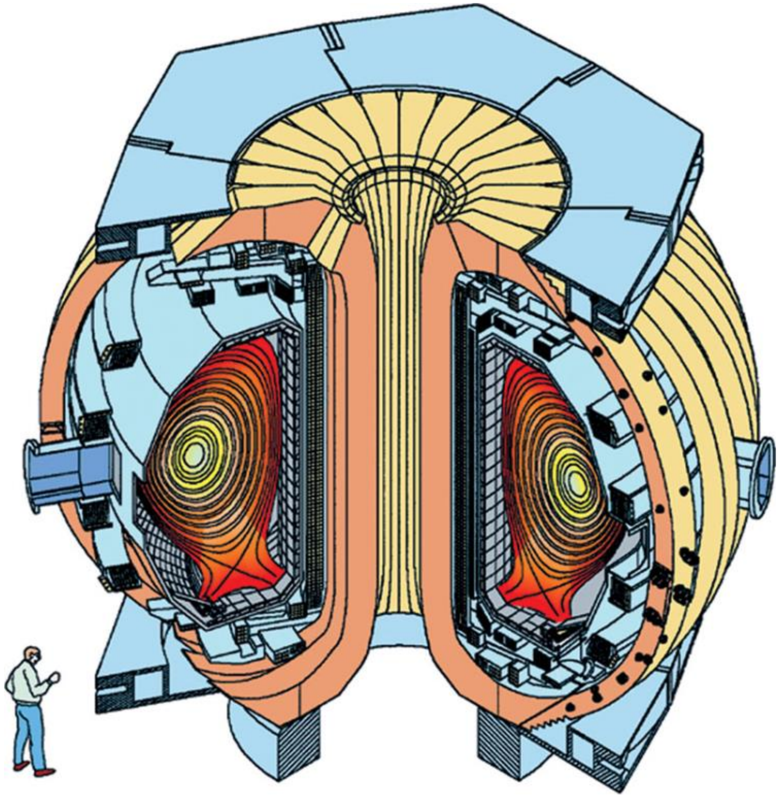


Source: FusEdWeb: Fusion Energy Educational Web Site

The Road to Nuclear Fission and Fusion

Fusion by Magnetic Confinement

- Plasma is so high in energy it requires magnetic fields to contain it
- Magnetic fields trap superheated fusion fuel in center of loop
- Immense temperatures/pressures



Source: FusEdWeb: Fusion Energy Educational Web Site http://fusedweb.pppl.gov/

The Road to Nuclear Fission and Fusion

Where does Tritium & Deuterium come from?

- **Tritium**
  - **Bombarding Lithium atom with a Neutron**

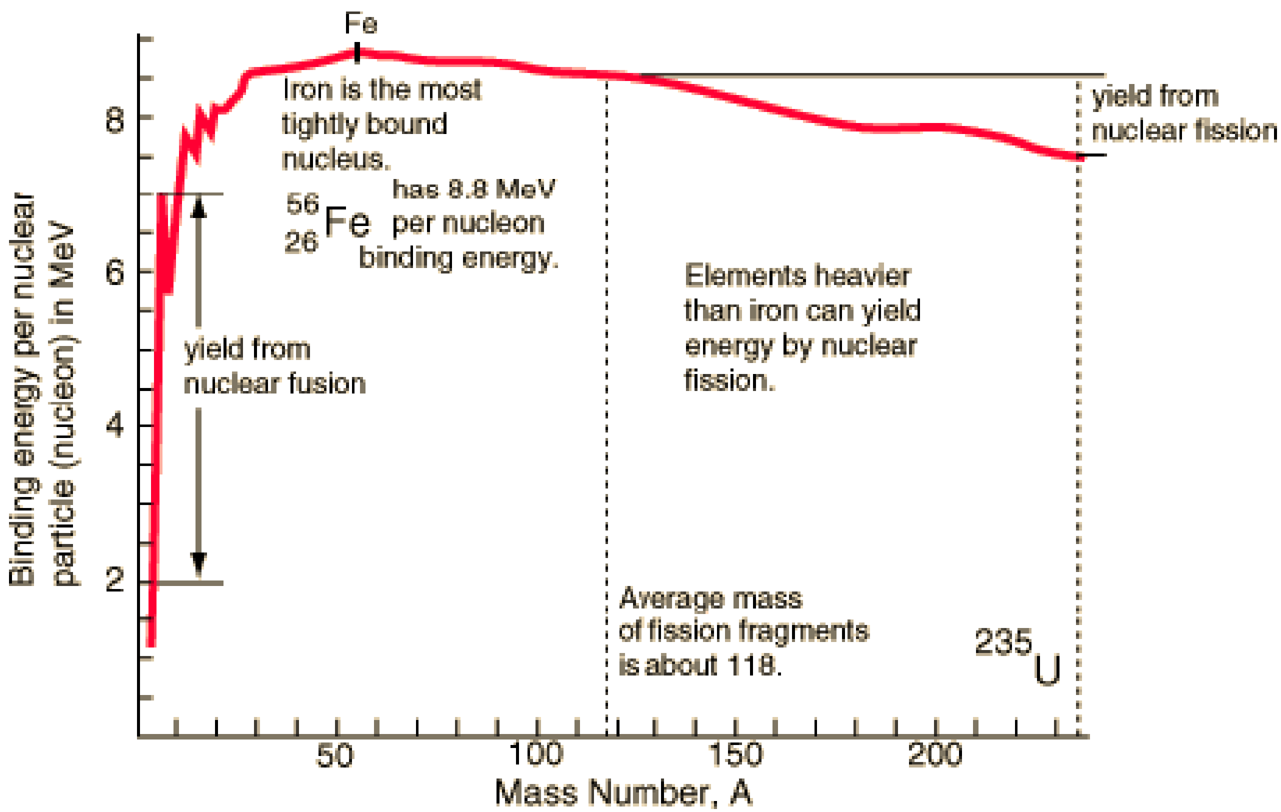
- **Deuterium**
  - **Plentiful in ordinary water (D_2O)**
  - **1/6500 hydrogen atoms in water is Deuterium**

    1 liter of water conceivably has the energy content of 300 liter of gasoline

Source: General Atomics, http://fusedweb.pppl.gov/

The Road to Nuclear Fission and Fusion

Yield of Fission vs. Fusion



Fusion yields about 7times more energy per kg fuel than fission!

The Road to Nuclear Fission and Fusion

Cold Fusion?

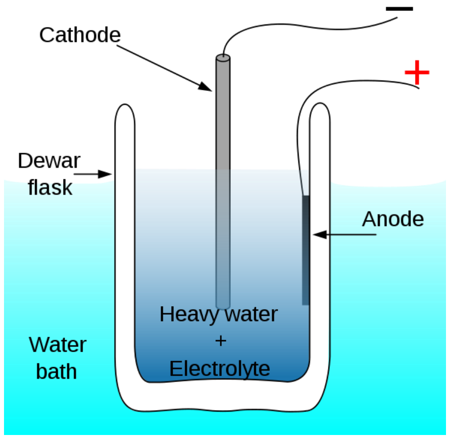
1927 **John Tandberg (1896 - 1968)**

Claimed a patent w.r.t. fusion of Hydrogen to Helium at Pd electrodes, which was rejected due to incompleteness

1989 **Martin Fleischmann (Univ. Southampton, UK) and Stanley Pons (Univ. Utah, Salt Lake City, US)**

Reported on fusion of protium, deuterium, and tritium during electrolysis at a Pd cathode, but confirmation failed…..

(J. Electroanal. Chem. 261 (1989) 301-308)



2021 **Vladimir Pines et al.**

Lattice fusion in ErD_3 initiated by hot neutrons

$D + D \rightarrow {}^3He$ (820 keV) + n (2.45 MeV)

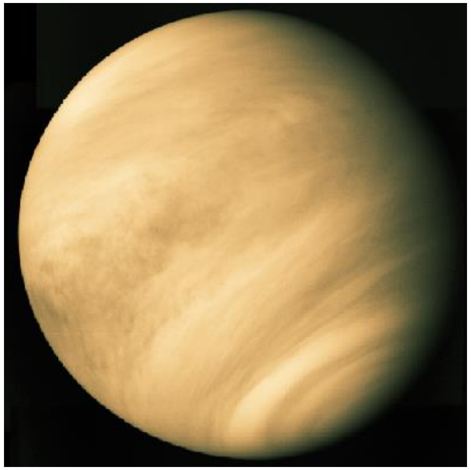
(Phys. Rev. C 101 (2021) 044609)

Source: General Atomics

The Road to Nuclear Fission and Fusion

21st Century: Reduction of fossil fuel use by nuclear or solar energy

Venus



2.61 kW/m^2
Albedo = 0.76
→ T_e = 232 K
96% CO_2 + 3% N_2 + SO_2 + H_2O + Ar (ppms)
93 bar → T_{eff} = 740 K

Earth

1.37 kW/m^2 = 1.56·10^{18} kWh/a
Albedo = 0.30
→ T_e = 255 K
78% N_2 + 21% O_2 + 0.9% Ar + CO_2 + H_2O + CH_4 (ppms)
1 bar → T_{eff} = 288 K
Life on our planet needs solar radiation + water + heat in appropriate amounts!

Mars

0.59 kW/m^2
Albedo = 0.15
→ T_e = 213 K
95% CO_2 + 3% N_2 + 1.5% Ar + H_2O (ppms)
5.6 mbar → T_{eff} = 225 K

Discovery of the Cosmic Toolbox - The PTOE

Groups

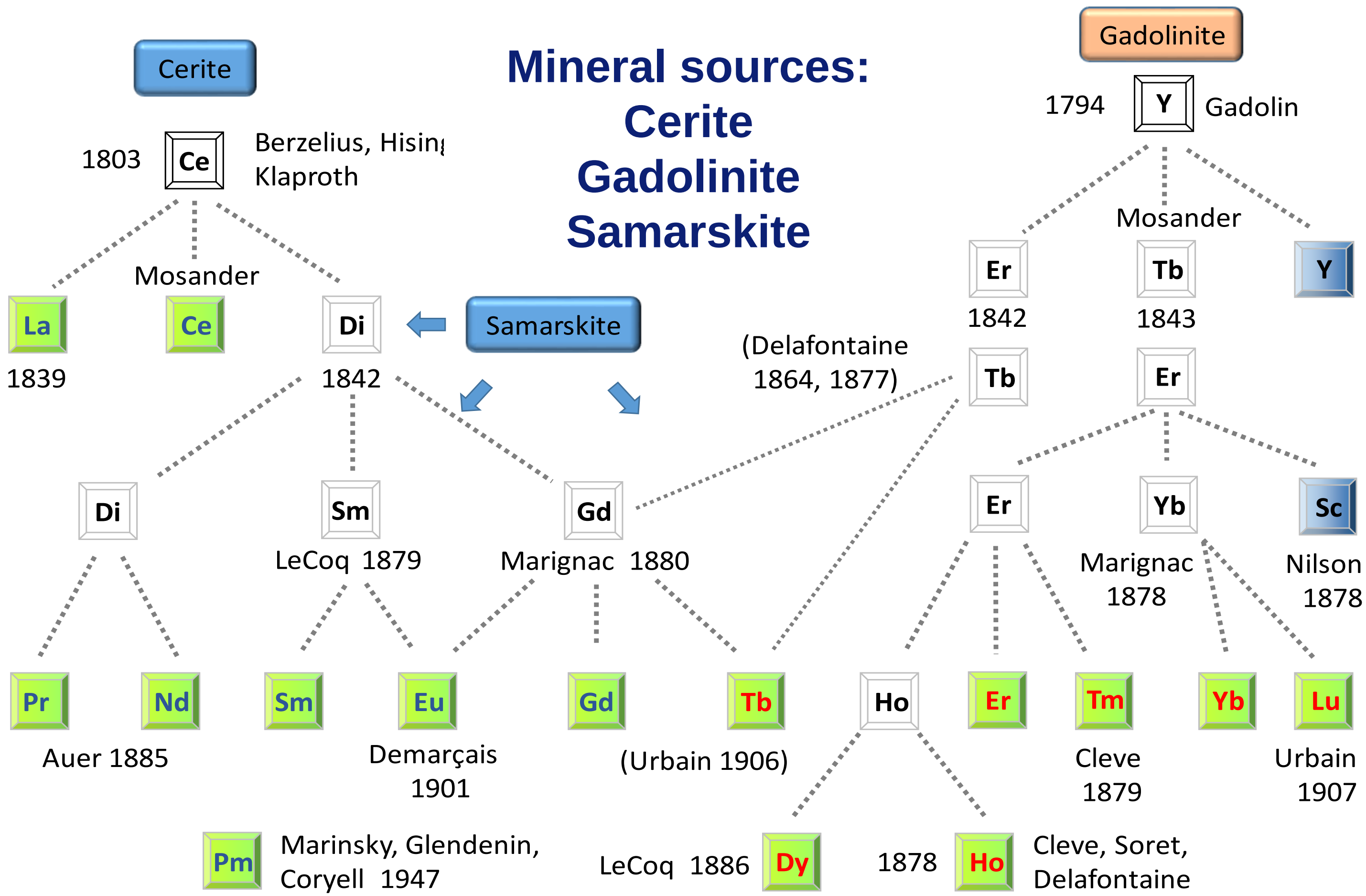
Periods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

Periods														
6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Prehistoric
9000 - 1400 BC
1400 BC - 1500 AD
16th - 17th century
20th century
18th century
21st century
19th century

Discovery of the Cosmic Toolbox - Lanthanides

Mineral sources: Cerite Gadolinite Samarskite



58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

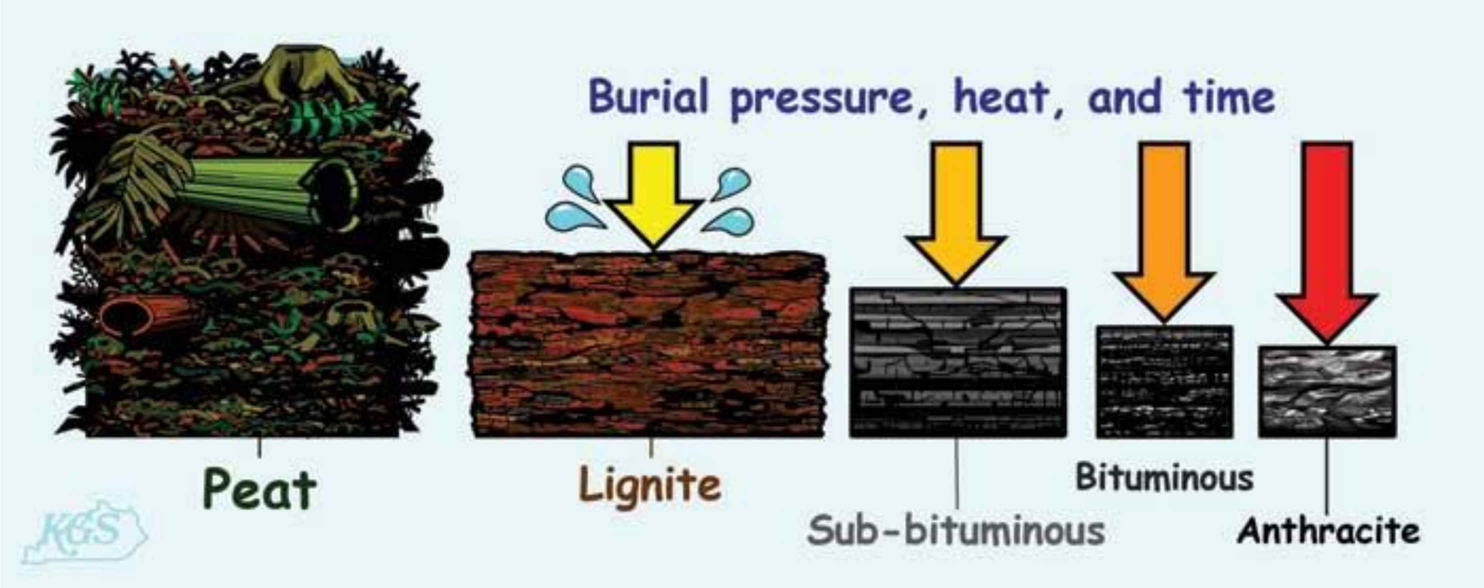
Adapted from Szabadvary, F., The History of the Discovery and Separation of the Rare Earths. In Handbook on the Physics and Chemistry of Rare Earths; Gschneidner Jr., K. A. and Eyring, L., Eds.; Elsevier Science Publ. B.V.: Amsterdam, 1988; Vol. 11, Ch. 73

Discovery of the Cosmic Toolbox - The PTOE

Why were Carbon and Sulphur known to ancient people?

Carbon C: Formation due to disintegration of organic matter

Organics → Peat → lignite (brown coal) → bituminous → anthracite



Sulphur S: Occurance at surface due to volcanism

$$16\ H_2S + 8\ SO_2 \rightarrow 3\ S_8 + 16\ H_2O$$

Discovery of the Cosmic Toolbox - The PTOE

Empedokles (495 - 435 BC, Sicily)

→ **First formulated the 4 Element theory**

Element	Quality	God	Season	Polyhedron
Fire	hot and dry	Zeus	Summer	Tetrahedron
Earth	cold and dry	Hera	Autumn	Hexahedron
Air	hot and wet	Hades	Spring	Octahedron
Water	cold and wet	Nestis	Winter	Icosahedron
Later added Quintessence (Aither)	origin of all	-	Constellations	Dodecahedron

Discovery of the Cosmic Toolbox - The PTOE

Democritus (460 - 370 BC, Abdera)

→ He and his mentor Leukipp came up with the atomic theory

Main statements

1. All matter consists of invisible particles called atoms
2. Atoms are indestructible
3. Atoms are solid but invisible
4. Atoms are homogenous
5. Atoms differ in size, shape, mass, position, and arrangement

→ Solids are made of small, pointy atoms
→ Liquids are made of large, round atoms
→ Oils are made of very fine, small atoms that can easily slip past each other

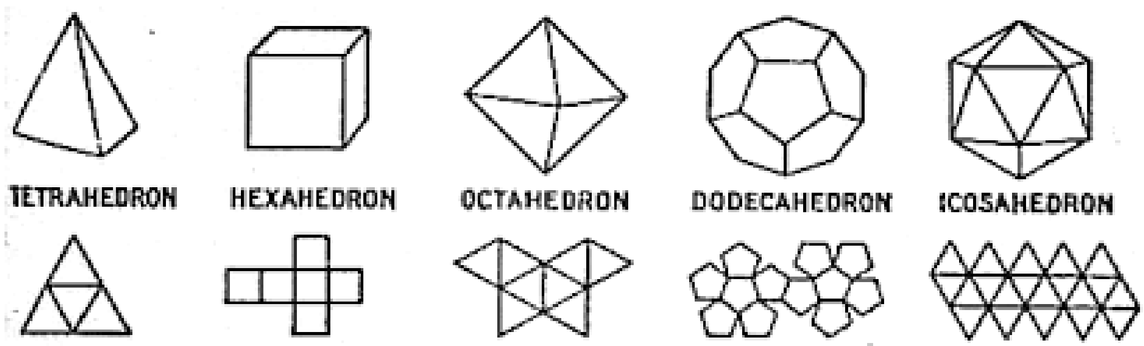
A cosmic whirl separated heavy atoms from light atoms
→ Earth (center)
→ Stars (universe)

Discovery of the Cosmic Toolbox - The PTOE

Platonic solids

Polyhedra	Faces (F)	Edges (E)	Vertices (V)	F + V - E =	Volume for E = 1	Assignment by Plato
Tetrahedron	4	6	4	2	$\sqrt{2}/12$	Fire
Hexahedron	6	12	8	2	1	Earth
Octahedron	8	12	6	2	$\sqrt{2}/3$	Air
Dodecahedron	12	30	20	2	$\sqrt{5}/2\phi^4$	Constellations
Icosahedron	20	30	12	2	$5/6\phi^2$	Water

with $\phi = (1+\sqrt{5})/2 = 2\cos(\pi/5)$ “the golden ratio”



Discovery of the Cosmic Toolbox - The PTOE

The basis of Alchemy: Ancient art of trying to achieve wisdom and immortality through the manipulation of elements

Conducted in Greece, Arabia, Medieval Europe, India & East Asia, …..

Some goals: A transmutation to obtain gold & the universal solvent

Triple concept: Planets ↔ Metals ↔ Gods (→ week days)

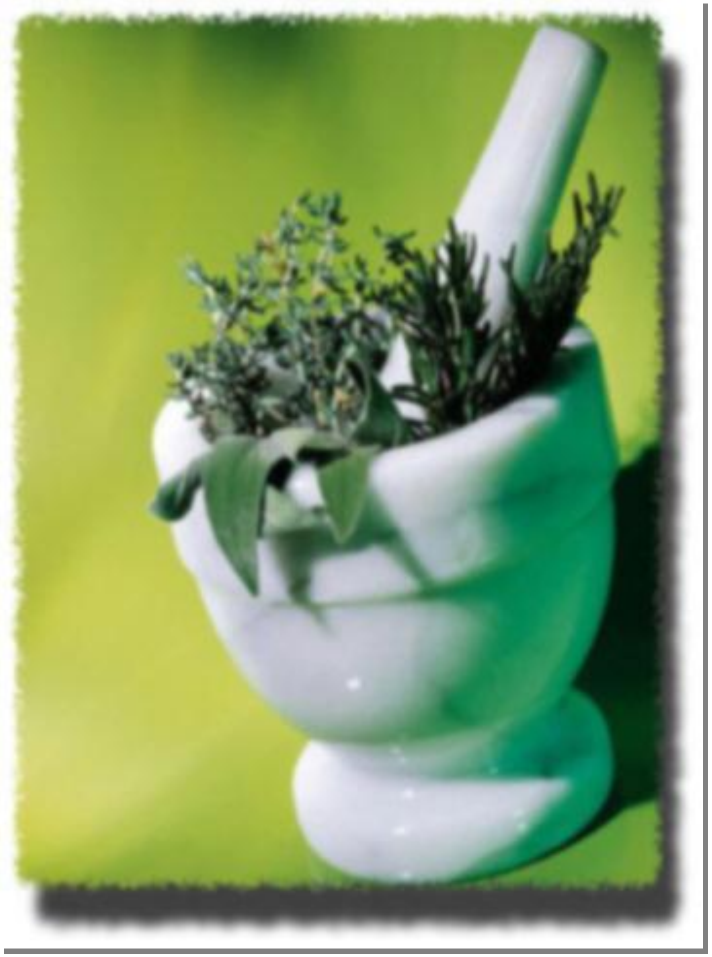
Planet	Metal (Greeks)	Metal (7th century)	Greek god
Sun	Gold	Gold	Helios
Moon	Silver	Silver	Luna
Mercury	Mercury & Tin	Mercury	Hermes
Venus	Copper	Copper	Aphrodite
Mars	Iron	Iron	Ares
Jupiter	Electron, Tin, Bronze	Tin	Zeus
Saturn	Lead	Lead	Kronos

Discovery of the Cosmic Toolbox - The PTOE

Alchemy = Protochemistry or Protoscience

Through alchemy we have gotten herbal remedies, alloys, and most importantly a desire to manipulate the world around us …

Sir Isaac Newton (1642 - 1727) was interested in alchemy too!



Discovery of the Cosmic Toolbox - The PTOE

Alchemists discovered further elements

1250 As **Albertus Magnus**

As_2O_3 (Arsenic) + C $\rightarrow$ 2 As + 3 CO

1669 P **Henning Brand**

$2\ Ca_3(PO_4)_2 + 10\ C + 6\ SiO_2 \rightarrow P_4 + 10\ CO + 6\ CaSiO_3$

17th century Zn India (“zinc” from Persian word “sing” = stone)

1748 Pt **Antonio de Ulloa**

Known in Egypt (was believed to be silver, spanish: plata, small silver: platina)

18th century Bi **Claude François Geoffroy, Johann Heinrich Pott, Carl Wilhelm Scheele & Torbern Olof Bergman**

Discovery of the Cosmic Toolbox - The PTOE

Johann Joachim Becher and Georg Ernst Stahl (1660 - 1734)

- Phlogiston theory (1680 - 1770 accepted)
- During the combustion of organic substances volatile material (Phlogiston) is released from burnt matter
- Plants absorb Phlogiston from air
- Reduction of metal oxides with wood returns Phlogiston back into „Metal lime”: Metal lime and Phlogiston = Metal

Antoine Lavoisier (1743 - 1794)

- Mass and volume change during chemical processes by using scale, volumentric apparates and so on
- Correct interpretation of the combustion process (1783)
- First elementar analysis (1788)

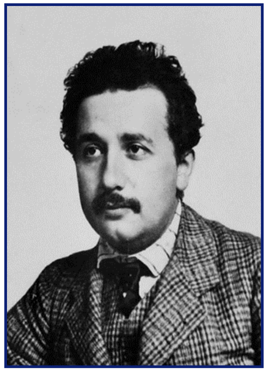
Discovery of the Cosmic Toolbox - The PTOE

Law of mass preservation: During all chemical reactions the total Mass of the reactants remains constant

Antoine Lavoisier 1774

Experimental confirmation by thorough determination of the mass of the educts and products **Hans Landolt 1908**

⇒ change of mass < 10^{-5}%



But: Chemical reactions are subject to energy conversion ΔE

Energy/mass equivalent: $E = mc^2$ **Albert Einstein 1915**

Highly exothermic reaction: ΔE = 500 kJ ⇒ change of mass ~ 10^{-9} %

⇒ Change of mass during chemical reactions is beyond weighing accuracy

Discovery of the Cosmic Toolbox - The PTOE

Law of constant proportions: Mass ratio of two chemical elements reacting to a product compound is constant

Joseph Louis Proust 1799

Hoffman's decomposition apparatus:

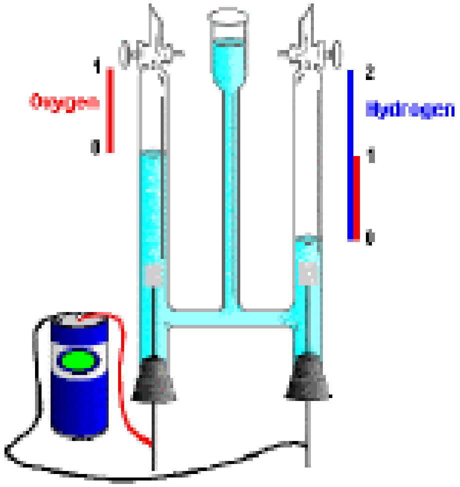
Volume ratio

H/O = 2:1 (H_2O)

Mass ratio

H/O = 1:7.936

Water electrolysis



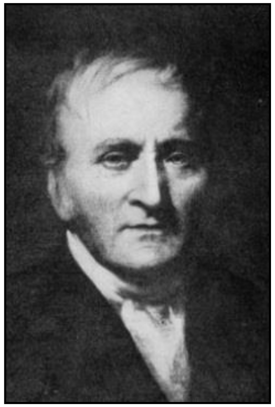
Further examples for constant mass ratios

Fe/S	=	1:0.57 (FeS)
Mg/O	=	1:0.666 (MgO)
Na/Cl	=	1:1.542 (NaCl)
H/N	=	1:4.632 (NH_3)

Discovery of the Cosmic Toolbox - The PTOE

Law of Multiple Proportions: The mass ratios of two chemical elements reacting to one compound are related by a simple number

John Dalton 1803



Examples for multiple mass ratios

Nitrogen oxides

- N/O = 1:0.571 = 1:1x0.571 N_2O Dinitrogen monoxide
- N/O = 1:1.142 = 1:2x0.571 NO Nitrogen monoxide
- N/O = 1:1.713 = 1:3x0.571 N_2O_3 Dinitrogen trioxide
- N/O = 1:2.284 = 1:4x0.571 NO_2 Nitrogen dioxide
- N/O = 1:2.855 = 1:5x0.571 N_2O_5 Dinitrogen pentoxide

Carbon oxides

- C/O = 1:1.333 = 1:1x1.333 CO Carbon monoxide
- C/O = 1:2.666 = 1:2x1.333 CO_2 Carbon dioxide

Discovery of the Cosmic Toolbox - The PTOE

Modern atom hypothesis: Atoms as smallest parts of matter

John Dalton 1808

1. Elements cannot be split indefinitely, since they consist of tiny non-cleavable particles, the so-called atoms
2. All atoms of an element are of one sort (mass & shape)
3. Atoms of different elements possess different properties

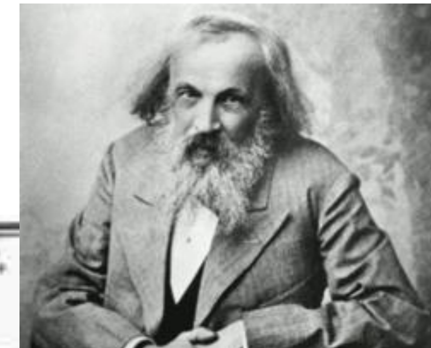
Symbole für die Elemente von John Dalton

$$2\,A + B \rightarrow A_2B$$
$$A + B \rightarrow AB$$
$$2\,A + 3\,B \rightarrow A_2B_3$$
$$A + 2\,B \rightarrow AB_2$$
$$2\,A + 5\,B \rightarrow A_2B_5$$

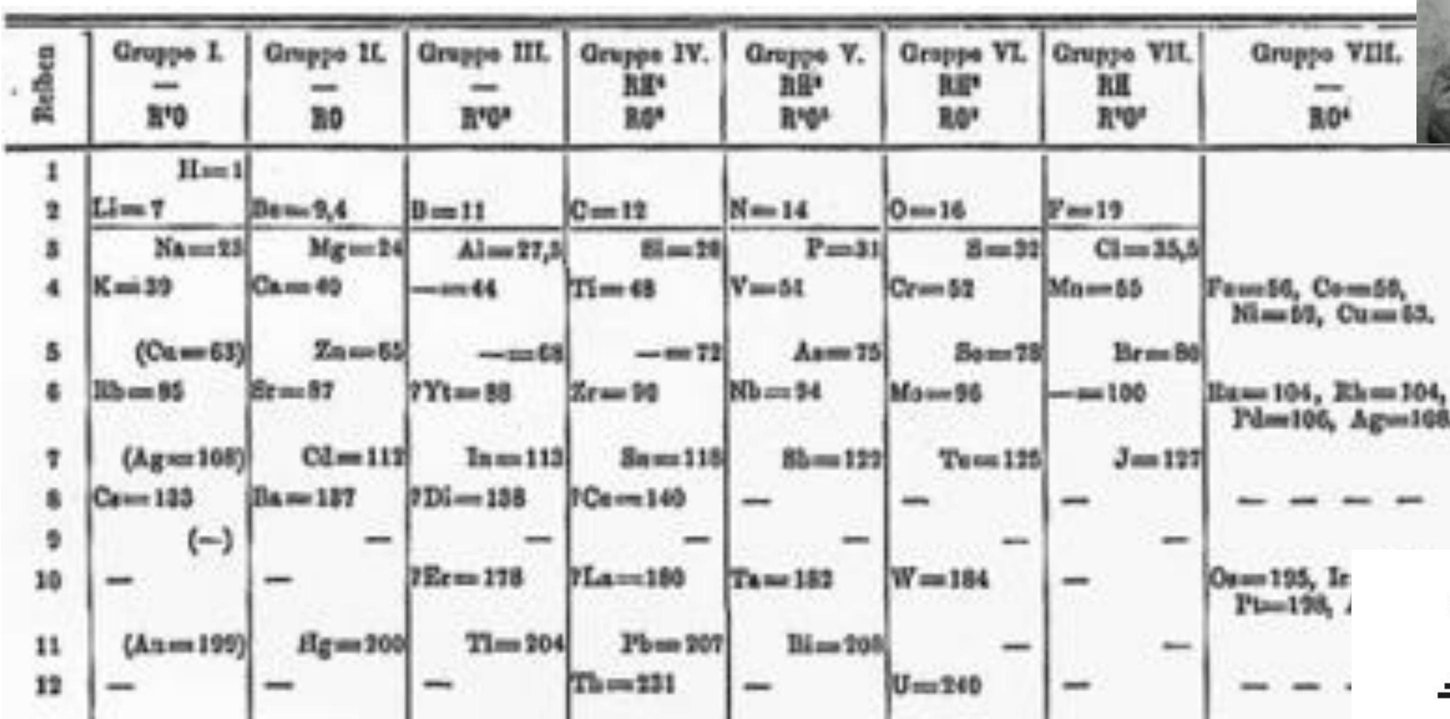
Relative atom masses cannot be measured directly as long as the exact ratio of the atoms in the newly formed compound is not know

Discovery of the Cosmic Toolbox - The PTOE

The first draft of the periodic table of the elements (PTOE)



Dmitri Mendeleev 1871 (Philishave not yet invented…)



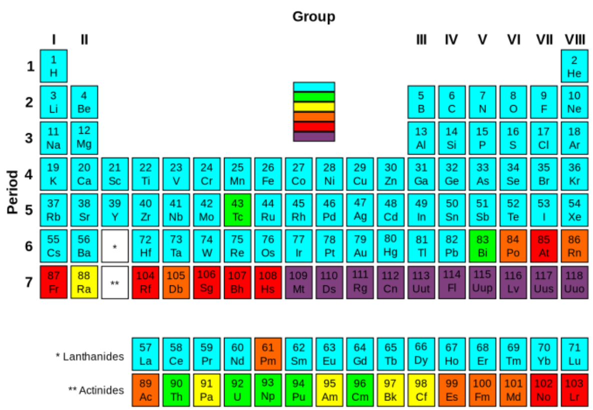
Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir… Pt=198, …
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — …

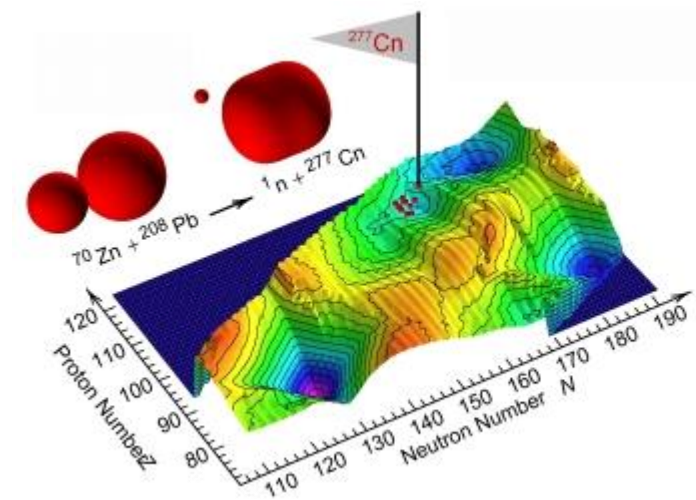
United Nations Educational, Scientific and Cultural Organization
International Year of the Periodic Table of Chemical Elements

Discovery of the Cosmic Toolbox - The PTOE

State of the PTOE at the dawn of the 21st century

- **All elements of first 7 periods are discovered, i.e. up to element #118**
- **Number of relevant metals in technology > 50! (→ critical metals)**
- **Transmutation is state-of-the-art in nuclear chemistry**
- **Search for elements on the isle of stability**





Chemistry - The Basis of Food Preservation

Transition from hunter-gatherer cultures to sedentary cultures required food storage due to seasonal agriculture production

~ 7000 BC	pickling, drying, smoking	
~ 3000 BC	soaking in oil	Mesopotamia
~ 2000 BC	soaking in acetic acid	Egypt
	and honey	Romain Empire
~ 1000 BC	soaking in alcohol	Arabia
	and lactic acid	East Asia
~ 50 AD	sulfuring	Romain Empire
~ 1400 AD	pickling	
~ 1900 AD	boric and salicyl acid	
~ 1950 AD	irradiation by UV or x-ray	
Today	Many physical methods and chemical additives	

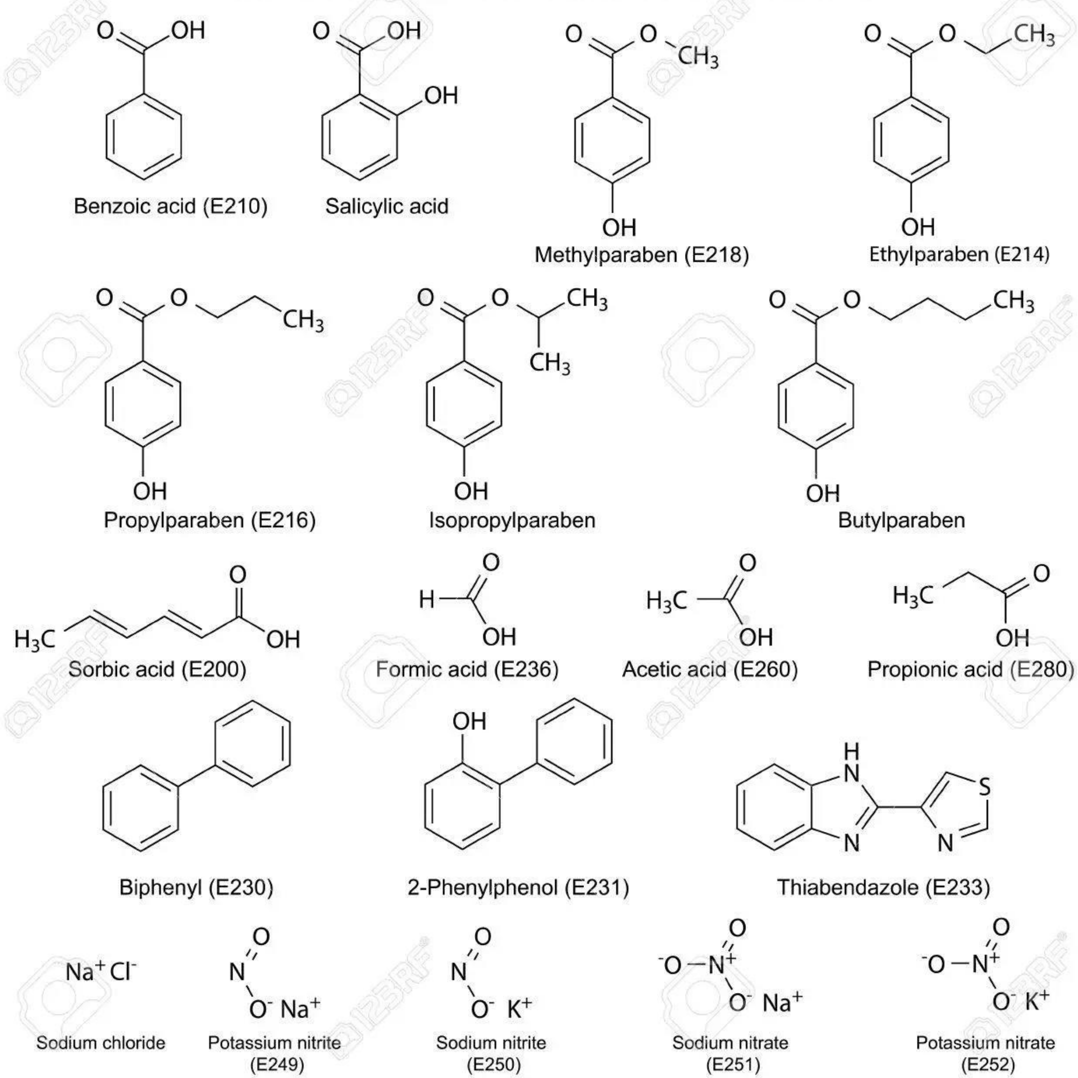
Chemistry - The Basis of Food Preservation

Modern food and cosmetic additives for preservation

Physicochemical methods

- pH value decrease
- dehydration
- antioxidation (reduction)
- irradiation
- antimicrobial additives
- cooling or freezing

Structures of Food and Cosmetic Preservatives



Chemistry - Simply Everything

The chemical revolution since the 19th century

Example: Friedrich Wöhler (1800 – 1882)

$(CN)_2 + 4\ H_2O \rightarrow H_2C_2O_4$ (oxalic acid)

$NH_4(OCN) \rightarrow (NH_2)_2CO$ (urea)

$CaC_2 + 2\ H_2O \rightarrow Ca(OH)_2 + C_2H_2$ (ethin)

→ Beginning of biochemistry
→ Tear down the border between organic and inorganic chemistry
→ Decline of the „vitalism“ theory

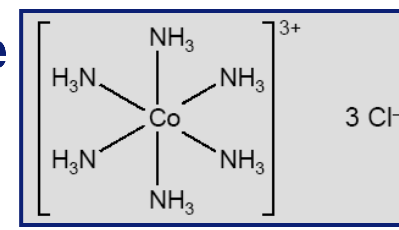
Chemistry - Simply Everything

The chemical revolution since the 19th century

Example: Alfred Werner (1866 – 1919), Nobel price 1913

a) $CoCl_3 \cdot 6NH_3$	yellow	Luteo
b) $CoCl_3 \cdot 5NH_3$	red	Purpureo
c) $CoCl_3 \cdot 4NH_3$	green	Praseo
d) $CoCl_3 \cdot 4NH_3$	violet	Violeo

Gravimetrical determination of chloride with $AgNO_3$ gave



a)	3 AgCl	$[Co(NH_3)_6]^{3+} + 3\ Cl^-$	
b)	2 AgCl	$[Co(NH_3)_5Cl]^{2+} + 2\ Cl^-$	
c, d)	1 AgCl	$[Co(NH_3)_4Cl_2]^{+} + 1\ Cl^-$	2 isomers (cis and trans)

→ Origin of coordination chemistry *and bioinorganic chemistry*

Chemistry - Simply Everything

The chemical revolution since the 19th century

History of coordination chemistry since Alfred Werner

1916	W. Kossel, A. Magnus	electrostatic complex theory
	classical description of complexes	
1923	N.V. Sidgwick, L. Pauling	valence bond (VB) theory
	quantum mechanical description of coordinative bonds	
1925	E. Wigner, H. Bethe	group theory in quantum mech.
	geometrical symmetry of coordinative bonds	
1930	F. Hund, R. Mulliken, G. Herzberg	molecule orbital(MO) theory
	quantum mechanical description of complexes	
1932	J.M. Van Vleck	crystal field theory
	semi-classical description of complexes	
1944	H. Hartmann	ligand field theory
	semi-empirical description of complexes	

Chemistry - Simply Everything

The chemical revolution since the 19th century

History of coordination chemistry since Alfred Werner

1954 Y. Tanabe, S. Sugano
term correlation diagrams

1958 C.K. Jörgensen, C.E. Schäffer
nephelauxetic series

1965 C.K. Jörgensen, C.E. Schäffer, H.B. Schmidtke
ligand field angular overlap model

1971 M. Kibler
equivalence between electrostatic ligand field and angular overlap model

Chemistry - Simply Everything

Chemistry enables new display technologies: LCDs, OLEDs, and µ-LEDs

Example: Discovery and development of liquid crystals (LCs)

1888 Friedrich Reinitzer, German University of Prague, discovered unique state of matter between solid and liquid

1890 Otto Lehmann, Technical University of Karlsruhe, coined the term "Flüssige Kristalle," which translates to liquid crystal in English

1911 Charles Mauguin, University of Paris, discovered the unique alignment liquid crystal material adopts on various surfaces

1922 Georges Friedel in France named the three main liquid crystal phases smectic, nematic, and cholesteric

Chemistry - Simply Everything

Chemistry enables new display technologies: LCDs, OLEDs, and µ-LEDs

1929 Zocher and Birstein in Germany first studied effects of magnetic and electric fields on liquid crystals

1931 Russian physicist V.K. Freedericksz discovered periodic hydro-dynamic domains in liquid crystals subjected to electric fields

1936 Barnett Levin and Nyman Levin at Marconi, a wireless telegraph company in England, obtained the first patent on a liquid crystal light valve

1962 George Gray, University of Hull in England, published the first book on liquid crystal structure and properties, opening the field to chemists and physicists

1963 Richard Williams reported the formation of domains in a nematic liquid crystal under electrical excitation

Chemistry - Simply Everything

Chemistry enables new display technologies: LCDs, OLEDs, and µ-LEDs

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Chemistry - Simply Everything

First LC display developed at RCA Laboratories, David Sarnoff Research Center, Princeton, NJ, USA

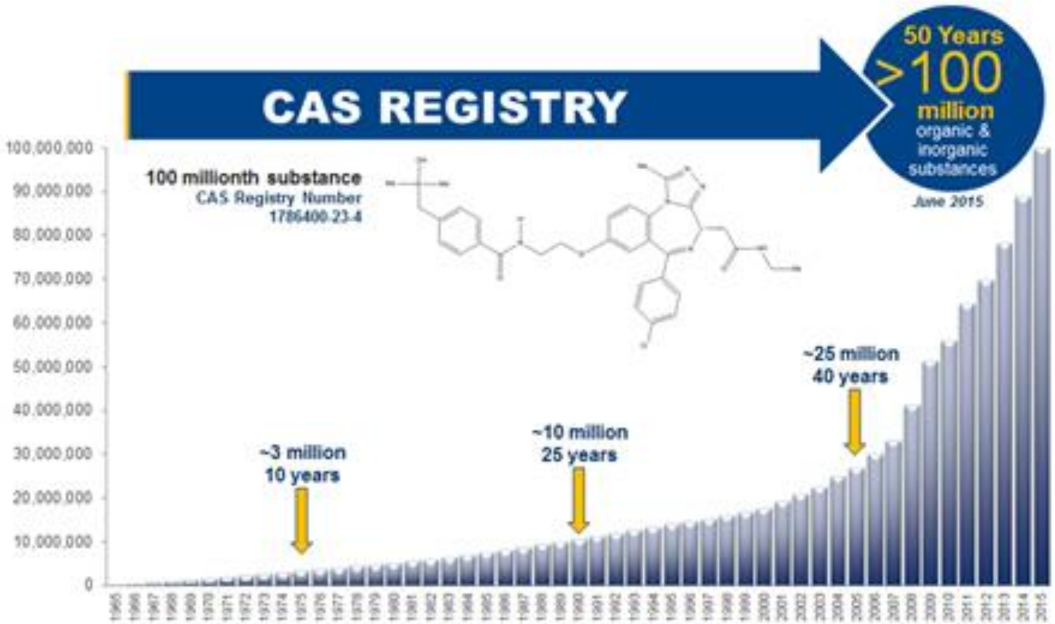
1965 George Heilmeier, Louis Zanoni, and Lucian Barton built the first liquid crystal display based on what Heilmeier called the "Dynamic Scattering Effect"
This was immediately recognized as a path to flat panel TV sets

Photograph of Ronald Friel demonstrating an LC device in 1967

More than 100 Million Compounds and no End?

Chemical Abstracts Service (CAS) started in 1957, CAS Chemical Registry System introduced in 1965

Organic chemistry	> $1 \cdot 10^8$ compounds (CAS, June 19th, 2015)
Polymer chemistry	> $1 \cdot 10^6$ compounds (2002)
Inorganic chemistry	> $3 \cdot 10^6$ compounds (2002)



The field of chemistry still shows exponential growth

Revolutions in Biology

- Microscopy
- Darwin‘s evolution theory
- Mendel's inherit laws
- The molecule of life (Watson & Crick)
- Biotechnology - Quo vadis?

Today’s Driver: Molecular Biology and Micro Biology

The Origin of Biology

- **Microscopic biology began in 1665 (→ Optics of 17th century)**
- **Robert Hooke (1635-1703) discovered organisms are made up of cells**
- **Matthias Schleiden (1804-1881) and Theodor Schwann (1810-1882) further expanded the study of cells in 1830s**



Major Events in the History of Molecular Biology in 19th Century

- **1865 Gregor Mendel discovered the basic rules of heredity of garden pea**
  - **An individual organism has two alternative heredity units for a given trait (dominant trait vs. recessive trait)**

- **1869 Johann Friedrich Miescher discovered DNA and named it nuclein**

Gregor Mendel: The Father of Genetics

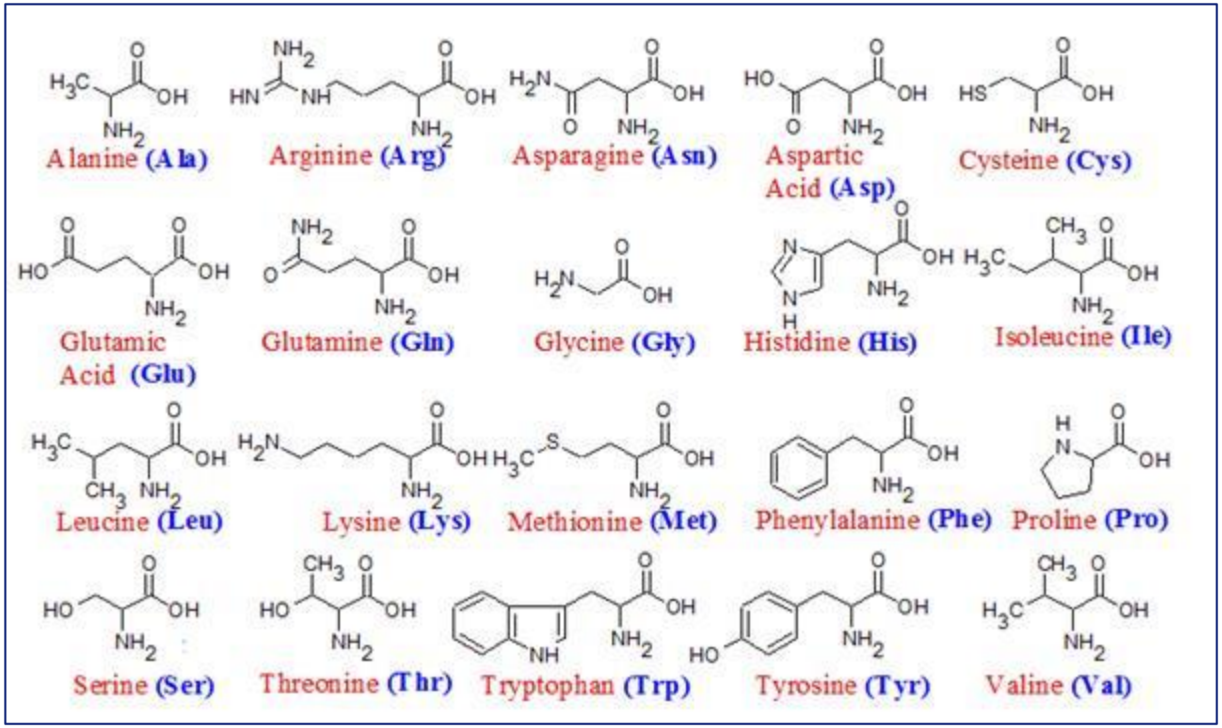
Johann Miescher

Major Events in the History of Molecular Biology in 19th Century

- **1881** **Edward Zacharias showed chromosomes are composed of nuclein**

- **1899** **Richard Altmann renamed nuclein to nucleic acid**

- **1900** **Chemical structures of all essential 20 amino acids were identified**



Major Events in the History of Molecular Biology in 20th Century

- **1902 Emil Hermann Fischer won Nobel prize: showed amino acids are linked and form proteins**

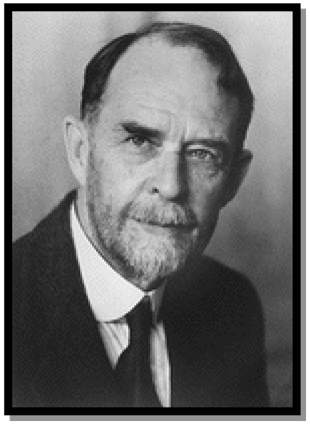
- **1911 Thomas Hunt Morgan discovered genes on chromosomes are the discrete units of heredity**

- **1911 Pheobus Aaron Theodore Lerene discovered RNA**

- **1917 Felix D'Herelle discovered microbe antagonistic toward bacteria Shigella: "Bacteriophages" which means bacteria eater**

- **1928 Alexander Fleming discovered antibacterial action of penicillium (Br. J. Exp. Pathol. 10 (1929) 226)**

Emil Fischer



Thomas Morgan

Major Events in the History of Molecular Biology in 20th Century

- **1941 George Beadle and Edward Tatum distangled that genes make proteins**

- **1950 Edwin Chargaff found Cytosine complements Guanine and Adenine complements Thymine**

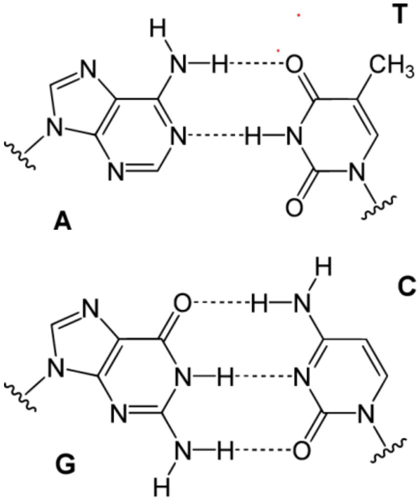
George Beadle

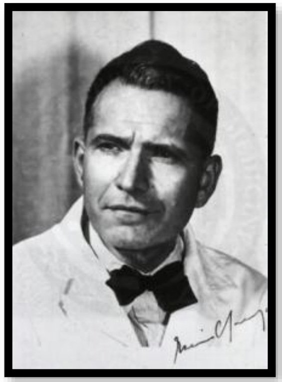
Edward Tatum

Chargaff rules:

1st %A = %T and %G = %C

2nd %A ≈ %T und %G ≈ %C,
for both DNA single strands



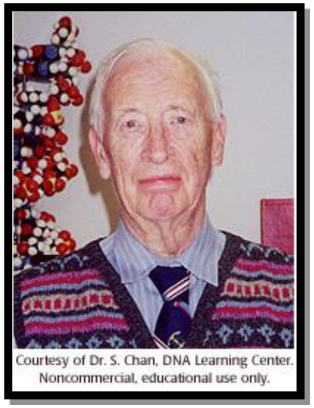


Edwin Chargaff

Major Events in the History of Molecular Biology in 20th Century

- **1950s Mahlon Bush Hoagland first to isolate tRNA**

- **1952 Alfred Hershey and Martha Chase made genes from DNA**



Mahlon Bush Hoagland

Major Events in the History of Molecular Biology in 20th Century

- **1952-1953 James D. Watson and Francis H. C. Crick deduced the double helical structure of DNA from x-ray diffraction images taken by Rosalind Franklin**

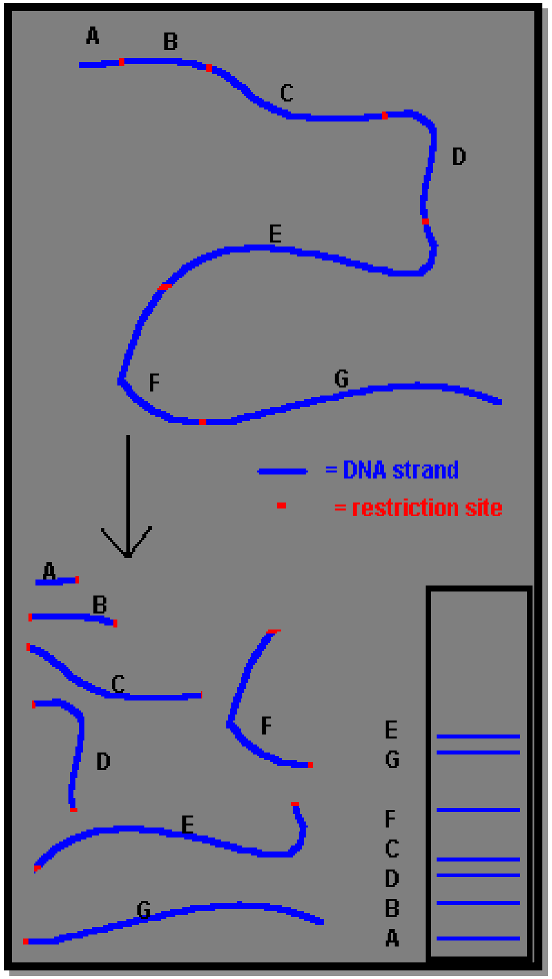
James D. Watson and Francis Crick

- **1956 George Emil Palade showed the site of enzymes manufacturing in the cytoplasm is made on RNA organelles called ribosomes.**

George Emil Palade

Major Events in the History of Molecular Biology in 20th Century

- **1970 Howard Temin and David Baltimore independently isolate the first restriction enzyme**
- **This means that: DNA can be cut into reproducible pieces at specific site by restriction enzymes called endonuclease**
- **The pieces can be linked to bacterial vectors and introduced into bacterial hosts**
- **This is called (gene cloning or recombinant DNA technology)**



Major Events in the History of Molecular Biology in 20th Century

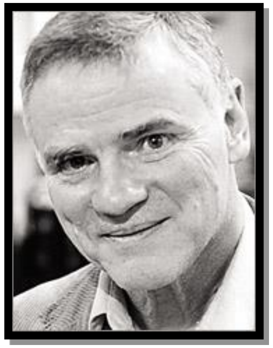
- **1977 Phillip Sharp and Richard Roberts demonstrated that pre-mRNA is processed by the excision of introns and exons are spliced together**

Phillip Sharp

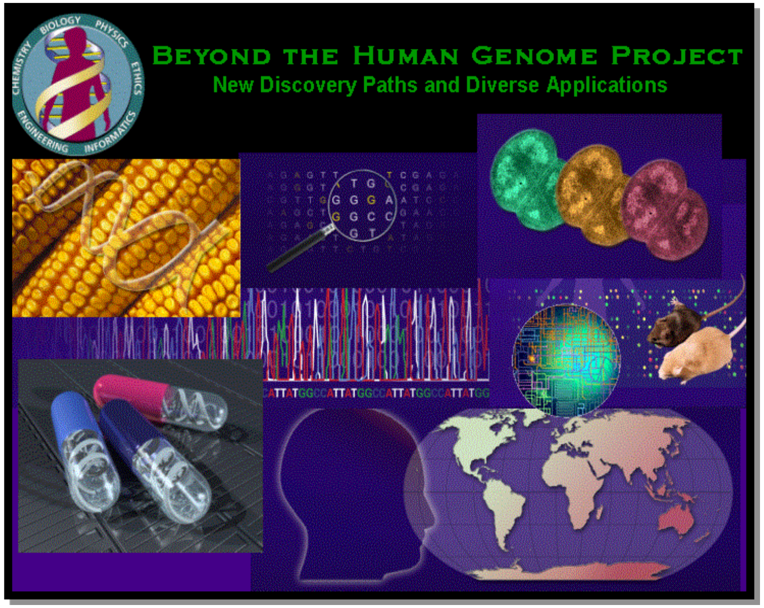
Richard Roberts

Major Events in the History of Molecular Biology in 20th Century

- 1986 Leroy Hood: Developed automated sequencing mechanism
- 1986 Human Genome Initiative announced
- 1987 Ishino discovered in E. coli „Clustered Regularly Interspaced Short Palindromic Repeats" (CRISPR)
- 1995 Moderate resolution maps of chromosomes 3, 11, 12, and 22 were published
- These maps provide the locations of "markers" on each chromosome to make locating genes easier



Leroy Hood



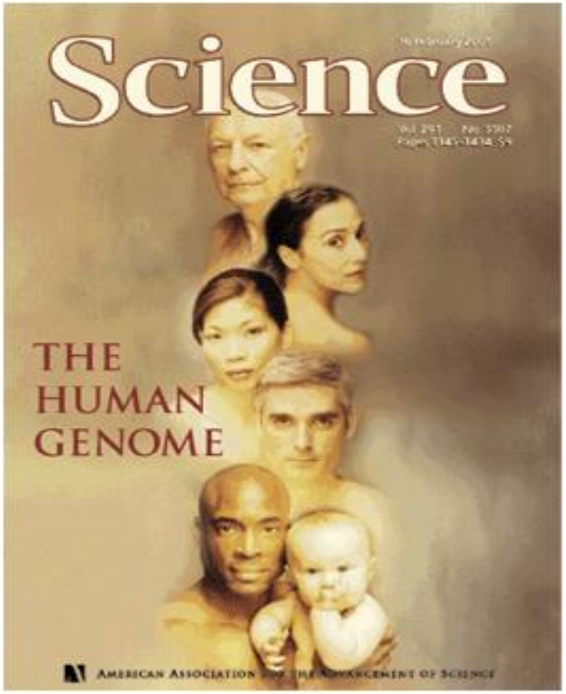
Major Events in the History of Molecular Biology in 20th Century

- **1995 John Craig Venter: First bacterial genomes (Haemophilus influenzae) sequenced**
- **1995 Automated fluorescent sequencing instruments and robotic operations**
- **1996 First eukaryotic genome-yeast-sequenced**

John Craig Venter

Major Events in the History of Molecular Biology in 20th Century

- **1999 First human chromosome (# 22) sequenced**
- **2001 International Human Genome Sequencing published the first draft of the sequence of the human genome**
- **2002 Jansen identified genes associated with DNA repeats in prokaryotes: CAS-genes (CRISPR Associated genes)**
- **2007 Immunity of bacteria towards phages caused by up-take of DNA into CRISPR areas**



- **2019 CRISPR used to treat a patient with a genetic disorder (sickle cell disease)**
- **2020 UK: Approval of first vaccine (BNT162b2) based on m-RNA**