Astroparticle Physics

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Lecture 1

Lectures Plan

Termine					
	Datum	Von	Bis	Raum	Lehrende/r
1	**Do, 16. Apr. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
2	**Mo, 20. Apr. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
3	**Do, 23. Apr. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
4	**Mo, 27. Apr. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
5	**Do, 30. Apr. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
6	**Mo, 4. Mai 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
7	**Do, 7. Mai 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
8	**Mo, 11. Mai 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
9	**Do, 14. Mai 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
10	**Mo, 18. Mai 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
11	**Mo, 25. Mai 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
12	**Do, 28. Mai 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
13	**Do, 4. Jun. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
14	**Mo, 8. Jun. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
15	**Mo, 15. Jun. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
16	**Do, 18. Jun. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
17	**Mo, 22. Jun. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
18	**Do, 25. Jun. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
19	**Mo, 29. Jun. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
20	**Do, 2. Jul. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
21	**Mo, 6. Jul. 2020**	**08:15**	**09:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria
22	**Do, 9. Jul. 2020**	**12:15**	**13:45**	**00 260 Seminarraum 1 Kernphysik**	Dr. Luca Doria

Notes and Slides:
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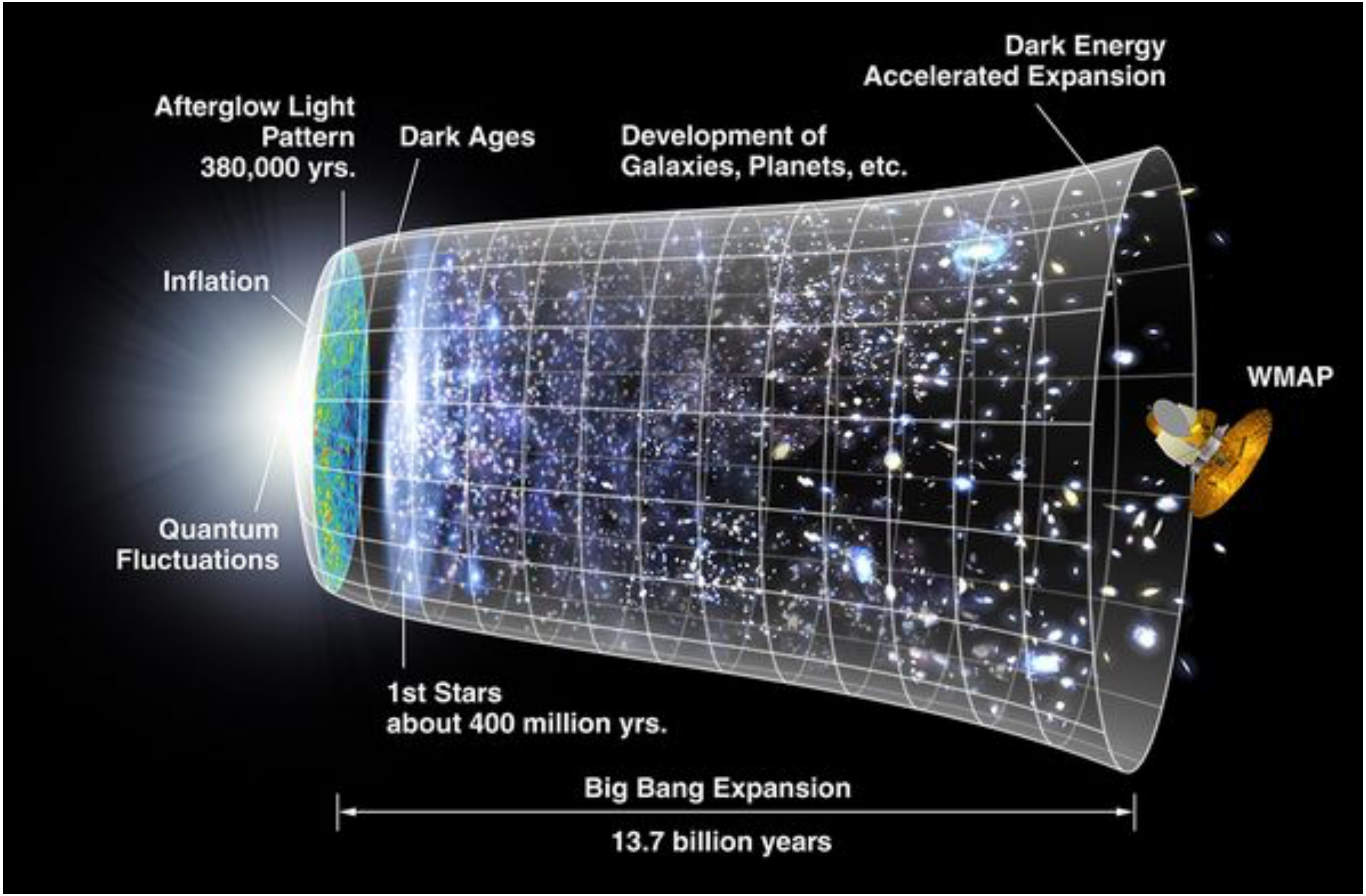
Topics

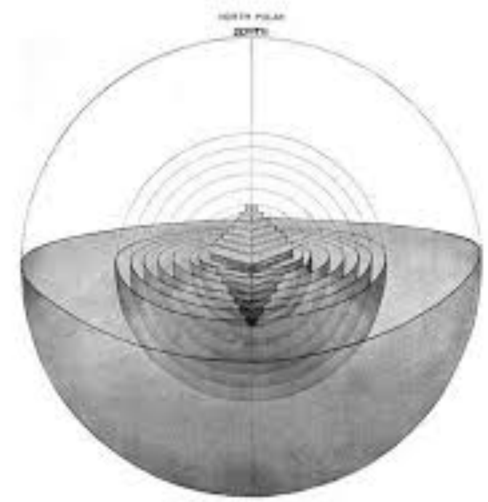
* General Introduction
* Cosmic History
* General Relativity and Cosmology
* Thermodynamics of the expanding Universe
* Big Bang Nucleosynthesis
* Cosmic Rays
* Stellar evolution
* Neutrinos in the Cosmos
* Dark Matter / Dark Energy
* Experimental Methods
* Gravitational Waves

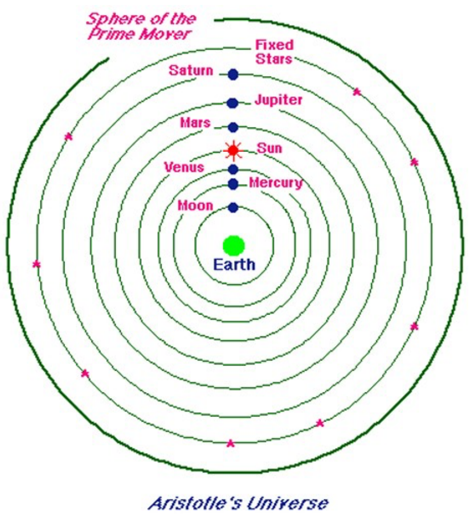
Cosmic History



(Ancient) History

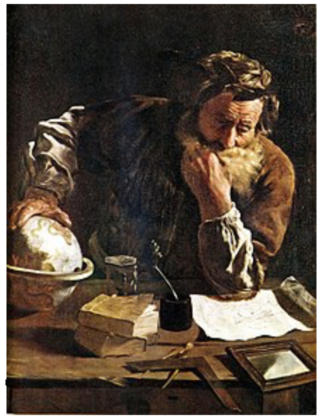
<16th century BC, Mesopotamian:
Flat, circular Earth in the middle of an ocean



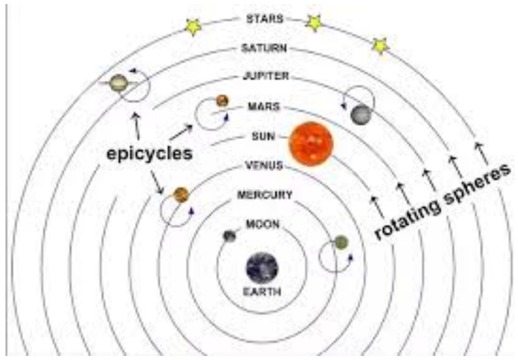


4th century BC, Aristotle:
Earth-centric, finite, immutable universe

3th century BC, Archimedes
“measured” the diameter of the Universe (2lyr !)

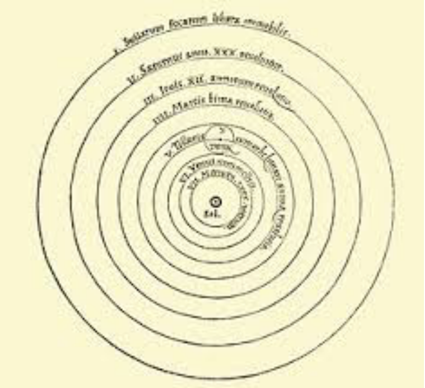


2th century BC, Ptolemy:
Earth-Centred universe, Sun and planets revolving



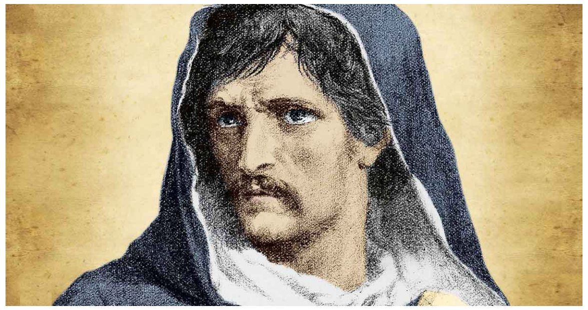
Non-European astronomers proposing Sun-centered theories

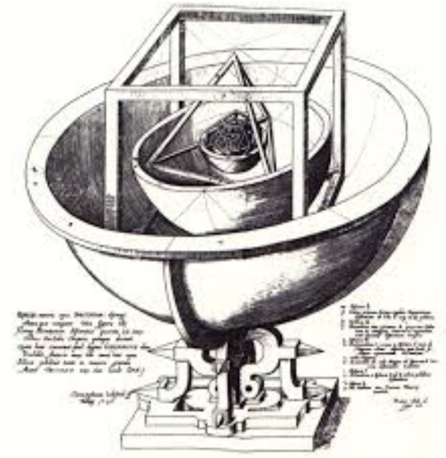
(non-BC) History



1540s: Copernicus
proposes the heliocentric theory

1584: Giordano Bruno
proposes a non-privileged position of the Sun in the cosmos.





1600s: Kepler
discovered his laws and elliptic motion.
He believed in a finite universe

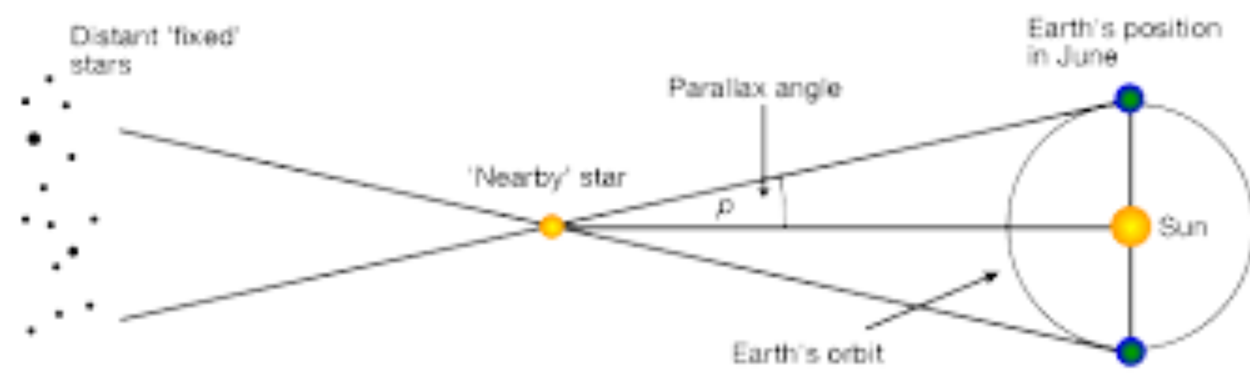
1680s: Isaac Newton:
Theory if Gravitation

(non-BC) History

1755: I. Kant
argues that nebulae are really separate galaxies

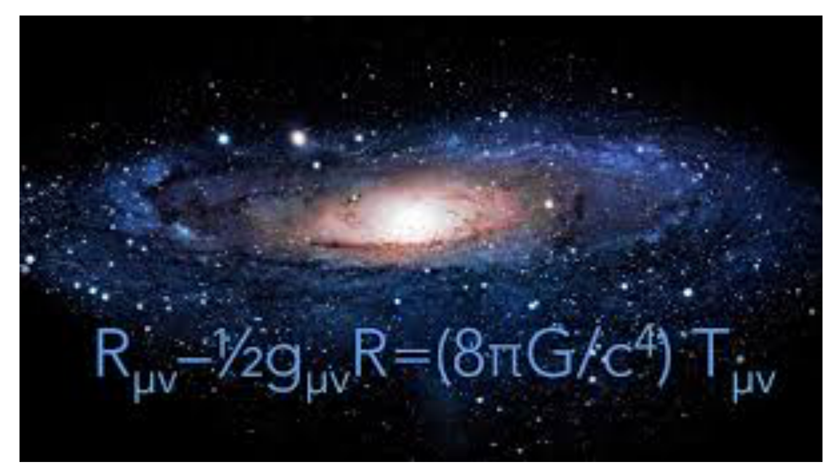
1826: Olber's Paradox

1837: Bessel
successfully measures the first parallax



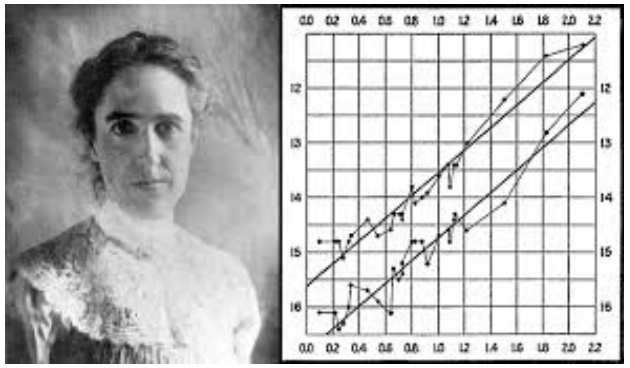
1911-13: V. Hess
Discovery of Cosmic Rays

1915: A. Einstein
publishes the General Relativity Theory

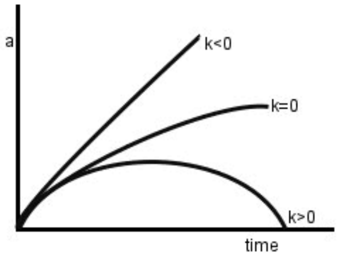


(after GR) History

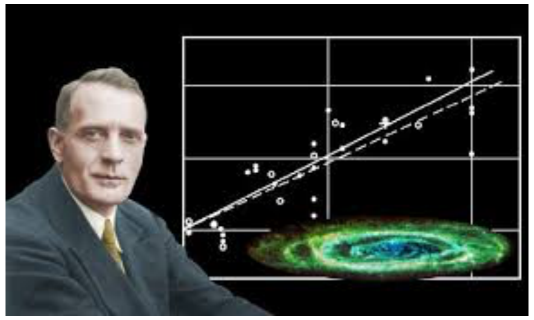
1912: Henrietta Leavitt discovers the Cepheid variable stars



1922: Friedmann finds expanding solutions of GR



1923: E. Hubble measures an apparent expansion of the universe



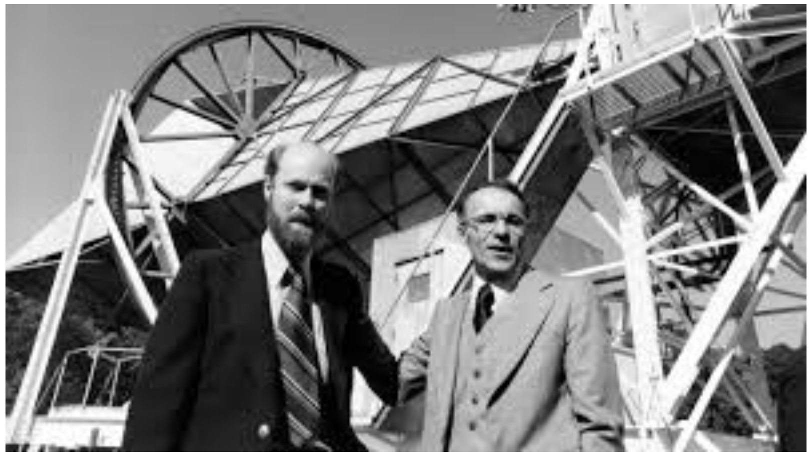
1933: E. Milne states the Cosmological Principle

1948: G. Gamow predicts the CMB

(after GR) History

1950: F. Hoyle coins the word “Big-Bang”

1965: A. Penzias and R. Wilson discover the CMB



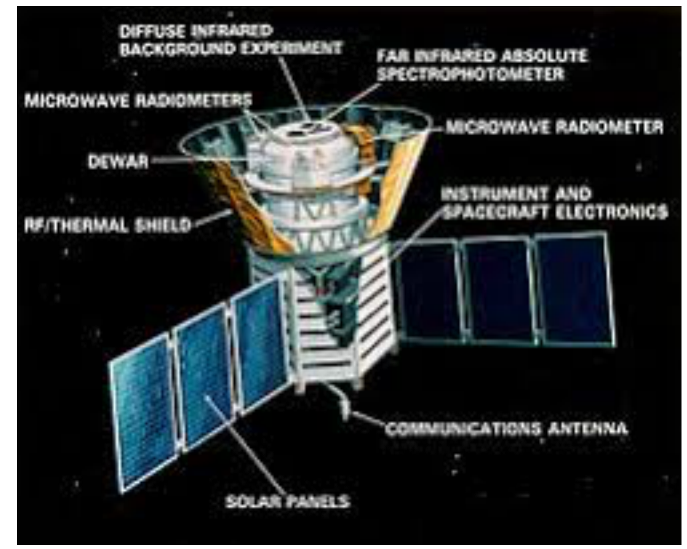
1967: A. Sakharov states the requirements for baryogengesis

1970: V. Rubin and K. Ford
present precise data on galaxy rotational curves

(Modern) History

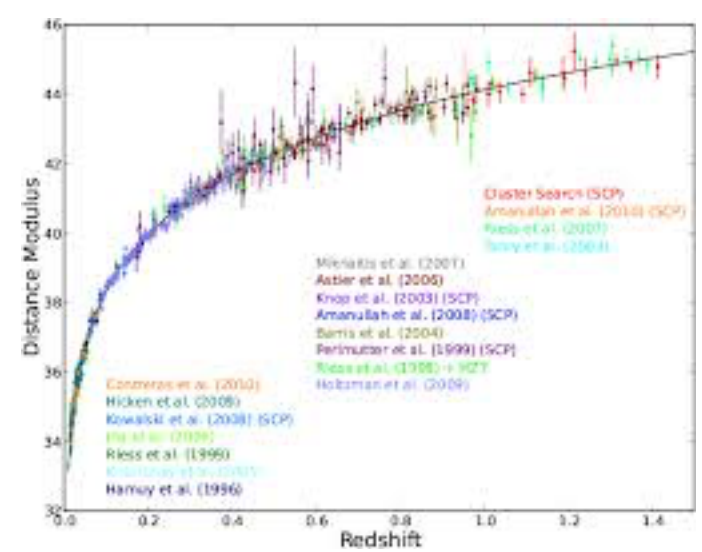
1980: A. Guth presents the idea of cosmic inflation

1982: J.Peebles and others propose CDM



1990s: COBE Mission
and the first measurement of CMB anisotropy

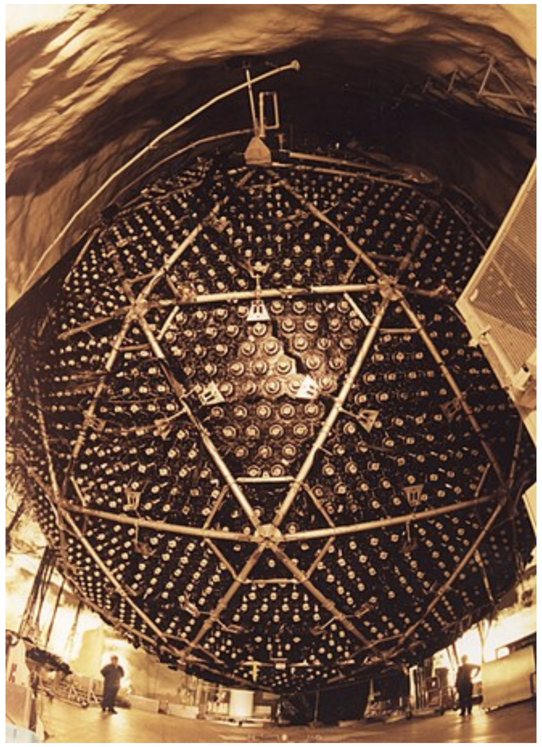
1996: Hubble Space Telescope deep-field pictures



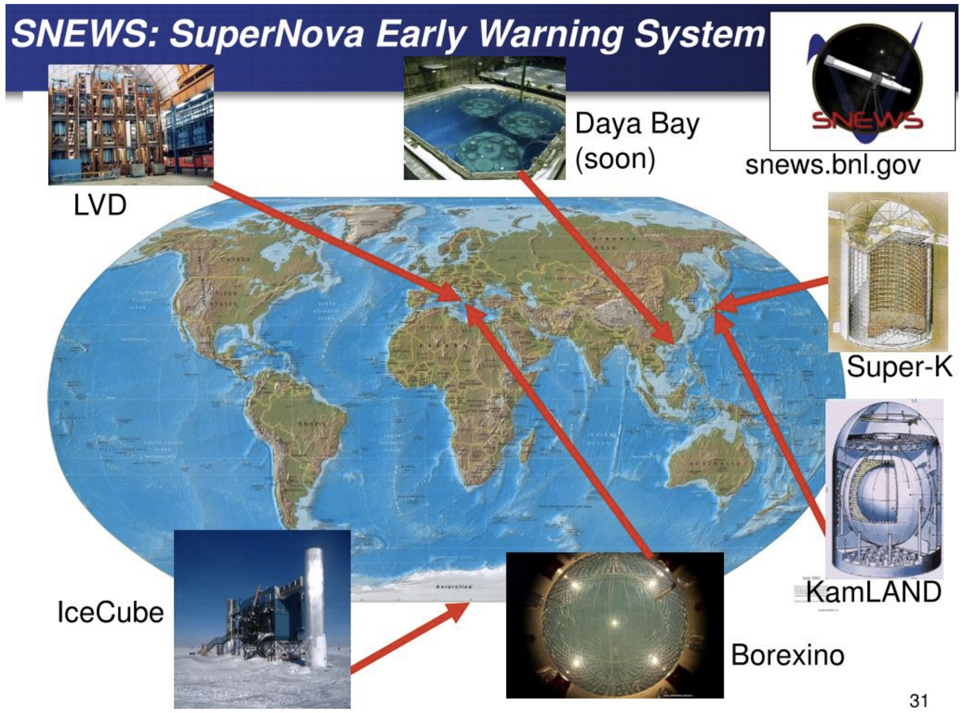
1998: Supernova Cosmology Project and High-Z Supernova Search

1999: More **COBE** data and **BOOMERanG** experiment

2001: The SNO Experiment
Oscillation of solar neutrinos

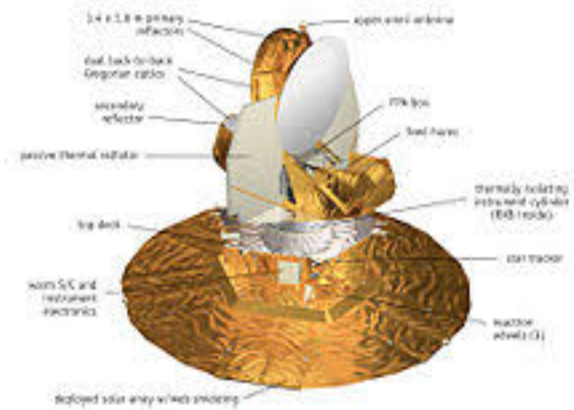


~2004: SNEWS
Different detectors around the world formed a network for an early-warning system for supernovae explosions based on neutrinos.



(Modern) History

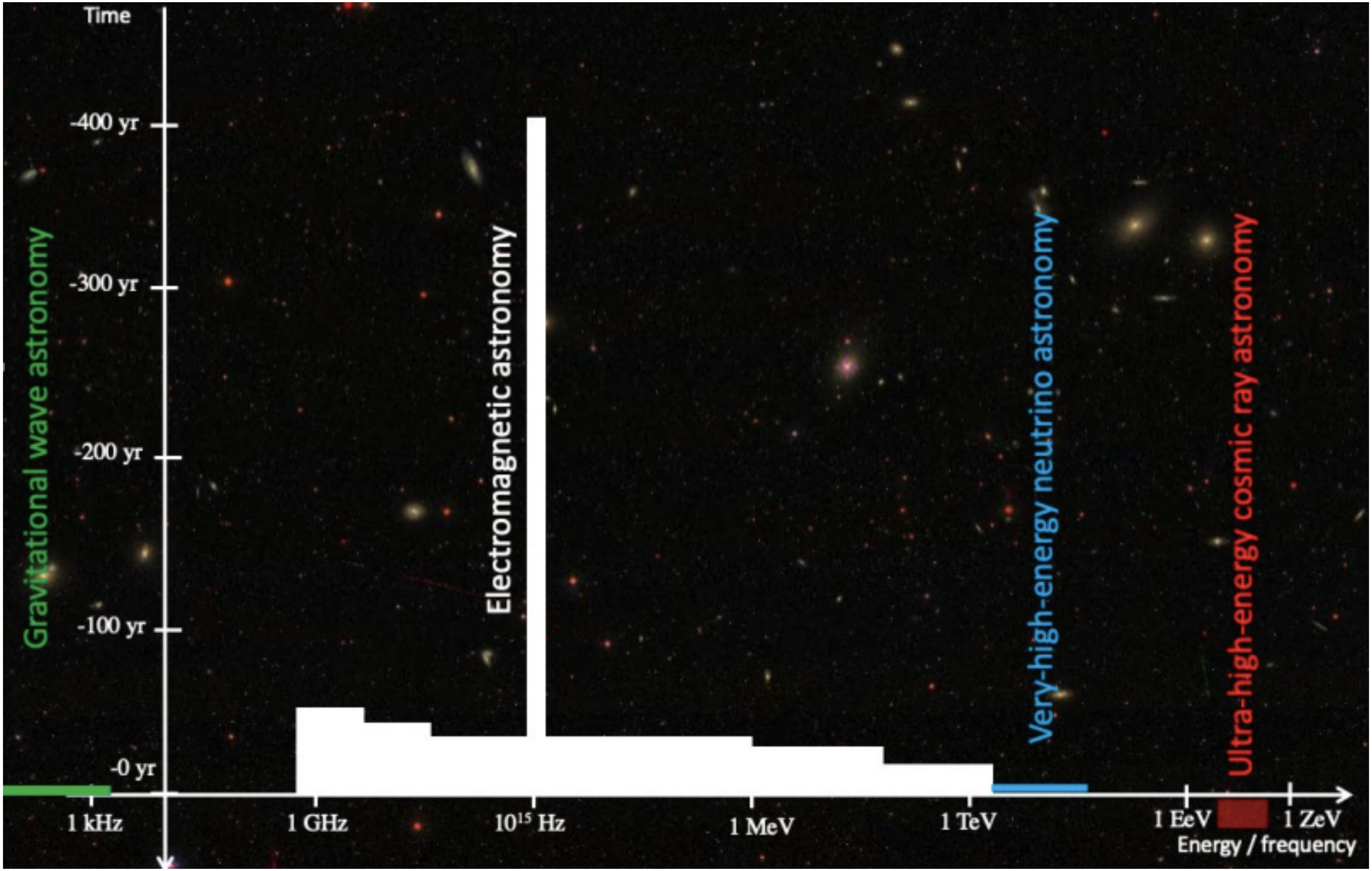
2003-2011: WMAP, Planck and LambdaCDM



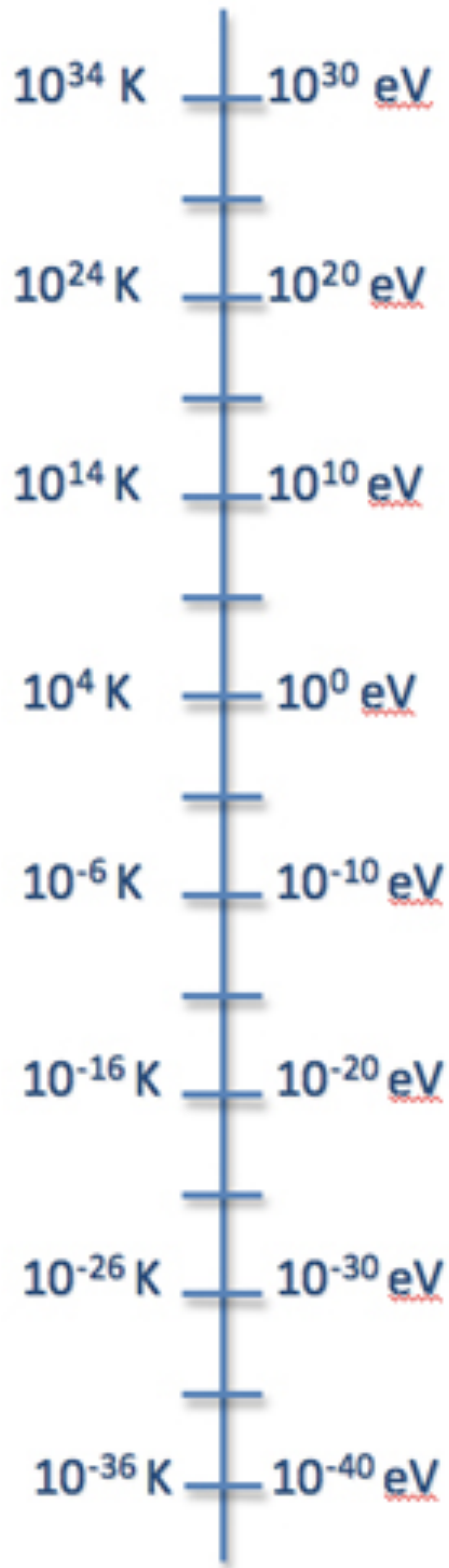
2014: BICEP2 and (the not confirmed) B-modes

2016: First Measurement on Earth of Gravitational Waves

TODAY: Multimessenger Astronomy



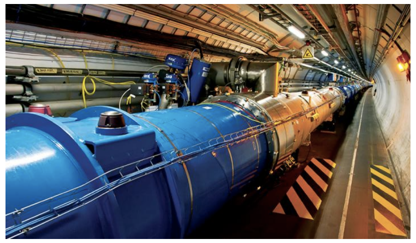
Energy and Length Scales

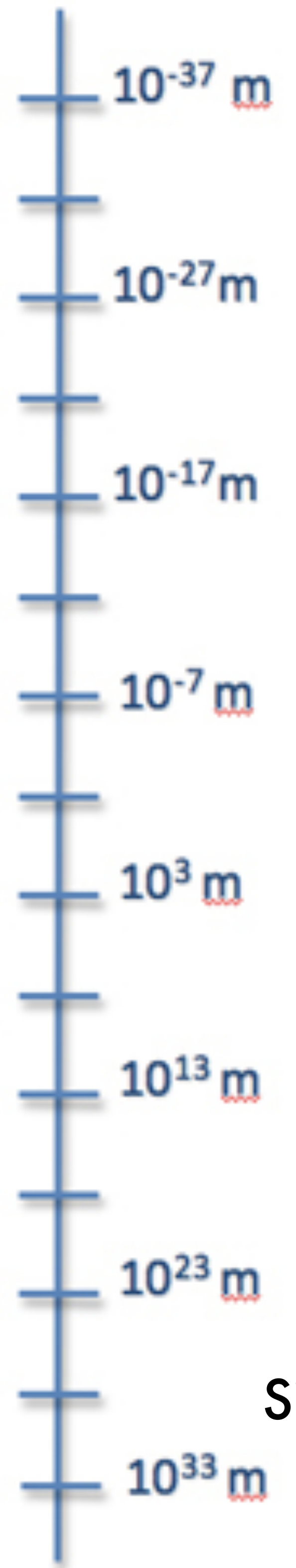


$$E_{\mathrm{P}} = \sqrt{\frac{\hbar c^5}{G}},$$

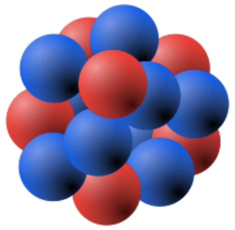
Planck Scale

LHC Collisions

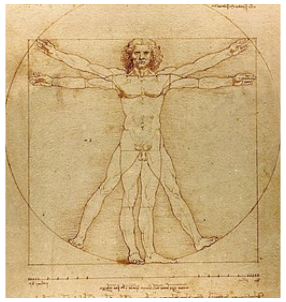




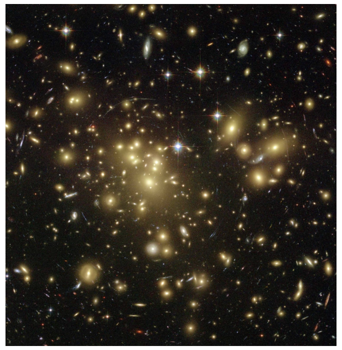
Nuclei



Atoms



Our Size



Galaxy Clusters

Size of the Universe

Units

Natural Units $\boxed{c = \hbar = \epsilon_\circ = k_B = 1}$

$$\boxed{\begin{aligned} c &= \text{speed of light} = 2.9979 \times 10^{8}\ \text{m/s} \\ \hbar &= \text{reduced Planck constant} = 1.0546 \times 10^{-34}\ \text{J s} \\ \epsilon_\circ &= \text{electric constant} = 8.8542 \times 10^{-12}\ \text{A}^2\ \text{s}^4\ \text{kg}^{-1}\ \text{m}^{-3} \\ k_B &= \text{Boltzmann constant} = 1.3806 \times 10^{-23}\ \text{J K}^{-1} \end{aligned}}$$

Consequences of this choice:

$$1s = 2.9979 \times 10^{8} m$$

$$1s^{-1} = 1.0546^{-34} J$$

Let's try to measure everything with Energy!

This means: $[time] = [length] = [Energy]^{-1}$

What about velocity, momentum, mass,...?

Conversions

Conversion form SI

SI units are combinations of mass/length/time units.
We would like to convert everything in energy, eventually setting hbar=c=1

$$kg^{\alpha} m^{\beta} s^{\gamma} = E^{a} \hbar^{b} c^{c}$$

Converting E, hbar, c in SI units and comparing the exponents, we obtain

$$\boxed{kg^{\alpha} m^{\beta} s^{\gamma} = E^{\alpha-\beta-\gamma} \hbar^{\beta+\gamma} c^{\beta-2\alpha}}$$

Common choice for [E] is GeV (1.6022×10^{-10} J)

Conversions

Variable	SI Unit	Natural Unit	Factor	Natural unit $\rightarrow$ SI unit
mass	kg	E	c^{-2}	1 GeV $\rightarrow 1.7827 \times 10^{-27}$ kg
length	m	E^{-1}	$\hbar c$	1 $\mathrm{GeV}^{-1} \rightarrow 1.9733 \times 10^{-16}$ m
time	s	E^{-1}	$\hbar$	1 $\mathrm{GeV}^{-1} \rightarrow 6.5823 \times 10^{-25}$ s
energy	kg m^2 s^{-2}	E	1	1 GeV $\rightarrow 1.6022 \times 10^{-10}$ J
momentum	kg m s^{-1}	E	c^{-1}	1 GeV $\rightarrow 5.3444 \times 10^{-19}$ kg m s^{-1}
velocity	m s^{-1}	dimensionless	c	1 $\rightarrow 2.9979 \times 10^{8}$ m s^{-1}
angular momentum	kg m^2 s^{-1}	dimensionless	$\hbar$	1 $\rightarrow 1.0546 \times 10^{-34}$ J s
area	m^2	E^{-2}	$(\hbar c)^2$	1 $\mathrm{GeV}^{-2} \rightarrow 3.8938 \times 10^{-32}$ m^2
force	kg m s^{-2}	E^2	$(\hbar c)^{-1}$	1 $\mathrm{GeV}^2 \rightarrow 8.1194 \times 10^{5}$ N
energy density	kg m^{-1} s^{-2}	E^4	$(\hbar c)^{-3}$	1 $\mathrm{GeV}^4 \rightarrow 2.0852 \times 10^{37}$ J m^{-3}
charge	$\mathrm{C} = \mathrm{A} \cdot \mathrm{s}$	dimensionless	1	1 $\rightarrow 5.2909 \times 10^{-19}$ C

Planck Scale

The fundamental constants of Nature set a natural scale for the measurement units:

Planck length: $$l_P = \sqrt{\frac{\hbar G}{c^3}} \qquad \sim 1.6 \times 10^{-35} m$$

Planck Mass: $$m_P = \sqrt{\frac{\hbar c}{G}} \qquad \sim 2.1 \times 10^{-8} kg$$

Planck Time: $$t_P = \sqrt{\frac{\hbar G}{c^5}} \qquad \sim 5.4 \times 10^{-44} s$$

Planck Energy: $$E_P = \sqrt{\frac{\hbar c^5}{G}} \qquad \sim 1.96 \times 10^9 J \sim 1.22 \times 10^{19} GeV$$

..etc...