

天文学正在发现

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outline

1. 膨胀宇宙的发现
2. 暗物质的发现
3. 暗能量的发现
4. 宇宙微波背景辐射的发现
5. 中微子的发现
6. 引力波发现
7. 脉冲星的发现
8. 宇宙第一缕曙光的“发现”

X类通识课

新生研讨课

(注重：自己查阅文献、小组讨论、公众表达)

天文系必修、外单位选修

上课需携带笔记本电脑

8周课 / 16学时 (双周)、每次讲授1学时、讨论 / 发言1学时



考核方式：

平时出勤、课上表现占60%

期末论文占40%

新生研讨课

每堂课后都会有一个论文（英文1000字）候选题目，选择其中之一

平时作业：

每堂课后都会布置，下一堂课的文献调研题目

每小组200字调研论文（英文）+ 口头报告（中 / 英）

答疑：

有问题及时问（课下、微信群、办公室）

http://astrowww.bnu.edu.cn/sites/hubin/bh_bnu_homepage/#teach

课件：



Google

Baidu  百度

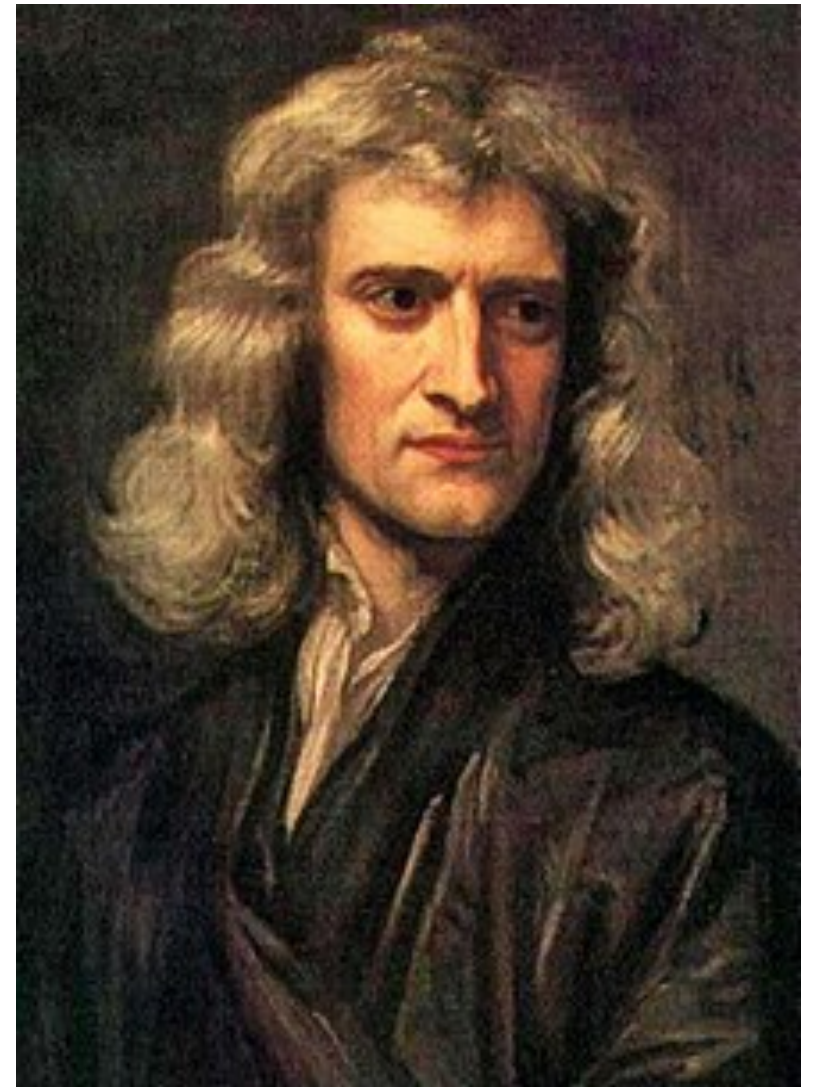
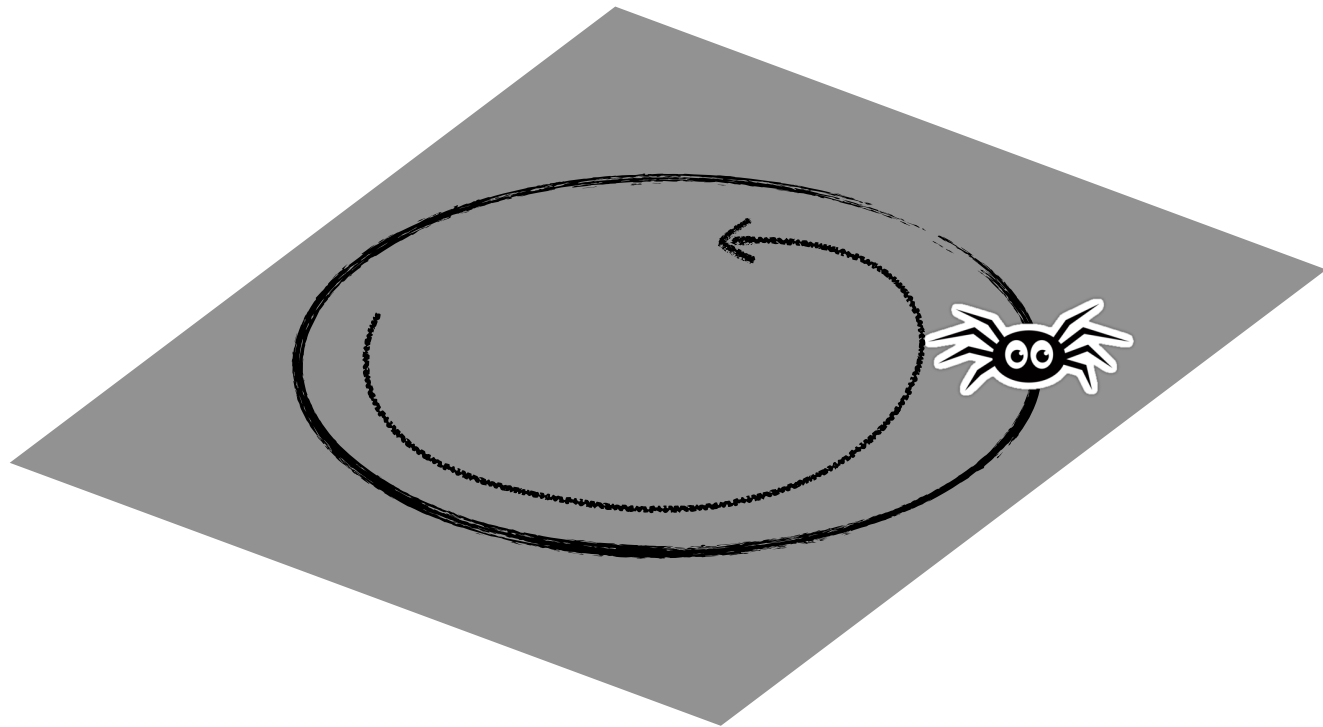
 Bing 

YAHOO! 

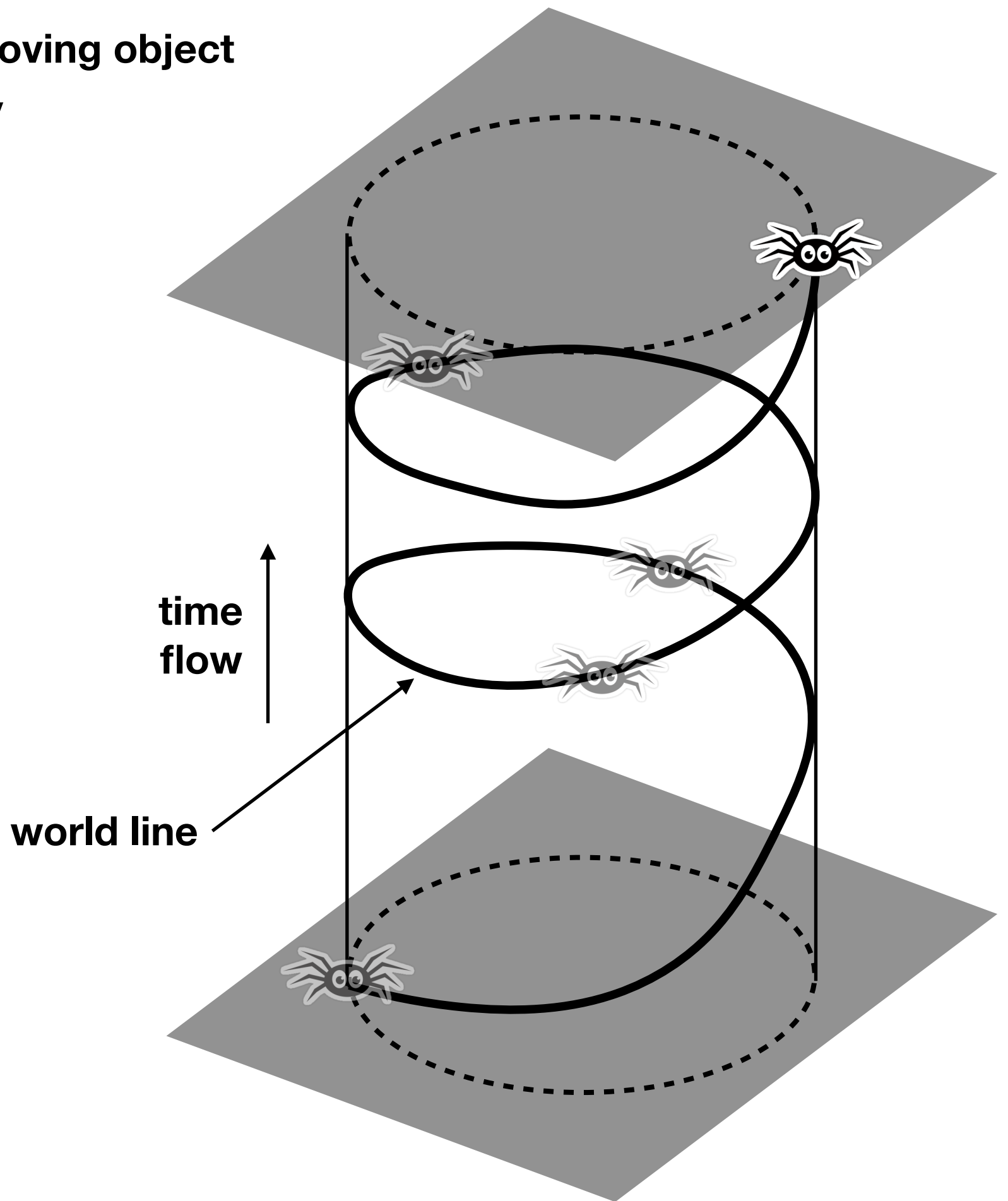
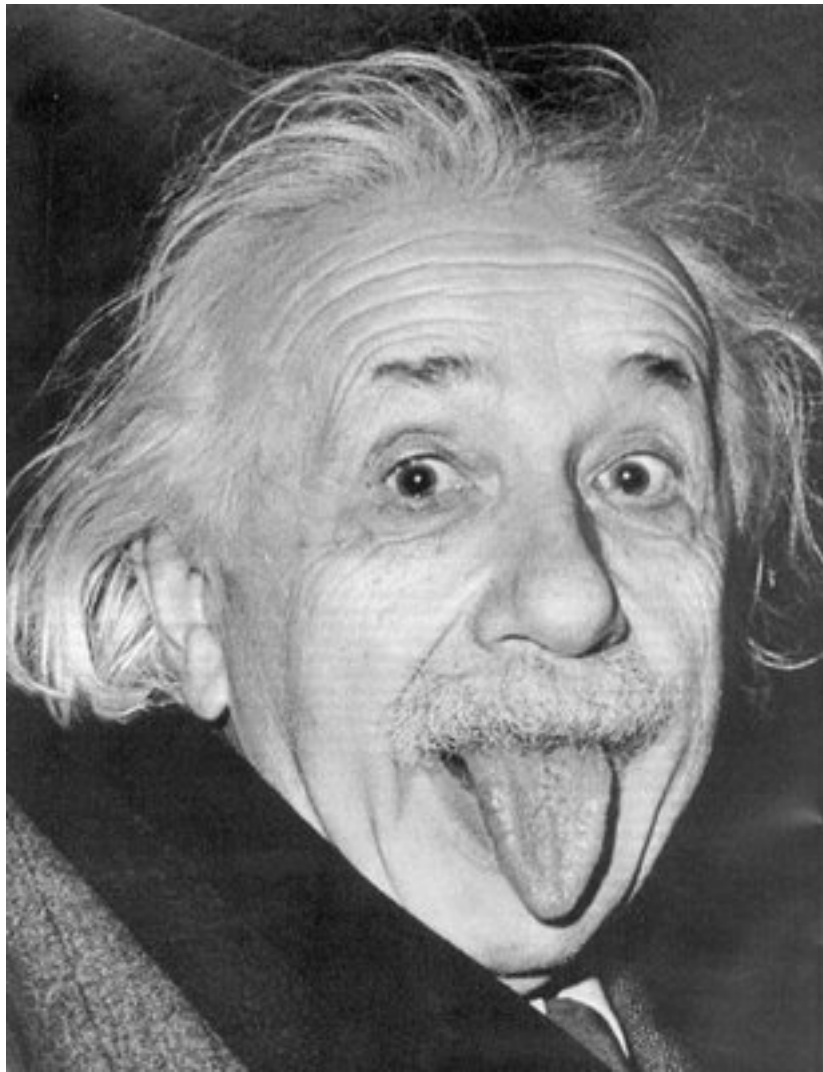
2018天文学正在发现
微信群二维码

助教：李四

1. 4维时空观 3+1维

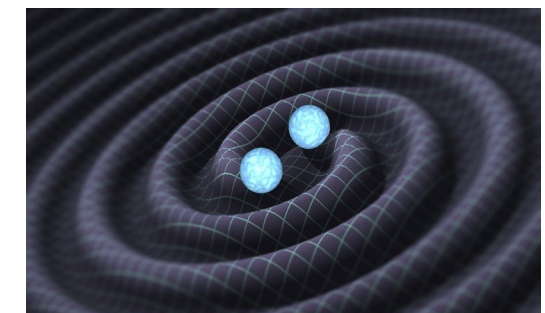
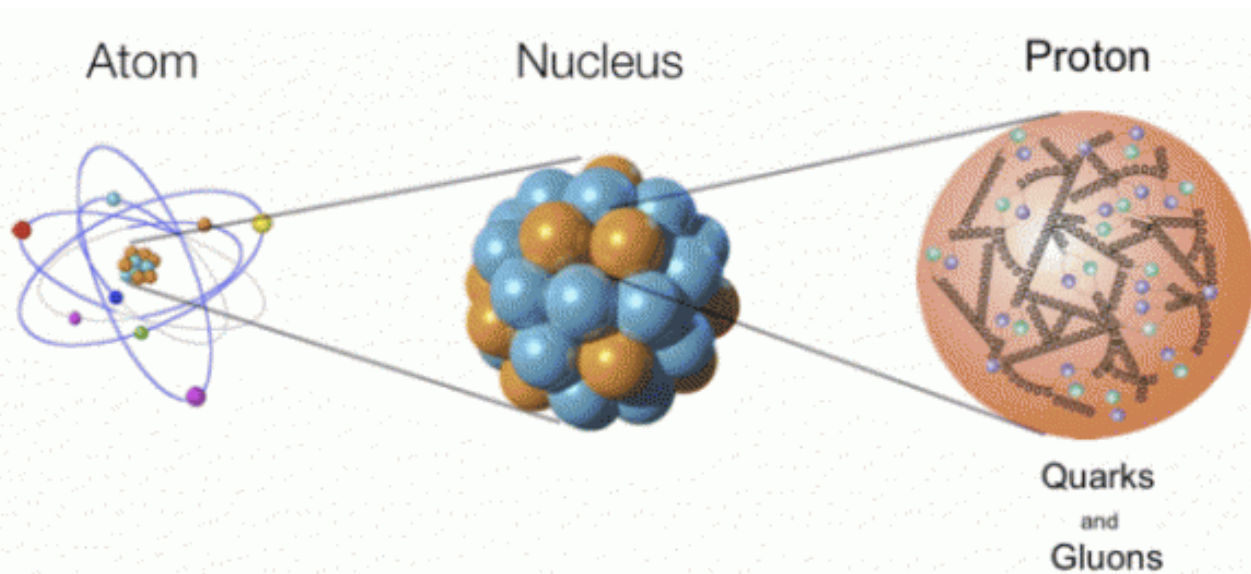
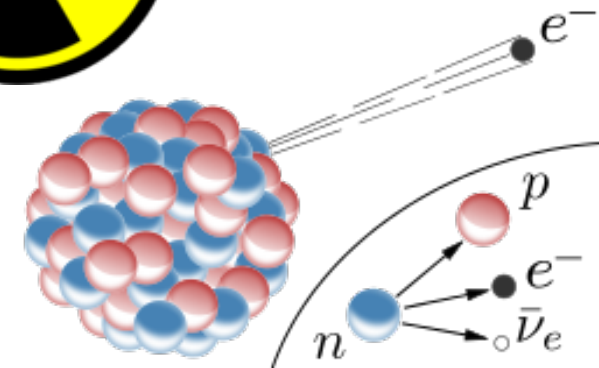
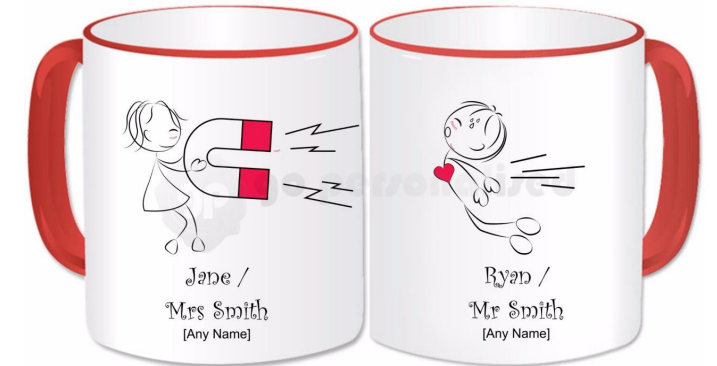


geodesic: the world line of the moving object
(最短线) under **ONLY** gravity



4 fundamental forces

Force	Diagram	Strength	Range (m)	Particle
<i>Strong</i>		1	10^{-15} (diameter of a medium sized nucleus)	gluons, π (nucleons)
<i>Electro-magnetic</i>		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
<i>Weak</i>		10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+ , W^- , Z_0 , mass > 80 GeV spin = 1
<i>Gravity</i>		6×10^{-39}	Infinite	graviton? mass = 0 spin = 2



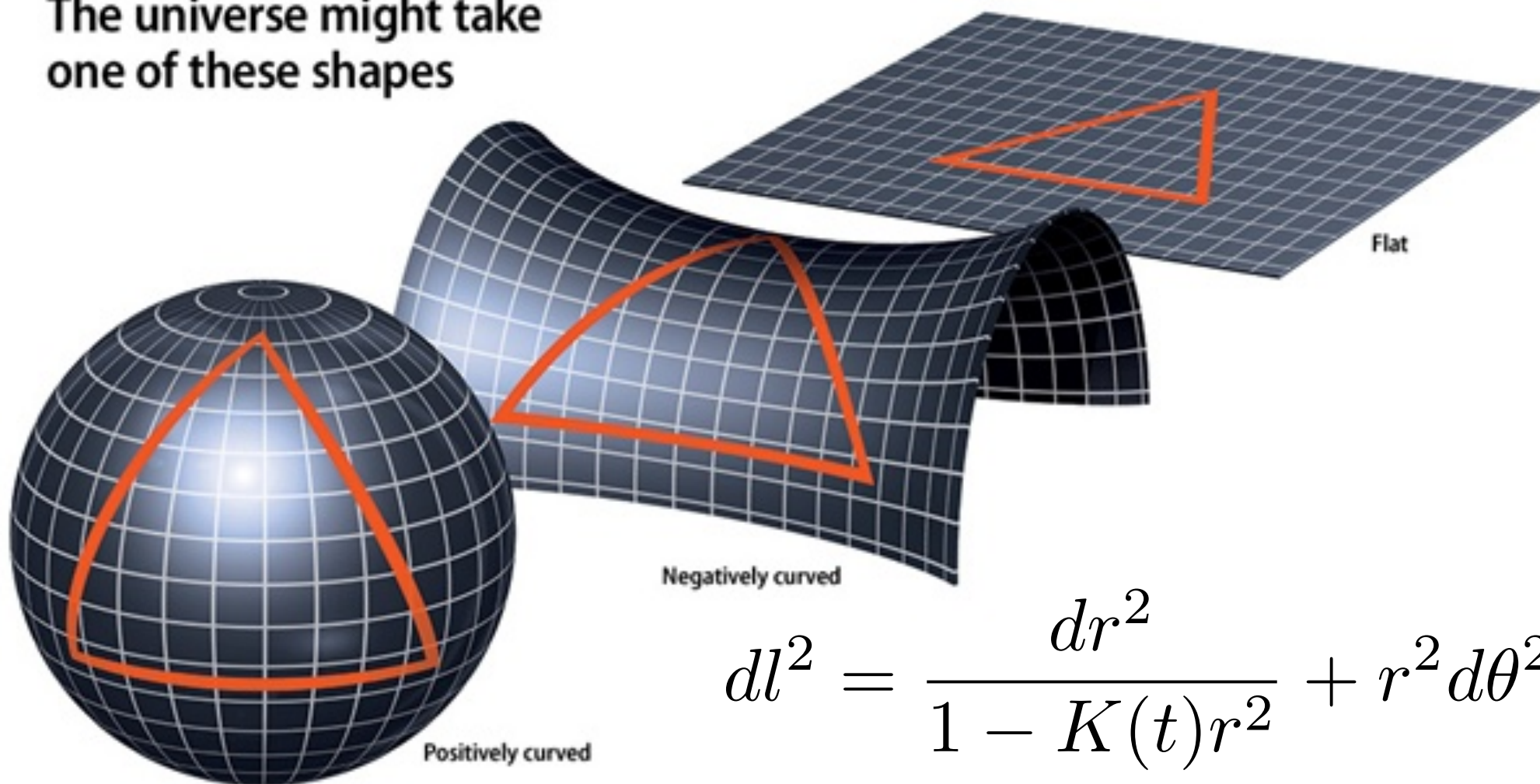
2. 时空几何 topology

$$dl^2 = dx^2 + dy^2 + dz^2$$

$$dl^2 = dr^2 + r^2 d\theta^2 + r^2 \sin^2 \theta d\phi^2$$



The universe might take one of these shapes



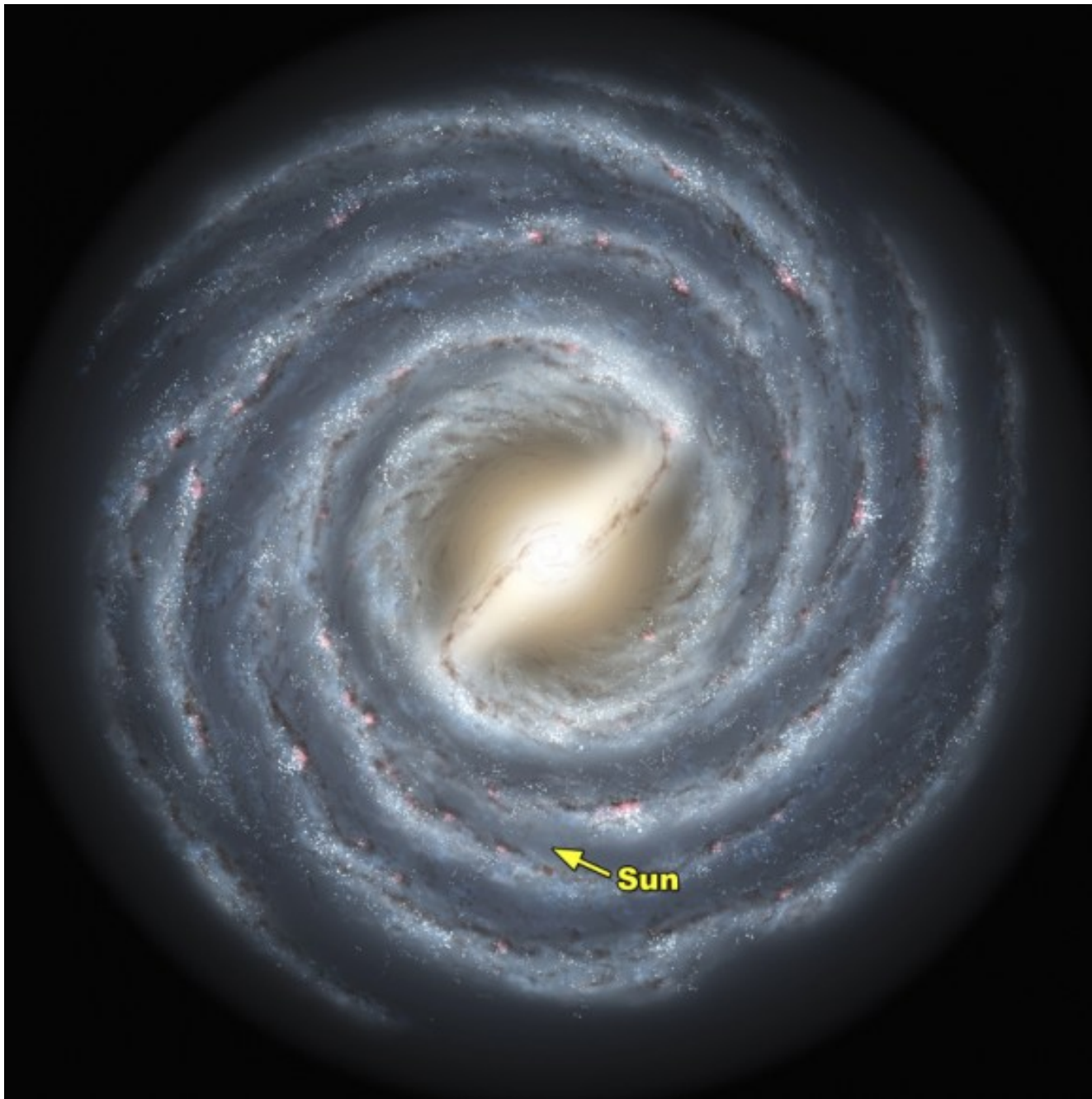
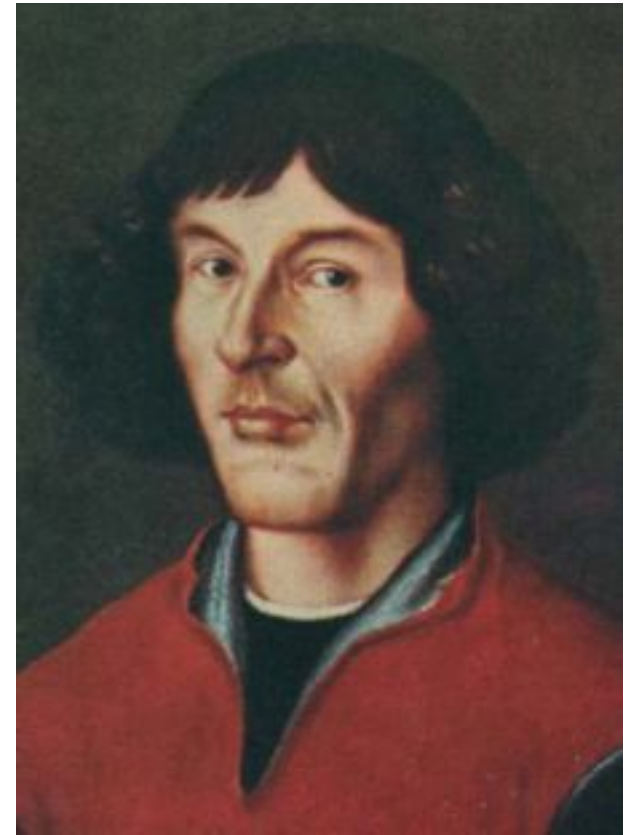
$$k = \begin{cases} +1 \rightarrow (\textit{close}) \\ 0 \rightarrow (\textit{flat}) \\ -1 \rightarrow (\textit{open}) \end{cases}$$

$$K(t) = \frac{k}{a^2(t)}$$

$$dl^2 = \frac{dr^2}{1 - K(t)r^2} + r^2 d\theta^2 + r^2 \sin^2 \theta d\phi^2$$

3. 宇宙学原理 (Copernican principle)

For a **co-moving observer**, on the **large** scale, the universe is **homogenous** and **isotropic**.

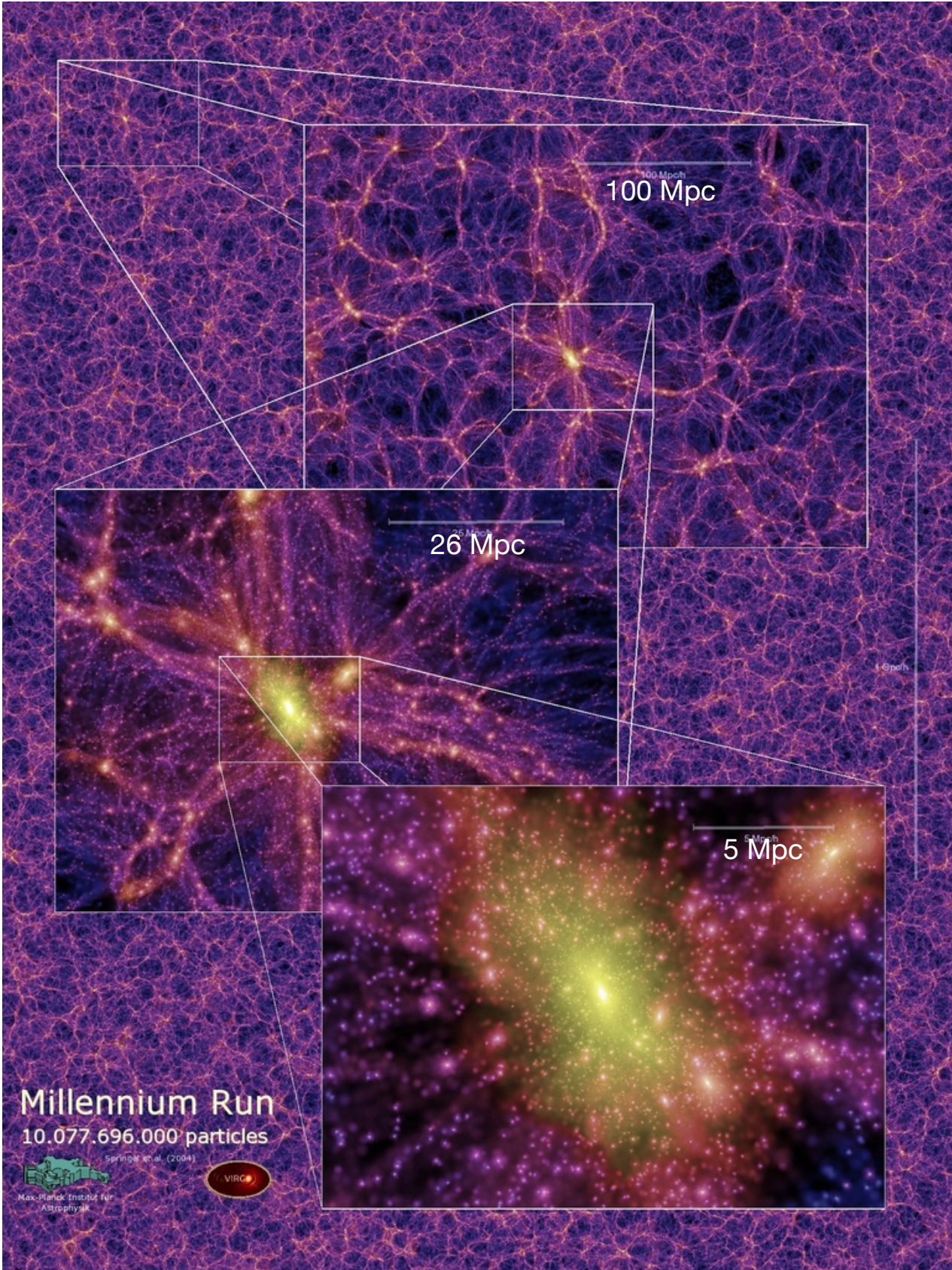
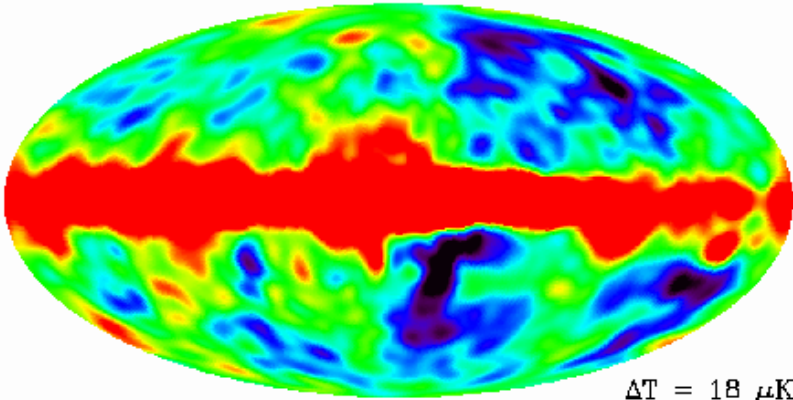
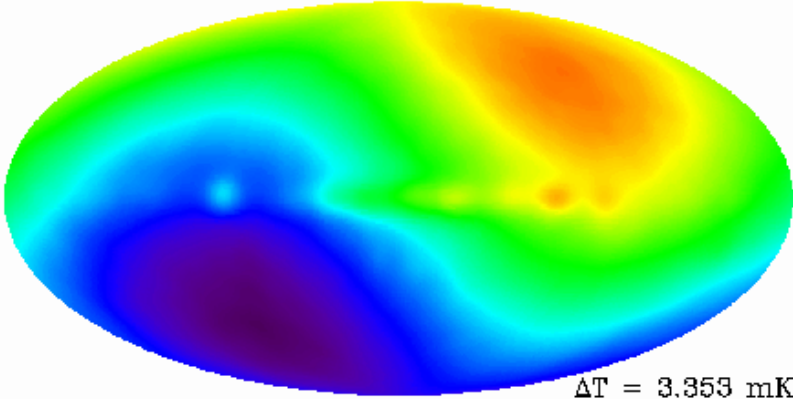


For a **co-moving observer**, on the **large** scale, the universe is **homogenous** and **isotropic**.

1. Observer: co-move with the background expansion

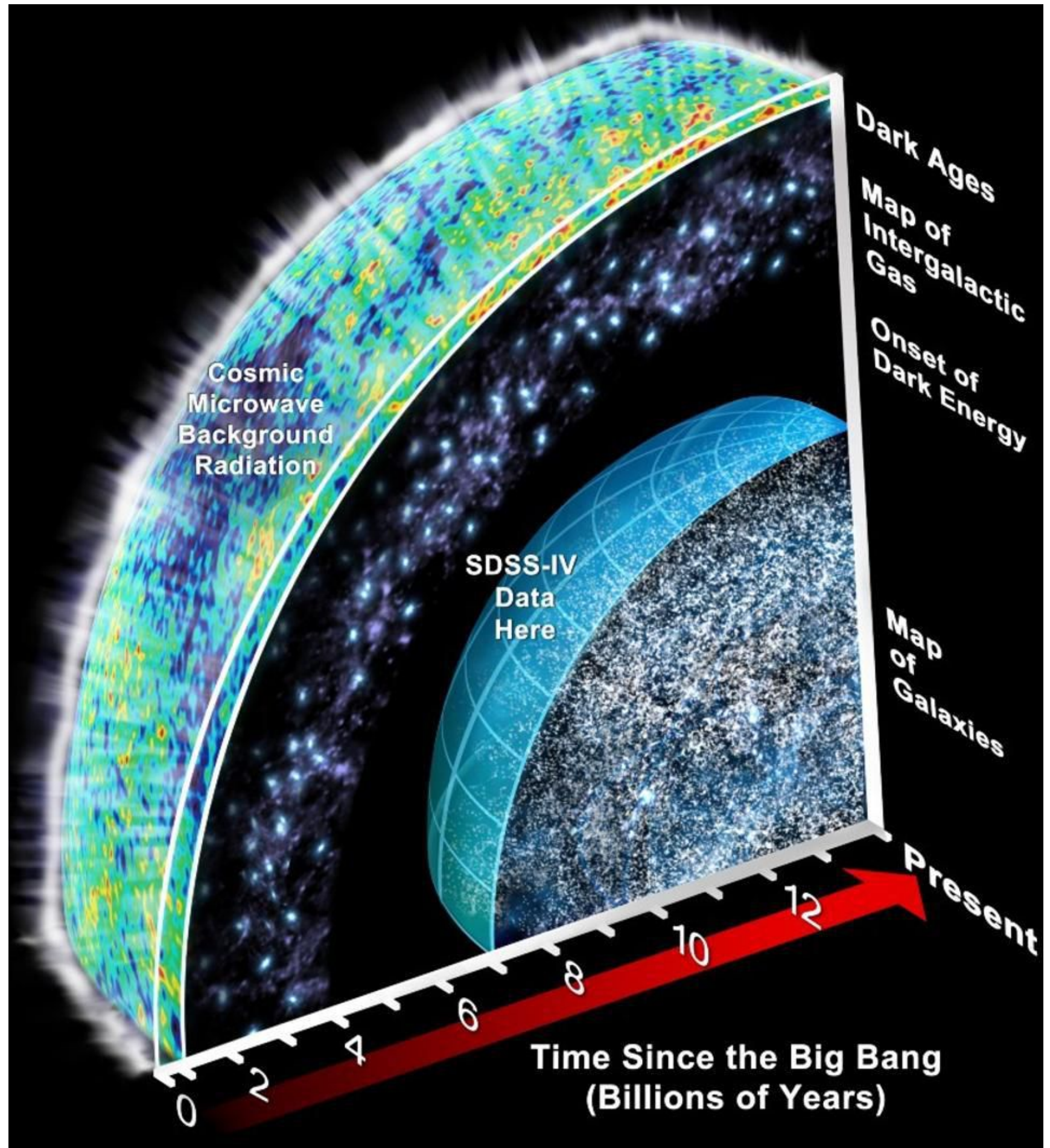
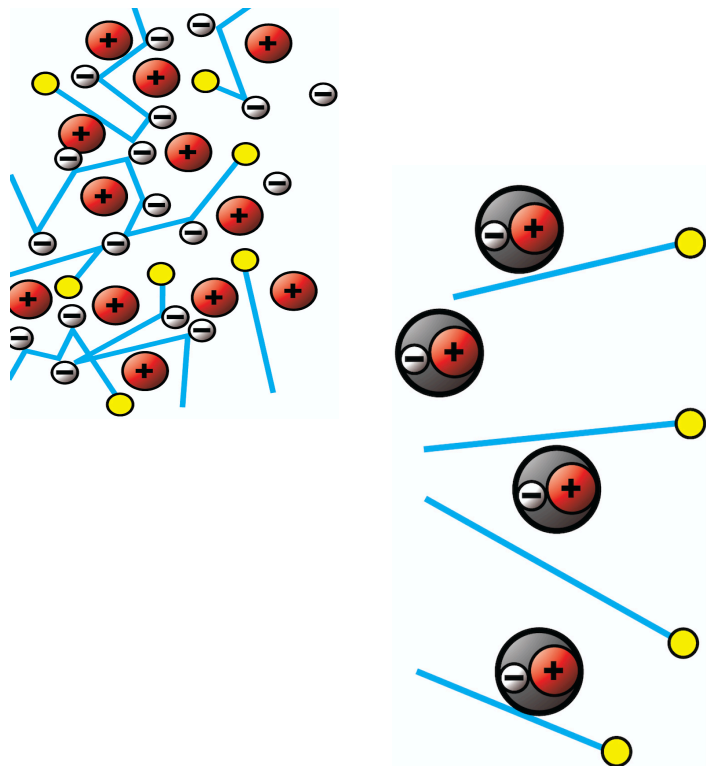
2. On this scale (> 1 Mpc):
each galaxy is like a test particle

[milky way ~ 15 kpc,
1 pc ~ 3 ly]



Cosmic
Microwave
Background

The **faintest**
light we can
ever see!



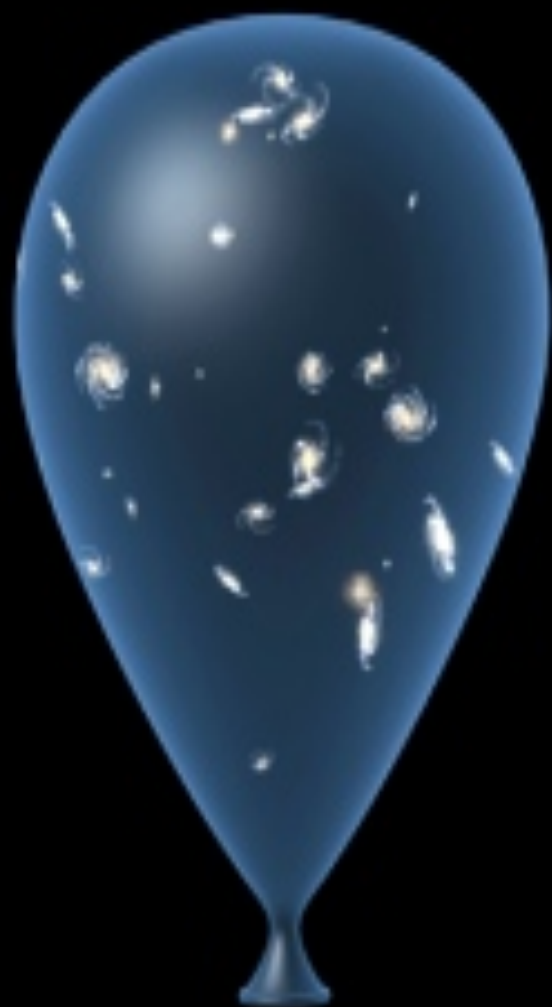
4. Hubble定律

$$H_0 \sim 70 \text{ [km/s/Mpc]}$$

$$v = Hd$$

$$H(t) = \frac{\dot{a}(t)}{a(t)}$$





How Large H_0 ?

Edwin Hubble 1929

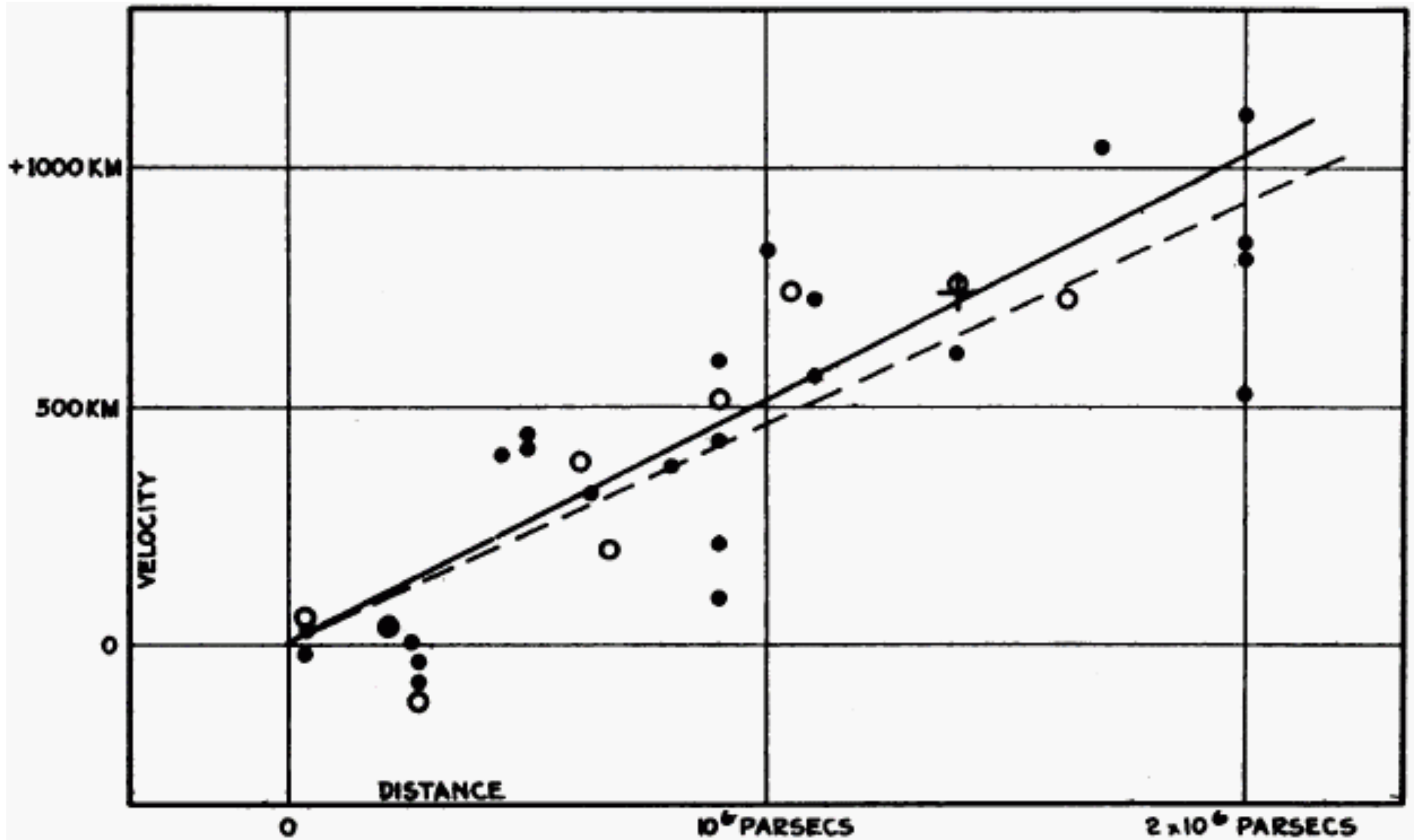


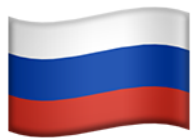
FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

5. Fridemann-Robertson-Walker-Lemaître universe



Friedmann 1920 Lemaître 1927 Robertson 1936 Walker 1936



ON GRAVITATIONAL WAVES.

BY

A. EINSTEIN and N. ROSEN.

ABSTRACT.

The rigorous solution for cylindrical gravitational waves is given. For the convenience of the reader the theory of gravitational waves and their production, already known in principle, is given in the first part of this paper. After encountering relationships which cast doubt on the existence of *rigorous* solutions for undulatory gravitational fields, we investigate rigorously the case of cylindrical gravitational waves. It turns out that rigorous solutions exist and that the problem reduces to the usual cylindrical waves in euclidean space.

1936

NAME	DATE IN	REFEREE	DATE IN	TO AUTHOR	TO N. Y.	ISSUE	RE-JECTED
Glasser	5/24	Juniper 6/4	6/8				6/12
Einstein & Rosen	6/1	Robertson 7/6	7/17	7/23			
.....				4/4	MAY 15, 1936	
Wasserman & Tolman	3/28		4/6	4/9	4/17/36	JUNE 15, 1936	

Figure 5. An early extract from the *Physical Review* logbook. The Einstein–Rosen article was received by the journal on 1 June 1936. After a delay of more than a month, John Tate sent a referral to Howard Percy Robertson on 6 July, finding him in Moscow, Idaho, on vacation after a sabbatical at Caltech. Robertson returned the manuscript and his review to Tate on 17 July. Six days later the package was sent back to Einstein. (Courtesy of Martin Blume, American Physical Society.)



John Wheeler

Spacetime tells matter how to move;
matter tells spacetime how to curve

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

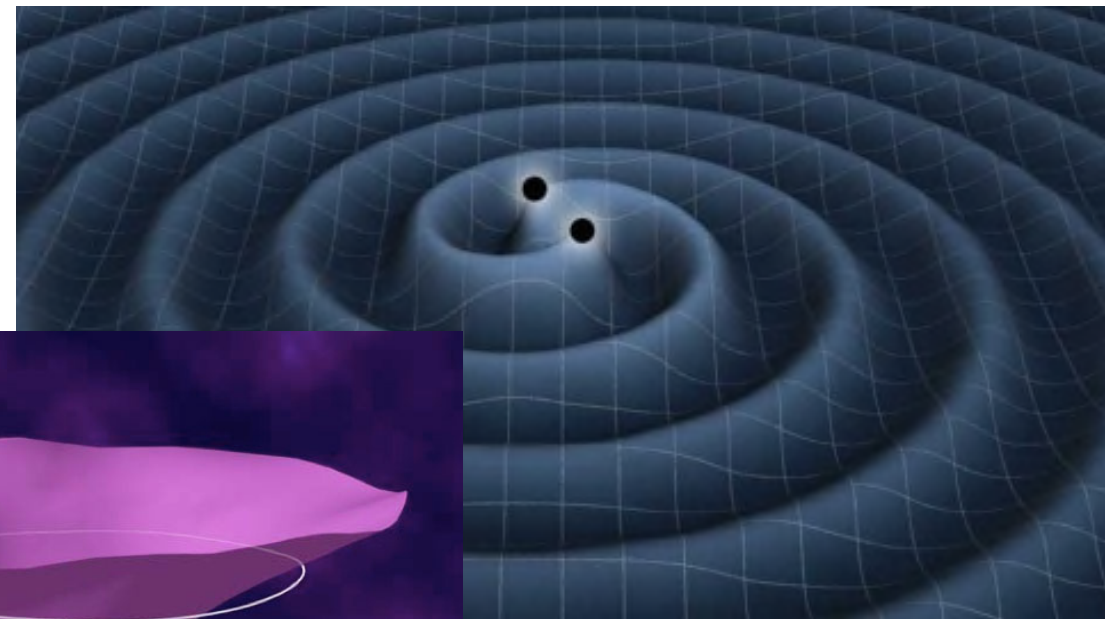
gravity sector
(Geometry of space-time)

gravitational
coupling constant

matter sector
(stress-energy tensor)

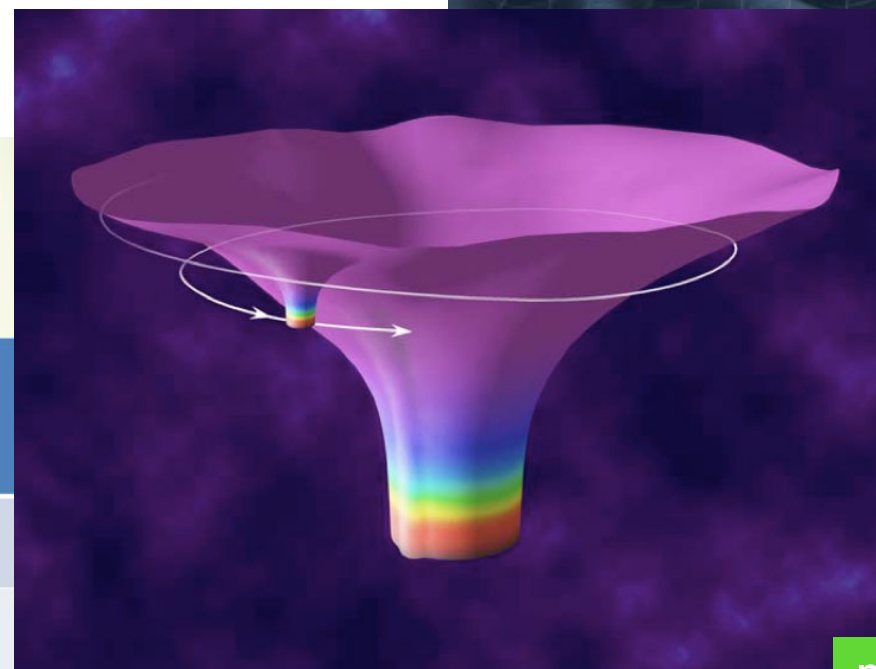
(EoM of gravitational d.o.f.)

Einstein eq.



Gravitation and the other fundamental interactions

Fundamental Interaction	Crucial years	Fundamental constant	Normalized Intensity
Gravity	1687	$Gm_p^2/\hbar c$	5.1×10^{-39}
Weak nuclear force	1934	$G_{Fermi} (m_p c^2)^2$	1.03×10^{-5}
Electromagnetism	1864	$e^2/(4\pi\epsilon_0\hbar c)$	$7.3 \times 10^{-3} \simeq 1/137$
Strong nuclear force	1935/1947	α_s	0.119



$$\begin{pmatrix} -\rho & 0 & 0 & 0 \\ 0 & +P & 0 & 0 \\ 0 & 0 & +P & 0 \\ 0 & 0 & 0 & +P \end{pmatrix}$$

model cosmic matter distribution by the fluid approach!

need a lots of energy to bend the space-time!

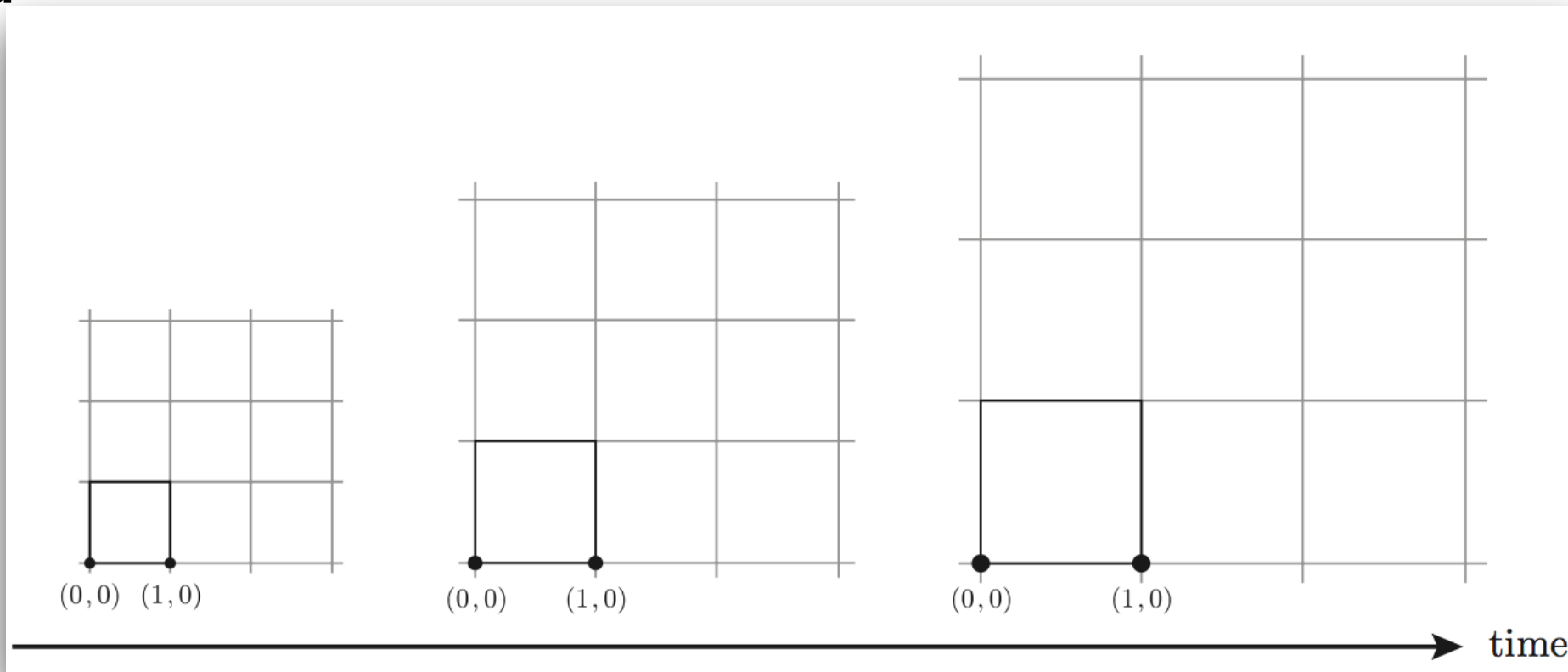
$$\nabla_{\mu} T^{\mu\nu} = 0$$

energy-momentum conservation eq.
(EoM of matter)

$$[ds^2 = g_{\mu\nu} dx^\mu dx^\nu]$$

gravity field

$$ds^2 = -dt^2 + a^2(t) \times dl^2$$



$$ds^2 = -dt^2 + a^2(t) \left[\frac{dr^2}{1 - K(t)r^2} + r^2 d\theta^2 + r^2 \sin^2 \theta d\phi^2 \right] \rightarrow dv^2 \text{ (physical)}$$

(co-moving) du^2

$dv = a du$

here, $du = 1$, but dv increase w.r.t. time

Friedmann eq.

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2},$$
$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P)$$

Problem-1

**What is the solution
of $a(t)$?**

Matter dominated epoch $P = 0, \rho = \rho_0 a^{-3}$

Radiation dominated epoch $P = \rho/3, \rho = \rho_0 a^{-4}$

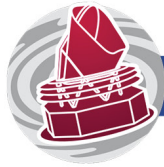
Dark energy dominated epoch $P = -\rho, \rho = \rho_0 a^0$

Software

Wolfram
Mathematica[®]



简述宇宙热历史



→ COSMIC HISTORY

10⁻³² seconds

1 second

100 seconds

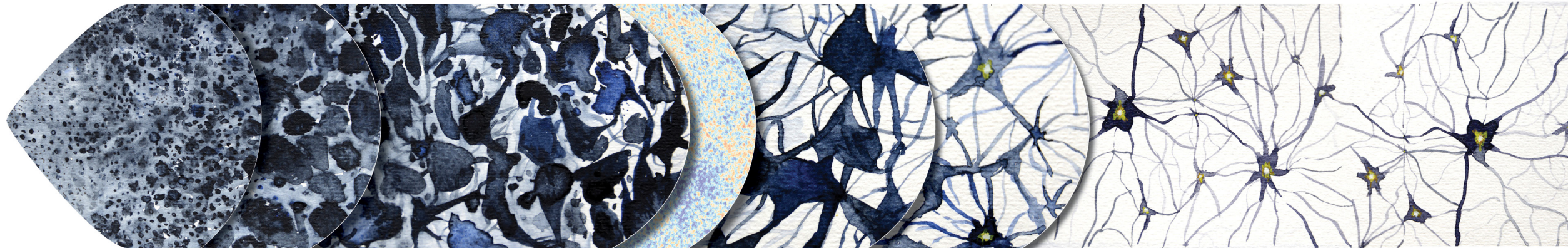
380 000 years

300–500 million years

Billions of years

13.8 billion years

Beginning of the Universe



Inflation

Accelerated expansion of the Universe

Formation of light and matter

Light and matter are coupled

Dark matter evolves independently: it starts clumping and forming a web of structures

Light and matter separate

- Protons and electrons form atoms
- Light starts travelling freely: it will become the Cosmic Microwave Background (CMB)

Dark ages

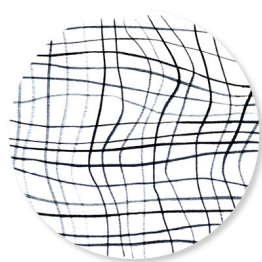
Atoms start feeling the gravity of the cosmic web of dark matter

First stars

The first stars and galaxies form in the densest knots of the cosmic web

Galaxy evolution

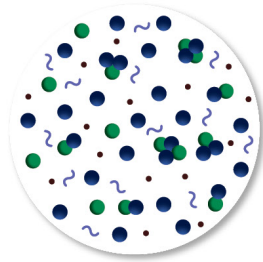
The present Universe



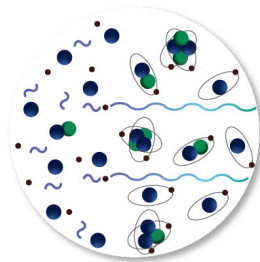
- Tiny fluctuations: the seeds of future structures
- Gravitational waves?



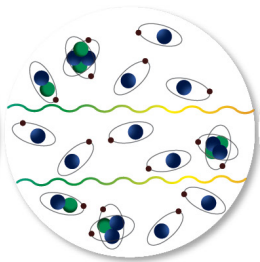
Frequent collisions between normal matter and light



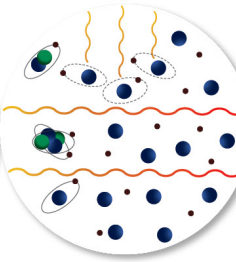
As the Universe expands, particles collide less frequently



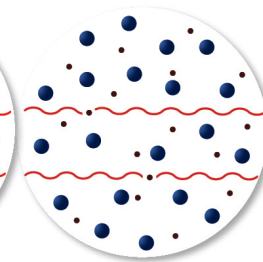
Last scattering of light off electrons
→ **Polarisation**



The Universe is dark as stars and galaxies are yet to form



Light from first stars and galaxies breaks atoms apart and "reionises" the Universe



Light can interact again with electrons
→ **Polarisation**