天文学正在发现

Bin HU

bhu@bnu.edu.cn

Astro@BNU

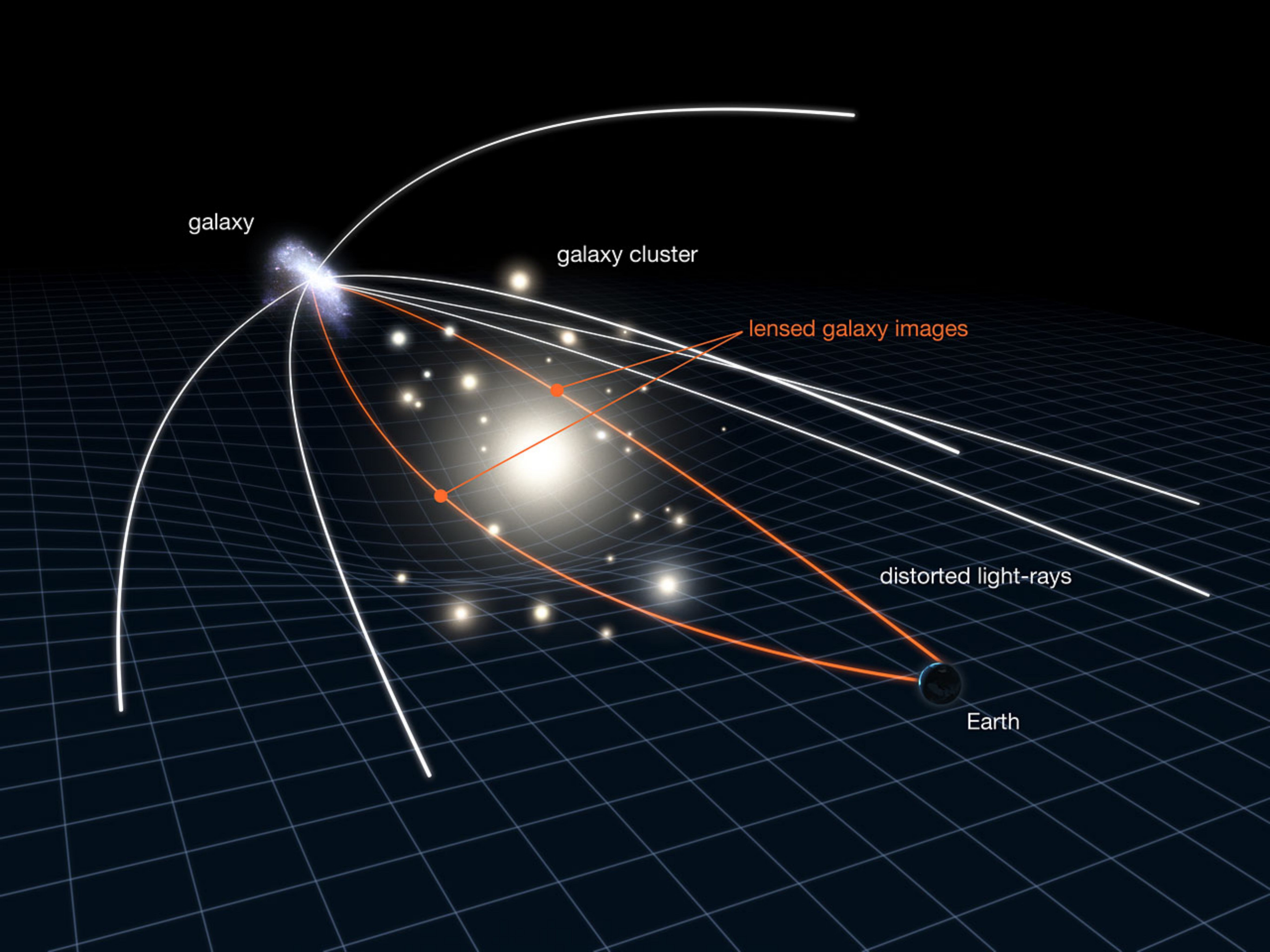
Office: 京师大厦9907

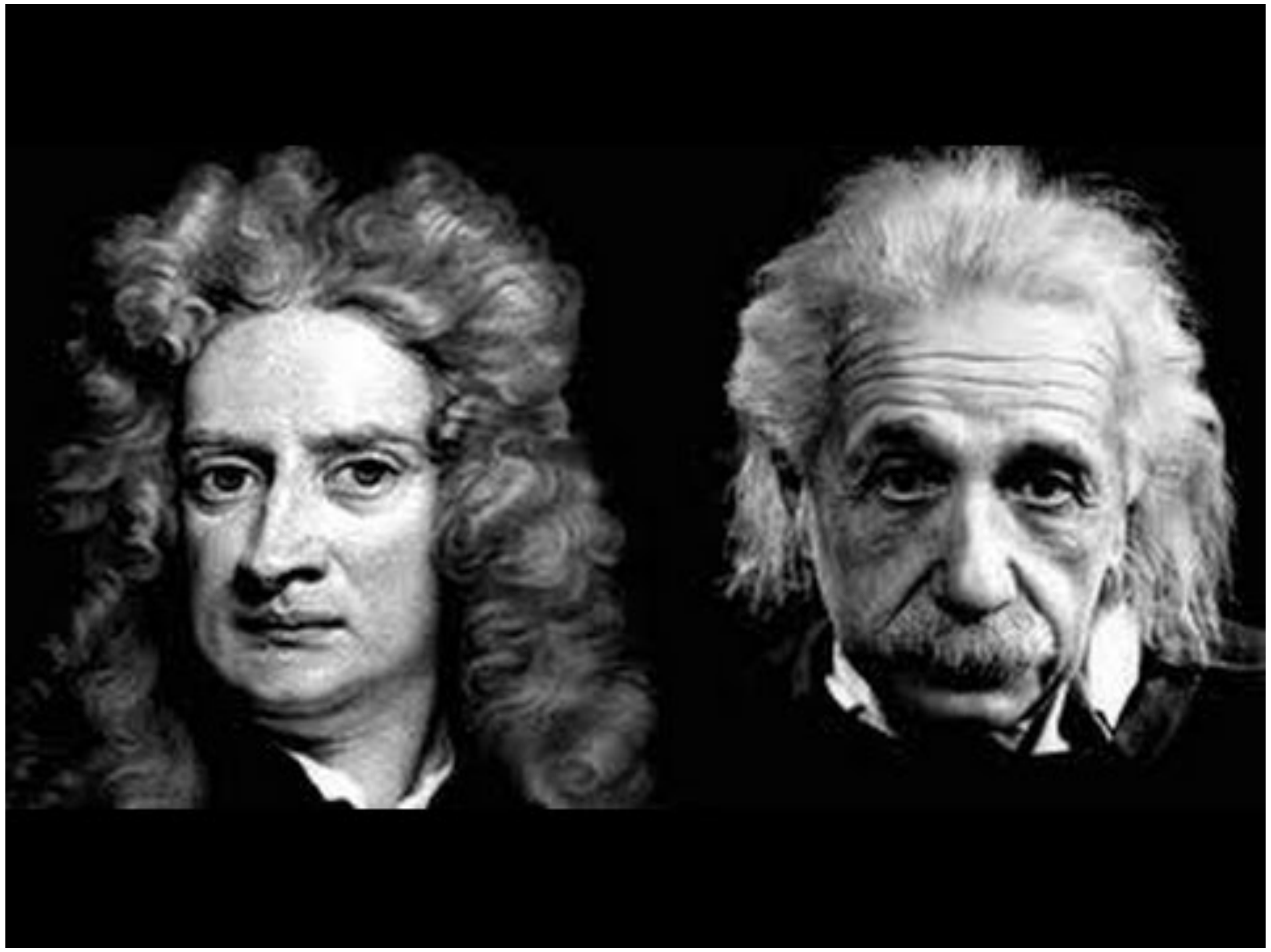
outline

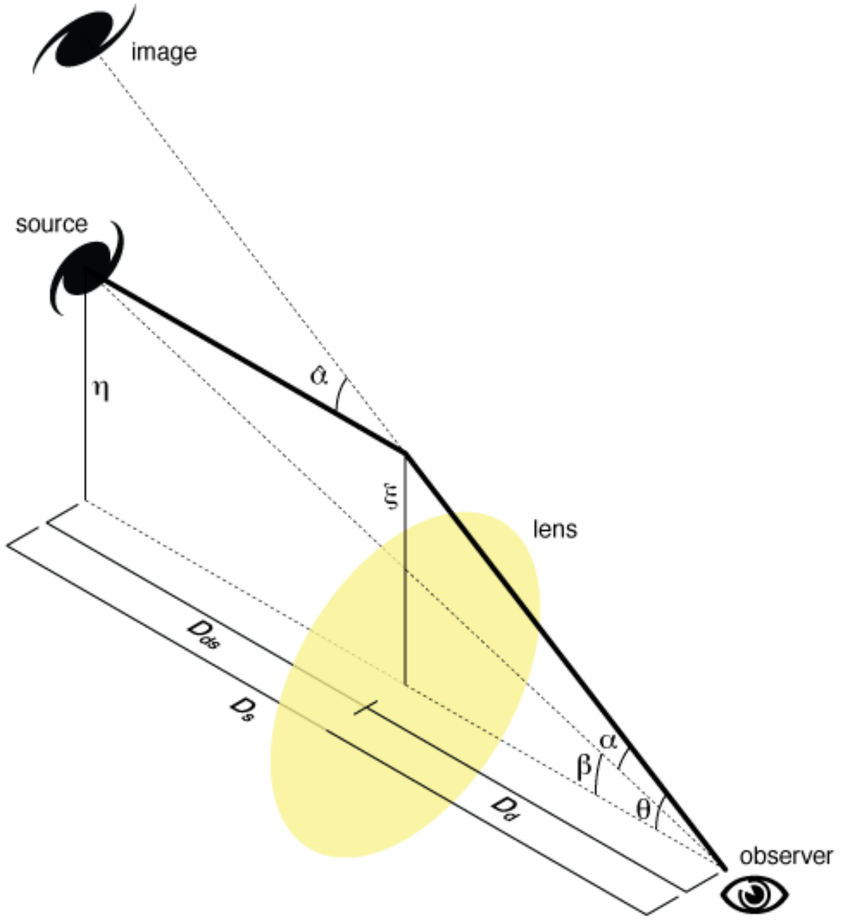
1. 膨胀宇宙的发现
2. 暗物质的发现
3. 暗能量的发现
4. 宇宙微波背景辐射的发现
5. 中微子的发现
6. 引力波的发现
7. 脉冲星的发现
8. 宇宙第一缕曙光的“发现”

谈一下你们对于引力现象的认识！

哪些是你所知的著名的引力现象？


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

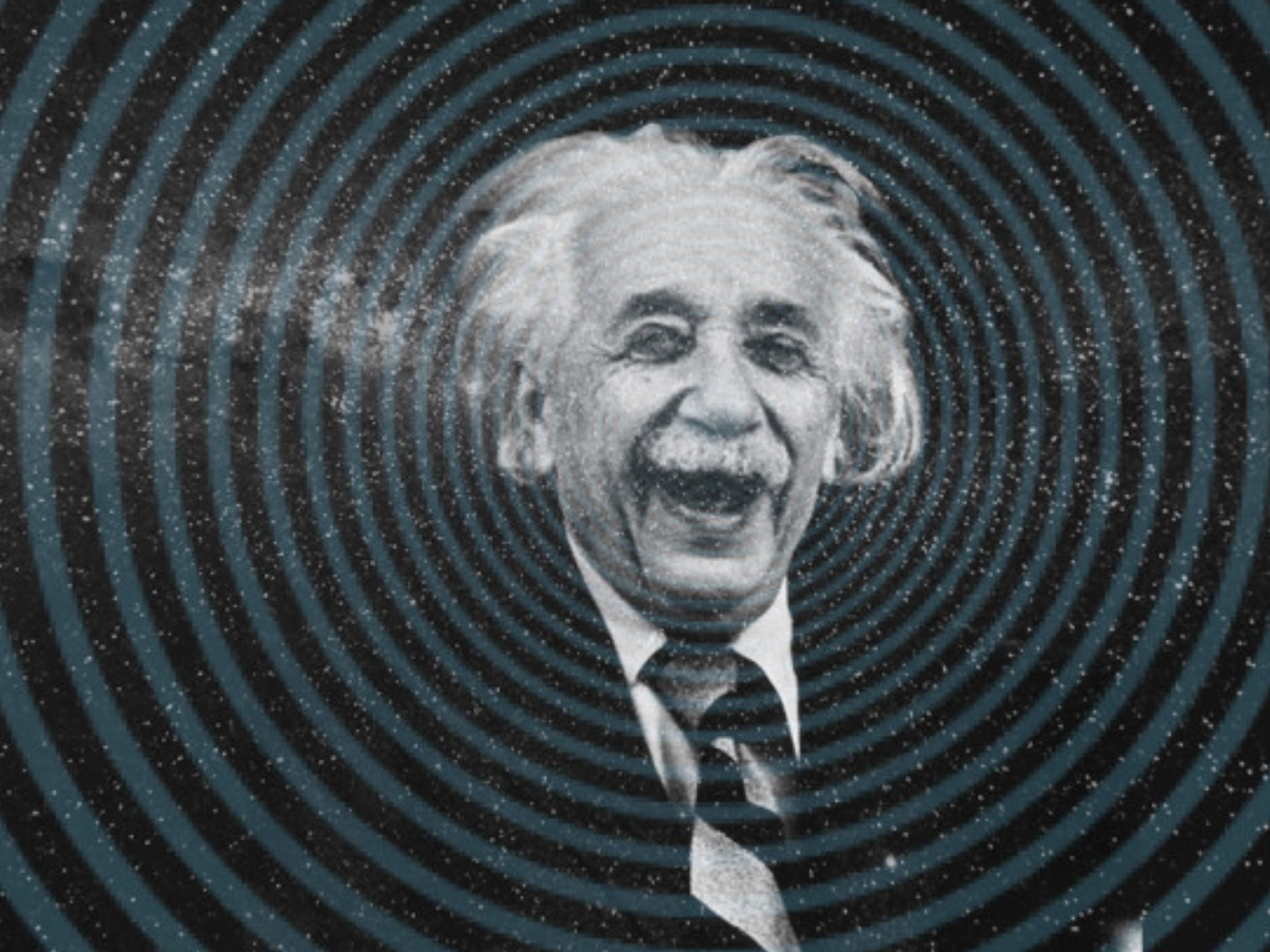




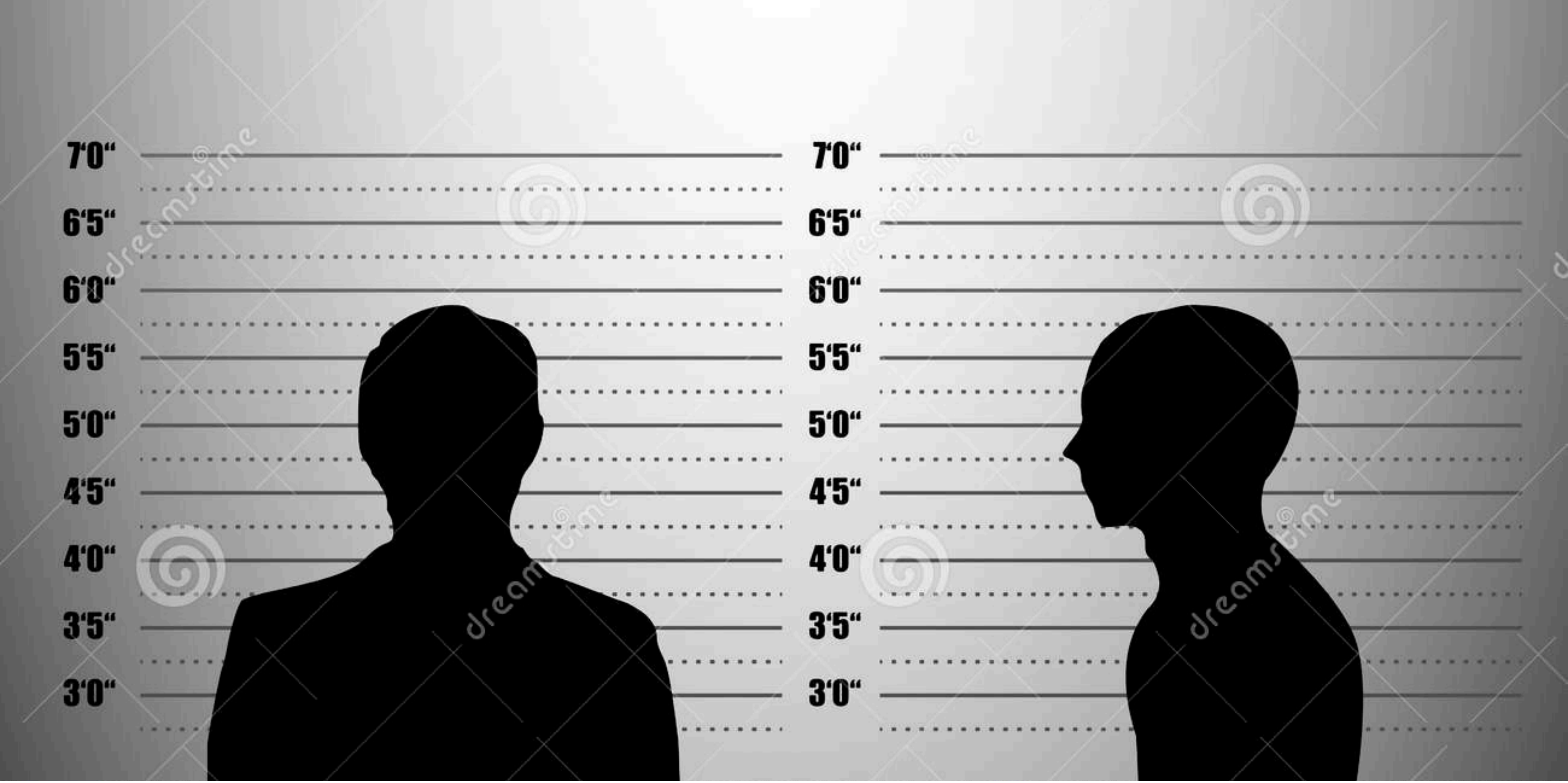
$$\alpha = \frac{2GM}{c^2 b}$$

$$\alpha = \frac{4GM}{c^2 b}$$

Why Einstein > Newton?




GW



Mass, Velocity, Spin, Polarization, …

Velocity & Mass

moving mass → m

rest mass → m_0

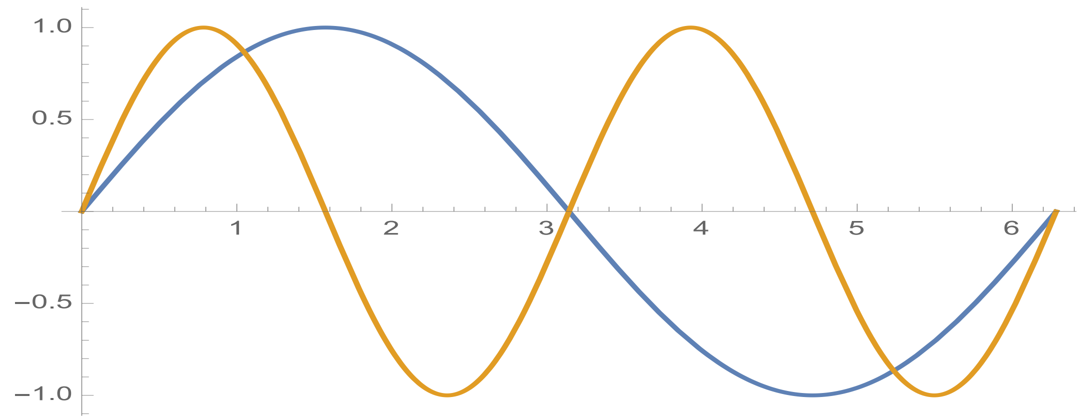
$$m = \frac{m_0}{\sqrt{1 - (v/c)^2}}$$

Graviton Massless

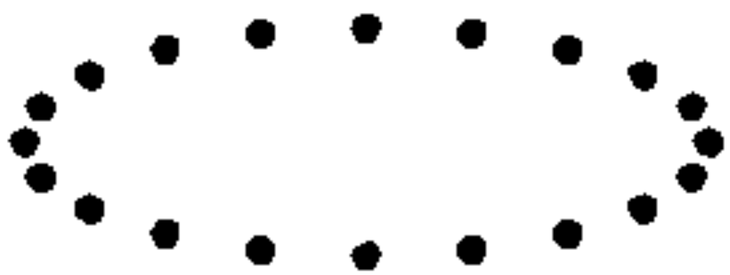
Spin = 2 (**NO** **negative** mass charge)

After half orbital period, the source mass distribution restore the original configuration

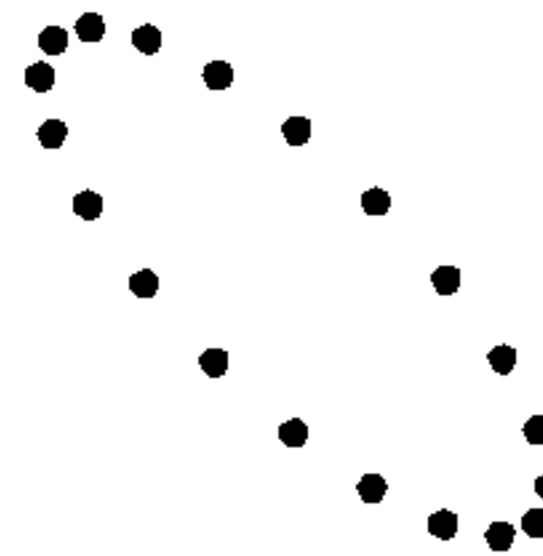
2 Polarisations



h+

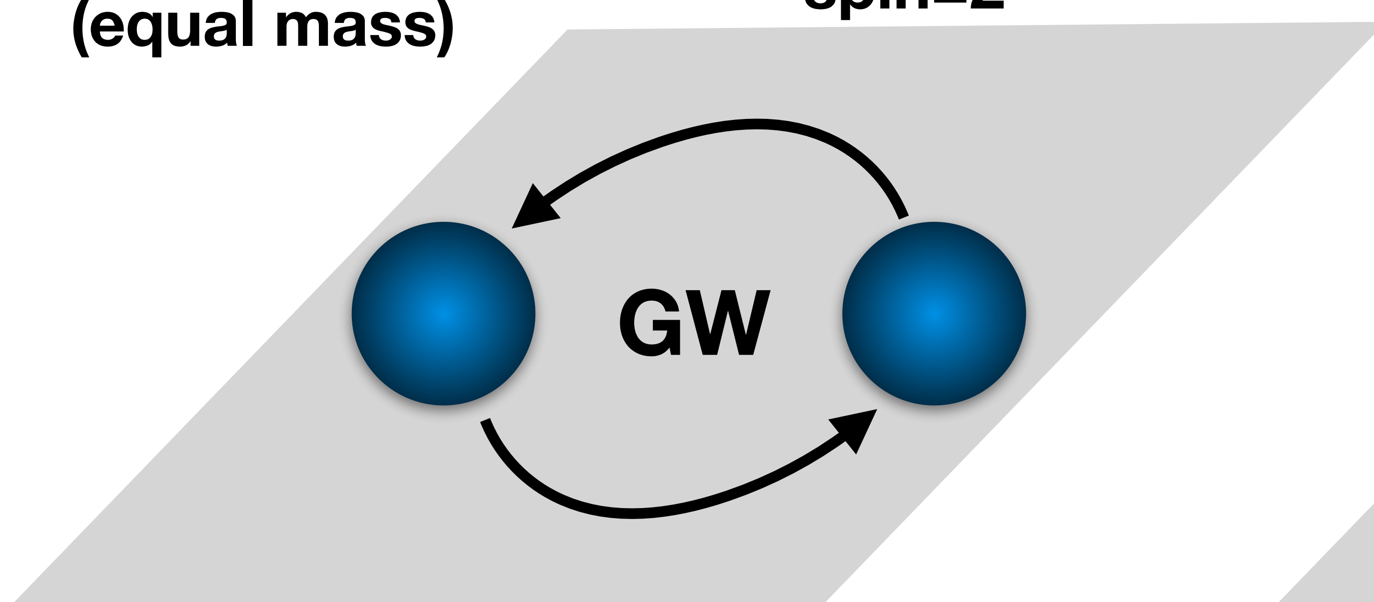


h×

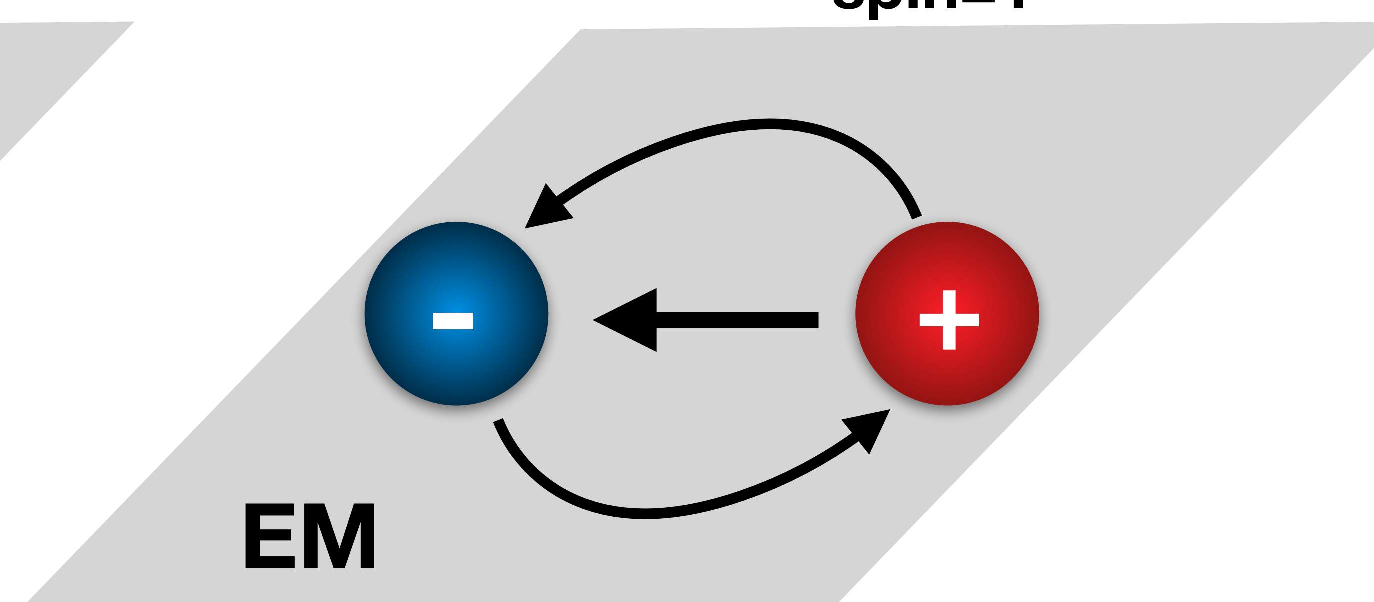


Circular Orbit (equal mass)

spin=2

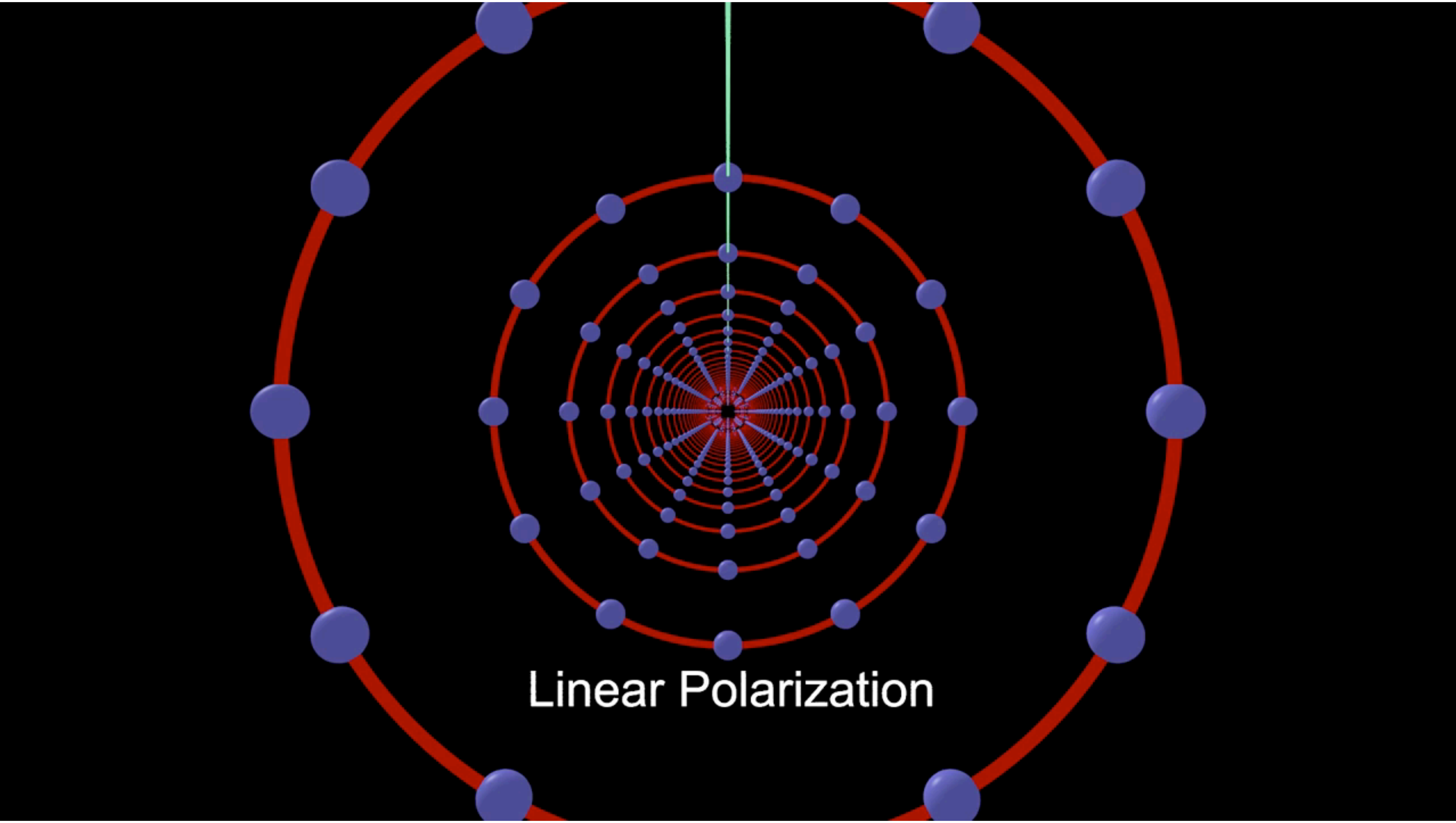


spin=1

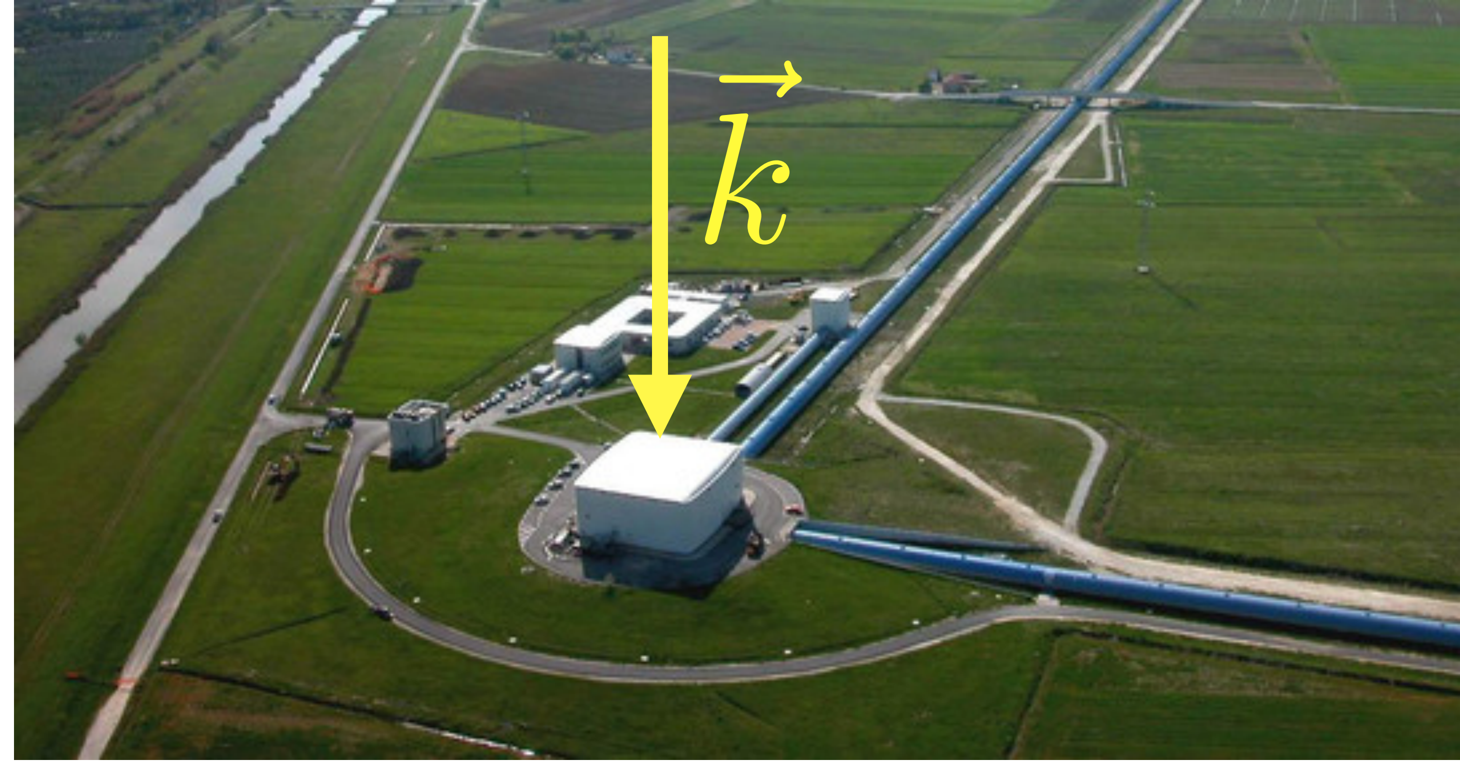


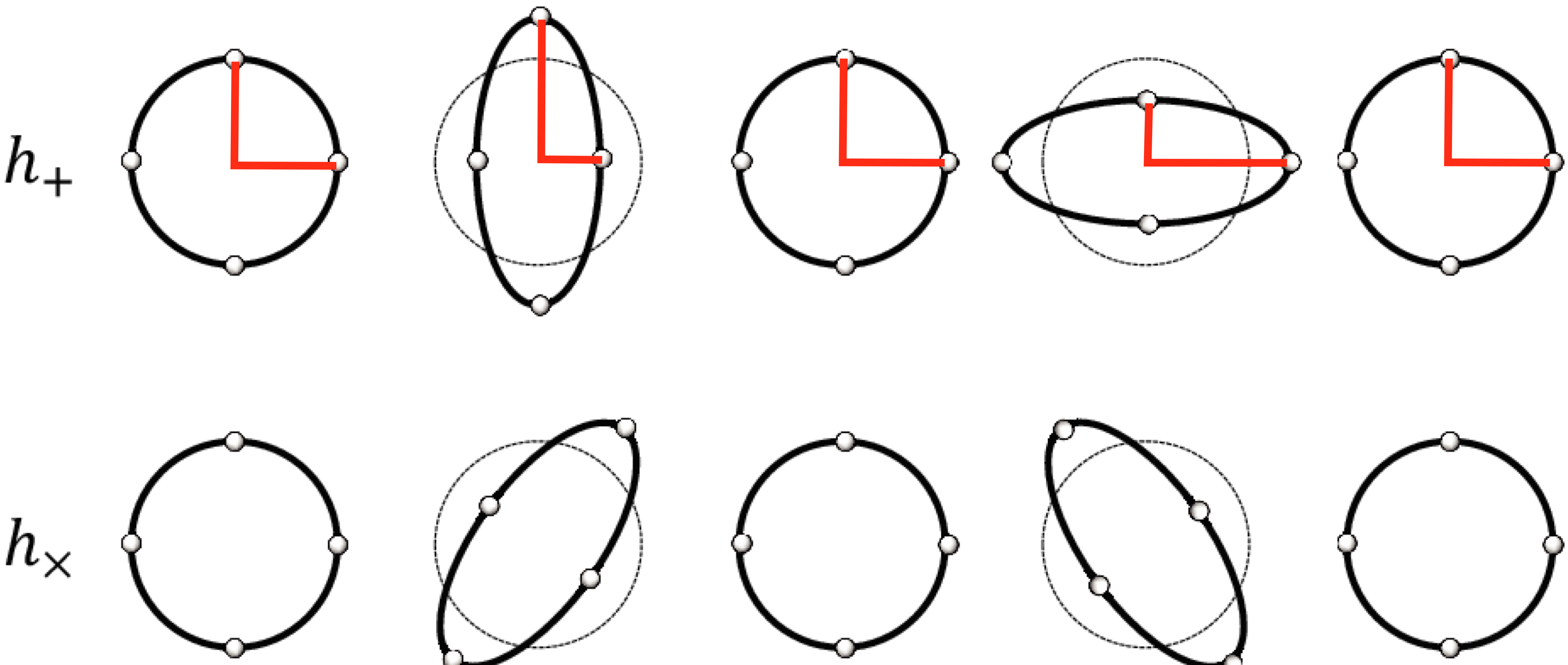
$\alpha_g \sim 10^{-39}$

$\alpha = 1/137$


Linear Polarization

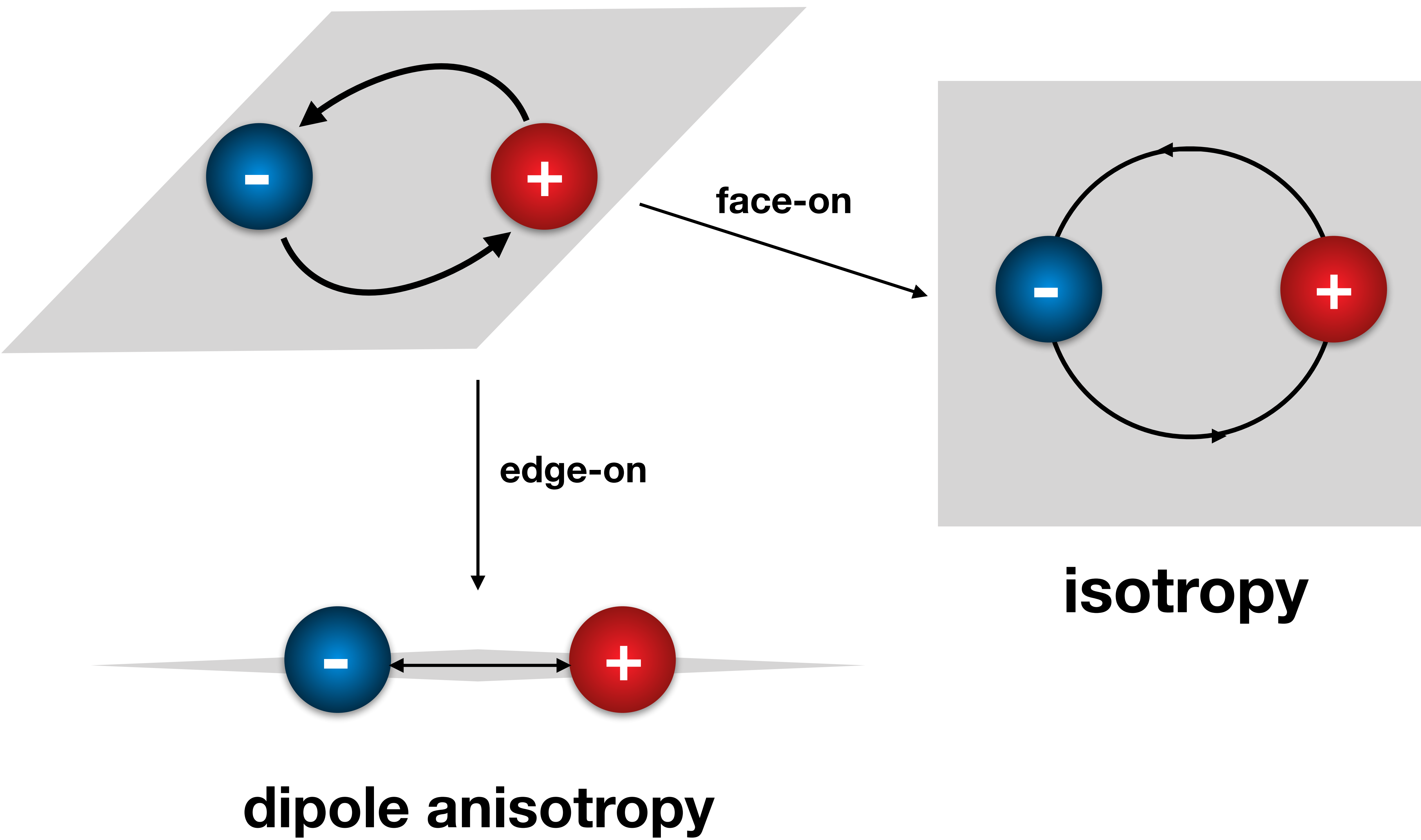
$$h \sim \Delta L / L$$



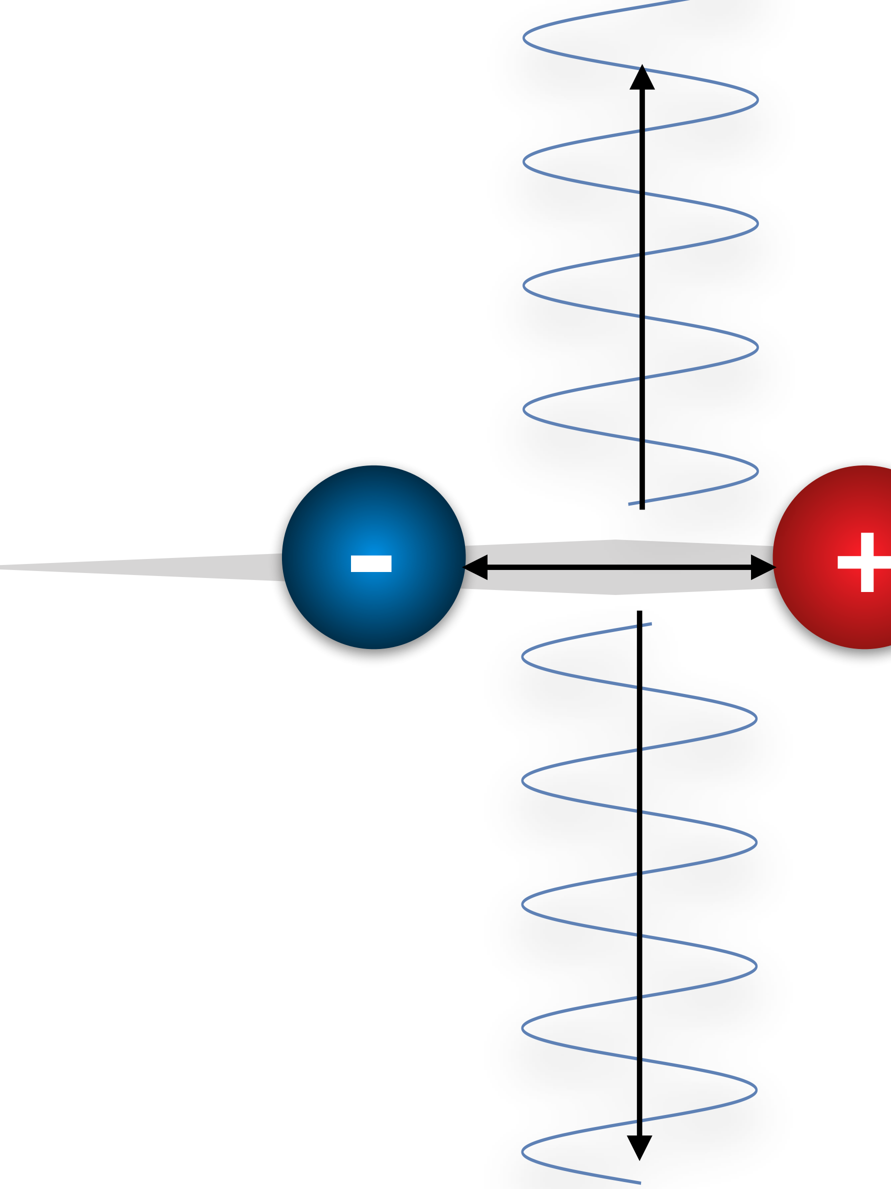


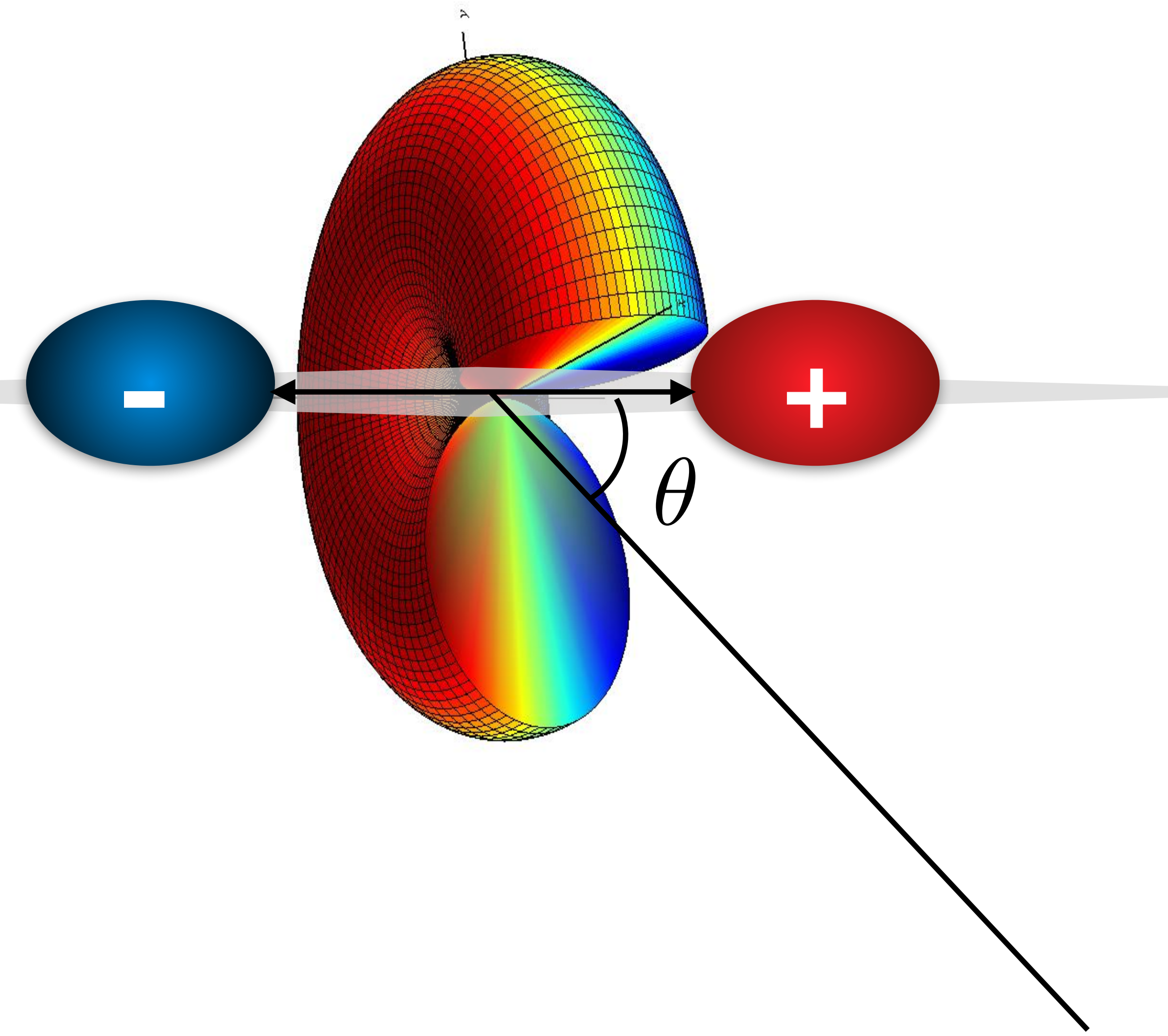
电磁波辐射是偶极辐射

加速的电荷会产生电磁辐射

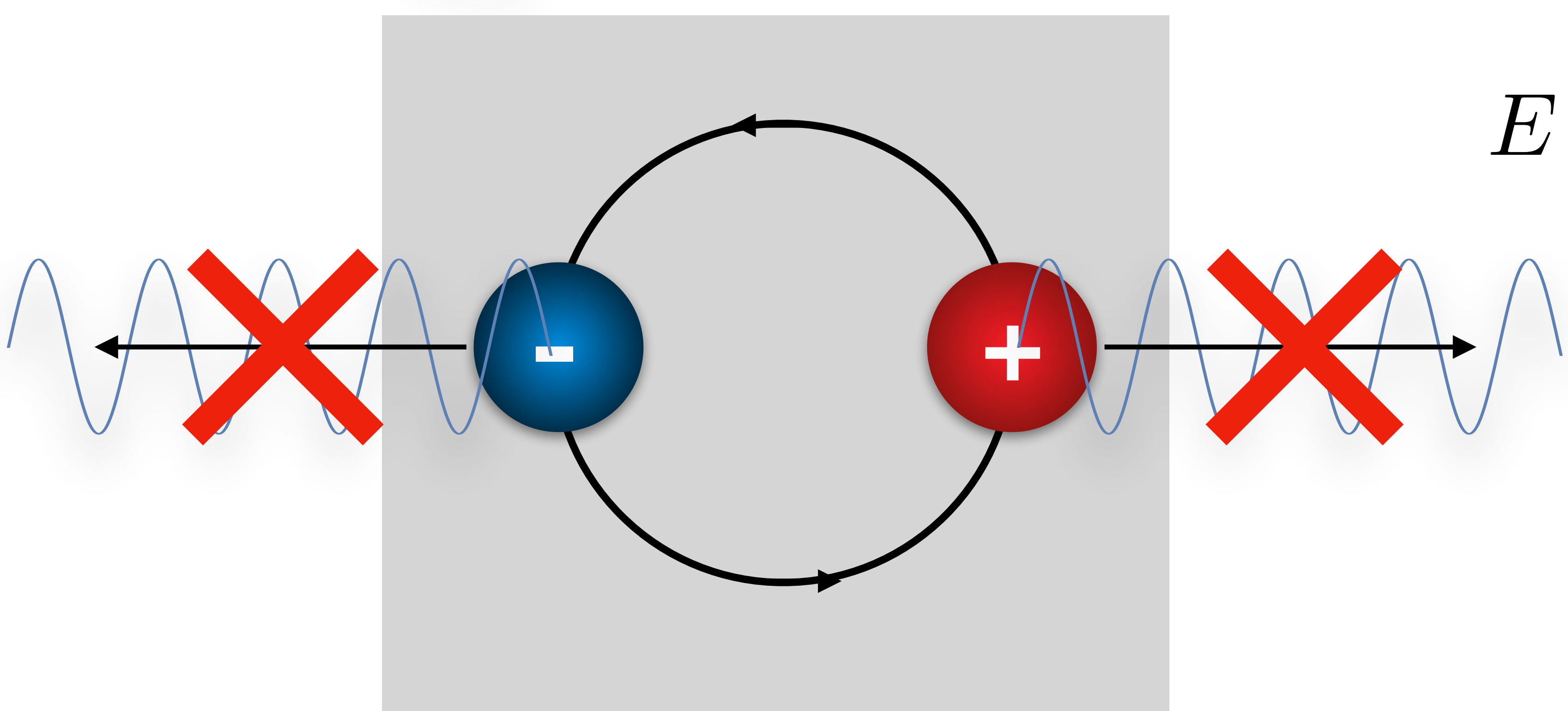


Only consider the TE-mode, i.e. ignore TM-mode





$$E \sim \frac{1}{r}\left(\frac{\cos(\frac{\pi}{2}\cos\theta)}{\sin\theta}\right)$$



Monopole: $E \sim \frac{Q}{r^2}, \quad \frac{\dot{Q}}{r}$ ← 电荷守恒

[L]=[t]

Dipole: $E \sim \frac{P}{r^3}, \quad \frac{\dot{P}}{r^2}, \quad \frac{\ddot{P}}{r}$

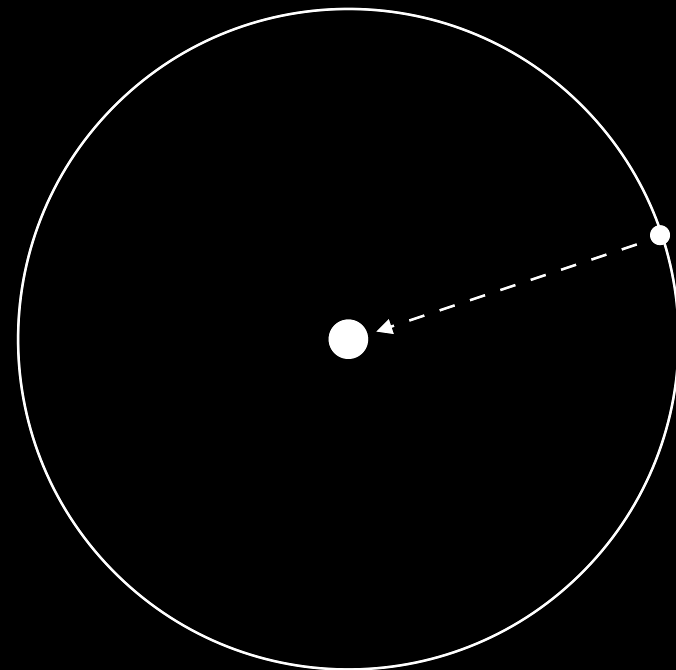
However, the first-order spatial moment of a charge distribution, $\boldsymbol{P} = \Sigma Q_i \boldsymbol{s}_i$, is *not* a conserved quantity: we can change it freely by moving a charge around, or by separating pairs of balanced positive and negative charges. This is also called the *electric dipole moment*, since it is the first and most significant nonzero moment of an electric dipole (i.e. a pair of balanced positive and negative charges). As shown ealier, we get $1/r$ transverse electromagnetic radiation, or *dipole radiation*, when $\partial^2\boldsymbol{P}/\partial t^2 = \Sigma Q_i \boldsymbol{a}_i \neq 0$

广义相对论的等效原理：引力效应可以被一个**局域**的加速参照系所替代。

局域的力

$$g \propto \frac{GM}{r^2}$$

(point mass)

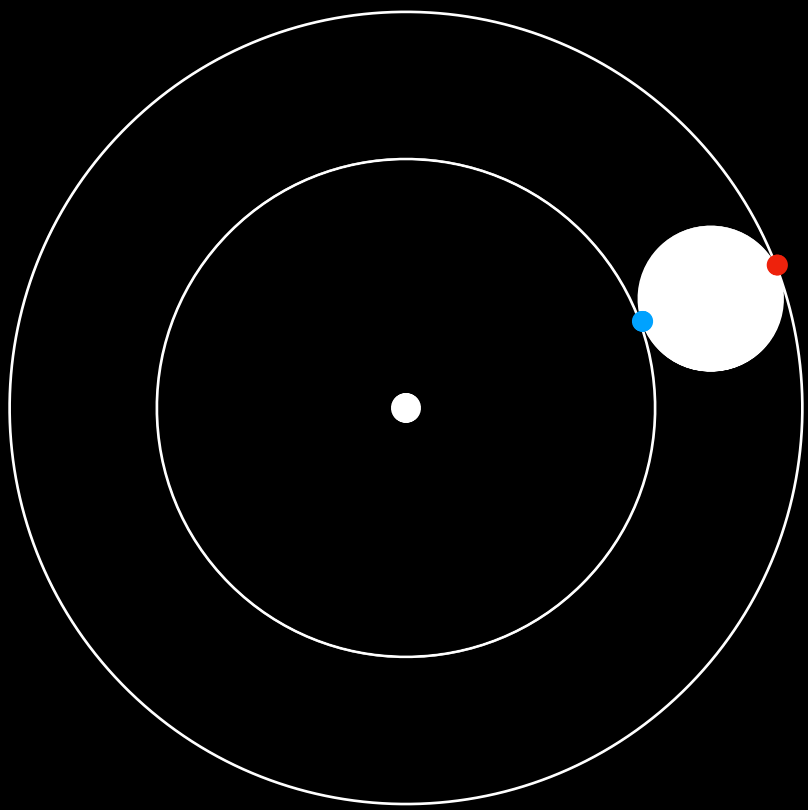


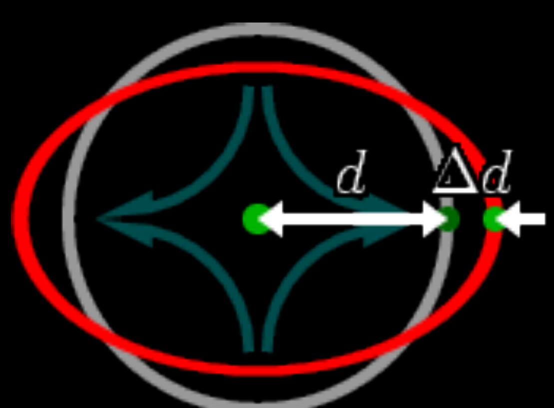
非局域的力：具有可观测效应！

tidal force

(sizable object)

$$g' \propto \nabla g \sim \frac{GM}{r^3}$$





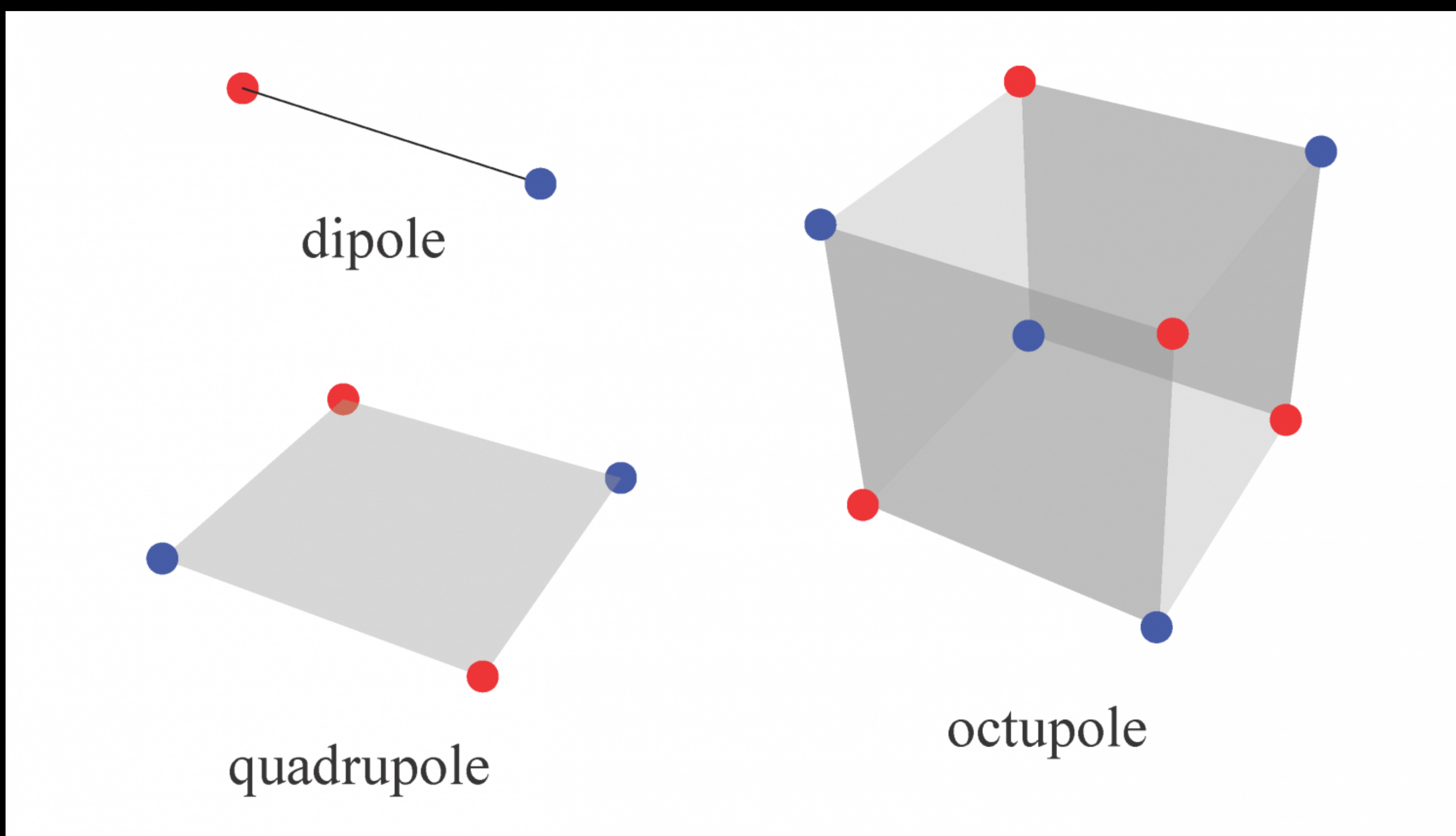
$$g' = \frac{\Delta g}{d} = \frac{\text{change in gravity}}{\text{displacement}}$$

$$h = \frac{2\Delta d}{d} = 2 \times \frac{\text{change in displacement}}{\text{displacement}}$$

Monopole: $g' \sim \frac{M}{r^3}$, ~~$\frac{\dot{M}}{r^2}$~~ ← 孤立系统：质量守恒

Dipole: $g' \sim \frac{P}{r^4}, \frac{\dot{P}}{r^3}$, ~~$\frac{\ddot{P}}{r^2}$~~ ← 孤立系统：动量守恒

Quadrupole: $g' \sim \frac{I}{r^5}, \frac{\dot{I}}{r^4}, \frac{\ddot{I}}{r^3}, \frac{\dddot{I}}{r^2}, \frac{\ddddot{I}}{r}$

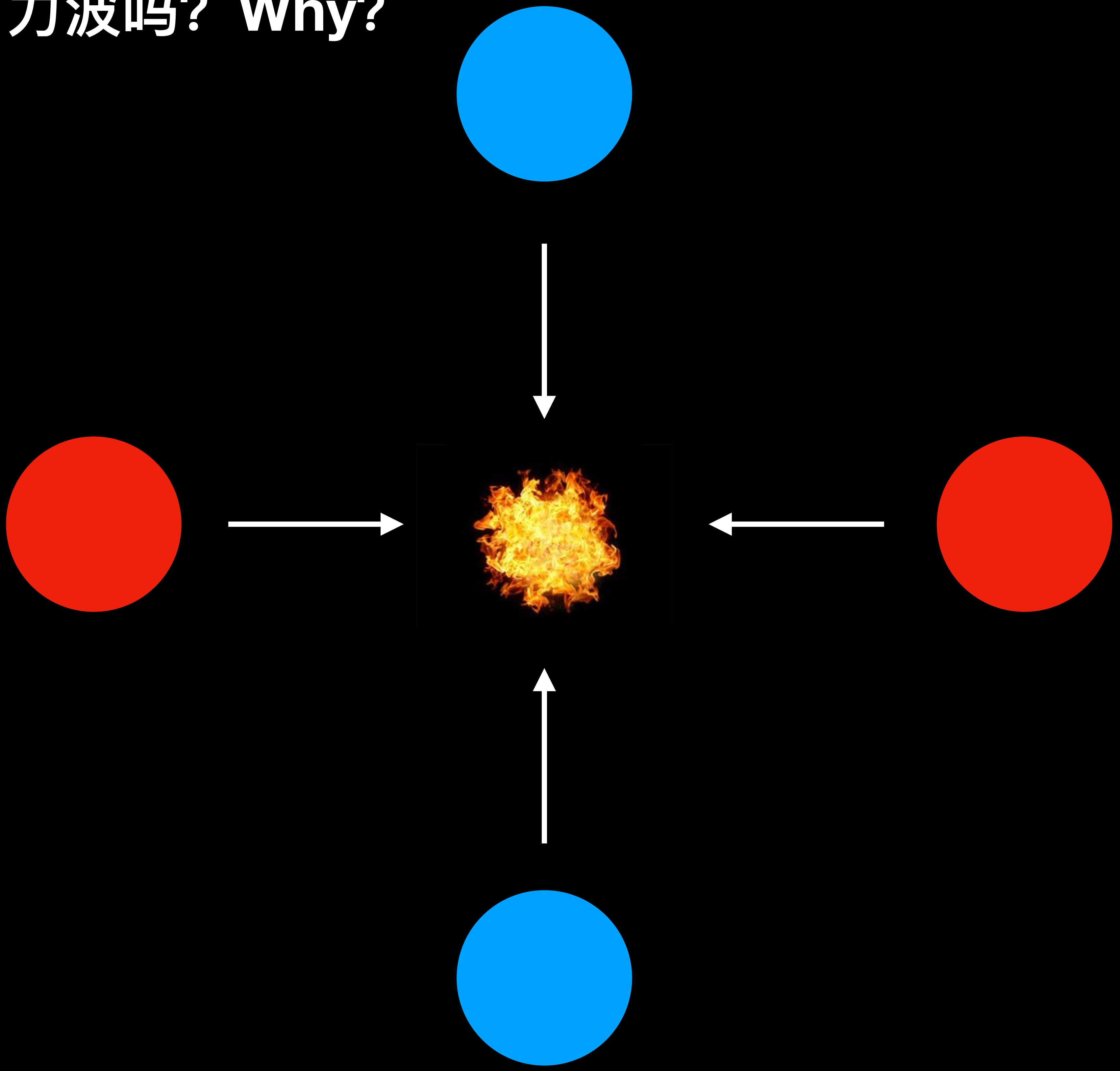


I: 刻画四极矩

不对称性的烈度

Q: 会产生引力波吗？Why?

Q: 会产生引力波吗？ Why?



A: we need **time varying** quadruple anisotropy!

$$\bar{h}_{ij}(t,r) = \frac{2G}{c^4 r}\ddot{I}_{ij}(t - r/c),$$

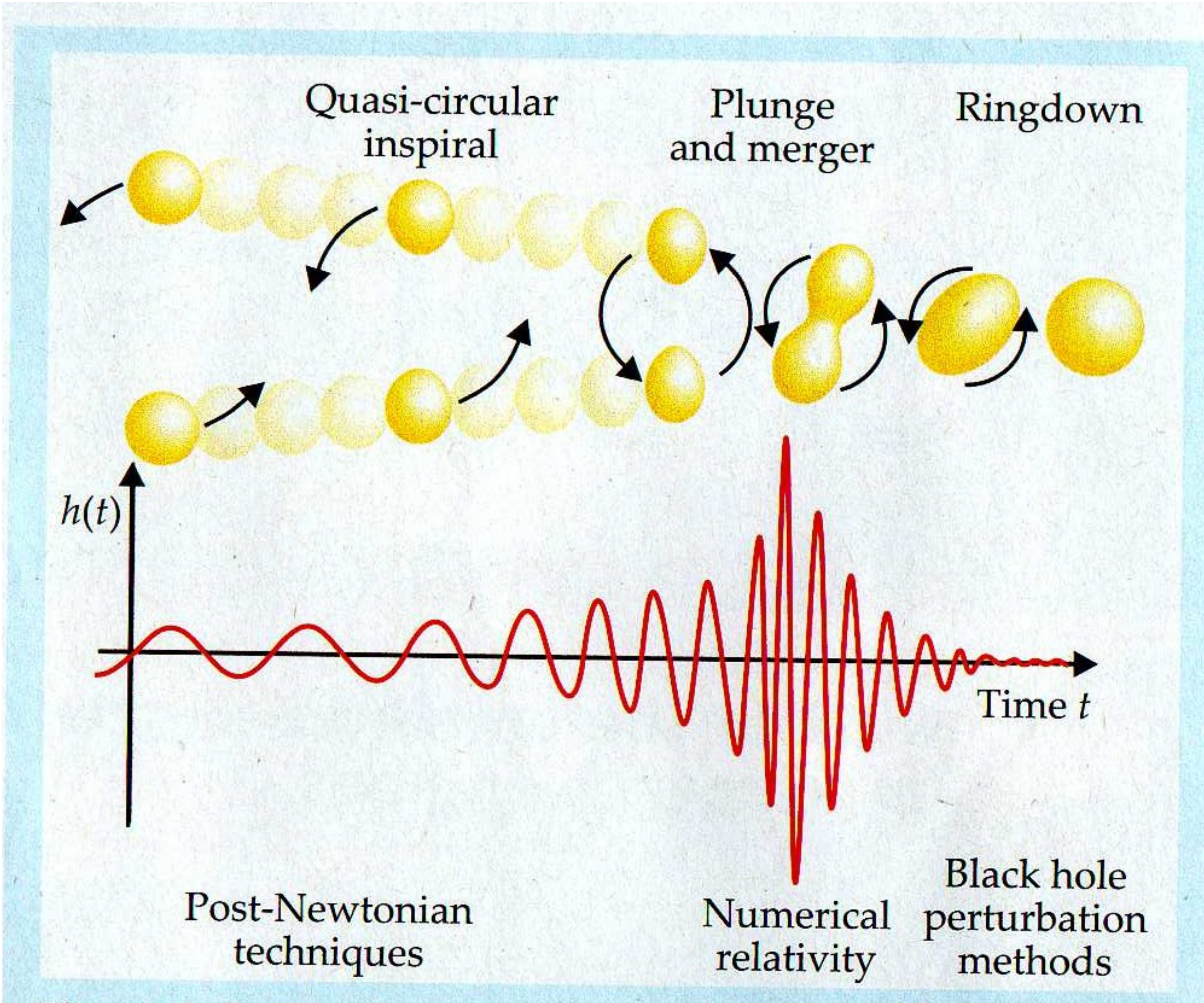
$$h \sim \frac{GM}{c^2} \times \frac{1}{r} \times \left(\frac{v}{c}\right)^2$$

The first term is roughly the size of a black hole of mass M, so the distance r to the system must clearly be much greater. Similarly, v/c is the ratio of the speeds of masses in the system to the speed of light, which must be less than (usually much less than) unity. Thus h approaches unity when one is standing in the immediate vicinity of black holes moving about at lightspeed, and is less for any other circumstance.

In particular, the length scale of a "typical" black hole 10× as massive as our Sun is 14km, and such objects achive speeds around *c* only when they collide, which might occur on a yearly basis within a volume of radius 6×10^{20}km (20 megaparsecs). So the *strongest* waves we expect to observe passing the Earth will have $h \sim 10^{-20}$ or less. This is enough to distort the shape of the Earth by 10^{-13} metres, or about 1% of the size of an atom. By contrast, the (nonradiative) tidal field of the Moon raises a tidal bulge of about 1 metre on the Earth's oceans.

Calculate the yellow number!

GW from binary system



Weber 🇺🇸

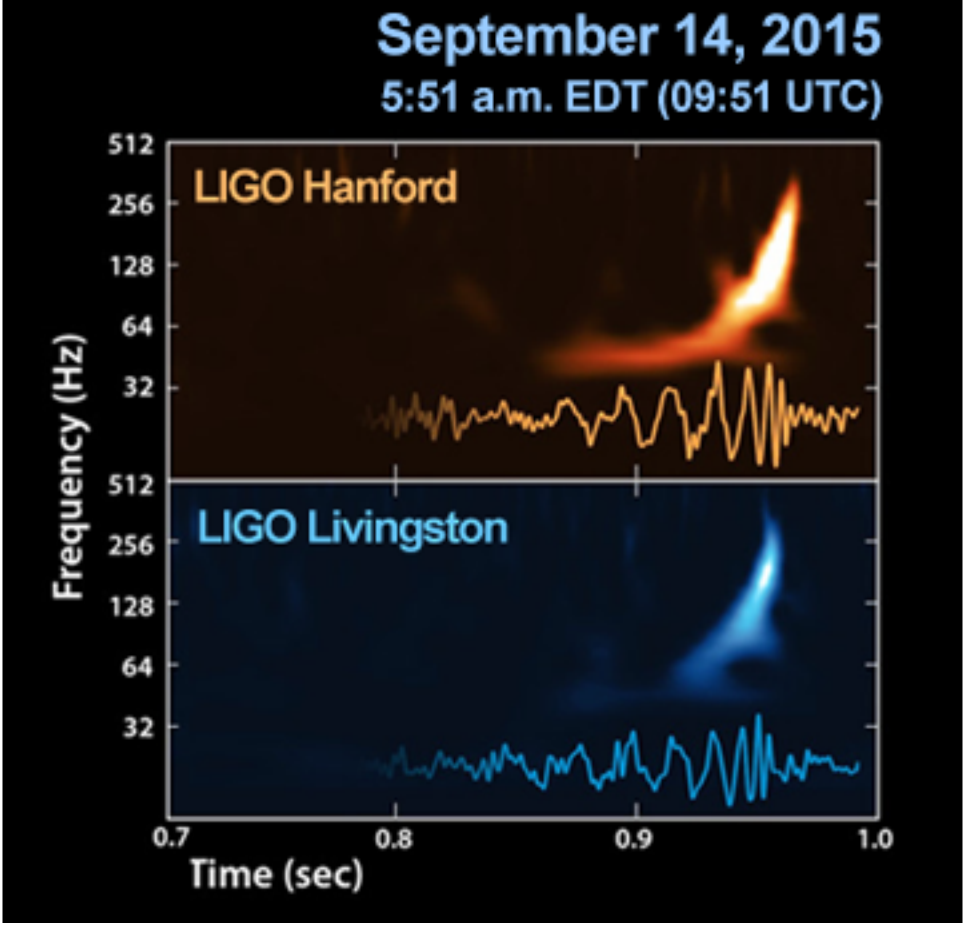
his claim to have detected gravitational waves from SN1987A in 1987, were widely discredited.

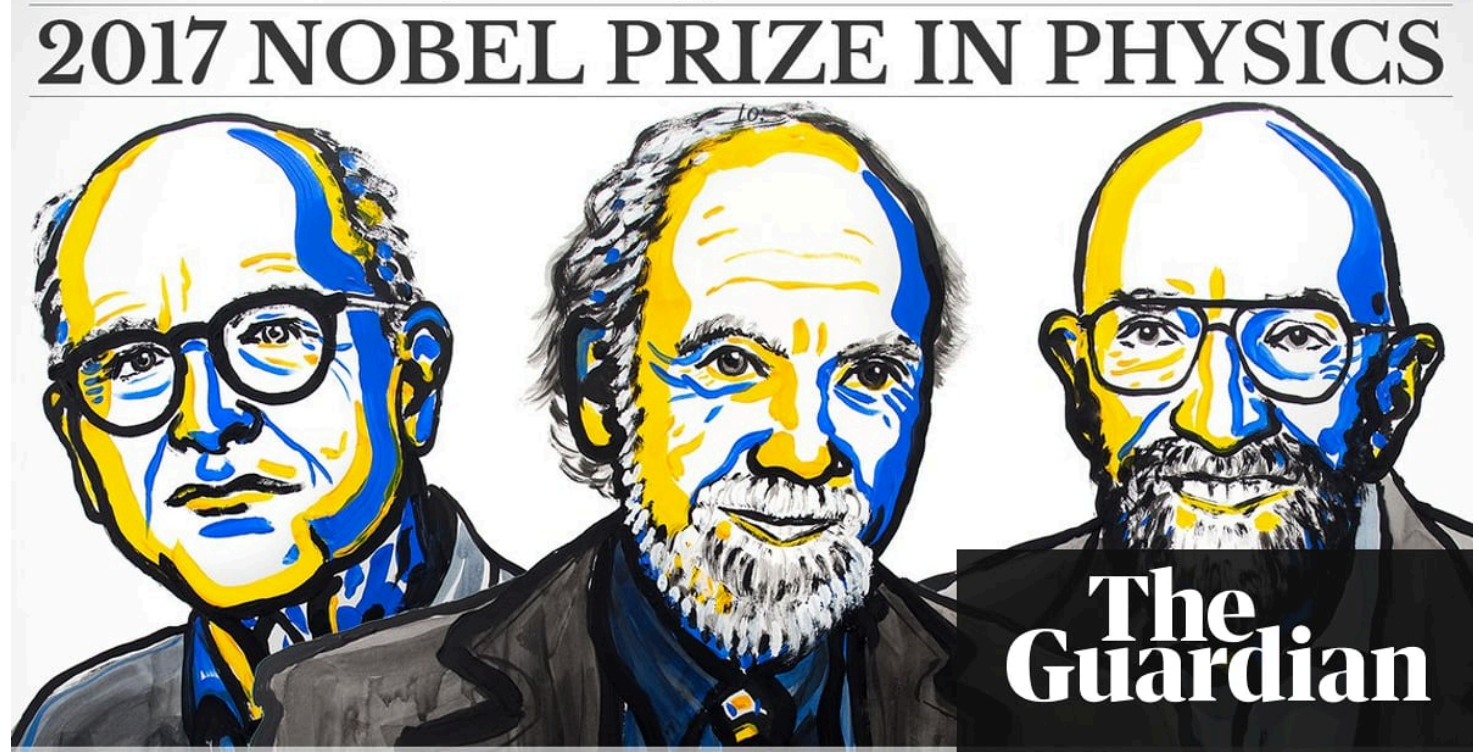
[Credit: 蔡少芬 & wangyi]


Smoot
www.lindau-nobel.org

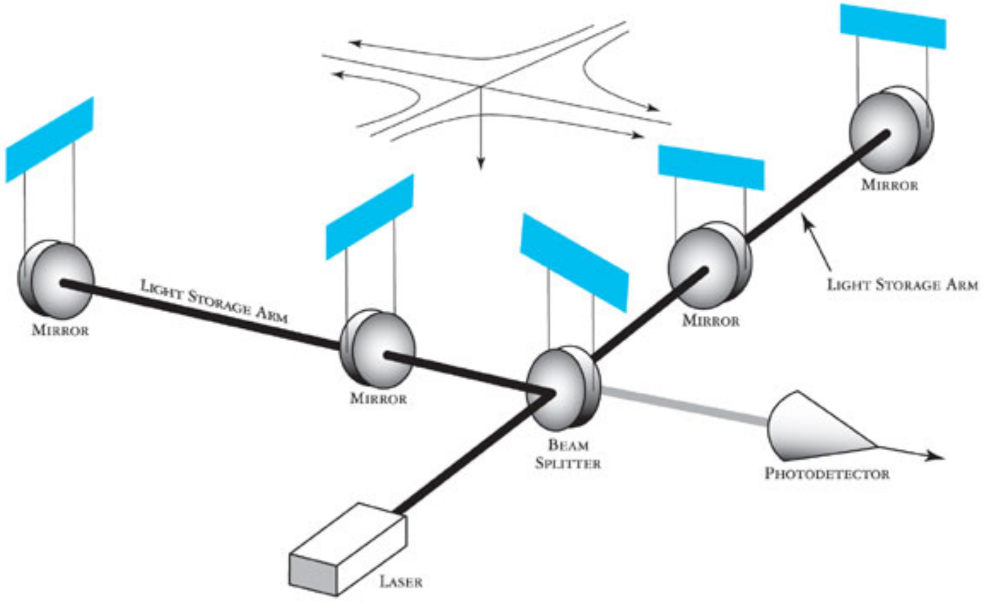

臣妾做不到啊
resonance frequency of 1660 Hertz

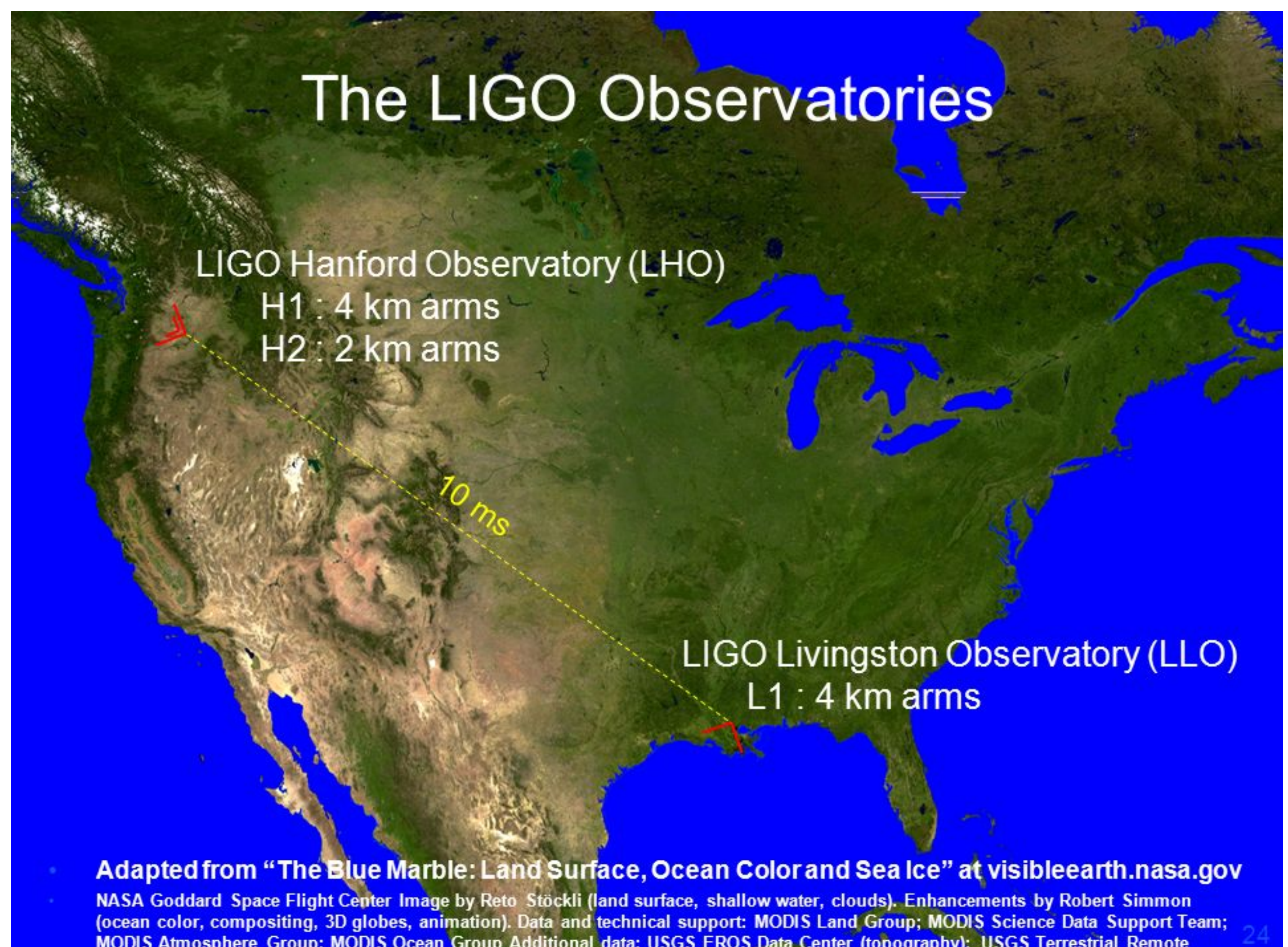
王一@港科大

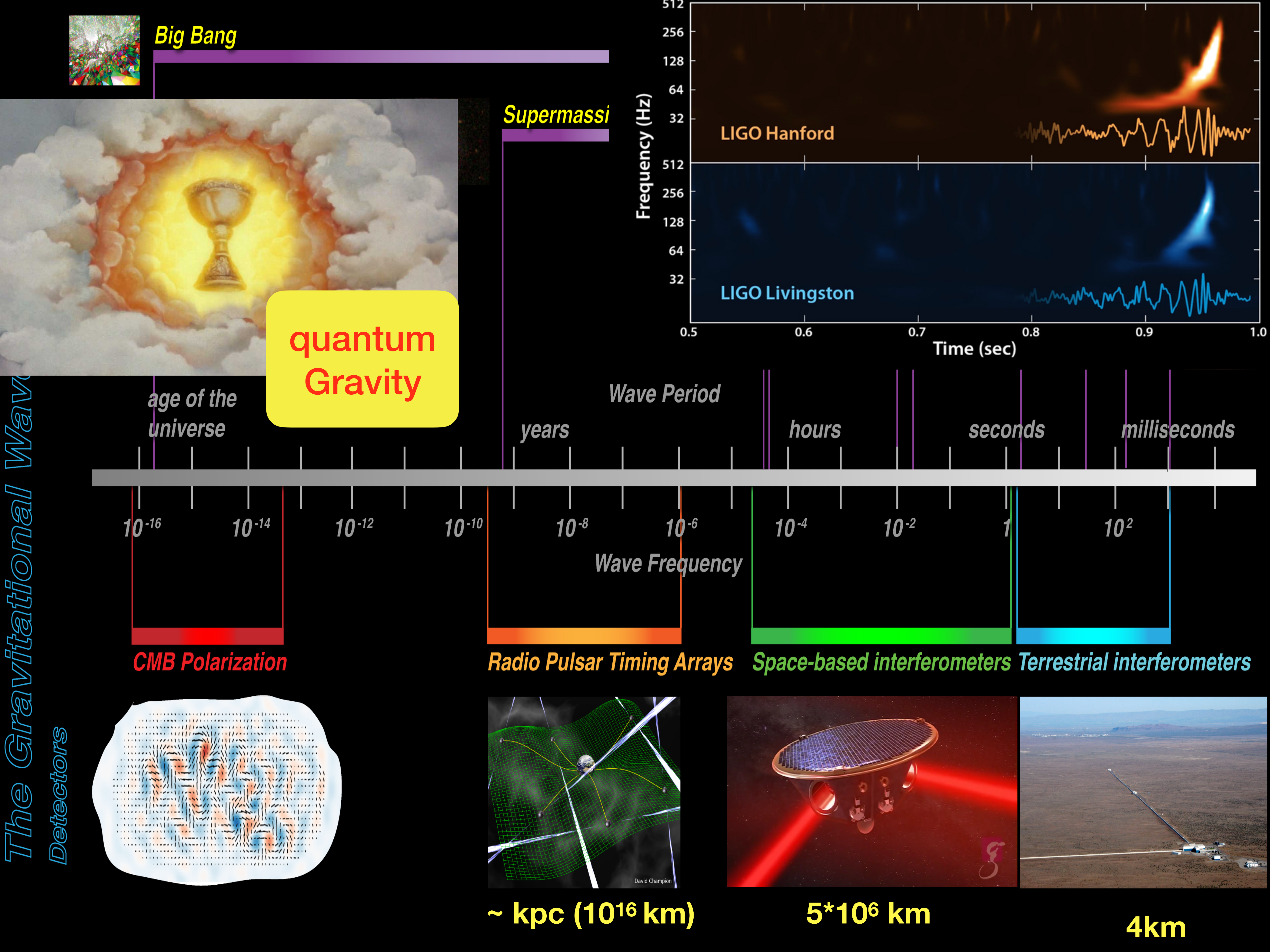




Weiss@MIT **Barish@Caltech** **Thorne@Caltech**







Big Bang
Supermassi
512
256
128
64
32
Frequency (Hz)
LIGO Hanford
LIGO Livingston
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)
quantum Gravity
age of the universe
Wave Period
years
hours
seconds
milliseconds
10^-16
10^-14
10^-12
10^-10
10^-8
10^-6
10^-4
10^-2
1
10^2
Wave Frequency
CMB Polarization
Radio Pulsar Timing Arrays
Space-based interferometers
Terrestrial interferometers
The Gravitational Wav
Detectors
David Champion
~ kpc (10^16 km)
5*10^6 km
4km

Problem-10: What are the possible sources of GW?
Briefly describe its mechanism.

Problem-10: 综述一下，当前LIGO / VIRGO探测情况。
以及未来，下一代GW探测实验的部署。