Image: National Observatory of Japan /EOS

The Cosmological Principle

On large scales, the Universe is homogeneous *and* isotropic

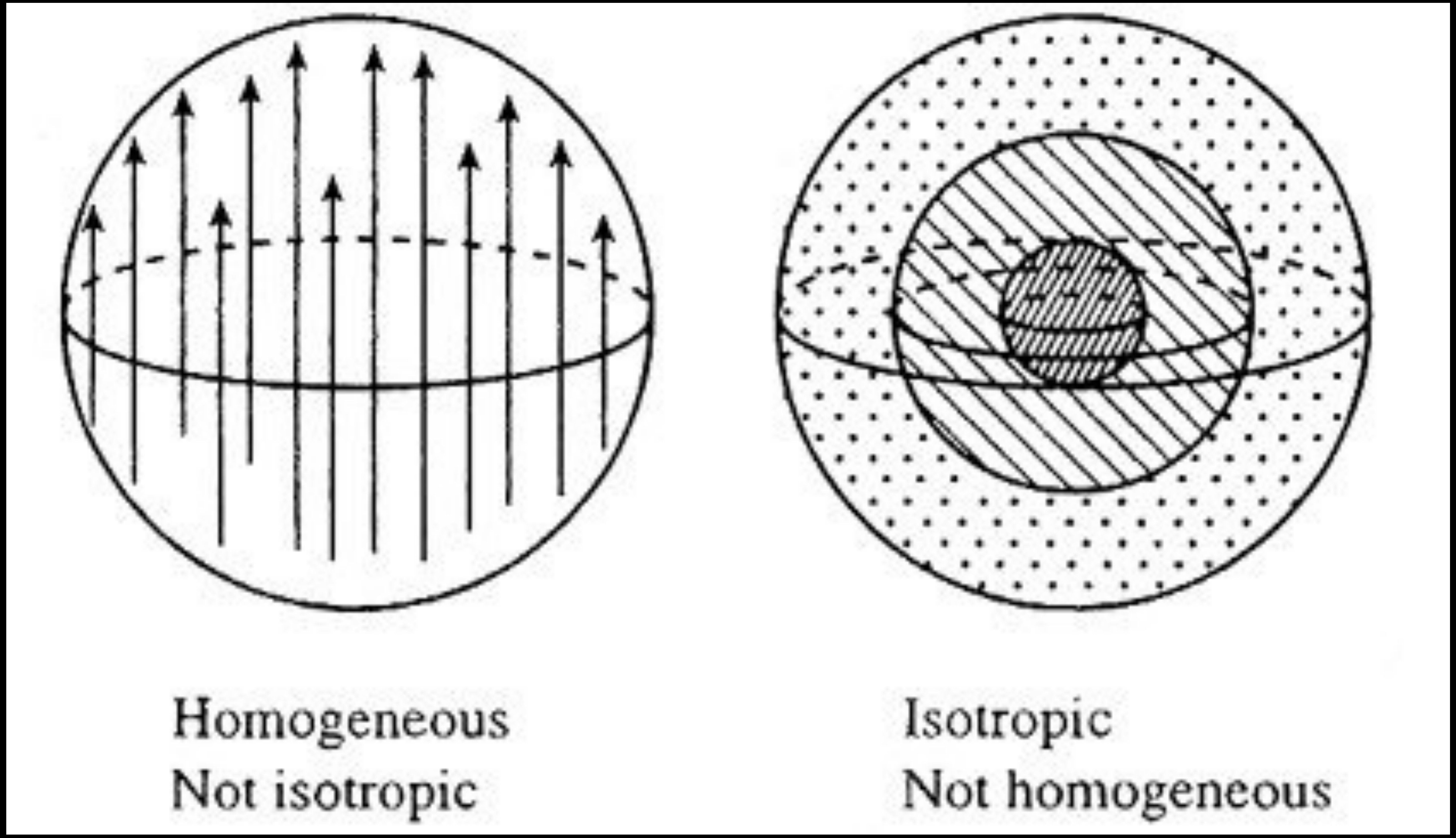


Image: University of Oregon

(Ignore the edges)

The Cosmological Principle

On large scales, the Universe is homogeneous *and* isotropic

Homogeneous:

Same distribution through

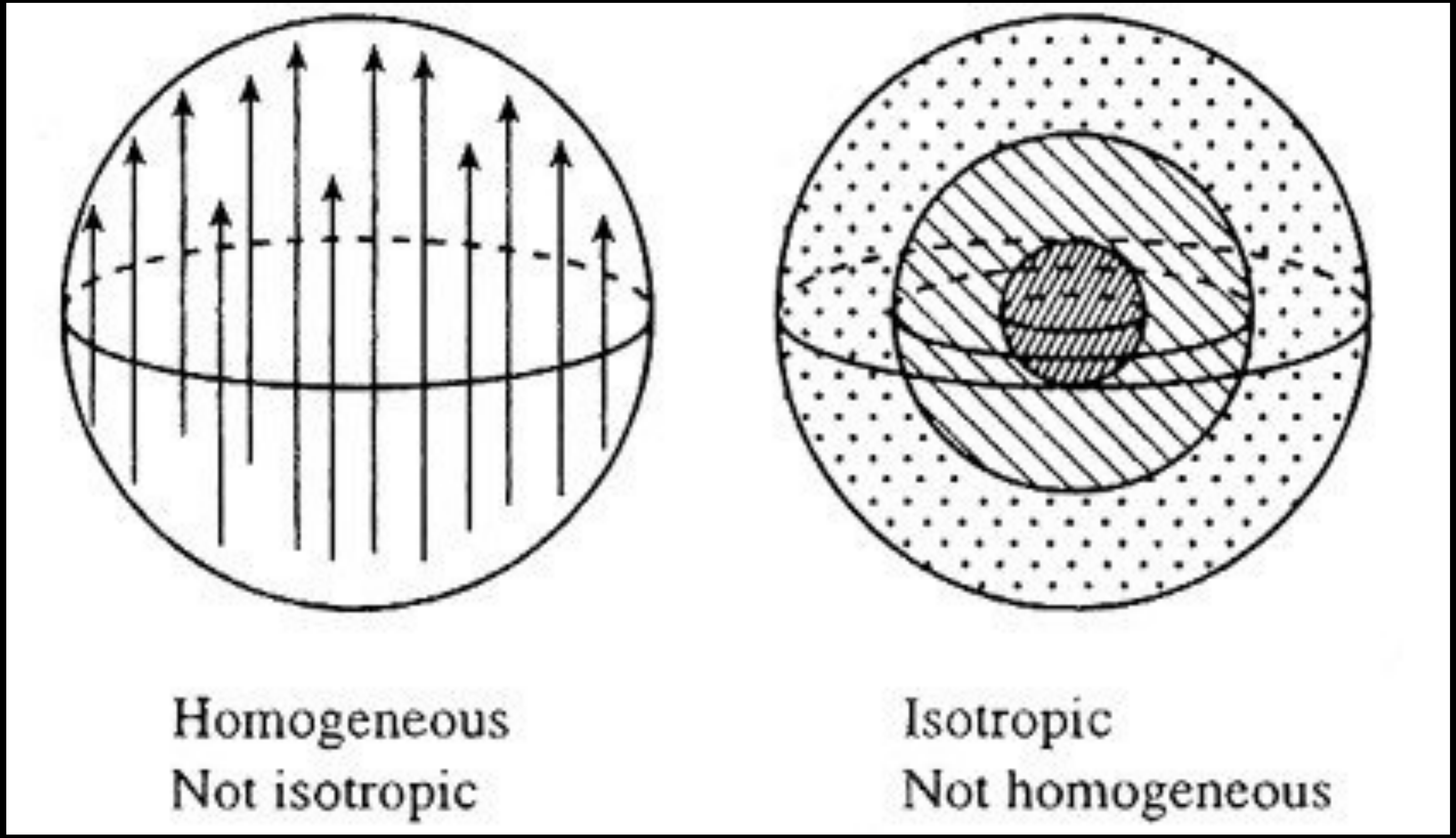


Image: University of Oregon

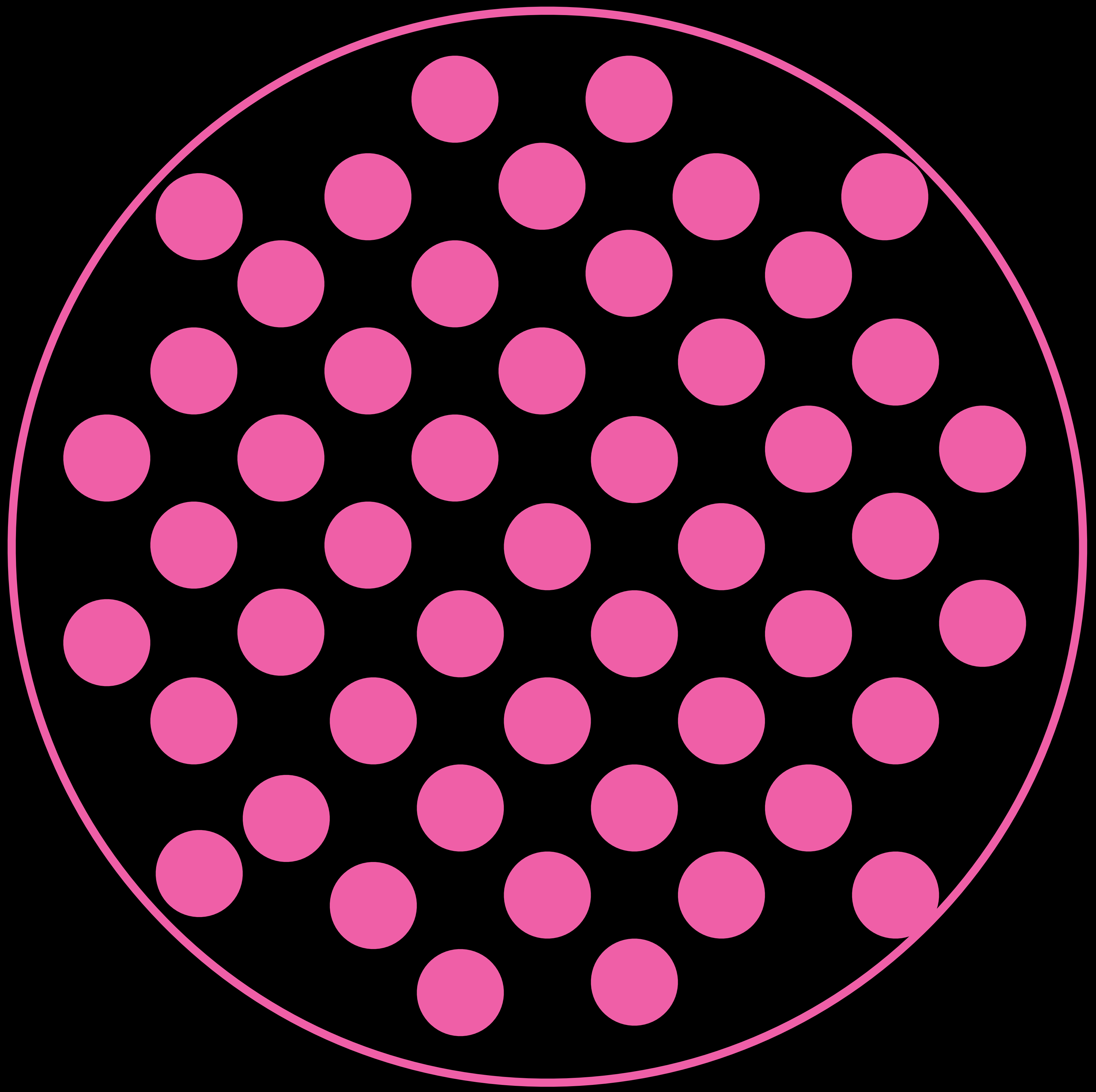
Isotropic:

Appears the same in all directions from one point

(Ignore the edges)

The Cosmological Principle

On large scales, the Universe is homogeneous *and* isotropic



(Ignore the edge)

The Universe is flat (Euclidean)

Parallel lines meet

Angles in triangle add up to > 180 degrees

Parallel lines diverge

Angles in triangle add up to < 180 degrees

Parallel lines remain equidistant, never meet

Angles in triangle add up to = 180 degrees

Closed

Open

Flat

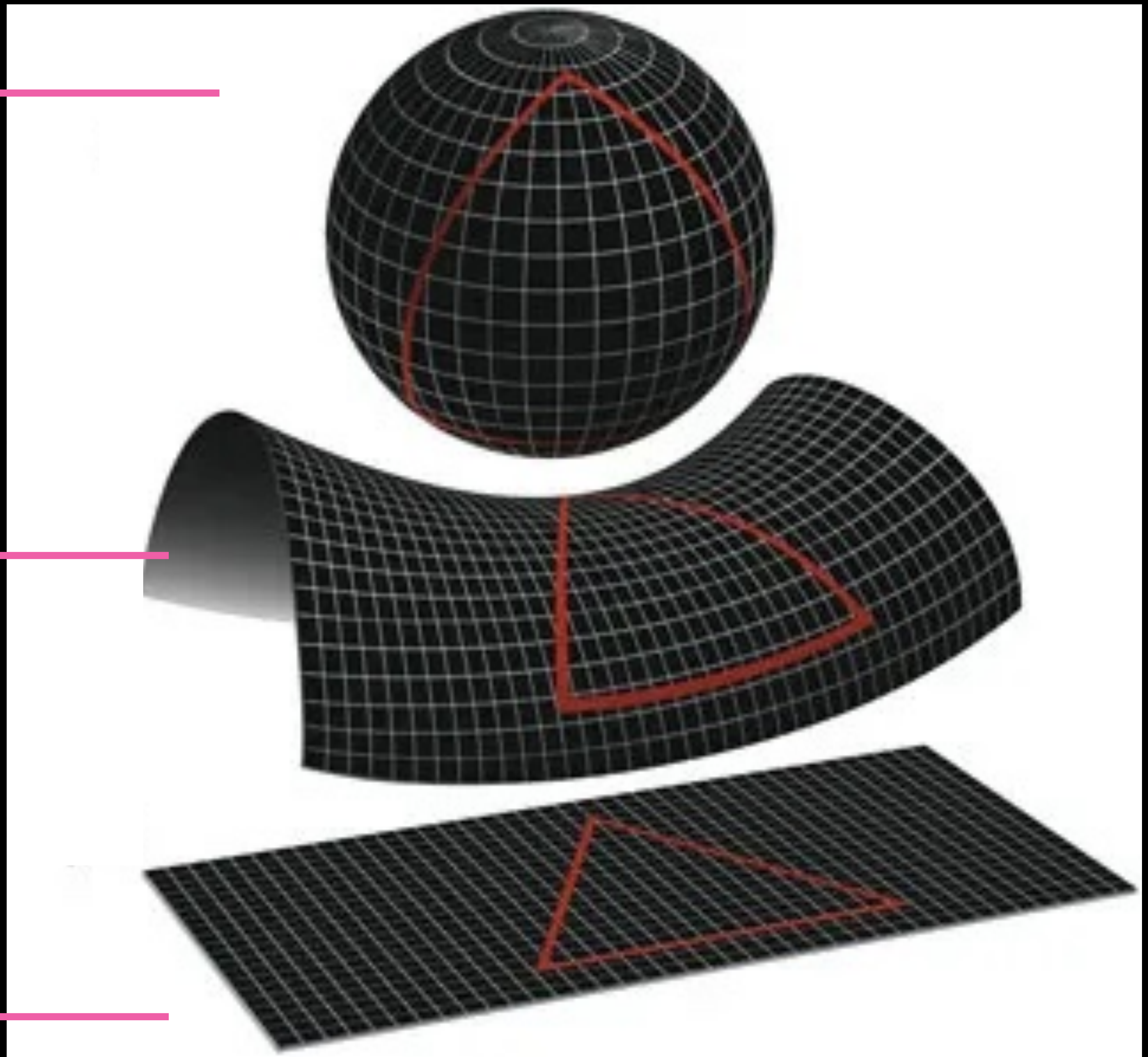


Image: NASA

Matter in the Universe

Matter in the Universe is made of baryonic matter *and* dark matter

Matter in the Universe

Baryons are what we can see as gas, stars, galaxies, (ordinary or atomic matter)


NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Dark matter is an unseen material only known by its gravitational effects.

The evidence for dark matter…

This is the Coma cluster of galaxies…

NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

In 1933, Fritz Zwicky of Switzerland measured…

mass of Coma cluster from motions of galaxies

NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

In 1933, Fritz Zwicky found that …

mass of cluster from motion

>

mass of cluster from luminous material

Mass of the Coma cluster from average velocity measurements was about 400 times greater than the mass inferred from luminous material!!

NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

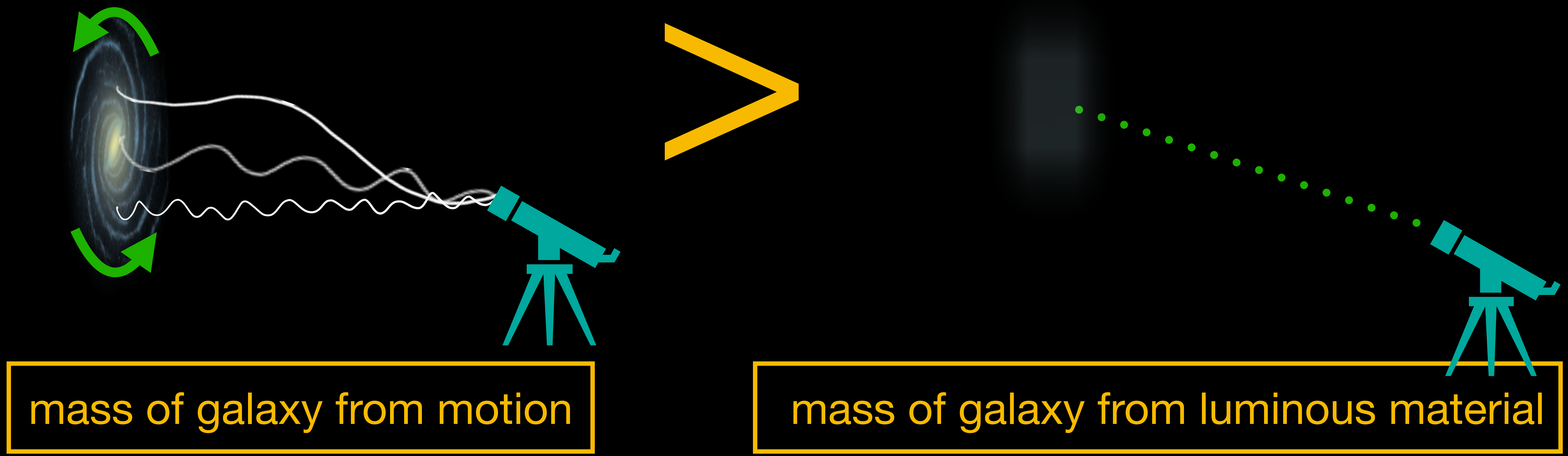
This is the Andromeda galaxy

Torben Hansen: Wikipedia

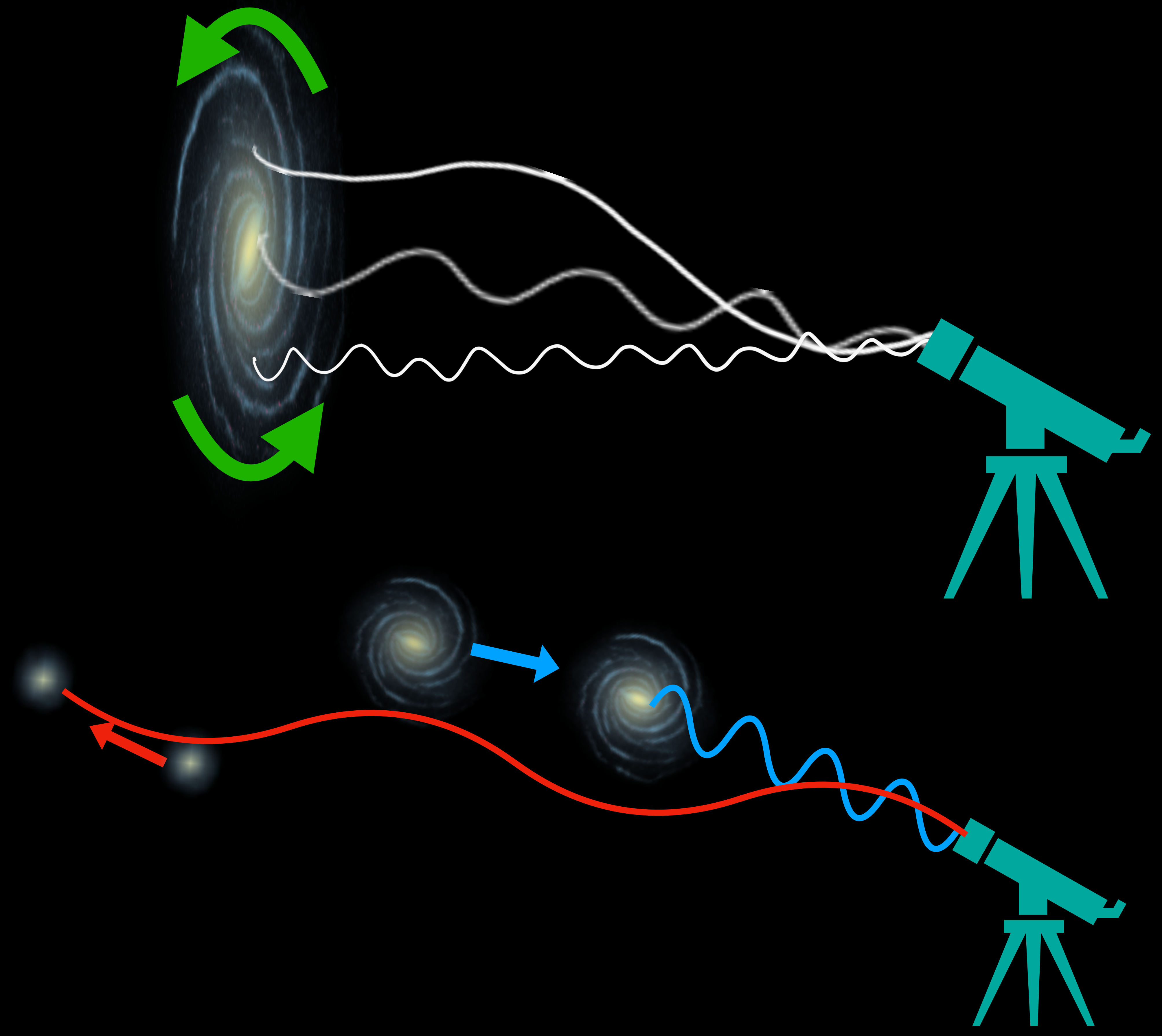
In 1970, Vera Rubin and Kent Ford measured the rotational velocity of the Andromeda galaxy.

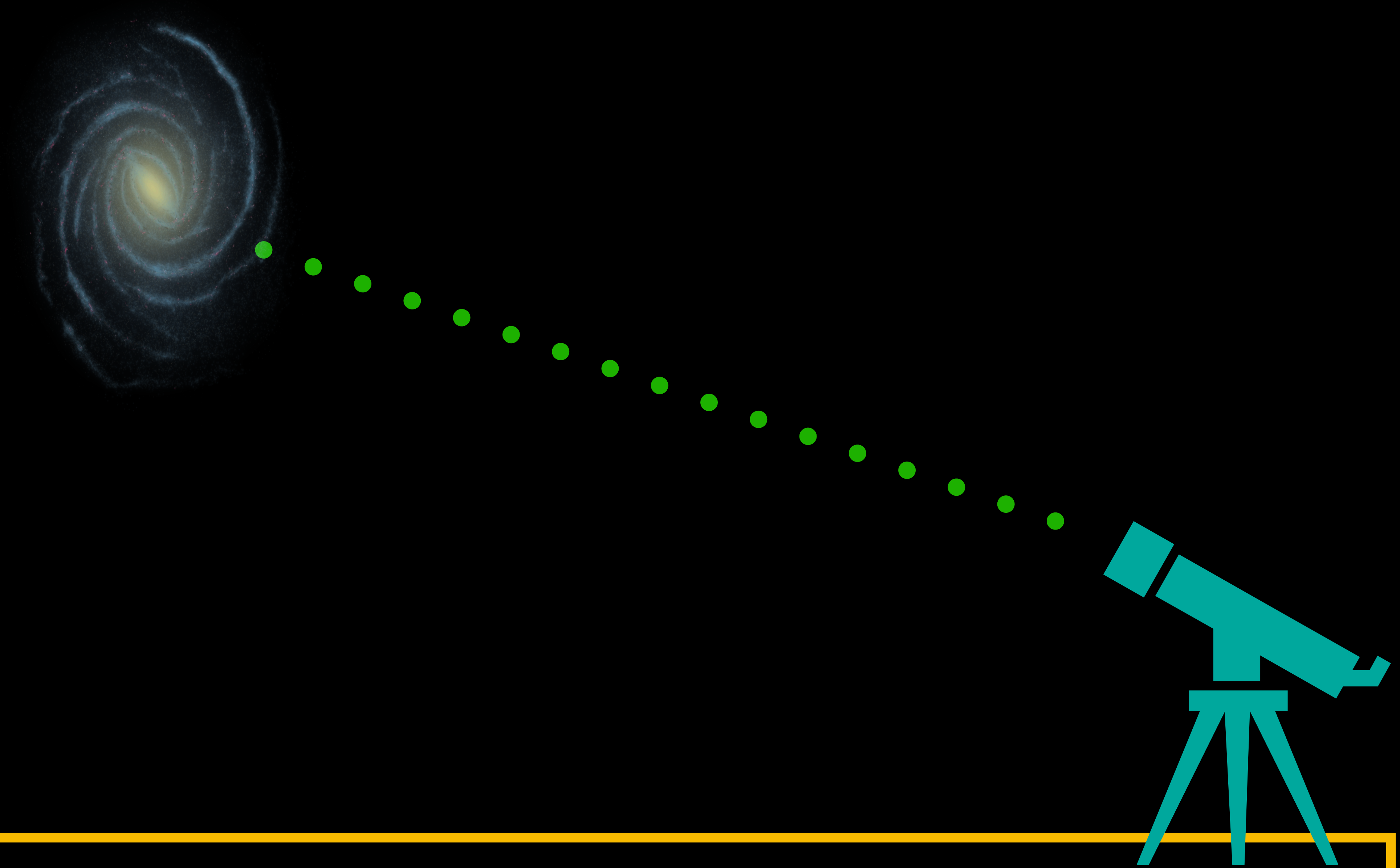
Torben Hansen: Wikipedia

In 1970, Vera Rubin and Kent Ford found that the masses inferred from the rotational velocity of individual spiral galaxies was much greater than the masses from luminous material.



There must be some missing material that we can’t see!

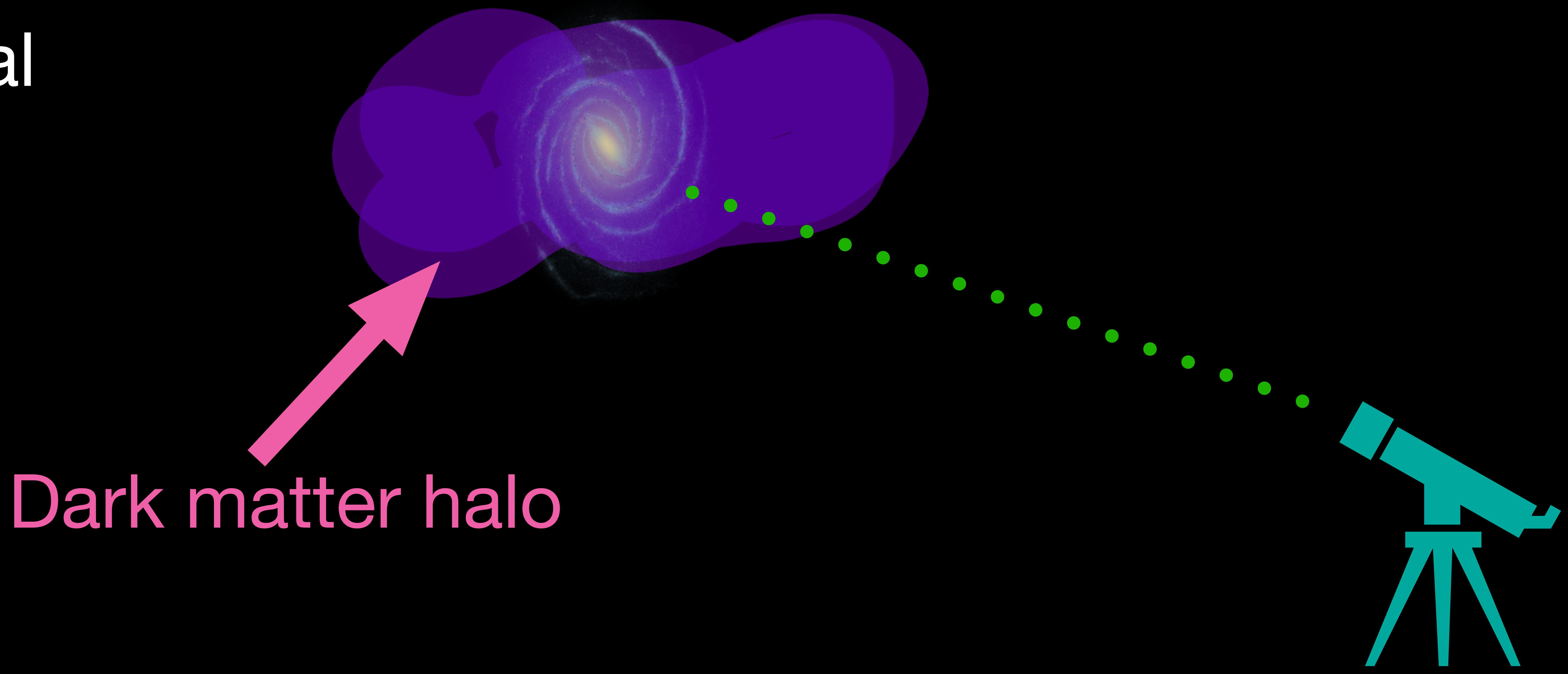




mass of galaxy from motion $>$ mass of galaxy from luminous material

There must be some missing material that we can't see!

We call that missing material dark matter!!



Composition of our Universe

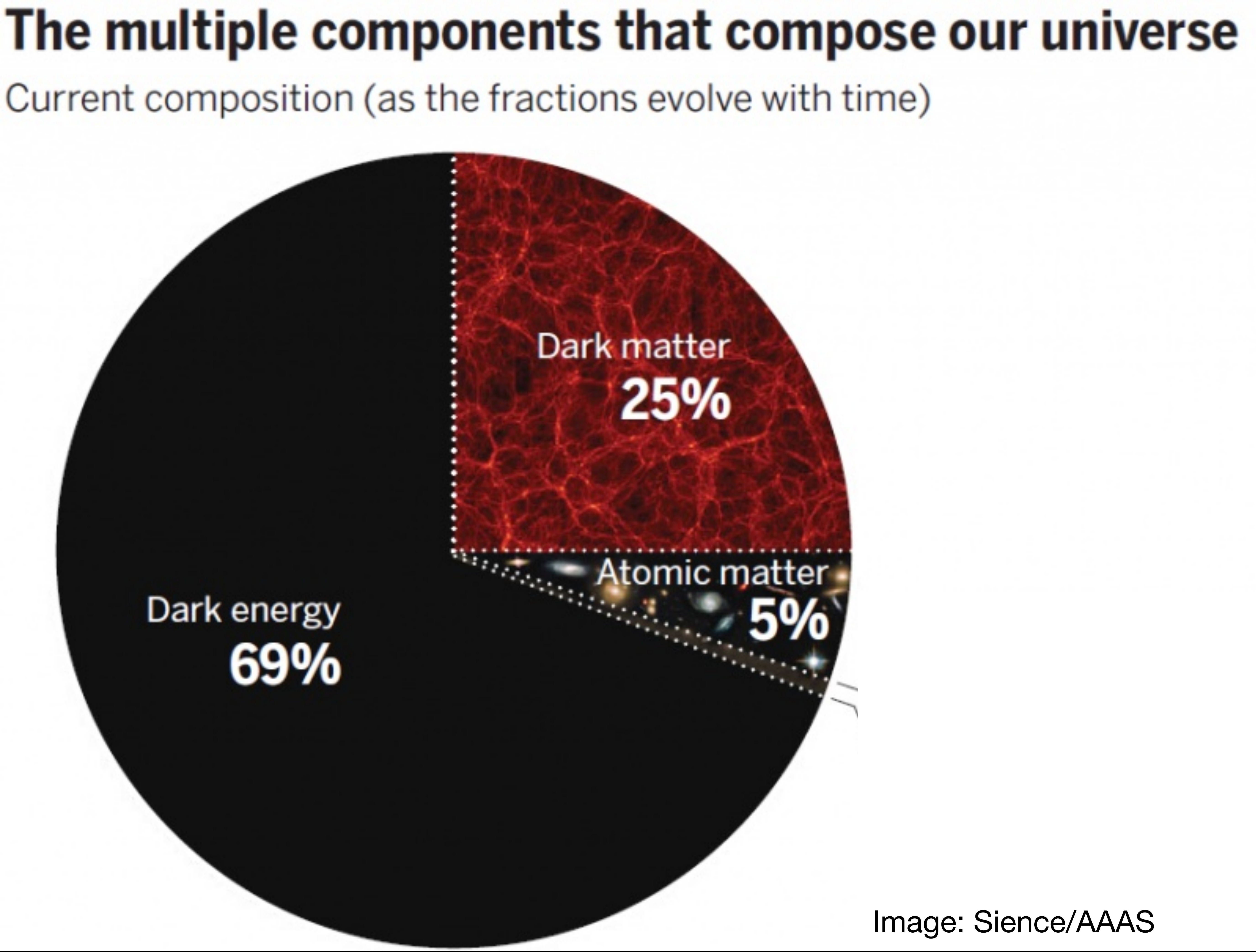


Image: Sience/AAAS

Our cosmological parameters

Ω_r

The fraction of the universe comprised of radiation

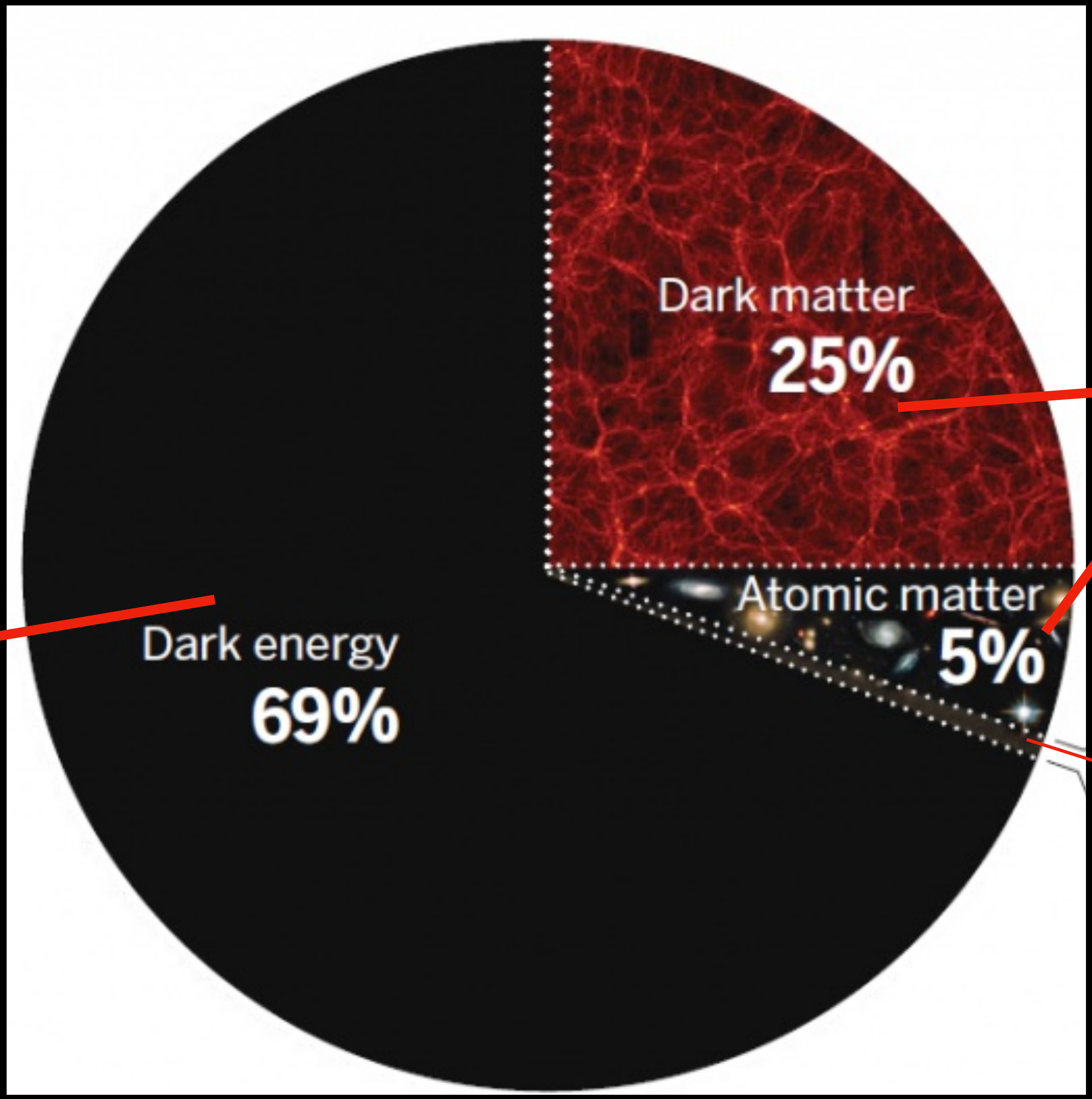
Ω_m

The fraction of the universe comprised of total matter (dark matter + baryons)

Ω_Λ

The fraction of the universe comprised of dark energy

Our cosmological parameters



Ω_m

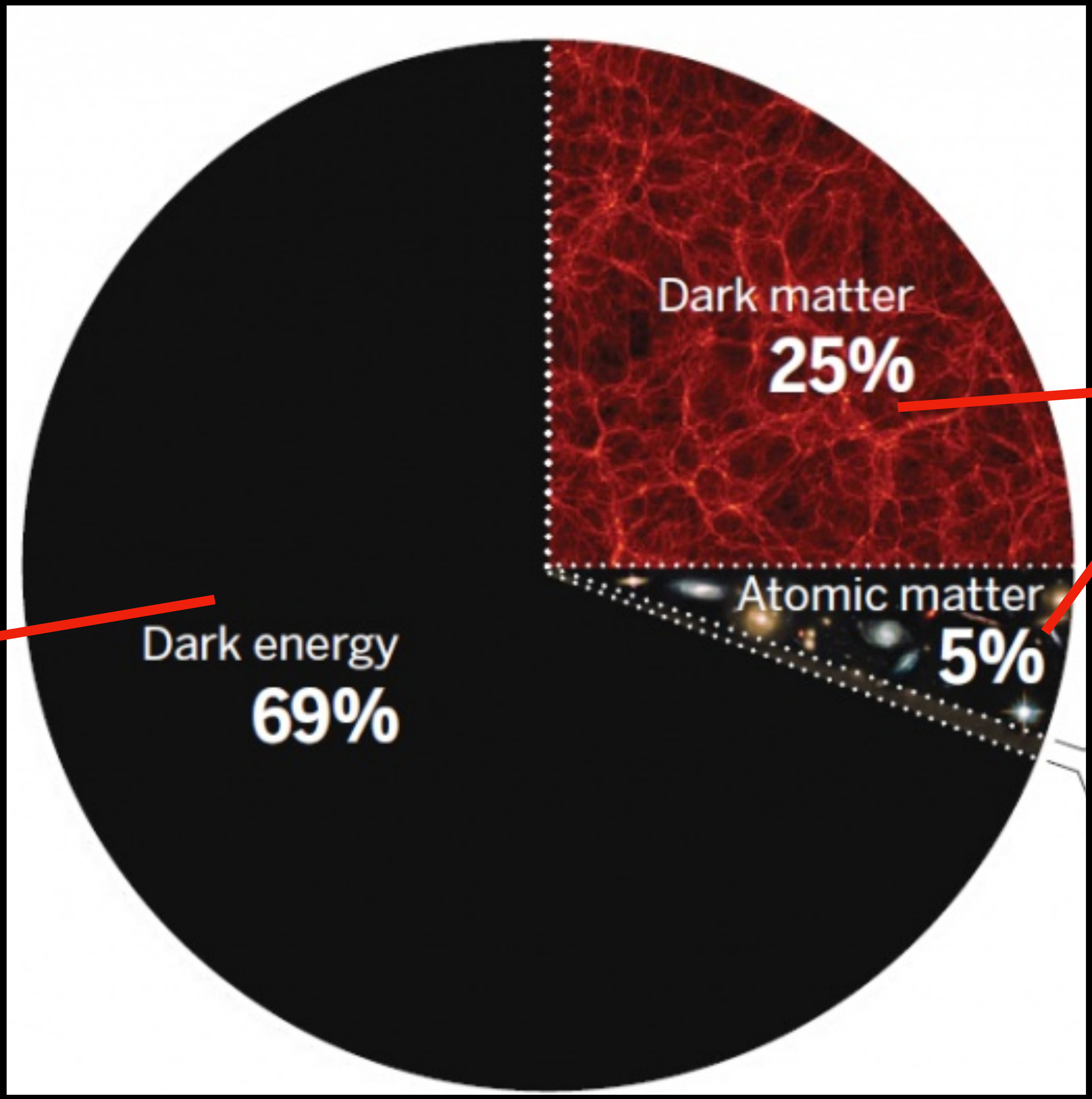
Ω_Λ

Ω_r

Image: Sience/AAAS

Our cosmological parameters

Ω_Λ



Ω_m

Image: Sience/AAAS

Our cosmological parameters

Ω_m

The fraction of the universe comprised of total matter (dark matter + baryons)

Ω_Λ

The fraction of the universe comprised of dark energy

Our cosmological parameters

$$\Omega_{\mathrm{m}}$$

Scales with the scale factor

$$\Omega_{\mathrm{m}}(1+z)^3$$

$$\Omega_{\Lambda}$$

Constant

Our cosmological parameters

$$\Omega_m + \Omega_\Lambda = 1.$$

The scale factor and redshift

The cosmic scale factor, a, is a dimensionless parameter in the equations that describe the expansion of the Universe

$$a = \frac{1}{1+z}$$

From here is where we get the term we so often see associated with *cosmological* redshift, z.

The scale factor and redshift

$$a = \frac{1}{1+z}$$

a=1 is the present scale factor, which makes the present redshift z=0

Back in time the scale factor was smaller, so redshift, z was larger.

Big Bang	Recombination	Today
$z = \infty$	$z = 1100$	$z = 0$

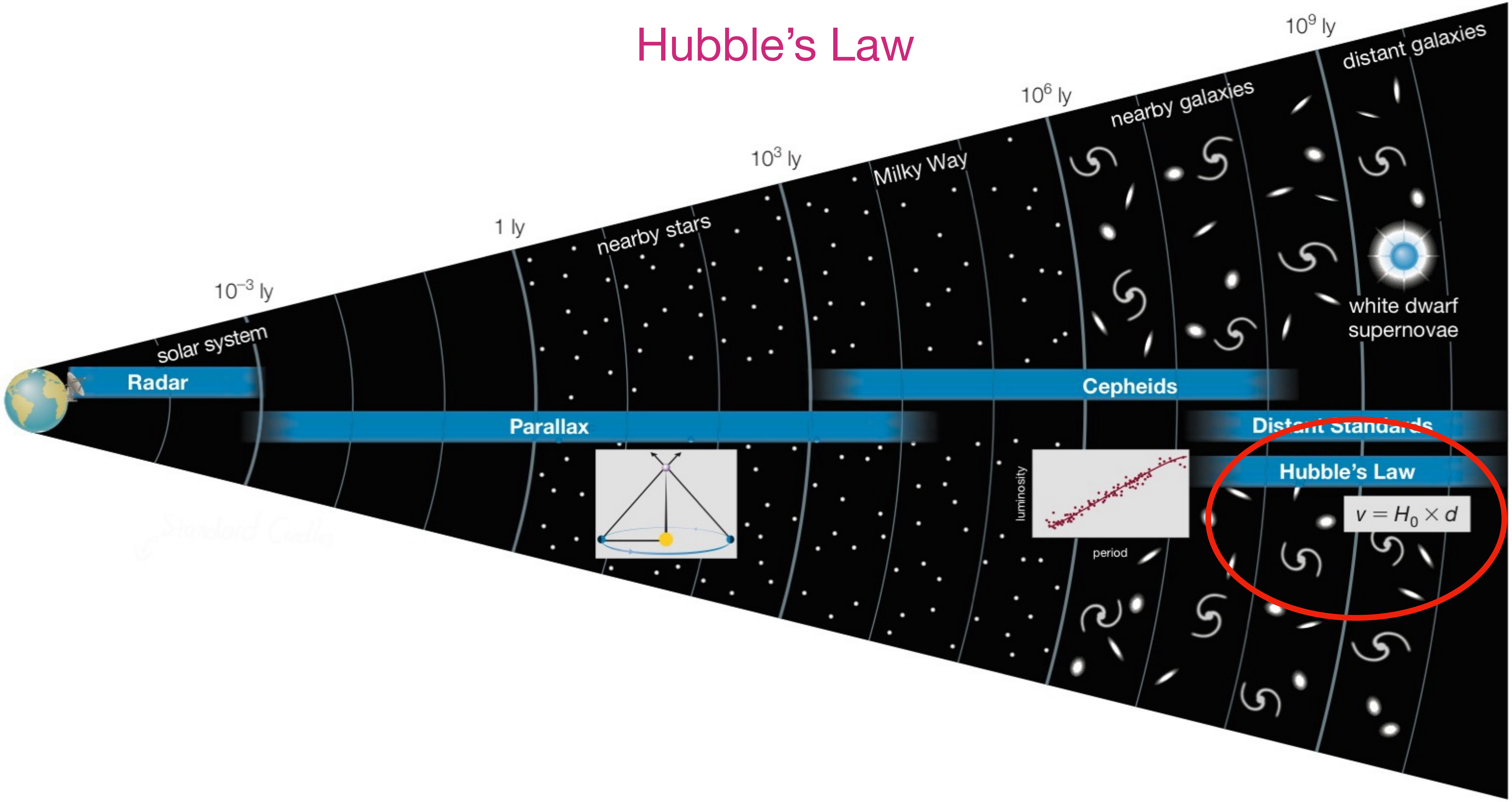
Hubble constant

The Hubble constant is a parameter that gives the *current rate of expansion*

H_0 has units $\left[\frac{\mathrm{km}}{\mathrm{s\ Mpc}}\right]$

The cosmic distance ladder

Hubble's Law



But Hubble's law is quite crude, it only works for the very nearby universe.

$$d = \frac{v}{H_0}$$

If we want to go out to z=1 or further, we must use other *cosmological distance models which are functions of the other cosmological parameters.*

$$D(z, \Omega_\mathrm{m}, H_0 \ldots)$$

These models will give us more accurate picture of the universe.