Parcours International
PHYSICS

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https://moodle1.u-bordeaux.fr/course/view.php?id=5388

RULES

1 Be on time
2 If you don't understand the *english* ... SAY SO !!
3 If you don't understand the *physics* ... SAY SO !!

Projects will be presented starting on April 6th

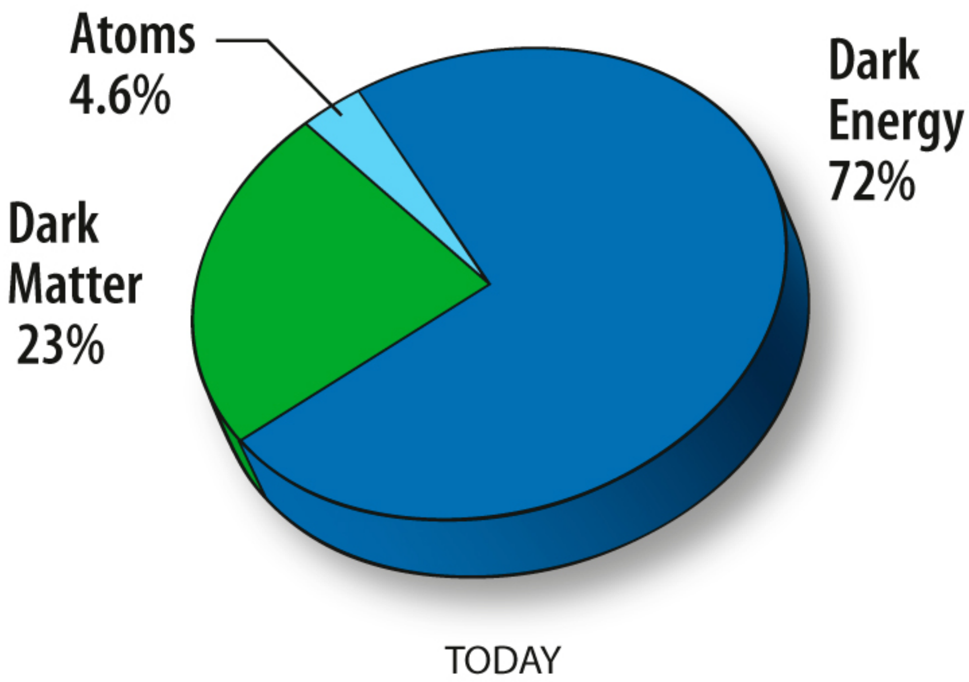
We will talk about Physics via Astrophysics. Many basic Physics problems require Astrophysical environments to be studied.

1 neutrinos
2 Gravitational waves (binary pulsar and now merging black holes and merging binary pulsars)
3 ***Dark Matter*** in this class
4 Dark Energy

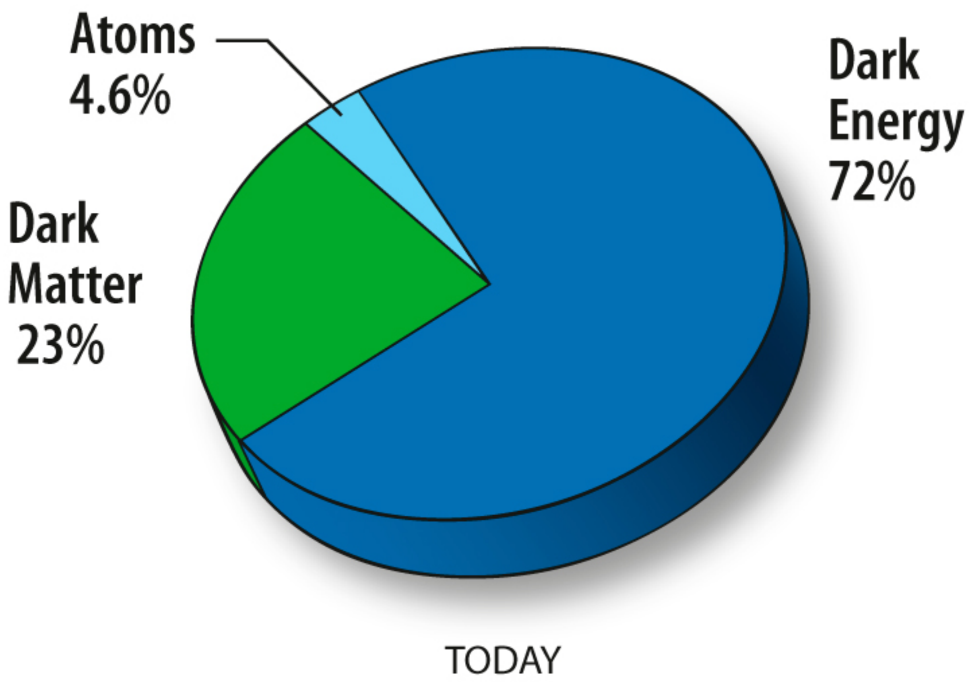
I have chosen ***Dark Matter*** as a topic because it is the major matter constituent of the Universe and it is fairly straightforward to show why physicists think it exists.

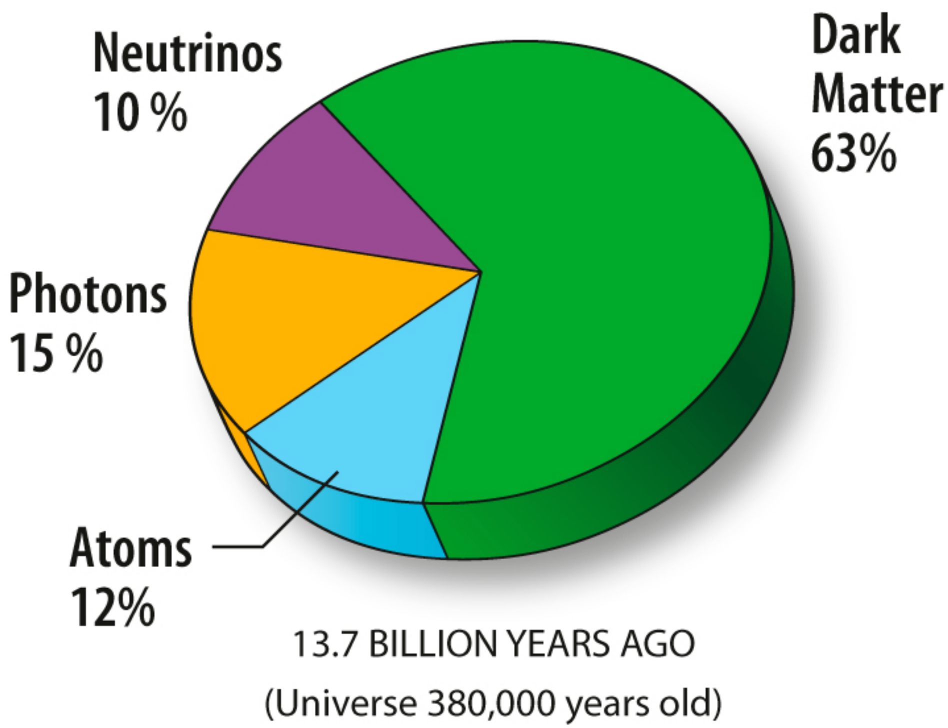
1 basic astro background
2 the ***Dark Matter*** problem via simple calculations
3 a few exercises and explanations
4 subjects for presentations and choice of subjects
5 fundamental particles as Dark Matter options
6 your presentations

What is the Universe made of?



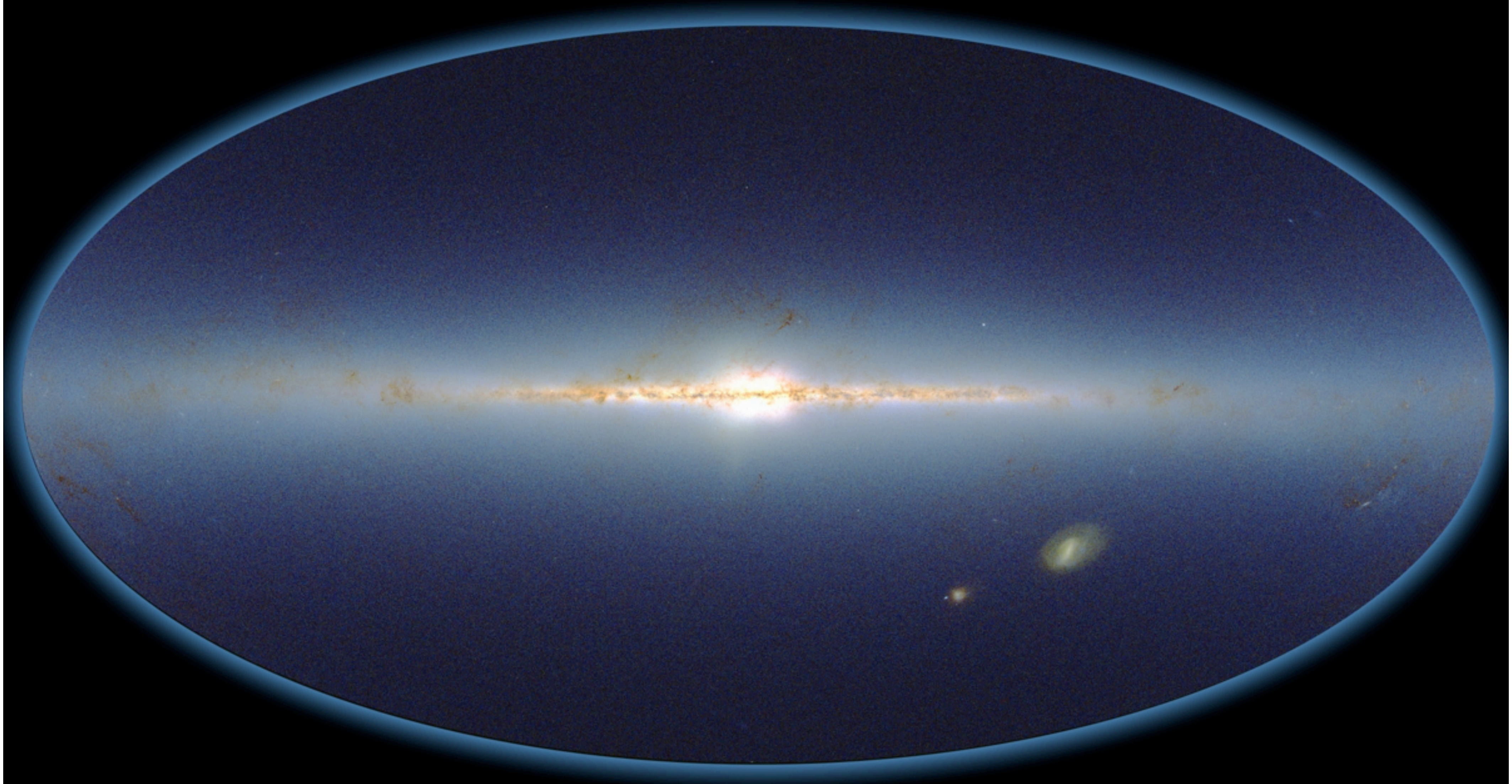
What is the Universe made of ?





From WMAP site
https://map.gsfc.nasa.gov/media/080998/index.html

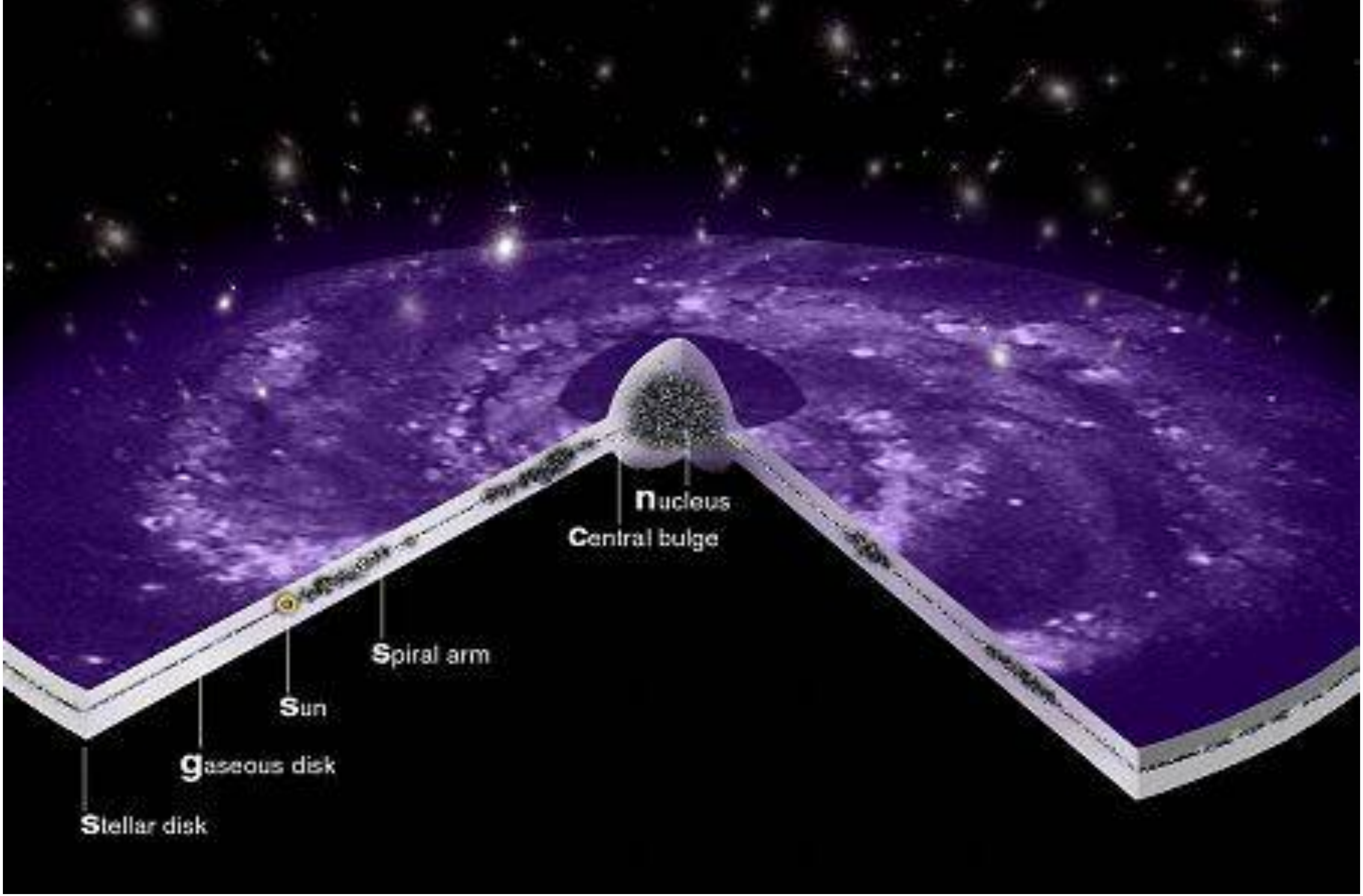
2MASS Covers the Sky



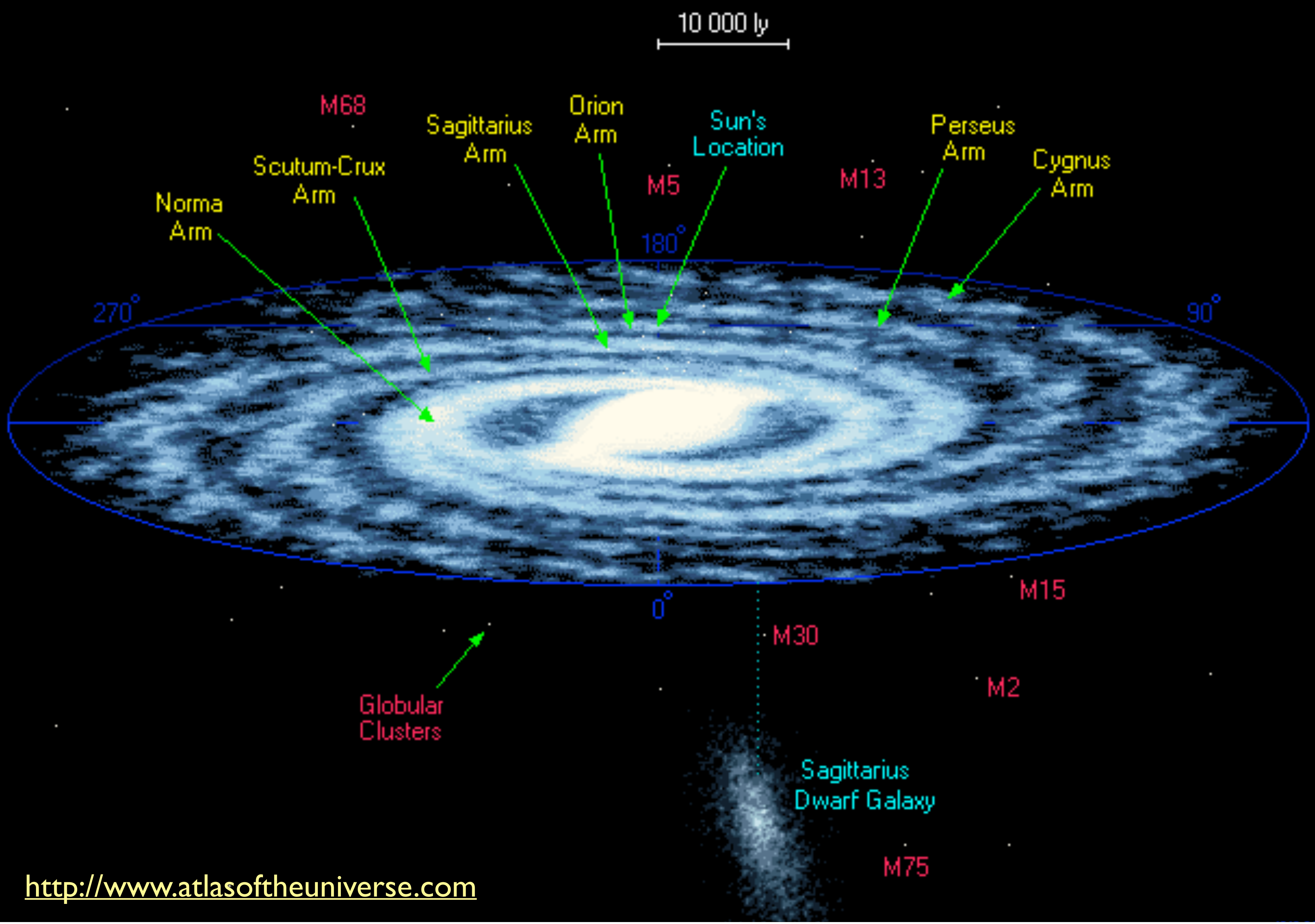
The Two Micron All Sky Survey

Infrared Processing and Analysis Center/Caltech & Univ. of Massachusetts

What does our galaxy, the Milky Way, look like?

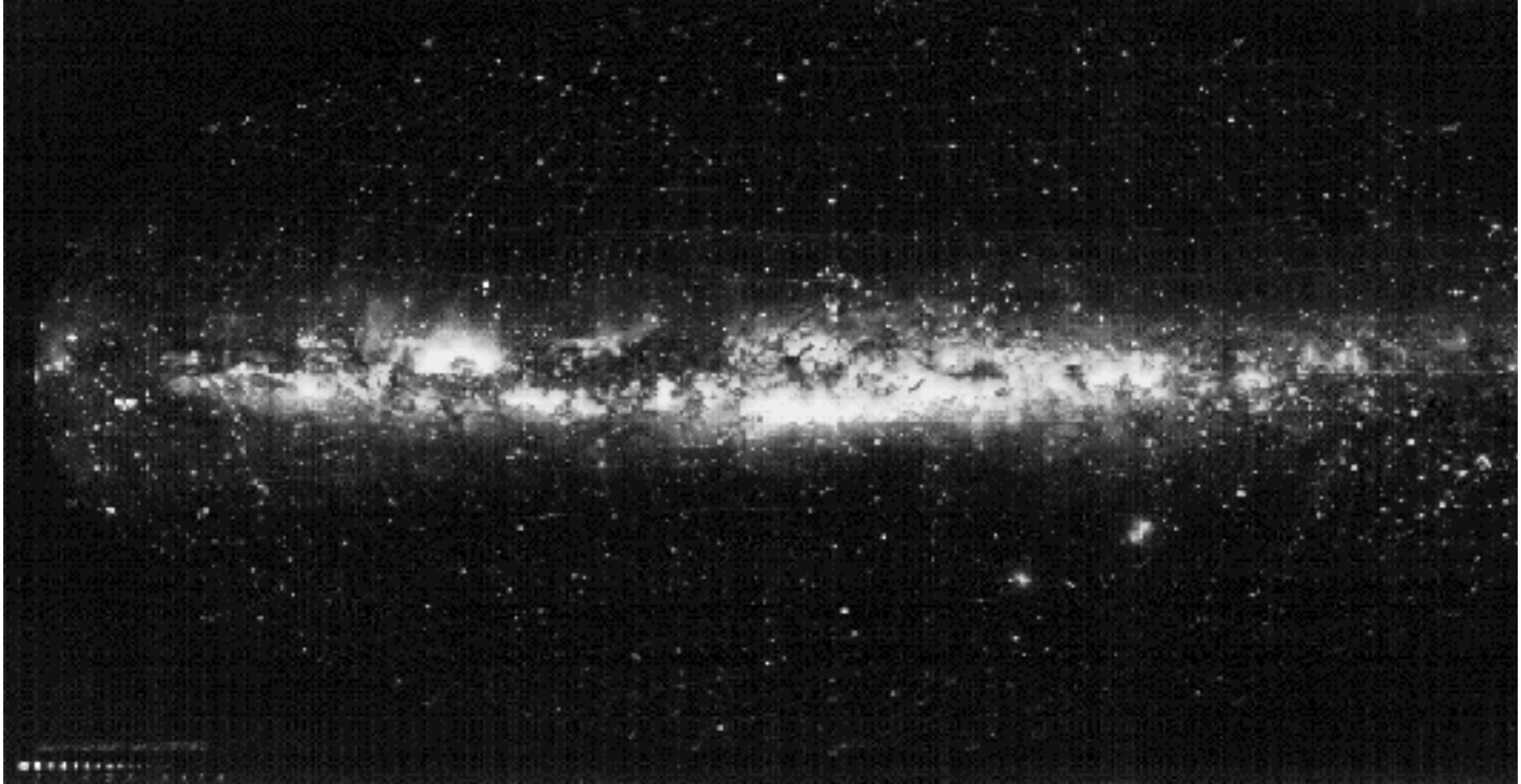


A different view of our local environment

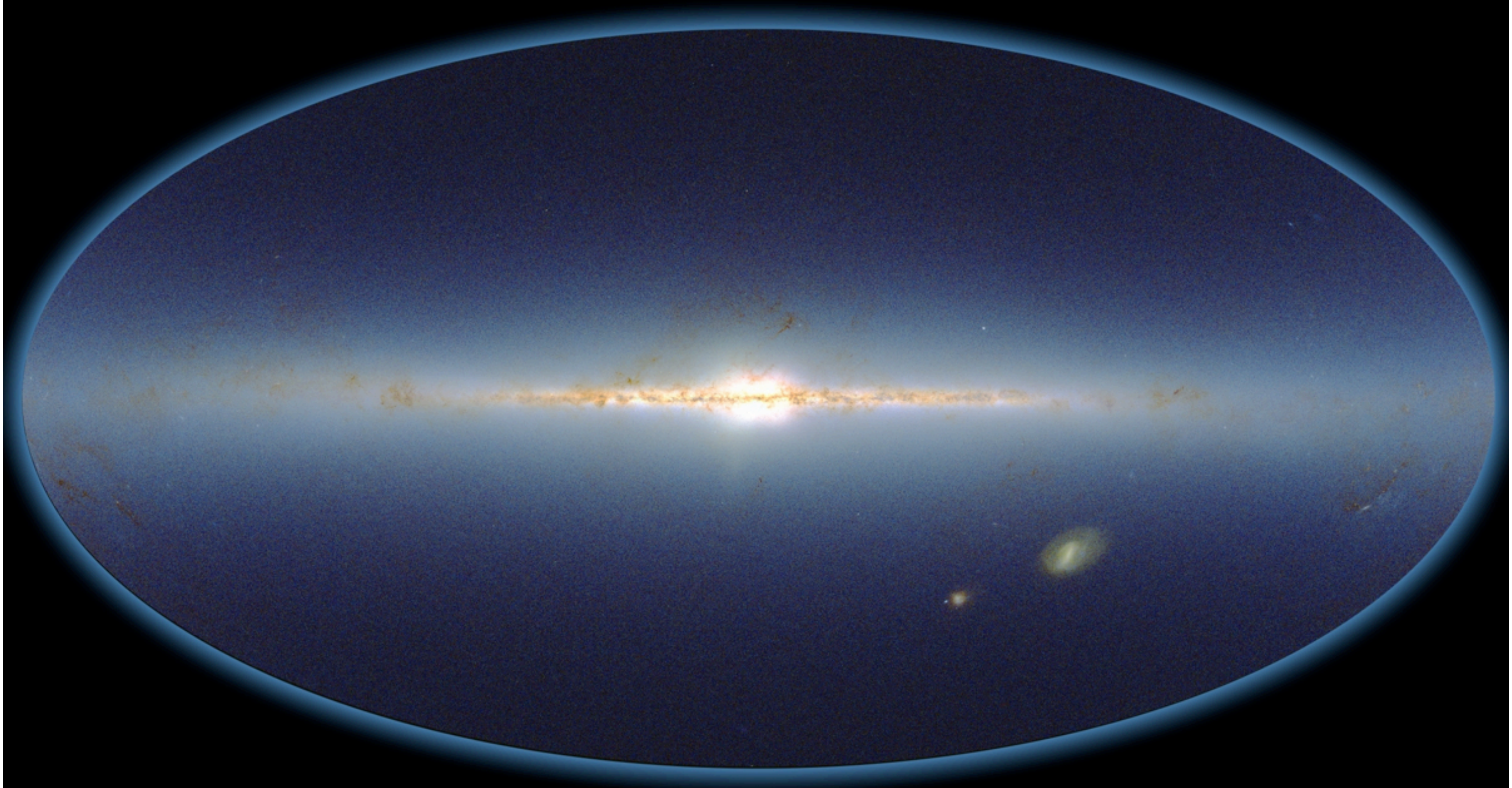


http://www.atlasoftheuniverse.com

The Milky Way... the way you could photograph it.



2MASS Covers the Sky



The Two Micron All Sky Survey

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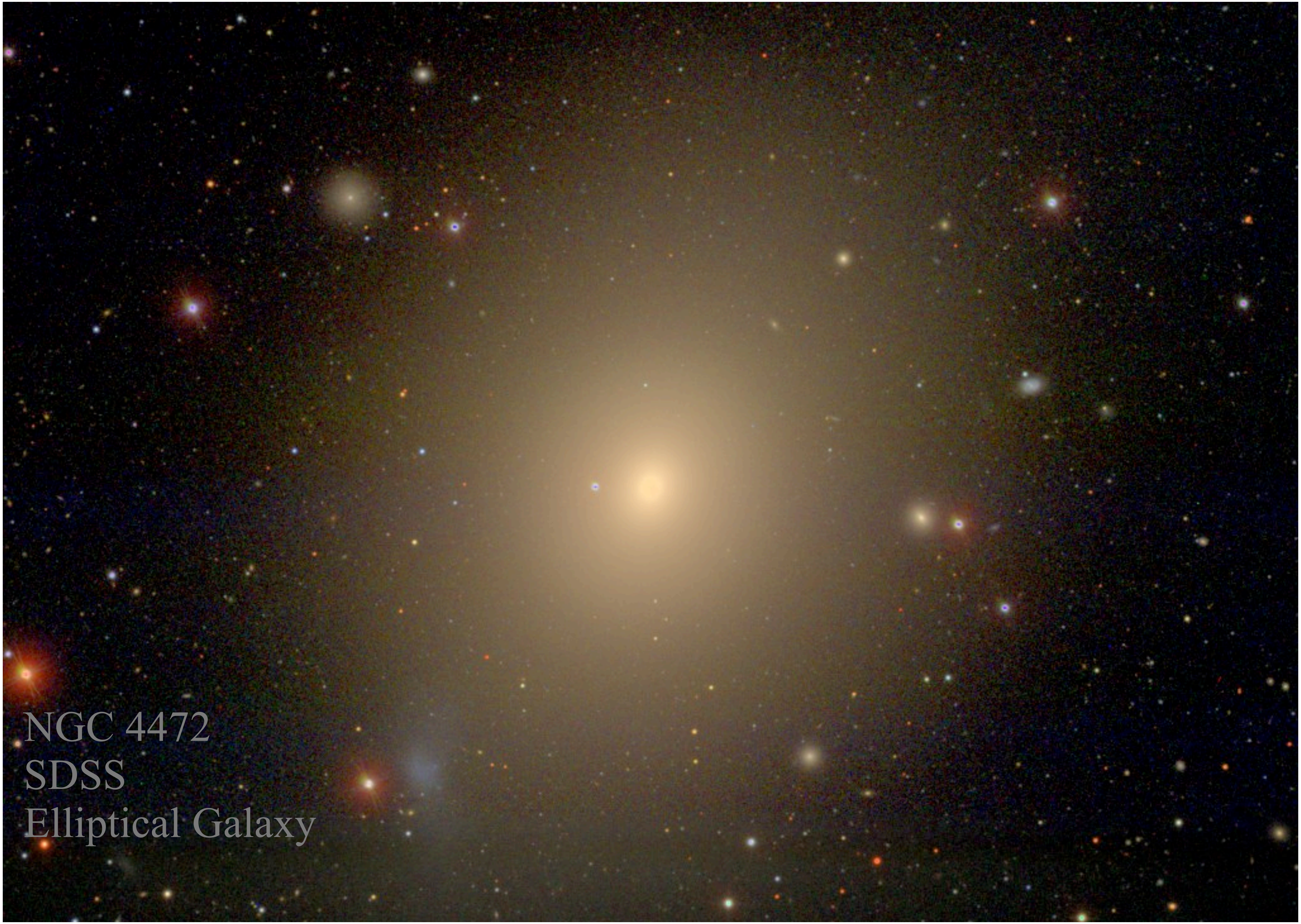

NGC 4472
SDSS
Elliptical Galaxy

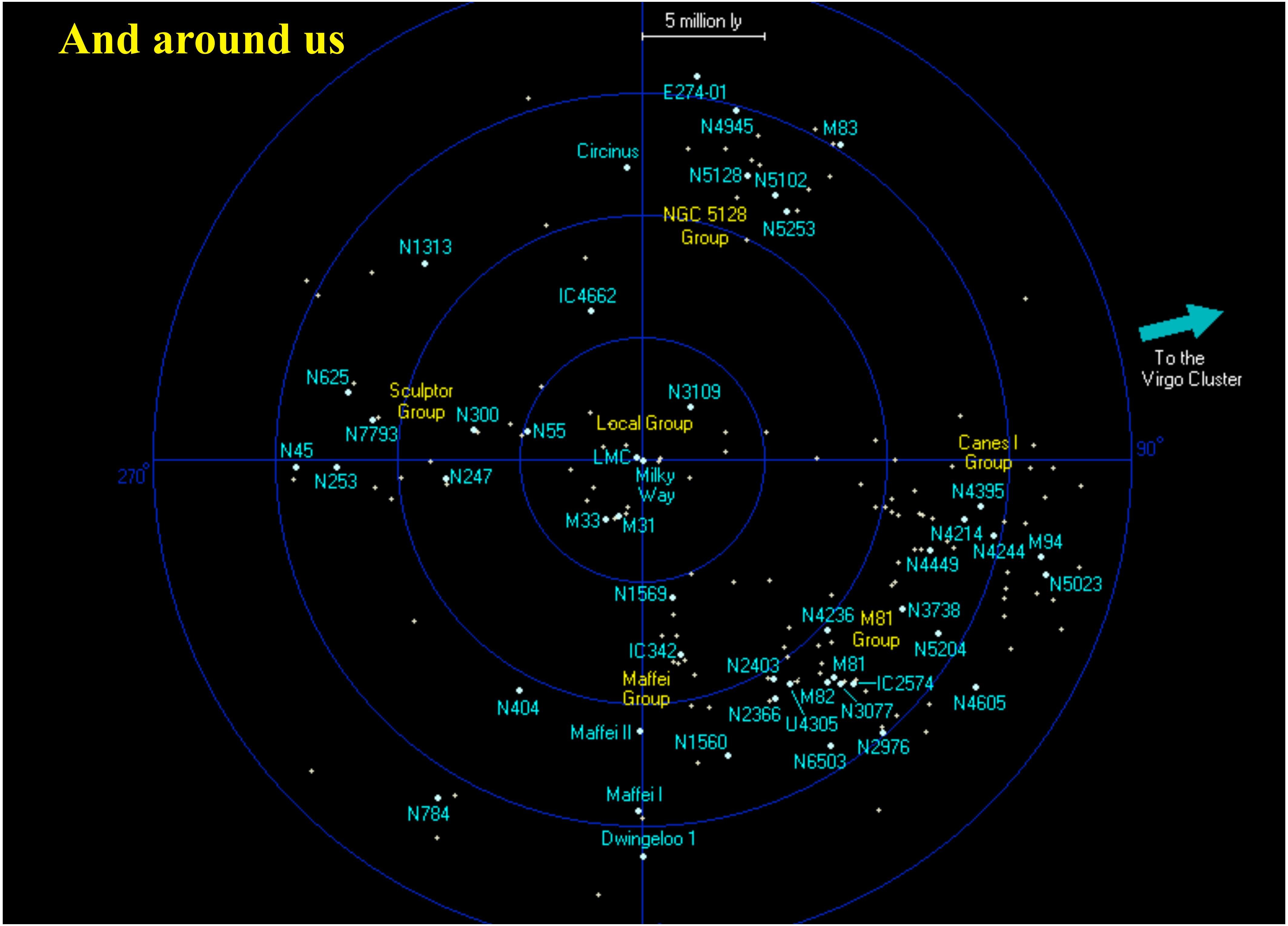
Disk <==> Rotation

The kinetic energy of spirals is in rotation (~200 km/s), with small random velocities (~20 km/s)

Elliptical galaxies are supported by the mostly "random" velocities of stars with little overall rotation.
==> little neutral gas in ellipticals
==> little star formation in ellipticals

==> formation et evolution spirals and ellipticals very different.

And around us



Cosmology

"Cosmologists are often in error but never in doubt"

Lev Landau (1962 Nobel prize)

At the time, Landau did not know that astrophysicists would claim to have a precise idea of the age and structure of the universe yet have no idea as to what 95% of it could be.

I will try to illustrate a small part of this.

Cosmology

Before the beginning of the 20th century, scientists believed that the universe had always been and would remain as we see it. A "stationary universe".

Then... Einstein and General Relativity.

and thinking about the consequences of the finite speed of light...

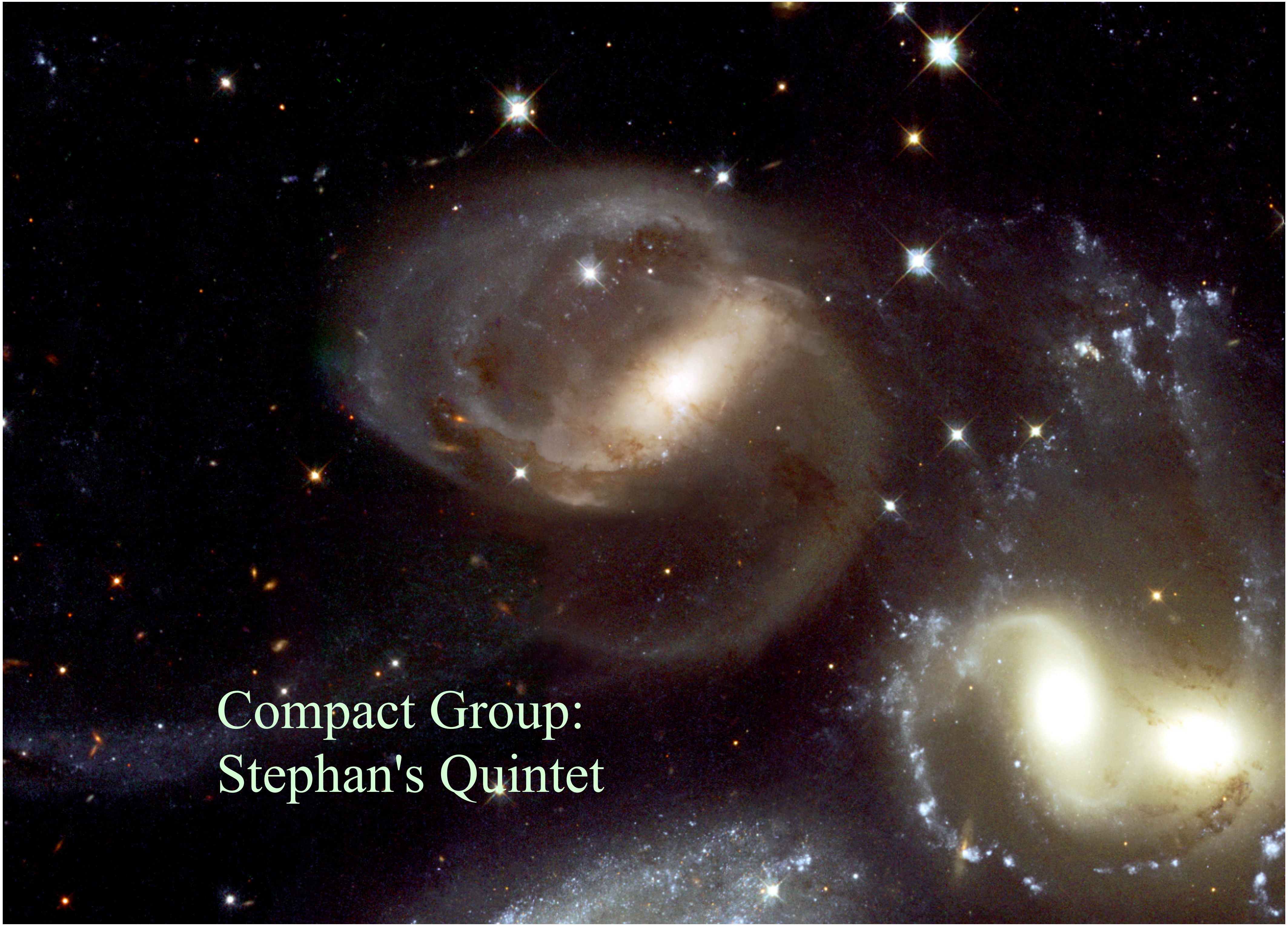
The Cosmological Principle

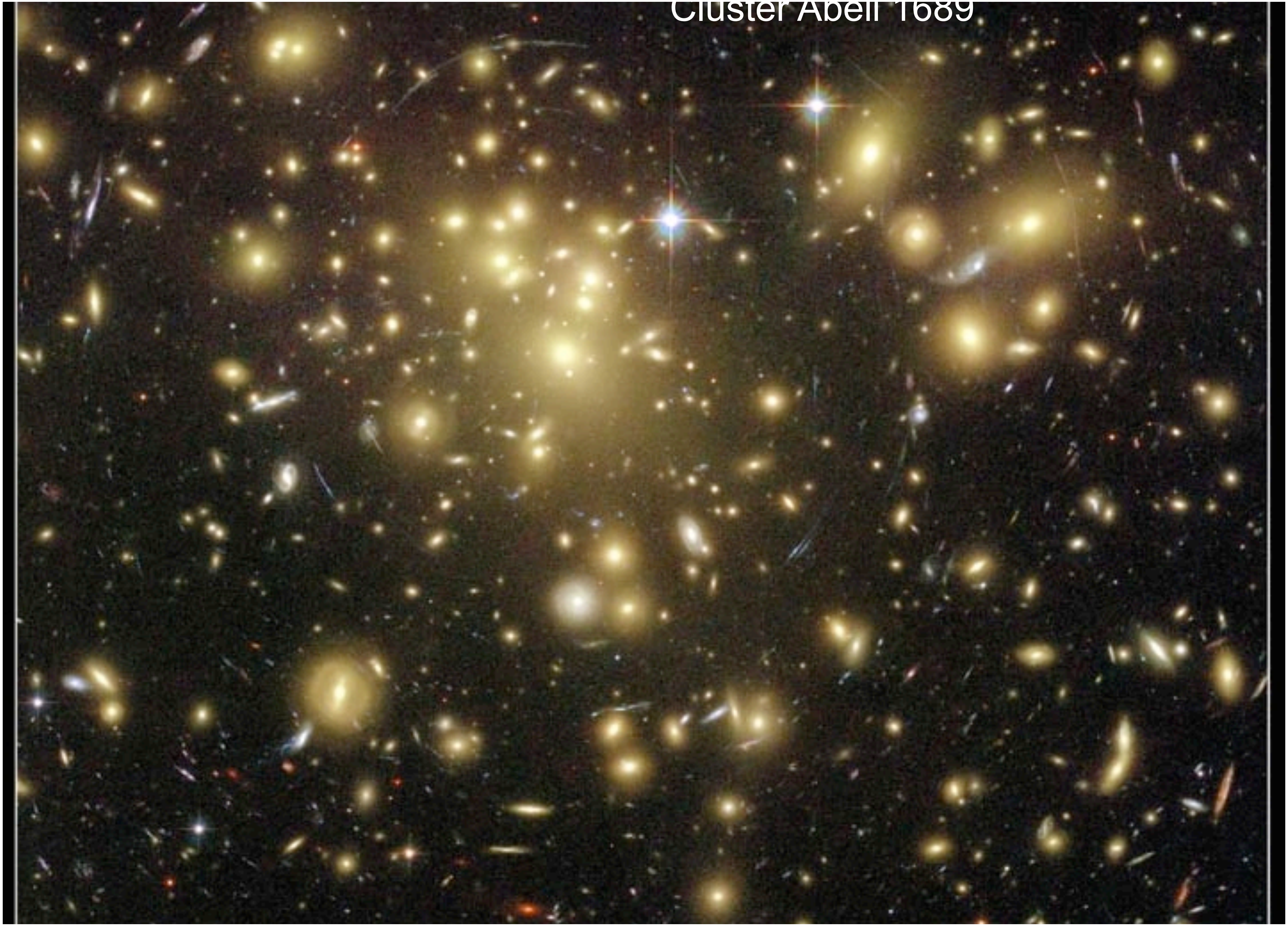
« *We are not in a special place* »
==> universe is homogeneous and isotropic at large scales
==> With Gen Rel, that apparently simple idea defines a metric, which is the way distances are measured. The metric contains the link between the space and time coordinates. Generally, the Robertson-Walker metric is used.

"This amounts to the strongly philosophical statement that the part of the universe which we can see is a fair sample, and that the same physical laws apply throughout. In essence, this in a sense says that the universe is knowable and is playing fair with scientists." Keel

(Note that this is not "at a special time", which is sometimes called the *perfect* cosmological principle)

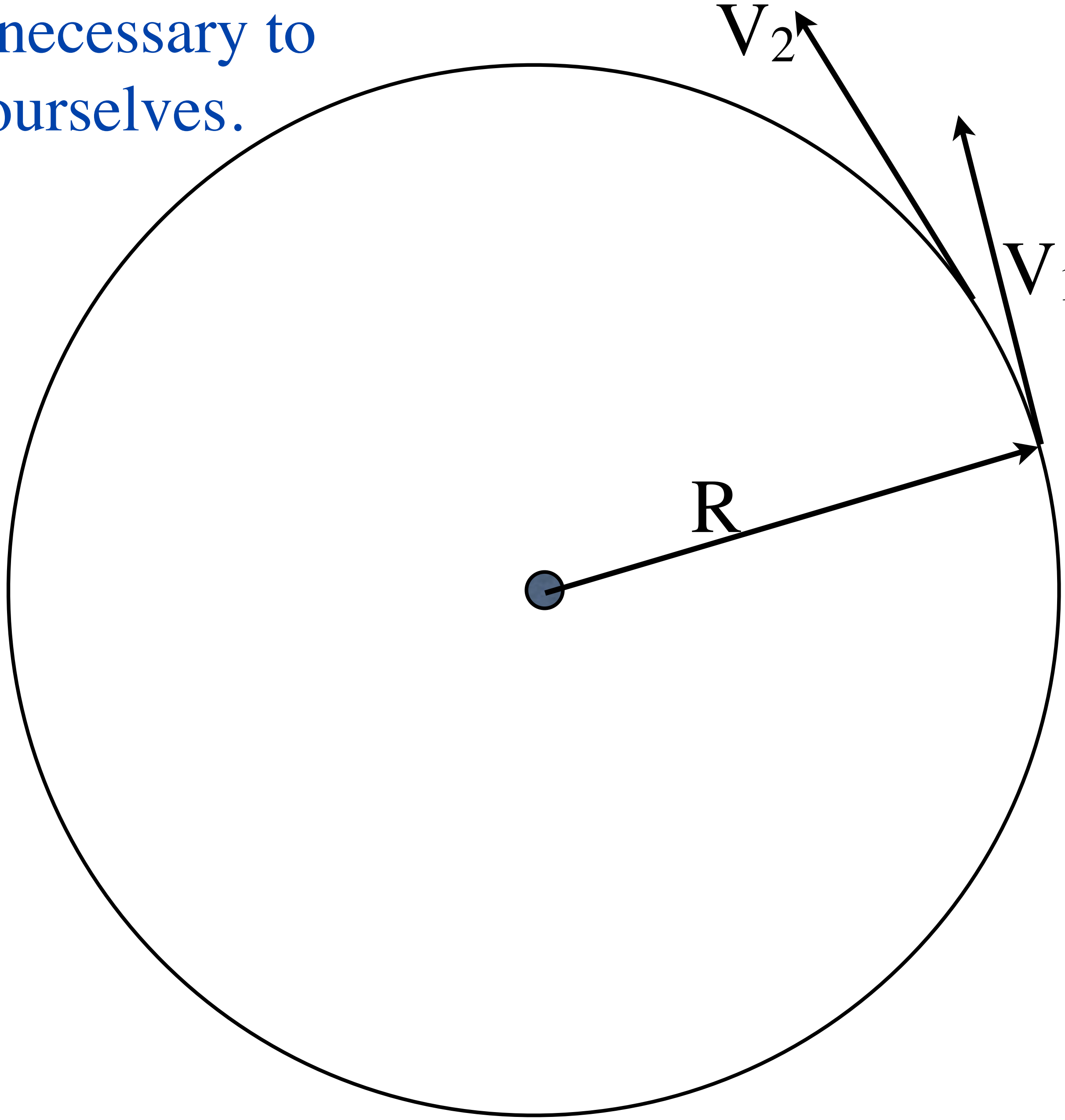

Groupe
NGC 3623,
NGC 3627,
NGC 3628


Compact Group:
Stephan's Quintet


Cluster Abell 1689

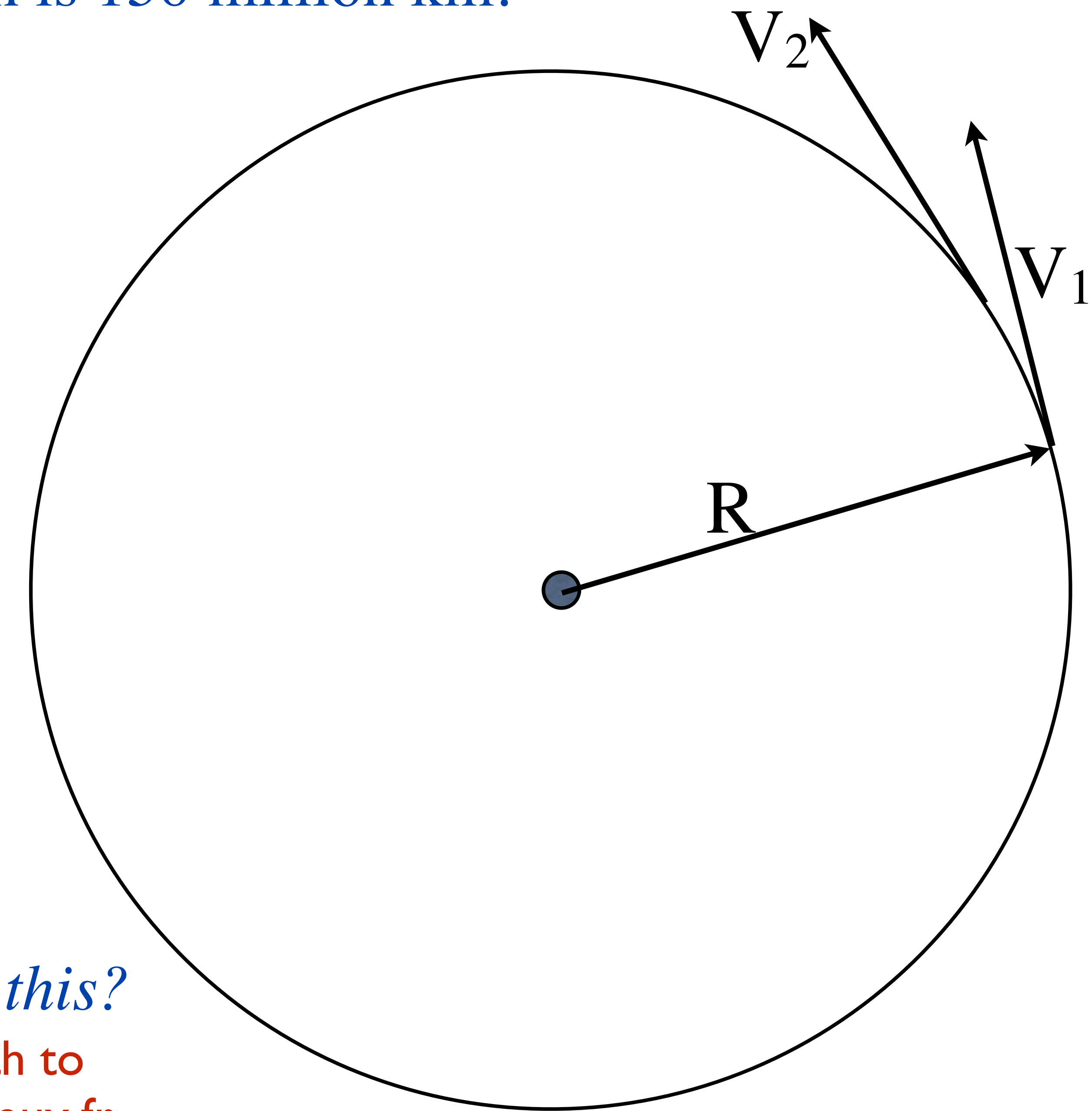
To keep a particle in a circular orbit, there has to be an acceleration towards the center. The acceleration is $a = dv/dt = V^2/R$.

Do what is necessary to convince yourselves.



Now use this to calculate the mass of the Sun, knowing that the distance from Sun to Earth is 150 million km.

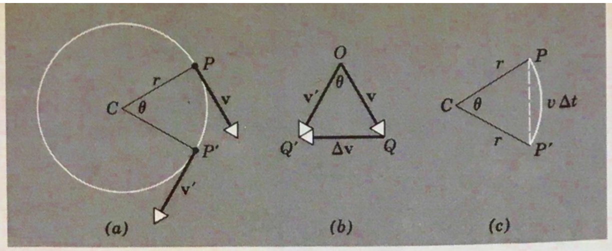
Just in case
year=365.25 days
day=24 hours
hour = 3600 seconds
pi=3.14159265 ~ 22/7



But didn't we learn that orbits are ellipses?

How serious a problem is this?

To be emailed for Feb 9th to
jonathan.braine@u-bordeaux.fr



Uniform circular motion. The particle travels around a circle at constant speed. Its velocity at two points P and P' is shown. Its change in velocity in going from P to P' is $\Delta \mathbf{v}$.

at a common point. We are free to do this as long as the magnitude and direction of each vector are the same as in Fig. 4-5*a*. This diagram (Fig. 4-5*b*) enables us to see clearly the *change in velocity* as the particle moved from P to P'. This change, $\mathbf{v}' - \mathbf{v} = \Delta\mathbf{v}$, is the vector which must be added to $\mathbf{v}$ to get $\mathbf{v}'$. Notice that it points inward, approximately toward the center of the circle.

Now the triangle OQQ' formed by $\mathbf{v}$, $\mathbf{v}'$, and $\Delta\mathbf{v}$ is similar to the triangle CPP' (Fig. 4-5*c*) formed by the chord PP' and the radii CP and CP'. This is so because both are isosceles triangles having the same vertex angle; the angle θ between $\mathbf{v}$ and $\mathbf{v}'$ is the same as the angle PCP' because $\mathbf{v}$ is perpendiculat to CP and $\mathbf{v}'$ is perpendicular to CP'. We can therefore write

$$\frac{\Delta v}{v} = \frac{v\,\Delta t}{r}, \qquad \text{approximately,}$$

the chord PP' being taken equal to the arc length PP'. This relation becomes more nearly exact as Δt is diminished, since the chord and the arc then approach each other. Notice also that $\Delta\mathbf{v}$ approaches closer and closer to a direction perpendicular to $\mathbf{v}$ and $\mathbf{v}'$ as Δt is diminished and therefore approaches closer and closer to a direction pointing to the exact center of the circle. It follows from this relation that

$$\frac{\Delta v}{\Delta t} = \frac{v^2}{r}, \qquad \text{approximately,}$$

and in the limit when $\Delta t \to 0$ this expression becomes exact. We therefore obtain

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{v^2}{r} \tag{4-9}$$

as the magnitude of the acceleration. The direction of $\mathbf{a}$ is instantaneously along a radius inward toward the center of the circle.

Figure 4-6 shows the instantaneous relation between $\mathbf{v}$ and $\mathbf{a}$ at various points of the motion. The magnitude of $\mathbf{v}$ is constant, but its direction changes continuously. This gives rise to an acceleration $\mathbf{a}$ which is also constant in magnitude (but not zero) but continuously changing in direction. The velocity $\mathbf{v}$ is always tangent to the circle in the direction of motion; the acceleration $\mathbf{a}$ is always directed radially inward. Because of this, $\mathbf{a}$ is called a radial, or *centripetal*, acceleration. Centripetal means "seeking a center."

Both in free fall and in projectile motion $\mathbf{a}$ is constant in direction and magnitude and we can use the equations developed for constant acceleration (see Table 4-1). We cannot use these equations for uniform circular motion because $\mathbf{a}$ varies in direction and is therefore not constant.

The units of centripetal acceleration are the same as those of an acceleration resulting from a change in the magnitude of a velocity.

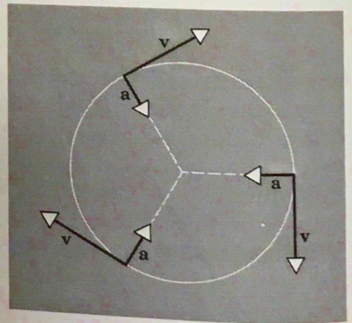


figure 4-6
In uniform circular motion the acceleration $\mathbf{a}$ is always directed toward the center of the circle and hence is perpendicular to v

taken from textbook
Physics, 3rd edition
by Halliday & Resnick

Dimensionally, we have

$$\frac{v^2}{r} = \left(\frac{\text{length}}{\text{time}}\right)^2 \Big/ \text{length} = \frac{\text{length}}{\text{time}^2} \quad \text{or} \quad \frac{L}{T^2},$$

which are the dimensions of acceleration. The units therefore may be ft/s^2 and m/s^2, among others.

The acceleration resulting from a change in direction of a velocity is just as real and just as much an acceleration in every sense as that arising from a change in magnitude of a velocity. By definition, acceleration is the time rate of change of velocity, and velocity, being a vector, can change in direction as well as magnitude. If a physical quantity is a vector, its directional aspects cannot be ignored, for their effects will prove to be every bit as important and real as those produced by changes in magnitude.

It is worth emphasizing at this point that there need not be any motion in the direction of an acceleration and that there is no fixed relation in general between the directions of **a** and **v.** In Fig. 4-7 we give examples in which the angle between **v** and **a** varies from 0 to 180°. Only in one case, $\theta = 0°$, is the motion in the direction of **a.**

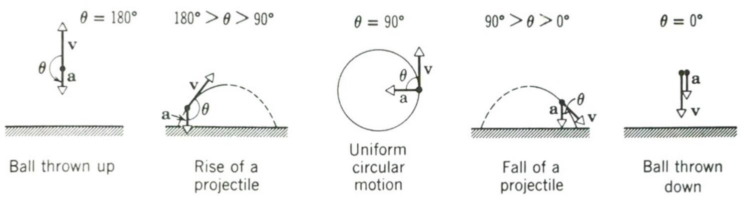


figure 4-7
Showing the relation between **v** and **a** for various motions.

EXAMPLE 4

The moon revolves about the earth, making a complete revolution in 27.3 days. Assume that the orbit is circular and has a radius of 239,000 miles. What is the magnitude of the acceleration of the moon toward the earth?

We have $r = 239{,}000 \text{ mi} = 3.85 \times 10^8$ m. The time for one complete revolution, called the period, is $T = 27.3 \text{ d} = 2.36 \times 10^6$ s. The speed of the moon (assumed constant) is therefore

$$v = 2\pi r/T = 1020 \text{ m/s}.$$

The centripetal acceleration is

$$a = \frac{v^2}{r} = \frac{(1020 \text{ m/s})^2}{3.85 \times 10^8 \text{ m}} = 0.00273 \text{ m/s}^2, \qquad \text{or} \quad \text{only } 2.78 \times 10^{-4}\, g.$$

EXAMPLE 5

Calculate the speed of an earth satellite, assuming that it is traveling at an altitude h of 140 miles above the surface of the earth where $g = 30$ ft/s^2. The radius R of the earth is 3960 mi.

Like any free object near the earth's surface the satellite has an acceleration g toward the earth's center. It is this acceleration that causes it to follow the circular path. Hence the centripetal acceleration is g, and from Eq. 4-9, $a = v^2/r$, we have

$$g = v^2/(R + h),$$

or

$$v = \sqrt{(R+h)g} = \sqrt{(3960 \text{ mi} + 140 \text{ mi})(5280 \text{ ft/mi})(30 \text{ ft/s}^2)}$$
$$= 2.55 \times 10^4 \text{ ft/s} = 17{,}400 \text{ mi/h}.$$

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taken from textbook
Physics, 3rd edition
by Halliday & Resnick

Project on galaxy clusters

project 1

The most common means of estimating the mass of a galaxy cluster is via the velocities of the galaxies and assuming a form of equilibrium such as Virial equilibrium. In this case (see class notes) $M_{vir} \approx 2RV^2/G$ where R is the outer radius of the cluster (typically about 3 Mpc) and V is approximately the velocity dispersion of the galaxies in the cluster.

A list of objects in the cluster as well as a "picture" is available using the links below. When available, the galaxies in the cluster will have blue band apparent magnitudes (BT - next-to-last column), recession velocities (Vhelio in km/s – last column). The galaxy coordinates are in equatorial format (i.e. like longitude and latitude) and the notation is such that *e.g.* 125641.3+274547 is equivalent to
RA = 12^h 56^m 41.3^s
Dec = $27°$ $45'$ $47''$.

Your mission is to :
a) identify the galaxies which are probable cluster members
b) determine the cluster velocity $V_{cluster}$, the velocity dispersion σ_r^2, and if possible an idea of the uncertainties
c) estimate M_{vir}. Give the value of the Hubble constant H_0 used to estimate the distance
d) Estimate the total stellar luminosity using the blue band apparent magnitudes. The absolute magnitude of the sun is $M_B = 5.48$.
e) from (c) and (d), give the M/L ratio in solar units ($M_\odot/L_\odot$). Could this be due to normal stars?

For a question or problem, jonathan.braine@u-bordeaux.fr or 05 4000 3274.

Links:

Only choose 1 cluster. Files for Coma and Abell496 are on the moodle page

NB: Do not use the "GSC STARS" part at the end. It is not useful for the project.

Project on simulating a galaxy cluster – for those who enjoy programming

project 2

The idea here is to try to develop a very simple numerical simulation of a galaxy cluster. The individual galaxies will be taken as point masses distributed around the cluster center with velocities taken around the mean velocity of the cluster. You will try to place the galaxies such that they follow a "reasonable" distribution (e.g. $1/(r+a)^3$ where a is small) and velocities following a gaussian distribution.

The first step is to set up the cluster as above and inject a simple cluster gravitational potential. Then let the simulation run and see what happens. How much mass (i.e. the cluster gravitational potential) is necessary to retain the galaxies?

You can use whatever computer language or software you are familiar with.

Bonus: give the galaxies mass and reduce or eliminate the cluster potential. What happens?

project 3 is below

Balancing pressure and gravity in a galaxy cluster to estimate the mass

project 3

Galaxy clusters are long-lived objects so they are *probably* in a state close to equilibrium. Hot gas (close to 10^8 K) is a major mass component in massive clusters and the pressure is quite easily defined if the temperature and density are known. For many clusters, measurements are available of the temperature and density. Pressure would dilate the cluster without a force balancing it. That force is gravity. Thus, it is possible to use the gas to estimate the total mass distribution in clusters, including any Dark Matter, by assuming that pressure and gravity balance each other. This is called hydrostatic equilibrium.

An article describing galaxy clusters in detail was written by Craig Sarazin in 1986 and starting on page 77 this is described.
http://journals.aps.org/rmp/pdf/10.1103/RevModPhys.58.1
One must click on an image after identifying the appropriate one and then it is possible to read and download the article.

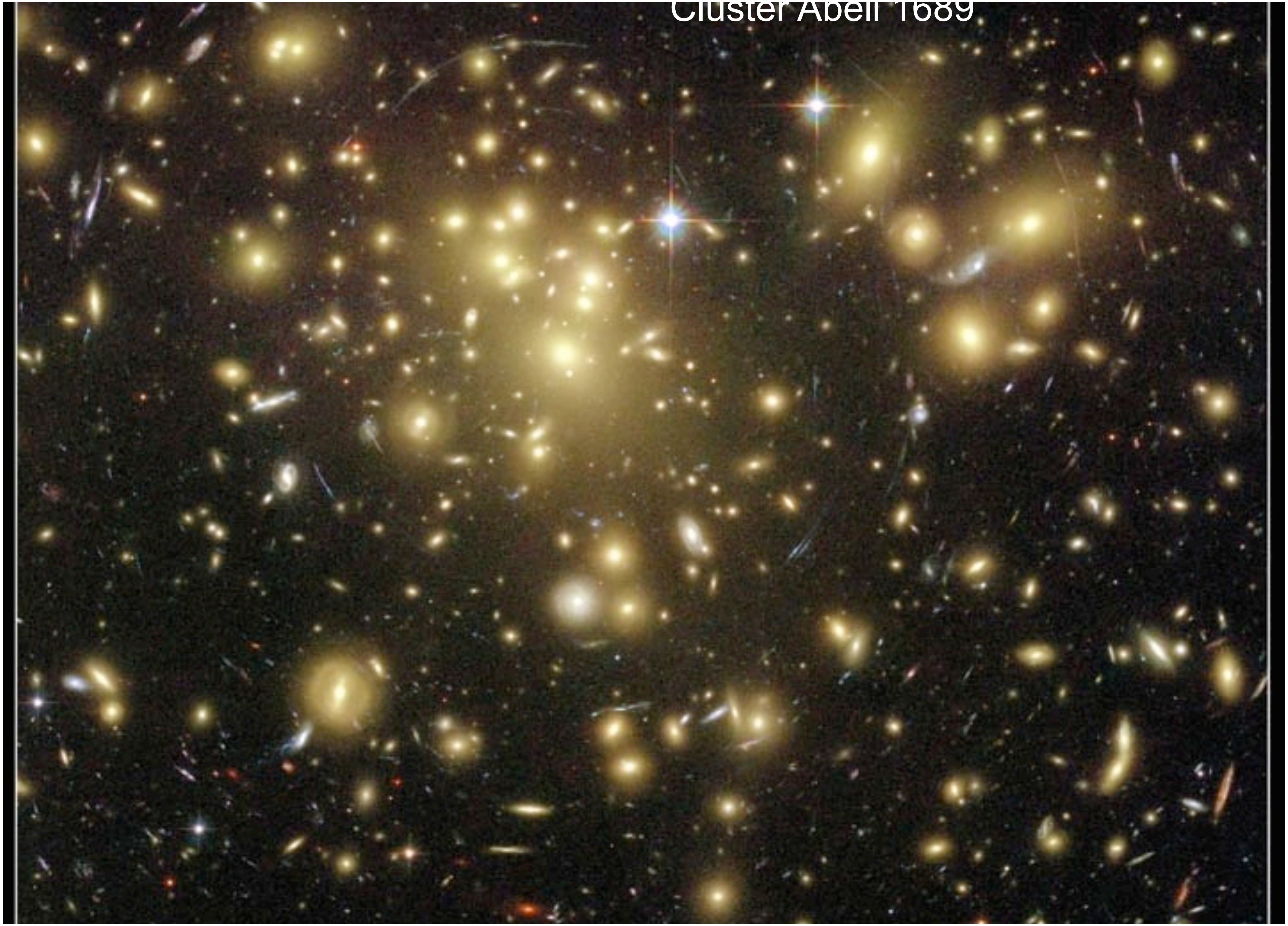
The idea here is to take a cluster for which the data are available and then determine the mass distribution and/or gravitational potential.

You can use whatever computer language or software you are familiar with.

OTHER PROJECTS

4) An alternative to Dark Matter has been proposed: a modification of gravitation, such that at very low accelerations (low values of GM/R^2), the acceleration would become GM/R. This results in flat rotation curves. *Modified Newtonian Dynamics* (MOND) was proposed by Milgrom (1983).

5) Suggestions or ideas?
You can propose a project. Gravitational waves?


Cluster Abell 1689

Einstein's Equation

After some manipulation....:

$\dot{R}^2 + k = 8\pi G\rho R^2/3 + \Lambda R^2/3$ where

$k = 0, \pm 1$ gives the direction of curvature :
flat, closed (+1), or open (-1)

Λ = cosmological constant, perhaps a "vacuum energy"

R = scale factor of the universe, radius of curvature

$\dot{R} = dR/dt$

Drop k and Λ ==> since density is non-zero, universe is either shrinking or growing ==> so Λ was added.

Then the expansion of the universe was discovered...

REDSHIFT,

= Doppler shift towards longer wavelengths

redshift = z = $(\lambda - \lambda_{lab}) / \lambda_{lab}$

observed λ is almost always greater than lab-frame wavelength due to expansion of the universe.

Except for the closest galaxies where Cepheid variables can be detected, we estimate distances from the redshift and the Hubble constant H_0.

For $z \ll 1$, $v = cz$

$H_0 = V / D \implies D(\mathrm{Mpc}) = V\ (\mathrm{km/s}) / H_0$

where $H_0 \approx 70$ km/s / Mpc