# Introduction to Galaxies

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## 1 Introduction

The night sky is known for it's beauty, magnificence but most importantly it's complexity. After learning in detail about stars we should naturally hop onto galaxies. Galaxies can be referred to as island universes containing astronomical objects of all types. With more than 100 billion galaxies in the observable universe, the exciting discoveries and unanswered questions are endless. This time not only we will study about galaxies but will go deeper into the universe on our first voyage to mysterious quasars and black holes. As always we will surely discuss the methods used to understand what actually they are. Let us begin the discussion with the topics to study.

## 2 Topics to Study

1) Our Galaxy: size, dust, spiral arms

2) Types of galaxies, Hubble "tuning fork", Global properties of galaxies

3) Quantitative morphologies, Relations between galaxies

4) Clustering of galaxies: Local Group, Clusters and superclusters

5) Growth of clusters, Galaxy interactions

6) The Galactic Center, Black holes and active galaxies, Relation between black holes and galaxies

# 3 Our Galaxy

The Milky Way galaxy is the second largest galaxy in the Local Group. It has a total diameter of 51-60 kpc and is approximately 0.3 kpc thick. It is home to our solar system. When talking about galaxies we need to remember the most indirect ways astronomers developed to understand them.

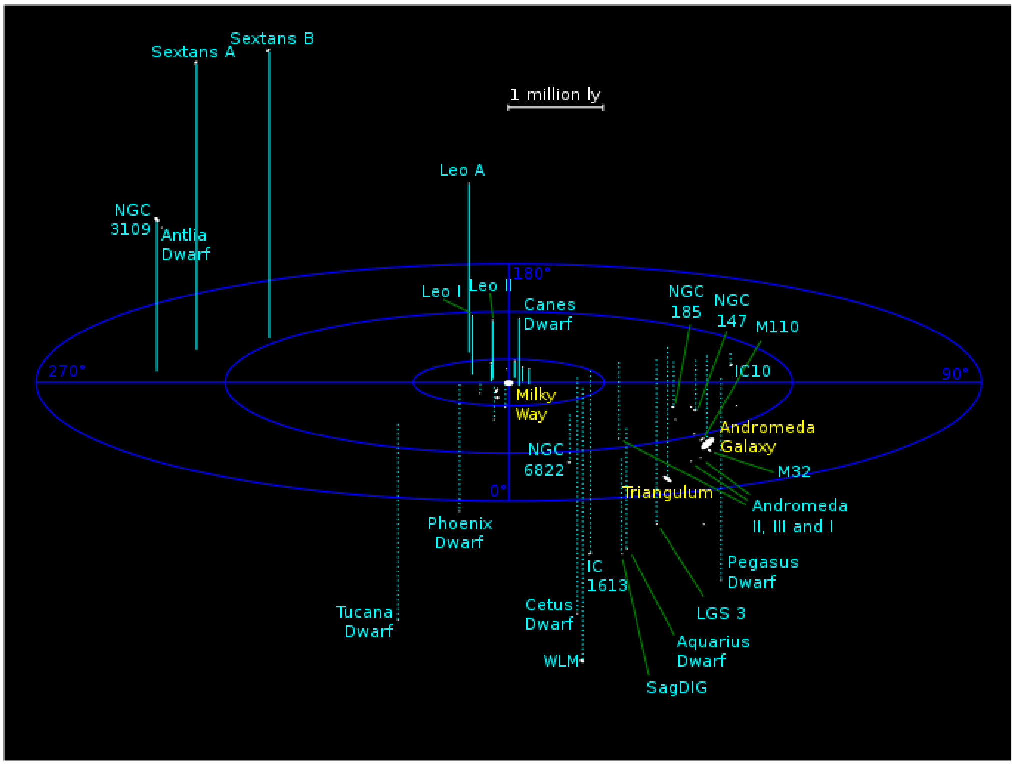


Figure 1: Map of the Local Grouo

## 3.1 Size

How did the scientists map out the size of the galaxy?

We have already discussed working out distances by the cosmic ladder method. Until the 20th century it was thought that the Sun is at galactic centre. The famous astronomer William Herschel came to this conclusion. Herschel's approach to determining the Sun's position within the Galaxy was to count the number of stars in each of 683 regions of the sky.

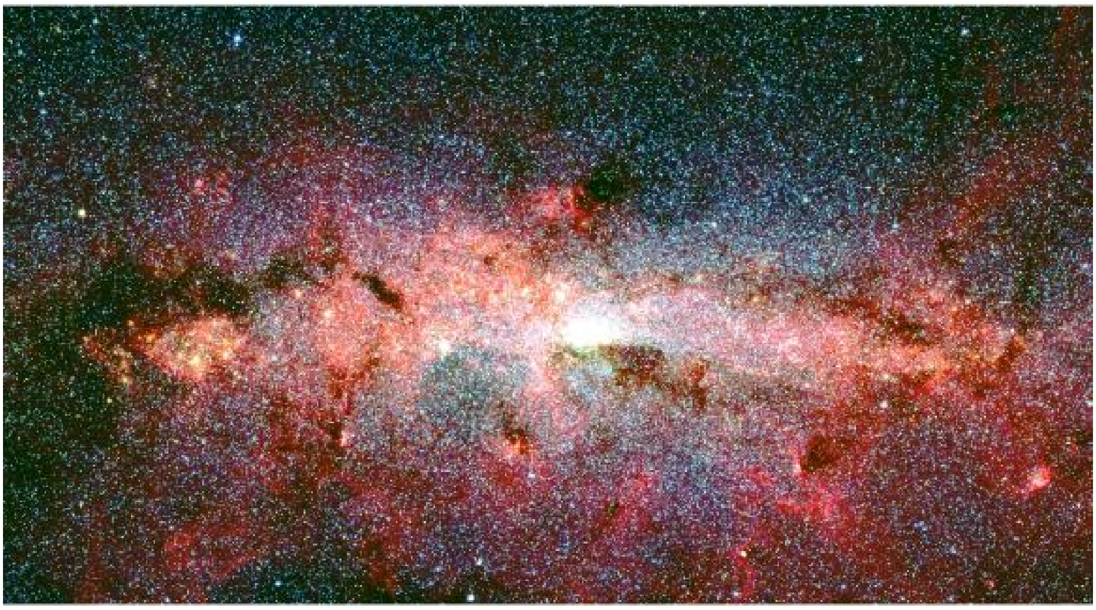

Figure 2: A false color Spitzer infrared image of the Milky Way's Central Molecular Zone (CMZ)
(Source : Spitzer/NASA/CfA)

### 3.1.1 Herschel's Star Gages

Herschel called his measurements of the Milky Way "star-gages." His method relies on two fundamental assumptions:

1) Stars are distributed more or less uniformly within the Milky Way and do not exist outside of it.

2) The telescope used for the star-gages is capable of resolving all stars within the Milky Way system.

He proceeded with the theory that an imaginary cone is formed with it's vertex at the telescope covering the whole galaxy with the apex angle being $\Theta$. Therefore, it leads to the volume being covered be $V = \pi/3h^3tan^\Theta$ where h is the distance from the telesope to the galaxy's end. Taking N as number of stars per unit volume and figuring $\Theta$ out using the field view angle we come to the conclusion that the radius of the galaxy is :

$$h = \sqrt[3]{\frac{3N}{\pi tan^2\Theta}}$$

But as it turned out it was wrong as a lot of stars which are not visible due to interstellar material was never counted in his assumption that we lie in the centre of the galaxy. Deviations from uniform star density can lead to results that distort the true shape of the Milky Way, exaggerating distances toward high-density regions and underestimating distances toward low-density regions. But nonetheless he was a fantastic astronomer who discovered the cold world of Uranus and cataloged many nebulae along his sister Caroline Herschel. She is also credited with the discovery of several comets. She was the first female astronomer to receive money for her scientific work.

### 3.1.2 New methods

The dimensions of the galaxy are worked out by the astronomers with the help of pulsating variable stars. Cepheids are stars that vary periodically in brightness. It was observed the stars with greater luminosity had greater time period. The famous astronomer Henrietta Leavitt worked on it. She correctly inferred that as the stars were in the same distant clouds they were all at much the same relative distance from us. Any difference in apparent magnitude was therefore related to a difference in absolute magnitude. When she plotted her results for the two clouds she noted that they formed distinct relationships between brightness and period(she studied small and large magellanic clouds).

Her plot showed what is now known as the period-luminosity relationship; cepheids with longer periods are intrinsically more luminous than those with shorter periods.

### 3.1.3 Calculating Distance

Cepheids are post-main sequence stars that occupy the instability strip in the H-R diagram. The period of pulsation can vary from days to even months. They exhibit an excellent correlation between mean luminosity (averaged over a pulsation cycle) and pulsation period. They are intrinsically bright stars.

Figure 3: A false color Spitzer infrared image of the Milky Way's Central Molecular Zone (CMZ)
(Source : Spitzer/NASA/CfA)

## 3.2 Galactic Dust

## 3.3 Spiral Arms

How come the scientists build up a model of our galaxy with spiral arms? How was it detected? Let us get into it as of right now.

We have understood the importance of the interstellar dust. Let us take four concentric circles(centre being the galactic centre). The velocity of all the points will be different along the LOS(line of sight)(S and point 4 relative velocity will be the same). Using the 21cm wavelength method and the Doppler method scientists worked out the details. radio waves from these various gas clouds are subjected to slightly different Doppler shifts. This permits radio astronomers to sort out the gas clouds and thus map the Galaxy. Due to different velocities the radio waves from different parts arrive at different wavelengths.

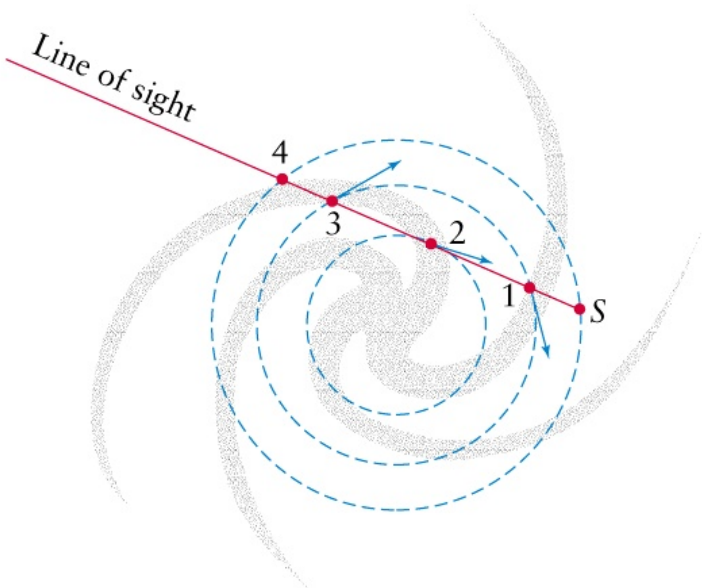


Figure 4: Schematic of a spiral rotating galaxy

### 3.3.1 Observations

Type O stars are about 10,000 times more luminous than the Sun, so the light from these stars dominates the picture of a spiral galaxy, making it look like a spiral. The concentration of dark dust lanes and cool molecular clouds (the birthplace of stars) is largest in the spiral arms. Hydrogen regions which glow red after being ionized by young O and B stars are mainly found in the spiral arms.

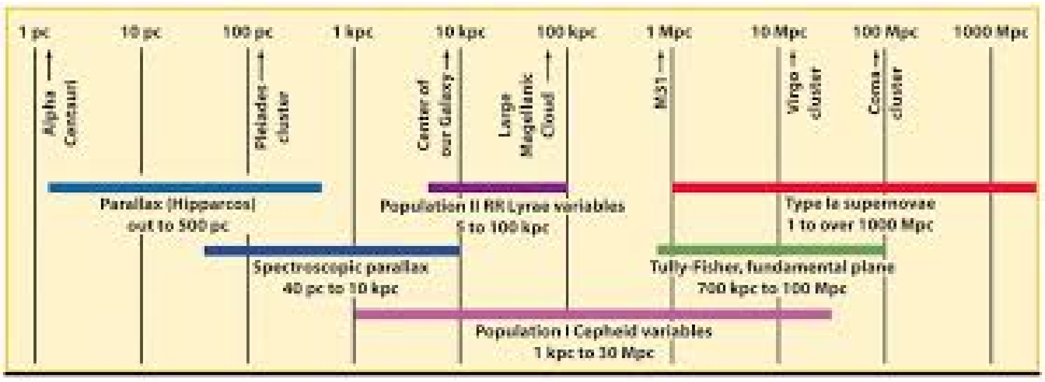


Figure 5: Schematic of a spiral rotating galaxy

# 4 Types of galaxies

Classification has a very important role in the understanding of science. Remember that the classification of organisms by Swedish biologist Carl Linneaus greatly helped in understanding how species evolved from one another. Similarly, the early classification of galaxies based on their morphology helped in the case of understanding their evolution, path and other properties.

Edwin Hubble invented a classification of galaxies and grouped them into four classes: spirals, barred spirals, ellipticals and irregulars. He classified spiral and barred spiral galaxies further according to the size of their central bulge and the texture of their arms. A large central bulge and broad central arms corresponds to a, while a small central bulge and well defined spiral arms corresponds to c. The Hubble classification even referred to as the tuning fork diagram, is still used today to describe galaxies.

1) Spirals - The spiral galxay is known for their arched lane of dust. They are one of the most prominent centre of star birthplace. The spiral arms contain

young, hot, blue stars and H II regions. Contrast to that the central bulge contains of old stars and therefore have a yellowish or reddish colour with poor metallicity. According to their arms and central bulge it is subdivided into Sa, Sb, Sc.

For a the galaxy will have less prominent arms(smooth and broad) and more prominent central bulge. For b the galaxy will have more prominent arms and moderate sized bulge. At last the c one will have well defined arms and the smallest bulge. Their differences are related to the relative amounts of gas and dust they contain.

2) Barred spirals - They are indeed different to spiral galaxies. The spiral arms originate at the ends of a bar-shaped region running through the galaxy's nucleus rather than from the nucleus itself. Just like the previous Hubble subdivided the galaxies into SBa, SBb, SBc. Going through them we observe SBa has tightly wrapped arms and more prominent central bulge. SBb has loosely wrapped arms and less huge central bulge. For SBc we will have a diminished central bulge with lumpy and loose arms. But according to researches the main difference b/w the spiral and barred spiral is the extent of presence of dark matter. It favours the structure of a barred galaxy.

3) Ellipticals - Ellipticals are those which have no spiral arms. They are subdivided from 0 to 7 with E0 being mostly round and E7 the counterpart being flat. Another important point is that the motion of stars in the E0 is isotropic whereas in E7 it is anisotropic. Being devoid mostly of interstellar material no new star formation activity is observed. They are mostly composed of old stars therefore giving the red - yellowish colour.

The lenticular galaxy is the mid way between spiral and elliptical. They are often referred to as armless spirals. They have both a central bulge and a disk like spiral galaxies, but no discernible spiral arms. They are denoted as SB0 and S0. All of these three together formed the Hubble tuning fork.

4) Irregulars - These like many people are the ones which do not fit or you cannot exactly put labels on. They are subdivided into Irr I and Irr II. Irr I has hints of organized structure, and have many OB associations and H II regions. Our cosmic neighbours LMC and SMC are examples of it. On the other hand Irr II is asymmetric and distorted.

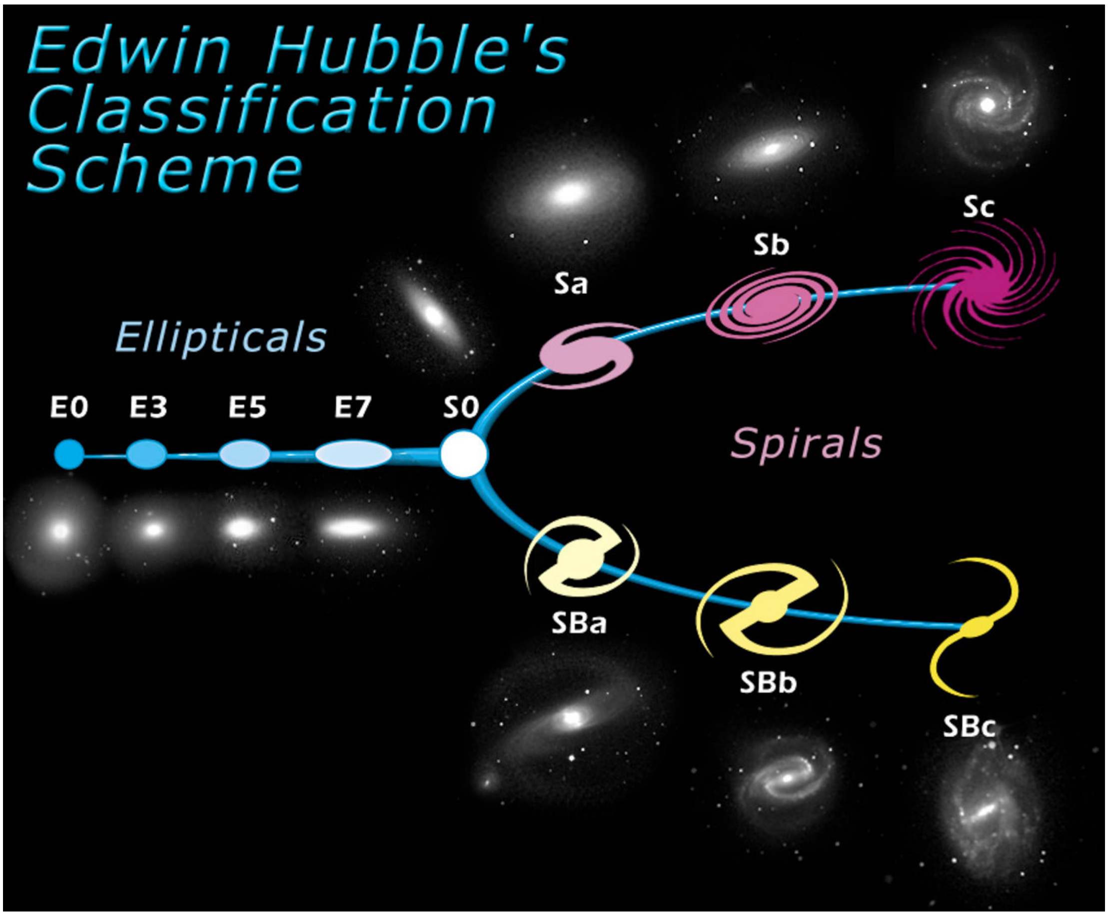


Figure 6: The Hubble tuning fork
Source: ESA/Hubble

# 5 Clusters

The universe is undeniably large and huge. Therefore, it is natural that the at this size scale there would be other huge structures, being even bigger than galaxies. These large scale structures are clusters of galaxy and some more. Let us understand their properties:-

## 5.1 Galaxy Clusters

1) Galaxy clusters of course are made of galaxies with size range upto 3 Mpc and containing upto thousands of them.

2) The constituents are gravitationally bounded but may not be stable.

3) Clusters have higher densities than groups, contain a majority of ellipticals and spirals while groups are dominated by spirals. Our galaxy is a part of the Local Group which has more than 40 constituents.

4) The cluster is divided into poor and rich number of galaxies.

# 6 The Galactic Center

Figure 7 depicts the astronomical object 3C 273. A look at the picture is enough to tell about how bright the object would be. A star emits radiation in the wavelength of infrared, ultraviolet and visible. Ordinary galaxies, too, emit most strongly in these wavelength regions. But this object proved to be quite different as it strongly emitted over an immense range of wavelengths from radio to X-ray.

## 6.1 Active galaxies

Active galaxies are named after their active galactic nuclei. We will study here about quasars, blazars, Seyferts and radio galaxies. First let us talk about the initial discovery related to AGNs.

In 1944 strong radio signals were detected by a radio telescope built by Grote Rober. These were coming from the constellation of Sagittarius, Cygnus and Cassiopeia. The three sources were Sagittarius A, Cygnus A and Cassiopeia A. But the most mysterious traits were shown by Cygnus A. Why was it the most mysterious :-

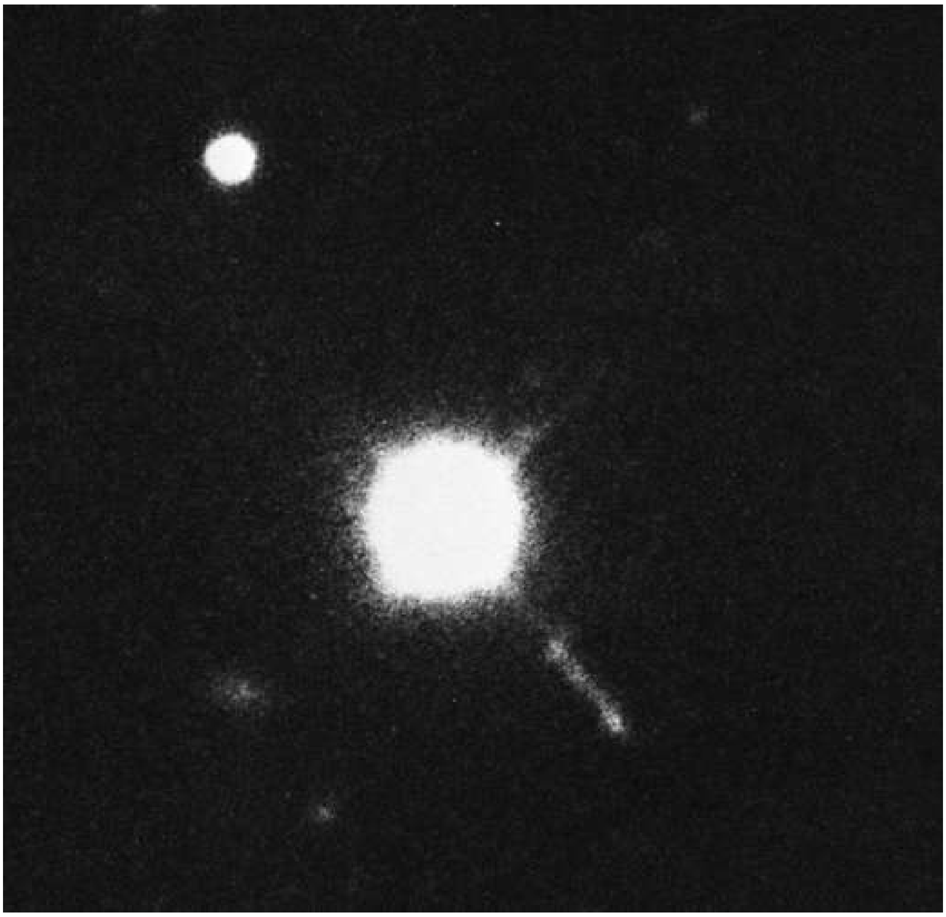

Figure 7: Quasar 3C 273
Source: National Optical Astronomy Observatories

1) A number of emission lines were observed rather than absorption lines which are quite common in the spectra of a galaxy. It also pointed to the fact that something would be ionzing the atoms to achieve so.

2) A redshift of z = 0.056 which indicated a recessional velocity of 16000km/s. This corresponded to a great distance. But the radio waves could be easily detected indicating a strong source.

3) The shown 3C 273 had also a luminous jet protruding from one side.

4) A research based on their spectra clearly shone light on the redshift resulting to a recessional velocity of 44000 km/s making it impossible to be a part of our galaxy(630 Mpc). It even established the fact that they lie at unfathomable distances. For 3C 48 redshift of 0.367 was detected(1400 Mpc).

Let us discuss their types one by one.

### 6.1.1 Quasars

With the exception of short-lived, powerful explosions responsible for supernovae and gamma-ray bursts, quasars are the brightest objects in the universe. They are ultraluminous sources situated in the centre of a galaxy. Situated in centre of remote galaxies their luminosity can range from $10^{38}$ watt to $10^{42}$ watt. Our own galaxy shines with approx luminosity of $10^{37}$ watt. Therefore, they have the ability to outshine their home galaxies.

Around 1980s the link b/w galaxy and quasar was strengthened when the spectra of the 'fuzz' around them showed absorption lines(linked with galaxies).

### 6.1.2 Seyfert Galaxies

As the topic describes they are active spiral galaxies with luminosity ranging from 0.1 to 10 times the luminosity of our galaxy. Seyfert's make upto 2 percent of total observable galaxies. As the name suggests they are named after the scientist Carl Seyfert.

Carl Seyfert used the Mount Wilson Observatory to study the spiral galaxies with bright, compact nuclei that seem to show signs of intense and violent activity. They too have a strong emission spectra. They are radio-quiet therefore having weak radio emissions.

## 6.2 Radio galaxies

The radio galaxies are radio-loud galaxies. They are dim, elliptical and have strong radio emissions unlike seyferts. Heber D Curtis was the discoverer of these. The central region has thermal radiation whereas the jets have non thermal radiation.