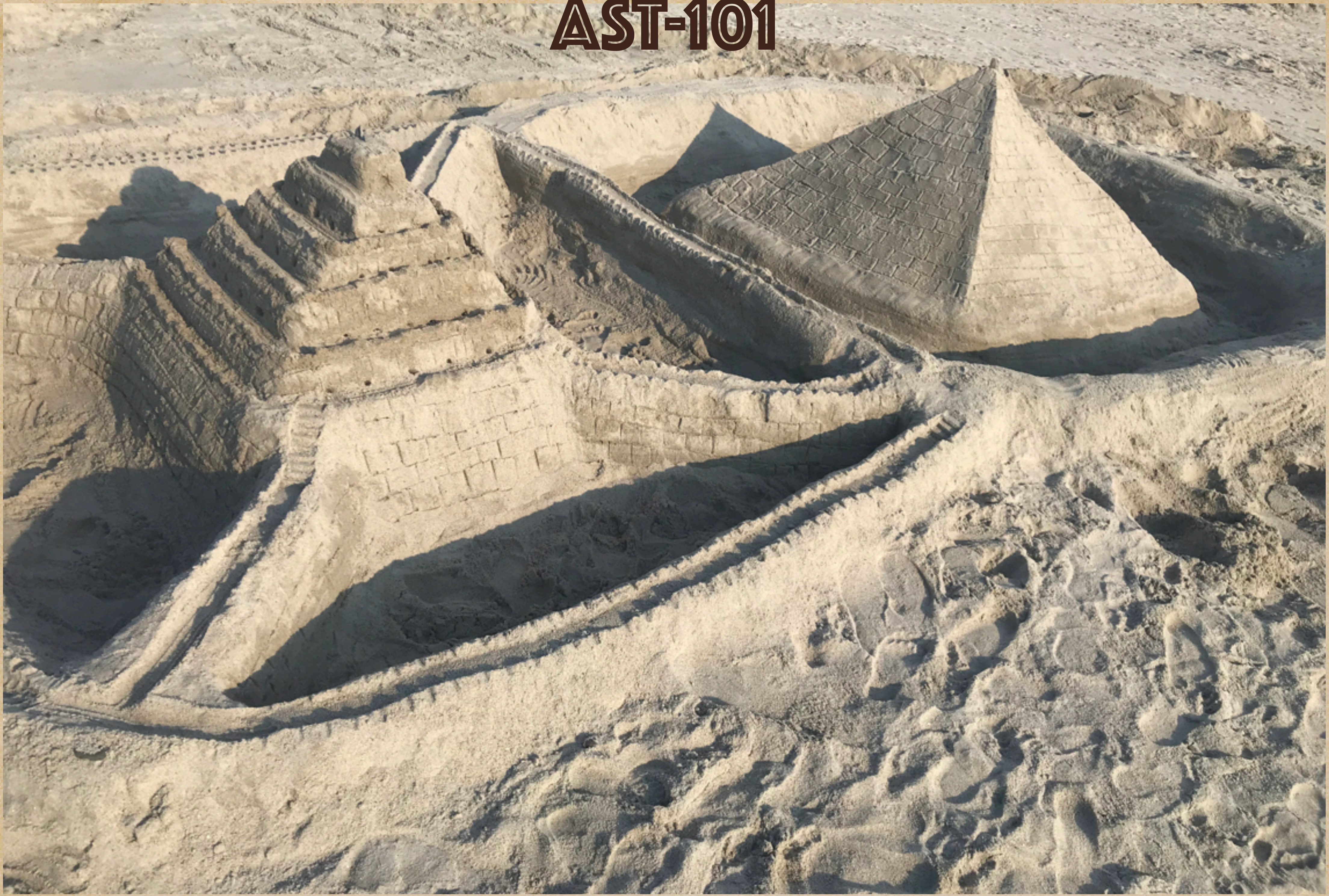
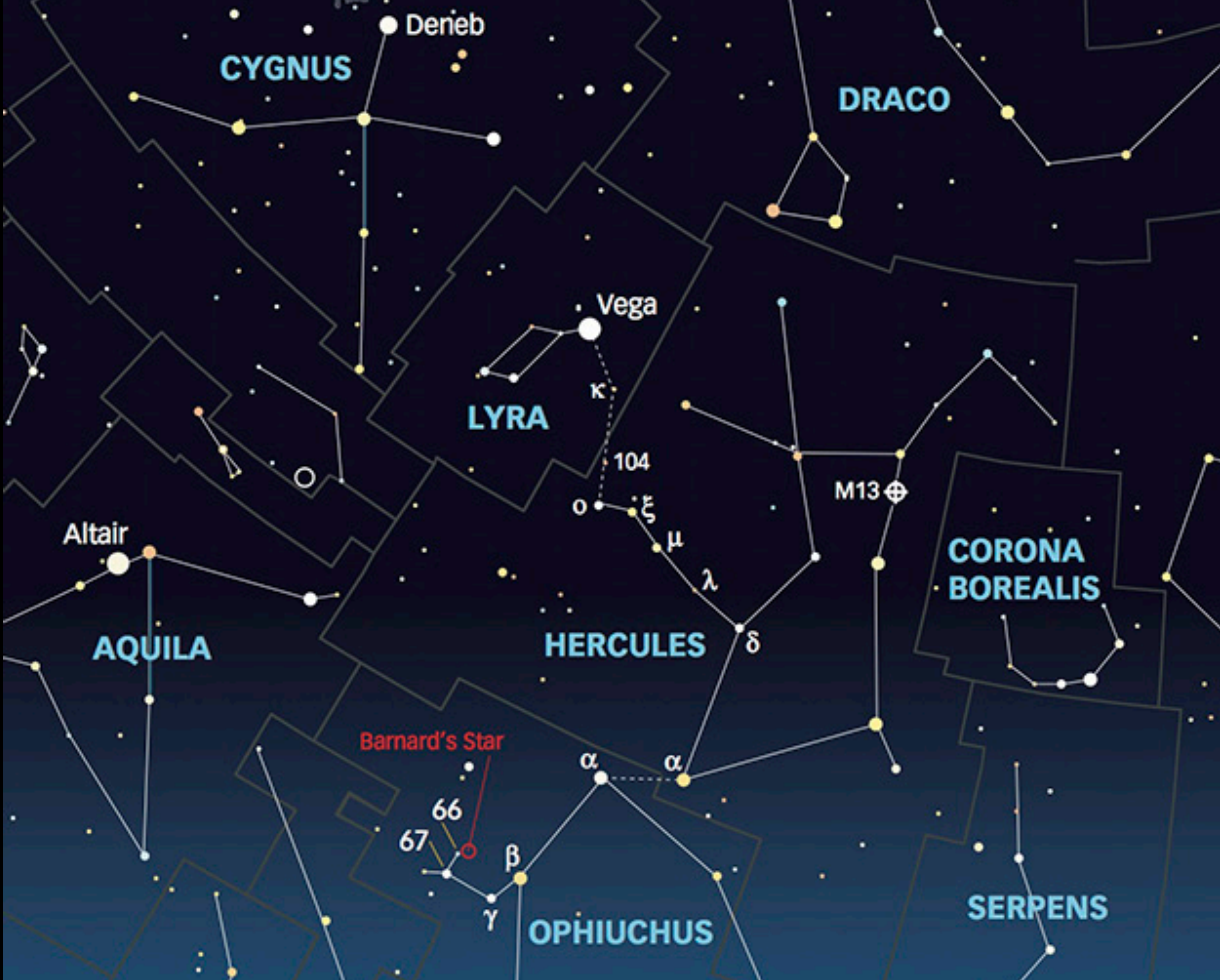


Stars and Galaxies: astronomically far away

Luis Anchordoqui

Night sky provides a strong impression of changeless universe

- Clouds drift across the Moon ☛ on longer times Moon itself grows and shrinks
- Moon and planets move against the background of stars
- These are merely local phenomena caused by motions within our solar system
- Far beyond planets ☛ stars appear motionless


Deneb
CYGNUS
DRACO
Vega
κ
LYRA
104
o
ξ
μ
λ
M13
Altair
CORONA
BOREALIS
AQUILA
HERCULES
δ
Barnard's Star
α
α
66
67
β
γ
OPHIUCHUS
SERPENS

[3]Impression of changelessness star background is illusory

[3]Impression of changelessness star background is illusory

3Impression of changelessness star background is illusory

[3]Impression of changelessness star background is illusory

[3]Impression of changelessness star background is illusory

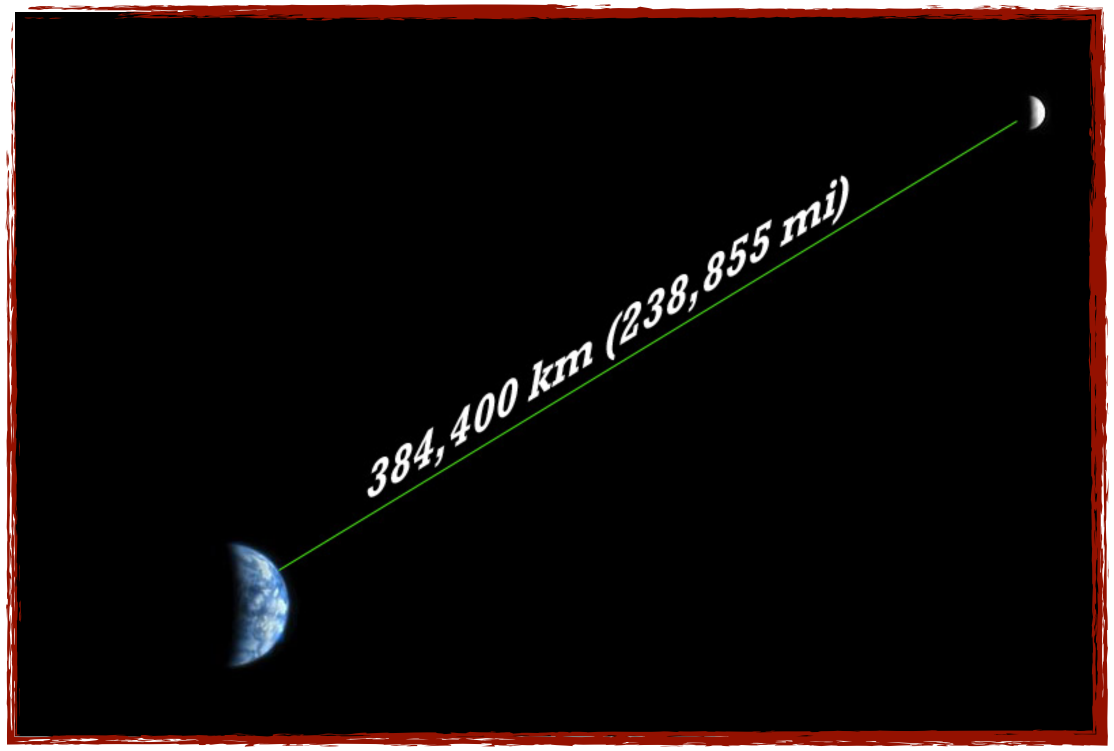
Distances involved are so large that we specify them in terms of the time it takes the light to travel a given distance

- ➢ **light second** ☛ $1 \text{ ls} = 1 \text{ s} \;\; 3 \times 10^8 \text{ m/s} = 3 \times 10^8 \text{m} = 300,000 \text{ km}$
- ➢ **light minute** ☛ $1 \text{ lm} = 18 \times 10^6 \text{ km}$
- ➢ **light year** ☛ $$1 \text{ ly} = 2.998 \times 10^8 \text{ m/s} \cdot 3.156 \times 10^7 \text{ s/yr}$$ $$= 9.46 \times 10^{15} \text{ m} \approx 10^{13} \text{ km}$$

How long would it take the space shuttle to go 1 ly?

Shuttle orbits Earth @18,000 mph ☛ it would need 37, 200 yr

For specifying distances to Sun and Moon we usually use km



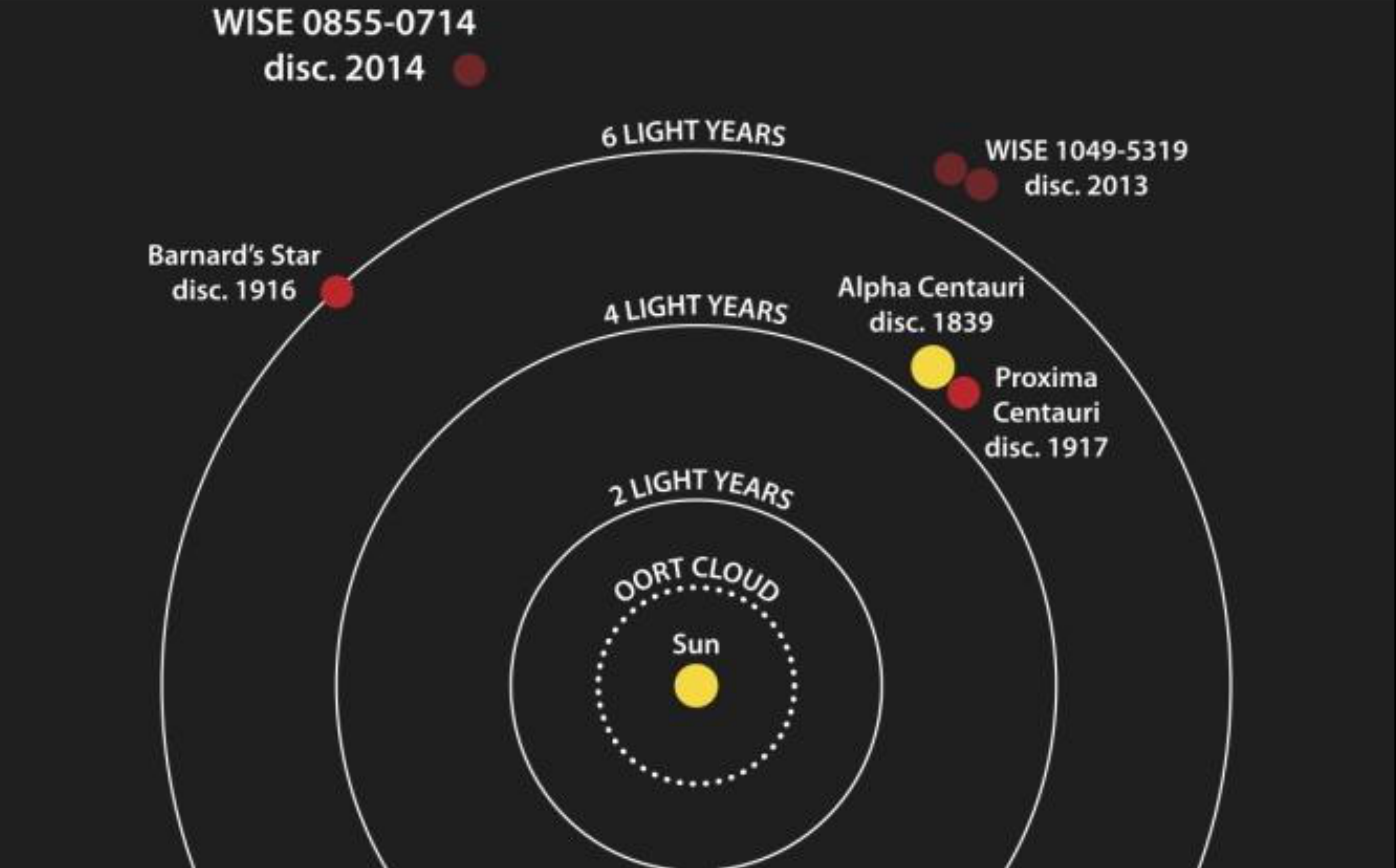
but we could specify them in terms of light

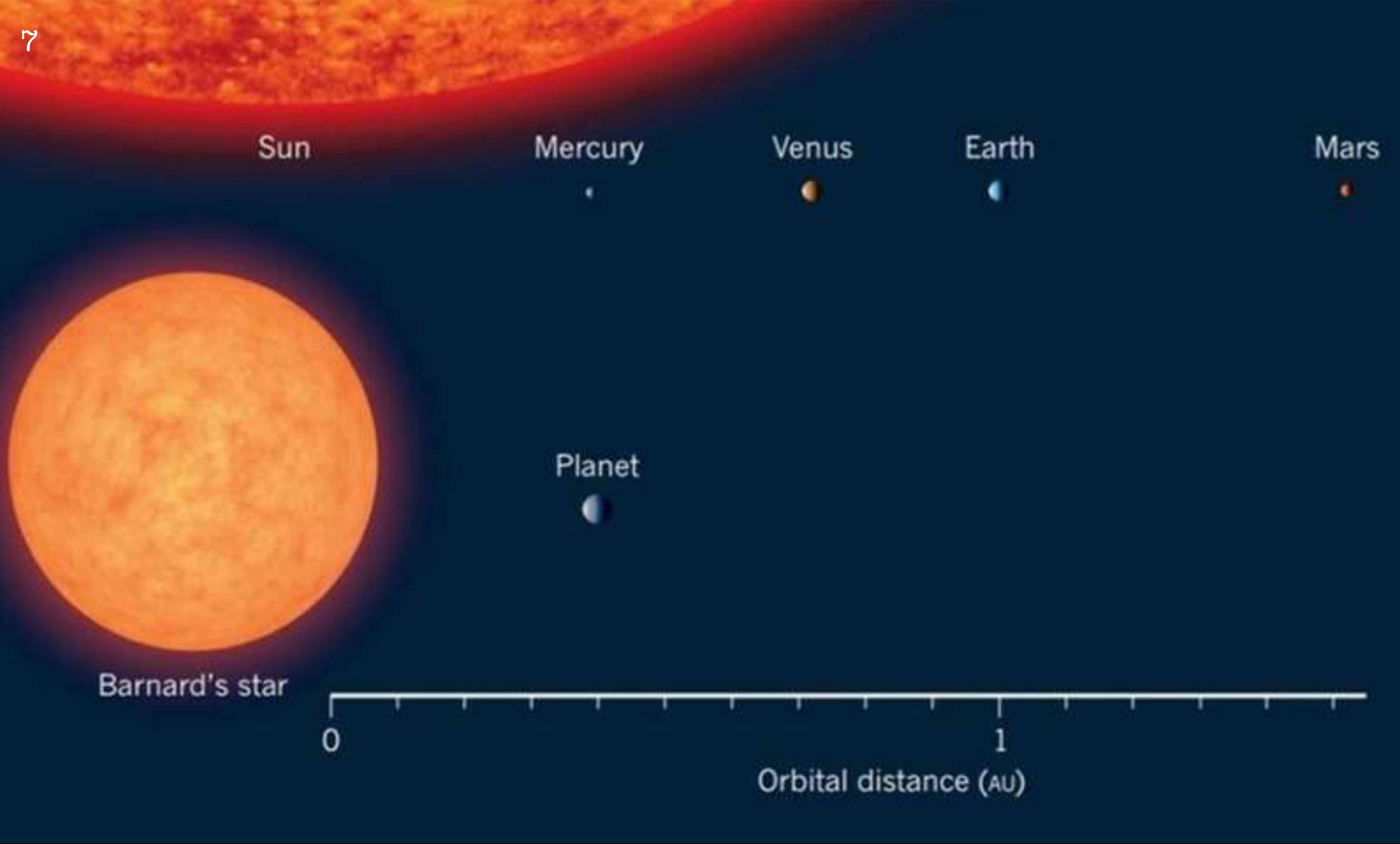
- Earth-Moon distance is 384,000 km ☛ 1.28 ls
- Earth-Sun distance is 150,000,000 km ☛ 8.3 lm
- Far out in the solar system

  Pluto is about 6 x 10^9 km from the Sun ☛ 6 x 10^{-4} ly
- Nearest star to us ☛ Proxima Centauri is about 4.3 ly away
- Nearest star is 10,000 times farther from us

  than outer reach of solar system

The Sun's Closest Neighbors





Potential for primitive life on icy Barnard b super-earth planet if geothermal activity exists

On clear moonless nights thousands of stars with varying degrees of brightness can be seen ☛ as well as the long cloudy strip known as Milky Way

Galileo first observed with his telescope that Milky Way is comprised of countless numbers of individual stars

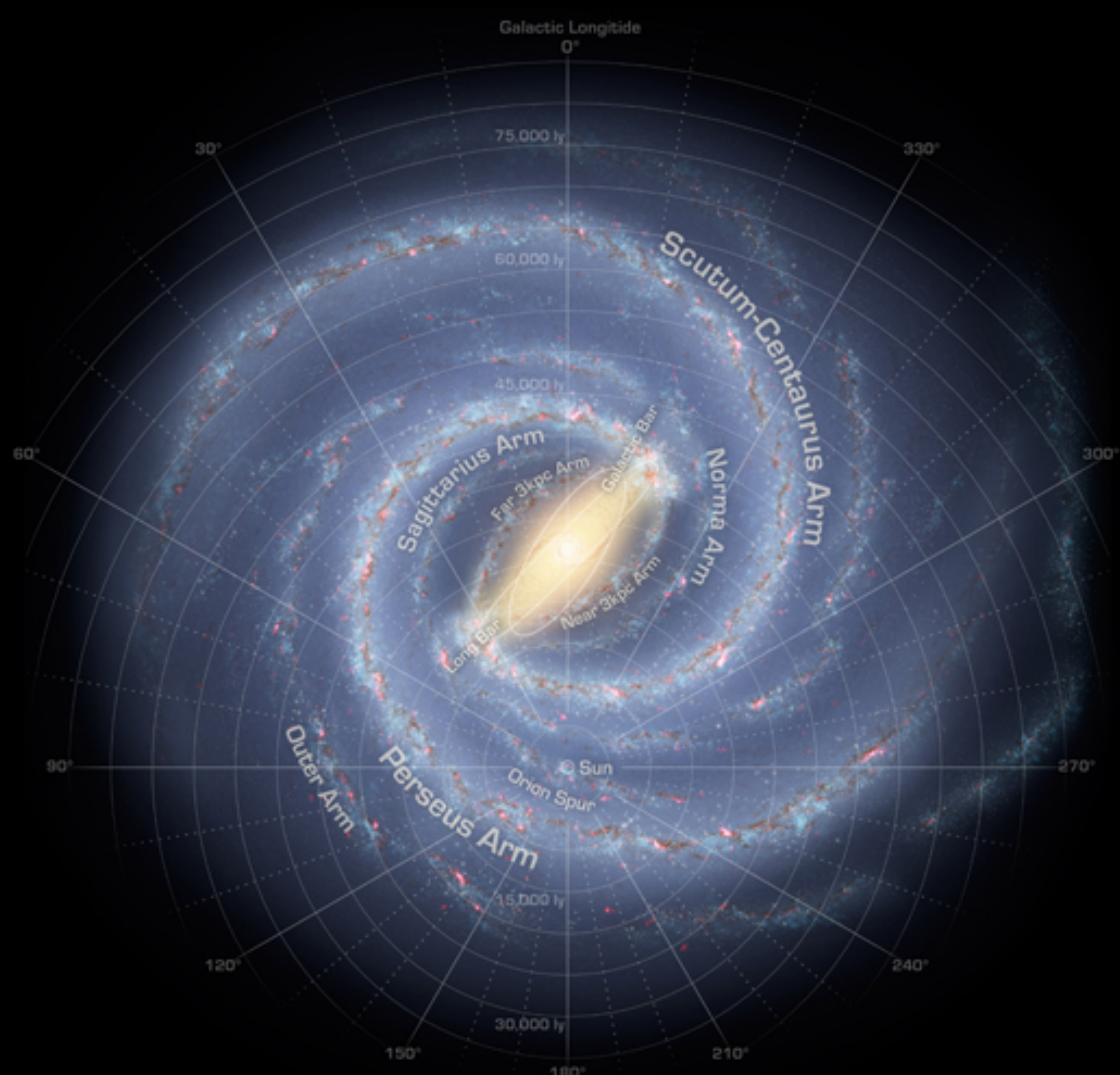
Half century later (about 1750) Thomas Wright suggested that Milky Way was a flat disc of stars extending to great distances in a plane which we call Galaxy (Greek for "milky way")

Milky Way over Quiver Tree Forest in southern Namibia

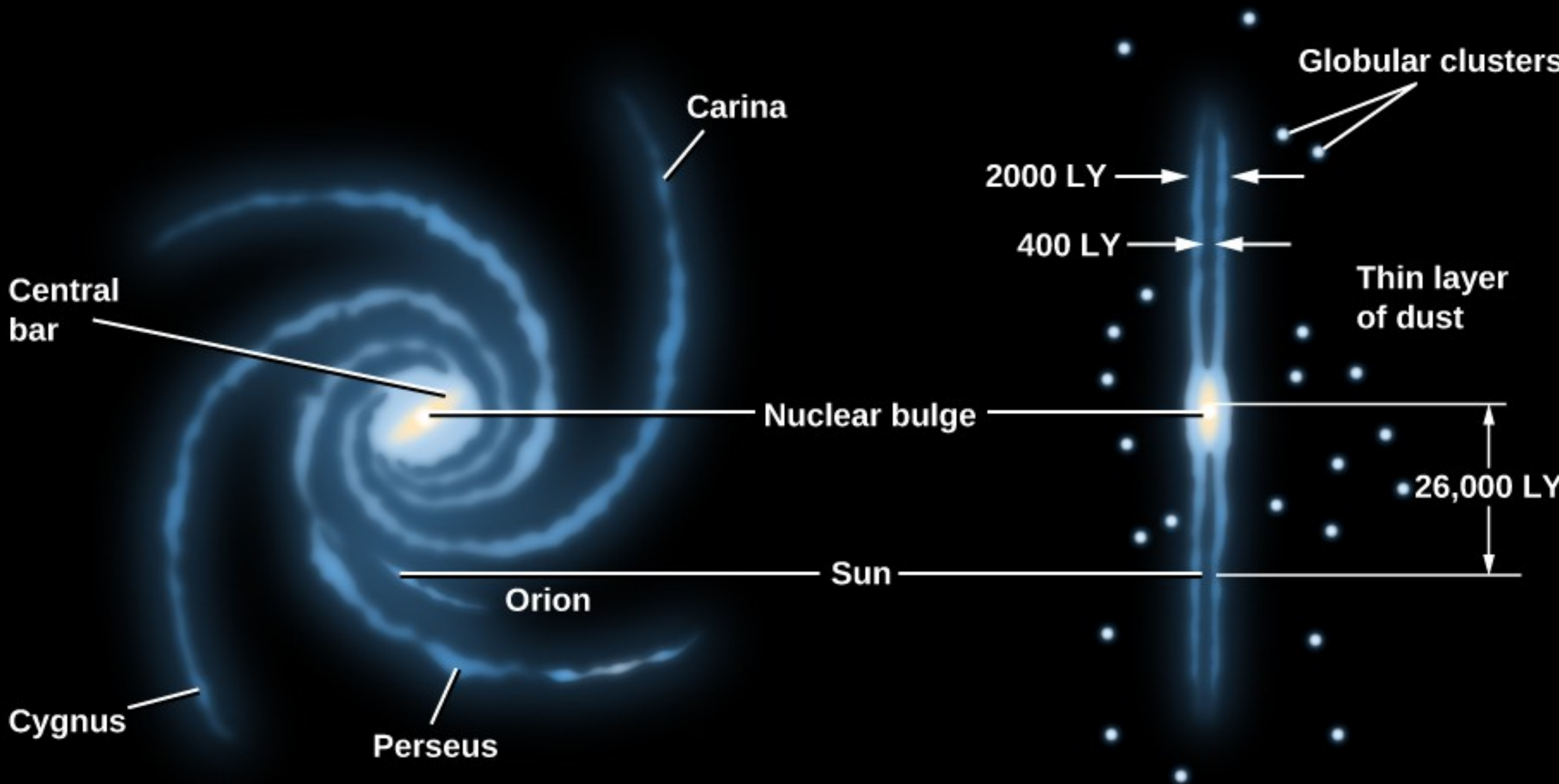
Milky Way...

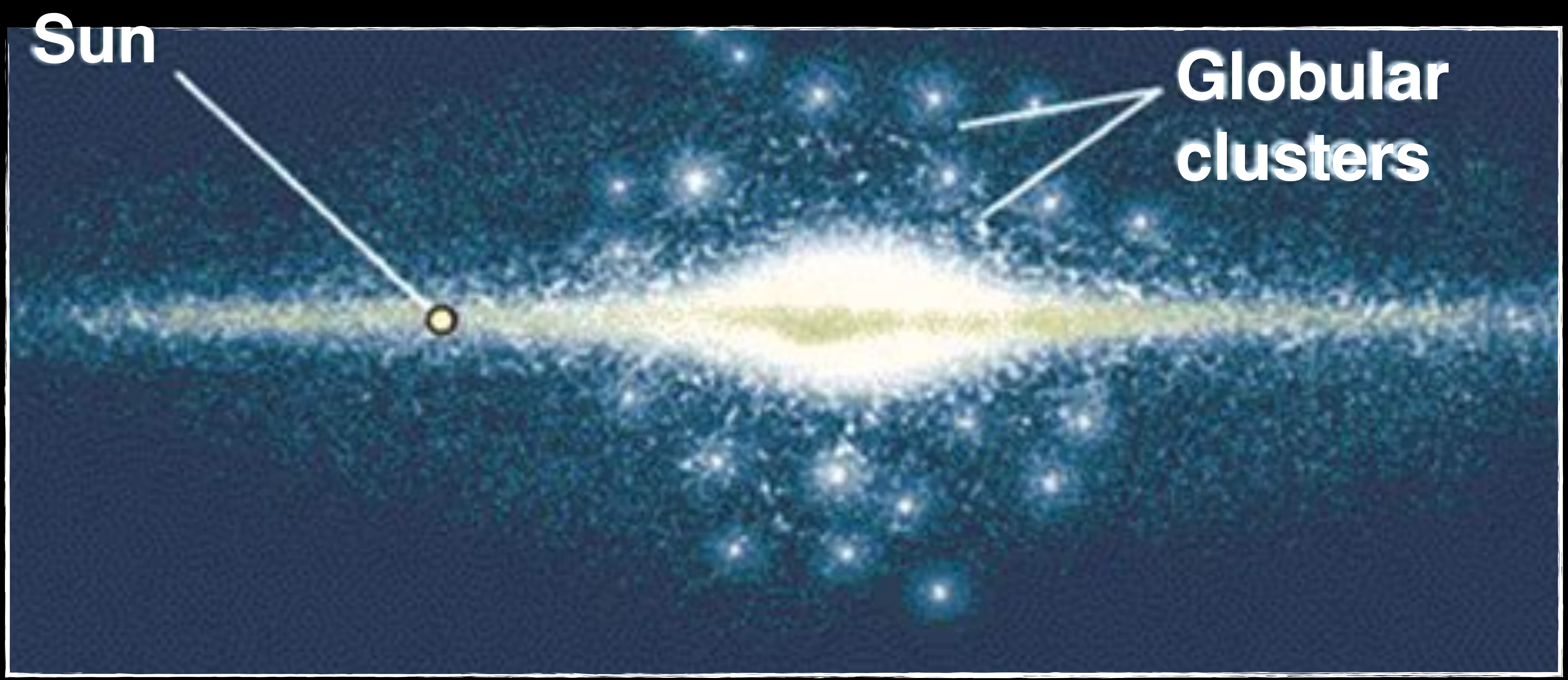
Spiral galaxy ☛ you could view it from top or bottom
and it would look like a spinning pinwheel

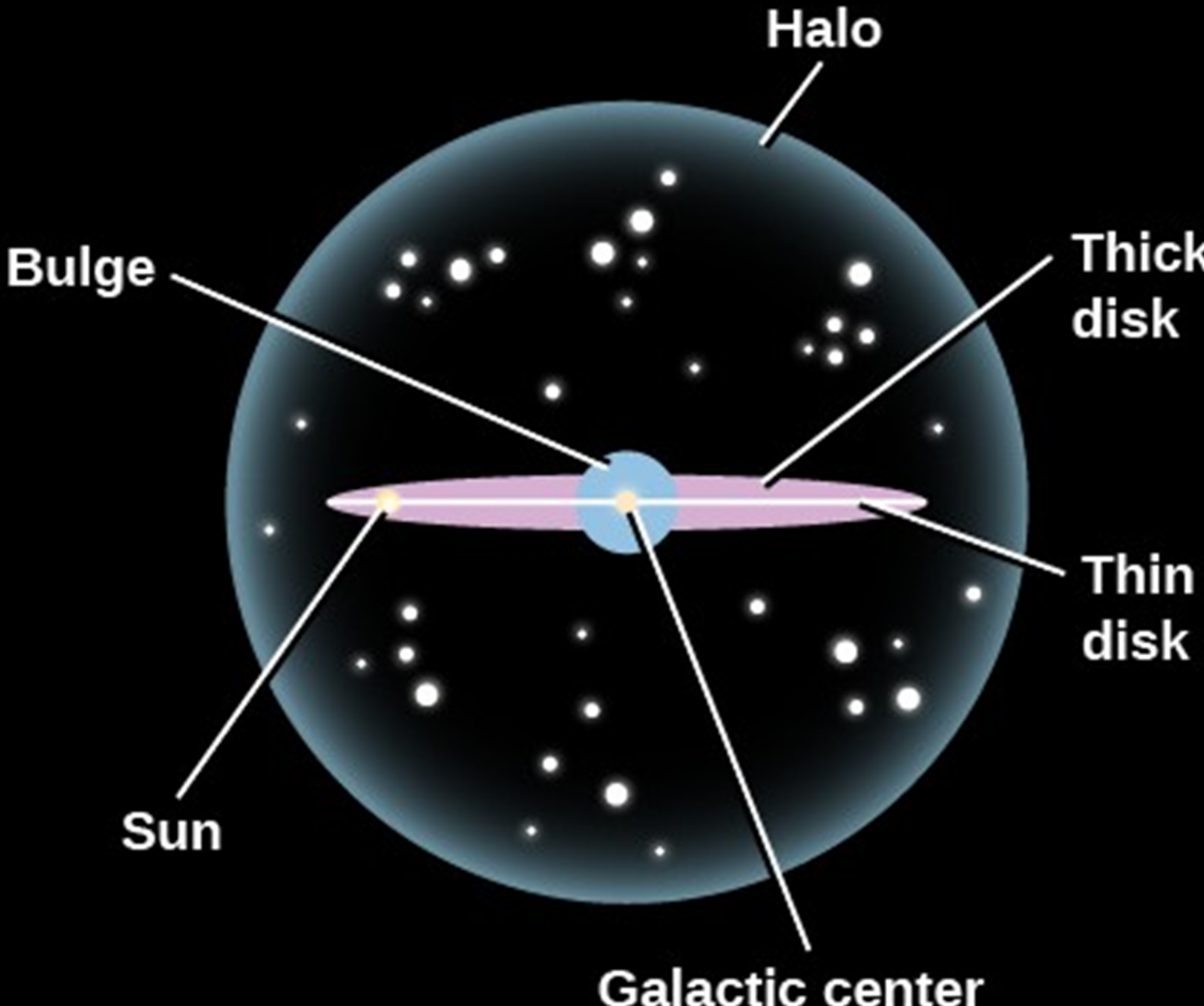
- Galaxy has diameter ~100, 000 ly and thickness ~ 2, 000 ly
- It has a bulging central “nucleus” and spiral arms
- Our Sun is located half way from the Galactic center to the edge

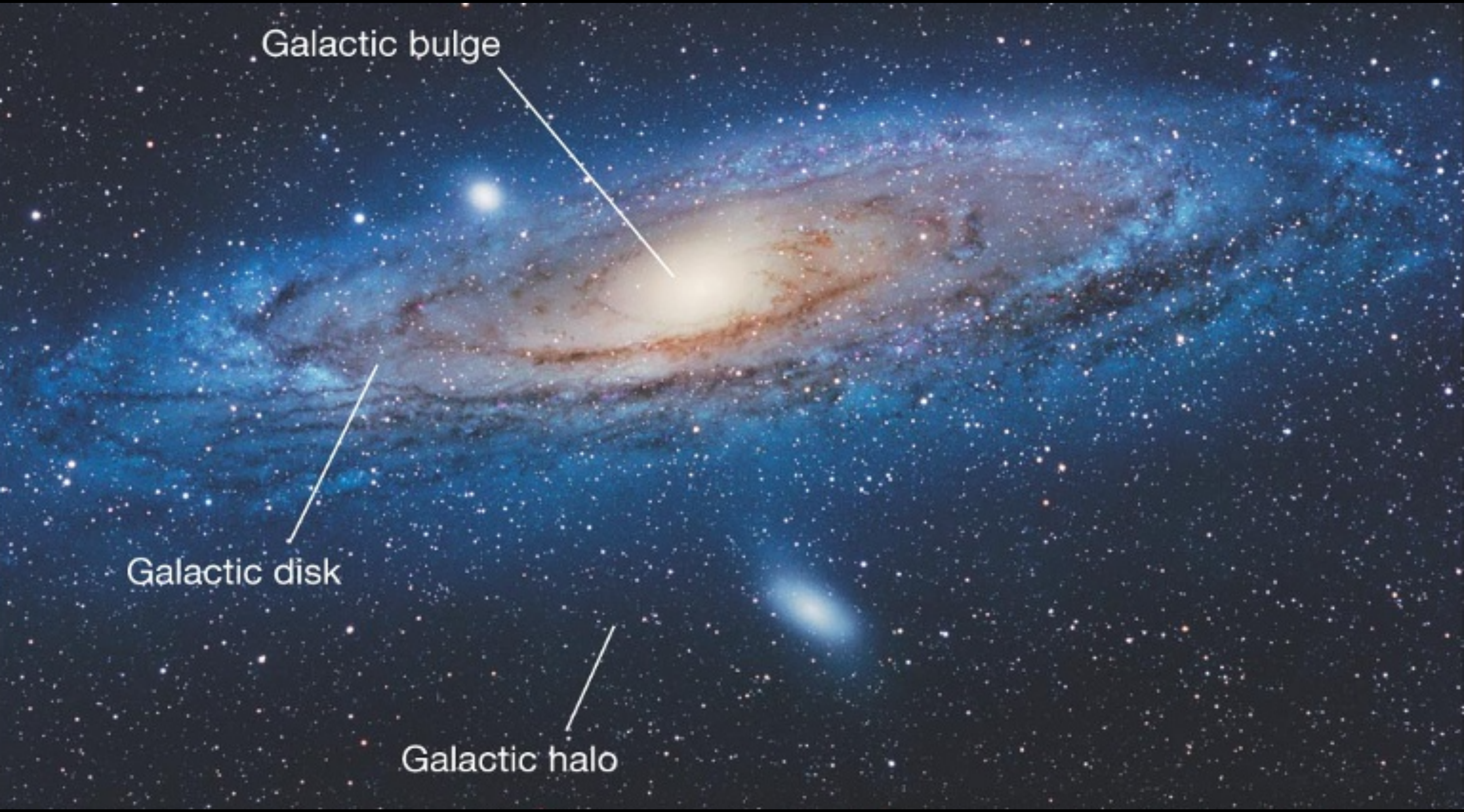


some 26, 000 ly from the center


Carina
Central bar
Nuclear bulge
Sun
Orion
Cygnus
Perseus
Globular clusters
2000 LY
400 LY
Thin layer of dust
26,000 LY


Sun
Globular clusters


Halo
Bulge
Thick disk
Thin disk
Sun
Galactic center


Galactic bulge
Galactic disk
Galactic halo

✧ Sun orbits Galactic center about once every 250 million years

✧ Its speed is ➘

$$v = \frac{2\pi \; 26,000 \times 10^{13} \; \text{km}}{2.5 \times 10^{8} \; \text{yr} \; 3.156 \times 10^{7} \text{s/yr}} = 200 \; \text{km/s}$$

✧ Total mass of all stars can be estimated using orbital data of Sun

✧ Assume most of the mass is concentrated near center of Galaxy

✧ Sun and solar system (of total mass m) move in circular orbit around Galaxy center (of total mass M)

✧ Apply Newton's laws $\frac{GMm}{r^2} = m\frac{v^2}{r}$

$$G = 6.674 \times 10^{-11} \; \text{N m}^2 \; \text{kg}^{-2}$$

$$M = \frac{rv^2}{G} \approx 2 \times 10^{41} \text{kg}$$

✧ Assuming all stars in Galaxy are similar to Sun $(M_\odot \approx 2 \times 10^{30} \; \text{kg})$ we conclude that there are roughly 10^{11} stars in the Galaxy

In addition to stars we can see with telescope
many faint cloudy patches that were once called "**nebulae**"

Those in the constellations of Andromeda and Orion
can actually be discerned with naked eye on clear night

At first it was not universally accepted that these objects
were extragalactic

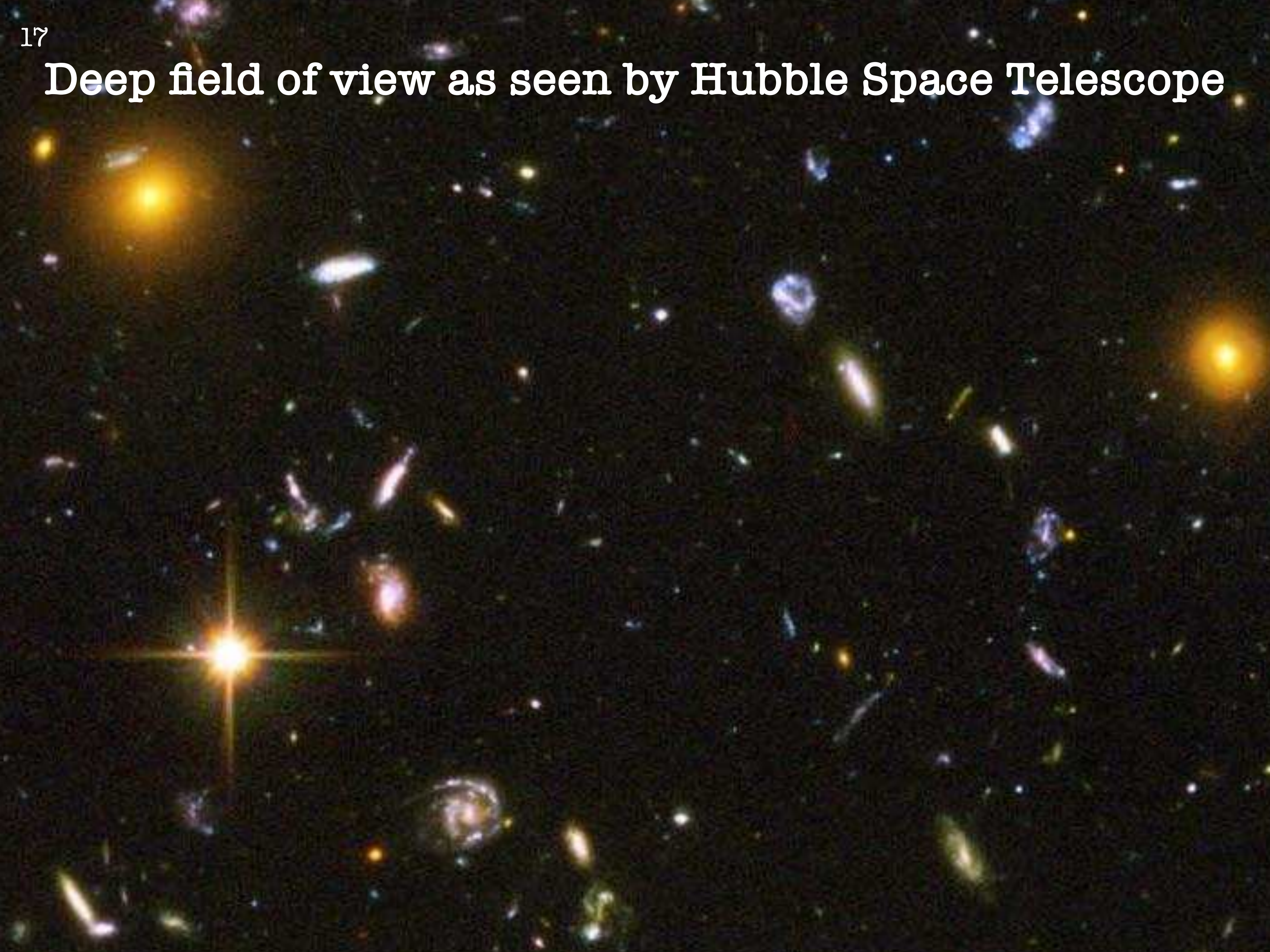
Very large telescopes constructed in XX century
resolved individual stars within these extragalactic objects
that also contain spiral arms

It became logical that nebulae must be galaxies similar to ours

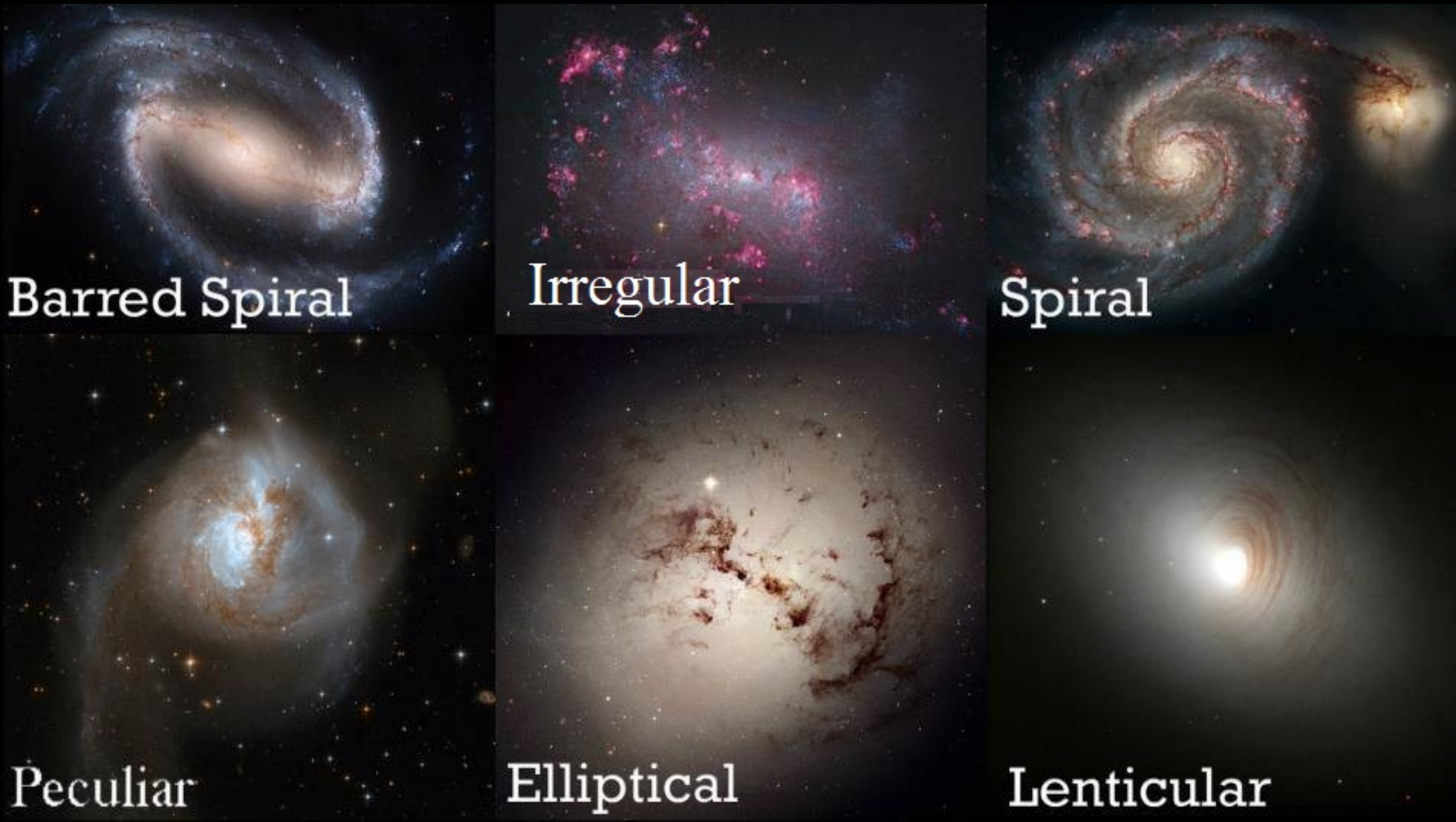
Distance to nearest spiral galaxy ☛ Andromeda over 2 million ly
a distance 20 times greater than the diameter of our Galaxy

Today it is thought there are $\sim 4 \times 10^{10}$ galaxies
that is as many galaxies as there are stars in the Galaxy

Deep field of view as seen by Hubble Space Telescope

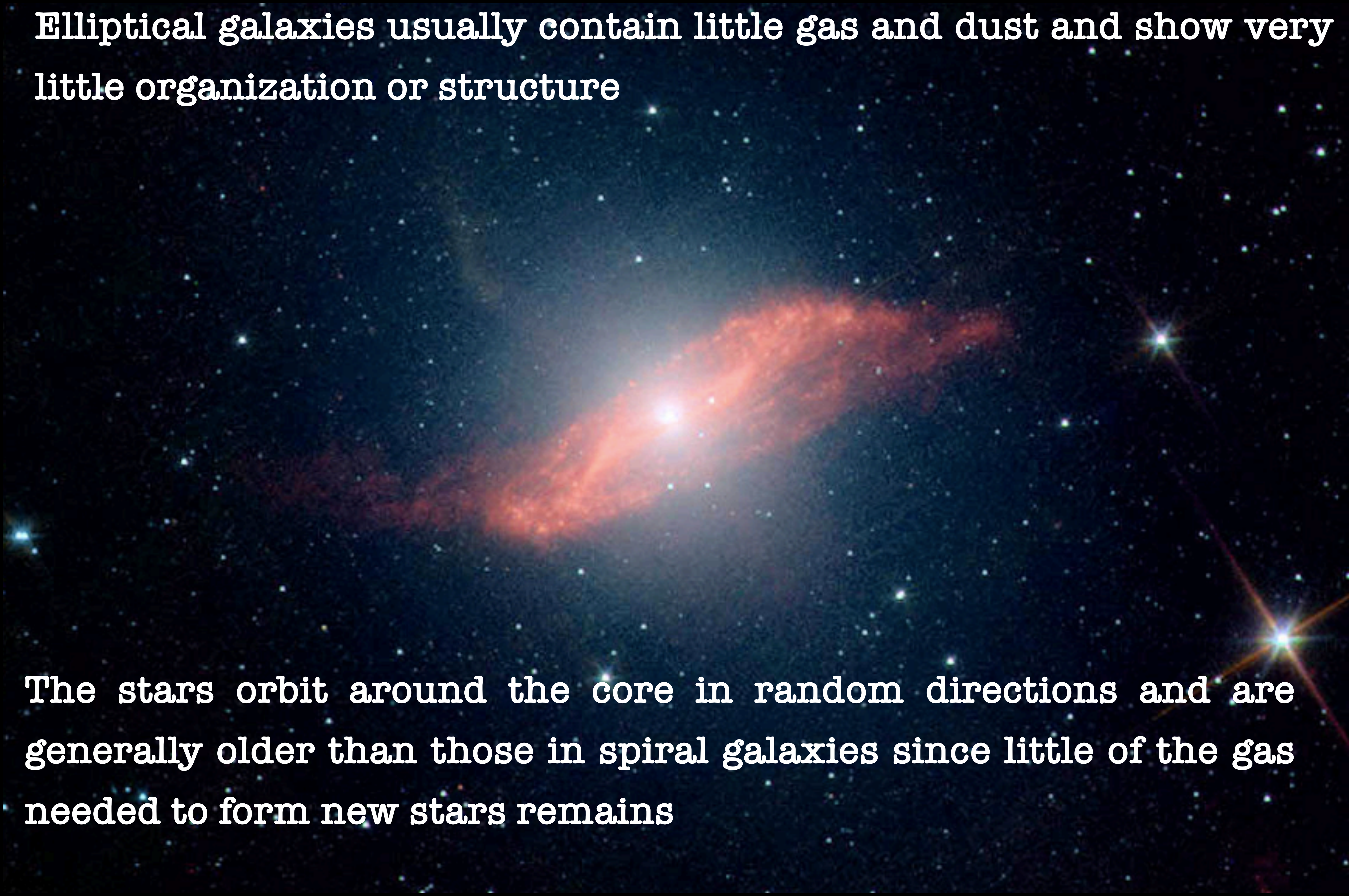


Types of Galaxies



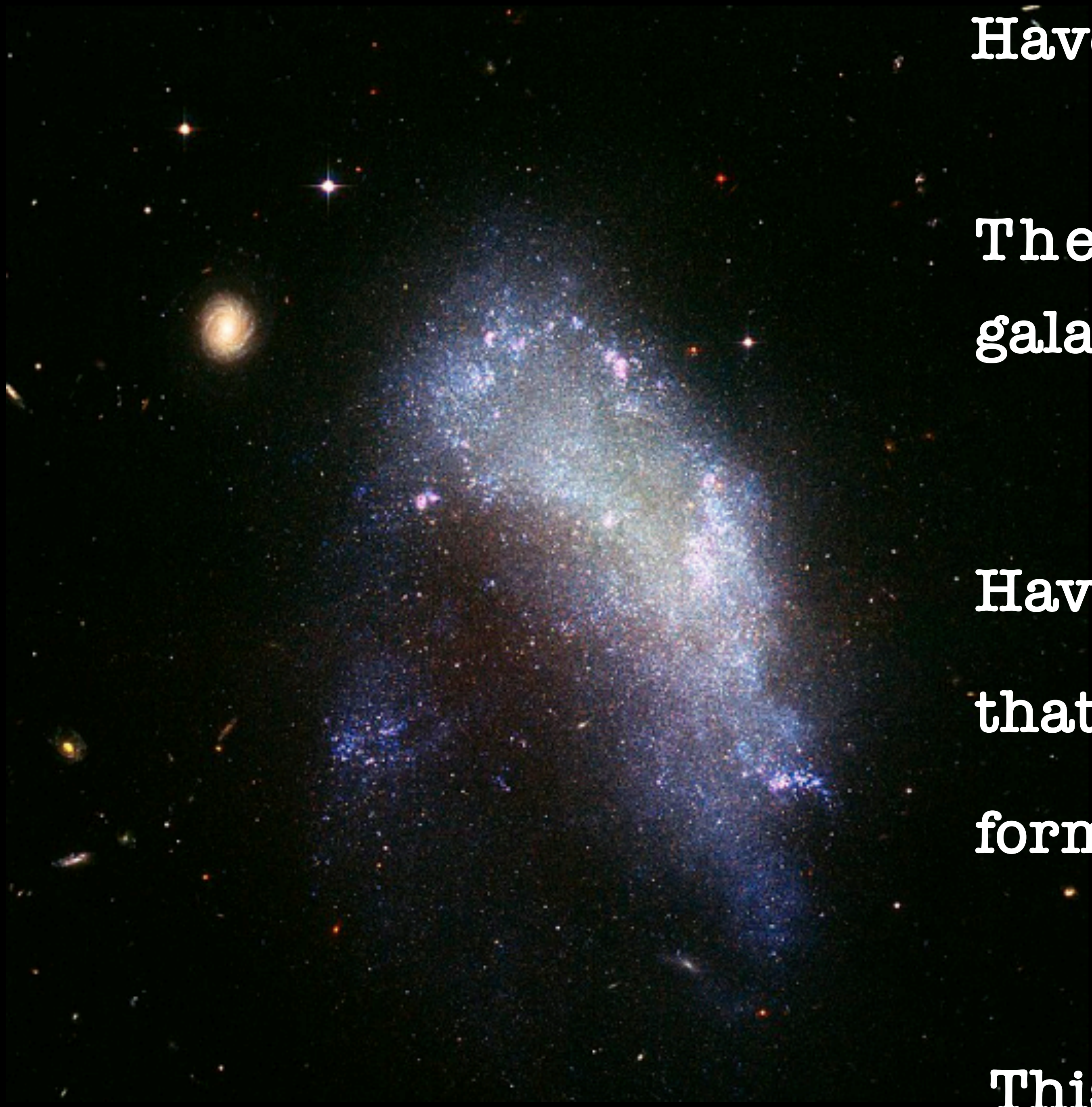
The spiral galaxy NGC 2008, located about 425 million light-years from Earth in the constellation of Pictor

Elliptical galaxies usually contain little gas and dust and show very little organization or structure



The stars orbit around the core in random directions and are generally older than those in spiral galaxies since little of the gas needed to form new stars remains

Irregular galaxies



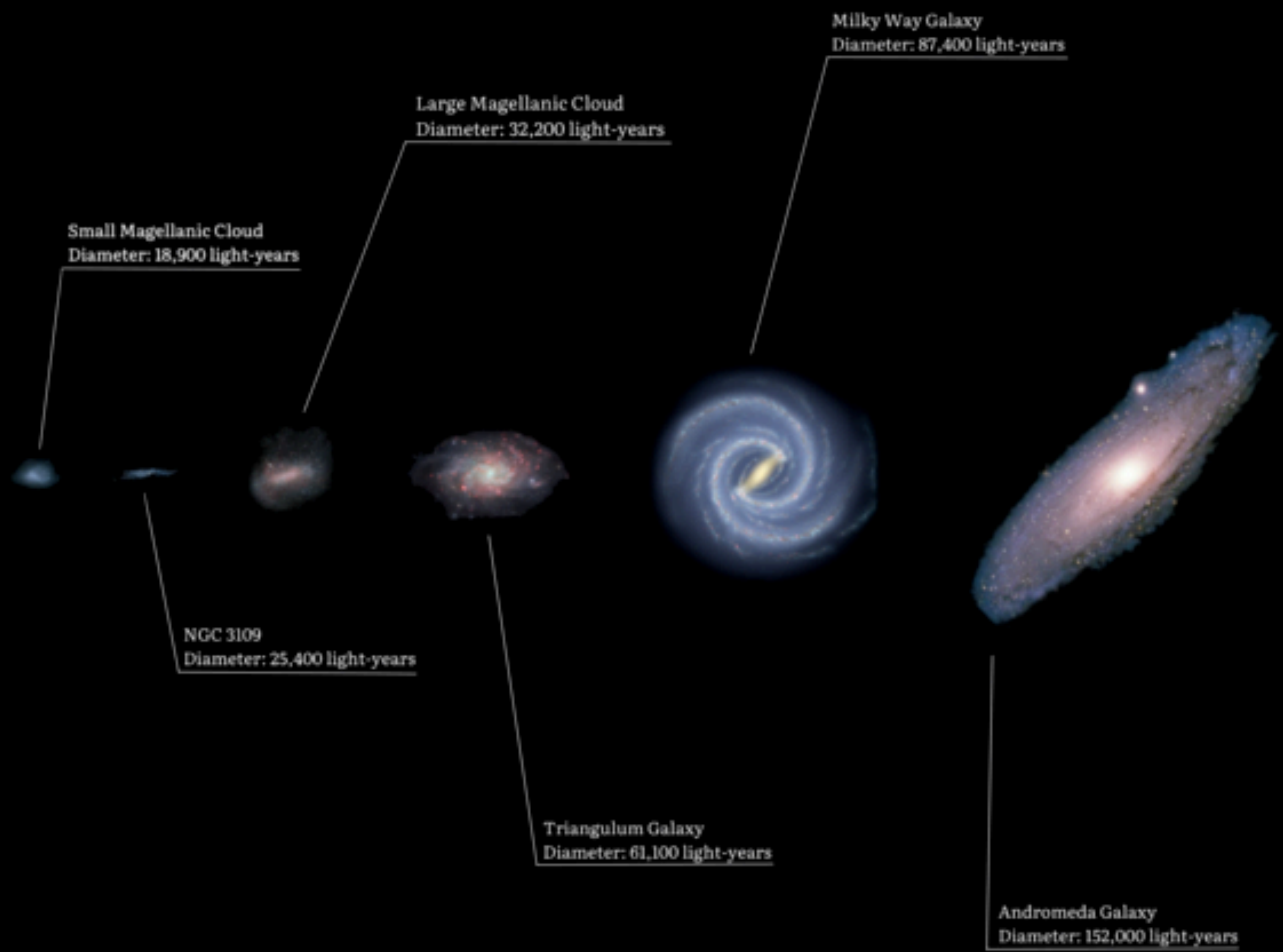
Have no particular shape

They are among the smallest galaxies and are full of gas and dust

Having a lot of gas and dust means that these galaxies have a lot of star formation going on within them

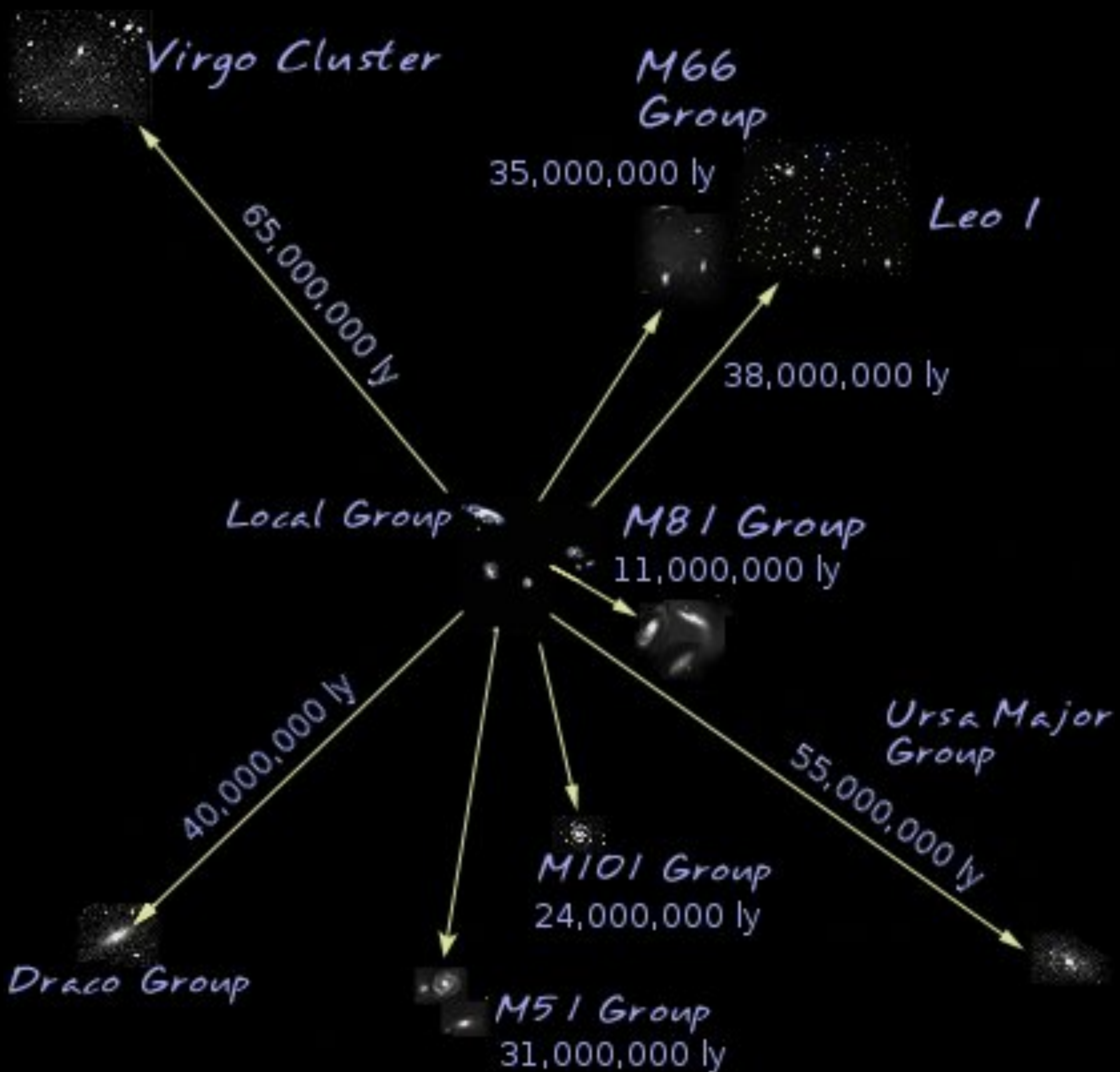
This can make them very bright

The Local Group



The Local Group is the Galaxy Group that includes the Milky Way
Diameter 10 million light years

Virgo Super Cluster



What is the Milky Way? It is:

A. an asteroid

B. a bright star

C. a comet

D. a galaxy

What is the Milky Way? It is:

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B. a bright star

C. a comet

D. a galaxy

Which of the following words best describes the shape of our galaxy?

A. Spherical

B. Elliptical

C. Spiral

D. Barred -Spiral

Which of the following words best describes the shape of our galaxy?

A. Spherical

B. Elliptical

C. Spiral

D. Barred -Spiral

This type of galaxy resembles a pinwheel?

A. Irregular

B. Globular

C. Elliptical

D. Spiral

This type of galaxy resembles a pinwheel?

A. Irregular

B. Globular

C. Elliptical

D. Spiral

This type of galaxy contains older stars and has very little gas and dust

A. Irregular

B. Elliptical

C. Spiral

D. Globular

This type of galaxy contains older stars and has very little gas and dust

A. Irregular

B. Elliptical

C. Spiral

D. Globular

This type of galaxy contains lots of gas and dust, and has no defined shape

A. Spiral

B. Globular

C. Irregular

D. Elliptical

This type of galaxy contains lots of gas and dust, and has no defined shape

A. Spiral

B. Globular

C. Irregular

D. Elliptical

One of these choices is NOT a type of galaxy

A. Globular

B. Elliptical

C. Spiral

D. Irregular

One of these choices is NOT a type of galaxy

A. Globular

B. Elliptical

C. Spiral

D. Irregular

The Milky Way galaxy is located in a group of galaxies called

A. The Orion Group

B. The Scorpio Group

C. The Saggitarius Group

D. The Local Group

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A. The Orion Group

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What is the definition of one Astronomical Unit?

A. the average distance from the Sun to Earth

B. the average distance from the Earth to Sun

C. average radius of Earth orbit

D. all of the above

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The diameter of the Milky Way galaxy is approximately

A. 10,000 AU

B. 100, 000 light years

C. 1000 light years

D. 100,000 AU

The diameter of the Milky Way galaxy is approximately

A. 10,000 AU

B. 100, 000 light years

C. 1000 light years

D. 100,000 AU

Our solar system is located on this part of the Milky Way

A. Pegasus center

B. Orion arm

C. Pegasus arm

D. Orion center

Our solar system is located on this part of the Milky Way

A. Pegasus center

B. Orion arm

C. Pegasus arm

D. Orion center

Our solar system is located this distance from the center of the Milky Way galaxy.

A. 26,000 AU

B. 26,000 light years

C. 4.2 light years

D. 2600 AU

Our solar system is located this distance from the center of the Milky Way galaxy.

A. 26,000 AU

B. 26,000 light years

C. 4.2 light years

D. 2600 AU

QUERY 12

How long does it take light to travel from the Sun to the Earth?

The Sun's nearest neighbor among the stars, a dim little star called Proxima Centauri, is at a distance of 206,000 AU from us

How long does it take light to travel from Proxima Centauri to the Earth?

QUERY 12

The average distance from the Sun to the Earth is

$$d = \ 1\text{AU}\ 1.5 \times 10^{11}\ \text{meters}\ = 1.5 \times 10^{8}\ \text{kilometers}$$

The speed of light is $c = \ 3 \times 10^{8}\ \text{meters/sec}\ = \ 300,000\ \text{kilometers/sec}$

The time it takes light to travel from the Sun to the Earth is thus

$$t = \frac{d}{c} = \frac{1.5 \times 10^{11}\ \text{meters}}{3 \times 10^{8}\ \text{meters/sec}} = \ 500\ \text{seconds}$$

In other words, it takes light 8 minutes and 20 seconds to reach the Earth from the Sun

The distance from Proxima Centauri to the Sun is

$$d_{\text{prox}-\text{C}} = \ 206,000\text{AU} \times \frac{1.5\ \times\ 10^{11}\ \text{meters}}{1\ \text{AU}} = \ 4.00\ \times\ 10^{16}\ \text{meters}$$

QUERY 12

Thus, the time it takes light to travel from Proxima Centauri to the Sun is

$$t_{\text{prox}-\text{C}} = \frac{d_{\text{prox}-\text{C}}}{c} = \frac{4.00 \times 10^{16} \text{ meters}}{3 \times 10^{8} \text{ meters/sec}} = 1.33 \times 10^{8} \text{ seconds}$$

This length of time can also be written as 2.22×10^6 min, or as 37, 100 hr, or as 1, 540 days, or as 4.23 years. (The travel time to the Earth, rather than the Sun, can differ from the number by as much as 8 minutes and 20 seconds, depending on where the Earth is on its orbit relative to Proxima Centauri.)

QUERY 13

The Voyager 1 spacecraft is presently 105.1 astronomical units from the Sun, and is moving away from the Sun at a speed of 17,260 meters per second. If it were traveling directly toward Proxima Centauri, and maintained its present speed for the entire journey, how long would it take to reach Proxima Centauri?

QUERY 13

The distance from the Sun to Proxima Centauri is $d_{\text{prox}-\text{C}} = 4.00 \times 10^{16}$ as we computed in the previous problem

The distance from the Sun to Voyager 1 is

$$d_{\text{Voyager}} = 105.1 \text{ AU } \times (1.5 \times 10^{11} \text{ meters/1AU}) = 1.58 \times 10^{13} \text{ meters}$$

This means that Voyager 1 has traveled only 0.04% of the distance to Proxima Centauri, and we can write the distance from Voyager 1 to Proxima Centauri as

$$d = d_{\text{prox}-\text{C}} - d_{\text{Voyager}} = 4.00 \times 10^{16} \text{ meters}$$

QUERY 13

The distance from the Sun to Proxima Centauri is $d_{\text{prox}-\text{C}} = 4.00 \times 10^{16}$ as we computed in the previous problem

The distance from the Sun to Voyager 1 is

$$d_{\text{Voyager}=105.1\ \text{AU}\ \times(1.5\times10^{11}\ \text{meters}/1\text{AU})\ =\ 1.58\times10^{13}\ \text{meters}}$$

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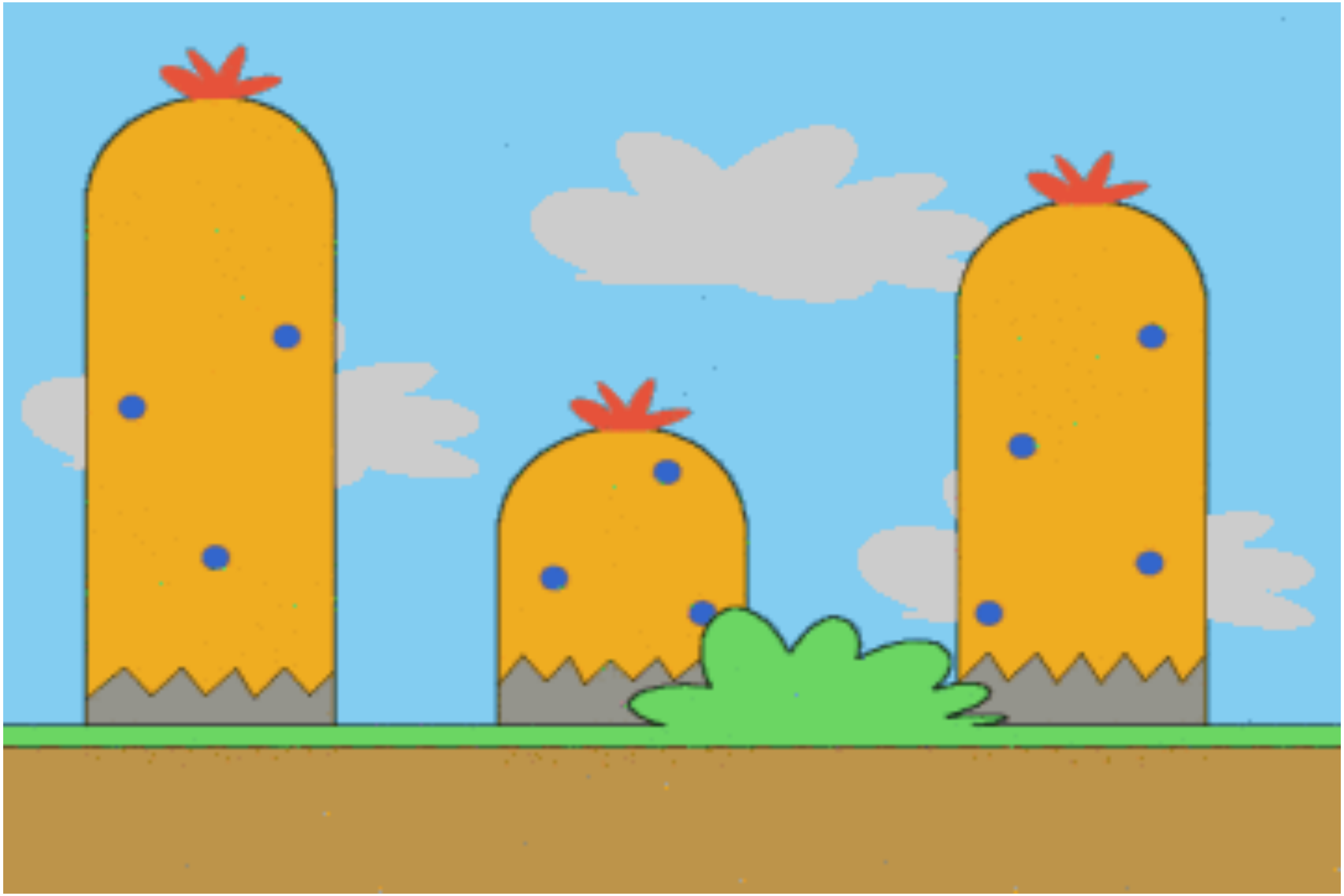
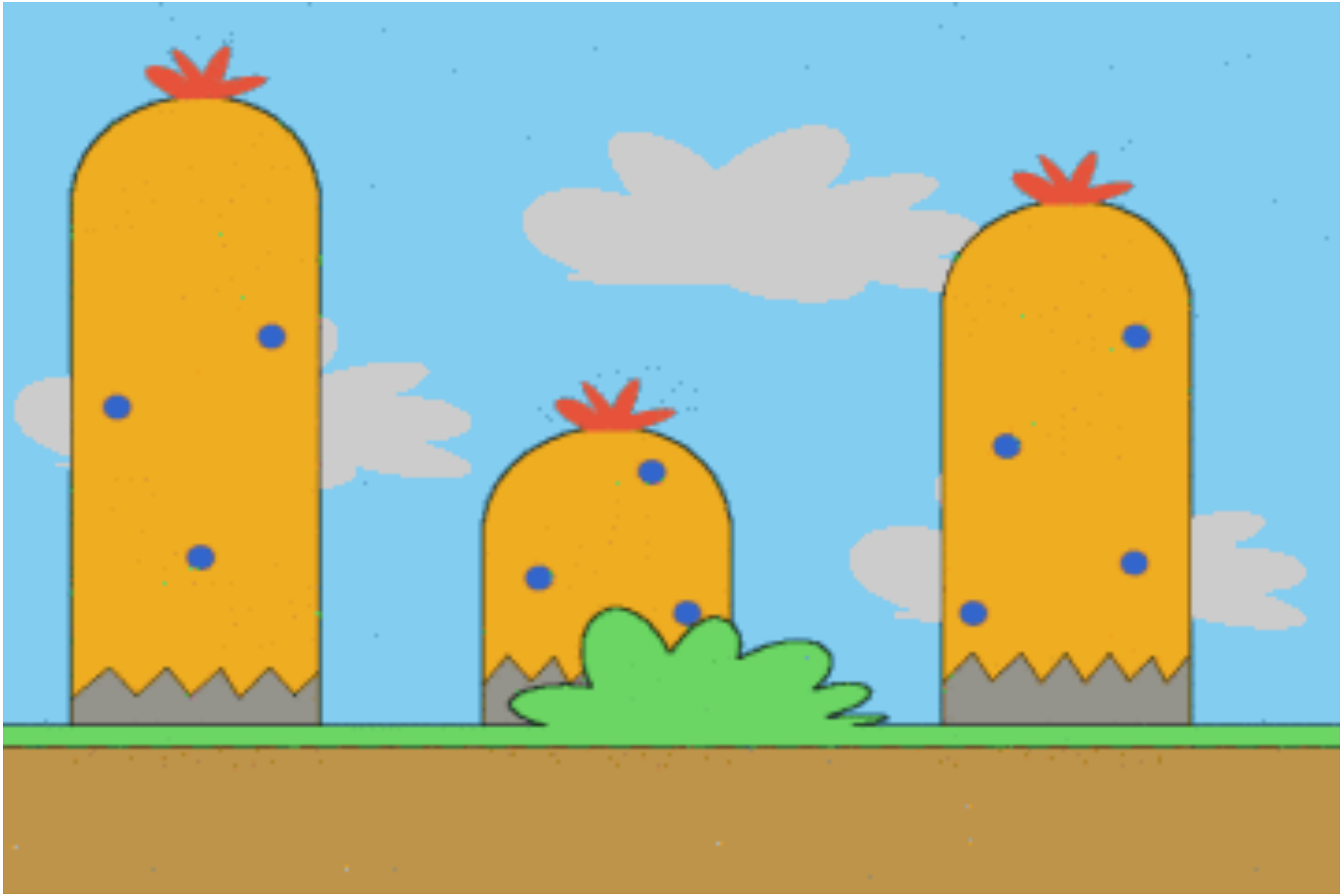
$$d = d_{\text{prox}-\text{C}} - d_{\text{Voyager}=4.00\ \times10^{16}\ \text{meters}}$$

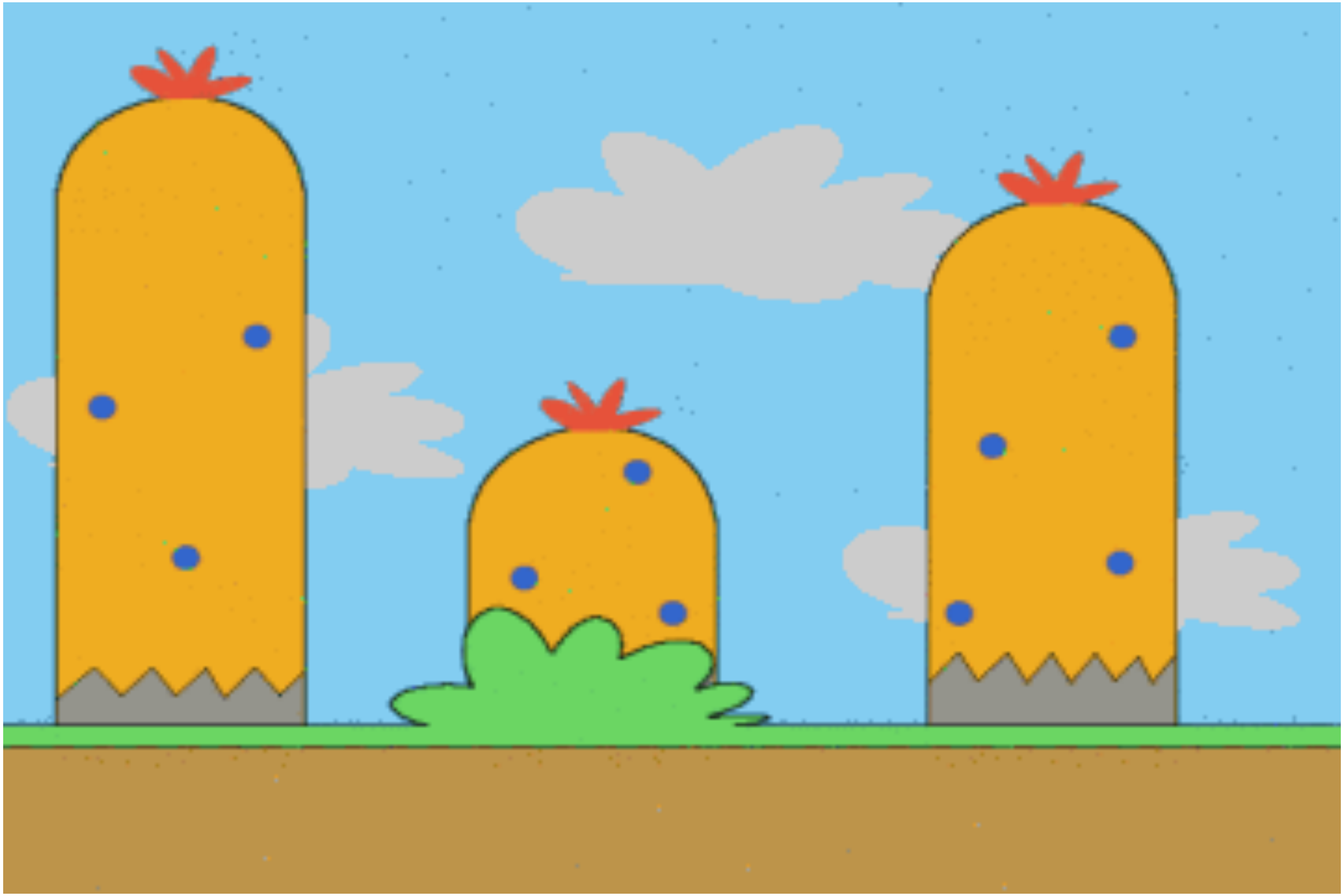
$$t = \frac{d}{v} = \frac{4 \times 10^{16}\ \text{m}}{17,260\ \text{m/s}} = 2.3 \times 10^{12}\ \text{s} = 74,000\ \text{yr}$$

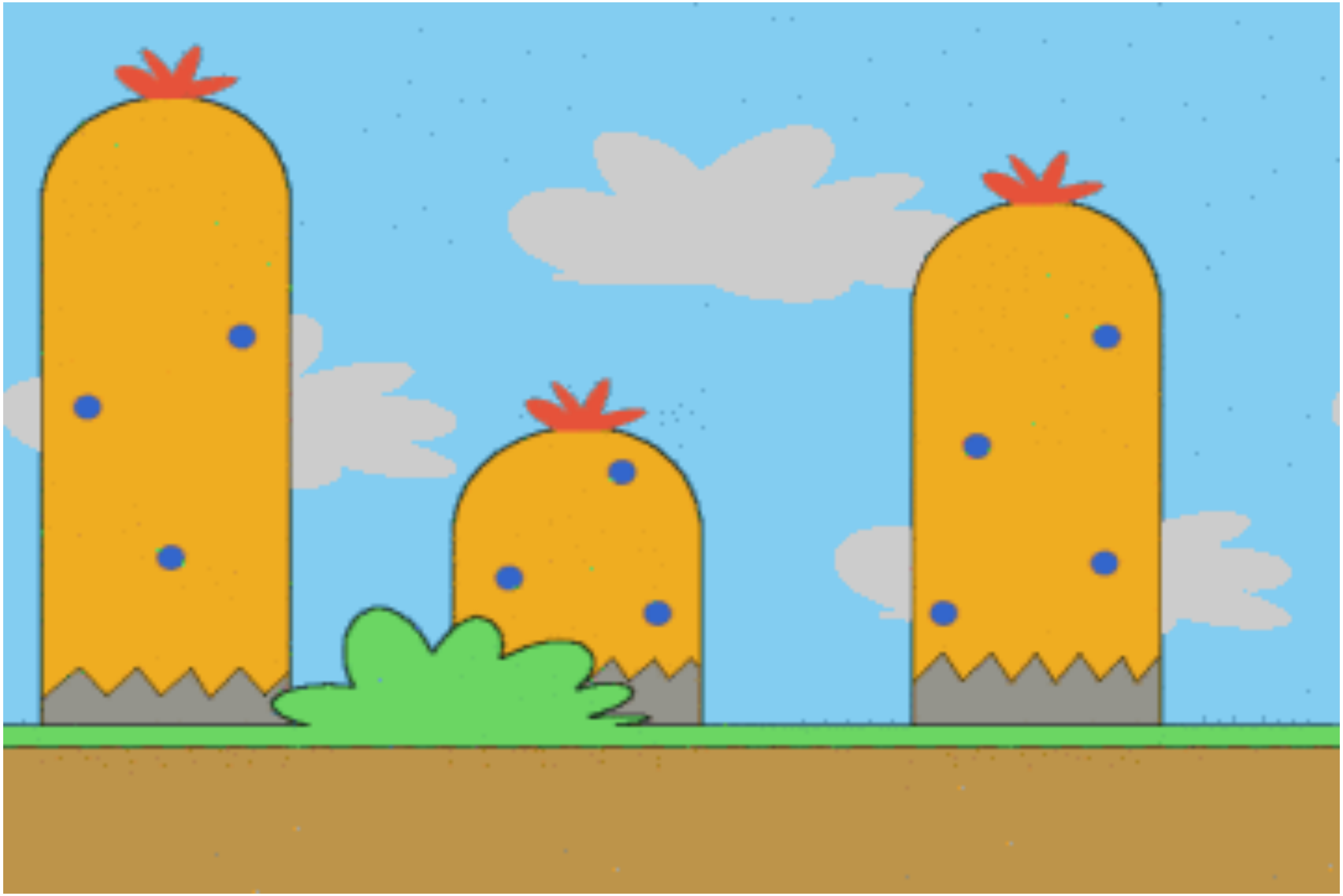
Why do far away objects appear to go slow when they are actually moving quite fast?

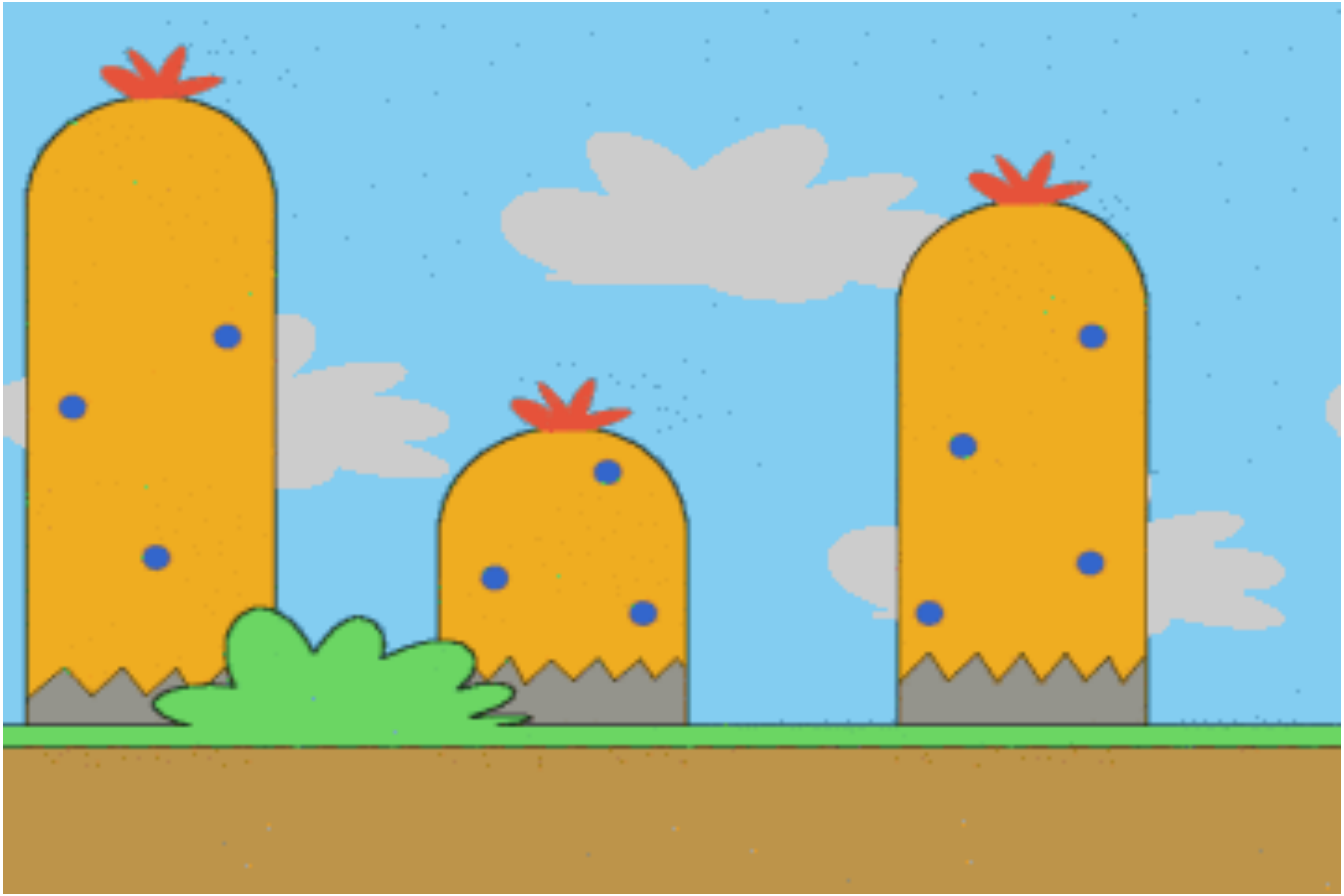
- ➢ The angular shift in position with time gives the perception of speed
- ➢ It is easier to see something moving across your field of vision than directly toward or away from you
- ➢ The further an object is away ☛ the longer it takes to cross your field of view
- ➢ Effectively ☛ this is the angle subtended by your "before" and "later" view of an object position
- ➢ When an object is close, say 100 m from you, and moves away at 10 km per hour ☛ you will see it moving away
- ➢ After an hour the object will be roughly 10 km away
- ➢ When the same object is 1000 km away and moves at the same speed away from you (or towards you, doesn't really even matter) the object will be about 1000 km away several hours later

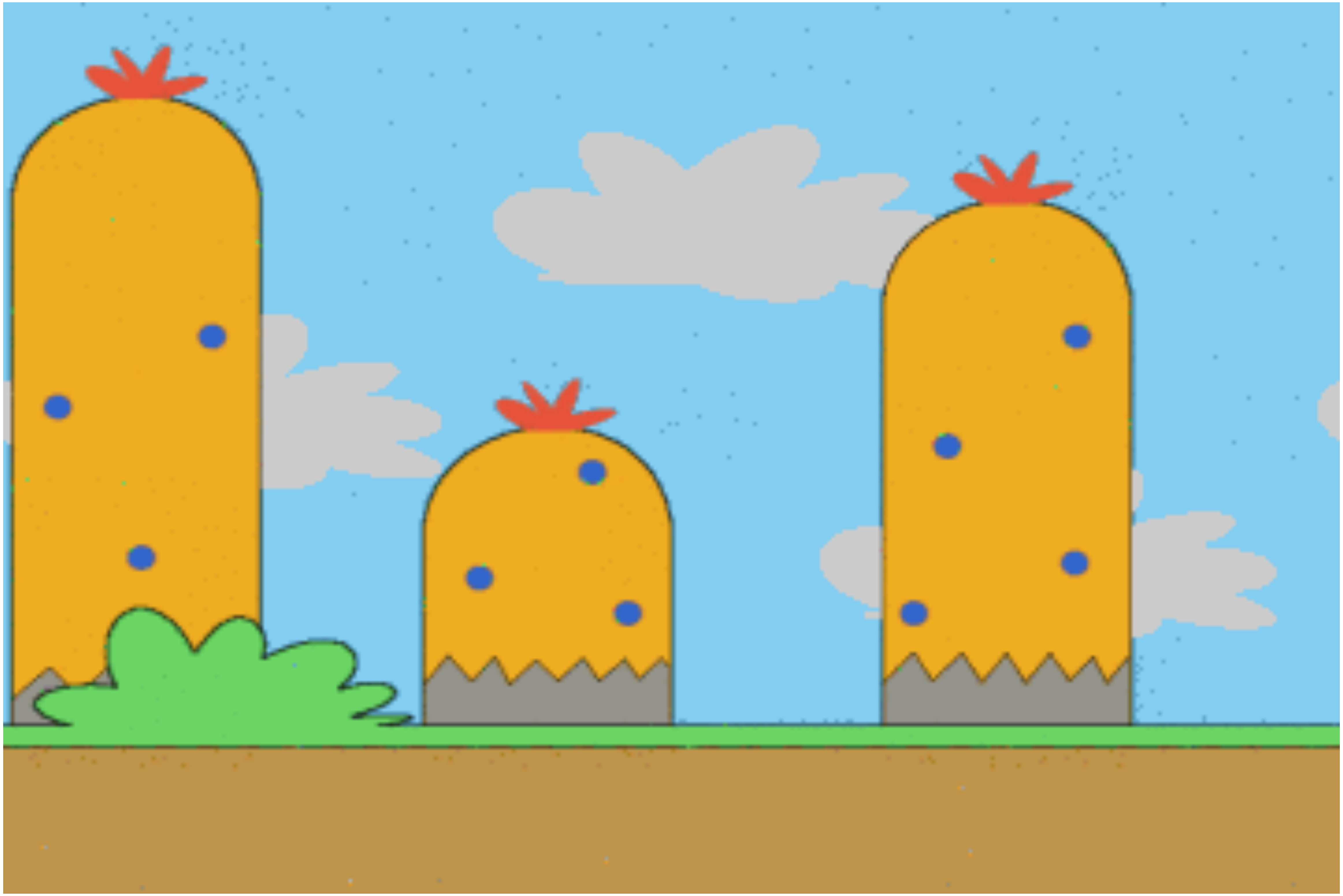


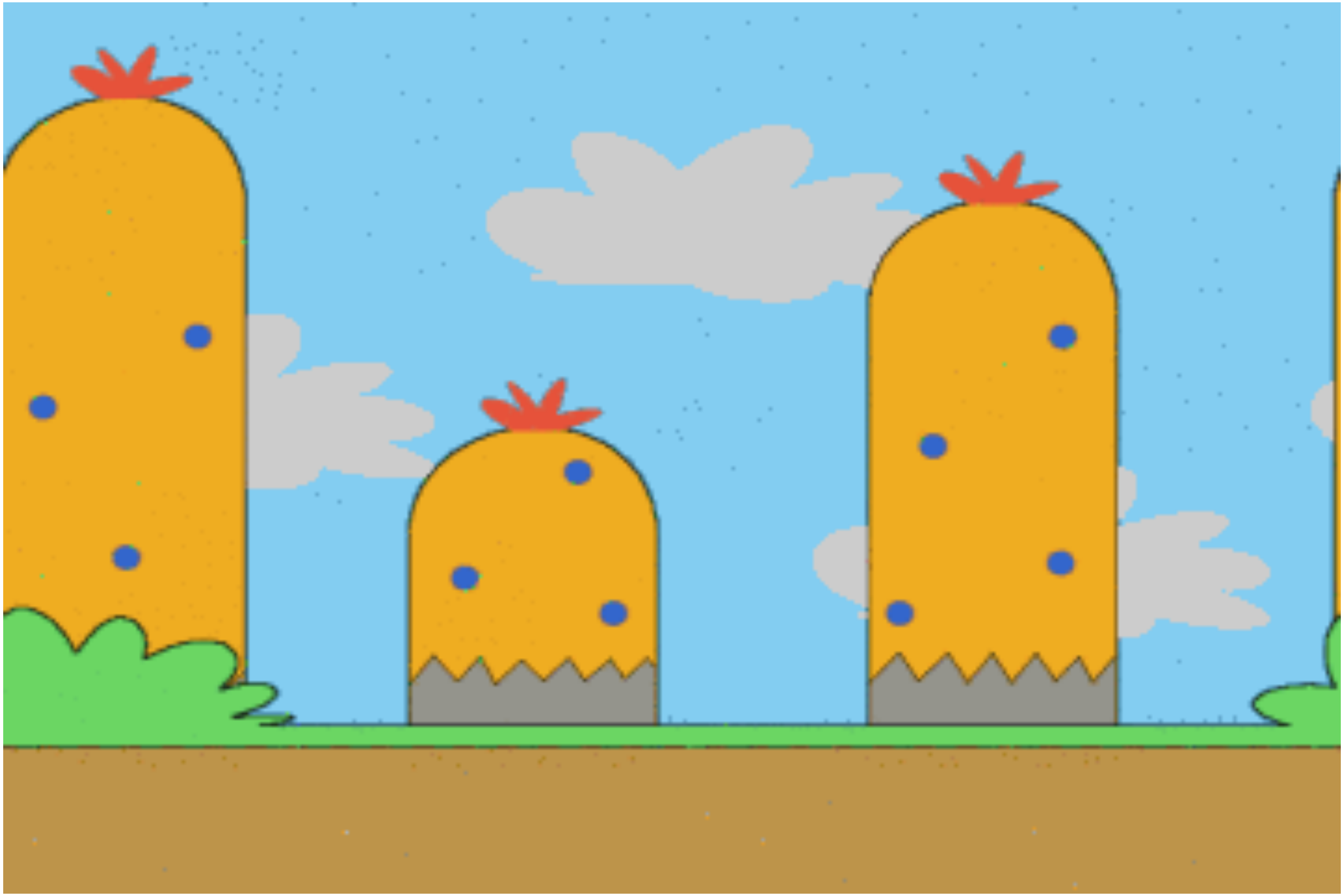


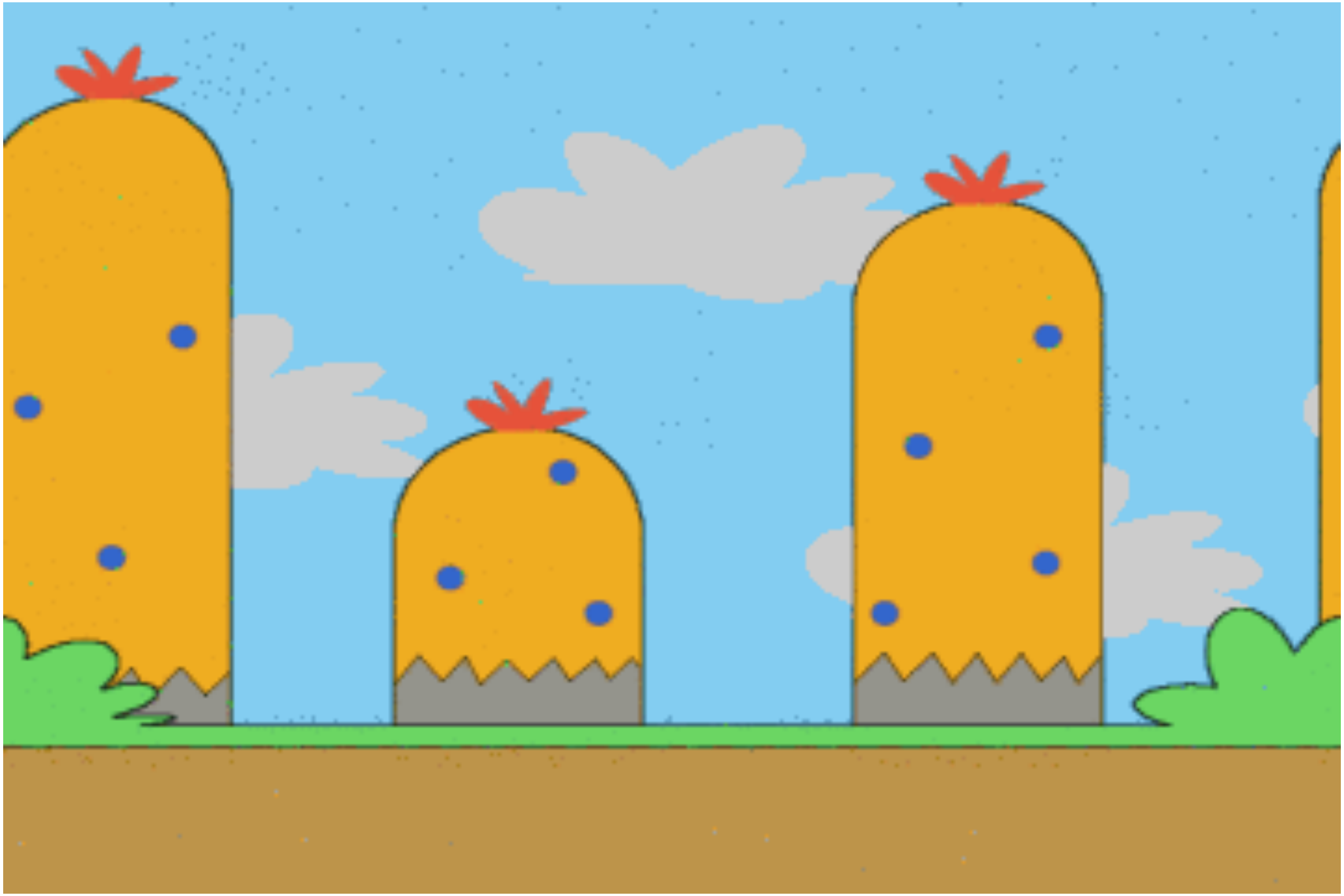


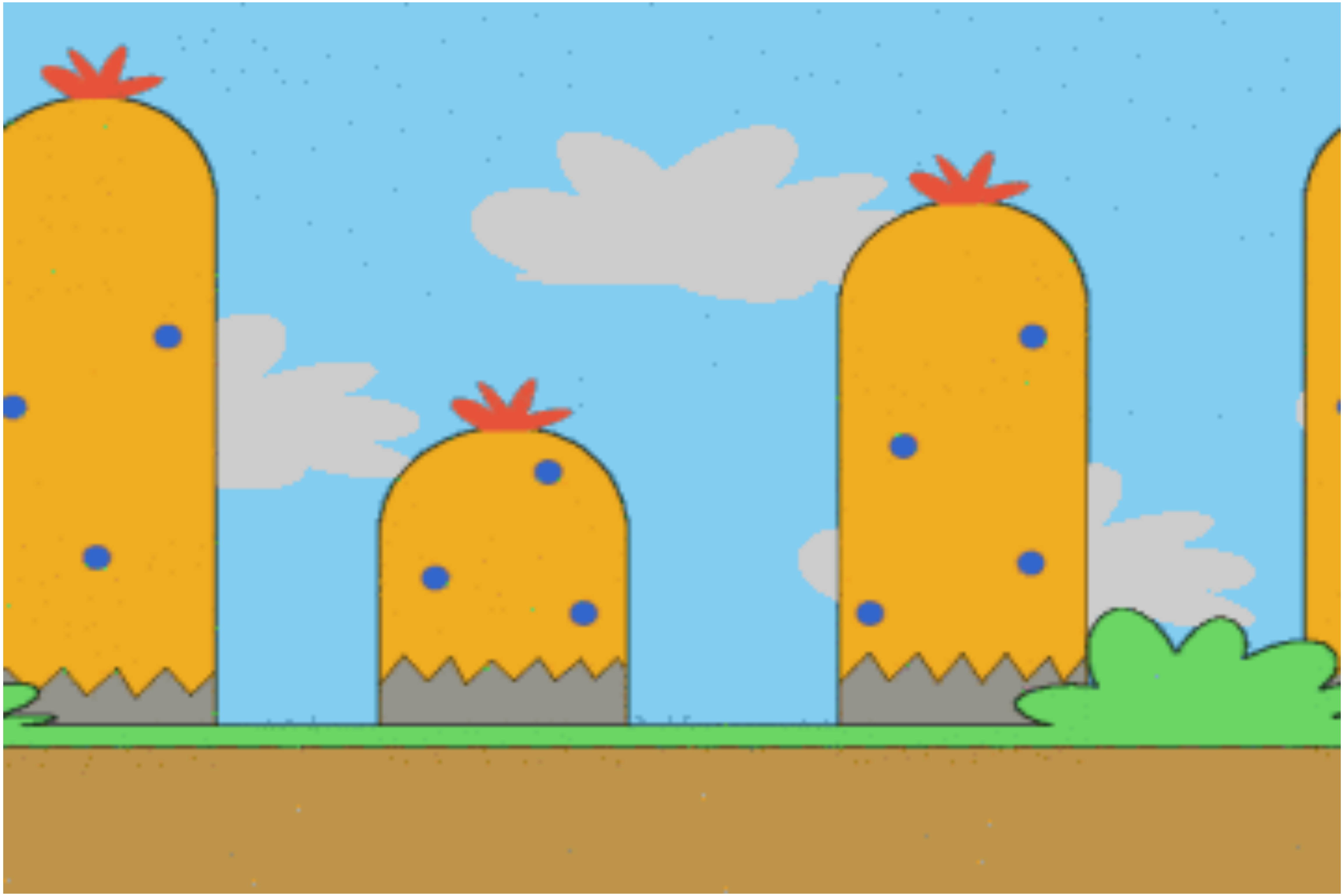


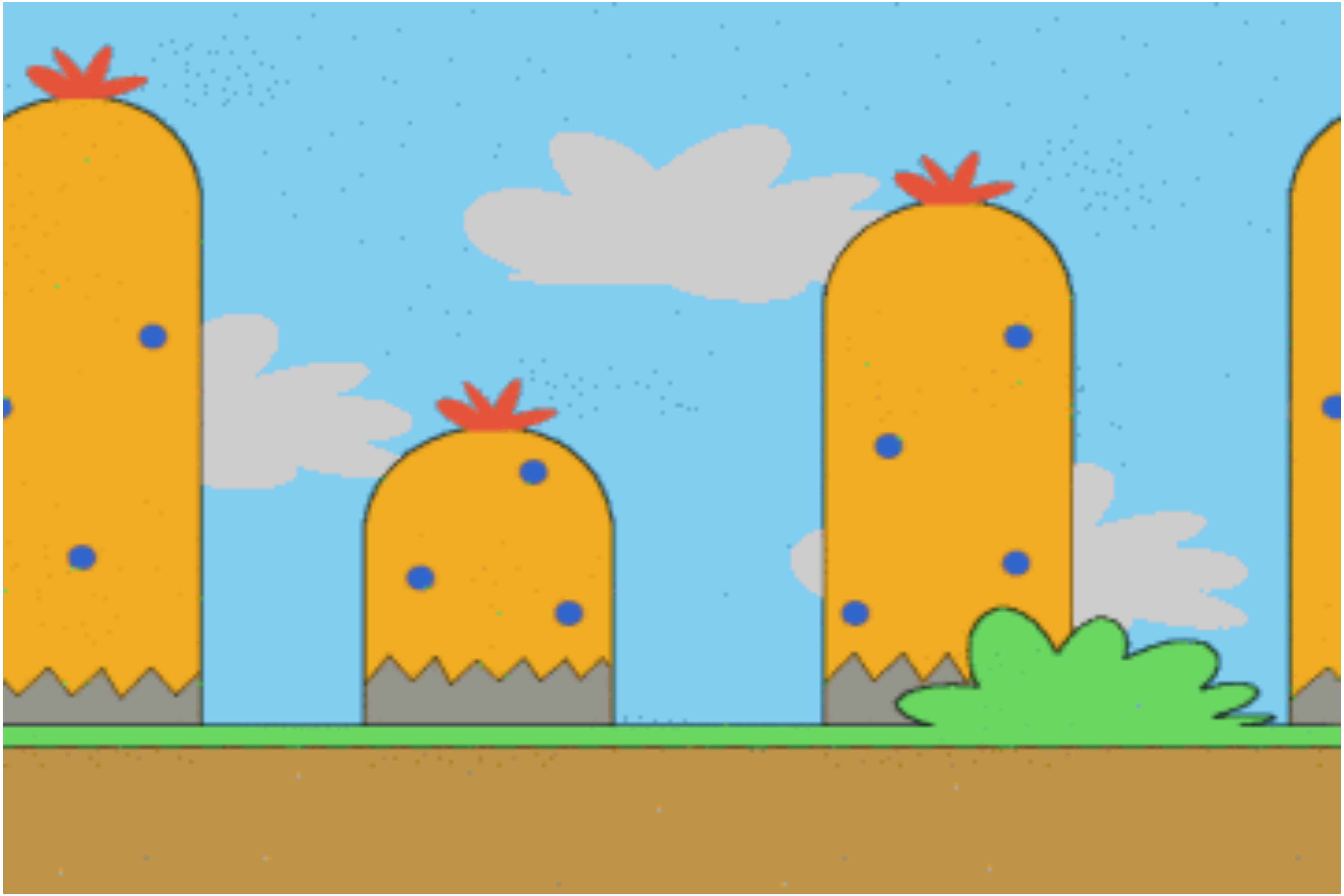


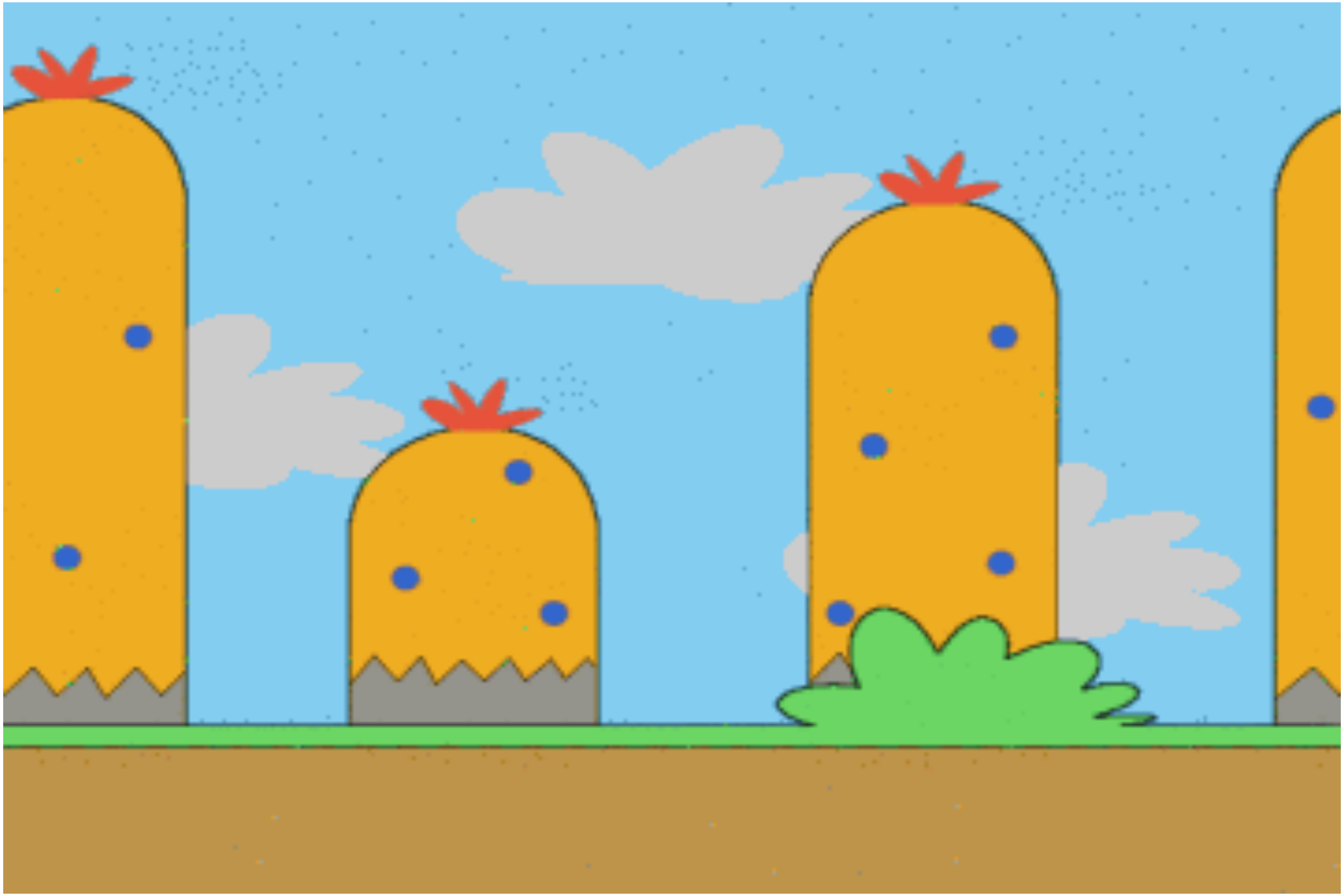


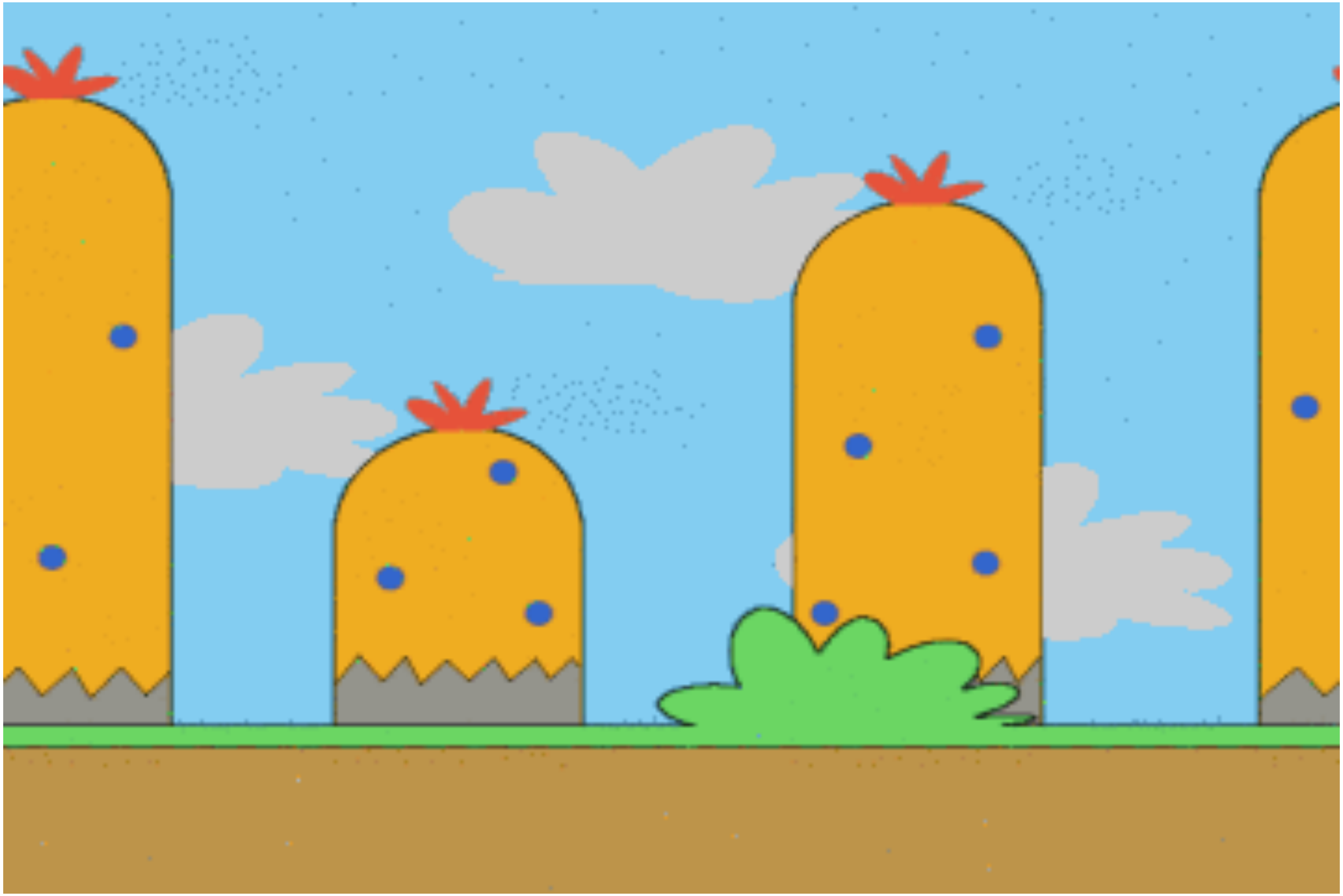


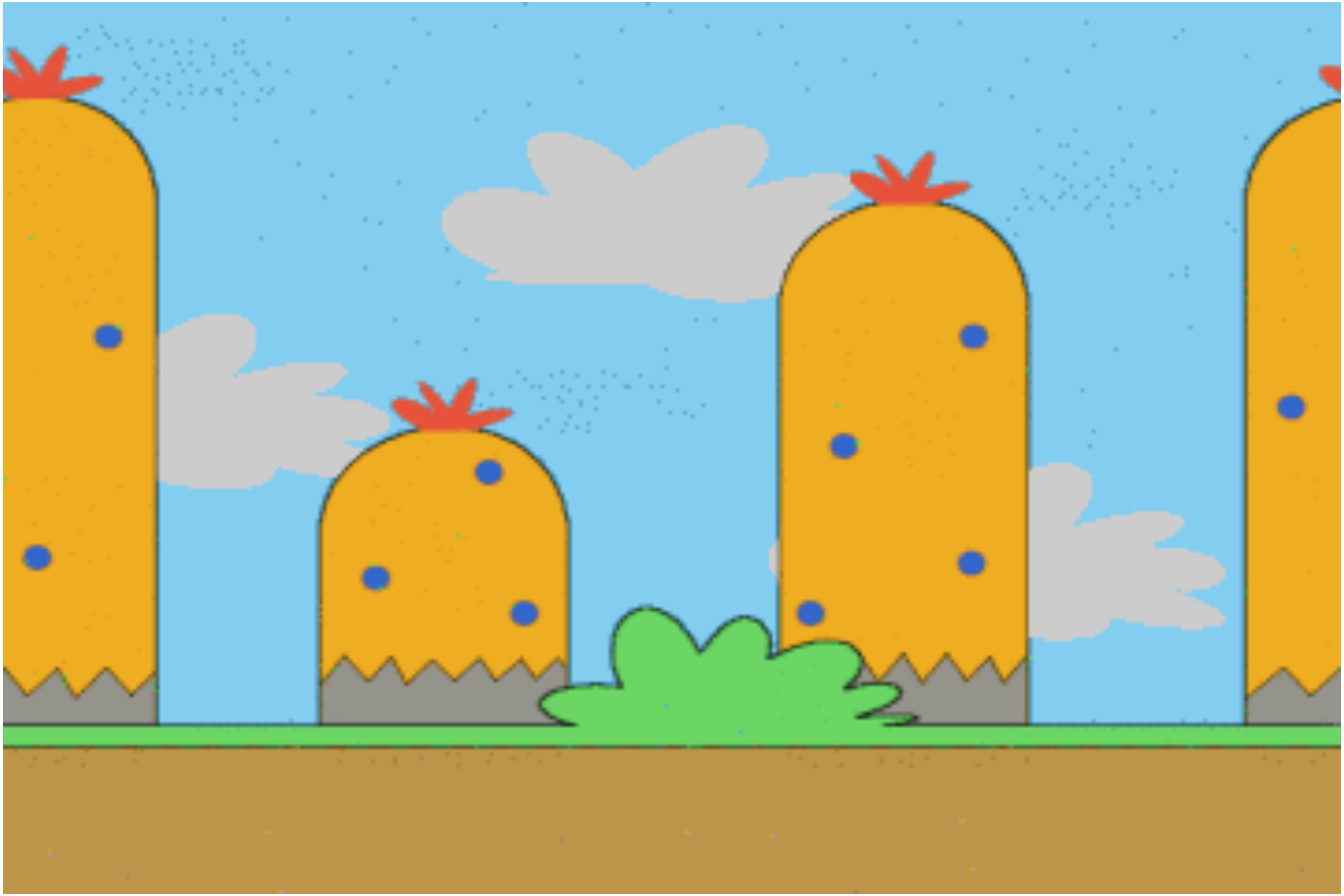


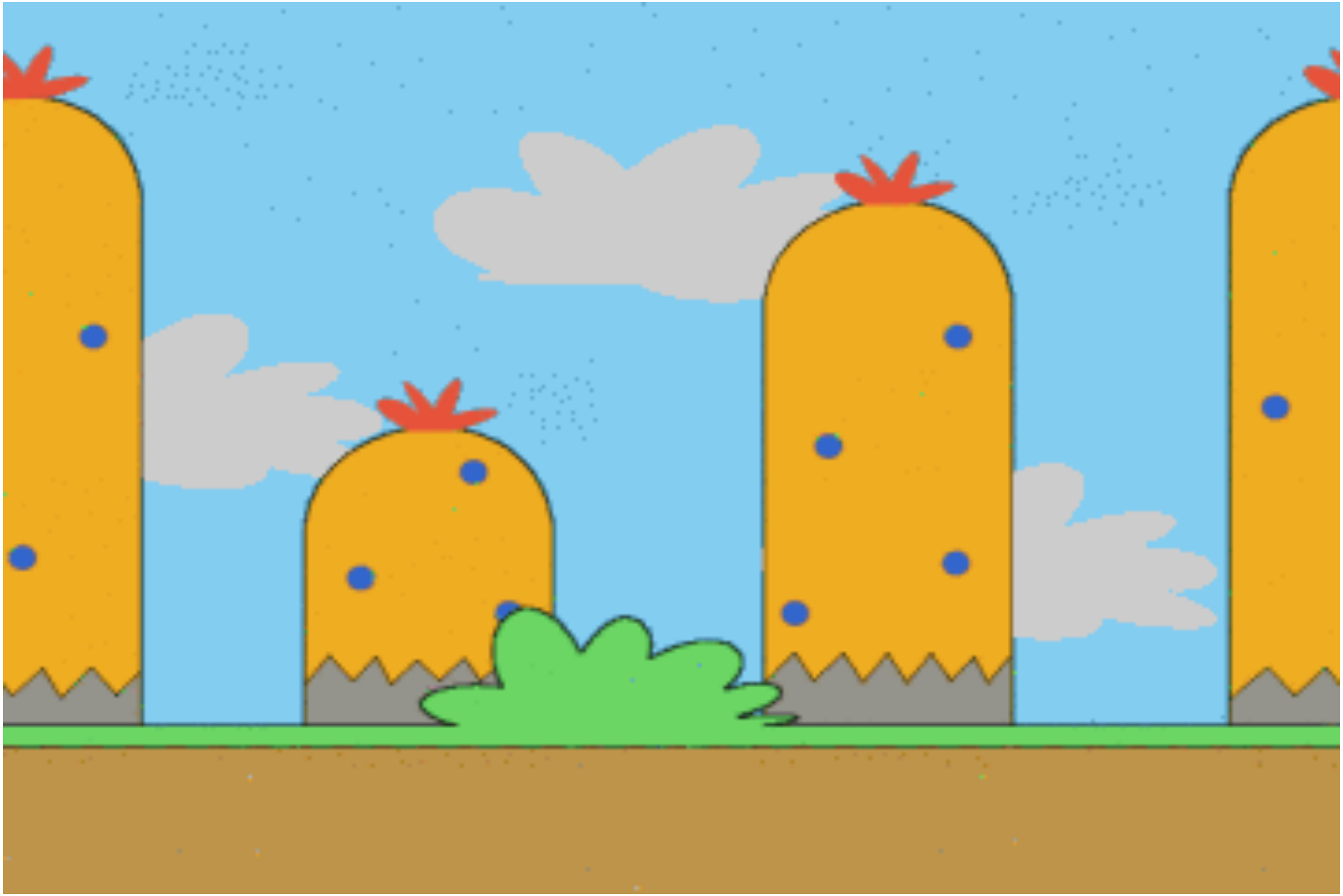


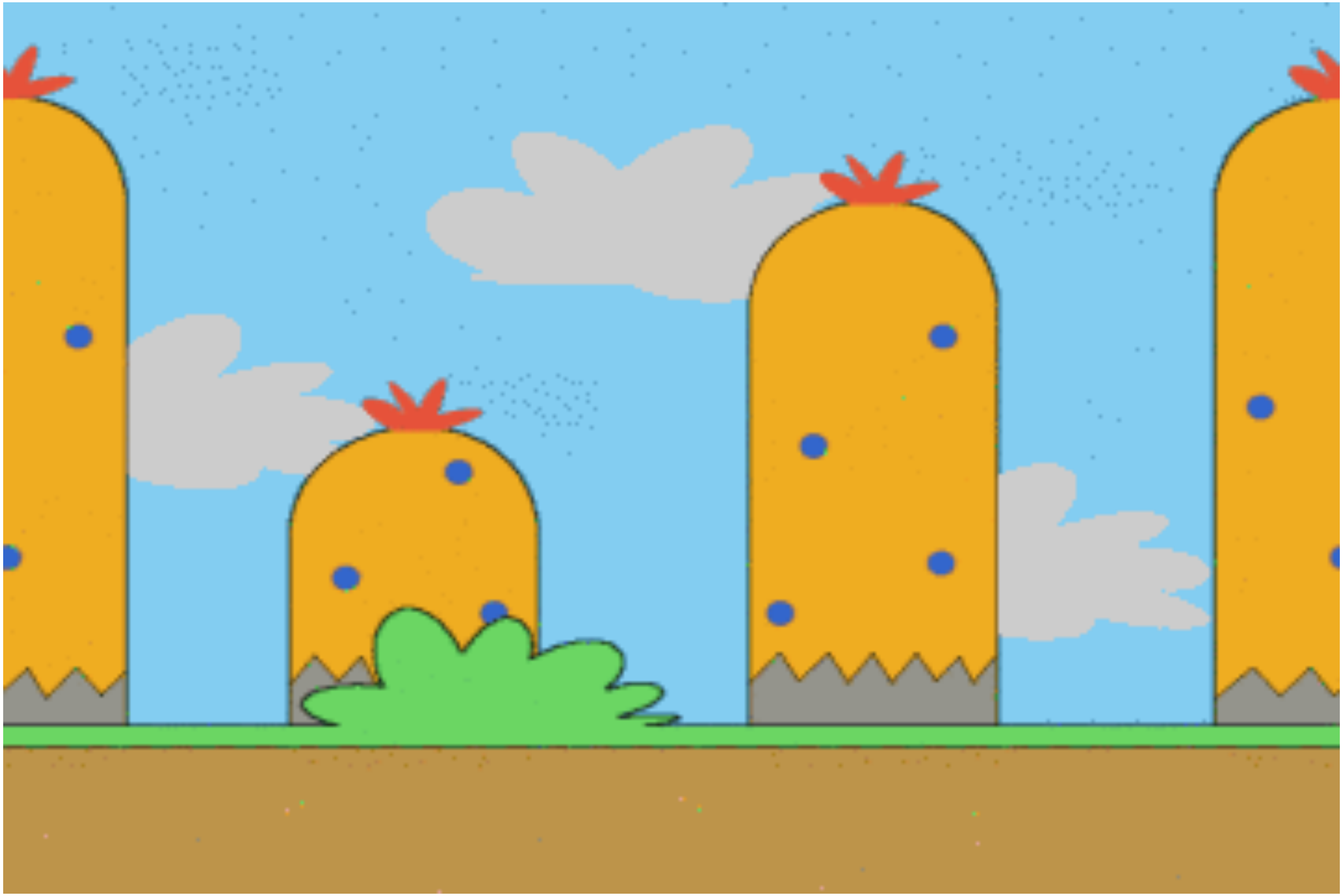


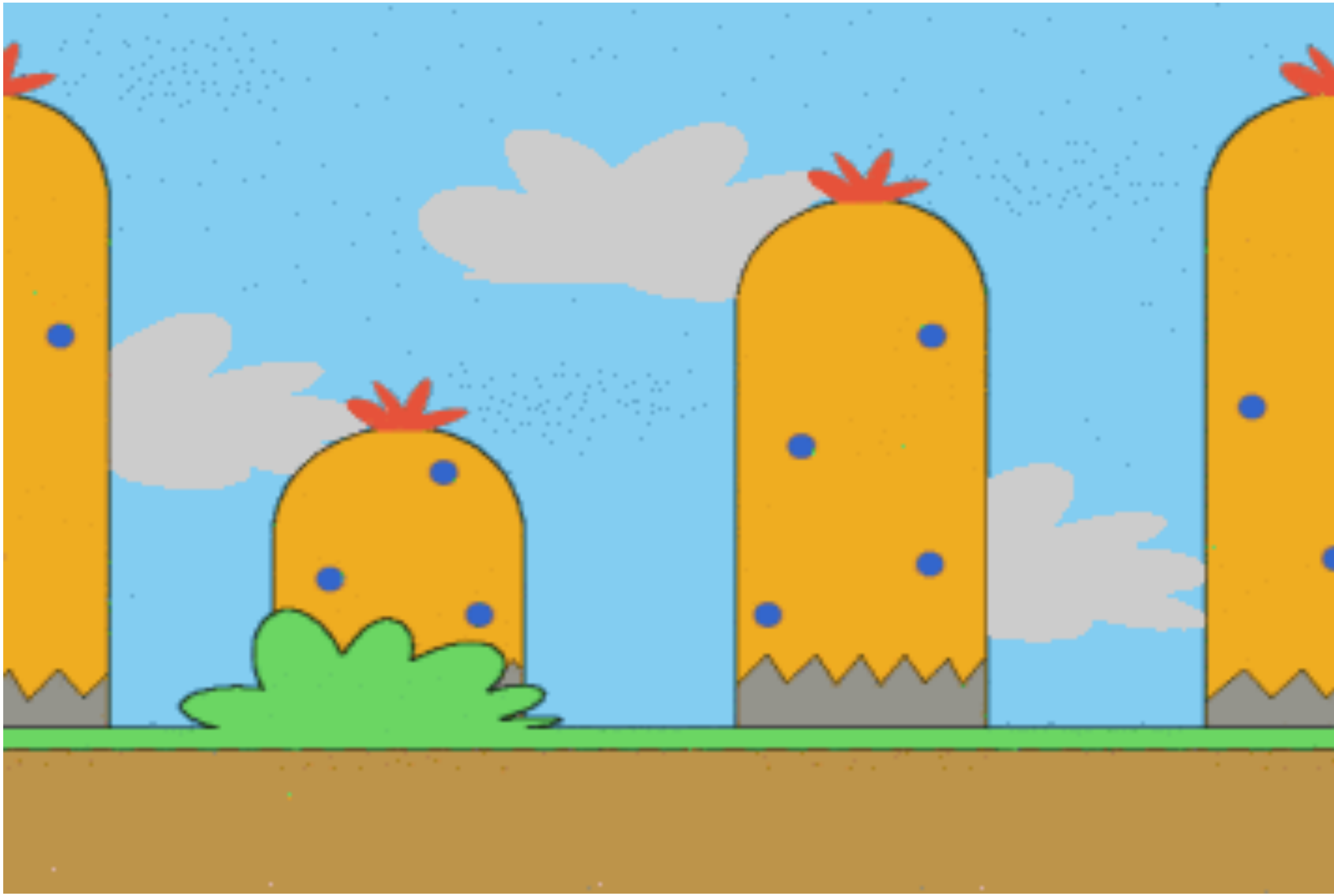


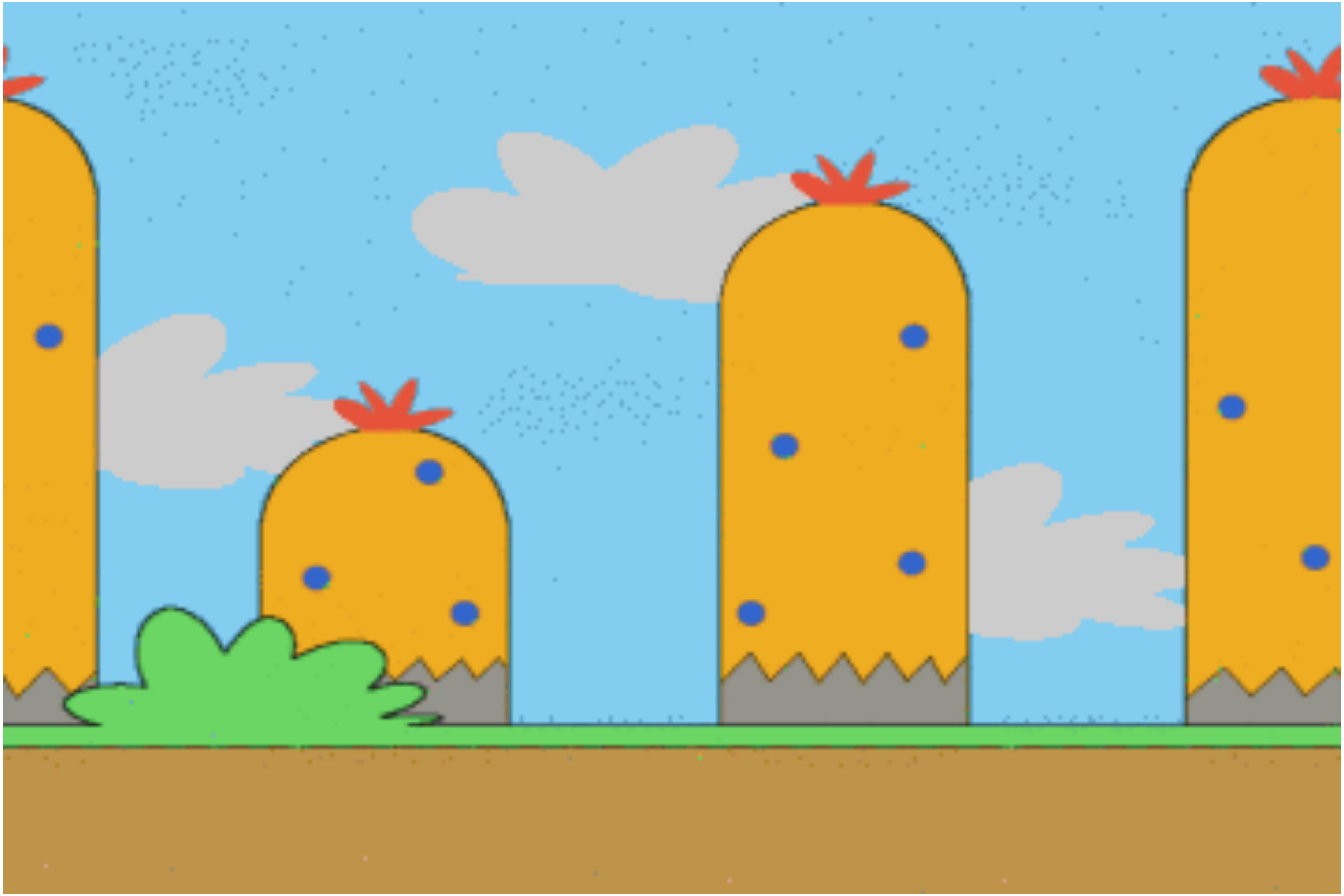










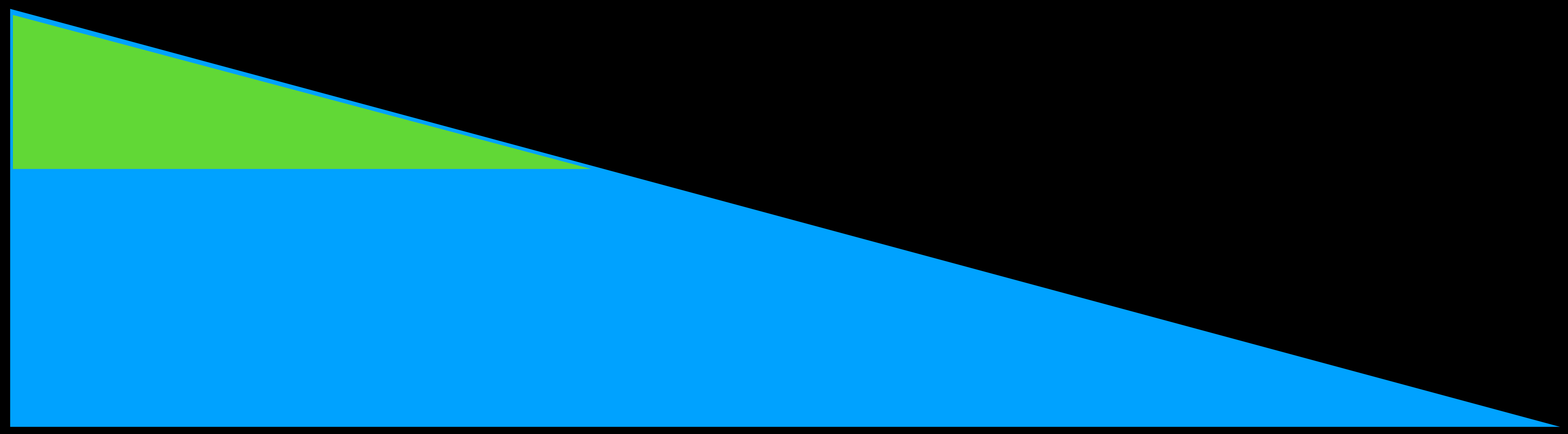


How can you measure the distance to an object you can’t reach?

How can you measure the distance to an object you can't reach?

➢ Use triangles…

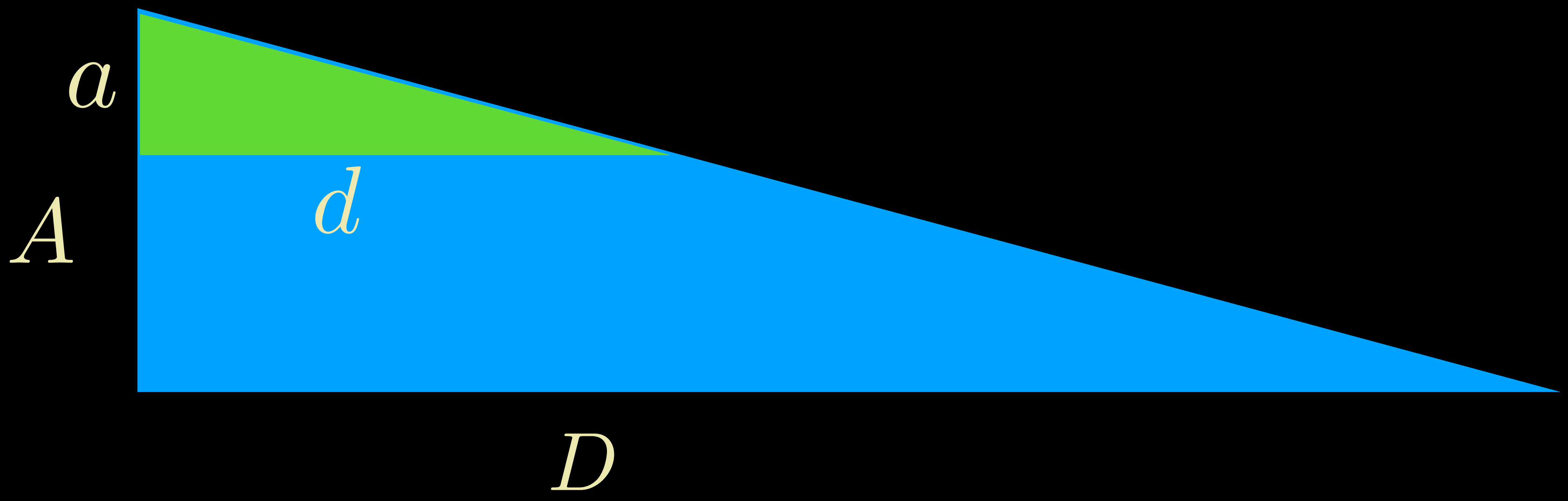
Triangles



The small triangle has the same shape as the large one

By measuring the two sides of the small triangle and the short side of the big triangle we can calculate the length of the long side of the big triangle

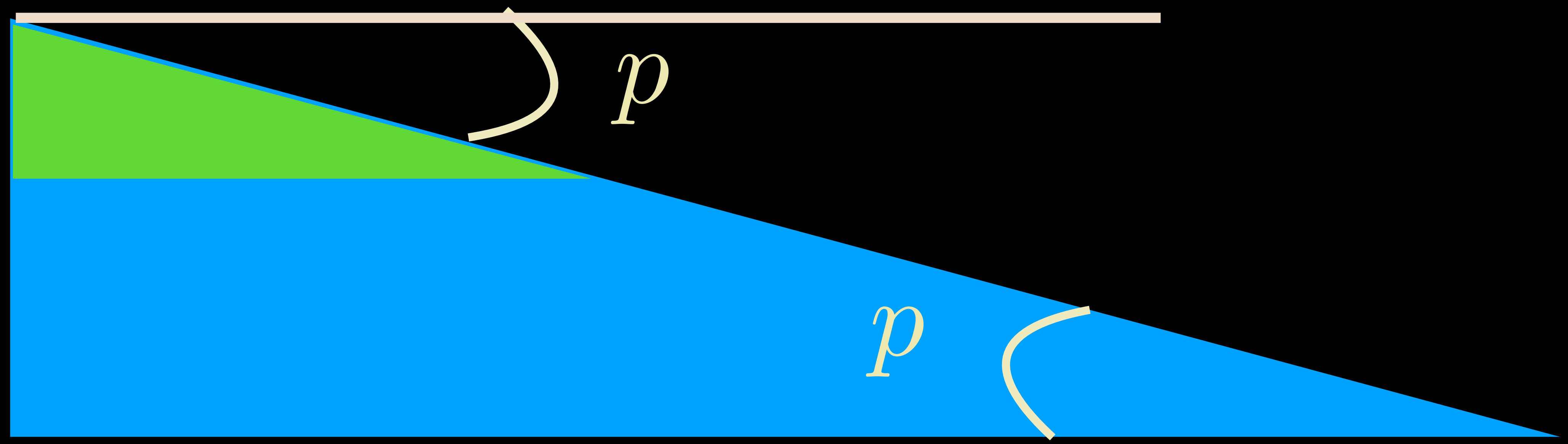
Measuring distance



$$\frac{D}{A} = \frac{d}{a}$$

$$D = A\,\frac{d}{a}$$

So, how can we measure the distance to stars?



Take two telescopes some distance apart and observe the same star

Measure the tilt between the two telescopes
this sets all the angles for the triangles

Then we can find the distance to the star from the distance between the telescopes and the angle of the tilt

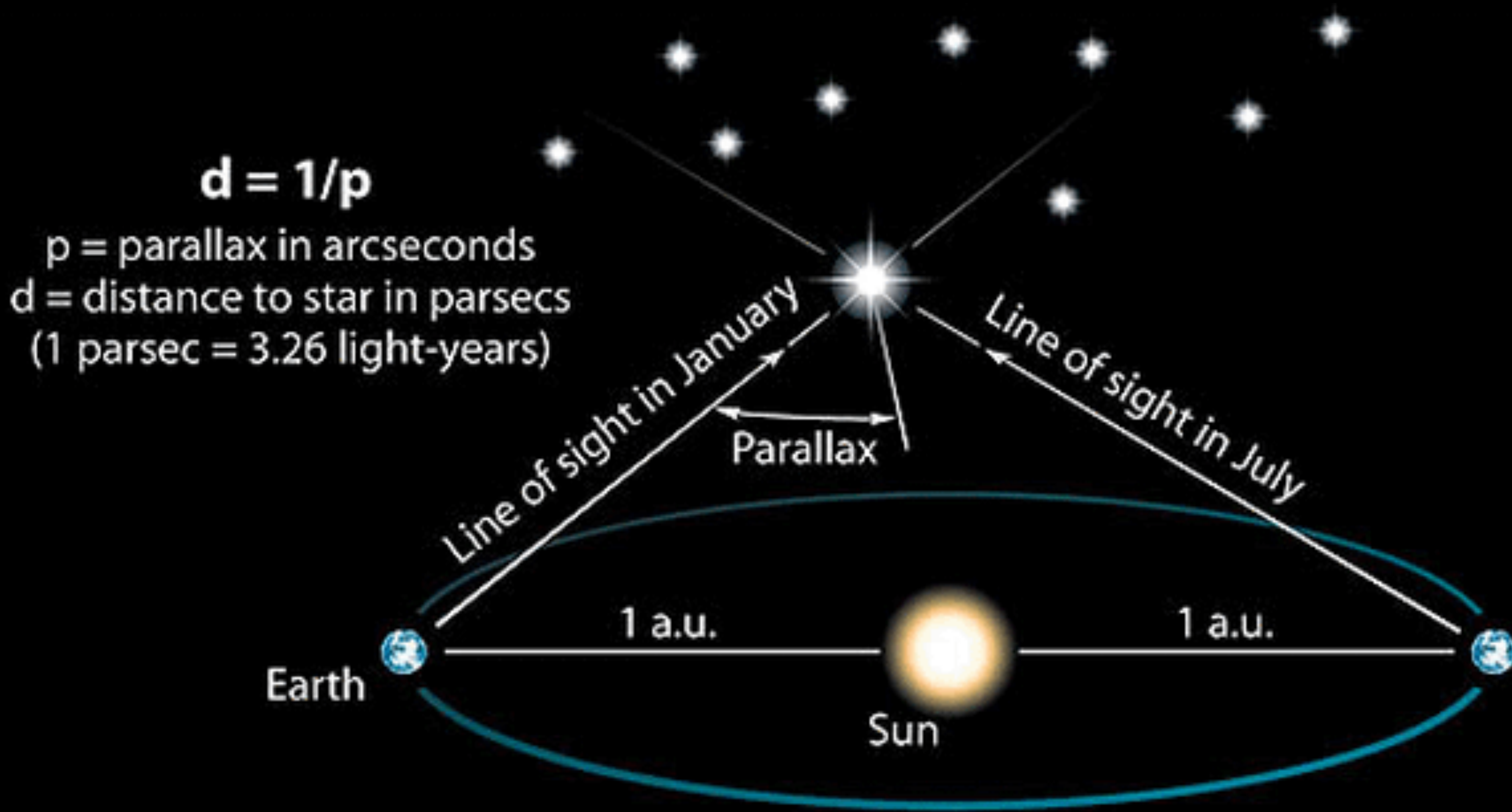
So, how can we measure the distance to stars?

We want to use the largest distance we can for the short side of the big triangle

What is the largest distance we can get between the two telescopes (if both of them have to be on Earth – no spacecraft).

The largest distance is not obtained by placing the two telescopes at opposite ends of the Earth

Instead, we can use one telescope and just let the earth move



A.U. = Astronomical Unit = distance from Earth to Sun

Distances to stars are often specified in terms of parallax angles given in seconds of arc:

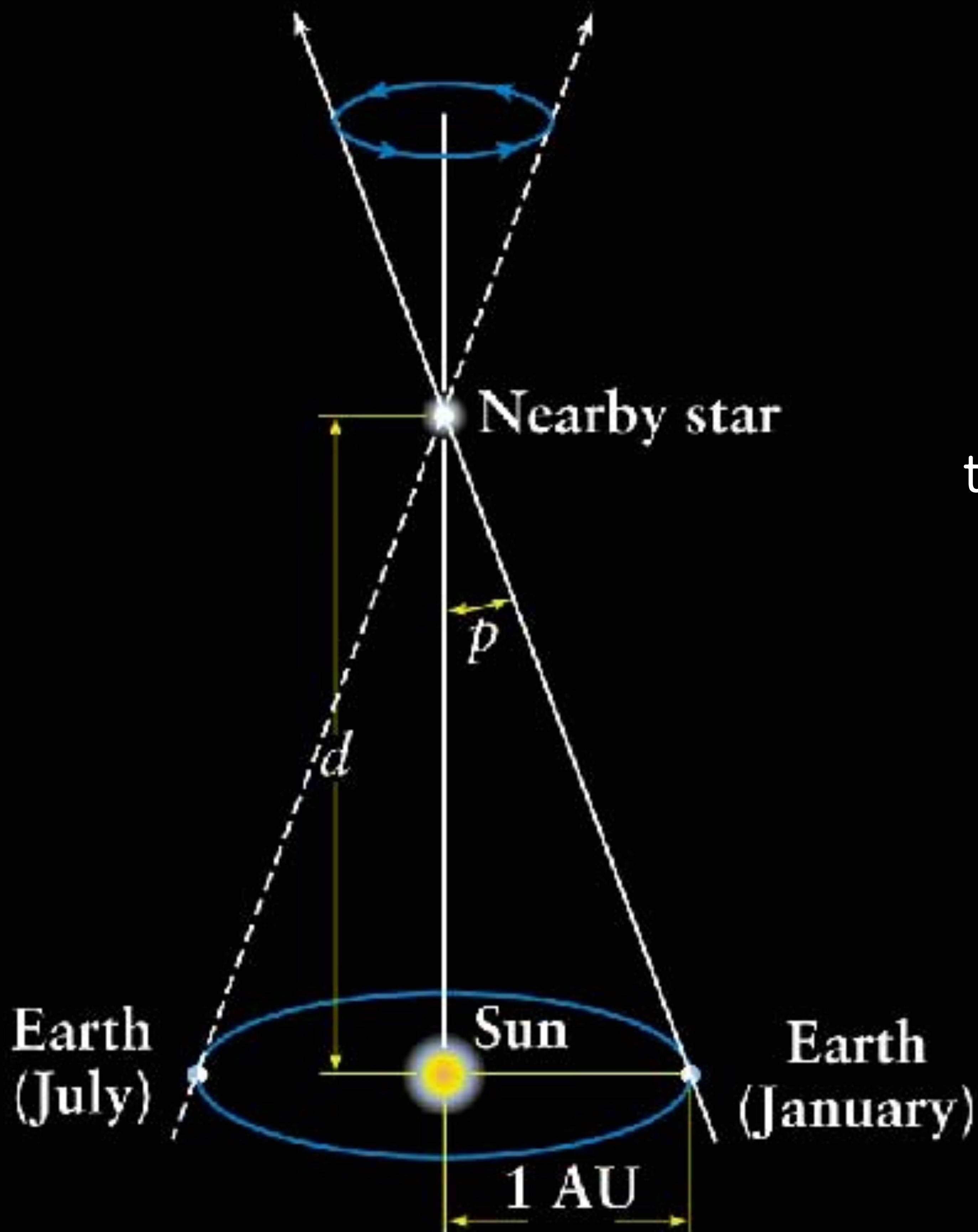
1 second (1") is 1/60 of a minute (1') of arc

which is 1/60 of a degree

so 1" = 1/3600 of a degree.

The distance is then specified in parsecs (meaning PARallax angle inSEConds of arc) where the parsec is defined as 1/p with p in seconds

Stellar Parallax

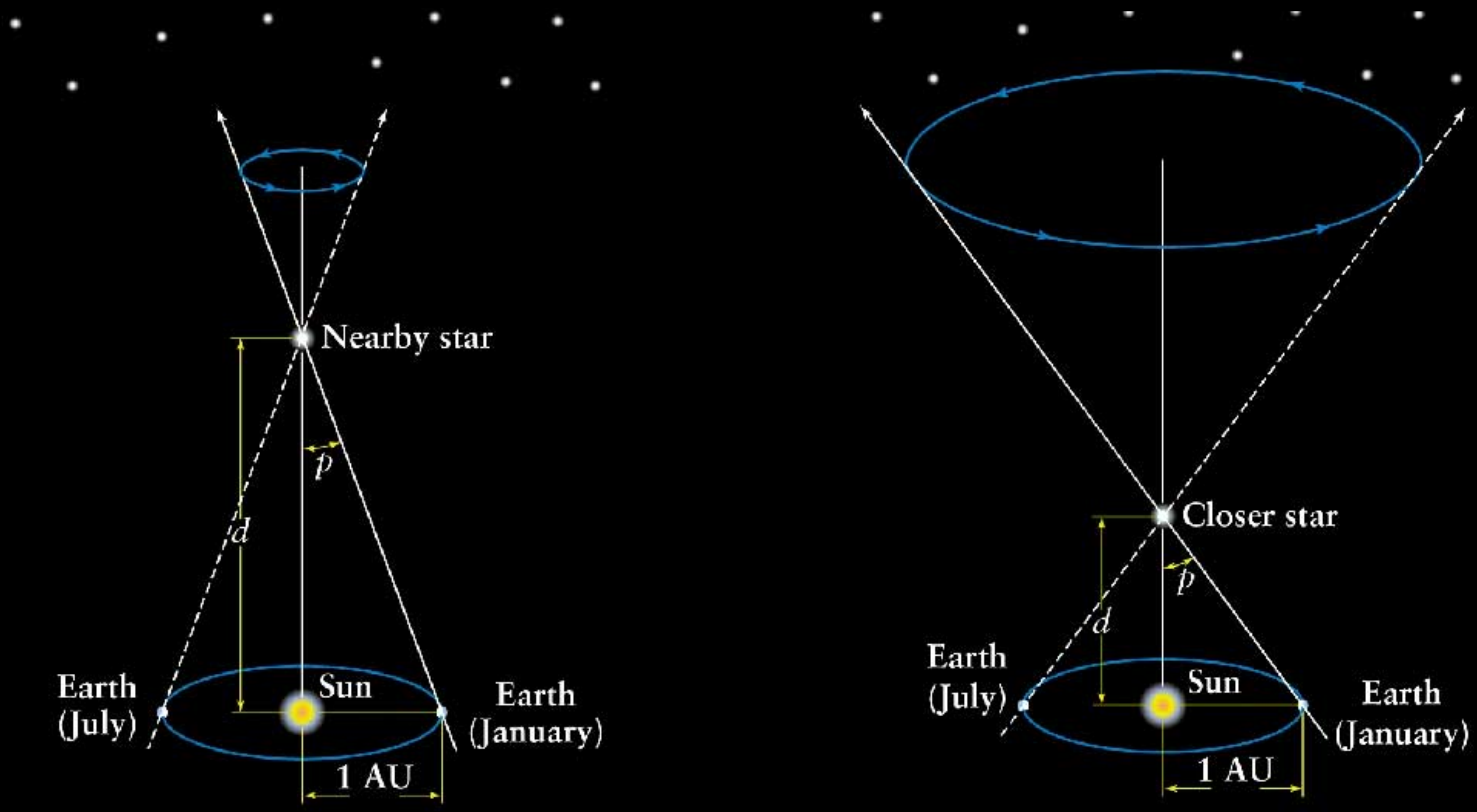


As Earth moves from one side of the Sun to the other, a nearby star will seem to change its position relative to the distant background stars

$$d = 1/p$$

d ☛ distance to nearby star in parsecs

p ☛ parallax angle of that star in arcseconds



Closer star – larger parallax

Example ☛ Using parallax to determine distance

The bright star Vega has a measured parallax of 0.1 arsec $(\mathrm{p} = 0.1")$

This means that Vega appears to move from $+\ 0.1$ to $-\ 0.1$

with respect to distant stars over a year of observation

$$D(\mathrm{pc}) \;=\; 1/\mathrm{p}(") = 1/0.1 = 10\ \mathrm{pc}$$

Vega is $10\ \mathrm{pc}\ (\mathrm{parsec})$ from Earth

Remember ☛ $1\ \mathrm{pc} = 3.26\ \mathrm{light\ years}$

Powers of ten are shorthand for writing very large numbers

$10^0 = 1$	One
$10^1 = 10$	Ten (deca)
$10^2 = 100$	Hundred (centa)
$10^3 = 1,000$	Thousand (kilo)
$10^6 = 1,000,000$	Million (mega)
$10^9 = 1,000,000,000$	Billion (giga)
$10^{12} = 1,000,000,000,000$	Trillion (tera)
$10^{15} = \ldots$	Quadrillion (peta)
$10^{54} = \ldots$	Septendecillion

Powers of ten are shorthand for writing very large numbers

$10^{0} = 1$	One
$10^{-1} = 0.1$	One tenth (deci)
$10^{-2} = 0.01$	One hundredth (centi)
$10^{-3} = 0.001$	One thousandth (milli)
$10^{-6} = 0.000{,}001$	One millionth (micro)
$10^{-9} = 0.000{,}000{,}001$	One billionth (nano)
$10^{-12} = 0.000{,}000{,}000{,}001$	One trillionth (pico)
$10^{-15} = \ldots$	One quadrillionth (femto)
$10^{-54} = \ldots$	One septendecillionth

Back to the solar system

Volume of solar system taken up by **stuff**

= (volume of Sun)/(volume of solar system)

= (radius of Sun)^3/(radius of Pluto's orbit)^3

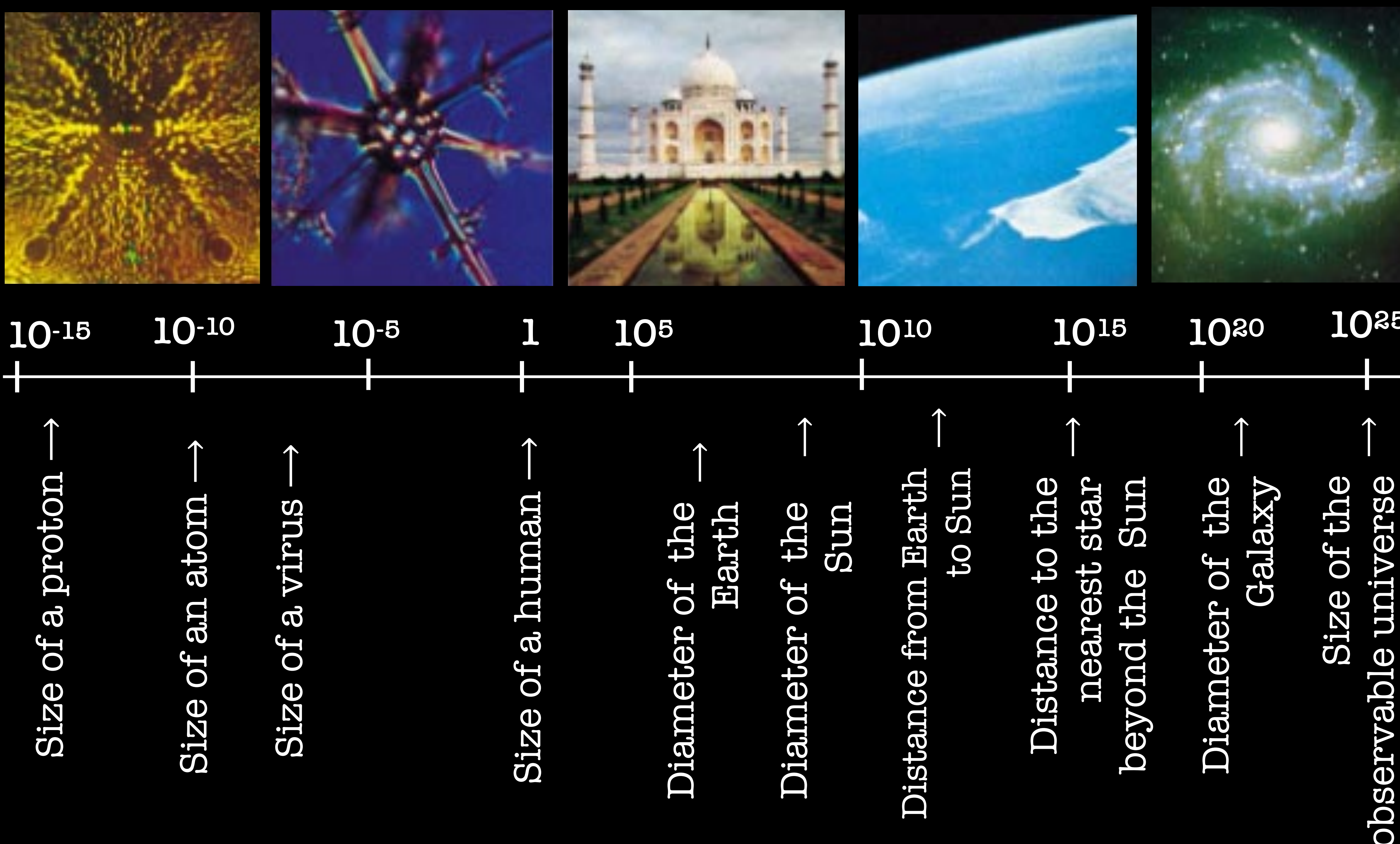
= $(7\times10^8)^3/(6\times10^{12})^3$

= $(7^3\times10^{8\times3})/(6^3\times10^{12\times3})$

= $(7^3/6^3)\times(10^{8\times3-12\times3})$

= 1.6×10^{-12} = about a millionth of a millionth

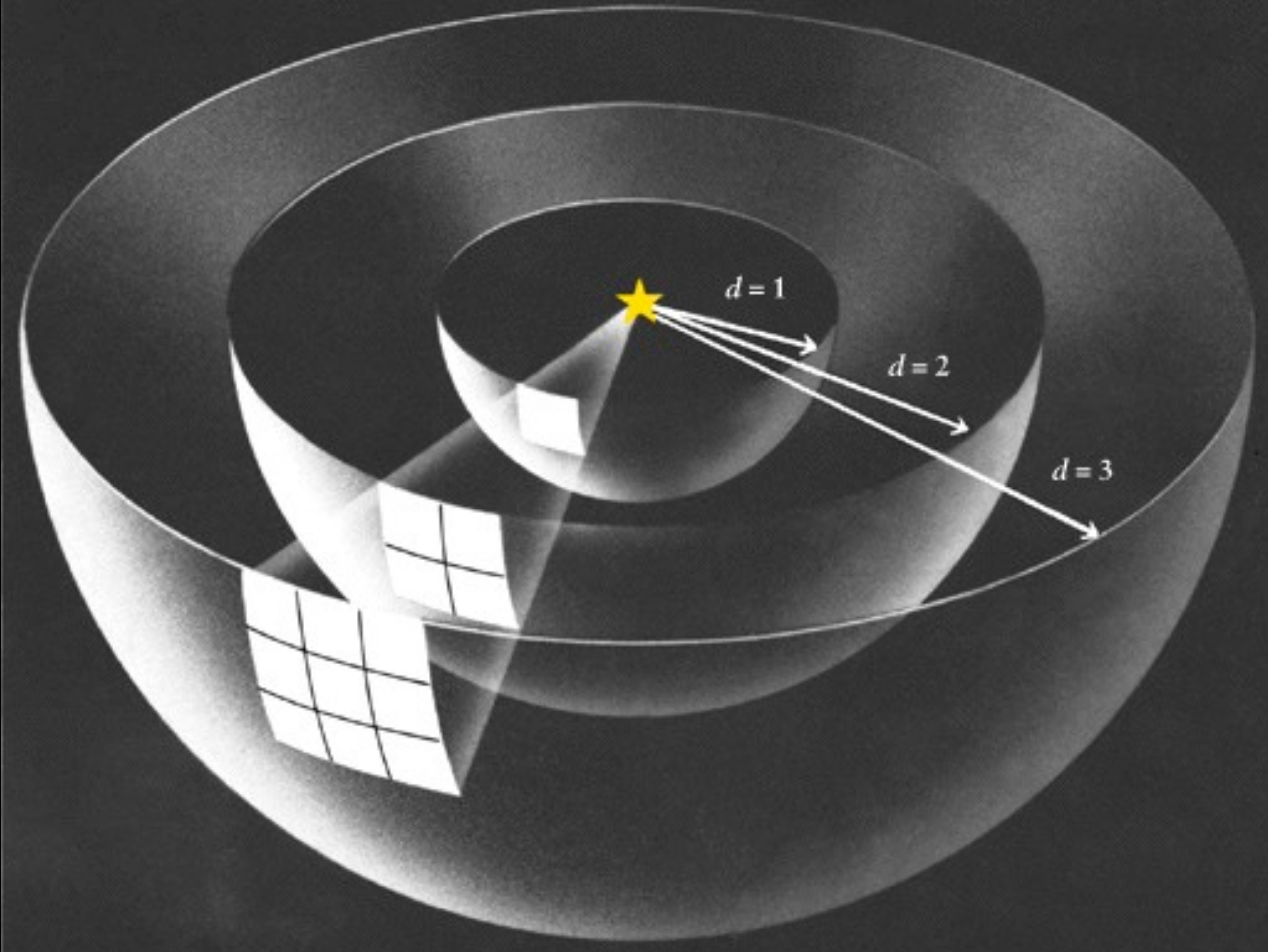
Sizes are in meters



Flux and luminosity

✧ A star produces light ☛ the total amount of energy that a star puts out as light each second is called its **Luminosity**

✧ If we have a light detector (eye, camera, telescope) we can measure the light produced by the star ☛ the total amount of energy intercepted by the detector divided by the area of the detector is called the **Flux**


d = 1
d = 2
d = 3

Flux and luminosity

- To find the luminosity, we take a shell which completely encloses the star and measure all the light passing through the shell

- To find the flux, we take our detector at some particular distance from the star and measure the light passing only through the detector

How bright a star looks to us is determined by its flux, not its luminosity

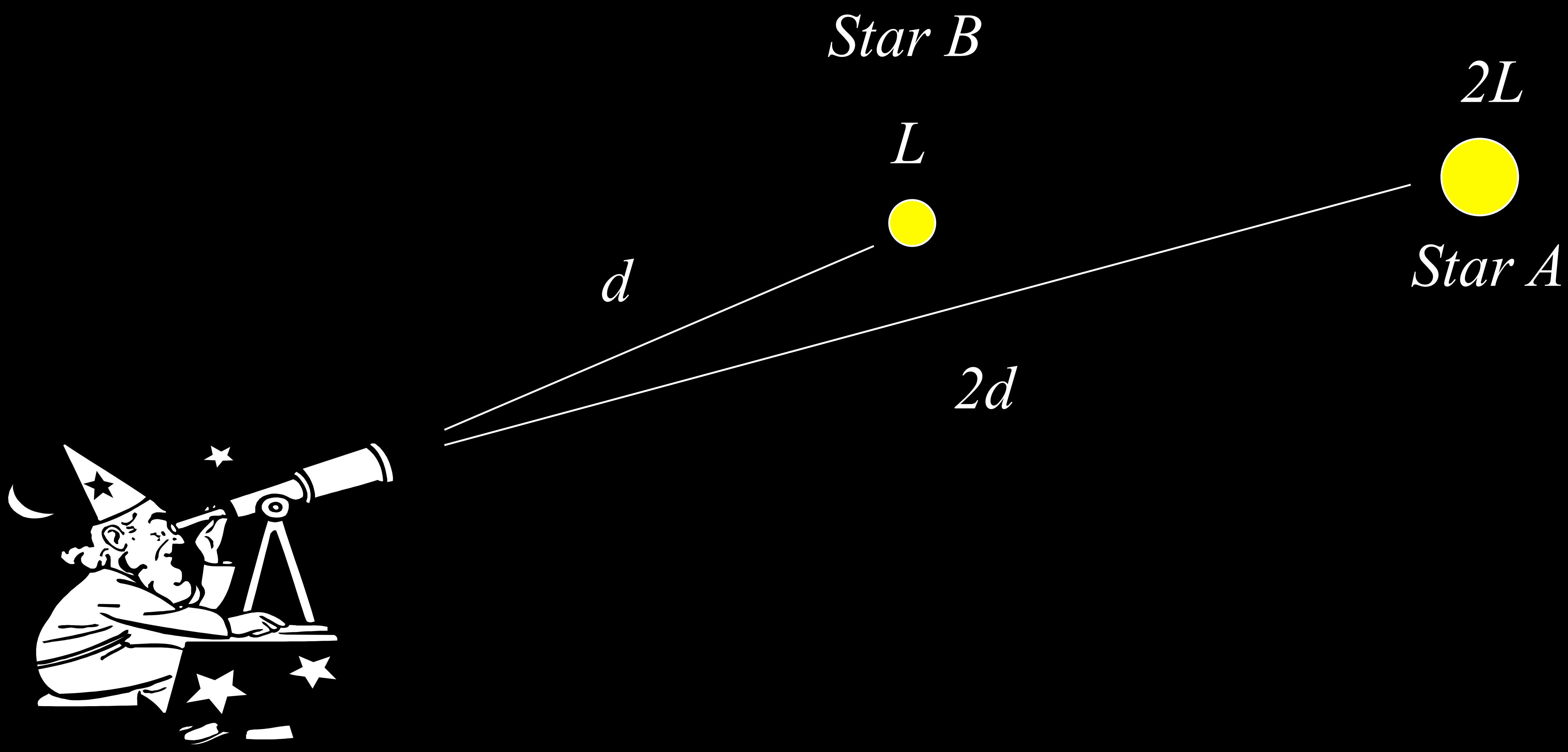
Brightness = Flux

Flux and luminosity

- ✧ Flux decreases as we get farther from the star – like $1/\text{distance}^2$
- ✧ Mathematically, if we have two stars A and B

$$\frac{\text{Flux}_\text{A}}{\text{Flux}_\text{B}} = \frac{\text{Luminosity}_\text{A}}{\text{Luminosity}_\text{B}} \left(\frac{\text{Distance}_\text{B}}{\text{Distance}_\text{A}}\right)^2$$

Distance - Luminosity relation



Which star appears brighter to the observer?

Flux and luminosity

$$\frac{\text{Luminosity}_\text{A}}{\text{Luminosity}_\text{B}} = 2 \qquad \frac{\text{Distance}_\text{B}}{\text{Distance}_\text{A}} = \frac{1}{2}$$

$$\frac{\text{Flux}_\text{A}}{\text{Flux}_\text{B}} = \frac{\text{Luminosity}_\text{A}}{\text{Luminosity}_\text{B}} \left(\frac{\text{Distance}_\text{B}}{\text{Distance}_\text{A}}\right)^2$$

$$= 2\left(\frac{1}{2}\right)^2 = 2\left(\frac{1}{4}\right) = \frac{1}{2}$$

Brightness of stars

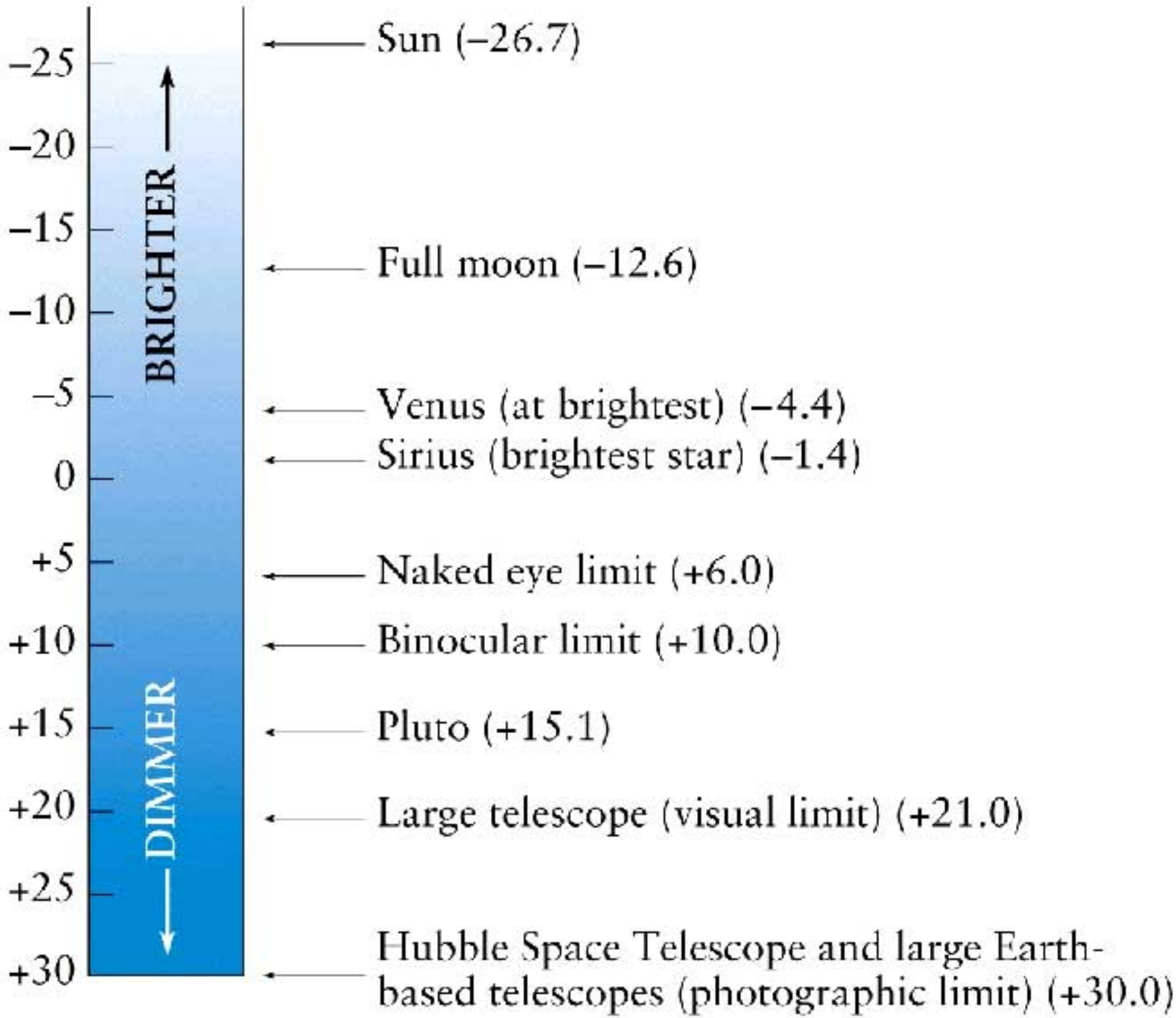
- Ptolemy (150 A.D.) grouped stars into 6 magnitude groups according to how bright they looked to his eye

- Herschel (1800s) first measured the brightness of stars quantitatively and matched his measurements onto Ptolemys magnitude groups and assigned a number for the magnitude of each star

Brightness of stars

- In Herschels system, if a star is 1/100 as bright as another then the dimmer star has a magnitude 5 higher than the brighter one

- Note that dimmer objects have higher magnitudes



Sun (–26.7)
Full moon (–12.6)
Venus (at brightest) (–4.4)
Sirius (brightest star) (–1.4)
Naked eye limit (+6.0)
Binocular limit (+10.0)
Pluto (+15.1)
Large telescope (visual limit) (+21.0)
Hubble Space Telescope and large Earth-based telescopes (photographic limit) (+30.0)
BRIGHTER
DIMMER
–25
–20
–15
–10
–5
0
+5
+10
+15
+20
+25
+30

Absolute magnitude

- ☑ The magnitude of a star gives it brightness or flux when observed from Earth

- ☑ To talk about the properties of star, independent of how far they happen to be from Earth, we use absolute magnitude

- ☑ Absolute magnitude is the magnitude that a star would have viewed from a distance of 10 parsecs

- ☑ Absolute magnitude is directly related to the luminosity of the star

If the DIAMETER of a circular sunspot is doubled, how many times as great would be its area?

A. 2

B. 6

C. 4

D. 8

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The determination of stellar parallax is important because it allows the determination of:

A. mass

B. acceleration

C. distance

D. velocity

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QUERY 14

Hipparcos (in full High Precision Parallax Collecting Satellite) was an Earth-orbiting satellite launched by the European Space Agency in 1989 that operated until 1993

The satellite measured the distances to more than 100,000 stars by direct triangulation using observations of parallax from either side of Earth's orbit around the Sun

If Hipparcos measured the parallax of a star to be 0.01 arc-seconds. What is the distance to the star?

QUERY 14

The apparent shift position of a star when it is view from 2 different locations is known as parallax.

It is used to measure the distances to nearby stars

The distance to the star in pc is ☛ $$D = \frac{1}{p}$$

with the parallax angle measured in arc sec

$$D = 100 \text{ pc}$$

QUERY 15

Why can we not make accurate measurements of parallax beyond certain distance?

QUERY 15

Why can we not make accurate measurements of parallax beyond certain distance?

The relation in $D = \dfrac{1}{p}$ can be inverted to obtain

$$p = \frac{1}{D}$$

As the distance of the star from Earth increases the parallax angle becomes very small

It becomes difficult to measure such small angles and thus calculation of distances becomes very challenging

Beyond a certain distance accurate measurement of distances cannot be done using the parallax method

Parallax angles smaller than 0.01 arcsecond are very difficult to measure..