In Galaxies and the Universe, the Dark Side Prevails

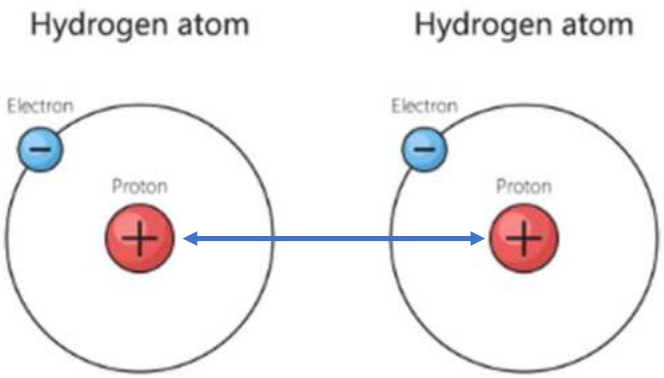
Patrick Hayes May 27, 2026 Museum Star Party

The Dark Side of the Universe consists of…

- Black Holes
- Dark Matter
- Dark Energy

Stellar Black Holes (Formed by Stars)

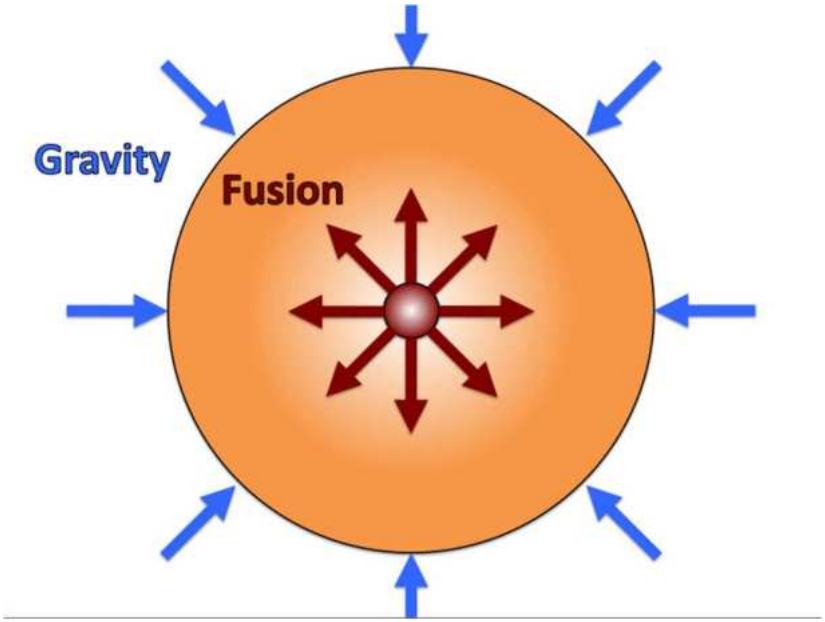
- Let's talk about what stellar black holes are and how they are formed.
- A star is powered by the "fusion reaction". During a star's infancy, two hydrogen atoms fuse together under intense pressure and heat, to create a heavier atom called helium (2 protons in nucleus). This process releases a lot of energy.



Need high temps/pressures to overcome proton repulsion
"Coulomb force"

What keeps a star stable

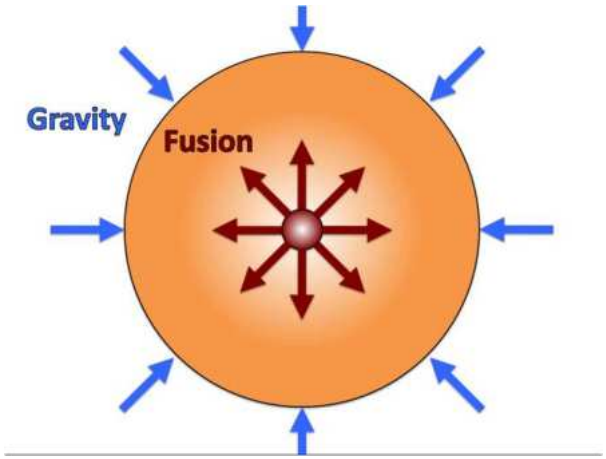
- If a star has sufficient fuel for fusion, e.g. hydrogen, helium, higher mass atoms, then “hydrostatic equilibrium” is maintained (star stays roughly the same size.



What happens with very massive stars

- Massive stars (at least 20 – 25 times the mass of our sun) eventually run out of fuel to get energy from fusion. Gravity starts to win and compresses the star.
- Last fusion reaction is Silicon (14 protons) into Iron.
- Iron is too stable to release energy on fusing so

no available fuel for the star

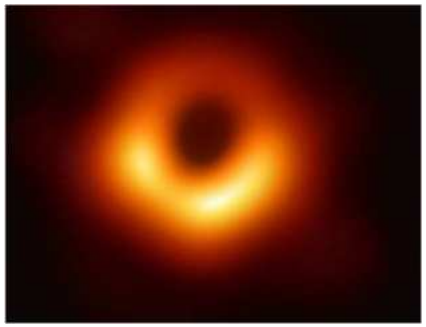


The Future Death of a Massive Star

- The shrinking iron core exerts tremendous gravity
- The core collapses from several hundred kms to a few km, in a fraction of a second.
- The outer layers get drawn in hard/fast towards the core, heating up and compressing.
- A massive shock wave emits from the core collapse, as well as a huge number of high energy neutrinos. These neutrinos carry away 99% of the star's energy (more than the energy produced by our sun in its **entire lifetime**)
- The compressed/dense outer layers absorb the shock wave and neutrinos, which causes them to explode in a massive Supernova explosion. During this explosion, most of the heavier elements are created

Stellar Black Hole

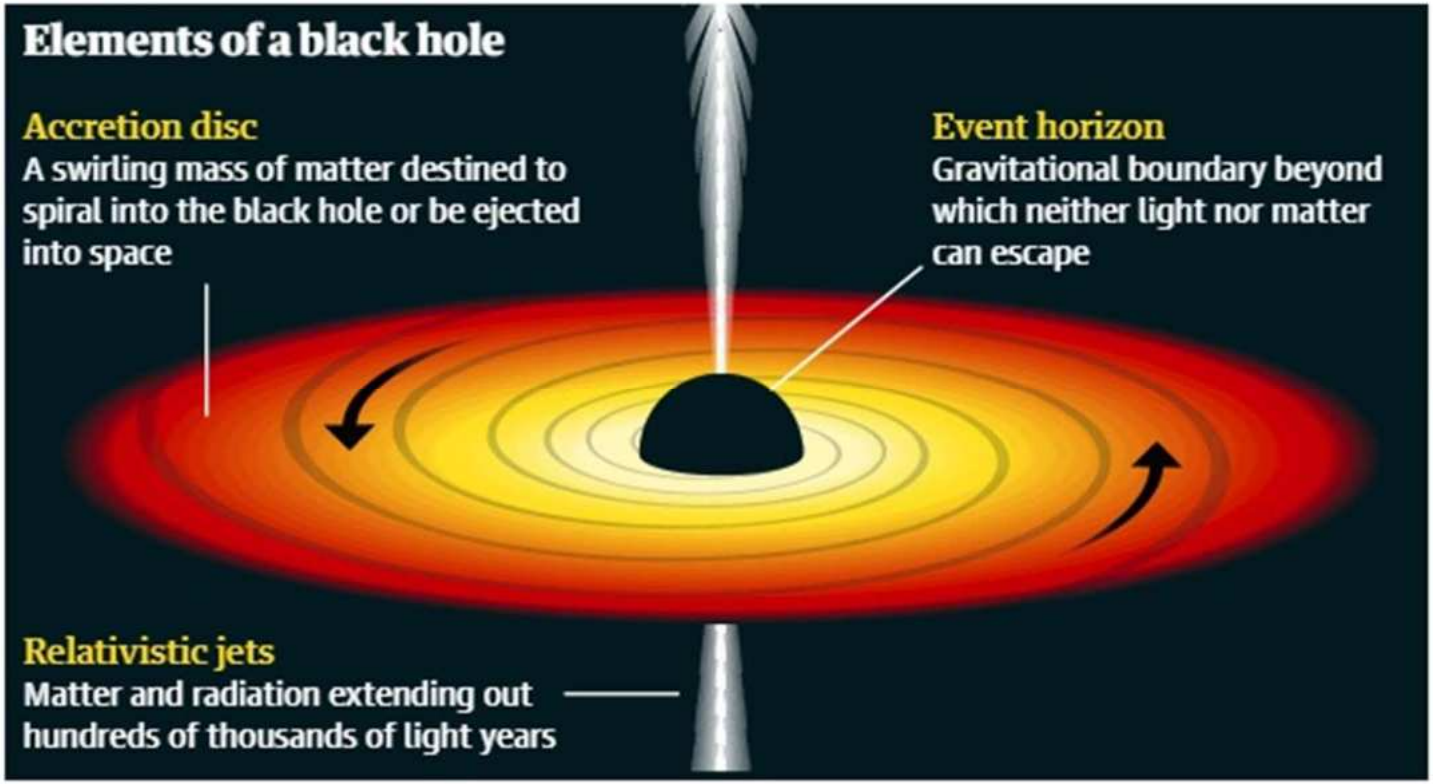
- Further core contraction continues until the star's core is reduced to a very small size (a black hole, black because not even light can escape its gravity)



The first recorded image of a black hole

Taken by the Event Horizon Telescope Collaboration team

Structure of Black hole

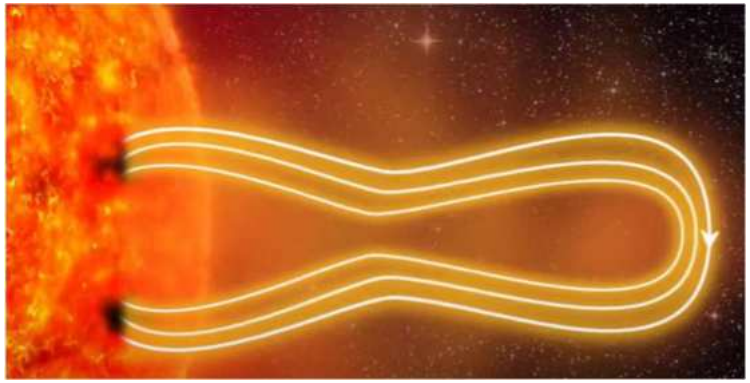


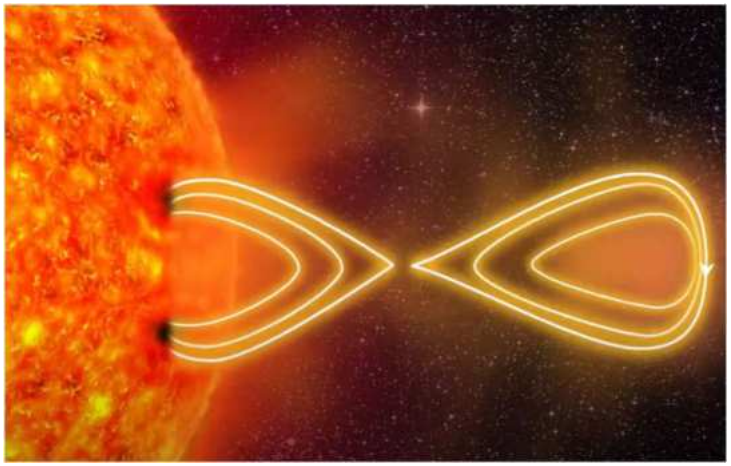
Black Holes

- The surface of the black hole is called the event horizon. Once something crosses this layer, gravity is so intense that not even light can escape.
- Escape velocity from earth is 40,270 Km/hr
- Escape velocity from a black hole is > 1,079,000,000 km/hr (speed of light)
- The black hole distorts space and time so nearby objects do not take a linear path to the accretion disk but more of a spiral
- Accretion disk is very hot (millions of degrees). Matter is in plasma form (electrons stripped away from atoms) and this causes electric current/magnetic fields.
- Magnetic fields can get twisted and thus matter/radiation can get ejected from accretion disk in high energy “jets” which can travel hundreds of thousands of light years

Our Sun's CME – Coronal Mass Ejection

- Magnetic field loop is stretched out until snaps, sending out several billions tons of plasma blob towards earth

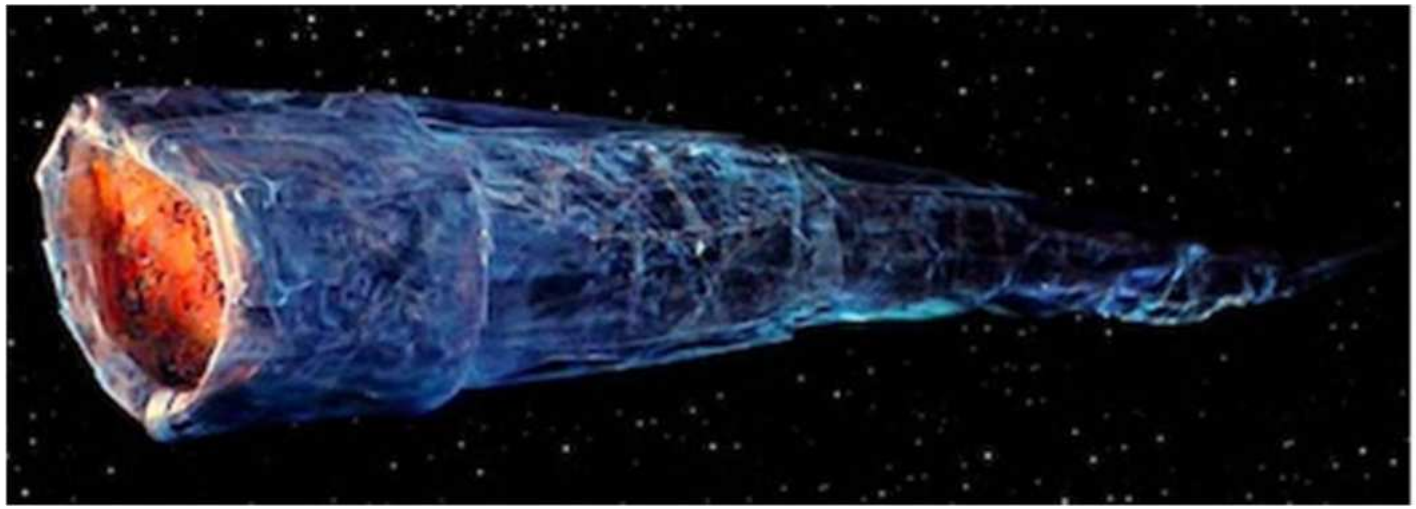




It takes about 18 hours to reach earth

Black Holes: Galaxy Architect/Conductor

- Black holes are not giant vacuum cleaners. They have high gravity but matter won't be sucked into them unless you get close to them.
- Not like the doomsday planet eater in the Original Star Trek series



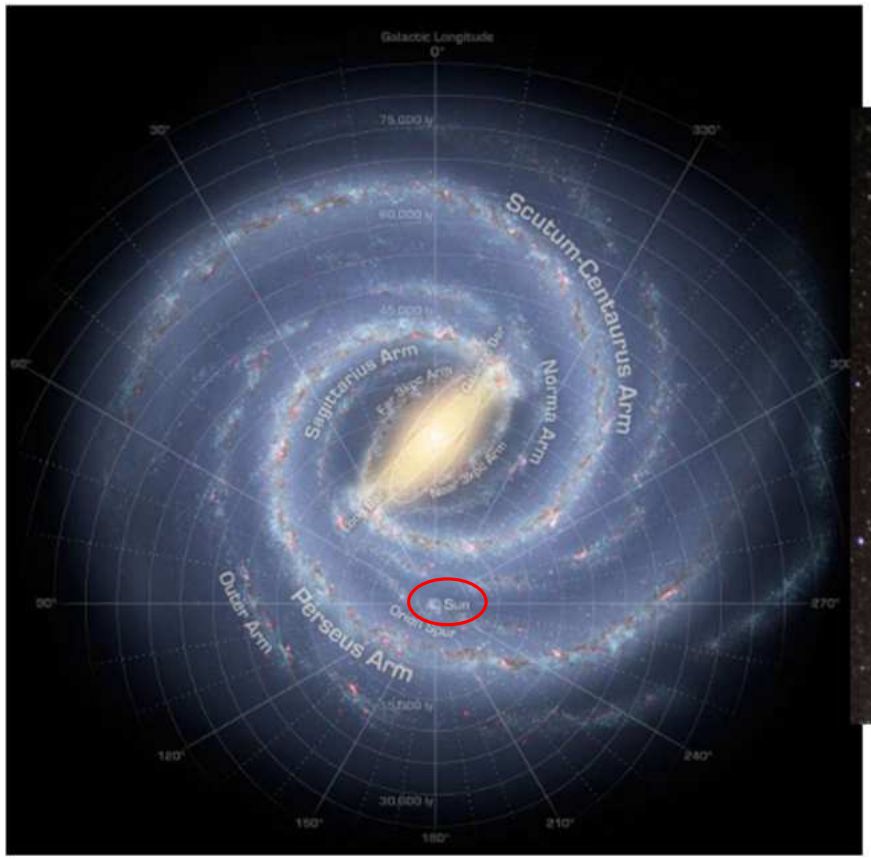
Black Holes: Galaxy Architect/Conductor

- Super Massive black holes at the centre of a galaxy can have profound effects on their galaxy
- Nearby: planets, stars and dust/gas clouds are pulled into them or disrupted (so stars can’t form)
- At the outer part of the galaxy, jets of radiation, matter, dust/gas and energy can help star formation

Our Galaxy

- A galaxy is defined as a system of millions or billions of stars, together with gas and dust, held together by gravitational attraction.
- Our galaxy is the Milky Way (only galaxy named after a chocolate bar)
- 100,00 – 200,00 light years in diameter, 100 – 400 billion stars
- Our solar system is 27,000 light years from the centre
- At its core is a supermassive black hole (Sagittarius A) which is approximately the size of 4 million solar masses. How was such a huge black hole formed? Stellar black holes usually form from a giant star which is typically no more 20 – 25 solar masses.
- It is thought that many, many black holes have combined and also the supermassive black hole may have sucked in large gas/dust clouds which fed their size.
- Various galaxies have been studied and it appears that almost every galaxy has a supermassive black hole at its centre.

Images of the Milky Way (looking down and what we see from earth)

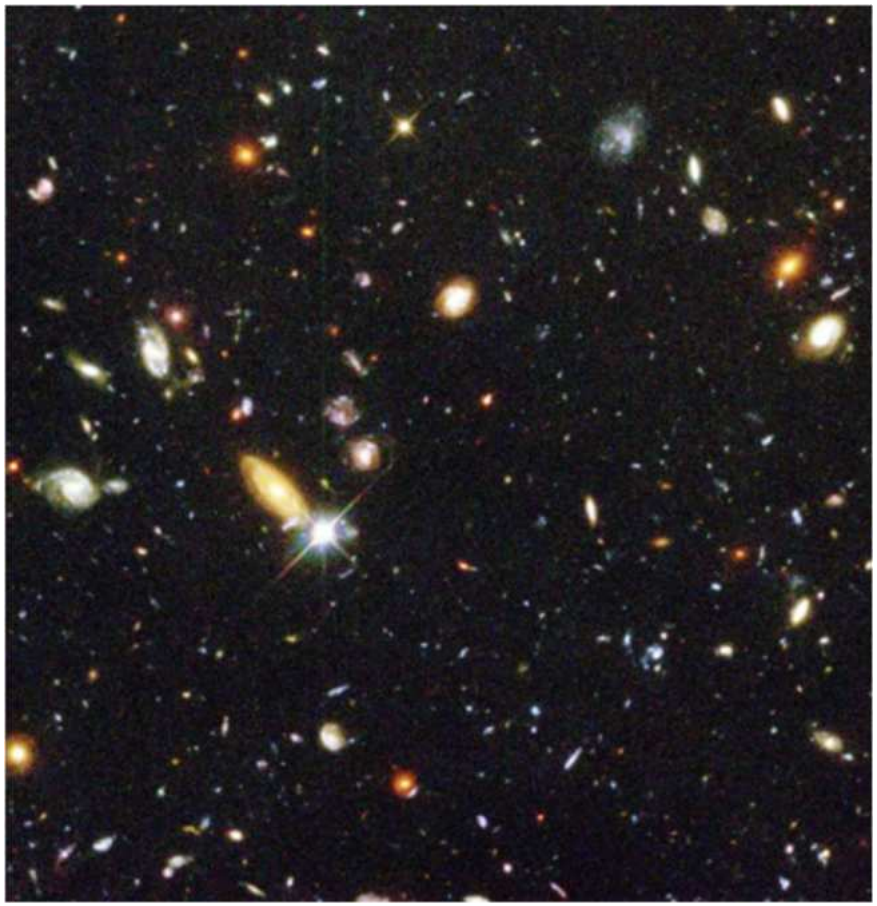


Edwin Hubble Settled the Debate re Andromeda

- In the early 1900's, most astronomers thought our galaxy was the entire universe. By 1929 Hubble examined the Andromeda "blur". He spotted a cepheid star (a star that pulses light with predictable regularity) in Andromeda and was then able to determine how far away it was. It proved to be much farther than the known size of the Milky Way, so now it was settled that there were other galaxies in the universe.

Andromeda Galaxy

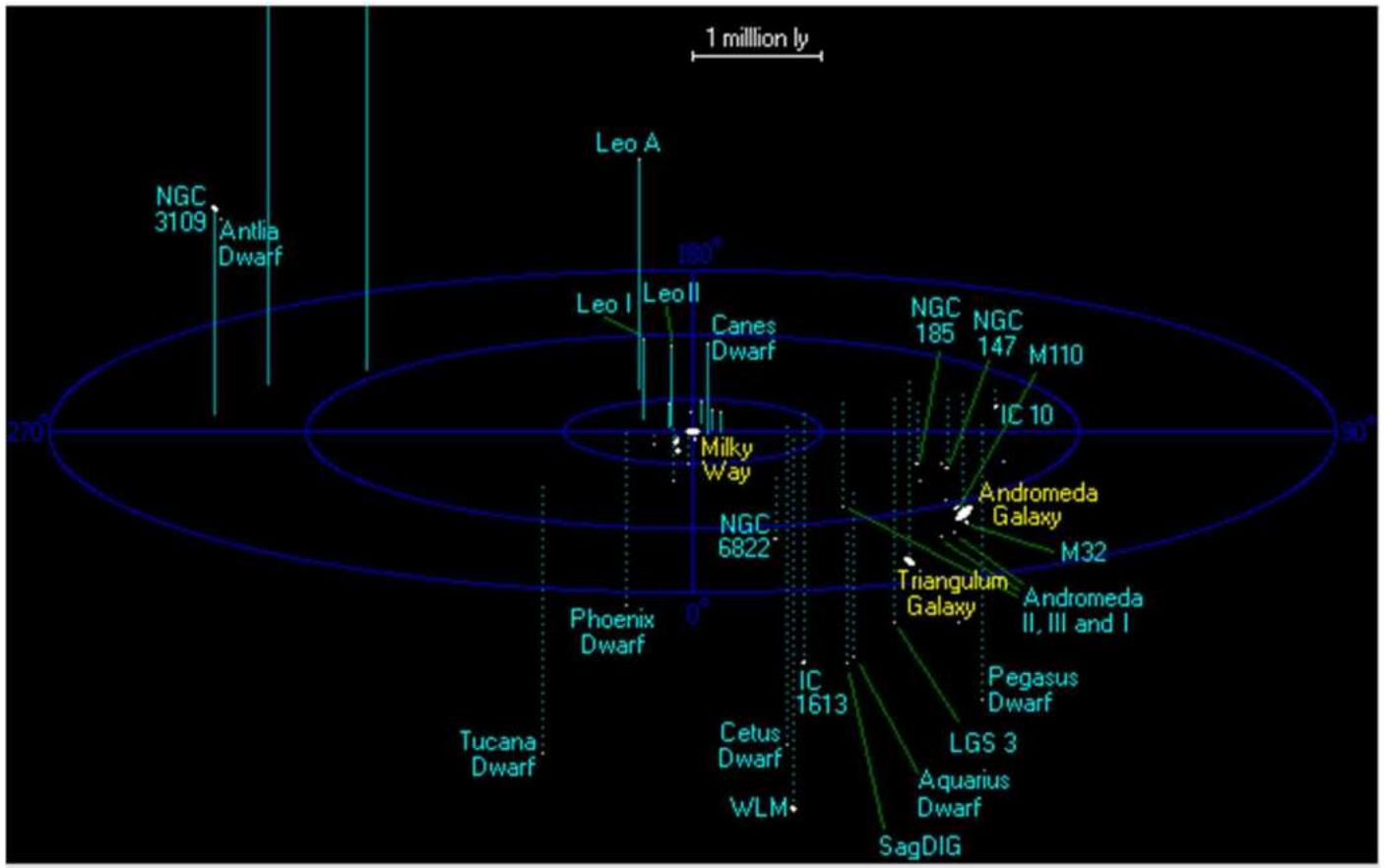
Hubble Telescope Deep Sky Image



Hubble telescope aimed at an "empty" area of space for 10 days, revealed around 3,000 galaxies

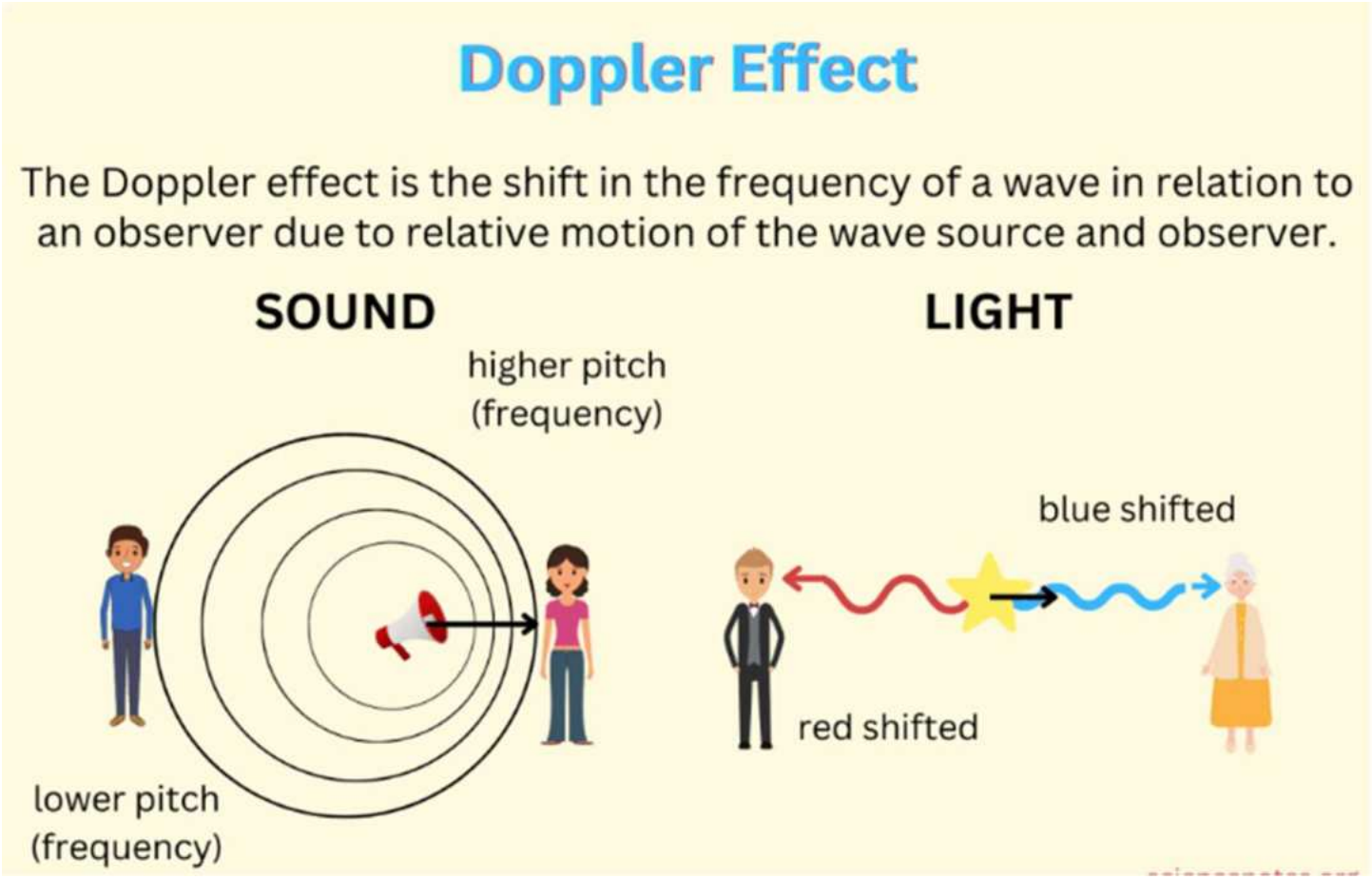
Field of view was no larger than what a full moon would occupy

The Local Group of Galaxies (50 – 54 galaxies)



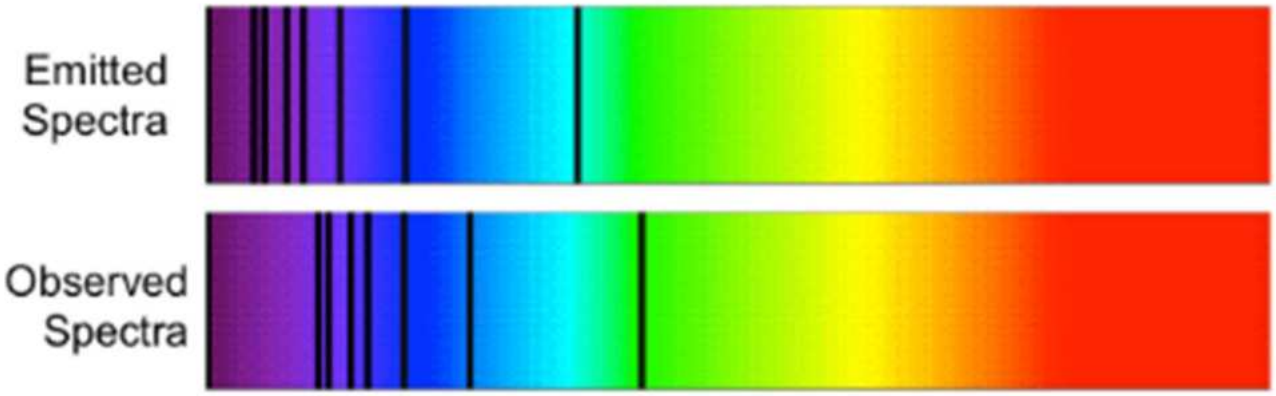
DARK ENERGY

Dark Energy - The Doppler Effect

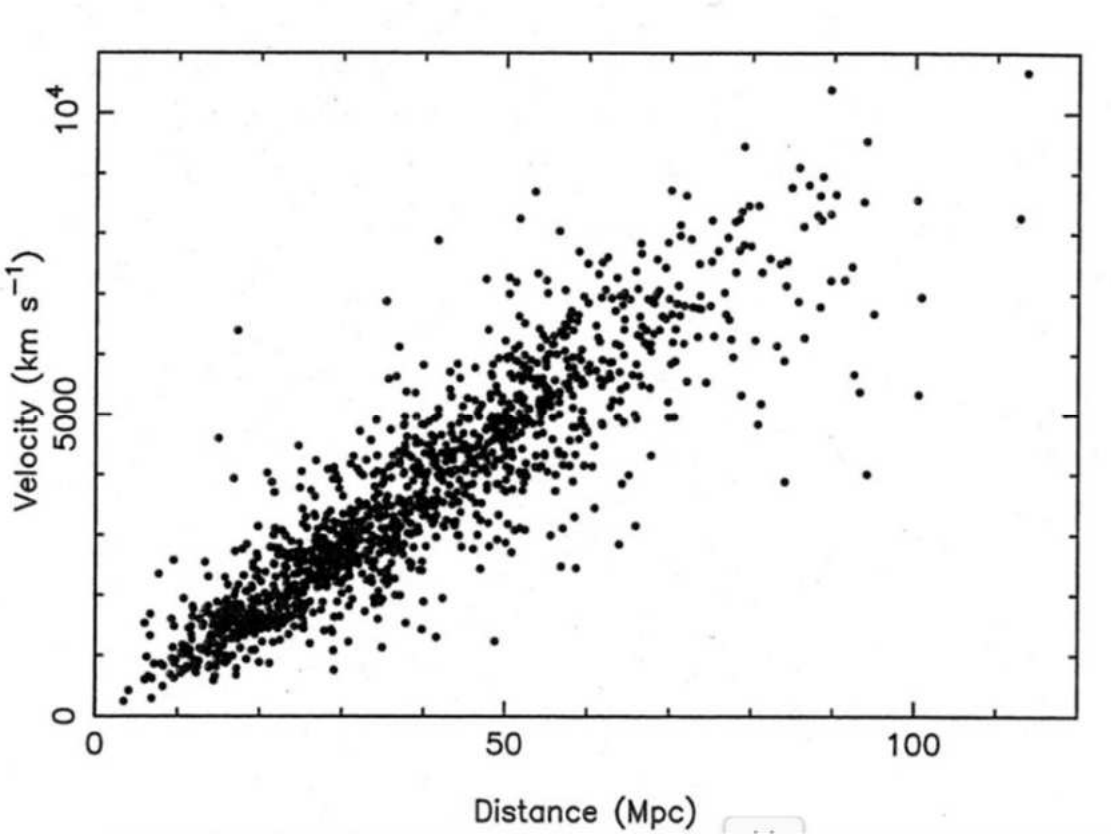


Hubble's Discovery About Stellar Movement

- Hubble was observing far away objects in 1929. His scope had a light splitting device which allowed him to measure the frequency of light from hydrogen and other atoms, across the full visible light spectrum
- He found that most stellar objects were "Red Shifted" (red is the lower frequency end) and thus moving away from us and that the farther away they were, the faster they were moving away



Hubble Graphed Distance and Velocity



The farther a galaxy/star is away from us, the faster it is moving away from us

What is Causing the Universe to Expand?

- Some unknown force/energy is causing the fabric of the universe to expand
- No current way to detect this energy so it is called **Dark Energy**

Some Exceptions

- The Andromeda galaxy is part of our local group of galaxies
- Gravitational interaction between Andromeda galaxy and the Milky Way are causing the two galaxies to move closer and closer together
- In about 4 - 5 billion years, the two galaxies will collide

DARK MATTER

Dark Matter

- In the 1930's armed with more powerful telescopes, astronomers started to take more accurate measurements of velocities within star clusters and galaxies.

Fritz Zwicky measurements of Coma Galaxy Cluster

Fritz Zwicky measurements of Coma Galaxy Cluster

- In 1933 Zwicky found that the galaxies of the Coma Cluster were moving too fast for the cluster to be bound together by the visible matter of its galaxies.
- Though the idea of dark matter would not be accepted for another fifty years, Zwicky wrote that the galaxies must be held together by "*dunkle Materie*" (dark matter).

Vera Rubin Measurements of galaxies

Vera Rubin Measurements of spiral galaxies

- In the early 1970s, she measured the velocity of the outer arms of spiral galaxies.
- She found that, counter to the laws of physics, the outer arms were travelling too fast (they should be flying off into space).
- She concluded that an invisible mass (dark matter) must form a controlling halo of gravity around the Milky Way
- Other astronomers studied other galaxies and found the same phenomenon
- A new and powerful telescope was named after her.

What is the Composition of Our Universe?

- Astronomers believe…
- 68 – 70% is dark energy
- 25 – 27% is dark matter
- 5% is normal matter (e.g. stars, planets, etc..)

Summary

- Stellar black holes are created when massive stars die. During their formation, the star creates all the heavier elements in the periodic table
- Supermassive black holes are found in almost all galaxies and they play a role in regulating star formation in their galaxy
- Dark energy is responsible for stretching the fabric of the universe such that galaxies are moving away from us and do so at a faster rate, the farther away they are. Exception is Andromeda galaxy and others in our local group of galaxies.
- Dark Matter helps to hold together galaxies by keeping outer layers from flying off into space
- Most of the universe is composed of dark energy and dark matter
- Conventional gravity and dark matter gravity are in a wrist wrestling contest versus dark energy