Observational Astronomy - Lecture 10
Galaxies - Structure, Types, and Evolution

Craig Lage

New York University - Department of Physics

craig.lage@nyu.edu

April 21, 2014

Galaxy Basics - 1

1. Galaxies are large groups of stars held together by gravity.
2. They vary widely in size:
   - Large galaxies like the Milky way have $10^{11} - 10^{12}$ stars.
   - Small dwarf galaxies may have only a few million stars.
3. They come in a wide variety of shapes, but there are two main types:
   - Spiral galaxies, which are blue in color because they are still forming stars.
   - Elliptical galaxies, which are no longer forming many stars and are therefore red in color.
   - The star formation rate of the universe peaked long ago and is declining.

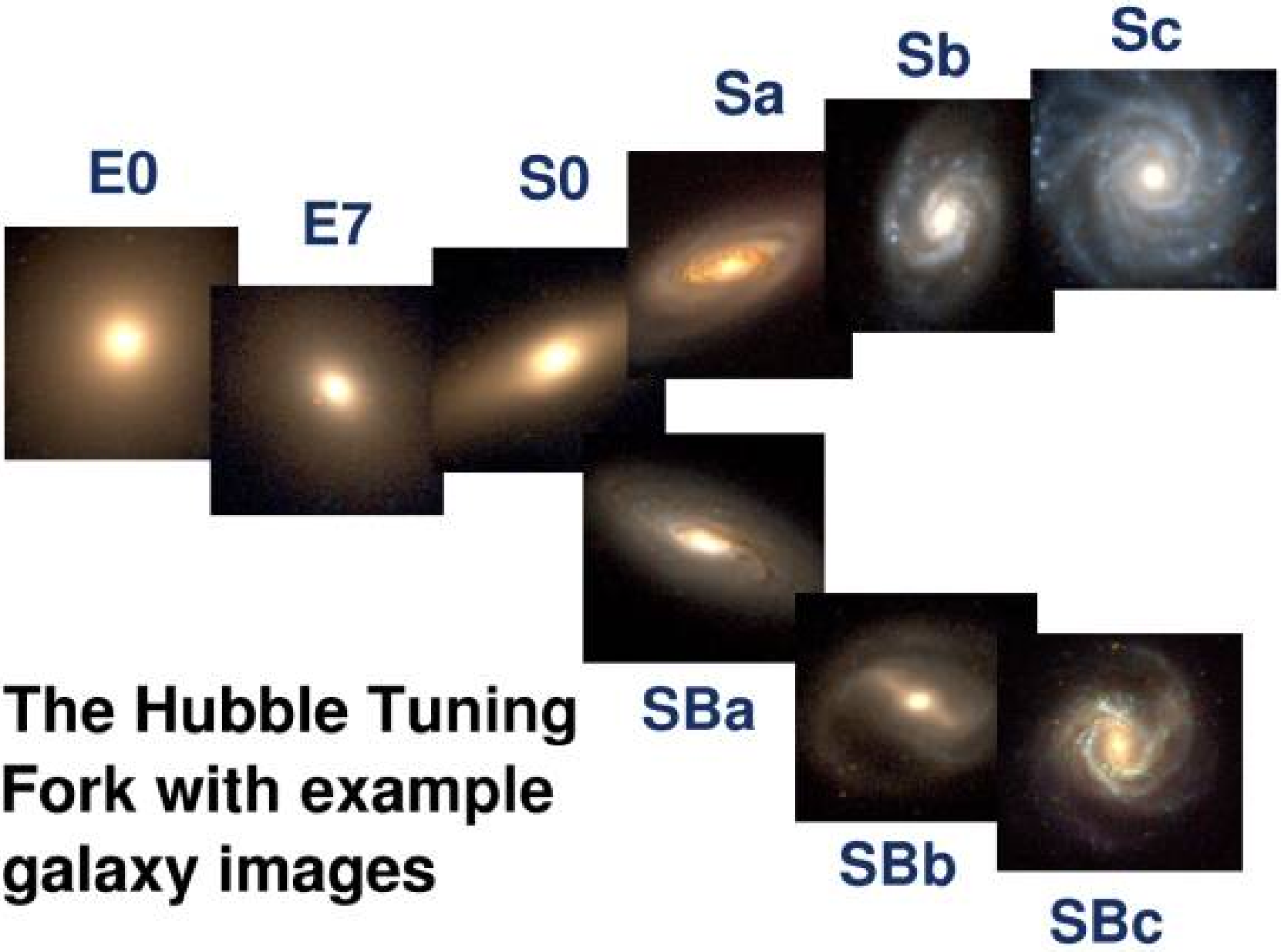
Galaxy Basics - 2

4. We believe that all galaxies have a Super-Massive Black Hole (SMBH) at their centers.

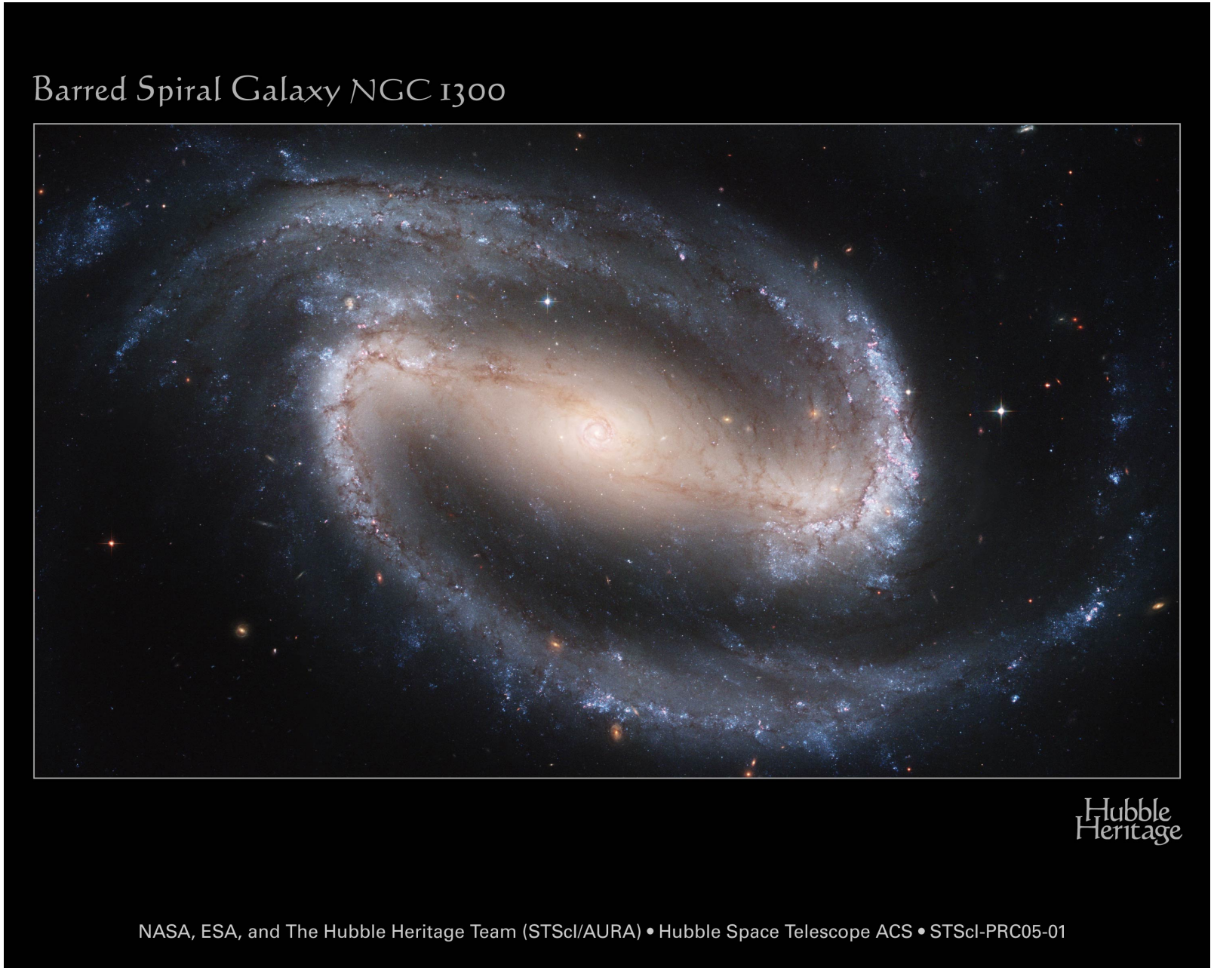
5. Galaxies grow through collisions and mergers.

6. Quasars (Quasi-stellar objects) are galaxies whose SMBH is accreting gas at a rapid rate:
   - Because the hot gas emits radiation, they are extremely luminous objects.
   - They were much more numerous in the early universe
   - There are no nearby quasars.

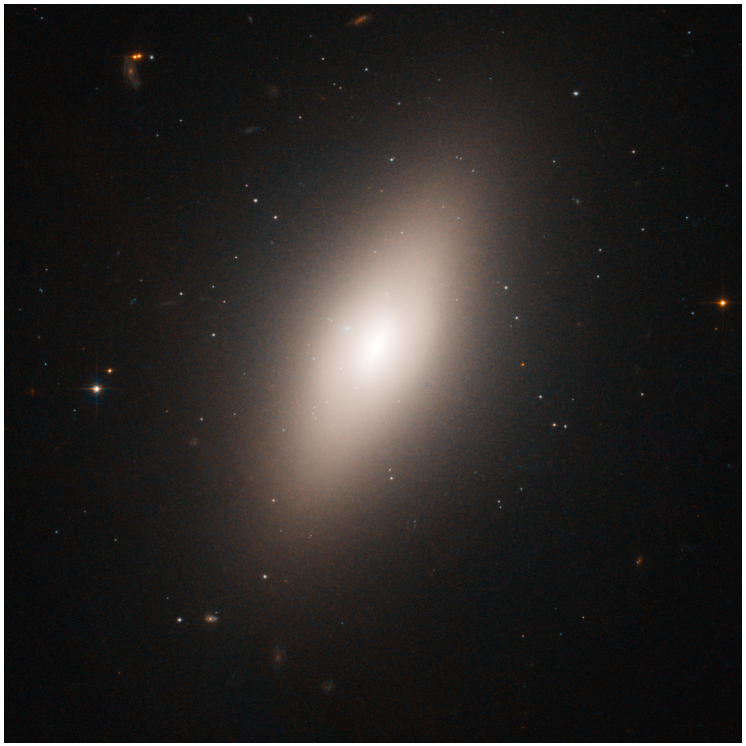
The Hubble Tuning Fork Diagram



NGC 1300: A Typical Barred Spiral



Red Ellipticals vs Blue Spirals

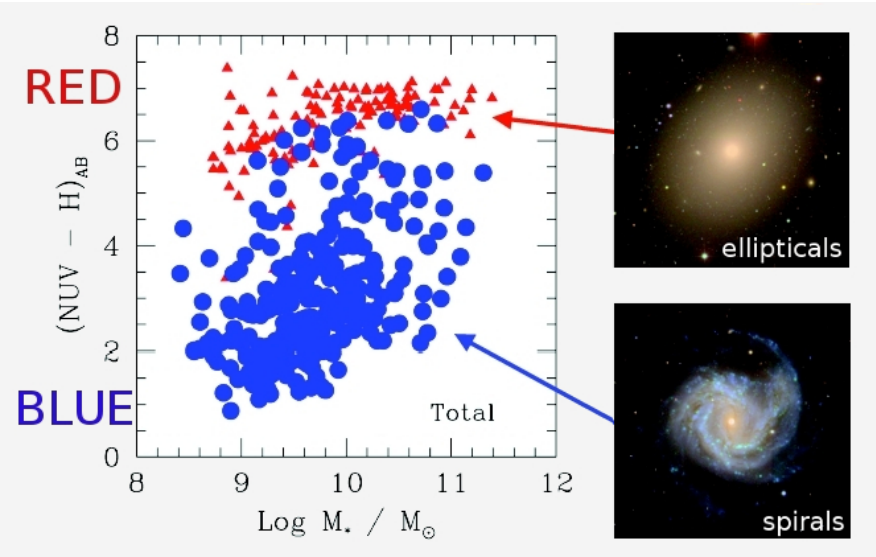


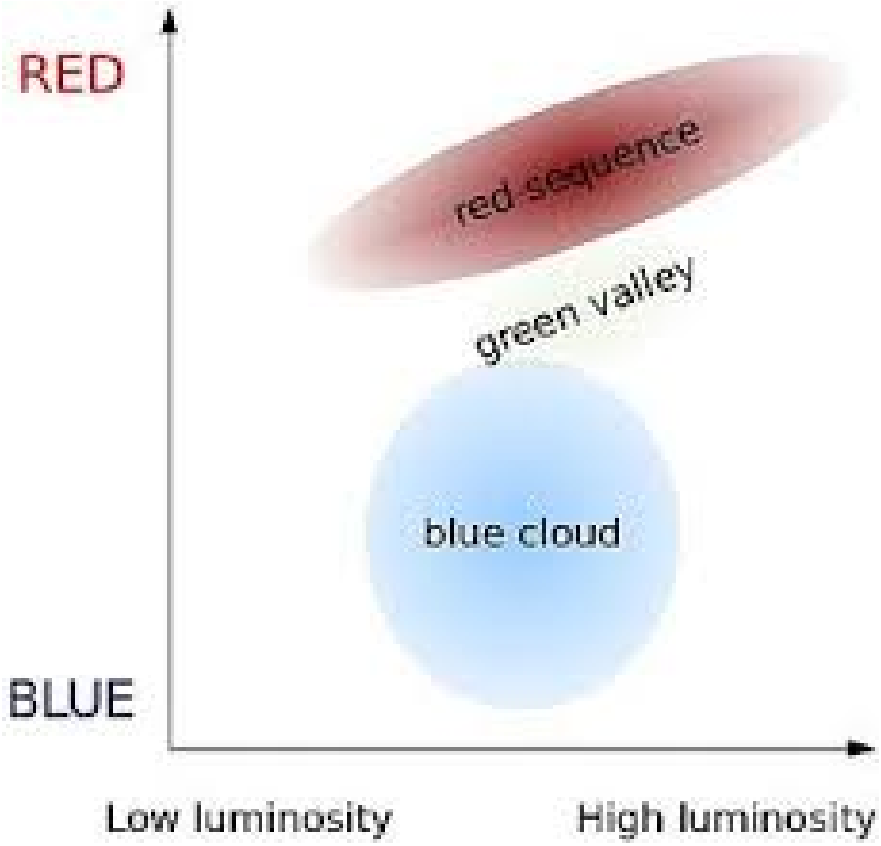
An Elliptical Galaxy.
"Red and Dead"

A spiral galaxy.
Still forming hot blue stars.

- Spiral galaxies like the Milky Way are still forming new stars.
- Elliptical galaxies have used up their gas and are no longer forming large numbers of stars.

The Red Sequence, the Blue Cloud, and the Green Valley





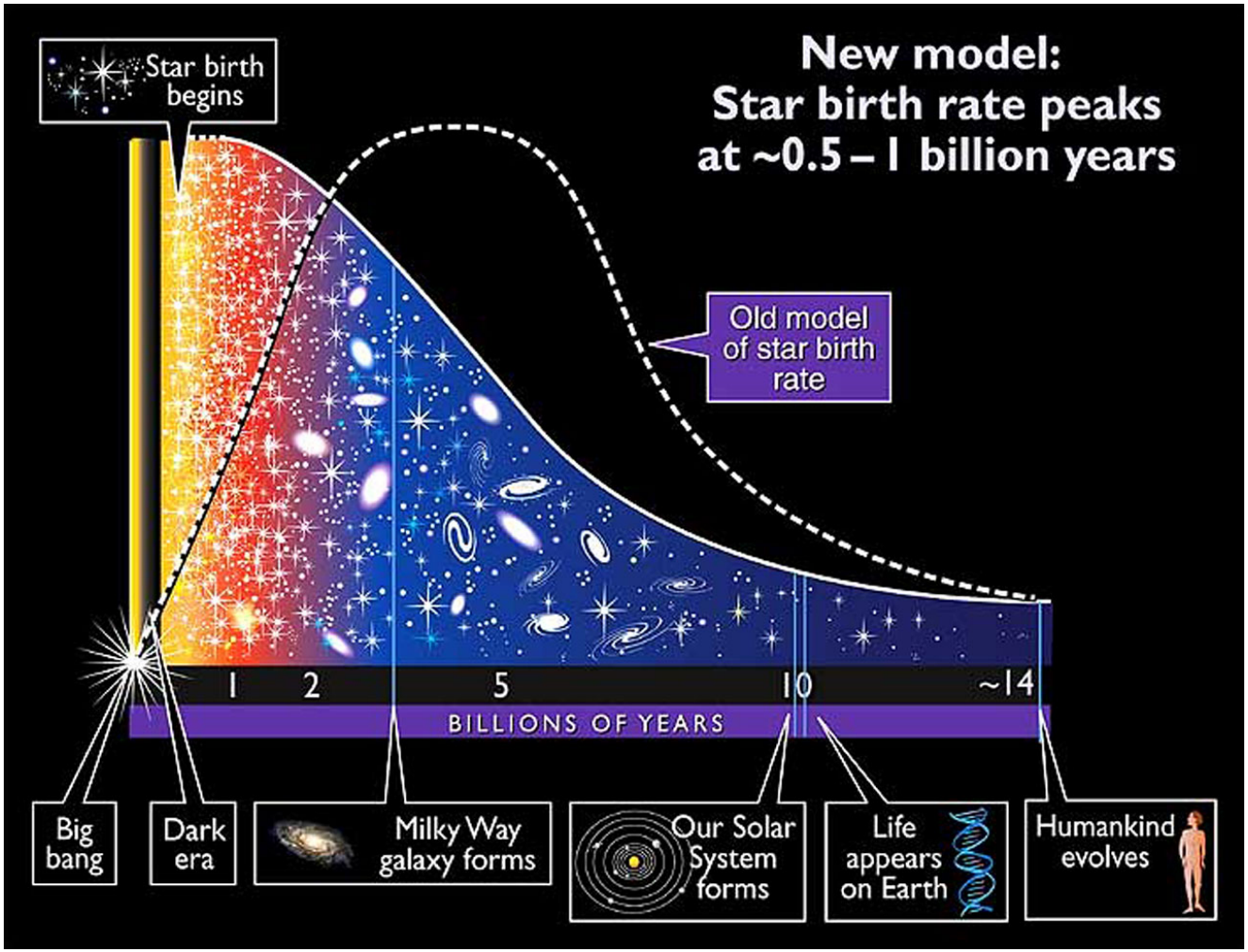
H-II Regions

The Orion Nebula is a nearby H-II region.

.

- The gas in H-II regions is heated to luminescence by embedded hot young stars.
- H-II regions are indicative of star formation.
- The pink color is due to emission from ionized hydrogen ($\mathrm{H}-\alpha$).

The Star Formation History of the Universe



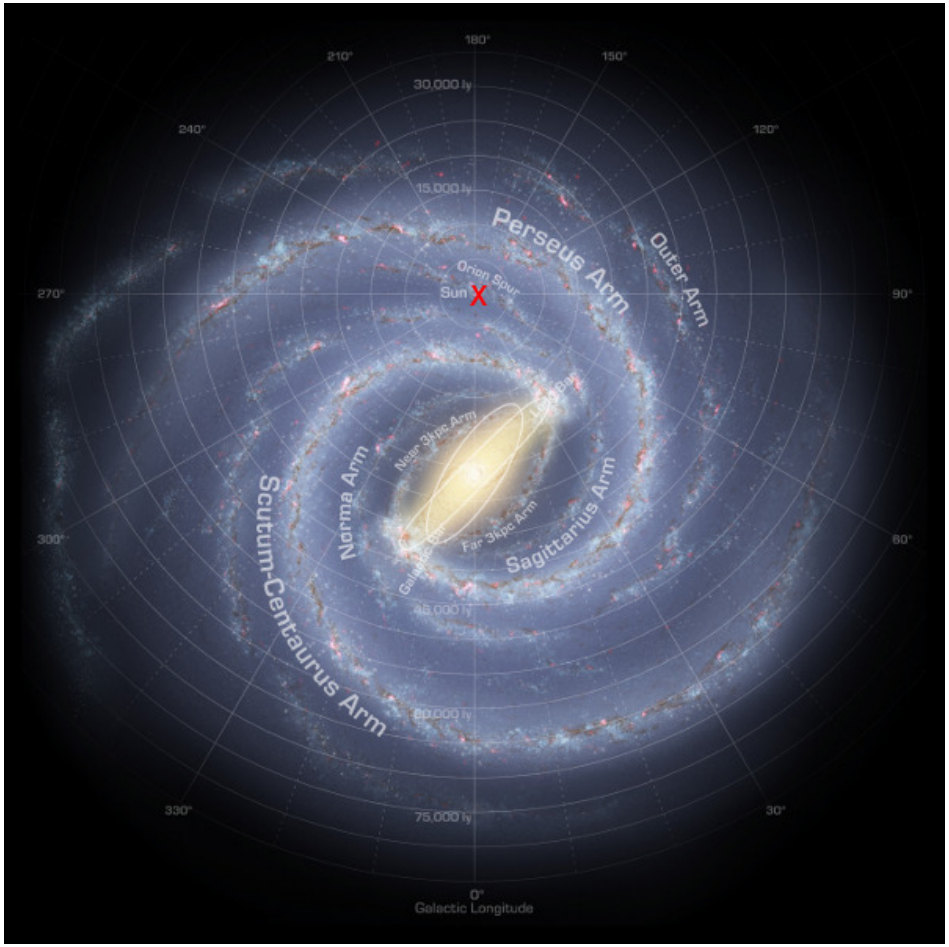
While the details are uncertain, it is clear that the star formation rate of the universe has dropped significantly

The Milky Way as seen from Mt. Haleakala

.

The Milky Way is visible with the naked eye from a dark-sky site.

A Map of the Milky Way



This is what we believe Milky Way would look like if seen from outside.

NGC 6744: A Milky Way Look-alike

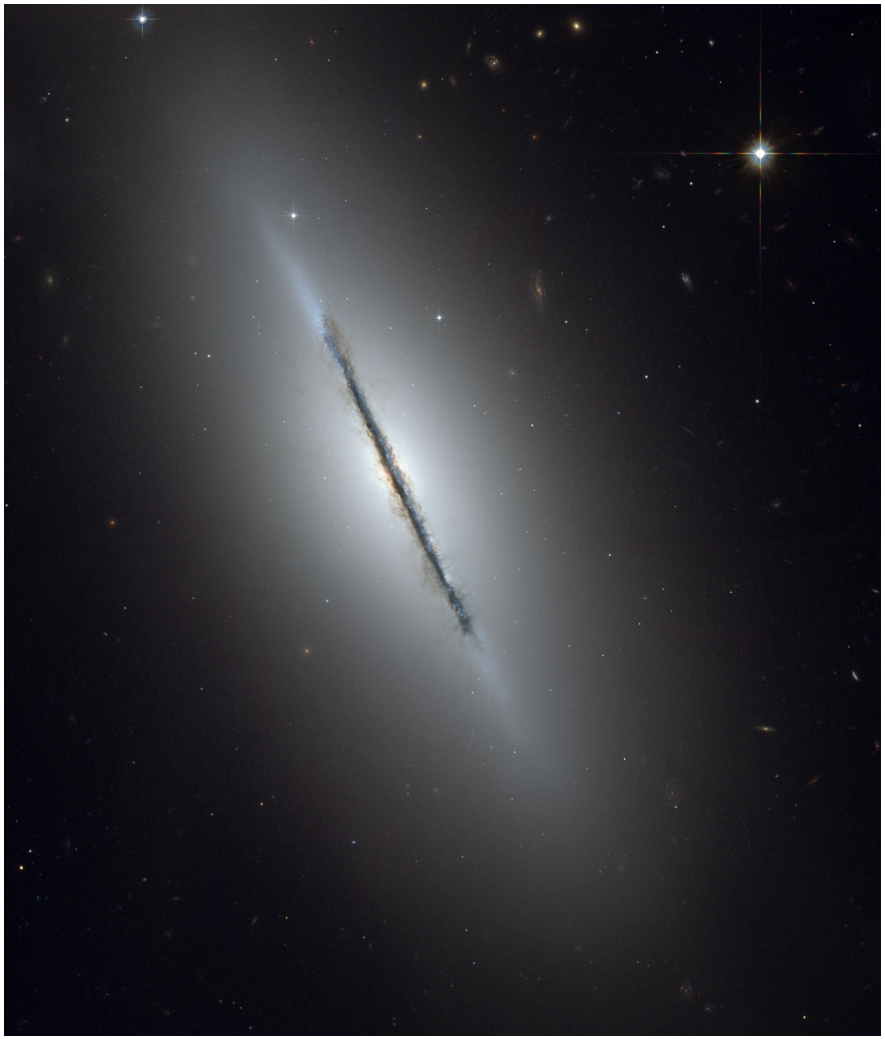
Gas, Dust, and Dark Matter - the Composition of Galaxies

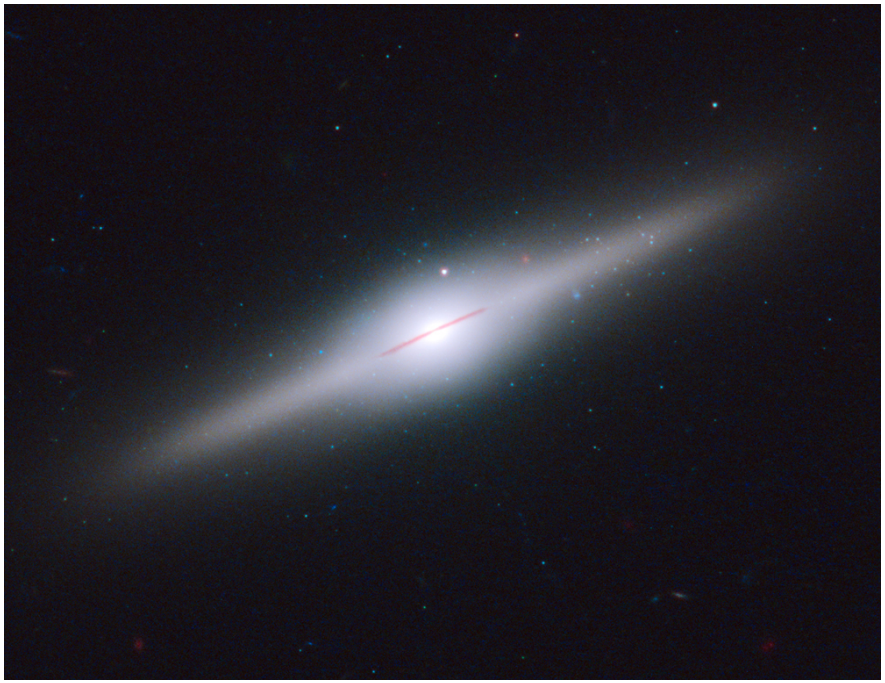
- As we will study in the coming weeks, we believe $\approx 80 - 90\%$ of the mass of galaxies is in the form of "Dark Matter". This matter is not made up of ordinary matter (i.e. it is not made up of atoms).
- The ordinary matter (which astronomers typically call "baryonic" matter), has the following components:
  - Stars and planets - these account for perhaps 10-50% of the ordinary matter.
  - Gas in the interstellar medium - this is most of the ordinary matter.
  - "Dust" - these are small solid particle made up of heavier elements.

Dust in Galaxies

- Dust particles scatter light and block our observations.
- The scattering rate of dust particles is proportional to $\frac{1}{\text{Wavelength}^4}$.
- Using long wavelengths (infrared and radio), we can see through the dust clouds.
- The dust in spiral galaxies is concentrated in the galactic plane.
- We cannot see the center of our galaxy in visible light - we need to use infrared and radio telescopes.

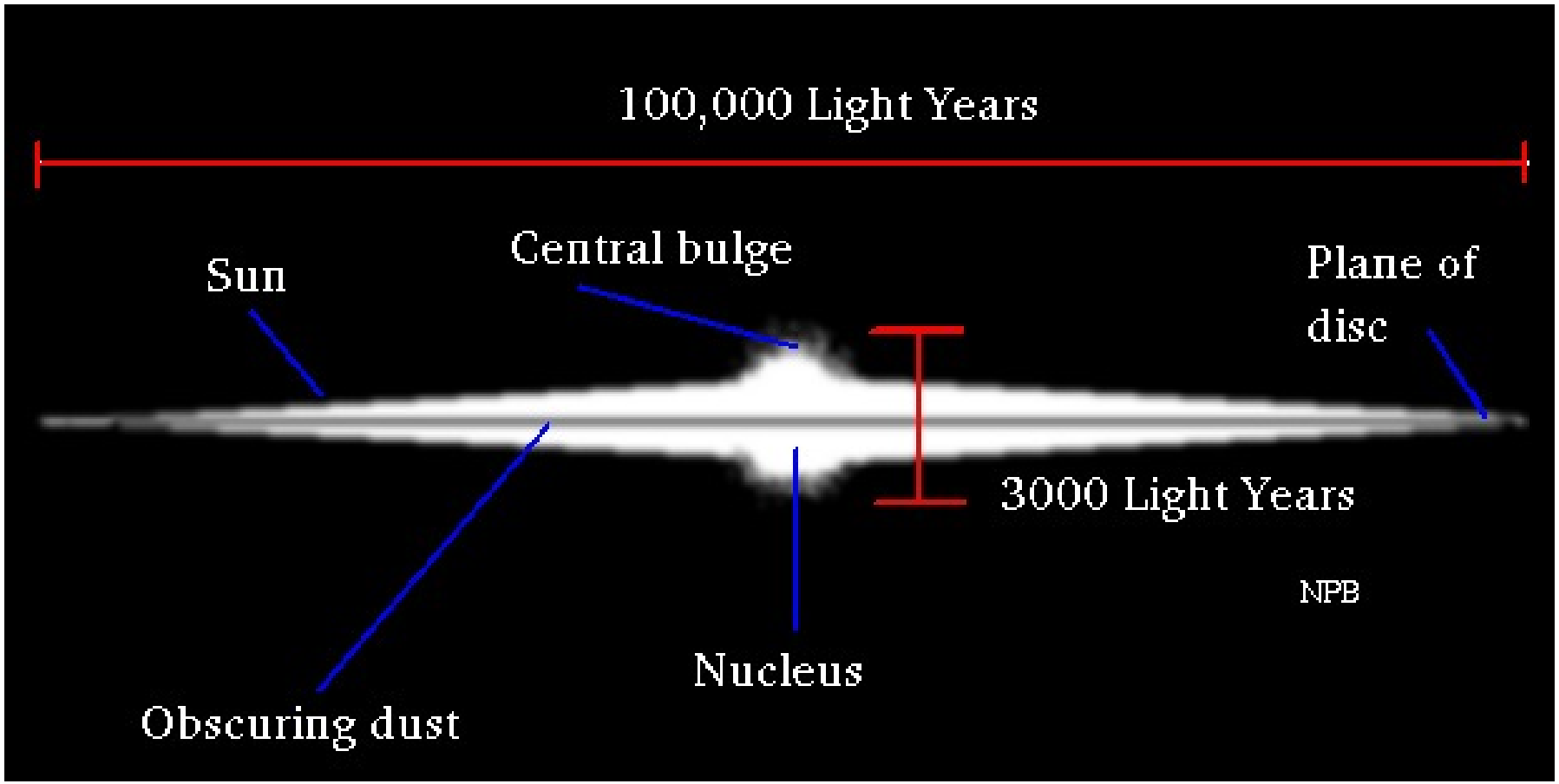
Edge-on Spiral Galaxies



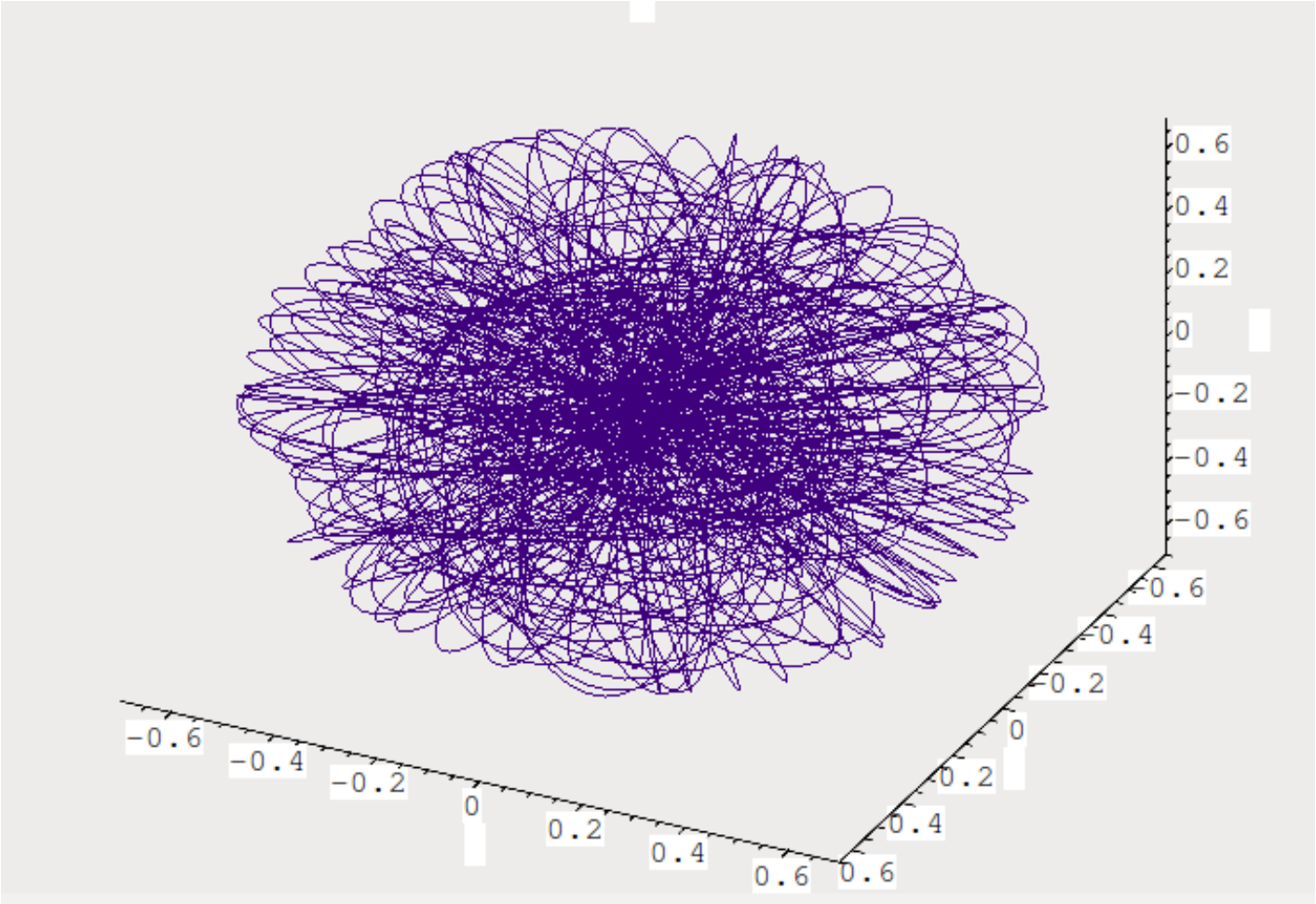


In Edge-on galaxies, we can clearly see the dust lane in the plane of the galaxy.

A Milky Way Edge-On Schematic

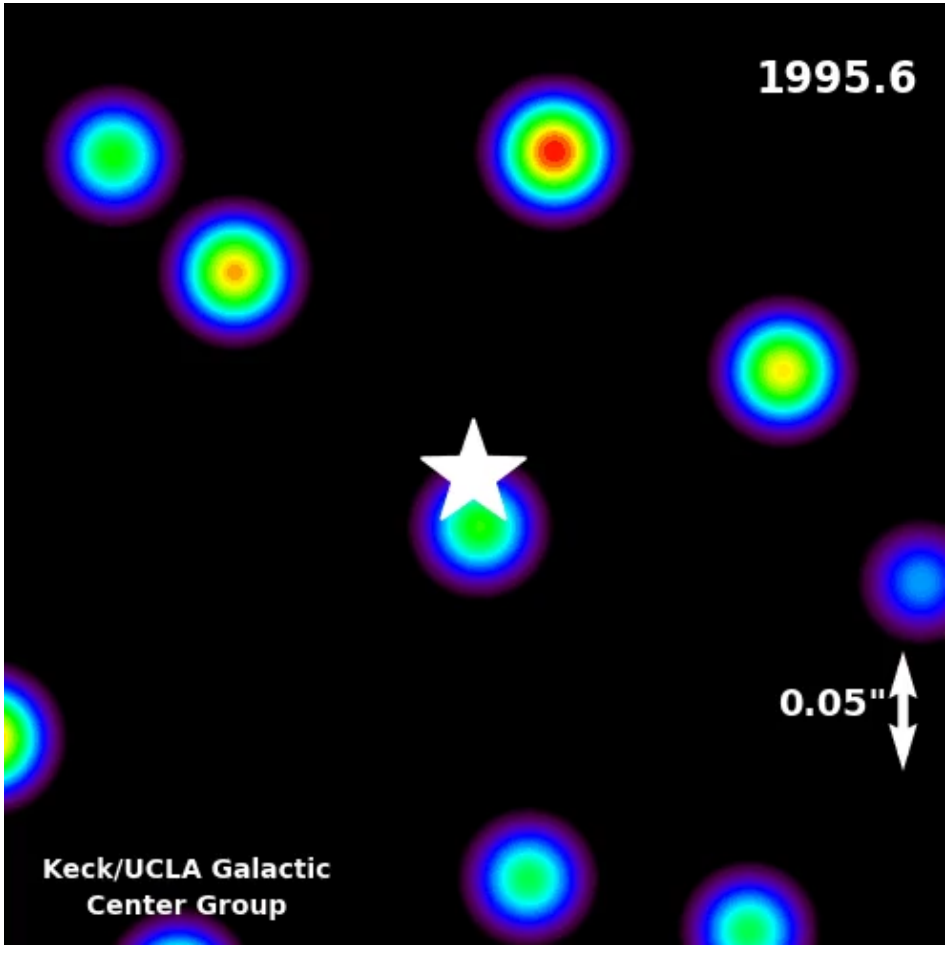


A Typical Stellar Orbit in a Galaxy



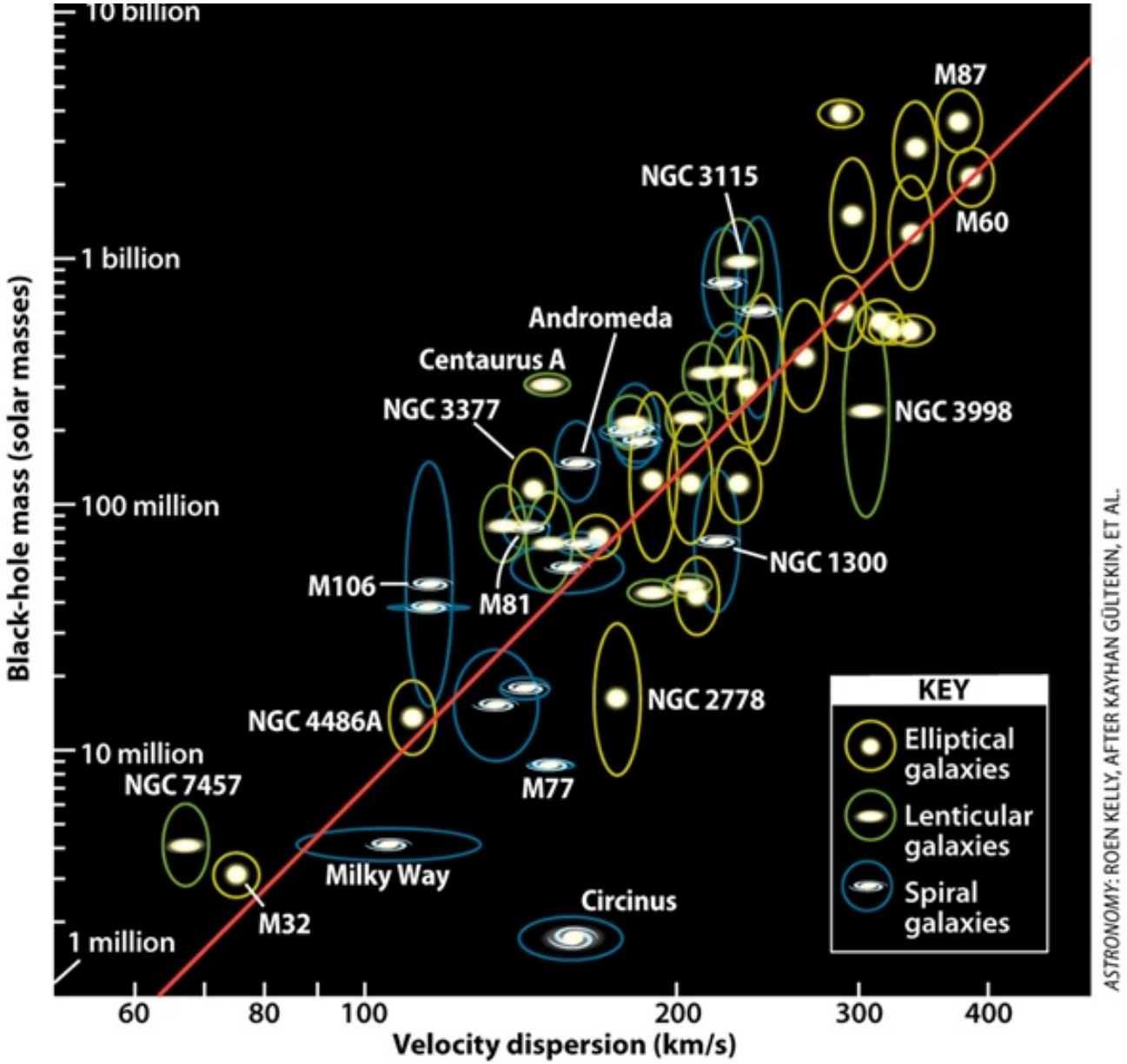
Unlike orbits in the Solar System, galactic orbits are typically not closed.

Movie of Stars Orbiting our Central Black Hole

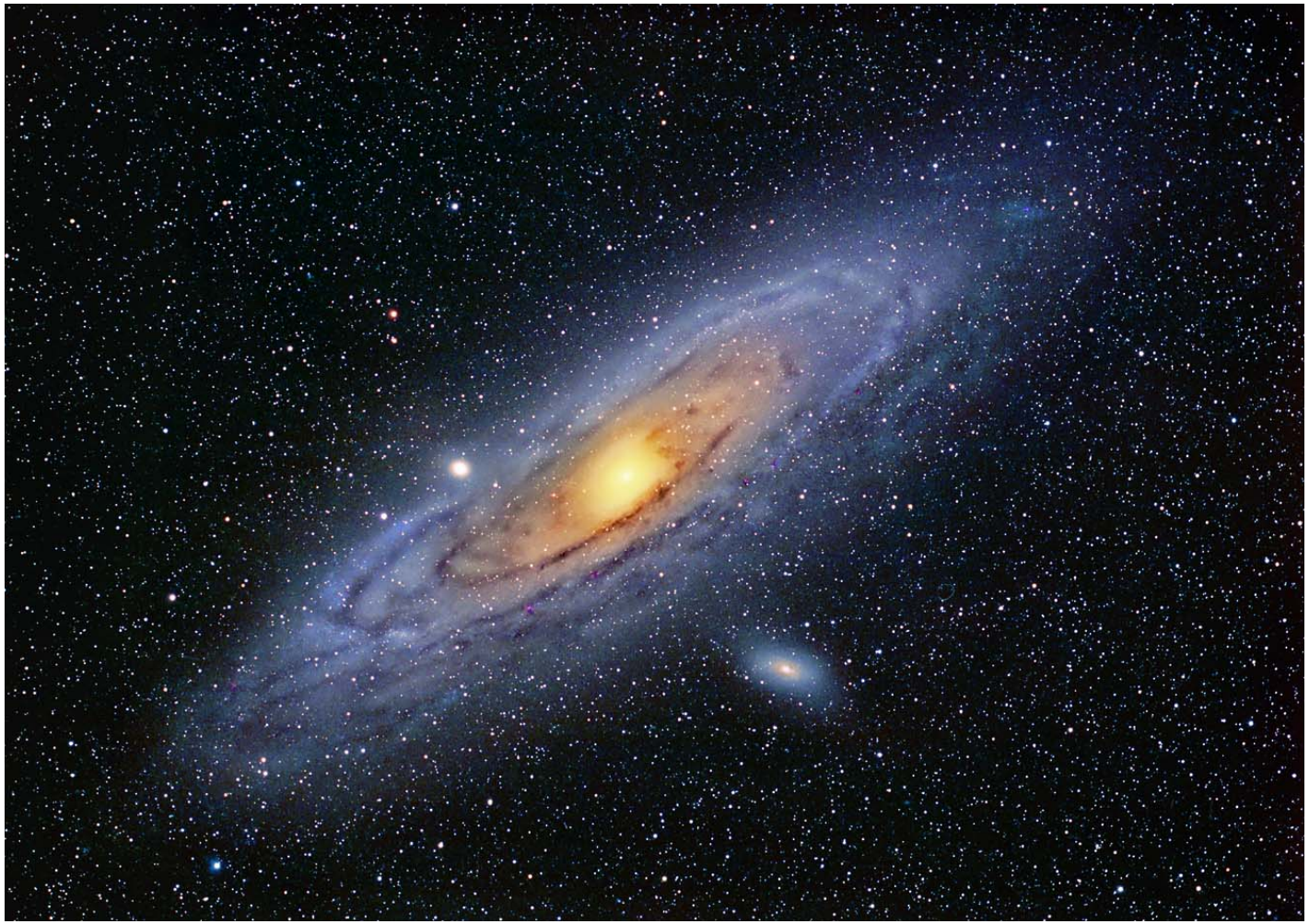


This movie shows stars orbiting our central black hole. From Kepler's laws, we can calculate that the black hole has a mass of about 4 million times the Sun.

Galaxy Mass is correlated with the mass of the SMBH



The Andromeda Galaxy (M31) - The Nearest Large Galaxy



This galaxy is visible with the naked eye from a dark-sky site
The Milky Way and Andromeda will merge in $\approx$ 4 billion years.

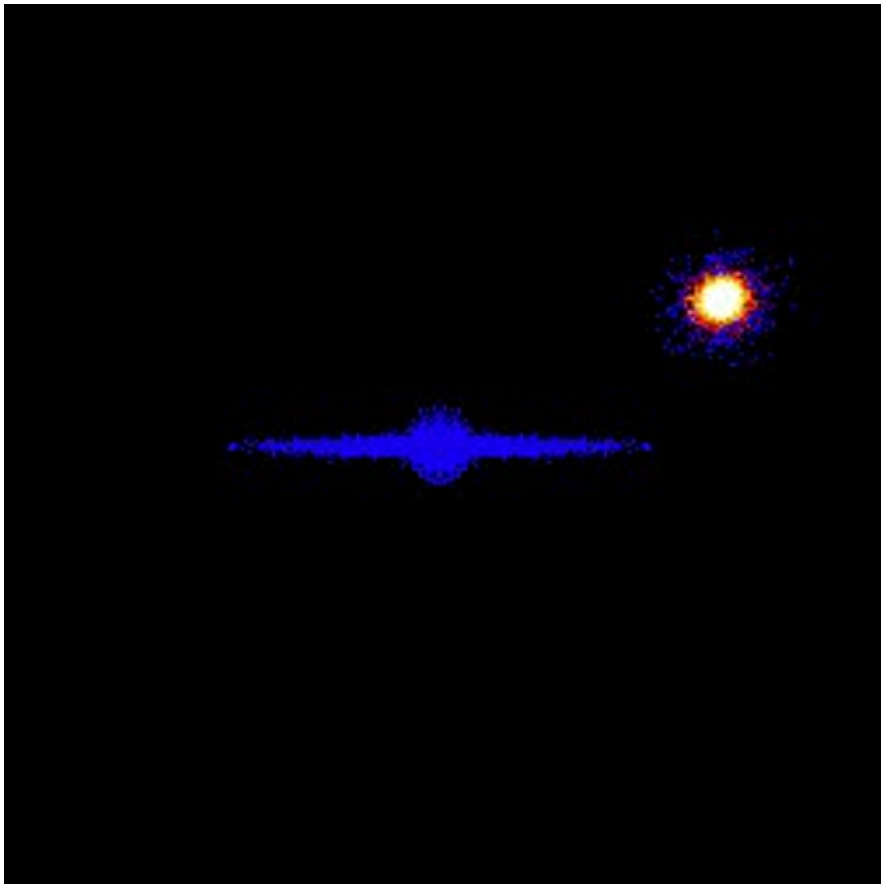
The Large and Small Magellanic Clouds - Nearby Galaxies

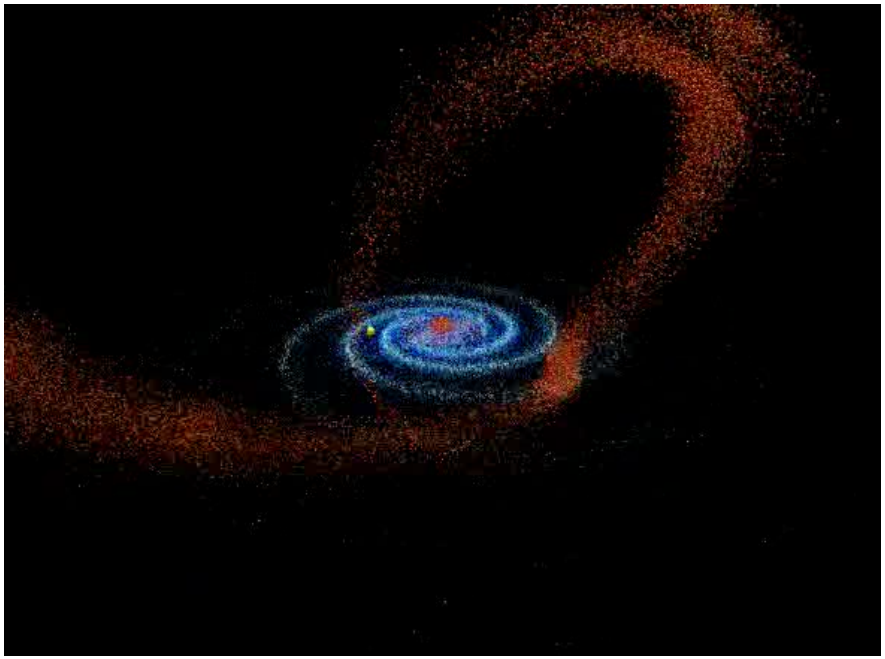
A "Warped" Galaxy

Interacting Galaxies - 1

Interacting Galaxies - 2

Movies of Milky Way merging with the Sagittarius Dwarf Galaxy

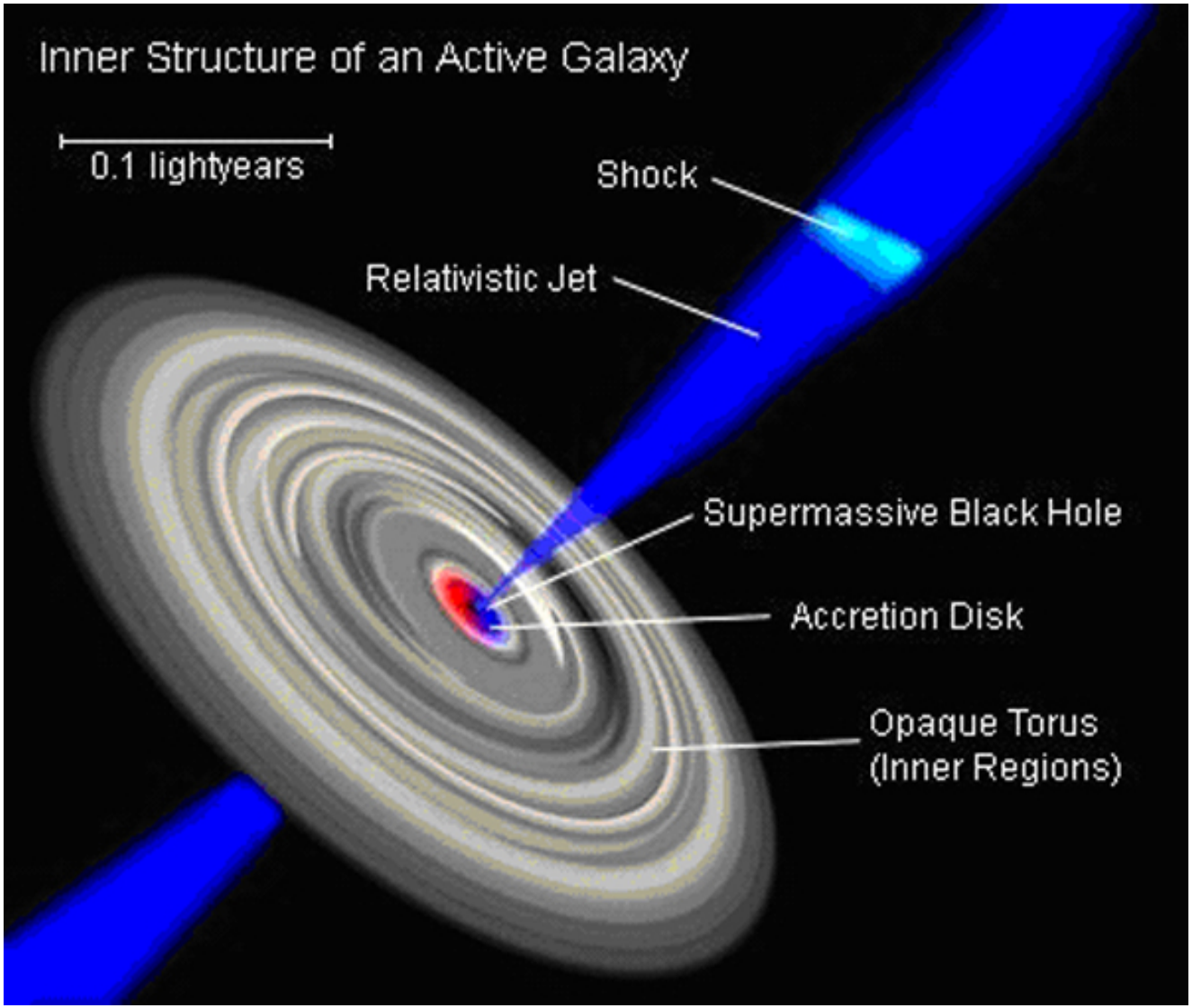




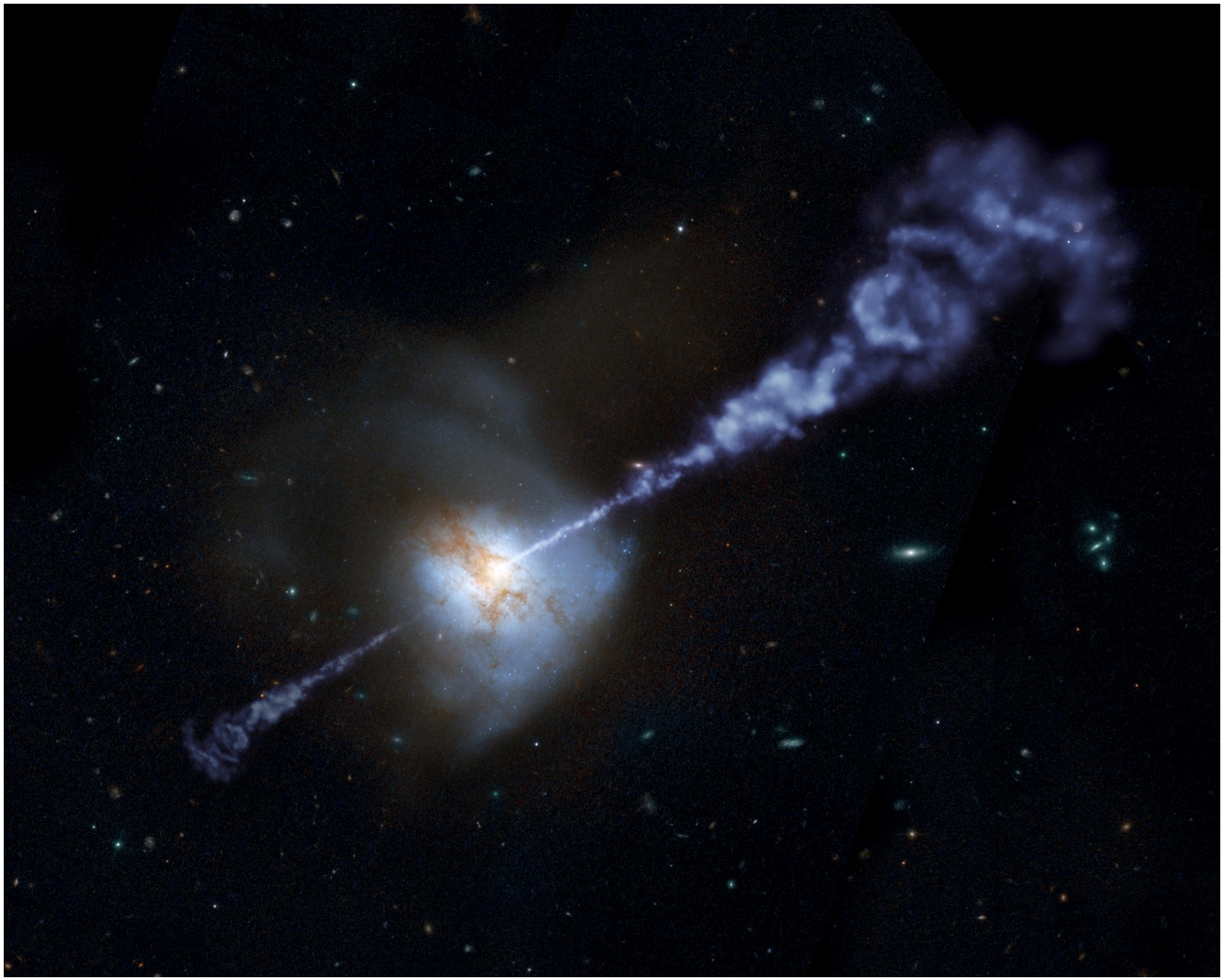
Active Galaxies and Quasars

- Quasars (QUASi-stellAr-Radio Sources) were initially discovered as very distant objects which appeared star-like.
- Over time, we understood that these are large galaxies whose SMBH is accreting large quantities of gas and shining very brightly across a wide range of wavelengths.
    - They can be 100's to 1000's of times more luminous than the Milky Way.
- They come in a wide variety of sizes, luminosities, and appearances, depending on:
    - The size of the SMBH.
    - How rapidly the SMBH is accreting gas.
    - The angle at which we are viewing it.
- Quasars, Blazars, Active Galactic Nuclei (AGN's) are all names used to describe these objects.

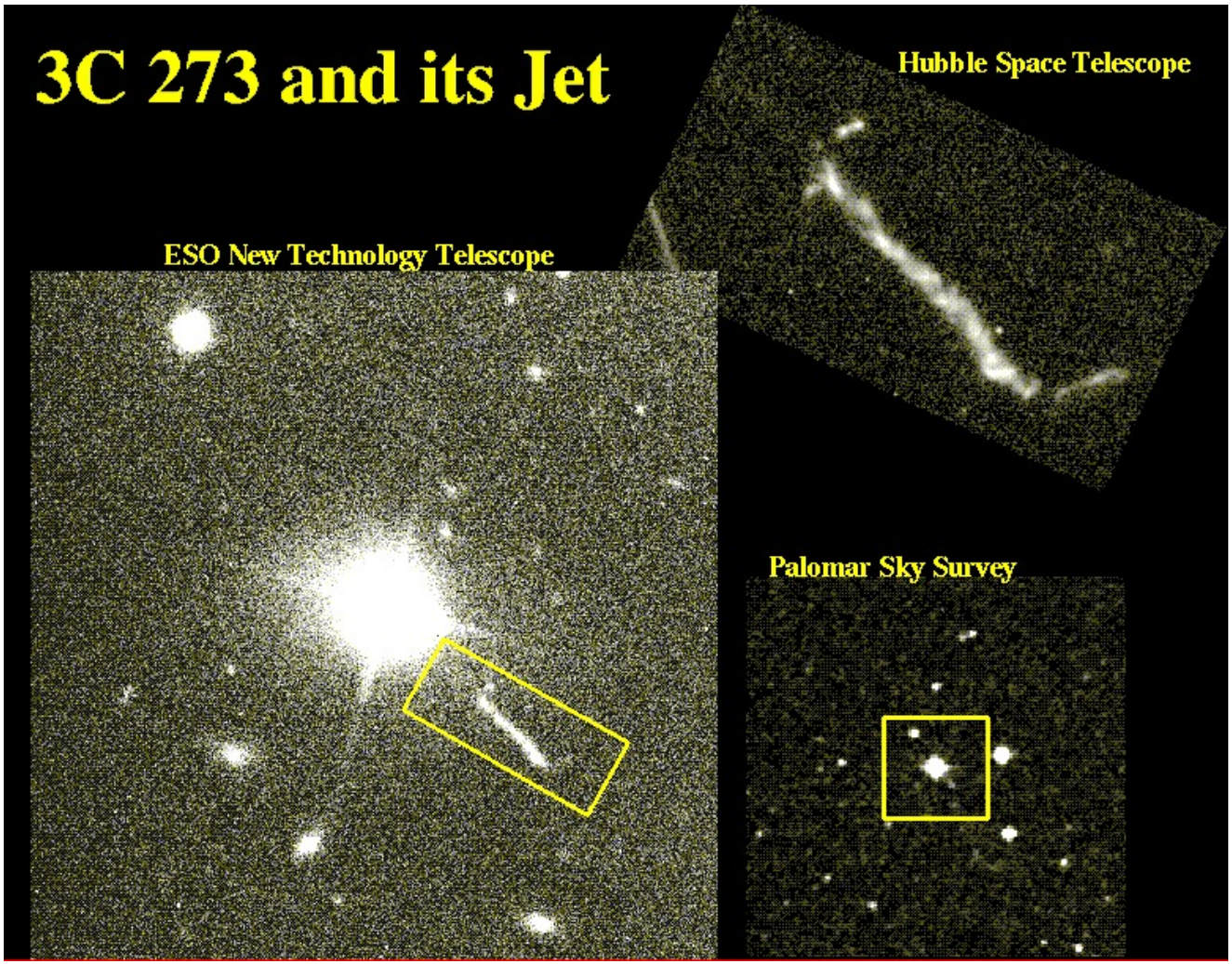
Schematic of an Active Galactic Nucleus



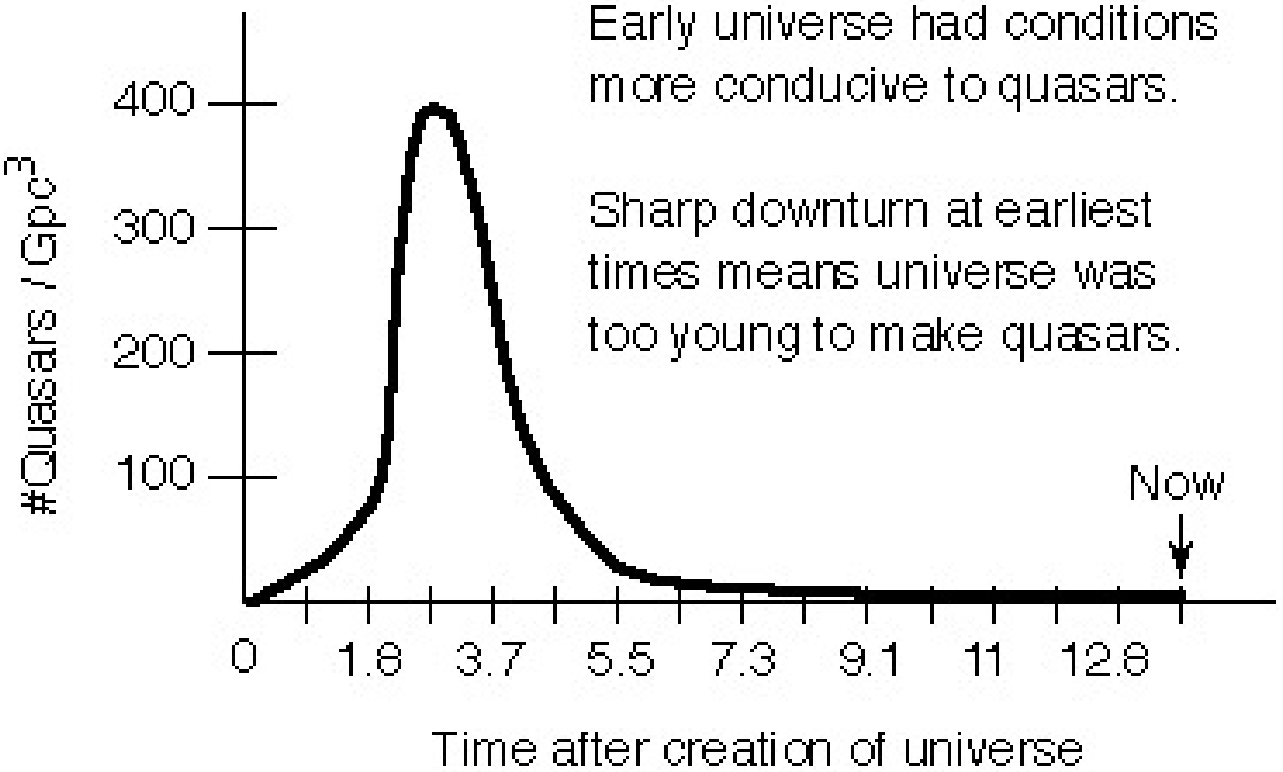
The Nearest Active Galaxy - M87 in the Virgo Cluster



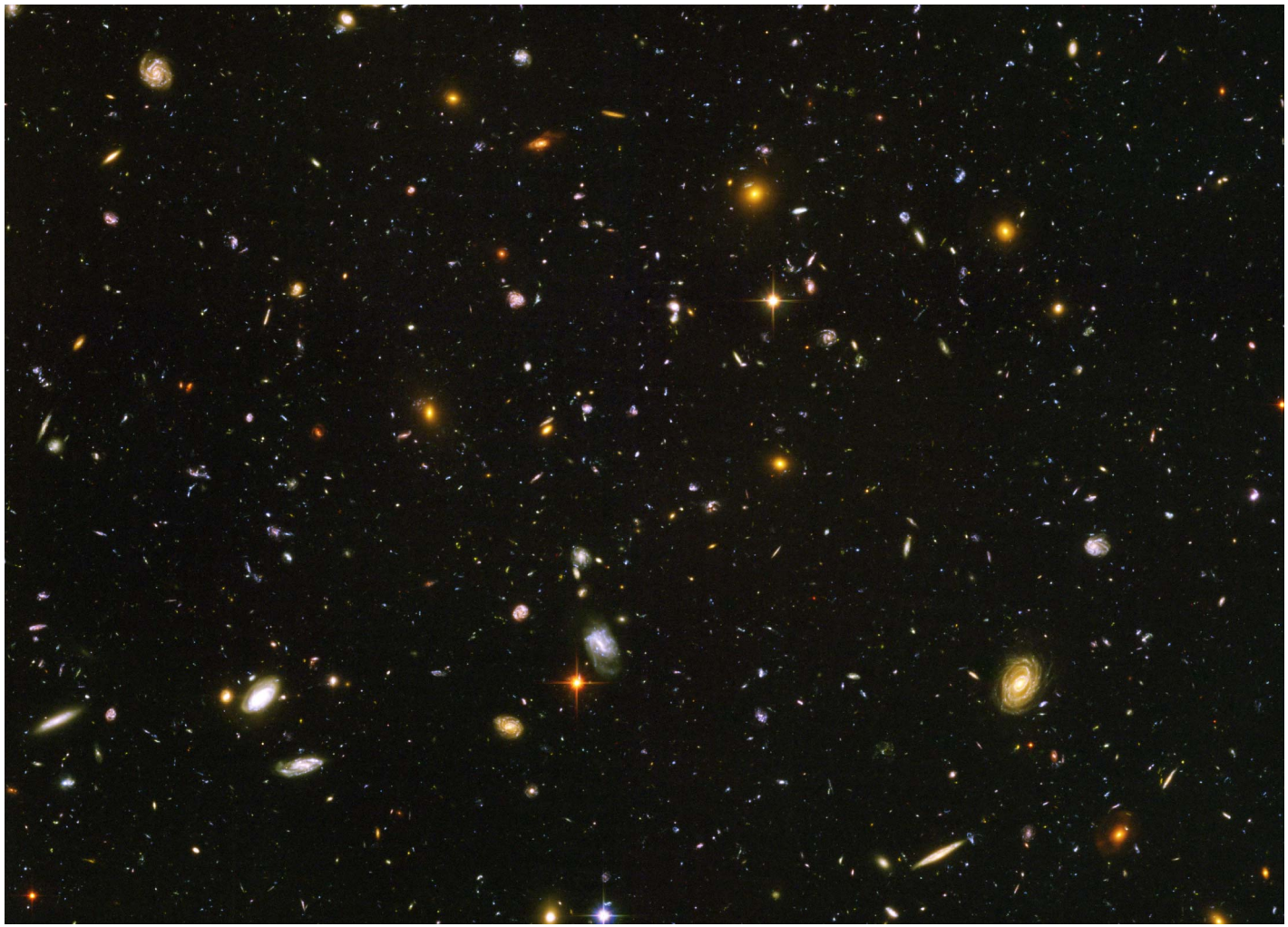
The Quasar 3C273



Quasars were much more common in the early Universe



The Hubble Ultra Deep Field



- This is a tiny patch of sky, about 1/10 the size of the moon.
- The observable universe contains at least 10^{11} galaxies!

Summary - 1

1. Galaxies are large groups of stars held together by gravity.
2. They vary widely in size:
   - Large galaxies like the Milky way have $10^{11} - 10^{12}$ stars.
   - Small dwarf galaxies may have only a few million stars.
3. They come in a wide variety of shapes, but there are two main types:
   - Spiral galaxies, which are blue in color because they are still forming stars.
   - Elliptical galaxies, which are no longer forming many stars and are therefore red in color.
   - The star formation rate of the universe peaked long ago and is declining.

Summary - 2

4. We believe that all galaxies have a Super-Massive Black Hole (SMBH) at their centers.

5. Galaxies grow through collisions and mergers.

6. Quasars (Quasi-stellar objects) are galaxies whose SMBH is accreting gas at a rapid rate:
   - Because the hot gas emits radiation, they are extremely luminous objects.
   - They were much more numerous in the early universe
   - There are no nearby quasars.