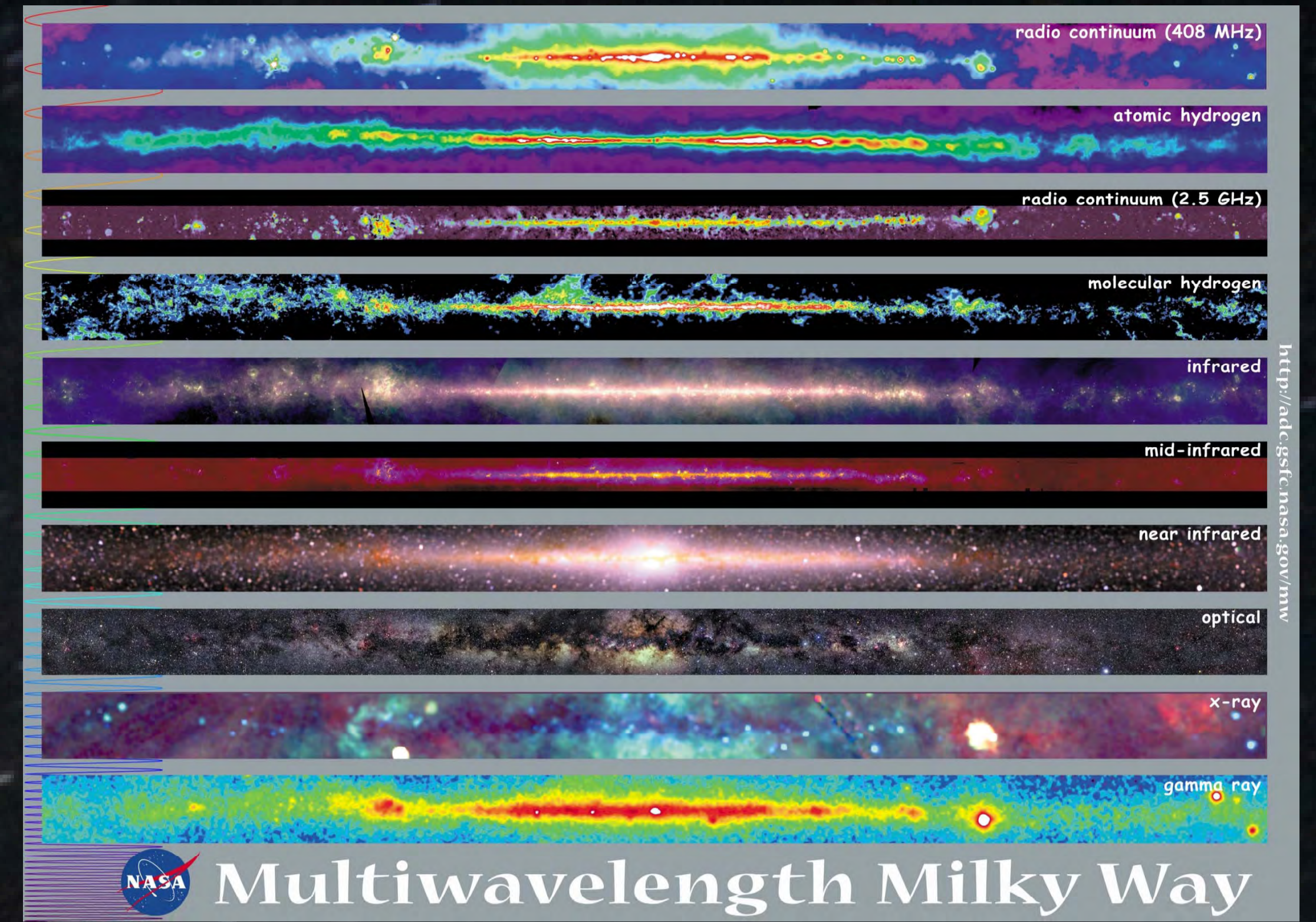
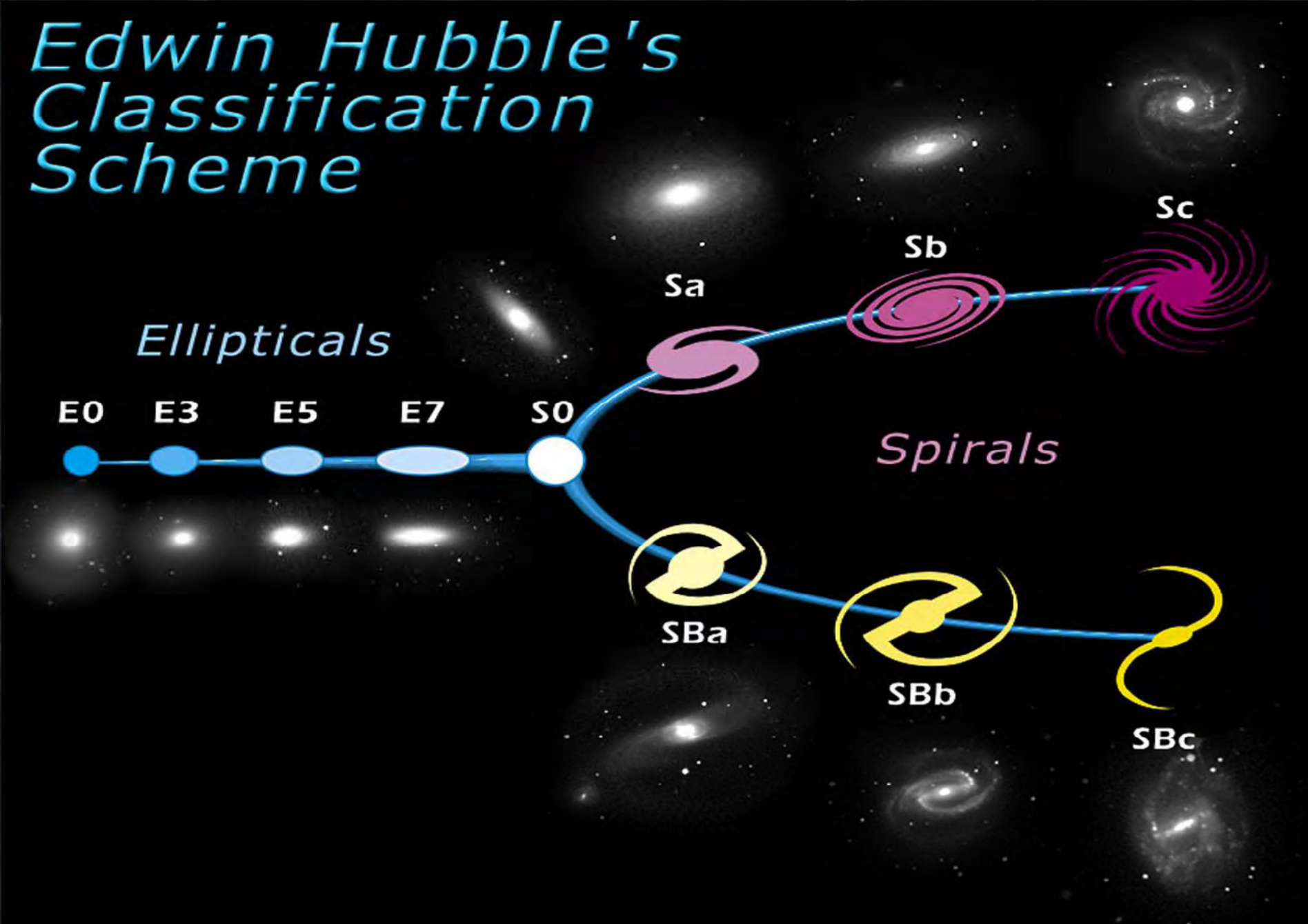
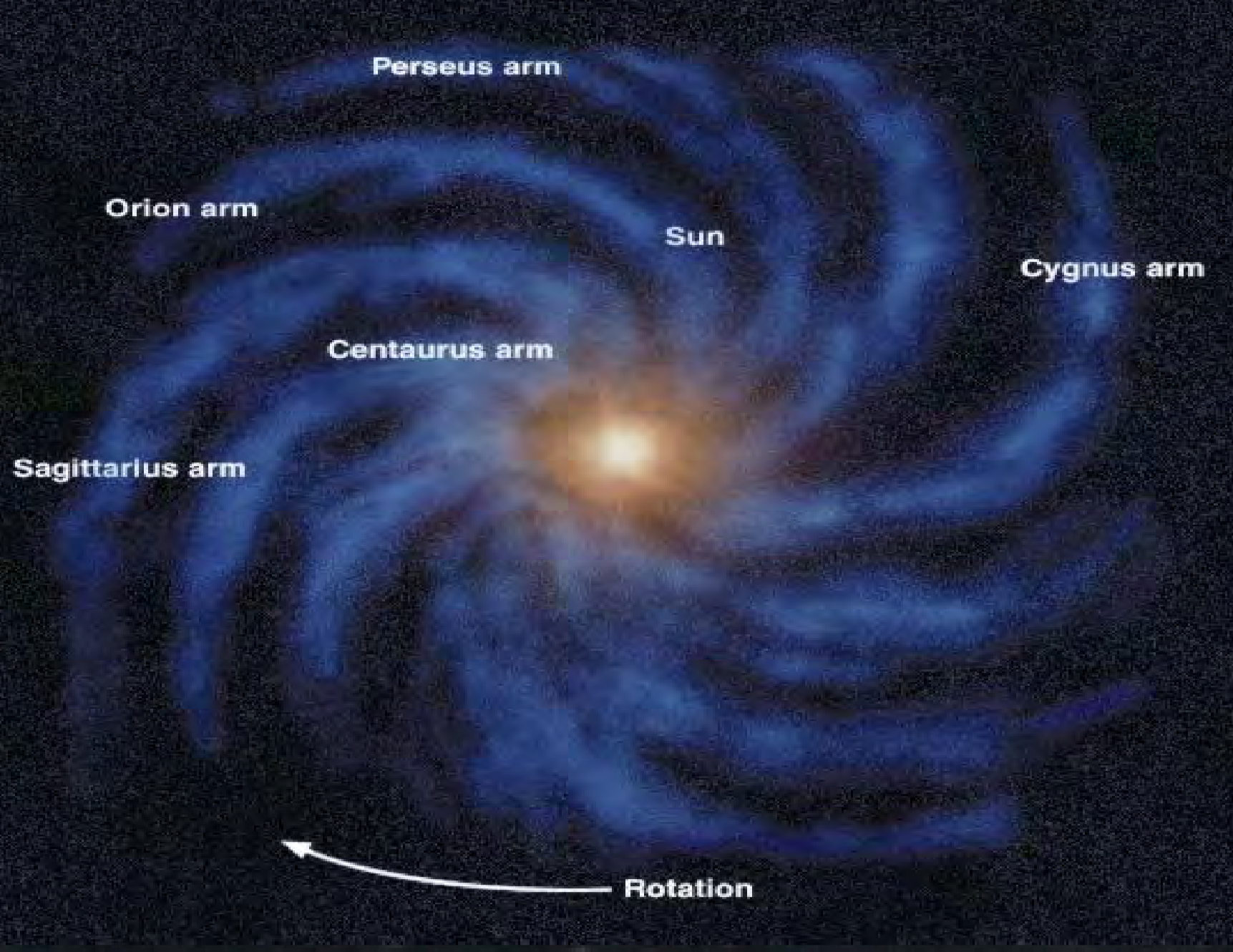


# Galaxies – The “Island Universes”

Galaxies are massive collections of stars. In a galaxy like our own Milky Way (artist's impression shown below), there can be as many as  $10^{11}$  stars! Other than stars, there is also gas and dust (inter stellar medium), dead star remnants, dark matter and a central super-massive black hole. In the universe, there are estimated to be  $10^{11}$  such galaxies! One can only imagine how big the universe is!



Images of our galaxy, the Milky-way seen edge-on at different wavelengths of the electromagnetic spectrum.

Galaxies were first classified by Edwin Hubble, and the different galaxy types are represented in the Hubble Tuning Fork diagram (right panel above).



**Elliptical** galaxies are smooth and featureless structures. At the center the EM-radiation is strongly concentrated and fades out towards the outer edges. These contain very old stars, have little dust and hardly any star formation is taking place in them. (The number (in E0, E3, E5, etc.) represents the ellipticity of the shape 0 – round and 7 – very flat.)

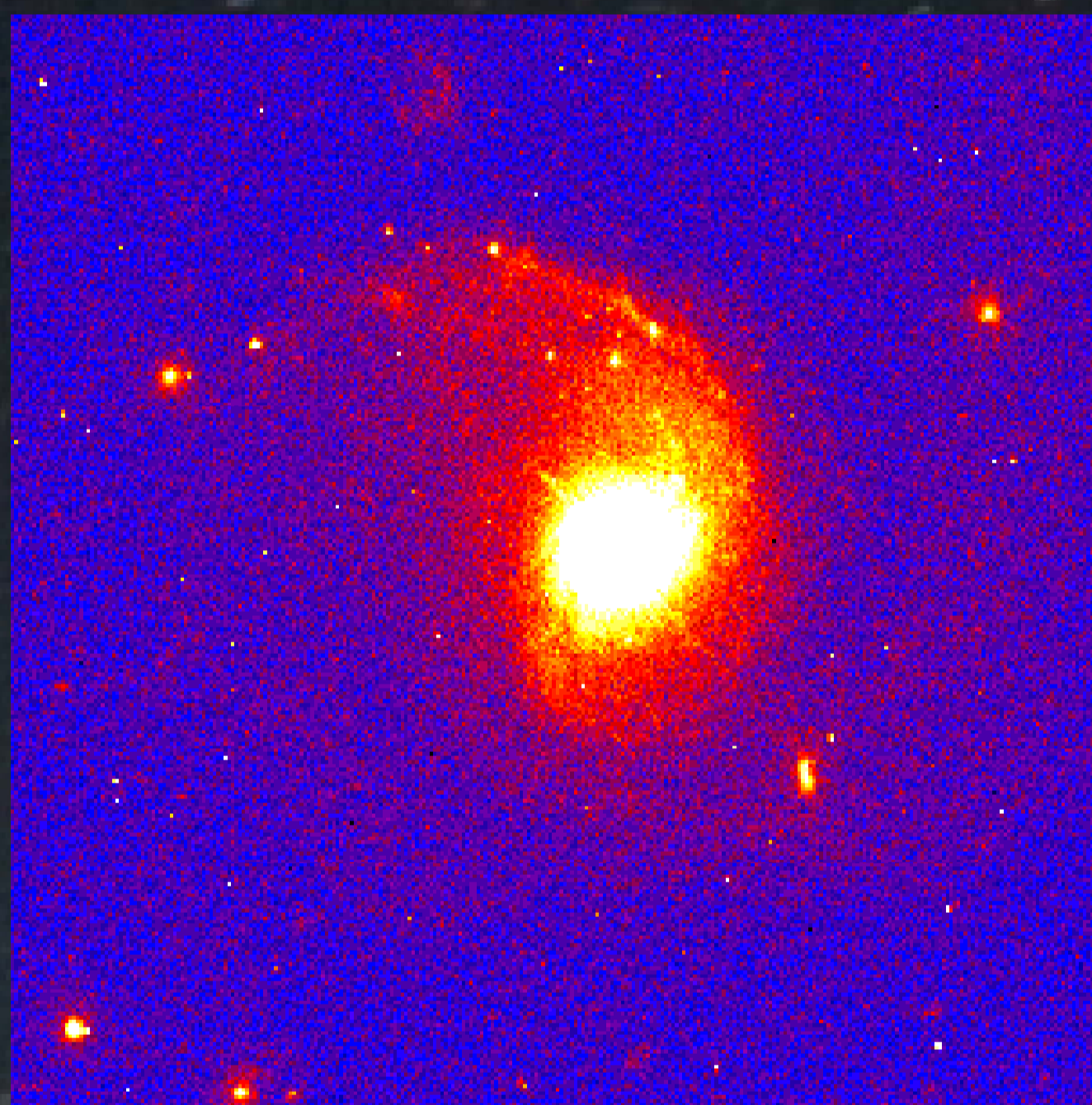


In between spirals and ellipticals are the “**lenticulars**”. They are neither as featureless as ellipticals nor feature-rich as the spirals. S0s have a large featureless bulge similar to the ellipticals but also have a prominent disk, with no spiral arms. SB0s are like S0s but have a bar at the center. (S0 – lenticular without bar. SB0 – lenticular with a bar.)



**Spiral galaxies**, beautiful and interesting objects. They have a central concentration of stars and spiral arms rotating around it. Unlike ellipticals, there is a lot of dust present in these galaxies and new stars are forming in them, especially in the spiral arms. Some of these even have a bar at their center. (S – spiral, SB – spiral with a bar. The a,b,c – denotes a sequence in dominance of the bulge, and tightness of spiral arms.)

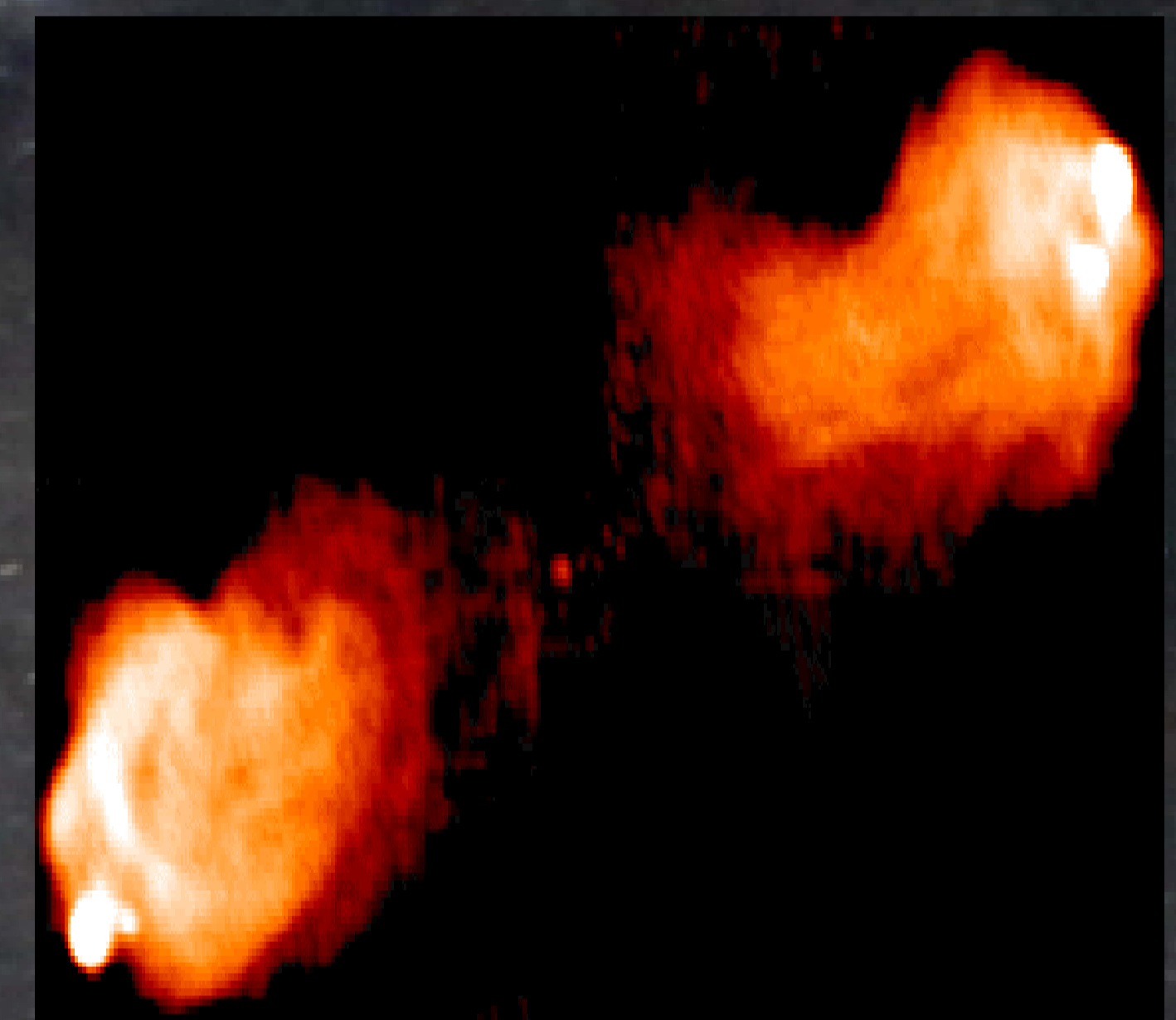
## Activities Seen in Different types of galaxies



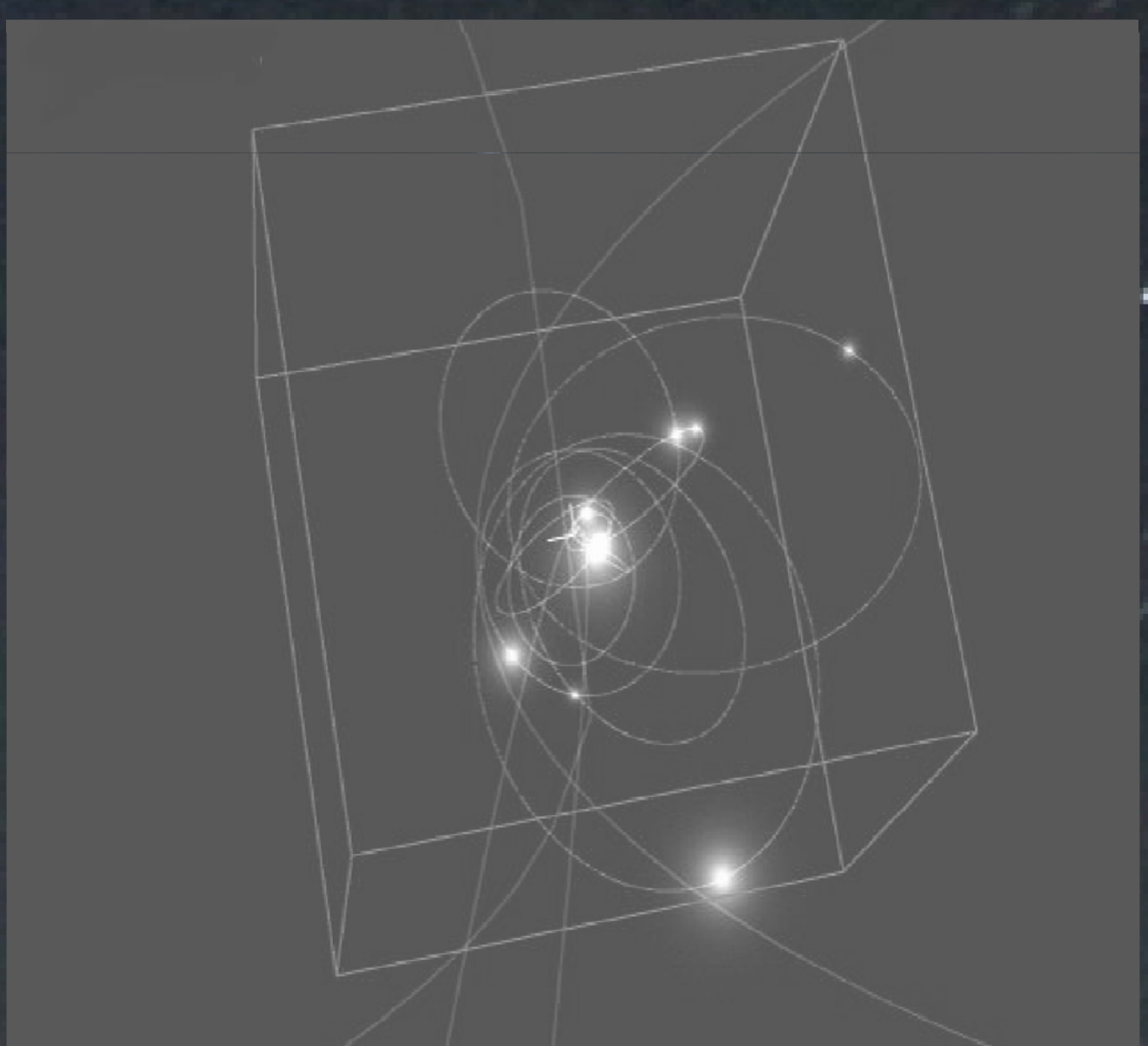
A false color image of a Quasar in X-Ray wavelength.

**Quasars/AGNs:** Active Galactic Nuclei (AGNs) are the central nuclei of some galaxies which emit vigorous EM-radiation outshining the galaxy itself. Quasars are AGNs emitting light predominantly from the nucleus than the host galaxy which make them appear like a star. AGNs are believed to be powered by accretion of gas on to a central super-massive black hole. AGNs are enigmatic objects and a lot remains to be understood about them.

**Radio Galaxies:** Using radio telescopes astronomers have observed certain galaxies with giant emission lobes as shown in this figure. These are again thought to be jets coming out from the central black hole. These jets are huge extending to the order of Mpc i.e. size bigger than the galaxy itself! It is still an unsolved question as to how such powerful emissions can be generated.



The above is a false color image of the radio galaxy Cygnus A in Radio Wavelength.



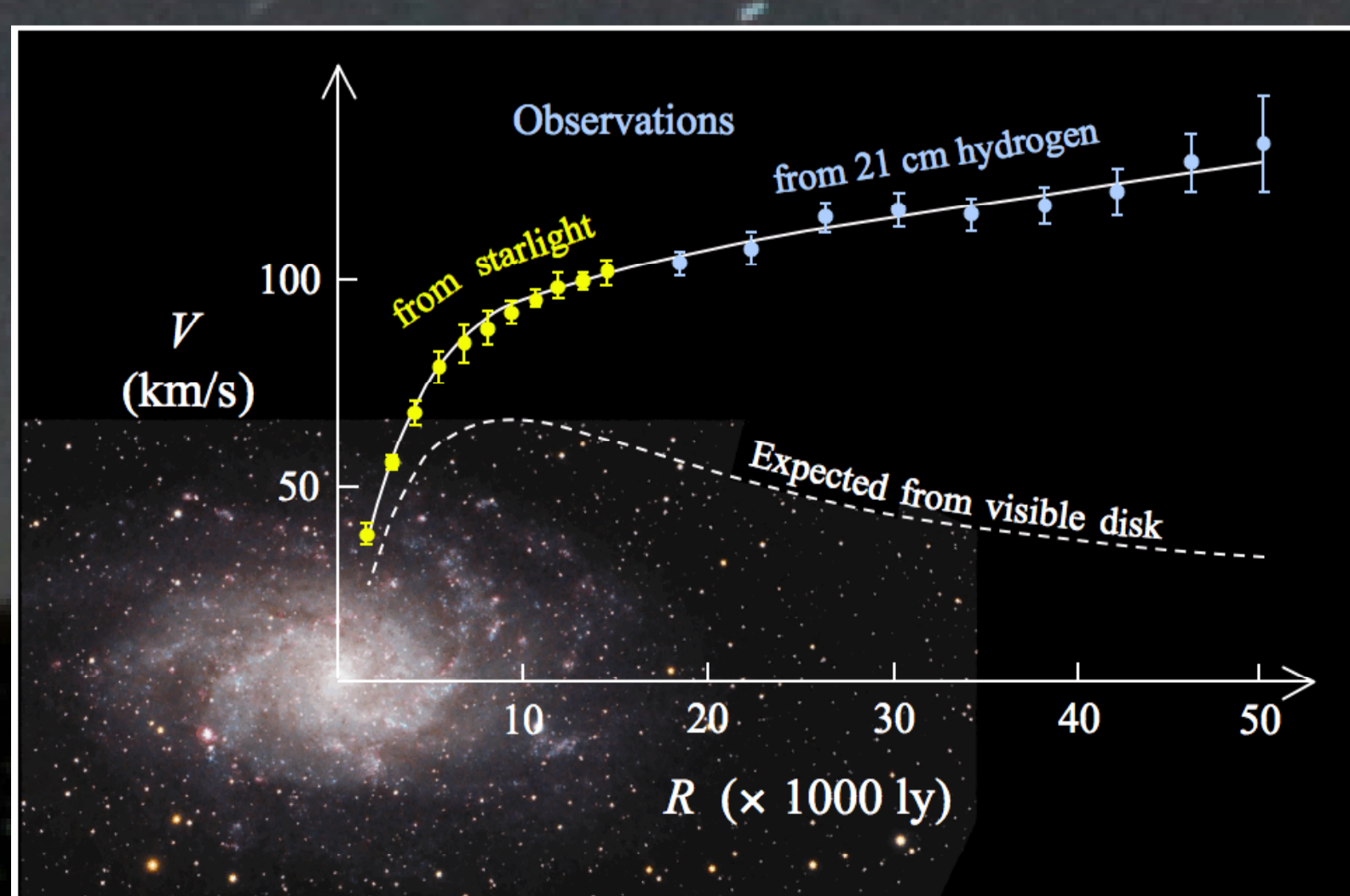
A computer generated depiction of the tracks traced by stars at the center of our own galaxy – The Milky Way

**Central Black Hole:** The support for the presence of a super-massive black hole in the center of our galaxy comes from the proper motion of individual stars that has been observed by astronomers for more than a decade. From the orbits traced by these stars one can infer that there is a very massive ( $10^6$  solar mass) object within a very small volume at the center of our Galaxy. It is most likely to be a super-massive black hole.

**Galaxy Clusters:** These are collections of few tens to hundreds of galaxies in a small region which extends in radius to only to few Mpc. Clusters are gravitationally bound dense regions, and their study reveal how galaxies evolve and how their evolution is governed by the environment around them. Since clusters also contain a significant portion of dark matter they often cause gravitational lensing of light from distant background objects.



Image of the Abell Cluster 1689



Stellar rotation curve from a typical spiral galaxy : observed and expected.

=> DARK MATTER??



This galaxy (NGC 4826) is full of violent activities with gas rotating opposite to that of stars. This is thought to be a galaxy formed by interactions (like the one on right) but not yet settled down.

This picture (right) shows galaxies interacting with each other. This interaction takes  $\sim 10^8 - 10^9$  yr. It is believed that elliptical galaxies have formed from such interactions.

