

http://icc.ub.edu/gp_ga.php

Galactic Astronomy: The study of the Milky Way.

Formation and Evolution of the Galaxy

Our Galaxy in Numbers

History:

- **5th century BC** Anaxagoras and Democritus propose the Milky Way is a group of very distant stars.
- **10th century AD** The Arabian astronomer Alhazen is the first to measure the parallax of the Milky Way. Finding it is null, he concludes it is a very distant object.
- **1610 AD** Galileo Galilei becomes the first to point a telescope to the Galaxy, thus proving that it is composed of a great number of faint stars.
- **1750 AD** Thomas Wright is the first to propose that the Earth is actually immersed in the Milky Way, in a region that 'locally approximates a flat layer of stars'. He also introduces the revolutionary idea that many of the faint nebulae observable from the Earth may actually be very distant galaxies such as the Milky Way.
- **1755 AD** Immanuel Kant supports Wright's ideas and adds that the Milky Way might be a rotating body, held together by gravitational forces on a very large scale. He introduces the term 'island universe' to describe the Milky Way and other galaxies.
- **1785 AD** William Herschel carries out the first attempt at graphically representing the Milky Way. He assumes that the Sun is near its center.
- **1845 AD** Lord Rosse constructs a telescope with which he is able to distinguish point sources in several nebulae, a fact which lent credence to Wright's original hypothesis.
- **1917 AD** Heber Curtis detects eleven very faint novae in the Great Andromeda Nebula and he roughly estimates its distance in 150,000 parsecs. This, and its appearance and significant Doppler shift, induce Curtis to conclude that the Great Andromeda Nebula is an 'island universe'.
- **Early 1920's** Edwin Hubble uses Cepheid variable stars in Andromeda to estimate its distance slightly more accurately and thus settles the matter: Andromeda is indeed an 'island universe'.

<http://curious.astro.cornell.edu/question.php?number=657>

Astronomers: A Day in the Life

Working in our offices, Traveling, Teaching, Reading, Writing, Observing

<http://curious.astro.cornell.edu/question.php?number=21>

Skills: I advise you to take as much math as you can. Having high school calculus under your belt will make your first physics classes much easier. Physics and other sciences should be a priority, too, but don't neglect other classes. Astronomers still need to be good writers and communicators, and good grades across the board are necessary for college admission and scholarships.

<http://research.pbsci.ucsc.edu/astro/extragalactic-cosmology/>

Extragalactic Astronomy: UCSC's efforts to understand the structure and evolution of the universe on the largest scales, including the formation and dynamics of galaxies, clusters and superclusters, the

large-scale-structure of the universe, and the evolution of the universe from the earliest times.

Enabled in large part by the great sensitivity of the Keck Telescopes, UCSC astronomers have pursued a broad range of extragalactic astronomy, from the kinematics of dwarf elliptical galaxies to the distribution of galaxies and quasars -- and the stuff in between them -- on the largest scales.

Modeling by Primack, Madau and Aguirre works to understand how galaxies connect with the intergalactic medium from which they form, and to understand the origin of the first stars and galaxies. As well, these models produce a wide array of predictions for the types, luminosities, morphologies, masses, and abundances of galaxies, which can be compared in detail to observational surveys.

- Galaxy formation and evolution
- The intergalactic medium
- Dark Matter

<http://www.astro.umd.edu/rareas/extragalactic/>

Extragalactic Group of the University of Maryland:

The extragalactic group's current members employ a wide range of observational and theoretical tools (with an emphasis on optical, radio and X-ray astronomy and computational astrophysics) in an attempt to understand the origin, dynamics, and evolution of both active and normal galaxies.

- **Alberto Bolatto** uses ground and space facilities to study the effects of heavy element abundance on the physics of the interstellar medium, the relationship between gas, dust, and star formation in galaxies, and the properties of dark matter galaxy halos in nearby galaxies.
- **Stacy McGaugh** is an observer interested in low surface brightness galaxies and the insights they provide into galaxy formation and the mass discrepancy problem.
- **Neil Miller** is an observational astronomer whose work investigates the role of environment in the evolution of galaxies.
- **Richard Mushotzky** is a renowned expert in high-energy studies of clusters of galaxies and active galactic nuclei.
- **Eve Ostriker** studies the structure and evolution of disk galaxies using large-scale numerical simulations as well as analytic models. She is particularly interested in the processes governing spiral structure, dynamics of the interstellar medium, and the regulation of star formation.
- **Chris Reynolds** is a theoretician interested in the central regions of black hole systems, as well as the physics of the jets that some black holes produce.
- **Massimo Ricotti** is a theoretical cosmologist interested in high redshift galaxy formation, nearby dwarf galaxies, and the physics of the intergalactic and interstellar medium.
- **Sylvain Veilleux** is an observer whose work centers on understanding the nature of starburst and black-hole driven activity in galaxies.
- **Stuart Vogel** studies the dynamics and evolution of galaxies with CO observations with the CARMA array of telescopes.

http://icc.ub.edu/gp_ea.php

History of Extragalactic Astronomy:

Up until the dawn of the 20th century, the Milky Way was thought to comprise the whole Universe: the notion that there might exist something *outside* our galaxy was unheard of!

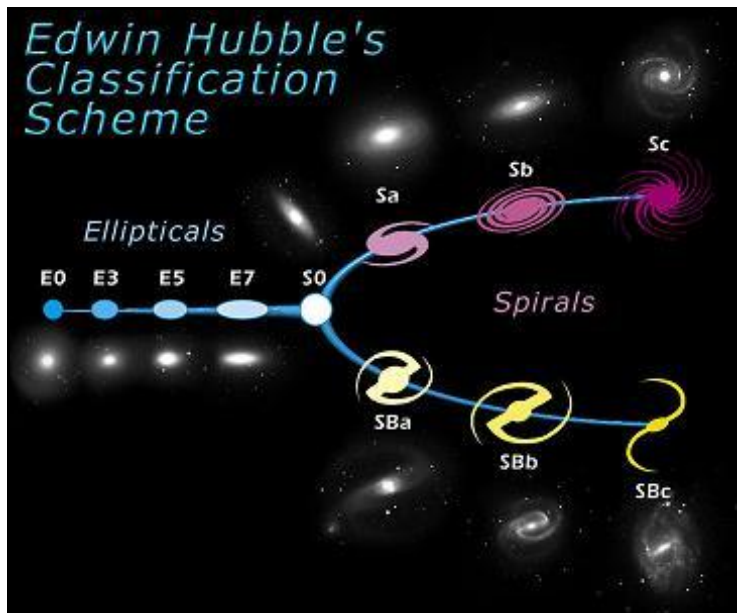
In 1917, American astronomer **Heber Curtis** pointed his telescope at the Great Andromeda Nebula, an object thought to lie relatively close by, and to be only slightly larger than the Solar System. He discovered *eleven* novae, all of them significantly fainter than those observed elsewhere in the Galaxy. Curtis thus concluded that this could not be a nearby stellar nebula he was dealing with, but was in fact a galaxy such as our own: an **island universe**. Extragalactic astronomy had just been born.

However, Curtis' hypothesis was met with resistance. That of the island universe was quite a revolutionary idea, and in the following years it sparked much debate. It was not until 1925 that Edwin Hubble settled the matter: his estimates based on Cepheid stars confirmed the extragalactic nature of Andromeda, which was then renamed **Andromeda Galaxy** (to the right; credit: Boris Strômar). Today we know that this galactic behemoth is roughly as massive as the Milky Way and much brighter, and a staggering 2.5 million light-years away!

A vast and fascinating field of study, extragalactic astronomy is concerned with everything that lies beyond the domain of galactic astronomy (i.e. the Milky Way). This includes a wild array of objects and phenomena ranging from galaxies to **superclusters** and spanning the last 13 billion years of the history of the Universe, which makes it fertile ground for the merging of many branches of physics (mainly high energy physics and cosmology).

Extragalactic astronomy is a popular subject at ICC, where two different groups are carrying out extensive research in related topics. Their work is mentioned further down.

Hubble's "Tuning-Fork"



The task of classifying galaxies as such was first undertaken by Hubble in 1926. Inspired by the theory (eventually discarded) that a nebula's morphology might reflect its evolutionary stage, his classification scheme was ultimately based on observable physical patterns. The result is popularly known as **Hubble's "tuning-fork diagram"**, and it is still widely used today (image to the right; credit: ESA and NASA).

In short, Hubble notice three recurring patterns underlying galaxies' appearance, and so he

distinguished between elliptical, spiral and irregular galaxies.

As the name suggests, an **elliptical galaxy** has the cross-sectional shape of an ellipse. The stars move along random orbits with no preferred direction. These galaxies contain little or no interstellar dust; few star-forming regions; and generally older stars. Elliptical galaxies are more commonly found at the core of galactic clusters, and may be formed through mergers of large galaxies.

A **spiral galaxy** is organized into a flat, rotating disk, usually with a prominent bulge or bar at the center, and trailing bright arms that spiral outward. The arms are dusty regions of star formation where massive young stars produce a blue tint. Spiral galaxies are typically surrounded by a halo of older stars. Both the Milky Way and the Andromeda Galaxy are spiral galaxies.

Irregular galaxies are chaotic in appearance, and are neither spiral nor elliptical. About a quarter of all galaxies are irregular, and the peculiar shapes of such galaxies may be the result of gravitational interaction.

Galaxy Formation and Evolution

Back when the Universe was only **a fraction of a second** old, matter and light were all smoothly mixed together in a primordial "soup" of sorts. There were, however, small clumps here and there: the **primordial density fluctuations**. These clumps attracted matter from their surroundings and over the next few million years they grew and developed structure. About **400 million years** later, some clumps had already developed into sizable, if still rather undeveloped, galaxies.

The plot thickens, however, as these **fledgling galaxies** attract one another and occasionally collide, merging to form larger structures. Therefore, through the growth of microscopic overdensities and the merging of smaller structures into larger, more massive ones, mature galaxies such as the Milky Way and Andromeda are formed. The preceding account makes the essence of the **hierarchical theory** of galaxy formation.

Gravitational clustering, i.e. gathering of smaller structures into larger ones through gravitational attraction, and the analytical modeling of galaxy formation are two lines of research of ICC's **Galaxy Formation and Evolution group**.

It seems, however, that once a galaxy reaches a certain stage in its development, an altogether different process takes hold of its subsequent evolution. It is now thought that most galaxies host a supermassive black hole (SMBH) in their midst. The enormous amounts of gas falling into the central SMBH of a relatively young galaxy ignite and transform the region into an **active galactic nucleus** (AGN).

AGN are the most persistently luminous objects in the Universe. Though other phenomena, such as supernovae, can reach high luminosity peaks, these will typically last for only a few weeks. AGN, on the contrary, shine over millions of years and only abate when their supply of gas wanes. A galaxy hosting an AGN is called an **active galaxy**. **Quasars**, famous for their brightness and usually, too, for their distance, are one of the many types of AGN.

These galactic candles are so energetic that their radiation and the force of their winds is thought to inhibit the formation of new stars, as well as preventing any gas surrounding the galaxy from falling into it. This process is called **AGN feedback**.

Groups, Clusters and Superclusters

Typical values for the mass of a given galaxy range from **10 million to a hundred trillion solar masses**. It is easy to see, therefore, that these supermassive objects will share a tendency to gather

together, or cluster, due to their interacting gravitational fields. The largest gravitationally bound object found in the Universe is the **galaxy cluster** (not to be confused with a *galactic* cluster!). This is a conglomerate of galaxies that are not only close to each other in space, but are also bound to each other by their combined gravity. A typical cluster has a mass of about one hundred trillion solar masses, and comprises somewhere between 50 and 1000 galaxies.

The large-scale structure of the cosmos is represented by these groups and clusters of galaxies. This structure is organized in a hierarchy of groupings, with the largest being the superclusters. The collective matter is formed into filaments and walls, leaving large voids in between.

Salary

According to the American Institute of Physics &
(<http://curious.astro.cornell.edu/question.php?number=23>)

Astronomer PhD

Average: \$78,000

Range: \$60,000-\$100,000

A post-doc right out of graduate school

Average: \$36,000

Range: \$35,000-\$42,000