SOME RECENT CHANGES IN OUR UNDERSTANDING OF NORMAL GALAXIES

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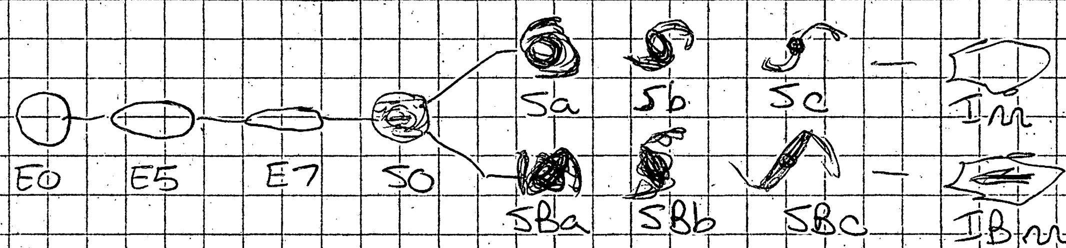
A. Normal galaxies are the dominant stellar systems in our universe: ~95% of all galaxies can be placed onto a rather simple classification scheme based on their optical appearance - Commonly known as the Hubble Sequence.

1) Tuning Fork Diagram (cf. Hubble Atlas)



Hubble-Sandage classification has been found to be very useful description of galaxies; most physical properties of galaxies appear to be continuously variable along this sequence, such as mixture of young/old stellar population; gas-to-luminosity ratio; rotation curve properties.

2) A Basic Question of Galaxy Study - How did the Hubble Sequence Originate? Are the physical properties of galaxies

a) primarily dictated by the initial conditions of galaxy formation; or

b) primarily determined by stochastic interactions with other galaxies; or

2.) c) determined through a combination of a) and b) above.

3.) The basic data for galaxies, such as mass distribution, luminosity distribution, total mass, total luminosity, are relatively difficult to obtain; only in a few, nearby galaxies can one measure individual stars. The lack of a large body of physical data on galaxies has meant that many different, but reasonable, theories of galaxy formation and evolution can be proposed, and be consistent with the available data.

Even with modern observational techniques, this situation is changing slowly. The main objective of this lecture is to describe two substantial changes in our physical understanding of galaxies that have occurred in the past five years; and a third change that may be on the horizon.

4.) Three useful concepts to get one through the remaining lecture:

a). Mass-to-luminosity ratio (M/L): $M \sim V^2 R$, where V is measured at a galactocentric radius, R; L is the total luminosity of the galaxy.

b) Rotation curves: In order to obtain V at a given R, one must measure the motion of "test particles" in the gravitational field - i.e., a rotation curve.

Emission line rotation curves come from the

4. b) gas (optical or radio), are relatively easy to detect, and refer to a specific area in the galaxy.

Absorption-line rotation curves refer to the integral of the stellar distribution function along the line of sight in the galaxy - much harder to measure and interpret, but the only choice in galaxies without emission lines.

An important consequence of the necessity of using "test particles" - Rotation curves are tied to the luminosity distribution of a galaxy, so M and L are not strictly independent of one another.

c) Stellar Populations: "Young" stars include massive stars which are very blue; however red stars (e.g. giants, supergiants, G, K + M stars) can also be "young". "Old" stars are basically red - all massive stars have evolved away. In a not-too-inaccurate shorthand, a blue stellar population implies young stars; a red stellar population usually implies old stars - all taken at a constant metal content in the stars.

B. Recent Changes in Our Understanding of Normal Galaxies

1.) The Structure of Elliptical Galaxies:

a) Everyone assumed that the ellipticity of ellipticals was due to angular momentum - rotation - and that ellipticals were oblate spheroids. It was the simplest interpretation of ellipticals and, with it, a large body of theory was developed which adequately described the known physical properties of ellipticals.

b) However, when observational techniques had sufficiently developed to where stellar absorption-line rotation curves could be reliably measured, it was found that most ellipticals rotate little or not at all; certainly not enough to support their shape! (1975-1979; Barbon + Cappacciolli; Illingworth; Schechter + Gunn; Davies).

Consequently, the large body of theory concerning rotating oblate spheroids has been incorporated as a special case of a new body of theories incorporating anisotropic stellar velocity distributions resulting from initial conditions (esp. Binney). Whether ellipticals are oblate, prolate or triaxial, or a combination of all three (i.e., some of each) is currently a matter of some debate.

2. Mass Distribution in Galaxies

a) Optically, galaxies are centrally-condensed, with rather well-defined centers; the total luminosity of a galaxy can be specified rather accurately. A long-cherished belief of astronomers had been that the mass in a galaxy was directly associated with the luminous material - stars & gas - in the galaxy. Since the radial luminosity distribution is a sharply decreasing function of galactocentric distance, most everyone assumed that the total mass of a galaxy can be specified and, as a result, rotation curves should reach a maximum velocity and then fall in an approximately Keplerian manner. Early (pre ~1970) rotation curves were noisy, and falling rotation curve models could be fit to the data. Few people thought it was important that such models were not unique.

b) Modern rotation curves, both from optical (mainly Rubin and collaborators) and radio HI observations (many authors - esp. Roberts; cf. Bosma's thesis) show that rotation curves of <u>normal</u>, <u>unperturbed</u> spirals do <u>not</u> fall. In fact, many rotation curves are rising at the last measured point, even when that point is on an HI 21 cm rotation curve at several times the optical radius of the galaxy!

(6)

2) c) It is probable that most of the mass in a galaxy is in an unseen or, at least, under-luminous form. Such a mass component in spiral galaxies was actually first proposed theoretically by Ostriker and Peebles in 1973 to provide enough mass to stabilize a stellar disk. Many attempts to detect this component via its radiation have failed - hence the term unseen; but its presence is known indirectly, through gravitational effects such as flat rotation curves. Percentage of unseen mass in a galaxy is unknown: not likely to be less than 50%, could be as much as 90%.

Footnote: Although evidence of flat rotation curves has been around for 10 years, only in last 1-2 years has evidence been so overwhelming that most astronomers have been forced to accept it.

3) A change on the horizon - The Ages of Stars in Galaxies

a) Since galaxies were recognized as such (only a little over 50 years ago) it has generally been assumed that stars almost as old as the universe made-up the underlying stellar population in spirals, and the population of stars in ellipticals. Globular clusters, especially red globular clusters, were considered to be very old, and globular clusters are found in all galaxies of the Hubble sequence. However, while it is true that an

3) a) old globular cluster is red; it may not necessarily be true that all red globular clusters are old and of the same age.

b) The Clouds on the Horizon:

1) It is very hard to distinguish a stellar population that is 7×10^9 yrs old from one that is 14×10^9 yrs old, especially when differences in chemical composition are invoked.

2) Recent methods to "date" globular clusters indicate

i) Globular clusters in the Magellanic Clouds have a wide range of ages, from $\leq 1 \times 10^9$ yrs. to $\geq 7 \times 10^9$ yrs (mainly from work of Searle & collaborators).

ii) Galactic globular clusters may also have a range in age, from 7×10^9 yrs to 16×10^9 yrs (Carney), but currently much debate on this point.

At the very least, available data show that formation of globular clusters ~~was~~ is not limited to the early history of a galaxy, but ~~took~~ can take place over a long period of time.

c) Studies of the integrated stellar population of a nearby "old" elliptical, M32, indicate that at least a significant percentage of its light comes from stars $\approx 7 \times 10^9$ yrs old (O'Connell)

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3) c) i) Observations of more distant, more luminous ellipticals indicate stellar populations similar to ~~that~~ of M32.

ii) At least one globular cluster in M31, B282, has a similar stellar population to M32. While an argument can be made for M32 ~~that~~ a young stellar component was due to a later influx of gas material onto an already-formed stellar system, such an argument does not apply to a globular cluster.

d) ~~Detection~~ of Carbon Stars in Dwarf Spheroidal Galaxies (Aaronson & Mould). Dwarf ellipticals have usually been assumed to be as old as normal ellipticals, but much more metal-poor.

i) Carbon stars are relatively massive and, hence must be young; thought to be supergiant evolution of A-F stars, $\lesssim 3 \times 10^9$ yrs old.

ii) ~~[illegible]~~ Their presence in dwarf ellipticals indicates significant fraction of ~~[illegible]~~ stars are young.

e) Overwhelming predominance of Carbon stars in the LMC and SMC, compared to the bulge of our galaxy (Blanco & McCarthy); cf. also work of Butcher).

f) No evidence of stars $\gtrsim 7 \times 10^9$ yrs old in the disk of our galaxy.

3) g) This issue is so new that it is not yet the subject of hot debate, but it probably will become one in the near future. Evidence for large age differences within a stellar population mainly circumstantial at the moment.