Galaxies: Structure, formation and evolution

Lecture 19

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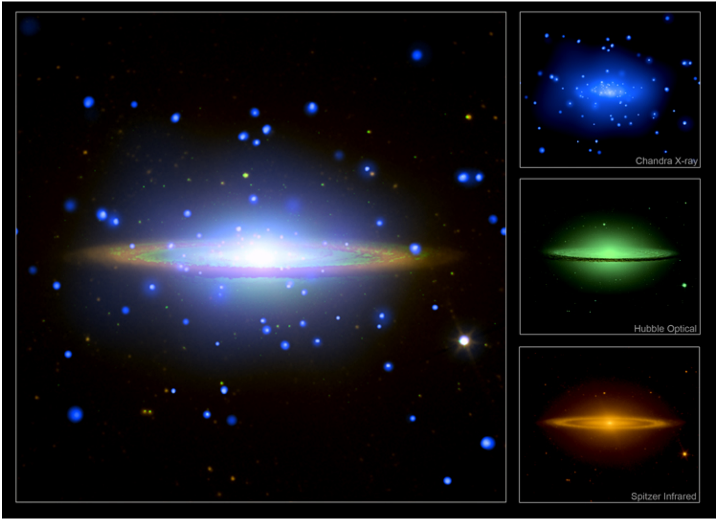
Measuring SFR from X-ray emission

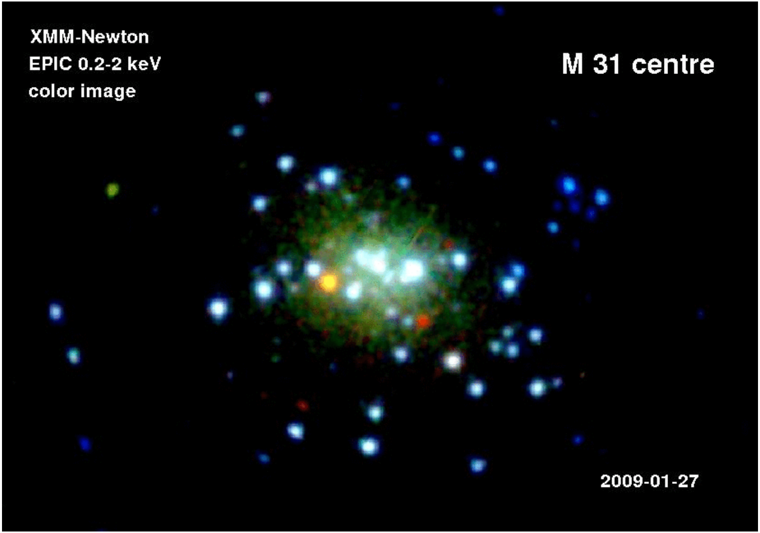
In star-forming galaxies, the X-ray luminosity is produced by high-mass X-ray binaries, massive stars, and supernovae, but non-negligible contributions from low-mass X-ray binaries are also present. The latter are not directly related to recent star formation, and represent a source of uncertainty in the calibration of SFR(X-ray).

ULX in star forming galaxies



Why resolution is important?

ULX in center of M31



GAMA seminars on 26/27 April 2022

- You will each have 17 minutes to speak with 3 minutes for questions.
- You will be graded on
  - Content (10 marks): Did you place the talk in context? Did you read and understand your paper and auxiliary papers? Did you answer the questions well?
  - Presentation (10 marks): Were the slides well ordered? Was text legible? Were figures readable? Did you pace the presentation well? Was your speech clear and confident?
  - Timeliness (5 marks): full marks for going -4 to +2 of specified time. Strong penalties outside this range.

Seminar Schedule on both days

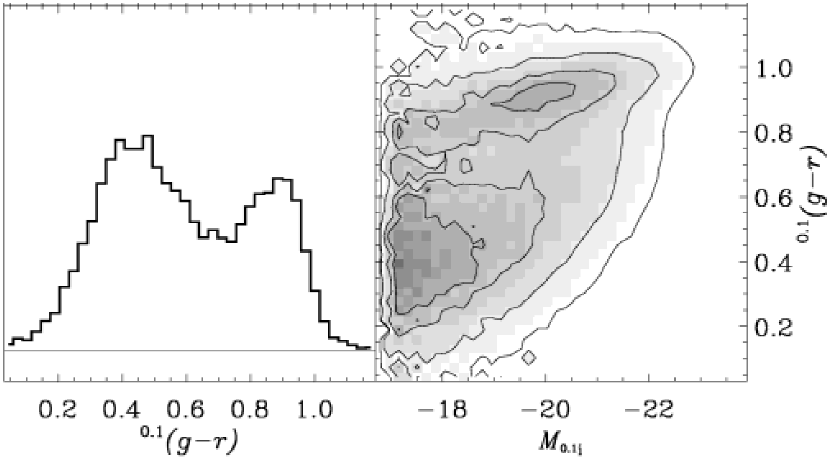
- Session 1: 9:30-11:10 (5 talks)
- Session 2: 11:30-1:10 (5 talks)

I will group and order your talks on the website.
Present your talk at a level that your classmates can understand and as if you did the work yourself.

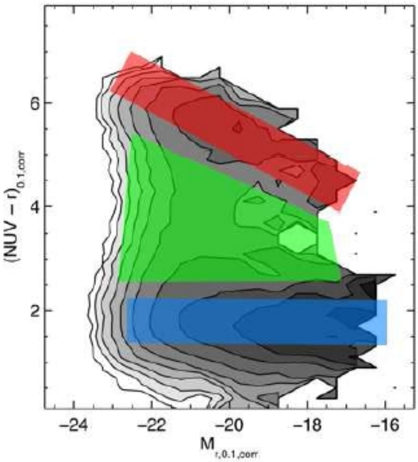
Connection between star formation history and morphology

Galaxy morphology, star formation history, stellar mass and projected

Red sequence, blue cloud and the green valley



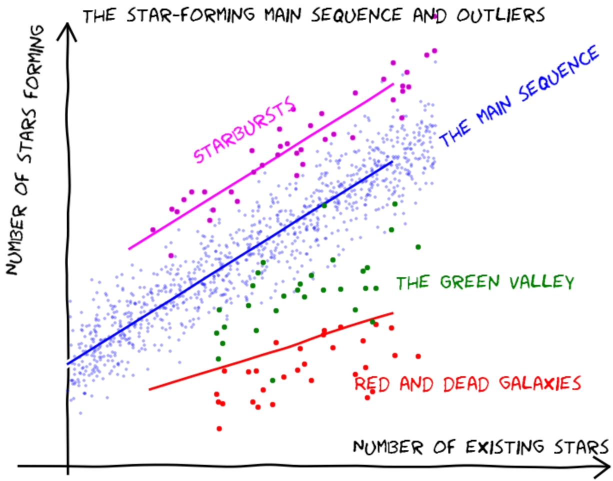
Another view



Red and blue galaxies

Galaxies are well known to divide into two large families: red, old ellipticals and blue, star-forming spirals. The SDSS has shown that, in the local universe, the division into these two large families happens at a stellar mass of $\sim 3 \times 10^{10} M_{\rm sun}$.

Galaxy main sequence



Note that both axes are log scale.

Galaxies differentiated by stellar mass

Low mass	**High Mass**
young stellar populations	old stellar populations
low surface mass densities	high surface mass densities
low concentration	high concentration
lots of gas	little or no gas
blue cloud	Red sequence
fast rotators	Slow rotators
spiral	elliptical

Gas supply and quenching seems to be most important parameters regulating this red/blue division

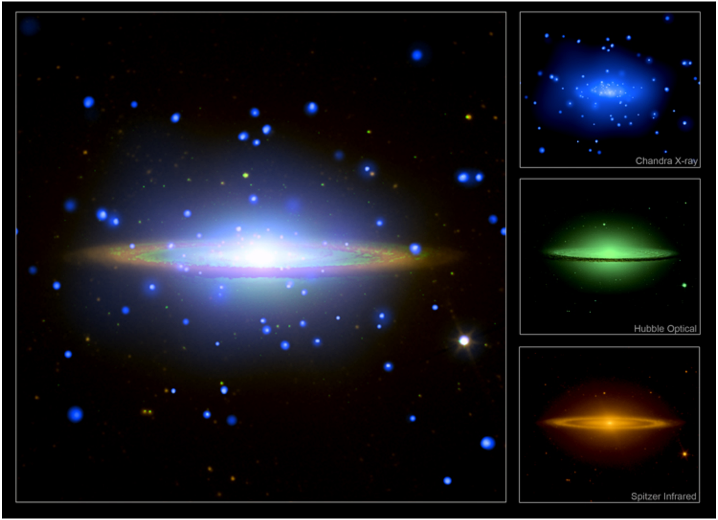
Question

Where does the Milky Way sit on this diagram? Where will it sit in the far future? What kind of galaxies are present in the green valley?

What inhibits star formation in the most massive ellipticals?

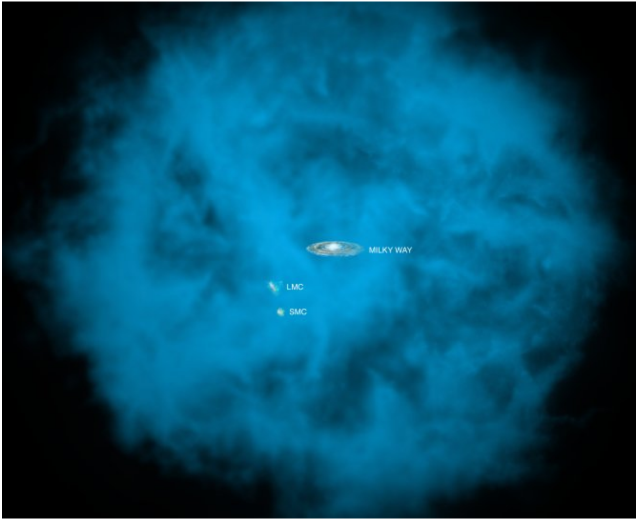
Various possibilities exist: Has star formation stalled in these galaxies because the gas supply has been fully consumed? Or has the gas been pushed to the outskirts of these galaxies e.g. by tidal effects or ram pressure stripping, or heated to temperatures that inhibit the gravitational collapse needed to form new stars?
For the most massive ellipticals, which mostly sit at the centers of rich clusters, it is the hot halo (seen in X-ray observations) that prevents further infall of gas.

The hot halo of the Sombrero galaxy



Pre-Chandra LMXBs unresolved.

Milky Way hot gas halo discovered in 2012



Anjali Gupta et al. (2012)

Evolution of the hot gas halo

The evolution of the hot halos is the result of a tug of war between the pull of gravity and the push of feedback from stellar evolution (SNe Ia) and AGNs, as well as interactions with the circum-galactic medium and galaxy encounters.

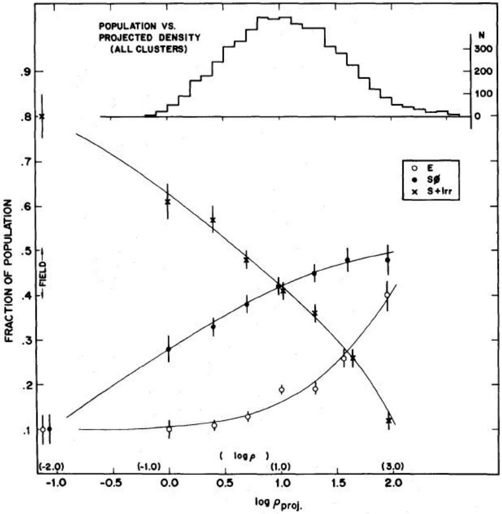
If there is equilibrium, then one can measure the mass of a galaxy or cluster via hydrostatic equilibrium.

The discovery of these hot halos and the characterization of their properties have been unique contributions of high resolution X-ray telescopes (Chandra/XMM) to astronomy.

The most important parameter

that defines how a galaxy will evolve seems to be **stellar mass** and **morphology**.

Morphology density relation



Dressler (1980)

classified 6000 galaxies in 55 clusters plus 15 field regions. He recorded positions and local projected galaxy density. He found:

- Strong dependencies of f(Sp), and f(E) on projected local galaxy density. In poor clusters, the trend is stronger with local density than with simple cluster radius
- The dependency of f(S0) is weaker than f(E) or f(Sp)
- The effect occurs in regions of sufficiently low density that gas stripping or encounters cannot operate.

He claimed: The primary effect is with local galaxy density NOT cluster radius. The effect occurs at galaxy formation, and is not an ongoing evolutionary process.

But there is major debate on its origin

- High densities inhibit the formation of spirals.
- Spirals may be stripped of gas to make S0s
- Bulges may “grow” by accretion of dwarfs
- S0s may not be a homogeneous class: some originate as spirals, others not. **Stellar mass** important.
- Spirals experiencing “harrassment” (Moore et al 1996) can resemble S0s. rapid gravitational shocks disturb spiral structure and “heat” the disk stars.
- Spiral mergers may create S0s and/or Es.

Ram pressure stripping - Gunn and Gott (1972)

One of the (several) possible environmental effects on galaxies in clusters is the stripping of ISM due to ram pressure as the galaxy moves through the ICM. We can measure the HI deficiency which is defined as (M - <M>)/<M>, where <M> is the mean HI mass for galaxies of the same Hubble type. HI deficiency is found to increase (a) towards the center of clusters , in richer clusters of higher X-ray luminosity,

However, whether this is sufficiently efficient is unclear :

(a) Studies show CO is not removed (denser and deeper in galaxy potential) (b) Only the outer HI is stripped (eg HI map of Virgo shows smaller sizes in the core)

What does HST tells us about galaxy evolution?

Only with HST has it been possible to study morphology at high-z ($z \sim 0.5$). This gives insight into whether the morphology-density relation stems from galaxy formation **nature** or galaxy evolution **nurture**. HST studies find :

- f(E) is the same as low-z
- f(S0) is lower by factor 2-3
- f(Sp) is higher by factor 2-3
- the morph-density relation is absent in irregular clusters.

What does this imply?

Galaxy evolution in clusters?

- Ellipticals formed earlier (at even higher z)
- For Es, the density at formation is most important
- Spirals are converted into S0s, in an ongoing process which depends on density (some combination of stripping, mergers, harassment)

This is an active area of research, with many details still to be worked out. The outline I have given here is cleaner than the true situation at this time.

What remains to be done?

A broad picture of galaxy evolution has now emerged, but the gaps still need to be filled. Many questions need definitive answers:
e.g. What is role of feedback processes - supernovae and AGN? How do stars in the late stages of life evolve? How much does obscured star formation contribute to luminosity density? What is the nature of dark matter?