Galaxies: Structure, formation and evolution

Lecture 1

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Galaxies are a very active field of research today!

Just over 25% of papers published on ADS in 2021 were on galaxies, 8084 refereed papers in 2021 alone.
Most things covered in this course were discovered in the last 20 years.

Course Website

http://www.ncra.tifr.res.in/∼yogesh/galaxies_2022/

Best way to reach me is by email at *yogesh@ncra.tifr.res.in*
The PDF file for each lecture will be put on the website immediately after it is given. So, don't bother copying stuff that is already on the slide.

Course will be in hybrid mode

Lectures will be live in the NCRA Lecture Hall. Remote participants can join via the Zoom link sent to you.

Introductions

Assessment

- 60% weightage for 2 assignments to be given at the end of the third week and the sixth week. Roughly 2.5 weeks time to hand in each assignment.
- 25% weightage for paper presentation at the end of the course
- 15% for class participation. Asking and answering questions
- No exams!

Assignments

Assignments gain you the majority of marks. So spend enough time on them. Many assignment problems will require modest amount of computer scripting and use of plotting software. Make sure that you are comfortable with computer programming. Good time to learn, if not!
If you want to learn Python from scratch, then my recent online course on Astronomical Data Analysis with Python may be helpful.
https://www.iucaa.in/∼ace/programs/

Paper review

Each one of you chooses a paper to study thoroughly and then gives a presentation on it at the end of the course.
Do discuss amongst yourselves, choose a paper no one else has chosen and let me know via email. If multiple people want to cover the same paper, we will need to resolve this amicably; get in touch with me.
You should present the paper as if you wrote it yourself!

Seminar papers to be selected from a long list

http://www.gama-survey.org/pubs/

Each talk will be 17 mins + 3 mins for questions. Discuss amongst yourselves, choose a paper and let me know by 23 March 2022. Choose a **refereed paper** from the list. You may want to make sure you choose a paper that is not too long or complicated to explain in 17 minutes.

Course tutor - Yash Bhusare

He will evaluate the assignments and also help me evaluate the paper review seminars.

The official syllabus and why I don't like it!

Galaxies : Structure, Dynamics and Evolution
Galaxies as self gravitating objects, virial equilibrium - Estimates of collision times - Collisionless Boltzmann equation and some steady state solutions - Globular clusters - stability - Spiral structure, bars and disc dynamics - Ellipticals - Galaxy morphology - Chemical evolution - Galaxy formation and evolution.
Many active research topics not covered in any other course are missing - e.g. star formation, stellar population synthesis, high redshift (emission/absorption line) galaxies.

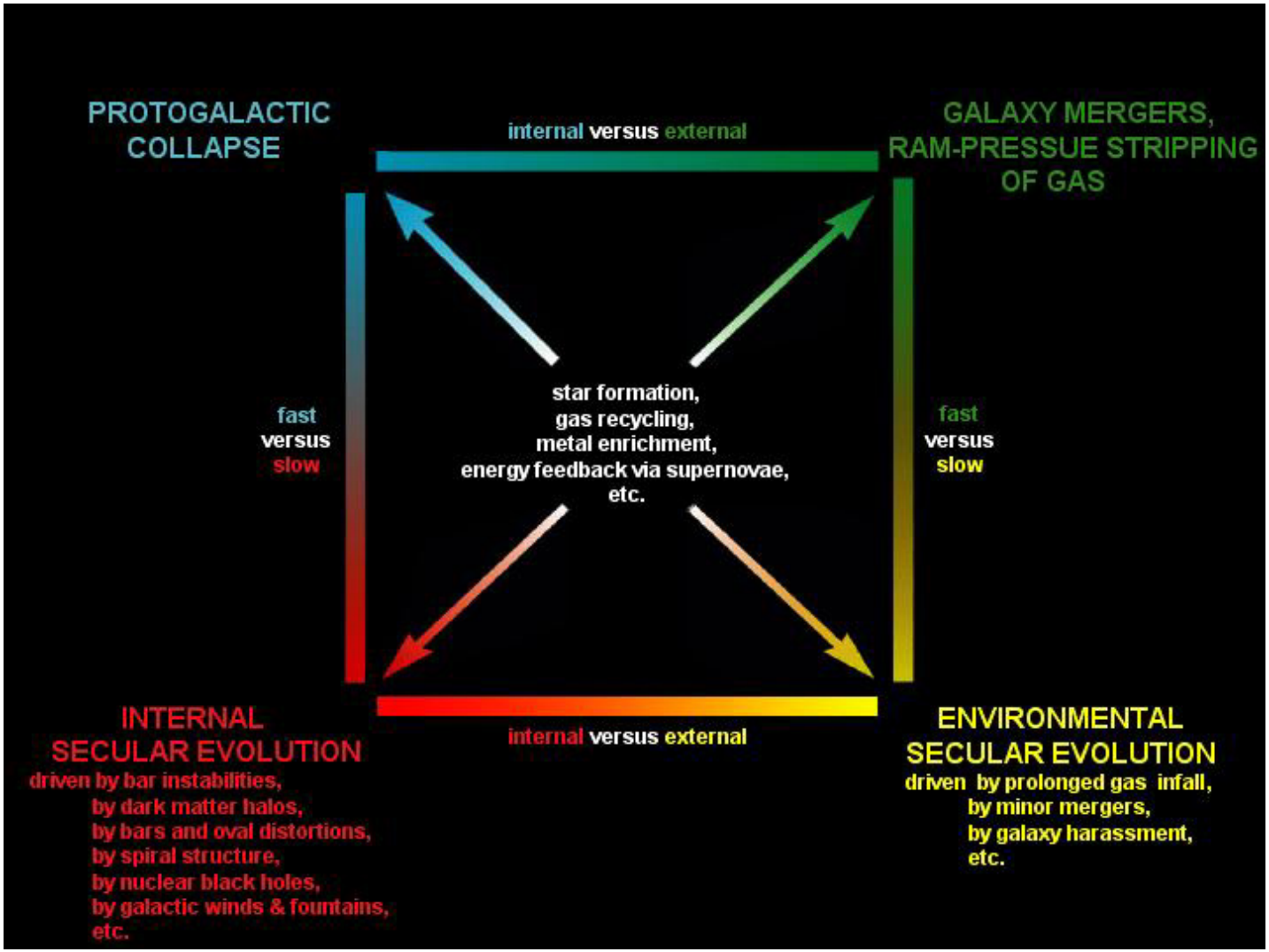
This course has linkages to many other courses

- Extragalactic Astronomy I (Cosmology): quasar absorption systems - high redshift galaxies in absorption
- Interstellar Medium: Extinction and reddening of star light, dust - Ionised gas - HII regions - Molecular clouds and star formation.
- Extragalactic Astronomy II (Radio Galaxies and Quasars): Phenomenology of AGNs

My course on galaxies will cover

- Background material and Overview
  1 A brief History of extragalactic research 2 **Morphological Classification** 3 **Surveys & Quantitative morphology** 4 Galaxy Luminosity Functions
- Normal galaxies
  5 Spiral and Irregular Galaxies 6 Stellar Kinematics I : Disks 7 Elliptical and Lenticular Galaxies 8 **Stellar Kinematics II : 3-D Systems** 9 Gas & Dust in Galaxies 10 **Stellar Population Synthesis**
- Interactions & activity
  11 **Star Formation & Starburst Galaxies** 12 Galaxy Interactions & Mergers 13 Galaxy Groups & Clusters 14 Galaxy Nuclei & Nuclear Black Holes 15 Active Galaxies & Quasars
- Formation and evolution 16 The Cosmological Framework 17 Growth of Large Scale Structure 18 Galaxy Formation, **high** z **galaxies& Evolution** 19 Reionization & the IGM 20 Dark Matter & Gravitational Lenses

The big picture



Textbooks and reference material

Unfortunately, I cannot find one textbook that is both comprehensive and current for our purposes. I have put up a list of books that I am refering to that you may also find useful, on the website.
I have put in a lot of effort to make good slides for my talks. Use these as your primary reference material and remember to stop me and ask questions if you don't understand something. Some of the slides will cite papers which you are encouraged to read to know more.

Questions about the course content and organisation?

Three ubiqitous structures in the Universe

- Atoms
- Stars
- Galaxies

Kant's "Island Universes"

In 1755 he wrote a book called *General Natural History & Theory of the Heavens* in which he said:

1. MW like huge solar system, rotating; origin from rotating cloud.
2. stars far from disk plane on different orbits
3. disks (like MW) project to ellipses
4. oval nebulae (seen by de Maupertius) = "Island Universe"

Major milestones since Kant

- 1755: Kant's Island Universes
- 1912: Slipher discovered that nebulae are rotating
- 1920: Shapley-Curtis debate "Are Spiral Nebulae Island Universes" - 30 minute presentations by each - Shapley "won" the debate, although Curtis was right.
- 1925: Hubble discovered Cepheids in the Andromeda galaxy

Extragalactic astrophysics $<$ 100 years old

What are galaxies?

- agglomerations of stars, dust, gas, dark matter.
- Average Mass ratio Gas:Stars:Dark Matter - 1:10:100
- they are the basic building blocks of the Universe on large scales
- they show a **broad range in their physical properties**
- Understanding of galaxy formation and evolution is one of the main outstanding problems in modern cosmology
- there are $\sim 10^{11}$ galaxies in the observable universe
- typical total mass of $10^8 - 10^{12}\ M_\odot$

Counting and cataloging galaxies

- In late 1700s,Messier made a catalog of 109 nebulae so that comet hunters wouldn't mistake them for comets! About 40 of these were galaxies.
- NGC New General Catalogue (Dreyer 1888) had 7840 objects, of which about 50% were galaxies. e.g. NGC 4993, 40 Mpc away where the first GW neutron star merger was detected in 2017.
- In the 20th century, many catalogs were produced UGC, RC3 etc.
- Nowadays we have automated digital surveys, e.g., DPOSS, SDSS, with tens to hundreds of millions of galaxies. How should we label them?
- Coming very soon are large surveys like Rubin/LSST which will provide photometry for 10^{10} galaxies, from the local group to redshifts $z > 6$. It will provide useful shape measurements and six-band photometry for about 4×10^9 galaxies

First step census, second step classification

third step understanding are common steps in any empirical science.
Hubble proposed a scheme for classifying galaxies (the ”tuning fork” diagram) in his 1936 book, *The Realm of the Nebulae*. This scheme survives in its essence to the present day.
ellipticals, lenticulars, spirals and irregulars (very diverse!) are the main types.
A better approach may be to look at the properties of kinematic subsystems within galaxies (e.g., disks, spheroids, halos, etc.), and deduce their origins and evolution.

Why is galaxy classification useful?

- Classes bring order to diversity of galaxy forms
- Span/include majority of galaxies
- Unambiguous & easily identified criteria
- Relate to important physical properties $\rightarrow$ provide insight into internal processes, formation, & evolution

Why classify galaxies in the optical band?

Historically, optical imaging was the method used to observe galaxies. Hence Hubble's classification is most widely used. Also, optical light is the best way to trace stars and dust (in absorption).
Today, many other criteria such as color indices, spectroscopic parameters (based on emission or absorption lines), the broad-band spectral energy distribution (galaxies with/without radio- and/or X-ray emission) are also used to group galaxies together.