Formation and Evolution of Galaxies

SUMMARY.
This METEOR deals with extragalactic astronomy and presents our current knowledge on the formation and evolution of galaxies, both from the observational and theoretical points of view. The intrinsic and statistical properties of galaxies as well as their evolution in time are reviewed taking into account the most recent observational data sets. Detection and measurement issues, especially of (very) high-redshift objects, are addressed on this occasion. Key ideas on the hierarchical growth of structures within a ΛCDM cosmology are given and physical processes involved in the formation/evolution of galaxies are explained. All these topics prepare the student for state-of-the-art research in that domain. Moreover, by reproducing some results by his own during the pratical part, the student will first gain practice in finding, downloading and manipulating data for the project he chose and second will learn basics in data/image analysis, error statistics, estimation theory and data modeling.

OBJECTIVES

- Students will know about our current knowledge about the formation and evolution of galaxies within an evolving universe dominated by dark components, about the key observational facts, signatures, and the main physical processes at play. Student will be able to measure galaxy shapes in parametric and non parametric ways, estimate star formation rates, compute luminosity densities, derive optical depths and ionisation fractions, model absorption or emission lines, etc.
- Students will be able to understand the scientific content of papers dealing with this topic, identify the main questions and hypotheses, compare applied methods, check conclusions against results from other similar papers. Students will also be trained by pratice in selecting, finding, downloading relevant data for their research using on-line databases and other electronic ressources, as well as in data analysis, estimation theory and model fitting.

PREREQUISITES

Having been teached the fundamental courses listed hereafter is not mandatory but recommended to take most benefit from this METEOR : General Astrophysics ; General Relativity, Extragalactics and Cosmology.

THEORY

by E.Slezak

The study of galaxy formation and evolution is an active and rich research area in astrophysics. It aims to provide us with a clear understanding on how the properties of each individual galaxies result from their formation mechanisms and the various physical processes playing a role during their evolution. Many factors indeed contribute to the morphological, dynamical and chemical development of a galaxy during its hierarchical build-up from smaller entities and gas infall evidenced by theoretical simulations. This investigation implies first to characterize in great detail the intrinsic properties (luminosity, morphology, color, activity, etc.) of galaxies over a large range in lookback times in relation to their environment (field, group, cluster). One also need to measure over cosmic time the statistical properties of the galaxy population as a whole in order to link these formation and evolution processes to the underlying evolving cosmological density field and get answers to key questions. For instance, what is the global star-formation history of the Universe or the relationship between the mass assembly of the galaxies, the interaction and merger rates, the build-up of the stellar content and the feedback processes (from stars to supermassive black hole growth) ?
In order to provide the background of the observations and physics required for understanding the formation and evolution of the galaxy populations in an Universe dominated by dark matter/energy, the syllabus covers the

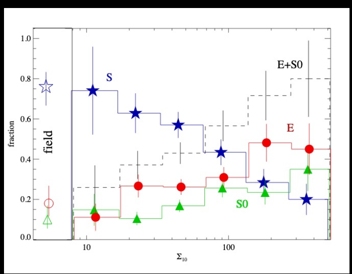
following topics : i) the galaxy properties, including morphologies, luminosities, spectra and dynamics with the fundamental correlations ; ii) the luminosity/size/colour/metallicity distributions of the galaxies and the nature of the environment dependence ; iii) galaxy interactions and mergers, with the related starbursts, structural transformations and kinematics signatures ; iv) the luminosity and mass assembly of galaxies, along with the methods used to identify high-redshift galaxies, the early stages of galaxy evolution and the mapping of the star-formation history ; v) the phenomenology of Lyman-α absorbers and the physics of the Lyman-α line ; vi) the phenomenology, physics and evolution of central black holes, active galaxy nuclei and quasars with their links to the evolution of galaxies.

APPLICATIONS

Different applications can be chosen.

APPLICATION 1

by E.SLEZAK



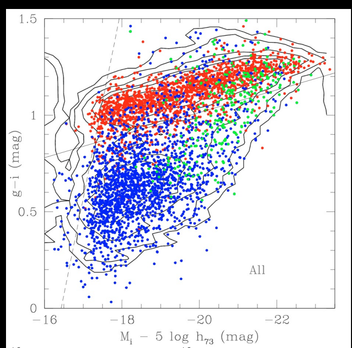
(Ma & Ebeling 2011)

Galaxies have different morphologies, colours, luminosities, and masses. It appears that the mix of the different morphological types do depend on the local environment conditions, with spheroidal-like objects like elliptical galaxies mostly found in high-density regions while disky objects like spiral galaxies dominate the population in the field regions. This result, which can be quantified in different ways, is thought to be a consequence of different physical processes acting onto galaxies and shows that the evolution of these galaxies is at least partly due to interactions with neighbours, the intergalactic medium or both.

In this applicative part, one will have to reproduce and study this result. To do so, one will first be provided with : i) more details on the physical processes at play in high density regions like mergers and ram-pressure stripping ; ii) a description of model fitting techniques and useful algorithms/softwares if necessary. Then, by making use of on-line databases, one will have to download data for different fields, either primary images or catalogues of galaxies depending on the skills of the attendee, and extract/obtain/compute the information required for the project accordingly, that is a proxy for the morphological type of each galaxy within the various fields and an estimate of the local number density of galaxies at each location. Finally, the dependence of the chosen proxy with the density of galaxies will be computed, discussed and compared to recent similar studies.

APPLICATION 2

by E.SLEZAK



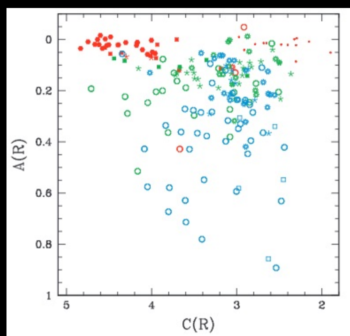
(Gavazzi+2010)

Galaxies with different morphological types have different colours and masses due to different merger histories and past/current star formation rates. This diversity is clearly exhibited in a colour-magnitude diagram which enables one to identify the so-called red sequence of passive elliptical galaxies, the blue cloud of spiral galaxies actively forming new stars, and the green valley of quenched spirals in between. Since elliptical galaxies are a tracer of over-dense regions of galaxies, namely clusters of galaxies, such a red sequence is used to detect dynamically relaxed clusters of galaxies, characterize them and identify their galaxy members.

In this applicative part, one will study the demographics of the galaxies for different fields with or without known (super)clusters of galaxies, at low and high redshifts. To do so, one will first be provided with more theoretical information about quenching mechanisms and AGN feedback processes. Then, colour-magnitude diagrams will be built for the different fields under study by downloading the relevant data using on-line databases. The transition between star-forming galaxies and quiescent ones will be mapped and the red sequence(s) used to identify existing clusters with their galaxy members in the various fields. (Automatic) detection issues of this red sequence will be addressed at this step. Finally, a modeling of these red sequences will be performed and the variation of the slope parameter with the redshift discussed in terms of mass assembly and star formation efficiency.

APPLICATION 3

by E.SLEZAK



(Conselice+2015)

Galaxy structural analyses provide unique information about the formation processes that change galaxy structures over time. Parametric fitting using bulge/disk decomposition and a Sersic function to measure galaxy sizes and surface brightness profiles is extensively used for local galaxies. Non parametric methods, based for instance on the concentration, asymmetry and clumpiness (CAS) system, appear well-suited for analyzing the major features of more distant objects lacking spatial resolution and therefore for deriving galaxy evolution over cosmic time. Such an approach is currently tested to get reliable morphologies for the forthcoming Euclid mission.

In this applicative part, one will classifiy realistic galaxies simulated for Euclid using a generative model and test the ability of the CAS system to discriminate among morphologies. To do so, one will first get a deeper insight into the assumptions, limitations and biases of the different methods used nowadays to quantify galaxy structural components and learn about generative adversarial (neural) networks. Questions related to noise issues, PSF blurring, reproducibility and parameter degeneracies will be addressed as well the benefit of using priors when modeling embedded physical components (eg. bulge, disk, bar, spiral arms). Then, one will implement the CAS measurements and perform the classification of a list of galaxies sampling the whole morphological range including peculiar (disturbed) cases. Finally, efficiency and completeness of this approach will be computed thanks to the truth table, and results discussed in terms of single/mutiple components, bright/faint features, regular/irregular shapes.

MAIN PROGRESSION STEPS

Basically, two courses are scheduled each week to provide theoretical/observational notions (12 sessions in total) as well as one session per week (6 in total) to introduce and supervise the practical project. In addition, students may benefit from remote assistance all along the period if requested.

- First third of the period : i) theoretical courses : main properties and demographics of the galaxy population in the local Universe, key physical processes at play in galaxy evolution within the ΛCDM hierarchical model of structure formation (+ exercices) ; ii) start of the homework bibliographical study and of the practical projet.
- Second third of the period : i) theoretical courses : structural parameters and evolution in time of sizes, evolution of the Hubble sequence, mergers, luminosity functions (+ exercises / presentation of a review paper) ; ii) homework is on-going, first results from the practical projet.
- Last third of the period : i) theoretical courses : evolution of the cosmic star formation rate density, the Lyman-α universe and the reionisation epoch ; ii) bibliographical study (report due), final results and report for the practical project.
- Last week : preparation of the final oral defense.

EVALUATION

- In addition to the oral defense in front of a jury, evaluation involves some regular exercices and the oral presentation of a review paper for the theoretical part as well as two reports corresponding to a bibliographical study and a data analysis project for the practical part.
- These different type of examination aim first to complement the course by providing some mathematical demonstrations and further information while training the student to : i) derive some astrophysical quantities or observational laws from physics principles ; ii) summarize a paper in terms of research questions, background, methods, and results ; iii) act as a junior researcher starting a new project. Second, the two practical homeworks enable the attendee to : i) make use of on-line ressources to retrieve relevant information and to relate them to notions learned during courses ; ii) learn how to get and analyze real data to reproduce some other results by developping and using his/her own codes.
- The final mark takes into account the oral defense (40%), the theoretical part (30%) and the practical part (30%). For the theoretical part, the weight of the exercices is 40% of the total. for the practical part, the homework and the project have equal weights.

CONTACT

☎ +334 9200 31 24 (E.Slezak)
✉ eric.slezak at oca.eu