Laurea Magistrale Interateneo in Fisica: **ASTROPHYSICS OF GALAXIES - 6 CFU**
**Prof.: Marisa Girardi – A.A. 2018/2019**

Text books and reviews (in Trieste libraries or ask to the teacher) and teacher notes on moodle [**My**]:

"FUNDAMENTAL ASTRONOMY", Karttunen, Kroger, Oja, et al. [**K**] for basics or phenomenology;
"EXTRAGALACTIC ASTRONOMY AND COSMOLOGY", Schneider 2nd ed. 2015 - Springer [**S**] for extragalactic astronomy or basics;
"GALACTIC ASTRONOMY", Binney and Merrifield - Univ. Press, [**BM**] advanced text for basics and phenomenology;
"GALACTIC DYNAMICS", Binney and Tremaine, (1st ed.,1988) Princ. Univ. Press [**BT1**] for dynamics, 2nd ed. (2008) [**BT2**] for observational applications.

Limited topis or further insights "PHYSICAL PROPERTIES AND ENVIRONMENTS OF NEARBY GALAXIES", Blanton and Moustakas Schneider - Ann.Rev. Astron. Astrophysics 2009, 47, 159 [**BM09**] (from ADS abstract); "THE PHYSICS OF CLUSTER MERGERS", C. Sarazin [**S02**] in "Merging Processes in Galaxy Clusters" (from ADS abstract); Sarazin 1986 Review for Galaxy Clusters [**S86**]; Gary Mamon's course [**M**] CT2.pdf course complet http://www2.iap.fr/users/gam/M2/index.html; http://www.wolframalpha.com/ to make computations, integrals and so on.

# 1 Basics and Phenomenology

## 1.1 Astronomical Measurements and Quantities

[BM+K] Equatorial System. Precession. Parallax. Parsec. Proper motions. Radial velocity. Redshift. Intensity, flux, and luminosity. Apparent Magnitude. Pogson's Law. Colors. Distance modulus and absolute magnitude (corrections for galaxies, too). Bolometric magnitude. Mass to light ratio. Spectra: continuum, lines and bands, equivalent width; 21 cm line; forbidden lines in astronomy.

## 1.2 Stars and Milky Way

**Stars**[BM+K]: Harvard classification (O,B,A...types) and discussion of main spectral features (HeII lines, HI Balmer lines; H and K CaII lines, G band); luminosity classes and the MK classification; Hertzprung-Russel/Colore-Magnitudine diagram. **Spectra of galaxies**[My]: emission lines, Dn(4000), Hdelta, poststarbust galaxies (E+A/k+A). **Stellar luminosity function**[BM]: luminosity function, star-counts, concepts of limited magnitude limit and magnitude limited samples, fundamental equation of stellar statistics, Malmquist bias, observational results about the luminosity function. **Milky Way**[K]: open and globular clusters; main properties of interstellar medium (ISM); Dynamics: the Oort constants, the rotation for $R > R_0$ - tangent point method, rotation velocity curve and the presence of a DM halo. Structure: an overview.

## 1.3 Galaxies

**The Hubble low**[BM] and the expansion of the Universe. **Galaxies**[S+BM+My]: Morphological classification. Deprojecting galaxy images. Ellipticals: cD, giants and dwarf, brightness profiles (de Vaucouleurs law and the sersic index, Hubble-Oemler law, Hubble law), composition, boxy and disky and other minor details of structure. Spirals: trends in the sequence, brightness profile (exponential for disk, decomposition), rotation curves, stellar populations and gas fractions, arm and corona (hints). **Morphology-Density relation**[S+BM]. **Luminosity function**[S+BM]. **Dynamics**[S+K+My]: Virial theorem and mass estimate, the Tully-Fisher relation, the Faber-Jackson relation, the fundamental plane, the Dn-sigmav relation. **Main properties and environment**[S]: optical broad bands and spectral measurements, LF and environment, spirals: other details, lenticulars, ellipticals and other details, brightests cluster galaxies (BCG) and cD galaxies, peculiarities (interactions, mergers, starbusrst and poststarbursts).

## 1.4 Clusters of Galaxies

**The Local Group**[S] and the mass estimate of MW+M31 with the 2-body model. **Optical view** [S] Abell catalog and problems in the optical search. Morphological classification. Density profiles. Galaxy groups. **ICM**[S]: X-ray emission, morphology, gas distribution, cooling flows heating by ejection from galaxies[My/S86], the Sunyaev-Zeldovich effect and

distance determination, interaction between galaxies and hot gas [My], X-ray catalogs. **The beta problem**[My] and cluster formation and galaxies/gas equilibrium. **Substructure and cluster mergers**: optical and X-ray views [My], the physics of cluster mergers [S02]. **Cluster mergers and radio halos/relics** [My].

# 2 Dynamics

## 2.1 Potential Theory [BT2, 1 similar]

**General results**: potential and gravitational field, Poisson eq., Laplace and Gauss theorem in gravitation theory, the potential-energy tensor. **Spherical systems**: Newton theory., circular velocity, escape velocity, the potential of simple systems (mass point, homogeneous sphere, Plummer model, Hubble modified model, model of power low density, model of 2 power lows density, Navarro model, Sersic model [My]). **Potential for flattened systems**: models of Kuzmin, Miyamoto and Nagai, logarithmic. potentials, eq. of Poisson in very flattened systems. **The potential of our Galaxy** [My].

## 2.2 The Orbits of Stars [BT2, 1 similar]

**Orbits in static spherical potentials**: spherical harmonic oscillator, Keplerian potential and eq. of orbits, constant and integral of motion (hints).

## 2.3 Equilibrium of Collisionless Systems [BT1]

**The relaxation time** (crossing and dynamical times defined in this chapter, too). **Basis of Fluid mechanics**: continuity eq., Euler eq., hydrostatic equilibrium, barotropic eq. of state, wave eq. and sound velocity, ideal gas (isothermal, adiabatic, politropic). **The collisionless Boltzmann equation**: distribution function and phase space (DF), collisionless Boltzmann equation, advantages and limitations [+BT2], connection with observational quantities, "coarse grained" DF [+BT2]. **The Jeans theorems and spherical systems**: Jeans theorems, applications to systems with isotropic vel. dispersion tensor (politropic and Plummer models, eq. of Lane-emden, isothermal sphere, King models). Hints to more complex systems. Method to obtain the DF for a given density. **The Jeans equation and the local equilibrium**: Jeans eq., eq. in spherical coordinates and the case of a simple spherical system (stationary, non rotating,...+my/M]), velocity anisotropy, system mass from the Jeans eq.), connection with observational quantities, deprojected velocity dispersion profile, practical and theoretical problems in solving the Jeans eq.. **The virial theorem and global equilibrium**: tensorial virial theorem, the rotation of elliptical galaxies. **Application to the internal dynamics of galaxy clusters**[My]: "generalized" virial theorem, the member galaxy selection, the M/L ratio and mass estimate, surface pressure correction to the mass, galaxy orbits and velocity anisotropy. **The choice of equilibrium**: the max entropy principle, phase mixing, violent relaxation and velocity equipartition, the gas "infall".

## 2.4 Stability of Collisionless Systems [BT1]

**The Jeans instability**: the Jeans swindle, the Jeans instability for fluids, the Jeans instability for stellar systems infinite and homogeneous. Hints for limited and finite systems.

## 2.5 Collisions and Encounters of Stellar Systems and of Galaxy Systems [BT1]

**Dynamical friction**: Chandrasekhar formula and applications [+BT2], observations of mass segregation [My]. **High-speed encounters and impulsive approx.**: coming back at the equilibrium and the mass loss, tidal approx. and penetrating encounters (no dim.), applications [+BT2]. **Galaxy Mergers**: merging criteria (hints).