Laurea Magistrale Interateneo in Fisica: **ASTROPHYSICS OF GALAXIES - 6 CFU**
Prof.: Marisa Girardi – A.A. 2019/2020

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**]; "Extragalactic Astronomy and and Cosmology", Schneider 2nd ed. 2015 - Springer [**S**]; "Galactic Astronomy", Binney and Merrifield - Univ. Press, [**BM**]; DYNAMICS: "Galactic Dynamics", Binney and Tremaine, (1st ed.) - Princ. Univ. Press I and II eds.[**BT1**] and [**BT2**], mainly BT1.

A small part from: "The Physics of Cluster Mergers", C. Sarazin [**S02**] in "Merging Processes in Galaxy Clusters" (from ADS abstract https://ui.adsabs.harvard.edu/abs/2002ASSL..272....1S/abstract).

USEFUL: Gary Mamon's course [M] CT2.pdf course http://www2.iap.fr/users/gam/M2/index.html is useful for the dynamics of galaxy systems; http://www.wolframalpha.com/ to make computations, integrals and so on.

1 Basics and Phenomenology

1.1 Astronomical Measurements and Quantities [mainly BM, cap2 and K]

Positions, motions, velocities: Horizontal system [K, cap2.4]. Equatorial system. Galactic coordinates. Precession. (Trigonometric) parallax. Parsec. Refraction of atmosphere [K]. Proper motion [K]. Moving-cluster method. Radial velocity and redshift [K]. *Magnitudes and colors:* Intensity, flux, and luminosity [K, cap4.1]. Apparent Magnitudes. Pogson's Law. Zero point. Colors. Absolute magnitudes. Distance modulus and corrections. Bolometric magnitudes. Mass to light ratios. Extinction and air mass [K, cap4.5]. Reminds and hints about radiation mechanisms [K, cap5]: ct. or line emissions, Lyman alpha and Balmer series, equivalent width, 21 cm line, forbidden lines in astronomy, luminosity from a black body.

1.2 Properties of Stars [mainly BM, cap3]

Classification and main properties: 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. Effective temperature. Mass-luminosity relation and lifetime on main sequence [S,B.2 and B.3, no details on stellar evolution!]. *The stellar luminosity function:* Stellar luminosity function. Star counts. Fundamental equation of stellar statistics. Magnitude limited samples and Malmquist bias. Uniform star distribution.

1.3 Milky Way [mainly S, cap2]

Distances: Photometric Distance, with color-color diagram too. Spectroscopic distance. Distances from binary stars. Distances of pulsating stars (hints). *Structure and content:* The structure of the Galaxy (basics): the Galactic disk (distribution of stars; dust and gas, open clusters), the Galactic bulge (the de Vaucouleurs profile); the stellar halo (distribution of stars; globular clusters). Summary tables for interstellar medium [K] and open/globular clusters [My,slides]. *Kinematics:* The Rotation of the Milky Way, Oort constants, the tangent method, rotation curve and dark matter [K,17.3].

1.4 Galaxies [mainly S, cap3]

The Hubble low and the expansion of the Universe. *Classification and main properties:* Morphological classification: the Hubble Sequence, the bimodal color distribution. Spectra of galaxies: emission lines, Dn(4000), Hdelta, poststarburst galaxies (E+A); SEDs [My,slides]. Surface photometry: the effect of seeing and deprojecting galaxy images [BM, 4.2.2 and 4.2.3]. *Ellipticals:* classification (cD, giants,dwarfs), brightness profiles (de Vaucouleurs law and the Sersic profile, Hubble-Oemler law, Hubble law, Kormendy relation), composition, kinematics, boxy and disky isophotes. *Spirals:* trends in the sequence, brightness profile (disk and bulge), Freeman law, rotation curves, arms and corona (hints). Virial theorem and mass estimate [K and My,notes]. *Scaling relations* [also My,notes]: the Tully-Fisher relation, the Faber-Jackson relation, the fundamental plane, the Dn-sigmav relation. *Population of luminous galaxies*: relations between morphology, n parameter of Sersic, color. *Extragalactic distance determination:* basics [also My,slides]. *Luminosity function:* Schechter LF.

1.5 Clusters of Galaxies [mainly S, cap6 and My]

The Local Group: phenomenology and the mass estimate of MW+M31 with the 2-body model. *Optical view:* Abell catalog and problems in the optical search, morphological classification, galaxy groups, spatial distribution of galaxies, virial mass, intracluster light (ICL). *Hot gas - ICM:* X-ray emission, morphology, gas distribution, hydrostatic equilibrium and mass determination, cooling flows, the Sunyaev-Zeldovich effect, X-ray vs. SZ catalogs. The beta problem [My]. Cluster mergers and radio halos/relics [My]. *Substructure and cluster mergers:* optical and X-ray views [My], the physics of cluster mergers [S02]. Relative mass distribution of matter, gas, and galaxies from multivawelenght observations: optical, X-ray, gravitational lensing [My]. *The galaxy population and environmental effects*: Morphology-Density relation; brightest cluster galaxies (BCG) and cD galaxies [My]; ram pressure of ICM [My]. *Scaling relations:* M200 and critical density; M-T, M-sigmav, Lx-T, E(z) factor. *Evolutionary effects:* the mass function (MF) and x-ray-luminosity function (LxF); Butcher-Oemler effect.

2 Dynamics

2.1 Potential Theory [BT1, cap2]

General results: potential and gravitational field, Poisson eq., Laplace and Gauss theorem in gravitation theory, potential energy, the potential-energy tensor. *Spherical systems*: Newton theorems, 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 [BT2 and notesEinasto from Mamon].

2.2 The Orbits of Stars [BT1, cap3]

Orbits in static spherical potentials: Keplerian potential and eq. of orbits, constant and integral of motion (hints, used for dynamical friction).

2.3 Equilibrium of Collisionless Systems [BT1, cap4]

Collisionless systems: the two-body relaxation, main applications to galaxies and galaxy clusters. *Basis of Fluid mechanics* [App.BT1]: 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, connection with observational quantities, "coarse grained" DF. *The Jeans equation and the local equilibrium*: Jeans eq., eq. in spherical coordinates and the case of a simple spherical system (stationary, non rotating, with avg. motions=0), velocity anisotropy, system mass from the Jeans eq.), connection with observational quantities (deprojection methods), 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, notes and slides]: "generalized" virial theorem, surface pressure correction to the mass, galaxy orbits and velocity anisotropy (slides). *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. *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, cap5]

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, cap7]

Dynamical friction: Chandrasekhar formula and applications, energy equipartition and mass segregation [slides]. *High-speed encounters:* impulsive approximation, coming back at the equilibrium and the mass loss, tidal approximation, penetrating encounters, applications [hints, BT2 for application to galaxy clusters]. *Tidal radii:* Jacobi integral and the tidal radius. *Galaxy Mergers*: criteria for merging (hints).