Laurea Magistrale Interateneo in Fisica: **ASTROPHYSICS OF GALAXIES - 6 CFU**
**Prof.: Marisa Girardi – A.A. 2021/22**

Text books and reviews (in Trieste libraries or ask to the teacher) and teacher notes/slides 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 K + BM, cap2]

*Positions, motions, velocities [mainly K]:* Horizontal system. Equatorial system. Galactic coordinates. Perturbation of coordinates (precession,etc.). (Trigonometric) parallax. Parsec. Refraction of atmosphere. Proper motion. Moving-cluster method [BM]. Radial velocity and redshift. *Magnitudes and colors [mainly K+BM]:* Intensity, flux [+BM], and luminosity. Apparent Magnitudes. Pogson's Law. Zero point. Colors. Absolute magnitudes. Distance modulus and corrections [+BM]. Bolometric magnitudes. Mass to light ratios [BM]. Extinction and air mass. Reminds and hints about radiation mechanisms: 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 K + BM, cap3]+S

*Classification and main properties [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/Color-Magnitude 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 [BM]:* Stellar luminosity function. Star counts. Fundamental equation of stellar statistics (dim.). Magnitude limited samples. Malmquist bias (dim.). Uniform star distribution.

## 1.3 Milky Way [mainly K+ S, cap2]

*Structure and content [K]:* The structure (disk+bulge+halo). Populations I and II. Basics about interstellar medium. Dust and dust extinction. Hints about open/globular clusters [only Myslides]. *Distances [K+S]:* Photometric Distance and MS fitting. Distances of pulsating stars. *Kinematics [K]:* The Rotation of the Milky Way, Oort constants (dim.), the tangent point method, rotation curve and dark matter.

## 1.4 Galaxies [mainly S, cap3 +BM]

The Hubble low and the expansion of the Universe [S cap1; My; BM]. *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 [BMcap4]. *Ellipticals:* classification (cD, giants,dwarfs), brightness profiles (de Vaucouleurs law and the Sersic profile, Hubble law [BM], 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). *Dynamics and scaling relatiions:* Virial theorem and mass estimate [dim., K and My,notes], the Tully-Fisher relation (dim.), the Faber-Jackson relation, the fundamental plane, the Dn-sigmav relation. *Population of luminous galaxies*: relations between morphology, n parameter of Sersic, color. *Luminosity function:* Schechter LF.

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

*The Local Group:* phenomenology. *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] (dim.). Cluster mergers and radio halos/relics [My]. *Scaling relations:* M200 and critical density; M-T, M-sigmav, Lx-T, E(z) factor. *The galaxy population and environmental effects*: morphology-density relation; brightest cluster galaxies (BCG) and cD galaxies [My]; ram pressure of ICM [My]. *Evolutionary effects:* the mass function (MF) and x-ray-luminosity function (LxF); Butcher-Oemler effect. *Substructure and cluster mergers:* optical and X-ray views [My], the physics of cluster mergers [S02] (dim. only dynamics no thermod.). *Relative mass distributions* of matter, gas, and galaxies from multivawelenght observations: optical, X-ray, gravitational lensing [My].

## 2 Dynamics

### 2.1 Potential Theory [BT2(∼ BT1), cap2+My]

*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, model of power low density. Models of two-power law density and Navarro model (only BT2). Einasto (=3D Sersic) model [My and Mamon].

### 2.2 The Orbits of Stars [BT1, cap3]

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

### 2.3 Equilibrium of Collisionless Systems [BT1, cap4]

*Collisionless systems*: the two-body relaxation (dim.), 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 in the phase space (DF), collisionless Boltzmann equation (dim.), advantages and limitations, connection with observational quantities. *The Jeans equation and the local equilibrium*: Jeans equation (dim.), 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 and the eq. of the projected velocity dispersion profile. *The virial theorem and global equilibrium*: tensorial virial theorem (dim.). *Application to the internal dynamics of galaxy clusters*[My, notes and slides]: "generalized" virial theorem, observational results about galaxy orbits. *The Jeans theorems and spherical systems*: applications to systems with isotropic vel. dispersion tensor: politropic and Plummer models, isothermal sphere. *The choice of equilibrium*: violent relaxation and velocity equipartition.

### 2.4 Stability of Collisionless Systems [BT1, cap5]

*The Jeans instability*: only hints.

### 2.5 Collisions and Encounters of Stellar Systems and of Galaxy Systems [BT1, cap7]

*Dynamical friction*: Chandrasekhar formula (dim.) and applications, energy equipartition and mass segregation (see My for "luminosity segregation in velocity"). *High-speed encounters:* impulsive approximation, coming back at the equilibrium and the mass loss, tidal approximation. *Tidal radii:* hints (only Jacobi radius). *Galaxy Mergers*: hints (only plot of criteria for merging).