Laurea Magistrale Interateneo in Fisica: **ASTROPHYSICS OF GALAXIES - 6 CFU**
Prof.: Marisa Girardi – A.A. 2022/23

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.

USEFUL: 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 (hints: precession, rifraction of atmosphere). (Trigonometric) parallax. Parsec. Refraction of atmosphere. Proper motion. Radial velocity and redshift. *Magnitudes and colors [mainly K+BM]:* Intensity, flux [+BM], and luminosity. Surface brightness. 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]

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]

Distances 1 [K+S]: Photometric Distance and MS fitting. Distances from pulsating stars (hints: period-luminosity relation for Cepheids). Moving-cluster method [BM]. Baade-Wesselink method [BM]. *Structure and content [K]:* The structure of Milky Way (disk+bulge+halo). Populations I and II. Basics about interstellar medium. Dust extinction. Hints about open/globular clusters [only Myslides]. *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]

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]. *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 relations:* 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. The Hubble low and the expansion of the Universe [S cap1; My; BM] *Distances 2:* Summary (TF, Dn-sigma, Hubble law). Surface brightness fluctuations of galaxies [S].

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

The Local Group: Phenomenology and mass (MW+M31 bimodal model, dim.). *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]. *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 [hints, My].

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: the Jeans swindle, the Jeans instability for fluids, the Jeans instability for stellar systems infinite and homogeneous (basic treatment and results, no precise dim.). Limited and finite systems.

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 slides in My for "luminosity segregation in velocity"). *High-speed encounters:* impulsive approximation, coming back at the equilibrium and the mass loss, tidal approximation (hints).