Laurea Magistrale Interateneo in Fisica: **ASTROPHYSICS OF GALAXIES - 6 CFU**
Prof.: Marisa Girardi – A.A. 2023/24

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]

Positions, motions, velocities: Horizontal system. Equatorial system. Galactic coordinates. Perturbation of coordinates (precession). Parallax. Parsec. Proper motion. Radial velocity and redshift. *Magnitudes and colors*: Intensity, flux, and luminosity. Surface brightness. Apparent magnitudes. Pogson's Law. Zero point. Color index. Absolute magnitudes. Distance modulus and flux/magnitudes corrections [+BM]. Bolometric magnitudes. Mass to light ratios [BM]. Extinction and air mass. Reminds about radiation mechanisms: continuum 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: 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. *The stellar luminosity function* [BM]: Stellar luminosity function. Star counts. Fundamental equation of stellar statistics [dim. BM]. Magnitude limited samples. Malmquist bias [dim. BM]. Uniform star distribution (exercise of K).

1.3 Milky Way [mainly K]

Distances 1: Photometric Distance and MS fitting [S]. Period-luminosity relation for Cepheids. Moving-cluster method [BM]. *Structure and content:* The structure of Milky Way (disk+bulge+halo). Populations I and II. Basics about interstellar medium. Dust extinction. Hints about open/globular clusters [My, only one slide]. *Kinematics:* The Rotation of the Milky Way, Oort constants [dim. K], the tangent point method, rotation curve and dark matter.

1.4 Galaxies [mainly S, +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]. 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], the Tully-Fisher relation [dim. S], 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. *Distances 2:* Summary (My, only one slide). Baade-Wesselink method [BM]. Surface brightness fluctuations of galaxies [S]. The Hubble low and the expansion of the Universe [e.g., S cap1; BM; also My]

1.5 Clusters of Galaxies [mainly S, +My]

The Local Group: Phenomenology and mass. MW+M31 bimodal model [dim. S]. *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/cool cores, the Sunyaev-Zeldovich effect and Y (hints). X-ray vs. SZ catalogs. The beta

problem [dim. My]. Cluster mergers and radio halos/relics [My]. *Scaling relations:* M200 and critical density; M-T, M-sigmav, Lx-T, M-Y, M-Lopt/NIR. *Environmental effects [S, +My]*: morphology-density relation; brightest cluster galaxies (BCG) and cD galaxies [My]; ram pressure of ICM [My]. *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, during merger too (bullet cluster) [My].

2 Dynamics

2.1 Potential Theory [BT2(∼ BT1), +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, gravitational radius, typical time. The potential of simple systems: mass point, homogeneous sphere and typical time, Plummer model, model of power low density. Models of two-power law density and Navarro model [BT2]. Einasto (=3D Sersic) model [My].

2.2 Equilibrium of Collisionless Systems [BT1]

Collisionless systems: the two-body relaxation [dim. BT1], 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. BT1], advantages and limitations, connection with observational quantities. *The Jeans equation and the local equilibrium*: Jeans equation [dim. BT1], eq. in spherical coordinates and the case of a simple spherical system (stationary, non rotating, with avg. motions=0) and mass determination M(r), velocity anisotropy, connection with observational quantities and the eq. of the projected velocity dispersion profile. *The virial theorem and global equilibrium*: tensorial virial theorem. *Application to the internal dynamics of galaxy clusters* [My]: "generalized" virial theorem and pressure term correction; comparison between mass from Jeans eq. and virial theorem. *The Jeans theorems and spherical systems*: applications to systems with isotropic velocity dispersion tensor: politropic and Plummer models, isothermal sphere. *The choice of equilibrium*: violent relaxation and velocity equipartition.

2.3 Stability of Collisionless Systems [BT1]

The Jeans instability: Basic treatment and results for gas [dim. BT1]. The Jeans swindle, the Jeans instability for fluids and stellar systems. Limited and finite systems.

2.4 Collisions and Encounters of Stellar Systems and of Galaxy Systems [BT1]

Dynamical friction: Chandrasekhar formula and applications. Mass segregation [My]. *High-speed encounters:* impulsive approximation, coming back at the equilibrium and the mass loss, tidal approximation. *Tidal radii.*