Extragalactic Astronomy Entries for A Comprehensive Dictionary of Geophysics, Astrophysics, and Astronomy[*]

Paola Marziani[†]

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aberration of stellar light Apparent displacement of the geometric direction of stellar light arising because of the terrestrial motion, discovered by J. Bradley in 1725. Classically, the angular position discrepancy can be explained by the law of vector composition: the apparent direction of light is the direction of the difference between the earth velocity vector and the velocity vector of light. A presently accepted explanation is provided by the special theory of relativity. Three components contribute to the aberration of stellar light with terms called diurnal, annual and secular aberration, respectively, as the motion of the earth is due to diurnal rotation, to the orbital motion around the center of mass of the solar system, and to the motion of the solar system. Because of annual aberration, the apparent position of a star draws cyclically every year an elliptical pattern on the sky. The semi-major axis of the ellipsis, which is equal to the ratio between the mean orbital velocity of earth and the speed of light is called the aberration constant. Its adopted value is 20.49552 seconds of arc.

accretion The infall of matter onto a body, such as a star, or a black hole, occurring because of their mutual gravitational attraction. Accretion is thought to be an important factor in the evolution of stars belonging to binary systems, since matter can be transferred from one star to the other, and in active galactic nuclei, where the extraction of gravitational potential energy from material which accretes onto a massive black hole is reputed to be the source of energy. The efficiency at which gravitational potential energy can be extracted decreases with the radius of the accreting body and increases with its mass. Accretion is therefore most efficient for very compact bodies like neutron stars (R $\sim$ 10 km) or black holes; in these cases, the efficiency can be higher than that of thermonuclear reactions. Maximum efficiency can be achieved in the case of a rotating black hole; up to 30% of the rest energy of the infalling matter can be converted into radiating energy. If the infalling

[*]Published by CRC Press, Boca Raton, in 2000

[†]*Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I–35122 Padova, Italia*

matter has substantial angular momentum, then the process of accretion progresses via the formation of an accretion disk, where viscosity forces cause loss of angular momentum, and let matter drift toward the attracting body. See *accretion disk*

accretion disks, in AGN Hot accretion disks surrounding a supermassive black hole, whose presence is part of the "standard model" of active galactic nuclei, and whose observational detection is as yet controversial. Active galactic nuclei are thought to be powered by the release of potential gravitational energy by accretion of matter onto a supermassive black hole. The accretion disk should dissipate part of the gravitational potential energy, and remove the angular momentum of the infalling gas. The gas should drift slowly toward the central black hole. During this process, the innermost annuli of the disk are heated to high temperature by viscous forces, and emit a "stretched thermal continuum" i.e., the sum of thermal continua emitted by annuli at different temperatures. This view is probably valid only in active galactic nuclei radiating below the Eddington luminosity, i.e., low luminosity AGN like Seyfert galaxies. If the accretion rate exceeds the Eddington limit, the disk may puff up and become a thick torus supported by radiation pressure. The observational proof of the presence of accretion disks in AGN rests mainly on the detection of a thermal feature in the continuum spectrum (the big blue bump), roughly in agreement with the predictions of accretion disk models. Since the disk size is probably less than 1 pc, the disk emitting region cannot be resolved with present-day instruments. See *accretion, big blue bump*

active galactic nuclei (AGN) Luminous nuclei of galaxies in which emission of radiation ranges from radio frequencies to hard-X or, in the case of blazars, to γ rays, and is most likely-due to non-stellar processes related to accretion of matter onto a supermassive black hole. Active galactic nuclei cover a large range in luminosity ($10^{42} - 10^{47}$ ergs s^{-1}) and include, at the low luminosity end, LINERs and Seyfert 2 galaxies, and at the high luminosity end, the most energetic sources known in the universe, like quasars and the most powerful radio galaxies. Nearby AGN can be distinguished from normal galaxies because of their bright nucleus; their identification however requires the detection of strong emission lines in the optical and UV spectrum. Radio-loud AGN, a minority (10-15%) of all AGN, have optical and radio luminosity comparable to radio quiet AGN; radio quiet AGN are not radio silent, but the energy they emit in the radio is a tiny fraction of the optical luminosity. The reason of the existence of such dichotomy as yet unclear. Currently debated explanations involve the spin of the supermassive black hole (i.e., a rapidly spinning black hole could help form a relativistic jet) or the morphology of the active nucleus host galaxy, since in spiral galaxies the interstellar medium would quench the relativistic jet.

advection dominated accretion disks Accretion disks in which the radial transport of heat becomes relevant to the disk structure. The advection-dominated disk differs from the so-called standard alpha disk model because the energy released by viscous dissipation is not radiated locally, but rather advected toward the central star or black hole. As a consequence, luminosity of the advection dominated disk can be much lower than that of a standard thin accretion disks. Advection dominated disks are expected to form if the accretion rate is above the Eddington limit, or on the other end, if the accretion rate is very low. Low accretion rate, advection dominated disks have been used to model the lowest luminosity AGN, the galactic center, and quiescent binary systems with a black hole candidate.

AXAF Acronym of Advanced X-ray Astrophysics facility, a space-borne astronomical observatory launched in July 1999, devoted to the observation of soft and medium energy X-rays, and renamed "Chandra" to honor Subrahmanyan Chandrasekhar. Imaging resolution is 0.5-1 seconds of arc (comparable to that of ground based telescopes without adaptive optics), over the photon energy range of 0.2 to 10 keV. The field of view is 31 x 31 square arcminutes. Two grating spectrometers yield a maximum spectral resolving power (E/ΔE) $\sim$ 1000 over the energy range from 0.09 to 10 KeV. AXAF provides an order of magnitude improvement in resolution and two orders of magnitude improvement in sensitivity over the imaging performances of the Einstein observatory (HEAO-2). Very significant is also the improvement in spectral resolving power: for comparison, the spectrometers on board the Japanese X-ray observatory ASCA, operating since 1993, had maximum energy resolving power E/Δ E $\approx$ 50 between 0.5 and 12 KeV. AXAF is expected to detect supernova remnants in M31, to resolve single galaxies in the Virgo Cluster, and distant quasars that may contribute to the diffuse X-ray background. The AXAF spectrometers are in principle able to resolve emission lines and absorption edges from hot plasmas, such as the intra-cluster medium in clusters of galaxies, making feasible a study of their physical properties and of their chemical composition, and to resolve the profile of the prominent iron K lines, which, in active galactic nuclei, are thought to be produced in the innermost regions of an accretion disk.

barred galaxies Disk galaxies showing a prominent, elongated feature, often streamed by absorption lanes due to interstellar dust. Prominent bars are observed in about 1/3 of disk galaxies; approximately 2/3 of galaxies do however show some bar-like feature. A bar can contribute to a substantial part, up to 1/3 of the total luminosity of a galaxy. The bar photometric profile is quite different from the photometric profile of galaxies: the surface brightness along the bar major axis is nearly constant but decreases rapidly along the minor axis. The bar occupies the inner part of the galaxy rotation curve were the angular speed is constant; bars are therefore supposed to be rotating end over end, like a rigid body.

big blue bump A feature in the spectral energy distribution of active galactic nuclei, dominating the emission shortwards of 4000 Å and in the UV. The shape, luminosity and spectral extension of the big blue bump are as yet uncertain, since the big blue bump lies mostly in the unobserved far UV, with maximum emission probably right below the Lyman limit. Only the low and high energy tails of the big blue bump have been actually observed. The high energy end of the big blue bump appears to be for several objects in the soft X ray domain, where a sharp rise toward lower energies, the so-called “soft X-ray excess” is observed. The current interpretation of the AGN spectral energy distribution, still highly debated, ascribes this feature to thermal emission from a hot accretion disk surrounding a supermassive black hole.

binary black holes Two black holes orbiting each other, like stars in a binary system. A binary system of two black holes may radiate away significant orbital energy by emission of gravitational radiation, with efficiency that increases with the eccentricity of the orbit; orbital energy loss may lead to orbital decay, with the two black hole spiraling down toward each other and ultimately coalescing to form a single black hole. There is as yet no definitive evidence from observations of the actual occurrence of binary black holes. Binary Black holes have been invoked to explain peculiar features of kpc-sized radio jets, of the photometric light curve of the blazar OJ 297, and of rarely observed peculiarities in the spectral line profiles of active galactic nuclei. It has been suggested that also galactic superluminal sources harbor a binary black hole.

blazars A class of active galactic nuclei which includes BL Lac objects and Optically Violently Variable (OVV) quasars, whose name derives from the contraction of the terms BL Lac and quasar. BL Lac and OVV quasars share several common properties, like high continuum polarization, and large luminosity changes on relatively short time scales. All known blazars – a few hundred objects – are radio loud AGN, and several of them have been revealed as strong γ-ray sources. Blazars are thought to be active galactic nuclei whose radio jets is oriented toward us, and whose non-thermal, synchrotron continuum is strongly amplified by Doppler beaming.

Broad Line Radio Galaxies Radio Galaxies showing optical spectra very similar, and in several cases almost indistinguishable, to those of Seyfert 1 galaxies. Broad Line Radio Galaxies are type 1, low-luminosity radio-loud active galactic nuclei the radio loud counterpart of Seyfert 1 galaxies. Differences between Seyfert 1 and Broad Line Radio galaxies encompass the morphology of the host galaxy (Seyfert 1 are mostly, albeit not exclusively, spirals, while Broad Line Radio Galaxies are hosted by ellipticals), and some features of the optical spectrum, like weaker FeII emission and larger internal absorption due to dust in Broad Line Radio Galaxies.

Broad Line Region The region where the broad lines of active galactic nuclei are produced. The strongest lines observed in the optical and UV spectrum are the Balmer lines of hydrogen, the hydrogen Lyα line, the line from the three time ionized carbon at 154.9 nm, and some recombination lines from singly ionized and neutral helium. Since no forbidden lines are observed, the BLR is most likely a relatively high density region (particle density in the range $10^9 - 10^{13}$ ions per cubic centimeter. The BLR is believed to be very close to the central source of radiating energy of the active galactic nucleus. Observations of variation of broad line profiles and fluxes suggest that the BLR line emitting gas is confined within 1 pc in Seyfert 1 galaxies. Models of the BLR invoke a large number of dense emitting clouds, rapidly rotating around a central illuminating source. In alternative, it has been suggested that at least part of the emission of the BLR could come from the middle and outer region of the accretion disk suspected to be an universal constituent of the central engine of active galactic nuclei.

Butcher-Oemler effect The increase in the fraction of blue galaxies in distant clusters of galaxies. H. Butcher and A. Oemler, in papers published in 1978 and 1984, discussed an excess of galaxies with color index B-V $\gtrsim 0.2$ magnitudes bluer than normal elliptical and S0 galaxies (after K-correction), found in clusters of galaxies at redshift near 0.4. They discovered that 20% of galaxies in clusters at redshift larger than 0.2 were blue galaxies, while blue galaxies accounted for only 3% of all galaxies in nearby clusters. Blue color suggests that galaxies are undergoing strong star formation. The detection of a large number of blue galaxies indicates that significant galactic evolution is still occurring at a very recent epoch, about nine-tenth of the present age of the universe.

CCD Acronym of charge-coupled device, presently the most widely used detector in optical astronomy. The CCD is a two dimensional detector, like a photographic film or plate. Each picture element (pixel) of a CCD is a photo-diode where electrons, freed by the incoming radiation via photoelectric effect, are being held in a positive potential for an arbitrary time (i.e., the exposure time). At readout time, an oscillating potential transfers the stored charges from pixel to pixel across each row of pixels to an output electrode where the charges are measured. Unlike photographic plates, CCD possess linearity of response, i.e., the number of electrons freed is proportional to the number of photons detected, and detective quantum efficiency (i.e. high ratio between detected and incident photons), which is very high, close to 100 % for red light. The pixel size can be as small as 15μm $\times 15\mu$m; and arrays by 4096×4096 pixels are among the high-end of available CCDs.

cD galaxies Luminous, large-size elliptical galaxies that are located at the center of dense clusters of galaxies. The notation "cD" indicates a cluster D galaxy in the Yerkes classification scheme. The photometric profile of a cD galaxy is different from that of other elliptical galaxies, since there is an excess of light at large radii over the prediction of the de Vaucouleurs law. cD galaxy posses a stellar halo that may extend up to 1 Mpc, exceptional mass and luminosity, and are thought to result from multiple merging of galaxies, and from cannibalism of smaller galaxies belonging to the cluster. An example of a cD galaxy is Messier 87, located at the center of the Virgo cluster.

compact group of galaxies Isolated groups of galaxies with at least four members, for which the separation between the galaxies is comparable to the size of the galaxies themselves. More quantitatively, compact groups of galaxies (often referred to as Hickson's compact groups) were isolated by P. Hickson from searches on the Palomar Observatory Sky Survey made according to three criteria: (1) there are at least four members whose magnitudes differ by less than 3 magnitudes from the magnitude of the brightest member; (2) if R_G is the radius of the circle on the sky containing all group members, then the distance to the nearest galaxy outside the group must be larger than 3 R_G. In other words, the group must be reasonably isolated and not an obvious part of a larger structure; (3) the mean surface brightness within R_G should be less than 26 mag per square second of arc, i. e. , the group must should not contain vast empty sky areas and hence be "compact."

compact steep spectrum radio sources A class of radio sources which includes radio galaxies and quasars unresolved at resolution ≈ 2 arcsecs. They are differentiated from other core-dominated radio sources by showing a steep radio spectrum. Observations at higher resolution show that compact steep spectrum radio sources are either classical lobe dominated sources whose lobe size is less than the size of the galaxy, or quasars with a core single-side jet morphology. In both cases, the radio morphology appears often to be disrupted and irregular.

Compton reflection The Compton scattering of hard X-ray radiation by a layer of dense and thick matter, such as the surface of a star, or of an accretion disk. Hard X-ray radiation is scattered off the surface of the layer after having lost parts of its energy. Compton reflection creates a distinguishing spectral feature, an enhancement in the spectral energy distribution between 10 and 50 keV. Such feature have been detected in the spectra of several Seyfert 1 galaxies and of one Galactic object, the black hole candidate Cyg X-1.

Compton scattering The inelastic scattering of high energy photons by charged particles, typically electrons, where energy is lost by the photon because of the particle recoil. A photon carries momentum. Like in a collision between two balls, one of which is initially at rest, part of the momentum is exchanged between the photon and the particle. Conservation of energy and momentum yields an increase in the photon wavelength (and hence to a decrease in photon energy) equal to

$$\lambda - \lambda_0 = \lambda_C(1 - \cos\theta),$$

where λ_0 is the wavelength of the incident photon, θ is the angle between the initial and final direction of propagation of photon, and λ_C is a constant, called the Compton wavelength, and defined by $\lambda_C = h/mc$, where h is the Planck constant, m the particle mass, and c the speed of light. In the case of scattering by electrons, $\lambda_C = 0.02426$ Å. If $\lambda \gg \lambda_C$ then the energy exchange is irrelevant, and the scattering is elastic (scattering Thomson). Compton scattering occurs for photons in the X-ray domain. See *Inverse Compton scattering, Thomson scattering*

core dominated quasars High luminosity, radio-loud active nuclei whose radio morphology is characterized by a luminous core which dominates the source emission. Mapped at milliarcsecond resolution, the core becomes partly resolved into a one-sided jet. Many core dominated radio quasars exhibit radio knots with superluminal motion, indicative of ejection of charged particles, i. e., electrons, at a velocity very close to the speed of light. The quasars 3C 273 and 3C 120 , whose name means that they were identified as radio sources 273 and 120 in the third Cambridge radio survey, are two of the brightest quasars in the sky and prototypical core-dominated superluminal sources. In the framework of the unification schemes of AGN, core- and lobe-dominated quasars are basically the same objects: core dominated objects are observed with the radio axis oriented at small angle with respect to the line of sight, while the radio axis and the line of sight form a larger angle in lobe dominated objects. The jet one-sidedness suggests that radiation is boosted by relativistic beaming: if the emitting particles are moving at a velocity close to the speed of light, the detection of the jet on the approaching side is strongly favored. In this case, and a very large dynamical range is needed to detect the radio-lobes, which, seen pole-on, may appear as a faint fuzz surrounding the core.

coronal lines Forbidden spectral emission lines emitted from highly ionized atomic species, in a high temperature, diluted medium where collision between ions and electrons dominate excitation and ionization, like in the solar corona. In such plasma the temperature (it is $1 \div 2\ 10^6$K in the solar corona) is so high that electrons have sufficient energy to ionize atoms. The first coronal emission lines was identified at 530.3 nm during the total solar eclipse of 1869. Only in the 1940s most of the coronal lines were identified as forbidden transitions from elements such as iron, nickel and calcium in very high ionization stages. Ratios of coronal line fluxes, similarly to ratios of nebular lines, are used as diagnostic of temperature and density. See *nebular lines, forbidden lines*

DDO classification scheme A variant of the Hubble classification scheme for galaxies, named after the David Dunlop Observatory (DDO) where it was developed. The emphasis is on the prominence and length of the spiral arms: the DDO scheme identifies a new class of spirals, the anemic spirals (indicated by the letter A), which are intermediate in terms of arm prominence between the S0 galaxies and the grand-design, or gas-rich, spirals. Other labels are as in Hubble's scheme. The original DDO scheme has undergone a major revision. The revised DDO type includes a luminosity class in addition to the morphological description. The luminosity class is indicated with a roman numeral and ranges from I to V, in order of decreasing luminosity. For example, Messier 31 is of type Sb I-II according to the revised DDO scheme. The luminosity class subdivision refines the separation into the three classes S0, A, and S, since a good correlation is found between the degree of spiral arm development and luminosity class, and it is therefore possible to assign a luminosity class on the basis of the appearance of spiral arms.

de Vaucouleurs' classification scheme A classification scheme that refines and extends the Hubble scheme of classification for galaxies, introduced by G. de Vaucouleurs in 1959. de Vaucouleurs' scheme attempts to account for the variety of morphologies observed for each Hubble type. His scheme employs three main parameters: (1) a refined Hubble type, where several intermediate stages are added to the Hubble sequence, notably E^+, $S0^-$, $S0^+$, which account for some lenticular features in ellipticals or weak arms in S0 galaxies, and Sd, Sm, and Im, which more closely details the transition from Sc to Magellanic irregulars; (2) a parameter describing the spiral design, as ring shaped (r) or s-shaped (s), or intermediate (rs); and (3) a parameter designating barred galaxies (SB), non-barred (SA) and intermediate (SAB), for galaxies where the bar less developed than in classical Hubble's barred galaxies. In addition, the presence of an outer ring or of a ring-like feature formed by joining spiral arms is indicated with an uppercase R preceding all other labels. The de Vaucouleurs classification scheme has been extensively used in the three editions of the Reference Catalogue of Galaxies, where de Vaucouleurs' types are given for several thousands galaxies. For example, Messier 31, the spiral galaxy nearest to the Galaxy, and the nearby spiral Messier 101 are classified as Sb and as Sc according to Hubble, and as SA(s)b and as SAB(rs)cd according to de Vaucouleurs.

De Vaucouleurs' law Empirical law describing the brightness profile of an elliptical galaxy. The surface brightness Σ of several giant elliptical galaxies is, apart from constants, decreasing with radius as

$$\log \Sigma(r) \propto (r/r_e)^{-1/4},$$

where r_e denotes a scaling parameter, the effective radius, within which half the light of the galaxy is emitted. The de Vaucouleurs' law applies more frequently to giant elliptical galaxies; dwarf elliptical galaxies are often better fitted by other laws. See *elliptical galaxies*.

diffraction grating A light analyzer, used to separate different chromatic elements in a light beam, based on the principle of light diffraction and interference by a series of parallel slits. The separation of colors results from the constructive and destructive interference of light entering from different apertures. A typical diffraction grating consists of a large number of equally spaced, tilted grooves ($\sim$ 100-1000 grooves per millimeter), which operate like a series of slits. The spectral resolving power increases with the number of grooves per millimeter for a fixed grating size. A diffraction grating can be either reflect or transmit light. To avoid loss of light because of maximum of the diffraction pattern at zero order, the grooves need to be tilted to shift the maximum of the diffraction pattern toward the first or, occasionally, toward the second or higher diffraction orders. In this case a grating is said to be blazed.

diffuse galactic light The diffuse glow observed across the Milky Way. Large part of the brightness of the Milky Way, which is the disk of our galaxy seen from the inside, can be resolved into stellar sources. The diffuse galactic light is a truly diffuse glow which accounts for the remaining 25 % of the luminosity and, by definition, is unresolved even if observed with large telescopes. The diffuse galactic light is due to light emitted within our galaxy and scattered by dust grains, and it is not to be confused with light coming from extended sources like reflection or emission nebulae. The brightness close to the galactic equator due to diffuse galactic light is equivalent to 50 10 magnitude stars per square degree; for comparison, the total star background is 170 10 magnitude stars per square degree, and the zodiacal light 80.

discordant redshift Redshift of a galaxy significantly differing from the redshift of other galaxies belonging to an apparently interacting system of galaxies, such as a group. For example, in the case of the Stephan Quintet, a group of five galaxies, four galaxies have redshifts around 6000 km/s, and one has a discordant redshift of only 800 km/s. Several other intriguing examples exist, in which two galaxies with large redshift difference are connected by bright filaments. Galaxies with discordant redshift can be explained as due to casual superposition of foreground and background galaxies. On the basis of cases of discordant redshift, however, H. Arp and collaborators have suggested the existence of "non-velocity" redshifts . They concluded that redshift is not a reliable distance indicator, questioning the validity of the Hubble's law, and especially of quasar distances deduced from their redshift.

disk warp A deviation from planarity of the disk of a galaxy, in which the outer parts of a galactic disk gradually tilt. More precisely, one can think to the disk of a galaxy as a sequence of concentric, adjacent rings; if the disk is flat, the rings are coplanar; if the disk is warped the inclination and the position angle of the intersection line between rings (line of nodes) varies with continuity from ring to ring. A disk warp is more frequently observed in the gaseous than in the stellar component of a galaxy. The distribution of the 21cm hydrogen emission line often reveal a warp outside the boundaries of the optical disk. Small warps are probably present in the outer regions of most disk galaxies (including the Galaxy); strong warps, where the disk plane tilts by $40 \div 50$ degrees, as in the case of NGC 660, are of rare occurrence.

Doppler beaming Beaming of radiation due to the rapid, i.e., close to the speed of light, motion of an emitting source with respect to an observer. Light emitted isotropically in the rest frame of a source is observed greatly enhanced if the source is moving toward the observed: for a radiating particle moving at a velocity close to the speed of light, corresponding to a Lorentz factor $\gamma \gg 1$ (γ is equal to $1\sqrt{(1-(v/c)^2)}$, where v is the velocity of the radiating matter, and c is the speed of light), the observer would see most light concentrated in a narrow beacon of half-opening angle $1/\gamma$ radians, and enhanced by a factor that can be proportional to a large power (3–4) of γ. Doppler beaming is relevant whenever there are charges moving at a velocity close to the speed of light (for example, if $v = 0.95c$ then $\gamma = 3$), as in the case of radio jets in radio galaxies and quasars.

dwarf spheroidal galaxies Low mass ellipsoidal galaxies, which differ from dwarf elliptical galaxies such as M32 (the dwarf companion of the Andromeda Galaxy) because of their much lower surface brightness. More quantitatively, a dwarf spheroidal (dSph) galaxy can be defined as a galaxy with absolute blue magnitude above -14 (up to -8.5 for the faintest dwarf spheroidal known), surface brightness lower than 22 visual magnitudes per square arcsec, and no nucleus. Dwarf galaxies have been discovered in the Local group, including the first ever, the Sculptor system, discovered in 1937 by H. Shapley. The Local Group dSph galaxies appear as a collection of faint stars, with no diffuse light coming a background of unresolved, less luminous stars. In addition, dSph galaxies are extremely poor of atomic gas. Observations with Hubble Space Telescope have allowed to reveal dSph galaxies in the nearby Virgo Cluster.

echelle spectrograph A grating spectrograph designed to achieve high spectral resolution, employed as an analyzer of optical and UV radiation. To increase resolution, the echelle spectrograph works with high diffraction orders ($10 \div 100$). The light diffracted by the echelle grating is made of several high order spectra, covering adjacent narrow spectral ranges. They would overlap spatially, if they were not separated by a cross-disperser, i. e., a grating with the grooves aligned perpendicular to those of the echelle grating. The final echelle spectrum is a sequence of spatially spaced spectra of increasing order, and must be recorded on a two-dimensional detector, such as a CCD or a photographic plate. With Echelle spectrographs, a spectral resolving power of several 10^4 can be achieved with a compact design. See *grating spectrograph, diffraction grating*

Eddington limit The maximum luminosity, or accretion rate, beyond which the spherical infall of matter on a massive body stops because the infalling matter is pushed outward by radiation pressure. In the case of spherical accretion, i.e., matter falling radially and uniformly onto a body, the Eddington luminosity can be written as

$$L_{Edd} = 1.3 \times 10^{38} (M/M_{\odot}) ergs\ s^{-1},$$

where the mass is expressed in units of solar masses. A consequence of the Eddington limit is that central black holes need to be very massive to radiate at $L \sim 10^{46 \div 48}$ ergs, the typical luminosity of quasars. Since the accretion luminosity can be written as $L = \eta \dot{M} c^2$ i.e., as the fraction η of the rest mass falling onto the black hole (per unit time, $\dot{M}$) that is converted into radiating energy, a limiting accretion rate is associated to the Eddington luminosity.

Eddington ratio The ratio between the bolometric luminosity of a source, and the Eddington luminosity. The Eddington ratio can be equivalently defined from the accretion rate. The Eddington ratio is a parameter reputed to influence the structure and the radiating properties of an accretion disk in a fundamental way: if the Eddington ratio is $\lesssim 1$ a geometrically thin disk is expected to form, while if $\gtrsim 1$ the accretion disk may inflate to form a radiation supported torus. See *Eddington Luminosity*

elliptical galaxies Galaxies of regular, ellipsoidal appearance, and of rather reddish colors. The photometric profiles of most elliptical galaxies are described by empirical laws in which the surface brightness decreases smoothly as a function of the distance from the galaxy center. Elliptical galaxies do not show features such as bars, spiral arms, or tails. Only a minority of them show ripples, shells, or asymmetric radial distribution of surface brightness. Elliptical galaxies are characterized by the absence of significant neutral or molecular gas, and hence of star formation, and by a stellar content mostly made of old stars belonging to stellar population II. They account for about 1/3 of all observed galaxies, and are the majority of galaxies in dense cluster environments. They cover a wide range of masses, from $\sim 10^6$ to $\sim 10^{11}$ solar masses, the most massive being located at the center of clusters of galaxies (cD galaxies), the less massive being dwarf elliptical galaxies.

Faber-Jackson law An empirical relationship between the total luminosity and the central velocity dispersion of elliptical galaxies: $L \propto \sigma^4$ i.e., the galaxy luminosity is proportional to the fourth power of the velocity dispersion σ. This law was first discussed by S. M. Faber and R. E. Jackson in 1976. Since the velocity dispersion can be measured from the broadening of absorption lines in the galaxy spectrum, the Faber-Jackson law can in principle be used to determine the luminosity, and, once the apparent magnitude of the galaxy is measured, to derive the distance of the galaxy. The Faber-Jackson law is analogous to the Tully-Fisher law for spiral galaxies: the stellar velocity dispersion substitutes the HI rotational width, since there is little atomic gas in early-type galaxies. See *velocity dispersion, Tully-Fisher law*

Fanaroff-Riley (FR) class I and II radio galaxies Lobe-dominated radio galaxies whose luminosity at 178 MHz is below (class I) or above (class II) 5×10^{32} ergs s^{-1} Hz^{-1}. B. L. Fanaroff and J. M. Riley noted in 1974 a dichotomy in the radio morphology of radio galaxies with a sharp threshold luminosity: FR I type galaxies, of lower luminosity, show smooth two-sided and poorly collimated jets and edge-darkened lobe structures. FR II type galaxies, of higher luminosity, show edge-brightened lobes, often with prominent hot spots at the inner end of the lobes, connected to the nucleus by pencil-like jets that is some source are not visible at all.

forbidden lines Spectral emission lines violating quantum mechanics selection rules for electric dipole emission. In both permitted and forbidden transitions, the photon of a spectral line is emitted when an electron moves from an upper to a lower energy level. The photon energy is equal to the difference between the energy of the two levels. In the case of forbidden lines, the probability of a spontaneous transition between the upper and lower energy level is very small, and the electron remains a much longer time in the excited state than in the case of a permitted transition. In this case, the upper level is said to be metastable. Forbidden lines in several astronomical sources are collisionally excited i.e., the electron bound to an ion is brought to an higher, metastable level via the collision with a free electron or with another ion. At densities typical of the terrestrial environment, subsequent collisions would quickly de-excite the atom without emission of radiation. At electron densities $n_e \lesssim 10^3 - 10^7$ electrons cm^{-3}, the probability of a collision is much lower, and the electron can decay to a lower level with the emission of a photon of the forbidden line. Forbidden lines are, therefore, very sensitive indicators of density in several gaseous nebulae, for example Hii regions, or planetary nebulæ.

galactic wind Large-scale outflow of gaseous matter from a galaxy. Evidence of galactic winds is provided by the morphology of X-ray emitting regions, elongated along an axis perpendicular to the major axis of a highly inclined disk galaxy. More rarely, it is possible to reveal, as in the case of the spiral galaxy NGC 1808 or of the prototype Starburst galaxy M82, the presence of optical filaments suggesting outflow the from inner disk. A galactic wind is currently explained as due to an intense, concentrated burst of star formation, possibly induced by gravitational interaction with a second galaxy. As the frequency of supernova blasts increases following the production of massive stars, supernova ejecta provide mechanical energy for the outflow and produce tenuous hot gas, which is seen in the X-ray images. Most extreme galactic winds, denominated super-winds, could create a bubble of very hot gas able to escape from the potential well of the galaxy and diffuse into the intergalactic medium. They are thought to be rare in present day universe, but may have played an important role in the formation and evolution of elliptical galaxies, and in the structure of the medium within clusters of galaxies.

gaseous shocks Abrupt compression and heating of gas, caused by matter moving at velocity larger than the sound speed of the surrounding medium. If material is moving supersonically, then the surrounding gas has no time to adjust smoothly to the change, and a shock front i.e., a thin region where density and temperature change discontinuously, develops. Shocks form in any supersonic ejection, as in the case of supernovae, flare stars, and in stellar winds. Since heating causes emission of radiation, including spectral lines, the excitation and chemical composition of the gas can be diagnosed.

grating spectrograph An instrument aimed at the analysis of radiation at different wavelengths, where light is dispersed by a diffraction grating. In a typical grating spectrograph design, light focused on the focal plane of the telescope is collimated (i.e., the rays of the beam are made parallel) on a blazed diffraction grating. Light of different wavelength is so diffracted along different directions, and it is then re-focused on a detector, for example a photographic plate or a CCD, by a lens or a mirror. The grating spectrograph is probably the radiation analyzer more widely used in optical astronomy. Several designs exist, based on different choices of the focusing and collimating elements, or on the use of a reflection or a transmission grating. The spectral resolving power, i. e., the ability to separate two close spectral lines spaced by $\Delta\lambda$ at wavelength λ is usually $\lambda/\Delta\lambda \lesssim 10^4$. See *diffraction grating*

gravitational radius The radius, also called Schwarzschild radius, at which gravitational attraction of a body becomes so strong that not even photons can escape. In classical Newtonian mechanics, if we set equal the potential energy of a body of unit mass at a distance r in the gravitational field of a mass M, GM/r, to its kinetics energy if moving at the speed of light, $1/2\ c^2$, the gravitational radius is $R_g = 2GM/c^2$, where G is the gravitational constant, and M is the mass of the attracting body. An identical expression is found solving Einstein's equation for the gravitational field due to a non-rotating, massive body. The gravitational radius is ≈ 3 km for the sun. The gravitational radius defines the "size" of a black hole, and a region that cannot be causally connected with our universe. In other words, no signal emitted within the gravitational radius of a black hole can reach a distant observer.

gravitational redshift Frequency or wavelength shift of photons due to the energy loss needed to escape from a gravitational field, for example from the field at the surface of a star, to reach a distant observer. Since the energy of a photon is proportional to its frequency and to the inverse of its wavelength, a lower energy photon has lower frequency but longer wavelength. The displacement toward longer wavelength is conventionally termed a shift to the red also if the photons are not in the visible range. The gravitational redshift is a consequence of Einstein's law of equivalence of mass and energy: even a mass-less particle, but with energy associated to it, like the photon is subject to the gravitational field. The shift increases with the mass of body generating the gravitational field, and with the inverse of the distance from the mass. A photon will be subject to a tiny frequency shift at the surface of a star like the sun, but to a shift that can be of the same order of the unshifted frequency if it is emitted on the surface of a compact body like a neutron star.

Great Attractor An as yet unidentified and somewhat hypothetical entity, probably a massive super-cluster of galaxies, whose existence is suggested by a large flow of galaxies toward an apex at galactic longitude $\approx 307°$, galactic latitude $\approx 9°$, and recessional velocity 4500 km s^{-1}. The Local Cluster, as well as the Virgo Cluster and the Hydra-Centaurus cluster, are thought to be falling toward the putative Great Attractor, located at a distance from the Galaxy which should be three-four times the distance to the Virgo cluster. The structure associated to the Great Attractor has yet to be identified, not last because the center of the Great Attractor probably lies close to the galactic plane, where gas and dust heavily obscure any extragalactic object. The very existence of the Great Attractor is subject of current debate, since there is no consensus of the observation of infall motions toward the Great Attractor of galaxies located beyond it.

grism A diffraction grating coated onto a prism (after the contraction of grating and prism). Grisms are instrumental to the design of highly efficient spectrographs devoted to the observations of faint objects. For example, in the Faint Object Spectrograph at the 3.6 meter William Herschel telescope on La Palma (Canary Islands), there is no collimator, and light allowed into the spectrograph by the slit directly illuminates a grism which is mounted of the corrector plate of a Schmidt camera to minimize optical elements, and consequently, light losses. The prism can act as a cross disperser, separating the first and second order spectrum produced by the diffraction grating, in a similar way as obtained with a second diffraction grating employed as a cross-disperser in an Echelle spectrograph. See *diffraction grating, echelle spectrograph*

H I 21-cm line Spectral line emitted in the radio domain, at a wavelength of 21 cm (corresponding to a frequency of 1420 GHz), due to the hyperfine transition between two energy states in the ground level of the hydrogen atom, the lower state with electron spin and proton spin anti-parallel, the higher state with the two spins parallel. The HI 21 cm emission line was first detected in 1951; it has since then used to map the distribution of neutral hydrogen within the Galaxy, and in external galaxies, with radio telescopes and interferometers. See *forbidden lines*

Holmberg radius The length of the semi-major axis of a galaxy, either expressed in angular or linear units, measured from the center to a minimum surface brightness of 26.5 photographic magnitudes per square second of arc (approximately 1.5 % the surface brightness of the night sky).

hot spot A bright, compact component observed in the radio lobes of powerful radio sources, such as radio galaxies and quasars. Hot spots are found frequently in radio source of Fanaroff-Riley class II, which include the brightest lobe dominated radio source. Hot spots are $\sim$ 1 kpc in size, and they appear unresolved when observed at moderate resolution. Their radio spectrum is described by a power-law over the frequency and a spectral index ≈ -0.5, suggesting that radiation is emitted via a synchrotron process. Their location, often in the outer end of the jet, suggests that hot spots are the site of impact between the high speed particles of the jet and the lobes. In other cases, hot spots have been ascribed to the impact between the radio plasma ejected by the radio source and the ambient interstellar gas.

Hubble deep field A high galactic latitude sky field (of width $\approx$ 2 arcmin), intensively observed in four colors with the Wide Field Planetary Camera mounted on board of Hubble Space Telescope in December 1995. Three sets of observations for a total of 35-hours exposure time were obtained with broad band filter centered at 450, 606, and 814 nanometer, and a set of a 50 hours exposure time with a near UV filter centered at 300 nm. The Hubble Deep Field was chosen in an area of low HI column density, small far-IR flux, with no radio source brighter than 1 mJy, no bright stars, and no nearby galaxy clusters. These selection criteria were aimed at making possible the identification and morphological study of a large number of faint, field galaxies. The observations allowed to count the number of galaxies in the field of down to a magnitude $\lesssim$ 29, an unprecedented achievement.

Hubble-Reynolds law Empirical law describing the brightness profile of an elliptical galaxy, introduced by J. H. Reynolds in 1913. According to Hubble-Reynolds law, the surface brightness depends upon the distance from the galaxy center, r, as $\Sigma(r) = \Sigma_0/(1 + r/r_0)^2$, where the scaling parameter r_0 is the radius at which the surface brightness falls to one quarter its central value Σ_0. This law, remarkable also because of its simplicity, predicts a deficit of light close to the center and more light in the outer envelope of a galaxy with respect to de Vaucouleurs' law.

Hubble Sequence A classification scheme of galaxies ideated by E. Hubble. In the Hubble sequence, galaxies are subdivided into elliptical galaxies, S0 galaxies (galaxies showing evidence of an amorphous disk and a bulge, but no spiral arm, also called lenticular galaxies), spiral galaxies, either barred or non barred, and irregular galaxies. An elliptical galaxy is conventionally indicated with the uppercase letter E and an integer number ranging from 0 to 7, increasing with the apparent flattening, and defined as the integer part of $10\times(1-(b/a))$, where (b/a) is the axial ratio measured on a photograph or digital image. Spiral galaxies are farther subdivided along the sequence in S0, Sa, Sb, Sc according to three criteria: (1) decreasing bulge prominence with respect to disk; (2) spiral arms less tightly wound; (3) appearance of arms more resolved. At the end of the sequence, irregular galaxies (subdivided into Magellanic and amorphous or M82-type) do not show regularly decreasing surface brightness nor spiral arms and are of patchy appearance. Elliptical and S0 galaxies are collectively referred to as "early morphological types," and Sc and irregulars as "late type" galaxies. Hubble attributed to these term an evolutionary meaning, i.e., he thought that an elliptical could be an evolved spiral galaxy. This view is not considered anymore appropriate, since the angular momentum per unit mass, a constant for an isolated galaxy, increases along the sequence from the elliptical to the most flattened galaxies (Sc). Nevertheless, gravitational interaction between galaxies can affect the morphology of spiral galaxies to the point of changing their Hubble type. See *elliptical galaxies, spiral galaxies*

Hubble Space Telescope (HST) A space-based telescope of 2.4 m aperture, launched in 1990 and orbiting in a low terrestrial orbit. Although the optical design of HST is similar to that of mid-sized ground based telescope, the absence of atmosphere allows the telescope to operate at a resolution close to the diffraction limit (0.03 arcsec at 3000 Å), and to detect UV light which is absorbed by the terrestrial atmosphere. Currently available instruments on board HST include two imaging cameras, a long-slit spectrograph, and a camera and spectrometer operating in the near infrared. The Wide Field Planetary Camera, which is composed of three CCD detectors in an L shape configuration plus a single, smaller CCD detector at the center of field, has limiting magnitude of 28, with one hour exposure time (and S/N ratio 5), and with a resolution of 0.053 arcsec. The highest resolution, 0.042 seconds of arc, is achieved with the Faint Object Camera which has a much smaller field of view, 7×7 square arcseconds. The Space Telescope Imaging Spectrometer, which operates between 115 and 1100 nm, offers spectral resolving power ranging from 150 to 100000, and long slit capabilities.

induced Compton scattering Compton scattering induced by an extremely intense radiation field, as found in compact radio sources and in pulsars. Induced Compton scattering is a form of stimulated emission, in which a photon of a given frequency stimulates the emission of a second photon of identical frequency, phase, direction of motion, and polarization. Unlike stimulated emission due to the transition of an electron between two-bound states of an atom or ion, induced Compton effect transfers energy to electrons.

Initial Mass Function (IMF) The distribution of newly formed stars as a function of mass. The initial mass function is estimated from the photometric and spectroscopic properties of stars in open clusters and associations of stars. Ideally, the IMF can be measured counting the stars of each spectral type in an association of stars so young that the shortest-lived massive stars are still in the main sequence.

The initial mass function is usually assumed to be of the form $\Psi(m) \propto m^{-\Gamma}$, where m is the mass of the star. The index Γ may vary for different mass ranges, but it is always positive, implying that high mass stars are formed less frequently than low mass stars. According to E. E. Salpeter, $\Psi(m) \propto m^{-2.35}$, for all masses. From this law, we expect that for one 20 $M_\odot \approx 1000$ stars of one solar mass are formed. According to G. E. Miller and J. M. Scalo, the IMF valid for the solar neighborhood can be approximated as $\Psi(m) \propto m^{-1.4}$, for $0.1 \lesssim m \lesssim 1 M_\odot$, $\Psi(m) \propto m^{-2.5}$, for $1 \lesssim m \lesssim 10 M_\odot$, and $\Psi(m) \propto m^{-3.5}$, for $m \gtrsim 10 M_\odot$. This law predicts fewer high mass stars ($m \gtrsim 10 M_\odot$) for a given number of solar mass stars than Salpeter's law.

interaction of galaxies The gravitational attraction between two or more galaxies, which can induce notable modifications in the their morphology, as well as and in their photometric and spectroscopic properties. Interacting galaxies are often classified as peculiar, since their morphology does not fit the criteria of any of the main classification schemes for galaxies. The effect of interaction among galaxies depends strongly on their mutual distance: gravitational forces are proportional to the inverse square of the distance, and tidal forces, in this case the difference between the force exerted on the near and far side of a galaxy by a companion galaxy, to the inverse cube of the distance. For disk galaxies, the effects of interaction on morphology encompass the formation or enhancement of a spiral pattern, the formation of a bar, and, in more extreme cases, the formation of tidal tails, or of a prominent outer ring, as in ring galaxies or, ultimately, the production of a remnant which resembles an elliptical galaxy (a merger). Collisions involving elliptical galaxies may lead to the production of ripples, extended halos, and asymmetries in the photometric profiles, as well as of mergers, but they do not produce such spectacular features as tidal tails. Interaction of galaxies has been linked to an enhancement of star formation in the host galaxies, and, most speculatively, to the occurrence of quasar-type nuclear activity.

inverse Compton effect Compton scattering of a photon by a particle, typically an electron, whose kinetic energy is comparable to the energy of the photon. In opposition to Compton scattering, where the photon loses energy, in the inverse Compton scattering part of the kinetic energy of the particle (typically an electron) is transferred to the photon. Calculations based on the theory of special relativity show that the emerging photon has its energy increased γ^2 times, where γ is the Lorentz factor, i.e., $\gamma^2 = 1/(1-\beta^2)$, and β is the ratio between the velocity of the electron and the speed of light. If electrons are relativistic i.e., they have been accelerated close to the speed of light and $\beta \sim 1$ and $\gamma \gg 1$. In this case inverse Compton scattering can dramatically increase the energy of initially low-energy photons. Inverse Compton scattering has been proposed as the mechanism producing hard X-rays and gamma rays in active galactic nuclei. See *Compton scattering*

ion torus A thick accretion disk, whose existence has been suggested to explain the collimation of radio jets, and the low bolometric luminosity (compared to the mechanical energy needed to produce radio lobes) of powerful radio sources. An ion torus is a structure supported by the pressure of the ions of very hot plasma, with kinetic energies as high as $\sim$ 100 MeV. It is expected to surround a supermassive black hole with steep walls creating a narrow funnel which collimates the highest energy radiation produced from inside the funnel, and, if a magnetic field is present, may be able to collimate the radio jet itself.

iron Kα line A spectral line at energy of $\approx$ 6.4 keV from the transition between the L and K shells (i.e, the second innermost and the innermost atomic shells, corresponding to quantum number n=2 and n=1, respectively) of an iron atom. The iron fluorescence Kα line is a strong emission feature in the X-ray spectra of active galactic nuclei and of cataclysmic variables. It can be produced by recombination following photoionization in gas irradiated by an intense X-ray source, as in systems powered by accretion. An electron of the K-shell may also be removed by Compton scattering due to an X-ray photon. Iron Kα line is excited collisionally in the hot gas of stellar flares, supernova remnants and in the intra-cluster medium in clusters of galaxies. Observations of the iron Kα line has been made possible by X-ray space-borne observatories. The instruments on board the Japanese observatory ASCA have revealed, in the Kα line profile of several Seyfert galaxies, some of the characteristic effects predicted for radiation coming from a gaseous, rotating disk at a few gravitational radii from a black hole.

irregular galaxies Galaxies that lack a central bulge, azimuthal symmetry, and that most often show a rather patchy appearance. They are of blue color, have high neutral gas content, and show evidence of on-going star formation. Irregular galaxies, often called "dwarf irregular" galaxies, are smaller and less massive than typical spirals, with masses $\sim 10^8$ solar masses, and have lower rotational velocity and lower luminosity. Although a small fraction in large catalogues of galaxies, such as the Revised New General Catalogue, irregular galaxies are thought to account for $1/2 \div 1/3$ of all galaxies. They have been further subdivided into the Magellanic type (from the prototype galaxy, the Large Magellanic Cloud), and the amorphous type (or M82-type) galaxies. Magellanic irregulars due their patchy appearance to clusters of hot stars in star forming regions spread over the whole galaxy, while amorphous irregulars are smoother in appearance, with a single supergiant star forming region at the center of the galaxy. This subdivision is now considered mainly of historical importance.

Kerr black hole A rotating black hole, i.e., a black hole with angular momentum associated to its spinning motion. The solution of the Einstein gravitational field equations for a rotating massive body where first obtained in 1963 by R. Kerr. A Kerr black hole possesses several distinguishing features compared to a non-rotating black hole (a Schwarzschild black hole). The Schwarzschild black hole is spherically symmetric, and no energy can be extracted from it. The spin axis of the Kerr black hole breaks the spherical symmetry, and identifies a preferential orientation in the space-time. In the vicinity of the hole, below a limiting distance called the static radius, the rotation of the hole forces every observer to orbit the black hole in the same direction in which the black hole rotates. The static radius and the gravitational radius (the event horizon) delimit the ergosphere of the Kerr black hole, a region where a particle can in principle escape, extracting some of the rotational kinetic energy of the black hole. The spinning motion of Kerr black hole, and the escape of particles from the ergosphere may play an important role as the power source and collimation mechanism of jets observed in radio galaxies and quasars.

Laing-Garrington effect The higher degree of polarization of the radio lobe associated to the jet, with respect to that associated to the counter-jet, observed in quasars, and to a lower level in radio galaxies. More precisely, R. A. Laing and S. T. Carrington reported in 1988 that, in a sample made mostly of quasars with double-lobed radio sources showing one sided-jets, the lobe on the jet side depolarized more slowly with increasing wavelength than the lobe on the other side. The Laing-Garrington effect is straightforwardly explained assuming that the there is no strong intrinsic difference between jet and counter-jet, and that the different surface brightness of the jet and counter-jet is due to relativistic beaming. Under these assumptions, the radio emission coming from the side of the counter-jet is more distant from the observer. The galaxy is expected to be embedded in a tenuous hot thermal medium. This medium de-polarizes intrinsically polarized radiation because of Faraday rotation. Radiation coming from the side of the counter-jet is then expected to travel a longer path across the region of thermal plasma embedding the galaxy, and therefore to emerge less polarized.

Lense-Thirring precession The dragging of space and time by a rotating mass, most evident in case of rapidly-rotating compact objects, such as Kerr black holes. Predicted using the equation of general relativity by J. Lense and H. Thirring in 1918, the effect has been presumably detected by the extremely tiny effects on satellites orbiting earth, and around distant, rotating objects with very intense gravitational field, such as neutron stars and black holes. The Lense-Thirring effect should give rise to a precessional motion if an object is not orbiting in the equatorial plane of the massive body. In the vicinity of a rotating black hole, within 100 gravitational radii, the dragging should be so strong to force all matter to orbit in the equatorial plane of the black hole. See *Kerr black hole*

Lindblad resonance A resonance in the orbital angular speed developed in non-axisymmetric gravitational potentials, such as the potential in a weakly barred galaxy, or of a planet slightly deviating from spherical symmetry, named after the Swedish astronomer B. Lindblad who introduced this class of resonances in 1965. Orbiting stars, like any other mechanical system subject to forces, have resonant frequencies. In the case of a barred galaxy, the bar supposedly rotates like a rigid body with a "pattern speed" Ω_B and thus gives rise to a non-axisymmetric gravitational potential. In non-axisymmetric potentials, orbits are not generally closed; if the deviation from axisymmetry is small, their orbital motion can be thought as due to the rotation associated to circular motion plus small radial oscillations. Lindblad resonances occur for stars orbiting at angular speed $\Omega = \Omega_P \pm\kappa/m$, where κ is the resonant angular frequency for radial oscillation, and it usually in the range $1 \div 2$ Ω_P, and m an integer number. The plus sign and the minus sign define inner and outer Lindblad resonances, respectively. Radii at which such resonances occur are called Lindblad radii. Rings or ring-like features are expected to form at and close to the Lindblad radii.

LINER Acronym of Low Ionization Nuclear Emitting Region. LINERs are narrow emission line galaxies that show optical and UV spectra with notable differences from classical Seyfert 1 and Seyfert 2 galaxies, namely lower nuclear luminosity, and stronger forbidden lines from low-ionization species, such as neutral oxygen, singly ionized sulfur and nitrogen. The ionization mechanism of the line-emitting gas is unclear. An appealing explanation sees LINERs as the lowest luminosity active galactic nuclei, photoionized by a non-stellar continuum weaker than that of more powerful active nuclei. In alternative, gas may be heated mechanically by shocks, or may be photoionized in dense clouds embedding hot stars of the first spectral types. LINERs are frequently observed in the nuclei of both spiral and elliptical galaxies, and might be detectable in nearly half of all spiral galaxies.

lobe dominated quasars High luminosity, radio-loud active galactic nuclei whose radio emission is dominated by extended lobe emission. Lobe dominated quasars have radio power and morphologies similar to those of Fanaroff-Riley class II radio galaxies. In quasars, the jet appear one-sided, and both core and jet have higher luminosity than in Fanaroff-Riley II galaxies.

Local Group of galaxies A group of approximately thirty galaxies, which includes the Galaxy and its closest neighbor galaxies within a distance ≈ 1 Mpc. Most members are thought to form a gravitationally bound system; the Local Group is therefore the closest example of a cluster of galaxies. The brightest members are the Galaxy, the spiral galaxy Messier 31 (the Andromeda galaxy), and the Sc spiral M33, although the majority of galaxies belonging to the Local Group are dwarf galaxies, either dwarf spheroidal or irregular galaxies. With present-day instruments, several galaxies of the Local-Group can be resolved into stars.

long slit spectroscopy A technique employed to obtain spectra of extended objects, such as galaxies or planetary nebulae. The spectrograph aperture on the focal plane of the telescope is limited by a slit, whose width is typically a few seconds of arcs or less, and whose height may cover an angular size of several minutes of arc. Only light coming from the narrow strip defined by the slit is allowed to enter the spectrograph to avoid contamination by adjacent strips: nearby sources could produce spectra that overlap spatially on the detector. Long slit spectroscopy has been employed in the measurement of continuum, absorption and emission lines from every extended object. An example is the construction of radial velocity and rotation curves of galaxies. See *velocity curve*

luminosity function of galaxies A function specifying the number density of galaxies per unit luminosity (or, equivalently, per unit magnitude). From counts and from measurements of the integrated magnitude of galaxies in rich clusters, P. Schechter derived the following law:

$$\Phi(L) = const \times (L/L^*)^\alpha \exp(-L/L^*),$$

where L is the galaxy luminosity, $L^* \approx 3 \times 10^{10} L_\odot$ is a turnover luminosity in units of solar luminosity, and α is found to be in the range $\approx -1.0 \div -1.5$. This law suggests that the most luminous galaxies are the rarest, and that the number of galaxies increases with decreasing luminosity. According to Schechter's law, a galaxy population in a magnitude limited sample – where galaxies are counted down to a fixed limit of brightness – is dominated by galaxies of luminosity near to L^*. On the contrary, in a volume limited sample – where ideally all galaxies are identified up to a fixed distance – the faintest galaxies would be by far the most numerous, and would contribute to the vast majority of light. Recent results suggest that the Schechter's law predicts fewer faint galaxies than observed.

Lyman α forest A large number of narrow (width ~ 10 km s^{-1}) absorption lines observed in quasars shortwards of the wavelength of the hydrogen line Lyman α. Spectra of many moderate and high redshift quasars show a characteristic "eroded" appearance due to the high number of absorptions per unit wavelength. It is very difficult to explain the Lyα forest as due to matter associated to the quasar; the current view is that the narrow lines are produced by relatively low density, cold hydrogen in shreds or clouds between the quasar and the observer. The absence of strong absorption lines of heavy elements suggests that the chemical composition should be very different from the chemical composition of the sun, with heavy elements $10 \div 100$ times less abundant in the absorbing clouds than in solar gas.

M 51 Object 51 in the Messier list, a bright Sc spiral galaxy notable for the grand design of its spiral arms (and sometime referred to as the "Whirlpool" galaxy). M 51 is perturbed by a smaller companion galaxy which appears to be in touch with and to distort one of its spiral arms. Optical spectra of the M 51 nucleus show emission lines suggestive of non-thermal nuclear activity, and whose intensity ratios are intermediate between those of LINERs and Seyfert 2 nuclei.

M 87 Object 87 in the Messier list, a giant elliptical galaxy (E0 in the Hubble sequence) at the center of the Virgo cluster, associated to the brightest radio source in Virgo, Virgo A. M 87 is remarkable for a jet whose length is ≈ 2 Kpc in the optical and which has been revealed in the radio, IR, UV and X-ray domain. At radio wavelengths the jet connects the central core of M 87 with the more diffuse emission of its north-western lobe. Another remarkable feature is the large number of globular clusters belonging to M 87 (~ 1000 have been detected with Hubble Space Telescope). According to A. Sandage and G. A. Tamman, the distance of M 87 using the luminosity function of globular clusters observed with HST as a distance indicator is ≈ 19 Mpc. See *cD galaxies*.

M 101 Object 101 in the Messier Catalogue, a bright, face-on, grand design Sc spiral galaxy (also known as the "Pinwheel Galaxy") in Ursa Major. The distance of M 101 from the Galaxy, measured using the period-magnitude relation of Cepheid variable stars detected by the Hubble Space Telescope, is 7.6±0.6 Mpc.

Markarian galaxies Galaxies showing an excess of blue and near UV emission, identified by B. E. Markarian through an objective prism survey with the 1 meter Schmidt telescope of the Byurakan observatory. The lists Markarian published in the 1970s include approximately 1500 objects, of which $\approx$ 10% are Seyfert galaxies, $\approx$2 % are quasars, $\approx$ 2% are galactic stars, and the wide majority are galaxies with enhanced star formation, such as star-forming dwarf galaxies and Starburst galaxies.

maser Acronym of microwave amplification of stimulated emission of radiation: amplification of radiation coming from excited states of molecules. Amplified lines have been observed at frequencies in the range 1-100 Ghz, in correspondence of dense molecular clouds associated to star forming regions, or in circumstellar envelopes of cold late-type stars, such as giant and supergiant M stars, Carbon and S stars, where diatomic or more complex molecules are not dissociated by the radiation from the star. Masers are produced by stimulated emission: a photon of frequency matching the frequency of a particular transition between two states induces the emission of a second photon, whose frequency and phase are identical to the first. Net amplification of the line radiation is achieved by population inversion, a condition realized when the higher energy level is more populated than the lower. Masers have been observed at several frequencies corresponding to rotational transition of di-and tri-atomic molecules. The most luminous masers have been observed in external galaxies at the frequency of 22.235 Ghz corresponding to a rotational transition of the water vapor molecule; they are known as water mega-masers.

maximally rotating black hole A Kerr black hole for which the angular momentum per unit mass reaches a maximum value. The maximum value expected from the solution of Einstein's field equation for a rotating body is equal to GM/c, and corresponds to a black hole rotating at the speed of light at a radius equal to GM/c^2, i.e, at the gravitational radius. As shown by K. S. Thorne, a real rotating black hole can come close to, but cannot reach this limit. The acquisition of angular momentum opposite to the spin, due to photons crossing the event horizon from a direction opposite to that of the black hole rotation sets a limit to the maximum angular momentum per unit mass equal to 0.998 G/c.

merger The remnant of a collision between two galaxies, in which the stars of each galaxy have been mixed together to form a single galaxy. In the process of merging, two galaxies behave like highly inelastic bodies that interpenetrate themselves, and transfer part of their orbital energy to their stars. Collisions among galaxies of similar mass with orbital velocity comparable to their internal velocity dispersion (typically a few hundred km s^{-1}) can produce mergers. If at least one of the merging galaxies is gas-rich, the compression of the gas in the disk leads to extensive star formation which, in turn, temporarily enhances the galactic luminosity. The morphology of a late-stage merger is expected to be nearly indistinguishable from that of an elliptical galaxy, It is however unclear which fraction of elliptical galaxies has been formed by merging of disk galaxies. A prototypical late-stage merger is the galaxy NGC 7252, also known as the "Atoms for Peace" galaxy. NGC 7252 appears still highly disturbed in a deep image taken with a long exposure time exposure, where tidal tails are visible, but resembles a regular elliptical galaxy in its central parts, with radial surface brightness profile following a de Vaucouleurs law, in an image taken with a shorter exposure.

Molecular torus A thick structure within the inner 1000 pc of a galaxy, made up of dense molecular clouds, which should obscure from view the innermost part of active galactic nuclei, if the torus axis is seen at large angles. Concentration of molecular gas in the regions surrounding the nuclei is observed in Starburst and several active galaxies, for example in the case of the prototype Seyfert 2 galaxy NGC 1068. However, properties such as the geometry, the thickening mechanism and the frequency of occurrence of molecular tori in active galactic nuclei are largely hypothetical.

narrow emission line galaxies A broad, heterogeneous class of galaxies showing permitted and forbidden emission lines in their optical nuclear spectra. The term "narrow" is used in juxtaposition to Seyfert 1 galaxies, which show much broader permitted lines. The profiles of narrow emission line galaxies, whose width is several hundred km s^{-1} and may reach 1000 km s^{-1}, are broad for normal galaxies. Narrow emission line galaxies are also collectively referred to as type-2 active galactic nuclei, again in juxtaposition to Seyfert 1 galaxies. NELG include Seyfert 2 galaxies or LINERs, and all other type-2 active galactic nuclei; several authors include among narrow emission line galaxies also galaxies whose nuclei show spectra of HII regions, which are not type-2 AGN.

Narrow Line Region (NLR) A region of active galaxies, where narrow permitted and forbidden emission lines are produced. The term narrow is used to distinguish lines whose width is typically $\gtrsim$ 300 km s^{-1}, hence already unusually broad for non-active galaxies, and lines whose full width at half maximum is several thousands km s^{-1}, emitted in a region of active nuclei (the Broad Line Region) distinct from the NLR. The strongest lines in the optical spectrum of the NLR are the Balmer lines of hydrogen, the forbidden lines of oxygen twice ionized at 500.7 nm and 495.9 nm, and the lines from ionized nitrogen at 654.8 and 658.3 nm. From the presence of strong forbidden lines, it is inferred that the density of the NLR gas must be $\sim 10^3 - 10^5$ particles per cubic centimeters. The absence of variability and the observation of nearby active galaxies, where the NLR is partly resolved, suggest that the NLR spans distances in the range from a few parsecs to a few hundred parsecs from the galactic center. The excitation mechanism of the line emitting gas is probably photoionization by the radiation from the active nucleus; it has been suggested that mechanical heating might also play a role. Images of several Seyfert 2 galaxies obtained with HST suggest that the morphology of the line emitting gas is closely related to radio plasma ejected from the nucleus. In several nearby AGN, emission lines whose intensity ratios are similar to those observed for the NLR extend far out from the nucleus, to a distance that can be a significant fraction of the size of a galaxy, typically several kpc, with in one case reaching 20 kpc. Since these regions appear resolved in long slit spectra, they are often referred to as the Extended NLR.

nebular lines Forbidden emission lines observed in optical spectra of gaseous nebulae, typically planetary nebulae, HII regions, and external galaxies. Strongest nebular lines are observed at 495.9, and 500.7 nm, at 654.8 and 658.4 nm, and at 372.7 nm. Nebular lines are forbidden lines, not observed in laboratory spectra. Once thought to be emitted by an unknown element, the "Nebulium", they were shown by I. S. Bowen in 1928 to be due to forbidden transitions between the lowest terms of singly and doubly ionized abundant atomic species, such as oxygen and nitrogen. See *forbidden lines*

non-thermal spectral energy distribution A spectral energy distribution of light produced if the atomic level population is not distributed according to the Maxwell-Boltzman law, or if the velocity distribution of the radiating particles is not a velocity distribution that follows Maxwell's law. A non thermal spectrum differs substantially from black-body (following Planck's law) or thermal free-free emission, in the case the source is optically thick or optically thin, respectively. Stars are regarded as thermal sources for excellence; hence non-thermal spectrum is often a synonym for non-stellar spectrum. A typical non-thermal spectrum is the spectrum of synchrotron radiation, as radiating electrons are accelerated to relativistic speed, and do not follow a Maxwellian distribution.

objective prism A prism of narrow apex angle (a few degrees) located at the objective of a telescope, most often of a Schmidt telescope. The objective prism, acting as a disperser, provides the spectrum of each object in the field of the telescope. A large number of low resolution spectra (up to $\sim 10^5$) can be recorded on a plate or electronic detector. Surveys based on objective prism spectroscopy have been very efficient in finding objects with peculiar spectral energy distribution, such as galaxies with UV excess, or objects with very strong and broad emission lines, such as quasars. Spectral resolving power achieved in common usage are ~ 100. Higher spectral resolving power can be achieved with wider apex angle prism. See *Markarian galaxies*

photoionization Ionization of atoms and ions by photons, a synonym of photoelectric effect. In the process of photoionization, a photon with energy greater than a threshold energy, the ionization potential, is absorbed, and an electron previously bound to an atom is freed from the atom potential well. The energy gained by the electron is equal to the difference between the photon energy $h\nu_0$ and the ionization potential ϵ_0, according to the formula $h\nu = h\nu_0 - \epsilon_0$. If gas is illuminated by a strong source of radiation that is capable of ionizing hydrogen, such as a single or a cluster of stars of the first spectral types (O and B), or an accretion disk, spectral lines are emitted following photoionization when the electron recombines. Photoionized nebulæ include HII regions, planetary nebulæ, extended envelopes surrounding hot stars, and the line emitting regions of active galactic nuclei.

Polarization The orientation of the electric vector of an electromagnetic wave along a preferential direction. Light coming from distant sources like stars can be thought as a sequence of plane waves, where the electric and magnetic vector oscillate along directions which are perpendicular to the direction of propagation of the wave. Polarization can be linear or circular. In the first case the direction of the electric vector is fixed in space, in the case of circular polarization the electric vector rotates in the plane with constant angular velocity. Light coming from thermal sources such as stars is normally unpolarized, i.e., the electric vector oscillates in all directions in the plane. Scattering by interstellar dust grains and charged particles can polarize previously non polarized light, in a similar way as non polarized sunlight becomes polarized after being reflected by the sea. Non-thermal radiation can be intrinsically highly polarized. For example, synchrotron radiation, which is an important emission mechanism especially at radio frequencies, has a high degree of linear polarization ($\lesssim$ 70 %).

POSS Acronym of Palomar Observatory Sky Survey, a survey which produced a collection of several hundreds of wide field, deep blue and red photographic plates originally covering the northern sky down to declination $\delta \approx -24°$ obtained with the Oshkin telescope at Palomar observatory, in the years from 1950 to 1955. With a scale of 67"/mm, and a limiting magnitude ≈ 20 in the red, the POSS plates have been instrumental to any source identification, including faint galaxies and quasars, for which later observations were being planned. The POSS plates have been digitized and supplemented with observations obtained in the southern hemisphere of similar scale and limiting magnitude to cover the entire sky. The Digitized Sky Survey (DSS) is stored on a set of 102 commercially available compact disks, covers the entire sky and includes an astrometric solution for each Schmidt plate, to readily obtain equatorial coordinates. In more recent years a second generation survey has been carried out at Palomar employing plates with finer emulsions. This second generation survey, known as POSS-II, was almost completed and in large part digitized as of 1999.

quantization of redshift A systemic trend in the radial velocity difference between galaxies that are members of a pair of galaxy, originally emphasized by W. Tifft in 1976 from the analysis of a sample of ≈ 100 isolated pairs of galaxies. According to Tifft, the radial velocity difference, deduced from redshift between pair members is preferentially an integer multiple of 72 km/s, i.e., $cz = n72km/s$, where c is the speed of light, z the redshift, and n an integer number. The word quantization is used in analogy with quantum mechanics. This finding is as yet unexplained in the framework of gravitational interaction between galaxies, since no quantization of any parameter is expected on such large scales.

quasar Acronym of quasi stellar radio source; an active galactic nucleus that is active, of high luminosity, radio loud, and that does not show, in visual images, any clear evidence of an underlying galaxy. It is customary to define as quasars all radio-loud active galactic nuclei above the luminosity $\approx 10^{11} L_\odot$, although this subdivision is somewhat arbitrary. Other defining properties of quasars are large UV flux, broad emission lines, large redshift and time-variable continuum flux. Some of the brightest radio sources are associated with quasars. The term "quasars" designates often, albeit improperly, the broader class of both distant radio quiet and radio loud active galactic nuclei whose image is nearly stellar, i.e., whose host galaxy is not clearly visible. The most distant quasars are now being observed at redshift $\lesssim 5$. The 8th Edition of "A Catalogue of Quasars and Active Nuclei" by M. - P. Veron-Cétty and P. Véron lists more than 11000 quasars (both radio-quiet and radio loud) known as of early 1998.

quasar galaxy association The observation of an unusually large number of quasars surrounding, bright, nearby galaxies. For example, more than 40 quasars have been found in a field by $\approx 3\times3$ square degrees centered on the spiral galaxy NGC 1097. This excess of quasars has been explained as due to gravitational lensing of the light of vary far, background quasars by the matter associated with a nearby galaxy. H. Arp and coworkers, on the contrary, have argued that the quasars surrounding the nearby galaxy must be physically associated with it, and that they are therefore not very far, background objects as implied by Hubble's law and by their redshift.

QSO Acronym of Quasi Stellar Object. QSOs are high luminosity active galactic nuclei which show optical appearance almost undistinguished from stars, and a spectrum with strong and broad emission lines invariably shifted to the red. The optical emission line spectrum closely resembles that of Seyfert 1 galaxies. Search for quasars have been carried out in several regions of the electromagnetic spectrum, from the infrared to the X-ray. The final identification of a quasar is, however, made on the identification of redshifted spectral emission lines. The terms QSO and radio-quiet quasar are a synonym of radio quiet high luminosity active galactic nucleus. While in typical Seyfert galaxies the luminosity of the nucleus is comparable to the luminosity of the host galaxy, in QSOs the nucleus can be hundreds of times more luminous. It is customary to define as quasars all radio-quiet AGN above the luminosity of $10^{11} L_\odot$, although this subdivision is somewhat arbitrary.

radio cores Compact radio emitting regions at the center of radio galaxies and quasars. Radio cores are usually unresolved at angular resolution $\gtrsim 0.1$ arcsecs. At resolution of the order of one milliarcsecond, achieved with Very Long Baseline Interferometers, cores are resolved into one-sided jets, whose size is typically of the order of a parsec in nearby radio-galaxies. Observations have shown that there is always a continuity with larger scale jets connecting the core to the radio lobs, although the jet often bend significantly passing to larger scale. The spectral energy distribution of a core is nearly constant over frequency in the radio domain, so that radio cores are said to be flat spectrum sources. In other word, the radio spectrum of a core can be described with a power-law function of frequency, with spectral index ≈ 0. Core-dominated (or equivalently, flat spectrum) radio sources do not show evident extended radio jets or lobes.

radio lobes Extended, often irregular and filamentary regions of radio emission observed at the end of radio jets on opposite sides of the nucleus, in powerful radio galaxies and quasars. Radio lobes often extend beyond the optical image of a galaxy, and typically reach end-to-end sizes of 50 kpc - 1 Mpc (the largest radio lobes known span 9 Mpc). The radio spectral energy distribution of lobes decreases sharply with increasing frequency; lobes are said to be steep spectrum sources in opposition to radio cores which show a flat spectral specific flux distribution. Emission is due to synchrotron processes, as in radio cores, but produced by electrons with lower energy. A prototypical lobe-dominated radio source is the elliptical galaxy Centaurus A (the brightest radio source in the Centaurus constellation), with two lobes extending far beyond the optical image of the galaxy, each ~ 300 kpc in projected linear size.

redshift The relative displacement toward longer wavelength (or equivalently, of lower energy) of radiation, measured from spectral features like emission or of absorption lines, and defined as

$$z = (\lambda - \lambda_0)/\lambda_0,$$

where λ_0 is the rest wavelength of a spectral feature. The displacement toward a longer wavelength is conventionally termed a redshift also if the photons are not in the visible spectral range. Galaxies and quasars, with the only exceptions of several galaxies very close to the Milky Way, invariably show all their spectral lines shifted to the red, with redshift increasing with distance according to Hubble's Law. Redshifts currently up to $z \approx 5$ are observed for quasars.

relativistic jets Collimated ejection of matter at velocity close to the speed of light, giving rise to a highly elongated, often knotted structures in radio-loud active galactic nuclei, for example radio quasars and powerful radio galaxies. Radio jets usually originate from an unresolved core and physically connect, or point to extended lobes. Linear sizes of jets mapped at radio frequencies in external galaxies range from several kpc or tens of kpc, down to a the minimum size resolvable with very long baseline interferometers (~ 1 parsec). Parsec-size jets show several indications of relativistic motion, including apparent superluminal motion, and jet one-sidedness ascribed to relativistic beaming of radiation. It is less clear whether jets observed at scales of several kiloparsecs are still relativistic. It is thought that only the most powerful radio galaxies, class II according to Fanaroff and Riley and quasars may sustain a relativistic flow along kiloparsec-sized jet. Jets emit radiation over a wide range of frequencies. This led I. S. Shklovskii in 1953 to suggest that the radio emission is electron synchrotron radiation. Galactic objects, like the evolved binary system SS 433, and galactic superluminal sources are also believed to harbor relativistic jets. See *superluminal motions*

ring galaxy A galaxy showing a bright, prominent outer ring encircling the whole galactic body. Ring galaxies are thought to be produced by the head-on encounter between a disk galaxy and a second galaxy: the second galaxy must approach the disk galaxy from a direction nearly perpendicular to the plane of the disk. After the collision, an outward moving density wave within the disk gives rise to the ring, which appears to surround a central area of much lower surface brightness. Ring galaxies are of rare occurrence (only a few tens are presently known), as their formation requires a special orbit orientation for the encounter of two galaxies. A prototypical example of ring galaxies is the Cartwheel galaxy, a galaxy that is believed to have been crossed by a smaller companion galaxy visible in its vicinity.

rotation curve A curve which describes the rotational velocity as a function of radius, typically of gas or stars in a disk galaxy. The rotation curve is obtained from the radial velocity measured on absorption or emission lines detected along the galaxy apparent major axis, and corrected for the inclination of the galaxy. A rotation curve, in a diagram where velocity in km s^{-1} is plotted against angular or linear distance, is usually made up of a linear trait, where velocity increases linearly from zero with radius, a turning point, where the curve flattens, and a long, nearly flat or slowly decreasing trait. The so-called Keplerian trait, or a part of it, in which the orbital velocity decreases with distance according to Kepler's third law, after all the matter of a galaxy is left behind, is almost never observed. The maximum rotational velocity depend on the galaxy morphological type; typical values are $\approx 200 \div 300$ km s^{-1}. See *long slit spectroscopy*

Seyfert-1 galaxies Seyfert galaxies showing two systems of emission lines, i.e. broad Balmer lines (and in general, broad recombination lines, which may include strong emission from singly-ionized iron), and narrower forbidden lines. The width of the Balmer lines can reach 30,000 km s^{-1} at the line base, and it is typically several thousands km s^{-1} at half maximum. The width of the forbidden lines is usually restricted to several hundreds km s^{-1} at half maximum. The presence of broad lines is a defining feature of "type-1" active galactic nuclei, a more general class which includes quasars and QSOs since they show emission line properties very similar to that of Seyfert 1 nuclei. Broad and narrow lines are emitted in different regions, called the "Broad Line region" and the "Narrow Line Region" respectively. The 8^{th} Edition of A Catalogue of Quasars and Active Nuclei by M. - P. Veron-Cétty and P. Véron lists more than 1100 Seyfert 1 galaxies known as of early 1998.

Sérsic-Pastoriza galaxies Galaxies that exhibit an anomalous luminosity profile near their center, and often structures due to unresolved, compact emission regions, which are sites of intense star formation. They were first catalogued as a peculiar class of galaxies by J. L. Sérsic and M. Pastoriza in 1965. Several Sérsic-Pastoriza galaxies have a nucleus showing a Seyfert-type or LINER spectrum, while other compact emission regions close to the nucleus (denominated "hot spots" in analogy to bright spot-like features often observed at the junction of jets and lobes in radio maps) show the spectrum of HII regions. Studies of Sérsic-Pastoriza galaxies have been aimed at clarifying a possible link between intense, localized, star formation, as in the hot spots, and the presence of non-stellar, nuclear activity.

Seyfert galaxies Galaxies showing a bright, star-like nucleus, whose optical and UV spectrum shows prominent emission lines. Seyfert galaxies are typically identified by their optical spectrum, which shows emission lines of the Balmer series, along with strong forbidden lines, like the nebular lines of the oxygen twice ionized, and of singly ionized nitrogen. Singled out in 1943 by C. Seyfert as an independent class of galaxies, the importance of Seyfert galaxies was largely unappreciated until the discovery of quasars. Quasars and Seyfert galaxies are now considered part of the broader class of active galactic nuclei. In this view, Seyfert galaxies are radio-quiet, low luminosity AGN, distinct from quasars since the host galaxy is visible and since their lower luminosity is lower. It is customary, albeit arbitrary, as there is no solution of continuity between nearby active galactic nuclei and quasars, to distinguish between Seyfert and quasars defining Seyfert nuclei as having luminosity lower than 10^{11} solar luminosity, the luminosity of a large galaxy.

Seyfert-2 galaxies Seyfert galaxies showing permitted and forbidden emission lines with similar width, typically several hundred km s^{-1}. In other words, Seyfert 2 galaxies do not show broad permitted lines as observed in Seyfert 1 galaxies. Seyfert 2 galaxies are of lower luminosity than Seyfert, and they are believed to be roughly two – three times more frequent than Seyfert 1 in a volume limited sample. The discovery of broad Balmer lines in polarized light in the prototype Seyfert 2 galaxy NGC 1068, and in other nearby Seyfert 2 nuclei, has led to a model in which Seyfert 2 galaxies are actually Seyfert 1, whose Broad Line Region is obscured from view by a thick torus of molecular gas. Free electrons slightly above the torus should scatter the broad line photons into the line of sight, letting them be detected only in polarized light. The applicability of this model to most Seyfert 2 galaxies is yet a subject of debate. Several works have pointed out that Seyfert 2 galaxies are an heterogeneous class, and that several Seyfert 2 could be genuinely different from Seyfert 1 galaxies, with features in their spectral energy distributions that could be related to intense star formation. The 8^{th} Edition of A Catalogue of Quasars and Active Nuclei by M. - P. Veron-Cétty and P. Véron lists about 560 Seyfert 2 galaxies known as of early 1998.

spectral energy distribution (SED) The relative intensity of light at different frequency, measured over a wide range of frequency, also across the entire range of the electromagnetic spectrum observable from ground and space. The spectral energy distribution is usually expressed in units of power per unit frequency or wavelength. Astronomers refer customarily to the term spectral energy distribution to focus on the continuum spectrum of an astronomical object, whereas the absorption or emission line spectrum is not considered. The spectral energy distribution can be very different for different astronomical sources and emission mechanisms; for example, stars emit radiation whose spectral energy distribution show minor deviations from the Planck function, as expected for high-temperatures black bodies. Synchrotron processes produce a spectral energy distribution that can be described by a power-law as a function of frequency or of wavelength over a wide spectral range.

spectral energy distribution, of active galactic nuclei A spectral energy distribution which is very different from the SED of stars and non-active galaxies and which is characterized by significant, in a first approximation almost constant, energy emission over a very wide range of frequencies, from the far IR to the hard X ray domain. In radio-loud AGN, roughly constant emission extends to radio frequencies; in radio quiet AGN, emission at radio frequencies is typically $\sim$ 100 times lower. In a first approximation, the AGN SED per unit frequency can be described as a power-law function of frequency ($f_\nu \propto \nu^{-\alpha}$), with a spectral index $\alpha \approx 1$ (hence, the emitted energy $\nu\{_\nu$, is constant). Superimposed to the power-law emission there is a broad feature, the big blue bump, which extends from the visible to the soft X-ray domain, with maximum emission in the far UV. The big blue bump has been ascribed to thermal emission, possibly by the putative accretion disk. This interpretation of the AGN continuum is however subject of current debate, as it is as yet not clear which amount of total emission is due to nonthermal processes. There are also significant differences between AGN subclasses. See *big blue bump, spectral energy distribution*

spectrophotometry The measurements of spectral line and spectral continuum fluxes, and their comparison, made over a wide range of frequency or, equivalently, of wavelength. Instrument sensitivity strongly depends on the frequency of the incoming radiation. To recover the radiation flux and the intrinsic spectral energy distribution due to an astronomical source reaching the telescope, a wavelength-dependent correction must be applied to the recorded spectrum. A spectrophotometric calibration is customarily achieved in optical and UV spectroscopy by the repeated observations of standard stars i. e., stars for which the intrinsic spectral energy distribution is already known. Accurate spectrophotometry, even if restricted to the visible spectral range ($\approx$ 400 - 800 nm) is difficult to achieve from ground based observations, and has been made possible only recently by the employment of linear detectors such as the CCDs.

spectropolarimetry The measurement of the degree of polarization of radiation, and of the polarized radiation flux, as a function of frequency or wavelength. Optical spectropolarimetric measurements are achieved inserting an half-wave or quarter-wave plate and a polarizer in the optical path of the light allowed into the spectrograph. Astronomical spectropolarimetry can in principle achieve high precision ($\sim$ 0.01 %). However, partly oblique reflections due to telescope and spectrograph design may polarize intrinsically unpolarized radiation and make spectropolarimetric measurements especially cumbersome. Even if some emission mechanisms like synchrotron processes can produce high degree of polarization, real sources show optical spectra with small degree of polarization, reducing the collected flux. As a consequence, spectropolarimetric measurements have been until recently rather sparse and limited to relatively bright objects.

spiral arm The part of the spiral pattern of a galaxy which is more or less continuously traceable. Spiral arms are very evident in the blue and visual bands (and hence were revealed since the early days of extragalactic astronomy) or, with a more "knotty" appearance, in narrow band images centered on the Hydrogen Balmer line Hα. This indicates that spiral arms are sites of recent star formation. Spiral arms accordingly become less and less prominent at longer wavelengths, and almost undetectable in the near infrared, where most of the light is produced by more evolved stars. Dust lanes, filamentary absorption features which appear dark on the emission background of the galaxy's disk are often associated to spiral arms. The physical origin of the spiral pattern of galaxies is a subject of current debate. "Grand design" spirals have been linked to the gravitational perturbation by a nearby companion galaxy, as in the case of M51. See also *M 51*.

spiral galaxy A galaxy showing a bright spiral pattern, superimposed to smooth disk emission. Spiral galaxies are composed of a spheroidal bulge and of a flattened system of gas and stars (the disk), over which the spiral pattern is seen. While the bulge of a spiral galaxy loosely resembles an elliptical galaxy, the disk shows an exponential decrease in surface brightness with increasing distance from the nucleus. Both the prominence of the bulge and the shape of the spiral pattern vary along the Hubble sequence. Sa galaxies show continuous, thin, and tightly wound spiral arms, and a prominent bulge. At the other end, Sc galaxies show a broken, more loosely wound spiral pattern, and a much smaller bulge. Spiral galaxies are preferentially found in regions of lower galactic density ("morphology-density relation"). See also *Hubble Sequence, spiral arm.*

starburst galaxy A galaxy undergoing a strong episode of star formation. Starburst galaxies can be more quantitatively defined as galaxies whose total SFR cannot be sustained over the age of the universe (the Hubble time). This criterion is very general, and includes spiral galaxies whose nuclei show emission lines typical of HII regions, as well as star-forming dwarf galaxies. Starburst nuclei are hosted by spiral galaxies, often interacting or merging with a companion galaxy, and exhibit, along with optical and UV nuclear spectra typical of star forming regions, an excess of mid and far infrared emission with respect to normal galaxies of the same morphological type. Prototype Starburst galaxies are the edge-on spiral NGC 253 and the dwarf irregular galaxy Messier 82. FIR-strong galaxies, blue galaxies, UV excess galaxies, or HII galaxies are often systems where star formation is enhanced with respect to normal galaxies, and can be synonyms of Starburst galaxies. The different names reflect the different technique and the different spectral range of observation and discovery.

star formation rate (SFR) The rate at which new stars are being formed in a galaxy, or in any star forming region, often measured in units of solar masses per year. The star formation rate can be estimated from measurement of the luminosity of the Hydrogen Hα spectral line, or from the luminosity emitted in the far infra-red, if the Initial Mass Function of stars is assumed. Elliptical galaxies are reputed to have experienced a burst of star formation at the epoch of their formation, but to be very quiescent now. Galaxies of late morphological types, are on the contrary, have yet to exhaust their molecular gas, and are still forming stars. The star formation rate in galaxies varies widely along the Hubble sequence: for galaxies in the local universe, typical values are close to zero for elliptical galaxies and ~ 10 solar masses per year for Sc spirals.

Sunyaev-Zeld'ovic effect A modification of the spectral energy distribution of the background microwave radiation at temperature ≈ 2.7 degrees Kelvin, described in 1972 by R. Sunyaev and I. Zeldovich, and due to inverse Compton scattering of the microwave radiation photons by free electrons in the hot gas filling the intergalactic space in clusters of galaxies (the intra-cluster medium). The background photons gain energy, causing a minimal, yet measurable change in the background radiation temperature. If the distribution of electron temperature and electron density of hot matter inside the cluster is known, then the value of the Hubble constant (and in principle of the deceleration parameter q_0) can be derived. Applications of the S-Z effect to the measurement of H_0 have the advantage of being independent from the distance ladder build on optical distance indicators, but require detailed X-ray observations of massive and dense clusters of galaxies. They have yielded until early 1998 values of $H_0 \lesssim 50$ km s^{-1} Mpc^{-1}, which are somewhat lower than other estimates. See *inverse Compton effect*

supercluster A cluster of clusters of galaxies. Superclusters are large scale structures, several tens of Megaparsecs or more in size. They became widely accepted as real structures when redshift surveys in the 1970s and early 1980s provided a three-dimensional view of the large scale distribution of galaxies in the local universe. Superclusters mapped until now are far from homogeneous. Their main condensations occupy a small fraction of the available volume and are connected by filamentary links (streams) of galaxies.

superluminal source A radio source showing plasma flowing at transverse velocity larger than the speed of light. Superluminal sources are revealed comparing two high resolution radio maps obtained at different epoch with Very Long baseline Interferometers. Superluminal motion is found usually in core dominated radio galaxies and quasars, and is made possible by the presence of highly relativistic motion and by a favorable orientation. The apparent transverse velocity is

$$v_{trans} = v \sim \sin\theta/(1 - v/c\cos\theta)$$

, where v is the velocity of the radiating particles, c the speed of light, and θ the angle between the jet and the line of sight. For example, the radio quasar 3C 273 shows blobs of gas moving out along the jet at an angular speed of $\approx$0.67 milliarcsec per year. If the radio jets points few degrees from the line of sights, then the observed apparent velocity is 6.2 times the speed of light. About 70 extragalactic superluminal sources have been catalogued in late 1993. In 1995, a galactic superluminal source was identified by F. Mirabel and L. F. Rodriguez, and as of early 1998, two galactic superluminal sources are known.

supermassive black hole A black hole of mass $\sim 10^6$-10^9 solar masses. Supermassive black holes are believed to be present in the nuclei of quasars, and, possibly, of most normal galaxies. A black hole of mass as large as 10^8 solar masses would so compact have a radius (the gravitational radius of the black hole) $\approx 3\times\ 10^8$ km, and thus linear dimension comparable to distance of the earth from the sun, much less than the size of the solar system. Evidence supporting the actual existence of supermassive black holes is not as yet conclusive, and rests mainly on the huge luminosity of quasars, and on the perturbations observed in the motion of stars in the nuclei of nearby galaxies, which are probably accelerated by the central black hole gravity.

synchrotron self-Compton (SSC) mechanism A mechanism suggested for the production of high energy photons in radio loud active galactic nuclei. In the synchrotron self-Compton scheme, low energy photons are produced in the radio domain by synchrotron emission. If the source is very compact, the same relativistic electrons then turn the radio photons into higher energy photons by inverse Compton scattering. The synchrotron self-Compton mechanism suggests that the spectral shape of the seed synchrotron photons is maintained in the scattered spectrum. This prediction has been apparently confirmed by observations of the blazar 3C 279; however, the general validity of the synchrotron self-Compton mechanism for active galactic nuclei is as yet controversial.

tidal radius The radius within which all the luminous matter of a galaxy is contained. The tidal radius can be measured for globular clusters and galaxies belonging to clusters, which are found to have well-definite outer limits (in contrast with brightness profiles of isolated elliptical galaxies, described by de Vaucouleurs' or Hubble's-Reynolds law). In the case of a cluster galaxy, repeated encounters with nearby galaxies can lead to tidal stripping of the outer stars, which are loosely gravitationally bound, and to the extinguishment of the outer envelope.

tidal stripping The escape of gas and stars gravitationally bound to a system, such as a galaxy or a globular cluster, due to tidal forces exerted by an object external to the system. For example, in a cluster of galaxies, tidal stripping may remove loosely-bound stars from the galaxy outer envelope; in a close encounter between galaxies, stars and gas can be transferred from one galaxy to the other.

tidal tail A highly elongated feature produced by tidal forces exerted on a spiral galaxy by a companion galaxy. A most notable example of tidal tails is observed in the "Antennæ" pair of galaxies (NGC 4038 and NGC 4039), where the tidal tail extends for a projected linear size of $\approx$ 100 kpc, much larger than the size of the galaxies themselves. Very extended tails, like the ones in the Antennæ, are produced by a prograde encounter between galaxies i. e., an encounter between a spiral galaxy and an approaching companion galaxy which moves in the same sense of the spiral rotation.

transverse Doppler shift A shift arising because of Doppler effect when the photon is emitted perpendicularly to the direction of motion. The transverse shift is not present in the classical Doppler effect (where a frequency shift is possible only if there is a non-zero component of the velocity along the direction of emission of the photon). It is a purely special relativistic effect which arises because of time dilatation i.e., because the observer in a different frame measures a different time interval than an observer comoving with the source.

Tully-Fisher law An empirical law which relates the width of the 21 cm neutral hydrogen spectral emission line to the luminosity of a spiral galaxy, named after R. B. Tully and J. R. Fisher who proposed it in 1977. More precisely, the total galaxy luminosity is proportional to the fourth power of the width of the 21 cm line. The relationship is best (i.e. data points show less scatter) if the luminosity is measured in the infrared. The infrared luminosity depends little on Hubble type, and is closely correlated to the amount of intermediate population and stars, which make up the largest fraction of the mass in a spiral galaxy. The physical basis of the Tully-Fisher law resides in equating two observable parameters that are independent estimates of the mass of a galaxy. Using the Tully-Fisher law, the intrinsic luminosity of a galaxy can be derived from the measurement of the broadening of the HI 21 cm line, which does not depend on distance. The Tully-Fisher relationship can be therefore used as a distance indicator. See *Faber-Jackson law*

unification of active galactic nuclei Theories attempting to explain the variegated phenomenology of active galactic nuclei on the basis of a few key parameters. In grand-unification schemes, the central engine should be basically the same for all active galactic nuclei (AGN) i.e., a supermassive black hole surrounded by a hot accretion disk, with orientation, black hole mass, accretion rate, and spin of the black hole (or, alternatively, the morphology of the host galaxy) accounting for all differences observed between AGN types. In the unification scheme for radio quiet AGN, different orientation of the accretion disk with respect to the line of sight could give rise to a Seyfert 1 galaxy (if the disk is seen at intermediate inclination), or to a Seyfert 2 galaxy (if the disk is seen at large inclination, the line emitting regions should be obscured by a molecular torus). Unification of radio-loud AGN relies on the effect of relativistic beaming to explain the different appearance of radio loud AGN, and to establish a link between the beamed and unbeamed (also called the parent) population. For instance, a low luminosity radio-loud AGN, should be classified as BL Lac in the optical and as a compact core in the radio if the disk is seen face-on. On the basis of the radio morphology, the same object would be classified as a low luminosity Fanaroff-Riley type I radio source if the line of sight is oriented at a large angle from the radio jet. The validity of unification models and the identification of the parent population for some AGN classes is a subject of current debate.

velocity dispersion A parameter describing the range of velocities around a mean velocity value in a system of stars or galaxies. For example, the radial velocity dispersion can be measured for the stars in an elliptical galaxy and for the galaxies in a cluster. In the first case the radial velocity dispersion is derived from the width of spectral lines, whose broadening is due to the motion of a large number of unresolved stars in the galaxy; in the second case from the redshift of each individual galaxy. From the measurement of the velocity dispersion, the mass of the aggregation can be estimated.

Virgocentric flow The motion of the galaxies in the Local Group toward the Virgo Cluster. The gravitational force exerted by the mass of the Virgo attracts all surrounding galaxies, including the galaxies of the Local group. The velocity of approach toward Virgo lies in the range $v_r 100 \approx \div 400 \approx$ km s^{-1}. A correction for Virgocentric flow should be applied to the radial velocity measured for nearby galaxies, especially if the recessional velocity is used as an indicator of distance according to Hubble's Law.

Virgo Constellation A zodiac constellation most visible in spring, covering the area of sky approximately ranging from 12 to 15 hours in rights ascension and from $\approx$ -15° to $\approx$ +15° in declination. The Virgo (Latin for Virgin) can be identified looking for an "Y" shaped configuration formed by four stars between Libra and Leo. The brightest star of Virgo(α Virginis, Spica, apparent magnitude = 1.0) is located at the lower tip of the "Y." The sky region of the Virgo constellation includes the Virgo cluster of galaxies. See also *Virgo Cluster, Virgo Supercluster.*

Virgo Supercluster A Supercluster, roughly centered on the Virgo Cluster of galaxies, which includes the Galaxy and which is accordingly known as the Local Supercluster. The Virgo Supercluster, first introduced by G. de Vaucouleurs, has a clumpy structure which includes several groups and clusters of galaxies, and whose somewhat flattened distribution shows a preferential plane defining a "supergalactic equator" and a "supergalactic" system of coordinates. The Galaxy is located in the outskirts of the Local Supercluster, at approximately 15 – 20 Mpc from the Virgo cluster. See also Superclusters.

water mega-masers Masers of a spectral line at 22.235 GHz due to a rotational transition of the water vapor molecule. Water mega-masers are more luminous than the most luminous Galactic masers by a factor 100, and observed in several active galaxies. Interferometric observations have shown that mega-masers are formed within 1 pc from the active nucleus of a galaxy, indicating that the source of pumping radiation is provided by the active nucleus itself. Approximately 20 water mega masers are known as of early 1998.

Yerkes classification scheme of galaxies A classification scheme of galaxies, conceived by W. W. Morgan, and based on the central concentration of light, which closely correlates to the stellar population of a galaxy. The concentration class of a galaxy is indicated with the same letter used for stellar spectral types, but written lower-case (i.e., k for ellipticals and a for Sc spirals whose spectrum is dominated by K giants and A stars respectively). A second parameter describes the "form family" of galaxies: S, indicates a spiral; B, a barred spiral; E, an elliptical; I, an irregular; R a galaxy having rotational symmetry without prominent spiral arms (an S0 galaxy according to the Hubble scheme); D indicates an elliptical galaxy with an extended envelope. A third symbol (a number from 0 to 7) describes the apparent flattening of a galaxy. For example, M31 is classified as kS5. Albeit no more widely in use, the Yerkes scheme is still used to denote supergiant elliptical galaxies often found at the center of clusters and groups of galaxies (cD galaxies).

Zwicky compact galaxies Galaxies originally defined by F. Zwicky as distinguishable from stars on the Palomar 1.2 m Schmidt telescope plate, and with angular diameter between 2 and 5 seconds of arc. "Compact" is, in astronomy, a loose synonym of "not fully resolved". The notion of compactness of a galaxy therefore depends on the resolving power of the observational equipment, although compact galaxies have, in general, high surface brightness and sharp borders. F. Zwicky circulated seven lists of compact galaxies including about 200 objects in the mid 1960s. Most of them are of blue color and show emission lines in their spectra. Zwicky's compact galaxies have turned out to be a rather heterogeneous class, which included star-forming dwarf galaxies, as well as several active galaxies. For example, the object I Zw 1 (the first object of Zwicky's first list) is a nearby quasar.