

Index

- 4000 Å break: *see under* stellar atmospheres
- absolute magnitude, 23
- abundances: *see* heavy elements
- accretion disk: *see under* active galactic nuclei
- acoustic peak, 347
- active galactic nuclei, 365ff
- γ-ray emission, 369, 371
 - absorption lines, 383, 390: *see also* gas, intergalactic
 - accretion disk or torus, 370, 372, 373, 387
 - black holes, 367, 374, 382
 - blazars, BL Lac objects, 368, 381, 383, 384, 386
 - broad-line region, 366, 372, 373, 383
 - Eddington luminosity, 371
 - fuel supply, 374
 - gas
 - heating in clusters, 299
 - maser, 240, 381
 - molecular, 240, 383
 - outflowing, 383
 - jets and relativistic beaming, 368–371, 373, 375–377, 380, 381, 383–389
 - life cycle, 342–344, 382
 - low-ionization nuclear emission regions (LINERs), 374
 - luminosity, 371
 - narrow-line region, 372, 373
 - quasars, 344, 367, 368, 380, 381
 - Types 1 and 2, 381
 - radio emission, 367, 369, 371, 375, 377, 382
 - radio galaxies, 374
 - Seyfert galaxies, 240, 287, 367, 369, 370, 373, 375, 376
 - Types 1 and 2, 367, 372, 373
 - space densities, 343, 344, 368
 - spectra, 366–370, 372, 374, 381, 382
 - starburst galaxies, 374, 402
 - superluminal motion, 383–386
 - unified model, 370, 372, 373
 - variability, 366, 368
 - X-ray emission, 369, 371–373, 382
- age
- galaxies, 238, 267, 268, 362, 401, 405, 406
 - dwarf, 163, 164, 187
 - Milky Way bulge, 86, 158, 175
 - Milky Way disk, 73, 83, 177
 - star clusters, 77–80, 82, 160, 163
 - stars: *see* stellar evolution, stellar age–metallicity relation
 - Sun, 11
 - Universe, 47, 48, 334
- age–metallicity relation, 72, 160, 176, 177, 181
- AGN: *see* active galactic nuclei
- angular momentum, 118, 149, 175, 263, 264
 - λ parameter, 354
 - tidal torque origin, 173, 175, 354
- angular-size distance, 336, 337, 339, 340
- anisotropy in velocities, 149, 150, 261
- antimatter, in early Universe, 51, 52
- apparent brightness, 4
- apparent magnitude, 18
- area radius σ , 325
- array detectors, 192–196, 204
 - cosmic-ray hits, 194
- asymmetric drift: *see under* Milky Way, stellar disk
- asymptotic giant branch: *see under* stars
- background radiation, 56
 - cosmic: *see under* cosmic expansion
 - night sky, 19, 43, 44, 244, 245, 255, 402
- Balmer jump: *see under* stellar atmospheres

- bars: *see under* disks of galaxies
- baryon oscillations, 323, 346, 347, 359
- baryons
- cosmic density, 48, 53, 54, 220, 300, 397
- benchmark cosmology: *see under* cosmic expansion
- Big Bang nucleosynthesis, 9, 50, 52
- Big Bang: *see* cosmic expansion
- binary stars, 2, 17, 157, 182, 270
- Lagrange points, 166, 167
 - microquasars, 386, 387
 - star clusters, 132
 - Type Ia supernova, 17, 18
 - X-rays, 17, 271
- black holes
- active nuclei, 367, 374, 382
 - from supernovae, 16
 - galaxy center, 169, 172, 184, 239, 240, 266, 273, 275–277, 287, 382
 - microquasars, 387
 - Milky Way center, 67, 68, 86–88
 - orbits around, 136
 - Schwarzschild radius, 276, 304, 367
 - stellar binaries, 271
- blackbody radiation, 3, 4, 33, 43, 51, 331
- blazars, BL Lac objects: *see under* active galactic nuclei
- bolometric correction, 21, 23–25
- bolometric luminosity, 2, 25
- bremsstrahlung: *see* free–free radiation
- brown dwarfs, 6
- bulges of galaxies, 169, 170, 191, 200, 236–238, 247, 275
- Milky Way, 26, 86, 87, 99, 158, 175, 180
 - rotation, 87, 237
 - counter-rotation, 214
- celestial poles, 34
- Cepheid variable stars, 15, 37
- period–luminosity relation, 161
- Chandrasekhar limit, 17, 182
- charge-coupled device (CCD), 192–196
- closed-box model: *see under* heavy elements
- closed Universe, 325
- clusters of galaxies: *see* groups and clusters of galaxies
- collisional ionization, 28
- collisionless Boltzmann equation, 140ff
- collisions and mergers: *see* galaxy collisions and mergers
- color, definition, 22
- comoving
- coordinates, 326, 352
 - density, 342
 - volume, 342, 343
- cooling
- curve for gas, 105, 106, 299
 - time, 105, 106, 298, 299
- coordinates
- comoving, 326
 - equatorial (α, δ), 34
 - Galactic (l, b), 36
 - Galactocentric (R, ϕ, z), 37
 - supergalactic, 154, 316
- core collapse of star cluster, 132
- core radius, 78, 80, 113, 122, 132, 163, 247, 249, 292
- correlation function $\xi(r)$: *see* large-scale structure
- cosmic background radiation (CMB): *see under* cosmic expansion
- cosmic expansion 46ff, 325ff
- age of Universe, 47, 81, 333, 334
 - angular-size distance, 336, 338, 339
 - area radius σ , 325
 - background radiation, 50–56, 344, 356, 357
 - baryon oscillations: *see under* large-scale structure
 - fluctuations, 344–347, 359
- benchmark model, 48, 330, 334
- initial fluctuations, 344, 359, 362
- cold dark matter, 358, 359, 362, 363, 405
- WIMPs, 176, 357, 358, 363
- comoving length and volume, 342, 343, 352
- cosmological constant Λ : *see* dark energy, inflation
- cosmological redshift, 50, 326, 327, 336
- dark energy, 48, 295, 329, 347
- dark matter: *see separate entry*
- density parameter $\Omega(t)$, 329
- distance radius χ , 338
- Friedmann models, 328
- growth of fluctuations: *see under* large-scale structure
- horizon, 332, 356
- hot dark matter, 358
- inflation, 328, 329, 332, 344
- lookback time, 333–335
- luminosity distance, 336, 338, 339
- matter-dominated Universe, 330, 331, 334, 351, 352, 353
- matter–radiation equality, 55, 330, 331, 356
- Olbers’ paradox, 335, 339
- photometric redshifts, 340, 341, 342
- radiation-dominated Universe, 330, 356

- recombination, 54, 55, 324, 331, 332, 344
 reionization, 395, 396
 scale factor $a(t)$, 331
 scale length $\mathcal{R}(t)$, 326
 surface brightness dimming, 337
 cosmic rays, 101, 107, 109, 375
 effect on array detectors, 194
 counter-rotation, 214, 238, 263
 critical density ρ_{crit} , 48
 critical surface density Σ_{crit} , 309
 crossing time t_{cross} , 128
 curved space, 325
- D*- σ relation for ellipticals, 258
 damped Lyman- α clouds, 390–395
 dark energy, 48, 295, 329, 347
 dark matter, 27, 48, 54
 between galaxies, 188–190, 283, 297, 299, 310, 312
 cold, 176, 358, 359, 362, 363, 405
 galaxies, 164, 176, 217–221, 256, 258, 273–275, 283
 hot, 358
 large-scale structure, 358
 Milky Way, 94, 95, 123, 145
 weakly interacting massive particles, 49, 176, 357, 358
 de Vaucouleurs law, 244, 245
 declination: *see* coordinates, equatorial
 density parameter $\Omega(t)$, 329
 deuterium
 produced in Big Bang, 50, 52, 54
 diffraction limit, 206
 disks of galaxies, 39, 41, 169, 191ff: *see also* Milky Way
 asymmetric drift, 160
 barred, 39, 40, 86, 191, 204, 232, 234ff
 classification, 39, 222
 exponential law, 70, 71, 198, 199, 337
 scale height h_z , 27, 71–74, 202
 scale length h_R , 27, 71, 86, 169, 171, 199, 202
 formation, 175, 181, 392, 393
 gas, 170–172, 206, 212, 226, 236
 atomic, 157, 209–212, 220, 223, 226, 392
 dusty, 205, 212, 234, 235, 239
 ionized, 157, 212, 226
 molecular, 213
 low-surface-brightness, 185, 186, 201, 202, 203, 211, 218
 mass density, 143, 144
 radial gradients, 179, 199
 radio emission, 212, 213
 rotation, 39, 156, 169, 184ff
 differential, 89, 217, 225, 228
 spiral pattern, 39, 172, 191, 204, 222, 223, 225ff, 235, 287
 Q parameter, 232
 corotation radius, 231, 233, 235, 236
 density-wave theory, 228, 230, 233
 flocculent, 227
 Lindblad resonances, 230, 231
 pattern speed, 230–236
 pitch angle, 227, 228
 theories, 229
 stability, 135, 136, 231–233
 star formation, 170, 205, 212, 239, 270
 stellar content, 157, 158, 170, 192, 197ff, 222ff
 thick disk, 27, 71, 72, 74, 75, 83, 202
 thin disk, 27, 71, 72, 74, 75
 Tully–Fisher relation, 220, 221, 222, 362
 vertical motions, 144–147
 warps, 171, 172, 216
- distance
 angular size, 336, 337, 339, 340
 kinematic, 96
 luminosity, 336, 337, 339
 modulus, 60
 distance radius χ , 338
 distances to galaxies, 160
 Cepheids, 160, 161
 kinematics, 257
 redshifts, 46
 standard candles, 160–162
 supernovae, 18, 69
 tip of red giant branch, 14, 316, 317
 Tully–Fisher relation, 221, 222
 distances to stars
 clusters, 76, 81, 160
 inverse-square law, 2, 18
 period–luminosity relation, 161
 photometric parallax, 70, 71
 spectroscopic parallax, 70
 trigonometric parallax, 59, 60
 distribution function, 140
 Maxwellian, 130
 polytrope, 147
 Doppler shift: *see under* redshift
 dust, 6, 33, 34, 56, 78, 182
 active nuclei, 371
 disk galaxies, 103, 169–171, 182, 192, 201, 204, 212, 226, 234, 235
 elliptical galaxies, 39, 184, 271, 302
 emission spectrum, 103, 205, 291
 extinction and scattering, 33, 34
 formation, 104
 heating, 34, 102, 103, 107, 290, 291
 high-redshift galaxies, 400, 402, 404, 405
 intergalactic gas, 395

- dust (*cont.*)
 Milky Way, 27, 34, 77, 78, 86, 87, 99,
 102–104, 107, 316
 opacity, 33
 polycyclic aromatic hydrocarbons (PAHs),
 103, 205
 starburst galaxies, 103, 239, 290, 291
 dynamical friction, 283, 285, 286
- early-type galaxy, 40, 410
 early-type star, 5, 410
 ecliptic plane, 35
 Eddington luminosity, 371, 372, 387
 effective radius R_e , 237, 243
 Einstein radius θ_E , 305
 elliptical galaxies, 37, 184, 241ff
 ages, 267, 301, 397ff
 boxy, 243, 253, 254, 302
 cD galaxies, 245, 246, 248, 257, 294,
 376
 centers, 248, 249, 257, 263, 275
 black holes, 275–277
 colors and spectra, 254, 267–270
 D – σ relation, 258
 dark matter, 256, 258, 273, 274
 de Vaucouleurs law, 244, 245, 337
 disk, 38, 243, 253, 254, 302
 dwarf: *see under* galaxies, dwarf
 Faber–Jackson relation, 257, 258
 formation, 300, 302, 405
 fundamental plane, 257, 258, 302, 362
 gas
 cool and dusty, 39, 184, 271, 274, 302
 hot, 272, 299
 globular clusters, 273, 274
 luminosities, 242, 245, 247, 248, 251
 masses, 256, 258, 273–275
 metal abundance, 267–273, 302
 mid-sized, 242, 244, 248, 249
 radio emission, 254, 276, 294, 376, 377
 rotation: *see* stellar motions
 Sérsic formula, 244
 shapes, 249, 253, 254, 261, 262
 shells around, 245, 246, 273
 stellar content, 184, 185, 263, 266–270
 stellar motions, 185, 254, 263ff
 surface brightness fluctuations, 316, 317
 triaxial, 251, 253, 263
 ultracompact, 247
 ultraviolet light, 271
 X-ray emission, 254, 271
- energy
 gravitational potential, 117, 119, 259, 301,
 370
 kinetic, 117, 119, 259, 281, 282, 284, 287
- epicycles: *see under* orbits of stars
 equinox, 35
 errata: *see online listing*
 extinction: *see under* dust
- Faber–Jackson relation, 257, 258
 fine structure lines, 29, 30
 flux, 2
 forbidden spectral lines, 28, 372
 free-fall time, 108, 116, 175, 318
 free–free radiation, 33, 213, 281, 290
 Freeman ‘law’ of disk brightness, 203
 Friedmann models: *see under* cosmic
 expansion
 fundamental plane of elliptical galaxies, 257,
 258, 302, 362
- G-dwarf problem, 180, 181
 Galactic poles, 37
 galaxies
 barred: *see under* disks of galaxies
 cD, 245, 246, 248, 257, 294, 376
 disk: *see* disks of galaxies
 dwarf, 163, 183, 185, 188, 294, 410
 age, 164, 183, 187
 elliptical, 38, 39, 184, 242, 248
 irregular, 40, 185–187
 rotation, 184, 186–188
 Sagittarius, 83, 84, 164, 169
 spheroidal, 38, 162, 169, 184, 187, 248
 ultracompact, 247
 early, 40
 elliptical: *see separate entry*
 giant, 38, 185, 242, 244, 376
 high redshift, 238, 397
 individual
 Andromeda (M31), 37, 39, 41, 152,
 169–171, 188
 Arp 220, 291
 M32, 152, 169, 184
 M33, 152, 163, 171, 172, 179, 239
 M81, 281, 287
 M82, 103, 281, 290, 291
 M87, 245, 246, 272, 273, 276, 292, 294,
 376, 377
 M104 (Sombrero), 200
 Magellanic Clouds and Stream, 69, 152,
 156ff, 168, 188, 286
 Milky Way: *see separate entry*
 NGC 1275, 294, 299, 367, 376
 NGC 1399, 245, 248, 249, 256, 257, 263,
 273, 292, 293, 299
 NGC 3923, 246, 273
 NGC 4258, 240, 367, 369, 370
 NGC 4676, 288, 289

- NGC 7331, 103, 197–199, 209–211, 213, 216–218, 220, 236, 238
- interacting: *see* galaxy collisions and mergers
- irregular, 40, 157, 185–187
- late, 40
- luminous infrared, 290, 291, 403
- Lyman break, 393, 399, 401, 402
- winds, 401
- Magellanic type, 39, 40, 202, 222
- nucleus: *see separate entry*
- peculiar velocities: *see under* large-scale structure
- photometric redshifts, 340–342
- post-starburst, 267, 399
- radio, 367, 374ff
- S0, 38, 40, 191, 213, 214, 223, 224
- satellite, 38, 151, 159, 169, 285, 286, 363
- Seyfert: *see under* active galactic nuclei
- spiral: *see* disks of galaxies
- starburst, 40, 224, 233, 239, 281, 287, 288, 291, 297, 374, 399, 404
- active nucleus cohabiting, 402
- dusty, 290, 291, 402
- winds, 109, 290, 401
- see also* Lyman break galaxies
- submillimeter, 403
- galaxy
- ages, 238, 267, 268, 362, 401, 405, 406
- angular momentum, 173, 354
- bulges: *see separate entry*
- catalogues and surveys, 22, 41, 42, 224, 279, 283, 292, 318, 374
- centers, 99, 169, 172, 239, 240, 248, 249, 276, 363: *see also* nucleus of galaxy
- cusps in brightness, 114, 117, 249, 266, 363
- classification, 38ff, 222, 223, 237, 242, 254
- collisions and mergers, 84, 159, 164, 170, 176, 188, 190, 245, 246, 273, 283ff, 287–289, 290, 292, 300, 302
- colors, 199, 201, 223, 237, 269, 302, 341, 399
- distribution in space: *see* large-scale structure
- formation, 172ff, 238, 300, 318, 354, 362, 397ff
- halo: *see separate entry*
- luminosities, 152, 163, 186, 199, 201, 203, 223, 224, 242, 398, 399, 401, 402, 405
- luminosity function, 293
- Schechter's L_* , 43, 45
- mass-to-light ratio: *see separate entry*
- masses, 163, 164, 169, 213, 214ff, 239, 274, 403, 404
- morphology–density relation, 278, 295, 300, 320, 321
- photometry, 42ff, 197ff, 243, 253, 335ff
- space densities, 43–46, 49, 293, 342, 405
- spectra, 6, 222, 223, 267, 268, 341, 367, 398–400, 402
- spheroid: *see under* halo, metal-poor
- star-formation rates, 72, 238, 270, 290, 399, 401–406
- galaxy clusters, galaxy groups: *see* groups and clusters of galaxies
- Galaxy: *see* Milky Way
- gamma-ray bursts (GRBs), 387–389
- afterglow, 388
- gas
- atomic
- fine structure lines, 29, 30
- forbidden emission lines, 103
- hyperfine transitions, 30
- collisional ionization, 28
- cooling, 105, 298
- forbidden emission lines, 28, 103, 372
- free–free radiation, 33, 281, 290
- ionized, spectral lines, 28
- molecular, spectral lines, 30, 31
- photoionization, 28
- ram pressure, 295
- synchrotron radiation, 33, 377
- Thomson scattering, 371
- gas around active galactic nuclei, 372, 373, 383
- molecular, 383
- outflowing, 383
- gas in galaxies: *see also* Milky Way
- cosmic rays, 101, 109
- dusty, 33, 34, 39, 86, 102–104, 107, 169–171, 182, 184, 201, 212, 226, 234, 235, 271, 400, 402, 404, 405
- flow in bars, 235
- heating and cooling, 106, 107
- hot, 28, 33, 100, 157, 213, 272, 299
- ionized, 28, 101, 102, 104, 157, 170, 212, 226
- HII region, 28, 101, 105
- magnetic fields, 101, 109
- masers, 31, 240
- molecular, 30, 31, 100, 102, 108, 172, 213, 289, 401
- formation, 104
- neutral hydrogen, 30, 100–102, 152, 157, 158, 170, 171, 186, 203, 209–214, 220, 223, 226, 271, 274, 295, 296, 392, 393
- high-velocity clouds, 99, 159

- gas in galaxy groups and clusters
 cool, 279, 281, 288
 heavy elements, 282, 297, 299
 hot, 279–281, 283, 293, 295–299
 ionized, 300, 395
 neutral hydrogen, 159
 warm, 294
- gas, intergalactic, 297ff, 390ff
 damped Lyman- α clouds, 390ff
 dusty, 395
 Gunn–Peterson test, 395
 heavy elements, 393–395
 hot, 393
 Lyman- α forest, 395ff, 399
 Lyman-limit clouds, 390
 molecular, 394
 neutral hydrogen, 390, 391, 393–395
 reionization, 395, 396
- globular clusters: *see under* star clusters
- Gould’s Belt: *see under* Milky Way
- gravitational lensing, 303ff
 caustics and critical curves, 311, 312
 critical density Σ_{crit} , 309
 Einstein radius θ_E , 305
 galaxies and clusters, 306–313
 image brightening, 305, 306, 311, 402
 image distortion, 306, 311–313
 lensing potential ψ_L , 307
 mass-sheet degeneracy, 313
 odd-image theorem, 311
 point mass (microlensing), 304, 305
 time delay, 311
 weak, 312
- gravitational N -body simulation, 129, 130,
 232, 233, 287–289, 302, 358, 359, 363
- gravity, Newton’s law, 111ff
- groups and clusters of galaxies, 47, 155, 278ff,
 315, 316, 318, 320, 321
 Abell catalogue, 155, 279, 292
 compact groups, 280
 core radius, 293
 dark matter: *see* masses
 density, 155, 293, 318
 galaxy mergers, 190, 280, 300
 galaxy morphology, 295, 300
 galaxy motions, 278, 280, 283, 293, 297
 gas, 293, 294, 300
 cool, 159, 279, 281
 hot, 279–283, 295–299
 ionized, 395
 gravitational lensing, 303
 growth and future, 188, 292, 295, 297
 individual
 Abell 383, 303, 310, 312
 Coma, 154, 258, 269, 278, 293–295, 297,
 299, 316
 Fornax, 292–294, 296, 316
 Local Group: *see separate entry*
 Perseus, 293–295, 299, 316, 367,
 376
 Stephan’s Quintet, 280, 293
 Ursa Major, 201–203, 221
 Virgo, 154, 269, 276, 292–297, 316, 318,
 347, 348
 infall toward, 347, 353
 intergalactic stars, 279
 masses, 189, 190, 282, 283, 293, 297, 299,
 310, 312
 morphology–density relation, 295
 virial radius, 361, 362
 X-ray emission, 279–283, 293, 297–300
 temperature–luminosity relation, 297,
 298, 362
- Gunn–Peterson test, 395
- HII region: *see under* gas in galaxies, ionized
 halo of galaxy
 dark, 27, 94, 95, 164, 176, 217–221, 274,
 283, 304
 hot gas, 99, 213
 metal-poor, 27, 84–86, 170, 174, 191
- Harrison–Zel’dovich spectrum, 324
- heavy elements, 9, 186, 269
 closed-box model, 177, 179, 180
 G-dwarf problem, 180, 181
 gas, 160, 177–180, 182, 272, 282, 297, 299,
 391, 393–396, 406
 missing metals problem, 397
 production, 8, 9, 15–17, 53, 174, 176ff, 182,
 270, 400, 406
 s-process, 15
 radial gradients, 80, 179, 269
 stars, 8, 13, 62, 74, 78–81, 83, 86, 160, 163,
 177–183, 269, 270, 302
- heliocentric velocity, 33
- helium, 8
 burning in stars, 13, 14, 62, 81, 82,
 160
 flash, 14
 produced in Big Bang, 50, 52–54
- Hertzsprung gap, 62
- Hertzsprung–Russell diagram: *see* stellar
 color–magnitude diagram
- Holmberg radius $R_{26.5}$, 43
- horizon, 332, 346
- horizontal branch: *see under* stars
- Hubble classification of galaxies, 38, 222, 242
- Hubble Deep Field, 397

- Hubble's law, 46, 47, 326
 Hubble constant H_0 , 46, 326
 Hubble time t_H , 47, 334
 parameter $H(t)$, 326
- hydrostatic equilibrium, 282
- hyperfine transitions, 30
- impulse approximation, 126
- inflation: *see* cosmic expansion
- integrals of motion, 145, 264
- intergalactic medium: *see* gas in galaxy groups and clusters *and* gas, intergalactic
- interstellar medium: *see* gas in galaxies
- isochrones, 77, 82, 164
- Jacobi constant E_J , 166
- jansky (Jy), 4, 407
- Jeans
 instability, 355–357
 length, 108
 mass, 108, 356–358
- jets and relativistic beaming, 368–371, 373, 375–378, 380–388
- k correction: *see* redshift, photometric
- kinematic distance, 96
- Kuzmin disk, 114
- L_* galaxy: *see* galaxy luminosity function
- Lagrange points, 166, 167
- large-scale structure, 314ff
 acoustic peak, 347
 baryon oscillations, 323, 346, 347, 359
 cold dark matter, 359, 362
 correlation function $\xi(r)$, 322–324
 density fluctuations, 318, 323, 324
 growth, 173, 344ff
 fluctuations in CMB, 344–347, 359
 Harrison–Zel'dovich spectrum, 324
 Jeans instability, 355–357
 peculiar velocities, 50, 314, 319, 348–353
 power spectrum $P(k)$, 322–324, 346, 359, 362, 363
 random-phase hypothesis, 324, 344
 supergalactic plane, 155, 315, 316
 walls and voids, 48, 295, 314, 315, 318–320, 355, 359, 396
- late-type galaxy, 40, 410
- late-type star, 5, 410
- Local Group, 48, 151ff, 318, 406
 collisions and mergers, 159, 164, 170, 176
 growth and future, 188
 membership, 152
 peculiar velocity, 56
- local standard of rest, 89
- lookback time, 333, 334
- low-surface-brightness galaxy: *see under* disks of galaxies
- luminosity
 bolometric, 25
 in-band: *see under* photometry, magnitude system
- luminosity distance, 336, 337, 339
- luminosity function
 galaxies, 44, 45, 293, 399
 stellar, 62–65
- luminous infrared galaxies (LIRGs), 290, 291, 402, 403
- Lyman- α forest, 395–397, 399
- Lyman-limit clouds, 390
- Magellanic Clouds, Magellanic Stream: *see under* galaxies, individual
- magnetic field, 171, 377
 active nuclei, 370, 380
 Milky Way, 87, 102, 107
- magnitude systems: *see under* photometry
- Malmquist bias, 75, 415
- maser, 31
 galaxy nucleus, 240, 381
- mass function, stellar
 initial, 66, 401, 406
 Salpeter, 66, 401, 406
- mass models
 dark halo, 95, 114, 168, 216, 286, 310, 311
 singular isothermal sphere, 114, 148
- King model, 149
- Kuzmin disk, 114
- Navarro–Frenk–White (NFW), 117, 363
- Plummer sphere, 113, 118, 120, 147, 216, 282, 310, 311
- polytrope, 113, 147
- self-consistent, 147, 148, 266
- softened potential, 129
- truncation (tidal) radius, 149
- mass segregation, 78, 131, 132
- mass-to-light ratio
 galaxies, 163, 164, 169, 213, 217–220, 222, 239, 256, 258, 273–275
 galaxy groups and clusters, 283, 297, 299, 312
- Milky Way, 64, 71, 74, 123
- on larger scales, 49, 190
- star clusters, 78, 122
- masses
 black holes, 68, 87, 88, 276, 277
 galaxies, 94, 95, 124, 160, 163, 214ff, 223, 274, 403, 404

- masses (*cont.*)
- galaxy groups and clusters, 282, 283, 293, 297, 299, 310, 312
 - Milky Way, 124
 - on large scales, 353
 - star clusters, 78, 121–123, 132, 239
 - stars, 2, 7
- matter-dominated Universe: *see under* cosmic expansion
- Maxwellian distribution function, 130
- metal abundance: *see* heavy elements
- microquasars, 386, 387
- Milky Way, 26ff, 58ff
- age–metallicity relation, 176, 177, 182, 183
 - bulge, 26, 86, 87, 99, 158, 180
 - age, 86, 158, 175
 - cannibalism, 84
 - cosmic rays, 101, 107
 - dark matter, 94, 95, 123, 145
 - disk, 26, 86
 - mass density, 144, 145, 147
 - formation, 174ff
 - G-dwarf problem, 180
 - gas, 95ff
 - cosmic rays, 101, 109
 - dusty, 27, 34, 77, 78, 86, 87, 101–103, 107
 - hot, 99, 100
 - ionized, 28, 97, 99, 101, 102, 104, 107
 - molecular, 30, 72, 96, 97, 99–102, 104, 107, 108
 - neutral hydrogen, 30, 72, 91, 96–102, 152
 - random motions, 101, 107
 - Gould’s Belt, 75
 - heavy elements, 176, 177, 179–183
 - luminosity, 27, 152
 - magnetic field, 101, 102, 109
 - mass, 94, 95, 117, 118, 124
 - metal-poor halo, 27, 83–86, 182
 - nucleus, 26, 33, 86, 87, 99
 - black hole, 67, 68, 87, 88
 - radio emission, 87, 102
 - rotation, 74, 86, 87, 89ff
 - Oort constants A , B , 92, 93, 136, 139, 140
 - satellites, 124, 156ff, 363
 - Magellanic Clouds, 69, 156ff
 - Sagittarius dwarf, 83, 84, 164, 169
 - spiral arms, 91, 97
 - star clusters: *see* separate entry
 - stellar disk, 27, 67ff, 72, 84–86, 144
 - age, 73, 83, 176, 177
 - asymmetric drift, 74, 139, 140
 - bar, 86, 99
 - thick, 27, 74, 75
 - thin, 27, 74, 75
 - vertex deviation, 139
 - stellar populations, 83, 85, 177
 - tidal streams, 84
 - see also* solar neighborhood
 - Monte Carlo simulation, 75, 349
 - moving groups of stars, 75, 86
- neutrinos, 16, 52
- neutron stars, 8, 16, 182
- Newton’s law of gravity, 111ff
 - theorems for spherical systems, 114, 115
- night-sky emission, 19, 43, 44
- nucleosynthesis: *see* heavy elements, production
- nucleus of galaxy, 169, 172, 238, 239, 247–249, 271, 276
 - active: *see* separate entry
 - black holes, 273, 275, 276
 - LINER: *see under* active galactic nuclei
 - Milky Way, 26, 33, 86, 87, 99
 - see also under* black holes, star clusters
- Olbers’ paradox, 335, 339
- Oort constants: *see under* Milky Way, rotation
- opacity, 33
- open clusters: *see under* star clusters
- open Universe, 325
- optical depth, 33
- orbits of stars, 235, 264
 - chaos, 265, 266
 - collisionless Boltzmann equation, 140ff
 - epicyclic approximation, 133ff, 229–231, 235
 - escape speed, 117, 122, 131
 - impulse approximation, 126
 - surface of section, 265, 266
 - triaxial potential, 263, 264, 266
- P Cygni profiles, 400
- parallax: *see also* distances of stars
 - photometric, 70, 71
 - spectroscopic, 69, 70
 - trigonometric, 59, 60
- parsec, 408
 - definition, 60
- pattern speed: *see under* disks of galaxies, spiral pattern
- peculiar velocities, 48, 50, 314, 319, 347ff, 418
 - growth, 349, 351, 353
 - Local Group, 56
- photoionization, 28
- photometric redshift: *see under* redshift
- photometry
 - array detectors: *see* separate entry
 - bolometric correction, 24, 25
 - colors, definition, 22

- effects of cosmic expansion, 335
- galaxies, 42ff, 192ff, 242, 337
- effective radius R_e , 237, 243
 - Holmberg radius $R_{26.5}$, 43
 - isophotes, 43, 197, 243, 253
 - photometric redshifts, 340–342
 - radius R_{25} , 43, 337
 - total magnitude, 199
- magnitude system, 18ff
- absolute magnitude, 23
 - apparent magnitude, 18
 - definition, 18
 - flux-based, 21
 - Johnson, Cousins, 18, 21
 - Sloan Digital Sky Survey, 21, 22
- seeing (Earth's atmosphere), 42, 244
- signal-to-noise ratio, 195
- sky brightness, 19, 42–44
- stars, 18
- photosphere of star, 3
- planetary nebula, 15, 296
- Plummer sphere: *see under* mass models
- Poisson's equation, 113, 144
- polycyclic aromatic hydrocarbons (PAHs): *see under* dust
- Population I and II: *see under* stellar populations
- potential
- effective Φ_{eff} , 134, 136, 165, 167
 - gravitational $\Phi(\mathbf{x})$, 112
 - lensing ψ_L , 306
 - velocity Φ_v , 352
- power spectrum $P(k)$, 322, 359, 362, 363
- proper motion, 67, 87, 89, 92
- proper time, 326, 379
- protostars, 10
- QSO absorption lines: *see* gas, intergalactic
- QSOs, quasars: *see under* active galactic nuclei
- radial velocity V_r , 67, 410
- radii R_e , R_{25} , and Holmberg radius: *see under* photometry, galaxies
- radio emission
- active galactic nuclei: *see separate entry*
 - disk galaxies, 212, 213, 369, 370
 - elliptical galaxies, 254, 276, 294, 377
 - Milky Way, 87, 99, 102
 - spectral lines, 29–31
 - synchrotron radiation, 33, 87, 102, 213, 369, 375, 377ff
- radio galaxies: *see under* active galactic nuclei
- radio telescopes, 32, 206ff, 404
- interferometry, 206, 208, 209
 - VLBI, 209, 240, 384
- ram pressure of gas, 295
- random-phase hypothesis, 324, 344
- recombination, 54, 55, 324, 331, 344
- reddening: *see under* dust
- redshift, 47
- cosmological, 50, 327, 336
 - Doppler, 32
 - gravitational, 344
 - photometric, 340–342
- reionization, 395
- relaxation
- time t_{relax} , 122, 128–130, 132
 - two-body, 124ff
 - violent, 262
- resolution of observations
- on the sky, 195, 206–208, 404
 - spectrum, 195, 206, 255
- right ascension: *see* coordinates, equatorial
- rotation, 214ff
- curve, 90, 215
 - disk galaxies, 156, 169, 184, 214
 - dwarf galaxies, 185–187
 - elliptical galaxies, 185, 256, 261, 262
 - galactic bulges, 87, 237
 - Milky Way, 27, 74, 83, 86, 87
 - tangent-point method, 93, 94
- scale factor $a(t)$, 331
- scale length $\mathcal{R}(t)$, 326
- seeing: *see under* photometry
- Sérsic formula, 244
- shocks, 102, 109, 234–236, 295, 374, 380, 388, 394
- signal-to-noise of observations, 195
- sky brightness: *see under* photometry
- Sloan Digital Sky Survey, 22, 270
- solar neighborhood, 59ff
- age–metallicity relation, 72–74, 177
 - asymmetric drift, 74
 - mass density in disk, 143–145
 - stellar motions, 72–74, 84, 118, 139, 140
 - stellar populations, 61, 63–65, 72, 73, 75, 139
- specific heat of gravitating system, 133
- spiral galaxies: *see* disks of galaxies
- star clusters
- ages, 77–80, 82, 160, 163
 - binary stars, 132
 - core collapse, 132
 - distances, 76, 78, 81–83
 - evaporation, 131
 - formation, 81
 - globular, 80–84, 122, 128, 133, 160, 163, 168–170, 174, 175, 184, 200, 273
 - Magellanic Clouds, 156, 160
 - mass models: *see separate entry*

- star clusters (*cont.*)
- mass segregation, 131, 132
 - masses, 78, 80, 121–123, 132
 - nuclear, 87, 163, 172, 239
 - open, 66, 76–78, 122, 128, 132
 - Pleiades, 66, 77, 132
 - super-star-clusters, 79, 160
 - tidal (truncation) radius: *see separate entry*
- star counts, 71, 85
- star death: *see stars, dead and supernovae*
- star-forming regions, 75, 77, 87, 158, 160, 170, 172, 185, 205, 212, 267, 370, 374, 401:
 - see also galaxies, starburst*
- starbirth, 10, 75, 108, 109
- starburst galaxies: *see under galaxies*
- starbursts, 40, 223, 233, 239, 281, 287, 288, 290, 291
- stars
- asymptotic giant branch (AGB), 15, 182
 - binary: *see separate entry*
 - brown dwarfs, 6
 - dead
 - gamma-ray bursts (GRBs), 387–389
 - neutron star, 8, 16
 - planetary nebula, 15, 296
 - supernova: *see separate entry*
 - white dwarf, 8, 15, 62, 182
 - early, 5
 - giant, 7
 - horizontal branch, 14, 81–84, 158, 164, 175, 183, 271
 - intergalactic, 279, 296
 - late, 5
 - main sequence: *see under stellar main sequence*
 - microquasar, 386, 387
 - protostars, 10
 - red clump, 14, 62, 187
 - red giants, red giant branch, 8, 11, 14, 24, 62, 187, 267, 317
 - subdwarf, 62
 - subgiant, 14
 - supergiant, 3, 7, 8, 11, 15, 16, 23, 24
 - temperatures, 11, 23
 - variable
 - Cepheid, 15, 37, 160, 161
 - RR Lyrae, 82, 84, 160, 161, 163, 183
 - Wolf–Rayet, 16
- Stefan–Boltzmann equation, 3
- stellar
- abundances: *see under heavy elements*
 - age–metallicity relation, 72–74, 79, 83, 86, 176, 177, 181
 - atmospheres, 3, 5, 15
 - 4000 Å break, 6, 267, 404
 - Balmer jump, 5, 401
 - model, 7, 22
 - Stark effect, 7
 - classification, 5ff, 7, 10, 20
 - color–magnitude diagram, 10, 61, 77, 82, 158, 164
 - Hertzsprung gap, 62
 - colors, 22, 24
 - densities
 - V/V_{\max} test, 72
 - distances: *see distances to stars*
 - effective temperature T_{eff} , 3
 - evolution (life cycle), 9
 - isochrones, 77, 82
 - lifetimes, 11
 - luminosities, 7, 11, 24
 - Wielen dip, 65
 - luminosity function: *see separate entry*
 - main sequence, 7, 11–13, 62
 - zero age, 10
 - masses, 2, 7, 11
 - Chandrasekhar limit, 17
 - see also mass function, stellar*
 - orbits: *see orbits of stars*
 - photometry: *see separate entry*
 - photosphere, 3
 - populations: *see stellar populations*
 - radii, 3, 7, 8
 - surface gravity, 7, 8
 - temperatures, 3, 5, 11, 24
 - winds, 15, 16, 99, 109, 171, 172, 186
- stellar populations, 155, 266–268, 302, 398, 399, 401, 402, 404
- ages, 267, 269, 401
 - Milky Way, 61, 63–65, 73, 75, 83, 85, 139, 177
 - Population III, 177
 - Populations I and II, 177
 - single-burst model, 268
- Sun, 2, 3, 5, 8, 10, 24, 25, 52, 408
- age, 11
 - heavy elements in, 9
 - location in Milky Way, 27, 67, 83, 90
 - motion, 27, 56, 73, 89, 90, 92
- supergalactic coordinates: *see under coordinates*
- superluminal motion, 383
- supernovae, 15, 69, 99, 101, 106, 158, 171, 172, 174, 182, 186, 270
- Type Ia, 17, 18, 182, 270, 400
 - Type Ic, 16, 389

- Type II, 16, 182, 270
see also gamma-ray bursts
 synchrotron radiation: *see under* radio emission
- tangent point, 90, 93
 tangential velocity V_t , 67, 92
 temperature
 effective temperature T_{eff} , 3
 stellar system, 133
 virial, 283
 tensor virial theorem, 259, 260, 262
 thermal infrared, 43
 Thomson scattering, 371
 tidal effects, 172ff, 175, 287, 288, 290, 292
 torques, 173, 354
 truncation (tidal) radius, 80, 133, 149, 163, 167
 Tully–Fisher relation, 220–222, 362
- Universe: *see also* cosmic expansion,
 large-scale structure
 age, 47, 48, 81, 333
 benchmark cosmology, 48, 330
 cosmic background radiation: *see under*
 cosmic expansion
 dark energy, 48, 329
 dark matter, 48
 density
 average, 220, 329, 331, 353, 404
 baryons, 53, 54, 220, 300, 393, 397
 critical, 48, 49, 329
 dark energy, 330
 luminosity, 46, 405
 matter, 330
 radiation, 330
 homogeneity and isotropy, 56, 325
- $\mathcal{V}/\mathcal{V}_{\text{max}}$ test, 72
 vacuum energy: *see* cosmic expansion, dark
 energy
- vertex deviation: *see under* Milky Way, stellar
 disk
 very long baseline interferometry (VLBI): *see*
 under radio telescopes
 Virgocentric infall, 347, 348, 353
 virial
 radius, 318, 361, 362
 temperature, 283
 tensor virial theorem, 259, 260, 262
 theorem, 120, 121, 260, 281–283, 287, 301,
 361
 visible light, 19
- website: *see preface*
 white dwarf: *see under* stars, dead
 Wielen dip, 65
 winds
 galaxies, 109, 290, 394, 401
 P Cygni profiles, 400
 stars, 15, 16, 99, 109, 158, 171, 172, 186
 Wolf–Rayet stars, 16
- X-ray emission, 28
 active galactic nuclei, 369, 371–373, 380,
 382
 binary stars, 17, 132, 157
 microquasars, 386, 387
 disk galaxies, 157, 172, 206
 elliptical galaxies, 254, 271, 272
 galaxies, 33
 galaxy groups and clusters, 279–283, 293,
 295, 297–300
 Milky Way, 99
- yield of heavy elements, 178
- zero-age main sequence: *see under* stellar main
 sequence
 zone of avoidance, 316