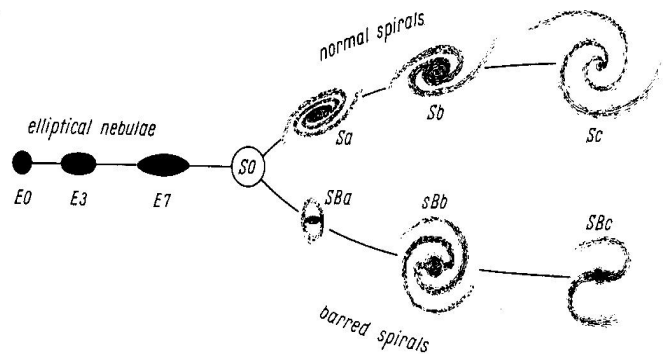


ASTRONOMY 8400 – SPRING 2026
Final Answers

1.



- a) Ellipticals – ellipticity increases to right, E_n where $n=10(1-b/a)$
 S0 – disk, no spiral arms
 Spirals – bulge/disk decreases to right
 Spirals – spiral arms less tightly wound to right
 - b) - three main classes of Spirals: S, SAB, SB
 - spiral subclasses (ab), extended to later type (d, m)
 - inner structure (r, s), outer structure (R), peculiar (p)
 - c) - increasing dust and gas to right (more H I)
 - increasing number of hot blue stars (bluer colors)
 - decreasing central surface brightness
 - more star formation
 - more H II regions
2. Four ways to determine SMBH masses using resolved spectroscopy:
- a) Stellar kinematics plus dynamical models
 - works for nearly all nearby galaxies
 - requires high angular resolution (HST)
 - b) Rotating disks of ionized gas
 - straightforward fit to a Keplerian velocity curve
 - only works for a few AGN, most gas pushed around by non-gravitational forces
 - c) H₂O maser disks
 - very accurate, VLBI allows separation of SMBH from surrounding matter (e.g., nuclear star cluster)
 - Works only for nearly edge-on AGN
 - d) Radial velocities and proper motions of individual stars
 - 3D map of velocity field for individual stars allows very accurate determination of SMBH mass
 - works only for the Milky Way

3. Rotating disk:

$$v_r = v_{sys} + v_{rot} \cos(\varphi) \sin(i)$$

$$v_{sys} = (1000 + 800) / 2 = 900 \text{ km s}^{-1}$$

$$a) i = \cos^{-1}(b/a) = \cos^{-1}(1/2) = 60^\circ$$

$$b) d = v_r / H_0 = 900 \text{ km s}^{-1} / 73 \text{ km s}^{-1} \text{ Mpc}^{-1} = 12.3 \text{ Mpc}$$

$$c) v_{rot} = v_r / \sin(i) = 100 \text{ km s}^{-1} / \sin(60^\circ) = 115 \text{ km s}^{-1}$$

$$d) v_r(45^\circ) = v_r(90^\circ) \cos(60^\circ) = 50 \text{ km s}^{-1} \text{ (in galaxy restframe)}$$

4. Spectral Synthesis:

- a) Start with an initial mass function (IMF).
- b) Specify a star formation rate (SFR).
- c) Add interaction with ISM to increase metallicity
- d) Fill in an H-R diagram and let it evolve.
- e) Weight each spectral type with luminosity function.
- f) Convolve spectrum with kinematic model.

Initial Mass Function:

- a) Build a stellar luminosity function for main sequence Φ_{MS} .
- b) Correct for stellar evolution to get cumulative value $\Phi_0(L)$
- c) Determine the Mass-Luminosity relation for main sequence.

$$d) \text{ IMF: } \xi(M) = \frac{dL}{dM} \Phi_0(L)$$

5. Observational evidence for dark matter:

- a. Flat rotation curves in spiral galaxies
- b. Velocities of planetary nebulae in elliptical halos
- c. Rotation of embedded disks in a few ellipticals
- d. Confinement of hot ($T \approx 10^7 \text{ K}$) gas in ellipticals
- e. Velocities of galaxies in rich clusters/ Virial Theorem
- f. Confinement of hot ($T > 3 \times 10^7$) gas in rich clusters

6. M/L increases from 5 to 200 as you go from a to f

7. dark matter is less concentrated than visible matter in the Universe (dark matter has a shallower density profile)

6. Definition of terms:

- a. Schechter luminosity function – # of galaxies per luminosity bin per Mpc^3

$$\Phi(L) = \frac{n^*}{L^*} \left(\frac{L}{L^*} \right)^\alpha \exp\left(\frac{-L}{L^*} \right)$$

- b. Effective radius – radius inside of which of the light from a galaxy is emitted

- c. Contributions to sky background (list) – zodiacal light, airglow, Galactic starlight, diffuse extragalactic light
- d. Holmberg radius: angular distance from center of galaxy at which the B-band surface brightness is $\mu_B = 26.5 \text{ mag arcsec}^{-2}$
- e. Distance limit for parallax: few kpc
- f. Corrections to the distance modulus (list): For the V-band, for example:
 $V - M_V = 5 \log(d) - 5 + A_V + K_V$
 A_V – extinction to source
 K_V – “K correction” for redshift of spectrum through bandpass
- g. Spider diagram – iso-radial-velocity curves for galaxy kinematics
- h. Radius of influence for a supermassive black hole – distance at which a SMBH affects the kinematics of the galaxy’s stars:

$$r = \frac{GM_\bullet}{\sigma_*^2}$$

- i. Inverse Compton scattering of CMB photons by high-energy electrons in hot intergalactic cluster gas
- j. Ways to measure the SFR (list) – measure UV, $H\alpha$, or IR flux compared to optical flux
- k. SFR main sequence – SFR nearly linear with galaxy mass
- l. Red sequence, blue cloud – concentrations of galaxies in color-magnitude diagram; star forming galaxies (blue cloud) and “dead” galaxies (red sequence) colors get redder with increasing luminosity
- m. ULIRG – ultraluminous infrared galaxy, extreme starburst galaxy in an early state of evolution
- n. Sersic profile – used to characterized surface brightness profile of a galaxy
 $I = I_e \exp\{-b_n[(R / R_e)^{1/n} - 1]\}$
- o. Gaia - European satellite designed to measure parallaxes, proper motions, and radial velocities to map positions and velocities of stars in the Galaxy
- p. Convergent point, velocities, and geometry give nearby (open) cluster distances
- q. Sun’s peculiar motion $\sim 4 \text{ AU per year}$
- r. Faber-Jackson, Tully Fisher
- s. Pulsating star (Cepheids, RR Lyrae)
- t. Period-luminosity relationship
- u. Limitations for Main-Sequence Fitting technique: need a cluster, best for lower main sequence (but M stars are faint); model dependent, metallicity effects, reddening effects
- v. Early-type galaxies, clean parts of spirals (no star formation)
- w. Supernova type Ia physical explanation Supernova Type Ia – mass transfer to white dwarf exceeds Chandrasekhar limit and it explodes.
- x. Globular clusters, planetary nebulae
- y. Discrepancy between early (CMB) and late (distance ladder) Universe measurements of H_0