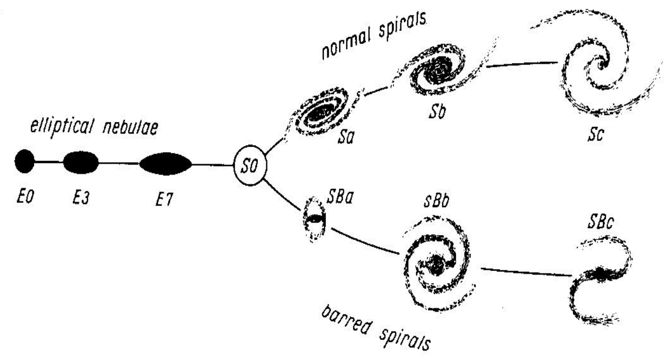
ASTRONOMY 8400 – SPRING 2024
Final Answers

1.



a) Ellipticals – ellipticity increases to right, En 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) H_20 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) $v_r(45^\circ) = v_r(90^\circ)\cos(30^\circ) = 87 \text{ km s}^{-1}$ (in galaxy rest frame)

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) 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 ($T \approx 10^7$ 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

   - M/L increases from 5 to 200 as you go from 1 to 6
   - 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 $\mu_B = 26.5$ 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 hole – distance at which a SMBH affects the kinematics of the galaxy's stars:
$$r = \frac{GM_\bullet}{\sigma_*^2}$$
i. Quasars, Supernovae
j. Ways to measure the SFR (list) – measure UV, Hα, 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 ~ 4 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 Chandrasehkar limit and it explodes.
x. Globular clusters, planetary nebulae
y. Discrepancy between early (CMB) and late (distance ladder) Universe measurements of H_0