Section A (53 points)

1. C
2. B
3. A
4. A
5. C
6. A
7. B
8. C
9. B
10. B
11. A
12. D
13. B
14. A
15. B
16. C
17. D
18. A
19. A
20. B
21. A
22. A
23. B
24. A
25. B
26. (a) Barnard 68
    (b) We are looking at the edge of the DSO, so the background is not blocked by as much material.
27. (a) Image 5
    (b) 10
28. (a) RCW 38
    (b) The young stars in the cluster are still surrounded by a lot of gas and dust.
29. (a) Image 2
    (b) ALMA
30. (a) Image 4
    (b) Hubble
    (c) Visible and IR
    (d) A cloud of gas and dust, that in the case of M42, is an area of star formation (i.e., a "stellar nursery").
31. (a) Image 12
    (b) A shock caused by colliding intergalactic gas
32. (a) Image 6
    (b) It's the group of galaxies the Milky Way belongs to.
33. (a) FU Orionis
    (b) Younger
34. (a) HOPS 383
    (b) Protostar
35. (a) HD 95086
    (b) VLT
    (c) Direct imaging
36. (a) HD 100546
    (b) Herbig Ae/Be
37. (a) Image 7
    (b) IR
    (c) Perseus

Section B (30 points)

38. (a)

$$F = \frac{Gm_1 m_2}{a^2} \tag{1}$$

(b) It would double.

(c) The center of mass is defined by:

$$m_1 a_1 = m_2 a_2 \tag{2}$$

Solving for a_1, we get

$$a_1 = \frac{m_2 a_2}{m_1} \tag{3}$$

39. (a) Very cold. The molecules within the cloud will be moving more slowly, which will reduce the outwards pressure that can resist collapse.

(b) Very dense. The molecules will be closer together, making the gravitational interactions between them stronger, aiding the collapse.

(c) In order to do this, all we have to do is write N in terms of other variables. The mass of the cloud will be

$$M = V\rho = \frac{4}{3}\pi R^3 \rho \tag{4}$$

If each gas molecule has a mass μ, then the total number of molecules in the gas is

$$N = \frac{M}{\mu} = \frac{4\pi R^3 \rho}{3\mu} \tag{5}$$

Plugging this into our equation for K, we get

$$K = \frac{3}{2} \times \frac{4\pi R^3 \rho}{3\mu} \times k_B T = \frac{2\pi R^3 \rho k_B T}{\mu} \tag{6}$$

(d) Here, all we need to do is replace M with an expression containing R and ρ. Using the result from Equation 4,

$$U = -\frac{3}{5}\frac{G\left(\frac{4}{3}\pi R^3\rho\right)^2}{R} = -\frac{16}{15}\pi^2 G R^5 \rho^2 \tag{7}$$

(e) Per the virial theorem, which says that $2\langle K\rangle = -\langle U\rangle$ in our system,

$$2\left(\frac{2\pi R^3 \rho k_B T}{\mu}\right) = \frac{16}{15}\pi^2 G R^5 \rho^2 \tag{8}$$

Solving for R gives

$$R = \sqrt{\frac{15 k_B T}{4\pi G \rho \mu}} \tag{9}$$

The cloud will collapse if R is **greater** than this value. We can gain some intuition for this from examining Equation 8. Notice how the left side of the equation, which represents the kinetic energy in the system, scales with R^3, while the right side, which represents the potential energy, scales with R^5. It follows that if we increase R, the right side will increase more quickly than the left side, leading to the gravitational potential energy overpowering the pressure of the cloud.

(f) Clouds are generally denser at the **center** than at the edges. This would make the gravitational potential energy a larger negative number, which in turn makes the Jeans length smaller.

40. Tiebreaker — answers will vary.