Answer Key

Section A [55 points]

1. (2 points) Barnard 68, HOPS 383, T Tauri, HD 95086
2. (2 points) HL Tauri, Messier 42, Baby Boom Galaxy, Stephan's Quintet
3. (a) Main sequence stars
   (b) F
   (c) Hydrogen
4. (a) Messier 42
   (b) A cloud of gas and dust in outer space; often (but not always) associated with star formation
   (c) Image 12
5. (a) Image 6
   (b) Pegasus
6. (a) Baby Boom Galaxy
   (b) Students should put (at least) one of the following: Hubble Space Telescope, Spitzer and Japan's Subaru Telescope in Hawaii
   (c) Gas
   (d) Star formation
7. (a) Barnard 68
   (b) It is close to Earth and very dense
   (c) It is easier when the gas cloud is cold, since the pressure is lower.
   (d) Jeans mass
8. (a) Image 11
   (b) Infrared
   (c) T Tauri
9. (a) NGC 1333
   (b) Infrared
   (c) Spitzer
   (d) Shock fronts
10. (a) Image 7
    (b) LMC
11. (a) L1527
    (b) JWST
    (c) Sporadic ejections from the protostar
12. (a) M42
    (b) Stellar wind "blowing" against the gas and dust clouds
13. (a) NGC 3324
    (b) JWST
    (c) Answers will vary (e.g., JWST is larger than HST)
14. (a) 13
    (b) Hubble
    (c) Libra
15. (a) Image 10
    (b) Forming planets
    (c) Radio
    (d) Reduced atmospheric interference; the light from space that hits the telescope has to pass through less of the atmosphere.
    (e) Signals from multiple telescopes are combined to make a higher resolution image. Theoretically, this process can produce images with the resolution of a huge telescope with an aperture equivalent to the distance across the array of telescopes.
16. (a) Image 2
    (b) Hubble
    (c) Herbig Ae/Be star
    (d) Q
17. (a) RCW 38
    (b) Very Large Telescope
    (c) more, shorter
18. (a) FU Orionis
    (b) D, E
    (c) V1057 Cygni

Section B [50 points]

19. (a) (2 points) 1 proton, 1 electron
    (b) (2 points) Add or remove an electron from the atom
    (c) (3 points) It takes 13.6 eV to remove an electron from its ground state in a hydrogen atom. Cool stars emit very few photons with energies that high. However, hotter stars emit more photons with that energy, so more hydrogen atoms can get ionized.
    (d) (3 points) Atoms typically "want" to have a "full" outermost electron shell, for lack of better words. Hydrogen atoms, for example, "want" to have two electrons in their outermost electron shell. When a hydrogen atom is on its own, it only has one electron. But, when it exists as H_2, the two hydrogen atoms in the molecule share their electrons in the form of a covalent bond, so both of the atoms feel like they have two electrons. (Quantum mechanics can explain this better, but is far beyond the scope of this event.)
    (e) (5 points) The rate at which H_2 forms in this situation depends on a number of factors. The frequency at which hydrogen atoms collide dust particles in the cloud increases when the cloud is denser, since the hydrogen and dust are closer together. Once the hydrogen atom and dust particle collide, we also need the hydrogen atom to stick to the dust particle, which is easier at lower temperatures. From the Ideal Gas Law, we can also intuit that lower temperatures will increase the density of the gas cloud. (Of course, the relationship between temperature, density, and reaction rate in this situation is more complicated than here, but the general ideas and trends are, in my opinion, close enough.)

20. (a) (3 points) A point in space where the gravitational pull of two large objects (for example, the Sun and the Earth) equals the centripetal force required for a small object to move with those objects. In essence, the objects can stay "still" relative to those two objects.
    (b) (3 points) JWST is an infrared telescope. Objects like the Sun, Moon, and Earth emit a lot of infrared light, so if JWST is facing them, it will add a lot of noise to the images it is taking. On top of that, the detectors on JWST need to be cold to function properly. If JWST is at L2, then it can face away from the Sun, Moon, and Earth with a insulating heat shield in between and look at the rest of the Universe.
    (c) (3 points) L2 is closer. As a result, it is easier and faster to transport JWST there and communicate with it afterwards.
    (d) (3 points) JWST orbits in a large halo orbit around L2 (larger than the distance between Earth and the Moon) such that it typically is not in the Sun-Earth line. JWST was specifically planned to avoid even partial moon or earth eclipse for 10.5 years in any possible JWST orbit due to power and thermal requirements.
    (e) (3 points) In the outer Solar System, missions opt for RTGs since solar panels are not able to produce enough energy (flux from the Sun falls off with r^{-2}). However, JWST is close enough for the solar panels to provide enough power. Beyond that, solar panels are generally relatively cheap lightweight compared to RTGs.

21. (a) (3 points) It has has balanced internal and external forces, preventing further collapse or expansion.
    (b) (3 points) Gravitational potential energy being released
    (c) (2 points) Higher density
    (d) (4 points) It will continue moving towards the center of the star, since it is denser than the surrounding gas.
    (e) (5 points) No. An object exhibiting this behavior would collapse very quickly until it reached hydrostatic equilibrium.

22. Answers will vary. Graded entirely based on effort, level of detail, and accuracy.