Answer Key

Section A [50 points]

1. Venus, Mars, Europa, Enceladus
2. 101955 Bennu, Enceladus, Titan, Venus
3. Enceladus, Europa, Mars, Venus
4. (a) Enceladus
   (b) Saturn
   (c) Tiger Stripes/Subsurface Ocean/Plumes
5. (a) Kepler-186f
   (b) The transit method: looking for dips in the parent star's brightness due to the planet crossing in front of the star.
   (c) Low-mass stars. Transit probability is approximately R_{star}/a, and Earth-like planets would orbit much closer to low-mass stars than high-mass stars, since low-mass stars are much cooler. Low-mass stars are smaller than high-mass stars, but not by as much. Also, there are way more low-mass stars than high-mass stars.
6. (a) 101955 Bennu
   (b) Asteroid
   (c) OSIRIS-REx
   (d) Image 12
7. (a) Infrared
   (b) Image 15
   (c) Cassini
   (d) Image 19
8. (a) Sulfuric acid
   (b) Sulfur from Io hit's Europa's trailing hemisphere, where it reacts with oxygen and hydrogen to form sulfuric acid.
   (c) Image 14
9. (a) Hydrocarbons (methane and ethane)
   (b) Image 19
   (c) Radar mapper
   (d) The lake on the right may be slowly drying out as northern summer approaches, causing it to look lighter than the lake on the left.
10. (a) Image 11
    (b) Ultraviolet
    (c) Hubble
    (d) Venus has a thick atmosphere (with lots of carbon dioxide) leading to a very strong greenhouse effect.
11. (a) Image 16
    (b) Phoenix
    (c) Image 10
12. (a) Europa
    (b) Galileo
    (c) White-blue: relatively pure water ice; red-orange: water ice with hydrated salts
13. (a) Regions of irregular, disrupted blocks of ice, cracks, and ridges.
    (b) This is a bit of a trick question. Europa's crust is probably relatively thick in most places, but in regions where there is chaos terrain, the crust is thinner, and there may be liquid water "lakes" only a few kilometers under the surface.
    (c) Conamara Chaos
    (d) Freckles or lenticulae
    (e) Upwelling of warmer ice while cooler ice sinks, or ice erupting onto the surface.
14. (a) 67P/Churyumov–Gerasimenko
    (b) Image 9
    (c) Isotope of hydrogen with one neutron instead of zero
    (d) No (or if it did, it can't be the only source). The water on Earth should have the same chemical composition/signature as the water from the source (or be some combination of the sources).
15. (a) Mars Reconnaissance Orbiter
    (b) HiRISE
    (c) Dust is dark, and it will absorb more light, causing the ice underneath it to melt more/faster
16. (a) Enceladus
    (b) Damascus Sulcus
    (c) Infrared
    (d) Enceladus is not a perfect sphere, which causes the tidal heating produced due to libration to increase dramatically.

Section B [45 points]

17. (a) (2 points) Closer. Red dwarfs are cooler and smaller, so in order for a planet around it to have the same temperature as Earth, it'll have to be closer. Imagine a scenario where you have two heaters during the wintertime. If one of them is weaker than the other, you'll have to stand closer to it to feel the same level of warmth as the stronger heater.

    (b) (3 points) The force of gravity is proportional to $1/r^2$. So, the closer you get to the star, the stronger the force of gravity, and it stronger at a faster and faster rate as you get closer. As a result, when you're close to the parent star, you'll have a much bigger difference between the force the near and far sides of the planet experience, and it is this *difference in gravitational force* that drives tidal locking. A habitable planet around a red dwarf will be very close to its parent star (for the reasons outlined in the part above), so it will get tidally locked faster.

    (c) (4 points) A graph of $1/r^3$ will have an even more pronounced curvature when close to the parent star, which would increase the tidal force a planet would experience, making it become tidally locked faster. "Close" is defined loosely here since we aren't even thinking about units.

    (d) (3 points) Answers will vary dramatically; this was meant to be a question where students can come up with whatever ideas they want, and as long as it seemed like they put some thought into it, they got points for it.

    (e) (2 points) Hinder. The high-energy radiation would generally break bonds in complicated biological molecules (like DNA) needed for life, leading to errors (like mutations). Students who put that it could help life got points if it seemed like they thought about it a lot (for example, one team mentioned that this could lead to photocatalysis and help make molecules more easily).

    (f) (2 points) Help. Life takes time to develop, and the more time you give it, the greater the probability is that something will happen.

18. (a) (2 points) It is the pressure corresponding to the *triple point* of water.

    (b) (2 points) Light molecules. At a given temperature, light molecules will have a higher average speed, so a higher fraction of them will have a velocity high enough to escape the atmosphere.

    (c) (2 points) High temperatures. The higher temperatures will increase the average kinetic energy of the molecules in the gas.

    (d) (3 points) Several mechanisms probably played a role (e.g., solar wind/radiation, impacts). Sputtering due to solar wind/radiation after Mars lost its magnetic field is probably the dominant cause.

    (e) (3 points) Noble gases are inert (i.e., they do not easily react with other elements). So, the scientists would not have to worry about it being chemically stored on the planet, say, in a rock.

19. (a) (2 points) Landmarks shifting so much in such a short amount of time suggests the crust is disconnected from the rest of the interior of the planet (maybe a subsurface ocean!)

    (b) (2 points) Titan's low conductivity icy surface means that these radio waves readily penetrate the crust rather than being reflected. So, for them to resonate they must be reflected by something in Titan, which is most likely the high conductivity water–ammonia subsurface ocean.

    (c) (5 points) As the mixture freezes, the water freezes first, increasing the concentration of the ammonia in the remaining liquid water. Freezing a substance is a process that decreases the entropy of the system (a bunch of molecules held in a lattice as a solid have way fewer accessible microstates than molecules that can freely move around as a liquid), and concentrating the ammonia makes the entropy change even more negative. We know ΔH is negative, and now ΔS is even more negative than it would be for a pure substance, so in order for the process to be thermodynamically spontaneous ($\Delta G < 0$), T (the freezing point) will be a smaller number.

    (d) (3 points) Temperature: about -97°C, composition: accept answers between 30-40% ammonia.

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