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CUME EXAM # 447

This exam is worth 59 points. It is based on the accompanying paper by Trilling et al. (2020), *Spitzer's Solar System studies of asteroids, planets and the zodiacal cloud,* Nature Astronomy, 4, `https://doi.org/10.1038/s41550-020-01221-y`. A grade of 70% or higher is expected to be a passing grade. **You may use a calculator, but only for algebraic and trigonometric types of calculations – you may NOT use a calculator to store formulae, constants, etc.**

Things You Might Need to Know

Symbol	**Value in cgs**	**Value in SI**
c	2.998×10^{10} cm s^{-1}	2.998×10^{8} m s^{-1}
G	6.674×10^{-8} dyn cm^{2} g^{-2}	6.674×10^{-11} N m^{2} kg^{-2}
k	1.3806×10^{-16} erg K^{-1}	1.3806×10^{-23} J K^{-1}
σ	5.670×10^{-5} erg cm^{-2} K^{-4} s^{-1}	5.670×10^{-8} W m^{-2} K^{-4}
m_p	1.673×10^{-24} g	1.673×10^{-27} kg
1 AU	1.496×10^{13} cm	1.496×10^{11} m
$M_\odot$	1.9891×10^{33} g	1.9891×10^{30} kg
$R_\odot$	6.955×10^{10} cm	6.955×10^{8} m
$L_\odot$	3.827×10^{33} erg s^{-1}	3.827×10^{26} W
$M_\oplus$	5.976×10^{27} g	5.976×10^{24} kg
$R_\oplus$	6.378×10^{8} cm	6.378×10^{6} m

Additional Instructions

- Write legibly! If I cannot read your writing, you likely will not receive as much credit as you deserve because I won't understand what you are trying to convey.
- The topics of the questions and their respective point values are as follows:
  Spitzer (#1-2): 15 points
  Asteroids (#3-5): 22 points
  Dust and Rings (#6): 6 points
  Ice Giants (#7-8): 10 points
  Putting it All Together (#9): 6 points

Spitzer Space Telescope

Spitzer was an 0.85 m infrared space telescope that operated from 2003-2020. It was equipped with three instruments:

- the Infrared Array Camera (IRAC), an imager that operated in 4 bands (3.6, 4.5, 5.8, and 8 μm)
- the Infrared Spectrograph (IRS), which operated in two low-resolution modes (5.3 – 14 μm and 14-40 μm) and two high-resolution modes (10.0-19.5 μm and 19-37 μm)
- Multiband Imaging Photometer for Spitzer (MIPS), three detectors operating at 24, 70, and 160 μm)

It was placed in an "Earth-trailing" heliocentric orbit.

1. Spitzer was cooled with liquid helium (LHe) until the cryogen ran out in 2009.

   a) Why do you think it required LHe instead of liquid nitrogen (LN2), a more commonly used cryogen? (3 points)

   b) Which instrument(s) do you think were able to operate during the "warm mission" phase? (3 points)

   c) Why do you think being in an Earth-trailing orbit was so critical for the success of this mission? (3 points)

2. The focal length of the Spitzer telescope was 10.2 meters.

   a) What was the corresponding focal ratio (or "f-ratio")? (4 points)

   b) Based on your answer to (a), would you say that this telescope had a relatively small or a relatively large field of view? Explain your reasoning. If you were unable to compute the focal ratio in part (a), you may answer by explaining the relationship between focal ratio and field of view. Feel free to supplement your explanation with a sketch. (2 points)

Asteroids

3. The Near-Earth objects section states that "NEOs escaped from their source regions – generally in the asteroid belt – via the Yarkovsky effect and planetary scattering, and therefore act as dynamical and composition tracers of small bodies throughout the solar system." Provide a qualitative explanation for what the Yarkovsky effect is and how it results in asteroids escaping from their source regions. Feel free to draw a diagram if it will aid in your explanation. (6 points)

4. Later in that same paragraph, the authors state that "NEOs have surface equilibrium temperatures in the range 200-400 K."

   a) Use this information to determine a range of expected albedos for NEOs. State whatever assumptions you make in order to answer this question. (6 points)

   b) Compare your results to those shown in Figure 1 of the paper. Define the term *geometric albedo* shown on the y-axis label. Are the albedos you computed in (a) geometric albedos or something else? (4 points)

5. If the fine-grained silicates covering Trojan asteroid Hektor (mass $\sim 9 \times 10^{18}$ kg, diameter $\sim$ 230 km) were part of a dense dust 'coma,' a possibility discussed by the authors in the first paragraph on page 943 (refer to the page numbers in the lower corners of the page, not the numbering within the PDF file), how extensive would that coma be? (in order words, what would be its maximum height above Hektor's surface?) (6 points)

Dust and Rings

6. The Spitzer observations revealed that Saturn's Phoebe ring has a normal optical depth of $\sim 2 \times 10^{-8}$. Suppose the Cassini spacecraft had passed directly below Saturn's Phoebe ring and took a measurement of one of its optical calibration stars, Vega, looking directly through the ring. During a normal observation, the star's flux at 1 μm was observed to be 3200 photons/cm^2/s/nm.

   a) What would be the flux decrease due to the ring? (4 points)

   b) In determining your answer to (a), what have you assumed about the dust that comprises the ring? (2 points)

Ice Giants

7. Fig. 6 (panel a) shows the disk integrated spectrum of Uranus. Let's focus on the portion of the spectrum shown in red, particularly the area labeled as C_2H_2 ν_5.

   a) What kind of spectrum of the acetylene (C_2H_2) molecule are we seeing here? (3 points)

   b) The acetylene portion of the spectrum shows no signal at approximately 730 cm^{-1} and then two sets of similar-looking emission features redward and blueward of 730 cm^{-1}. What causes the spectrum to be split in that fashion? (3 points)

8. The authors discuss the lack of temporal variability in Uranus' stratospheric hydrocarbon abundances over timescales of decades. What is/are some possible source(s) of these hydrocarbons, and which one(s) are unlikely given these results from the Spitzer data? (4 points)

Putting it All Together

9. The James Webb Space Telescope is next in the line of NASA's Great Observatories, and as the next infrared space telescope it will be Spitzer's successor. Discuss at least two ways in which you expect JWST to make vast improvements in our understanding of the solar system over Spitzer, building upon what you just learned about Spitzer's contributions in this area. If you don't know anything about JWST, then describe two design or performance improvements that you would make to any future infrared space telescope to build upon the planetary science done with Spitzer. (6 points)