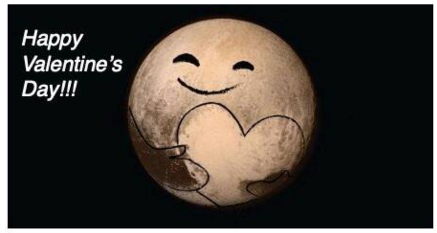

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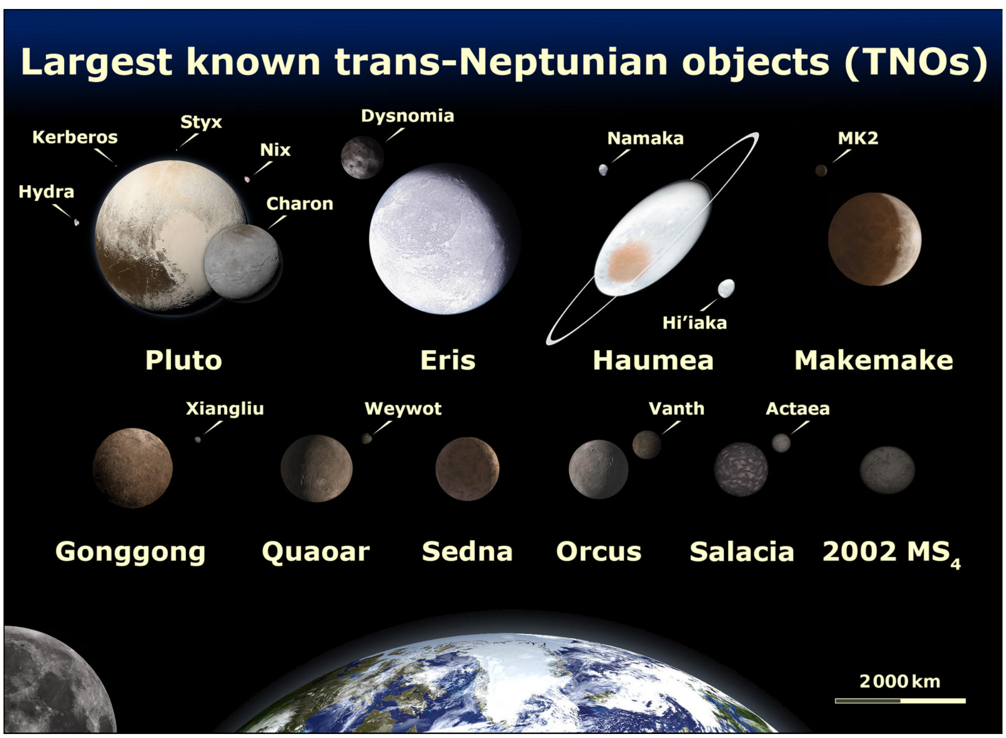

Some Kuiper belt objects. Aren't they *lovely*?

This adorable cume is based on the paper **OSSOS Finds an Exponential Cutoff in the Size Distribution of the Cold Classical Kuiper Belt**, by Kavelaars *et al.* (2021, ApJL, 920, L28). The paper is a short letter and should be a quick read (you may "skim-read" Sect 2.1 and 2.2).

The exam contains 12 questions, worth 54 total points. 40 points (75%) guarantees a pass.

Please make sure your writing is legible. I am not fluent in hieroglyphs and I cannot grade what I cannot read! Also, please show all work and do attempt each problem, showing your thought process even if you cannot solve it completely. If during the exam you have any question please email me (wlyra@nmsu.edu). I will also be accessible at the virtual zoom office `https://nmsu.zoom.us/j/7631131283`.

At the end of the exam, put your responses in question order, scan or photograph them, and upload them to the canvas assignment.

1. The classical Kuiper belt is loosely defined as comprised of objects free from significant perturbation from Neptune. Based on your reading of the paper, explain
   (a) (3 points) what you understand by *cold* classical Kuiper belt,
   (b) (3 points) why this population is supposedly primordial. Give three lines of evidence.
2. (6 points) The graphs in Fig. 1 show the results of a planetesimal formation model by streaming instability (Schäfer *et al.*, 2017, A&A, 597, 69, "Initial mass function of planetesimals formed by the streaming instability"), referenced in the cume paper.

   Briefly ($\sim$ 5 sentences) explain the main result of the cume paper, in terms of the observational result and the implications for models of planetesimal formation.
3. (3 points) The subscript r in the absolute magnitude H_r indicates that the observation is done in the r' SDSS photometric band (5640–6850 Å). Given that Kuiper belt objects are at temperature $\approx$40 K, their thermal emission peaks in the far infrared (70μm). Why is the observation done in optical and not in the far infrared?
4. Absolute magnitudes of minor bodies are quoted not with respect to a distance of 10 pc but of 1 AU (1.496×10^8 km), more appropriate for bodies in the solar system. Thus, the absolute magnitude H is defined as the magnitude that a body would have if it was 1 AU from the Earth and 1 AU from the Sun, while having a phase angle of 0°.
   (a) (3 points) Explain why this physical configuration is impossible.

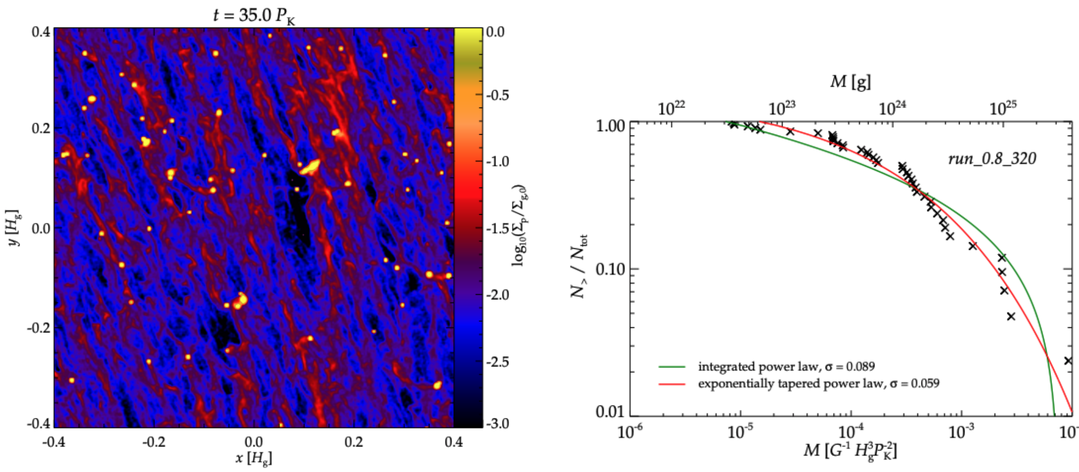

Figure 1. *Left:* Pebble column density Σ_p, integrated over the vertical dimension of the simulation box, as a function of radial location x and azimuthal location y at $t = 35$ orbits (P_K). The box is centered at 2.5 AU, and the length unit H_g is roughly 0.1 AU. Bright dots indicate locations of planetesimal formation. *Right:* the mass distribution of planetesimals formed in the simulation, well-fit by an exponentially-tapered power law.

(b) (8 points) Considering that the apparent magnitude of the Sun is -26.76, show that

$$H \approx 5\log_{10}\left(\frac{1330\,\mathrm{km}}{D\sqrt{p}}\right) \tag{1}$$

where p is the geometric albedo and D is the diameter of the object.

(c) (3 points) Given that the abstract of the paper states that the range $H = 5 - 12$ in figures 1 and 2 implies diameters 400-20 km, what is the typical geometric albedo of minor Kuiper belt objects?

5. Pluto and Charon have absolute magnitudes -0.7 and 1.

   (a) (6 points) What is the combined absolute magnitude when the system is unresolved?

   (b) (3 points) What is the apparent magnitude of the system when in perihelic opposition, seen from Earth 28 AU away?

6. (6 points) The article notes that a discrepancy exists between the model predictions and the observations, with respect to the mass of the objects. Explain the authors' preferred solution for the discrepancy in light of Fig. 2, which shows the dust continuum emission from the disk around MWC 758, a young (3.5 ± 2 Myr) A3 star.

7. A recent model suggests that Jupiter formed beyond 30 AU, and perhaps as far out as 45 AU (Öberg & Wordsworth 2019, AJ, 158, 194, "Jupiter's Composition Suggests its Core Assembled Exterior to the N_2 Snowline"). This is based on the idea that

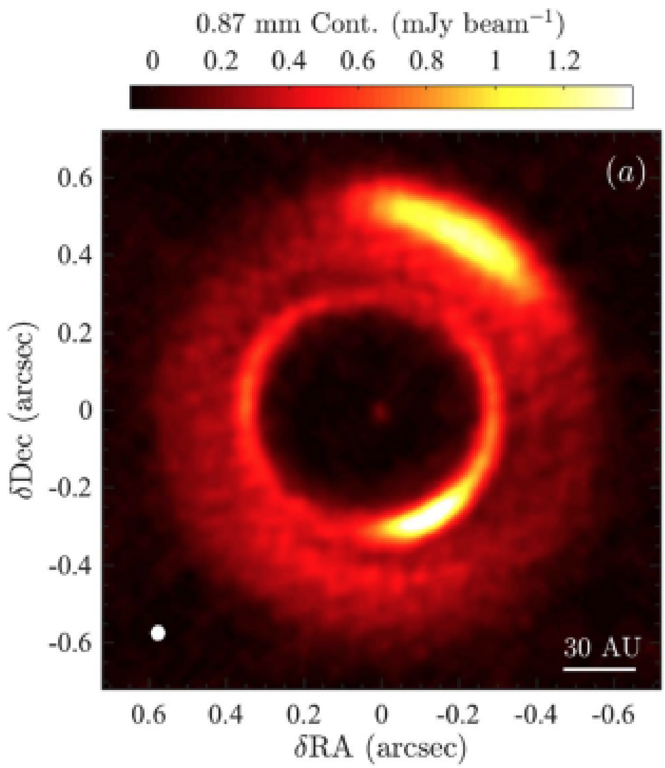

Figure 2. ALMA 0.87 mm dust continuum emission from MWC 758 with a beam size 43 × 39 mas (6.9 × 6.2 au; labeled at the lower left corner). North is up and east is to the left.

the nitrogen and argon abundances of Jupiter are explained if these elements were accreted as solids, which would happen if Jupiter formed beyond the N_2 and Ar snowlines.

(a) (4 points) How does the existence of the cold classical KBO population contradict this idea?

(b) (6 points) Suggest a theoretical study to test if the "far Jupiter" hypothesis can be reconciled with the cold classical Kuiper Belt.