AST SPECIAL TOPICS: EXOPLANETS
MISC. LECTURE NOTES: SPRING 2015

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HOMEWORK 2

Due in class on Thursday, Feb. 19

(1) Consider the plot `exo_periodirrad.png`. Based on with the definition of irradiation and the data contained in the NASA Exoplanets database, answer the following.

(a) What explains the "bimodal" behavior of planetary irradiation as a function of orbital period? *For full credit, your answer must include a quantitative comparison of representative systems chosen from among the two "classes" of irradiation vs. period behavior.*

(b) What explains the height (spread) of the main locus of points (i.e., the irradiation vs. period "class" that lies to the left in the diagram)? *For full credit, your answer must include a quantitative comparison of representative systems chosen from near the extremes of irradiation at a given orbital period.*

(c) Why doesn't the long-period, higher-irradiation locus of data points include planets discovered via the transit method (i.e., why have all of these objects been discovered via the RV technique)?

(2) *Reverse-engineering the minimum mass solar nebula. (Parts (c)–(e) required for grad students; extra credit for undergrads.)*

(a) Suppose you pulverized (atomized?) the eight planets in the solar system and spread their masses evenly within annuli bounded by their respective orbits. Make a log-log plot showing the resulting (*discrete*) surface density distribution, $\Sigma(R_i)$, where $\Sigma(R_i)$ is the surface density at the position of the i^{th} planet in g cm^{-2} and R_i is in AU. (Why log-log? Why g cm^{-2}? Well, keep going...)

(b) Overlay a curve (actually a line, in log-log space) representing the theoretical (*continuous*) power-law surface density distribution (SBD) theorized to characterize the "minimum mass solar nebula" (MMSN)[1] — a concept generally credited to Hayashi (1981, *Progress of Theoretical Physics Supplement*, **70**, 35). Qualitatively describe the deviations of the "observed" $\Sigma(R_i)$ points you

[1] See Seager's "Exoplanets"

plotted for the present-day "pulvarized solar system" relative to the theoretical (Hayashi) MMSN distribution.

(c) Use the deviations of the "observed" Σ points from the theoretical MMSN SBD — i.e., the ratios of the present-day $\Sigma(R)$ values to the theoretical values at the same R — to estimate the fraction of primordial disk material at each radius that became "locked up" in each planet.

(d) Discuss the implications of the results you obtained in (c): what does this comparison of theory and "observations" imply for the final (present-day) compositions of the terrestrial vs. gas giant planets, relative to the primordial (original) composition of the disk out of which they formed? Which planet best matches the theory, and what is "special" about this planet?

(e) Integrate the theoretical Hayashi MMSN SBD to obtain the total mass of the MMSN, and compare to the mass of the Sun and Jupiter.

(f) *Bonus for all students:* Compare the MMSN mass to the mass recently estimated/published for a specific protoplanetary disk — any disk. Be sure you give the reference for the mass estimate, and briefly describe the method used to obtain the estimate.