Name:

ASTR 3710: Midterm #1

Closed book, no notes or access to Internet. Calculators are fine. Partial credit will be given for correct reasoning even if numerical answers are incorrect, so please state as clearly as possible what you're trying to do!

(1) The "Minimum Mass Solar Nebula" provides a description of possible initial conditions for Solar System planet formation. How is the MMSN estimated from the measured properties of Solar System planets?

(1) AUGMENT MASS OF PLANETS
(2) SMOOTH OVER ANNULI

2

(2) Give one example of a planetary property that can be measured from a radial velocity survey for planets, but not from a transit survey.

MASS OR M. SIN (i)
ECCENTRICITY

2

(3) Give one example of a planetary property than can be measured from a transit survey, but not from a radial velocity survey.

PLANETARY RADIUS

2

(4) Give two examples of observed extrasolar planet properties that are surprising or unexpected based on our knowledge of Solar System planets.

ONE POINT FOR EACH REASONABLE EXAMPLE

2

(5) Why do we expect star formation to lead to the formation of protostars surrounded by protoplanetary disks, rather than just stars?

ANG^N MOMENTUM

2

(6) The vertical distribution of gas in protoplanetary disks is determined by *hydrostatic equilibrium*. This is an equilibrium between which forces?

GRAVITY

PRESSURE GRADIENT

2

(7) The disk temperature corresponding to where the *snow line* is located is often estimated to be 150-170 K. Why is this much lower than the normal freezing point of water (273 K)?

LOW PRESSURE

2

(8) Why are small particles in the protoplanetary disk more affected by aerodynamic forces than large ones?

RATIO OF SURFACE AREA TO MASS

2

(9) The "radial drift problem" results because *gas* in the protoplanetary disk orbits the star slightly slower than the Keplerian velocity appropriate to a point mass. Why is this the case?

RADIAL PRESSURE GRADIENT

2

(10) An extrasolar planet is discovered orbiting its star at a (very) close-in location where the temperature of the protoplanetary disk would have been in excess of 2000 K. Explain why forming this planet in situ would appear to be difficult.

ABOVE CONDENSATION T FOR ALL SOLIDS

2

(11) A protoplanetary gas disk has a surface density profile $\Sigma(r) = C\, r^{-1/2}$, where C is a constant. Derive an expression for the mass in the disk between radii r_{in} and r_{out}.

$$M_{disk} = \int 2\pi r \,.\, \Sigma \,.\, dr$$

$$= \int 2\pi r \,.\, C r^{-\frac{1}{2}}\, dr$$

$$= 2\pi C \int r^{\frac{1}{2}}\, dr$$

$$= 2\pi C \left[\frac{r^{3/2}}{3/2} \right]_{r_{in}}^{r_{out}}$$

$$= \frac{4}{3}\pi C \left[r_{out}^{\frac{3}{2}} - r_{in}^{\frac{3}{2}} \right]$$

4

(12) A planet with the radius of Jupiter (70,000 km) is observed to transit its host star. During the transit, the light from the star drops to 0.91 times its pre-transit value. Determine the radius of the host star.

$$f = \left(\frac{R_p}{R_*}\right)^2 \qquad f^{1/2} = \frac{R_p}{R_*} \qquad f = 0.09$$

$$R_* = \frac{R_p}{f^{1/2}} = 233{,}000 \text{ km} \qquad (2.3 \times 10^{10} \text{ cm})$$

4

(13) A baseball pitcher can throw a fastball at a speed of 40 ms^{-1}. What is the largest spherical asteroid, of density 3 g cm^{-3} (or 3000 kg m^{-3}), from which he can throw the ball so that it escapes? [The escape velocity $v = \sqrt{2GM/R}$, with G = 6.67 x 10^{-8} cm^3 g^{-1} s^{-2}, or 6.67 x 10^{-11} m^3 kg^{-1} s^{-2}]

$$V = \left(\frac{2GM}{R}\right)^{1/2} \qquad M = \frac{4}{3}\pi R^3 \rho.$$

4

$$V = \left(\frac{8\pi}{3} G R^2 \rho\right)^{1/2}$$

$$R = V \Big/ \left(\frac{8\pi}{3} G\rho\right)^{1/2}$$

$$R = 3 \times 10^6 \text{ cm}$$

$$R = \cancel{34}\ 31 \text{ km}$$

(14) For large particles (not the small ones we discussed in class), the aerodynamic drag on a spherical particle of radius s, moving at relative velocity v to gas of density ρ, is given by the Stokes formula,

$$F_D = -\frac{C_D}{2}\pi s^2 \rho v^2$$

where C_D, the drag coefficient, is a constant. If the particle is made of material with density ρ_m, determine the formula for the settling velocity (or terminal velocity) within a protoplanetary disk. [The formula for the vertical gravitational force on a particle of mass m at height z above the mid-plane is $F_g = m\Omega^2 z$]

F_D

$\uparrow$

$\bigcirc$

$\downarrow$

F_g

$$\frac{C_D}{2}\pi s^2 \rho v^2 = m\Omega^2 z$$

$$m = \frac{4}{3}\pi s^3 \rho_m$$

$$\frac{C_D}{2}\cancel{\pi}\cancel{s^2}\rho v^2 = \frac{4}{3}\cancel{\pi} s^{\cancel{3}} \rho_m \Omega^2 z$$

$$v^2 = \frac{8}{3C_D} s \frac{\rho_M}{\rho}\Omega^2 z \qquad v = \left(\frac{8}{3C_D}\frac{\rho_m}{\rho}\Omega^2\right)^{1/2}\sqrt{sz}$$

4

(15) Two protoplanets on different orbits collide and merge completely to form a larger planet. If we know the total energy and angular momentum of each of the colliding planets, we might try and determine the orbit of the collision product using either conservation of energy or conservation of angular momentum. Which of these conservation laws do you expect to be most relevant, and why would the other not give a reliable answer?

ANGR MOMN

ENERGY LOST IN COLLISION

4