Temperature estimates for the solar nebula

1. Estimate the free-fall time of the molecular cloud core, from which the Solar System was born. The mass can be taken as $\sim 1\ M_\odot$, and the initial radius as 5000 AU.

2. Assume that $1\ M_\odot$ has accreted into the proto-Sun and consider the final stages of this accretion. Estimate the mass flux through the accretion disk by requiring that $1\ M_\odot$ passes through any circular boundary during the free-fall time.

3. Consider the following values for the surface density of the disk, which correspond to the so-called *minimum mass solar nebula*. At the Earth's orbital radius (1 AU), we have $\Sigma = 3000$ g/cm^2, and at the distance of Jupiter (5.2 AU) we have $\Sigma = 1000$ g/cm^2. Since these are just minimum values, and the active accretion disk may have been more massive, consider also other values, larger than these.

4. For each value of Σ, compute the radial velocity by which the disk material has to pass in the inward direction in order to maintain the required mass flux at the Earth's and Jupiter's distances.

5. Consider for each planet a narrow ring of radial width Δr, which is arbitrary but has to be $<< r$. As the material flows through this annulus, it loses gravitational potential energy. Assume that half of this energy is converted into heat. Compute the amount of energy per unit mass that the material thus obtains, while passing through the annulus, for a certain assumed width.

6. Multiply by the total mass of the annulus to find the total amount of energy that it acquires during the passage time.

7. Use the specific heat c_V of hydrogen gas to estimate the average temperature rise within the annulus.

8. Balance the total amount of energy acquired by the amount of energy radiated away from the part of the disk surface within the annulus during the passage time, and find the necessary *effective temperature* of the disk at the Earth's and Jupiter's distances.

9. Estimate what the temperatures near the midplane may be, using the previous results.