OBSERVATIONAL SIGNATURES OF PLANETS IN PROTOPLANETARY DISKS. H. Jang-Condell, *Carnegie Institution of Washington, Department of Terrestrial Magnetism, Washington, DC 20015, USA, (hannah@dtm.ciw.edu).*

Radiative transfer is an important process in protoplanetary disks. Stellar illumination, in particular, is primarily responsible for setting the temperature and density structure of passively accreting protoplanetary disks. Perturbations in the structure of a disk, such as clumping, gap-opening, and dust-settling, can create shadows and bright spots which in turn further perturb the disk's structure. Density and temperature variations resulting from the dynamical interactions between a planet and a disk can be further enhanced by these cooling and heating effects, leading to alterations in planetary migration rates, planetary growth, and other important planet formation processes.

In previous work (Jang-Condell & Sasselov, 2004), we calculated the effects of radiative transfer on the surface of a disk perturbed by the presence of a planet. We found that the gravitational potential of the planet alters the density structure of the disk to create a depression or "dimple" in the surface of the disk. When this surface is illuminated by the central star at grazing incidence, the side of the dimple closer to the star is shadowed and cooled, and the far side is brightened and heated (see Figure 1).

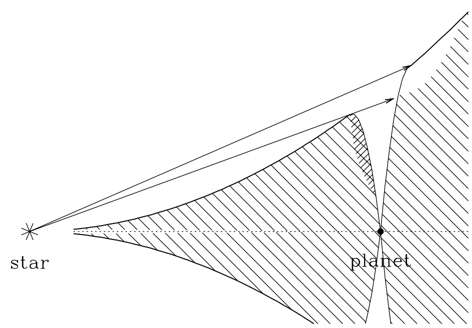

Figure 1: Incident radiation intercepted by the depression at the disk's surface.

In Figure 2, we show what the thermal emission from such perturbations might look like, given sufficient angular resolution and sensitivity. Here, we show a set of four planets of masses 2, 5, 10, and 25 $M_\oplus$ (Earth masses) located 4 AU from the 1 $M_\odot$ parent star. The scale bar indicating 0.2 AU shows the spatial scale of the images. Supposing the disk is face-on to the observer at a distance of 100 parsecs, 0.1 AU translates to 1 milliarcsecond. No current or proposed instrument will achieve milliarcsecond resolution in the mid-infrared.

However, these calculations did not calculate the feedback between the density and temperature structures of the disk. The heated side of the disk should expand and the cooled side should contract. This means that the shadowed part of the dimple will deepen further, and the bright side expand upward, perhaps creating a "wall" that captures more incident radiation. The overall effect would be even more pronounced

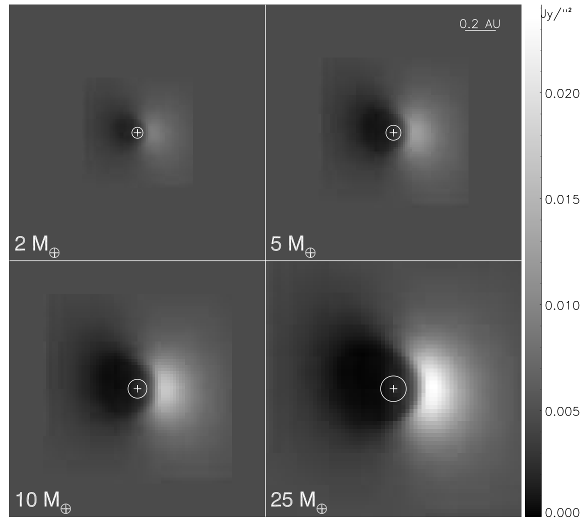

Figure 2: Simulated images at 20 microns of disk perturbations around a planet at 4 AU from a 1 $M_\odot$ star, not including feedback between density and temperature perturbations. The planet, with mass indicated above, is located at the cross. The star is located to the left in each case.

cold and hot spots in the vicinity of the planet than previously calculated.

In this work, we present radiative transfer calculations in 3D on the perturbations induced by a protoplanet on a gaseous disk, taking feedback between density and temperature perturbations into account. We restrict the study to sub-Jovian mass planets, since larger planets would be expected to open full annular gap in the disk. We find that the effects of feedback are quite important, since the spatial size of the perturbation and the amount of temperature change are much larger than in the case where density response to temperature variations are not considered.

The disk perturbations are large enough that the plane-parallel approximation for the disk breaks down. The disk model must be calculated taking the radial variation of the temperature and density into account, in addition to the detailed vertical structure. The resulting temperature perturbations may be sufficiently large to be observed by high resolution infrared interferometry in the near future. The sizes and shapes of these signatures will be described in more detail.

The changes in disk structure also have consequences for planet formation. The heating and cooling in the vicinity of the disk will affect ice formation near the planet, as described in Jang-Condell & Sasselov (2004). The amount and spatial distribution of ice near the planet will affect the growth rate and composition of the planet. In addition, temperature perturbations affect the Type I migration rate of the planet by modifying the radial pressure gradient. Jang-Condell & Sasselov (2005) showed that the small temperature changes calculated in the fixed density case do slow migration rates, albeit not by much. With the increased temperature perturbations calculated in our improved model, Type I migration may be further slowed.

The effects of shadowing and illumination near an embedded protoplanet may be more significant than indicated in previous work. These effects might be large enough to observable, even for Neptune-mass or smaller planets. If planets embedded in protoplanetary disks exhibit signatures that we can observe, then we can learn a lot about the planet formation process. We may be able to identify when planet formation begins, where in the disk they arise, whether they form through core accretion or gravitational instability, the size distribution of planets, and much more.

References

Jang-Condell, H. & Sasselov, D. D. 2004, ApJ, 608, 497

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