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A STUDY ON THE SPECTRAL ENERGY DISTRIBUTION OF THE CURVED WALL OF A GAP OPENED BY A PLANET IN A DISK AROUND A STAR

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$M_{\jupiter}$ Mass of Jupiter.

$M_{\odot}$ Mass of the Sun.

Abstract

In a small fraction of young stellar systems, disks with a low excess in the near–infrared but a high excess in longer wavelengths have been discovered. This has been interpreted as evidence that these disks called transitional disks (TDs) have central holes which have practically no dust. More recently, disks that show a significant excess in the near–infrared have been discovered. Such an excess indicates the presence of an optically thick inner disk. This inner disk is separated by an outer disk which also has a high optical depth. In this way the spectral energy distribution (SED) suggests the incipient development of a gap between both disks, these disks are called pre–transitional disks (Pre–TDs). Several physical mechanisms have been suggested to explain the gaps or holes in protoplanetary disks. The one implemented in this work is driven by forming giant planets.

A key element that produces characteristic features in the SEDs of protoplanetary disks is the inner wall of the gap or hole. To simplify SED wall models, it is often assumed that the wall is vertical and frontally irradiated by the central star. However, for walls of dust sublimation it has been proposed that the wall is curved, where the dust grain growth and its fall into the mid–plane of the disk, and the heigh–dependent gas density are the physical mechanisms responsible for such curvature.

In the current work, in order to create more realistic SED wall models of gaps and holes in protoplanetary disks with planet formation, we developed a computational and geometrical code, ARTeMiSE, which analyses tri–dimensional simulations of the disk–planet interaction to find the geometry or shape of the wall, by considering the wall is located at the points (x, y, z) where the optical depth is $\tau_{wall} = \frac{2}{3}$. We developed a second code, RHADaMAnTe, to construct the SED of the wall by using the wall geometry. In both codes the disk opacity is calculated by using the Mie theory. It is assumed that the disk consists of a mixture of dust grains composed of silicates, organics and troilite. Where we considere two populations of spherical grains, obeying the standard MRN grain size distribution $n(a) \sim a^{3.5}$.

We applied our codes to study the young stellar system LkCa 15. So as to find the geometry of the wall of the outer dik, we launched several tri–dimensional spherical simulations of the disk with a 10 $M_♃$ embedded planet, via the free hydrodynamical code FARGO–3D. We found that the forming planet located at 32.3 AU opens a gap with radius $R_{\rm wall} = 53$ AU as suggested by observations. The wall of the gap is curved, and it starts at $R_{\rm wall}$ and finishes at 68.7 AU with 12 AU in height.

Based on the wall geometry we found, we presented a SED curved wall model where the outer disk consists of small ($a_{\rm min} = 0.005\mu$m, $a_{\rm max} = 0.25\mu$m) and big ($a_{\rm min} = 0.005\mu$m, $a_{\rm max} = 1000\mu$m) dust grains of glassy olivine with 50% Fe and 50% Mg and with a small amount of organic and troilite grains. In addition, we also presented a model where is considered the contribution of the central star, the inner disk curved wall, and a partial region of the outer disk curved wall, due to the inner disk shadow. Any of the two models cannot fit the *Spitzer* IRS SED. However, the second one is reasonable fitted for wavelengths between ∼15.5 and ∼18.0 μm (we estimated $\chi^2 \sim 0.076$), and it shows a silicate feature at ∼10 μm. To get a best fit to the observed SED we require to construct a model where we also consider the contribution of the inner and outer disks, and an optically thin region in the gap.

Finally, from a comparison between vertical and curved SED wall models, considering the shadow cast by the inner disk, via the RHADaMAnTe code, we found that vertical walls located at 53, 58.11, 60.85 and 68.7 AU with 12 AU in height, show a diffrence in flux in about one order of magnitude compared to the flux emitted by a curved wall, with 12 AU in height and starting at 58.11 AU and finishing at 68.7 AU, for wavelegths between 8 and 35 μm. It means that vertical walls show an excess in flux, which suggests that curved wall instead of vertical walls should be considered to fit the observed SED of LkCa 15.