Abstract

The first stages of planetary formation begin with the agglomeration of protoplanetary dust to form bigger bodies. However, this dust growth is not fully understood and the standard accretion scenario model still contains different growth barriers. Several scenarios have been proposed to overcome these barriers, for example irregular dust, e.g., fractal aggregates and grains, contrary to compact spherical dust that was accepted to simplify models. Scattered light observations of protoplanetary disks can be done with nowadays telescopes, obtaining indirect information on this dust. But how can we interpret these scattering information to know if this dust has different morphologies and therefore help to improve understanding of these barriers? how can we do this when we do not have direct information about dust? One solution is to study the analogy of scattered dust with laboratory experiments where the control of the experimental conditions is possible and therefore the interpretation of scattering information is also possible.

This thesis is dedicated to provide more realistic tools to interpret protoplanetary disk observations with microwave scattering experiments, where our dust analogs are geometrically controlled thanks to additive manufacturing, using a refractive index similar to astronomical silicate. The size of these analogs is chosen to have a similar size proportion as real dust compared to the used wavelengths to do the observations, in order to respect the electromagnetic scale invariance rule and thus reproduce similar scattering behaviors as real dust.

During my PhD I studied the scattering parameters such as the phase function, degree of linear polarization and other Mueller matrix elements of three dust morphologies, e.g. fractal aggregates, and two families of grains with different types of roughness. The goal was to understand their scattering properties and thus give insights or tools to understand the indirect information that is gathered with scattered light observations.

Measurements of dust analog were performed in the anechoic chamber of CCRM and cross-validated with numerical simulations. Thanks to the multi-orientation and multi-wavelength that our setup provides, two types of analyses were performed with the three types of morphologies: first, scattering parameters averaged over several orientations of analogs at different wavelengths, and second, scattering parameters including a power-law size distribution. Based on these two analyses, I was able to identify characteristic scattering properties of each morphology showed with their scattering parameters. I identified the differences of their scattering parameters between a given morphology and between the different morphologies, and I compared them with scattering parameters of similar morphologies found in literature, verifying

the coherence of our results.

Our results proved that the control of geometry, refractive index and orientation of our analogs are key to interpret their scattering properties, providing unique scattering measurements thanks to our microwave experiment in CCRM and to the additive manufacturing. Furthermore, these results suggest that porosities of our aggregates and roughness of our compact grains clearly affect in specific ways their scattering properties. Moreover, I showed the interest to continue the instrumental development of telescopes to obtain more than the total scattered intensity (phase function) and degree of linear polarization. Indeed, the other scattering parameters can give more clues about the morphology of dust in protoplanetary disks. Finally, I suggested to increase the size of our analogs and test other refractive indices that are found in forming disks to obtain closer scattering parameters, as well as to perform measurements in backscattering angles.

Keywords: protoplanetary dust, scattering, microwave analogy, analogs, fractal aggregates, grains, chondrules, refractive inclusion, phase function, degree of linear polarization, Mueller matrix elements.