Super-resolution Imaging of the Protoplanetary Disk HD 142527 Using Sparse Modeling

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Recent Atacama Large Millimeter/submillimeter Array (ALMA) observations have provided new insights for planet formation process and simultaneously highlighted fundamental importance to pursue higher angular resolutions of observations to address opened questions. With the emphasis on improving the fidelity even at a super-resolution regime, many imaging techniques have been intensively developed in the last several years, which may provide substantial improvements in interferometric observations of protoplanetary disks. The CLEAN technique has been widely used, but recently, a new technique using the sparse modeling approach is suggested. This technique directly solves a set of undetermined equations and has been shown to behave better than the CLEAN technique based on mock observations with VLBI (Very Long Baseline Interferometry). However, it has never been applied to ALMA-like connected interferometers nor real observational data. In this work, for the first time, the sparse modeling technique is applied to observational data sets taken by ALMA. We evaluate the performance of the technique by comparing the resulting images with those derived by the CLEAN technique. We use two sets of ALMA archival data at Band 7 (~350GHz) for the protoplanetary disk around HD 142527. One is taken in the intermediate-baseline array configuration, and the other is in the longer-baseline array configuration. The image resolutions reconstructed from these data sets are different by a factor of ~ 3. With the two data sets independently taken by different array configurations, we show that SpM indeed achieves a higher fidelity than a multi-scale CLEAN technique, and provides consistent images from two data sets even beyond significant differences in angular resolutions by a factor ~ 3-4. Two SpM images consistently resolve radially and azimuthally asymmetric dust-grain emission of the outer disk, including a non-circular ridge shape well characterized by a simple logarithmic spiral. Resolved asymmetric structure of the outer disk provided by two SpM images may suggest complex gas kinematics near the inner-edge of the outer disk. Our results demonstrate that ongoing intensive developments of new imaging techniques will be ubiquitously beneficial to current and next-generation radio interferometers.

Keywords: Atacama Large Millimeter/submillimeter Array (ALMA), Radio Interferometer, Image Processing Techniques, Protoplanetary Disk, Planet Formation