Recent progresses of the observational study on planet formation with ALMA and the future prospects including the connection with ngVLA

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Observations of protoplanetary disks are essential in understanding the origins of diversity found in the exoplanets. In the last few years, ALMA observations have made significant progress in two directions. First, ALMA observations reveal that ring-gap structure is ubiquitous in the protoplanetary disks. The ALMA Large Program ” DSHARP" detected gaps potentially carved by a planet in ~20 protoplanetary disks. Secondly, ALMA has obtained several hints of a circum-planetary disk, which can be regarded as direct evidence for a forming planet in the protoplanetary disks. Small-scale dust continuum sources, possibly corresponding to circumplanetary disks, were detected around the two T Tauri stars TW Hya and PDS 70. A feature indicative of meridional flows, an accretion flows nearly vertically towards the surface of a circum-planetary disk, may also be detected in the disk around HD163296 by CO observations with ALMA. All these results strongly suggest that planet formation is taking place in the protoplanetary disks, but the parameters for putative planets estimated from the observed ring-gap structure in the disks do not well match the statistics of expolanets. In order to make direct comparisons between exoplanets and gaps in the disks, both the planet search at larger orbital radii and further gap search in the inner disk regions will be required. In this presentation, I also discuss the importance of the next generation Very Large Array (ngVLA) in the studies of exoplanets and planet formation in the future. While ALMA will remain powerful instrument to search for a gap in a low-surface-density regions, ngVLA will explore high-surface-density regions in dust continuum emission at longer wavelengths (3mm-15mm) at higher angular resolution (< 10 milli-arcseconds). These two instruments will be complementary with each other in search for planetary gaps, allowing us to study the formation of a planetary system consisting of more than two planets. The above observed wavelength range of ngVLA also contains molecular lines of large organic molecules and ammonia, the most important building block of N-bearing species such as formamide and glycine. These will be precious probes for protoplanetary disks to enhance synergies with astrobiology and satellite mission for asteroids in our solar-system.

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