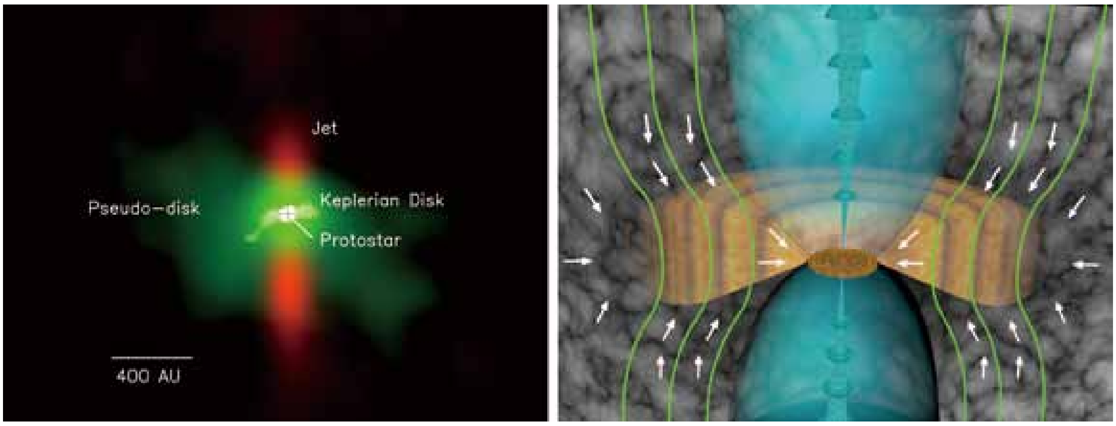

Figure 3: Left panel: ALMA composite image of HH 212, showing a pseudo-disk (green) and a Keplerian disk (bright green) in dust continuum, and a bipolar jet in HCO^+ gas (red). (Lee et al. 2014) Right panel: An artist's conception showing the pseudo-disk (brown), Keplerian rotating disk (dark brown), and bipolar jet in a collapsing model of a magnetized rotating core. Green lines are magnetic fields. Arrows indicate gas motion. Credit: Change Tsai (ASIAA).

ALMA Observation of Gas Spirals as a Nursery of Binary Stars

More than half of stars with a mass similar to that of the Sun are known to be binaries (Raghavan et al. 2010). It is thus crucial to unveil the physical mechanism of binary formation observationally to obtain more comprehensive understanding of star formation. We have observed the protostellar binary L1551 NE with ALMA in dust-continuum emission at a 0.9-mm wavelength, a tracer of the distribution of interstellar materials, and carbon monoxide molecular emission, which can be used to study gas motion with the Doppler Effect. The 0.9-mm ALMA image shown in Figure 4 (the left panel) exhibits a component associated with each binary star (the two central components), and a disk surrounding both stars, a circumbinary disk, with a radius of 300 AU. The circumbinary disk consists of a southern U-shaped feature and northern emission protrusions pointing to the northwest and the northeast.

To understand these features around the protostellar binary, we conducted a supercomputer numerical simulation of binary formation in L1551 NE (the right panel of Figure 4). The observed southern U-shaped feature and northern emission protrusions are reproduced with a pair of spiral arms stemming from each star. We also investigated the gas motion as seen in the ALMA observation of carbon monoxide molecular emission, and identified faster rotating motions in the spiral arms and slower rotating motions in the inter-arm regions. The inter-arm regions also exhibit an infalling gas motion toward the central binary stars, namely, the ongoing feeding process of the materials to the binary. These gas motions are consistent with those predicted by our numerical simulation, and our ALMA observation has unveiled the ongoing process of the growth of the binary stars (Takakuwa et al. 2014).

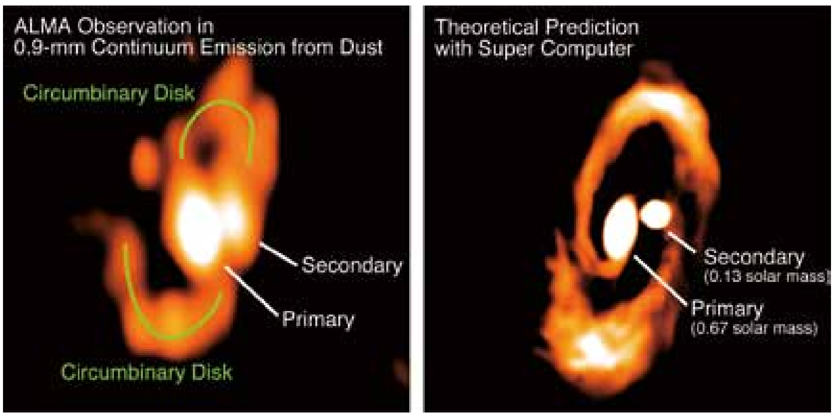

Figure 4. 0.9-mm dust-continuum image of the protostellar binary L1551 NE observed with ALMA (left), and that predicted from our supercomputer numerical simulation (right). Green curves in the left panel traces the observed structures of the circumbinary disk.

Proto-Planetary Disks

Near the end of star formation, circumstellar disks evolve to proto-planetary disks where planets are formed. Planet formation, an exciting and active area for astronomical research, has long fascinated many scientists. From the Strategic Explorations of Exoplanets and Disks with the Subaru (SEEDS) project, Takami et al. (2013) unprecedentedly found a layer of dust almost transparent in the near infrared sitting above the protoplanetary disk around RY Tau (the left panel of Figure 5). This finding, achieved by comparing observations and simulations, has brought significant insights to planet evolution theories.

The star is about 460 light years away from Earth in the constellation Taurus and is about half a million years old. The dust layer could be a remnant of the dust that fell onto the star and the disk during earlier stages of planet formation (see the right panel of Figure 5). It may act as a special blanket to warm the interior of the disk for baby planets born therein. This may affect the number, size, and composition of the planets born in this system. Therefore, this may be one of the key features for understanding how a variety of exoplanetary systems exist. (Takami et al. 2013, ApJ, 772, 145)

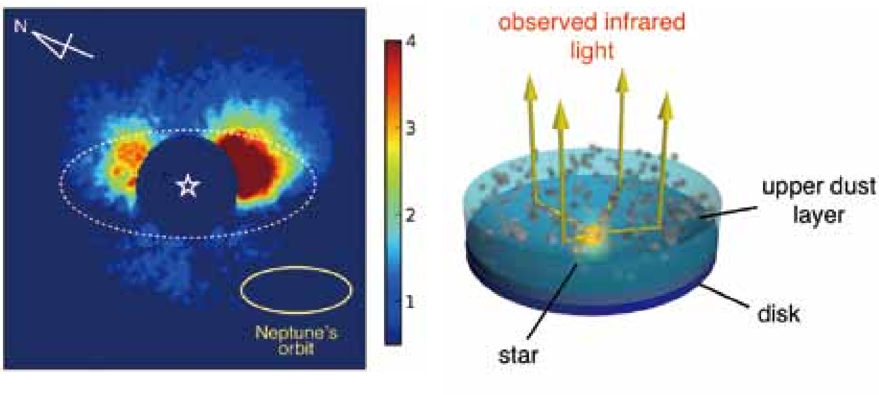

Figure 5. Left panel: an image in the near infrared (1.65 μm) around RY Tau, observed using the HiCIAO coronagraph of the Subaru Telescope. This type of observation is preferred for faint emissions associated with scattered light around planet-forming disks, as there is less light from the much brighter star. A coronagraphic mask in the telescope optics blocks the central star, with its position marked at the center. A white ellipse shows the position of the midplane of the disk. Scattered light observed in the near infrared is offset to the top of the image compared with the disk. Right panel: schematic view of the observed infrared light. The light from the star is scattered in the upper dust layer, which leads to the offset of the observed light from the midplane.

Complex Molecules in Protoplanetary Disks

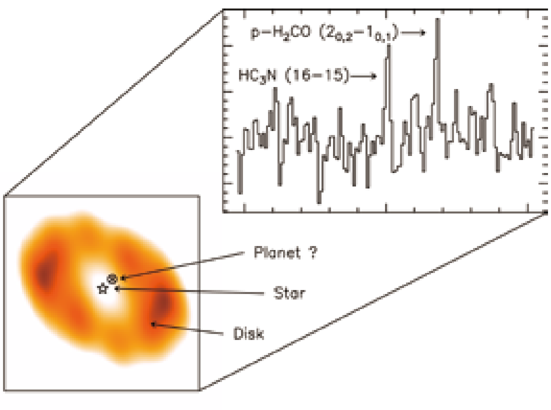

Figure 6. Top: the spectra of HC_3N and H_2CO towards LkCa15 in the 3.5" beam of the IRAM interferometer. Bottom: the 0.5" image of the 1.3 mm thermal dust emission from the circumstellar disk of LkCa15. (Picture Credit: Vincent Piètu)

Protoplanetary disks are the birthplaces of planets, and a study of their structure and content will shed light on the origin of planets. Using the IRAM facilities (30 m telescope and Plateau de Bure Interferometer), Chapillon et al. (2012) detected for the first time the molecule of cyanoacetylene (HC_3N) in the disks around Sun-like stars, e.g., LkCa15 and GO Tau. Here LkCa15 already shows a cavity in the disk (the bottom panel of Figure 6) that could be attributed to the presence of a Jupiter-like planet recently detected in the infrared. HC3N is so far the heaviest and most complex molecule detected in protoplanetary