Millimeter/Submillimeter Astronomical Instrument -ALMA Telescope-

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1. What is ALMA Telescope

ALMA (Atacama Large Millimeter/submillimeter Array) is a gigantic radio interferometer array with 66 parabola antennas, consisting of fifty 12-m antennas and "Atacama Compact Array (ACA)" composed of four 12-m antennas and twelve 7-m antennas. By spreading these transportable antennas over the distance of up to 18.5 km, ALMA achieves angular resolution equivalent to a telescope of 18.5 km in diameter, with the world's highest sensitivities and angular resolutions at millimeter and submillimeter wavelengths.

Figure 1: ALMA artist conception

(Credit: ALMA: ESO/NAOJ/ NRAO)

2. ALMA Observation Site

ALMA is under construction in the Atacama Desert at an altitude of approximately 5000 meters in northern Chile. The annual rainfall of the area is less than 100 mm, and the sky is always clear almost throughout the year. In the Atacama Desert at high altitudes, incoming radio waves are less susceptible to absorption

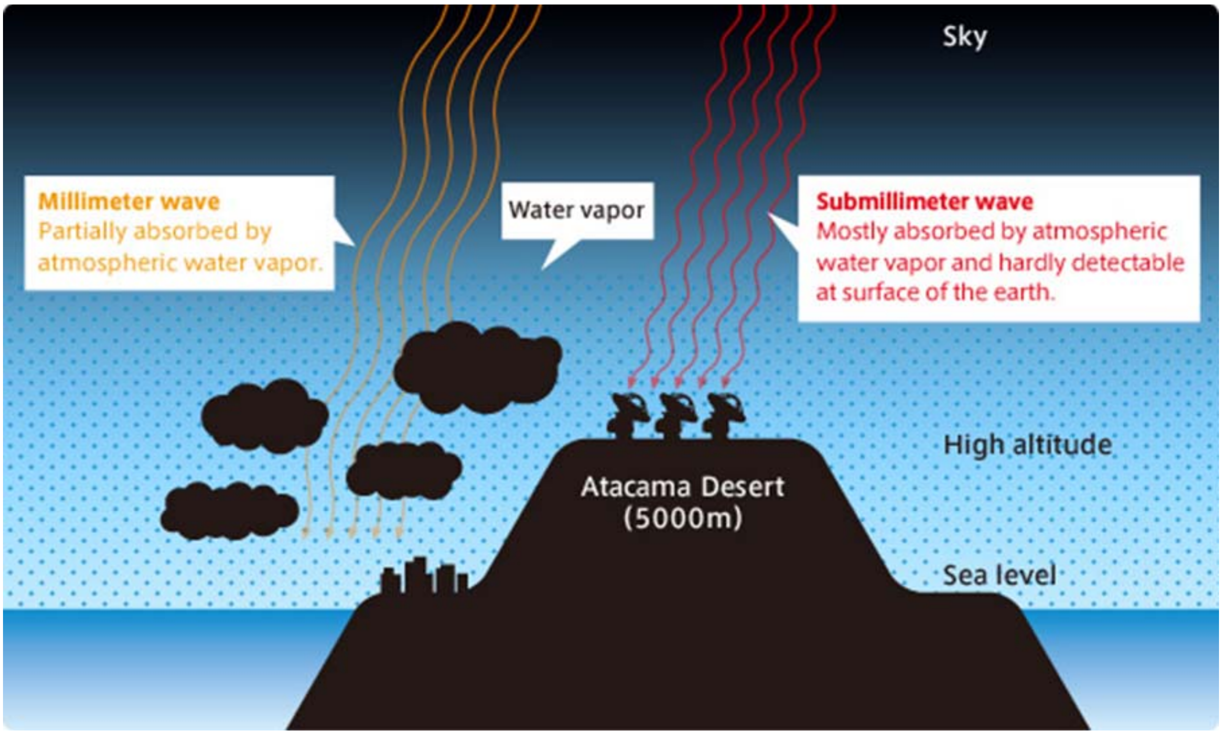

Figure 2: ALMA is constructed at high altitudes for submillimeter observations (Credit: NAOJ)

Figure3: Magnificent view of the Atacama Desert (Credit: NAOJ)

by terrestrial water vapor and thus we can observe radio waves at relatively shorter wavelengths (at higher frequencies). Combination of these favorable conditions opens the way for the submillimeter observations with ALMA. A flat and wide space of the Chajnantor Plateau is also perfect for the construction of a large-scale array.

3. Millimeter/submillimeter Waves

Any materials in the universe (including stars, interstellar gas, and the Sun) emit radio waves. Radio astronomy studies what is invisible at optical wavelengths using radio waves. At millimeter and submillimeter wavelengths, we can observe cold and even ultra-cold universe. The optically-dark regions between stars are very cold regions at -270 degrees Celsius, but there some substances exist. The Horsehead Nebula in Orion is a dark cloud that has a shape similar to the profile of a horse's head against the red emission background. This optically-invisible region is emitting gas observable at millimeter and submillimeter wavelengths, from which we can study its composition in detail.

Radio waves and lights from celestial objects are very weak when received at the surface of the Earth; especially millimeter and submillimeter waves are more susceptible to atmospheric absorption by water vapor and dusts. This is why very sophisticated receivers are required (receivers are equivalent to the

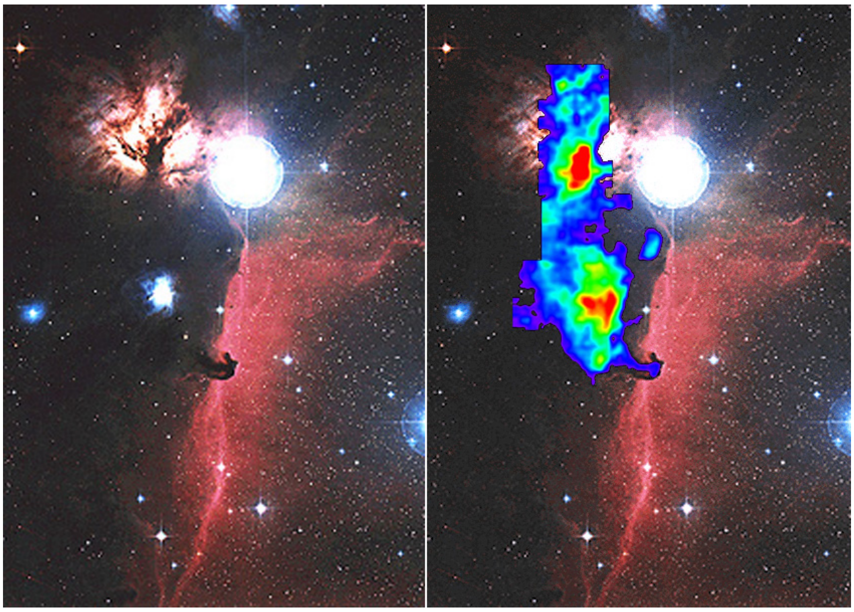

Figure 4: Optical image of Horsehead Nebula (left) is overlapped with a radio map (right).

Optically-dark region emits strong radio waves. (Credit: NAOJ)

"eyes" of a radio telescope). In particular, submillimeter waves are mostly absorbed by atmosphere and hardly observable at lower altitudes. However, these problems will be solved by ALMA which is constructed in a very dry region at 5000 m above sea level to explore the mysteries of the universe and the origin of life. “How was the first galaxy formed after the Big Bang?” “How were planetary systems formed?”, and finally, “Where did the origin of life come from?” These various mysteries of the universe will be revealed by a revolutionary telescope ALMA with angular resolution 10 times better than that of Subaru and the Hubble Space Telescope.

4. Mysteries of the Universe Explored by ALMA

4.1 Birth of the Universe and Evolution of the Galaxy

Expansion of the Universe began with the Big Bang that occurred 13.7 billion years ago. After 400,000 years, the universe cooled to 3000 K (Kelvin) and atoms were generated from electrons combined with atomic nuclei. As a result of this, the space became transparent to radiation, which enabled observations of

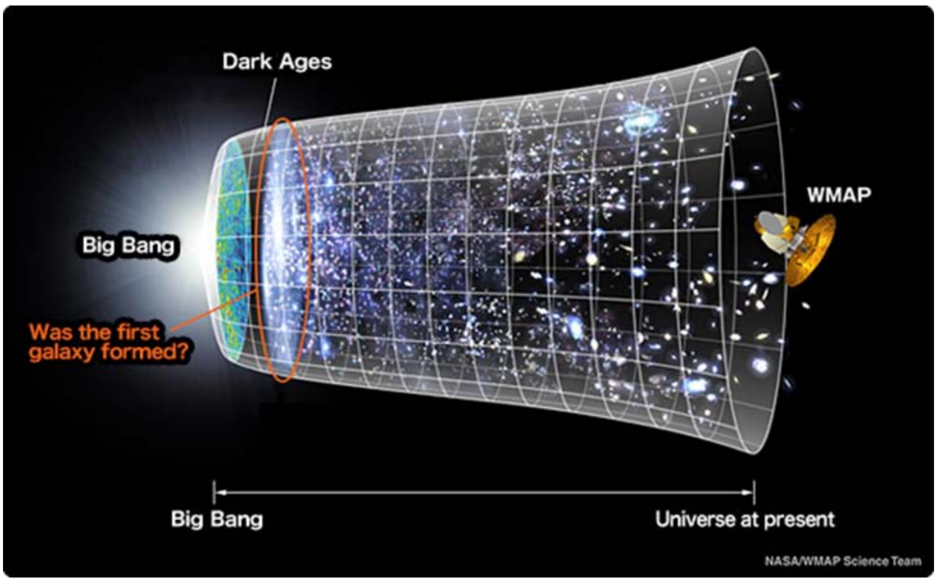

Figure 5: The Universe from the Big Bang to present

(Credit: NASA/WMAP)

radio waves. The emissions of radio waves at this time are extended (redshifted) by the expansion of the universe (red shift) and filled the universe. In astronomical terms, these emissions are called "cosmic microwave background radiation," and the temperature of the radiation is equivalent to 2.7 K (-270 degrees Celsius).

In 1992, it was discovered that there is a 1/100000 fluctuation in the temperature of the cosmic microwave background radiation (which was thought to be uniformly distributed) from the observation results obtained by the NASA's COBE (Cosmic Background Explorer) satellite. In 2001, the properties of such deviations were further studied by the WMAP (Wilkinson Microwave Anisotropy Probe). As a result of these studies, astronomers now believe that this fluctuation contributed to the formation of various cosmic structures such as galaxies and clusters/superclusters of galaxies, but it is still unknown how it led to the formation of these structures.

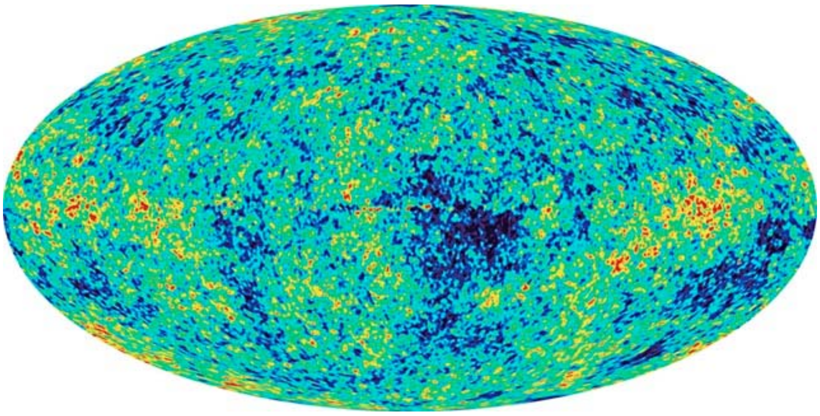

Figure 6: Cosmic microwave background radiation observed by WMAP
(Credit: NASA/WMAP)

We can observe the universe dating back about 800 million years after the birth of the universe with a high angular resolution optical telescope such as Subaru Telescope, but we cannot see the universe prior to this point with any optical telescope, due to the redshift effect. On the other hand, in the spectrum of millimeter/submillimeter waves, redshifted galaxies are seen brighter and dust contained in galaxies is also observable. Possibly, with ALMA, we may be able to observe the birth of the galaxies that occurred just after the cosmic "Dark Ages."

4.2 Formation of Planetary Systems

“How were the planetary systems like our solar system formed?” Since the discovery of the first planet outside the solar system in 1995, about 800 planets have been found directly or indirectly outside the solar system so far. The observation results on these planets show that planetary systems have a wide variety of

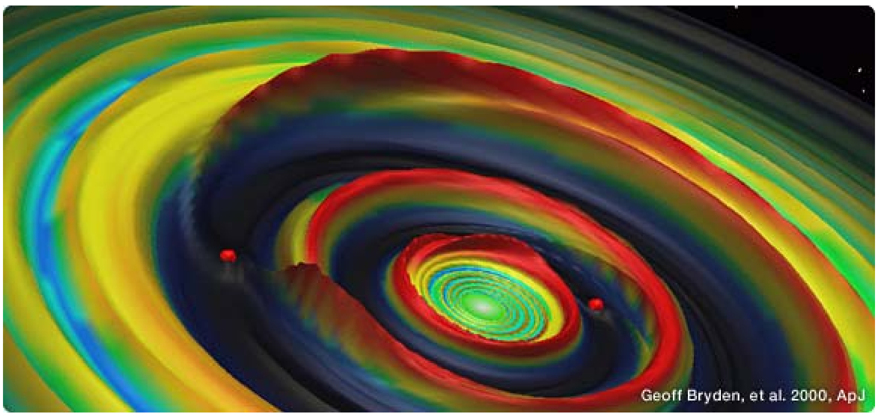

Figure 7: Computer simulation of formation of planets in a protoplanetary disk

forms. To explore their formation process, it is necessary to observe the birth of the planetary system, but ingredients of planets (e.g. gas and dust) are too cold to be observed by optical telescopes.

On the other hand, with millimeter/submillimeter telescopes, we can observe gas and dust before evolving into stars and planetary systems. Although existing radio telescopes are only capable of seeing object structures vaguely due to lack of angular resolution, ALMA with high angular resolution far better than previous radio telescopes is capable of observing with unimaginable clarity the formation process of stars as well as that of planetary systems. ALMA aims to observe unexplored regions of the universe that have not ever been reached by any existing telescopes.

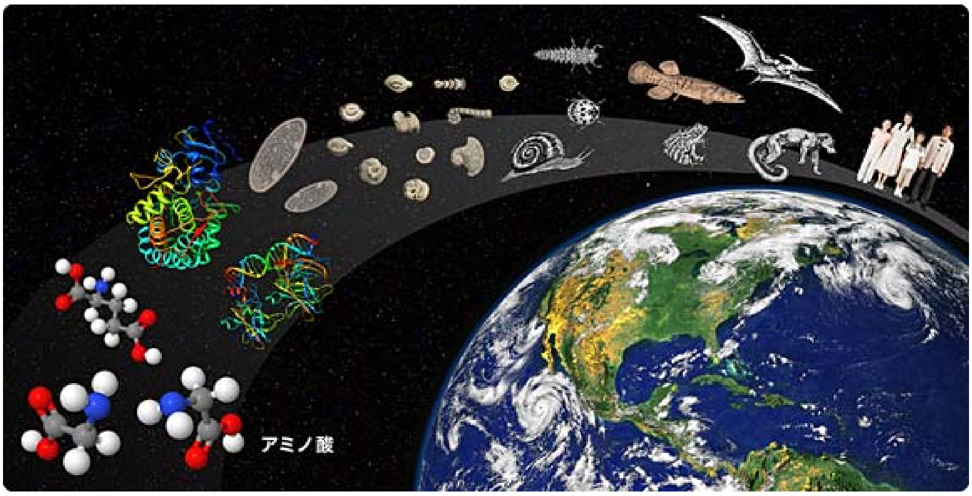

Figure 8: Search for the origin of life (Credit: NAOJ)

4.3 Origin of Life

“Is the beginning of life a mere result of chemical reactions that occurred only on the Earth?”, “Did our planetary system have the seed of life from its beginning?”, and “Did the space hold any materials that could be an origin of life?” There are various theories about the beginning of life. Obtaining a clue to the origin of life is one of the main goals of ALMA.

In the universe after the Big Bang, various celestial objects and interstellar matters have been formed in the course of gradual evolution of materials, eventually leading to the beginning of life on the Earth. The study results of past millimeter /submillimeter observations show that there is a great variety of interstellar matters in the universe, and their evolution processes differ widely. With ALMA, we will analyze interstellar matters composed of various molecules and study its evolution process, aiming to reach to the origin of life and the evolution process of interstellar matters that have yet to be discovered.

5. Conclusion

Since the great progress of science in the 20th century, many astronomers have been tackling unexplained phenomena of the universe by means of astrophysics. However, these mysteries still remain unsolved and will continuously attract the curiosity of scientists as inspiring research themes.

Entering the 21st century, astronomers embarked on a new field called “astrobiology” to search for a clue to the origin of life. The ALMA Telescope will play a key role in achieving this big goal. ■