論文の内容の要旨

論文題目

The Development of a Near-Infrared Integral Field Unit for Spatially Resolved Studies of Starburst Galaxies

（ 空間分解したスターバースト銀河研究のための近赤外線面分光ユニットの開発 ）

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In the optical and near-infrared astronomy, obtaining spatially resolved spectra (i.e. integral field spectroscopy; IFS) is increasingly important year by year since they provide a clue to understanding a connection between a local star formation process and a global star formation activity in a galaxy. It is also important to observe nearby starburst galaxies whose specific star formation rates are nearly two orders of magnitude higher than those of nearby normal star-forming galaxies. They are rather close to high-z galaxies at z = 1–2, at which the cosmic star formation activity peaks (“cosmic noon”). Since high spatial resolution and spectroscopic observations can be easily achieved in the nearby universe, performing an IFS observation of nearby starburst galaxies with high specific star formation rates is important to investigate the origin of star formation activity at the cosmic noon.

In this thesis, we present a development of a near-infrared integral field unit (IFU) and results of a high-spatial resolution imaging of the nearby starburst galaxies. In Part I, we first introduce a concept of a module-like compact IFU, called SWIMS-IFU. SWIMS-IFU provides a new observation mode of SWIMS, which is one of the first generation instruments of the University of Tokyo Atacama Observatory (TAO) 6.5-m infrared telescope. Its optical parameters are optimized for a seeing-limited observation and SWIMS-IFU has the wide field-of-view of 145 □″ and 220 □″ at the Subaru and the TAO 6.5-m telescope, respectively, as well as the wide spectral coverage of 0.9–2.5 μm. These capabilities will realize wider science targets and an efficient IFS survey, which is still rare in the near-infrared wavelength, although such surveys have been already implemented in the optical wavelength (e.g. CALIFA, SAMI, and MaNGA). To realize this concept, a very tight limitation is imposed on an optical layout, which requires a compact size of < 60 × 170 × 220 mm^3. We employ aspheric surfaces and carefully take account of manufacturability and alignment procedure of optics throughout optimizations. As a result, we succeed in constructing a compact optical layout satisfying the size specifications and an optical performance for seeing-limited observations.

We next perform a proof-of-principle experiment of fabrication of a slicing mirror array, which is the heart of the IFU optics. We demonstrate monolithic test fabrications using an end-mill process of a nickel phosphorus (NiP) coated mirror array. The mirror array has an aperture size of 10 mm × 12.5 mm and twenty-five reflective surfaces with a slice width of 500 µm. We optimize the processing conditions by finding out the cause of various shape error based on preliminary experiments. A surface roughness of 10 nm and a shape error of 80 nm P-V has been achieved by simultaneous two-axis control of a diamond end-mill tool. This is the first demonstration of monolithic fabrication of a NiP coated slicing mirror array.

Further we verify a diamond cutting performance of various mirror materials such as a conventional and special aluminum alloy, an oxygen free copper, and an electroless NiP plating. We show surface a roughness of ~ 5 nm can be achieved by diamond cutting, especially for special aluminum alloy and oxygen free copper. We also experimentally confirm that high silicon-containing aluminum optimized to match the CTE of NiP plating obviously suppresses the shape deformation at cryogenic condition. Our results indicate that this high-Si containing alloy coated with NiP is optimal for use on infrared mirror material in terms of the both surface roughness and shape.

In Part II, we have carried out spatially-resolved study of nearby starburst galaxies using an AO-assisted Paα imaging at the Subaru telescope. Two starburst galaxies are observed, one is at a mid-merger stage and the other probably at an early stage, and bright star formation clumps emitting in Paα are detected clearly in both targets. We find a strong correlation between the star formation rate surface density (Σ_{SFR}) and the stellar mass surface density (Σ_{M*}). This relationship is the near-infrared version of the Σ_{SFR}-Σ_{M*} relationship which has been reported by optical IFS observations, and we detect it in starburst galaxies using the near-infrared Paα line for the first time. Our relation shows a specific star formation rate higher those found in local star-forming galaxies by an order of magnitude. We also find that star formation is active not only in the Paα clumps but also at non-clump regions of the galaxy. The detected Paα clumps have star formation rate surface density of Σ_{SFR} ~ 3–4 $M_\odot$ yr^{-1} kpc^{-2}, which is higher compared with those of HII regions in nearby normal galaxies. They are similar to giant star forming clumps in clumpy galaxies at z = 1–2. Based on gas surface density and gas fraction derived from the Kennicutt-Schmidt law, these Paα clumps may be local analogs of those of z ~1–2 clumpy galaxies.

The samples obtained with the Paα imaging will be good candidates to follow-up with SWIMS-IFU and their dynamical information will be useful for understanding their star formation activities, which will provide important information on star-formation at high-z galaxies.