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研究課題名（和文）The FMOS-COSMOS survey of star-forming galaxies at z~1.6 using Subaru/FMOS

研究課題名（英文）The FMOS-COSMOS survey of star-forming galaxies at z~1.6 using Subaru/FMOS

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研究成果の概要（和文）：我々はすばる望遠鏡を用いて1500個の高赤方偏移（z~1.6）の星形成銀河の包括的な研究を行ってきた。近赤外分光装置FMOSは大規模な銀河サンプルの為の光学的輝線を効率的に検出する。これらの測定が行われた大規模銀河サンプルは本研究以前に存在し得なかった。研究の成果として高赤方偏位の星形成銀河の物理的性質が近傍の銀河(z ~ 0)における性質とどのように関連づけられ、宇宙の歴史の中で銀河進化の特徴をあたえたかを確立した。分光データにより特に星形成率、活動銀河核や爆発的星形成の性質、星間ガスの物理的状態（ダスト減光、金属量、イオン化状態等）や大規模な銀河の空間分布の測定を行った。

研究成果の概要（英文）：We have carried out a comprehensive study of 1500 star-forming galaxies at z ~ 1.6 using Subaru. The near-infrared spectrograph FMOS provided the means to efficiently detect key rest-frame optical emission lines for a large sample of galaxies. Prior to this study, no such sample of galaxies with these measurements had existed. As a result, we are able to establish how the physical properties of star-forming galaxies at high redshift relate to those in the local (z ~ 0) Universe hence provide a characterization their evolution with cosmic time. In particular, this spectroscopic data set allowed us to measure the rates of forming new stars, presence of Active Galactic Nuclei, properties of starbursts, and physical conditions of the interstellar medium including the amount of dust obscuration, level of chemical enrichment, ionization state of the gas and large-scale distribution of galaxies.

研究分野：　ovservational astoronomy

キーワード：　Interstellar medium　star formation　galaxy evolution

１．研究開始当初の背景

The star formation history of galaxies depends on a number of processes both internal and external to the galaxy itself. These factors leave their imprint on the galaxy population as a whole by the global decline in average star formation rate density from z ~ 2 to the present (z = 0). While mechanisms such as feedback from supernova or active galactic nuclei are likely important, their activity may be in response to more fundamental external influences such as cold gas accretion. Further progress demands stringent observational constraints, from large-scale spectroscopic surveys, on semi-analytic models of galaxy formation.

Optical spectroscopic surveys (e.g., SDSS) over the last few years have amassed samples ~106 galaxies that provide a map of the galaxy distribution up to z~1, and enable a measure of the intrinsic properties of galaxies such as their stellar populations and ongoing star formation rate. An important step forward is the disentangling of relations between star formation rate, stellar mass, and environment. While such studies have greatly benefited from large spectroscopic redshift surveys, at low and high-z, there had been a wide gap at $1.4 \lesssim z \lesssim 1.8$, namely ‘the redshift desert ‘ (historically a difficult redshift regime to study galaxies), i.e., precisely at the peak cosmic epoch in galaxy growth. Therefore, this wide critical “slice" of our Universe has not yet been adequately mapped

２．研究の目的

New spectroscopic capabilities in the near-infrared with high multiplex capabilities, such as those with Subaru/FMOS, offered the potential to efficiently acquire spectroscopic redshifts (i.e., accurate distances), measure star formation rates, and establish the level of chemical enrichment for a large statistical sample of galaxies (> 1000) to shed light on the following key questions:

(a) What fundamentally regulates star formation in galaxies at z~1.6? Perhaps the most important event that can happen to galaxies is the essentially complete quenching of star formation which turns them into quiescent galaxies. In the local Universe, almost 60% of the stellar mass is within red and dead spheroids (i.e., ellipticals and bulges), and understanding how quenching proceeds as a function of cosmic time, galaxy mass, and environment, is crucial to further our understanding of galaxy evolution.

(b) Does the star formation rate depend on environment? A characterization of the large-scale environment (~Mpc scale) of galaxies at z > 1 would answer questions relating to whether environmental quenching has begun at these early epochs where the galaxy group potential is being built up.

３．研究の方法

The combination of accurate redshifts (i.e. distance measures), accurate SFRs based on Halpha, corrected for dust extinction (using the Balmer decrement), and environmental information within the COSMOS field, a survey region of the sky with remarkable multi-wavelength data (e.g. X-ray, radio, far-infrared) provides a unique opportunity to elucidate the stellar

growth of galaxies at the peak epoch of formation. For this purpose, we successfully acquired a sample of 1500 star-forming galaxies with near-infrared spectra in the COSMOS field to address the aforementioned questions.

４．研究成果

The program as detailed in Silverman et al. (2015a) has met the stated goals by furthering our understanding of star formation at high redshift including the evolution of the interstellar medium. Our first science question, "What regulates star formation?" has been the focus of four scientific papers (Zahid et al. 2014a,b; Rodighiero et al. 2014; Kashino et al. 2017a). Two of these papers have established the observed relation between the stellar mass of galaxies and their chemical composition of the interstellar medium, indicative of the rate of stellar evolution.

Our second science question " Does the star formation rate depend on environment?" has been addressed in a paper under review by D. Kashino entitled "The FMOS-COSMOS survey of star-forming galaxies at z~1.6. V: Properties of dark matter halos containing Halpha emitting galaxies" (arXiv:1703.08326) that measures the dark matter halo masses of star-forming galaxies at high-redshift.

Additional studies based on the FMOS program include the cold gas content of starburst galaxies using ALMA (Silverman et al. 2015b). We show that starbursts at high redshift are similar to local Ultraluminous Infrared galaxies by having a heightened efficiency of converting gas to stars. Two followup studies are in progress (Silverman et al. 2017a,b). These studies demonstrate the role of galaxy mergers in generating rapid and more efficient star formation due to the interaction.

In total, ten papers have been accepted for publication that use the FMOS-COSMOS data. A final catalog of spectroscopic redshifts and emission-line strengths has been produced and released to the public (Silverman et al. 2015; http://member.ipmu.jp/fmos-cosmos/FMOS-COSMOS.html). A final catalog along with 1D spectra will be made available to the public within the next year.

The FMOS-COSMOS project has been recognized by both the domestic and international scientific community as evidence by citations to papers, followup programs (ESO/VLT, Keck and ALMA) by international collaborators and invitations to conferences. This survey includes the largest number of galaxies with bright emission lines to aid in the design of future cosmological surveys (Baryon Acoustic Oscillations) with Euclid and WFIRST. Finally, FMOS-COSMOS is improving the accuracy of photometric redshift estimate (Laigle et al. 2016) and contributing to the design of galaxy surveys with the next generation multi-object spectrograph on Subaru, Prime-Focus Spectrograph.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　9 件）

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③ J. Silverman, “Molecular gas content of Extreme Outliers from the star-forming main-sequence at z~1.6”, Transformational Science in the ALMA Era, August 4, 2014, Charlottesville, VA, USA

〔図書〕（計　0 件）

〔産業財産権〕

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〔その他〕
ホームページ等
Press release by ALMA observatory
http://www.almaobservatory.org/press-room/press-releases/896-alma-telescope-unveils-rapid-formation-of-new-stars-in-distant-galaxies

Press release by Subaru Telescope (2013)
http://subarutelescope.org/Pressrelease/2013/12/05/index.html

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