【Grant-in-Aid for Scientific Research (S)】

Study of structure formation and galaxy evolution based on big data set from Subaru Telescope

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Project Information	Project Number: 23H05438 Keywords: Subaru telescope, ultra-wide field,big data,precision data analysis	Project Period (FY): 2023-2025

Purpose and Background of the Research

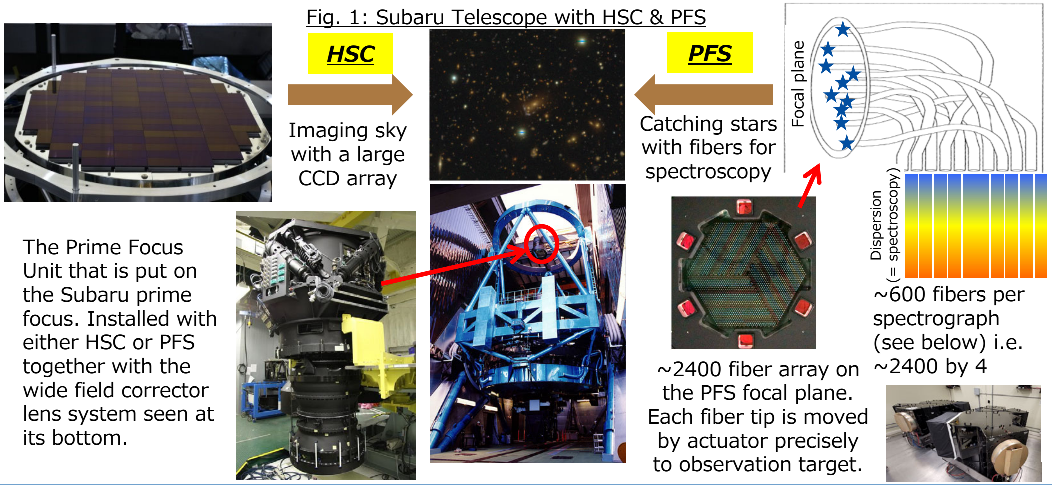
●Outline of the Research

<The universe is wide and deep>The night sky with so many twinkling stars overwhelmingly tells us the enormity of the universe. But one should remember that some stars and galaxies we can see there are somewhere relatively close to us while some others are farther away, and such a depth is projected onto the sky that is sort of an imaginary plane. The universe is huge in both ways of being wide and deep.

<Understanding the universe by looking into its contents>While lots of efforts are underway in various ways to understand the universe, our approach is to generate a 3-dimensional (3D) map of galaxies in a very large volume of the universe. . In a sense, we are trying to reveal the characteristics of a container (i.e. the universe) by understanding the distribution of the contents (i.e. galaxies) in it.

<Ultrawide-field instruments HSC & PFS on the 8.2m Subaru telescope>To generate a 3D map of galaxies, firstly one should take images of the sky across its very wide area and find galaxies. The fainter galaxies can be found the better, as we can very likely find galaxies farther from us and therefore explore the universe more deeply. Hyper Suprime Cam (HSC) on the Subaru telescope is actually a perfect device. Thanks to the the Subaru's large (8.2m) primary mirror, HSC can deliver clear images of very faint galaxies. In addition, one exposure of HSC can cover such a wide area as 9 times larger than the full Moon. So it can take wide and deep images of the sky highly efficiently. Then, what is important next is to know the distances of the galaxies from us. This requires a measurement of a galaxy's redshift and requires a method so-called spectroscopy. Subaru will soon equip a perfect device in this regard as well that is Prime Focus Spectrograph (PFS). It enables simultaneous spectroscopy with ~2400 fibers and hence enhances a survey speed revolutionarily.

Fig. 1: Subaru Telescope with HSC & PFS



●PFS under commissioning

Since the fall in 2021, we are continually conducting engineering observations (EO) with PFS to verify its functions and performances. The fiber positioning accuracy is a key performance and is now quite good. One important strength of PFS is its wide wavelength coverage from 380nm to 1260nm in one exposure. This is allowed by 3 cameras, and the ones for the near-infrared (NIR) wavelengths are the hardest to develop. But one of them started its operation and data acquisition. We will continue developments and EOs obs to start scientific operation from late 2024.

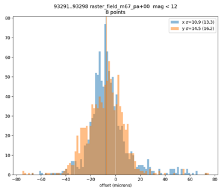


Fig. 2: Measured offsets of the fibers from the targeted bright stars. The typical error of 15um is quite small with respect to the fiber diameter.

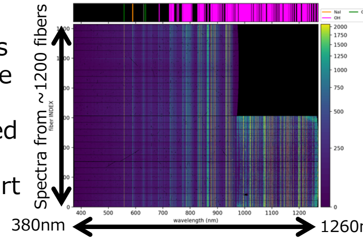


Fig. 3: ~1200 spectra from the 2 working spectrographs. The bottom half goes up to 1260nm with NIR camera.

Expected Research Achievements

●Implication & limitation of HSC wide-field imaging survey

We conducted a ultrawide-field imaging survey with HSC spending the Subaru's ~330 nights from 2014 to 2021, and accurately measured the parameter "S_8" characterizing the growth of the structures in the universe. The result seems to deviate from the value obtained by the data from the Planck satellite and its extrapolation using the standard model of the universe. This may be an important discovery implying a defect in the standard model of the universe and a requirement of a new physics. But the data are yet insufficient as galaxy redshifts from HSC are inaccurate.

●Redshift measured by PFS with high-precision calibration

Accordingly, we are developing a plan to conduct a ultrawide-field spectroscopic survey and measure redshifts of the galaxies found in the HSC survey. The major difficulty here is that the sky is much brighter than faint galaxies of our interest. In other words, we can see the spectrum of a faint galaxy only after the sky is subtracted very accurately. Moreover, in PFS observations, a subset of fibers are allocated to purely observe the sky, and based on the data from those fibers, the sky in the other fibers needs to be accurately modelled and subtracted. To meet these demands, it is crucial to construct a physical model of the instrument with Zernike polynomials, considering such aspects as how the beam comes into the fibers at the telescope prime focus, how the beam comes into the spectrograph, how the beam gets through the optics and mechanics in the spectrograph and so on. This enables to simulate the images on the spectrograph detectors as functions of fiber and wavelength. This type of attempt is new in this research area, but we have got some success in the initial modeling on a specific camera. We will continue efforts to build accurate models on all the 12 cameras. This is the development of high precision calibration system and data analysis software as the core of it.

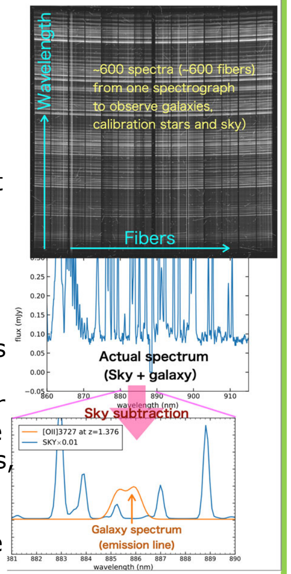


Fig. 4: It is crucial to subtract the sky that is much brighter than a faint galaxy of interest.

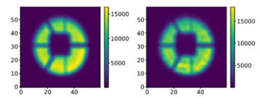


Fig. 5: An example of PFS physical model on the left, real data on the right.

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