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MOIRCS Upgrade Project: A NIR Redshift Survey of the Cluster RXJ1716 at z=0.8

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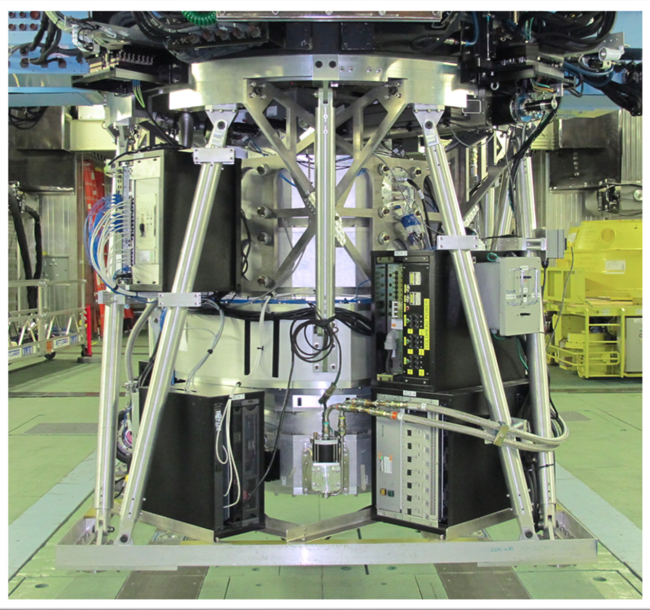
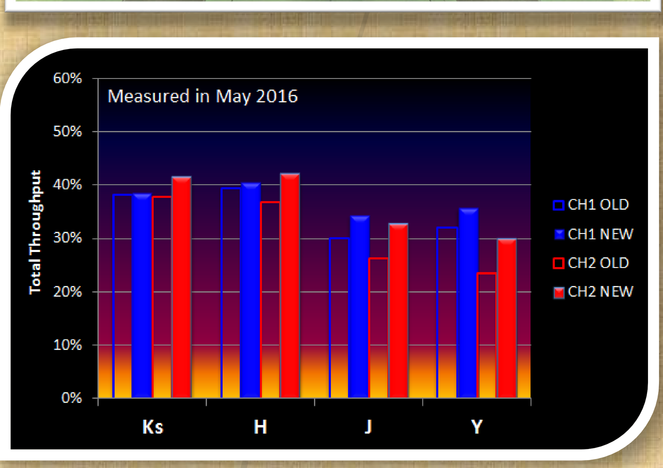
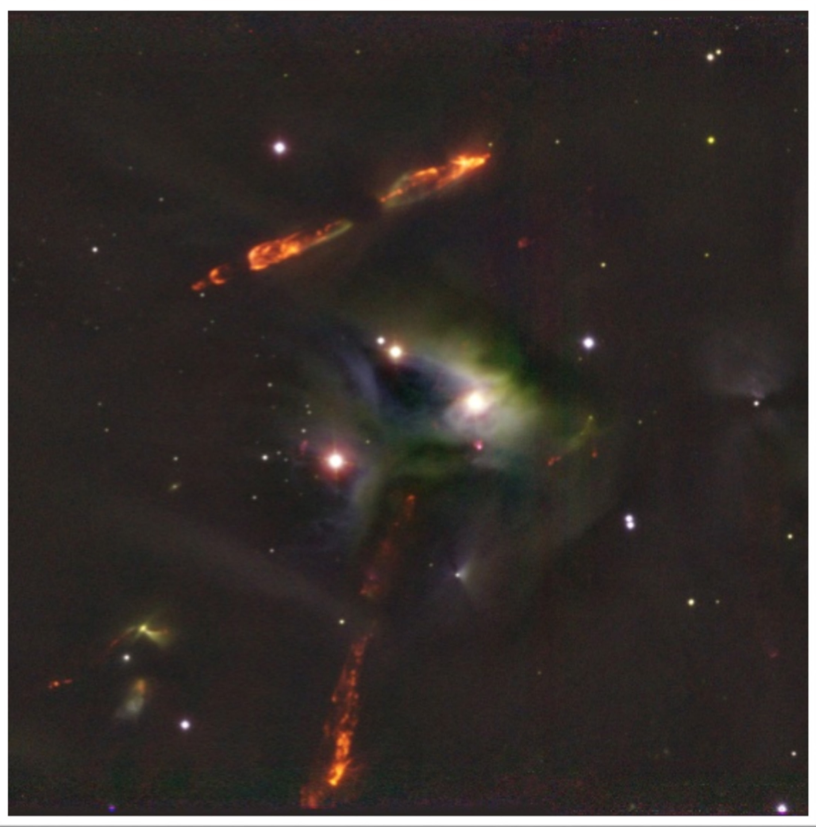
MOIRCS is Subaru's Near Infrared Camera and MOS Spectrograph. We have upgraded the detector from the old Hawaii2 to Hawaii2 RG in late 2015. Through the series of Engineering observations in 2016, we have shown that the overall on-sky performance has improved much, especially in the shorter wavelength.

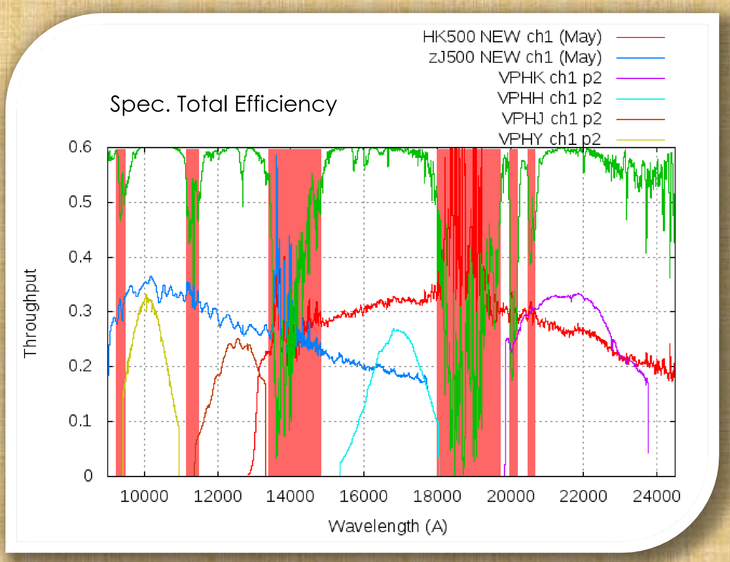
As a part of the science verification test, we took the J-band spectra of the star-forming galaxies in the rich X-ray cluster RX J1716+6416 at z=0.81 in MOS mode. Koyama et al. (2010 MNRAS, 391, 1758) has investigated the environmental dependence of the star-formation activity using the sample of the Hα emitters (HAEs) detected through the deep and wide MOIRCS Narrowband (NB) imaging as well as the multiwavelength data. As the spectroscopic follow-up of their detected HAEs, we tried to measure the redshift of their HAE sample for the cluster kinematics. By using the zJ500 grism + J imaging filter, we can cut well over 100 target slits in a single MOS mask. We have successfully measured the redshift of 42 objects (including all the 31 HAEs) in only 45-minutes exposure under less good condition (EL~30 degrees, seeing ~0.8"). This makes more than double the number of objects with measured redshifts from Gioia et al.(1999). With the unpublished FOCAS spectroscopic data provided by YK, the kinematical properties of the cluster is examined. We have shown that, as inferred from the previous analysis by Koyama+2011, there is a clear substructure kinematically distinct from the main cluster. Interestingly, the fraction of the HAEs in the structure show the gradual decline towards the direction of the main cluster, despite that there is no clear concentration of galaxies. The suppression of the star-formation before the direct interaction with main cluster may already be on work. Behind the contact front, there is the area with the unusually high HAE fraction which we newly found from the data. Our result nicely demonstrates the improved performance of the MOIRCS.

1. MOIRCS Upgrade



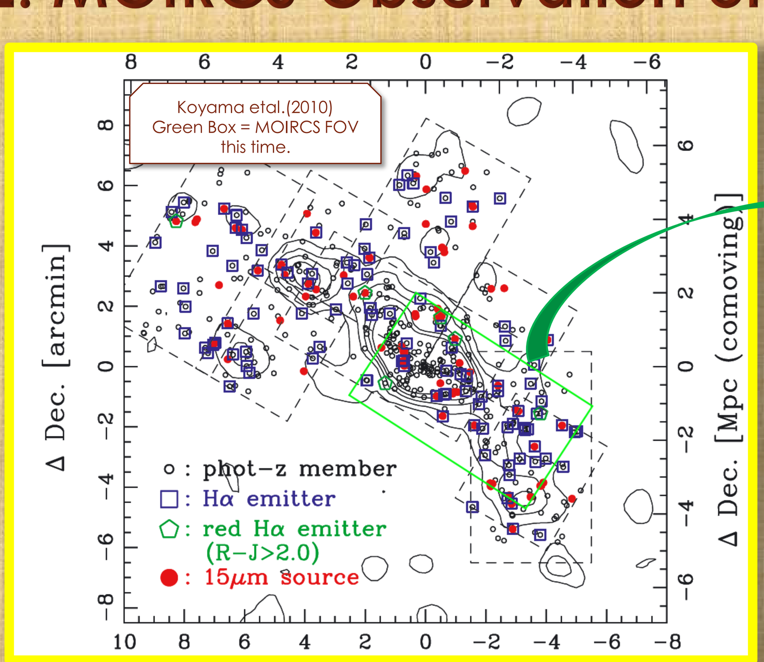


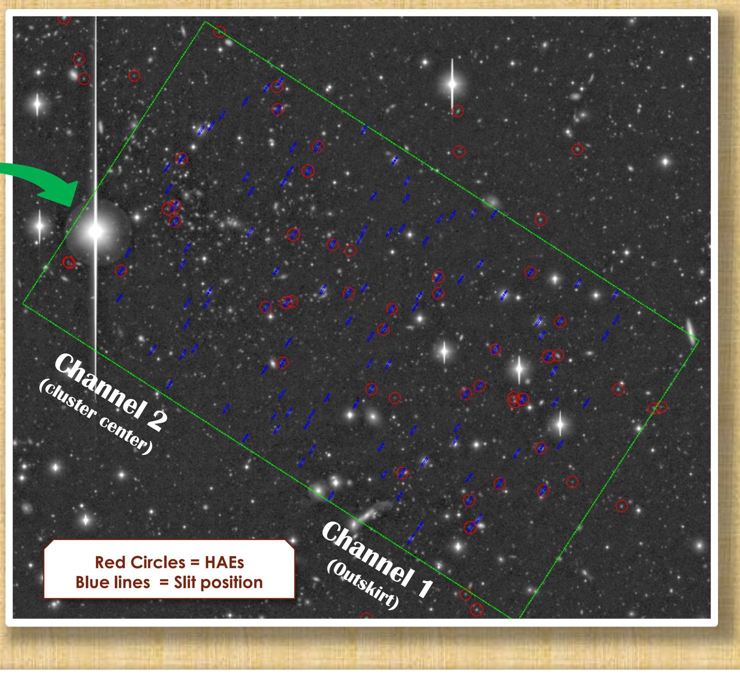


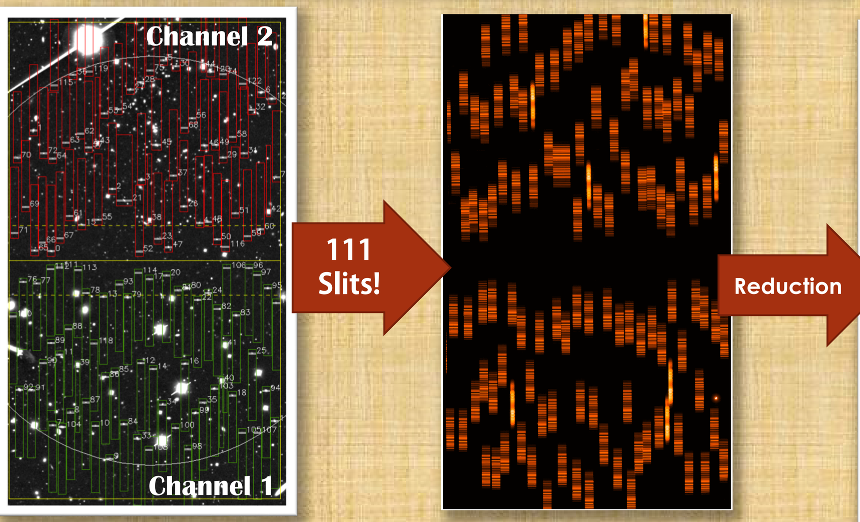


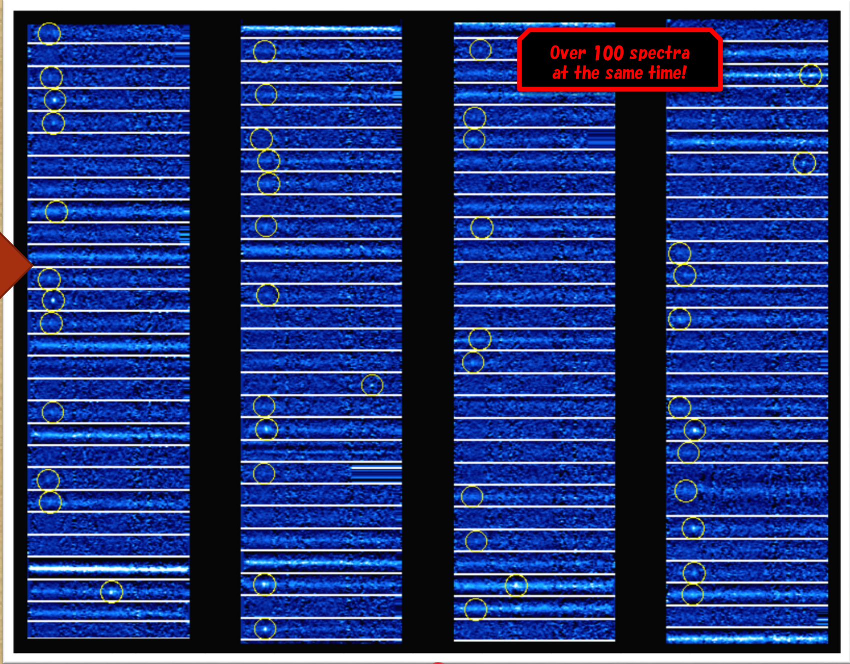
MOIRCS is Subaru's Near Infrared Camera and MOS Spectrograph. It has been working over 10 years since its first light. In order to keep its competitiveness, we started the MOIRCS Upgrade Project since 2012. As the part of the project, we have replaced the detector from the old Hawaii2 to Hawaii2 RG in late 2015. We have shown that, through the series of Engineering observations in 2016, the overall on-sky performance has improved much, especially in the shorter wavelength.

2. MOIRCS Observation of RX J1716 Cluster at z=0.81









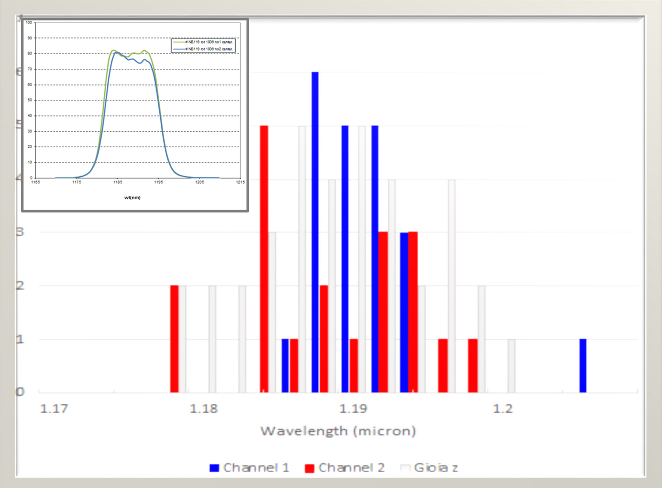
As a part of the science verification program, we have executed the spectroscopy of the Hα Emitters (HAEs) in the cluster RX J1716+6416 at z=0.81 with MOS mode. The HAEs sample were selected via the deep MOIRCS NB imaging by Koyama et al. (2010). Though there are large number of HAEs in the cluster, very small number of them were with spec-z. Using a special layout of J+zJ500 grism, we can easily locate over 100 slit at the same time (x3-4 of the usual setting) !

The 2-D spectra. Emission-line detection is 42, 31 of which are HAEs. 31 are the first-time z measurement (among published data: YK actually has more).

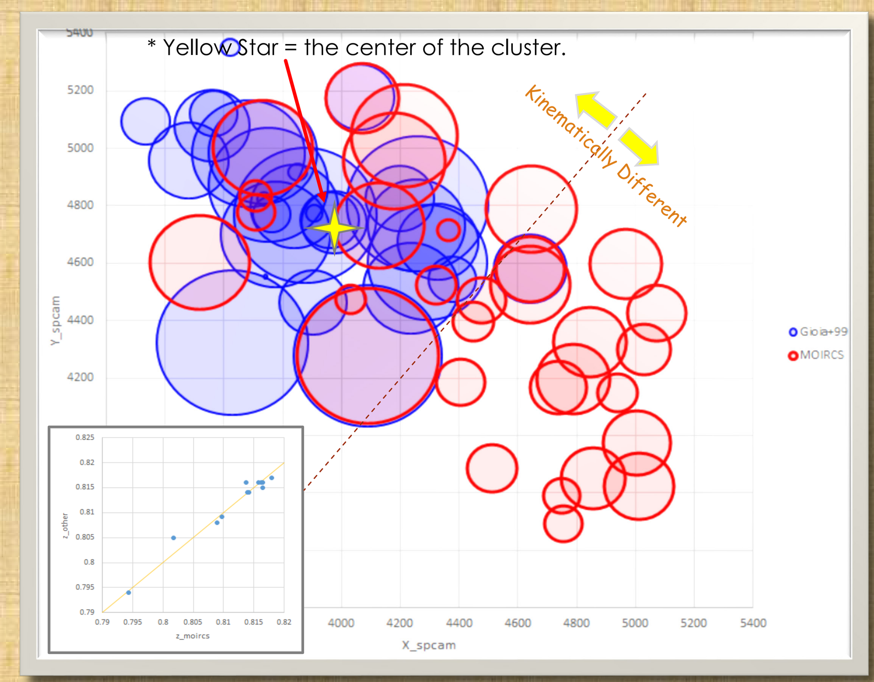
3. Observation and the Data

The Data:
Observing Date: 2016-06-17 27:00-28:00
Total Exposure Time: **2700 sec (45 min.)**
Data taken at the target **EL~30 degrees**, very slight cirrus, and **the ~0.8" seeing**.
Definitely Not a Great Condition!

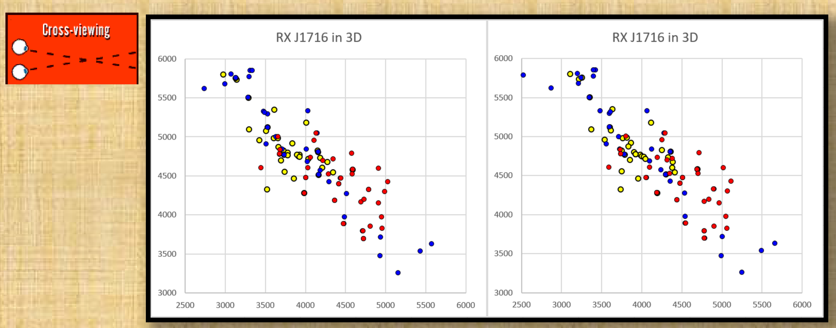
(Left) The measured distribution of the emission line wavelengths of our data (red: ch1, blue: ch2) is compared with the data by Gioia et a l. (1999: grey). Blue and red bar show slight difference of the distribution. But overall they represent that of Gioia+99. The distribution is well matched to the NB transmission window (see inset) for the HAE selection.



4.1. Result-1: 3D Distribution



(Right) The size of bubble represents the redshift (large=close, small=far). The red bubble represents the MOIRCS data, while blue bubble represents the data from Gioia+99.



(Right) 3-D view (cross view) of the cluster galaxy distribution. In the figure, red, yellow, and blue marks each represent the current data, Gioia+99, and YK's unpublished FOCAS data.

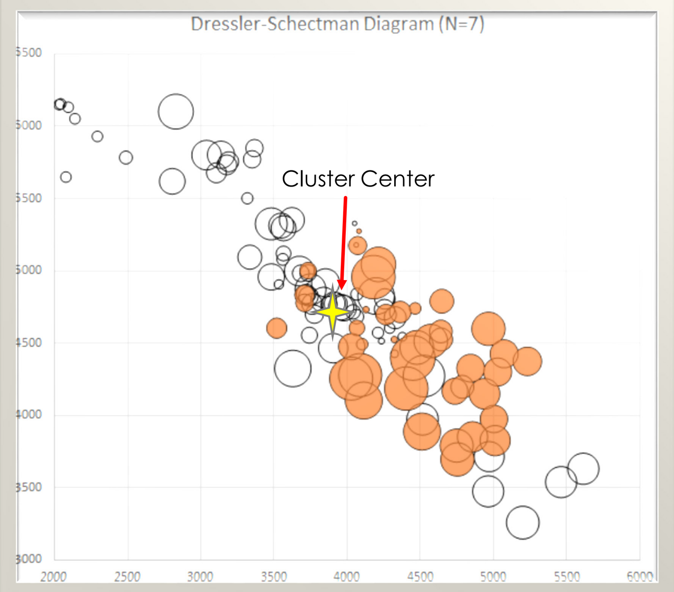
4.2. Result-2: Cluster Substructure

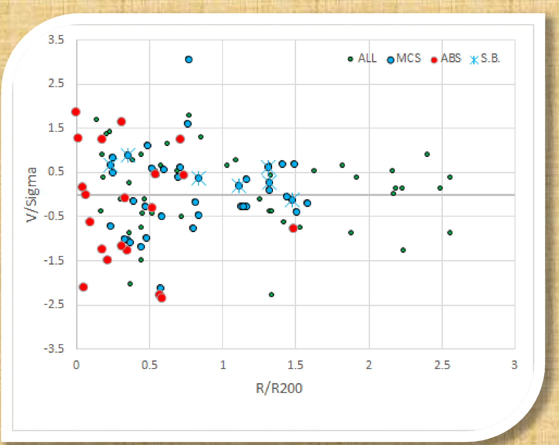
To see the significance of the dynamical substructure, Dressler & Schectman (1986) employed the formula below to express the significance of the substructure of a cluster (δ: hereafter DS86 parameter).

$$\delta^2 = (11/\sigma^2)\left[(\bar{v}_{\mathrm{local}} - \bar{v})^2 + (\sigma_{\mathrm{local}} - \sigma)^2\right].$$

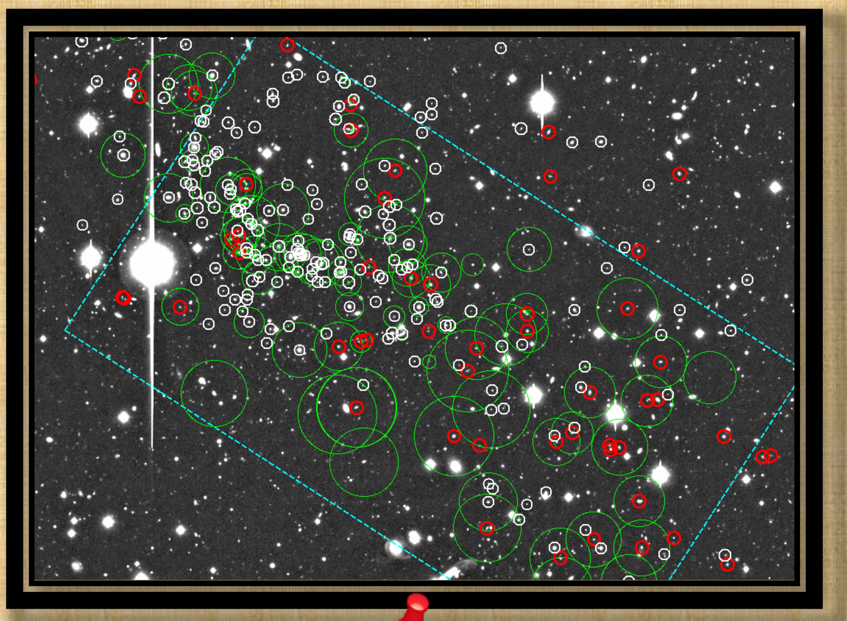
In **the left figure**, the diameter of the bubble represents the DS86 δ value. Orange circles are the data from this work., while the open circles are from Gioia+99 and our FOCAS data (by YK).

The kinematic properties of the area taken by MOIRCS (red) is strikingly different from the cluster center (yellow star), suggesting that the region observed this time is a large subcluster.

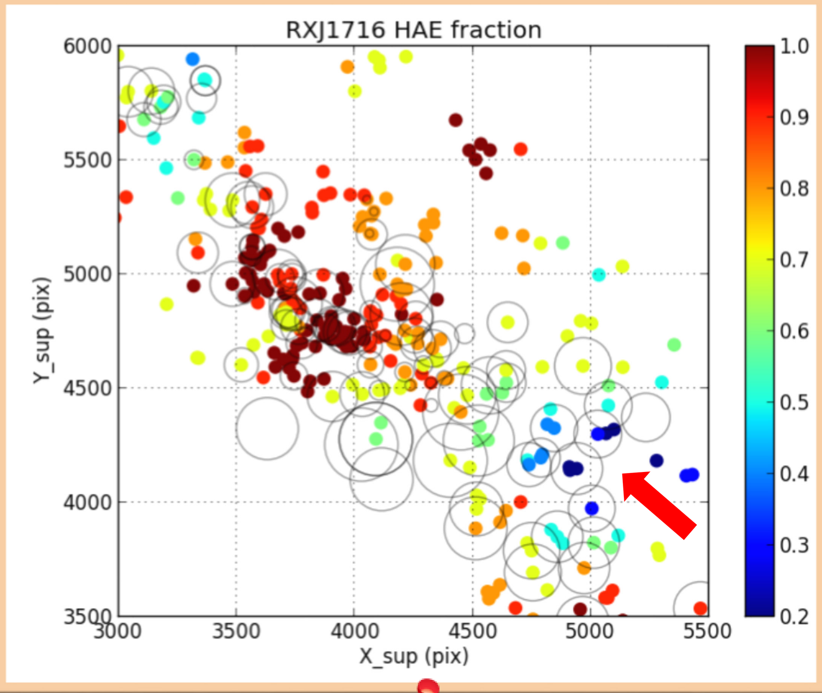




(Right) The phase space diagram. The substructure is not well recognized in the figure. Red = quiescent galaxies from Gioia99, Blue=MOIRCS HAEs, Green=Koyama+. Asterisks are the Hα-brightest-7 HAEs. Distribution is well within the area where the star-forming cluster galaxies are typically seen (0.5 - 2 R/R200, +-1 from V/sigma=0.

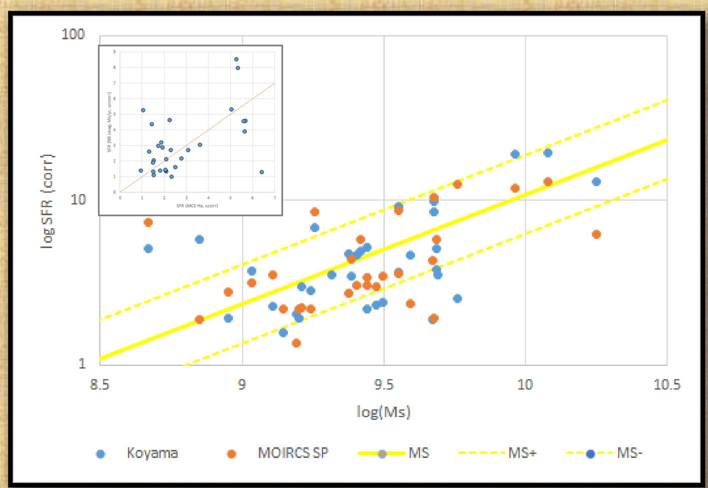


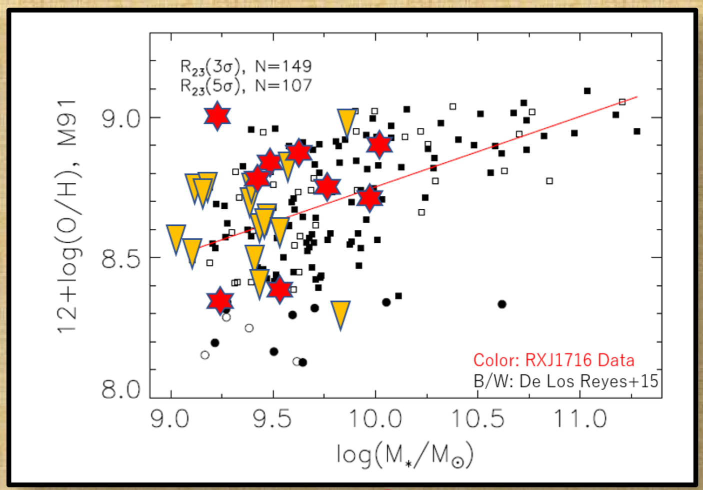
Zoom-up of the observed field. The white and red circles each represents the photo-z selected and the HAE members. The green large circle represents the DS86 δ parameter (larger = more likely substructure). The fraction of HAEs among the photo-z member and the existence of the substructure is evident.



"Non-HAE fraction": for each galaxy, the fraction of HAEs among the adjacent 10 galaxies (include itself) is evaluated and is expressed in the color scale. The overlaid open circle indicates the DS86 δ parameter. Note that for field members the non-HAE fraction is typically 0.6-0.7. There are a pocket of stunningly-high HAE fraction at the lower right area (arrow).

4.3. Result-3: Main Sequence & M-Z Relation





The relation between the Stellar Mass and the Star-formation rate (Main Sequence). The SFR from the NB filter data (blue: YK) and from the current spec data (orange: this work) is compared (inset), finding no systematic bias. Overall the two estimate agrees within uncertainty. Yellow line is for the field value at 0.81 Speargel et al.(2014).

Mass-Metallicity Relation for RXJ 1716. Background is for the field sample at z~0.8 from De Los Reyes et al.(2015). The Metallicity is estimated by the N2 index. Though the current shallow data is shallow and the [NII] is only the upper limit for most of the sample, we can expect a more detection by a few hours' observation.

5. Discussion and Conclusion

Our (only) 45-minutes performance verification data effectively demonstrates the improved performance of MOIRCS. We can **measure the redshift of ALL the known HAEs,** and can add more than 30 **new redshifts** for the cluster. Some of them have the [NII] detection too, enabling us to measure metallicity. The analysis of the dynamical condition of the cluster has revealed **the presence of the sheet-like substructure** at the south-west of the cluster center. There we also find **a "pocket" of the significantly-enhanced star-formation activity**. We will try to measure the metallicity by the N2 index in the future.

With the technique we demonstrated here, we can get the spectra for **a few hundreds objects per a night** for the crowded region. We can study the dynamics, star-formation activity, and even metallicity of the cluster at z~1 based on ~300 spec data in only a night. MOIRCS is the ideal instrument for the follow-up studies of z~1 clusters discovered by the HSC SSP (e.g. Yamamoto et al. HSC-HSC; etc).