Evolutionary Phases of Gas-rich Galaxies in a Galaxy Cluster at z=1.46

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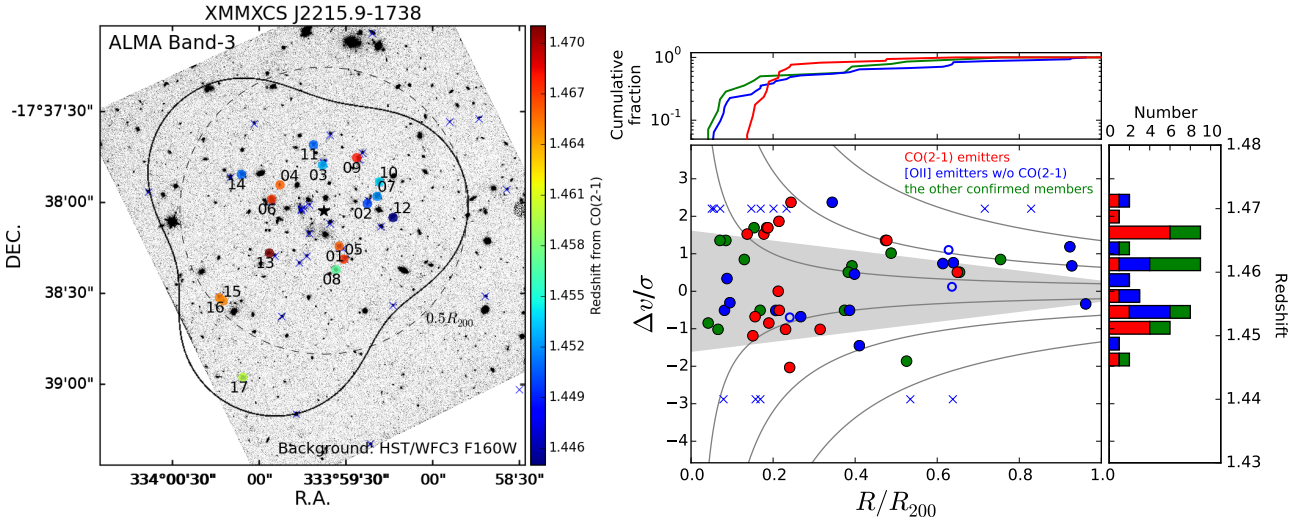
We present **evolutionary phases of gas-rich galaxies** associated with the **massive galaxy cluster, XMMXCS J2215.9-1738, at z = 1.46**. For the first time, we succeed in detecting **emission lines from as many as 17 galaxies in ALMA Band 3 data** within a radius of R_{200} from the cluster center, all of which are identified to be a **CO J=2–1 ($\nu_{\rm rest}$ = 230.538 GHz)** emission line from cluster members at $z \sim 1.46$ by their spectroscopic redshifts and/or the colors of their optical and near-infrared counterparts. Please refer to our paper, **Hayashi et al., 2017, ApJL, 841, L21**, for detailed discussion.

- Spatial distribution (left figure): The CO emission-line galaxies (filled circles) disappear from the very center of the cluster, i.e., $R < 0.14R_{200}$ or 0.11 Mpc. The star-forming [O II] emitters (crosses symbols) tend to be more centrally concentrated than the CO emitters. The redshifts of the CO emitters show a bimodal distribution with the peaks at $z \sim 1.452$ and 1.466 as if they avoid the central redshift of the cluster at $z = 1.457$ (see also right figure). The [O II] emitters are distributed around the cluster redshift. The results suggest that there is a difference in the spatial distributions of galaxy populations between gas-rich galaxies with detection of CO emission lines and the others.

- Phase space diagram (right figure): The gray region shows a virialized area defined by Jaffé et al. (2015). The gray lines show the curves of constant $v \times R$ values (Noble et al. 2016). The CO emitters (red circles) tend to be distributed at the edge of the virialized region or in the region of relatively recent accretion, while most of the [O II] emitters without CO detections (blue symbols) and the other member galaxies that do not have strong [O II] and CO emissions (green symbols) tend to be in the virialized region. Therefore, the results imply that the gas-rich galaxies with CO detections have spent only relatively short times within the cluster, while the other member galaxies with the amount of gas smaller than the detection limit tend to have spent longer times as members of the cluster.



- Implications for the evolution of cluster galaxies: Let us first consider from star-forming galaxies in the general fields at $z \sim 1.5$ or in the outskirts of the cluster. They must have a massive gas reservoir with the gas mass fraction of ~ 0.4 on average according to the previous studies. When the galaxies are accreted onto the cluster, the first mechanisms that can be at work include galaxy mergers or harassment. Then, because this cluster has hot gas showing the extended X-ray emission, during the passage of cluster core, galaxies would suffer from ram-pressure stripping and the gas trapped in the galaxies would be removed from the systems. The main component of the stripped gas is HI gas and the molecular gas is relatively much less affected by the ram-pressure. Therefore, CO(2–1) emission lines can be detected in the galaxies in the accretion region of the phase-space diagram. The CO(2–1) luminosities correspond to $M_{\rm H2}$=(2.0–9.4)$\times 10^{10}$M$_\odot$, under the assumptions of $L'_{\rm CO(2-1)}/L'_{\rm CO(1-0)} = 1$, and $\alpha_{\rm CO}$ =4.36. Since the star-forming member galaxies have the SFRs of several dozens of M$_\odot$ yr^{-1} (the median SFR = 88 M$_\odot$ yr^{-1}), a depletion time scale is estimated to be an order of $\sim 10^9$ yr. This is comparable to the typical dynamical time scale of galaxy clusters. The order estimation suggests that it is possible that a gas reservoir of a galaxy is fully consumed by newly formed stars before it settles into the virialized region, unless new fuel is supplied to the galaxy. If a starvation mechanism is at work in a cluster galaxy, the HI gas is stripped from the reservoir and the supply of fresh gas to the galaxy is terminated. The molecular gas is consumed rapidly by remaining star formation, and star-formation activity is eventually truncated. Therefore, since no CO emission line is detected in the very center of the cluster, our results suggest that the starvation as well as the ram-pressure stripping is likely at work in the galaxies. By the time the galaxies settle in the virialized region of the central region, the star-formation activity would be fully quenched.