disrupted proto-GCs in the early history of the Milky Way. We will also discuss the implications of this result on the formation of the early-type galaxies in general.

[구 GC-14] Stellar populations of the M87 globular cluster system

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Globular clusters (GCs) are one of the excellent tools to trace the assembly history of their host galaxies. Especially, the ages and abundances of the GCs give important clues about the star formation epochs and merging progenitors. We investigate the stellar population of the GCs in M87 based on a stacking analysis using about 900 MMT/Hectospec spectra of the GCs. We measure the ages, [Z/H], and [a/Fe] from the stacked spectra of the GCs within radial bins based on Lick indices. We find clear radial gradients for [Z/H] and [a/Fe] in the GC system. In addition to the radial trends, we investigate the stellar populations of the GC subgroups divided according to colors, radial velocities, and spatial locations. We discuss the formation history of M87 based on the stellar populations of the GCs.

[구 GC-15] How are S0 galaxies formed? A case of the Sombrero galaxy

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S0 galaxies are mostly known to be formed in dense environments from spiral progenitors. Recently, however, a new formation scenario has been suggested that field S0s can be formed from elliptical progenitors. The Sombrero galaxy (M104, NGC 4594) is a massive disk galaxy located in the field environment, and its morphological type has been controversial from Sa to E. Thus, it is an ideal target to test the new scenario. We trace the giant halo of M104 with globular clusters to test this scenario. From the wide images obtained with CFHT/MegaCam, we find a large number of globular clusters in this galaxy. We also confirm their membership by measuring the radial velocities from the spectra obtained with MMT/Hectospec. The color distribution of these globular clusters is bimodal, and blue (metal-poor) globular clusters are more spatially widely spread than red (metal-rich) globular clusters. This indicates that M104 hosts a giant metal-poor halo as well as an inner metal-rich halo. Combining this result with the fact that M104 is unusually massive and brighter than other spiral galaxies, we infer that M104 was indeed a massive elliptical galaxy that had formed a metal-rich halo by gas-rich mergers and a metal-poor halo by gas-poor mergers. In addition, we find young star clusters around the disk of M104, which shows that the disk formed after the spheroidal halos had formed. In conclusion, we suggest that M104 was originally a massive elliptical galaxy and was transformed to a lenticular galaxy by acquiring its disk later.

[구 GC-16] Passive spiral galaxies: a stepping stone to S0s?

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We investigate the stellar population properties of nine passive spiral galaxies in the CALIFA survey. They have NUV−r > 5 and no/weak nebular emission lines in their spectra. They lie in the redshift range of $0.001 < z < 0.021$ and have stellar mass range of $10.2 < \log(M\bigstar/M\odot) < 10.8$. We analyze the stellar populations out to two effective radius, using the best-fitting model to the measured absorption line-strength indices in the Lick/IDS system. We compare the passive spirals with S0s selected in the same mass range. S0s cover a wide range in age, metallicity, and [α/Fe], and stellar populations of the passive spirals are encompassed in the spread of the S0 properties. However, the distribution of passive spirals are skewed toward higher values of metallicity, lower [α/Fe], and younger ages at all radii. These results show that passive spirals are possibly related to S0s in their stellar populations. We infer that the diversity in the stellar populations of S0s may result from different evolutionary pathways of S0 formation, and passive spirals may be one of the possible channels.

[구 GC-17] A deep and High-resolution Study of Ultra-diffuse Galaxies in Distant Massive

Galaxy Clusters

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Ultra-diffuse galaxies (UDGs) are intriguing in the sense that they are much larger than dwarf galaxies but have much lower surface brightness than normal galaxies. To date, UDGs have been found only in the local universe. Taking advantage of deep and high-resolution HST images, we search for UDGs in massive galaxy clusters in the distant universe. In this work, we present our search results of UDGs in three massive clusters of the Hubble Frontier Fields: Abell 2744 (z=0.308), Abell S1063 (z=0.348), and Abell 370 (z=0.375). These clusters are the most distant and massive among the host systems of known UDGs. The color-magnitude diagrams of these clusters show that UDGs are mainly located in the faint end of the red sequence. This means that most UDGs in these clusters consist of old stars. Interestingly, we found a few blue UDGs, which implies that they had recent star formation. The radial number densities of UDGs clearly decrease in the central region of the clusters in contrast to those of bright galaxies which keep rising. This implies that a large fraction of UDGs in the central region were tidally disrupted. These features are consistent with those of UDGs in nearby galaxy clusters. We estimate the total number of UDGs (N(UDG)) in each cluster. The abundance of UDGs shows a tight relation with the virial masses (M_200) of thier host systems: M_200 \propto N(UDG)^(1.01+/-0.05). This slope is found to be very close to one, indicating that efficiency of UDGs does not significantly depend on the host environments. Furthermore, estimation of dynamical masses of UDGs indicates that most UDGs have dwarf-like masses (M_200 < 10^11 M_Sun), but a few UDGs have L*-like masses (M_200 > 10^11 M_Sun). In summary, UDGs in distant massive clusters are found to be similar to those in the local universe.

[구 GC-18] The first detection of intracluster light beyond a redshift of 1

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Not all stars in the Universe are gravitationally bounded to galaxies. Since first discovered in 1951, observations have revealed that a significant fraction of stars fills the space between galaxies in local (low-redshift) galaxy clusters, observed as diffuse intracluster light (ICL).

Theoretical models provide mechanisms for the production of intracluster stars as tidally stripped material or debris generated through numerous galaxy interactions during the hierarchical growth of the galaxy cluster. These mechanisms predict that most intracluster stars in local galaxy clusters are long-accumulated material since z~1.

However, there is no observational evidence to verify this prediction. Here we report observations of abundant ICL for a massive (above 10^{14} solar masses) galaxy cluster at a redshift of z=1.24, when the Universe was 5 billion years old.

We found that more than 10 per cent of the total light of the cluster is contributed by the diffuse ICL out to 110 kpc from the center of the cluster, comparable to 5–20 per cent in local, massive galaxy cluster. Furthermore, we found that the colour of the brightest cluster galaxy located in the core of the cluster is consistent with that of the ICL out to 200 kpc.

Our results demonstrate that the majority of the intracluster stars present in the local Universe, contrary to most previous theoretical and observational studies, were built up during a short period and early (z>1) in the history of the Virgo-like massive galaxy cluster formation, and might be concurrent with the formation of the brightest cluster galaxy.

[구 GC-19] Newly discovered galaxy overdensities and large scale structures at z~1

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Galaxy clusters are the largest gravitationally bound structures in the universe and located in the densest peak of the dark matter. They can constraint cosmologicals model from their dark matter halo distribution and they are good laboratories to study how galaxy evolution varies with their environment. Especially, studies of galaxy clusters at $z \gtrsim 1$ are important because (i) galaxy evolution at z >1 is still controversial (Elbaz et al. 2007; Faloon et al. 2013) and (ii) some studies show that mass of galaxy clusters at z>1 seems to be higher than expected value from the concordance LCDM cosmological model (Kang & Im 2009; Gonzales et al. 2012). In spite of their significance, there have not been many studies of galaxy clusters at $z \gtrsim 1$ because of the lack of