Star Clusters: From the Milky Way to the Early Universe
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Detecting the dark matter halos with star clusters in M31/M33 with PFS, SDSS-V and LAMOST

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Abstract. Since a great number of star stream and substructures near M31/M33 have been discovered in Pan-Andromeda Archaeological Survey (PAndAS) and variations of star stream density may trace the dark matter sub-halos, it is good opportunity to study the dark matter sub-halos with the star streams. Further it has been proved that dozens of halo star clusters have the relations with the star stream. As Prime Focus Spectroscopy (PFS) of the 8.2-m Subaru telescope have the powerful ability ($i \sim 22.3$ mag) to observe ∼2400 objects at a time, it can be used to observe the giant star streams, faint halo star clusters and dwarf galaxies, which provides excellent opportunity to investigate the sub-halos of M31. In addition, we are involved with the Local Volume Mapper (LVM) of SDSS-V program, which may also provide more informations for the star clusters of the Local Group, especially for M31. Finally since we have done series of work with Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), we will continue the spectroscopic observations for more star clusters and giant stars of M31/M33.

Keywords. globular clusters: general - galaxies: formation - galaxies: kinematics and dynamics - galaxies: haloes - galaxies: individual (M31)

1. Detecting the dark matter sub-halos of M31

It is well-known that star clusters play a crucial role to develop our understanding of the formation and evolution of galaxies. More and more observational evidence shows the hierarchical assembly of galaxies through accretion of satellite dwarf galaxies (Searle & Zinn 1978). For M31, the Pan Andromeda Archeological Survey (PAndAS) (McConnachie *et al.* 2009) have discovered large number of star streams and substructures in M31 halo, extended to around 150 kpc from the galaxy center, with deep observations of CFHT ($g = 26.0$ and $i = 24.8$ at signal-to-noise ratio of $S/N = 5$ for the point sources, please see Mackey *et al.* 2019). Recent studies imply that the variations of star stream density could trace the dark matter sub-halos. Carlberg *et al.* (2011) analyzed the density variations in the star stream of M31 in the PAndAS and indicated the existance of sub-halos. Their simulation could show that the amount of substructure increases from the visible dwarf galaxies to thousands of dark matter sub-halos that the LCDM model predicted. More recently, Mackey *et al.* (2019) systematically investigated the relations of the outer halo star clusters and the stellar halos of the M31 at the projected radii 25–150 kpc, with the observational data of PAndAS. The links between the bright substructures in the metal-poor field halo and globular clusters positions have been found in the density map. It also shows that 35%−60% of clusters may have been accreted into the outskirts of M31 along with their host satellite dwarf galaxies. Thus it is important to study the halo star clusters as they record information of galaxy formation and interaction.

Since the dwarf spheroidal (dSph) galaxies are dark matter dominated systems and they contain resolved star members which could be used to measure the line-of-sight velocities, Hayashi & Chiba (2015) have studied the property of the non-spherical density structure dark halos for 12 dSphs in M31 and Milky Way with their revised axisymmetric mass models. They found that the elongated dark halos are generally associated with these galaxies. Thus more dSphs could be observed and investigated in the future work.

2. Our previous work for M31/M33 star clusters

Previously, Fan & Yang (2014) described how to trace the substructures and the interaction of M31–M33 with the associated star clusters via observations of the Xinglong 2.16-m telescope (Fan *et al.* 2016), Lijiang 2.4-m telescope (Fan *et al.* 2015) and the Multiple Mirror Telescope (MMT) 6.5-m telescopes. Their radial velocities can be measured from the spectroscopy and ages, metallicities and masses also can be derived with Lick absorption-line indices or spectroscopic fit with the stellar population synthesis models.

Later, Chen *et al.* (2015) presented a catalog of 356 globular clusters (GCs) and candidates in the field of M31 and M33, with the observations of LAMOST (Zhao *et al.* 2012; Cui *et al.* 2012). The catalogs includes five bona fide GCs and 23 likely GCs, which are distributed at projected distances from the M31 center ranging from 13 to 265 kpc. Chen *et al.* (2016) measured the metallicities, ages, and masses of a sample of 306 massive star clusters with the stellar population synthesis models. The star clusters are selected from the sample of Chen *et al.* (2015), which were observed by LAMOST. It is found that the sample is dominanted by the old population (>1 Gyr) with masses ranging from 10^3 to $10^7 M\odot$. They also found a metallicity gradient of -0.038 ± 0.023 dex kpc^{-1} for the old clusters in the inner disk of M31 (0–30 kpc).

3. The future work with the large observing facilities and projects

In our work, the data and facilities will be used as follows.

The Prime Focus Spectroscopy (PFS) of the Subaru 8.2-m telescope has a field of view of 1.3 deg, with ∼2400 fibers on the spectrograph from 380–1260 nm at one time exposure (Tamura *et al.* 2018). For the study of the near-filed cosmology, it enable us to measure precisely spectroscopic data for not only brighter GCs and dSphs but also fainter ones, and observe faint objects up to $i \sim 22.3$ mag. For exposure time of 3 hours, it could reach $g \sim 23$ mag. In order to place constraints on global dark halo structures of M31/M33, a sufficient number of kinematic data of tracers such as halo globular clusters (GCs), giant stars and dwarf satellite galaxies are required. The special color-color diagram will be used to select the star candidates and star cluster candidates for the PFS survey and perform the follow-up observations. It will help us to better understand the distribution of dark matter by observing the motion of about one million stars in the Milky Way and Andromeda galaxies.

Moreover, NAOC has formally joined the SDSS-V project (Kollmeier *et al.* 2017) since 2018. One program of SDSS-V project is called the "*Local Volume Mapper* (*LVM*)", which will map the local universe with integral field spectral (IFS), including M31 and other nearby galaxies. It covers the area larger than 3,000 deg^2 from 360 to 1000 nm, with the resolution of $R \sim 4000$. At the distance of M31/M33, the spacial resolution is 20 pc. We are focusing on the young star clusters and the HII regions.

Finally since the LAMOST 4-m telescope has 4000 fibers and a field of view of 5 degree, it is powerful for spectroscopic survey. Besides, other 2-m class telescopes in China, i.e., Xinglong 2.16-m telescope, Lijiang 2.4-m telescope also could be used to perform low resolution spectroscopic observations of star clusters of M31 and M33, which can trace a large number of sub-halos. The chemical abundance, the ages, masses as well as the spatial distributions could be obtained by fitting the observational spectra with the stellar population synthesis models.

Further, the recently SAGE (Stellar Abundances and Galactic Evolution) survey (PI: Gang Zhao, see Fan *et al.* 2018; Zheng *et al.* 2018; Zheng *et al.* 2019) covers 12,000 deg^2 of the northern sky with eight intermediate/ narrow bands. So far, the observations of u_{SC}, v_{SAGE}, gri-bands have been almost completed and they can be used for deriving the age, metallicity of the stellar populations of M31/M33, as well as the precise extinctions.

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