OBSERVING REQUEST
Telescope Access Program, China

Year: 2017 **Term:** A **Proposal type:** short-term⋆

Extend SDSS: to the Faint End

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Abstract of Scientific Justification

We propose to use MMT/Hectospec for 2 nights to measure the redshift of$\sim$1700 galaxies satisfying the bivariate limits of r<22 and z<0.3 in the CFHT Large-Area U-band Deep Survey (CLAUDS) fields (DEEP2-3 & XMM-LSS). This study extents the characterization of the galaxy bimodality to much fainter magnitudes. The combined data will be used to estimate the galaxy luminosity function at the faint end and study the low stellar mass ($10^8 M_\odot$) galaxy populations. The 27 AB mag deep CLAUDS image data allows an effective pre-selection of galaxies at z<0.3. With a better classification of galaxy populations using spectroscopic redshifts, the deep u- and r-band morphologies of this sample will be used to understand how a galaxy moves from the blue cloud to the red sequence, and also how a low mass galaxy moves along the red sequence to the massive end. We have been awarded 2.5 nights in TAP2016B and 2 nights in TAP2017A. However, **because of poor weather, we only received 7 hour exposure data at 2016B, much lower than we expected**. The preliminary results show a 76% redshift successful identification rate up to $r\simeq$22 and a very high efficiency in finding low mass galaxies, demonstrating that our technique for finding these objects is successful. From the extrapolated mass function of the local galaxies, red and blue galaxy number ratio is about 1:50 in the $10^{8.5} M_\odot$ mass bin. To obtain a sample of 10 low mass red galaxies, we need to survey a population of at least 500 low mass objects, assuming the ratio will not decrease toward the low mass end. Our 2016B results show that 4 hours worth of data can provide 55 low mass galaxy, thus even if the 2017A observations are 100% successful, we still need 2 nights to complete the project, which requires observing an additional 200 low mass galaxy to find enough red galaxies.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/5	Hectospec			2.	bright	Sep.	Sep-Oct.	yes	yes
or:											
1a										no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: The distance between target and moon must be larger than 40 degree.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	DEEP2-3	23:30:00.00	00:00:00	$r = 22$, galaxy
2	XMM-LSS	02:25:00.00	-04:30:00.0	$r = 22$, galaxy

If this program uses a PI instrument, attach the approval email from the PI to this proposal.

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page.)*

Student's Name	Advisor's Name	Thesis
Xu, Hai	Huang, Jiasheng	yes

Scientific Justification *Describe the overall significance to astronomy and within the proposal's discipline. Limit text to one page, with a limit of two additional pages for figures, captions, and references.*

Motivation Galaxy populations are bimodally distributed in color, morphology, metallicity and so on, which indicates a divergence in the galaxy evolution path (Faber et al. 2007). The observational evidence indicates that galaxies evolve from the blue cloud to the red sequence (Fig. 1). Many previous works focused on galaxy evolution at the massive end. However, small galaxies also play a critical role in understanding the whole picture of galaxy formation. Investigating the local faint galaxies can reveal the bimodally to the low mass end, the origin of the galactic bulge, etc. But because of their intrinsically faintness and low surface brightness, our understanding of the low mass galaxy population is not as complete as the massive galaxies.

Critical for this study is having spectroscopic redshift measurements of low mass galaxies, as the uncertainties of photometric redshifts will lead to a large variation of the stellar masses. Photometric redshift is not reliable for the faint galaxy because of the in-accurate photometry. On the other hand, previous spectroscopic surveys such as GAMA have only been targeted galaxies brighter $r = 19.8$. Thus the local galaxies can be hardly complete to $10^9 \mathrm{M}_\odot$ (the left panel of Fig. 1). Deeper redshift surveys like Deep2 or VVDS would only targeted mainly galaxies at high redshift ($z > 0.5$) or only covered small area. **Thus we proposed a spectroscopic survey that specifically targets the identification of low redshift faint galaxies.**

We were awarded 2.5 + 2 nights in TAP2016B and TAP2017A for this local faint galaxy survey project. Together with the previous redshift survey data, it is expected to build a galaxy sample ($z < 0.3, r < 22$) containing about 10000 galaxies in 4 degree square. However, **we were only able to obtain 7 hours exposure time data rather than 2.5 nights in 2016B** (4 hours on XMM-LSS, 3 hours on deep2-3), yielding a highly incomplete survey. Finally, about 60% targets in XMM-LSS have spec z together with the previous redshift survey project (VVDS, VIPERS). But **the spec-z coverage for deep2-3 is less than 30%**.

The preliminary results have demonstrated the success of our survey strategy and have shown remarkable potential to study the low mass galaxy population. Most of the targets are $z < 0.3$ galaxies (Fig. 2). The redshift identification successful rate is about 76%. Fig. 3 shows two examples of $M_r \simeq -16$ galaxy in our survey. The blue galaxy's redshift is easily identified because of the emission lines. The right panel of Fig. 3 is an example of clear absorption line galaxy about $r = 20$. So we conclude our survey can reach to $r = 22$ for the blue galaxies and $r = 21$ for the red ones. Fig. 4 is our results (color dots) compared with the SDSS results (black dots). The galaxies we observed are much fainter than SDSS in all redshift bins. The color mass diagram also shows a high efficiency in discovering the low mass galaxies. The 4 hours XMM-LSS data yields 55 low mass ($< 10^9 \mathrm{M}_\odot$) galaxies out of 921 galaxies. Moreover, even the $10^{9-10} M_\odot$ galaxies we observed are located at higher redshifts than those sampled by SDSS, thus we can study the evolution of galaxy properties like metallicity in different redshift bins for the same stellar mass.

Finding enough low mass galaxies to characterise the bimodality has proved to be difficult, because of the paucity of low mass red galaxies. If we extrapolate the blue and red galaxy ratio from the GAMA stellar mass function (Fig. 1), there would be about 2% red galaxy in the $10^{8.5} M_\odot$ bin (Kelvin et al. 2014). Thus **10 low mass red galaxies would require obtaining a sample of 8000 local faint galaxies**. So the 4.5 MMT/Hectospec nights we have been awarded could be expected to find 10 low mass red galaxies. However, **even if the 2017A observation comes to a great success, we would still need 2 MMT/Hectospec night to get enough amount of low mass galaxies.**

We are proposing to complete the redshift survey in the DEEP2-3 and XMM-LSS fields. We will study the $M_* \sim 10^8 M_\odot$ galaxy population. The scientific goals are: (1) the faint part of the u-band luminosity function; (2) the low mass galaxy bimodality properties; (3) the bulge formation at the low mass end of red sequence using the deep u-band image. Two MMT/Hectospec nights will allow us to **complete** this project.

A critical component to this study is the use of the deep u band CLAUDS image data (27 AB mag), which allows selecting objects based on their color-color properties (Fig. 2) and guarantee the $r < 22$ selected sample is unbiased to $u - r < 5$ (Fig. 4). The u-band images will also be used to identify the residual star formation and the morphologies (bulges, disks) of low mass galaxies up to the resolution limit of the ground-based imaging ($\sim$ 1").

Target Selection Fig. 2 plots our target selection method, which has been proved to be robust in 2016B.

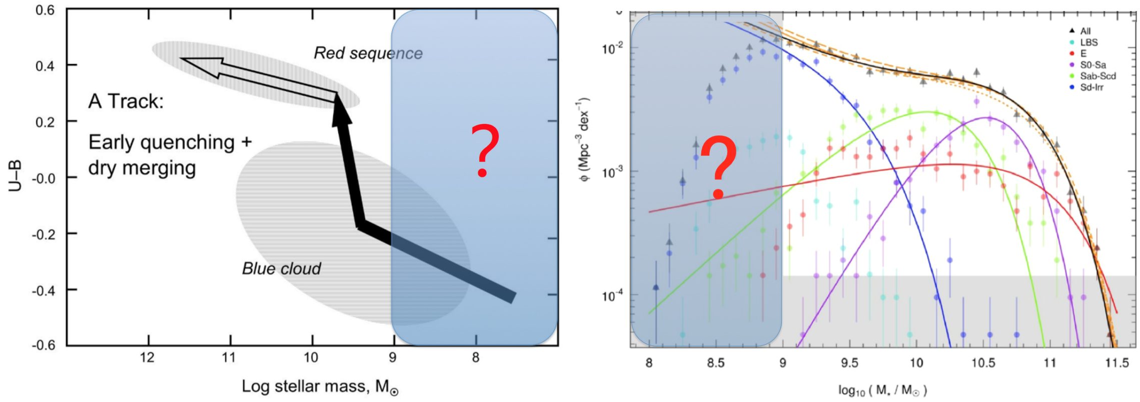

Figure 1: Galaxy evolution scenarios for red galaxy formation (Faber et al. 2007). Galaxy mergers might account for the formation of massive red galaxies. However, the origin of faint red galaxies is still unclear. This proposal will focus on the galaxy populations at the low mass end ($\sim 10^8 M_\odot$) and by targetting specifically the faint red galaxies we will explore the physical processes at work in their formation. A $10^8 M_\odot$ galaxy stellar mass corresponds to about$M_r \simeq -16$ (Based on the COSMOS catalog by Muzzin et al. 2013.), which is about r band 20 to 22 AB magnitudes for redshifts less than 0.3. **Right panel:**Stellar mass function from GAMA project (Kelvin et al. 2014). The red and blue galaxy number ratio is about 1:50 at about $10^{8.5} M_\odot$ stellar mass bin if we extrapolate the relation from the massive end.

References

Faber, S., M., et al. 2007, ApJ, 665, 265;

Huang, J. et al. 2013, ApJ, 766, 21 ;

Muzzin, A. et al. 2013, ApJS, 206, 8;

Kelvin, J et al. 2014, MNRAS, 444, 1647

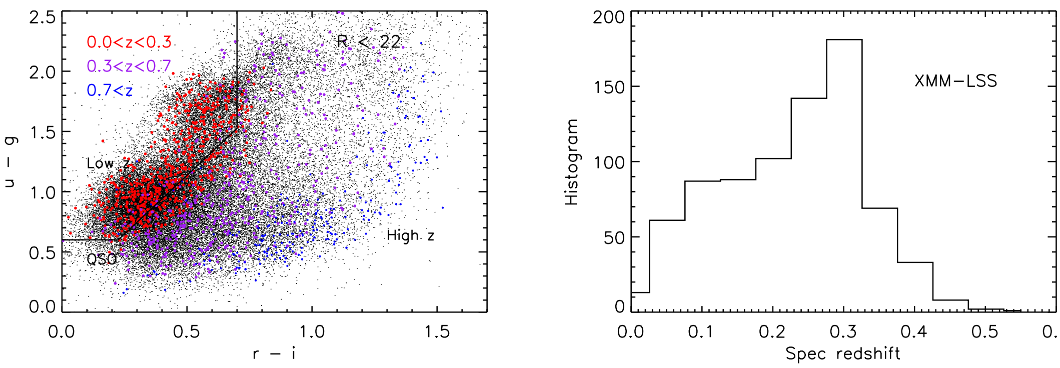

Figure 2: **Left panel**:Illustration for our target selection method: color-color diagram for galaxies with spectroscopic redshifts in the XMM-LSS field with magnitudes $r < 22$. Red dots in the diagram are galaxies at $z < 0.3$, and both purple and blue dots are galaxies at $z > 0.3$. The dashed lines enclose the region of parameter space where galaxies with $z < 0.3$ are found. **right panel**: Redshift distribution of our TAP2016B MMT/Hectospec data. The redshift successful identification rate for $r \simeq 22$ is 76%.

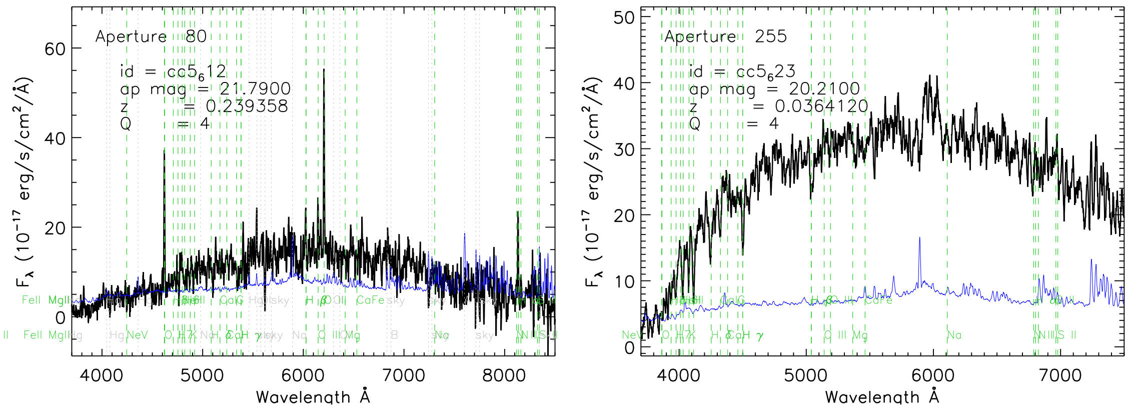

Figure 3: Example of MMT/Hectospec spectra obtained by TAP2016B for both faint red and blue galaxies with an exposure time of 60 min. The black lines are the spectrum and the thin blue lines are the sky lines. For the galaxies with redshifts $z < 0.3$, optical emission lines from [OII] to Hα are all present in the spectral wavelength range and make it easy for the redshift identification. The 60 min exposure time with MMT/Hectospec permits to identify blue galaxies up to $R = 22$ and red galaxies up to $R = 21$.

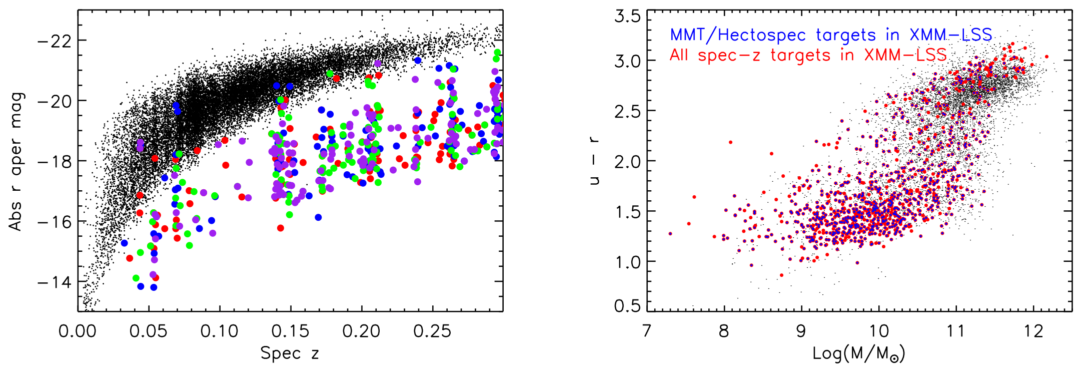

Figure 4: Preliminary results from our TAP2016B XMM-LSS field data. The black dots are 20000 SDSS galaxies while the color dots are the data we obtained from MMT. **Left panel:** The absolute magnitude distribution along the redshift. Different color stands for the four observation date. Our survey reaches about 4 magnitudes fainter than SDSS. At a given mass, SDSS and our survey contain galaxies at different redshifts, which allows us to investigate the evolution undergone by the low mass galaxies. **Right panel:** The color mass diagram of all the XMM-LSS spec-z targets compared to SDSS. The blue dots are the galaxies we obtained from 2016B. Our survey is very efficient at finding low mass galaxies, facilitating us to study the low mass galaxy population. Based on the mass function and this result, we conclude that this project needs 2 more MMT/Hectospec nights to obtain about 10 low mass red galaxies.

Experimental Design *Describe your overall observational program design. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? Include information such as why the specific targets were selected, the sample size, the analysis plan, instrument choice, etc. Also briefly explain what expertise or effort each team member will contribute to the project. Describe any necessary non-standard calibrations (**up to one page**).*

Survey strategy.

Our sample is selected with $r < 22$ within two of the CLAUDS fields: XMM-LSS and deep2-3. The photometry data come from the newly released HSC survey data including the g, r, i, z, y image and catalog, deep to about 25.5 AB mag and the CLAUDS deep u band data (27 AB mag). These data can provide us reliable photometry for the targets $r < 22$. The ultra-deep u band image can guarantee the r band selected sample unbiased to the $u-r < 5$, which is rarely red color for the local universe. **Thus the u band luminosity function derived from the observation data will not biased only to the blue galaxies.**

These two fields also have been covered by several previous spectroscopy redshifts projects, e.g., VVDS, VIPERS, PRIMUS etc. We will exclude all sources with reliable spectroscopic redshifts to increase our survey efficiency. The total number of selected objects will be $\sim$1700, permitting a significant improvement in the statistics for galaxies below $z = 0.3$. In this run we are proposing to observe two other available fields: Deep2-3 and XMM-LSS. The spectra will cover a wavelength range from about 4000Å to 9000Å at 6Å resolution. For most targets this includes typical optical lines used for redshift identification and characterisation of spectral properties. Observations of F stars selected from the SDSS will allow flux calibrating the spectra. The data will be reduced with an already existing pipeline, so that the statistical analyses will be initiated as soon as the observations are completed. The spectra will also allow classifying the objects between quiescent, star forming and identifying the presence of AGN.

The rank of guide stars and F stars will be set as 0 and 2 individually. The faint red galaxies ($20.5 < r < 22$) will appear twice in the configuration file and be ranked as 1. The min and max number of the rank 2 sources are set as 10. This method will guarantee all the faint red galaxies have twice the exposure time than that of brighter sources, as well as enough F stars for each configuration. We have fully tested this method when we prepared the 2016B observations

Data Plan.

Cheng Cheng, Jiasheng Huang and Hai Xu will come to MMT to perform the observations. Cheng has already reduced MMT/Hectospec data and carried out emission lines measurement using data we obtained in 2016B.

Technical Justification *Justify the instrument configuration, the required signal-to-noise, exposure times. All requests for dark or gray time must include a detailed justification for the requested lunar phase. Specify the total time needed, and (if applicable) the minimum requested time (**up to one page**).*

Exposure times.

We have obtained a 76% redshift successful identification rate from the 2016B, which is well enough to this study.

After excluding sources with already existing spectroscopy, the number density of our targets is about 850 per deg^2. There are in total 1700 galaxies for the two fields. We intend to double the number of faint red galaxies with high confidence spectroscopy. To enable this, we will give exposure times twice as long for red galaxies than for blue ones. We will do this by placing red galaxies in two configurations while blue galaxies will be in only one. As the number ratio of the $u - g$ blue and red galaxy is about 4, this will equivalent to 2100 targets with 1.5 hr exposure time each.

Based on our previous observations, the Hectospec has 1 deg^2 FOV with 300 fibers, which allows obtaining 220+ sources per Hectospec setup. So that 9 configurations will be required. Assuming an overhead of about 30 minutes per field, a total of 9 configurations $\times$ (90 minutes integration + 30 minutes overhead) = 18 hours total are being requested. This corresponds to about 2 nights in October.

Total Request. Most of our sources are faint in r band (~ 22), but since the emission lines are bright enough for the redshift identification and based on our experiences, we can accept bright - grey nights; To minimize the effect of large airmass, the best time for the observations is in October and acceptable times are between October and November.

TAP Usage and Context *The TAC needs to understand the scope of this project — (1) How many total TAP nights have already been allocated for this project (if any), how many are you requesting this semester, including any CFHT time from a linked proposal, and if more time will be necessary in future semesters, how many nights will you need to complete the project (best guess)?; (2) If a observing for this project comes from, or is being requested from, resources outside TAP, tell us about that observing, and how the TAP part fits in. (3) List any time from partner institutions, going toward (or being requested for) this project from TAP partners (e.g., Arizona, UC, Caltech, CFH, etc.), and who is the lead investigator on that time; (3) If you are collaborating with people who have access to other telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how TAP time and your participation fit in. 4) Please explain any ways in which this program would help fulfill the goals of the Telescope Access Program. (**up to one page**)*

There are currently 2.5 + 2 MMT nights from TAP times allocated to this project (2016B PI: Cheng Cheng; PROPID: 21; TITLE: *Extend SDSS: to the Faint End*; 2017A PI: Cheng Cheng; PROPID: 27; TITLE: *Extend SDSS: to the Faint End*). The observations will take place in 2017 Apr. 21-22, after the proposals for 2017B are submitted. We have obtained 1 hour data in Feb, obtaining a redshift identification successful rate about 90%.

We are requesting 2 nights from TAP on the MMT in 2017B because of the shortage observation time in the 2016B. This will be sufficient to **complete** the project. This program will increase the expertise of Chinese astronomers in multi-object spectroscopy, and will train one undergraduate student in observing. The collaborators on this team are from NAOC, Steward Observatory, THU and STJU, and all the data reduction and analysis will also be done in China.

Previous Use of TAP Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through TAP during the past 2 years, together with the amount of time awarded (e.g. 2 nights, 6 hours), the percentage of this that was useful (e.g. 80), and text describing the current status of any data obtained. Cite publications that were based (to a significant extent) on data obtained at TAP facilities. Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

⋆ PI Cheng Cheng received 4.5 MMT/Hectospec nights from TAP, and has learnt the Hectospec observation and data reduction process from Christopher Willmer in Steward Observatory.

Co-I Jiasheng Huang received 7 MMT/Hectospec nights from Harvard TAC, and has a lot experience in Hectospec observation and data reduction.

Co-I Christopher Willmer has wide experience in the preparation, execution and reduction of MMT/Hectospec data, having been awarded several nights of Hectospec observations by the University of Arizona TAC.