Subaru Telescope
National Astronomical Observatory of Japan

Semester	S02B
Proposal ID	S02B- 101
Received	/ /

Application Form for Telescope Time

1. Title of Proposal

EIS Deep 3a Survey (Part 1) - Sampling of 500 Ellipticals at $z > 1$

2. Principal Investigator

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3. Scientific Category

- [ ] Solar System
- [ ] Compact Objects and SNe
- [ ] Nearby Galaxies
- [ ] Clusters of Galaxies
- [ ] Large-Scale Structure
- [ ] Normal Stars
- [ ] Milky Way
- [ ] Starburst Galaxies
- [ ] Gravitational Lenses
- [ ] Cosmological Parameters
- [ ] Extrasolar Planets
- [ ] Local Group
- [ ] AGN and QSO Activity
- [ ] High-z Galaxies
- [ ] Miscellaneous
- [ ] Star and Planet Formation
- [ ] ISM
- [ ] QSO Absorption Lines and IGM
- [*] Deep Surveys

4. Abstract *(approximately 200 words)*

We propose to establish the luminosity function of early-type galaxies in the uncharted region above $z = 1$, by supplementing existing deep EIS (ESO Imaging Survey) fields with deep optical imaging by using the Subaru Suprim-Cam, so that the redshifted 4000Å break is straddled with complete R, I, z', J, and K imagings. With continuous coverage of the spectrum across the break we will obtain reliable photometric redshifts to $z \simeq 2$ for E/S0's, thus extending ongoing spectroscopic surveys to the range $20 \leq K \leq 22$ where spectroscopy cannot be currently done. This survey is cheap, building upon the EIS and using only gray time, producing an estimated 500 early-type galaxies at $z > 1$, and surpassing all other efforts world-wide to answer the question of whether hierarchical evolution is resoponsible for the formation of E/S0 galaxies. The sensitibity of Suprim-Cam CCDs permits deeping imaging in z' band, which is critical for locating the sharp 4000Å break at high redshift.

5. Co-Investigators

Name	Institute	Name	Institute
C. Ikuta	Nottingham Univ. (UK)	T. Broadhurst	ESO
Y. Yamada	Univ. of Tokyo	A. Renzini	ESO
K. Ohta	Kyoto Univ.	A. Cimatti	Florence Univ. (Italy)
N. Tamura	Durham Univ. (UK)		
M. Akiyama	NAO		

6. List of Applicants' Related Publications *(last 5 years)*

I.Tanaka, T.Yamada, A.Aragon-Salamanca, T.Kodama, K.Ohta, N.Arimoto, "A Rich Cluster of Galaxies near the Quaser B2 1335+28 at $z = 1.1$: Color Distribution and Star Formation Properties", 2000, ApJ, 528, 123

A.Vazdekis, N.Arimoto, "A Robust Age Indicator of Old Stellar Populations", 1999, ApJ, 525, 144

T.Kodama, N.Arimoto, A.Barger, A.Aragon-Salamanca, "Evolution of the Colour-Magnitude Relation of Early-Type Galaxies in Distant Clusters", 1998, A&A, 334, 99

T.Yamada, I.Tanaka, A.Aragon-Salamanca, T.Kodama, K.Ohta, N.Arimoto, "Clustering of Red Galaxies near the Radio-loud Quaser 1335+2834 at $z = 1.1$", 1997, ApJ, 487, 125

T.Kodama, N.Arimoto, "Origin of the Colour-Magnitude Relation of Elliptical Galaxies", 1997, A&A, 320, 41

T.Broadhurst, R.J.Bouwens, "Young Red Spheroidal Galaxies in the Hubble Deep Fields: Evidence for a Truncated IMF at $\sim 2M_\odot$ and a Constant Specе Density to $z \sim 2$", 2000, ApJ, 530, 53

A.Cimatti et al., "New Clues on the Nature of Extremely Red Galaxies", 1999, A&A, 352, 45

Pages 2 and 3 will be used for technical review by observatory staff. Please provide here clear and detailed information for these purposes. The entire proposal including scientific justification will be passed to support astronomers for preparation of observations upon acceptance.

7. Title of Proposal

EIS Deep 3a Survey (Part 1) - Sampling of 500 Ellipticals at $z > 1$

8. Observing Run

Instrument	# Nights	Moon	Preferred Dates	Acceptable Dates	Observing Modes
Suprime-Cam	3	Gray/Dark	late March 2003	March 2003	Imaging

Total Requested Number of Nights: 3   Minimum Acceptable Number of Nights: 3

9. List of Targets *(Use an additional sheet if this space is not sufficient)*

☐ I do **not** want observatory staff to see the target names for the technical review.

Target Name	RA	Dec	Equinox	Magnitude (Band)
EIS Deep 3a	11 24 50	−21 42 00	J2000.0	$R = 27.3$, $I = 26.2$, $z' = 25.5$

10. Scheduling Requirements

Dark or gray nights from late February to late March

11. Instrument Requirements

Johnson-Cousin filters R and I, SDSS filter z'

12. Experience

N.Arimoto and C.Ikuta have 5 nights experience with Suprime-Cam observation. K.Ohta and N.Tamura have also several nights Suprime-Cam experience. T.Broadhurst and A.Cimatti have numerous experience with HST and VLT observations. The reduction of photometry and calculation of photometric redshifts have been carried out by many in this team.

13. Backup Proposal in Poor Conditions *(specify object names)*

Galactic open and globular clusters

Proposal ID S02B–101

14. Observing Method and Technical Details

Describe your proposed observations. Please explicitly state the instrument configuration (filters, grisms, slit width, readout mode), intended exposure time, and required sensitivity to achieve your scientific goals. If you propose AO observations, please describe the nature of the target (extended or point source) as well as the guide star properties (separation, brightness, acceptable minimum Strehl ratio). Please read the Call for Proposals carefully.

Exposure Time Calculation: We can determine the required depth for detecting L* E/S0 galaxies at $z > 1$ quite accurately. Taking ellipticals in the HDF as a guide, at $K = 21$ there is approximately 1.2 E/S0 galaxy per square arcmin (Broadhurst & Bouwens 2000, ApJ, 530, 53L). Thus we expect about 500 E/S0's in our field. We estimate that $K = 21.9$ is deep enough to provide many E/S0 galaxies at $z > 1$ (Fig.1). It is fortunate that $K = 21$ is comfortably within the limit of the EIS wide field IR imaging data already taken in February 2000 and we do not need to supplement this further in the IR. Since we know the form of the SED and we have chosen $K = 21.9$, we can determine the limiting magnitudes in the other bands for this work: $R = 27.6$, $I = 26.5$, $z' = 25.8$; for $z = 2$. Taking the exposure time calculator for the Suprim-Cam, we find that for 5σ detection of an E/S0 spectrum galaxy in Subaru median seeing of 0.8″ requires for the desired maximum redshift of $z = 2$: $R = 27.6$, $t = 6.3$ hrs, $I = 26.5$, $t = 4.5$ hrs, and $z' = 25.8$, $t = 13.0$ hrs (including the readout time; grey 0.8″, aperture 1.0″), therefore we require 23.8 hrs in total. However the EIS **deep 3a** field is observable 6 hours per night, we have plan to observe R(6.3 hrs), I(4.5 hrs) and z'(7.0 hrs) in this S02B semester (March), and propose additional 1 night for the rest exposure of z'(6.0 hrs) in S03A semester (April). Thus, thanks to a very large field of view of Suprim-Cam, he required observing time to obtain such a large sample of ellipticals ith accurate photometric redshifts is in fact not outrageous, which seems almost a bargain.

15. Proposal Status

☐ The proposed observations are a continuation of previous observations or previously unsuccessful observations with Proposal ID ______ and Title ______.

16. Previous Use of Subaru Telescope

Please describe your previous use (in last 3 years) of Subaru Telescope and the status of data reduction/analysis and publication.

Year/Month	Proposal ID	PI name	Status: data reduction/analysis	Status: publication
2001/03	S00-009	N. ARIMOTO	data in reduction	in preparation to PASJ
2001/06	S01A-067	N. ARIMOTO	no data due to bad weather	none
2001/11	S01B-091	N. ARIMOTO	data in reduction	in preparation
2002/04	S02A-001	M. G. LEE	waiting data	
2002/04	S02A-053	N. ARIMOTO	waiting data	

17. Thesis Work

☐ This proposal is linked to the thesis preparation of ______

18. Subaru Open Use Intensive Programs

☐ This is a proposal for Intensive Programs.

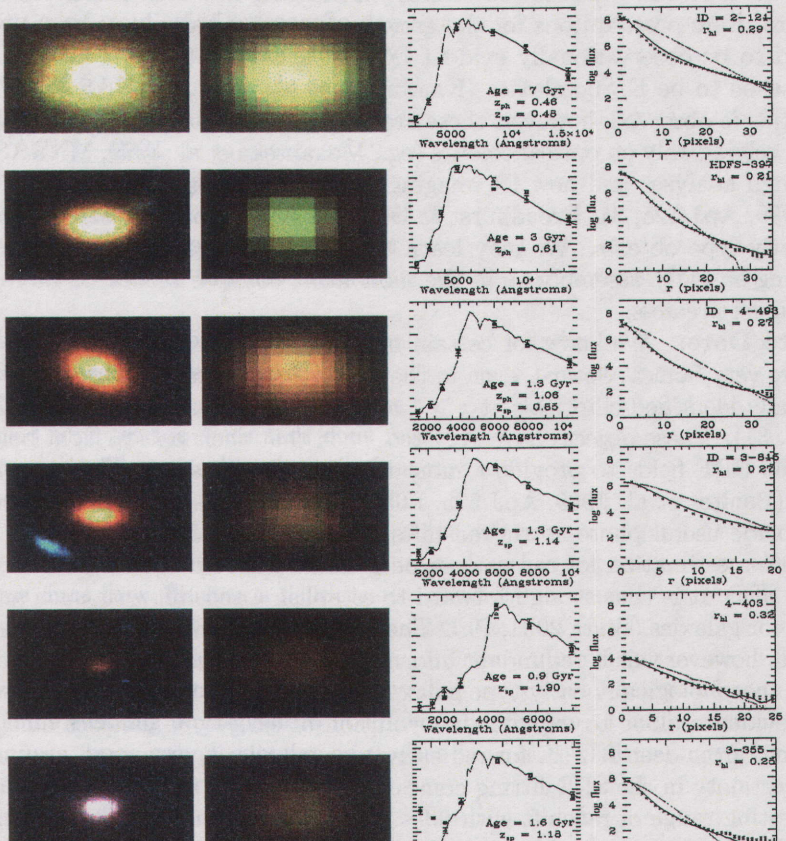
Scientific Rationale: Despite great observational advances we are still largely in the dark regarding the early history of E/S0 galaxies. Until recently it was safe to assume that this class of galaxy collapsed at high redshift and after a short period of vigorous star-formation passively evolved to become the extinct entities we see all around us today (e.g., Arimoto & Yoshii 1987, A&A 173, 23). However, the morphology of some local ellipticals has led to the conclusion that ellipticals encounter regular low-level interaction with dwarf galaxies and the notion that elliptical galaxies form when pairs of disk galaxies collide has been widely entertained. On the other hand, the uniformity of elliptical galaxy properties (in both the field and clusters) argues that the bulk of stars formed at a very early epoch (e.g., Bower, Lucey & Ellis 1992, MNRAS 254, 601; Kodama et al. 1998, A&A 334, 99). Recent photometric studies suggest that late gas rich merging is not widespread (Silva & Bothun 1998, AJ 116, 2793). While a fraction of early-type galaxies do contain a surprising excess of A stars (post starburst galaxies) and typically a small amount of gas and dust, in general chemical composition is consistent with a simply old "closed box" of stars evolving from gas. The predominance of α-elements relative to solar is taken to imply simply that the duration of early star-formation was limited to ~ 1 Gyrs, so that it ceased before the later forming SNIa Iron-element enrichment could be incorporated into stars (Renzini 1996, IASU Col.145, 77; Arimoto et al. 1997, ApJ 477, 128). In addition, the lack of a large low metallicity stellar contribution is easily ascribed to an early pre-enrichment of the gas from which the galaxy formed (Worthey et al. 1996, AJ 112, 1975).

Hierarchical and Spectral Evolution: A renewed interest in merging has been prompted by recent models of the hierarchical growth of structure. Here prescriptions for the growth of massive halos have been proposed and the process of merging has been predicted to be observationally evident by $z \sim 1$, manifested as a marked reduction in the space density of merger products– taken to be E/S0 galaxies (Kauffmann et al. 1997, MNRAS 286, 795). Claims have been advanced that indeed a reduction is observed, however, these are largely optimistic, based on small samples with a heavy correction for selection effects, relying only on optical colours (eg., Menanteau et al. 1999, MNRAS 309, 208). At variance with these claim, more thorough analyses and new IR imaging in the HST deep fields indicate no such decline all the way to $z \sim 1$ (Shade et al. 1999, ApJ 525, 31; Broadhurst & Bouwens 2000, ApJ 530, 53). In the region beyond $z = 1$, something must happen to early-type objects. We may learn that they become blue and the number density remains unchanged, basically supporting an early assembly as in the monolithic collapse model, or there may be a reduction in space density as the merger-model predicts.

Results of Deep Imaging to Date: We know for certain now that there are intrinsically red early-type galaxies at high redshift and that these are very faint in optical, even in the HDF (Broadhurst & Bouwens 2000, ApJ 530, L53). The only examples of morphologically identified ellipticals at $z > 1$ are handfuls detected in deep NICMOS images with HST (Benitez et al. 1999, ApJ 527, 31). These objects have very red, such that their optical light below the 4000 Å break is too poorly detected even in the HDF fields to provide a morphological classification. The morphology is only obtained from the deep NICMOS data (Benitez et al. 1999, ApJ 515, L65). These objects have spectral energy distributions with fluxes in UBVRIJHK and provide useful photometric redshifts, thanks to the distinctive break in their spectra. Fig.1 clearly demonstrates that photo-z estimation for red early-type galaxies is not problematic with optical-IR photometry, given the peaked shape of the SED. It is thus straightforward to establish a redshift with such an SED by using a newly built spectral evolution model for galaxies (Ikuta 2001, PhD Thesis, Univ. Tokyo). We will not have detailed morphology measurements from the ground, however this is redundant information because we know that the correspondence between a red early type spectrum and morphologically early type galaxy is virtually exact at all redshifts so far measured. Hence we may rely on photometric evidence alone to explore the evolution of early-type galaxies efficiently. The accuracy of photometric redshifts determined from deep RIz'JK for red early-type galaxies is very good, around ~ 10 % for $z < 1$. At higher redshift, the major uncertainty in the SED fitting comes for objects where the 4000 Å break occurs between the I and J bands, i.e., in the interesting range of redshift with $0.9 < z < 1.4$, because in all these deep field the intermediate z'-band is missing. Also, existing R and I-bands data are not deep enough to allow us to study galaxies at $z > 2$. These are easily remedied with the Suprim-Cam. The Suprim-Cam can produce deep accurate R, I, and z'-band data. Note that determining spectroscopic redshifts is very time consuming for $K > 19$, even if very important (Cimatti et al. 1999, A&A 352, 45), and becomes virtually un-feasible for E/S0 galaxies fainter than $K \sim 20$. So, the photometric option is by far the most efficient means of exploring down to $K = 21.6$ (EIS Deep 3a limiting magnitude) in a statistical survey such as this, where the mean redshift of red elliptical galaxies is predicted to lie at $z \sim 2$, as shown in Fig.2.

ERO's and High-z QSO's: The term ERO has until recently been taken to mean objects with large optical-IR colour ($R-K > 5.5-6$) but now that the bands in between have been measured for such red objects and morphology established from HDF and NICMOS, it seems that the majority of such red objects are garden variety of E/S0 galaxies at $z > 1$ with some minor populations of dusty star-bursts such as HR10. In the large sample we are proposing here, we will of course detect the more exotic ERO's including luminosity dropout galaxies and QSO's at $z > 4$, and potentially further examples of $z > 5$ QSO's like the recently discovered example at $z = 5.5$ (Stern et al. 2000, ApJ 533, 75). Dusty red objects and late-type stars will be present at a low level and will be readily distinguished from E/S0's by their decline flux towards to blue. The late-type stars will be separated with complete confidence using R-J, J-K colours, even rare L stars and WD with anomalous I-J, which are needless to say very interesting objects by themselves!

Our Aims: The purpose of this proposal is to accurately measure the space density of ordinary early-type galaxies (global) out to $z \sim 2$ and to track the steady rate of passive evolution into largely uncharted territory from the general evolution of the SED. This is achievable simply with Suprim-Cam photometry in R, I, z' with the Subaru, to complement existing data in J, K taken with SOFI in the deep EIS (ESO Imaging Survey) field, **deep 3a**. The size of the EIS deep 3a is $32' \times 32'$ and the area observed with SOFI is $16' \times 16'$, thus a single shot with the Suprim-Cam ($34' \times 27'$) would cover the entire field we wish to observe. For the first time the data obtained in our survey will definitively measure the evolution of the E/S0 luminosity function to $z > 1$ for comparison with local samples (eg., Bromley et al. 1997, ApJ 475, 414). With accurate RIz'JK photometry to the limits proposed below (equivalent to K=21.6) we can track the luminosity function of red early-type SED galaxies to $z \simeq 2$. The EIS survey already provides the necessary IR data in J and K, so only R, I, and z' bands are required for our purpose. In the next couple of years, there is no plan for the Subaru to provide its own deep IR images as wide as the EIS deep 3a, while it would take too long with FORS on the VLT which has only a 7 arcmin field to get the optical images we seek with the Subaru. Also we need good seeing to reject red stars and to fit the profiles of the galaxies we detect to really restrict the red galaxies to EROs – so this also favours the Subaru since we would be much more likely to get good seeing in a reasonable amount of observing time. A similar proposal, Subaru/XMM-Newton Deep Survey (SXDS) in optical, is currently conducted as one of the key long standing projects of the NAO Subaru Observatory. SXDS aims to reach down B=29, R=28, I=27, and z'=26.5 with a FOV of 1 deg^2 (15 nights). Admittedly, SXDS is much deeper and the field is wider than the EIS Deep 3a, but our scientific aim is specifically targetted to understand the dark area of galaxy evolution (1<z<2) and the FOV is sufficiently large to uncover if what has been observed in HDF (a sharp decline in the number of E/S0's at z>1) is either universal or simply due to a biased formation of E/S0 galaxies. We should stress that we need no additional NIR observations, which SXDS cannot expect for coming 3-4 years. In summary, this program is something that the Subaru is uniquely capable of achieving at the present time, owing to an extremely large field of view of the Suprim-Cam and large area of deep data now covered by the EIS deep survey. ESO-VLT has no plan equivalent to this proposal.



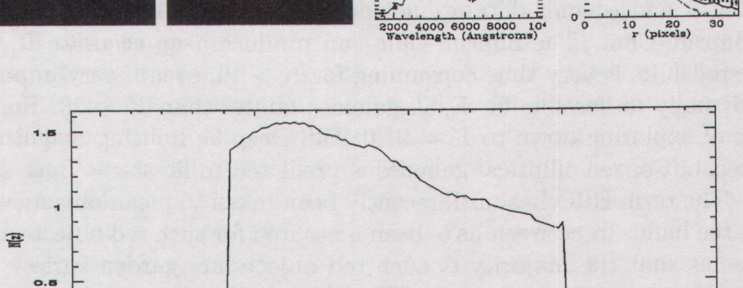


Fig.1 (upper). Photometric redshifts in HDF North and South. This illustrates several points relevant to our proposal. Firstly that photometric-z estimation for red early-type galaxies is not problematic with optical-IR photometry, given the peakd shape of the SED. The redshift accuracy depends on the location of the break with respect to the broad band filters. The z' band is not present here, but falls in the large gap between the J (3rd from right in the SED panel) and the I (4th) bands helping to constrain the location of the break at z>1.

Fig.2 (lower). This is the expected distribution of early-type galaxies to a limit of $K = 21$ (slightly brighter than ours), with no density evolution and only minimal passive evolution and an imposed red cut-off of $R - K > 5$ to remove the early blue stage which will not on the basis of SED be distinguishable from later type galaxies in the general field. The average expected redshift is close to $z = 2$ but extended from $0.8 < z < 3$.