NOAO Observing Proposal
Kitt Peak National Observatory

Date: October 5, 1998	*TAC:* Extragalactic	*Proposal number:*

TITLE: Measuring Ω_M in the Near-Infrared

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Abstract of Scientific Justification *(may be made publicly available for accepted proposals)*:

The CNOC1 cluster redshift survey has determined the mass density of the universe Ω_M to $\pm 30\%$ statistical uncertainty. A dominant possible source of systematic error in this measurement is any differential redshift evolution between cluster and field galaxies. Existing g- and r-band observations suggest that any such evolution is small, but it is important to verify this using near-infrared light which more closely traces galaxy mass and is much less affected by different star formation histories. Thus we propose H-band imaging of all 15 CNOC1 clusters (1□°) plus 0.4□° of the CNOC2 field galaxy redshift survey to obtain H-band luminosities for $\sim$1100 cluster and >1100 field galaxies with existing redshifts. These data will provide the most precise measurements ever made of the H-band galaxy luminosity function at z=0.2–0.55 in clusters and the field. Simple, direct tests of differential evolution in the H band will constrain possible systematic errors in Ω_M, help determine the astrophysics of galaxy evolution using the largest available homogeneous cluster and field galaxy redshift samples, and serve as a benchmark for higher-z cluster studies in the 8m era.

- *Is this proposal part of a PhD thesis? If 'Y', you must send a letter; see instructions.* N
- *Are you requesting long-term status? If 'Y', please give details on the line below.* N

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, gratings, filters, camera optics, multislits, etc.
1	2.1m	ONIS + JHK_s
2	2.1m	ONIS + JHK_s
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	3	14	Feb 1 - Mar 15	Feb 1 - Apr 30
2	1	14	June 1 - July 31	May 1 - July 31
3				

- *Scheduling constraints and non-usable dates.*

Scientific Justification *Be sure to include overall significance to astronomy. Limit text to one page with figures (up to three), captions and references on no more than two additional pages.*

The Canadian Network for Observational Cosmology redshift survey (CNOC1) obtained $\sim$2600 cluster and field galaxy redshifts in the fields of 15 X-ray luminous clusters at z=0.2–0.55. These were used to measure the mass density of the universe, Ω_M, to 30% accuracy as follows. Cluster virial masses M_v were calculated from their velocity dispersions and corrected for the bias whereby M_v measured within a finite radius overestimates the true mass. Dividing by the total luminosity of the cluster galaxies yields $(M/L)_{cl}$. Converting this to the field $(M/L)_f$ requires that any differential luminosity evolution between cluster and field galaxies be accounted for. CNOC1 data shows no evidence for increased star formation activity in clusters relative to the field, and that any fading is certainly $<0\overset{\mathrm{m}}{.}5$ in r [1,3]. From CNOC1 g and r imaging, an estimated fading of cluster galaxies relative to the field of $0\overset{\mathrm{m}}{.}11\pm0\overset{\mathrm{m}}{.}06$ in r was adopted, yielding $(M/L)_f$=213$\pm$59h $M_\odot/L_\odot$. Field galaxies from the same survey yield the total field luminosity density j at the average cluster redshift z=0.33; the required M/L for an Ω_M=1 universe is then ρ_c/j=1136$\pm$138h $M_\odot/L_\odot$. Thus Ω_M=$[(M/L)_f]/[\rho_c/j]$=0.19$\pm$0.06$\pm$0.04 (random and estimated systematic errors, respectively) [3].

Reducing the statistical uncertainties on this Ω_M measurement simply requires more redshifts. However, it is also important to understand the systematic uncertainties, the most important of which is any possible differential evolution between cluster and field galaxies. Despite the necessarily very different star formation histories between cluster and field galaxies, their overall luminosity functions are very similar (Fig. 1). Differential evolution in B and r was estimated and found to be small [3,6-7], but careful comparison of cluster and field luminosity functions (LFs) indicates they may have different redshift evolution at the $\sim3\sigma$ level (Yee et al., in prep. [9]). Our observations show that, on average, galaxies experience no burst of star formation when they join a cluster [1-3], so the data are still consistent with galaxies simply ceasing most of their star formation, and thus fading and reddening, after they enter clusters. However, the morphological mix in clusters is different from the field, and so there is likely a mixture of luminosity evolution, density evolution, and morphological type transformation occurring in clusters. To minimize the effects of these evolutionary processes on measuring Ω_M, it is best to measure near-IR galaxy luminosities which are dominated by the stars that form the bulk of a galaxy's mass and are largely unaffected by different star formation histories. We propose to measure H magnitudes for 95% of the 1100 cluster and 400 field galaxies with z=0.2–0.55 and r<21.5–22 in CNOC1, and for $\sim$700 additional field galaxies from the CNOC2 field survey [4], and **re-calculate Ω_M using H-band luminosities.** Although the mass terms in the Ω_M equation will be identical to those in the original CNOC1 calculation, the cluster luminosities L_H and field luminosity density j_H will be essentially independent measurements, a straightforward consistency check for understanding and constraining systematic errors.

Our completeness limits of H=19–19.8 will sample $1\overset{\mathrm{m}}{.}5$–$2\overset{\mathrm{m}}{.}5$ below M_H^* at z=0.2–0.55. This is similar to existing limits in r and will enable direct comparison of cluster and field LF evolution in r and H. Using r-H instead of g-r, we will examine the radial distribution of galaxy colors to look for differences between clusters and the field and to examine population gradients within clusters [3].

The CNOC1 field sample must be enlarged for adequate comparison with the cluster data. KPNO H-band imaging of the 0.4$\square^\circ$ northern patch of the CNOC2 field redshift survey [4] will provide $\sim$700 more r<21.5 field galaxies. Along with NTT/SOFI imaging of two southern patches scheduled for Nov. '98, this will yield $\sim$2500 field galaxies for the best measurement yet of the H-band LF at z=0.2–0.55. Imaging several patches is necessary to reduce the uncertainties from large scale structure. With $\sim3\times10^4$ galaxies to H=20 (3σ) [8], this dataset will also extend and improve photometric redshifts and spectral types from existing $UBgRI$ CNOC2 imaging and precisely define the H-band $N(m)$ relation and the evolution in the correlation function of IR-selected galaxies.

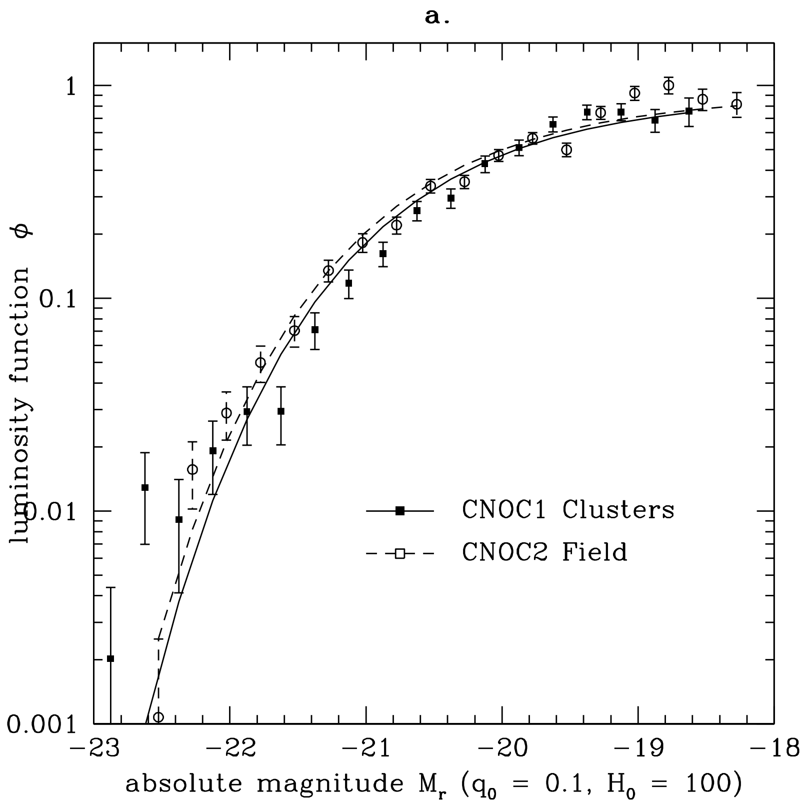

Figure 1: The CNOC1 cluster galaxy luminosity function (LF) (**solid**) and the field galaxy LF from 2 of the 4 CNOC2 patches (**dashed**). Both LFs are single Schechter function fits to 0.2<z<0.55 galaxies with $-23<M_r<-18.5$ (CNOC2 calculations were done for Kron-Cousins M_R and translated to Gunn M_r using a simple zeropoint shift of $+0\overset{m}{.}35$). The number density agreement is expected because the cluster LFs are normalized by the cluster masses [2], but the LF shapes are remarkably similar given the different star formation histories of galaxies in these different environments. The slightly fainter cluster M^* is consistent with most star formation ceasing when galaxies join clusters. But modelling the LFs as single Schechter functions neglects differences in the morphological distributions of galaxies in clusters and the field, as well as differential evolution and transformations between them. H-band LFs are needed to more closely trace the underlying galaxy mass functions.

References

1. Balogh, Schade, Morris, Yee, Carlberg & Ellingson 1998, ApJ, 504, L75
2. Carlberg, Yee, Ellingson, Abraham, Gravel, Morris & Pritchet 1996, ApJ, 462, 32
3. Carlberg, Yee & Ellingson 1997, ApJ, 478, 462
4. Carlberg et al. 1998, astro-ph/9805131
5. Hall & Green 1998, ApJ, in press; and Hall 1998, Ph.D. Thesis, University of Arizona
6. Schade, Carlberg, Yee, Lopez-Cruz & Ellingson 1996a, ApJ, 464, L63
7. Schade, Carlberg, Yee, Lopez-Cruz & Ellingson 1996b, ApJ, 465, L103
8. Yan, McCarthy, Storrie-Lombardi & Weymann 1998, astro-ph/9804234
9. Yee et al., 1998, in preparation

Experimental Design *Justify the number of nights requested as well as the specific telescope, instruments, and lunar phase. If you've requested long-term status, justify why this is necessary for successful completion of the science. List objects, coordinates, and magnitudes (or surface brightness, if appropriate), desired S/N ratio, wavelength coverage and resolution (or include in Target Tables section).* **NOTE:** *If this project involves observations on other telescopes as well, list all telescopes on which you have applied for or been granted time for observations related to this project. For each, indicate the nature of the observations, and describe the importance of the observations proposed here in the context of the entire program. For WIYN proposals, see special WIYN instructions.*

The CNOC1 cluster survey consists of 35 $\sim 9' \times 7.6'$ CCD fields covering 15 clusters. The CNOC2 field survey consists of 1 northern & 3 equatorial "patches" with 19 CCD fields each. We have been granted 2 nights at the ESO NTT with SOFI to image 2 equatorial CNOC2 patches in H (Infante et al.), but the northern patch cannot be reached from La Silla and so we propose to observe it from KPNO. It is important to observe more than one patch to reduce variations due to large-scale structure. The field of view of ONIS on the KPNO 2.1m is $6' \times 3'$. We will cover each $\sim 9' \times 8'$ CCD field using 6 ONIS pointings overlapped by $3'$ along the long axis and 20–30$''$ along the short axis. These large overlaps will typically contain enough objects to enable calibration of any nonphotometric data, and will yield a $3' \times 8'$ strip $0\overset{\mathrm{m}}{.}4$ deeper in the center of each CCD field.

Ideally we would like to observe in the reddest bandpass easily accessible from the ground: K (or K_s). However, our need to cover a large area makes the H band a better choice due to its somewhat lower sky background. A 100% completeness limit of H=19.0 (8σ, 5 pixel = 1.7$''$ diameter aperture) will detect $\sim$95% of all galaxies with r<21.5 and z<0.55, based on typical $H-K$ and $r-K$ colors from the literature [5]. Reaching this depth with ONIS requires 3.5 minutes integration, split into four slightly dithered sub-exposures to ensure a sky background of <8000 ADU so that linearity corrections are <0.2%. For the 4 z>0.4 clusters (6 CCD fields) where spectra were obtained to r<22, we will use 14 min integrations to reach H=19.8 (8σ), sufficient to reach $1\overset{\mathrm{m}}{.}5$ below M^*_H at z=0.55. Each CCD field will require 21 min total for 6 pointings (84 min at z>0.4). This sums to 18.55 hrs integration for the 35 CNOC1 fields, and 6.65 hrs for the 19 fields of the northern CNOC2 patch. Including overhead and calibration, our observations will require 4 nights. We request 3 nights in February or March and 1 night in May or June so that we can efficiently observe all 15 CNOC1 clusters in one semester.

This project is ideally suited for ONIS on the 2.1m. The FOV of the CFHT Redeye-Wide array is only $2' \times 2'$, 4.5$\times$ smaller than ONIS. This smaller size is not fully compensated for by the 3$\times$ larger collecting area of CFHT; thus, this project would require 50% longer to accomplish at CFHT.

Previous Use of NOAO Facilities *List allocations of telescope time on NOAO facilities to the Principal Investigator during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal.*

- **Hall**, Green, Kennefick, Osmer, Smith: 8 nights (5 usable) Spring 1997 & 1998 w/BTC+CTIO4m for a Big Faint z=3.5–5 Quasar Survey; object cataloguing underway, data paper in preparation
- Falco, Kochanek, Schechter; Green, **Hall**, Kennefick, Osmer, Smith; Postman: 8 nights total Spring & Fall 1997 with BTC on CTIO 4m for BTC40 survey, a "shallow" z>5 quasar / z$\sim$1 cluster / gravitational lens survey; 40 deg^2 covered; reduction and cataloguing complete
- Kennefick, Falco, Green, **Hall**, Osmer, Smith; 3 nights Spring 1998 for longslit spectra of candidate BTC40 z>5 quasar & gravitational lenses; <1 night usable; no quasars or lenses found
- Kennefick, Falco, Green, **Hall**, Osmer, Smith; 4 nights Fall 1998 for Z-band coverage of BTC40 fields to reduce contamination of z>5 quasar candidates by very late M stars
- Impey, Conti, Falco, **Hall**, Kennefick, Kochanek, Smith; 5 nights Fall 1998 for 32 deg^2 U-band extension of BTC40 survey for a sample of 6000 faint quasars and many B,V-dropout galaxies
- Green, He, & **Hall**: 6 nights on 2.1m+Goldcam in Feb. 1997 & 1998, for spectroscopic confirmation of X-ray/optical selected AGN, data reduced, project continuing.

Why CTIO? *(For CTIO proposals only.) Explain why access to the southern hemisphere is needed to achieve your scientific goals.*

Target Tables *Provide information for your intended observations in tabular form. This information is required for WIYN proposals but is optional for all other telescopes.*

Observations for the KPNO 2.1m with ONIS

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	MS0016+16											z=0.5479, 1 CCD field
2	MS0302+17											z=0.4244, 1 CCD field
3	MS0440+02											z=0.1967, 3 CCD fields
4	MS0451+02											z=0.1996, 4 CCD fields
5	MS0451−03											z=0.5391, 1 CCD field
6	MS0839+29											z=0.1931, 4 CCD fields
7	0920+37											CNOC2 patch, 19 CCD fields
8	MS1006+12											z=0.2605, 1 CCD field
9	MS1008−12											z=0.3062, 1 CCD field
10	MS1224+20											z=0.3255, 1 CCD field
11	MS1231+15											z=0.2349, 3 CCD fields
12	MS1358+62											z=0.3290, 3 CCD fields; 8′x8′ WFPC2 mosaic
13	MS1455+22											z=0.2582, 1 CCD field
14	MS1512+36											z=0.3711, 3 CCD fields
15	MS1621+26											z=0.4275, 3 CCD fields
16	CL2151+17											z=0.2279 (A2390), 5 CCD fields