NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: September 30, 1999 **Category:** High Z Galaxies

Connecting *J*-dropout and *U*-dropout Galaxies

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
Selection of "U-dropout" galaxies has proved an efficient way to assemble samples of star-forming galaxies at z=2.4–3.6. However, rest-frame UV selection of galaxies may be a poor way to survey the entire z$\sim$3 galaxy population, as it is insensitive to galaxies with little ongoing star formation. While studying the candidate host cluster of the quasar Q 1126+101 at z=1.52, we have discovered an overdensity of "J-dropout" galaxies with J-K>2.5 whose SEDs suggest they are serendipitous dusty galaxies background to the quasar at z>2.5, with their 4000 Å breaks redward of the J band. By adding deep UB imaging to 15 arcmin^2 of existing rJK imaging of this field we can address two important science goals: **(1)** Deep UB imaging will be used to isolate Lyman-break galaxies at z=2.4–3.6 to study the correspondence between U- and J-band dropouts. These J-band dropouts may represent a population of relatively old or dusty galaxies overlooked by Lyman-break selection techniques, or they may have sufficient rest-frame far-UV flux to be selected as U-dropouts but star formation rates higher than estimated from far-UV fluxes due to dust obscuration. **(2)** Deep U imaging also samples rest-frame 1350-2000Å at z=1.52 and can detect star formation rates as small as 0.3 $M_\odot$/yr (neglecting dust). This will provide a first look at star formation rates in clusters at this epoch when the global SFR of the universe began to decline to its current value. Deep B imaging coupled with existing deep rJK and proposed VRIz data will provide additional constraints on stellar populations and dust through broadband SED fitting, in particular on the dust reddening in the far-UV using the B-r or B-V colors.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon age	Optimal months	Accept. months
1	WIYN	MIMO	2	3	Mar - Apr	Feb - Jun
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

We have recently detected several candidate high-redshift galaxy clusters as excesses of faint, red galaxies around radio-loud quasars (RLQs) at $z{\sim}1.5$ using deep narrow-field r, J, and K_s imaging (Hall 1998, Hall & Green 1998; Hall, Green & Cohen 1998). The magnitude, spatial, and color distributions of the excess galaxies in these fields are consistent with most of them being at the quasar redshifts. Some of these galaxies are so red in $r-K$ that they may already be considerably more than 3 Gyr old at $z{\sim}1.5$ (Fig. 1). However, some galaxies — particularly in the field of Q 1126+101 — are so red in $J-K$ that they must be dust-reddened for any reasonable cosmology (Fig. 2; cf. Cimatti et al. 1997), and some or all of those are probably background to the quasar as well (Fig. 3; Hall, Sawicki, Pritchet, Hartwick, & Evans 1999). A handful of similar IR-identified z>2 galaxies are known (Francis et al. 1997; Dickinson et al. 1999), but the fraction of z∼3 galaxies visible in the IR but missed by U-dropout selection is not known. **Thus we propose to obtain deep UB data with WIYN** to select "U-band dropout" galaxies at z=2.4–3.6 in the field of Q 1126+101 for comparison with the sample of "J-band dropout" galaxies in hand.

Deep U and B data will be used to select galaxies at $z = 2.4 - 3.6$ where the Lyman forest and Lyman break have depressed the flux in the U band. The B data combined with existing r data will also constrain the dust reddening in the far-UV (Steidel et al. 1996). Fig. 1 shows a small portion of the Q 1126+101 field, which contains an overdensity of J-band dropouts (Fig. 2). Fig. 1 also contains a z-band dropout whose colors are consistent with an old early-type galaxy at z_{QSO}=1.52. The J-band dropouts, on the other hand, may be star-forming galaxies at z_{QSO} which are red due to dust, or galaxies background to the quasar which are red due to the redshifted 4000Å break as well as dust or age. A preliminary photometric redshift for one J-dropout suggests that it is in fact a very dusty galaxy at z=3.5±0.5 (Fig. 2; Hall *et al.* 1999). Thus the J-dropouts may represent a population of relatively old or dusty high-redshift galaxies overlooked by Lyman-break selection techniques (Francis et al. 1997). Alternatively, they may have sufficient rest-frame far-UV flux to be selected as U-dropouts but star formation rates higher than suggested by the far-UV flux due to dust obscuration. The only way to test this directly is to obtain deep UB imaging.

Deep U data (rest-frame ∼1500Å at z=1.52) will also be used to constrain current star formation rates (SFRs) in photometrically identified z=1.52 cluster galaxies, especially late-type ones. A SFR of 1 $M_\odot$/yr corresponds to $L_{1500\AA} = 10^{40.1}$ erg/s/Å (Salpeter IMF, upper mass cutoff 80 $M_\odot$; Steidel et al. 1996). This far-UV light is produced by short-lived massive stars, and so directly reflects the current SFR; only dust and the IMF slope can substantially affect the conversion from 1500Å flux to SFR (Leitherer 1995). Imaging to U=27.2 (3σ) enables detection of z=1.52 cluster galaxies with star formation rates of $\geq$0.3 h_{50}^{-2} $M_\odot$/yr (q_0=0.05) This assumes no dust extinction, but photometric spectral types for these galaxies will enable a reddening correction estimate to be made. The fraction of cluster galaxies with negligible star formation will have direct bearing on the question of when the last major epoch of star formation occurred in early-type cluster galaxies.

We have also proposed deep VIz imaging with CFHT to obtain rest-frame U images of candidate z=1.52 cluster galaxies and photometric redshifts for galaxies to I=23.5 in preparation for targeted spectroscopic followup. This proposal and the CFHT proposal are independent, but each dataset will benefit the other. "U-dropout" galaxy selection from WIYN UB data and existing rJK data will benefit from more accurate photometric redshifts and SED typing incorporating CFHT VIz data. Photometric redshifts using CFHT VIz and existing rJK data will benefit from the UB data, which covers the 4000Å and Lyman breaks at low and high redshifts, respectively.

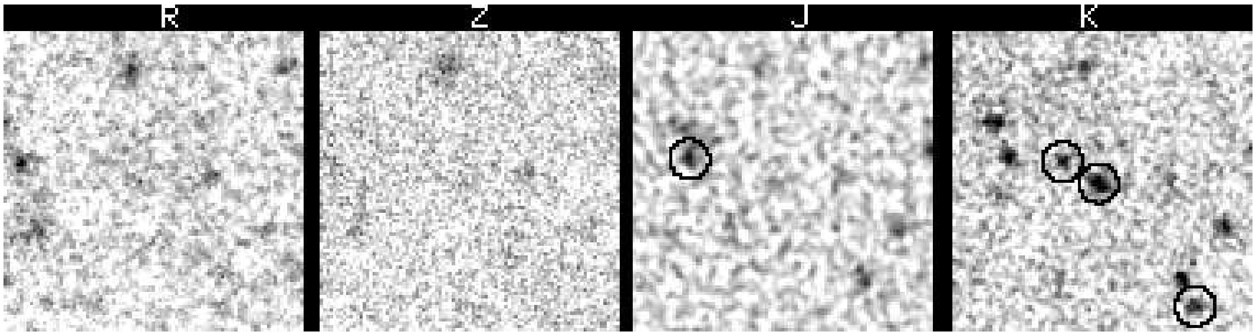

Figure 1: Several "J-dropouts" (J-K>2.5) in the Q 1126+101 field, circled in K. The central object appears extended at K and is detected at r$\sim$25. The object circled in J is a z-dropout, but is strongly detected in J. Its SED is consistent with a 4-5 Gyr old galaxy at the quasar redshift.

References

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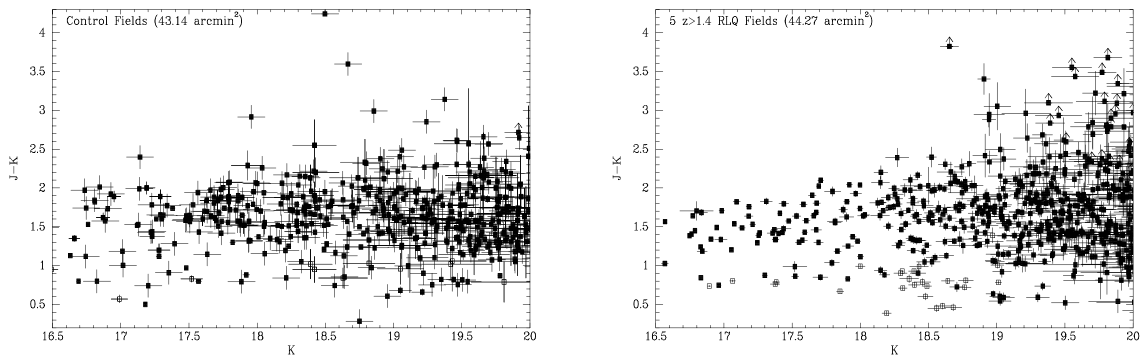

Figure 2: $K/J{-}K$ color-magnitude diagrams from HG98 for control fields (left) and five $z \sim 1.5$ quasar fields (right). Most of the overdensity of J-dropouts ($J{-}K{>}2.5$) is in the Q 1126+101 field.

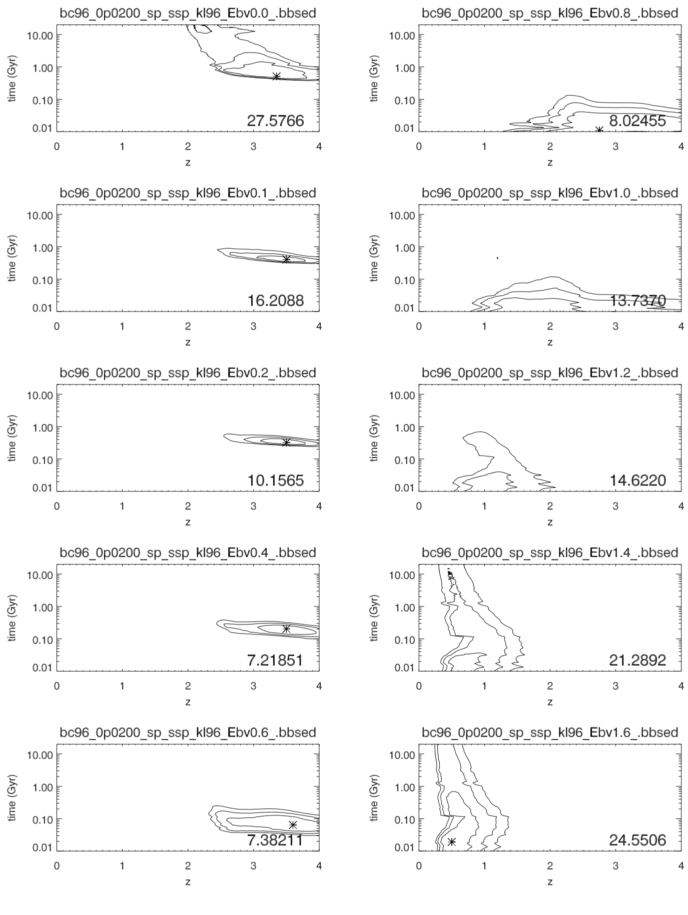

Figure 3: χ^2 contour plots for instantaneous burst fits to the SED of the brightest J-dropout in the Q 1126+101 field. Each panel corresponds to a different $E(B-V)$, starting with 0 at top left and increasing to 0.6 at the bottom of the first column and 1.6 at the bottom of the second. The asterisk shows the point with minimum χ^2 in each panel; from smallest to largest, the error contours enclose the 90, 99 and 99.9% probability regions. The contours are drawn for each panel independently relative to the minimum *unreduced* χ^2 for that panel, which is printed in the bottom right corner. **The lowest χ^2 is given by $E(B-V) \sim 0.5$, and the object is background to the z=1.52 quasar at >99.9% confidence for all $E(B-V) \lesssim 0.7$.**

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. 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.*

The required depth is set by the need to detect U-band dropout galaxies. The UGR selection criteria of Steidel *et al.* (1998) is equivalent to $U - B > B - R - 0.06$ for $B - R < 1.44$. To select U-dropouts to R=25 requires imaging to B=26.44 and U=27.82. We propose imaging to B=26.44 (6σ in 100 minutes) and U=27.67 (2σ in 13hrs), which will enable selection of U-dropouts to R=24.85 at all $B - R < 1.44$, and to R=25 for $B - R < 1.29$ (sufficient to select $\gtrsim$85% of all U-dropouts found by Steidel *et al.*). All exposure time calculations were done using the KPNO on-line calculator, assuming seeing=$0''.7$, airmass=1.2, apertures $0''.8$ square for measuring the $U - B$ color and $1''.6$ square for object detection in B, and using the parameters for the S2KB chip, which is less blue-sensitive than the Mini-Mosaic.

This deep imaging will also provide a very sensitive look at star formation in candidate cluster galaxies around the quasar at z=1.52. A SFR of 1 $M_\odot$/yr produces a luminosity per rest-frame wavelength interval of $10^{40.1}$ erg/s/Å at rest-frame 1500Å (Steidel *et al.* 1996). This corresponds to a luminosity per *observed* wavelength interval of $10^{40.1}/(1+z)$ erg/s/Å at the redshifted wavelength corresponding to rest-frame 1500Å (~3800Å for galaxies at z=1.52), or equivalently to a luminosity per observed frequency interval of $10^{28.0}\times(1+z)$ erg/s/Hz. The luminosity distance at z=1.52 is 4.7 10^{28} h_{50}^{-1} cm (q_0=0.05), so the redshifted far-UV flux density for 1 $M_\odot$/yr will be 8.87 10^{-31} erg/s/cm^2/Hz (88.7 nJy), which is U=25.8 (U_{AB}=26.55). Thus our deep imaging will enable detection of z=1.52 cluster galaxies with star formation rates of 0.27 h_{50}^{-2} $M_\odot$/yr for q_0=0.05 (0.14 h_{50}^{-2} $M_\odot$/yr for q_0=0.5), in the absence of dust. Photometric and eventual spectroscopic redshifts will be used to isolate samples of candidate cluster galaxies for study of their far-UV star formation rates.

The PI at Toronto has access to CFHT, to which we have proposed unrelated but complementary VIz imaging for photometric redshifts in this field. However, the CFH 8x12k imager has no U sensitivity and the MOS imaging spectrograph has lower U sensitivity than WIYN, coarser sampling, and considerable optical distortions of the PSF which results in a much smaller useful field than with WIYN. WIYN queue scheduling also provides a better opportunity for obtaining useful data on this field than classicial scheduling, especially since photometric conditions are not strictly required for this project as long as some photometric images are obtained. CoIs at Ohio State have access to the ONIS 2.5′x5′ FOV IR imager used to obtain our near-IR data, but for optical imaging only have access to a 2.3m telescope on which this project would be prohibitively time-consuming.

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: 1 night Mar. 1999 w/HYDRA+CTIO4m (shared-risk) for Spectroscopic Followup of a Big Faint Quasar Sample; 1 project & 1 backup field observed, data reduced.
• **Hall**, Ellingson, Carlberg, Yee, Lin & Marzke; 3 nights Feb. 1999 (2.5 usable) and 1 night June 1999 with ONIS on KPNO 2.1m for near-IR survey of CNOC1 cluster fields as a quasi-independent Ω_M measurement; data being reduced and paper in preparation
• **Hall**, Green, Kennefick, Osmer, Smith: 8 nights (5 usable) Spring 1997 & 1998 w/BTC+CTIO4m for BRI imaging to assemble a Big Faint Quasar Sample; processing pipelines up and running; data paper nearing submission (by end of 1999)
• Kennefick, Falco, Green, **Hall**, Osmer, Smith, Monier, Conti; 3 nights Fall 1999 w/CTIO4m for longslit spectra of candidate z>5 quasars & gravitational lenses from the BTC40 40 deg^2 BVIZ survey; observations scheduled for November 1999
• Yee, Gladders, Barrientos, Ellingson, **Hall**, Infante, Kodama; 3 nights Fall 1999 w/CTIO4m+MOSAIC for RZ imaging survey for 0.5<z<1.4 clusters; observations scheduled for January 2000
• Impey, Conti, Falco, **Hall**, Kennefick, Kochanek, Smith, Osmer; 32 deg^2 U-band extension of BTC40 survey to assemble a sample of 6000 faint quasars, plus luminous U-dropout galaxies; 5 nights Fall 1998 on KPNO 4m: 2.5 nights usable, but seeing $\sim 2''$ and only 0.5 night photometric; 4 nights Fall 1999 on KPNO 4m: scheduled for December 1999
• Kennefick, Falco, Green, **Hall**, Osmer, Smith; 6 nights (5.5 usable) total 1998 & 1999 CTIO4m for Z-band BTC40 imaging to reduce contamination of z>5 quasar candidates by very late M stars; data reduced, cataloguing complete, candidate selection underway
• Kennefick, Falco, Green, **Hall**, Osmer, Smith; 3 nights Spring 1998 CTIO4m for longslit spectra of candidate z>5 quasars & gravitational lenses; <1 night usable; no quasars or lenses found
• 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
• Green, He, & **Hall**: 6 nights on 2.1m+Goldcam in Feb. 1997 & 1998, for spectroscopic confirmation of X-ray/optical selected AGN, data reduced, paper in preparation, project continuing.

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

Observing Run Details for Run 1: WIYN/MIMO

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN, YALO, and CT-0.9mQ SSTO runs).*

We require deep B imaging in $\leq 1''.1$ seeing and deep U imaging in $\leq 0''.85$ seeing. The required combination of depth and seeing is set by the need to detect very faint U-band dropout galaxies. The UGR selection criteria of Steidel *et al.* (1998) is equivalent to $U - B > B - R - 0.06$ for $B - R < 1.44$. Thus to select U-dropouts to R=25 requires imaging to B=26.44 and U=27.82. We propose imaging to B=26.44 (6σ in 100 minutes) and U=27.67 (2σ in 13hrs), which will enable selection of U-dropouts to R=24.85 at all $B - R < 1.44$, and to R=25 for $B - R < 1.29$ (sufficient to select $\gtrsim$85% of all U-dropouts found by Steidel *et al.*).

This can be accomplished in two 10-hour nights as follows:
100min = 4x25min B exposures
10min = 4x2.5min B overhead
780min = 26x30min U exposures
65min = 26x2.5min B overhead
240min = photometric calibration
5min = target overhead (1 target)
1200min = total

All exposure time calculations were based on the KPNO on-line calculator, assuming seeing=$0''.7$, airmass=1.2, dark time 3 days from new moon, and the parameters for the S2KB chip (which is less blue-sensitive than the Mini-Mosaic), and using apertures $0''.8$ square for measuring the $U - B$ color and $1''.6$ square for object detection in B.

Instrument Configuration

Filters: UB	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Photometric conditions are only required for some observations in each filter; photometric calibration of that data can be bootstrapped to all data. However, very little cirrus can be tolerated since very deep imaging is needed.

Target Table for Run 1: WIYN + MIMO

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	Q 1126+101	11:26:38.7	+10:08:32	1950.0	V=18	U	1800.	26	3	phot/spec	0.85	See special requirements
001	Q 1126+101	11:26:38.7	+10:08:32	1950.0	V=18	B	1500	4	3	phot/spec	1.1	See special requirements

NOAO observing proposal LaTeX macros v2.1.