Optical Selection of Star-forming Galaxies at Redshifts $1 < z < 3$

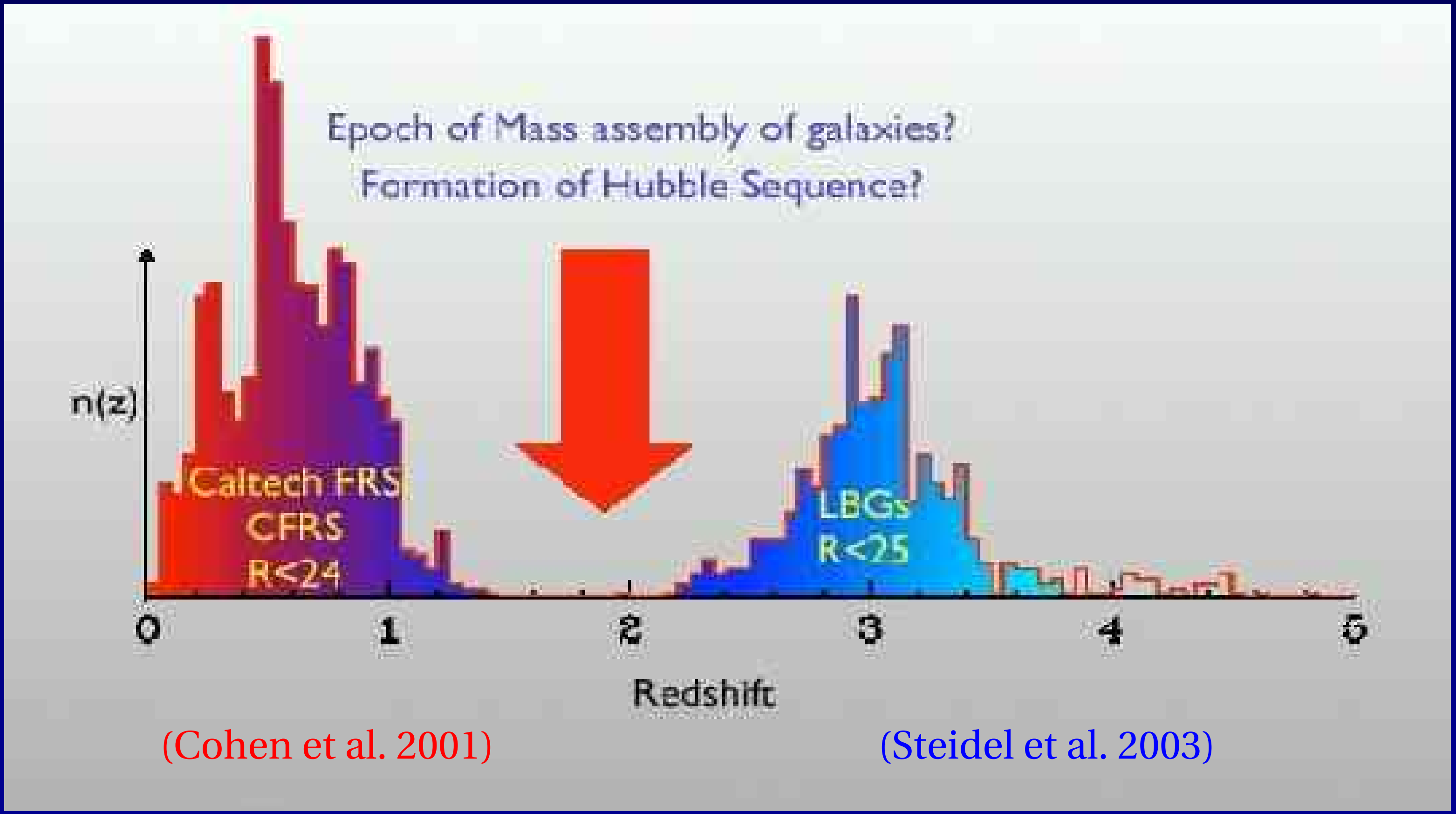
Adelberger K. L., Steidel C. C., Shapley A. E., Hunt M. P., Erb D. K., Reddy N. A., & Pettini M.: 2004, ApJ, 607, 226

Astro-ph for Busy People by Yulia Goranova

16th November 2004, USM

The 'Redshift Desert'

It is often assumed that studying galaxies in the redshift interval $1.4 < z < 2.5$ will be tremendously difficult. The lack of prominent features in the optical spectra seems to be the main reason many to refer to this region as the *spectroscopic* 'redshift desert' (Bullock et al. 2001)



Gemini Deep Deep Survey (http://www.ociw.edu/lcirs/gdds.html)

Why so interesting?

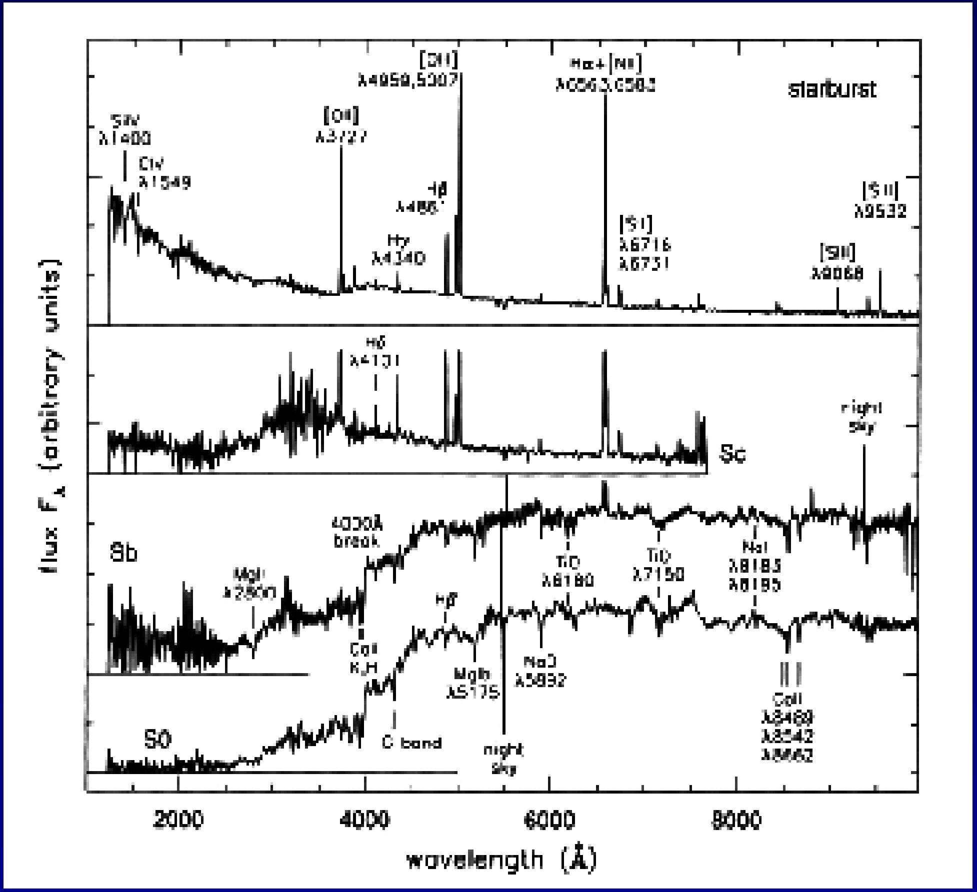
Observations of the low-redshift universe up to $z \sim 1$ (CFRS; Lilly et al. 1996) yields important insight
into the evolution of massive galaxies, while the study of the Lyman-Break galaxies (Steidel et al., 2003) and the luminous but heavily obscured sub-mm (SCUBA)/radio sources (Chapman et al. 2003, 2004) provide the first picture of galaxy population at redshifts beyond $z \sim 2.5$.

A number of recent studies (Dickinson et al. 2003, Fontana et al. 2003, Rudnick et al. 2003, Glazebrock et al. 2003, Di Matteo et al. 2003, Drory et al. 2004) point to the ‘desert’ range $1.4 < z < 2.5$ as a particularly important epoch in the history of galaxy formation and evolution when:

- much of the present-day stellar mass was assembled
- heavy elements were produced
- number density of luminous quasi-stellar object (QSOs) peaked ??
- the Hubble sequence has been established

Why so difficult?

- <u>Galaxy spectral features</u>
  - lack of strong emission lines / breaks

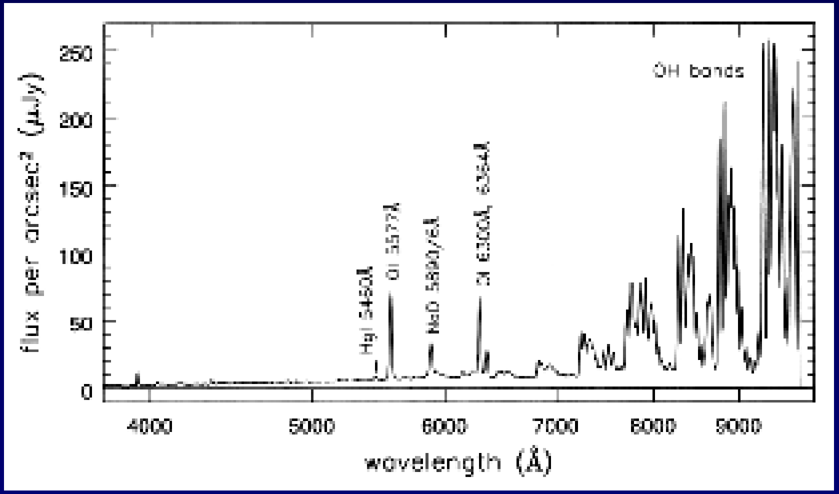


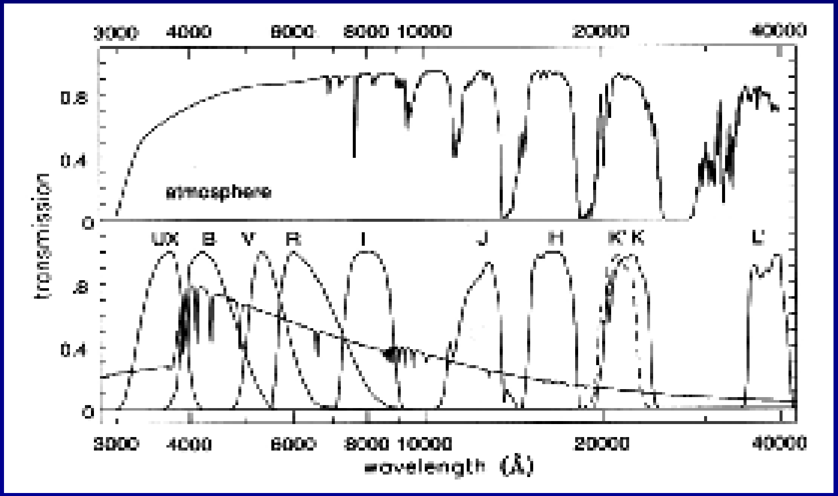
Why so difficult?

- <u>Galaxy spectral features</u>
  - lack of strong emission lines / breaks

- <u>Observing window</u>
  - night sky emission lines (Opt)
  - atmospheric transmission (Opt + NIR)

⇨





Why so difficult?

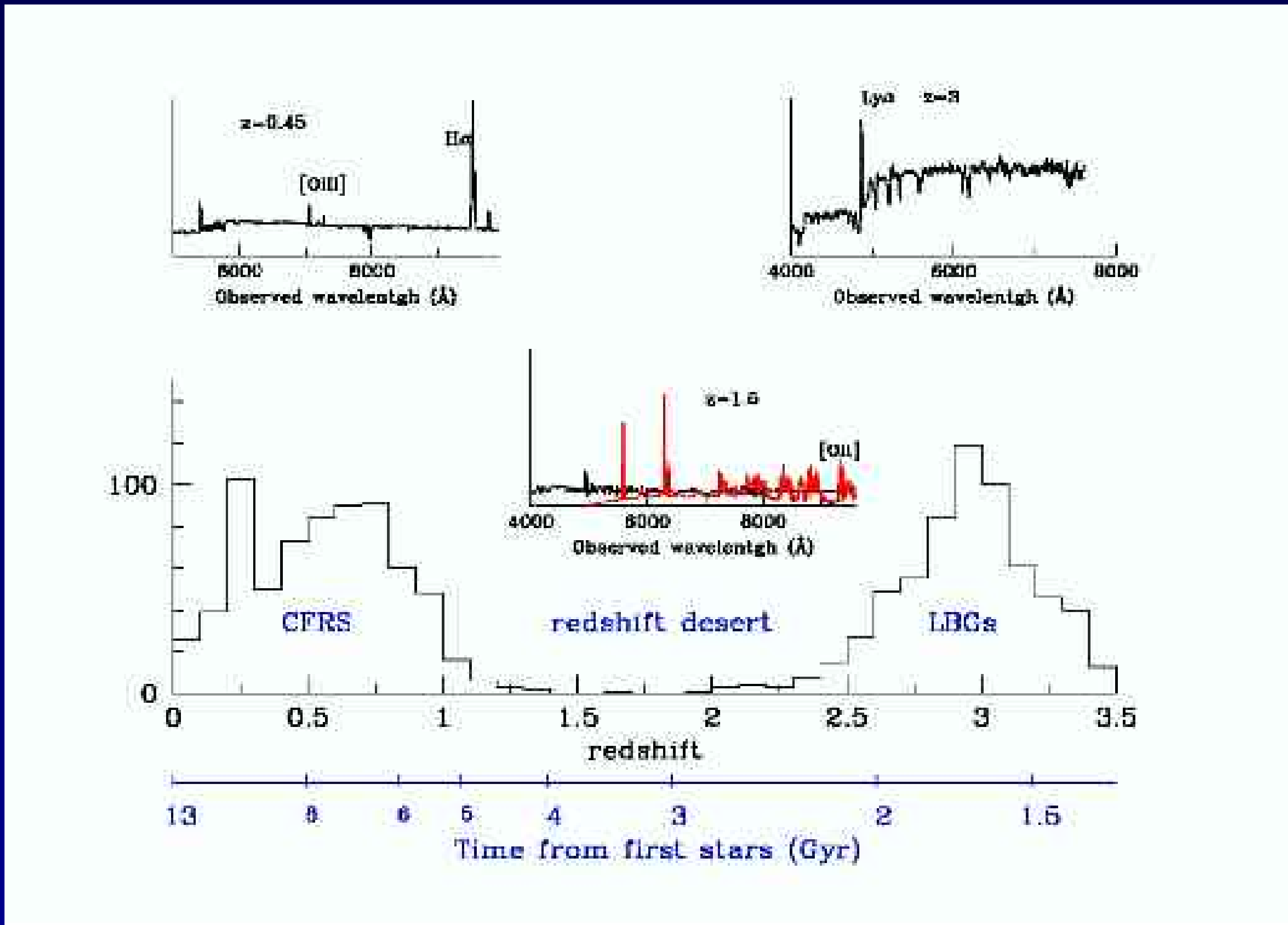
- Galaxy spectral features
  - K-correction above z = 1 significant

- Observing window
  - night sky emission lines (Opt)
  - atmospheric transmission (Opt + NIR)

- Ground-based technologies
  - UV/blue sensitive detectors
    (falling near-UV transmission, low CCD quantum efficiency)
  - near-IR spectrographs
    (extremely bright sky, detector's thermal background, small field-of-view)

⇨ *large telescopes, best observing cites, (in)finite exposure times, new techniques/technologies*

To make the story short...



S. Savaglio & GDDS team (Garching, 2003)

Possible solutions?

Adelberger et al. (2004)

THE ASTROPHYSICAL JOURNAL, 607:226–240, 2004 May 20

OPTICAL SELECTION OF STAR-FORMING GALAXIES AT REDSHIFTS $1 < z < 3$[1]

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Received 2003 November 6; accepted 2004 January 28

ABSTRACT

Few galaxies have been found between the redshift ranges $z \lesssim 1$ probed by magnitude-limited surveys and $z \gtrsim 3$ probed by Lyman break surveys. Comparison of galaxy samples at lower and higher redshift suggests that large numbers of stars were born and the Hubble sequence began to take shape at the intermediate redshifts $1 < z < 3$, but observational challenges have prevented us from observing the process in much detail. We present simple and efficient strategies that can be used to find large numbers of galaxies throughout this important but unexplored redshift range. All the strategies are based on selecting galaxies for spectroscopy on the basis of their colors in ground-based images taken through a small number of optical filters: *GRi* for redshifts $0.85 < z < 1.15$, *GRz* for $1 < z < 1.5$, and U_nGR for $1.4 < z < 2.1$ and $1.9 < z < 2.7$. The performance of our strategies is quantified empirically through spectroscopy of more than 2000 galaxies at $1 < z < 3.5$. We estimate that more than half of the UV luminosity density at $1 < z < 3$ is produced by galaxies that satisfy our color selection criteria. Our methodology is described in detail, allowing readers to devise analogous selection criteria for other optical filter systems.

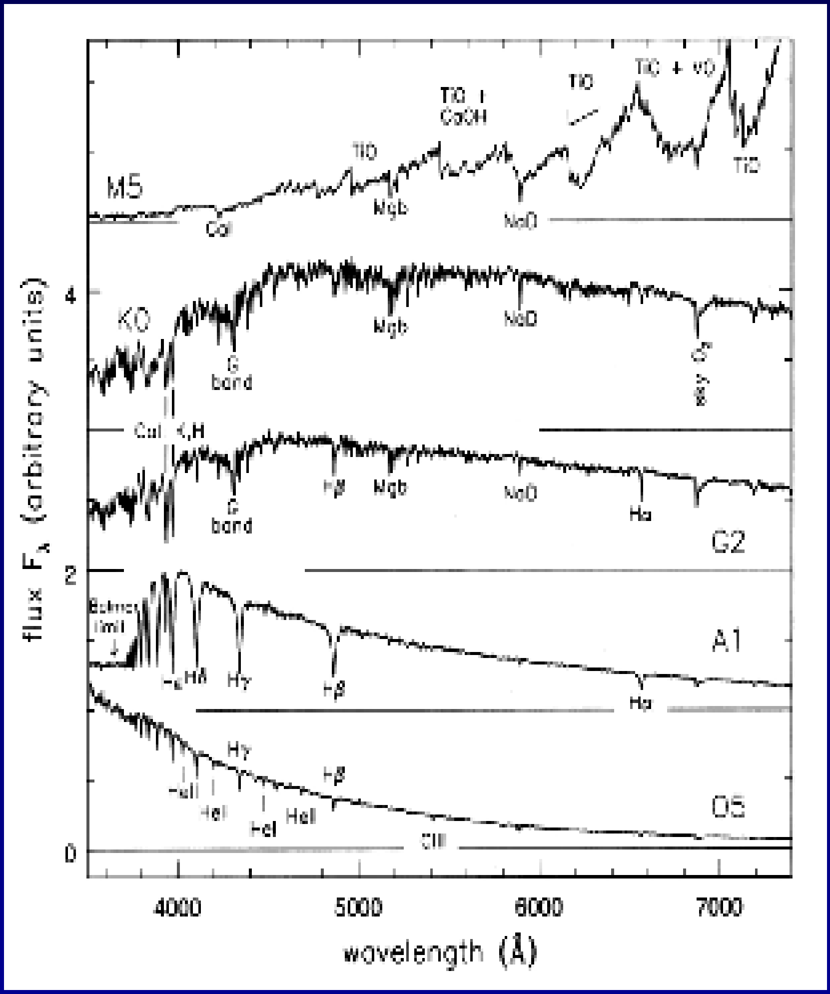
Subject headings: galaxies: evolution — galaxies: formation — galaxies: high-redshift

On-line material: color figures

The Data Set

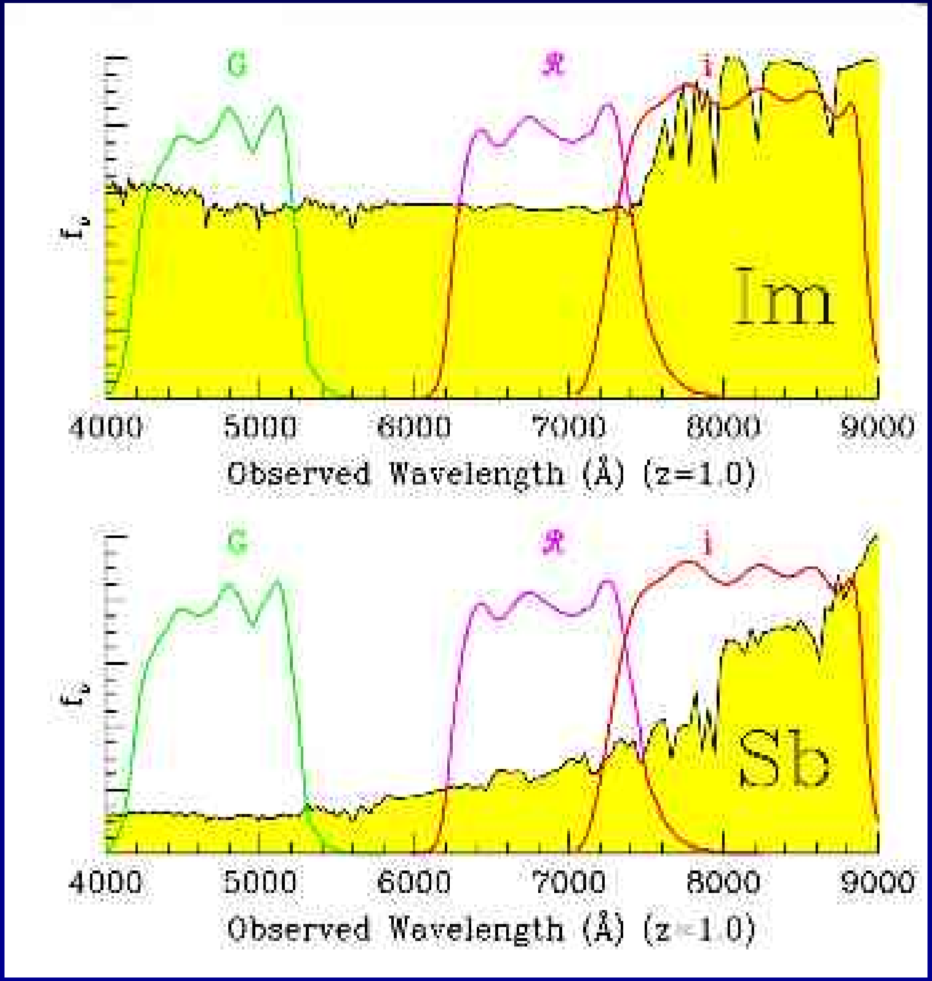
- <u>Model galaxy spectra</u>
  - galaxy's broad band colours are determined by the mixture of stellar types it contains
  - Bruzual & Charlot (1996) models

- <u>Observations</u>
  - $U_n GRi$: Palomar 1.5m, WHT 4.2m, Kitt Peak 4m, and Keck-I
  - *Uz*: GOODS public release
  - spectroscopic follow-up: LRIS-B@Keck-I/II NIRSPEC@Keck-II



Colour Selection @ $0.85 \leq z \leq 1.15$

- Balmer break @ $z \sim 1.0$



- Balmer break @ 3700 Å
  - continuum absorption in B, A, F-stars
  - younger galaxies (Im model)

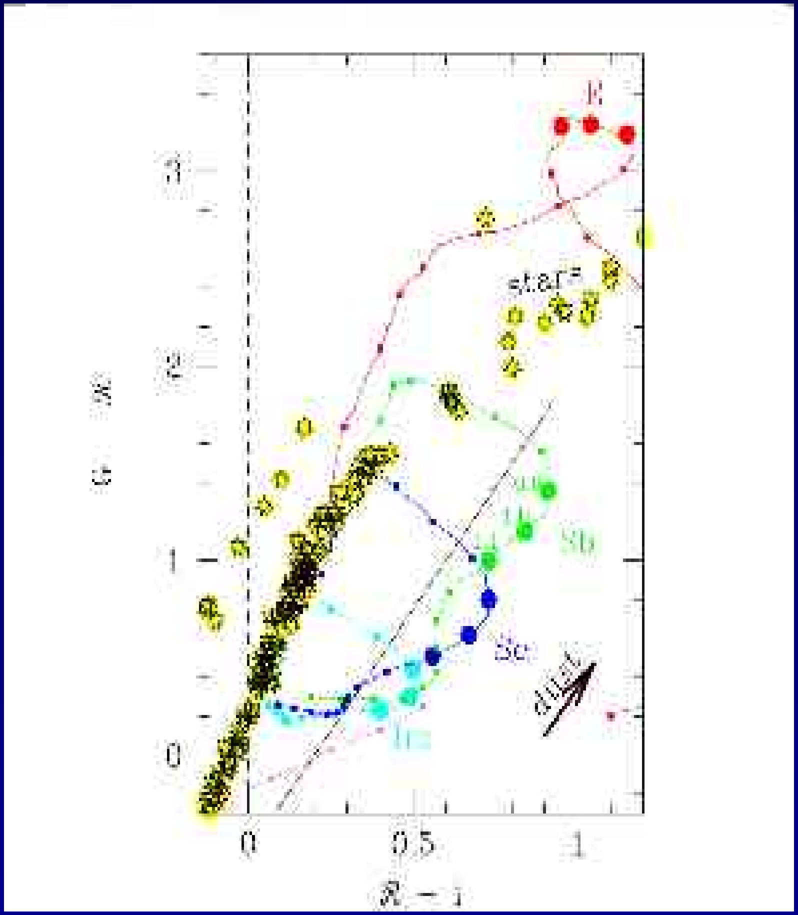
- 4000 Å break
  - CaII H and K absorption in F, G, K-stars
  - older galaxies (Sb model)

⇨ Distinctive colours to galaxies @ z ~ 1

Colour Selection @ $0.85 \leq z \leq 1.15$

Expected locations of stars / galaxies

- curved tracks: colours of model galaxies
- circles: redshift intervals dz = 0.1
- stars: from Gunn & Striker (1983)
- dust reddening: Calzetti (1997)
- dotted line: model galaxy with const. SFR



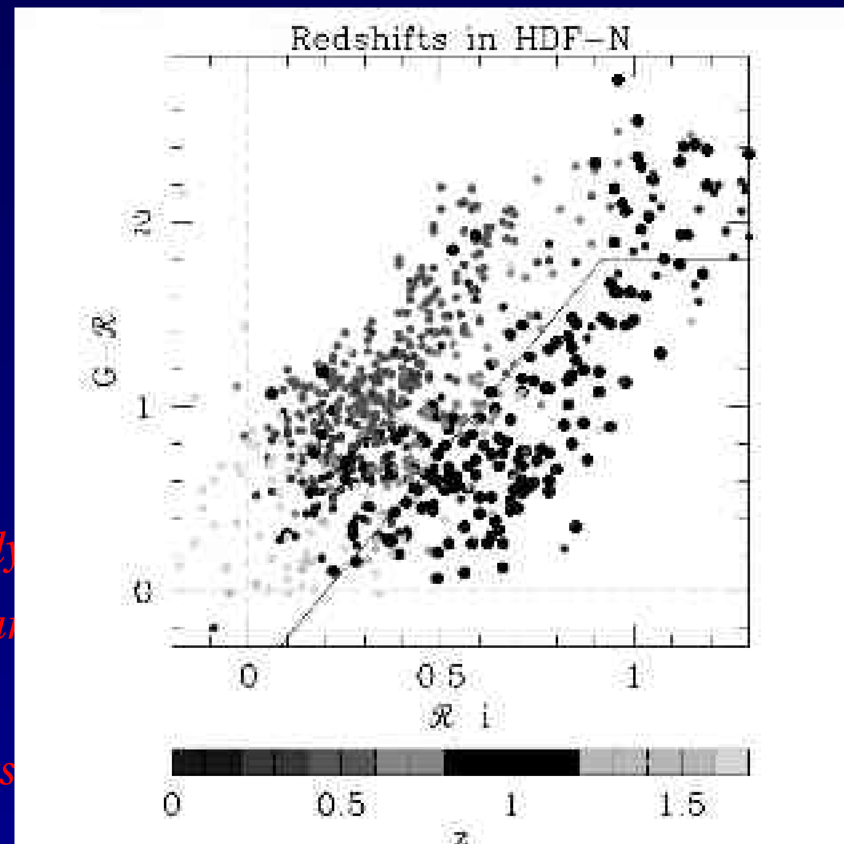
Balmer break selection criteria (z~1):

(1.1) $R - i \geq 0.4\,(G - R) + 0.2$

(1.2) $G - R \leq 1.8$

Colour Selection @ $0.85 \leq z \leq 1.15$

These are galaxies with present SFRs much higher than their past average. Their spectra are dominated by massive O-stars, (too hot to have neutral hydrogen, resp. Balmer break). Since a Balmer break starts to be discernible when a SF episode has lasted longer than ~10^7 yr and most SF in the local and z~3 universe occurs in episodes lasting substantially longer than ~10^7 yr, we suspected that our relia on the Balmer break in our selection criteria would not cause us to miss significant numbers of star-forming galaxies at z~1.



Colour Selection @ $0.85 \leq z \leq 1.15$

left panel:

Distribution of colours for all objects

middle panel:

Probability that an object has

$\mathbf{0.85 \leq z \leq 1.15}$ as a function of *GRi* colour

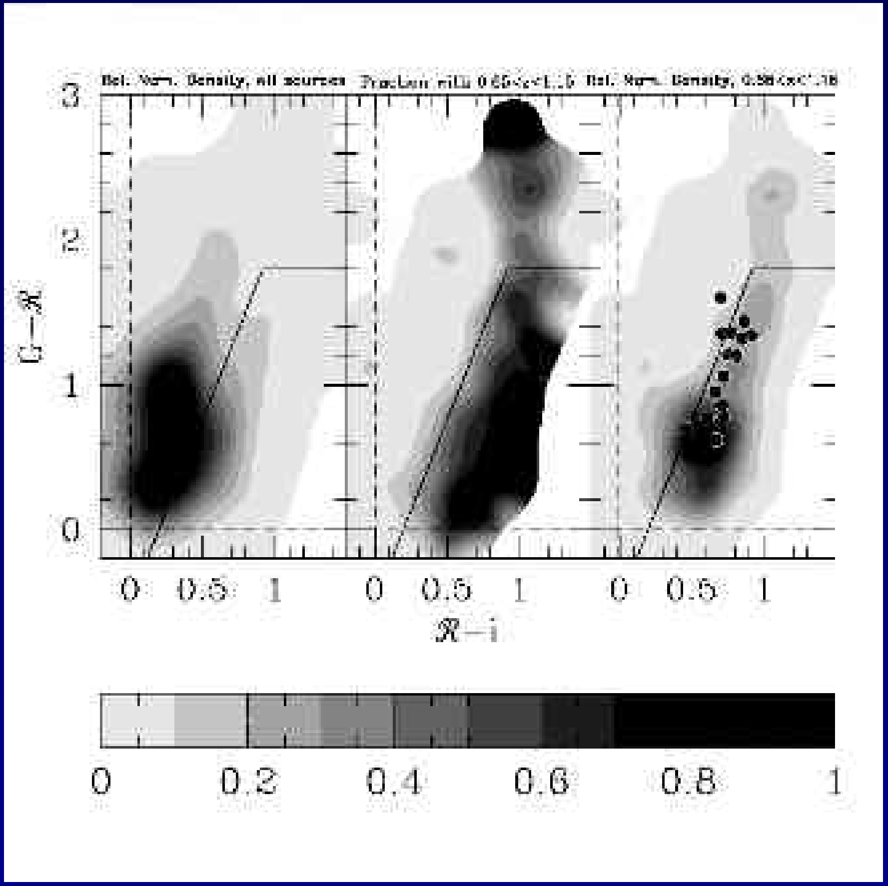
right panel:

Distribution of colours for objects with

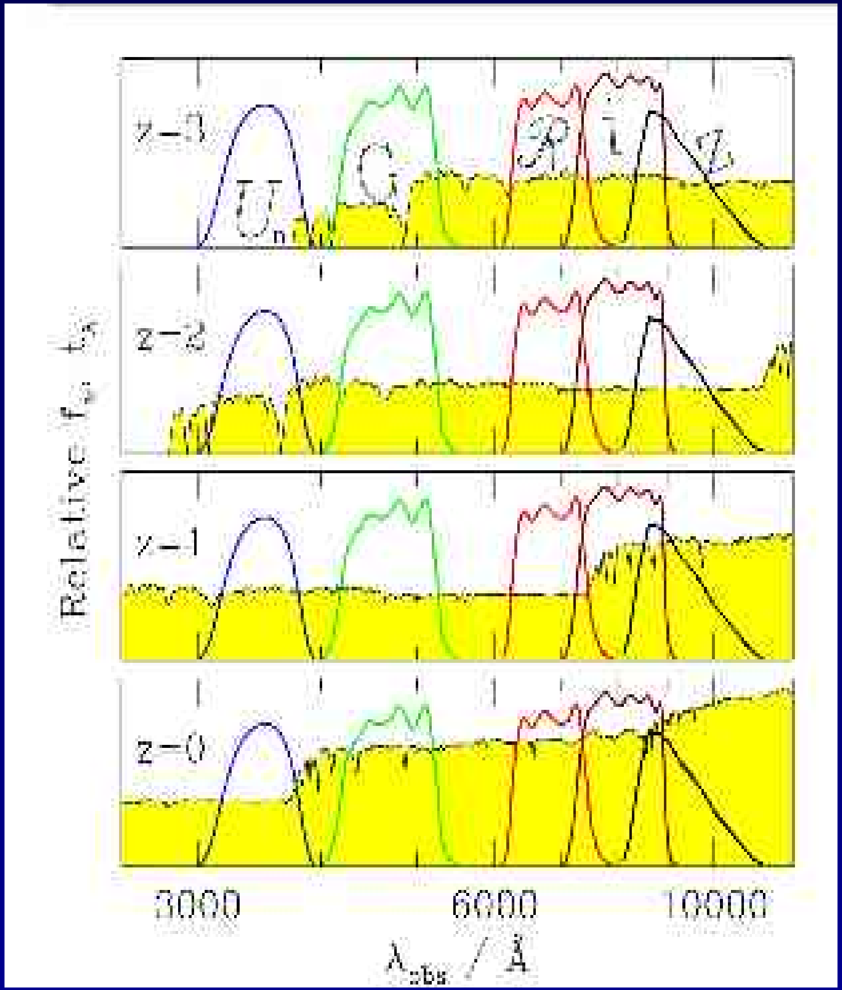
$\mathbf{0.85 \leq z \leq 1.15}$

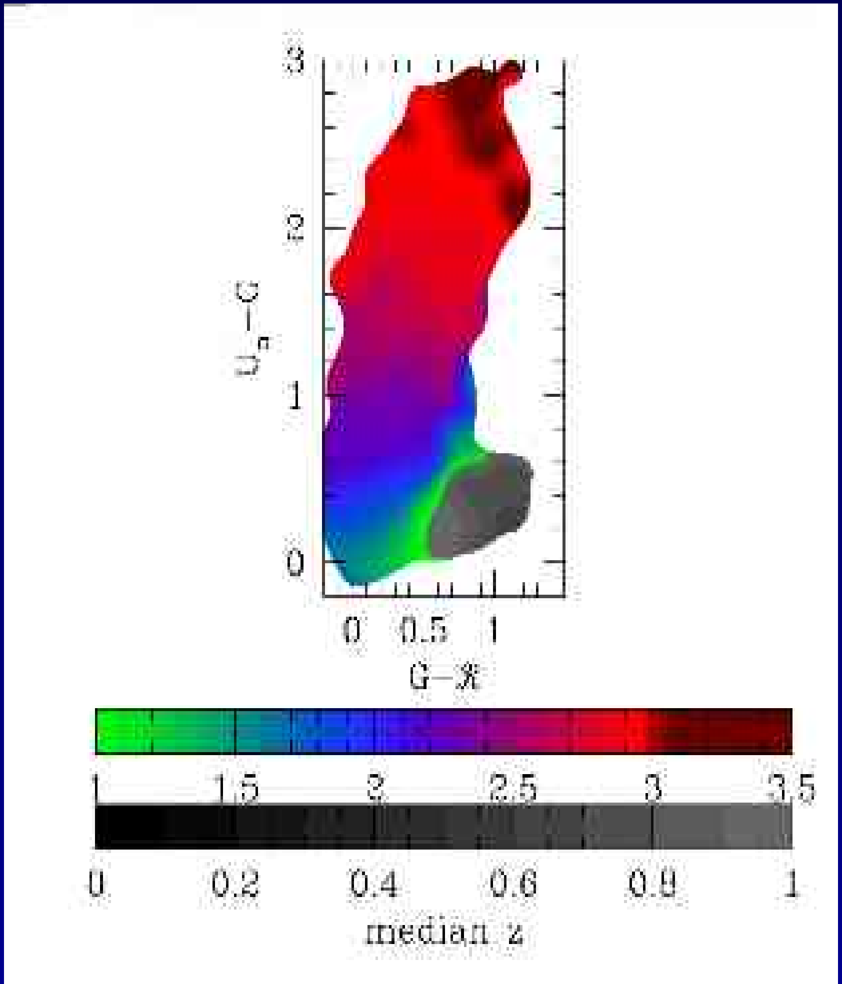
dots:

16 ISO 15 μm sources with $\mathbf{0.84 \leq z \leq 1.15}$



Colour Selection at higher redshifts





Summary of the Discussion

- The optical colours of galaxies at redshifts $1 < z < 3$ *are* distinctive
- These galaxies are easy to locate in deep images using simple colour selection criteria
- With an appropriately chosen spectroscopic setup, redshifts are as easy to measure from absorption lines as from the Lyα or [OII] λ3727 emission lines
- A major benefit of colour-selected spectroscopy is that it lets one draw statistically significant conclusions from large number of high redshift galaxies without having to measure a redshift for every one
- The weakness of colour-selected surveys is that not all galaxies at the targeted redshifts will satisfy the adopted selection criteria. In any case, all observational strategies require some compromise between efficiency and completeness
- Magnitude-limited optical surveys are not the only alternative to colour-selected optical surveys. Many have advocated finding galaxies at $1 < z < 3$ with photometry outside of the optical window
- The developed criteria relied solely on optical photometry because ground-based optical imagers offer an unrivalled combination of *high sensitivity*, *high spatial resolution*, and *large field-of-view*.

Instead of Conclusions

It seems likely to us that much of what we will learn about galaxies at $1 < z < 5$ in the coming decade will come from large optical surveys selected with color criteria similar to ours. Attentive readers may have recognized that the derivation of these criteria did not require much thought. That is exactly the point. The value of this paper, if any, lies not in our photometric selection criteria themselves but in the proof that large samples of galaxies at $1 < z < 3$ can be created with trivial techniques that rely solely on ground-based imaging and well-developed CCD technology. The spectroscopic desert is a myth.

The spectroscopic desert is a myth!!!

Other Approaches to the 'Redshift desert'

- Nod & Shaffle technique
  - GDDS: GMOS@Gemini-N – both red and blue objects (Glazebrock et al. 2003, Savaglio et al. 2003)
- Red optimized spectrographs
  - DEEP2 Galaxy Redshift Survey: DEIMOS spectrograph@Keck-II – red object up to z ~ 1.5 (Coil et al. 2004)
- Near-IR observations should provide a more complete census of older stars, and far-IR/sub-mm surveys should yield more reliable estimate of SFRs