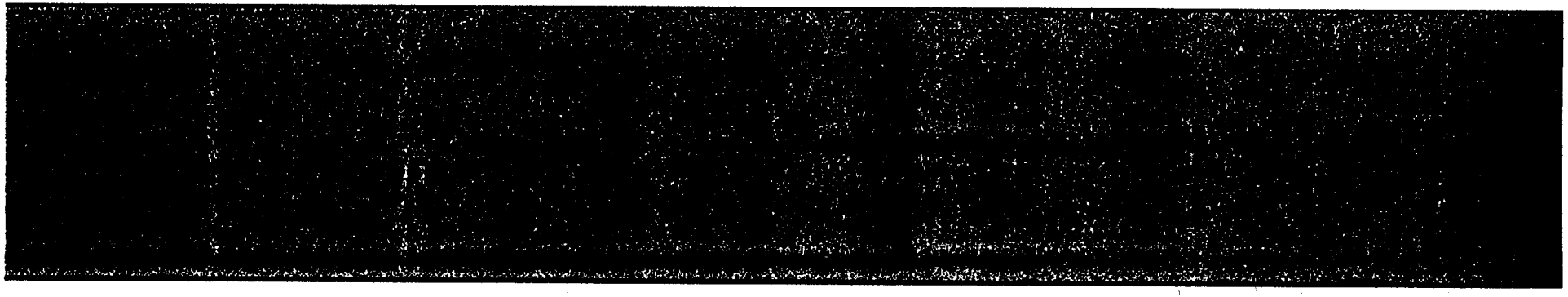
A LONG TIME AGO IN SOME GALAXIES FAR, FAR AWAY



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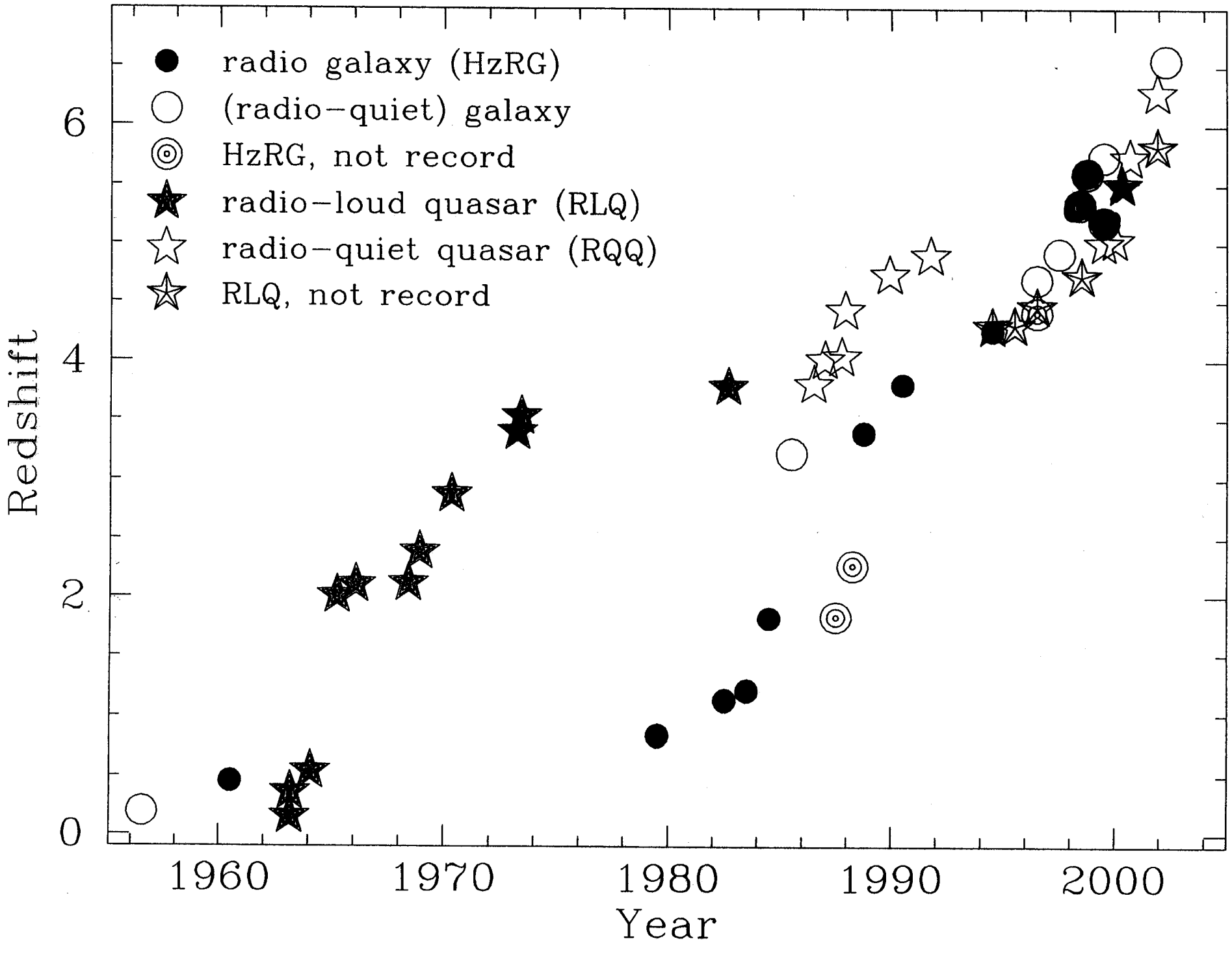
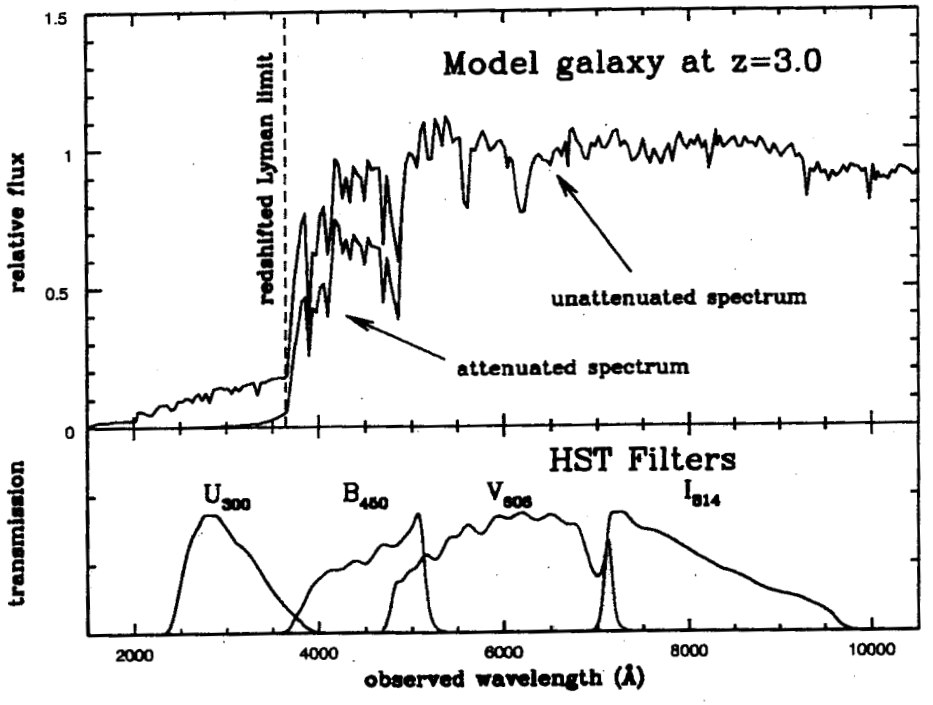

radio galaxy (HzRG)
(radio−quiet) galaxy
HzRG, not record
radio−loud quasar (RLQ)
radio−quiet quasar (RQQ)
RLQ, not record
Redshift
0
2
4
6
1960
1970
1980
1990
2000
Year

OUTLINE

1. high-redshift galaxies & quasars
   - how to find 'em
   - what are we learning?
2. the highest redshift supernova
   - how was she found?
   - what did we ~learn~?
3. prospects for SIRTF, esp. GOODS



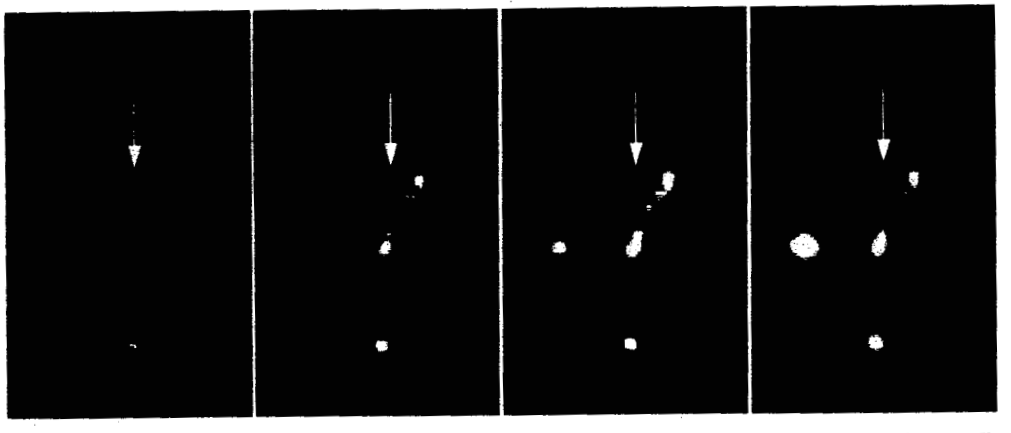
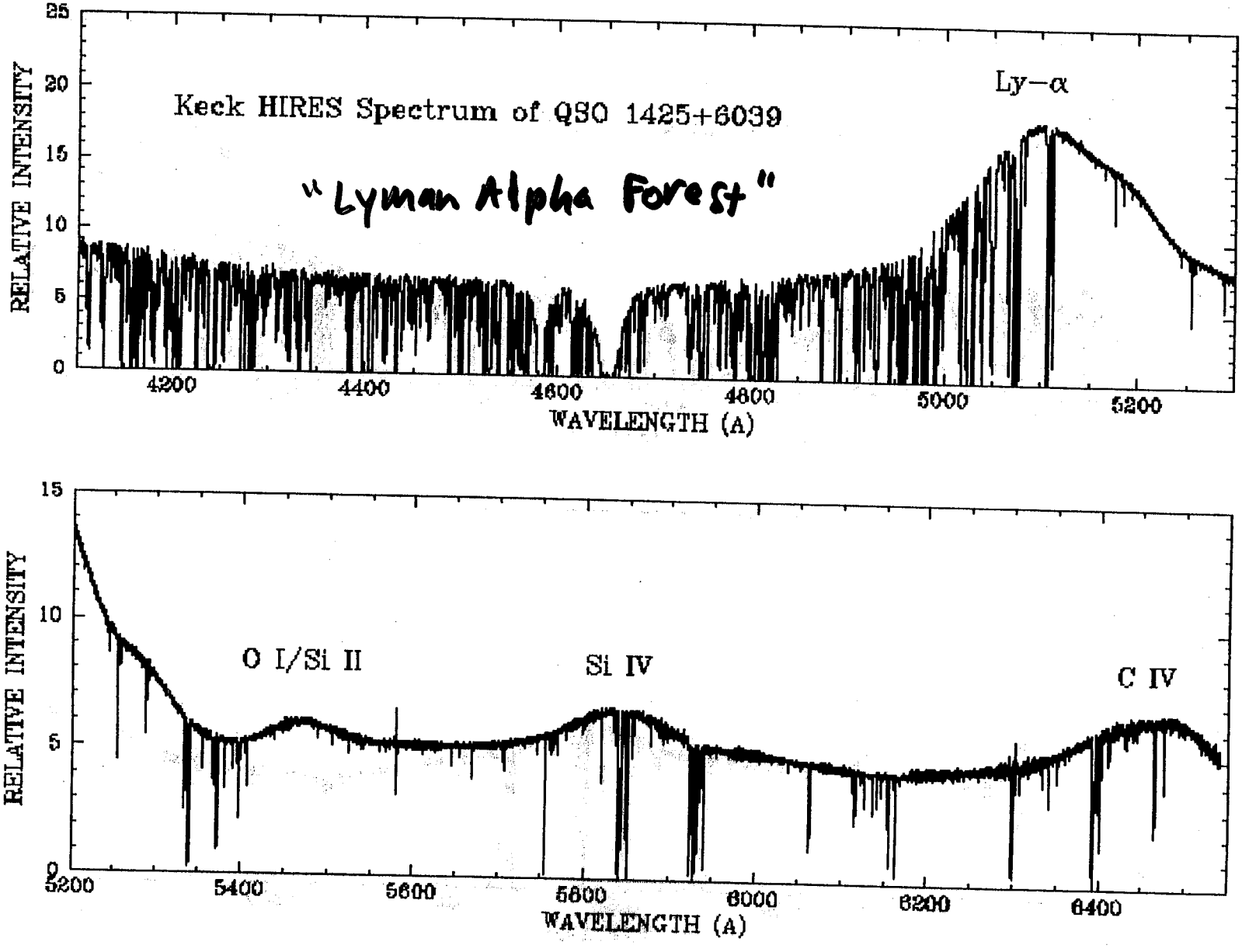


FIGURE 1. Illustration of the Lyman break technique as applied to the Hubble Deep Field. The upper panel shows a model spectrum of a star forming galaxy observed at $z = 3$. Its flat UV continuum is truncated by the 912Å Lyman limit, which is redshifted between the U_{300} and B_{450} filters (WFPC2 bandpasses shown below spectrum). In addition to photospheric absorption in the UV-emitting stars, the effects of intergalactic neutral hydrogen further suppress the continuum in the U_{300} and B_{450} bands. At bottom, an HDF galaxy is shown in the four WFPC2 bandpasses. Clearly visible at I_{814}, V_{606} and B_{450}, it vanishes in the U_{300} image. This galaxy has been spectroscopically confirmed to have $z = 2.8$.

of advantages. The HDF can be used to detect Lyman break galaxies at fainter apparent magnitudes than has been achieved in ground-based data, and the precision of the B_{450}, V_{606} and I_{814} photometry ensures small random errors on color measurements. Moreover, the depth and resolution of the WFPC2 imaging permits detailed morphological study of these objects. The primary *disadvantage* of the HDF is its small field


Keck HIRES Spectrum of QSO 1425+6039
"Lyman Alpha Forest"
Ly−α
RELATIVE INTENSITY
WAVELENGTH (A)
O I/Si II
Si IV
C IV

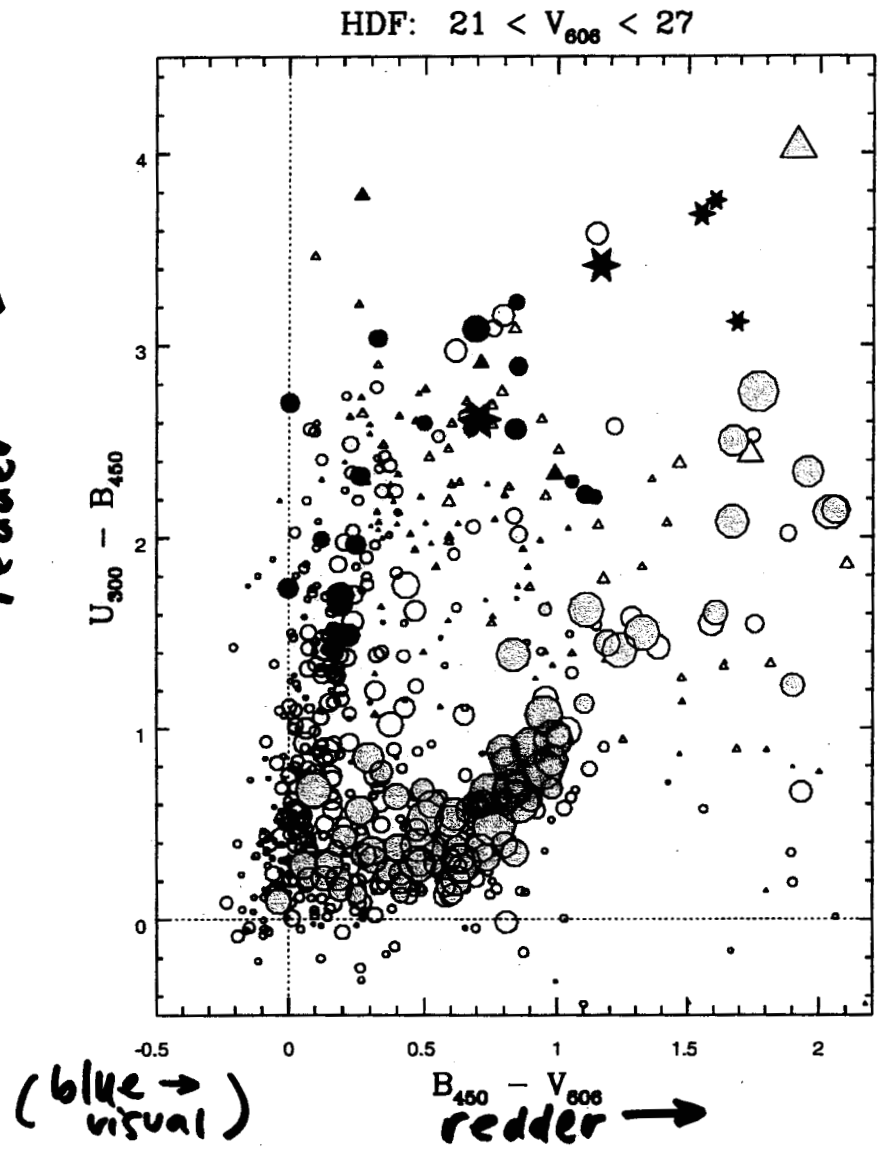


FIGURE 2. Color–color diagram of faint galaxies in the Hubble Deep Field, illustrating the "plume" of Lyman break objects rising from $U_{300} - B_{450} = B_{450} - V_{606} = 0$. These are nearly all galaxies at $z > 2$. Spectroscopically confirmed objects in this redshift range are shown as darker filled symbols; galaxies with measured redshifts $z < 2$ are shown as light filled circles, and stars are indicated by star–shaped points. Triangles mark lower limits (1σ to the $U_{300} - B_{450}$ color for objects undetected in U_{300}. Symbol size scales inversely with apparent V_{606} magnitude.

of view, and hence the rather small comoving volume which it samples. This limits its utility for statistical studies (e.g. of luminosity functions, redshift distributions, etc.), as small number statistics, galaxy clustering, and field–to–field variations may introduce significant uncertainties.

z ≥ 4

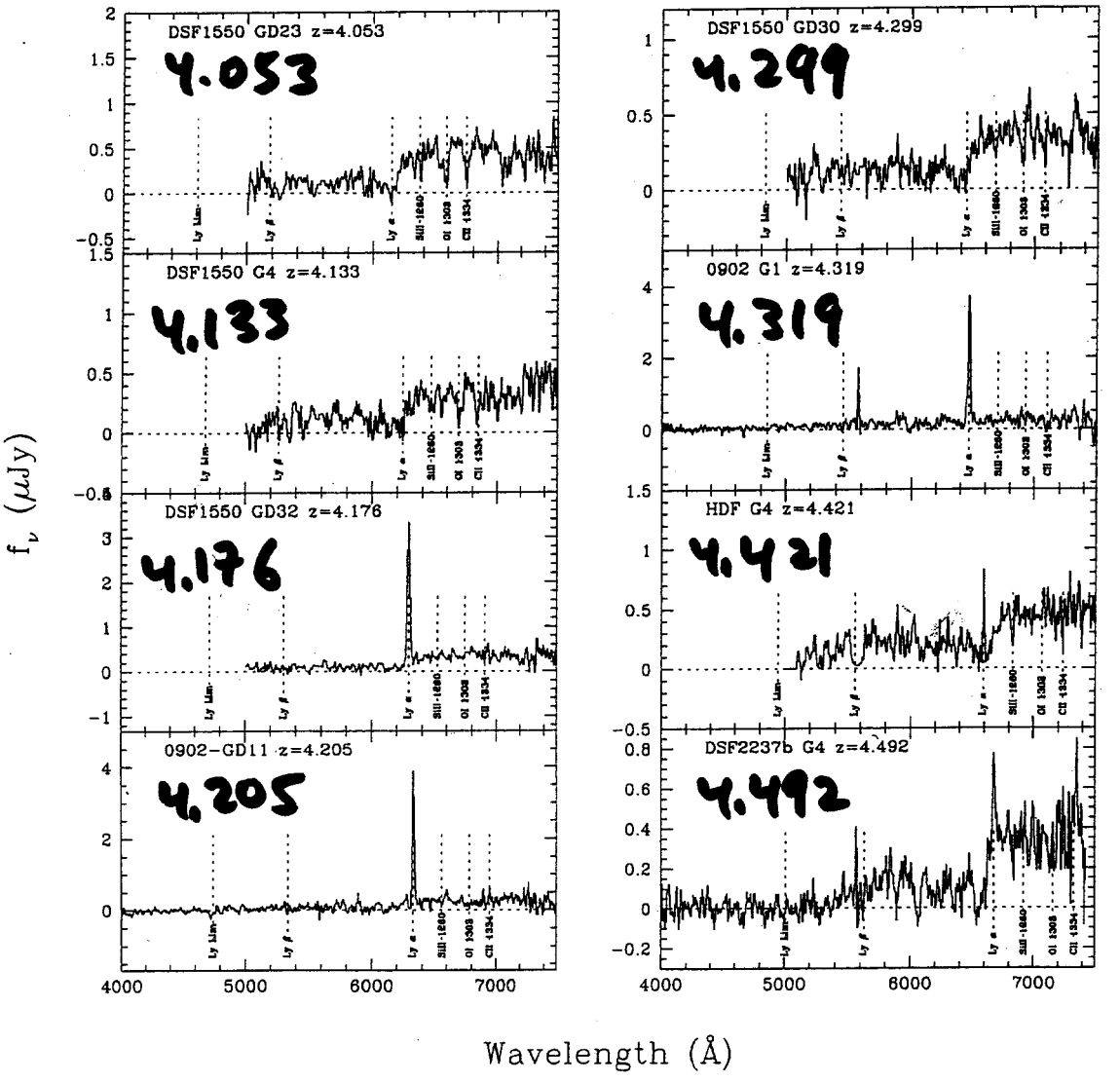
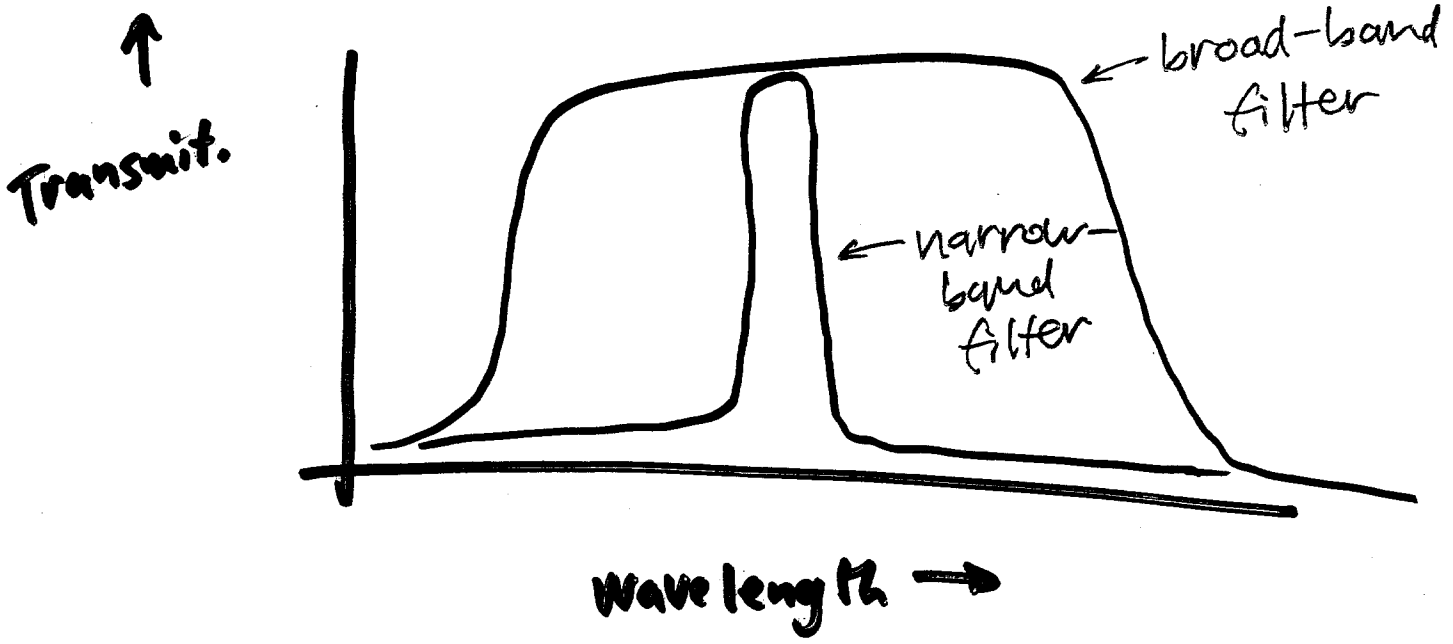
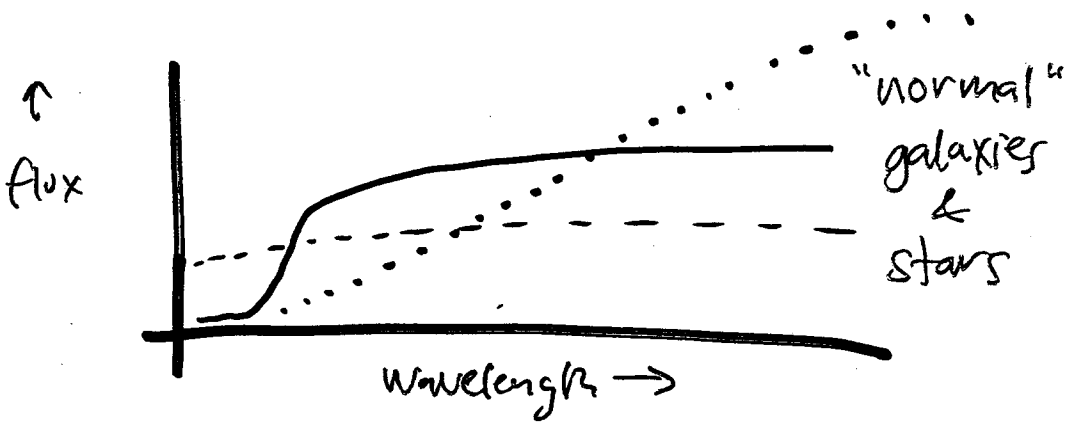
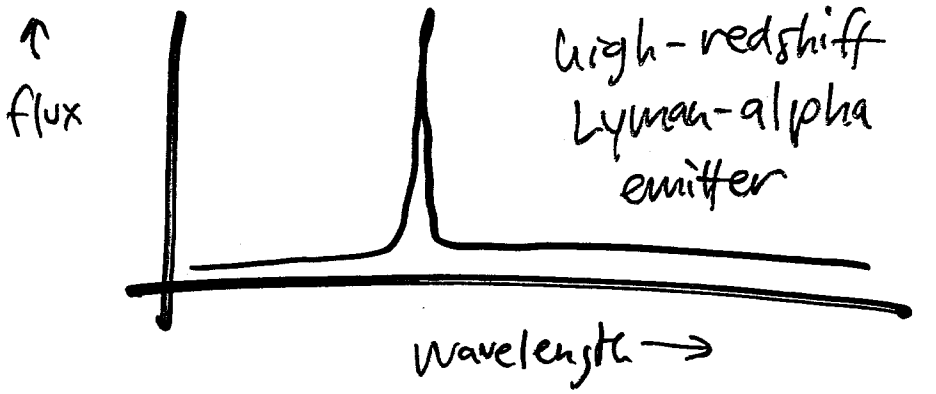


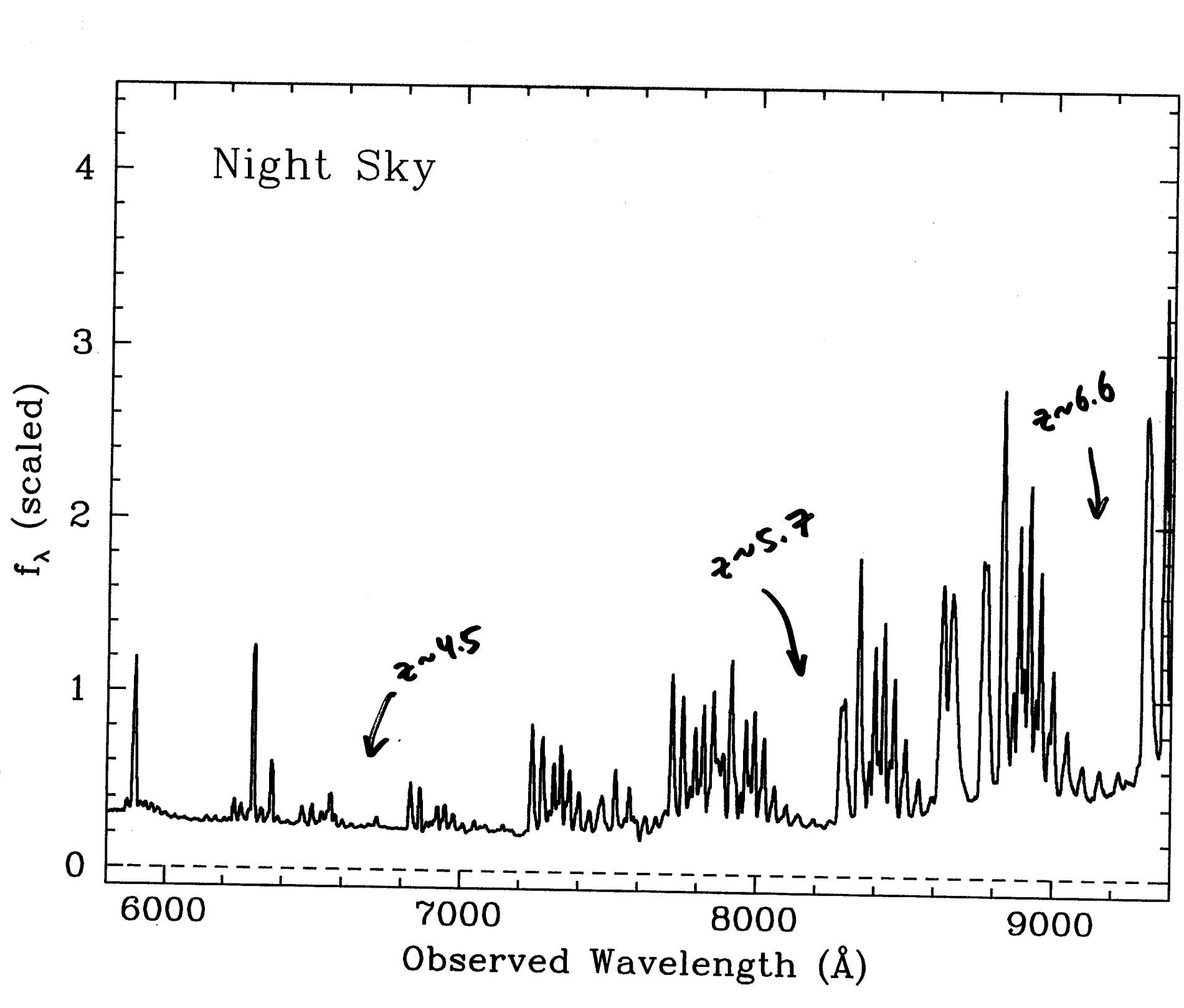
Fig. 3.— Example spectra of G-band break objects. Note that, as for the $z \sim 3$ sample, the $z \sim 4$ Lyman-break galaxies have a widely varying Lyman α line strength, from strong emission lines, to very strong and broad absorption. Overall, the spectra are very similar to the $z \sim 3$ objects at correspondingly bright UV luminosities.

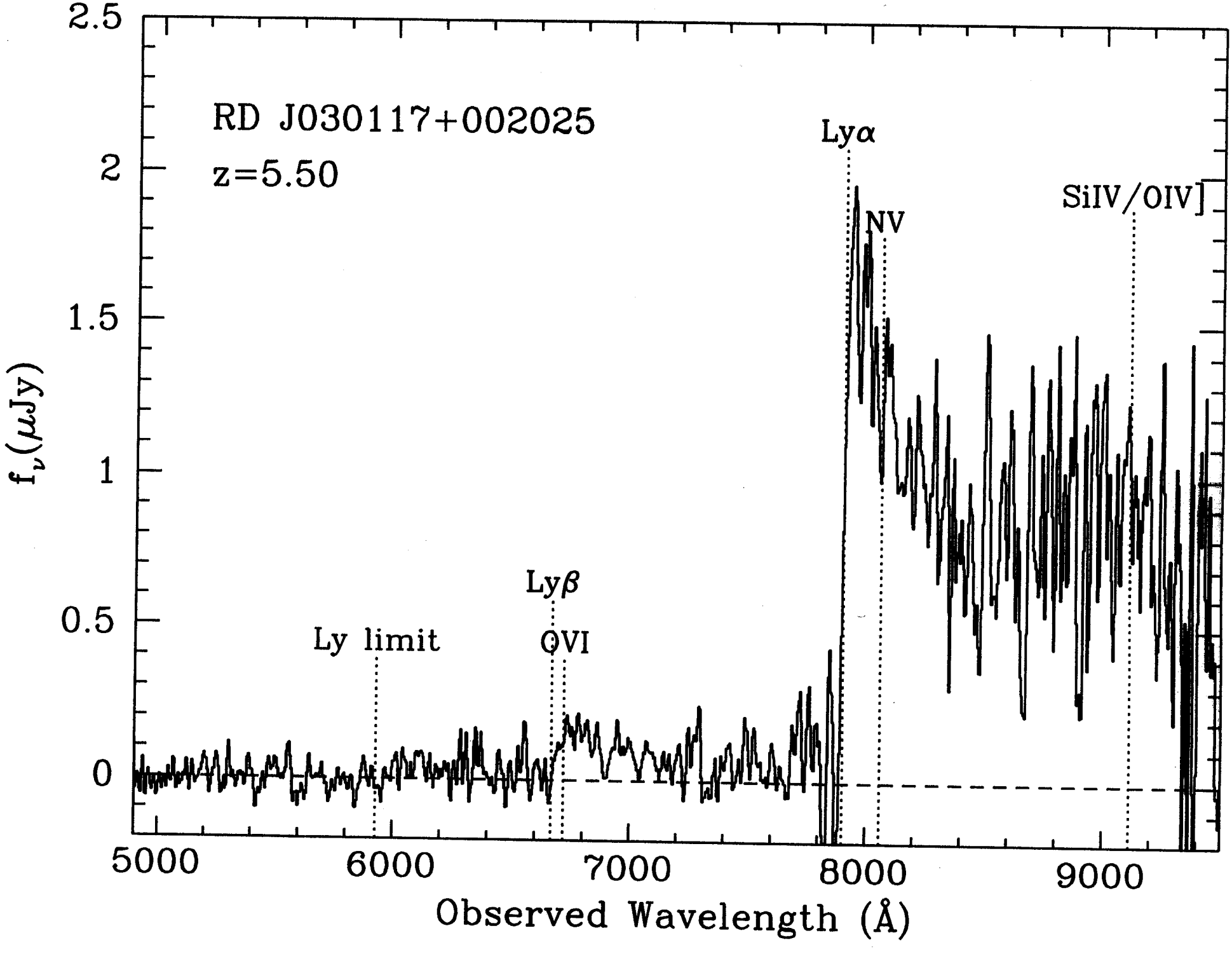
Steidel et al 1999

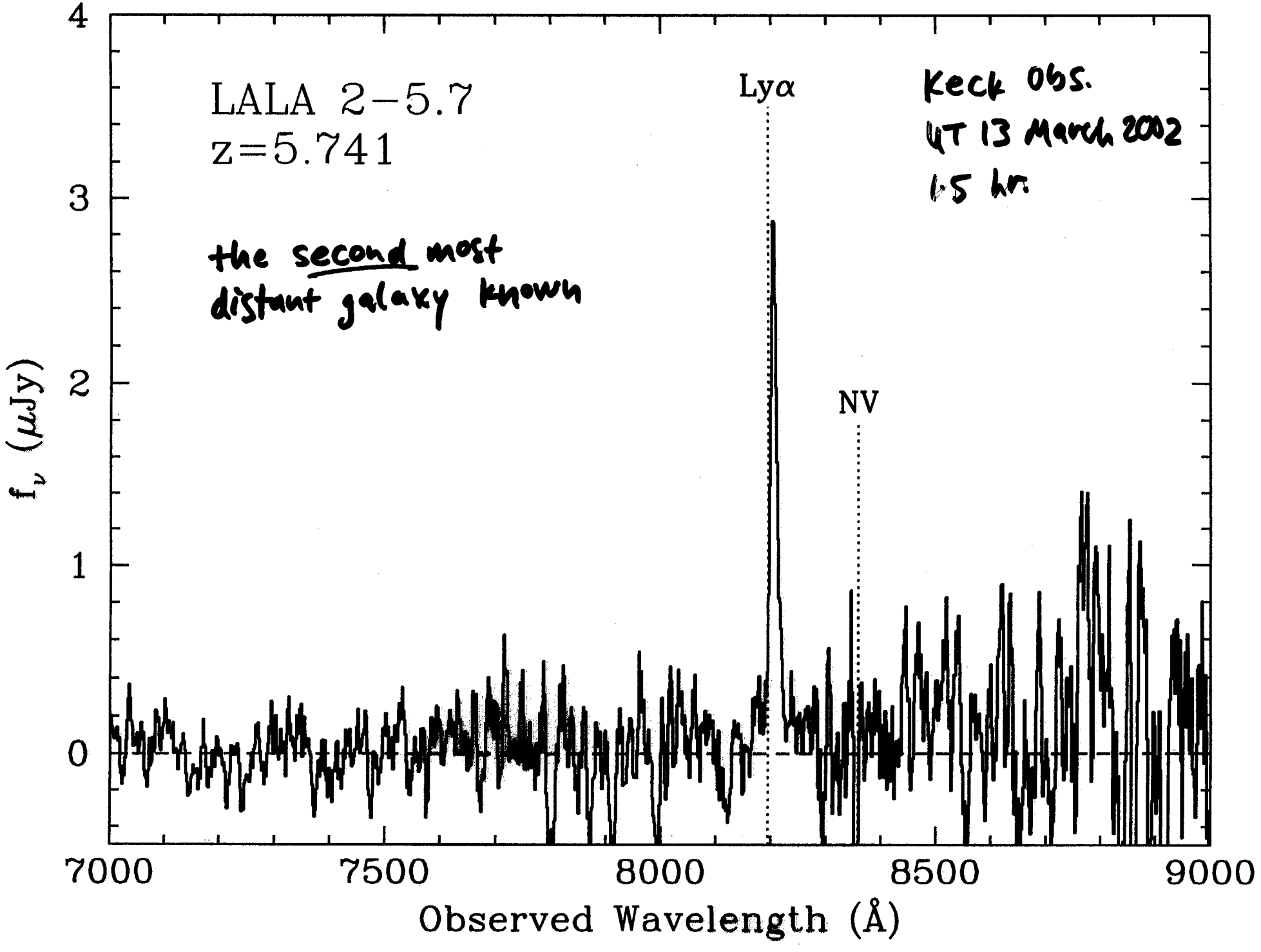

Transmit.
broad-band filter
narrow-band filter
Wavelength


flux
"normal" galaxies & stars
Wavelength


flux
high-redshift Lyman-alpha emitter
Wavelength


Night Sky
z~4.5
z~5.7
z~6.6
f_λ (scaled)
0
1
2
3
4
6000
7000
8000
9000
Observed Wavelength (Å)


RD J030117+002025
z=5.50
Lyα
NV
SiIV/OIV]
Lyβ
OVI
Ly limit
2.5
2
1.5
1
0.5
0
5000
6000
7000
8000
9000
$f_\nu(\mu Jy)$
Observed Wavelength (Å)


LALA 2−5.7
z=5.741
Lyα
NV
Keck Obs.
UT 13 March 2002
1.5 hr.
the second most
distant galaxy known
f_ν (μJy)
Observed Wavelength (Å)
0
1
2
3
4
7000
7500
8000
8500
9000

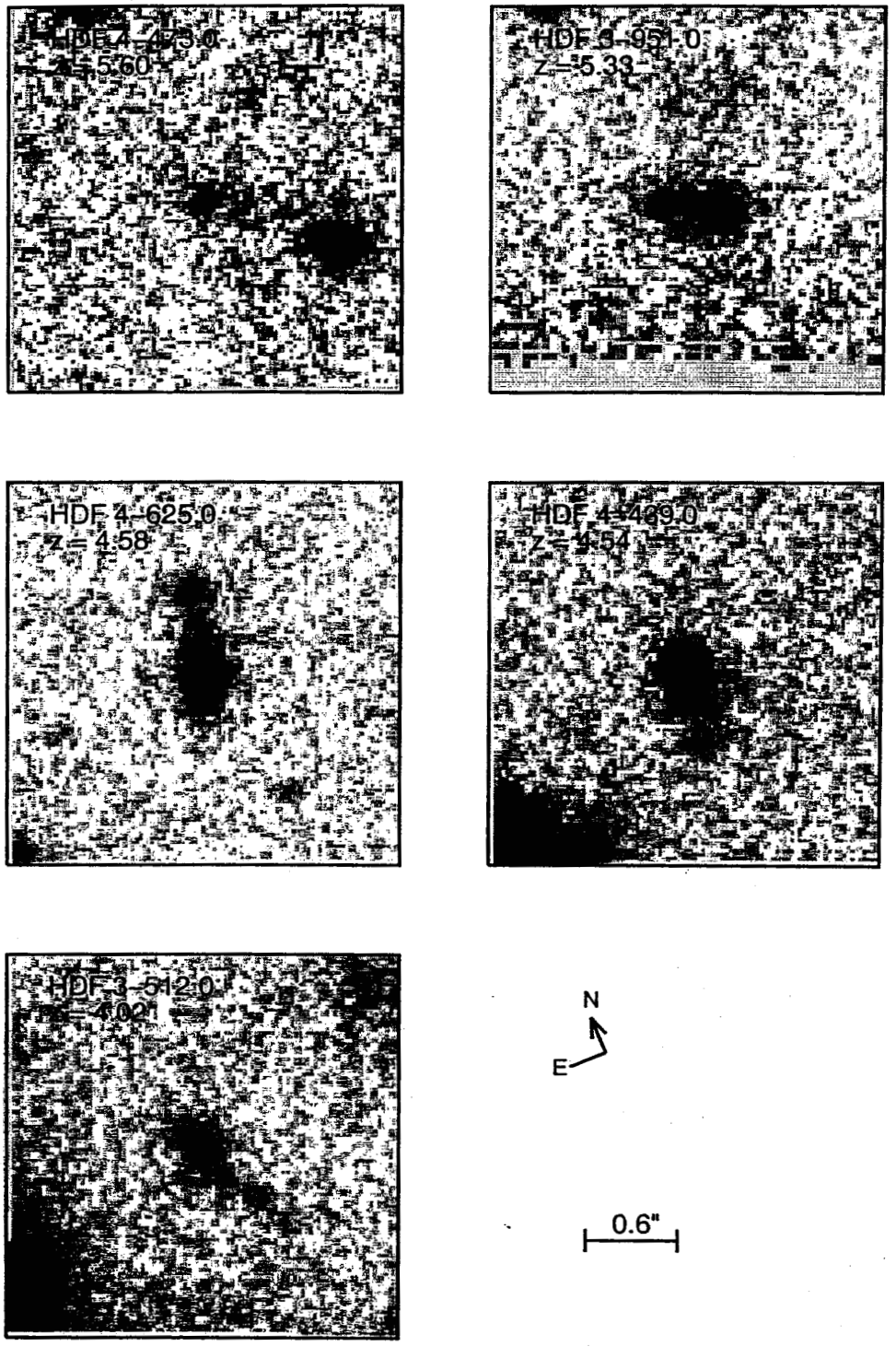


FIG. 13.—Montage of spectroscopically confirmed $z > 4$ galaxies in the HDF, from the drizzled F814W (I_{814}) images. Note that most of the galaxies are compact, but show evidence of merging activity (interactions), in the form of multiple nuclei, multiple components, and/or extended, low surface brightness tidal tails.

What is the Reionization Era?

A Schematic Outline of the Cosmic History

Time since the Big Bang (years)

~ 300 thousand

~ 500 million

~ 9 billion

~ 13 billion

← The Big Bang

The Universe filled with ionized gas

← The Universe becomes neutral and opaque

The Dark Ages start

Galaxies and Quasars begin to form
The Reionization starts

The Cosmic Renaissance
The Dark Ages end

← Reionization complete, the Universe becomes transparent again

Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!

S.G. Djorgovski et al. & Digital Media Center, Caltech

DK