A Wide-Field Heirarchical Photometric HyperSuprimeCam Survey

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Galaxy formation research today

- *The cosmological model is known well enough that the uncertainties of the large-scale physics of the universe almost certainly have no significant effect on the physics of galaxy formation*

- *Large surveys like the SDSS, GALEX, ALFALFA and smaller targeted surveys like SINGS now characterize the present population of galaxies very well:*

  Stellar populations and stellar masses
  Luminosities
  Sizes and luminosity profiles
  Environmental dependence
  Chemistry
  Structural morphology

- *To go forward, need a new deep survey. Subaru/HSC is the ideal instrument.*

Princeton's Role:

- *Survey Design – Using SDSS experience*

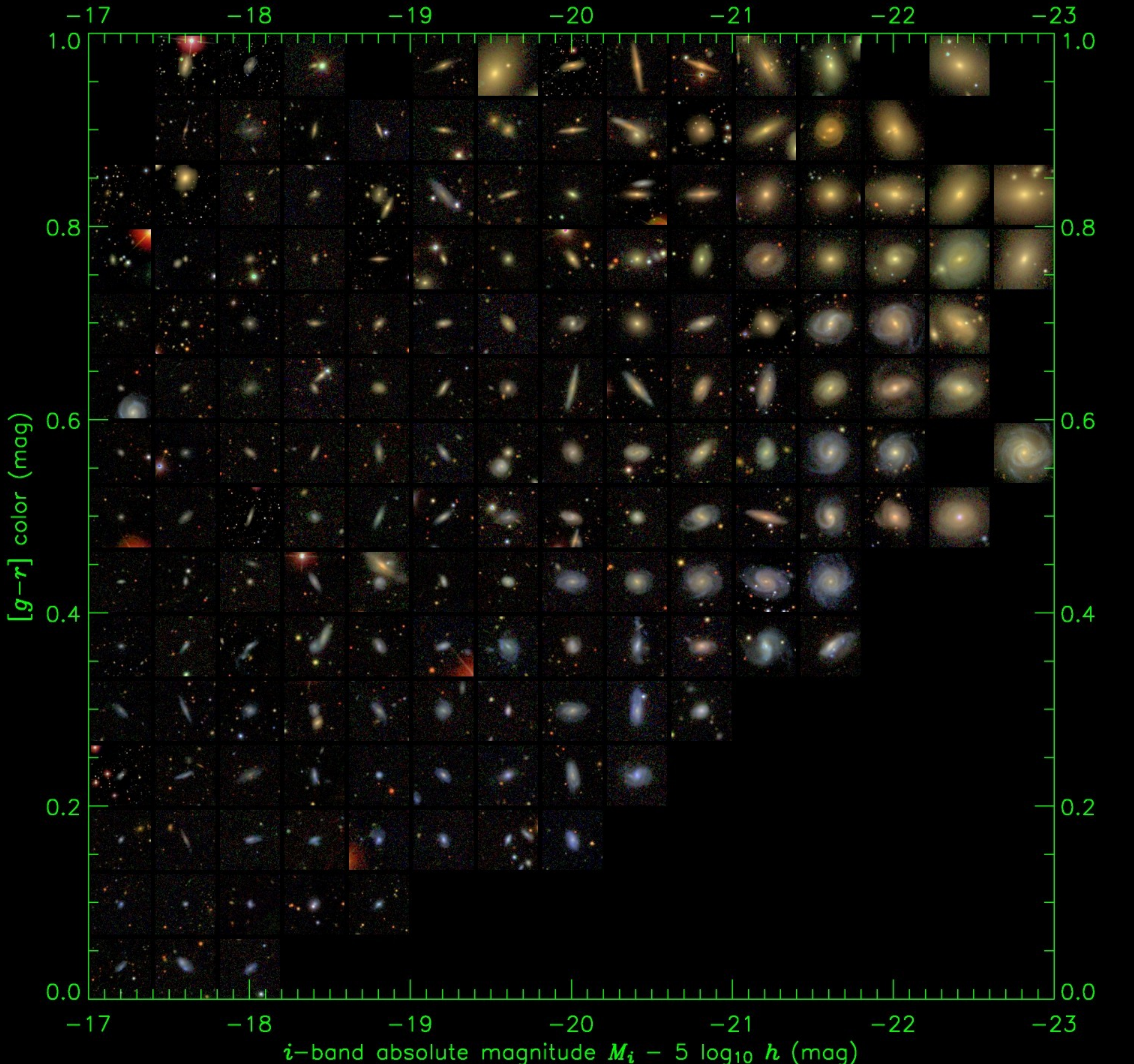
- *Data Handling – SDSS, PanSTARRS, and especially LSST*

  HSC Etendue is ~0.3 LSST, HSC on air substantially before LSST. Easily ~5 magnitudes fainter than SDSS over substantial areas. Ideal instrument for large surveys.

- *Help with HSC design and construction*

- *Science from Large Surveys*

This mosaic from Hogg and Blanton illustrates the sequence of properties of normal galaxies with color and luminosity.



To Design a Survey for Galaxy Evolution

The goal is , eventually, to understand how the diagram in the last slide is populated from the earliest phases of galaxy formation in the universe.

We cannot do this observationally with current capabilities.

The proposal is much more modest.

Can we push the measurement of the primary parameters of the population of at least typical bright galaxies ($L > L^*$) back to high redshifts, and understand the dependence on environment well enough to be able to connect populations at different redshifts?

Environment:

- *The rank of densities on scales of several megaparsecs (still ~ linear) is well-preserved*

So if we can map regions ranked in density on suitable scales, we can connect populations early in the universe with populations today.

To do this well requires redshifts, but it should be possible to do crudely with photometric redshifts.

However:

**Any* such survey must have spectroscopy of at least a small subset of galaxies to calibrate photometric redshifts and density-finding algorithms.*

What would we like to measure?

Hogg and Blanton have characterized the nearby galaxy population with 7 parameters; it would be useful to use these or a related set for distant galaxies as well.

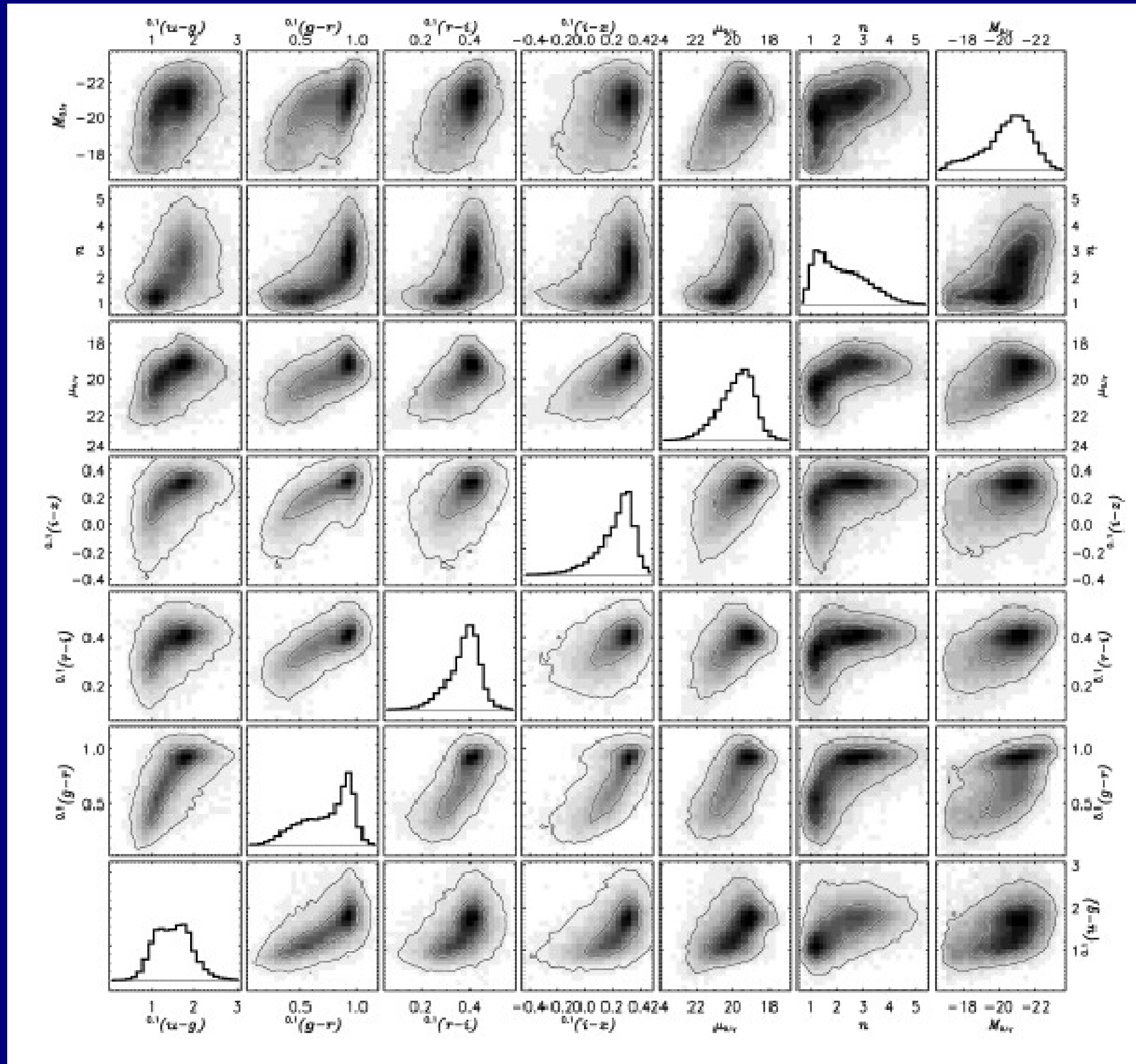
The SDSS has five bands, so they use 4 colors.
To use the same *rest-frame* colors requires infrared photometry.

Luminosities – again, need at least crude redshifts

Sizes – effective radii (surface brightnesses)

Radial profiles – Sersic law $B = B_0 \exp (r/r0)^{-1/n}$

This diagram shows the distribution of the parameters at z=0.1. The grayscale intensity is proportional to the space lminosity density of objects at those parameter values per unit area in the diagram.



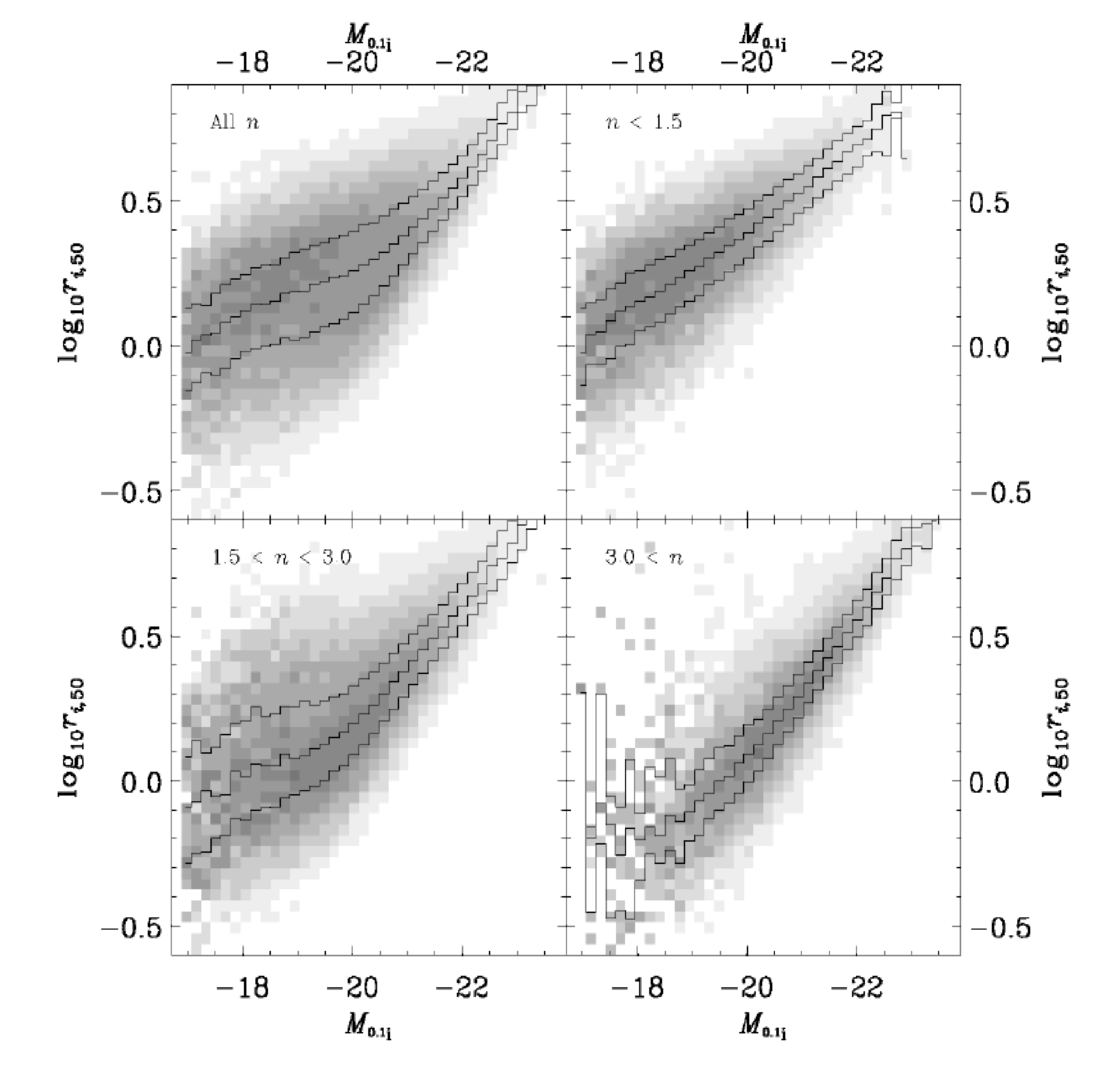
There is strong structure in the diagram, and corresponding structure is expected to be present at higher z.

Half-light radii for galaxies with various Sersic profiles.

L galaxies have R_es between 2 and 4 kpc, larger for late-type systems*

($R_e \sim 1.7/\alpha$ for an exp. disk)

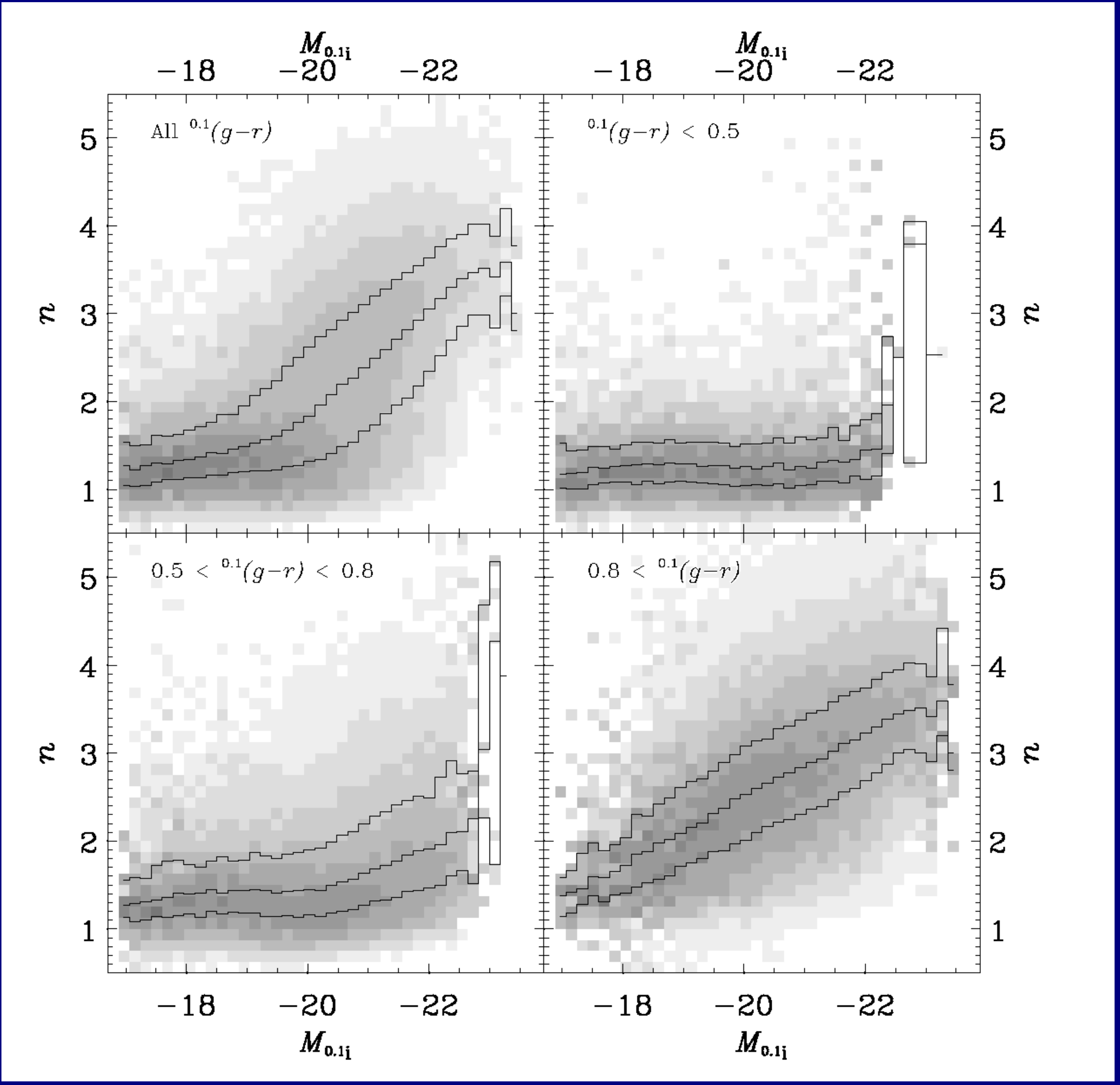
relations similar for all n.



Sersic index as a function of luminosity and color.

All blue galaxies are exponential

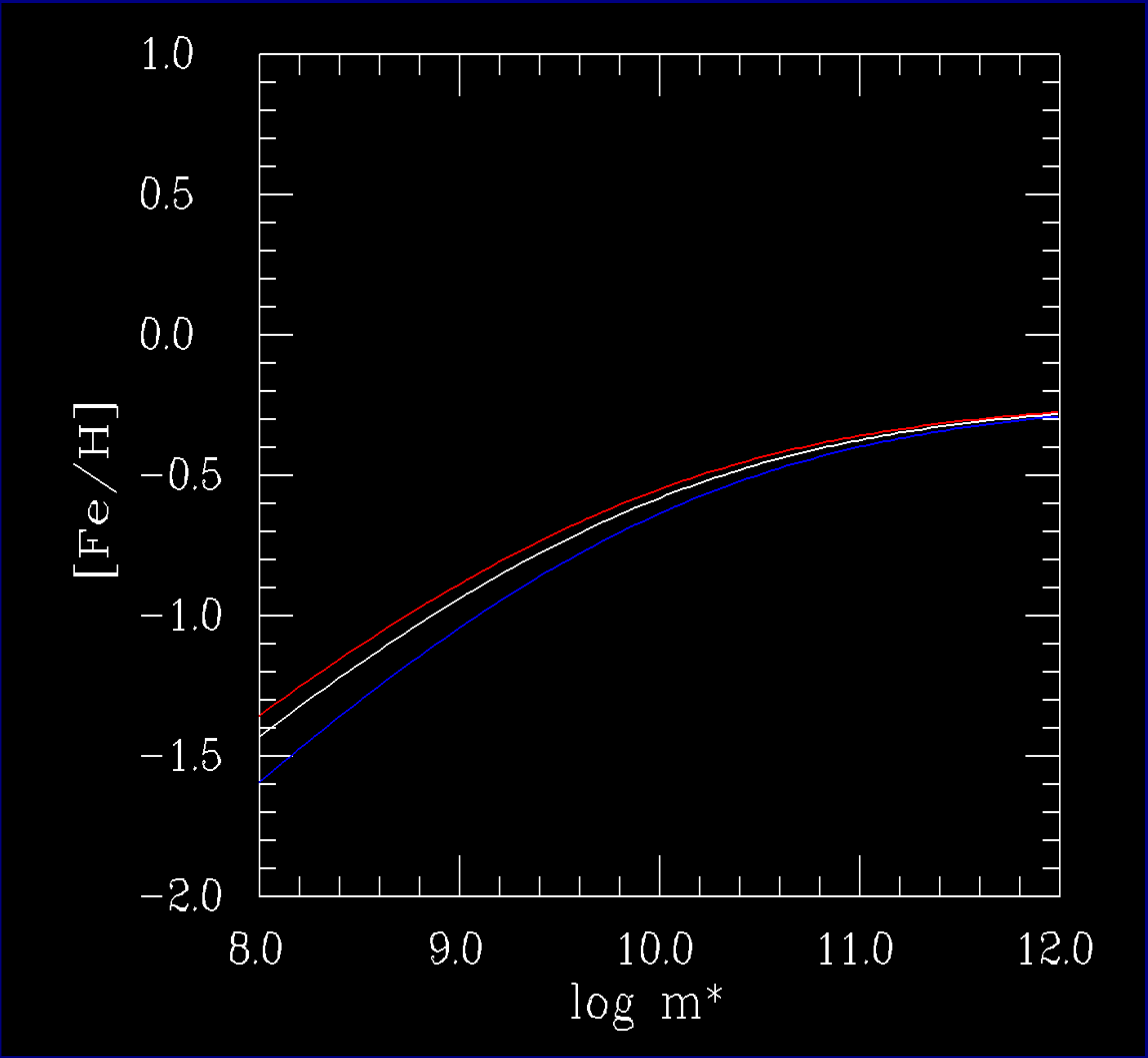
There is a well-defined index-absolute magnitude relation among the reddest galaxies



We can use population models to see what we might expect in a distant survey; need abundance estimates.

We can use the work of Tremonti and Kanappan to estimate.

Here is the derived stellar metallicity as a function of stellar mass for the red and blue sequences and the mean.



Some Basic Cosmological Data

bin	zc	zrange	vol/deg^2 (Mpc^3)	Area 1 Gpc^3 (deg^2)	Modulus (mono-chrom)	age (Gyr)	1" is (kpc)	lam 4000 (μ)	lam Ly alpha	lam Ly lim
1	1.0	0.84-1.19	1.08e6	925	42.6	5.87	5.75	0.80	0.24	0.18
2	1.41	1.19-1.68	1.96e6	507	43.4	4.53	6.09	0.97	0.29	0.22
3	2.0	1.68-2.38	3.26e6	307	44.1	3.31	6.07	1.20	0.36	0.27
4	2.83	2.38-3.36	4.62e6	216	44.7	2.31	5.71	1.53	0.47	0.35
5	4.0	3.36-4.75	6.02e6	168	45.3	1.56	4.68	2.00	0.60	0.46
6	5.66	4.75-6.72	7.19e6	139	45.9	1.01	4.32	2.66	0.80	0.61
7	8.0	6.72-9.50	7.90e6	126	46.5	0.65	3.54	3.60	1.09	0.82

The SDSS covers about
~0.2 Gpc^3 for the main sample ($z<0.2$),
~1.4 Gpc^3 for the LRG spectroscopic sample ($z<0.4$),
~4 Gpc^3 for the LRG photoz sample ($z<0.6$)

How much sky do we need to cover?

IDEALLY, would explore large range in structure. One Coma cluster is found in ~.01 h^{-3} Gpc^3, about the same volume as the baryon oscillation correlation shell (r ~ 120h^{-1} Mpc). Volumes this size are essentially uncorrelated. We would like enough volumes this size to do 10% statistics, or ~ 1 h^{-3} Gpc3. This may not be possible, but is a reasonable goal, but is not very feasible; the SDSS main sample, for instance, covers only ~0.2 h^{-3} Gpc3

How deep do we need to go?

*This depends on what we want to do. At least good detections (5σ) for the full range of galaxies presently of luminosity ~ L**

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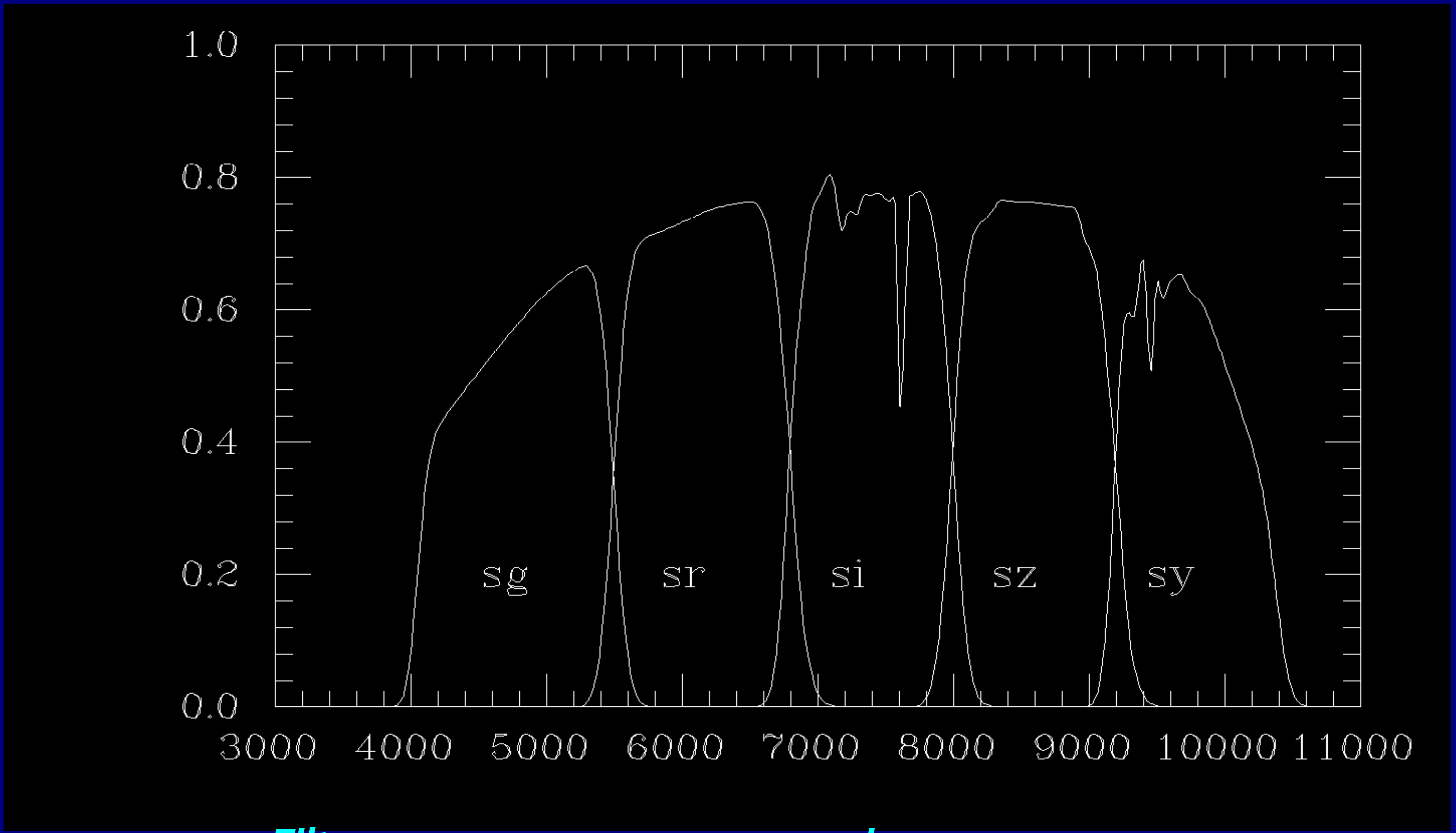
The Proposed Survey: Filters



Filter	sg	sr	si	sz	sy
λeff	4810	6140	7380	8580	9720
qtdl/l	0.169	0.157	0.122	0.105	0.068

The Proposed Survey: Depth and Areas

We propose a 3-layer survey: a shallow one covering 300 square degrees, a deeper one covering 20 square degrees, and a very deep one (3 HSC fields) covering 5 square degrees; each layer receoves 10 times the exposure time of the next shallower. The depths below are AB magnitudes, point source, for 5:1 S/N. Galaxies are on average 0.7 mag shallower.

	sg	sr	si	sz	sy	Area	time (hr)		Vol/z (Gpc^3/z)
	15m	15m	15m	15m	30m		fld	total	
X1	27.3	26.8	26.4	25.8	25.3	300	2	340	~0.5/0.7-1.3
X10	28.6	28.1	27.7	27.1	26.6	20	20	225	~0.1/1.5-2.5 ~0.1/2.5-3.5
X100	29.8	29.3	28.9	28.3	27.8	5	200	560	~0.05/4-6

The total time is 1125 hours, 140 *good* nights, ~200 allocated nights.

Science with the Shallow Layer

1. Weak lensing; we have heard about this from the Camera team; This sample will provide the most powerful lensing sample to date, reaching sources reliably to z~1.3 with reasonably accurate photometric redshifts over a very large area. Of order 10^8 source galaxies, ~$3x10^5$ per square degree. 80 per square arcminute. Good z imaging results in better seeing, more regular galaxies (less shape noise),

2. Galaxy evolution to z~1.3. We can get good photometric redshifts to this redshift using ONLY HSC data, very accurate for massive red galaxies . Use correlation techniques for redshifts of satellites (Majesdi, Newman). Need FMOS data for a subset, or collaborate with Carnegie for PRIMUS-2 redshift data

3. Quasars to redshift ~7.5, explore reionization

4. Solar system (Amaya will discuss)

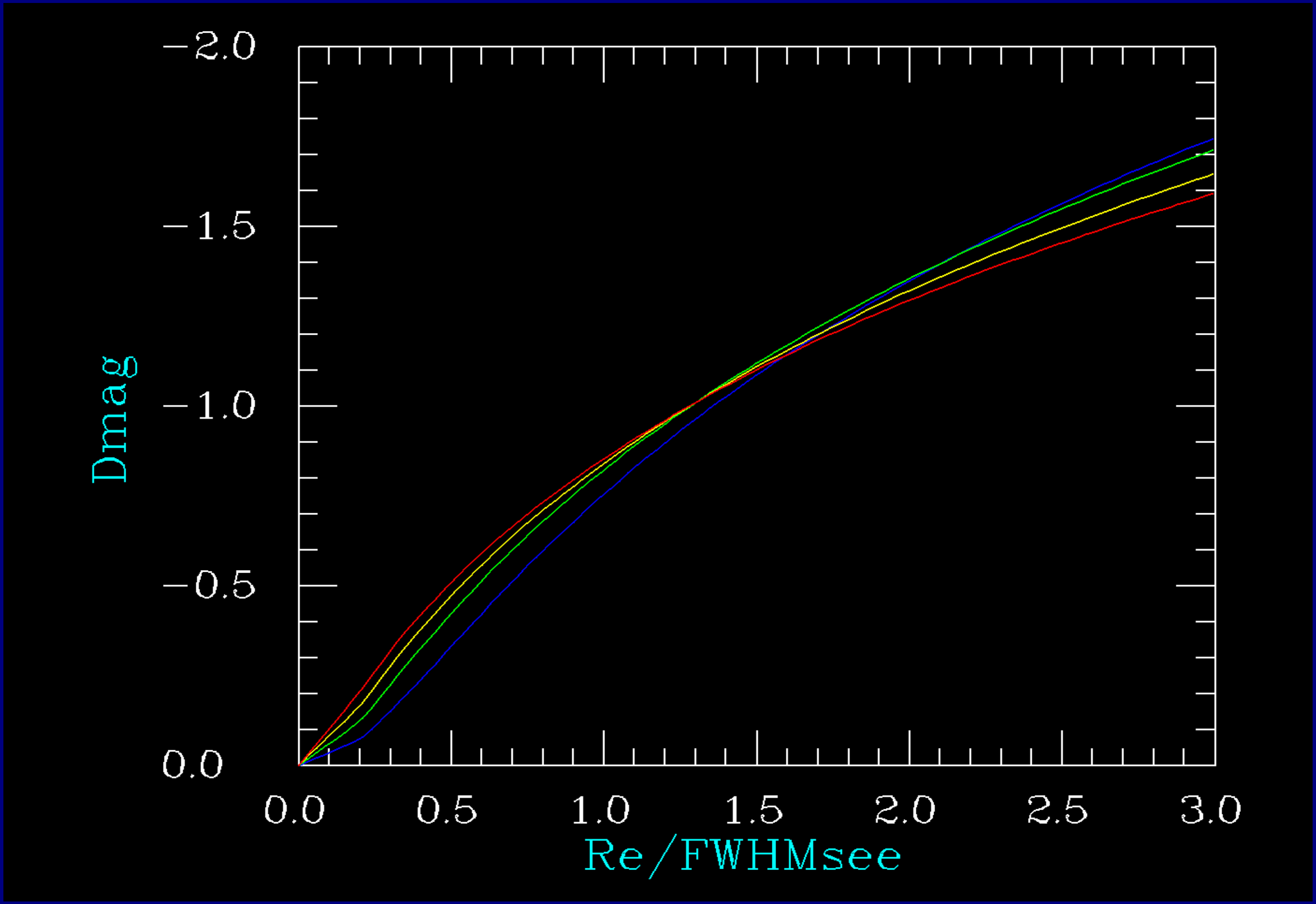
5. Galactic science. K giants to >1 Mpc, little contamination

Talk a little more about galaxy evolution.

Galaxies are extended sources

For 1 < z < 2.5, angular diameters change almost not at all, and 1 arcsec ~ 6 h^{-1} kpc. So 0.7 arcsec seeing is 4 kpc FWHM, and Re ~ 0.7 seeing diameters for L* galaxies. If we measure fluxes using profile fitting, this costs ~0.7 magnitude.

red: n=4
yel: n=3
grn: n=2
blu: n=1



New 5σ limits are

g	26.5
r	26.0
i	25.6
z	25.0
y	24.5

Galaxy Evolution in the Shallow Survey

Can we do the science effectively with this survey?

We will check with simple evolutionary models.

In the SDSS main sample, galaxies at L* have a mean g-r color of 0.78, with a dispersion of 0.18 magnitudes. ~75% of L* galaxies have g-r between 0.60 and 0.96

We parametrize the models with a simple SFR of the form

$$SFR = x \exp(-x) , x = t/t0$$

and use the Maraston (06) burst models for the basis SEDs, with the Tremonti/Kannappan stellar metallicities. Match z=0 colors with t0, fix metallicity, obtain magnitues and masses as functions of redshift.

Galaxies are extended sources, and this subtracts ~0.7 magnitudes from the point-source limits.

But we have stellar mass/stellar metallicity relation from the SDSS main sample, so one can find the correct mean metallicity. The mass is insensitive to the metallicity, so this is well determined.

Using the data from the main sample, we find

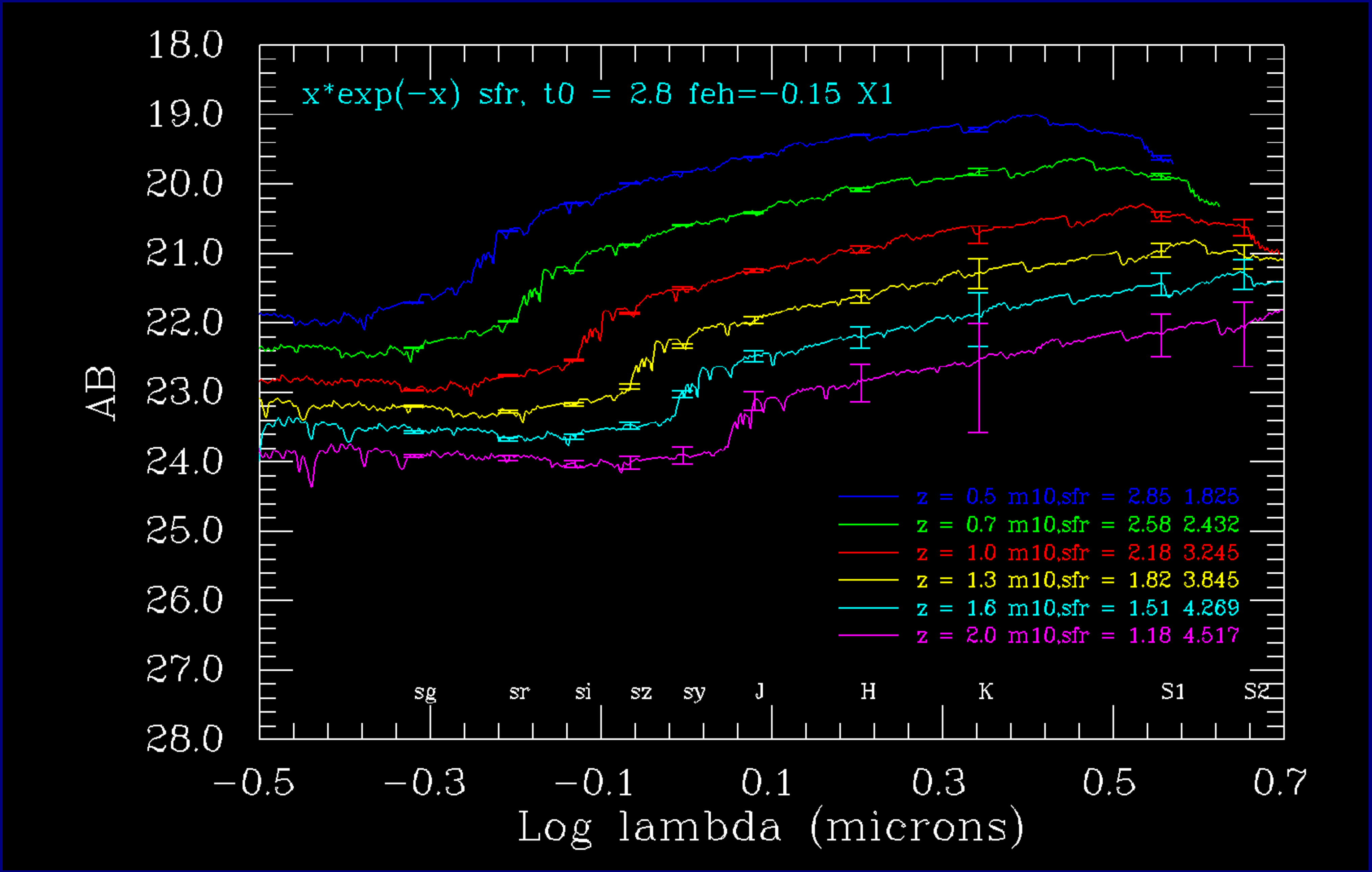
g-r	<[Fe/H]>	t0	m*
0.60	-0.3	4	2.1e10
0.78	-0.15	2.8	3.2e10
0.96	0.0	1.6	5.5e10

and the very reddest end:

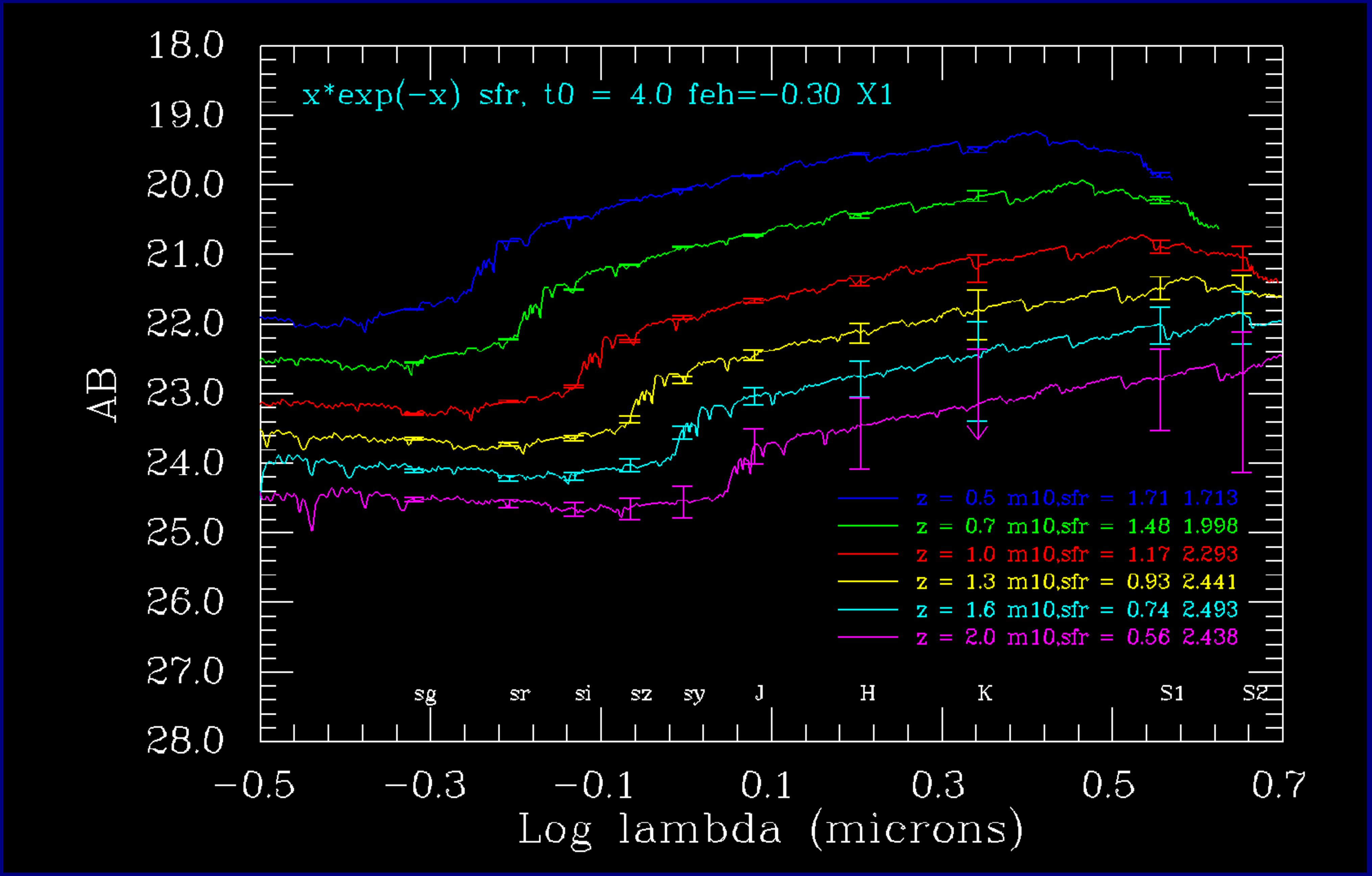
1.06	0.0	0.5	9.3e10

These models look like this:

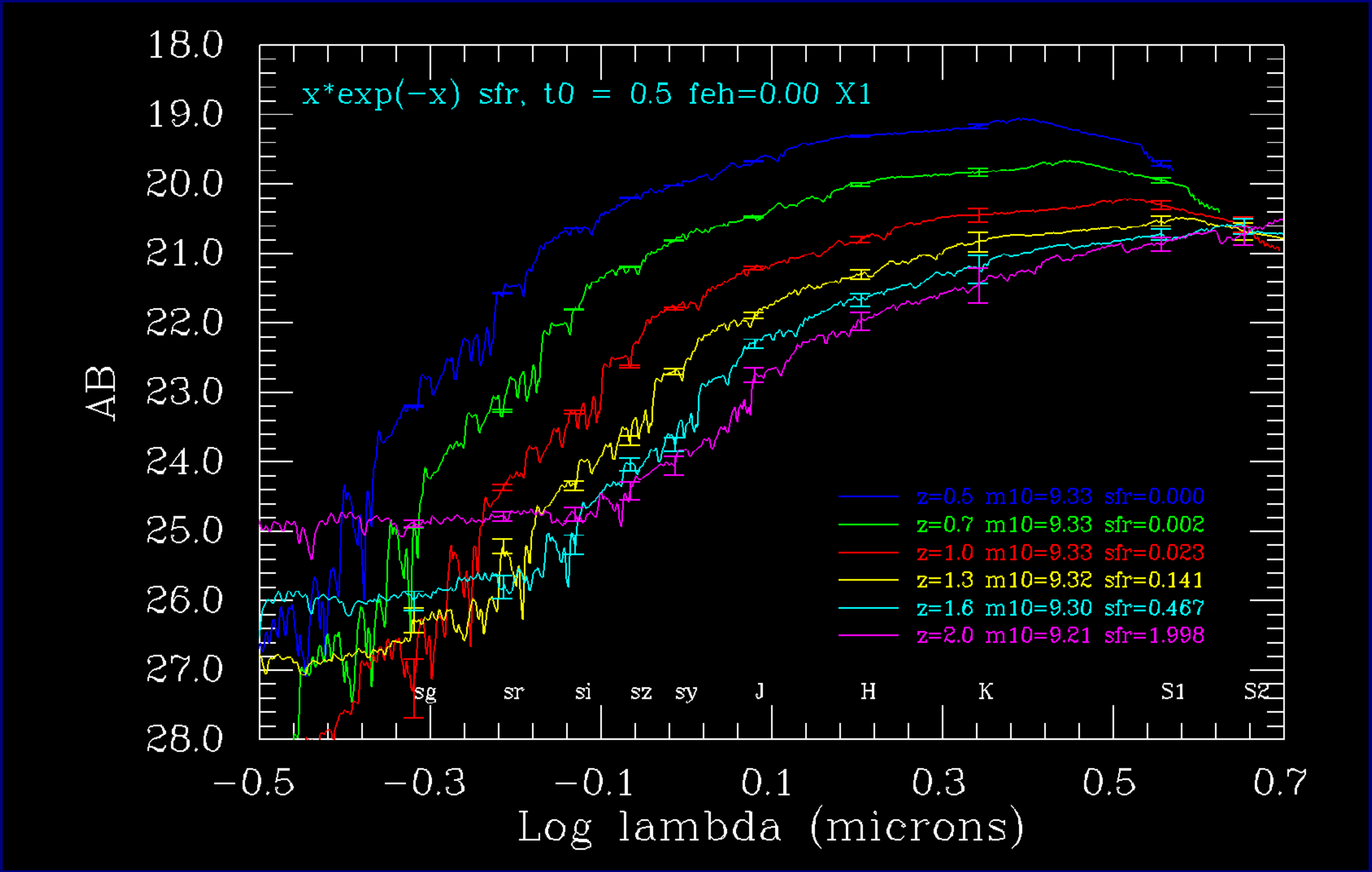
This is a galaxy of intermediate color (g-r = 0.78), with the shallow survey Subaru error bars, 36 minute VISTS JHK error bars, and 200 sec IRAC error bars/.



This is a bluer galaxy, near the blue limit for L, at g-r=0.60.*



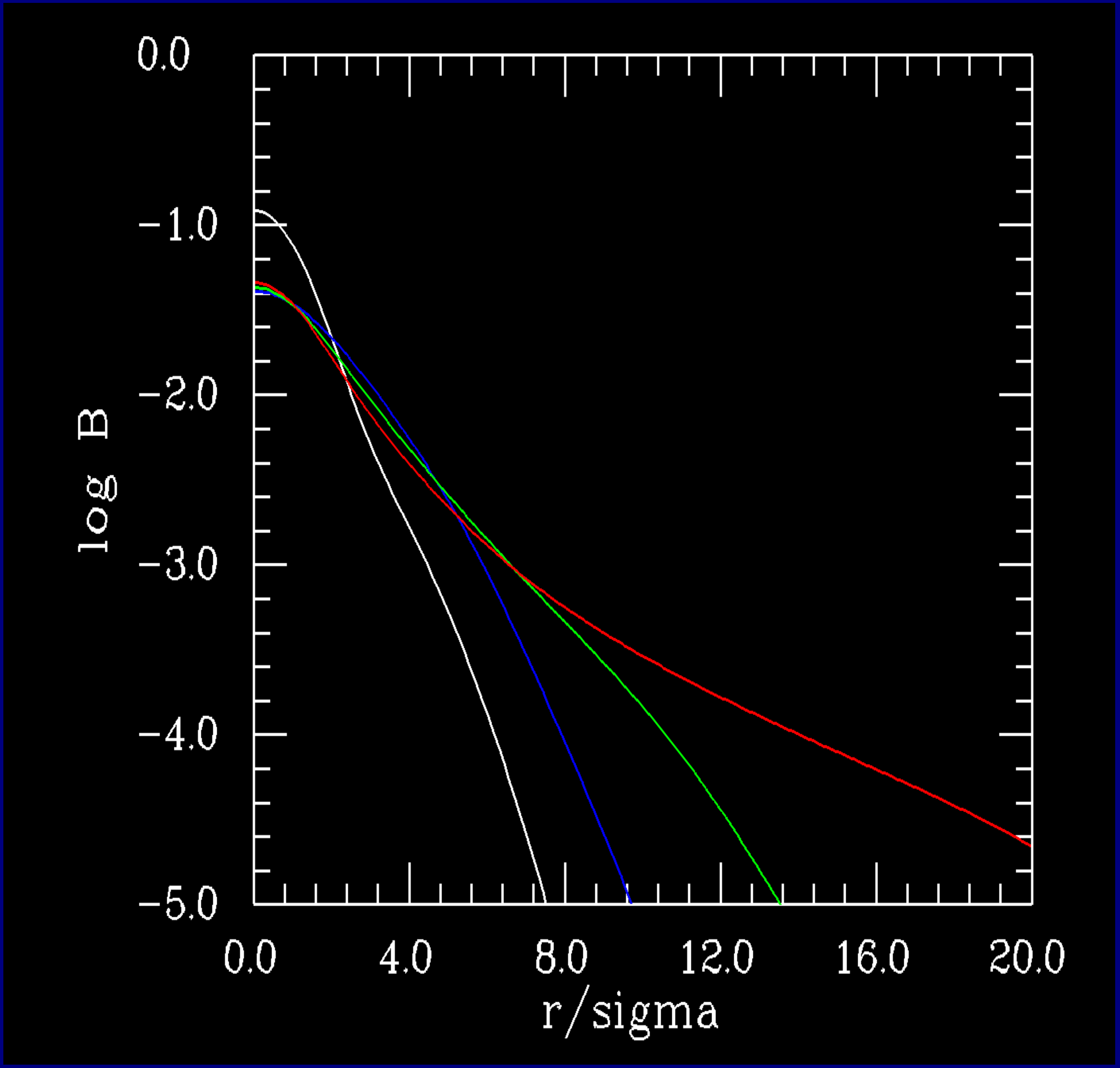
This is a very red galaxy with a characteristic time of only 0.5Gyr.



But there are some problems:

We would like to measure shapes, sizes, surface brightness, etc.

1. The profiles for various Sersic indices are very similar with seeing (here Re = 0.8 FWHM)*



If one does least sq fitting,

$\sigma(\ln n) \sim 6\sigma(m)$,

So must have high S/N images to measure n, S/N ~ 10-20

But we do. At z=1.3, we are at least 1.5 mag above the limit in at least 2 bands, so S/N >~ 30. For the bluer galaxies, get independent shapes in several bands.

There is no hope of getting photoZs for any of these galaxies more distant than about z=1.5 without at least one redder band (in any of the surveys).

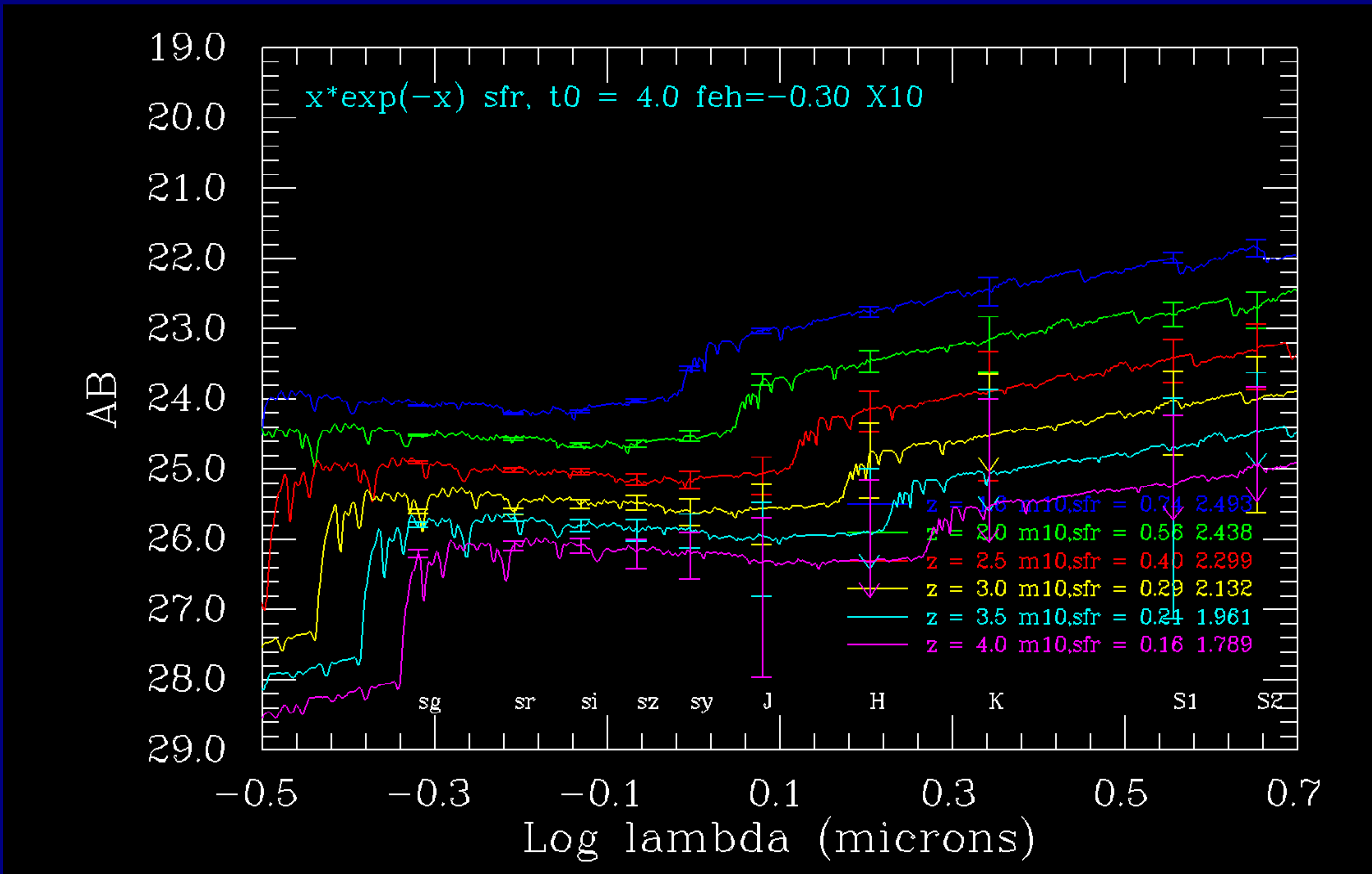
The plots show J, H, and K from VISTA with half-hour exposures. K is hopeless, but J and H are interesting. VISTA covers 0.6 sq. degrees in one pointing, so 300 sq degrees is 500 pointings, 500 hours, 60 nights, Probably possible.

The plots also show bands 1 and 2 (3.6 and 4.5 microns) of Spitzer?IRAC with 120s integrations. If the warm extension is approved, this can be done after the cryogen is exhausted. 300 sq degrees is 2400 hours, again maybe possible (1/10 of total time)

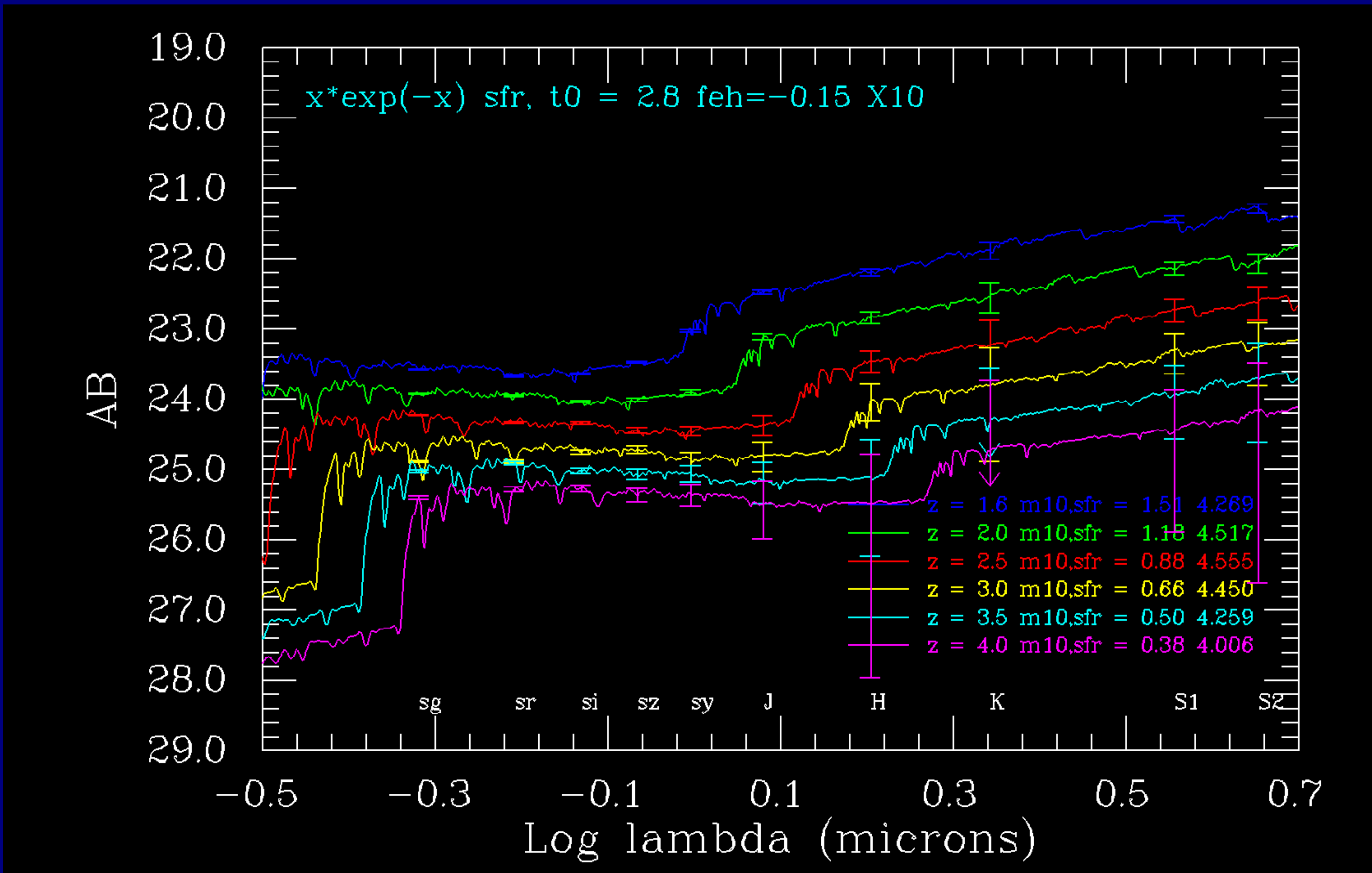
BUT...

The deeper layers need the near IR MUCH more, and it is likely that we want to concentrate our efforts to obtain IR imaging for them.

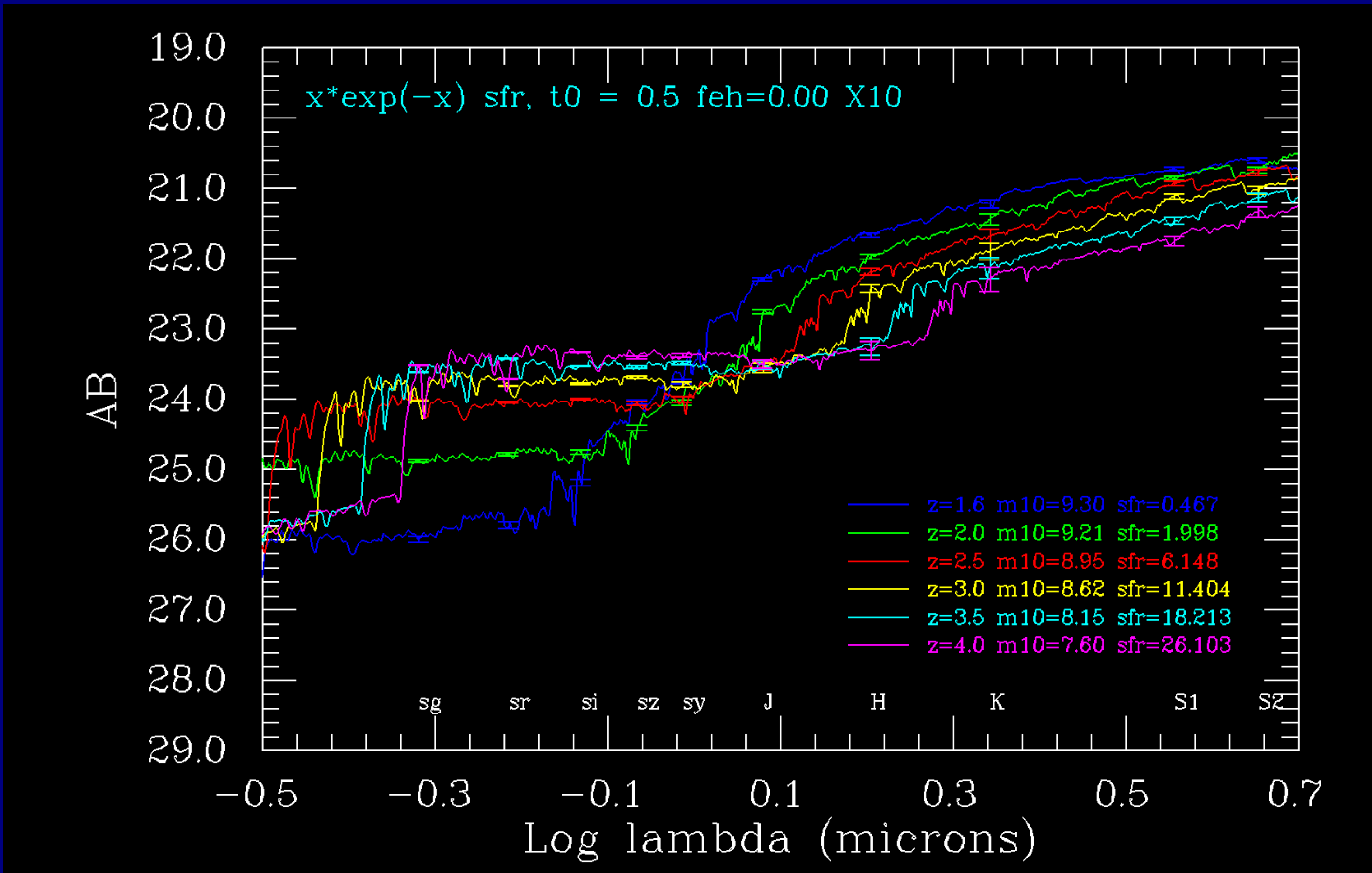
Intermediate layer, blue z=0 galaxy



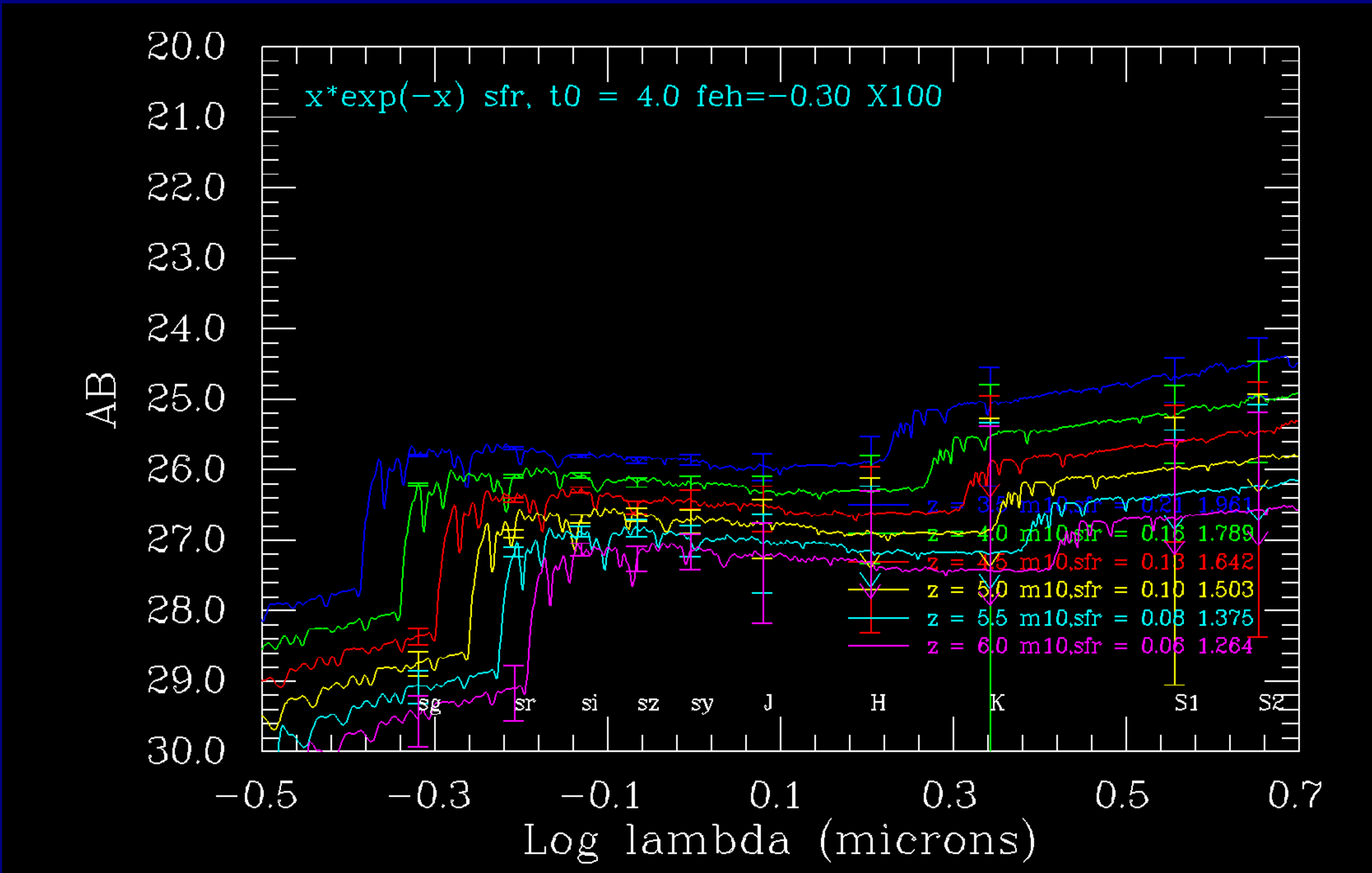
Intermediate layer, yellow z=0 galaxy



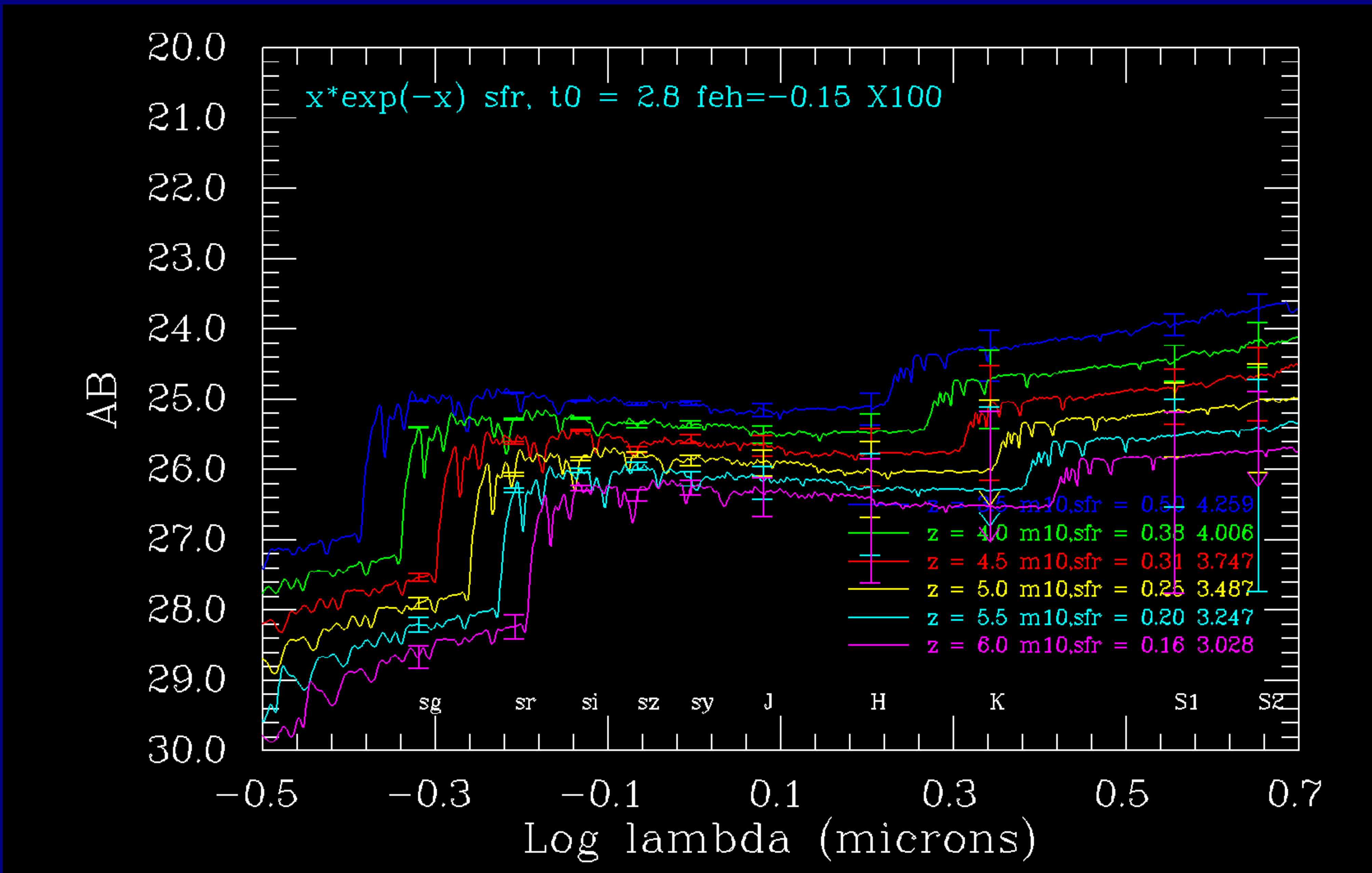
Intermediate layer, very red z=0 galaxy



deep layer, blue z=0 galaxy



Deep layer, yellow z=0 galaxy



Deep layer, very red z=0 galaxy