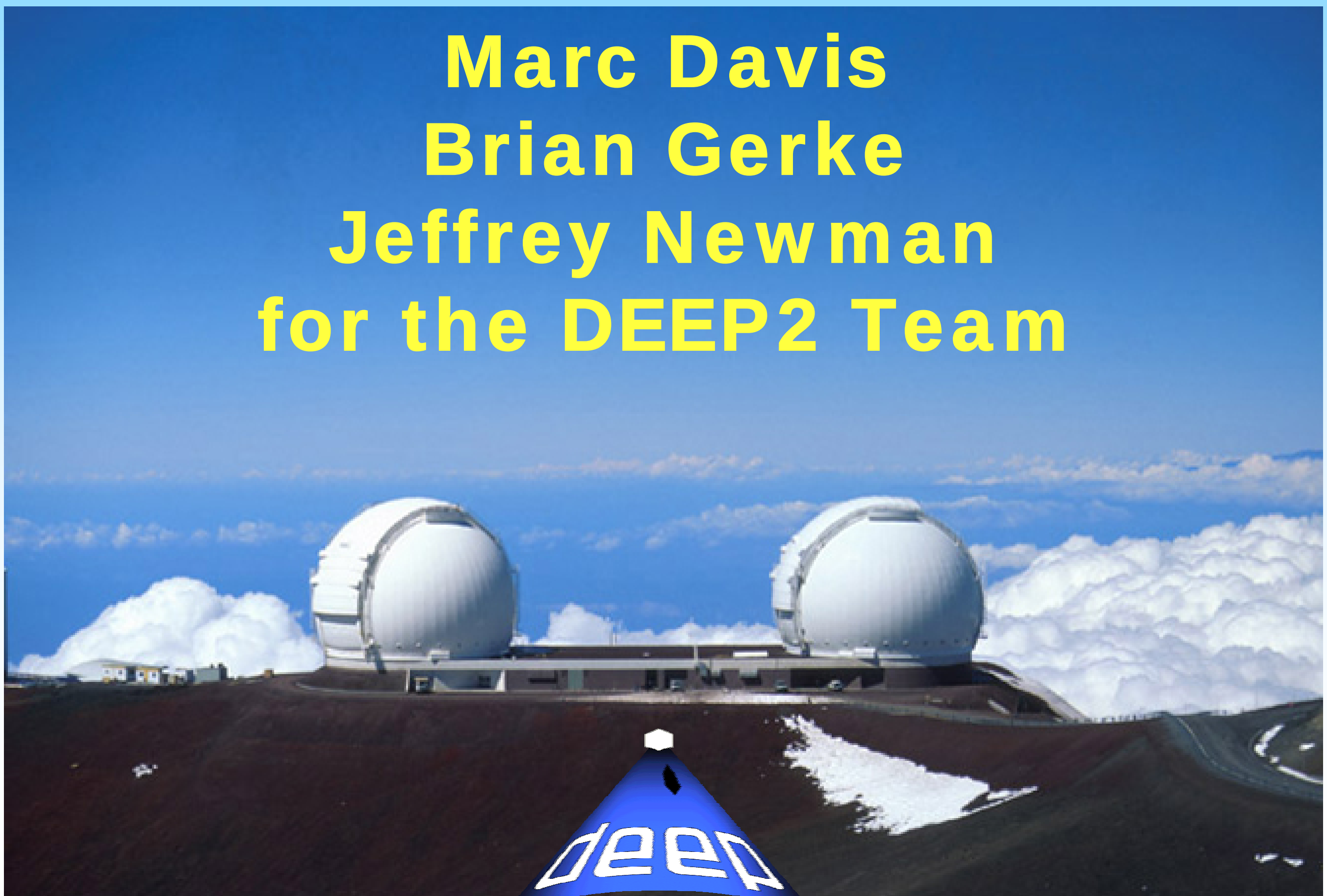
Constraining the Dark Energy with the DEEP2 Survey

Texas-Stanford December, 2004



The DEEP2 Collaboration

Team Members:

U.C. Berkeley: M. Davis (PI), A. Coil, M. Cooper, B. Gerke, R. Yan, C. Conroy

U.C. Santa Cruz: S. Faber (Co-PI), D. Koo, P. Guhathakurta, D. Phillips, C. Willmer, B. Weiner, R. Schiavon, K. Noeske, A. Metevier, L. Lin, N. Konidaris, G. Graves

U. Hawaii: N. Kaiser, G. Luppino

LBNL: J. Newman

U. Pitt.: A. Connolly

JPL: P. Eisenhardt

Princeton: D. Finkbeiner

Keck: G. Wirth

K survey (Caltech): K. Bundy, C. Conselice, R. Ellis, P. Eisenhardt

Progress on many fronts:

- Progress on observations
  - Completed survey over 2.3 square degrees
  - ~45,000 spectra taken so far
  - 2005A is to finish the EGS
- Progress on assembling a comprehensive dataset in the Extended Groth Strip
  - *HST*/ACS (126 orbits) and *Chandra*/ACIS (1.4Msec) imaging awarded; deep *Spitzer* MIPS and IRAC observations now complete; GALEX underway
- Progress on science
  - Many papers in draft and expected to be submitted by the end of the year

Survey strategy: imaging

We have obtained deep CFHT 12k imaging in three bands (*BRI*) to allow photometric pre-selection of targets with *z*>0.7; otherwise, the majority of objects observed would be at lower *z*. The imaging is complete and fully reduced.

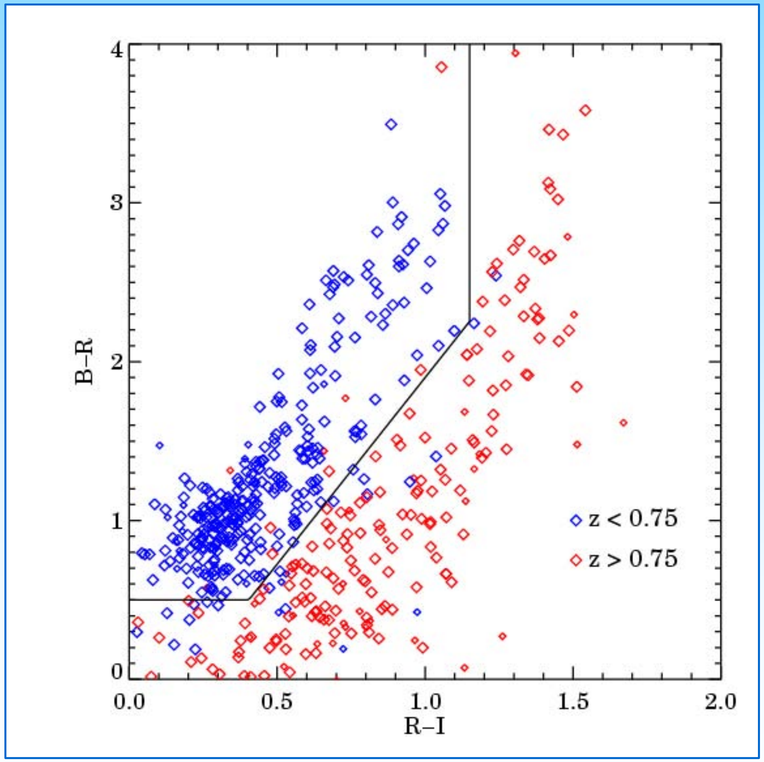
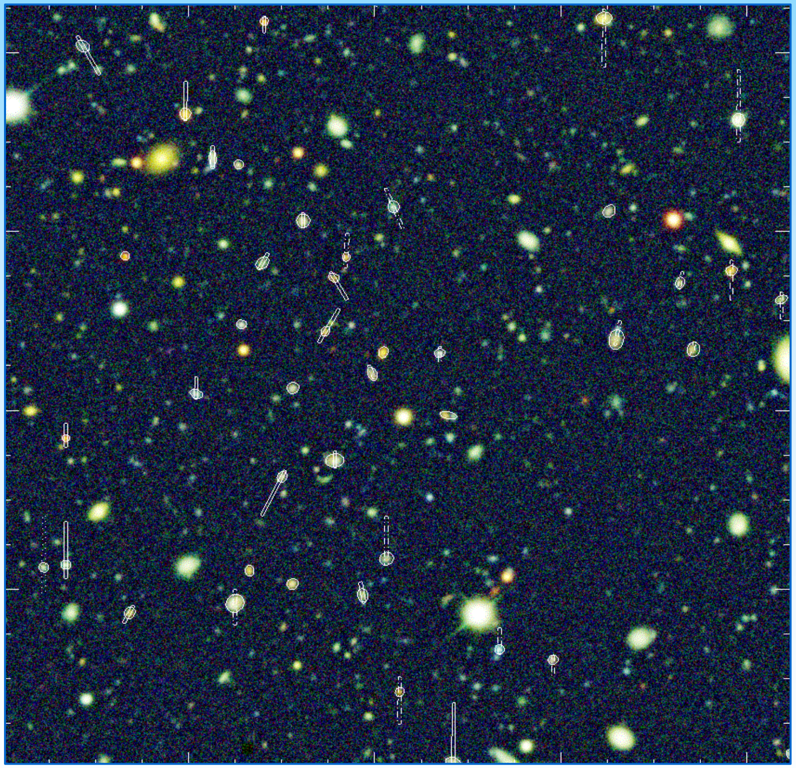


Photo-z preselection of targets

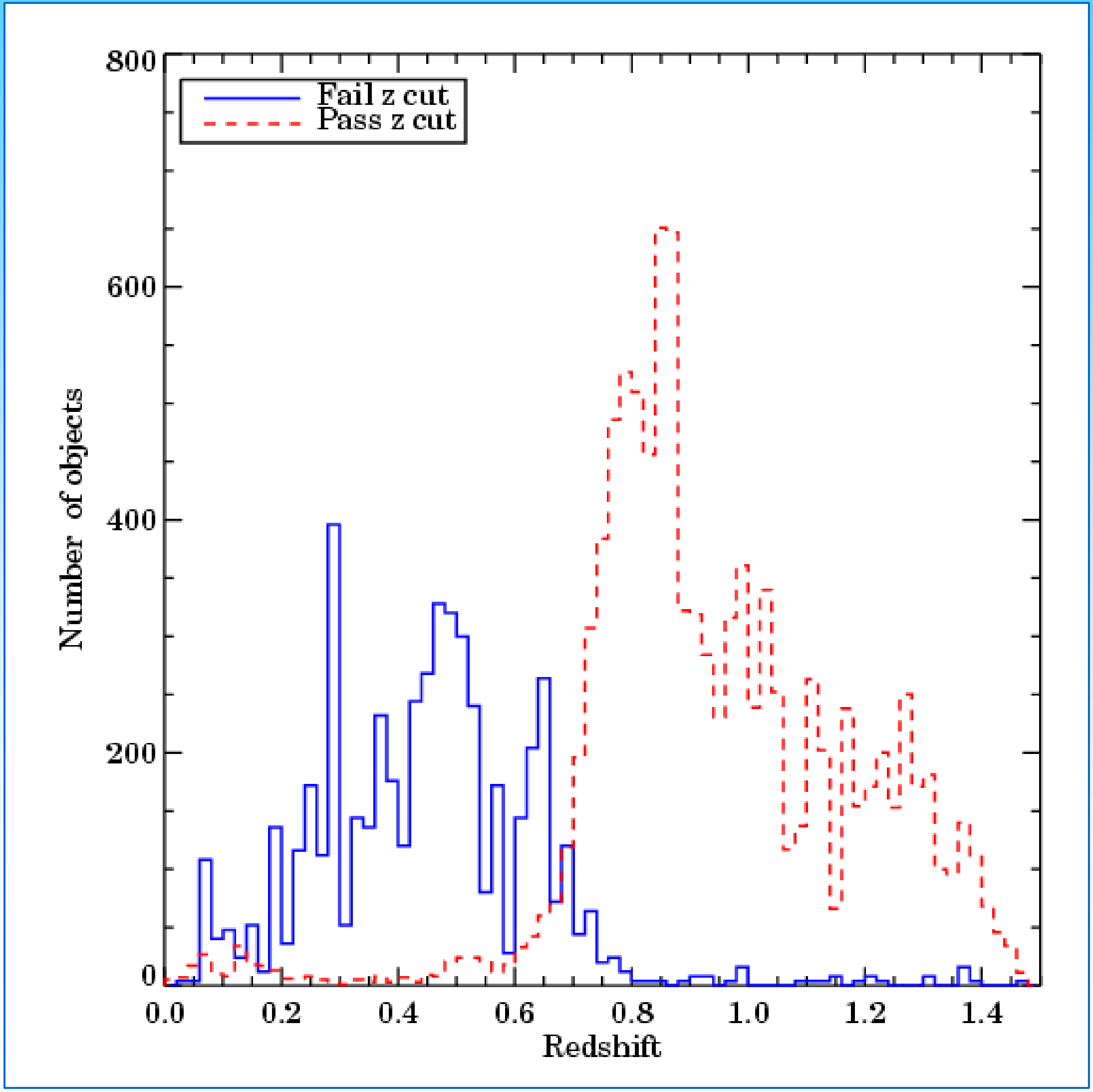


A 200″ × 200″ *BRI* image from one of our fields

Basic survey strategies

In three of the four DEEP2 fields, we apply a *BRI* color cut, which yields a R_{AB}<24.1 sample that is 13% z<0.75, vs. >60% with no cut. Only 3% of objects that we reject are at z>0.75 (5% are at >0.7).

In the Extended Groth Strip, we apply no color cut, enhancing multi-wavelength studies.



Status of the DEEP2 Survey

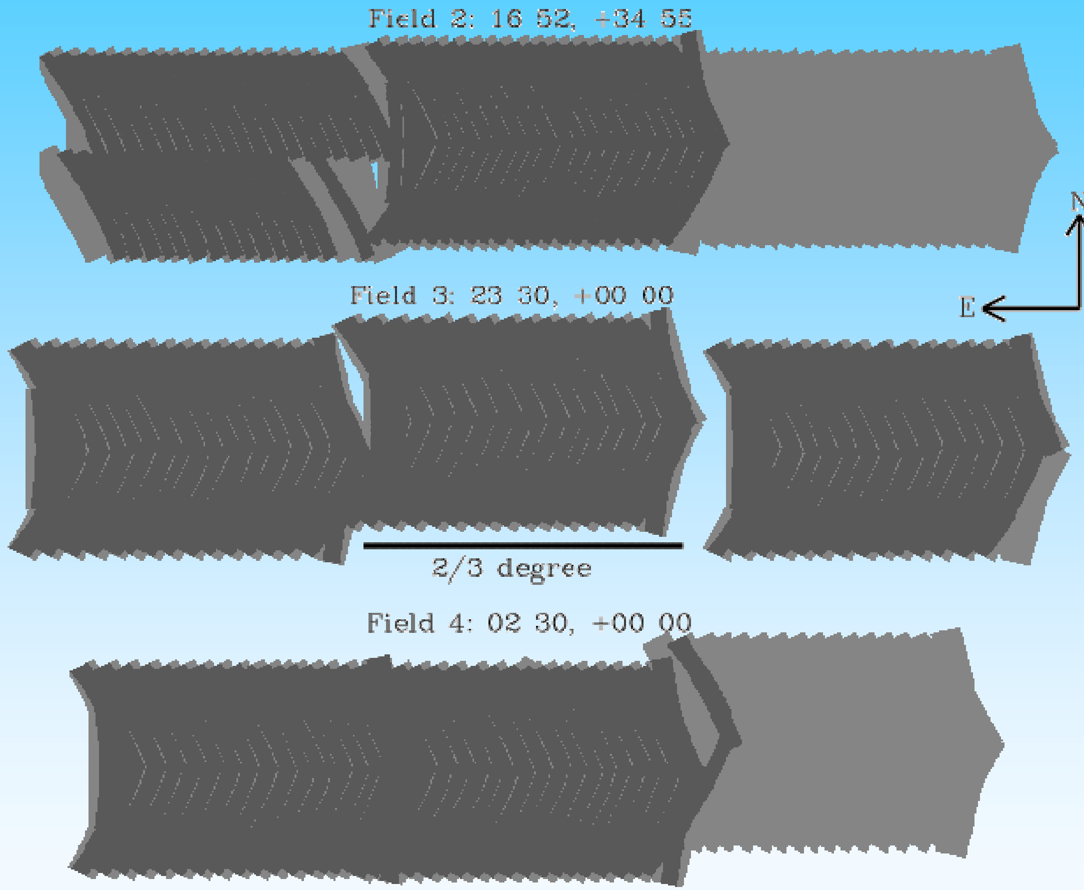
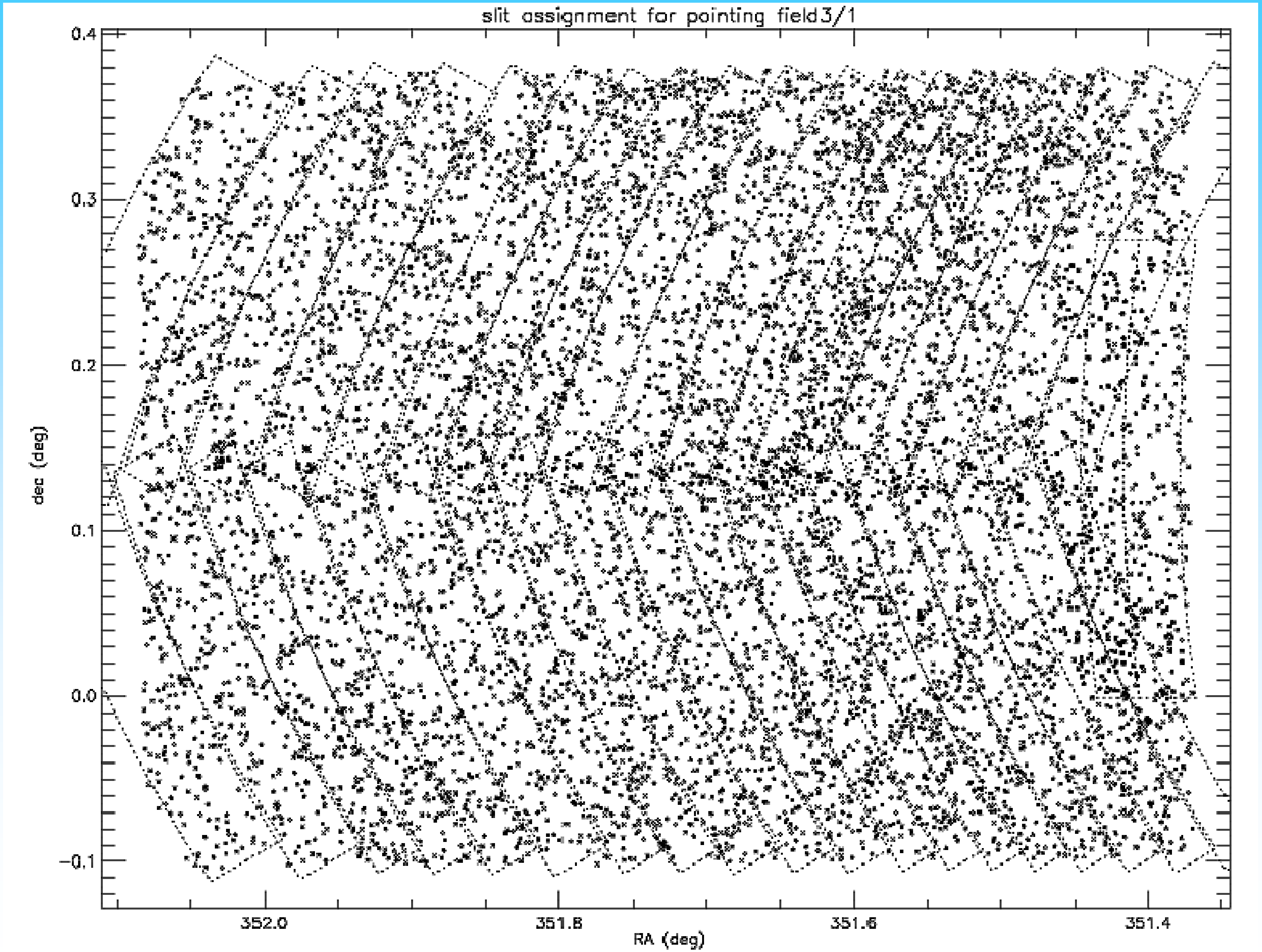


Figure by M. Cooper

Dark = done!

Masks tiled across a 42’x28’ CFHT pointing



What to remember about the DEEP2 sample:

1) In all fields but the Extended Groth Strip, z<0.7 galaxies are excluded by our preselection effectively.

2) The sample is magnitude-limited in CFHT R_{AB}. This corresponds to restframe ~4000 Å at *z*=0.7, 2800 Å by *z*=1.4 .

3) Even very bright galaxies with red rest-frame U-B will not be detected at our magnitude limit for *z*>~1.1-1.2 .

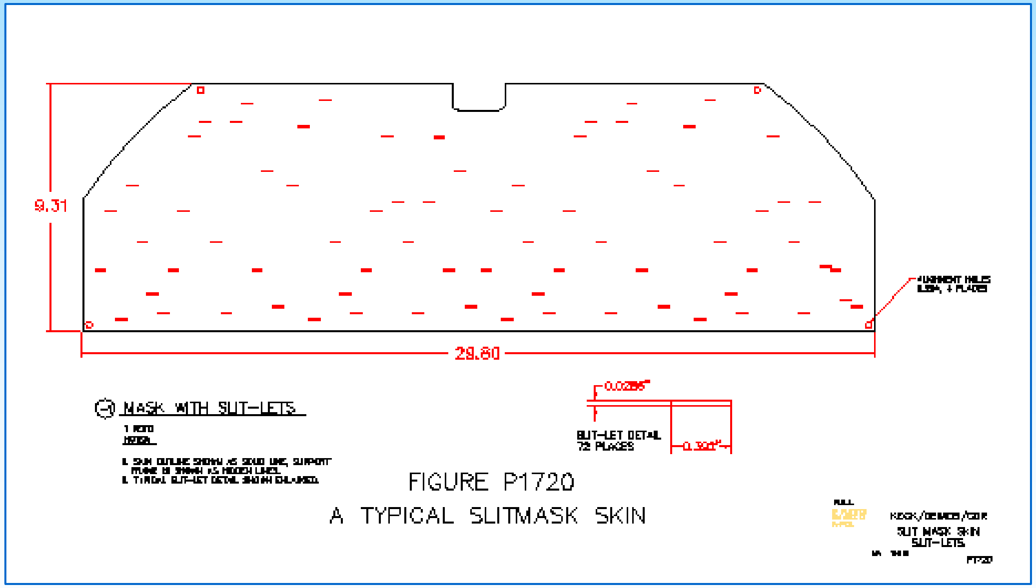
4) We observe only 60-70% of possible targets due to slitmask-making constraints (spectra cannot be allowed to overlap on the detector). Even with adaptive tiling, 3” slitlets, etc., we do worse than this in dense regions.

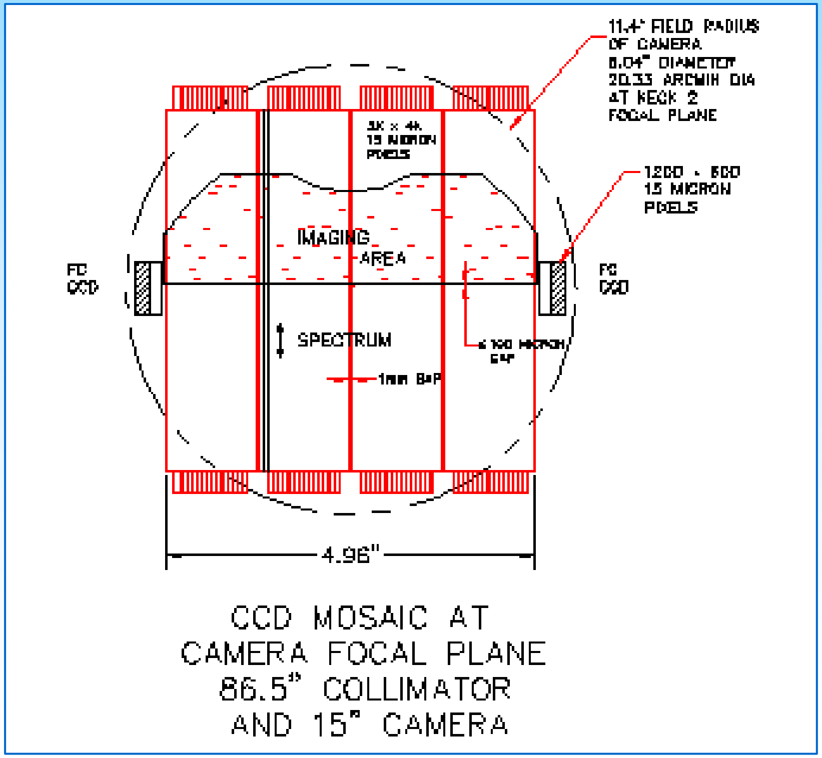
DEEP2 has been made possible by DEIMOS, a new instrument on Keck II

DEIMOS (PI: Faber) and Keck provide a unique combination of wide-field multiplexing (up to 160 slitlets over a 16'x4' field), high resolution (R~5000), spectral range (~2600 Å at highest resolution), and collecting area.

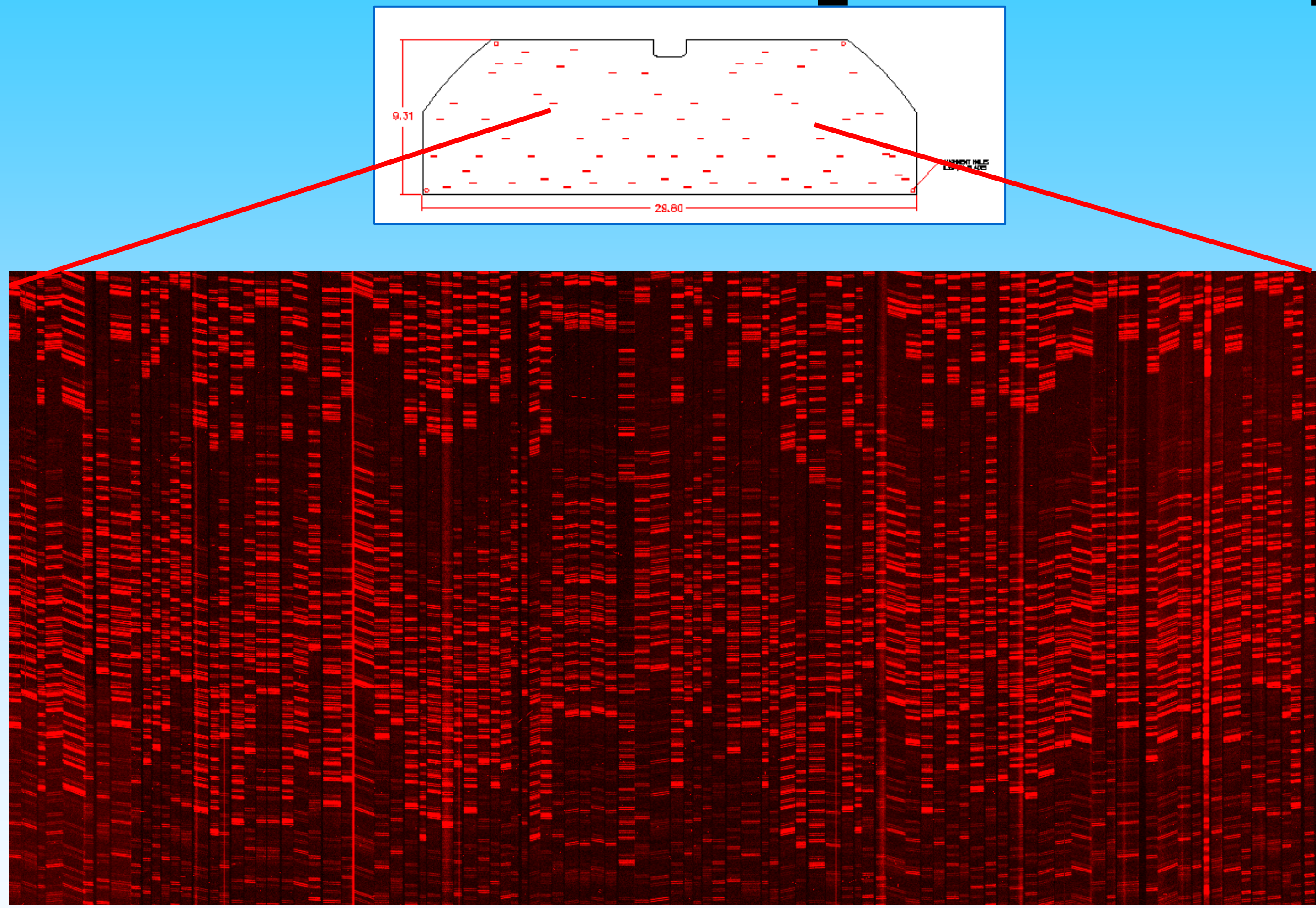
DEIMOS slit masks and detector

- Aluminum slit masks are curved to match the focal plane and imaged onto an array of 8 2k×4k MIT-LL CCDs. 480 custom-made masks are required for the survey.
- Readout time for full array (150 MB!) is 40 seconds (16 amplifier mode)





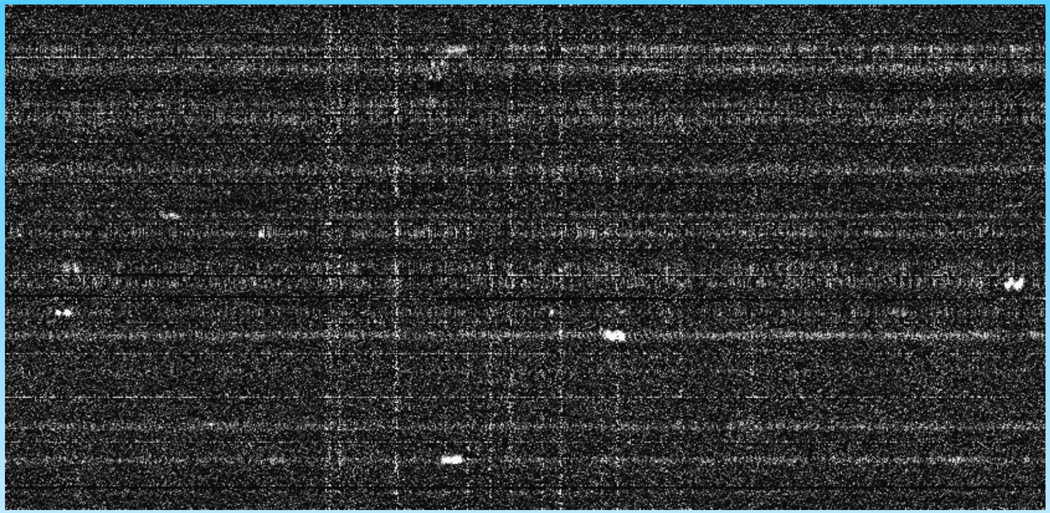
DEEP2 slitmask spectroscopy

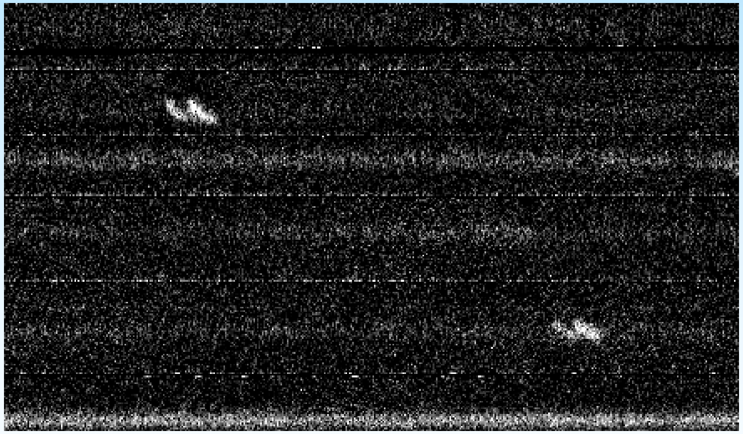


Using custom-milled slitmasks with **DEIMOS** we are obtaining spectra of ~130 targets at a time. A total of 400 slitmasks was required for the survey; we can tilt slits up to 30 degrees to obtain rotation curves.

DEIMOS reduced data

Right: A small percentage of one mask: [OII] everywhere!

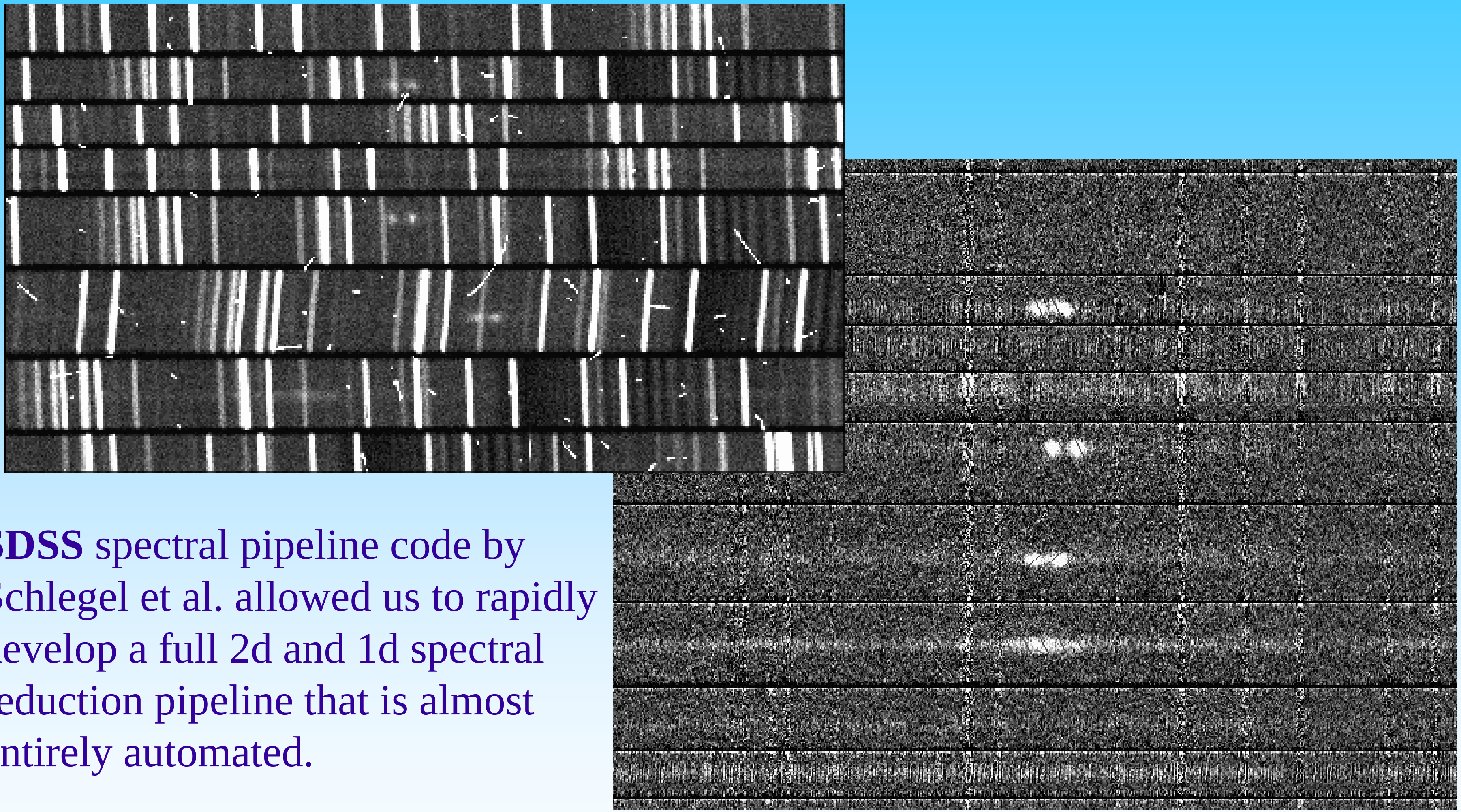




Left: We obtained thousands of well-resolved rotation curves

Below: Analysis of a tilted slitlet; reduced data above, raw data below. We routinely achieve Poisson-limited sky subtraction in most cases.

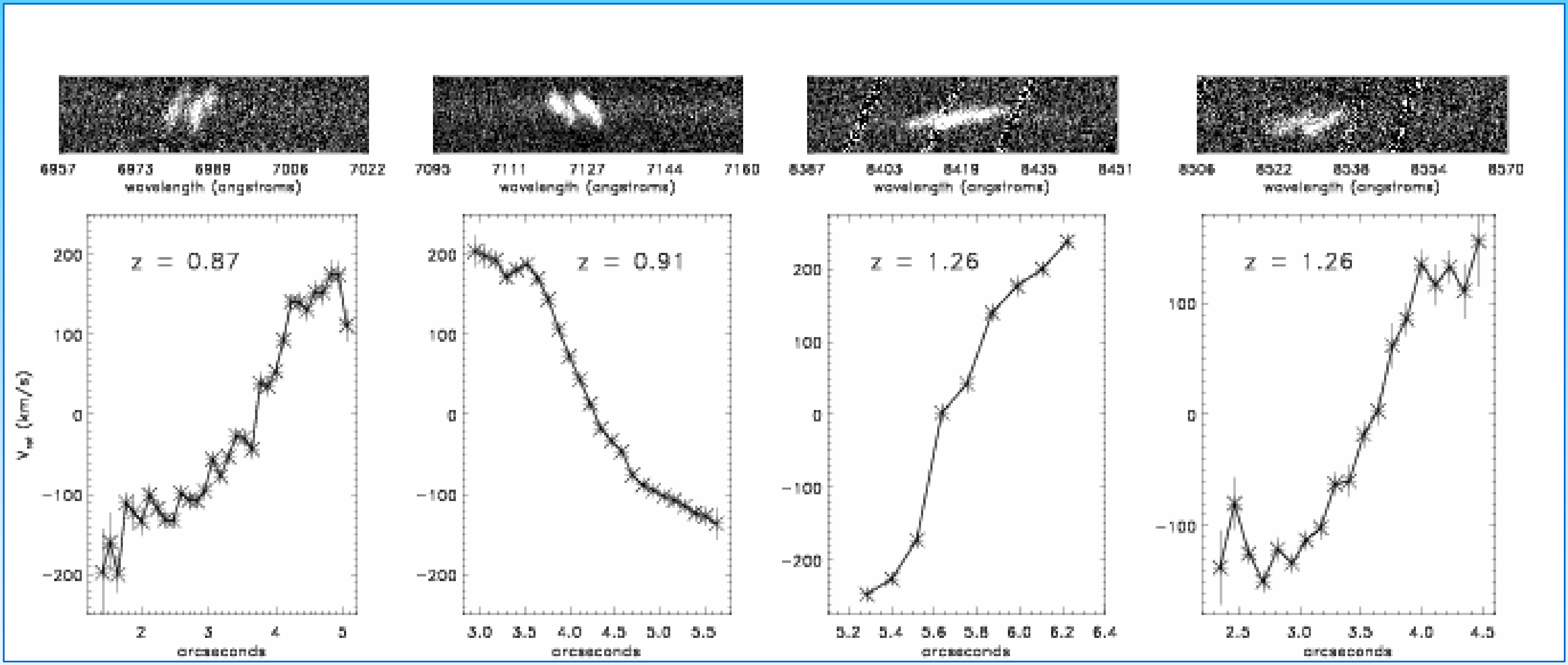
A fully automated reduction pipeline



SDSS spectral pipeline code by Schlegel et al. allowed us to rapidly develop a full 2d and 1d spectral reduction pipeline that is almost entirely automated.

A few percent of one DEEP2 mask, rectified, flat-fielded, CR cleaned, wavelength-rectified, and sky subtracted. Note the resolved [OII] doublets. Shown is a small group of galaxies with velocity dispersion $\sigma \approx 250$ km/s at $z\sim1$. Note the clean residuals of sky lines!

Advantages of a high-dispersion survey



The high resolution used for DEEP2 observations yields well-resolved linewidths for all objects, and rotation curves as a free byproduct for thousands. Shown are four 2d spectra exhibiting resolved [OII] emission and the derived circular velocity $V_c(r)$. **Cooper et al. 2004**

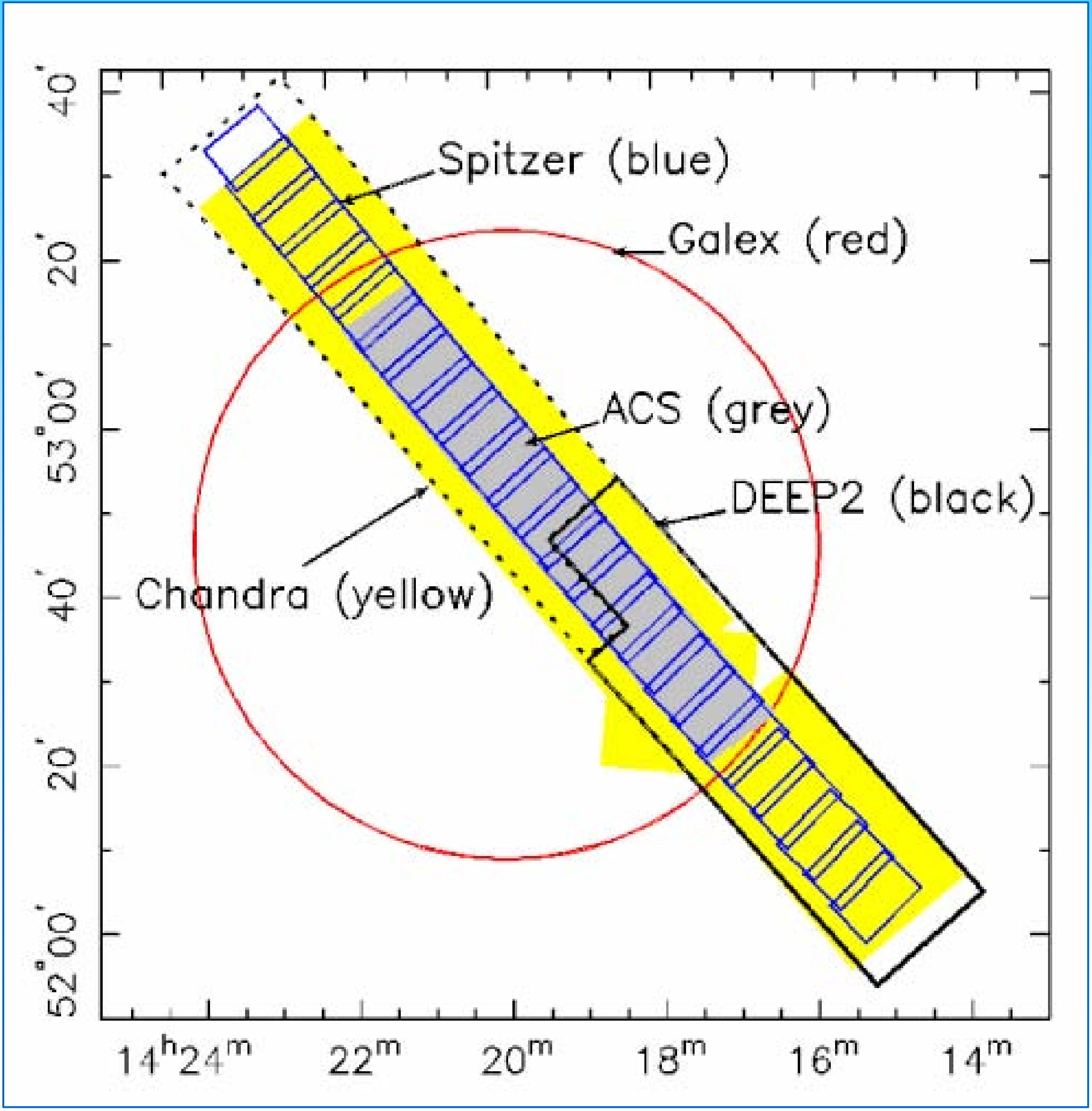
Observing conditions this spring have been frustrating…

The CFHT dome as seen from Gemini

Causing EGS coverage to lag behind other fields

In our high-redshift fields, we are currently finished; EGS is only 45% done (region outlined in solid black).

With decent weather in 2005A, it will still be possible to finish the EGS within our originally-planned six semesters.



Progress on coordinated observations of the Extended Groth Strip

— *Spitzer* MIPS, IRAC

— DEEP2 spectra and Caltech / JPL K_s imaging

— *HST*/ACS V,I (Cycle 13)

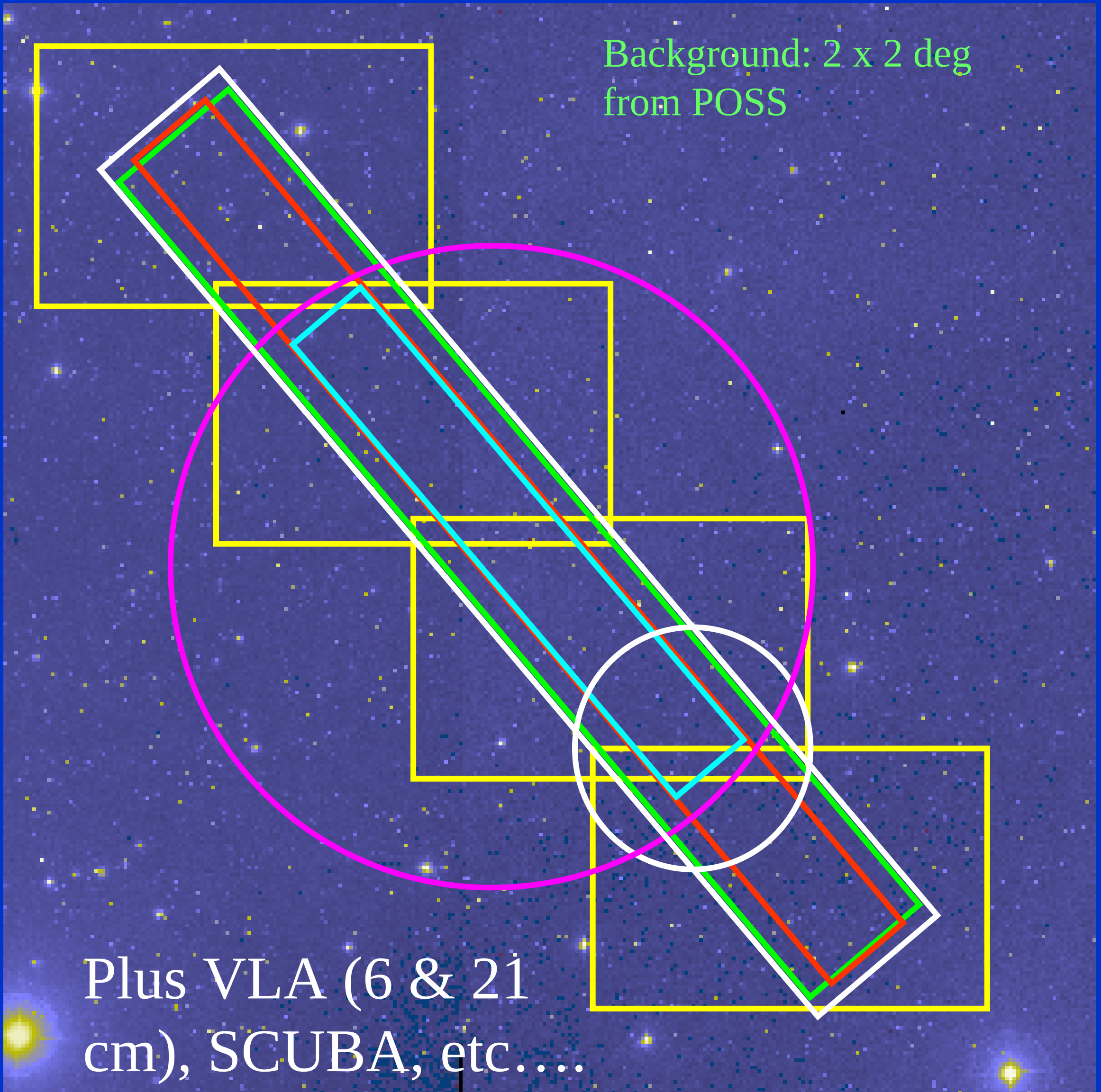
— DEEP2/CFHT *B,R,I*

— *GALEX* NUV+FUV

— *Chandra* & *XMM*:

○ Past coverage

□ Awarded



Cone plots for the 4 DEEP2 fields, 0.7<z<1.2

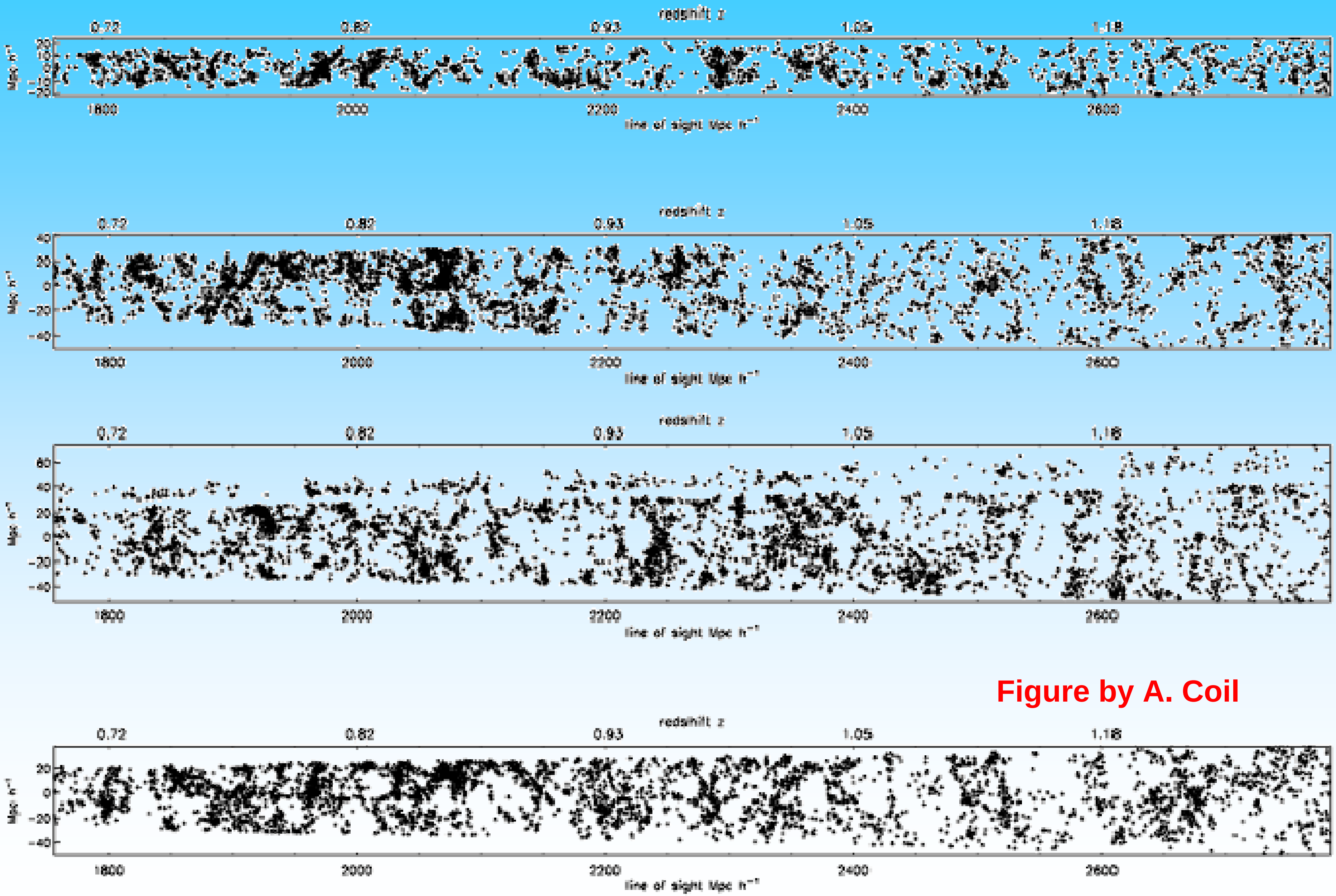


Figure by A. Coil

DEEP2 and dark energy: The classical dN/dz test

The apparent abundance per unit redshift and solid angle of a class of object depends on fundamental cosmological parameters :

$$dN/dz \sim n(z) \times D_C^2 / E(z)\, d\Omega\,,$$

where $n(z)$ is its comoving number density,

$$E(z) \equiv H(z)/H_0 = (\Omega_m (1+z)^3 + \Omega_\Lambda + \ldots)^{1/2}$$

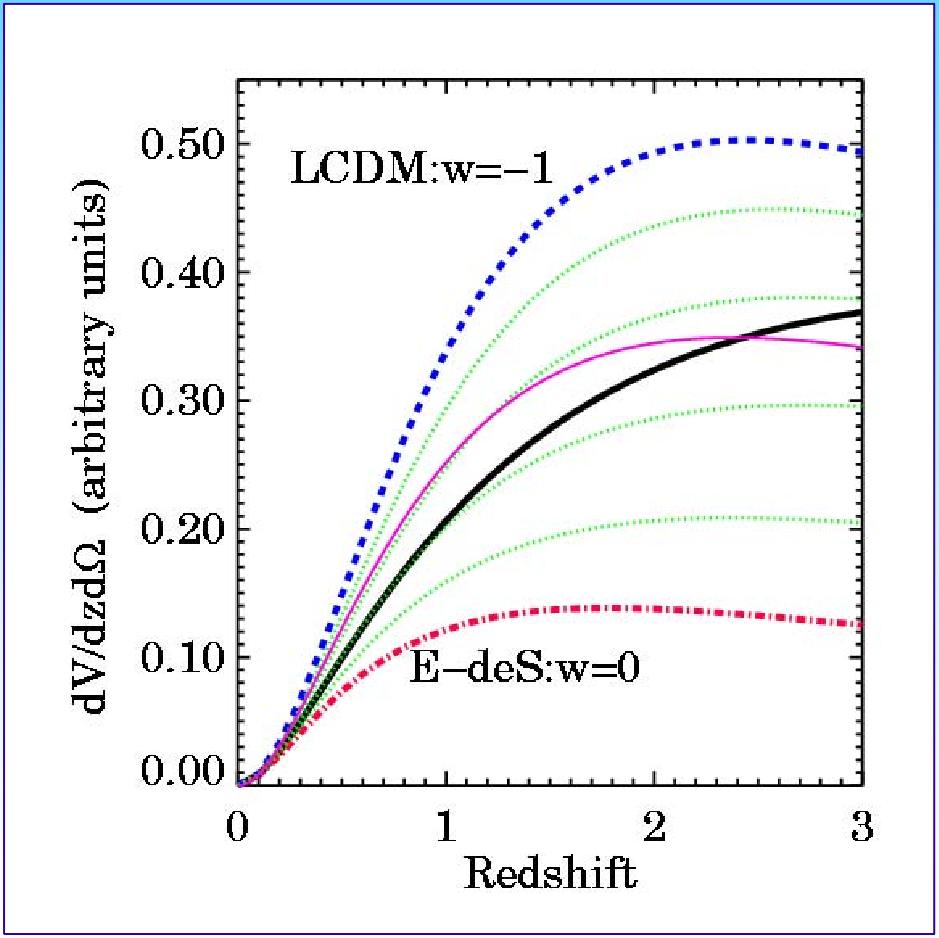
and D_C is the comoving distance to the redshift of interest:

$$D_C = (c/H_0) \int dz/E(z)$$

$$\propto \int \frac{1}{E(z)} dz$$

From Counts to Cosmology

Thus, the observed abundance per unit redshift per unit solid angle, *dN/dz d*Ω of a tracer with known *n(z)* can reveal the underlying geometry. Alternatively, could count objects whose abundance is sensitive to cosmology (e.g., clusters of galaxies).



In more detail…

Two basic routes to cosmological parameters via *dN/dz* :

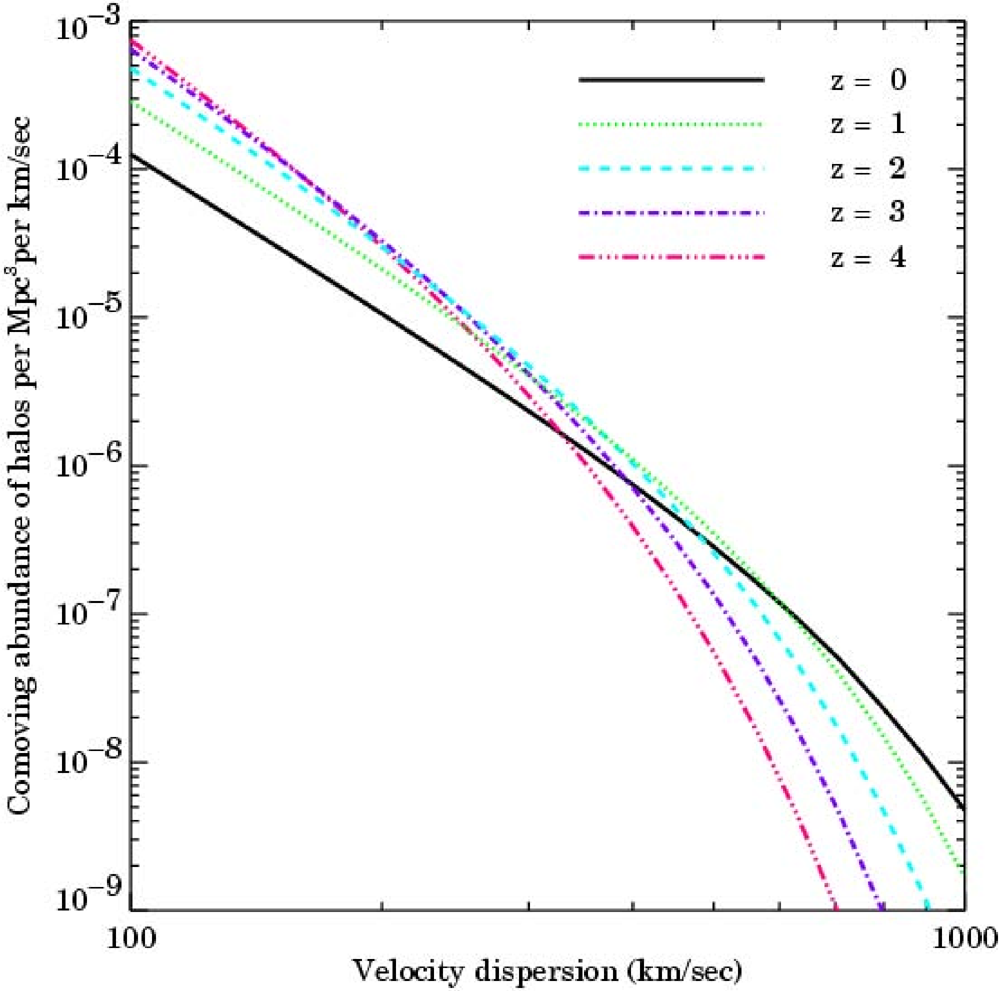
1) Study objects for which *n(z)* is independent of cosmological parameters, giving a measure of comoving volume
   - E.g. galaxies of fixed linewidth/rotation speed (equivalent to potential well depth of the dark matter halo) at *z*~1 normalized to *z*~0: cf. Newman & Davis 2000
2) **Count objects whose comoving abundance *n(z)* is more sensitive to cosmology than the volume element**
   - E.g. galaxy clusters of fixed mass/S-Z decrement/X-ray luminosity. . . **or velocity dispersion σ** ($v_c^2 \sim 2\sigma^2 \sim GM/r$).
     - $n(\sigma,z)$ is independent of H_0 and can be calculated directly in extended Press-Schechter formalisms, vs. e.g. $n(>L_X,z)$

A New Spin

- In the past, galaxies were used as a tracer assuming that the total comoving *n(z)* is constant (e.g., Hubble 1926, Loh & Spillar 1986).
  - Problems: assumption may fail, many biases
    - We cannot avoid these problems without a full theory of galaxy formation and evolution!

- The physics of dark matter halos is much better understood. It would therefore be preferable to use the abundance of dark halos (as a function of circular velocity, observable through the linewidths of galaxies or the velocity dispersions of clusters) to measure *dN/dz*, rather than looking at integrated counts of galaxies or clusters.

Behavior of $n(\sigma,z)$



Ω_m=0.3 ΛCDM

Either semi-analytic methods (e.g. Newman & Davis 2000) or *N*-body simulations (e.g. Sigad *et al*. 2000) can be used to predict $n(\sigma,z)$.

Both yield simple power-law behavior for modest σ, providing an effective diagnostic for incompleteness or systematic effects in counts of galaxies.

Group finding to high z is difficult...

- **Virialized clusters may be found locally using their X-ray emission, but $(1+z)^4$ surface brightness dimming means only the most extreme, most massive systems will be visible.**
- **Photometric methods have high false positive rates and most can find only clusters that have many old, red galaxies.**
- **Sunyaev-Zel'dovich surveys haven't yet achieved fruition, though promising.**

Finding groups and clusters in DEEP2

- In the DEEP2 fields, we find clusters using the locations of galaxies in redshift space.
- This removes most of the background contamination problems of photometric methods, but not all (as galaxies cluster with each other and velocity dispersions can correspond to ~10 Mpc in length, interloper contamination is inevitable).
- Furthermore, we can’t get spectroscopy for every object, especially in the densest regions – sometimes we will lose 2 members out of a 4 member group...

The Voronoi-Delaunay Group-Finding Algorithm

- Uses Voronoi cell volume to find dense regions: potential ‘cluster seeds’
- Uses the Delaunay mesh, its dual, to estimate density of cluster core
- Then searches adaptively for group members based on central density estimate
- We have been testing VDM extensively using realistic DEEP2 mock catalogs

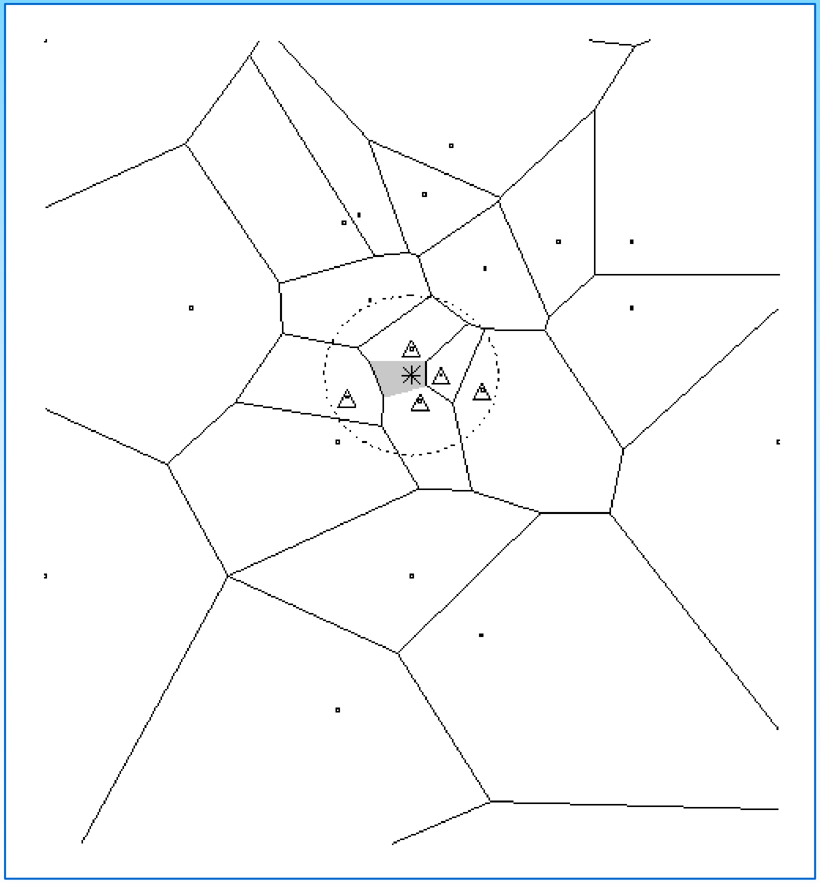
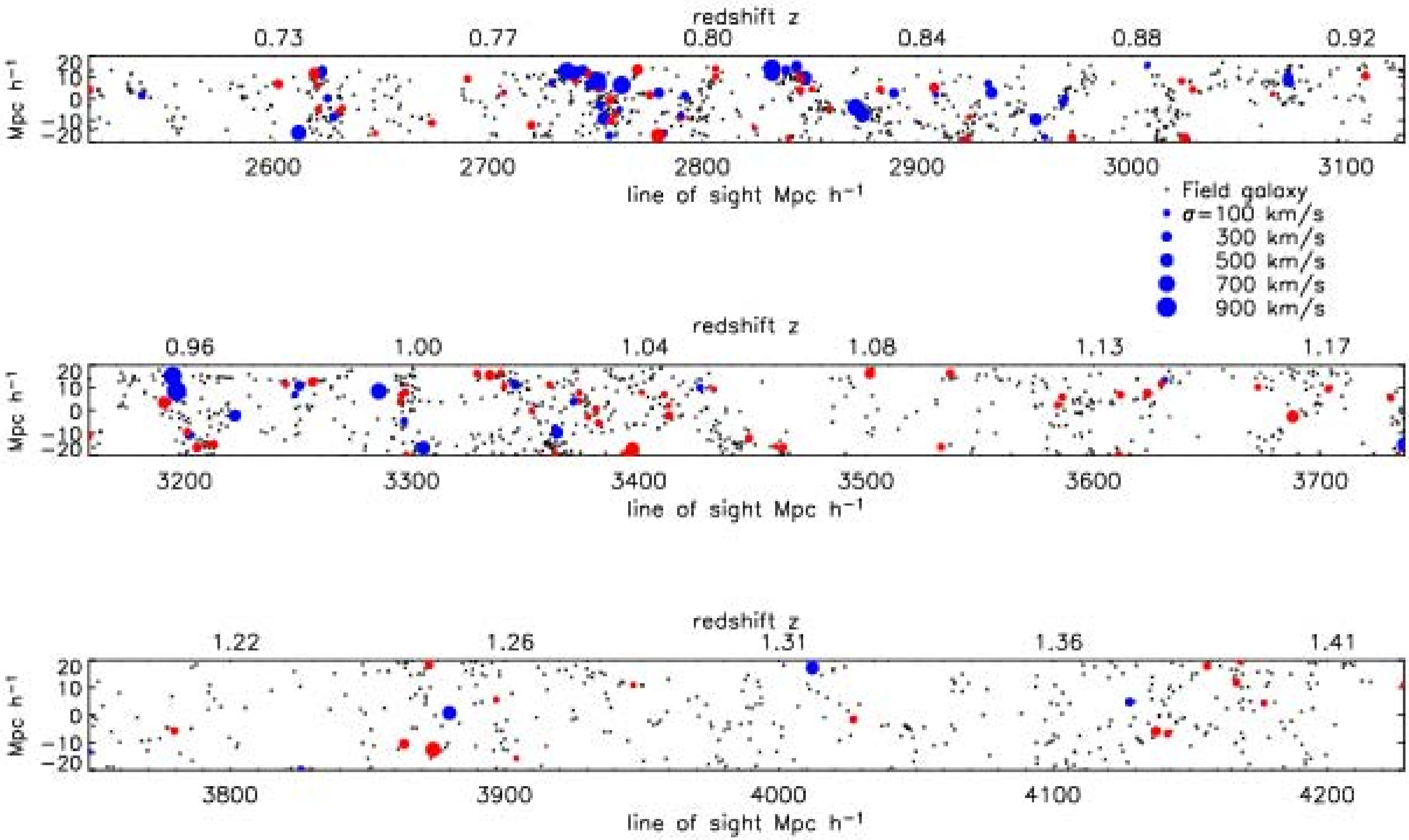


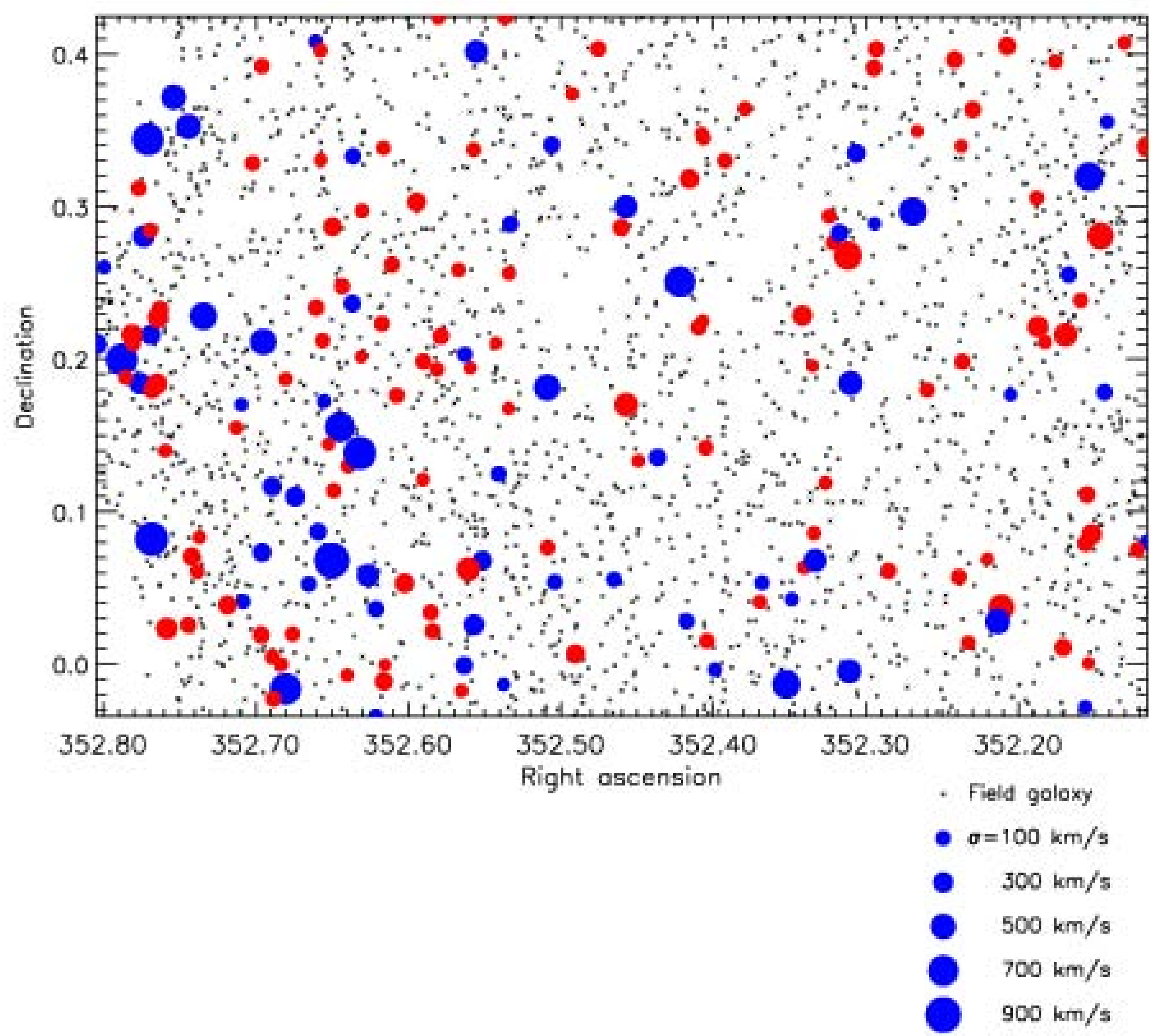
Figure from C. Marinoni, et al. (original implementation)

First DEEP2 Group Catalog



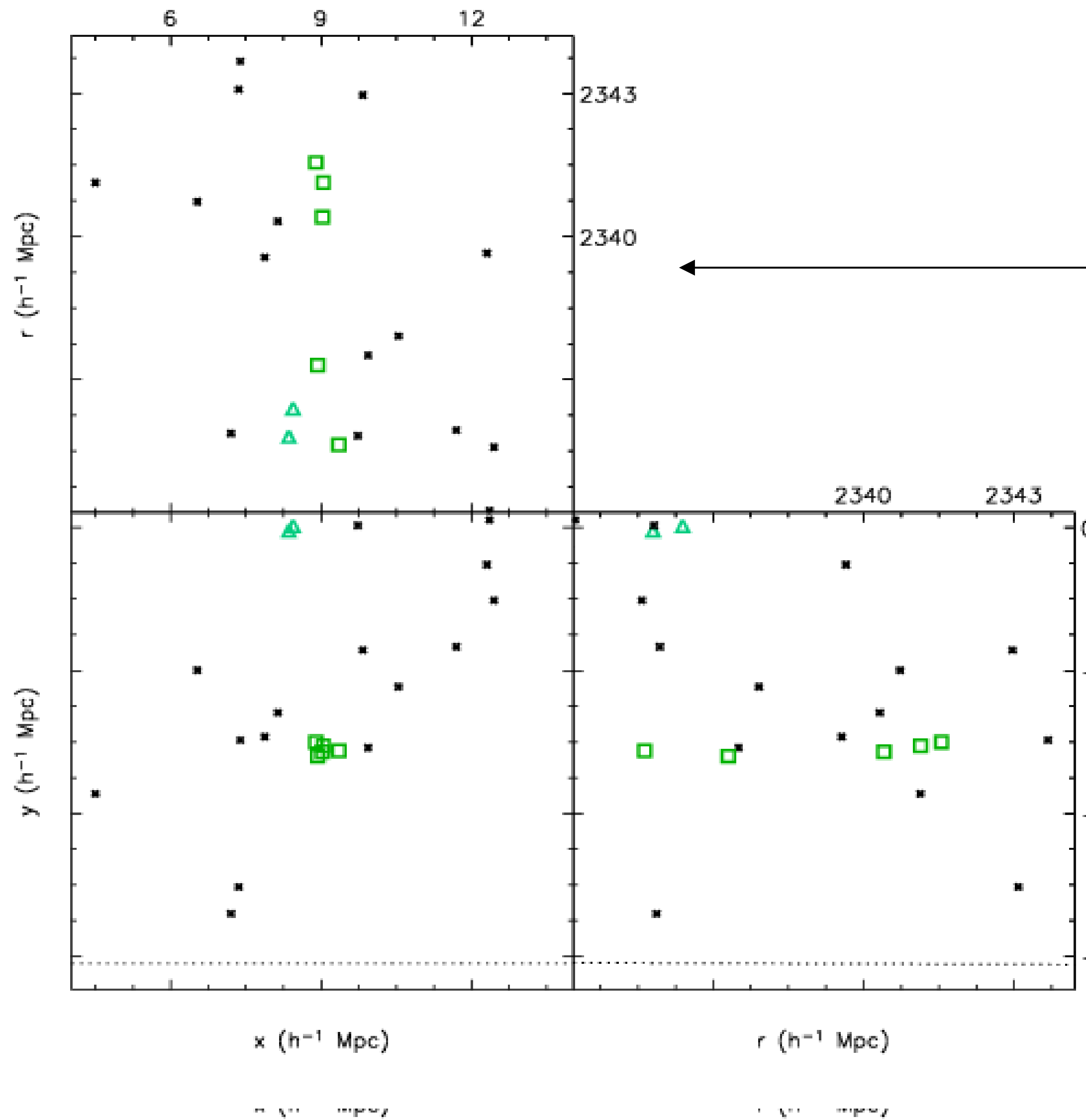
Gerke et al. 2004

First DEEP2 Group Catalog



Real Groups/Mock Groups

galaxies shown in 3 projections



x-r redshift plot

y-r redshift plot

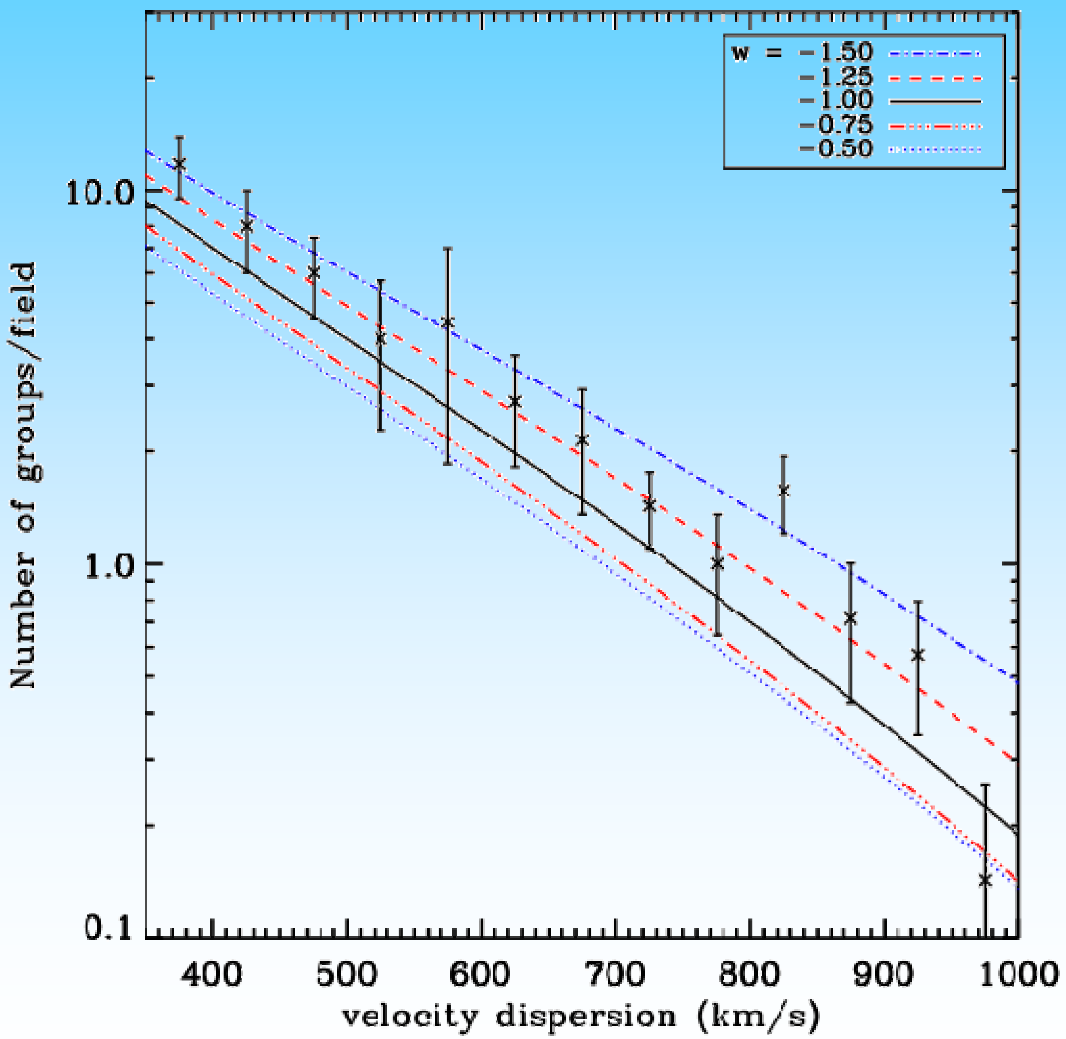
Real or Mock???

Measurement of w in DEEP2 Survey

Results from 314 clusters are plotted. Error bars include cosmic variance.

Curve is sensitive to value of w, but also to other cosmological variables, which must be settled first!

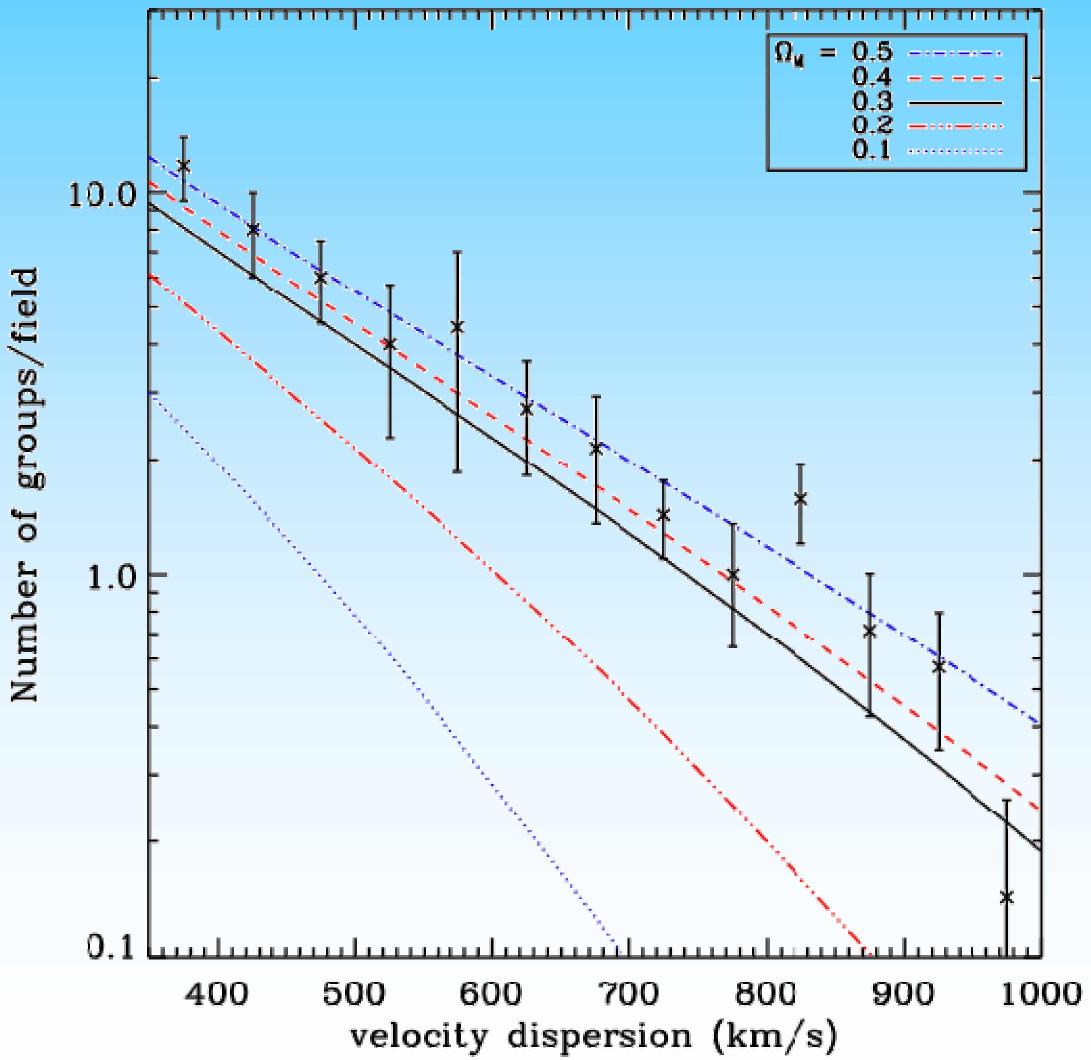
Furthermore, we are still checking systematics!!



Measurement of w in DEEP2 Survey

Number of groups is sensitive to Ω_M

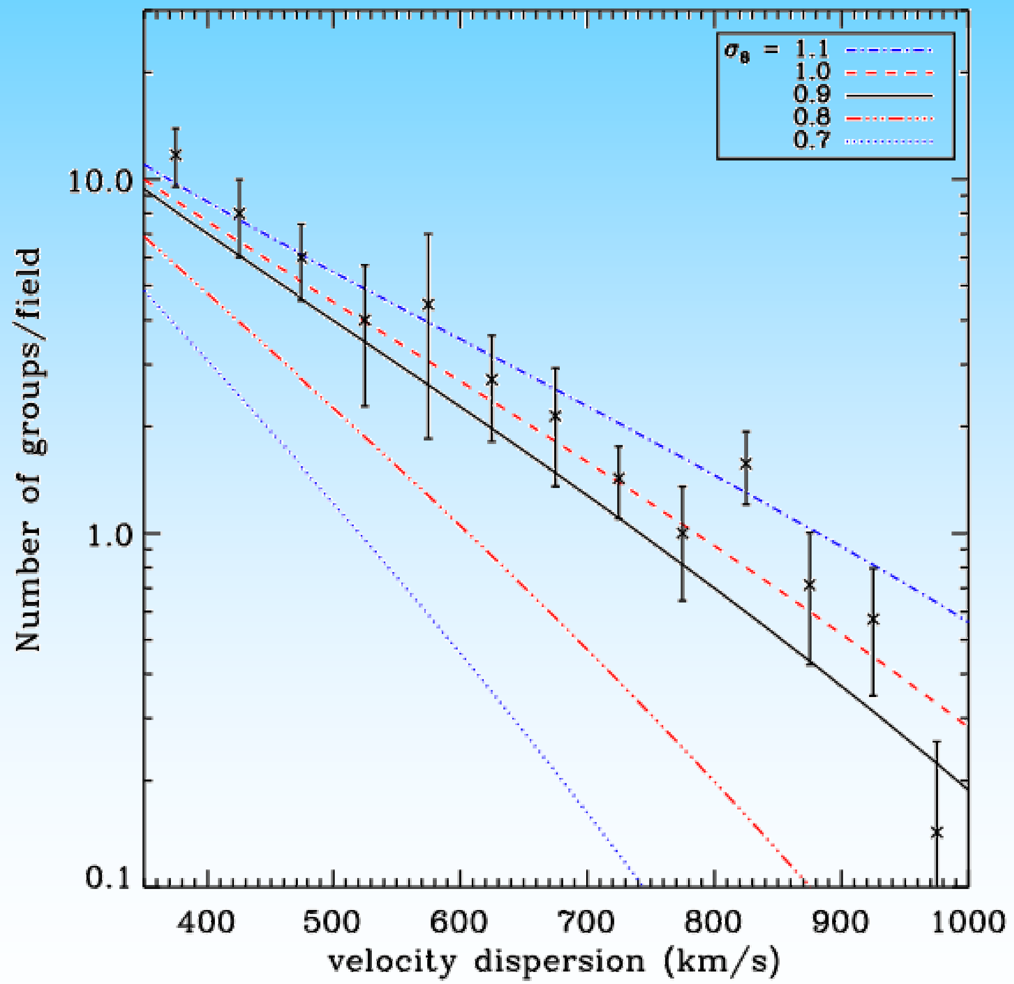
$\Omega_M = 0.3$



Measurement of w in DEEP2 Survey

σ_8 is normalization of Power Spectrum, thought to be .9+-0.05

Need accurate measurement of σ_8 !

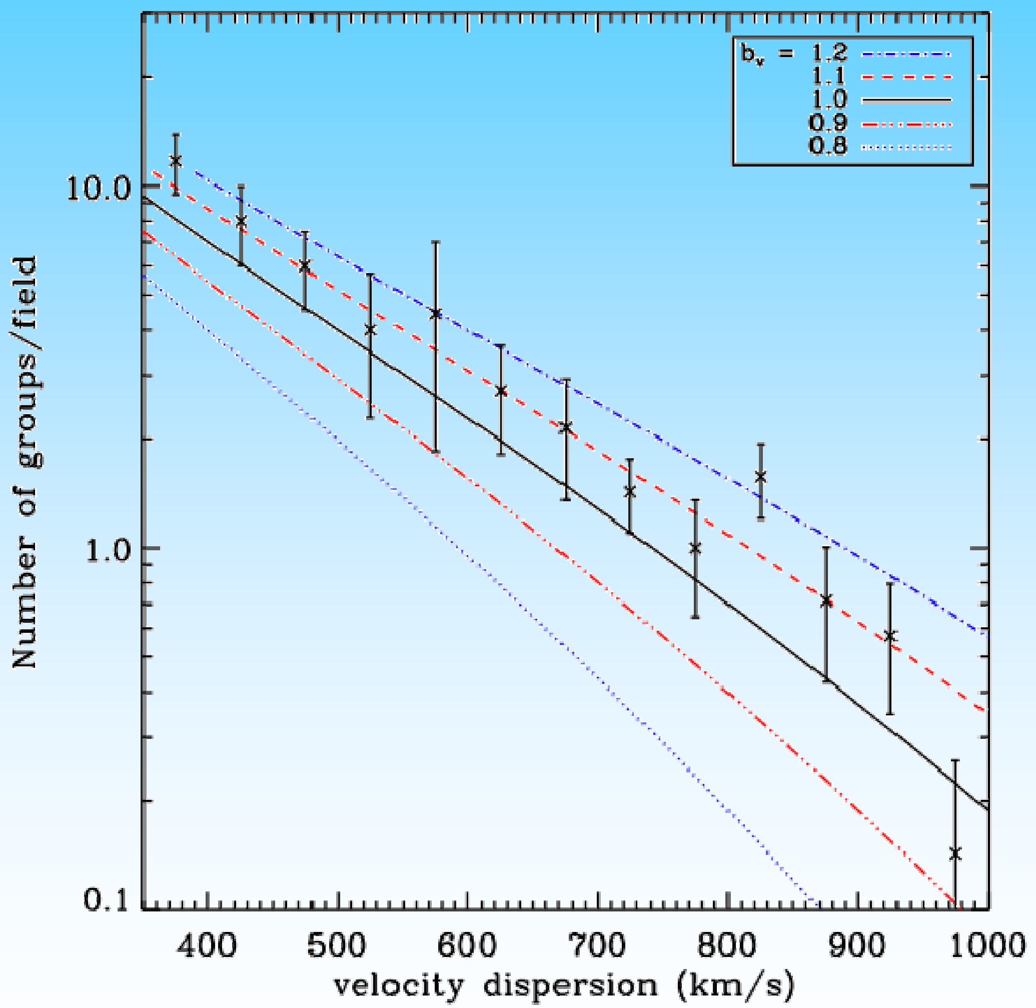


Measurement of w in DEEP2 Survey

b_v is the **bias of velocity field**

b_v= 1? , 1.1?, .9?

This should be set by careful nbody study.



DEEP2 Conclusions

- The DEEP2 Redshift Survey is nearly finished. We have >45,000 high-resolution spectra, most of them for galaxies with z>0.7; we hope to be done after 2005A.
- The Extended Groth Strip will be a unique Northern field for its combination of deep multiwavelength data over a wide area (compare to CDF-S/GEMS in the South). We intend to produce a public archive combining all datasets - more observations there are very welcome.

- Counting clusters works as a means to set constraint on w. **Data is now in hand! Checking for Systematics**

- Data Release Nov. 2004: http://deep.berkeley.edu/DR1 *the data taken in 2002: 2d, 1d spectra, catalog of redshifts*