The 6dF Galaxy Survey: Initial results on large-scale structure and galaxy evolution

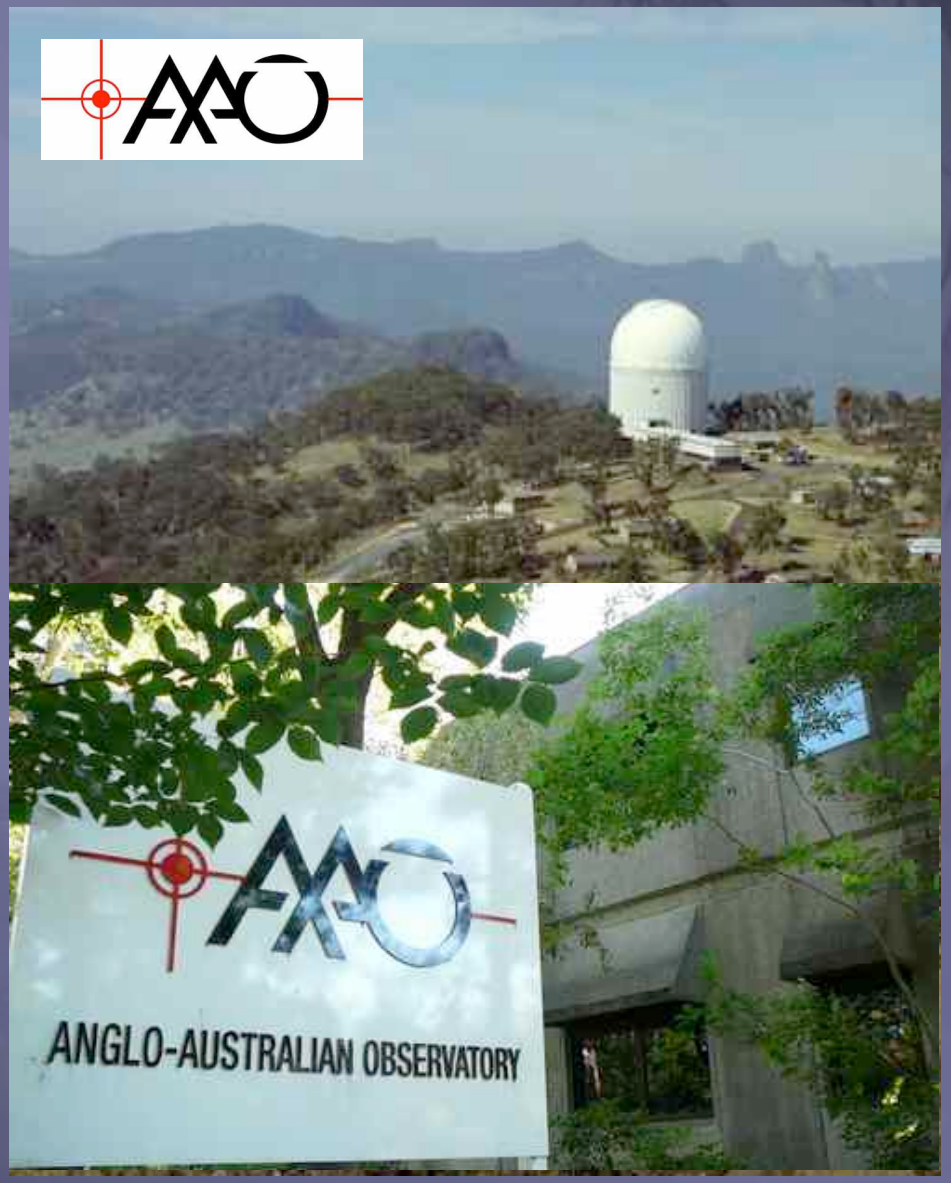
Heath Jones (AAO)

Matthew Colless, Bruce Peterson, Will Saunders,

Tom Jarrett, Rob Proctor, Philip Lah, Mike Read & the 6dFGS team

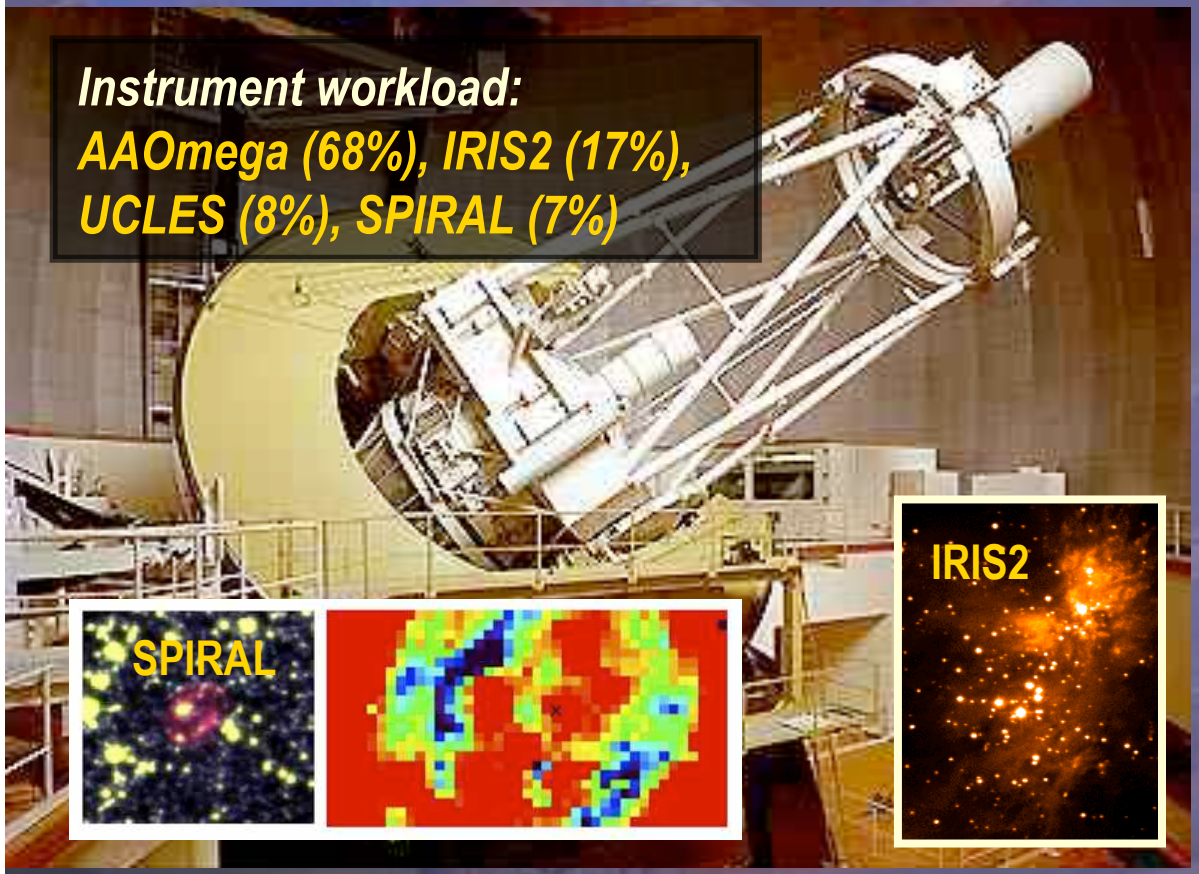
The Anglo-Australian Observatory

- The Anglo-Australian Observatory was created in 1974 as part of a bi-national agreement between Australia and Britain, to operate the 3.9m Anglo-Australian Telescope
- It employs around 70 people based at two sites:
  - –Siding Spring Observatory, located ~450 km northwest of Sydney in the Warrumbungle Mountains,
  - – its Headquarters, located in the Sydney suburb of Epping
- In 1988 it took over management of the 1.2m UK Schmidt Telescope (from the Royal Observatory in Edinburgh)



The Anglo-Australian Telescope (AAT)

- 3.9 m diameter Ritchey-Chretien telescope with focal stations at prime (f/3.3), cassegrain (f/8 and f/15) and coude (f/36).
- Open to international subscription with successful proposals charged time proportional to Aus/UK/other participation: over-subscription rate ~3 to 5 times.



- Current instrumentation:

IRIS2: infrared imager/spectrograph (7.7' x 7.7' FOV in JHK)

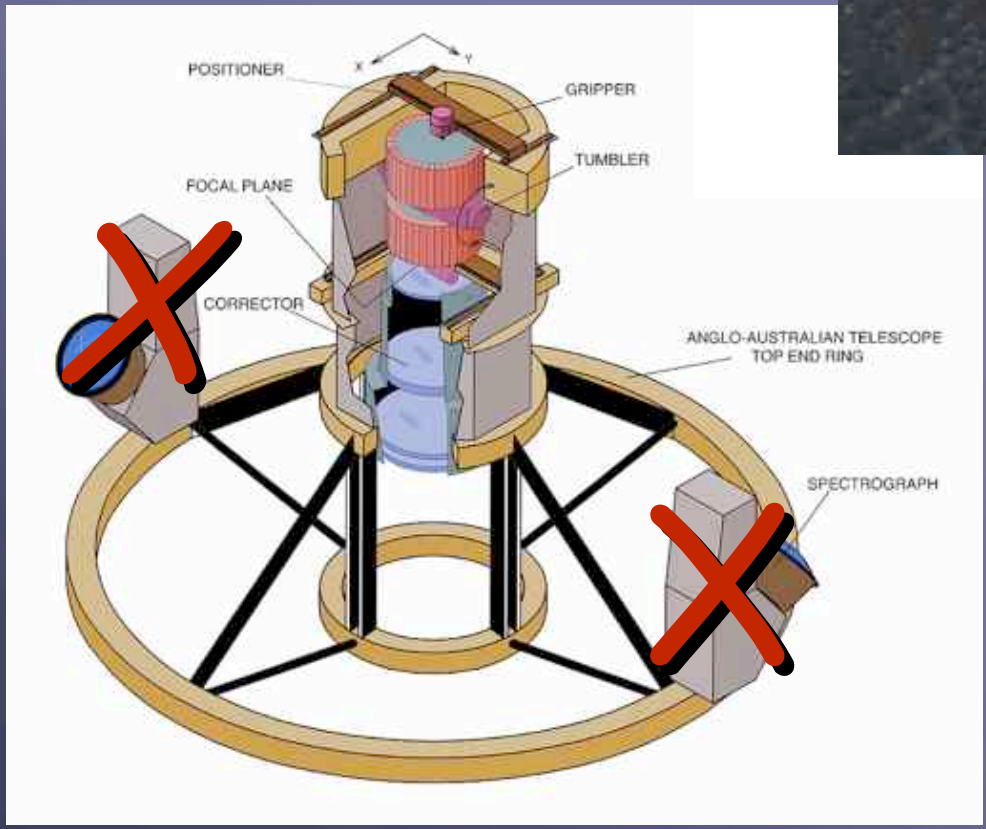
SPIRAL: 512-element, 22.4" x 11.2" FOV integral field unit

UCLES / UHRF: high resolution echelle spectrograph (R ~ 40k to 100k and ~300k to 940k)

AAOmega: 392-fibre, 2° FOV, multi-object optical spectrograph

AAOmega

- *The centrepiece of AAOmega (and its predecessor, 2dF) is a robotic fibre-positioner at prime focus*
- *It can configure fibres for ~400 sources in ~70 mins -- the same time it takes to complete an observation*



- *As there are 2 switchable field plates, no time is lost between observations*
- *The transformation of 2dF to AAOmega saw both spectrographs replaced*

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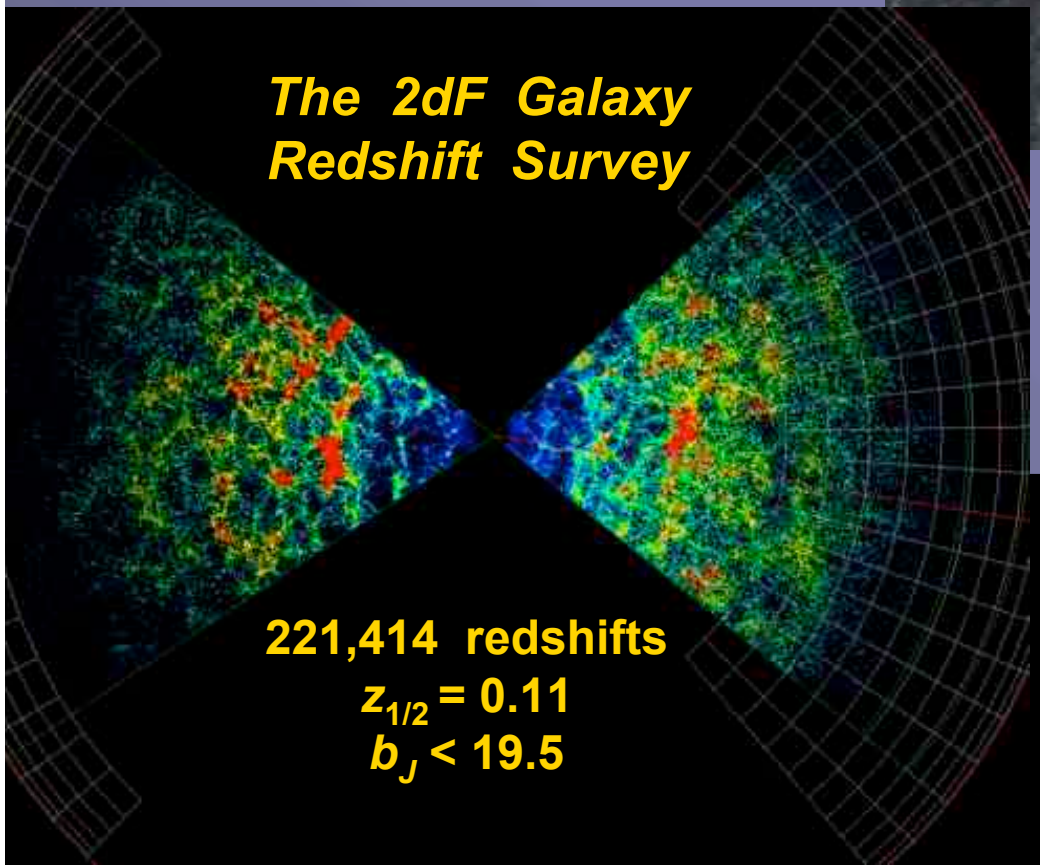

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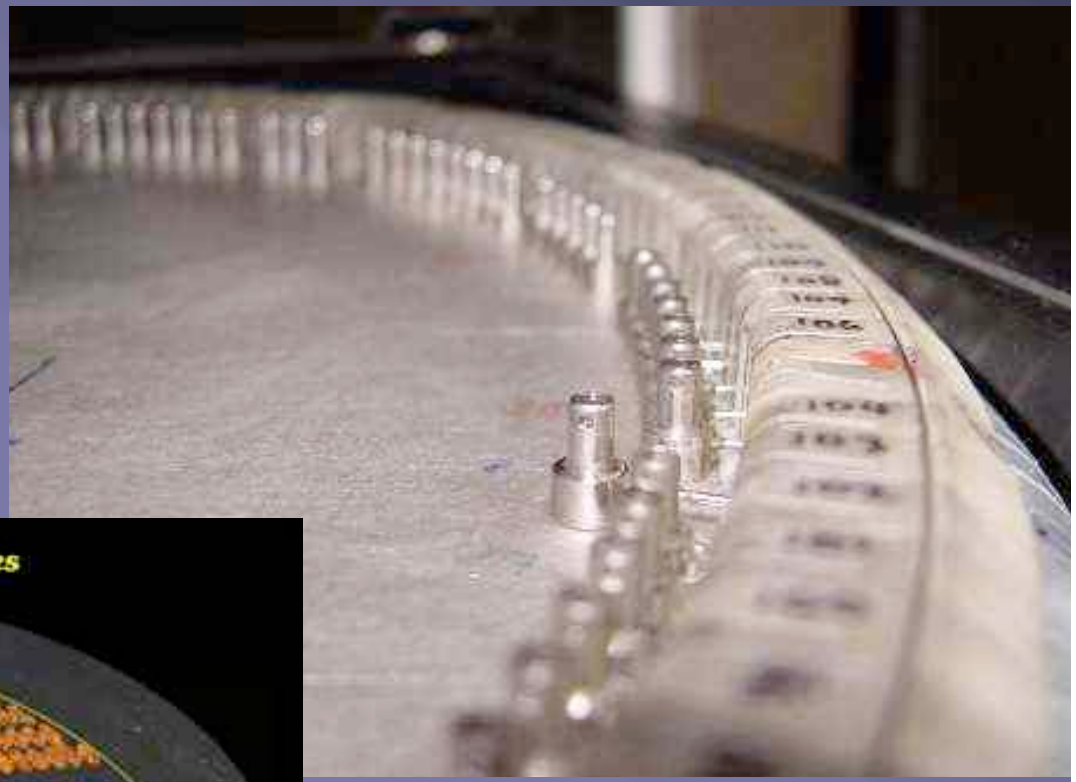
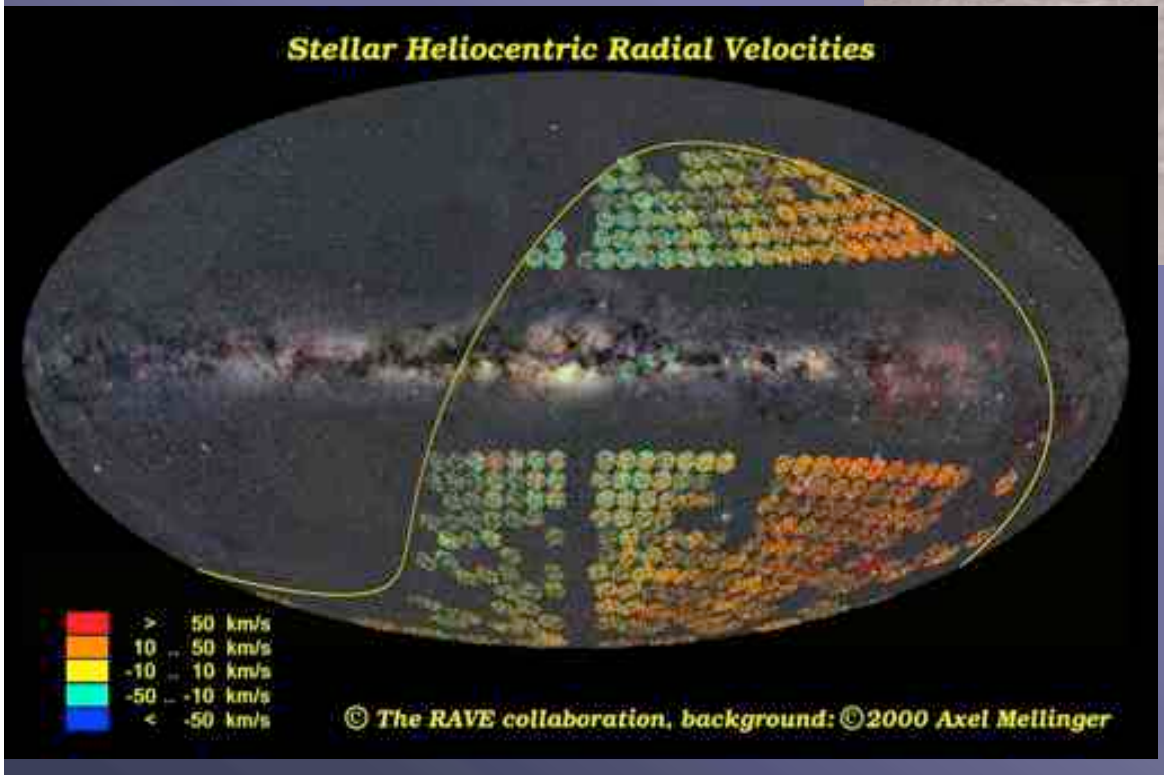
2dF Galaxy Redshift Survey (1998 - 2003): 221k redshifts,

>130 publications, >600 citations for main survey paper alone

The United Kingdom Schmidt Telescope (UKST)

- Built around the same time as the AAT, as a wide-field photographic survey telescope
- Managed by AAO since 1988
- Six-Degree Field instrument (2001): multi-object spectroscopy of up to 150 objects over a 5.7° FOV



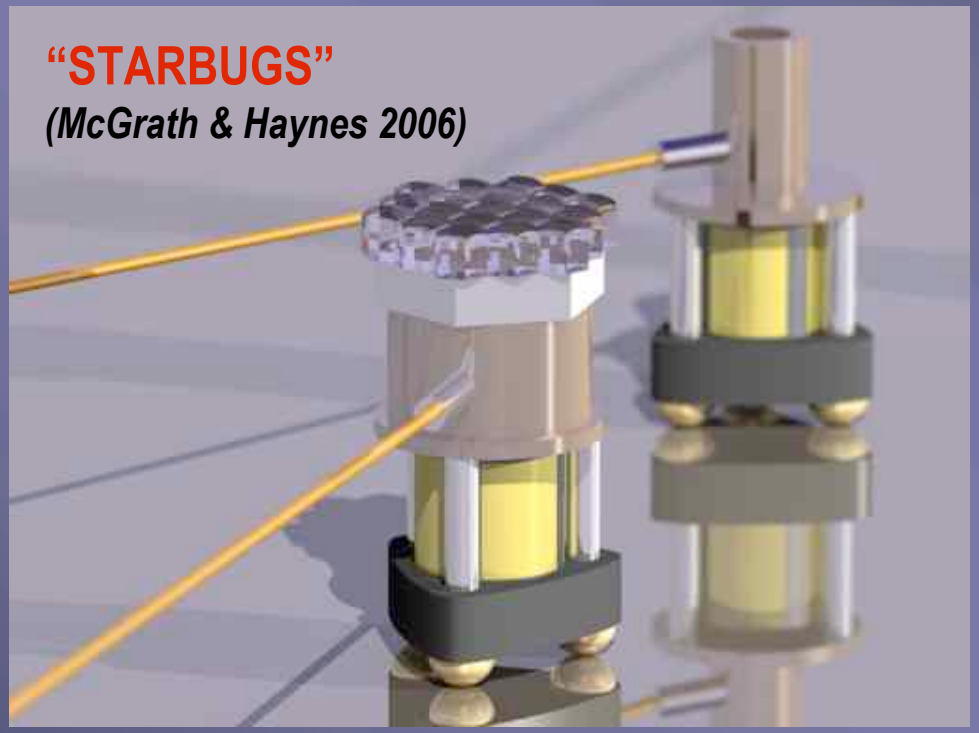


- Current survey: RAVE - the RAdial Velocity Experiment (2004 to ~2011)
  - Radial velocities, metallicities and abundances for up to a million disk and halo stars
- Previous survey: The 6dF Galaxy Survey (2001 to 2006)

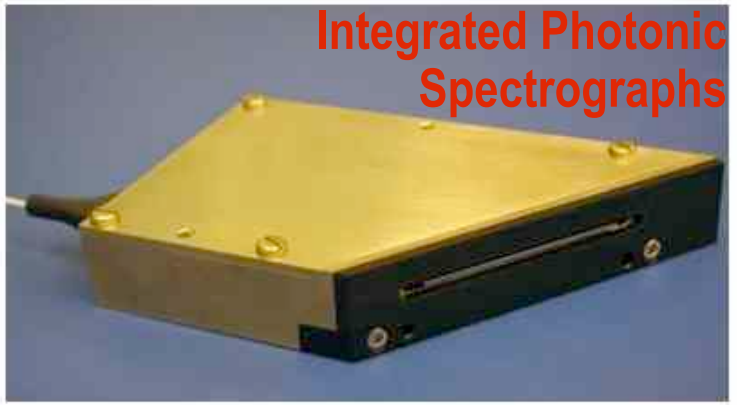
Ongoing Instrumentation Projects

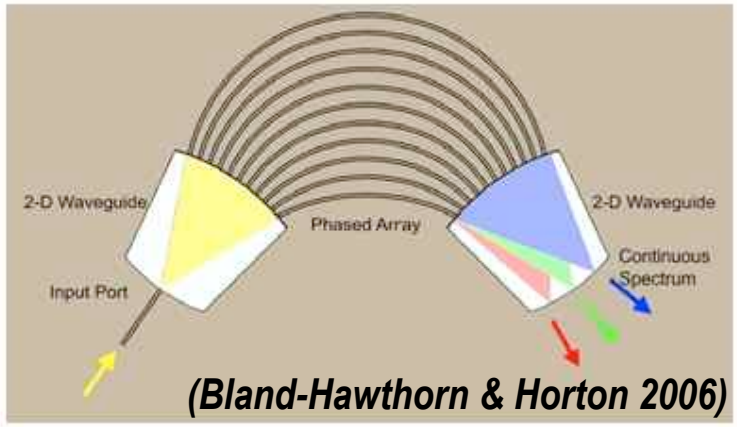
"STARBUGS"

(McGrath & Haynes 2006)



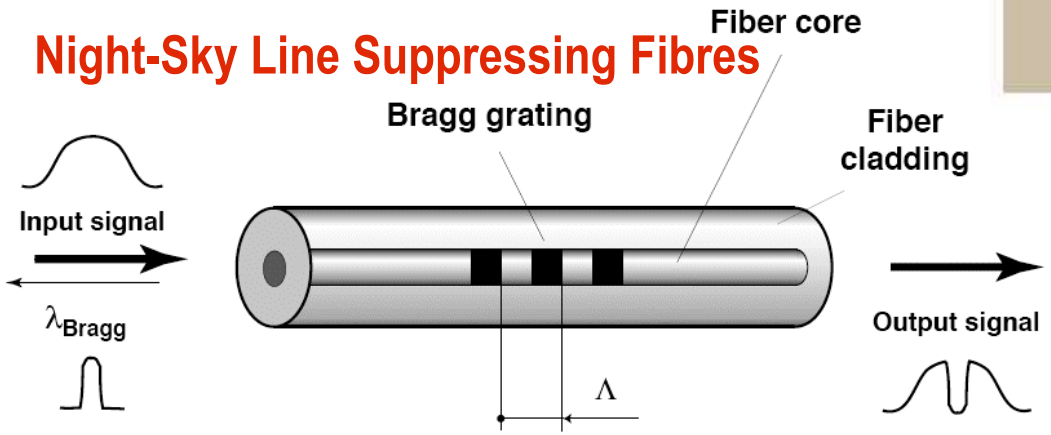
Integrated Photonic Spectrographs





(Bland-Hawthorn & Horton 2006)

Night-Sky Line Suppressing Fibres



- *Aiming to suppress 98% sky emission over z, J, H bands*

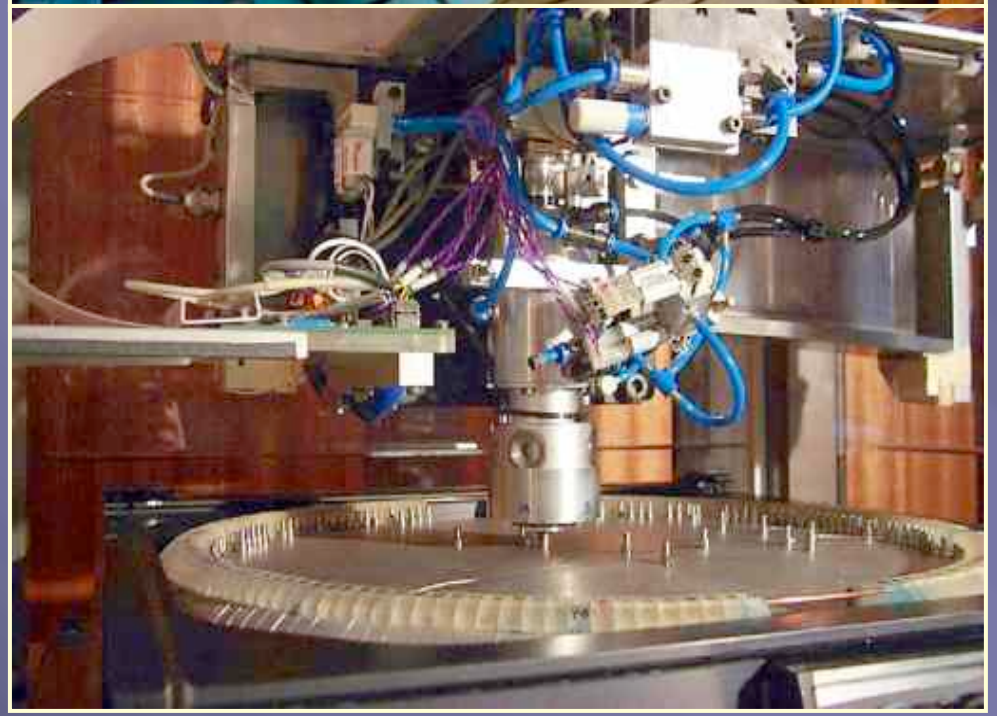
–Need to solve for single-mode and then multi-mode

The AAO in 2008 and beyond

- The AAO and its facilities are now 33 years old
- The UK will withdraw from the AAT agreement on 30 June 2010
- A government review of the AAO in 2007 recommended that the AAT continue operating for at least a decade
- It also recommended that the AAO become Australia's national optical observatory, (serving the AAT, and also Gemini & Magellan)
- The AAO and all facilities will then transfer to Australian ownership and control
- However, the UK is steeply ramping down for the AAT, starting 2006-07
- Meanwhile, the AAO was also successful in obtaining $10M in special government funding
  - –$4M to refurbish the AAT for the coming decade
  - –$6M for a new AAT instrument

The 6dF Galaxy Survey - an introduction

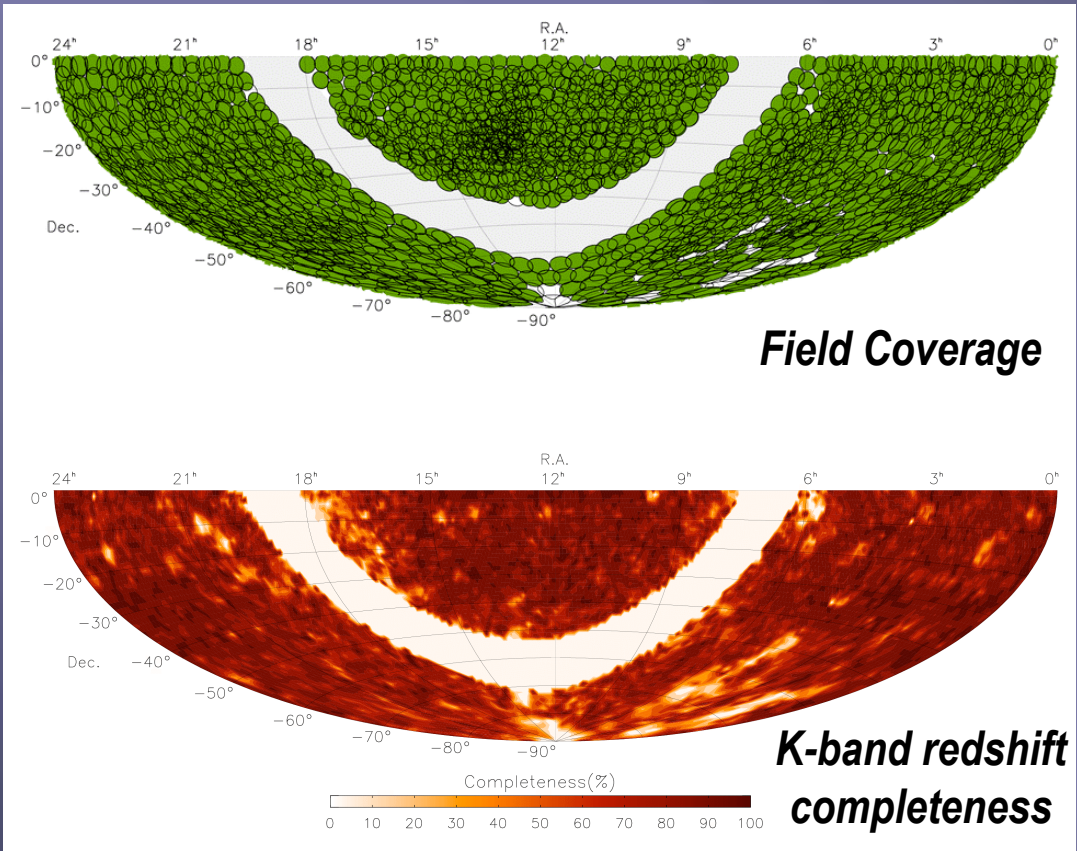
- The 6dFGS is a combined redshift and peculiar velocity survey of the local volume of the universe…
  - –Near-infrared selected primary sample (from 2MASS)
  - –Also redshift survey of other 'interesting' source samples
  - –Peculiar velocities from Fundamental Plane distances
- The survey uses the 6dF spectrograph on the AAO's UK Schmidt Telescope…
  - –5.7º diameter FoV (25.5 deg^2)
  - –up to 150 objects simultaneously



Redshift Survey - Goals

- Measure the luminosity function of NIR-selected galaxies (i.e. the stellar mass function of collapsed structures) and its variation with local environment and spectral type.
- Map the local galaxy distribution (especially close to the Galactic equator).
- Quantify the small- and large-scale clustering of galaxies weighted by stellar mass, and so constrain the scale-dependence of the biasing of the galaxies with respect to the dark matter.
- Measure the power spectrum of galaxy clustering on very large scales, comparable to the scales achieved by the 2dFGRS and SDSS.
- Construct a large, all-sky, volume-limited sample of early-type galaxies as the basis for the peculiar velocity survey.

The 6dF Galaxy Survey - an introduction



- *Survey strategy…*
  - *–Cover the whole southern sky with $|b|>10^{o}$*
  - *–Primary sample selected from 2MASS to $K_{tot}<12.65$*
  - *–Secondary samples: H<13.0, J<13.75, r<15.6, b<16.75*
  - *–11 additional samples: radio, X-ray, IRAS…*
  - *–Peculiar velocity sample: 15,000 brightest early-type galaxies*

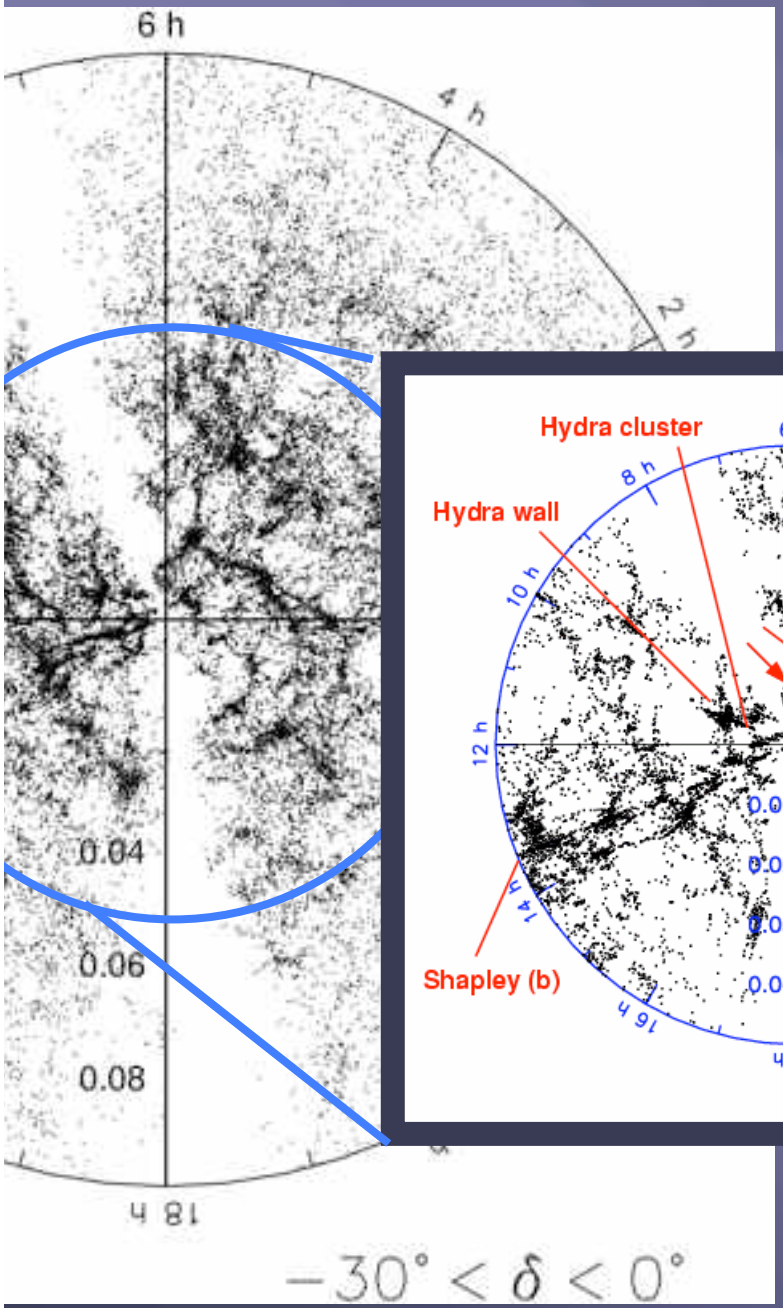
- *Observations now complete: May 2001 to Jan 2006*
  - *–137k spectra, 120k galaxy redshifts over 80% of southern sky*
  - *–Data releases: Dec 2002, Mar 2004, May 2005 & February 2008*

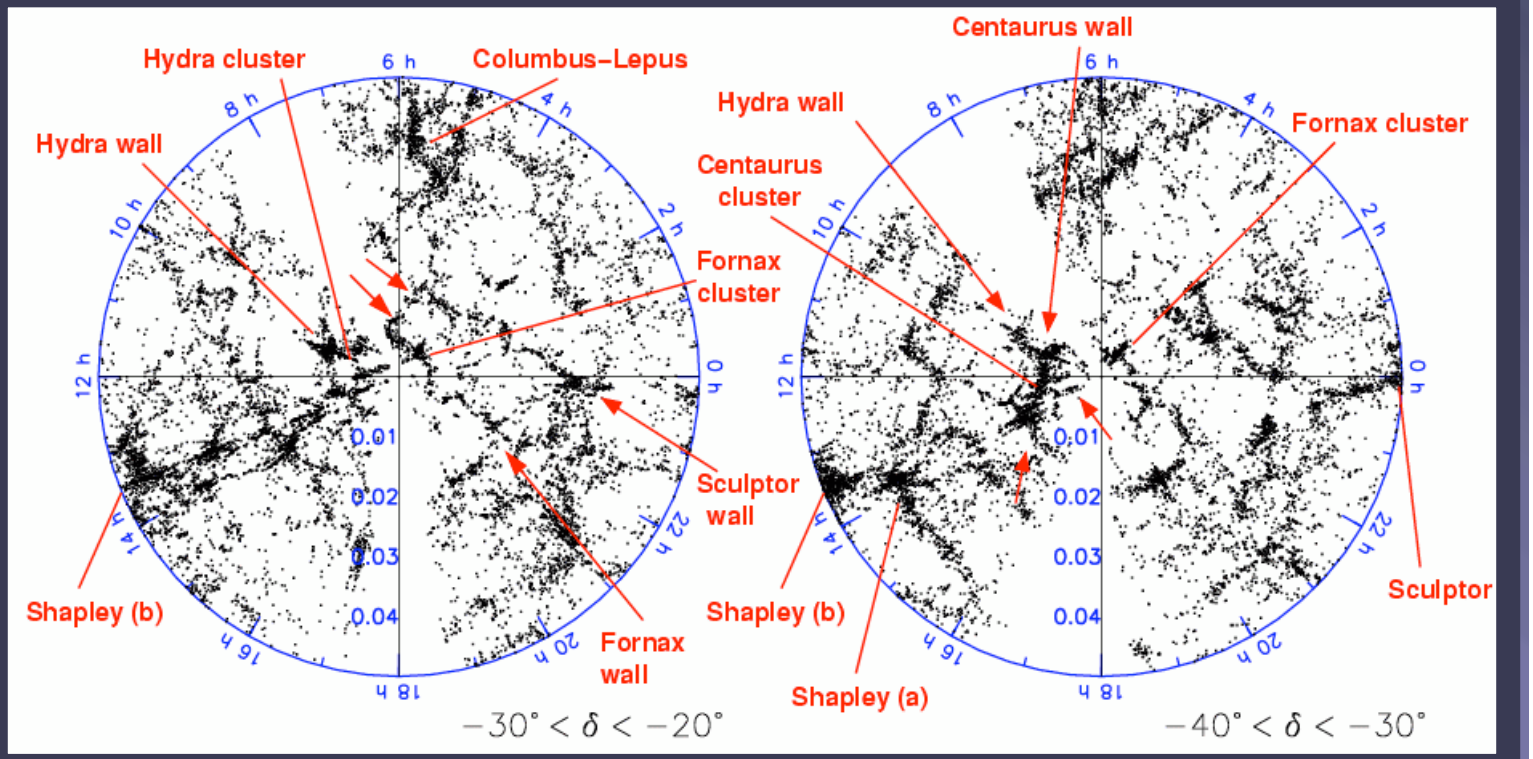
Additional target samples

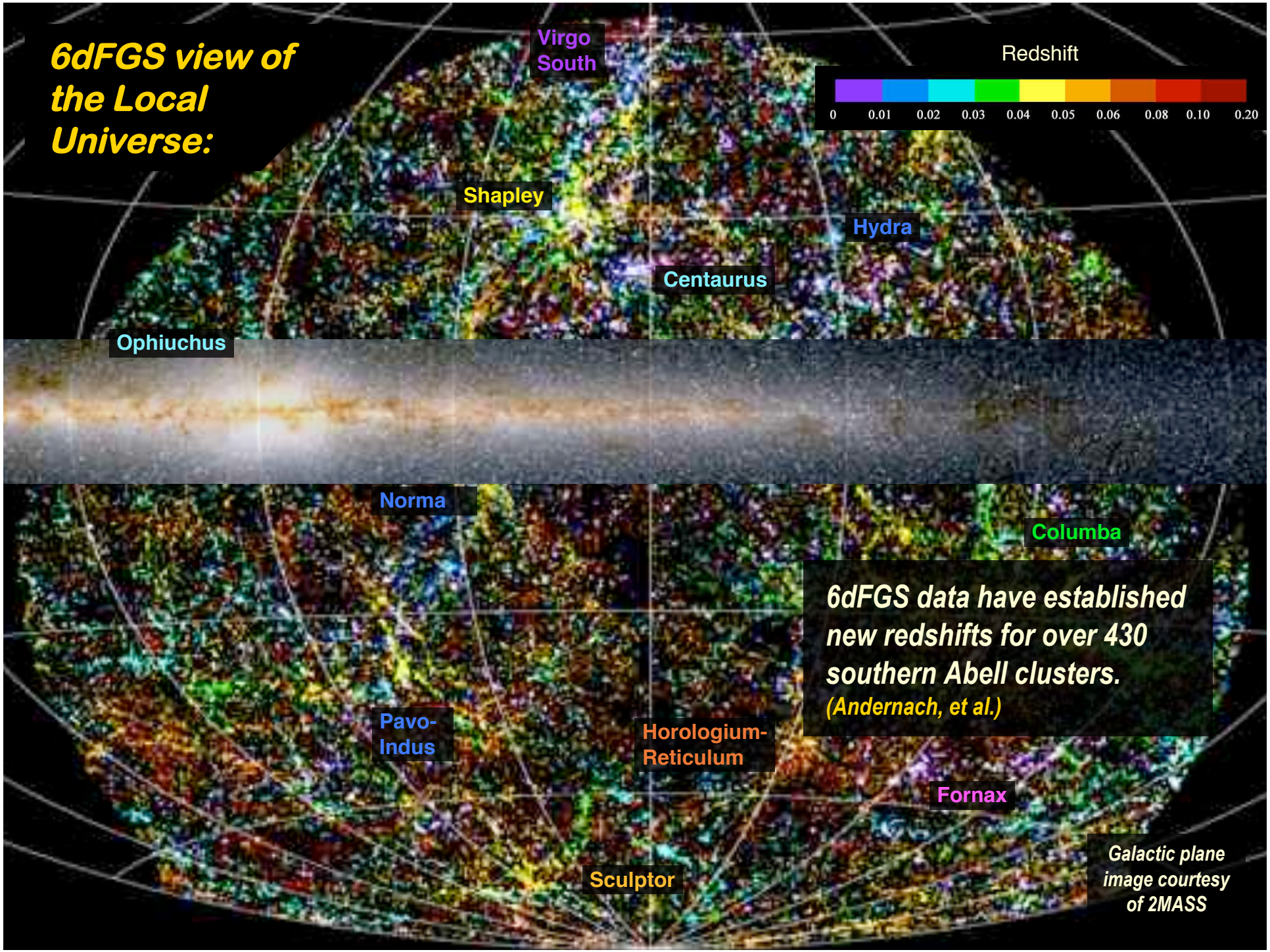
- Additional target samples extend science grasp and fully exploit this whole-hemisphere redshift survey.
- AT programs include targets from:
  - 2MASS NIR sky survey
  - DENIS NIR sky survey
  - SuperCosmos galaxy catalogs
  - ROSAT All-Sky Survey (RASS)
  - HI Parkes Sky Survey (HIPASS)
  - IRAS Faint Source Catalog (FSC)
  - NVSS and SUMSS radio surveys
  - Hamburg-ESO QSO survey

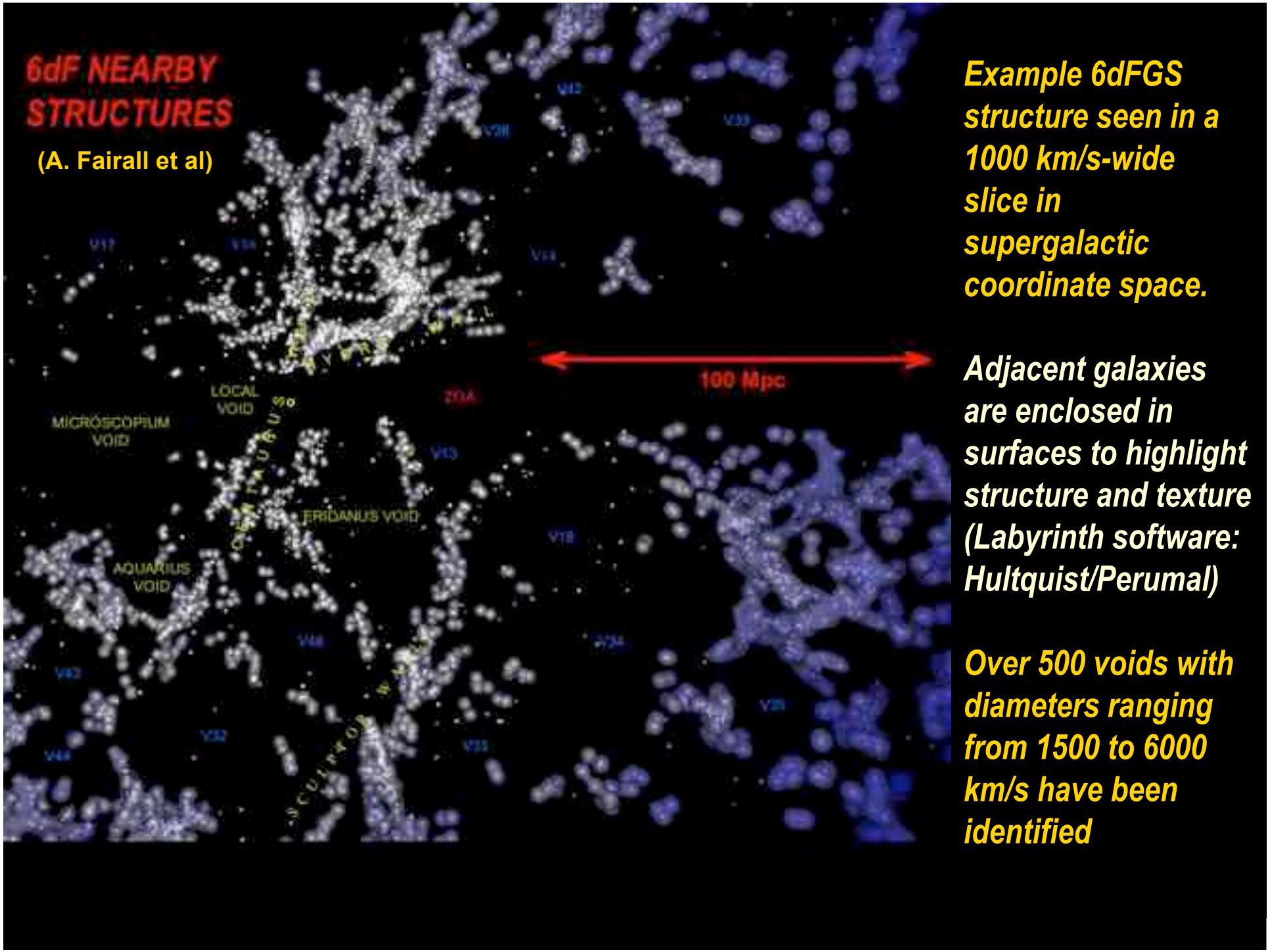
Sample	Priority	Total	Sampling
2MASS K_s < 12.75	8	113988	94.1%
2MASS H < 13.05	6	3283	91.8%
2MASS J < 13.75	6	2008	92.7%
SuperCosmos r_F<15.7	6	9199	94.9%
SuperCosmos b_J<17.0	6	9749	93.8%
Shapley	6	939	85.7%
ROSAT All-Sky Survey	6	2913	91.7%
HIPASS (> 4-sigma)	6	821	85.5%
IRAS FSC	6	10707	94.9%
Denis J < 14	5	1505	93.2%
Denis I < 15	5	2017	61.7%
2MASS AGN	4	2132	91.7%
Hamburg-ESO Survey	4	3539	90.6%
NOAO-VLA Sky Survey	4	4334	87.6%

Large Scale Structure:
Redshift Maps






6dFGS view of the Local Universe:
Virgo South
Redshift
0
0.01
0.02
0.03
0.04
0.05
0.06
0.08
0.10
0.20
Shapley
Hydra
Centaurus
Ophiuchus
Norma
Columba
6dFGS data have established new redshifts for over 430 southern Abell clusters.
(Andernach, et al.)
Pavo-Indus
Horologium-Reticulum
Fornax
Sculptor
Galactic plane image courtesy of 2MASS

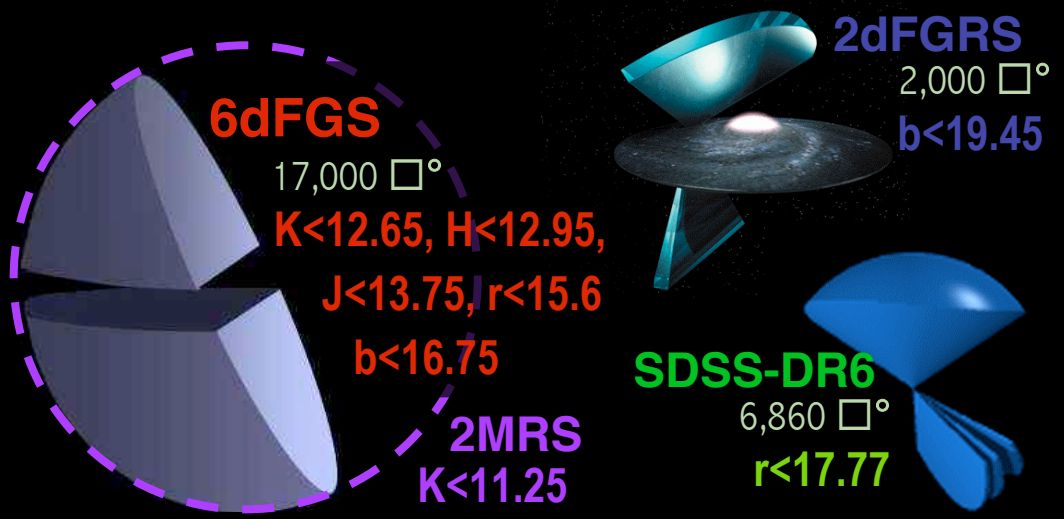


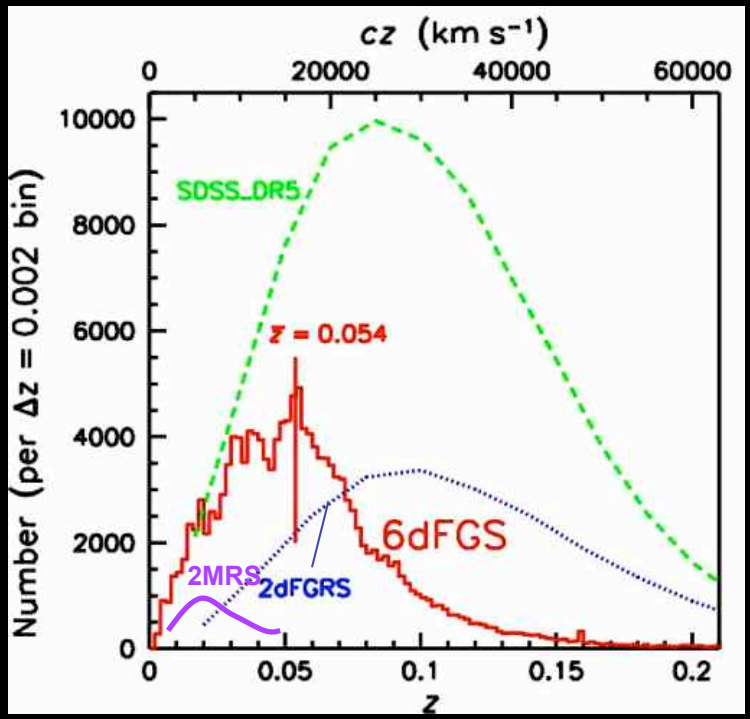
Example 6dFGS structure seen in a 1000 km/s-wide slice in supergalactic coordinate space.

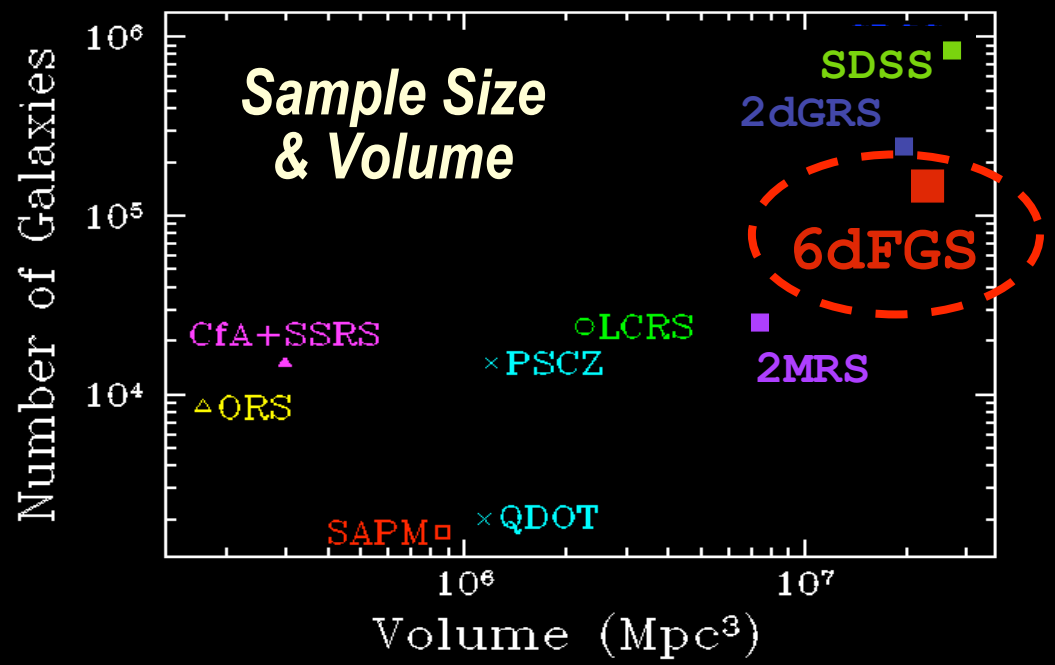
Adjacent galaxies are enclosed in surfaces to highlight structure and texture (Labyrinth software: Hultquist/Perumal)

Over 500 voids with diameters ranging from 1500 to 6000 km/s have been identified

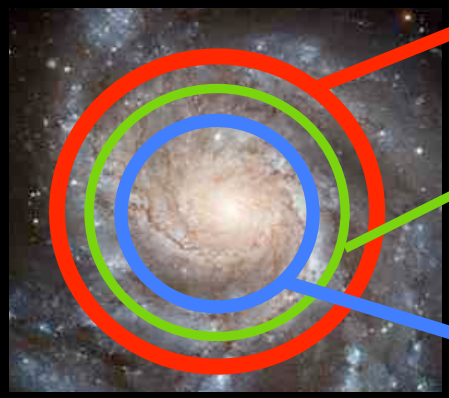
6dFGS compared to other wide redshift surveys







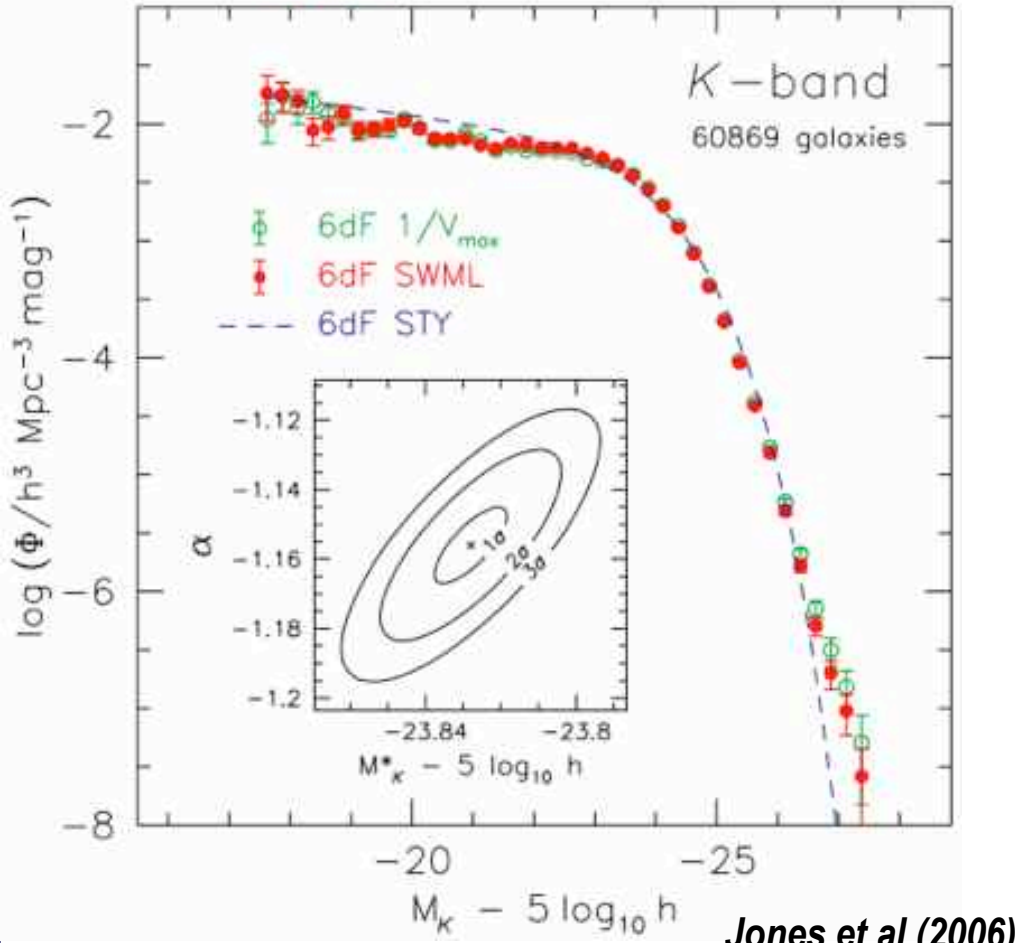
Aperture Size



6dFGS
6.6 kpc
SDSS
5.5 kpc
2dFGRS
3.7 kpc

Near-infrared Luminosity Functions

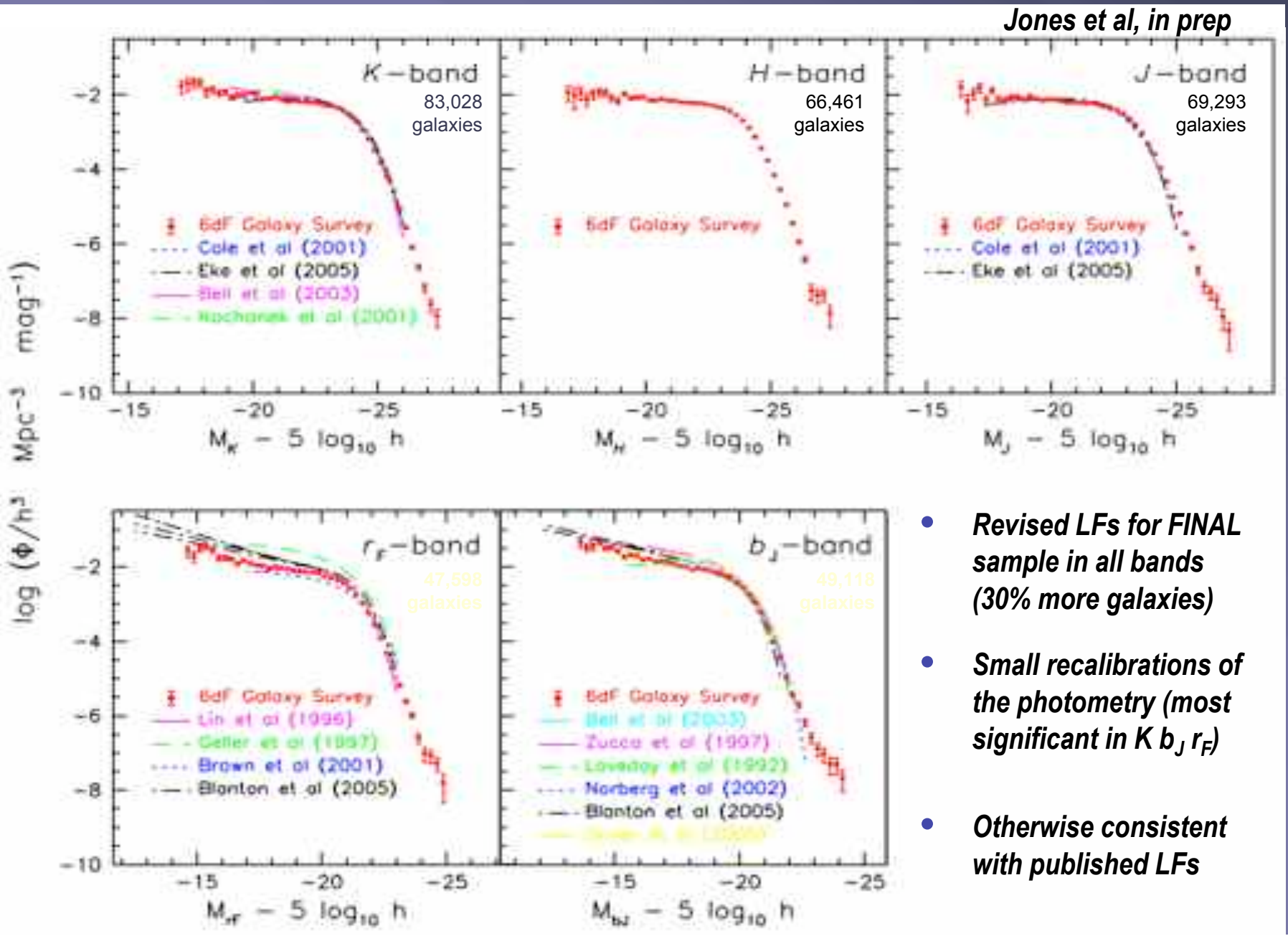
- *The 6dFGS K-band LF extends 1.5-2 mags further at both bright and faint ends (covers a factor of 10^4 in L)*
- *Agrees with other recent LF measurements up to small differences between magnitude systems*
- *Previous, smaller samples have larger uncertainties in their normalisations*



Jones et al (2006)

Final NIR and optical luminosity functions

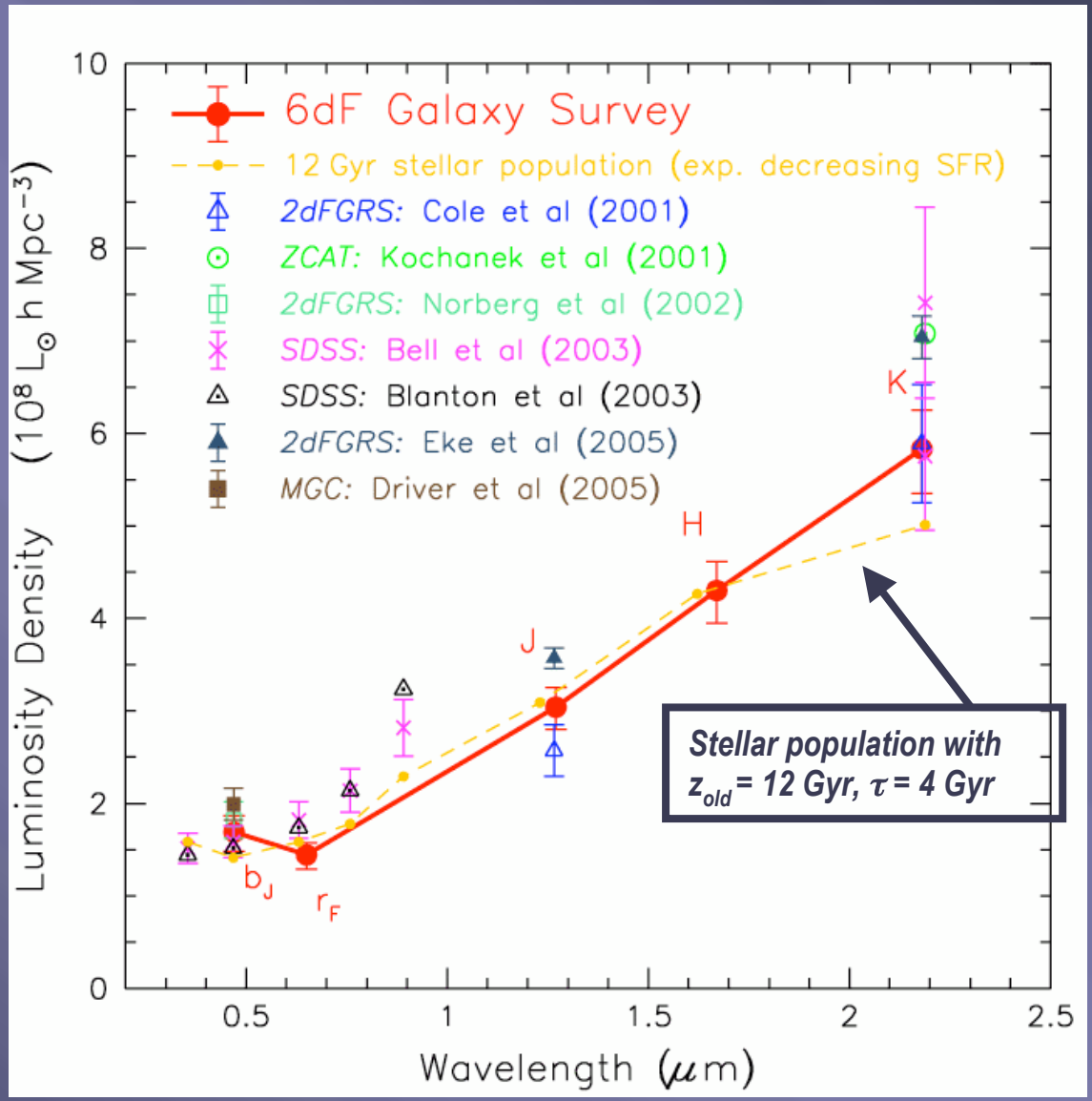
Jones et al, in prep



- *Revised LFs for FINAL sample in all bands (30% more galaxies)*
- *Small recalibrations of the photometry (most significant in K b_J r_F)*
- *Otherwise consistent with published LFs*

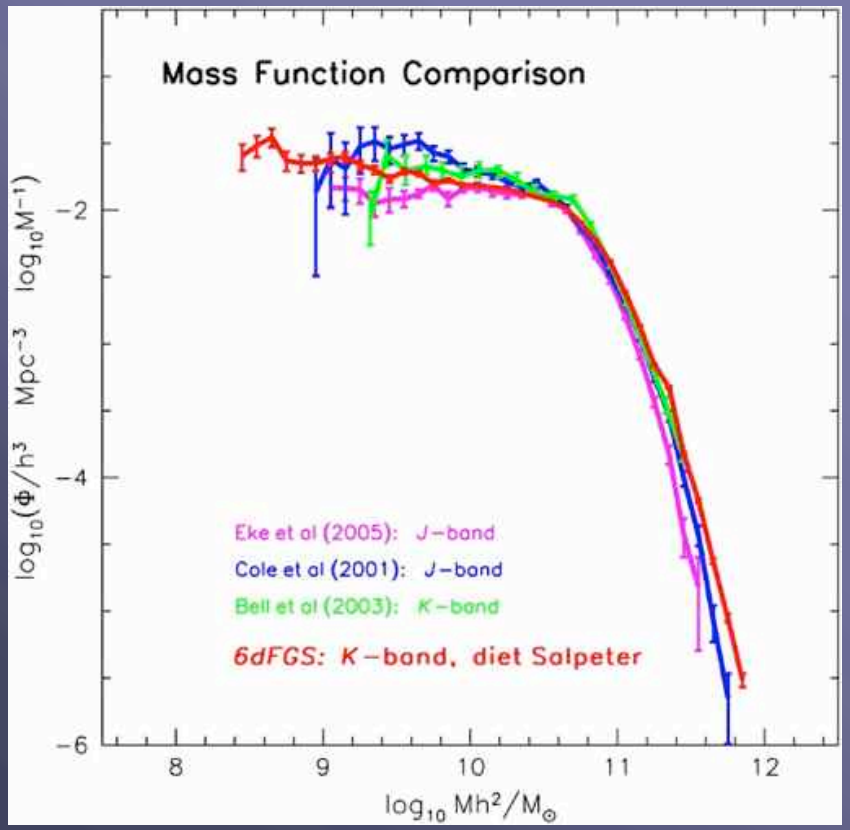
Luminosity density in optical and NIR

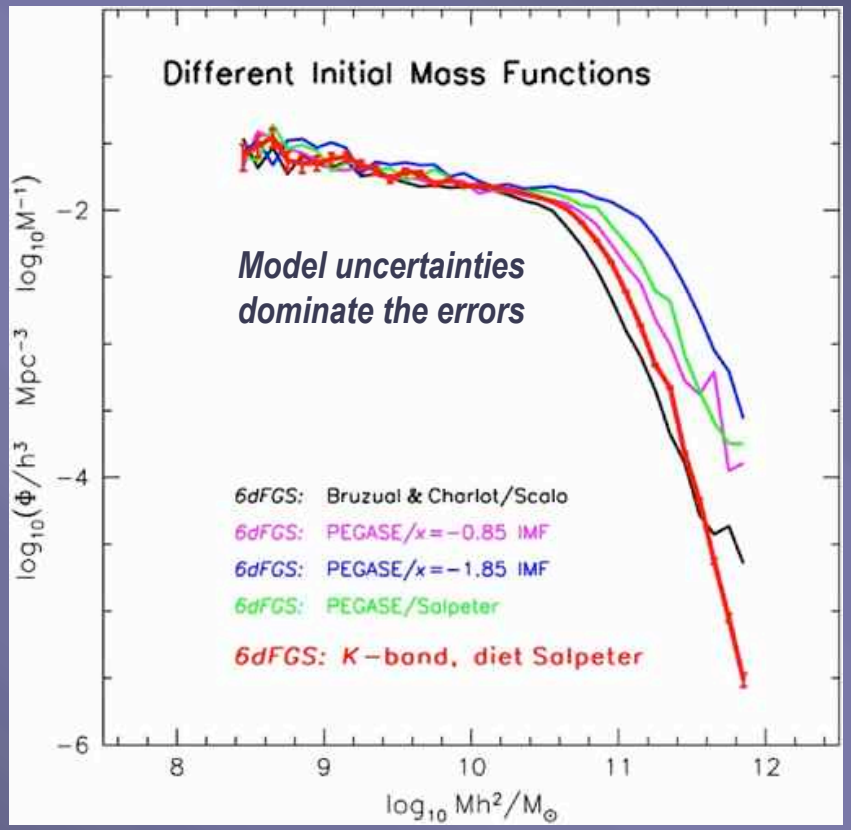
- *The luminosity densities in optical and NIR estimated from 6dFGS are broadly consistent with the 2dFGRS and SDSS results*
- *K-band luminosity density lies at lower end of range*
- *From optical through NIR, the variation of luminosity density with wavelength is consistent with models for an old stellar population*



Stellar Mass Function

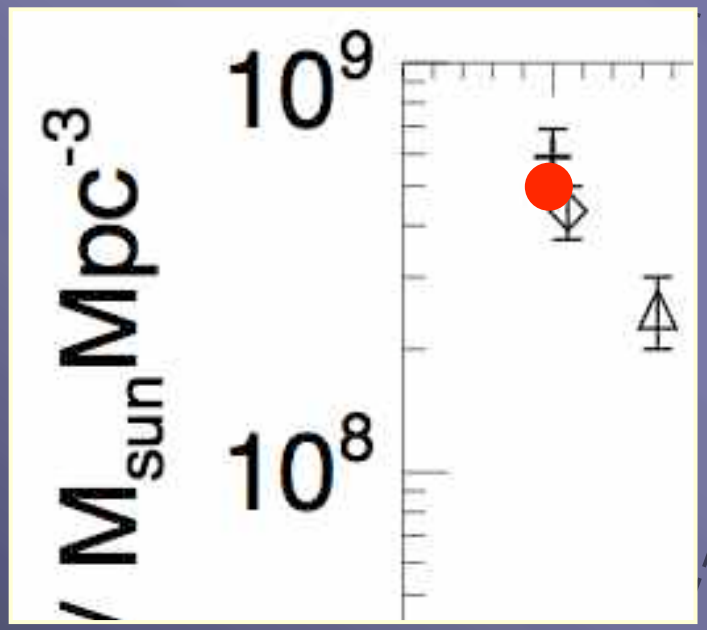
- *NIR luminosities are good proxies for the total stellar masses in galaxies, so we can estimate the stellar mass function from the K-band luminosity function…*
- *NIR light is dominated by the older and cooler stars comprising the bulk of the stellar mass*
- *NIR mass-to-light ratios are well constrained, and k-corrections & extinctions are smaller in NIR*

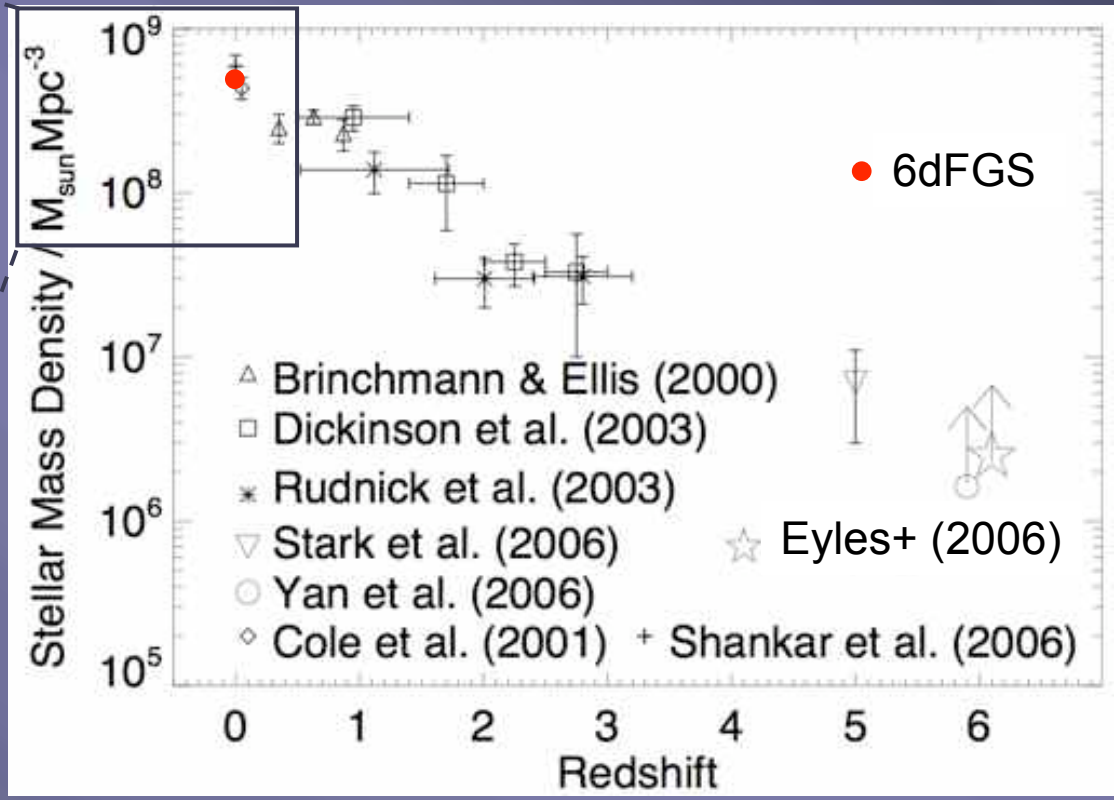




The present-day stellar mass density

- The 6dFGS data provides (up to systematic errors in the models) the most precise measurement of the stellar mass density today





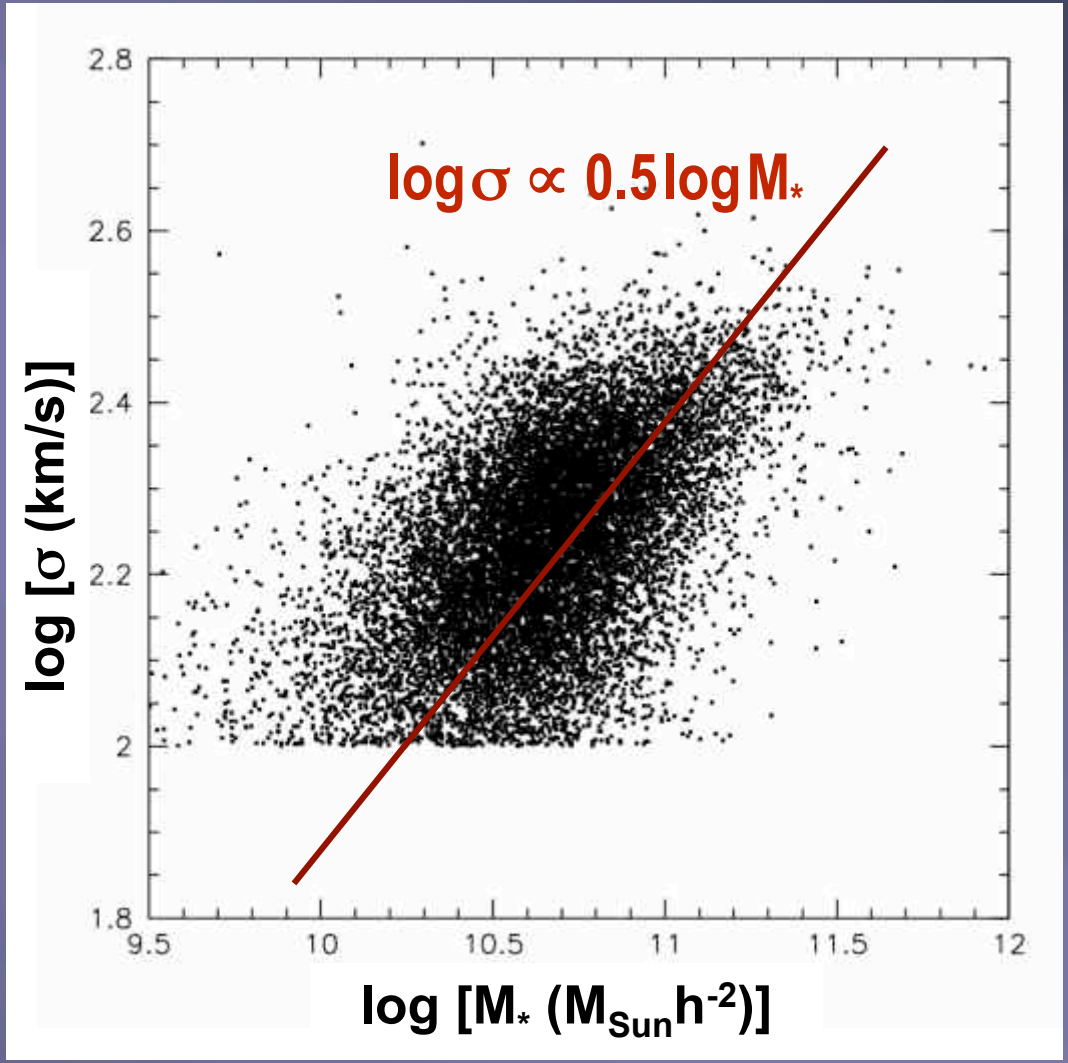
- **Stellar mass density is**

$\Omega_* h = (1.80 \pm 0.04) \times 10^{-3}$

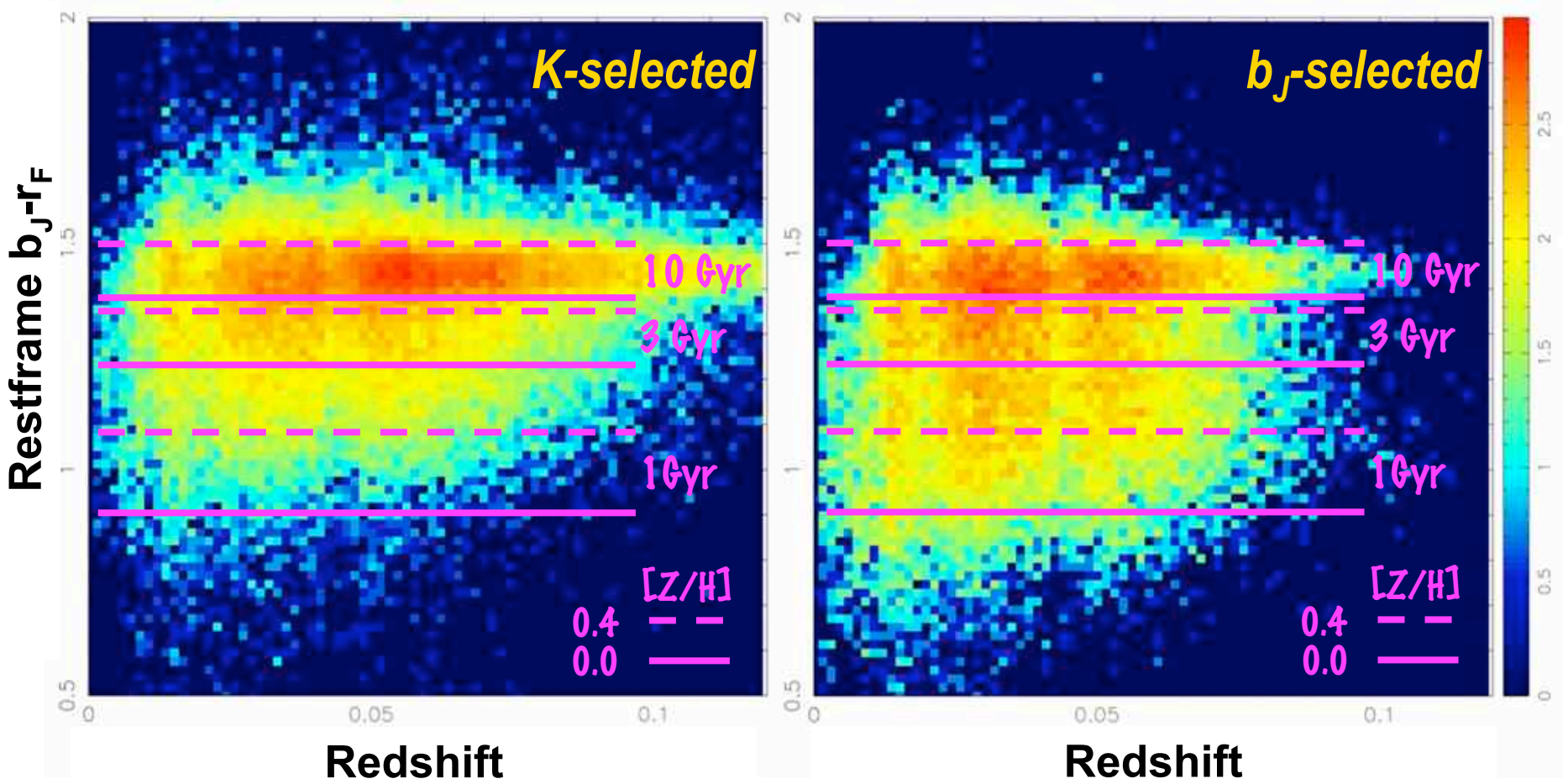
$\rho_* = (5.00 \pm 0.11) \times 10^8 \, h \, M_\odot \, Mpc^{-3}$

Stellar and Dynamical Masses

- The relation between velocity dispersion and stellar mass is consistent with $M_* \propto \sigma^2$
- This is implies that star-formation efficiency in galaxies is roughly independent of their dynamical masses - i.e. $M_*/M_{dyn} \approx$ const (cf. Gallazzi et al 2006)
- The scatter in the relation translates to a scatter in star-formation efficiency of about 40%



Galaxy colours and stellar populations

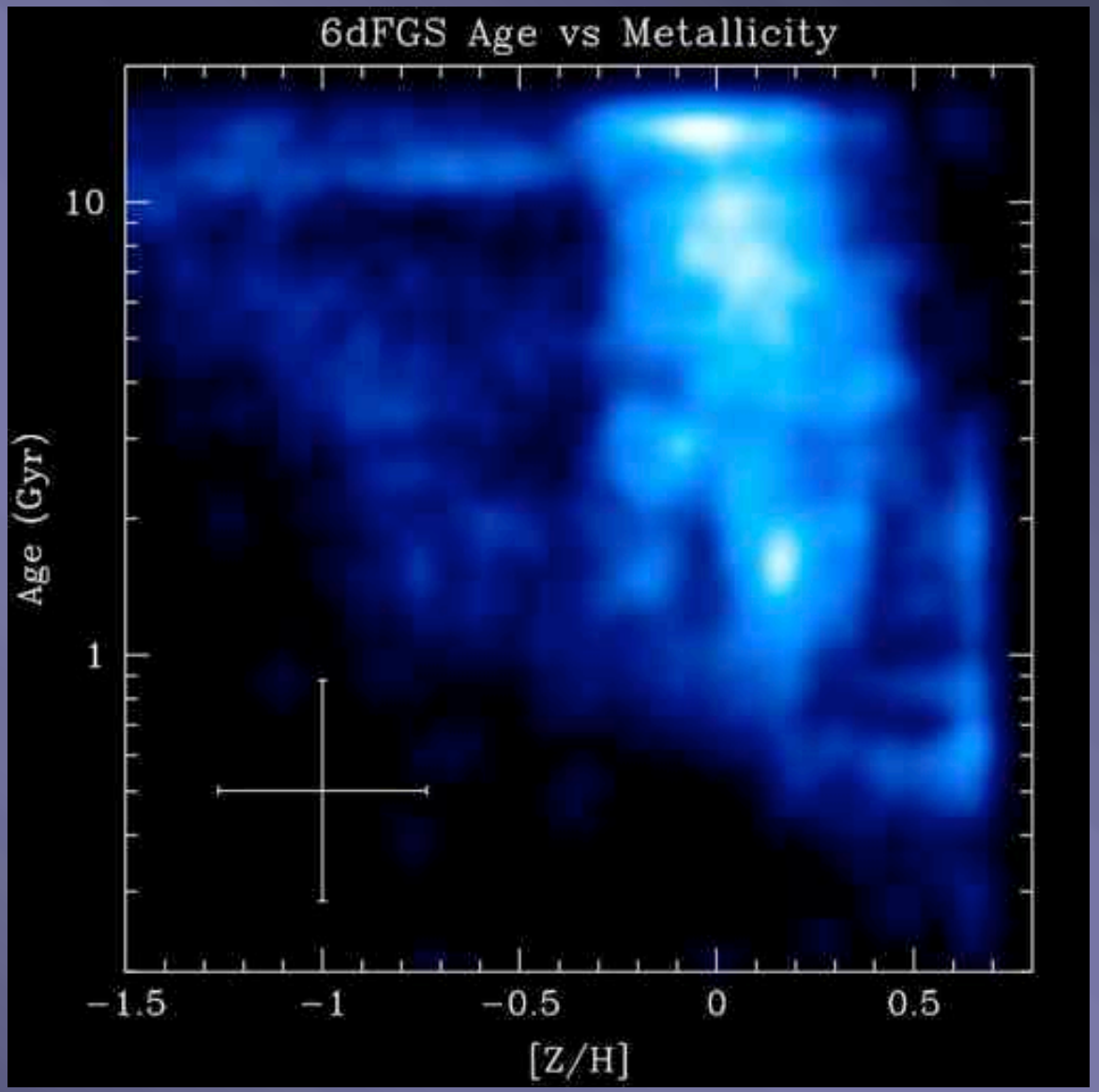


- *NIR and optical samples have different mixes of galaxy types*
- *Age and metallicity are substantially degenerate w.r.t. colours*

Galaxy ages and metallicities

- *For 7000 DR1 galaxies we can measure Lick indices and emission lines at high S/N and get ages & metallicities*

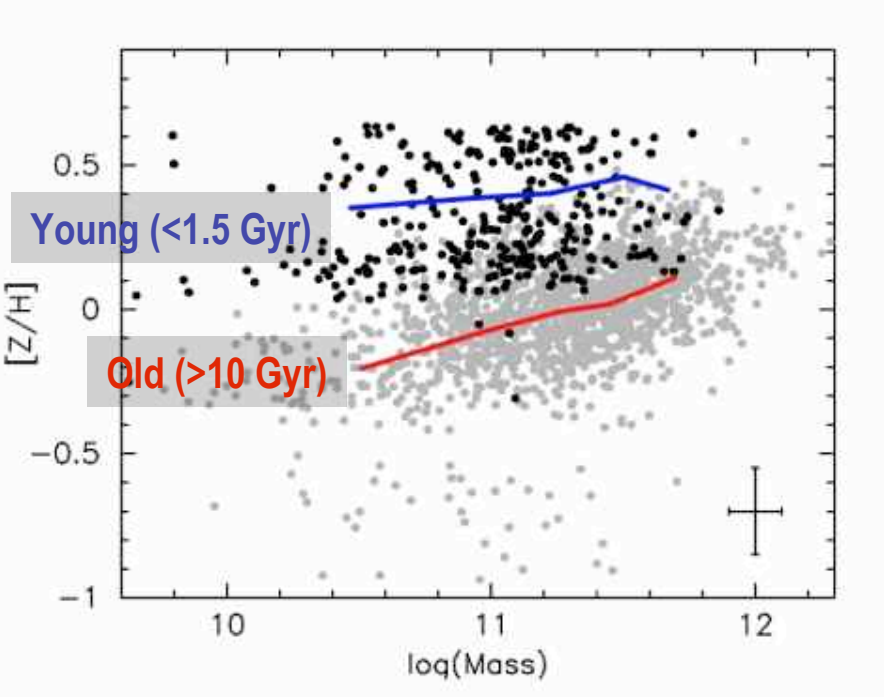
- *The distribution of ages & metallicities shows…*
  - *Most galaxies have -0.2<[Z/H]<0.3*
  - *The youngest galaxies have higher minimum metallicities*
  - *The least metal-rich galaxies have older minimum ages*

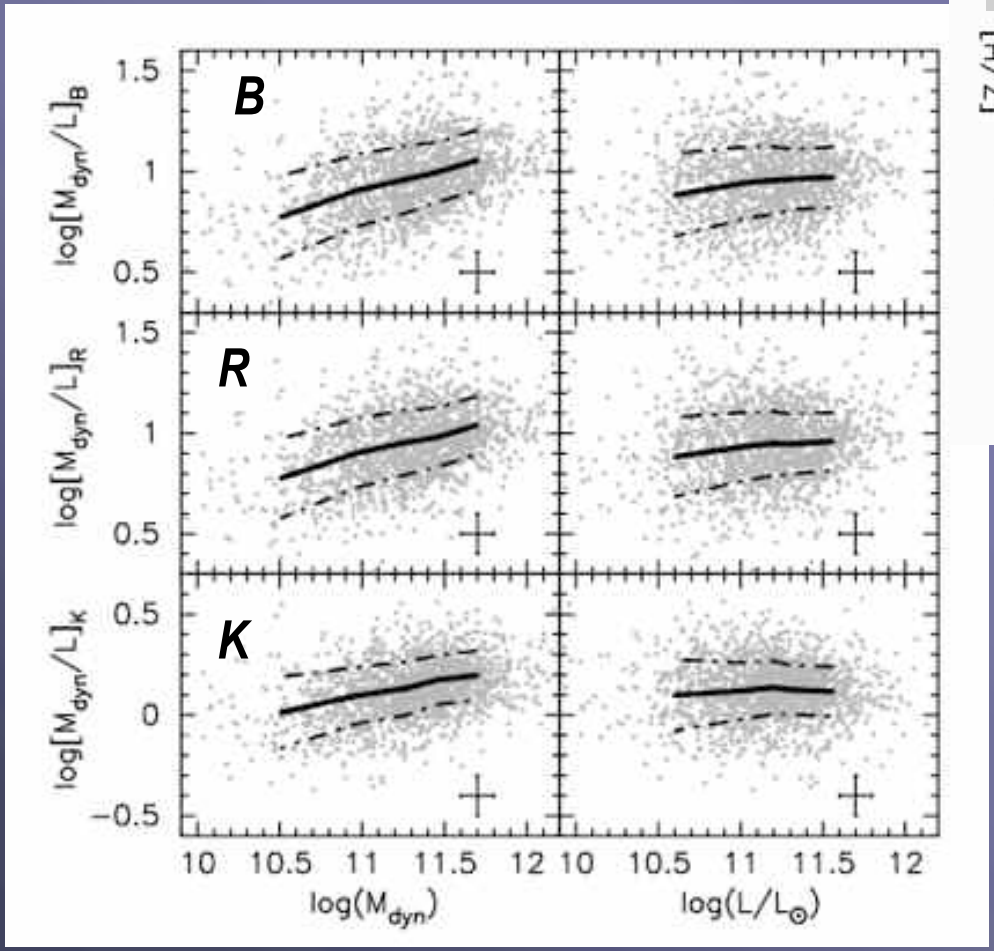


(Proctor et al, in prep)

Metallicity and Mass-to-Light Ratios

- *Old galaxies show a clear mass-metallicity relation. Young galaxies do not.*





(Proctor et al, in prep)

- *Dynamical mass-to-light ratios of the **old population** alone, in the B, R, and K-bands.*
- *While the effects of age have been eliminated (by our deliberate selection), metallicity has not.*

Metallicity and Mass-to-Light Ratios

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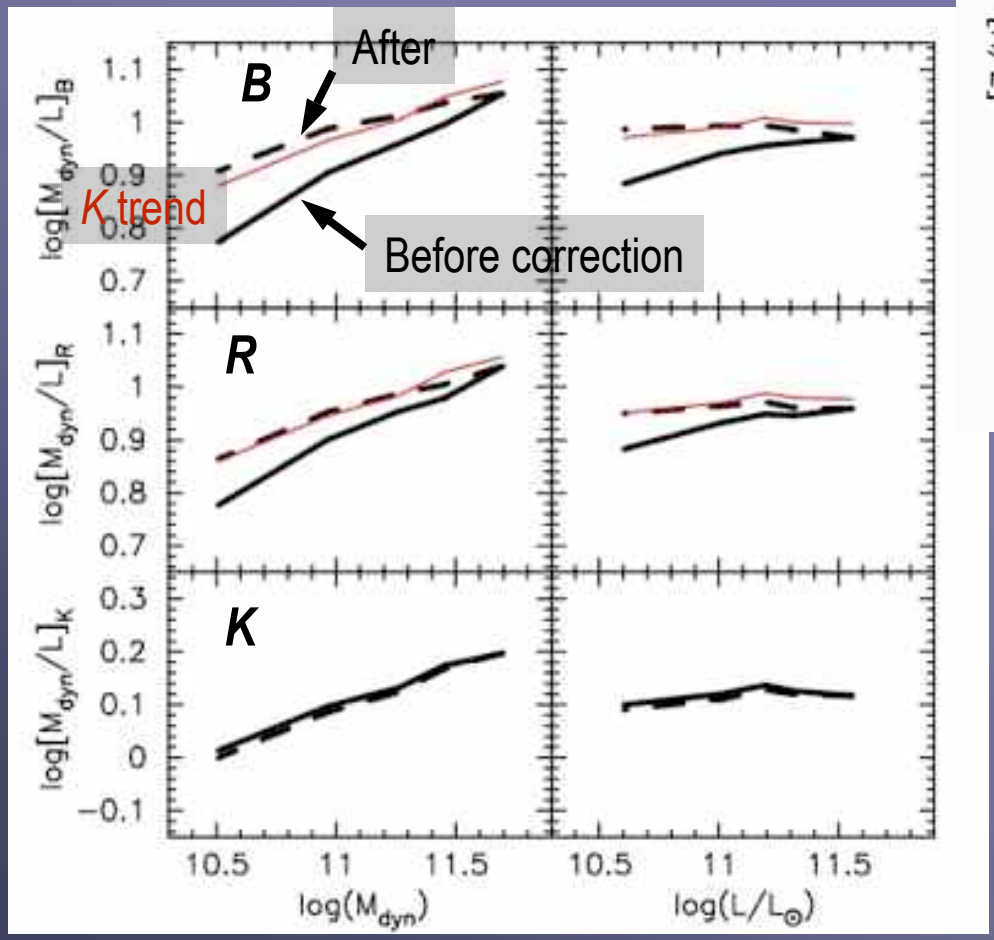

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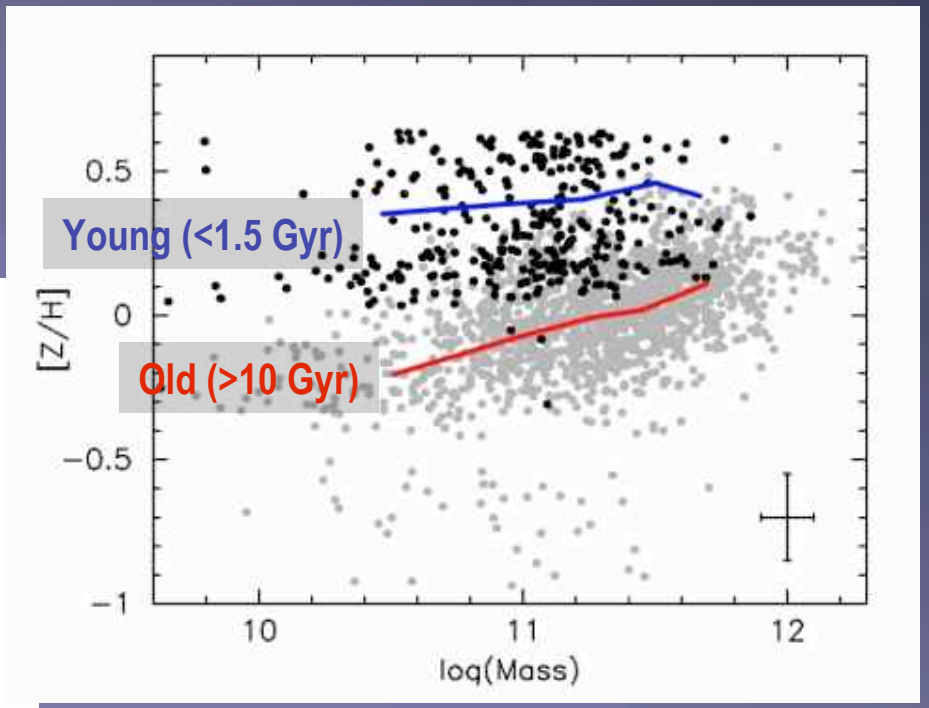

- *When metallicity is accounted for, all three bands show remarkable agreement in the (M_{dyn}/L) relations*
- *From the (M/L)~$M^{0.15}$ relation found, one would expect (M/L)~$L^{0.18}$. Infact, (M/L)~L^{0}.*
- *Therefore simple (M/L) variations with M or L can not be used to explain the 'tilt' of the Fund Plane*

6dFGS science from the redshift survey

- Studies of large scale structure (Fleenor et al 20005, 2006; Proust ey al 2006, Radburn-Smith et al 2006, Doyle & Drinkwater 2006, Andernach et al 2005)
- Luminosity and mass functions (Jones et al 2006; Jones et al in prep)
- The influence of local density and velocity distributions (Erdogdu et al 2006a,b; Inoue & Silk 2006)
- Galaxy groups and their properties (Brough et al 2006a,b; Forbes et al 2006, Firth et al 2006, Kilborn et al 2006)
- Studies of special interest samples such as radio sources (Sadler et al 2006, Mauduit & Mamon 2007, Mauch & Sadler 2007), infra-red luminous galaxies (Hwang et al 2007) among many others.

6dFGS Peculiar Velocity Survey

- To map in detail the density and peculiar velocity fields over half the local volume to ~15,000 km/s.
- To provide additional constraints on cosmological models, and better measurements of fundamental parameters, from statistics of these fields.
- To study the ages, metallicities and star-formation histories of early-type galaxies over a wide range of masses and environments.

6dFGS Database

- 6dFGS online database
  - Searchable using either SQL query commands or a WWW form
  - Each source has its own multi-extension FITS file, of spectra & postage stamps
  - The different target catalogues are also fully searchable online
- Current - Data Release 2
  - Released April 2005
  - Data Jan 2002-Oct 2004
  - 89211 spectra
  - 83014 unique redshifts
  - 936 fields
- Final Data Release
  - Expected Feb 2008
  - Complete dataset from May 2001 to Jan 2006
  - 137k spectra
  - 120k unique redshifts
  - 1464 fields