Synergies with multi-wavelength surveys

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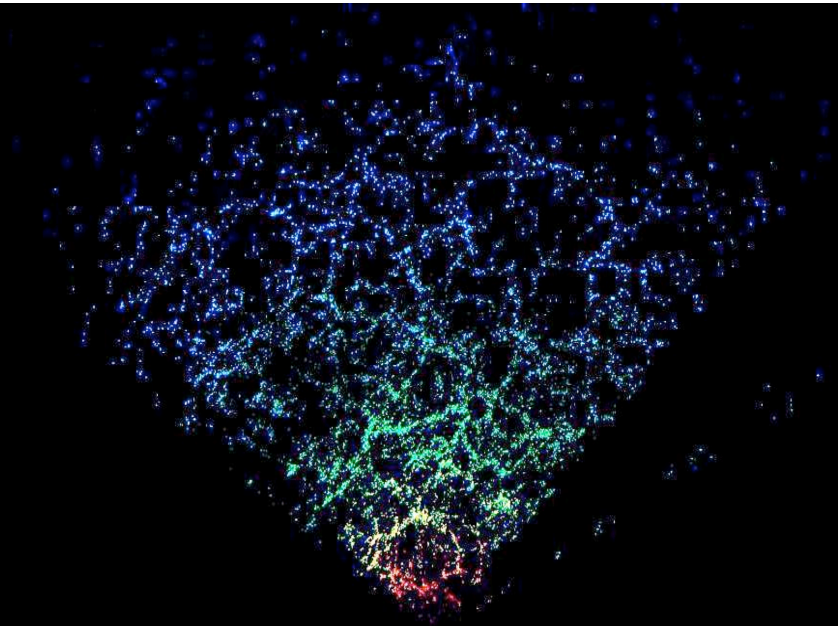
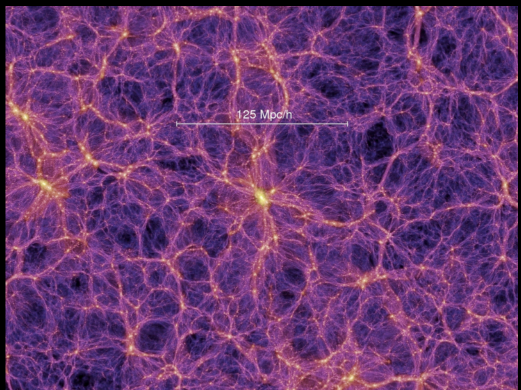
Cosmology

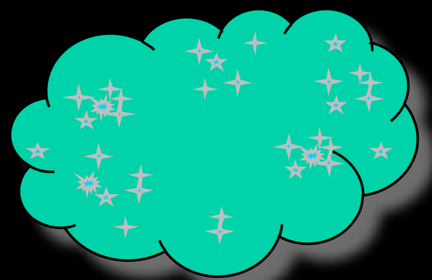


Galaxy Formation Models



N-body simulations

+



Messy physics
(gas, star-formation,
Black holes, dust, etc...)

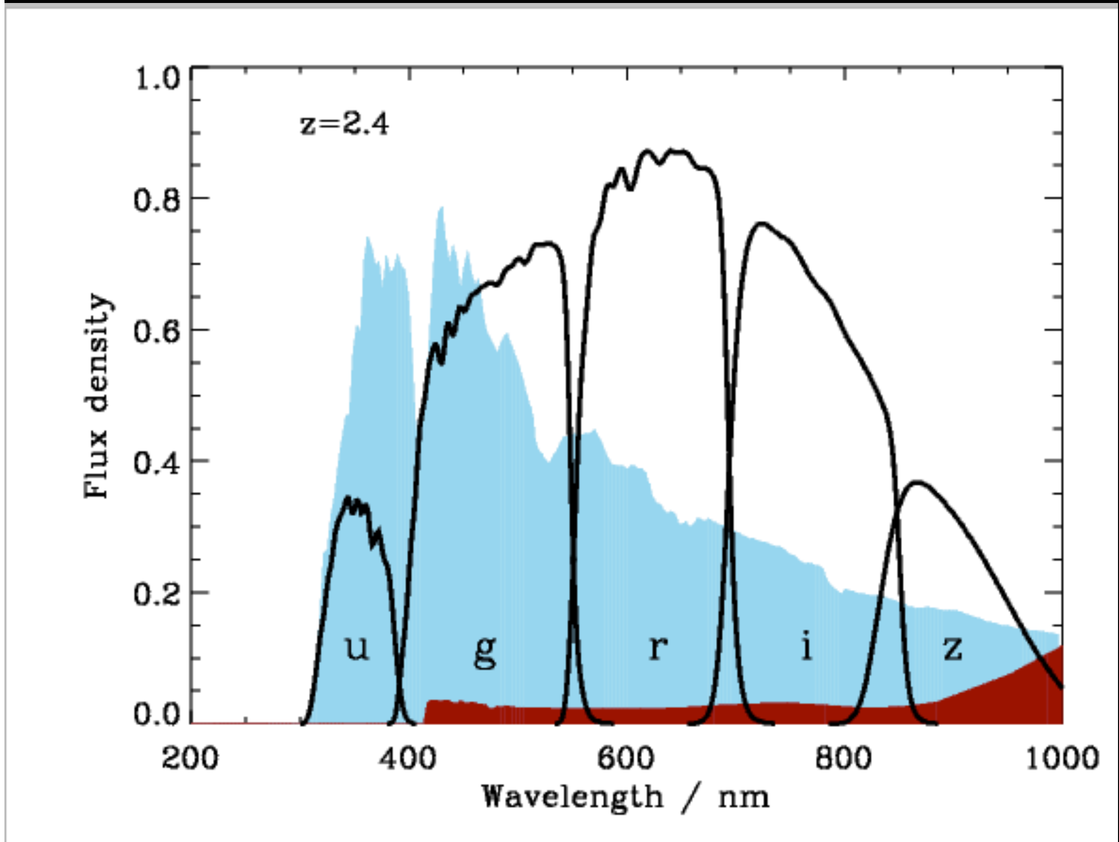
=

Need to test the models with observations as the Universe evolves

But what will we be able to do over the next few years to decades?

We need to trace AGN, star forming galaxies and ‘normal’ galaxies across the whole of the Universe and over the largest scales!

How do you trace galaxy evolution? The optical view



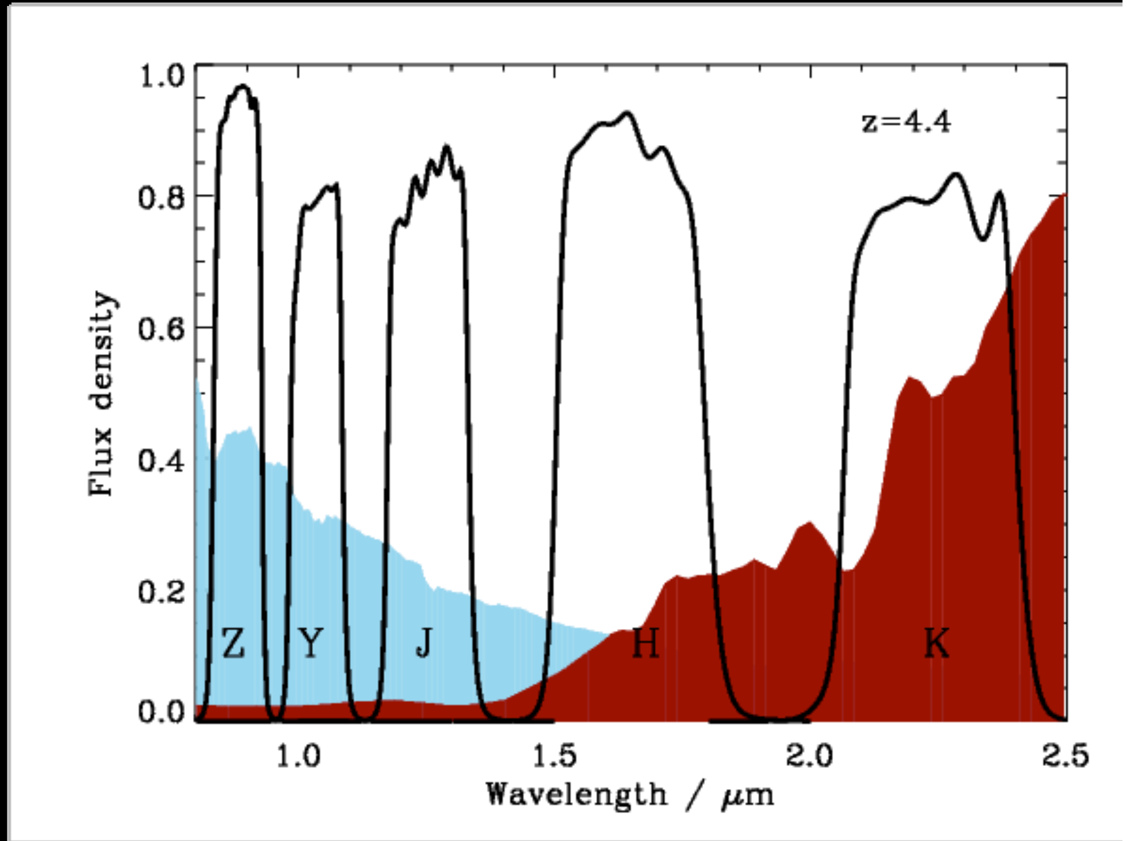
Different filters sample different galaxy properties at different redshifts

So difficult to get a consistent picture of galaxies over the history of the Universe.

How do you get a *complete* picture galaxy evolution?

We can move to longer wavelengths.

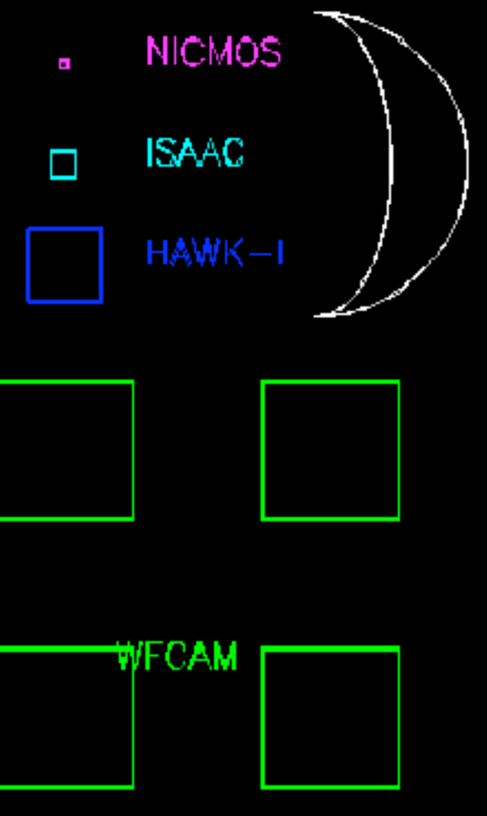
But need different detectors, telescopes and techniques.



Facilities for the next decade

Optical	SDSS1-2 Pan-STARRS SDSS-3 SkyM DES LSST	Now → 2009 → 2010 → 2011 → 2015
Near-IR	UKIDSS VISTA *JWST* ELT	Now → 2009 → 2013 → 2020
Mid/Far-IR	*Spitzer* SCUBA2 *Herschel* *WISE* ALMA	Now → 2009 → 2009 → 2010 → 2012
Radio	eMerlin LOFAR EVLA KAT/ASKAP SKA	2009 → 2010 → 2013 → 2020

The near-infrared view of galaxy formation and evolution



Survey speed >3x faster than WFCAM and better sensitivity in the Z,Y,J wavebands

ESO-VISTA public surveys

- VHS (Richard McMahon) ~17000sq.deg (z<0.6ish)
- VIKING (Will Sutherland) ~1000sq.deg (z<1.2ish)
- VIDEO (Matt Jarvis) ~13sq.deg (1<z<6ish)
- Ultra-VISTA (LeFevre/Dunlop/Franx/Fynbo)~1sq.deg (z>5)
- VVV (Dante Minitti & Phil Lucas)
- VMC Survey (Maria-Rosa Cioni)

VISTA Hemiphere Survey (McMahon/Lawrence)

Lowest mass and nearest stars
Merger history of the Galaxy
LSS to z~1
Dark Energy
z > 7 QSOs.

3 components;

VHS-ATLAS ~5000sq.deg

Y=20.9, J=20.9, H=20.3, Ks=19.8 (5s AB mags)

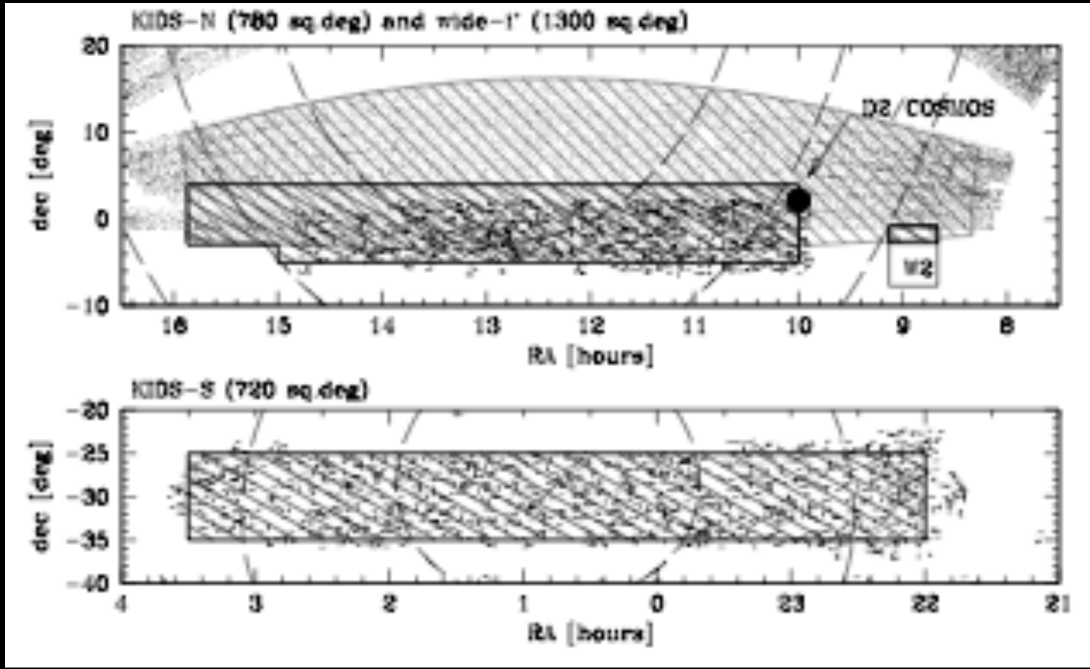
VHS-DES ~4500sq.deg

J=21.2, H=20.8, Ks=20.2

VHS-GPS ~8200sq.deg

J=21.1, Ks=19.8

VIKING (PI Sutherland)

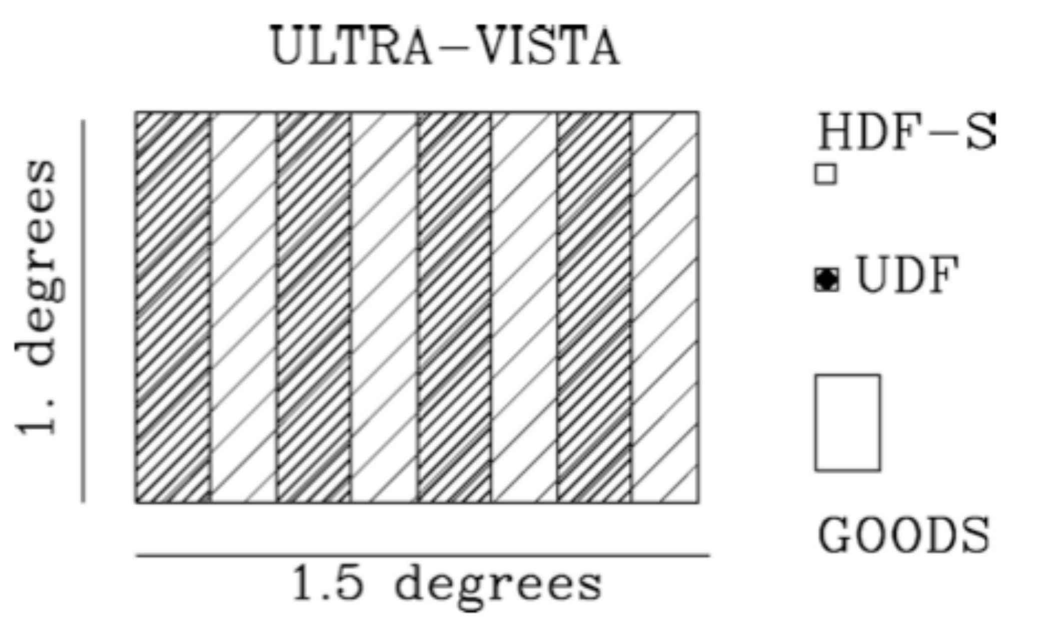


Combine with KIDS to provide a deep 9-band photometric survey.

Photo-zs for cosmology, dark energy, weak lensing. Z > 7 QSOs, galaxy morphologies, galactic structure, brown dwarfs

Z=23.1, Y=22.3, J=22.0, H=21.5, Ks=21.2 (AB)

UltraVISTA (PIs Dunlop, Franx, Fynbo, Le Fevre)



The first galaxies

The growth of stellar mass

Dust obscured star formation

all in a `representative volume'.

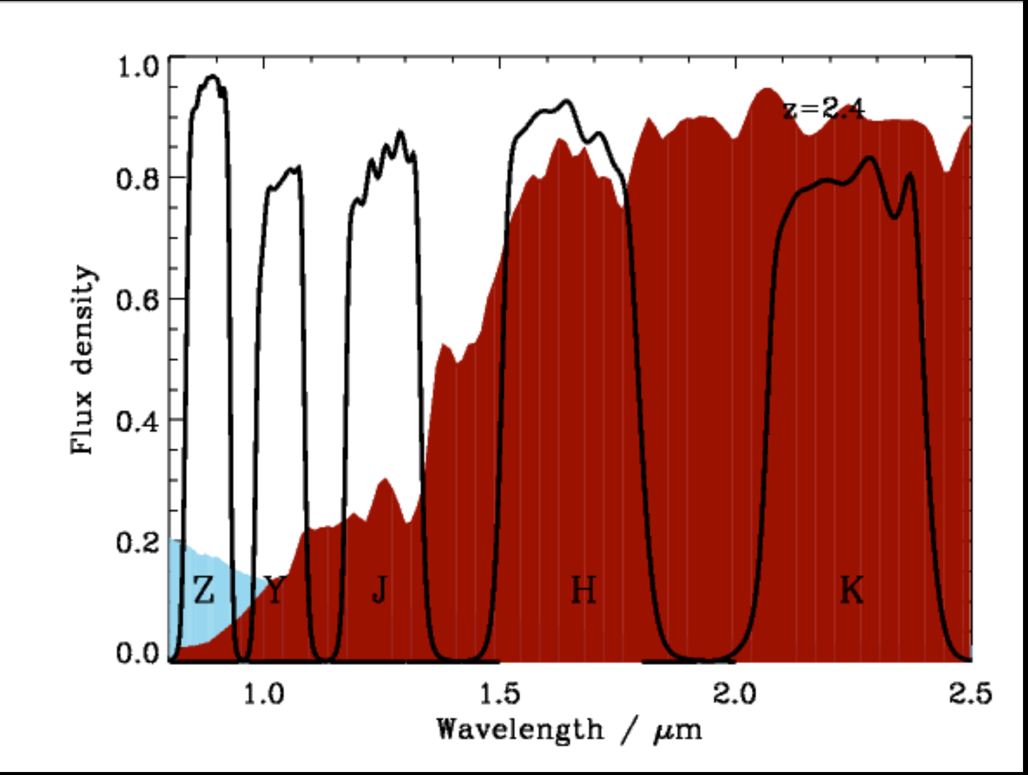
Ultra-Deep

Y=26.7, J=26.6, H=26.1, Ks=25.6, NB=24.1 (AB)

Deep

Y=25.7, J=25.5, H=25.1, Ks=24.5

VIDEO Survey (starting 2009)

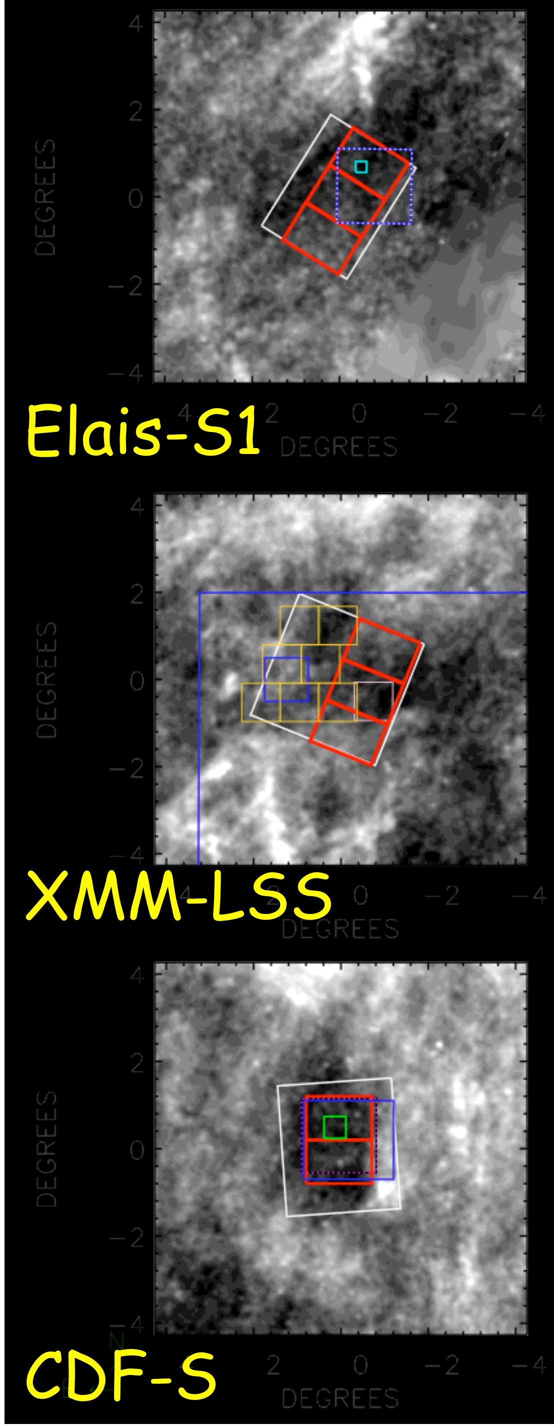


Z=25.7, Y=24.6, J=24.5, H=24.0, K_s=23.5 (5σ AB mag)

Deep enough to probe an L* elliptical galaxy out to z~4

Over 12 square degrees

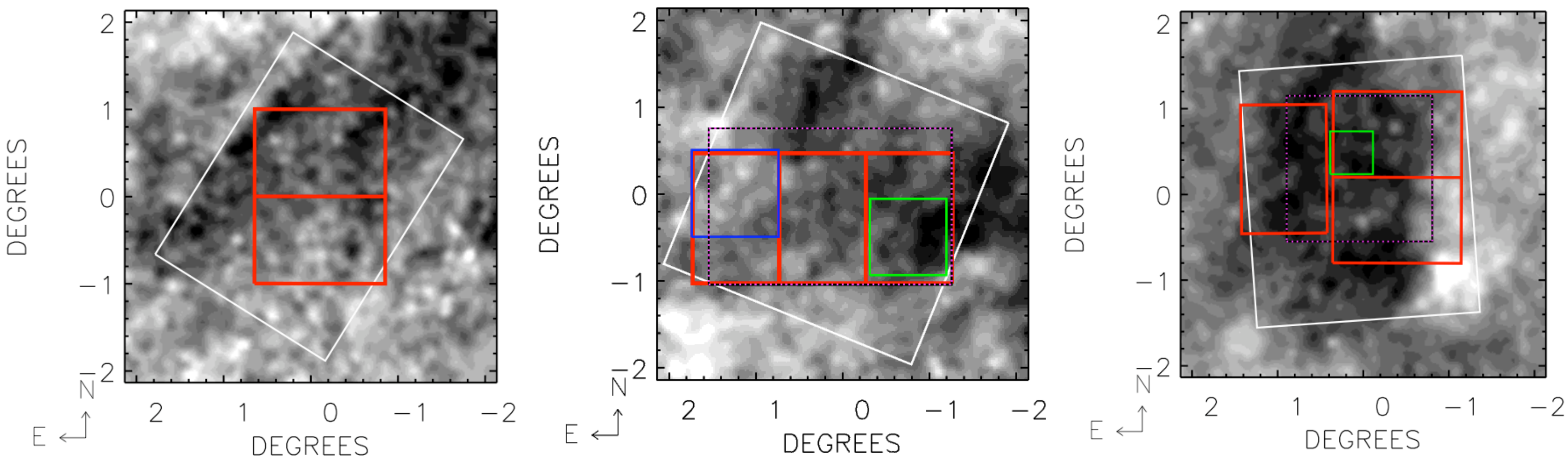
Wide enough to sample the full range of galaxy environments, from the richest clusters to the field galaxy population.



VIDEO Survey

- Trace the formation and evolution of massive galaxies from z~1 up to and above z~6
- Measure the clustering of the most massive galaxy up to and above z~6
- Trace the evolution of galaxy clusters from their formation epoch until the present day.
- Quantify the obscured and unobscured accretion activity over the history of the Universe.
- Determine the quasar luminosity function at z>6
- Determine near-infrared light curves for Sne
- Determine the nature of SNe host galaxies to high redshift

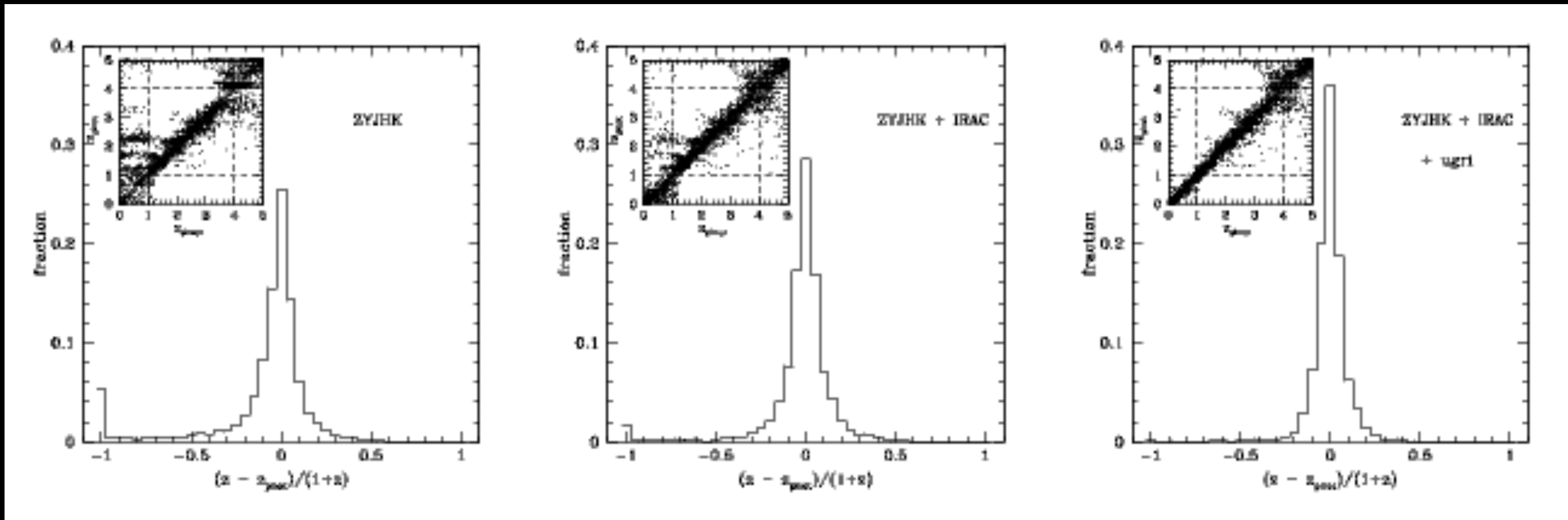
The VIDEO Survey



Filter	Time (per source)	Time (full survey)	5σ AB	5σ Vega	UKIDSS -DXS	Seeing	Moon
Z	17.5 hours	456 hours	25.7	25.2	-	0.8	D
Y	6.7 hours	175 hours	24.6	24.0	-	0.8	G
J	8.0 hours	209 hours	24.5	23.7	22.3	0.8	G
H	8.0 hours	221 hours	24.0	22.7	22	0.8	B
K_s	6.7 hours	180 hours	23.5	21.7	20.8	0.8	B

The VIDEO Survey

Photometric redshifts

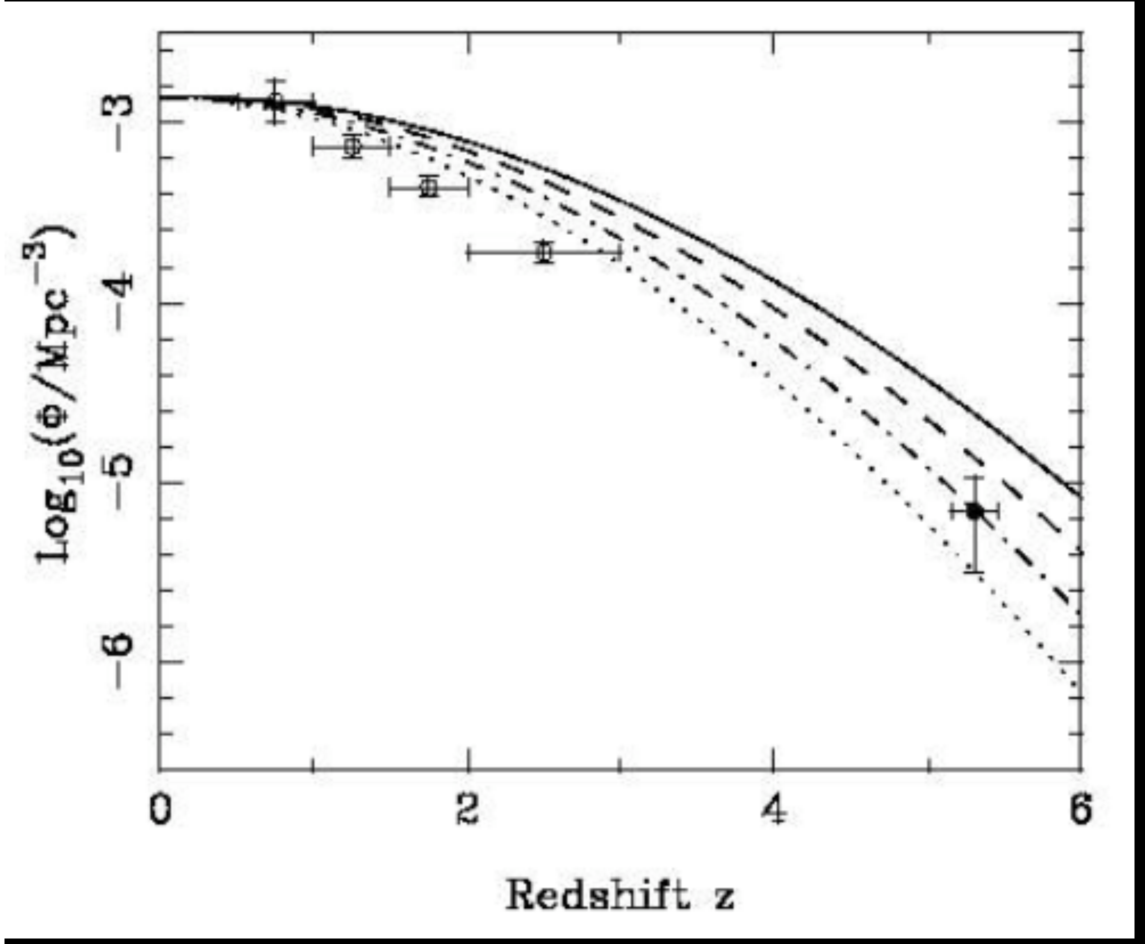


Get to σ~0.1 with VIDEO+optical+SWIRE

As has been the case for the UDS, we will no longer have to rely on coarse colour cuts. Can carry out full probabilistic analyses based on photo-z probability distribution functions.

The VIDEO Survey

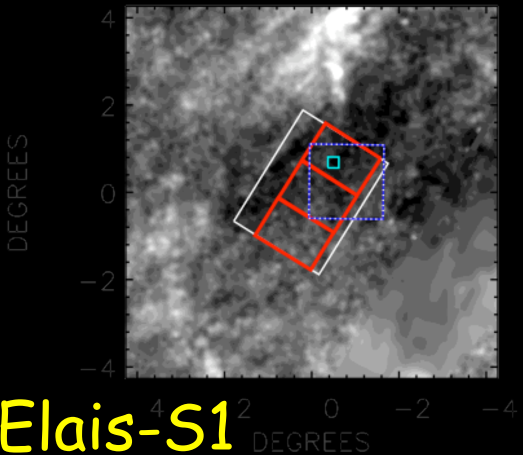
Galaxy Evolution – high-z galaxy space density



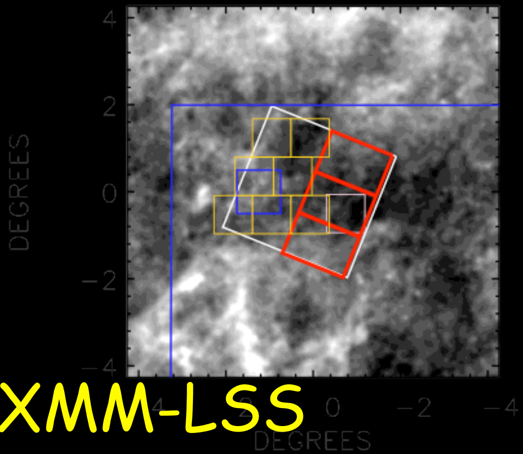
McLure et al. 2006

Number of galaxies with $M \sim 10^{11} M_{\odot}$ (Based on 9 galaxies).
Curved lines from SAM of Bower et al. 2006 for various values of σ_8

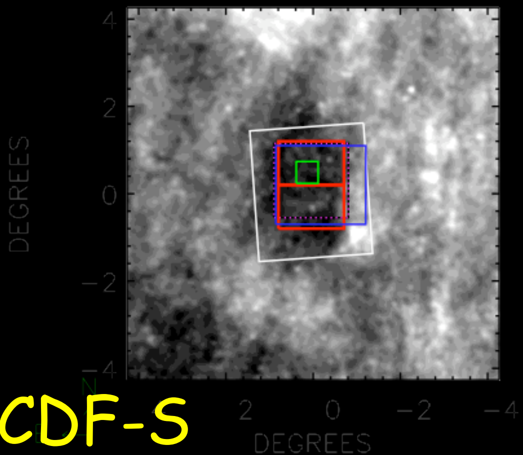
VIDEO will do this to 1mag fainter and 30x the area. Expect ~270 massive galaxies at z~5 and 140 at z~6.



Elais-S1



XMM-LSS



CDF-S

VIDEO+SERVs+DES

Spitzer Representative Volume Survey (SERVS) approved to cover VIDEO survey regions + LH and Elais-N1

(1400 hours allocated – PI Mark Lacy

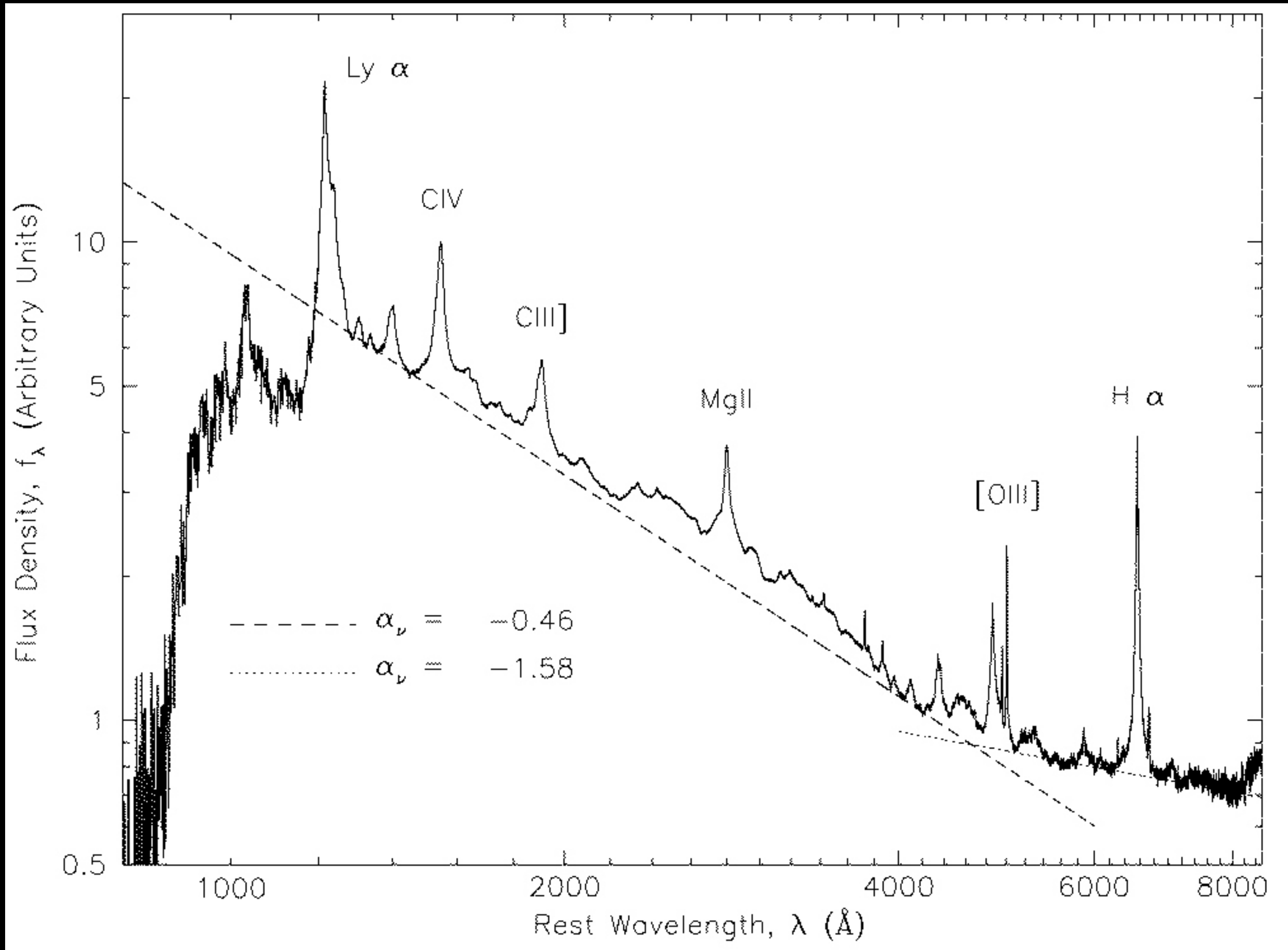
Management: Matt Jarvis, Seb Oliver and Duncan Farrah

Will provide 3.6 and 4.5um data to slightly deeper levels than the VIDEO depths (L* at z>5)

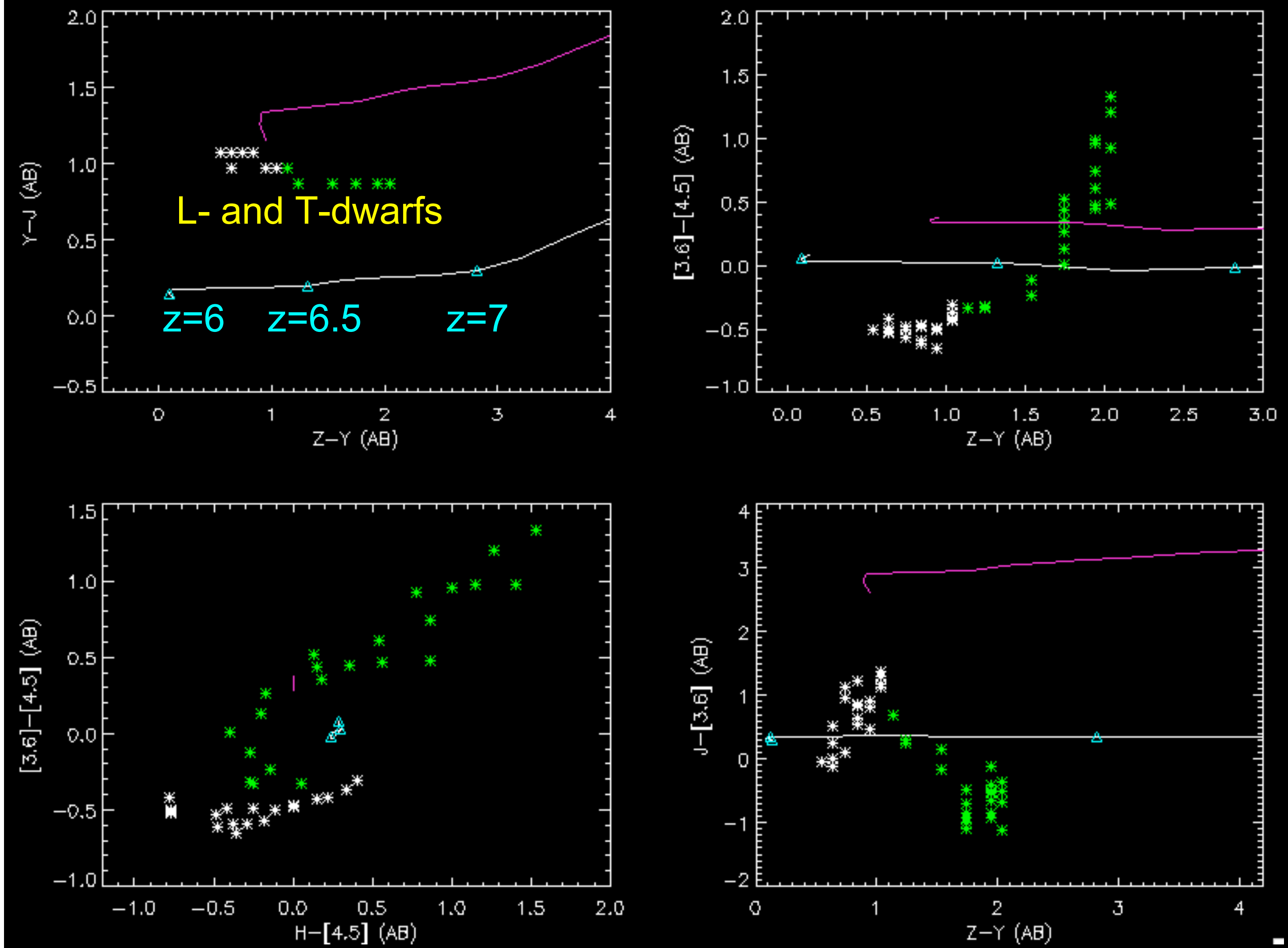
VIDEO entering data sharing agreement with the Dark Energy Survey. DES will have grizy photometry over VIDEO regions to depths of AB~27 (5sigma)

Concentrating on SNe science initially.

Finding the first black holes



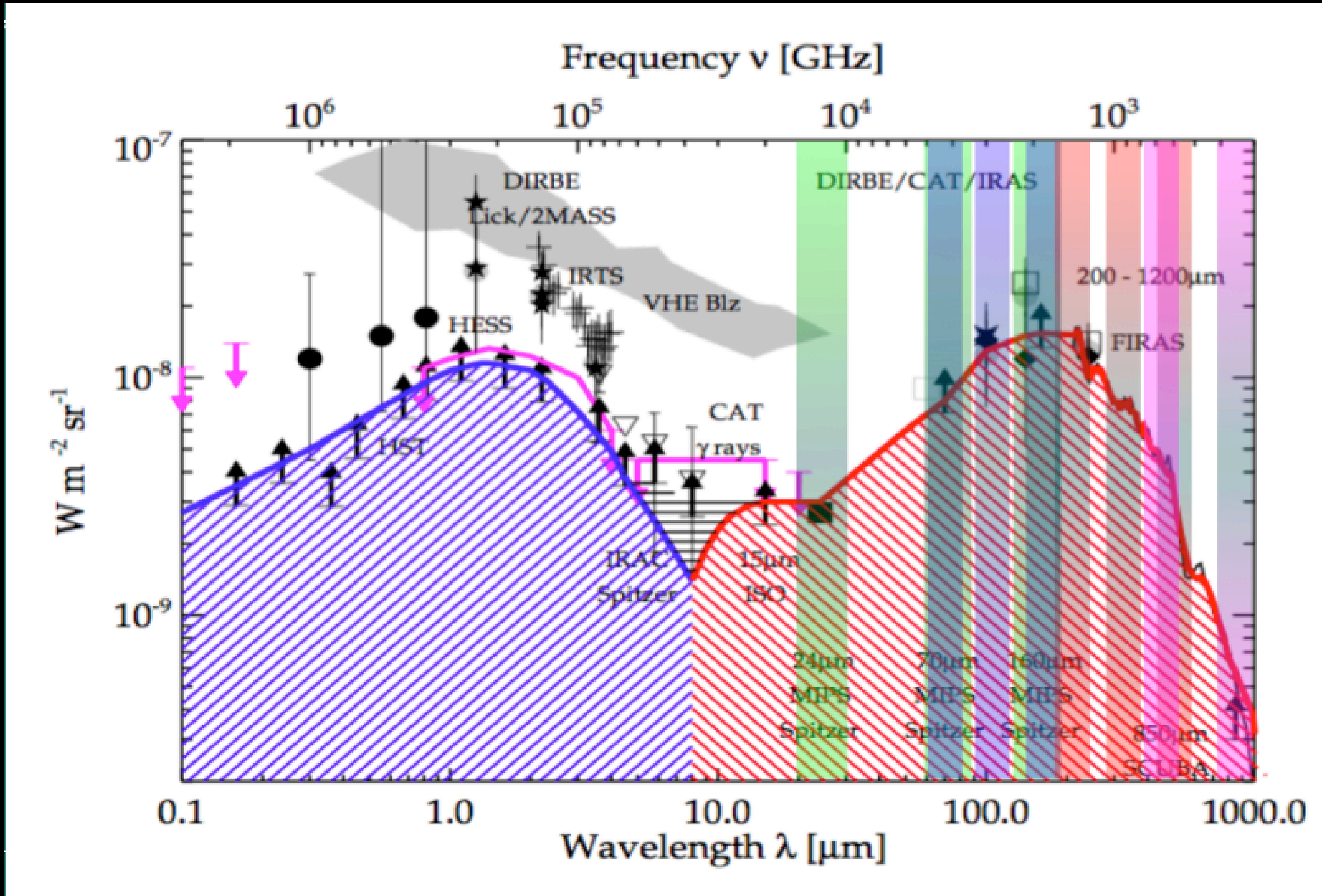
What can we learn about AGN?



Depending on the QSO LF slope expect 10-30 z>6.5 QSOs in VIDEO

Z-Y vs Y-J very efficient at selection z>6.5 QSOs. VIDEO+SERVs crucially allows us to find the reddened high-z QSOs

Herschel



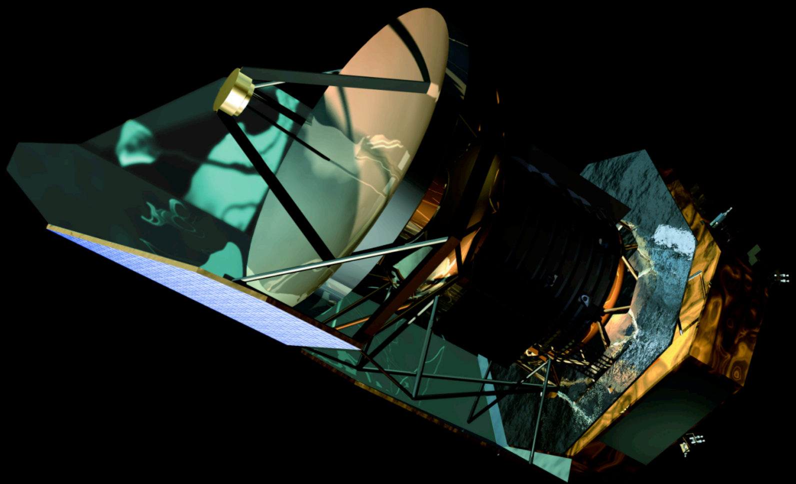
Frequency ν [GHz]
10^6
10^5
10^4
10^3
10^-7
10^-8
10^-9
W m^-2 sr^-1
DIRBE
Lick/2MASS
IRTS
VHE Blz
HESS
HST
CAT
γ rays
IRAC
Spitzer
15μm
ISO
DIRBE/CAT/IRAS
200 - 1200μm
FIRAS
24μm
MIPS
Spitzer
70μm
MIPS
Spitzer
160μm
MIPS
Spitzer
850μm
SCUBA
0.1
1.0
10.0
100.0
1000.0
Wavelength λ [μm]

HerMES

Level	Fields	RA	Dec	Area [sq. deg.] Nom.	Donut	Cum.	Number of SCANs in each mode PACS-MED	PACS-SLOW 25"	PACS-SLOW 50"	PARALLEL	SPIRE-FAST	SPIRE-NOM	5-sigma sensitivity (ignoring confusion) 110	160	250 ↓	350	500
Clusters Deep	Various			0.01	0.01	0.01		72				400	2.0	3.0	3.4	4.7	4.0
Cluster Shallow	Various			0.04	0.04	0.05		30				240	3.1	4.7	4.4	6.0	5.1
Level-1	GOODS-S	03h32m30.4s	-27d48m17s	0.11	0.11	0.16		112		4	20	240	1.6	1.7	4.2	5.7	4.9
Clusters Highz	Various			0.03	0.03	0.19		24				120	3.5	5.2	6.2	8.5	7.2
Level-2	GOODS-N	12h36m54.9s	+62d14m19s	0.11	0.11	0.30		30				60	3.1	4.7	8.8	12.0	10.2
	ECDFS	03h32m25s	-27d48m50s	0.25	0.14	0.39			16	4	20	38	5.9	8.3	8.7	11.9	10.1
Level 3	Lockman-ROSAT	10h52m43s	+57d28m48s	0.25	0.25	0.64			24	4	20	14	4.8	6.8	11.1	15.2	12.9
	UDS	02h17m48s	-05d05m45s	0.25	0.25	0.89			21	7		14	5.1	7.2	11.1	15.2	12.9
	Groth	14h19m17.4s	+52d49m34s	0.25	0.25	1.14			20	7		14	5.2	7.4	11.1	15.2	12.9
	Lockman-OWEN	10h46m00s	+59d01m00s	0.25	0.25	1.39			18	4	20	14	5.5	7.8	11.1	15.2	12.9
	HDFN	12h36m49.4s	+62d12m58s	0.25	0.14	1.53						30			12.4	17.0	14.4
Level-4	COSMOS	10h00m28.6s	+02d12m21s	2	2.0	3.53	52					40	6.2	8.7	10.8	14.7	12.5
	UDS	02h17m48s	-05d05m45s	0.7	0.5	3.98			7	7		14	8.3	11.8	11.1	15.2	12.9
	VVDS	02h26m00s	-04d30m00s	0.7	0.7	4.68			7	7		14	8.3	11.8	11.1	15.2	12.9
Level-5	XMM	02h21m36s	-04d39m00s	5	3.6	8.3				7			20.4	29.3	14.0	19.3	16.3
	ELAIS-N1-SCUBA2	16h10m00s	+54d30m00s	2	2.0	10.3				7			20.4	29.3	14.0	19.3	16.3
	Bootes-SCUBA2	14h32m06s	+34d16m48s	2	2.0	12.3				7			20.4	29.3	14.0	19.3	16.3
	EGS-SCUBA2	14h19m12s	+52d48m00s	1.3	1.1	13.3				7			20.4	29.3	14.0	19.3	16.3
	CDFS	03h32m00s	-28d16m00s	8	7.8	21.1				4	20		27.0	38.8	14.0	19.3	16.3
	Lockman	10h45m00s	+58d00m00s	11	10.5	31.6				4	20		27.0	38.8	14.0	19.3	16.3
Level-6	XMM	02h21m20s	-04d30m00s	9.3	4.3	35.9				2			38.2	54.8	26.2	36.1	30.4
	ELAIS S1 SWIRE	00h38m30s	-44d00m00s	7	7.0	42.9				2			38.2	54.8	26.2	36.1	30.4
	ELAIS N1 SWIRE	16h11m00s	+55d00m00s	9.3	7.3	50.2				2			38.2	54.8	26.2	36.1	30.4
	ELAIS N2 SWIRE	16h36m48s	+41d01m45s	4.8	4.8	55.0				2			38.2	54.8	26.2	36.1	30.4
	NDWFS/Bootes	14h32m06s	+34d16m48s	8	6.0	61.0				2			38.2	54.8	26.2	36.1	30.4
	FLS	17h18m00s	+59d30m00s	4.7	4.7	65.7				2			38.2	54.8	26.2	36.1	30.4
	0444 Akari	04h41m24s	-53d22m12s	7	7.0	**72.7**				2			38.2	54.8	26.2	36.1	30.4

Herschel-ATLAS Survey
Steve Eales, Loretta Dunne, Matt Jarvis, ++

Aim is to survey ~550sq.deg with Herschel at 110, 170, 250, 350 and 550mm. (600hrs allocated)



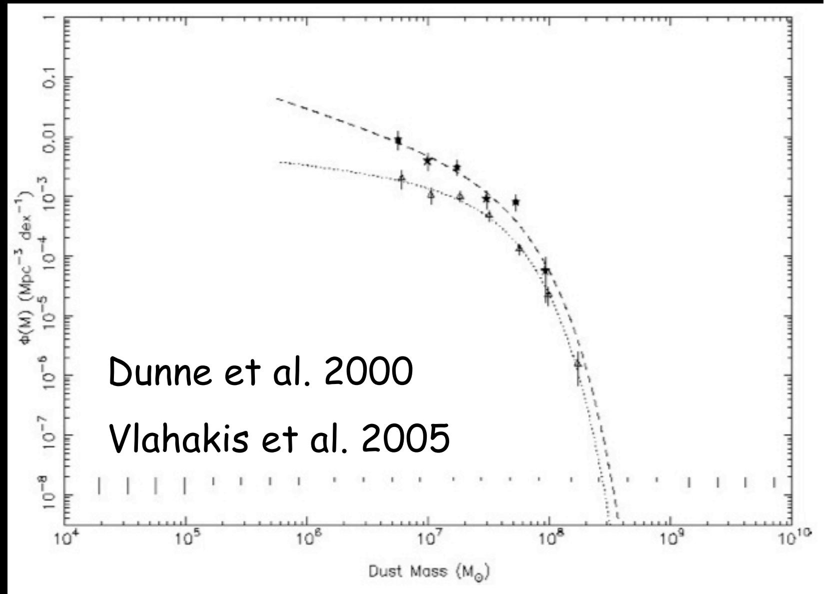
Local(ish) Galaxies

- Planck synergies
- Efficient lens survey
- Rare object science
- Large-scale structure
- Clusters
- Galactic science

Herschel-ATLAS Survey

Low-z Galaxies

- First submm survey large enough to detect a significant number of galaxies in the nearby Universe (40,000 - 140,000 out to z~0.3)
- Carried out over SDSS and 2dfGRS areas, ~50% will have spectroscopic redshifts (~95% at z<0.1)



Science:

LFs and dust along the Hubble Sequence

Complete SEDs of the dust emission (combined with UV-radio)

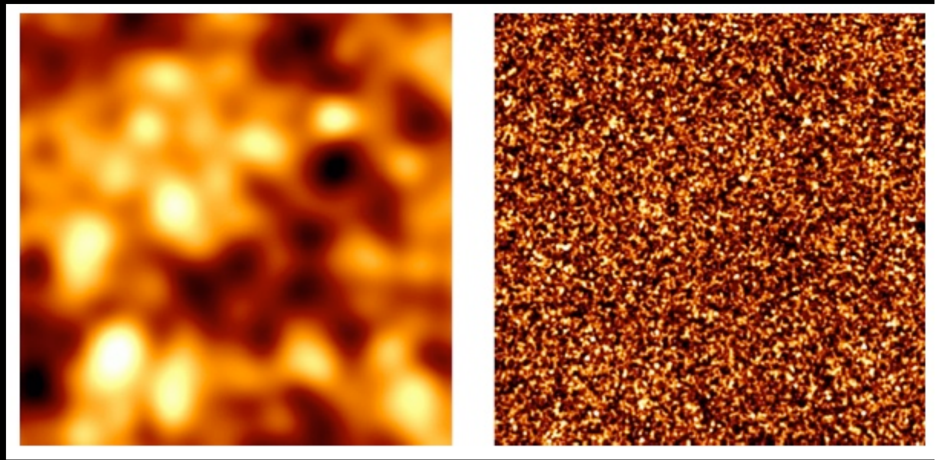
Environmental dependence of star formation

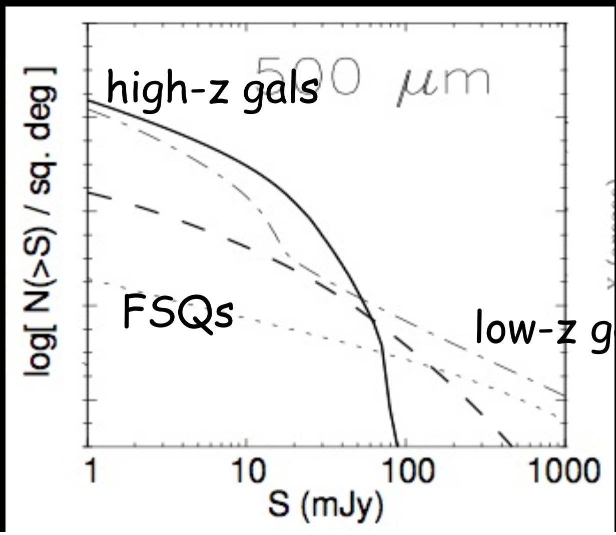
Evolution of dust and obscured star formation

Herschel-ATLAS Survey

One of the Planck survey's main goals is to detect 1000s of high-z clusters through ths SZ-effect.

• H1K will be able to determine the composition of the distant clusters in 1/40 of the Planck sky.





Submm surveys possibly ideal way to find lenses. Large -ve k-correction means sources at z>1.

• H1K will contain ~3000, 1600 and 700 strongly lensed galaxies at 250, 350 and 500um, with a lens yield of ~100% at 500um.

Herschel-ATLAS Survey

AGN in H1K

Investigate relationship between starformation and AGN activity.

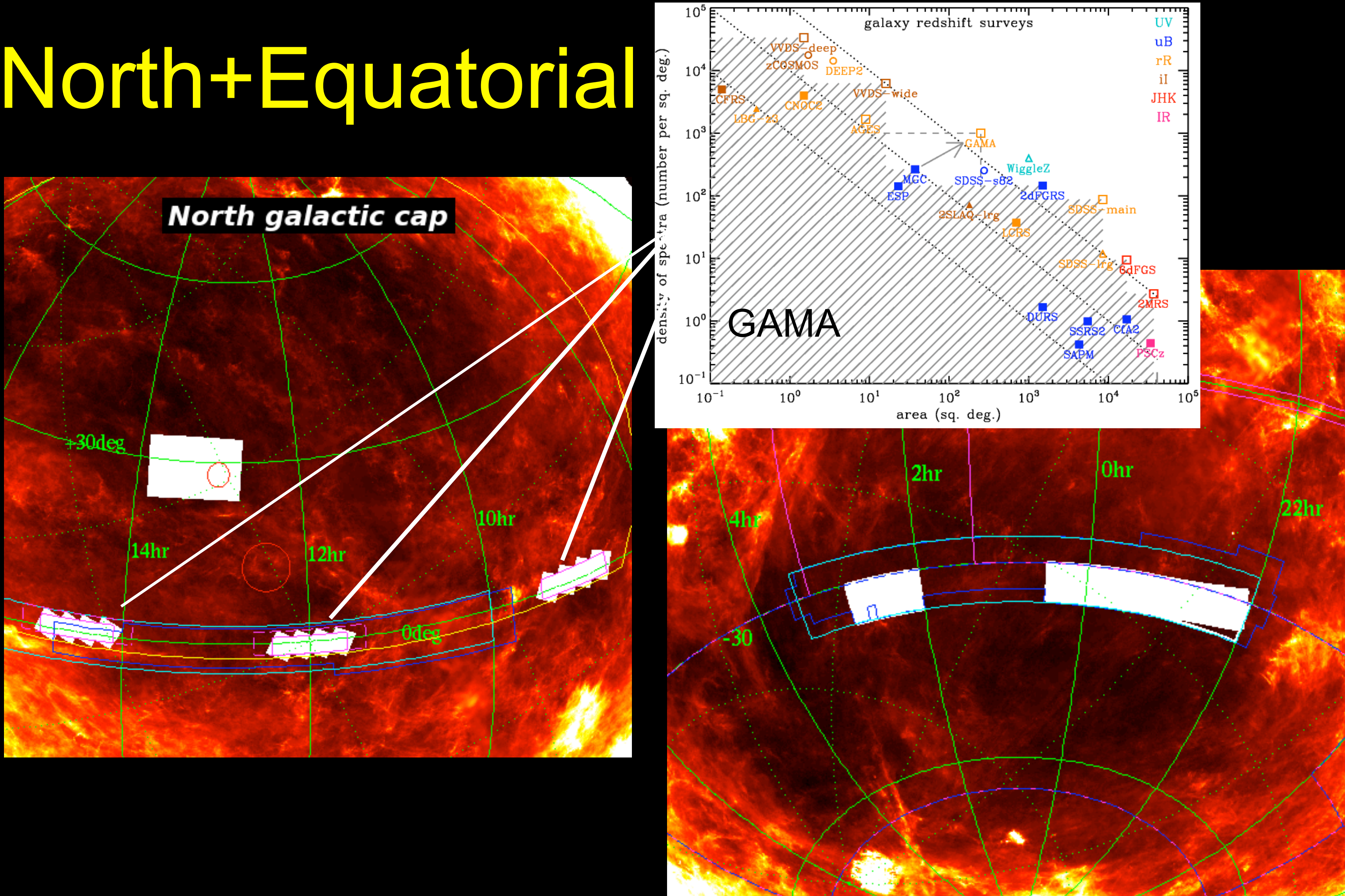
- Estimate detections of ~450 SDSS QSOs at z<3 and ~200 at z>3 (~15times higher than current submm detections of SDSS QSOs)
- Perform stacking analysis for all QSOs (~20000) in H1K fields.

Large-Scale Structure H1K

H1K will detect ~400,000 sources with a median redshift of z~1.

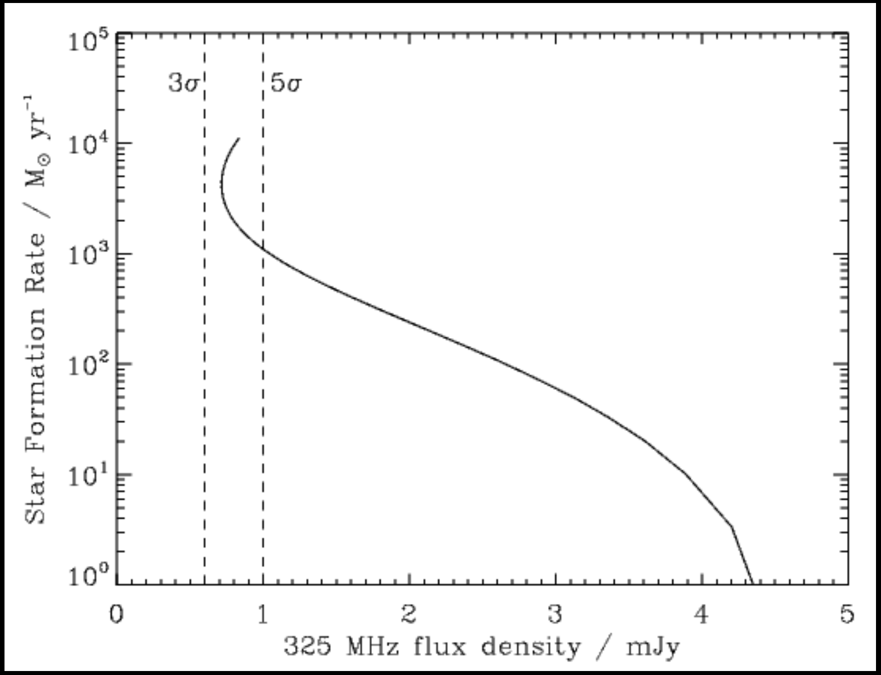
- Large amount of information about LSS up to ~1000 Mpc scales at z~1.
- Without other data, limited to angular correlation functions but allowing measurement of DM-halo mass for obscured SFGs.
- Clustering of fluctuations in the unresolved background to get below confusion.

North+Equatorial



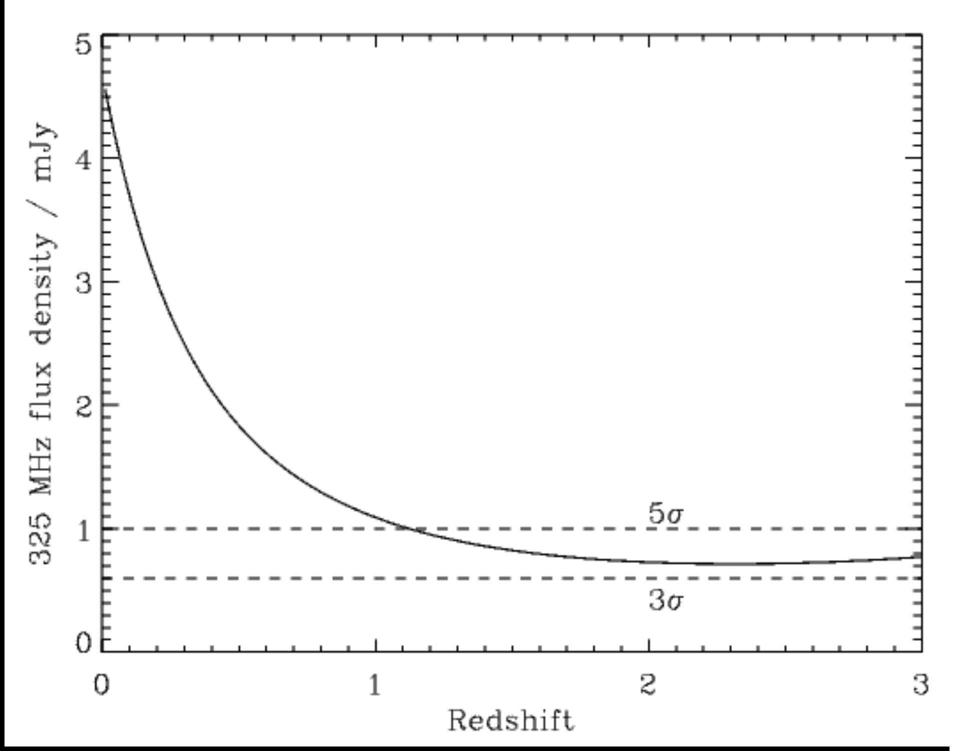
South

GMRT-ATLAS



Identify all H-ATLAS sources at z<1
With better positional accuracy

- Far-IR – radio correlation
- Star-formation – AGN connection
- High-latitude star-forming regions
- 3-d clustering of radio source populations
- Charactoerize point source contamination for 21cm EoR surveys



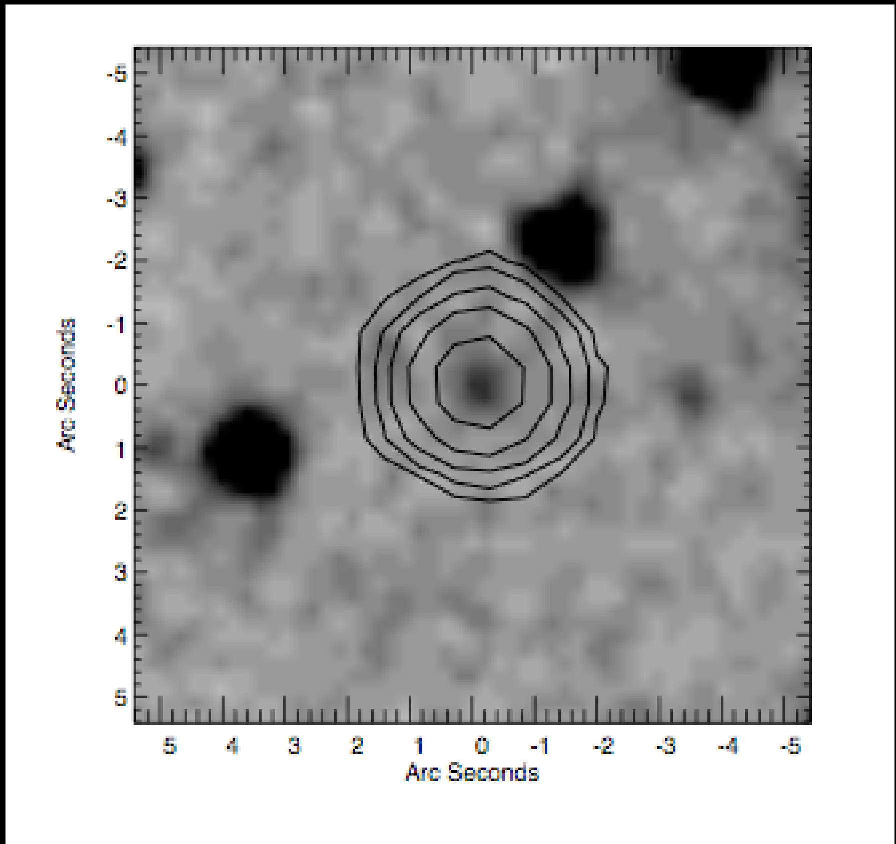
Spectroscopic data!!!

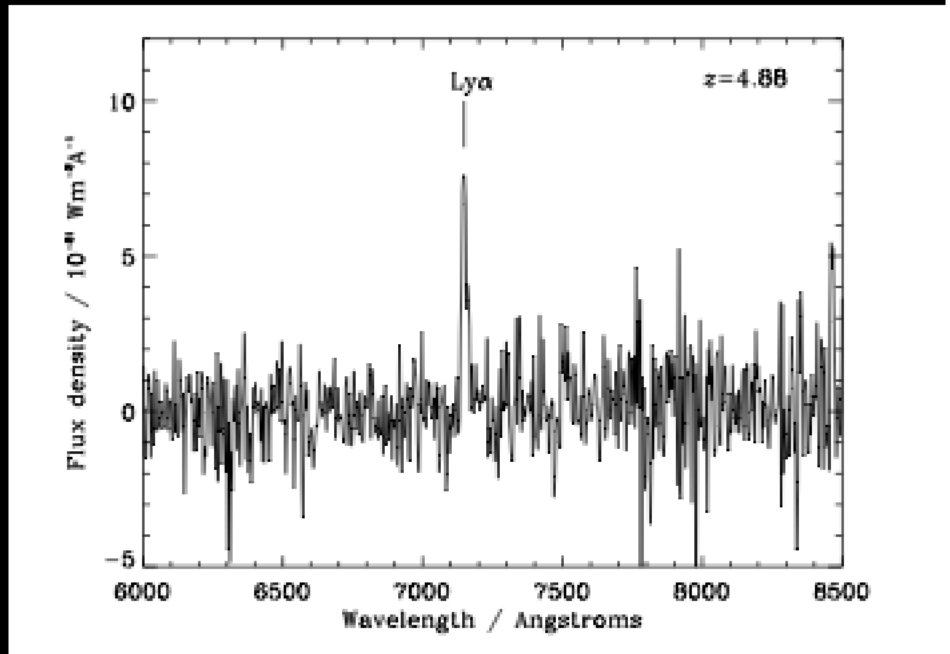
To really get the most science (redshifts) out of all of this data then spectroscopic observations are crucial

- ESO will issue call for very large spectroscopic campaigns with VIMOS - possibly next year! VIMOS will have red-optimized CCDs
- FMOS (0.5sq.deg JH-band MOS on Subaru) will start next year
- SALT with blue sensitive CCDs could start large spectroscopic surveys next year
- OSIRIS on GTC will begin large MOS campaigns next year (blue and red)

If there are people here interested in joining a large consortium to obtain spectroscopy (over the VIDEO/SERVs/HerMES fields) using the combined power of these telescopes then please talk to me or email me (M.J.Jarvis@herts.ac.uk) very soon.

A demonstration of combining radio surveys with multi-wavelength data…





Jarvis et al. 2009

A typical HzRG at z=4.88

Log(L(1.4))=26.5W/Hz/sr

α=0.75

EUCLID/IDECS

1.2m telescope in Space with 0.5sq.deg FoV

Visible and near-infrared telescope with both imaging and spectroscopic capabilities

Broad science aims but particularly in determining the Dark Energy equation of state with a combination of weak lensing, SNe and Baryon Acoustic Oscillations.

Science is very complementary to SKA. SKA will trace the gas predominantly in late-type galaxies, EUCLID will trace the stellar light predominantly in early-type galaxies.

20000 sq.deg survey to H=24 and spectroscopic survey to H=22. Deep field to H=26 spectroscopy to H=24.

Projected launch 2017/2018 if approved in the Cosmic Visions process later this year.

Summary

• Observations at all wavelengths are needed if we are to obtain a complete picture for the formation and evolution of galaxies

• Broad-band optical surveys need commensurate data at other wavelengths to find high redshift, particularly the older galaxies

• VISTA offers the possibility to get this data

• Narrow-band observations give us the best possibility, currently, of pushing the discovery of galaxies toward $z>7$

• All of these surveys will suffer some effects due to dust, even VISTA at the higher redshifts

• SKA Pathfinders offer us the best chance of finding the most active star-forming galaxies in the early Universe, both obscured and unobscured, thus unbiased.

• Although the continuum surveys are rightly concentrating on galaxy evolution - there is a wealth of other things that can be done, particularly in Cosmology.

Finally…

Most of these surveys and projects are manpower limited and use a lot of time.

VIDEO - ~1800hours

VIKING - ~2000hours

Ultra-VISTA - ~1800hours

VHS - ~2000hours

DES - 550 nights

HerMES - 900 hours

H-ATLAS - 600 hours

SERVs - 1400 hours

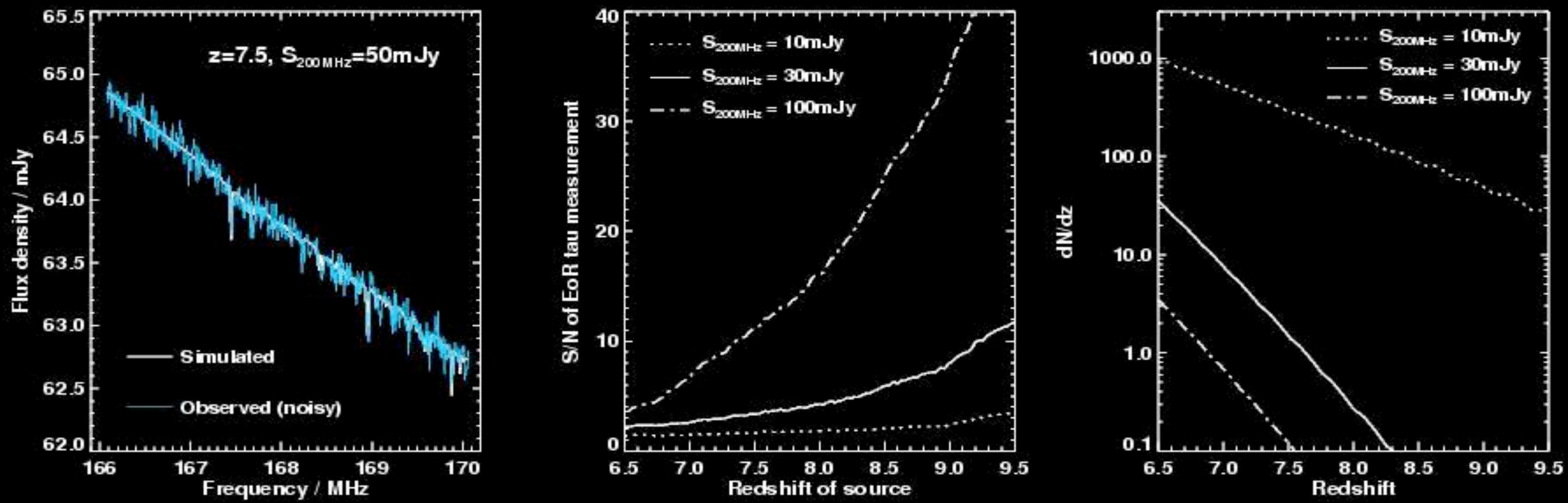
EUCLID - 2-3 YEARS!

If you want to get involved and do something with all of this data then please contact me!

A Case study in the need for multi-wavelength surveys in the SKA era

The EoR via the 21cm forest

- Using powerful radio sources within the EoR, the properties of the EoR can be studied in absorption, via the 21 cm forest.
- Surveys KSP will find these.



Left: a simulated 1500-hr (1-beam) LOFAR observation of a 50mJy radio source at z=7.5. EoR absorption features are visible at f > 167MHz.

Middle: the S/N obtained for sources of different S,z in a 1500-hr spectrum.

Right: the predicted number of such sources in the LOFAR surveys.

The problem

For the FIRST survey at 1mJy (1.4GHz)…

- ~83 sources per sq.degree
- ~6 local(ish) starburst galaxies
- ~77 AGN (6 FRIIs where we should detect emission lines)

Splitting in redshift…

- 57 AGN at $z<2$ (2 FRIIs)
- 67 AGN at $z<3$ (4 FRIIs)
- 73 AGN at $z<4$ (6 FRIIs)

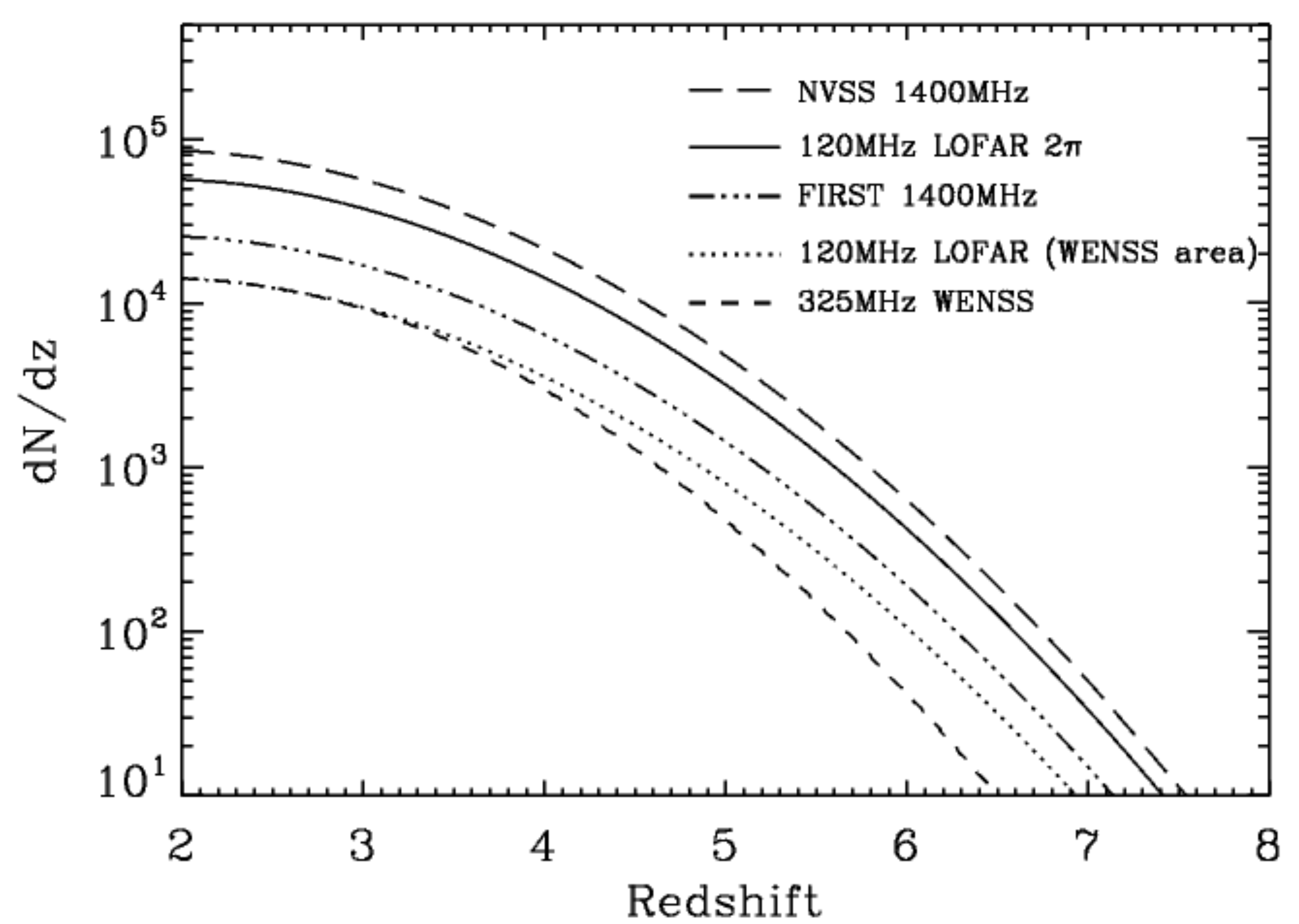
The problem

Traditionally….

- 1.4GHz may not be the best frequency to search for HzRGs as they have steep spectra (optically thin lobe emission).
- High frequency surveys at high flux density dominated by flat-spectrum quasars
- Most searches for HzRGs have been conducted at low frequency (<400 MHz)

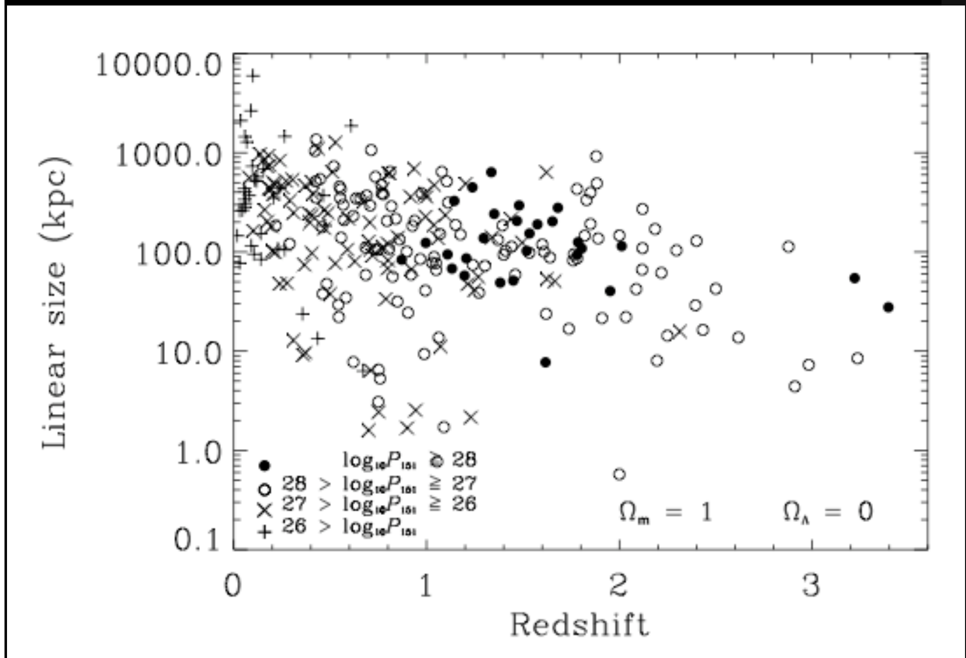
But this is because of the high flux-density limits of past surveys

Comparison of WENSS, FIRST, NVSS and LOFAR for detecting HzRGs (FRIIs with α=0.8)

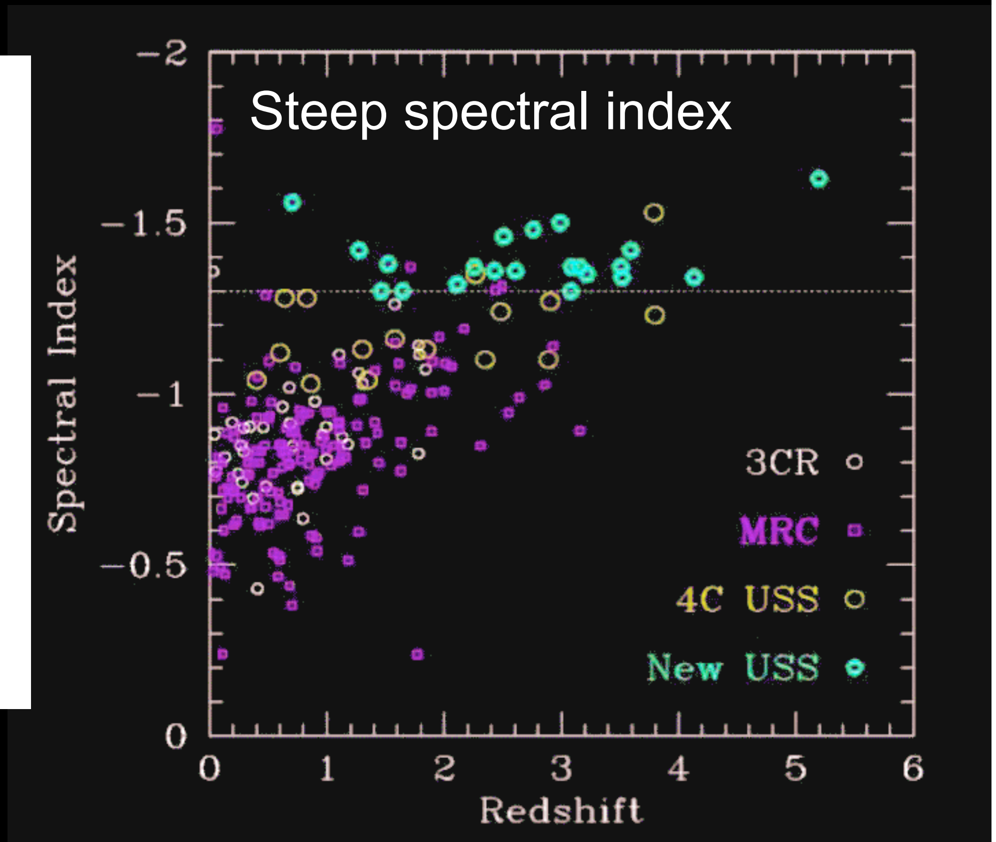


Past searches for HzRGs…

Many have utilized the properties of the radio sources themselves to filter out the low-z contaminant sources.

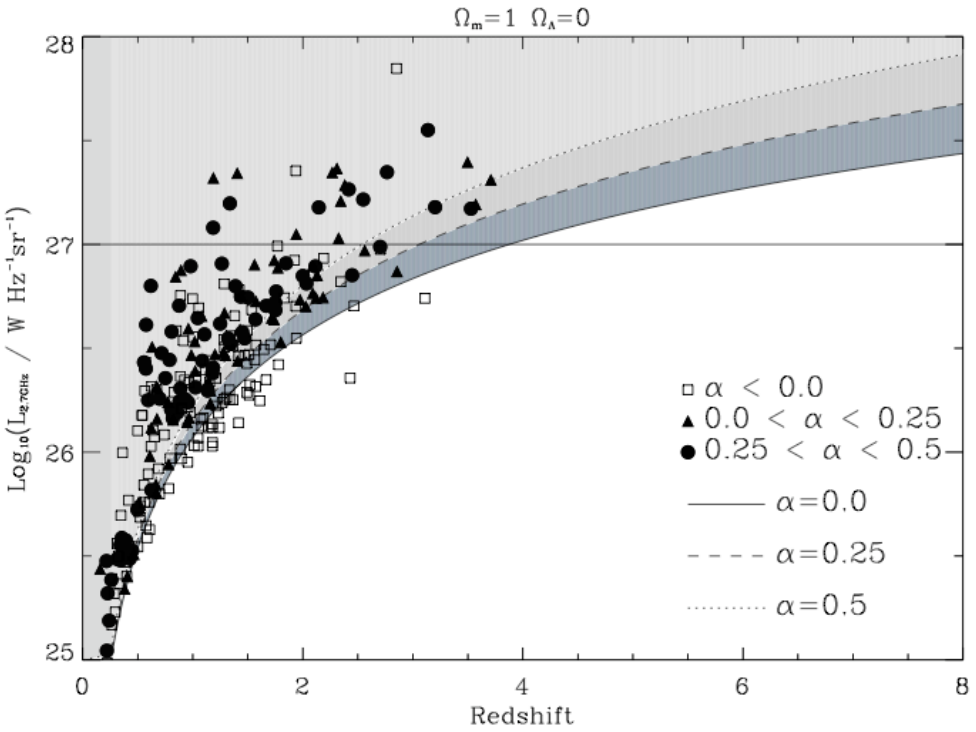


Blundell et al. 1999



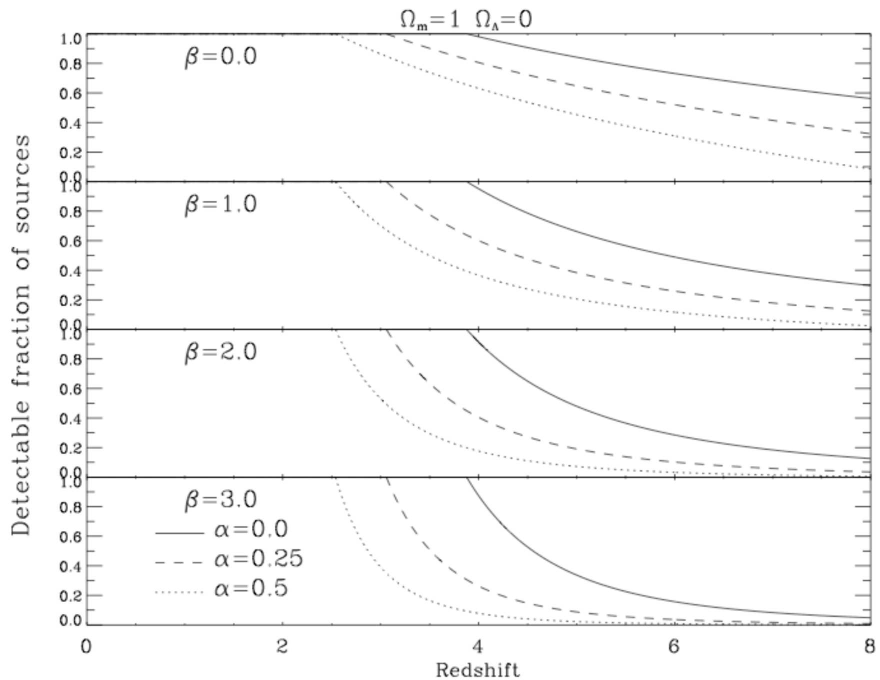
De Breuck et al. 2000

Issues with Spectral Index



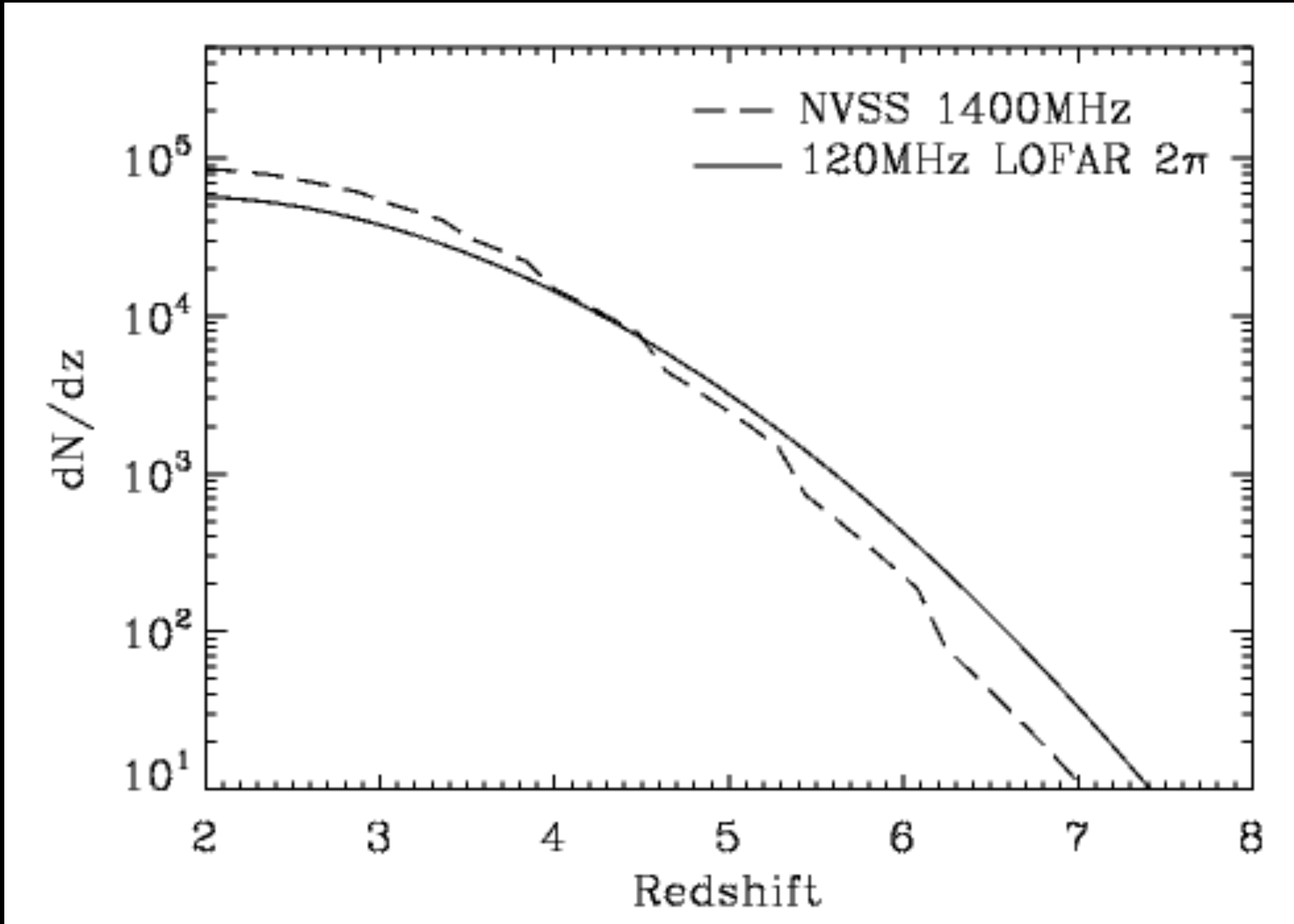
But steep spectrum sources fall out of flux-limited surveys more quicky than flat-spectrum sources.

Means that if HzRGs have steep spectra then you need to observe them at low frequency



Jarvis & Rawlings 2000

Changing the spectral index to α=1.3

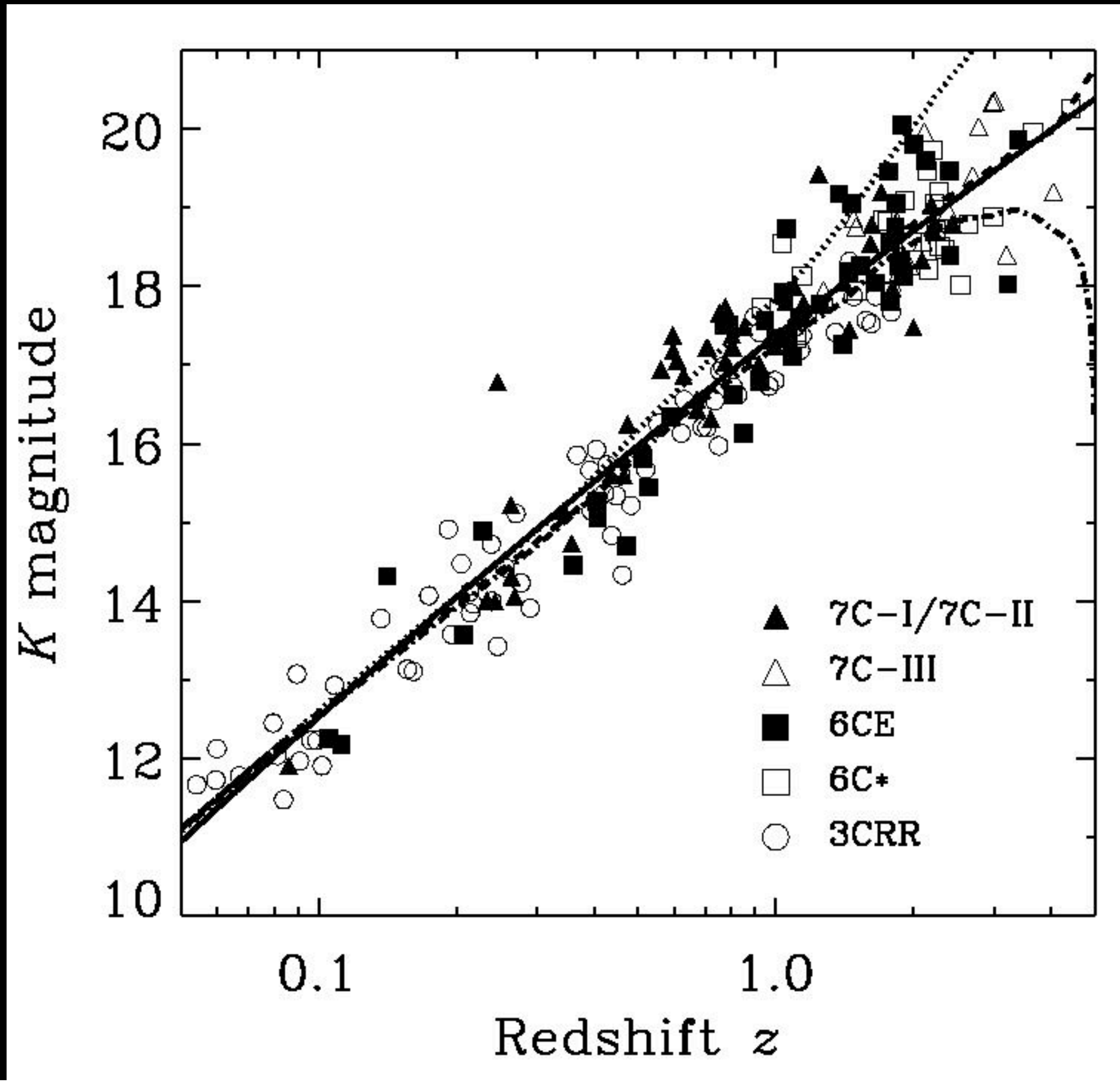


Multi-wavelength surveys over the next decade

Optical	**SDSS1-2 Pan-STARRS SDSS-3 DES**
	Now → 2009 → 2010 → 2011
Near-IR	**UKIDSS VISTA *JWST* ELT**
	Now → 2009 → 2013 → 2020
Mid/Far-IR	***Spitzer* SCUBA2 *Herschel* *WISE* ALMA**
	Now → 2009 → 2009 → 2010 → 2012
Radio	**eMerlin LOFAR eVLA KAT/ASKAP SKA**
	2009 → 2009 → 2011 → 2020

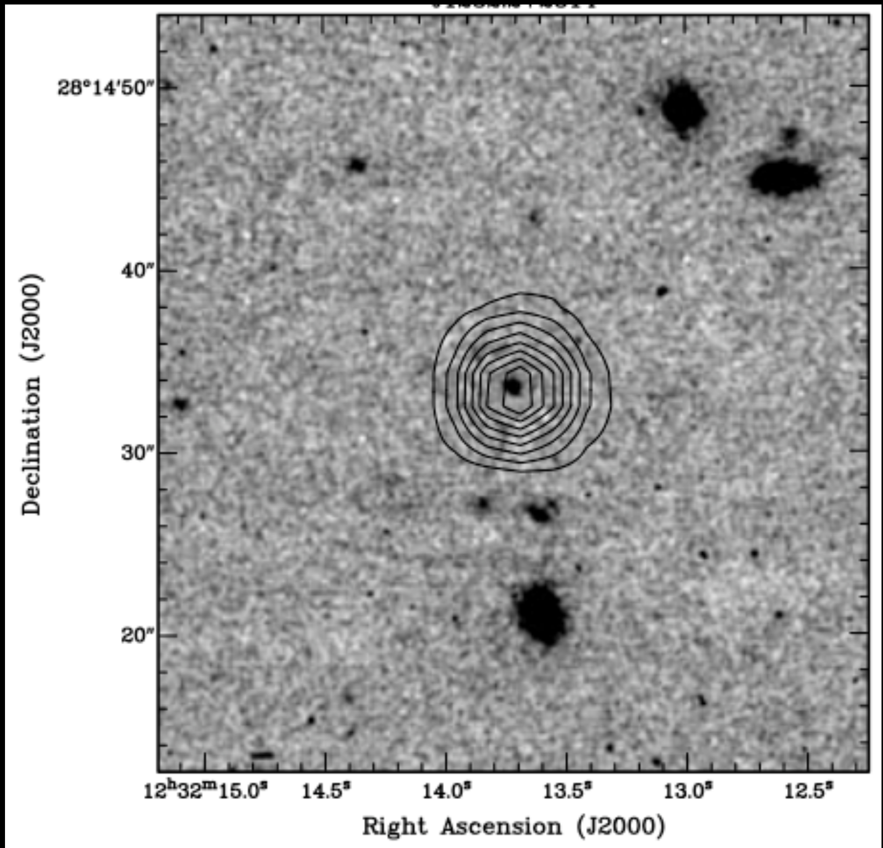
Use information at other wavelengths to eliminate low-z contaminants

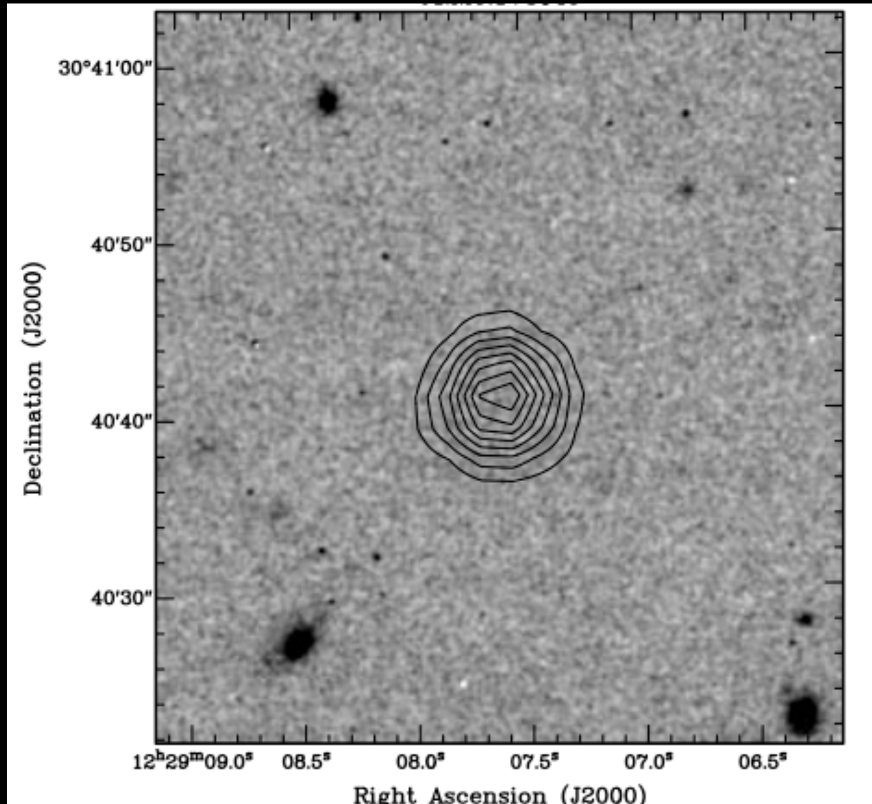
Willott et al. 2003



Use information at other wavelengths to eliminate low-z contaminants

Jarvis et al. 2004



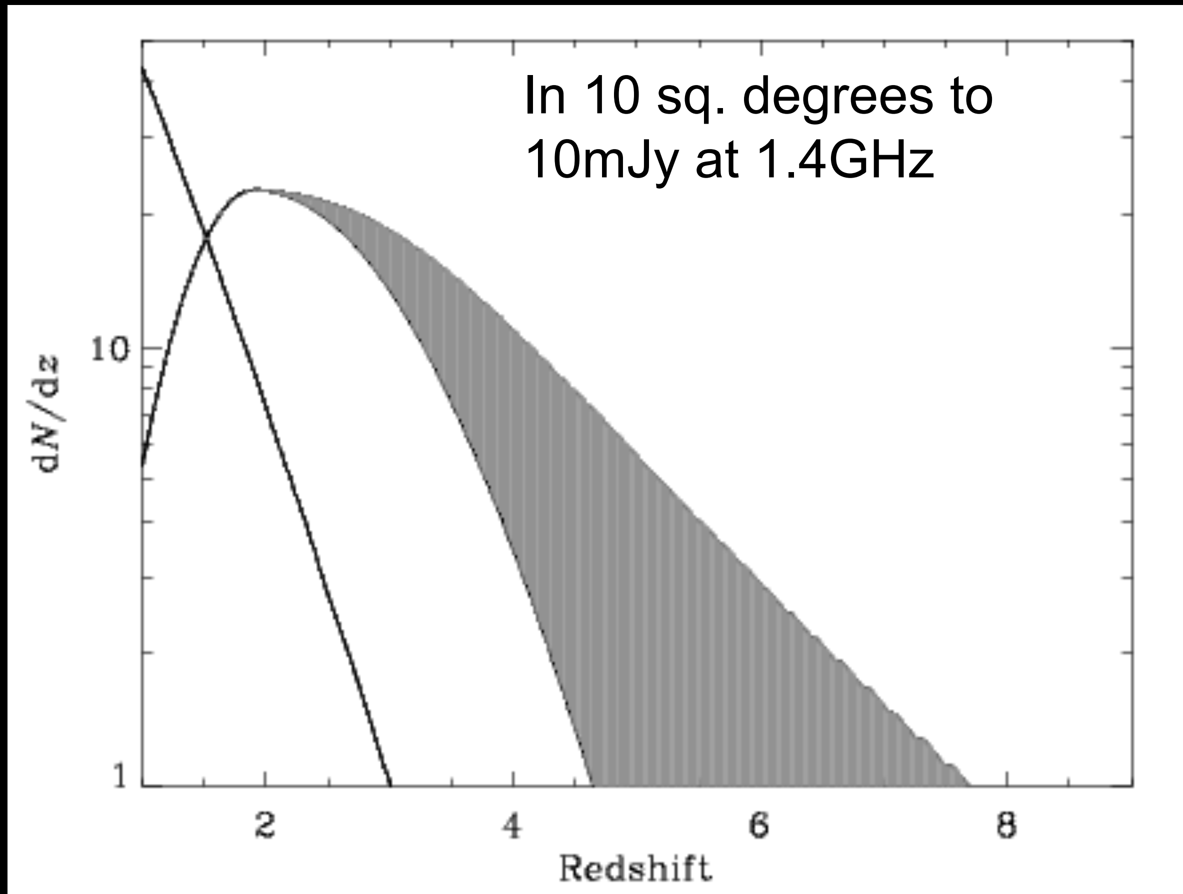


Use existing survey data….

(similar strategy to CENSORS – Best et al. (2003), Brookes et al. (2006,2008)

Use UKIDSS-DXS + Spitzer-SWIRE and a variety of radio surveys (e,g. FIRST).

Try and get spectra for all of the objects undetected in the near-IR



LOFAR Surveys KSP will need to adopt such a strategy to be most efficient, so will the SKA. Pan-STARRS/UKIDSS/VISTA/WISE