Deprojecting astronomical surveys

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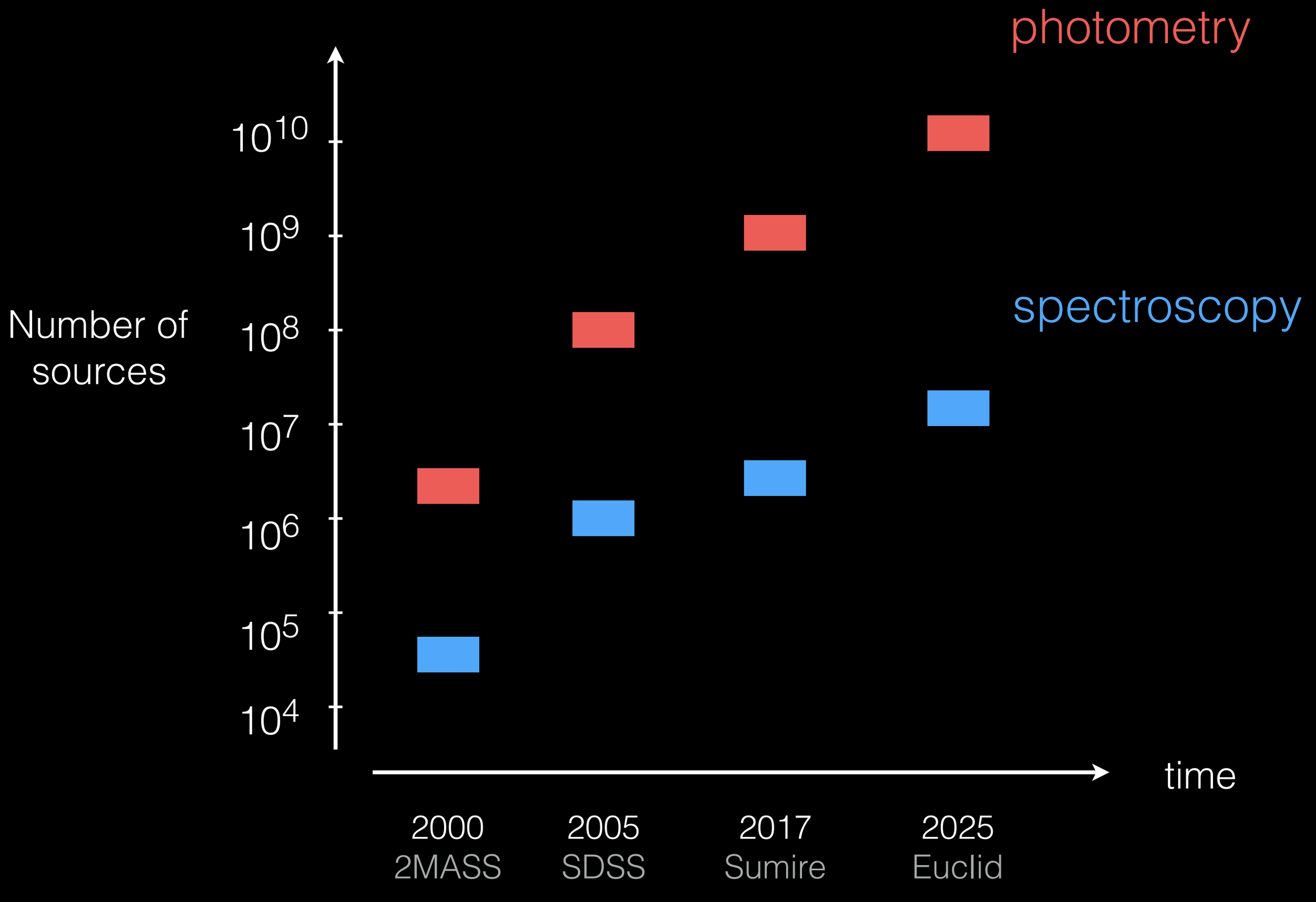
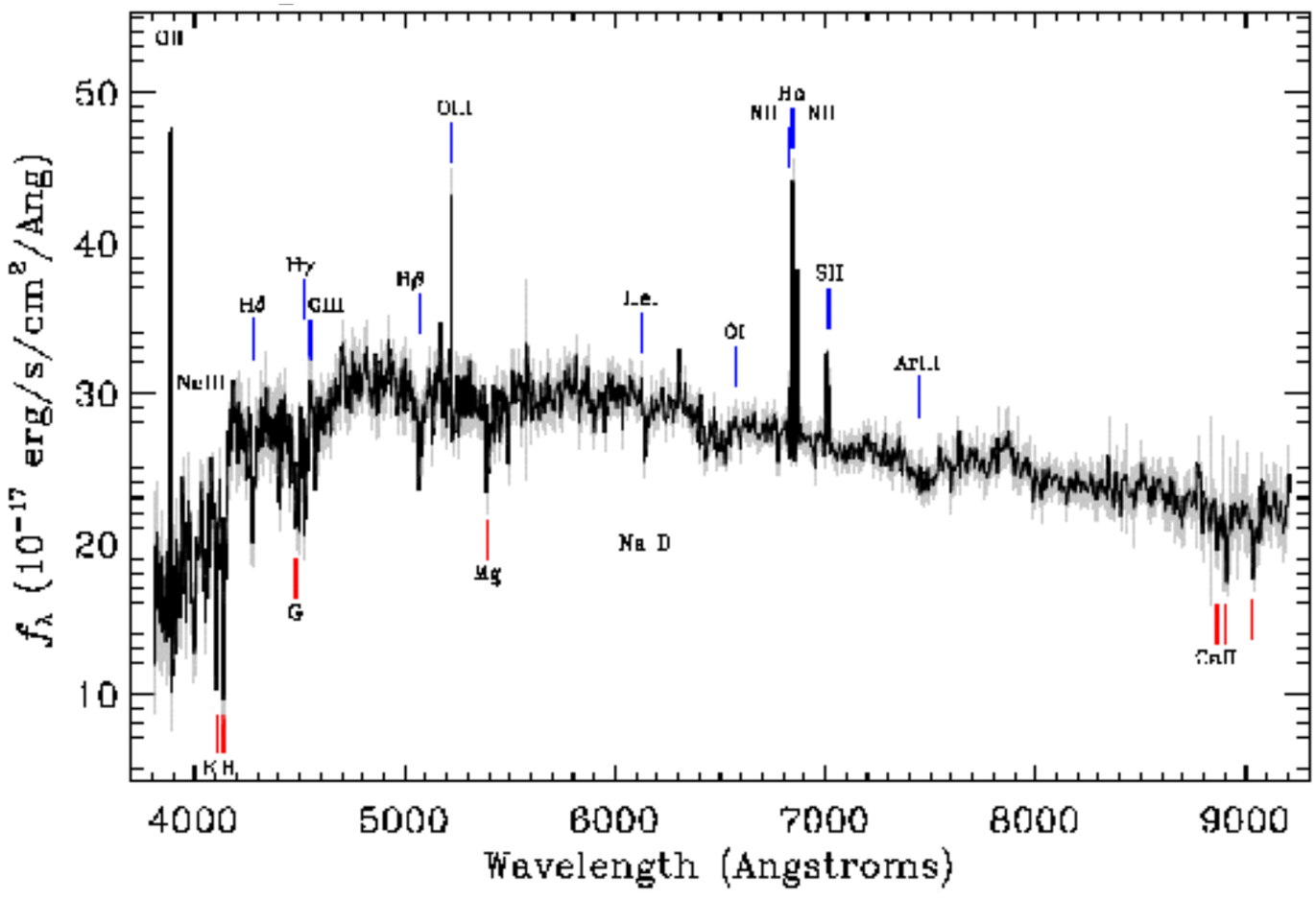
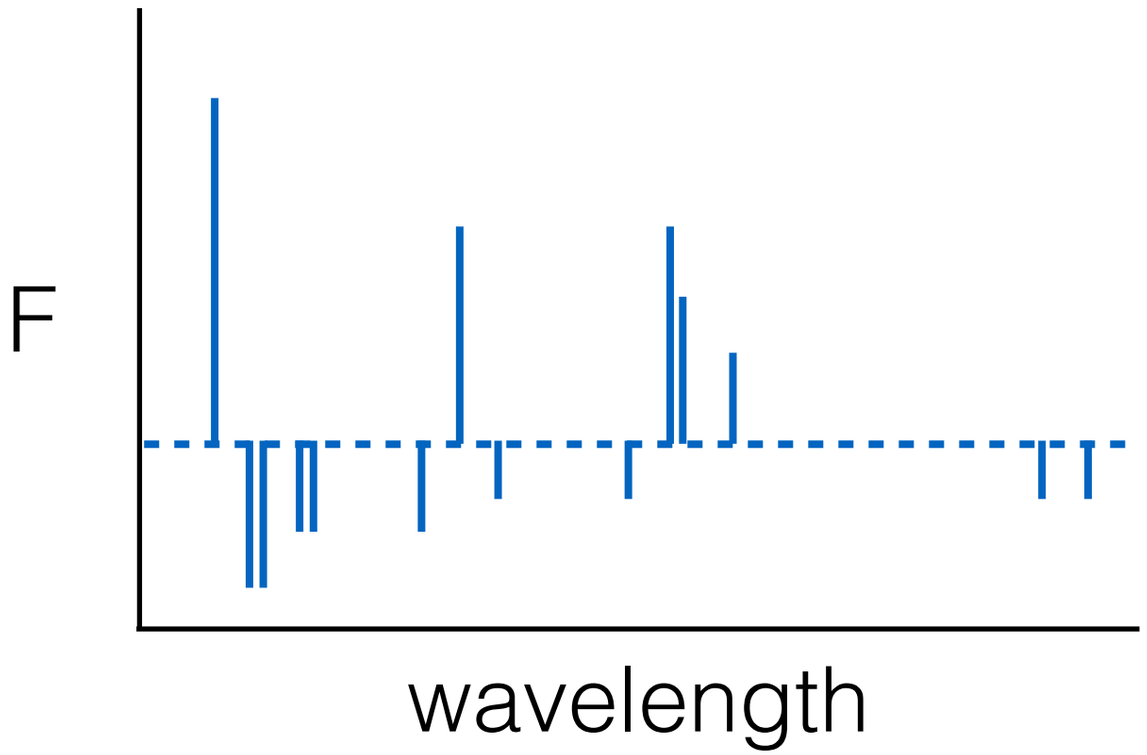
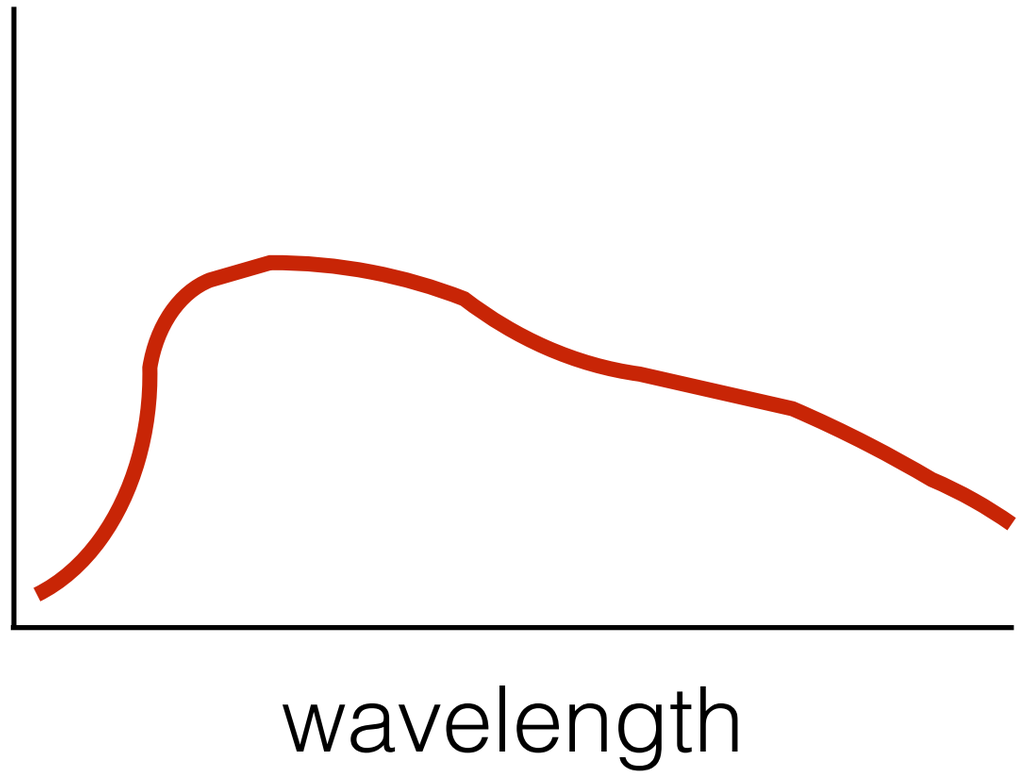

photometry
spectroscopy
Number of sources
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
time
2000
2MASS
2005
SDSS
2017
Sumire
2025
Euclid



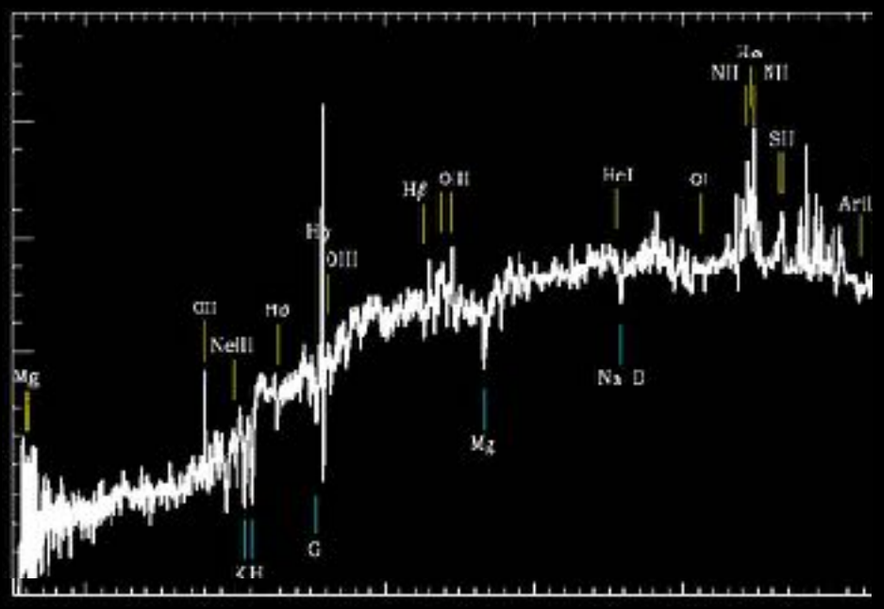
Spectroscopic redshift



Photometric redshift



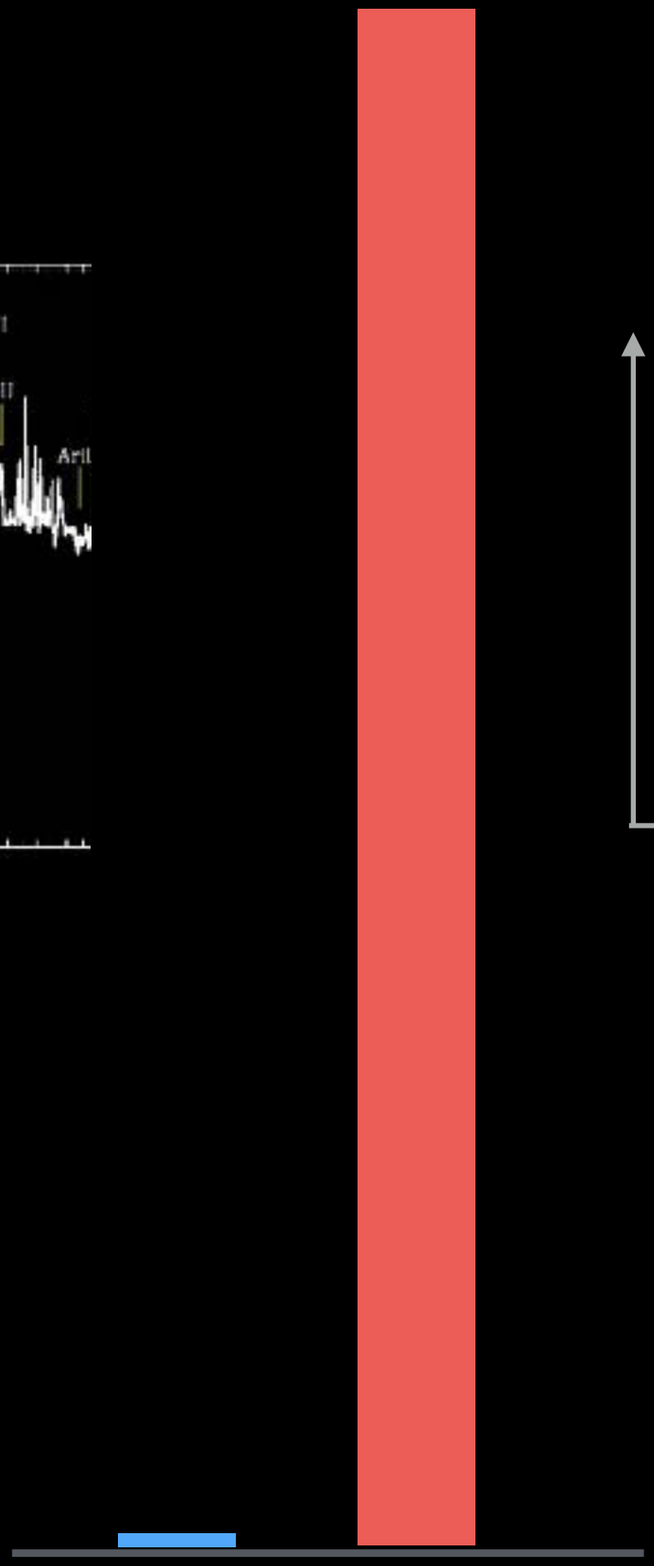
spectroscopy



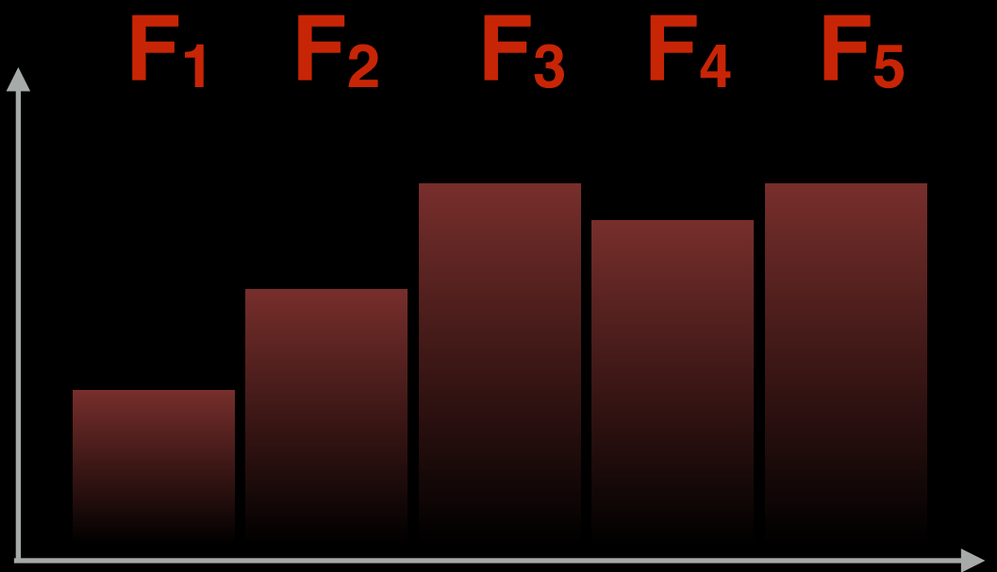
flux

wavelength

1%

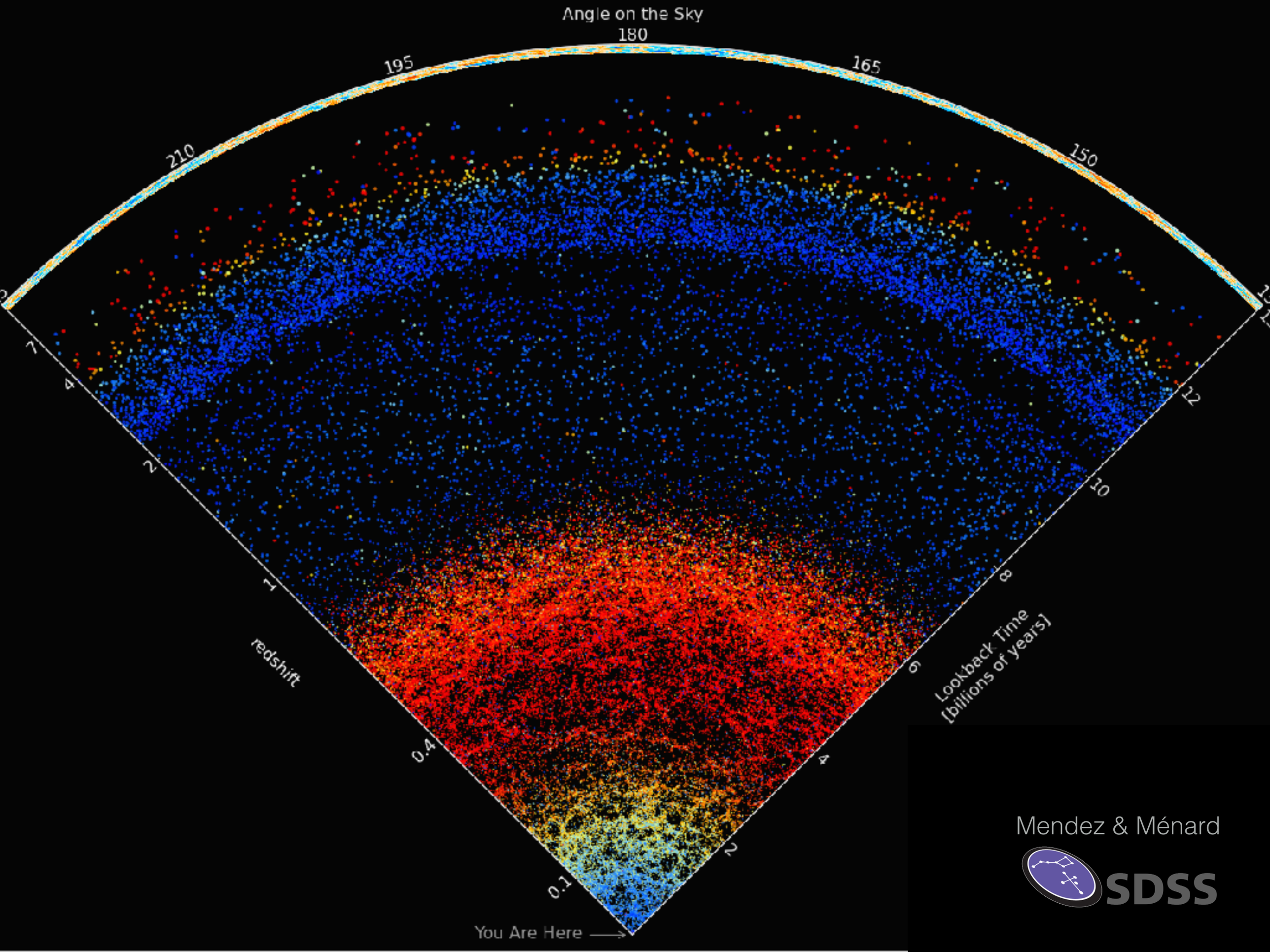


imaging



wavelength

99%


Angle on the Sky
180
195
165
210
150
2
4
7
redshift
0.4
0.1
You Are Here
2
4
6
8
10
Lookback Time
(billions of years)
Mendez & Ménard
SDSS

How much information goes into the catalogs?

main data product:
pixel based

working environment:
object based

reduced photometric space

brightness
ra,dec
size
ellipticity
…

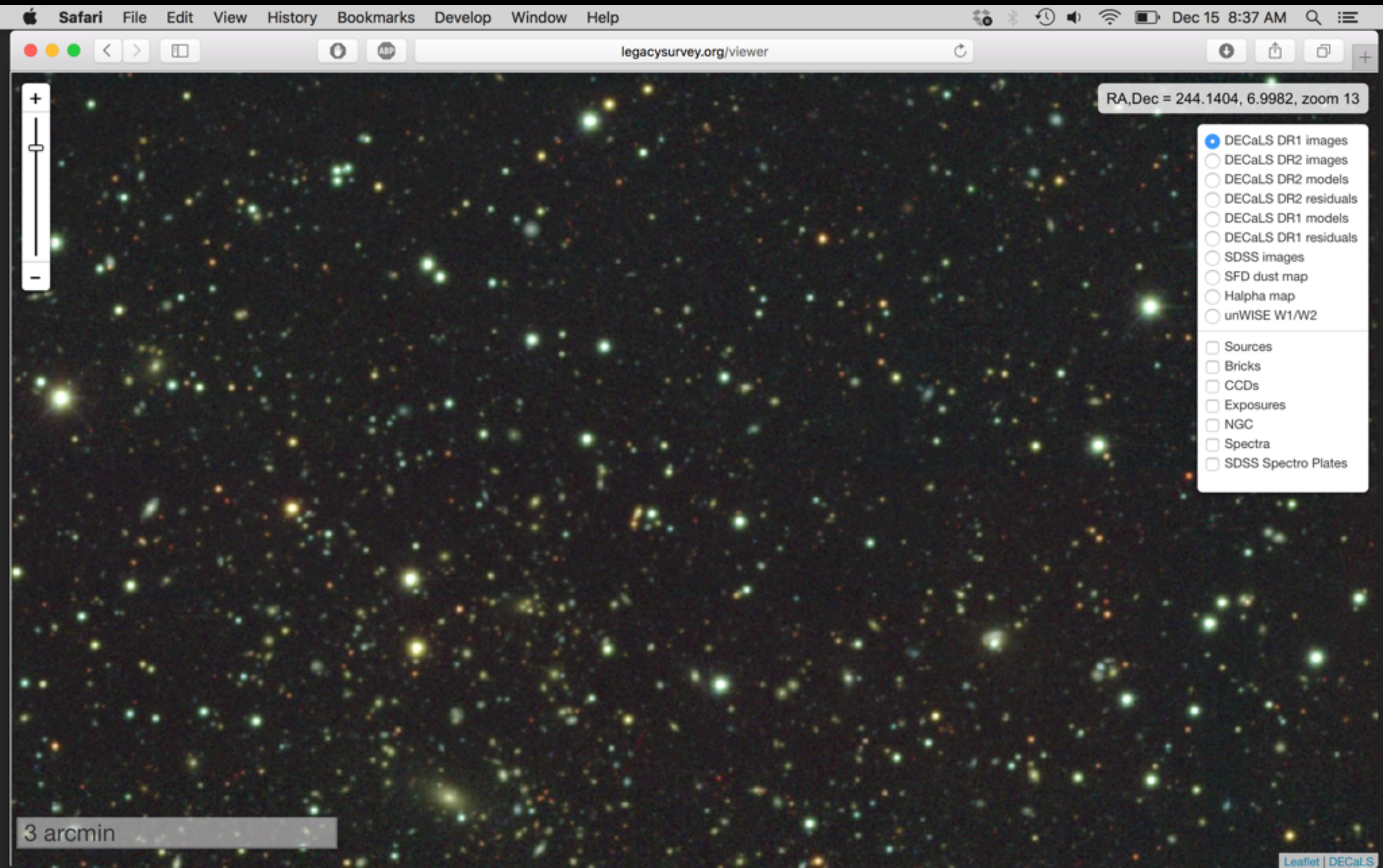
N~4 colors

Dimensionality ~ 10-20

DECaLS survey

PIs: Dey & Schlegel

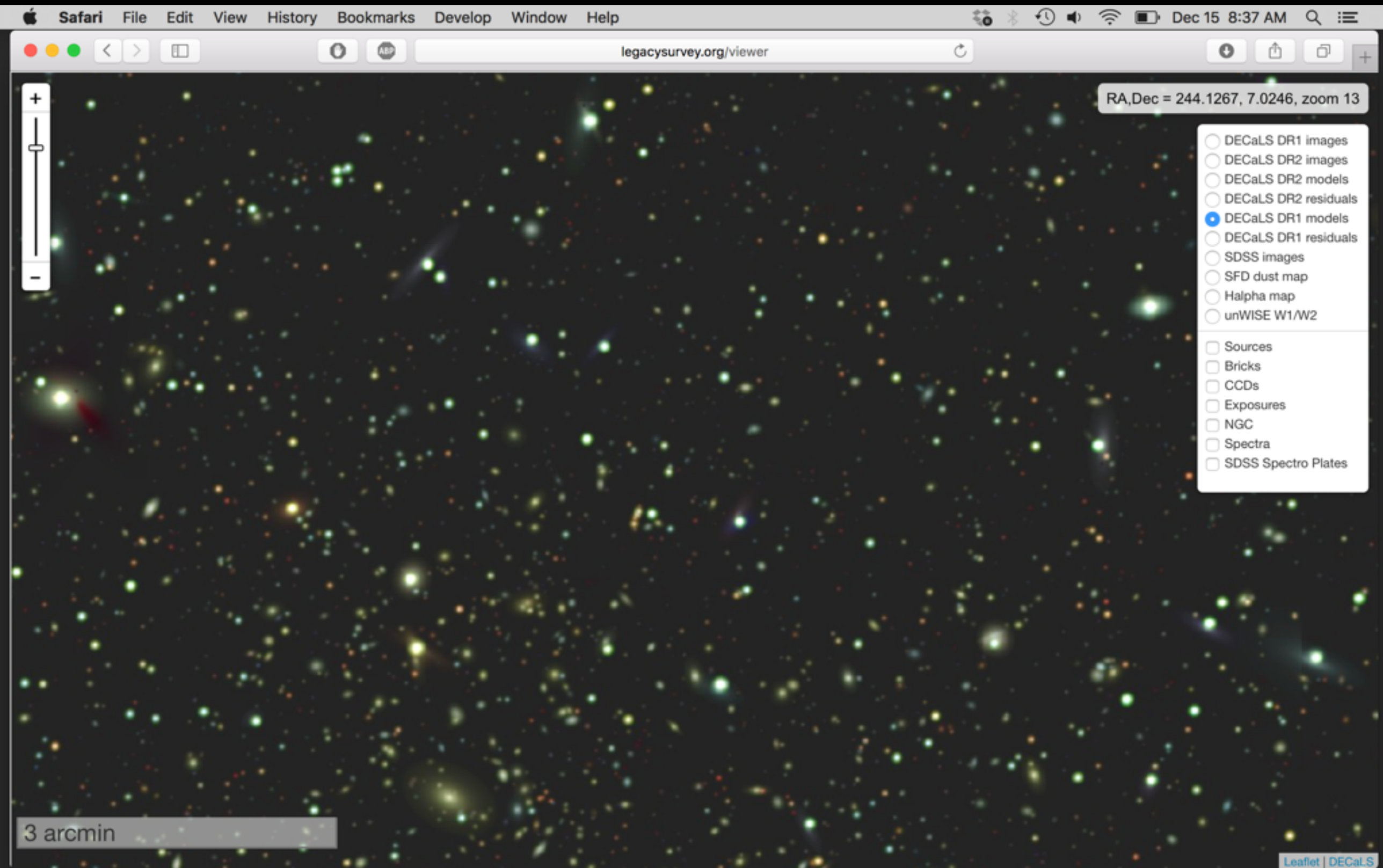
Visualization: D. Lang



DECaLS survey

PIs: Dey & Schlegel

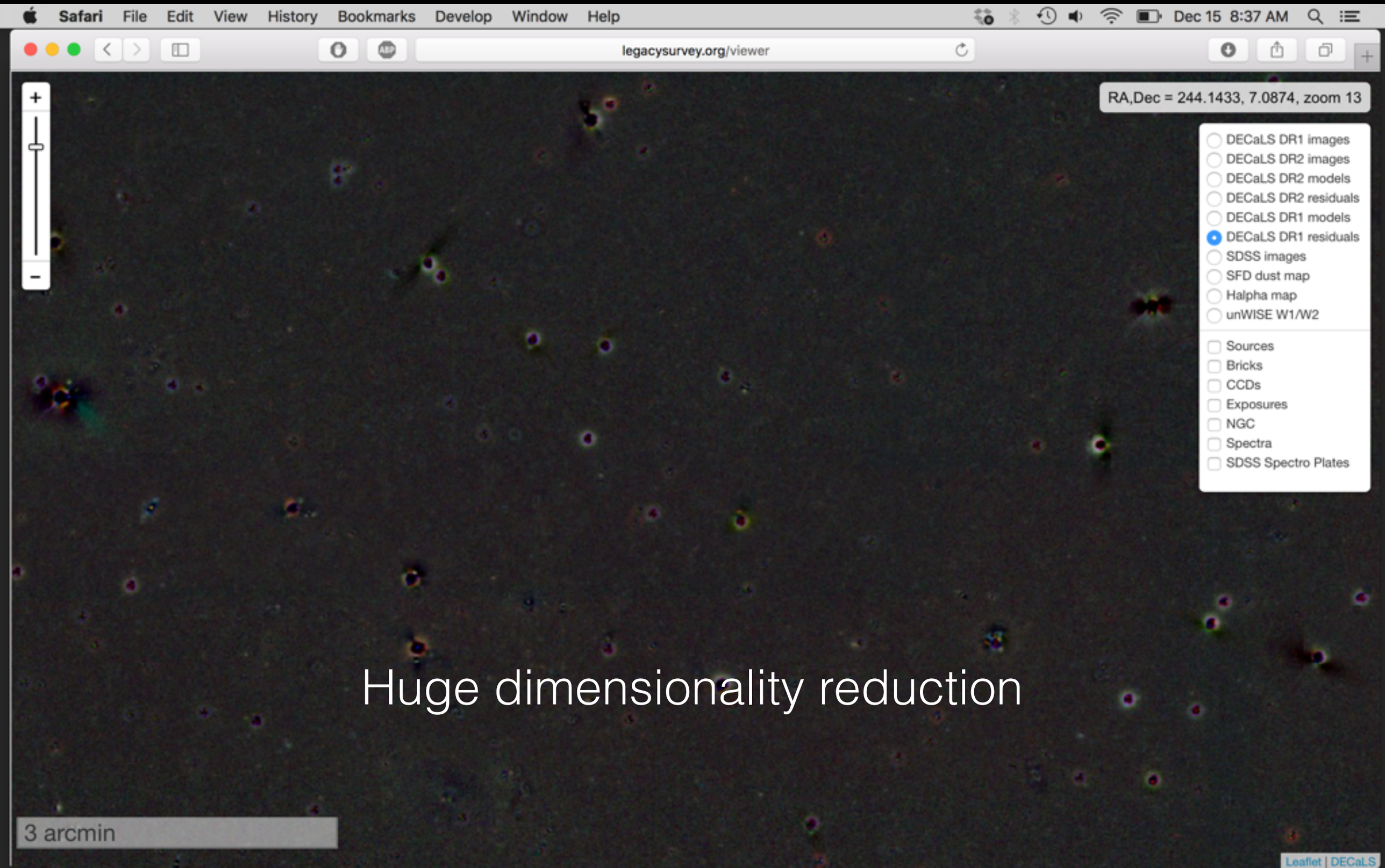
Visualization: D. Lang



DECaLS survey

PIs: Dey & Schlegel

Visualization: D. Lang



Huge dimensionality reduction

Mapping the photometric space to redshift space

Photometric space
Dim ~ 10

brightness
ra,dec
size
ellipticity
…

N~4 colors

p(z | photometry)

redshift space
Dim = 1

Mapping the photometric space to redshift space

Photometric space
Dim ~ 10

brightness
ra,dec
size
ellipticity
…

N~4 colors

redshift space
Dim = 1

Photometric Redshifts
p(z | colors, SED templates)

Mapping the photometric space to redshift space

Photomet

Dim

brigh

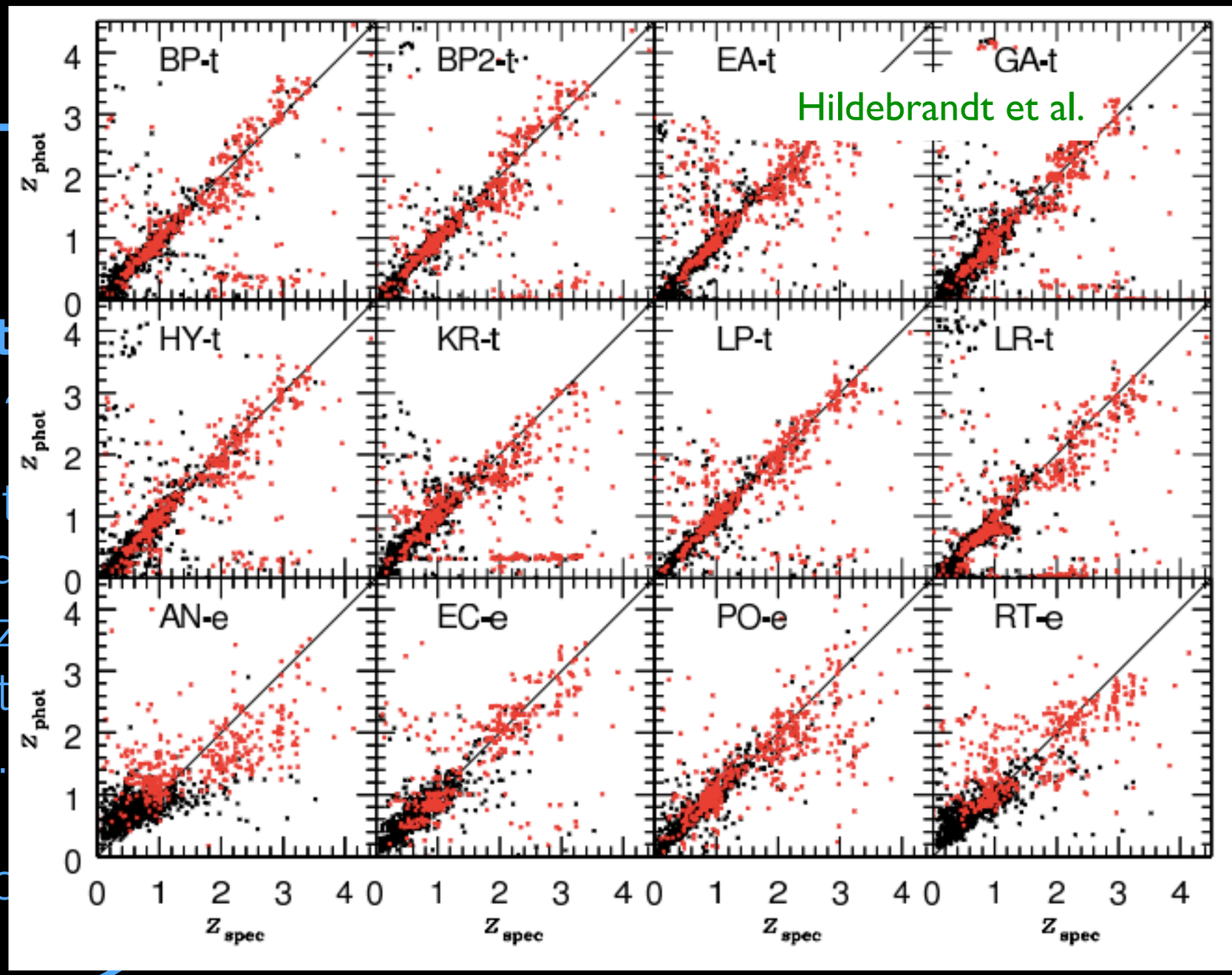
ra,c

siz

ellipt

..

N~4 c



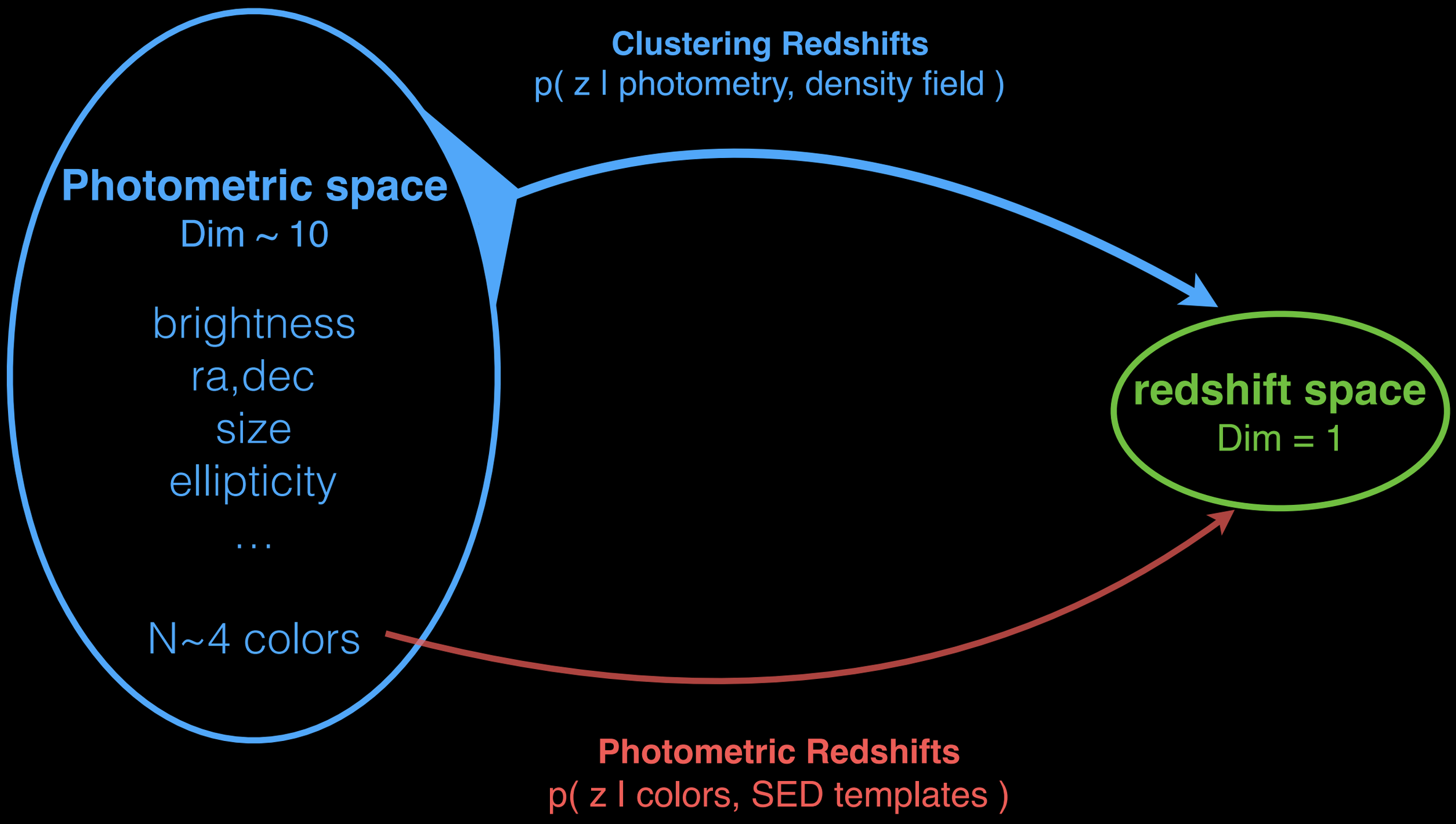
t space

= 1

Photometric Redshifts

p(z | colors, SED templates)

Mapping the photometric space to redshift space



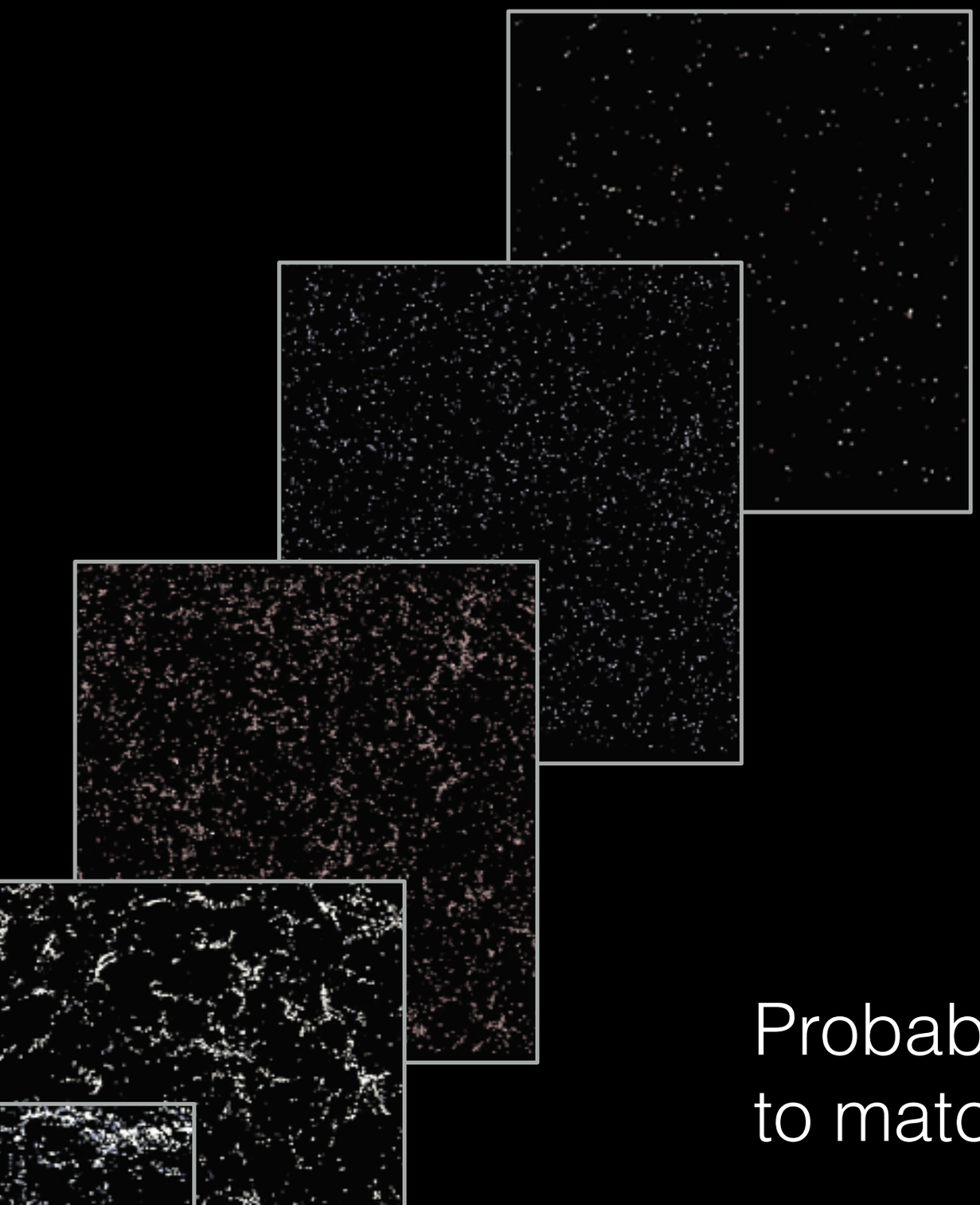
?

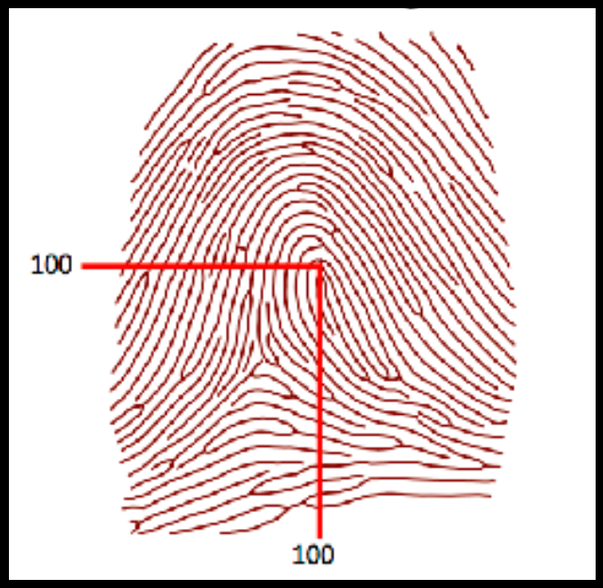
$< \partial_i \, . \, \partial_{unknown} >$

?

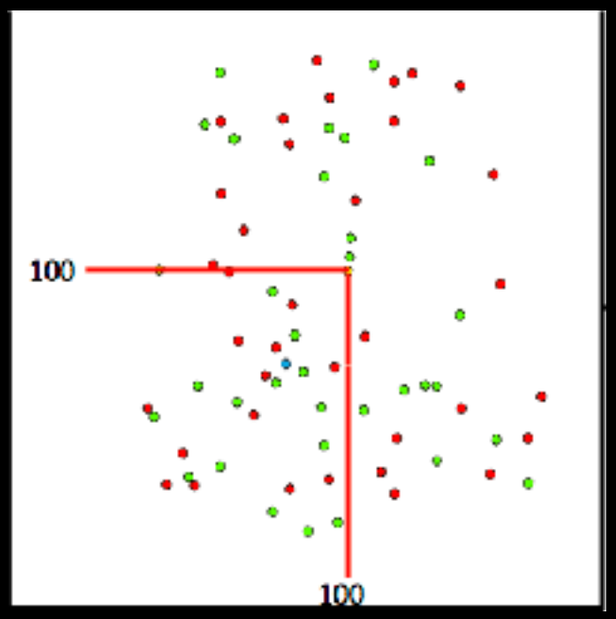
$< \partial_i \, . \, \partial_{unknown} >$

∂_i





fingerprint minutiae



Probability for two different fingerprints to match ~ 1/68 billion

Galton (1892)

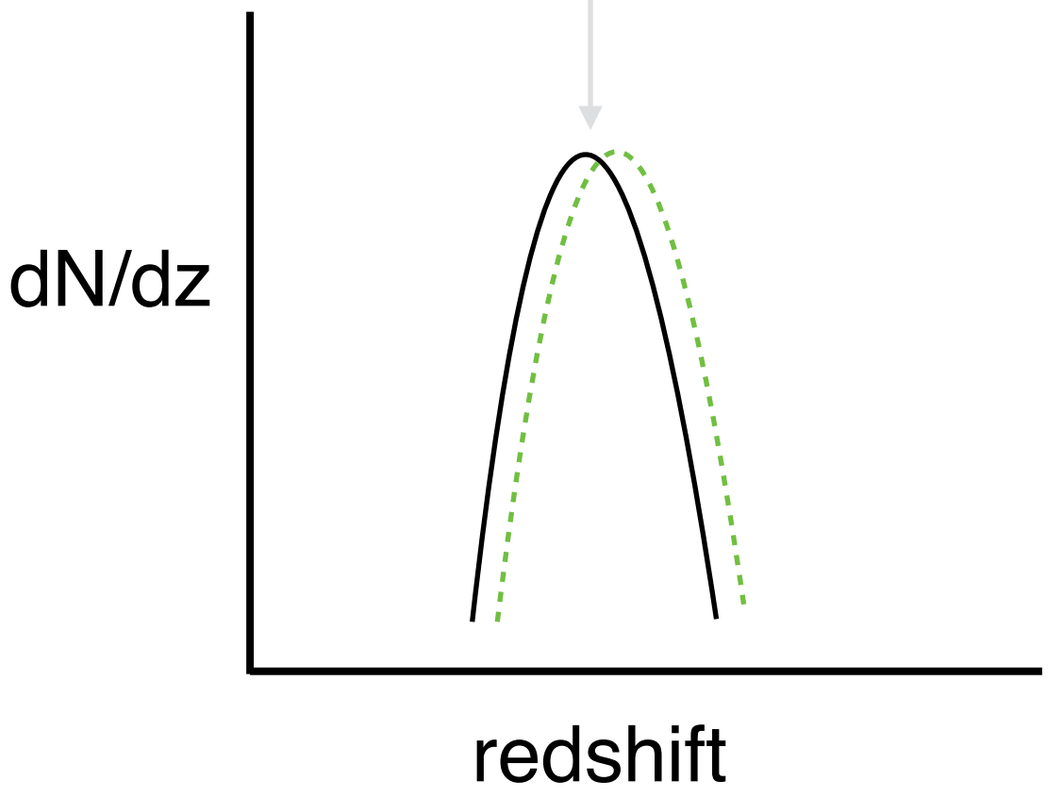
The clustering redshift technique

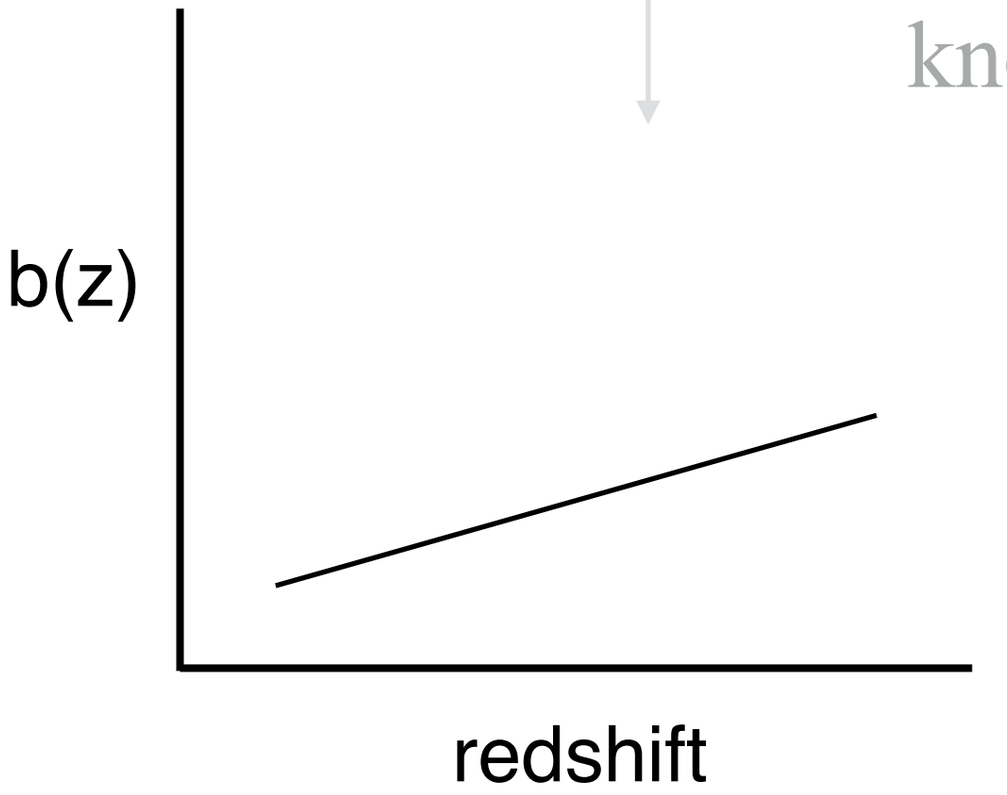
The idea: $$\bar{w}_{ur}(z_i) \propto \frac{\mathrm{dN_u}}{\mathrm{d}z}(z_i)$$

We can locate the unknown sample through a series of angular cross-correlations with a reference, spectroscopic sample

The limitation: $$\bar{w}_{ur}(z_i) \propto \frac{\mathrm{dN_u}}{\mathrm{d}z}(z_i)\,\bar{b}_u(z_i)\,\bar{b}_r(z_i)$$

known



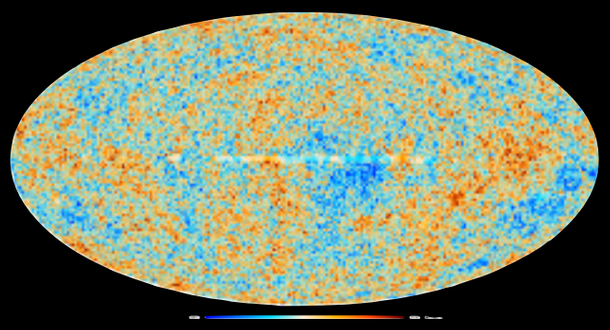


Applications of clustering redshifts

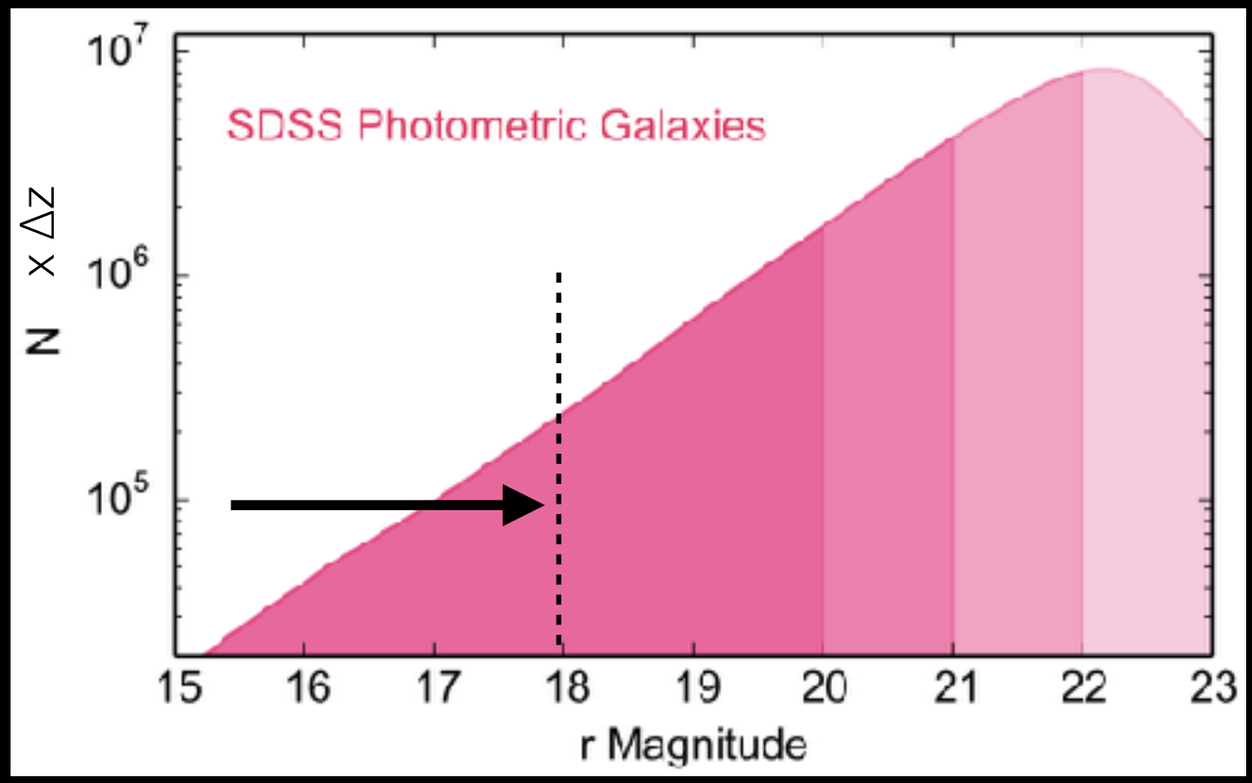
SDSS
optical

2MASS
near infrared

WISE
infrared



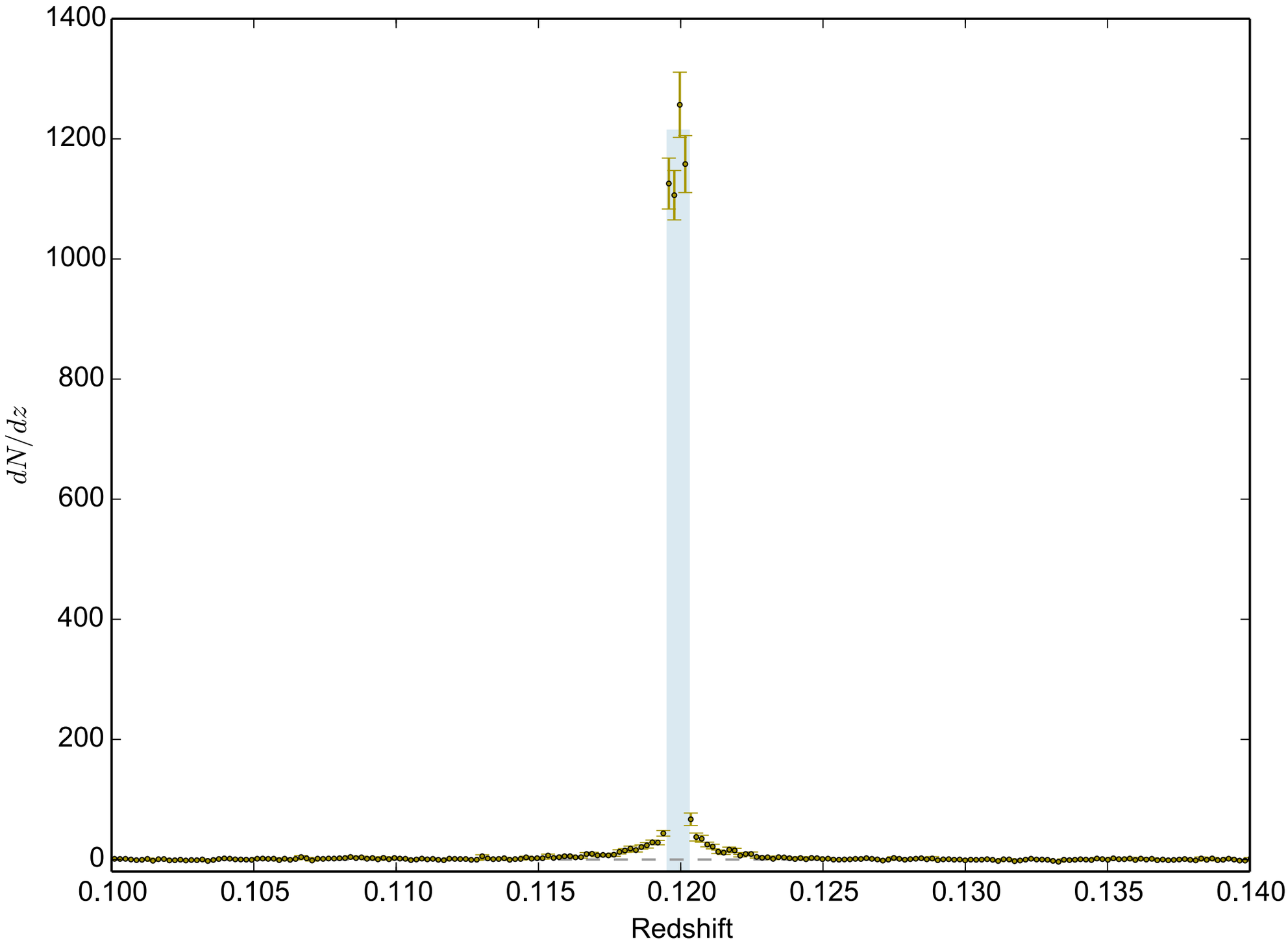
Planck
millimetric



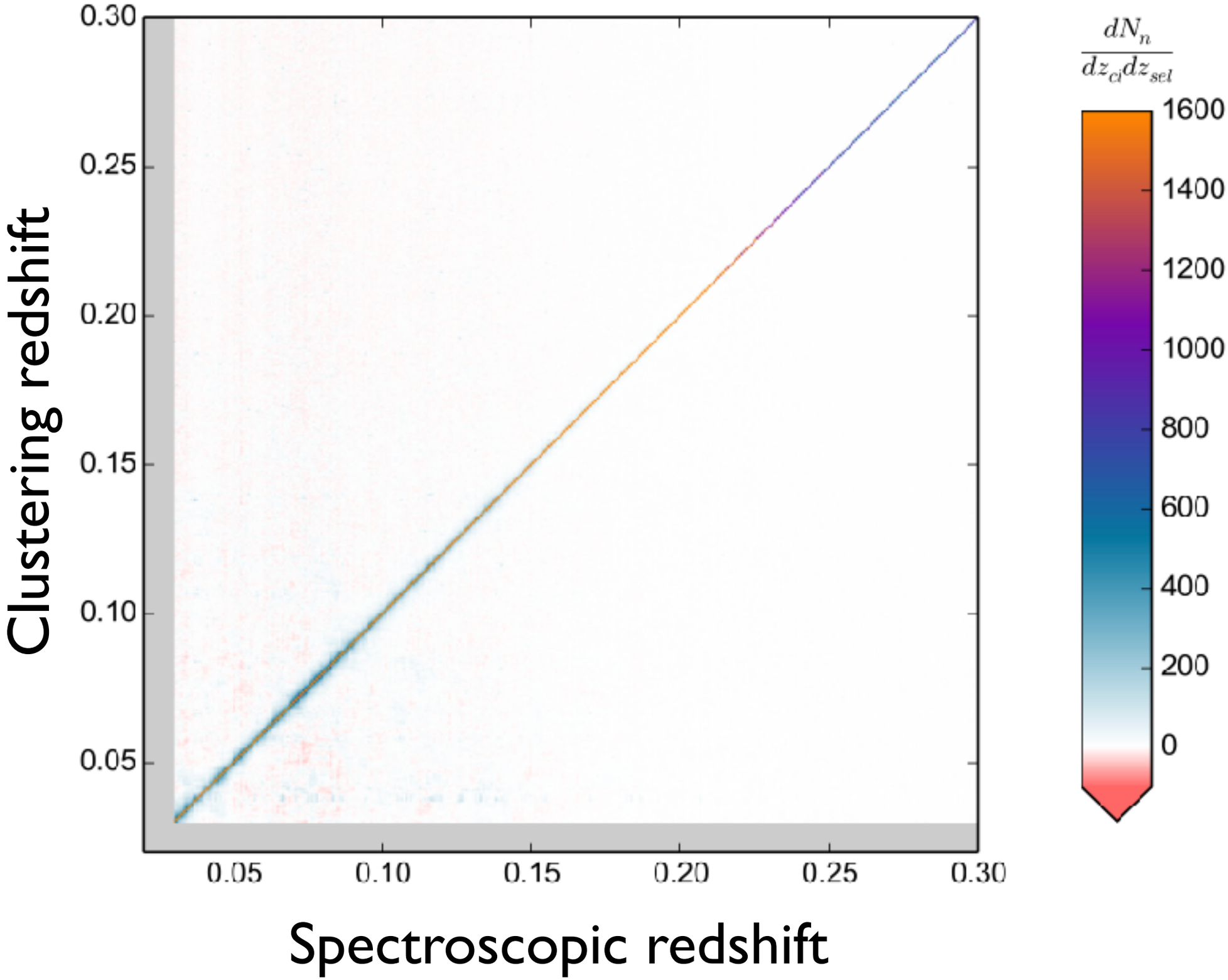
spectroscopic galaxy sample

r < 18 mag

1 million objects



Rahman, BM et al. (2015)



Rahman, BM et al. (2015)

Photometrically-selected galaxies

sample 1: 0.5 < g-r < 0.6

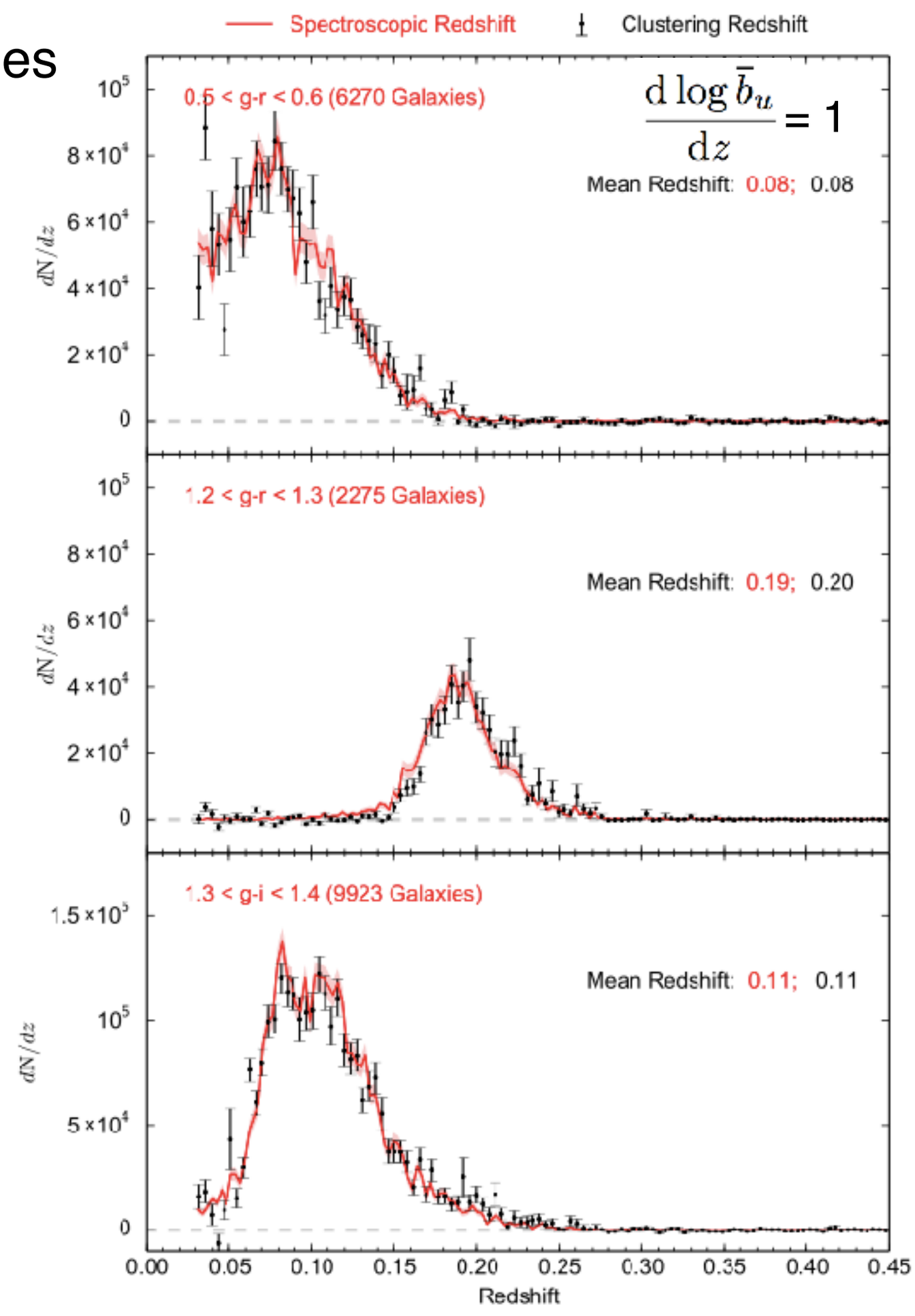
~ 6,300 galaxies

sample 2: 1.3 < g-i < 1.4

~ 10,000 galaxies

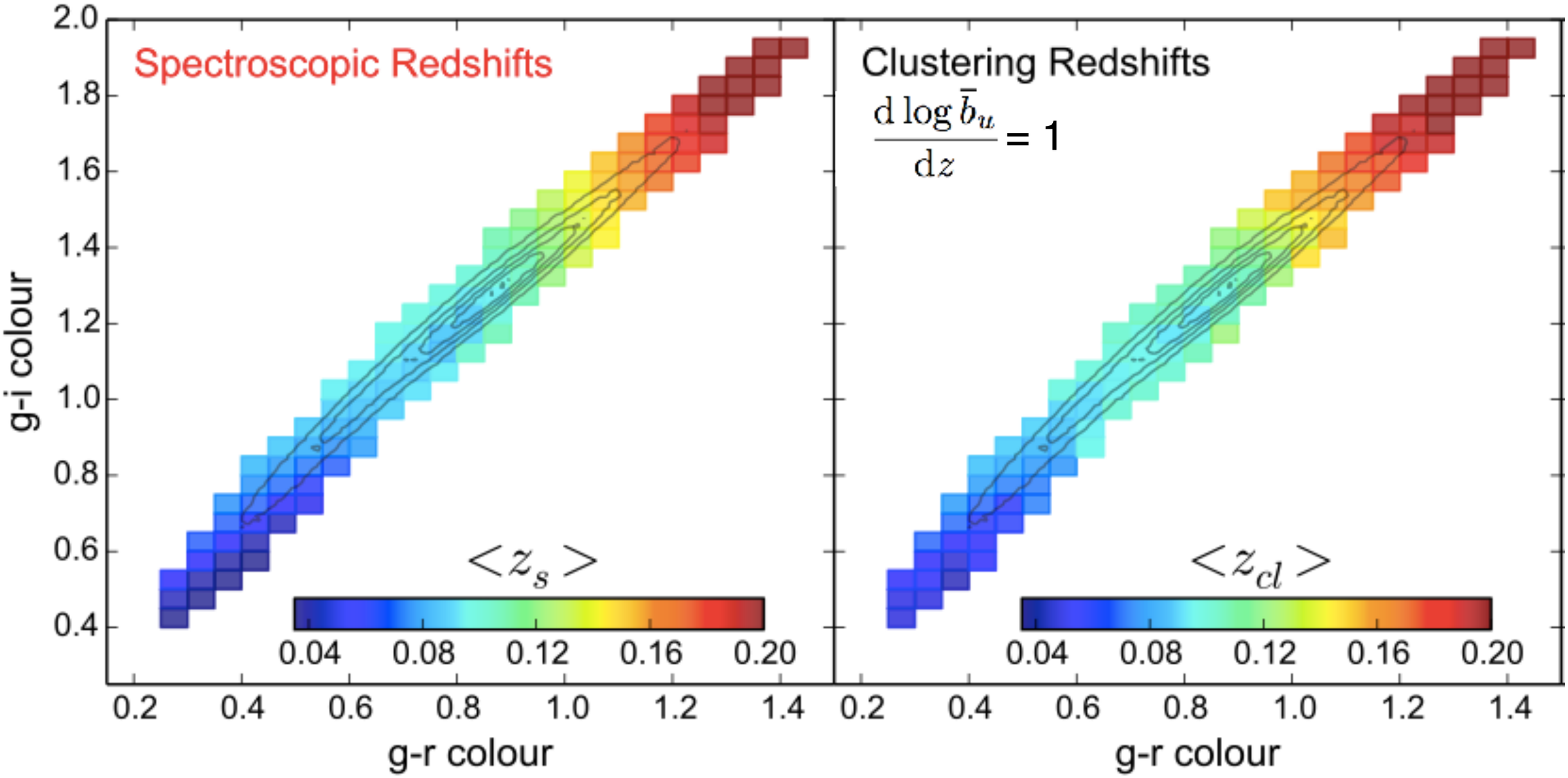
sample 3: 1.2 < g-r < 1.3

~ 2,500 galaxies



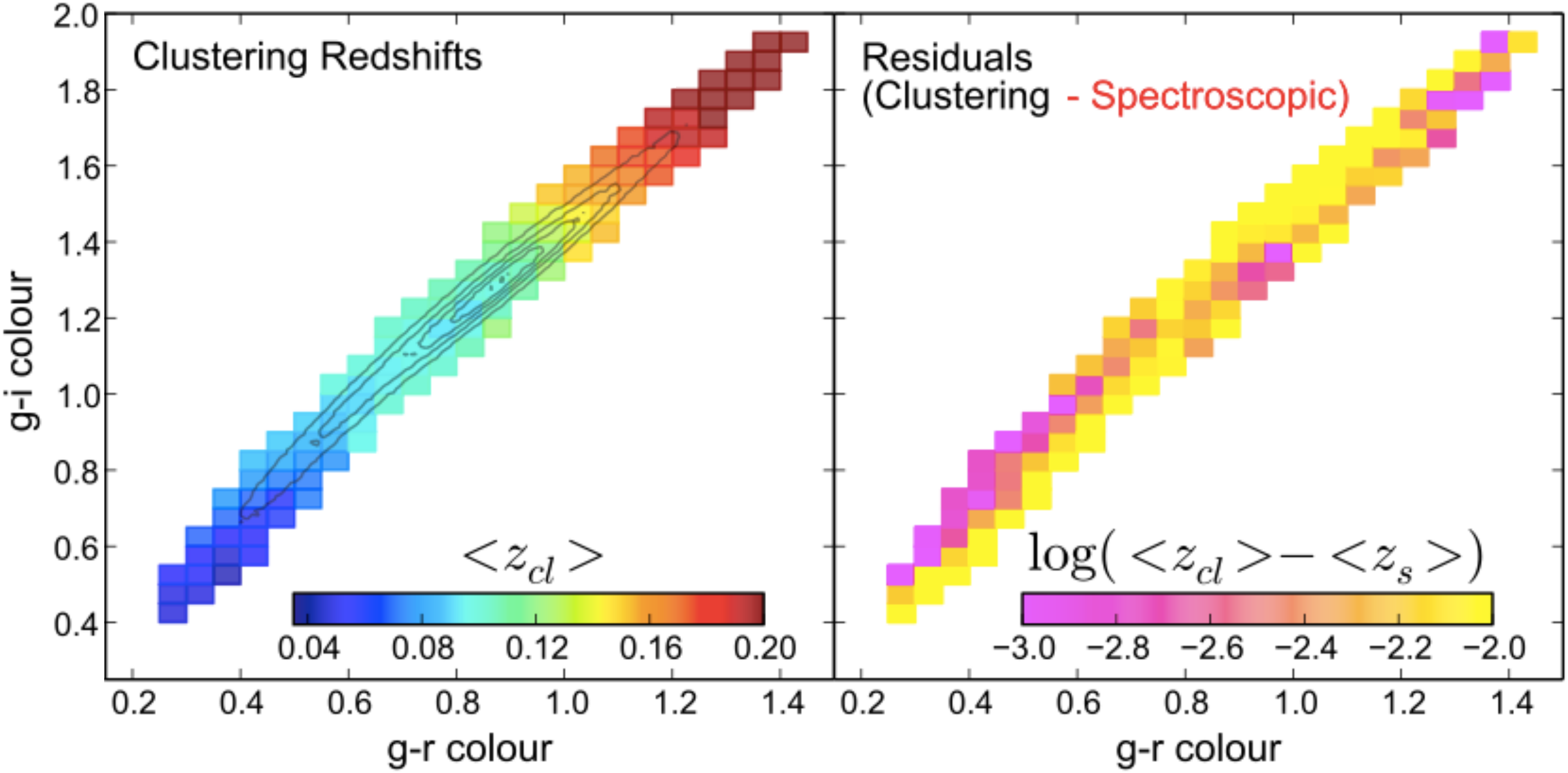
Rahman, BM et al. (2015)

Generalization to one million galaxies



Rahman, BM et al. (2015)

Generalization to one million galaxies

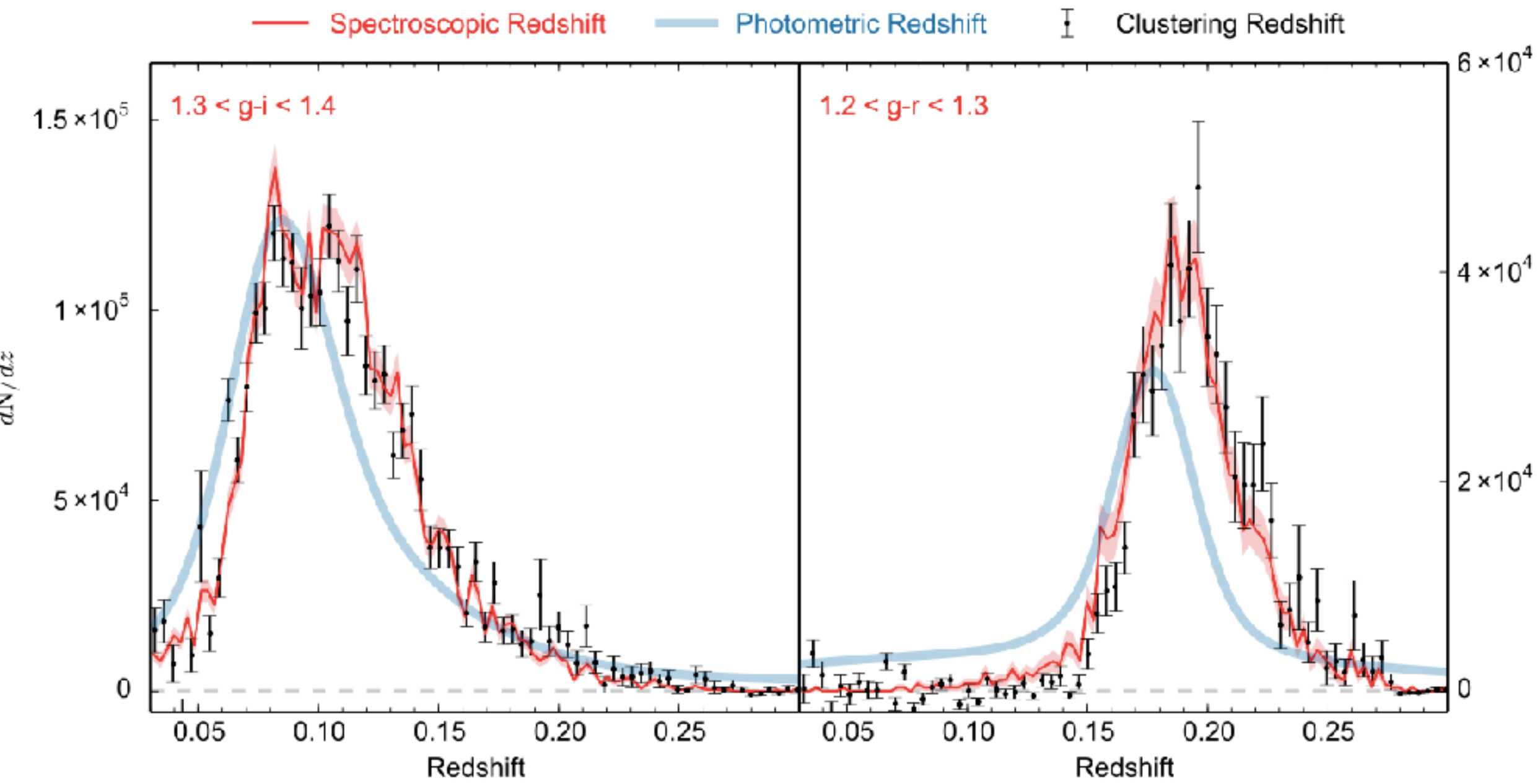


Rahman, BM et al. (2015)

Comparison to photometric redshifts

sample 2

sample 3



SDSS KD-tree photometric redshifts

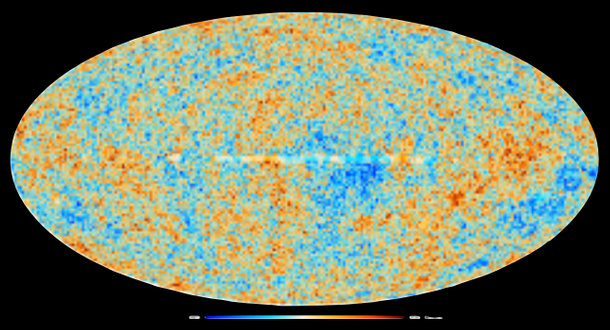
Rahman, BM et al. (2015)

Applications of clustering redshifts

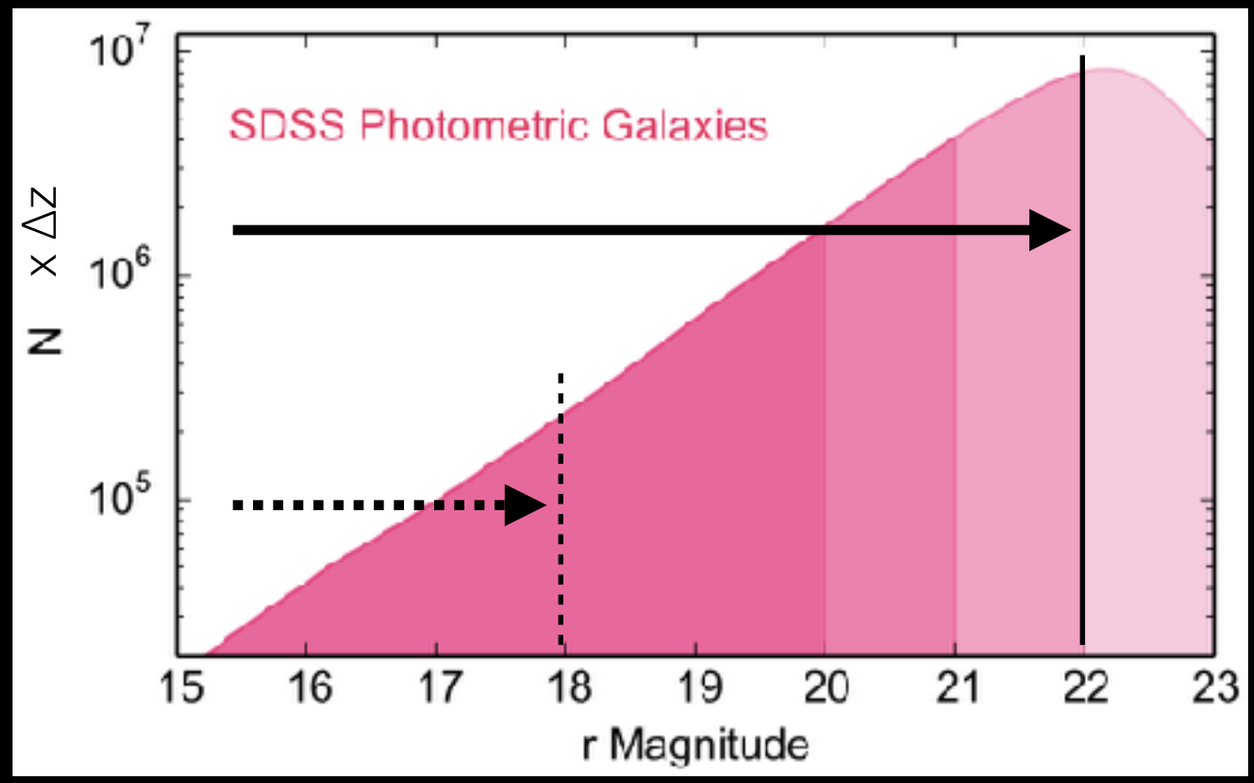
SDSS
optical

2MASS
near infrared

WISE
infrared



Planck
millimetric



Entire photometric sample

r < 22 mag

100 million objects

Photometrically-selected galaxies

sample 1: 0.53 < r-i < 0.54

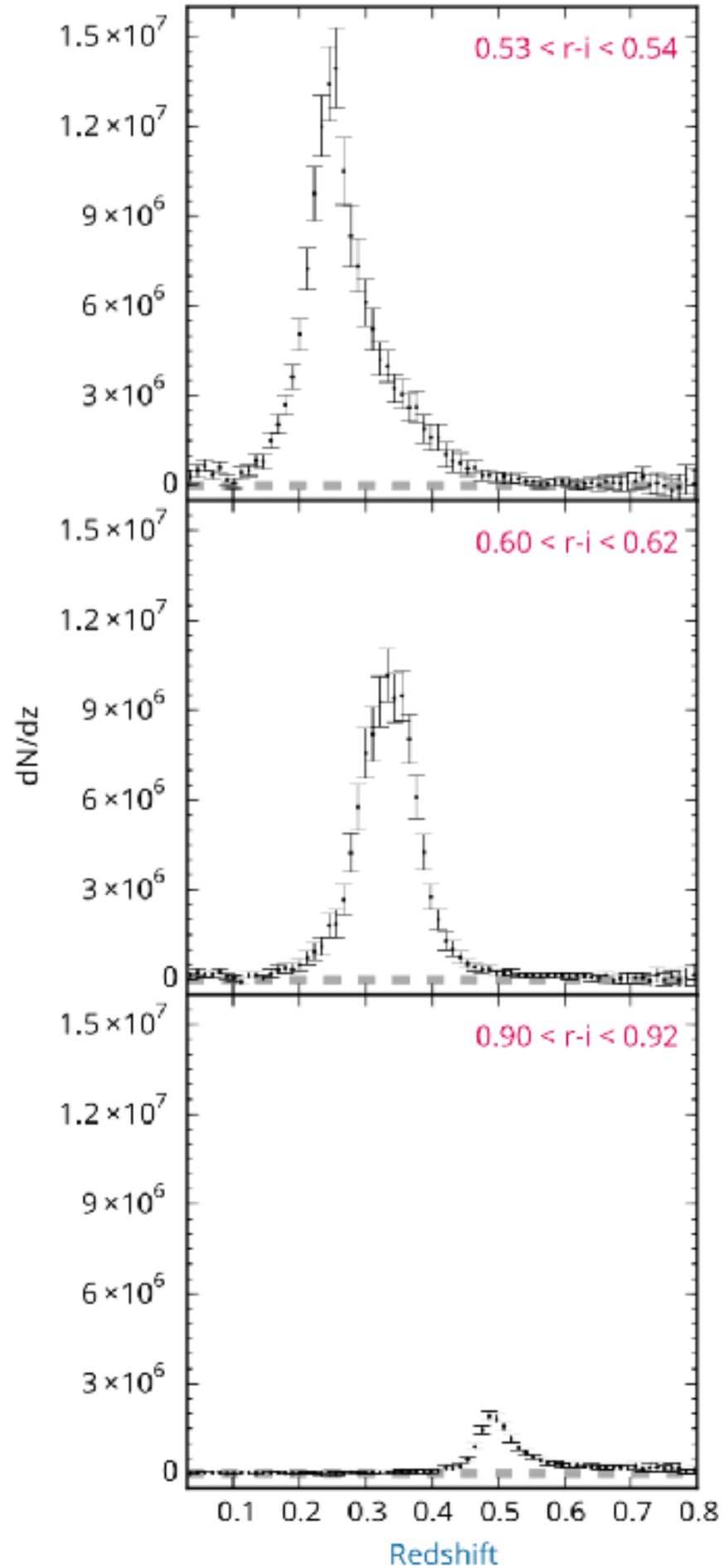
1.6 million galaxies

sample 3: 0.60 < r-i < 0.62

1.2 million galaxies

sample 3: 0.90 < r-i < 0.92

0.2 million galaxies



Rahman et al. (2015)

$\frac{d^2 b_u N}{d(col) dz_{cl}}$

min 0 max

clustering redshift

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

0 1 2 | 0.0 0.5 1.0 1.5 | 0.5 1.0 1.5 | 0.2 0.4 0.6 0.8

color u-g g-r r-i i-z

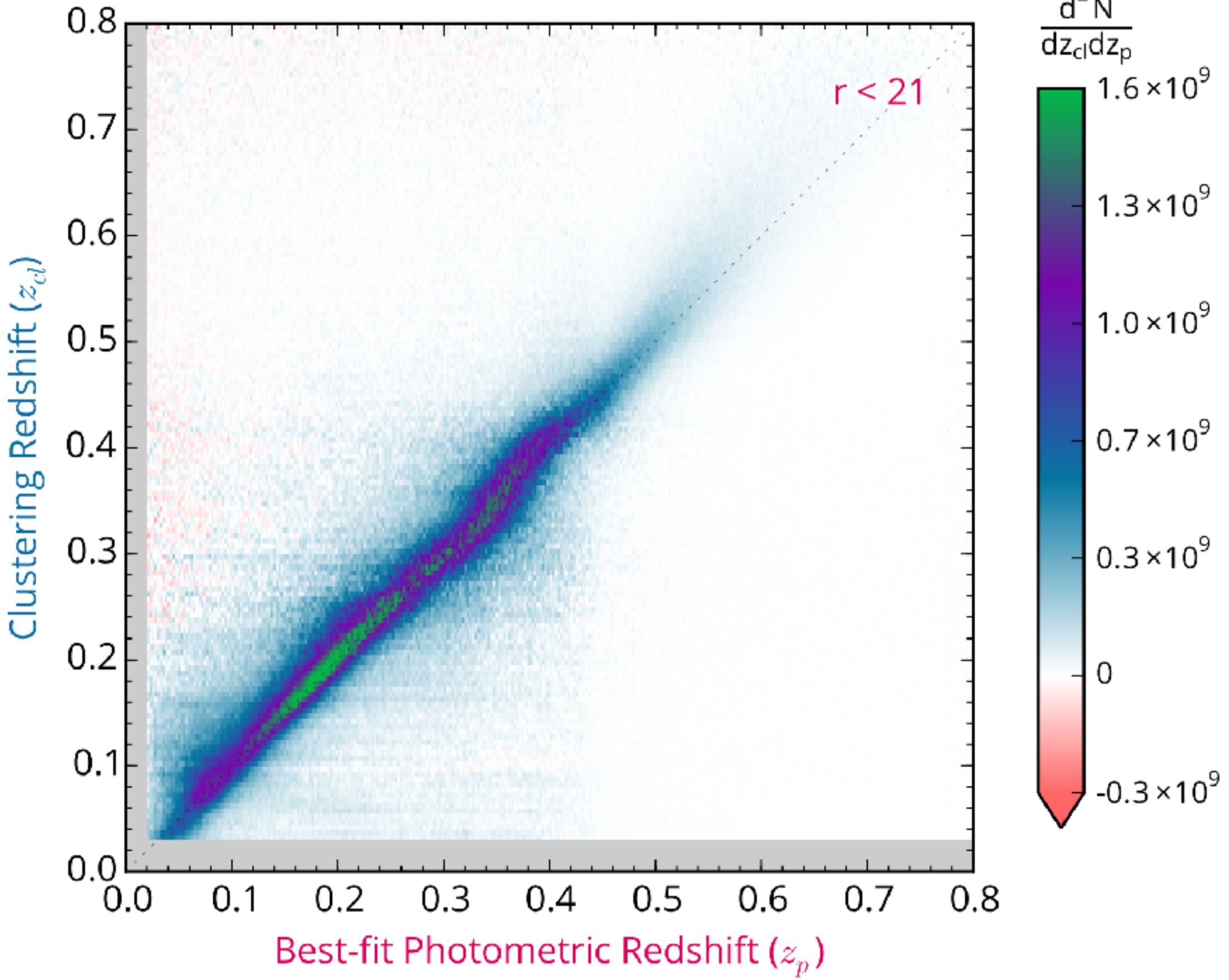
QSO
Seyfert
Starburst (M82)
Starburst (Arp 220)
Spiral (S0)
Elliptical

clustering redshift

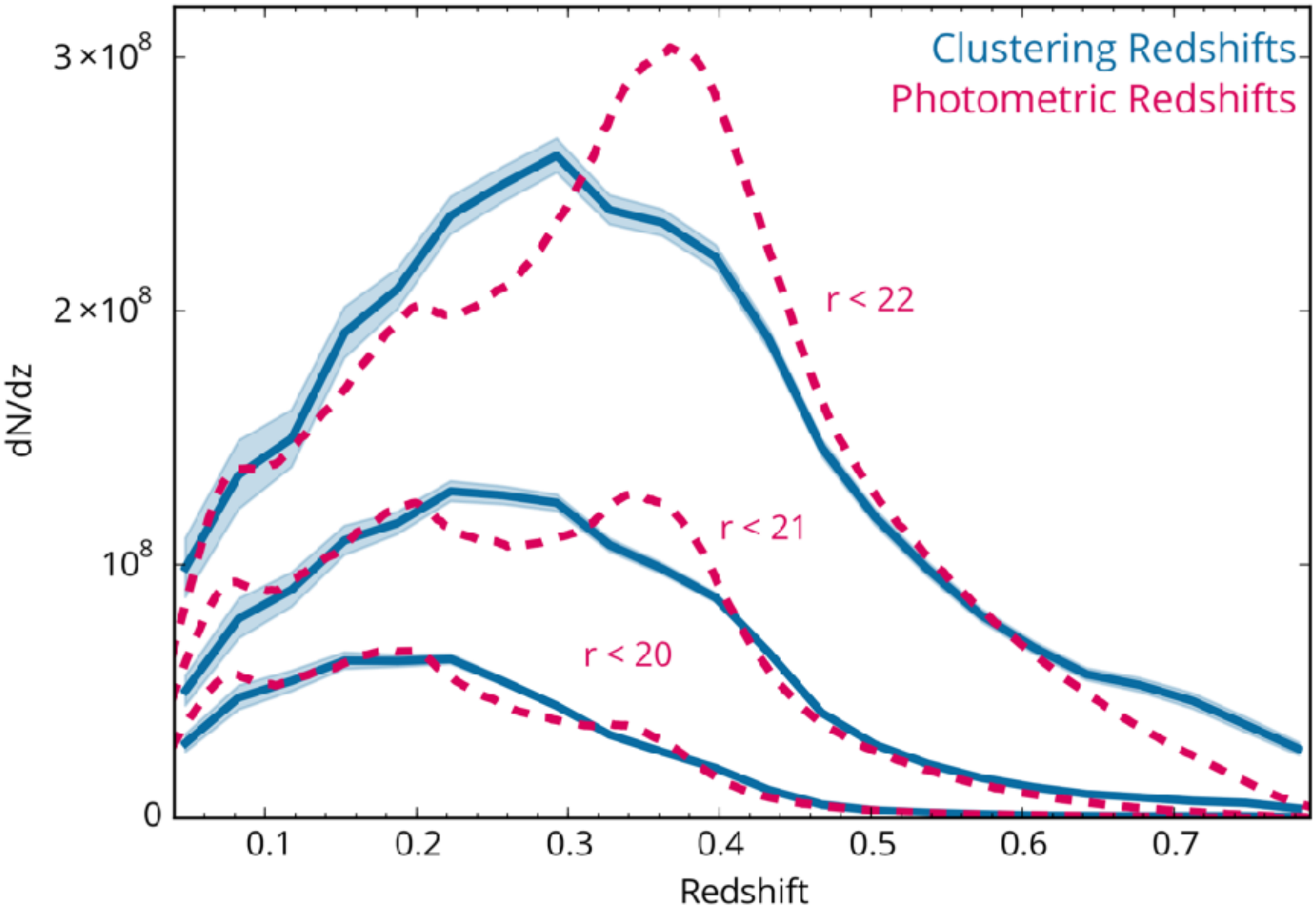
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

0 1 2
0.0 0.5 1.0 1.5
0.5 1.0 1.5
0.2 0.4 0.6 0.8

color
u-g
g-r
r-i
i-z


r < 21
Clustering Redshift (z_{cl})
Best-fit Photometric Redshift (z_p)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
$\frac{d^2N}{dz_{cl}dz_p}$
1.6×10^9
1.3×10^9
1.0×10^9
0.7×10^9
0.3×10^9
0
-0.3×10^9

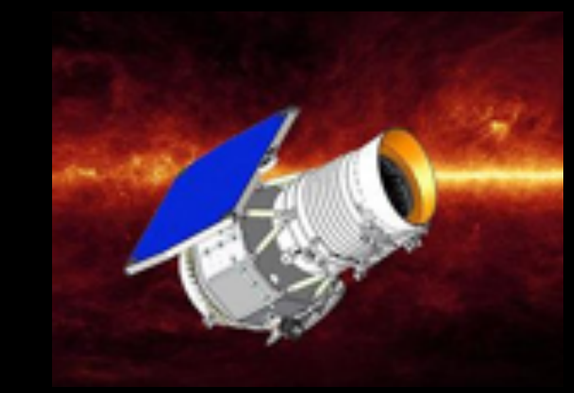
Redshift distribution of 100 million SDSS galaxies



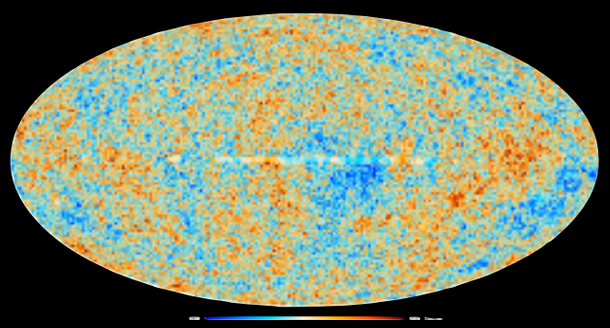
Applications of clustering redshifts

SDSS
optical

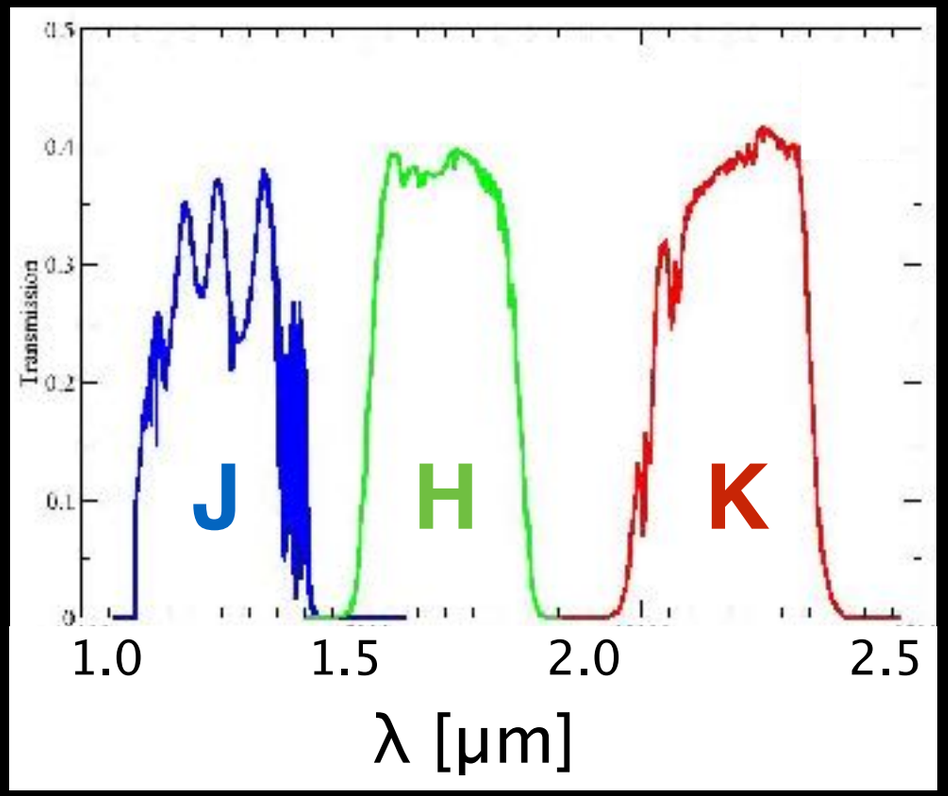
2MASS
near infrared



WISE
infrared



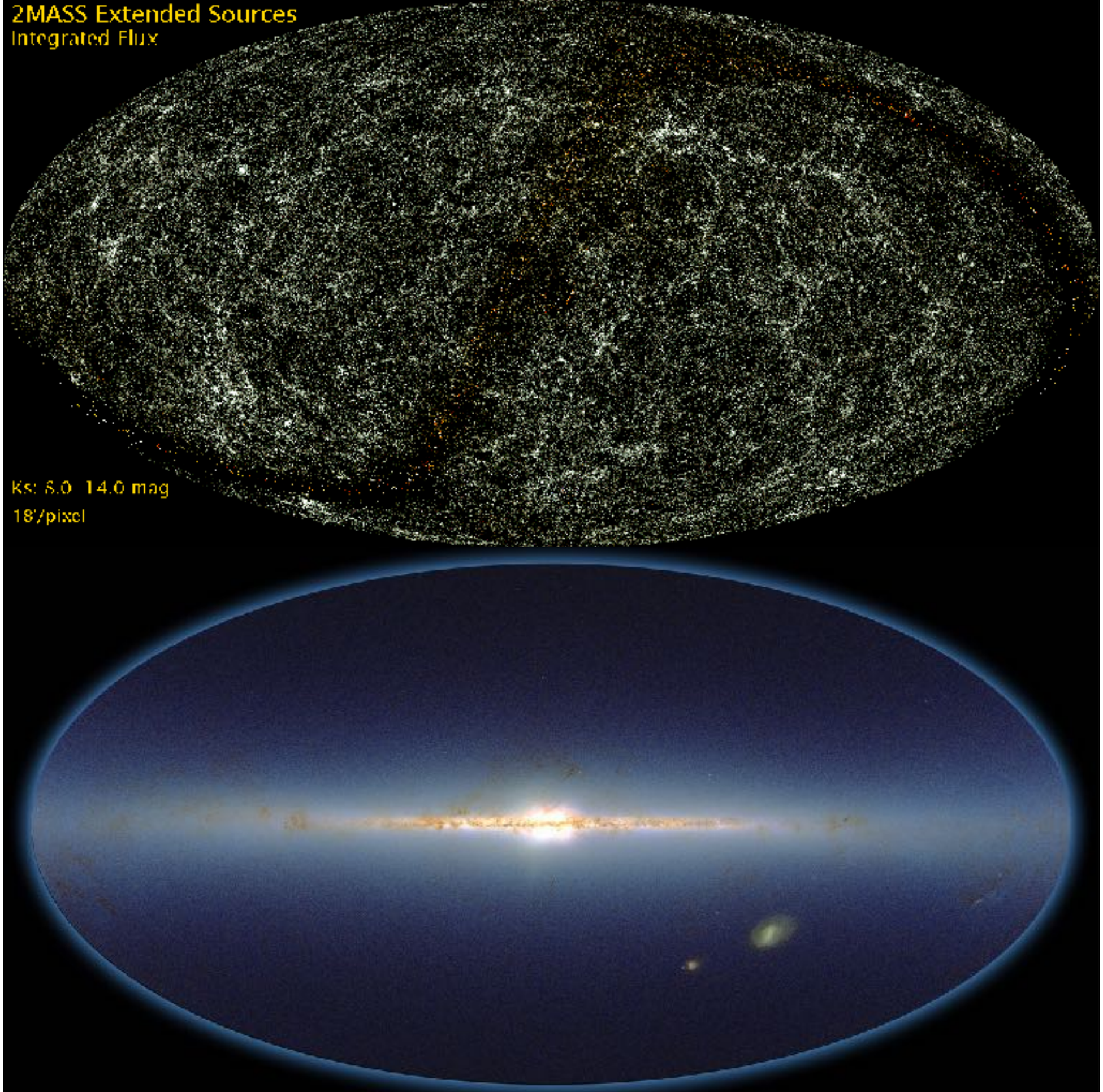
Planck
millimetric

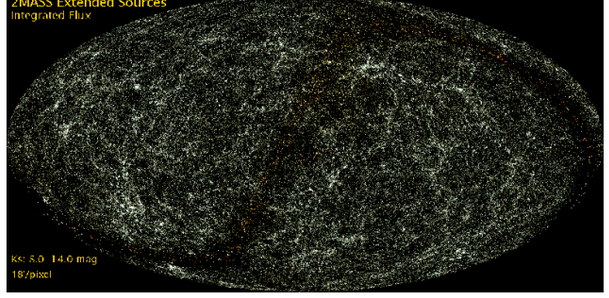


2MASS K < 14 mag

1.5 million extended sources

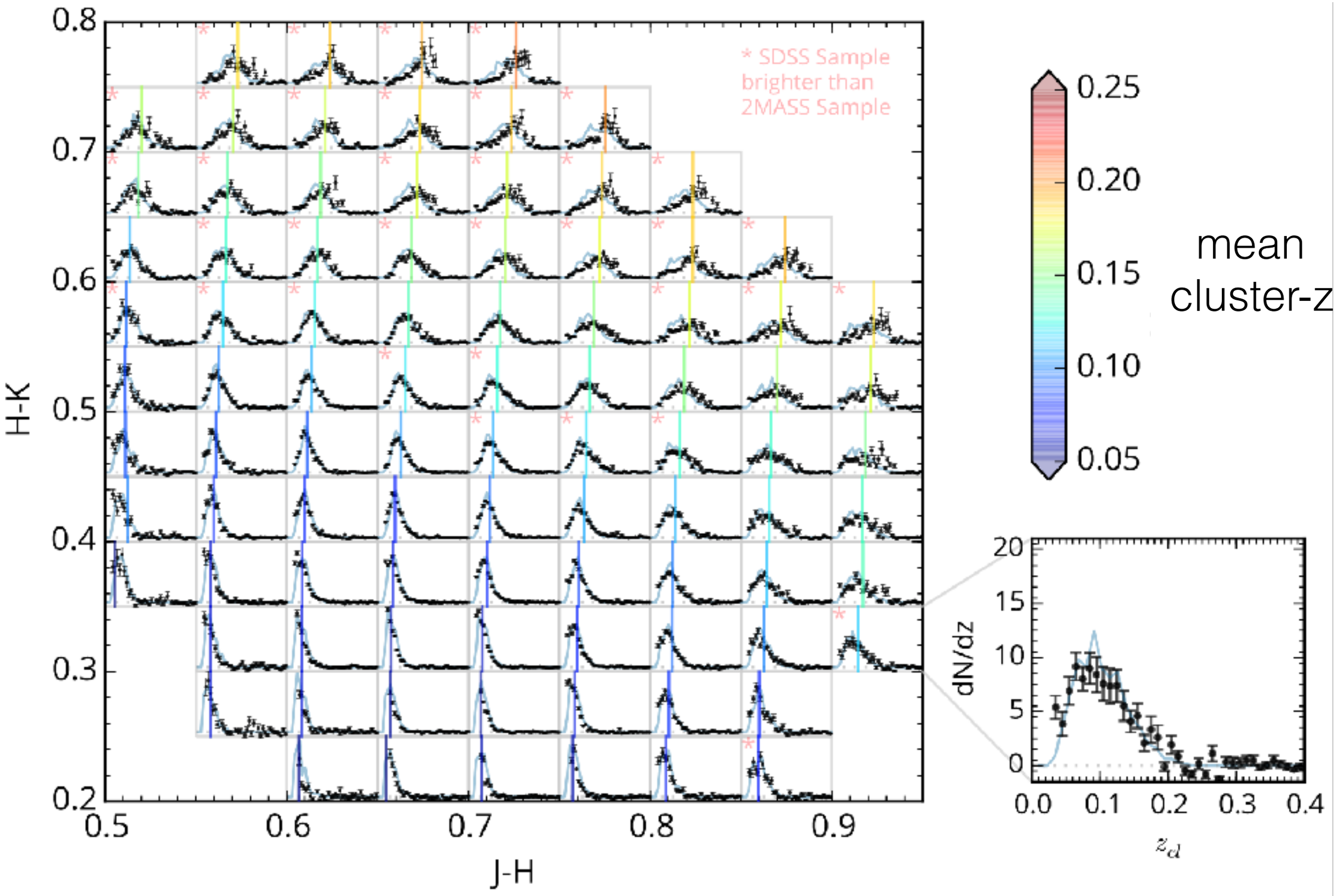
470 million point sources

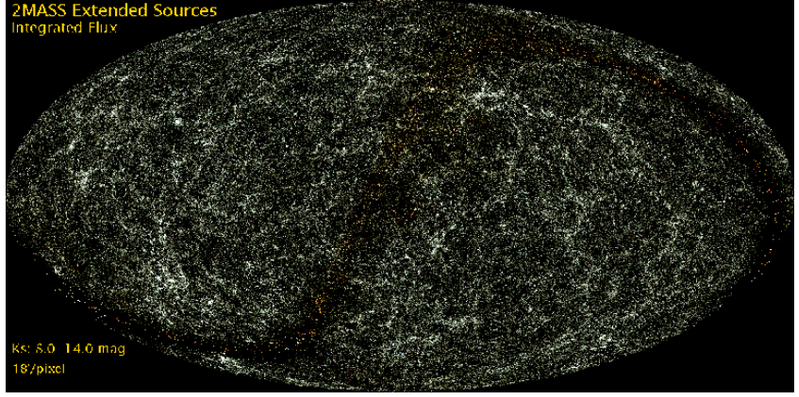

2MASS Extended Sources
Integrated Flux
Ks: 8.0 14.0 mag
18"/pixel



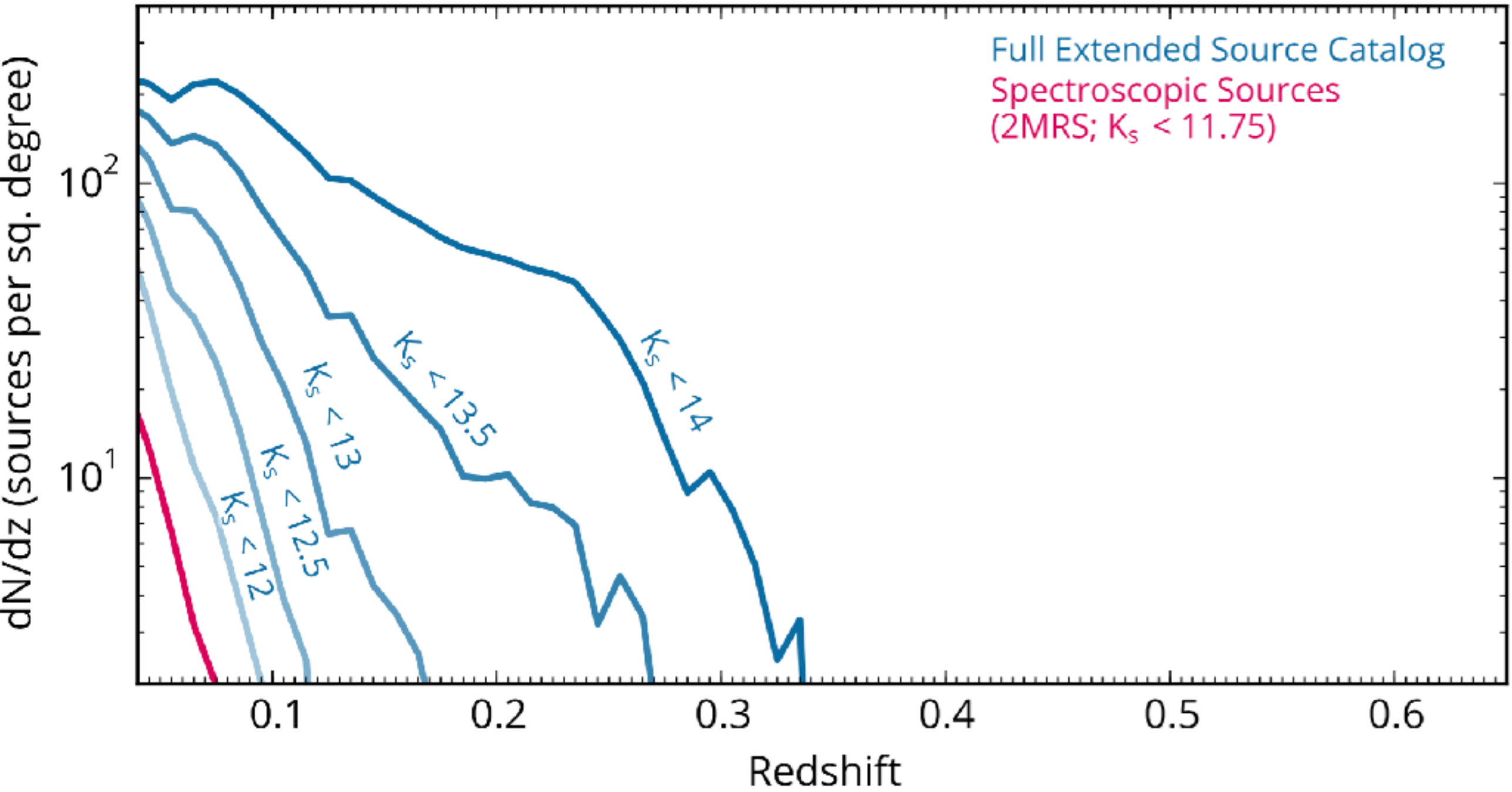
Skrutskie et al. (2006)

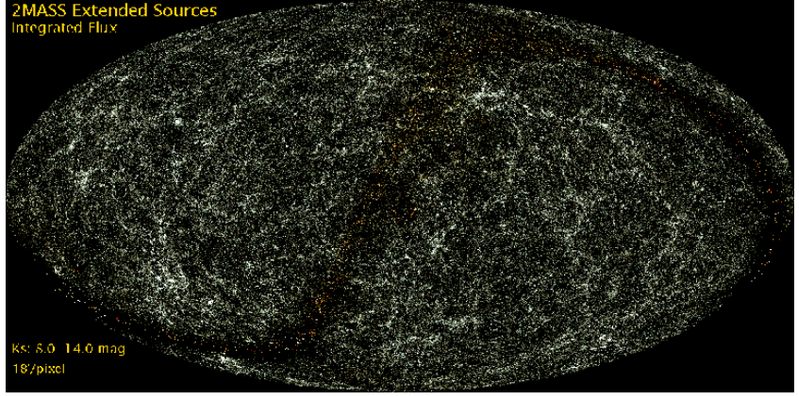
Observations: 1997-2001, J, H & K bands

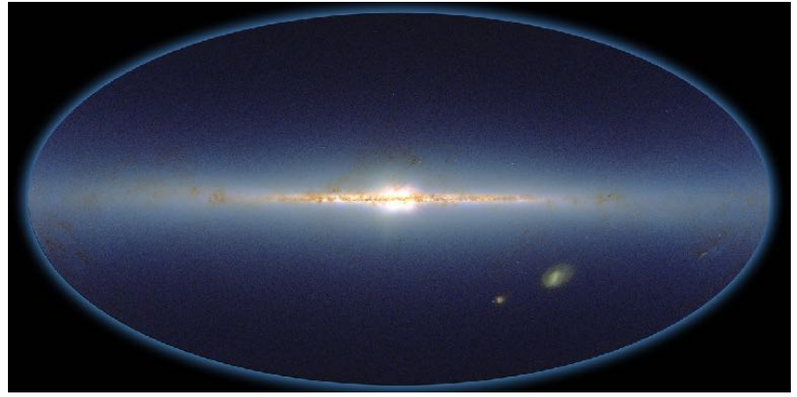




extended sources







extended

point sources

$K_s < 14$

dN/dz (sources per sq. degree)

10^3

10^2

10^1

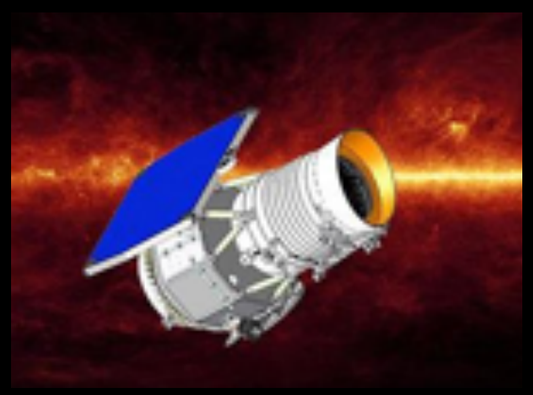
0.1 0.2 0.3 0.4 0.5 0.6

Redshift

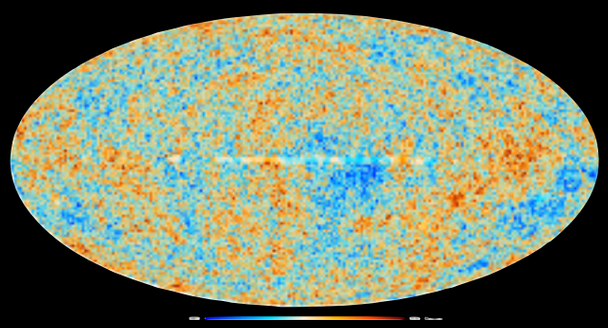
Applications of clustering redshifts

SDSS
optical

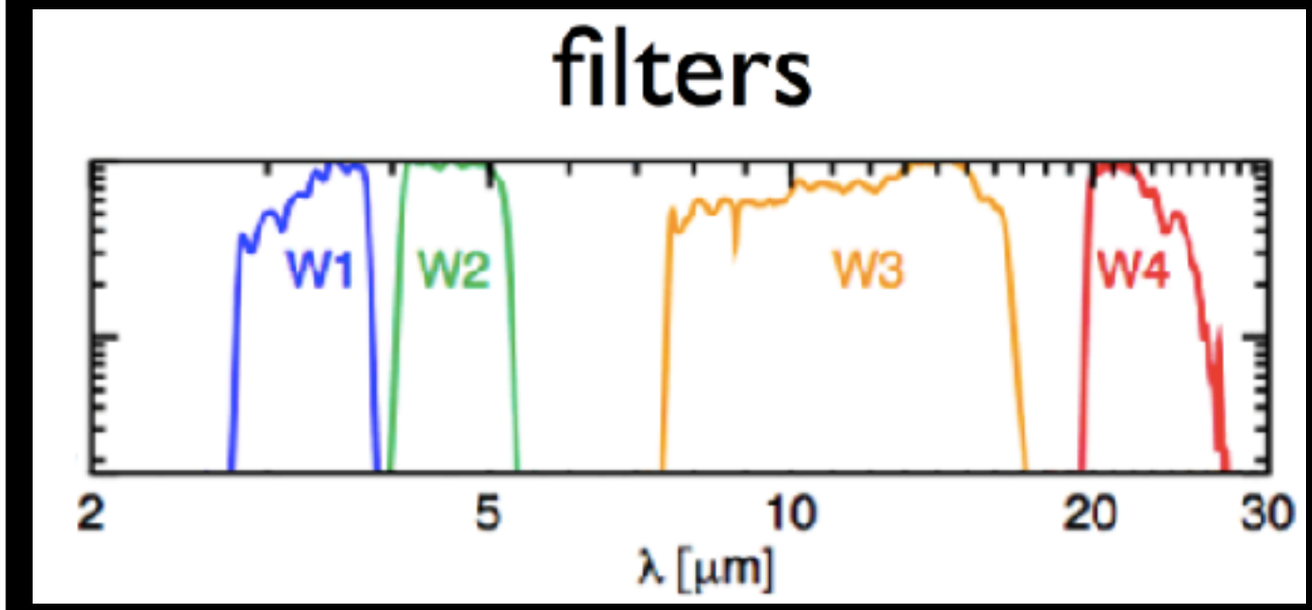
2MASS
near infrared



WISE
infrared



Planck
millimetric

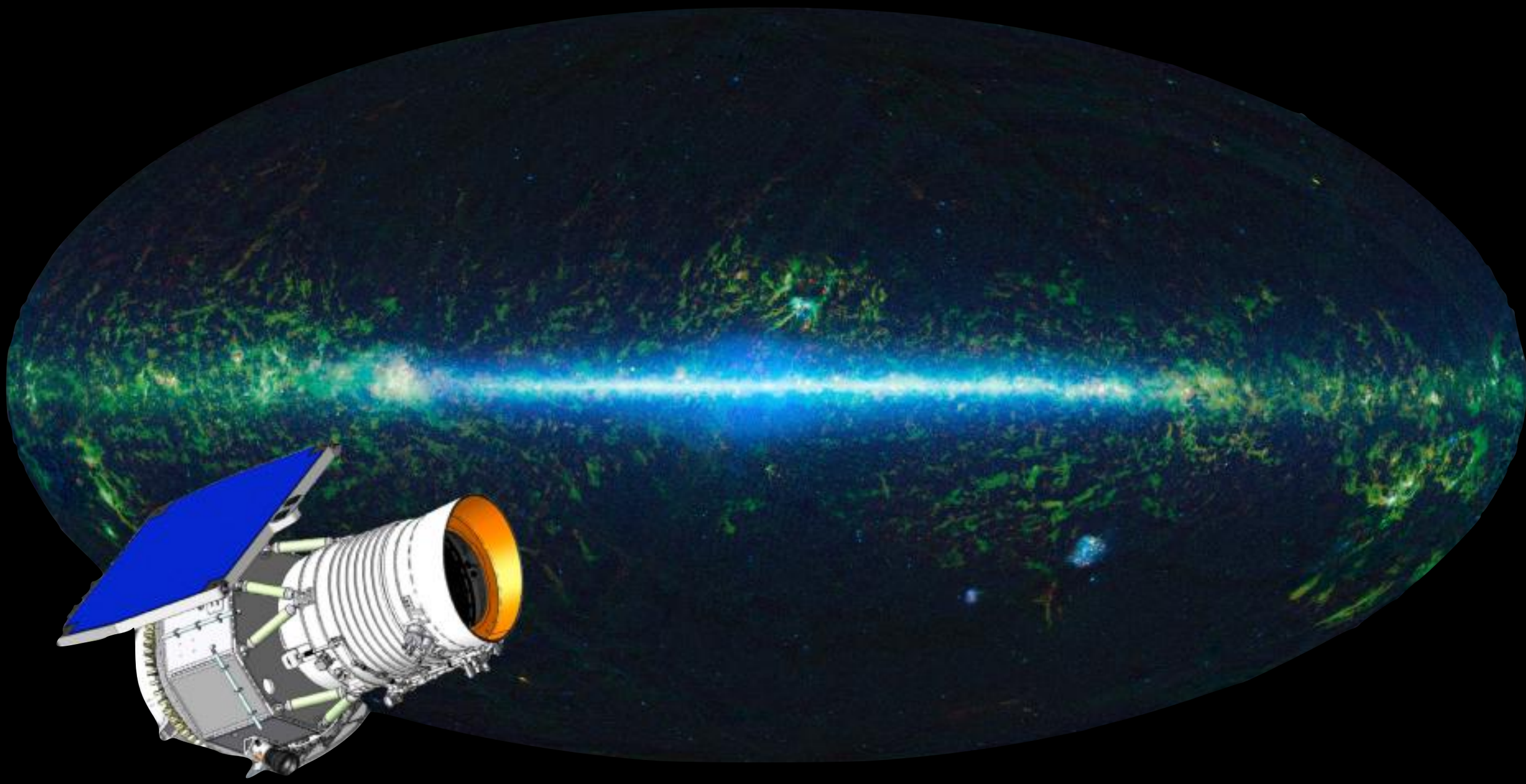


PSF ~ 6 arcsec
mostly point sources

W1(3 μm) < 16 mag

millions of objects

The Wide-field Infrared Survey Explorer (WISE)



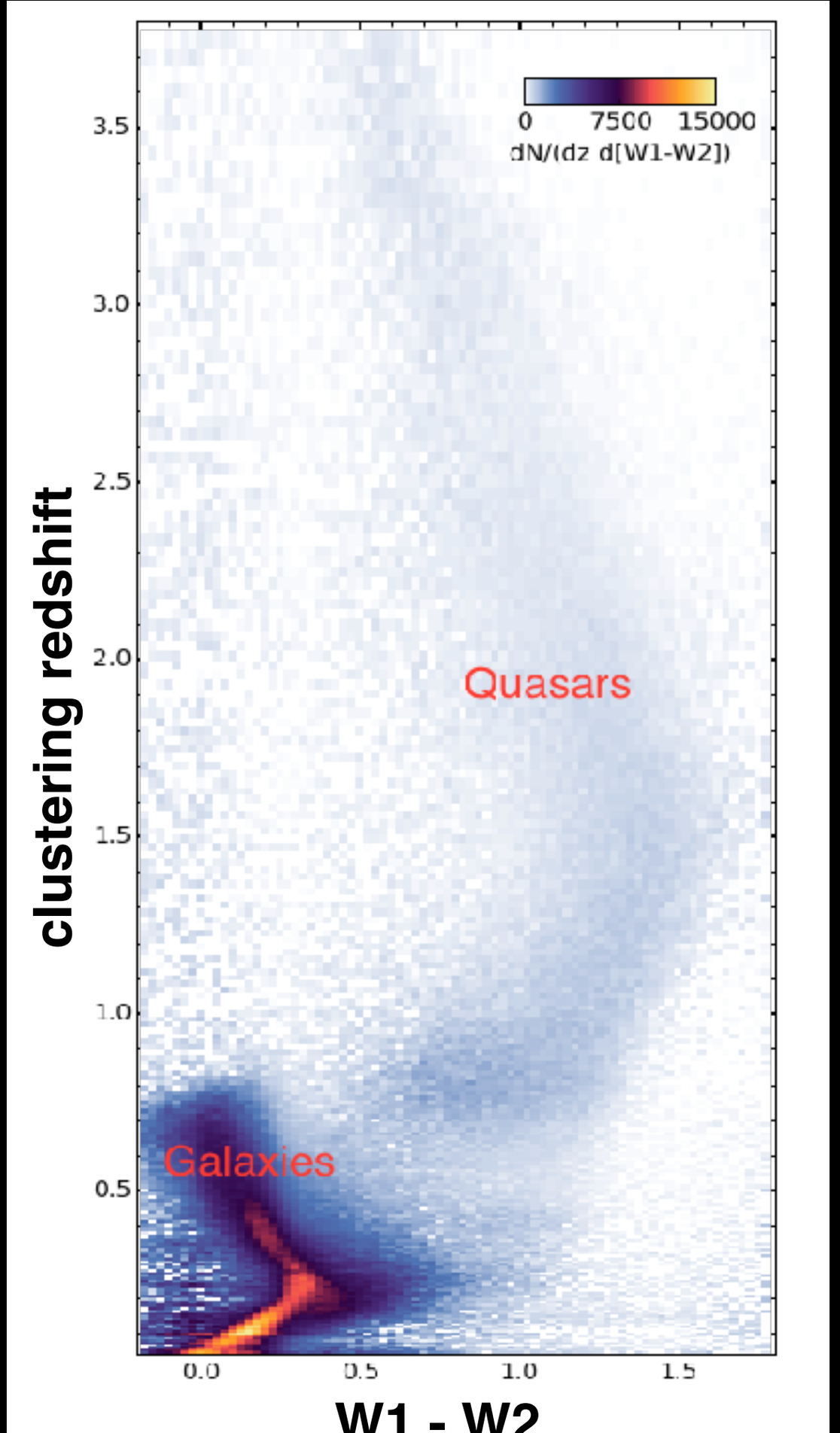
Full sky survey
500,000,000 sources:

- galaxies
- quasars
- stars
- asteroids

Clustering redshifts as a function of color: W1-W2

> preliminary

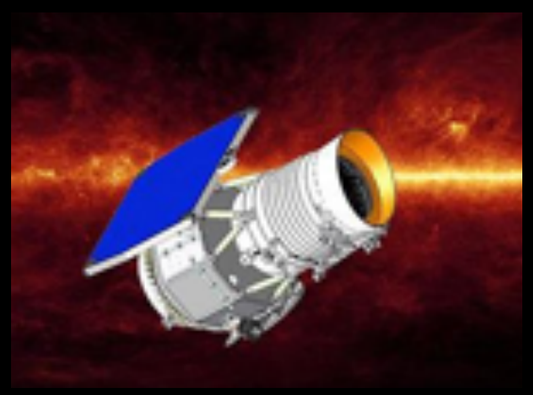
(Alex Mendez, Donghui Jeong)



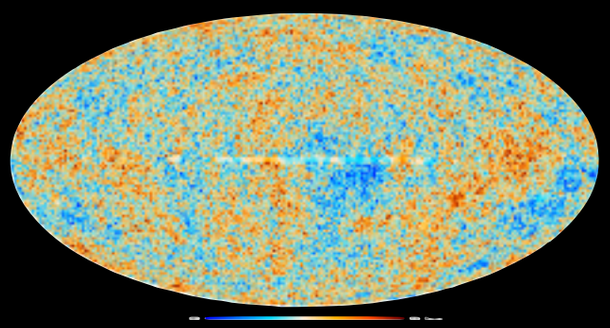
Applications of clustering redshifts

SDSS
optical

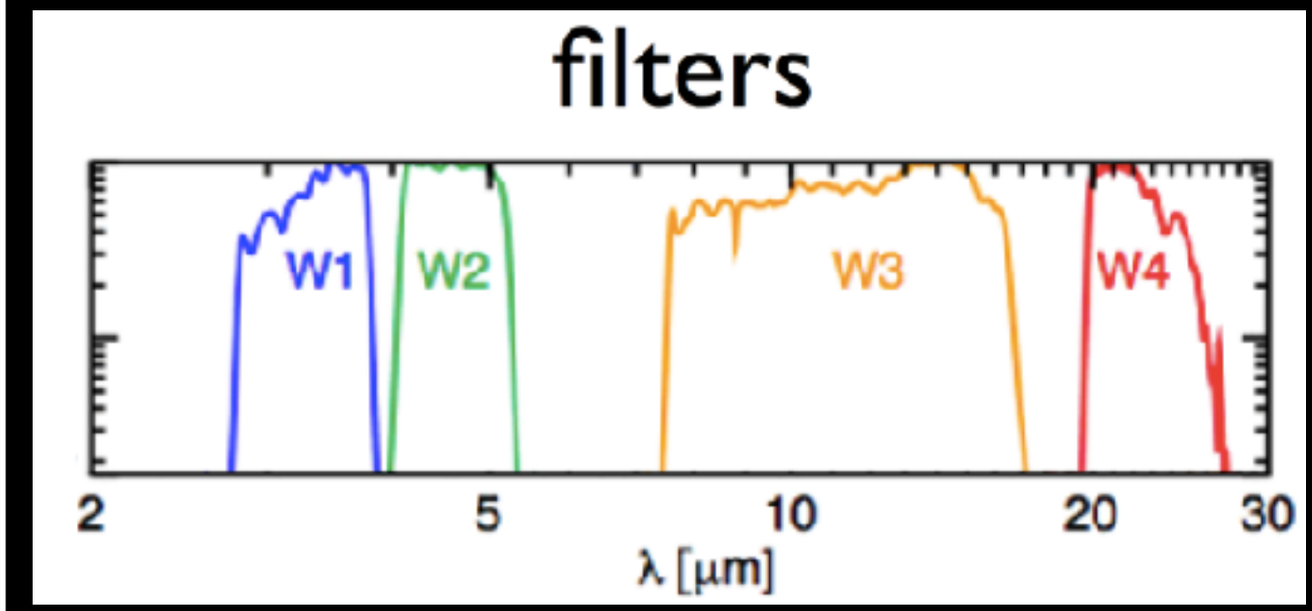
2MASS
near infrared



WISE
infrared



Planck
millimetric

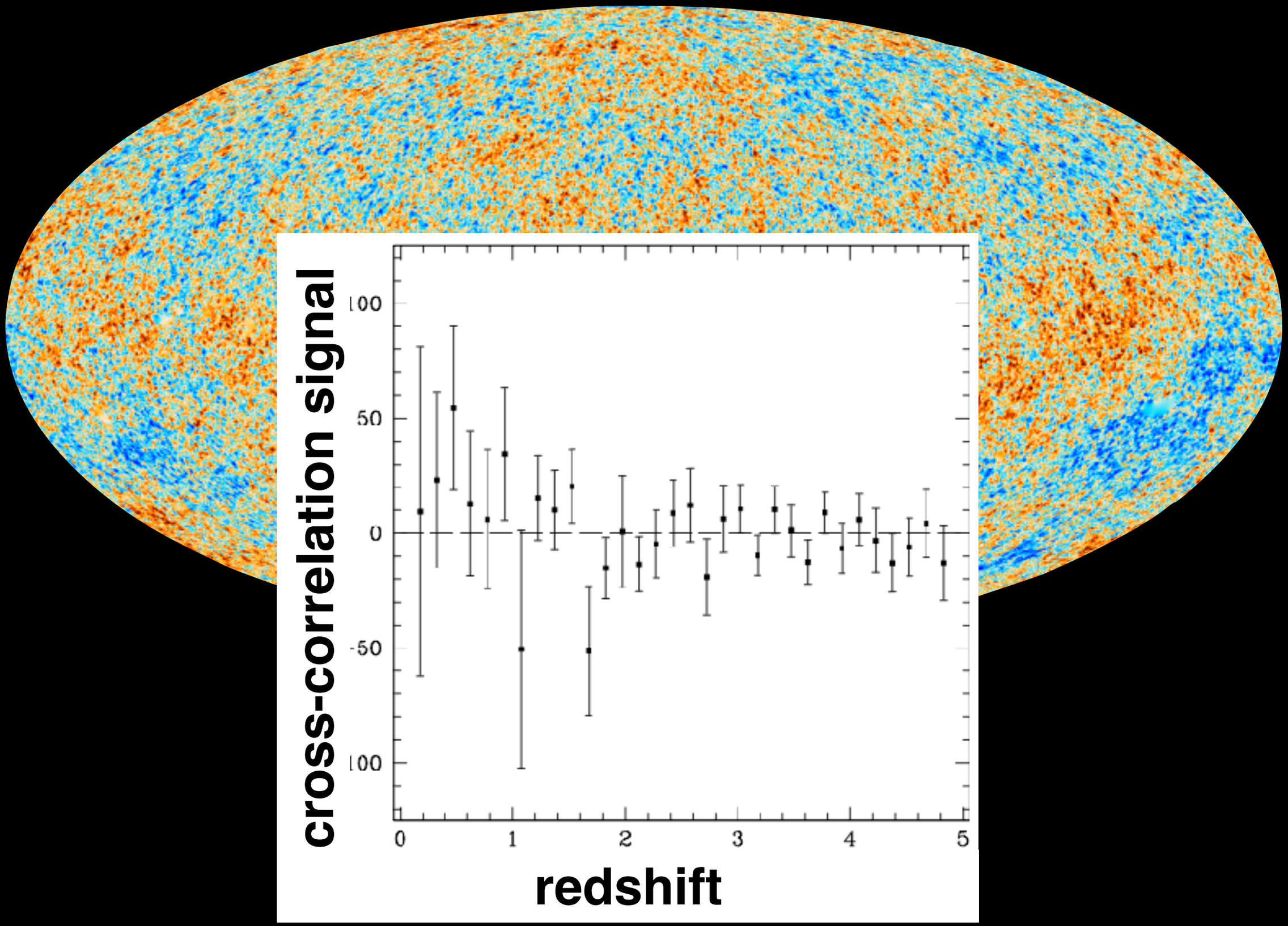


PSF ~ 6 arcsec
mostly point sources

W1(3 μm) < 16 mag

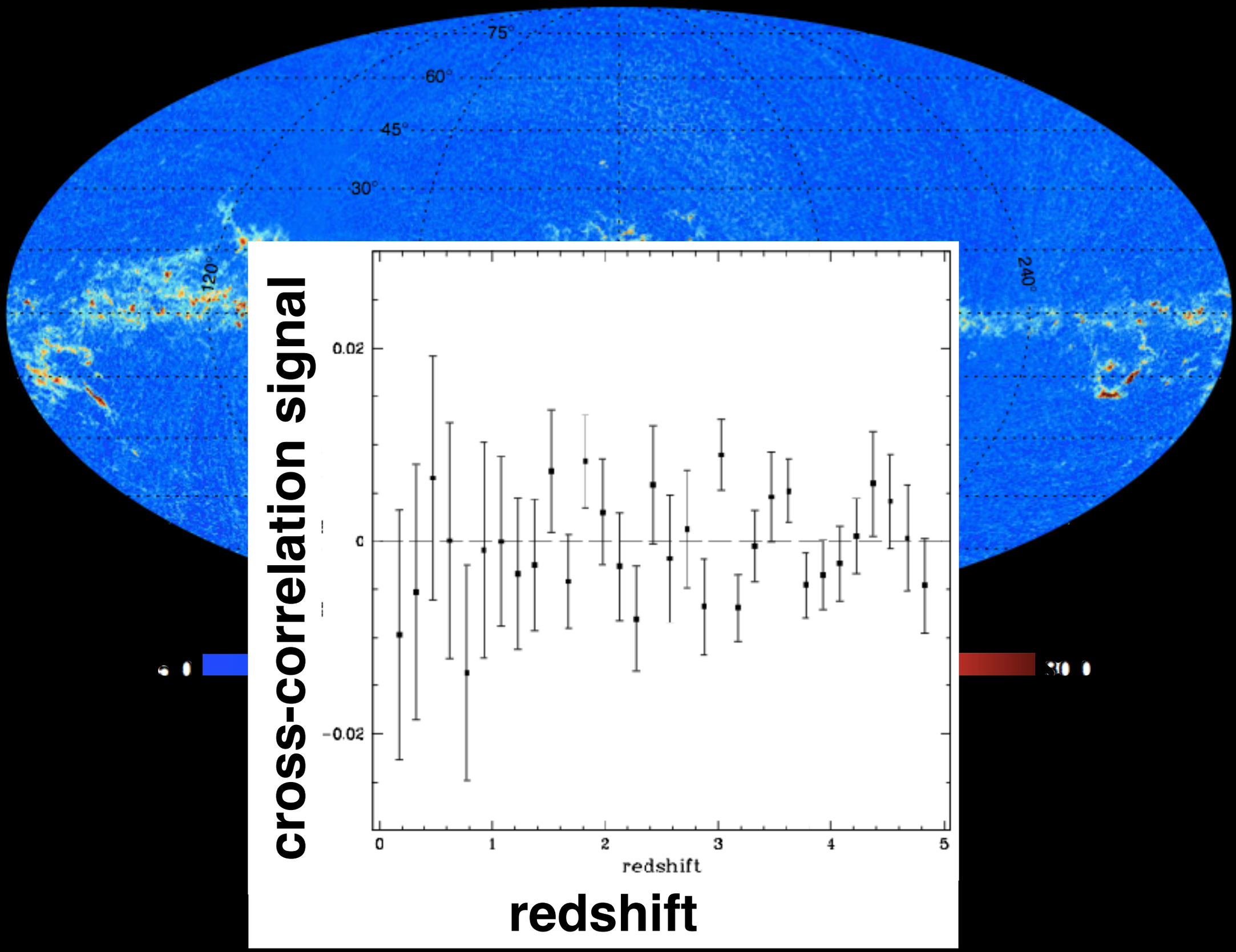
millions of objects

Planck CMB - SMICA map



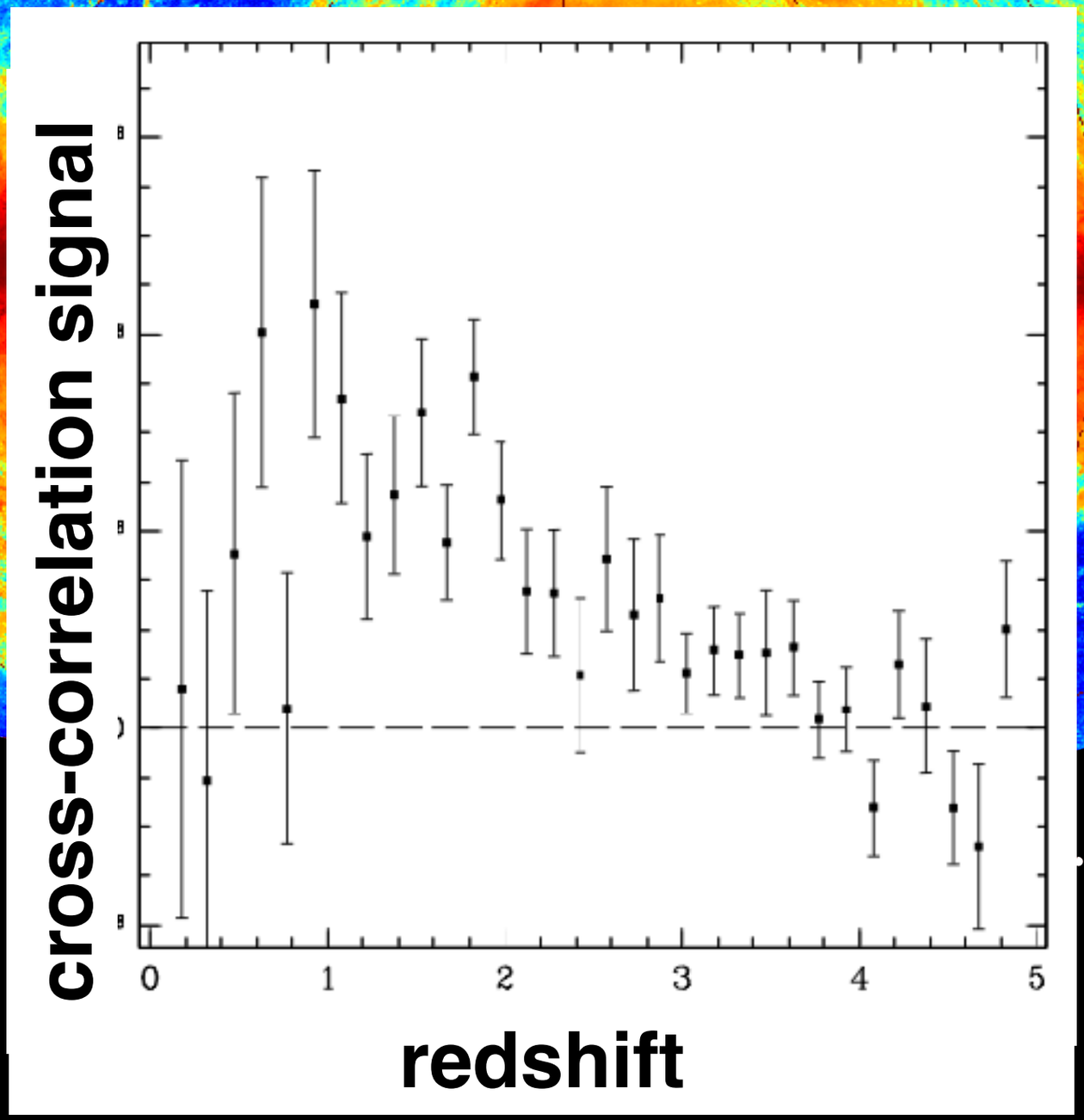
Schmidt, Ménard et al. (2014)

Planck CO map J=0-1



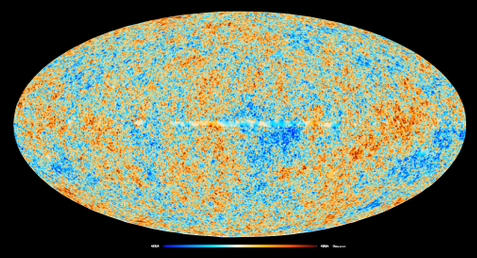
Schmidt, Ménard et al. (2014)

Planck dust opacity map



Schmidt, Ménard et al. (2014)

SDSS
optical



Planck
millimetric

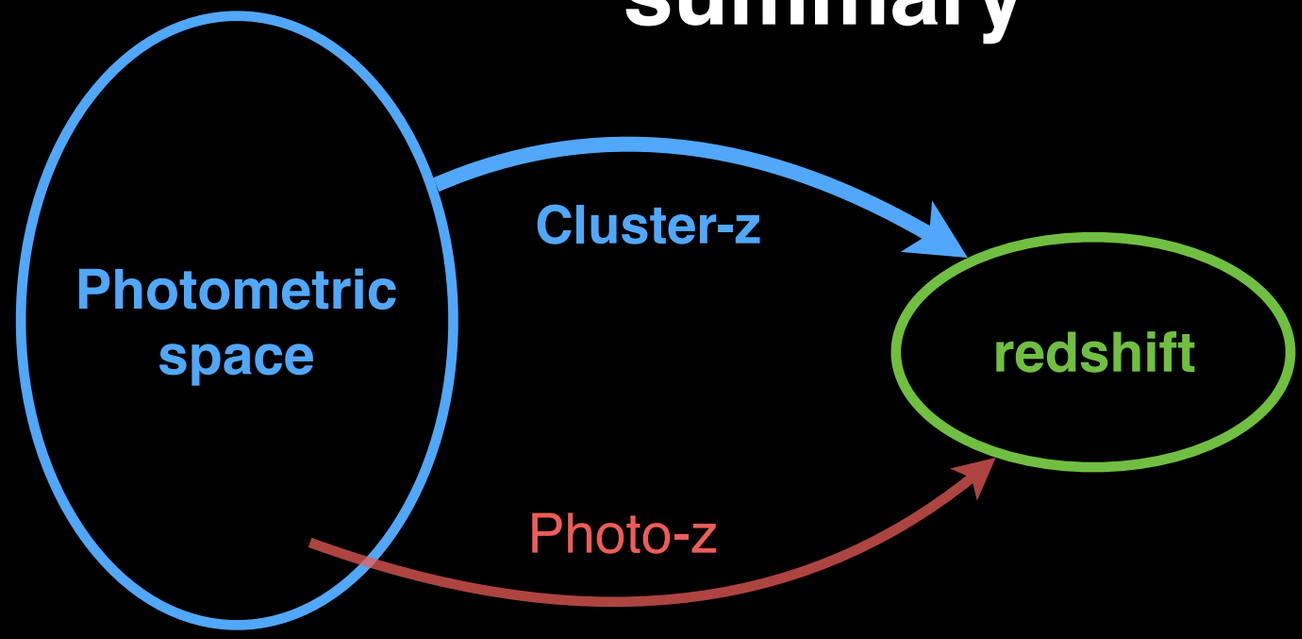
WISE
infrared

2MASS
near infrared

UV (GALEX), radio (FIRST, NVSS, …), Gamma rays (Fermi), …
as well as *combinations* of datasets

Clustering redshifts summary

We have a new tool in hand to estimate the redshifts of photometric sources

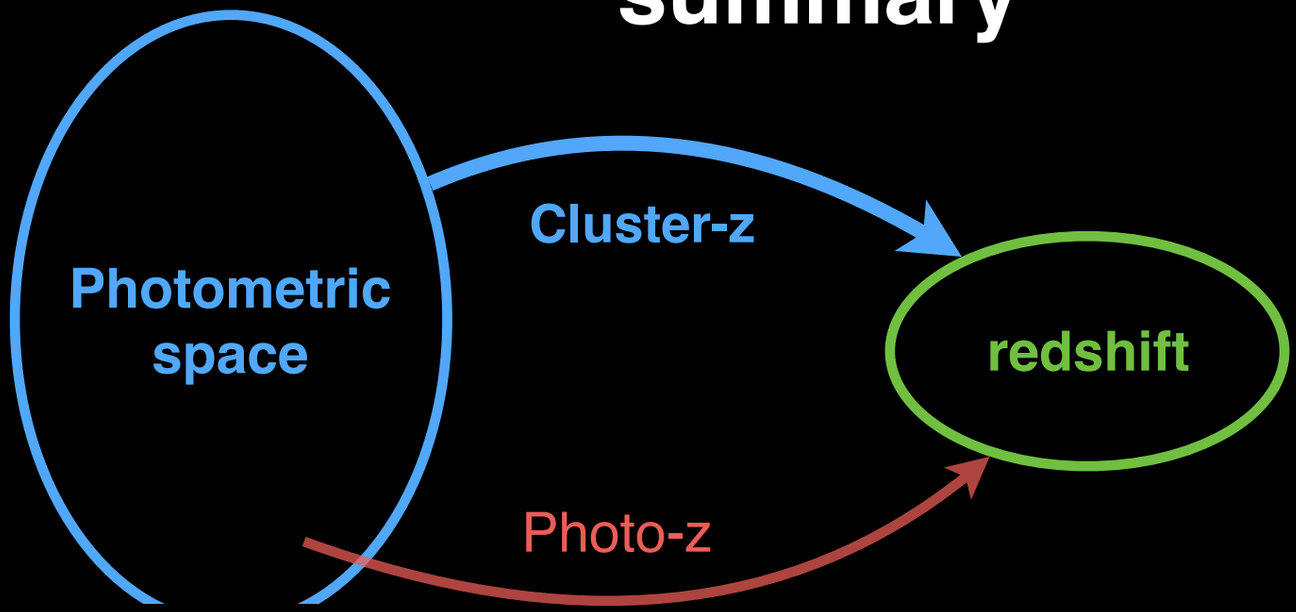


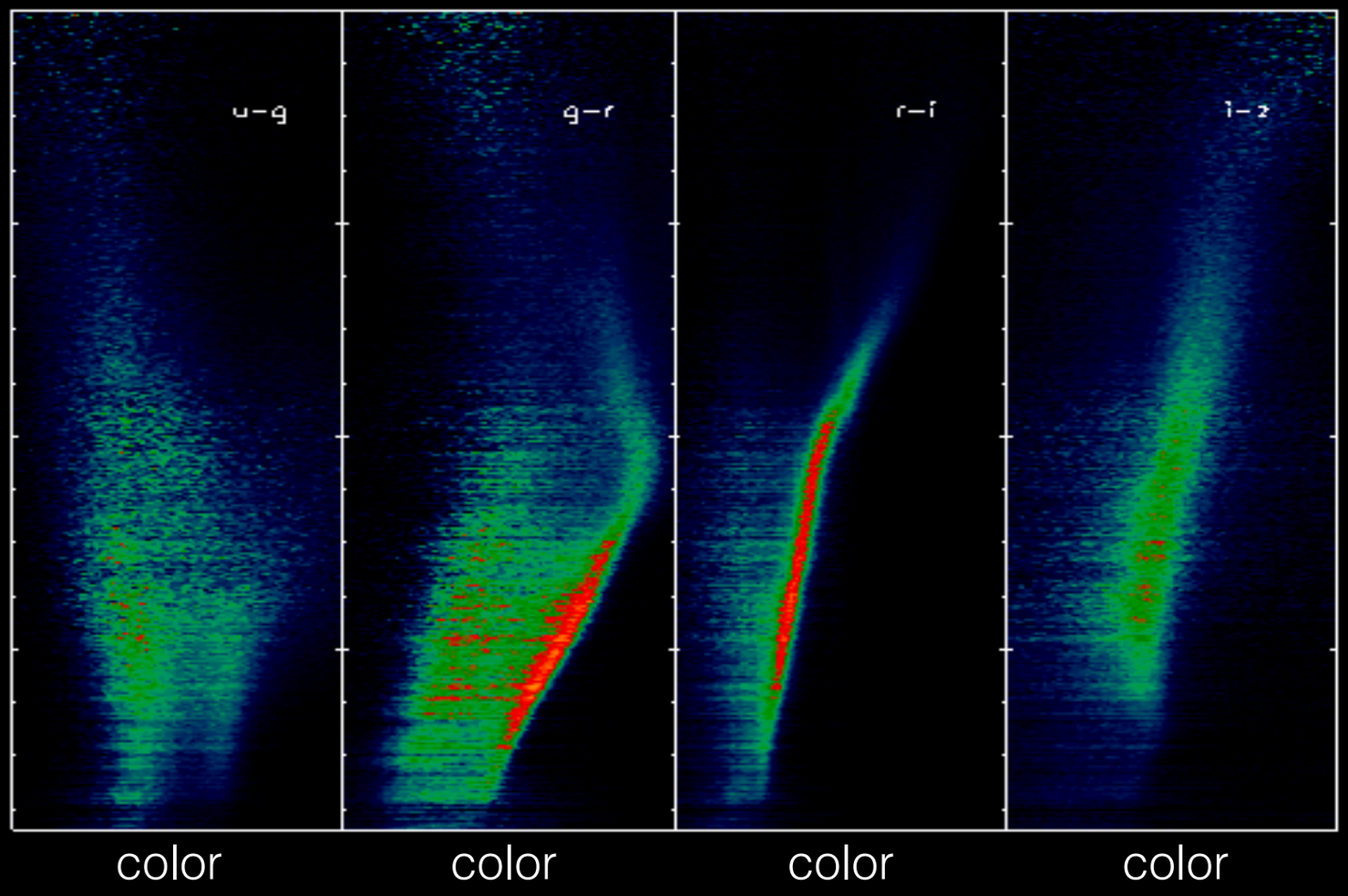
We do not have to rely on source colors to estimate redshifts.

We now have two independent estimation techniques.

Clustering redshifts summary

We have a new tool in hand to estimate the redshifts of photometric sources





We can now “deproject” any photometric dataset, at any wavelength.