CALIFA Survey

The Star Formation History of Galaxies: CALIFA perspective

The Stellar population properties to trace the evolution of galaxies from the blue cloud to the red sequence

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CALIFA team & IAA-GRID team

INSTITUTO de ASTROFISICA de ANDALUCIA CSIC I·A·A

CSIC

CALIFA (The CALAR ALTO Legacy Integral Field Area Survey)

survey of 600 galaxies in the local universe using 250 nights with PPaK@3.5m CAHA

CALIFA Survey

S.F. Sánchez et al. A&A 2012

http://www.caha.es/CALIFA/

~ 80 members / 13 countries

P.I.: S. F. Sánchez (Granada)

P.S.: C. J. Walcher (Potsdam)

Board chair: R. Kennicutt (Cambridge), J.V. Vílchez (Granada)

250 dark nights in 3 years:

PPAK@3.5m CAHA

Full optical wavelength range

FOV: 64″ x 74″ 60% filling factor

bundle: 382 fibers (2.7arcsec), 331 on galaxy

3-fold dithering pattern

~2000 spectra per galaxy

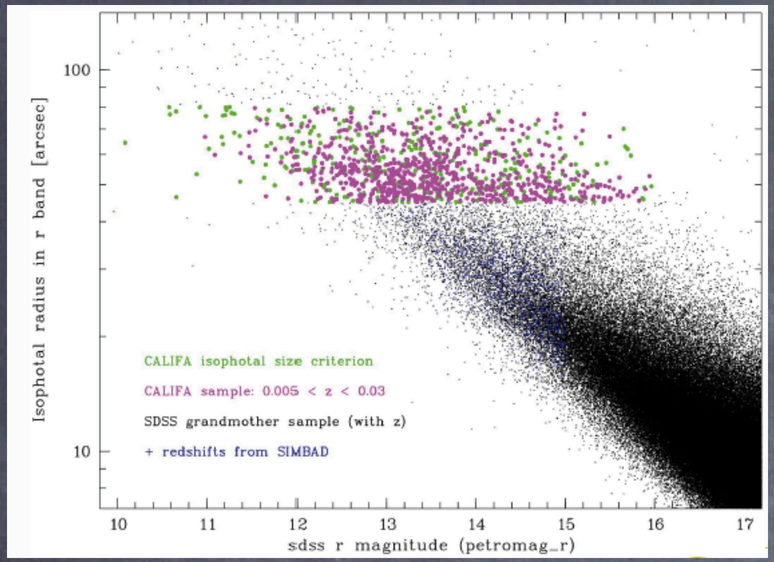
Sample:

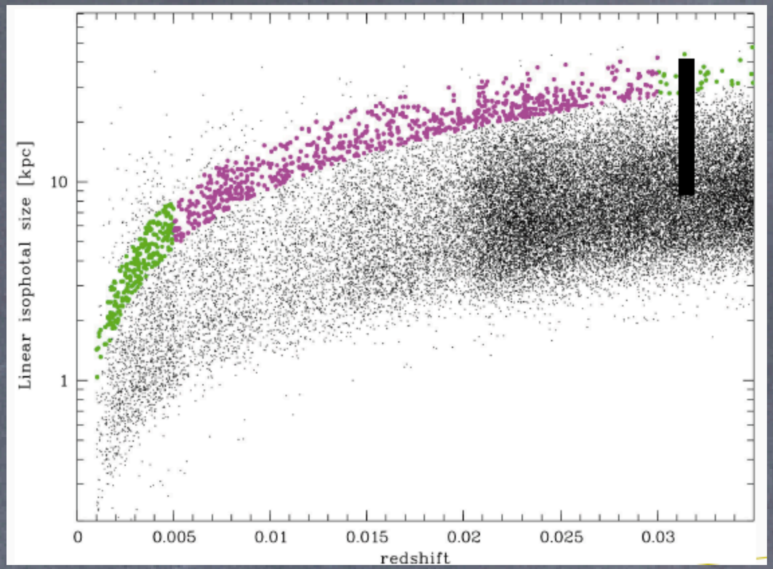
- 600 galaxies 0.005 < redshift < 0.03
- ~20 galaxies per 1x1 mag bin in the CMD
- + diameter selection …

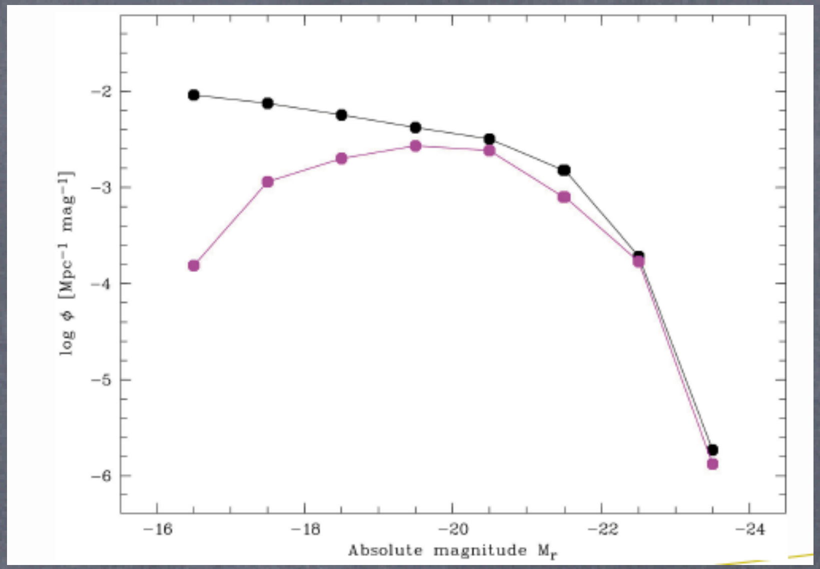
The Sample: diameter selected mother sample (937 galaxies)

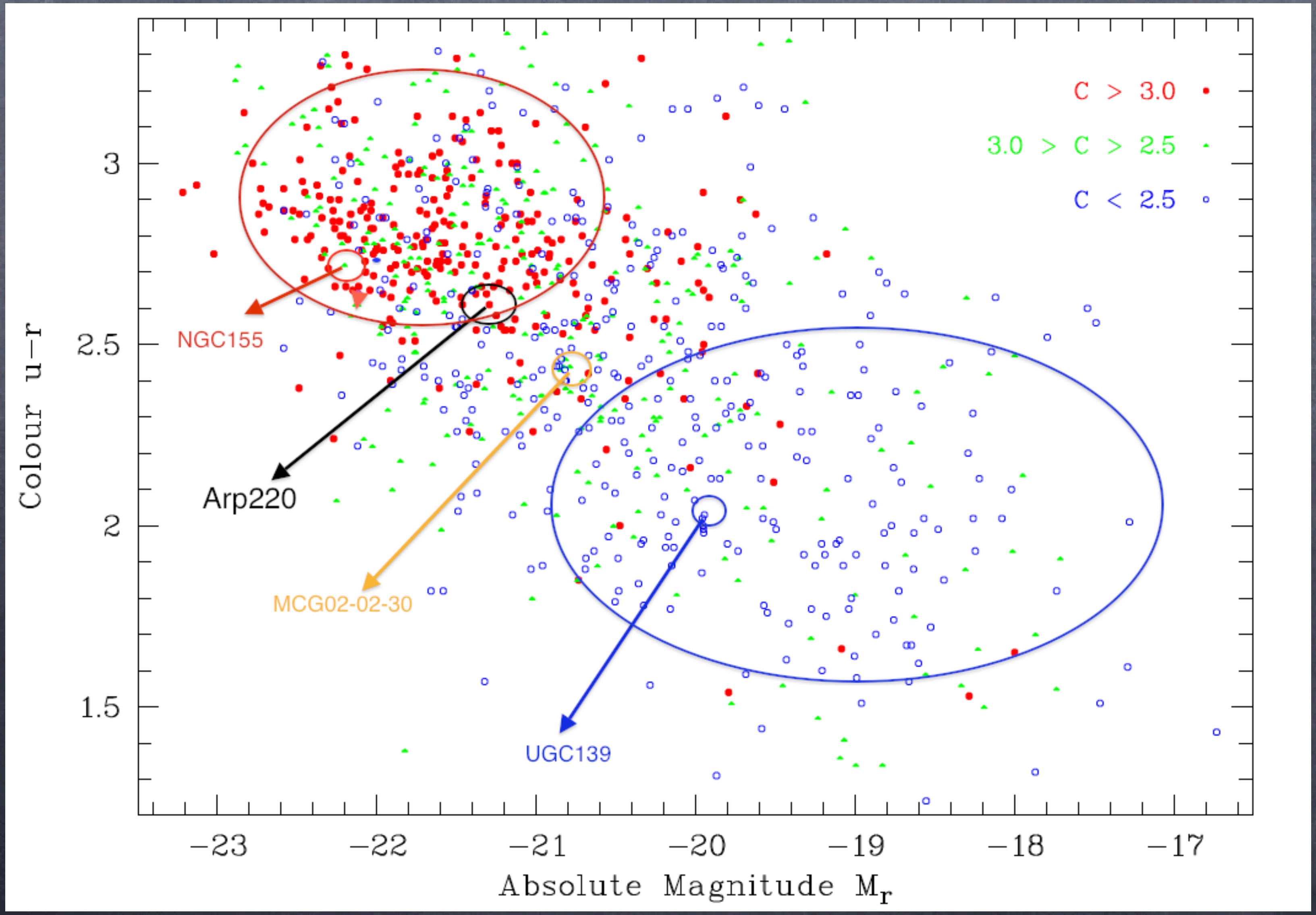
Isophotal radius at 25 mag/arcsec2 : 45-80 arcsec

Volume-corrected LF: close to SDSS for Mr>-19





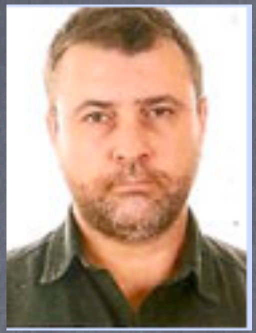




PopStar: Tracing the evolution from the blue cloud to the red sequence

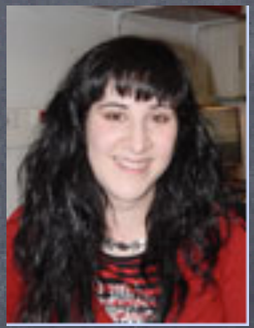
CALIFA IAA
Stellar
Population group

CALIFA team
and
IAA-GRID team


Enrique Pérez   Roberto Cid Fernandes   Rosa González Delgado





Ruben García-Benito   Rafael López   Clara Cortijo-Ferrero

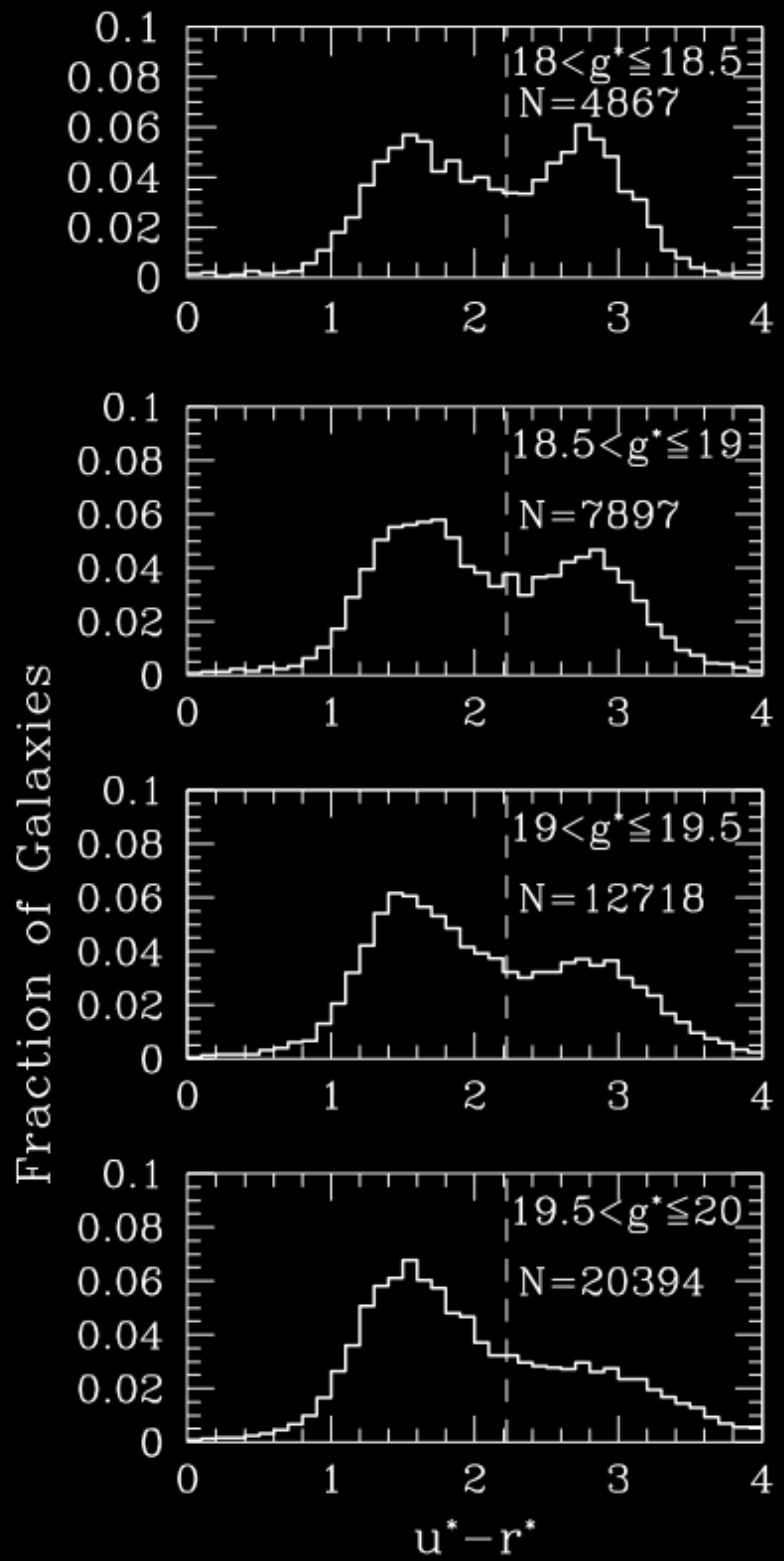

Bernd Husemann

Sebastián F. Sánchez   Damián Mast

Strateva 2001 Astron.J.

SDSS

1D spectra
3″ fiber

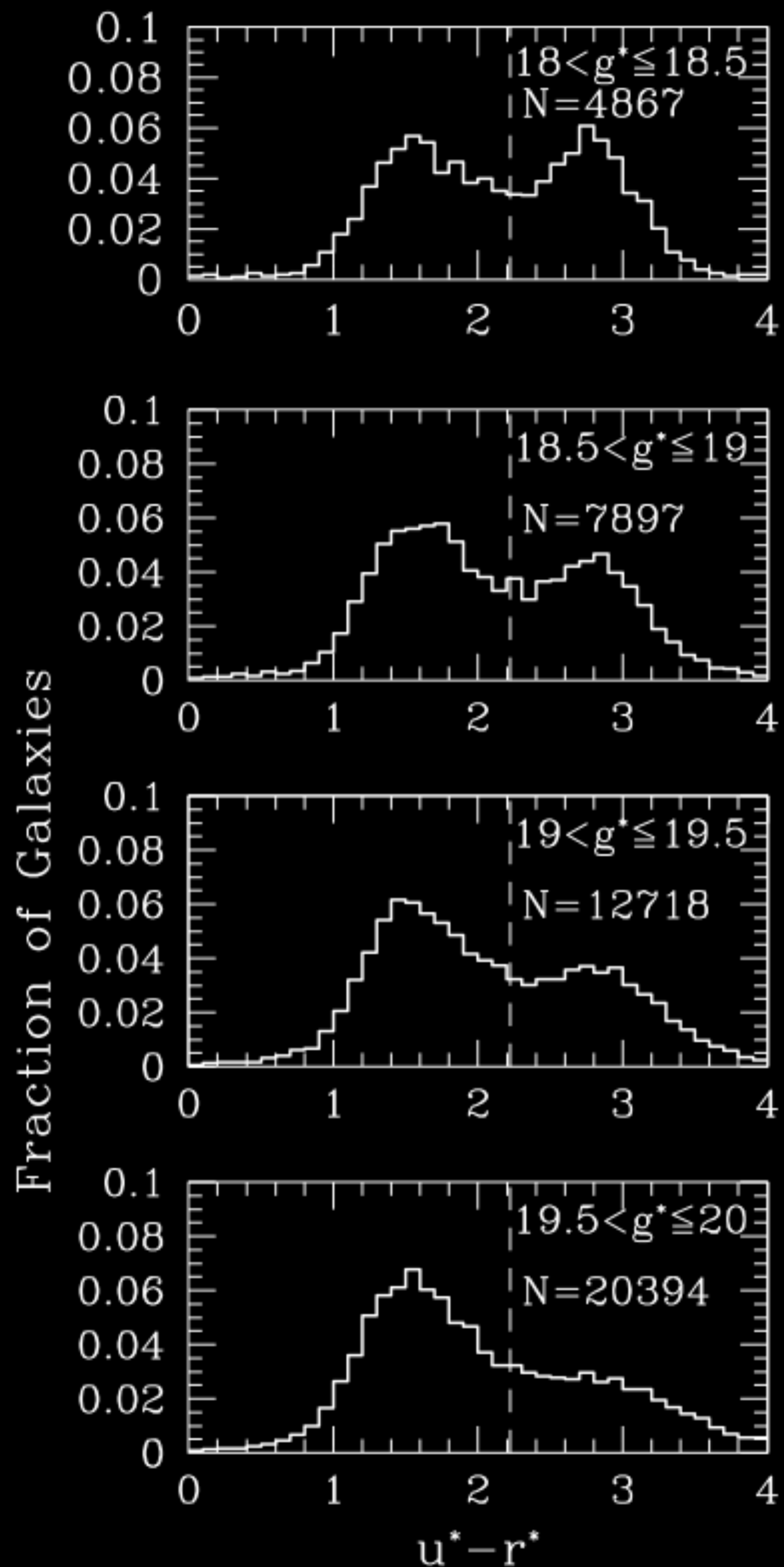


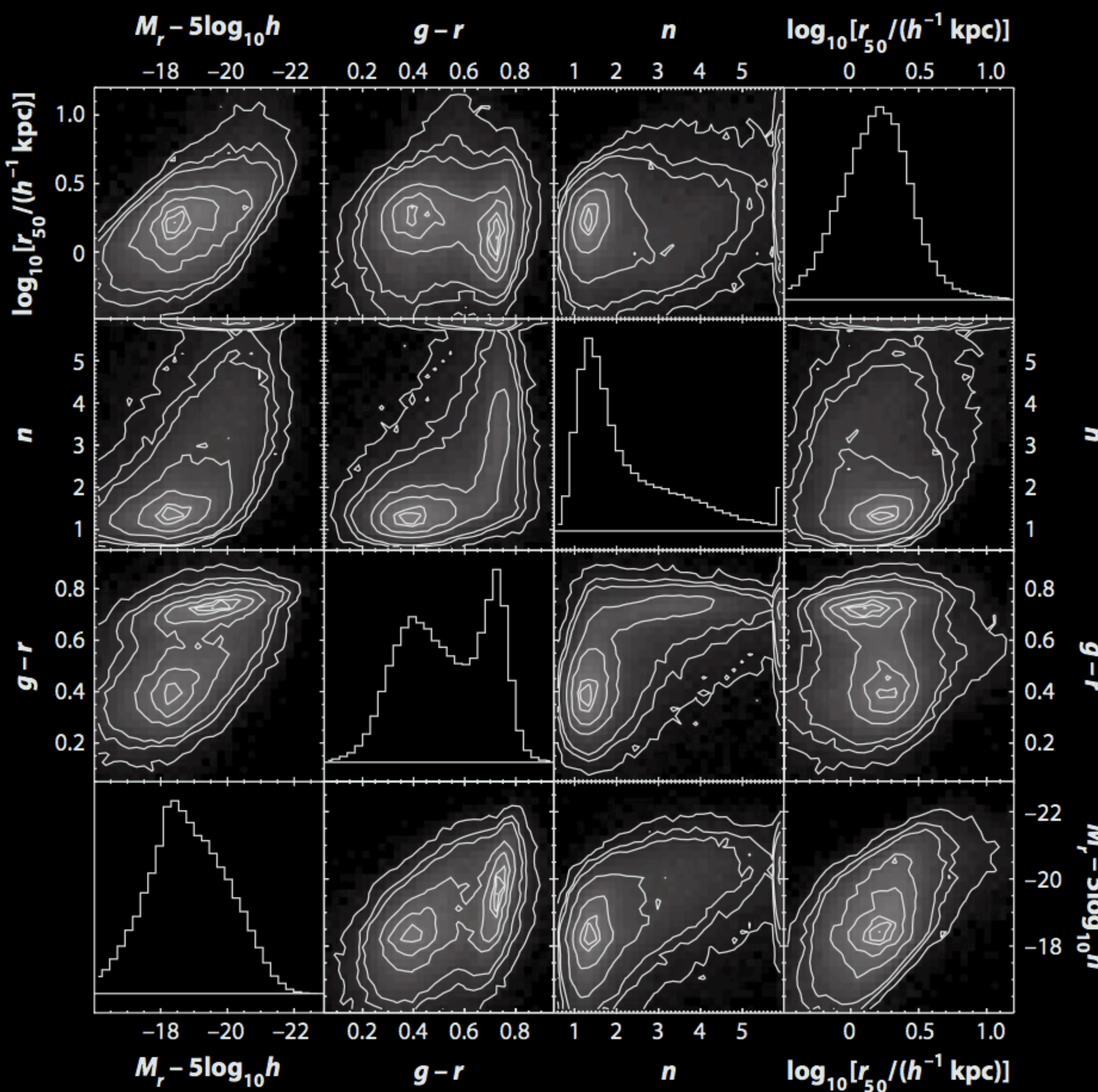
Strateva 2001 Astron.J.

SDSS

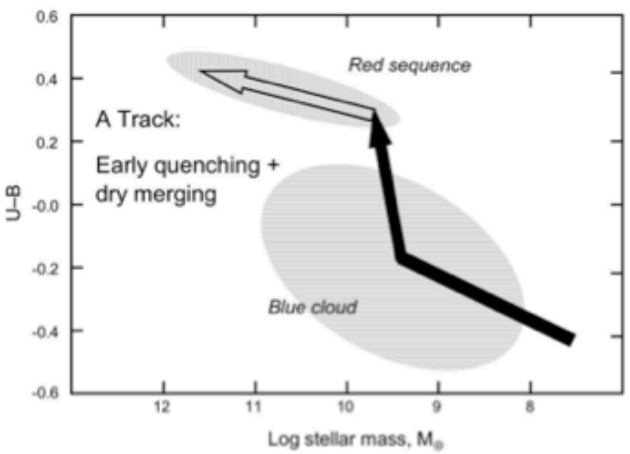
Blanton 2007 A.R.A.A.

1D spectra
3″ fiber

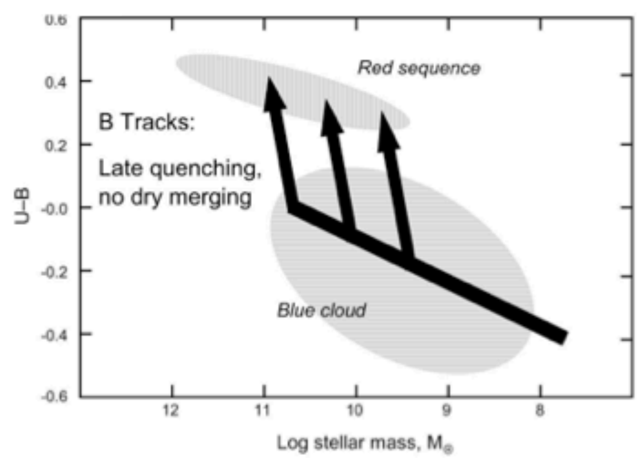


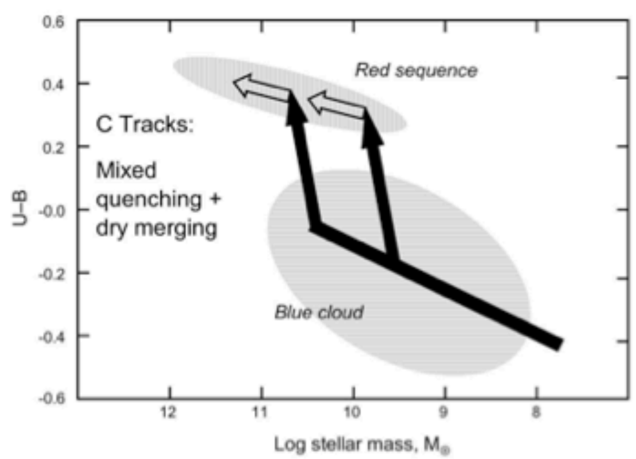


PopStar: Tracing the evolution from the blue cloud to the red sequence



Different scenarios will leave distinct inprints in the stellar populations and metallicity



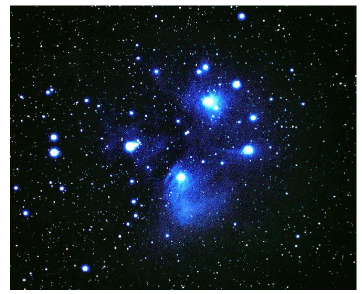
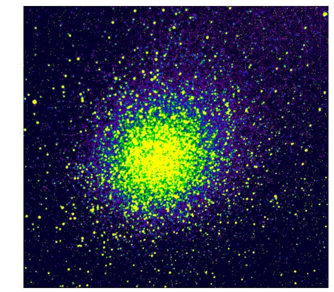


S. Faber et al, 2007, ApJ 665, 265

<u>Fossil method</u>

Recovers the SF <u>History</u> of a galaxy from its spectrum

= "spectral synthesis"

 $= M_1$  $+ M_2$  $+ M_3$  $+ \ldots$

$$L_{gal}(\lambda) = \sum_{t,Z} M_{SSP}(t,Z) \times SSP(\lambda\,;\,t,Z)$$

☺ Observables

Full spectrum or indices

(F_λ, B-V, Mg_2 ...)

Star Formation History + Chemical Evolution (inversion methods)

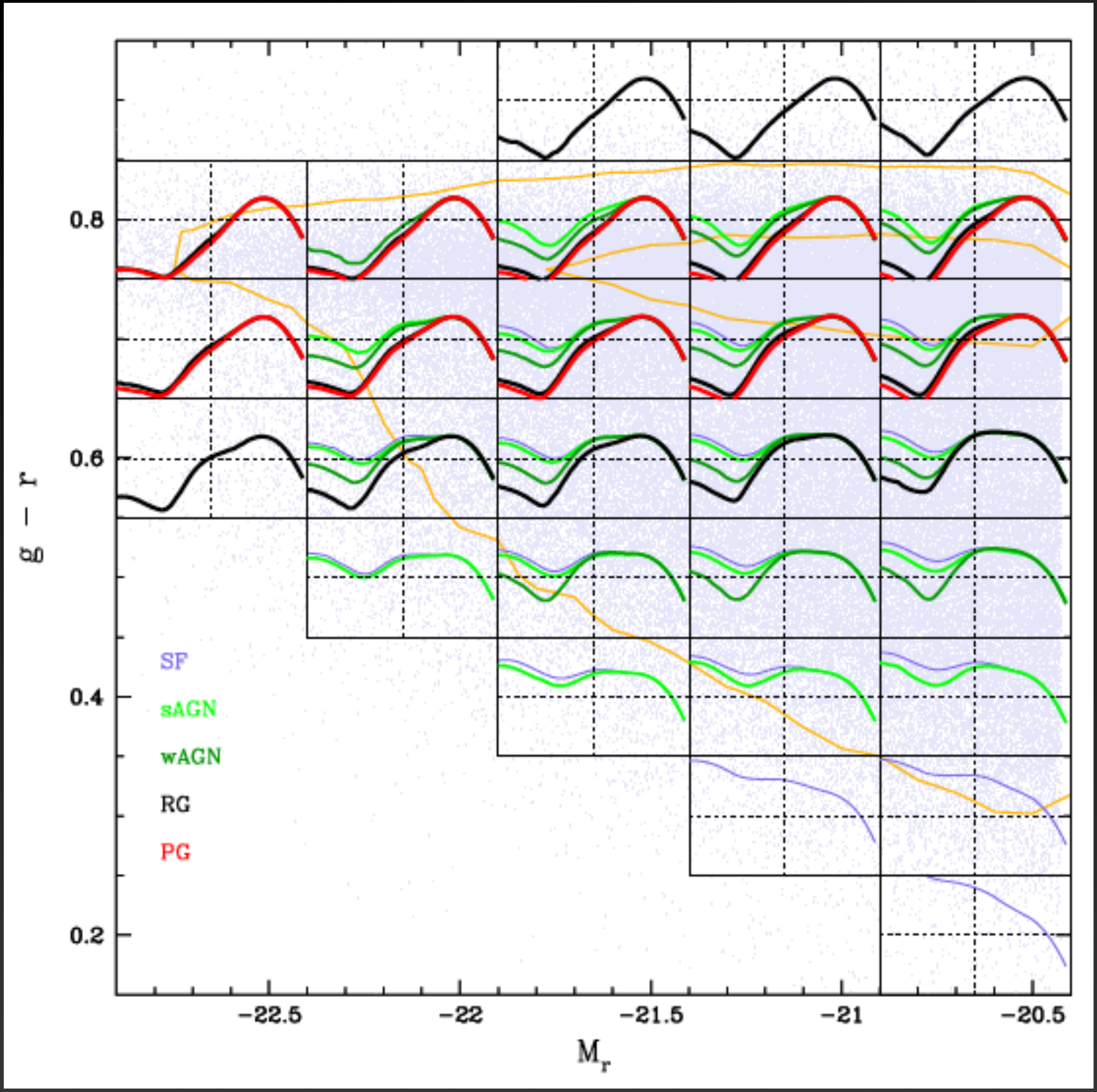
☺ Spectral Base

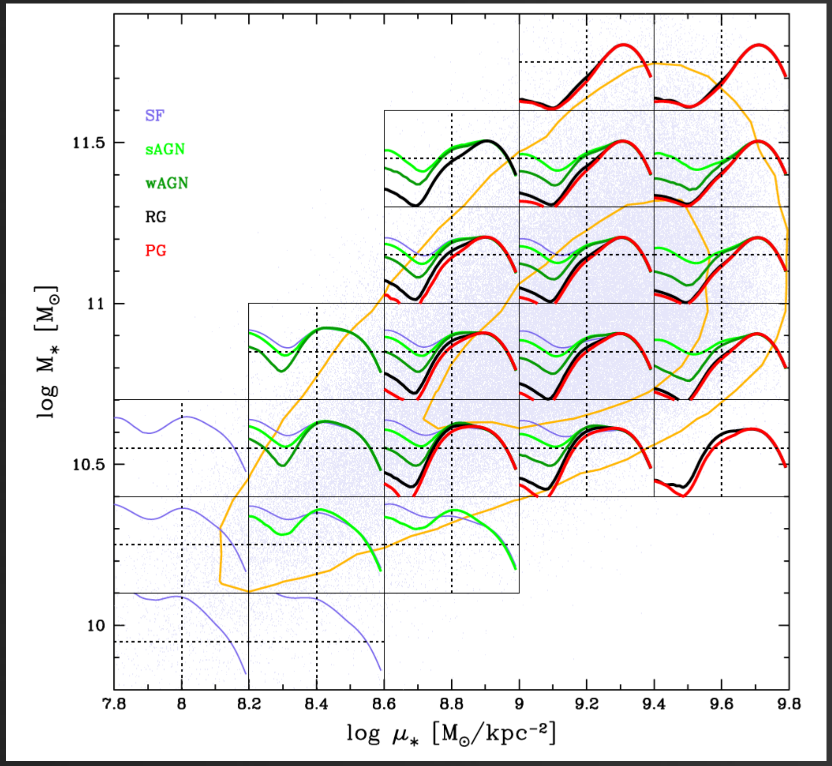
Model or Observed SSPs / star-clusters

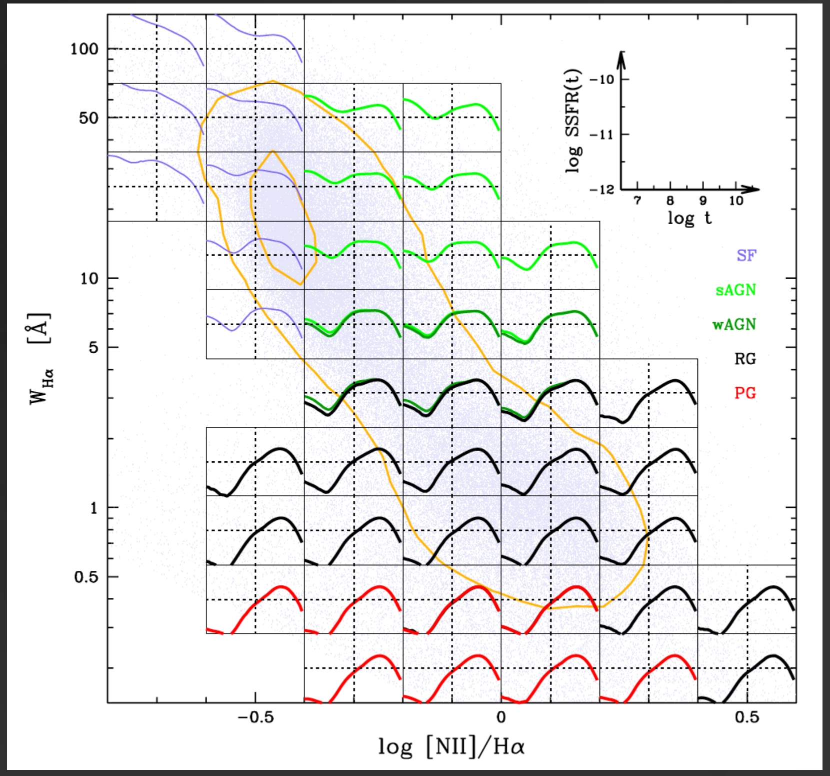
(BC03, SED@,...)

SFHs in the CMD, and etc

CF et al 11







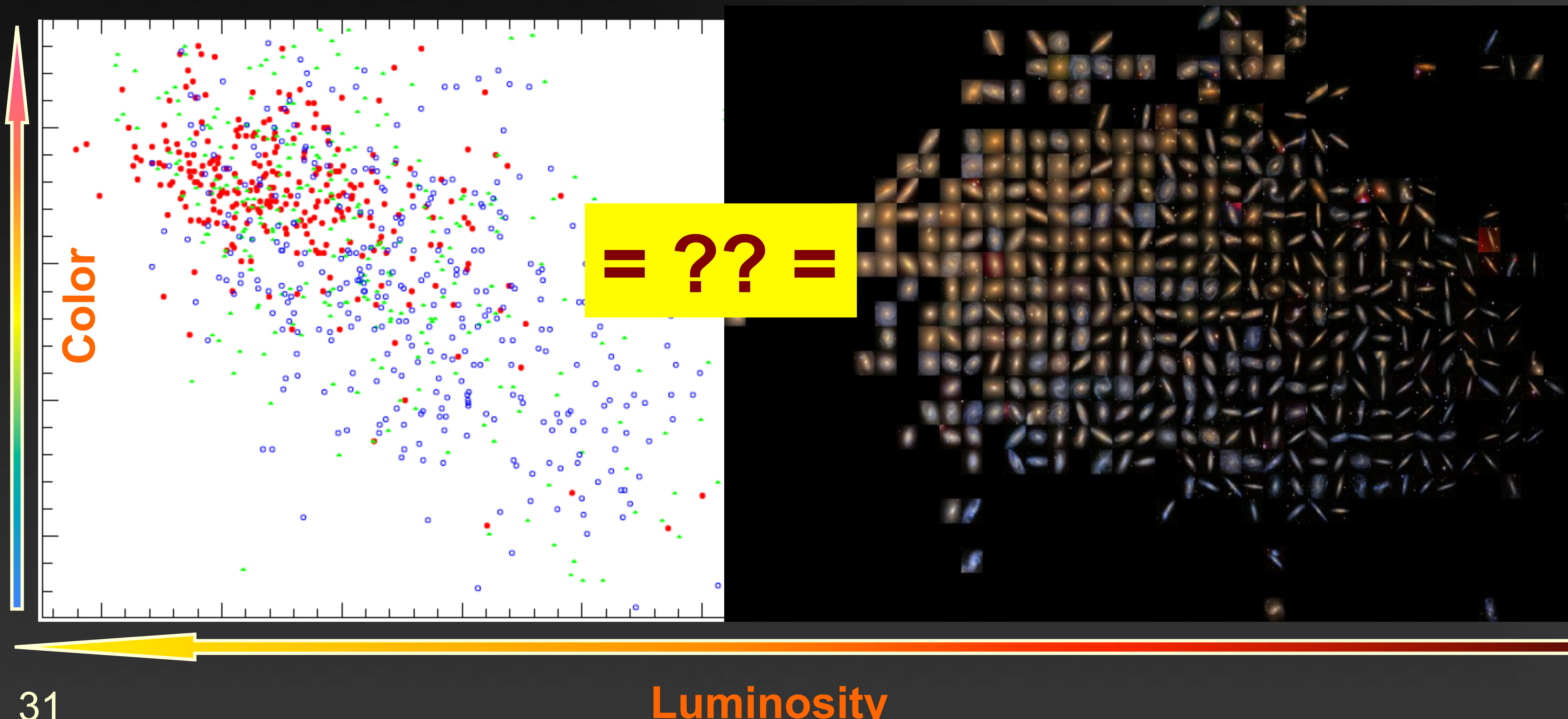
etc …

Great, but this is all **1D**! (integrated spectra)

Do size / shape / looks matter?

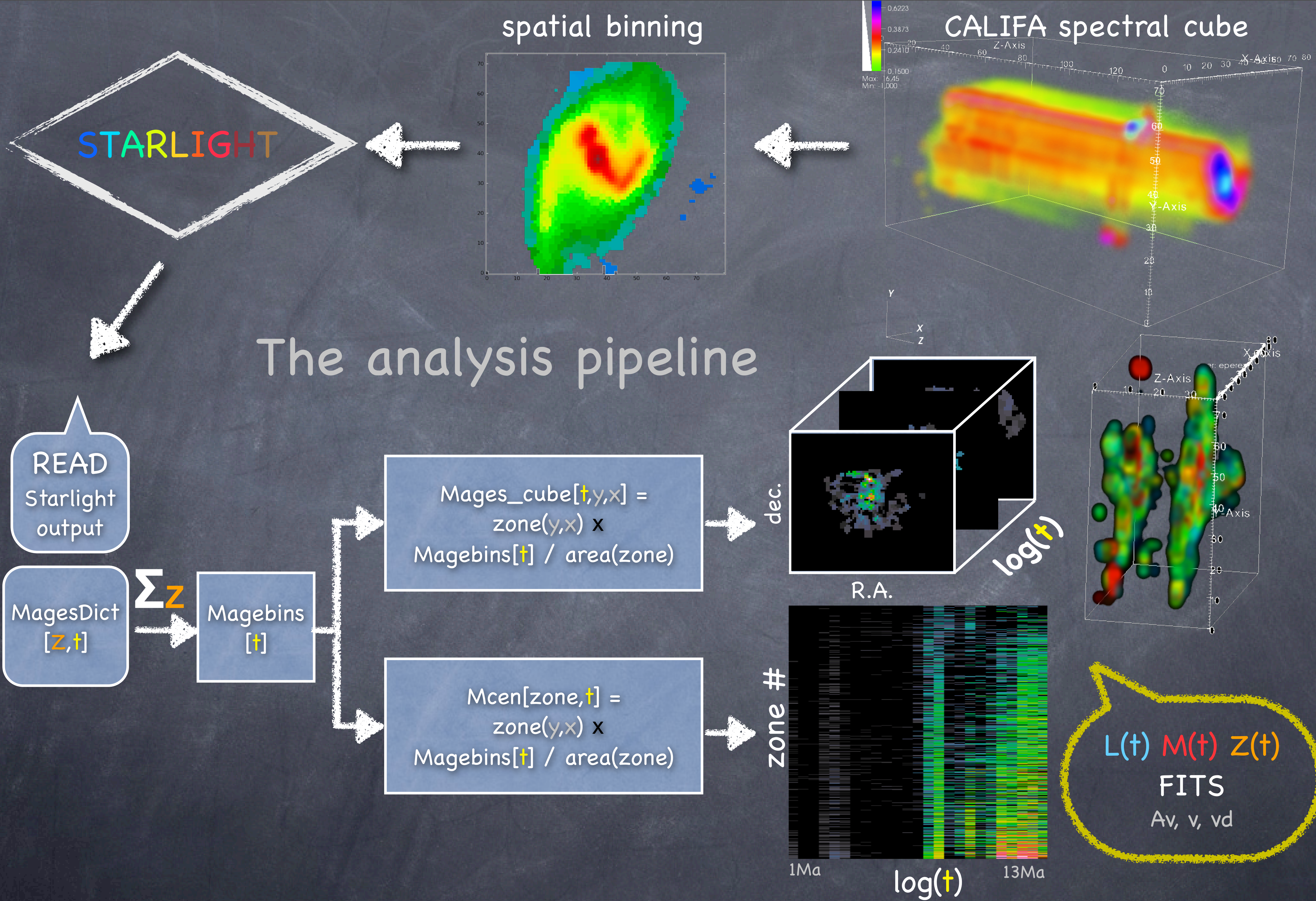
Can galaxies be treated as point sources?

What can we learn from F(λ,x,y)?



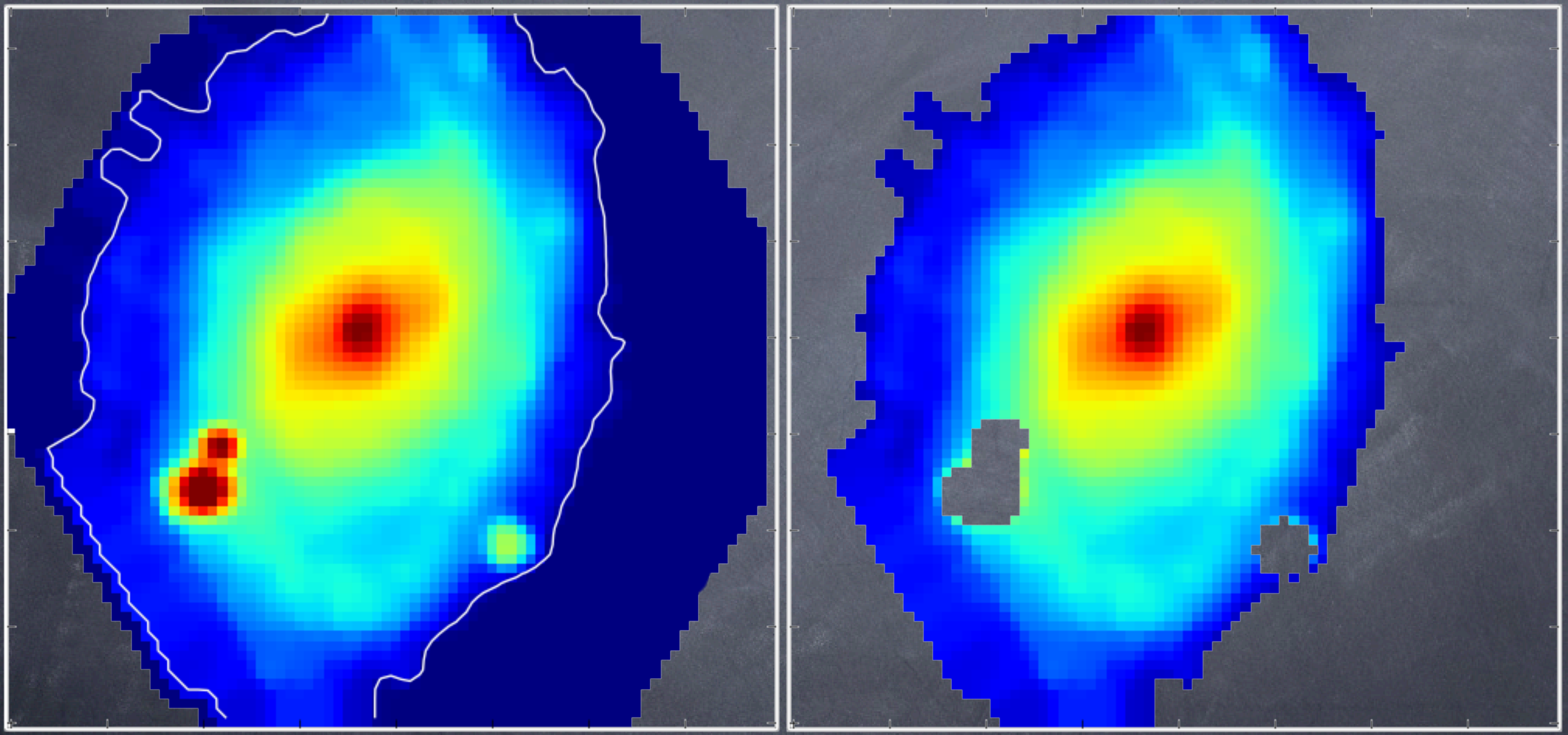
The Method of Analysis

The analysis pipeline



The Method of Analysis
Pre-processing
Masks and Spatial binning

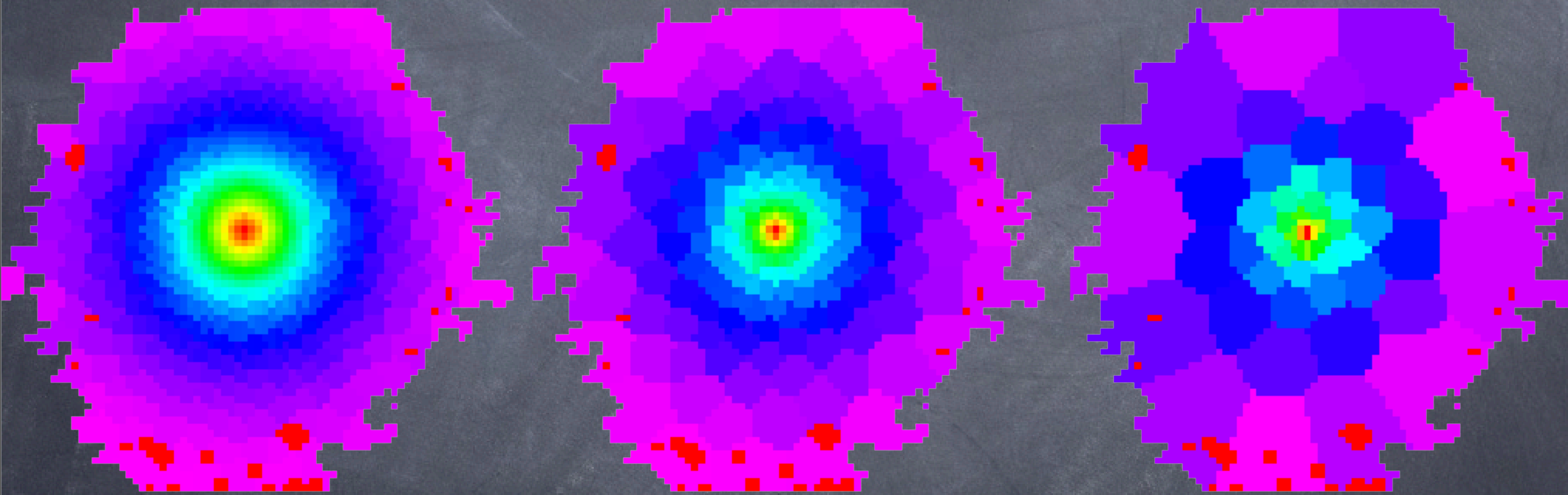
spatial masks



Nadine Backsmann & Rubén García Benito

Spatial Binning

20 | 40 | 60

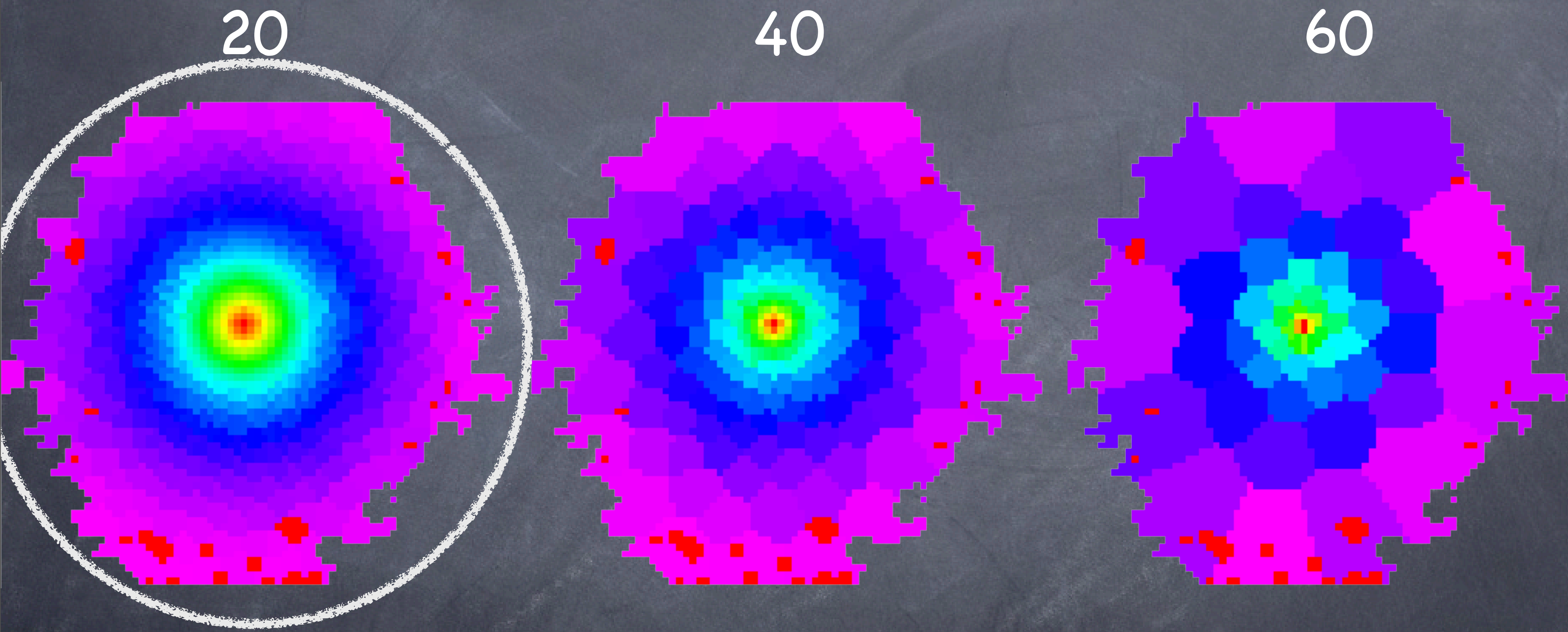


Daniel Kupko's
Voronoi code

+

PopStar +
Bernd Husemann
error covariances

Spatial Binning



Daniel Kupko's Voronoi code

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STARLIGHT

- ~1000 spectra per galaxy
- millions of iterations per spectrum
- 120 (600) galaxies
- five different sets of SSP models

STARLIGHT

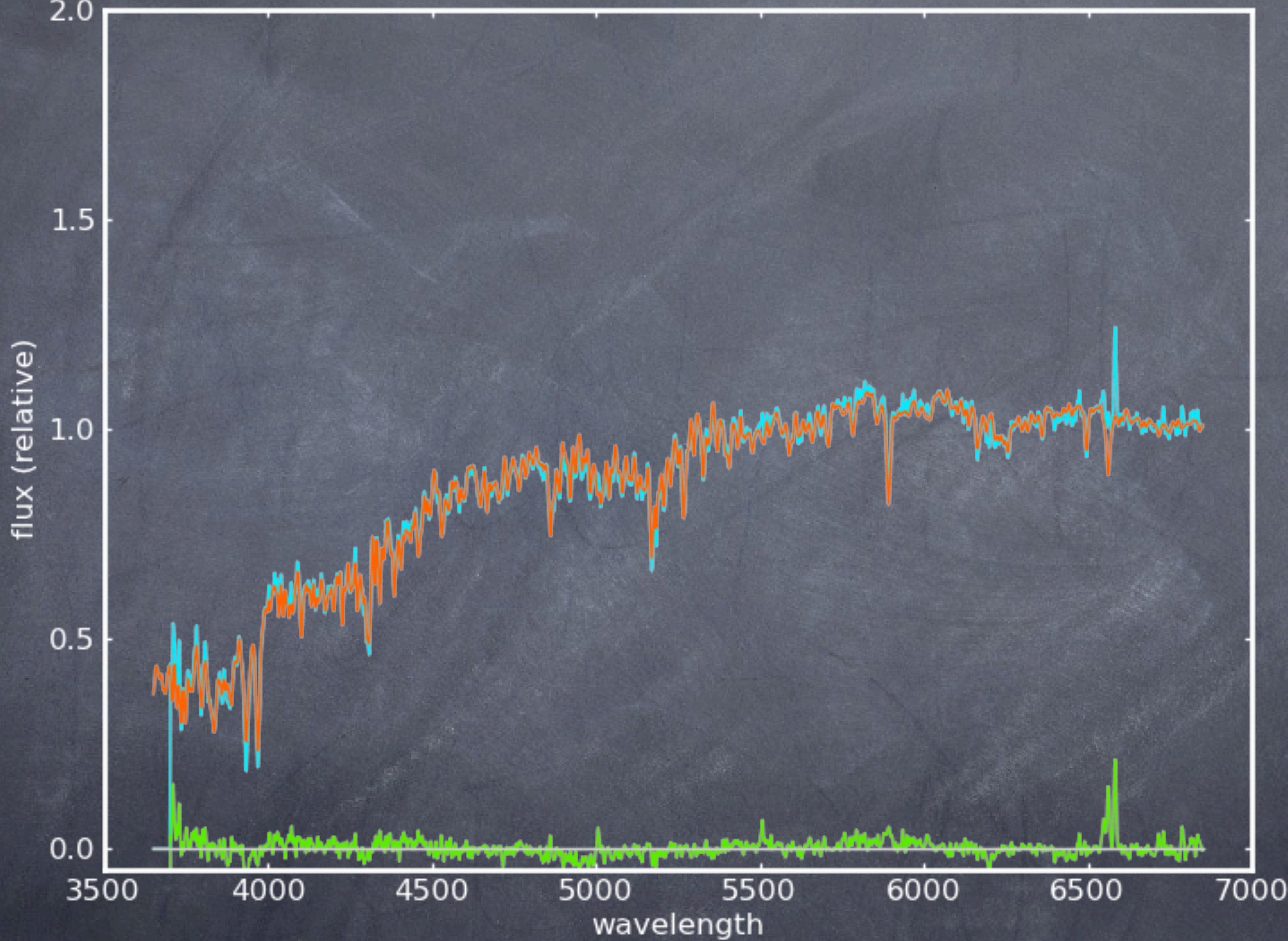
- ~1000 spectra per galaxy
- millions of iterations per spectrum
- 120 (600) galaxies
- five different sets of SSP models

GRID computing:

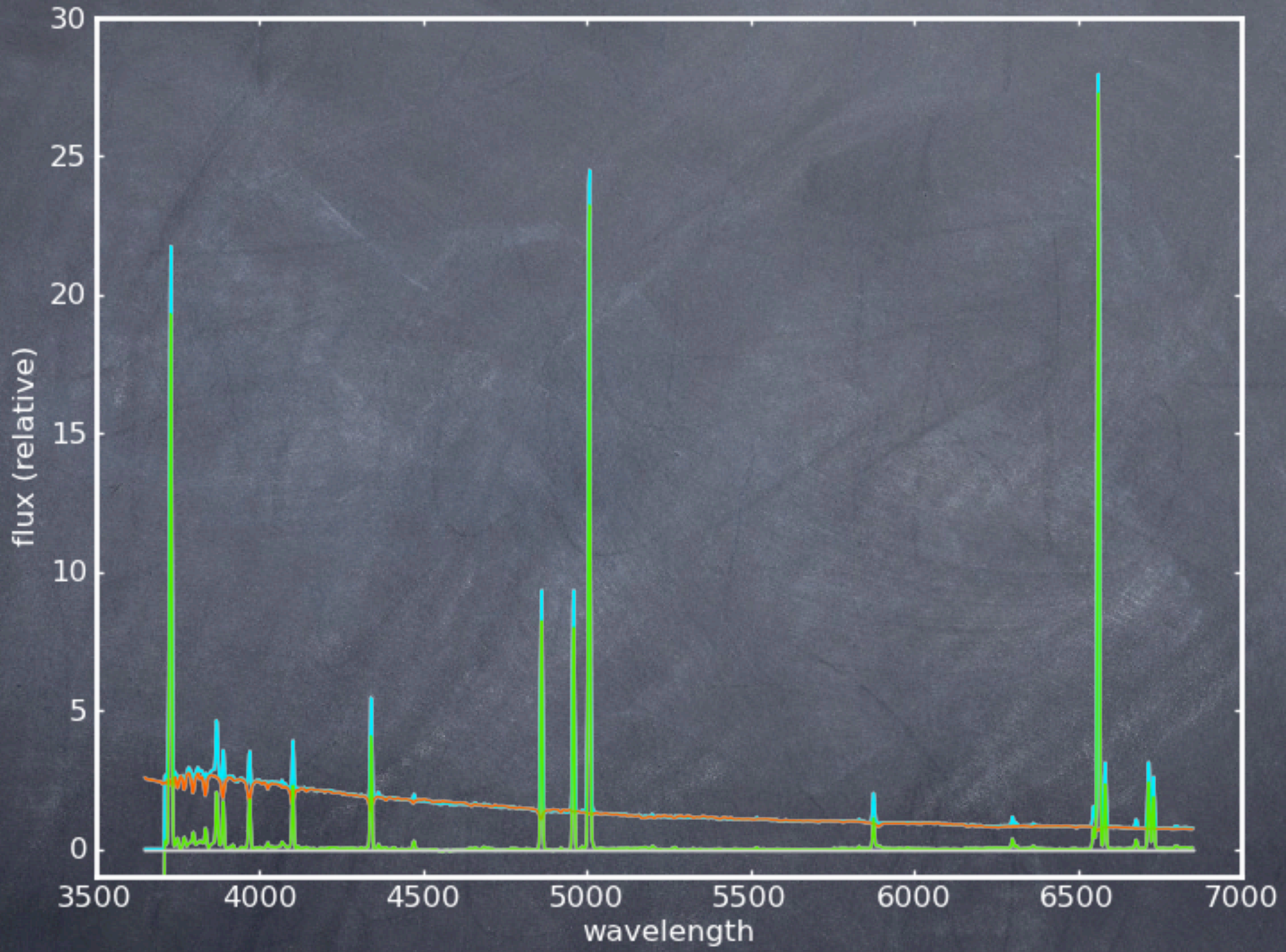
~20 hours / 100 gxs

200-400 CPUs

The results: spectral fits



The results: spectral fits



The Products

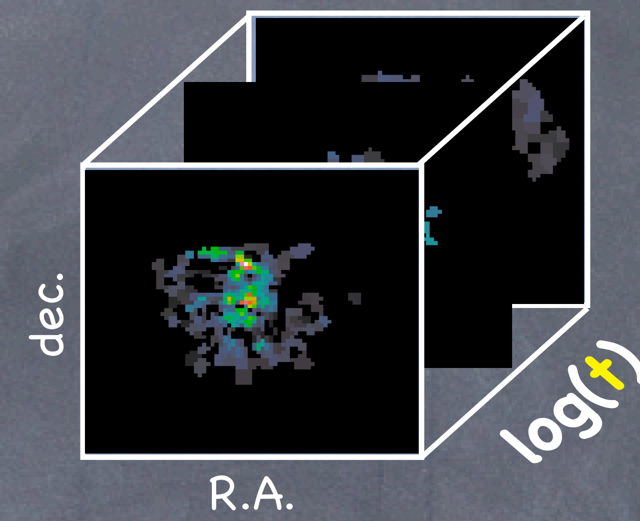
READ
Starlight
output

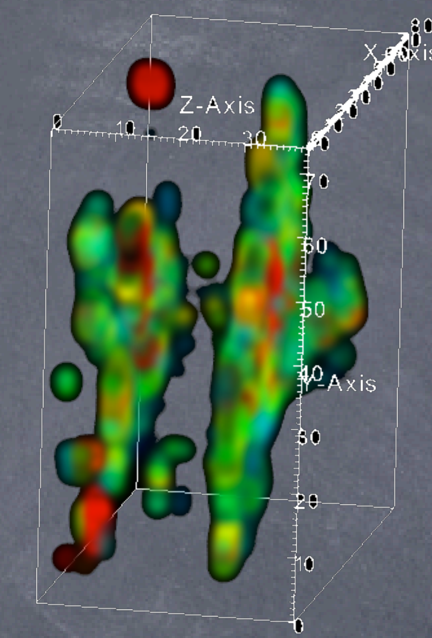
MagesDict[Z,t]

Σ_Z

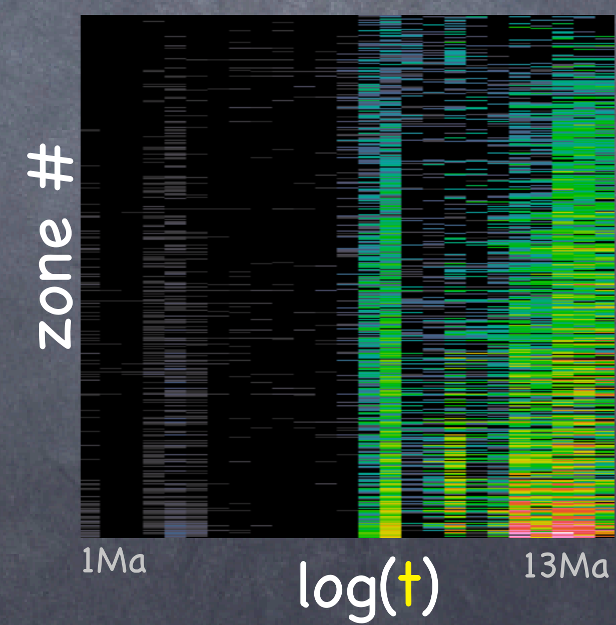
Magebins[t]

Mages_cube[t,y,x] = zone(y,x) x Magebins[t] / area(zone)





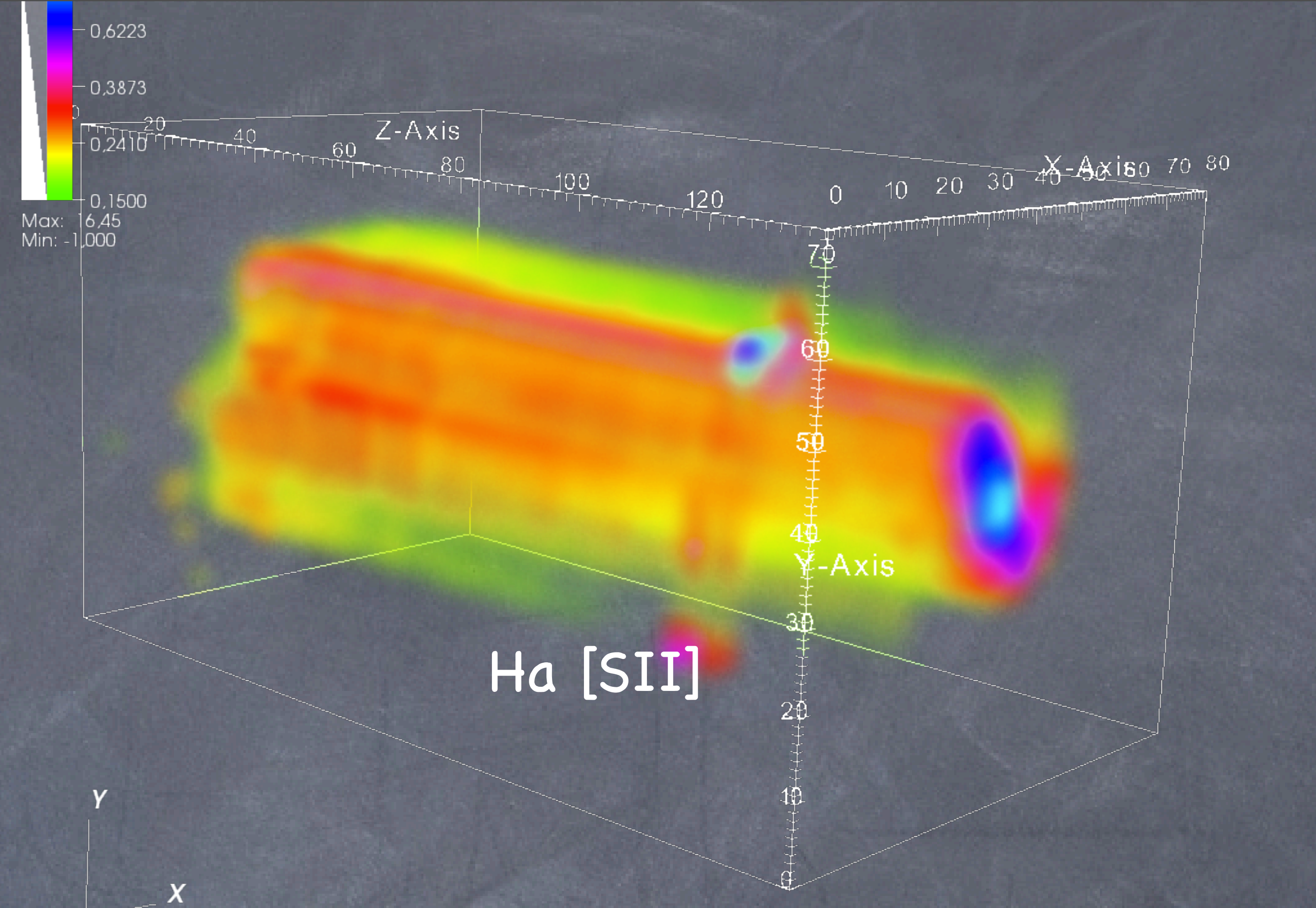
Mcen[zone,t] = zone(y,x) x Magebins[t] / area(zone)

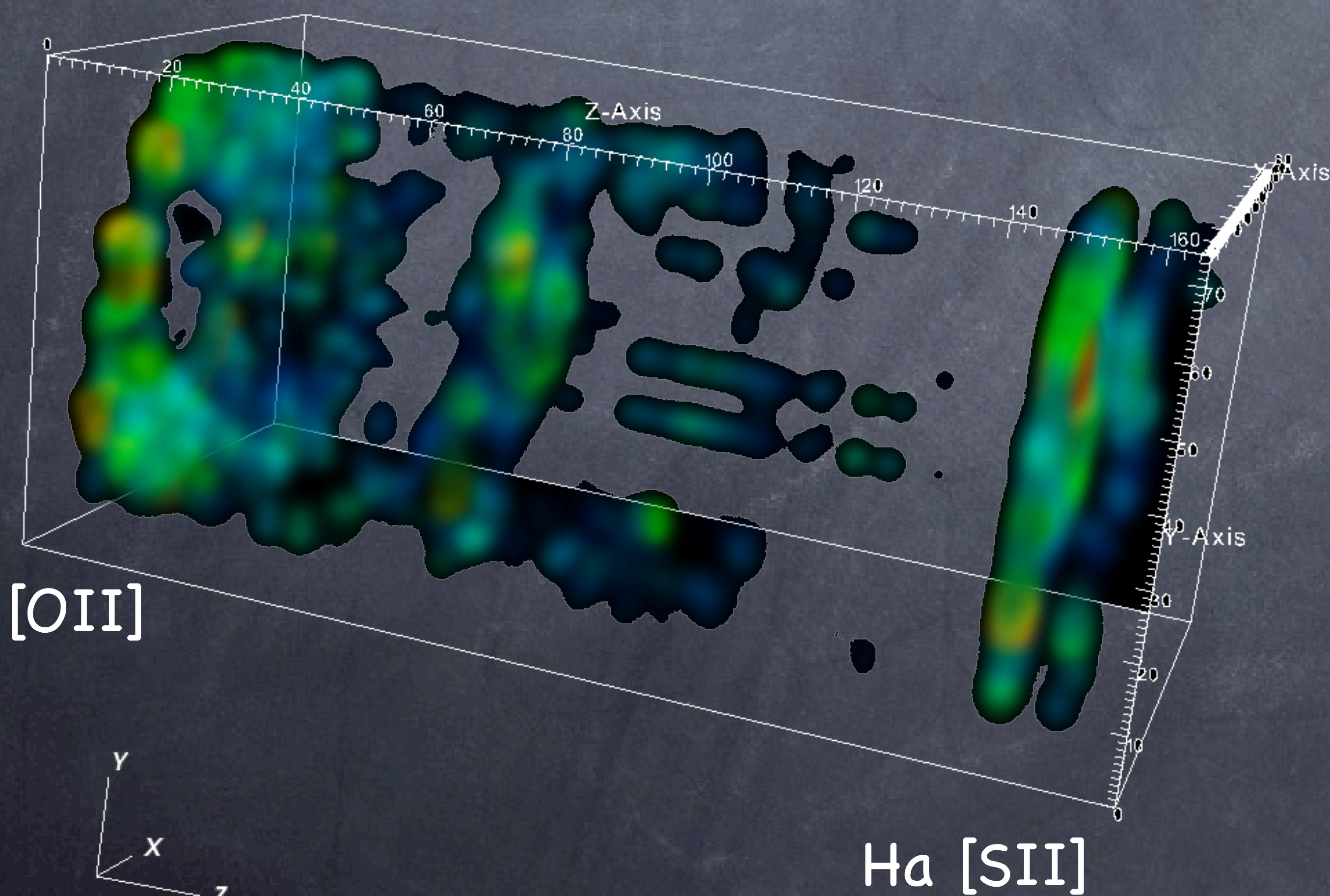


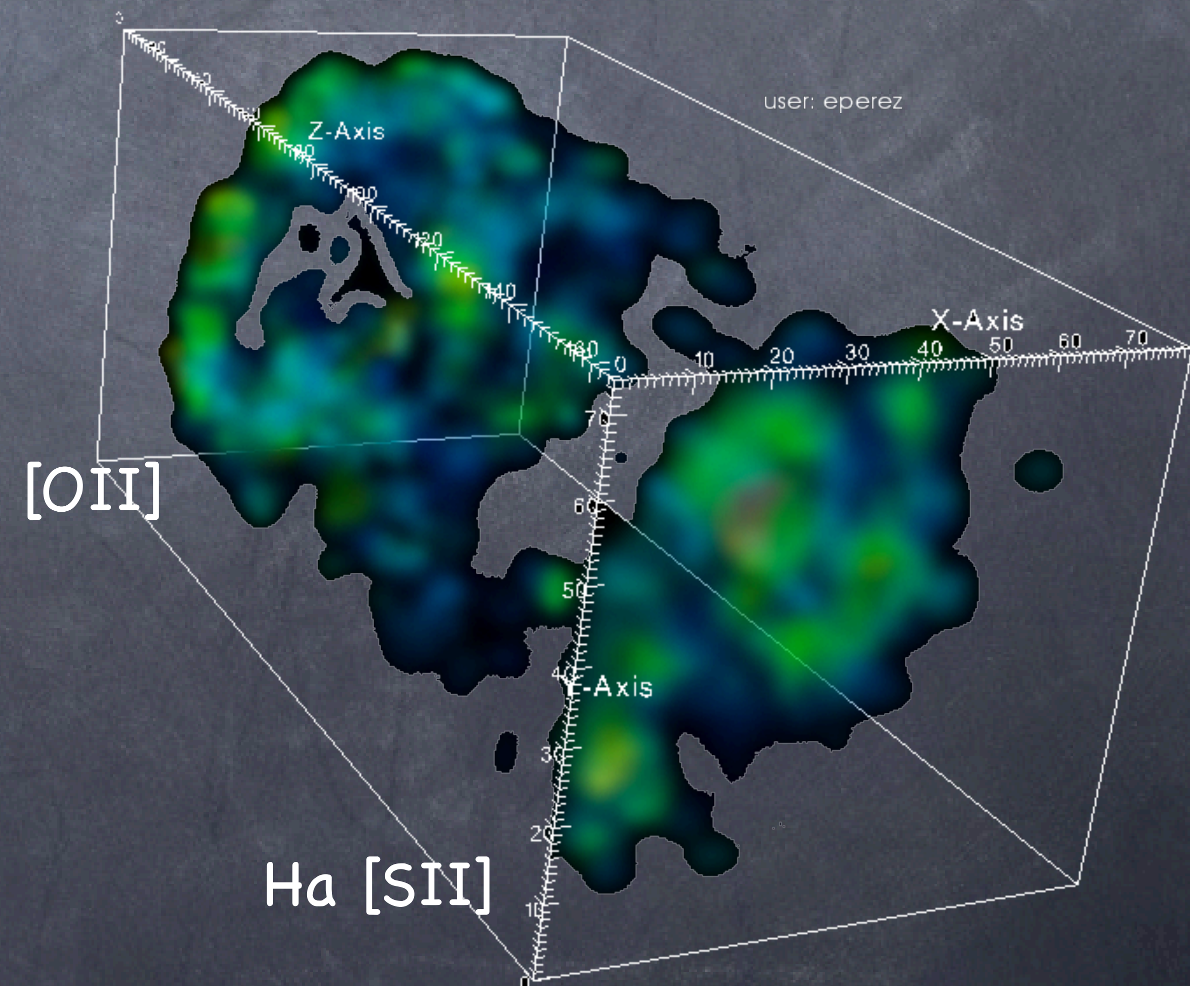
L(t) M(t) Z(t)
FITS
Av, v, vd

Spectral cubes:

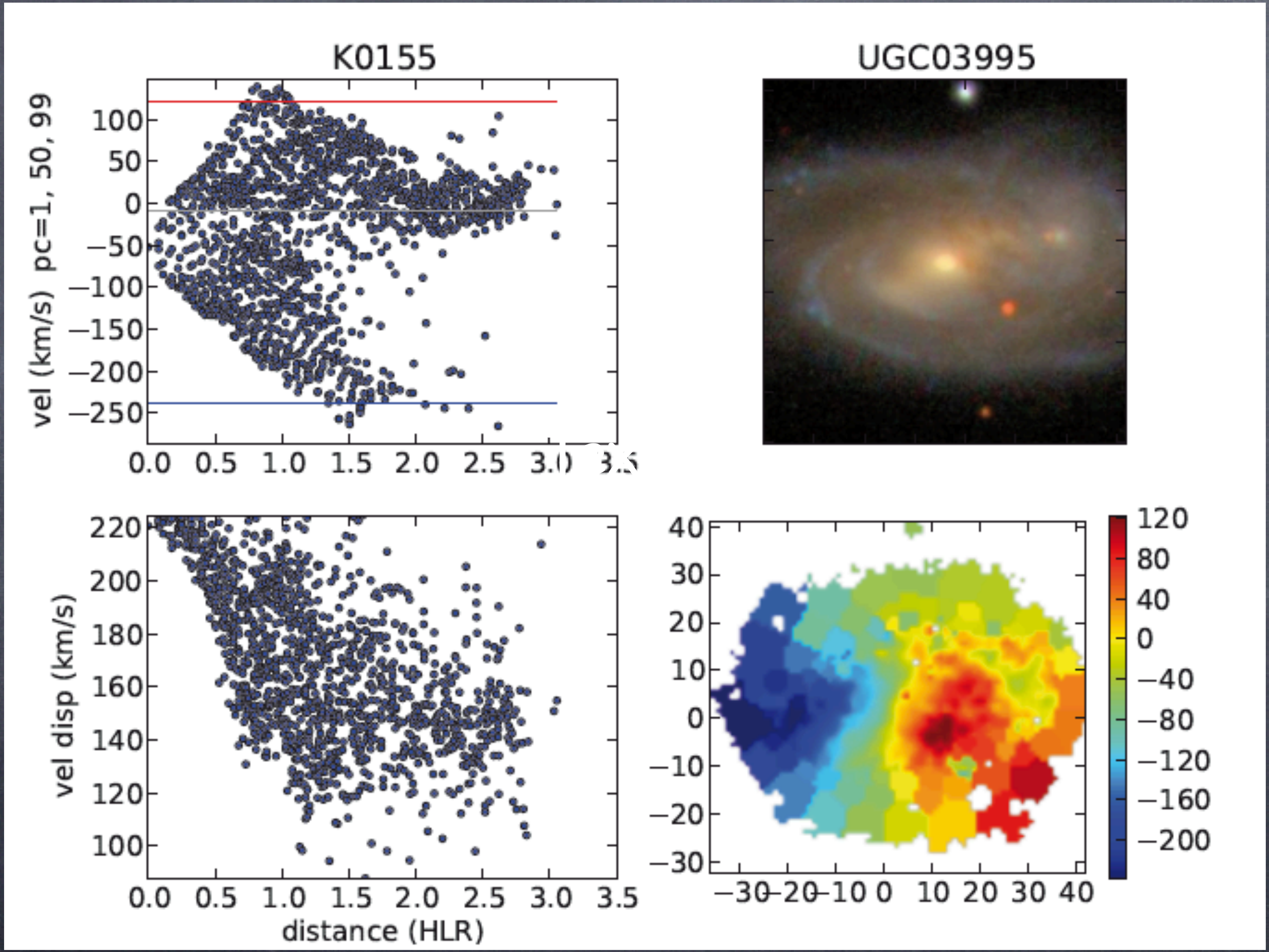
- data
- fit: stars
- residual: gas

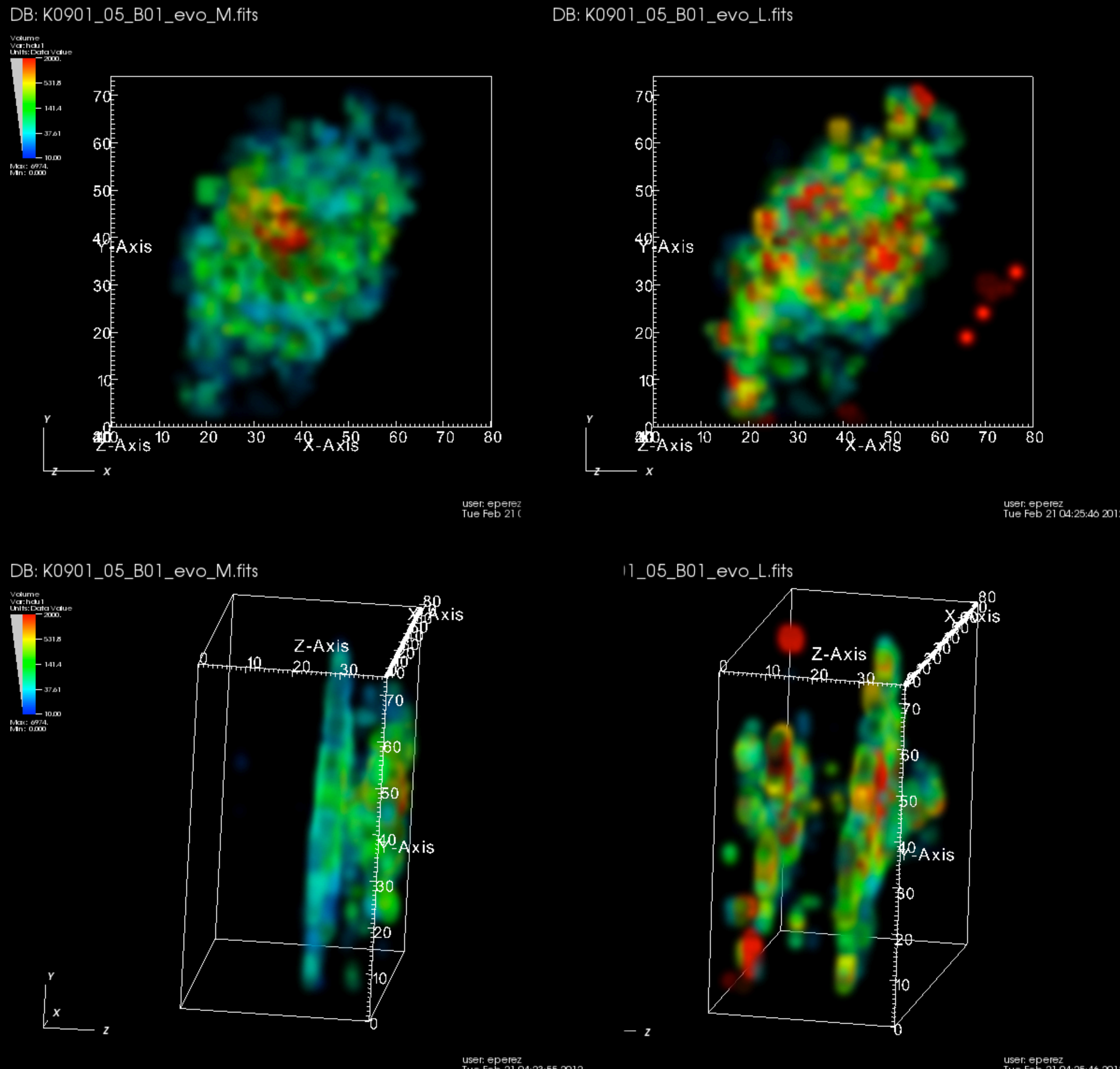






The stellar velocity dispersion and velocity maps

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Volume
Var: hdu1
Units: Data Value
2000.
531.8
141.4
37.61
10.00
Max: 6974.
Min: 0.000
Y-Axis
X-Axis
Z-Axis
user: eperez
DB: K0901_05_B01_evo_L.fits
Y-Axis
X-Axis
Z-Axis
user: eperez
Tue Feb 21 04:25:46 2012
DB: K0901_05_B01_evo_M.fits
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X-Axis
Y-Axis
user: eperez
Tue Feb 21 04:23:55 2012
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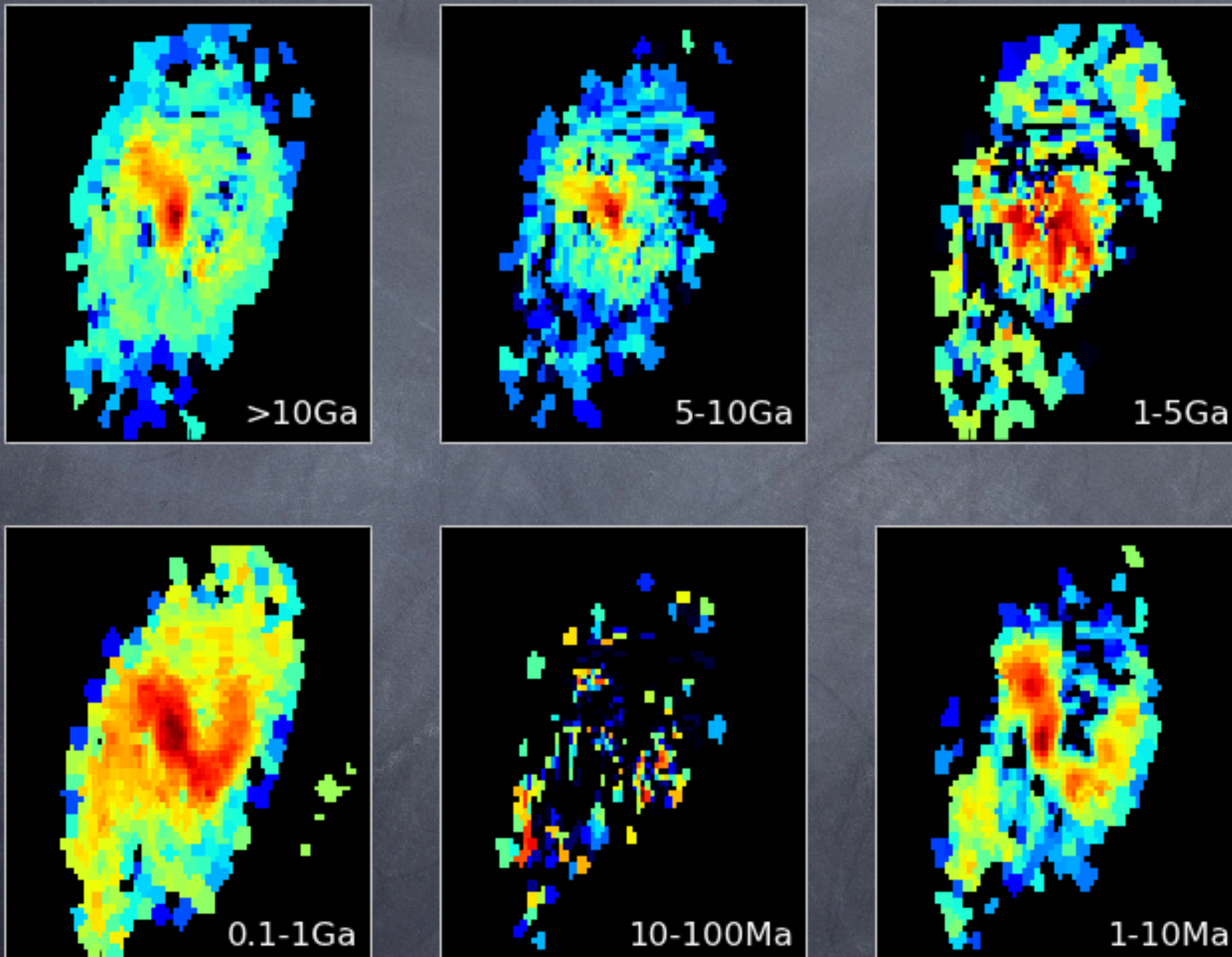
Tue Feb 21 04:25:46 2012

M

L


>10Ga
5-10Ga
1-5Ga
0.1-1Ga
10-100Ma
1-10Ma

(r.a., dec, lookbacktime) 3D Mass evolution

The Products

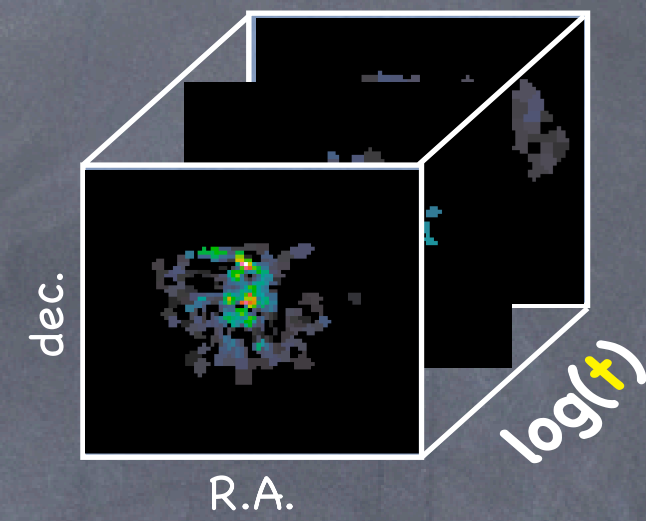
READ
Starlight
output

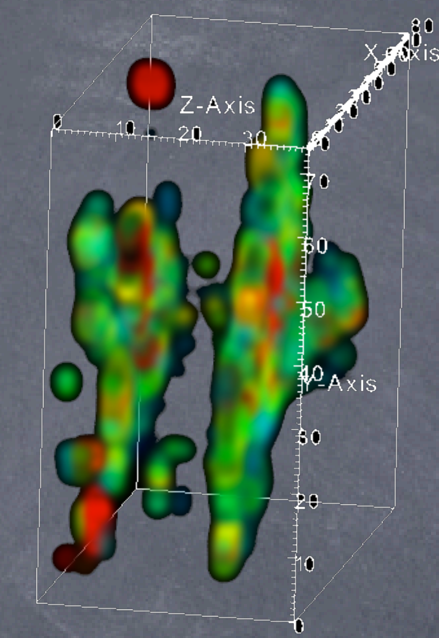
MagesDic
t[Z,t]

Σz

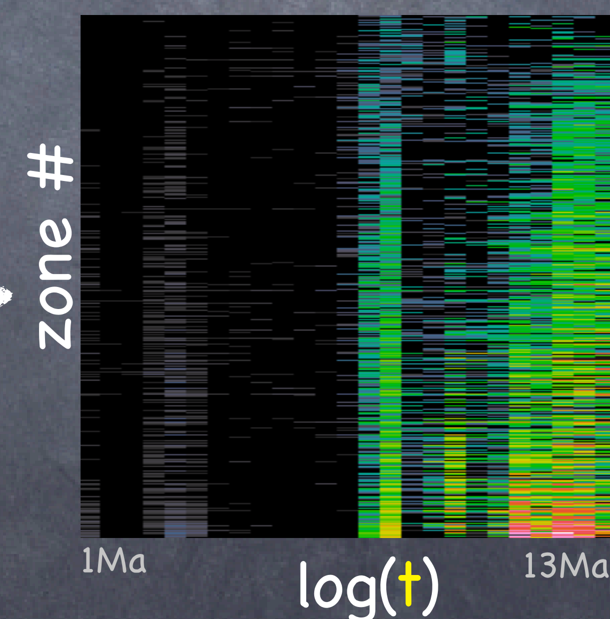
Magebins[t]

Mages_cube[t,y,x] =
zone(y,x) x
Magebins[t] / area(zone)



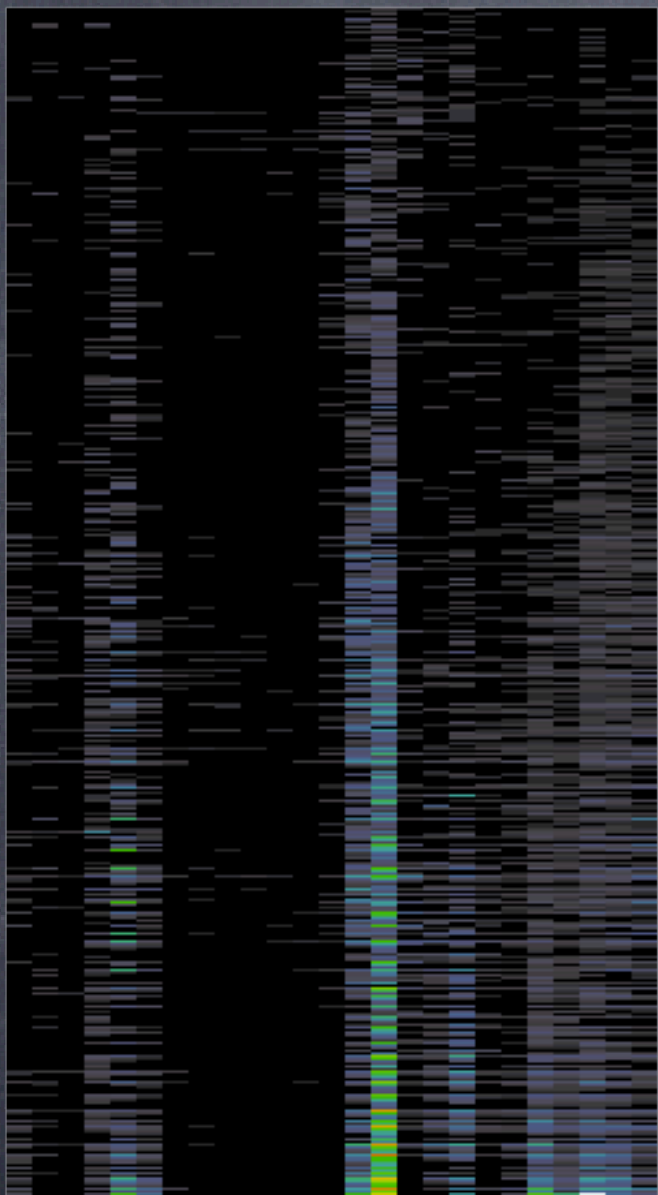


Mcen[zone,t] =
zone(y,x) x
Magebins[t] / area(zone)



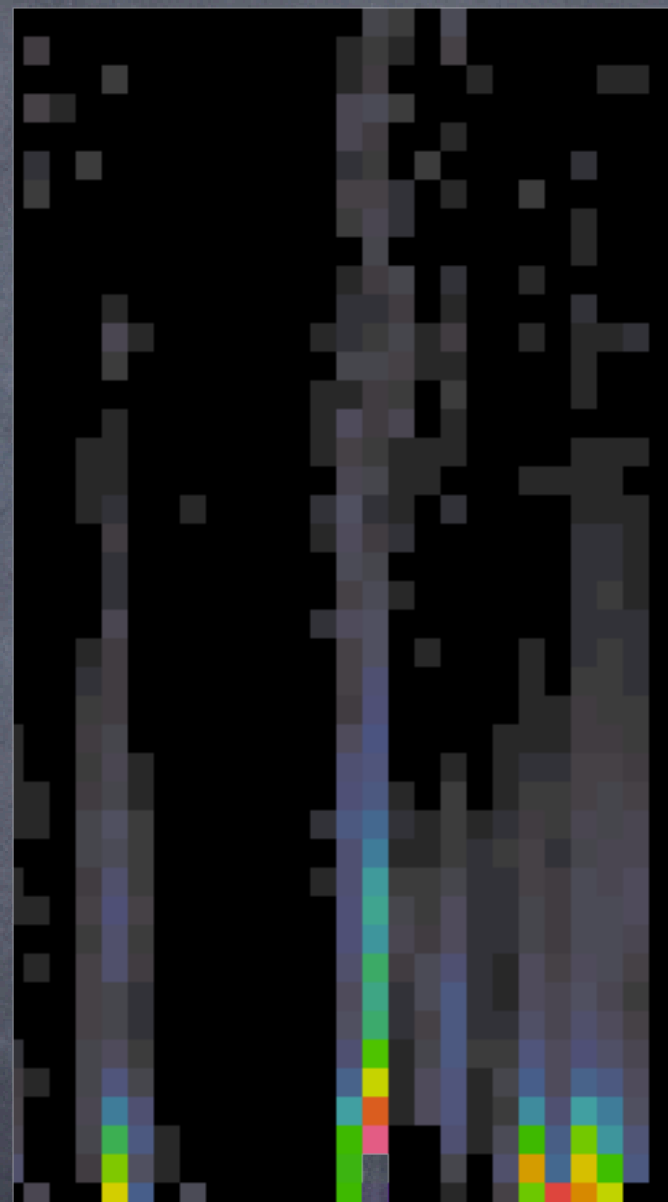
L(t) M(t) Z(t)
FITS
Av, v, vd

Starlight output



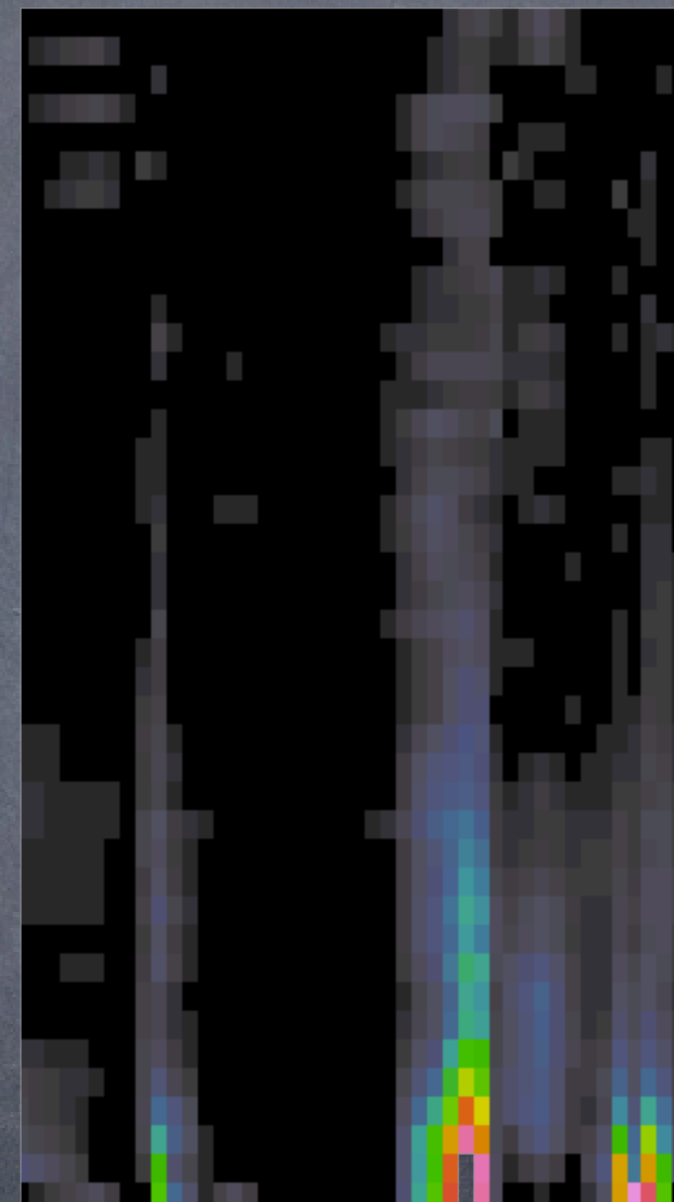
zone# , log(t)

radial average



radial (1") , log(t)

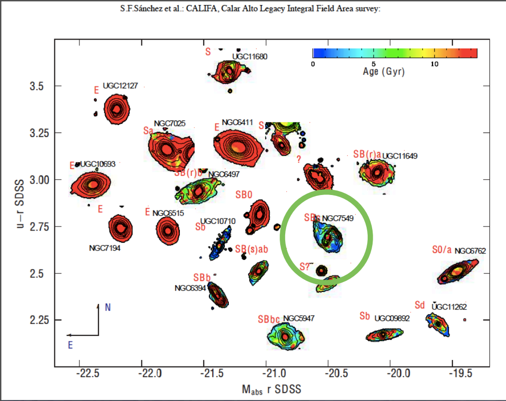
age interpolated 0.1dex



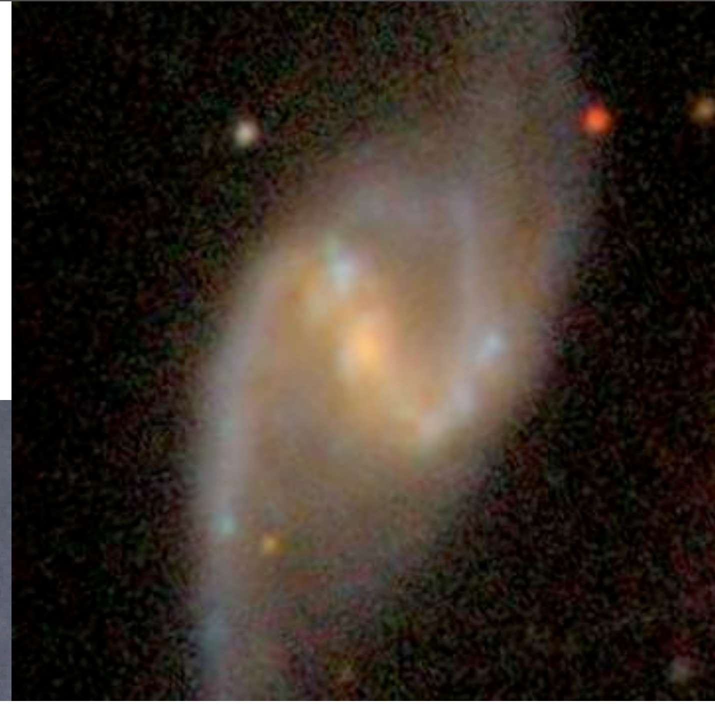
radial (1") , 0.1 dex

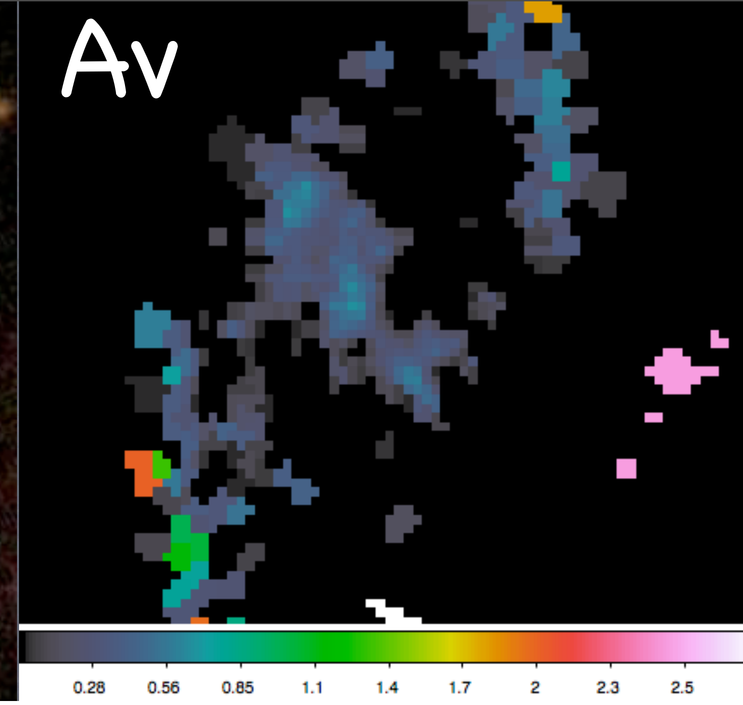
radial interpolated 0.1 HLR

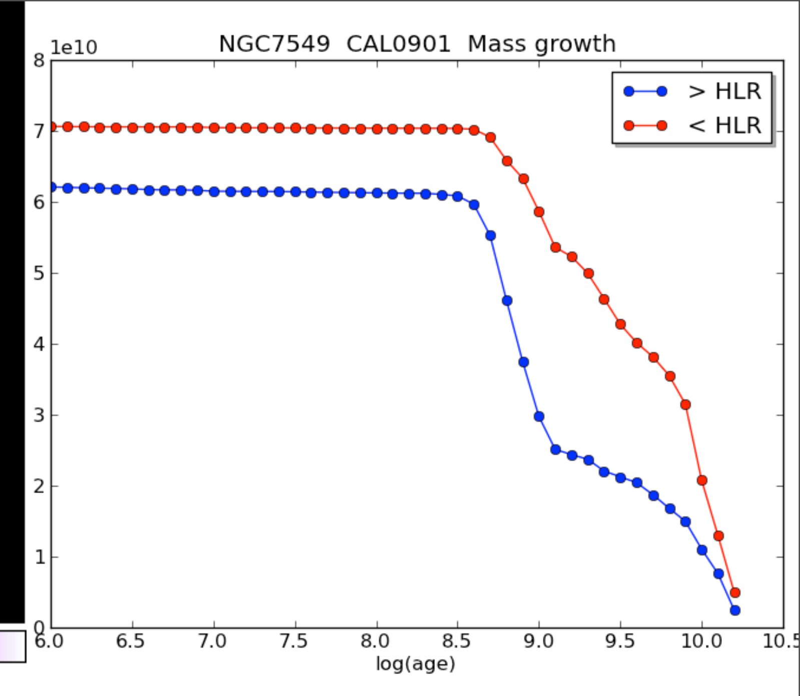
0.1 HLR , 0.1 dex

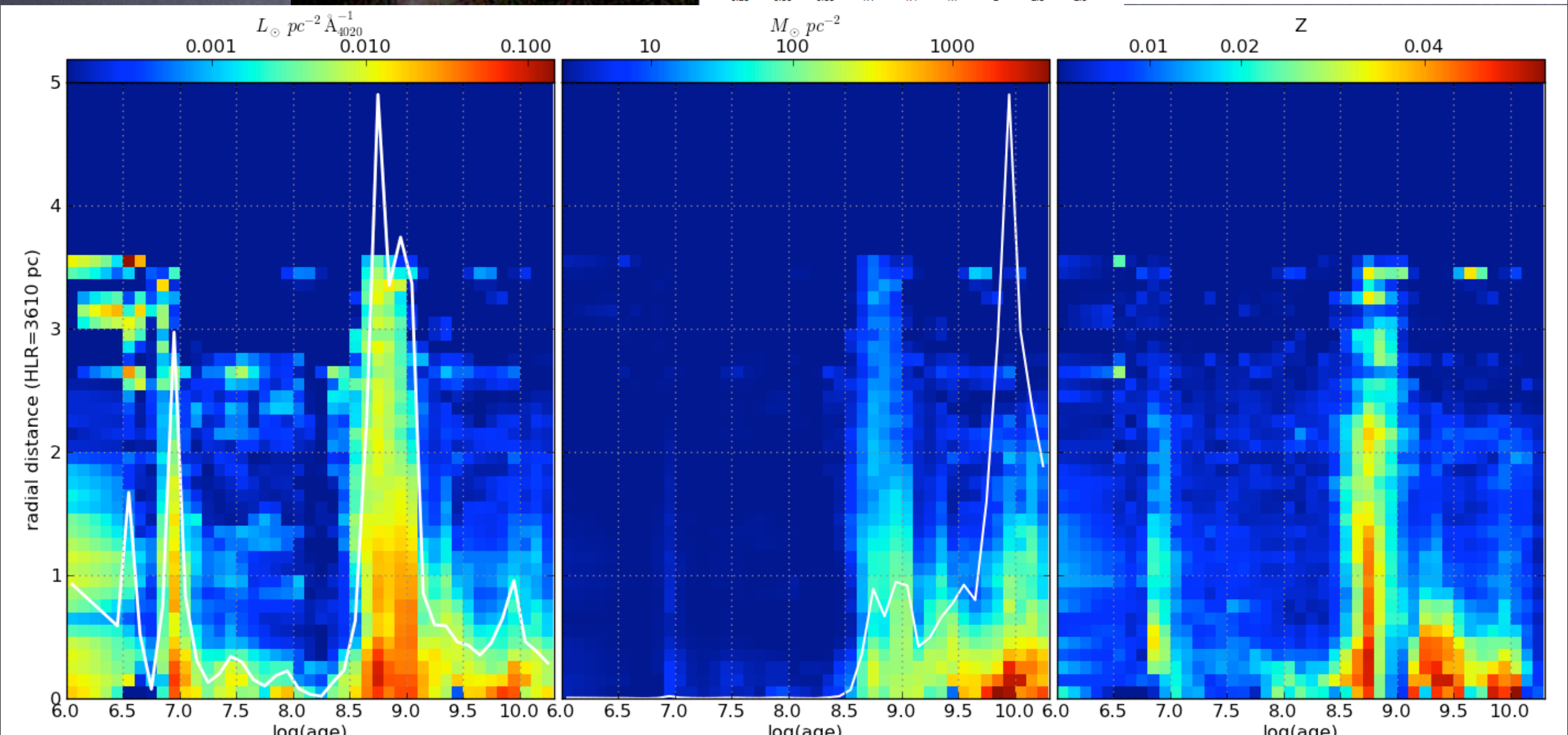


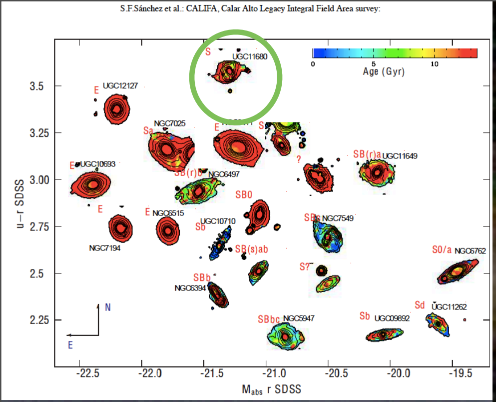
NGC7549
K0901



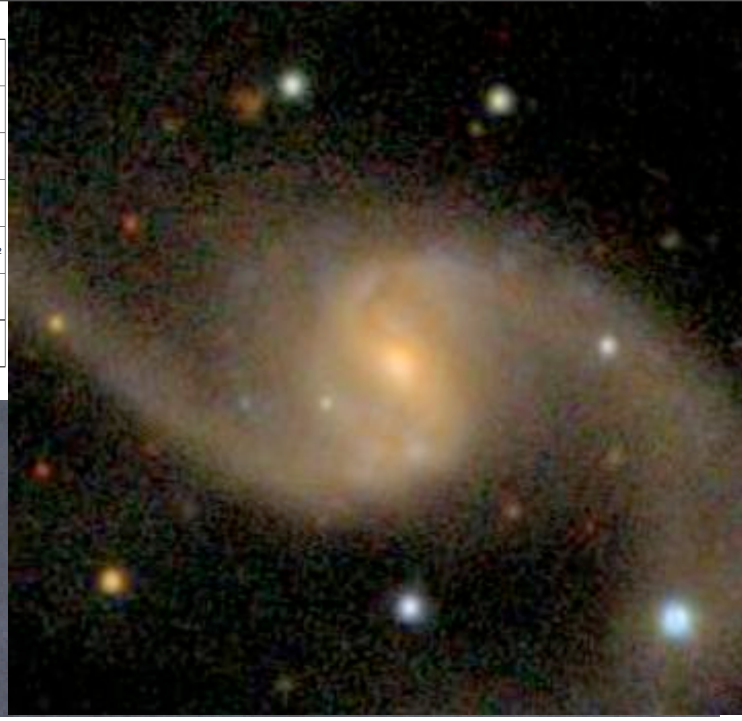


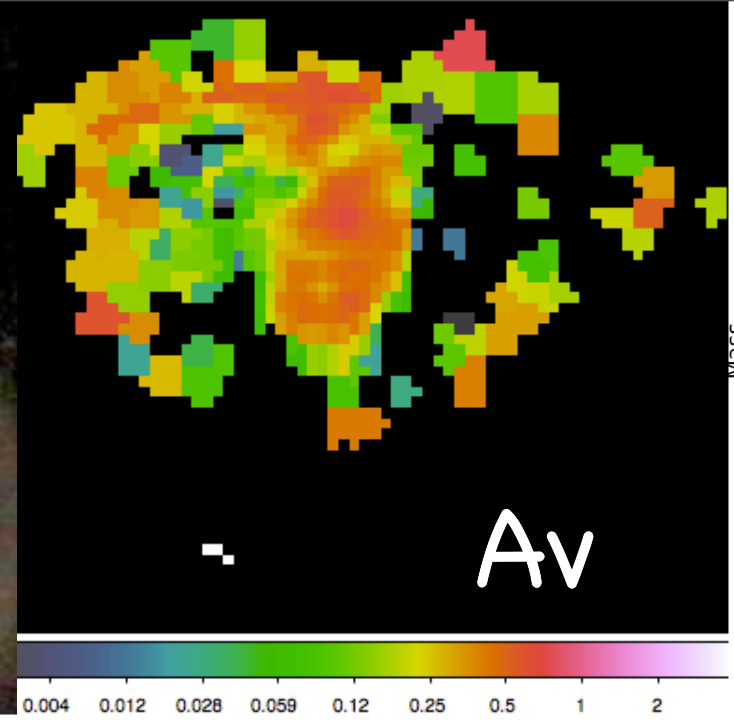


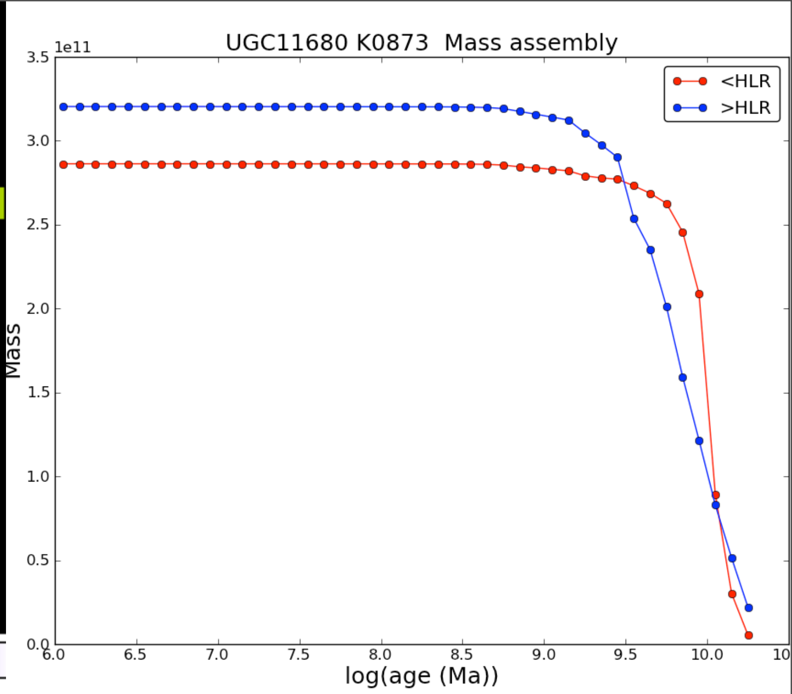


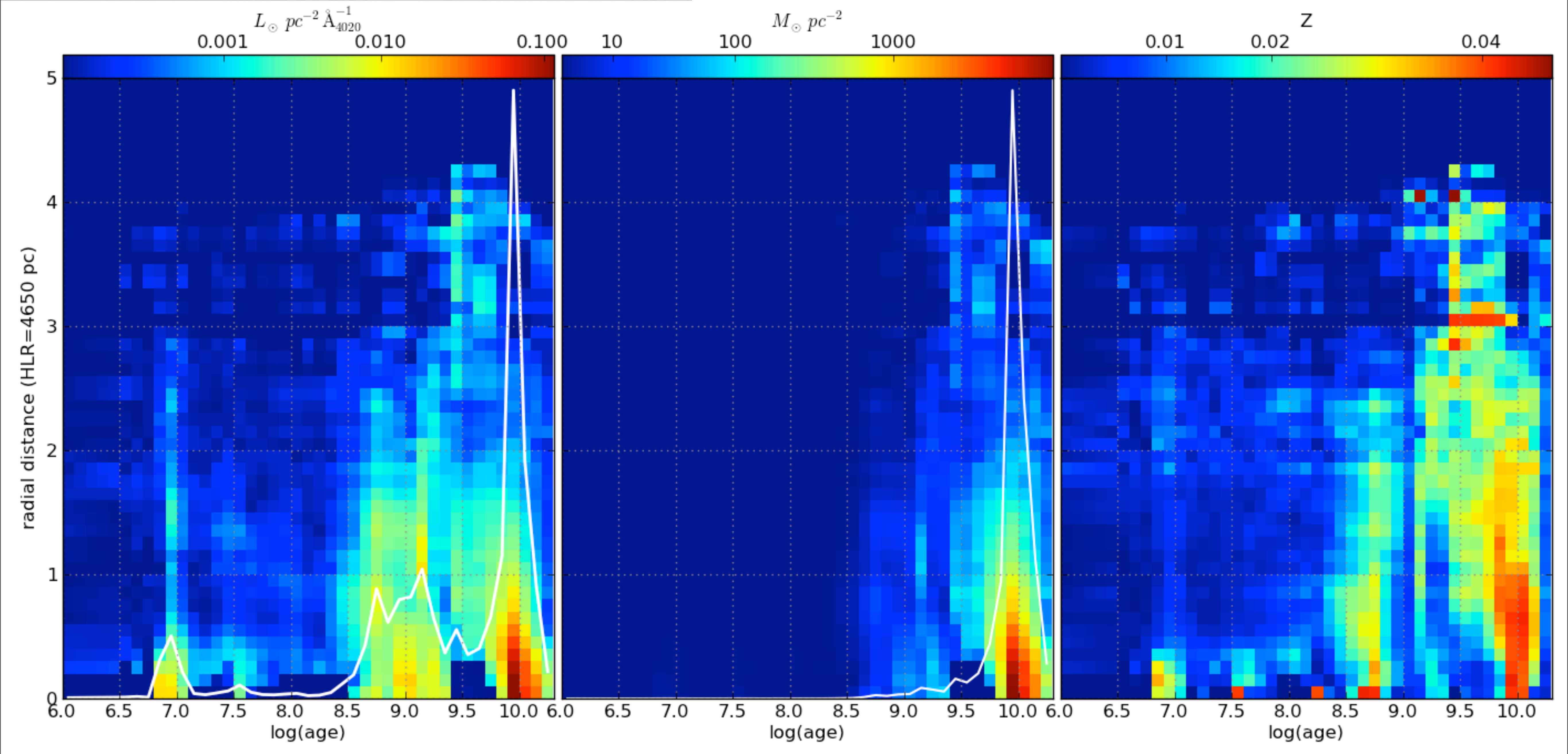


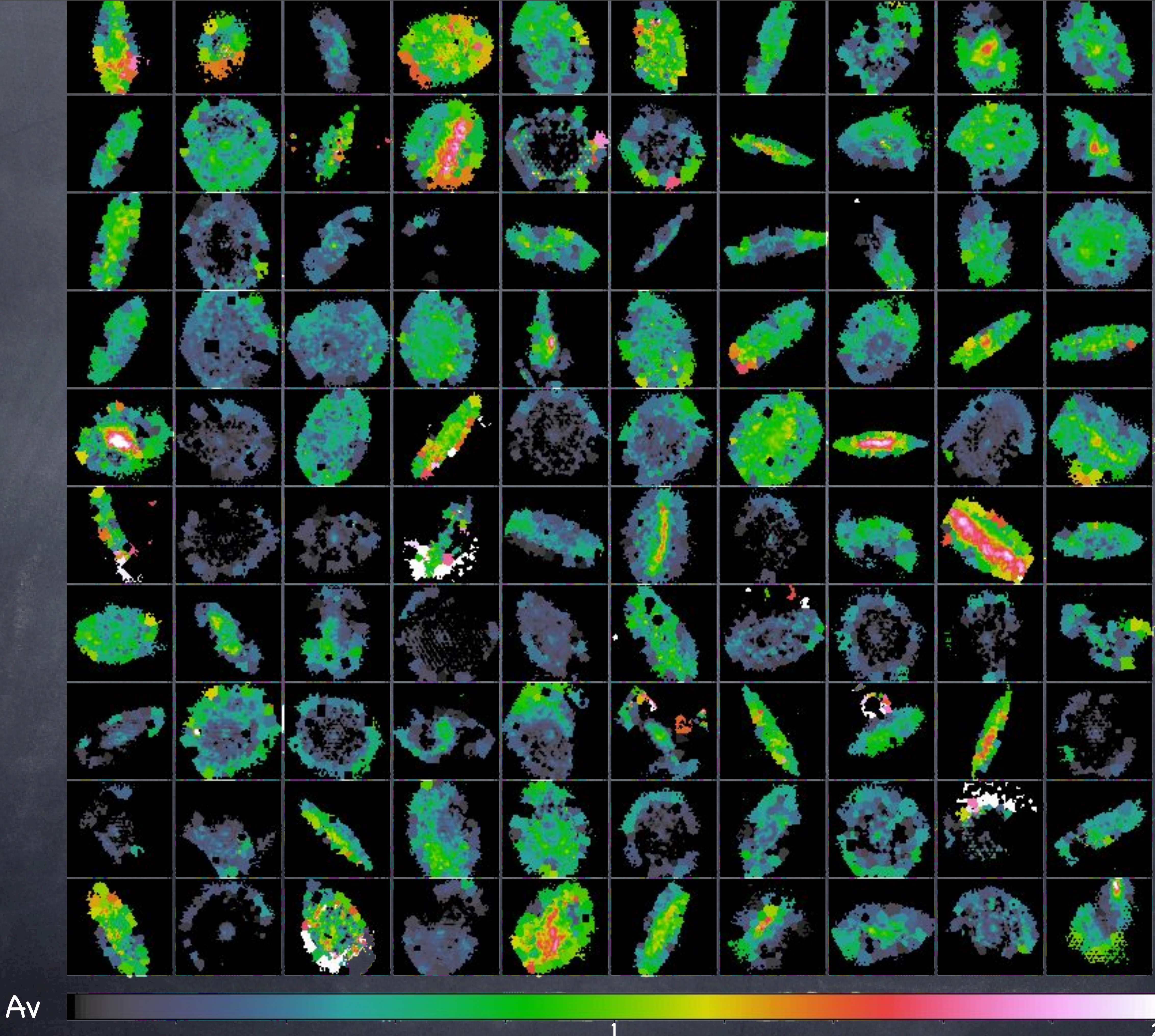
UGC11680
K0873










Av
1
2

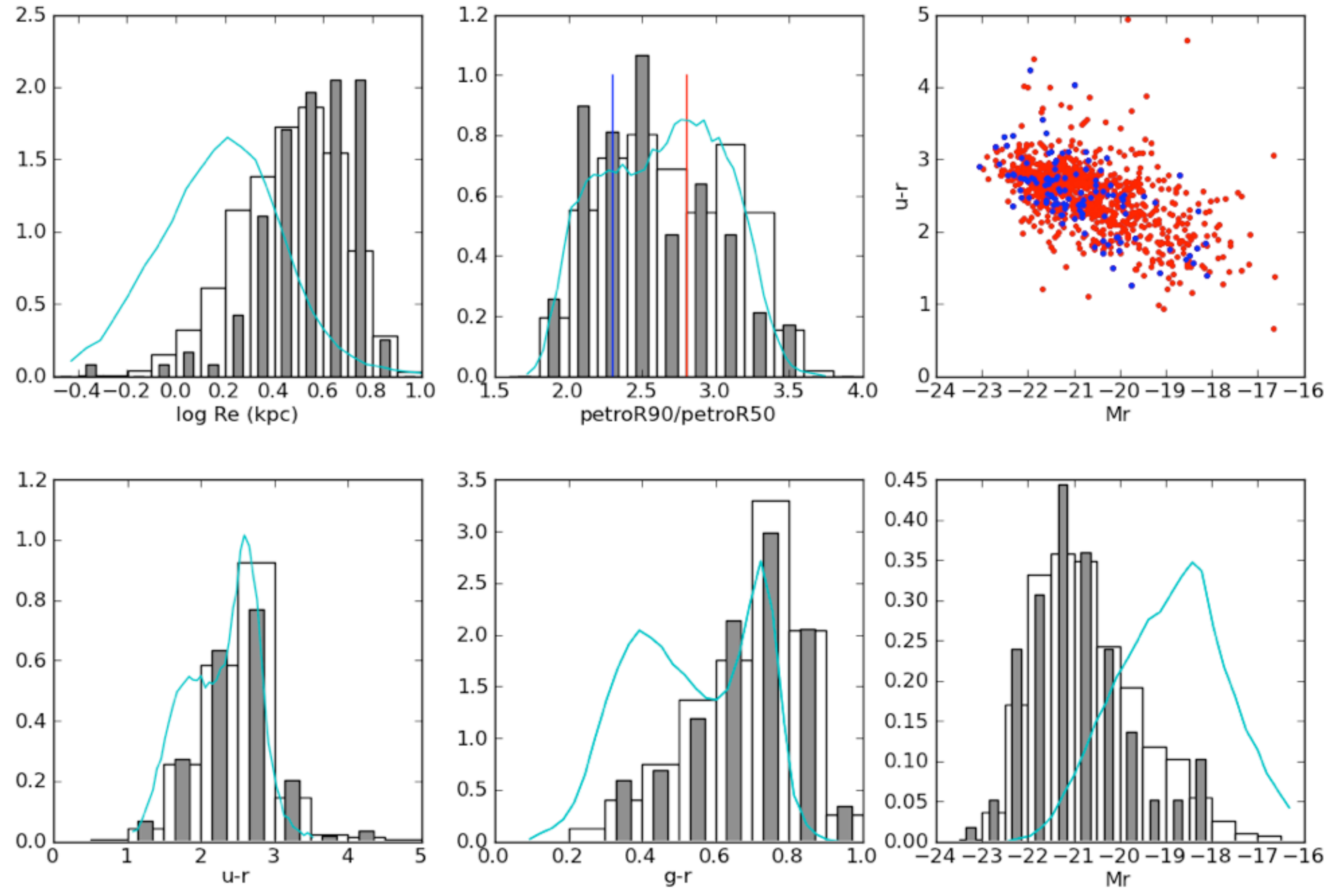
Results:

The growth of Mass

Cosmic evolution of stellar metallicity radial gradients

Stacking the results in the Color-magnitud diagram

The first 120 CALIFA galaxies well spread in the Color-Magnitude diagram

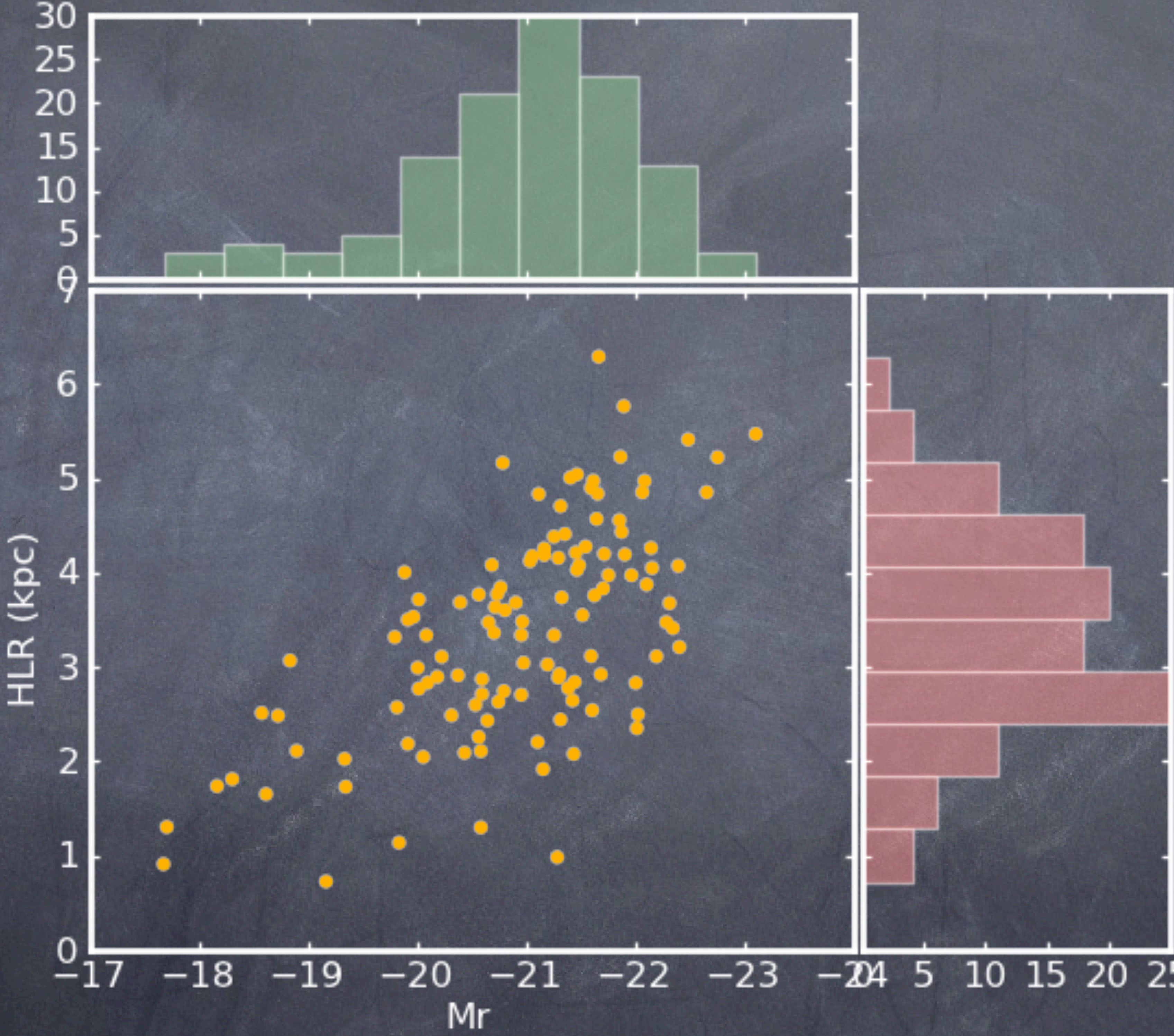


Results:

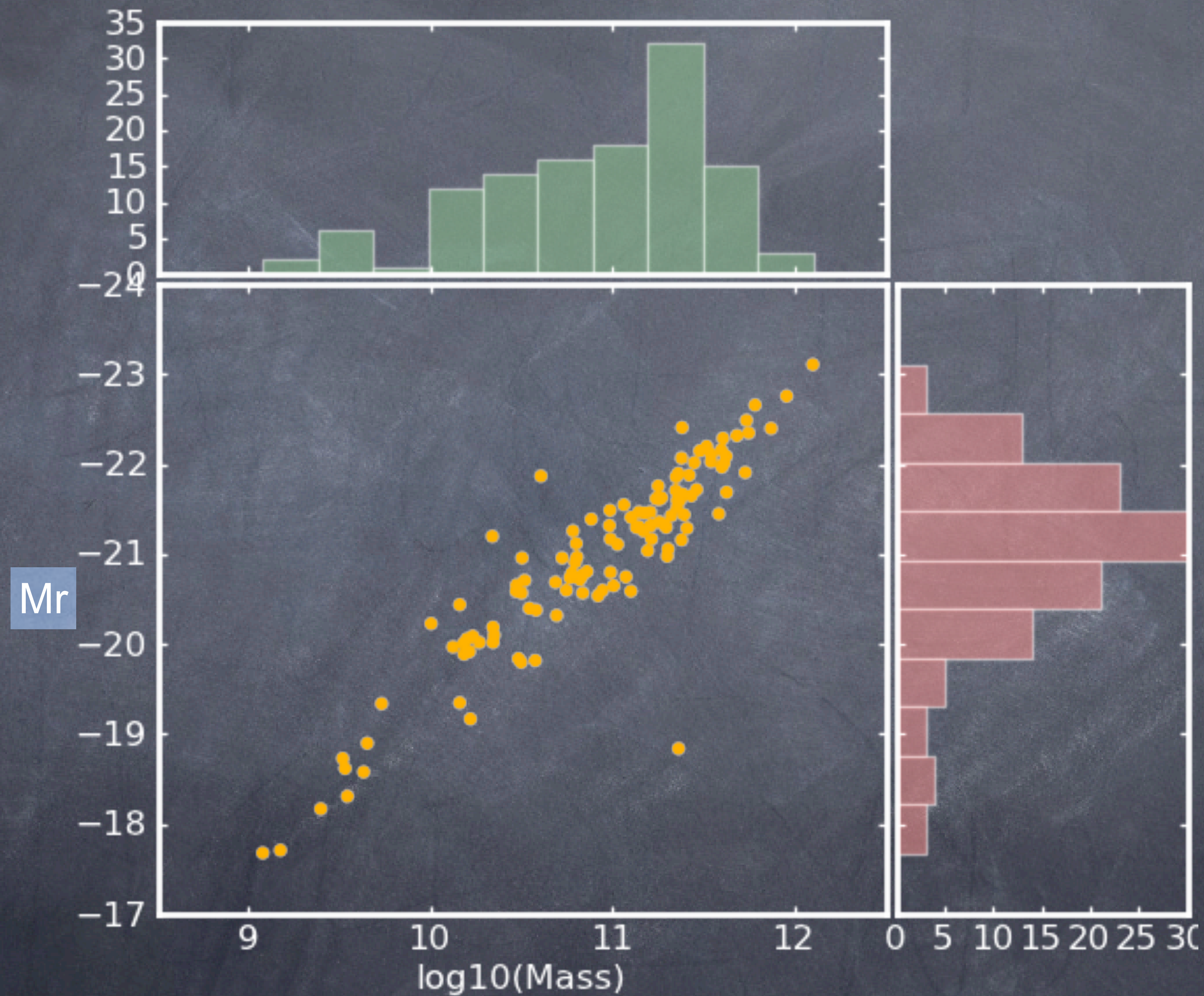
The growth of Mass and metallicity

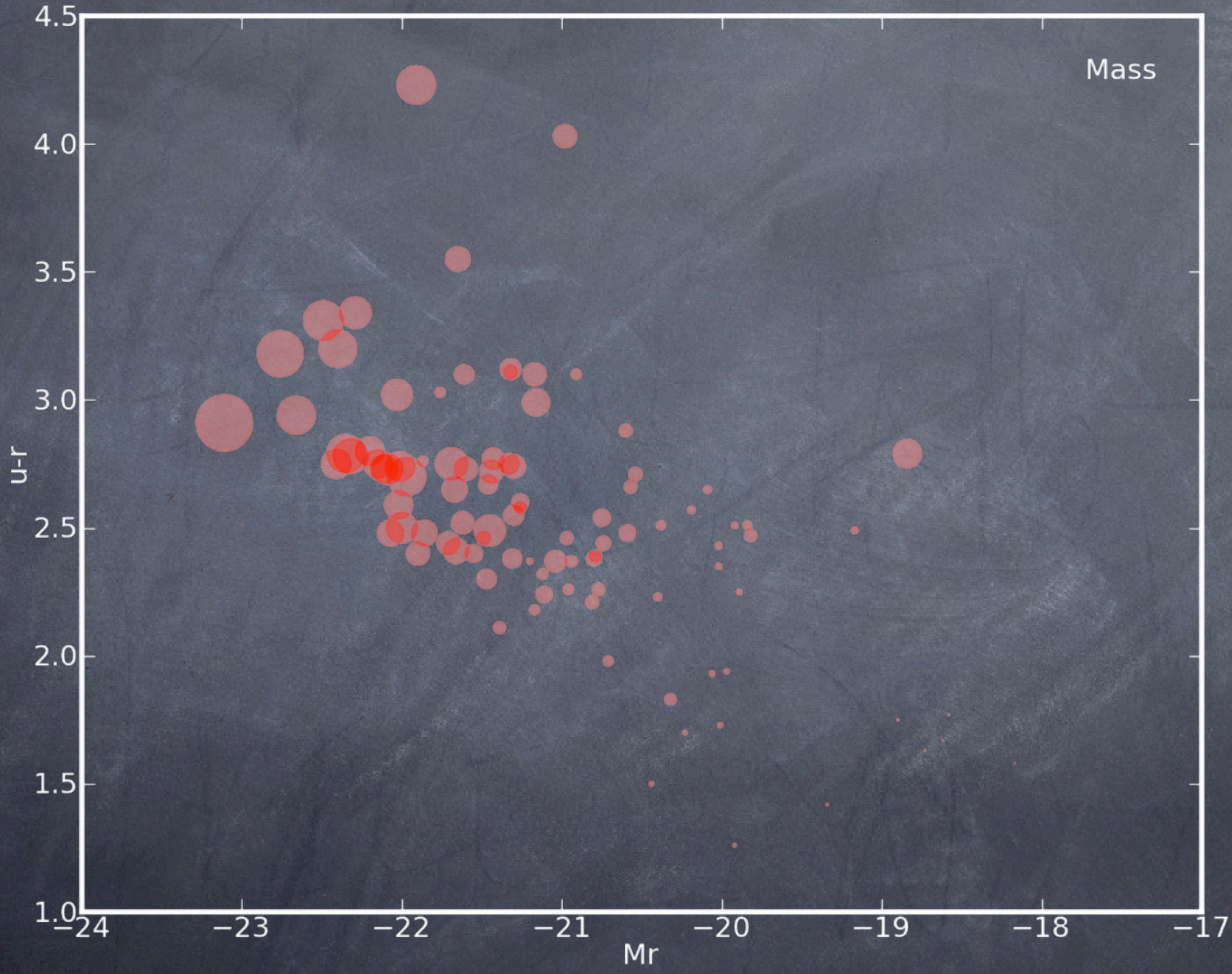
Cosmic evolution of stellar metallicity radial gradients

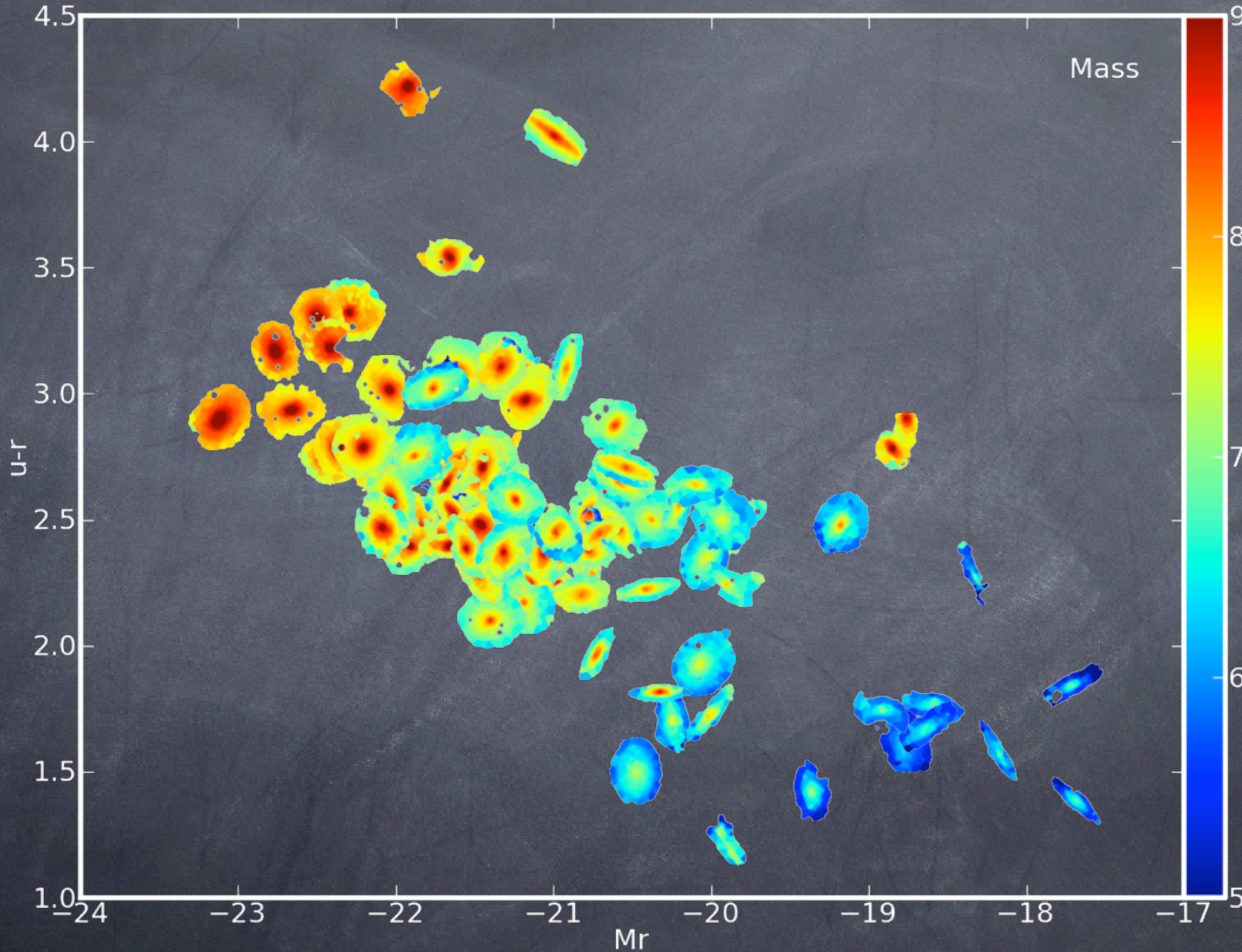
Stacking the results in the Color-magnitud diagram



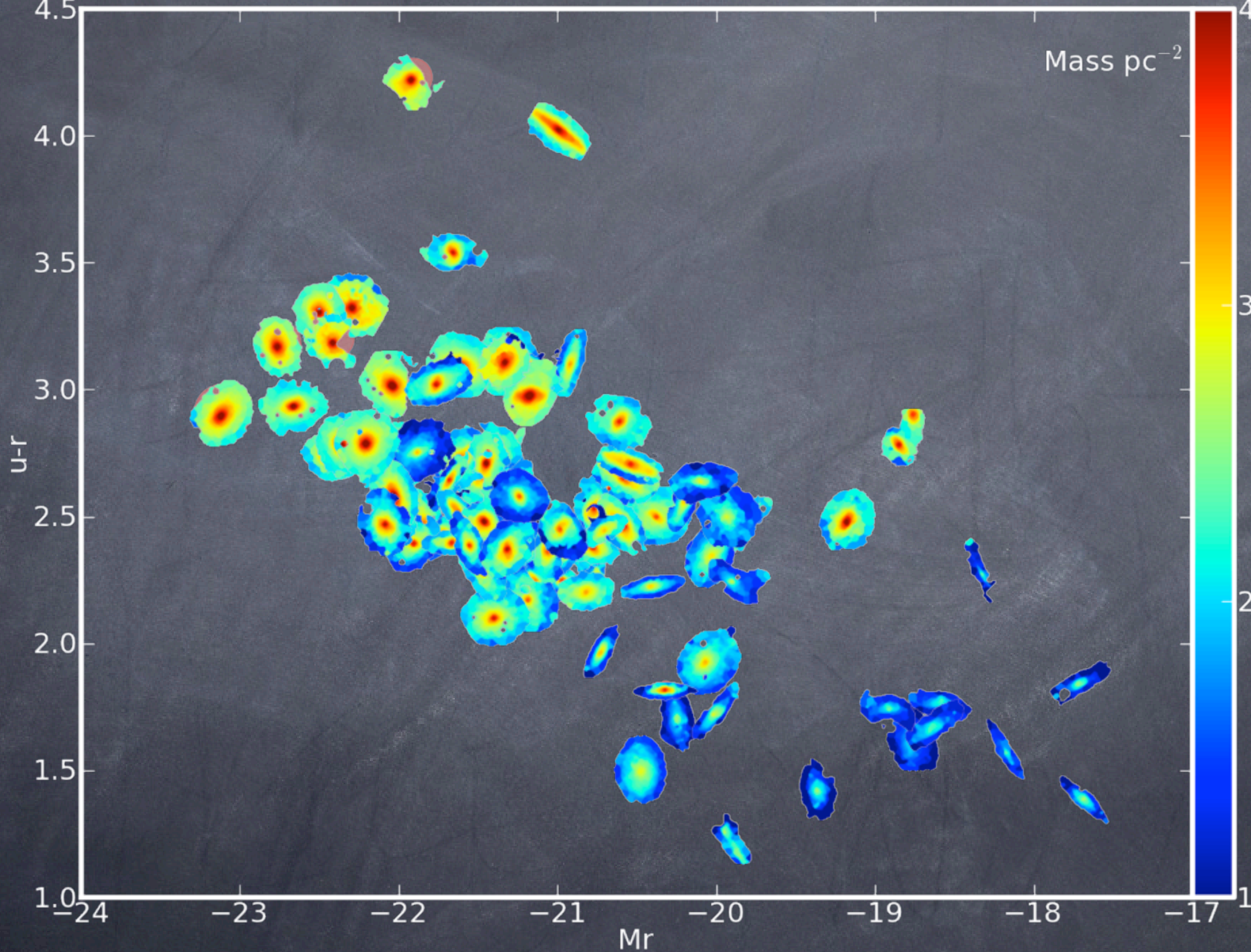
HLR (kpc)
Mr


35
30
25
20
15
10
5
0
−24
−23
−22
−21
Mr
−20
−19
−18
−17
9
10
11
12
log10(Mass)
0
5
10
15
20
25
30

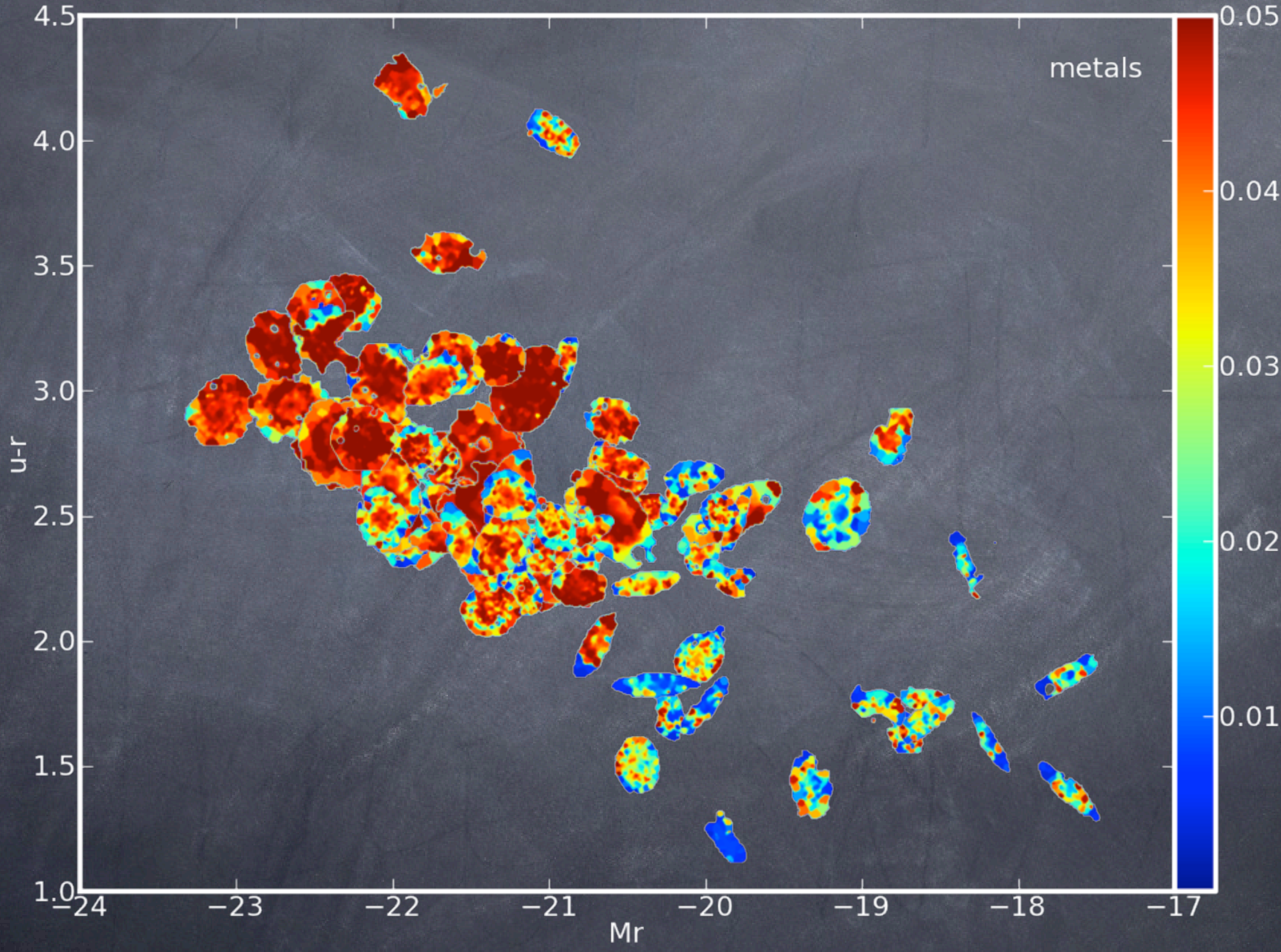

Mass
u-r
Mr
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
−24
−23
−22
−21
−20
−19
−18
−17



Mass
u-r
Mr
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
−24
−23
−22
−21
−20
−19
−18
−17
9
8
7
6
5



Mass pc^{-2}
4
3
2
1
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
u-r
−24
−23
−22
−21
−20
−19
−18
−17
Mr



metals
u-r
Mr
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3.5
3.0
2.5
2.0
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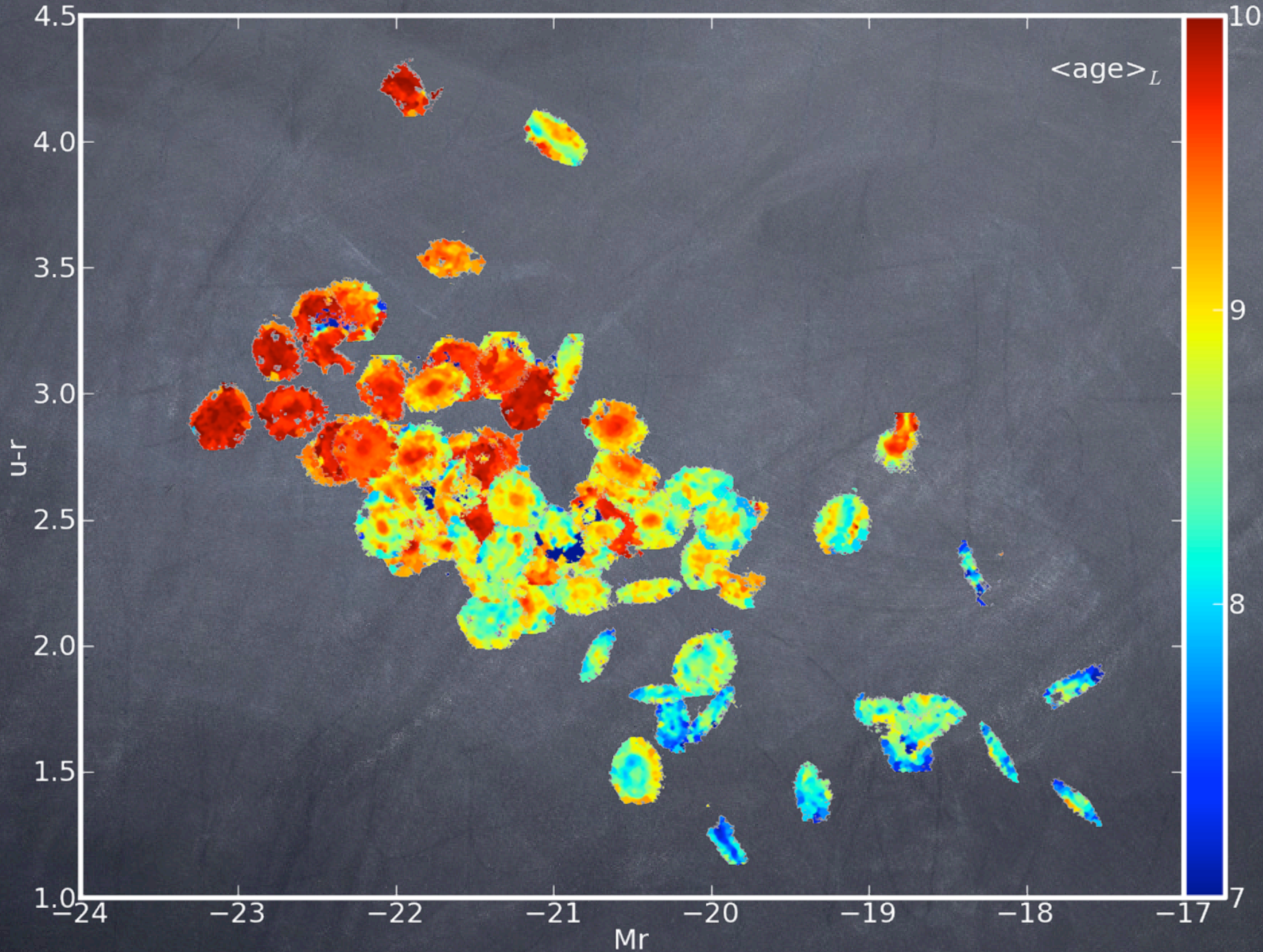

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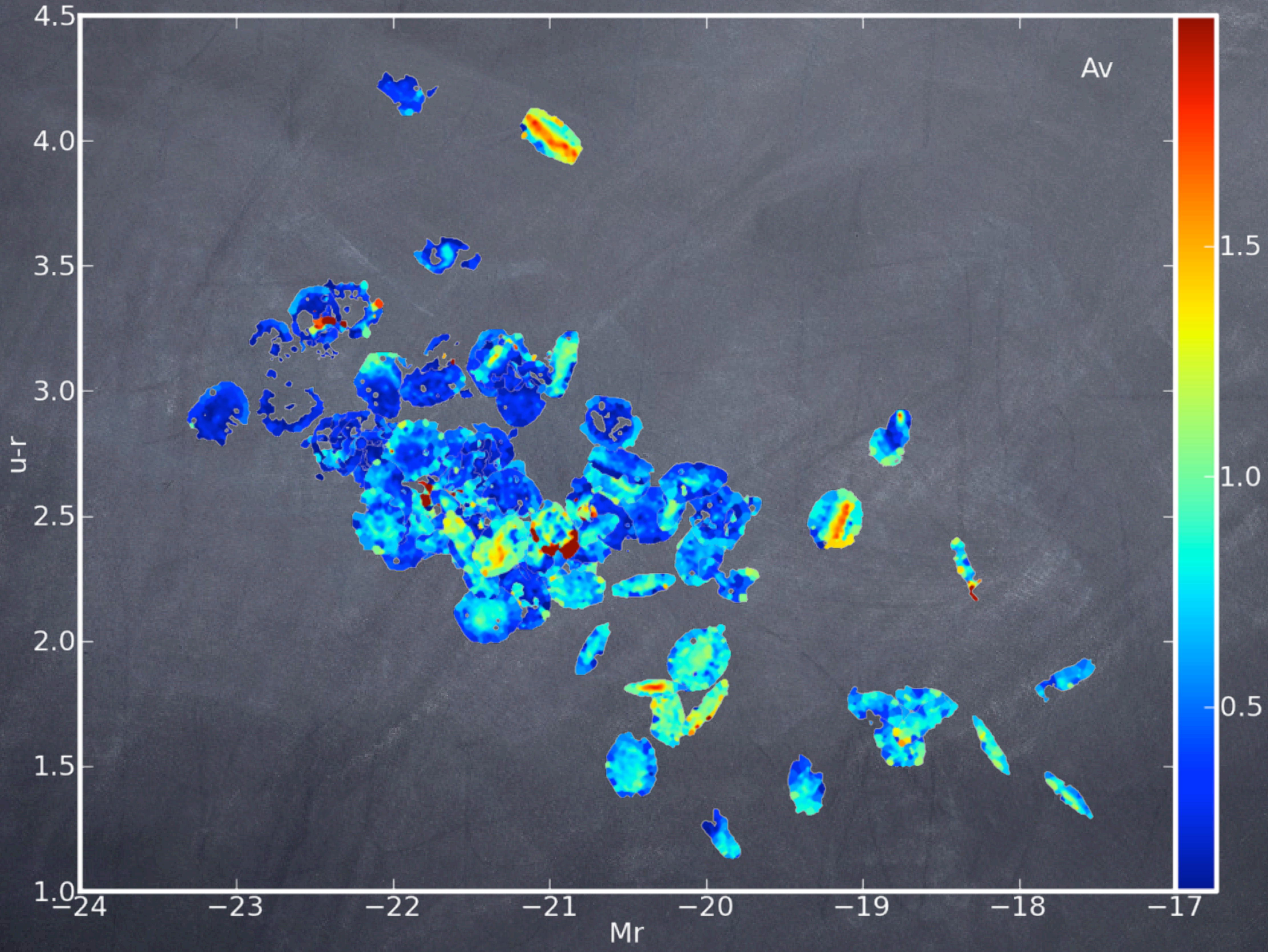

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−23
−22
−21
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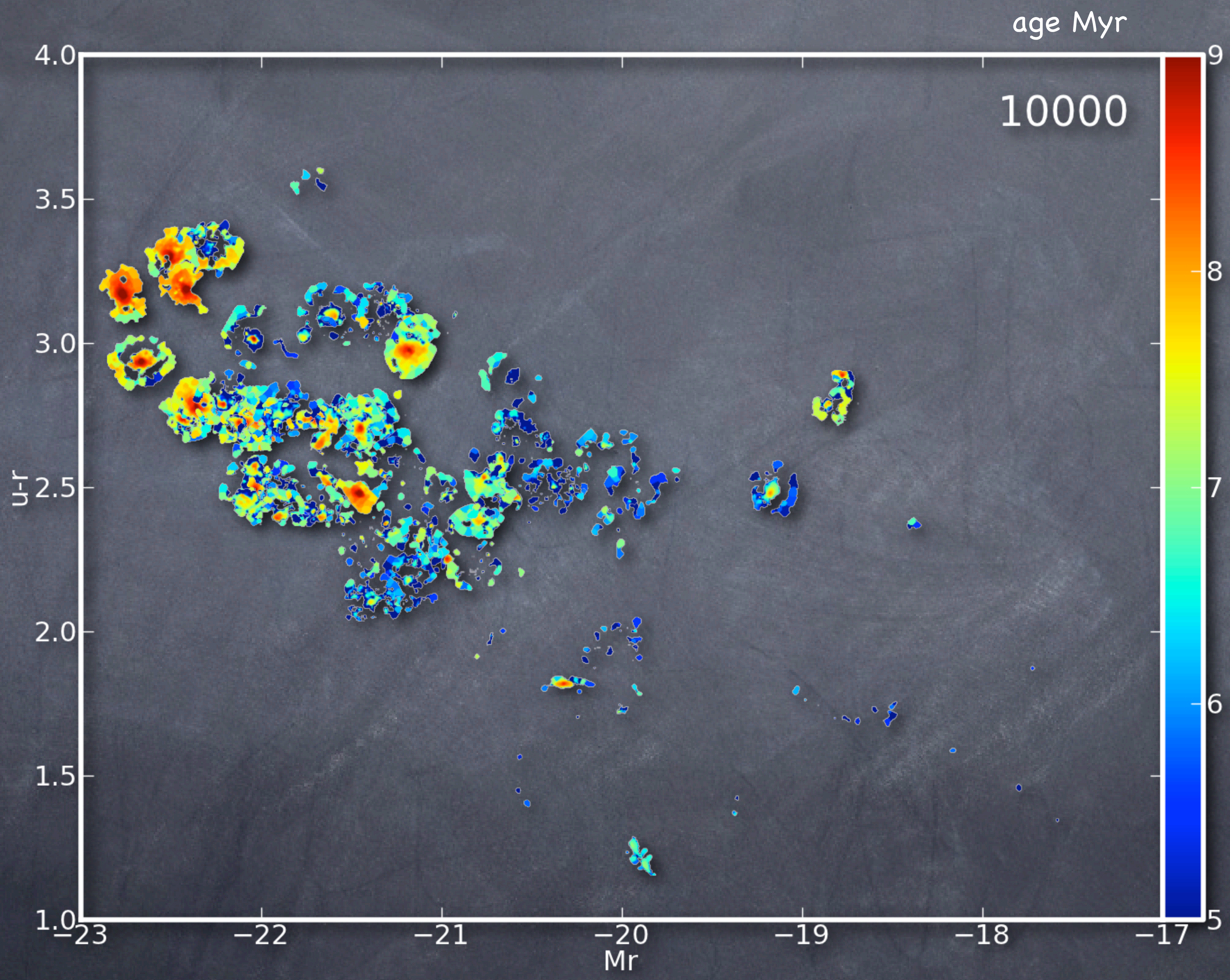
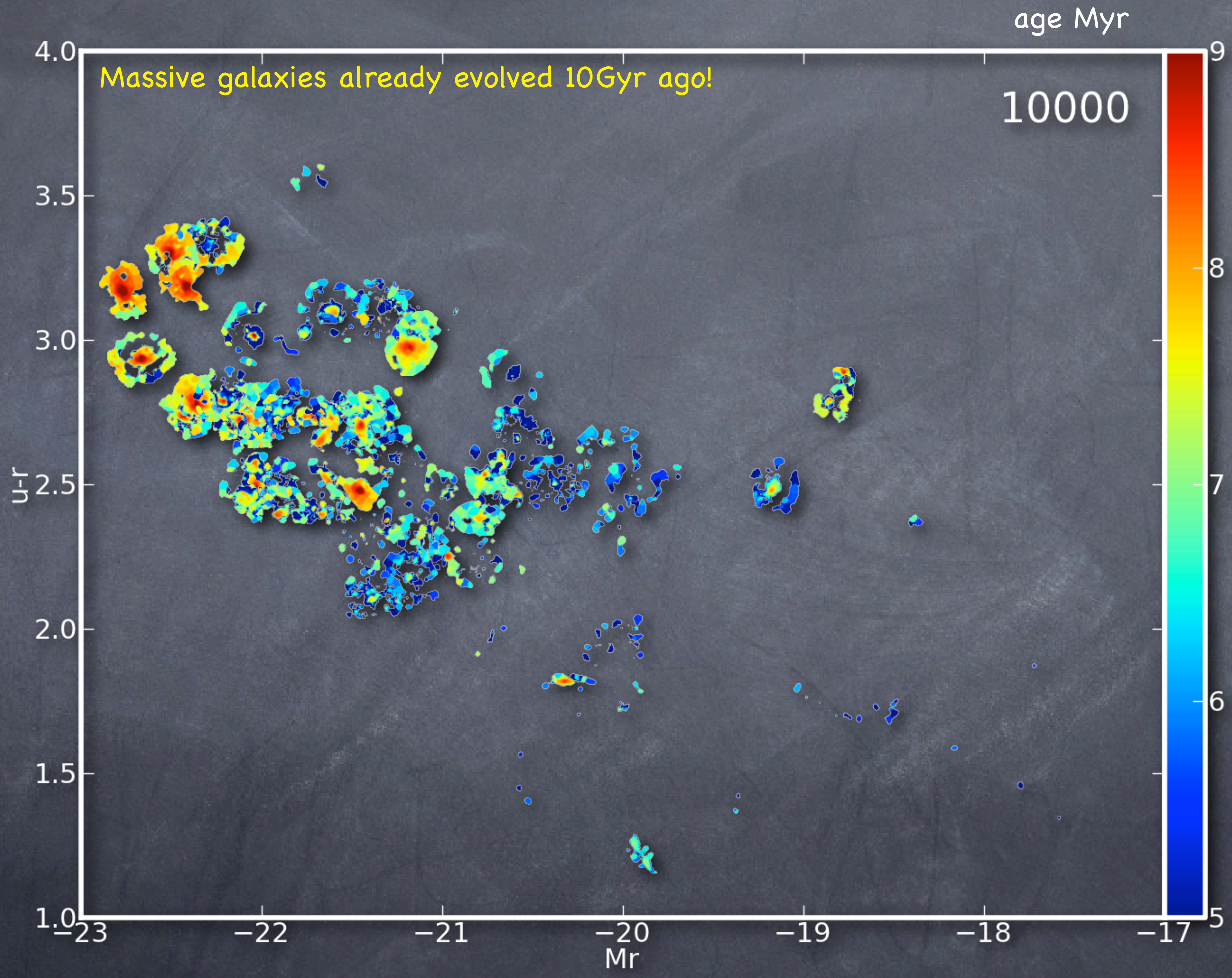
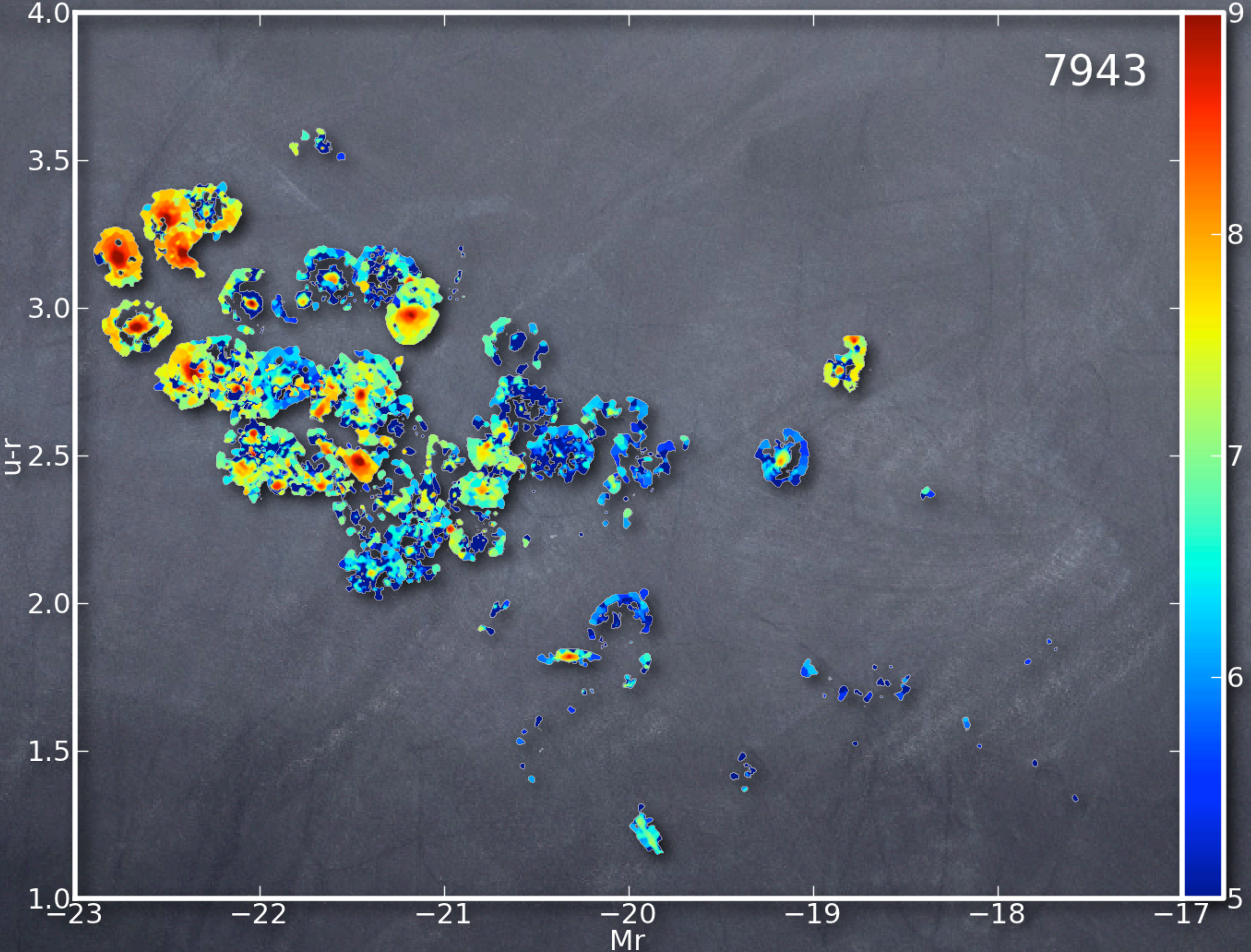
−18
−17
Mr

How Mass builds up in time



How Mass builds up in time





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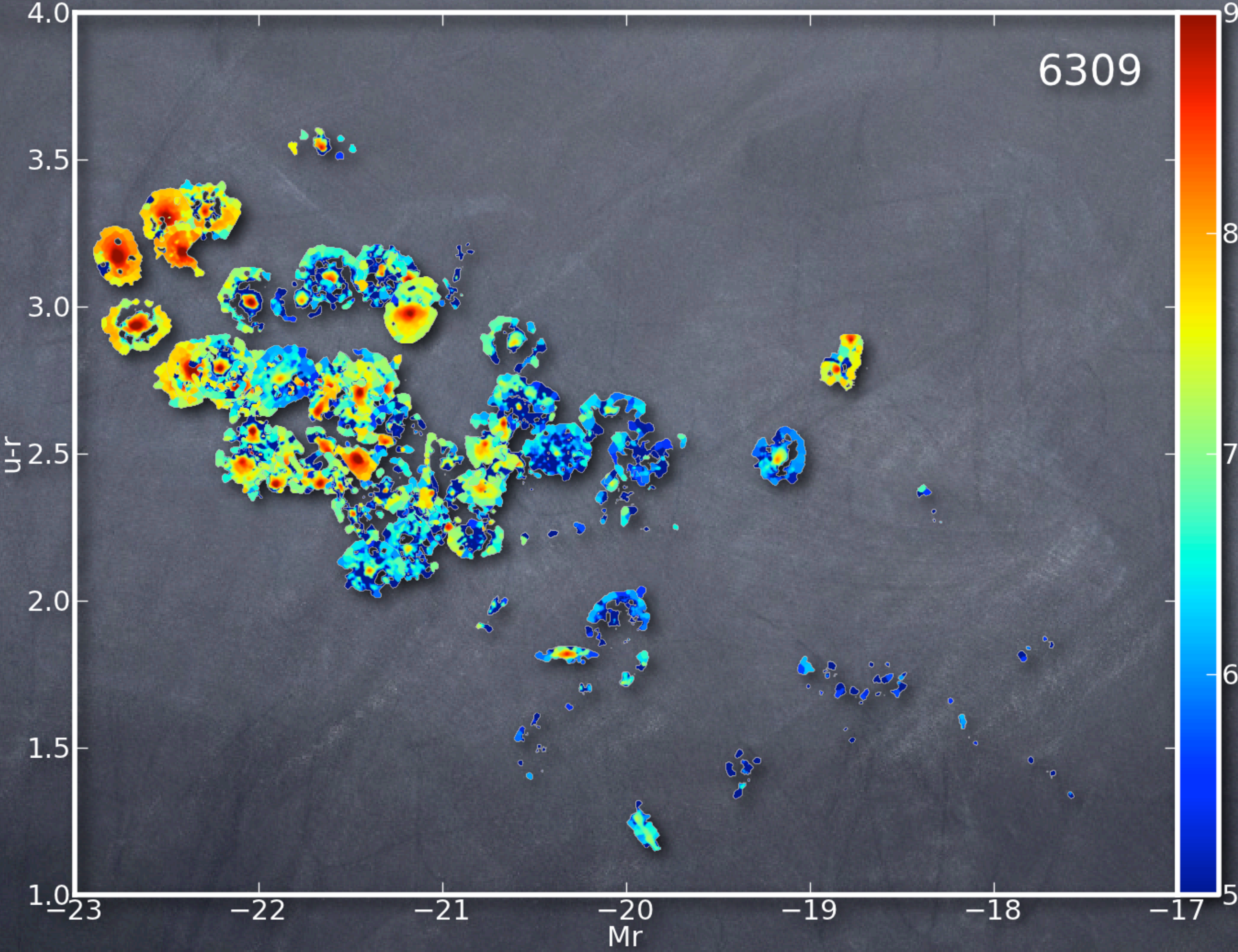
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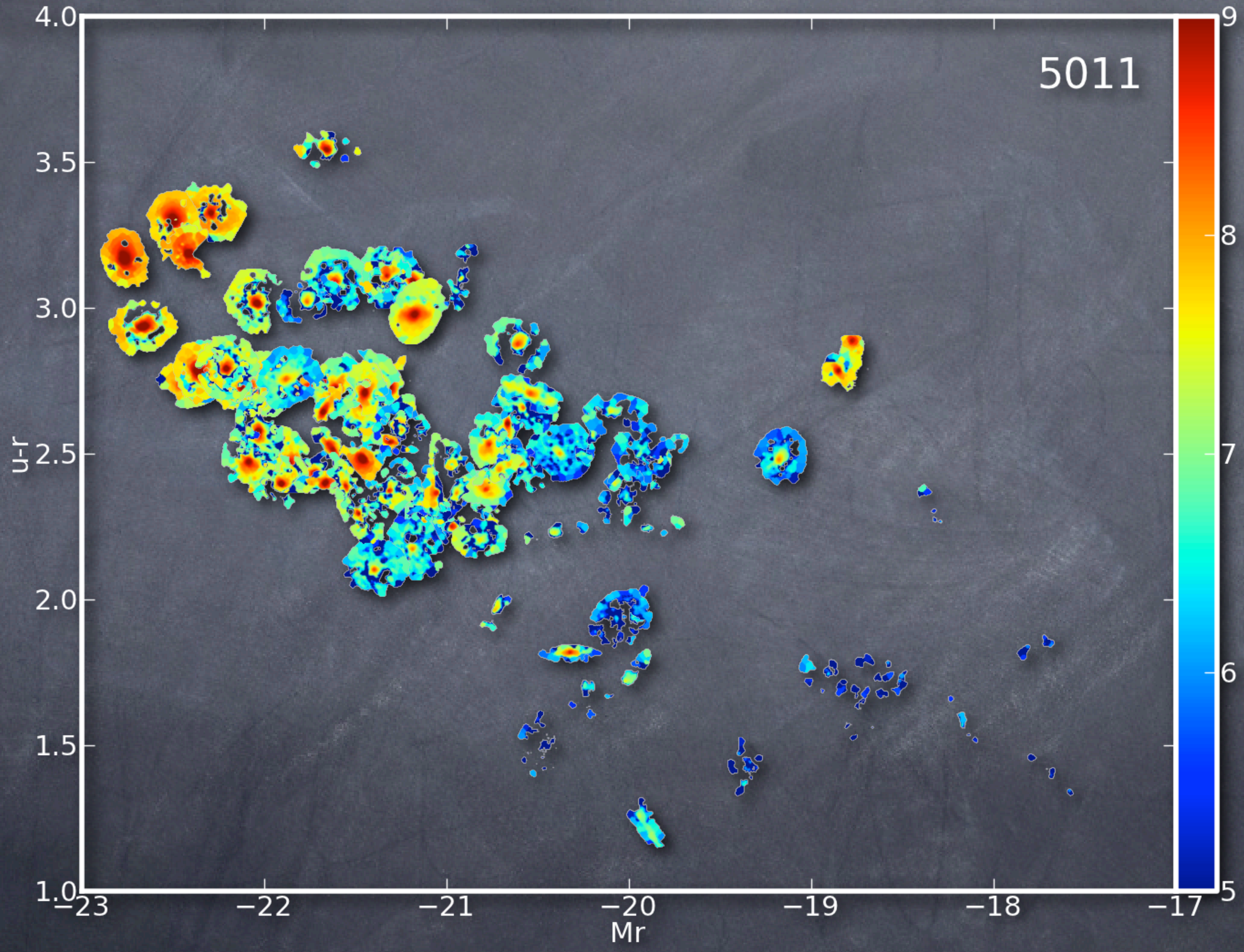
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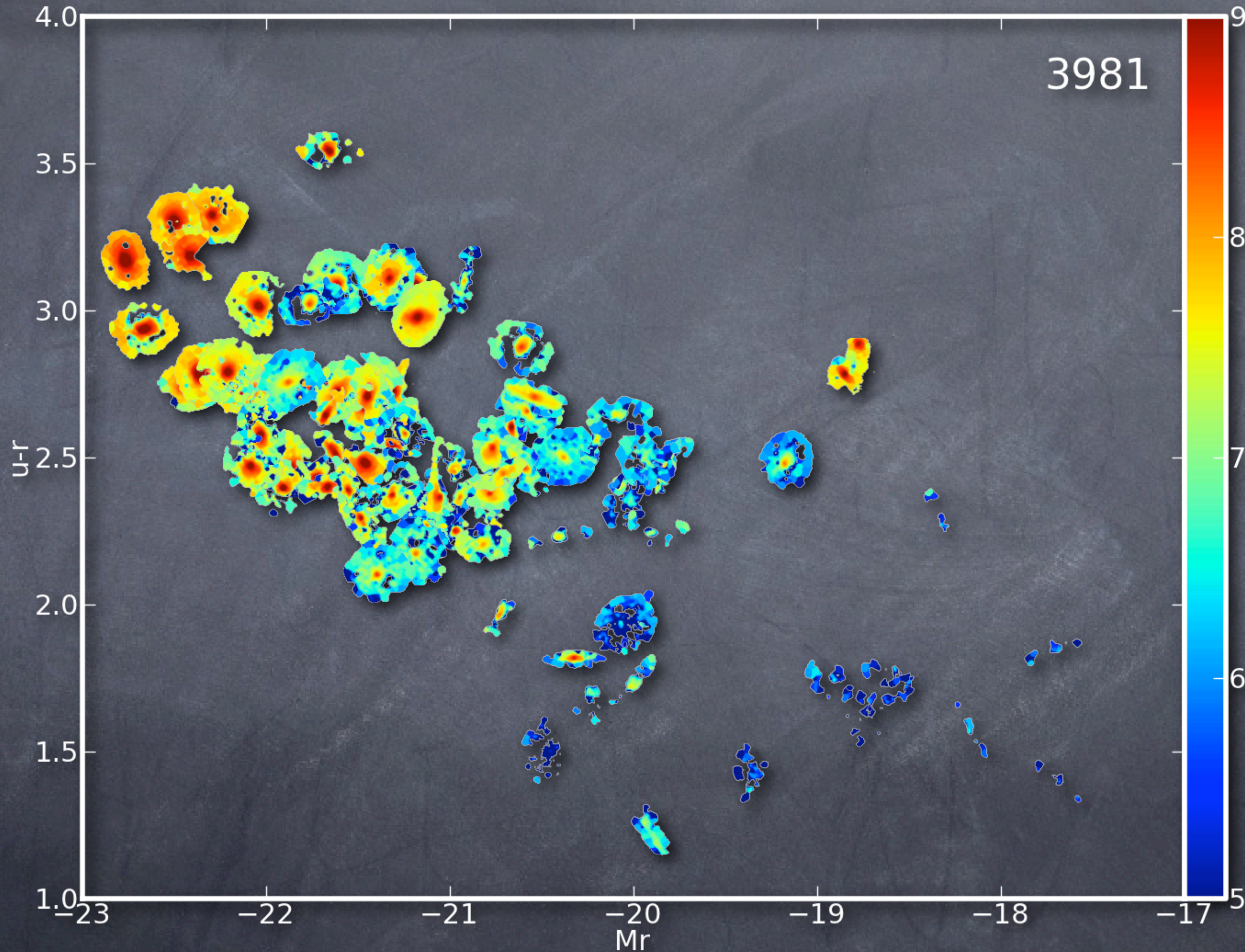
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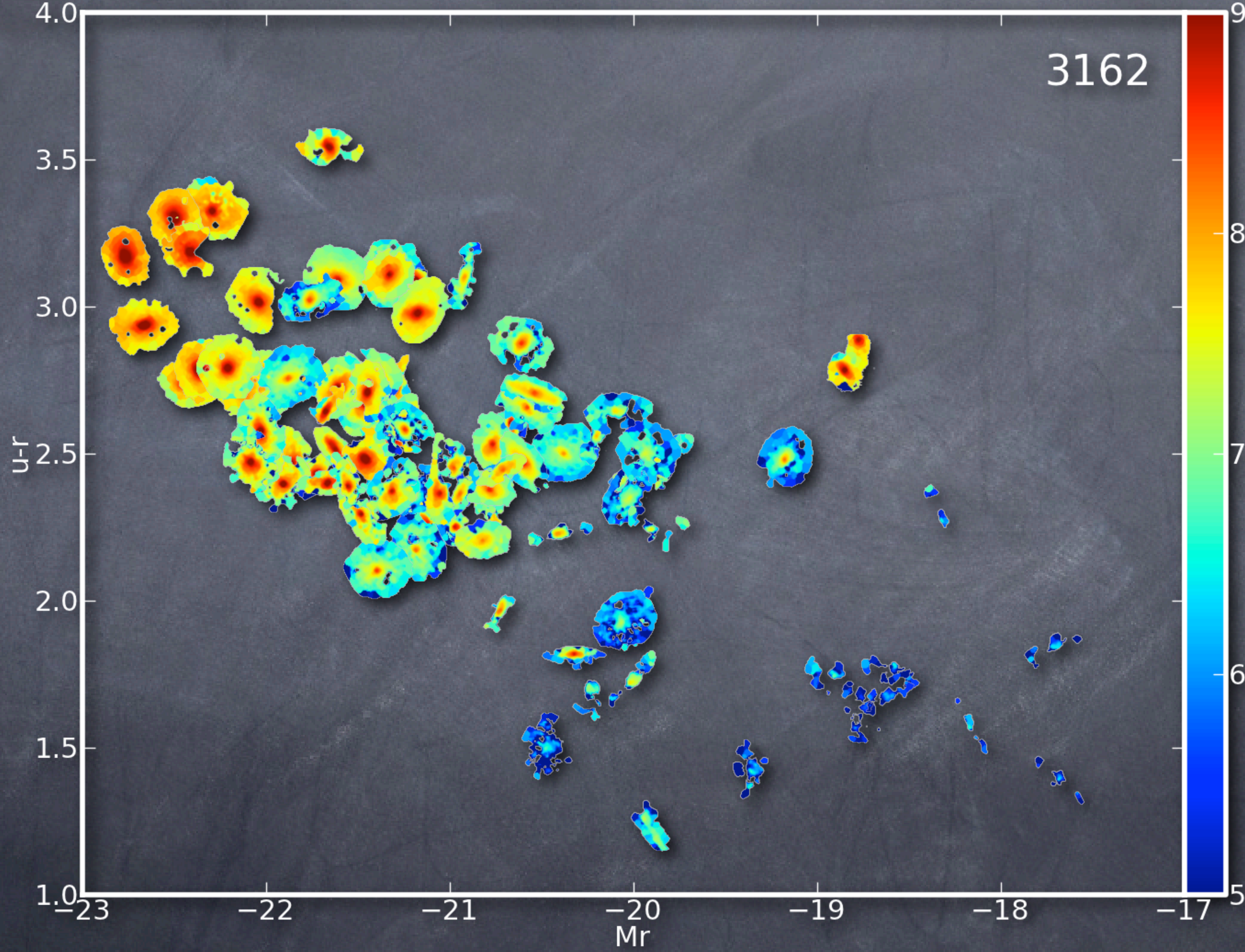
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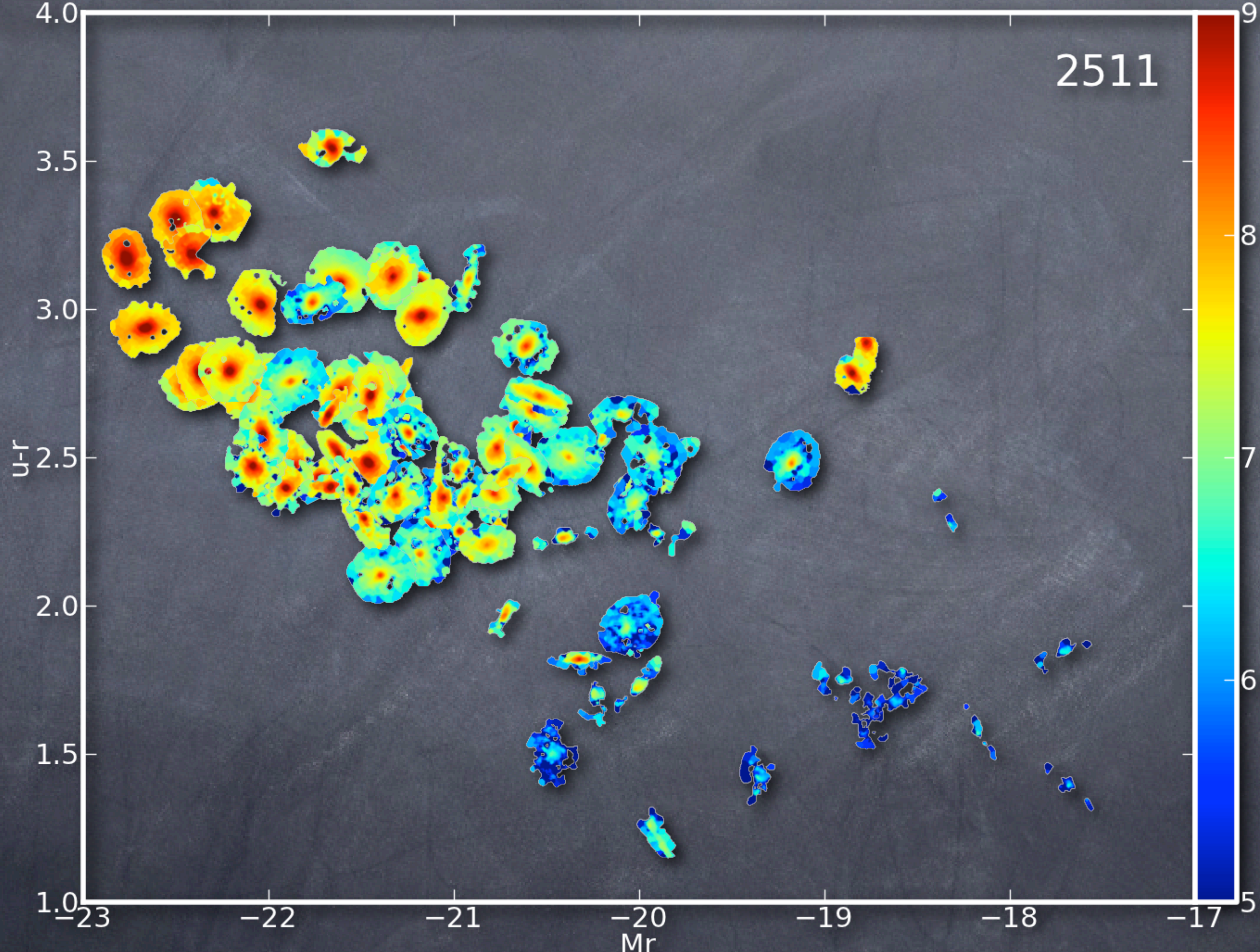

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Mr
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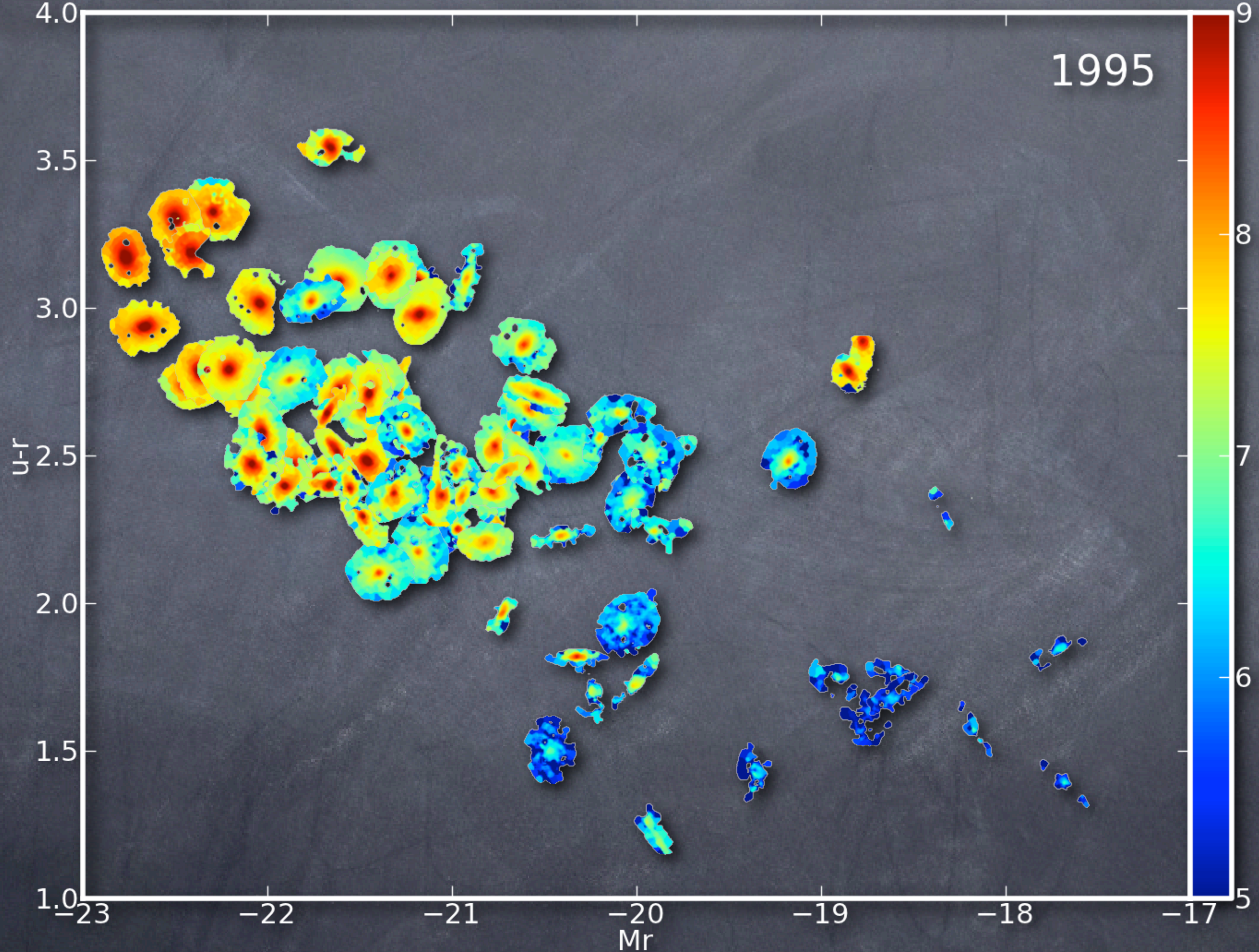
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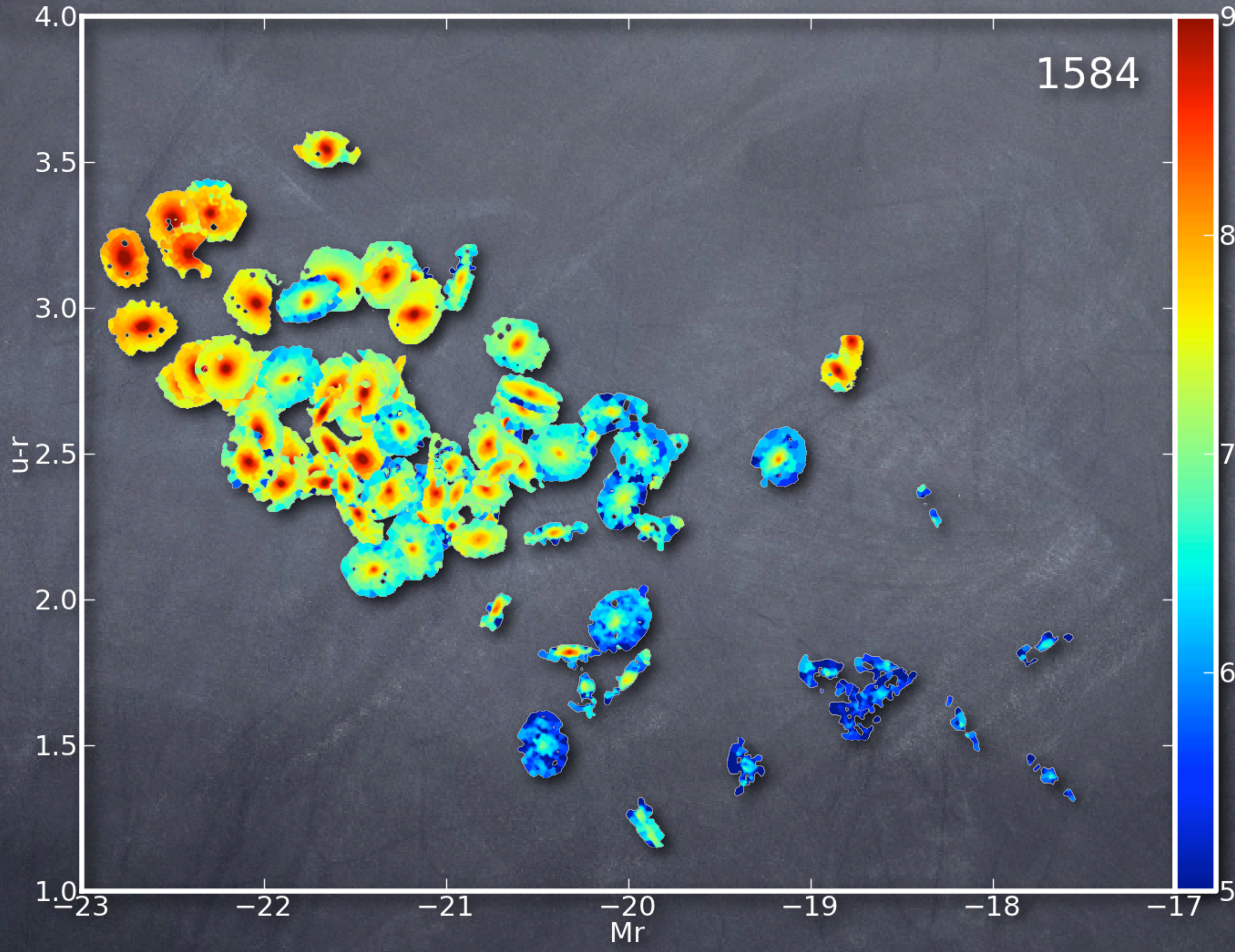
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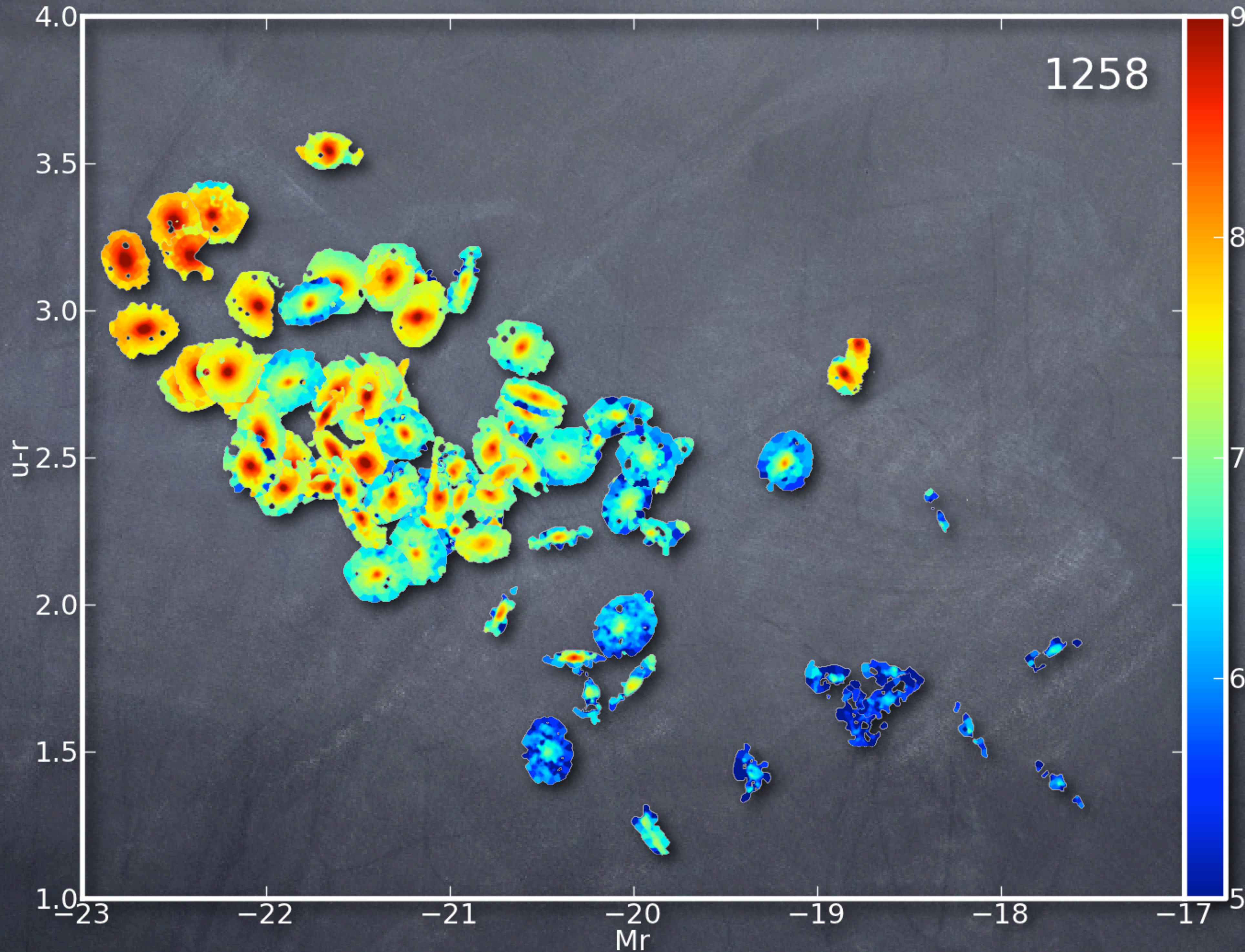

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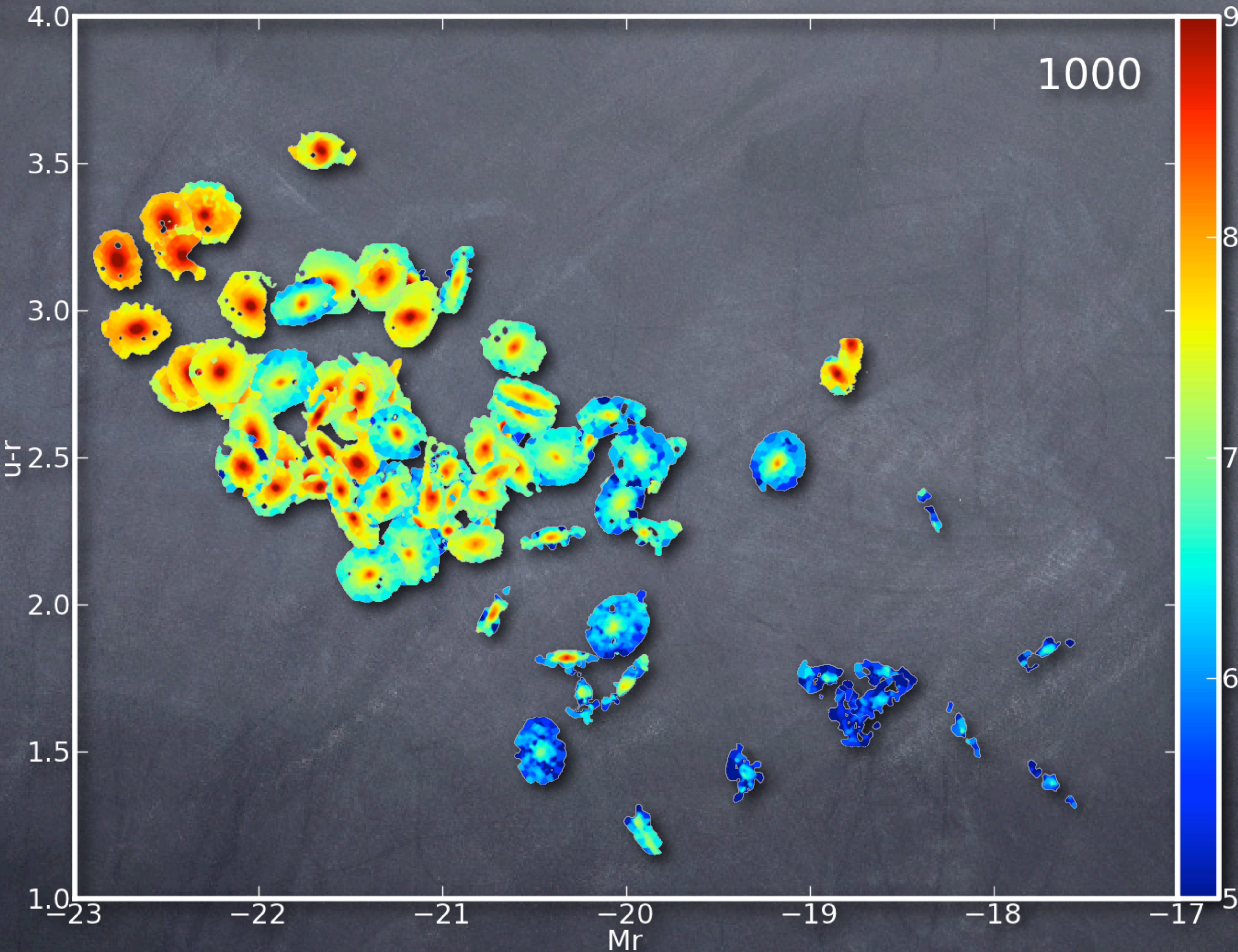
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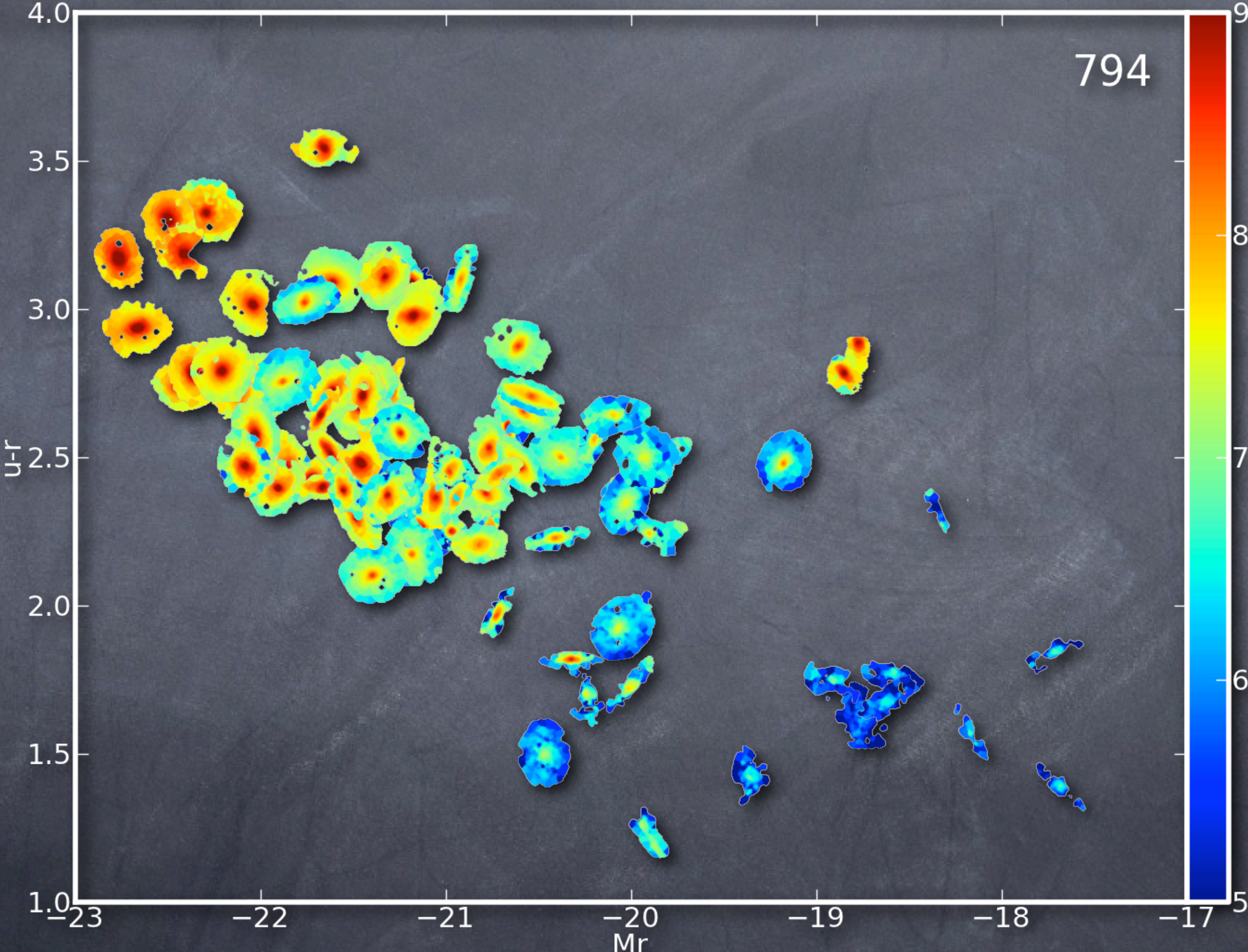

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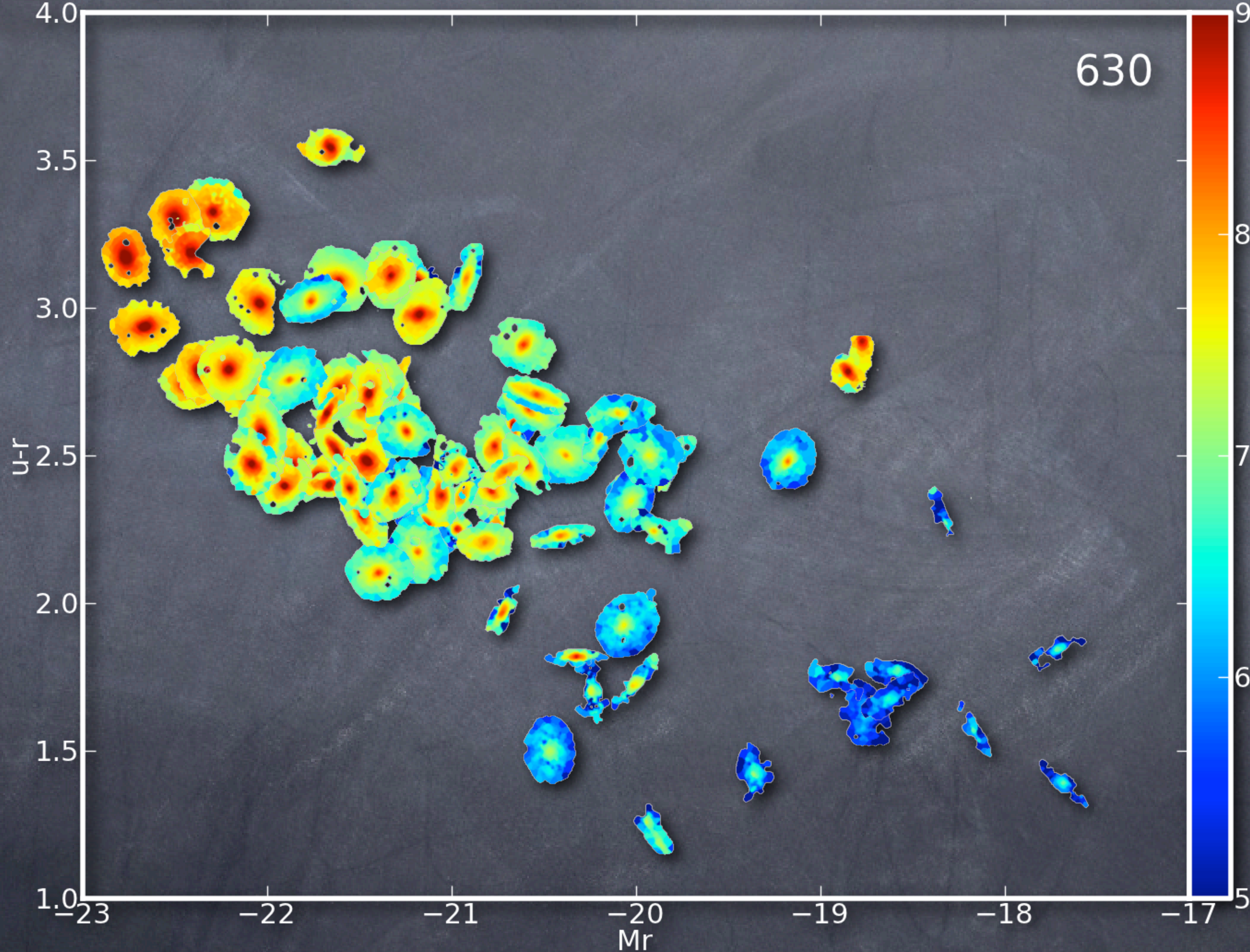
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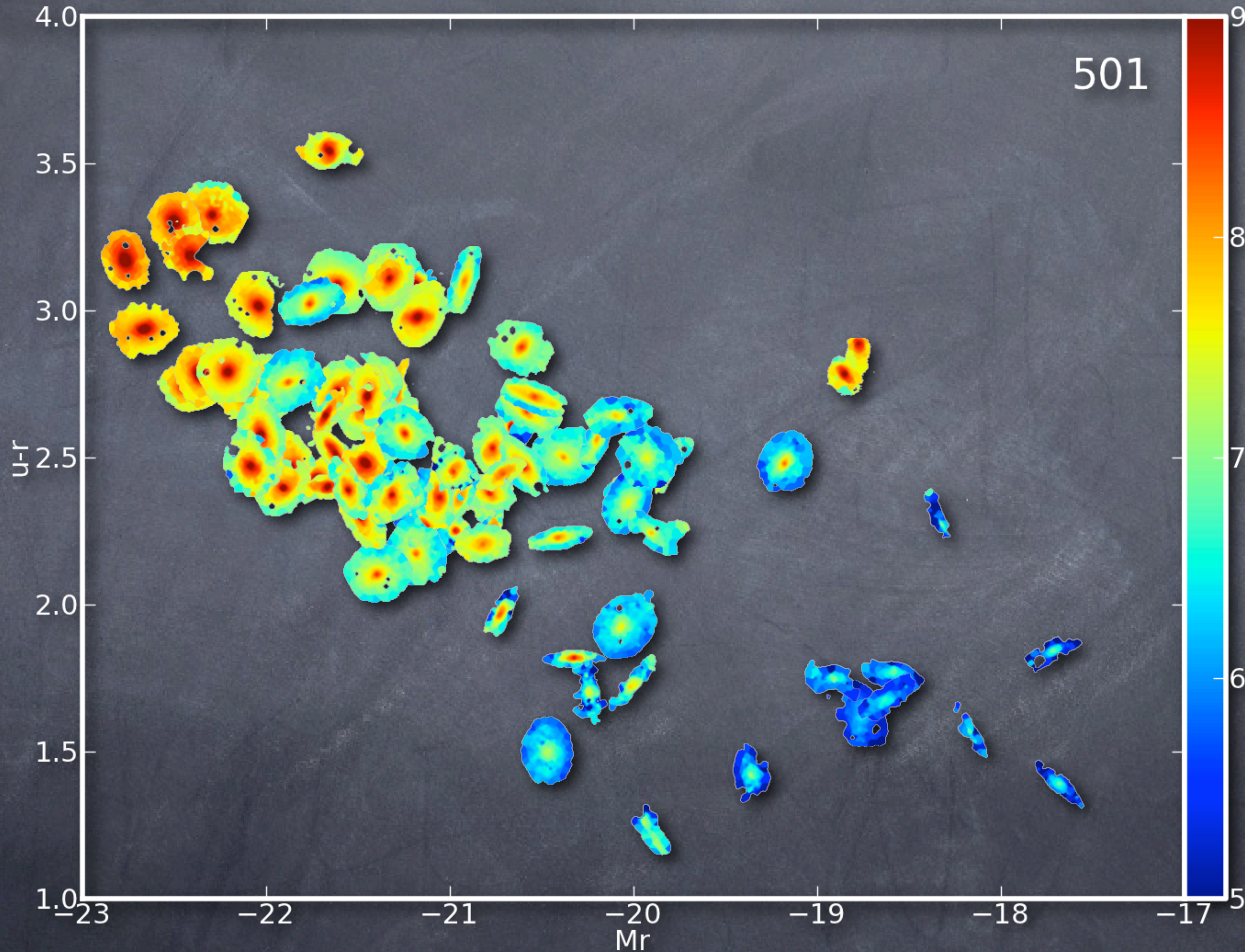

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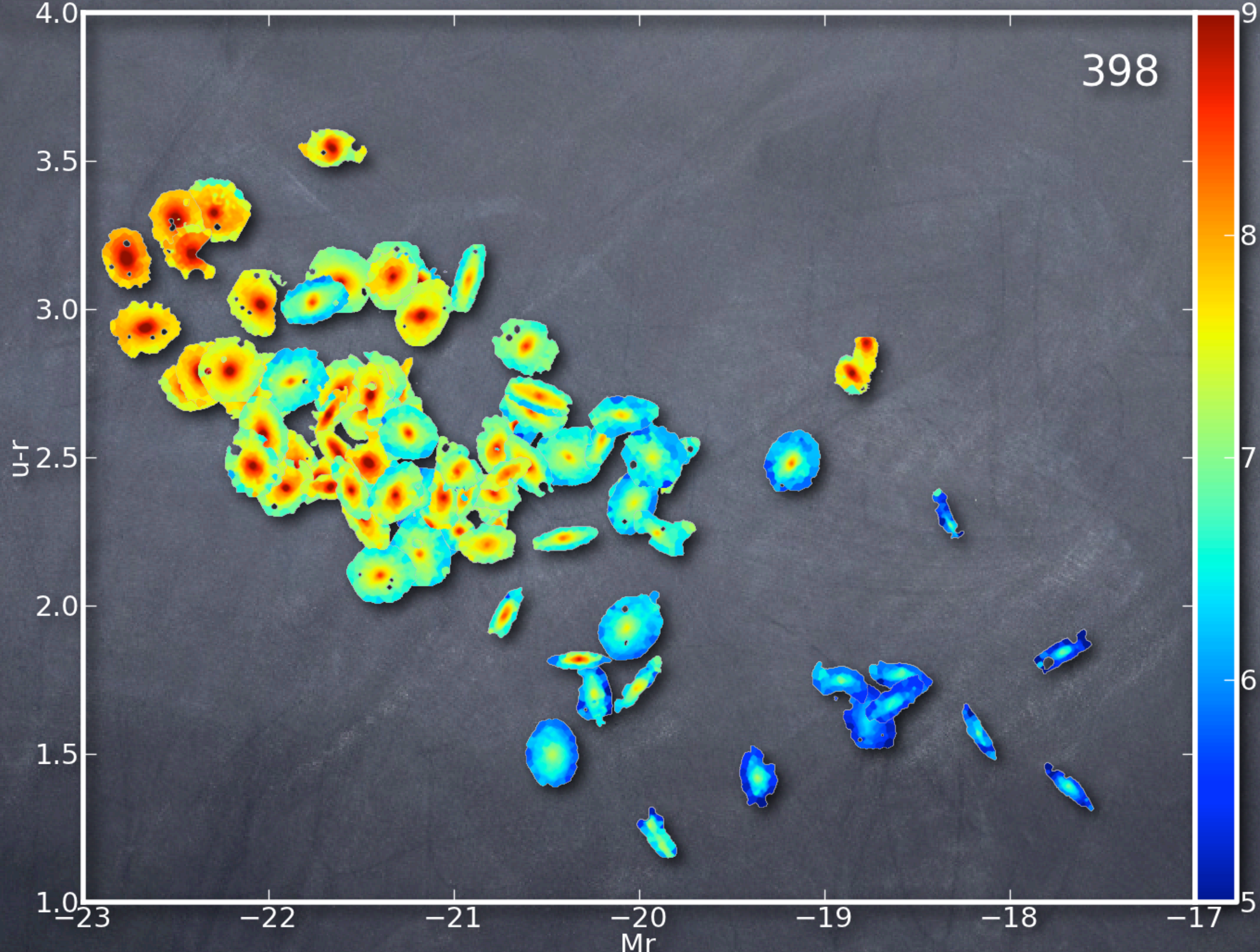
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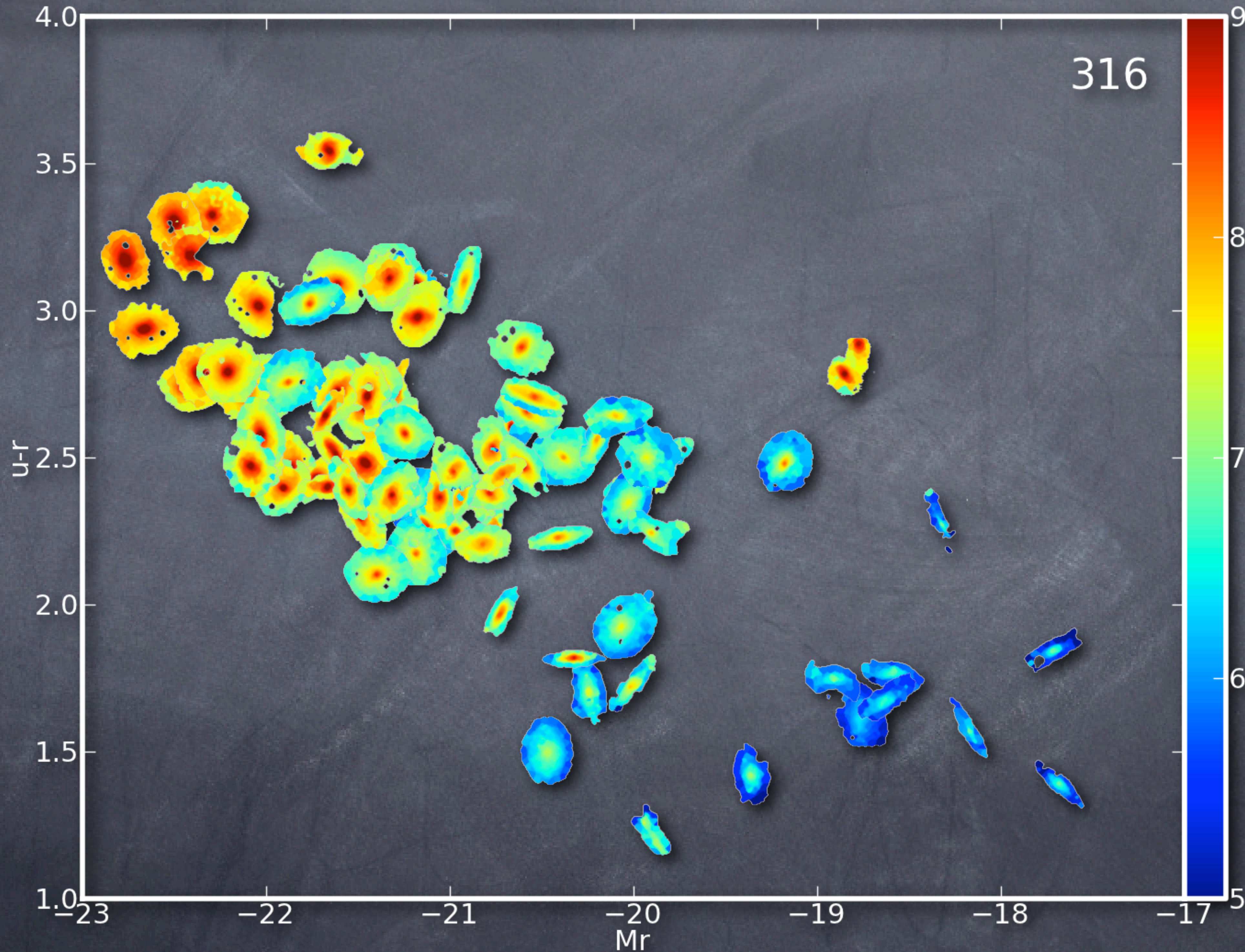

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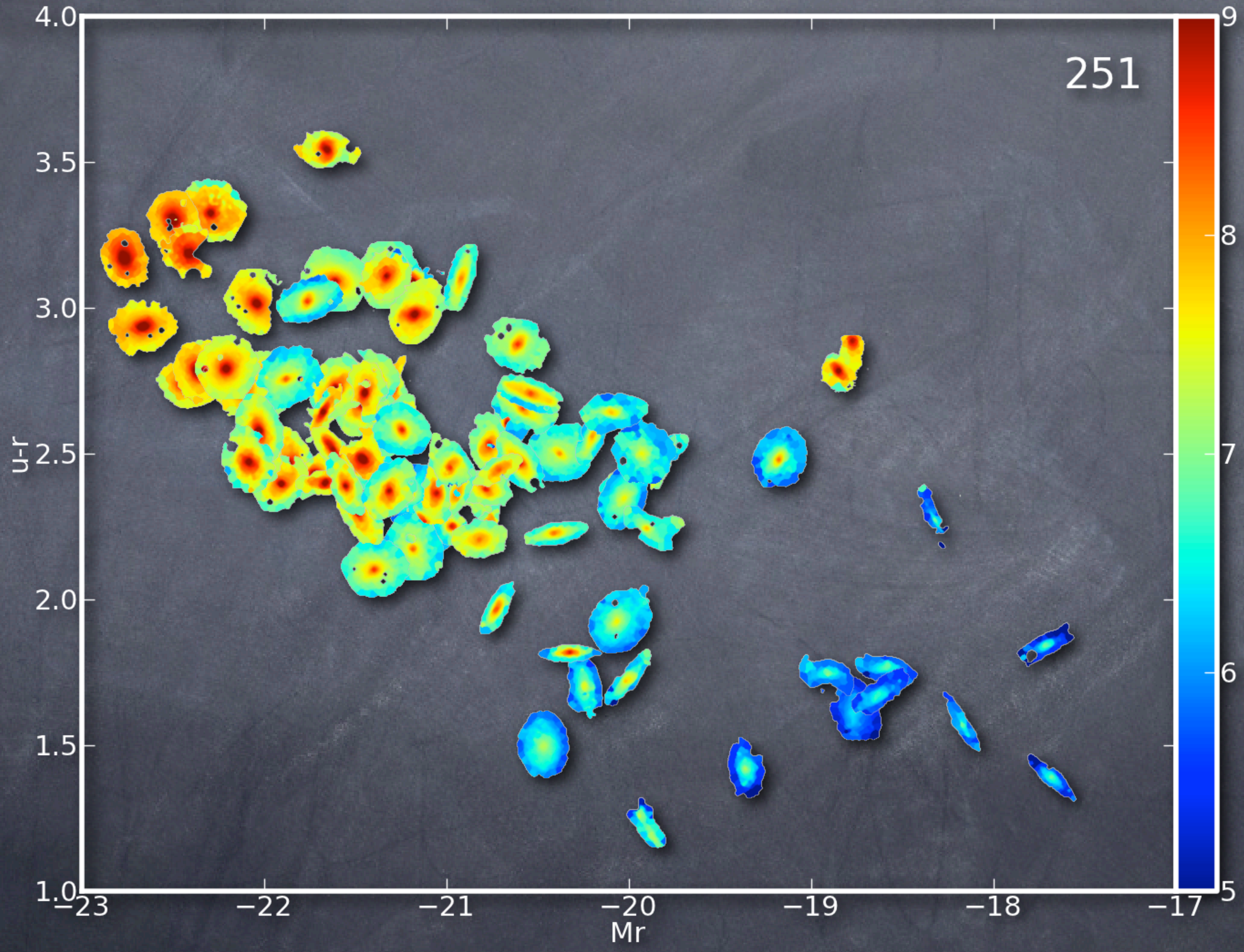
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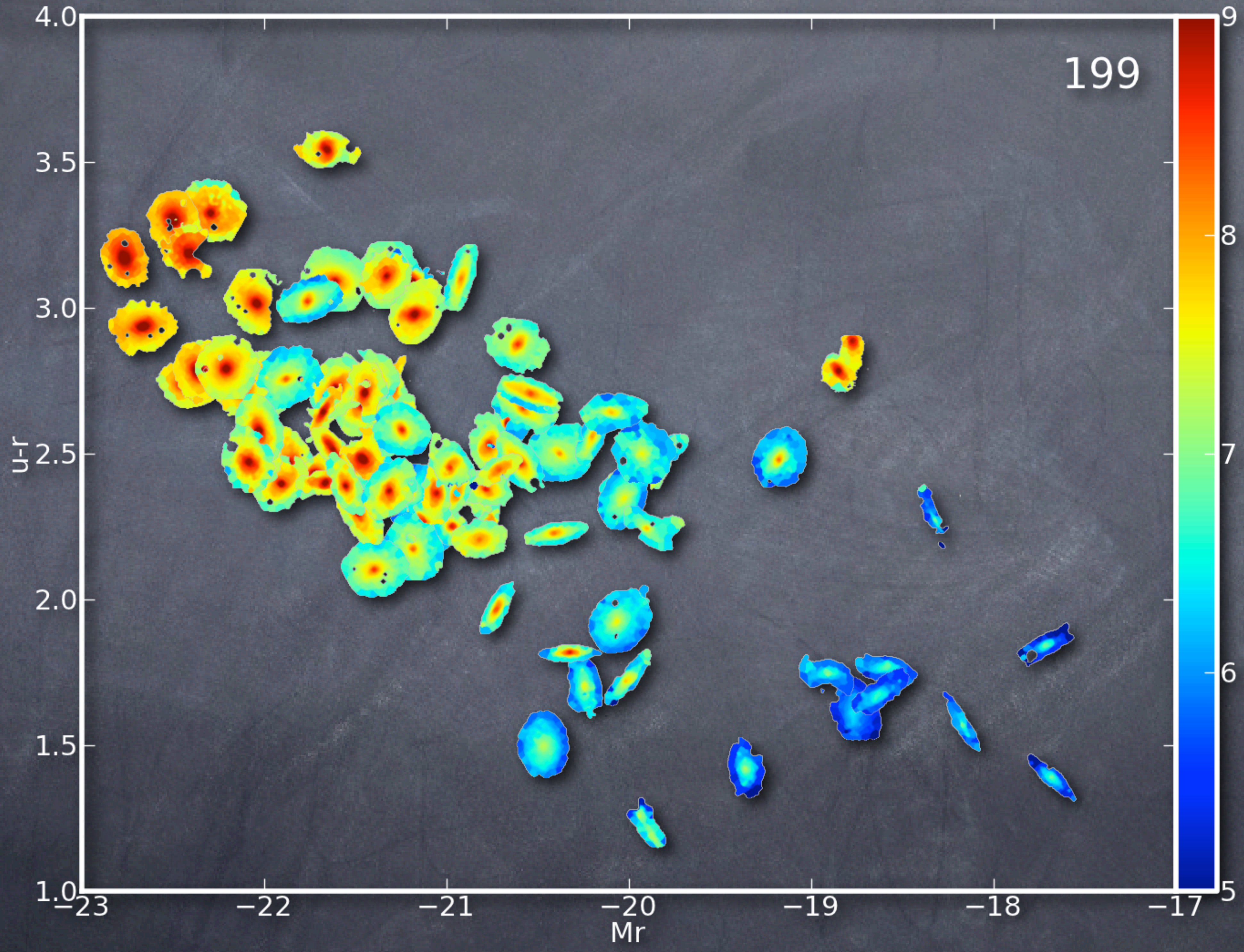

199
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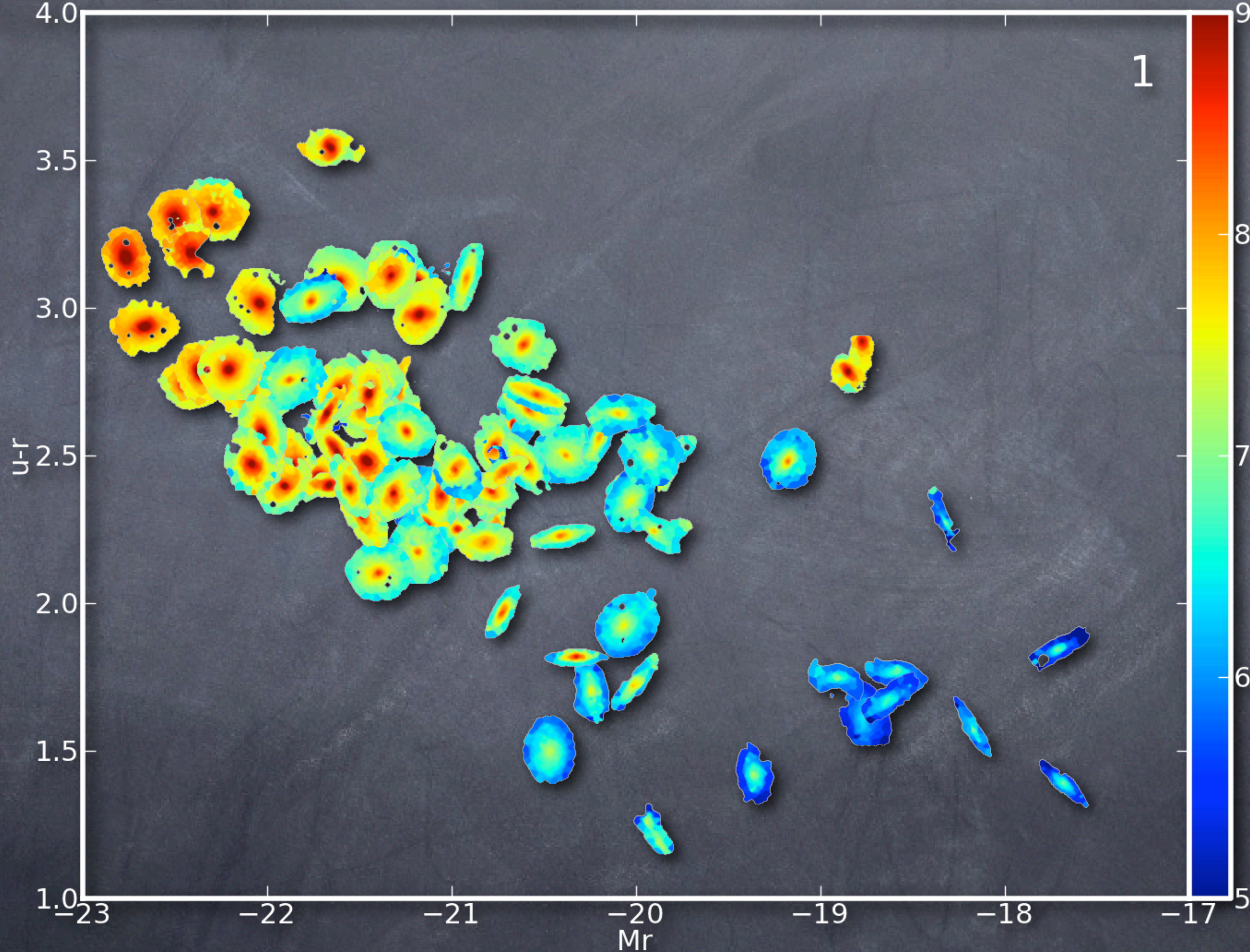
1
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Mr
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1.5
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−23
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−20
−19
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9
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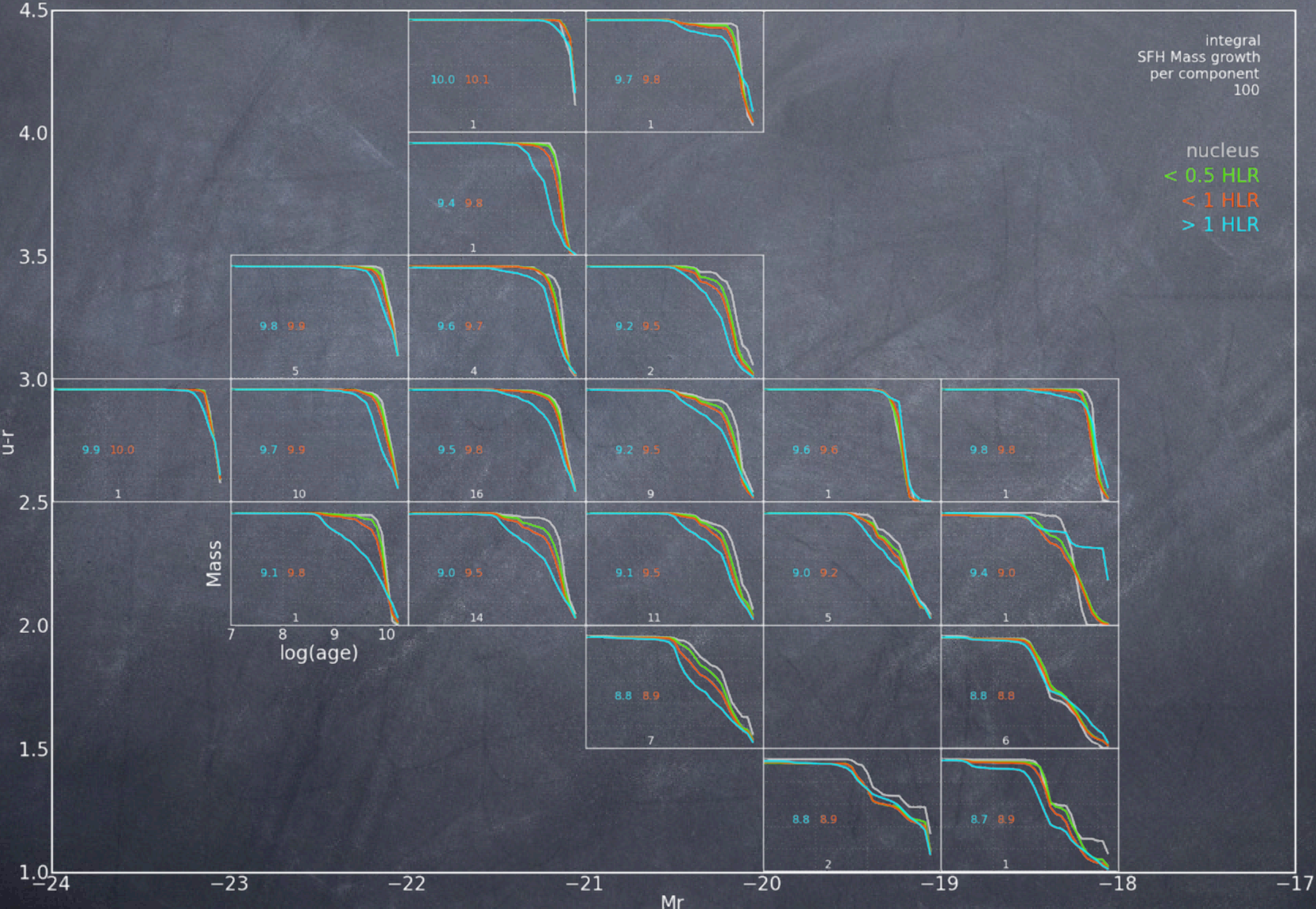
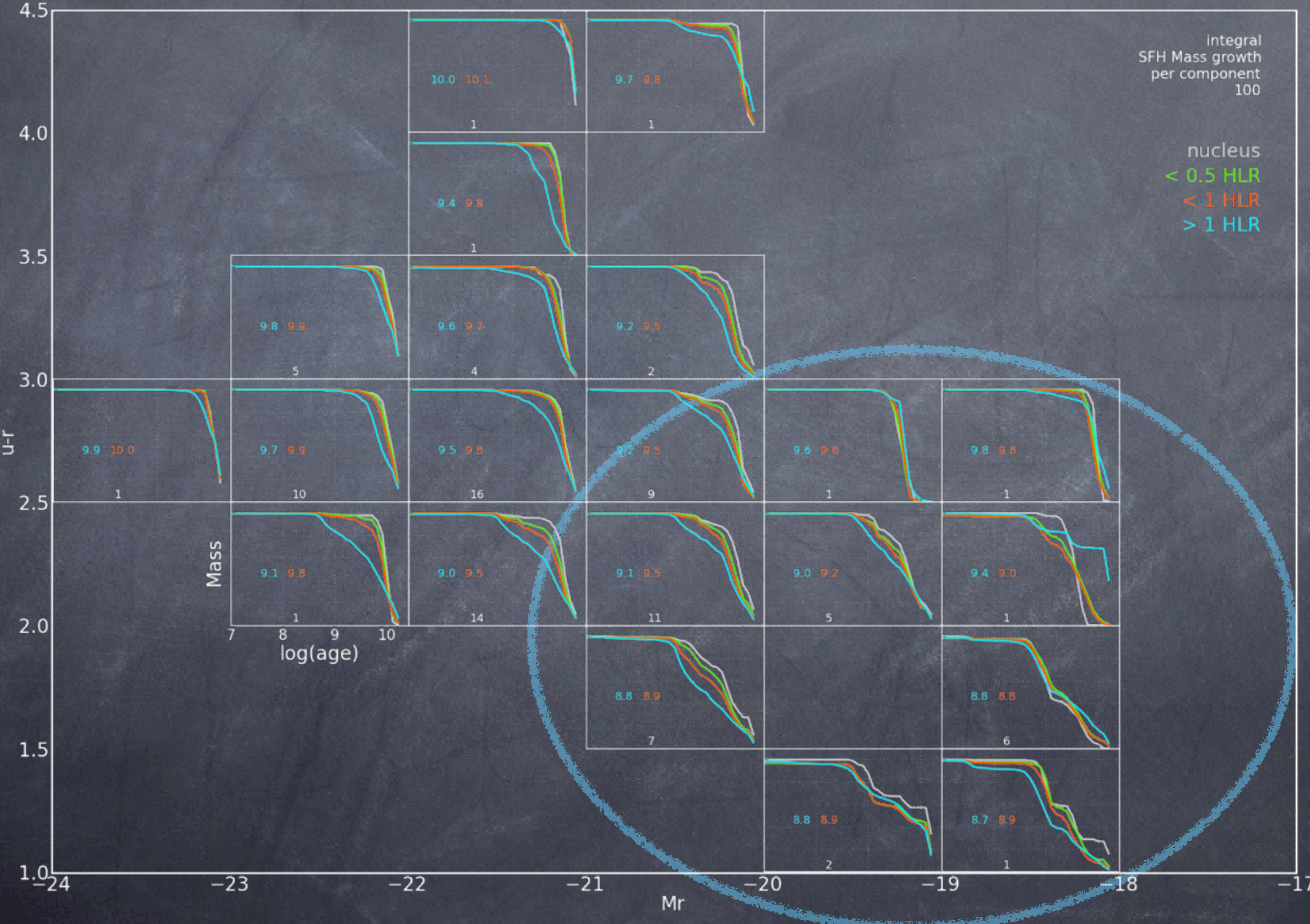
6
5

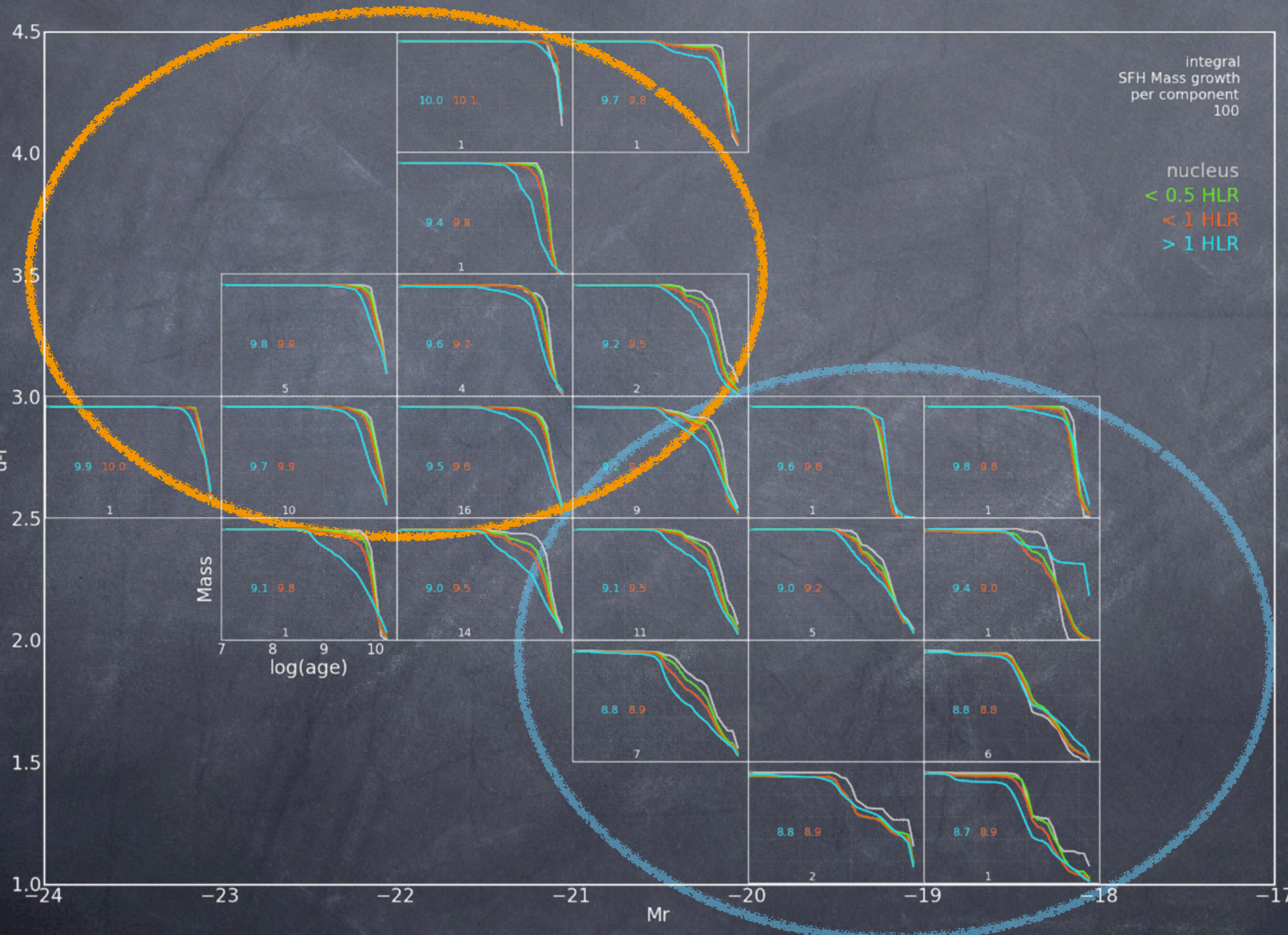
Mass build up



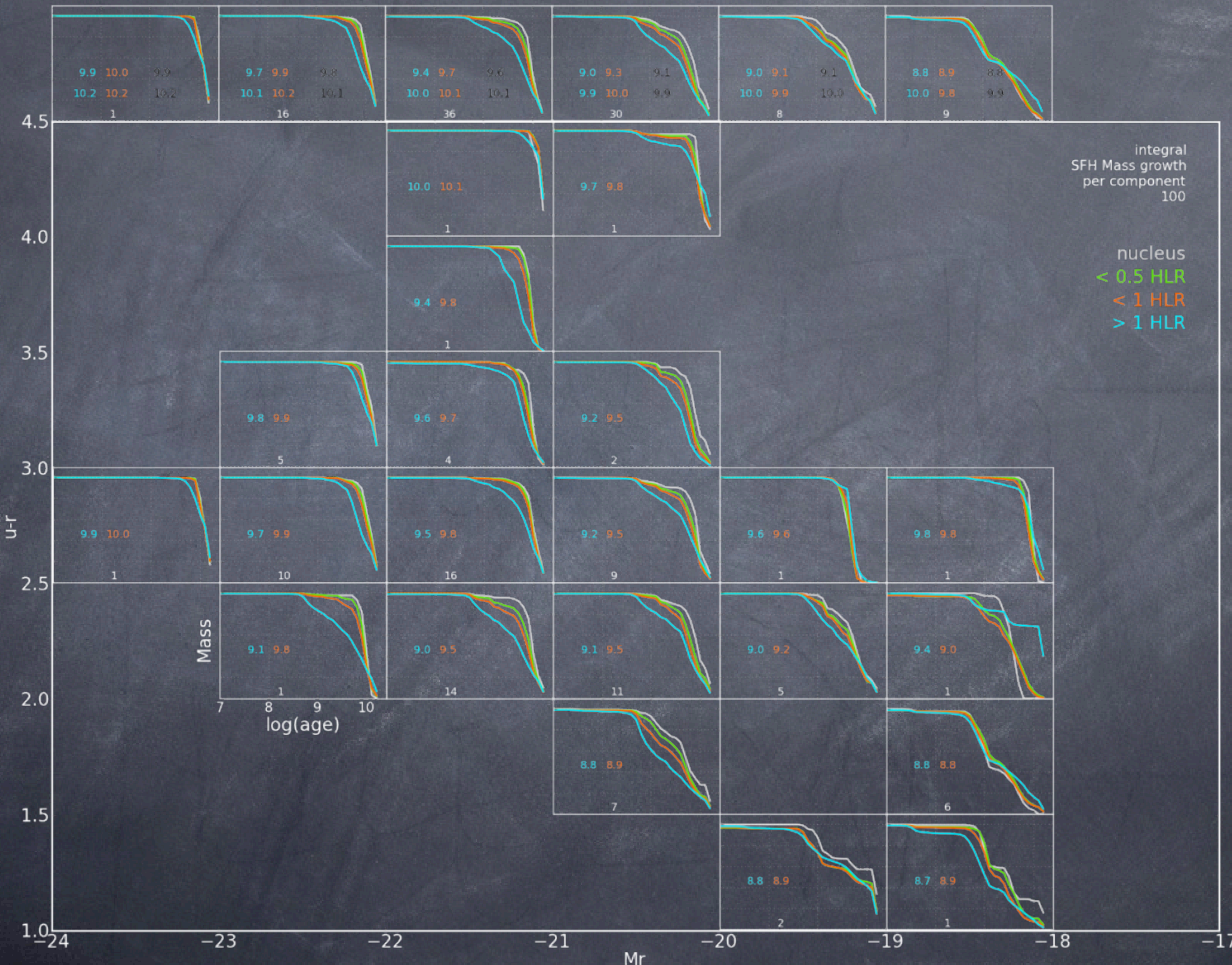
Mass build up



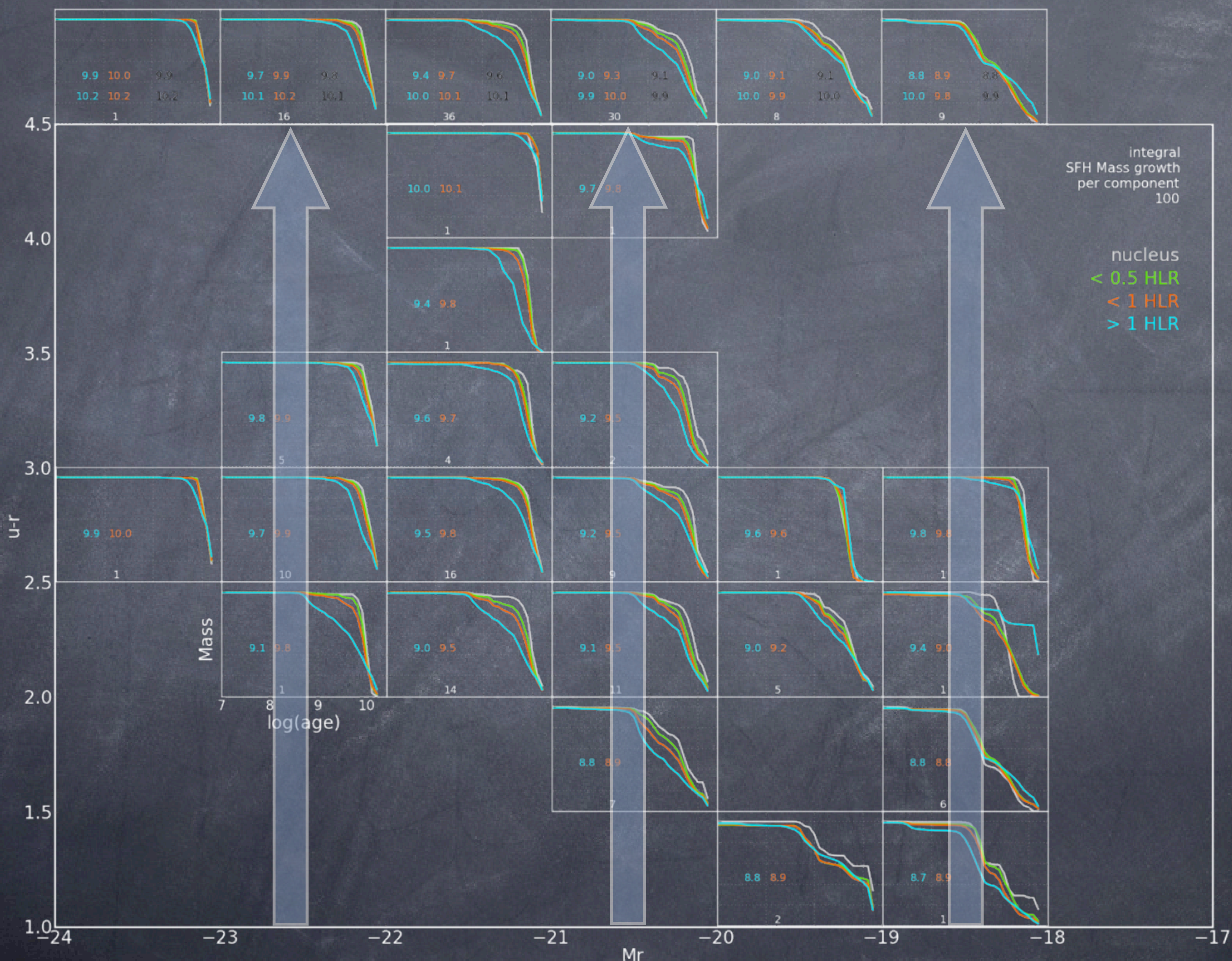
Mass build up



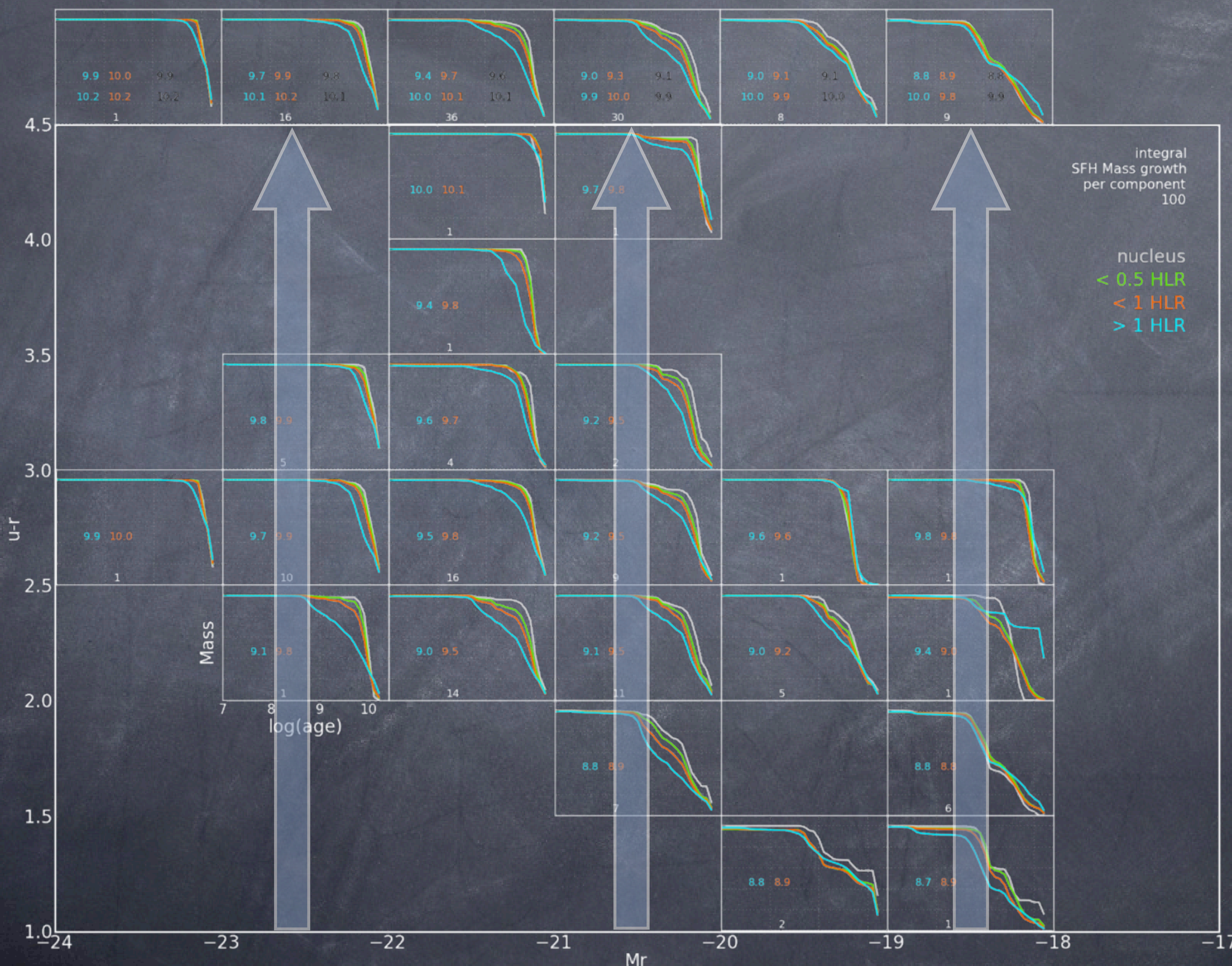
Mass build up

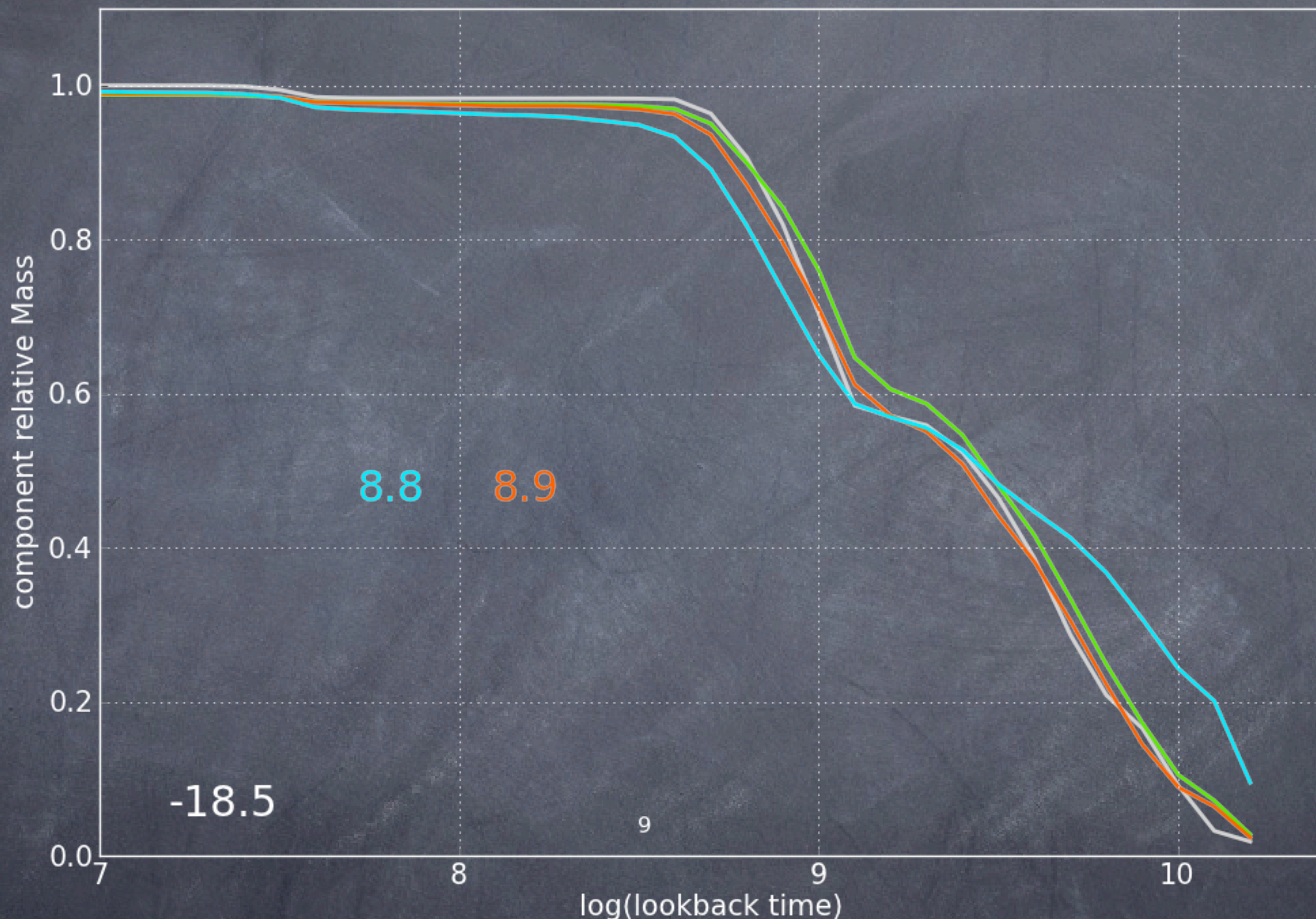


Mass build up



Mass build up





component relative Mass
log(lookback time)
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0.8
0.6
0.4
0.2
0.0
7
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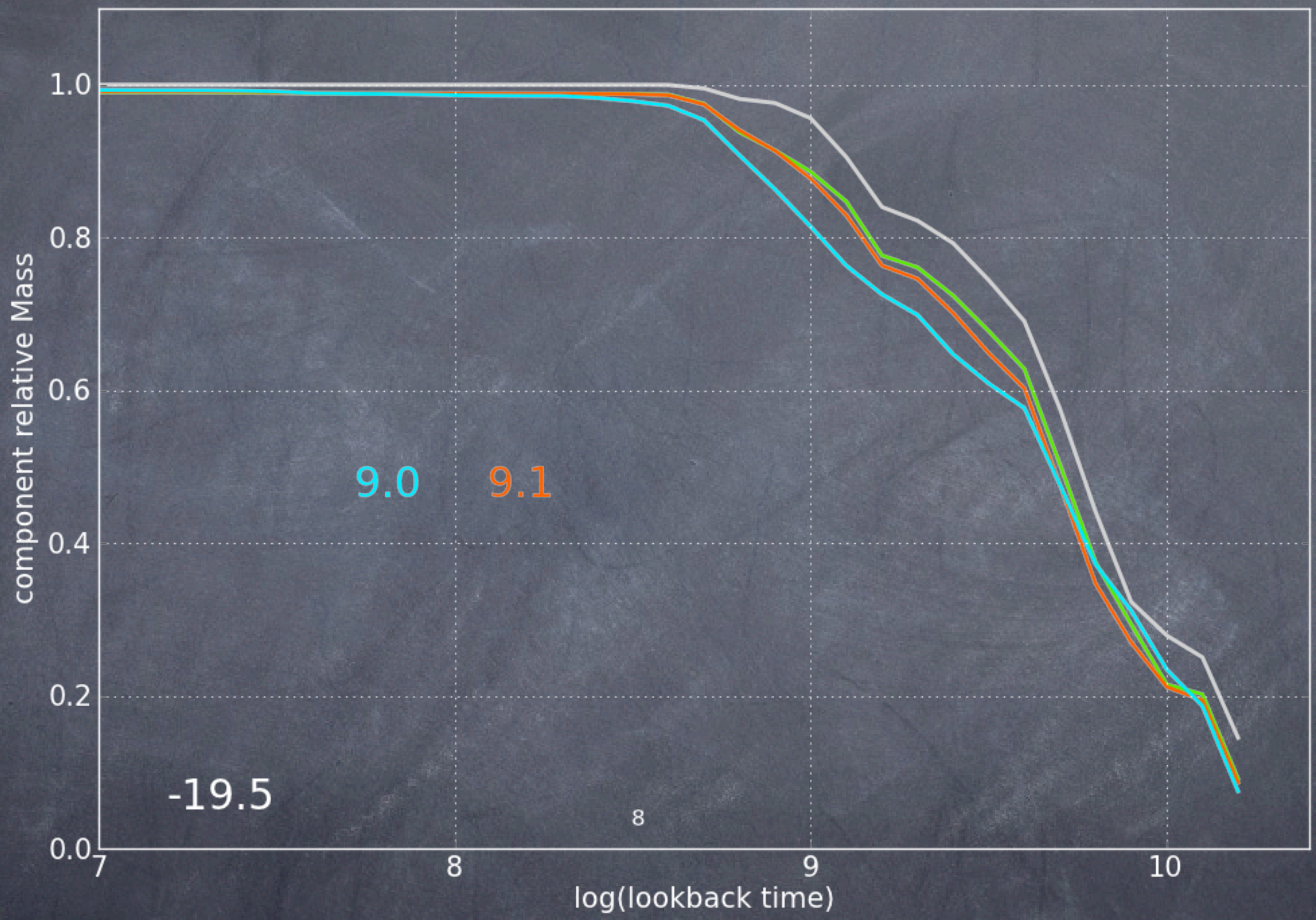
9
10
8.8
8.9
-18.5
9



component relative Mass
log(lookback time)
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0.4
0.2
0.0
7
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10
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9.1
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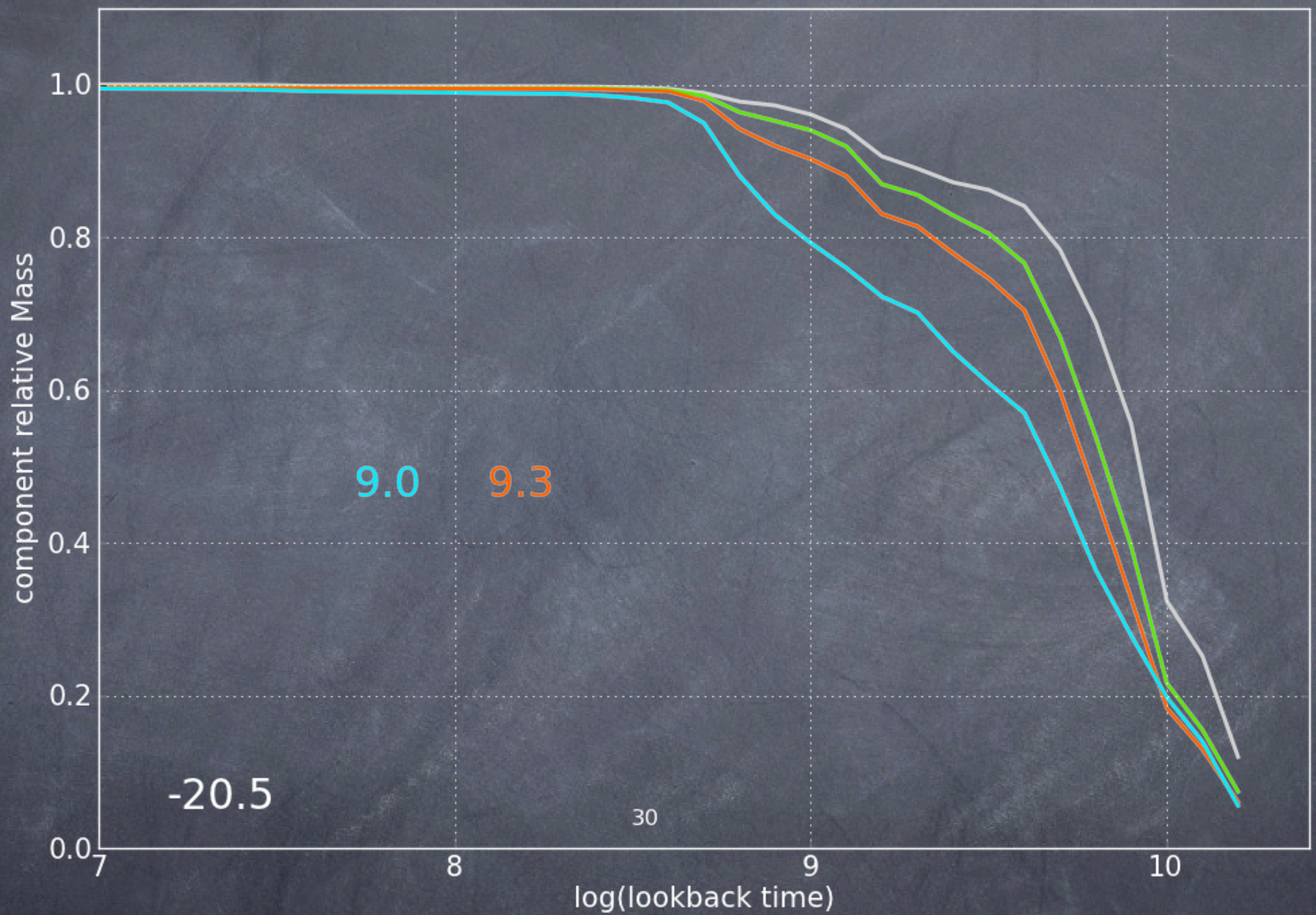
8



component relative Mass
log(lookback time)
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0.4
0.2
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9
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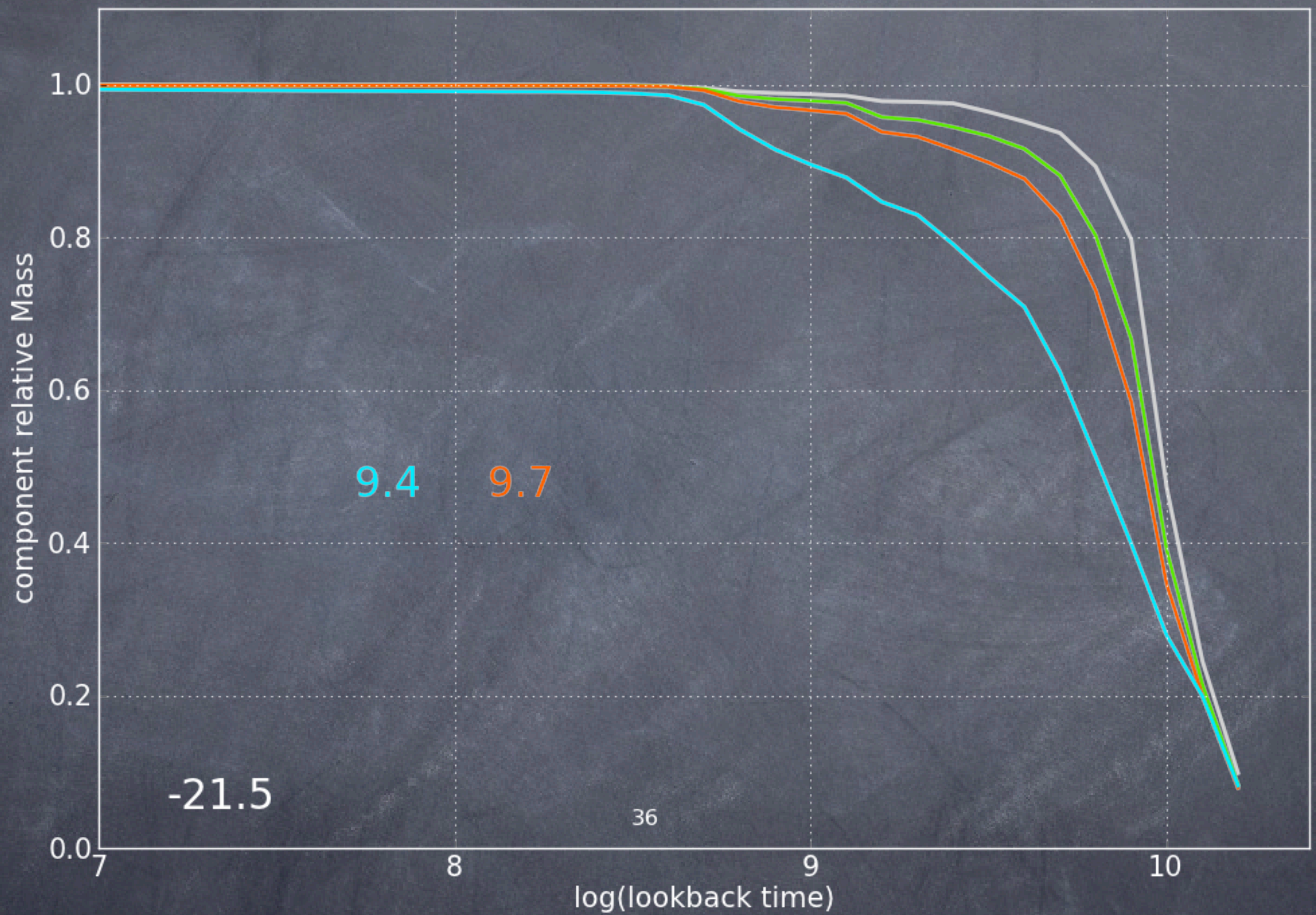

component relative Mass
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0.8
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0.2
0.0
7
8
9
10
log(lookback time)
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9.7
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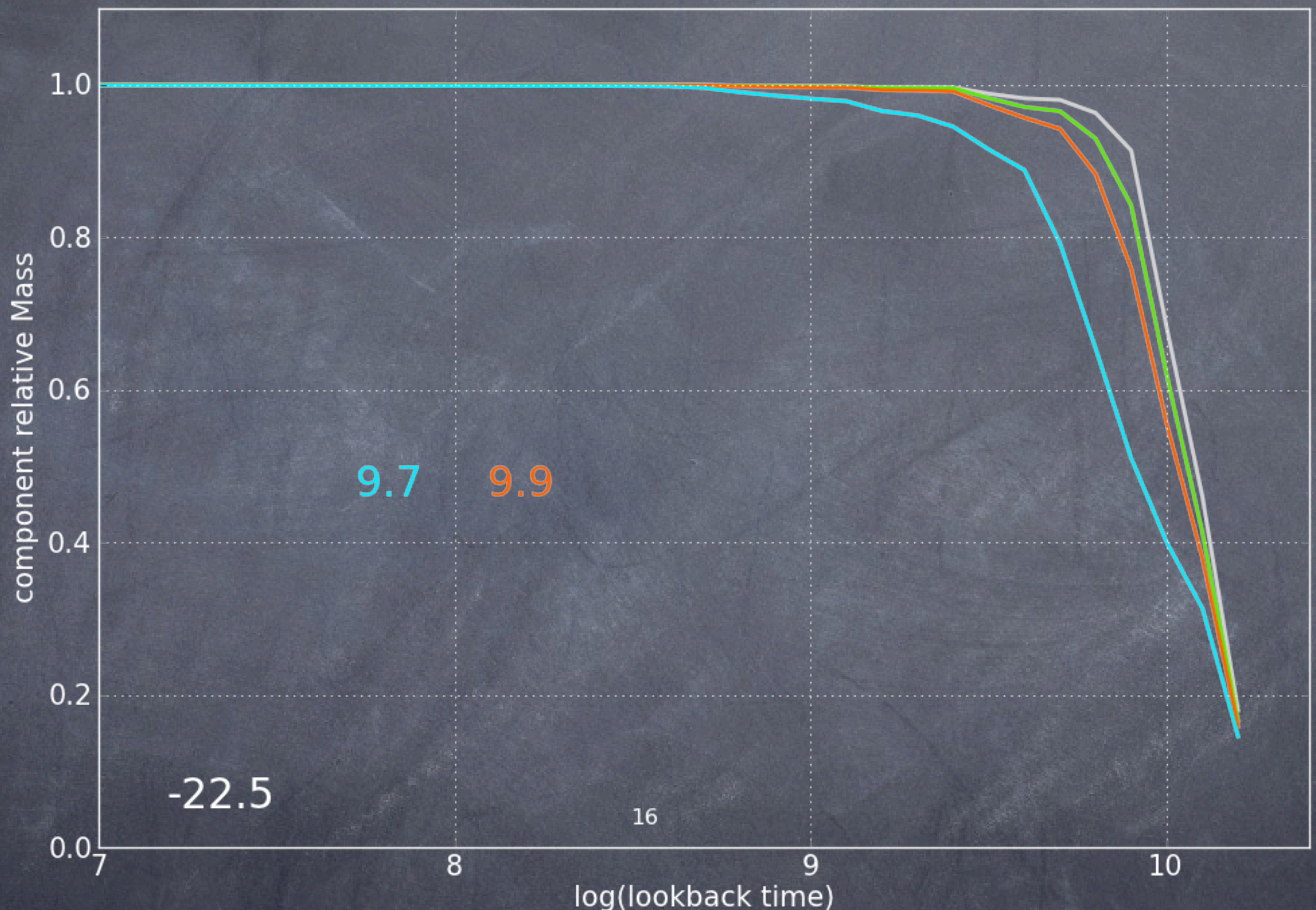
36



component relative Mass
log(lookback time)
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0.6
0.4
0.2
0.0
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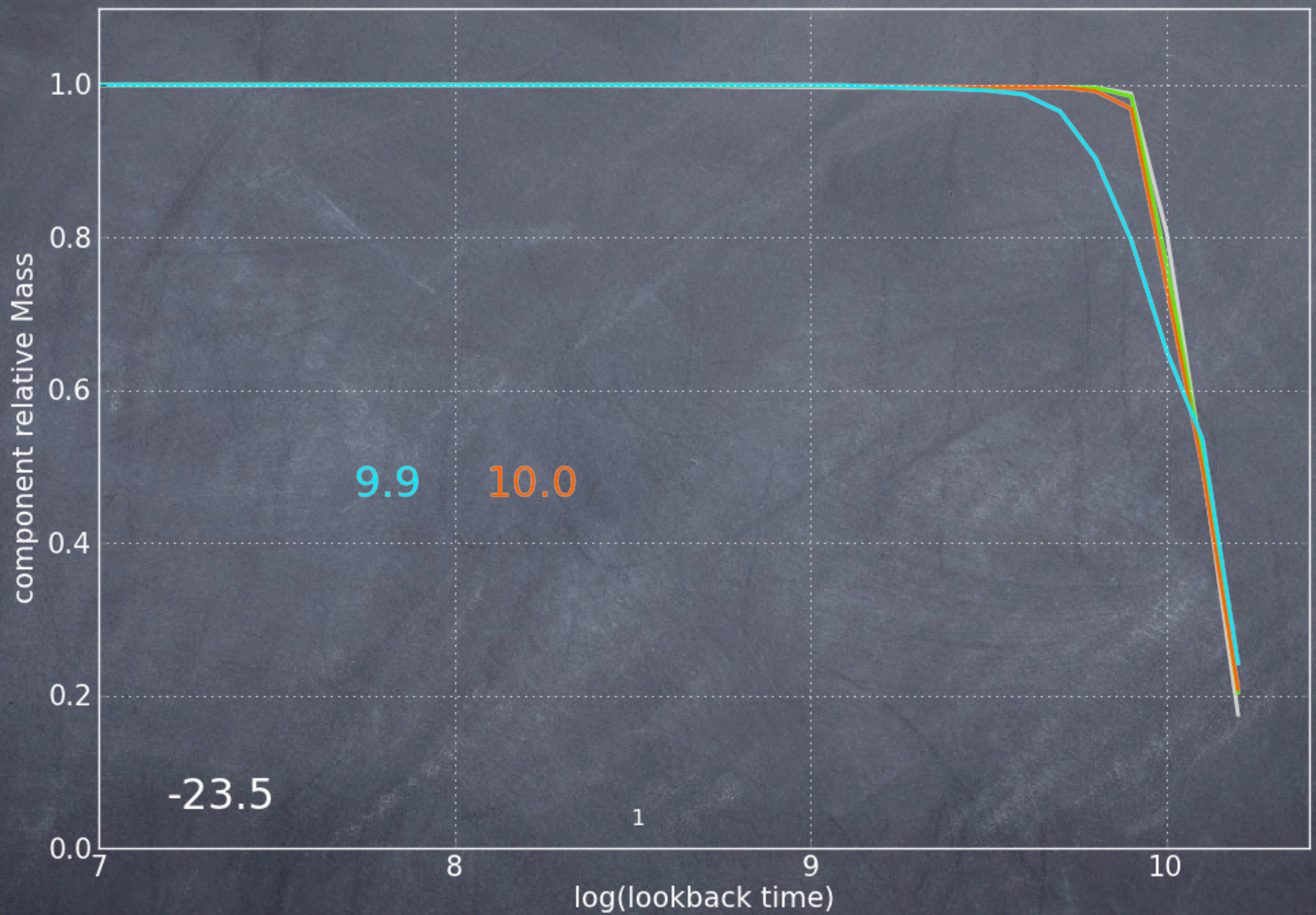
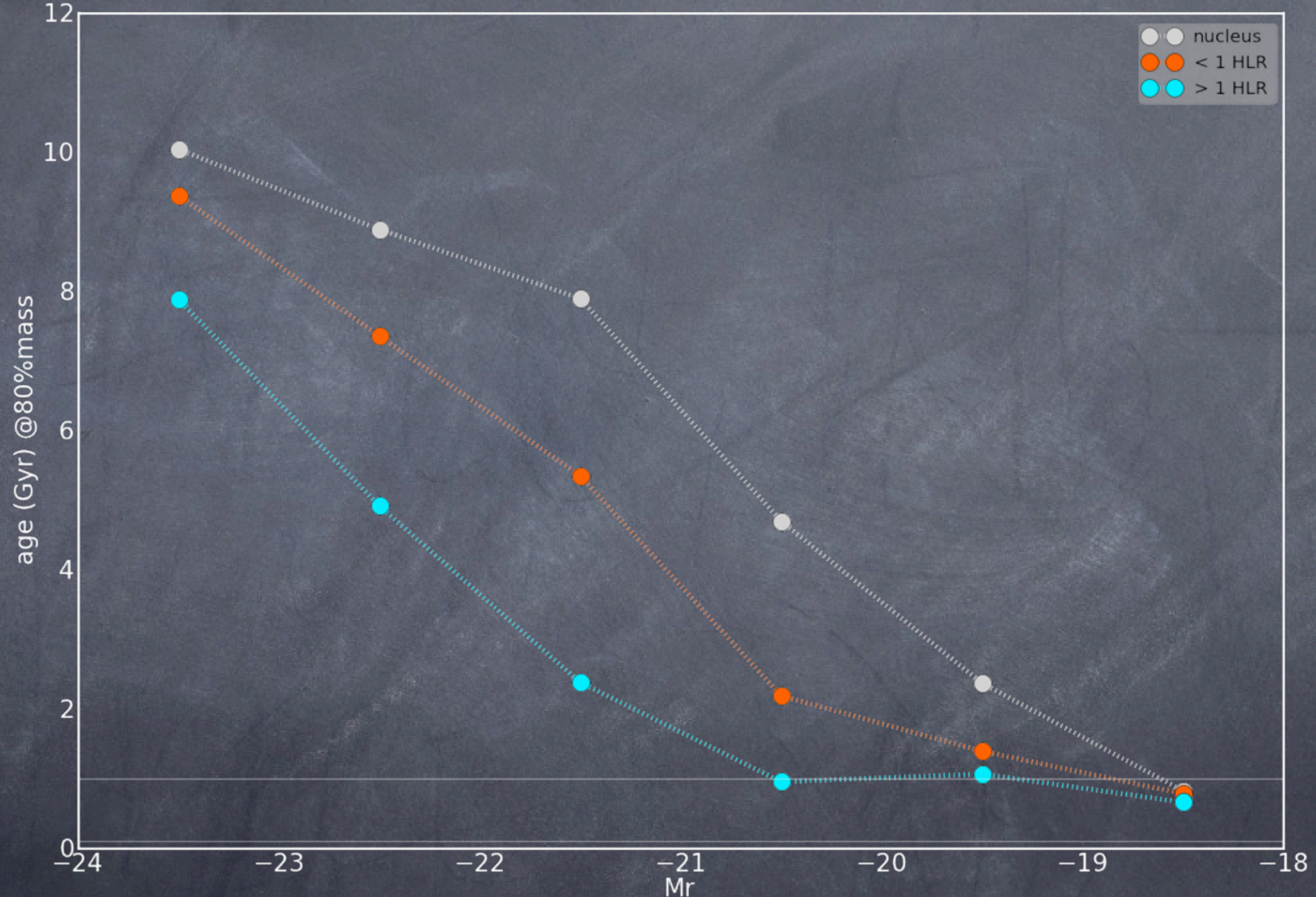
8
9
10
9.7
9.9
-22.5



1.0
0.8
0.6
0.4
0.2
0.0
component relative Mass
9.9
10.0
-23.5
1
7
8
9
10
log(lookback time)

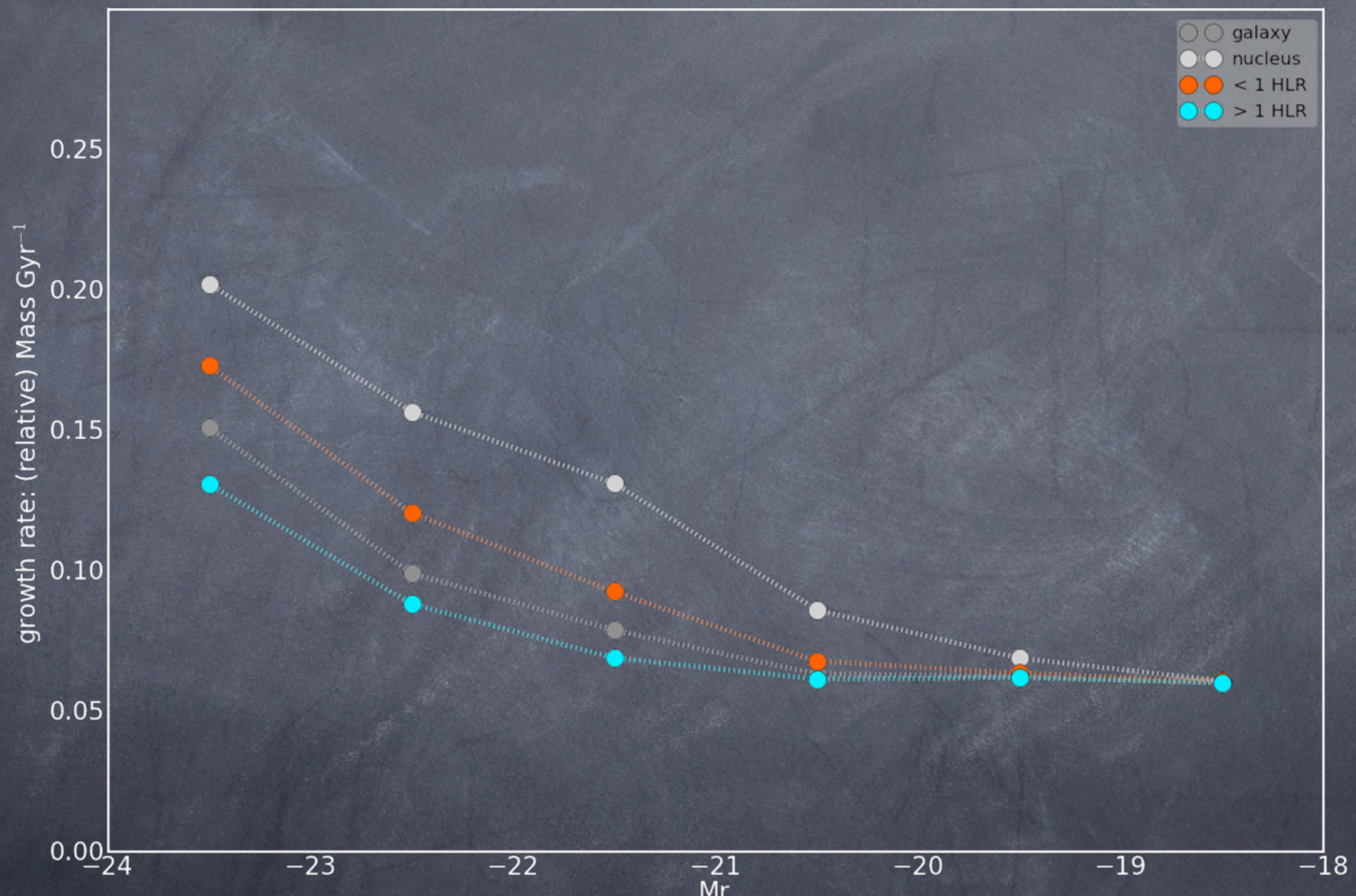
age @80% Mass



nucleus
< 1 HLR
> 1 HLR
age (Gyr) @80%mass
Mr
0
2
4
6
8
10
12
−24
−23
−22
−21
−20
−19
−18

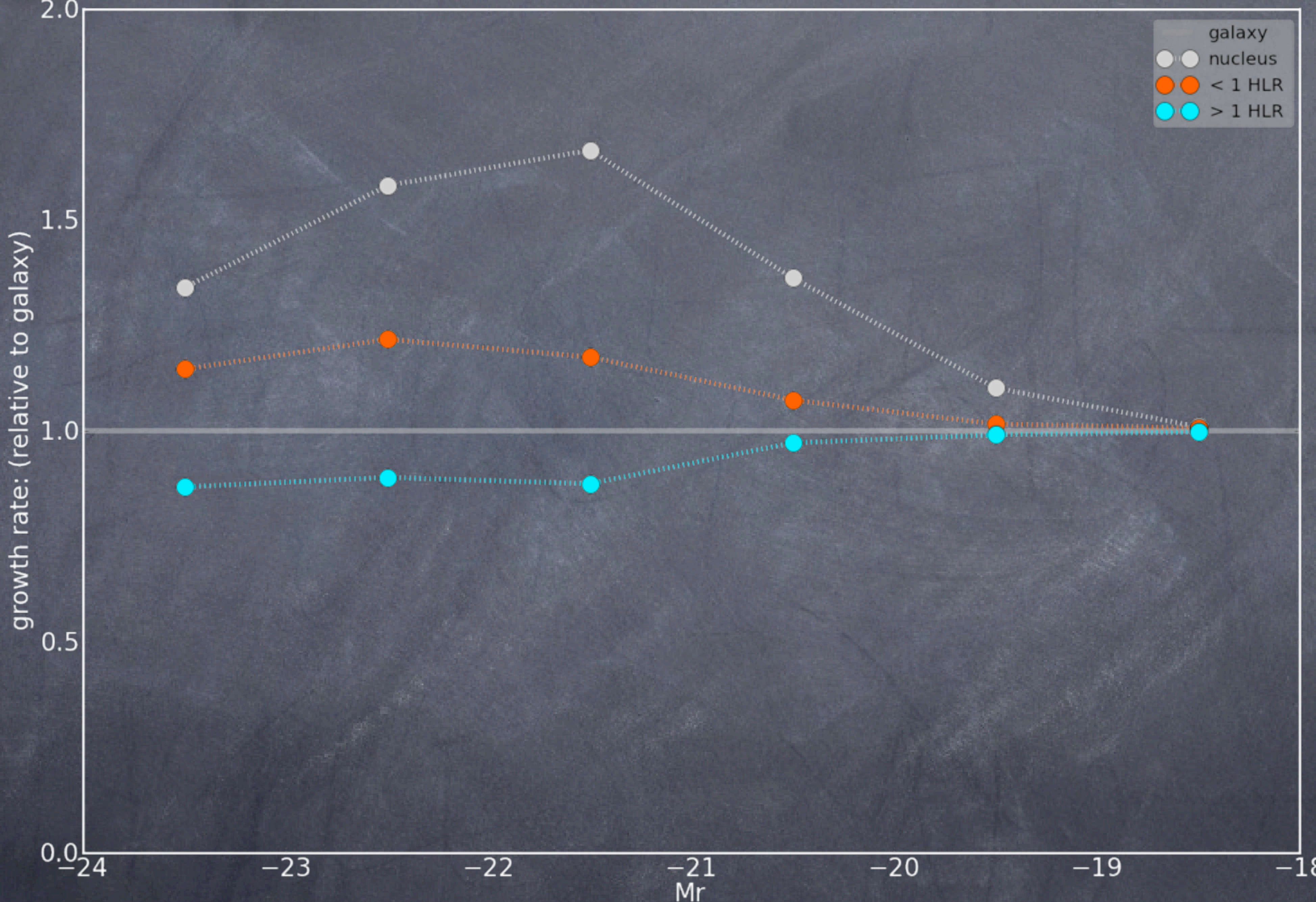
Mass growth rate Gyr^{-1}

normalized per component

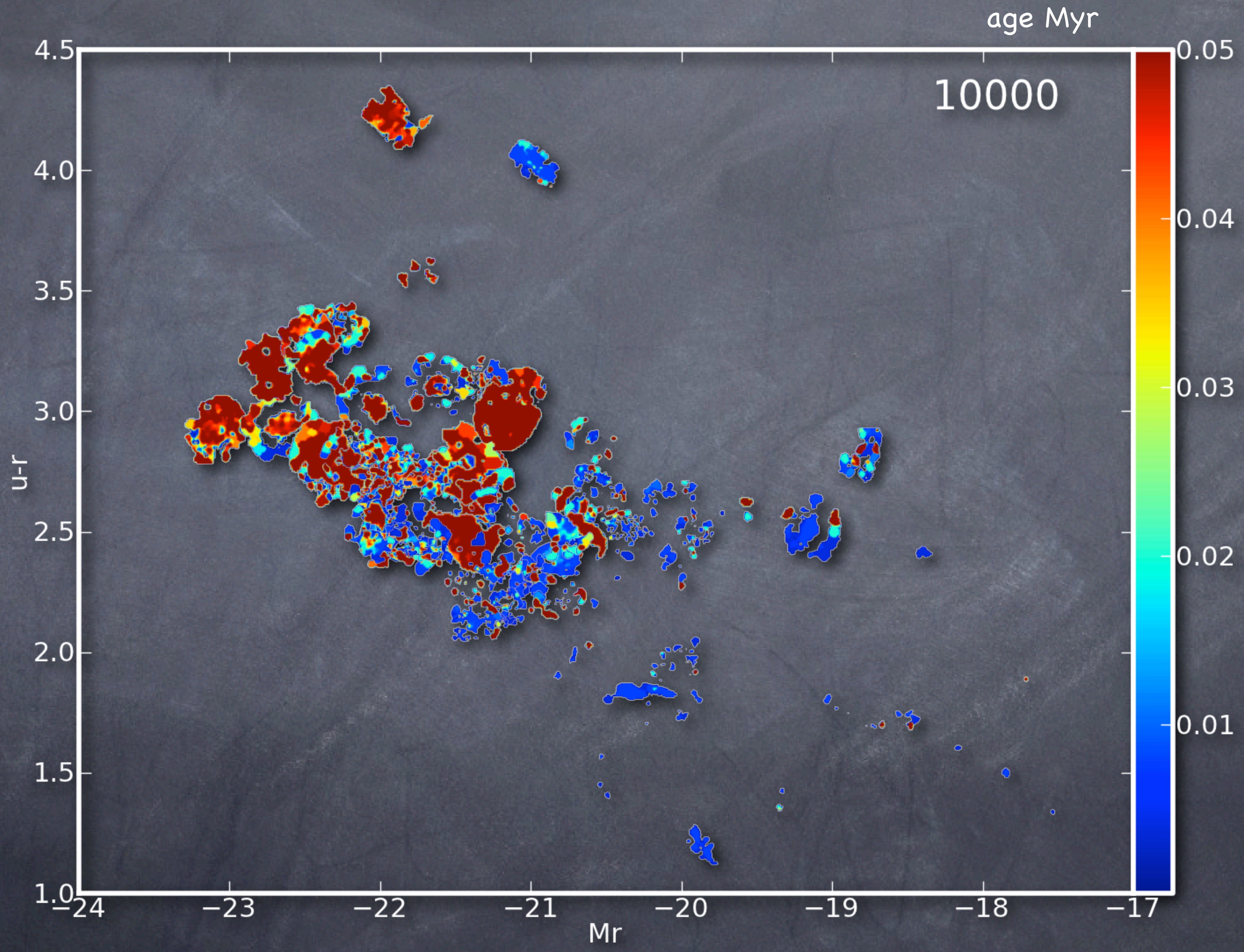


Mass growth rate

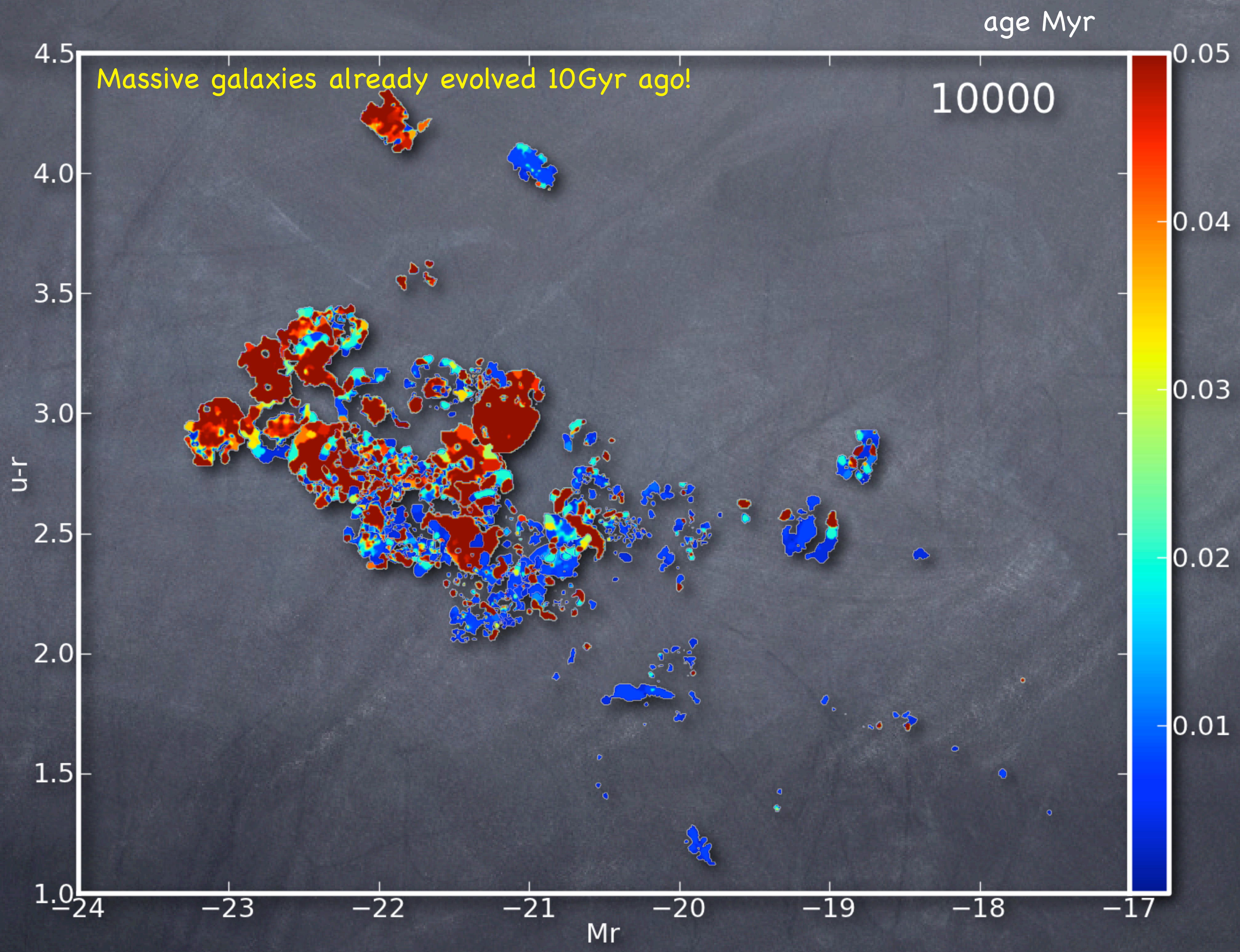
normalized to galaxy mass

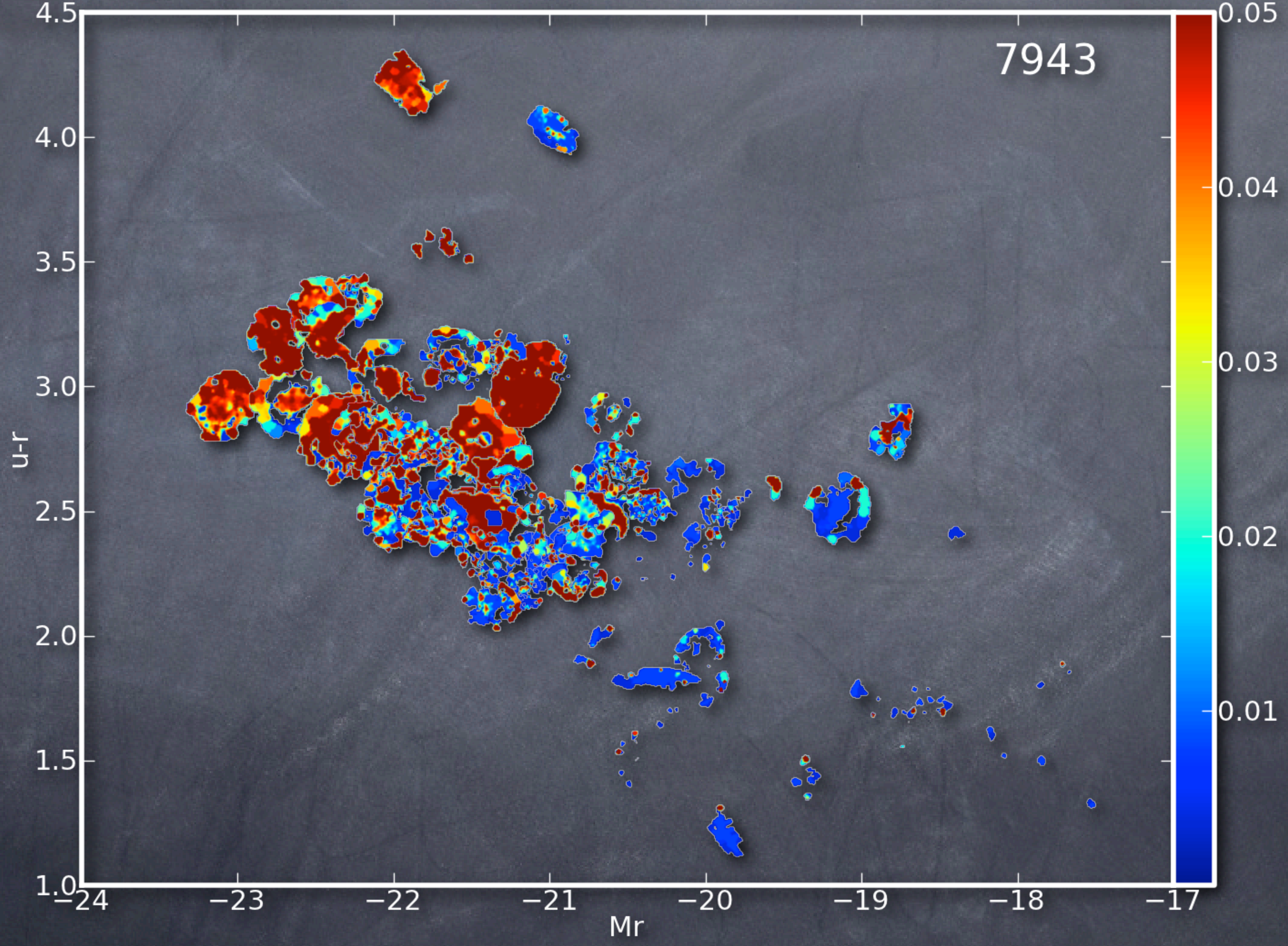


How metals build up in time



How metals build up in time





7943
u-r
Mr
4.5
4.0
3.5
3.0
2.5
2.0
1.5
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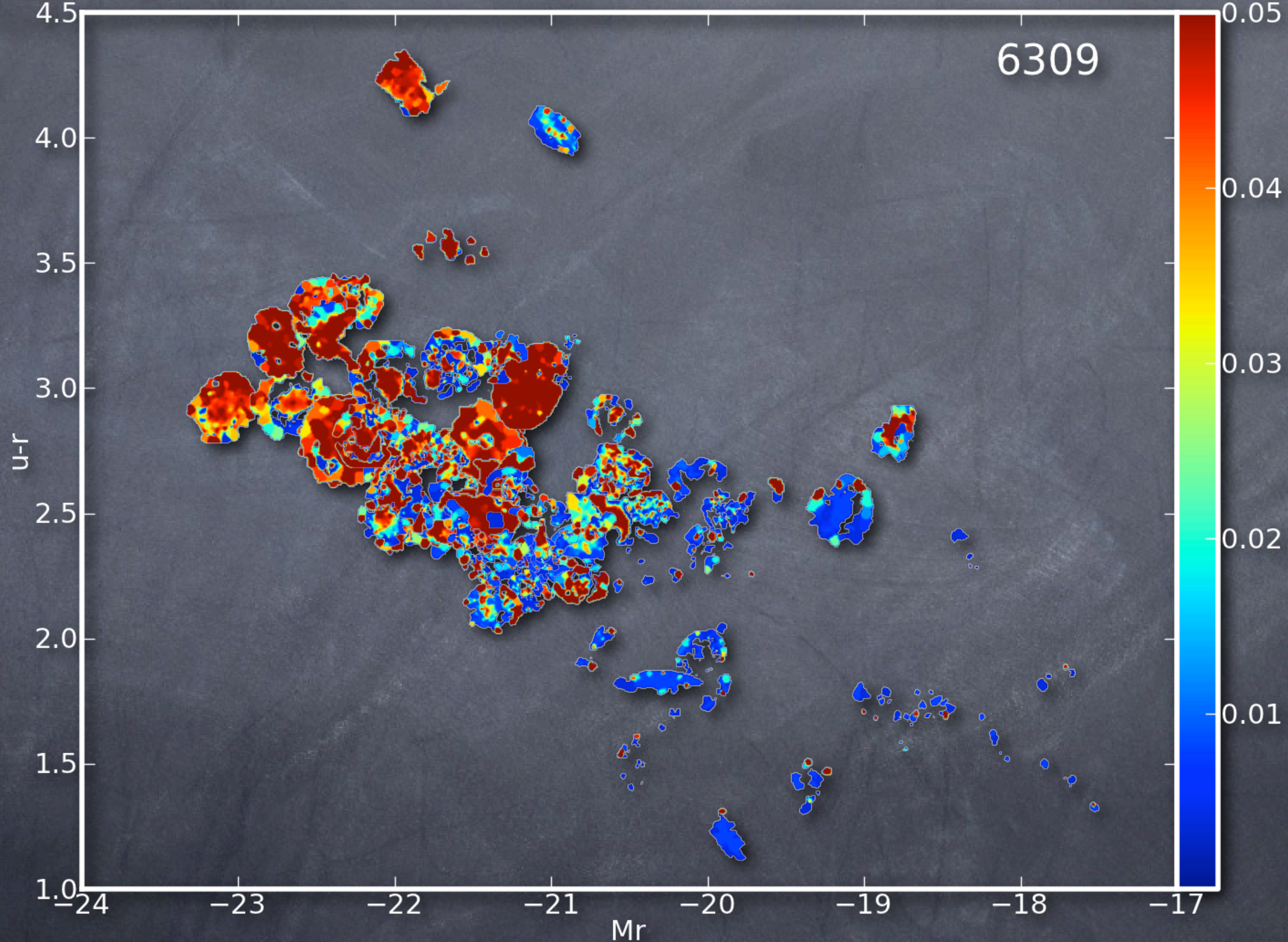
0.01



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Mr
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4.0
3.5
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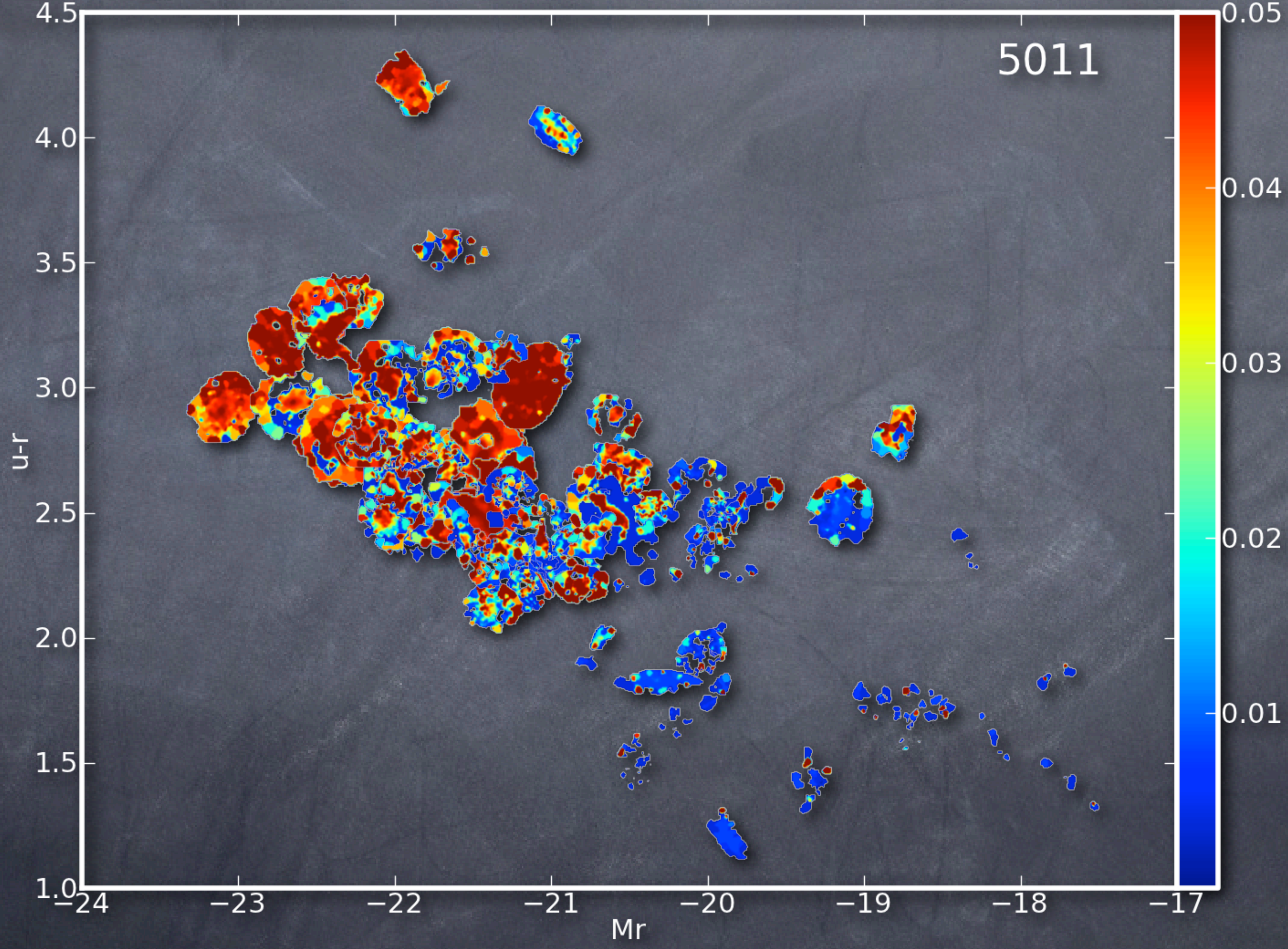

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Mr
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4.0
3.5
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2.5
2.0
1.5
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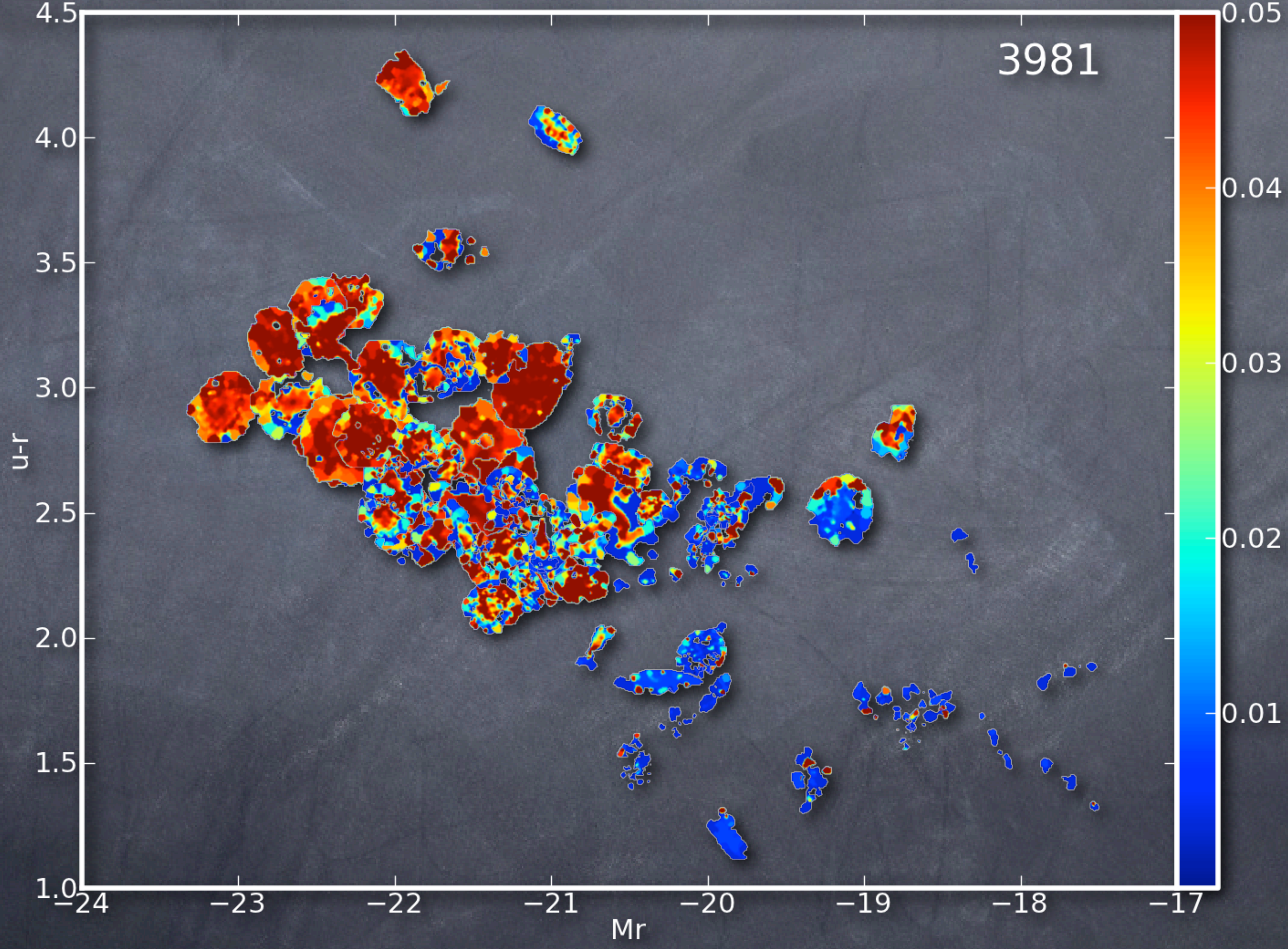

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4.0
3.5
3.0
2.5
2.0
1.5
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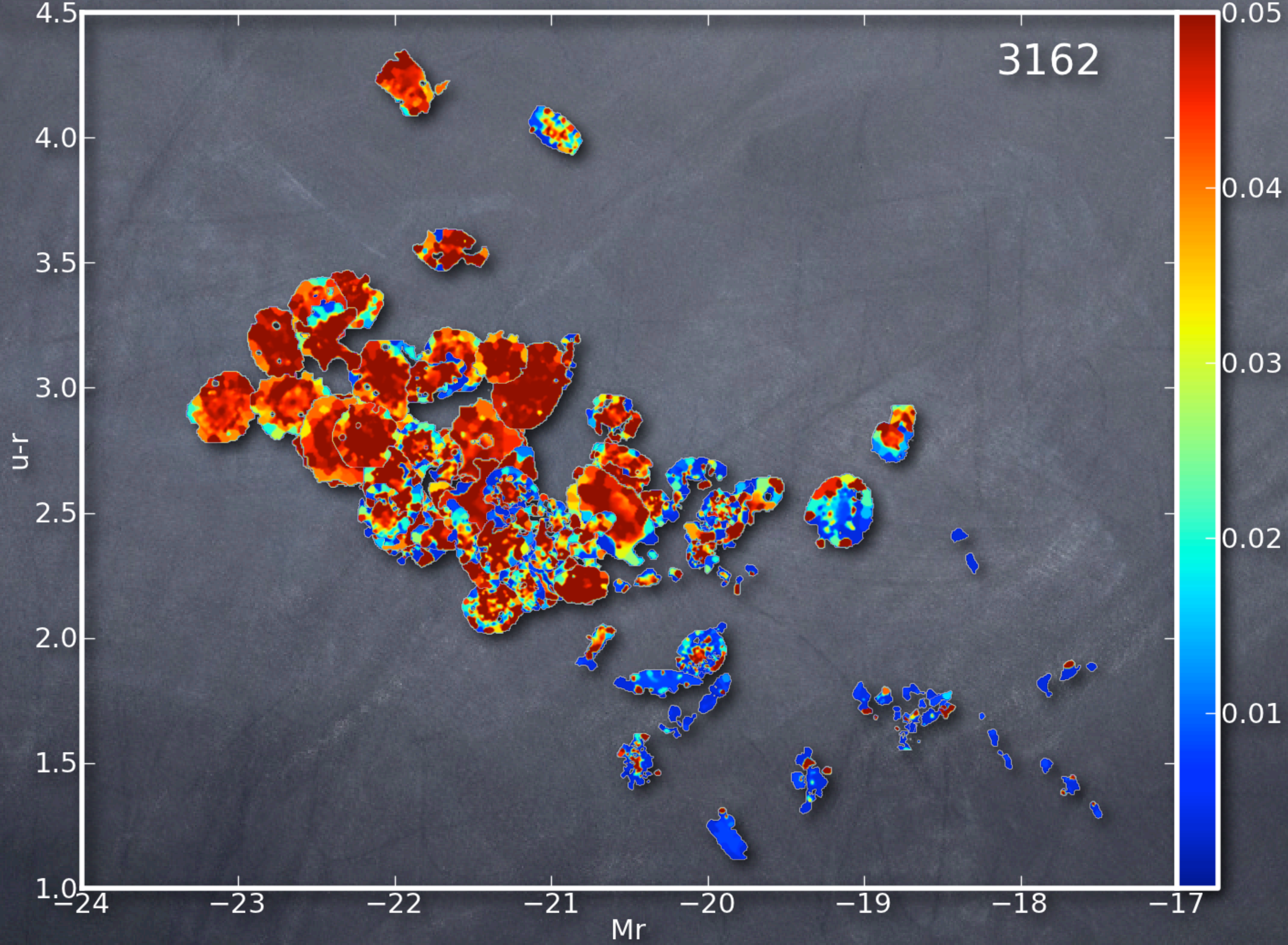

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Mr
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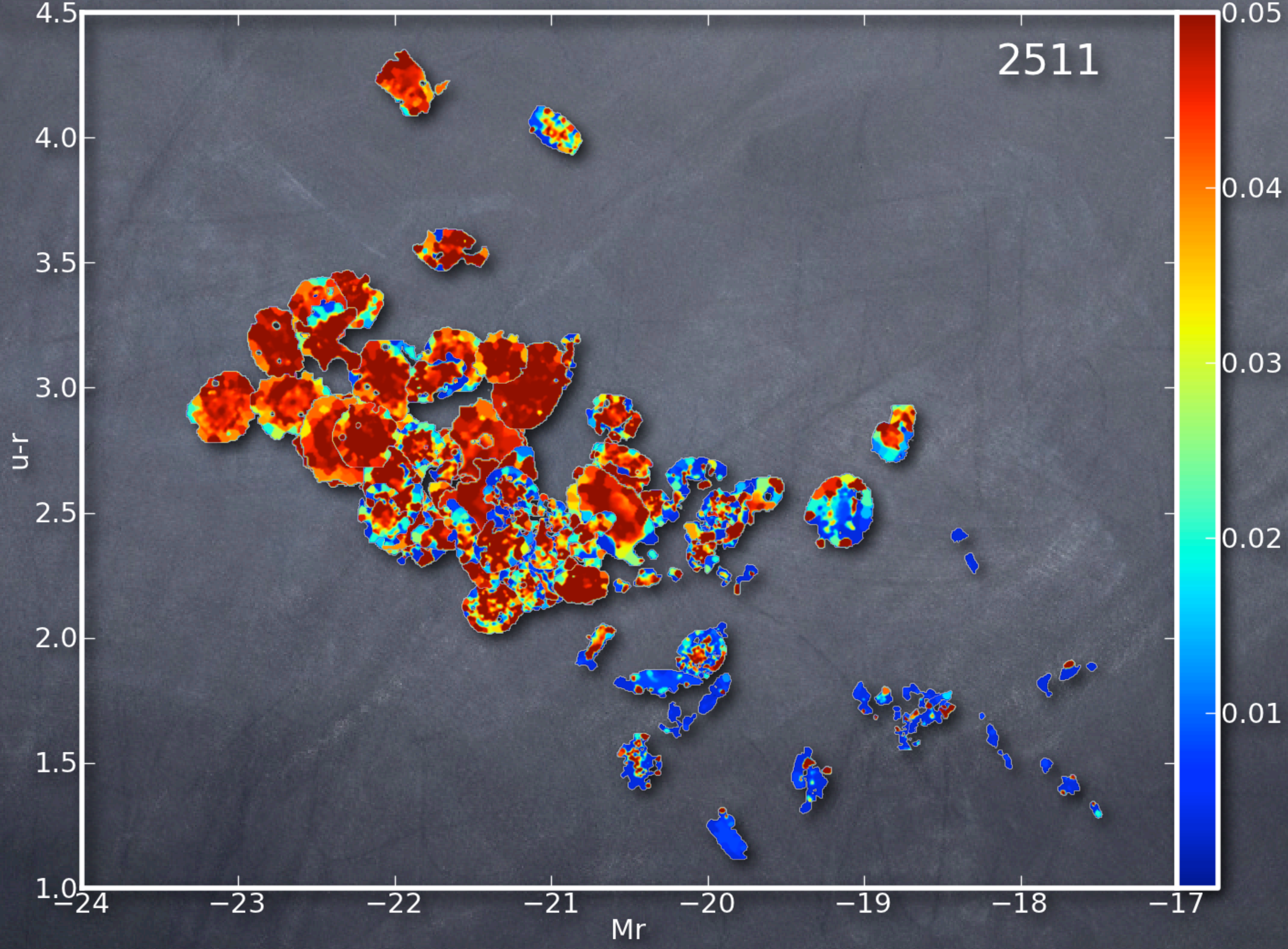

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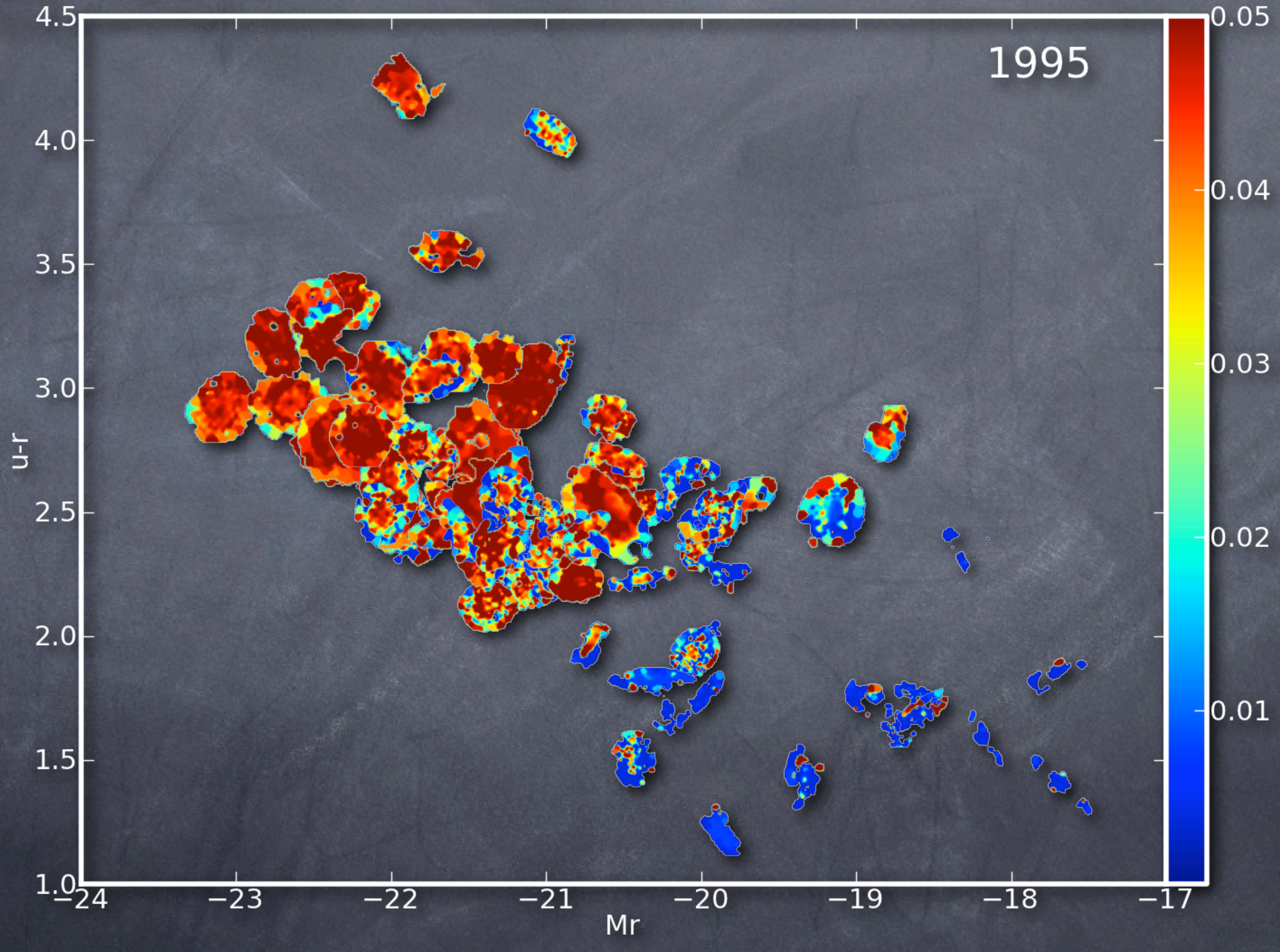

1995
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3.5
3.0
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1.0
u-r
−24
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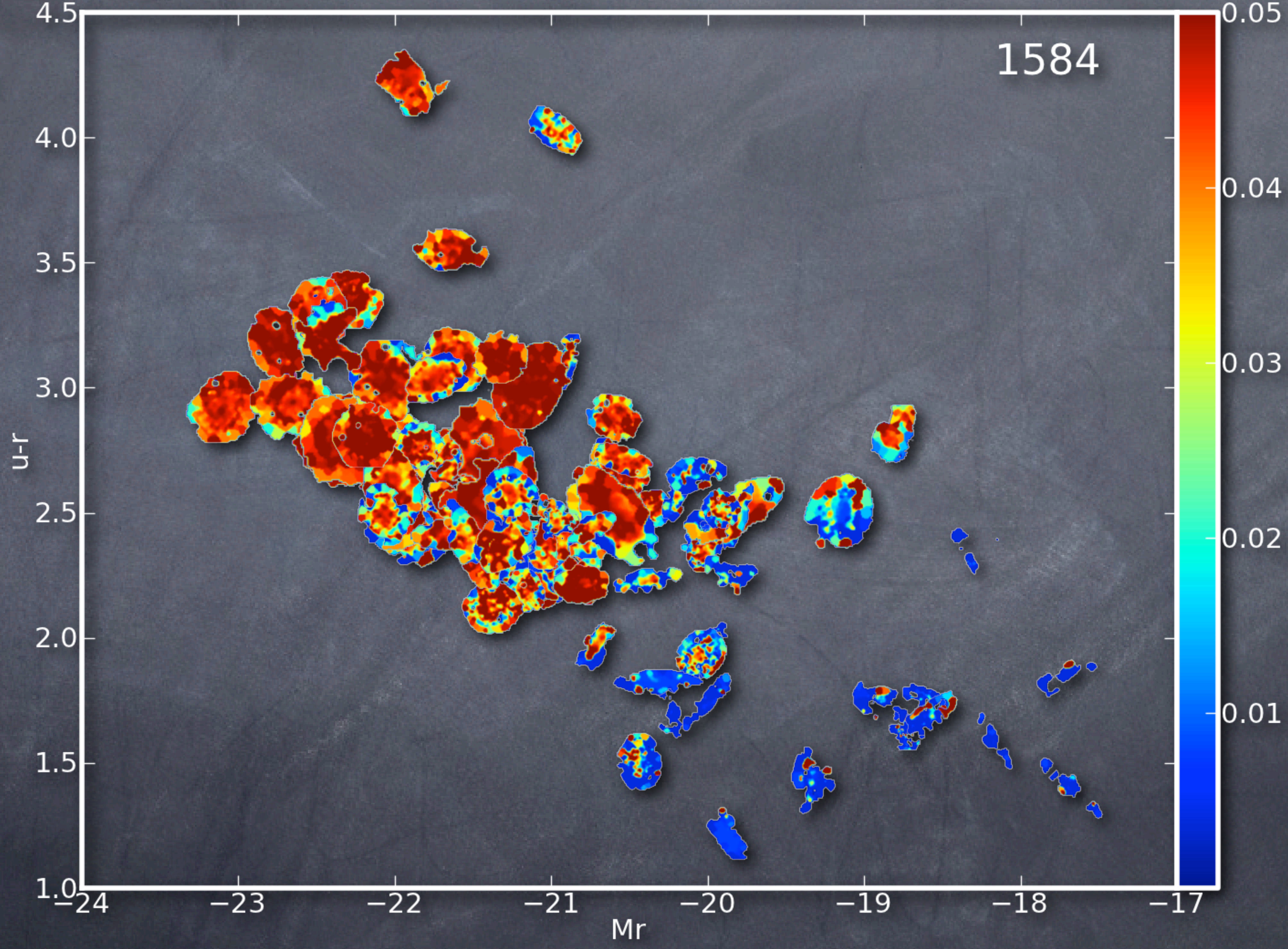
Mr
0.05
0.04
0.03
0.02
0.01



1584
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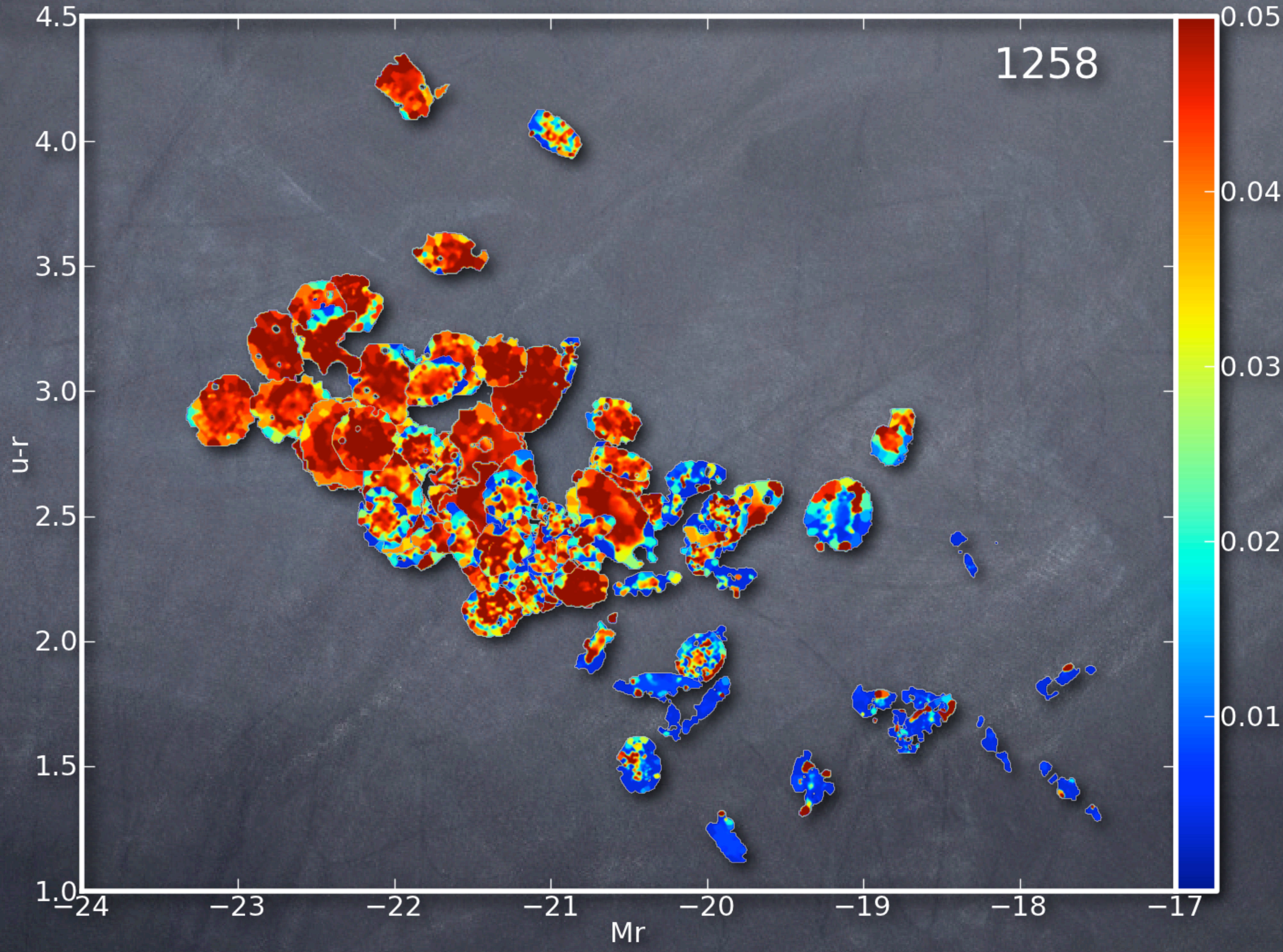
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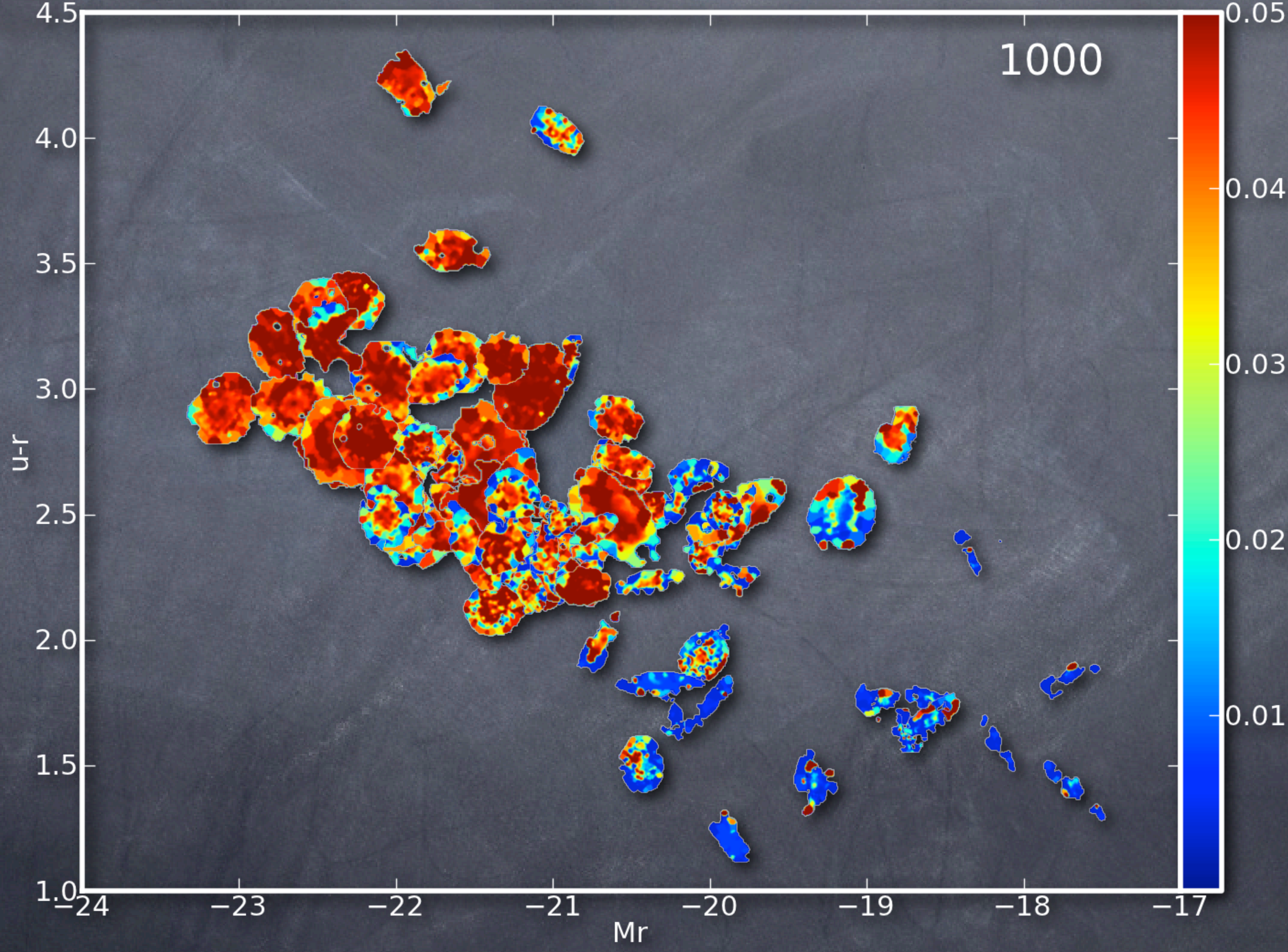

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3.0
2.5
2.0
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1.0
u-r
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−21
−20
−19
−18
−17
Mr
0.05
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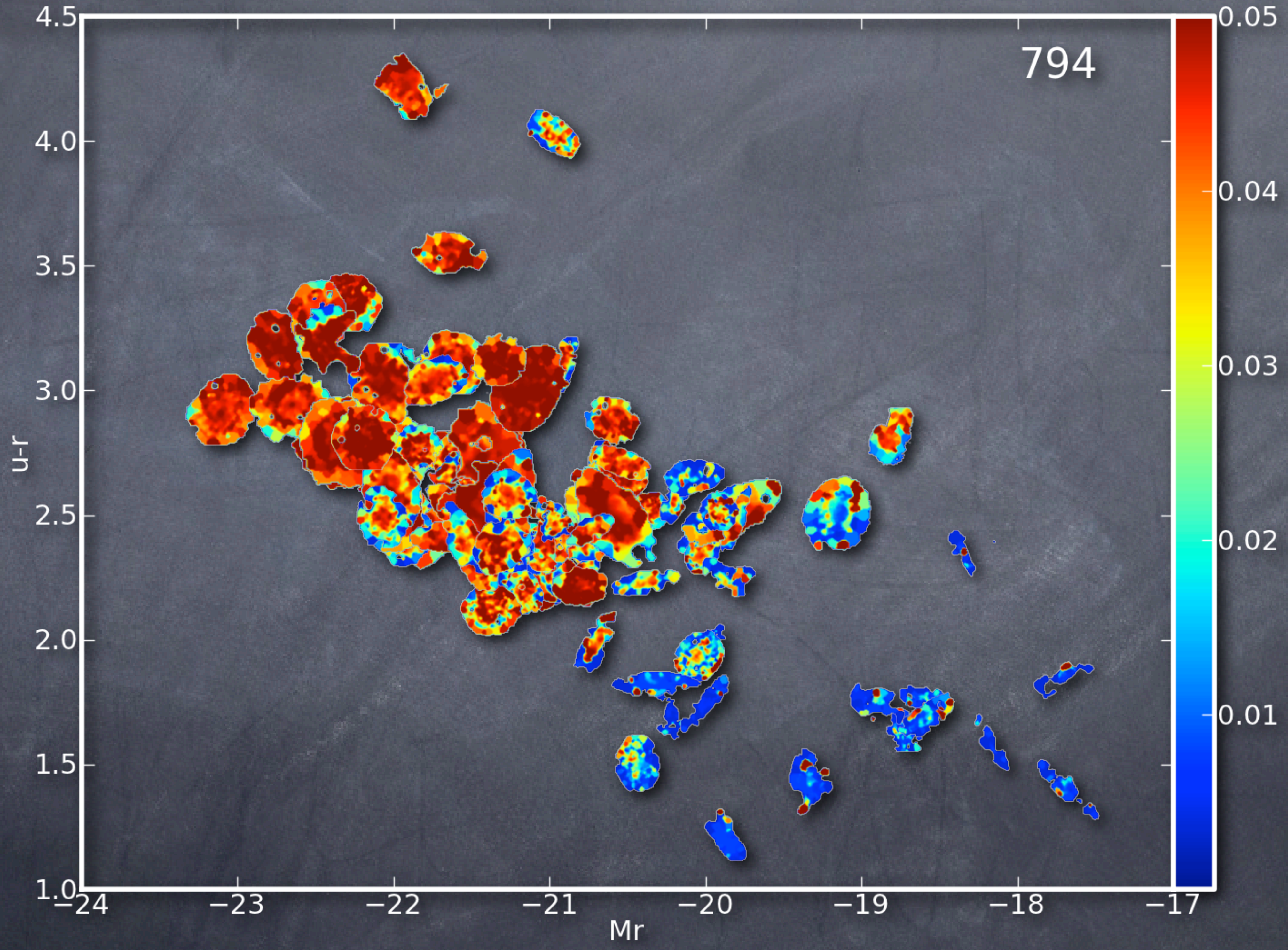
0.01



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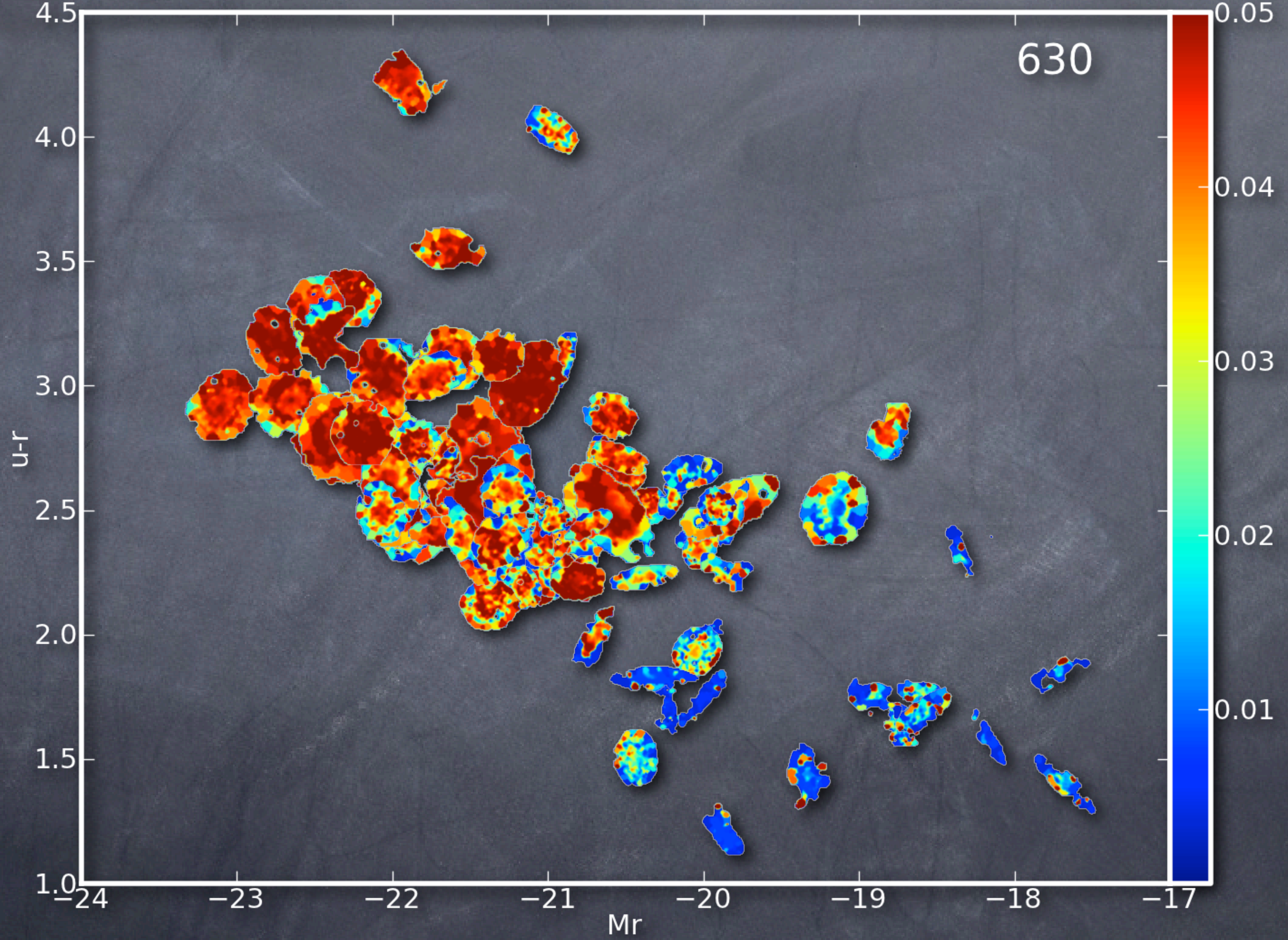

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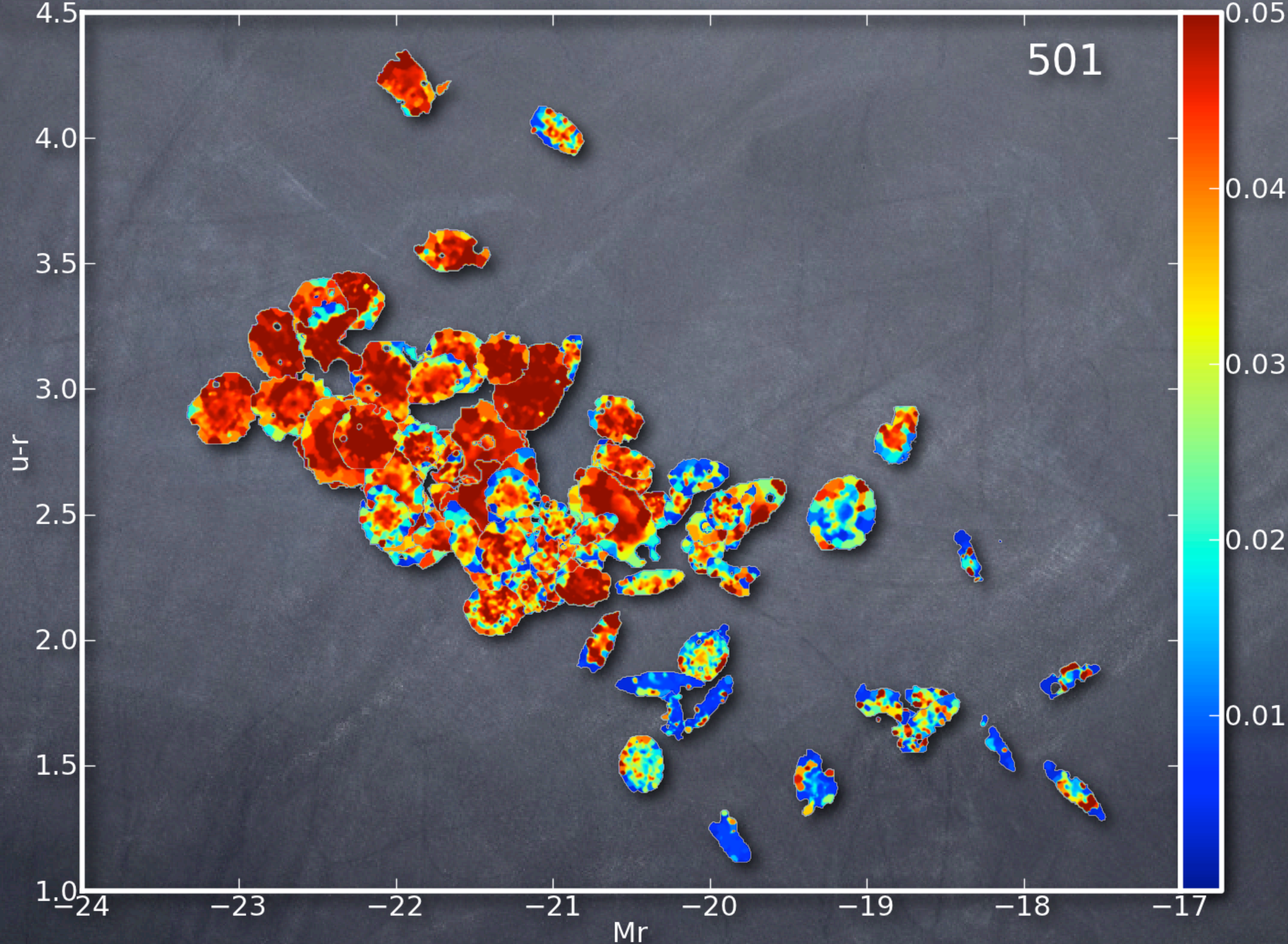

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−18
−17
Mr
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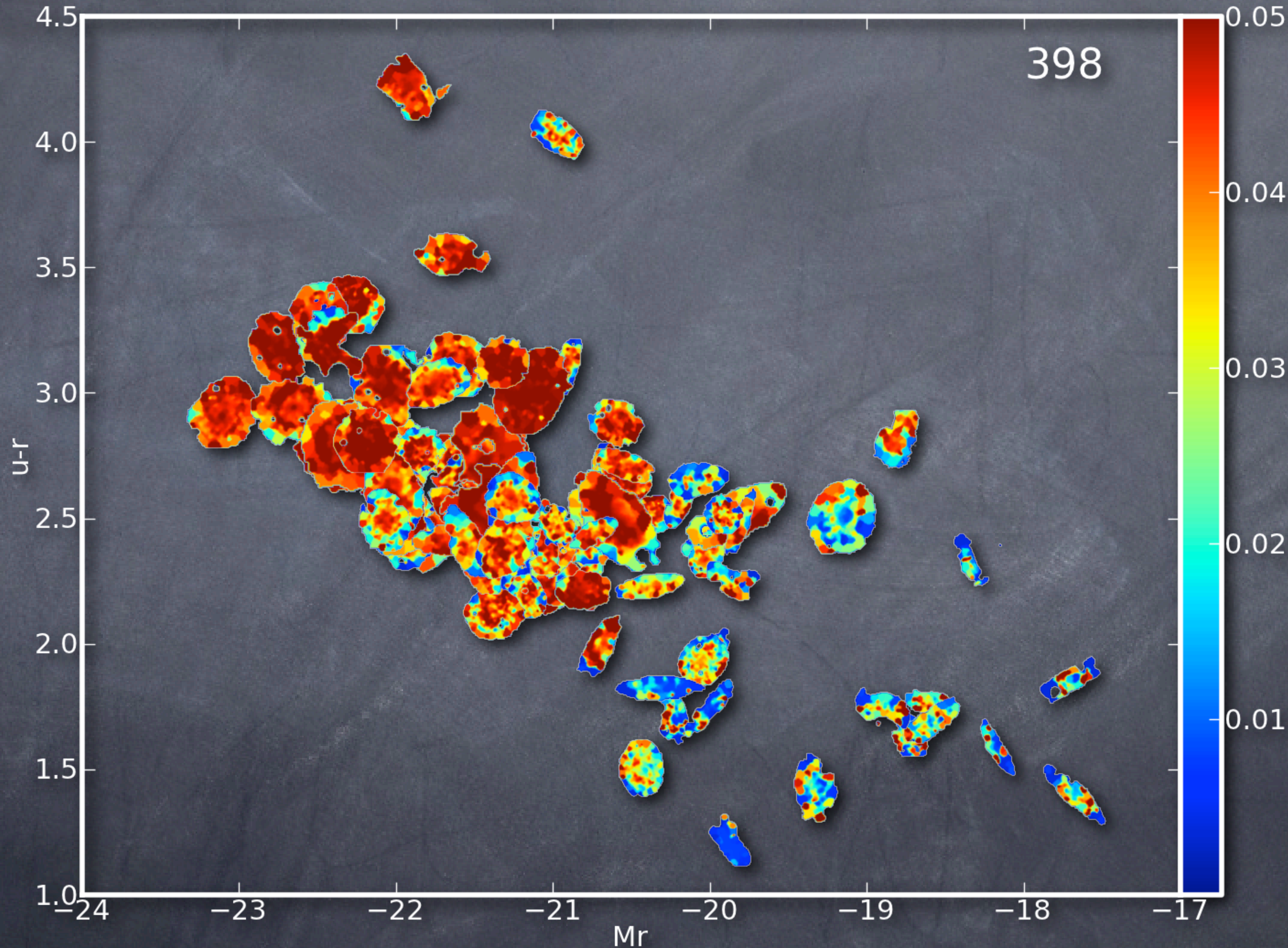
0.01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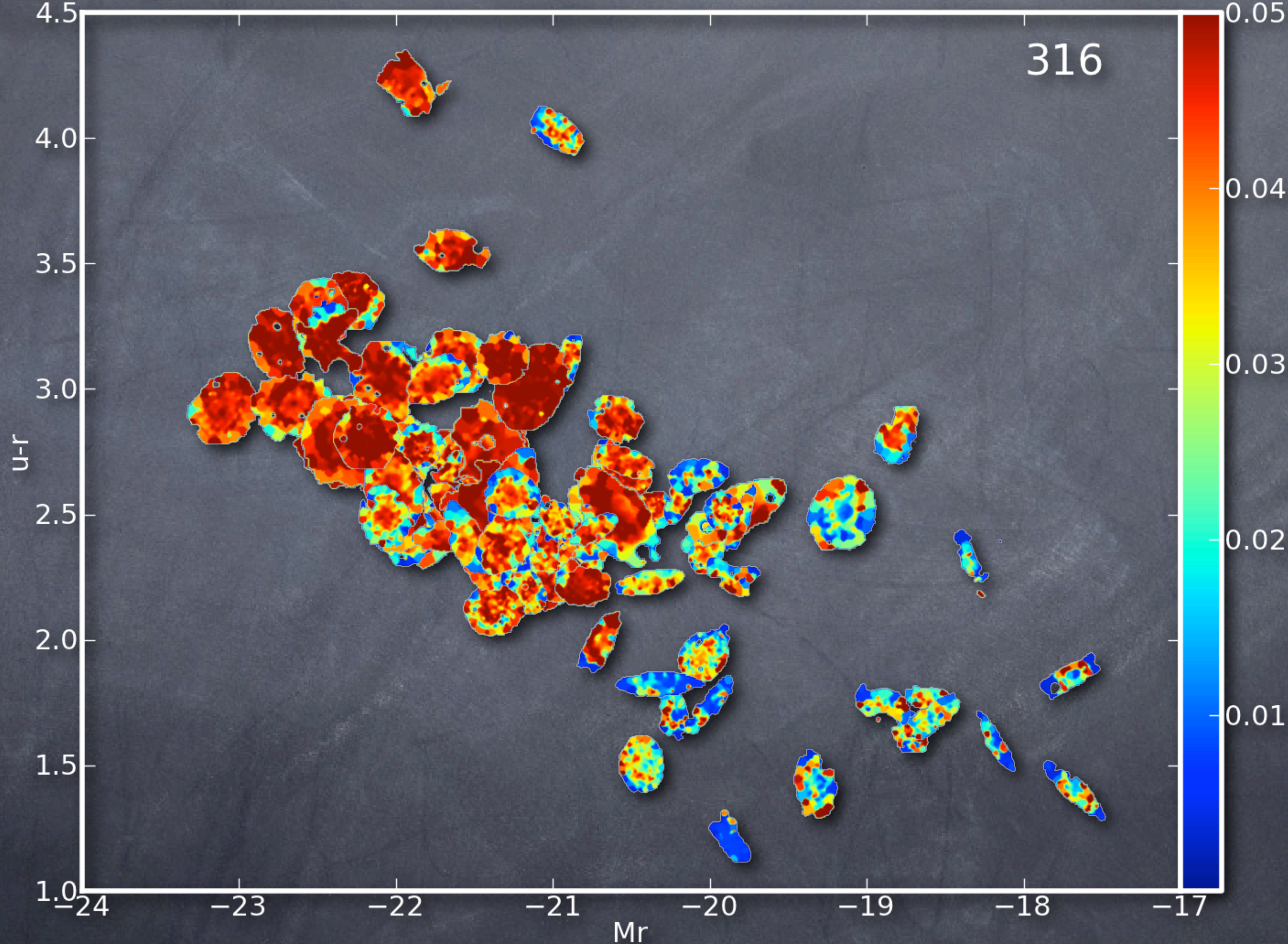

316
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2.5
2.0
1.5
1.0
u-r
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−18
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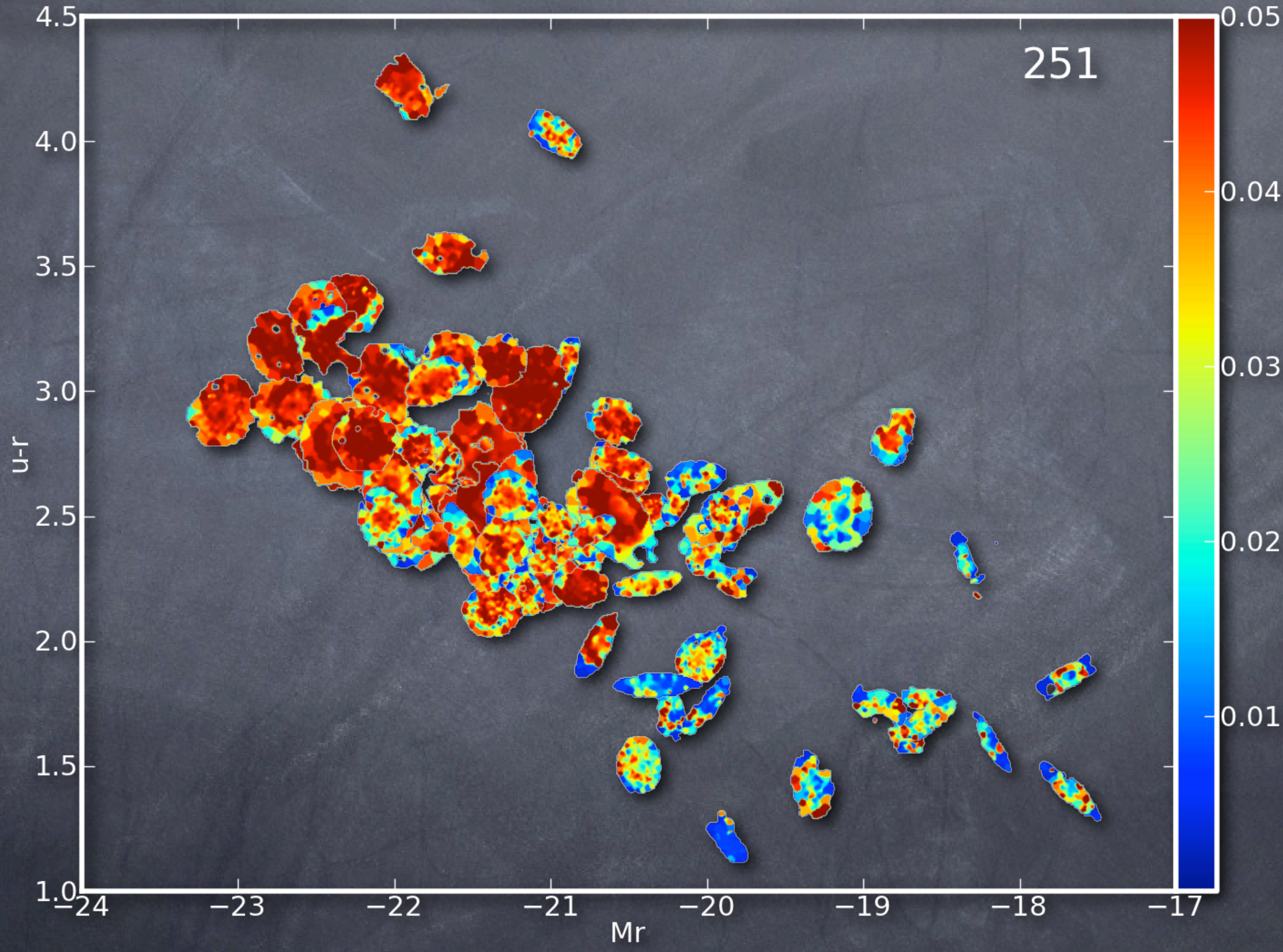
0.02
0.01



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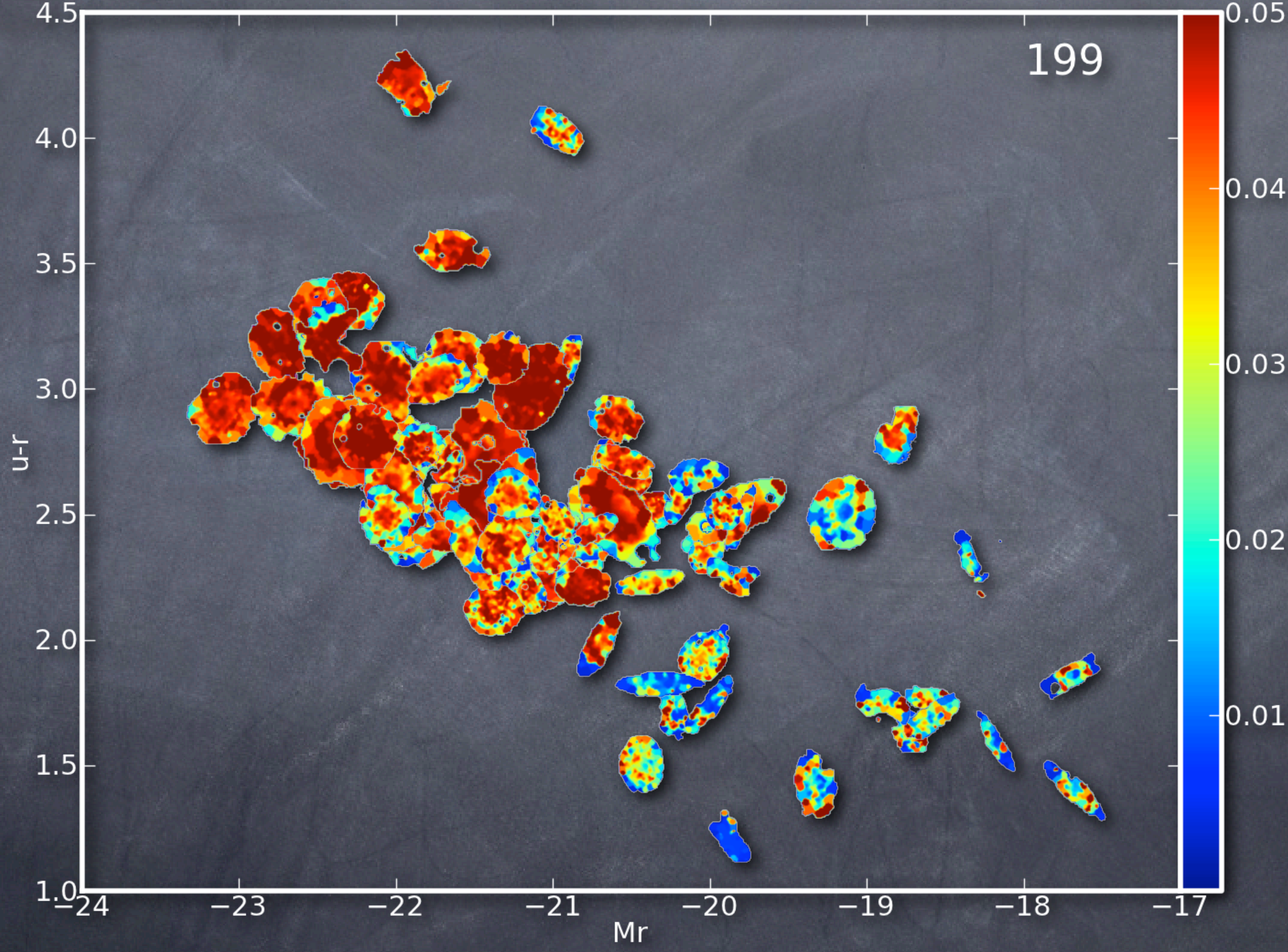

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u-r
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−20
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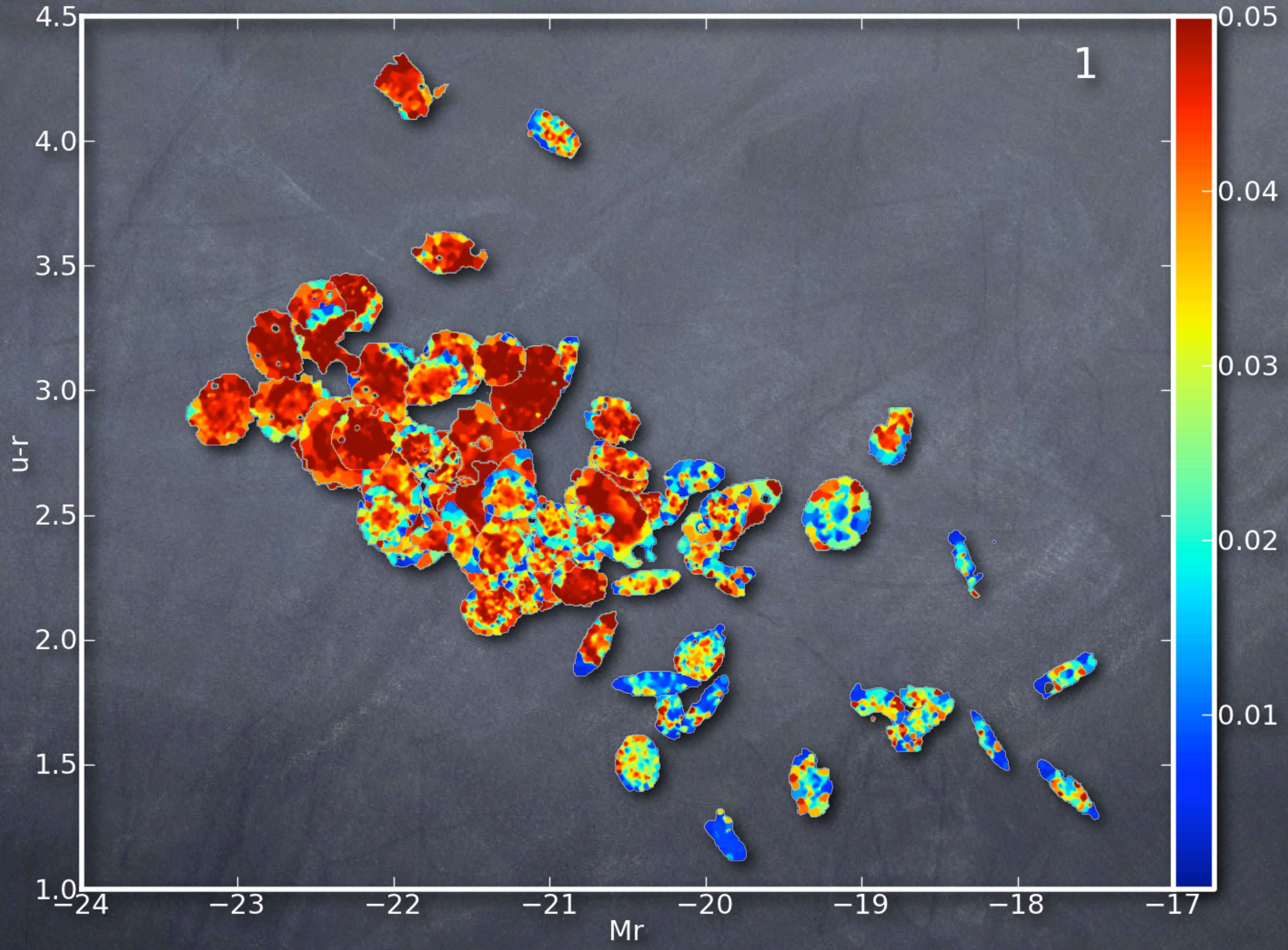
−17
0.05
0.04
0.03
0.02
0.01



1
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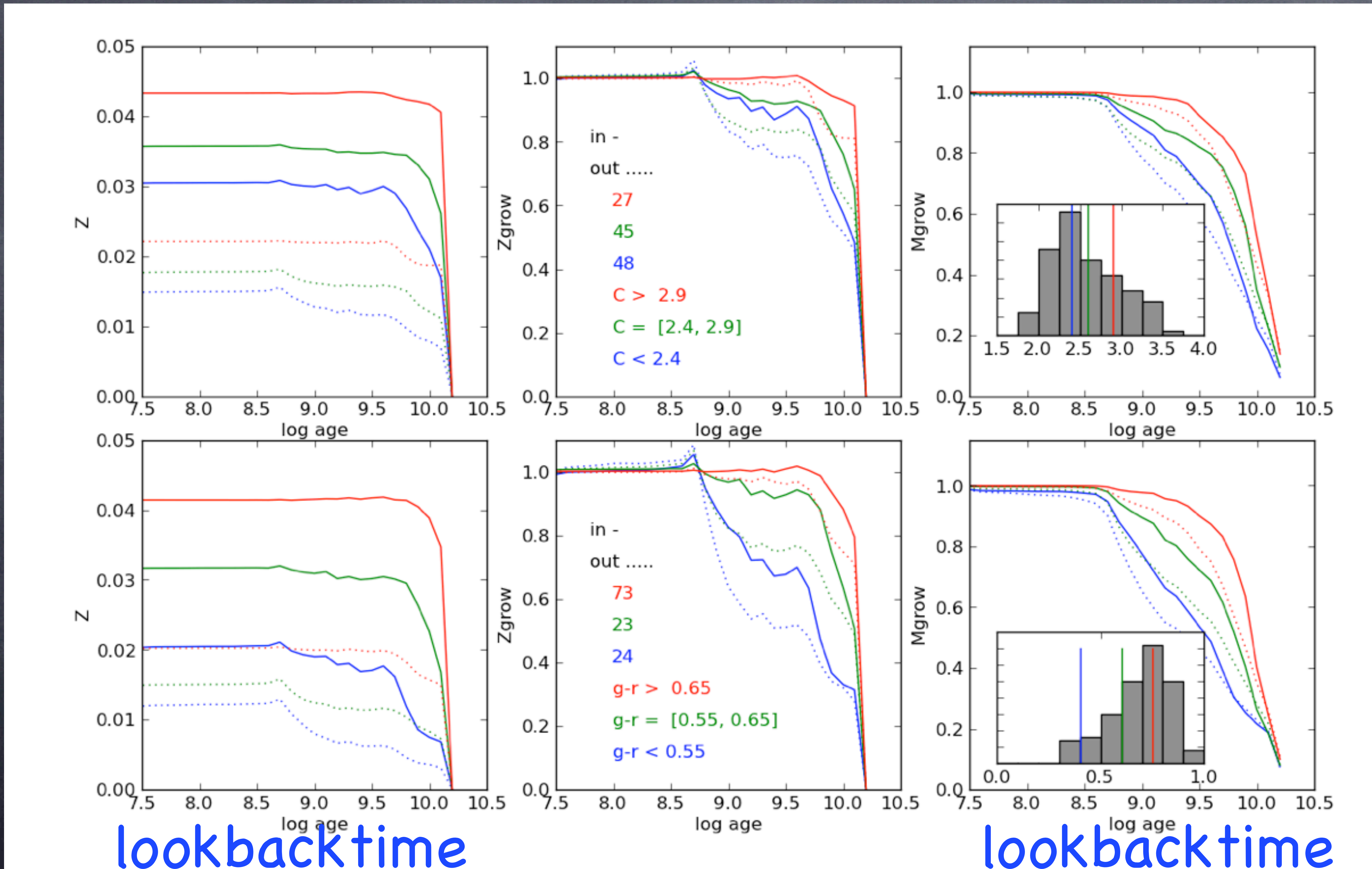
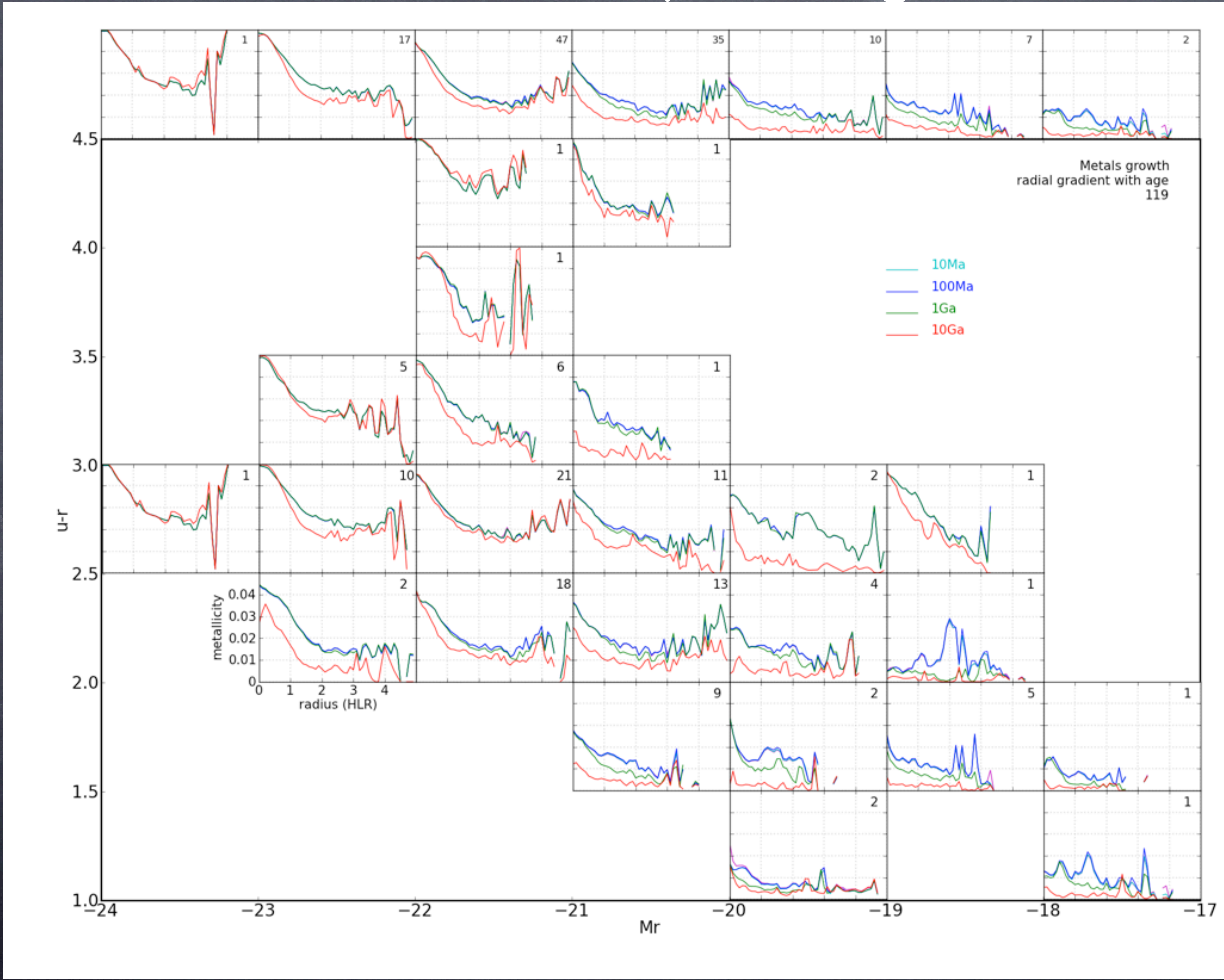
4.0
3.5
3.0
2.5
2.0
1.5
1.0
u-r
−24
−23
−22
−21
−20
−19
−18
−17
Mr
0.05
0.04
0.03
0.02
0.01

Metallicity assembly:
red sequence, green valley and blue cloud



Metallicity radial gradients



Conclusions

Galaxies grow inside-out

Galaxies more luminous than Mr < -20.5-- -21. (Mass = severals 10^10 Msol) (depending of the IMF) build up their mass and metals faster and with steeper gradients than less luminous galaxies

Galaxy Evolution research

We need data of several thousands of galaxies covering a wide range of stellar masses (10^9-10^12 Msol) with SFH spatially resolved up to 3-4 Re to do statistically robust analysis of the stellar mass density profiles, and ages and metallicity gradients as a function of galaxy mass, morphological type, and environments.

- Redshift range < 0.5 (to cover at least the rest frame 3700--5200 A at optical wavelengths)

- Multi-object spectrograph + IFU (one PPaK like + several bundles or MUSE like) to be deployed in a 1 deg^2 with spatial sampling of 1 arcsec or less

- Adaptive optics maybe required to observe the smaller (less massive galaxies, 10^9 Msol) and more distance galaxies (at z > 0.1, 1 arcsec > 2000 pc (Reff))

- Intermediate spectral resolution (2000-5000) covering the optical range (3700-9000 A) (wish: covering in one shot 3700--6000 A to avoid problems with flux calibration)

HEXA @ CAHA, WEAVE @ , and MUSE @ VLT

Work mode: Legacy survey as CALIFA