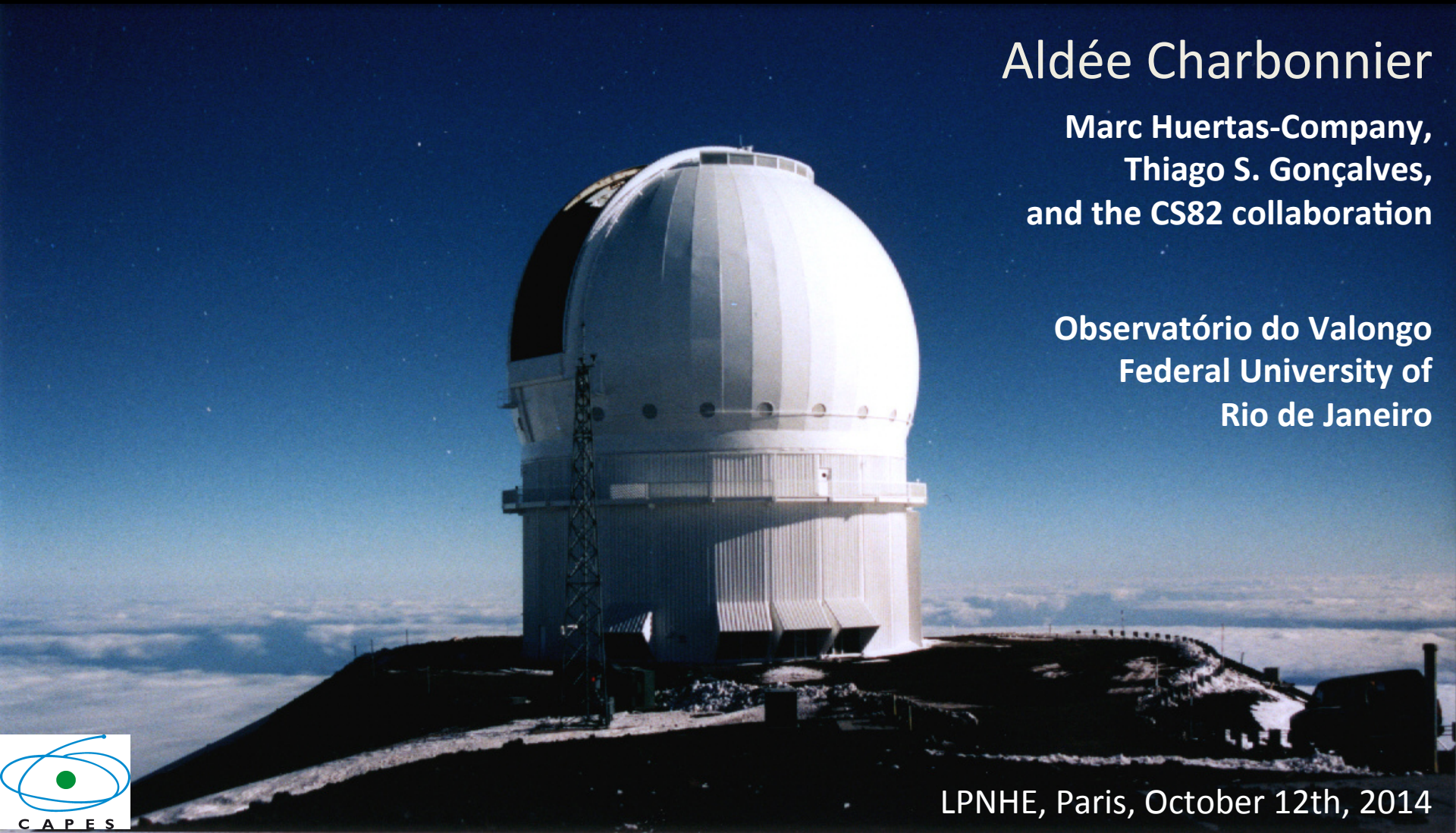
Compact massive galaxies in the Stripe-82 region



Aldée Charbonnier

Marc Huertas-Company, Thiago S. Gonçalves, and the CS82 collaboration

Observatório do Valongo
Federal University of Rio de Janeiro

LPNHE, Paris, October 12th, 2014

Outline

- Compact massive quiescent galaxies:

  why do we care?

- CFHT Stripe-82 survey

- Looking for them

Morphology of galaxies

Mo + 2010
Hubble 1936

Morphology of galaxies

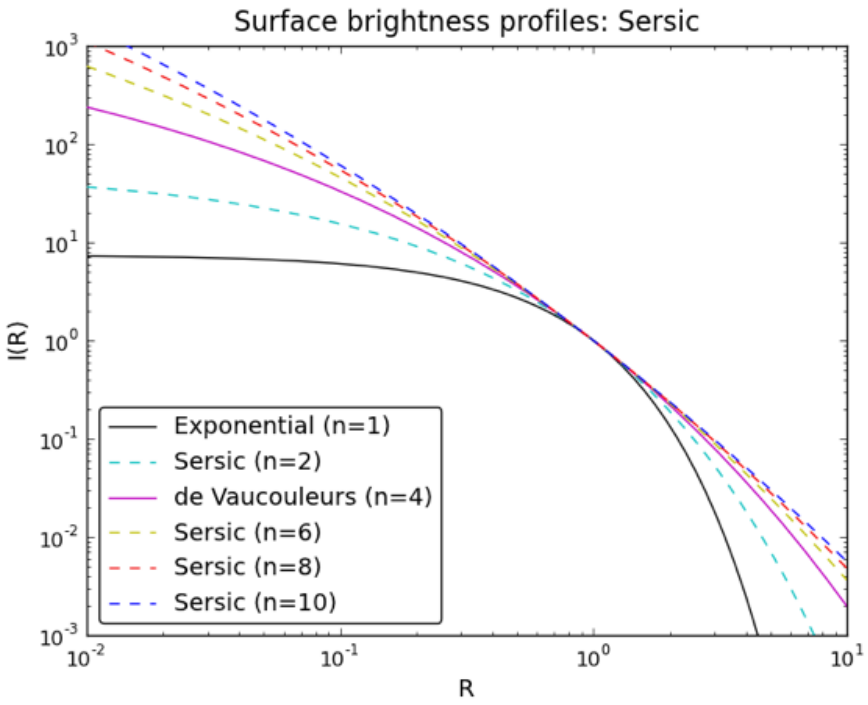
Mo + 2010

Table 2.6. Relative number densities of galaxies in the local Universe.

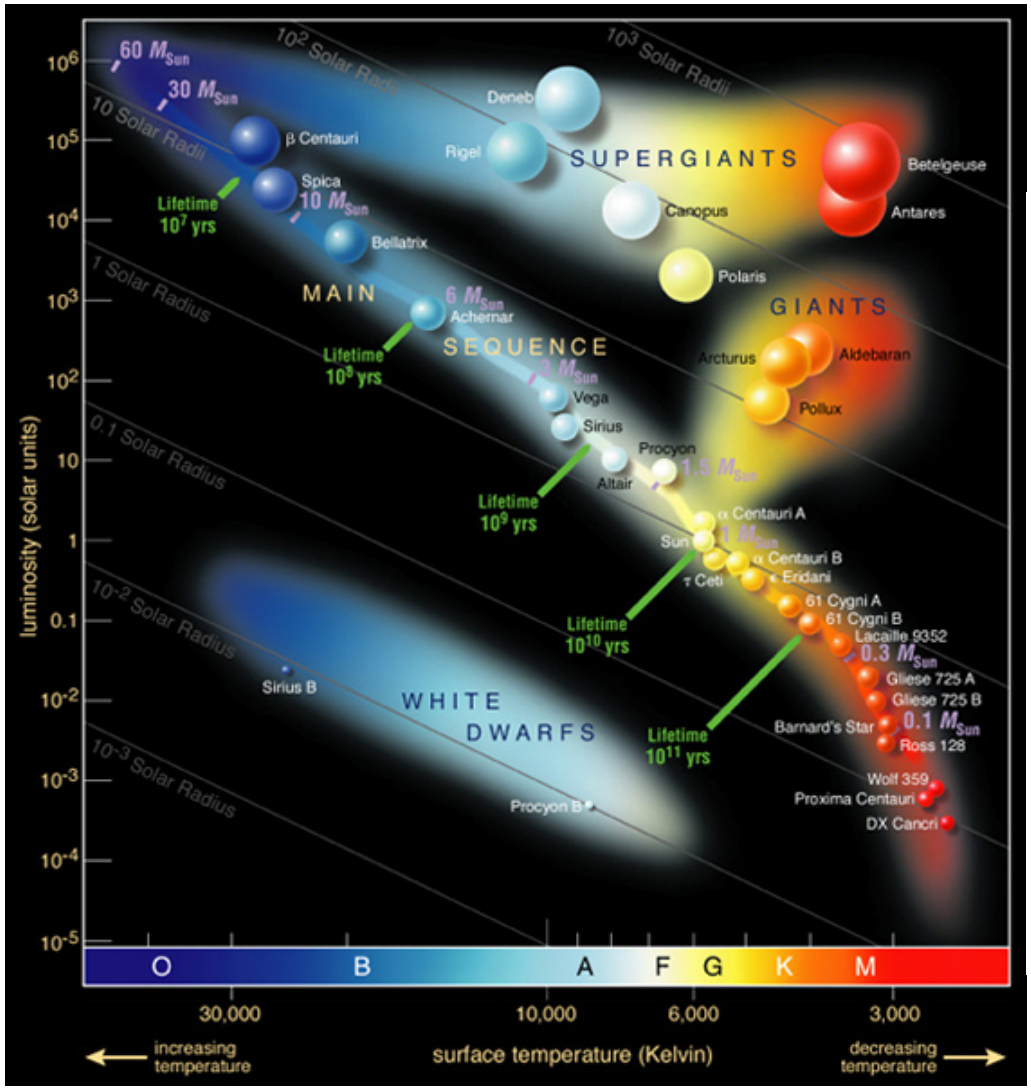
Type of object	Number density
Spirals	1
Lenticulars	0.1
Ellipticals	0.2
Irregulars	0.05
Dwarf galaxies	10
Peculiar galaxies	0.05
Starbursts	0.1
Seyferts	10^{-2}
Radio galaxies	10^{-4}
QSOs	10^{-5}
Quasars	10^{-7}

Sérsic 1963, 1968

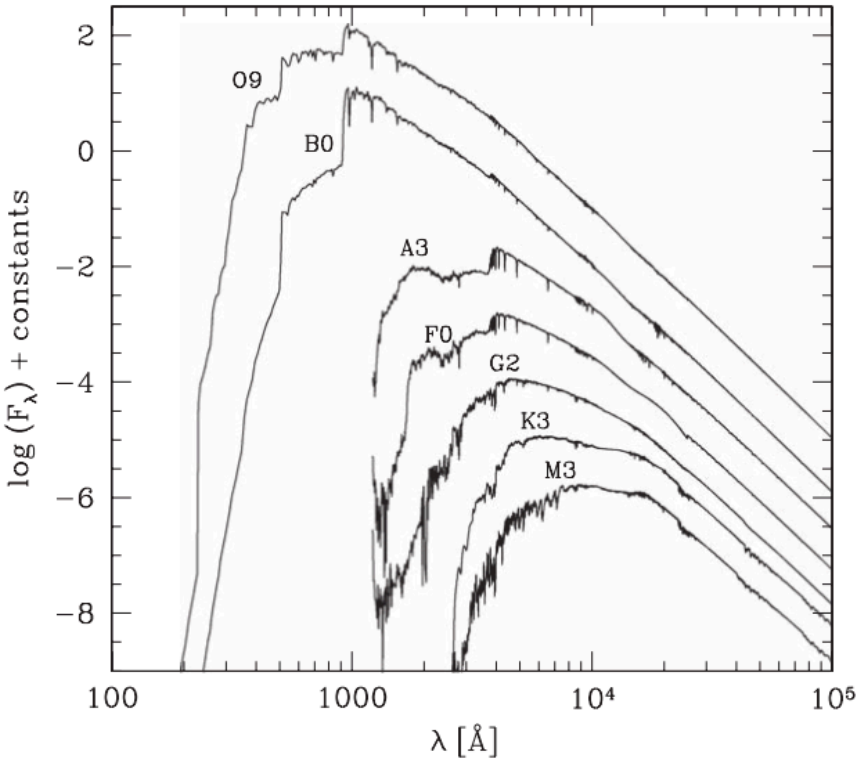
$$I(r) = I_0 \exp\left[-\left(\frac{r}{r_e}\right)^{1/n}\right]$$



Stellar Population Synthesis

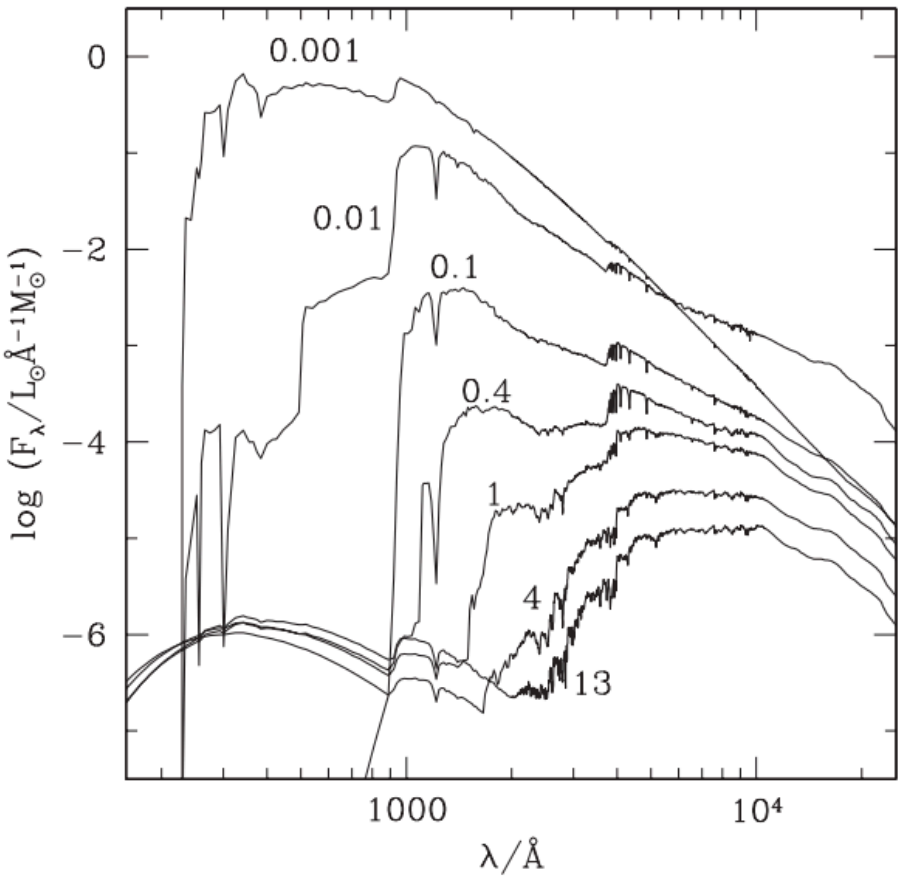


Mo + 2010



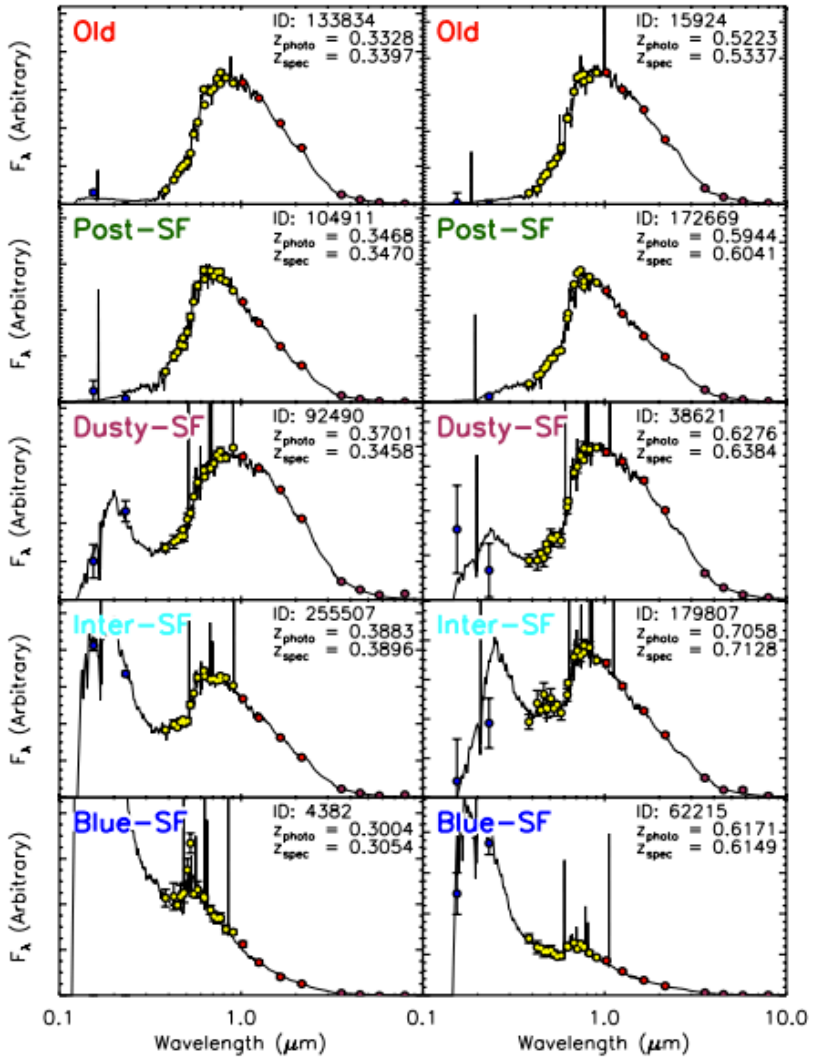
Stellar Population Synthesis

Single starburst at time t (in Gyr)



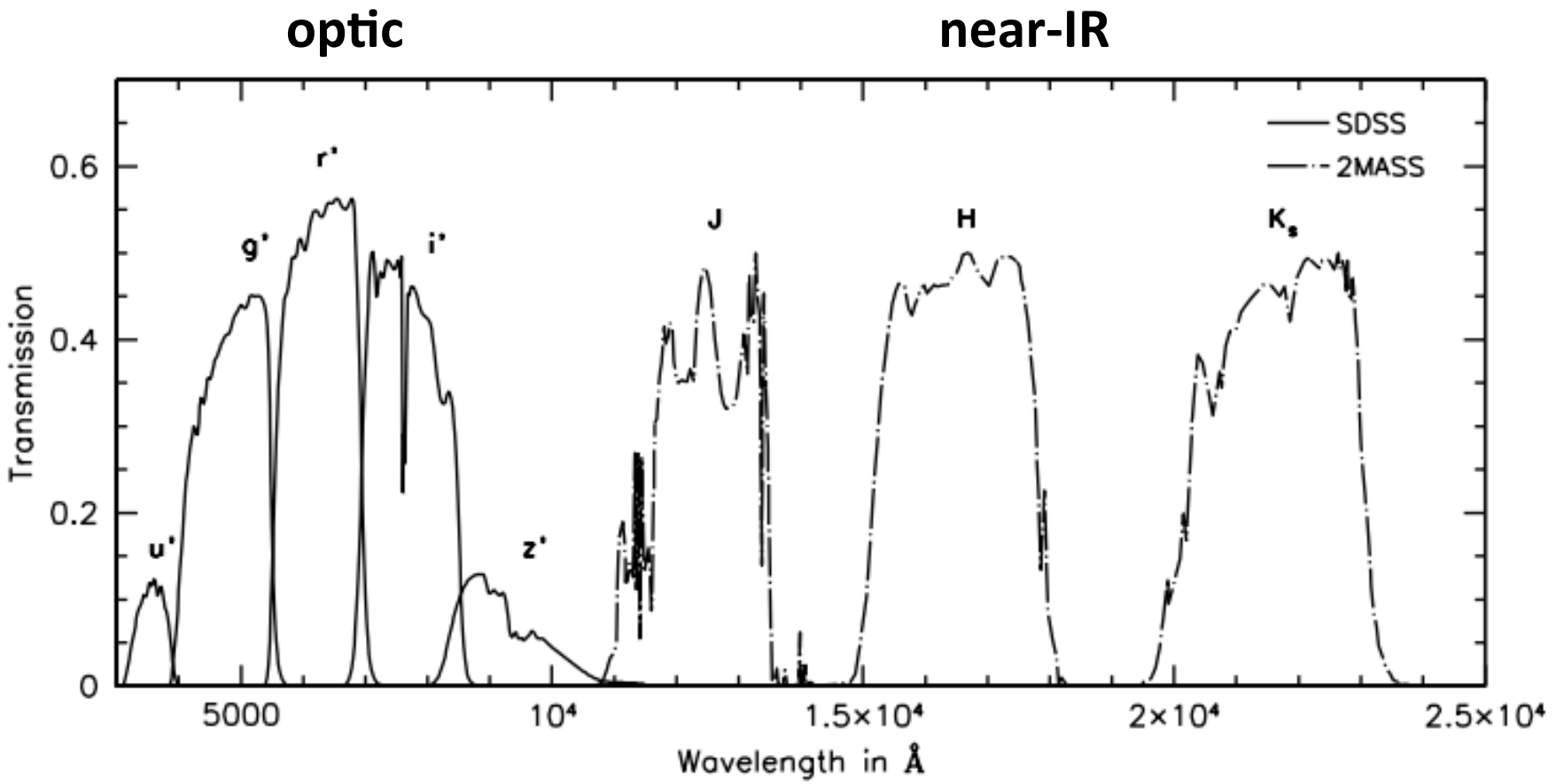
Bruzual & Charlot 1993, 2003

Real data

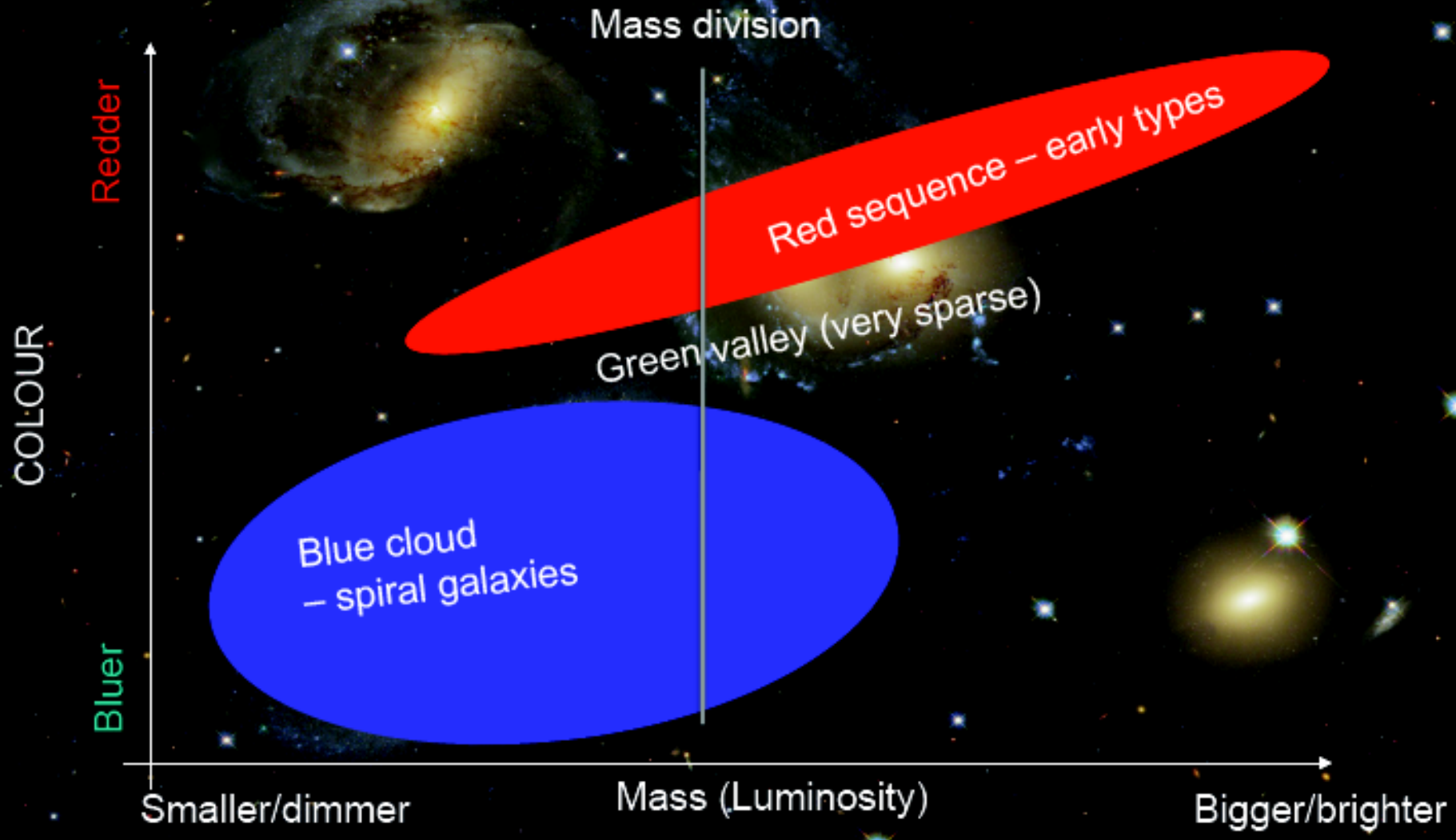


Muzzin + 2013

Commonly used filters



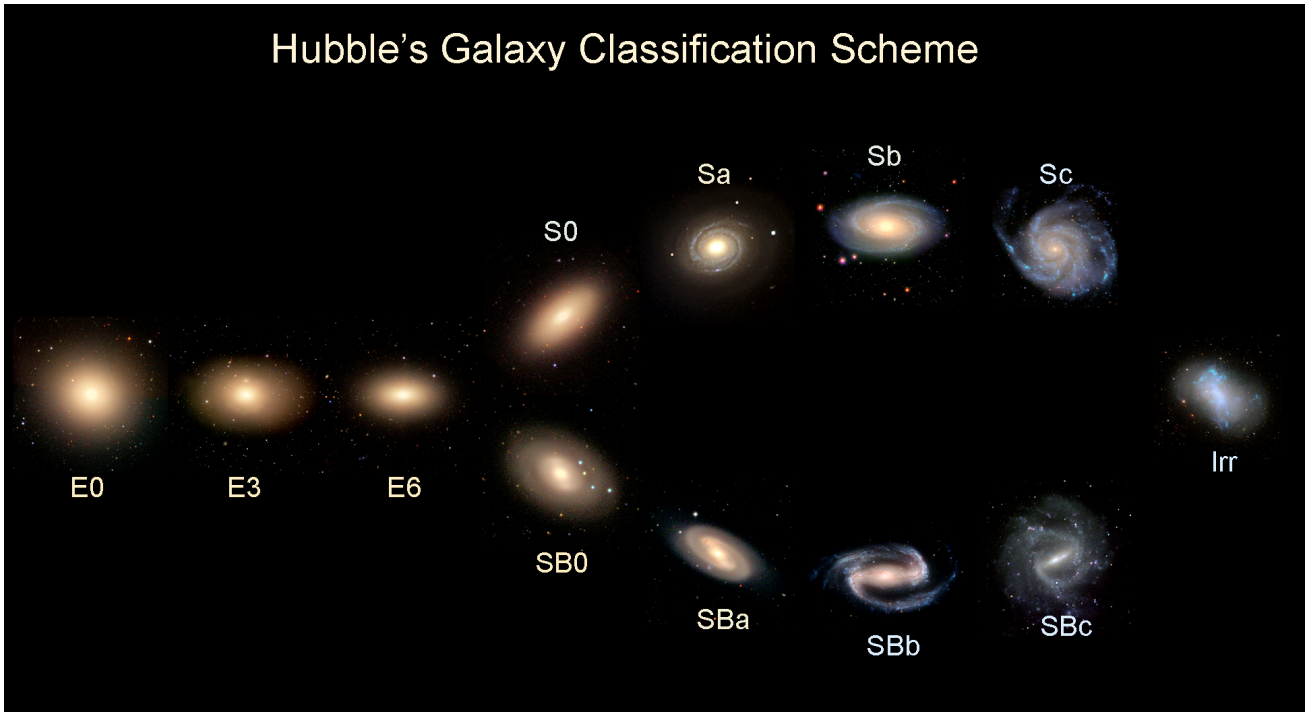
Why Look – galaxies aren't all the same…



Bi-modality of the classification

Early type

Late type

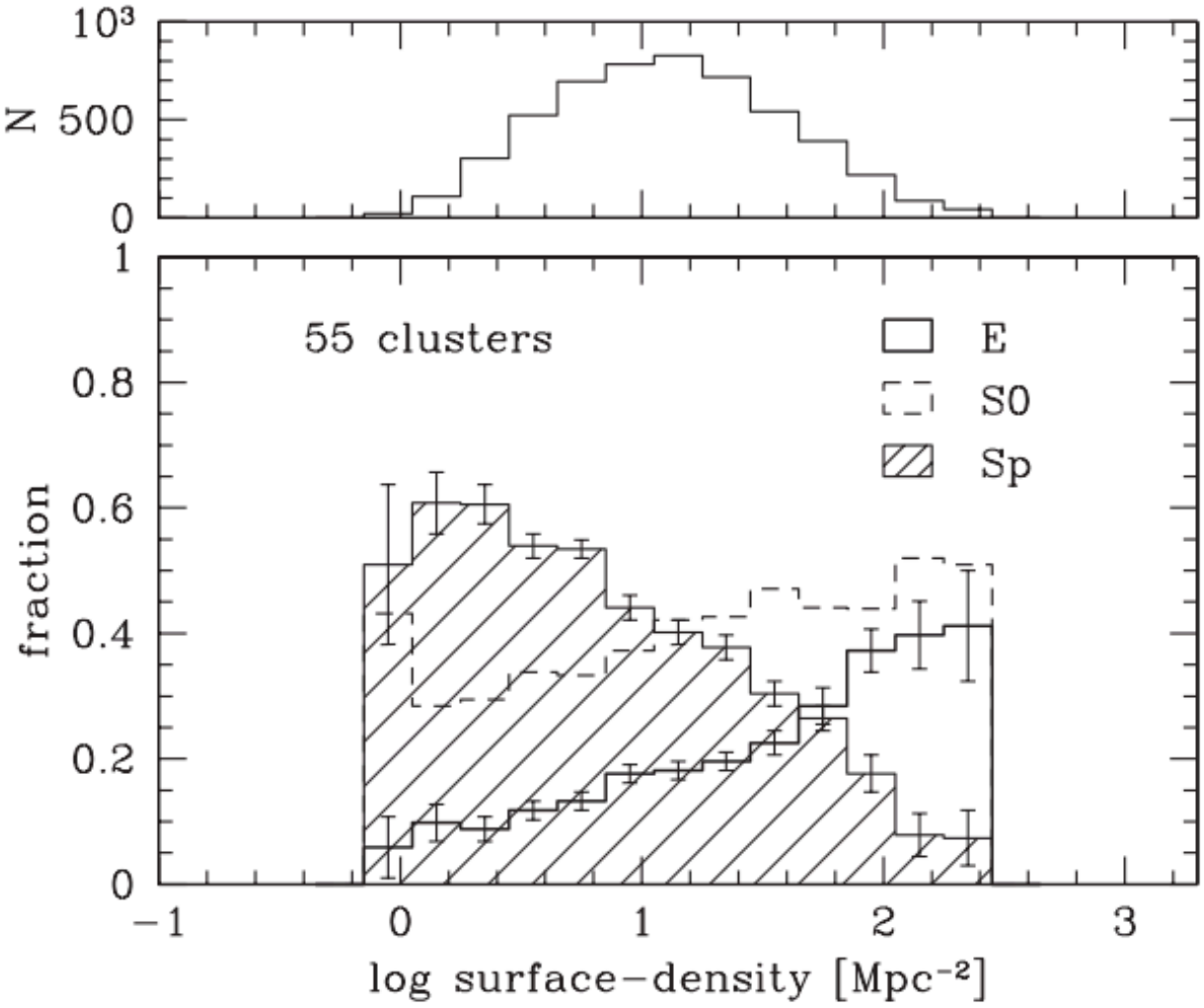


Elliptical or lenticular, bulge
« red sequence »
Passive galaxies
$n_{Sersic} > 2.5$ (**de Vaucouleurs** profile)

Spiral disk, with disk/bar
« blue cloud »
Actively star-forming galaxies
$n_{Sersic} < 2.5$ (**exponential** profile)

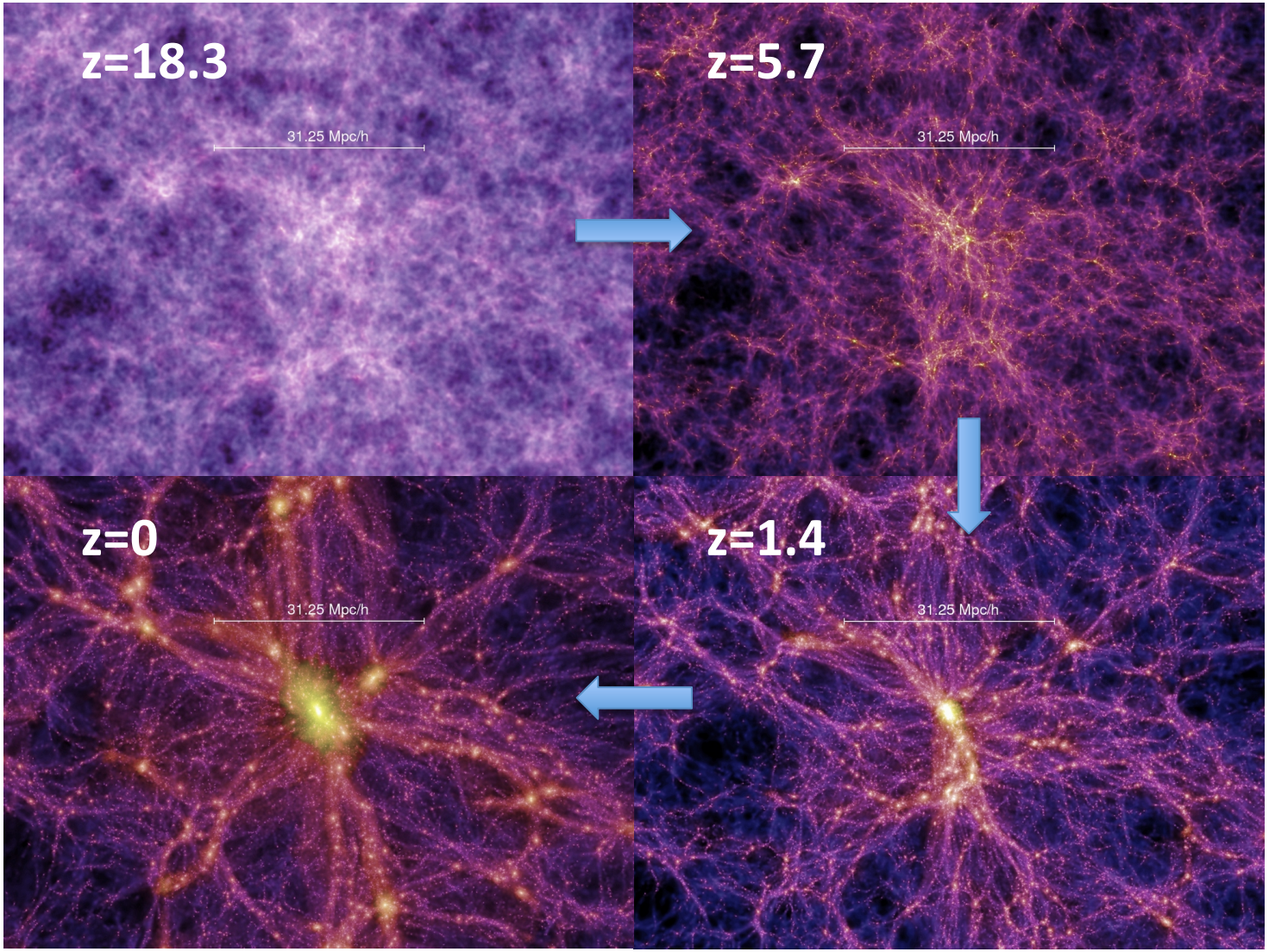
Morphology-density relation

Dressler 1980



N-body simulations

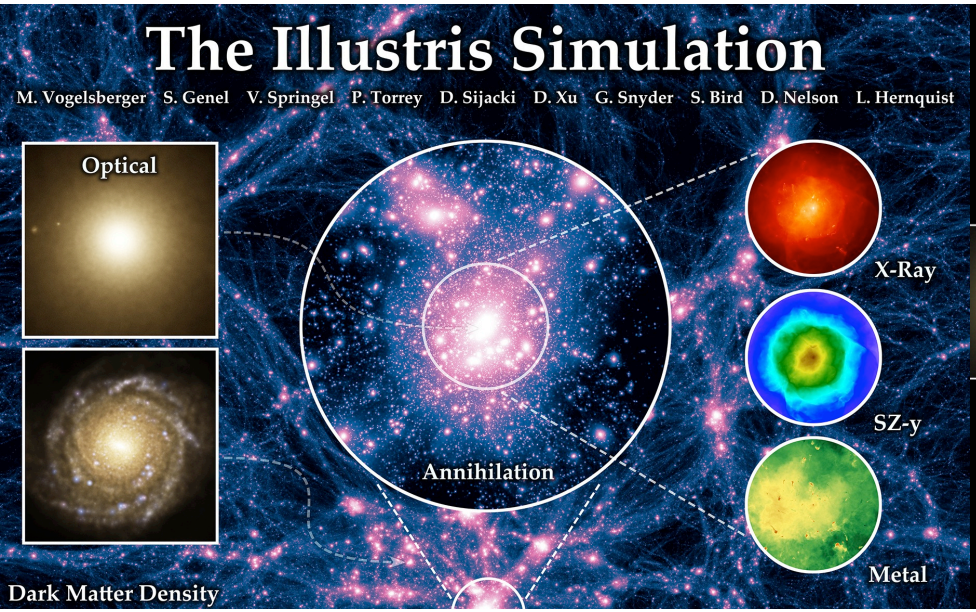
Structure formation (Dark Matter): Millenium Simulation Project



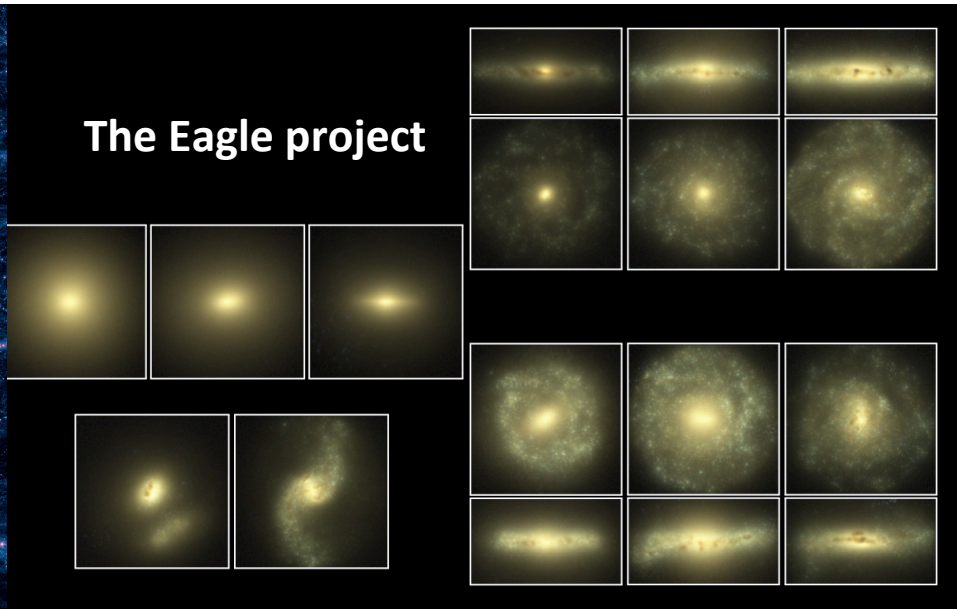
Baryonic Matter

Cosmological hydrodynamical simulations (inc. feedback)
Simulating the evolution and assembly of galaxies

Vogelsberger + 2014



Schaye + 2014



Massive-compact-quiescent: first observations

2005: Daddi + Hubble Ultra Deep Field **(1.4<z<2.5)**
7 quiescent massive galaxies: quite compact

2006: Kriek + K-bright galaxies survey (Gemini Near-IR Spectrograph)
~45% have evolved stellar populations or no ongoing star formation

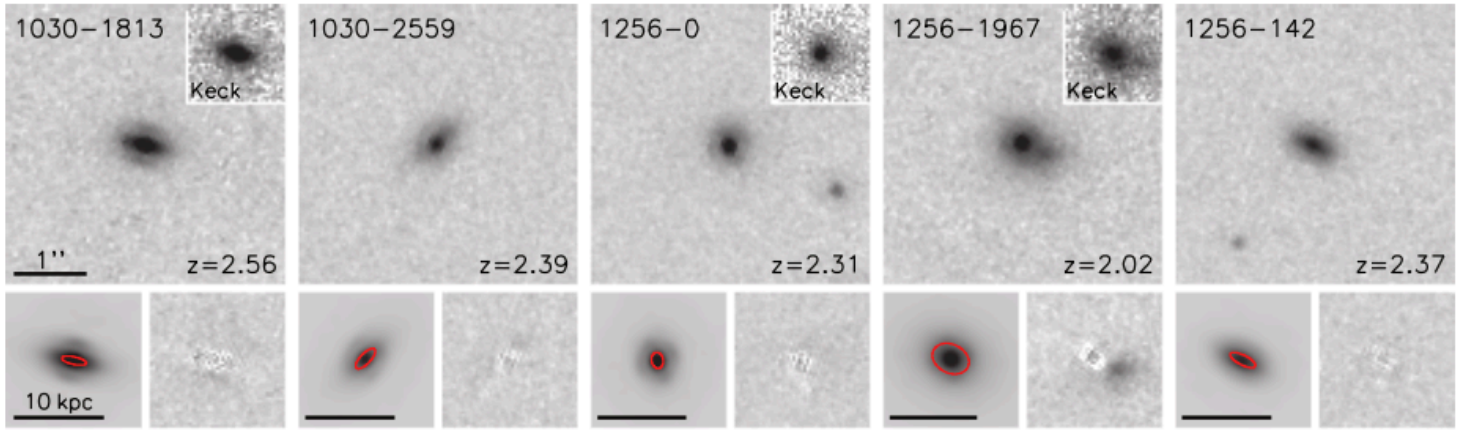
2007: Toft + HST/NICMOS+ACS & Spitzer/IRAC+MIPS **(2<z<3.5)**
quiescent galaxies are more compact than star forming ones

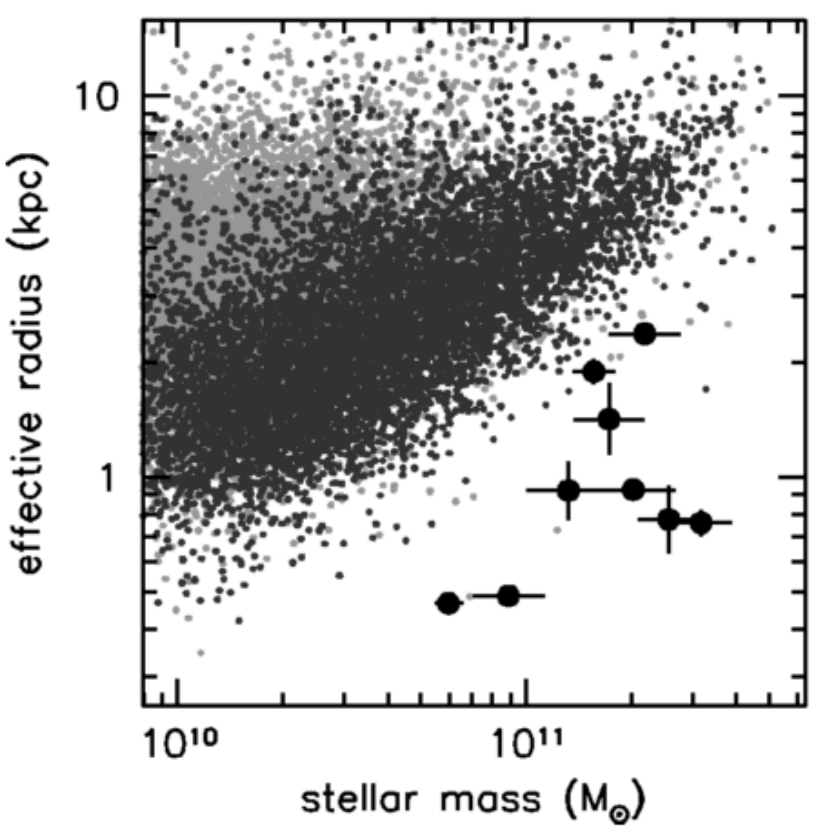
(…)

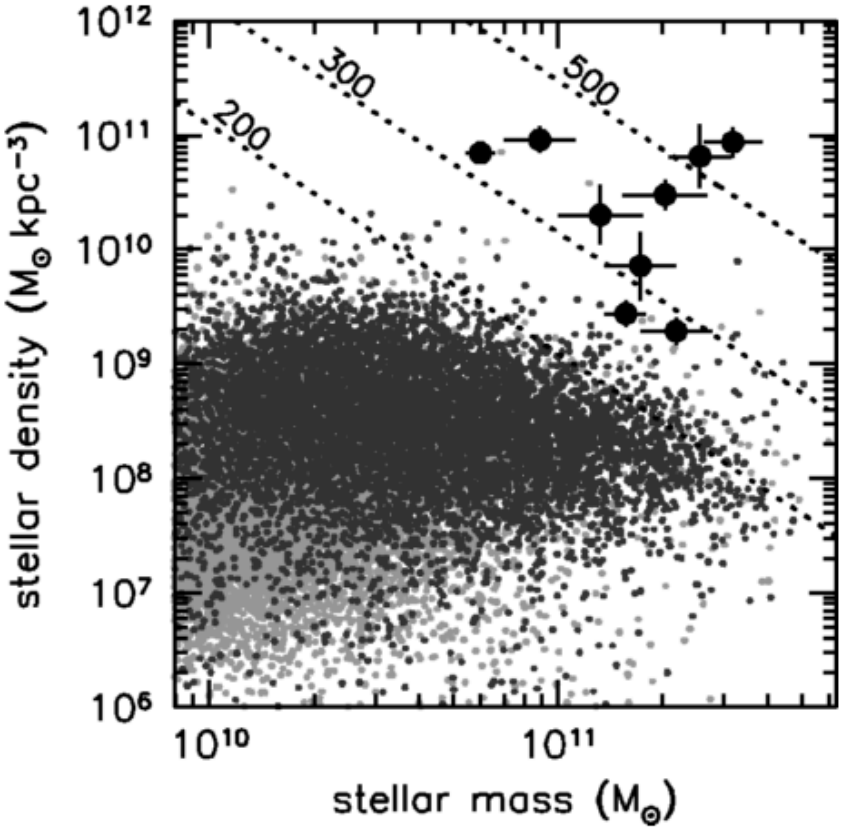
2008: Van Dokkum + HST/NIC2 data of 9 quiescent galaxies **(2<z<2.7)**
r_{eff}<1 kpc, $M_{\star}>10^{11}\ M_{\odot}$

2009: Damjanov + “red nuggets”
(1.2<z<2) HST/NICMOS observation of 19 high mass passively evolving galaxies identified by GDDS

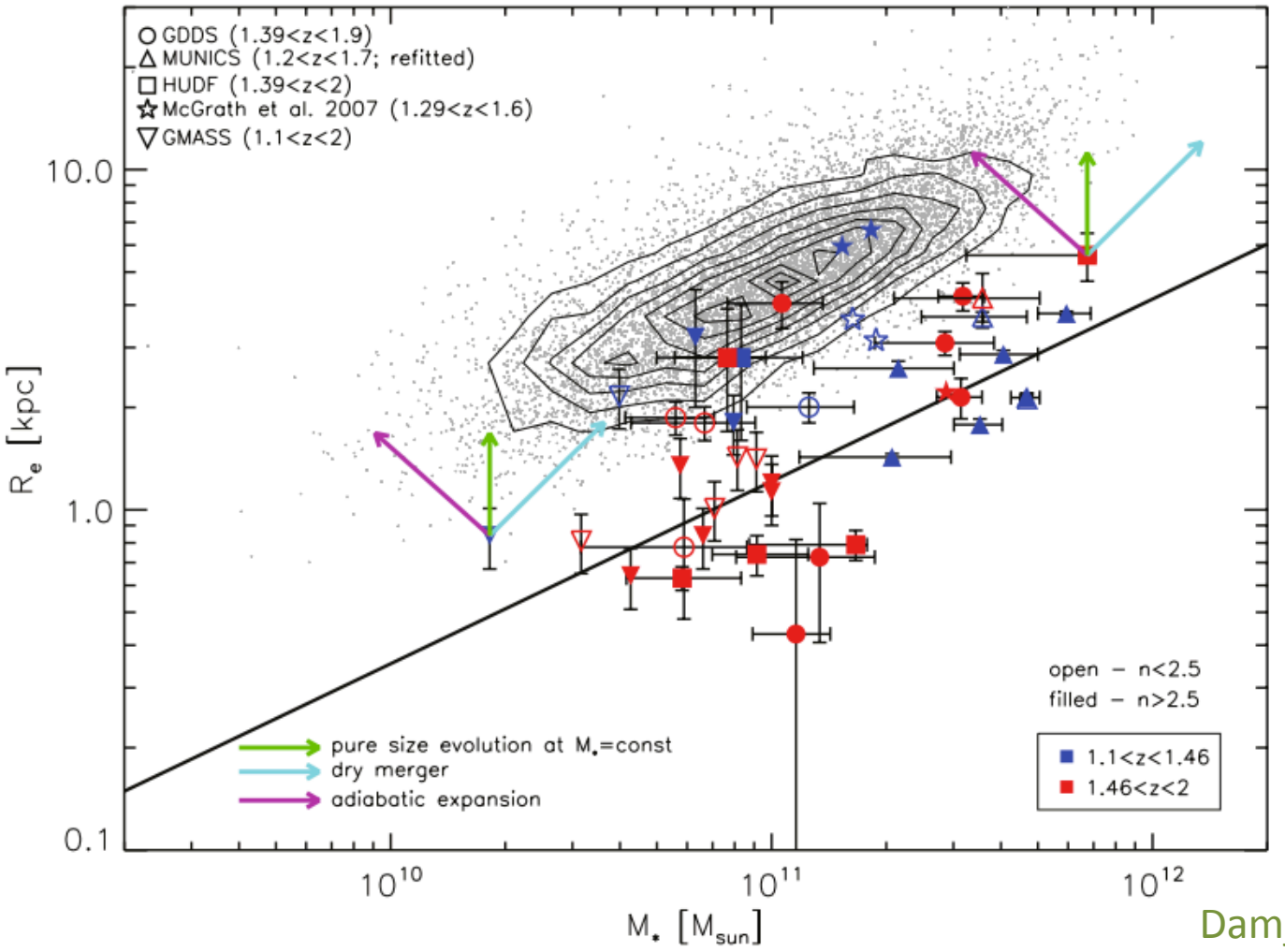
Van Dokkum + 2008







Mechanisms of size evolution?



Damjanov + 2009

pure size evolution at $M_\star$=const

dry merger

adiabatic expansion

Towards lower redshifts

2010: Valentinuzzi + WIde field Nearby Galaxy cluster Survey **(0.04<z<0.07)**
Isaac-Newton, MPG/ESO telescopes, + spectroscopy
high density of superdense candidates

2010: Taylor + SDSS spectroscopic sample **(0.066<z<0.12)**
63 candidates, but different from high-redshift ones

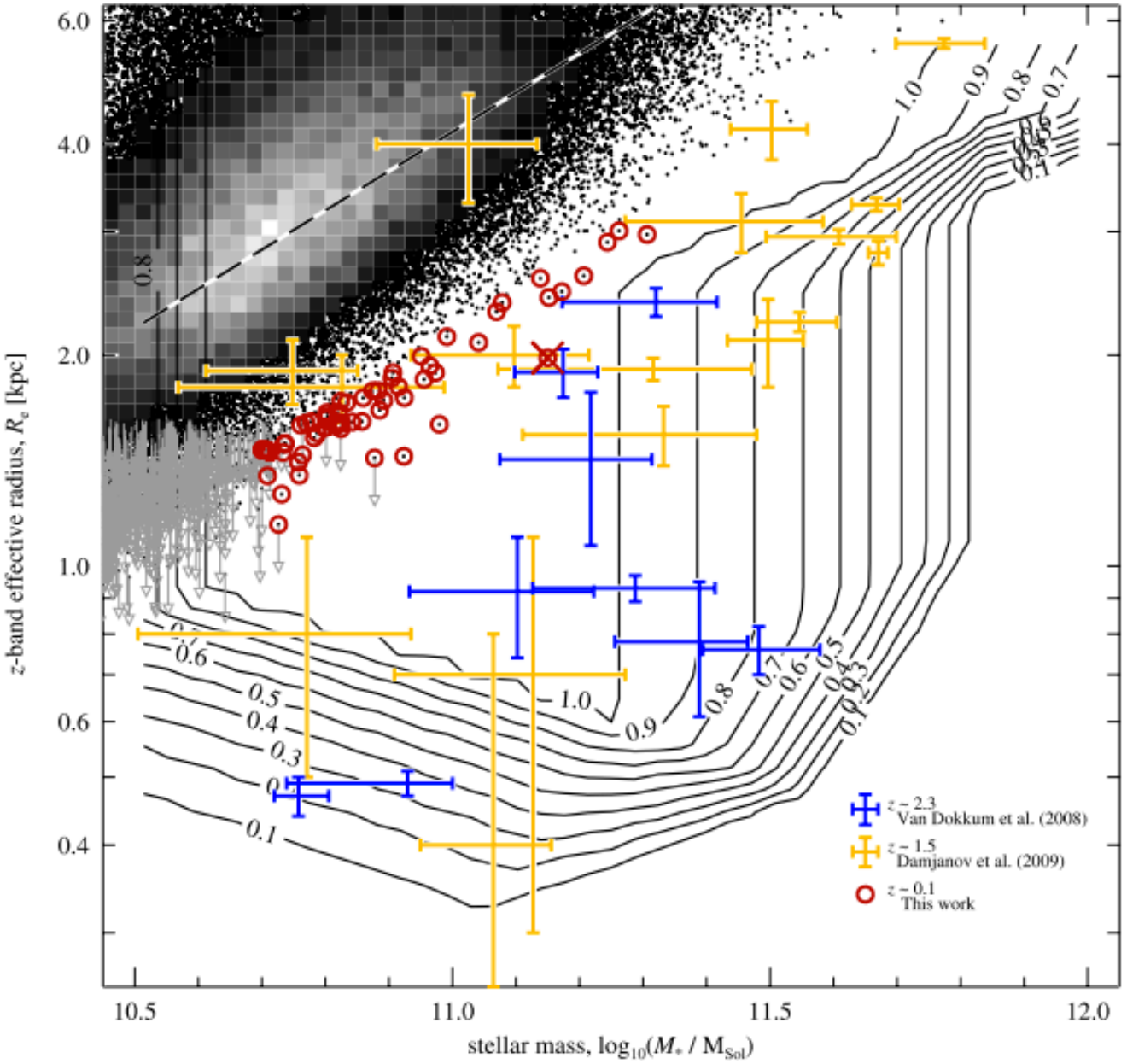
2013: Quillis & Trujillo Millennium N-body simulation **from z~2 to z~0**
10% to 30% of increase of the mass
fraction of massive relics: 0.1% to 1%

2013: Damjanov + SDSS spectro=GALAXY, image=STAR **(0.3<z<0.5)**
+ HST/ACS data: 9 identified, similar to high-redshift

2014: Stockton + SDSS + UKIRT, follow-up: Keck spectroscopy and AO **(z~0.5)**
2/5 candidates for relics, prolate morphology

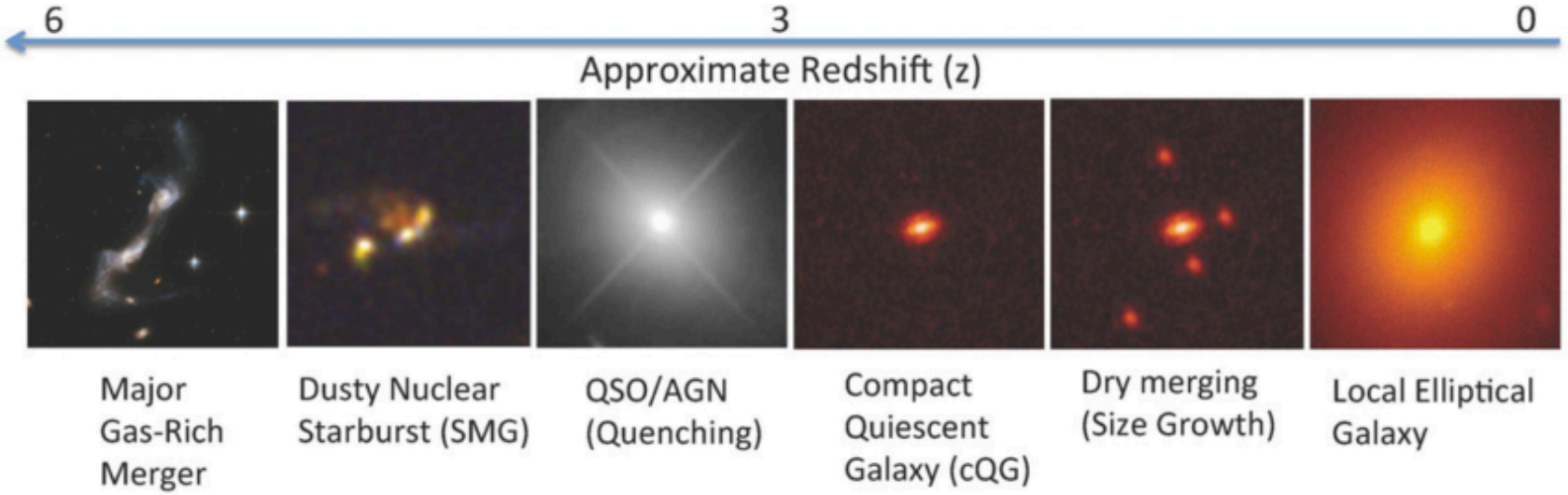
2014: Trujillo + NGC 1277, HST/ACS, Long slit spectro @Hershell **(z=0.0169)**
Massive, compact, old stellar population: closest candidate

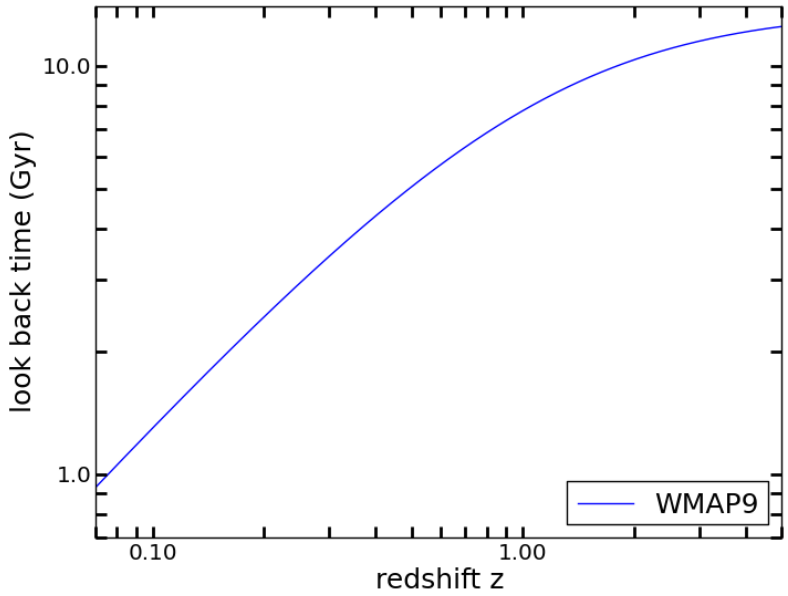
Taylor + 2010


6.0
4.0
2.0
1.0
0.6
0.4
z-band effective radius, R_e [kpc]
10.5
11.0
11.5
12.0
stellar mass, $\log_{10}(M_* / M_{Sol})$
0.8
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.1
z ~ 2.3
Van Dokkum et al. (2008)
z ~ 1.5
Damjanov et al. (2009)
z ~ 0.1
This work

A possible scenario

Toft + 2014

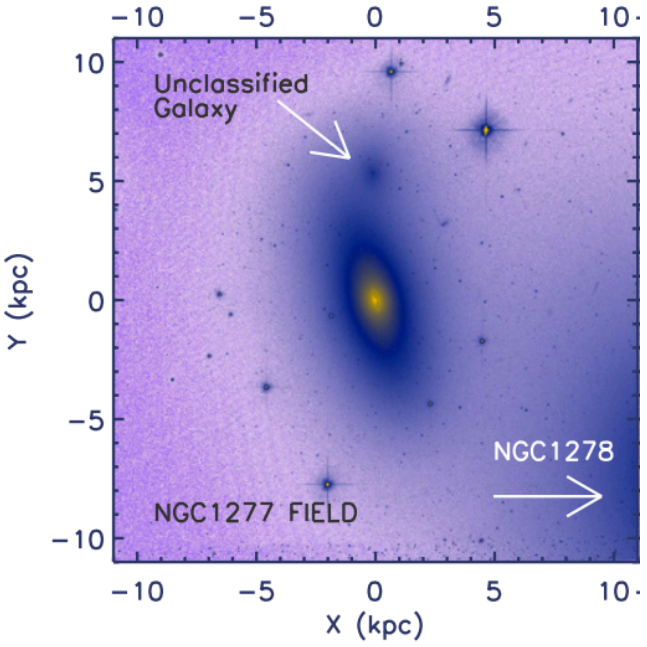




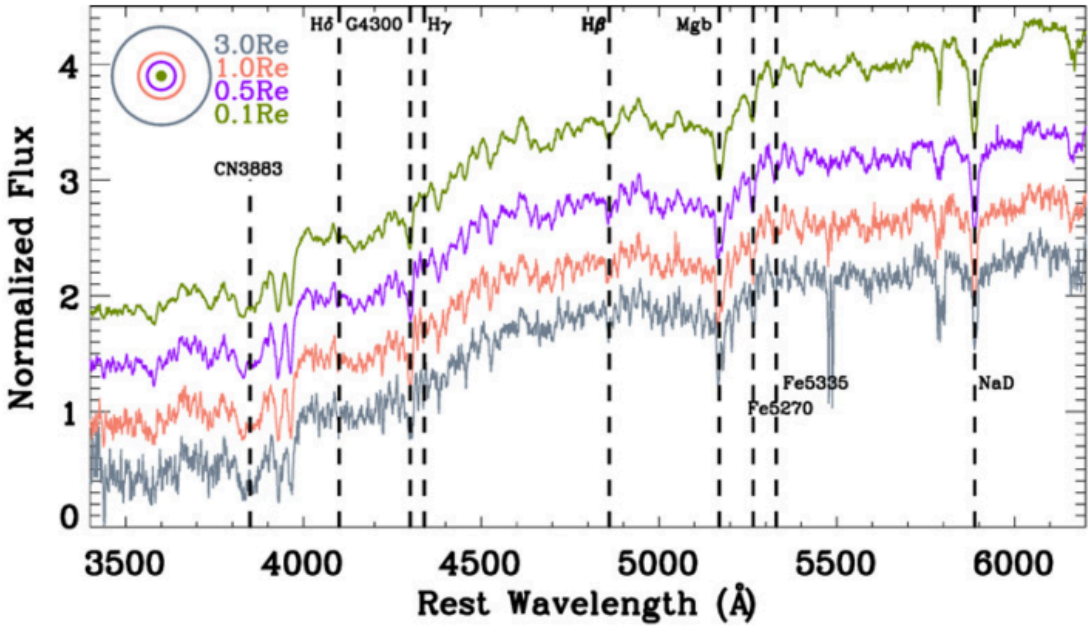
How to look for them?

1) ideal situation:

HST-quality image



Detailed spectrum

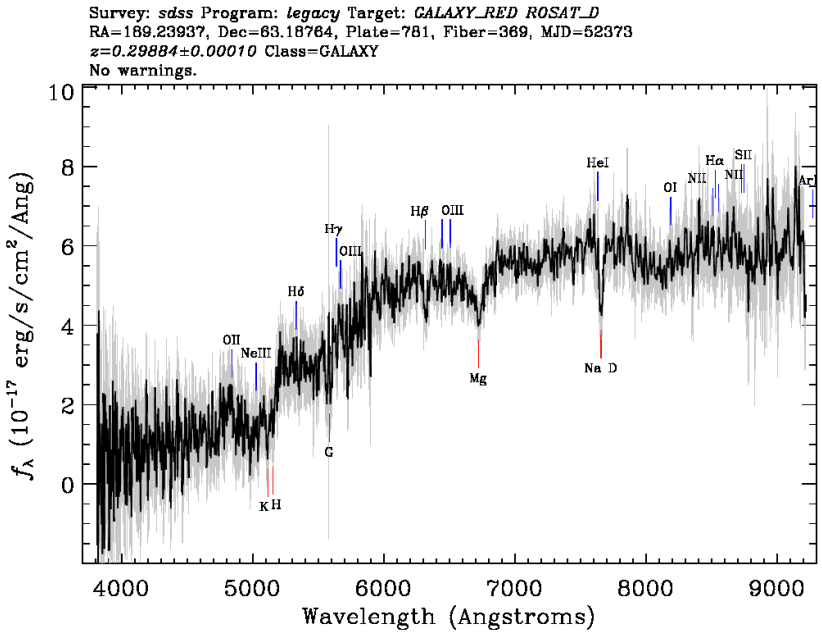


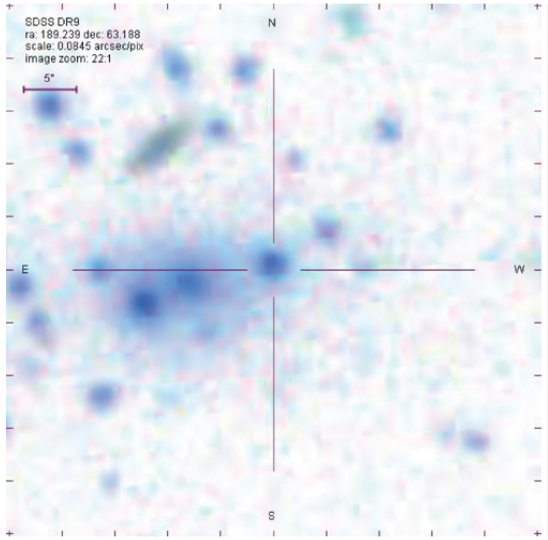
Trujillo + 2014: NGC1277

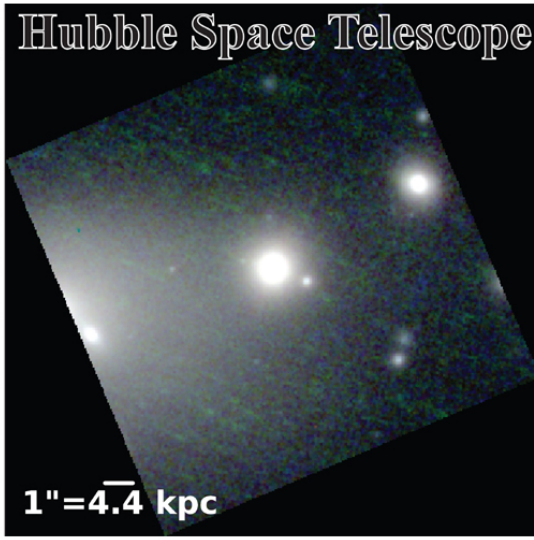
How to look for them?

1) ideal situation

2) real life – A: from spectrum to image







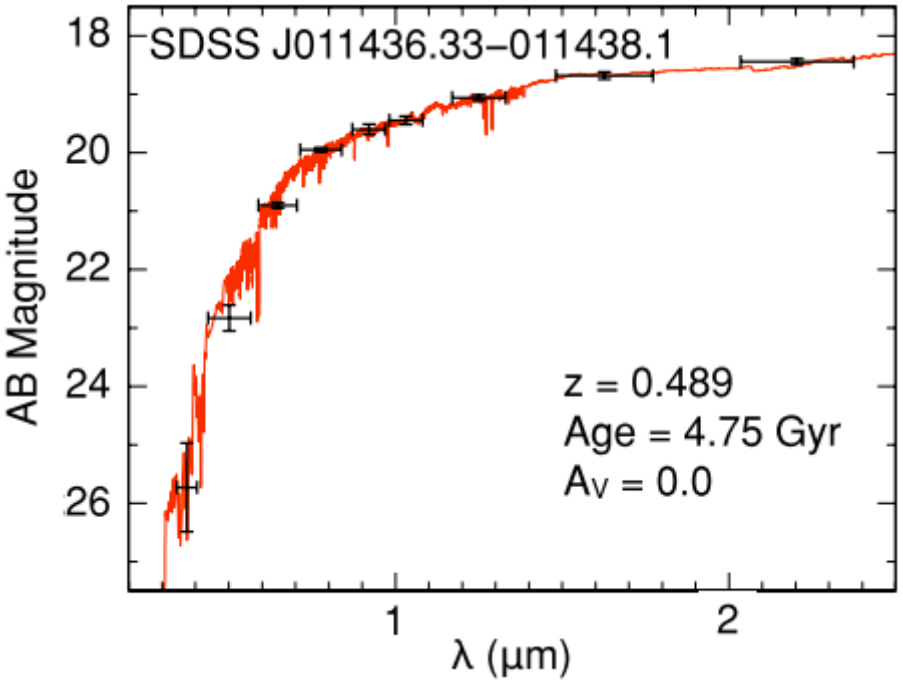
Damjanov + 2013

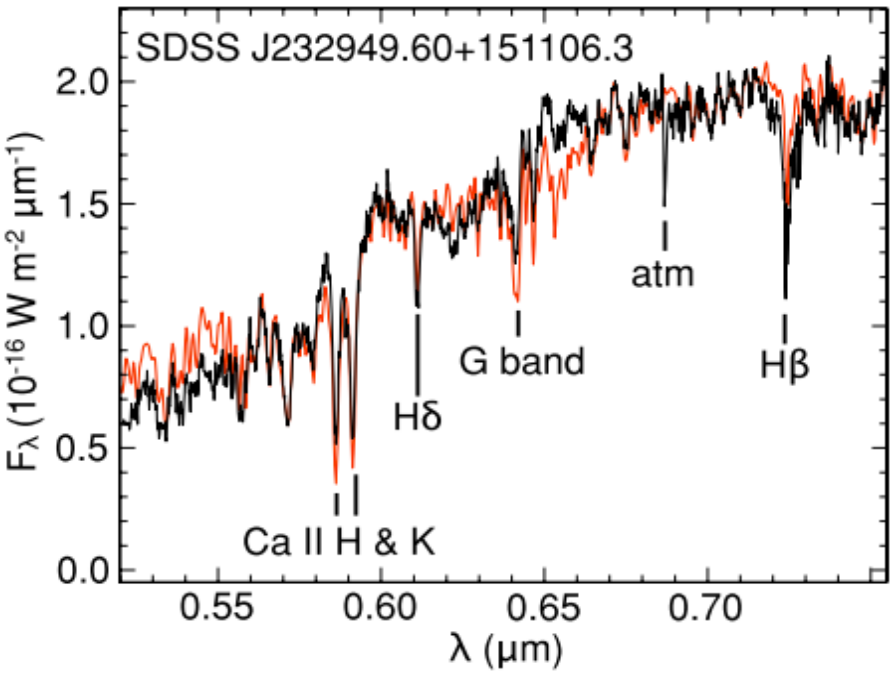
How to look for them?

1) ideal situation

2) real life – A: from spectrum to image

3) real life – B: from image to spectrum





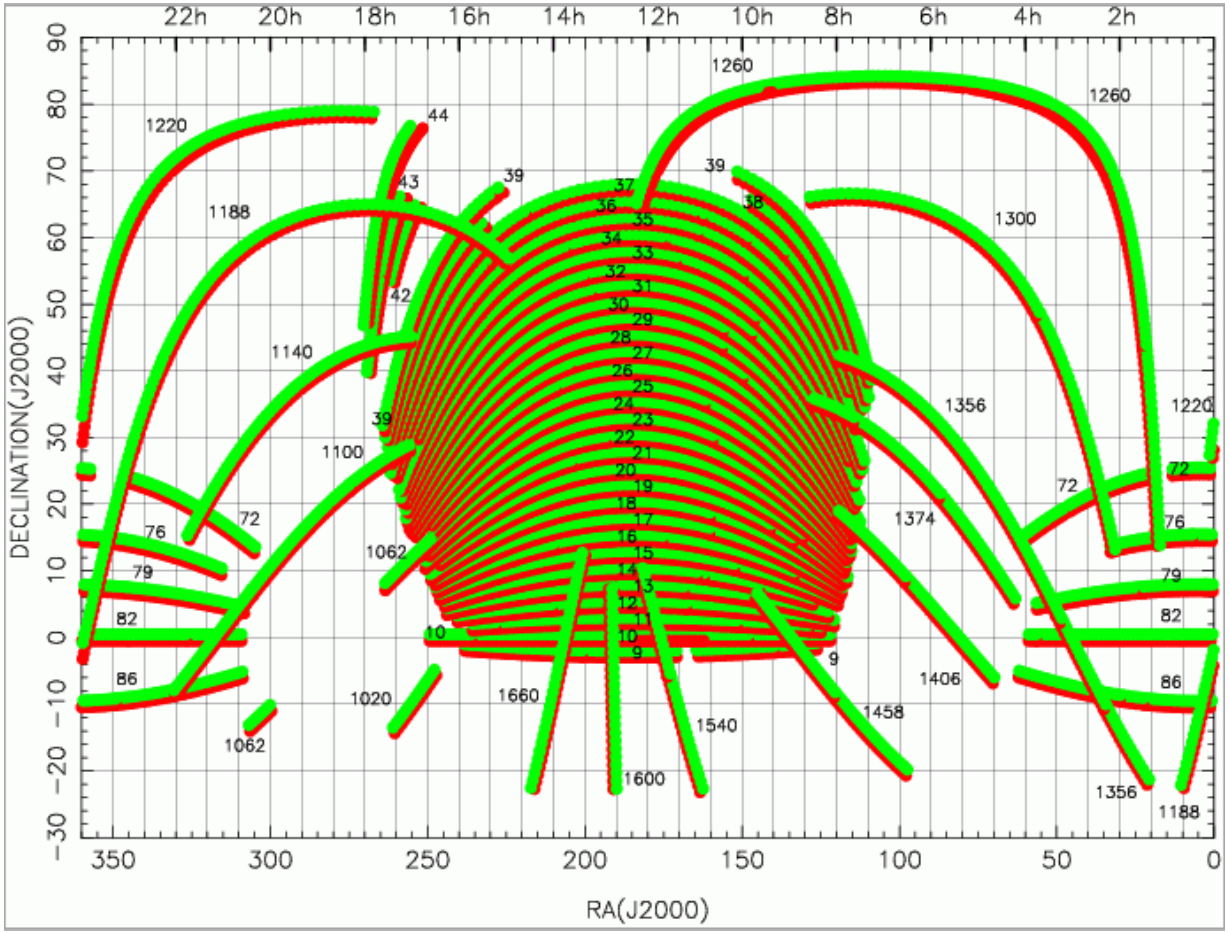
CFHT-Stripe 82 survey

Why “Stripe-82”?

Gunn + 2006

Sloan Digital Sky Survey (SDSS) uses Earth’s rotation

http://dame.dsf.unina.it/catalogues.php



Stripe-82 Multi-WL coverage

- Optical/UV Imaging:
  - SDSS Co-adds (Jiang, Annis, Huff & LSST)
  - CFHTLS
  - CFHT i-band (CS82, Leauthaud)
  - DES, HSC
  - Pan-STARRS, PTF, Skymapper
  - GALEX
- Near-IR:
  - UKIDSS
  - VHS
  - NEWFIRM (Jiang)
  - 2MASS
- Mid-IR:
  - SHELA (Mehrtens)
  - SpIES (Ross), IRAC high-z quasars
  - WISE (Stern)
  - VICS82 (Makler)
- Far-IR:
  - HELMS (Viero)
  - HerS (Viero)

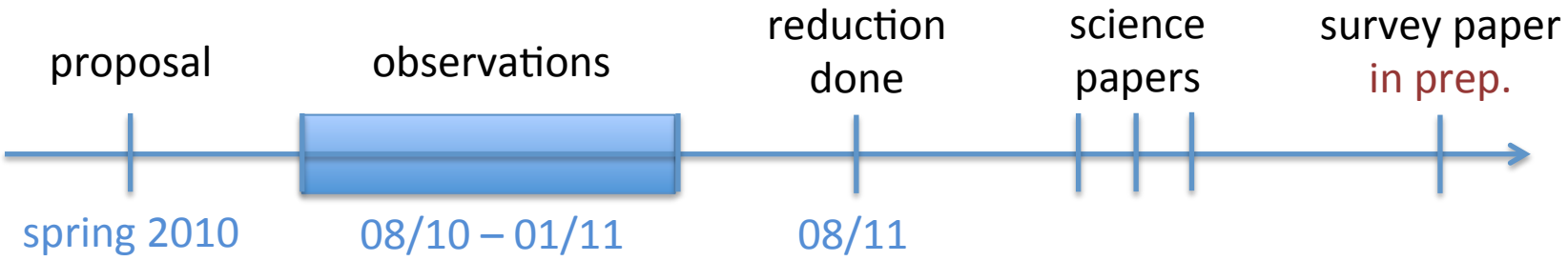
- Radio/mm:
  - VLA-L, A-array (Hodge et al. 2011)
  - VLA-L, C-array (Jarvis)
  - VLA-S (Hallinan)
  - ACT, ACTPol (Marriage)
  - Planck
  - CCAT
- X-ray:
  - Chandra (LaMassa)
  - XMM (LaMassa)
  - Swift (UVOT also)
  - NuSTAR (Civano)
- Spectra:
  - SDSS-I/II,III,IV
  - HETDEX (Gronwall)
  - Wigglez (DR1)
  - VVDS
  - PRIMUS (Coil)
  - DEEP2
  - AUS/2SLAQ
  - DESI
  - SuMIRe/PFS

Credit: Gordon Richards

CS82 survey in a nutshell

- France-Canada-Brazil
- **CFHT**, **MegaCam**
- 173 pointings
- 'Stripe 82'

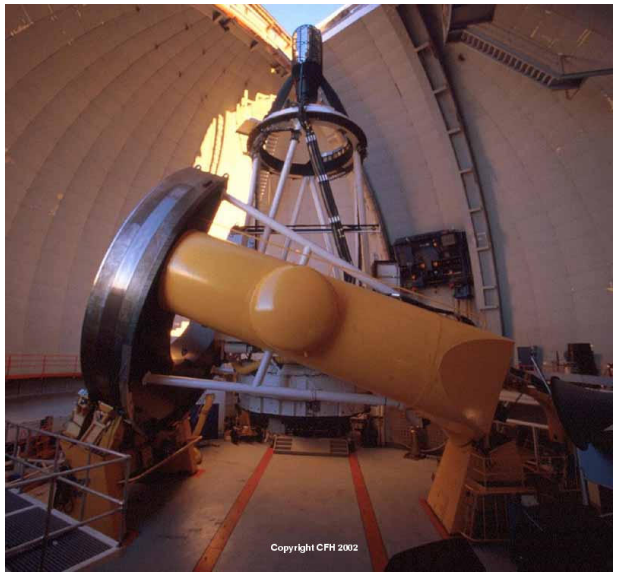
- **lensing** survey
- i-band
- seeing ~ 0.6"

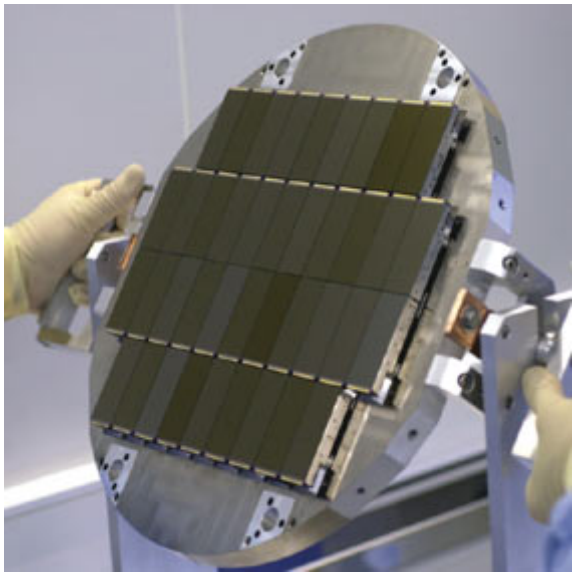


CFHT - MegaCam

- Diameter: 3,6 m
- Summit of the Mauna Kea volcano
- 4200 m high
- Big Island of Hawaï, U.S.A.
- Construction in 1979

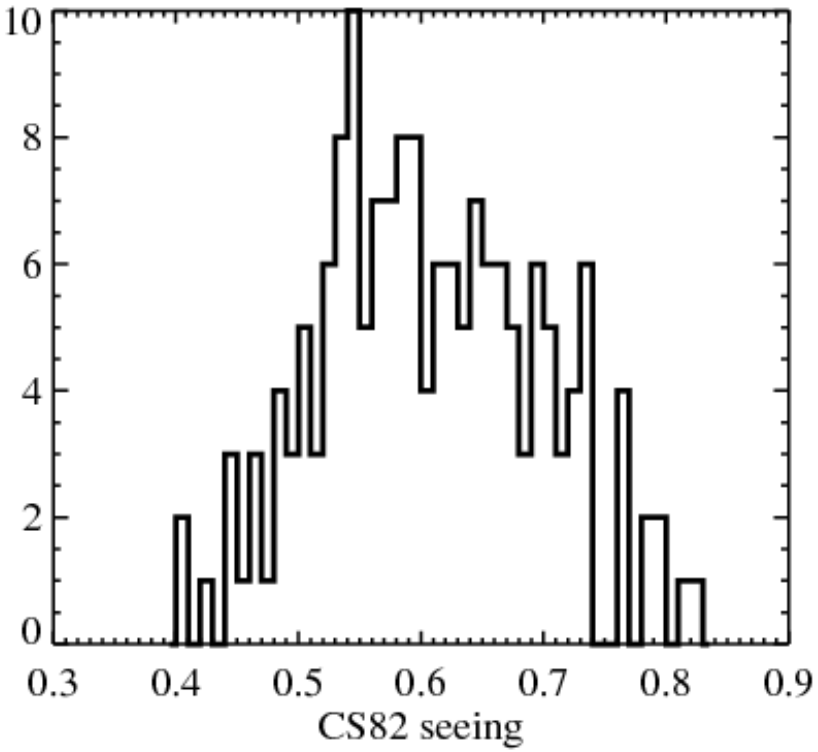
- Mosaic of 40 CCDs
- 375 billions pixels
- Commissioning in 2003



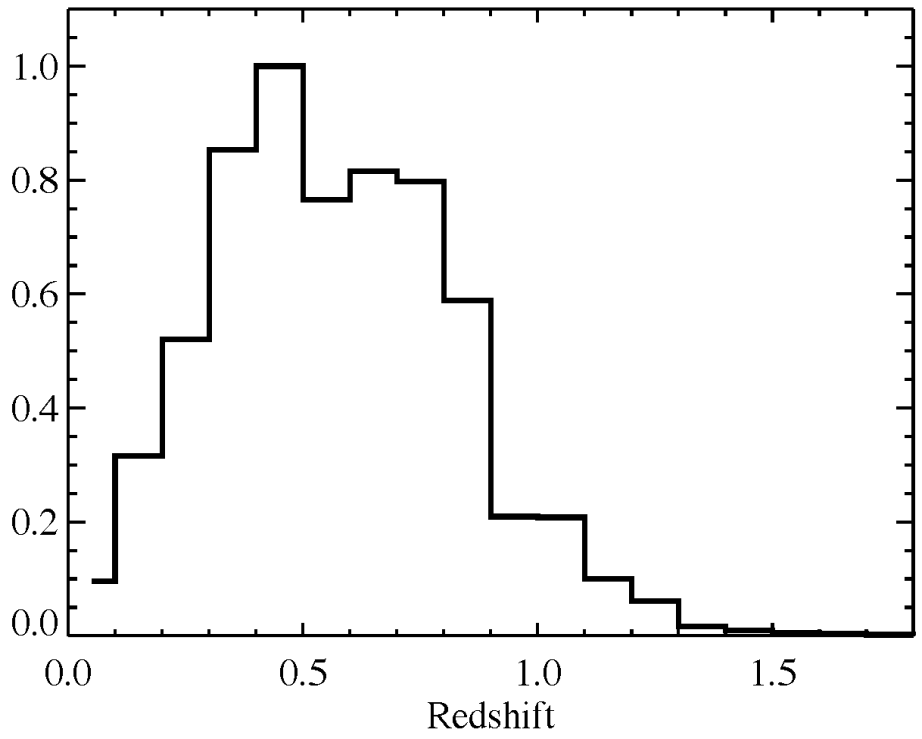


Properties of CS82 images

Mean seeing 0.6''

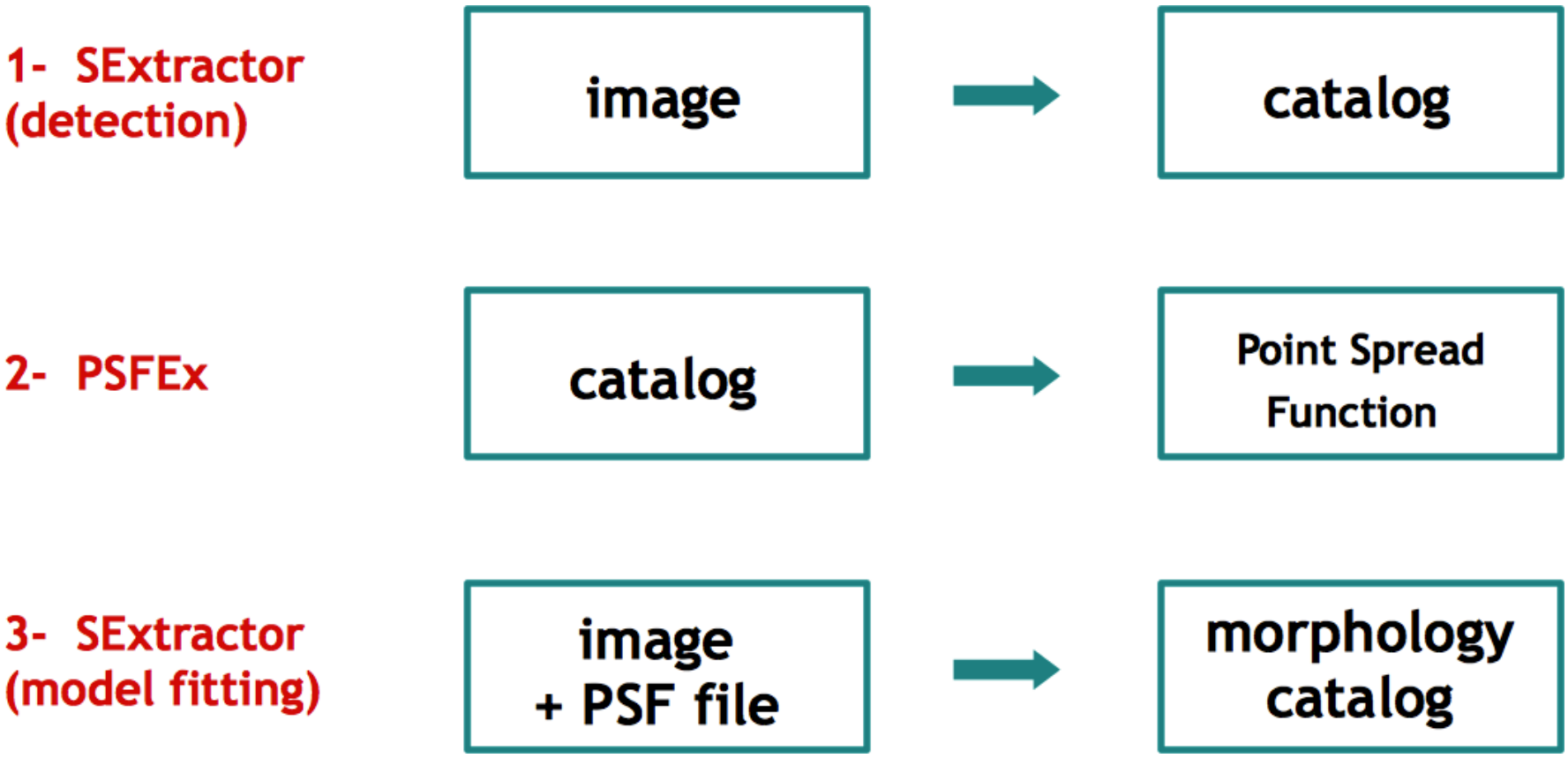


Redshift distribution



Magnitude limit: ~23.5 for galaxies

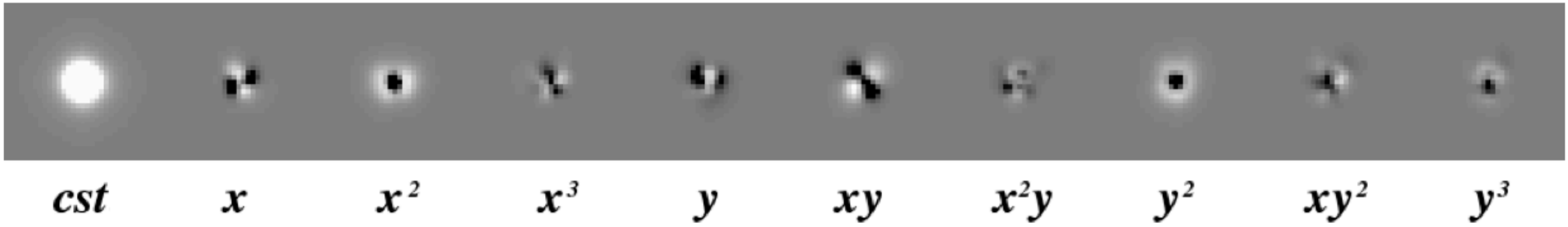
Morphology extraction



SExtractor: http://www.astromatic.net/software/sextractor
PSFEx: http://www.astromatic.net/software/psfex

PSFEx

- Solving in direct space (≠ Fourier)
- Automatically selects the point like sources
- PSF modeled as a linear combination of basis functions
- Weighted χ^2 minimization
- **PSF variations may be decomposed on a polynomial basis**



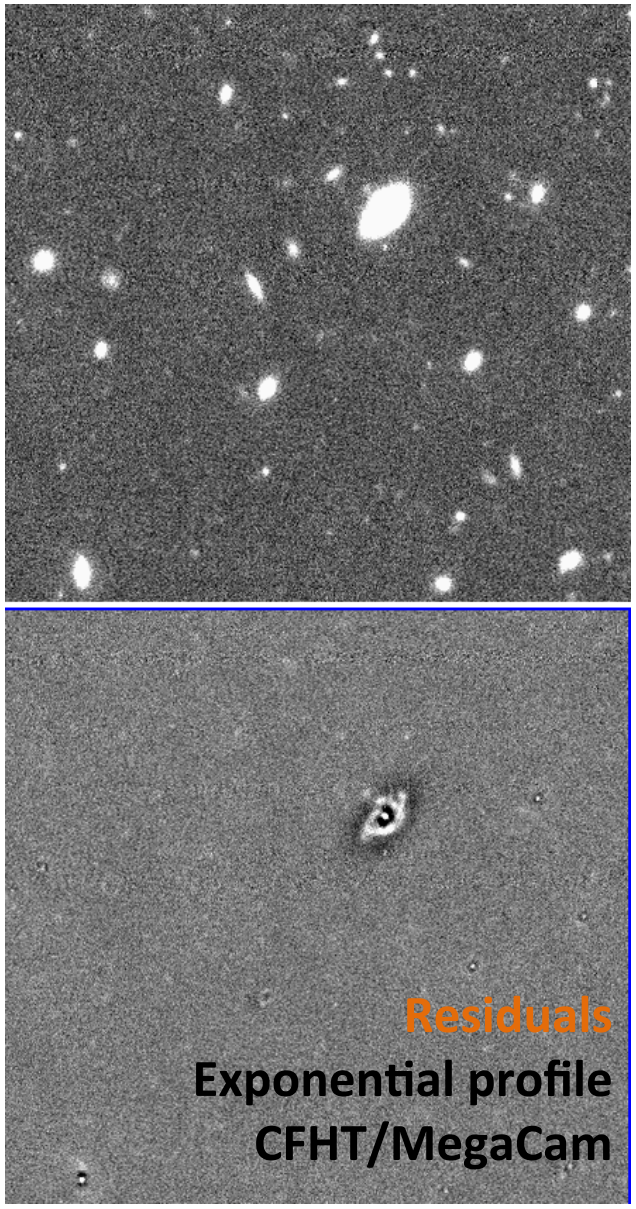
Morphology catalogues

on coadds (4 x single exposures)

~**16,700,000** objects (150,000/tile)

4 profiles: de Vaucouleurs
exponential
general Sérsic
deV + exp

CPU time: 12h/profile/tile



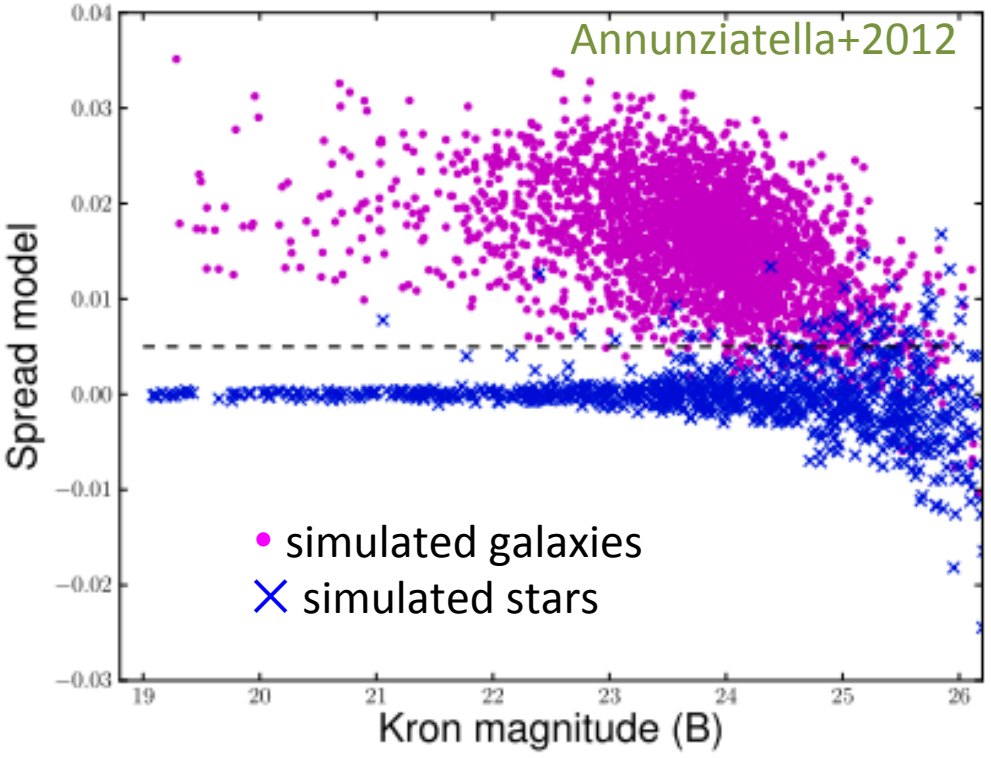
Moraes, Charbonnier + 2014 (in prep.)

SPREAD_MODEL parameter

- **Star/galaxy discriminator from SExtractor**
- **Diagnostic for a good PSF reconstruction**

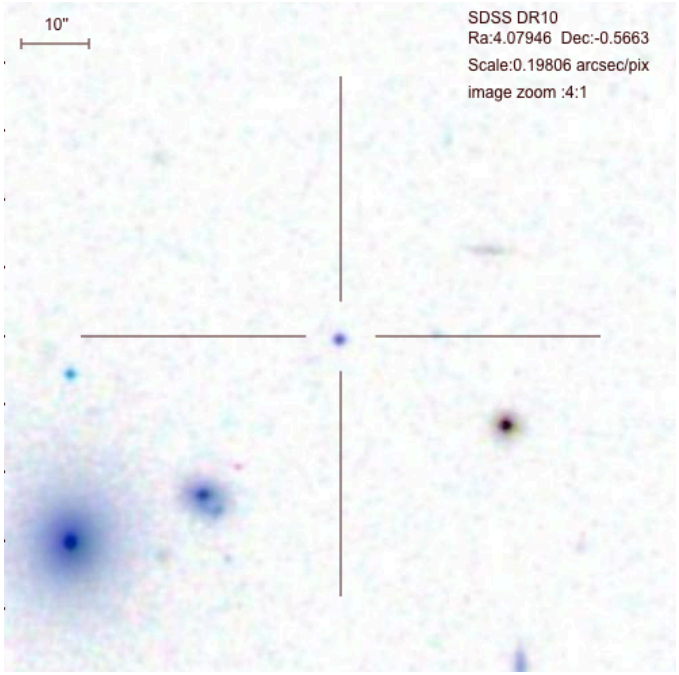
$$\texttt{spread\_model} = \frac{\boldsymbol{\phi}^{\mathbf{T}}\mathbf{x}}{\boldsymbol{\phi}^{\mathbf{T}}\boldsymbol{\phi}} - \frac{\mathbf{G}^{\mathbf{T}}\mathbf{x}}{\mathbf{G}^{\mathbf{T}}\boldsymbol{\phi}}$$

ϕ: PSF model
G: slightly more extended model

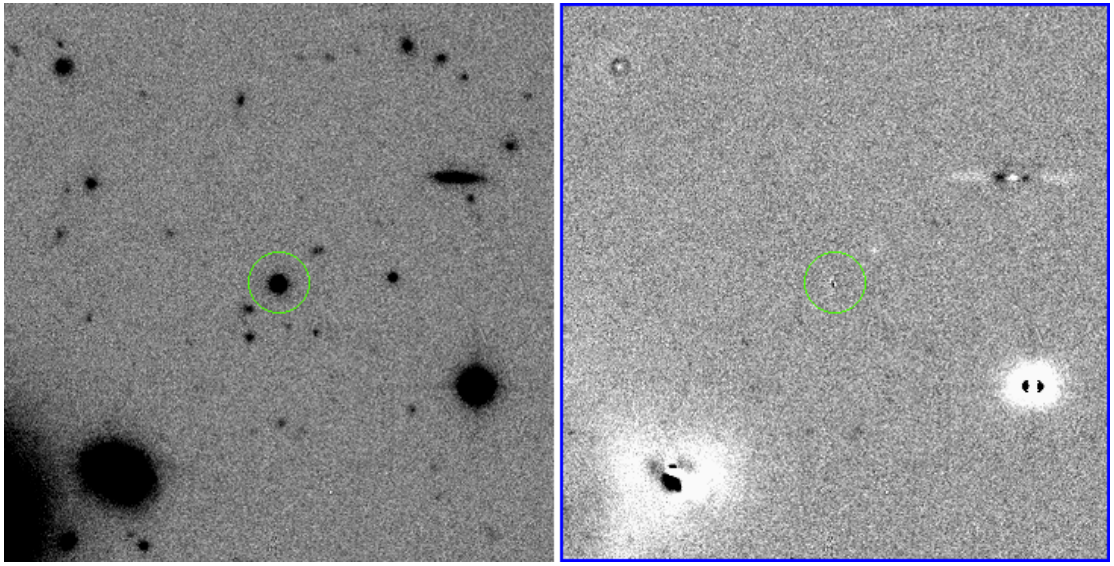


Example: Damjanov objects

Damjanov + 13: SDSS image: Point-like
SDSS spectrum: Galaxy
HST images available



SDSS cutout



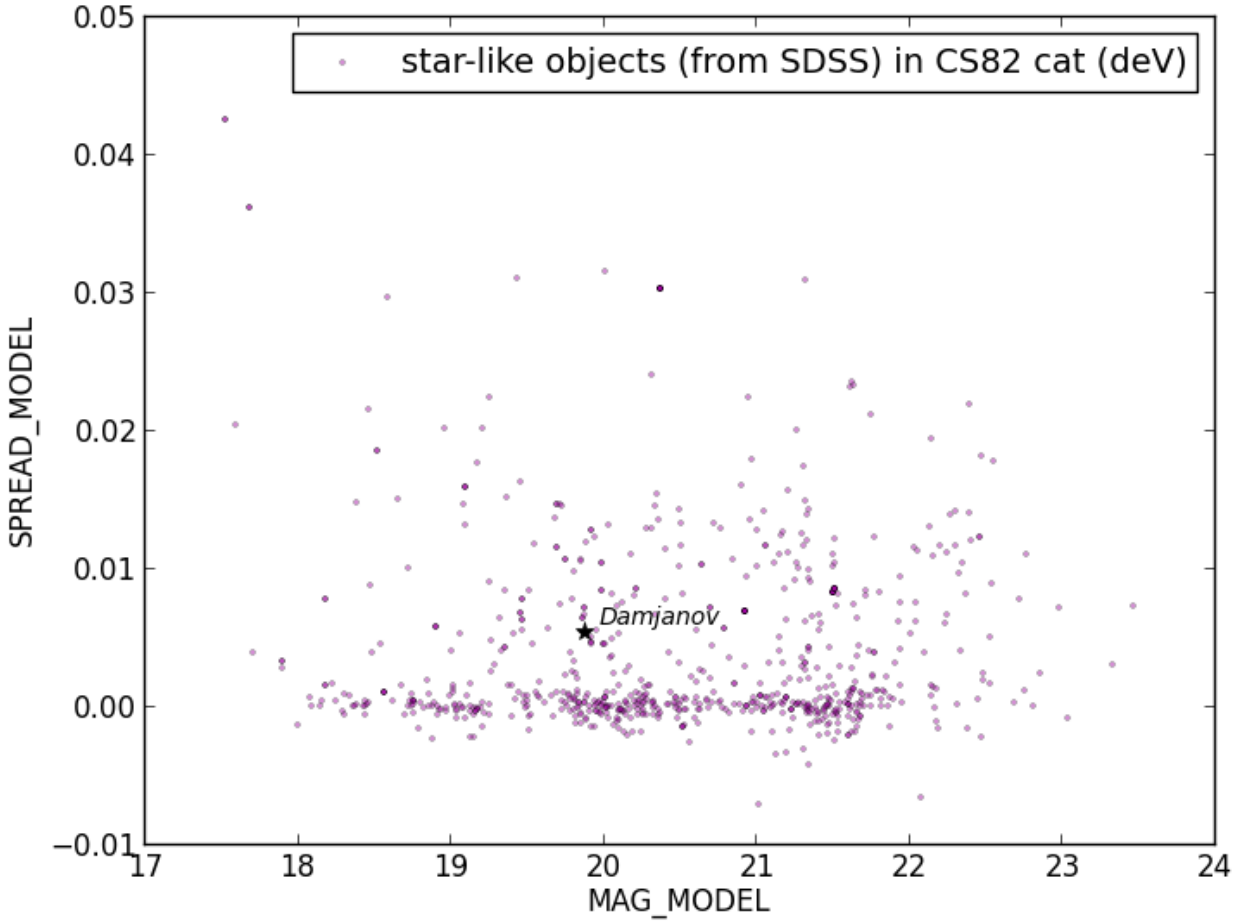
CS82 cutout

residuals
deV profile

Example: Damjanov objects

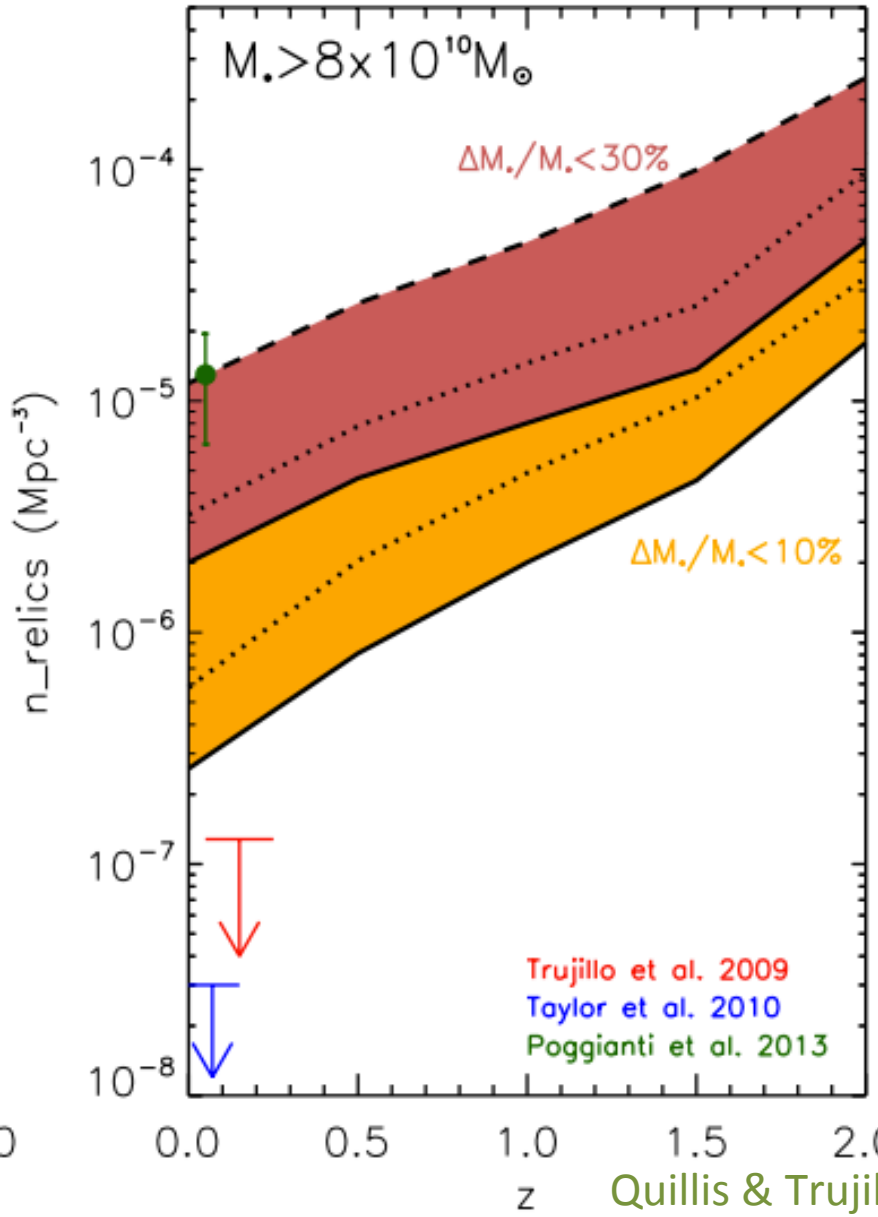
SDSS query:
- galaxy spectrum
- point-like in the image
- 0.1 < z < 0.7

Result:
- Matching with CS82 catalogue
- ~750 objects



Looking for massive compact quiescent galaxies

Expectations



Quillis & Trujillo 2013

Estimated density of high redshift relics:

Hyp - all objects are detected
- WMAP7 cosmology

Comoving volume between 0.2<z<0.6:

$V_{0.6} - V_{0.2} \sim 43.5\ Gpc^3$

Solid angle of Stripe-82 (A_{eff}~124 deg^2):

$\Omega_{stripe\ 82} \sim 0.038\ sr$

For <n_relics> ~ 10^{-5} Mpc^{-3}

$n_{expected} \sim$ **1300**

For <n_relics> ~ 5.10^{-7} Mpc^{-3}

$n_{expected} \sim$ **65**

Sample selection

Morphology:

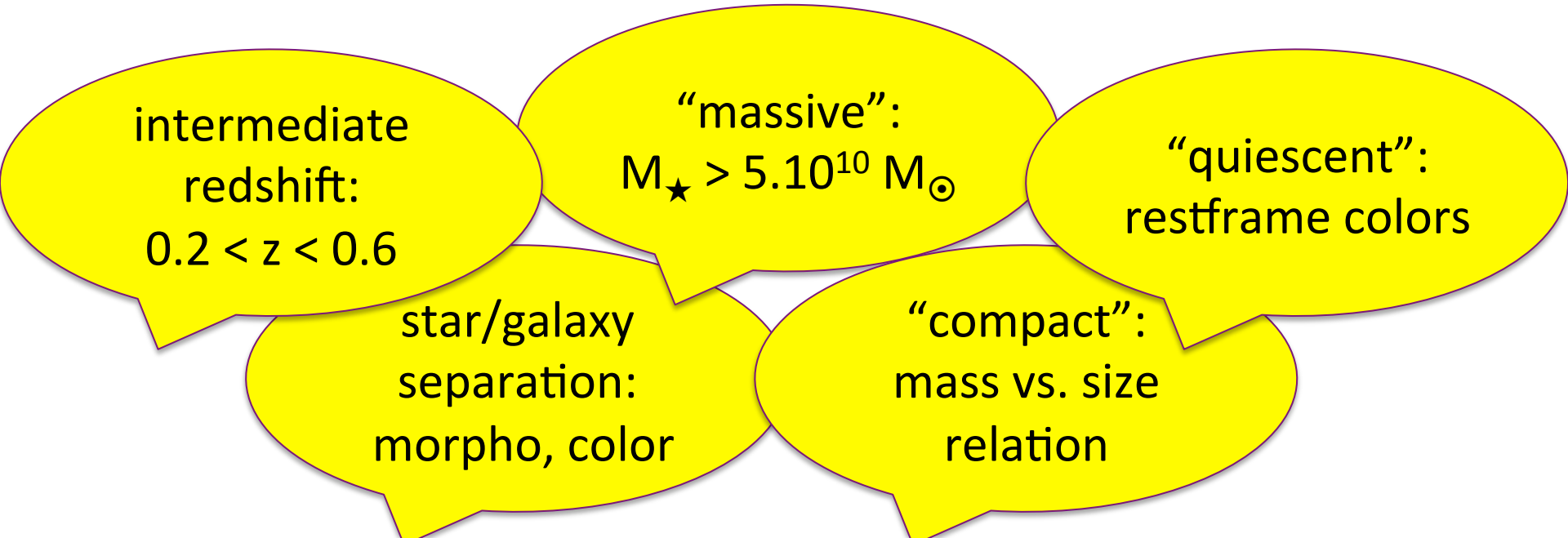
CS82 catalogue

Redshift:

SDSS photometry + spectroscopy Reis + 2012

Stellar masses:

+ near IR, Kevin Bundy's code, SYNMAG Bundy+2012



Star/Galaxy separation

Ivezic + 2007:

SDSS Stripe 82 candidate star catalogue
non-variable unresolved sources, color selection
1,006,849 objects

Betoule + 2013:

SDSS Stripe 82 tertiary star catalogue
Calibration of Supernova surveys (SDSS & SNLS)
601,578 objects

SDSS request:

Morpho: star, Spectro: galaxy, $0.1<z<0.7$
15,190 objects

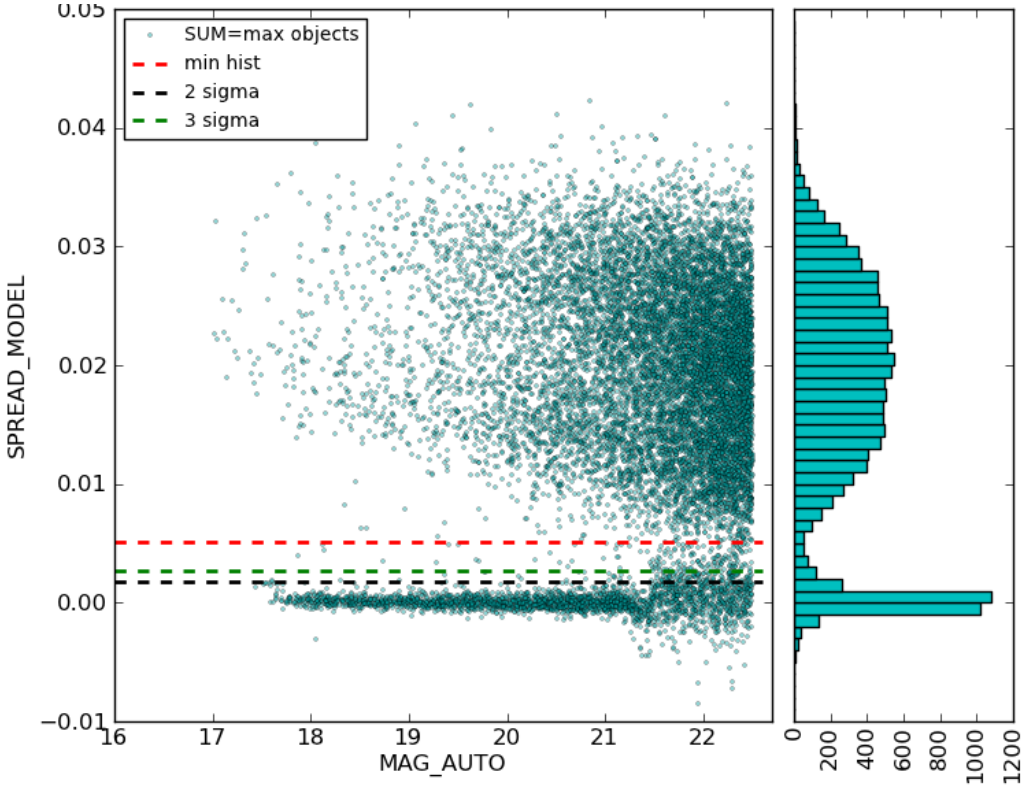
Matched:

Betoule + 2013: 103
Ivezic + 2077: 421

Star/Galaxy separation -I-

- fit by a gaussian of the star branch

- objects with SPREAD_MODEL > μ+2σ are potentially galaxies (black dashed line on the graph)



possible contamination by stars
corrected later by a color selection

A bit of numerology

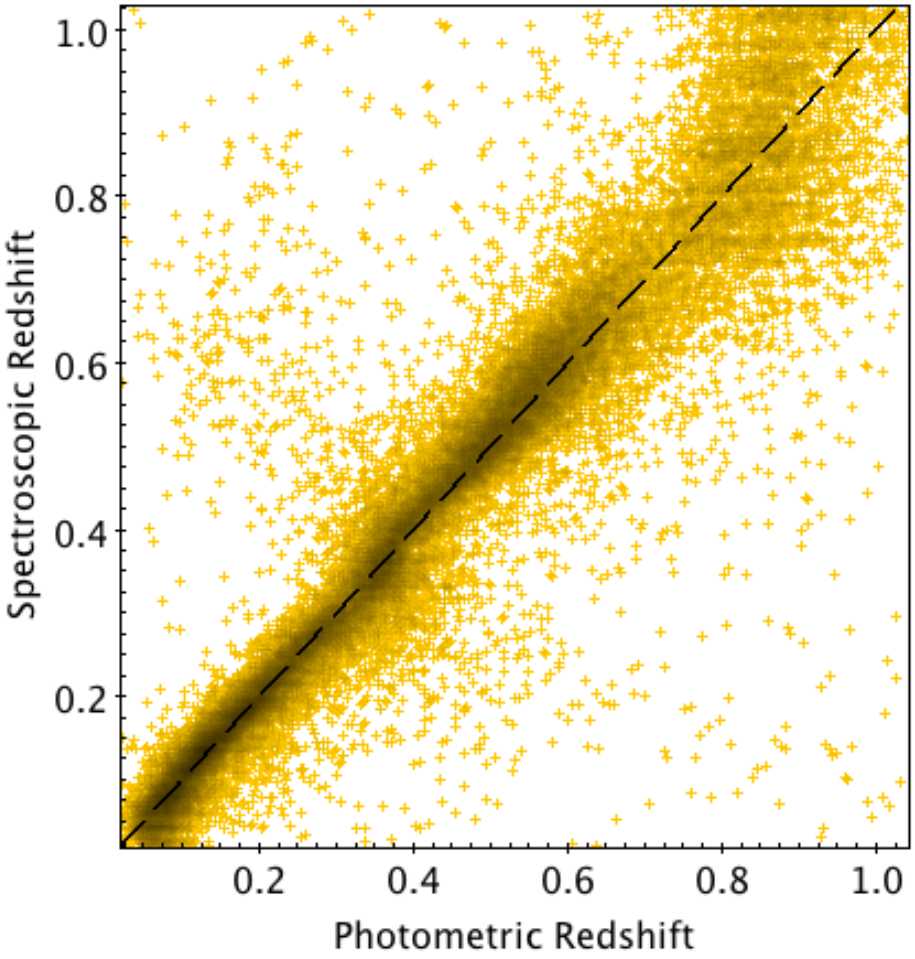
- full SDSS-Stripe 82 15,342,585
- masked CS82 9,647,535

- matched 5,928,169

- stars 930,379
- galaxies 4,997,790

near-IR photometry + redshift

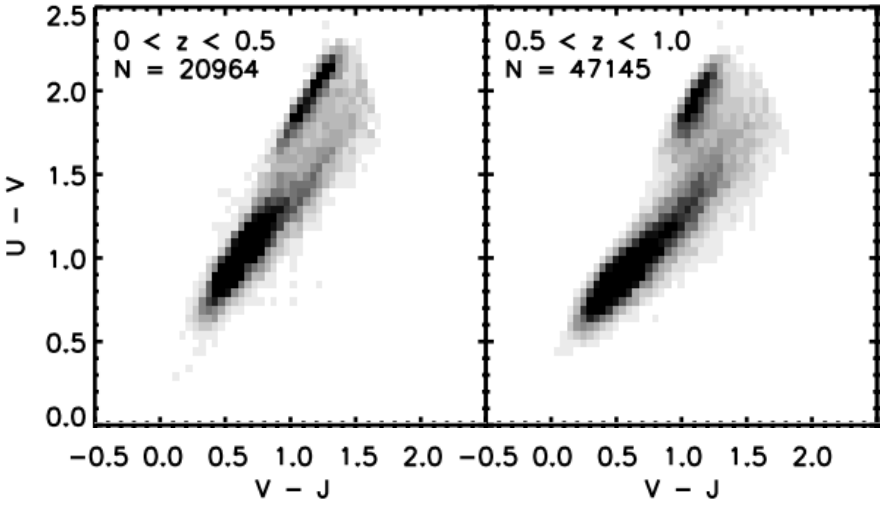
643,441

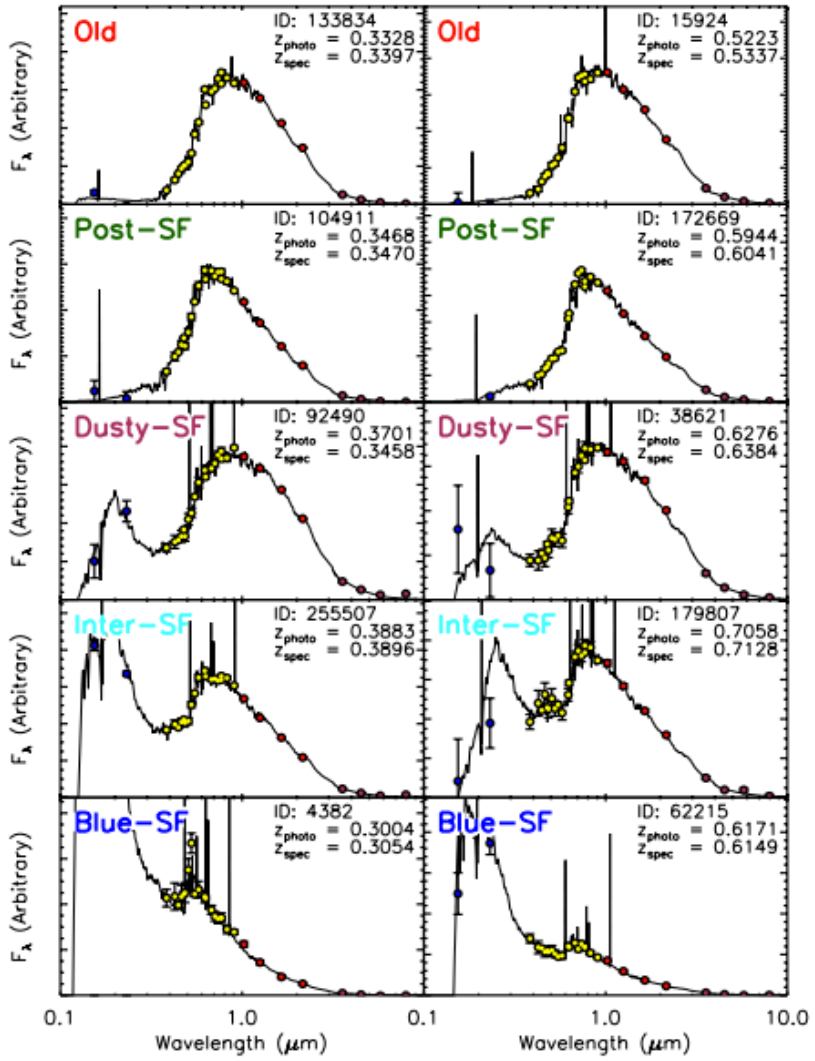


Quiescent/Star Forming selection

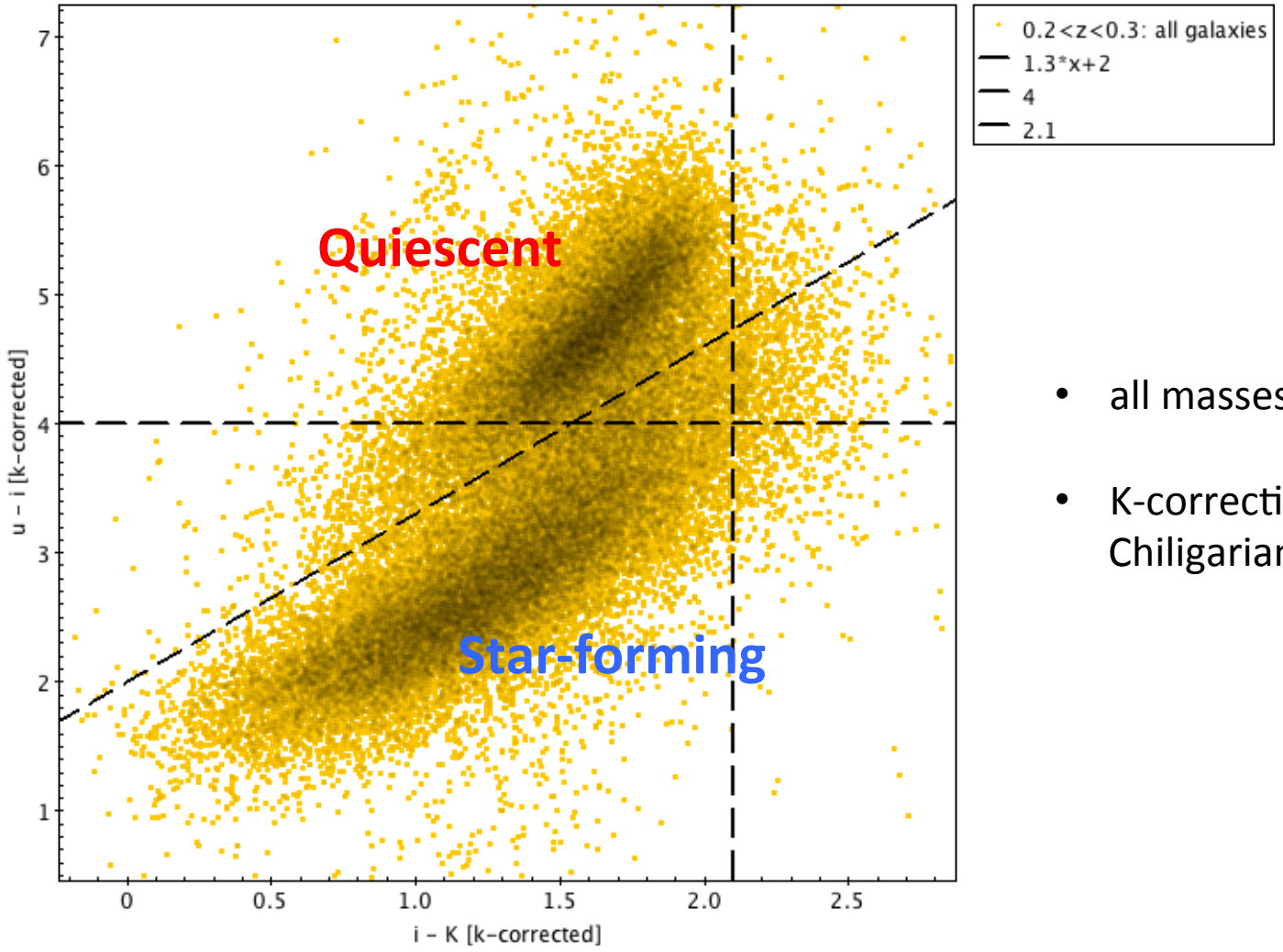
Muzzin+2013

- restframe colors
- (U-V)
  4000 A break
- (V-J)
  stellar populations



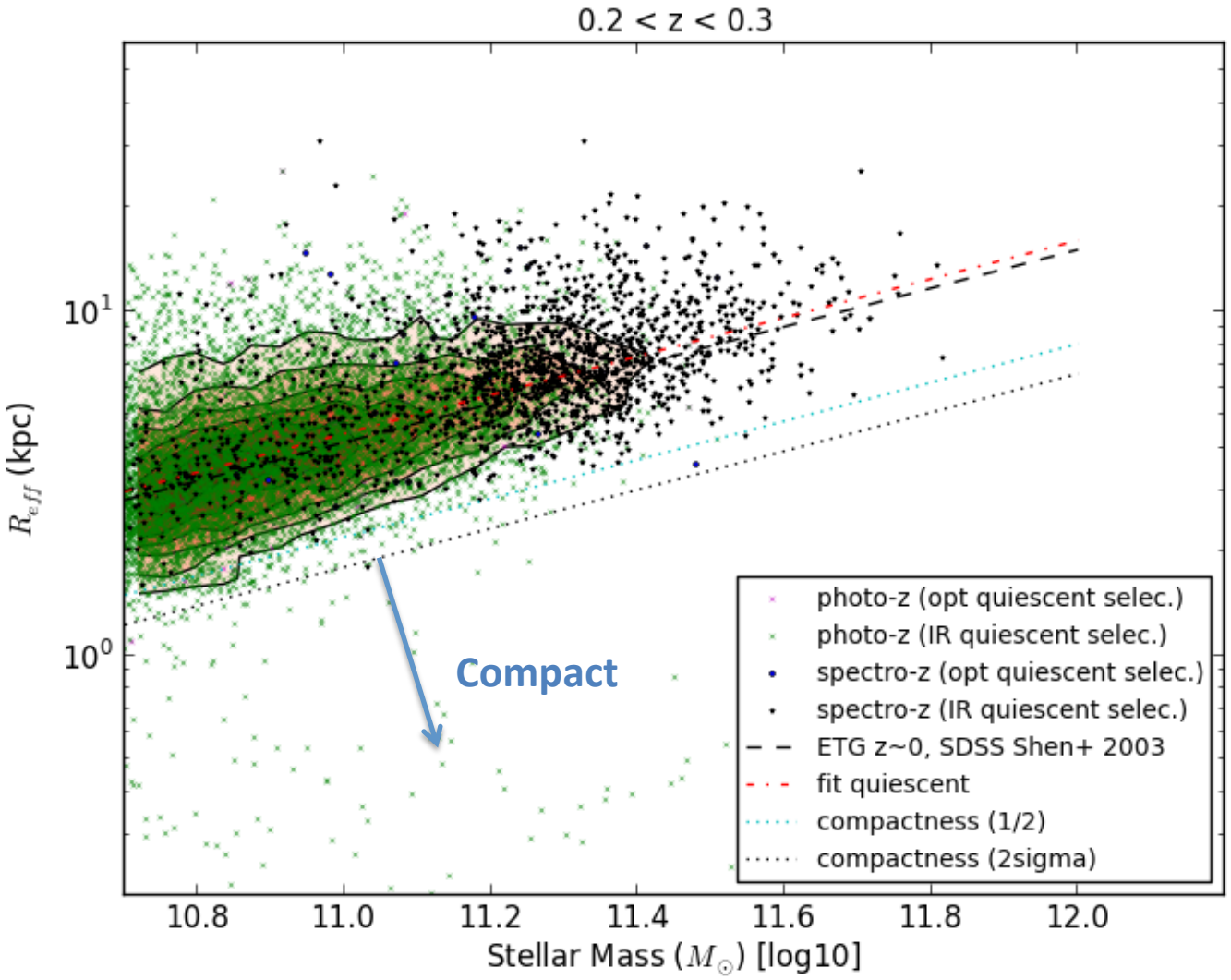


0.2 < z < 0.3
(u-i) vs. (i-K) with K-correction

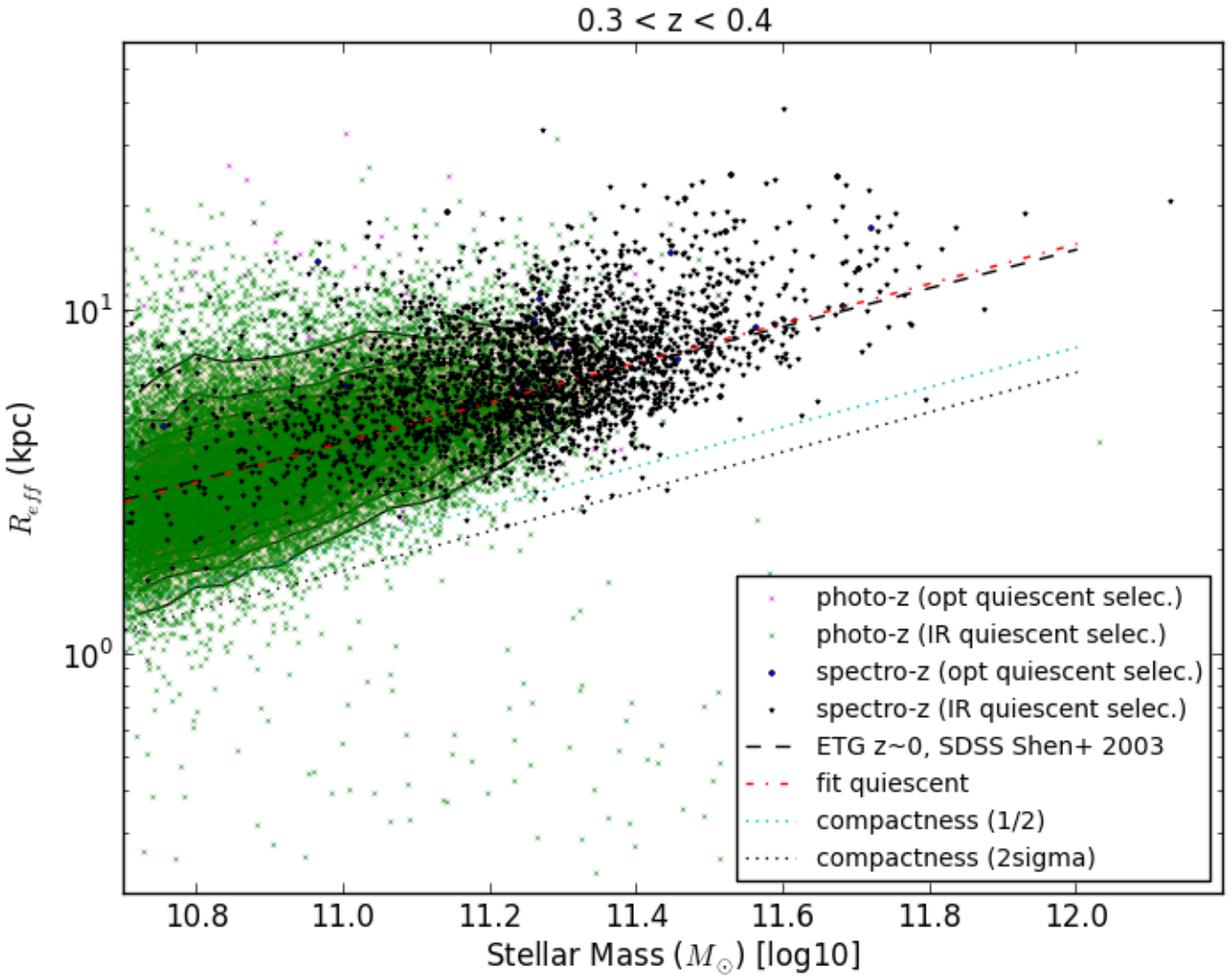


- all masses
- K-correction: Chiligarian+2010

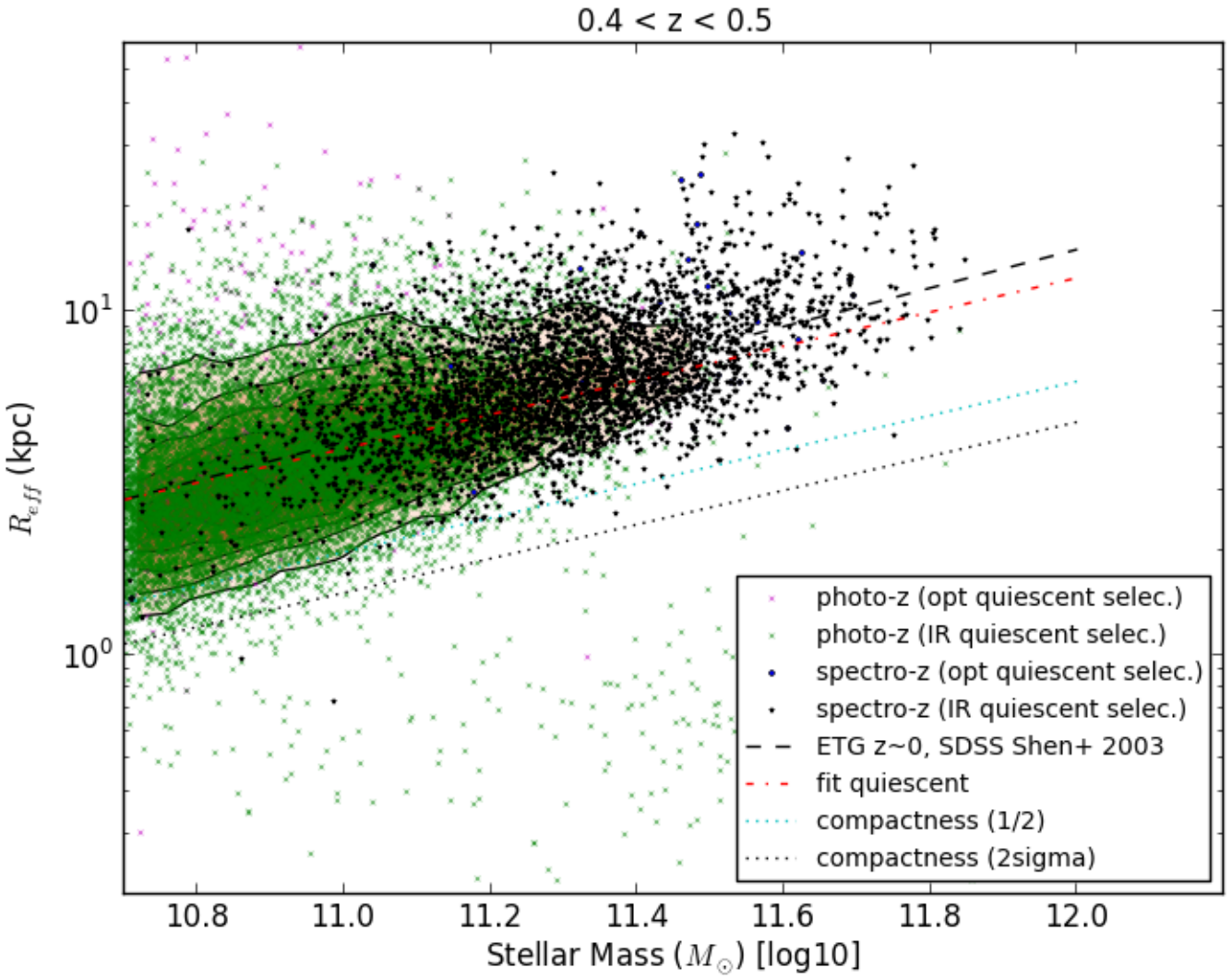
Selection of compact galaxies



0.3 < z < 0.4


0.3 < z < 0.4
10^1
10^0
R_{eff} (kpc)
10.8
11.0
11.2
11.4
11.6
11.8
12.0
Stellar Mass ($M_\odot$) [log10]
photo-z (opt quiescent selec.)
photo-z (IR quiescent selec.)
spectro-z (opt quiescent selec.)
spectro-z (IR quiescent selec.)
ETG z~0, SDSS Shen+ 2003
fit quiescent
compactness (1/2)
compactness (2sigma)

0.4 < z < 0.5


0.4 < z < 0.5
10^1
10^0
R_{eff} (kpc)
10.8
11.0
11.2
11.4
11.6
11.8
12.0
Stellar Mass ($M_\odot$) [log10]
photo-z (opt quiescent selec.)
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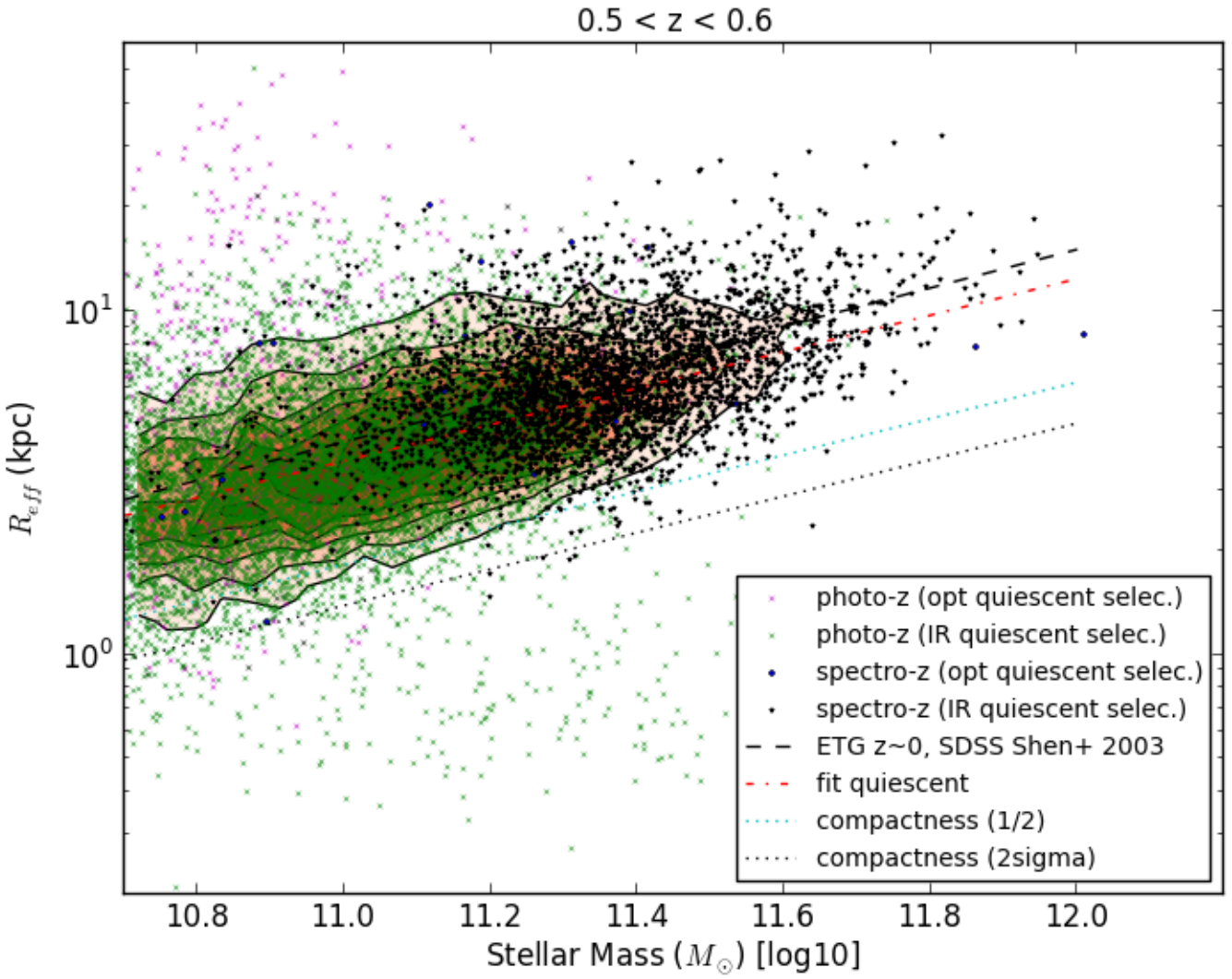
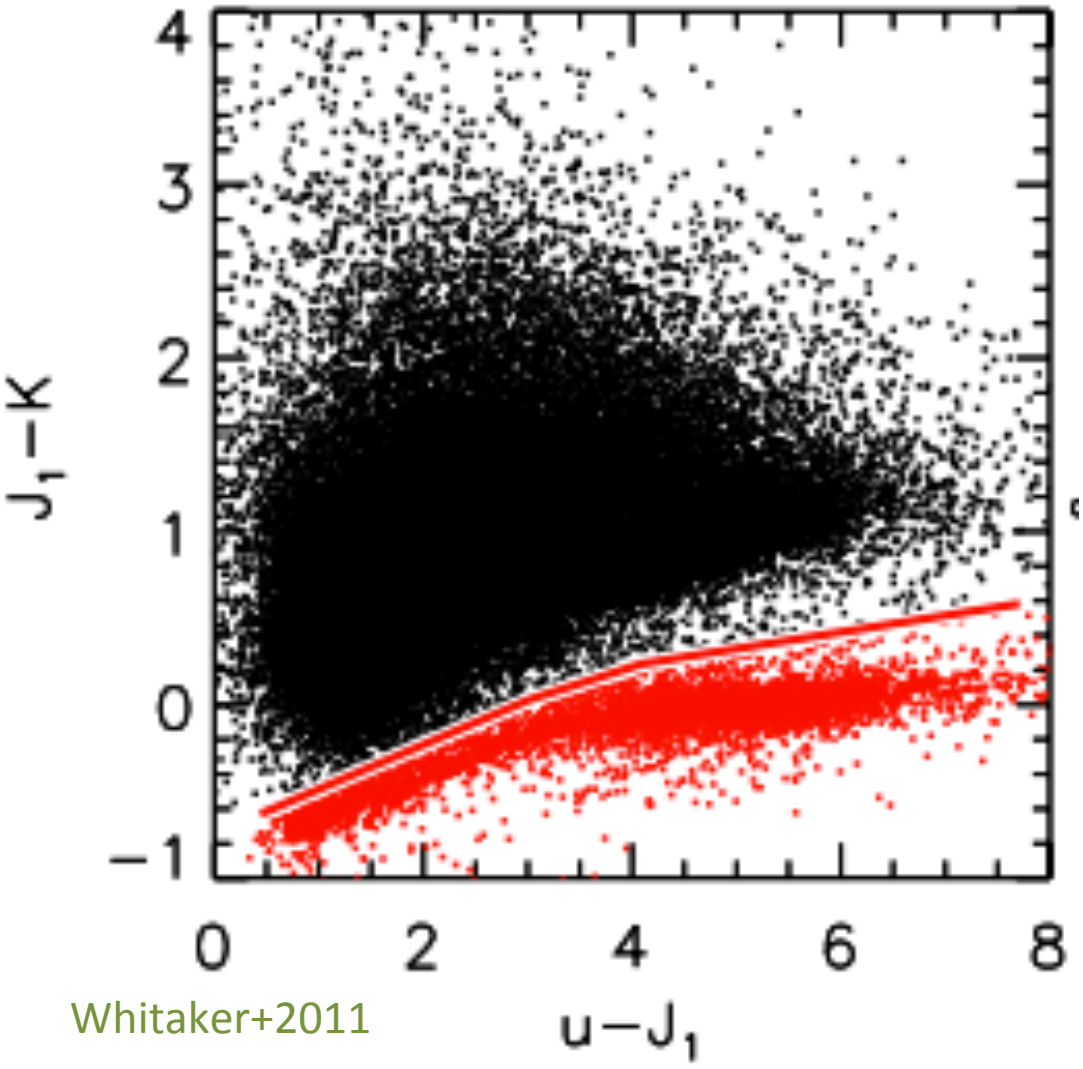
spectro-z (opt quiescent selec.)
spectro-z (IR quiescent selec.)
ETG z~0, SDSS Shen+ 2003
fit quiescent
compactness (1/2)
compactness (2sigma)

0.5 < z < 0.6


0.5 < z < 0.6
10^1
10^0
R_{eff} (kpc)
10.8
11.0
11.2
11.4
11.6
11.8
12.0
Stellar Mass ($M_\odot$) [log10]
photo-z (opt quiescent selec.)
photo-z (IR quiescent selec.)
spectro-z (opt quiescent selec.)
spectro-z (IR quiescent selec.)
ETG z~0, SDSS Shen+ 2003
fit quiescent
compactness (1/2)
compactness (2sigma)

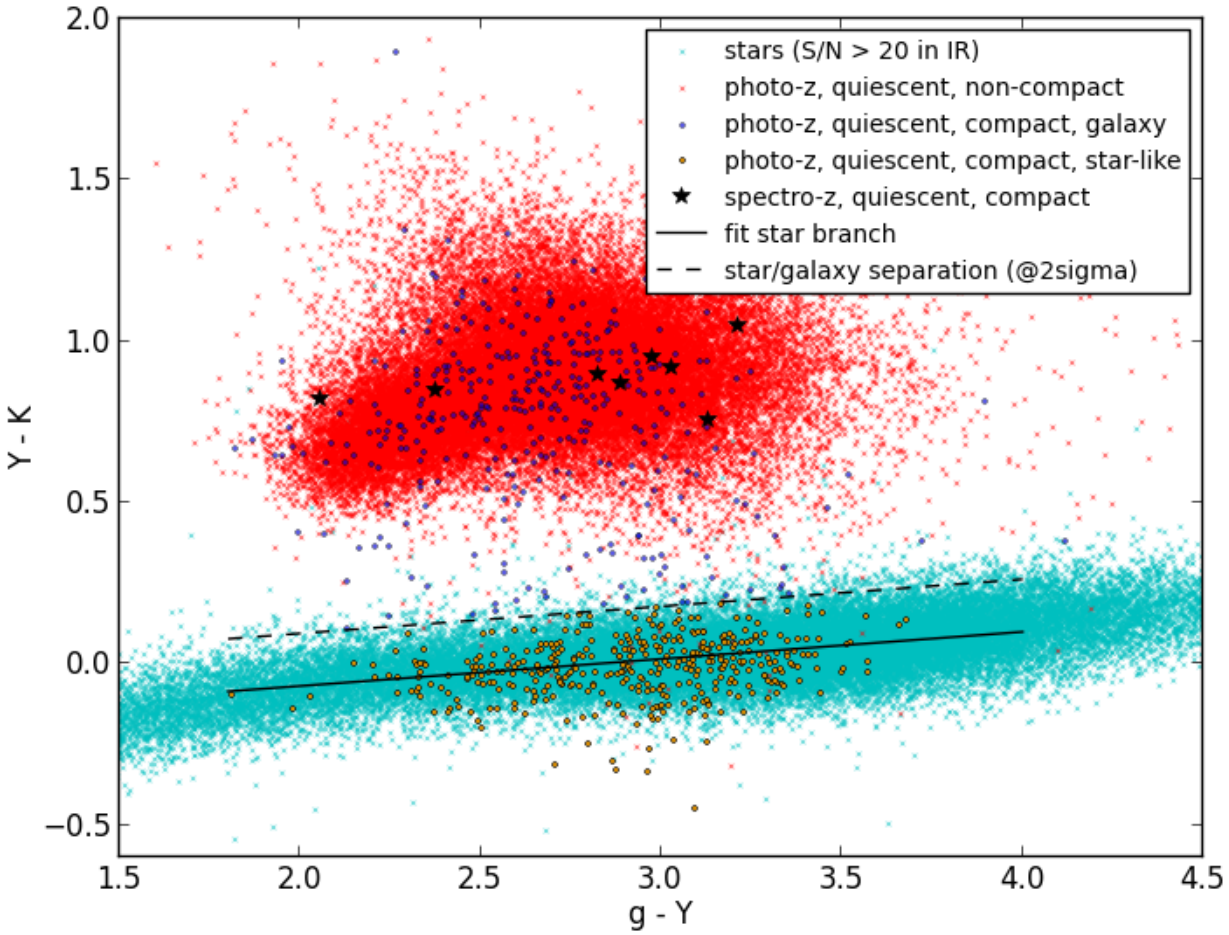
Star/Galaxy separation -II-

- galaxies
- stars

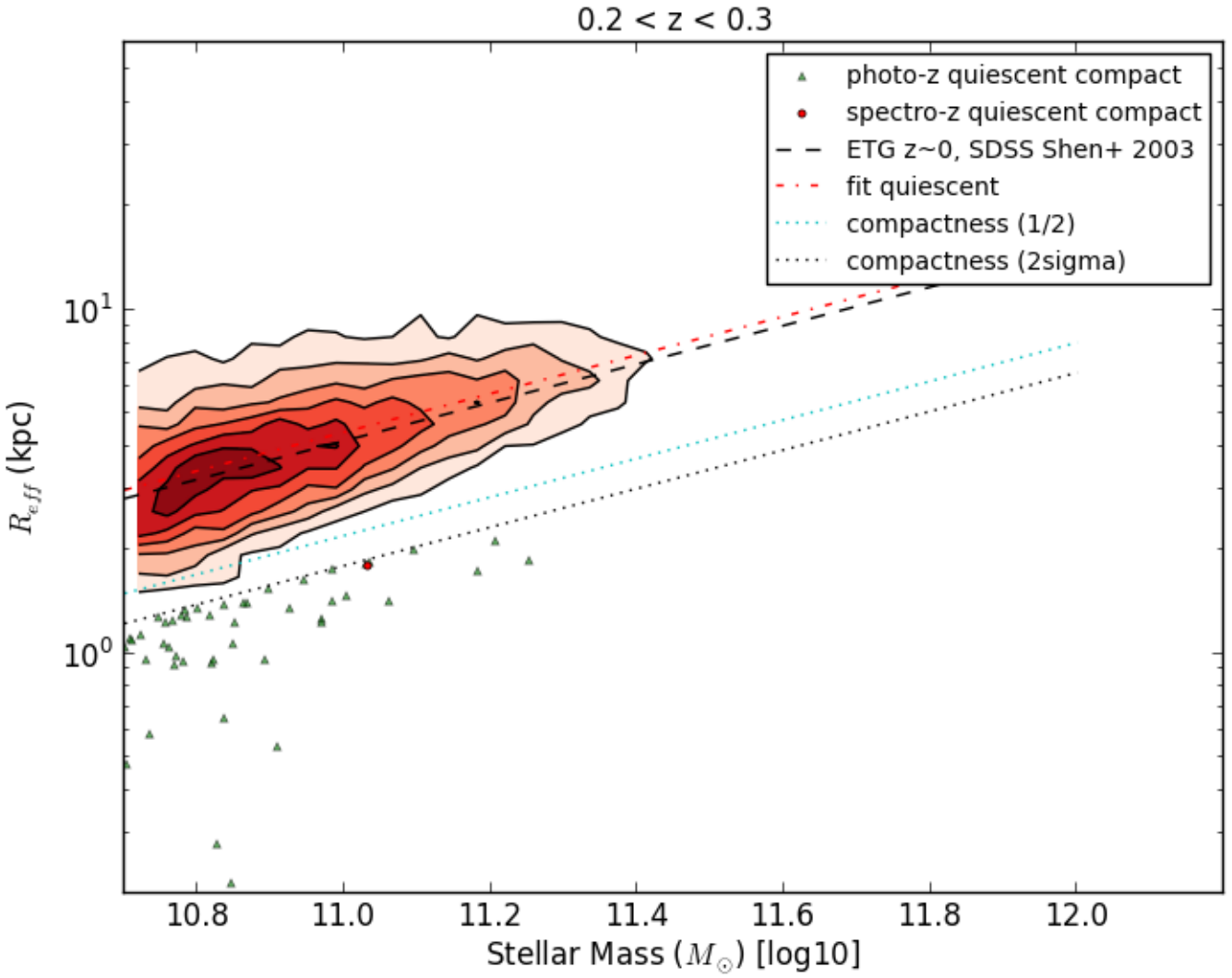


Whitaker+2011

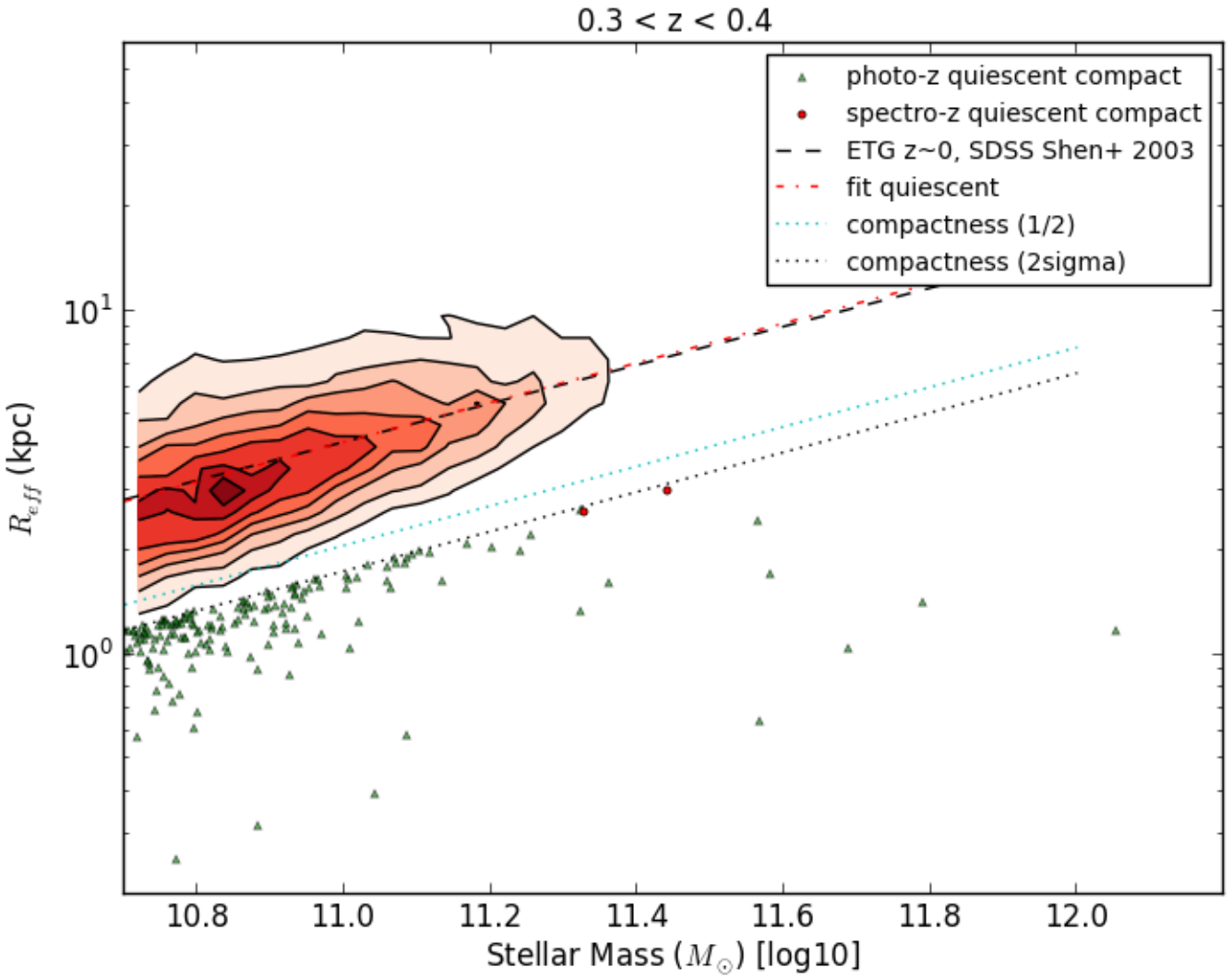
Star/Galaxy separation -II-



0.2 < z < 0.3


0.2 < z < 0.3
photo-z quiescent compact
spectro-z quiescent compact
ETG z~0, SDSS Shen+ 2003
fit quiescent
compactness (1/2)
compactness (2sigma)
10^1
10^0
R_{eff} (kpc)
10.8
11.0
11.2
11.4
11.6
11.8
12.0
Stellar Mass ($M_\odot$) [log10]

0.3 < z < 0.4


0.3 < z < 0.4
photo-z quiescent compact
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ETG z~0, SDSS Shen+ 2003
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Stellar Mass ($M_\odot$) [log10]

0.4 < z < 0.5

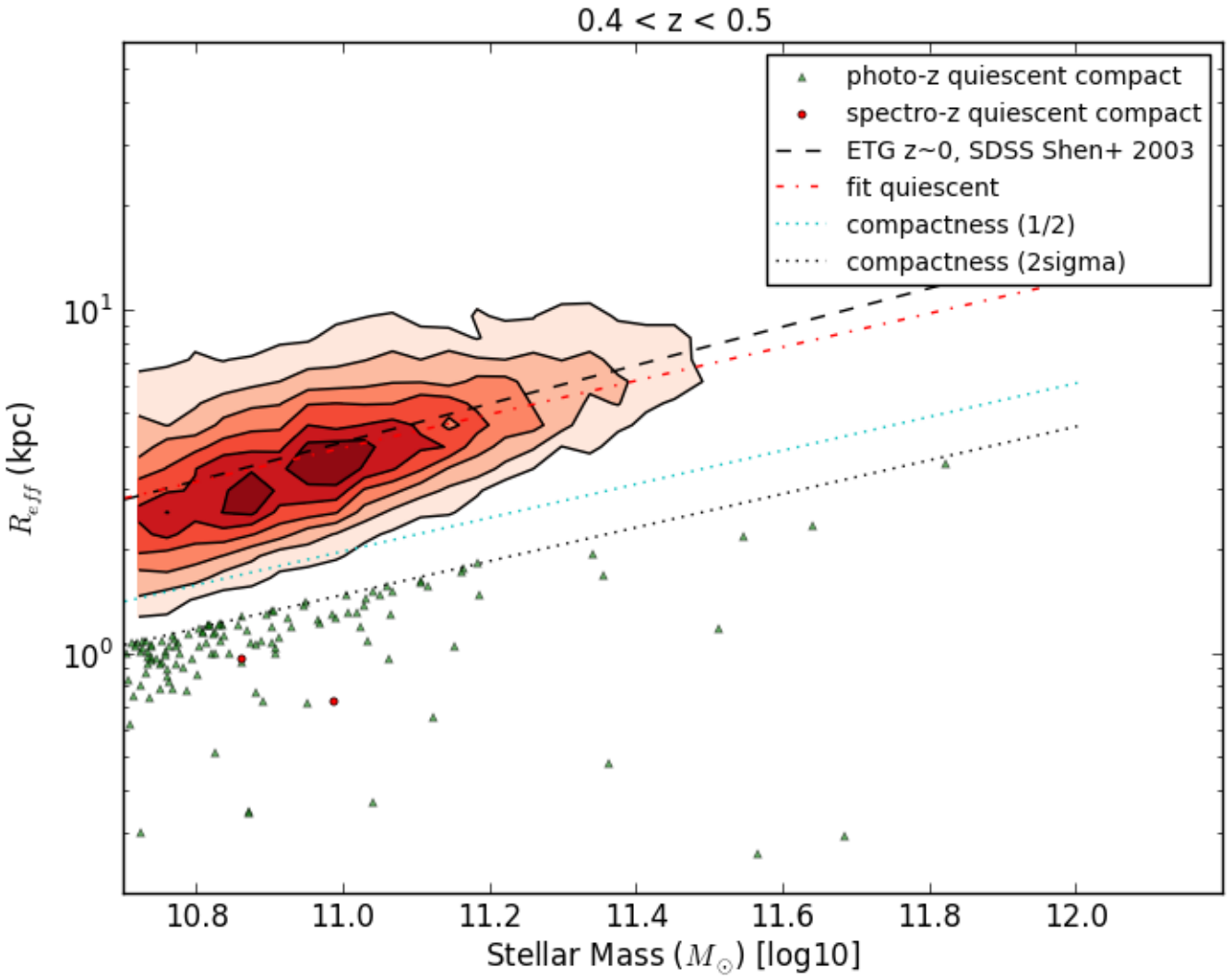
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photo-z quiescent compact
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ETG z~0, SDSS Shen+ 2003
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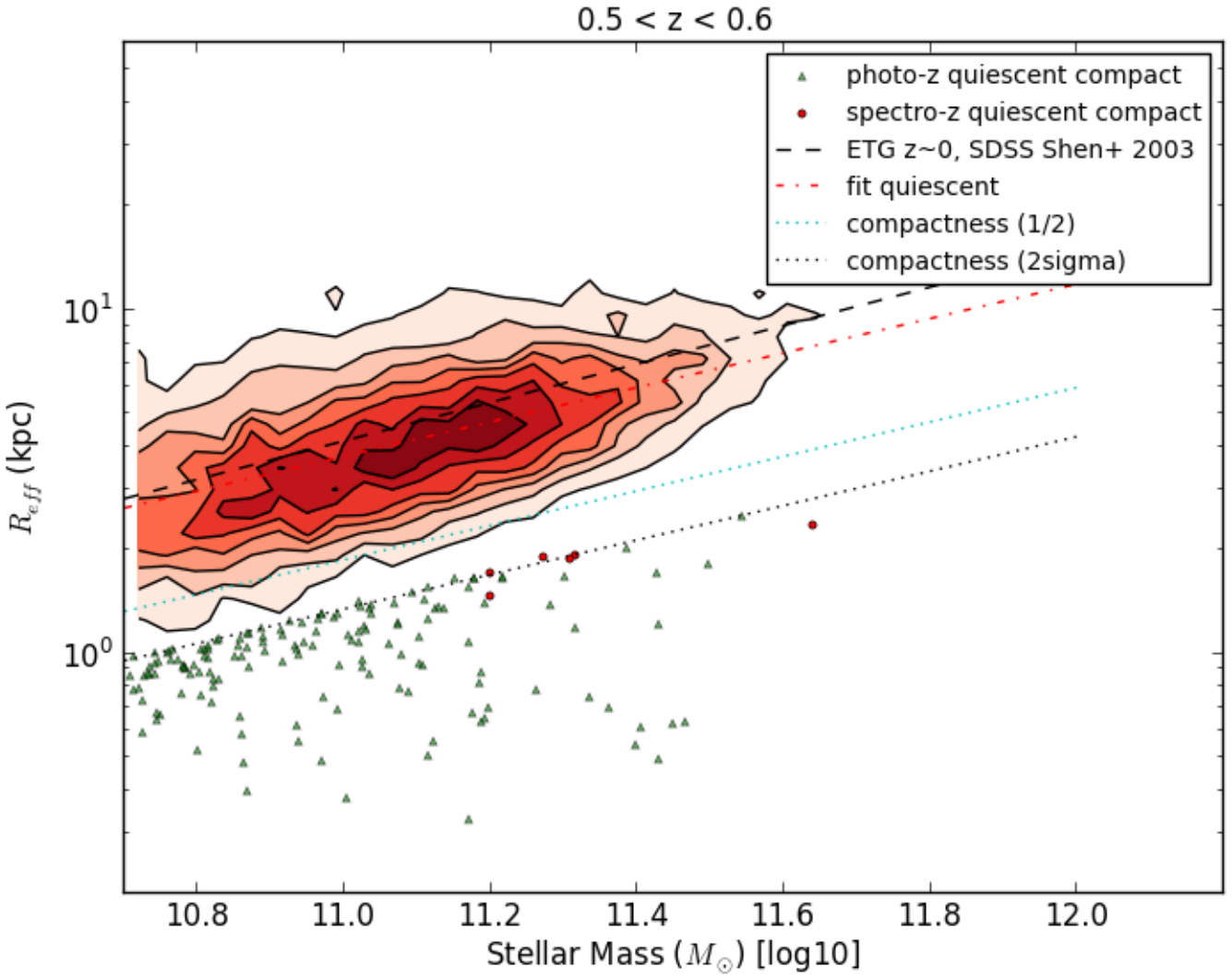
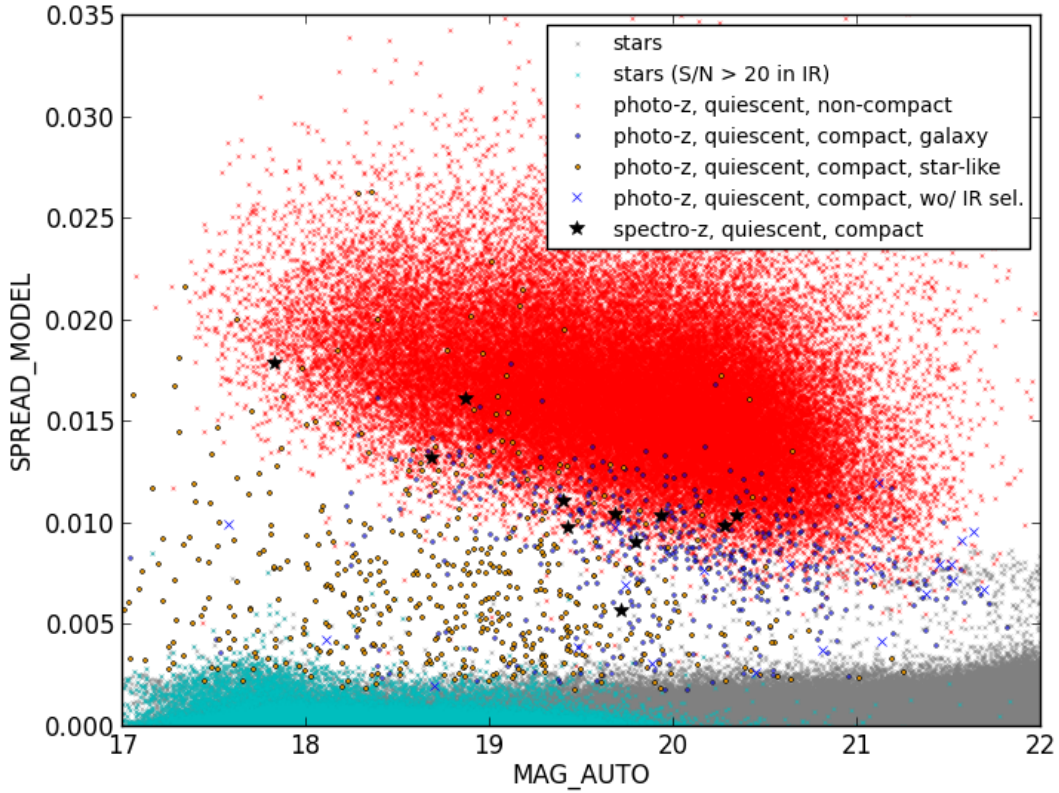
12.0
Stellar Mass ($M_\odot$) [log10]

0.5 < z < 0.6

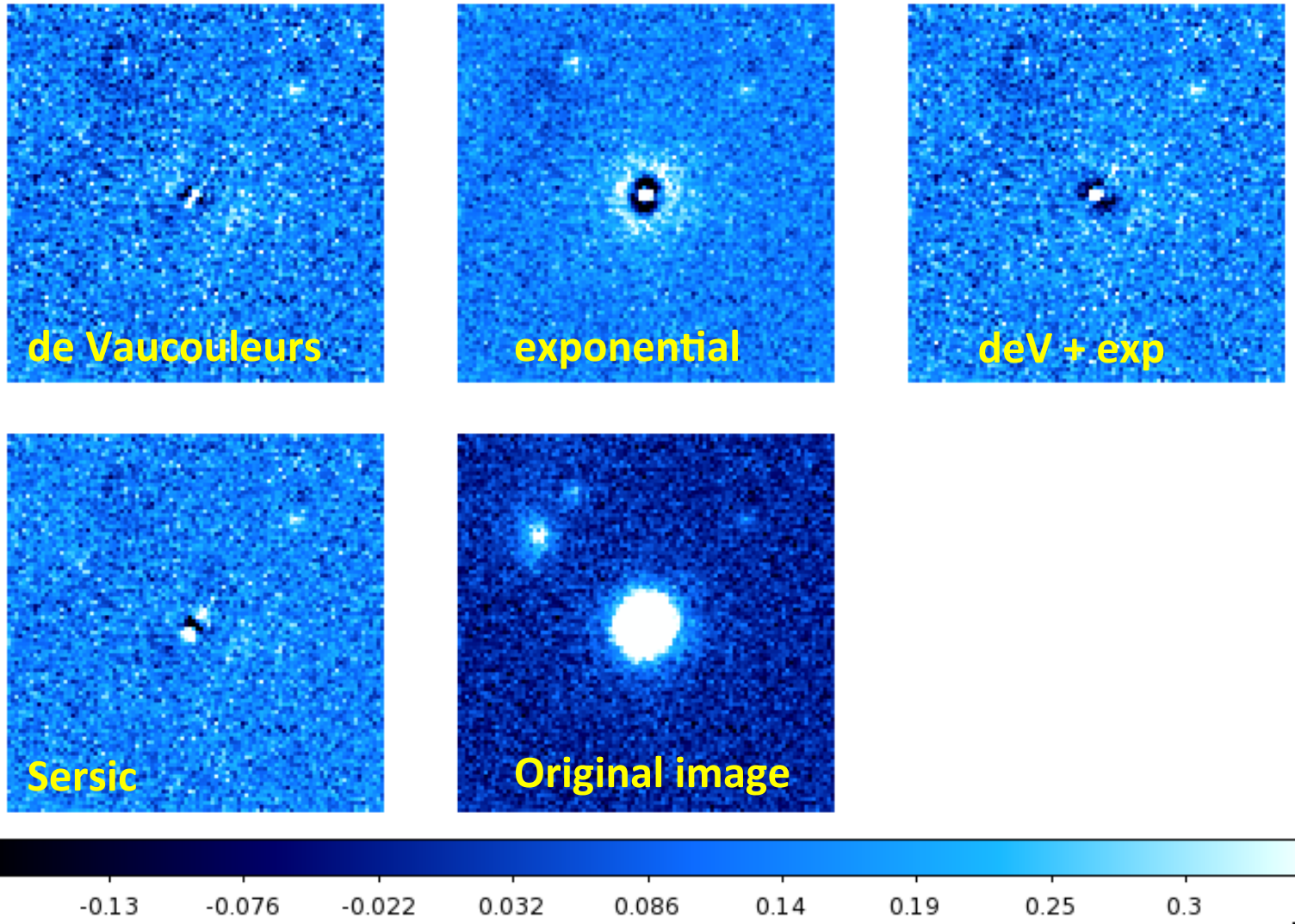

0.5 < z < 0.6
photo-z quiescent compact
spectro-z quiescent compact
ETG z~0, SDSS Shen+ 2003
fit quiescent
compactness (1/2)
compactness (2sigma)
10^1
10^0
R_{eff} (kpc)
10.8
11.0
11.2
11.4
11.6
11.8
12.0
Stellar Mass ($M_\odot$) [log10]

Compact quiescent massive galaxies

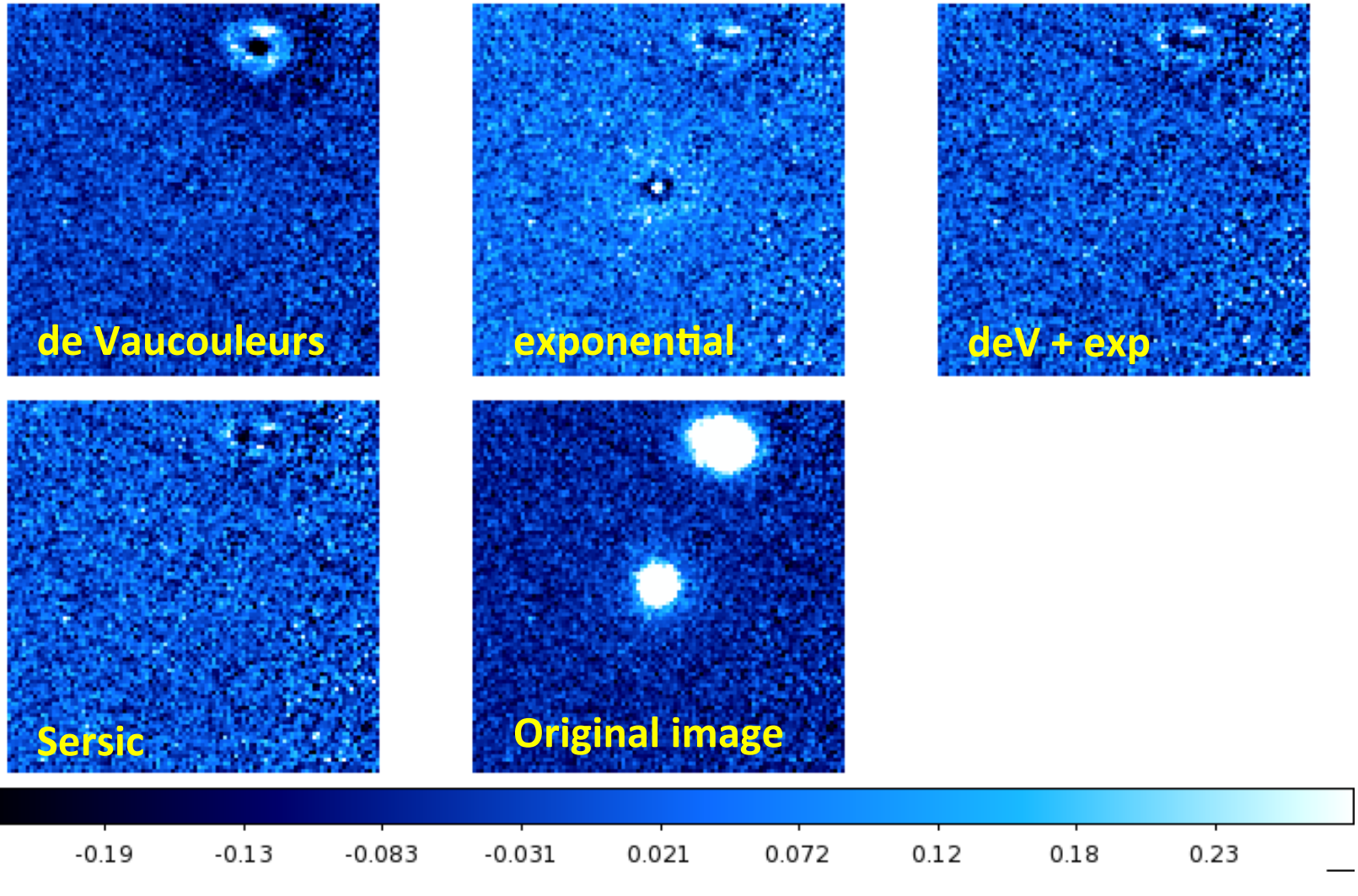
	Spectro-z Sample	Photo-z Sample
Quiescent	6422	51243
Quiescent compact	11	966
Quiescent compact galaxy-like	11	477



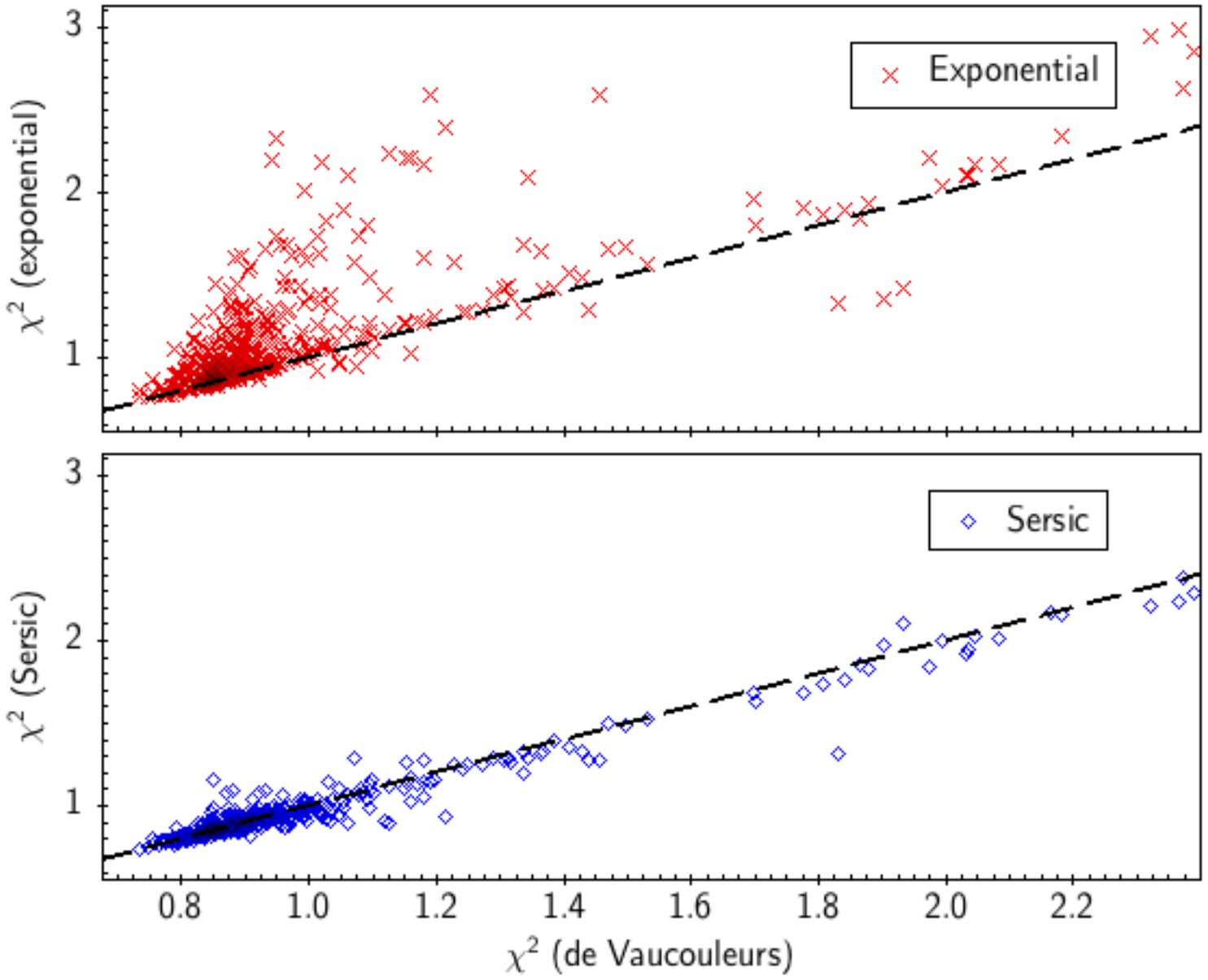
Residuals of the morphology



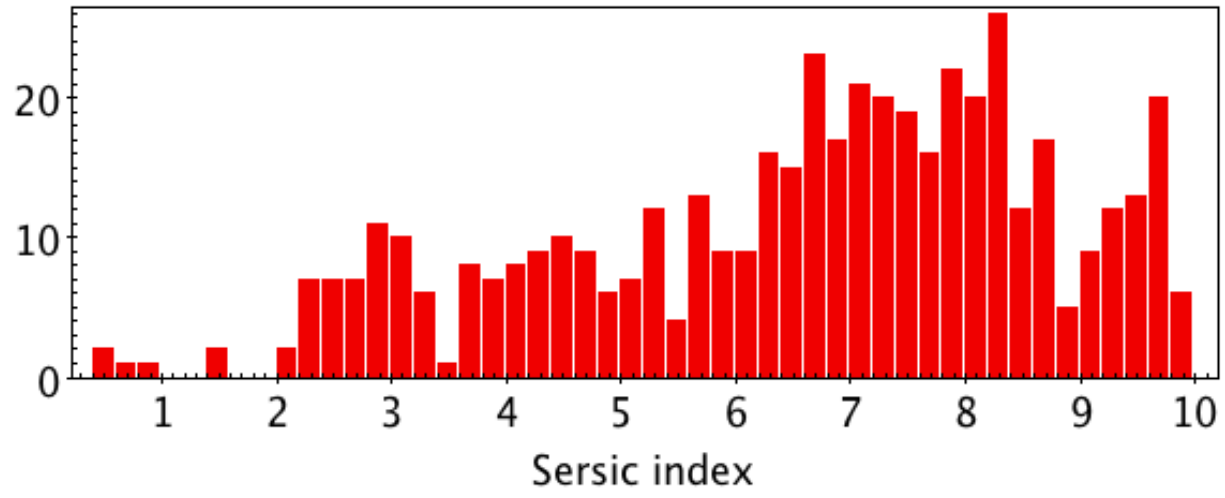
Residuals of the morphology

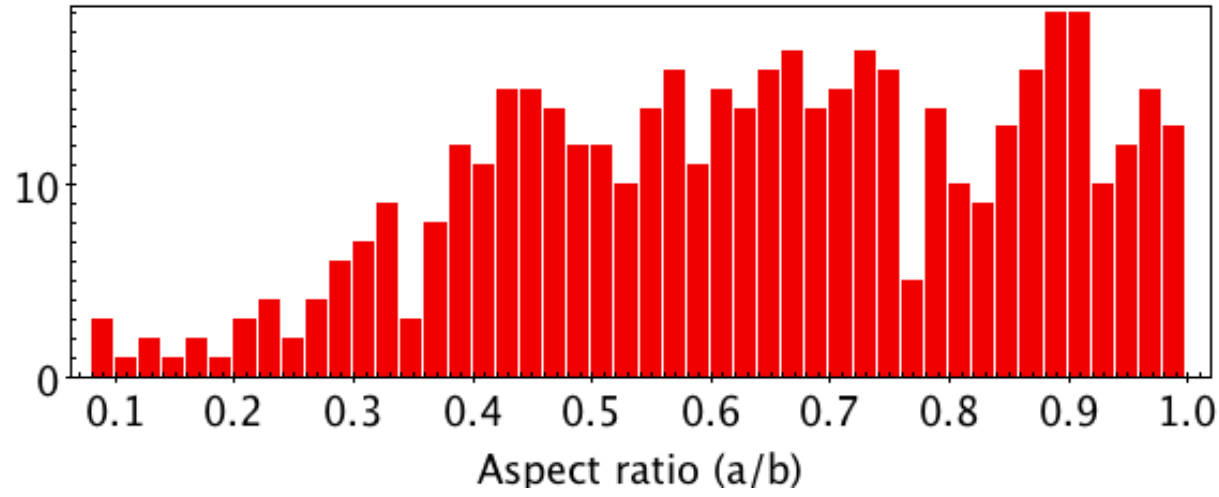


Exp/deV comparison



Morphology of C.M.Q. galaxies





Exponential profile is not preferred (chi^2, residuals)

Sersic/de Vaucouleurs equivalent

Sersic index > 2.5
early-type morphology

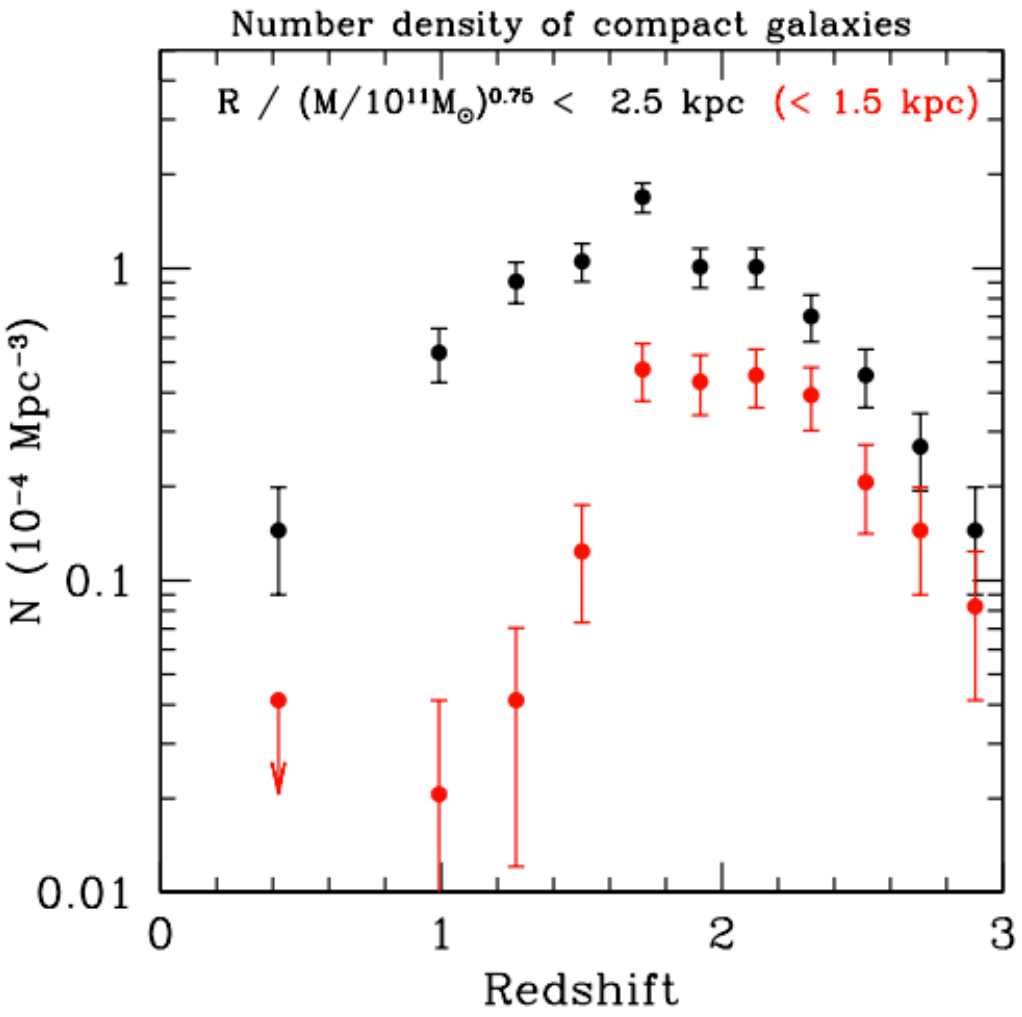
Objects mainly roundish

Density evolution with redshift

Redshift	10^{-4} Mpc^{-3}
0.2 – 0.3	0.032
0.3 – 0.4	0.061
0.4 – 0.5	0.032
0.5 – 0.6	0.028

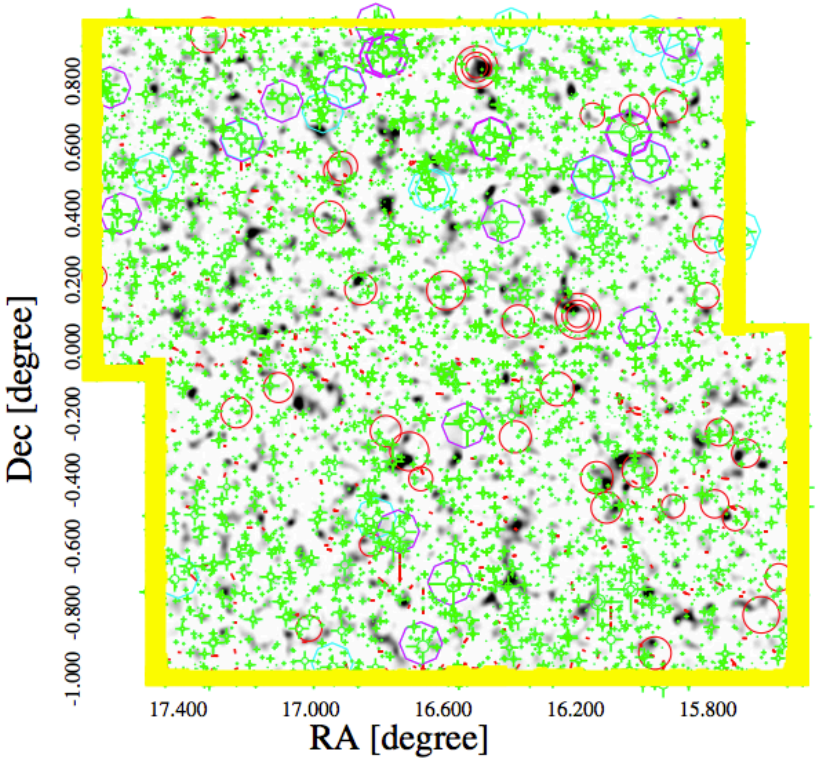
- good order of magnitude
- sample not complete

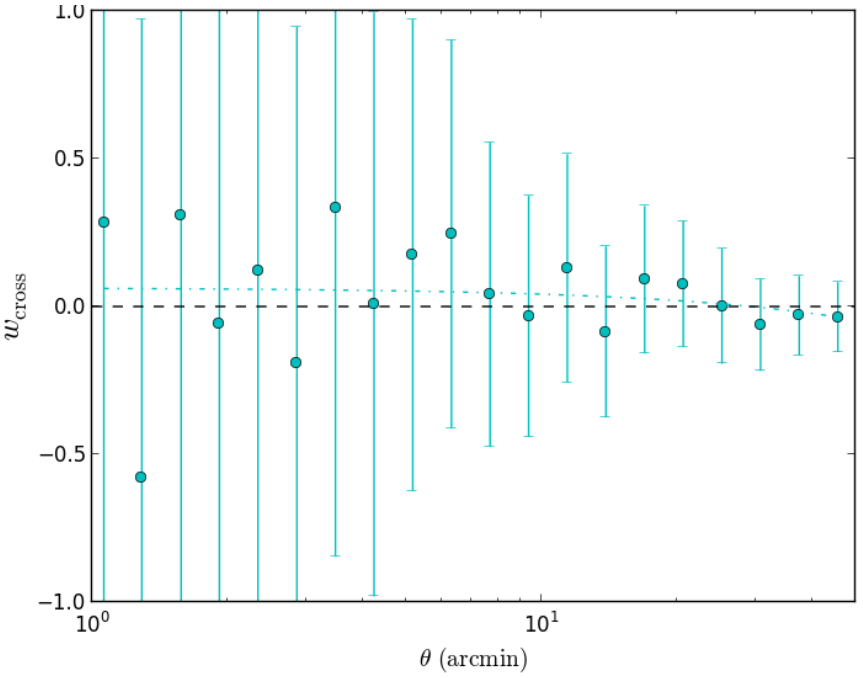
van der Wel+2014



Weak lensing mass map

Shan + 2014





- **Convergence field (z_m=0.75)**
- **Dark matter distribution**
- **Noisy**

currently no angular correlation with DM..!

Conclusion & perspectives

CFHT/Stripe-82 survey: exceptional image quality
Looking for massive passive compact galaxies:

- **$0.2 < z < 0.6$**
- **~500 candidates in the Stripe-82 region**
- **Early type morphology**

Environment analyses

- **Density evolution estimation**
- **Correlation with the Luminous Red Galaxies (LRGs) distribution**
- **Correlation with the cluster distribution**

Perspectives

- **More from N-body simulations**
- **Application of the morphology measurements with SExtractor + PSFEx to the next generation of large surveys (DES, LSST, Euclid, J-PAS)**