# Low-mass satellite galaxies and faint diffuse stellar halos of isolated central galaxies

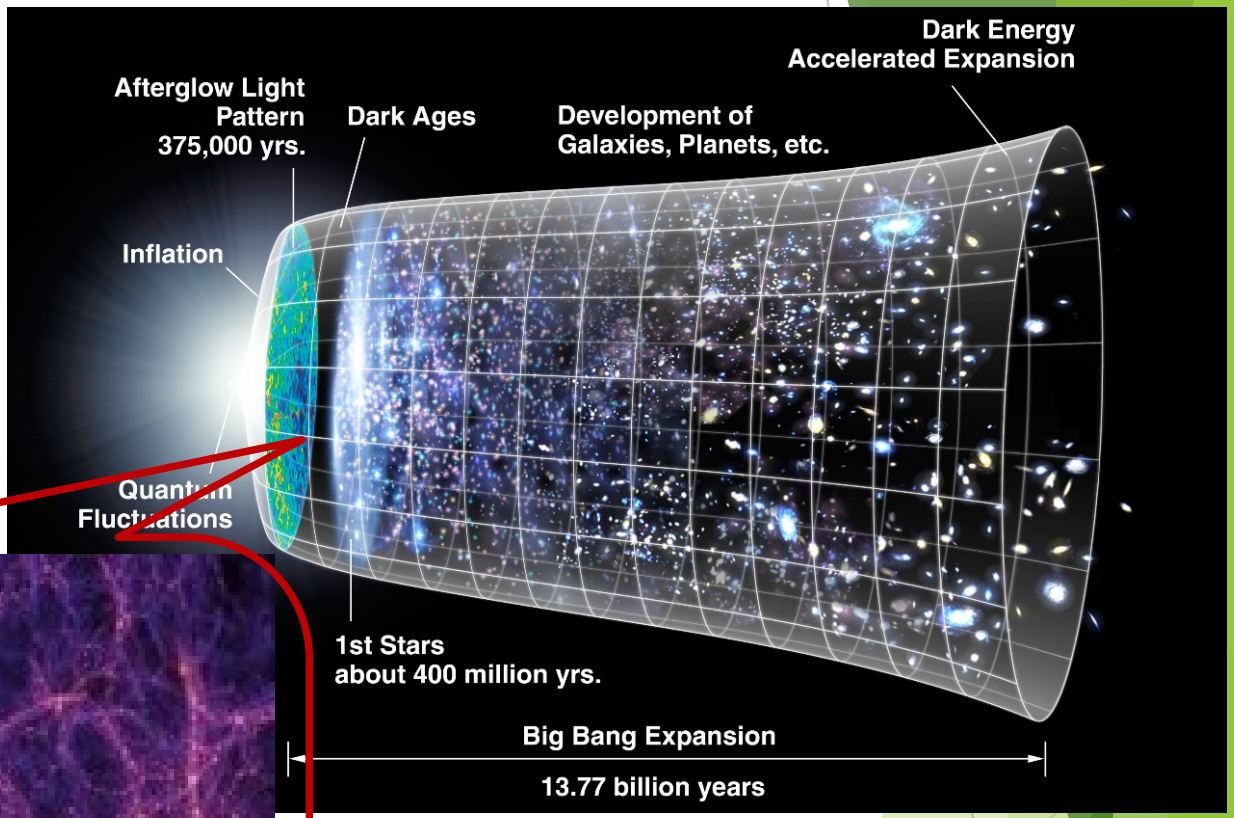
Wenting Wang

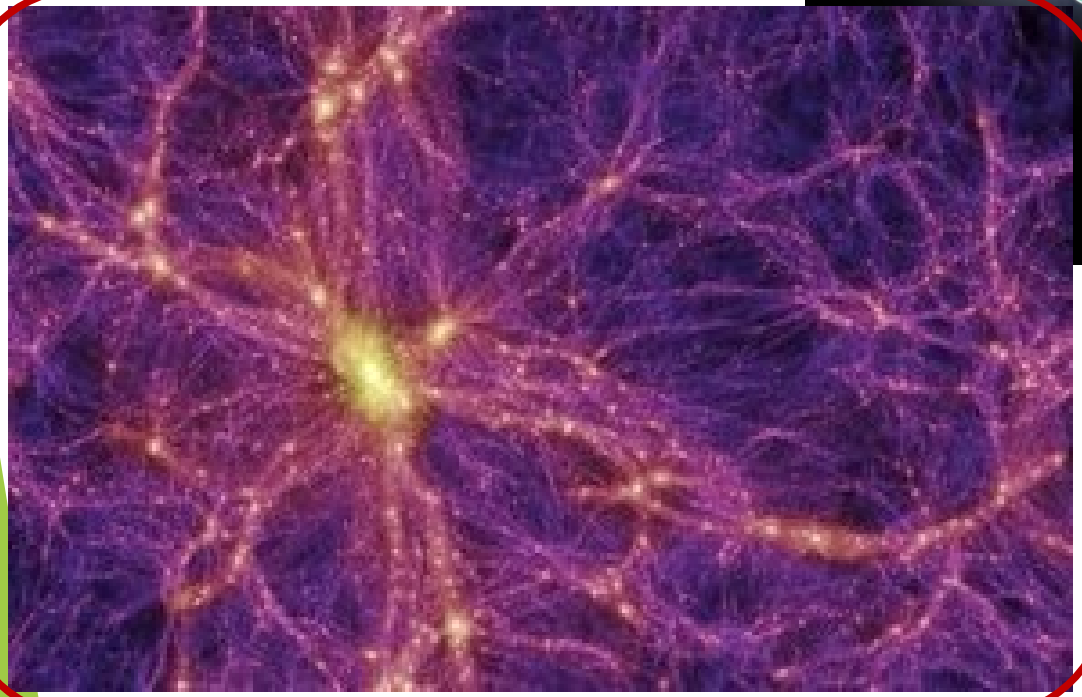
Shanghai Jiaotong University

2020/3 at Beijing

# Background

Hierarchical structure formation in the Universe



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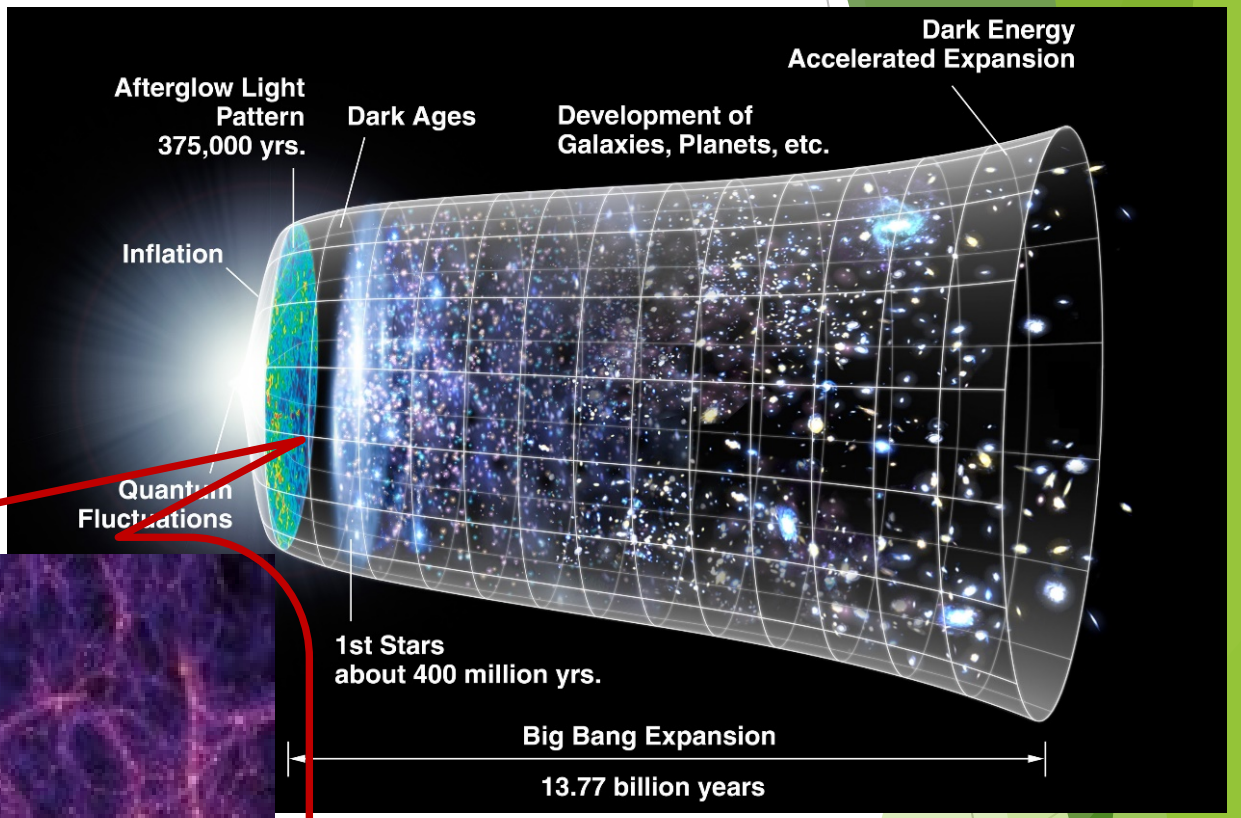


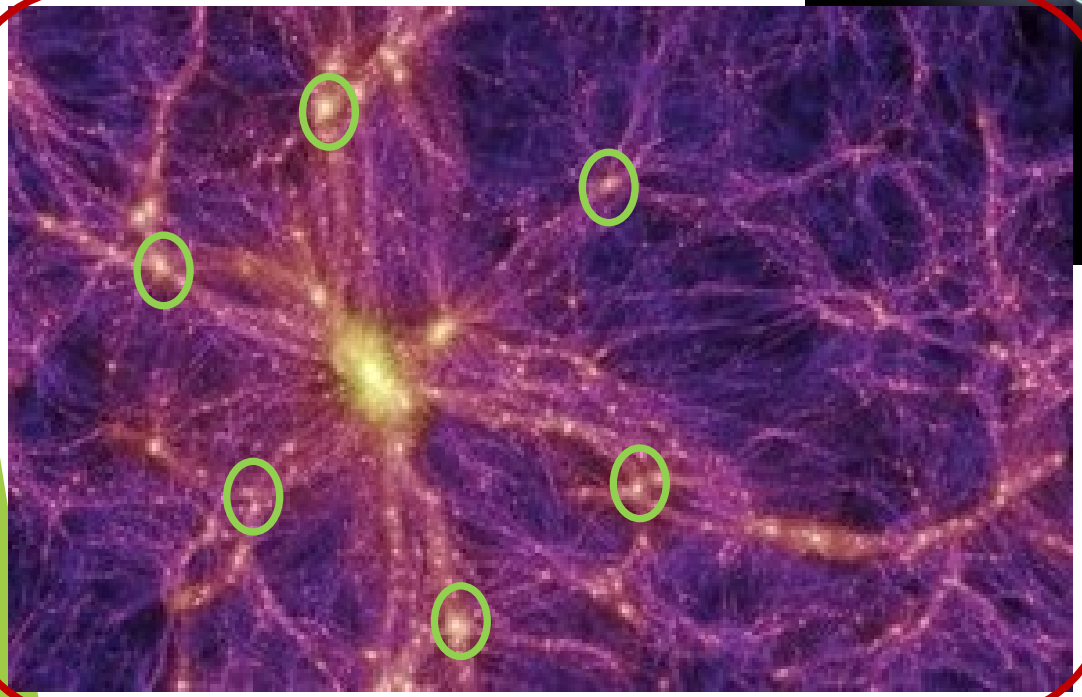

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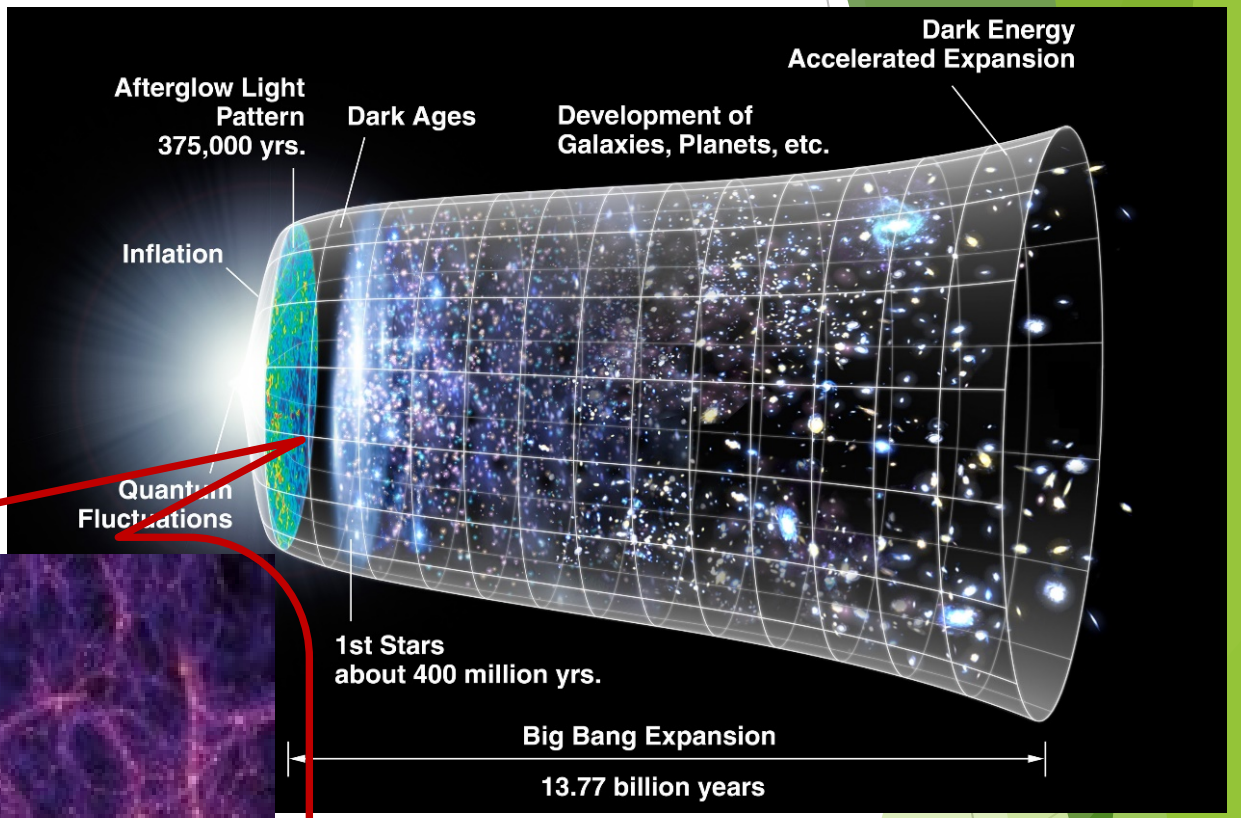


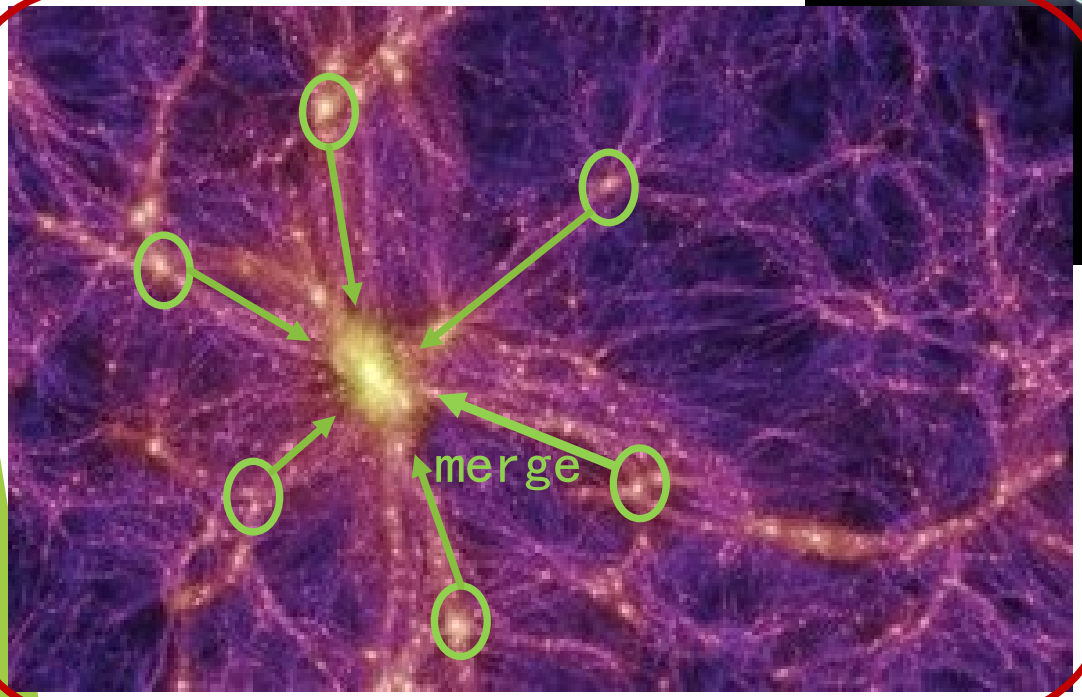

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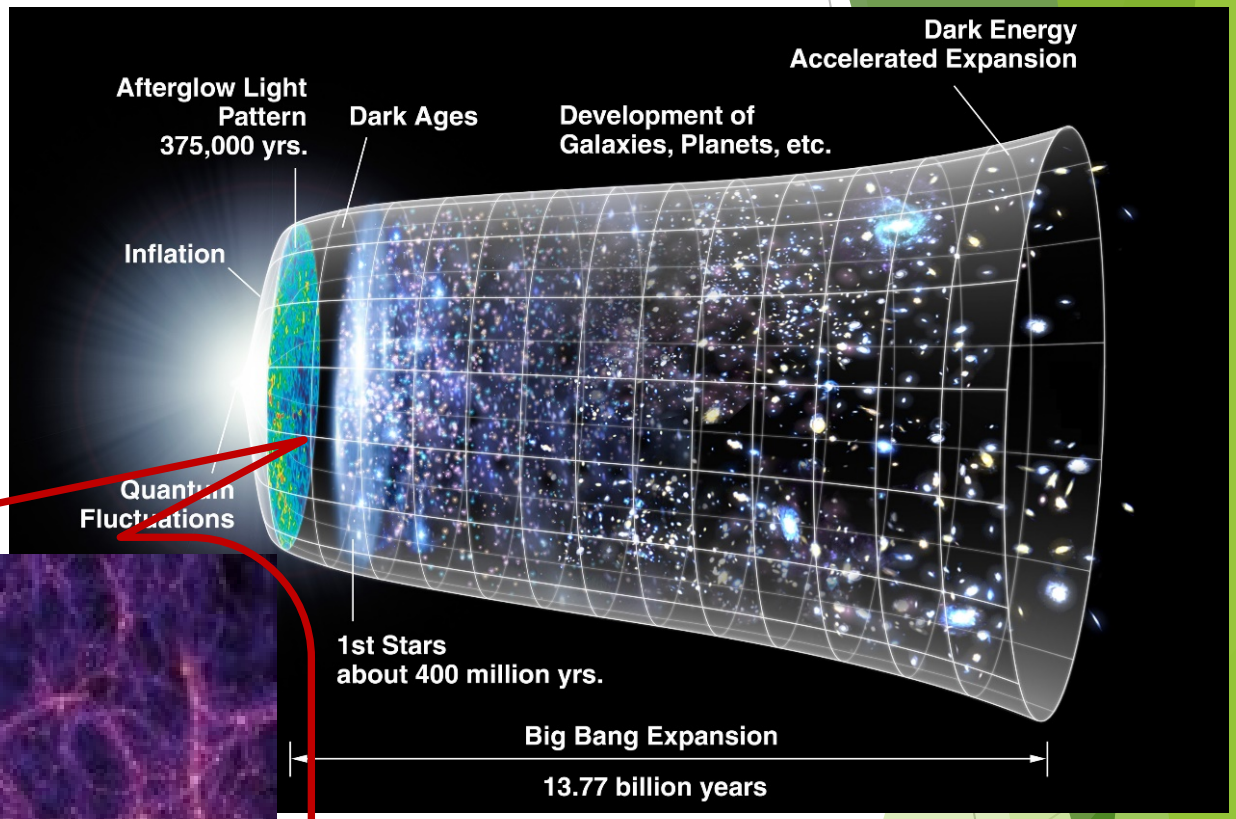


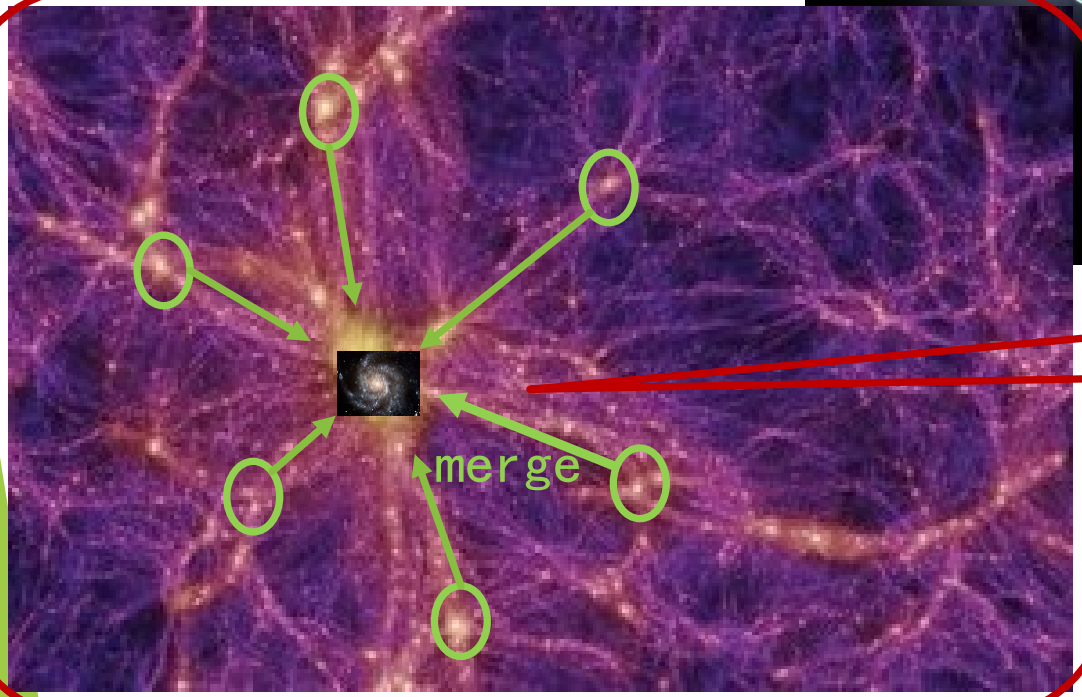


Galaxies form in halos

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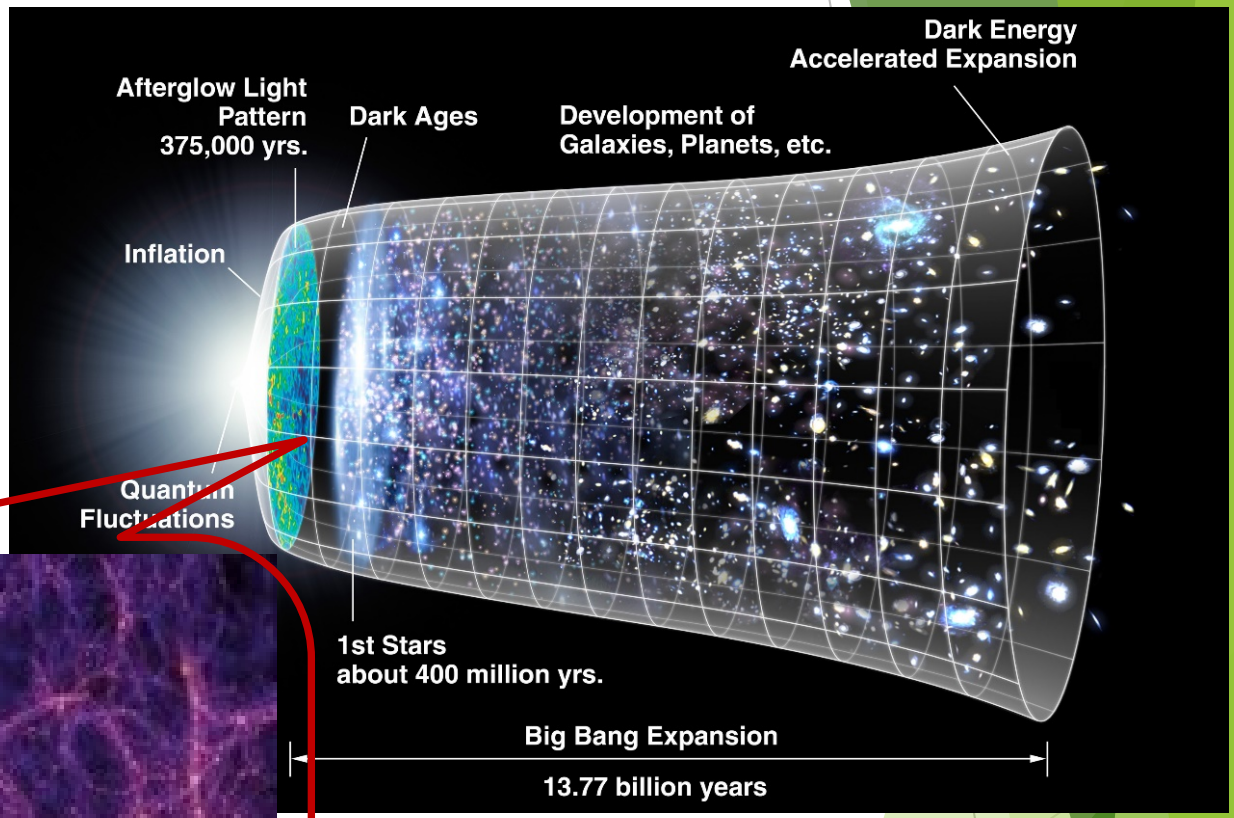
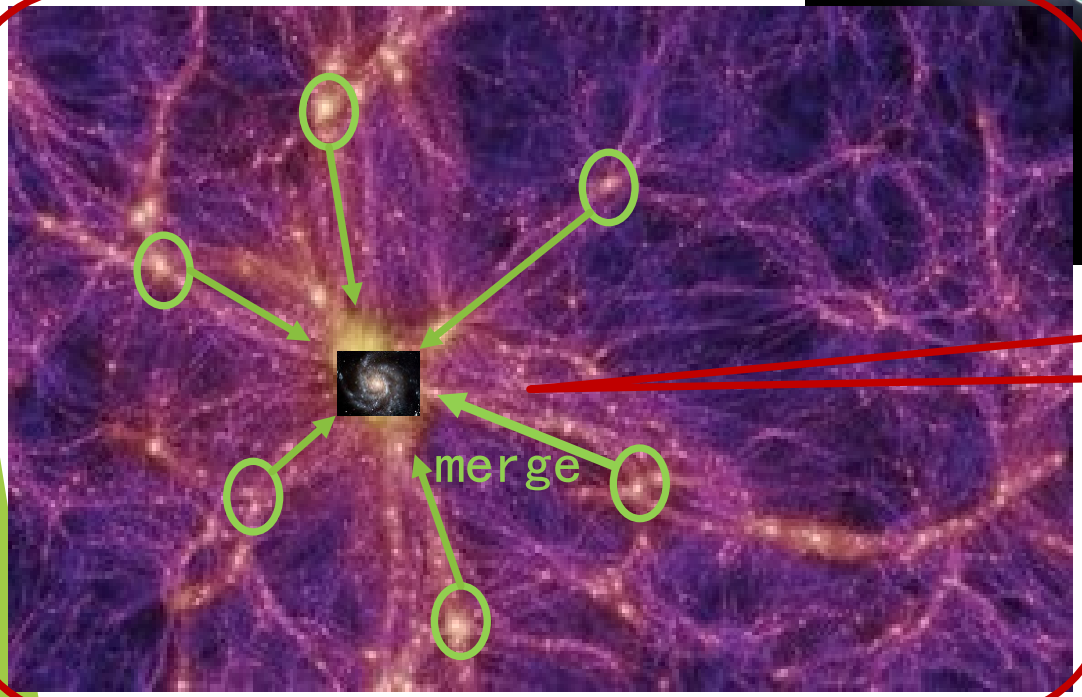
Hierarchical structure formation in the Universe



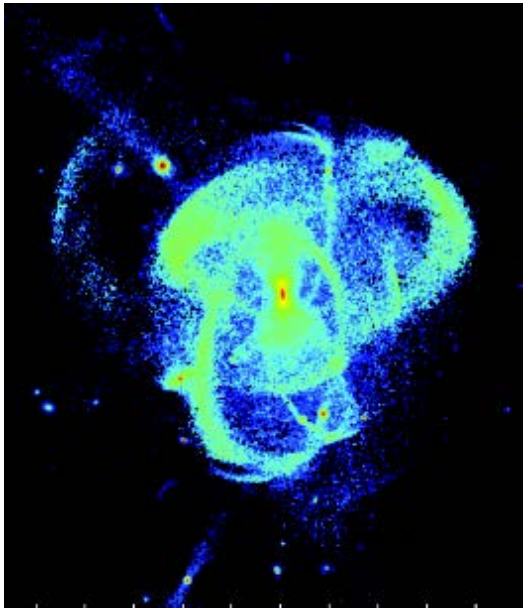




Galaxies form in halos

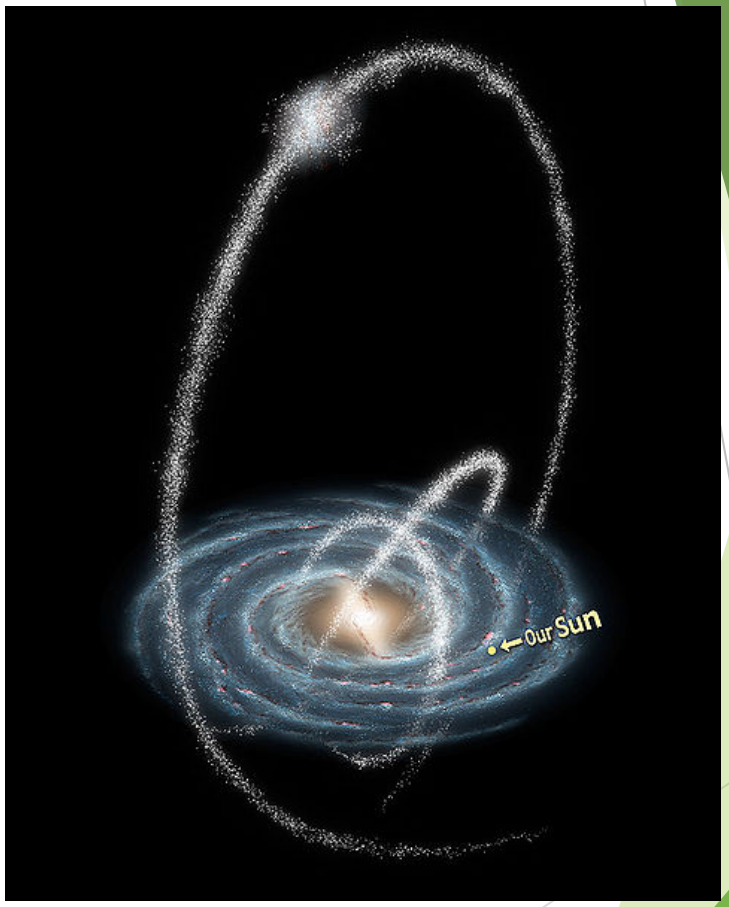

satellites

# Stellar streams and stellar halos

Satellites get stripped, which form stellar streams and stellar halos.



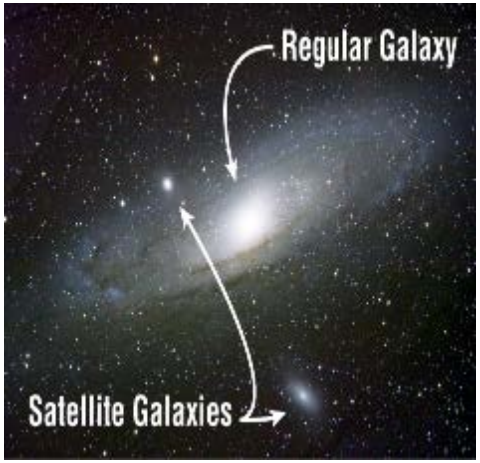
Predicted low surface brightness structures/stellar halos by numerical simulations.



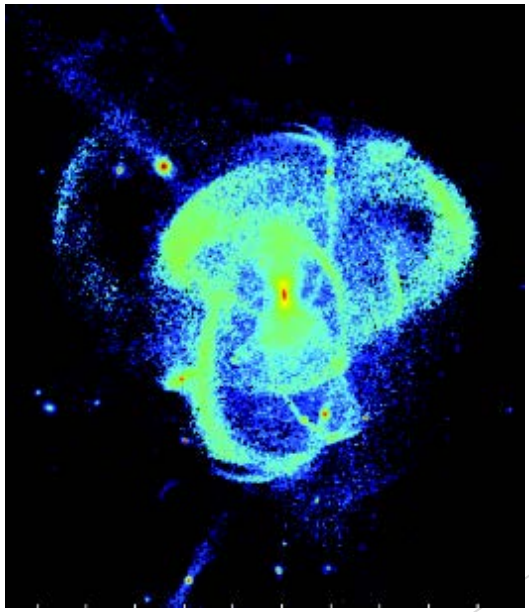

Artist's imagination of stellar streams around our Milky Way.

# Topics of the talk

- Low-mass satellites




- Faint diffuse stellar halos



# Low-mass satellites

Low-mass satellites can be used to distinguish different dark matter models.

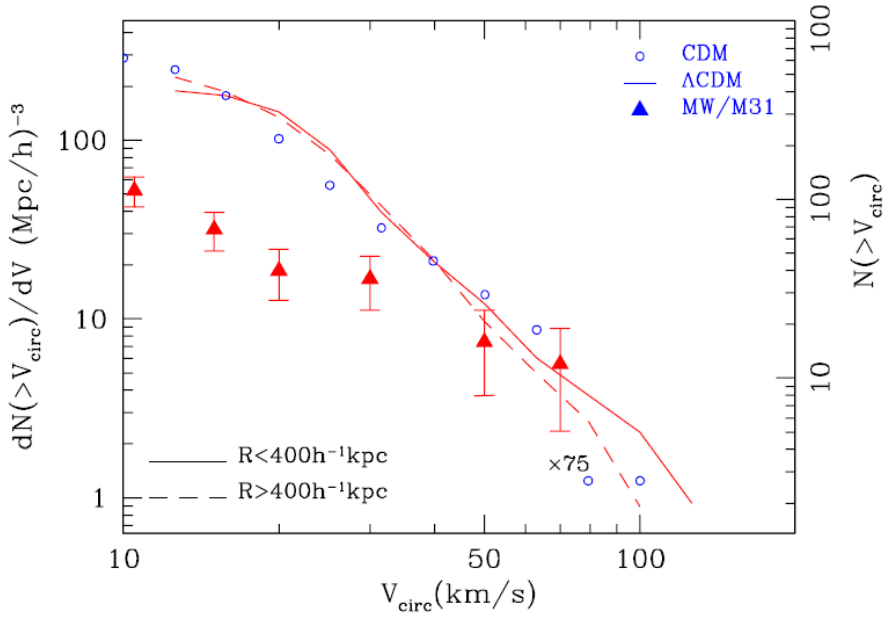
Faint distant satellites do not have spectroscopic observations.



Lovell, et al., 2014

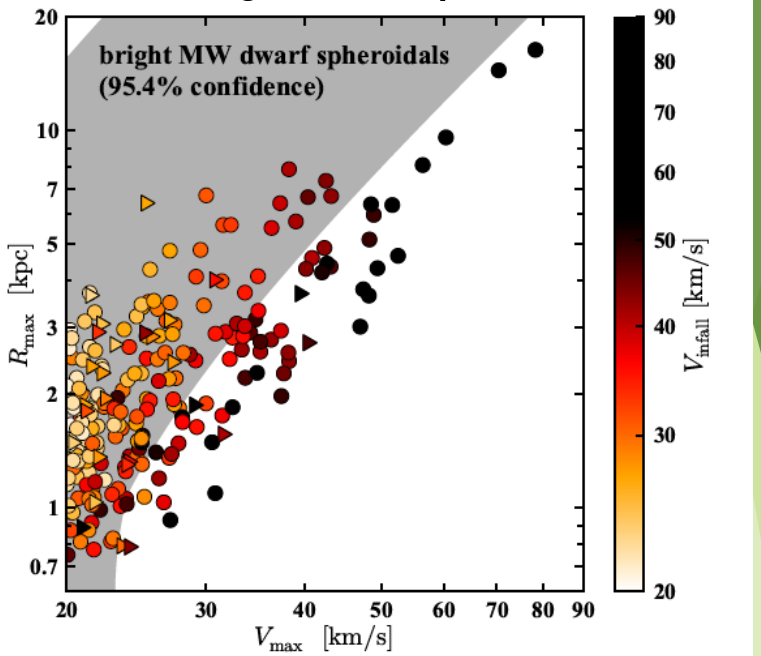
# Small scale crisis to the standard cosmological model…

Missing satellite problem




Klypin, et al., 1999

Too big to fail problem




Boylan-Kolchin, et al., 2011

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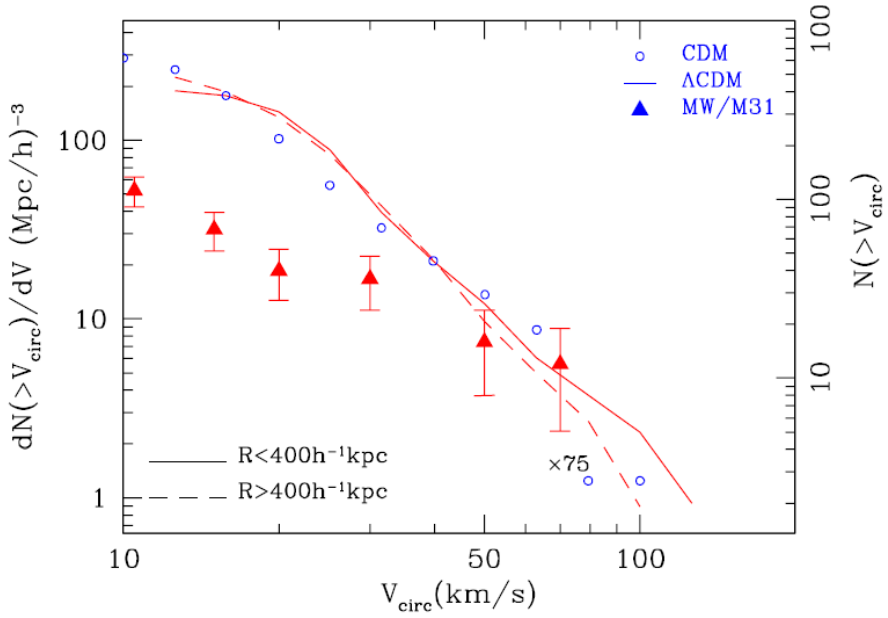


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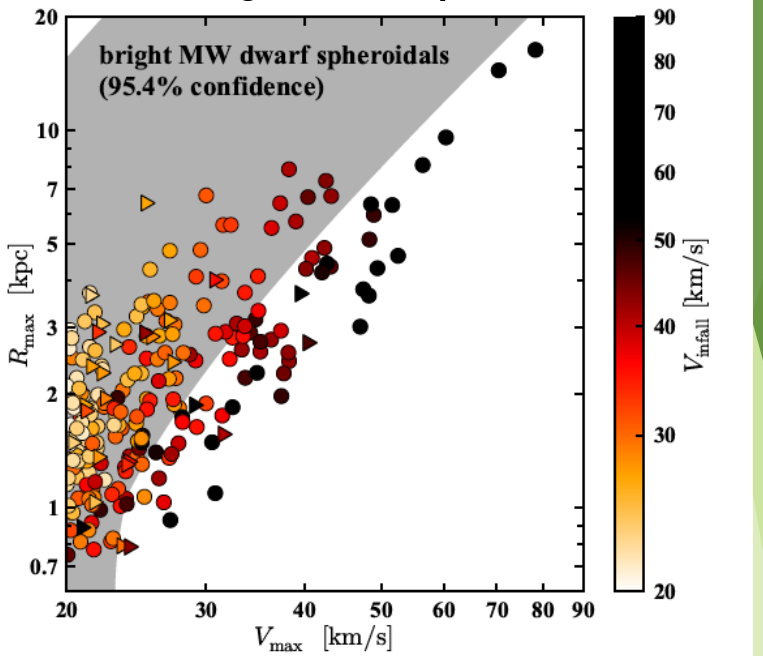


Boylan-Kolchin, et al., 2011

Whether conclusions based on observations within our MW is universal or not?

# To obtain intrinsic properties of faint satellites……

➢Count photometric satellites around spectroscopic central galaxies:

1) central galaxies have accurate distances;

2) faint photometric sources used to count satellites.

- Satellite counts around different centrals are added together and averaged.
- Distance of the central is used to calculate intrinsic properties.

Wang, et al., 2011, 2012, 2014

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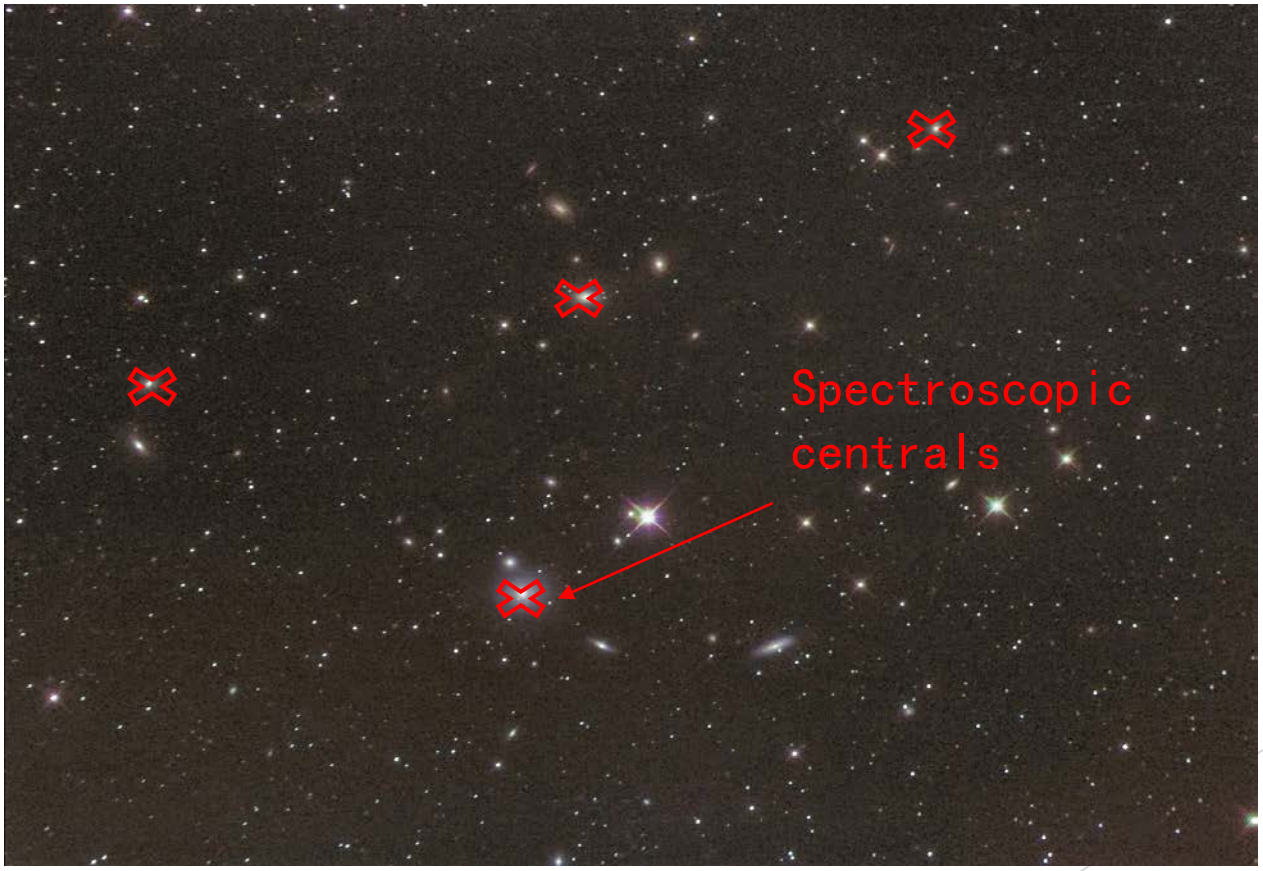


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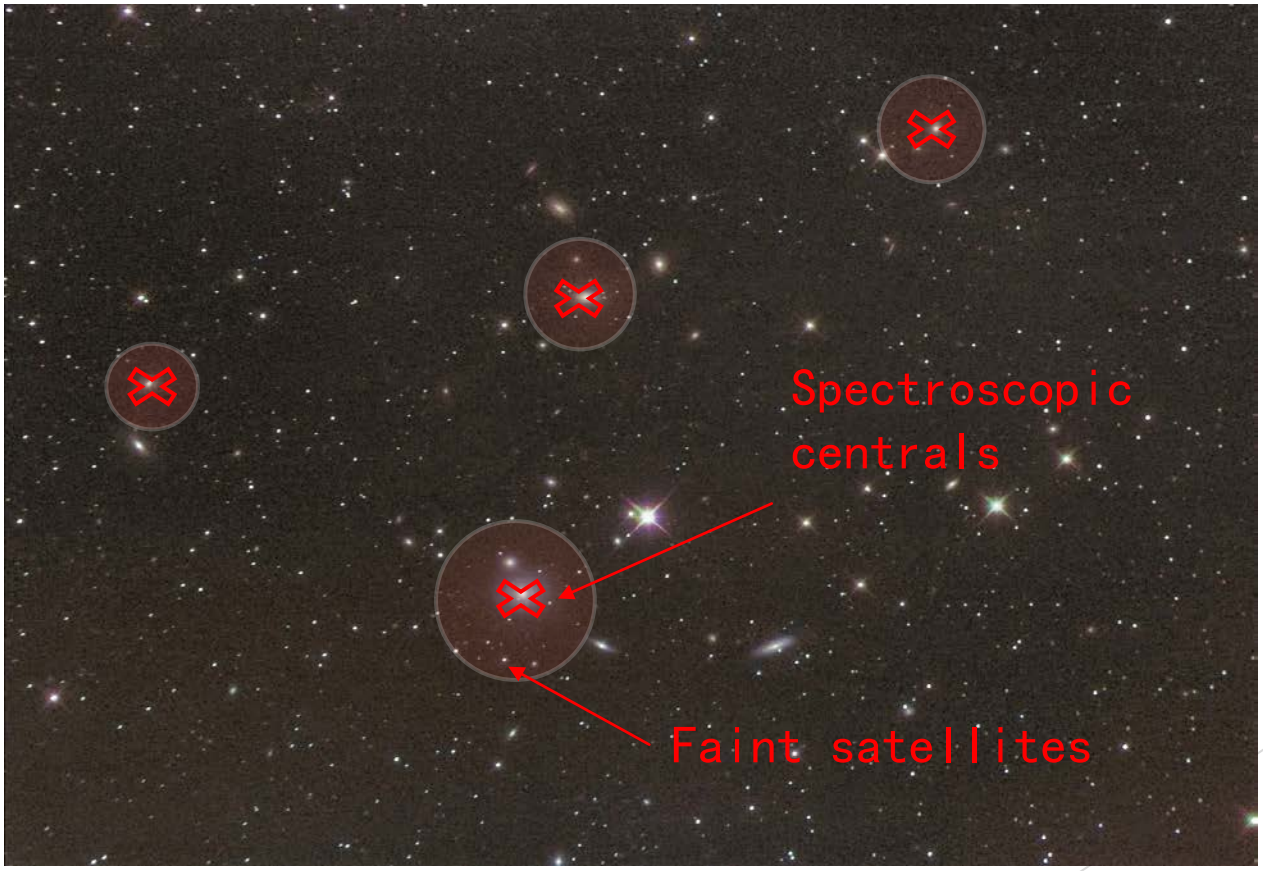


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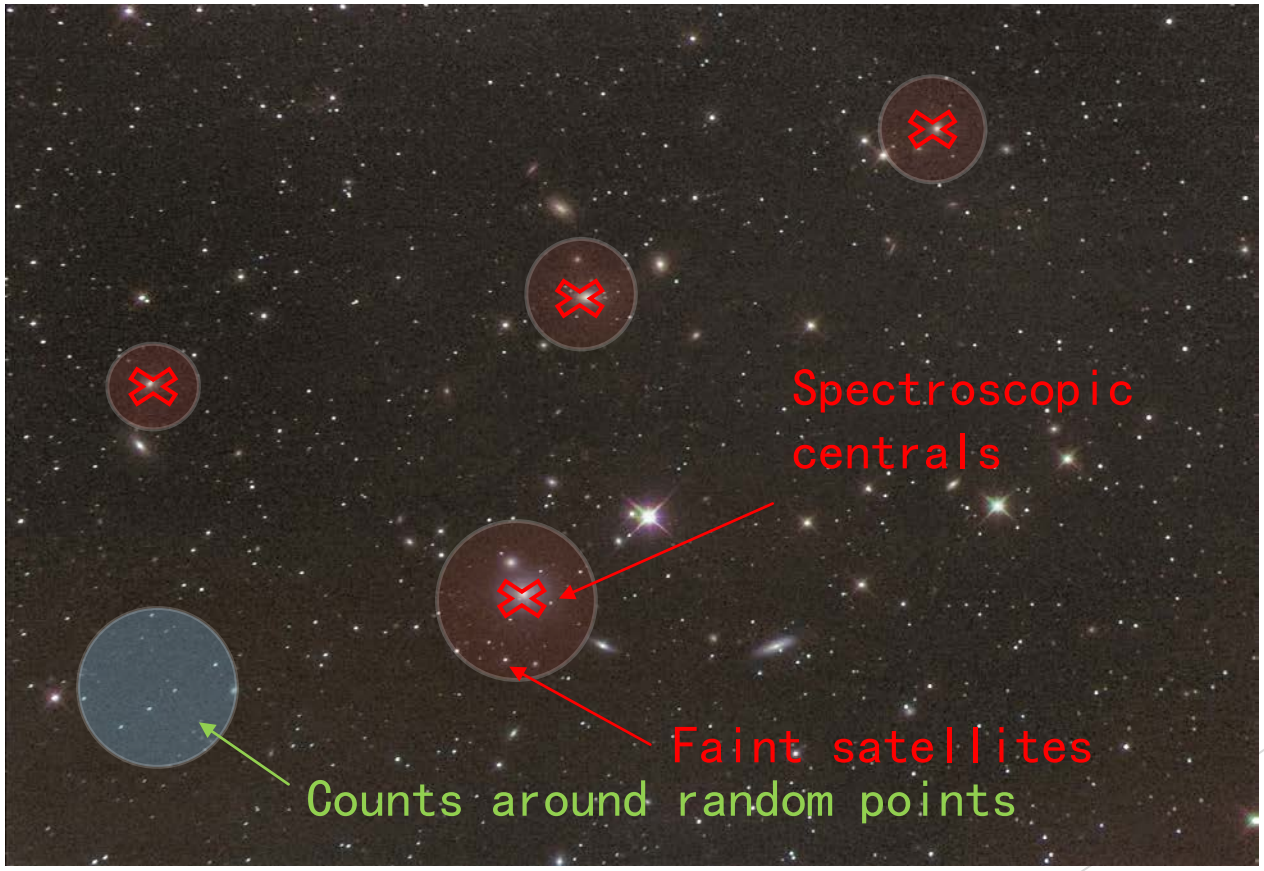


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Wang, et al., 2011, 2012, 2014

# To select centrals……

- Parent sample:

  SDSS spectroscopic Main galaxies, <z>=0.1 ~400Mpc

- Isolated central galaxies 1 (ICG1):

  brighter than all other companions within rvir and 3 times vvir along the line of sight

- Isolated central galaxies 2 (ICG2):

  at least one magnitude brighter than all other companions within rvir and 3 times vvir along the line of sight

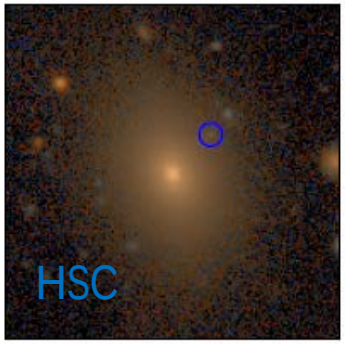
- Galaxy pairs:

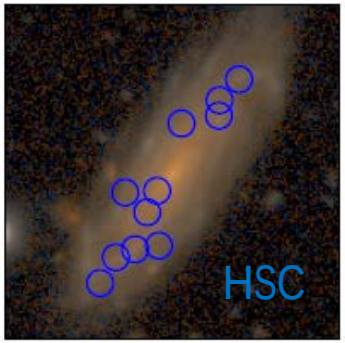
  separated in between max(rvir1, rvir2) and 1500 kpc, and all other companions centered on the middle point should be at least one magnitude fainter

# To count photometric companions

- Three surveys: HSC、 DECaLS and SDSS

an elliptical galaxy





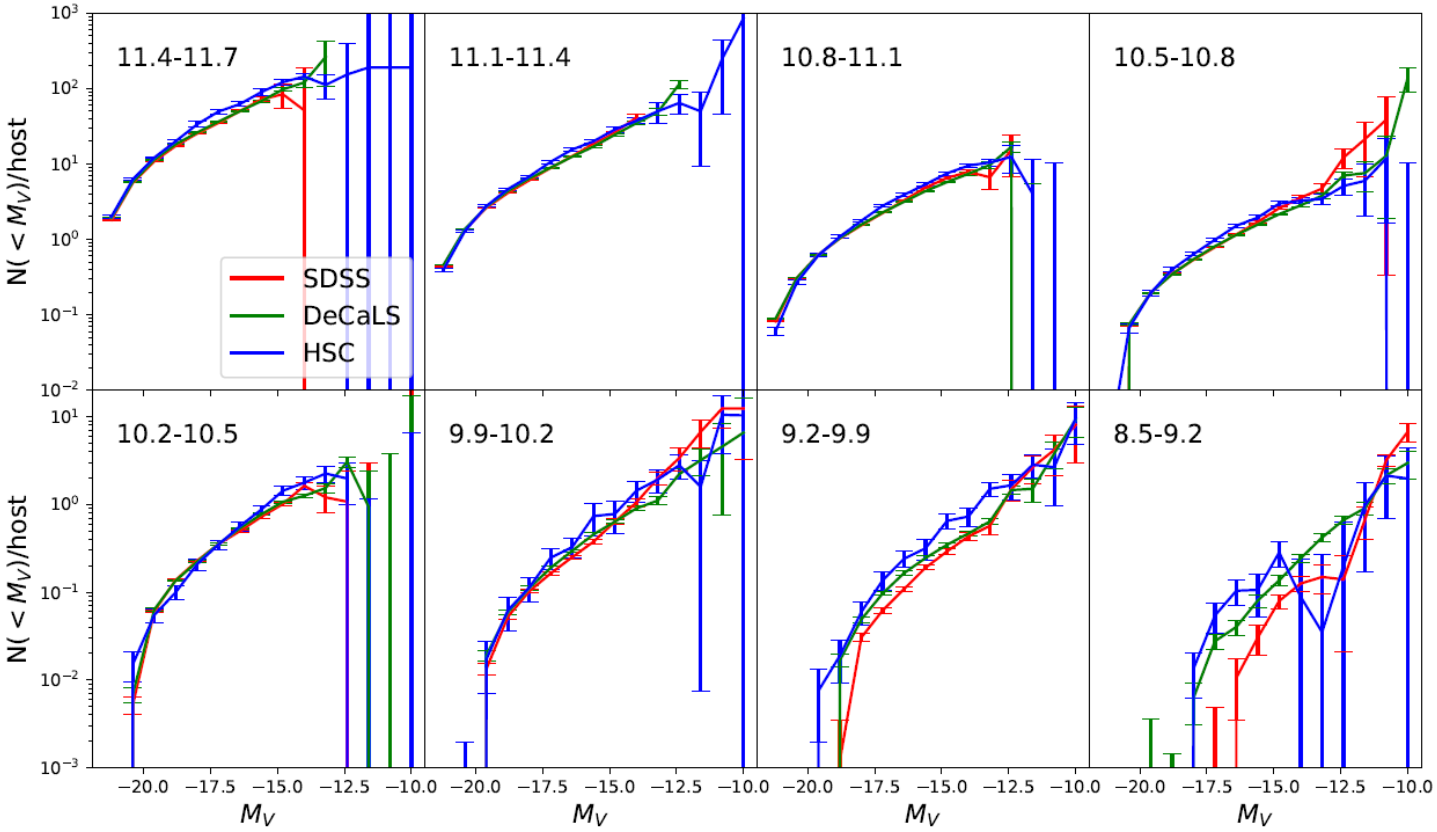

a spiral galaxy


# Averaged satellite LFs…

- Three surveys:

  HSC、DECaLS and SDSS

Satellite luminosity function around ICG1s




Wang, et al., 2021

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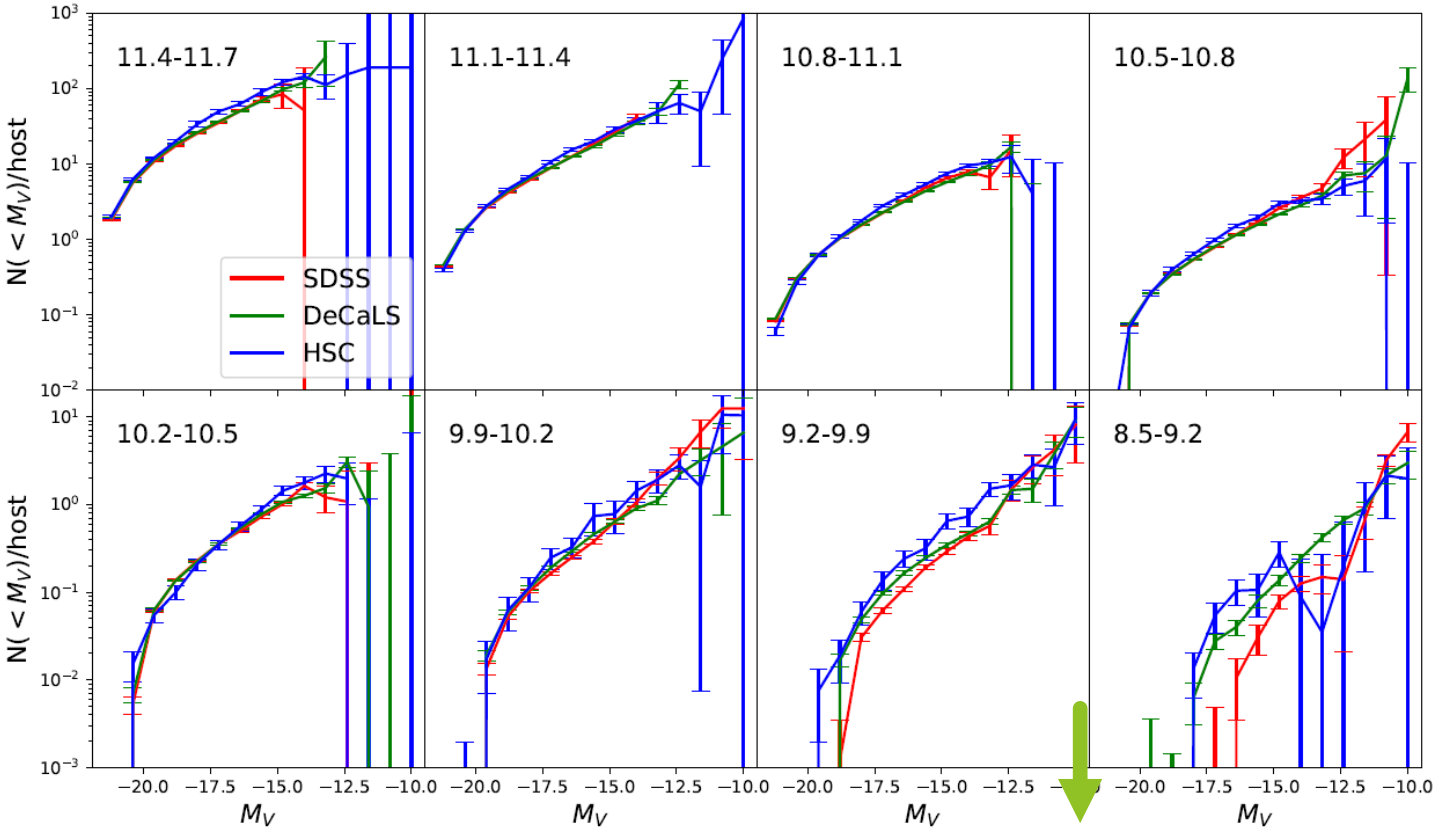


Wang, et al., 2021

Mass of LMC!

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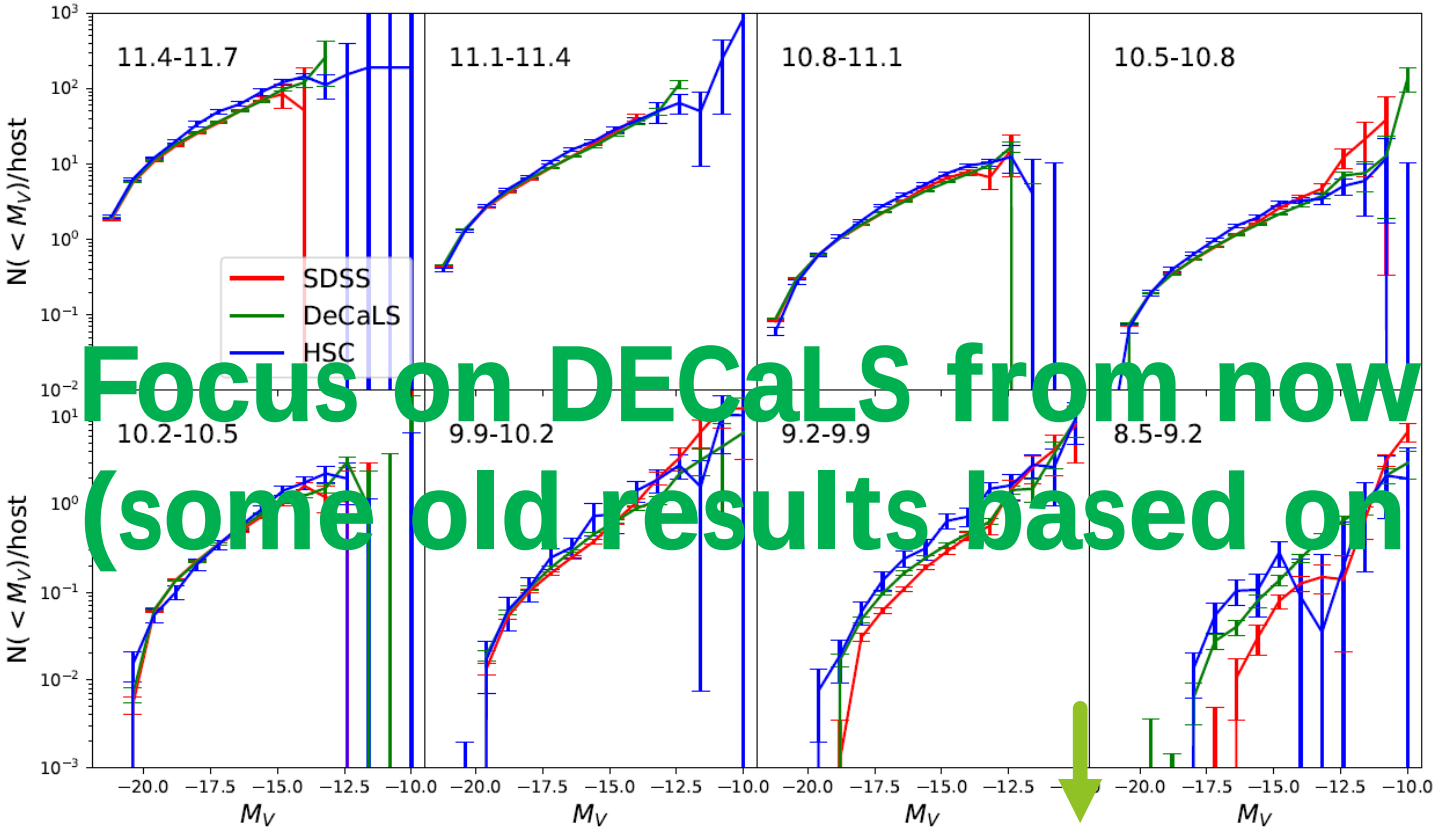



**Focus on DECaLS from now on …**

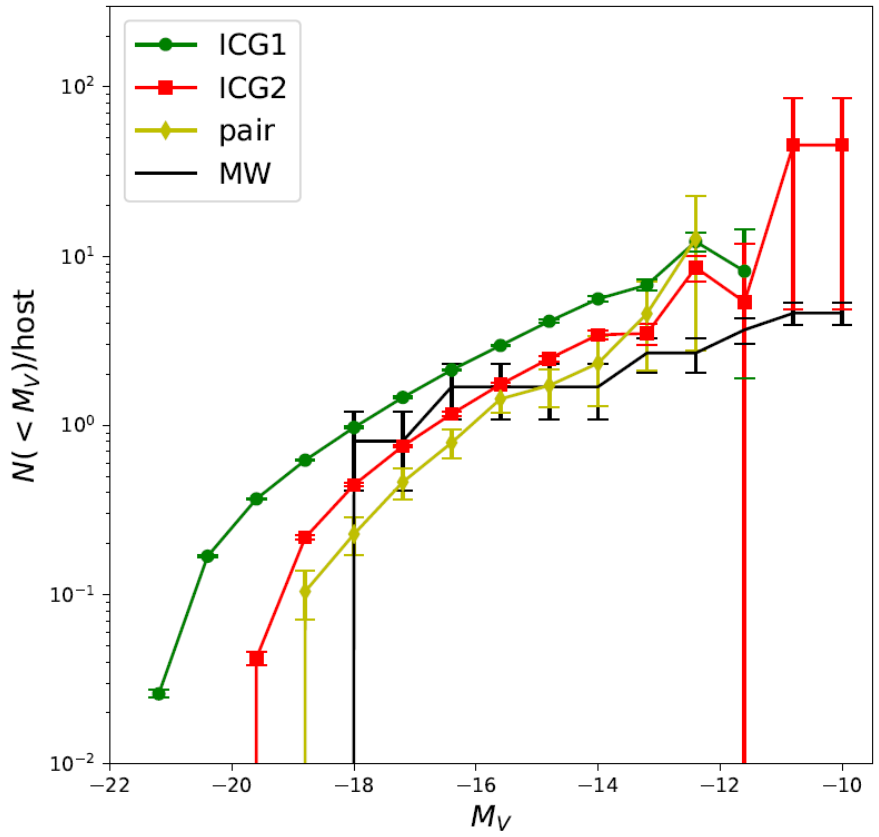
**(some old results based on SDSS)**

Wang, et al., 2021

Mass of LMC!

# Averaged satellite LFs of MW-mass centrals...

- more satellites than the MW at the faint end!




Wang, et al., 2021

**Black:**
MW satellite LF after projected along 600 random line-of-sight directions and with the same inner radius cut of 30 kpc

Mass range of central ICGs
For olor curves:

$$10.63 < \log_{10} M_*/M_\odot < 10.93$$

(Licquia and Newman, 2015)

# Averaged satellite LFs of MW-mass centrals...

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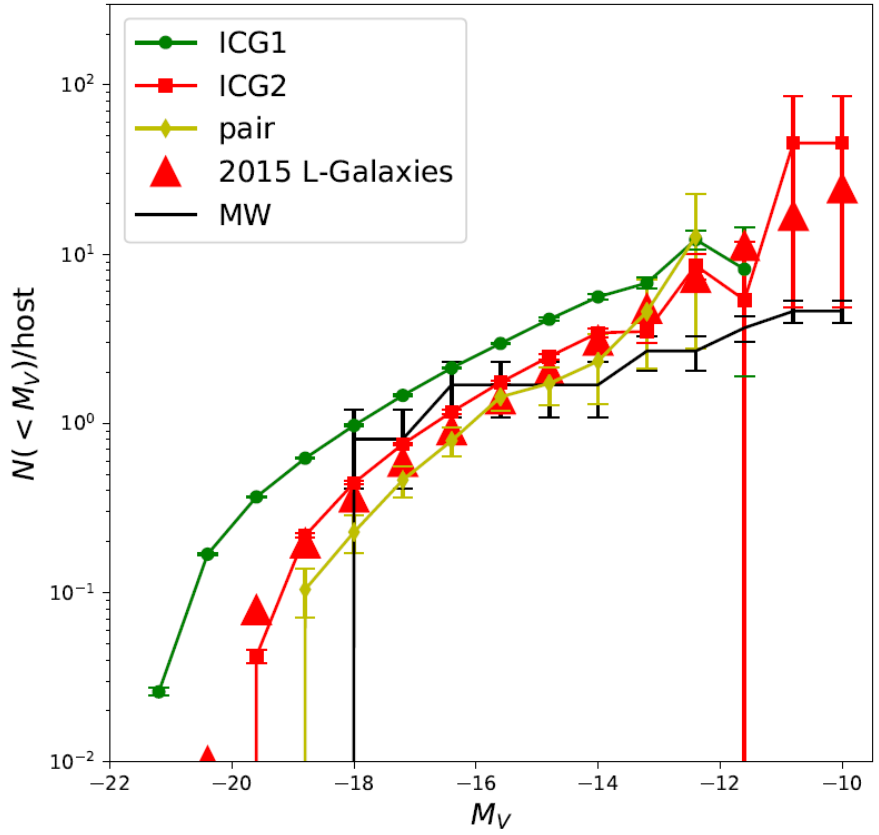


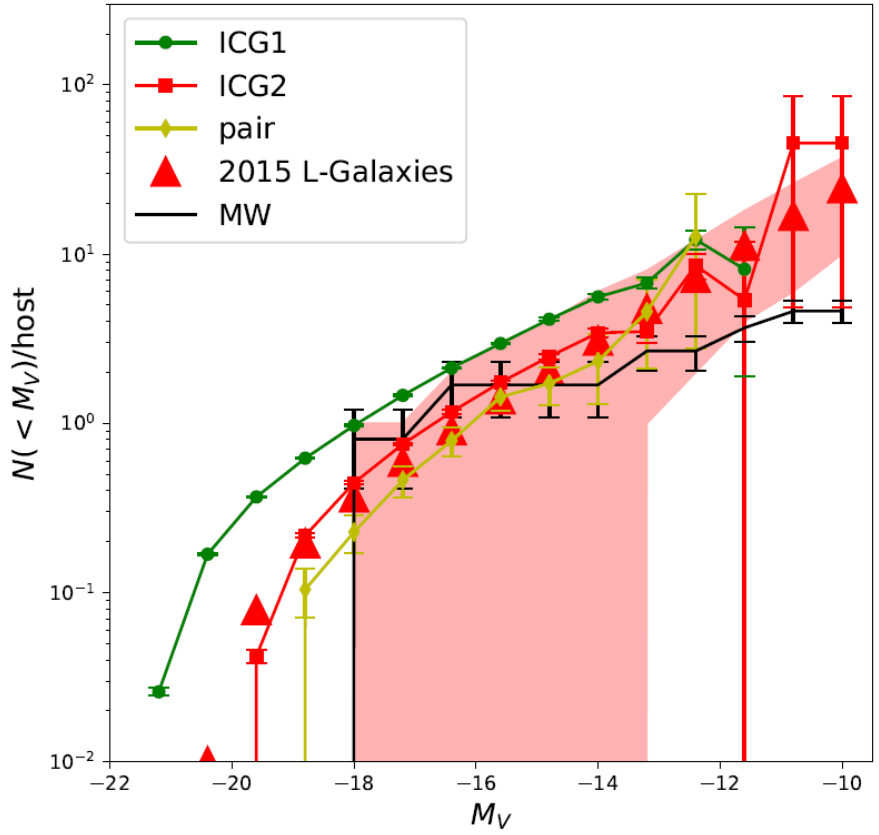

Wang, et al., 2021

Red triangles: L-Galaxies model prediction of satellite LF around ICG2s (Henriques, et al., 2015)

- agree very well with real data

# Averaged satellite LFs of MW-mass centrals…

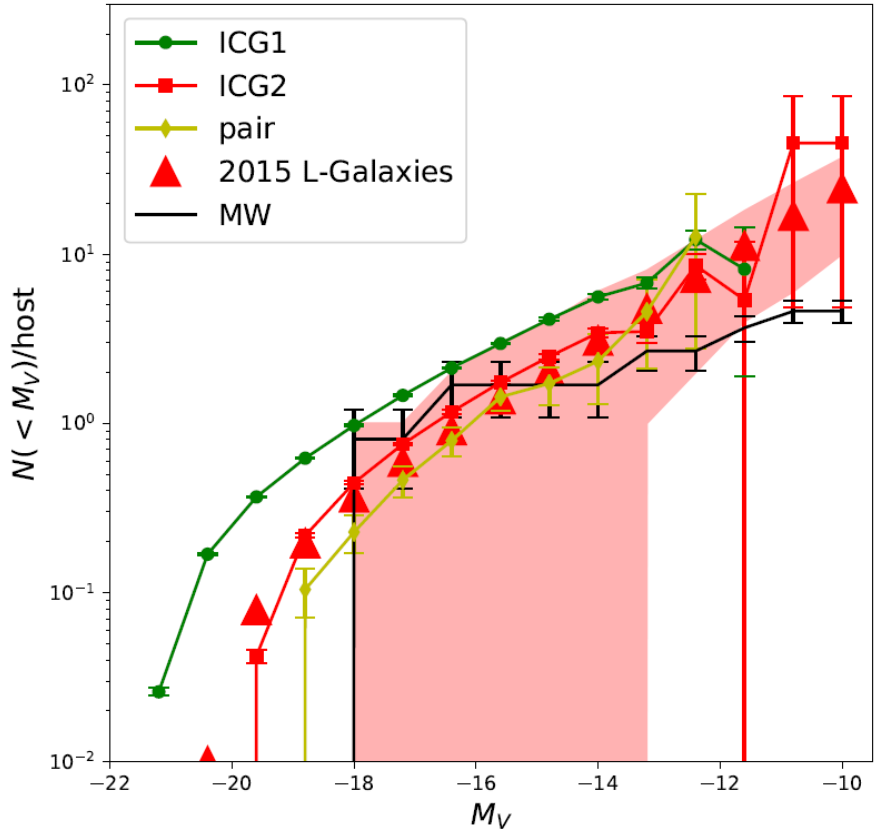
- Very large scatter …



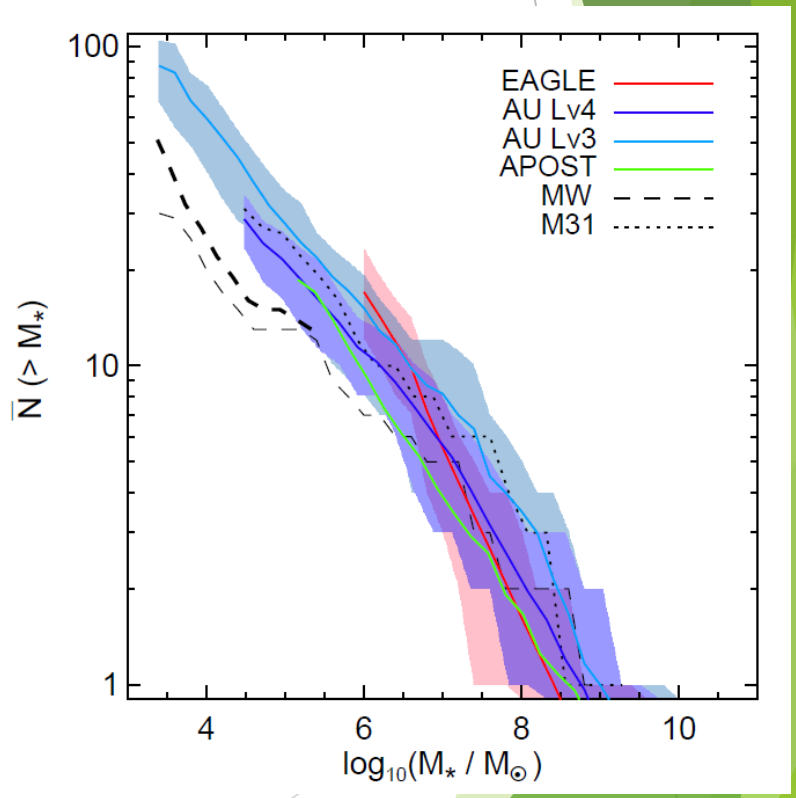

Wang, et al., 2021

# Averaged satellite LFs of MW-mass centrals…

- MW-like systems can be predicted by simulation, but rare…




Wang, et al., 2021



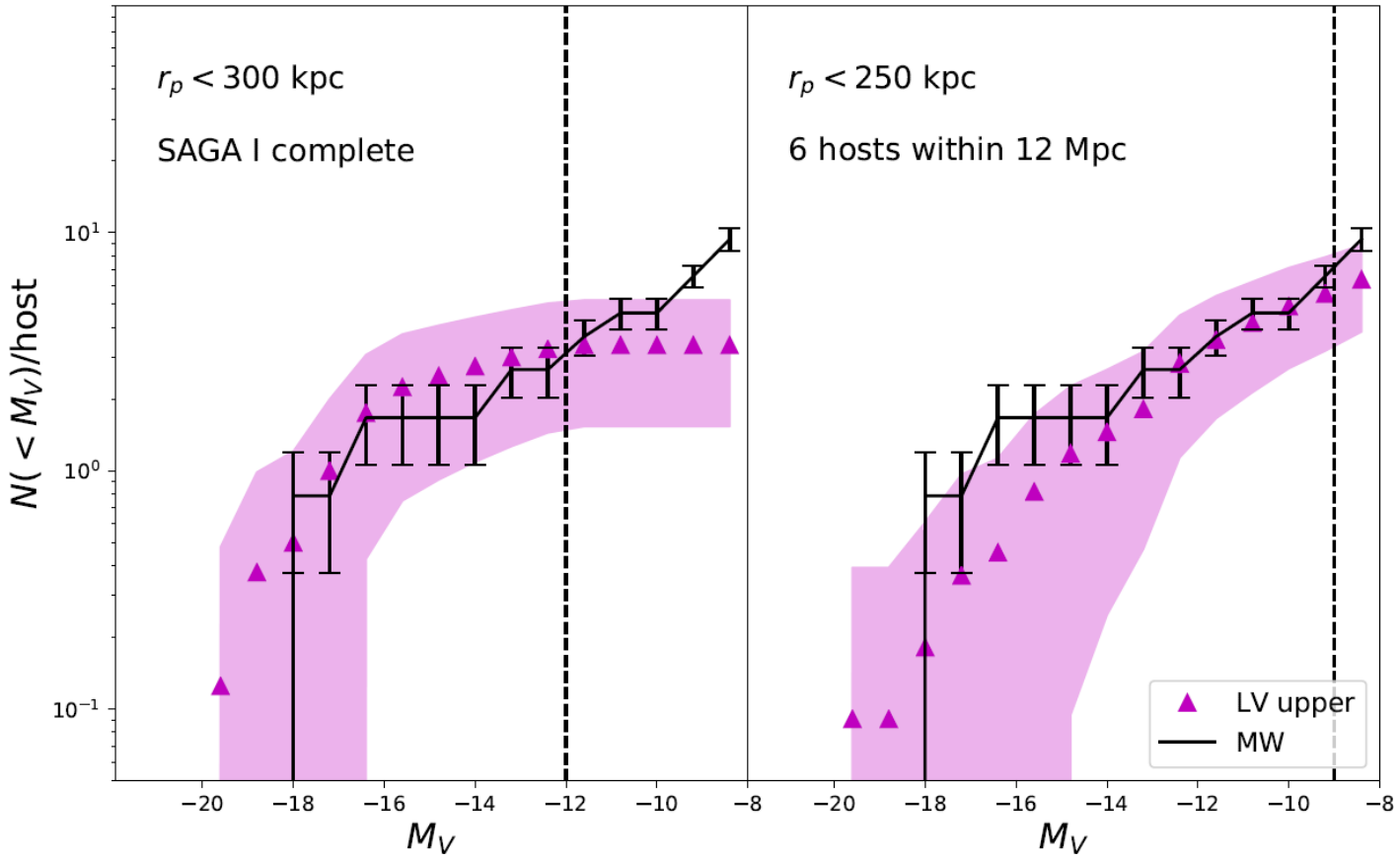

Shao, et al., 2020

# Averaged satellite LFs of MW-mass centrals...

- It does not rule out the theory.
- However, the MW system is rare in both the real Universe and simulations.
- We can not use our MW to represent other MW-mass systems in the Universe.

# Other Local Volume systems …

- MW tends to be more typical in the local volume
- Local volume is an under-dense region?



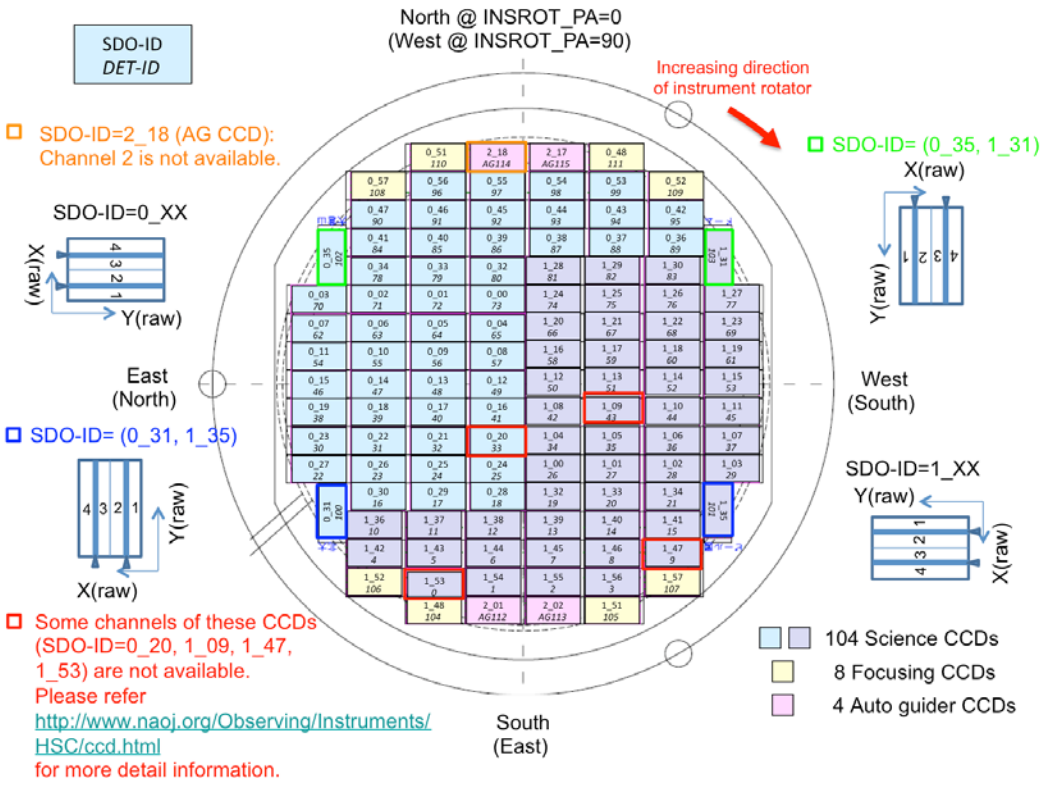

Wang, et al., 2020

# Summary

- The bright end cutoff of satellite LFs and the satellite abundance are both sensitive to the magnitude gap between the primary and its companions, indicating galaxies with larger magnitude gaps are on average hosted by less massive dark matter halos.
- There are on average 1.5 to 2.5 satellites with MV<-16 around ICGs, consistent with our MW.
- The averaged satellite LFs of centrals selected in different ways all show steeper slopes and more satellites than the MW satellite LF at fainter magnitudes, which cannot be fully accounted for by the large scatter.
- Our MW is more typical in other similar systems in the Local Volume.

# The stellar halo of isolated central galaxies in the Hyper Suprime-Cam imaging Survey

# Hyper Suprime-Cam




- 104 science CCDs, 1.5 deg FOV in diameter, pixel size of ~0.168 arcsec.
- The HSC pipeline is an enhanced version of the LSST.

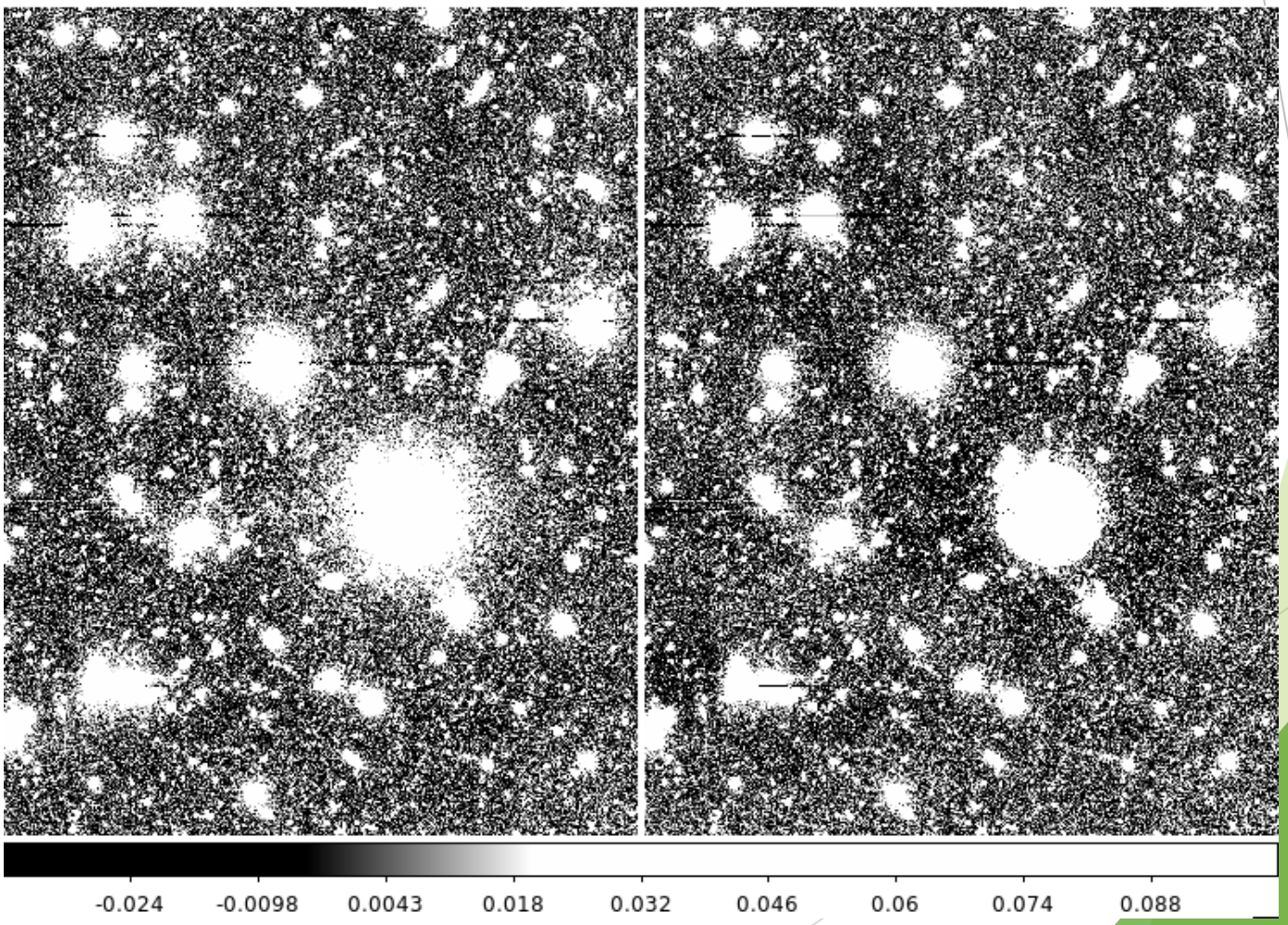
❑ Single exposures → ❑ Coadd image products

sky background and instrumental features removed by the pipeline

# HSC photometry and data reduction

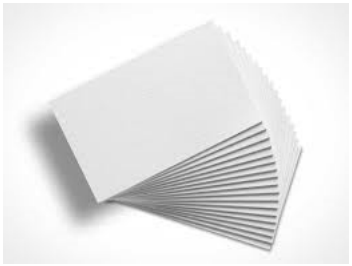
- The S18a release improves the over-subtraction of the extended emission of bright objects.

S18a

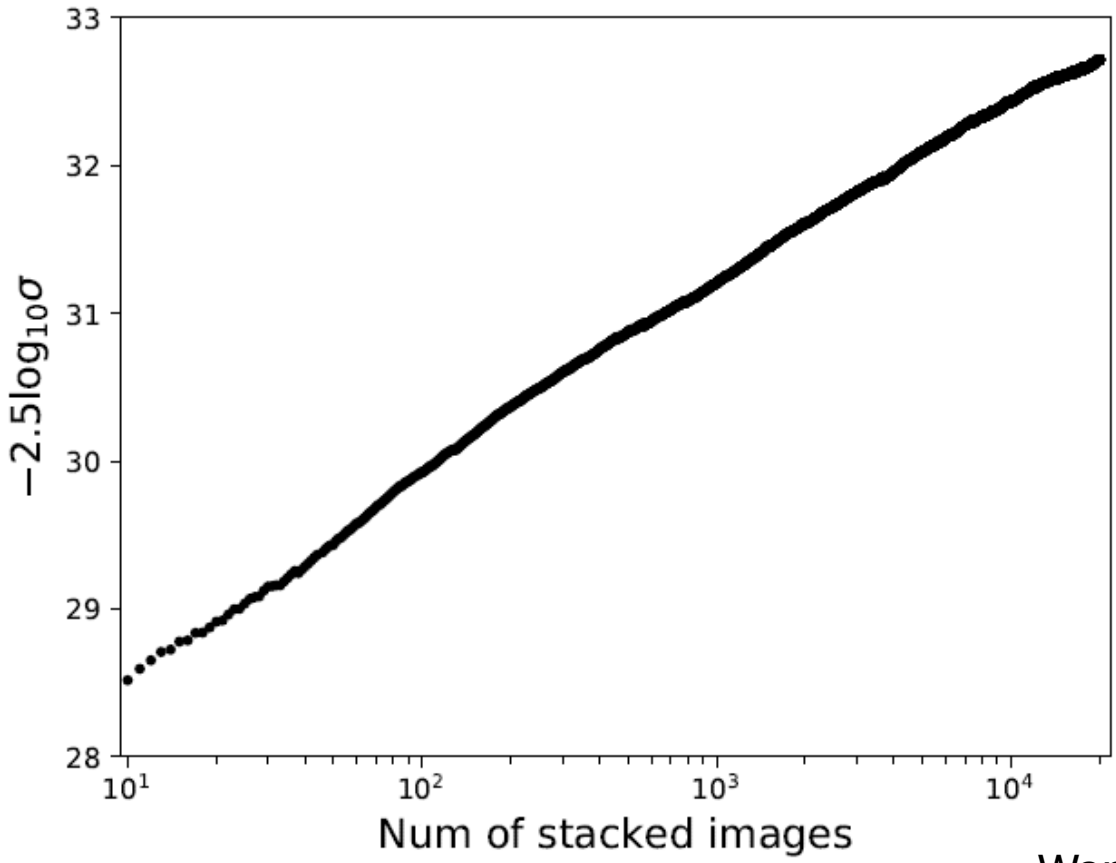



S15b

# Methodology



Galaxies with similar properties are stacked!




Wang et al., 2019

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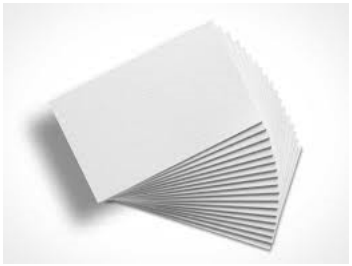

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- Image cutouts for ICG1s
- Cosmic dimming correction

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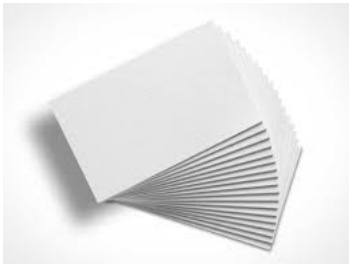

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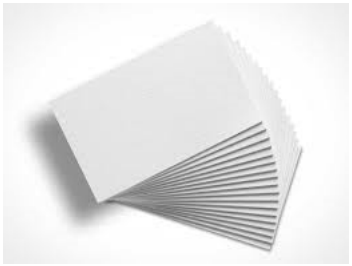

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- Clipping and stacking galaxies with similar properties

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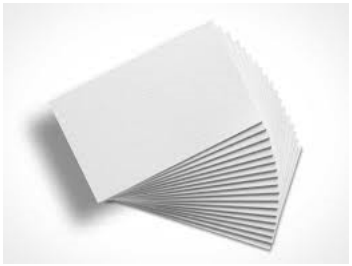

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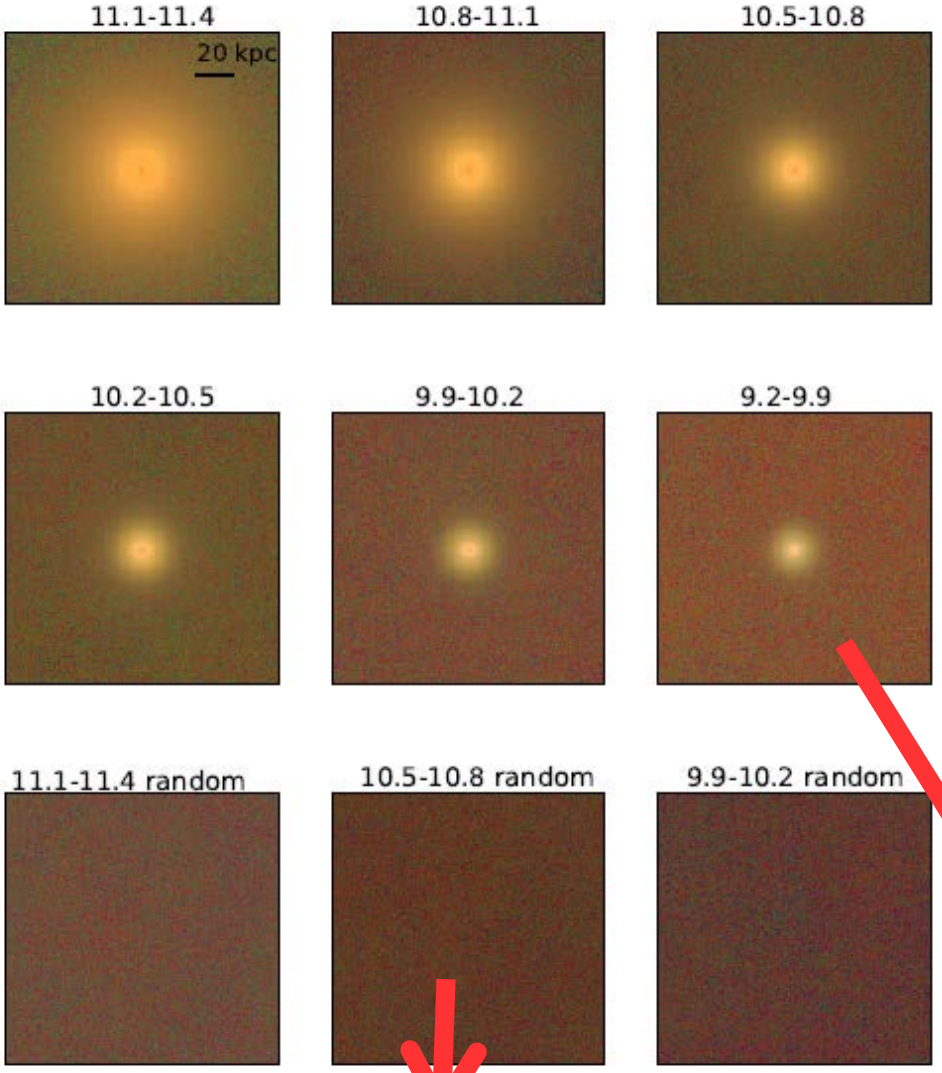
- Random sample **correction for residual background**

# Surface Brightness

HSC g,r,i-bands mapped to RGB (Lupton et al. 2004)




10^9.2-9.9 solar mass

Random stacks are ideally flat.

Wang et al., 2019

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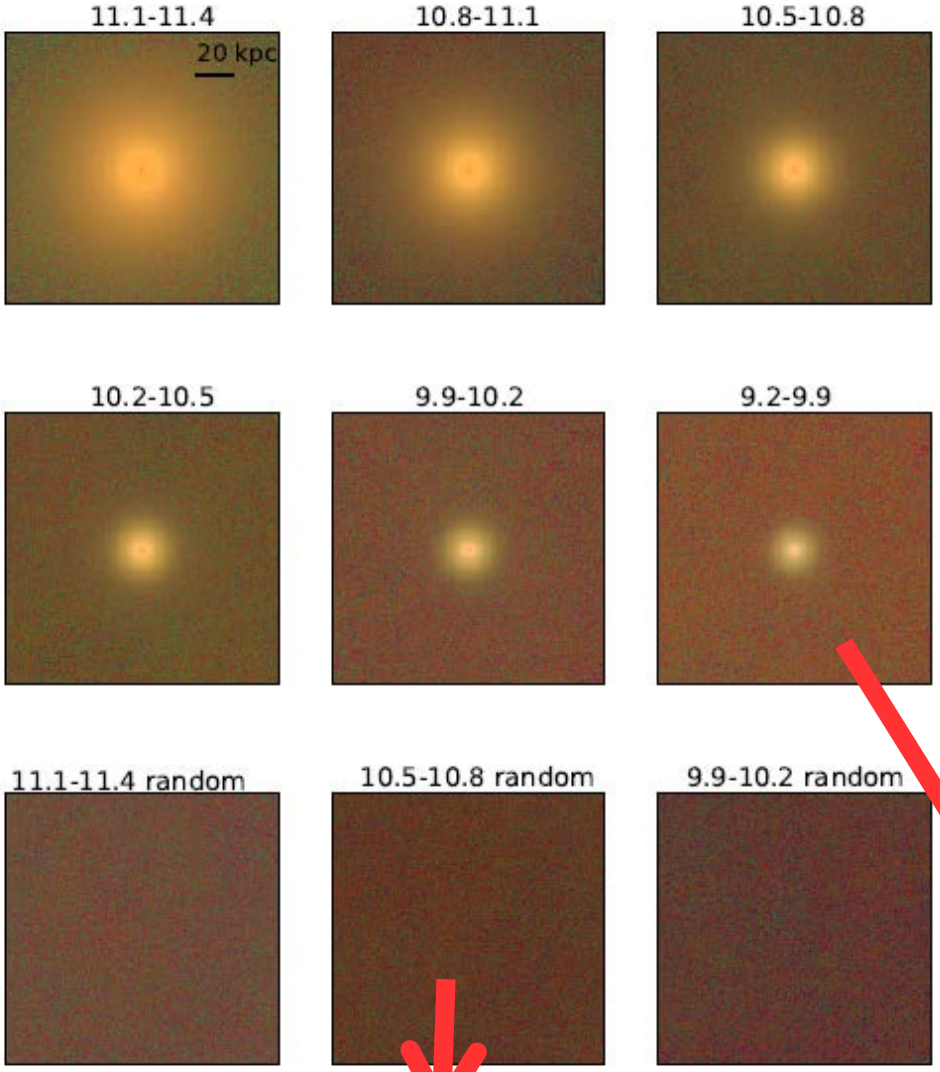


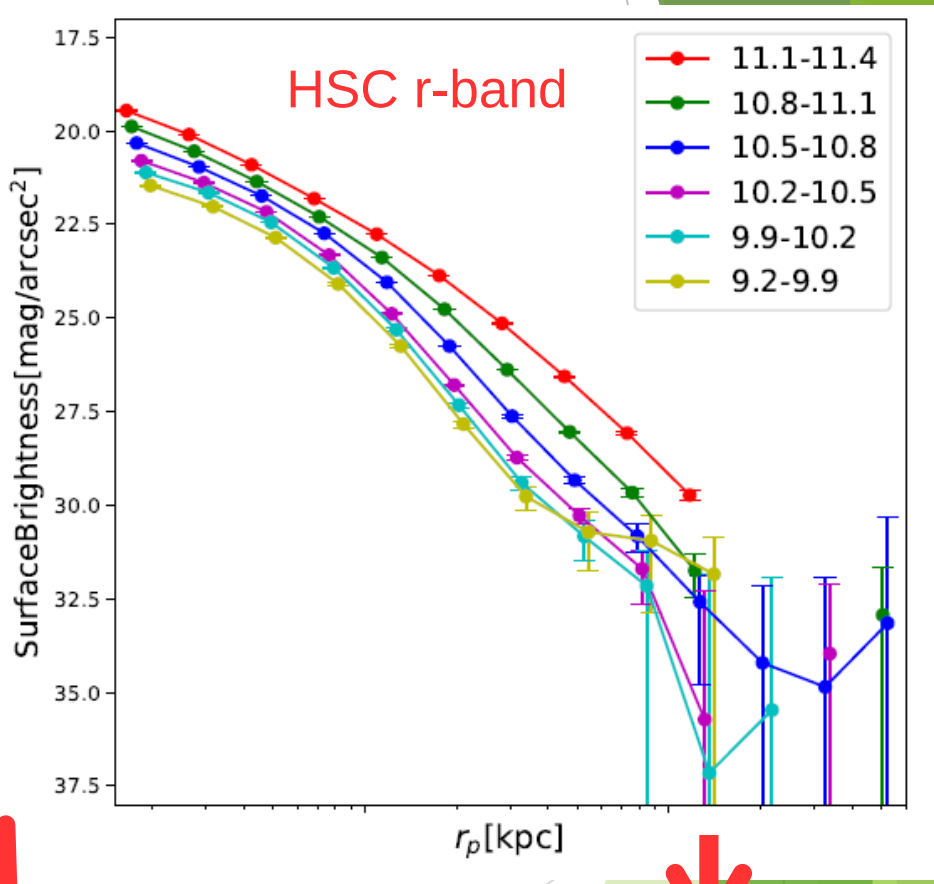


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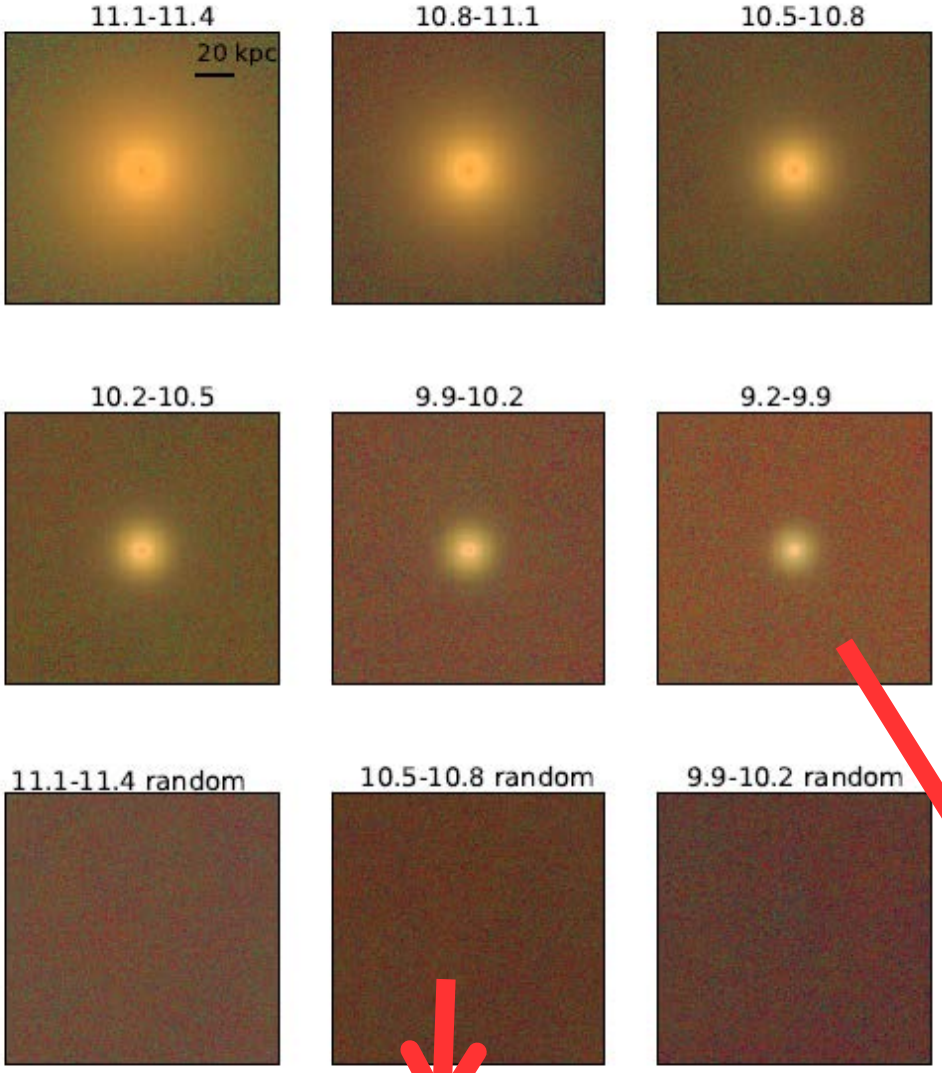


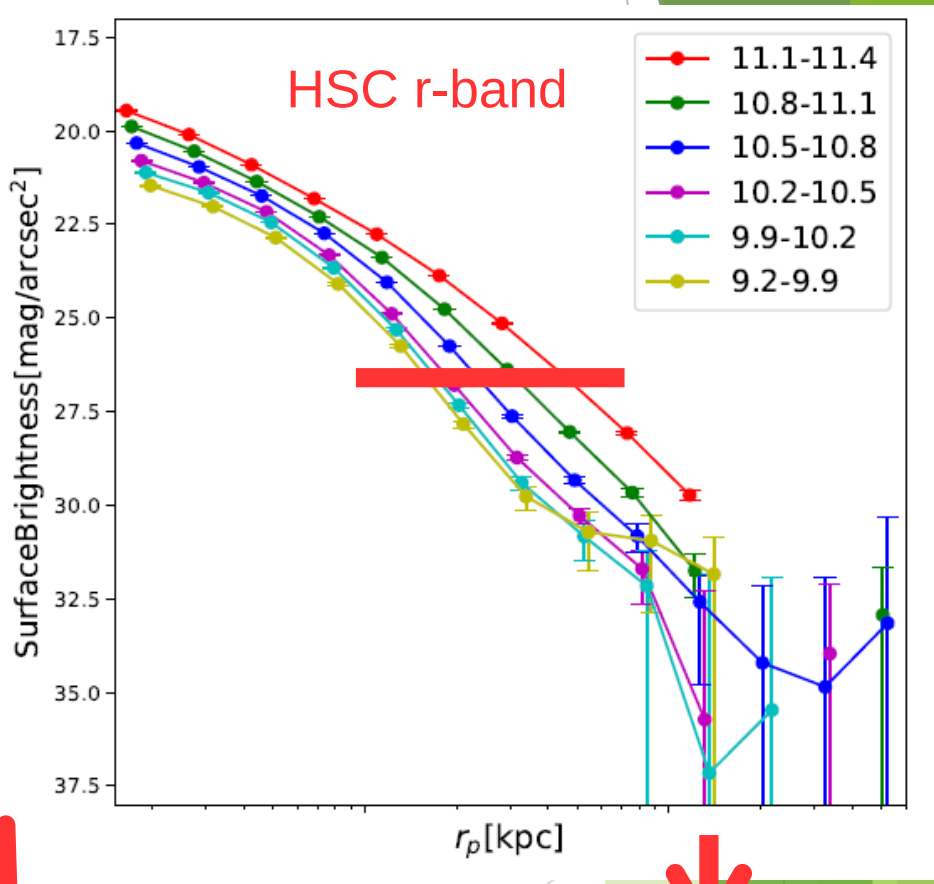


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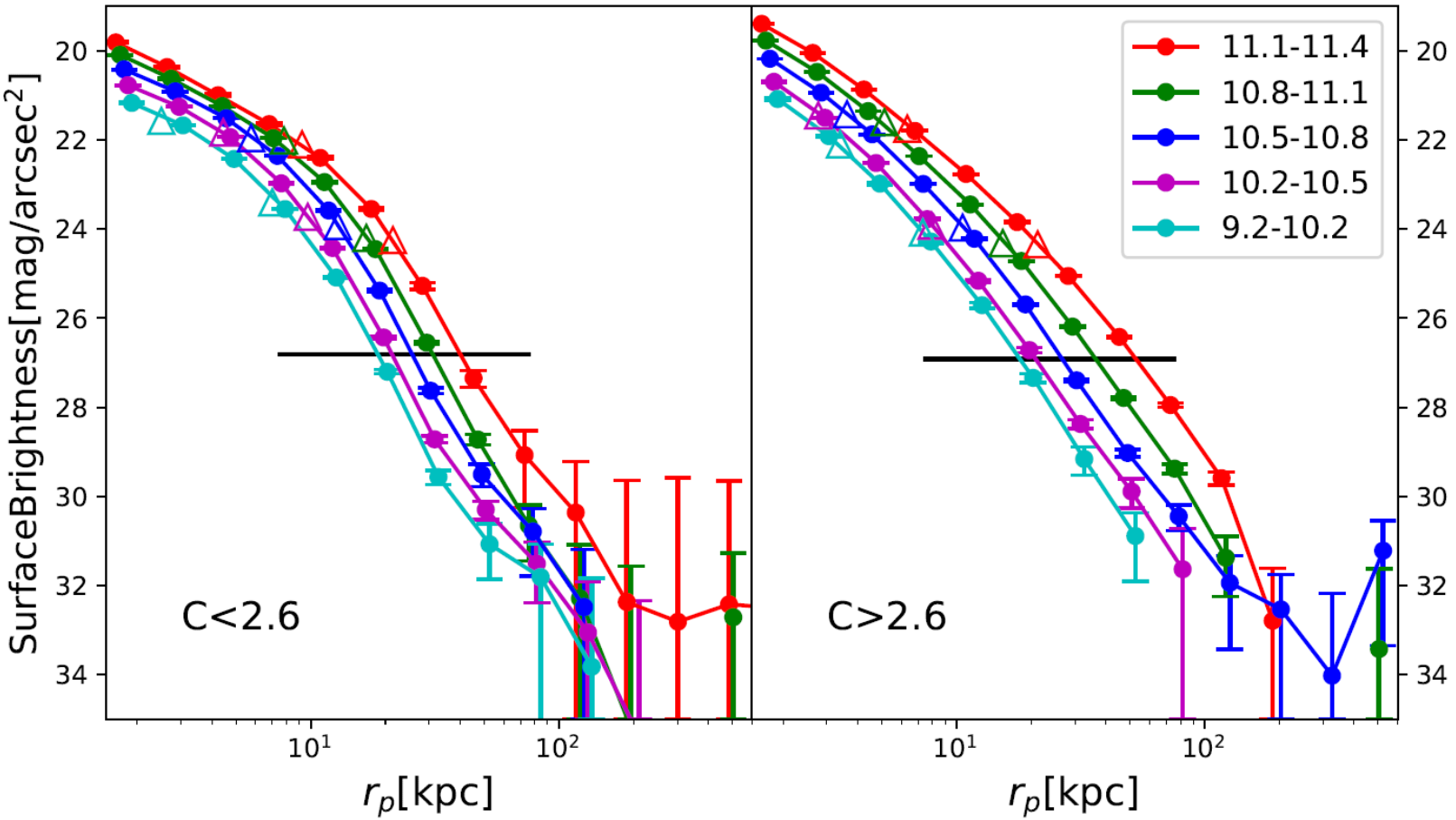
# Low and high concentration

Wang et al., 2019

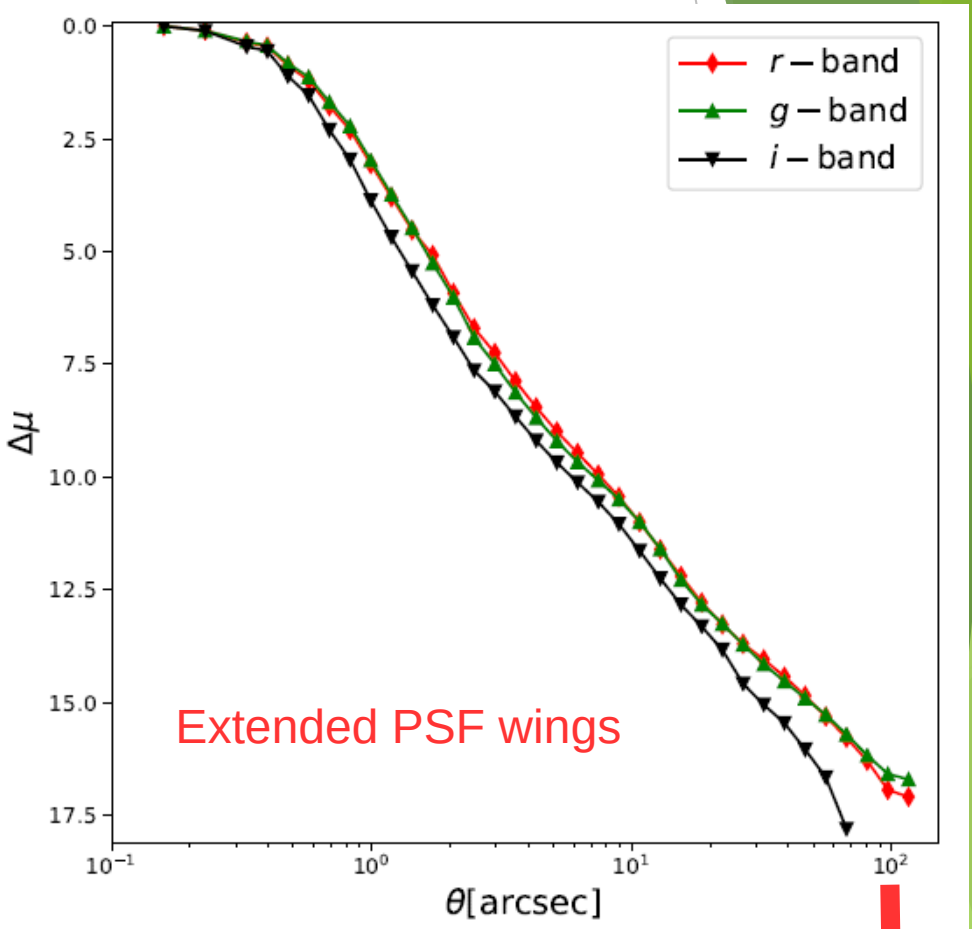



- Low and high concentration galaxies show distinct features in their outer stellar halos.

# PSF effect

**Inner PSF**
atmosphere turbulence

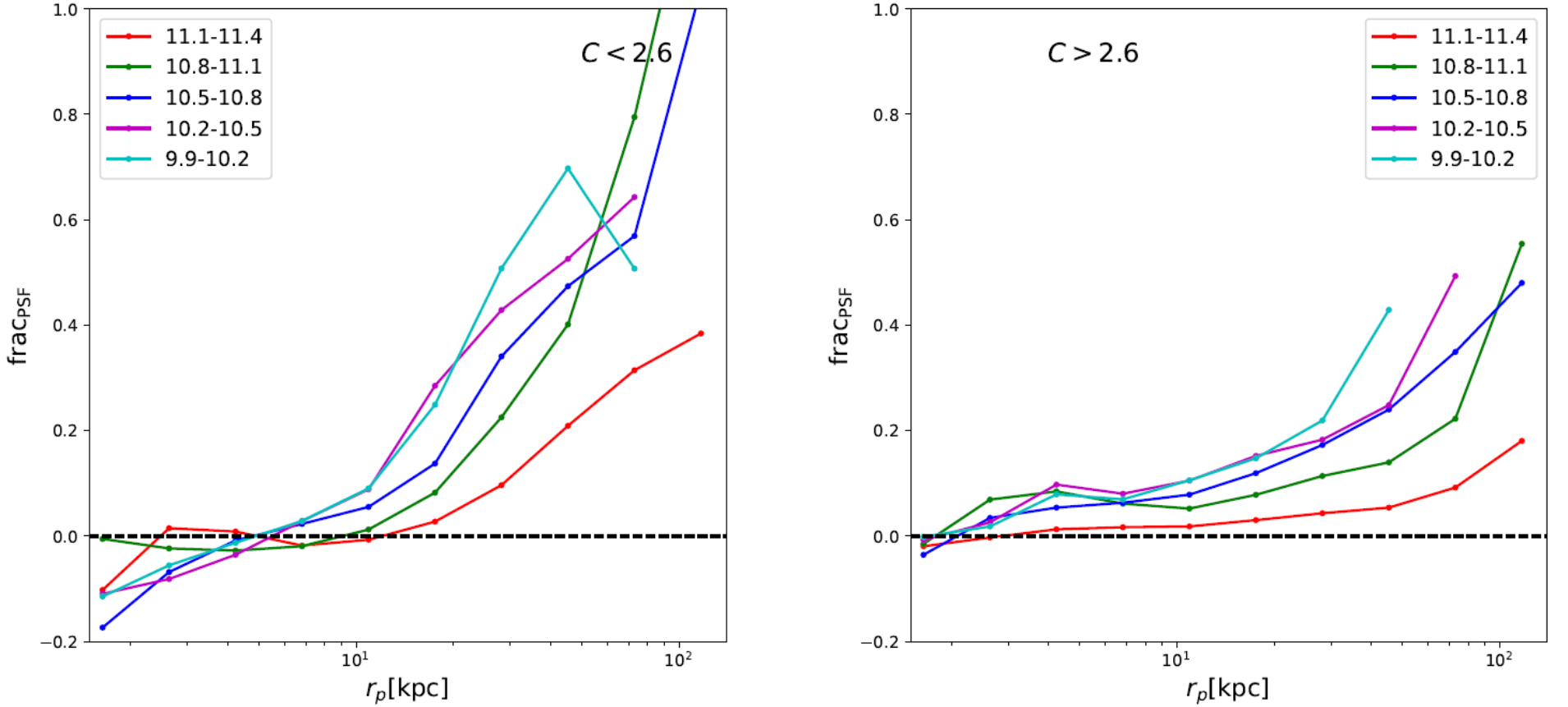
**Outer PSF**
CCD+ Instrument+
atmosphere scattering




Wang et al., 2019

100arcsec

# PSF effect

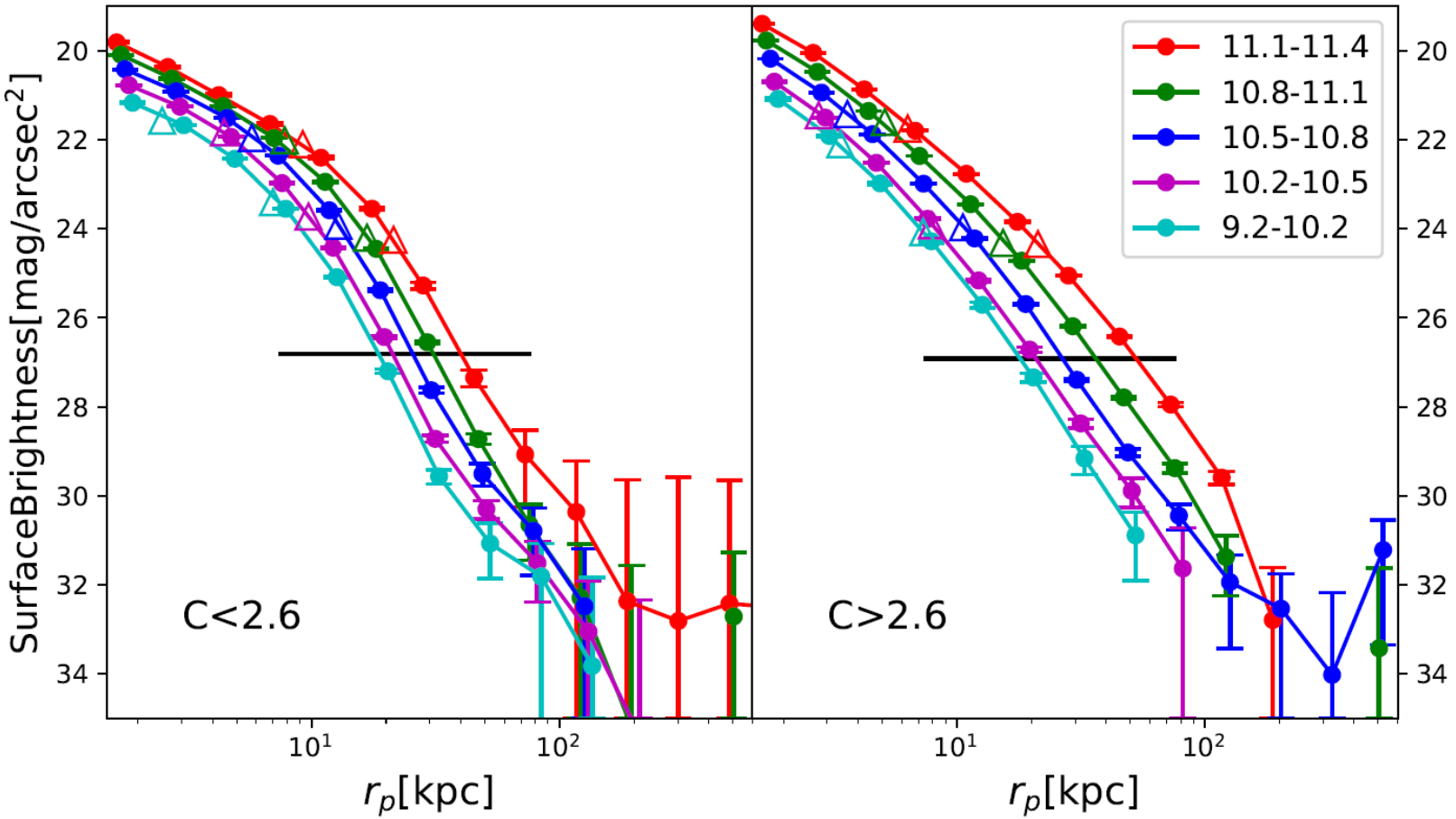



Wang et al., 2019

Outer stellar halos of small and lowC galaxies are more strongly affected by PSF.

# Low and high concentration

Wang et al., 2019

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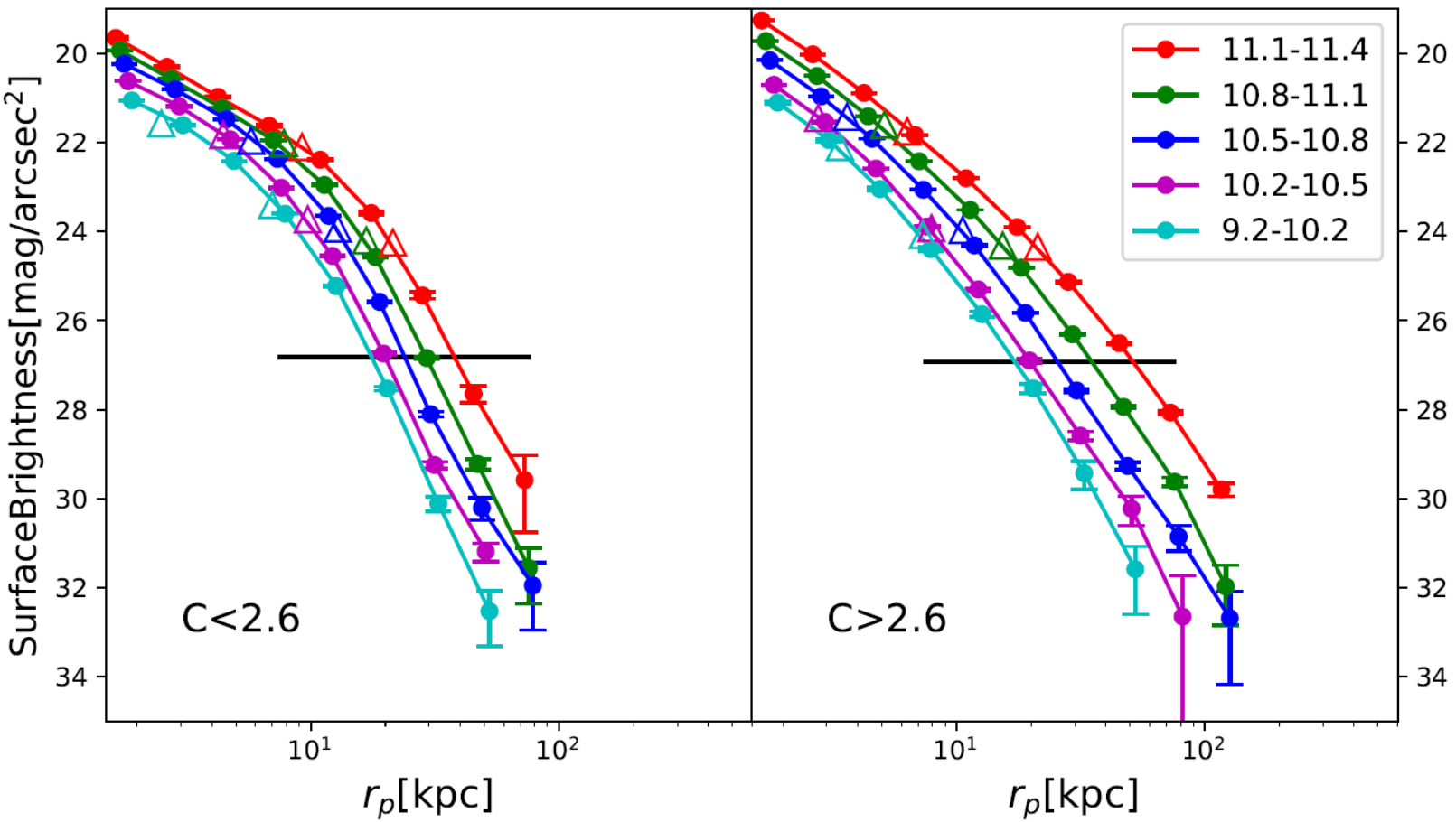
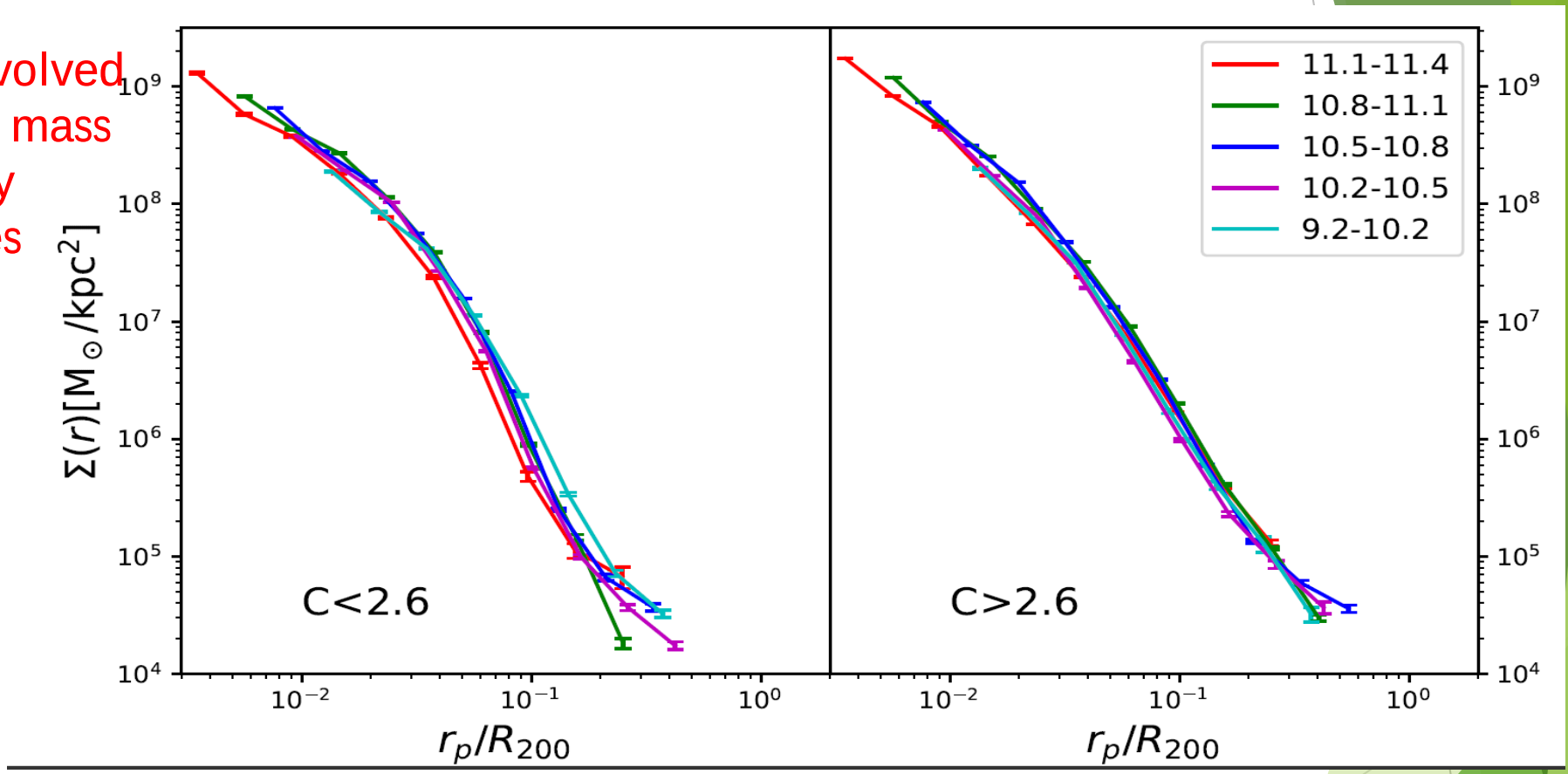



After PSF correction.

# Universality of the stellar halo

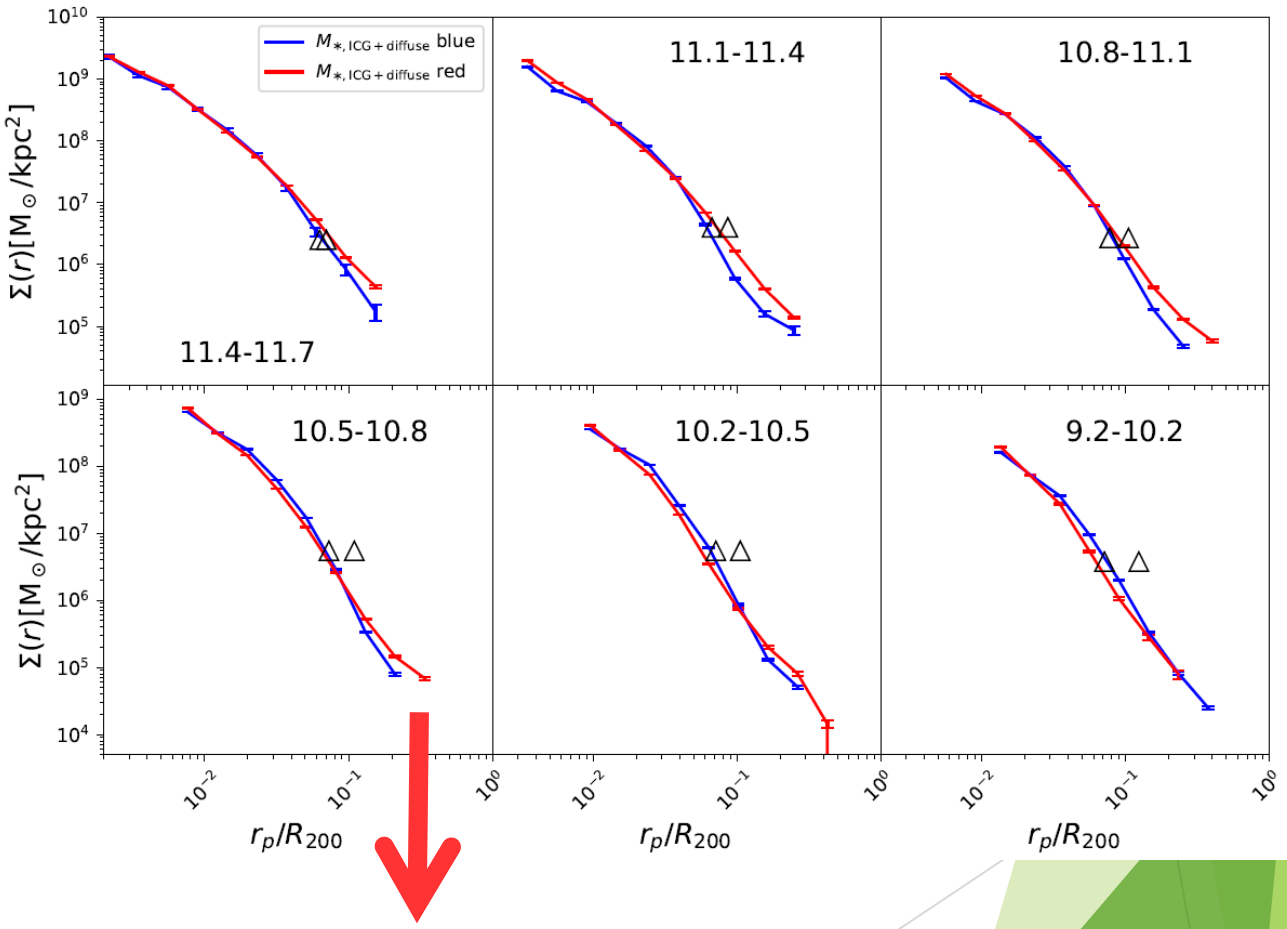
PSF-deconvolved stellar mass density profiles




Profiles are close to universal after r_p is scaled by R_200.

# Low and high concentration

- PSF-deconvolved stellar mass density profiles




Wang et al., 2021
In preparation

HighC/red galaxies have more extended outer stellar halos.

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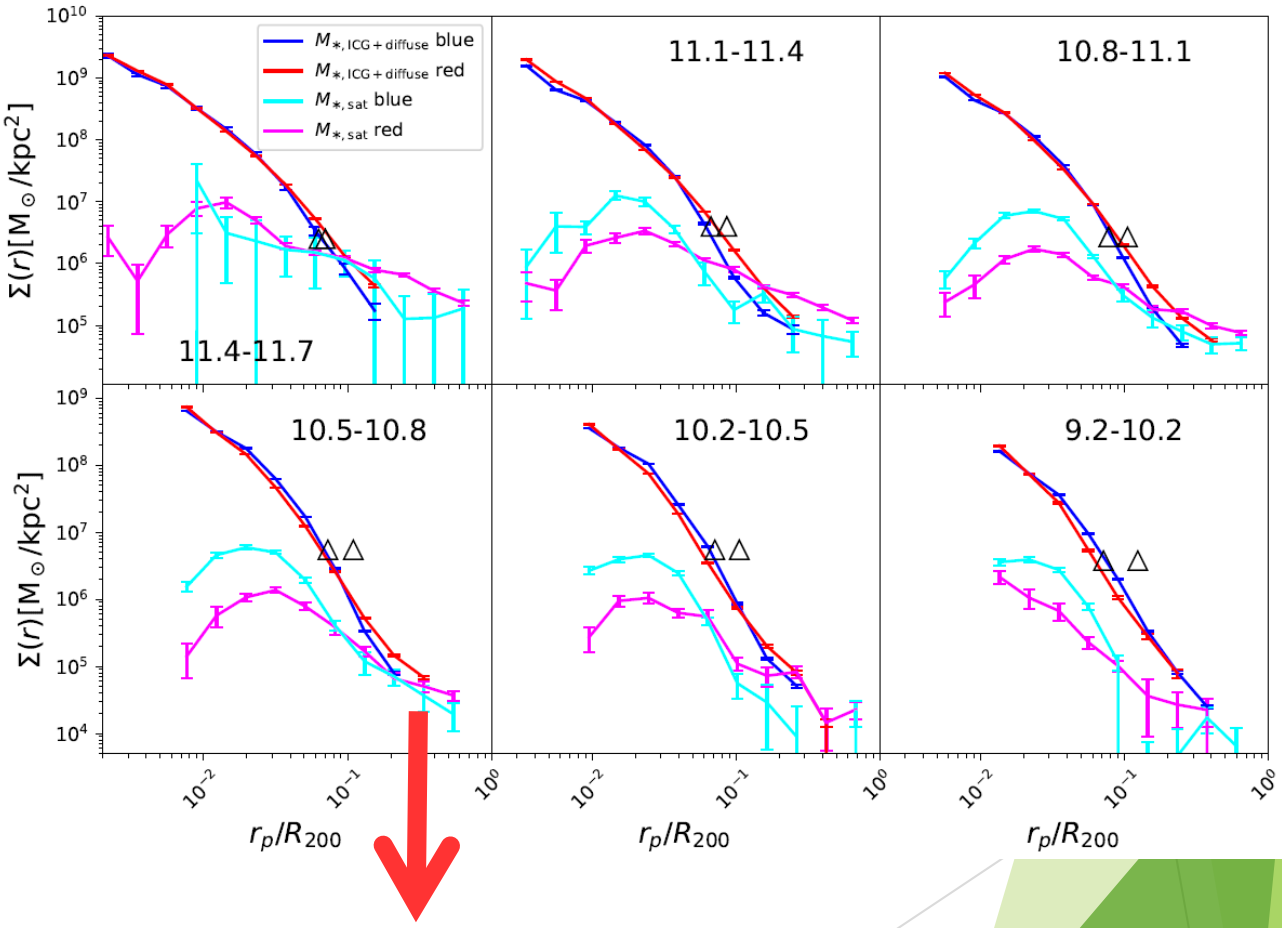
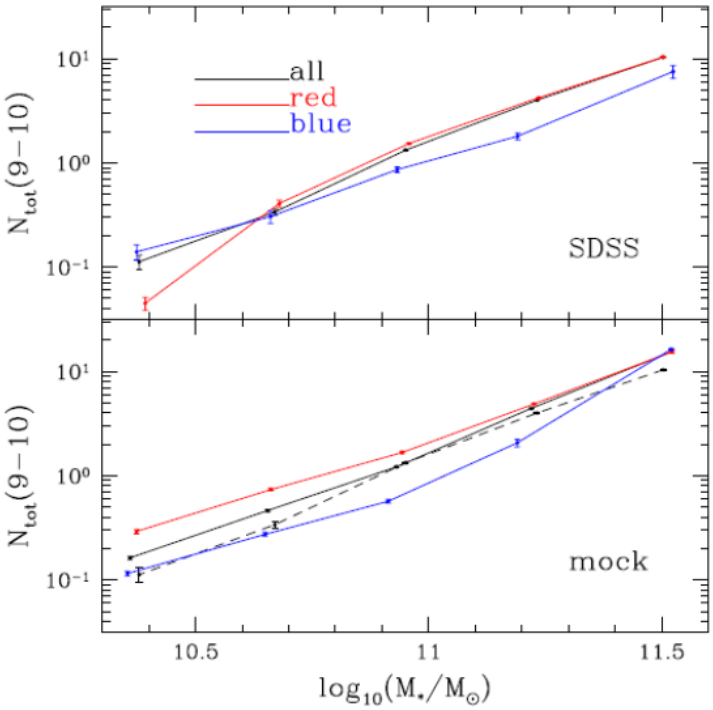
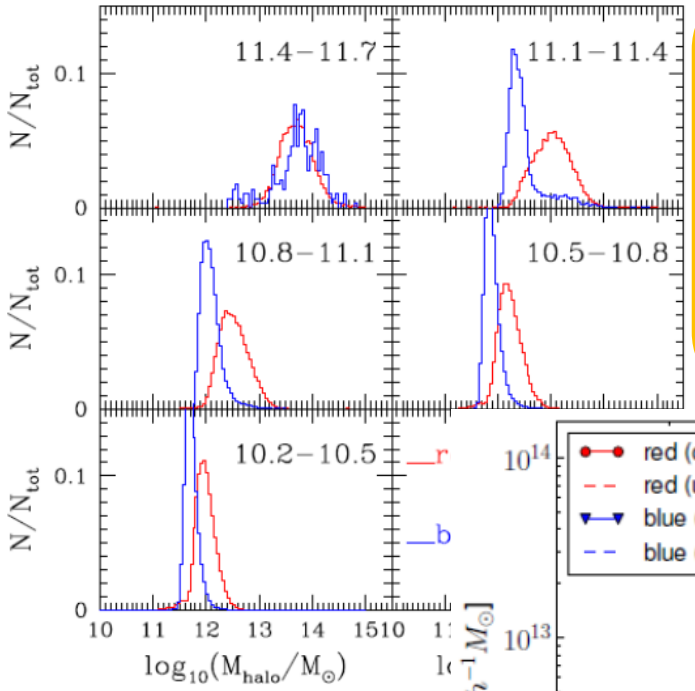



Wang et al., 2021
In preparation

HighC/red galaxies have more satellites.

# Satellite abundance as proxies to host halo mass...

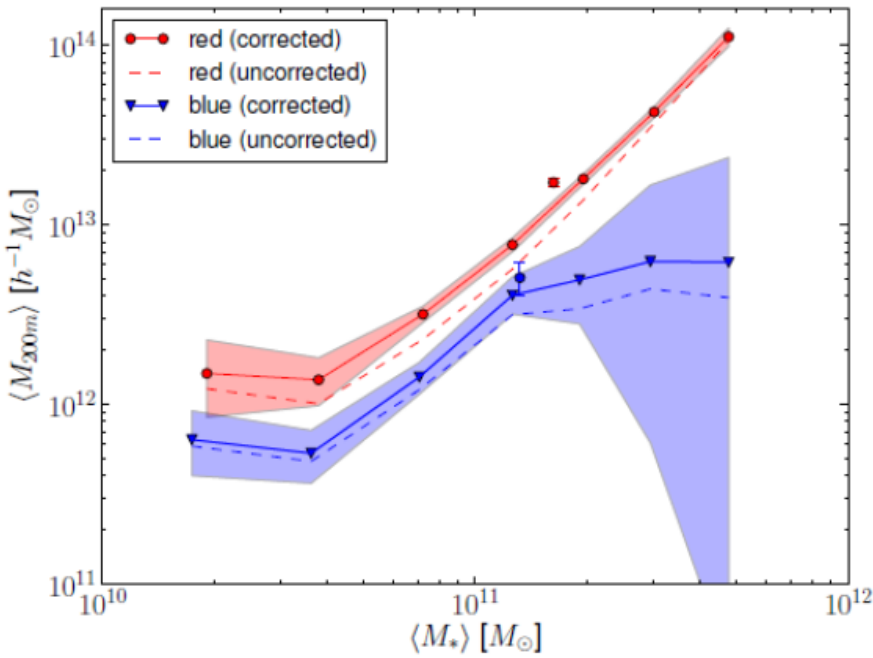



Please see also e.g.
Peng et al. 2012
Man et al. 2019

Wang &White, 2012 , Wang, et al., 2014

Red centrals are hosted by more massive dark matter halos.




Mandelbaum, Wang, et al., 2016

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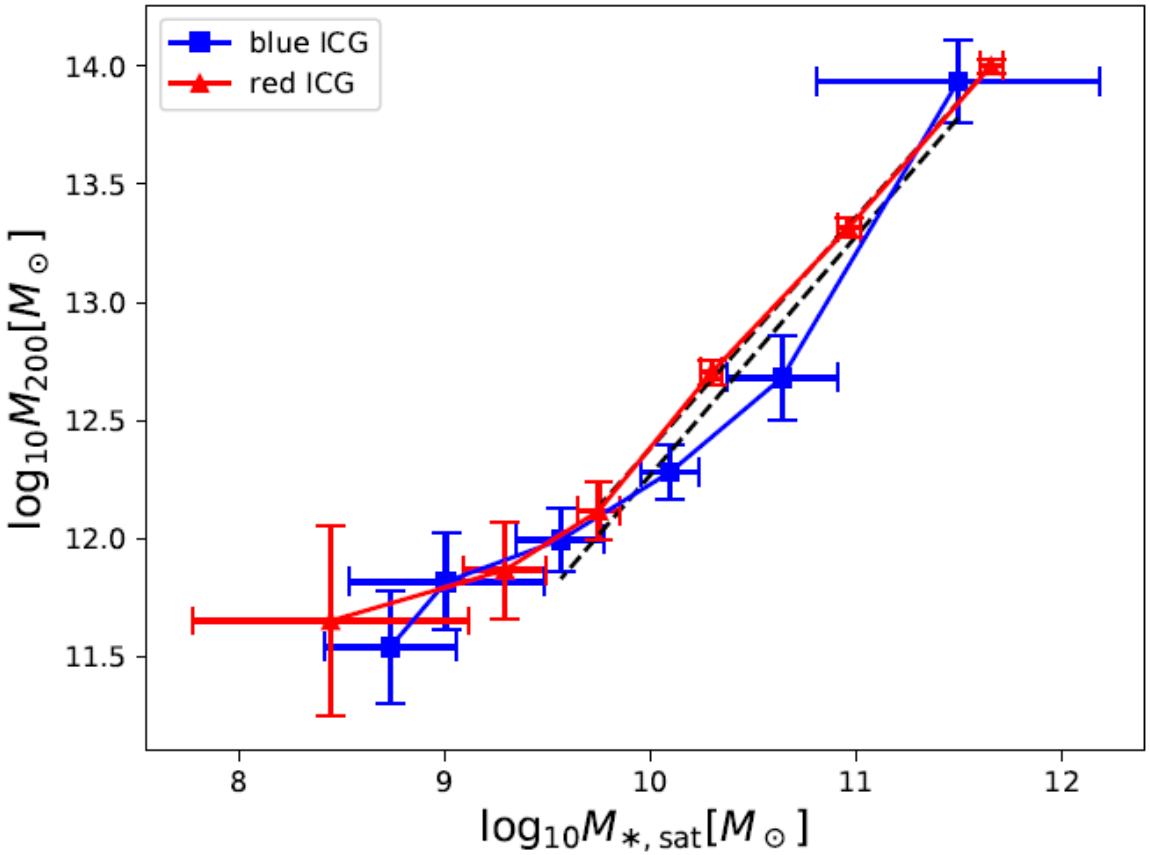
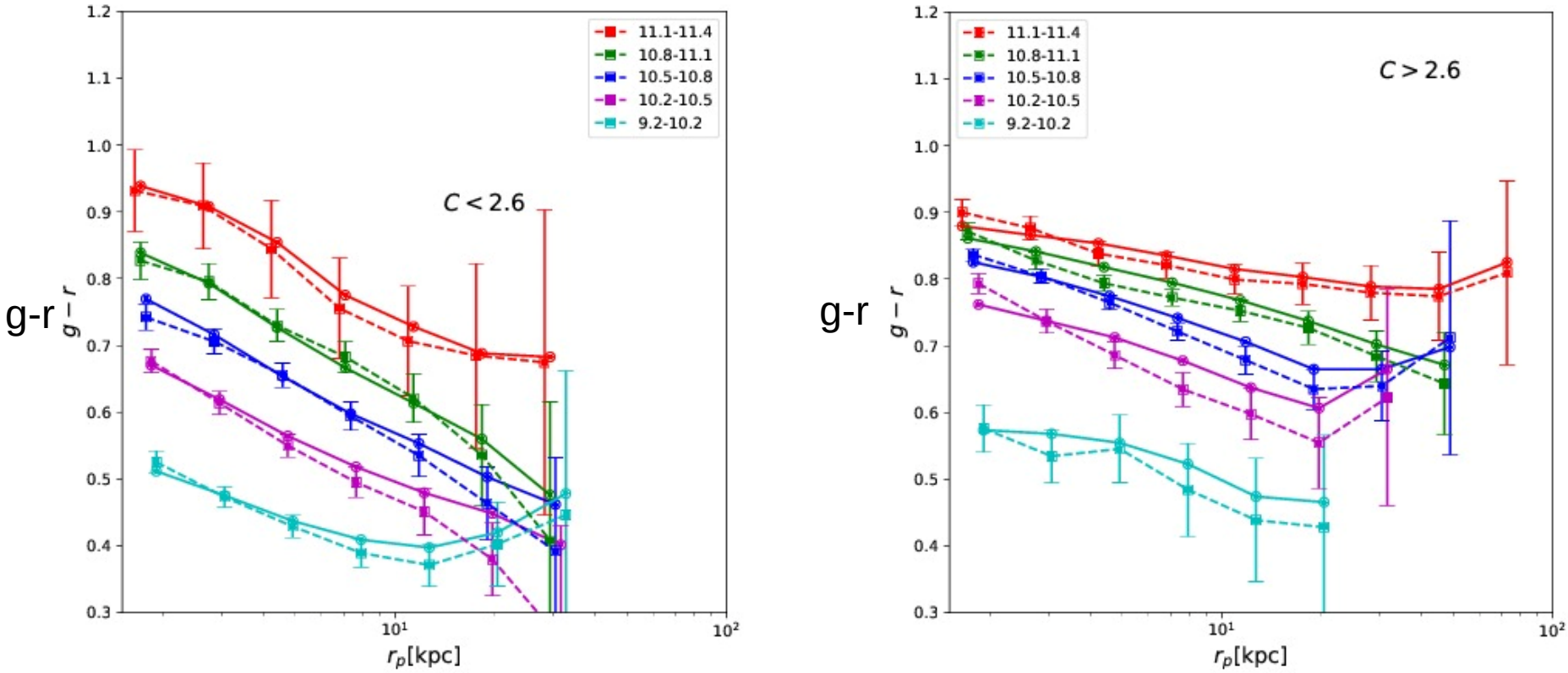



Wang et al., 2021
In preparation

The stellar mass in satellites is proportional to the best-fitting host halo mass from weak lensing.

# Color profiles

Low and high concentration galaxies with 0.05<z<1



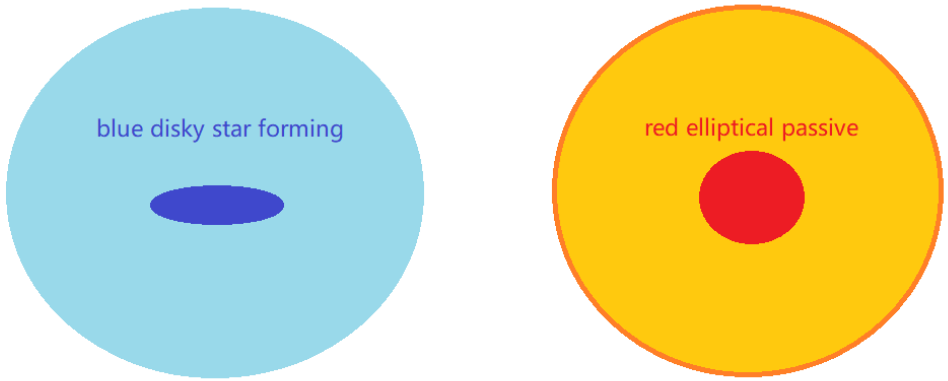

Dashed: PSF-free color profiles

Wang et al. 2019

The extended PSF wings slightly flattens the color profiles.

# Galactic conformity

- Related to galactic conformity: satellites around red passive galaxies are redder (e.g. Weinmann et al. 2006)



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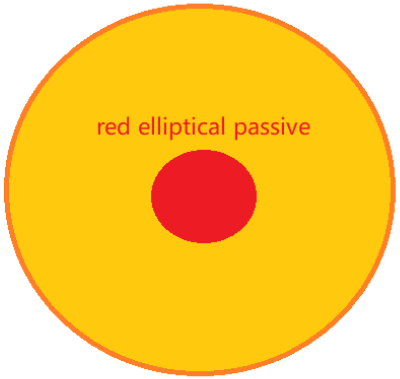
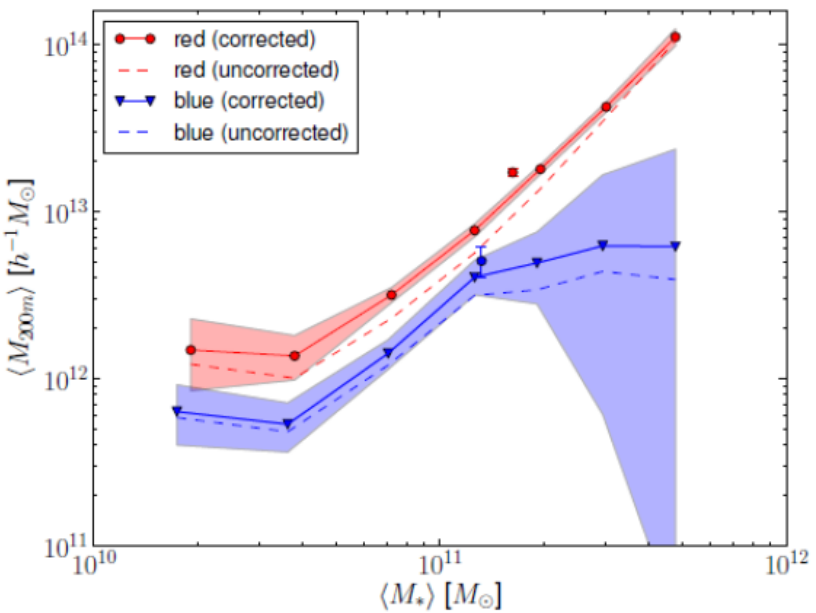



➢ The difference in halo mass partly explains the 1-halo conformity signals.




Mandelbaum, Wang, et al., 2016

# Red versus blue galaxies

- High concentration (mostly red) galaxies have redder and more flattened color profiles.

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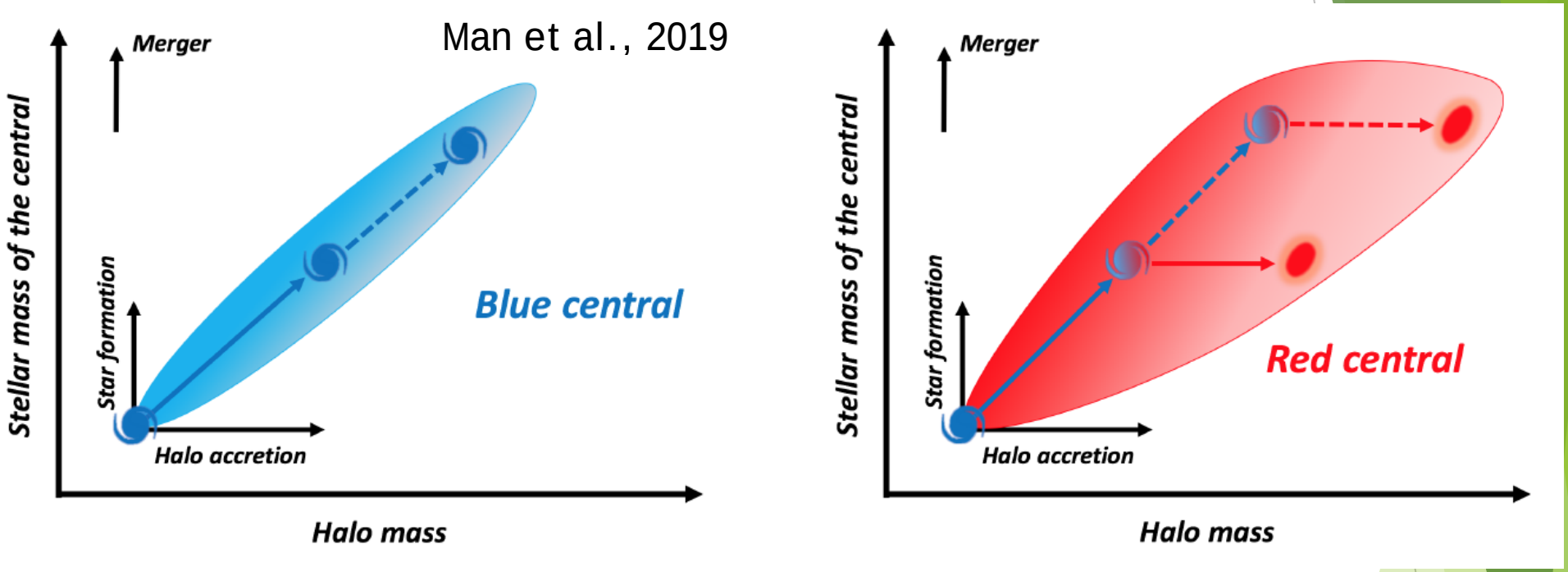
# Red versus blue galaxies

Man et al., 2019

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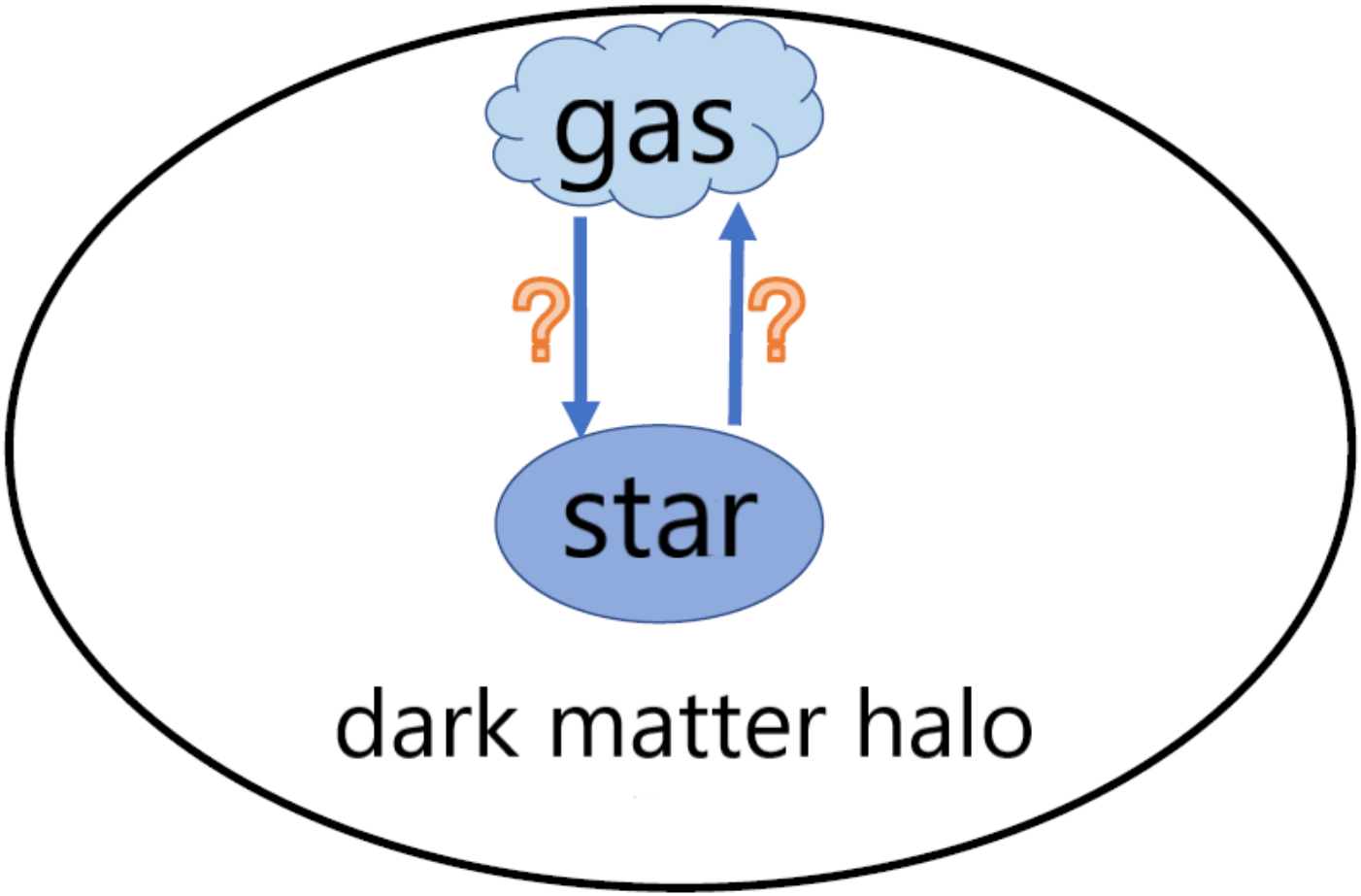
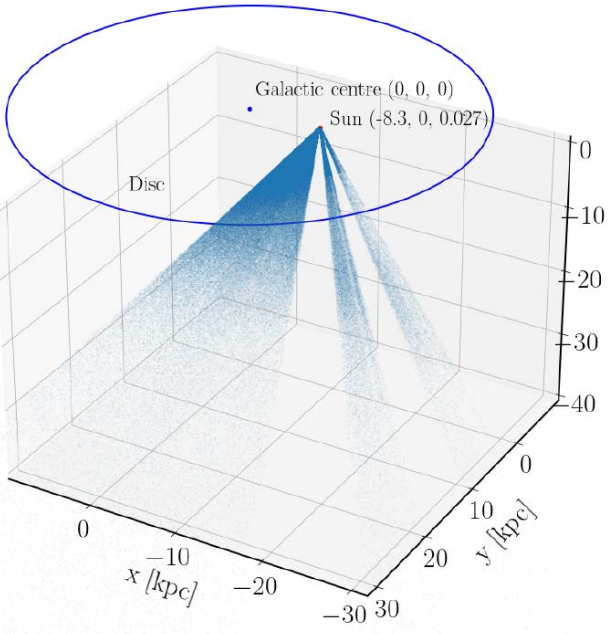
Is there any difference between morphology and color?

# Quench of red galaxies

AGN feedback: does it work?



# Proper motion measurements based on HSC and SDSS Stripe 82




邱天
Kavli-IPMU

Source of systematics:

- Galaxy contamination
- Difference in ref frame
- DCR
- Uncertainty in D_photo
- Contamination by WD/giants

Qiu, Wang, Takada, et al., 2021

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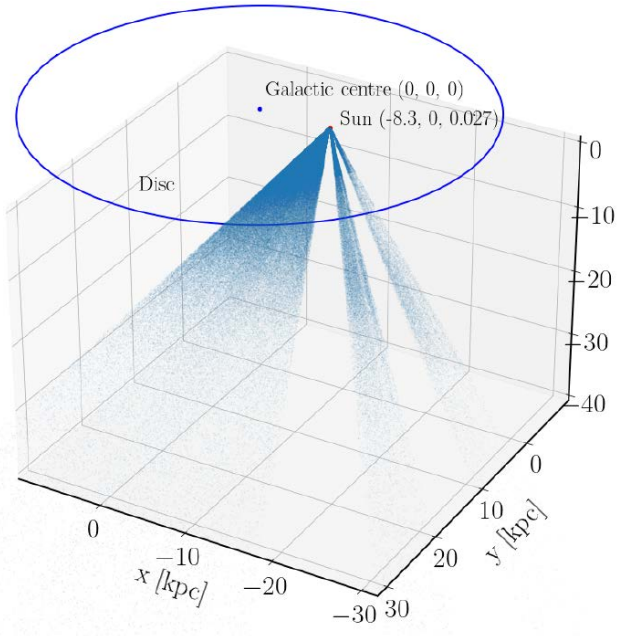


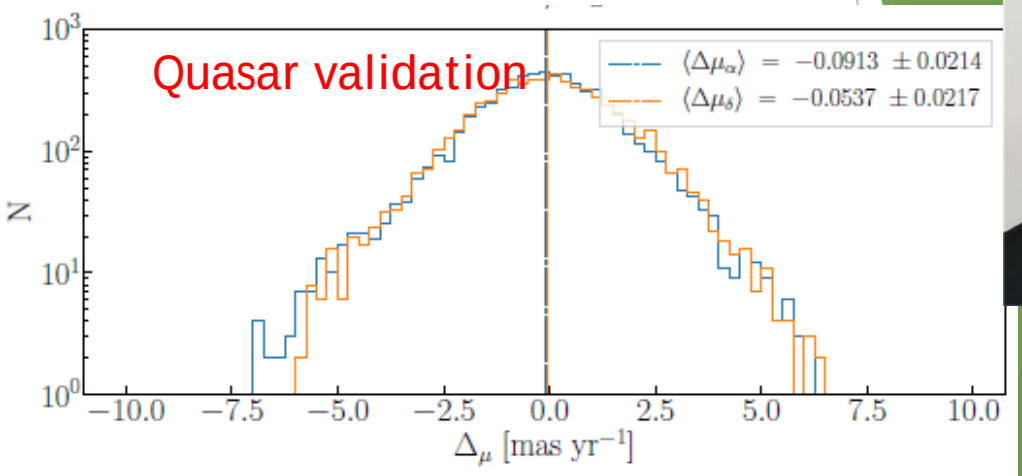


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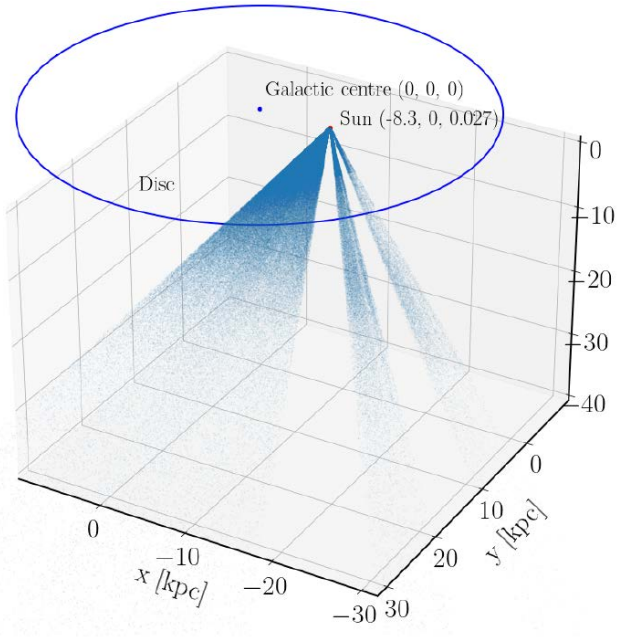


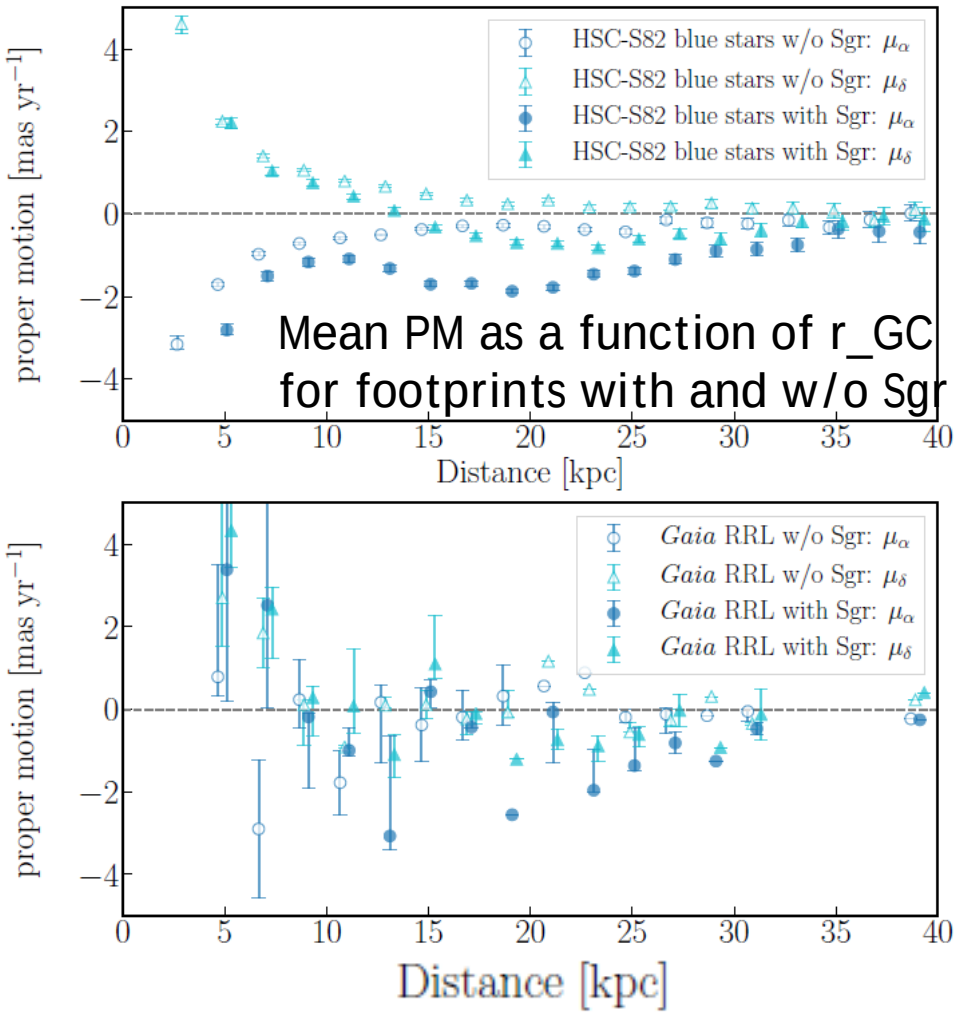



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Qiu, Wang, Takada, et al., 2021

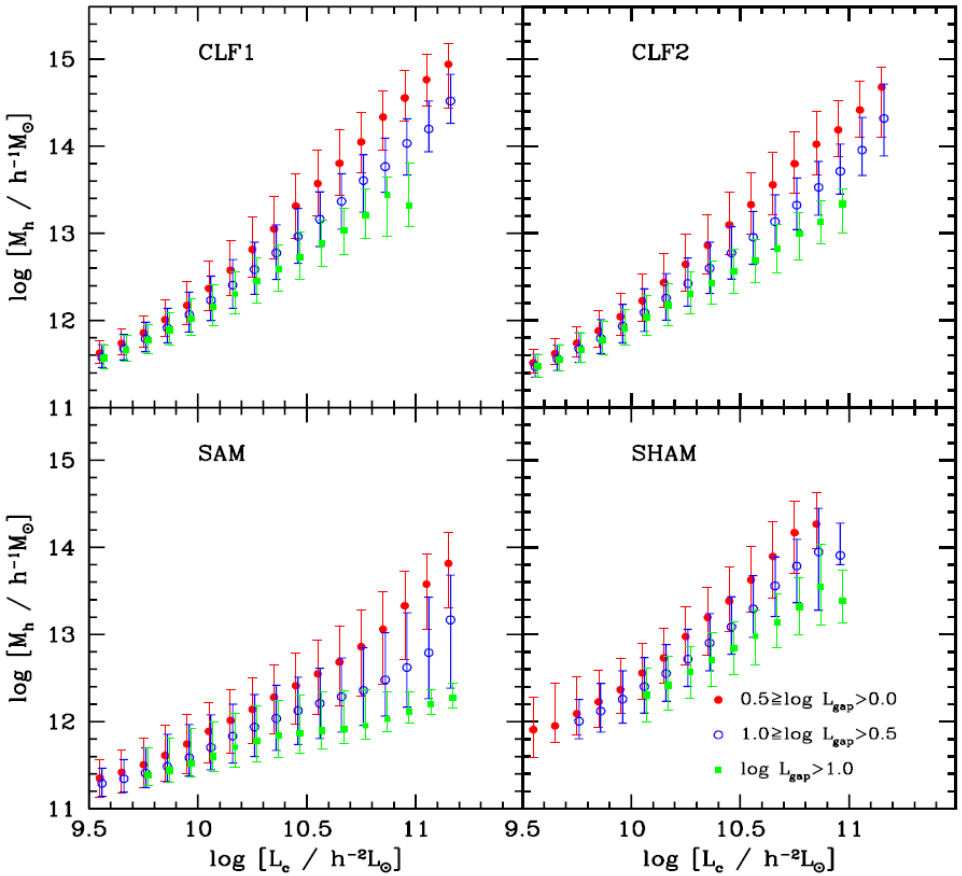
# Summary

- Our measurements cover a wide stellar mass range of isolated central galaxies (**9.2<logM*/Msun<11.4**).
- Stellar halos are **close to be universal after** the projected radius is scaled by the halo virial radius.
- **High concentration galaxies have more extended outer stellar halo profiles, and have shallower color profiles** – related to Galactic conformity.
- The **extended PSF wings** significantly contaminate the outer stellar halo for smaller and late-type galaxies.

# 谢谢！

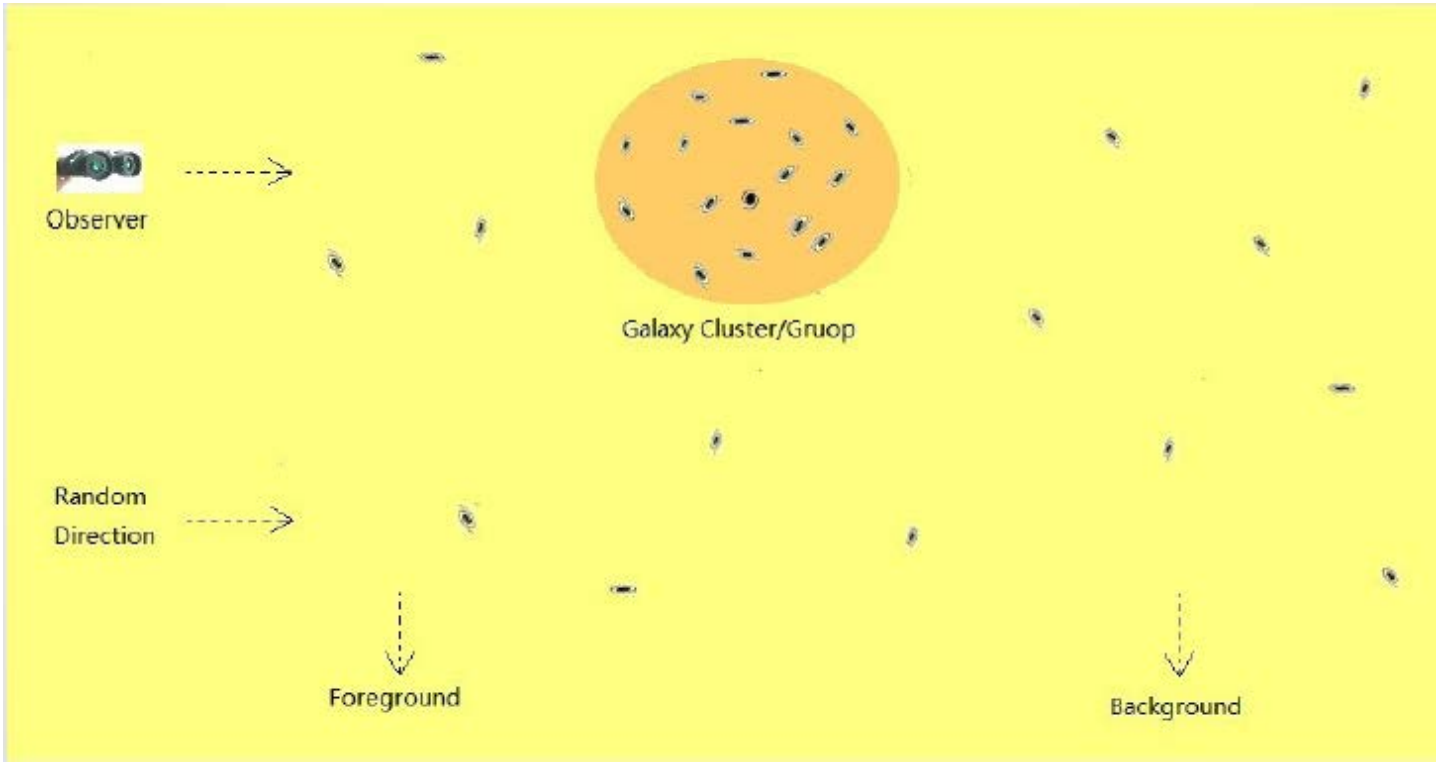
# Magnitude/luminosity gaps …

- ICG1s have more satellites than ICG2s…
- Magnitude gaps are connected to host halo mass?




Lu et al., 2015

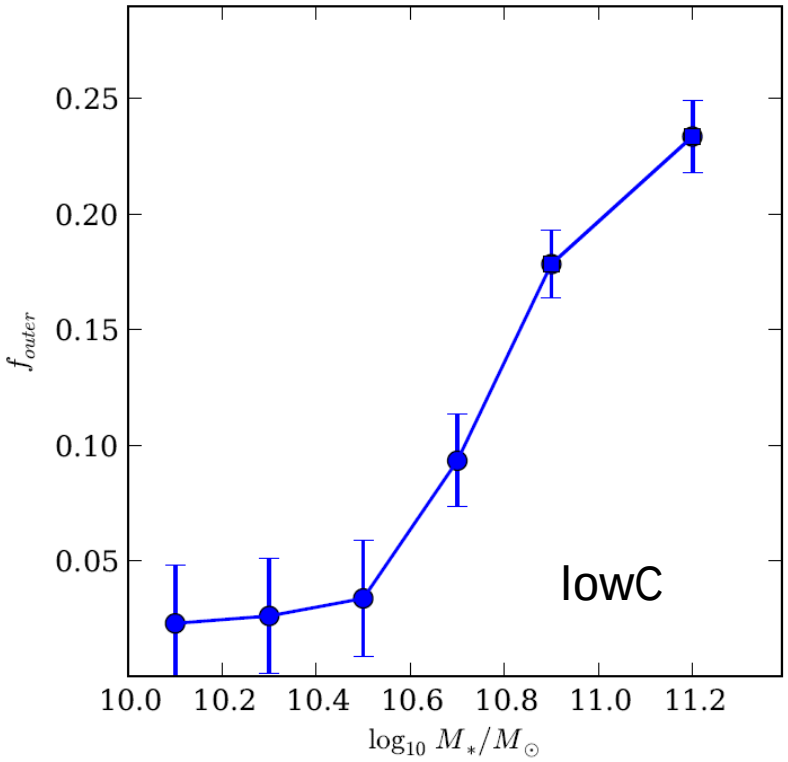
# Random stacks

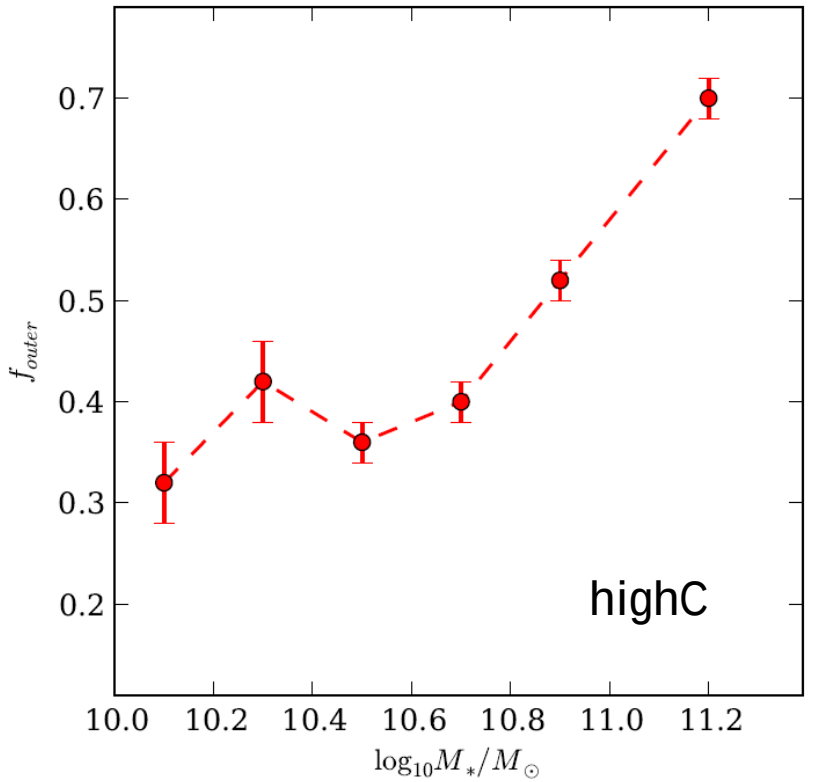



- Random stacks cannot account for incomplete masking of true satellite galaxies.

# Low and high concentration

- Red galaxies accrete more material from their satellites.



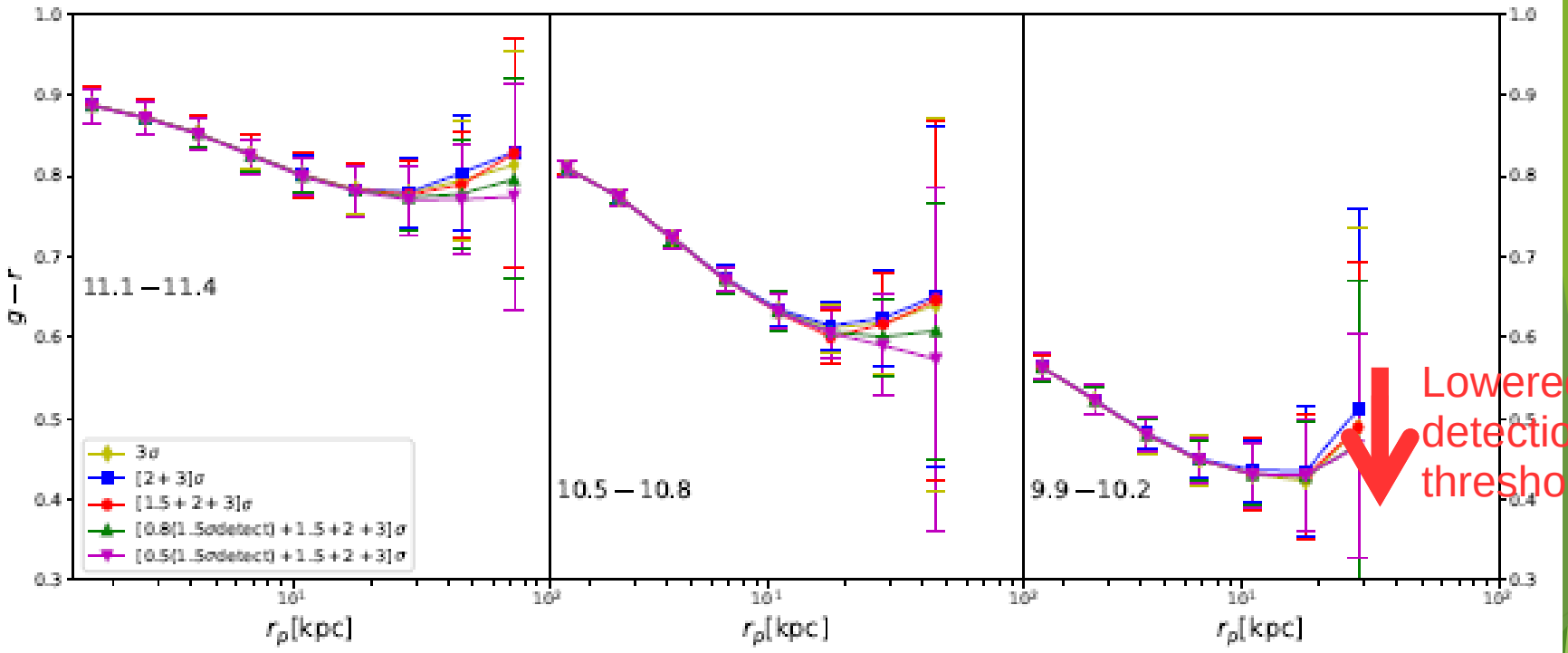




D'Souza et al. 2014

# Systematics in color profiles

Galaxies with 0.05<z<1 - to minimize K-corrections

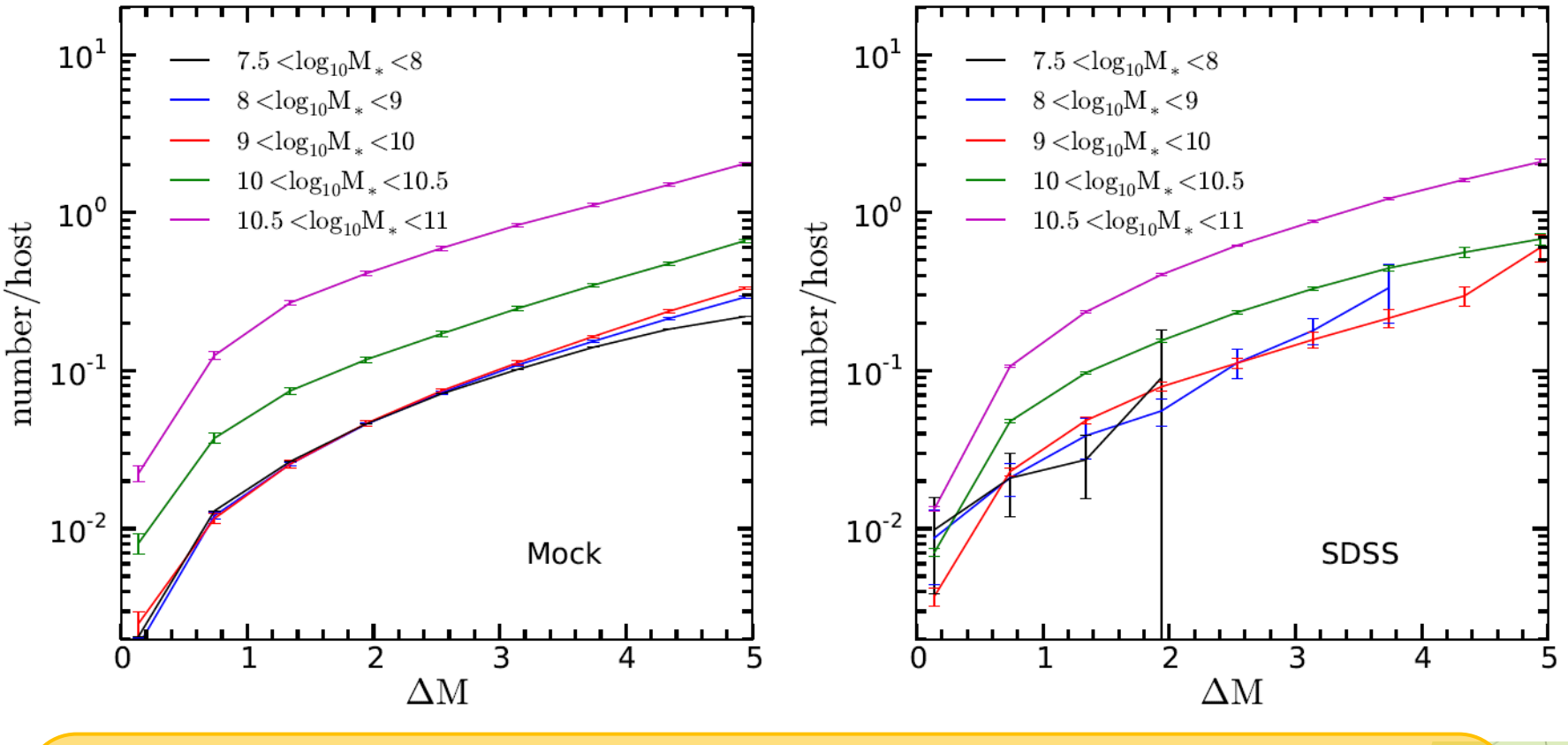
g-r




- Positive color gradients are sensitive to how satellite galaxies are masked!

# Satellite abundance as proxies to host halo mass...

Sales, Wang, et al., 2016




For galaxies smaller than 10^10Msun, a significant change in stellar mass causes almost no change in satellite abundance.