

# The formation of the ultra-compact dwarf galaxies (UCDs)



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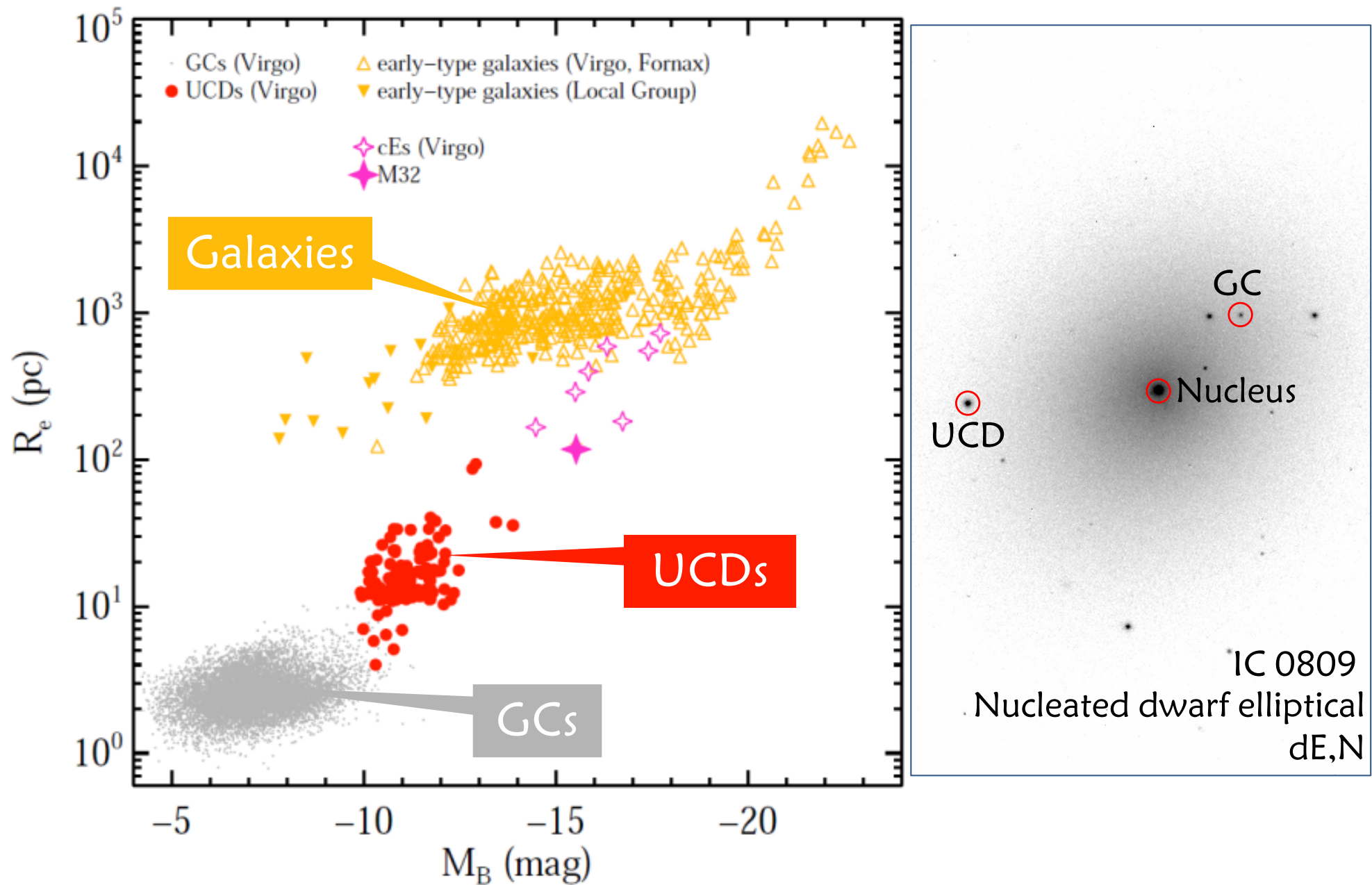
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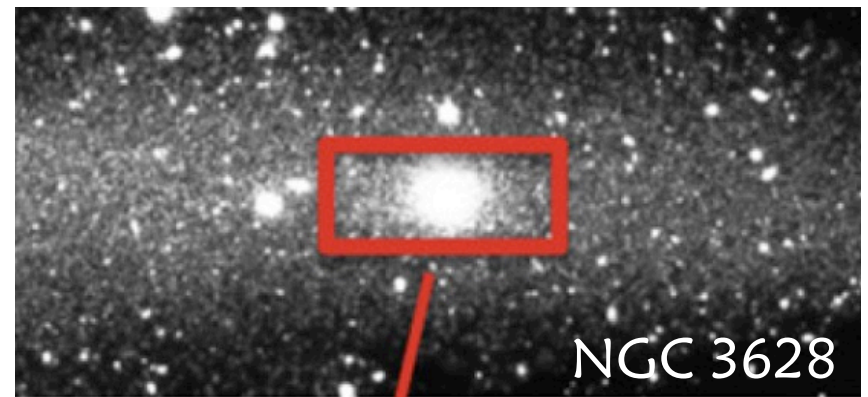
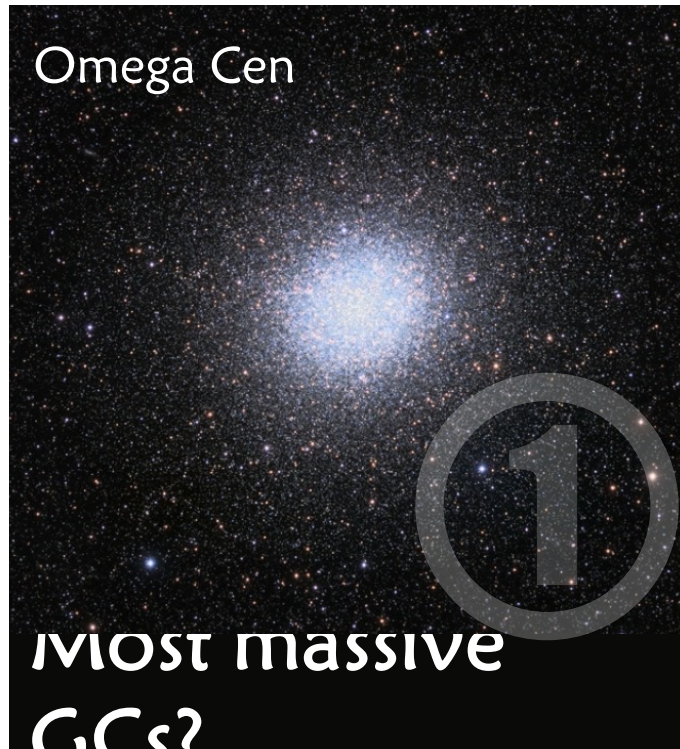
@The 2nd Shanghai Assembly



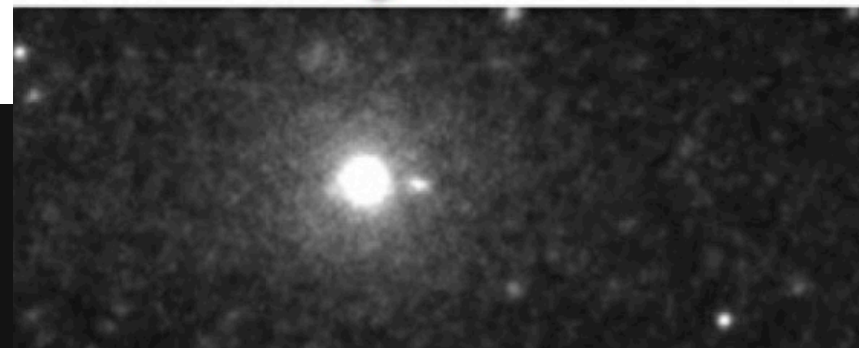
# Bridge the GCs and galaxies



# The origin of UCDs

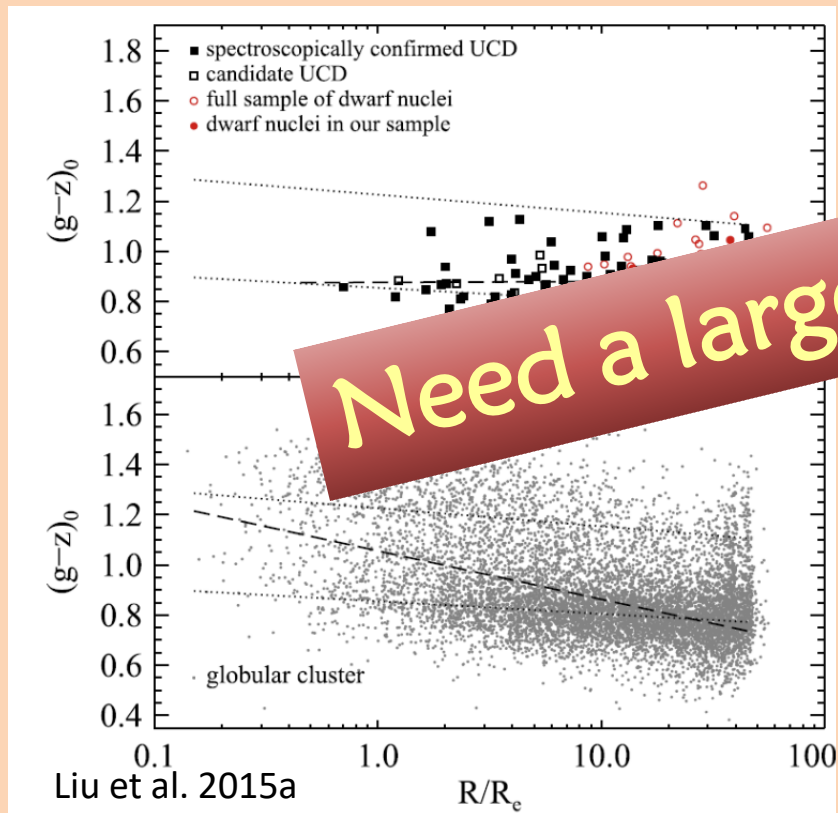


**2** Remnant nuclei of dwarf galaxies?

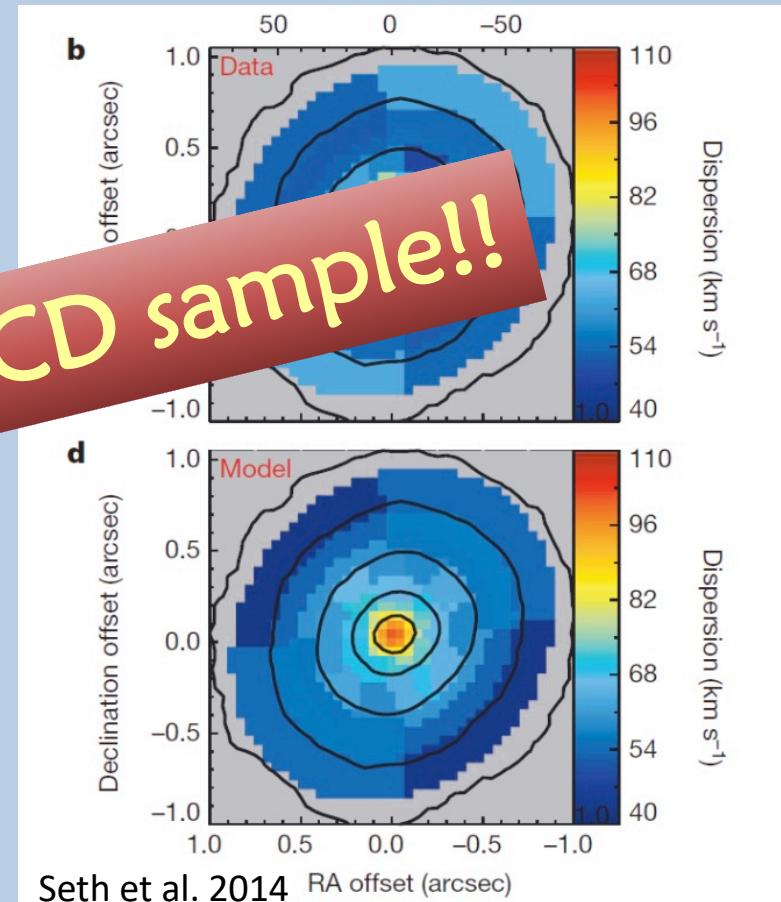


# Constraints on UCD origin

How their properties compare to those of GCs and dwarf nuclei



Individual UCD with special properties



Need a large UCD sample!!



# UCD samples

Reference	UCDs	Location
Drinkwater+ 2003	5	Fornax cluster
Mieske+ 2004	100	Abell 1689
Hacsegan+ 2005	13	Virgo cluster
Johns+ 2006	9	Virgo cluster
Evstigneeva+ 2007	5	Dorado group
Mieske+ 2007	1	Centaurus cluster
Mieske+ 2007	21	NGC1023 group
Elizabeth+ 2007	29	Hydra cluster
Blakeslee+ 2008	15	ABELL S0740
Chilingarian+2008	1	Virgo cluster
Gregg+2009	60	Fornax cluster
Hau+2009	1	M104
Mieske+ 2009	3	Centaurus cluster
Madrid+2010	25	Coma cluster
Chiboucas+2011	27	Coma cluster

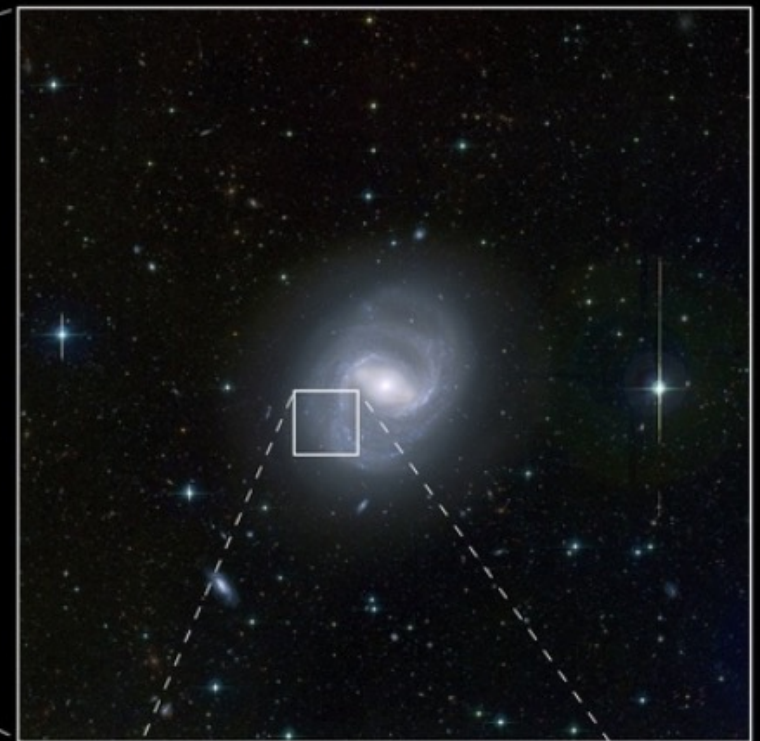
Reference	UCDs	Location
Misgeld+2011	52	HydraI cluster
Madrid+2011	11	NGC1132 group
Norris+2011	1	NGC4546
Penny+2012	84	Perseus cluster
Caso+2013	11	Antlia cluster
Jennings+2014	6	NGC 3115
Liu+2015	127	Virgo cluster
Liu+2015	1	Virgo cluster
Jennings+2015	1	NGC 3628
Lee+2016	147 ± 26	Abell 2744
Ko+2017	55	Virgo cluster
Faifer+2017	1	NGC5044 group
Schweizer+2018	1	NGC7727
DeBortoli+2020	5	NGC3613 group
<b>Liu+2020</b>	<b>612</b>	<b>Virgo cluster</b>

Most of the UCDs were found in groups and clusters.

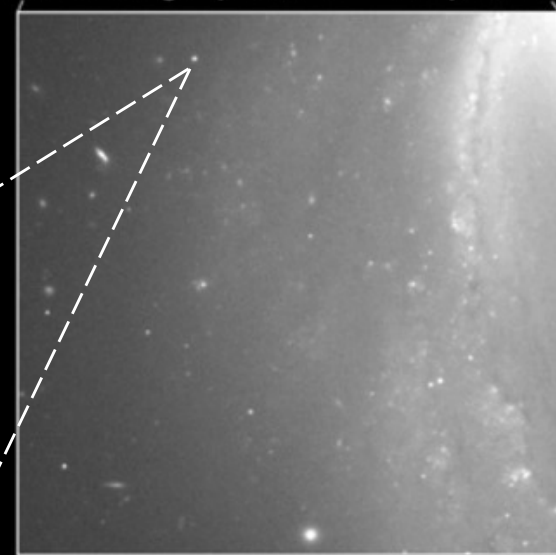
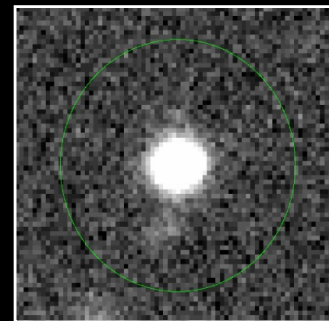
104 square degrees



Completed 104 sq. deg. mosaic in MegaCam g'i'z' bands  
Image quality: 0.8", 0.6", 0.7" (53/34/64 mn per pixel)  
Point source detection at SNR=5: g'=26.2 i'=24.9 z'=24.2



Messier 91 in u\*g'i' (NGVS u\* = 0.9"), 20'x20' field



i'-band, 0.55", 2'x2' field



# UCDs in the NGVS image

The NGVS is a sub-arcsecond survey  
thanks to Mauna Kea's superb seeing





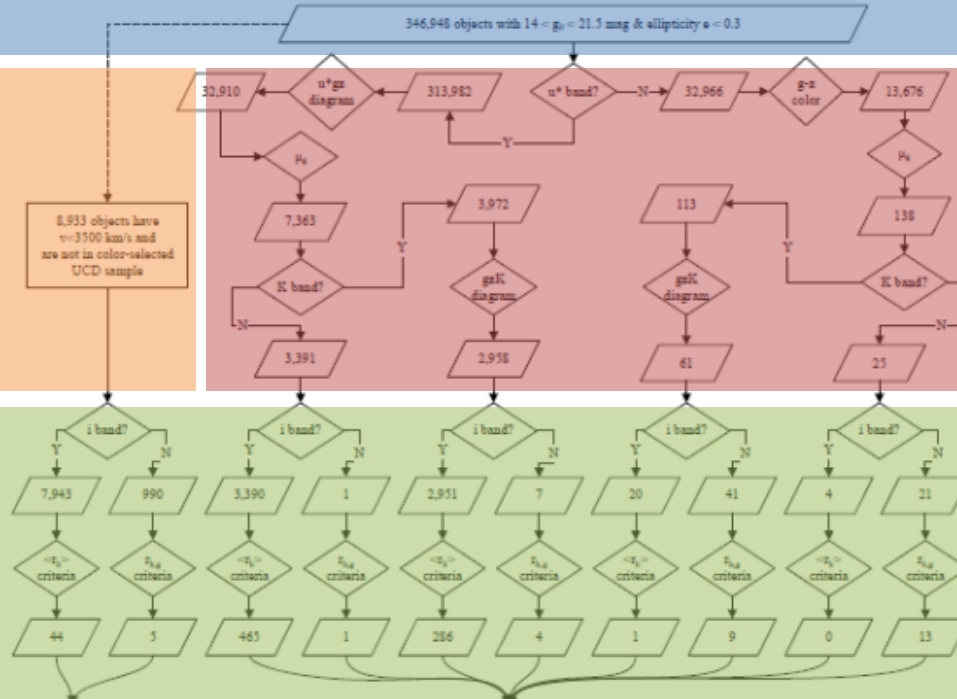
# Search for UCDs

Magnitude and ellipticity

Velocity

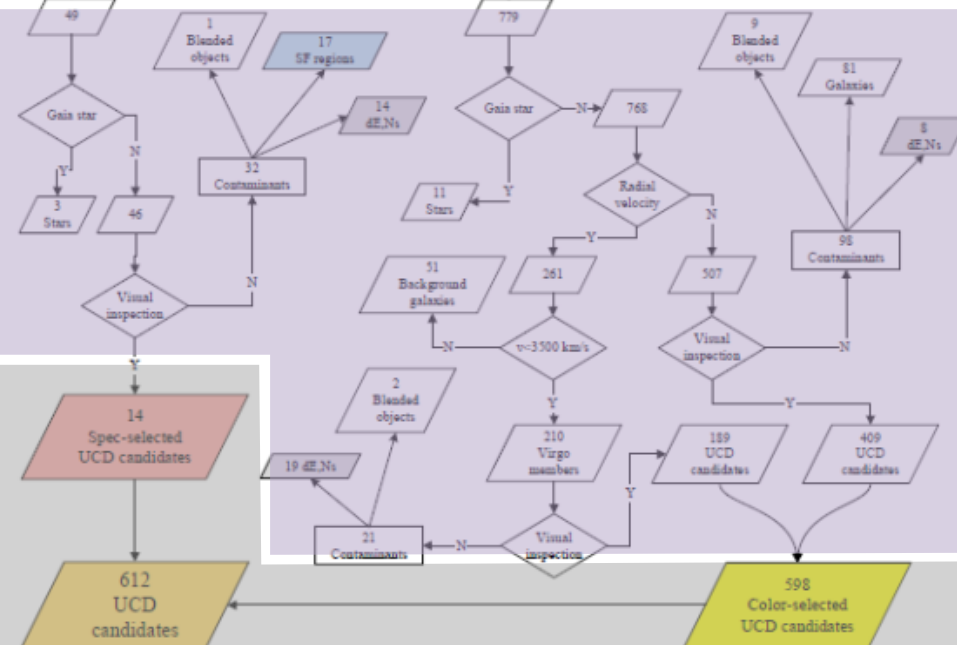
Color-color diagram and surface brightness

Objective

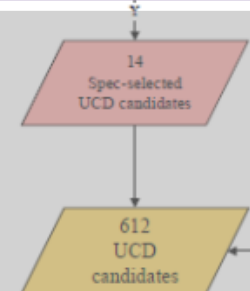


Half-light radius

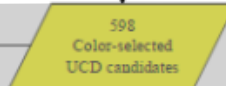
Subjective



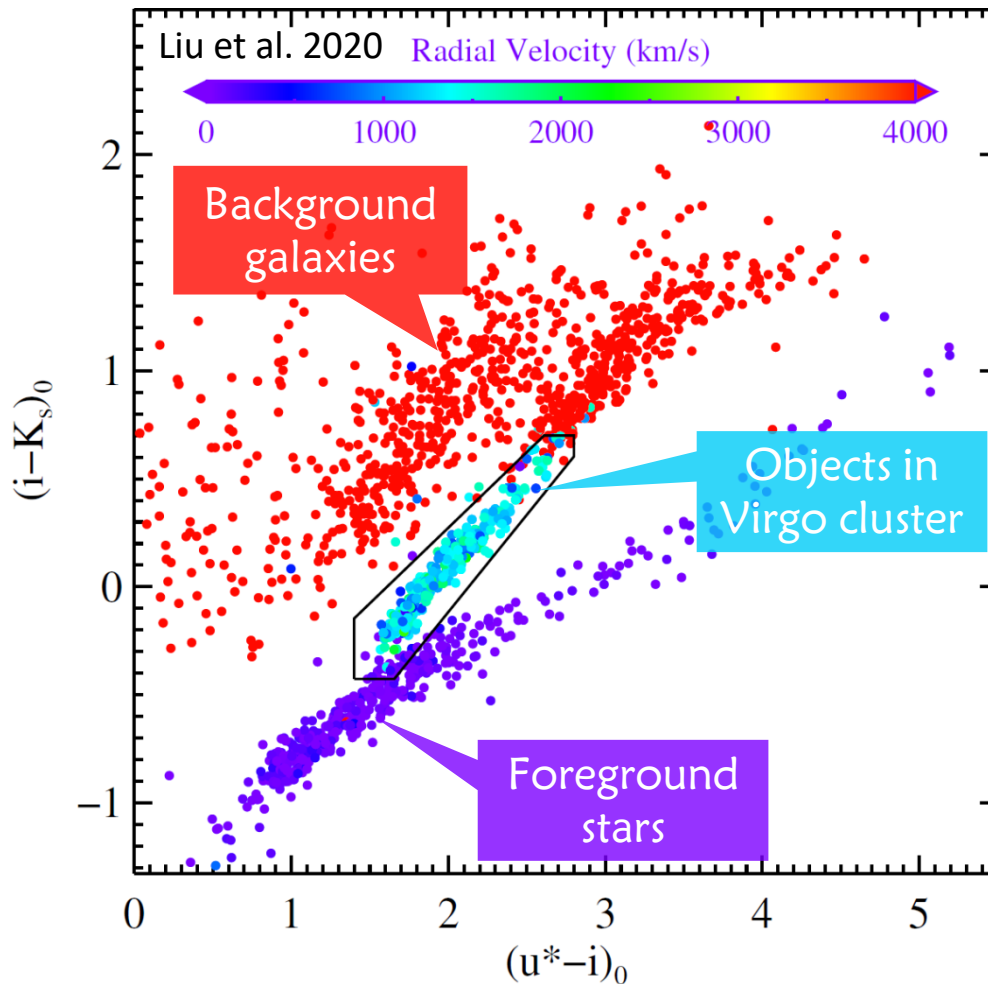
Visual inspection



Final sample



# Sample selection



- Galactic nucleus
  - Obvious stellar halo
- Globular cluster
  - $r_h < 11 pc$
- UCD
  - $11 < r_h < 100 pc$

We select nuclei, GCs and UCDs simultaneously.



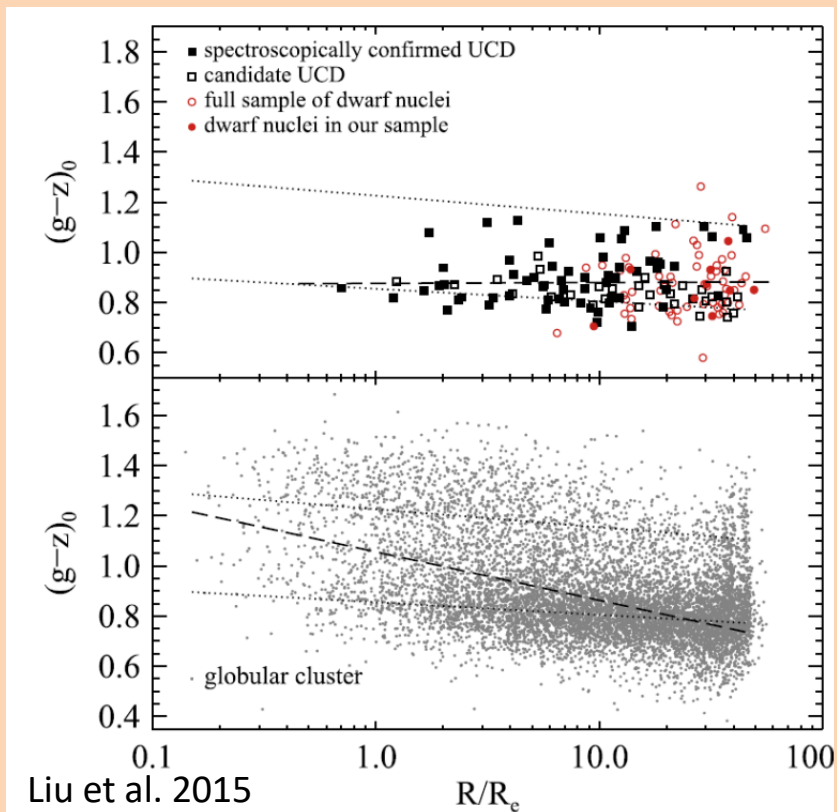
# Samples

- **UCD** sample ( $g < 21.5$  mag)
  - 612 UCD candidates
  - The largest UCD sample up to date
- **Bright Nuclei** sample ( $g < 21.5$  mag)
  - 339 bright nuclei (Ferrarese et al. 2020, Sanchez-Janssen et al. 2019)
- **Bright GC** sample ( $g < 21.5$  mag)
  - Thousands of bright GCs

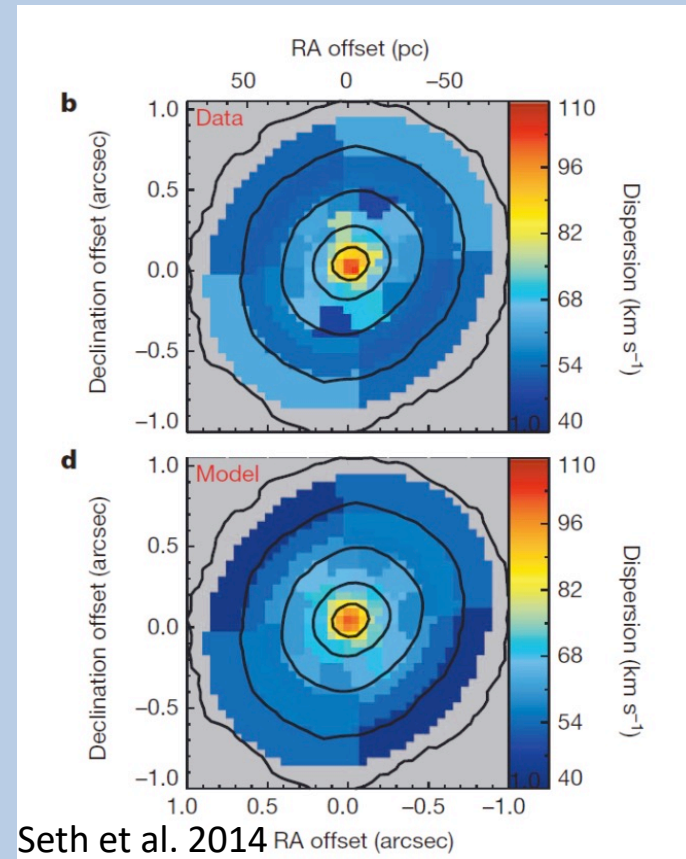
At the first time, we have homogeneous samples of UCDs, GCs and Nuclei that based on one data set!!!

# Constraints on UCD origin

Compare the properties of UCDs, GCs and dwarf nuclei

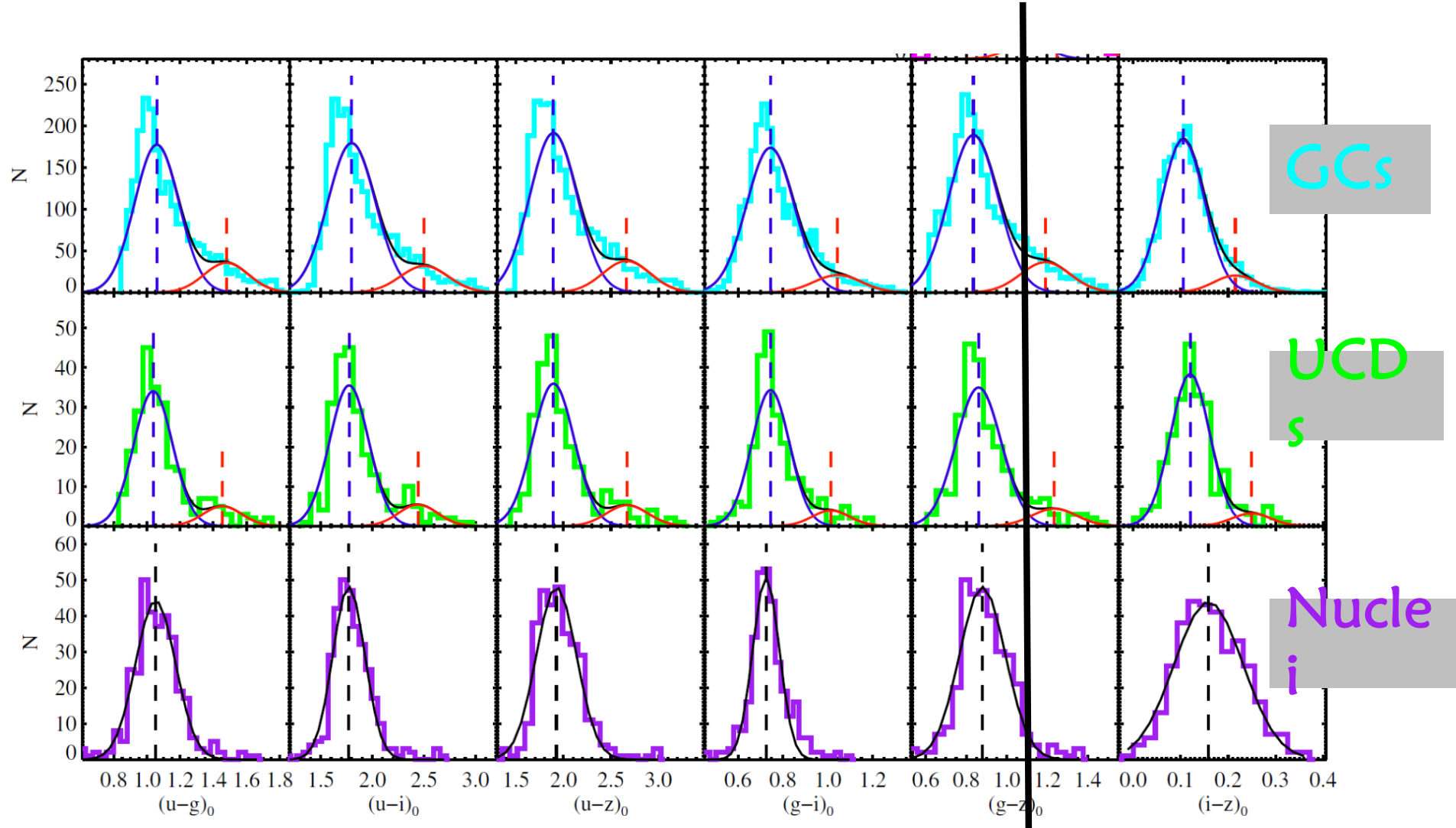


Individual UCD with special properties





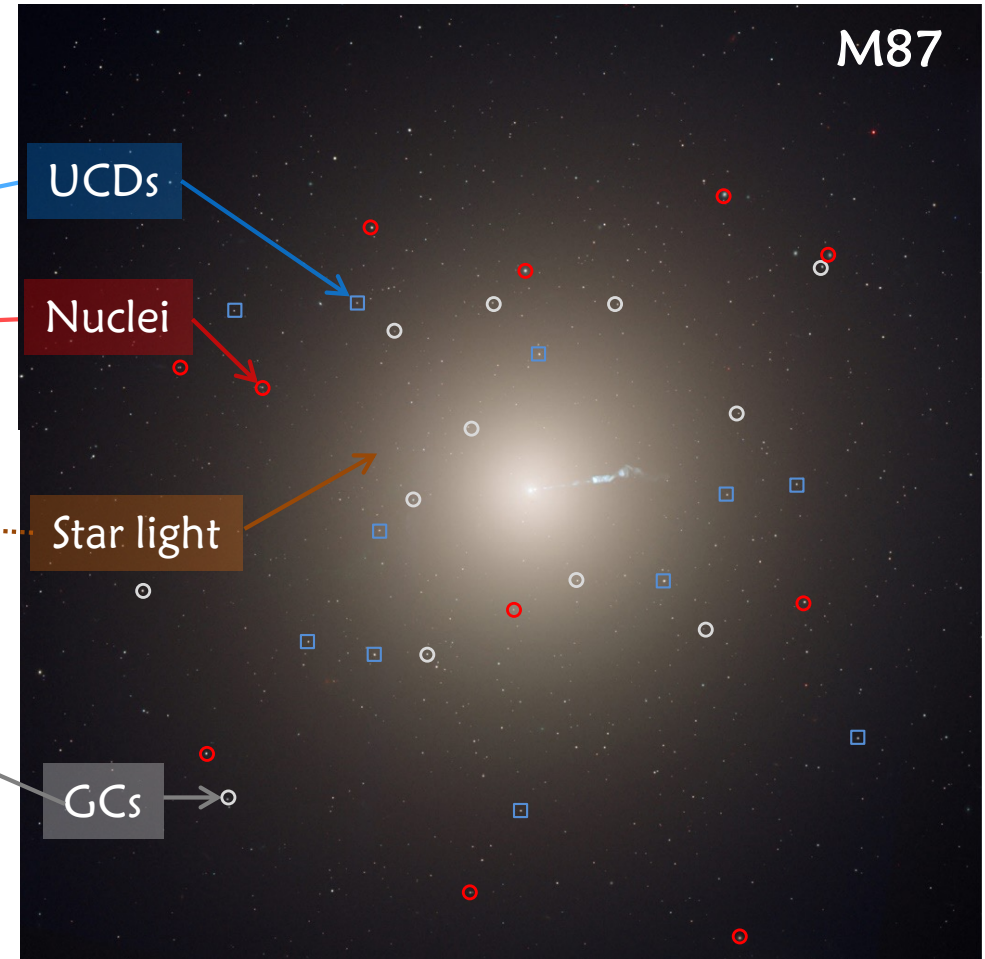
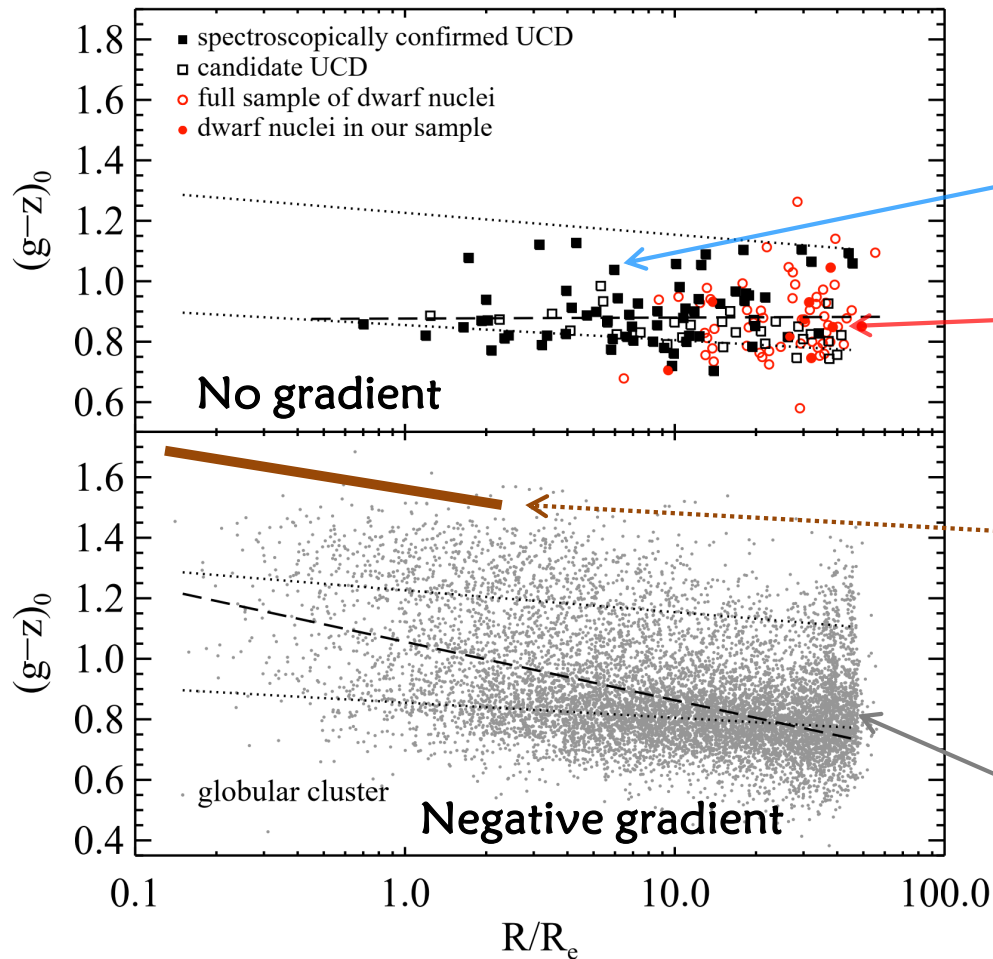
# Color distribution



Bimodal distribution

$f_{red}: GCs > UCDs > Nuclei$

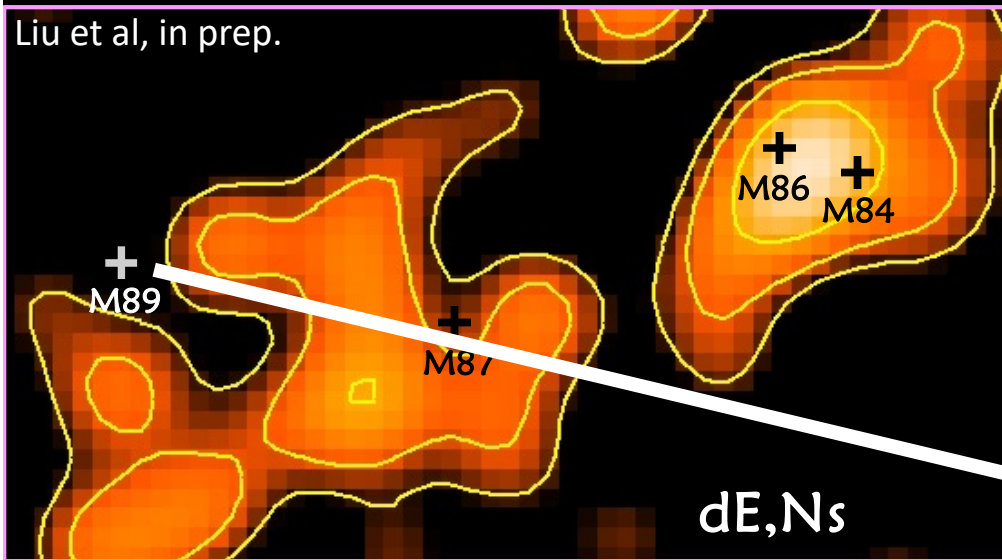
# Color gradients



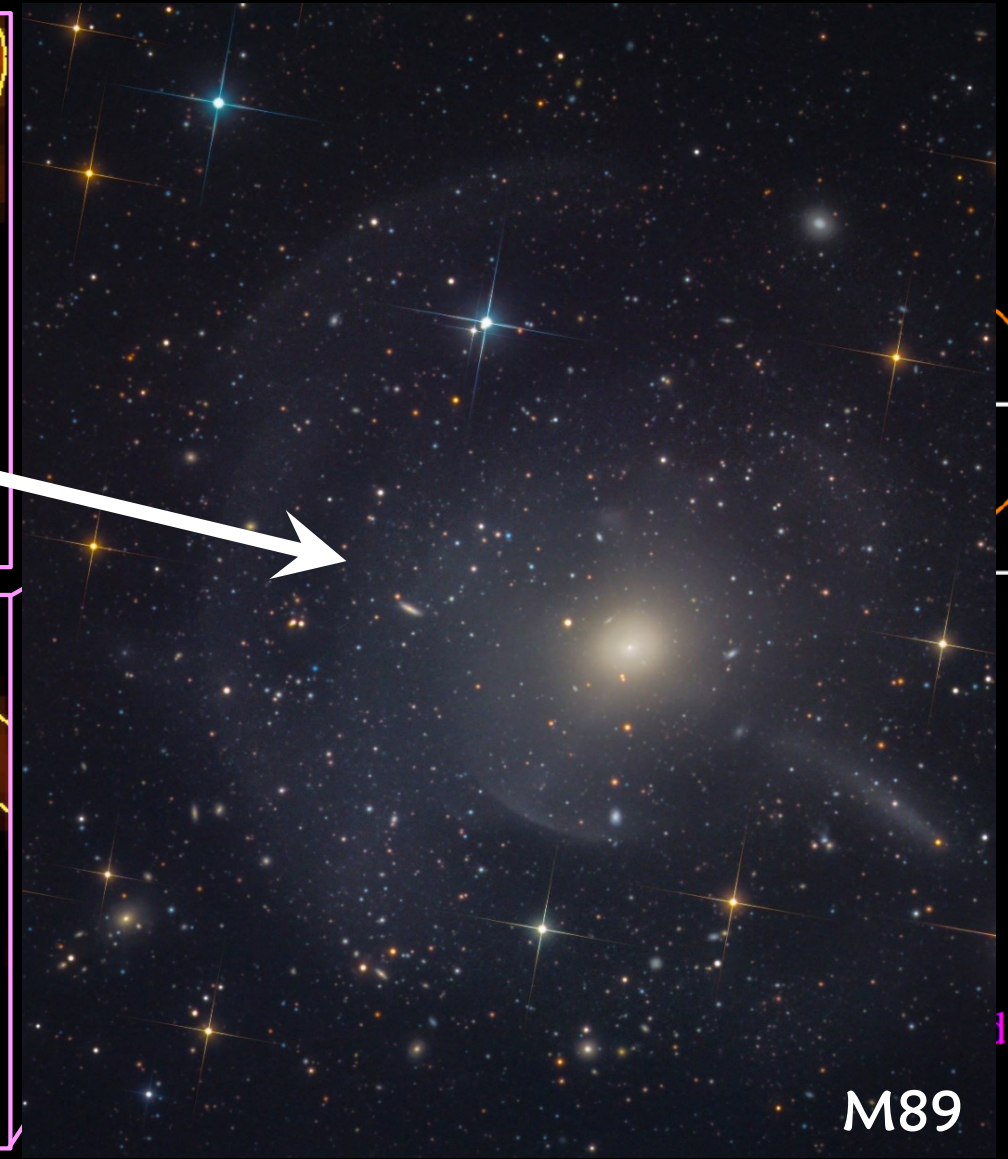
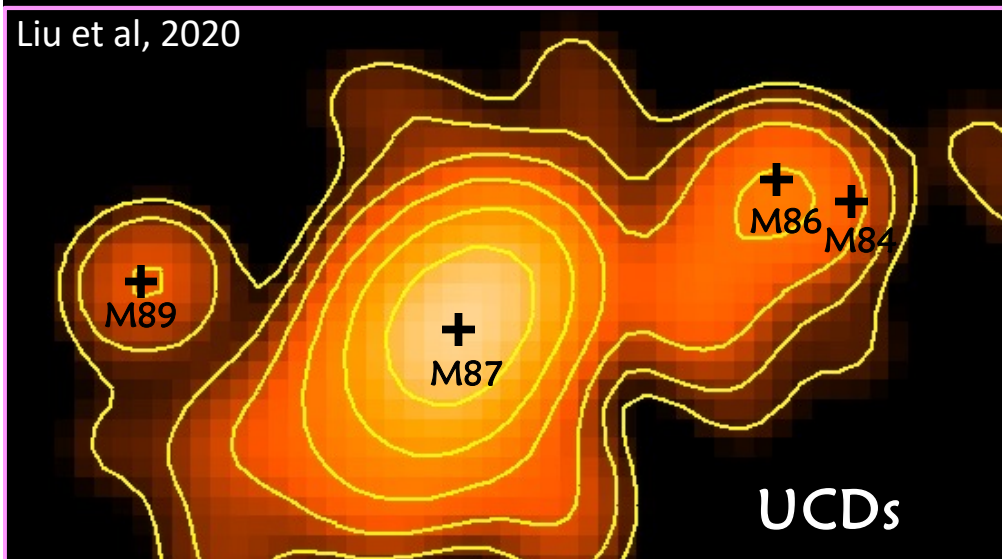
UCDs and Nuclei may have similar formation scenarios.

# Spatial distribution

Liu et al, in prep.



Liu et al, 2020



Many dE,Ns have evolved to UCDs in some regions.

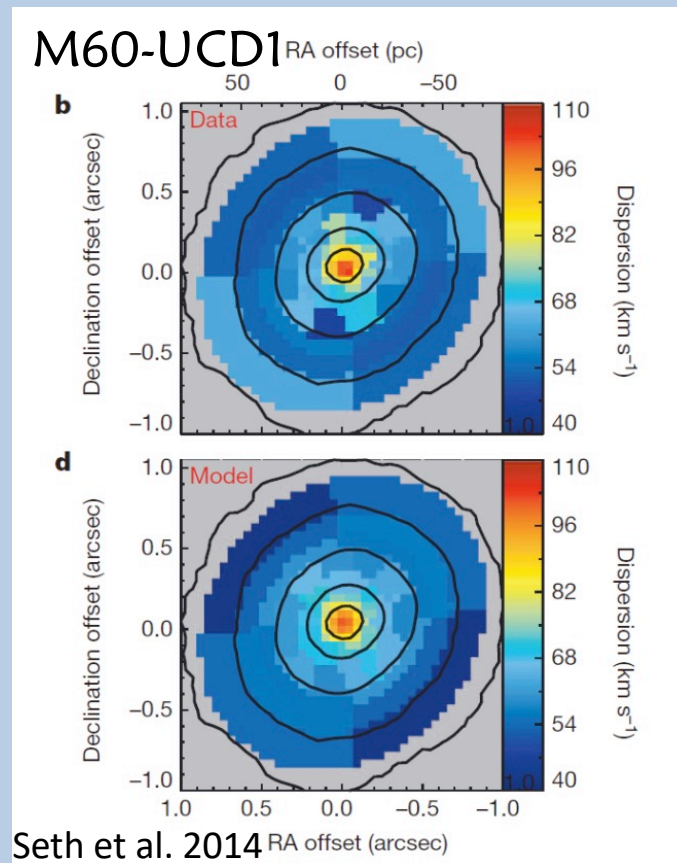


# Constraints on UCD origin

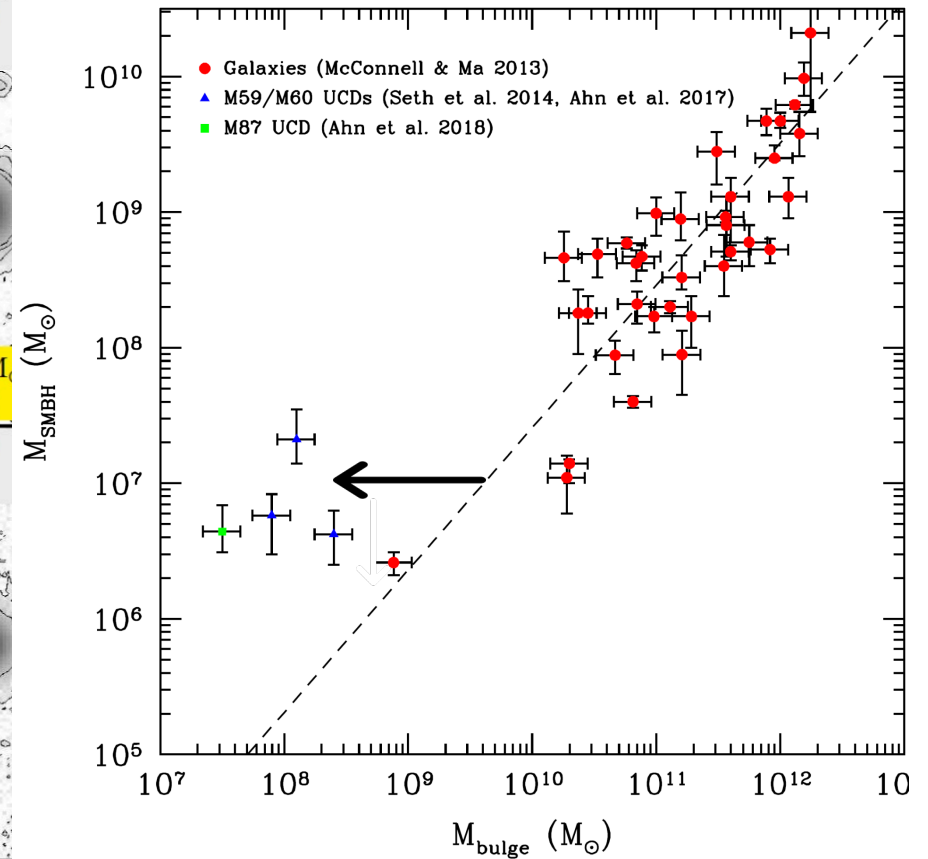
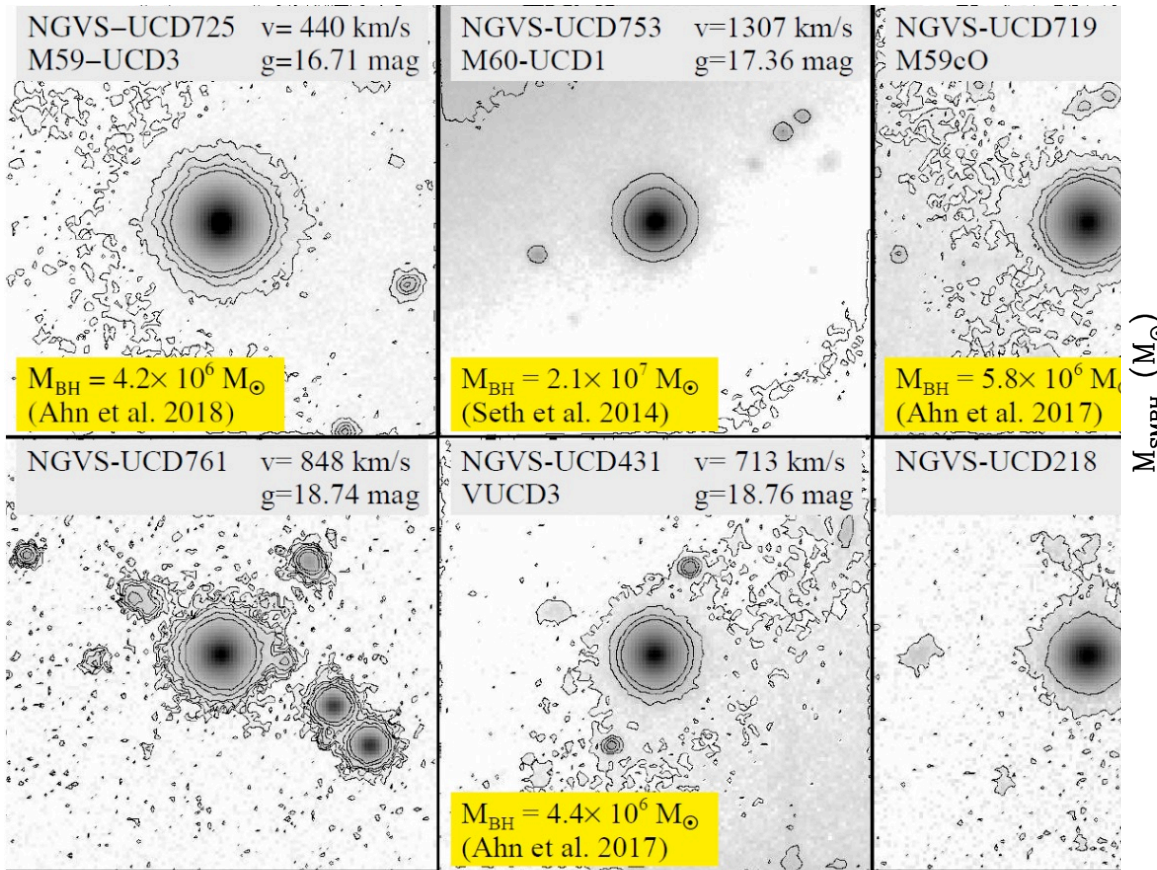
Compare with GCs  
and dwarf nuclei

- Color distribution  
**No significant difference  
among GCs, Nuclei and  
UCDs**
- Color gradient
- Spatial distribution  
**Tight connection  
between UCD and dE,N**

Individual UCD with  
special properties



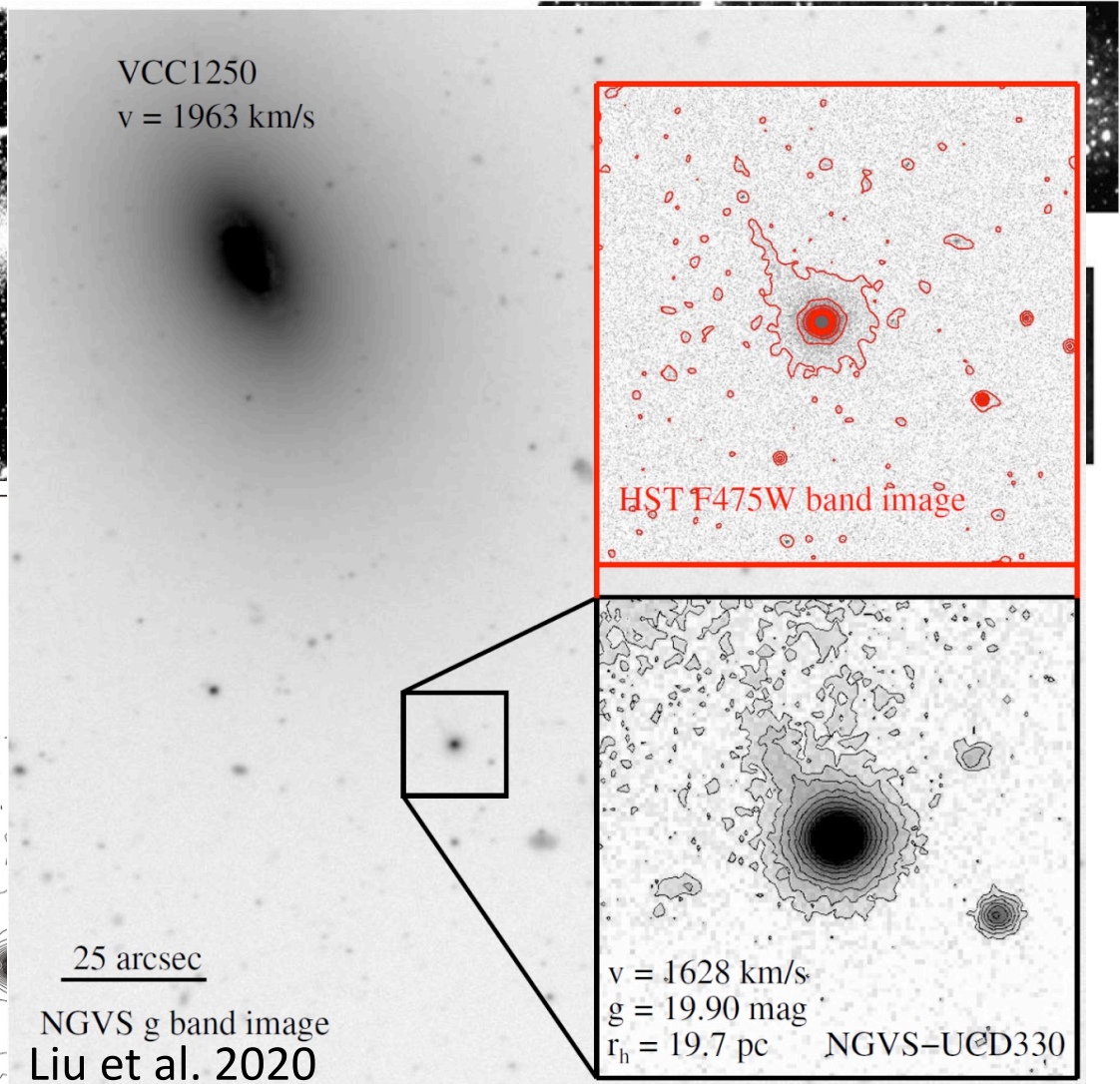
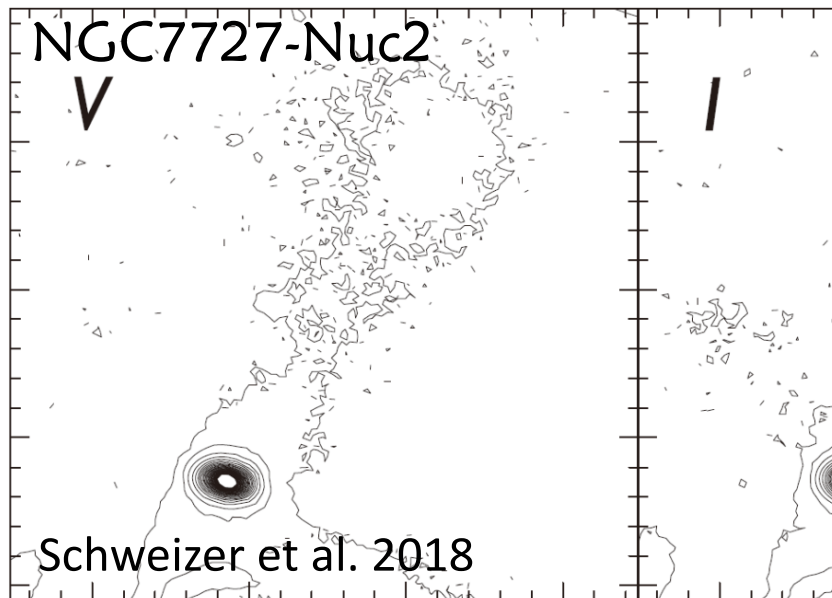
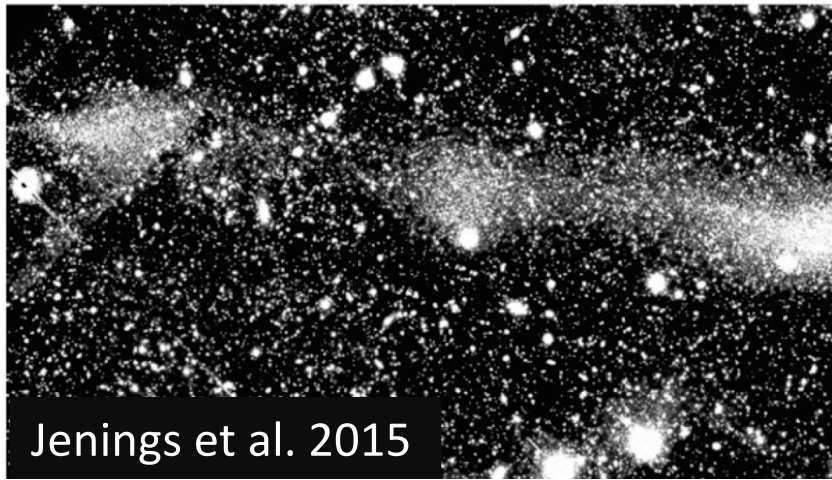
# Luminous UCDs



The progenitors of luminous UCDs are galaxy.



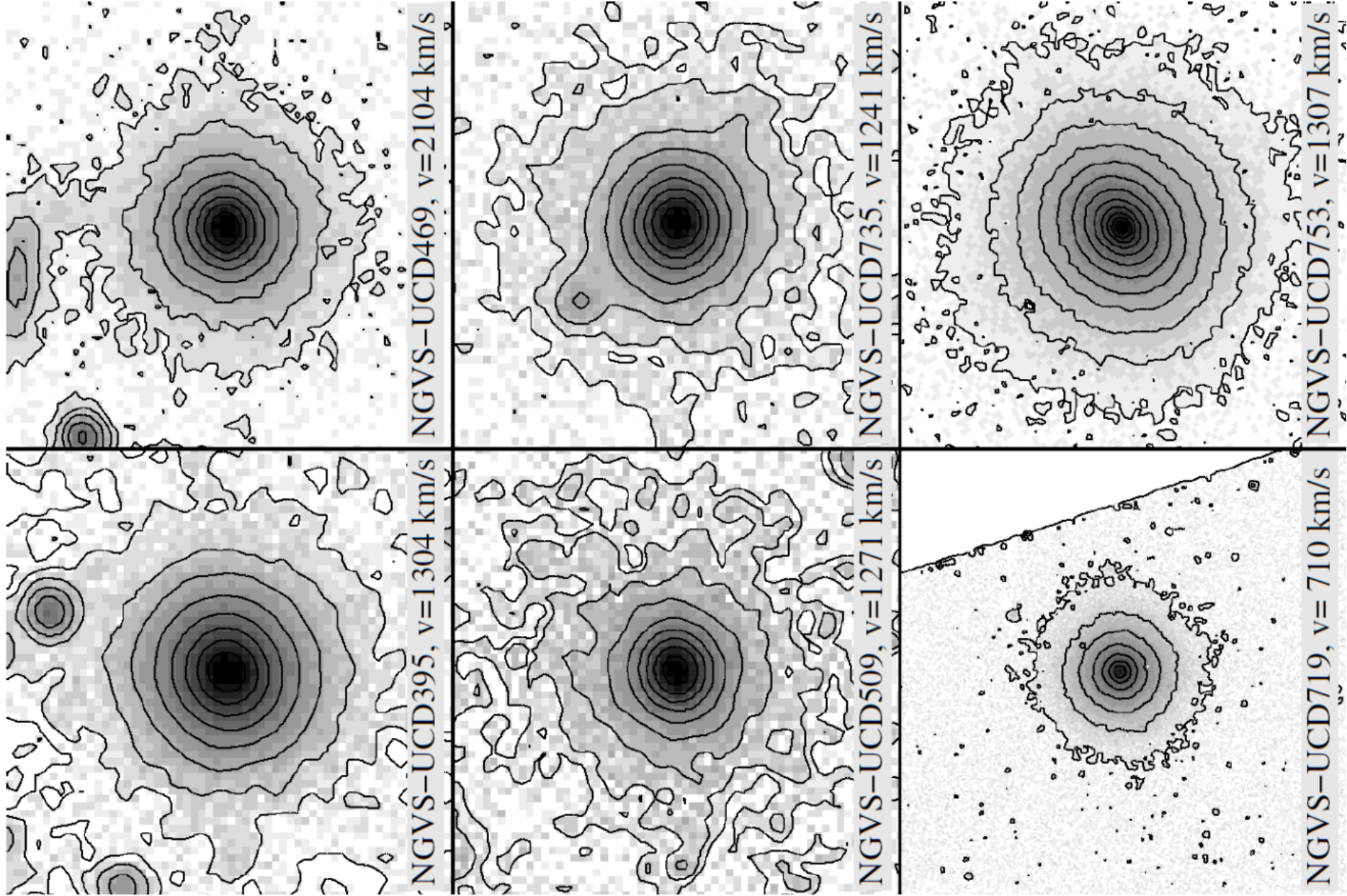
# UCDs with tidal structures



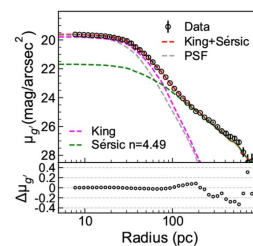
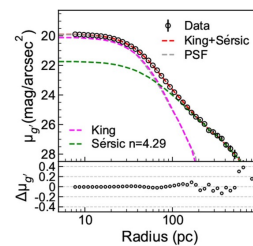
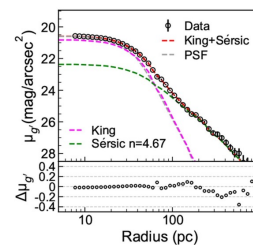
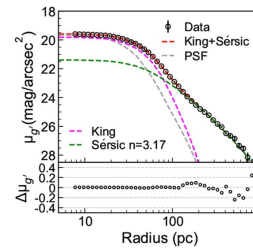
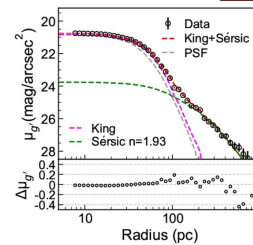
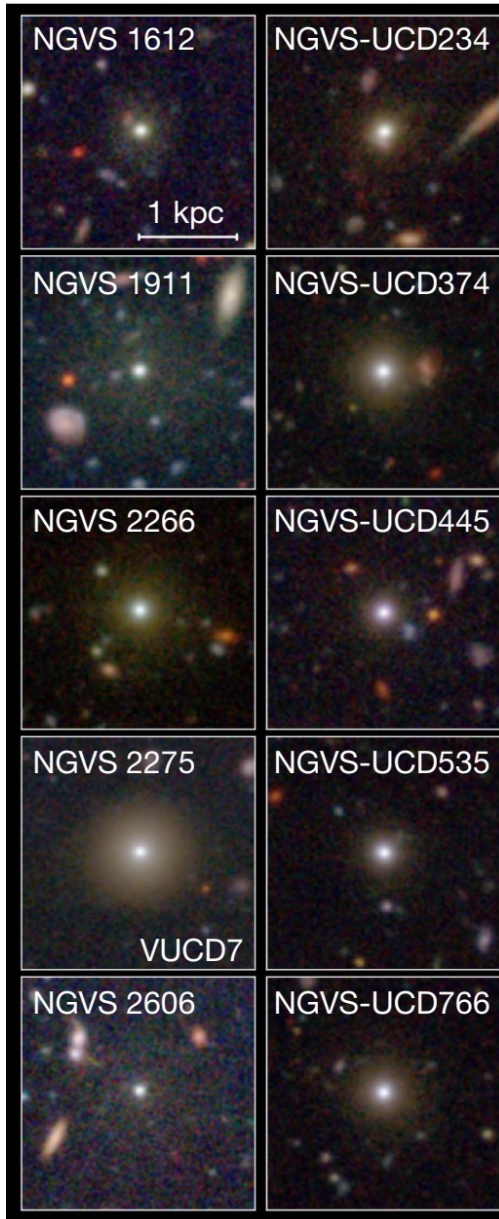
A transient stage from dE,Ns to UCDs.



# UCDs with envelopes



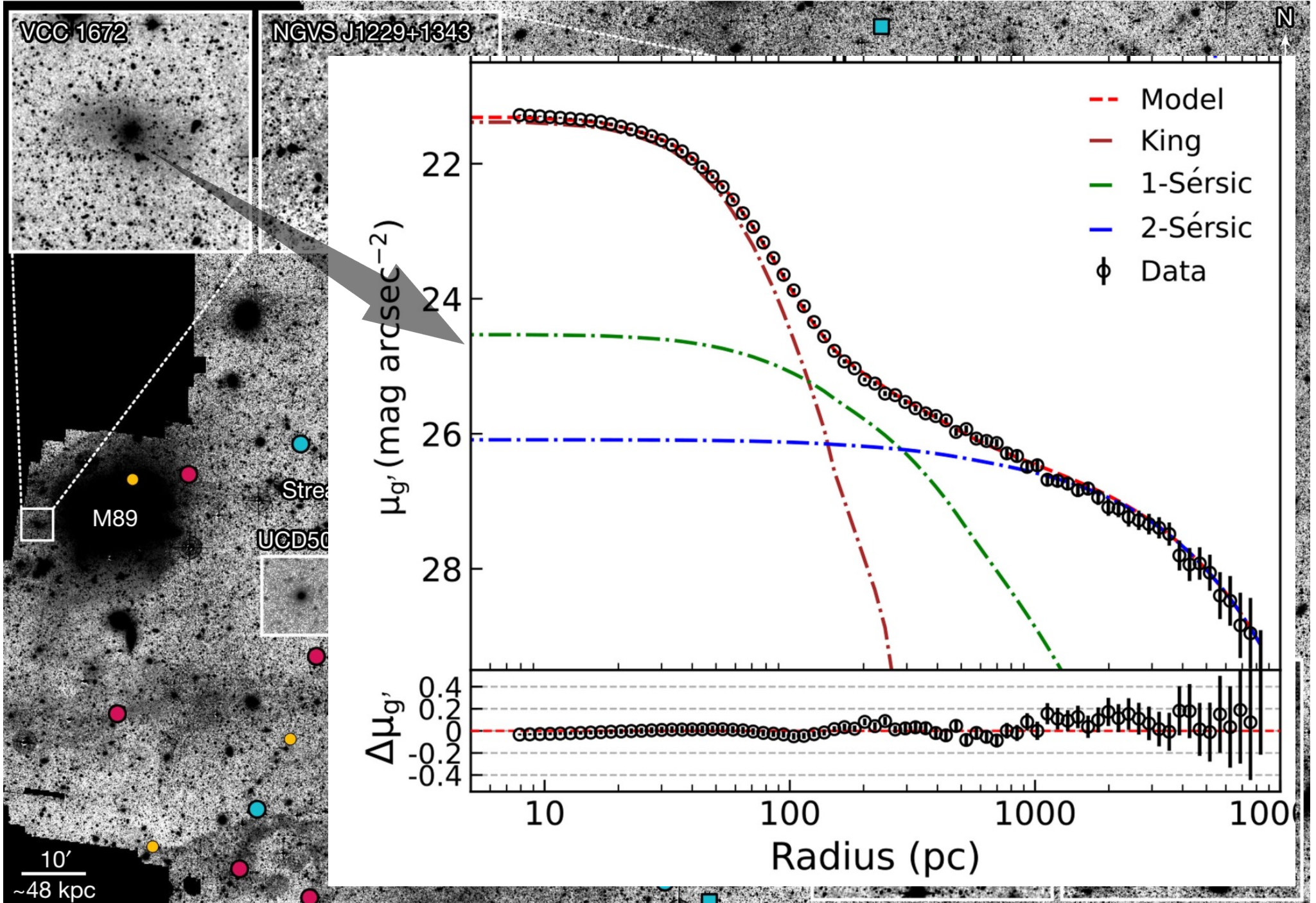
# Strongly nucleated dEs VS. eUCD



- Typical dE,N
  - Nucleus + stellar halo
  - $f_n < 8\%$
- Strongly nucleated dE
  - $f_n > 8\%$
  - $f_n \lesssim 35\%$
- eUCD
  - $30\% < f_n < 80\%$
- Typical UCD
  - Only one component

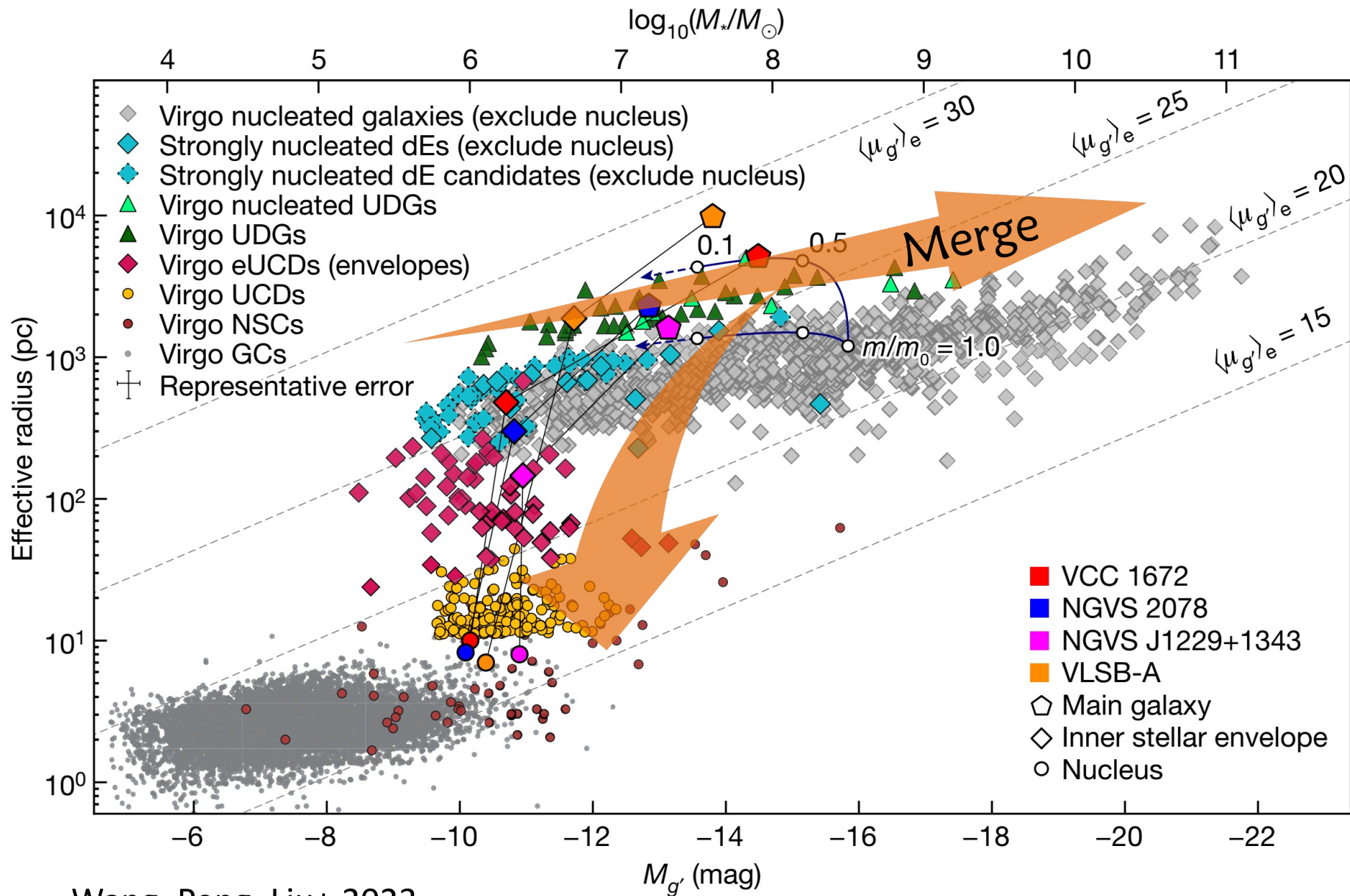


# Galaxies with three components

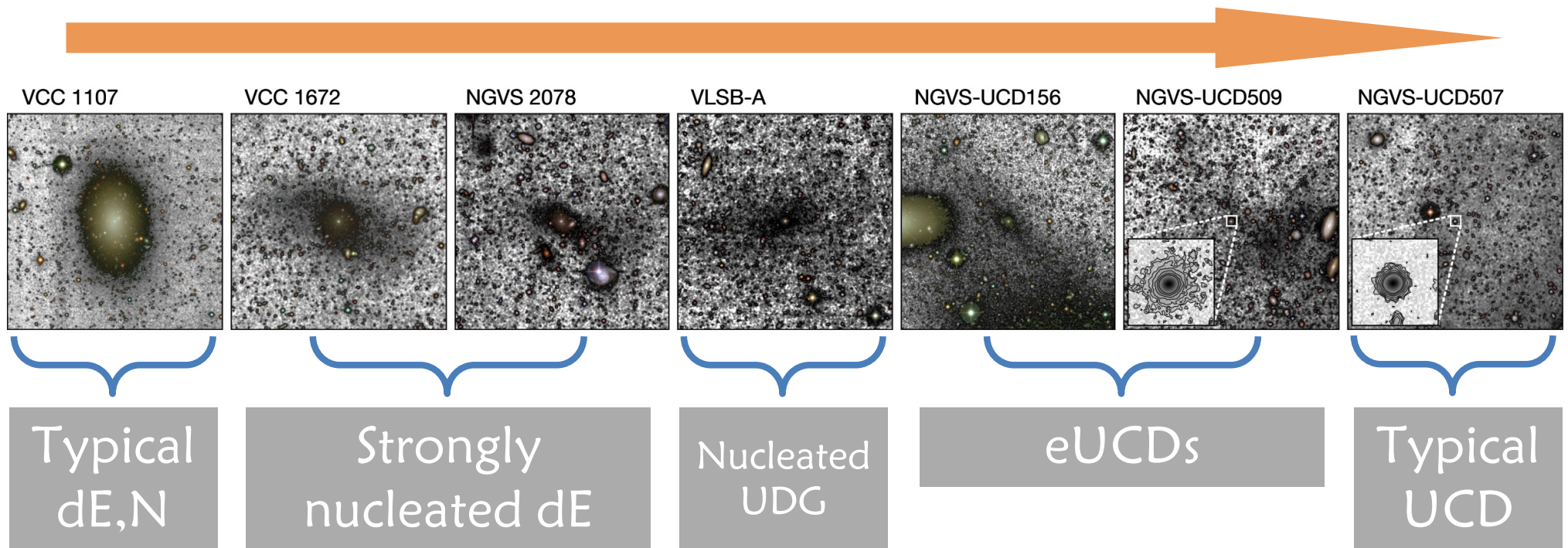




# Size-magnitude diagram



# Morphological evolution sequence



The most diffuse galaxies and the most compact galaxies may have the same origin.

Nucleated UDG might be an intermediate stage from dE,N to UCD.

# Constrains on UCD origin

## Compare with GCs and dwarf nuclei

- Color distribution  
**No significant difference among GCs, Nuclei and UCDs**
- Color gradient
- Spatial distribution  
**Tight connection between UCD and dE,N**

## Individual UCD with special properties

- Luminous UCDs
- UCDs with tidal structures
- UCDs with envelopes
- Morphological sequence

**Evolutionary connection between dE,N and UCD**



# Summary

- We found  $\sim 600$  UCDs in Virgo cluster
  - The first complete sample of UCDs in a cluster.
  - The largest sample of UCDs up to date.
- Many results support the galactic origin of UCDs
  - At least some UCDs are the stripped remnants of nucleated dwarf galaxies.
  - We do not exclude other formation scenarios.
- **Search for UCDs in local universe with the upcoming wide-field space-based surveys**