# Characterisation of an Isolated Galaxy Sample: Astrophysical Implications

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# Overview of the presentation



Introduction

Revision of the isolation of the CIG galaxies

Effects of the environment on the CIG galaxies

Isolated galaxies, isolated pairs, and isolated triplets

Conclusions

# Overview of the presentation

# Motivation

- Role of the environment in the formation and evolution of galaxies
- Which properties are due to internal secular evolution and which to external influences
- Reference sample with minimum influence from the environment

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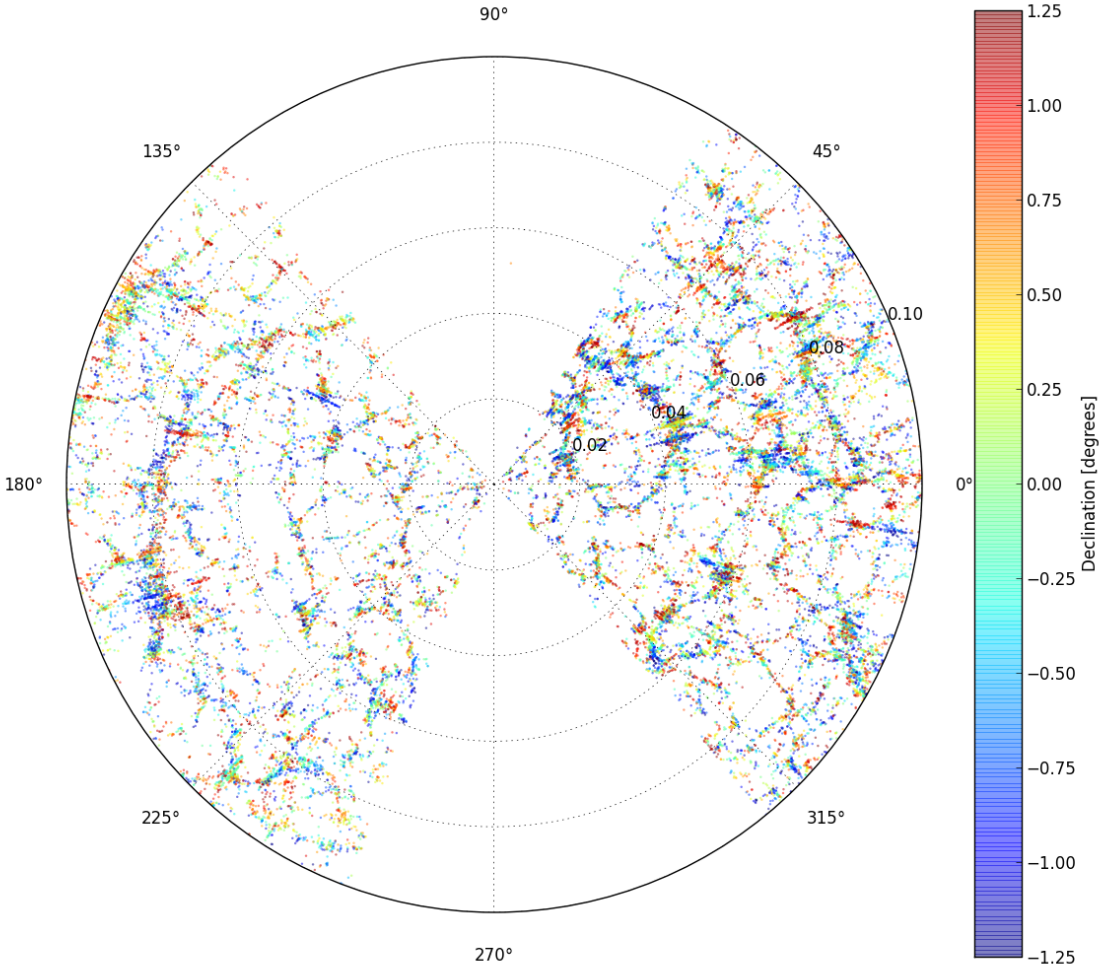
# Galaxies in the Universe

$-1.25° < \delta < 1.25°$



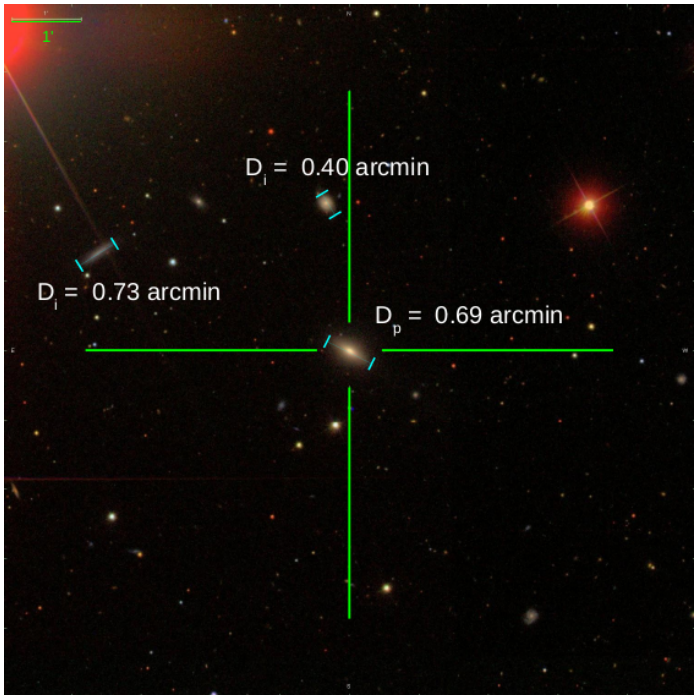
# Galaxies in the Universe

[Kent 2013, S. Duarte Puertas & E. Ramos Carmona] http://www.blender.org

# AMIGA project

http://amiga.iaa.es

- **A**nalysis of the interstellar **M**edium of **I**solated **GA**laxies
- **C**atalogue of **I**solated **G**alaxies [CIG, Karachentseva 1973]




1050 CIG galaxies
2D isolation criterion:

- $\frac{1}{4} D_P \leq D_i \leq 4 D_P$
- $R_{iP} \leq 20 D_i$

No similar-size galaxies in their close environments

# AMIGA project

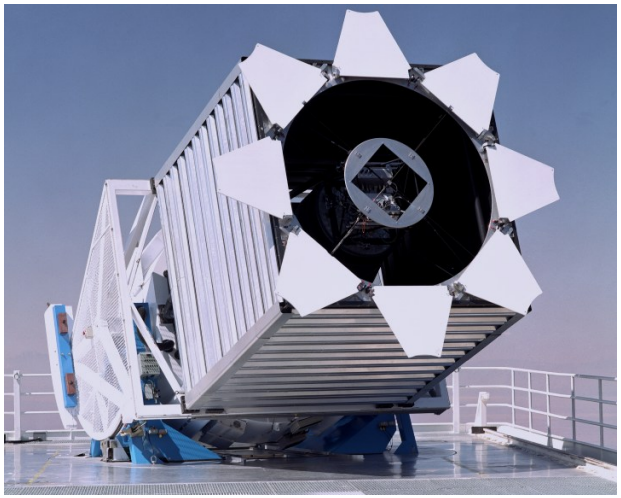
http://amiga.iaa.es

1. Refinement of the sample
   - Positions [Leon & Verdes-Montenegro 2003]
   - Redshift and distances [Verdes-Montenegro et al. 2005]
   - Morphologies [Sulentic et al. 2006]
   - Isolation degree [Verley et al. 2007b,c]
2. Multiwavelength characterisation of the ISM
   - Optical [Sulentic et al. 2006, Durbala et al. 2008, 2009, Sabater et al. 2008, 2012, Fernández Lorenzo et al. 2012, 2013]
   - H$\alpha$ [Verley et al. 2007a]
   - Near & far infrared [Lisenfeld et al. 2007]
   - Radiocontinuum [Leon et al. 2008]
   - Atomic gas [Espada et al. 2005, 2011]
   - Molecular gas [Lisenfeld et al. 2012]
3. Public database

# The SDSS

[York et al. 2000]

http://www.sdss3.org



## **S**loan **D**igital **S**ky **S**urvey

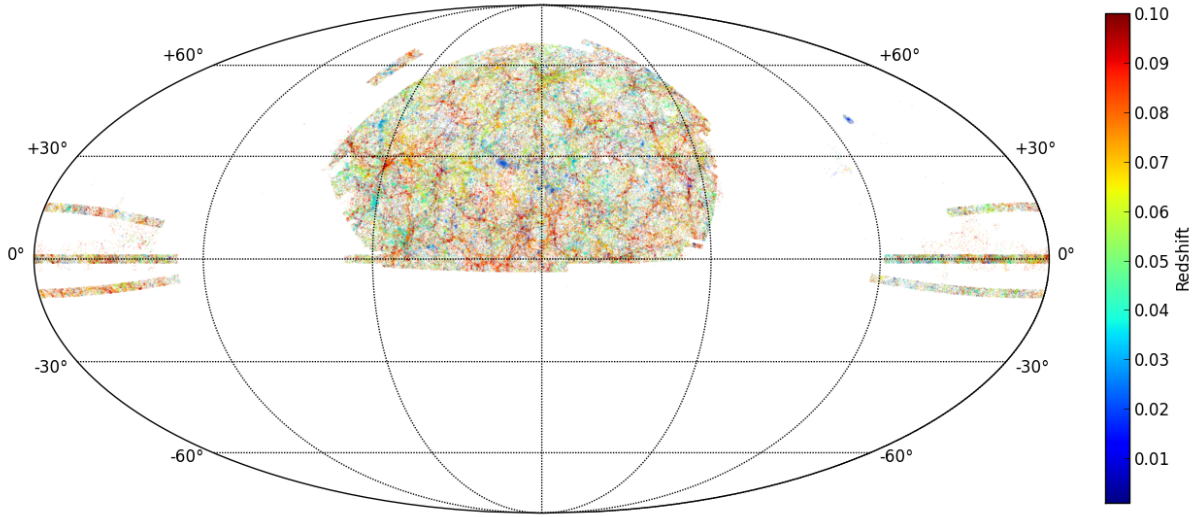
2.5 m Telescope [Gunn et al. 2006]

Apache Point Observatory, New Mexico

SDSS-DR9 [Eisenstein et al. 2011]

Photometry: 208,478,448 galaxies

Spectroscopy: 952,740 galaxies



# Quantification of the environment

[Verley et al. 2007b,c, Sabater et al. 2013, Argudo-Fernández et al. 2013a]

- Projected density to the k$^{th}$ nearest neighbour:

$$\eta_k \propto \log\left(\frac{k-1}{V(r_k)}\right)$$

$$V(r_k) = \frac{4}{3}\pi r_k^3$$

- Tidal strength (estimation of gravitational interaction):

$$Q_{iP} \equiv \frac{F_{\rm tidal}}{F_{\rm bind}}$$

$$\log Q_{iP} \propto 0.4\,(m_r^P - m_r^i) + 3\log\left(\frac{D_P}{R_{iP}}\right)$$

and $Q = \log(\sum_i Q_{iP})$

# Aims

The **main aims** of this thesis are:

- to refine the **photographic-based CIG** and to provide an **improvement of the quantification of the isolation degree** with respect to previous works, using both photometry and spectroscopy;
- to identify and quantify the **effects of the physical satellite distribution** around galaxies in the CIG, as well as the effects of the **Large Scale Structure** (LSS);
- to construct a catalogue of **galaxies isolated in 3-dimension**, and build catalogues of physically associated **isolated pairs and isolated triplets**.

# Overview of the presentation

# Methodology: photometry

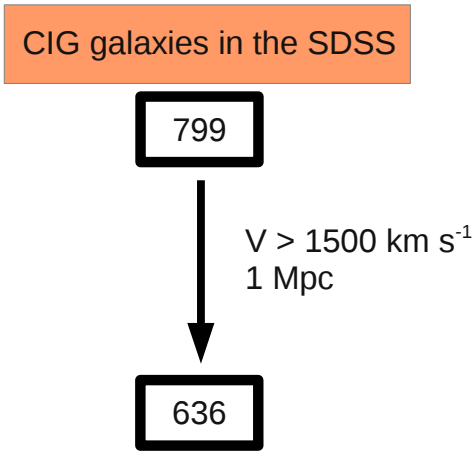
[Argudo-Fernández et al. 2013a]

CIG galaxies in the SDSS

799

# Methodology: photometry

[Argudo-Fernández et al. 2013a]



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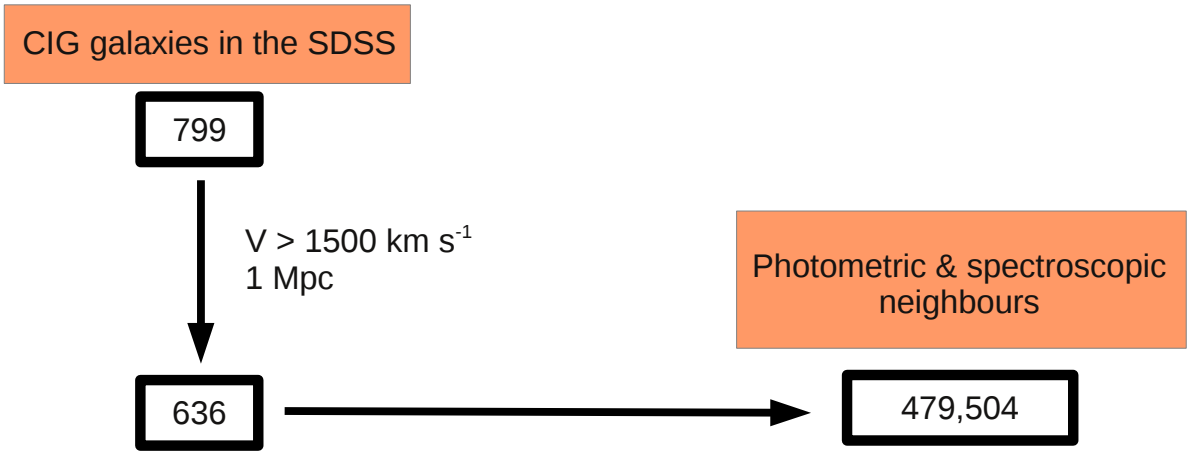

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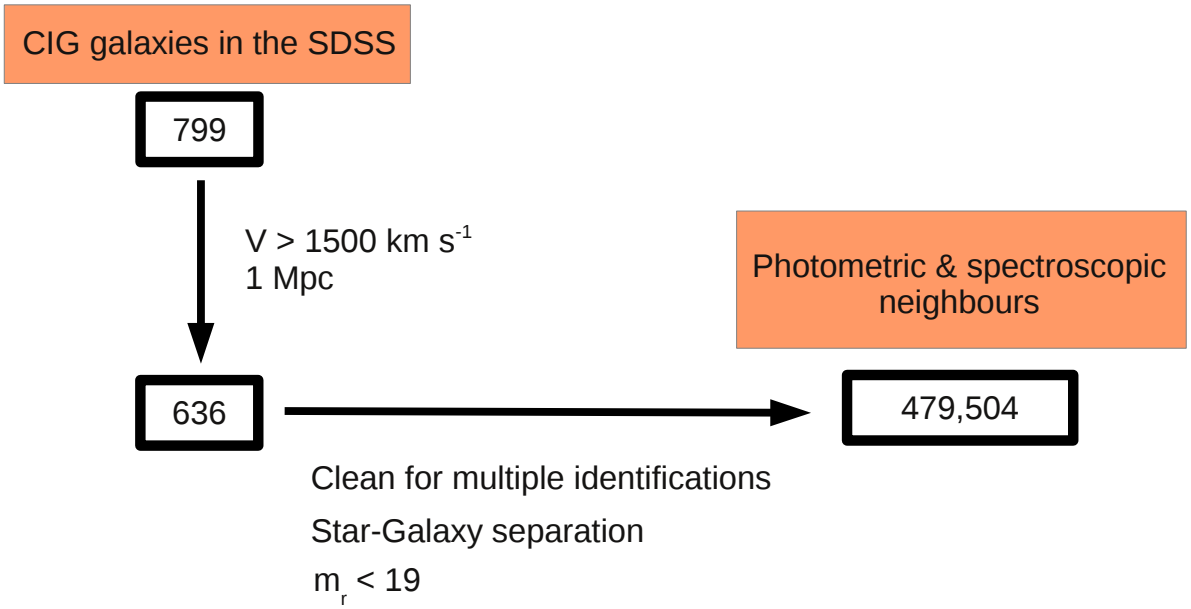
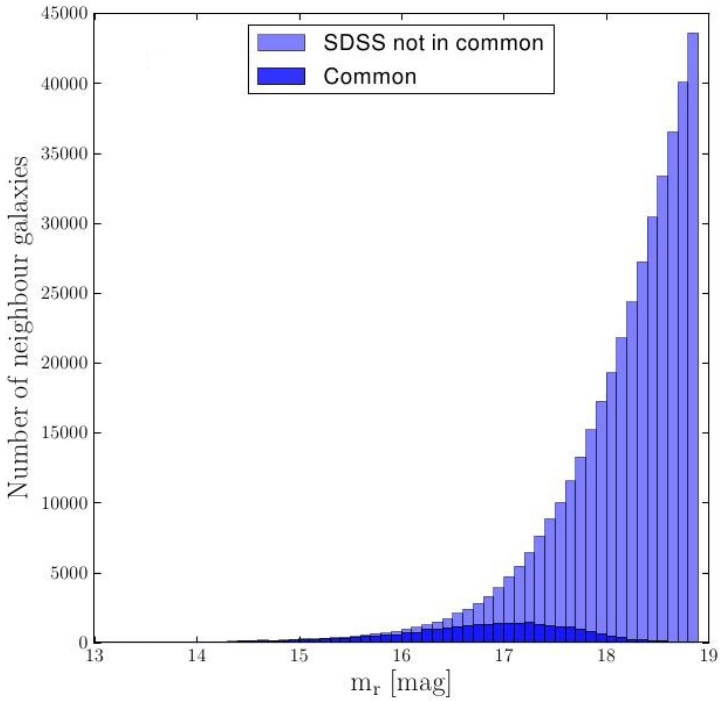


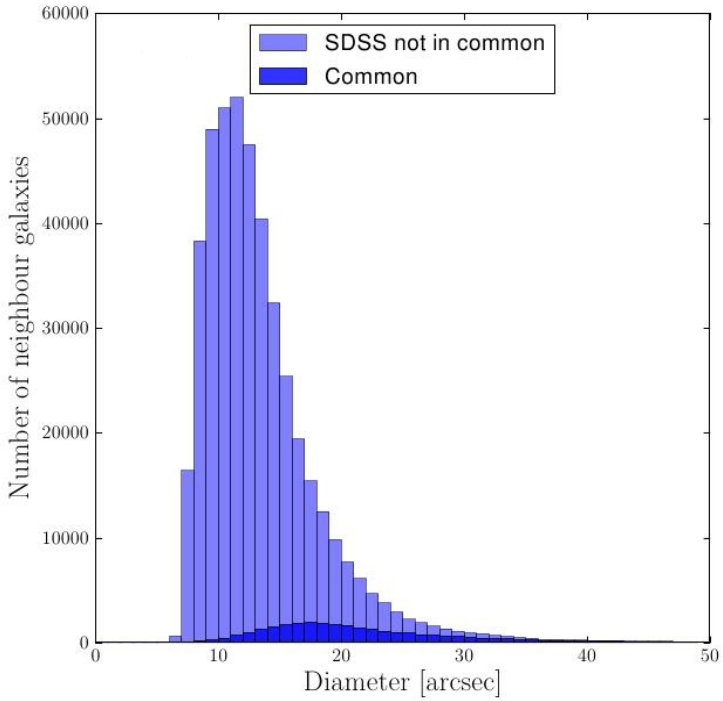
# SDSS vs POSS-I & II

[Verley et al. 2007b,c, Argudo-Fernández et al. 2013a]



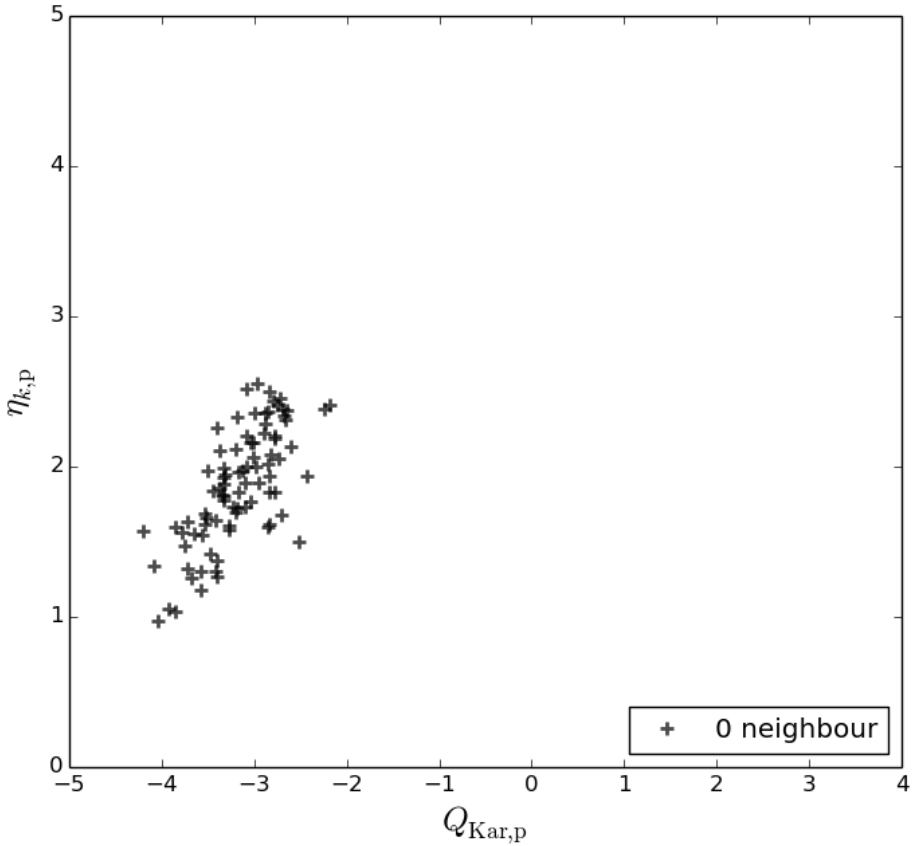
- Fainter & smaller neighbours



# Photometric isolation parameters

- 636 CIG galaxies in the photometric SDSS
- 86 CIG galaxies pass the CIG isolation criterion



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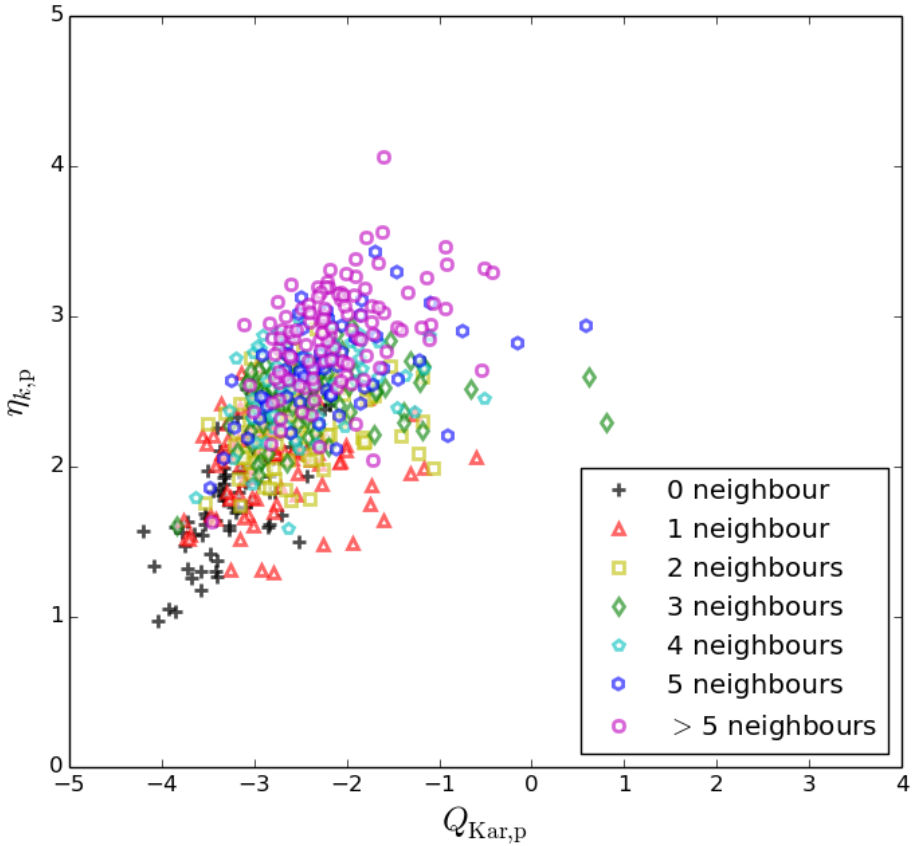

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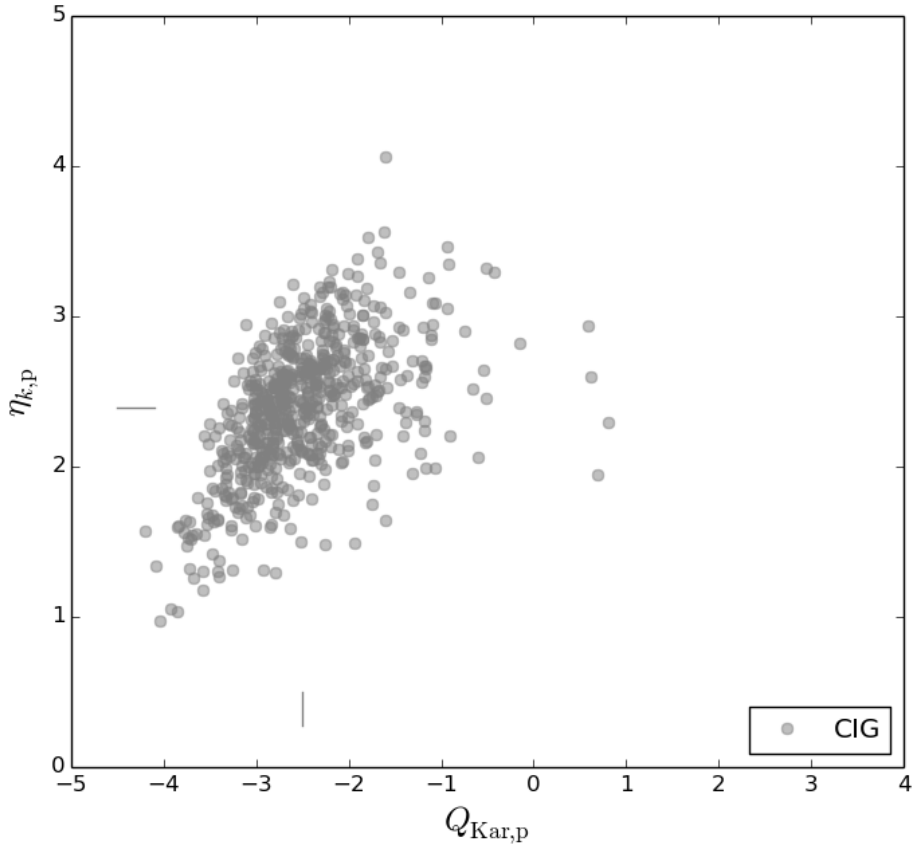

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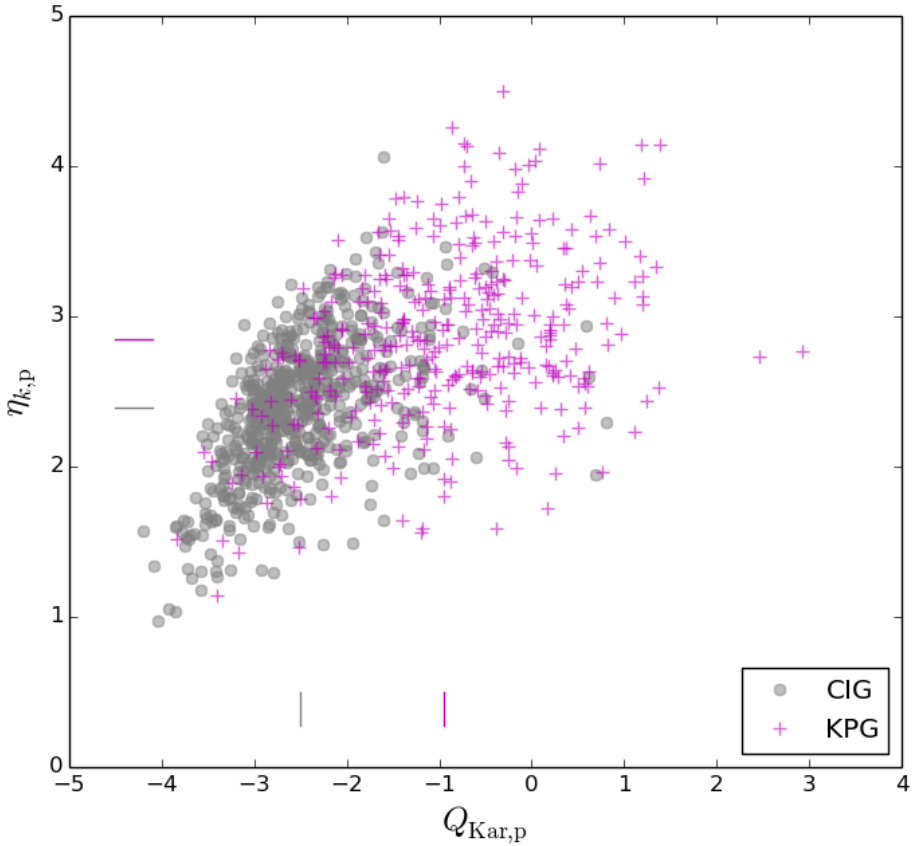

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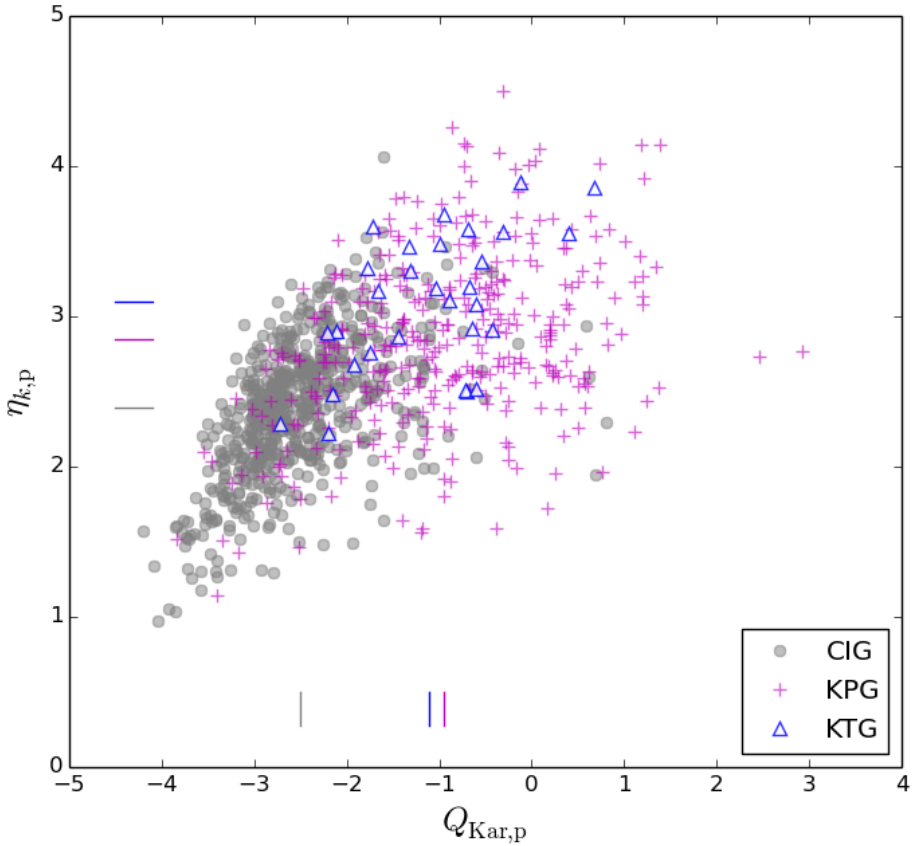

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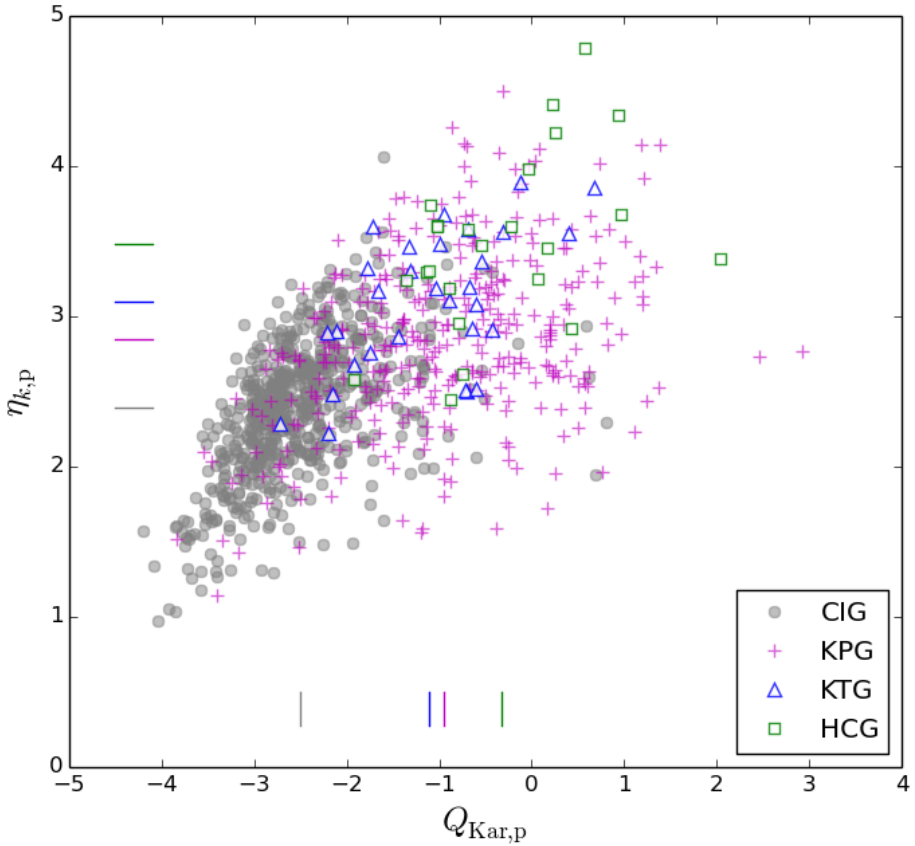

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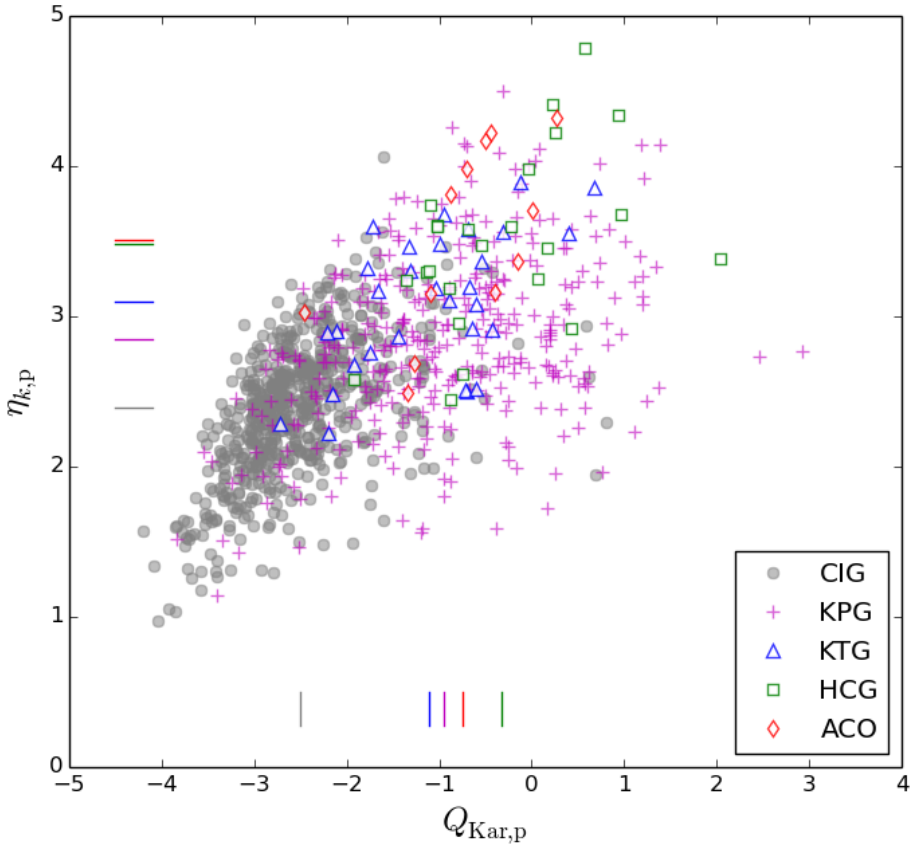
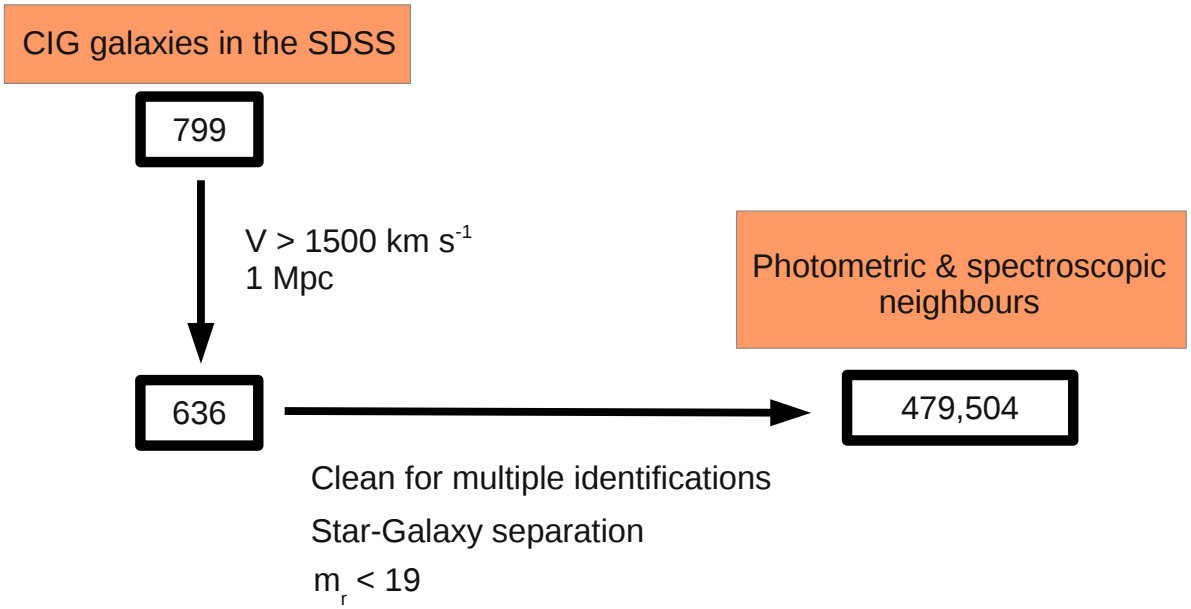


# Methodology: spectroscopy [Argudo-Fernández et al. 2013a]



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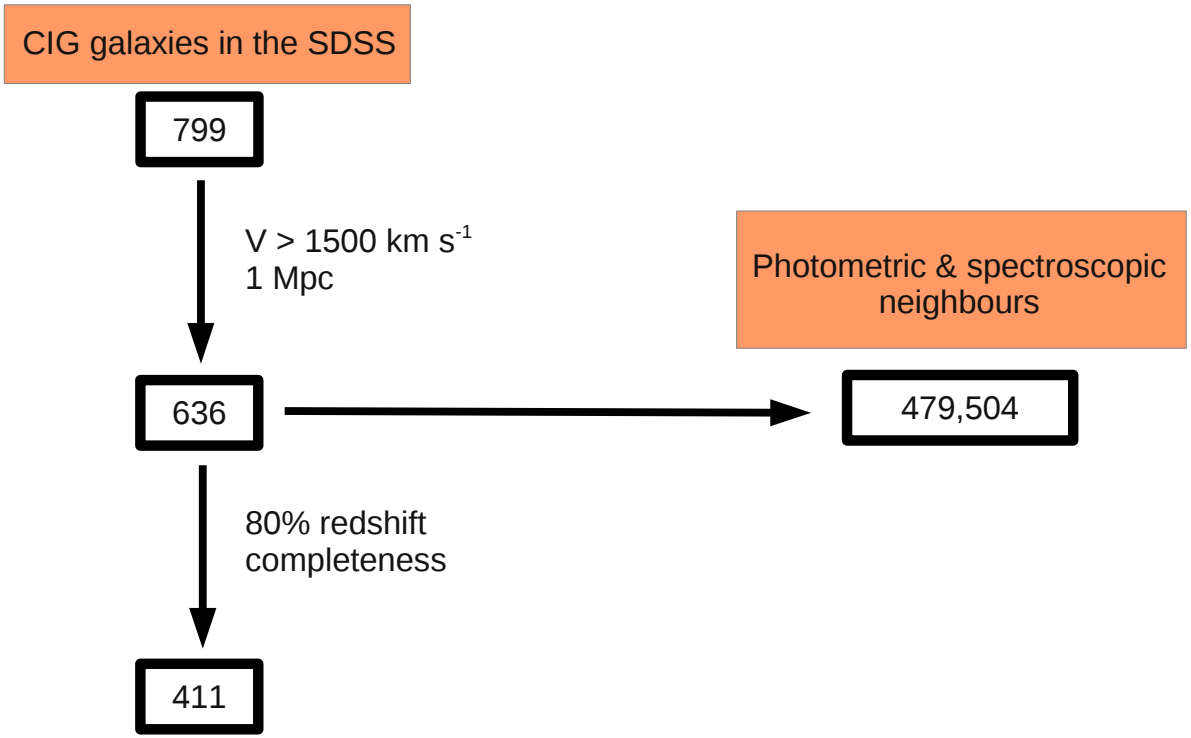

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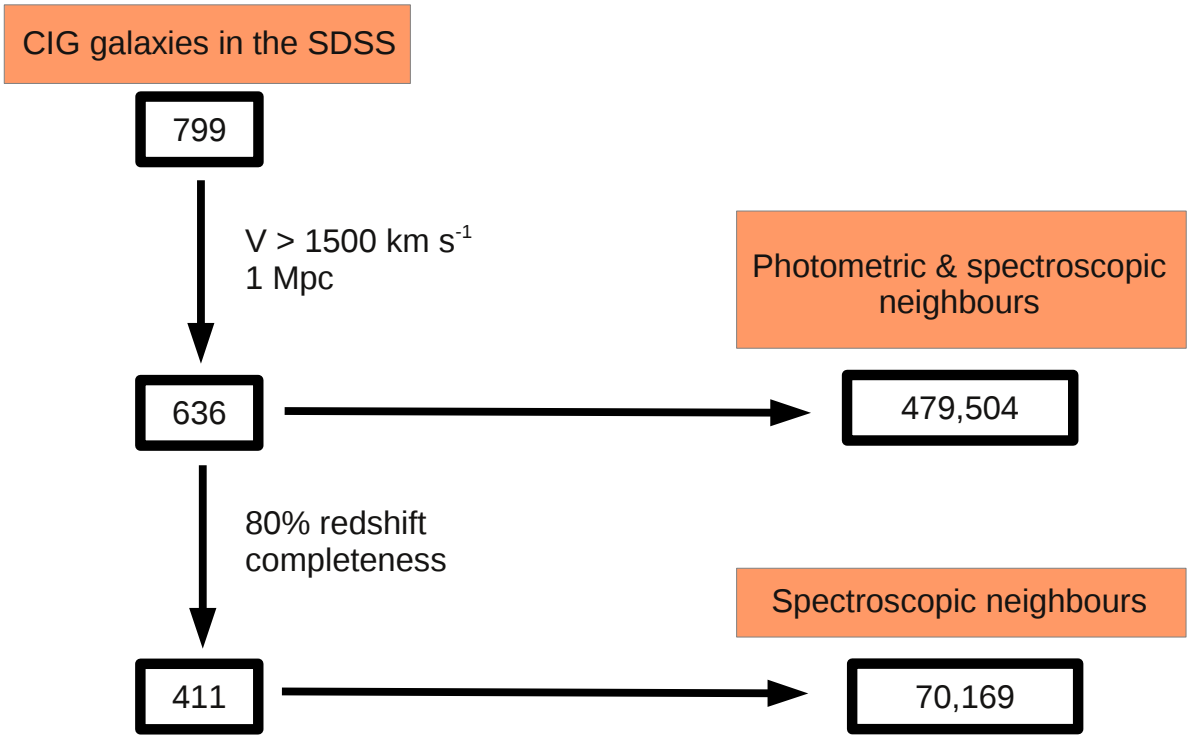
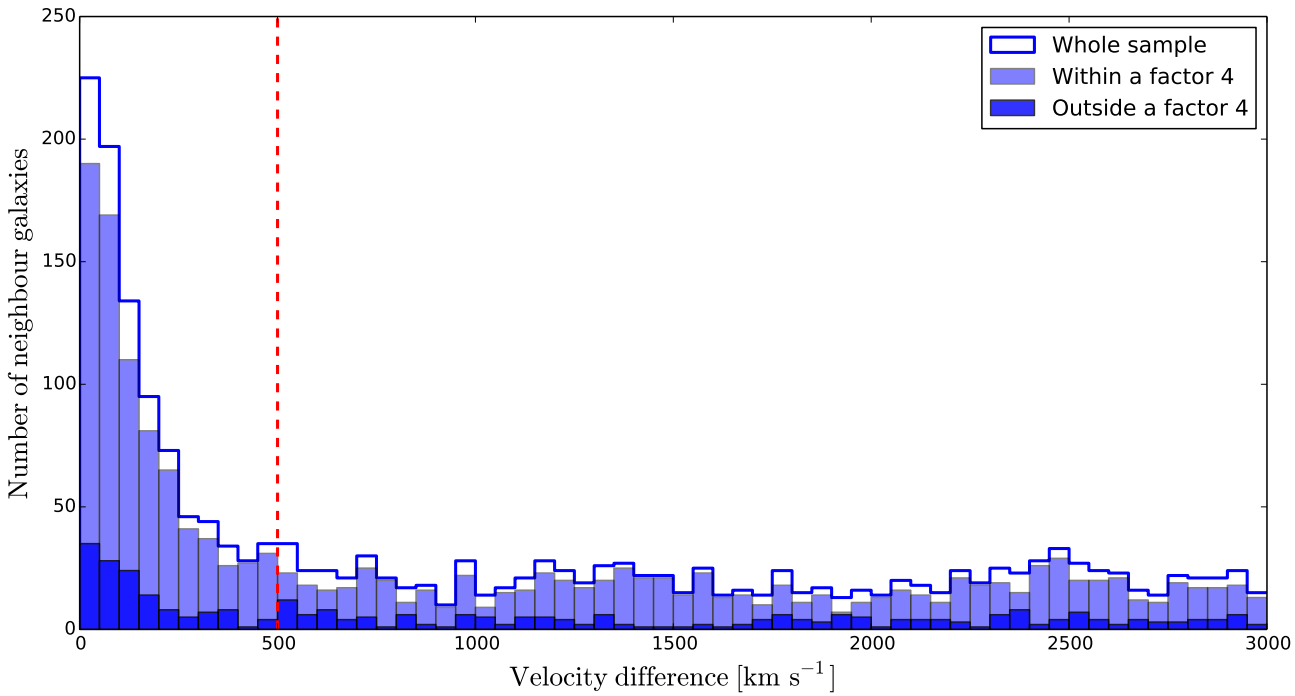


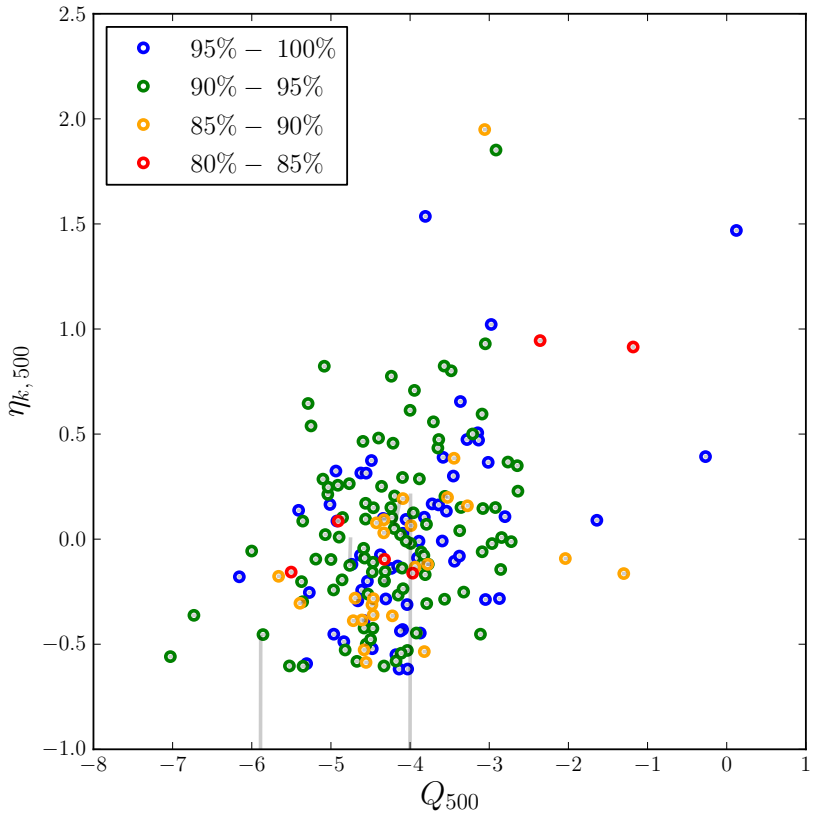
# Spectroscopic isolation criterion

- 411 CIG galaxies in the spectroscopic SDSS
- 347 CIG galaxies pass the CIG isolation criterion
- 105 CIG galaxies pass $\Delta v \leq 500\,\mathrm{km\,s^{-1}}$
- 50% of the companions by the CIG isolation criterion show very high $\Delta v$
- 92% of similar $\Delta v$ are not considered as companions



# Spectroscopic isolation parameters

- Correction for redshift incompleteness
- More than 80% of neighbours have spectroscopic redshifts
- Photometric redshifts up to 20% of neighbours



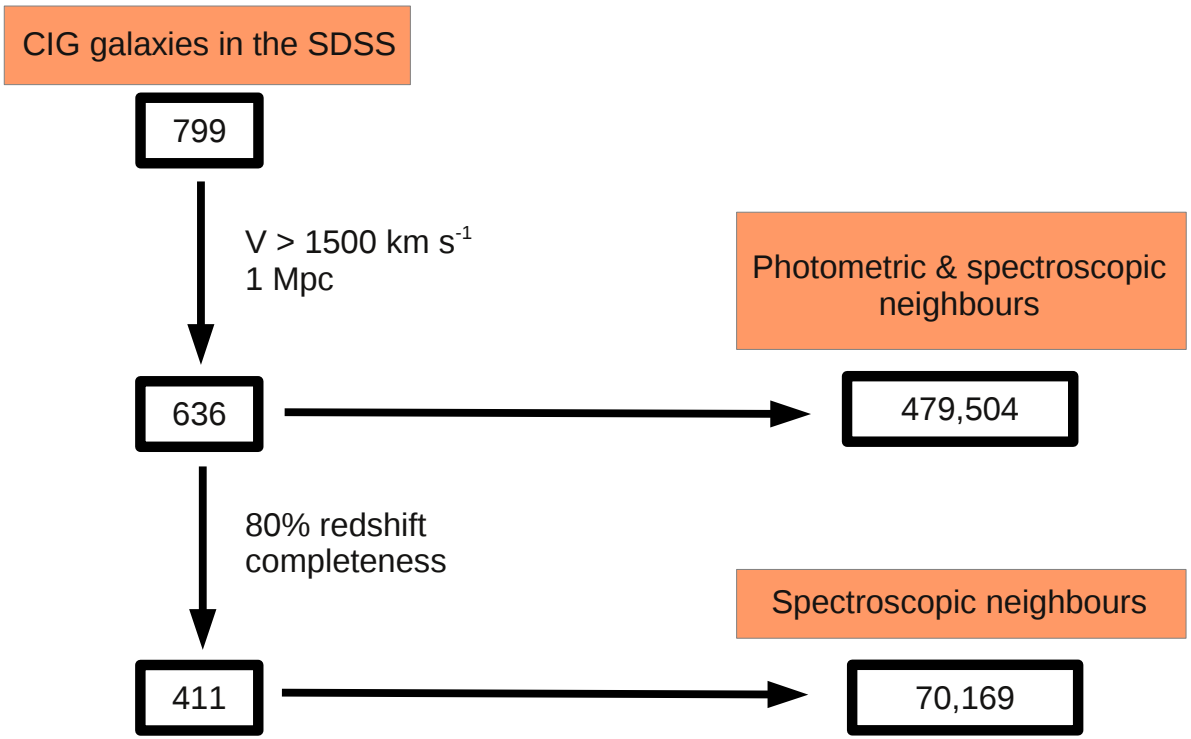
# Conclusions

- ***Fainter & smaller*** *neighbours*
- ***Nearby dwarf galaxies*** *not taken into account by the CIG isolation criterion*
- ***50%*** *of the companions by the CIG isolation criterion are* ***background galaxies*** *showing very high* $\Delta v$
- ***92%*** *of similar* $\Delta v$ *are* ***not considered as companions***

# Overview of the presentation

# Methodology

[Argudo-Fernández et al. 2013b, submitted]



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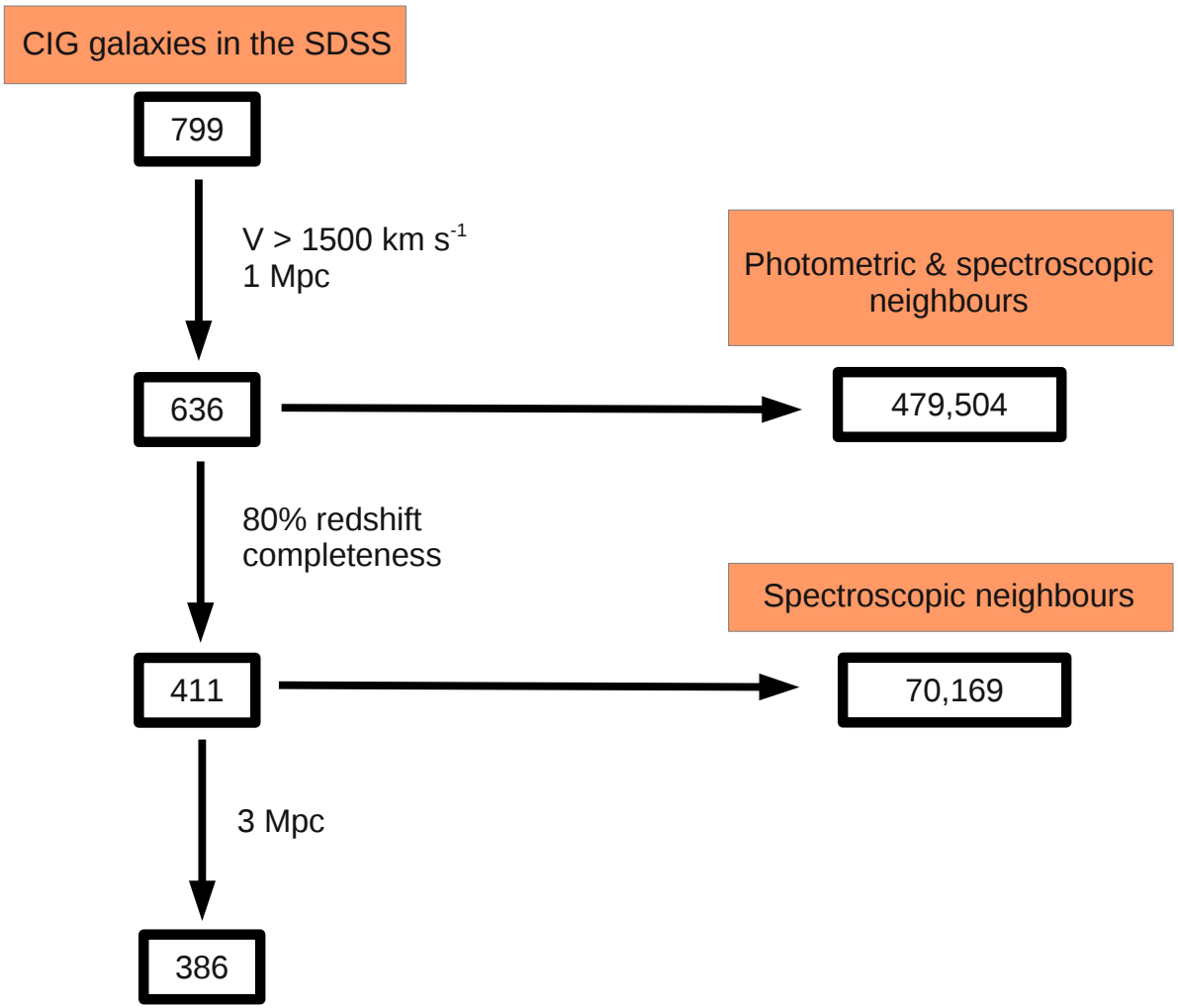

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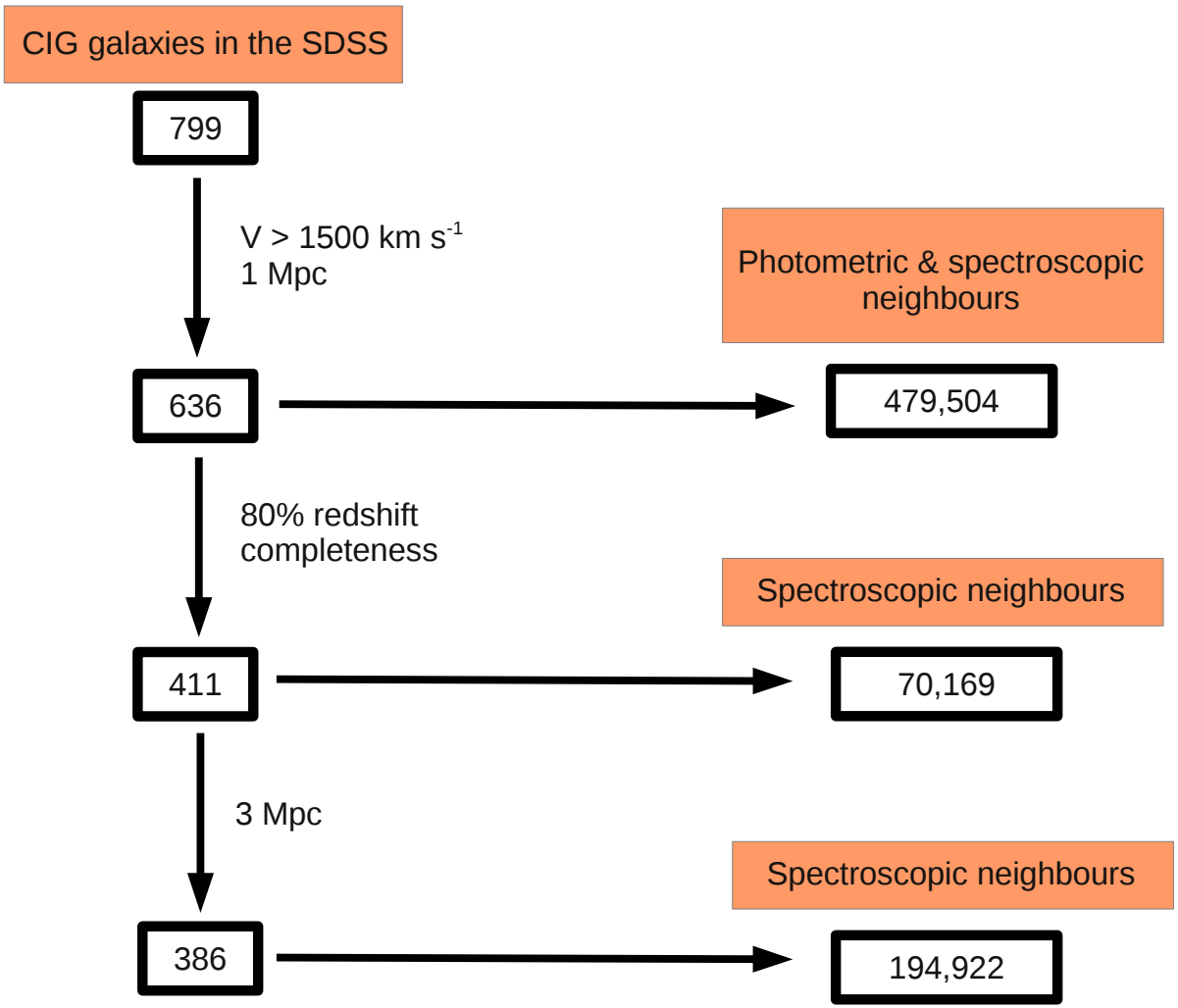
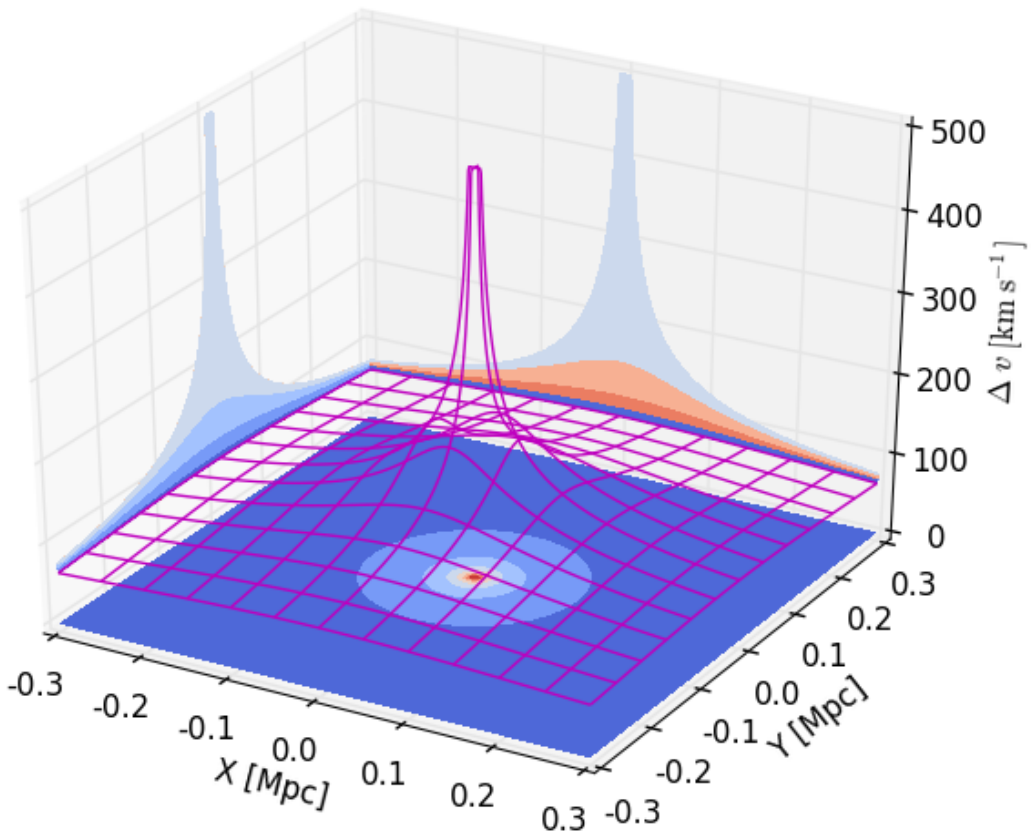


# Escape speed

[Kaiser 1987]

$$v_{\rm esc} = \sqrt{\frac{2GM_P}{R_{iP}}}$$



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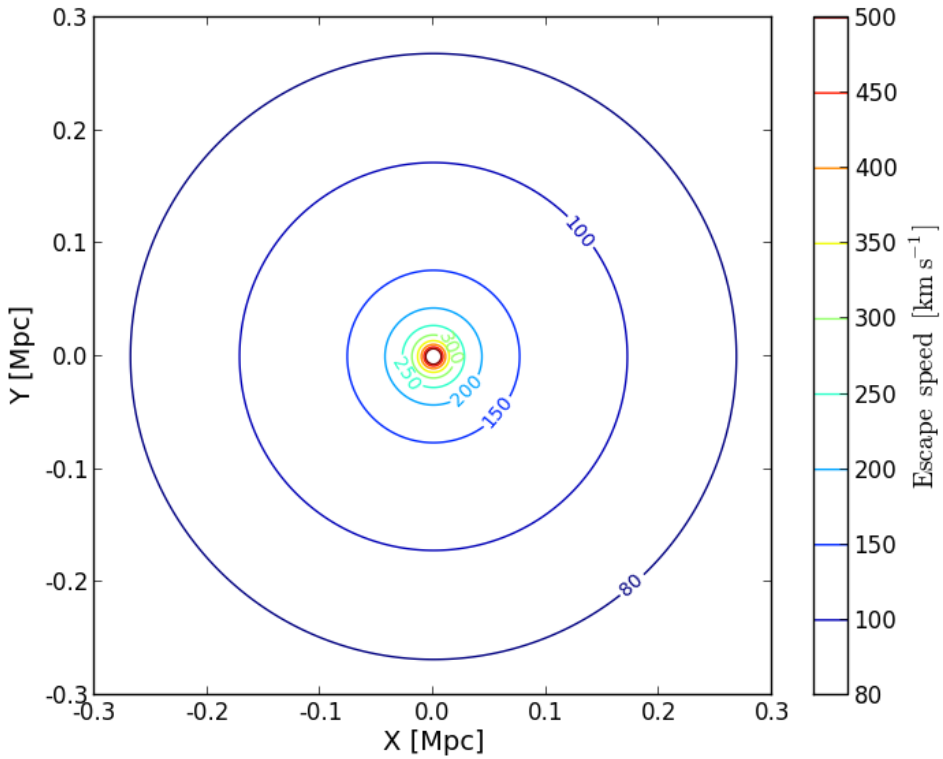
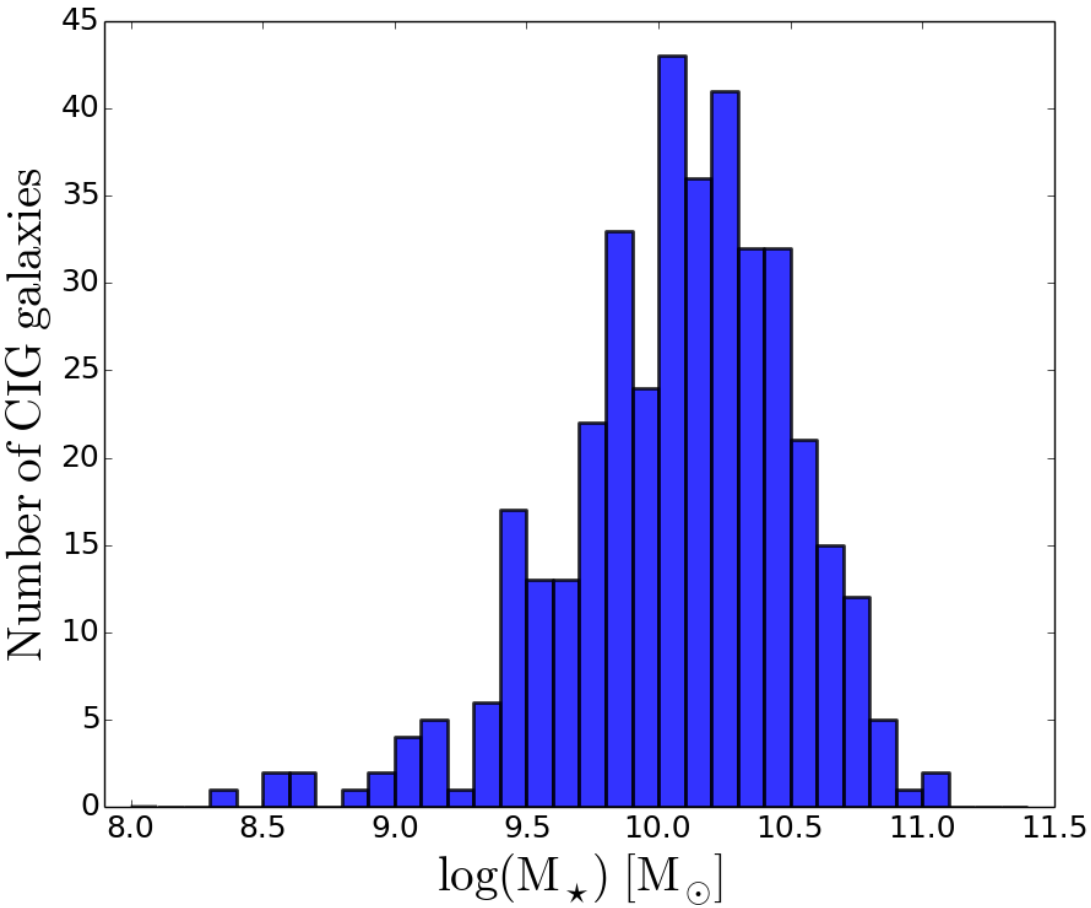


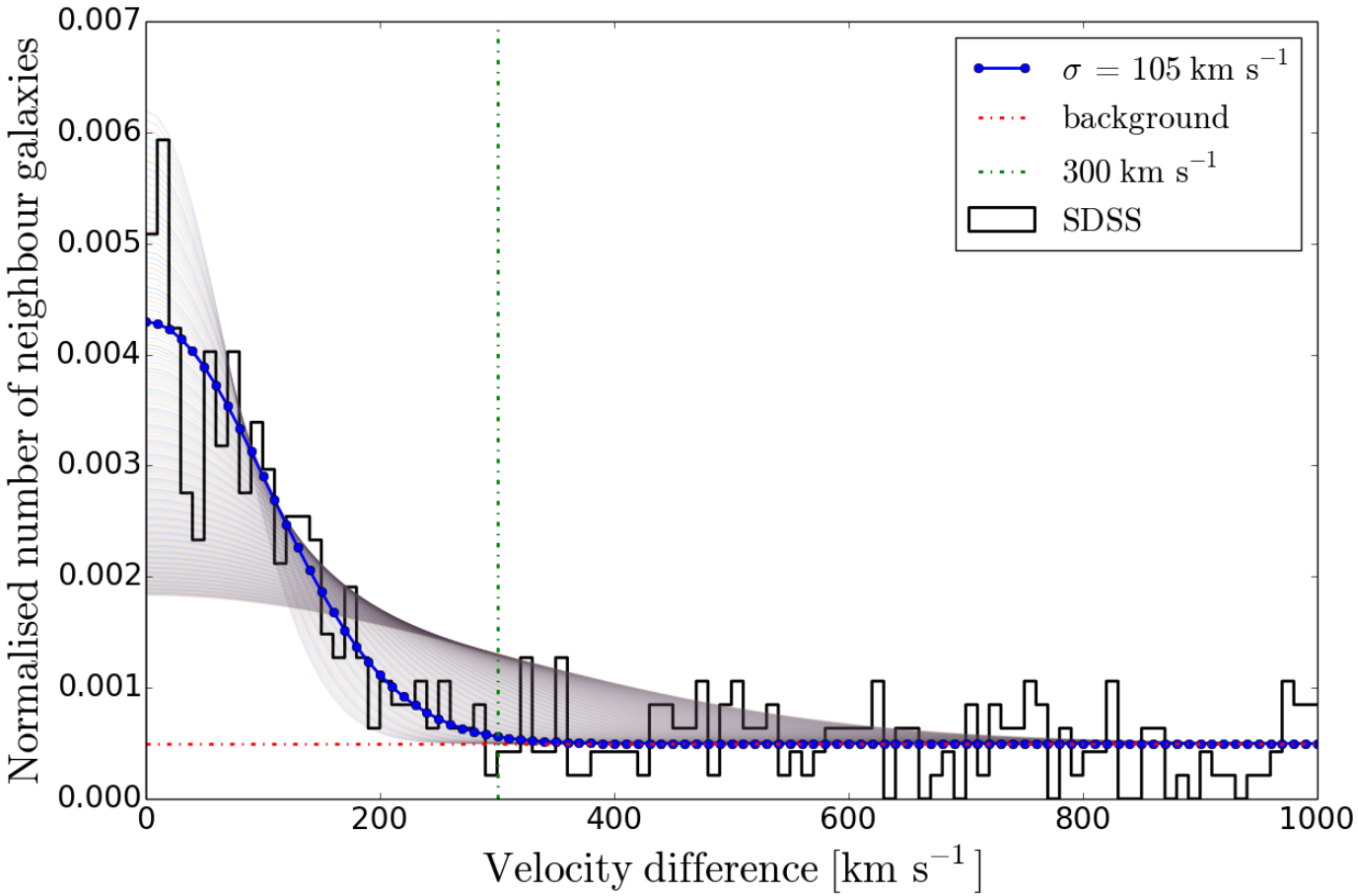
# Stellar masses

[Fernández Lorenzo et al. 2013]

- Derived optical parameters on SDSS *g*-, *r*-, and *i*-images using SExtractor [Bertin & Arnouts 1996]
- *K* correction rest-frame magnitudes and stellar masses [Blanton et al. 2007]



# Physical satellites



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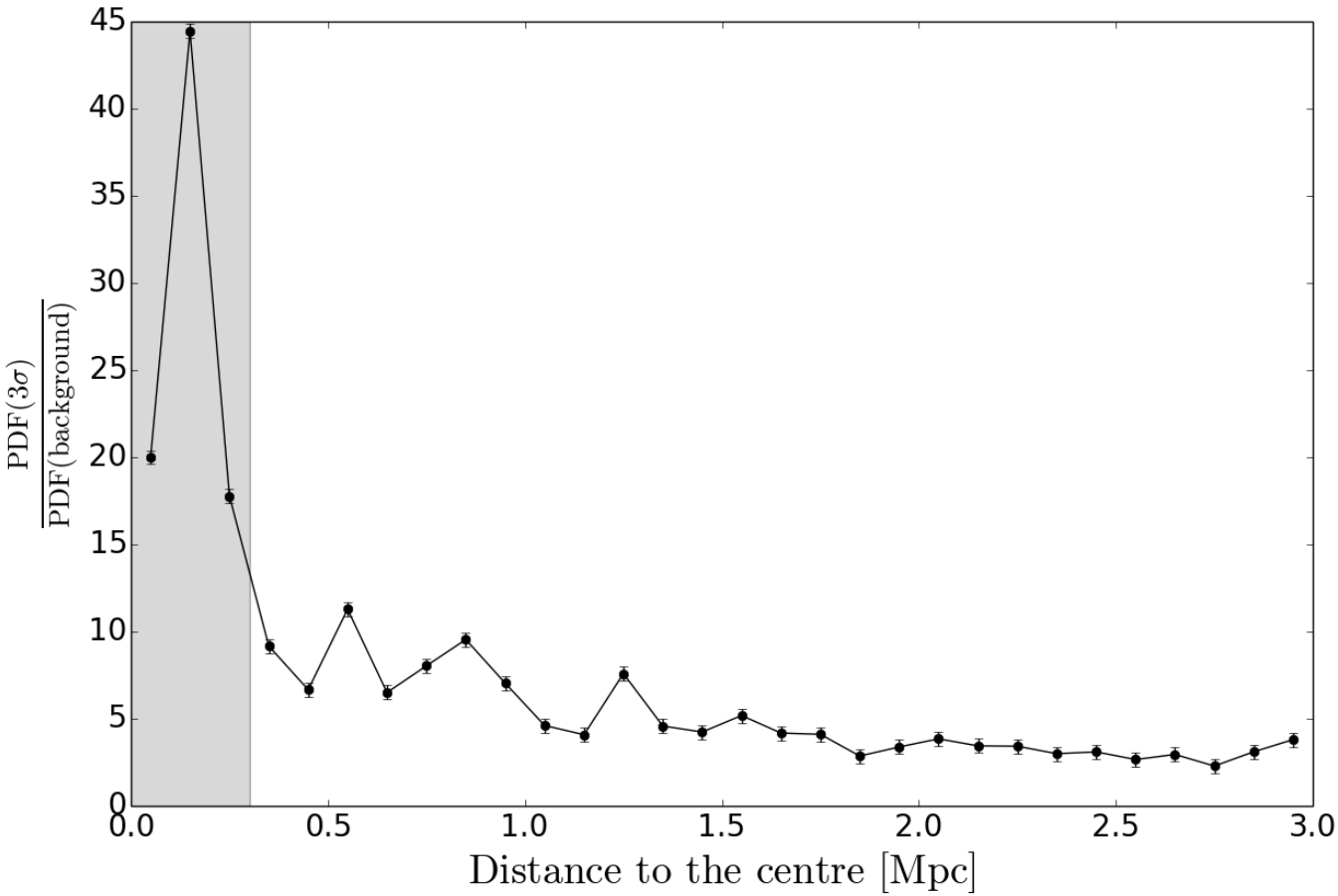
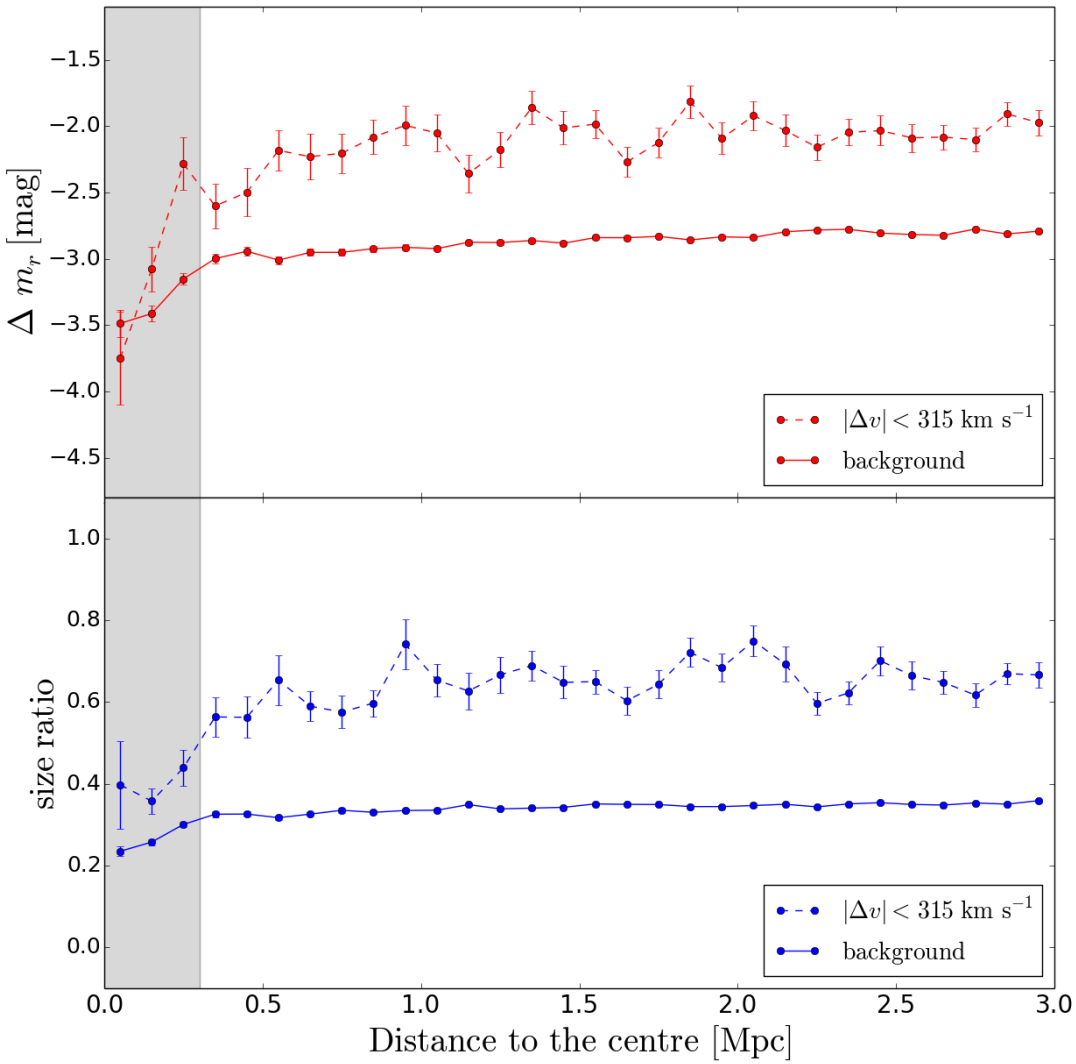
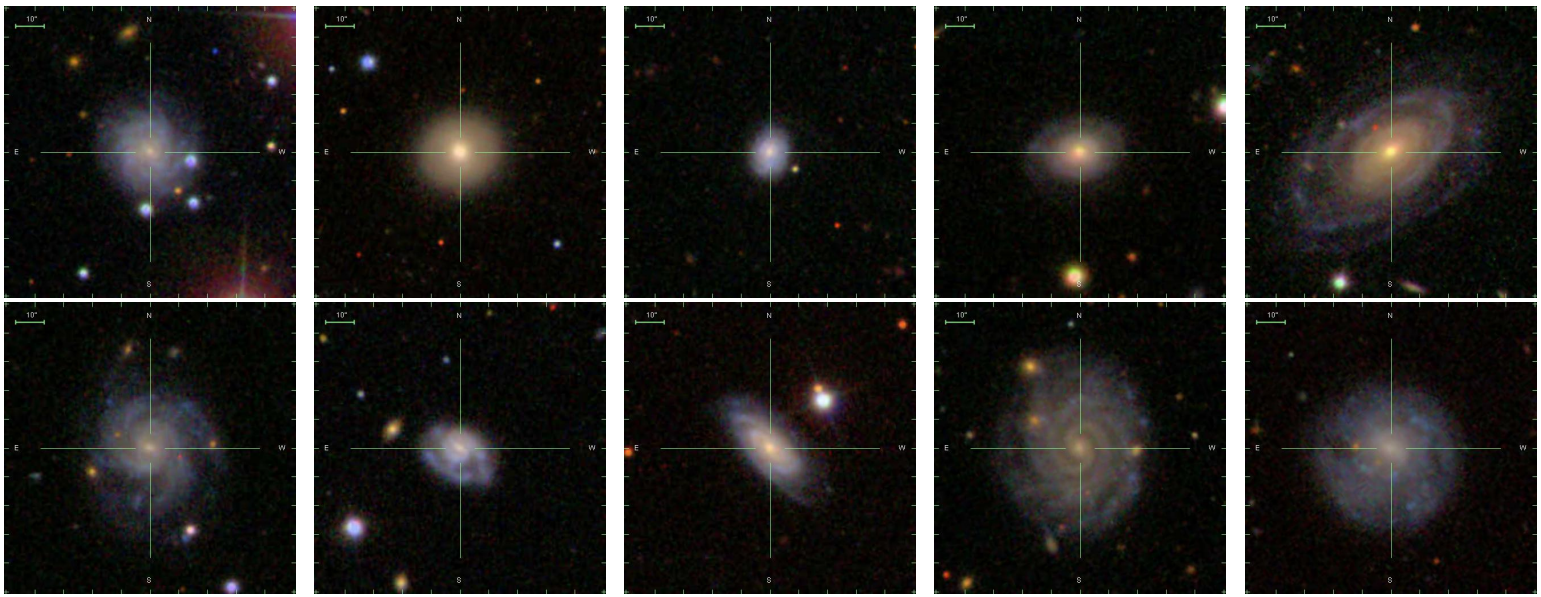


# Physically bound satellites

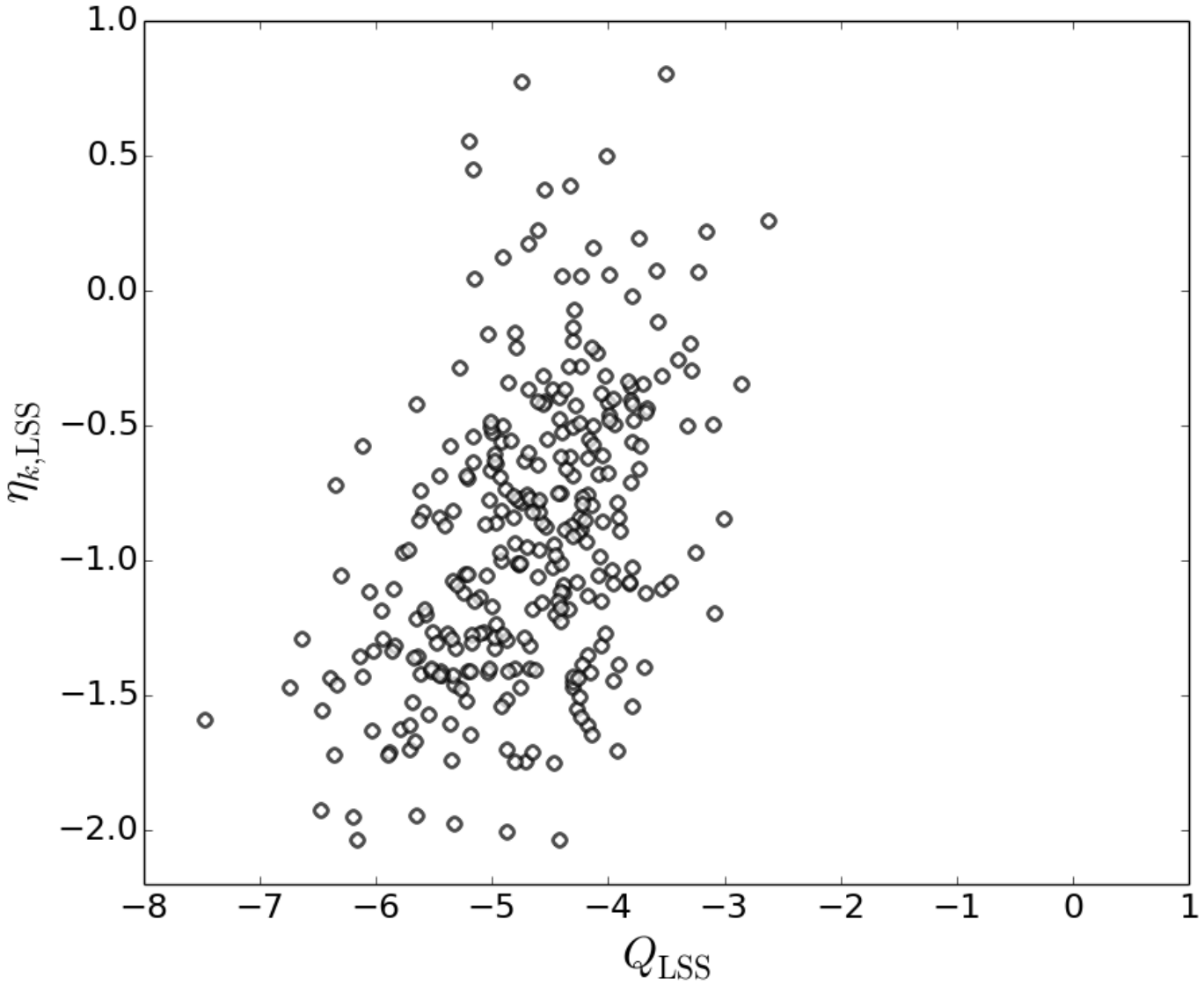


# Isolation criterion

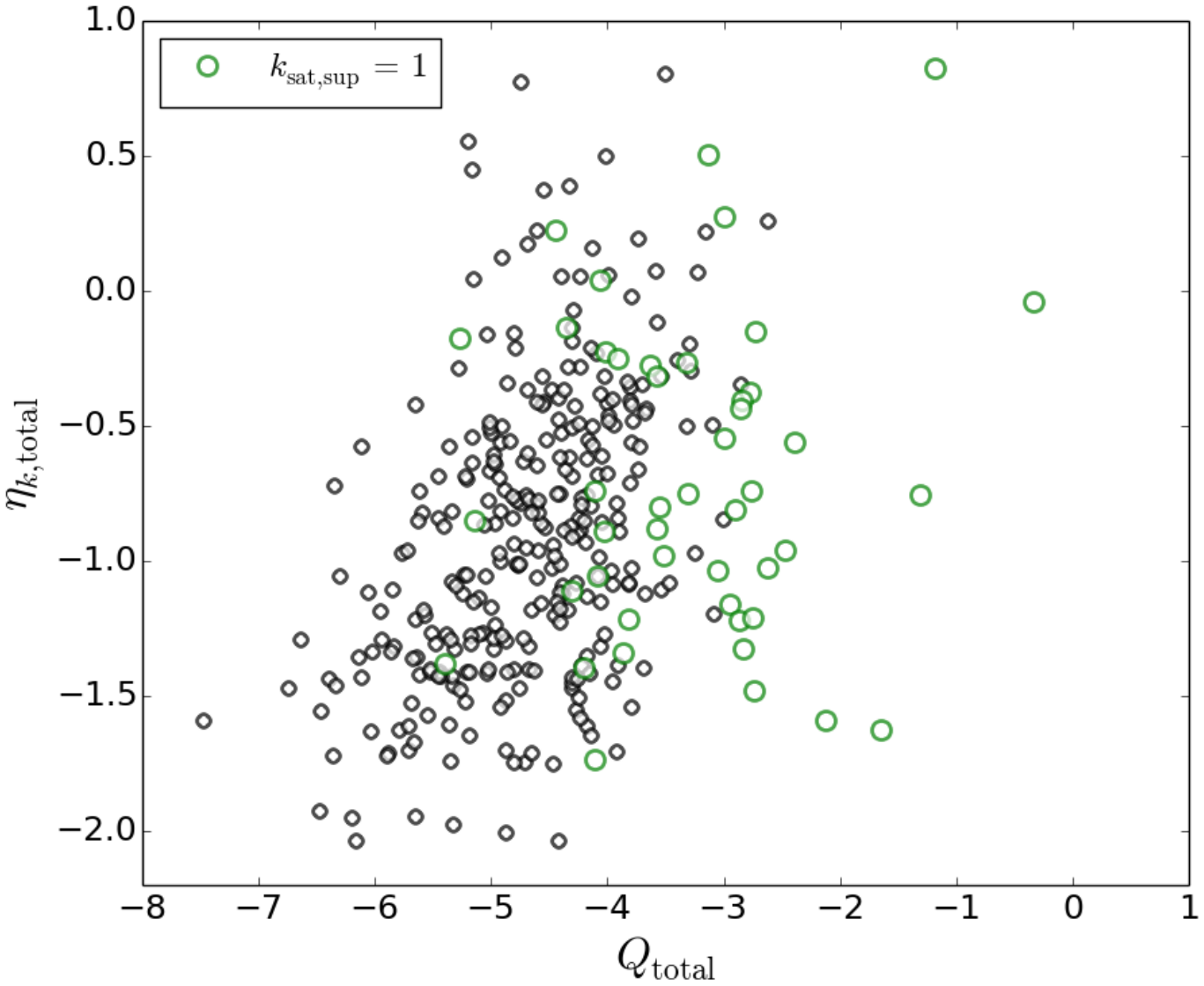
- 386 CIG galaxies
- 37 CIG galaxies (10% of the sample) with physically bound satellites
- 10 most isolated (no neighbours within 3 Mpc):



# Large Scale Structure (LSS)



# Influence of the environment



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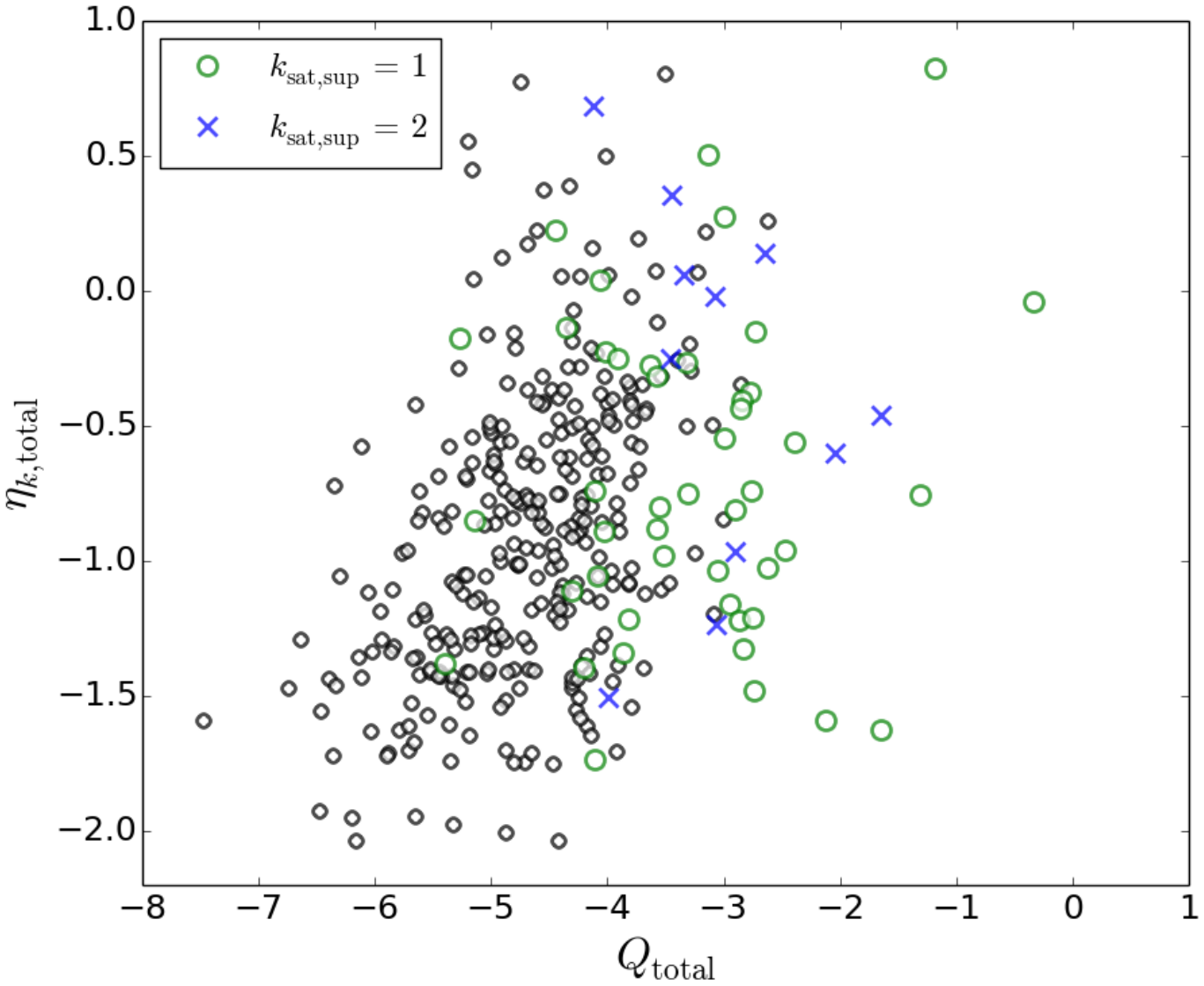

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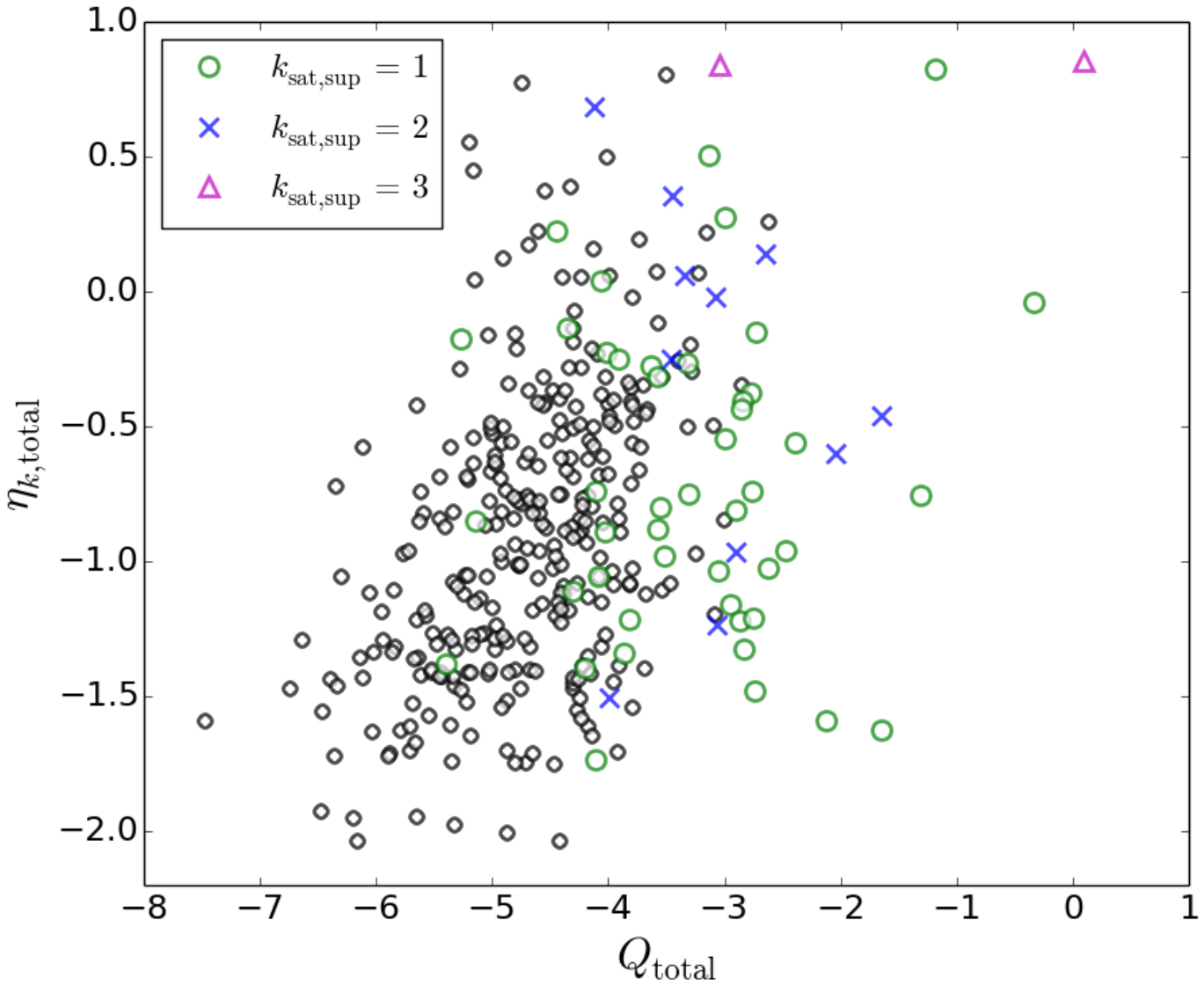

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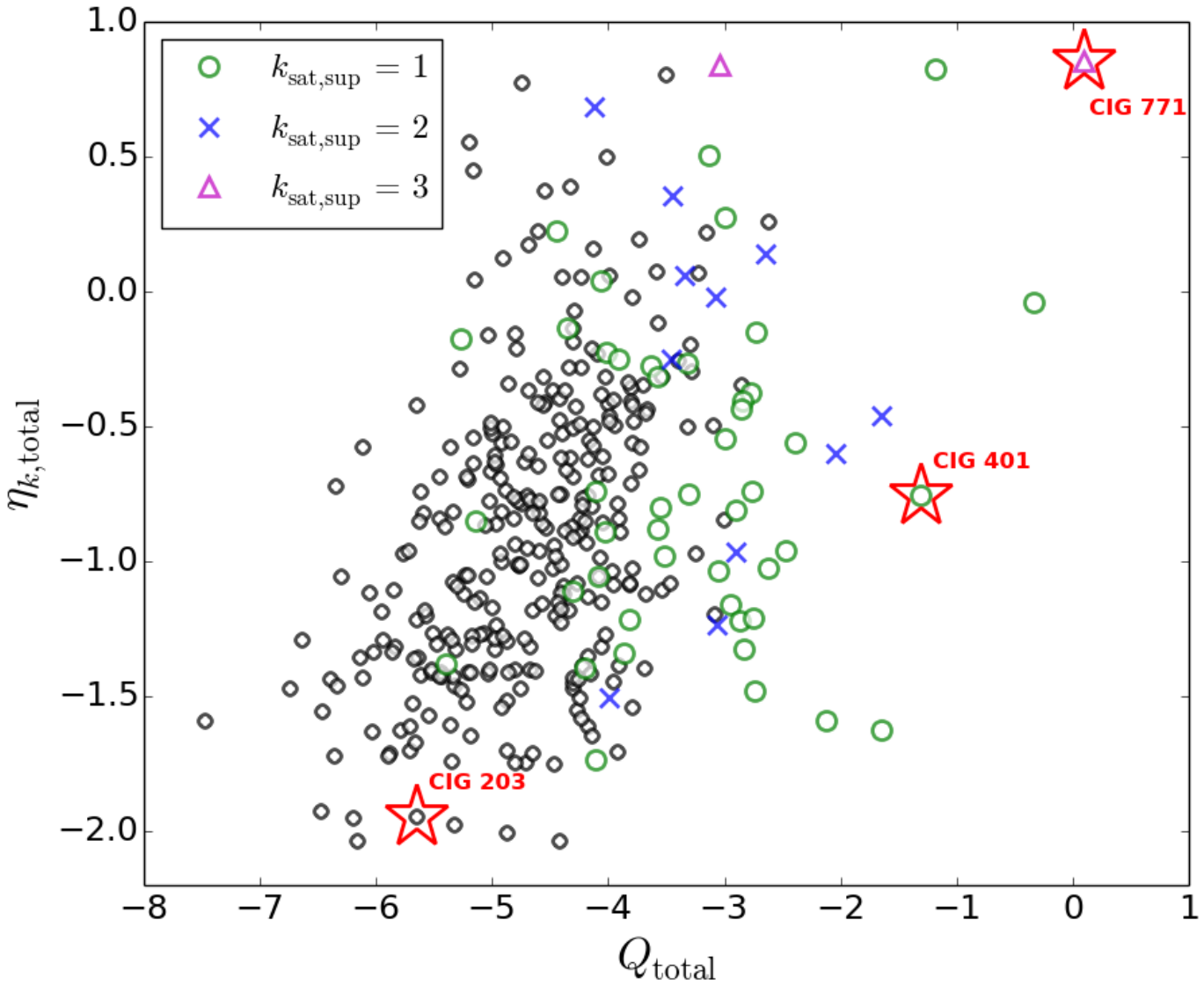
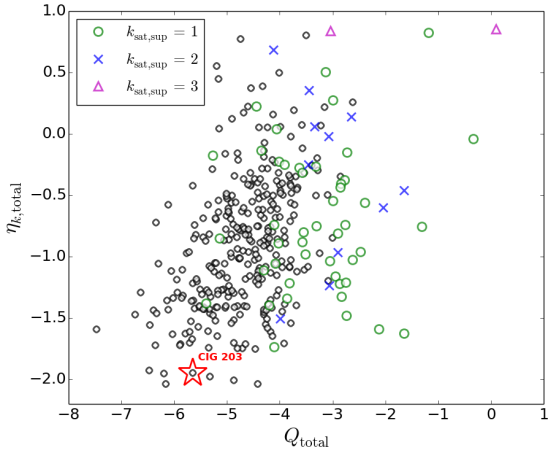
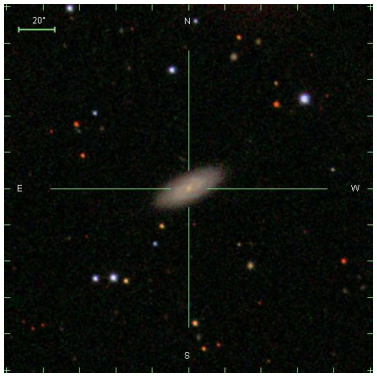
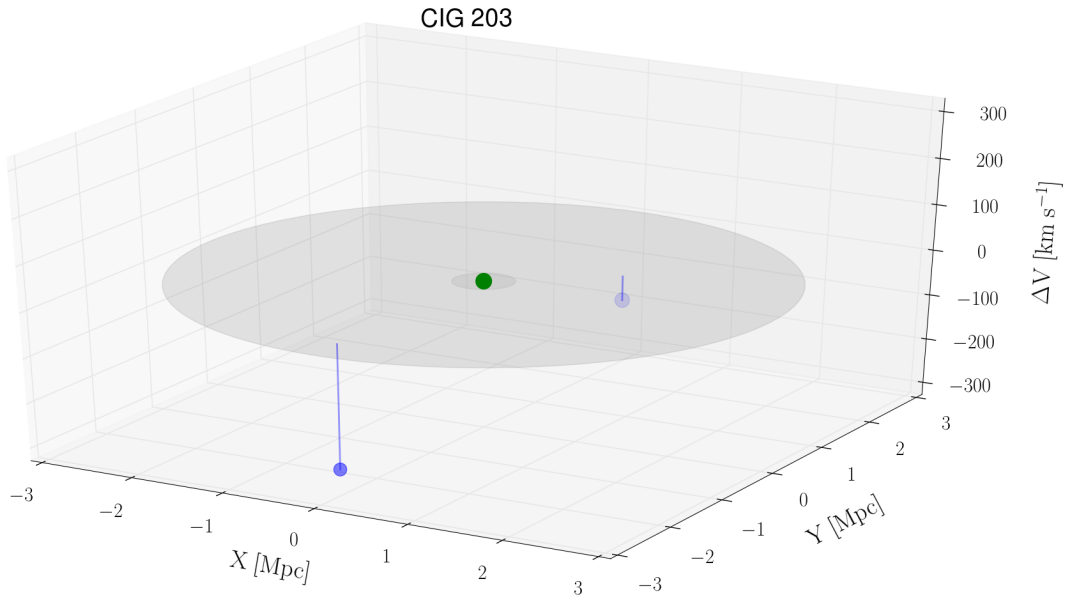


# 3-Dimensional environment

CIG 203



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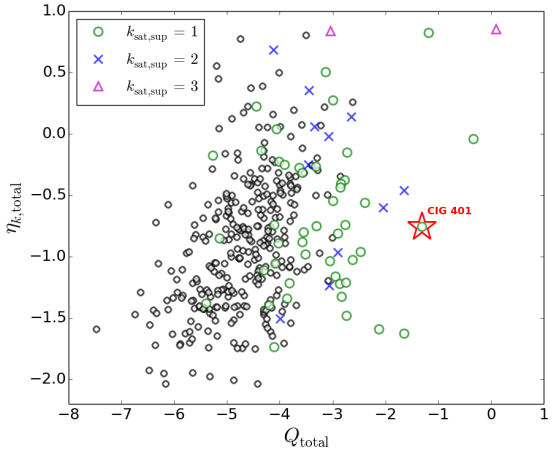


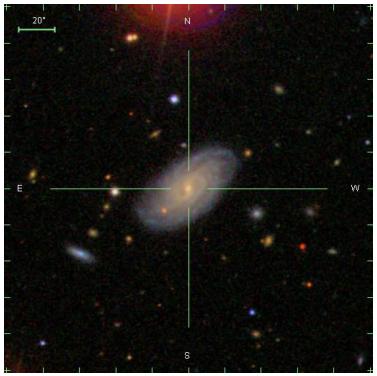


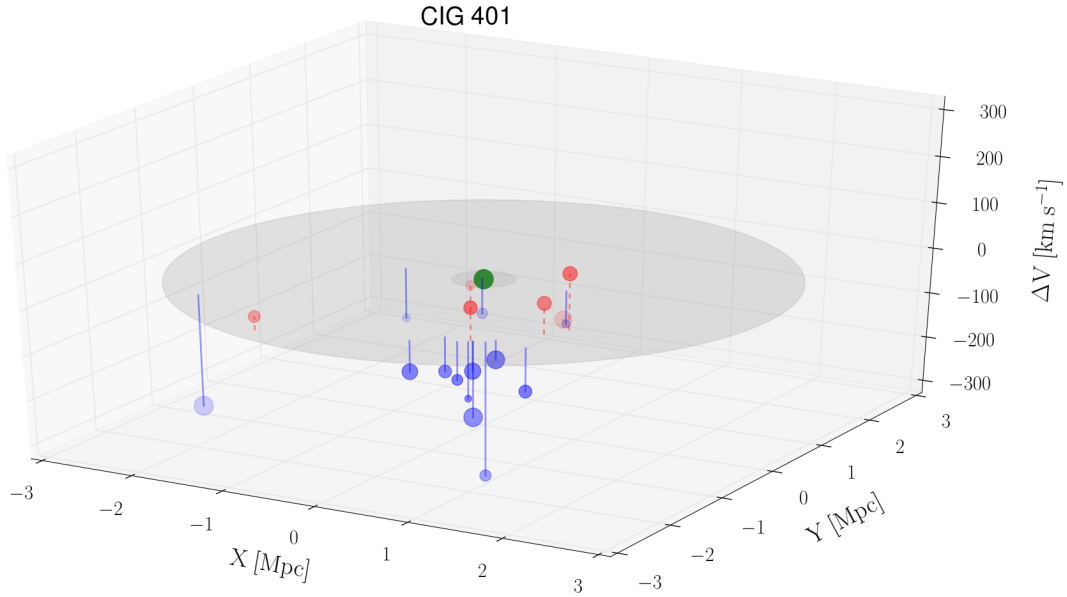

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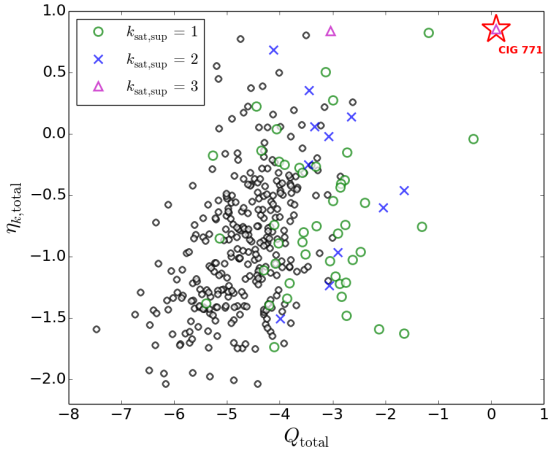
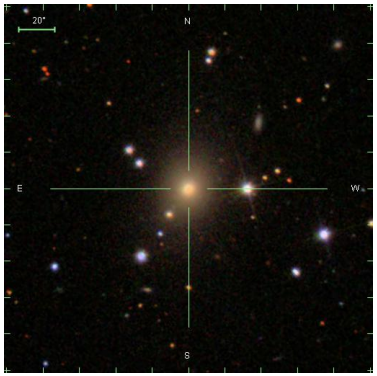
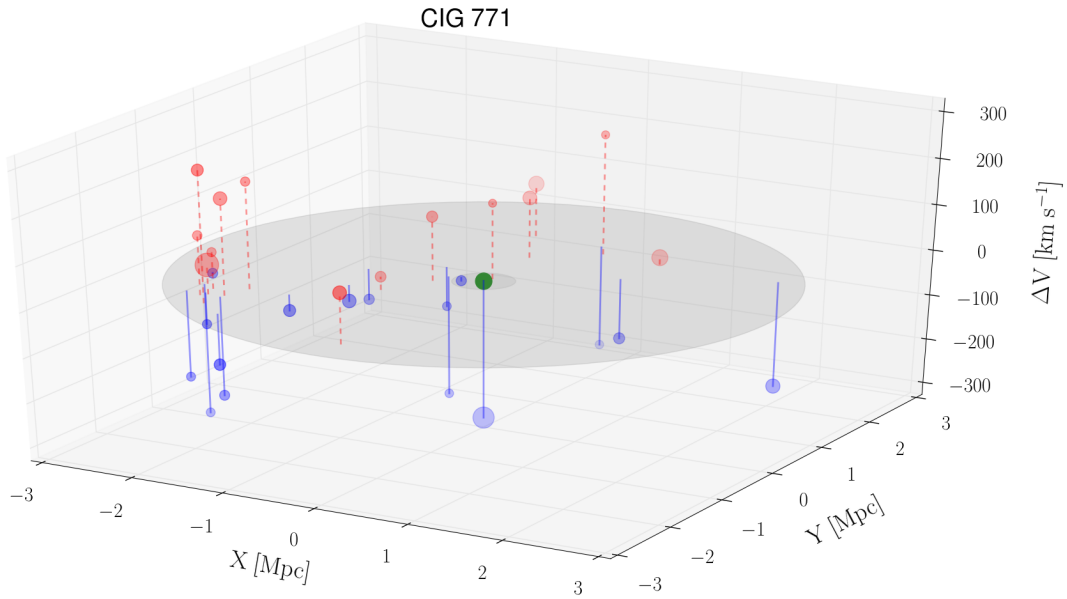
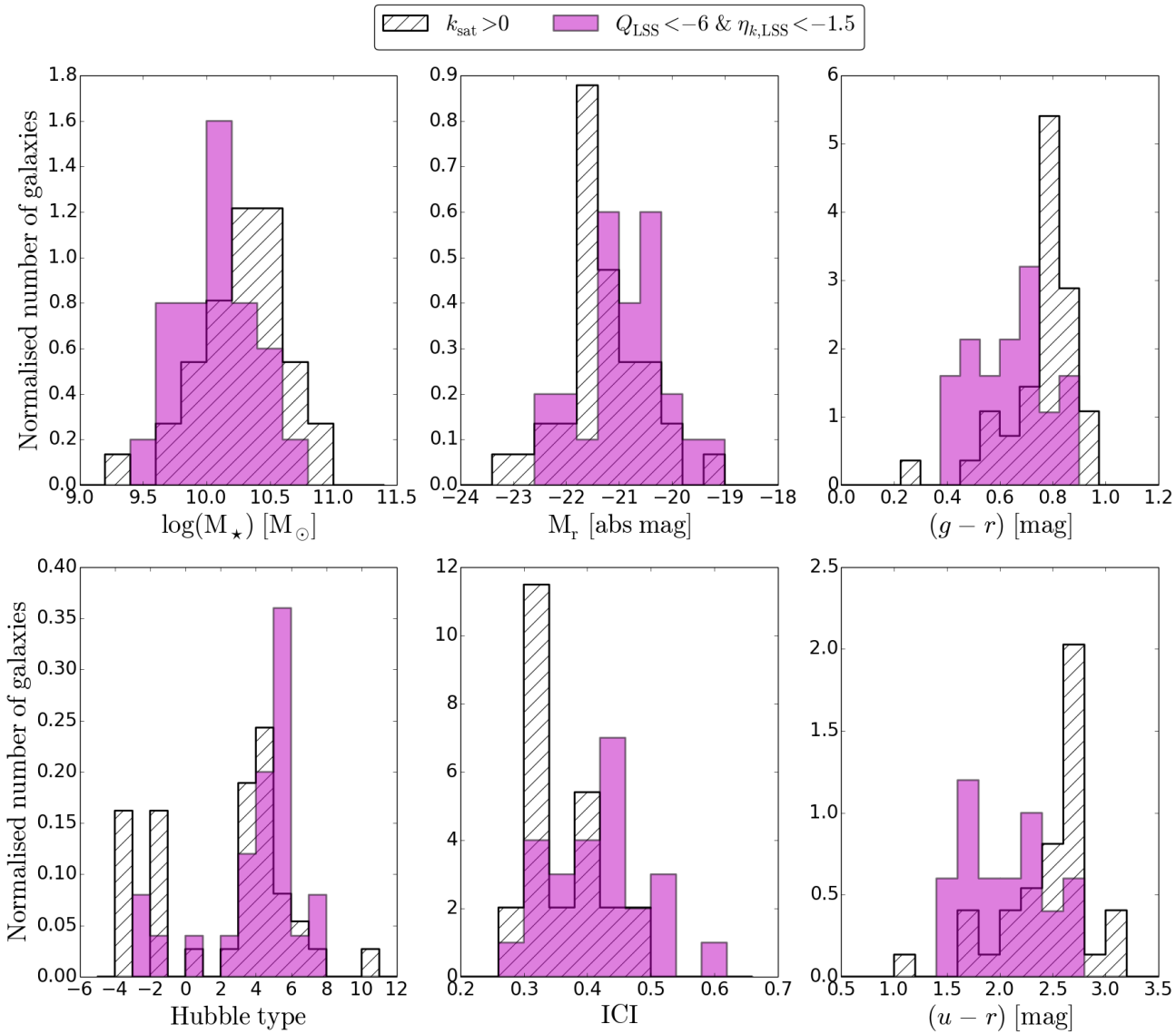


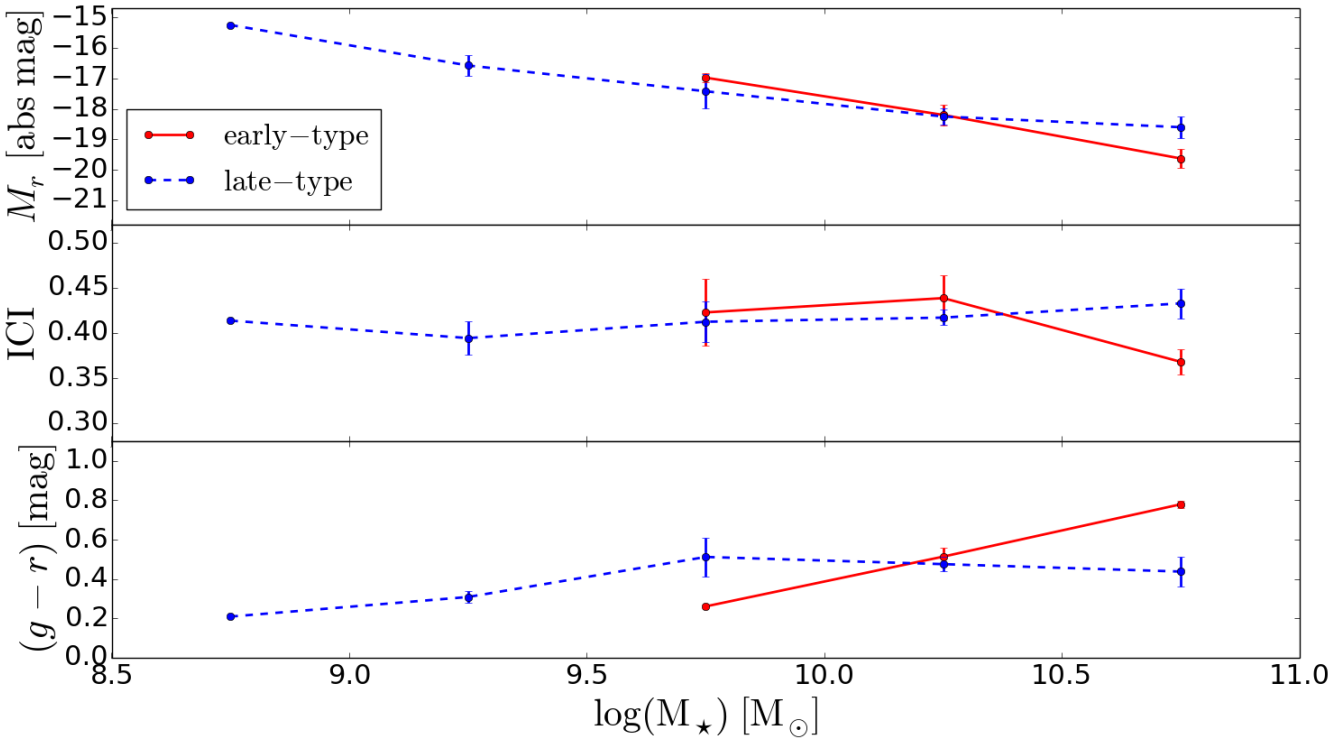



# Effects of the environment on primary galaxies



# Effects of the environment on satellites



# Conclusions

- *__10%__ of the sample have __physically bound satellites__*
- *__90%__ of the sample have no physically bound satellites but __may suffer interactions with fly-by galaxies__*
- *CIG galaxies show __continuous degree of connection__ with the LSS*
- *Clear segregation between __younger and older systems__, confirmed by the nature of the physically associated galaxies*

# Overview of the presentation

# Methodology

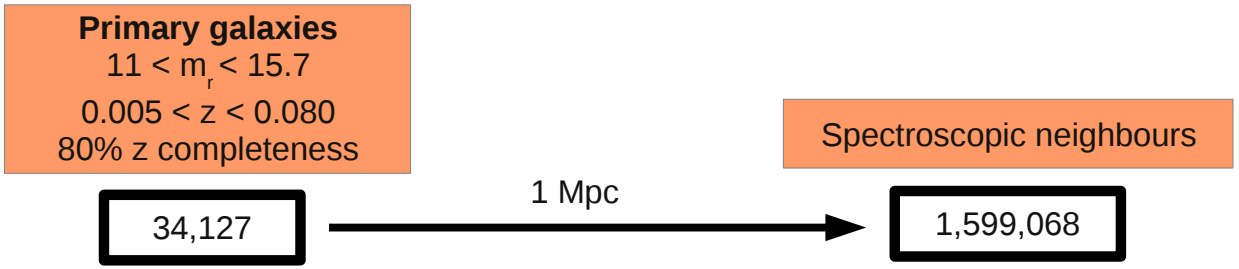
[Argudo-Fernández et al., in prep.]

**Primary galaxies**
$11 < m_r < 15.7$
$0.005 < z < 0.080$
80% z completeness

34,127

# Methodology

[Argudo-Fernández et al., in prep.]



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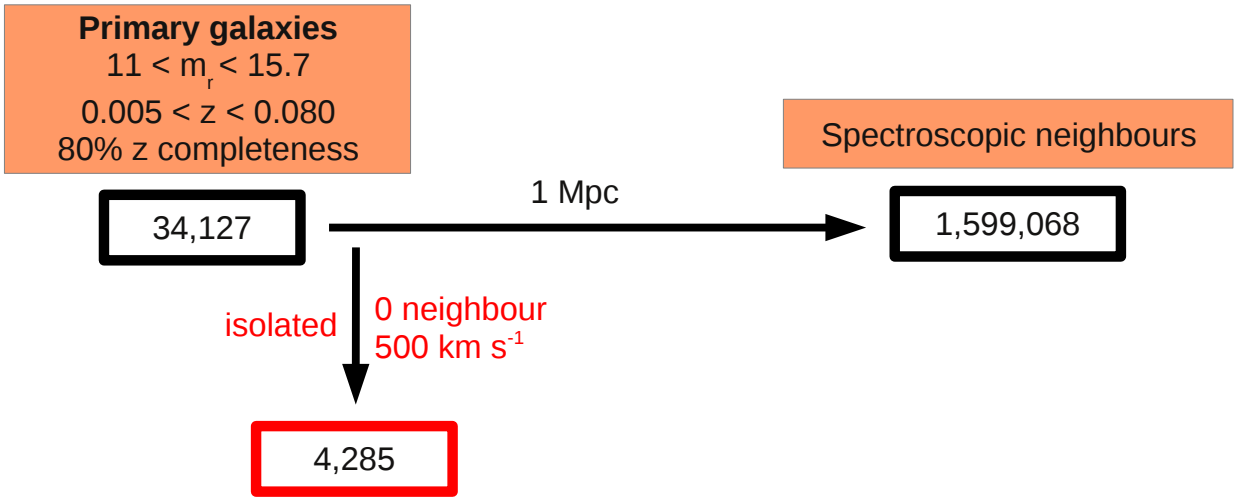

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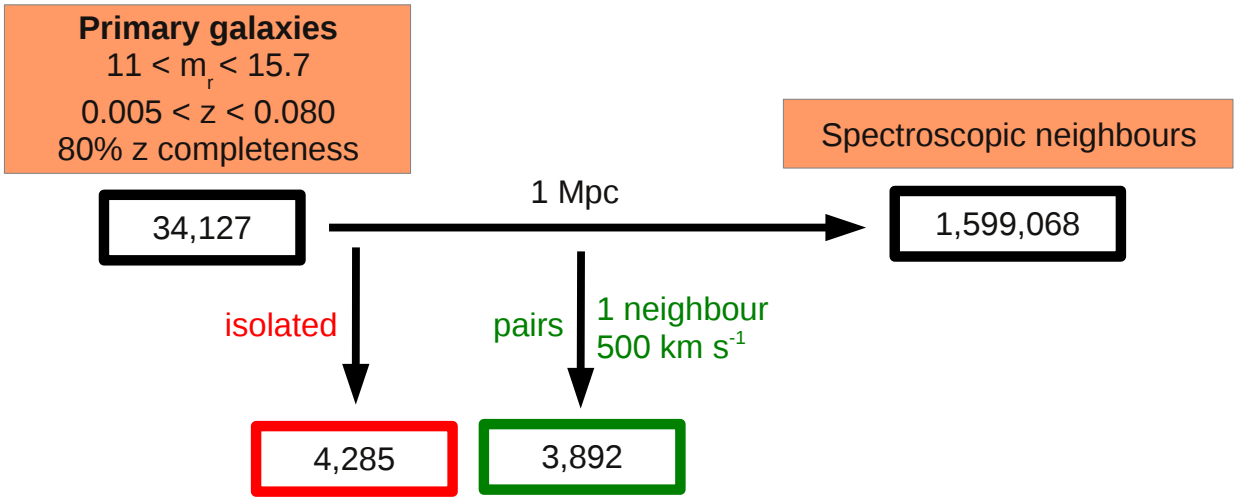
[Argudo-Fernández et al., in prep.]



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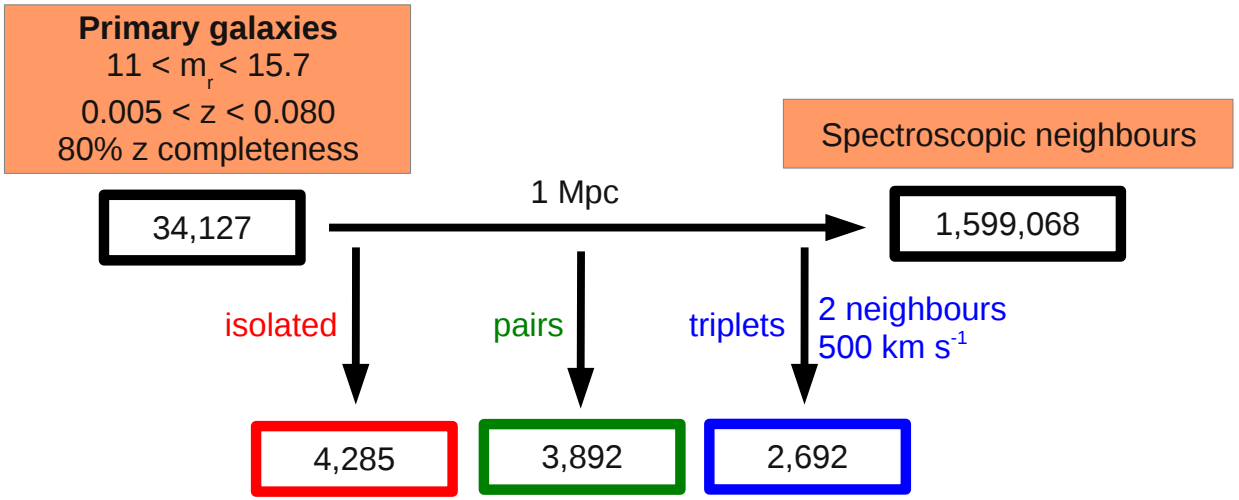

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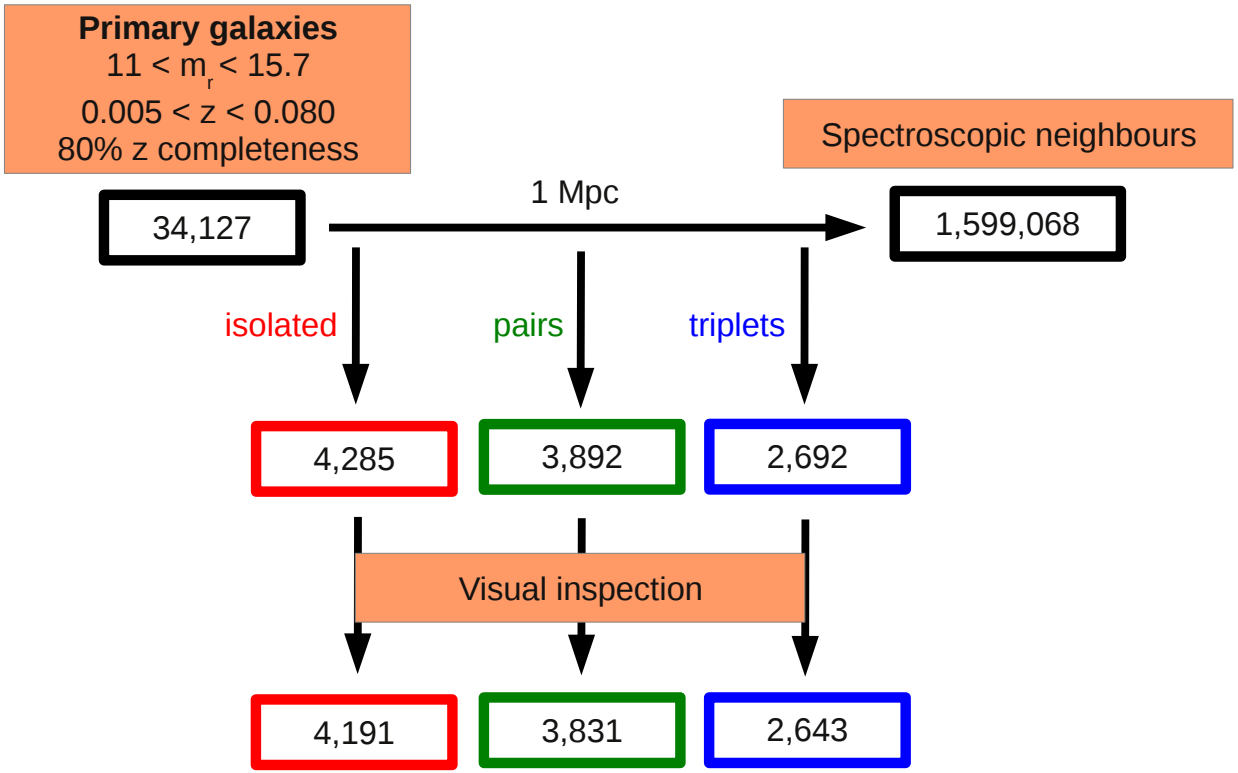
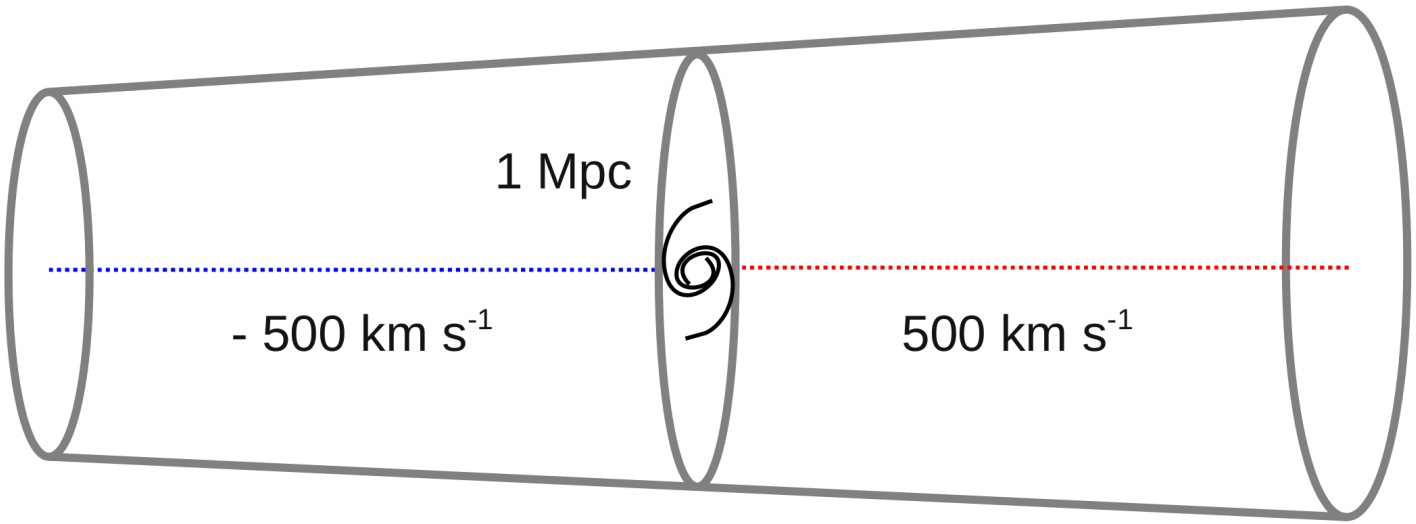
[Argudo-Fernández et al., in prep.]



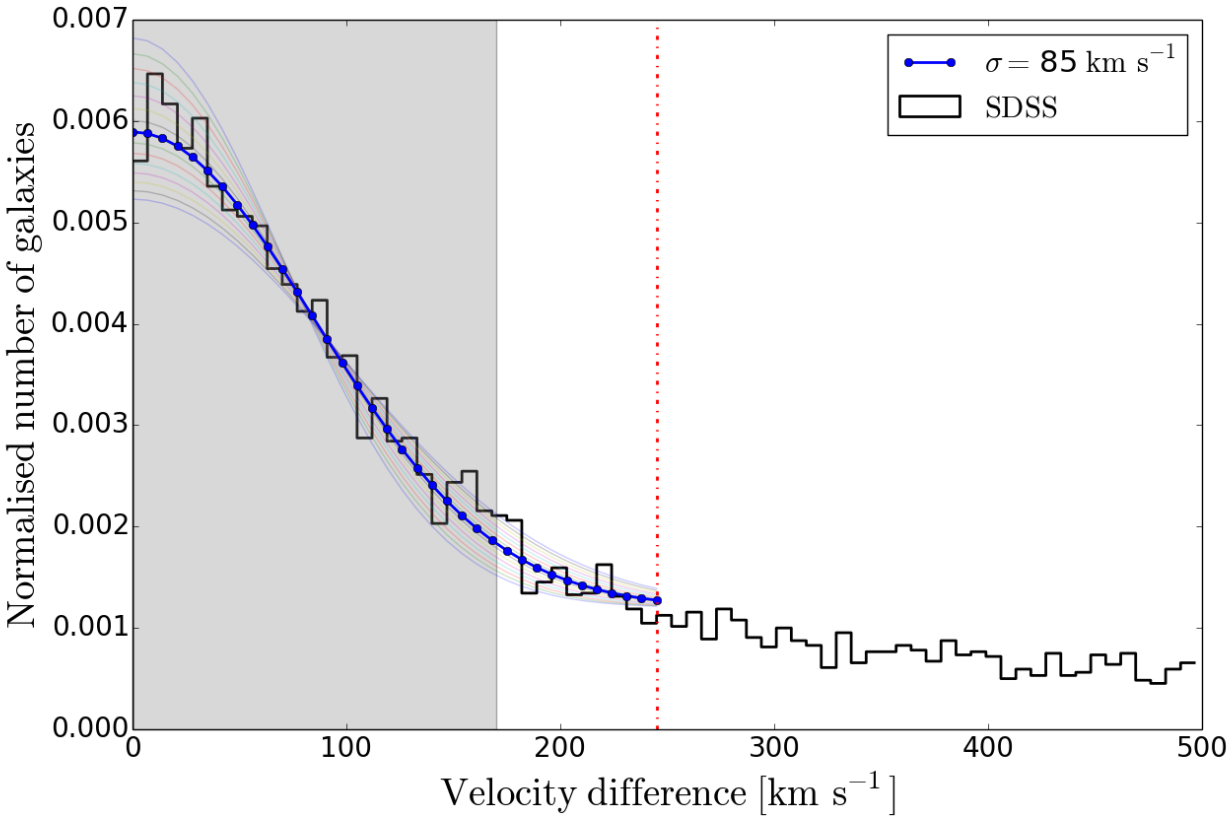
# Physical definition of isolated galaxies

- Field radius of 1 Mpc: crossing time $\sim$ 5.2 Gyr
- $\Delta v \leq 500\,\mathrm{km\,s^{-1}}$ to avoid physical associations
- 4,191 isolated galaxies



# Physical definition of isolated pairs & triplets

- Gaussian distribution $\sigma = 85\,\mathrm{km\,s^{-1}}$
- Pairs & triplets: $\Delta v \leq 170\,\mathrm{km\,s^{-1}}$ & $d \leq 450\,\mathrm{kpc}$
- Close pairs & triplets: $\Delta v \leq 170\,\mathrm{km\,s^{-1}}$ & $d \leq 160\,\mathrm{kpc}$



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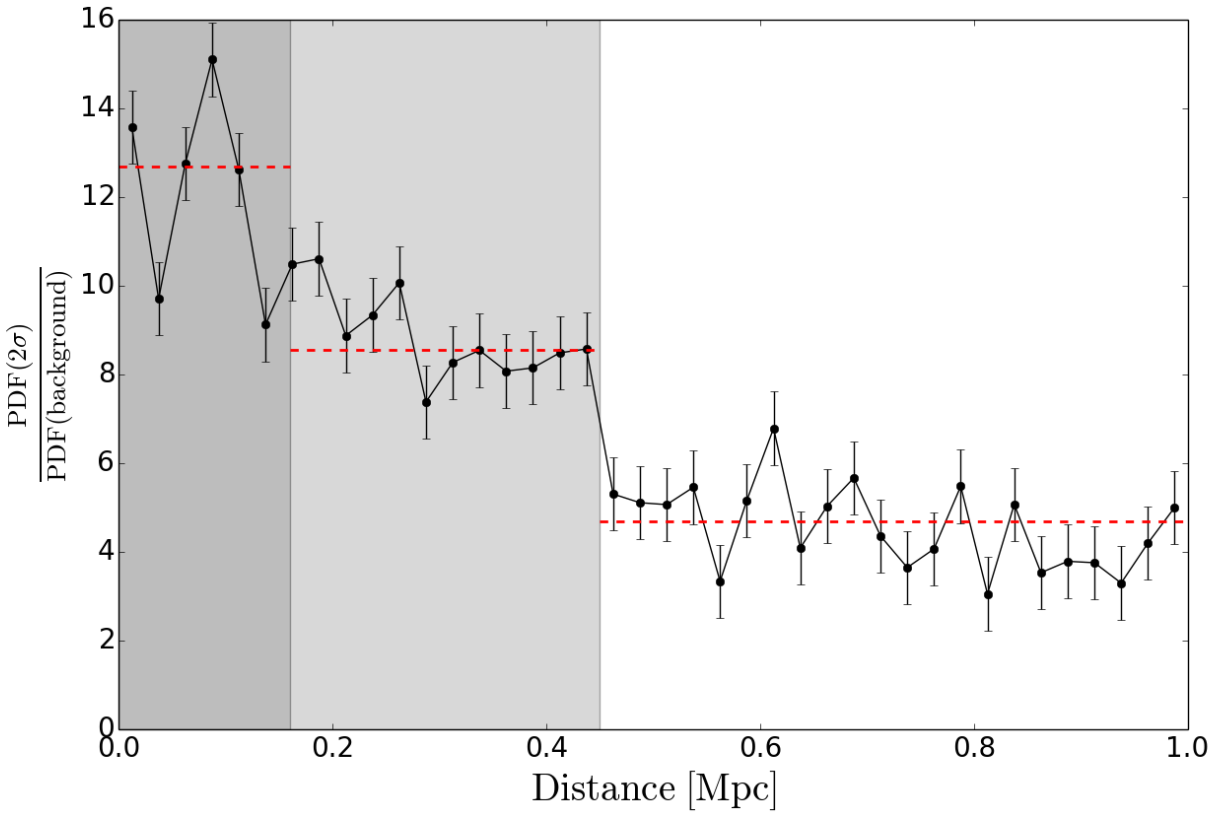

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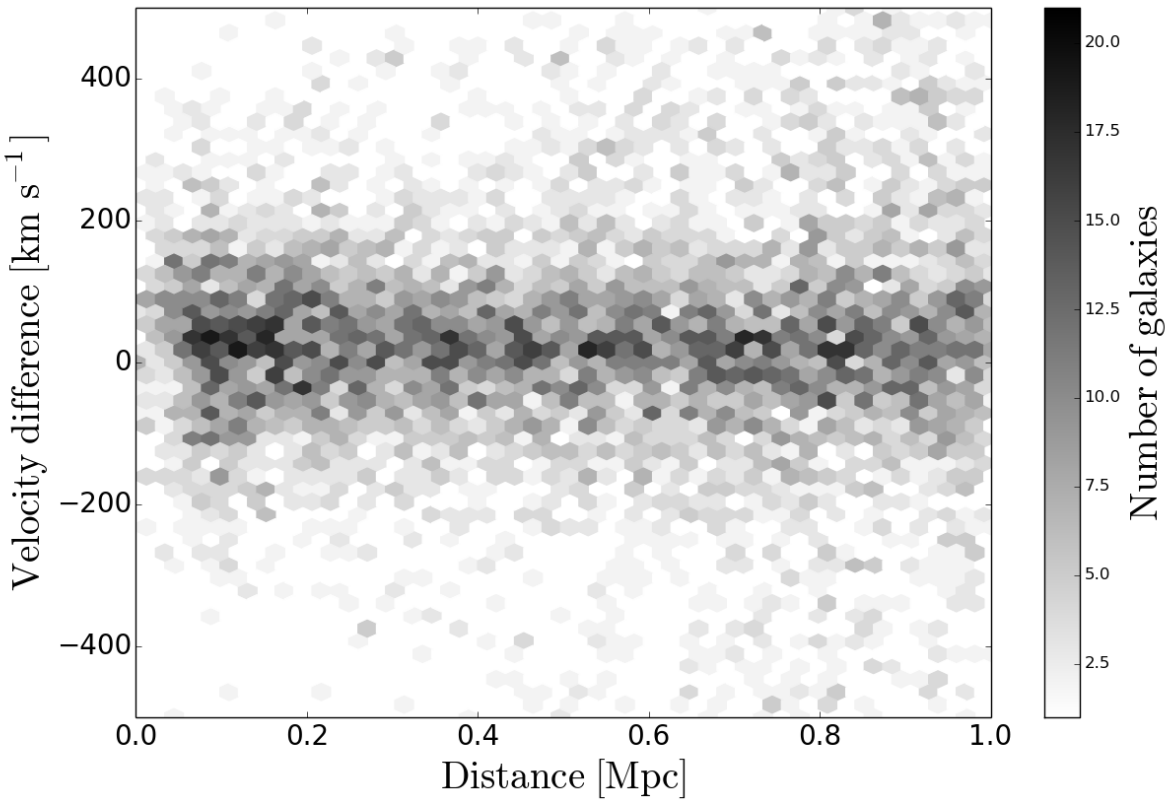

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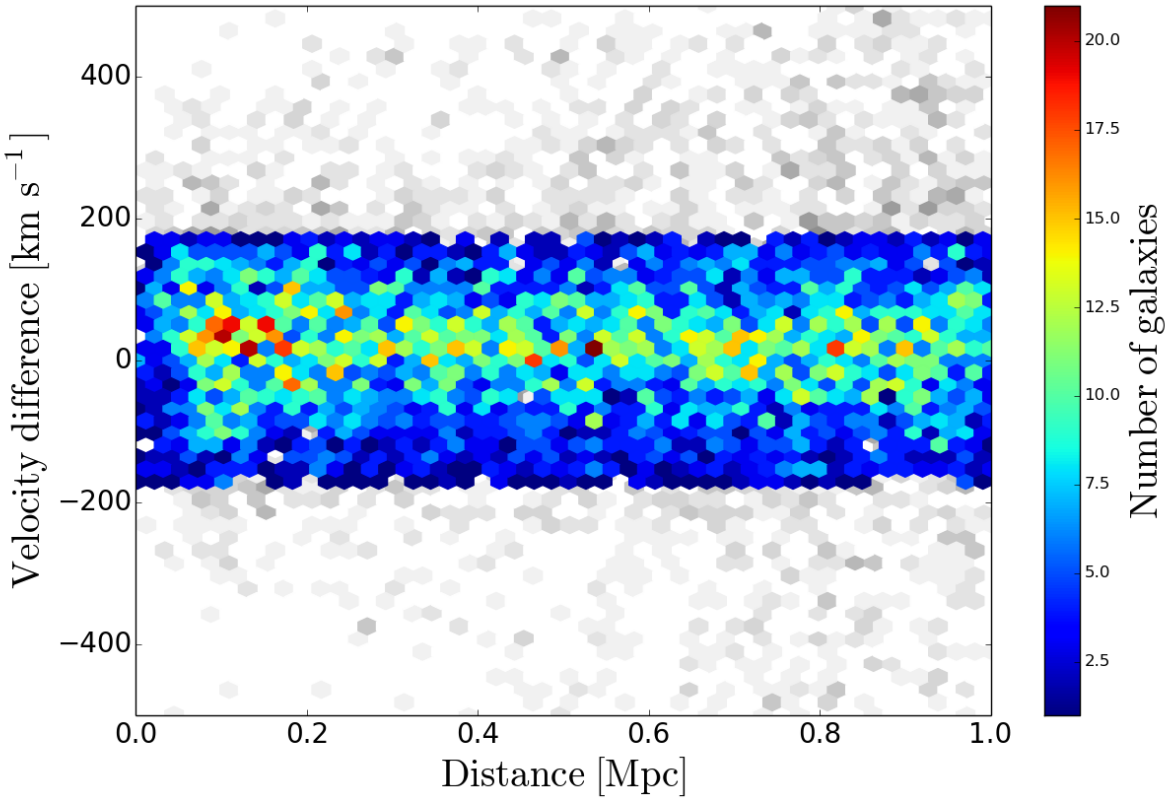

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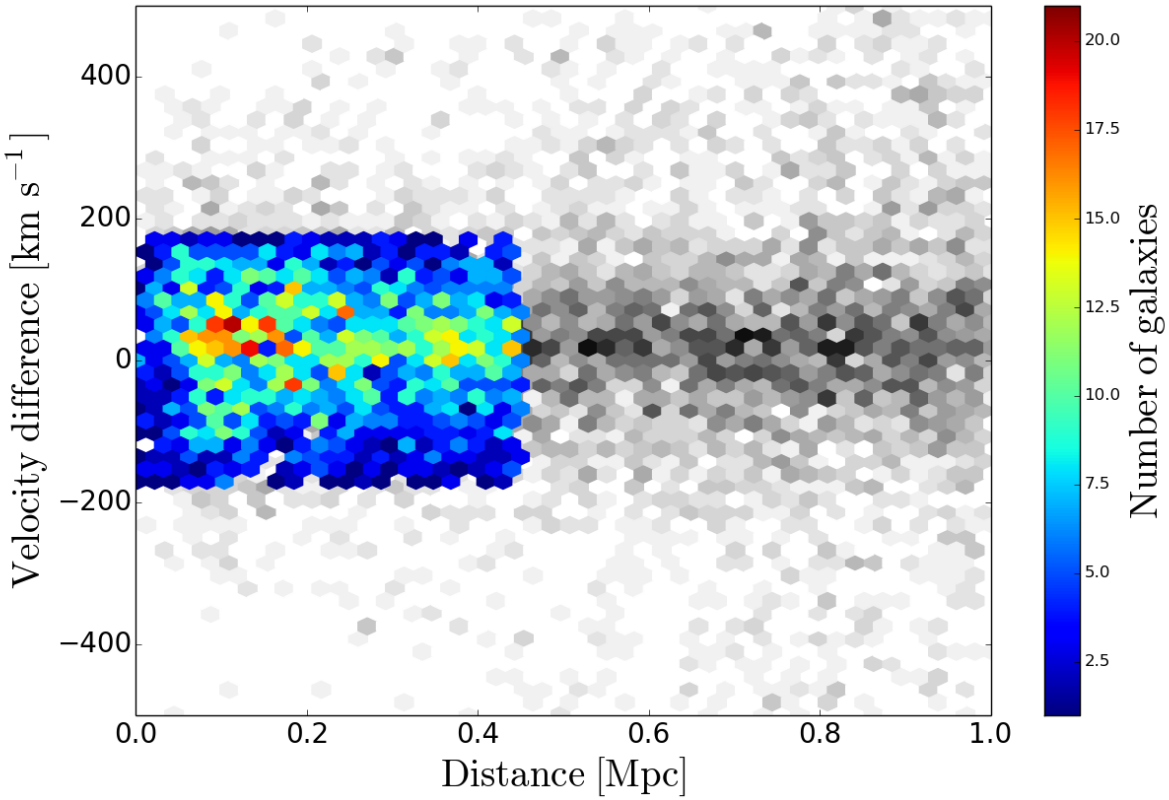

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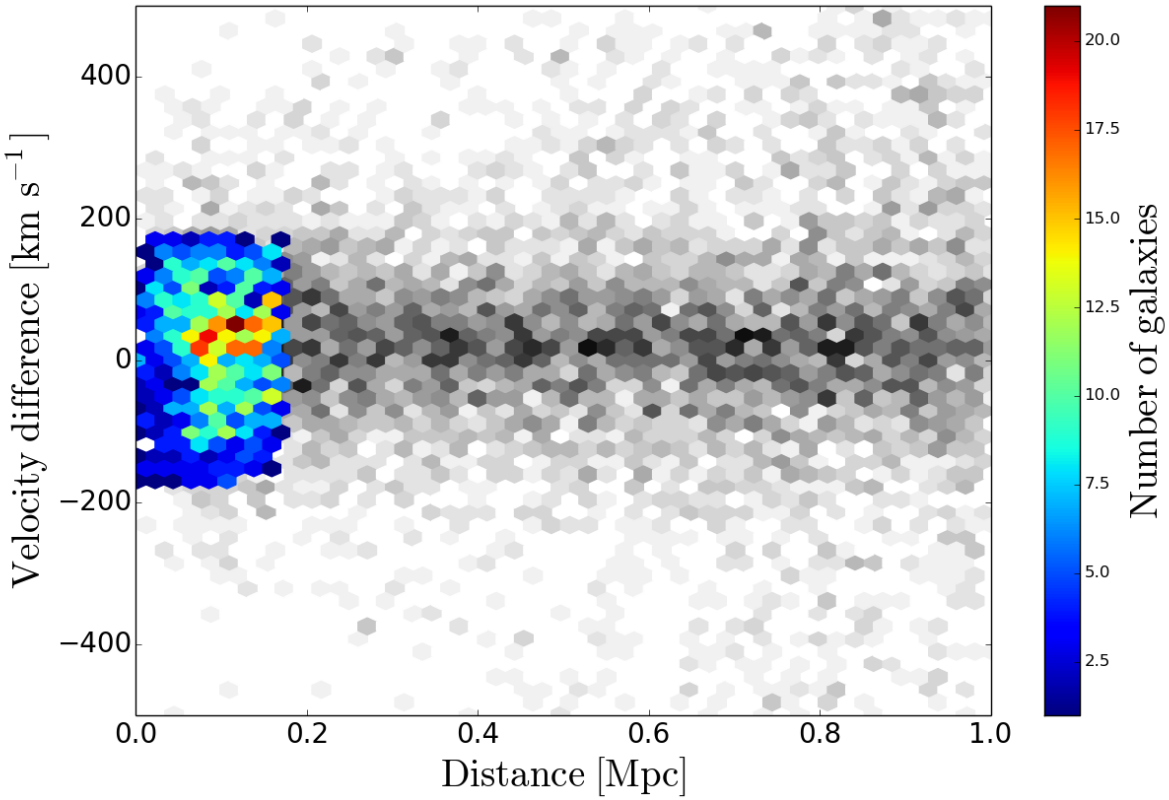
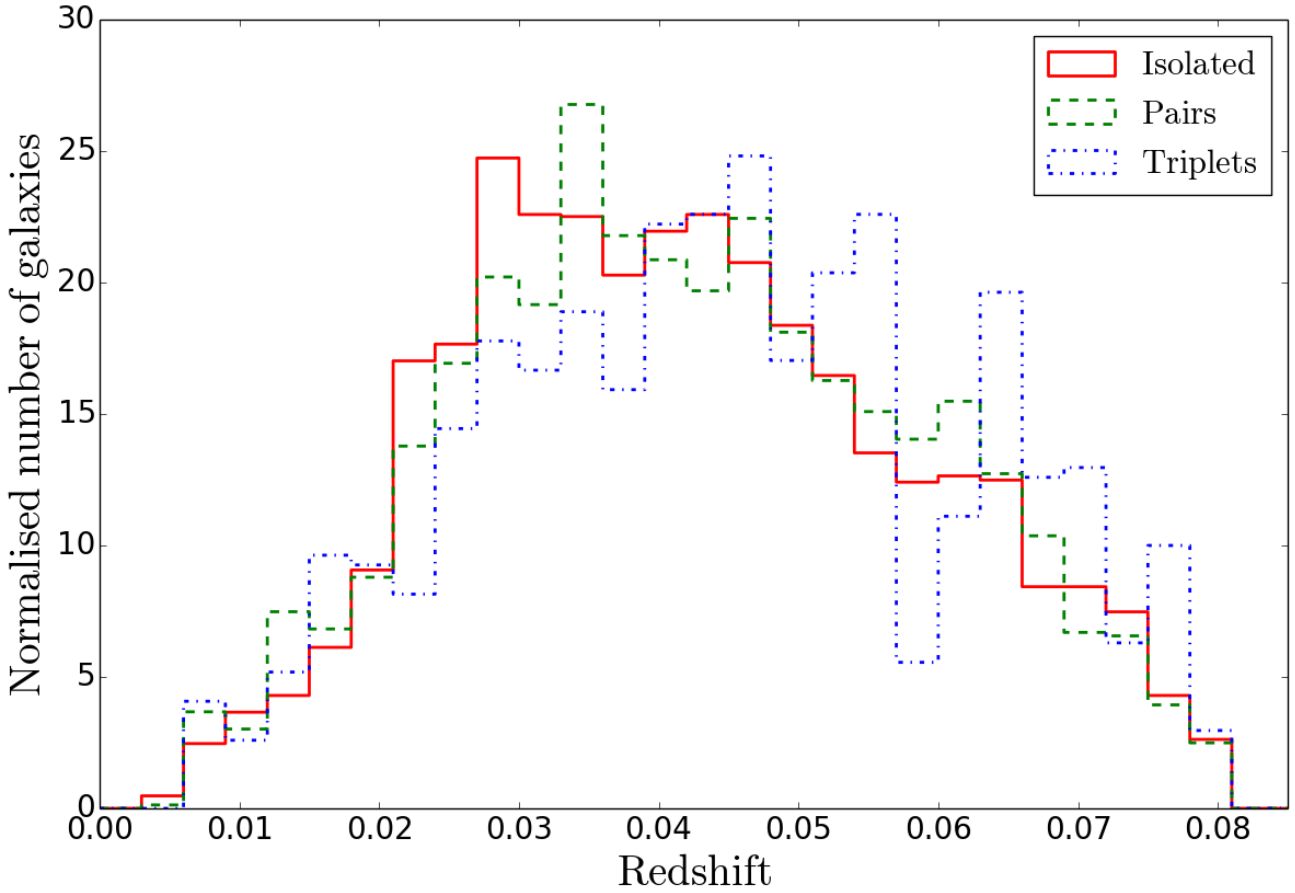


# Redshift distributions

- 4,191 isolated galaxies — **S**loan **I**solated **G**alaxies (SIG)
- 1,270 isolated pairs — **S**loan **I**solated **P**airs (SIP)
- 300 isolated triplets — **S**loan **I**solated **T**riplets (SIT)



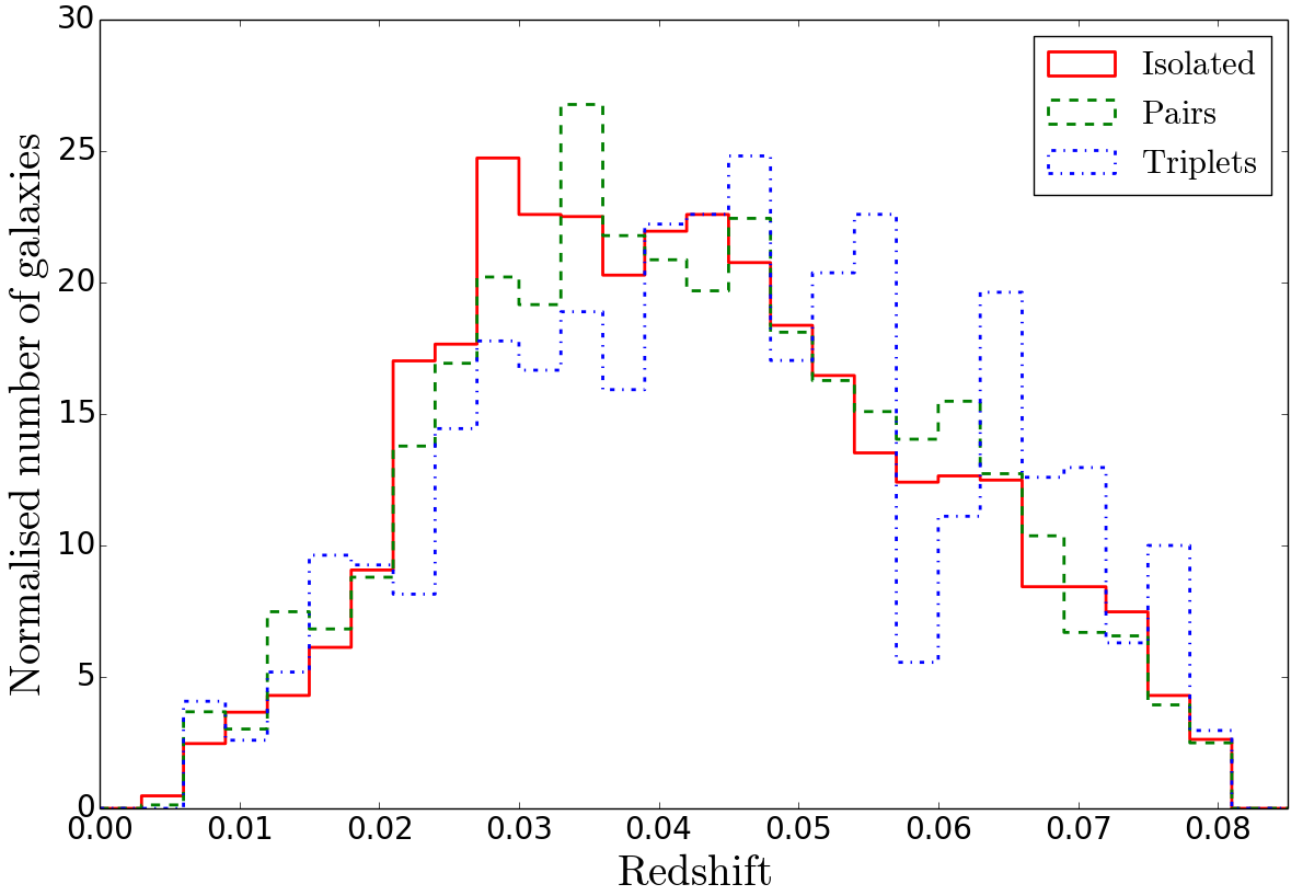
# Redshift distributions

- 4,191 isolated galaxies
- 494 isolated pairs
- 45 isolated triplets

**S**loan **I**solated **G**alaxies (SIG)

**S**loan **I**solated **P**airs (SIP)

**S**loan **I**solated **T**riplets (SIT)



# Redshift distributions

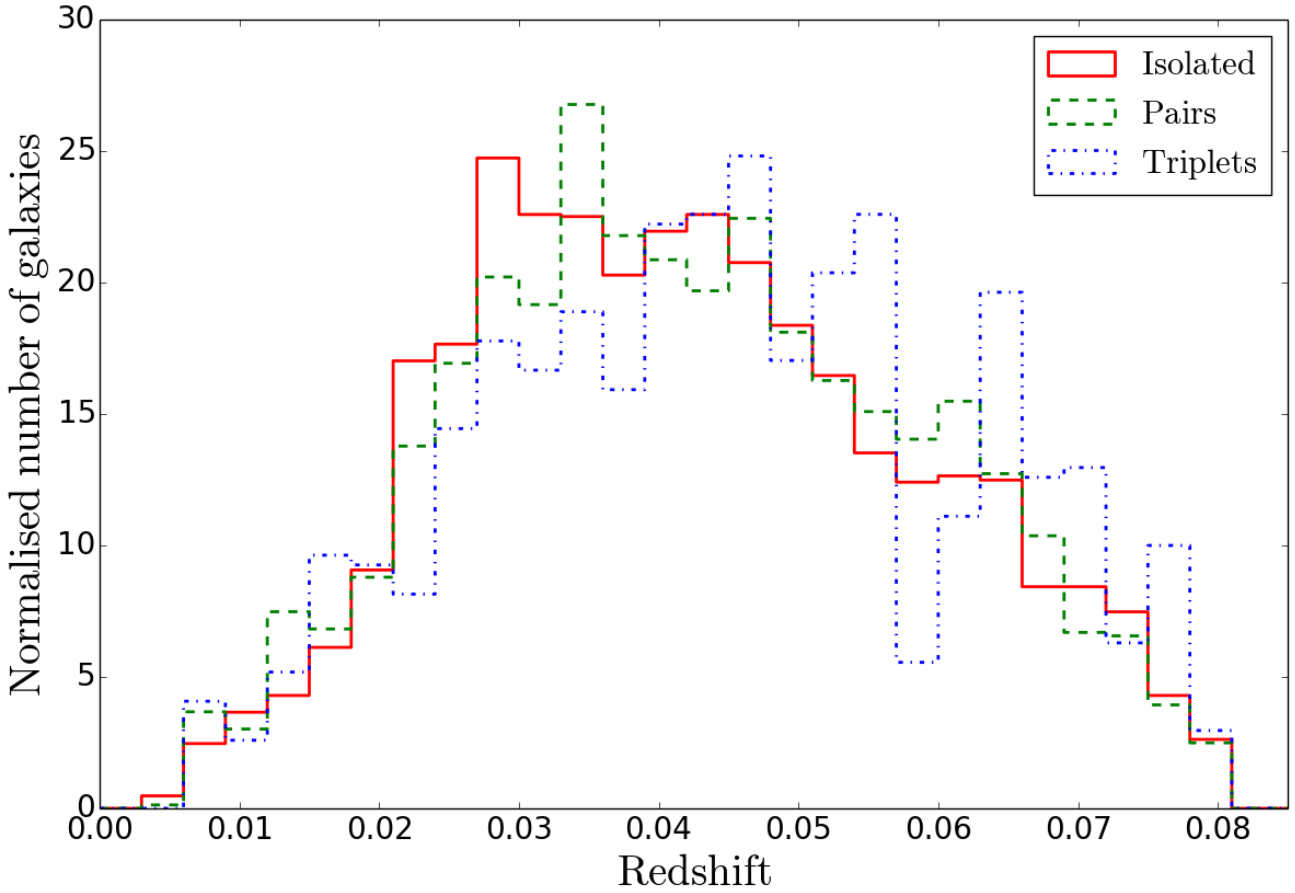
No neighbours up to 5 Mpc

- 801 isolated galaxies
- 217 isolated pairs
- 16 isolated triplets

**S**loan **I**solated **G**alaxies (SIG)

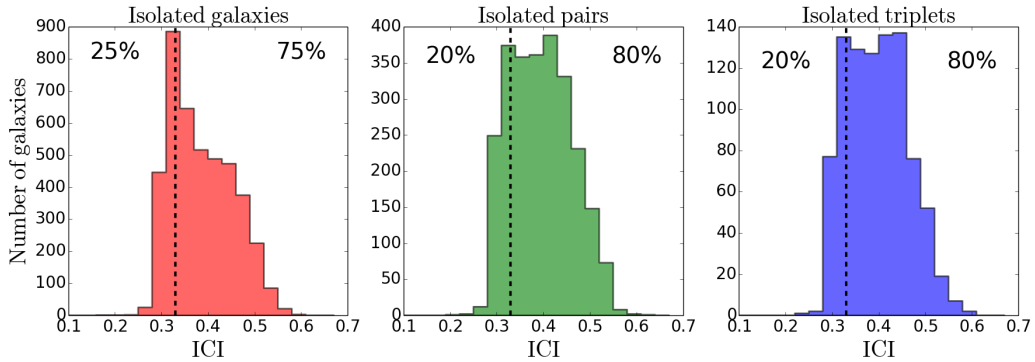
**S**loan **I**solated **P**airs (SIP)

**S**loan **I**solated **T**riplets (SIT)



# Morphology segregation?

ICI = 0.33



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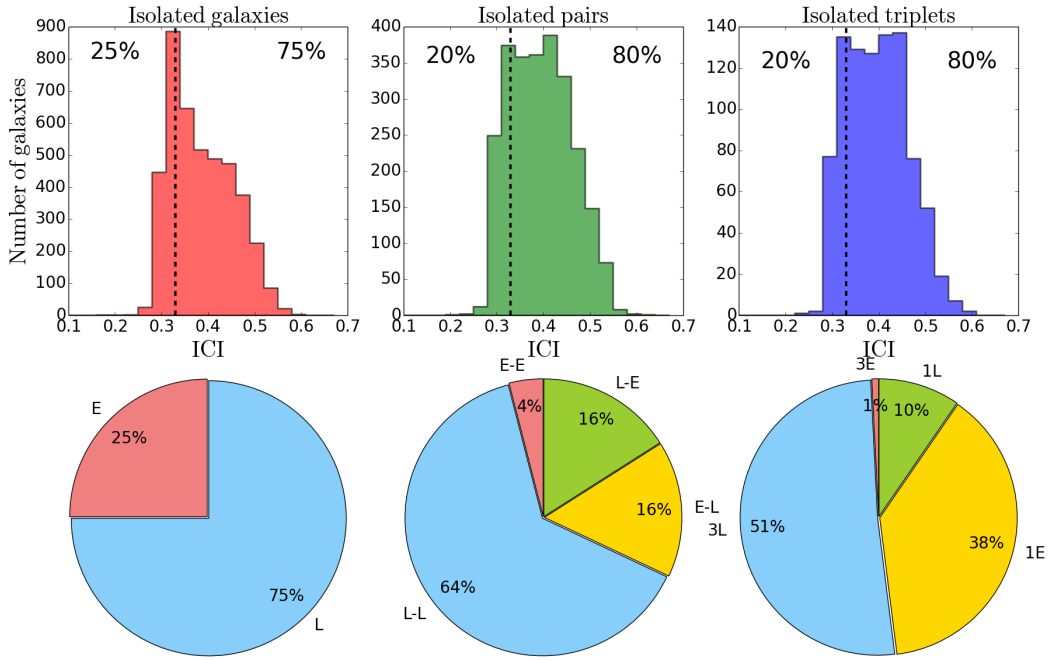
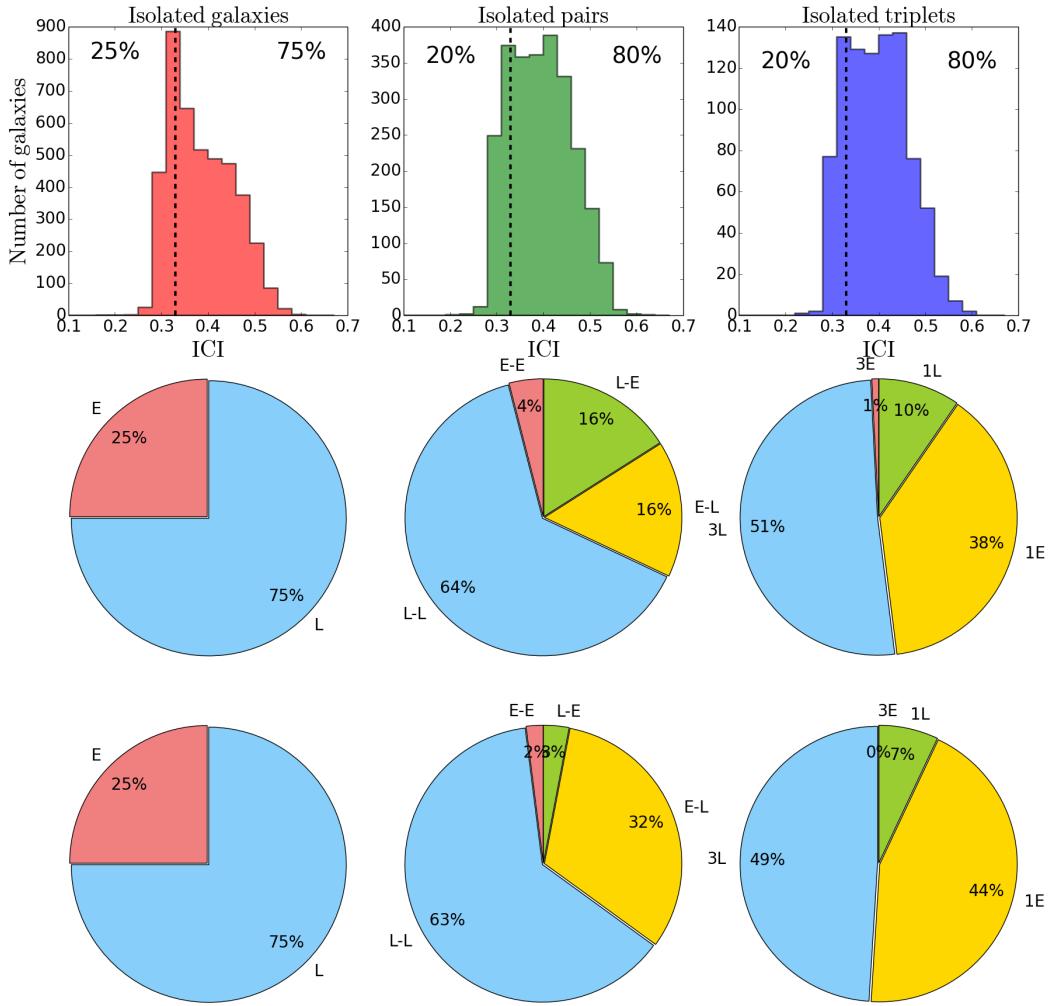


# Morphology segregation?

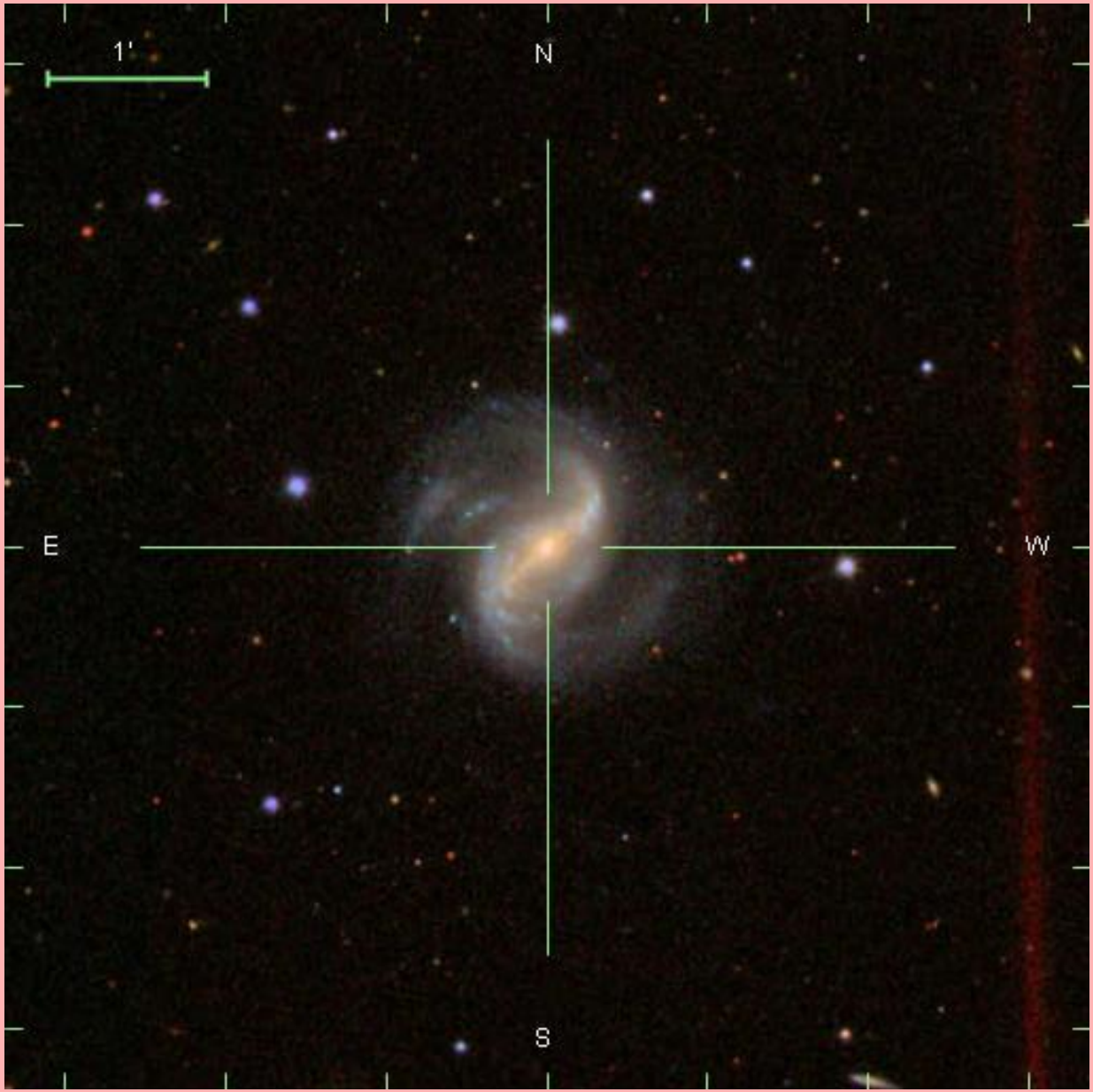






# Isolated galaxies





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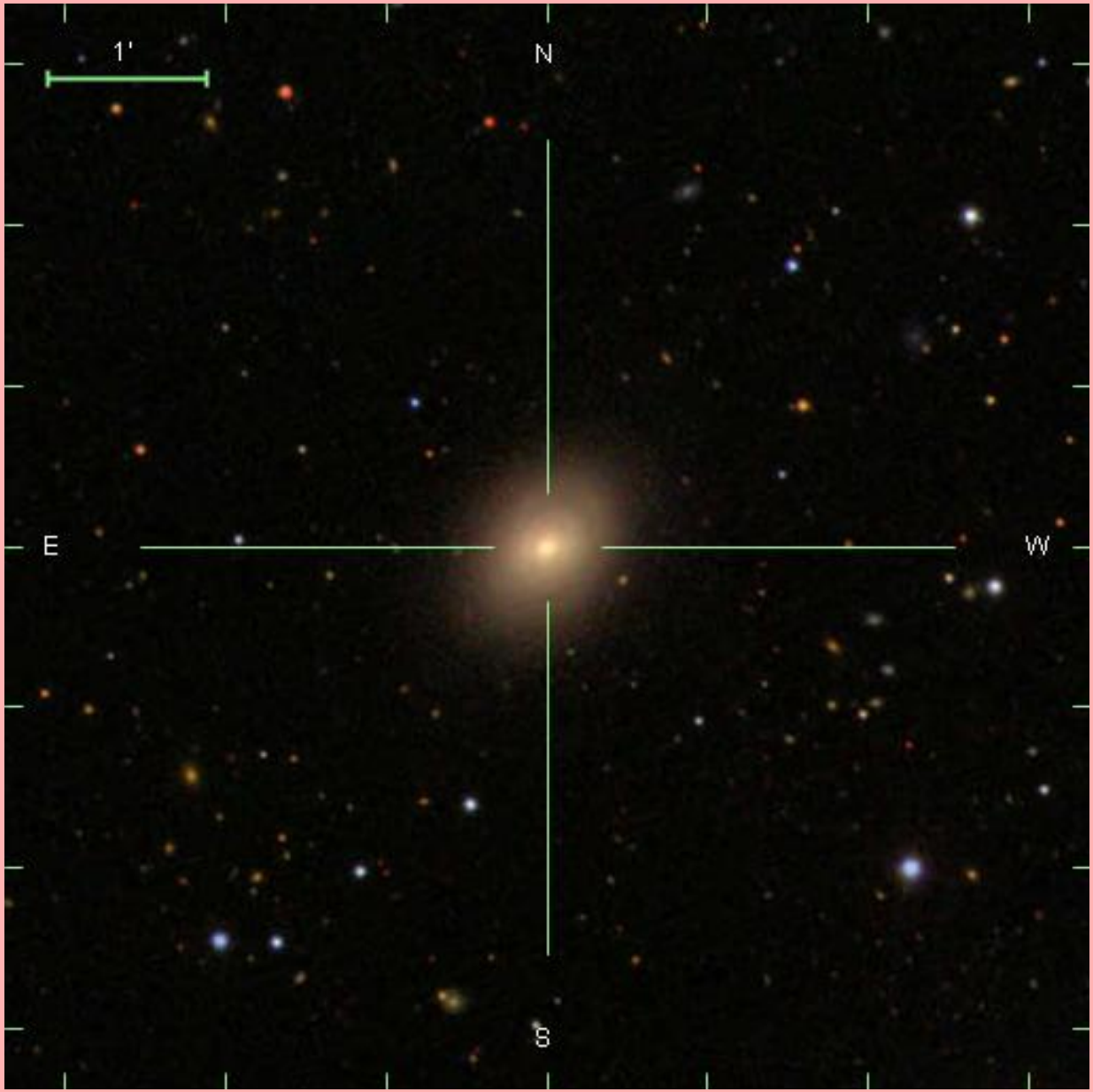
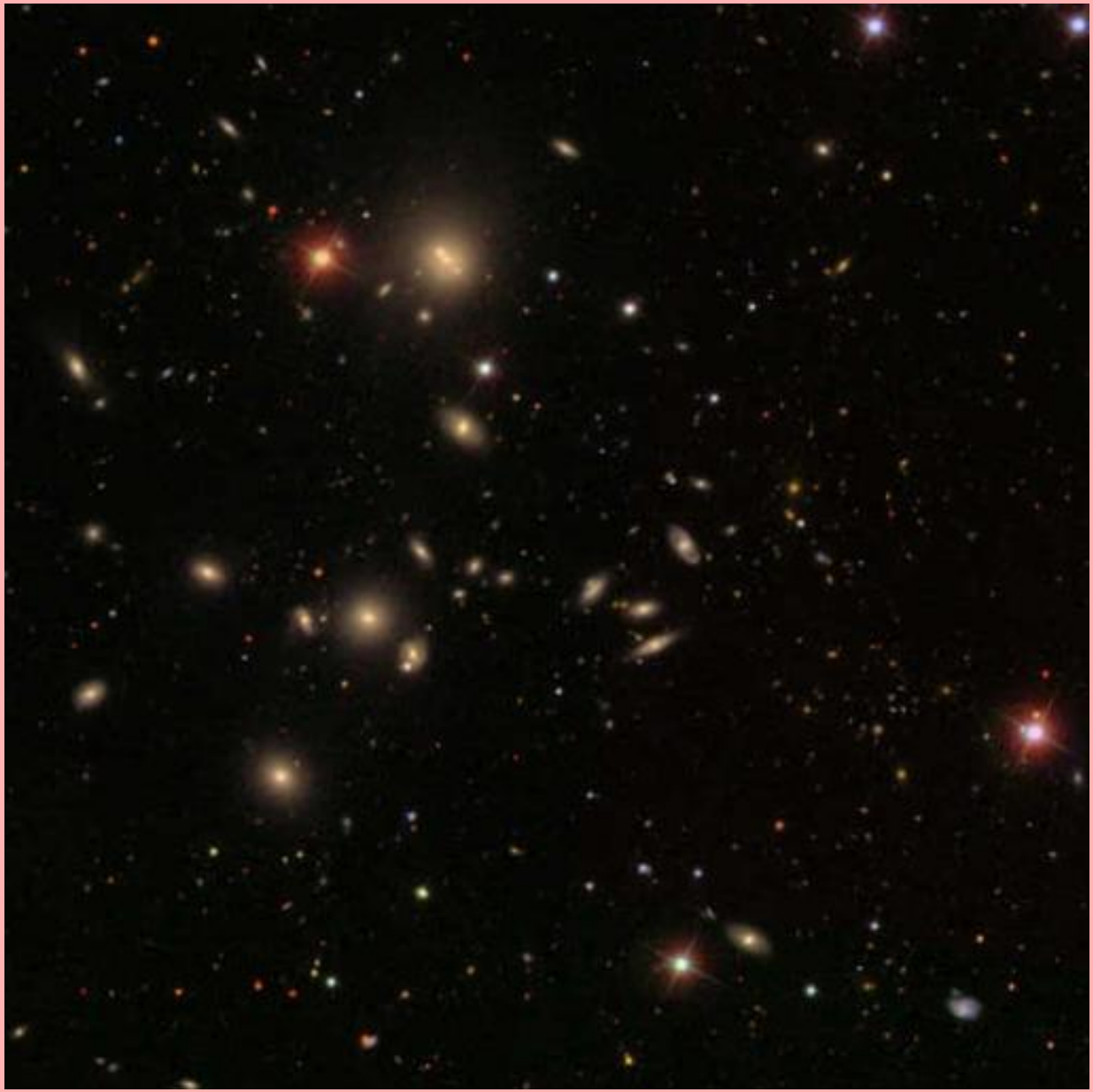


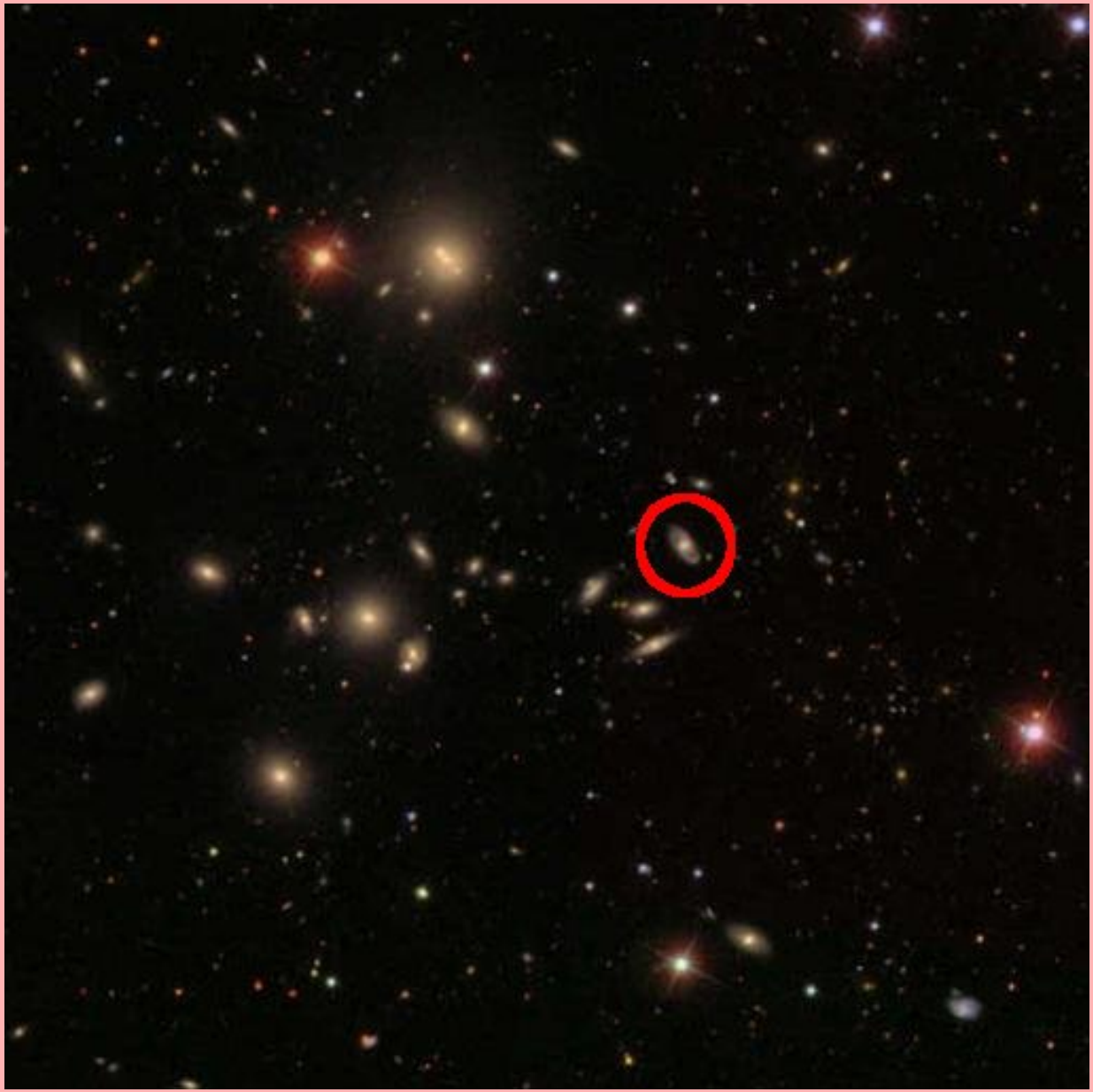
# Isolated galaxies

SIG 3962



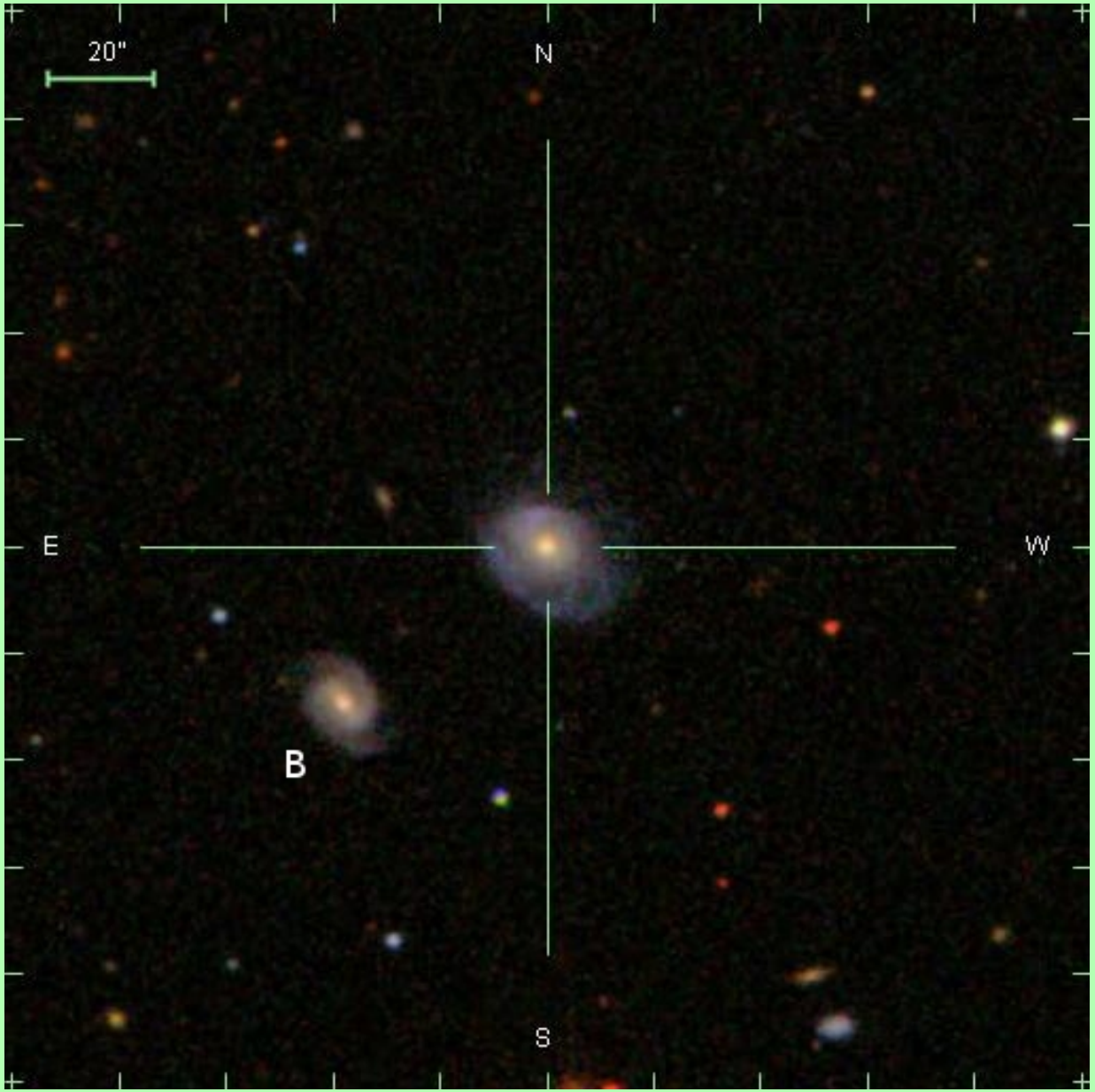
# Isolated galaxies

Abell 1185, $\Delta v = 11{,}362\,\mathrm{km\,s^{-1}}$



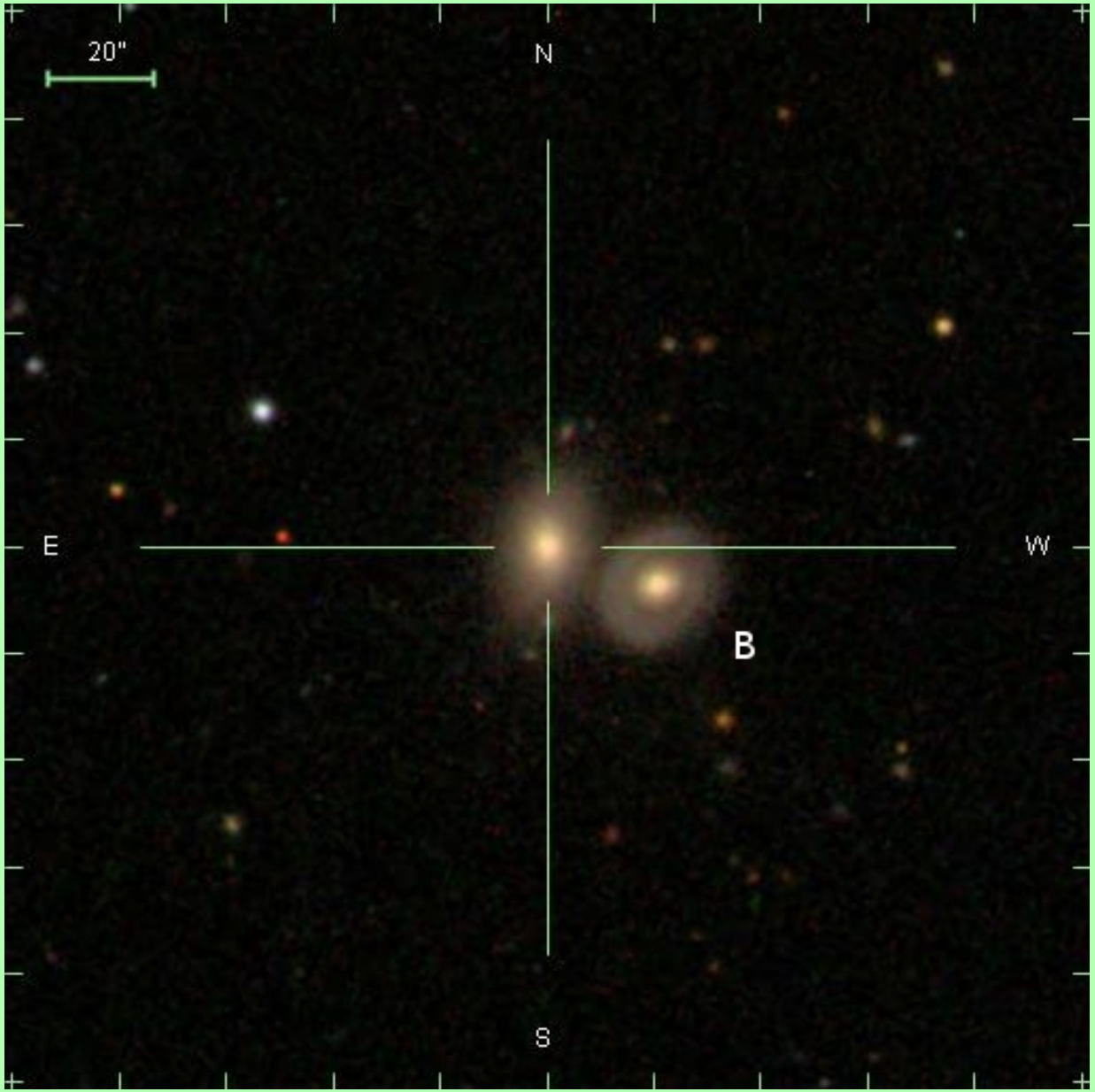
# Isolated pairs

SIP 986



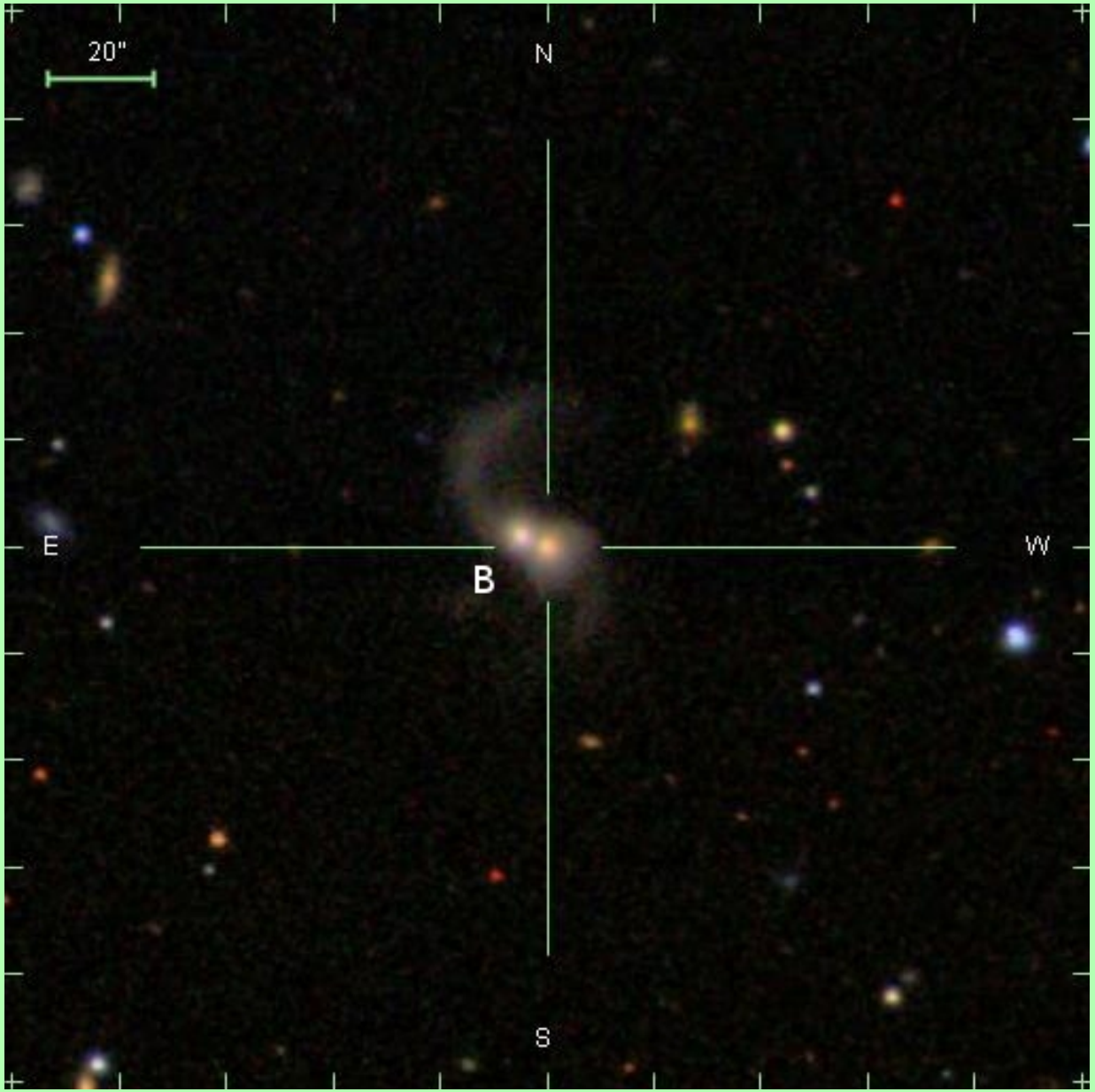
# Isolated pairs

SIP 669



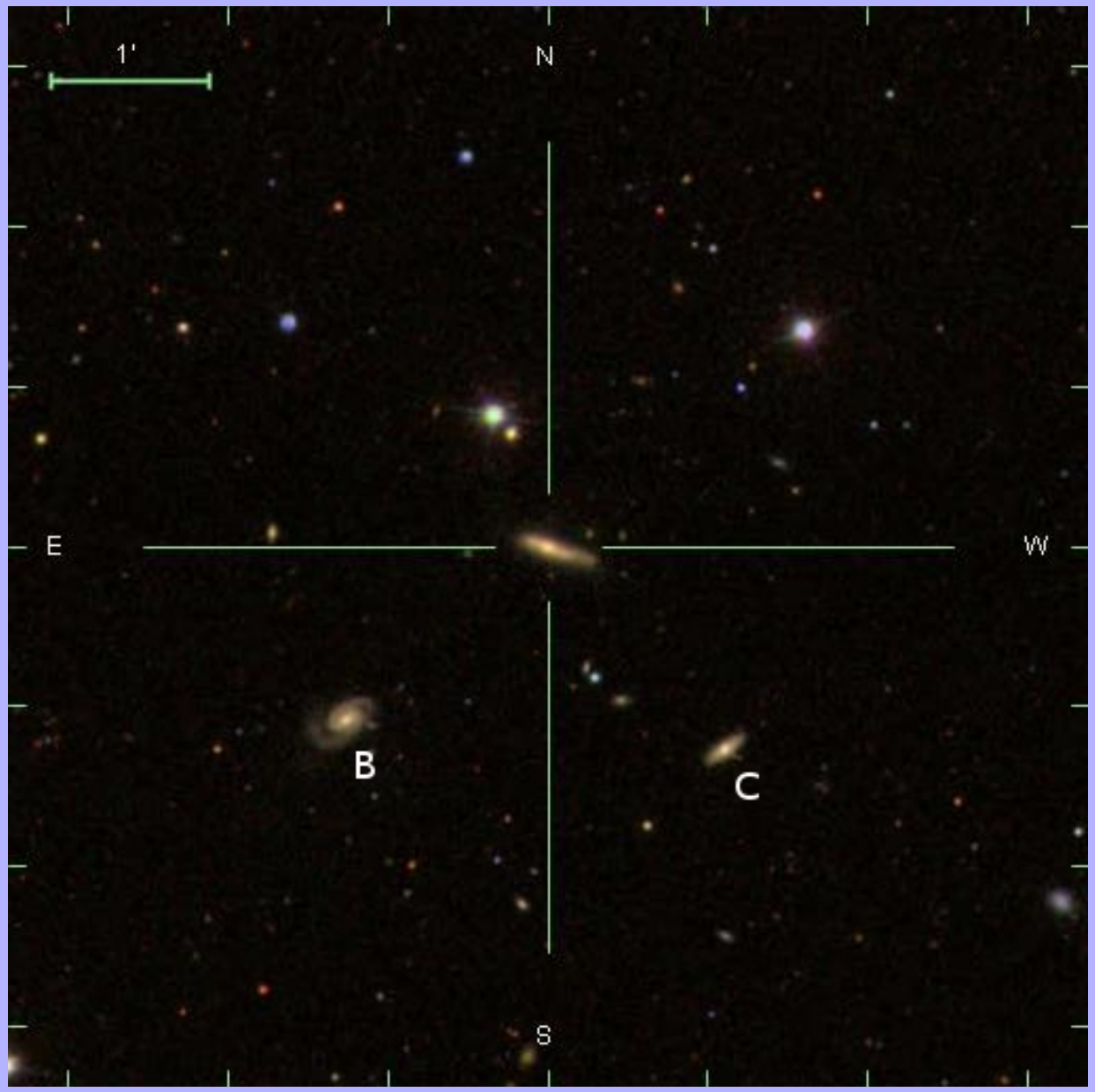
# Isolated pairs

SIP 791



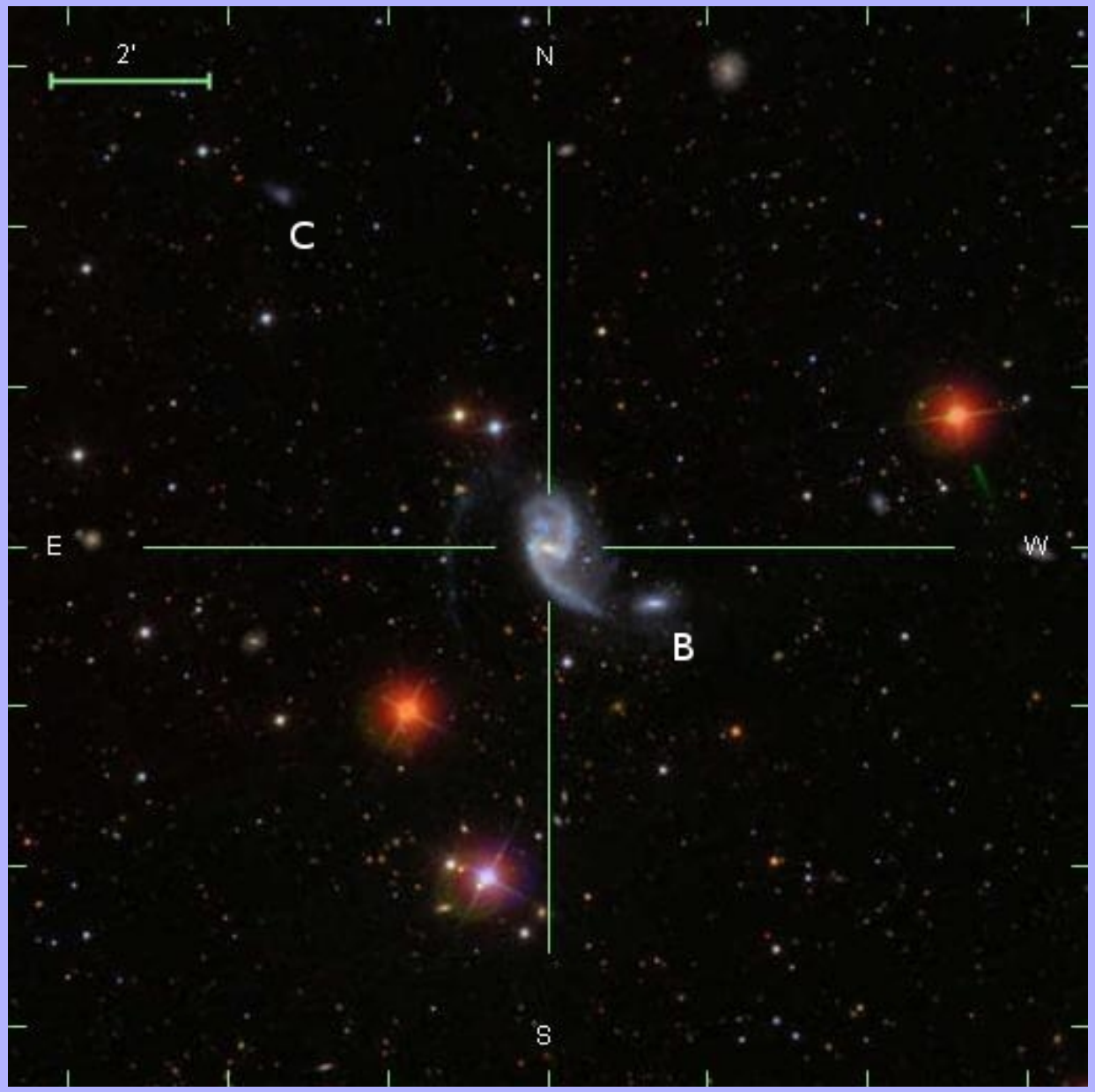
# Isolated triplets

SIT 262



# Isolated triplets





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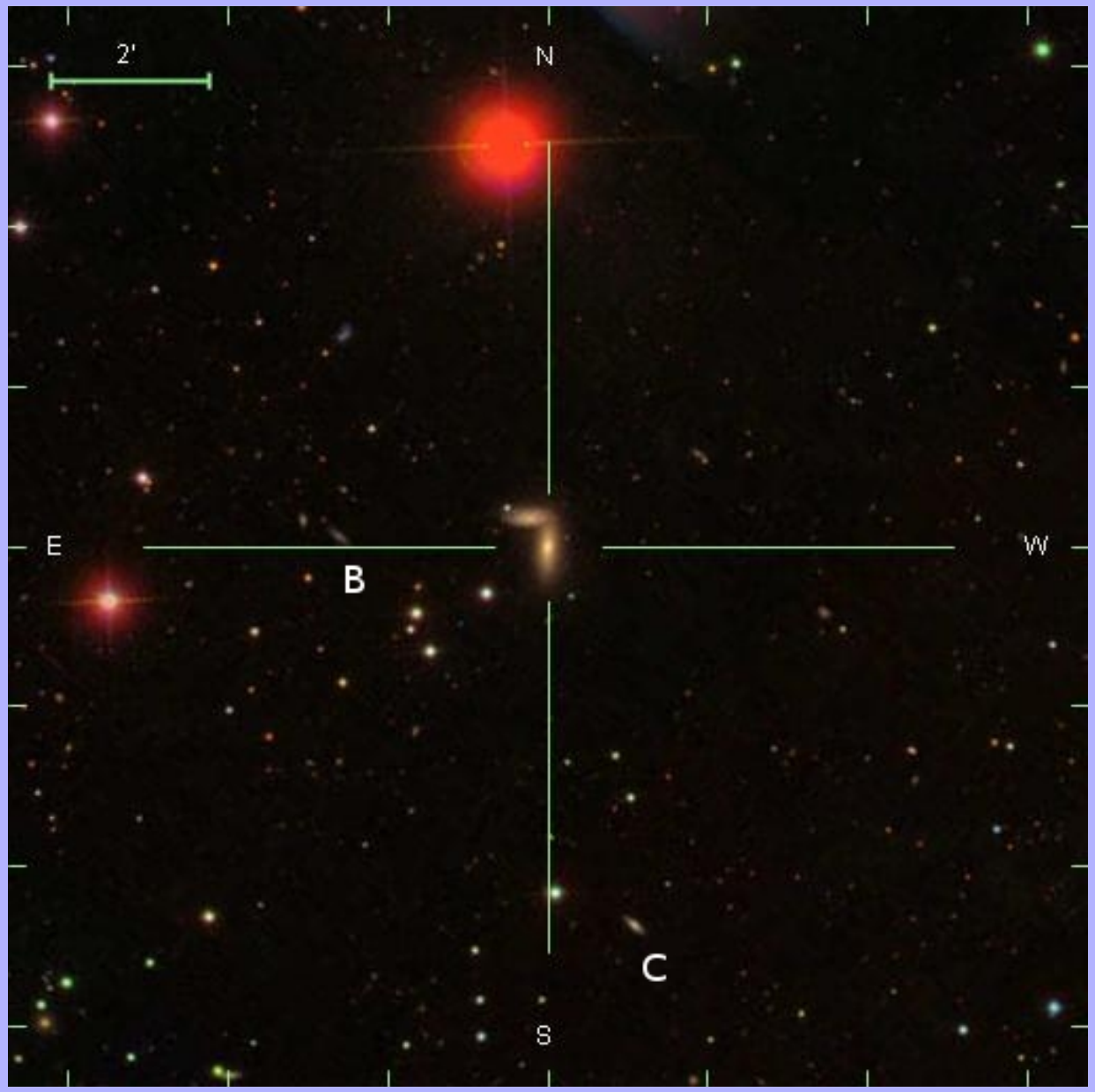
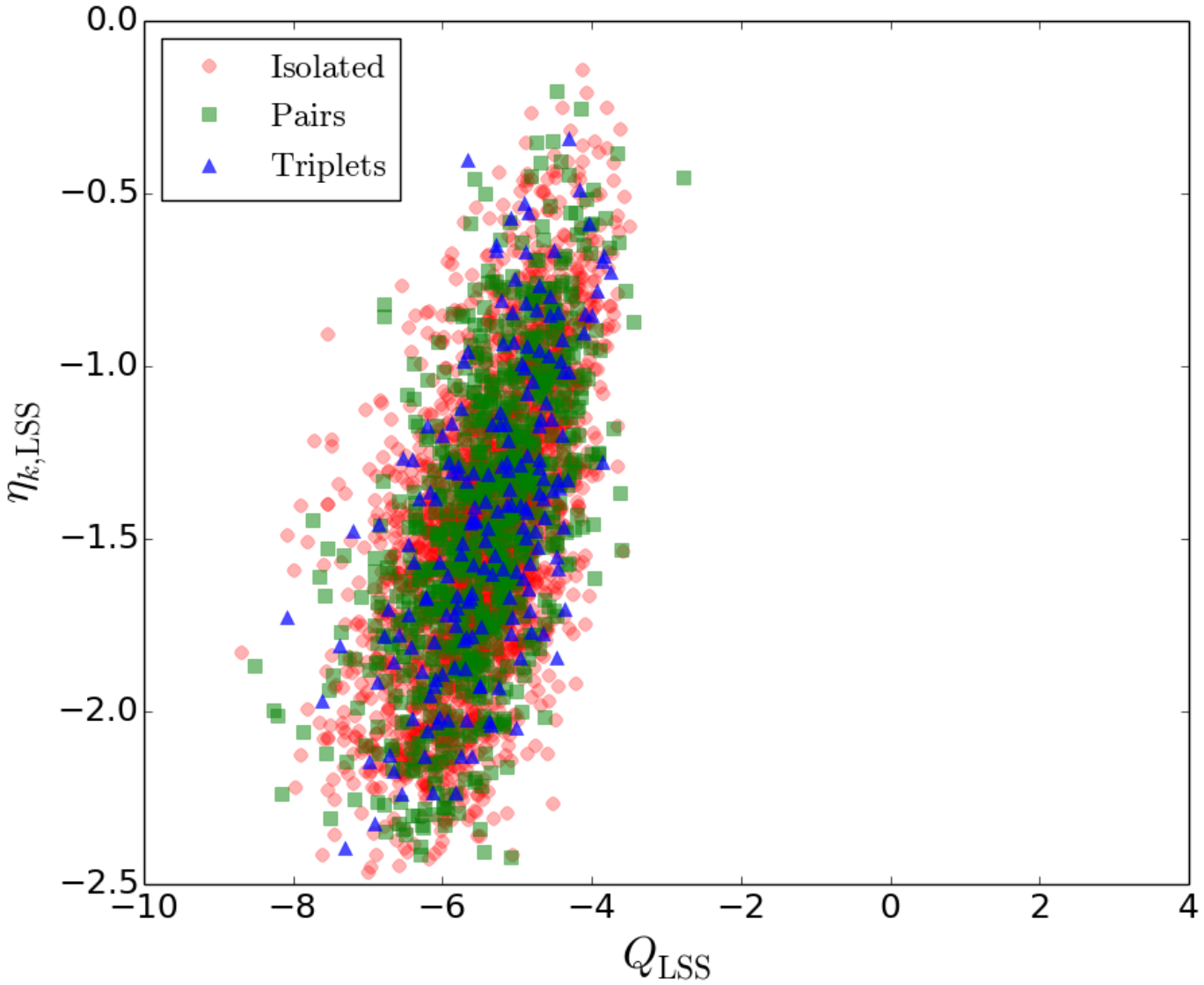


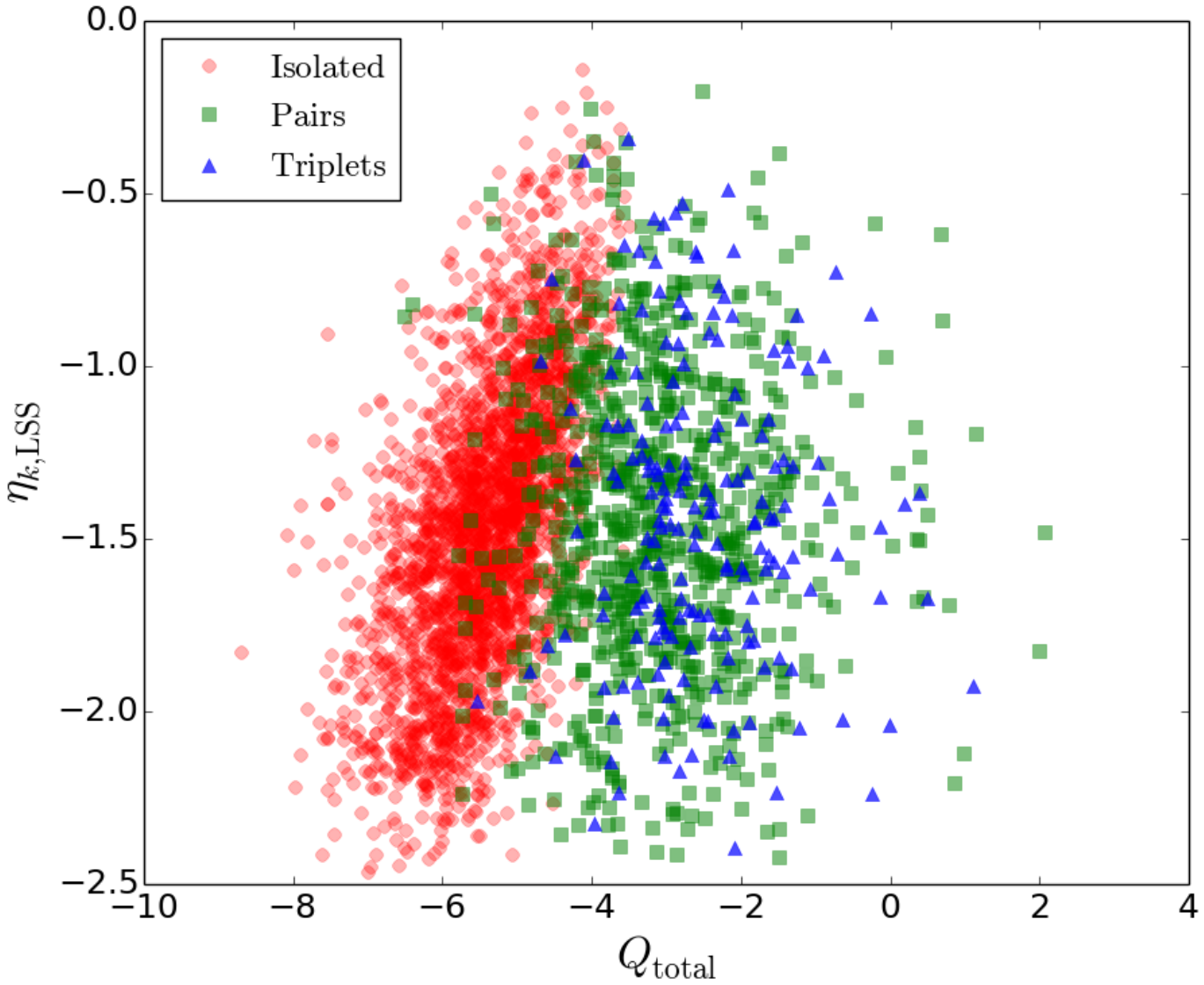
# LSS isolation parameters

From 1 to 5 Mpc



# Effects of physical associations

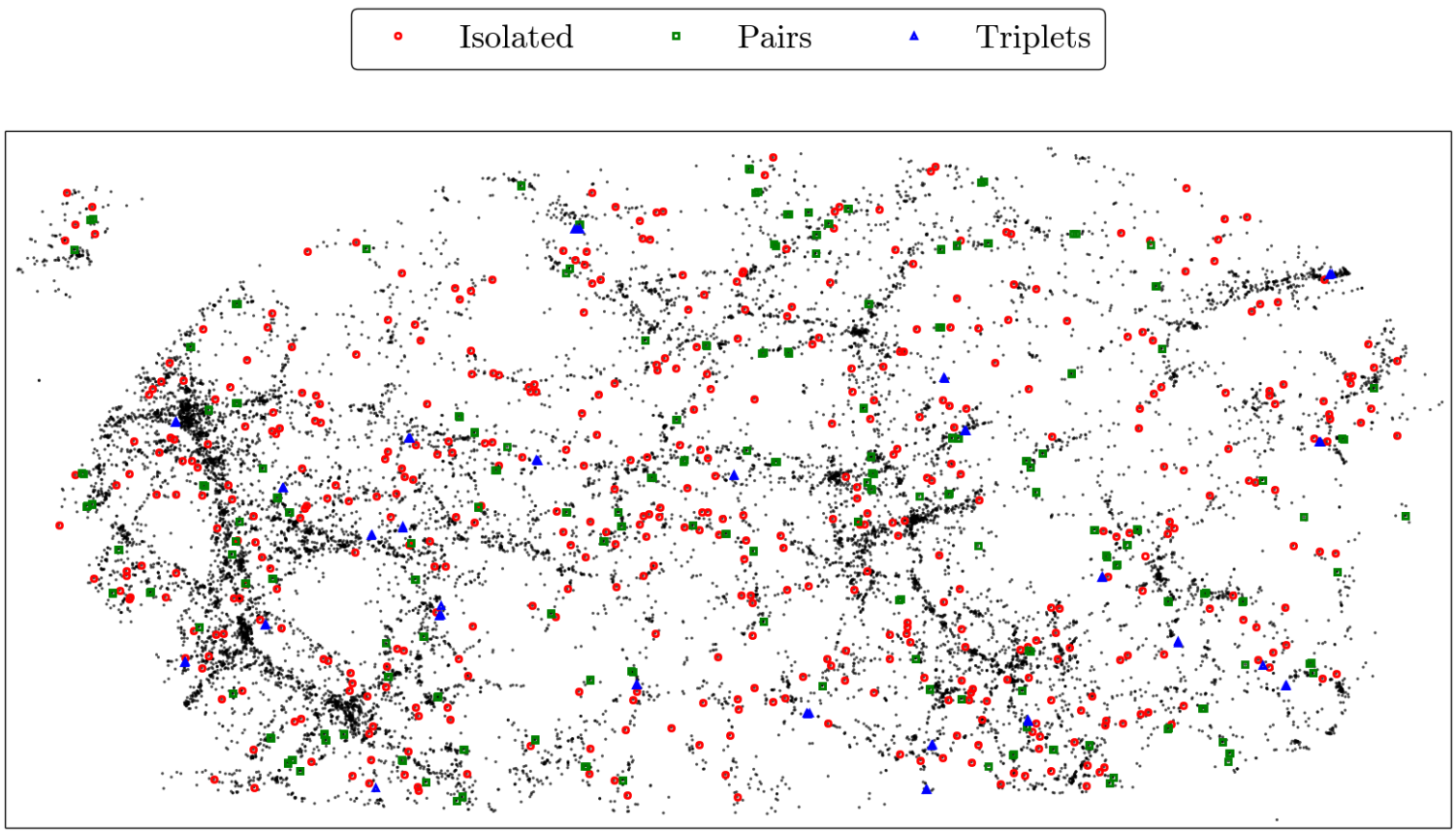
From 0 to 5 Mpc



# Relation to the LSS

Equidistant cylindrical projection

$0.030 < z < 0.035$

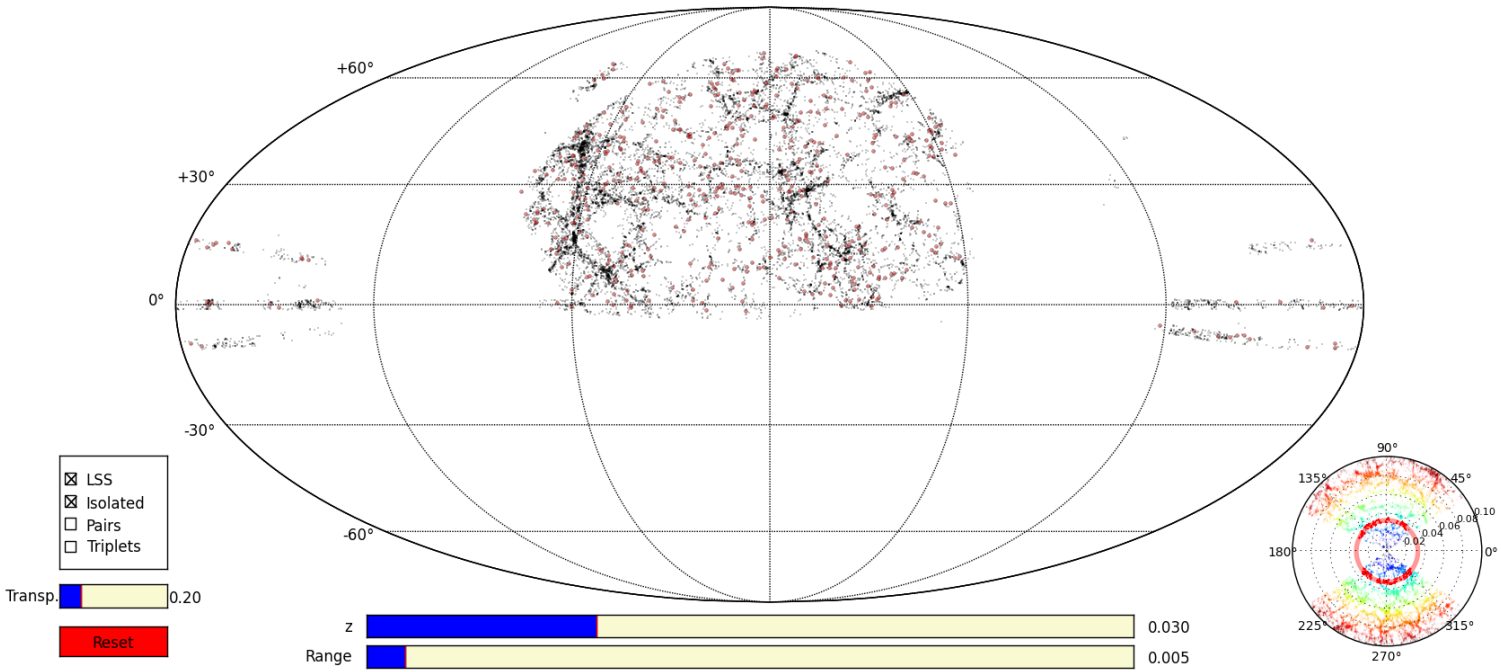


# Relation to the LSS

S. Duarte Puertas & E. Ramos Carmona

Mollweide projection

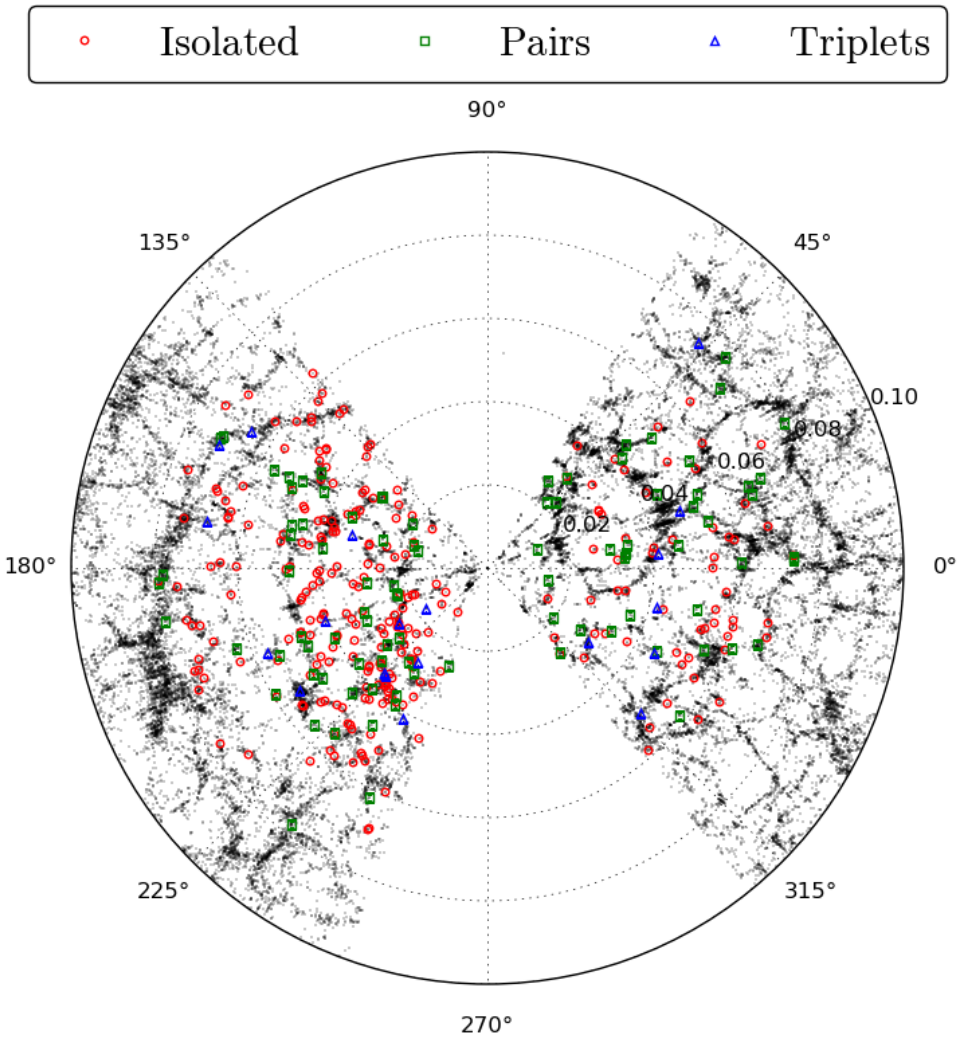
$0.030 < z < 0.035$

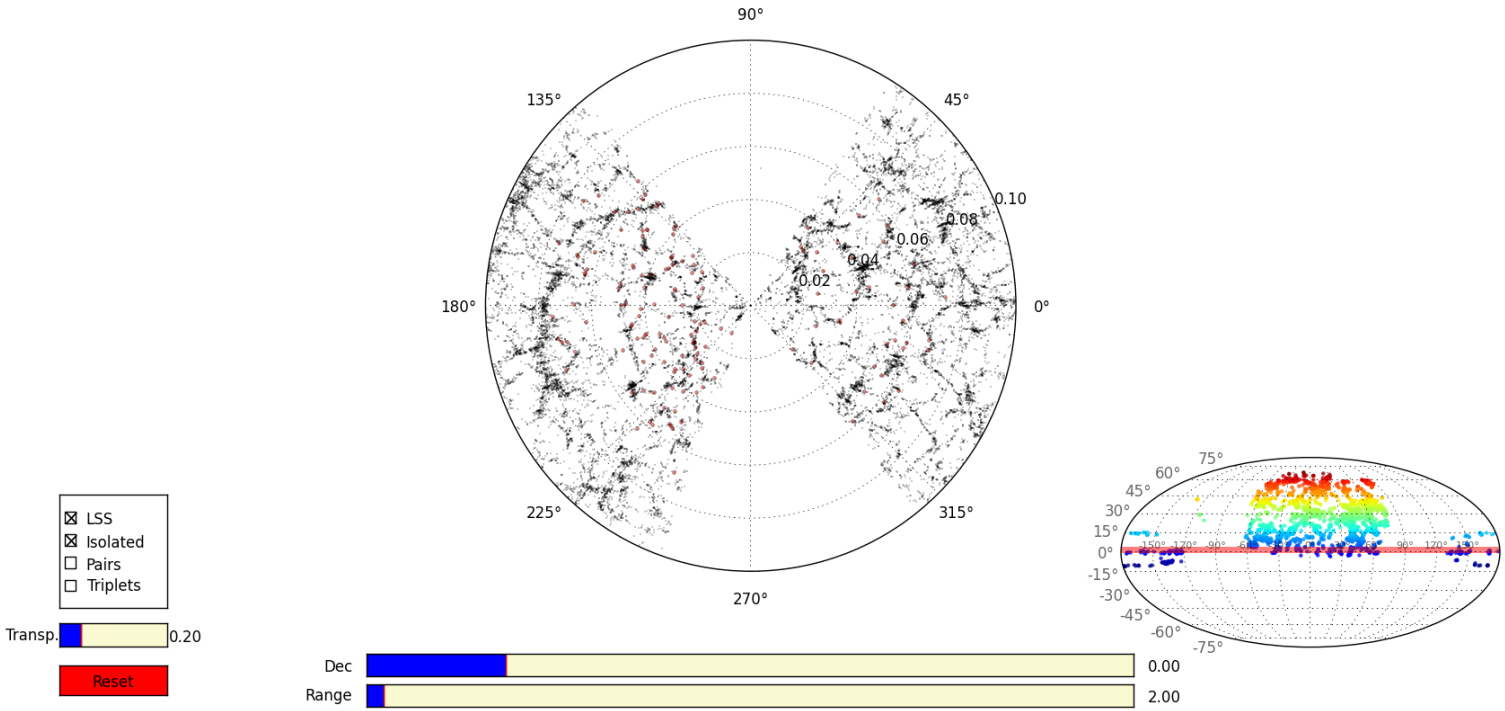


# Relation to the LSS

Wedge diagram

$-2° < \delta < 2°$

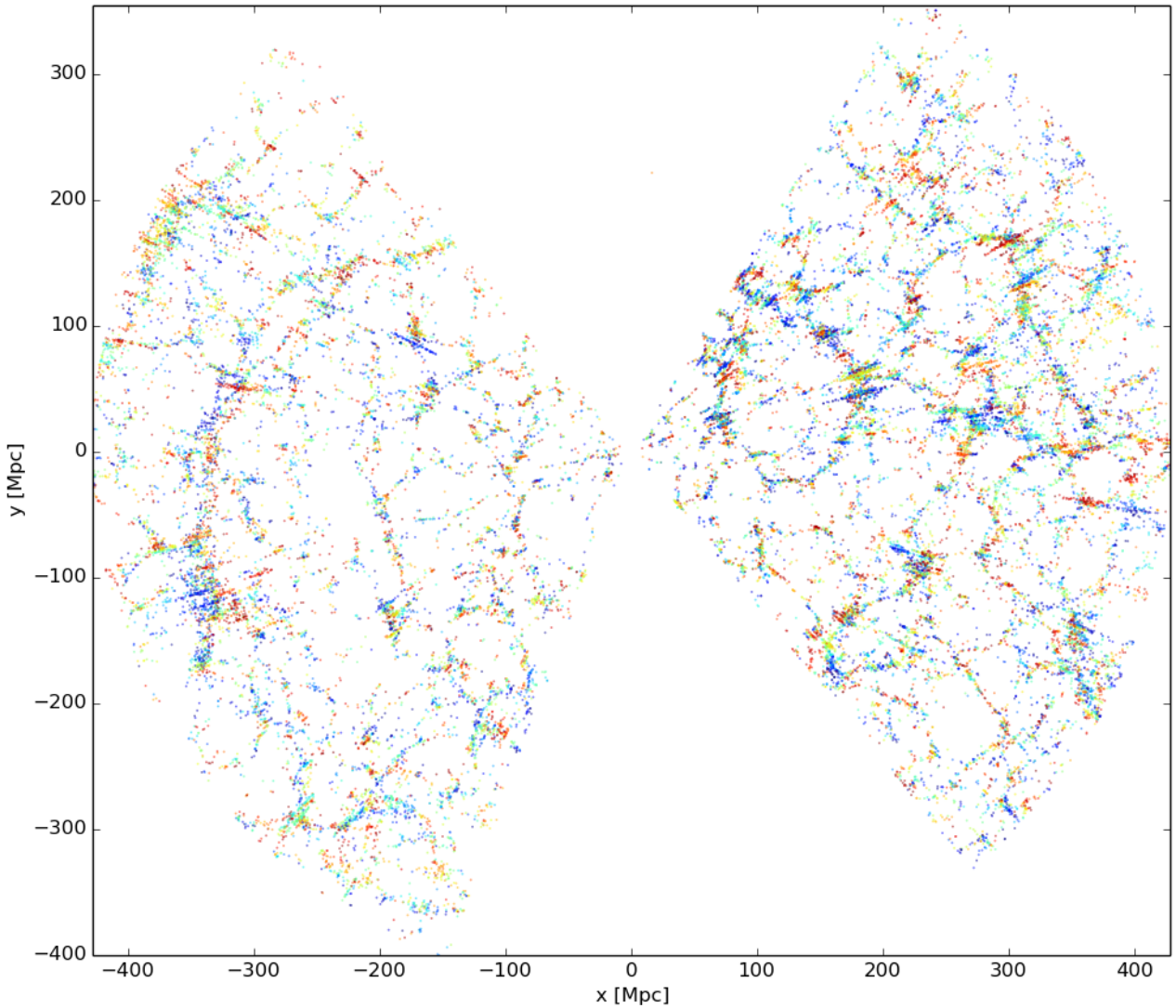




# Minimum Spanning Tree

[Vanderplas et al. 2012, Ivezic et al. 2013]

$-1.25° < \delta < 1.25°$



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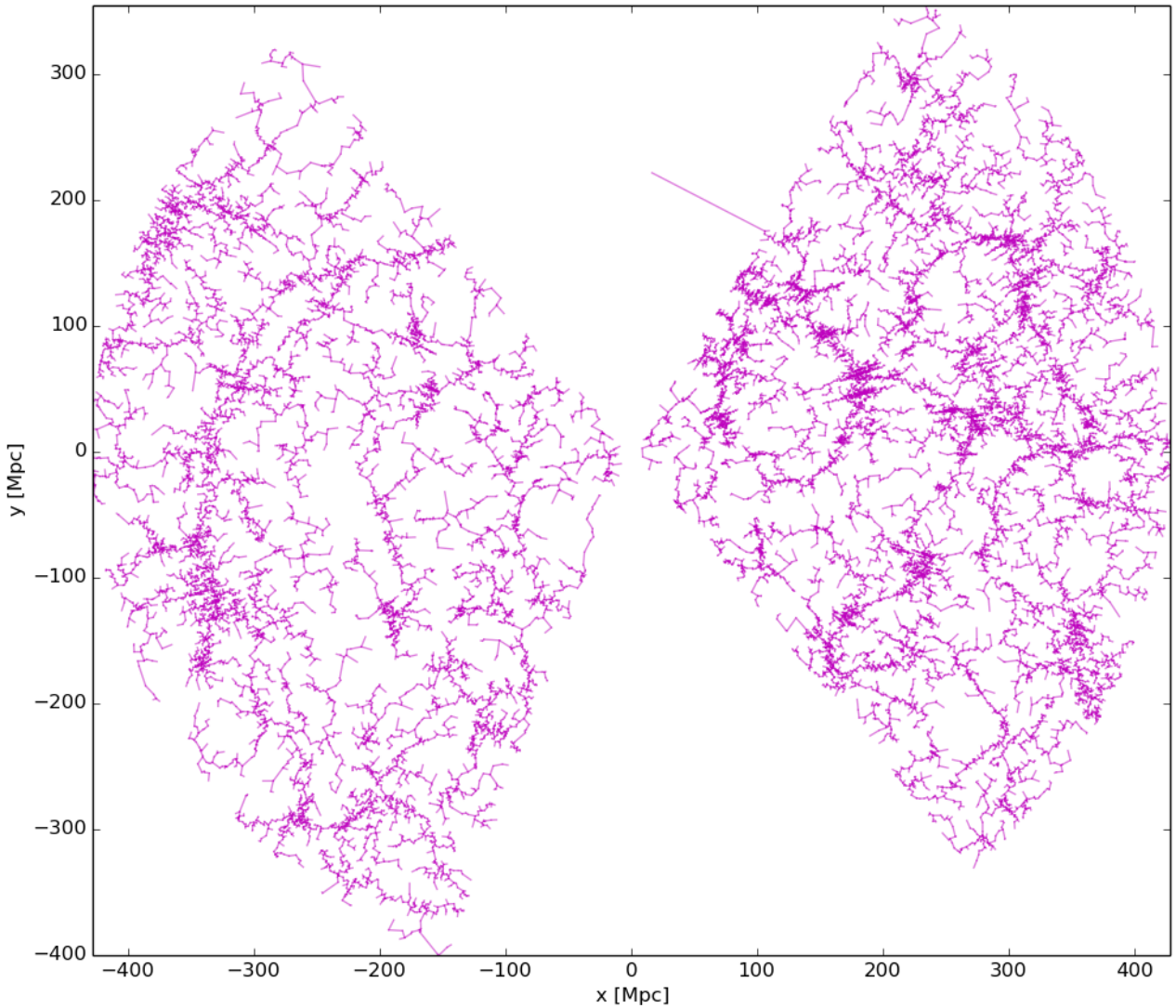

# Minimum Spanning Tree

[Vanderplas et al. 2012, Ivezic et al. 2013]

Threshold 2.9 Mpc

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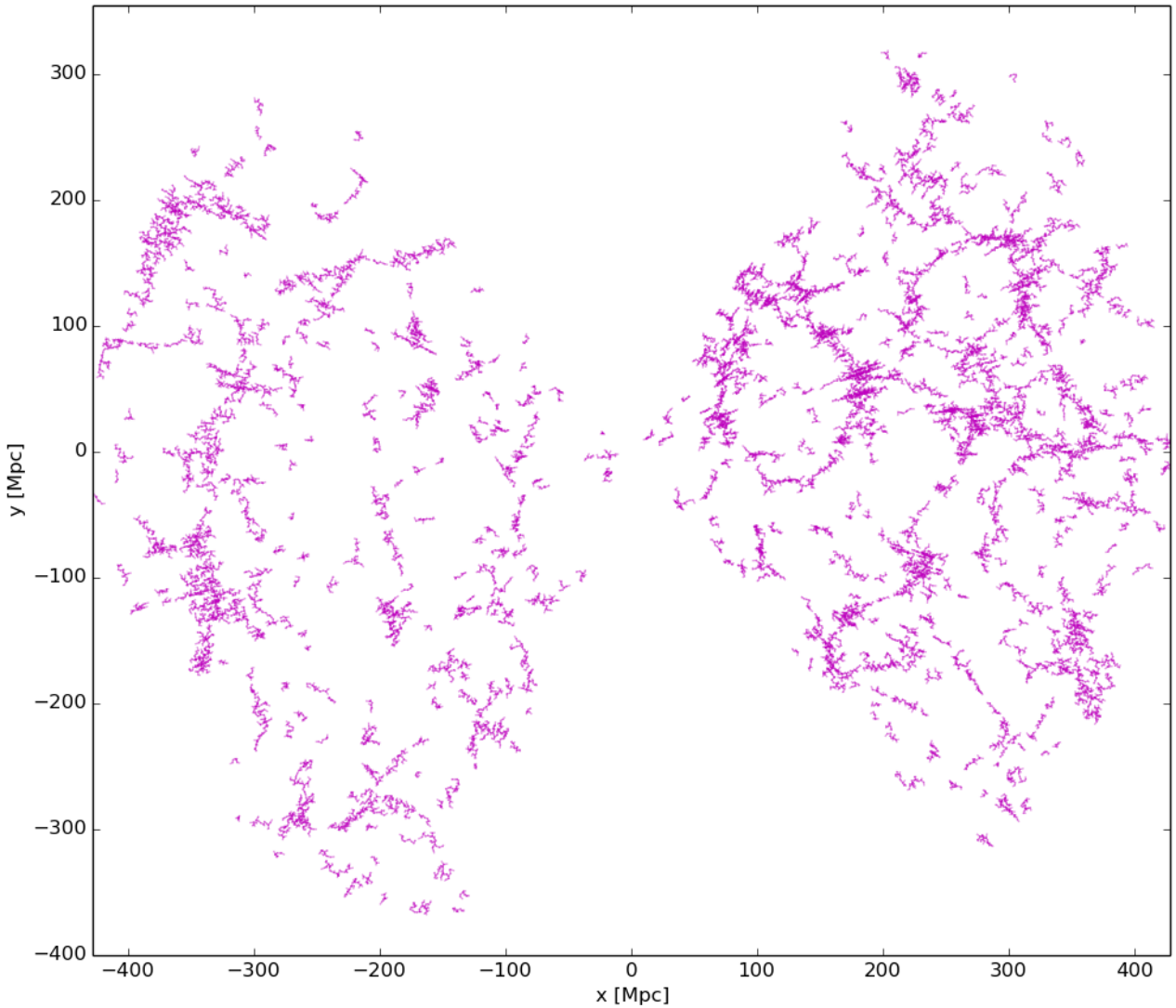

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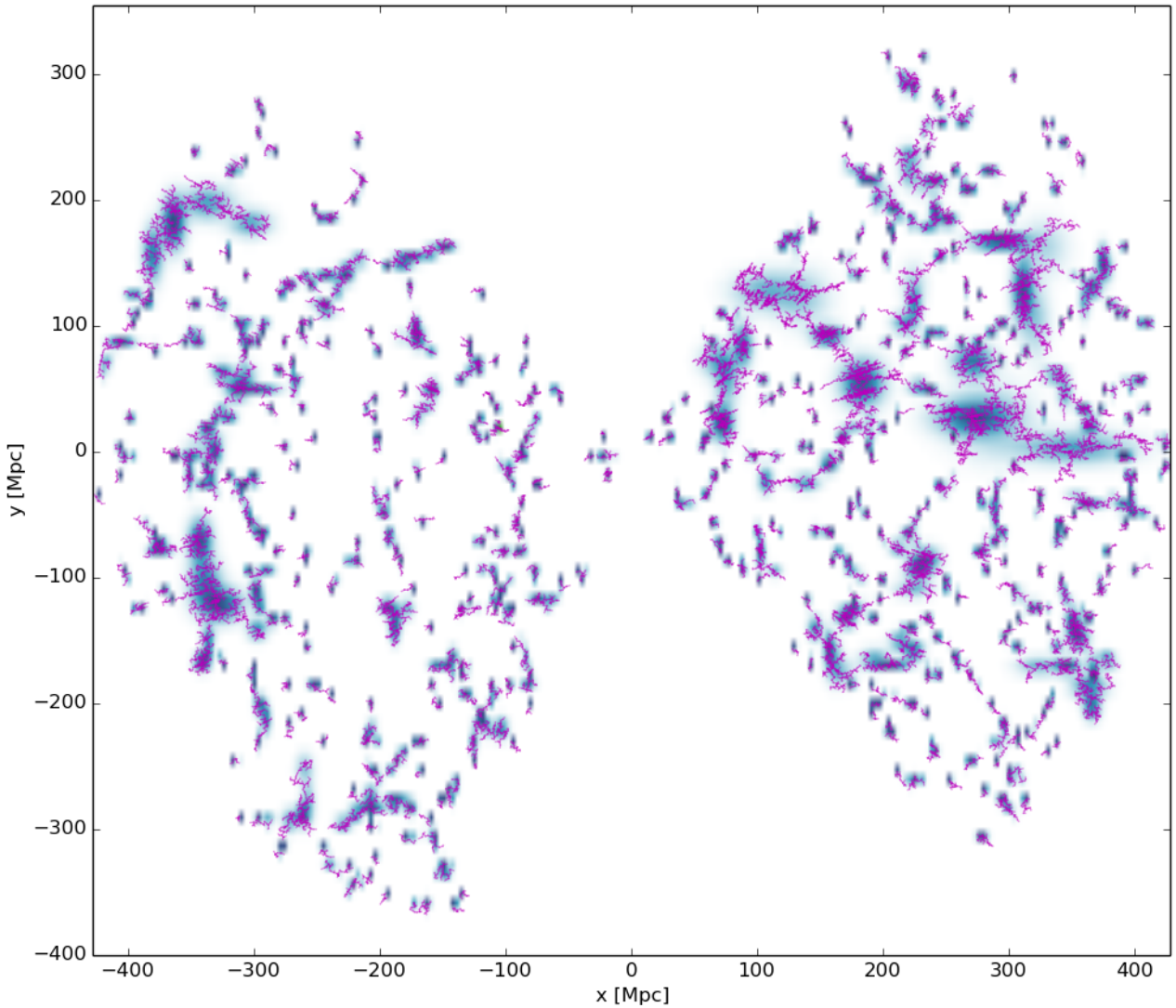

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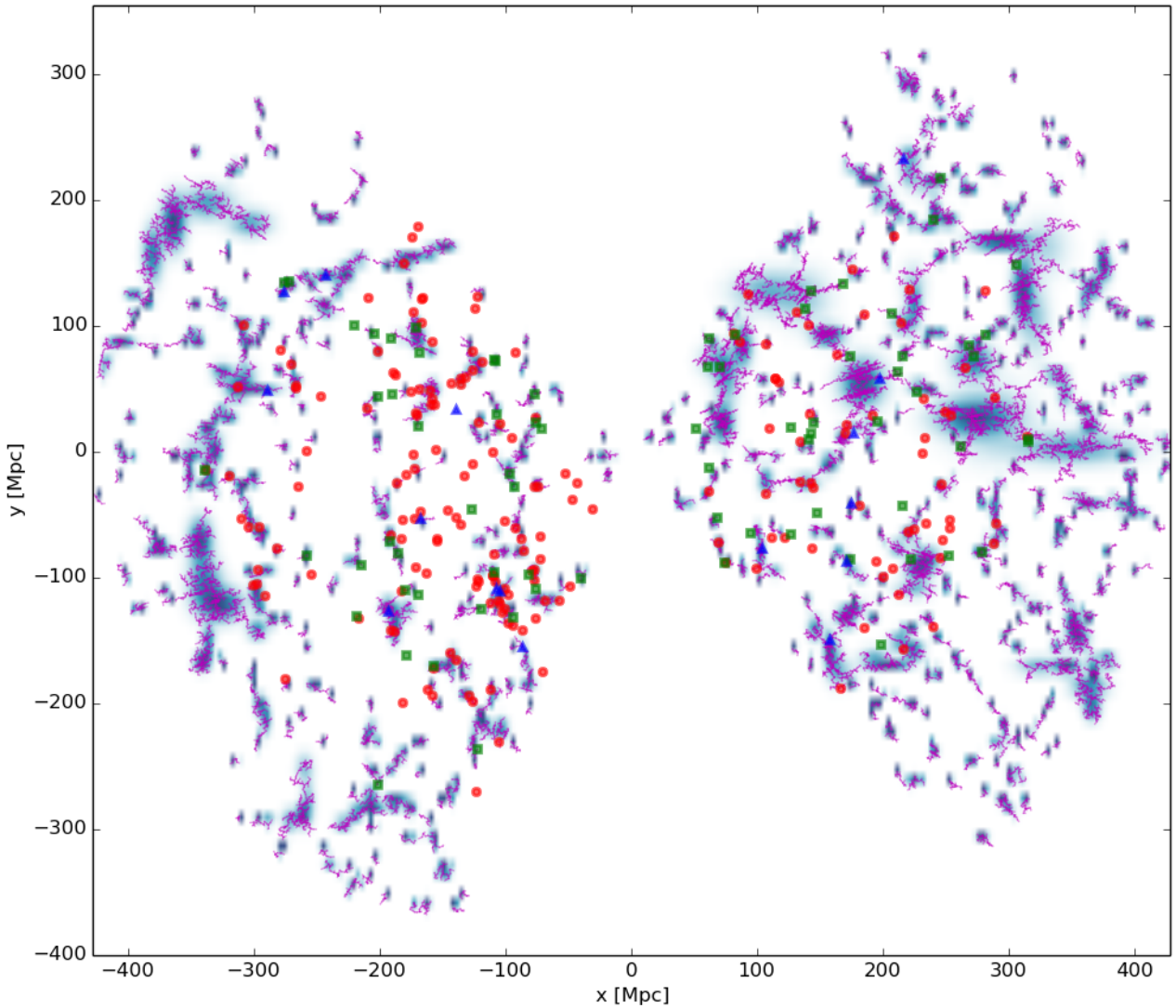

# Conclusions

- ***SIG catalogue: 4,191 isolated galaxies*** *which represent about* ***12%*** *of the considered galaxies in the local Universe*
- ***SIP catalogue: 1,270 isolated pairs*** *which represent about* ***7%*** *of the considered galaxies in the local Universe*
- ***SIT catalogue: 300 isolated triplets*** *which represent about* ***3%*** *of the considered galaxies in the local Universe*
- *Generally* ***differ from the void*** *population of galaxies*
- *Most of the isolated galaxies, isolated pairs, and isolated triplets, belong to the* ***outer parts of filaments, walls, and clusters***

# Summary

*To understand the **role of the environment in the formation and evolution of galaxies** it is necessary to have a reference sample where the effects of the environment are minimised and quantified.*

- *Revision of the isolation of the CIG galaxies*
- *Effects of the environment on the CIG galaxies*
- *Isolated galaxies, isolated pairs, and isolated triplets*

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- *Effects of the environment on the CIG galaxies*
- ***Isolated galaxies, isolated pairs, and isolated triplets***

# Overview of the presentation

# Main conclusions

[Argudo-Fernández et al. 2013a]

*In the first part of this thesis work, we aim to* ***refine the photographic-based CIG*** *and to provide an improvement of the quantification of the isolation degree with respect to previous works,* ***using both photometry and spectroscopy from the SDSS-DR9****. Our main conclusions are the following:*

- *The availability of the spectroscopic data allows us to check the validity of the* ***CIG isolation criterion within a field radius of 1 Mpc****, and we conclude that it is not fully efficient.*
- *About* ***50% of the neighbours*** *considered as potential companions in the photometric study are in fact* ***background*** *objects.*
- *On the other hand, we also find that about* ***92% of neighbour*** *galaxies that show recession velocities similar to the corresponding CIG galaxy are* ***not considered*** *by the CIG isolation criterion as potential companions.*
- *These neighbours are most likely* ***dwarf systems*** *which may have a considerable* ***influence on the evolution*** *of the central CIG galaxy.*

# Main conclusions

[Argudo-Fernández et al. 2013b, submitted]





*In the second part of this thesis work we identify and quantify the **effects of the physical satellite distribution** around galaxies in the CIG, as well as the effects of the **Large Scale Structure (LSS)**. Our main findings are the following:*

- *The CIG galaxies are distributed **following the LSS** of the local Universe, although presenting a large heterogeneity in their degree of connection with it, from galaxies with **physically bound satellites (10% of the sample)** to galaxies without neighbours in the first 3 Mpc around them.*
- ***Isolated galaxies are in general bluer**, with likely younger stellar populations with respect to older, **redder CIG galaxies with physical satellites**. Reciprocally, the satellites are redder and with **older stellar populations around massive early-type CIG galaxies**, while they have a **younger stellar content around massive late-type** CIG galaxies.*
- *There is a clear segregation between **younger and older systems**, confirmed by the nature of the physically bound galaxies.*

# Main conclusions

[Argudo-Fernández et al., in prep.]

*In light of the above findings, we use spectroscopic data from the SDSS to* ***automatically and homogeneously*** *compile catalogues of* ***4,191 isolated galaxies***, ***1,270 isolated pairs***, *and* ***300 isolated triplets*** *in the local Universe ($z \leq 0.080$) without being biased by projected neighbours. Our main results are the following:*

- *Most of the isolated galaxies, isolated pairs, and isolated triplets, belong to the* ***outer parts of filaments, walls, and clusters***, *and generally* ***differ from the void population*** *of galaxies.*
- *The* ***physical companions in pairs and triplets*** *play a prevailing role in the tidal strengths $Q_{\rm pair}$ and $Q_{\rm triplet}$ exerted on the primary galaxies. This local tidal strength due to the physical companions is* ***two orders of magnitude higher*** *than the tidal strength due to the LSS.*
- *We find* ***no difference*** *in their degree of interaction with the LSS, which may suggest that they have a* ***common origin in their formation and evolution***.