



Interacting and  
merging galaxies  
in

S-PLUS

Claudia, Gustavo, Natanael, Jose Andrés, Ângela,  
Geferson, Fernando, Clecio, Arianna, Sergio, Gissel, Erik,  
Antonela, Kadu, Ana, Hellen, Analia, Luís, Laerte



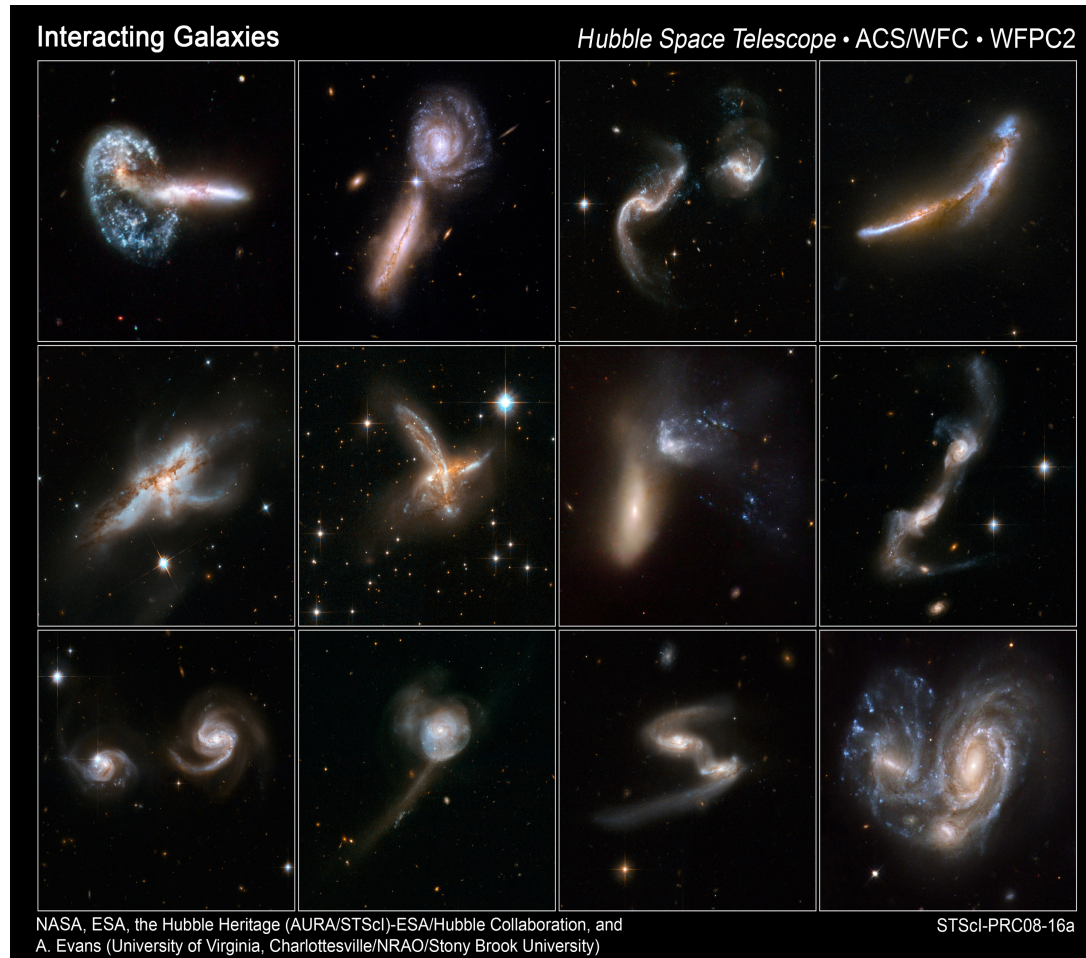
# Interactions of galaxies

We have mainly 2 broad categories:

- Gravitational (incl. tidal, mergers, harassment....)
- Hydrodynamical (Ram pressure and strangulation)

# Galaxy collisions are rare in the local universe – but were frequent at high $z$

Collision rate is thought to be about 1% in the local universe

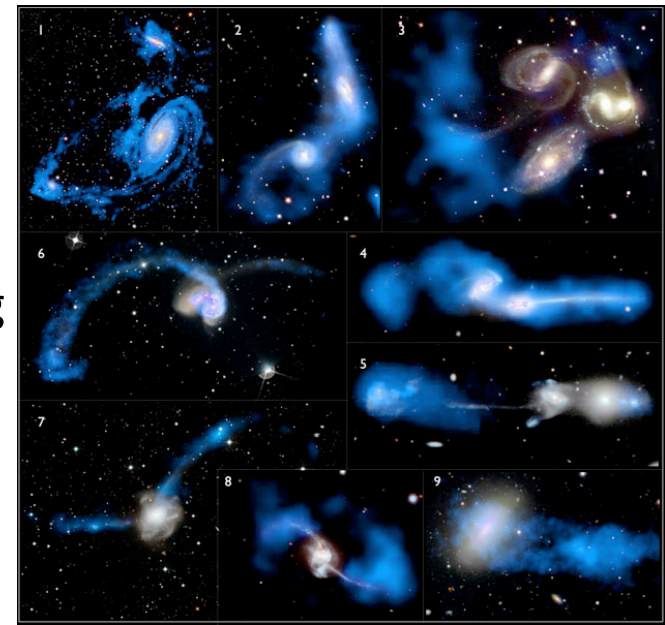


Interactions happened much more often in the early universe (40% by  $z=1$ )

# If interactions are so rare in the nearby universe and S-PLUS is a nearby Universe survey - why are we specifically interested in these objects?



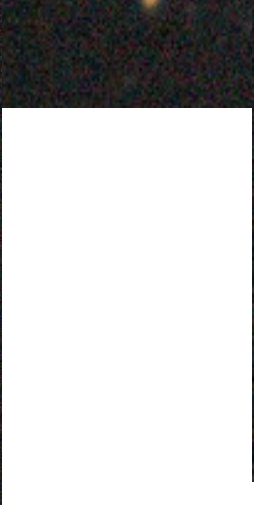
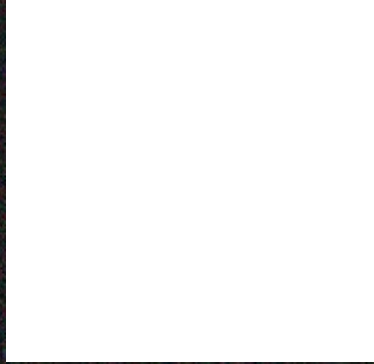
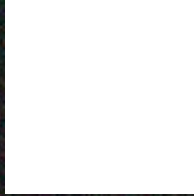
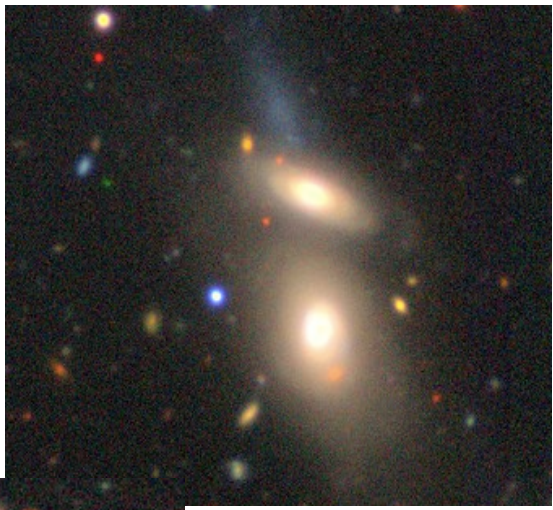
- They are the sites of formation of new objects, new clusters and the so-called tidal dwarf galaxies.
- Collisions can cause SF to get to remote places away from main galaxies, this can happen in low-density sites and also in clusters (with infalling galaxies or groups onto clusters).
- One can study ram-pressure stripping mechanisms in clusters and filaments by looking for jelly-fish galaxies
- One can study SF and stellar populations of interacting and merging galaxies in different stages of evolution





# How to find interacting galaxies?

Galaxies from galaxy zoo with  $P_{\text{merger}} > 0.99$



How can we increase the numbers of known interacting, stripped or mergers in our lists given that the numbers of P\_merge galaxies are small in S-PLUS?



# Ways to increase the #s of bonafide peculiar objects

-- Visual inspection of galaxies in nearby groups and clusters  
(Hellen, Ana Chies)

-- Automatic search for the strongest emission-line galaxies and matching them with known structures (Gustavo, Natanael, Luis Gutierrez, Analia, Kadu)

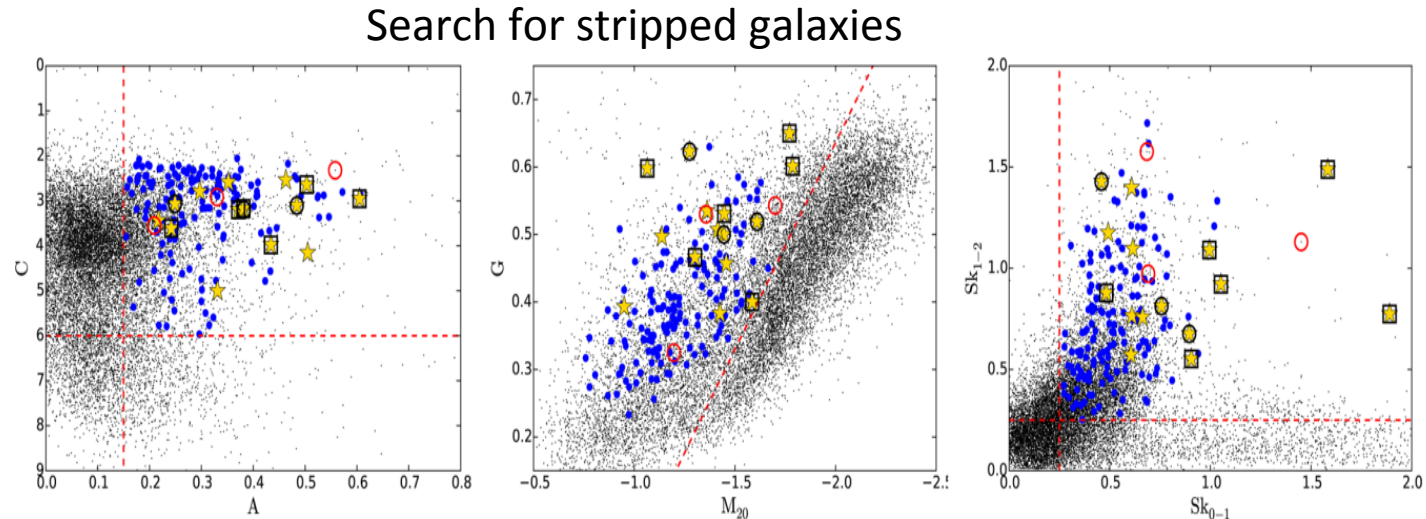
-- Use  $G \times M20$ ,  $A \times C$  and other plots (Geferson, Fernando)

-- Revisiting existing catalogues of interacting galaxies (Jose Andres, Angela)

-- Characterizing CGs in S-PLUS (Sergio, Gissel, Antonela)

-- Setup a citizen science experiment and have the public classify different types of interacting galaxies (all of us)

Having in mind that stripped galaxies usually do not appear in galaxy-zoo merger category, the best way to find stripped objects in clusters and groups is using  $G \times M_{20}$  and  $A \times C$  plots



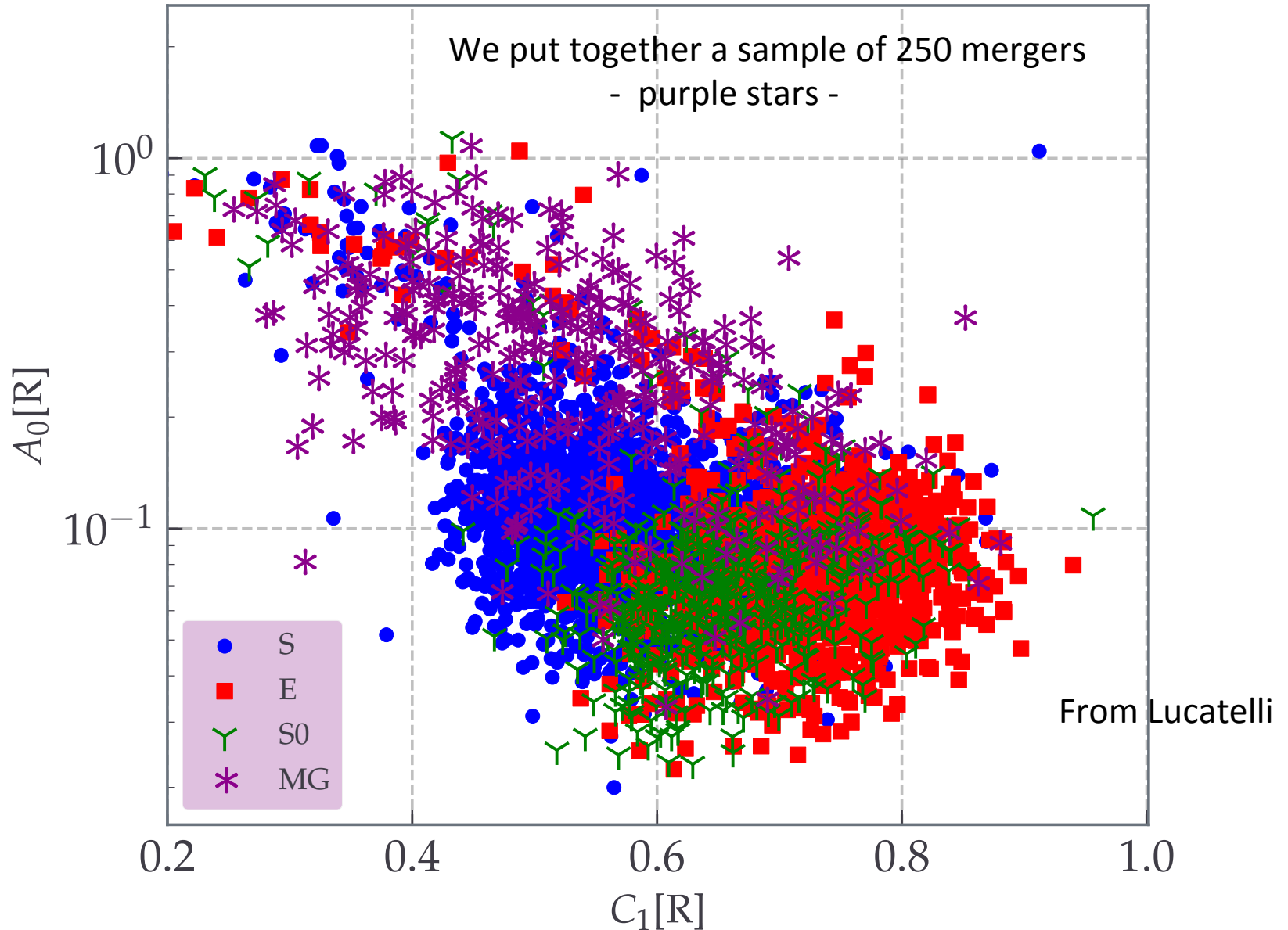
**Figure 2.** The distribution of all galaxies in our target fields in various parameter spaces. Left: concentration-asymmetry; centre: Gini- $M_{20}$ ; right:  $Sk_{0-1}-Sk_{1-2}$ . Our final sample of RPS candidates is marked by filled blue circles; the morphologically most compelling examples are shown as yellow asterisks. Members of our training set (see Fig. 1) are shown with open symbols. Squares show the six systems published in Ebeling et al. (2014), and circles show the six additional galaxies from their extended sample. Three members of our training set, all part of the extended ESE sample, were recently found not to be cluster members (see Section 3.2.1) and are shown in red. The cuts defining our final morphological selection criteria are indicated by red dashed lines.

McPartland et al. 2015

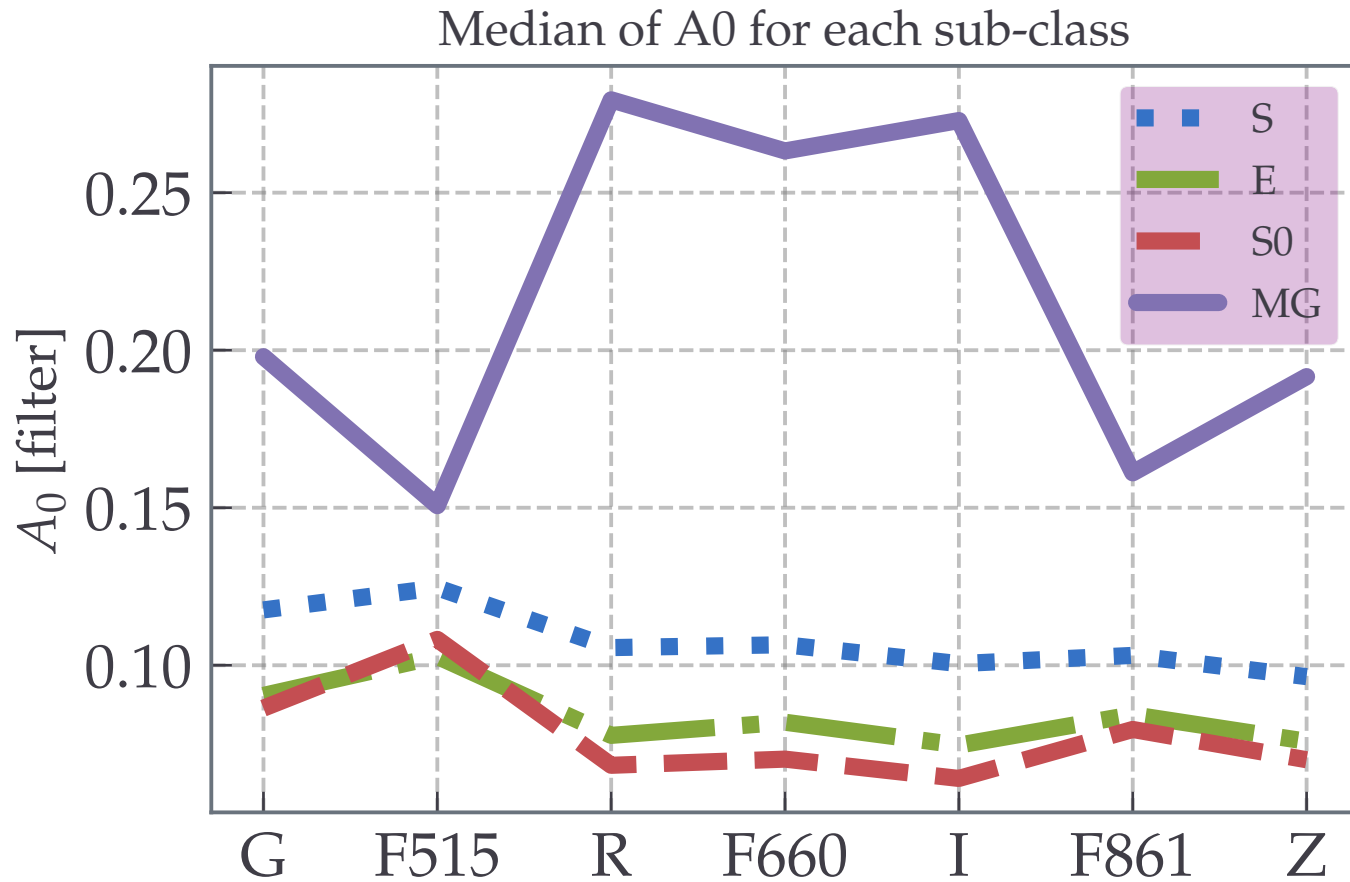
Note these were specifically for stripped galaxies but we will use it for interacting galaxies in general



# A good parameter space to find mergers



# Average $A_0$





# Looking for the galaxies with the strongest H $\alpha$ lines in the nearby universe

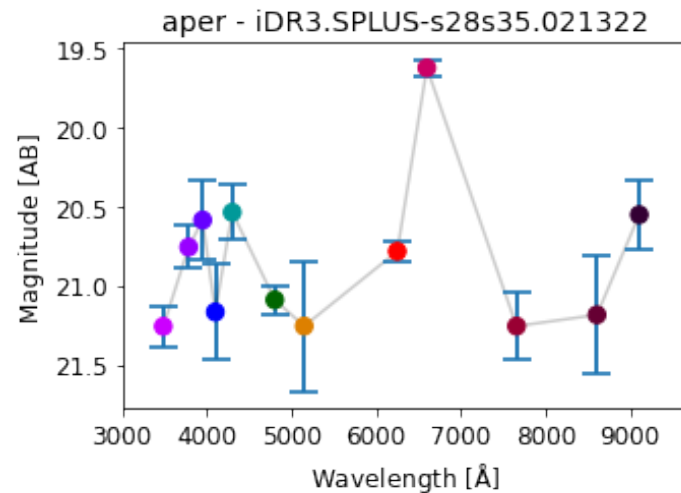
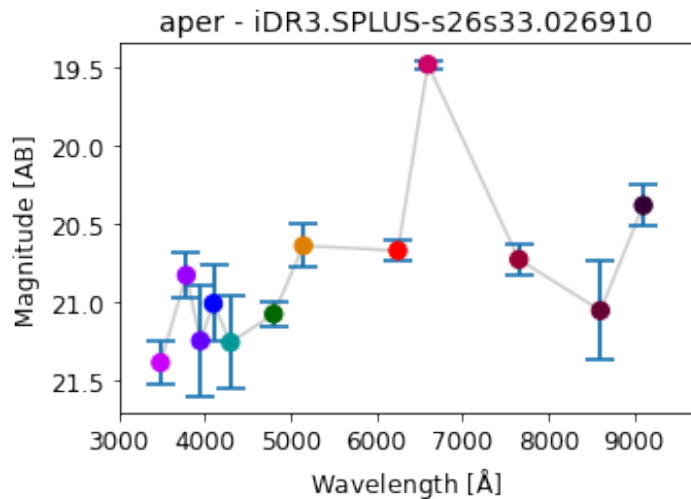
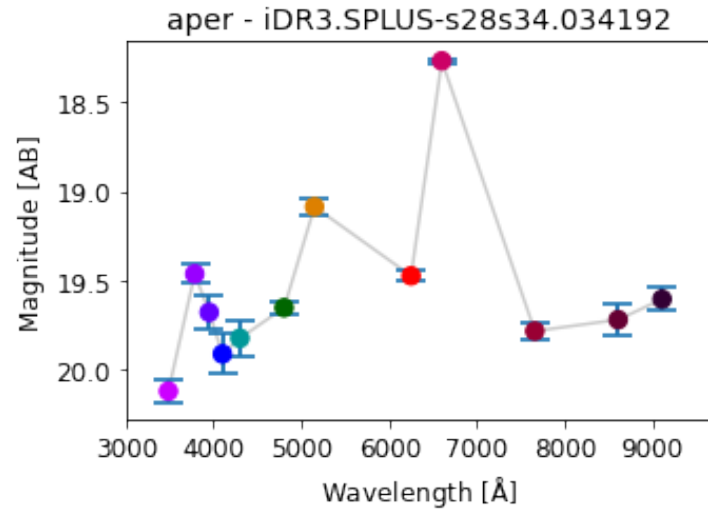
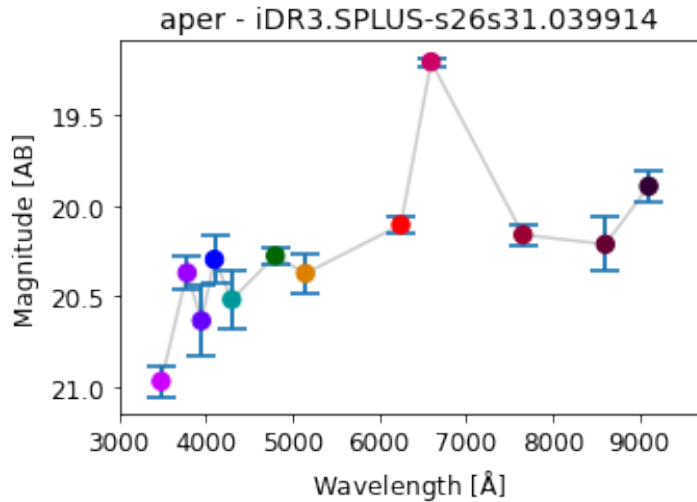
We assume that interacting galaxies will have strong emission lines due to star formation.

We restricted the search for the case when H $\alpha$  is inside the H $\alpha$  filter (more nearby objects than  $z=0.015$ )

Fornax is a good first-target.

# Area: 23 x 1.4 x 1.4 grau2

Found 6 objects – Here I show 4 examples of S-spectra





**Halpha**

**Emission**

**Line maps**

(superimposed over a color  
image)





What is new: we decided to look in a larger radius and use a different way to look for the high-emission line objects **using a color-color diagram** (see talk by Luís Gutierrez on Thursday)

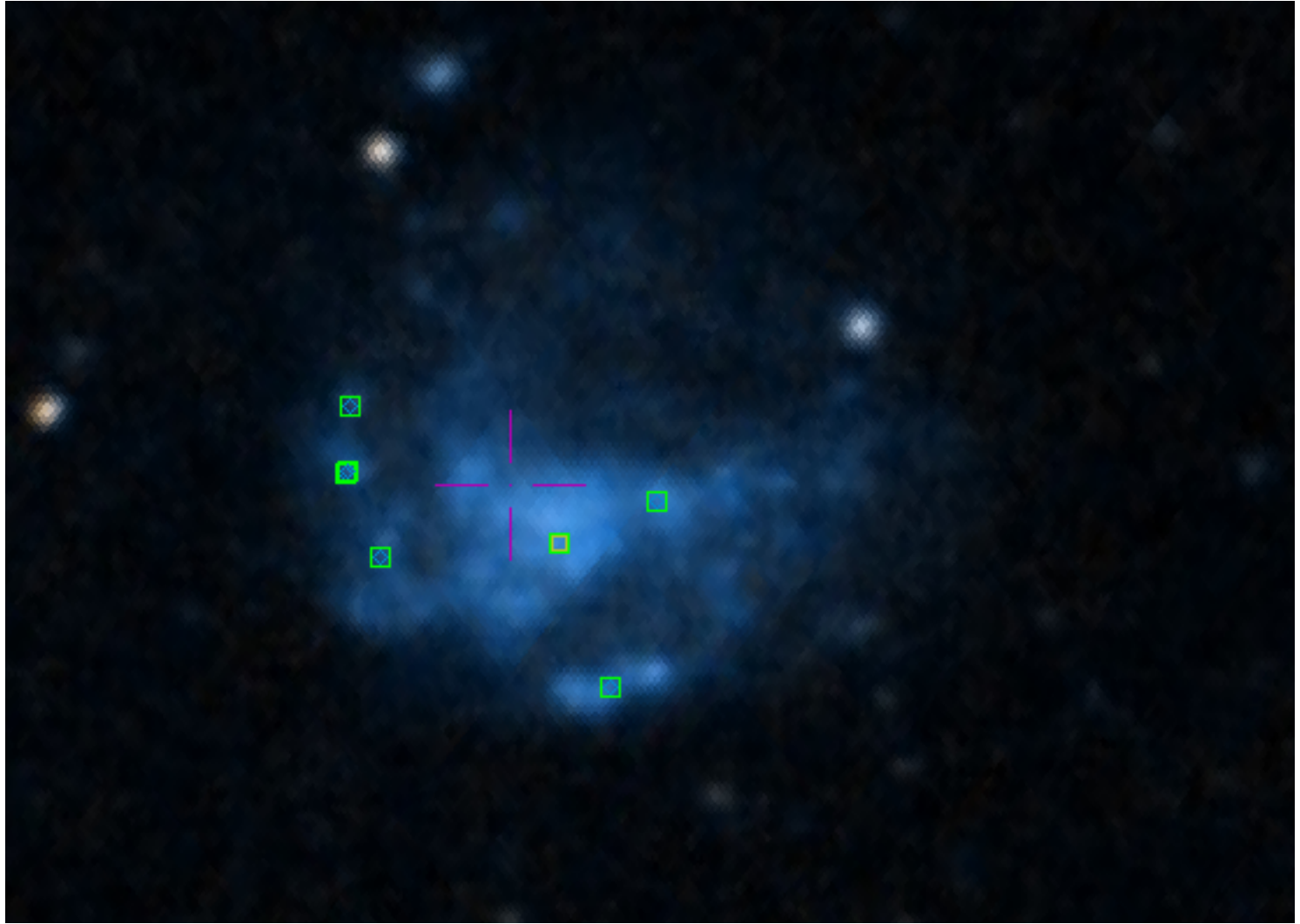
Search within a radius of 10 degrees

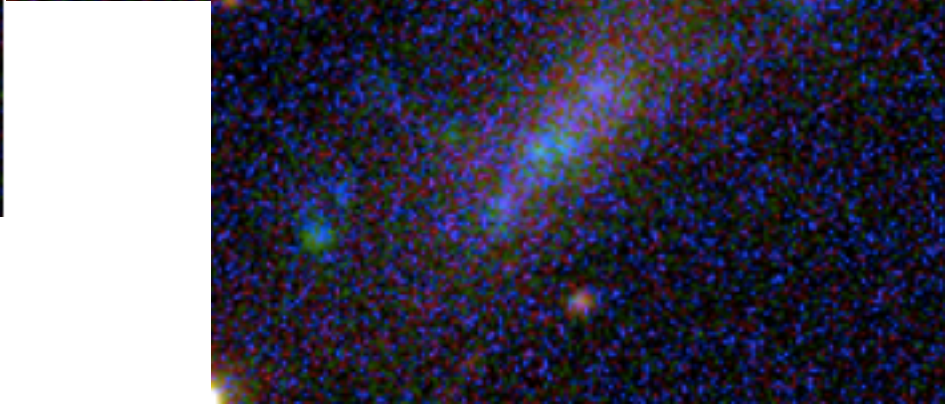
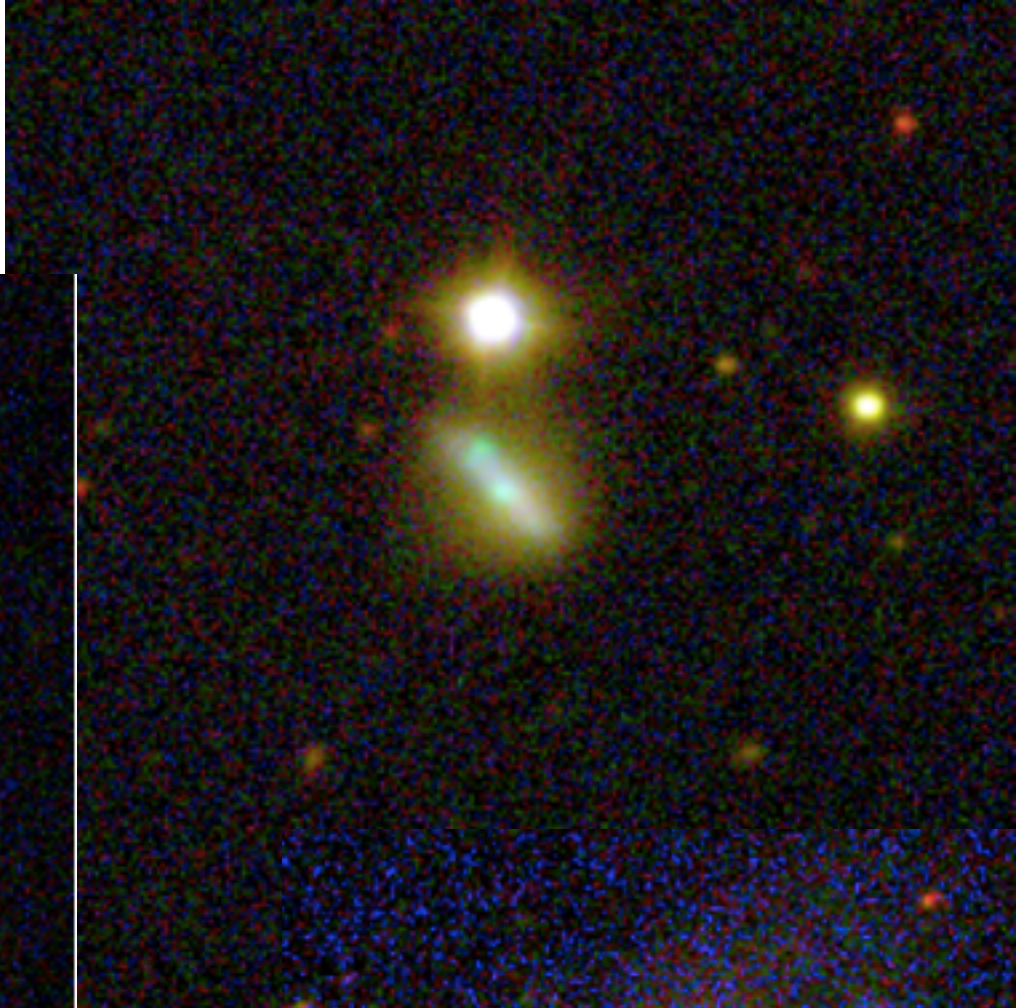
- Virial radius of the Fornax cluster is

$r_{200}=0.7$  Mpc or  
2.2 degrees (Drinkwater et al. 2002)

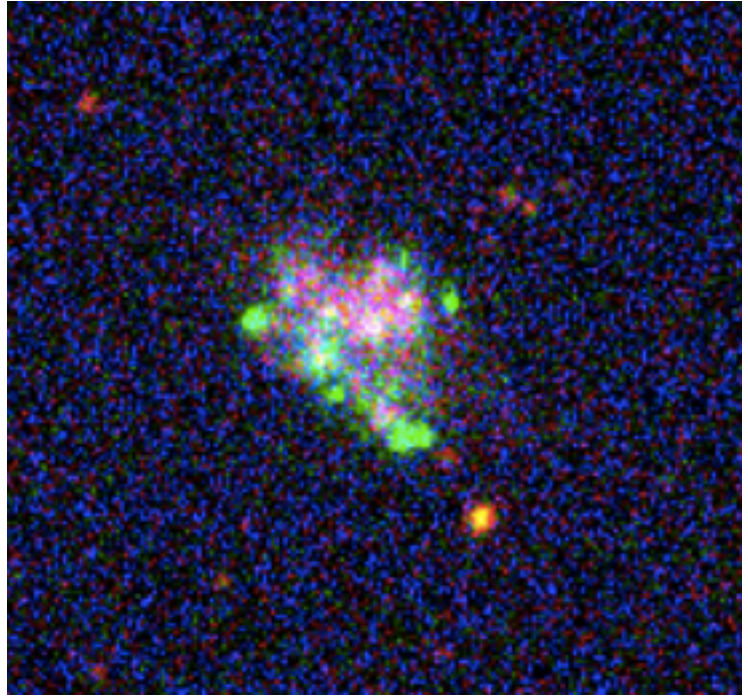
## Some lessons learned:

- Do not restrict parameters – we were originally requiring photoflag 0 – found few
- Be aware of multiple detections for each galaxy in the catalogues



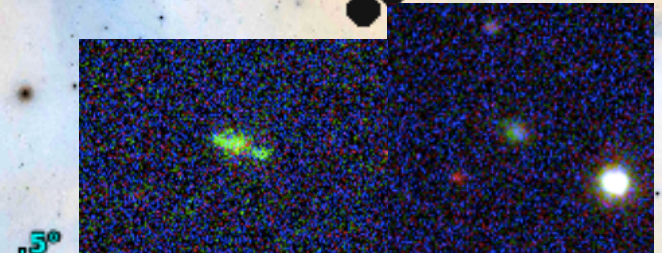
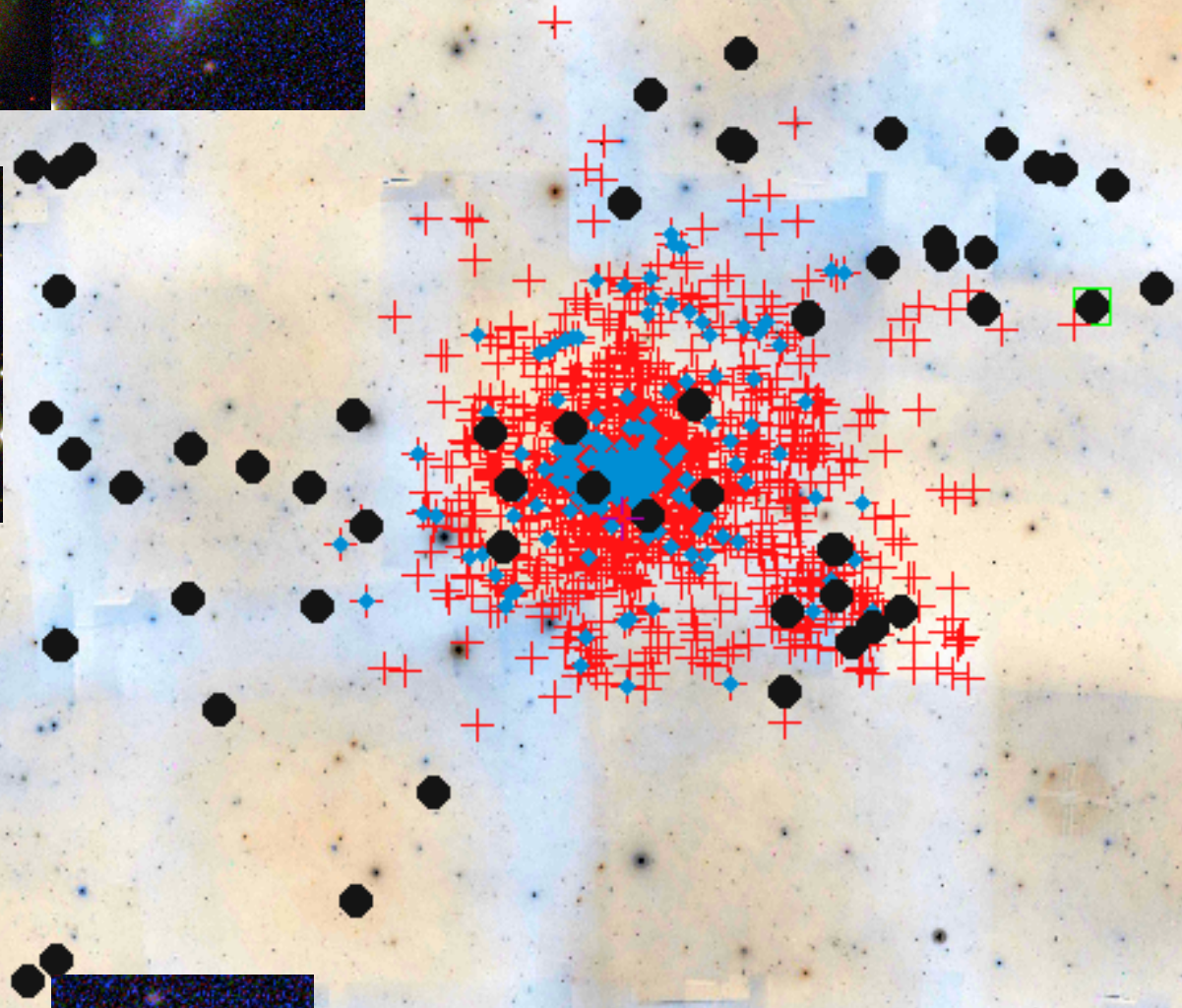
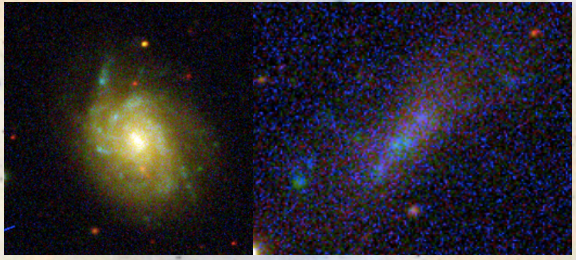




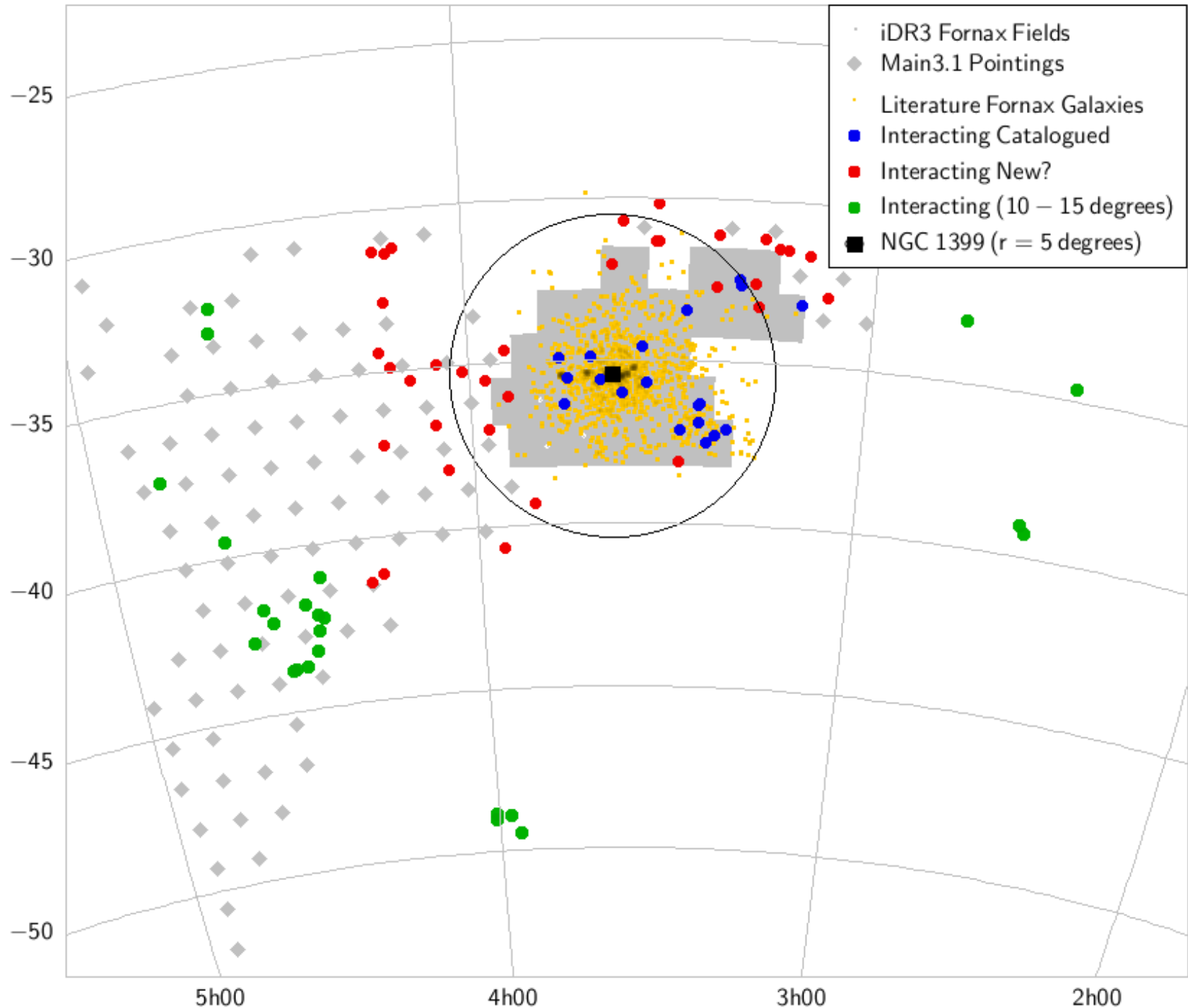




DSS2 color

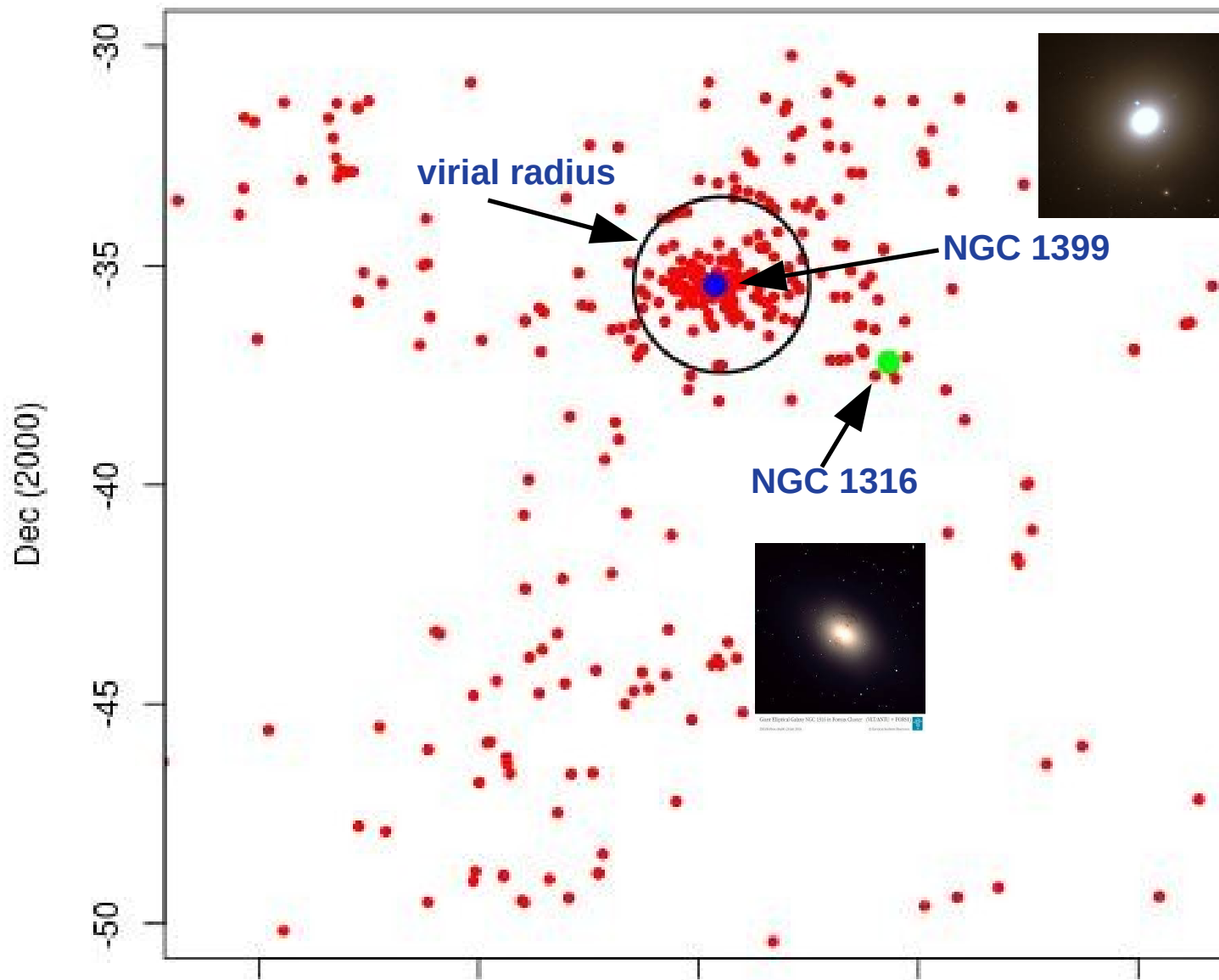


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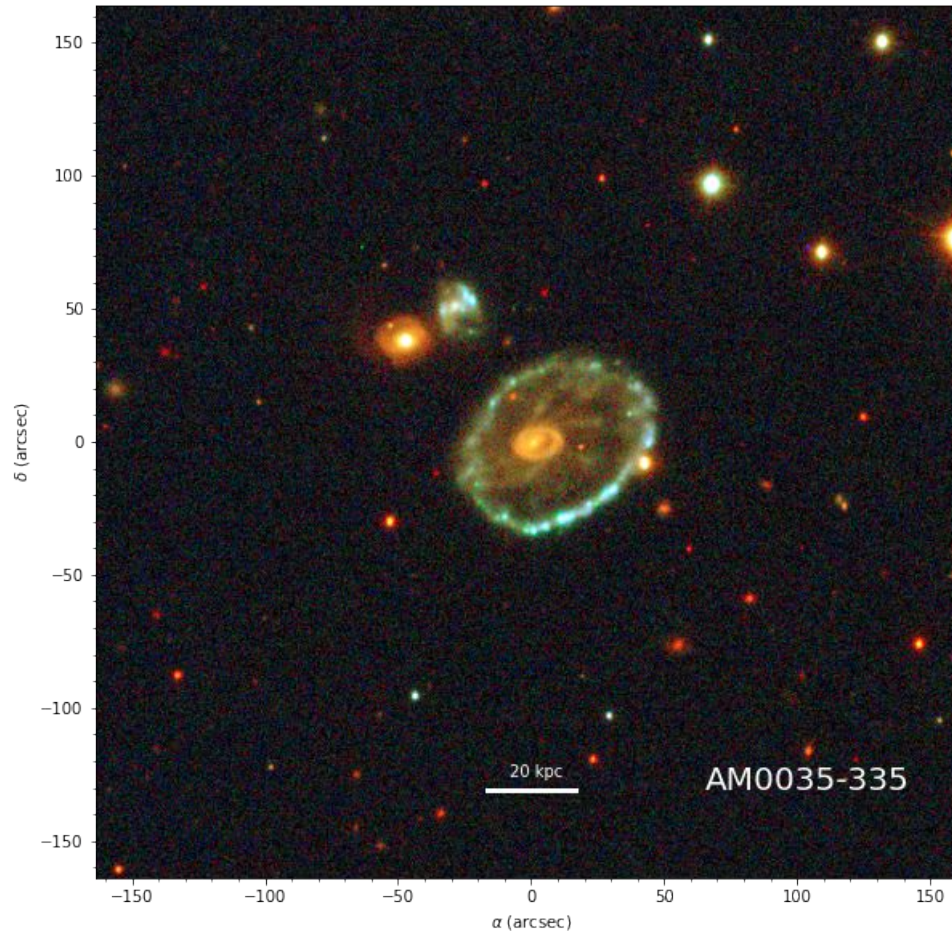
# The Fornax cluster environment from $z_{\text{spec}} < 0.01$



# *Interacting Galaxies in S-PLUS*

Jose A. Hernandez-Jimenez, Claudia M. de Oliveira, Angela Krabbe, Geferson, Fernando Caro, Clecio, Arianna, Erik, Kadu, Ana, Hellen, AN et al.

Cartweel  
Galaxy



# Revisiting Arp & Madore catalogue of southern peculiar galaxies and associations (1987)

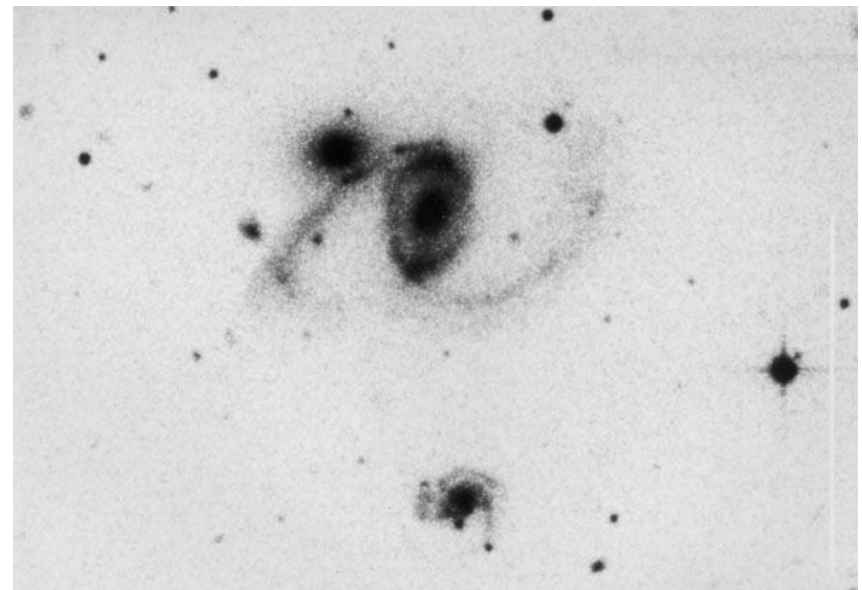
An effort of more ten years by Arp and Collaborators working on plates collected from *ESO/SRC Southern Sky*.

Link: [https://ned.ipac.caltech.edu/level5/SPGA\\_Atlas/SPGA\\_contents.html](https://ned.ipac.caltech.edu/level5/SPGA_Atlas/SPGA_contents.html)

The images were taken with IIIa-J Emulsion (3950–5400 Å)

- 25 Categories, some examples:
  - [CATEGORY 1: GALAXIES WITH INTERACTING COMPANIONS](#)
  - [CATEGORY 2: INTERACTING DOUBLES](#)
  - [CATEGORY 3: INTERACTING TRIPLES](#)
  - [CATEGORY 6: RING GALAXIES](#)
  - [CATEGORY 12: PECULIAR DISKS](#)
  - [CATEGORY 15: GALAXIES WITH TAILS, LOOPS OF MATERIAL OR DEBRIS](#)
  - [CATEGORY 18: GROUPS](#)
  - [CATEGORY 19: CLUSTERS](#)

Category I example





# Revisiting Arp & Madore Catalogue

\* Title: S-plus catalog of interacting galaxies: stellar populations and star formation rates (<http://extranet.on.br:8000/splus/wiki/Project029>)

Main Goals:

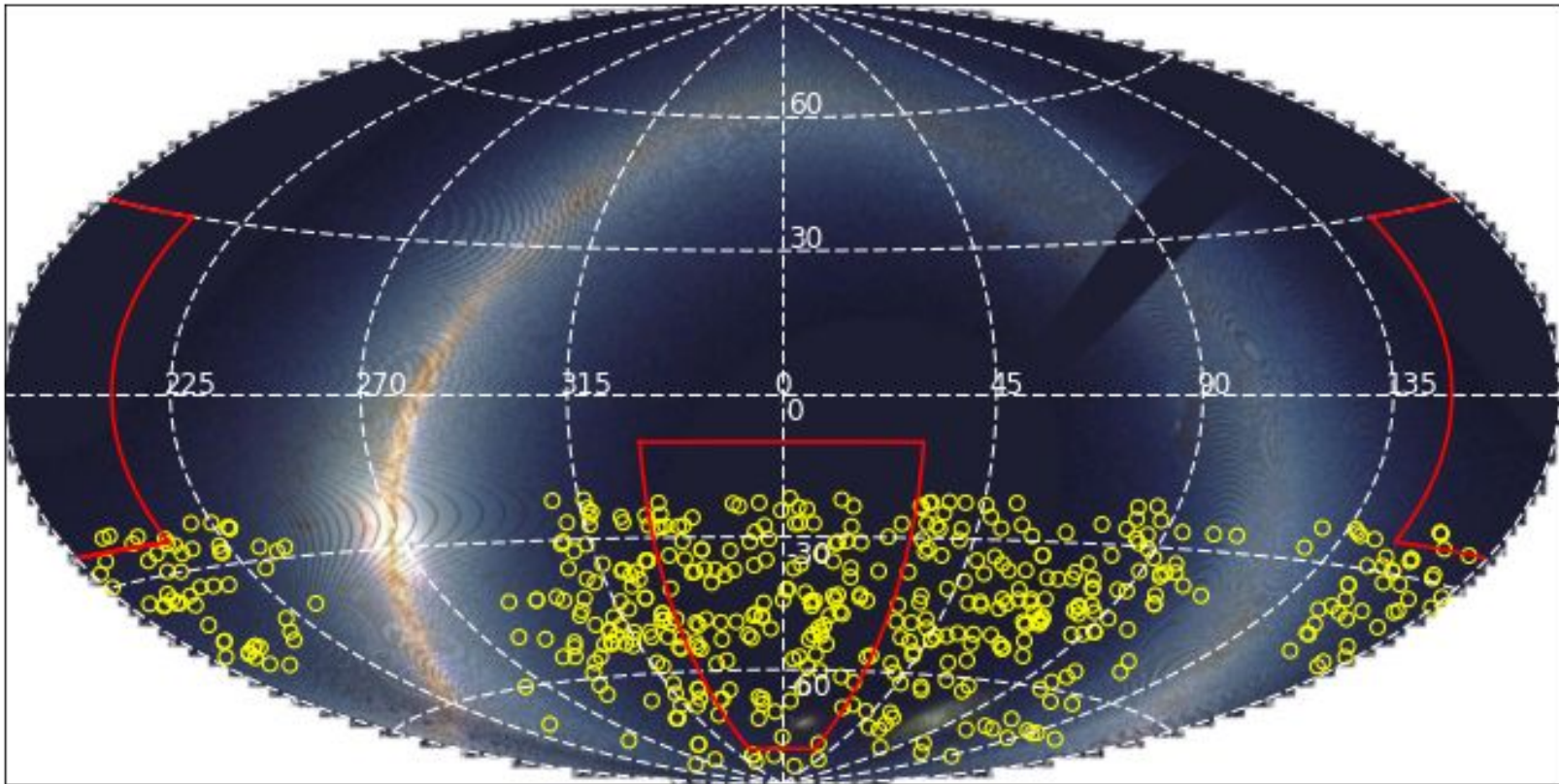
- **Determination whether the associations are physical systems** or not out to  $z \sim 0.1$  (Photometric Redshift).
- **Classification in color-color or color-magnitude diagrams** (they are blue, red or green valley galaxies?)
- **Stellar Masses** (from color empirical relations, e.g., Taylor et al. 2011, or SED fitting AISTAR, CIGALE, LEPHARE, etc.), and computing of **ratio masses** and strength of **tidal parameter Q**.
- **Morphological parameters:**
  - Gini–M 20 (Lotz et al. 2004) statistics.
  - concentration–asymmetry–smoothness stat. (CAS, Conselice 2003)
  - STATMORPH and MORPHOMETRYCA CODES.
  - These properties are related with interaction stage?
- **Stellar population analysis** (products such as star-forming history, metallicity, etc.) (SED fitting AISTAR, CIGALE, LEPHARE, etc.)

## Arp & Madore Catalogue and SPLUS footprint

CATEGORY 1: GALAXIES WITH INTERACTING COMPANIONS

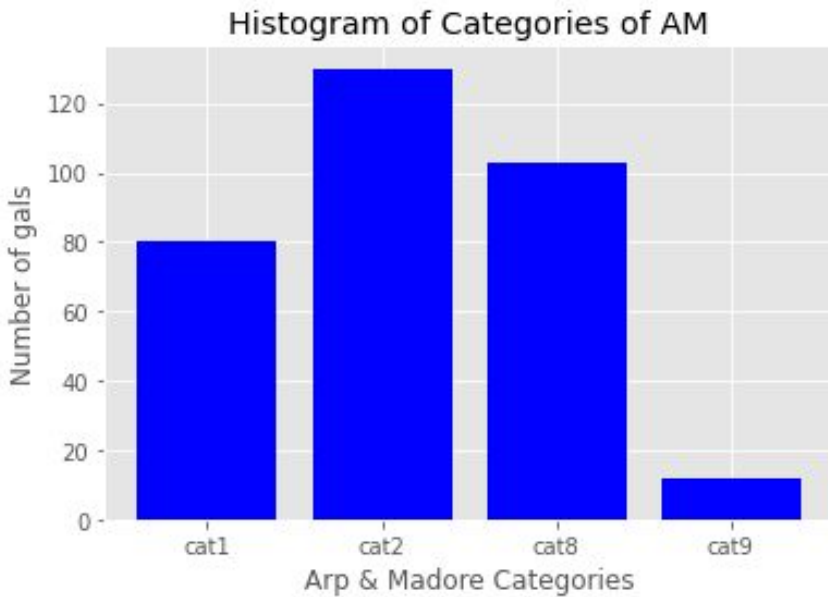
Number of systems of the Category 1 of Arp & Madore Catalogue: 487

Number of systems of Category 1 within **Splus survey**: **186 (~38%)**



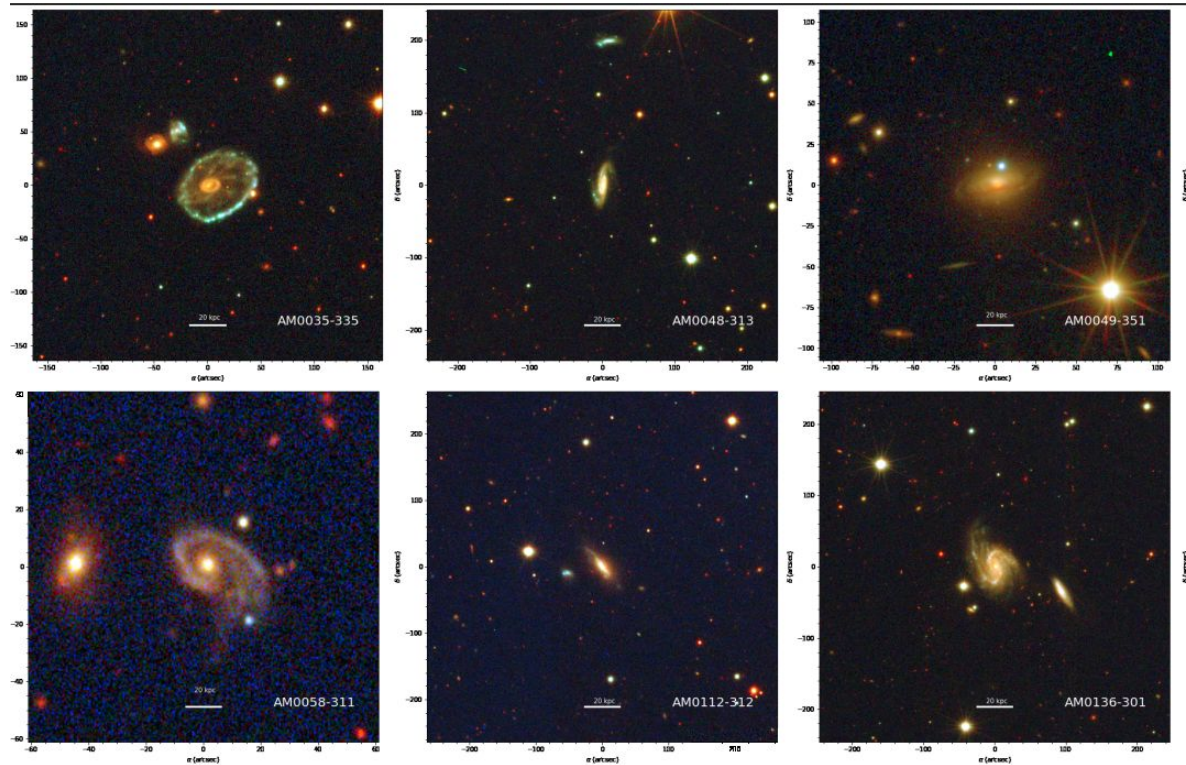
# Crossmatch AM Catalogue with S-PLUS DR2

Matching categories 1, 2, 8 and 9 with S-PLUS iDR3 -325 galaxies



# Environment Study up to 100 kpc

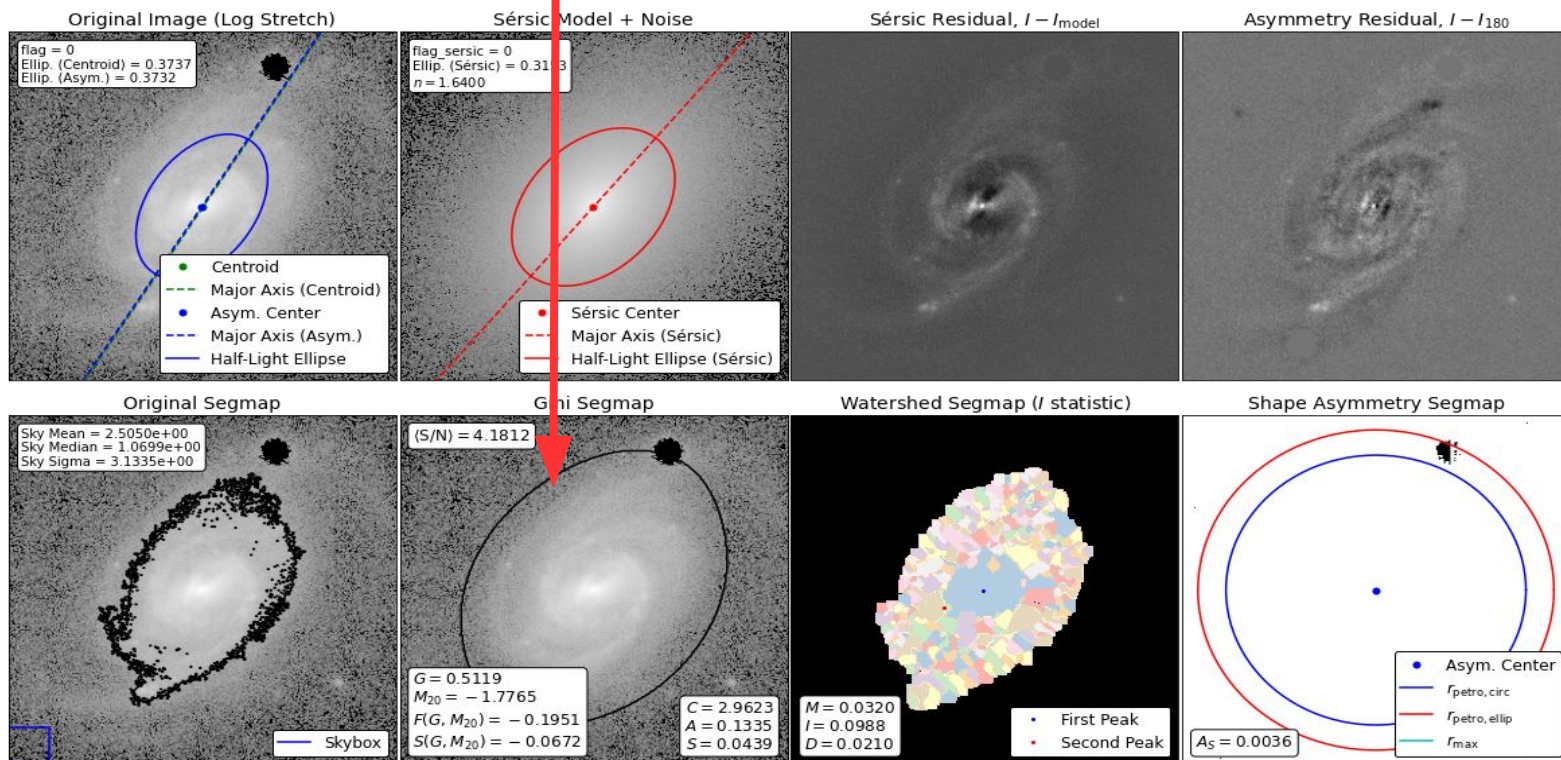
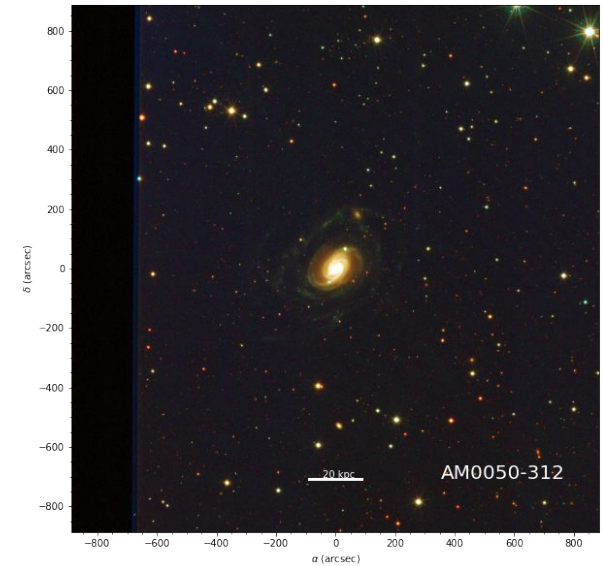
Mosaic from 12 band images by using Gustavo's routine.





# Photometric Analysis (e.g., AM0050-312)

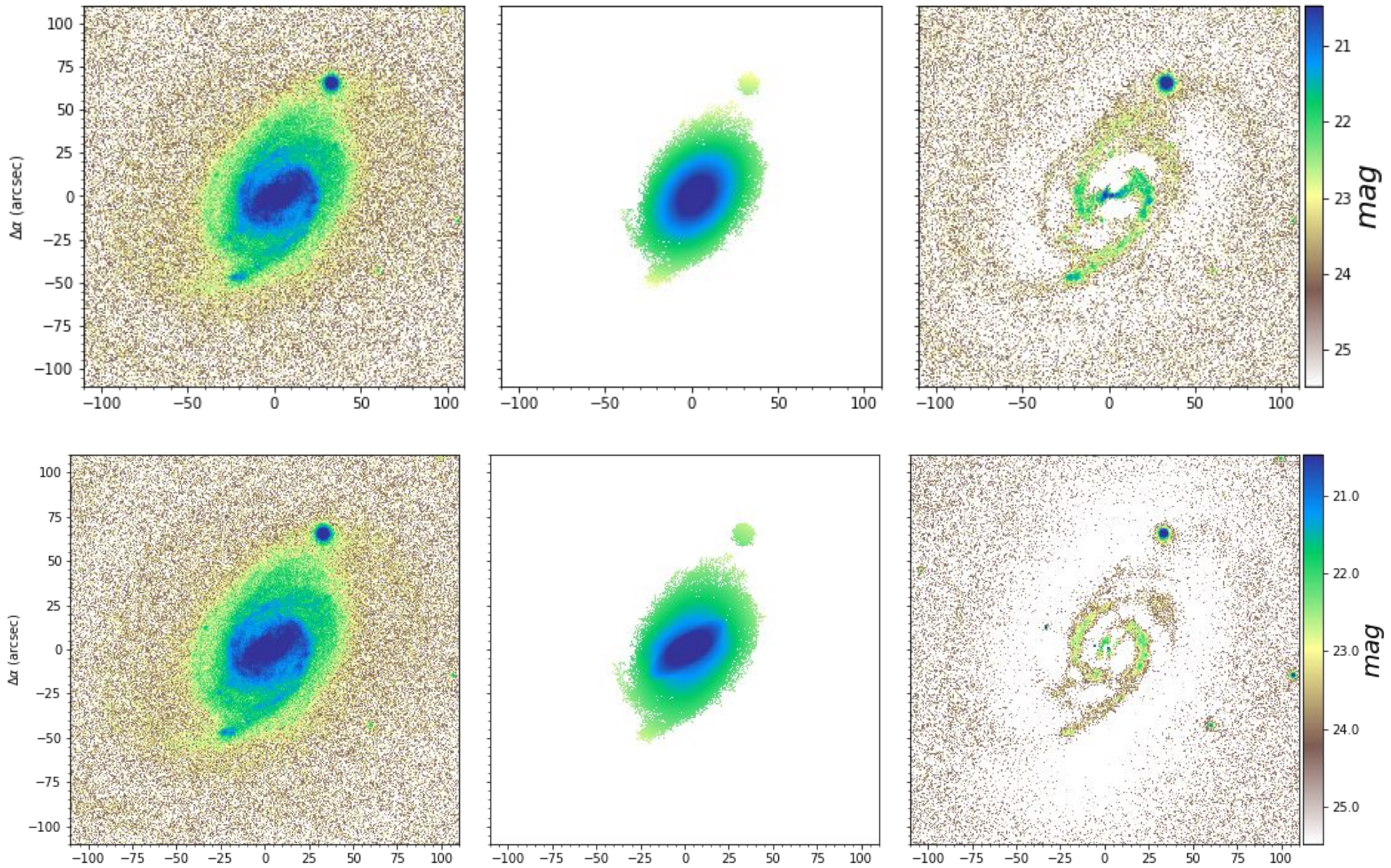
- By using STATMORPH software (Rodriguez-Gomez+19), we will compute morphological parameters such as:
- Gini-M 20 (Lotz + 04) statistics. ( Merger Classification, see Claudia's part)  
concentration-smoothness (CAS, Conselice +03) statistics.





# Photometric Analysis (e.g., AM0050-312)

- We will modeled the **symmetric image** in i'-band by using a 2D models of the subcomponents such as bulge (Sersic), bar (Ferrer) and disc (Freeman) convolved with PSF of the image.



# Interaction of Hot Dynamical Systems (Elliptical Galaxies)

\* Title: **Tidal effects on hot dynamical systems.**

\* Motivation: **Interaction of hot systems** can produce effects such as **non-concentric isophotes at inner radii** and **enhancement in surface brightness profile at outer radii.**

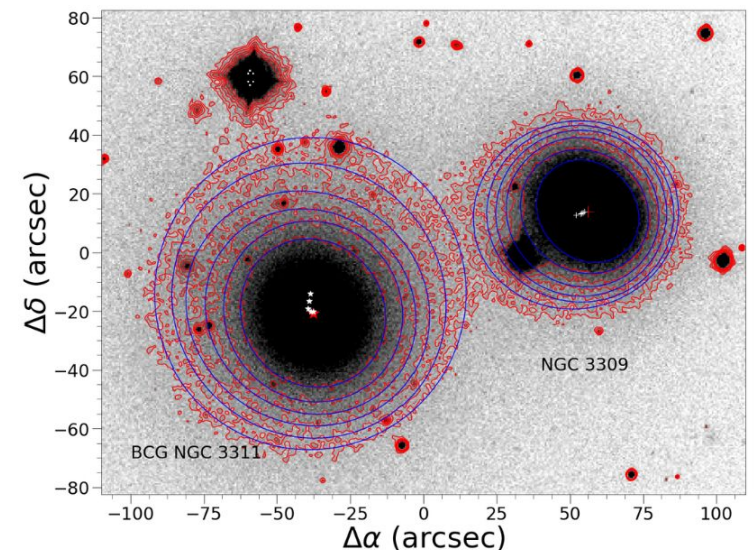
These features are directly related with the **dynamical time of the galaxy-galaxy encounter**, and therefore, they are important observational constraints of the interaction.

\* Sample is taken from the category 2 “interacting doubles” (specifically E+E and E+S pairs) of Arp & Madore (1987) catalog.

Main Goals:

- Quantifying Non-concentric isophotes (off-center profiles).
- Fitting surface brightness profiles and looking for enhancements at outer radii.
- Modelling interactions with N-body simulations (collab. Irapuan Rodrigues)

Hydra's center galaxies show this phenomenon

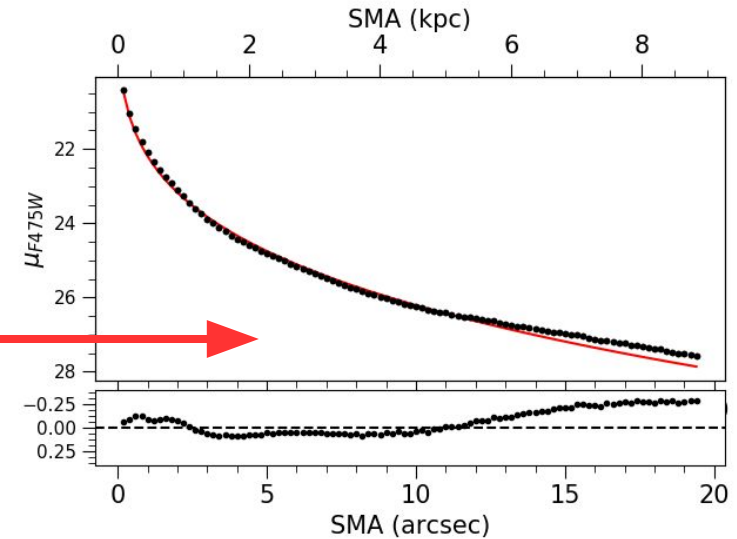
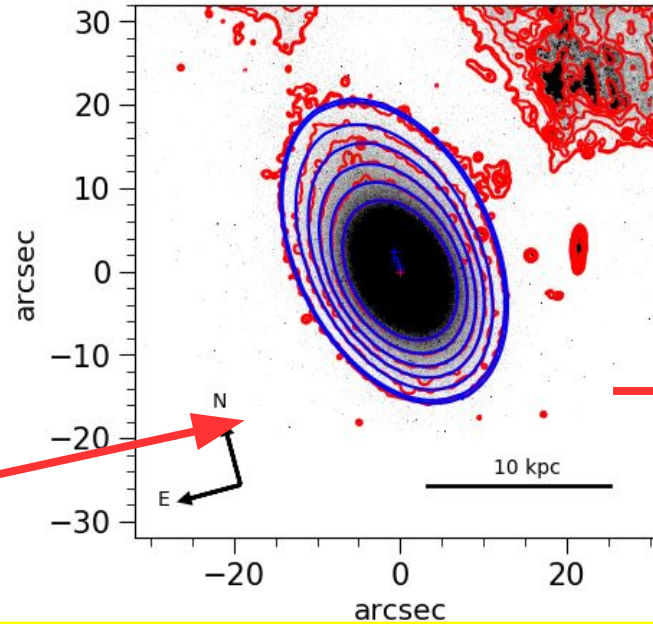
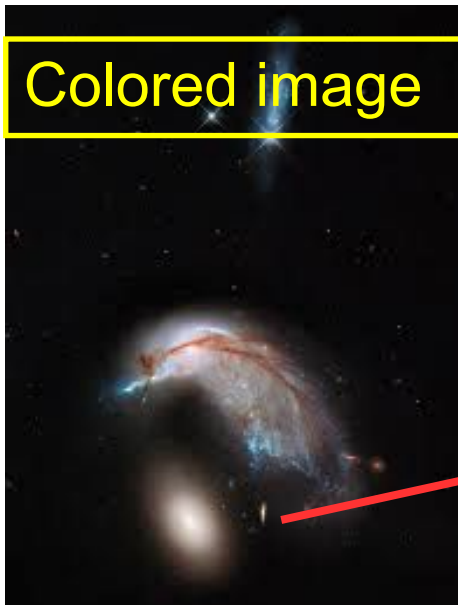




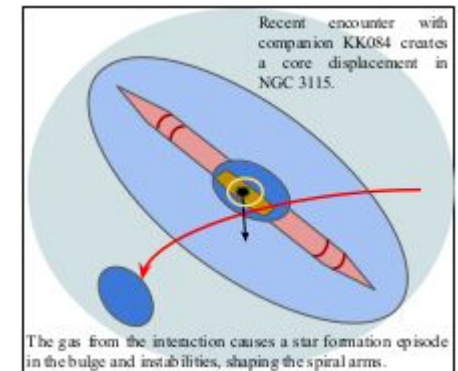
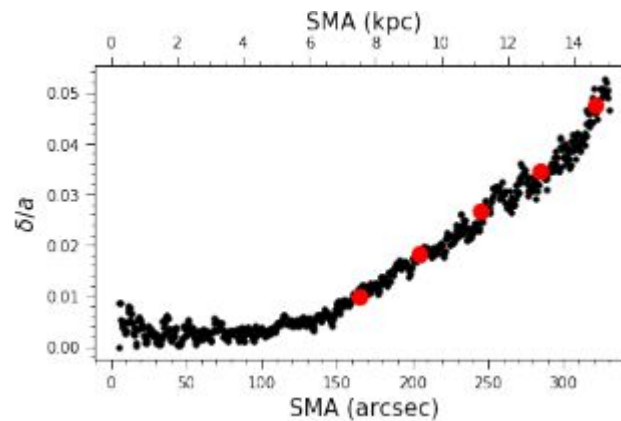
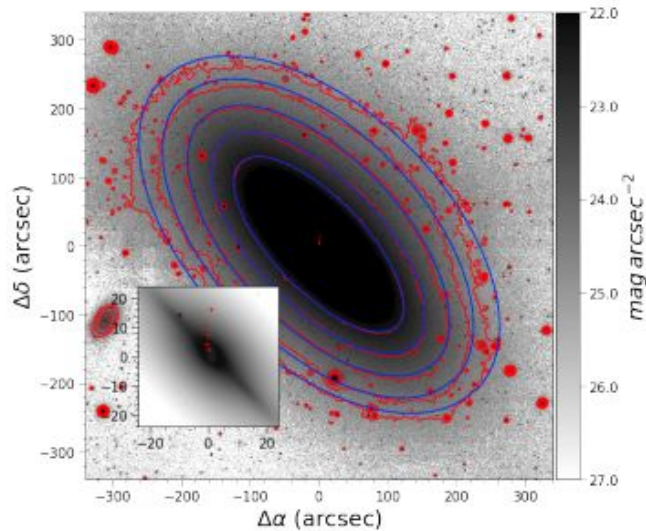
# Results so far

- The Penguin System (NGC 2936/37, Mora, ..., Hernandez-Jimenez + 19)

Colored image



- The closest S0 (NGC315, Buzzo, Cortesi, Hernandez-Jimenez + 21)



# Hernandez-Jimenez + in prep.

- Brightest cluster galaxy of Hydra Cluster (NGC 3311) and its companion (NGC3309), both galaxies have off-centered isophotes and an enhancement of the brightness at outer radii

