

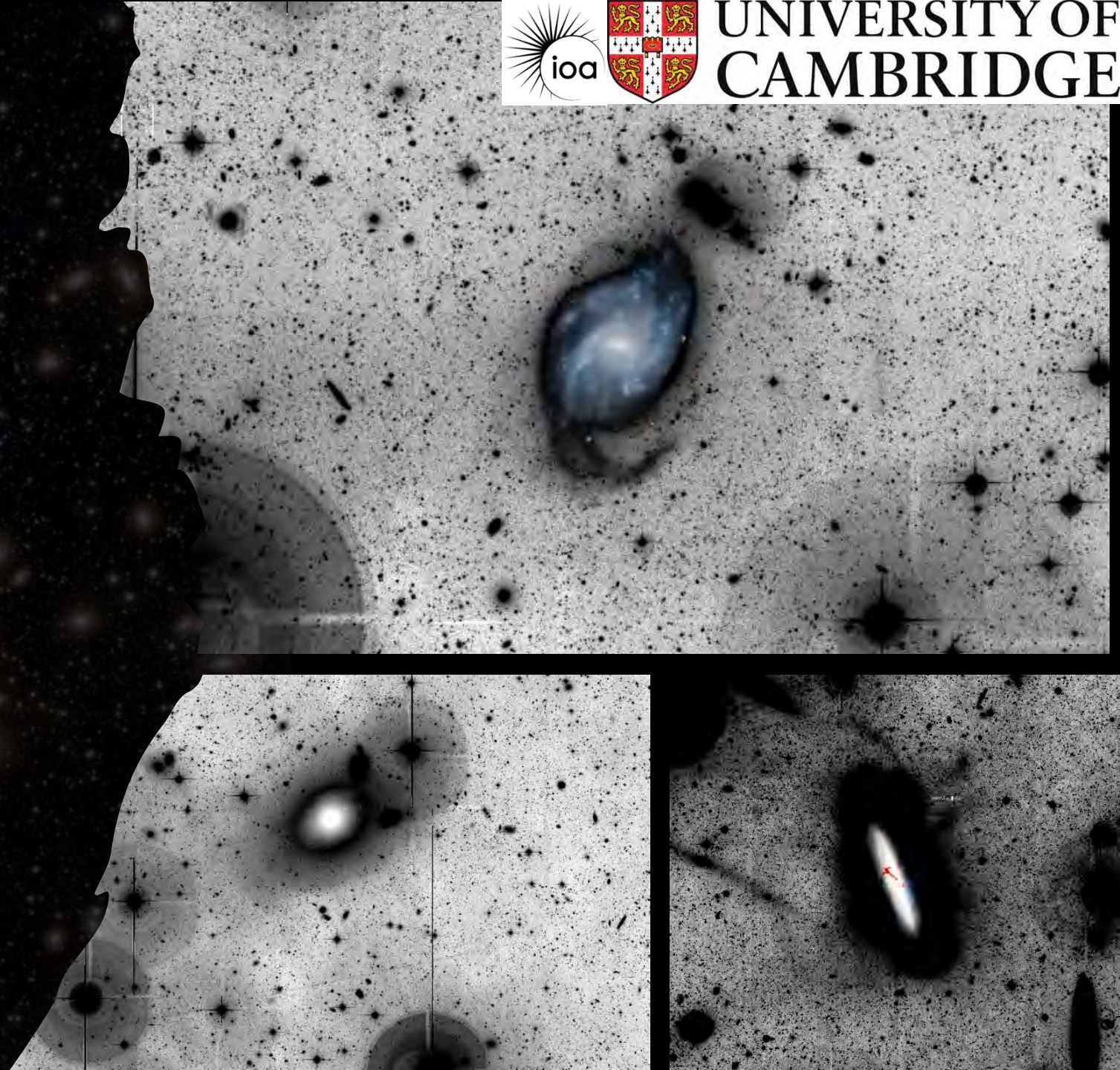


# DIS MPhil : Lecture 14

Tidal features +  
Hands-on session

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DIS MPhil – 11/03/2025





# Outline of this block

## Block C: Low Surface Brightness Universe & image analysis

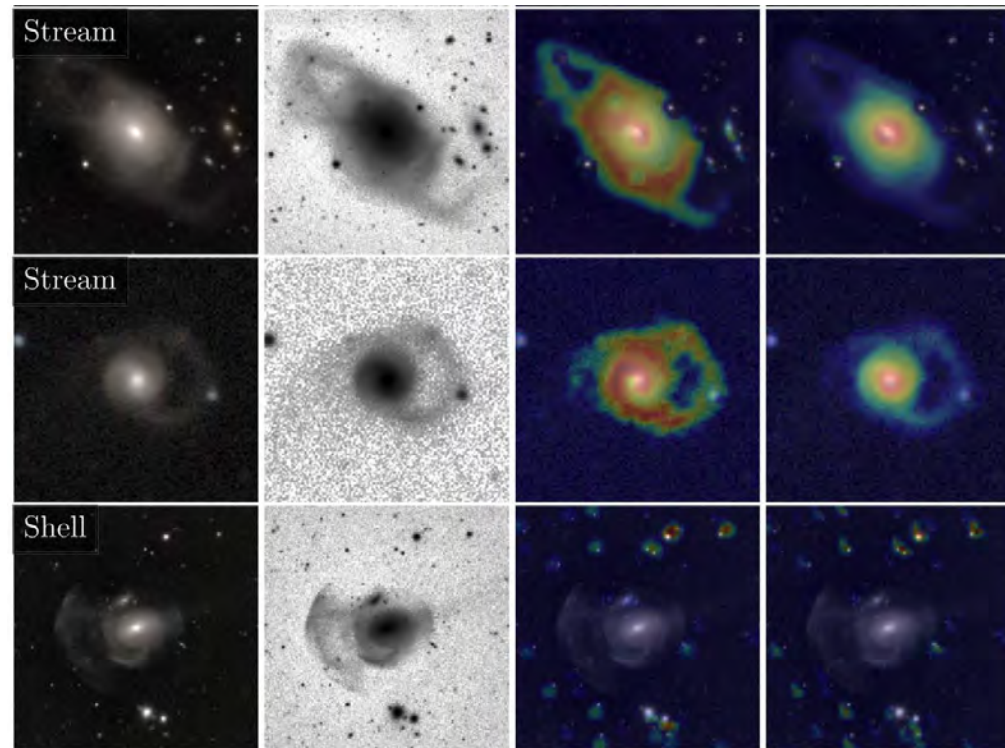
- 1.28/02/2025: Galaxies in the Local Universe:** Introduction to models of galaxy formation and evolution. Galaxy mergers and tidal features. Tidal features in the Local Group and beyond.
- 2.02/03/2025: Exploring the LSB Universe:** Deep astronomical imaging and data processing techniques. The LSB Universe. Hunting for tidal features in the LSB realm.
- 3.11/03/2025: LSB features and galactic evolution:** LSB features as probes of galactic evolution. Ongoing and future surveys. Machine learning for LSB features.
- 4.11/03/2025: Hands-on session:** explore astronomical images and catalogues with Aladin, DS9, Topcat, Python

# Recap of Lecture 13

- Ongoing and future surveys such as Euclid or Rubin will push further the realm of the LSB Universe
- Machine learning needed to deal with the deluge of data
- Tidal features hold the imprints of late galactic assembly + probes of DM haloes



*Cuillandre+2024b*



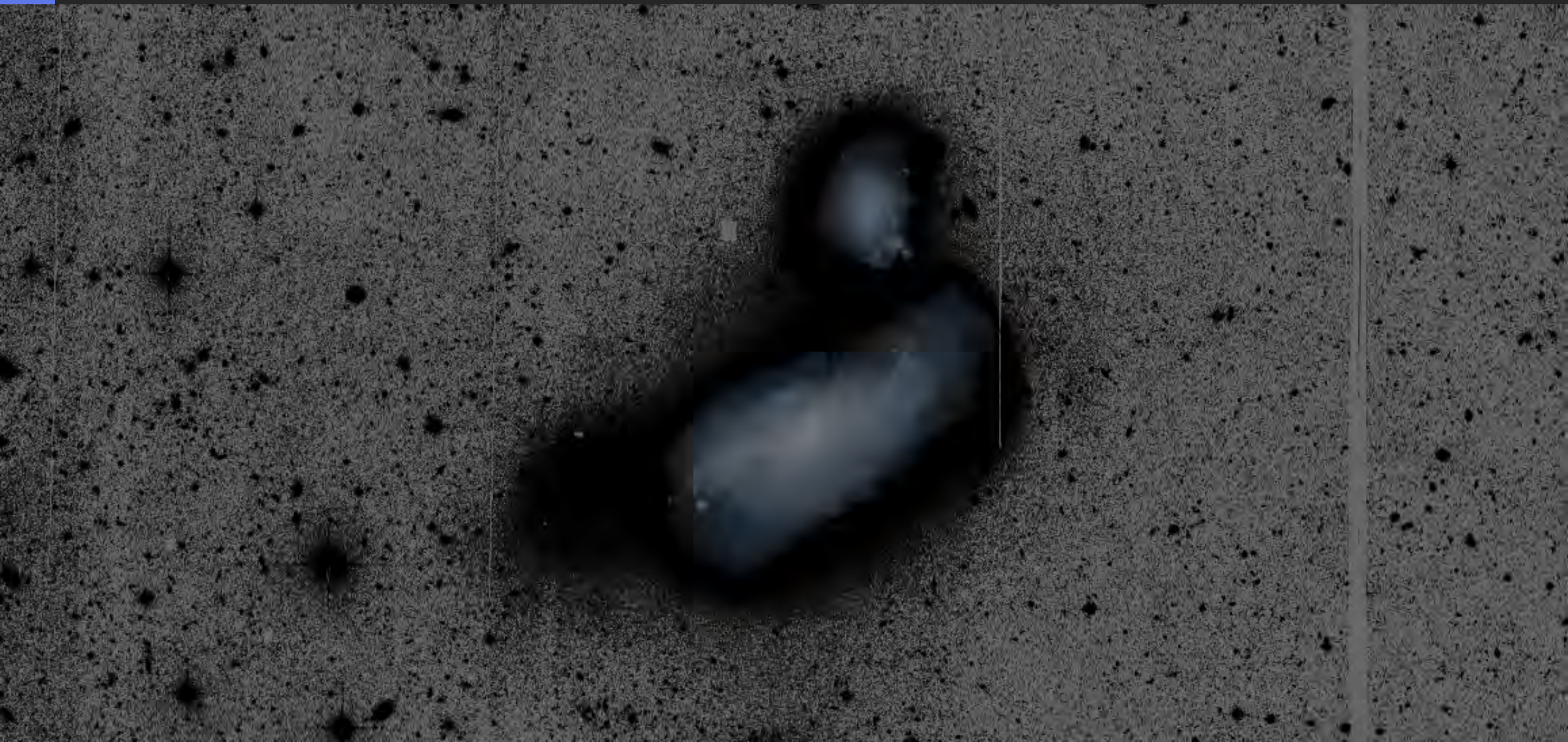
*Gordon+2024*

# Outline Lecture 14

- Tidal features and galactic growth
- Hands-on session: see corresponding Jupyter notebook



# Tidal features and galactic growth



# Tidal features and galactic growth

- NB: the following slides are biased towards some of my results, biased towards diffuse light (unresolved), and they are not exhaustive
- Non-exhaustive list of tidal feature properties that can be studied:
  - Census
  - Geometry
  - Photometry
  - Colour...

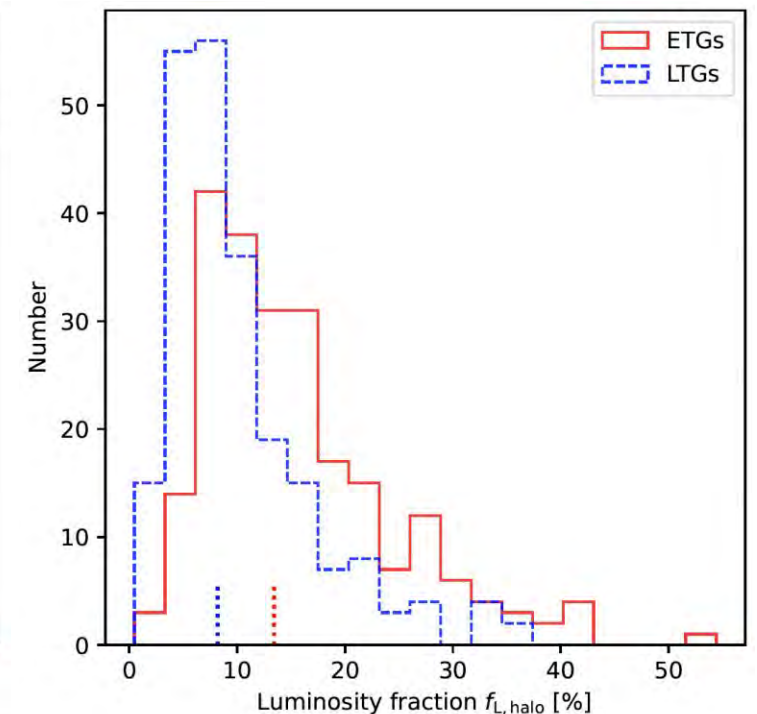
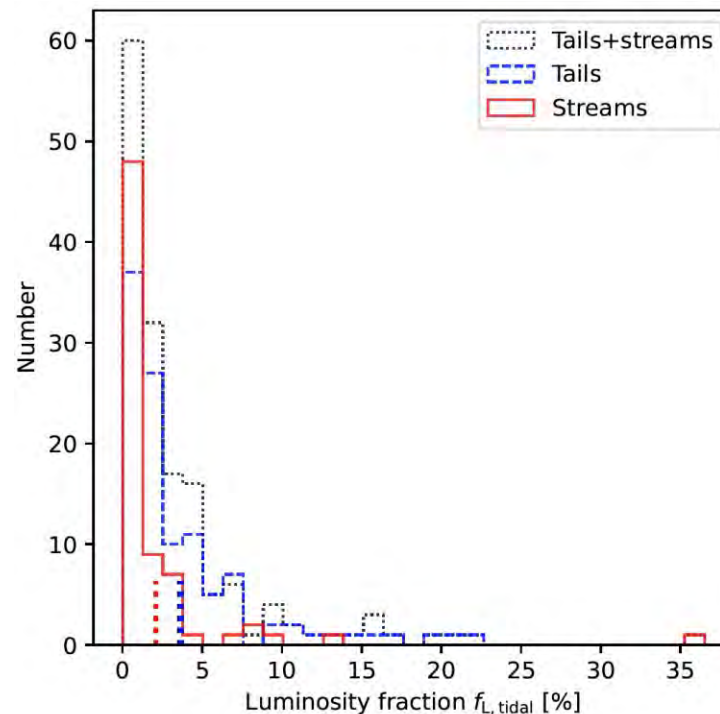
VS:

- Mass
- Environment
- Morphological type
- Kinematics
- ...

# Global statistical results

- *Sola+2022,2025*: study tidal features of 475 nearby ( $D < 45\text{Mpc}$ ), massive galaxies
- Database of +10,000 annotated features, including **199 tails**, **100 streams** and **455 haloes**
- **36%** of galaxies host tidal features: 23% host tails, 15% streams and 12% shells

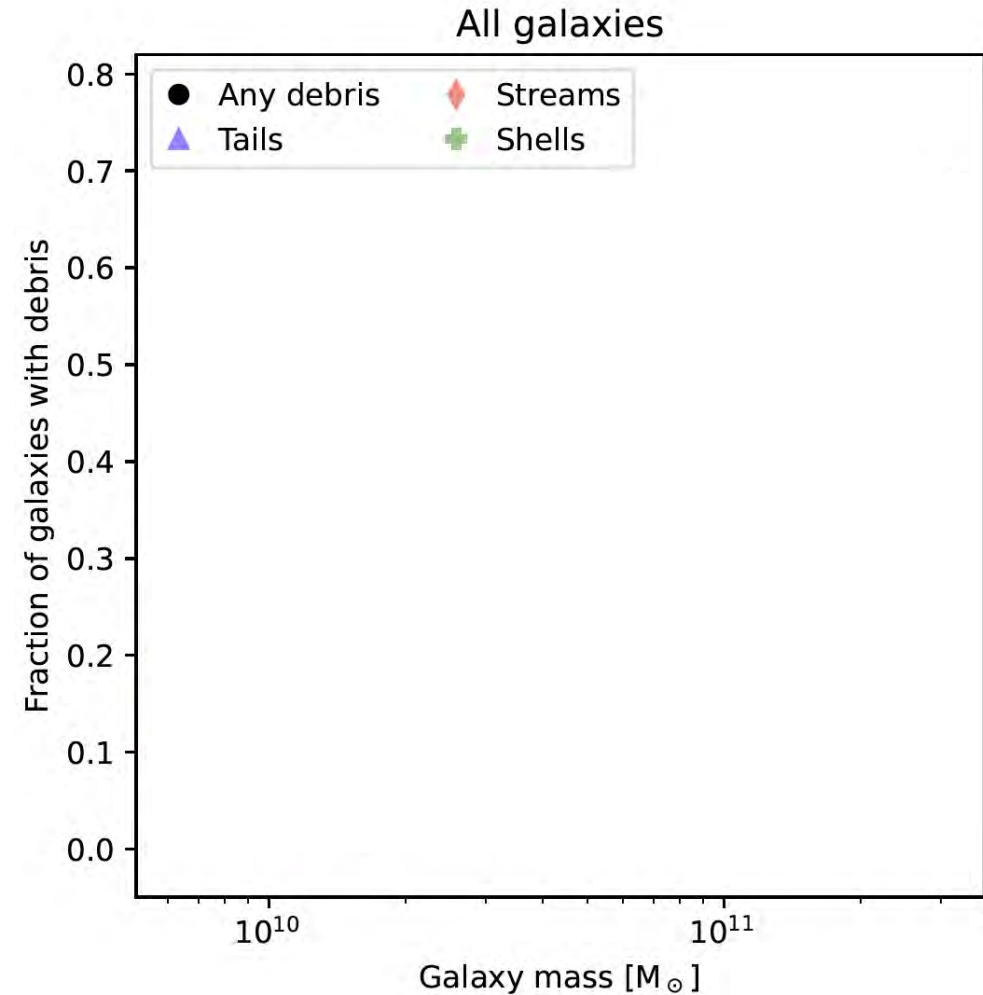
- Tails+streams account for **2-4% of the total galaxy luminosity**, while haloes account for **10%**





# Trends as a function of galaxy mass

- The fraction of galaxies hosting tidal features more than **doubles** from 25% to 60% for the **highest-mass** galaxies.
- **Increase** visible for all **feature types**
- Similar trends for ETGs and LTGs separately

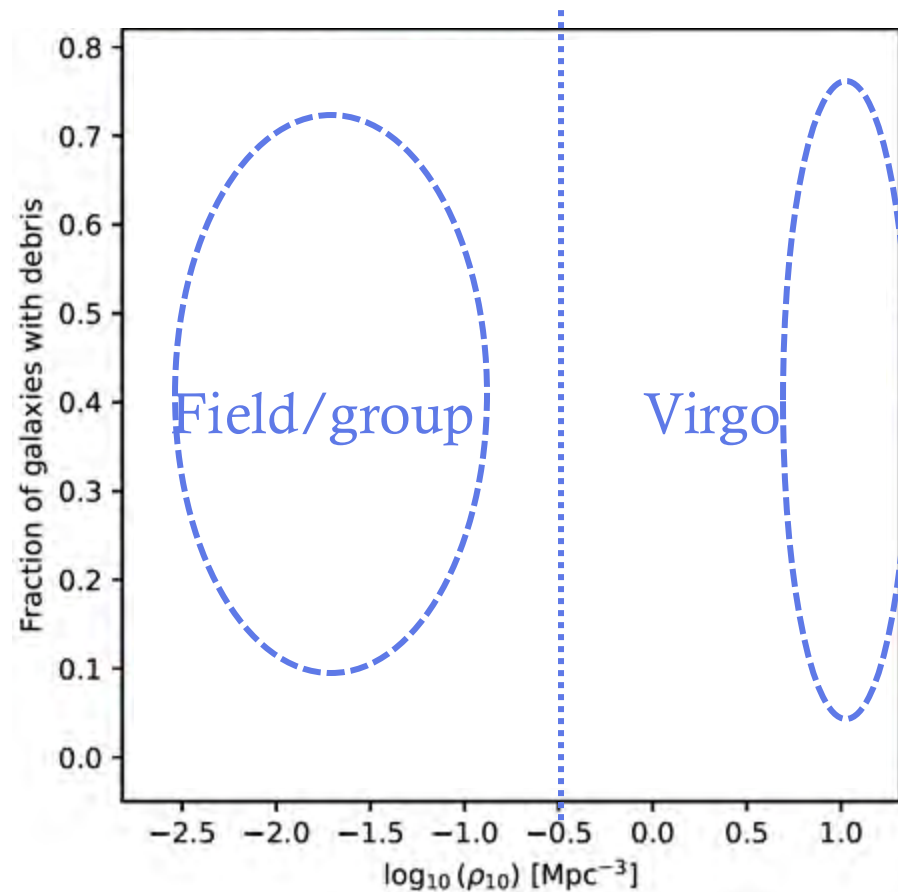


*(Sola+ under review)*



# Trends as a function of the environment

- Large-scale environment: Virgo cluster vs field/group



Overall similar fractions of galaxies with debris in Virgo cluster and in field/group

But two **peaks**: on-going interacting galaxies ?

► Separate between isolated and in-pair galaxies

No peak, no trend  
with  $\rho_{10}$

2 peaks: on-going  
interactions

*(Sola+ under review)*

# LSB features vs galaxy mass and environment

## Mass

- **More massive** galaxies have **more tidal features**
  - **More massive ETGs** have **more luminous haloes** (not LTGs)
  - Presence of a mass threshold ( $\sim 4\text{--}7 \times 10^{10} M_{\odot}$ ) above which the increase is steeper
- Support the **hierarchical** paradigm: more massive galaxies have undergone more merger events and their assembly is driven by mergers (rather than accretion)

## Environment

- Large-scale environment: does not impact much tidal features
- **Small-scale environment** (presence of companion): mergers between interacting galaxies trigger tidal features
- **LTGs** have more extended haloes in the Virgo **cluster** (no evolution for **ETGs**): sign of **ram-pressure stripping**

► Galaxy **mass** seems to be the dominant factor that affects tidal features and haloes

# Comparison to literature

- **Comparison** between works **far from being straightforward**: not the same image depth, definition of what a tidal feature is, not the same methods, not the same metrics (*e.g., Atkinson+2013, Hood+2018*) ...
- Can lead to **large discrepancies**: e.g., the fraction of galaxies with debris can range from a few percents up to 70% (*e.g., Malin & Carter 1983, Bridge+2010, Miskolzi+2011, Atkinson+2013, Bílek+2020, Yoon+2023...*)
- But still the **increase** of the fraction of galaxies with debris and their luminosities **with stellar mass** has also been reported in observations and simulations (*e.g., Atkinson et al. 2013; Duc et al. 2015; Bílek et al. 2020; Yoon & Lim, 2020; Huang & Fan 2022; Vázquez-Mata et al. 2022, Rodríguez-Gomez et al. 2015; Martin et al. 2022*)
- Previous slides: examples of how tidal features can be used to probe galactic assembly. But what else can we learn ?



# Tidal features and dark matter haloes

- Streams: useful probes of the properties of the **Dark Matter** (DM) haloes surrounding galaxies. With 6D information ► strong constraints can be put on DM shape and mass (*e.g., Springel and White 1999, Dubinski+1999, Ibata+2001, Helmi+2004, Johnston+2005, Koposov+2010, Bovy+2016, Koposov+2023....*)
- What about streams with only **2D information** (spatial position + photometry) ?
  - ➔ *Nibauer+ 2023* : light constraint on DM shape only from 2D position
  - ➔ What about a population of streams ?
- *Chemaly+, in prep*: constrain the flattening of DM haloes from 2D information of streams (position + photometry), at a population level, using hierarchical Bayesian inference



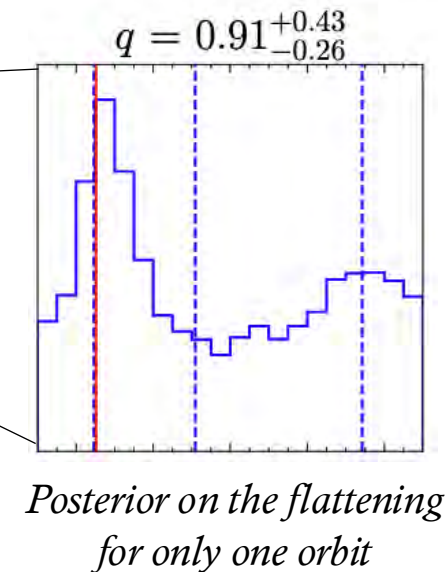
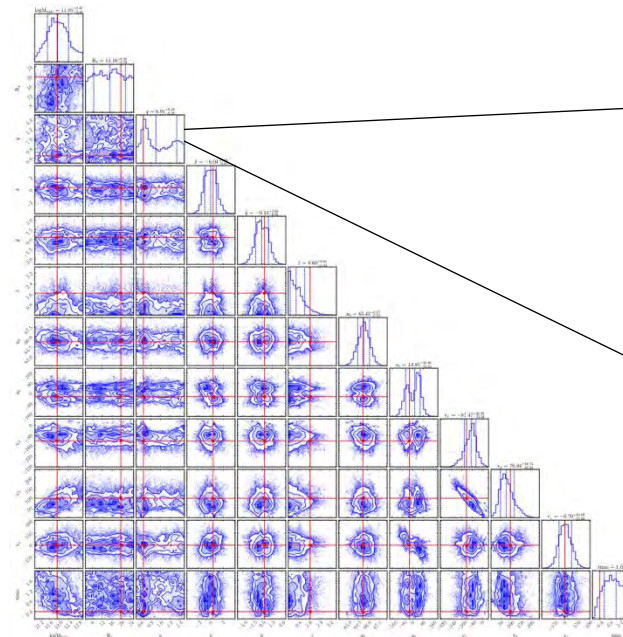
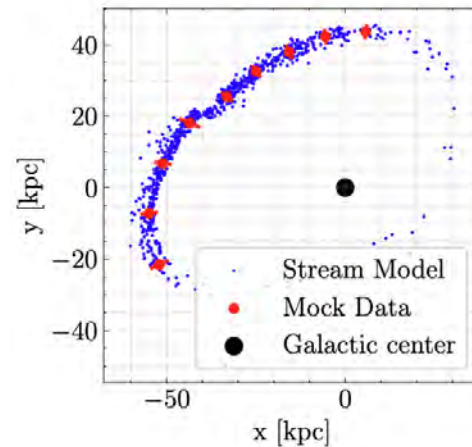
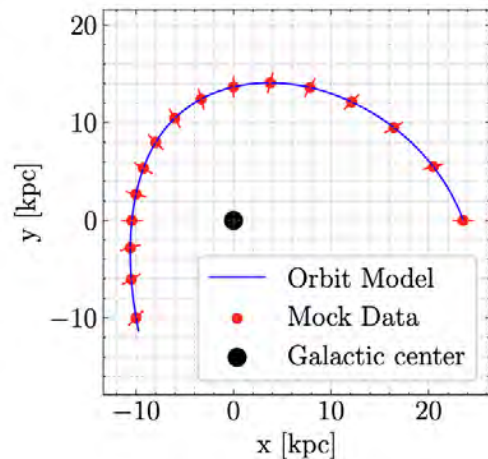
# Streams and DM flattening

Mock data

Hierarchical Bayesian Inference

Model

Either orbits or streams



- Next: apply to real data on a large sample of ‘best’-looking streams (long, curved, faint) but no consensus in the literature, no large catalogue of these streams
- *Sola+*, in prep: catalogue of tidal features and modelable streams in DESI Legacy Imaging surveys

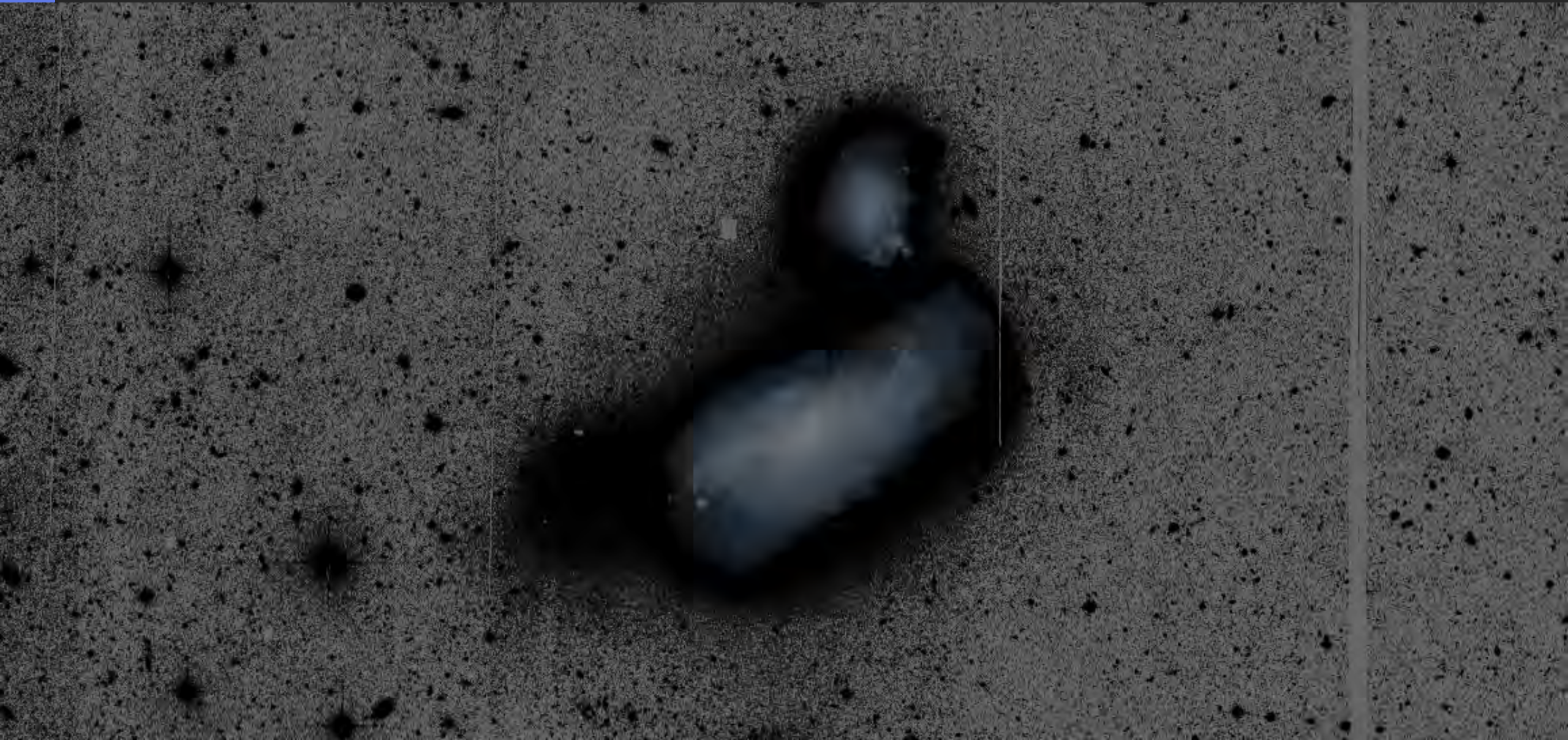


# Summary

- Future/ongoing large sky surveys, depth multi-band, great resolution ► push further the limit of the LSB Universe
- **Euclid**: already proved its wonderful capabilities with the Early Release Observations, soon the Quick data release (Q1) will be public. So many papers about LSB science !
- Tidal features in deep images found mostly by visual inspection...
- ... but impossible to do in ongoing/future large surveys: need **machine learning**
- CNN-based networks largely used but other methods, including using foundation models
- Tidal features fraction, geometry and luminosity give clues about the **late mass assembly** of galaxies and can be used to constrain **dark matter haloes'** shapes



# Hands-on session



# See Jupyter Notebook

## MPhil in Data Intensive Science

Folder Settings More ▾

### Python Notebooks

Edit



hands-on

Lecture14\_hands-on

images

Lecture14\_hand-on\_fits\_catalogues.ipynb

matlas\_dwarfs\_on\_ngc3230.txt

matlas\_ngc3230.fits

Lecture6\_hands-on\_Gaia-RVS.ipynb

Lecture15\_hands-on\_Gaia-CMD.ipynb

mock\_stream\_generation\_demo\_hands-on.ipynb

Download  
this folder

```
import numpy as np
import matplotlib.pyplot as plt
from astropy.table import Table, Column
from astroquery.vizier import Vizier
from astropy.io import fits
from matplotlib.colors import LogNorm
from astropy import wcs

# Your base directory here
base_dir = '/Users/esola/Documents/Postdoc/Lectures/DIS_MPhil_2025/notebook/'
```

### --- I. Catalogues -----

#### Direct download of online tables

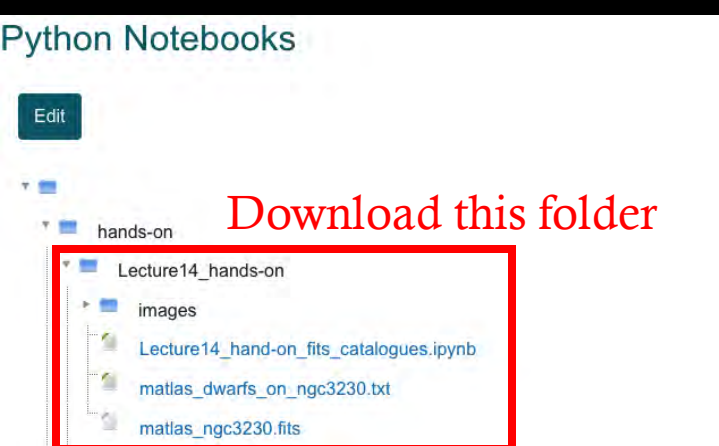
```
# Either you found the table somewhere already...
# Or you can use services such as Vizier to access published catalogues

catalogue_name = 'J/MNRAS/506/5494' # Poulain+2021 MATLAS dwarfs structure and morphology
# https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=J/MNRAS/506/5494&-out.max=50&-out.form=HTML%20Table&-out.add=_r&-out.add=_RAJ,_DEJ&-sort=_r&-oc.
# Download with 'Unlimited' rows the catalogue as VOTable file (and rename it as poulain21.vot)
```

```
## Read the downloaded table
catalogue_path = base_dir + 'poulain21.vot'
catalogue = Table.read(catalogue_path, format = 'votable', table_id = 0)
catalogue
```



# See Jupyter Notebook



NB: If the images in the notebook do not appear (broken link), double-click on the cell and replace the path by `src='images/the_image_name.png'` instead of `src='notebook/images/the_image_name.png'`

Select the subset of galaxies that are dE/dEN and dI/dIN

Go to Subset > click on the green + and add the expression (beware of the syntax for str)

```
1 
```

```
1 
2
```



# Supervision session on 14/03

## MPhil in Data Intensive Science

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### Python Notebooks

Edit

hands-on

Lecture6\_hands-on\_Gaia-RVS.ipynb

Lecture15\_hands-on\_Gaia-CMD.ipynb

mock\_stream\_generation\_demo\_hands-on.ipynb

### DIS GA Minor Module - supervision practice exercise

The goal of this exercise is not to write the best code ever, but to explore the data.

We will go through how to approach the exercise in the second-to-last lecture on March 14 (the usual room). Please try the exercise beforehand, and see how far you get.

- Try to do as much as you can for this supervision practice exercise
- Lecture15\_hands-on\_Gaia-CMD.ipynb