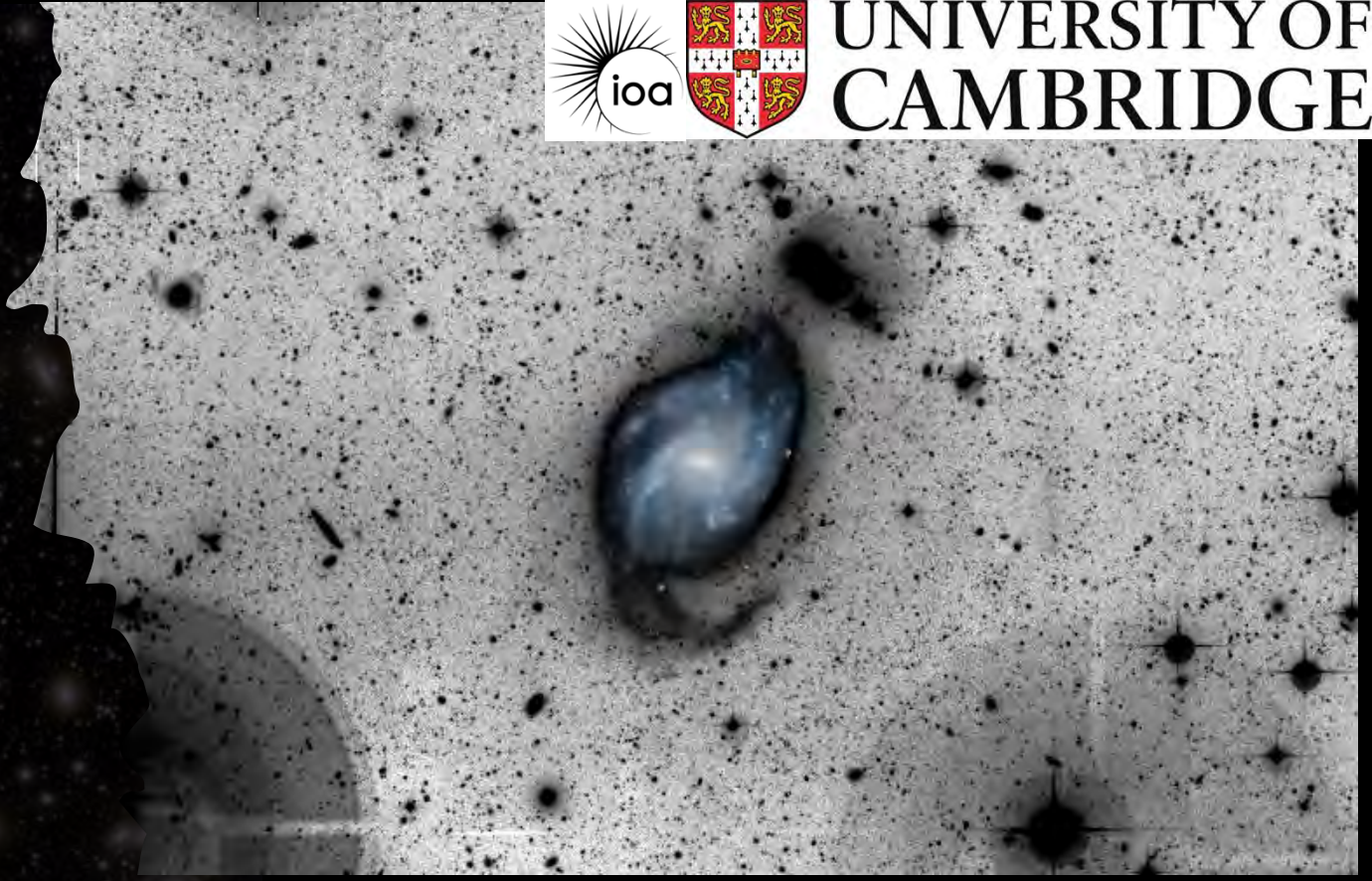
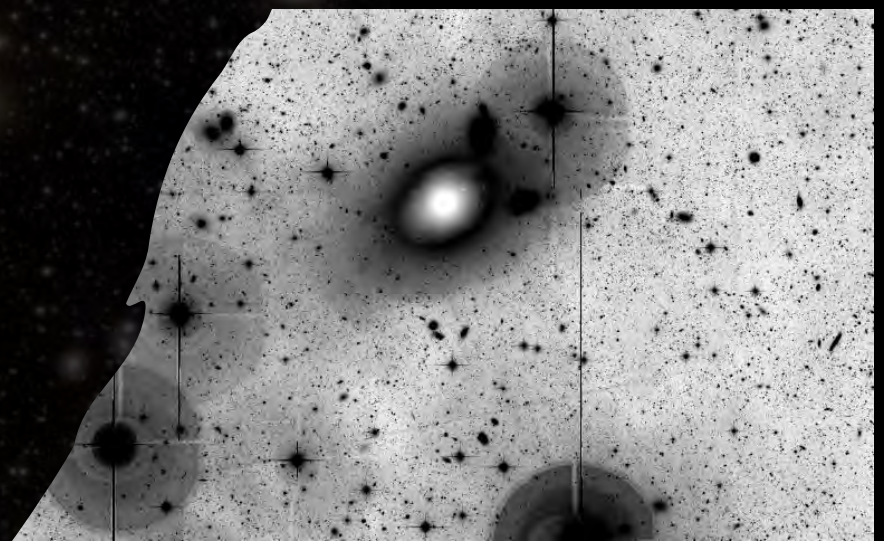
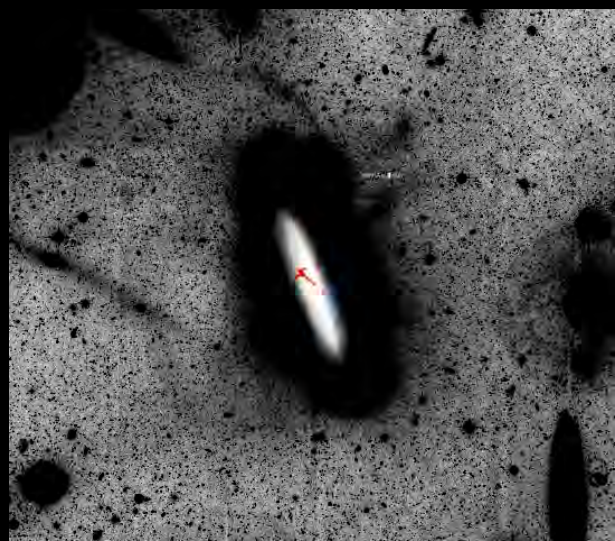
DIS MPhil : Lecture 14

Tidal features + Hands-on session







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DIS MPhil – 11/03/2025

Outline of this block

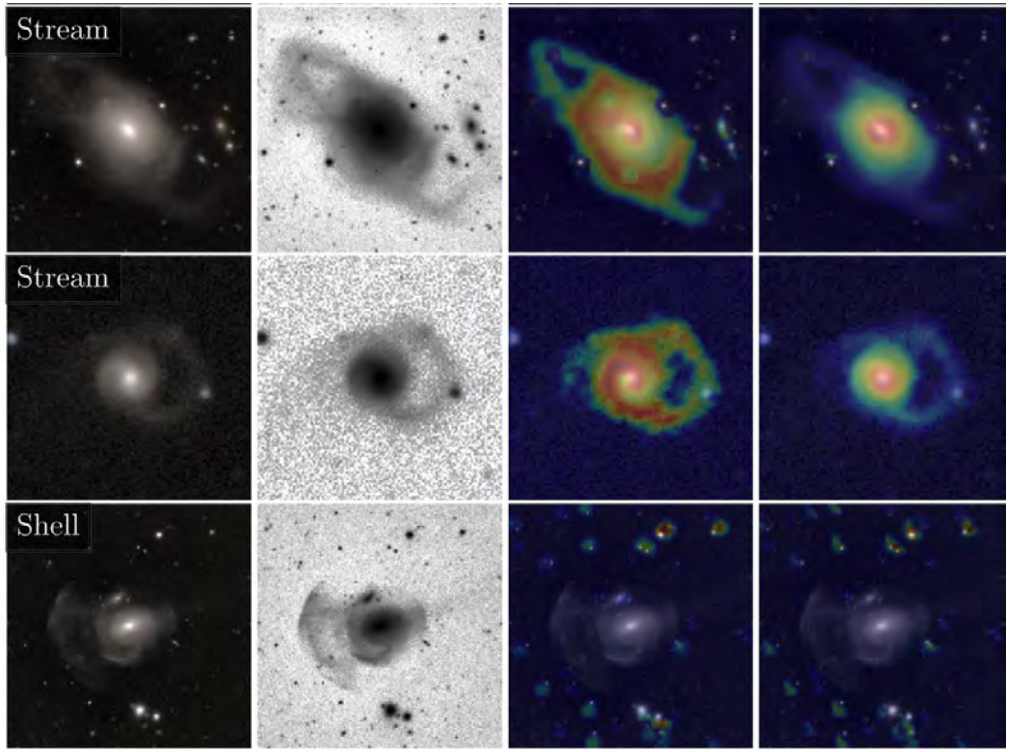
Block C: Low Surface Brightness Universe & image analysis

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

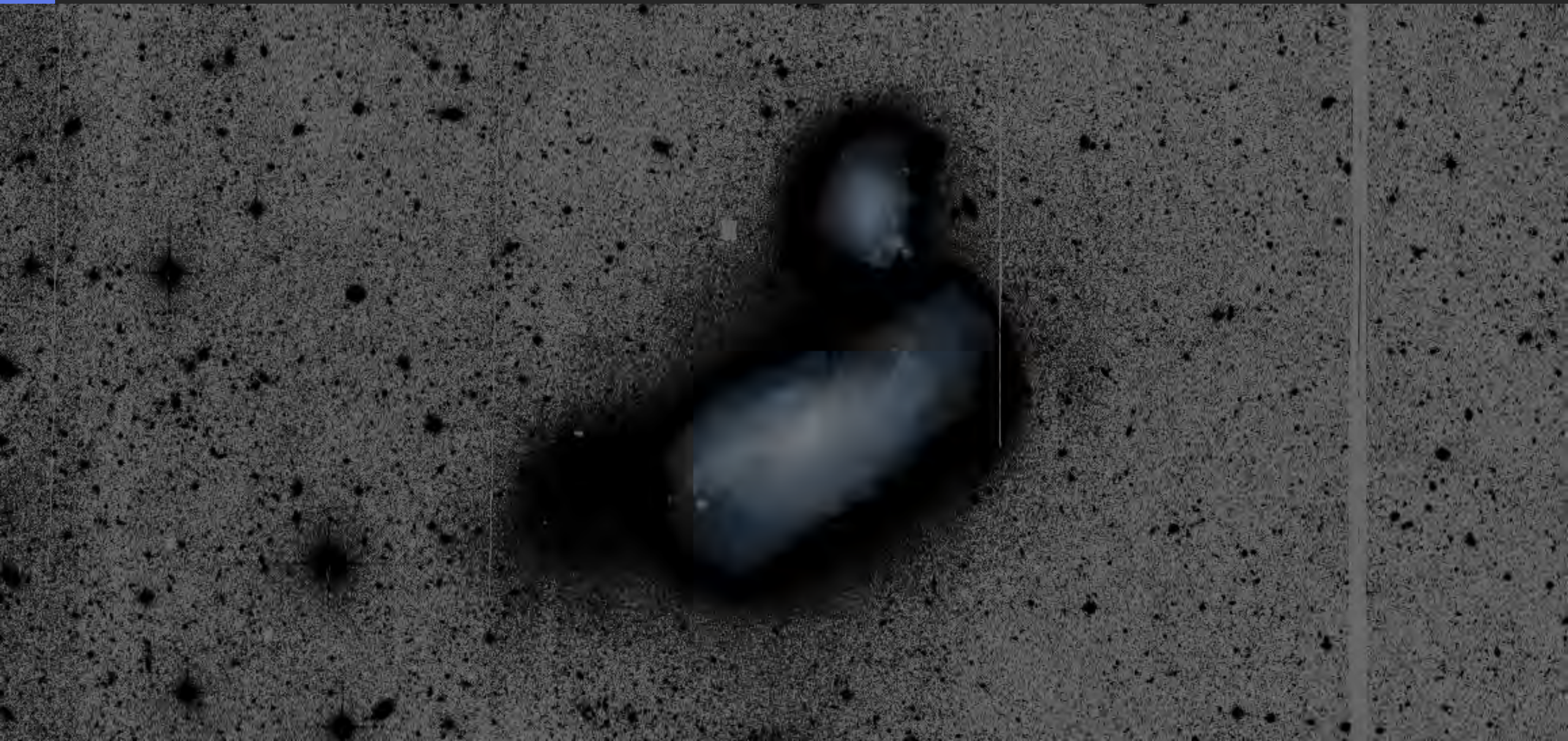


Gordon+2024

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…

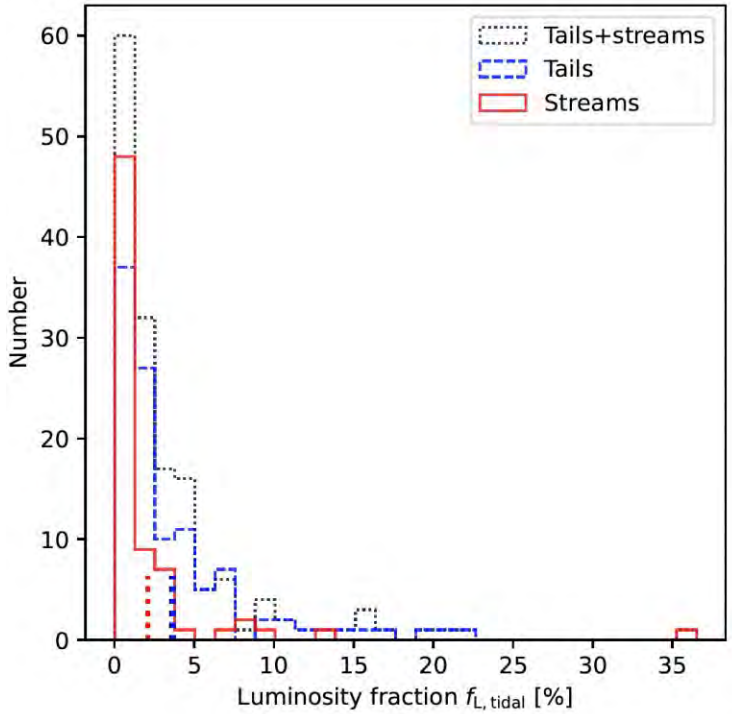
VS:

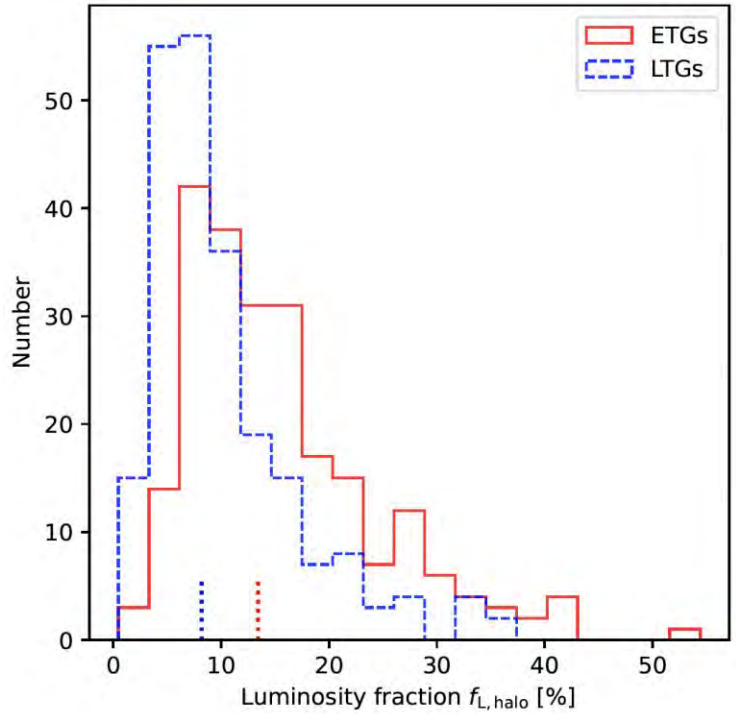
- Mass
- Environment
- Morphological type
- Kinematics
- …

Global statistical results

- *Sola+2022,2025*: study tidal features of 475 nearby (D<45Mpc), 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

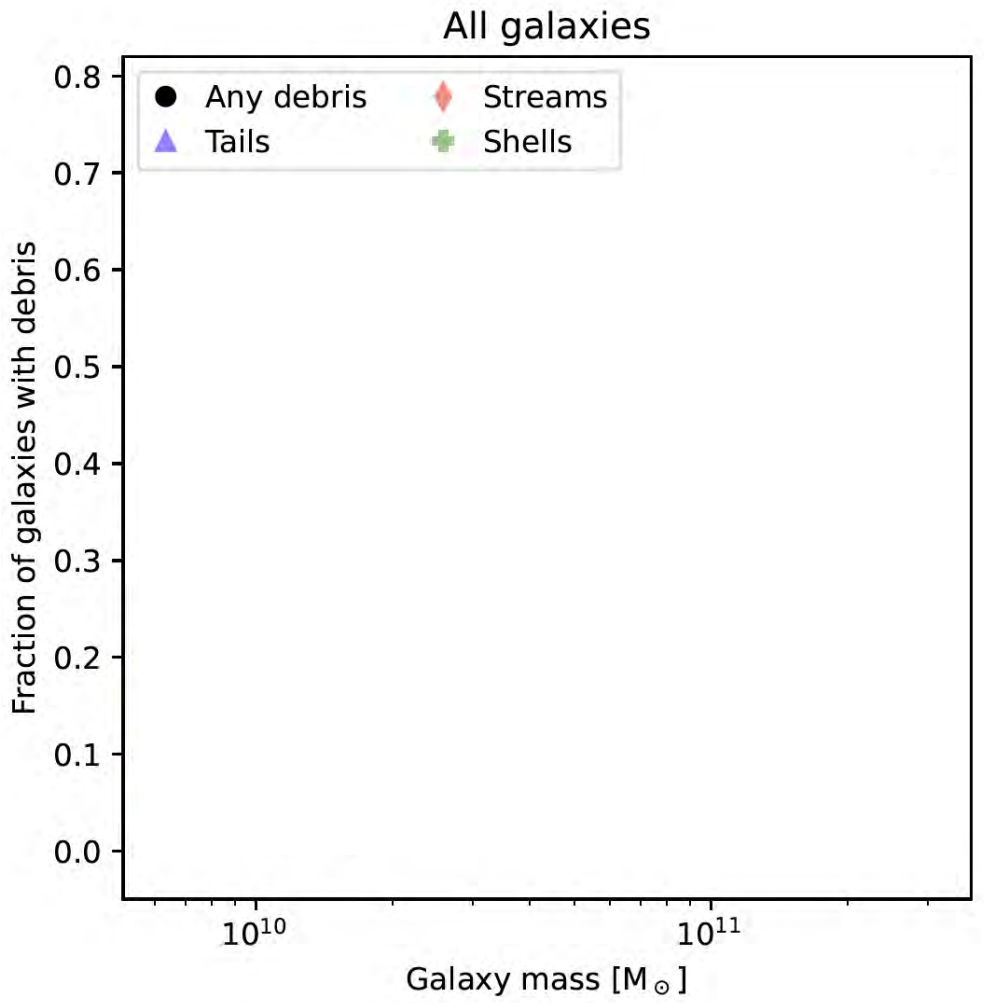
- Tails+streams account for **2-4% of the total galaxy luminosity**, while haloes account for **10%**





Trends as a function of galaxy mass

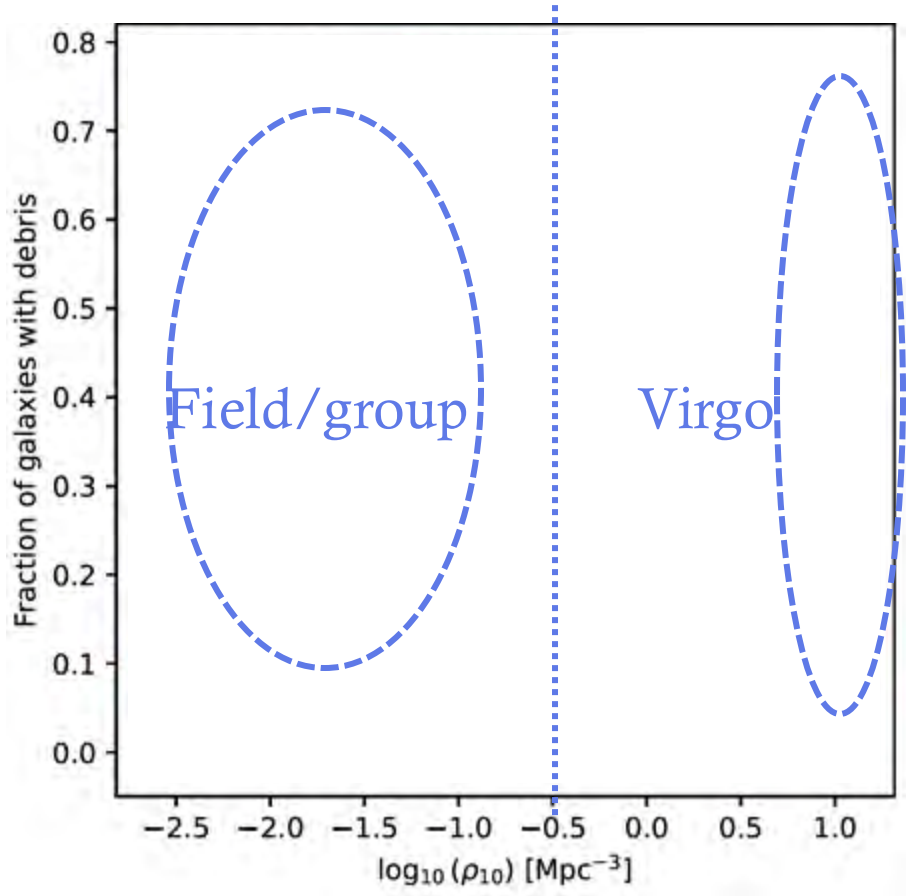
- The fraction of galaxies hosting tidal features more than **doubles** from 25% to 60% for the **highest-mass** galaxies.
- **Increase** visible for all **feature types**
- Similar trends for ETGs and LTGs separately



(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 ρ_{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 (~4-7×10^{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, Rodriguez-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 ?

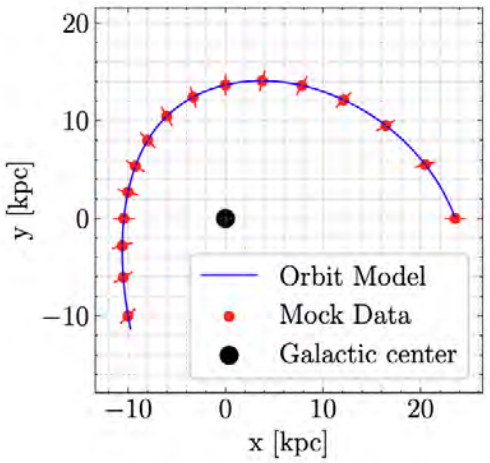
- *Chemaly+, in prep*: constrain the flattening of DM haloes from 2D information of streams (position + photometry), at a population level, using hierarchical Bayesian inference

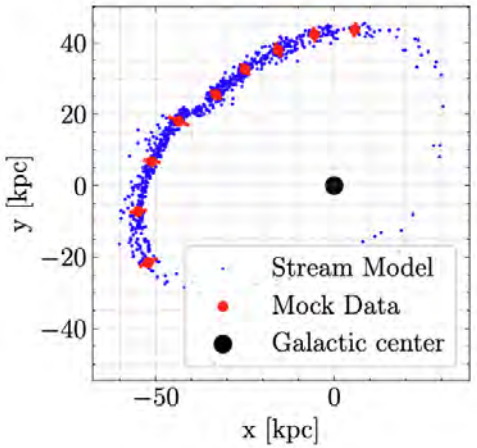
Chemaly+ in prep

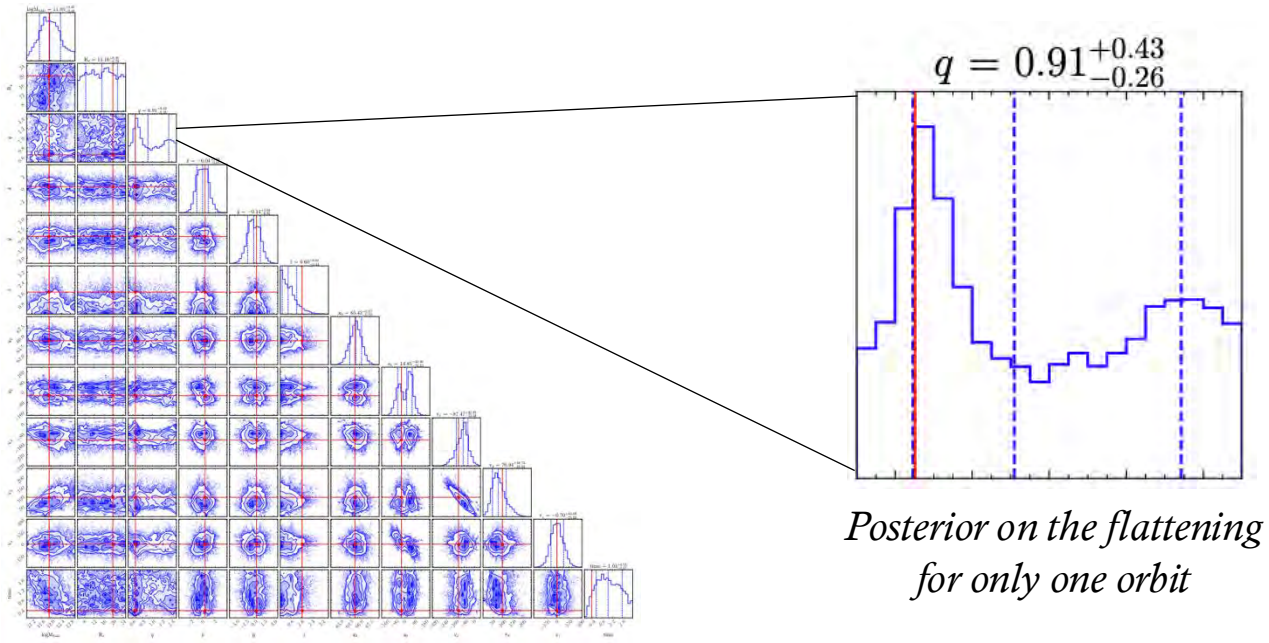
Streams and DM flattening

Mock data → Hierarchical Bayesian Inference ← Model

Either orbits or streams







Posterior on the flattening for only one orbit

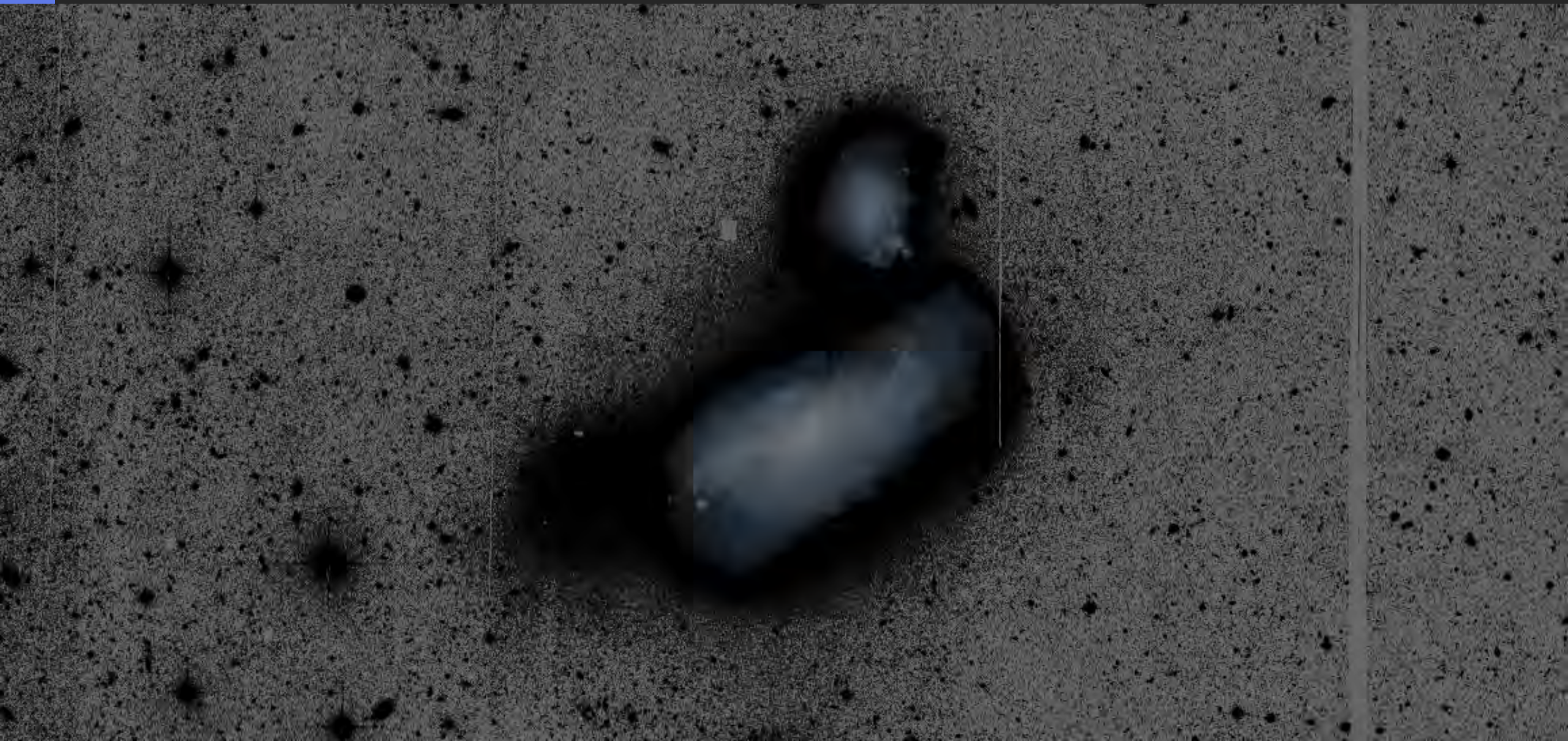
► Next: apply to real data on a large sample of 'best'-looking streams (long, curved, faint) but no consensus in the literature, no large catalogue of these streams

► *Sola+, in prep*: catalogue of tidal features and modelable streams in DESI Legacy Imaging surveys

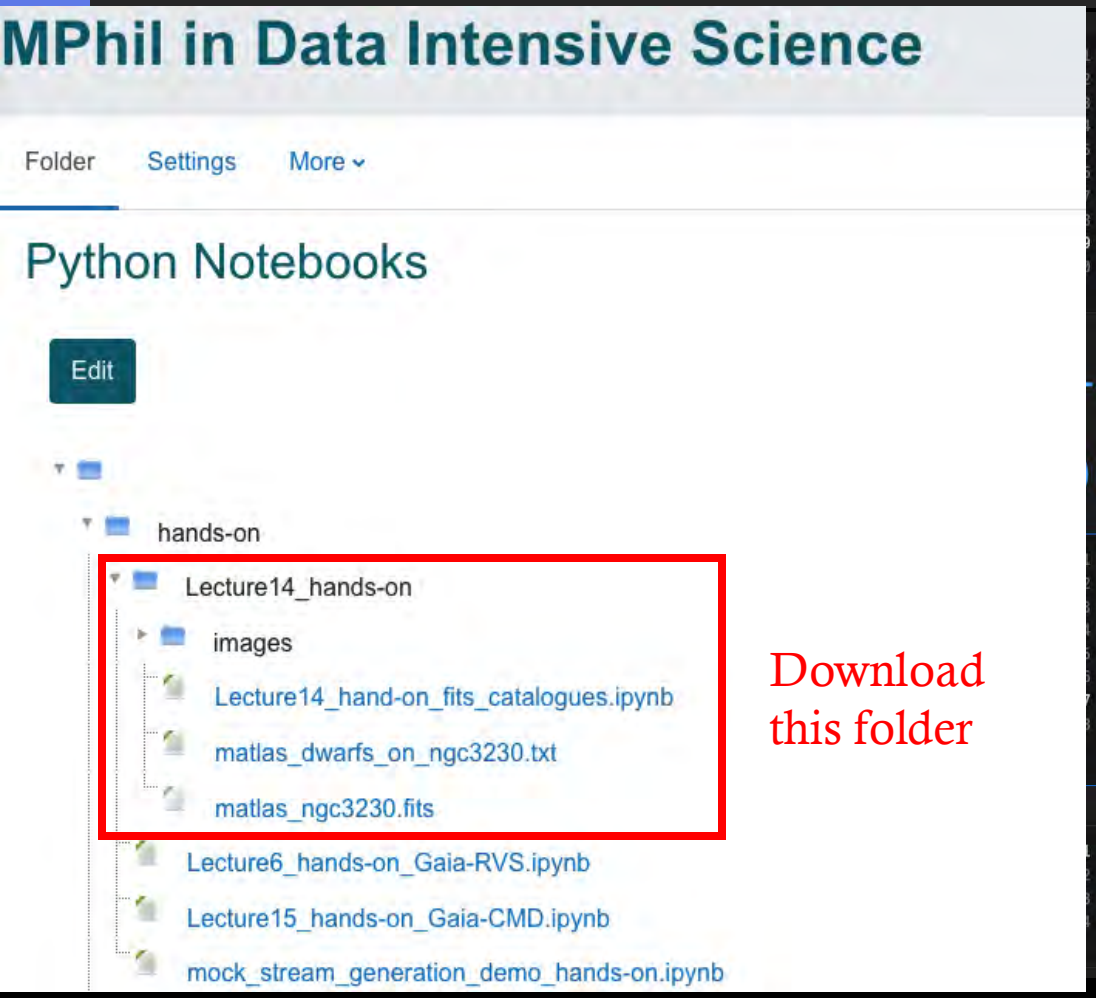
Summary

- 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



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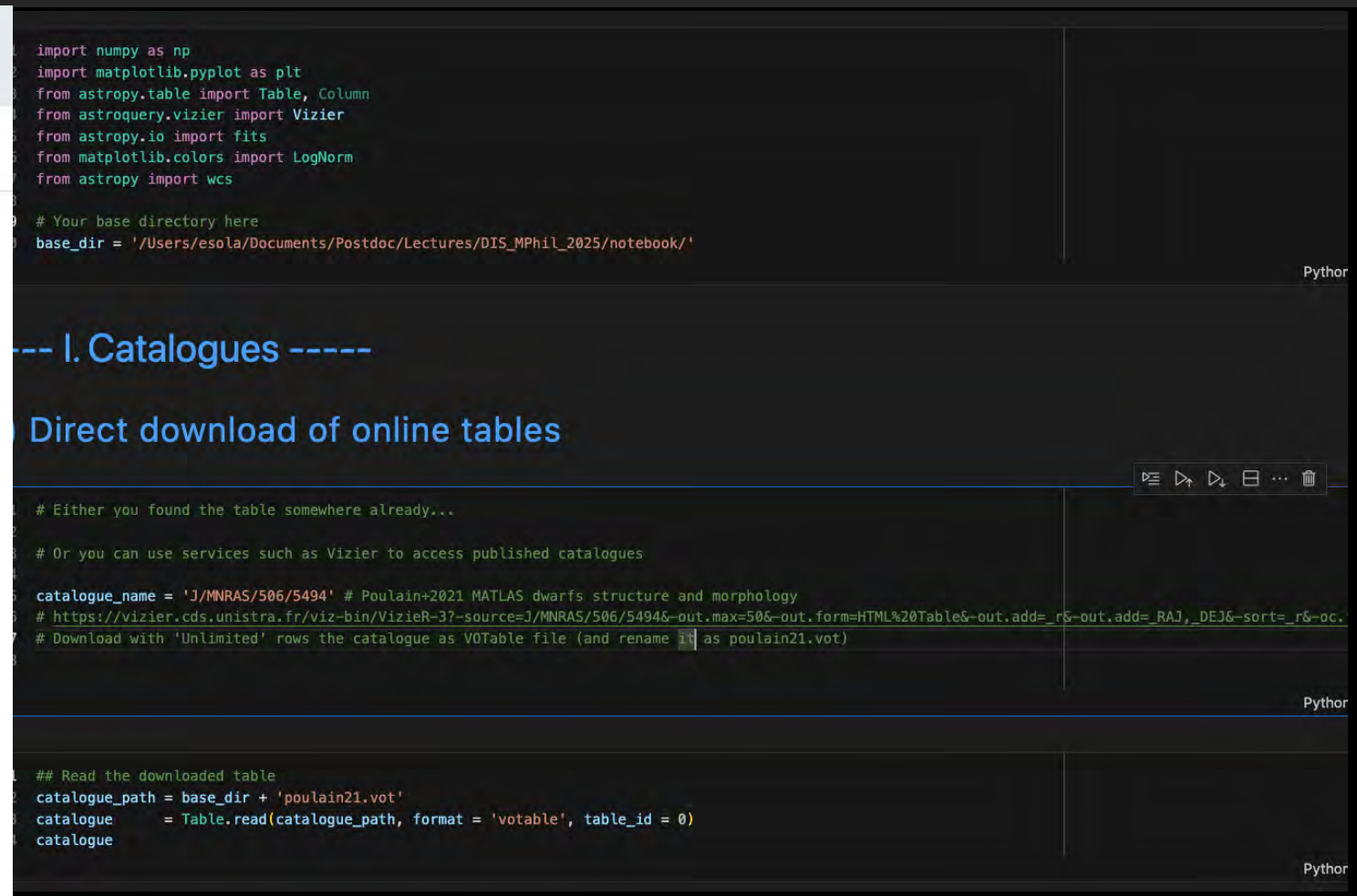

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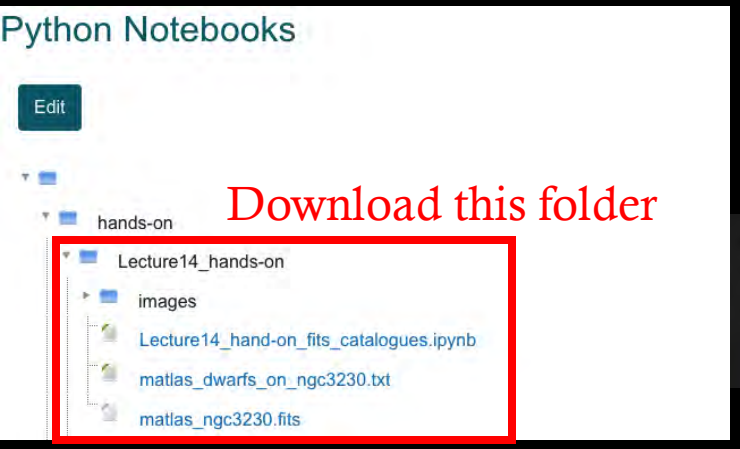

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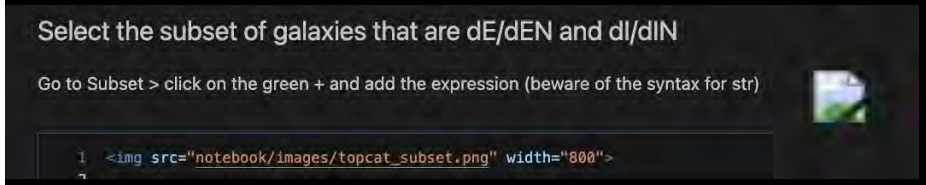
NB: If the images in the notebook do not appear (broken link), double-click on the cell and replace the path by src='images/the_image_name.png' instead of src='notebook/images/the_image_name.png'

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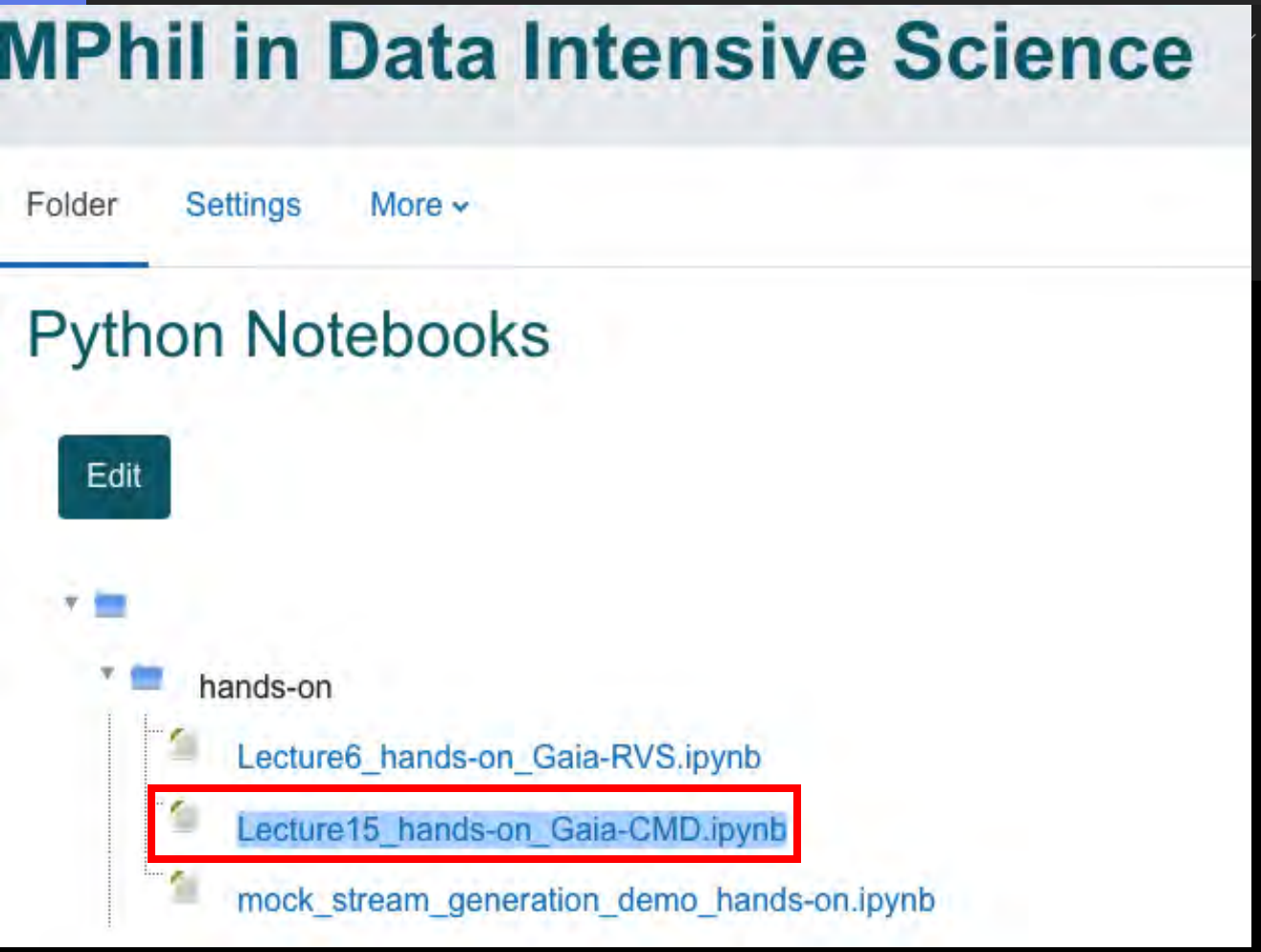
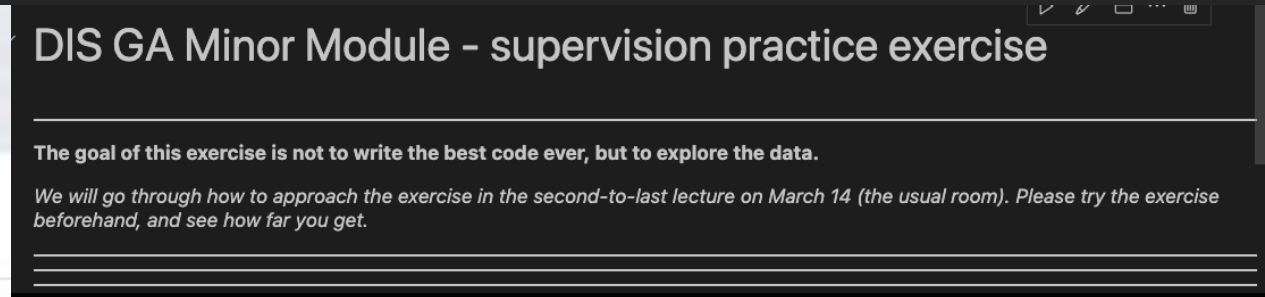
Supervision session on 14/03





- Try to do as much as you can for this supervision practice exercice
- Lecture15_hands-on_Gaia-CMD.ipynb