MNRAS, 513, 1, pp.1459-1487, arXiv:2203.07675

Korea Astronomy and Space Science Institute

THE UNIVERSITY OF ARIZONA
COLLEGE OF SCIENCE
Astronomy
& Steward Observatory

Informing low surface-brightness astronomy with the Rubin Observatory using the next generation of cosmological simulations

Garreth Martin

with

LSST Galaxies LSB Working Group

Warwick, *2022-07-12*

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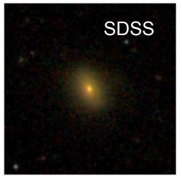
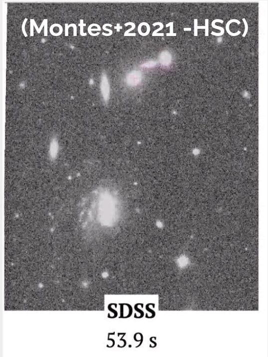
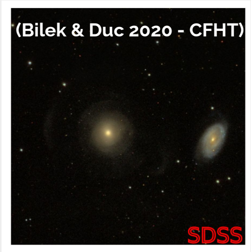
Deep imaging in the era of the Rubin Observatory/LSST







- Rubin Observatory pathfinders like Subaru / Hyper-SuprimeCam give us some idea of the quality imaging that can be expected of the Rubin Observatory ($\mu^{lim}_{r}(3\sigma, 10'' \times 10'') > 30.5$ mag arcsec^{-2})

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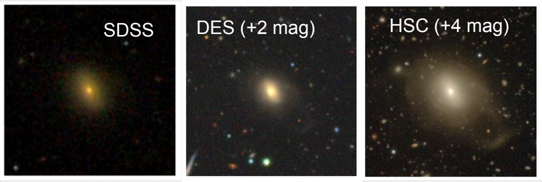

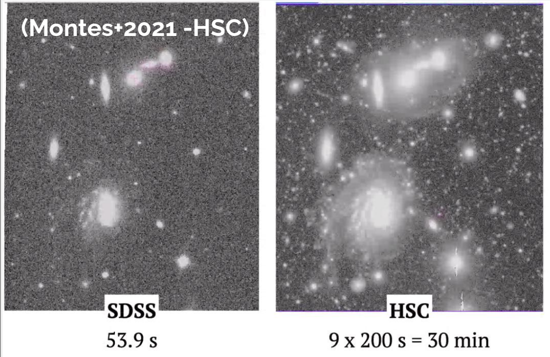

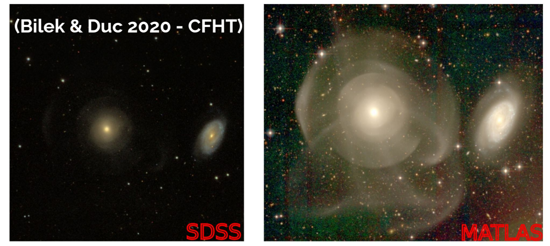

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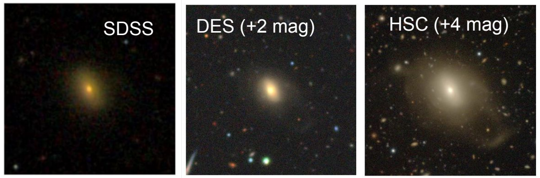

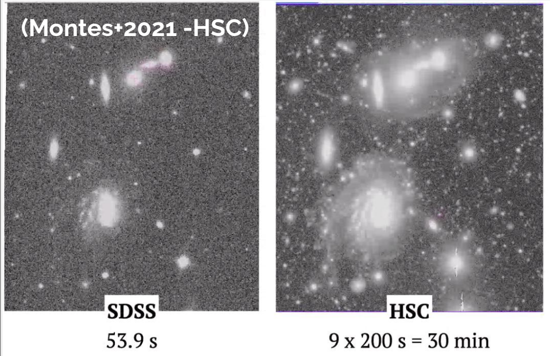

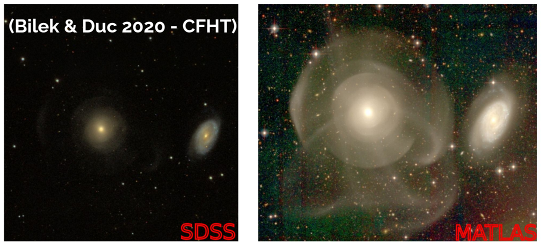

Deep imaging in the era of the Rubin Observatory/LSST

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- Rubin Observatory will greatly increase the sample size of galaxies with similar quality observations
  - Detailed ΛCDM predictions will allow us to understand the capabilities of this new dataset and make predictions for
    - Frequency and distribution of tidal features as a function of halo mass
    - Detectability of tidal features
    - Biases from orientation, redshift, etc.

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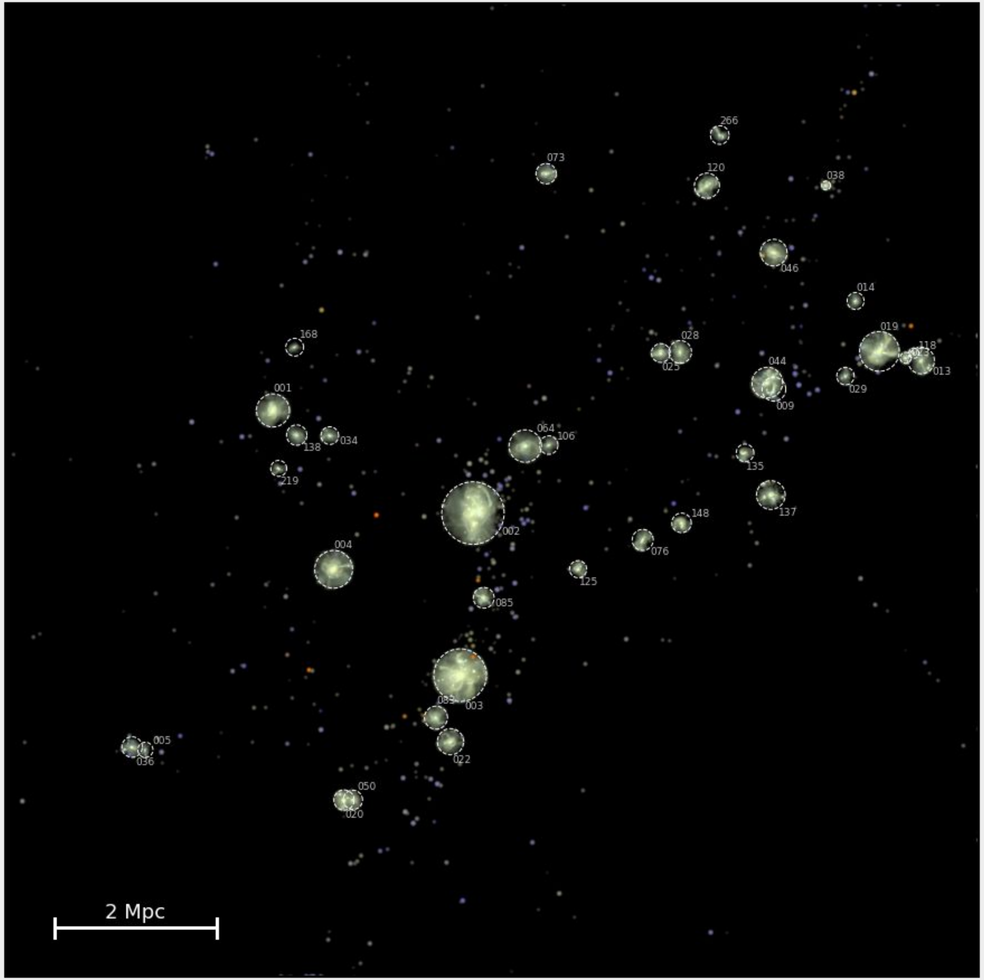

The New Horizon Simulation (Dubois+21)

- **New Horizon is a high resolution cosmological simulation**
  - Contiguous volume of $(16\ \mathrm{Mpc})^3$
  - High spatial and stellar mass resolution of **34 pc / 10^4 M$_\odot$**
  - Sufficient mass resolution to resolve the stellar halo around <MW mass galaxies

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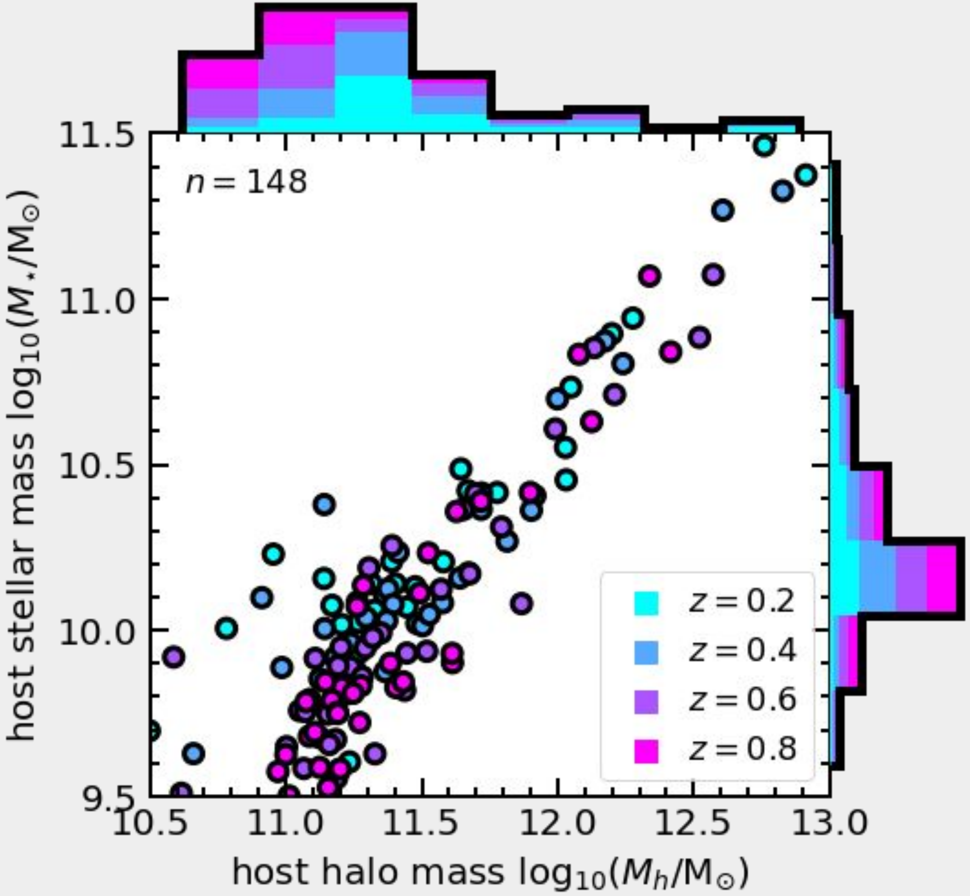

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- **Sample**
  - $\log_{10}(M_*/M_\odot)$ = 9.5 -> 11.5
  - 4 different simulation snapshots
  - ~150 objects

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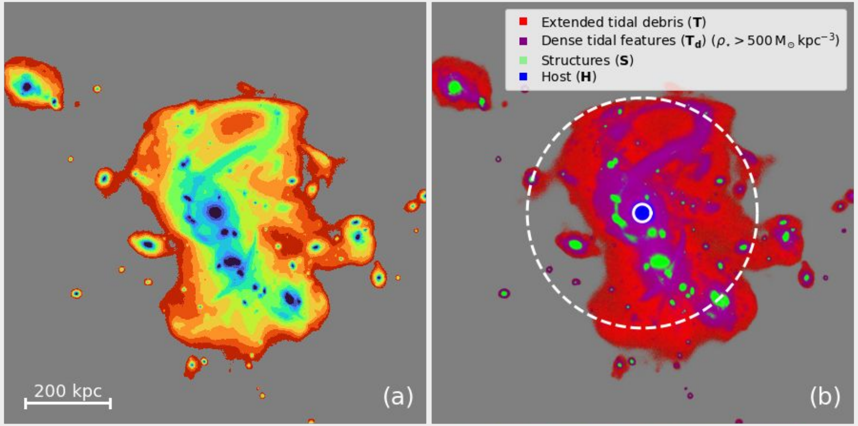
Measuring flux distributions in the stellar halo



- Decompose galaxy stellar haloes into:

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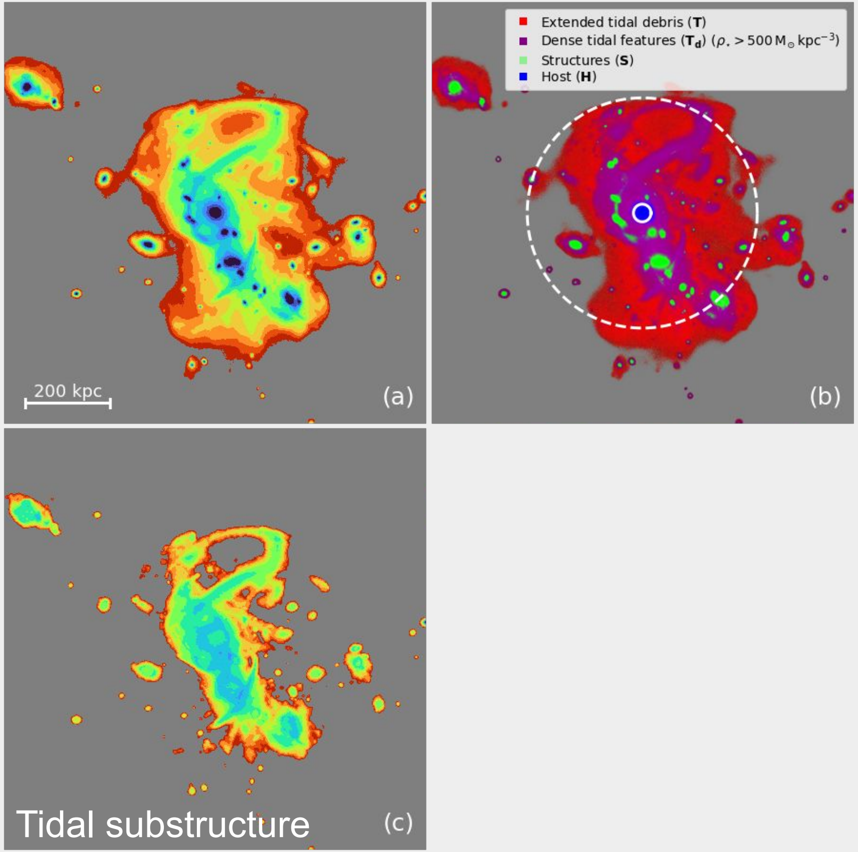

- Decompose galaxy stellar haloes into:
  1) Dense tidal substructures (density cut maximising high spatial frequency features <50 kpc **Sola+2022**)

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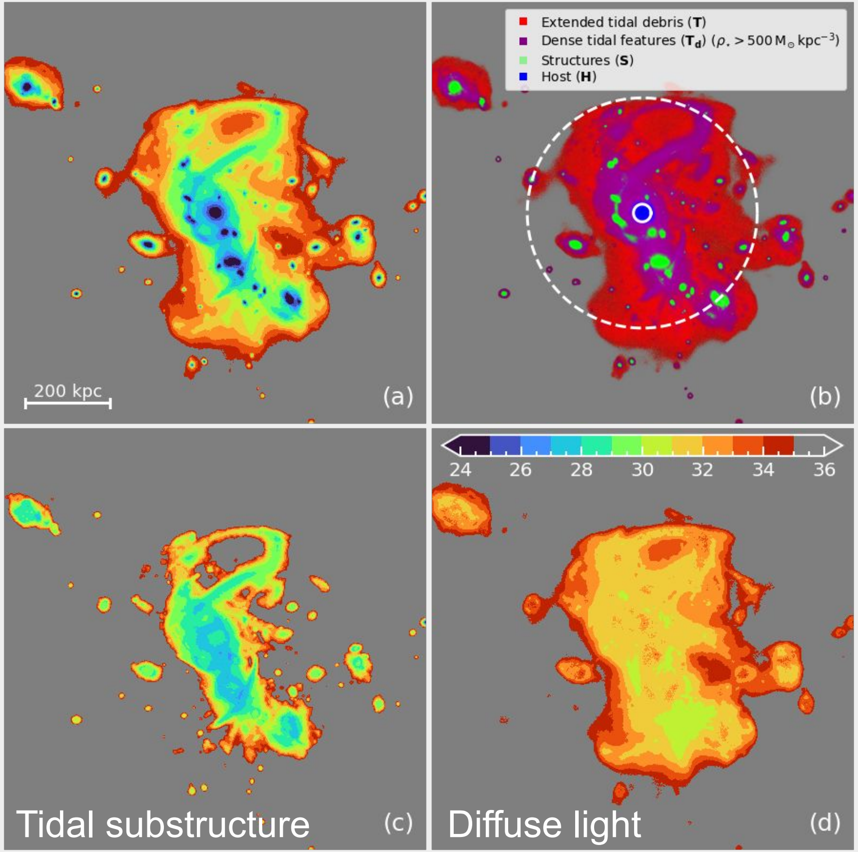

- Decompose galaxy stellar haloes into:
  1) Dense tidal substructures (density cut maximising high spatial frequency features <50 kpc **Sola+2022**)
  2) Diffuse light / debris (low spatial frequency features)

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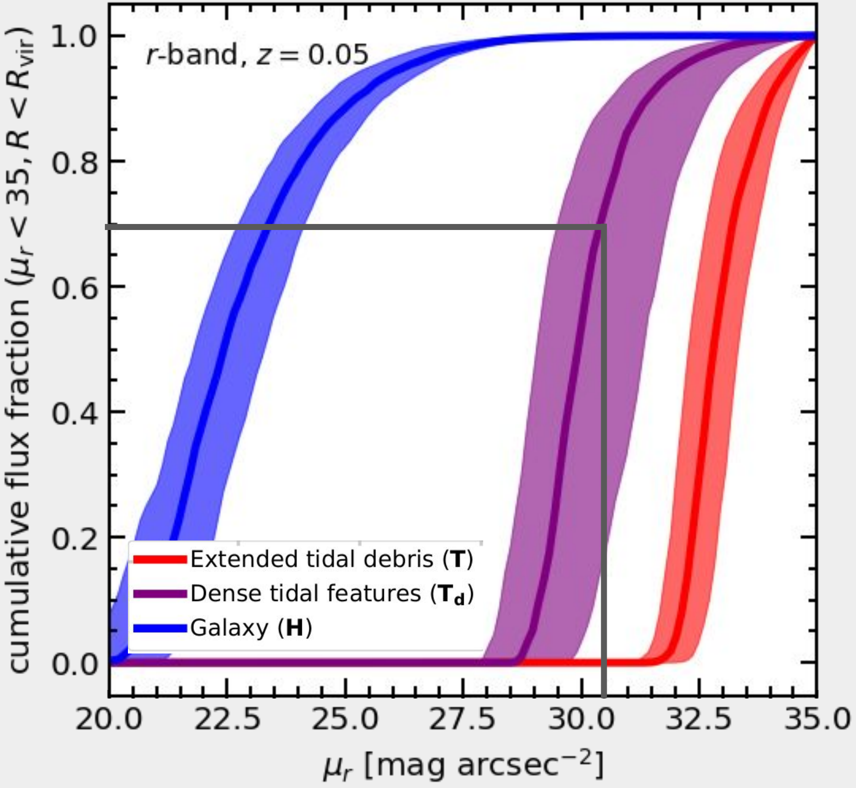

- SB limit of 30.5 mag / sq. arcsec is sufficient to recover over half the flux within tidal features

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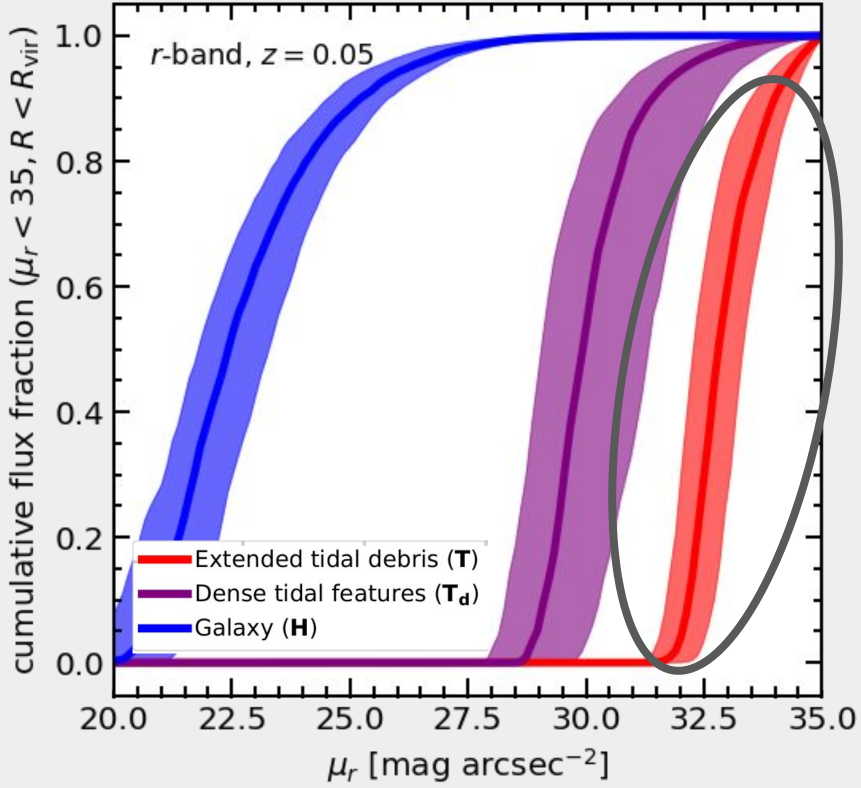

- SB limit of 30.5 mag / sq. arcsec is sufficient to recover over half the flux within tidal features
- Very diffuse light in the stellar halo is inaccessible (without binning) at expected LSST SB limits
    - It accounts for 25% of the total halo light on average

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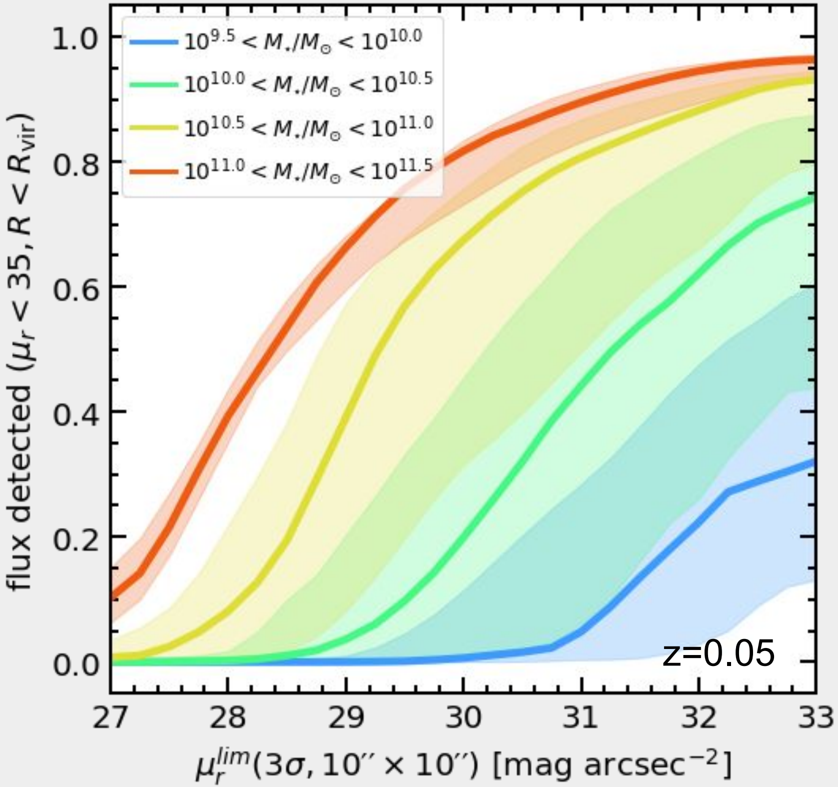
Measuring flux distributions in the stellar halo



- In the nearby Universe (z~0.05), lower mass galaxies ($M_*/M_\odot$<10^{10}) remain unlikely to host detectable tidal features at Rubin Observatory 10-year depth.

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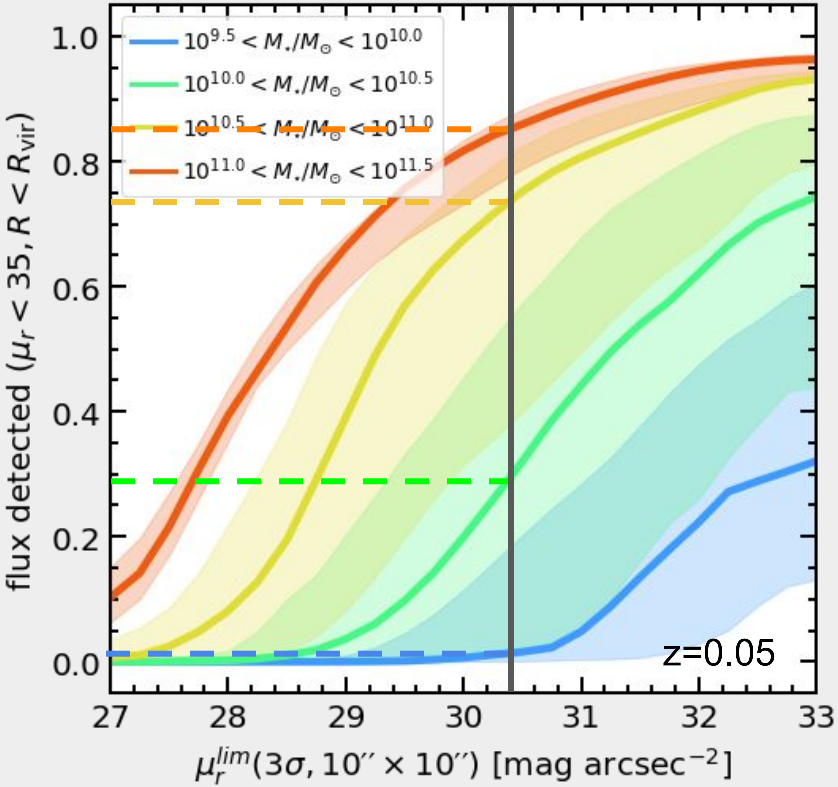

- In the nearby Universe (*z*~0.05), lower mass galaxies ($M_*/M_\odot<10^{10}$) remain unlikely to host detectable tidal features at Rubin Observatory 10-year depth.
- But a majority of massive galaxies host tidal features with detectable flux at 10-year depth
    - 80% in MW mass galaxies or 60% with a more conservative 29.5 mag arcsec^{-2} cut

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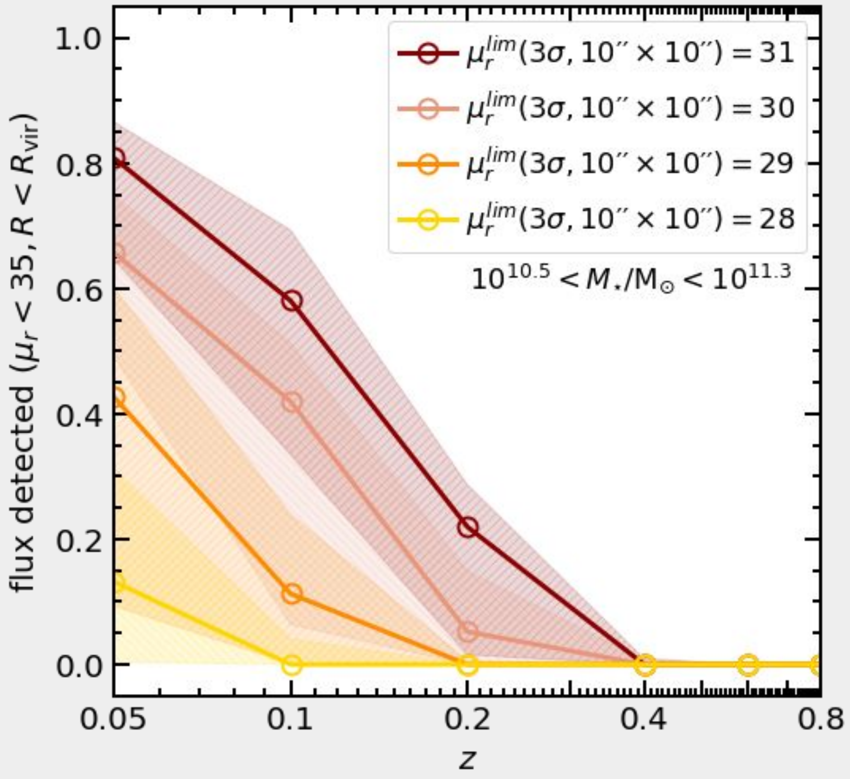

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- But a majority of massive galaxies host tidal features with detectable flux at 10-year depth
    - 80% in MW mass galaxies or 60% with a more conservative 29.5 mag arcsec^{-2} cut

- Falling with redshift so that <10% flux in the stellar haloes of MW mass galaxies is detected by z=0.2 for a 30.5 mag arcsec^{-2} cut

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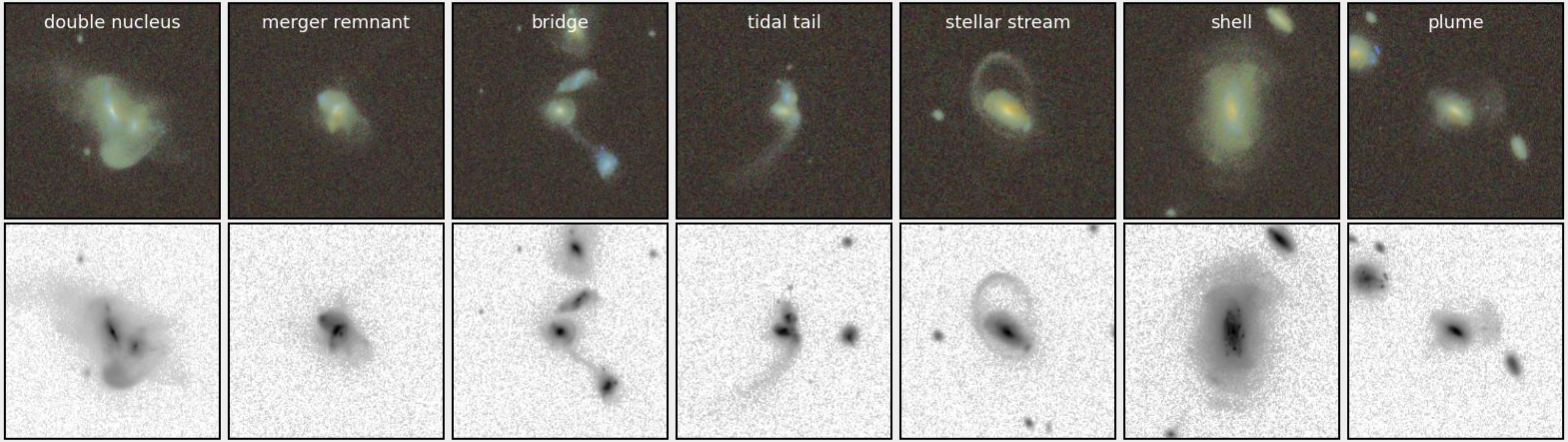
Visually classifying LSB features in the stellar halo

- ~50 volunteers visually classified tidal features mock Rubin Observatory images
  - Classified for a range of:
    - Limiting surface brightness (single visit → 10 year depth + 35 mag arcsec^{-2} to probe beyond the limits of LSST)
    - Redshift (z = 0.05 → 0.8)
    - Orientations (projected along *xy*, *xz*, *yz*)



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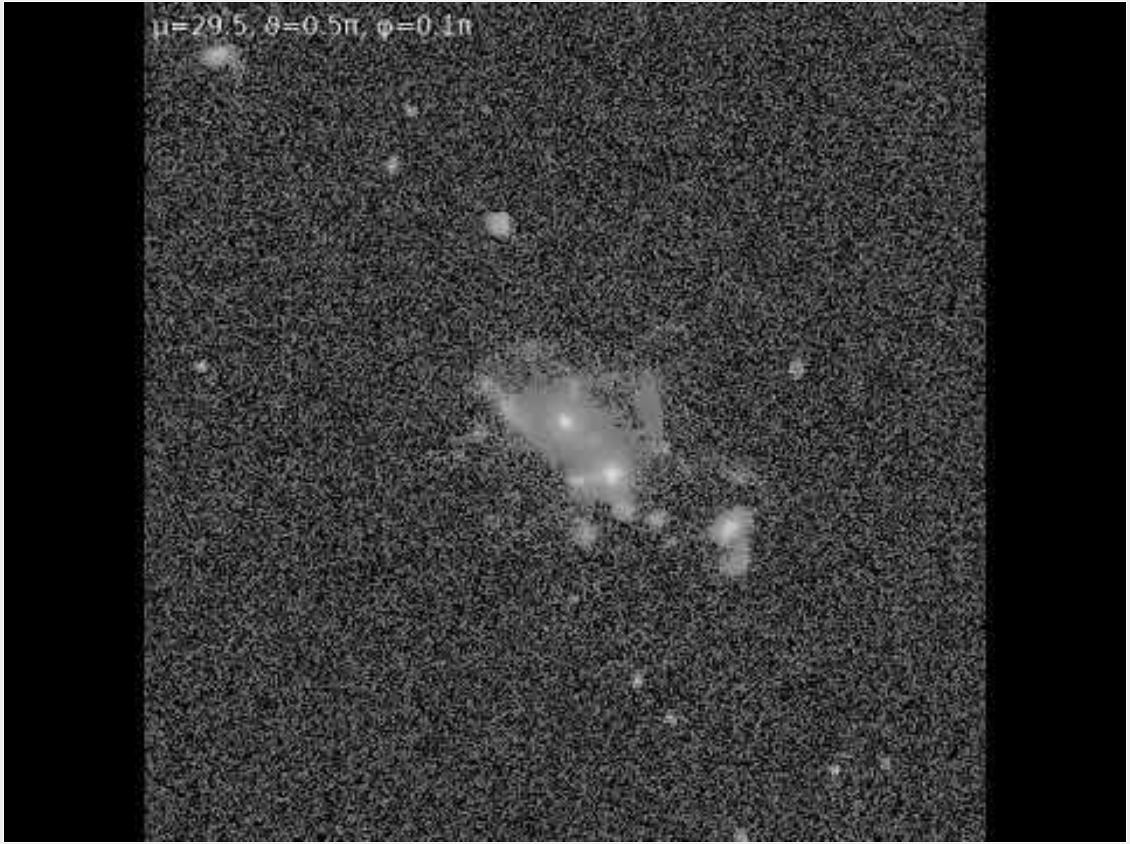
Visually classifying LSB features in the stellar halo

- Sources of uncertainty
  - Limiting surface brightness
  - Surface brightness dimming and decrease in spatial resolution with redshift
  - Orientation
  - PSF
  - Chance projection of other objects
  - Ambiguity in tidal feature classification



https://youtu.be/hZg_5FbnnyE

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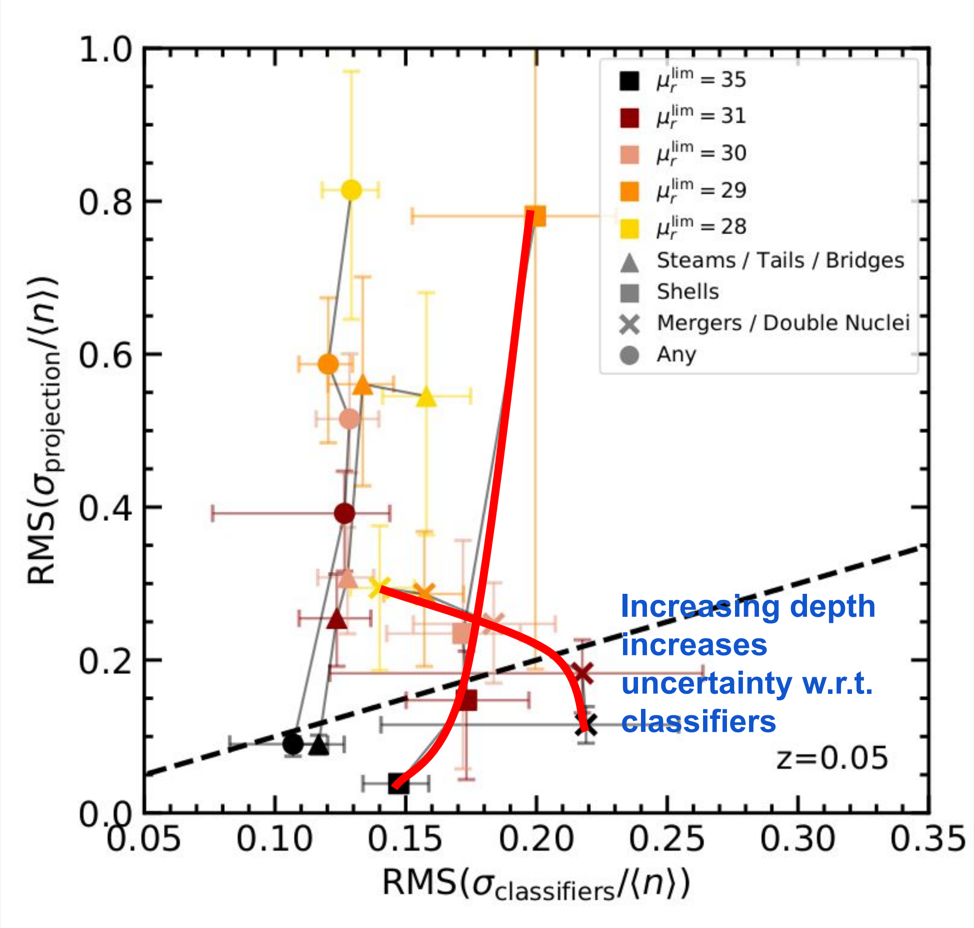
Visually classifying LSB features in the stellar halo

- We explore how the scatter in visual classifications changes with image depth
  - We consider the average scatter in classifications among different classifiers for the same image vs the average scatter in classifications for different projections of the same object
- In most cases, deeper imaging means classifiers and more likely to agree with each other and agree across projections
- However, for some categories, increasing the depth makes classification ambiguous
  - As depth improves, morphologies can become more complex, introducing uncertainty in precise characterisation
- Generally, there is significant disagreement between human classifiers at achievable limiting surface brightnesses



Conclusions and future plans

Conclusions

- After its 10 year survey, LSST will have sufficient depth to resolve a significant fraction of the flux found in tidal substructures of MW galaxy stellar haloes
- Around 75% of flux lies in these denser tidal features rather than more diffuse tidal debris which lie beyond the surface brightness limits accessible to LSST
- At sufficient depth, almost 100% of galaxies ($M_*/M_\odot < 10^{9.5}$) possess tidal features
- Surface brightness limits, galaxy orientation, redshift, etc. have a clear effect on the ability of expert classifiers to visually identify and characterise tidal features
- Concurrence between classifiers generally improves with deeper imaging but morphologies can become more complex, introducing uncertainty in precise characterisation

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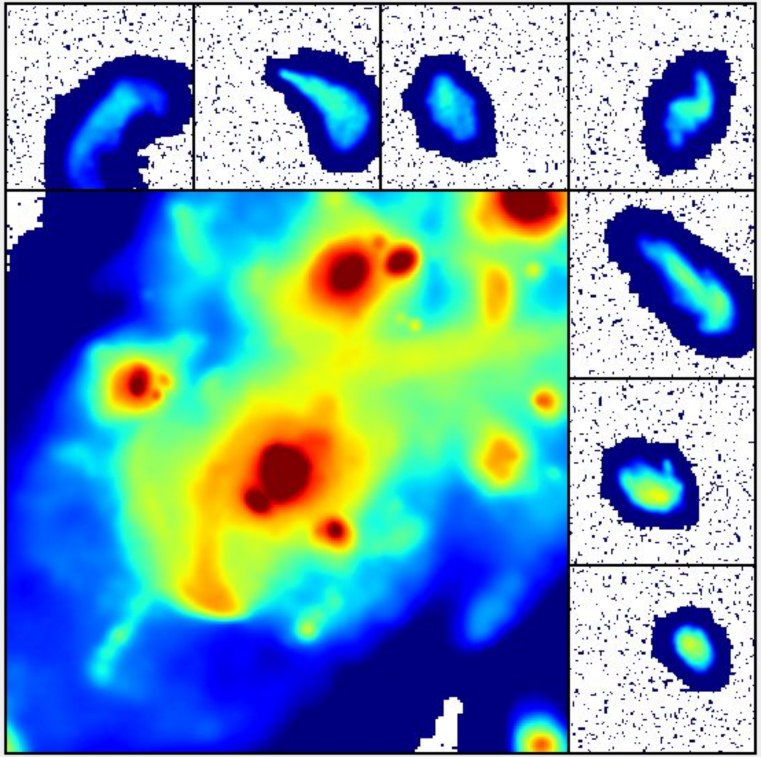
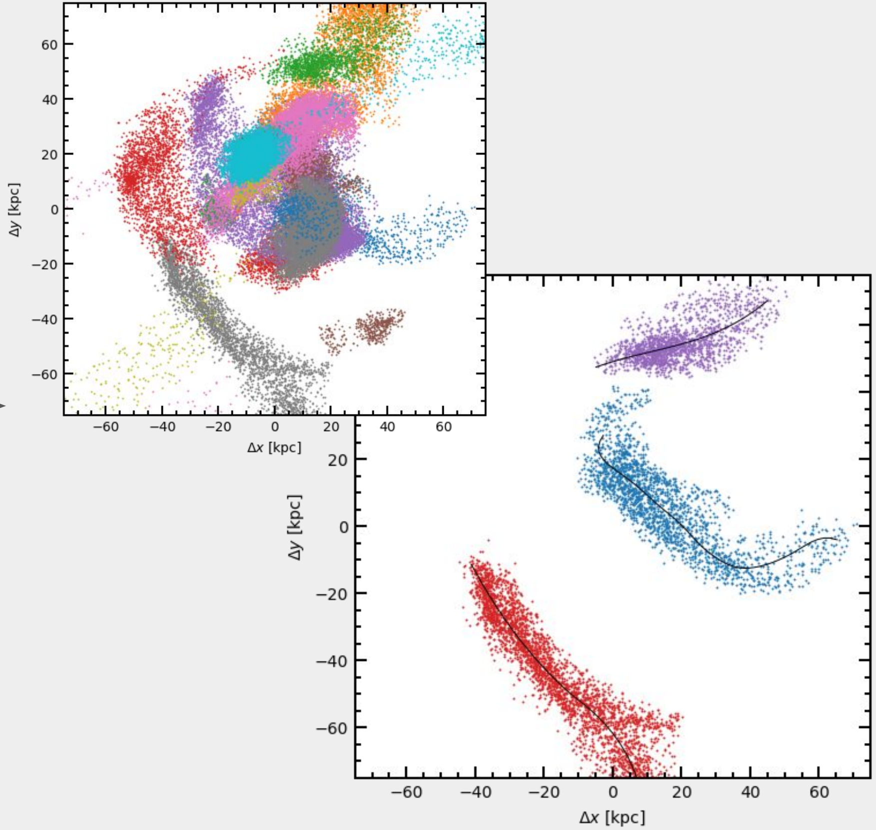
Future work: automatic identification and measurement of tidal features

6-D Kinematically coherent features identified using clustering hierarchical density-based clustering (HDBSCAN, McInnes+2017)



Measure properties of individual tidal features along the medial spine of each tidal feature



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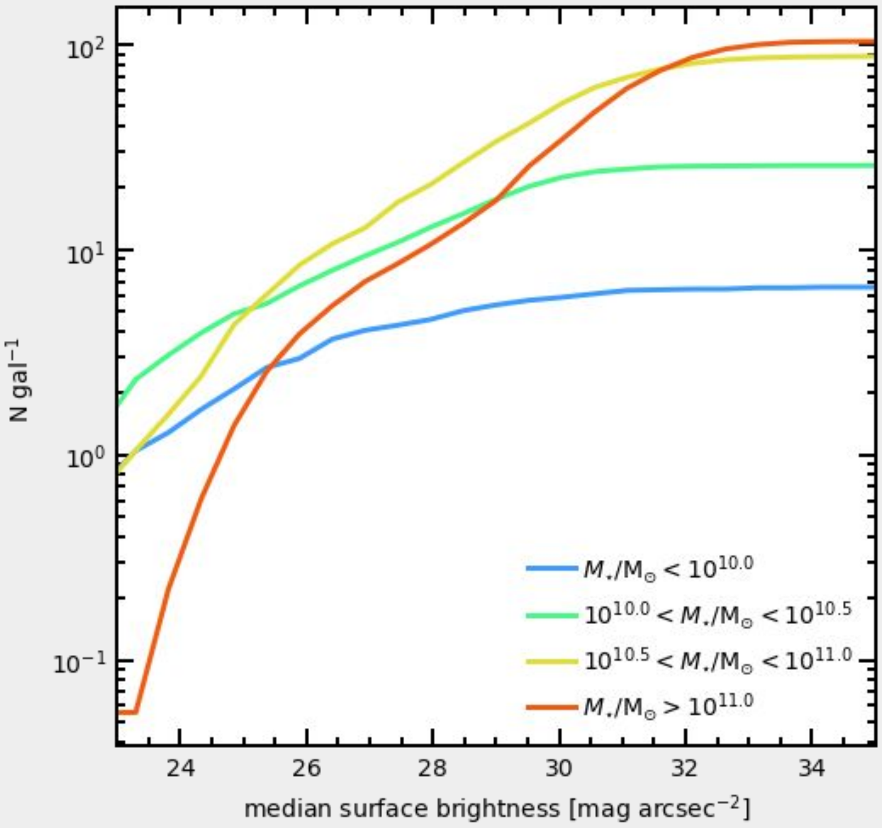
Future work: automatic identification and measurement of tidal features



- We can then measure the distribution of tidal feature properties from the simulation
- And use as a ground truth to compare with human classifications
- Use the statistical and dynamical properties of tidal tails and streams to construct a more realistic test of cosmological models (e.g. **Mihos+98/Dubinski+99**, **Bonaca+19**, **Ren+20**)

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Future work

- Directly compare automated measurements of simulated tidal features with human classifications
- Expected frequency and distribution of tidal features as a function of surface brightness
- Expected distribution of tidal feature properties – length, curvature, colour etc.
- Statistical properties of tidal tails can provide a possible test of cosmological models (e.g. **Ren+2020**)

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