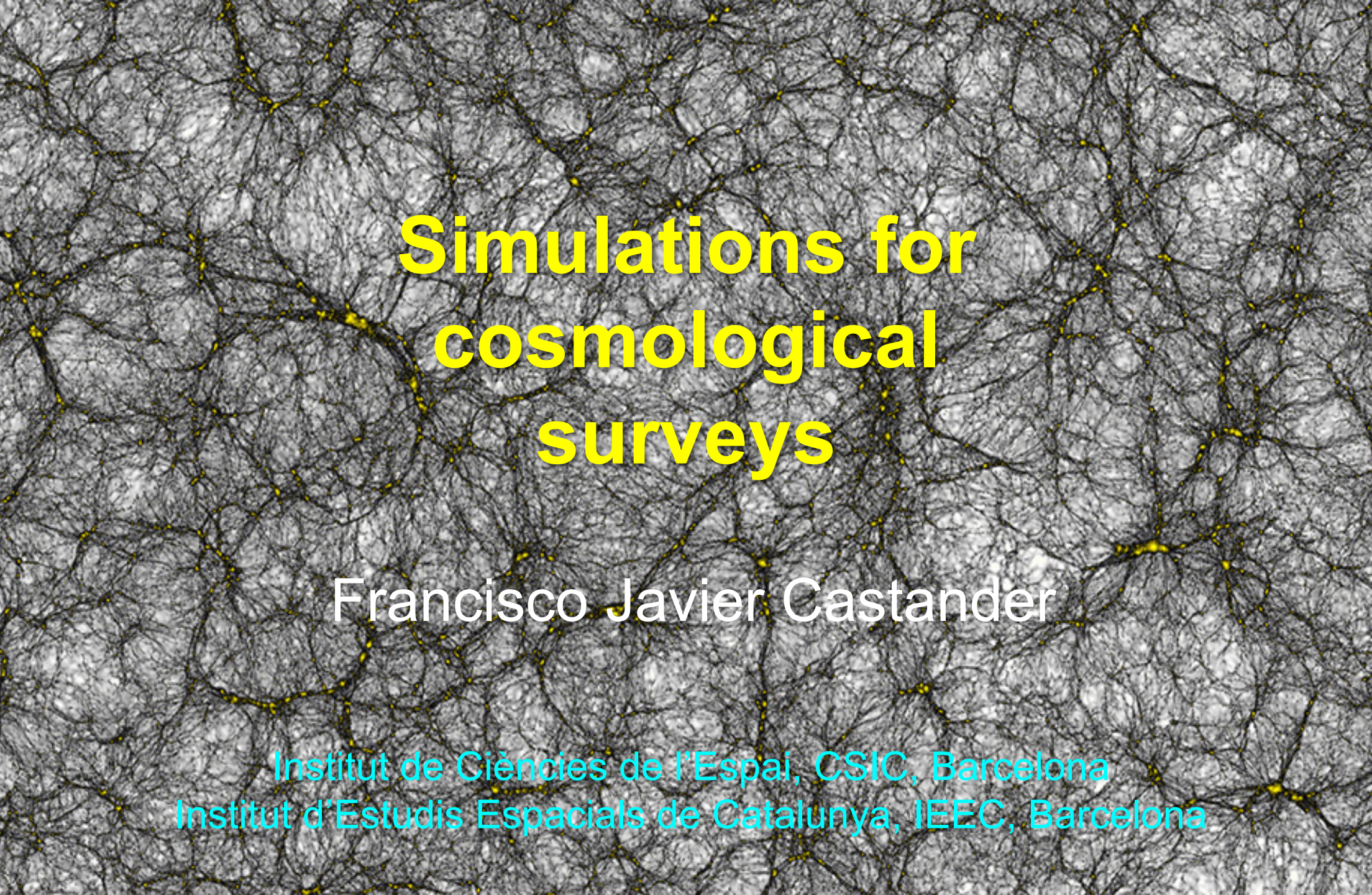


The background of the slide is a complex, grayscale simulation of the cosmic web, showing a dense network of dark, filamentary structures with numerous bright yellow nodes representing galaxy clusters or individual galaxies.

Simulations for cosmological surveys

Francisco Javier Castander

Institut de Ciències de l'Espai, CSIC, Barcelona
Institut d'Estudis Espacials de Catalunya, IEEC, Barcelona

Motivation

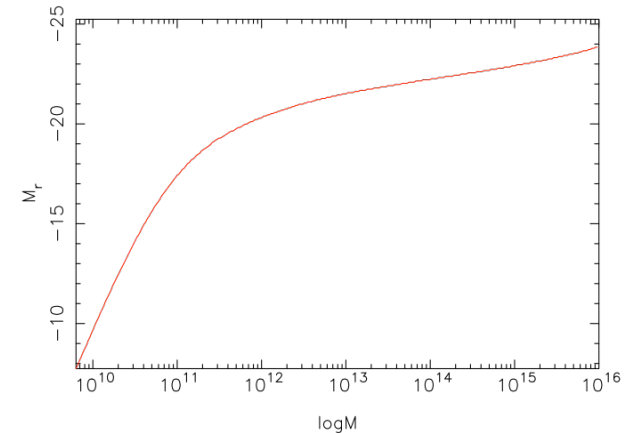
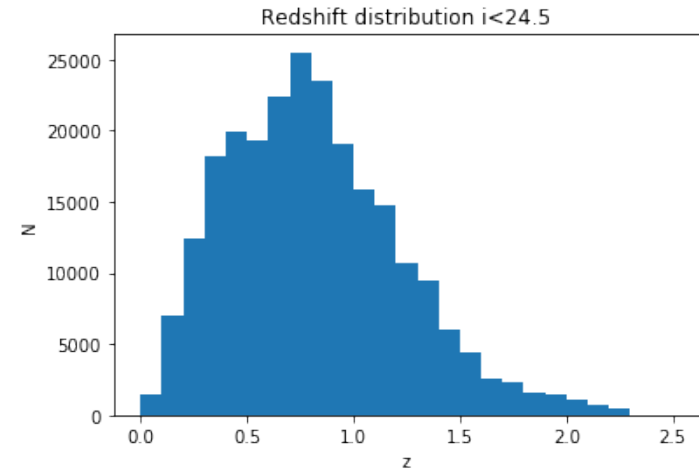
- Simulations essential for large cosmological surveys
 - survey definition and optimization
 - survey planning
 - develop analysis code
 - data analysis & interpretation
 - error estimation (systematic and statistical)

Simulations needs for Euclid (Roman)

- focus on end-2-end simulations, but other needs as well
- Euclid main probes: weak lensing and galaxy clustering
- Combined probes analysis (e.g., 3x2pt) => Comprehensive simulations needed for Euclid
 - use of self consistent observables
 - clustering: emission line selected samples consistent with observations
 - lensing: lensing properties assigned self-consistently with clustering and galaxy properties
 - photo-z: realistic galaxy colour distributions
- Most relevant properties: luminosity function, colour distributions, emission lines fluxes, galaxy sizes, galaxy shapes, galaxy clustering

Simulations needs for Euclid

- Euclid simulations needs:
 - Euclid volume:
 - clustering $0.9 < z < 1.8$
 - lensing $VIS < 24.5$ ($z \sim 2.5$)
 - area 15000 deg^2
 - volume $\sim 100 \text{ (Gpc/h)}^3$
 - Euclid mass resolution:
 - absolute mags ~ -13
 - halos $\sim 10^{10} \text{ Msolar}$
 - particle mass $\sim 10^9 \text{ Msolar}$
 - number of particles $\sim 10^{13}$



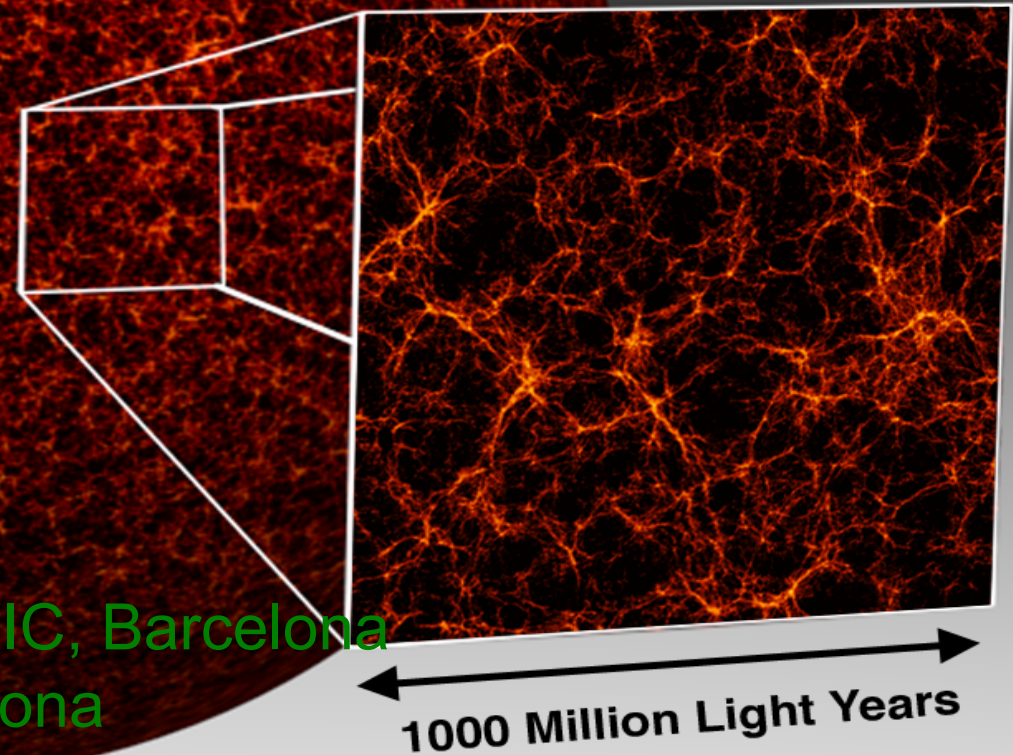


Euclid Simulations: Flagship Galaxy Mock

F. Castander, P. Fosalba, J. Carretero,
L. Blot, P. Tallada, M. Crocce, E.
Gaztañaga, K. Hoffmann, A. Alarcon,
C. Bonnett, M. Eriksen, A. Bauer,
S. Serrano, D. Reed, M. Manera, N.
Tonello, D. Piscia, I. Ferrero, A.
Pezzotta, I. Tutusaus, F. Torradeflot,
A. Pocino + U. Zurich group +
validation group

Institut de Ciències de l'Espai, IEEC-CSIC, Barcelona
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cosmohub.pic.es



Flagship simulation

Flagship Dark Matter simulation

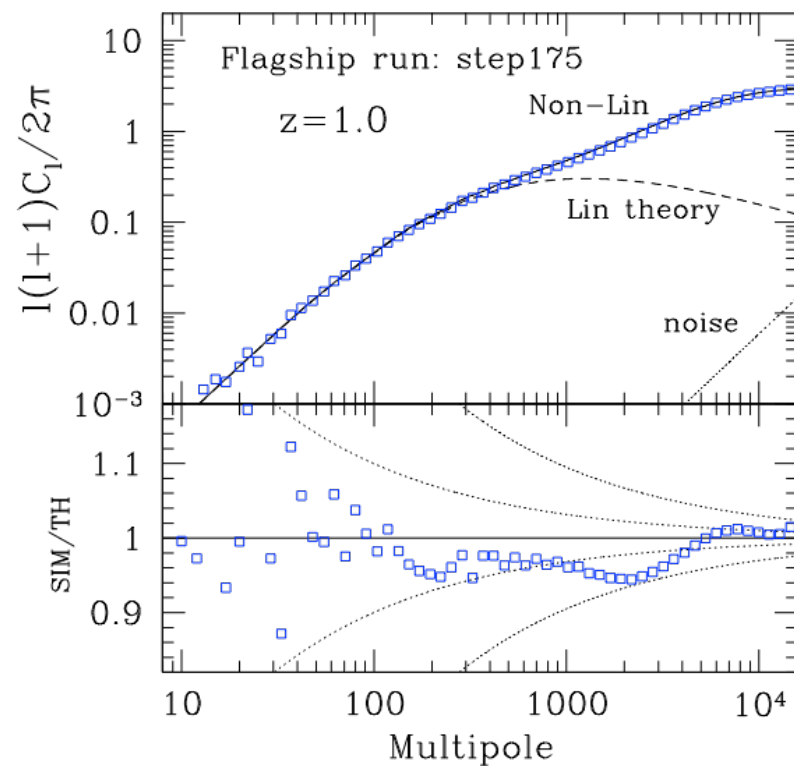
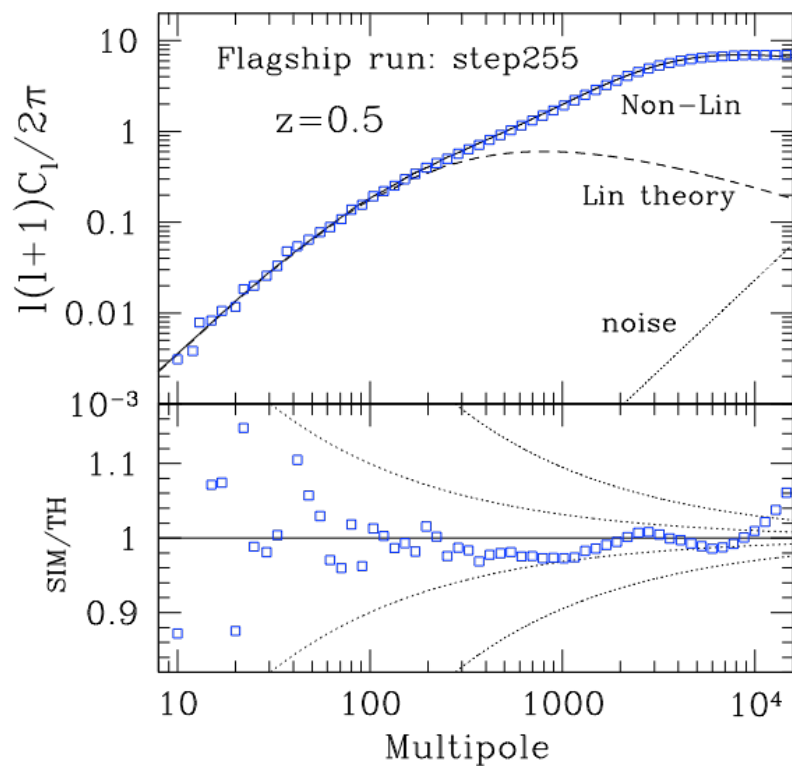
- Produced to match Euclid needs (SPV2, M-CDR, SC8)
- Run at Swiss supercomputer centre: Piz Daint
- Code: pkdgrav3
- two trillion particle simulation: $N_p \sim 12600^3$
- Planck cosmology
- size: 3.78 Gpc/h
- redshift $z=2.3$
- particle mass: $m_p = 2.4 \times 10^9 M_{\text{solar}}$
- particle softening: 6 kpc/h
- lightcone produced on the fly
- healpix dark matter maps
- halo catalogues using Rockstar

Flagship simulation

- Given the huge data volume of the dark matter distribution, we use simplified methods to build the galaxy catalogues from the halos
- we also build the lightcone as the simulation is run to avoid costly post-processing
- We have adopted a hybrid technique of halo occupation distribution (HOD) and abundance matching (AM) techniques complemented with phenomenological prescriptions and observed relations to build the galaxy catalogue mock

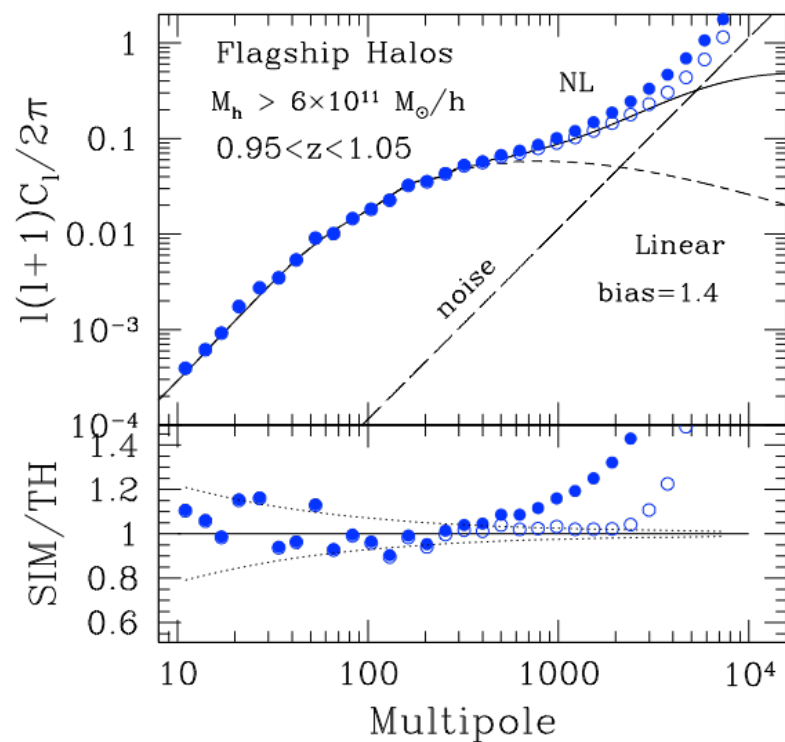
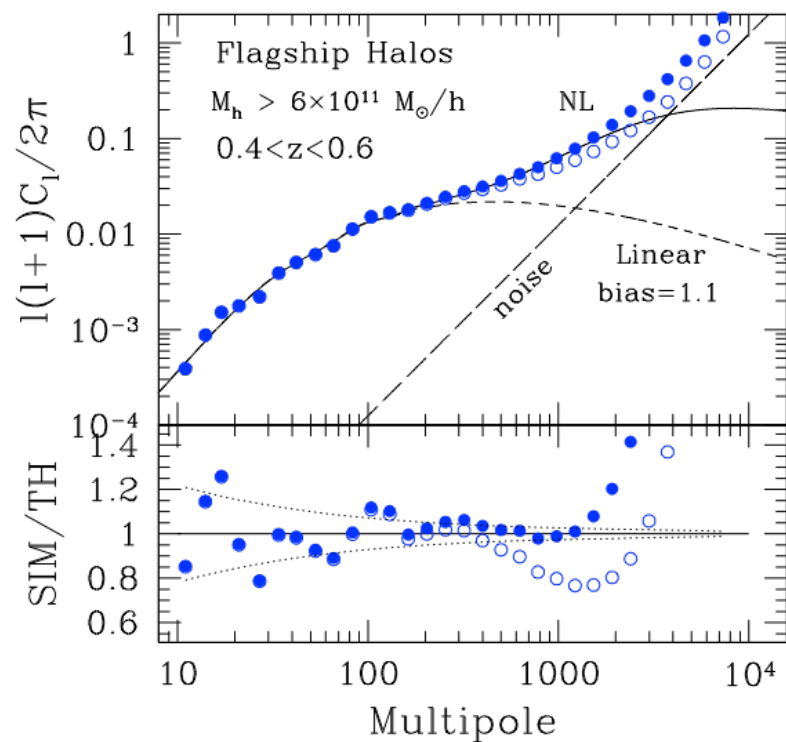
Flagship simulation

Flagship Dark Matter clustering



Flagship simulation

Flagship Dark Matter Halos clustering



Flagship galaxy mock

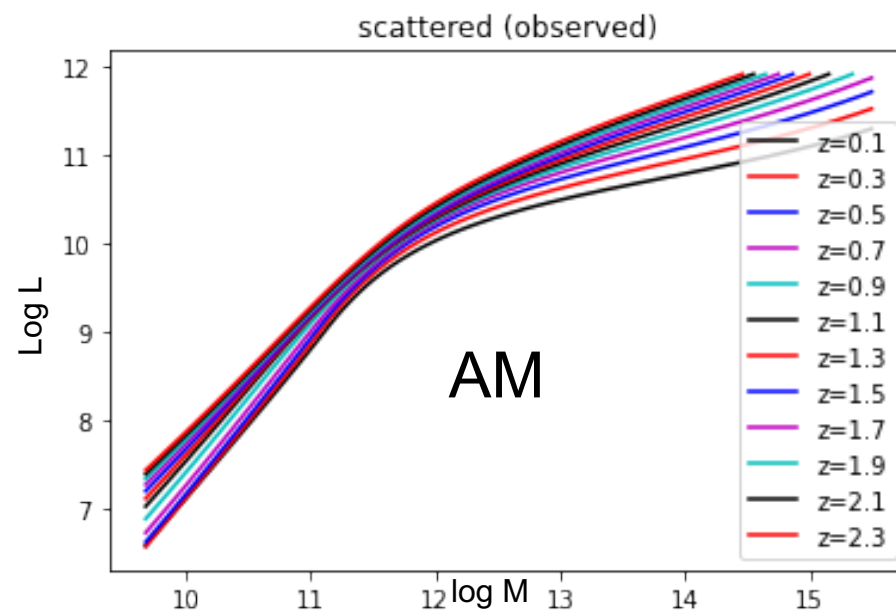
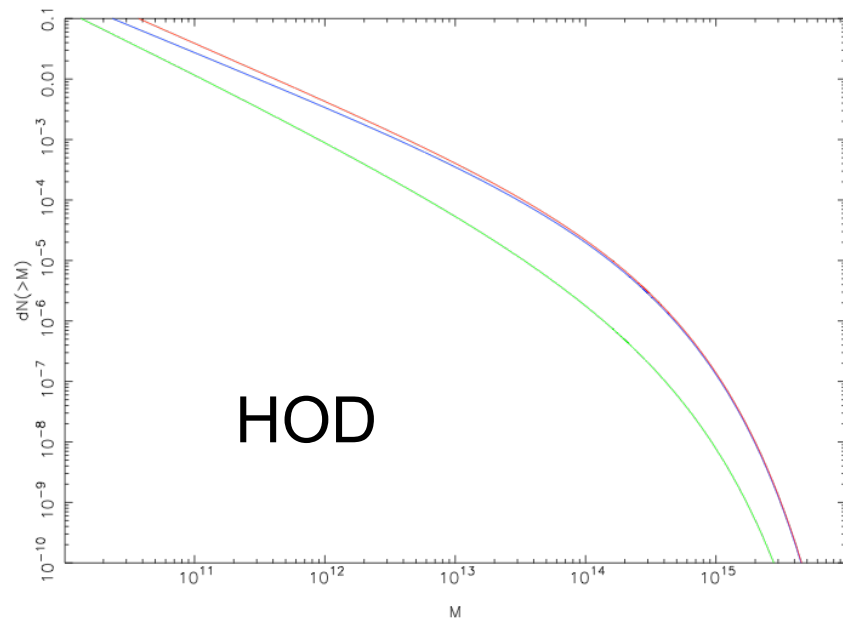
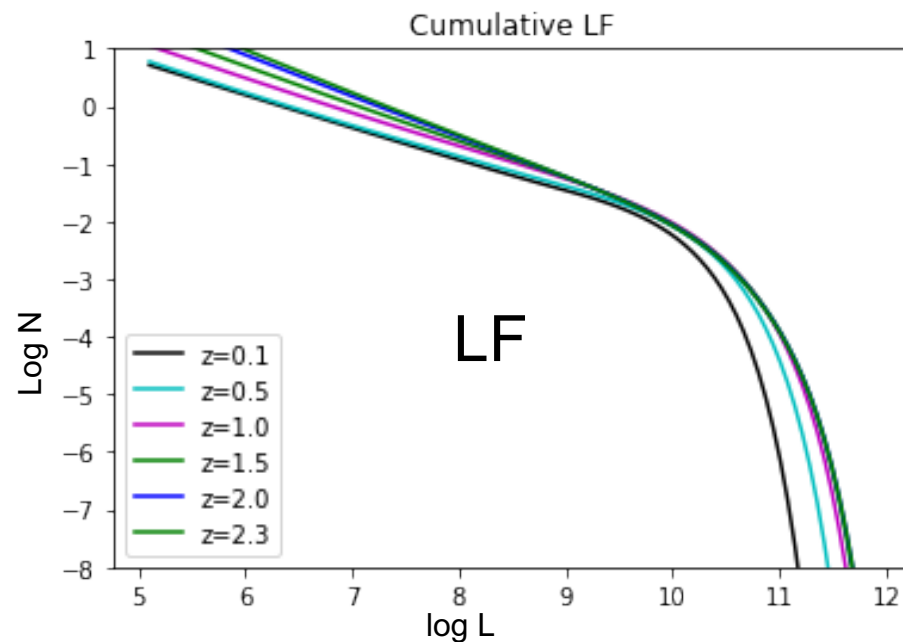
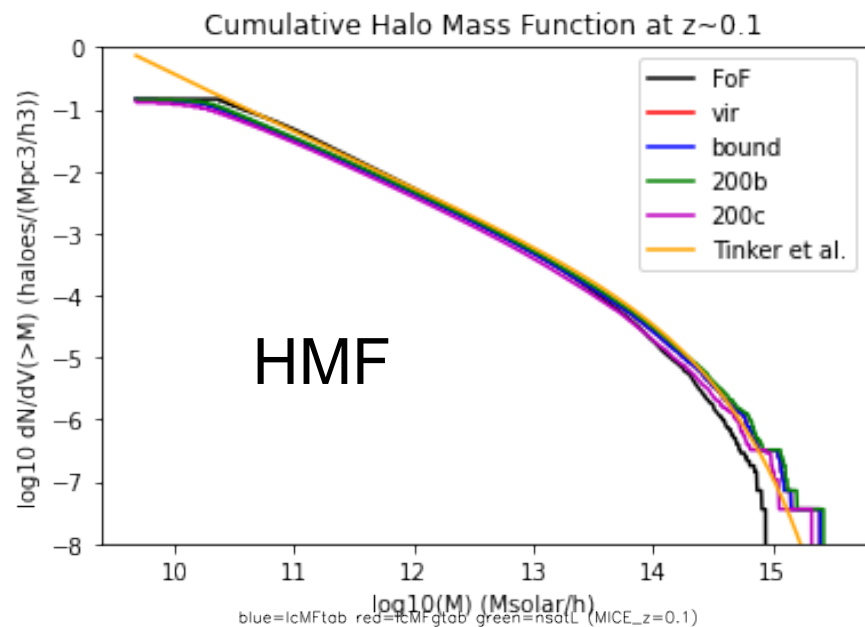
Input

- Halo catalogue:
 - halo mass
 - positional properties: positions, velocities, redshift
 - other properties: ellipticity, angular momentum, concentration

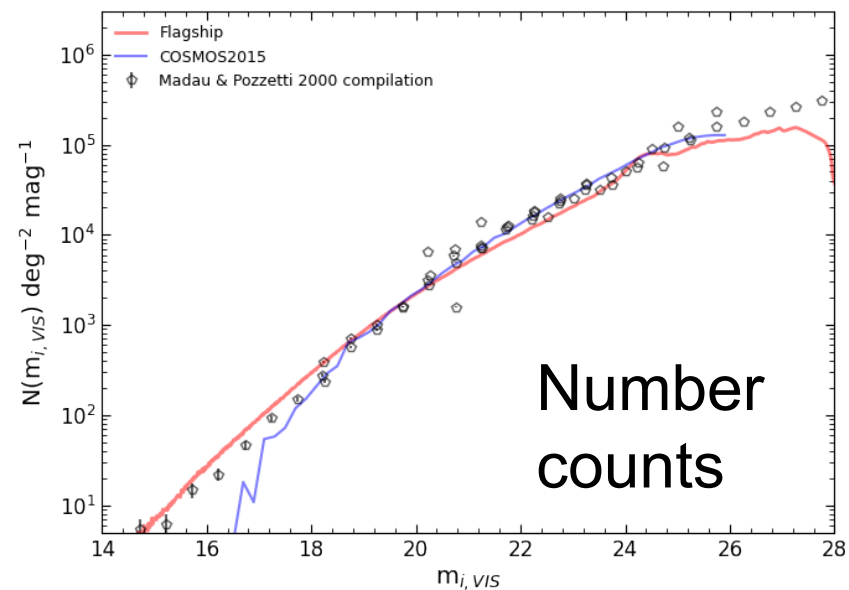
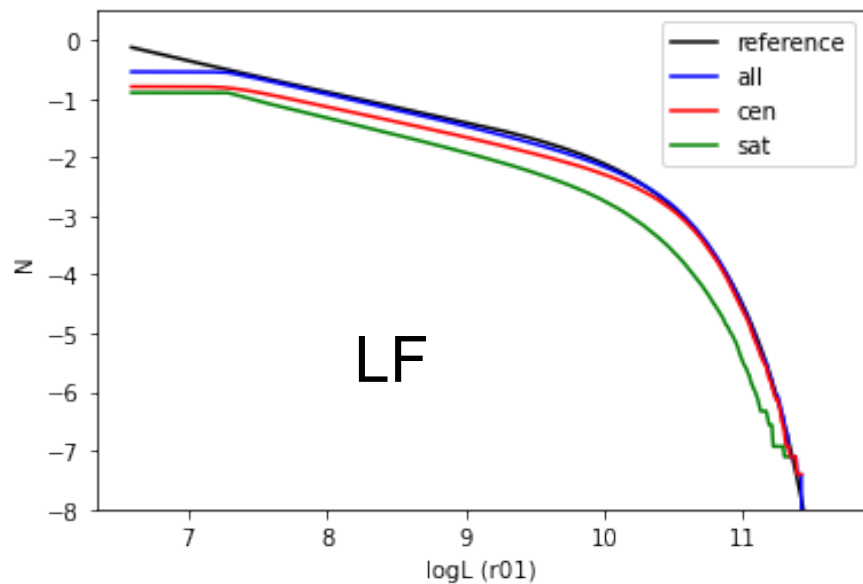
Output

- Galaxy catalogue:
 - positional properties: positions, velocities, redshift
 - photometric properties: luminosities, fluxes/magnitudes, SEDs, extinction, emission lines
 - physical properties: Stellar mass, SFR, metallicities
 - lensing properties: convergence, shear and displacements

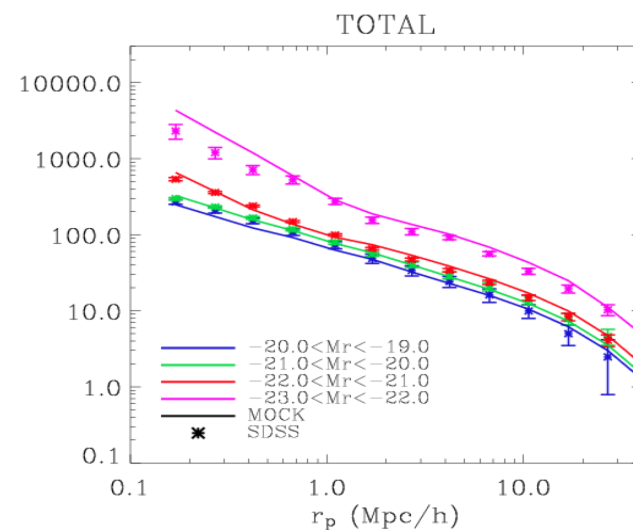
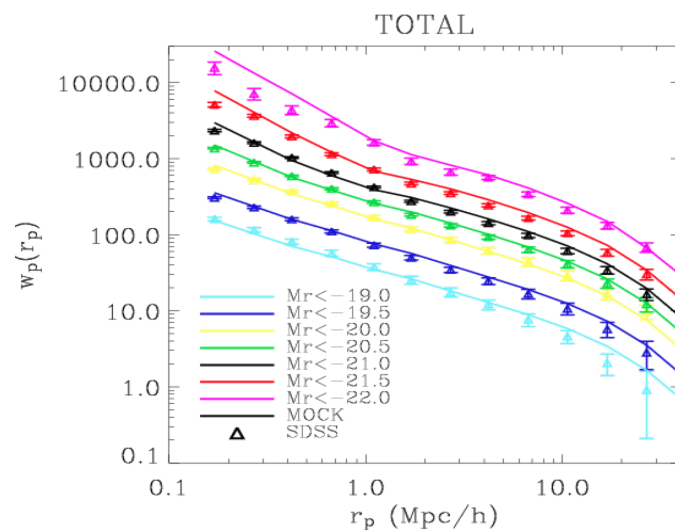
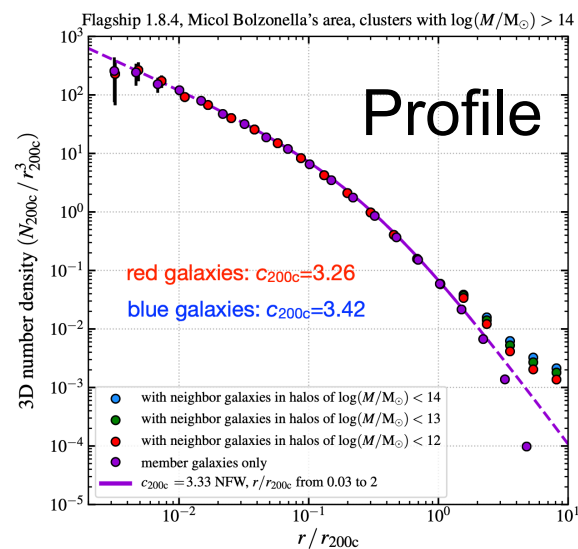
Flagship galaxy mock



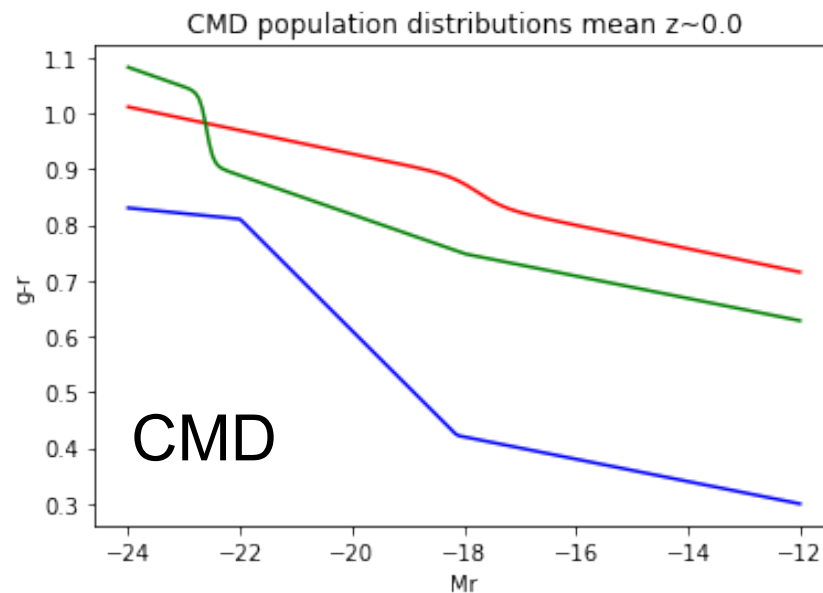
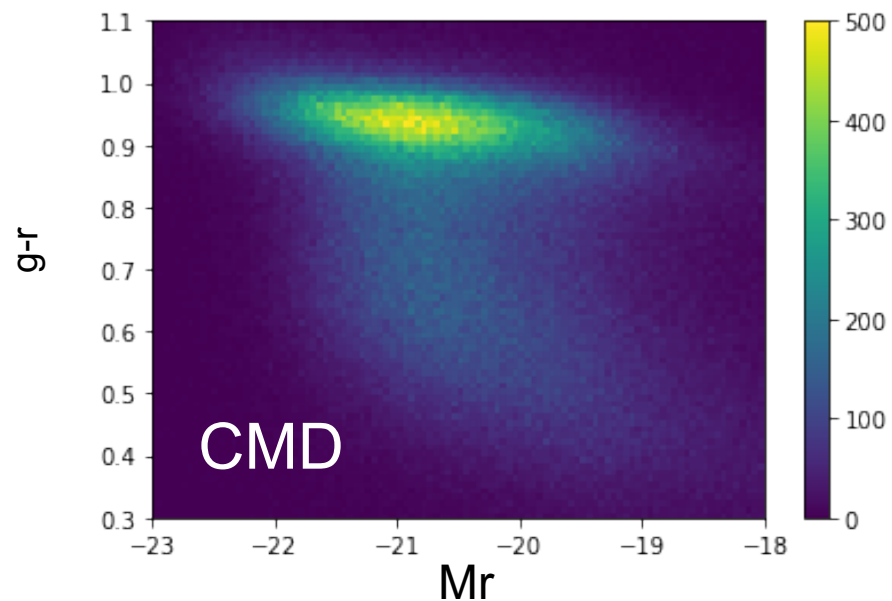
Flagship galaxy mock



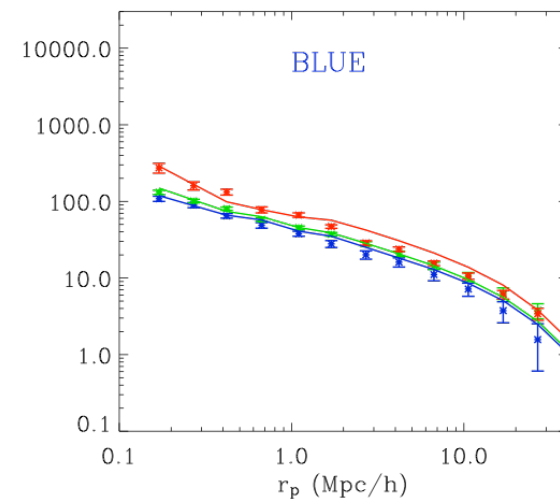
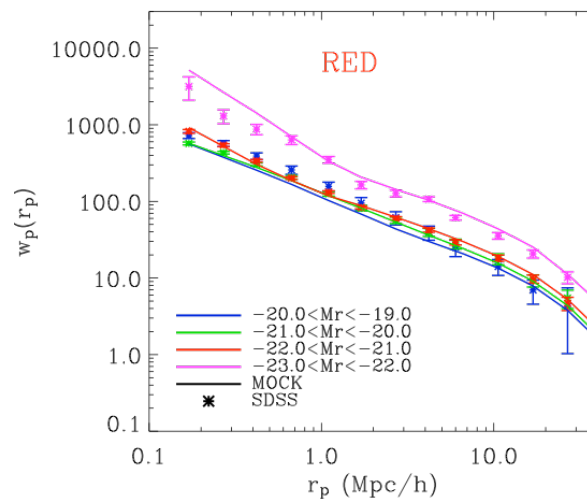
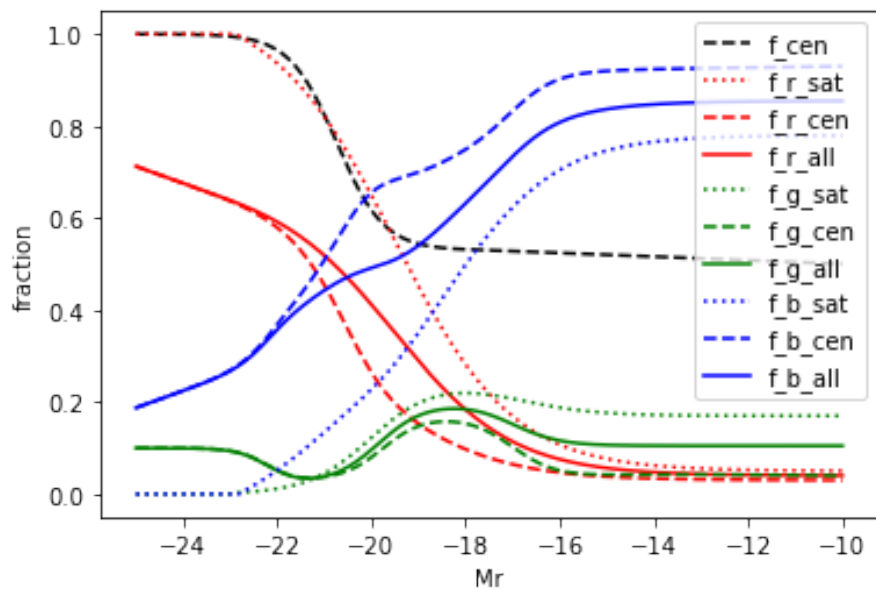
Clustering



Flagship galaxy mock

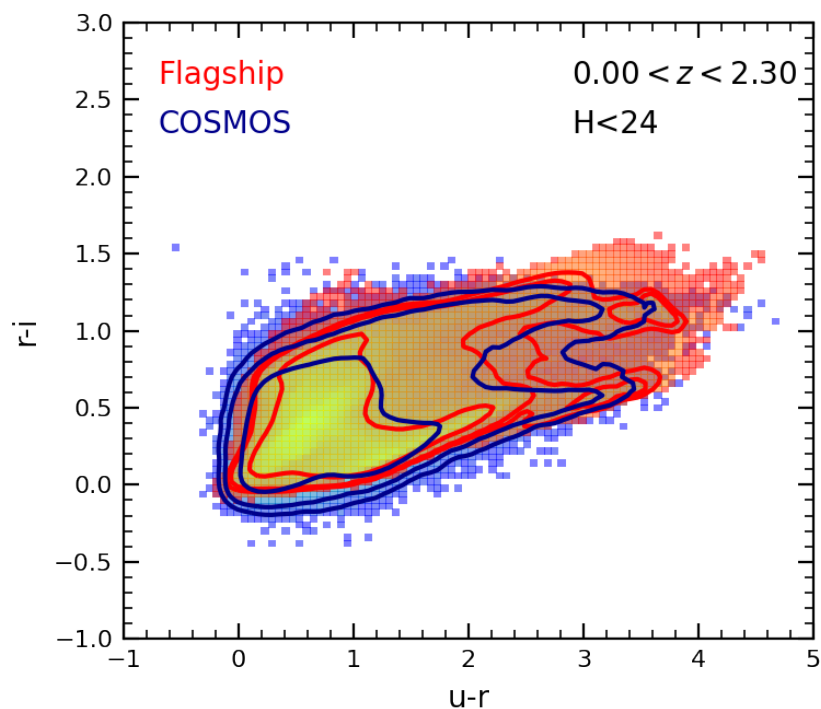


Clustering



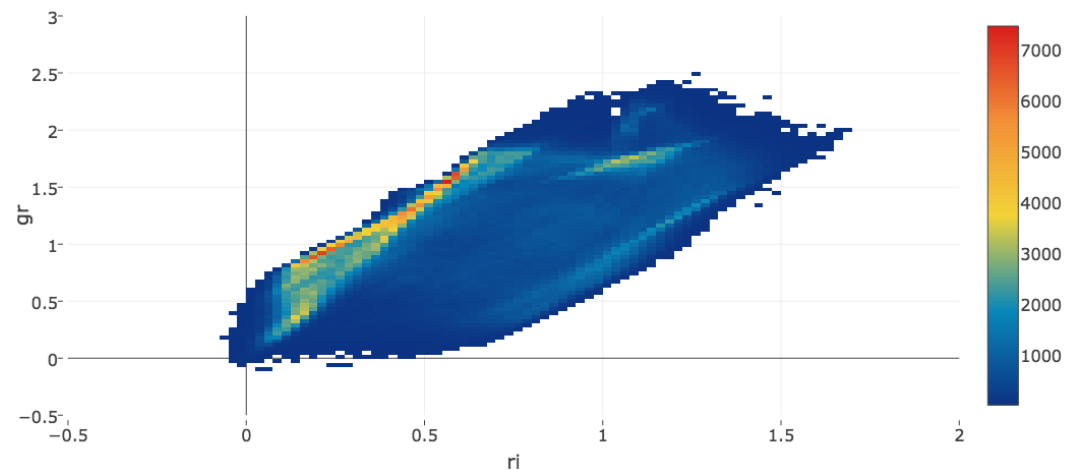
Flagship galaxy mock

Colour distributions

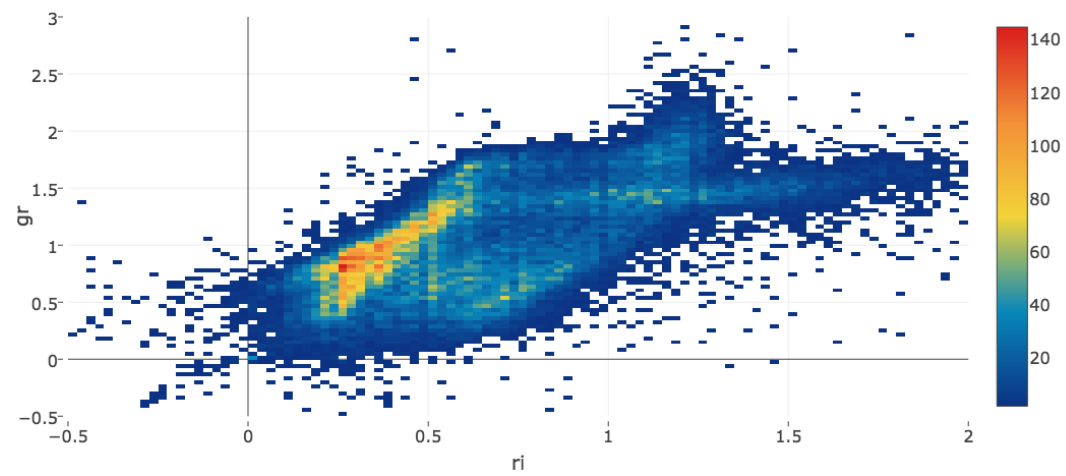


$i < 23.0$

Flagship

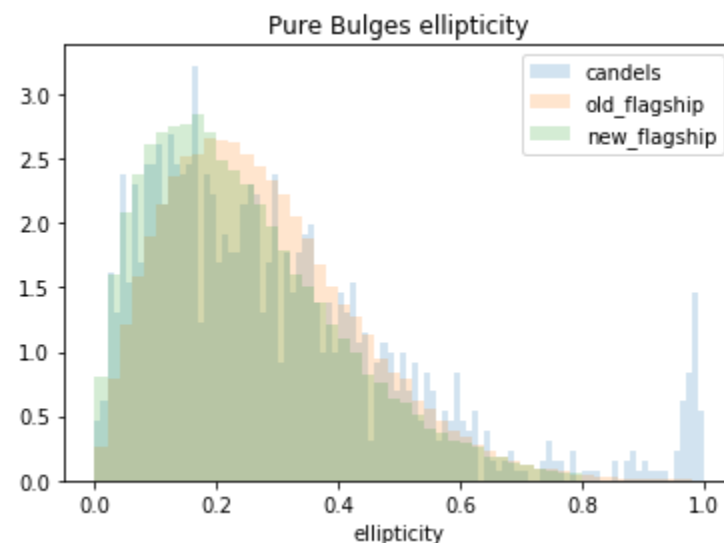
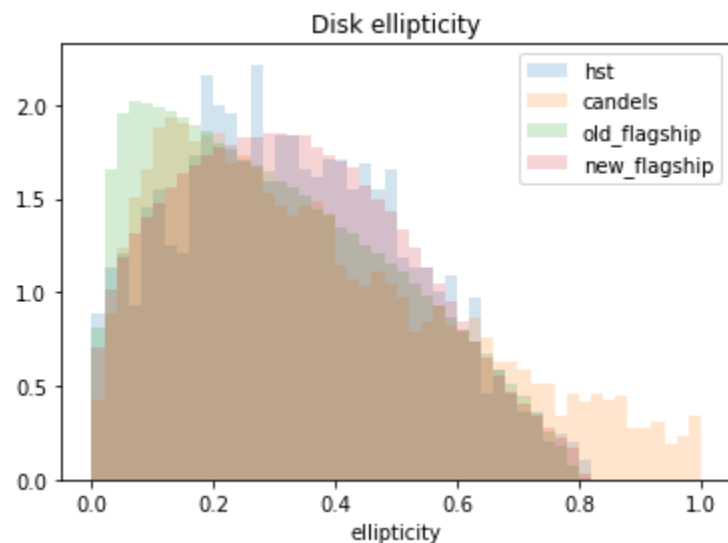
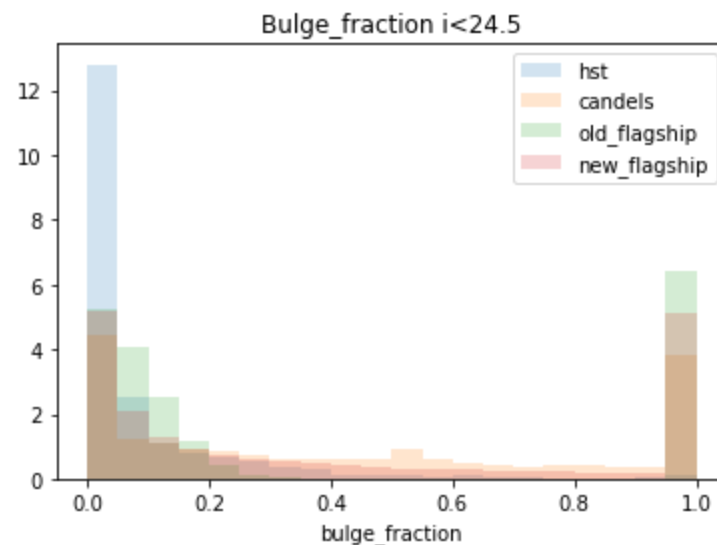
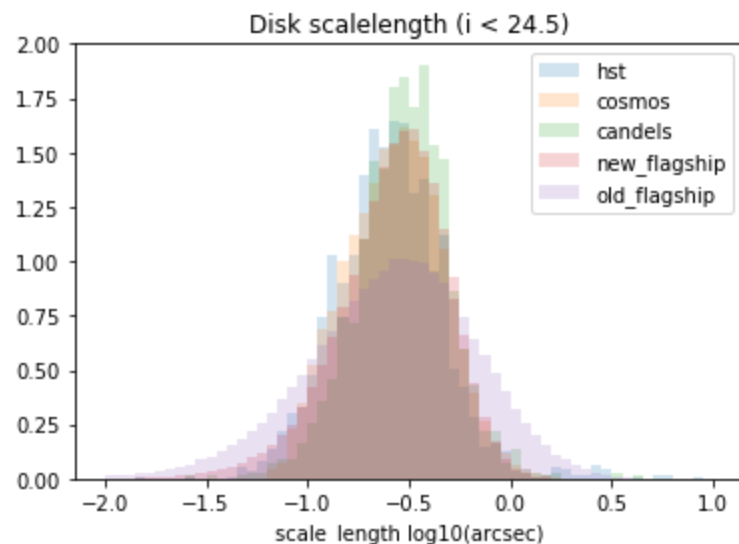


COSMOS



Flagship galaxy mock

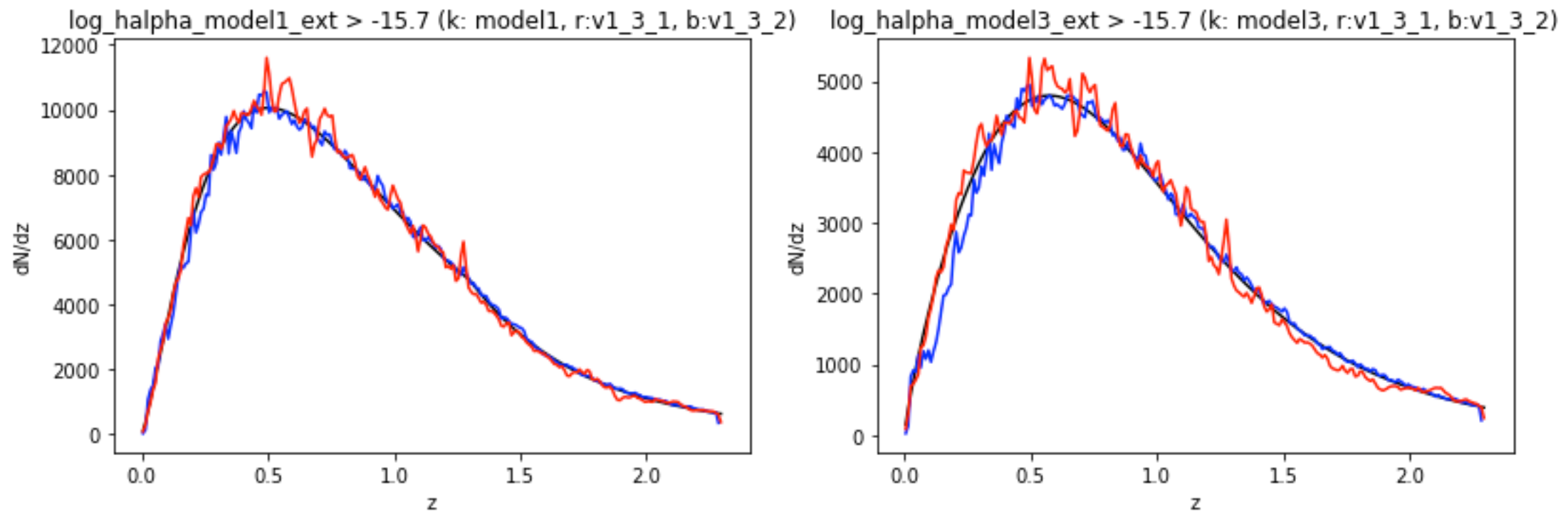
Assign sizes and shapes



Flagship galaxy mock

Halpα redshift distributions

$\log_{\text{flux_halp}\alpha_ext} > -15.7$



Model 1

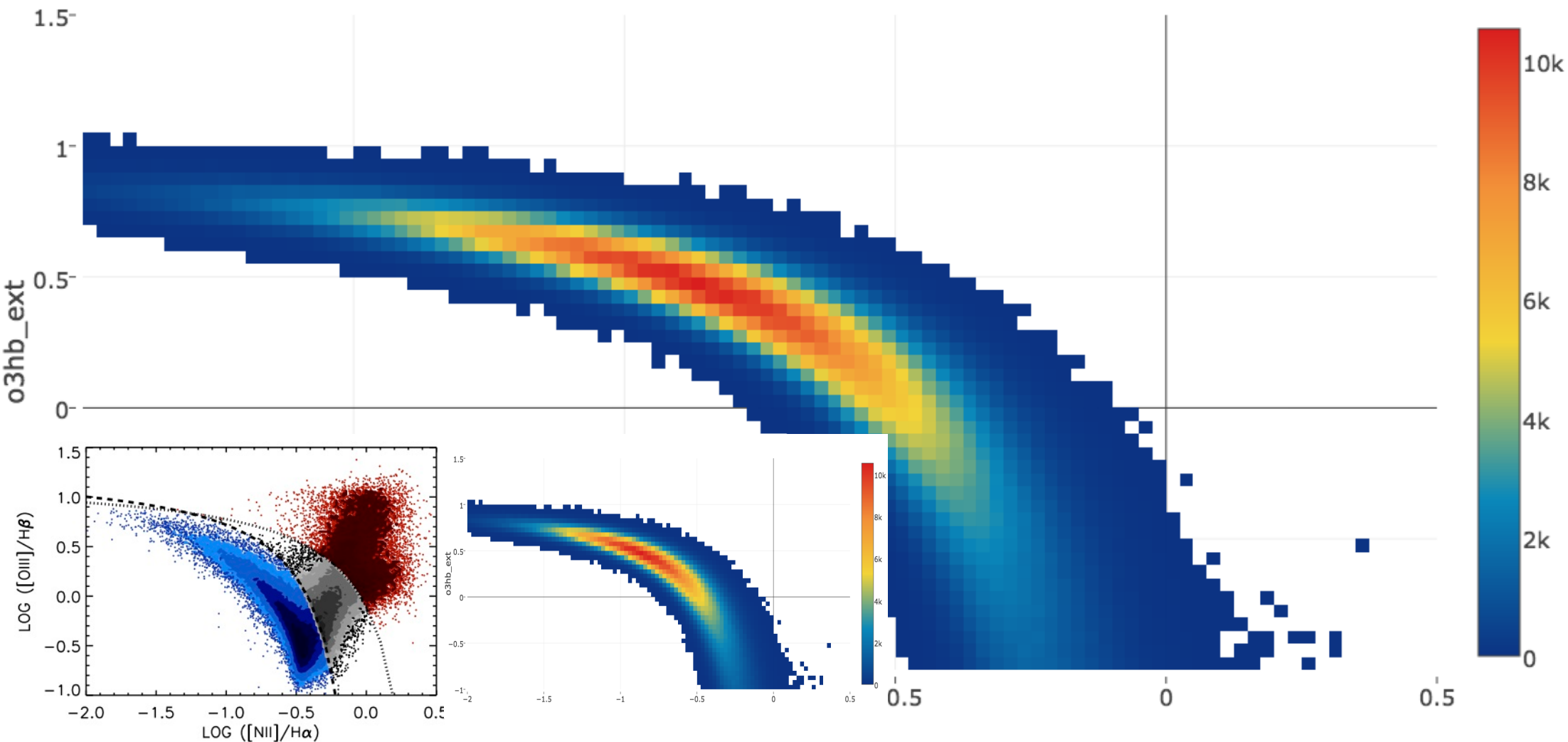
Model 3

Flagship galaxy mock

Emission lines diagnostics

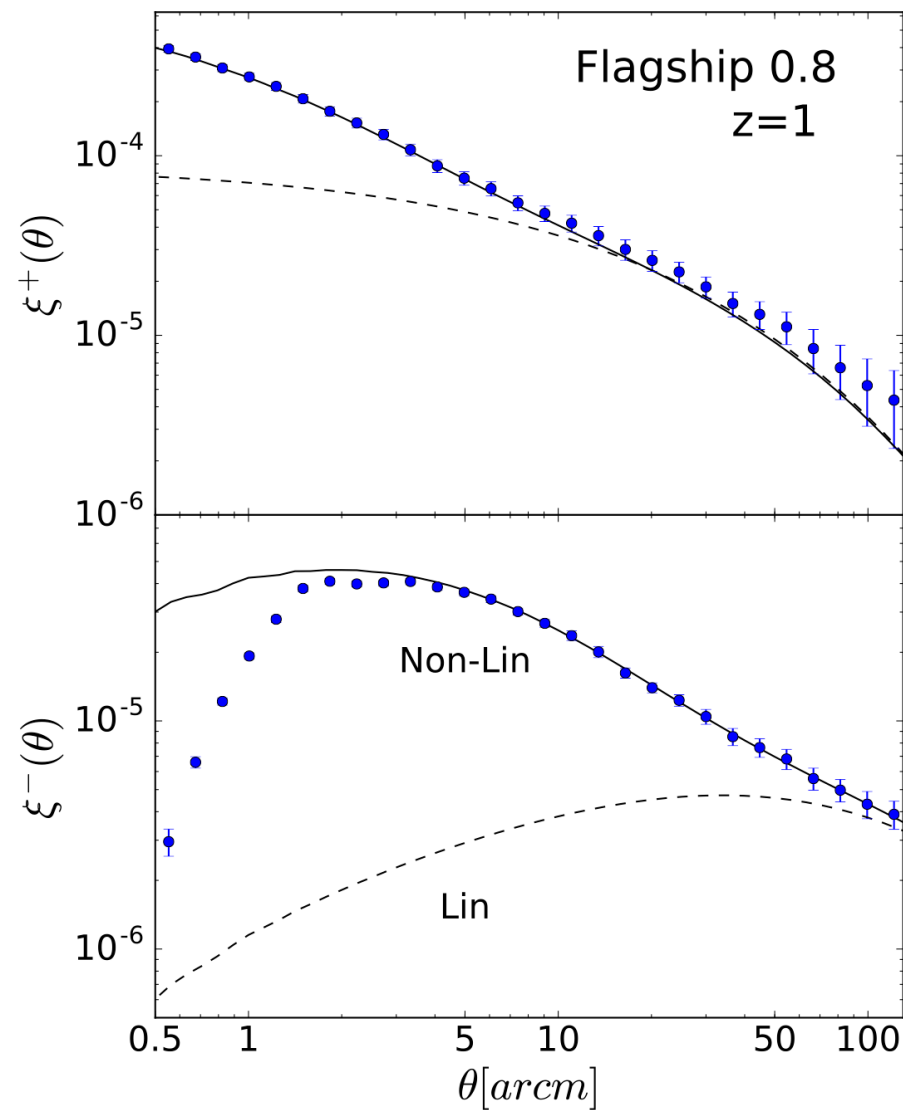
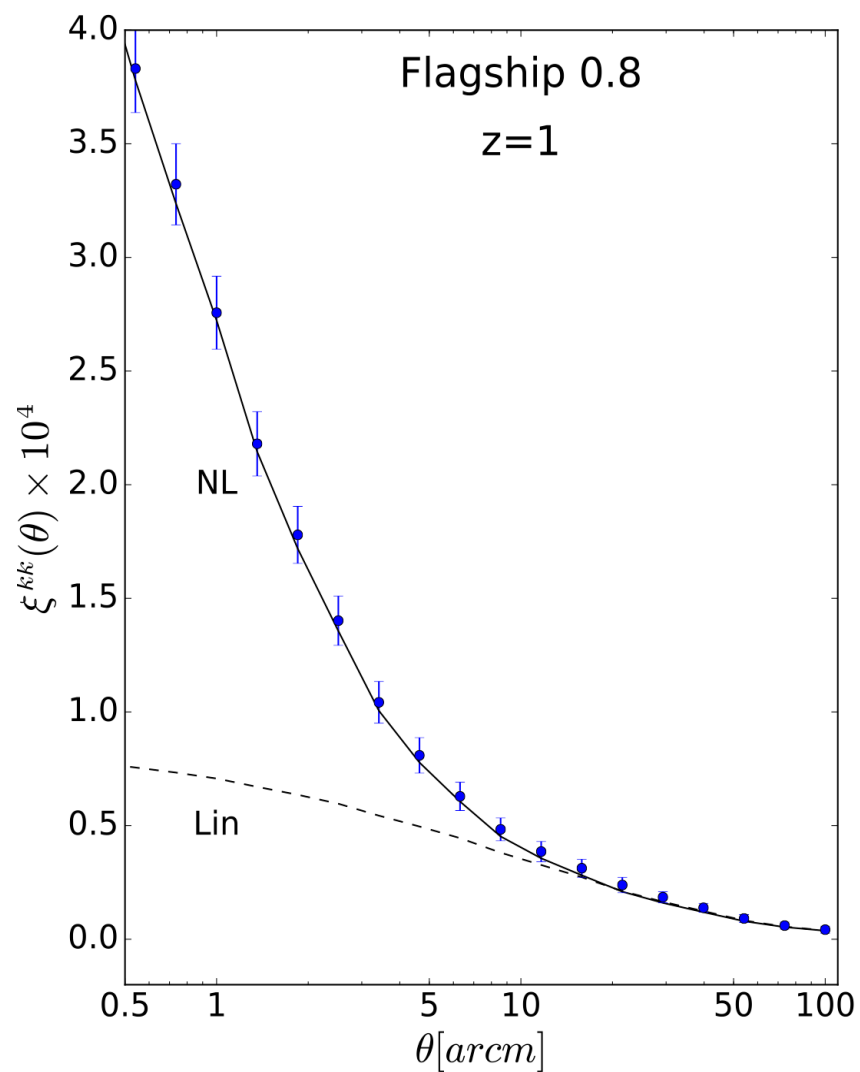
$[\text{OIII}]/\text{H}\beta$.vs. $[\text{NII}]/\text{H}\alpha$

$H < 22.0$ $\log f_{\text{H}\alpha_model3_ext} > -15.7$



Flagship galaxy mock

Lensing



Flagship galaxy mock

Euclid Flagship Galaxy Mock in numbers

- 60 billion galaxies
- 2.6 billion galaxies with cut at $H < 26$ or $\log (F_{H\alpha}) > -16 \text{ erg/s/cm}^2$
- 1/8 sky (one octant)
- around 100 properties per galaxy
- 0.83 Tb of data with cut (20 Tb without)
- 30 (60) million $H\alpha$ galaxies at $F > 2 \times 10^{-16} \text{ erg/s/cm}^2$ for model 3 (model 1)
- 10 (20) million $H\alpha$ galaxies at $F > 2 \times 10^{-16} \text{ erg/s/cm}^2$ and $0.9 < z < 1.8$ for model 3 (model 1)



COSMO HUB on Hadoop

<https://cosmohub.pic.es>

A web portal to analyze and
distribute cosmological data

J.Carretero, P.Tallada, J.Casals, M.Caubet, C.Neissner, N.Tonello, J.Delgado,
F.Torradejot, M.Delfino, S.Serrano, P.Fosalba



ICE  CSIC - IEEC 



Other simulation needs

- e2e simulations
 - Flagship
- Pixel level simulations
 - OU-SIM
- Covariance matrices: many simulations
 - Fast approximate methods
- Project specific / Understanding physical processes
 - Hydrodynamical simulations
 - Semi-analytical codes

Large simulation in other surveys

- SDSS/eBOSS
 - DM: Outer Rim + HODs (Rossi et al 2021, Alam et al 2021, Avila et al 2021)
- DES
 - Buzzard (DeRose et al, arXiv2105.13547)
 - MICE (Fosalba et al 2015, Crocce et al 2015, Carretero et al 2015)
- DESI
 - AbacusSummit (Garrison et al 2018)
 - Uchuu (Ishiyama et al 2021)
- Rubin-LSST DESC
 - DC2; DM: Outer Rim (arXiv.2021.05926)
- Roman
 - UNIT simulations + Galacticus (SAM)

Large simulations collaboration

- Similar simulations needs for Rubin-Roman-Euclid
- Many simulations/tools being developed independently
- As requirements become more stringent and precision improves, simulations turn more challenging
- Data volumes difficult to manage (especially for covariances)
- Collaborative effort can be beneficial