

# Status update of Durham Lightcones: Synthetic galaxy survey catalogues from GALFORM

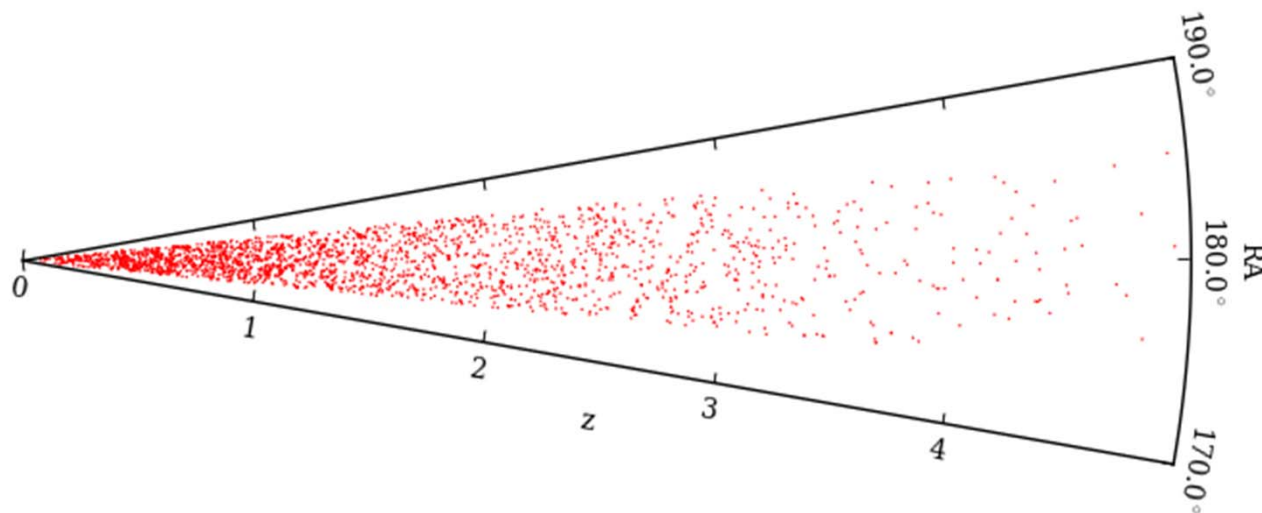
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# Outline

- Why do we need mock catalogues?
- How are the lightcone mocks constructed?
- What mocks are available currently?
- Ongoing and near-future developments.



Wedge of a PanSTARRS MDS lightcone in redshift and RA, 0.01 deg wide in declination, of the predicted distribution of all galaxies with grizy magnitude selection

# Why are lightcone mocks useful?

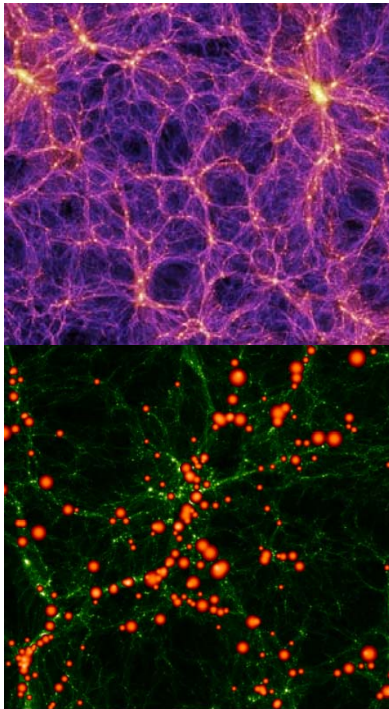
## Prediction

- Lightcone mocks can be made for different:
  - dark energy cosmologies
  - galaxy formation models
  - scales/wavebands already/not yet probed by observations

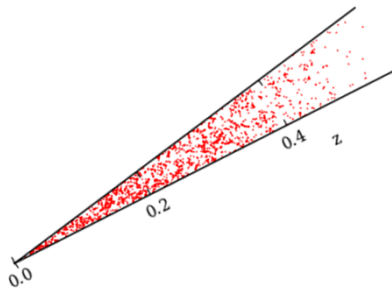
## Calibration

- Test existing estimators: e.g. group-finders
- Define new estimators/statistics
- Uncover systematic effects
- Estimate errors

# Building lightcones



- Dark Matter N-body simulation
  - Cosmological model
- Populate simulation with galaxies
  - Galaxy Formation models
- Apply survey specific limits



# Building lightcones: Millenium Simulations

Dark Matter N-body simulations available:

Millennium Simulation	Cosmology	Box Length (Mpc/h)	Equivalent maximum z	Min Halo Mass ( $M_{\odot}/h$ )	Useful for surveys like ...
I	WMAP1	500	0.17	$1.7 \times 10^{10}$	PS1 MD
WMAP7	WMAP7	500	0.17	$1.9 \times 10^{10}$	PS1 MD
MXXL	WMAP1	3000	0.72	$1.4 \times 10^{11}$	PS1 3pi
II	WMAP1	100	0.03	$1.1 \times 10^8$	Converg. Testing
WMAP7 for 977 snapshots	WMAP7	125	0.04	$1.9 \times 10^{10}$	Converg. Testing
Milli	WMAP1	62.5	0.02	$1.7 \times 10^{10}$	Code testing
GPICC	Sanchez et al (2009)	1000	0.3	$1.4 \times 10^{11}$	Testing

WMAP1 :  $\Omega_m = 0.250, \Omega_{\Lambda} = 0.750, \Omega_b = 0.0450, h = 0.730, \sigma_8 = 0.90$

WMAP7 :  $\Omega_m = 0.272, \Omega_{\Lambda} = 0.728, \Omega_b = 0.0455, h = 0.704, \sigma_8 = 0.81$

Sanchez et al (2009) :  $\Omega_m = 0.261, \Omega_{\Lambda} = 0.739, \Omega_b = 0.0440, h = 0.716, \sigma_8 = 0.80$

# Building lightcones: GALFORM

Define hierarchical galaxy formation model using:

- Gas cooling & disk formation
- SF & feedback
- Galaxy mergers
- Chemical evolution & enrichment
- Dust extinction



Compare with observations for

- LF
- HI MF
- gas metallicity
- disk radii
- morphological fraction
- ...

**Galform**



Cole et al (2000) - Original  
Baugh et al (2005) - absorption/  
emission of radiation by dust.

Bower et al (2006) - AGN  
feedback

Font et al (2008) - ram-pressure  
stripping of satellites

Lagos et al (2011) – new star  
formation law(s)

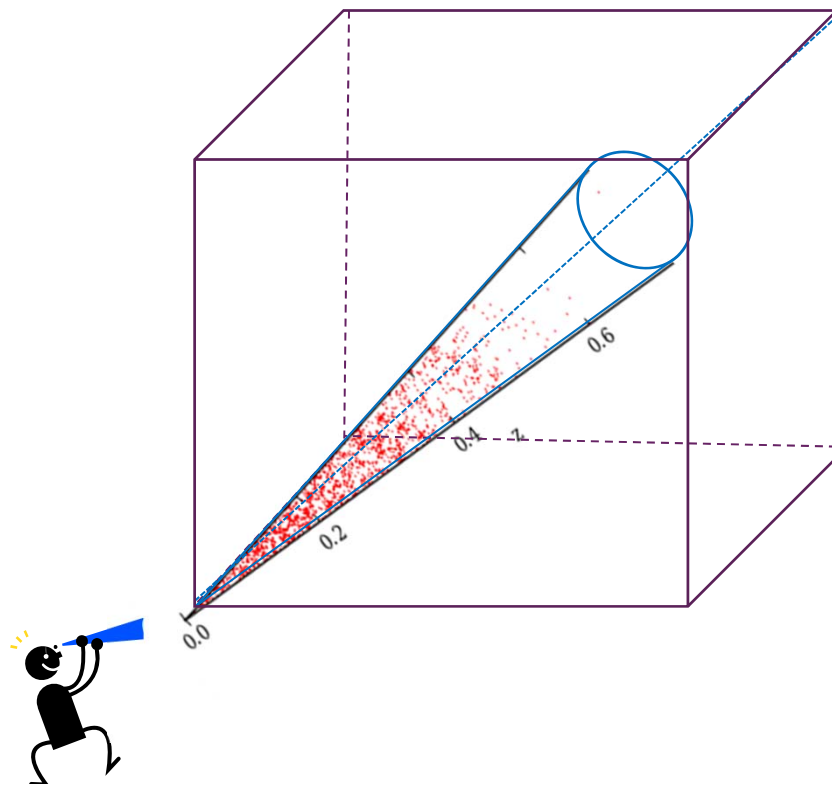
Lagos et al (2012) – change in  
starburst durations

Perez-Gonzalez (2013) – Lagos  
2012 for WMAP 7 cosmology

Lacey et al (2013) – sub-mm

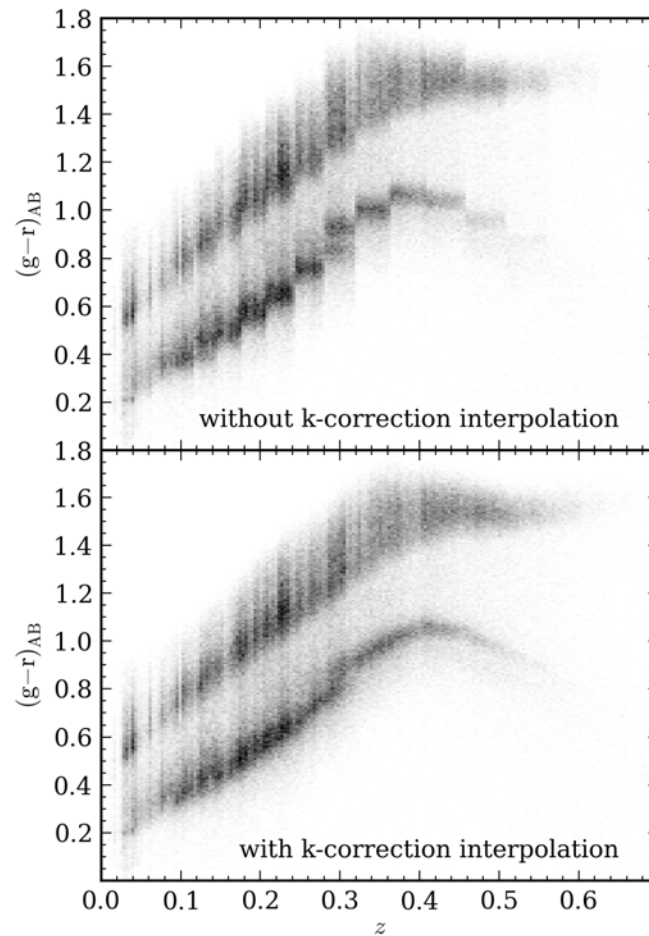
# Building lightcones: Survey Specific limits

Merson et al (2012)



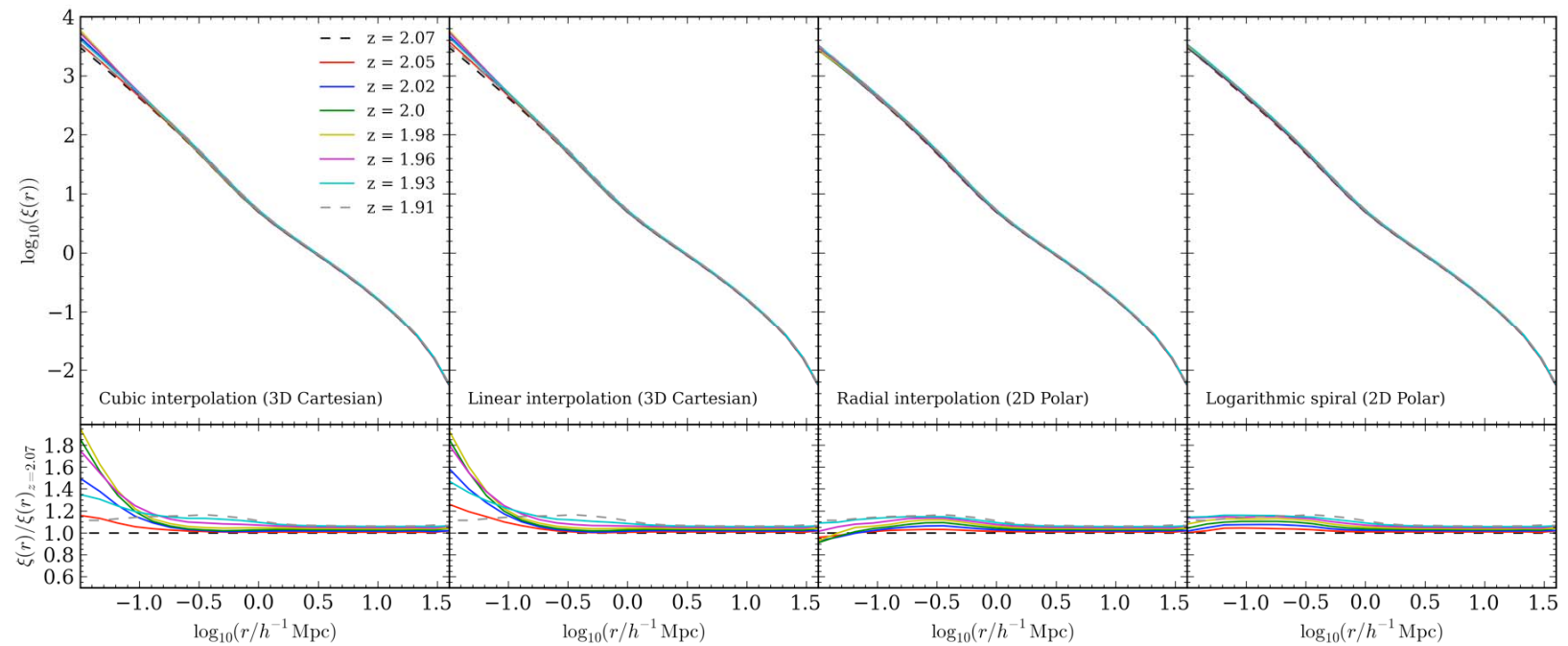
- Given cube of galaxies
- Tile to get required volume
- Position observer
- Apply solid angle mask
- Calculate galaxy redshift that enters the observers lightcone
- Interpolate positions of galaxies
- Interpolate magnitudes
- All other properties take values from previous snapshot
- Apply survey specific flux limits

# Building lightcones: Survey Specific limits cont.





# Building lightcones: Survey Specific limits cont.

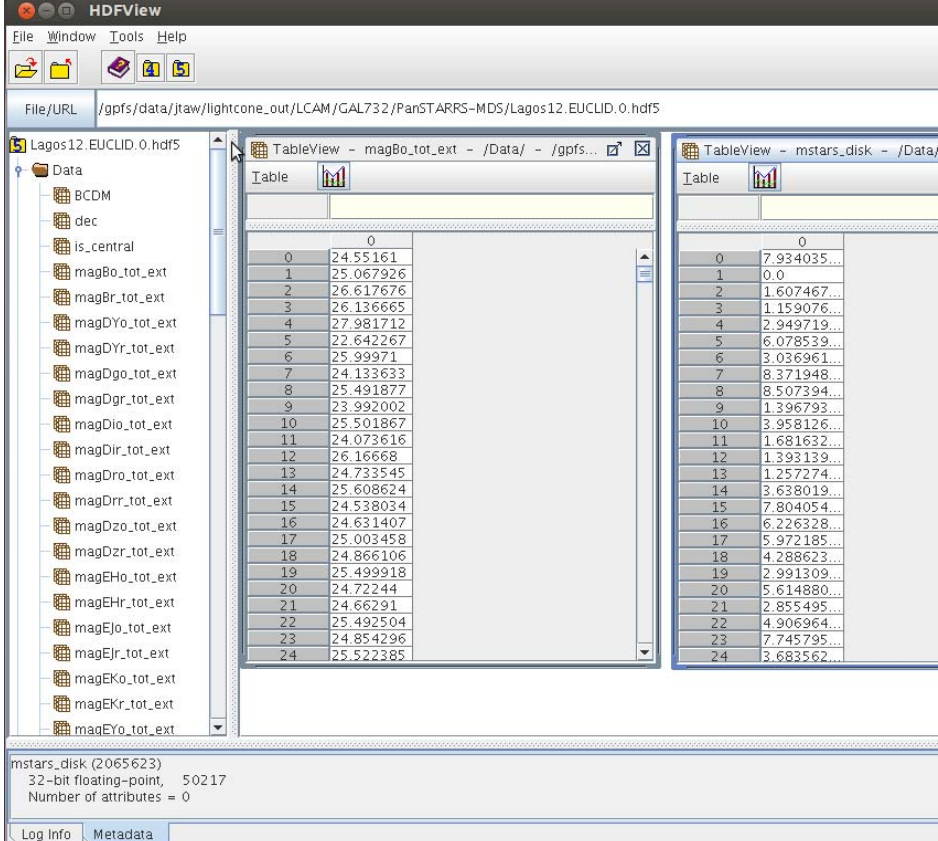


# PanSTARRS mocks available

Date	Solid angle coverage	Selection Criteria	Model	Details
2008	81 deg <sup>2</sup>	redshift <2 r < 27.5	Bower06 + M I	'Halo lightcone' - Redshift and photometric information but no angular positions [Cai, Baugh & Angulo] 'Galaxy lightcone' contains angular positional information as well [Helly & Cole]
2010	1000 deg <sup>2</sup>	redshift <2 r < 27.5?	Bower06 + M I	Magnitudes include K-corrected. [Merson]
2012	10 & 100 deg <sup>2</sup> 50 & 1000 deg <sup>2</sup> 100 deg <sup>2</sup>	r < 26 grizy grizy redshift <3	Lagos11 + M I Lagos11 + M I Lagos12 + M I	[Not on wiki currently ] [Merson]
2013	?	?	?	?

# Lightcone deliverable

- Lightcone
  - hdf5 files (512, 64, or ... )
  - contains galaxy & halo
    - positions
    - velocities
    - masses
    - apparent magnitudes
    - redshifts
    - etc ....
- Accompanying pdf readme file
  - Description of how lightcone was made for different:
    - cosmologies
    - galaxy formation models
    - survey limits etc
  - Validation plots
    - Number counts, luminosity functions, HOD and mass functions
    - Plots compared with observational results.



The screenshot shows the HDFView application interface. The main window displays two data tables side-by-side. The left table, titled 'Table - magBo\_tot\_ext', contains 25 rows of data with indices 0 through 24 and corresponding numerical values. The right table, titled 'Table - mstars\_disk', also contains 25 rows of data with indices 0 through 24 and numerical values. The application's file path is '/gpfs/data/jtaw/lightcone\_out/LCAM/GAL732/PanSTARRS-MDS/Lagos12.EUCLID.0.hdf5'. The status bar at the bottom indicates 'mstars\_disk (2065623) 32-bit floating-point, 50217 Number of attributes = 0'.

Index	magBo_tot_ext	mstars_disk
0	24.55161	7.934035...
1	25.067926	1 0 0
2	26.617676	2 1.607467...
3	26.136665	3 1.159076...
4	27.981712	4 2.949719...
5	22.642267	5 6.078539...
6	25.99971	6 3.036961...
7	24.133633	7 8.371948...
8	25.491877	8 8.507394...
9	23.992002	9 1.396793...
10	25.501867	10 3.958126...
11	24.073616	11 1.681632...
12	26.16668	12 1.393139...
13	24.733545	13 1.257274...
14	25.608624	14 3.638019...
15	24.538034	15 7.804054...
16	24.631407	16 6.226328...
17	25.003458	17 5.972185...
18	24.866106	18 4.288623...
19	25.499918	19 2.991309...
20	24.72244	20 5.614880...
21	24.66291	21 2.855495...
22	25.492504	22 4.906964...
23	24.854296	23 7.745795...
24	25.522385	24 3.683562...

# PanSTARRS-MDS Lightcone README

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## Summary

This PanSTARRS-MDS lightcone has been constructed using the `Lagos10 GALFORM` model. The lightcone covers the redshift range  $z = 0.0$  to  $z = 3.0$  and has a sky coverage of  $50.25\text{deg}^2$ , centred on a sky position of (RA,DEC) = (353.29°, -14.48°). Galaxies were selected for inclusion using the following criteria:

$-9.90000E+01 \leq \text{mag}g\text{Po}_{\text{tot\_ext}} \leq 2.62200E+01$   
 $-9.90000E+01 \leq \text{mag}r\text{Po}_{\text{tot\_ext}} \leq 2.58600E+01$   
 $-9.90000E+01 \leq \text{mag}i\text{Po}_{\text{tot\_ext}} \leq 2.58200E+01$   
 $-9.90000E+01 \leq \text{mag}z\text{Po}_{\text{tot\_ext}} \leq 2.51900E+01$   
 $-9.90000E+01 \leq \text{mag}y\text{Po}_{\text{tot\_ext}} \leq 2.37500E+01$

Descriptions of the galaxy properties included, along with further specifications, are provided in the tabulated data in this document.

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## 3 Galaxy properties

Listed in Table 3 are all the galaxy properties (except magnitudes, fluxes and emission lines, see Section 4) that have been included in the lightcone. A one line description is provided for each property.

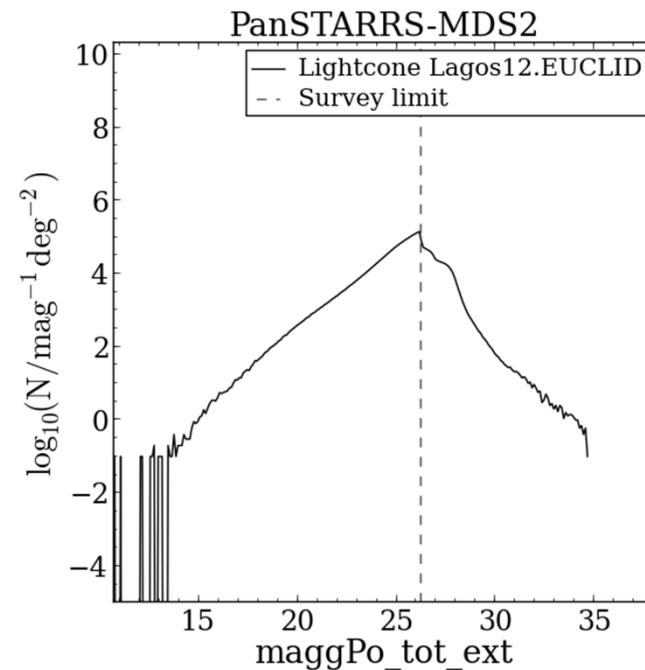
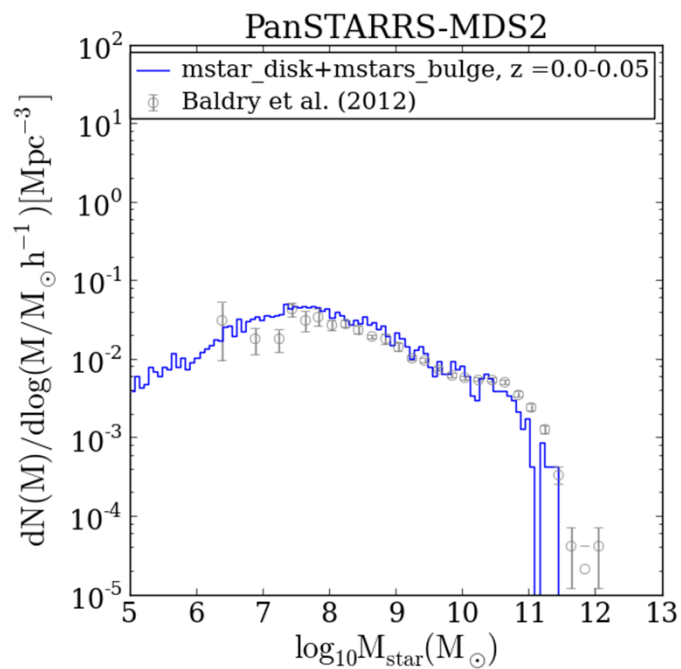
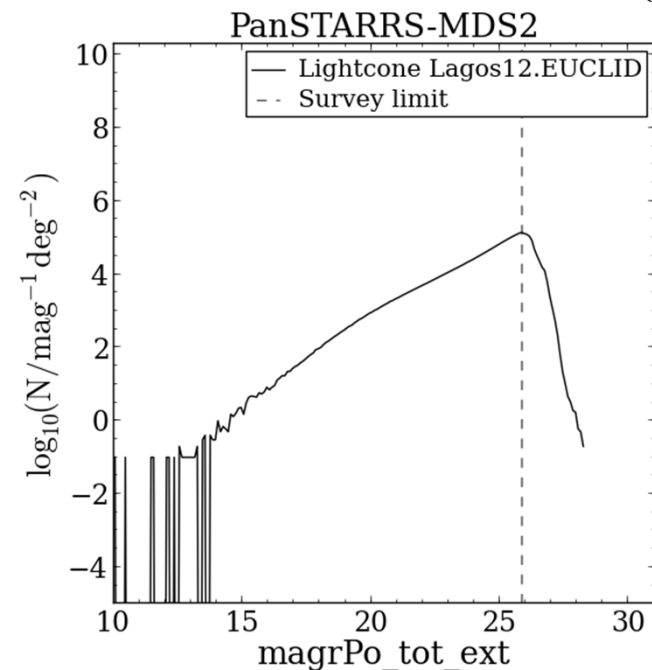
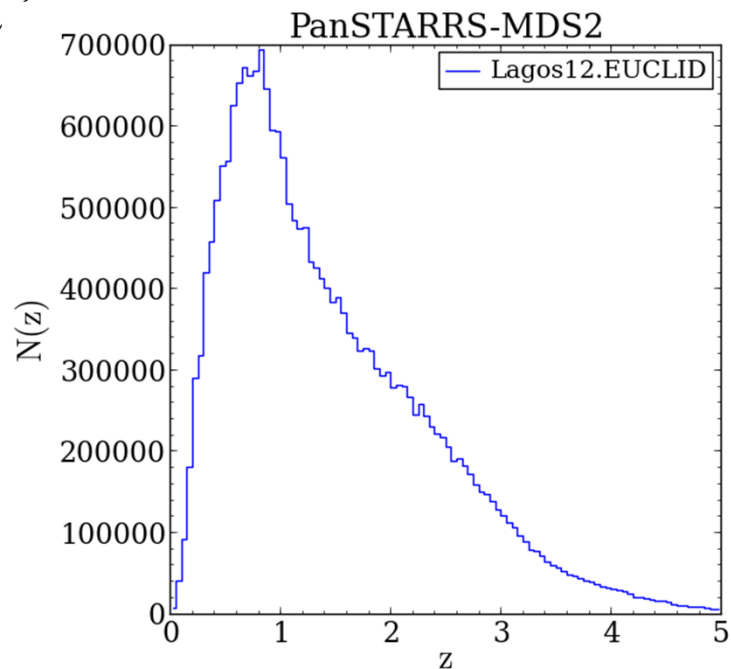
Table 3: List of properties (excluding magnitudes, fluxes and emission lines) included in the lightcone. Units are provided where necessary.

Property	Description
BCDM	Band Corrected Distance Modulus = $5\log_{10}(d_L/\text{Mpc}) + 25 - 2.5\log_{10}(1+z)$
dec	declination of galaxy (radians)
is_central	is the galaxy a central or a satellite galaxy in its DM halo (1 = central, 0 = satellite)
mhalo	mass of the host halo ( $M_{\odot}/h$ )
mstardot	(instantaneous) quiescent SFR in disk ( $M_{\odot}/h/\text{Gyr}$ )
mstardot_average	quiescent SFR in the disk averaged over last timestep ( $M_{\odot}/h/\text{Gyr}$ )
mstardot_burst	SFR in bursts ( $M_{\odot}/h/\text{Gyr}$ )
mstars_bulge	stellar mass in bulge of galaxy ( $M_{\odot}/h$ )
mstars_disk	stellar mass in disk of galaxy ( $M_{\odot}/h$ )
mw_bias	Mo & White bias
r	comoving distance to this galaxy (Mpc/h)
ra	right ascension of galaxy (radians)
rbulge	half-mass radius of bulge (Mpc/h)
rdisk	half-mass radius of disk (Mpc/h)
smt_bias	Sheth, Mo & Tormen bias
vdisk	circular velocity of the disk at the half mass radius (km/sec)
vxgal	Cartesian X component of peculiar velocity of this galaxy (km/s)
vygal	Cartesian Y component of peculiar velocity of this galaxy (km/s)
vzgal	Cartesian Z component of peculiar velocity of this galaxy (km/s)
xgal	Cartesian X coordinate of this galaxy relative to the observer (Mpc/h)
ygal	Cartesian Y coordinate of this galaxy relative to the observer (Mpc/h)
z_cos	cosmological redshift of galaxy
z_obs	observed redshift of galaxy (peculiar velocities included)
zgal	Cartesian Z coordinate of this galaxy relative to the observer (Mpc/h)

### 3.1 Depending on the file format...

- If file format is **ASCII**: the list of properties included in the lightcone is provided in the last line of the header. The properties are listed in the column order in which are found from left to right.
- If file format is **HDF5**: the list of properties correspond to the names of the various datasets in the group `\Data`. For instance, the cosmological redshifts for all the galaxies in that file are stored under `\Data\z_cos`.

# Lightcone deliverable



# Current improvements – Developer

- Speeding up generation of lightcones
  - Milli Millenium mocks available
  - Combining GALFORM runs if extra bands required.
- Making file easier to deliver
  - reducing file sizes by having core file plus additional files for survey specific magnitudes
  - Looking at implementing new database to allow data to be selected by column as well as row
  - file type converter for hdf5 to fits
  - training sets for using hdf5 files
  - Also can do ascii (but small areas to test)
  - Splitting up hdf5 by area
- More emphasis on reducibility
  - Generating database of lightcones from different models

# Current improvements – End User

- Including more useful observational quantities:
  - $M_{200}/M_{500}$  values rather than the dhalo mass for more direct comparison with observations
  - What else what be useful?
- Dark Matter Halo Lightcones
- These are currently ‘perfect’ mocks. Ideas for post processing of the lightcones include:
  - photo z and errors?
  - Noise?

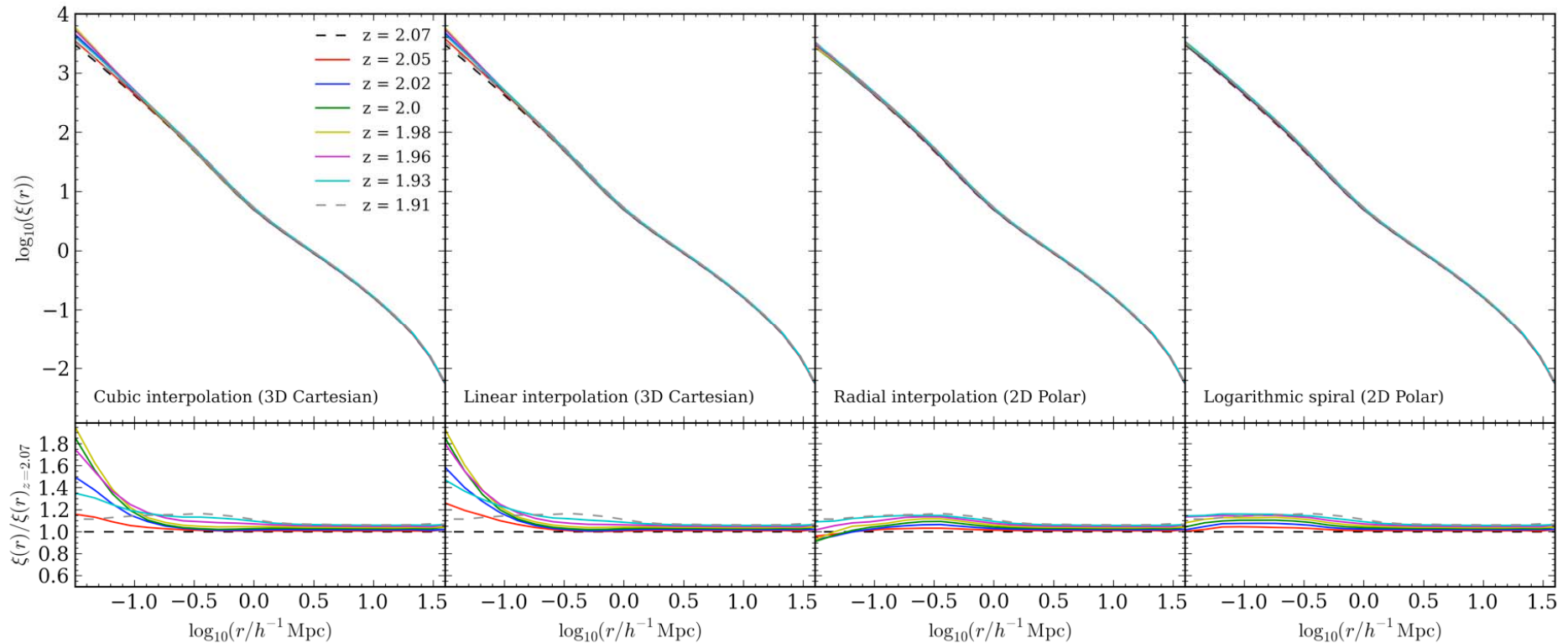
# Summary

- Lightcone synthetic "mock" catalogues
- Constructed from Millennium Nbody simulations + GALFORM models
- Select galaxies in multiple bands simultaneously
- Developments to make output more user friendly
- Looking for user feedback



# Additional Info

# Interpolation of satellite positions



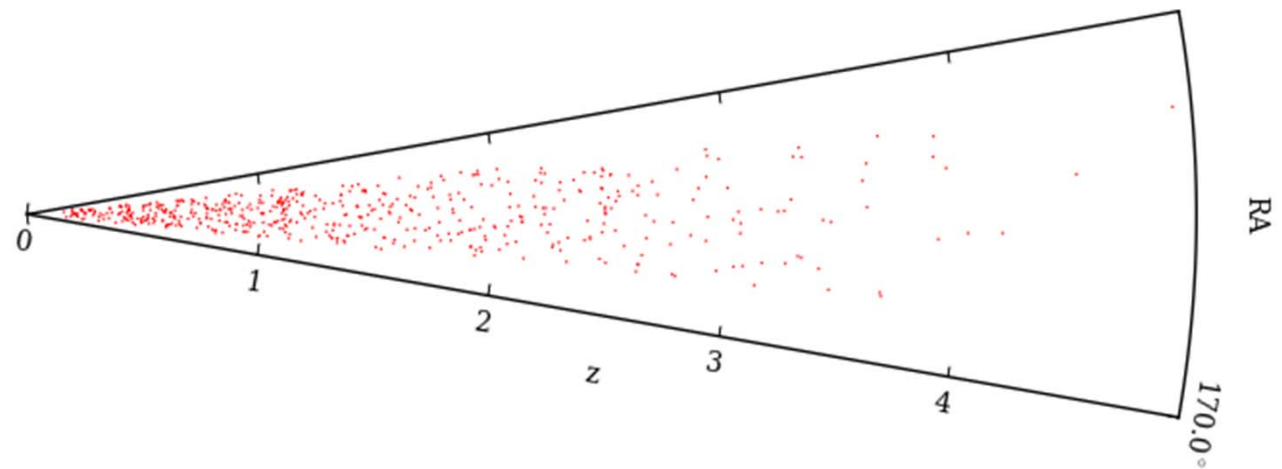
The real-space correlation function of galaxies predicted using four different satellite interpolation schemes.

The upper panels show the correlation function for galaxies at two adjacent simulation snapshots (corresponding to redshifts  $z = 1.91$  and  $z = 2.07$ ) and the same galaxies at six intermediate redshifts. T

The lower panels show the ratio of each correlation function, relative to the correlation function measured at the  $z = 2.07$  snapshot.

# grizy selection

- $g < 26.22$
- $r < 25.86$
- $i < 25.82$
- $z < 25.19$
- $y < 23.75$



Wedge of a PanSTARRS MDS lightcone in redshift and RA, 0.01 deg wide in declination,  
Of the predicted distribution of all galaxies with grizy magnitude selection