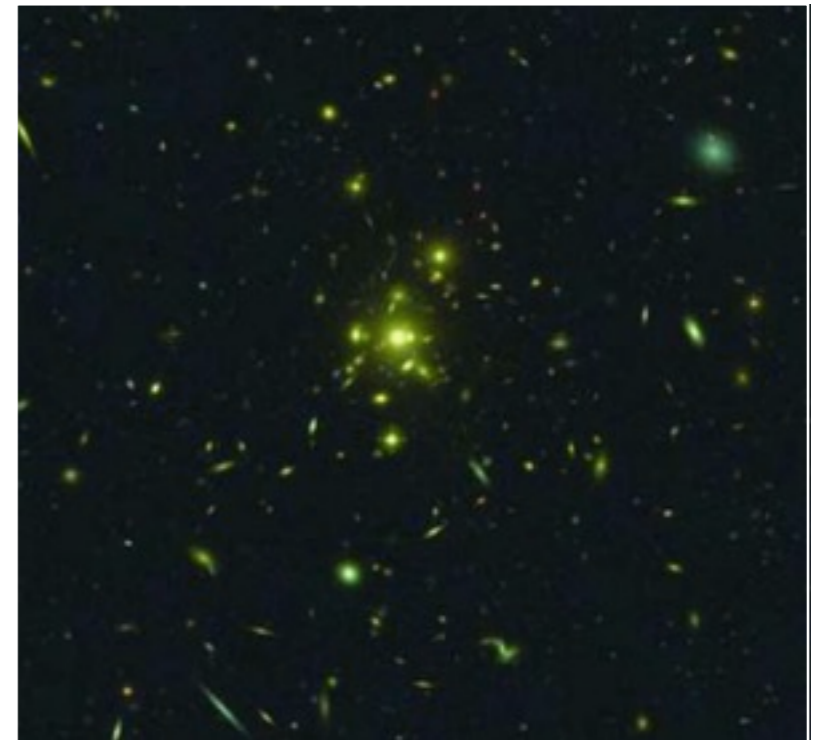
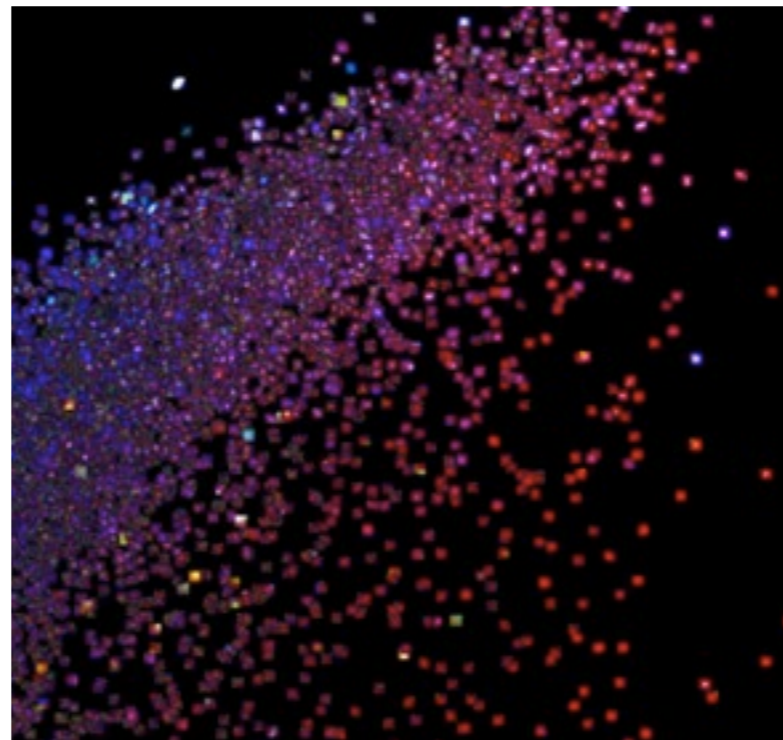


# The Millennium Run Observatory

**Roderik Overzier (UT Austin) + Gerard Lemson + Galformod**

**Part I: Concept and First Results**

Part II: How-to, Data, and new User Services



- **Motivation:** more direct and less biased interaction between theory predictions and the observations...
- **Method:** create a legacy facility producing telescope-quality data from simulations for analysis using standard observing techniques
- **Goal:** better understand observations & produce better models

# The Millennium Run Observatory

*a Theory-observational interface*

How to link simulations (theorists) and observations (observers)?

- What information from simulations is most useful, and in what form?

Currently two approaches

## **1. Predict observables from simulations**

- typically too idealized, how to compare with real data?

## **2. Derive physical quantities from observations**

- observational astrophysics is hard!

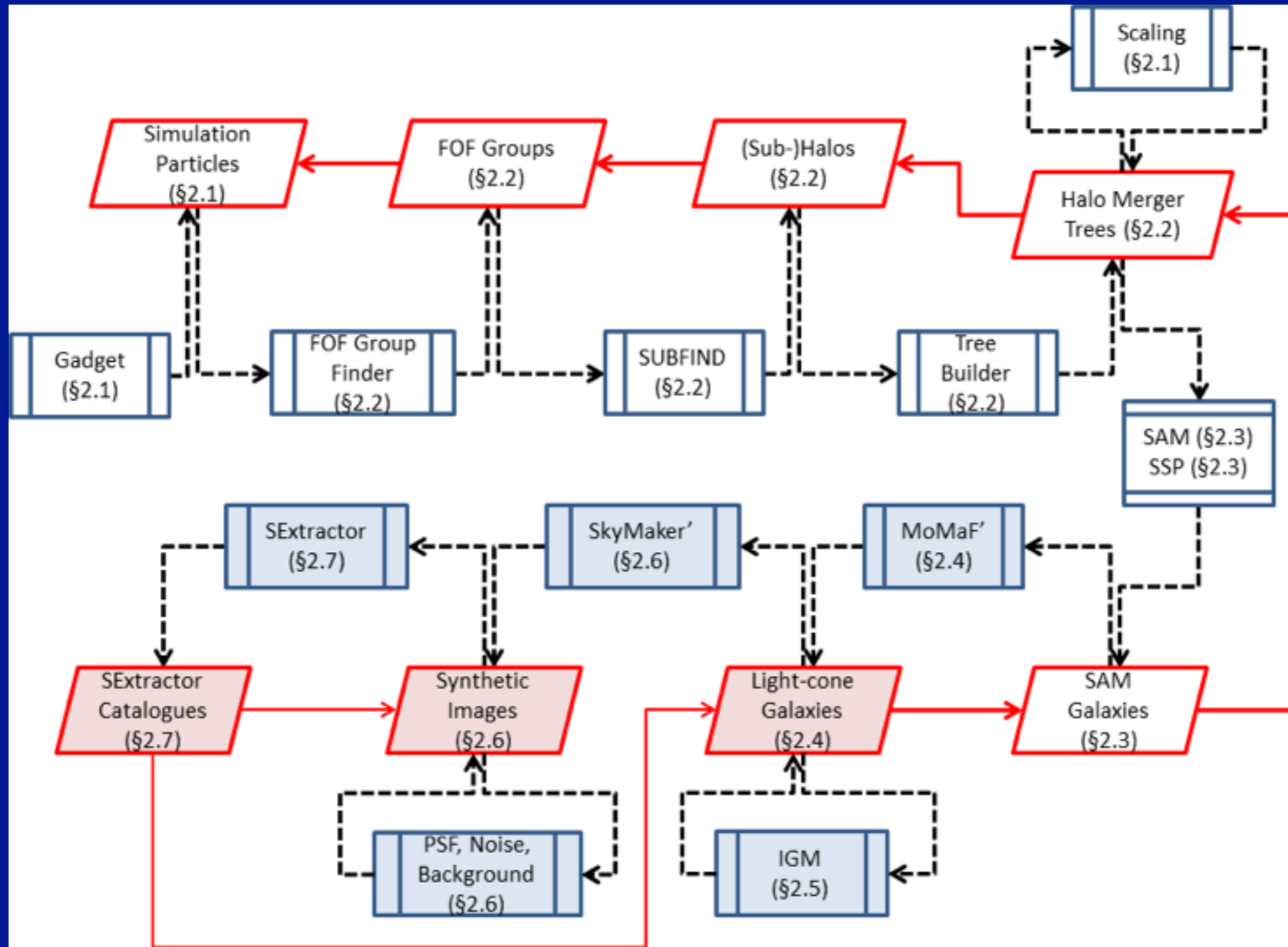
## **Our approach**

Link the two approaches using a Virtual Theoretical Observatory  
(easier to add “noise” to simulations than to take it out of data)

# Millennium Run Observatory Workflow

theorist

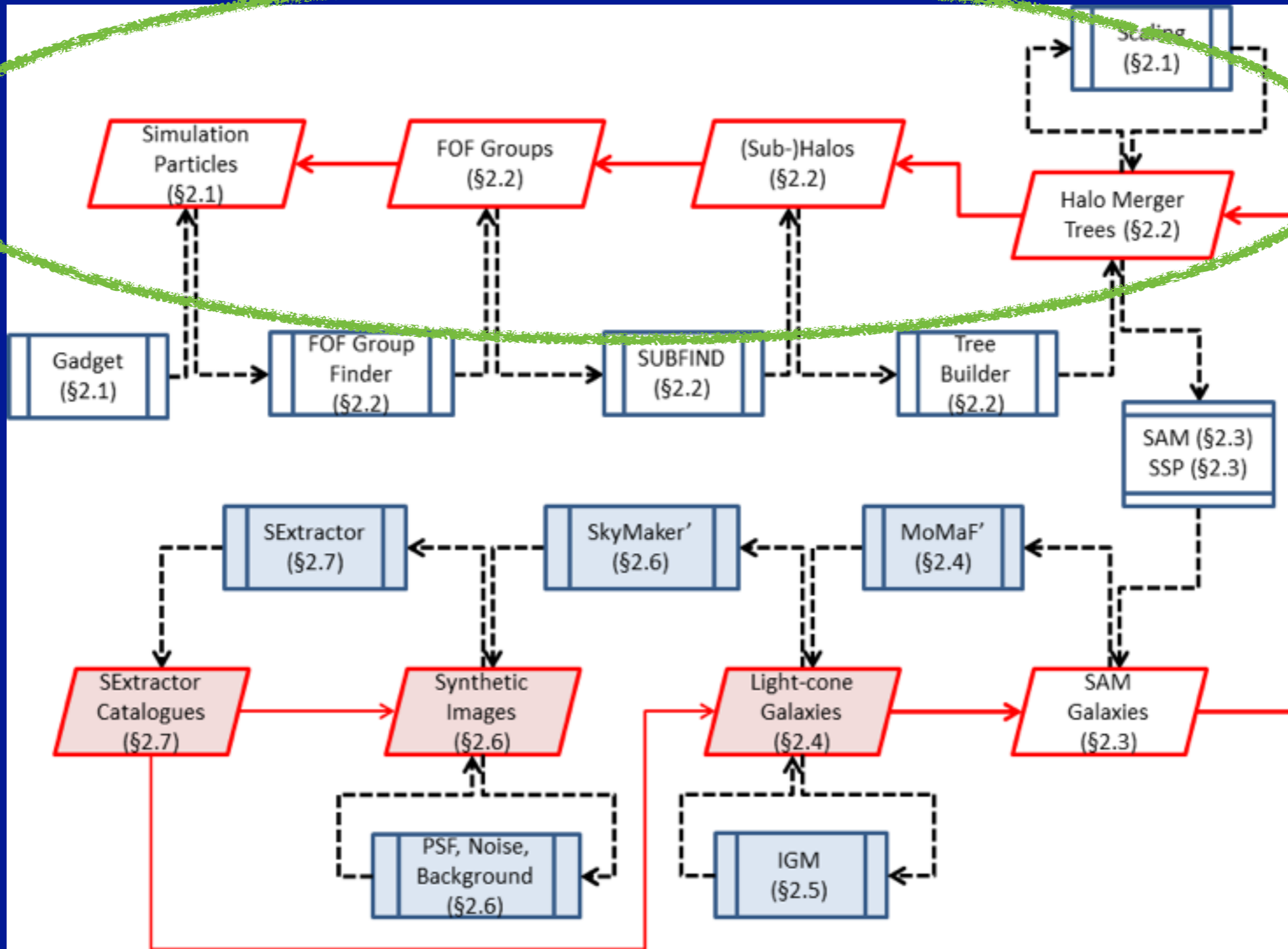
observer



# Millennium Run Observatory Workflow

theorist

observer

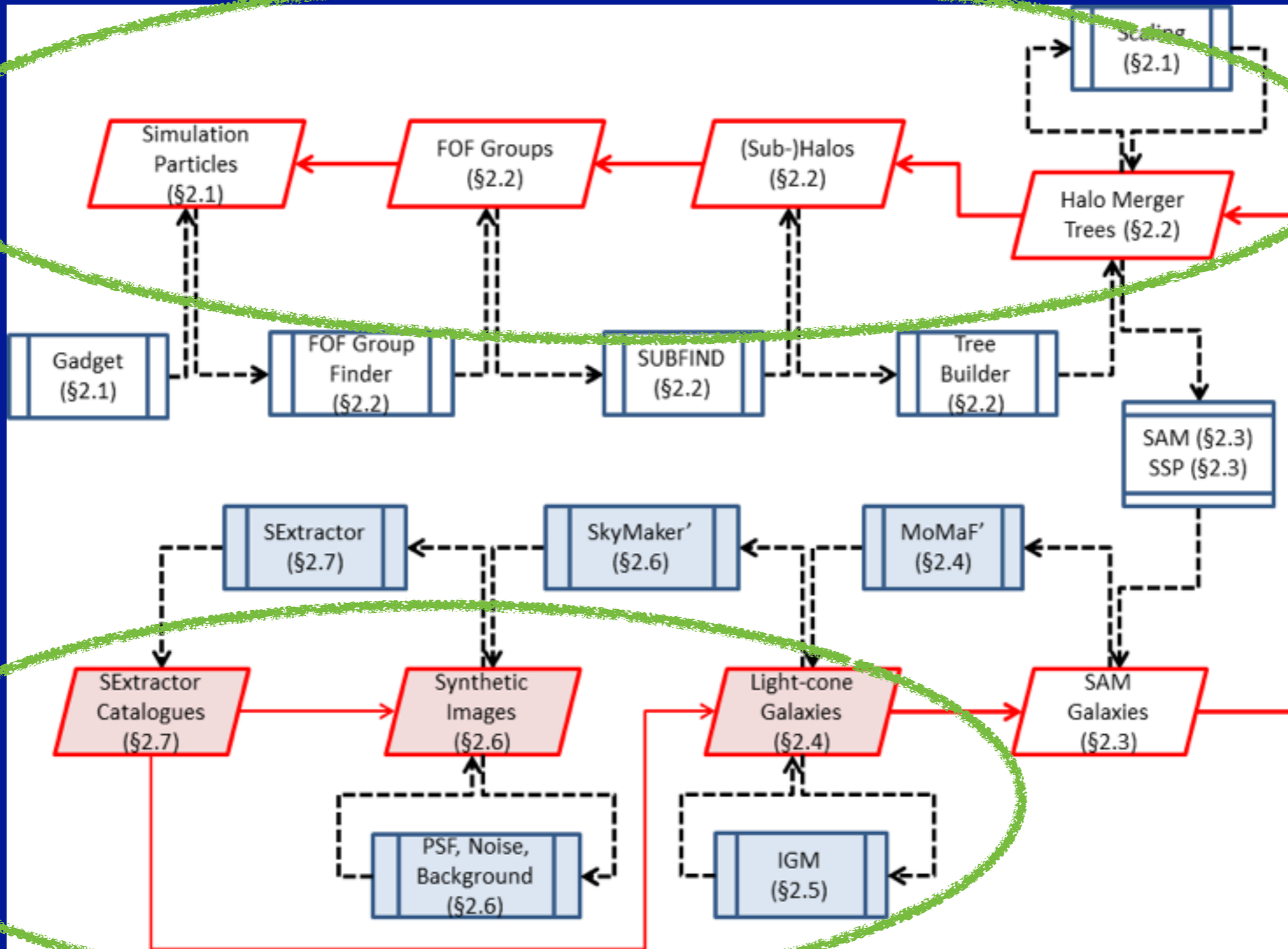




# Millennium Run Observatory Workflow

theorist

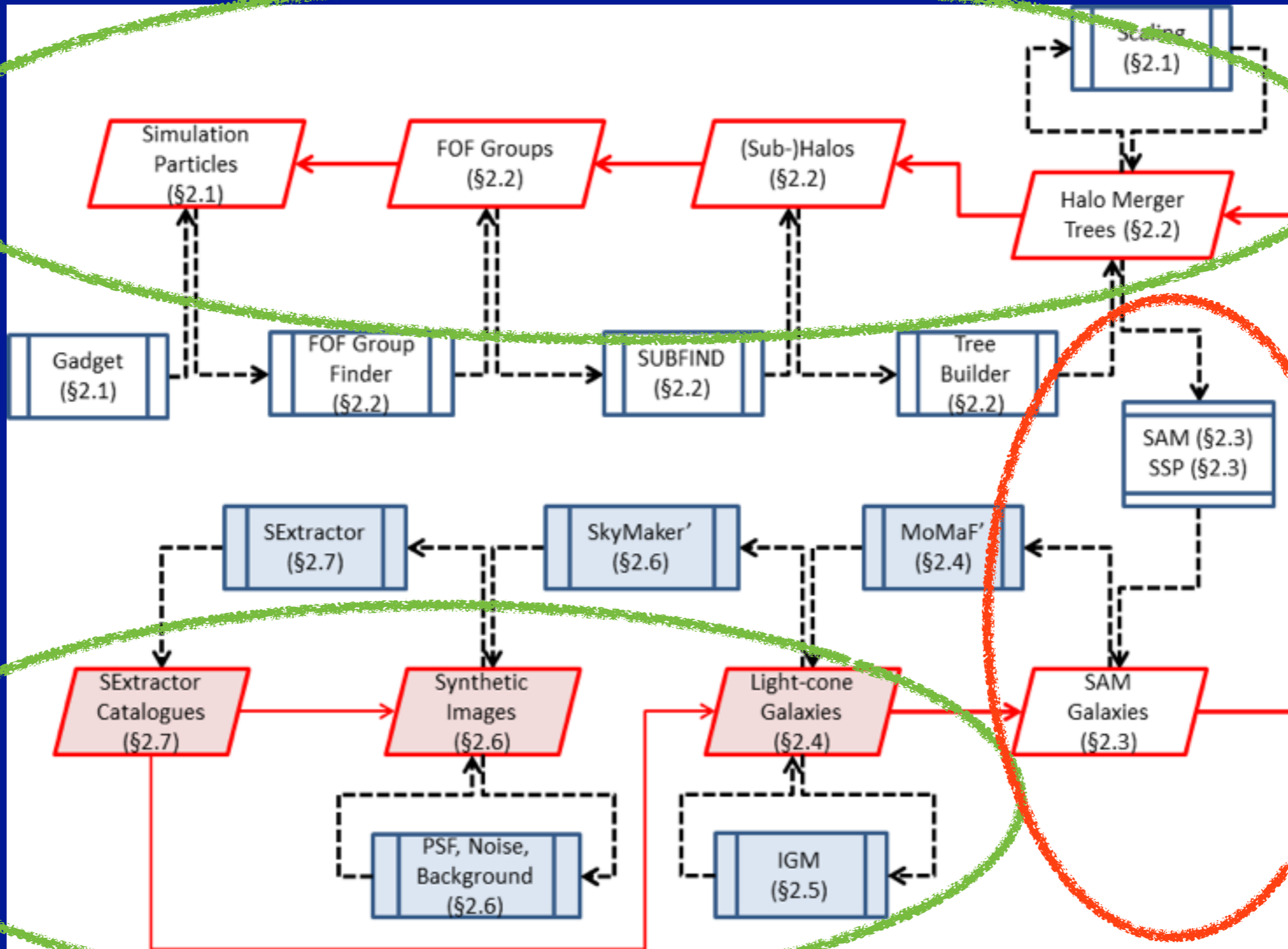
observer



# Millennium Run Observatory Workflow

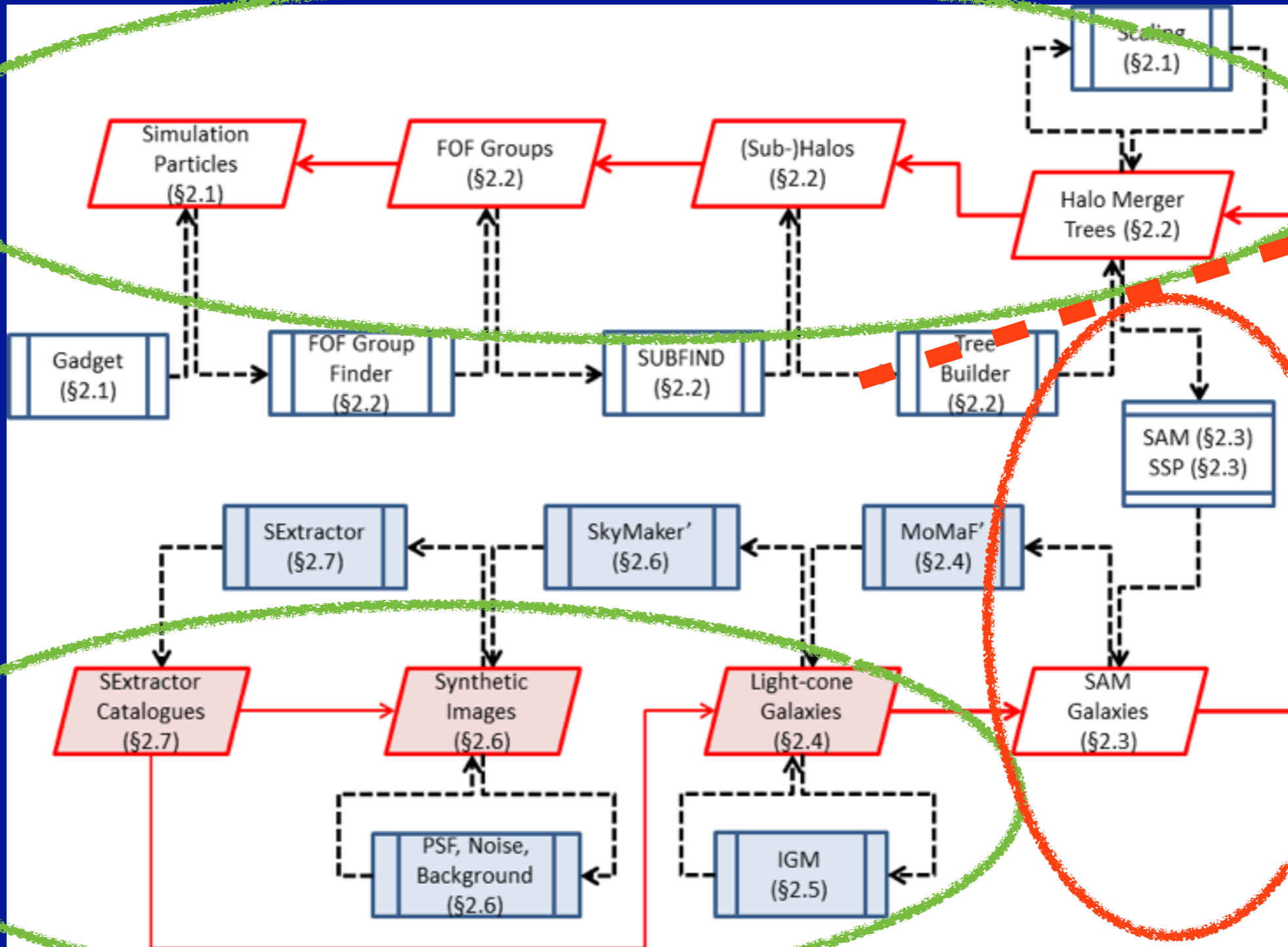
theorist

observer



messy  
baryonic  
physics

# Millennium Run Observatory Workflow



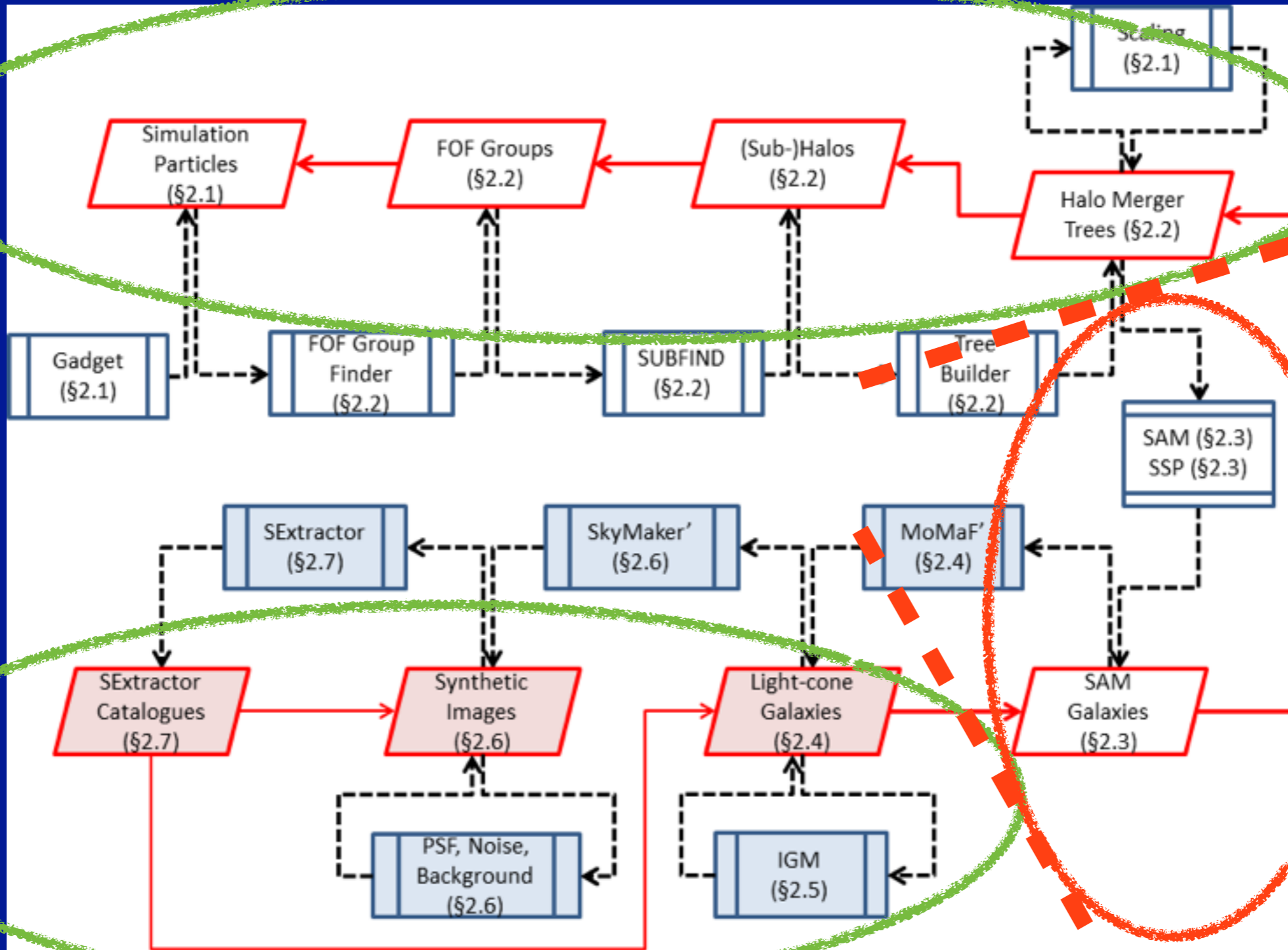
theorist

observer

hard!

messy baryonic physics

# Millennium Run Observatory Workflow



theorist

observer

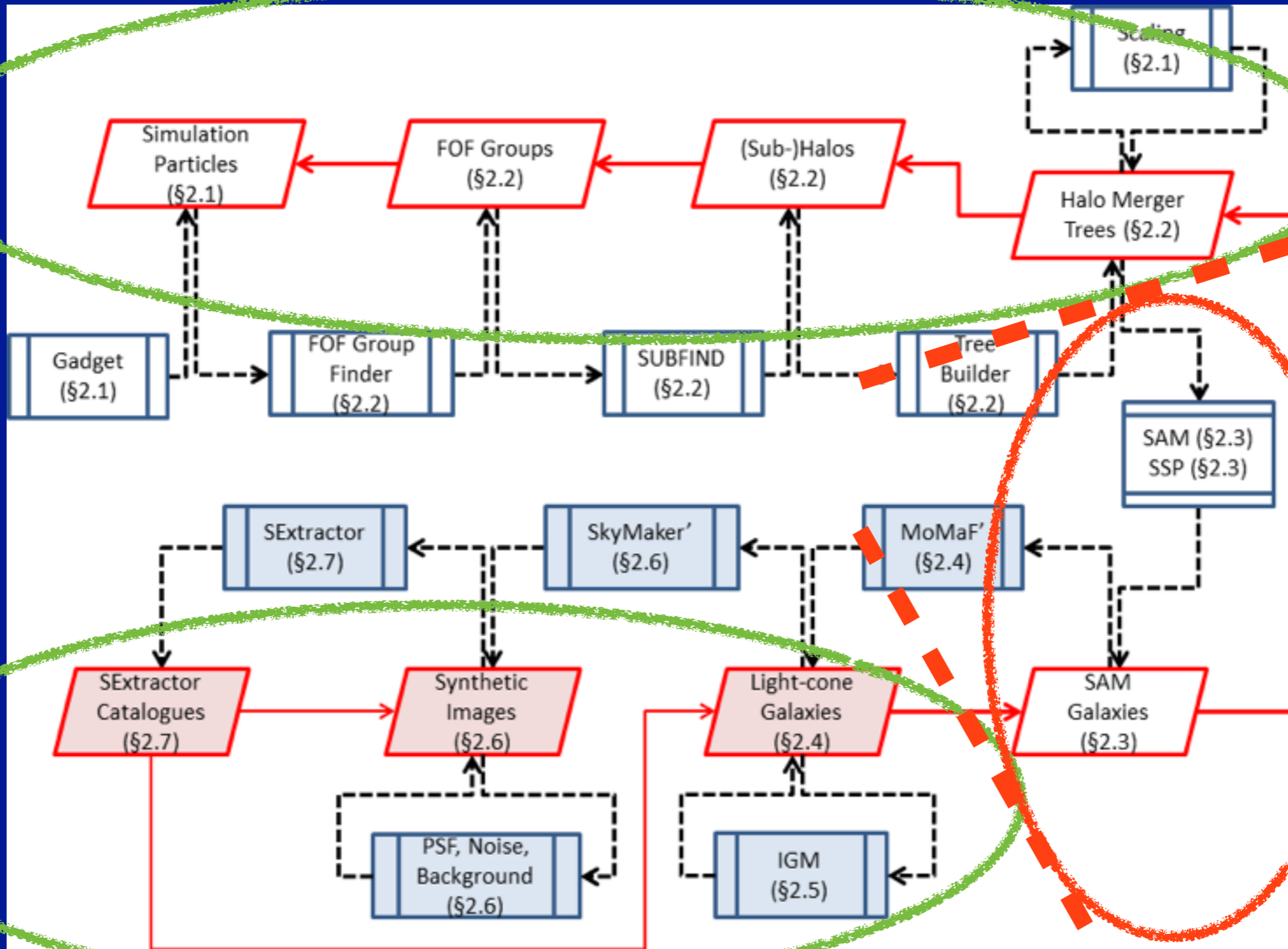
hard!

messy baryonic physics

hard!



# Millennium Run Observatory Workflow



theorist

observer

hard!

messy  
baryonic  
physics

easy!

hard!

# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

# *Comparison Method*

# Observations

Detected Objects  
("Galaxies")  
(mags, colors, sizes, (z))

# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

## *Comparison Method*

number counts/clustering



# Observations

Detected Objects  
("Galaxies")  
(mags, colors, sizes, (z))

# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

SAM/Hydro  
( $M_{\text{stars}}$ , SFR, size, ...)

# *Comparison Method*

number counts/clustering



SED fitting of Data



# Observations

Detected Objects  
("Galaxies")  
(mags, colors, sizes, (z))



# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

SAM/Hydro  
( $M_{\text{stars}}$ , SFR, size, ...)

SAM+synthesis modeling  
(rest-frame mags, colors)

# *Comparison Method*

number counts/clustering



SED fitting of Data



SEDs applied to Simulation,  
selection function affects data



# Observations

Detected Objects  
("Galaxies")  
(mags, colors, sizes, (z))

# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

SAM/Hydro  
( $M_{\text{stars}}$ , SFR, size, ...)

SAM+synthesis modeling  
(rest-frame mags, colors)

Mock/Lightcone  
(obs-frame mags, colors)

# *Comparison Method*

number counts/clustering



SED fitting of Data



SEDs applied to Simulation,  
selection function affects data



Realistic comparison  
**but still idealized!**



# Observations

Detected Objects  
("Galaxies")  
(mags, colors, sizes, (z))

# Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

SAM/Hydro  
( $M_{\text{stars}}$ , SFR, size, ...)

SAM+synthesis modeling  
(rest-frame mags, colors)

Mock/Lightcone  
(obs-frame mags, colors)

Simulated (Noisy) Image  
(mags, colors, sizes)

# *Comparison Method*

number counts/clustering



SED fitting of Data



SEDs applied to Simulation,  
selection function affects data



Realistic comparison  
**but still idealized!**



This Talk

**“True Comparison”**



# Observations

Detected Objects  
 (“Galaxies”)  
(mags, colors, sizes, (z))

Fully known / No assumptions

## Simulations

N-body or LT  
Dark Matter  
( $M_{\text{halo}}$ , pos, vel)

SAM/Hydro  
( $M_{\text{stars}}$ , SFR, size, ...)

SAM+synthesis modeling  
(rest-frame mags, colors)

Mock/Lightcone  
(obs-frame mags, colors)

Simulated (Noisy) Image  
(mags, colors, sizes)

## *Comparison Method*

number counts/clustering



SED fitting of Data



SEDs applied to Simulation,  
selection function affects data



Realistic comparison  
**but still idealized!**



This Talk

**“True Comparison”**



## Observations

More assumptions



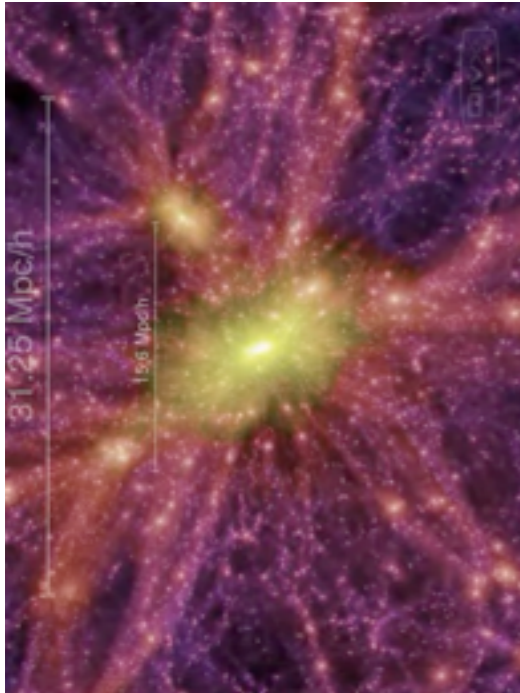
Fewer assumptions

Detected Objects  
 (“Galaxies”)  
(mags, colors, sizes, (z))

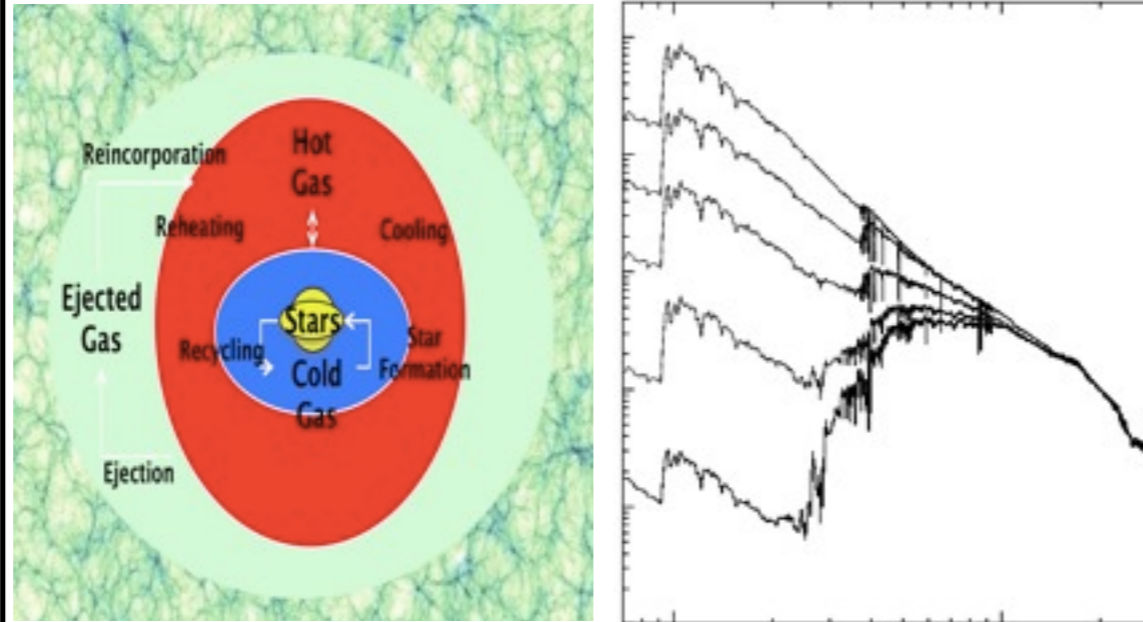


# The Millennium Run Observatory in a nutshell

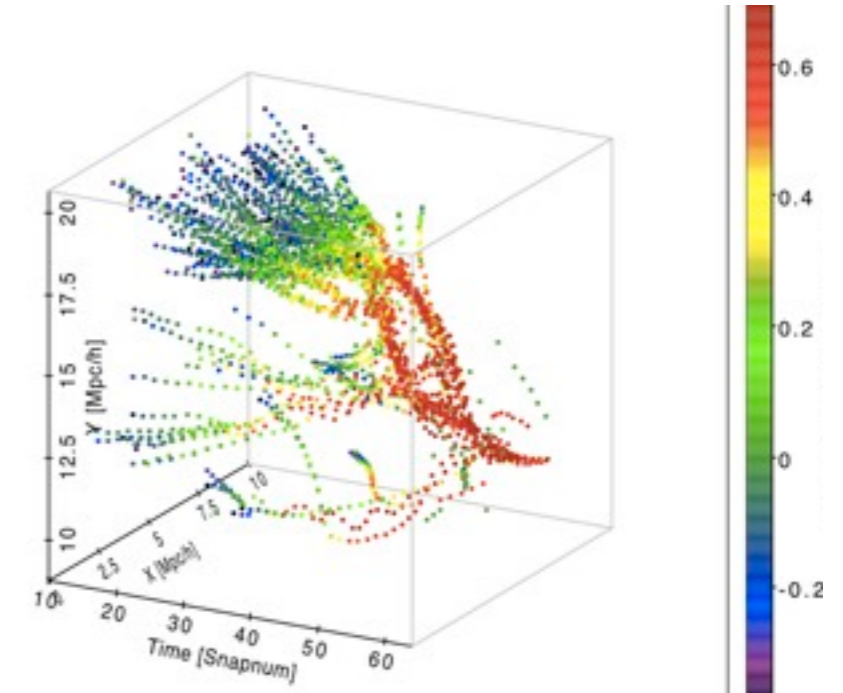
## 1. DM simulation



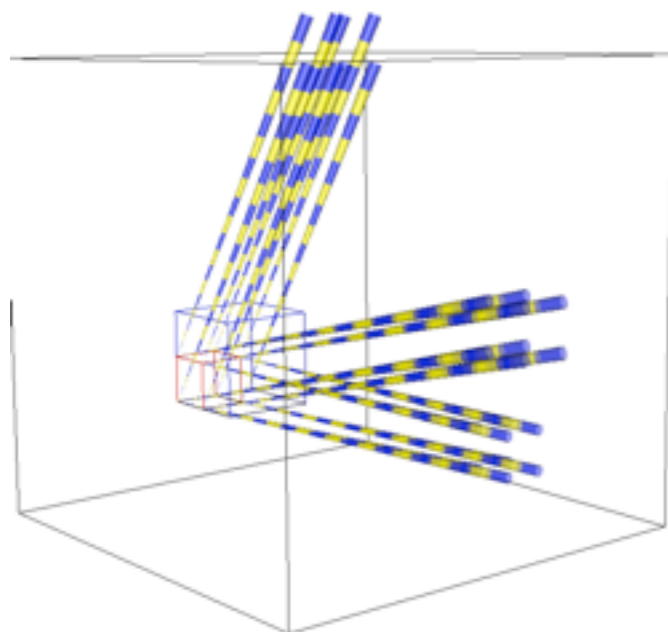
## 2. Semi-analytic Models + SSP Library



## 3. Evolving Galaxy Population



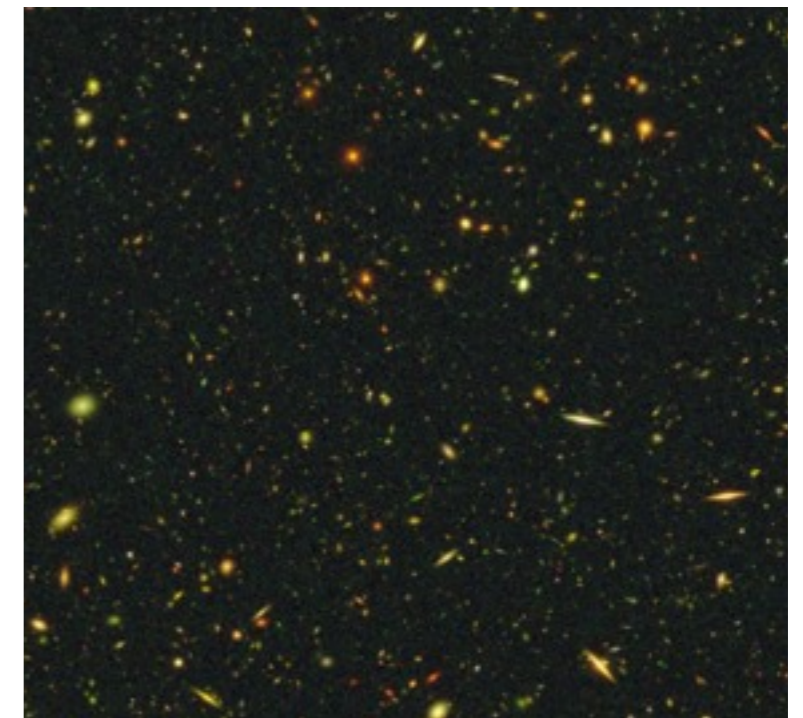
## 4. Observer's Lightcone



## 5. Virtual Telescope model + Survey Description



## 6. FITS-quality Simulated Data



# Precise predictions from the *Millennium Run Observatory*

Simulating the Hubble Ultra Deep Field

**MRObs**

**HUDF**  
*Viz*

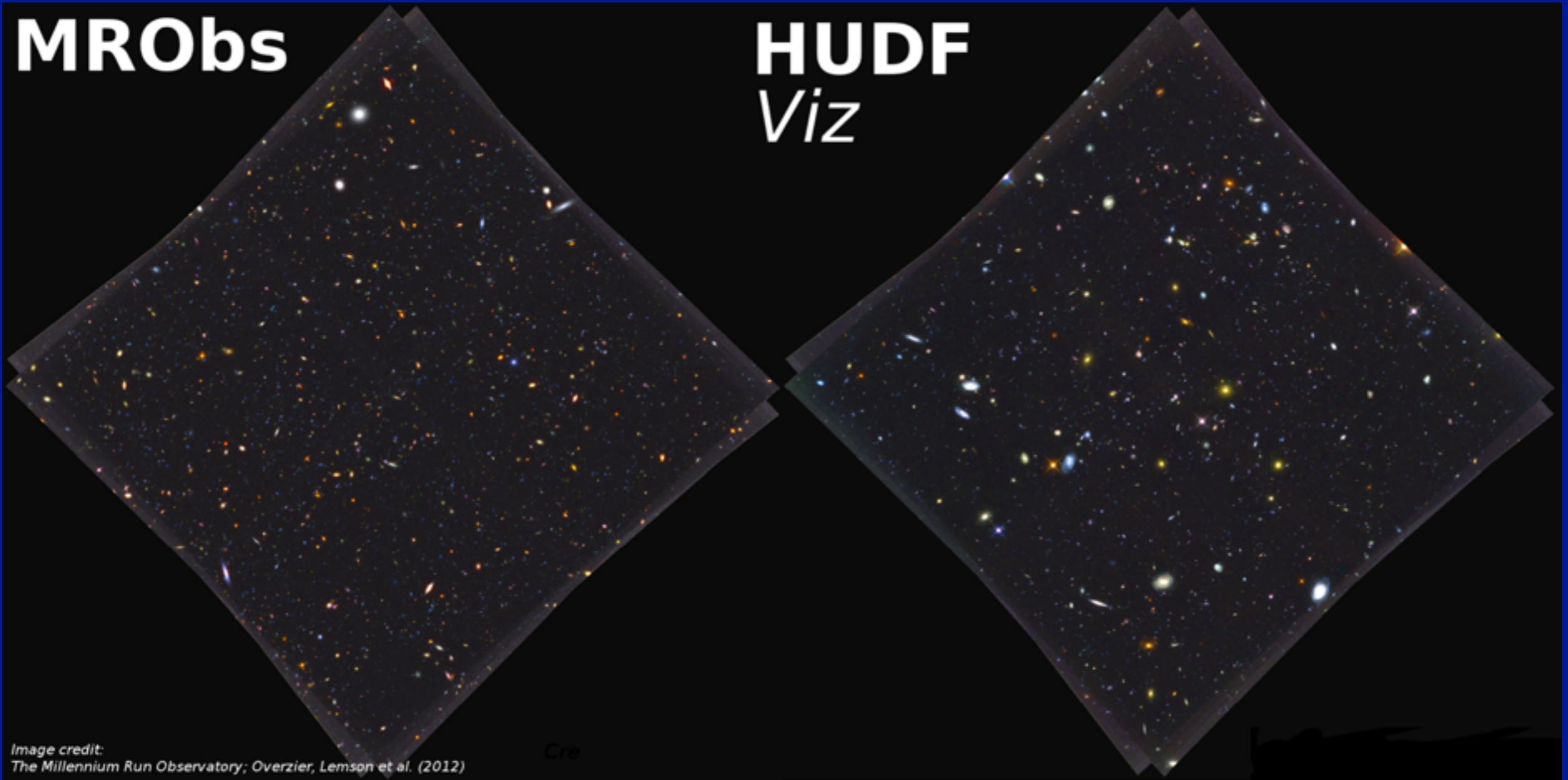


Image credit:  
The Millennium Run Observatory; Overzier, Lemson et al. (2012)

## Full SAM prediction, NO artist's impression

- ▶ positions
- ▶ disks & bulges
- ▶ sizes
- ▶ inclination & position angle
- ▶ magnitudes w/ dust

## Flexible

- ▶ Multi-Wavelength
- ▶ Multi-Cosmology
- ▶ Multi-SAM
- ▶ Multi-SSP
- ▶ Multi-IGM
- ▶ Multi-Telescope



# Precise predictions from the *Millennium Run Observatory*

Simulating the Hubble Ultra Deep Field



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# Precise predictions from the *Millennium Run Observatory*

Simulating the Hubble Ultra Deep Field



## Full SAM prediction, NO artist's impression

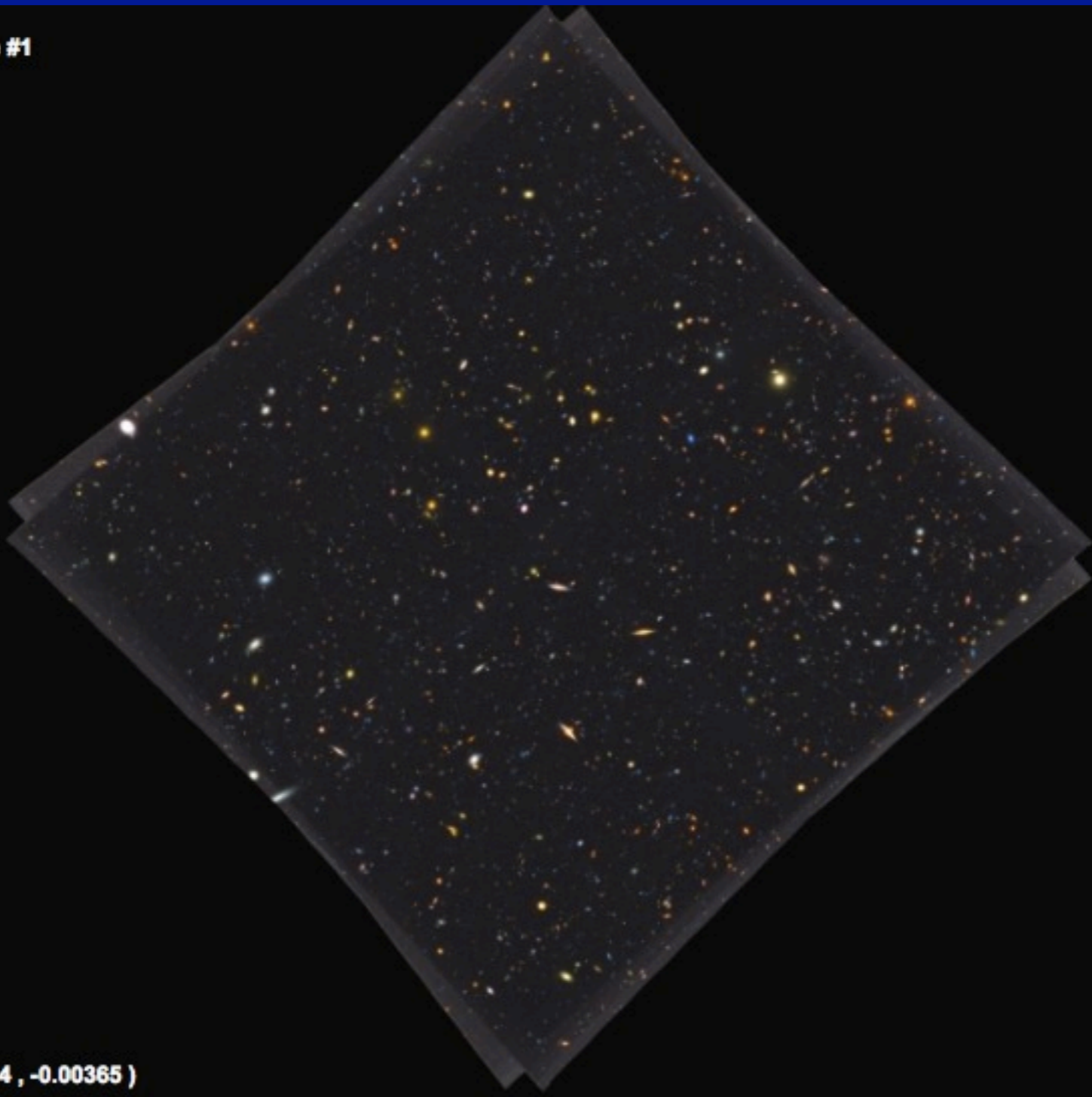
- ▶ positions
- ▶ disks & bulges
- ▶ sizes
- ▶ inclination & position angle
- ▶ magnitudes w/ dust

## Flexible

- ▶ Multi-Wavelength
- ▶ Multi-Cosmology
- ▶ Multi-SAM
- ▶ Multi-SSP
- ▶ Multi-IGM
- ▶ Multi-Telescope



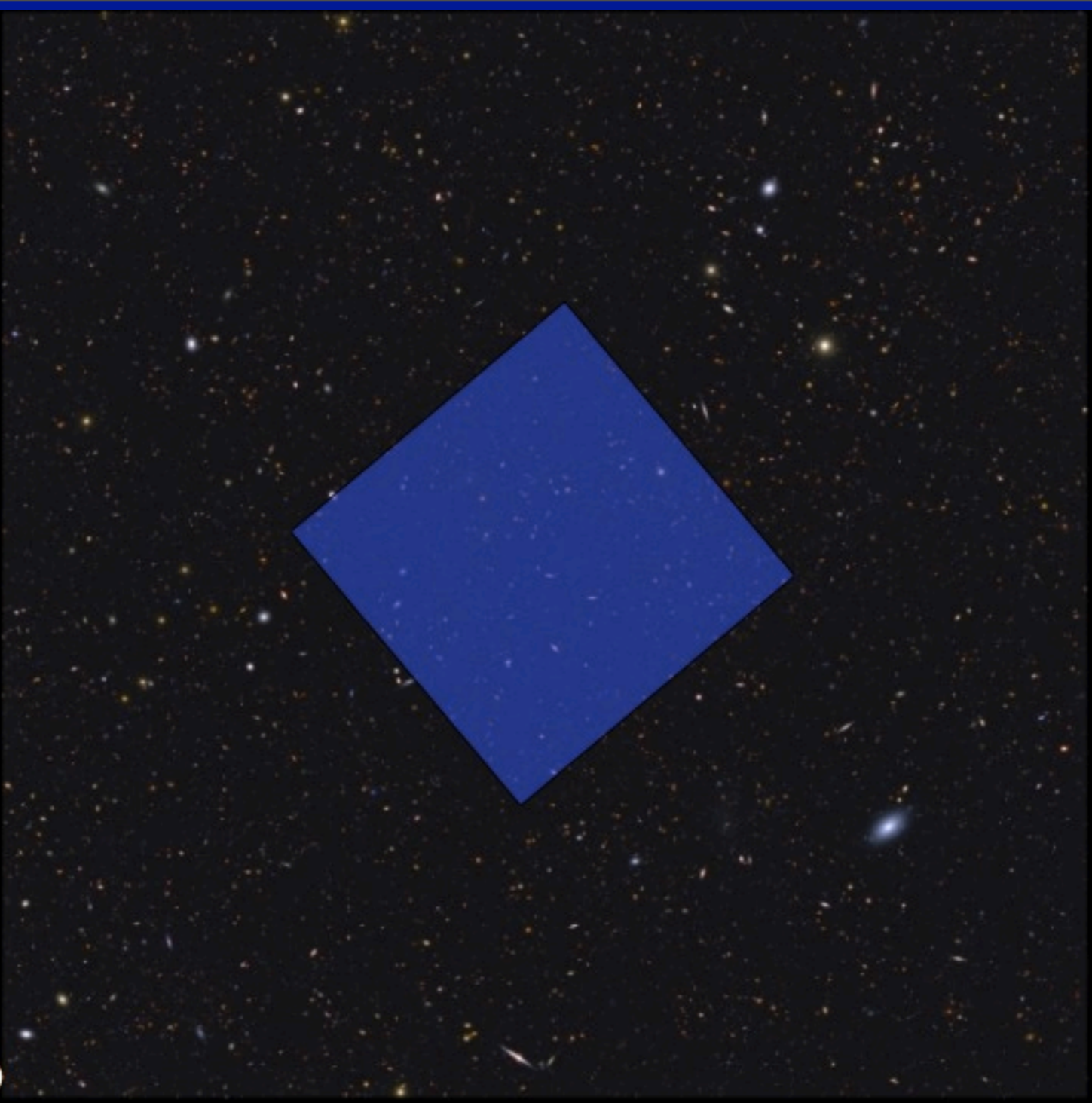
UDF Viz Image w/ real UDF noise #1



-1:59:59.150 -0:0:13.144 ( -0.00354 , -0.00365 )



UDF Viz Image from STIFF



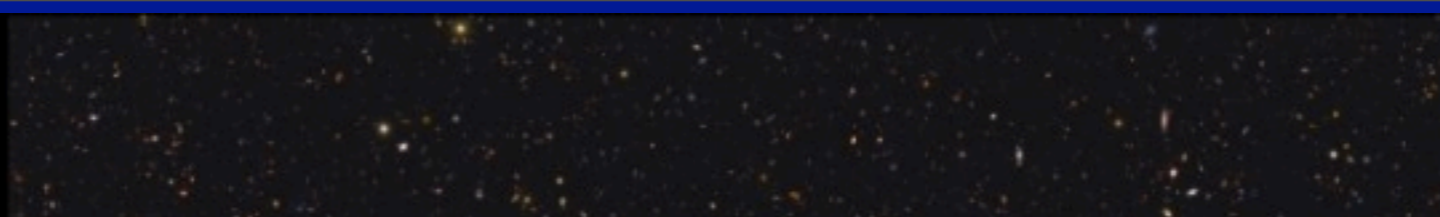
0:0:13.208 -0:0:13.844 ( 0.05504 , -0.00385 )

-1:59:59.150 -0:0:13.144 ( -0.00354 , -0.00365 )

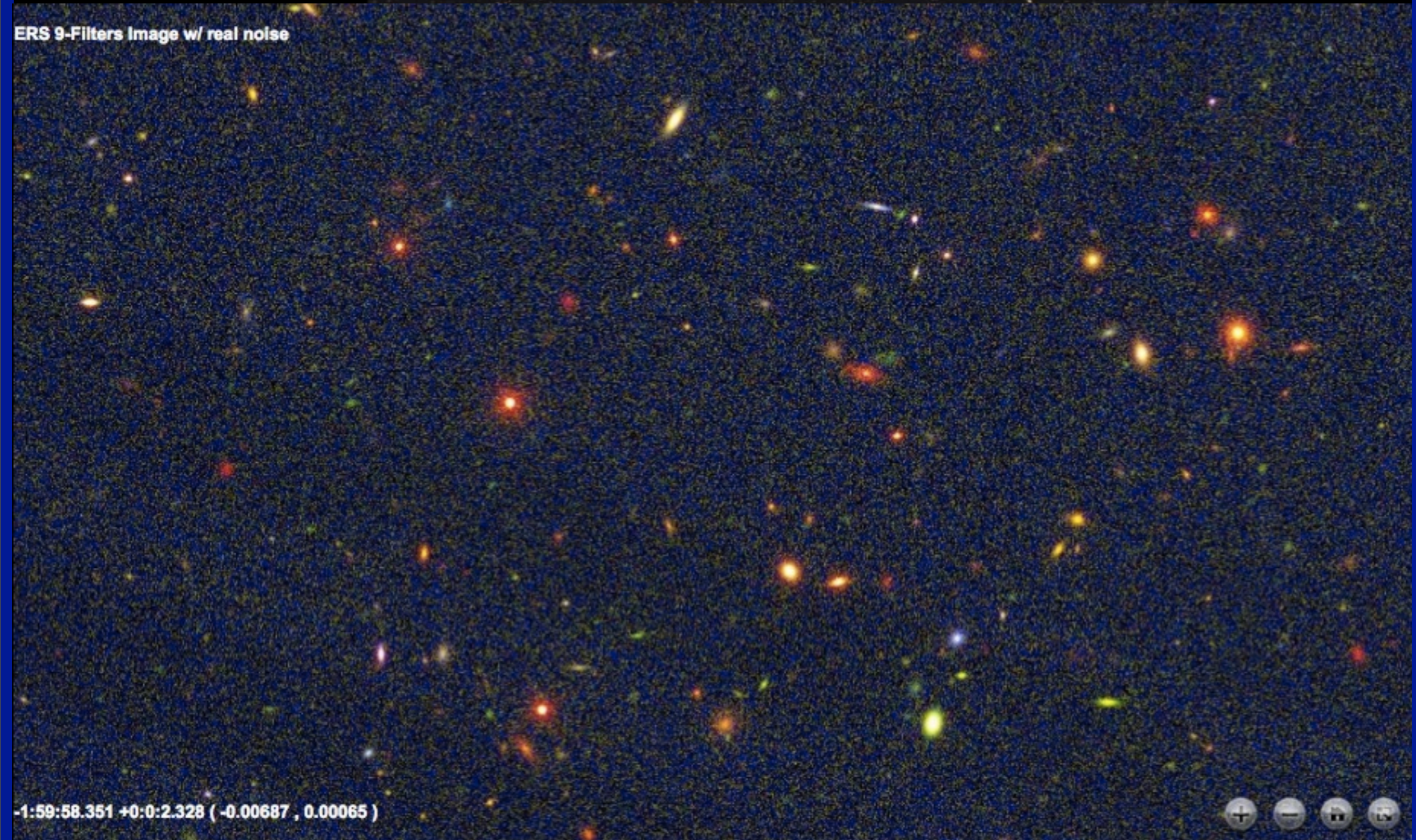




UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise



-1:59:58.351 +0:0:2.328 ( -0.00687 , 0.00065 )





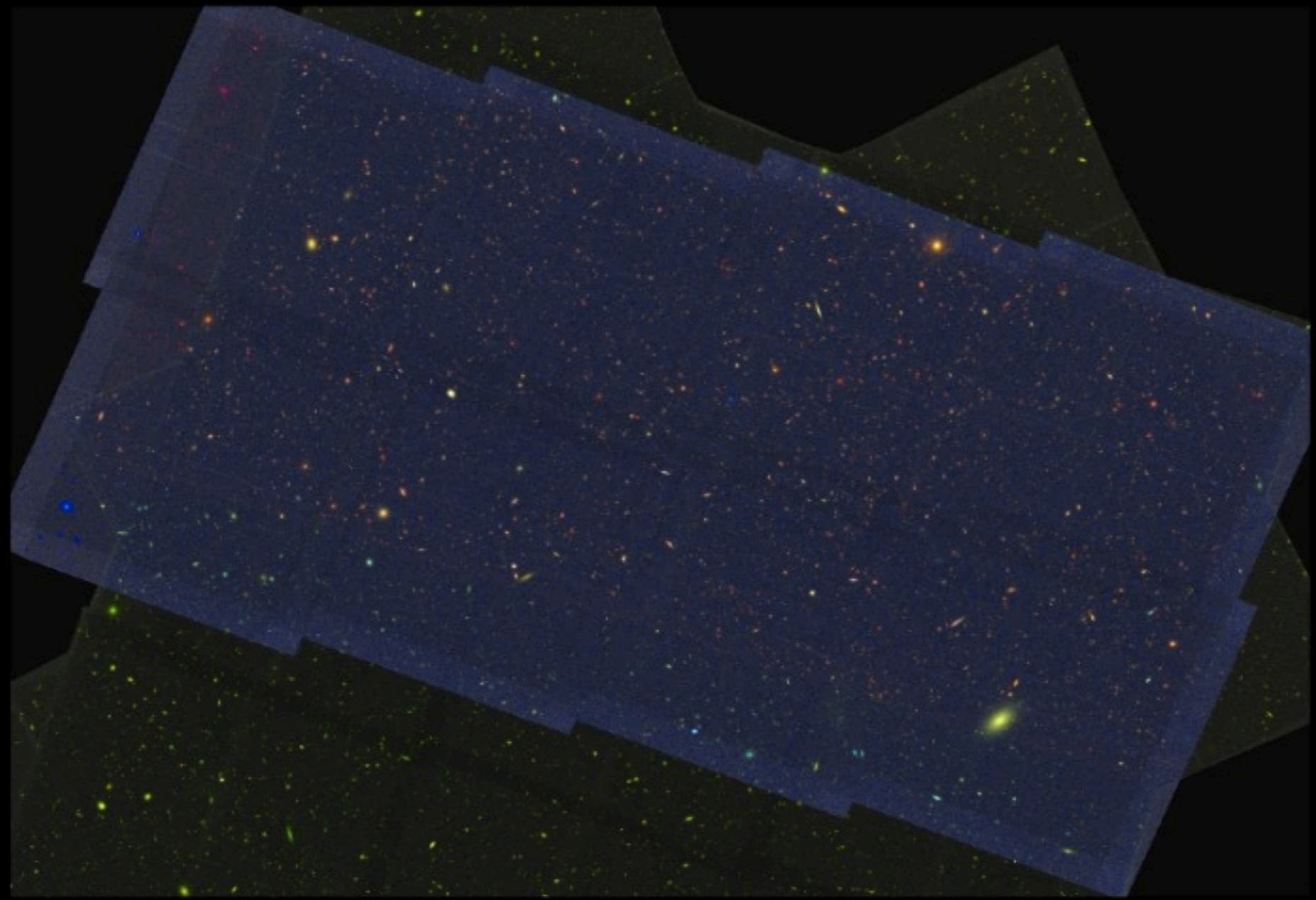
UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise



ERS 9-Filters Image w/ real noise



-1:59:58.964 -0:0:6.572 ( -0.00432 , -0.00183 )





UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise

ERS 9-Filters Image w/ real noise

HSC WIDE r<sub>iz</sub> Image



-1:59:58.778 -0:3:55.948 ( -0.00509 , -0.06554 )





UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise

ERS 9-Filters Image w/ real noise

HSC WIDE r<sub>iz</sub> Image

HSC DEEP r<sub>iz</sub> Image



0:0:5.353 -0:2:45.061 ( 0.02231 , -0.04585 )





UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise

ERS 9-Filters Image w/ real noise

HSC WIDE r<sub>iz</sub> Image

HSC DEEP r<sub>iz</sub> Image

HSC ULTRADEEP r<sub>iz</sub> Image



-1:59:57.639 +0:0:54.649 ( -0.00984 , 0.01518 )





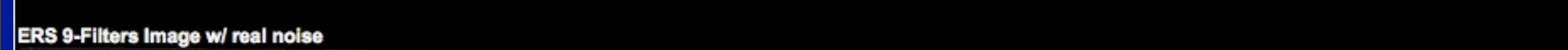
UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise



ERS 9-Filters Image w/ real noise



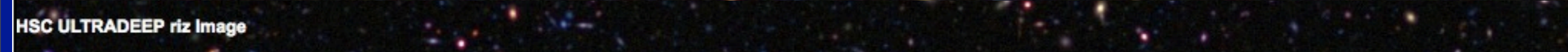
HSC WIDE riz Image



HSC DEEP riz Image



HSC ULTRADEEP riz Image



CFHTLS-Wide gri Image from RGBVIEW





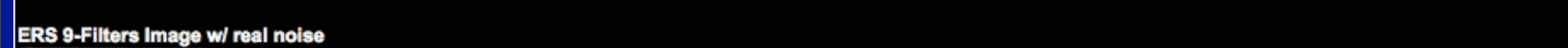
UDF Viz Image from STIFF



ERS 9-Filters Image w/ real noise



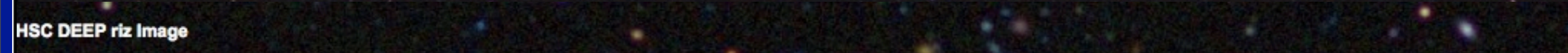
ERS 9-Filters Image w/ real noise



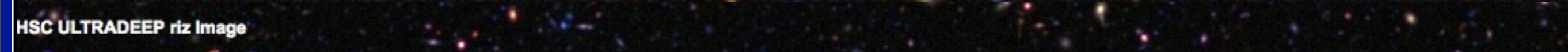
HSC WIDE riz Image



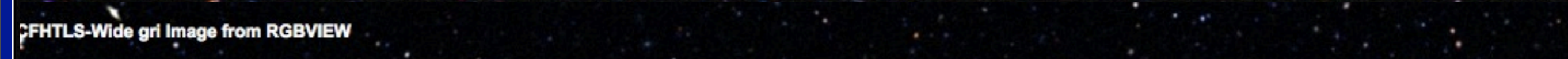
HSC DEEP riz Image



HSC ULTRADEEP riz Image



CFHTLS-Wide gri Image from RGBVIEW



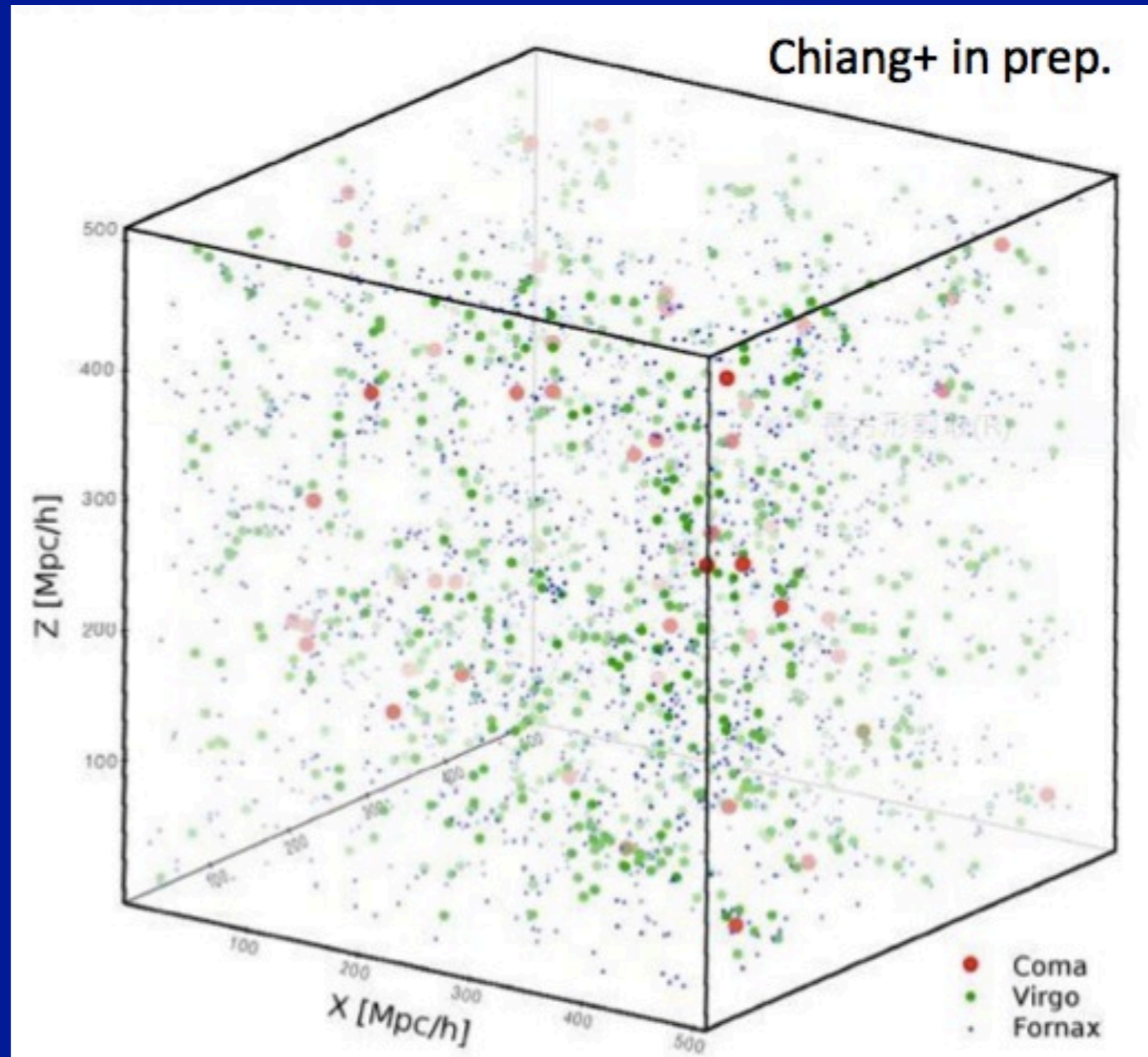
CFHTLS-Deep gri Image





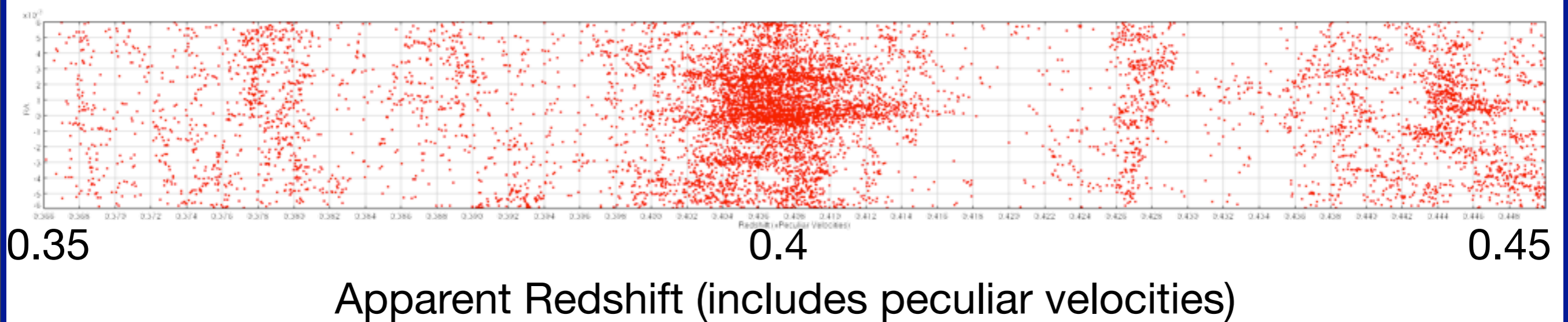
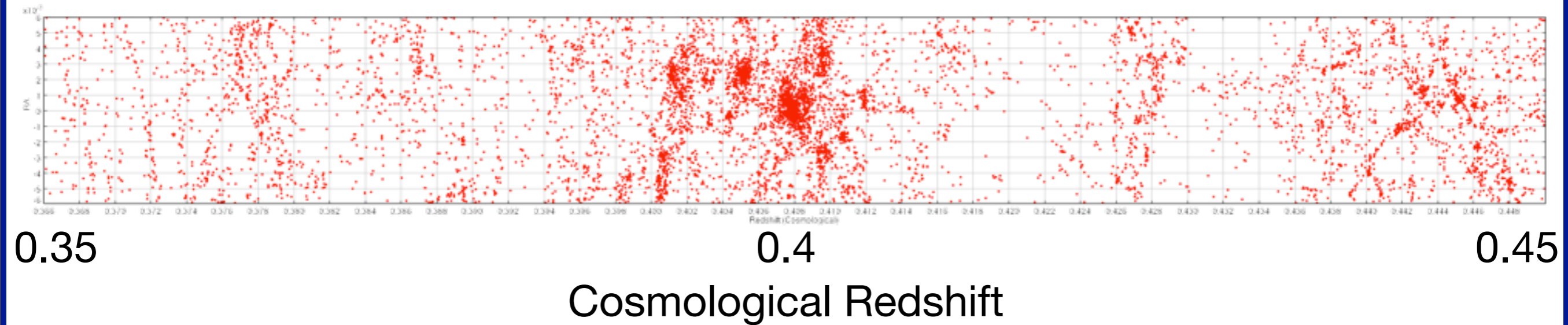
# Lightcones aimed at a specific object at a specific redshift

locations of 3,000 clusters in the MR





a massive cluster selected at  $z=0$ , 'observed' in the lightcone at  $z=0.4$ :

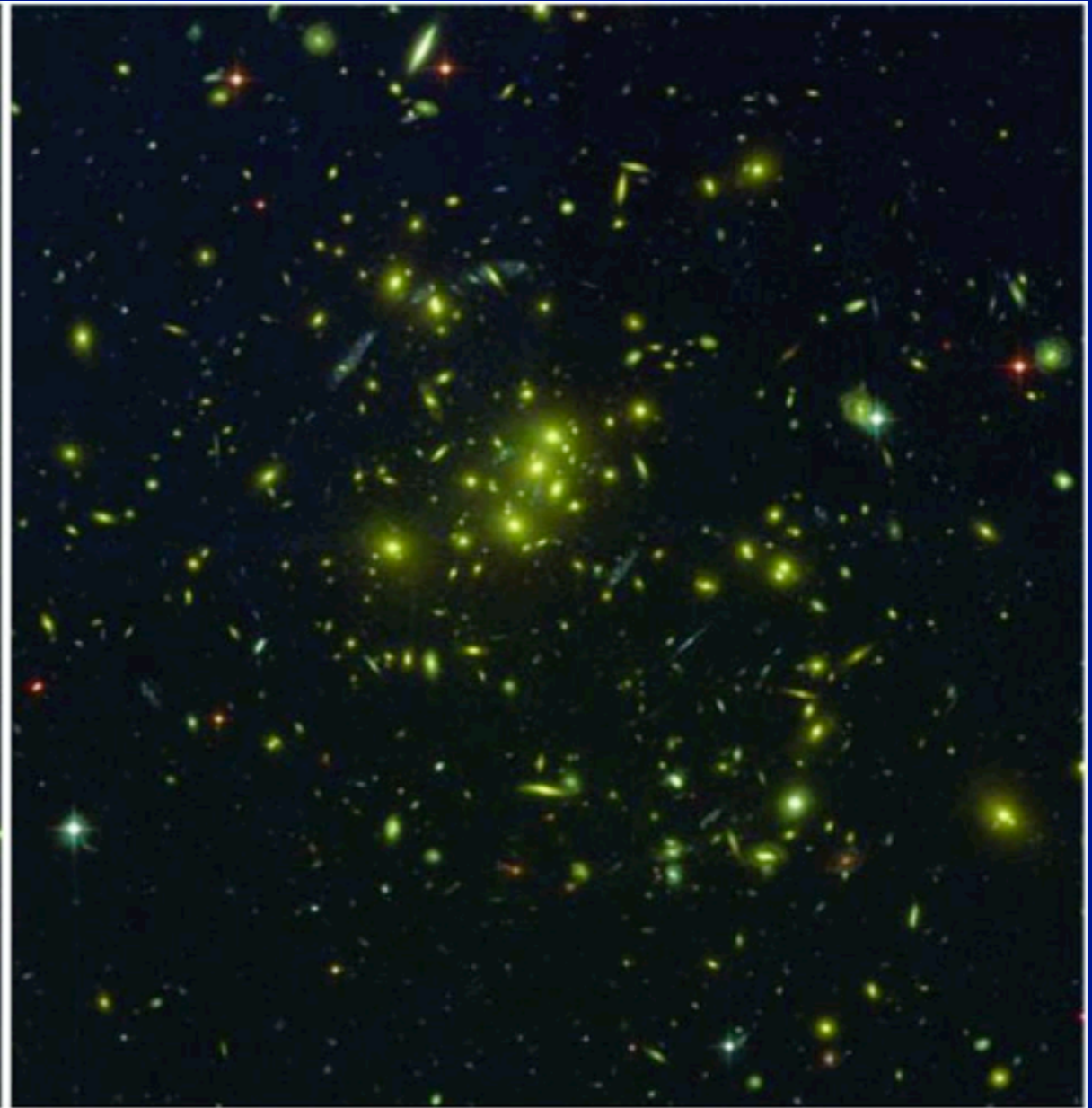
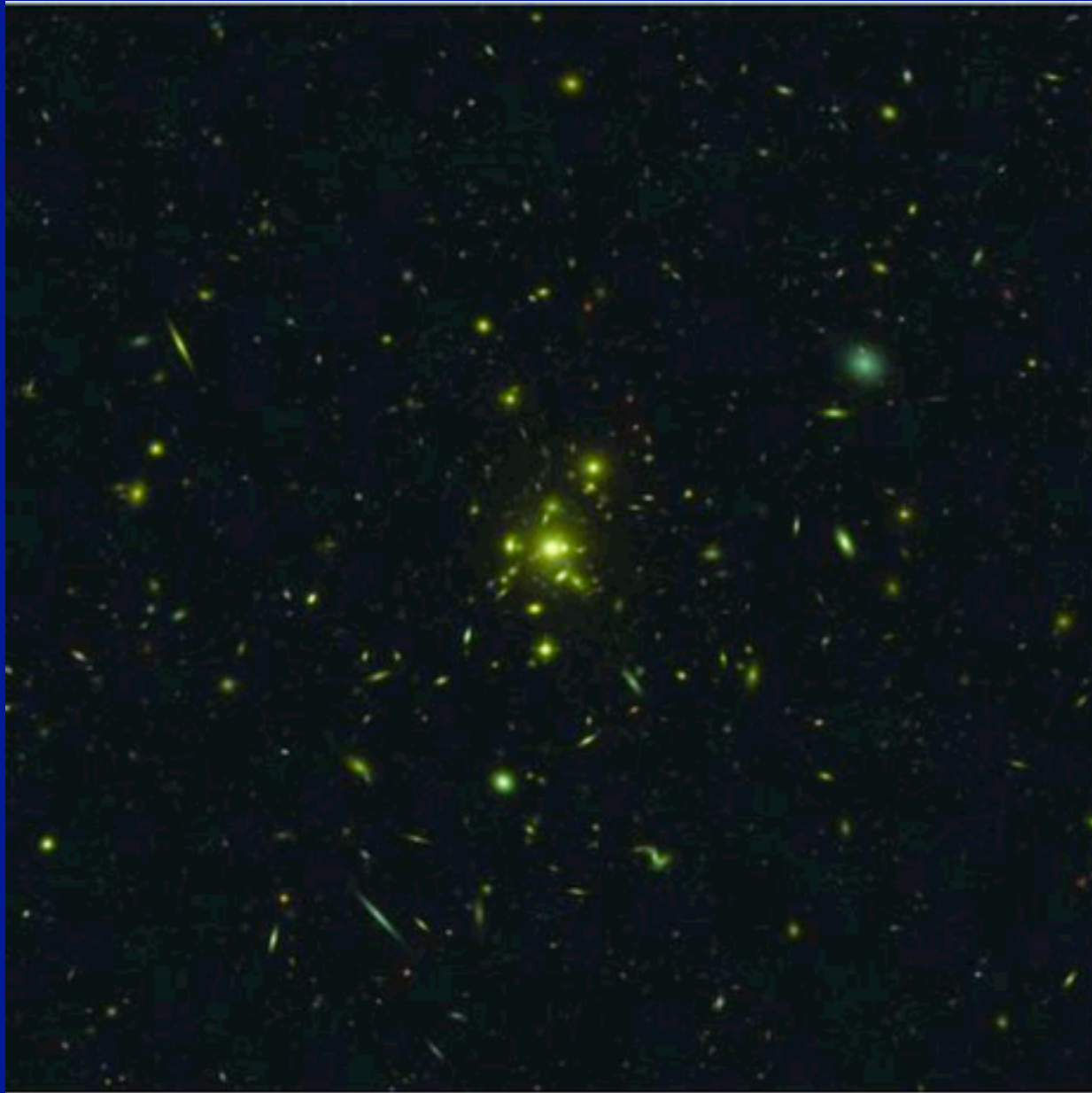


# Precise predictions from the *Millennium Run Observatory*

$z = 0.4$  Massive cluster

MRObs Mock HST observation

Cluster Cl0024 at  $z \sim 0.4$





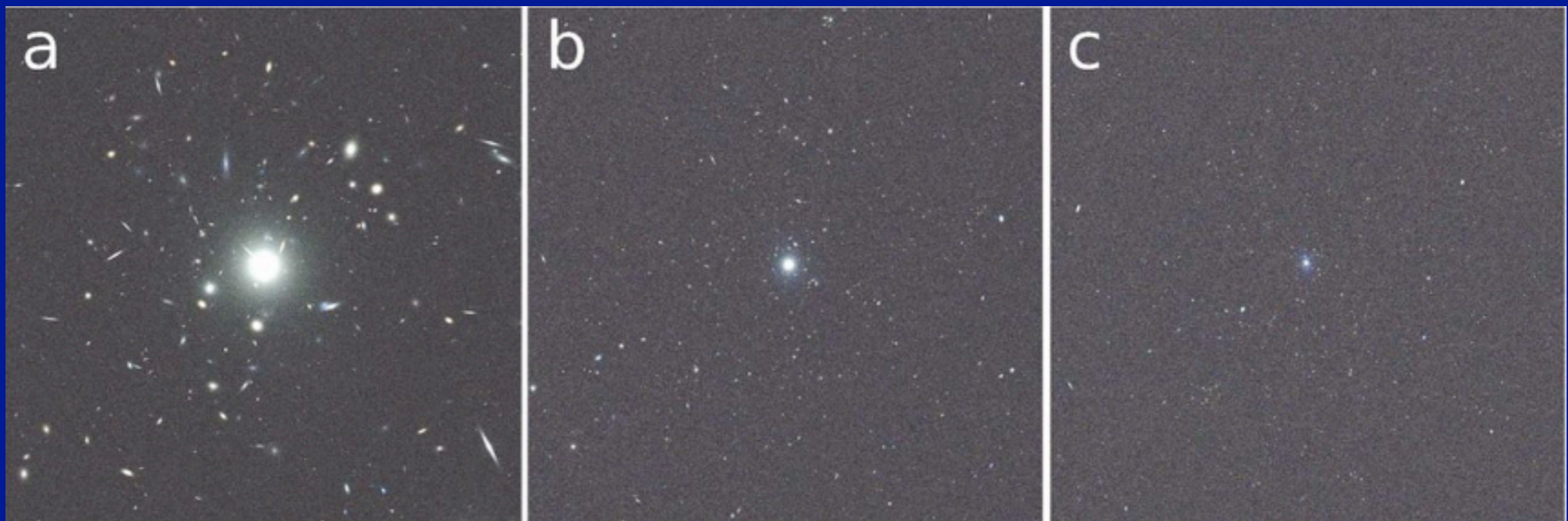
# Precise predictions from the *Millennium Run Observatory*

MRObs Mock SDSS observations of clusters

$z = 0.02$

$z = 0.09$

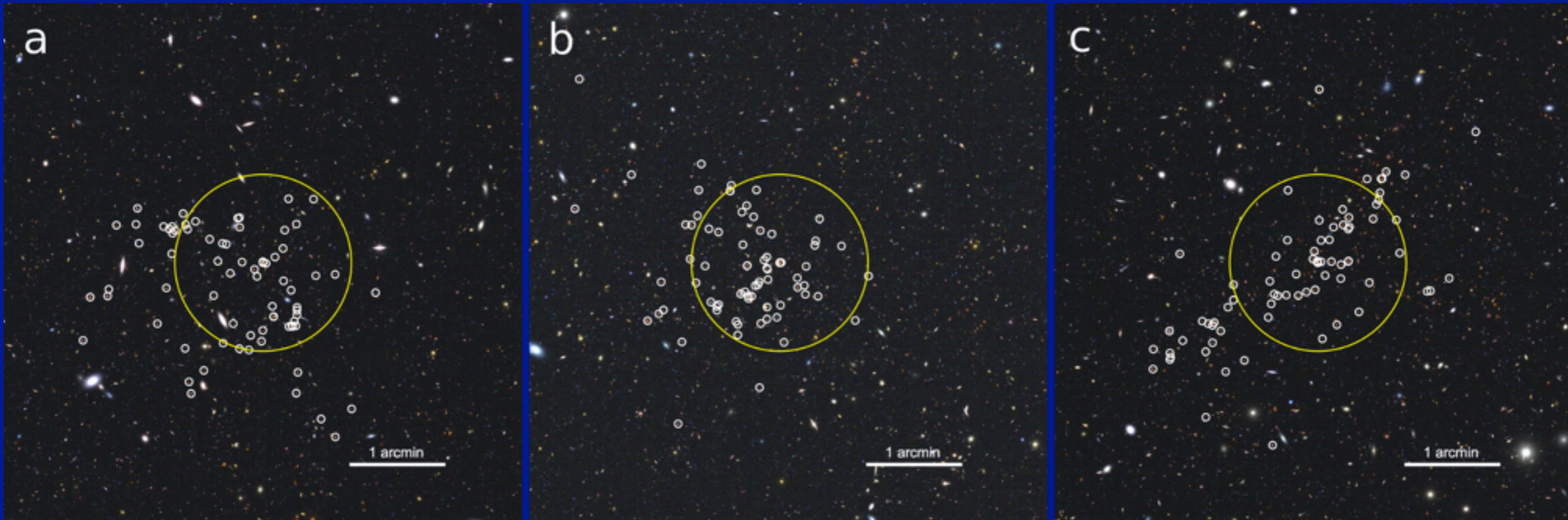
$z = 0.21$





# Precise predictions from the *Millennium Run Observatory*

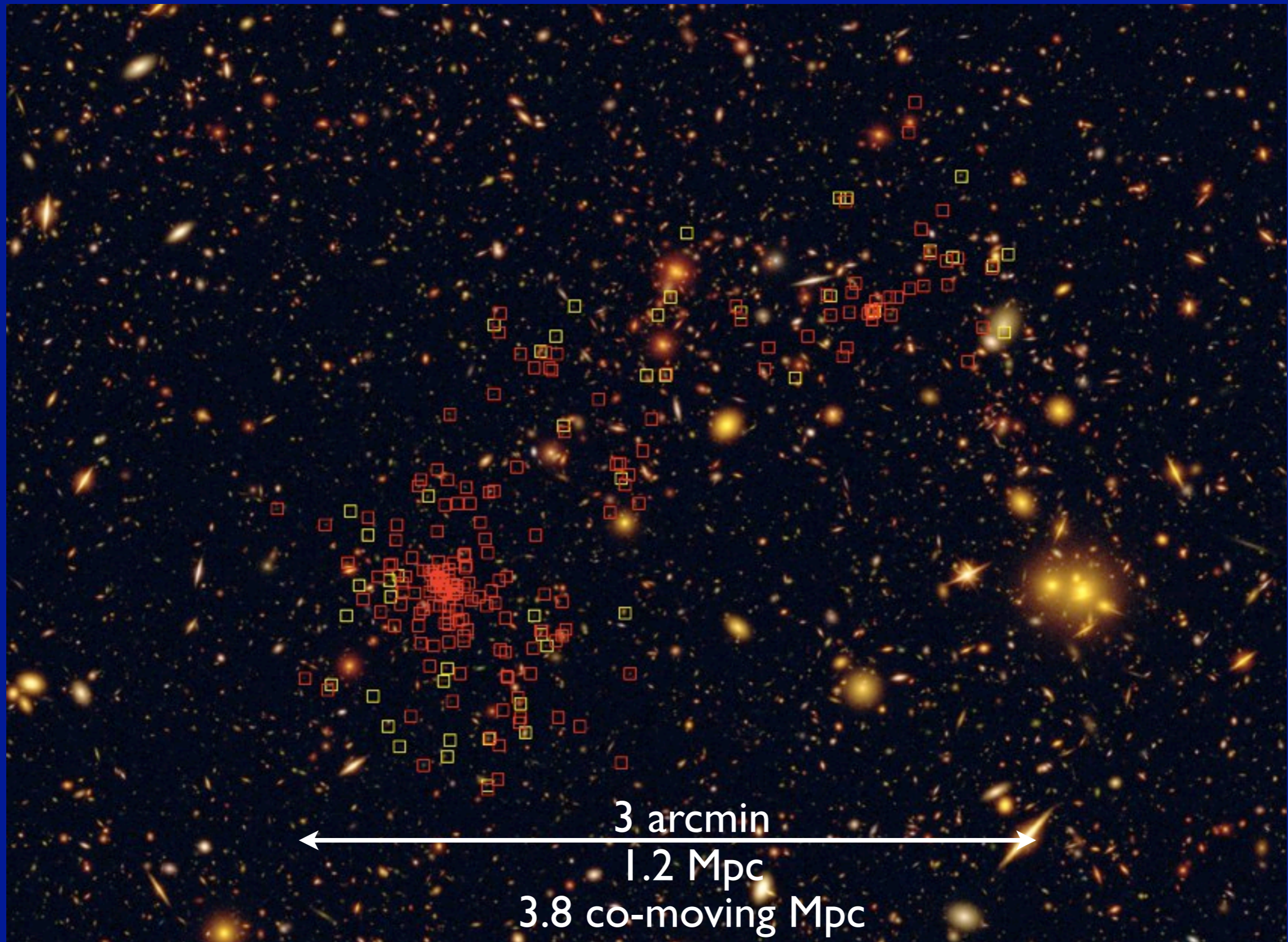
$z = 1$  Massive cluster seen from 3 different directions





# Precise predictions from the *Millennium Run Observatory*

$z = 2.1$  Massive “Proto-cluster”





# MRObs image simulations for the HST CANDELS survey

*HST-WFC3/*

*Y<sub>105</sub>J<sub>125</sub>H<sub>160</sub>*





# MRObs image simulations for the HST CANDELS survey

*HST-WFC3/  
Y<sub>105</sub>J<sub>125</sub>H<sub>160</sub>*



RA: 02:01:57.232 (DEC: 00:26:07.03256)



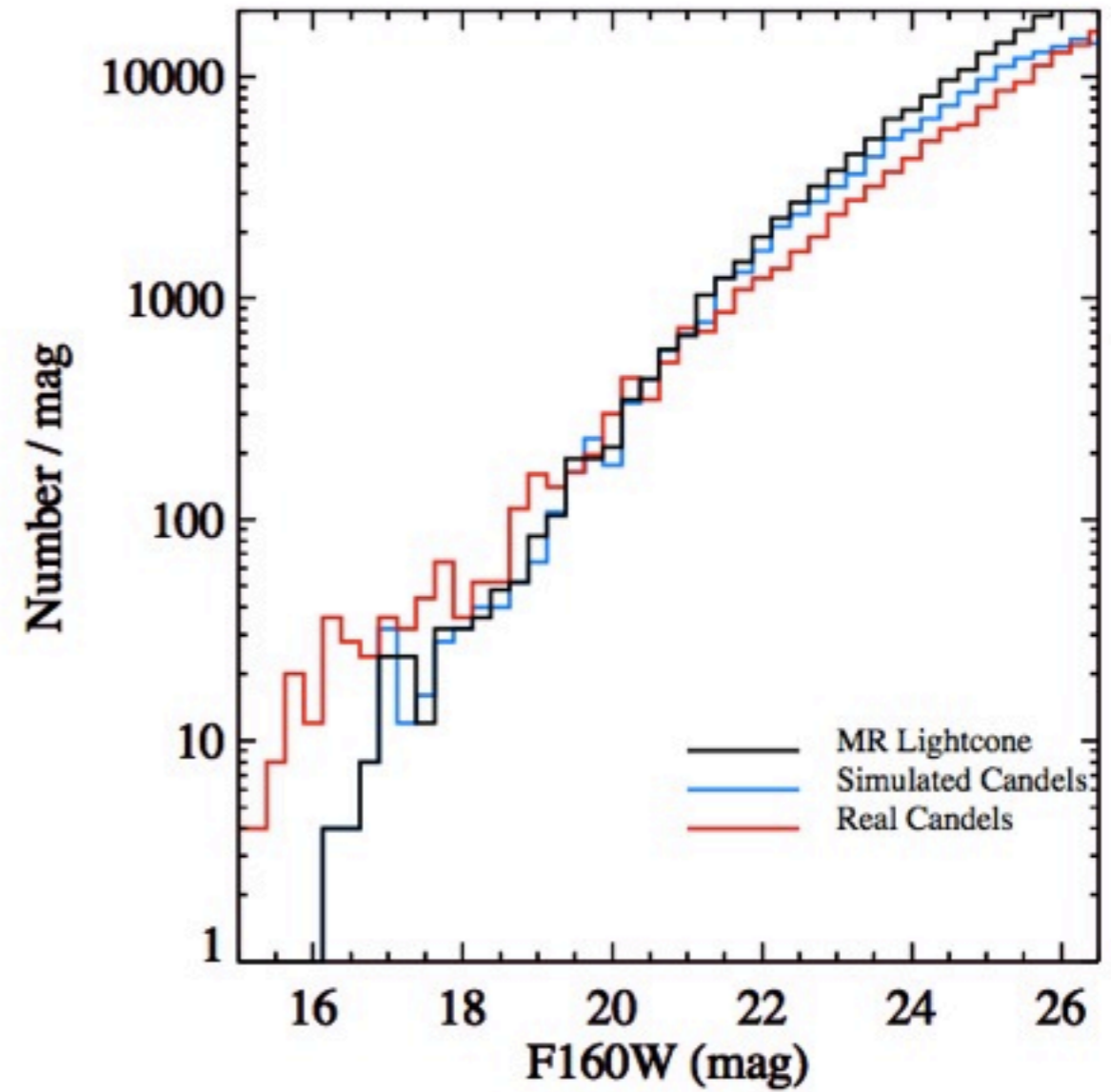
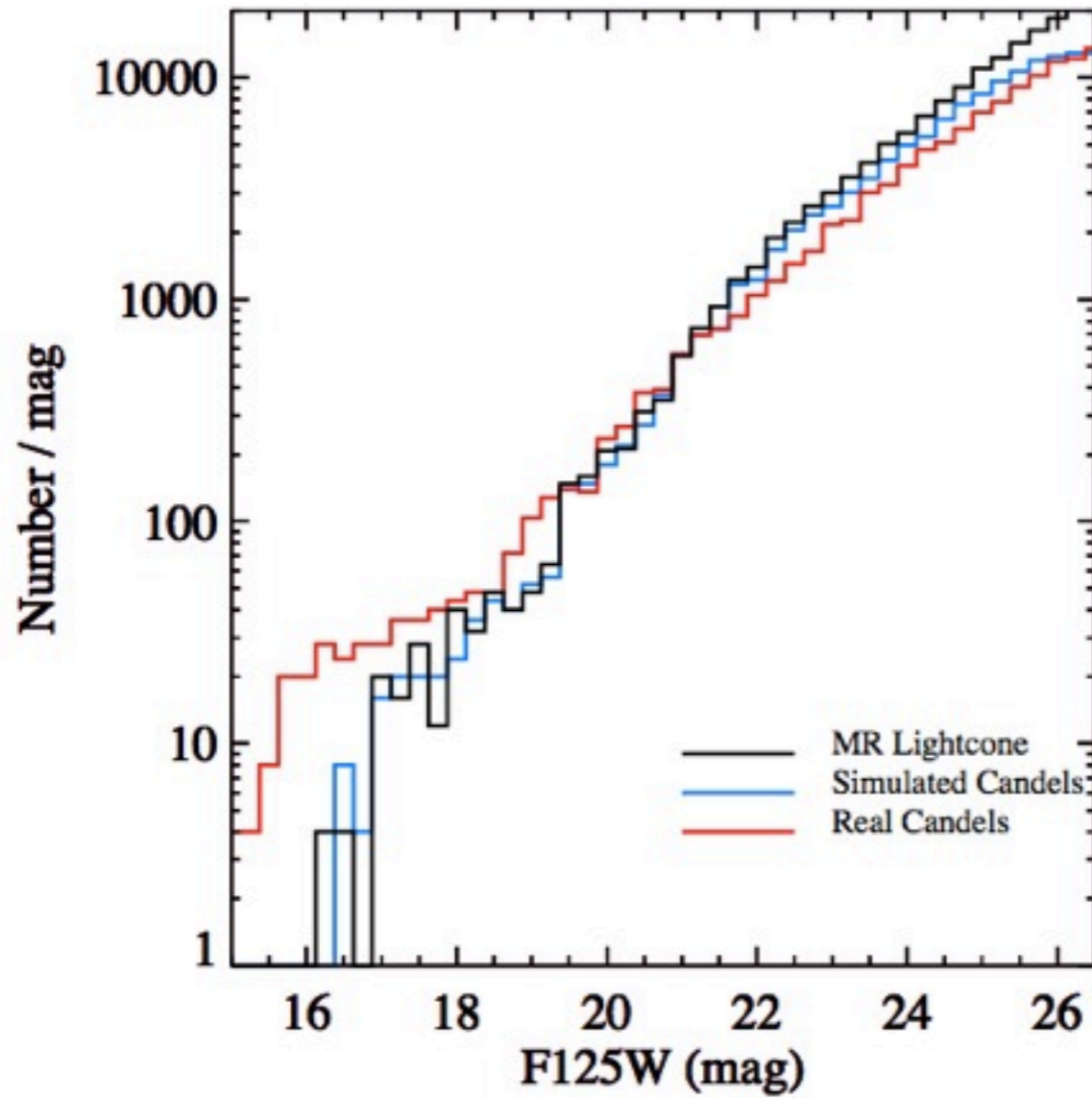
# MRObs image simulations for the HST CANDELS survey

HST-WFC3/  
Y<sub>105</sub>J<sub>125</sub>H<sub>160</sub>





# SAMs and Lightcones alone do not tell the whole story!



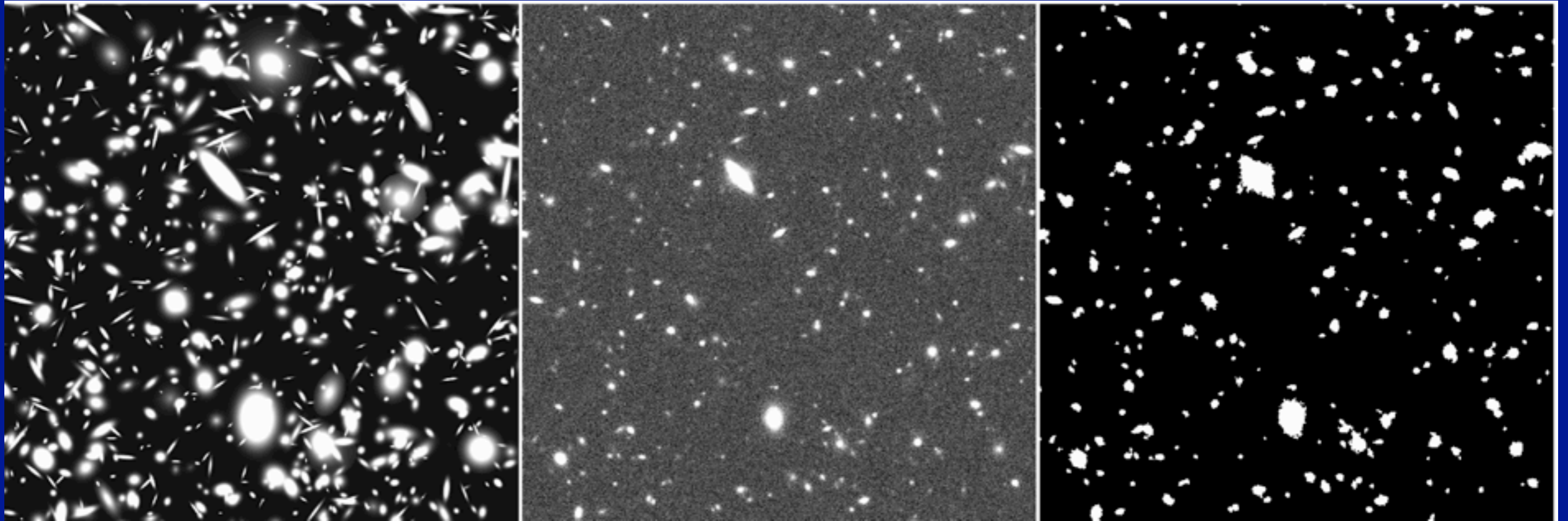


# Source Extracting the Millennium Simulations...

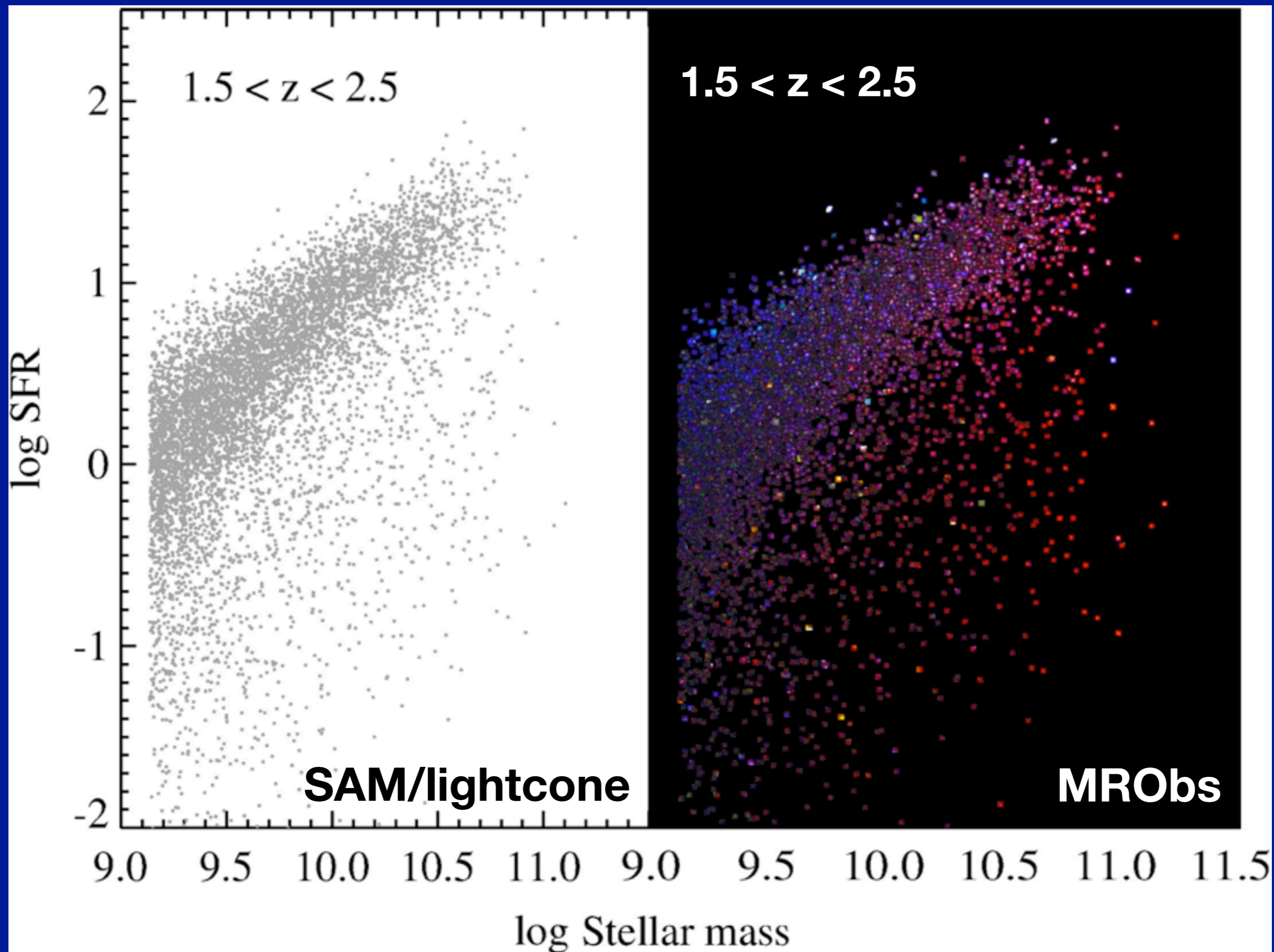
perfect image

telescope image

Source Extractor objects



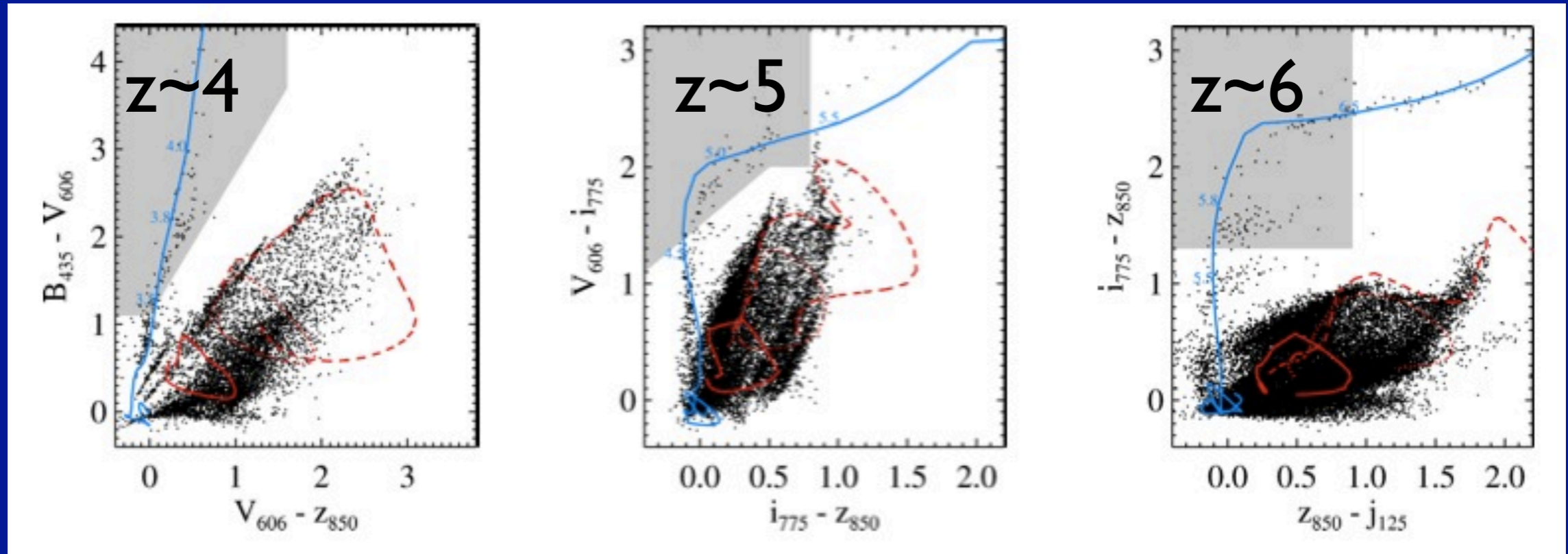
# Viewing SAMs from the actual observer's perspective



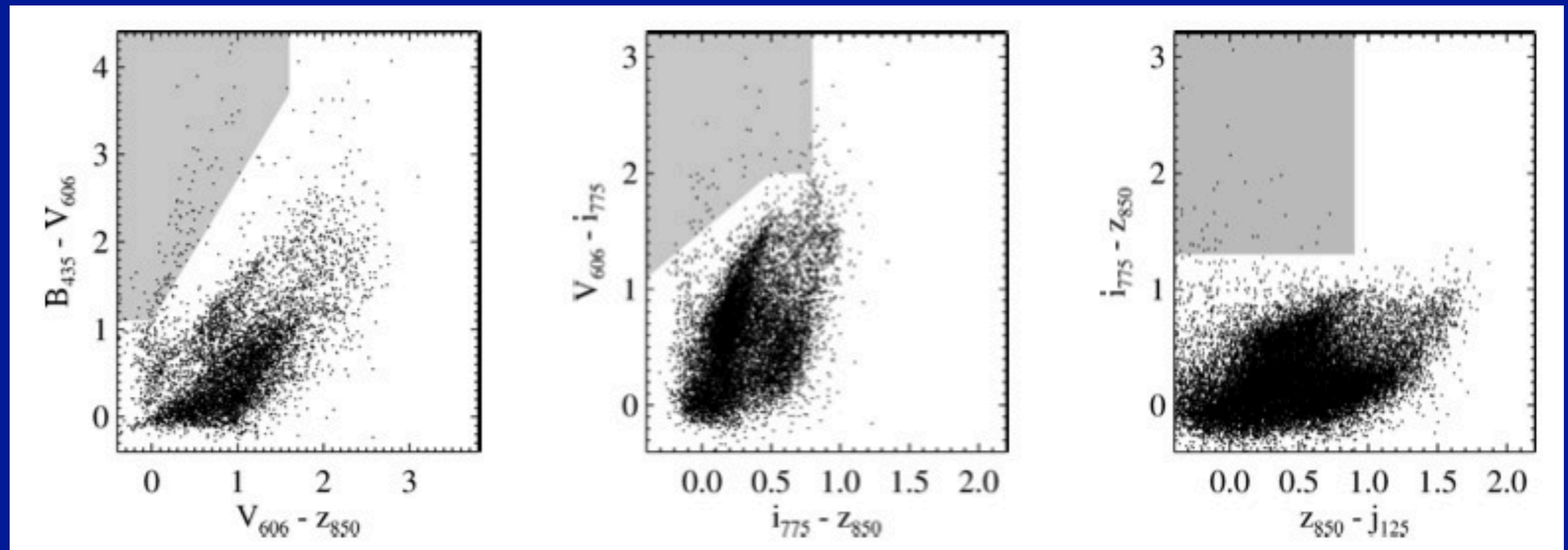


# MROBs allows more realistic sample selections

Based on lightcone:

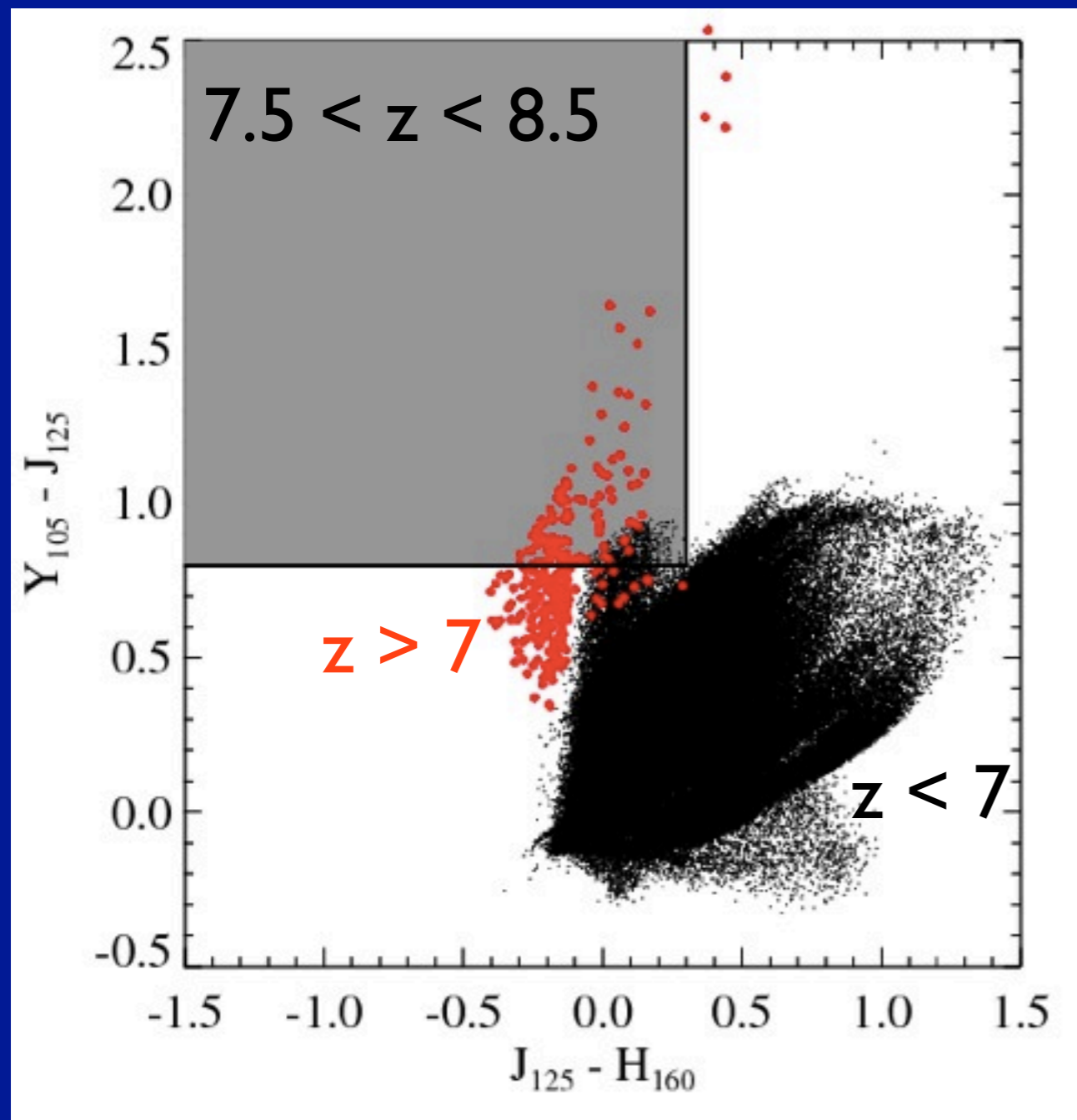


Based on Source Catalogs built from MROBs images (based on the same lightcone):

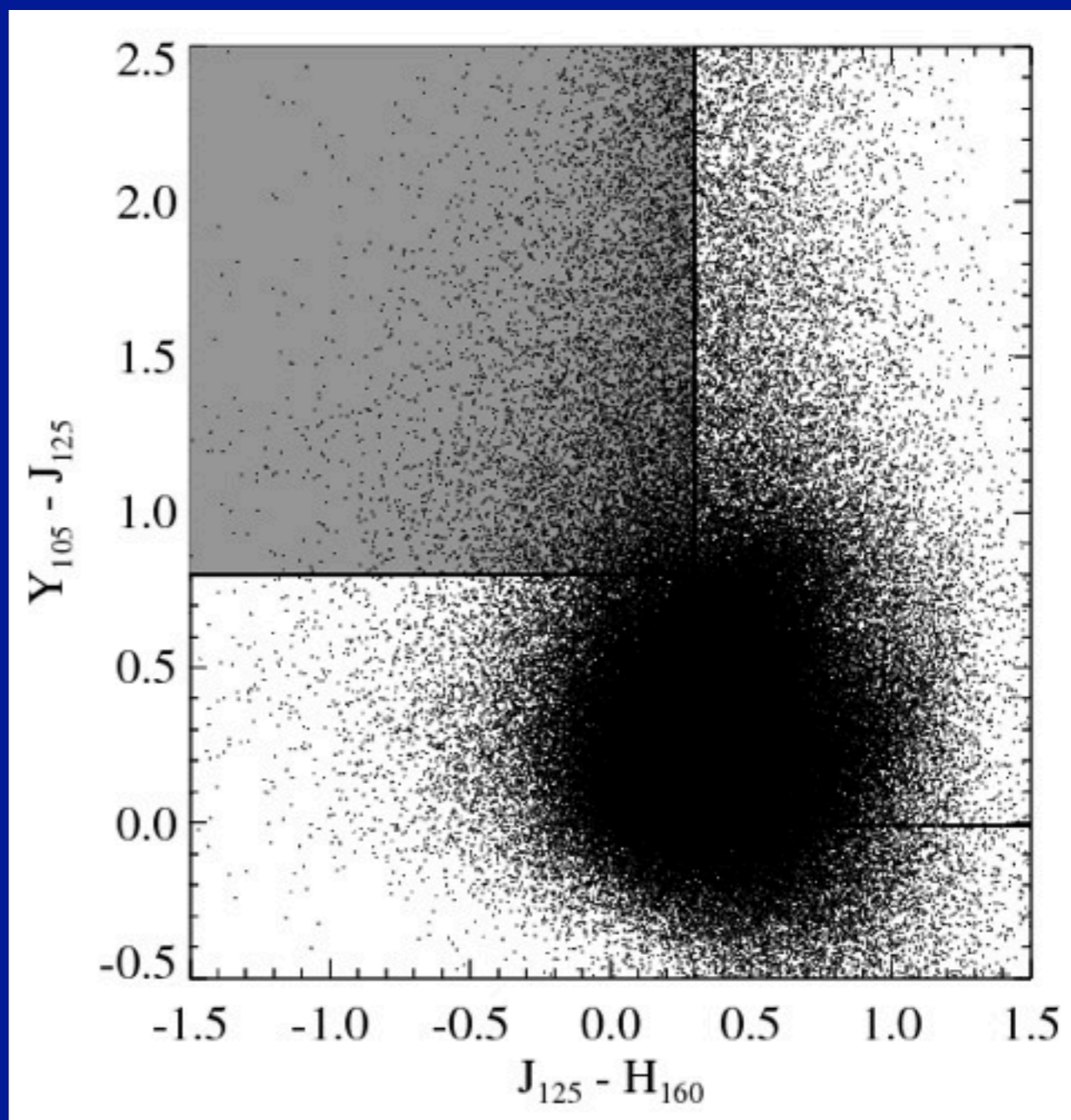


# High-z dropouts in the CANDELS/GOODS-S Simulation

From Lightcone (with  $J < 27.0$  AB mag)

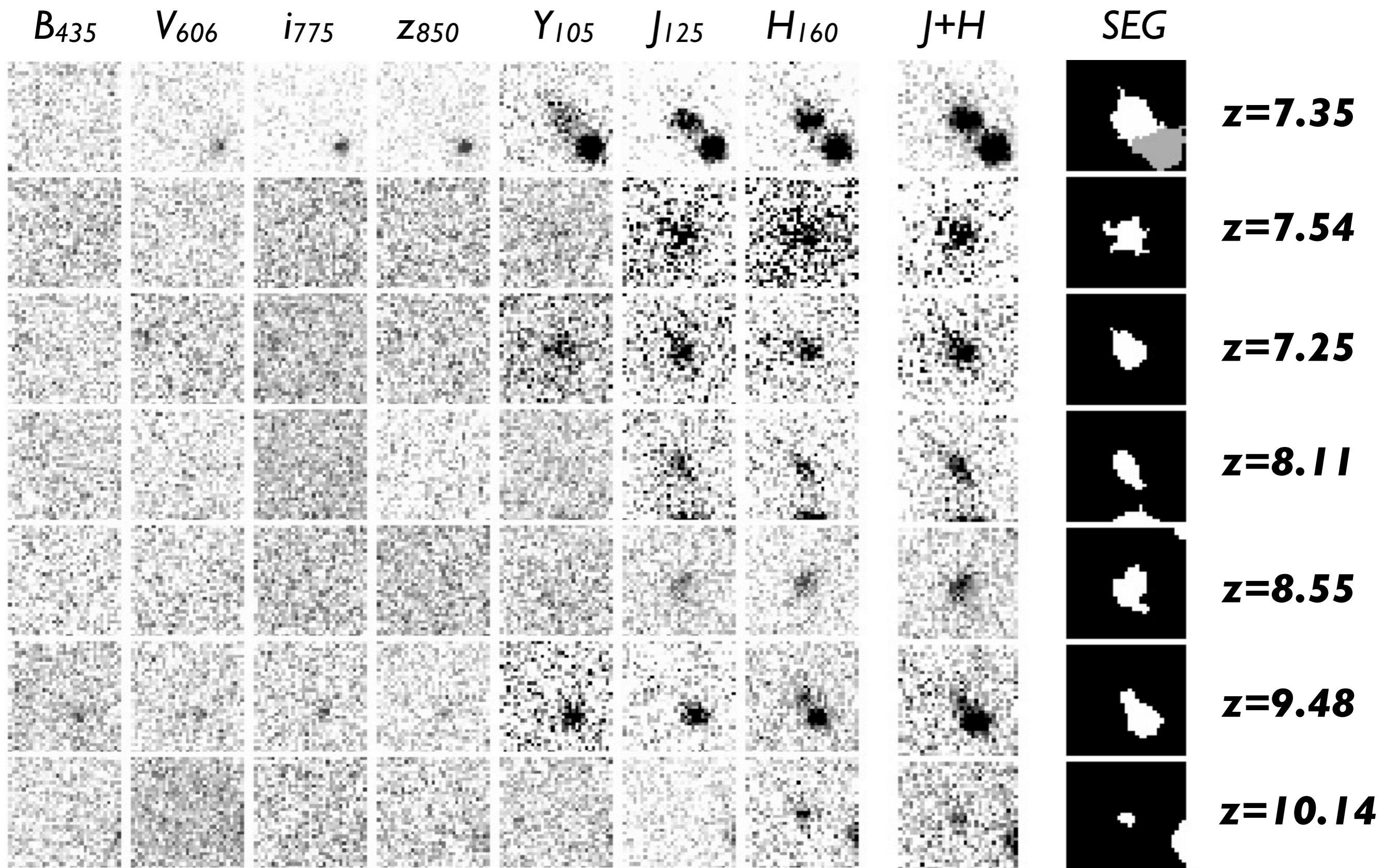


From MRObs Images





# High-z dropouts in the MRObs CANDELS/GDS-S Simulation



# Summary

MRObs image simulations bring an entirely new perspective to the semi-analytic modeling of galaxies

## Important for, e.g.

- Realistic, accurate predictions
- Revealing the main flaws/limitations of the models
- Tests of data analysis methods
- Interpretation of data
- ...

## Where to go from here?

- Extend to other models (e.g. GALFORM)
- Fully-integrated workflow combining cosmology, SAMs, lightcones, and MRObs images for maximal flexibility and parameter space studies constrained by observations



# The Millennium Run Observatory

Roderik Overzier (UT Austin) + Gerard Lemson + Galformod

Part I: Concept and First Results

Part II: How-to, Data, and new User Services



The screenshot displays the Millennium Run Observatory web interface. On the left, a sidebar lists various image types for galaxy 'bc03.m24\_001'. The central panel shows a large field of galaxies with a small white box highlighting a specific galaxy. On the right, the 'Galaxy Details' section for 'Galaxy 80000285000201' includes a spectral energy distribution (SED) plot and a table of properties.

**Galaxy Details**  
Galaxy 80000285000201

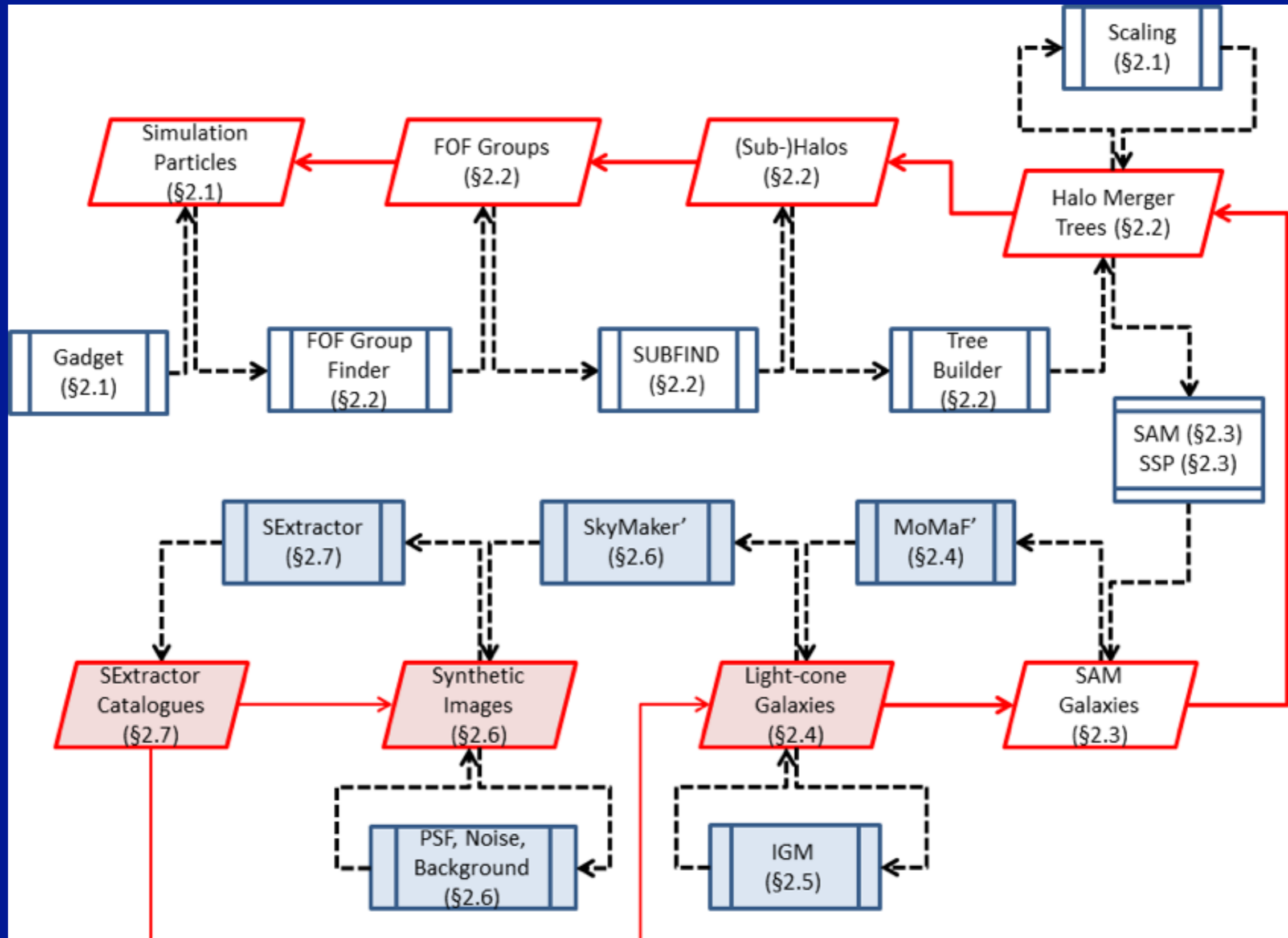
Wavelength (Ångstrom)

Show 100 entries

index	Property	value
1	galid	80000285000201
2	haloid	80000285000163
3	ra	0.07169607
4	dec	-0.0076653347
5	z_geo	2.7833347
6	z_app	2.7825243
7	diskradius_arcsec	0.5418869224368056
8	bulgesize_arcsec	0
9	pa	30.107199
10	inclination	43.62655
11	u	26.391722
12	b	25.619392
13	v	25.402982
14	rc	25.526402
15	ic	25.54193

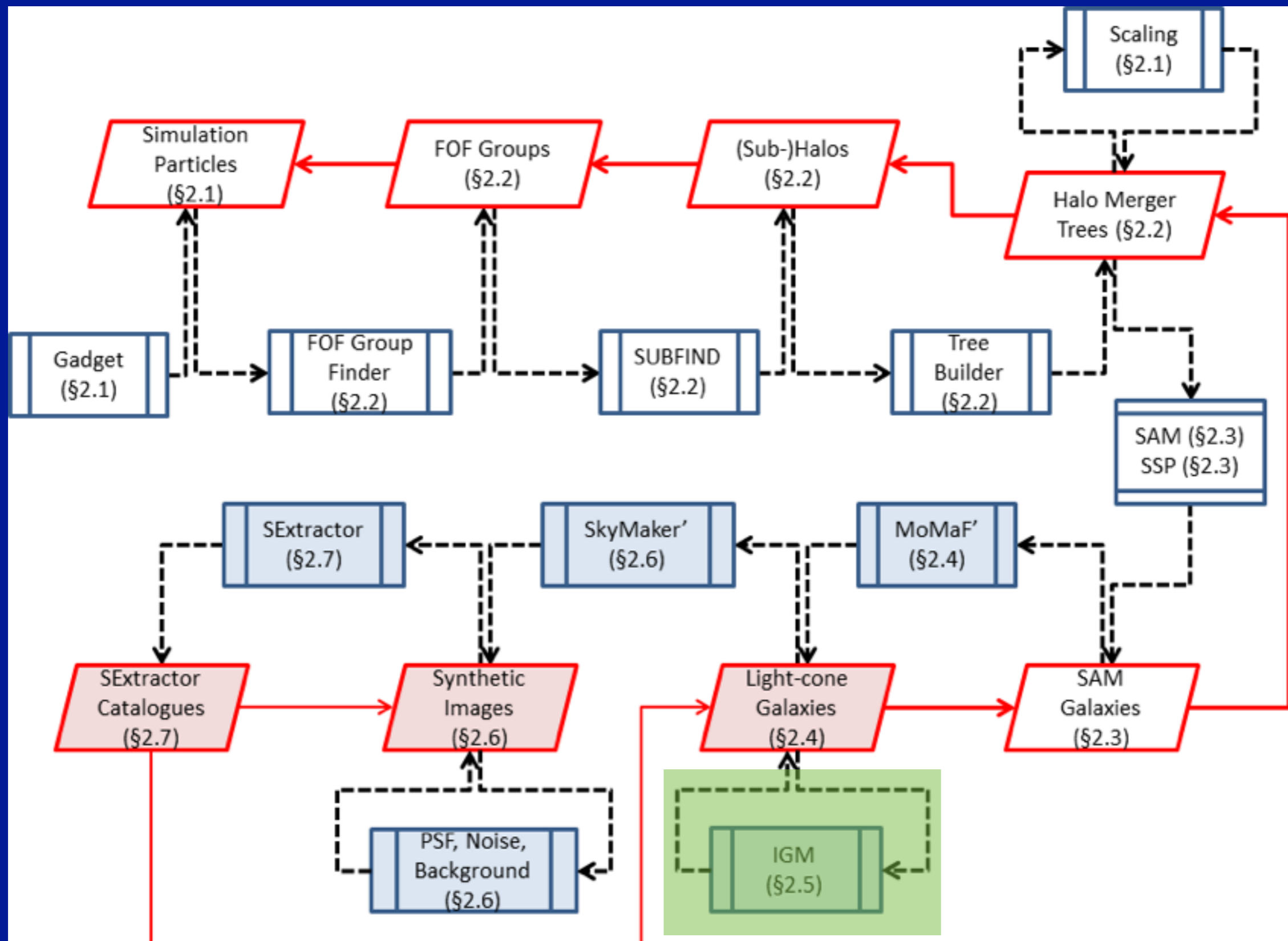
see Overzier, Lemson, Angulo, et al. 2013, MNRAS, 428, 778

# Millennium Run Observatory Workflow





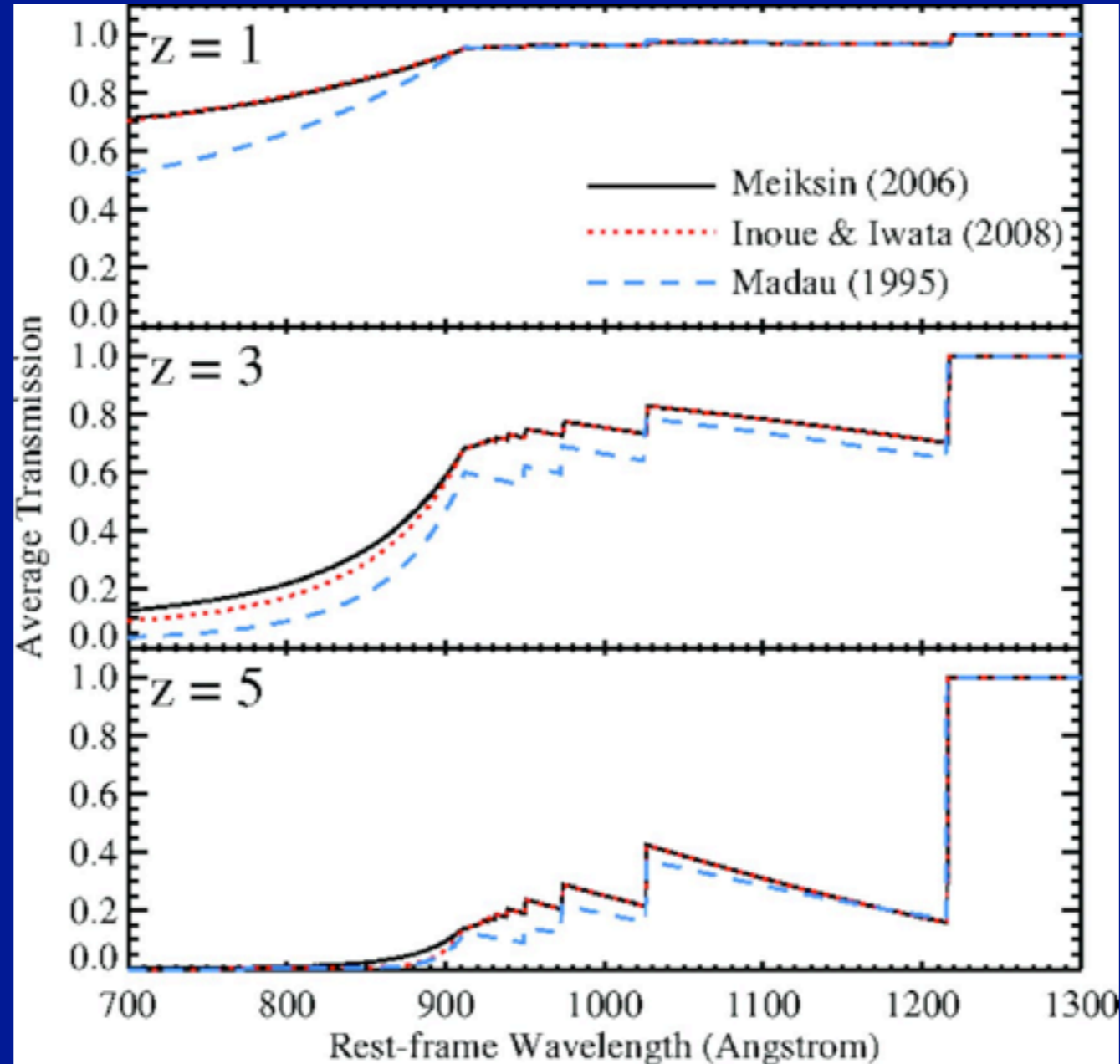
# Millennium Run Observatory Workflow



# IGM corrections

We need to correct intrinsic magnitudes of galaxies in lightcones due to absorption by Lyman Limit Systems, the optically thin component of the IGM, and the Ly $\alpha$  Forest:

Average IGM Transmission



Rest Wavelength



# IGM corrections for 3 models & 40 filters now available in the MRDB

mrobs\_db.igm.madau

mrobs\_db.igm.meiksin

mrobs\_db.igm.inoueiwata

*Example:  
Give the offsets in  
SDSS r'-band  
magnitudes for  
galaxies at  $z \sim 5$   
due to the IGM for  
the three different  
IGM models:*

```
select g1.redshift,  
       g1.sdss_r as dm_r_madau,  
       g2.sdss_r as dm_r_meiksin,  
       g3.sdss_r as dm_r_inoueiwata  
  
from mrobs_db.igm.madau g1,  
     mrobs_db.igm.meiksin g2,  
     mrobs_db.igm.inoueiwata g3  
  
where g1.redshift > 5 and g2.redshift = g1.redshift and g3.redshift= g1.redshift
```

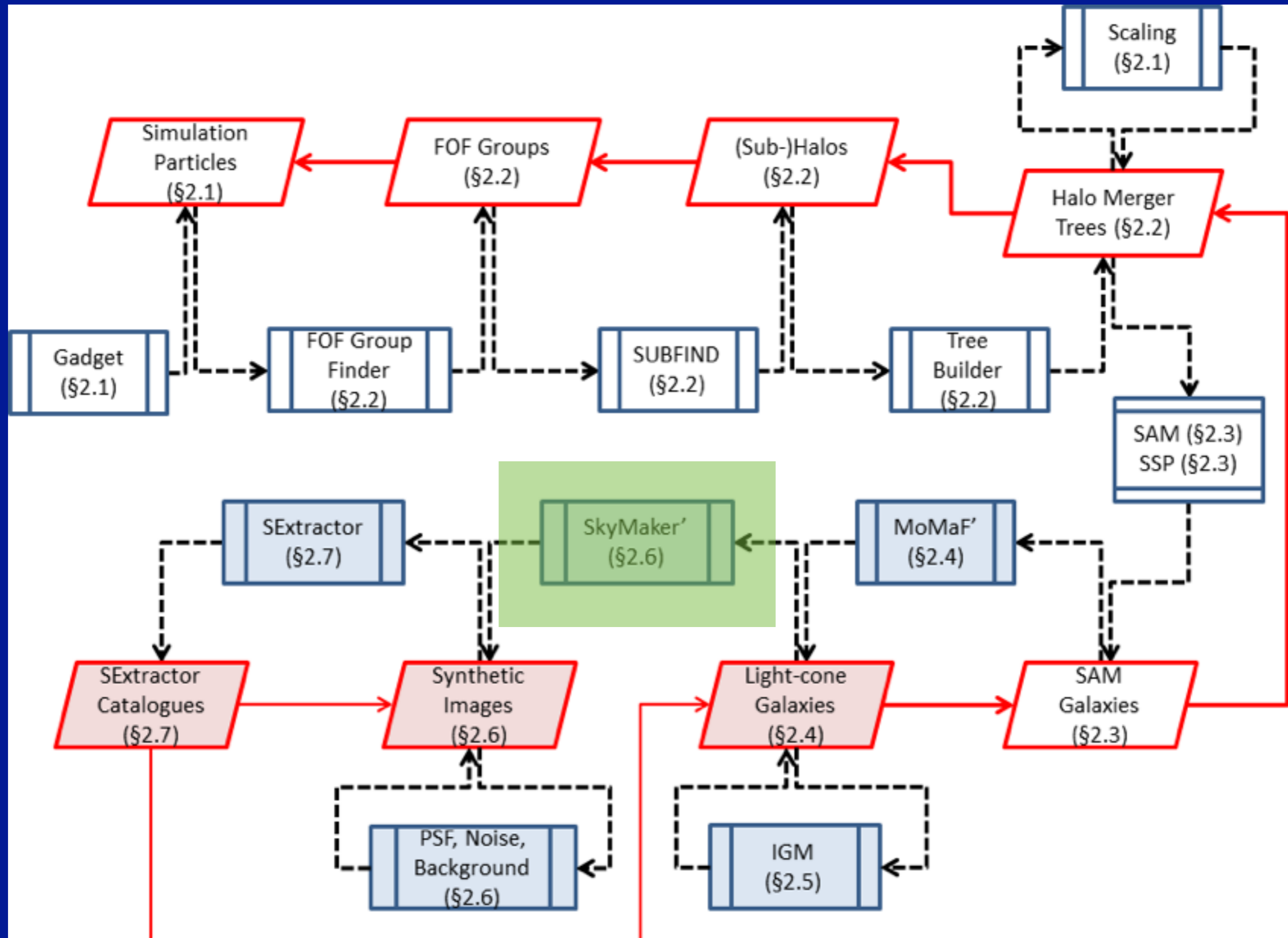
Maximum number of rows to return to the query form:

*Output:*

redshift	dm_r_madau	dm_r_meiksin	dm_r_inoueiwata
5.1	1.62615	1.42231	1.42235
5.2	1.76954	1.5497	1.54974
5.3	1.94041	1.71196	1.71199
5.4	2.17735	1.91627	1.91629
5.5	2.49564	2.19895	2.19897
5.6	2.85594	2.49572	2.49573
5.7	3.16415	2.76459	2.76461
5.8	3.49667	3.05191	3.05191
5.9	3.92382	3.41224	3.41224
6.0	4.3945	3.81938	3.81938

*values can be refined using interpolations  
between redshifts, and applied “on-the-fly”  
when retrieving a lightcone from the DB  
(ask me or GL for the SQL)*

# Millennium Run Observatory Workflow





# Galaxy Modeling Technique

$$\begin{aligned}\mu_S(R) = m - 2.5 \log_{10}(B/T) + 8.3268(R/R_e)^{1/4} \\ + 5 \log_{10}(R_e) - 4.9384\end{aligned}$$

(1)

$$\begin{aligned}\mu_D(R) = m - 2.5 \log_{10}(1 - B/T) \\ + 1.0857(R/R_h) + 5 \log_{10}(R_h) + 1.9955,\end{aligned}$$

(2)

exactly like galaxies  
are being modeled in,  
e.g., Guo et al. (2010)

$$\begin{aligned}I_D[x', y'] \propto e^{-(C_{XX}x'^2 + C_{YY}y'^2 + C_{XY}y'x')^{1/2}} \\ I_S[x', y'] \propto e^{-7.6693(C_{XX}x'^2 + C_{YY}y'^2 + C_{XY}y'x')^{1/8}},\end{aligned}$$

$$\begin{aligned}C_{XX} &= \frac{\cos^2(\theta)}{A^2} + \frac{\sin^2(\theta)}{B^2} \\ C_{YY} &= \frac{\sin^2(\theta)}{A^2} + \frac{\cos^2(\theta)}{B^2} \\ C_{XY} &= 2 \cos(\theta) \sin(\theta) \left( \frac{1}{A^2} - \frac{1}{B^2} \right).\end{aligned}$$

$A = R_e$  for bulges

$A = R_h$  for discs

$B = A \cos(\phi)$

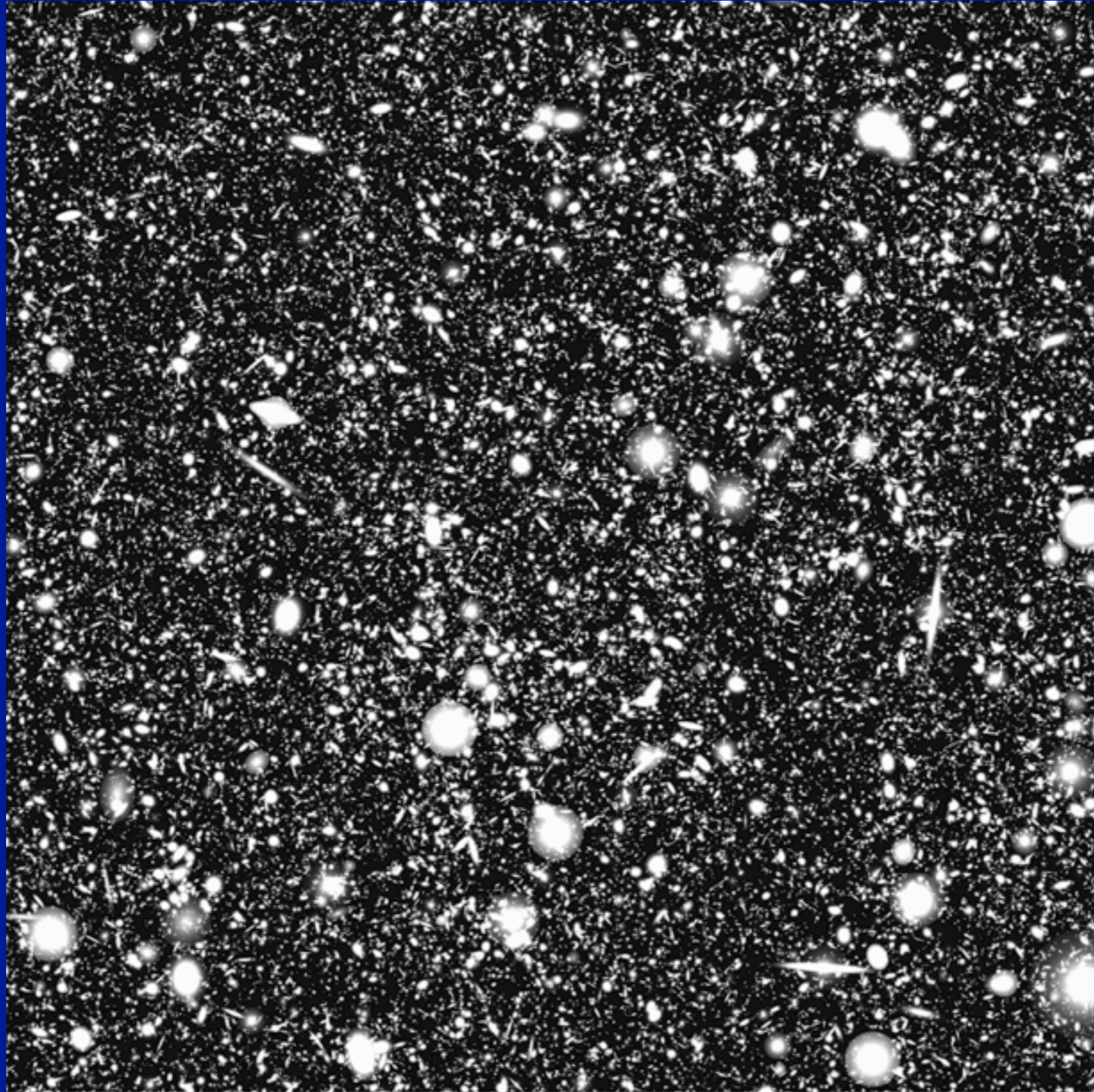
# Minimal Requirements from the SAM+lightcone are

$x_c, y_c$	←	ra,dec from <i>lightcone</i> + image pixel scale + pointing
$m$	←	dust-attenuated filter magnitude from <i>lightcone</i> , corrected for IGM absorption (added to MRDB)
$B/T$	←	ratio of bulge-to-total filter flux
$R_h, R_e$	←	stellardiskradius/ $3D_A$ , bulgesize/ $D_A$
$\theta$	←	disk position angle from disk spin axis
$\cos(\varphi)$	←	disk projected aspect ratio from disk spin axis

if you can provide these to us, we're in business



# A “perfect” image of the sky





# Interesting computer science aspects as well

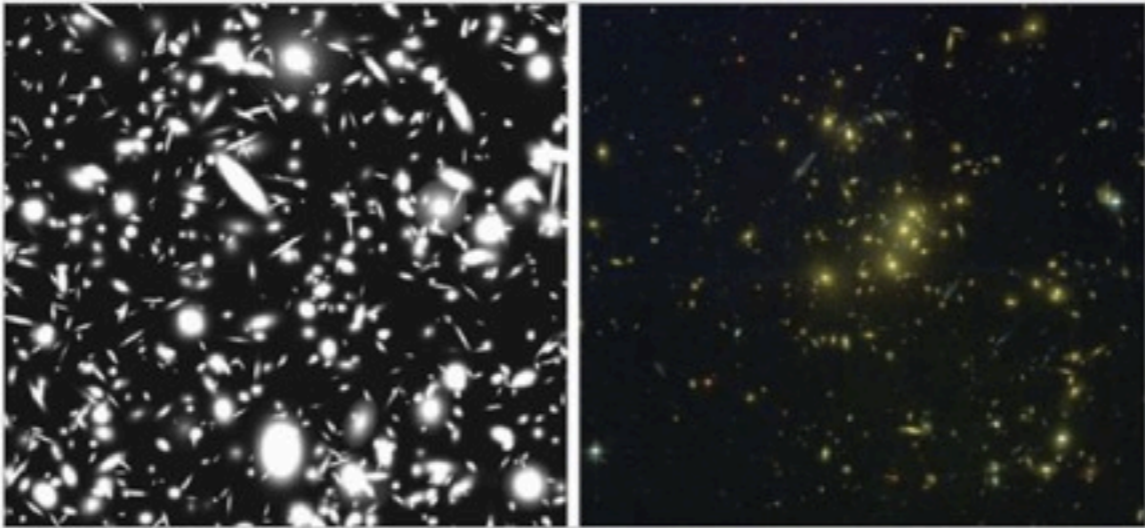
tum.3D Technische Universität München TUM

**Teaching**

- Teaching
- ▶ Theses
  - ▶ Available Topics
    - ▶ GPU-based acceleration of the Millennium Run Observatory (MRObs)
    - A Network Streaming System for Terrain Rendering
    - Terrain Editing with Haptic Feedback
    - Parallel Rendering Framework for Virtual Reality Installations
    - Screen space curvature smoothing
    - Development of a multimodal volume-editing environment in the field of neuro-planning
    - Photorealistische Visualisierung bestimmter Oberflächentypen von Automobilen
    - Terrain Rendering on Android and OpenGL ES 2.0
    - Exploiting web services and OpenGL (WebGL/OpenGL ES) to render meteorological forecast data

▶ Teaching ▶ Theses ▶ Available Topics ▶ GPU-based acceleration of the Millennium Run Observatory (MRObs)

## GPU-based acceleration of the Millennium Run Observatory (MRObs)



Overview

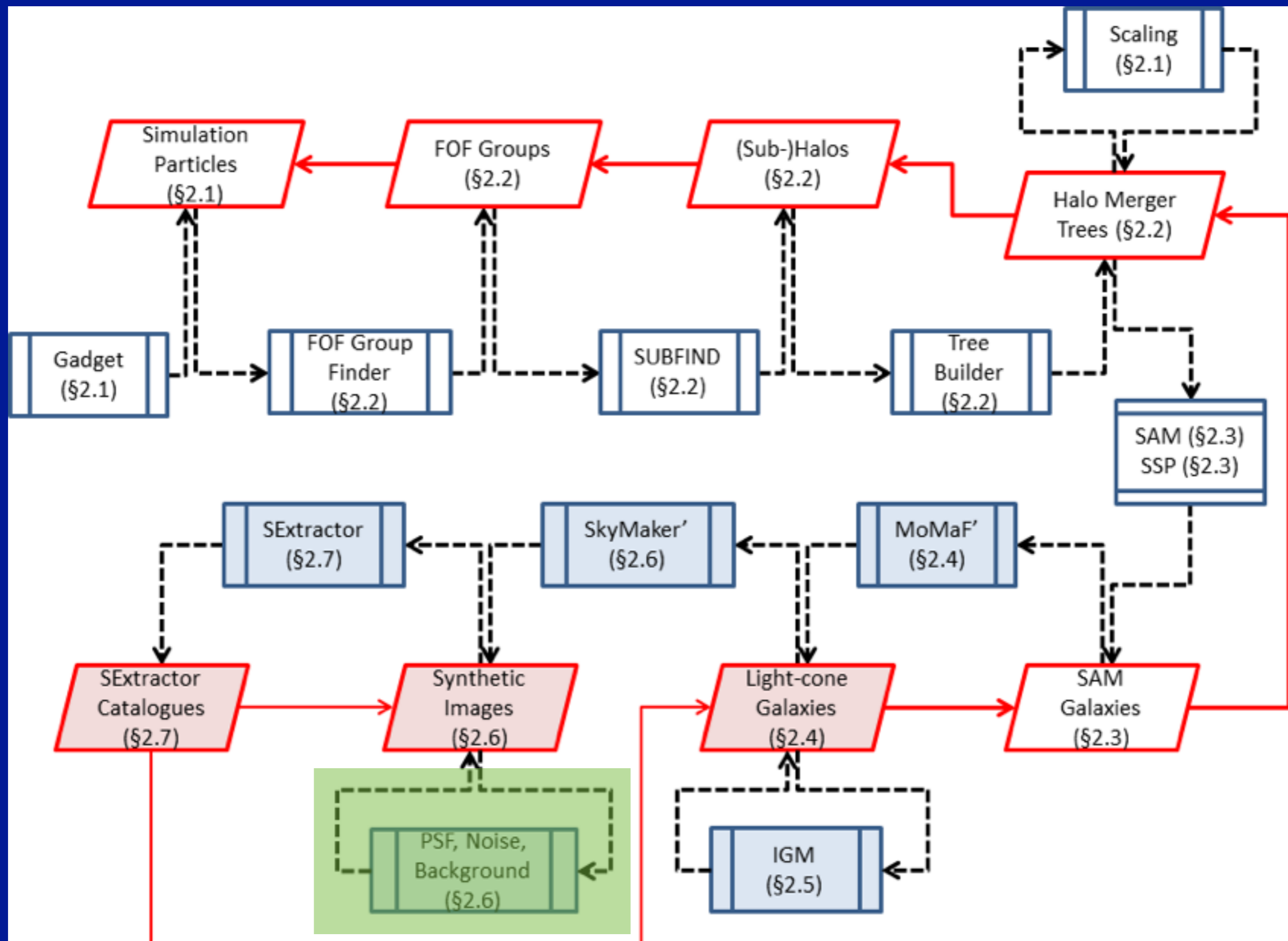
**Quick Access**

- ▶ Winter Term 12/13
- ▶ Theses: Available Topics
- ▶ Publications
- ▶ Persons
- ▶ Job Offers

with Kai Bürger (TUM), Gerard Lemson, and unknown TUM student



# Millennium Run Observatory Workflow



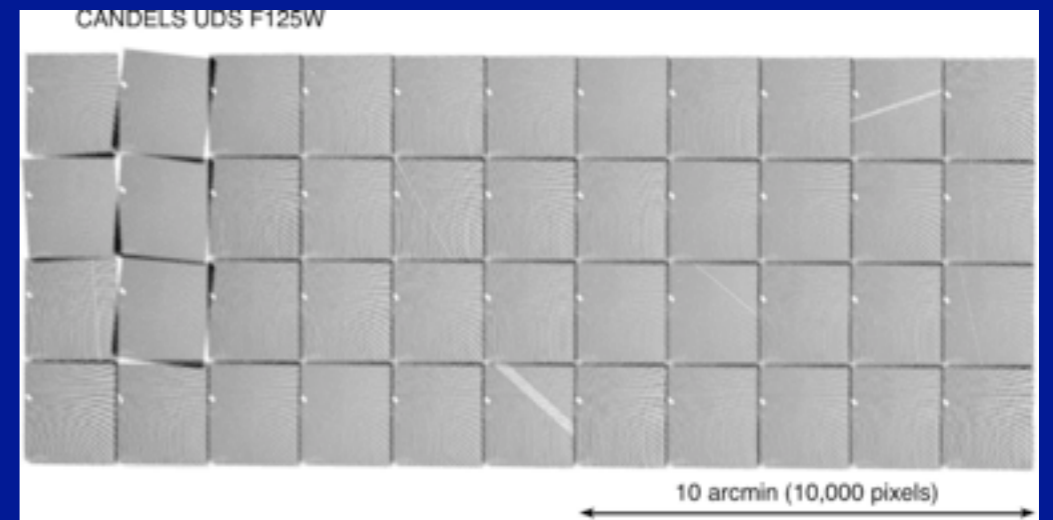
# From “perfect” image to mock observation

$$F_{e-} = 10^{-0.4(m_{AB} + ZP)} \cdot T_{\text{exp}} \cdot G / \sum_{i \in S} \sum_{j \in S} I[x'_i, y'_j],$$

(5)

Current MRObs pipeline performs the following post-processing steps:

- Single or multiple exposures
- Site Sky Background
- PSF convolution
- Dark current
- Poissonian object and sky noise
- Normally distributed read-noise
- (Galactic Extinction)
- (Galactic Stars)
- Observed sensitivity variations



*Example of complicated tiling and noise patterns in the HST CANDELS survey*



# Master table with mock telescope/instrument properties

*telescope, camera, filter, wavelength, pixel\_size, fov, gain, RON, DC, sky, zp,...*

*Example: cameras on-board the Hubble Space Telescope*

```
hst,acs_hrc,acs330,3334,0.025,1024,1,155000,65535,4.7,0.0058,24.32,24.09
hst,acs_sbc,acs150,1619,0.025,1024,1,200000,20000,0.0,1.24E-05,31.5,22.45
hst,acs_wfc,acs435,4297,0.05,4096,1,84700,65535,4.2,0.0062,22.96,25.68
hst,acs_wfc,acs475,4760,0.05,4096,1,84700,65535,4.2,0.0062,22.65,26.06
hst,acs_wfc,acs606,6060,0.05,4096,1,84700,65535,4.2,0.0062,22.20,26.49
hst,acs_wfc,acs625,6318,0.05,4096,1,84700,65535,4.2,0.0062,22.09,25.91
hst,acs_wfc,acs775,7764,0.05,4096,1,84700,65535,4.2,0.0062,21.92,25.68
hst,acs_wfc,acs814,8333,0.05,4096,1,84700,65535,4.2,0.0062,21.89,25.94
hst,acs_wfc,acs850,9445,0.05,4096,1,84700,65535,4.2,0.0062,21.85,24.86
hst,wfc3_ir,wfc105,10552,0.13,1024,2.5,93000,70000,21,0.022,21.80,25.28
hst,wfc3_ir,wfc125,12486,0.13,1024,2.5,93000,70000,21,0.022,21.78,25.26
hst,wfc3_ir,wfc140,13923,0.13,1024,2.5,93000,70000,21,0.022,21.78,25.47
hst,wfc3_ir,wfc160,15369,0.13,1024,2.5,93000,70000,21,0.022,21.80,24.97
```

*Example: the SDSS*

```
sdss,sdss,sdss_u,3551,0.396,9000,1.47,62500,62500,3.7,0.0,22.42,23.3559
sdss,sdss,sdss_g,4686,0.396,9000,4.05,62500,62500,2.1,0.0,21.98,24.1419
sdss,sdss,sdss_r,6165,0.396,9000,4.73,62500,62500,2.0,0.0,21.02,23.9169
sdss,sdss,sdss_i,7481,0.396,9000,4.64,62500,62500,6.0,0.0,20.10,23.5969
sdss,sdss,sdss_z,8931,0.396,9000,3.48,62500,62500,2.5,0.0,18.88,22.3149
```



# Master table with mock telescope/instrument properties

*telescope, camera, filter, wavelength, pixel\_size, fov, gain, RON, DC, sky, zp,...*

*Example: cameras on-board the Hubble Space Telescope*

```
hst,acs_hrc,acs330,3334,0.025,1024,1,155000,65535,4.7,0.0058,24.32,24.09
hst,acs_sbc,acs150,1619,0.025,1024,1,200000,20000,0.0,1.24E-05,31.5,22.45
hst,acs_wfc,acs435,4297,0.05,4096,1,84700,65535,4.2,0.0062,22.96,25.68
hst,acs_wfc,acs475,4760,0.05,4096,1,84700,65535,4.2,0.0062,22.65,26.06
hst,acs_wfc,acs606,6060,0.05,4096,1,84700,65535,4.2,0.0062,22.20,26.49
hst,acs_wfc,acs625,6318,0.05,4096,1,84700,65535,4.2,0.0062,22.09,25.91
hst,acs_wfc,acs775,7764,0.05,4096,1,84700,65535,4.2,0.0062,21.92,25.68
hst,acs_wfc,acs814,8333,0.05,4096,1,84700,65535,4.2,0.0062,21.89,25.94
hst,acs_wfc,acs850,9445,0.05,4096,1,84700,65535,4.2,0.0062,21.85,24.86
hst,wfc3_ir,wfc105,10552,0.13,1024,2.5,93000,70000,21,0.022,21.80,25.28
hst,wfc3_ir,wfc125,12486,0.13,1024,2.5,93000,70000,21,0.022,21.78,25.26
hst,wfc3_ir,wfc140,13923,0.13,1024,2.5,93000,70000,21,0.022,21.78,25.47
hst,wfc3_ir,wfc160,15369,0.13,1024,2.5,93000,70000,21,0.022,21.80,24.97
```

*Example: the SDSS* (filter names correspond to columns in Henriques2012a lightcones)

```
sdss,sdss,sdss_u,3551,0.396,9000,1.47,62500,62500,3.7,0.0,22.42,23.3559
sdss,sdss,sdss_g,4686,0.396,9000,4.05,62500,62500,2.1,0.0,21.98,24.1419
sdss,sdss,sdss_r,6165,0.396,9000,4.73,62500,62500,2.0,0.0,21.02,23.9169
sdss,sdss,sdss_i,7481,0.396,9000,4.64,62500,62500,6.0,0.0,20.10,23.5969
sdss,sdss,sdss_z,8931,0.396,9000,3.48,62500,62500,2.5,0.0,18.88,22.3149
```



## Parameters that further define the mock survey

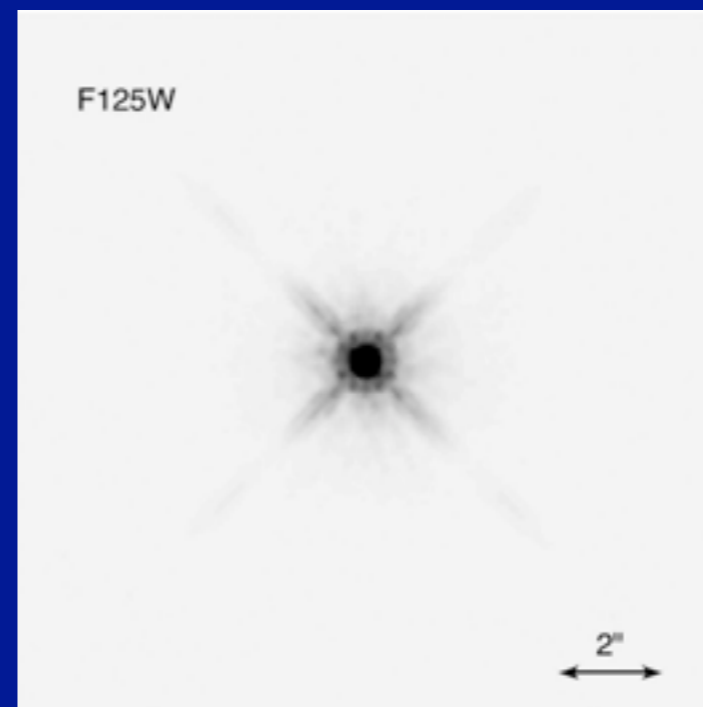
***telescope, camera, filter,  $N_{exp}$ ,  $T_{exp}$ , PSF file***

*Example: the Hubble Ultra Deep Field*

```
hst,acs_wfc,acs435,112,134880,UDF/acs/0.03/udf_psf_f435w.fits  
hst,acs_wfc,acs606,112,135320,UDF/acs/0.03/udf_psf_f606w.fits  
hst,acs_wfc,acs775,288,347110,UDF/acs/0.03/udf_psf_f775w.fits  
hst,acs_wfc,acs850,288,346620,UDF/acs/0.03/udf_psf_f850lp.fits
```

## Extensive library of 2D point spread function image kernels

*Example: the HST/WFC3 J-band PSF*



## Parameters that further define the mock survey

***telescope, camera, filter,  $N_{exp}$ ,  $T_{exp}$ , PSF file***

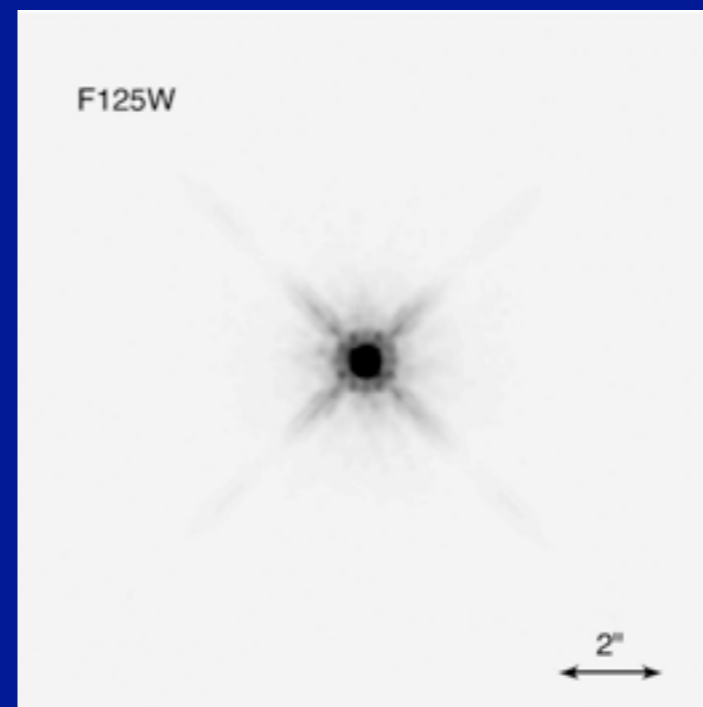
*Example: the Hubble Ultra Deep Field*

```
hst,acs_wfc,acs435,112,134880,UDF/acs/0.03/udf_psf_f435w.fits  
hst,acs_wfc,acs606,112,135320,UDF/acs/0.03/udf_psf_f606w.fits  
hst,acs_wfc,acs775,288,347110,UDF/acs/0.03/udf_psf_f775w.fits  
hst,acs_wfc,acs850,288,346620,UDF/acs/0.03/udf_psf_f850lp.fits
```

(first three columns provide a unique match to the instruments table)

## Extensive library of 2D point spread function image kernels

*Example: the HST/WFC3 J-band PSF*



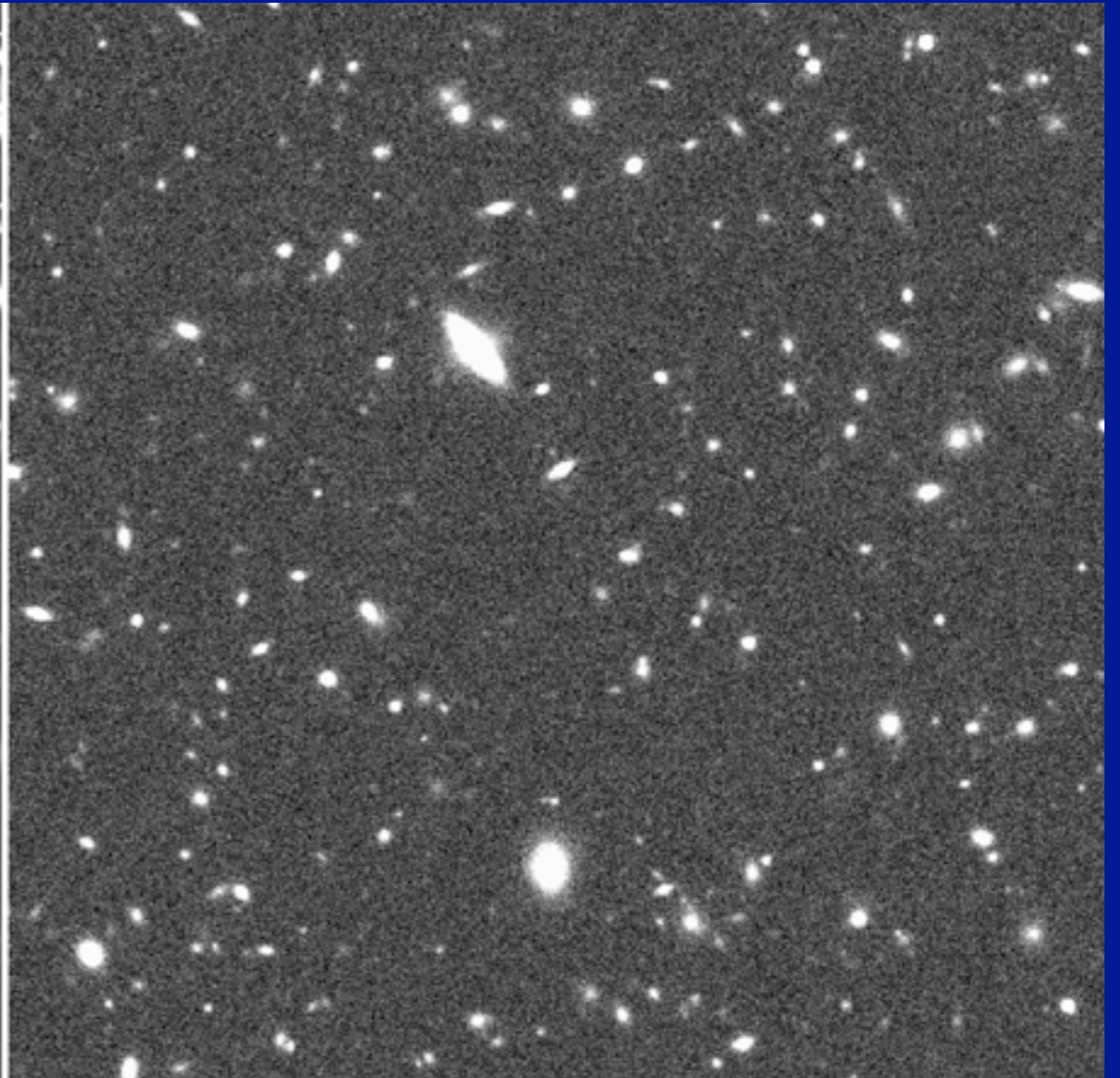


# From “perfect” image to mock observation

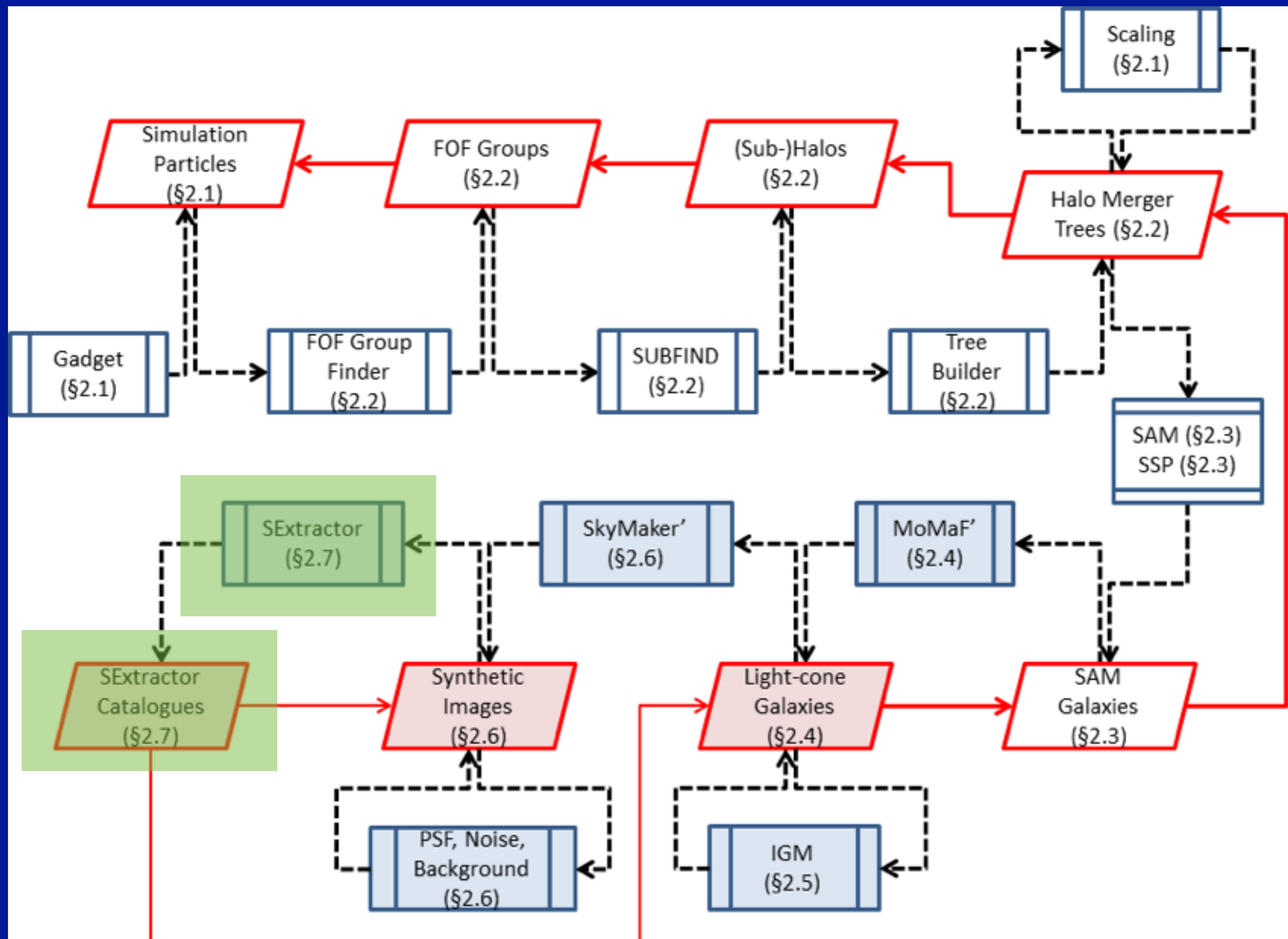
perfect image



telescope image



# Millennium Run Observatory Workflow





# Source Extracting the Millennium Simulations...

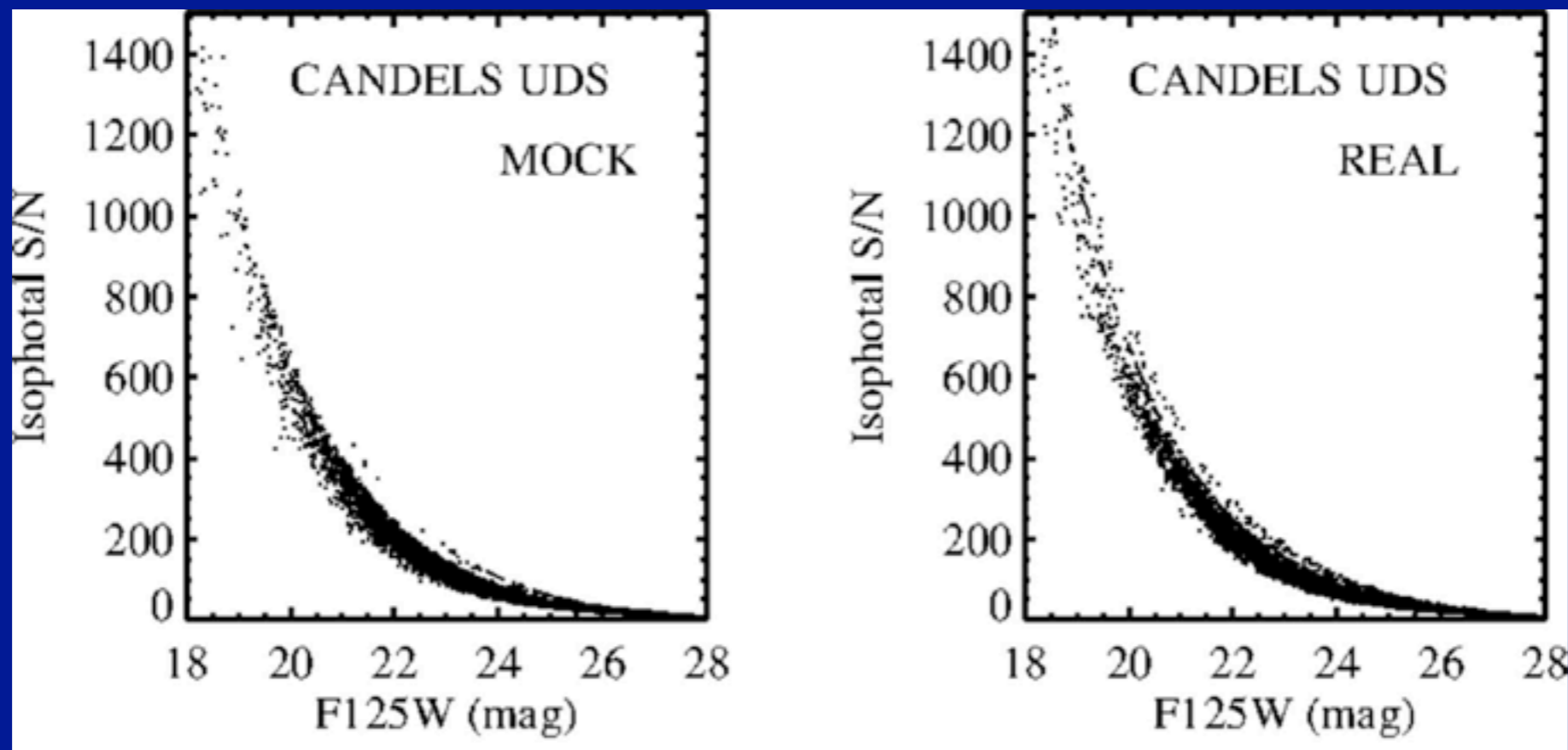
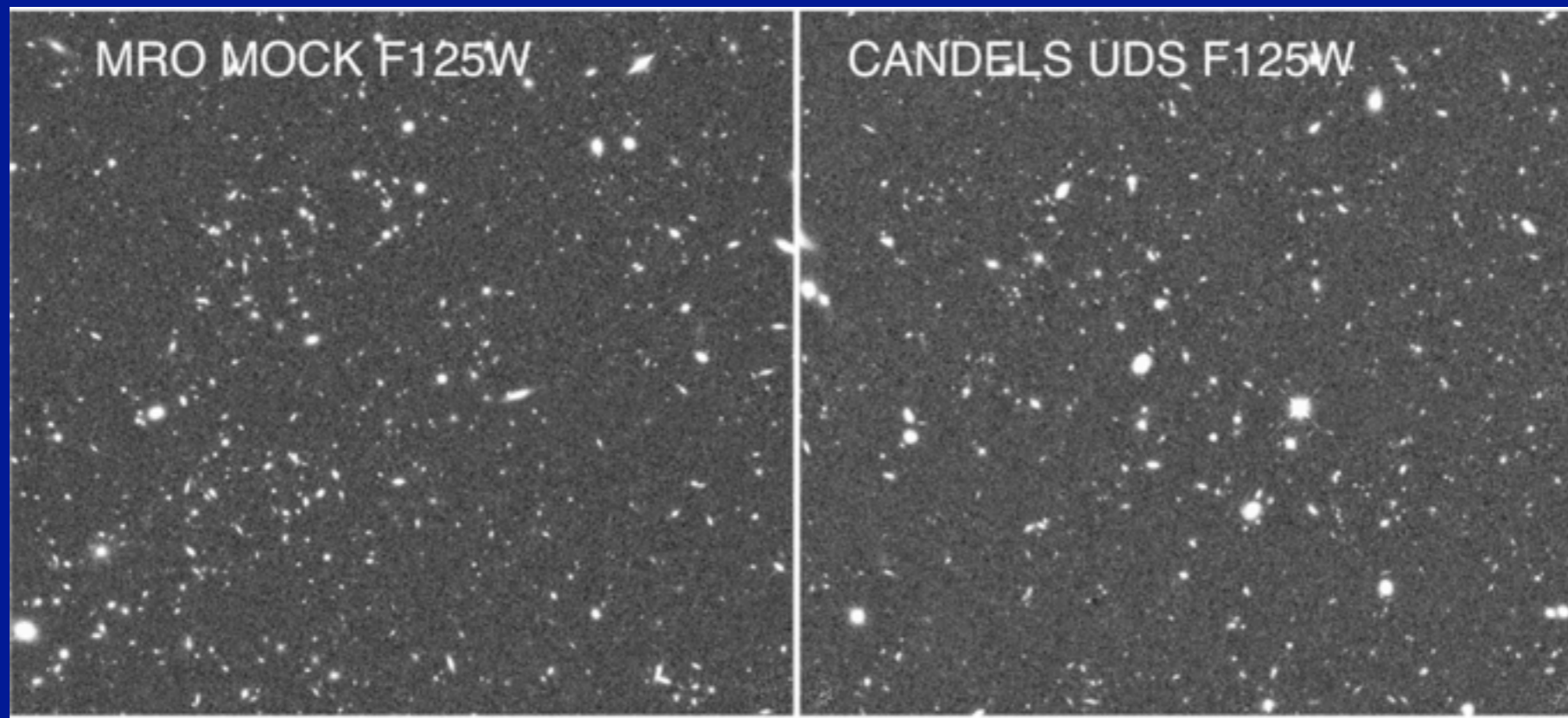
perfect image

telescope image

Source Extractor objects



# Critical test: is the quality of the mock and real images the same?





### Surveys Overview Table

Show  entries

Search:

Survey	Instrument/Filter	Stellar Population	IGM Model	Cosmology	Download
CANDELS/COSMOS	HST/ACS F606W HST/ACS F814W WFC3/IR F105W WFC3/IR F125W WFC3/IR F160W	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	<a href="#">v0.5</a>
CANDELS/UDS	HST/ACS F606W HST/ACS F814W WFC3/IR F105W WFC3/IR F125W WFC3/IR F160W	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	<a href="#">v0.5</a>
CFHT-LS Deep	Megacam u Megacam g Megacam r Megacam i Megacam z	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	<a href="#">v0.5</a>
CFHT-LS Wide	Megacam u Megacam g Megacam r Megacam i Megacam z	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	<a href="#">v0.5</a>
GOODS v2.0	HST/ACS F435W HST/ACS F625W HST/ACS F775W HST/ACS F850LP  WFC3/UVIS F225W WFC3/UVIS F275W WFC3/UVIS F336W	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	<a href="#">v0.5</a>

# Distribution of new kinds of MR Data



Max-Planck-Institut für  
Astrophysik

## The Millennium Run Observatory Data Holdings - GOODS/ERS Survey

### Synthetic Images

Show  entries

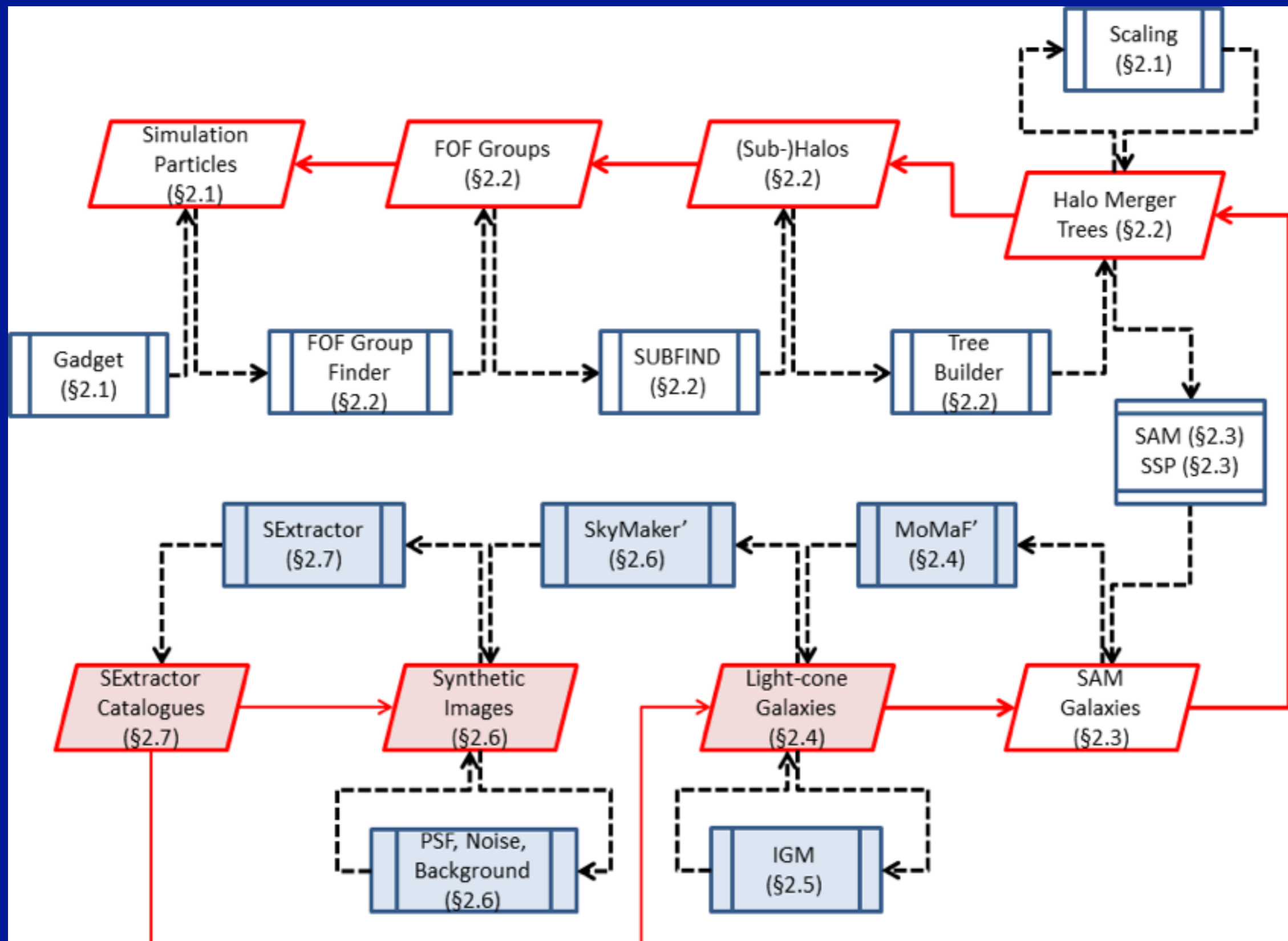
Search:

Cosmology *	Lightcone	SSP	IGM	Survey	Filter	SQL	CSV	PRE	PSF	SCI
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc225	<a href="#">hst_wfc3_uvis_wfc225.sql</a>	<a href="#">hst_wfc3_uvis_wfc225.csv</a>	<a href="#">hst_wfc3_uvis_wfc225.fits</a>	<a href="#">F225W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc225_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc275	<a href="#">hst_wfc3_uvis_wfc275.sql</a>	<a href="#">hst_wfc3_uvis_wfc275.csv</a>	<a href="#">hst_wfc3_uvis_wfc275.fits</a>	<a href="#">F275W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc275_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc336	<a href="#">hst_wfc3_uvis_wfc336.sql</a>	<a href="#">hst_wfc3_uvis_wfc336.csv</a>	<a href="#">hst_wfc3_uvis_wfc336.fits</a>	<a href="#">F336W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc336_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_acs_wfc_acs435	<a href="#">hst_acs_wfc_acs435.sql</a>	<a href="#">hst_acs_wfc_acs435.csv</a>	<a href="#">hst_acs_wfc_acs435.fits</a>	<a href="#">F435W_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs435_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_acs_wfc_acs606	<a href="#">hst_acs_wfc_acs606.sql</a>	<a href="#">hst_acs_wfc_acs606.csv</a>	<a href="#">hst_acs_wfc_acs606.fits</a>	<a href="#">F606W_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs606_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_acs_wfc_acs775	<a href="#">hst_acs_wfc_acs775.sql</a>	<a href="#">hst_acs_wfc_acs775.csv</a>	<a href="#">hst_acs_wfc_acs775.fits</a>	<a href="#">F775W_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs775_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_acs_wfc_acs850	<a href="#">hst_acs_wfc_acs850.sql</a>	<a href="#">hst_acs_wfc_acs850.csv</a>	<a href="#">hst_acs_wfc_acs850.fits</a>	<a href="#">F850LP_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs850_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_ir_wfc125	<a href="#">hst_wfc3_ir_wfc125.sql</a>	<a href="#">hst_wfc3_ir_wfc125.csv</a>	<a href="#">hst_wfc3_ir_wfc125.fits</a>	<a href="#">F125W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_ir_wfc125_post.fits</a>
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_ir_wfc160	<a href="#">hst_wfc3_ir_wfc160.sql</a>	<a href="#">hst_wfc3_ir_wfc160.csv</a>	<a href="#">hst_wfc3_ir_wfc160.fits</a>	<a href="#">F160W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_ir_wfc160_post.fits</a>
wmap1	MRObs.wmap1.BC03_004	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc225	<a href="#">hst_wfc3_uvis_wfc225.sql</a>	<a href="#">hst_wfc3_uvis_wfc225.csv</a>	<a href="#">hst_wfc3_uvis_wfc225.fits</a>	<a href="#">F225W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc225_post.fits</a>
wmap1	MRObs.wmap1.BC03_004	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc275	<a href="#">hst_wfc3_uvis_wfc275.sql</a>	<a href="#">hst_wfc3_uvis_wfc275.csv</a>	<a href="#">hst_wfc3_uvis_wfc275.fits</a>	<a href="#">F275W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc275_post.fits</a>
wmap1	MRObs.wmap1.BC03_004	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc336	<a href="#">hst_wfc3_uvis_wfc336.sql</a>	<a href="#">hst_wfc3_uvis_wfc336.csv</a>	<a href="#">hst_wfc3_uvis_wfc336.fits</a>	<a href="#">F336W_psf_127x127_v3.fits</a>	<a href="#">hst_wfc3_uvis_wfc336_post.fits</a>
wmap1	MRObs.wmap1.BC03_004	bc03	madau	GOODS/ERS	hst_acs_wfc_acs435	<a href="#">hst_acs_wfc_acs435.sql</a>	<a href="#">hst_acs_wfc_acs435.csv</a>	<a href="#">hst_acs_wfc_acs435.fits</a>	<a href="#">F435W_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs435_post.fits</a>
wmap1	MRObs.wmap1.BC03_004	bc03	madau	GOODS/ERS	hst_acs_wfc_acs606	<a href="#">hst_acs_wfc_acs606.sql</a>	<a href="#">hst_acs_wfc_acs606.csv</a>	<a href="#">hst_acs_wfc_acs606.fits</a>	<a href="#">F606W_psf_127x127_v3.fits</a>	<a href="#">hst_acs_wfc_acs606_post.fits</a>

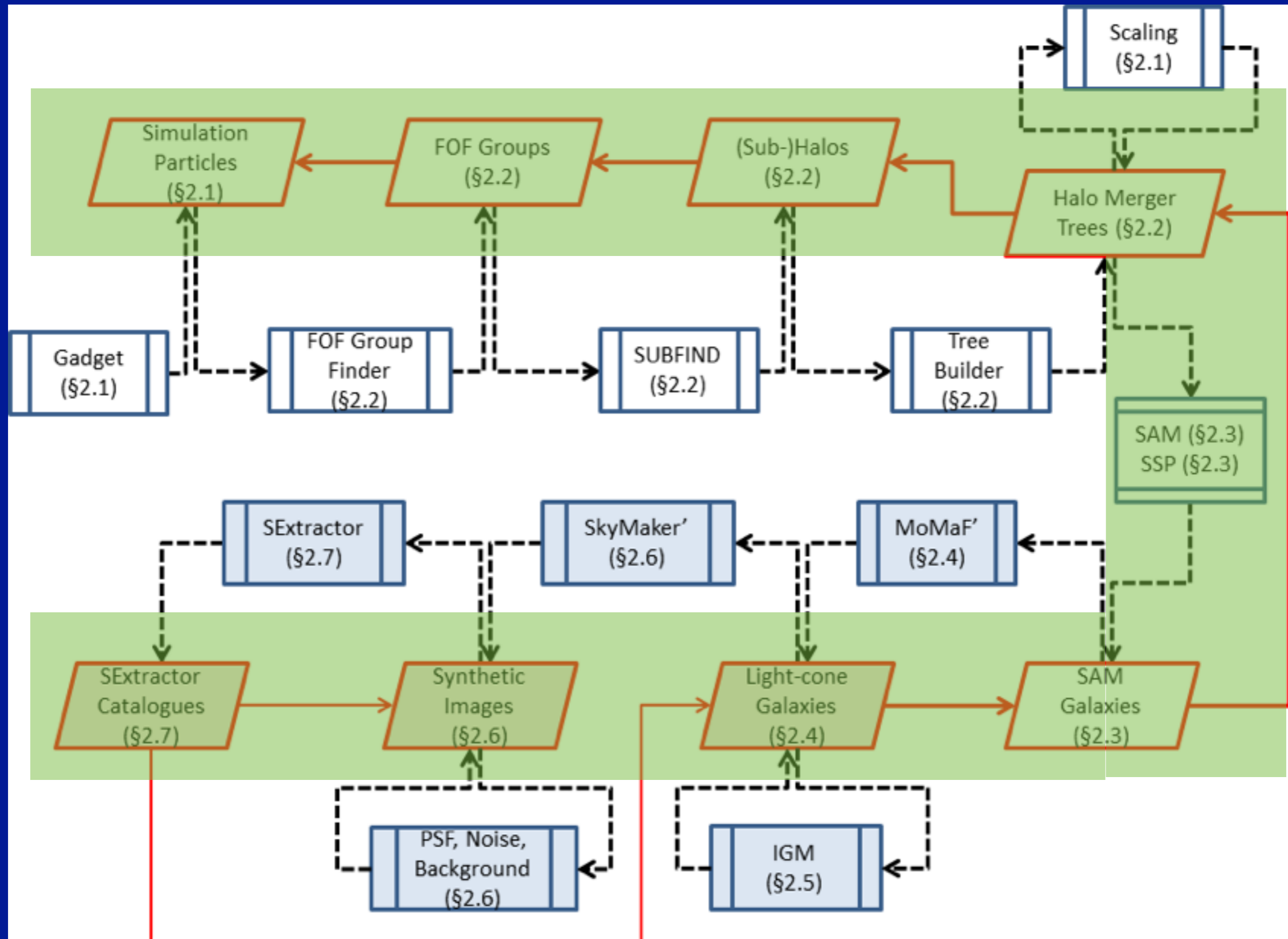
- **Simulation Identifier: cosmology, SAM, SSP, lightcone, IGM, survey, filter**  
*Example: WMAP1, Guo2010a, BC03, Henriques2012a.001, Madau, HUDF, B-band*
- **SQL query used to generate input (.txt)**
- Object input lists that can be read by Skymaker (.csv)
- **“Perfect” or model images (.fits)**
- PSF kernel image (.fits)
- **Mock telescope image (.fits)**



# Millennium Run Observatory Workflow

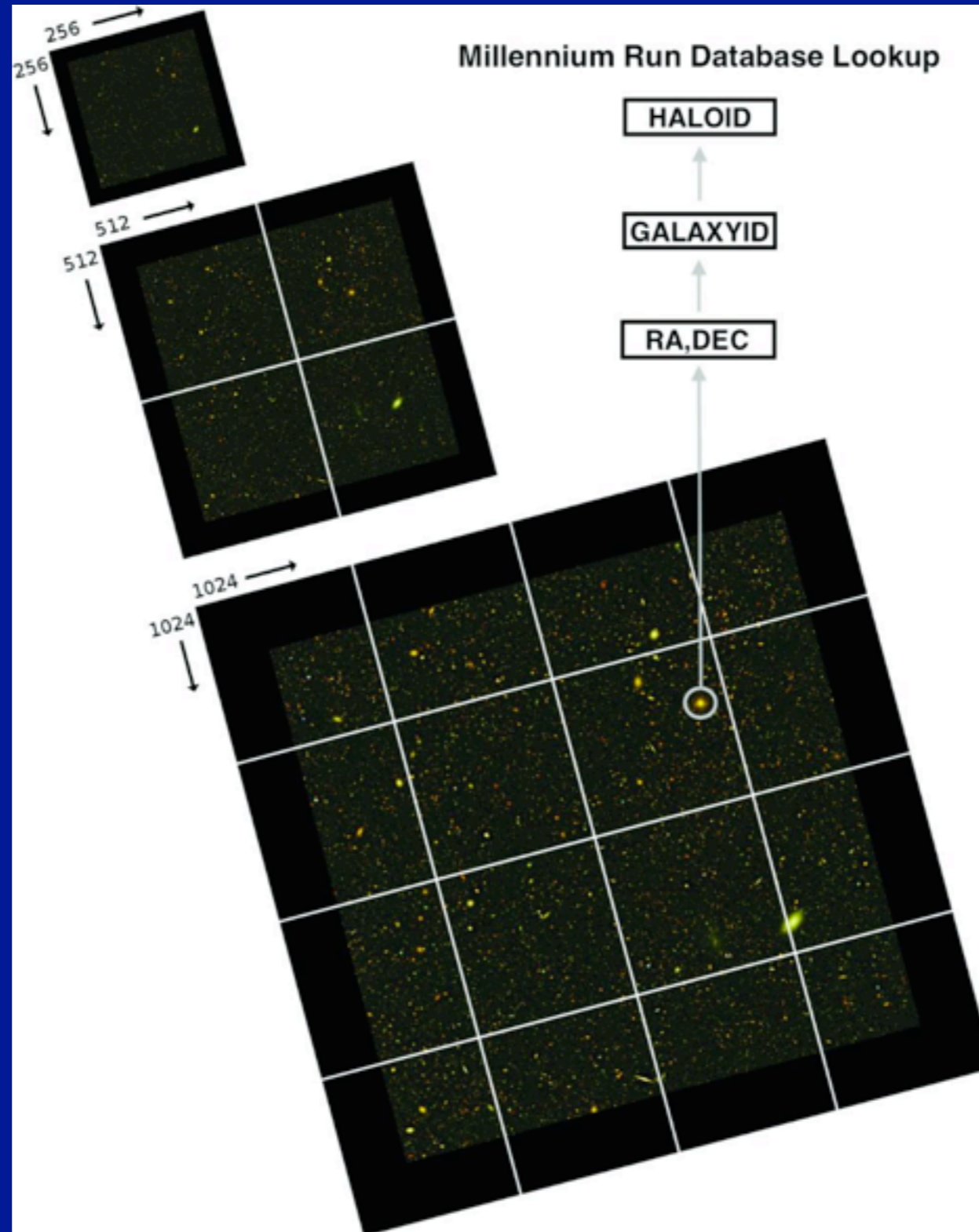


# Millennium Run Observatory Workflow





Direct links between image (coordinates), lightcones, snapshots, halotrees, fof groups, density fields, particles through the MRDB:



# The MRObs browser is one way to explore those links


 **THE MILLENNIUM RUN OBSERVATORY**  
MRObs - Interactive Browser

legal notice  
portal  
about & credits  
help


bc03.m24\_001

Images:  
UDF Viz Image w/ real UDF...  
UDF Viz Image w/ real UDF...  
SDSS gri Image  
CFHTLS-Wide gri Image  
CFHTLS-Deep gri Image  
CFHTLS-Deep riz Image  
HSC/Wide riz Image  
HSC/Deep riz Image  
HSC/Ultra-deep riz Image  
GOODS v2.0 BVz Image  
GOODS v2.0 Viz Image  
HUDF BVz Image  
HUDF Viz Image  
GOODS/ERS 9 filters Image  
GOODS/ERS UVIS Image  
GOODS/ERS SExtractor S...  
CANDELS/GSD YJH Image...  
CANDELS/GSD BVz Image...  
CANDELS/COSMOS F125...  
CANDELS/COSMOS F160...  
CANDELS/UDS J,J+H,H R...  
CANDELS/UDS F125W Im...  
CANDELS/UDS F160W Im...  
CANDELS/UDS J,J+H,H R...

Highlights:  
Blue Galaxy  
Red nuggets  
Big Galaxy  
Face-on bulge+disk  
Cluster (z=0.14)  
Low-mass Group (z=0.36)  
High-mass Group (z=0.37)  
Y-dropout 1 (z=7.4)  
Y-dropout 2 (z=8.1)  
Y-dropout 3 (z=8.4)  
Y-dropout 4 (z=7.5)  
J-dropout 1 (z=8.5)  
J-dropout 2 (z=9.5)  
J-dropout 3 (z=10.3)



**Galaxy Details**  
Galaxy 80000285000201



Wavelength (Ångstrom)

Show 100 entries Search:

index	Property	value
1	galid	80000285000201
2	haloid	80000285000163
3	ra	0.07169607
4	dec	-0.0076653347
5	z_geo	2.7833347
6	z_app	2.7825243
7	diskradius_arcsec	0.5418869224368056
8	bulgesize_arcsec	0
9	pa	30.107199
10	inclination	43.62655
11	u	28.391722
12	b	25.619392
13	v	25.402882
14	rc	25.526402
15	ic	25.54193

<http://galformod.mpa-garching.mpg.de/mrobs/private/browser/>



# Create your own simulated observations from lightcones in the MRDB

Max-Planck-Institut für Astrophysik

Galformod Common Jobrunner (dev)  
Simple UWS Web Client

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### Applications & Models

Applications & Models

Available Applications:  UWS based job submission portal for Mrobs codes

Application Models:  choose the model to load (into input form below)

---

### Parameter Input Form

MODE	<input type="text" value="produce perfect image"/>	Choose the pipeline mode
OBSERVER	<input type="text" value="mrobuser"/>	Give your name
CONTEXT	<input type="text" value="my_observation"/>	Give a label for your observation
TELESCOPE	<input type="text" value="HST"/>	Specify the telescope
CAMERA	<input type="text" value="HST/ACS/WFC"/>	Specify the detector
FILTER	<input type="text" value="HST/ACS/WFC F606W"/>	Specify the filter
TOTAL_EXPTIME	<input type="text" value="1,000"/>	Specify the total exposure time
NEXP	<input type="text" value="10"/>	Specify the number of sub-exposures
COMBINE	<input type="text" value="mean"/>	Specify the image combination method
KEEP_SUBEXPOSURES	<input type="text" value="No"/>	
FINAL_PIXEL_SIZE	<input type="text" value="0.06 arcsec"/>	Specify the desired output pixel size
IMAGE_SIZE_PIXELS	<input type="text" value="32768x32768 pixels"/>	Specify the desired image size
APPLY_STARS	<input type="text" value="No"/>	Do you want to add stars?
APPLY_IGM	<input type="text" value="Yes"/>	Do you want to apply IGM absorption?
IGMTABLE	<input type="text" value="Madau (1995) model"/>	Specify the IGM absorption model
TABLENAME	<input type="text" value="henriques2012a 001"/>	Select the lightcone
SCHEMA	<input type="text" value="Bruzual and Charlot (2003)"/>	Select the SED library

(under construction, see Matthias Egger's talk)

## On-going developments

- MRObs simulations of important surveys to better study the data  
e.g. HST UDF, CANDELS, CLASH (JWST)  
ESO VST/VISTA public surveys  
Dark Energy Surveys (HETDEX, DES, LSST, HSC, PFS, JPAS, Euclid)
- make it possible for people to run their own simulations online
- gravitational lensing (see talk by Ben Metcalfe)
- combine MR and MS-II to ease volume and resolution limitations  
(e.g. useful for dwarf galaxies nearby or typical galaxies at very high redshifts)
- develop a fully-integrated workflow that combines SAMs, lightcones, and MRObs images for maximal flexibility and parameter space studies constrained by observations