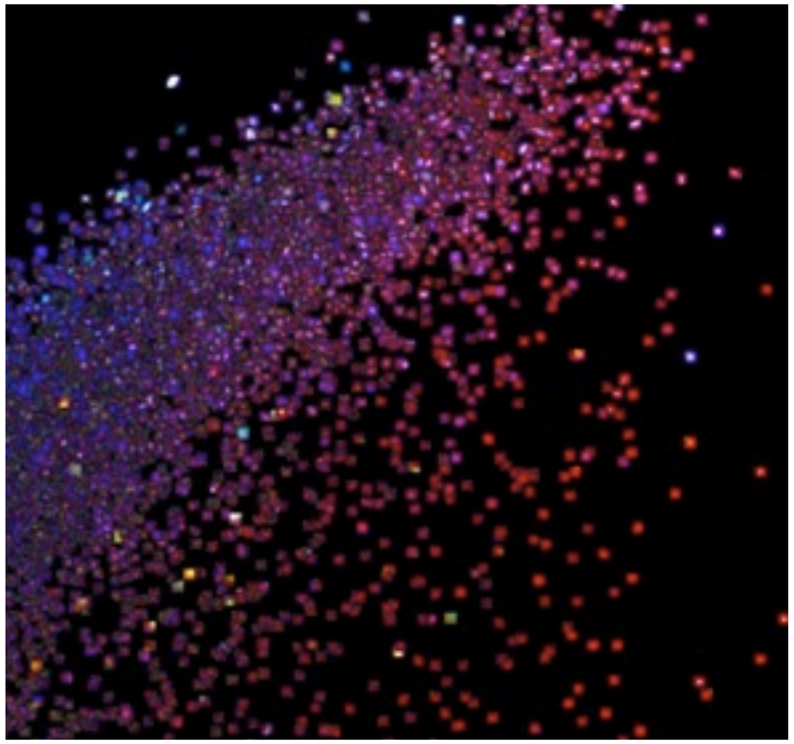
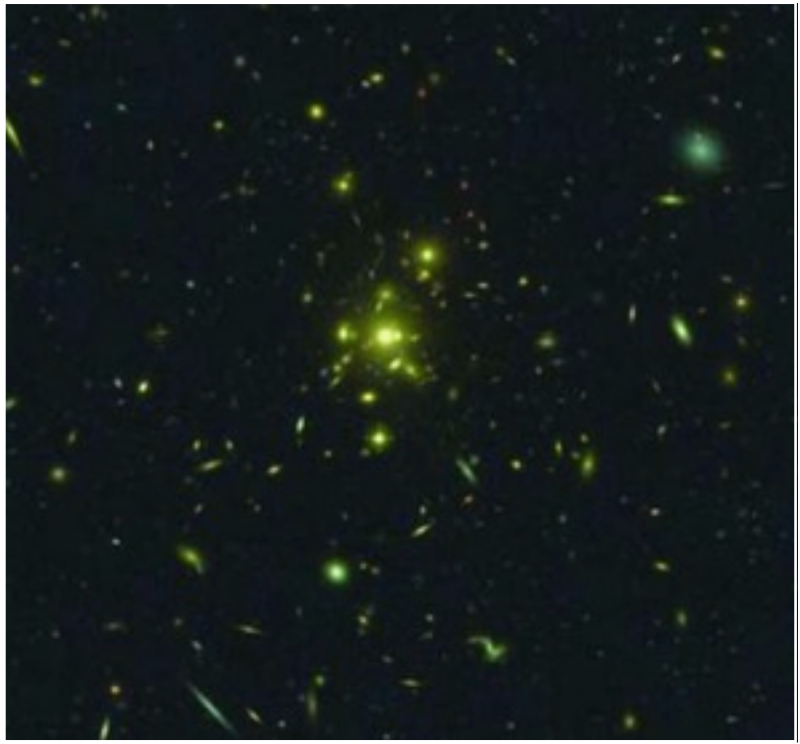
The Millennium Run Observatory

Roderik Overzier (UT Austin) + Gerard Lemson + Galformod

Max-Planck-Institut für Astrophysik

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***

see Overzier, Lemson, Angulo, Bertin, Blaizot, Henriques, Marleau, White 2013, MNRAS, 428, 778

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?

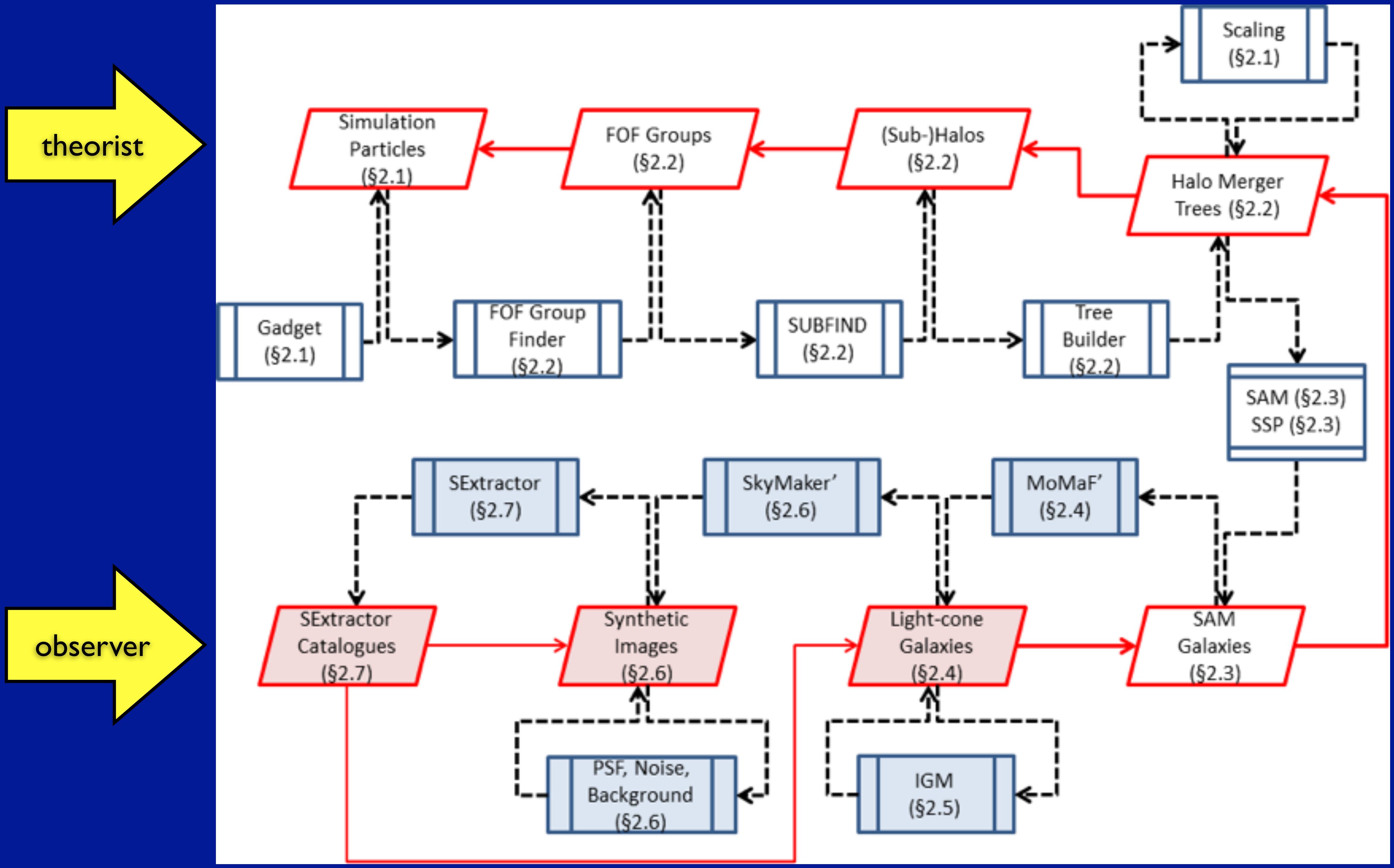
2. Derive physical quantities from observations

- observational astrophysics is hard!

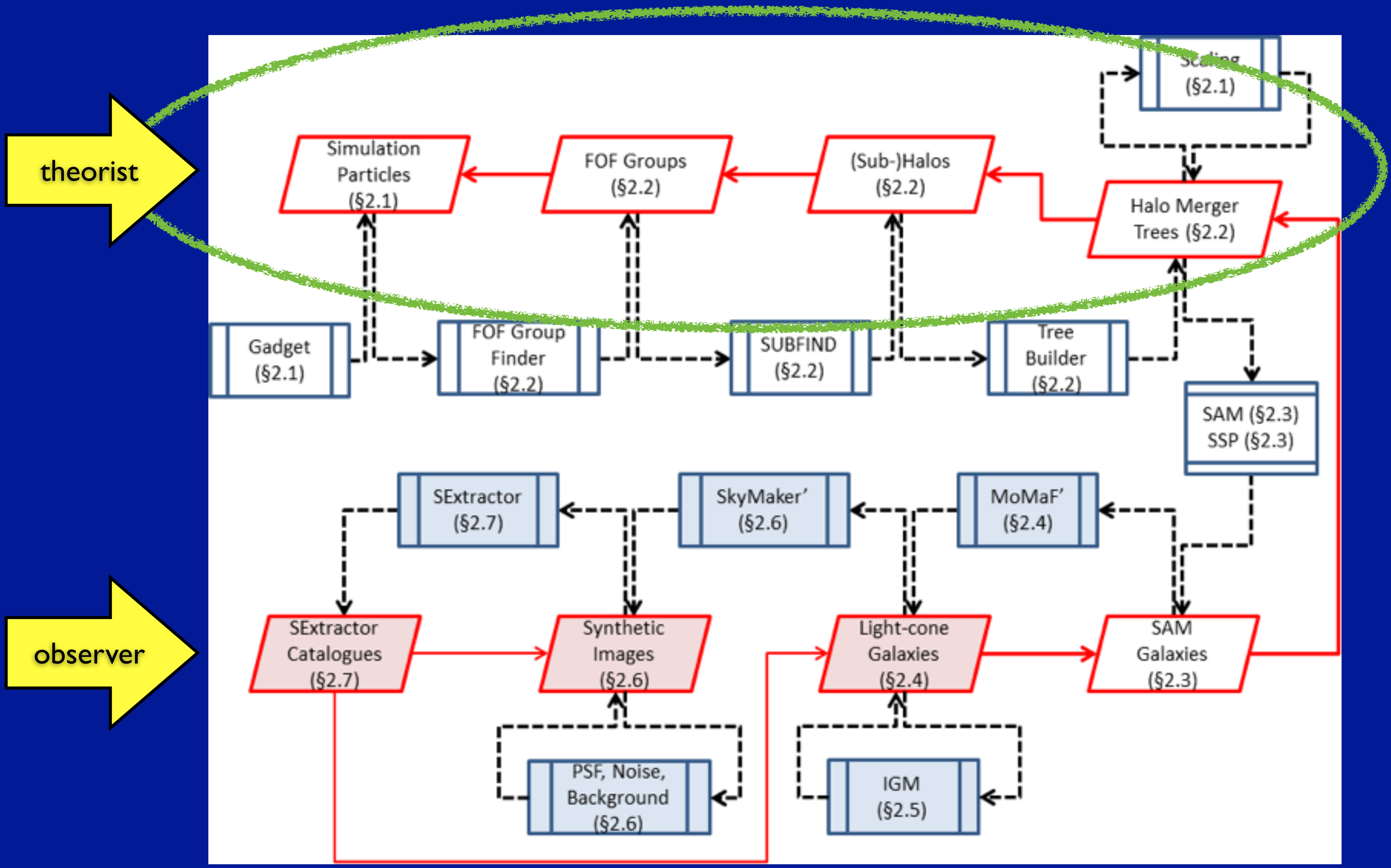
Our approach

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



Millennium Run Observatory Workflow



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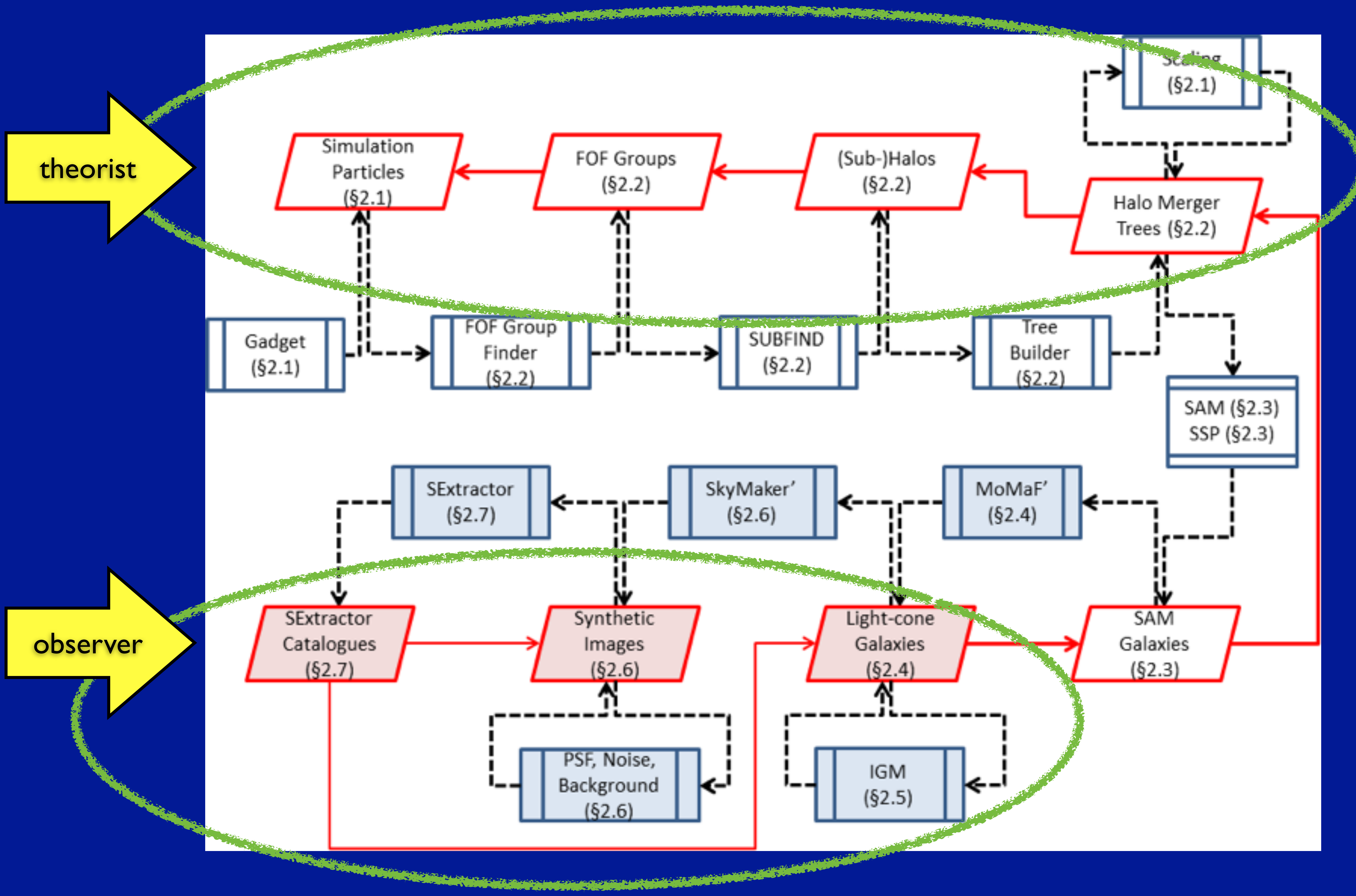

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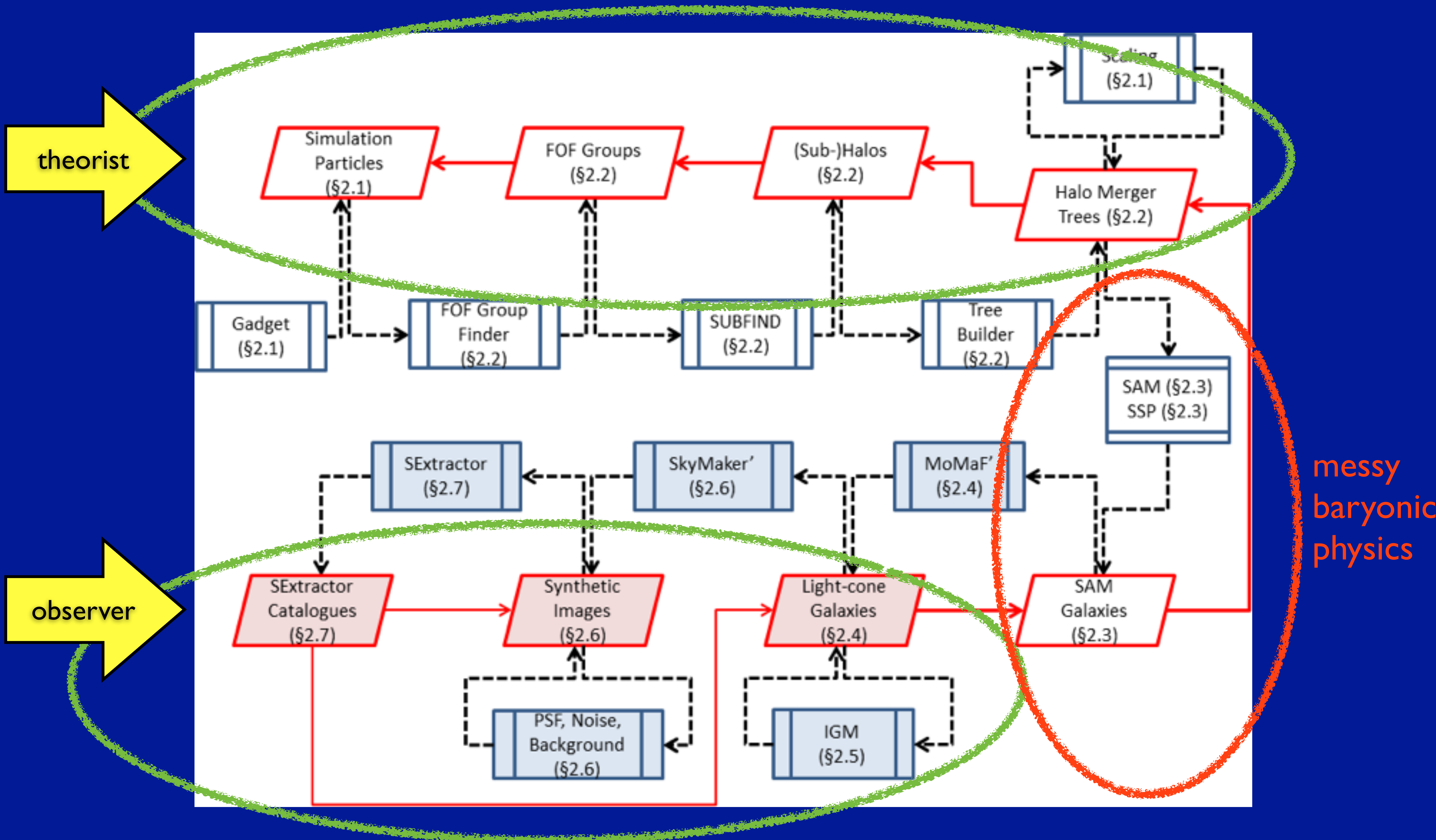

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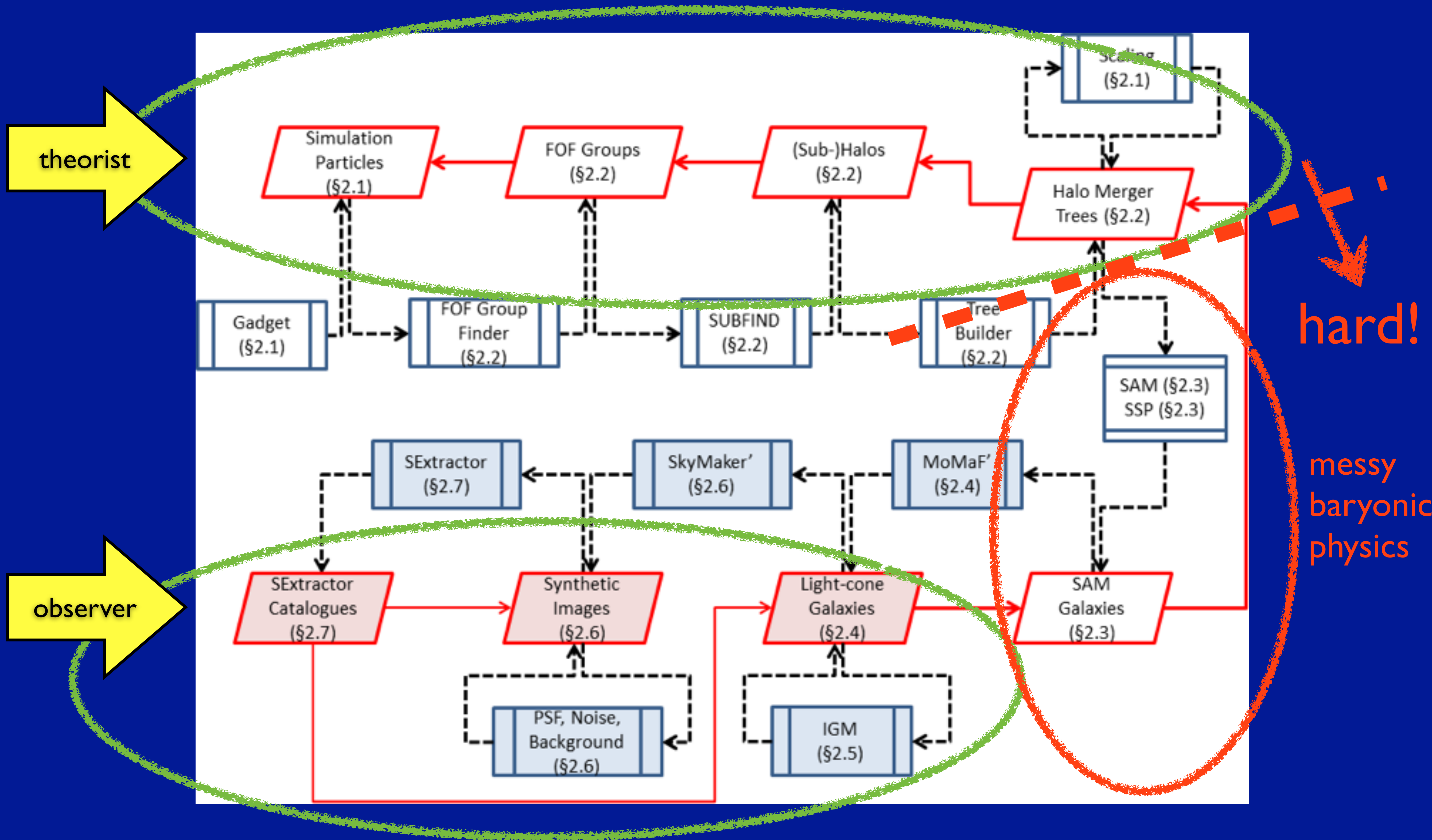

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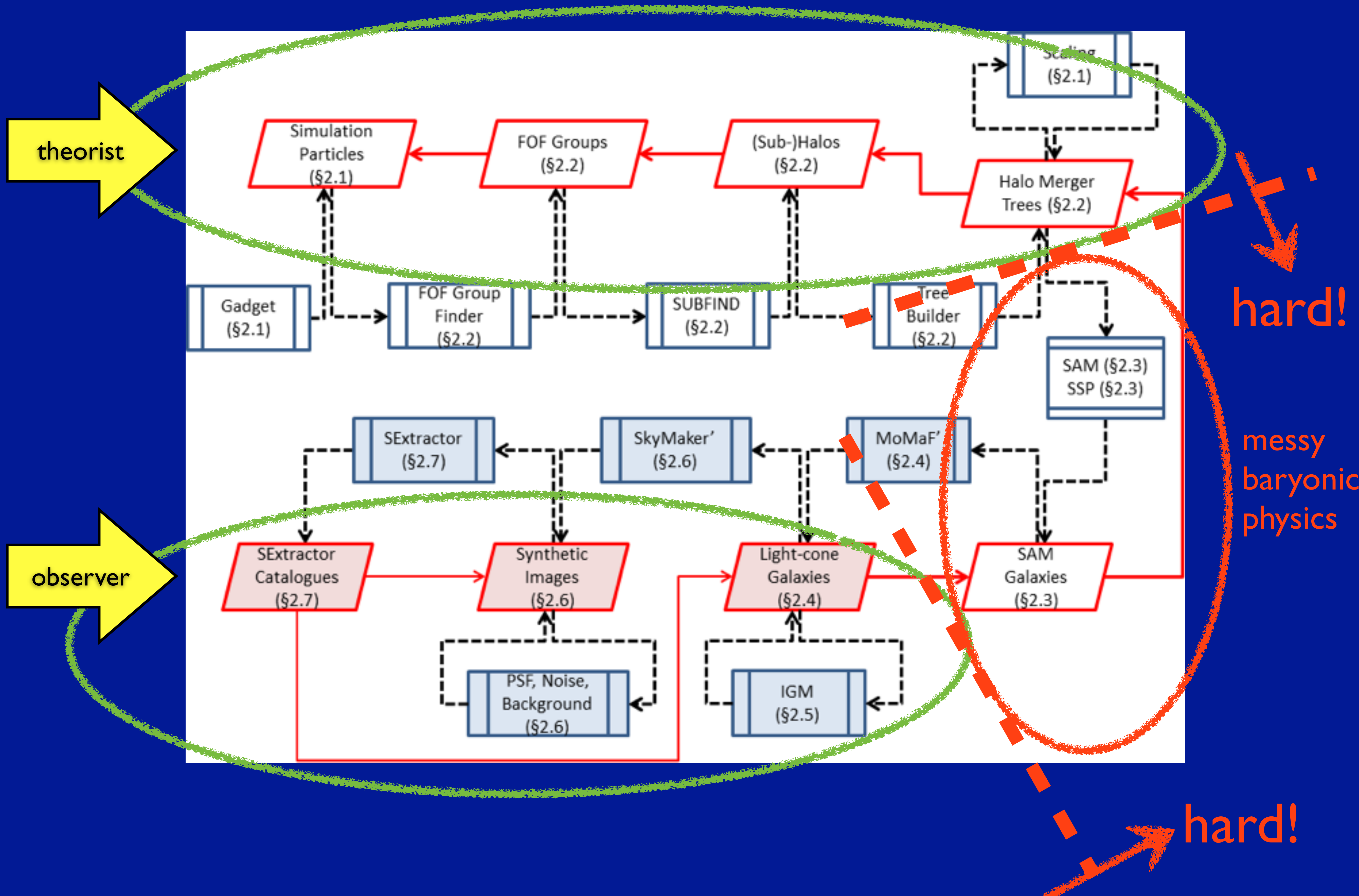

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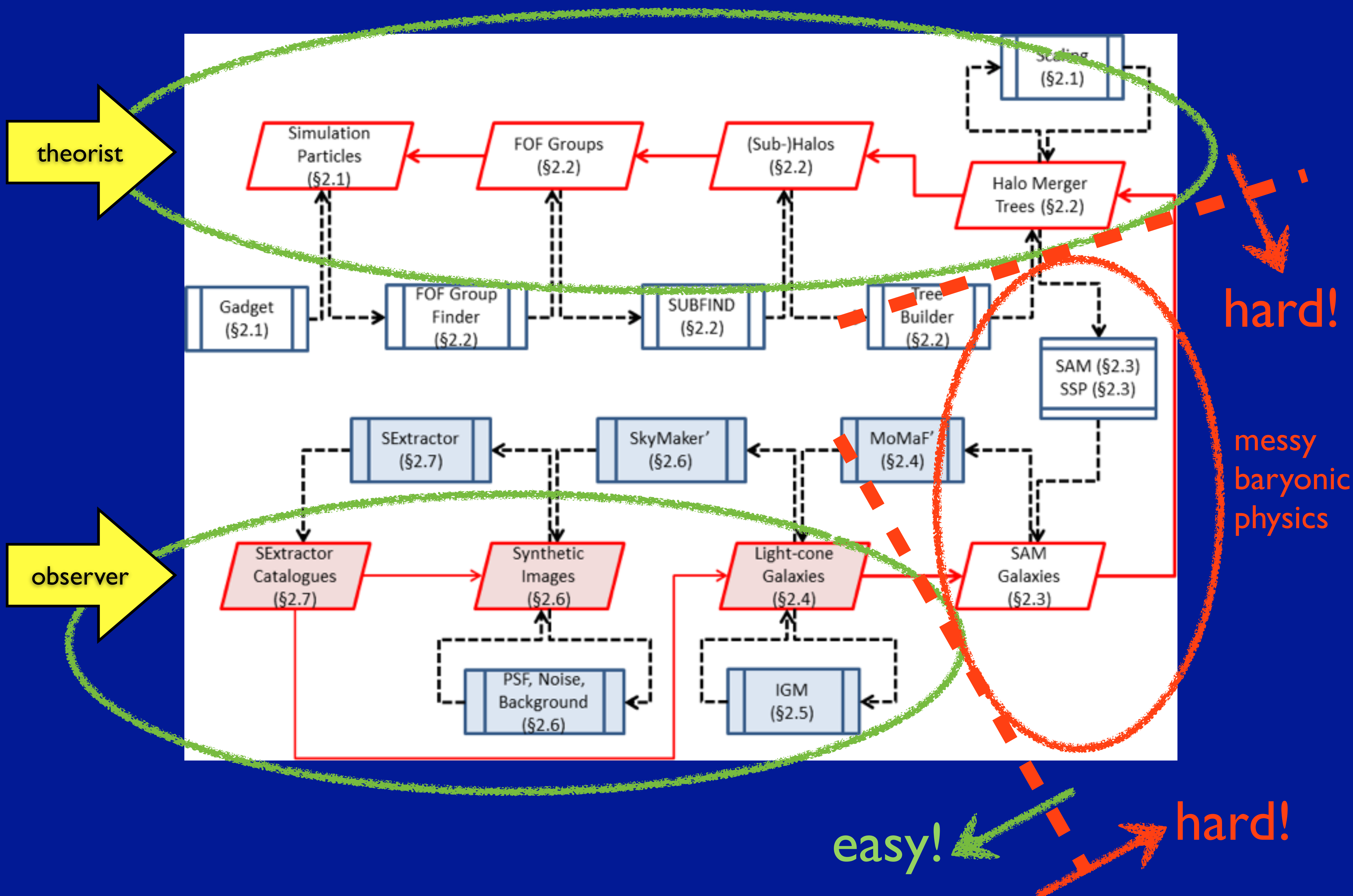


<u>Simulations</u> *Comparison Method* <u>Observations</u>

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

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

Simulations | *Comparison Method* | Observations

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

number counts/clustering

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

Simulations	*Comparison Method*	Observations
N-body or LT Dark Matter (M_{halo},pos,vel)	number counts/clustering ⟷	
SAM/Hydro (M_{stars},SFR,size,...)	SED fitting of Data ⟷	
		Detected Objects ("Galaxies") (mags, colors, sizes, (z))

Simulations	Comparison Method	Observations
N-body or LT Dark Matter (M_{halo},pos,vel)	number counts/clustering ⟷	
SAM/Hydro (M_{stars},SFR,size,...)	SED fitting of Data ⟷	
SAM+synthesis modeling (rest-frame mags, colors)	SEDs applied to Simulation, selection function affects data ⟷	
		Detected Objects ("Galaxies") (mags, colors, sizes, (z))

Simulations	*Comparison Method*	Observations
N-body or LT Dark Matter (M_{halo},pos,vel)	number counts/clustering ⟷	
SAM/Hydro (M_{stars},SFR,size,...)	SED fitting of Data ⟷	
SAM+synthesis modeling (rest-frame mags, colors)	SEDs applied to Simulation, selection function affects data ⟷	
Mock/Lightcone (obs-frame mags, colors)	Realistic comparison but still idealized! ⟷	
		Detected Objects (“Galaxies”) (mags, colors, sizes, (z))

Simulations | *Comparison Method* | Observations

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

number counts/clustering

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

SED fitting of Data

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

SEDs applied to Simulation, selection function affects data

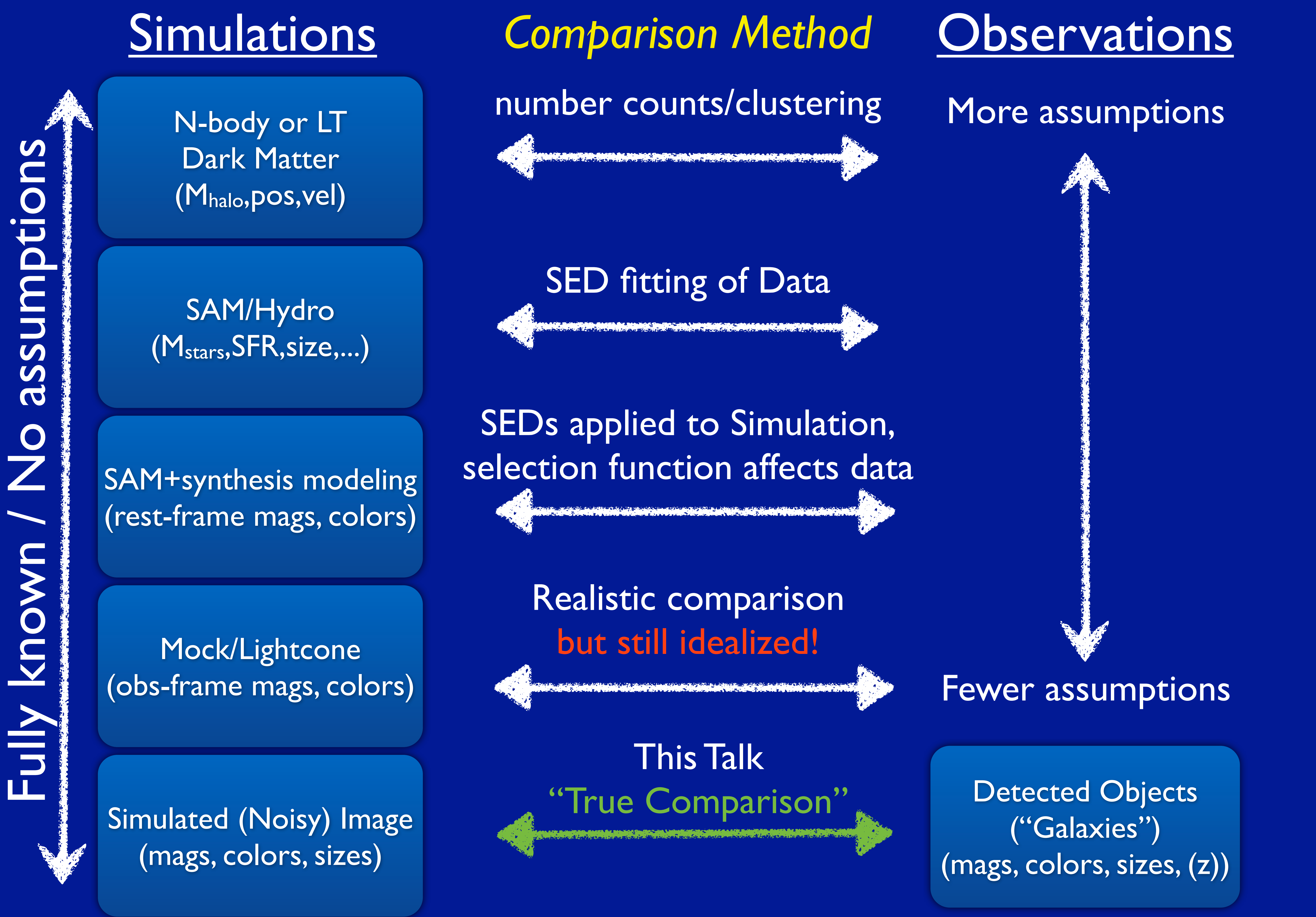
Mock/Lightcone (obs-frame mags, colors)

Realistic comparison
but still idealized!

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

This Talk
"True Comparison"

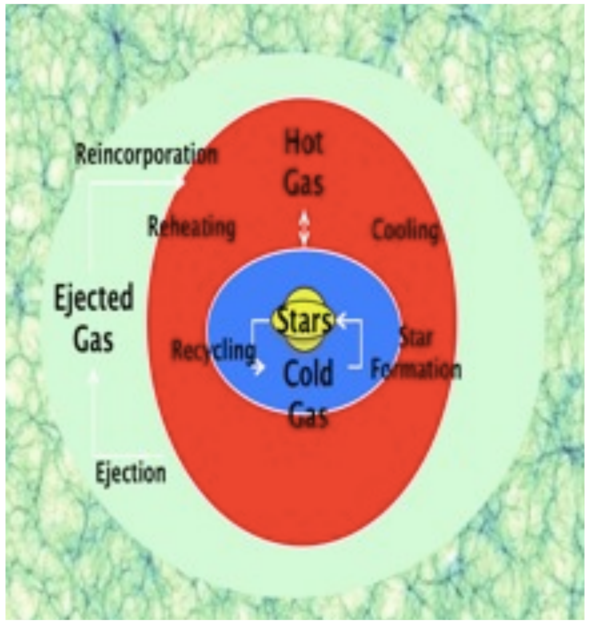
Detected Objects ("Galaxies") (mags, colors, sizes, (z))

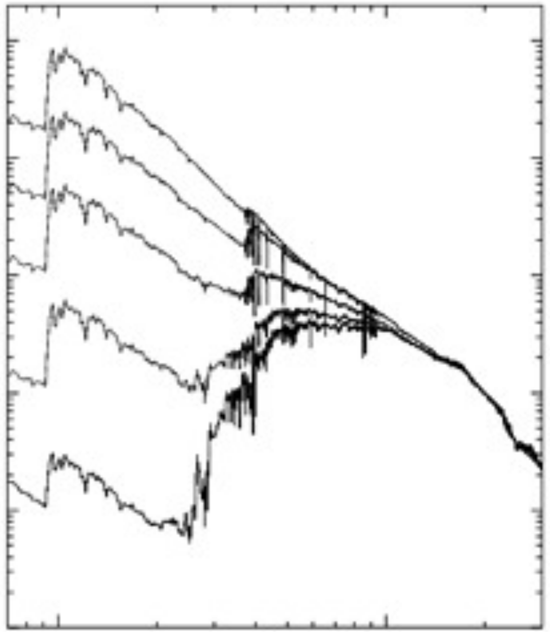

Simulations
Comparison Method
Observations
Fully known / No assumptions
N-body or LT
Dark Matter
(M_{halo},pos,vel)
number counts/clustering
More assumptions
SAM/Hydro
(M_{stars},SFR,size,...)
SED fitting of Data
SAM+synthesis modeling
(rest-frame mags, colors)
SEDs applied to Simulation,
selection function affects data
Mock/Lightcone
(obs-frame mags, colors)
Realistic comparison
but still idealized!
Fewer assumptions
Simulated (Noisy) Image
(mags, colors, sizes)
This Talk
"True Comparison"
Detected Objects
("Galaxies")
(mags, colors, sizes, (z))

The Millennium Run Observatory in a nutshell

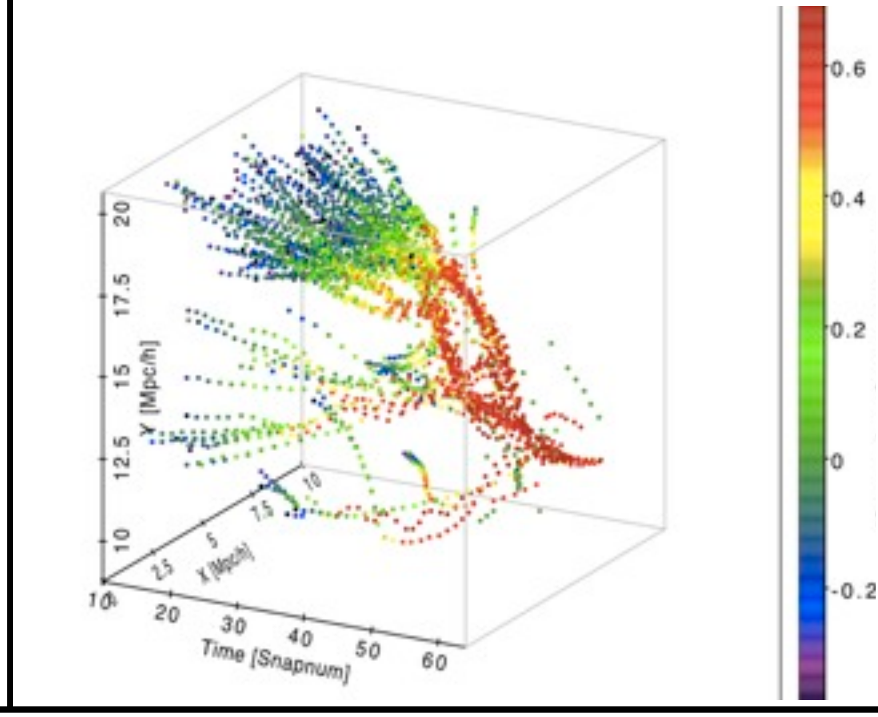
1. DM simulation

2. Semi-analytic Models + SSP Library

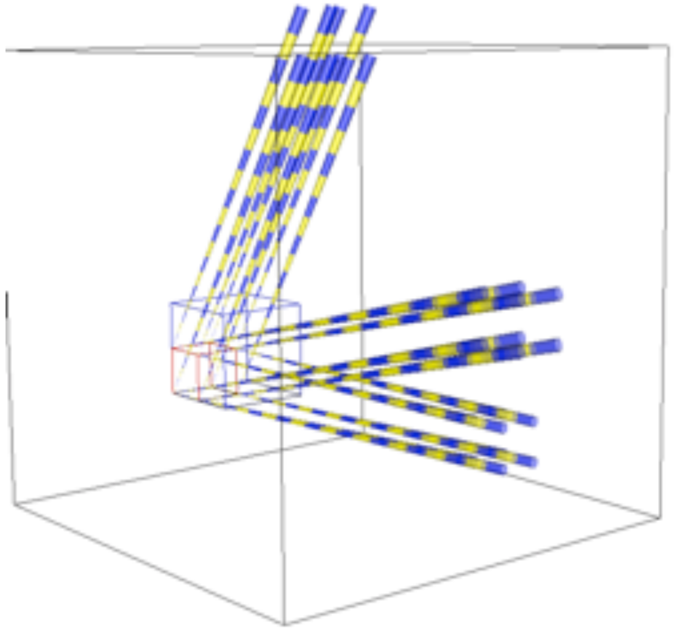




3. Evolving Galaxy Population

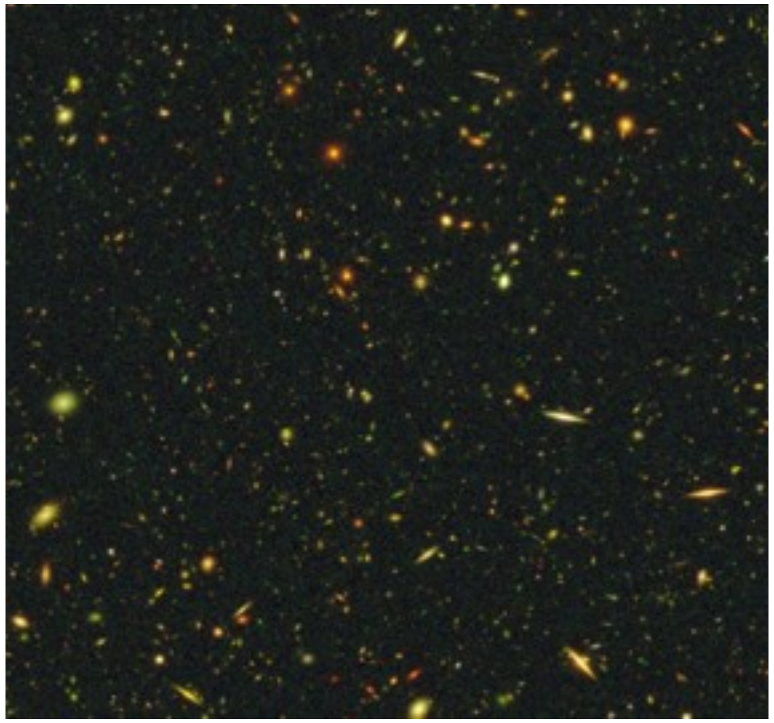


4. Observer's Lightcone



5. Virtual Telescope model + Survey Description

6.*FITS-quality* Simulated Data



Precise predictions from the *Millennium Run Observatory*

Simulating the Hubble Ultra Deep Field

Full SAM prediction, NO artist's impression

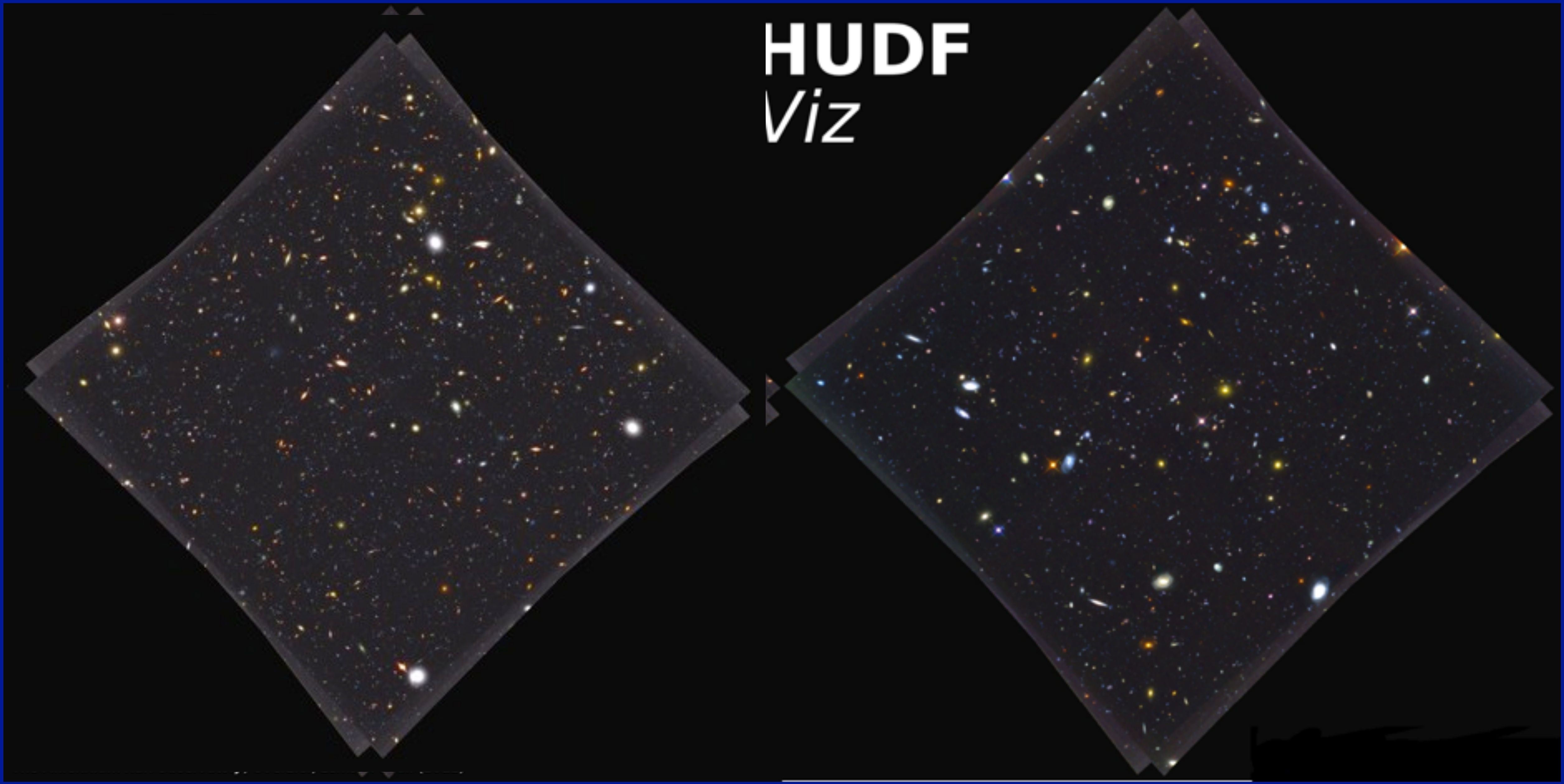
- positions
- disks & bulges
- sizes
- inclination & position angle
- magnitudes w/ dust

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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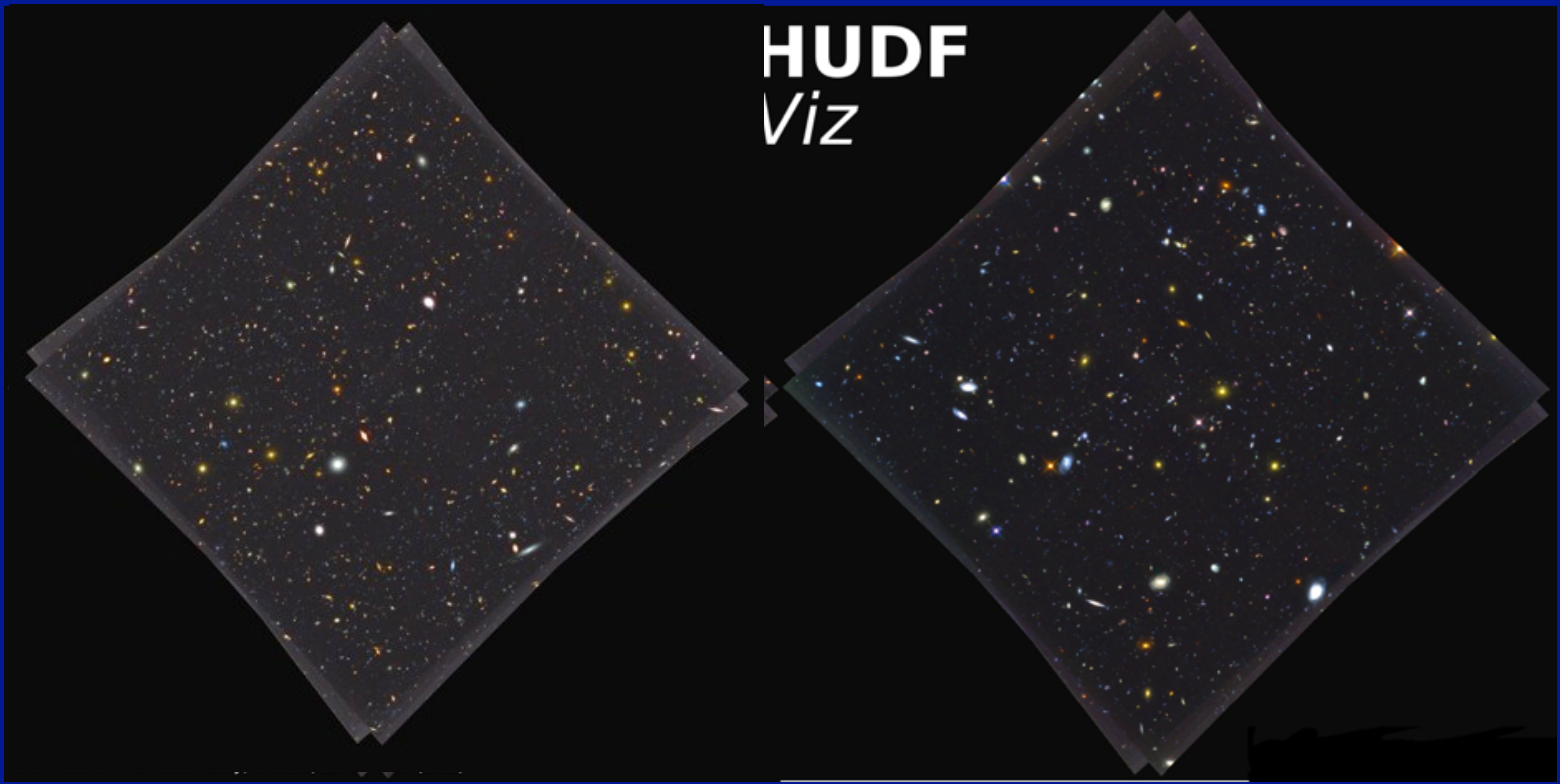

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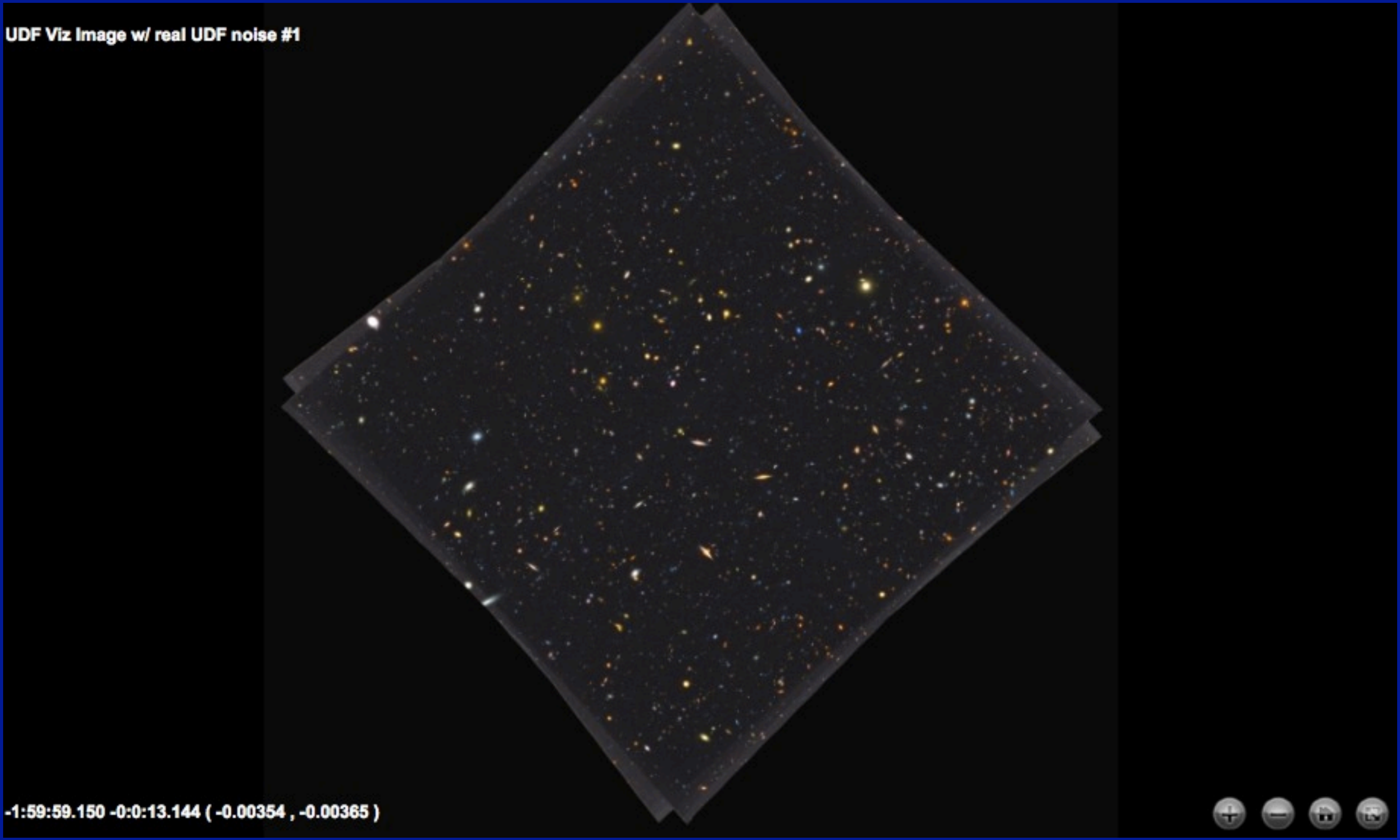
UDF Viz Image w/ real UDF noise #1
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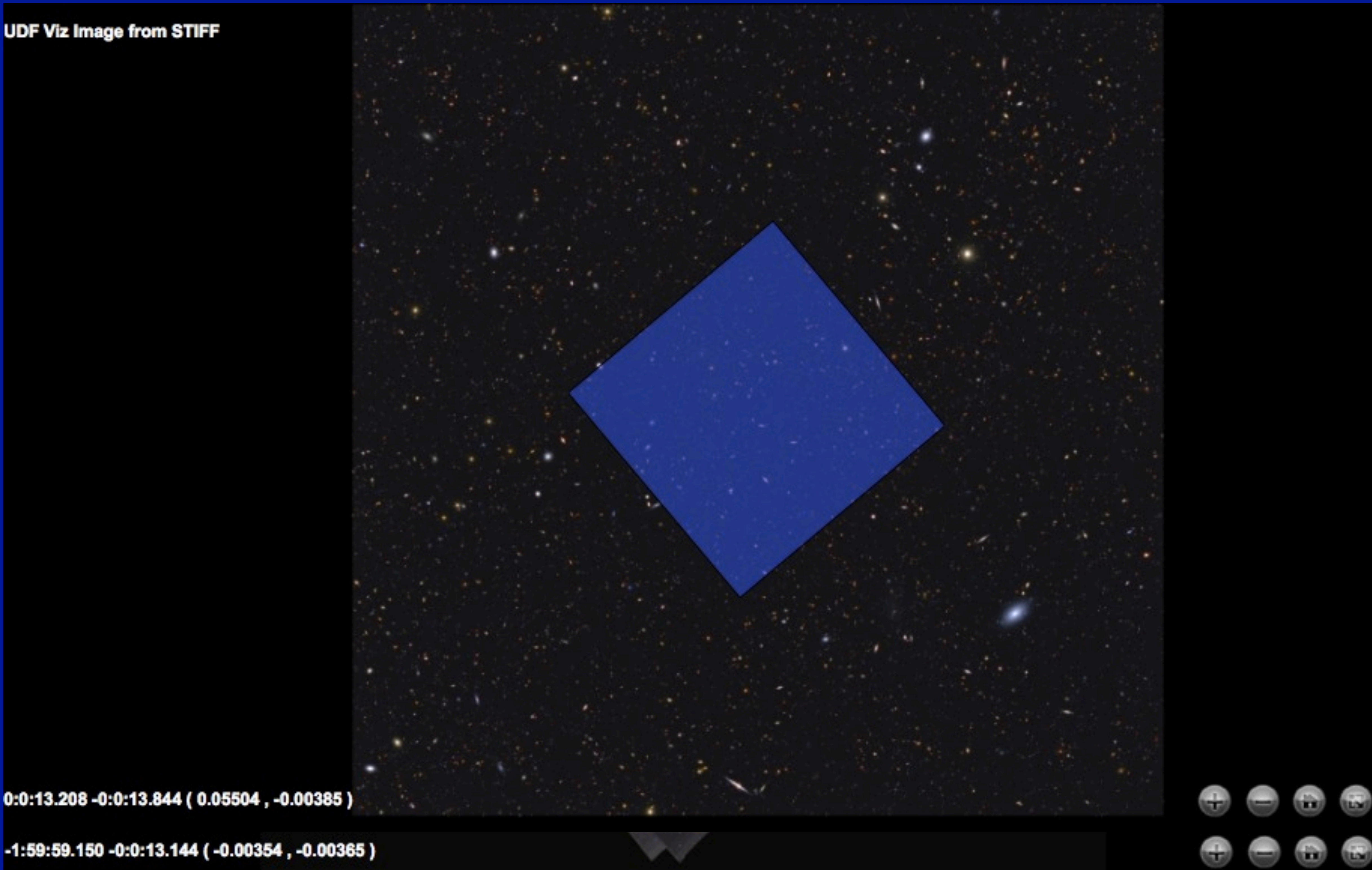
UDF Viz Image from STIFF
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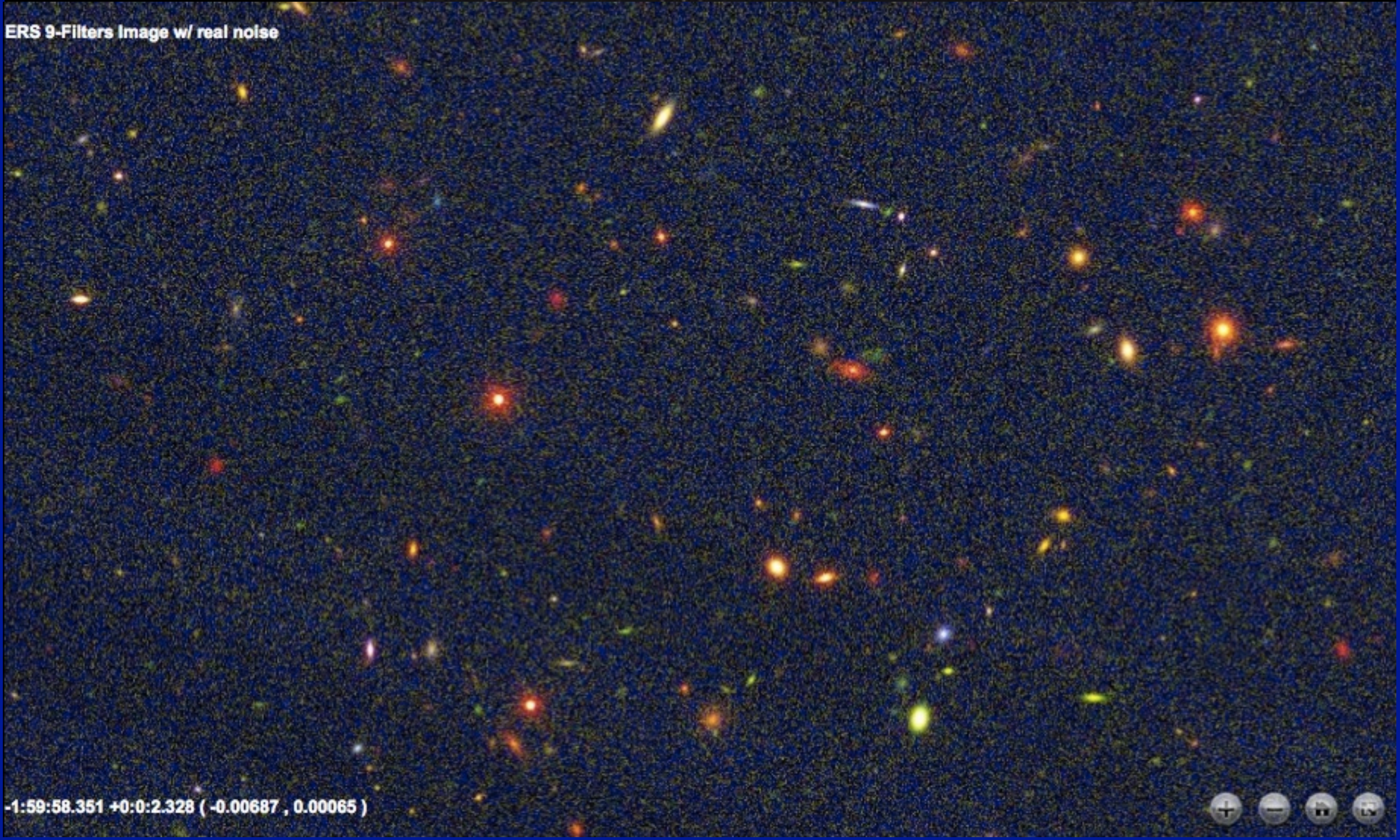
-1:59:59.150 -0:0:13.144 (-0.00354 , -0.00365)


UDF Viz Image from STIFF


ERS 9-Filters Image w/ real noise
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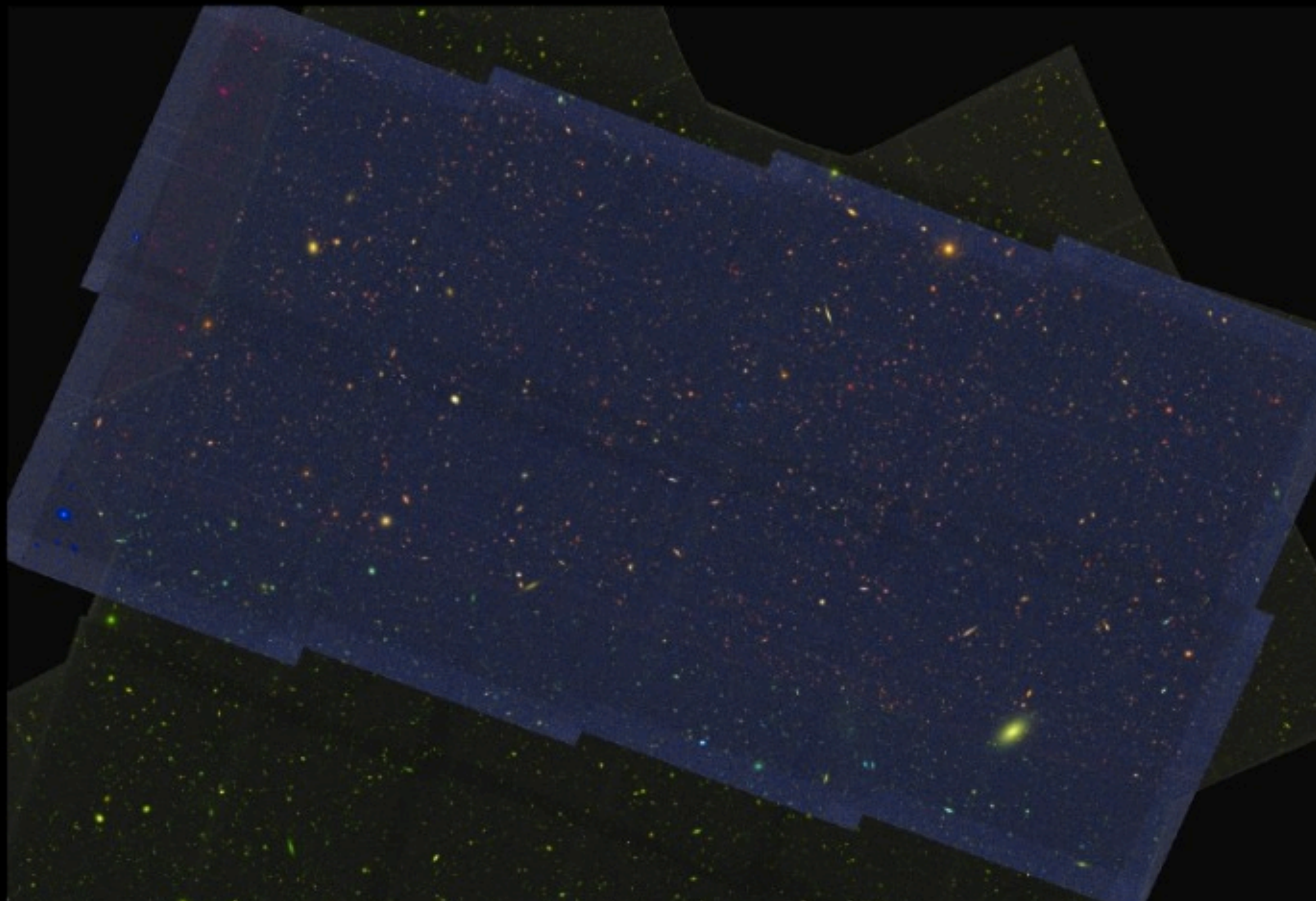
UDF Viz Image from STIFF

ERS 9-Filters Image w/ real noise

ERS 9-Filters Image w/ real noise



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UDF Viz Image from STIFF
ERS 9-Filters Image w/ real noise
ERS 9-Filters Image w/ real noise
HSC WIDE riz 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 riz Image
HSC DEEP riz Image
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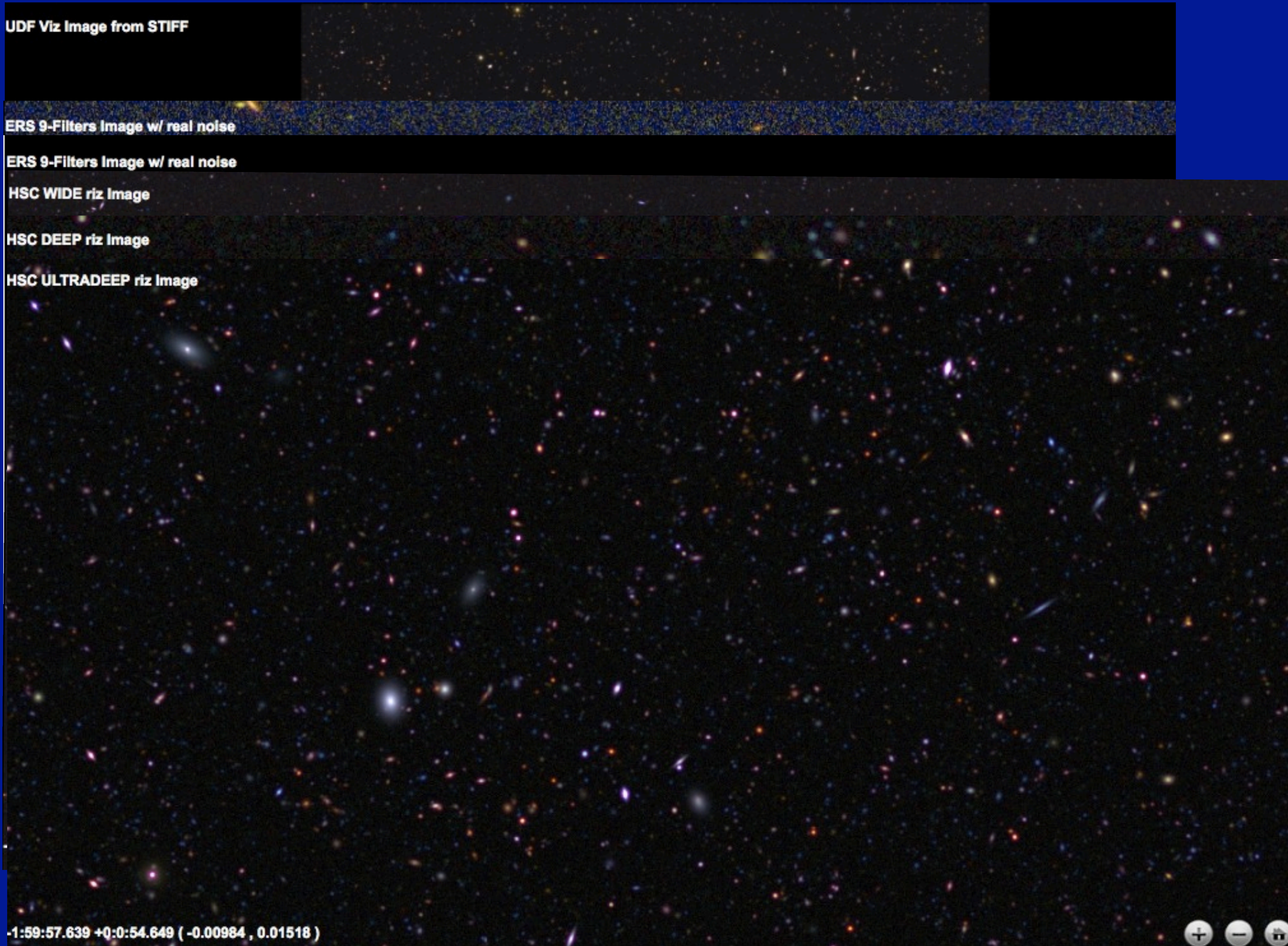

UDF Viz Image from STIFF
ERS 9-Filters Image w/ real noise
ERS 9-Filters Image w/ real noise
HSC WIDE riz Image
HSC DEEP riz Image
HSC ULTRADEEP riz Image
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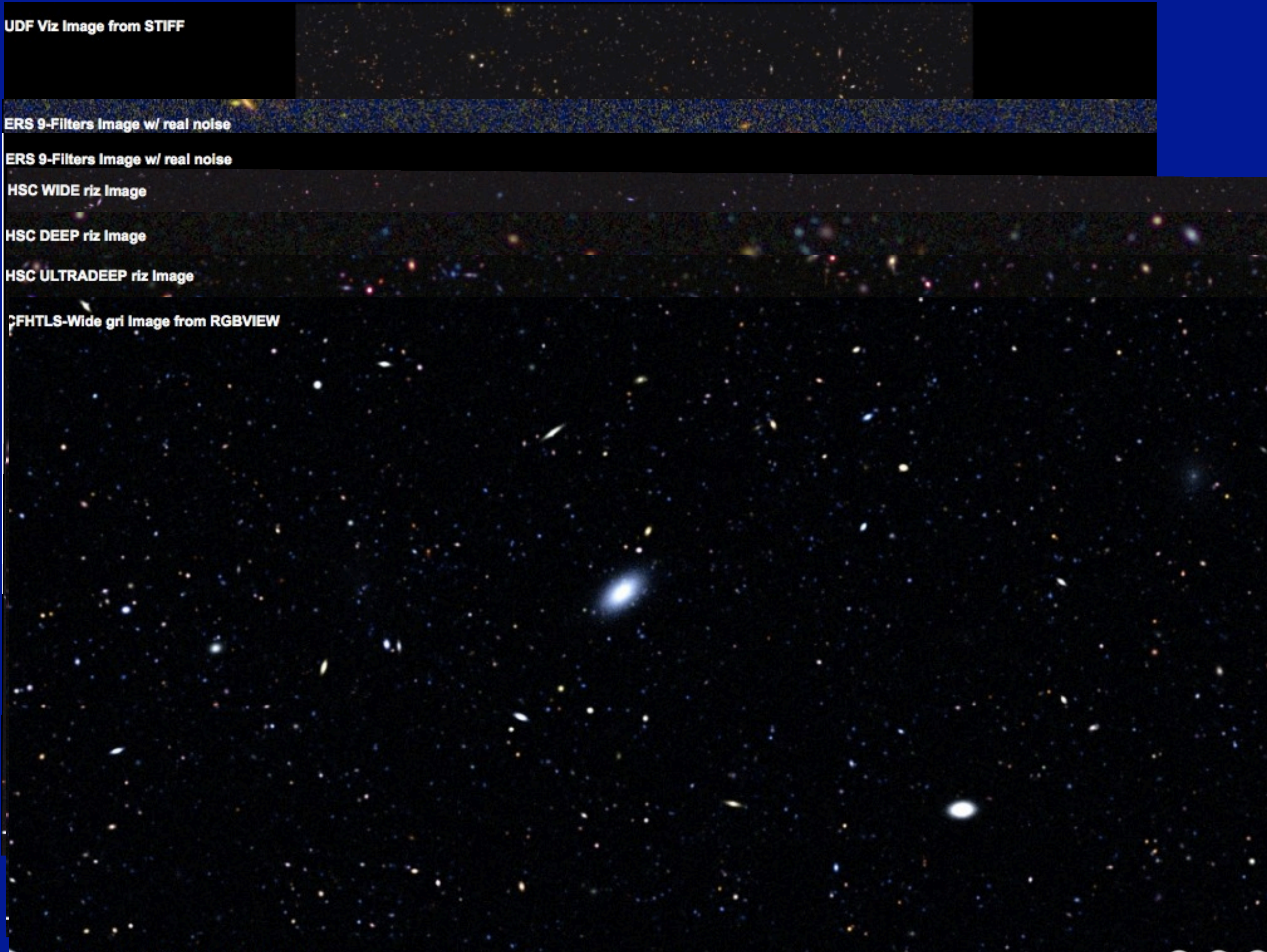
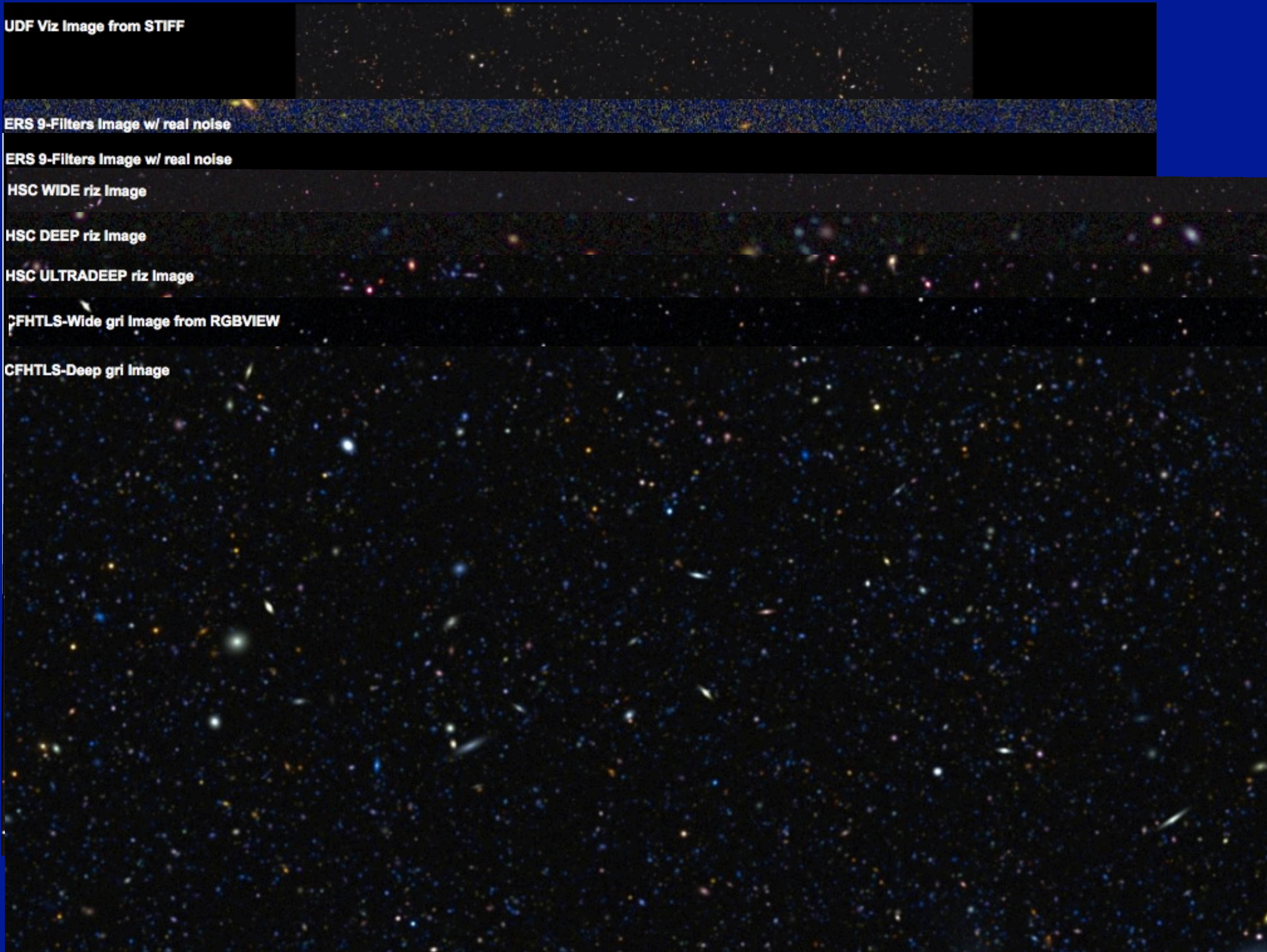
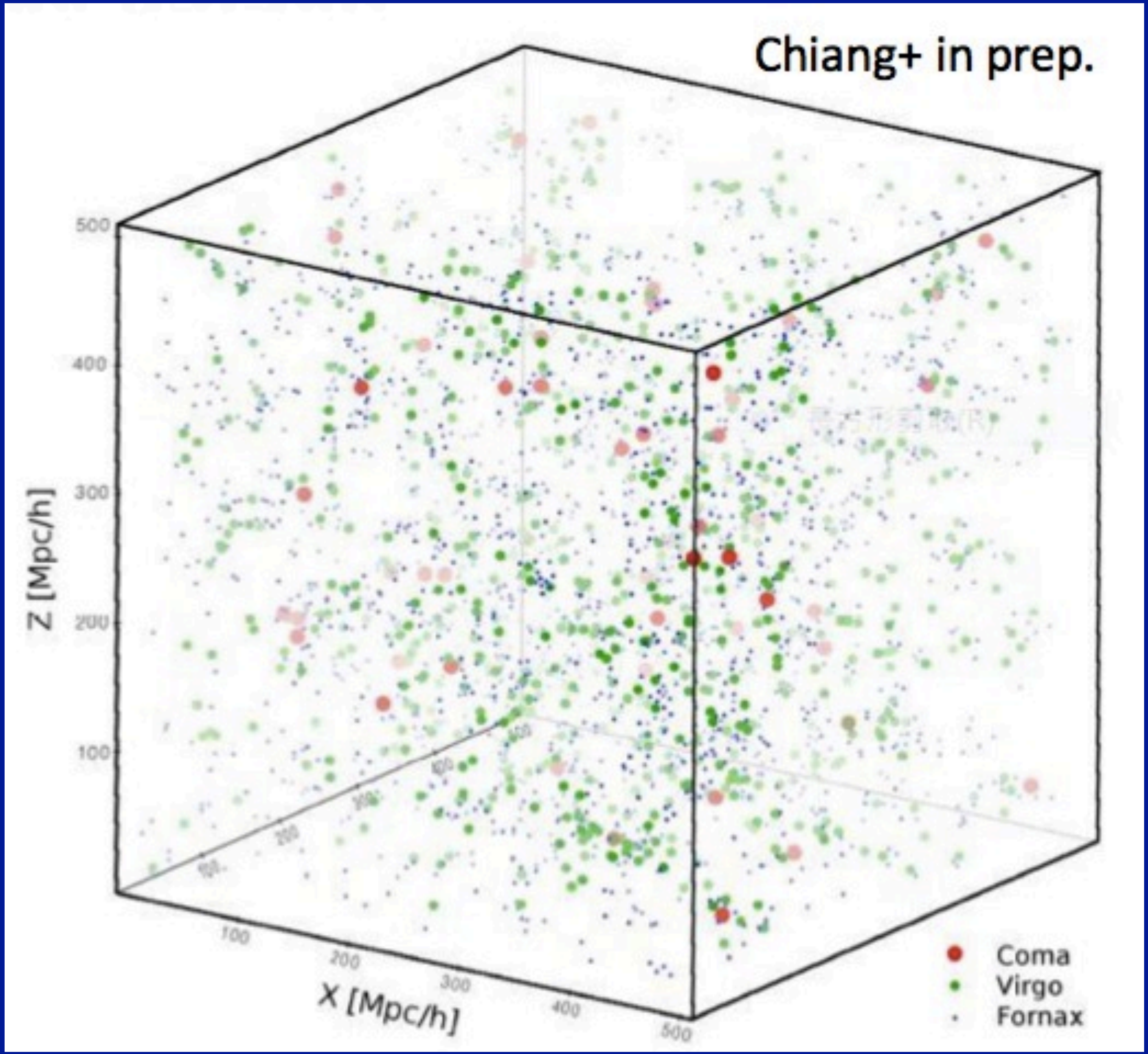

UDF Viz Image from STIFF
ERS 9-Filters Image w/ real noise
ERS 9-Filters Image w/ real noise
HSC WIDE riz Image
HSC DEEP riz Image
HSC ULTRADEEP riz Image
CFHTLS-Wide gri Image from RGBVIEW

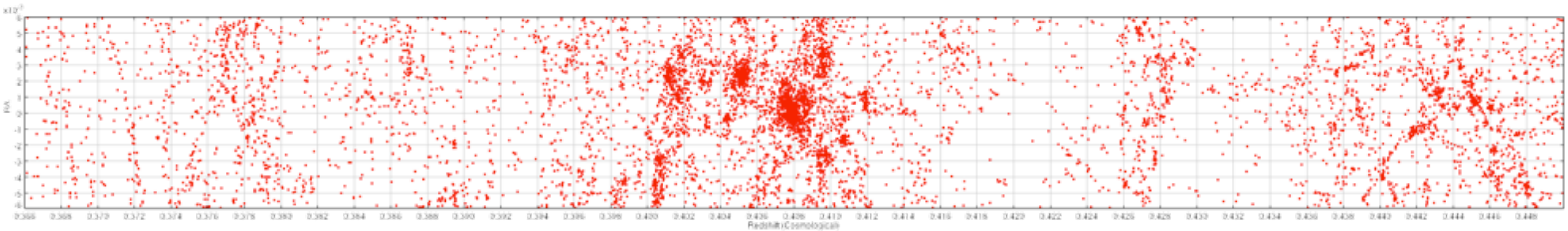

UDF Viz Image from STIFF
ERS 9-Filters Image w/ real noise
ERS 9-Filters Image w/ real noise
HSC WIDE riz Image
HSC DEEP riz Image
HSC ULTRADEEP riz Image
CFHTLS-Wide gri Image from RGBVIEW
CFHTLS-Deep gri Image

Lightcones aimed at a specific object at a specific redshift

locations of 3,000 clusters in the MR

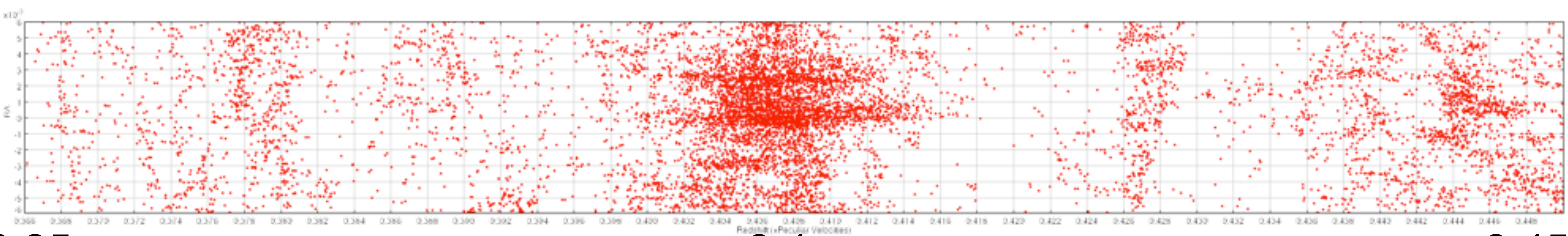


a massive cluster selected at z=0, ‘observed’ in the lightcone at z=0.4:



0.35 0.4 0.45

Cosmological Redshift



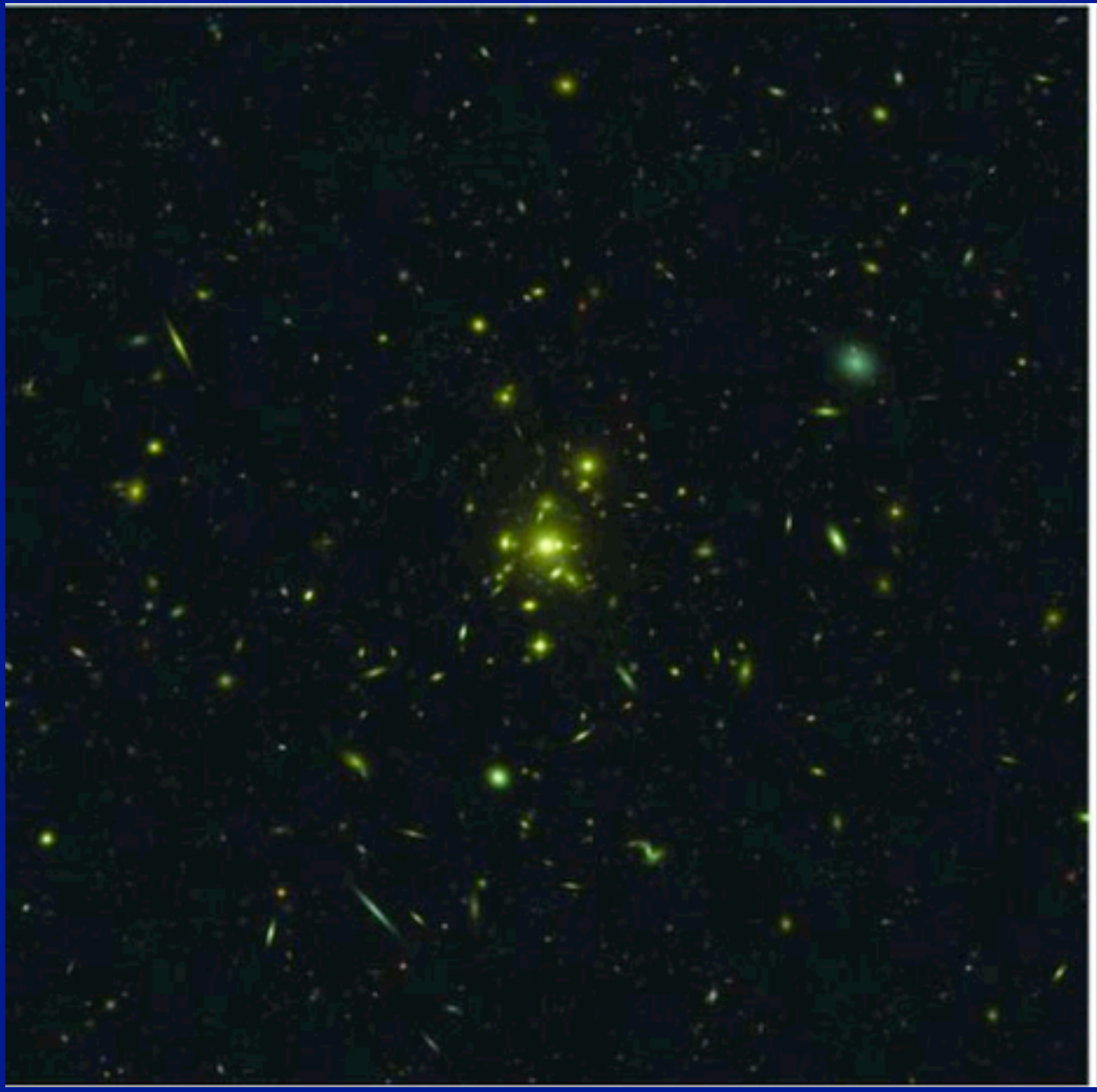
0.35 0.4 0.45

Apparent Redshift (includes peculiar velocities)

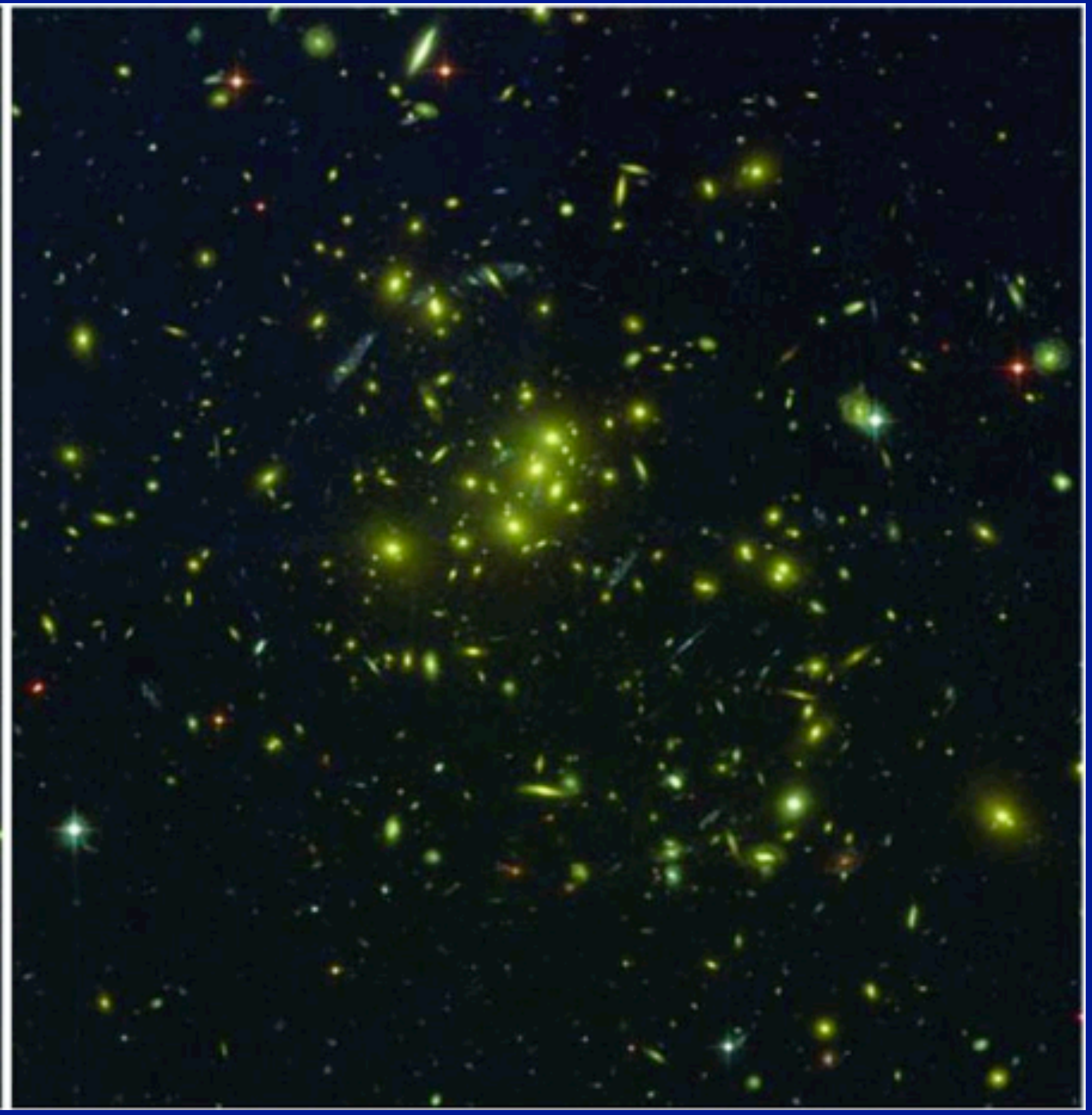
Precise predictions from the *Millennium Run Observatory*

z = 0.4 Massive cluster

MRObs Mock HST observation



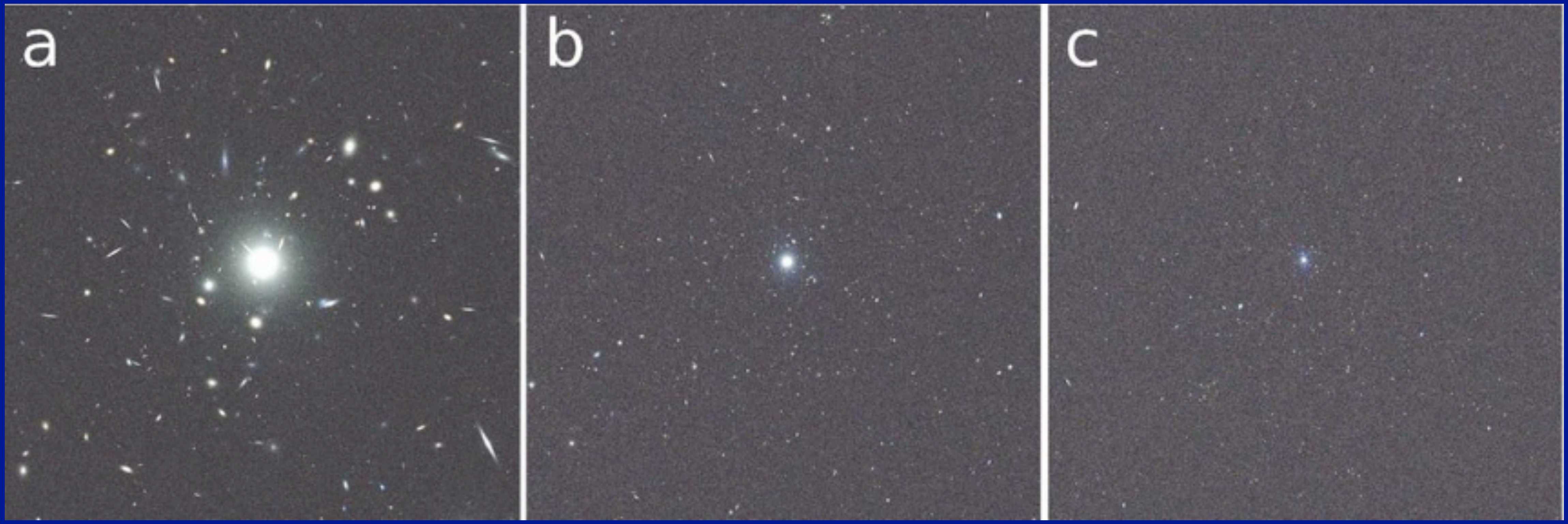
Cluster Cl0024 at z~0.4



Precise predictions from the *Millennium Run Observatory*

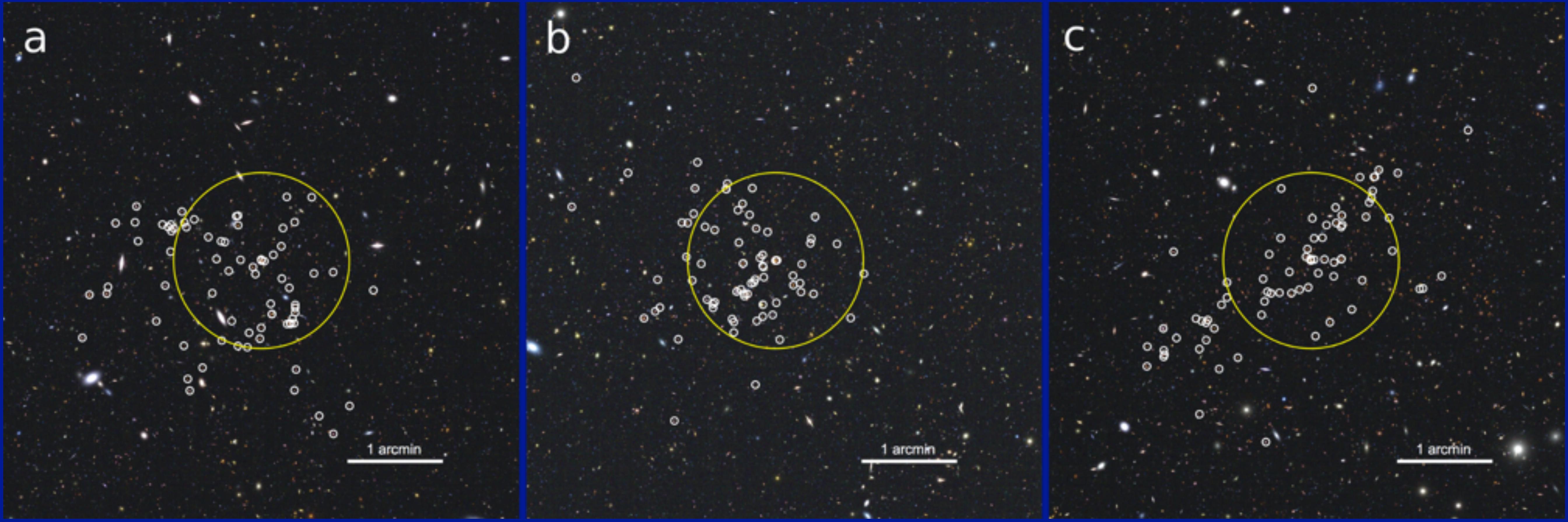
MRObs Mock SDSS observations of clusters

z = 0.02 z = 0.09 z = 0.21



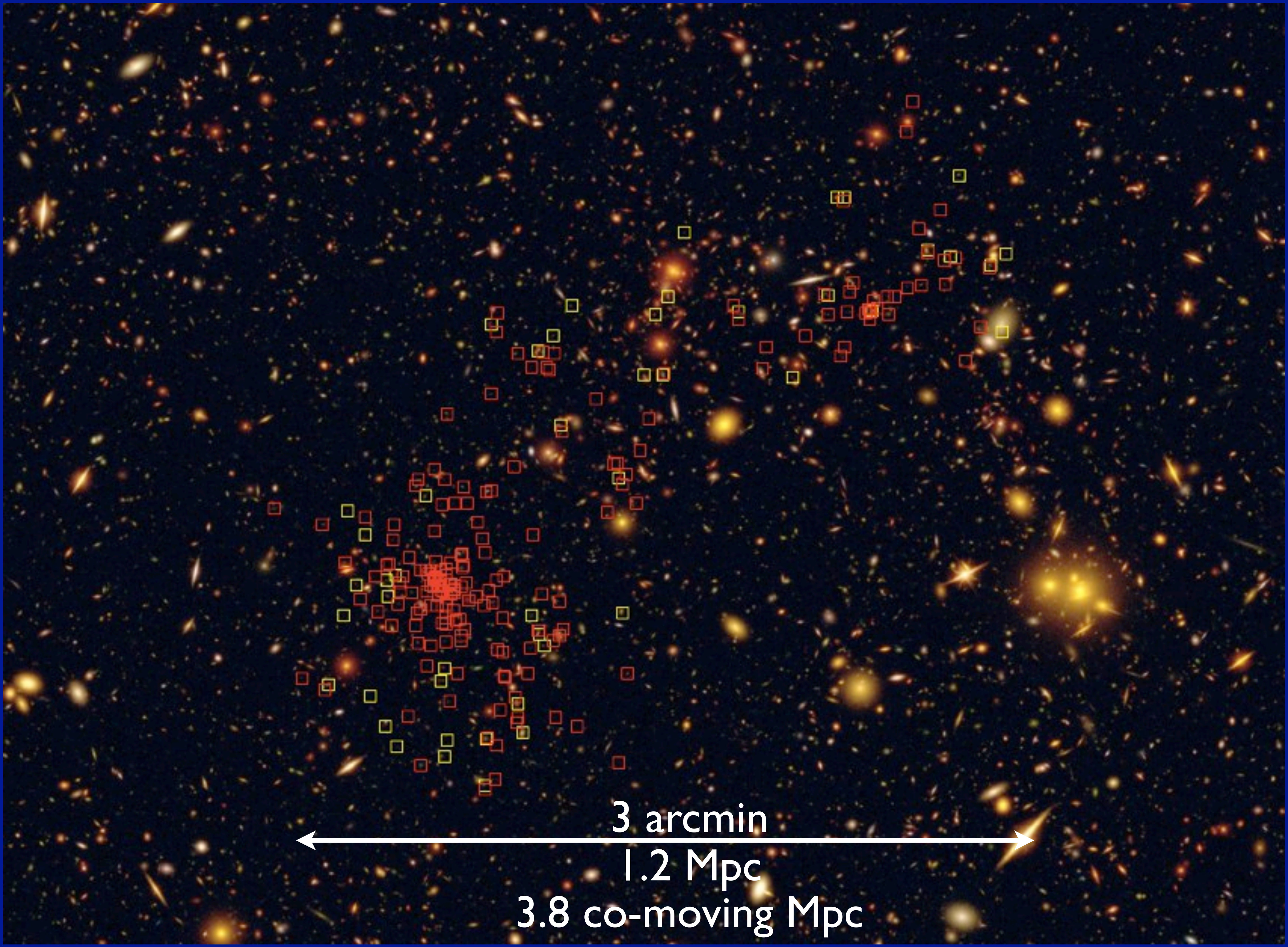
Precise predictions from the *Millennium Run Observatory*

z = 1 Massive cluster seen from 3 different directions

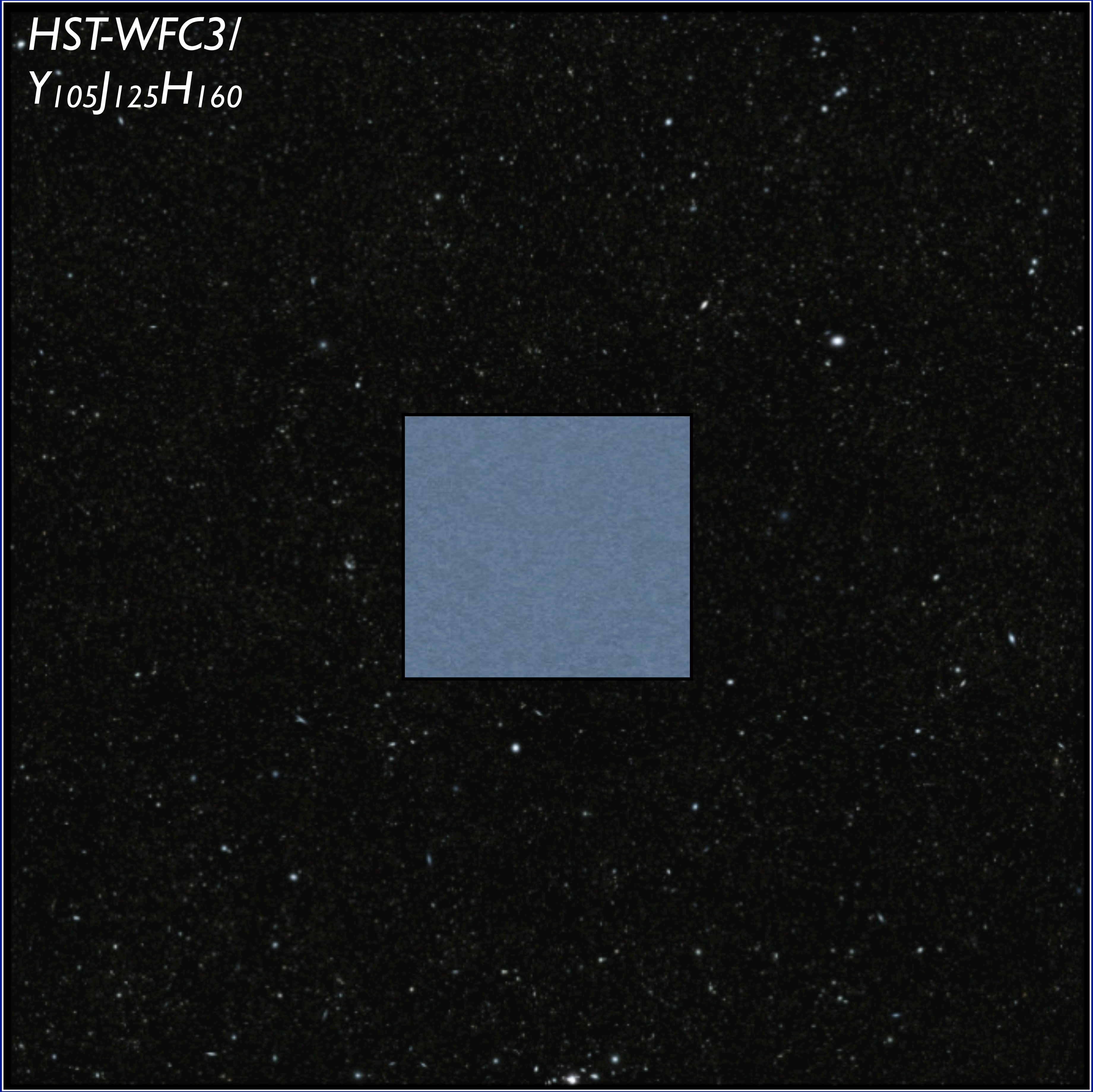


Precise predictions from the *Millennium Run Observatory*

z = 2.1 Massive "Proto-cluster"



MRObs image simulations for the HST CANDELS survey



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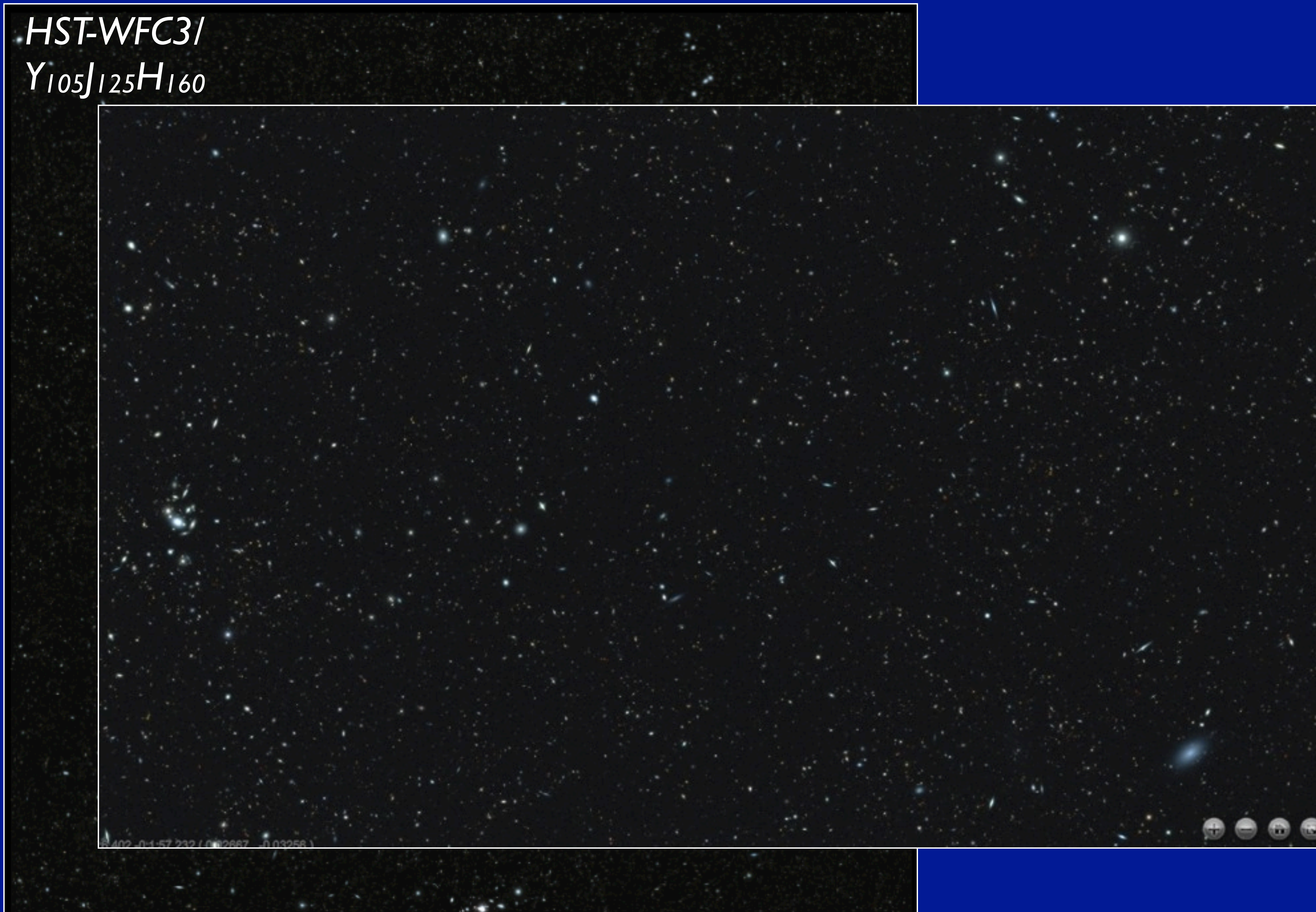

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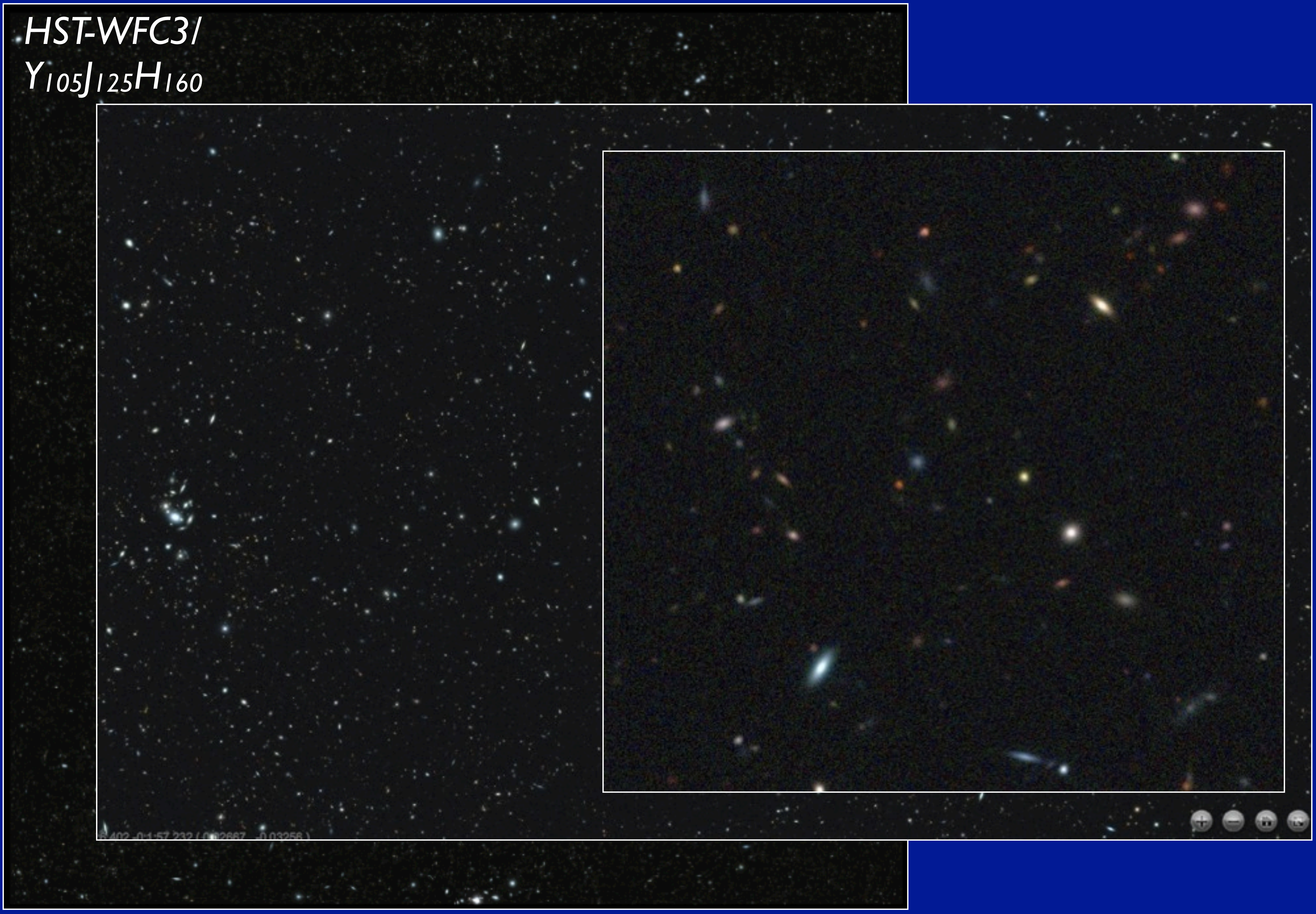
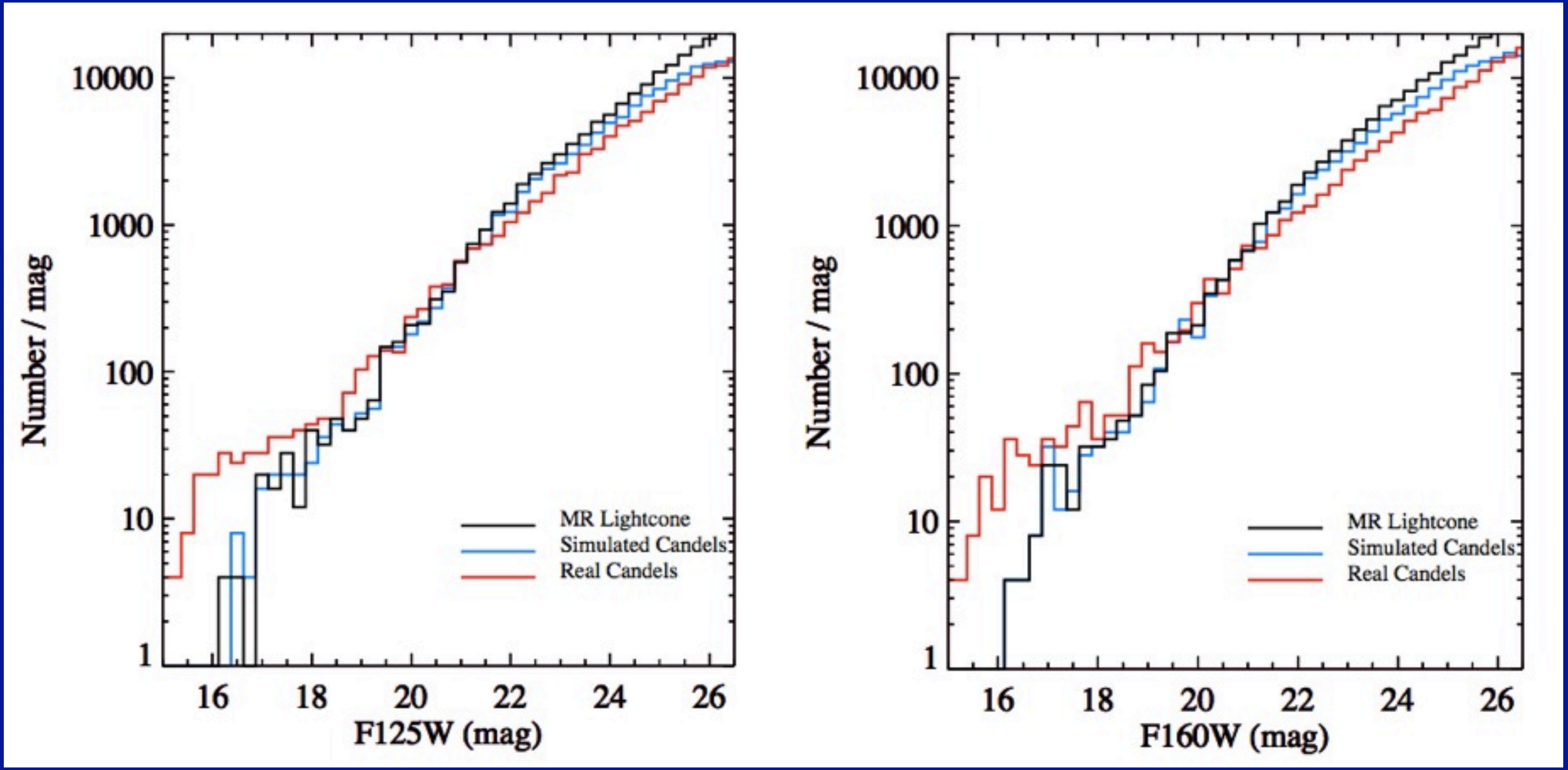
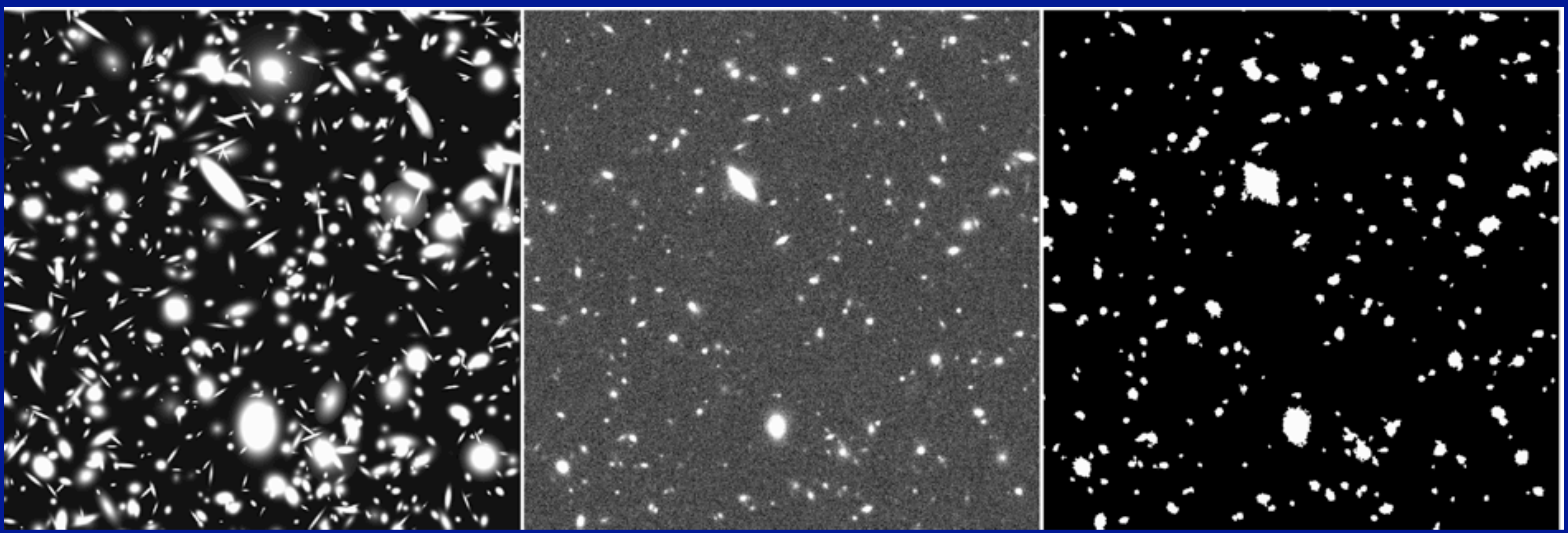


SAMs and Lightcones alone do not tell the whole story!

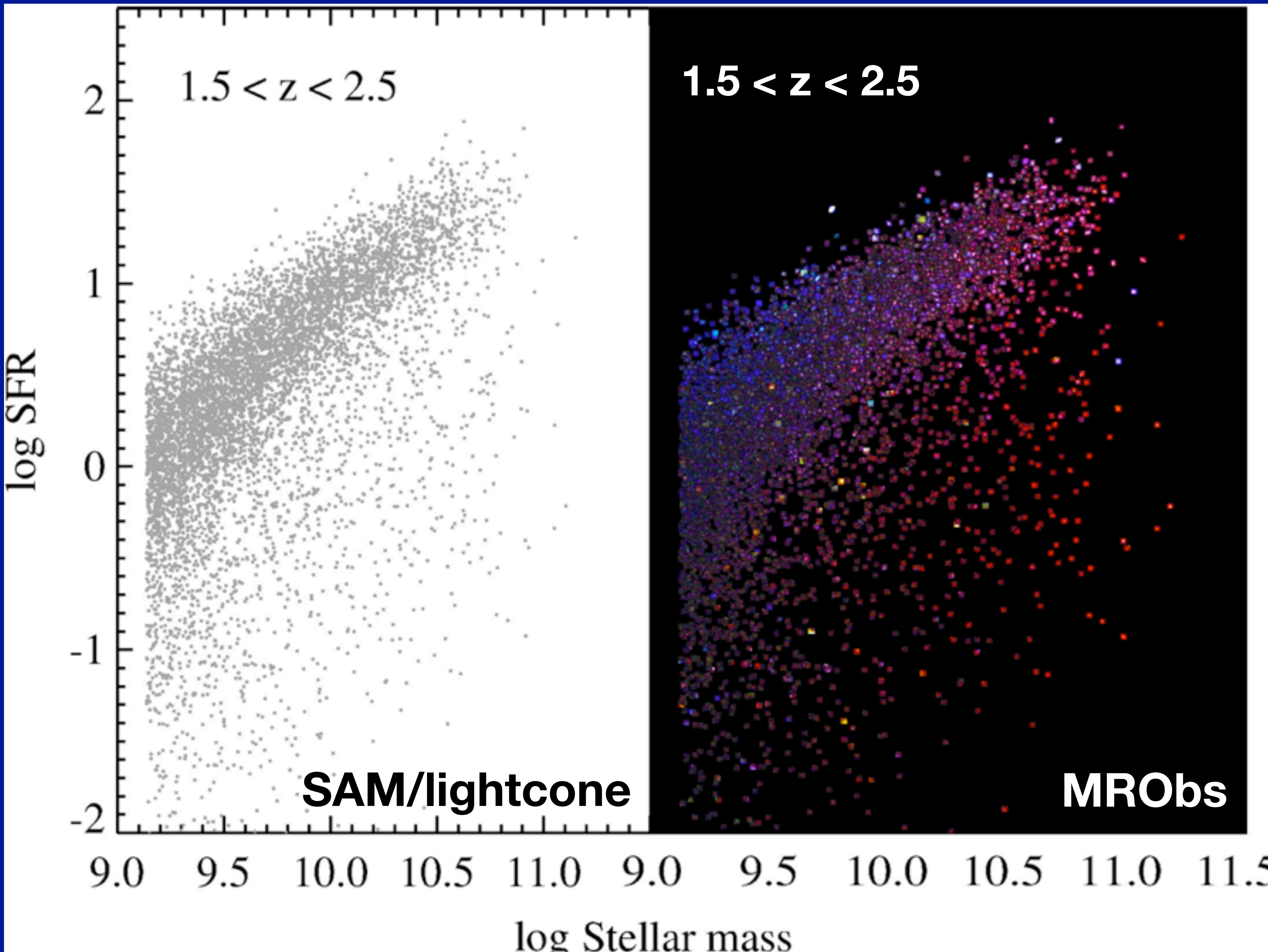


Source Extracting the Millennium Simulations...

perfect image **telescope image** **Source Extractor objects**

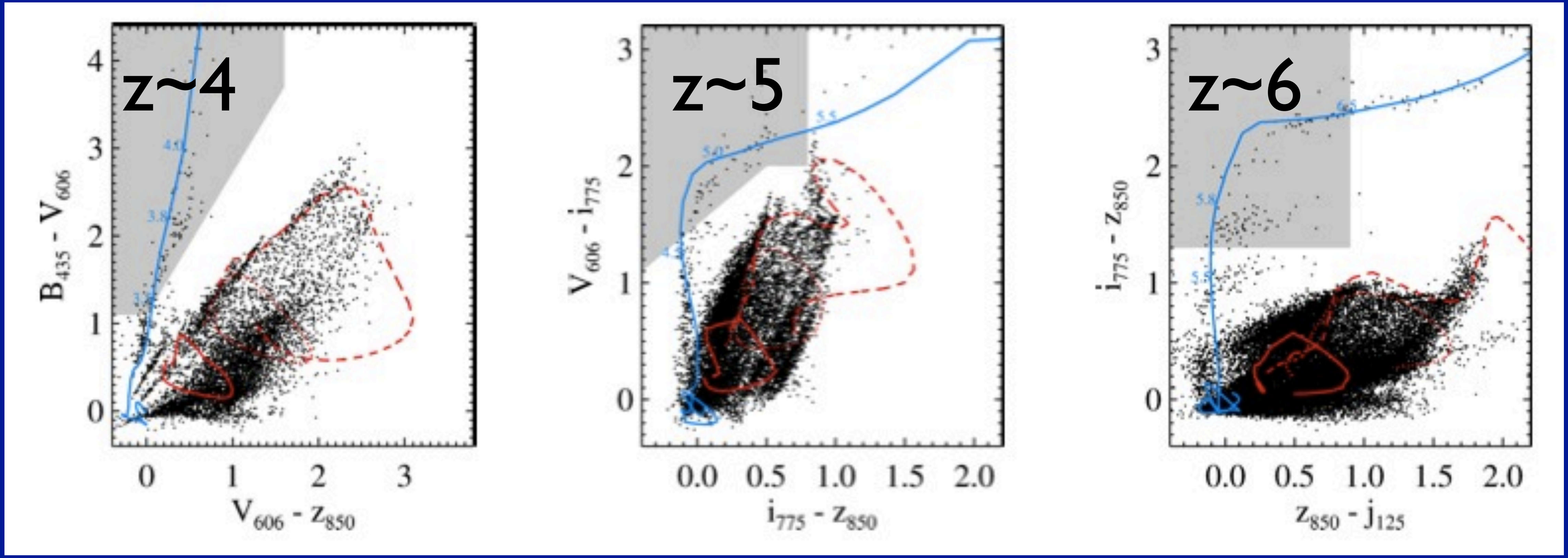


Viewing SAMs from the actual observer's perspective

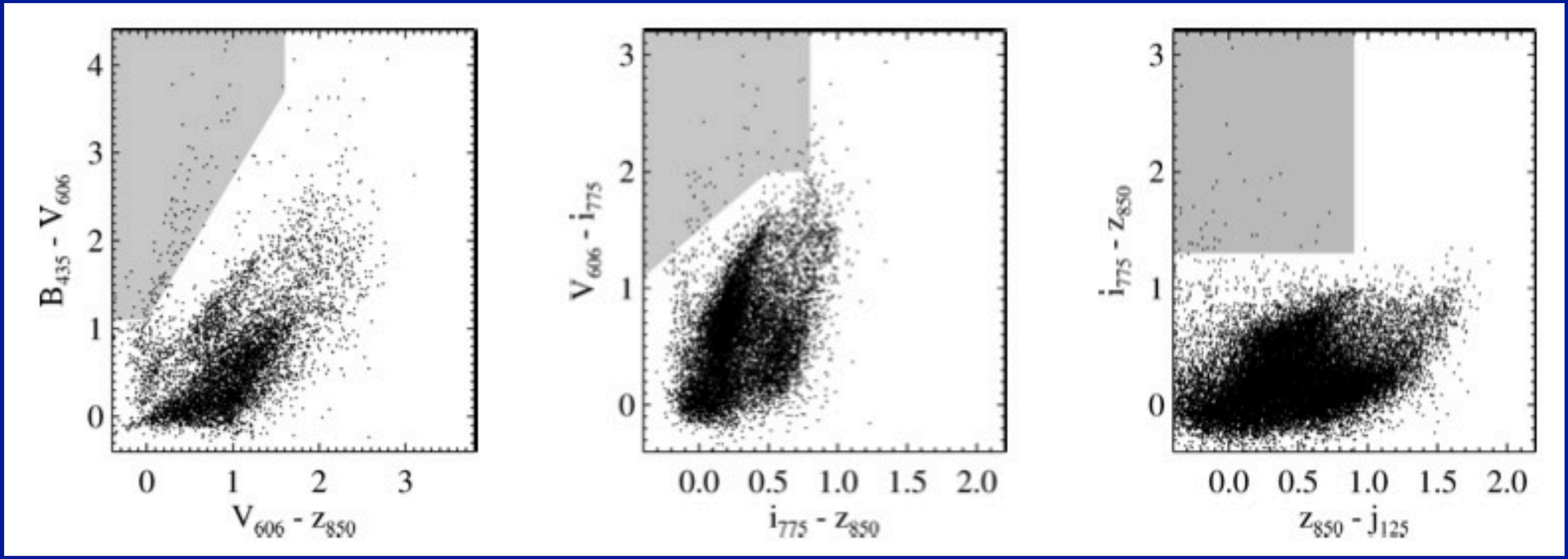


MRObs allows more realistic sample selections

Based on lightcone:

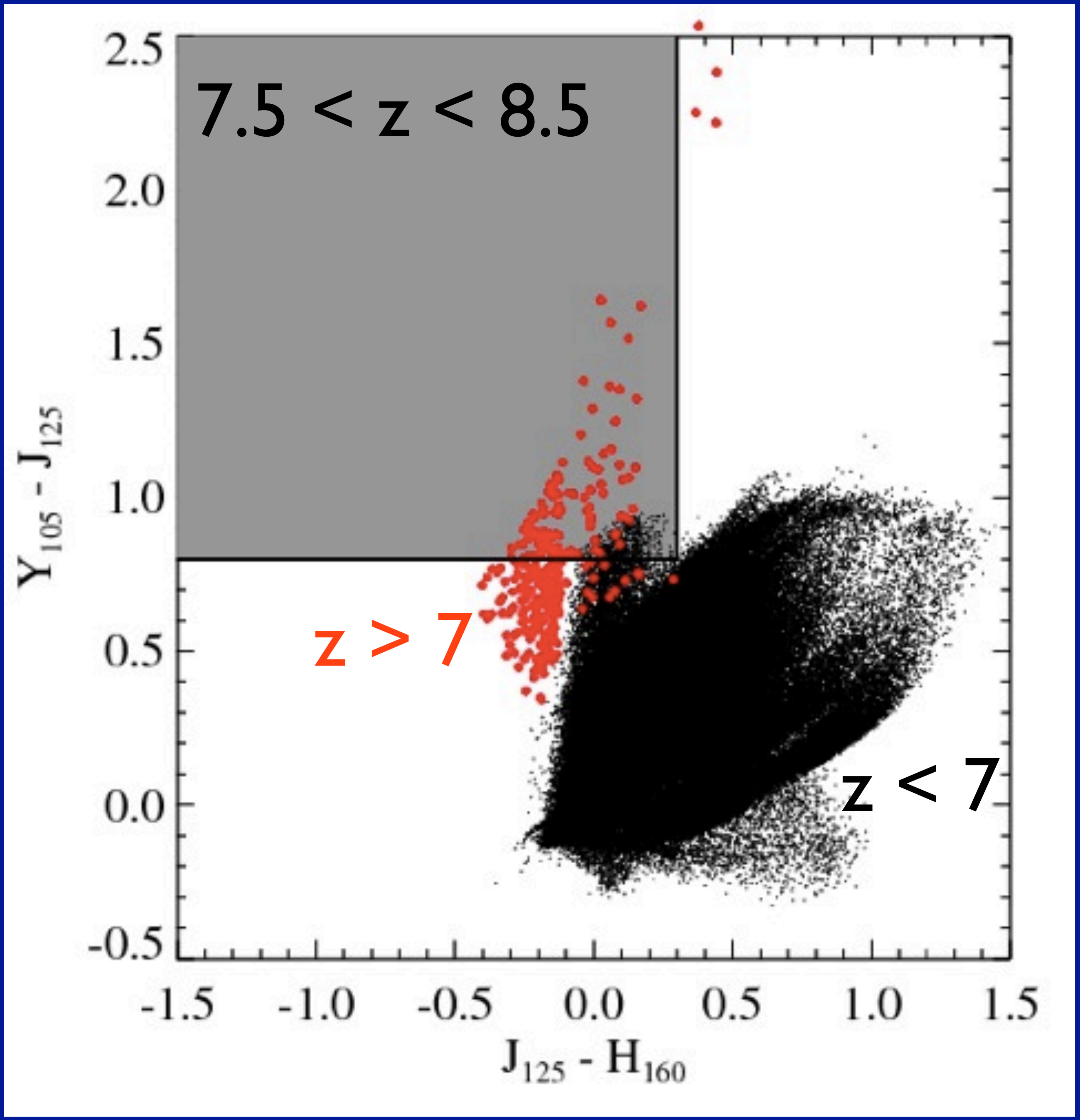


Based on Source Catalogs built from MRObs images (based on the same lightcone):

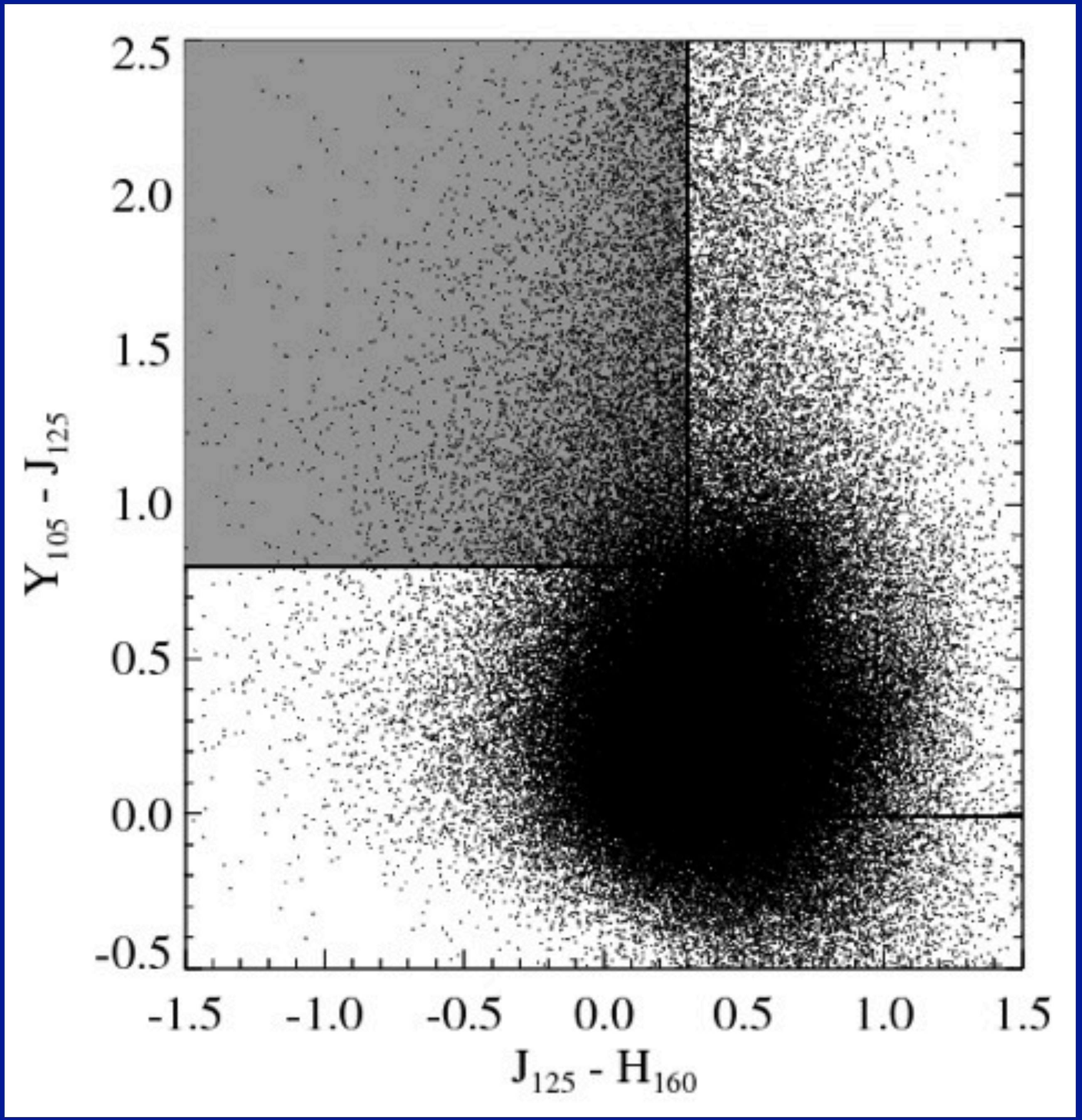


High-z dropouts in the CANDELS/GOODS-S Simulation

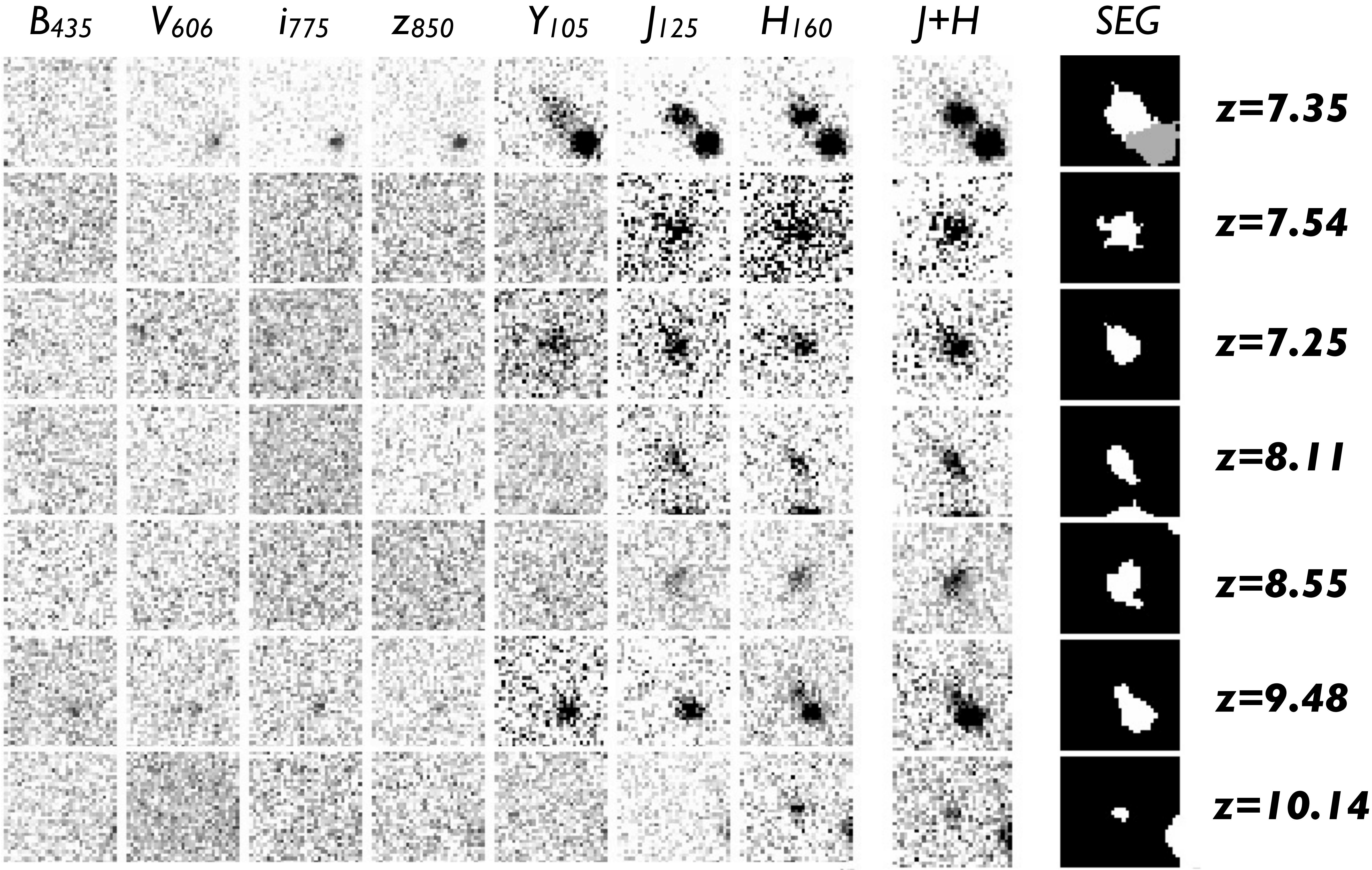
From Lightcone (with J < 27.0 AB mag)



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

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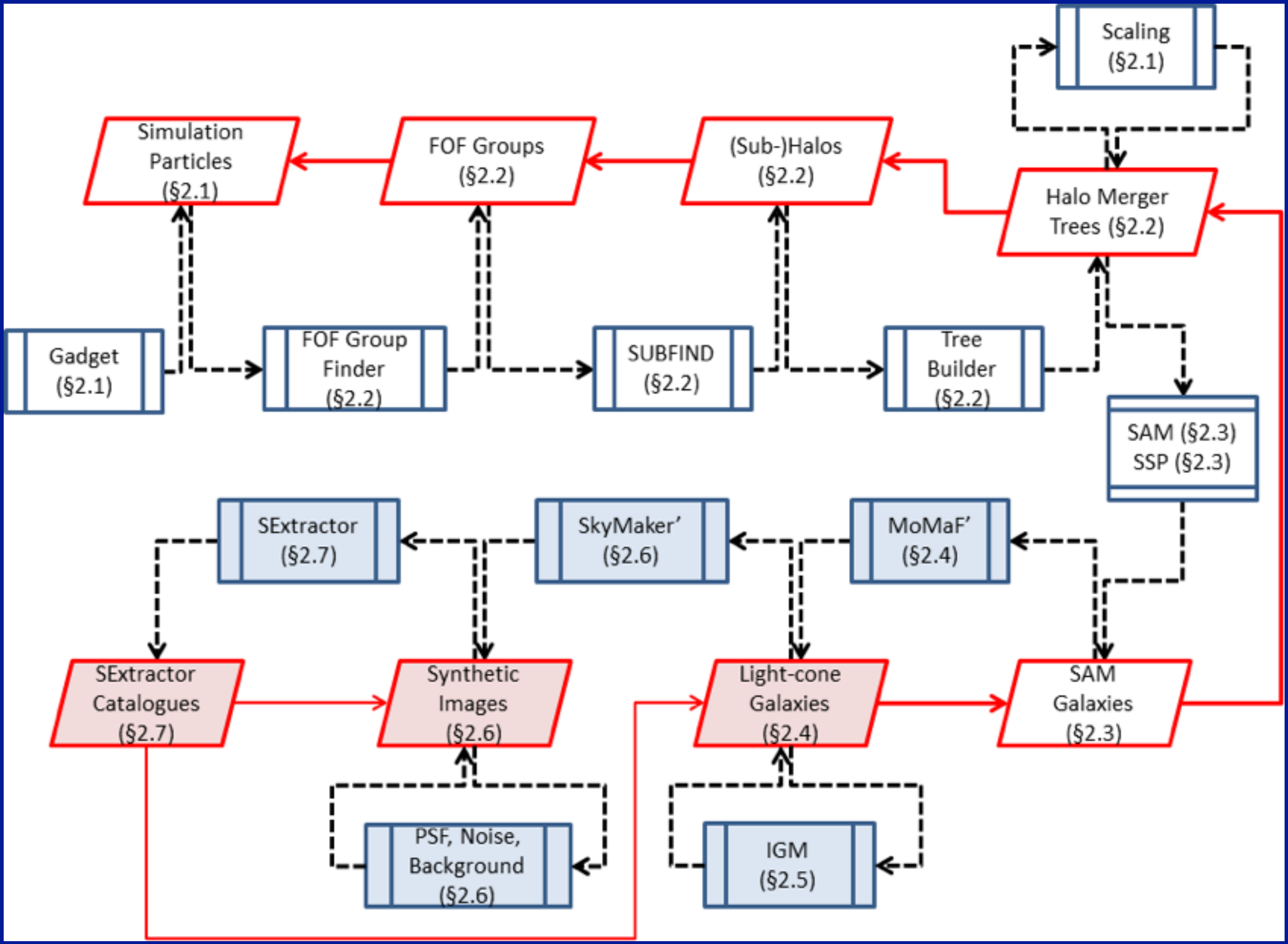
Part I: Concept and First Results

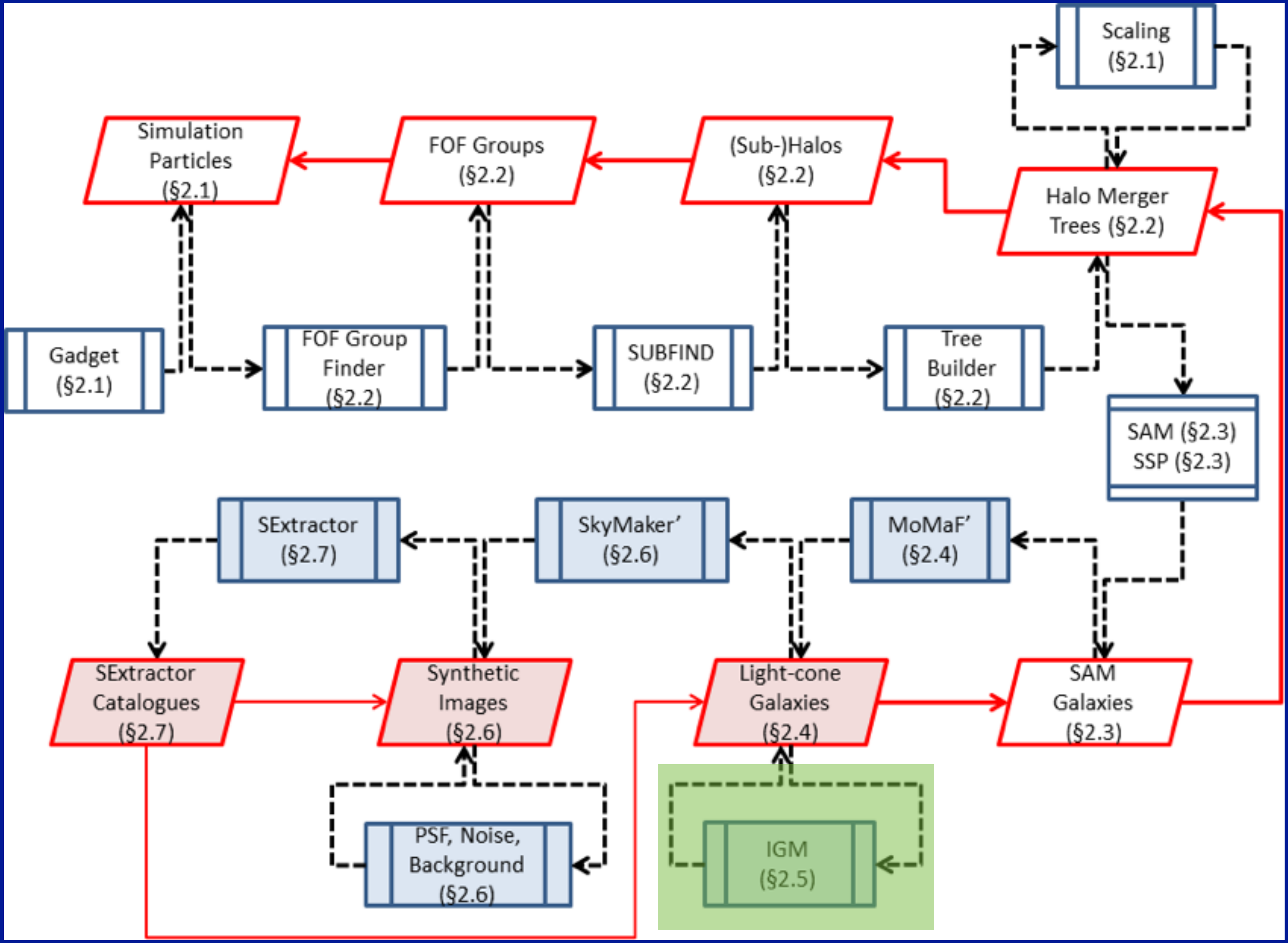
Part II: How-to, Data, and new User Services

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

Millennium Run Observatory Workflow



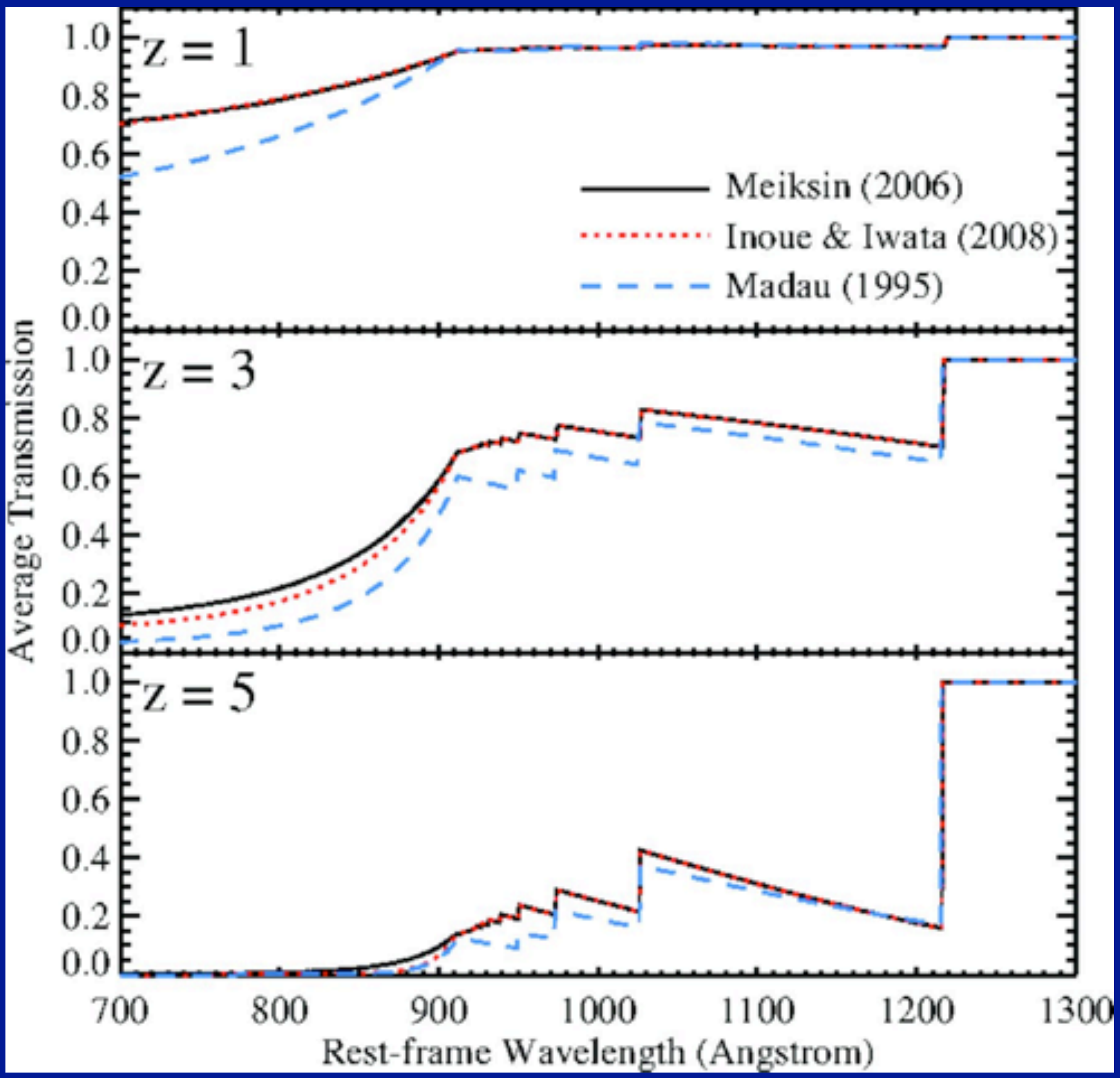
Millennium Run Observatory Workflow



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 Lya 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 ~ 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
```

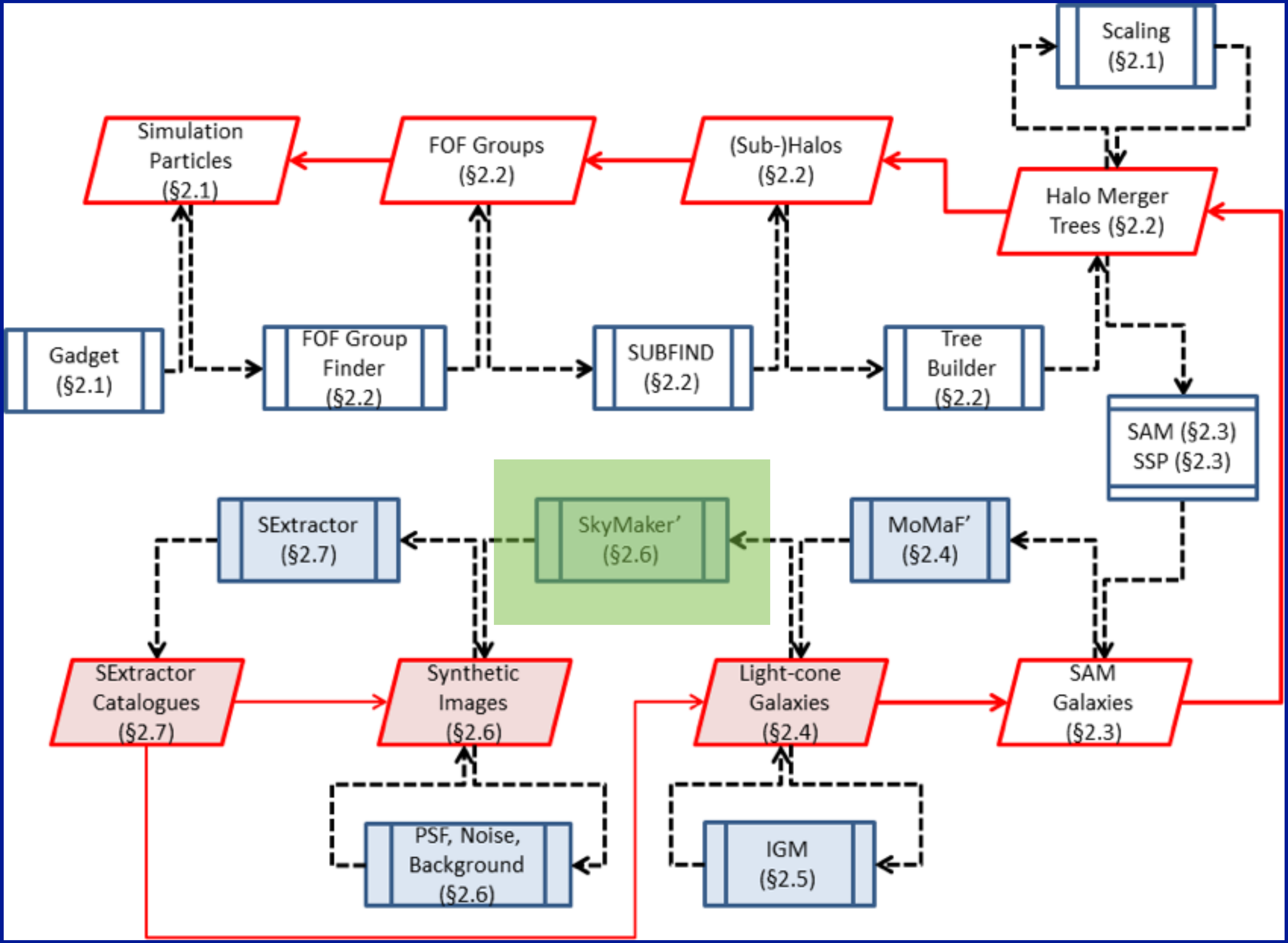
Maximum number of rows to return to the query form: 10

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

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

$$\mu_D(R) = m - 2.5\log_{10}(1 - B/T) + 1.0857(R/R_h) + 5\log_{10}(R_h) + 1.9955, \quad (2)$$

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

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

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

$A = R_e$ for bulges

$A = R_h$ for discs

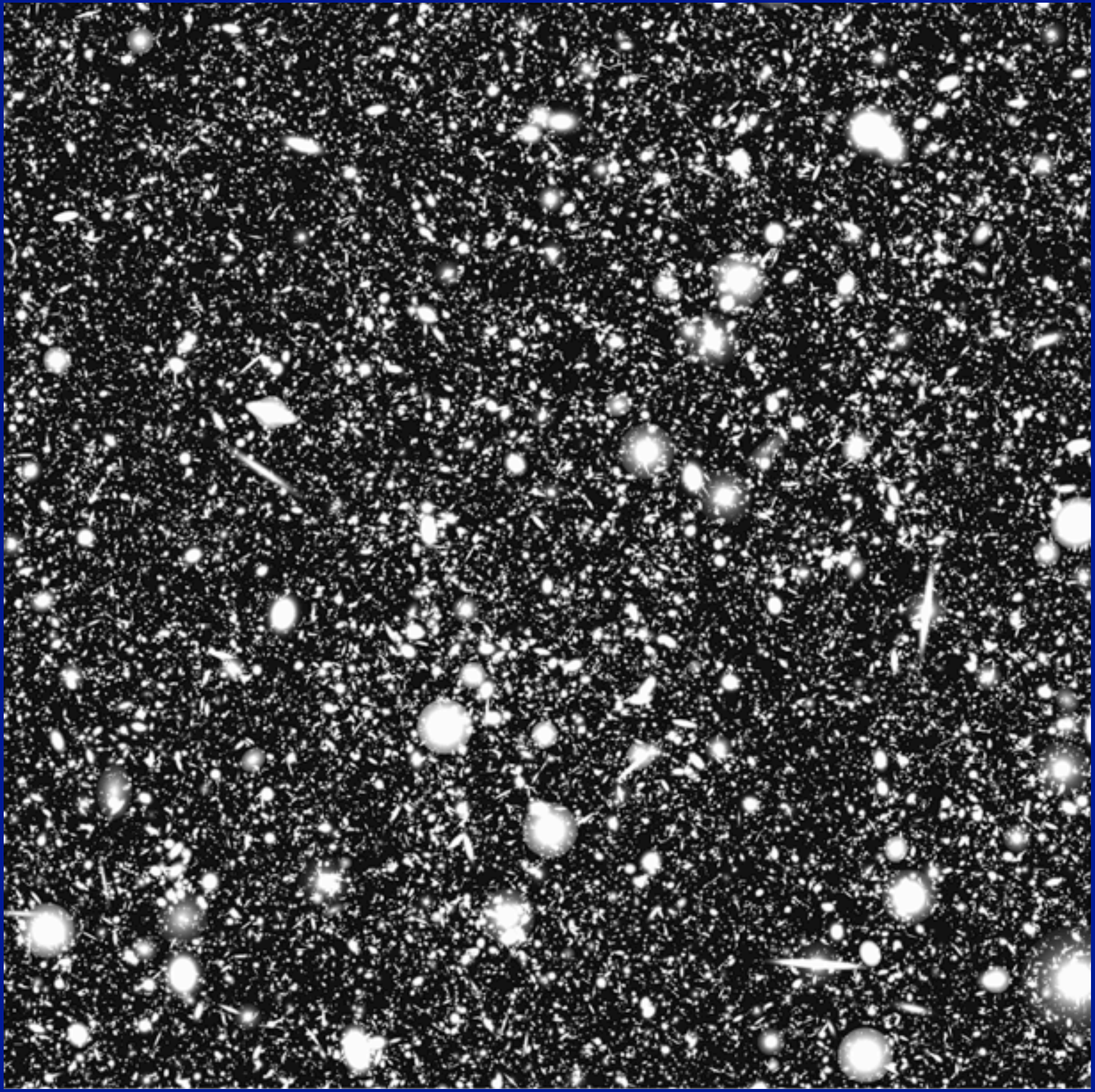
$B = A\cos(\phi)$

Minimal Requirements from the SAM+lightcone are

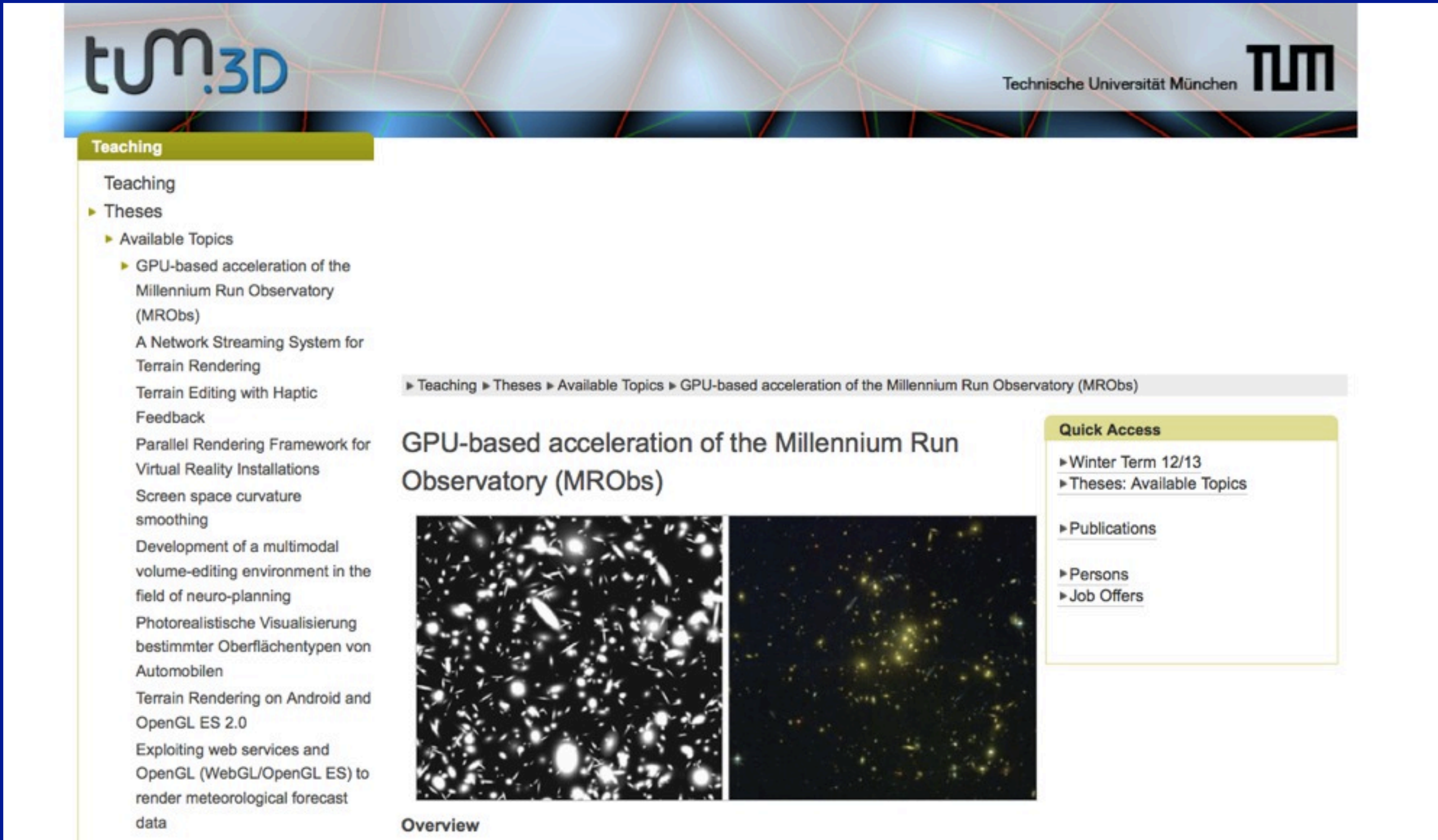
x_c, y_c	←	ra,dec from *lightcone* + image pixel scale + pointing
m	←	dust-attenuated filter magnitude from *lightcone*, corrected for IGM absorption (added to MRDB)
B/T	←	ratio of bulge-to-total filter flux
R_h, R_e	←	stellardiskradius/3D_A, bulgesize/D_A
θ	←	disk position angle from disk spin axis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

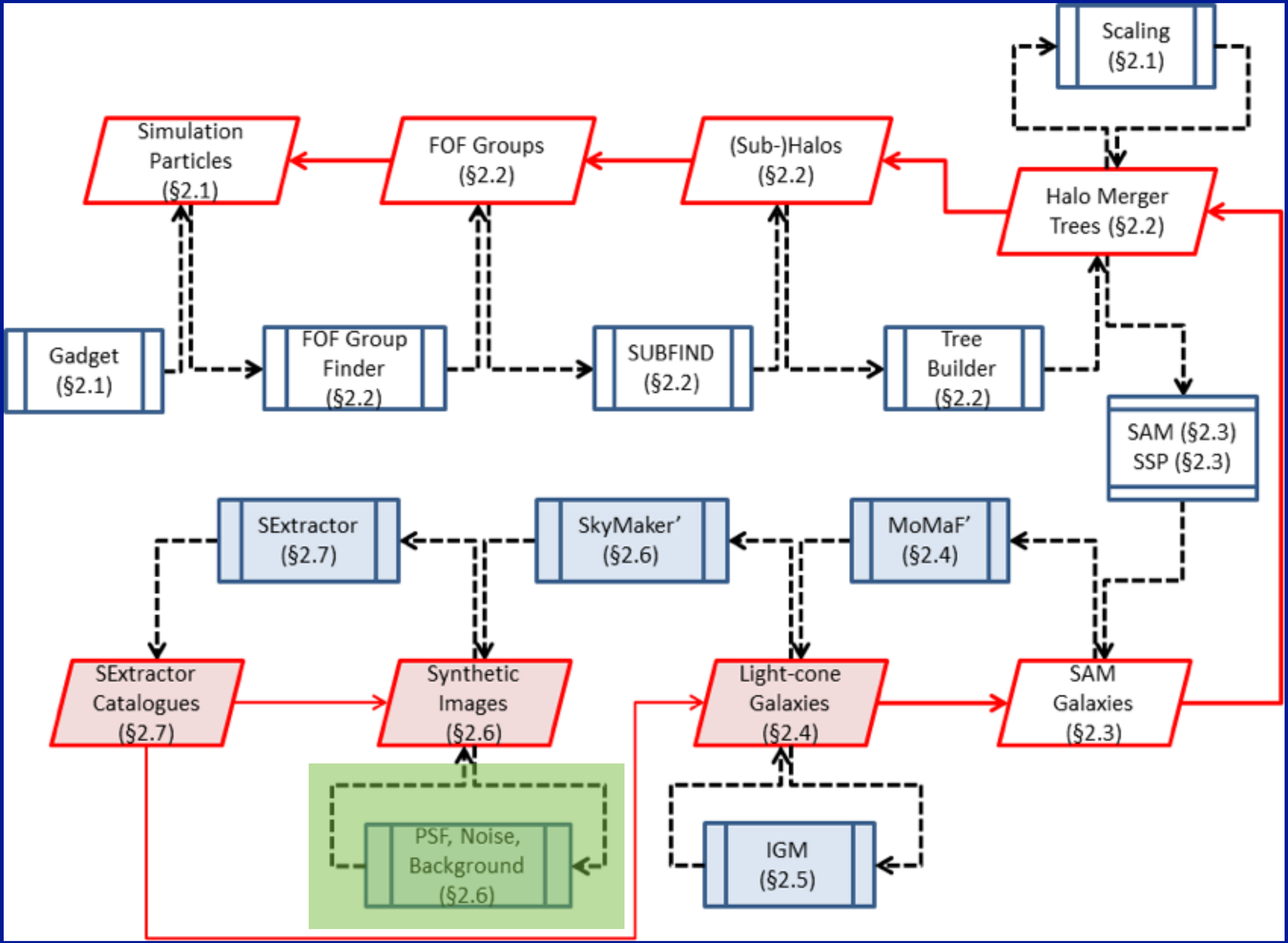


Interesting computer science aspects as well



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

Millennium Run Observatory Workflow

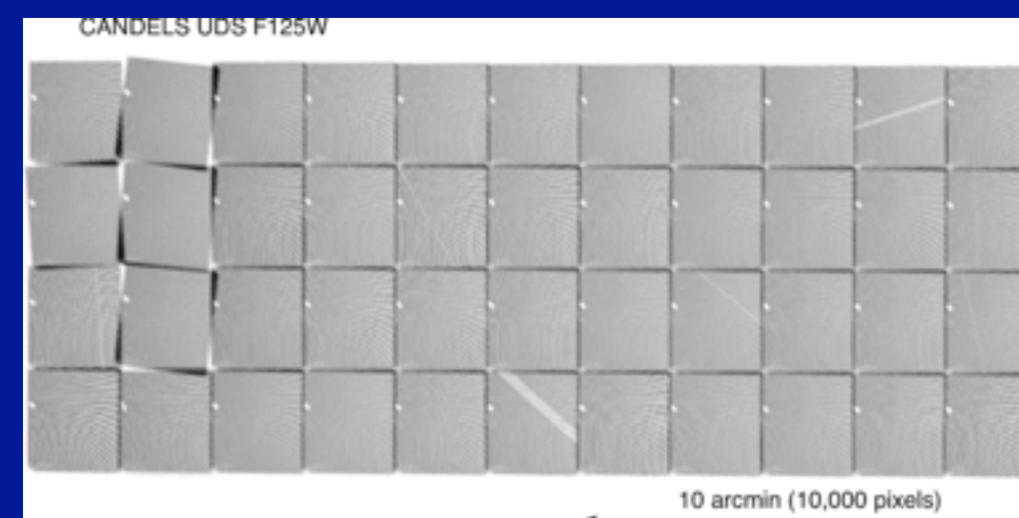


From "perfect" image to mock observation

$$F_{e_-} = 10^{-0.4(m_{AB}+ZP)} \cdot T_{\exp} \cdot G / \sum_{i \in S} \sum_{j \in S} I[x'_i, y'_j], \quad (5)$$

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

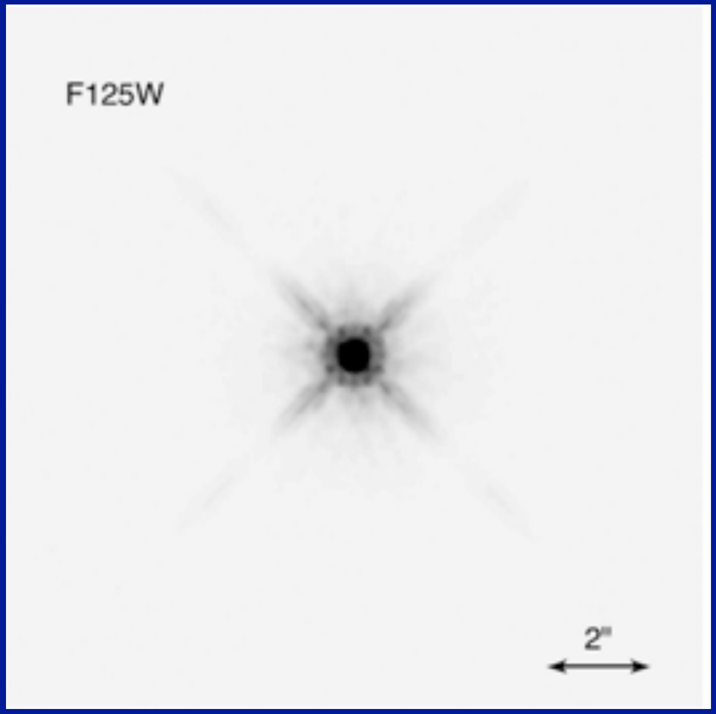
telescope, camera, filter, N_{exp}, T_{exp}, PSF file

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

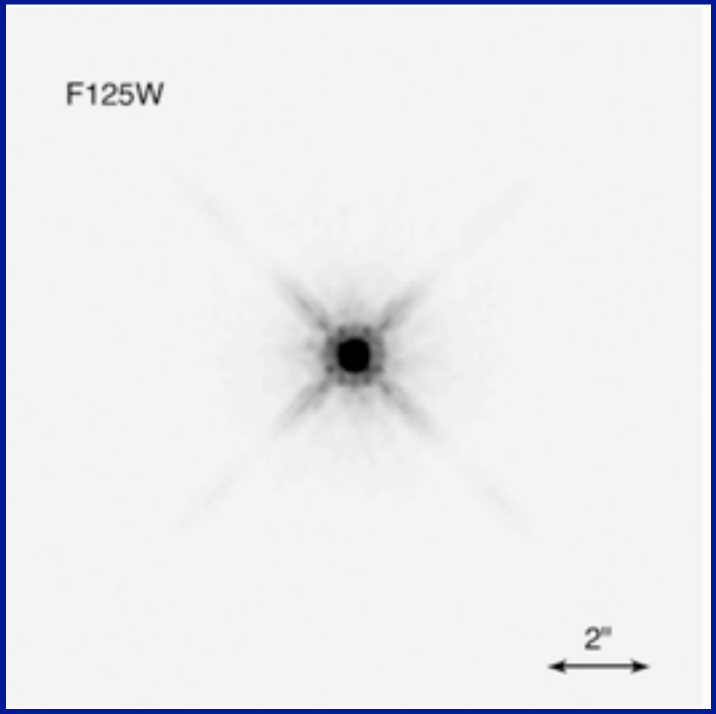
Example: the Hubble Ultra Deep Field

```
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)

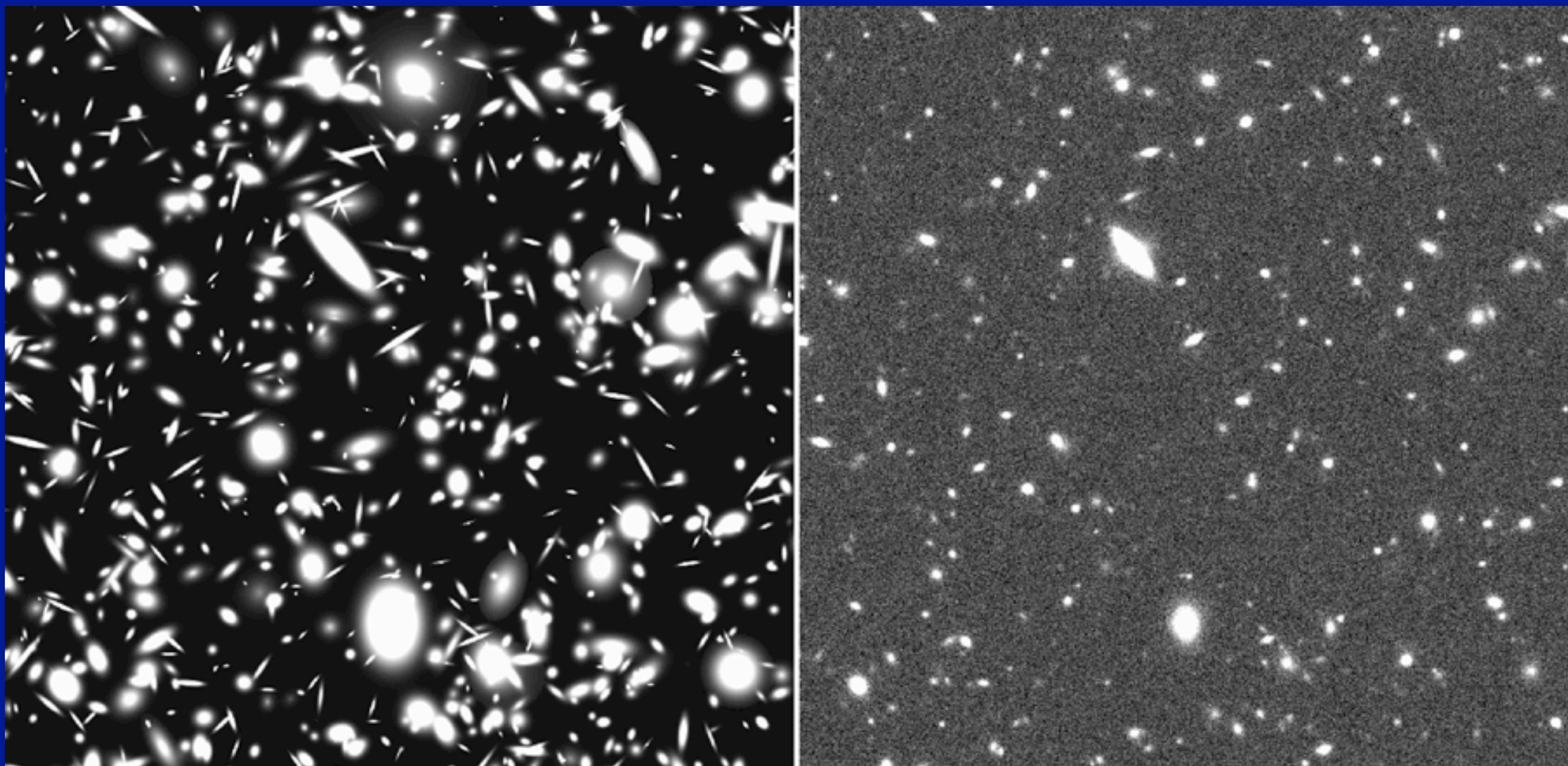
Extensive library of 2D point spread function image kernels

Example: the HST/WFC3 J-band PSF

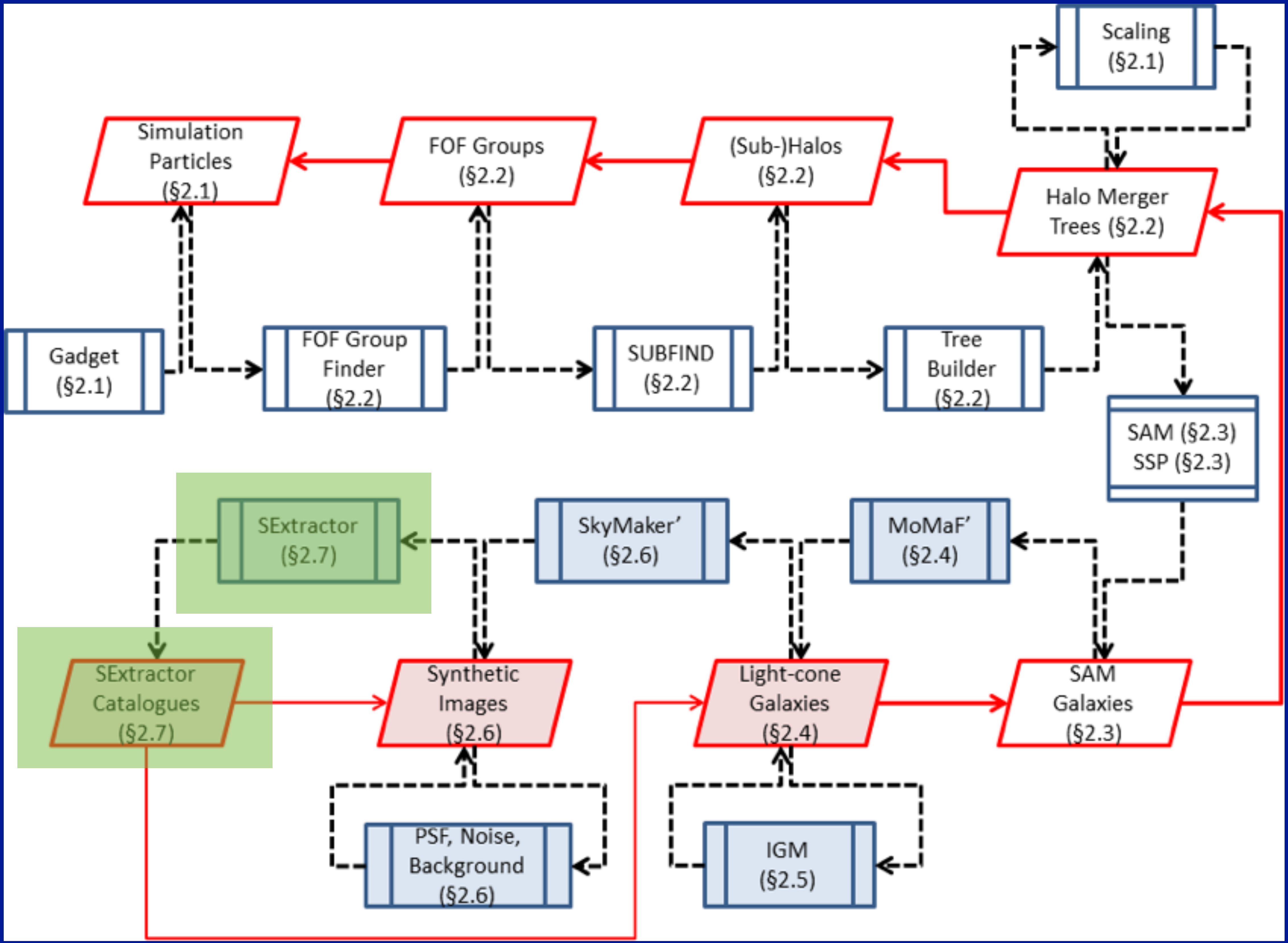


From “perfect” image to mock observation

perfect image **telescope image**

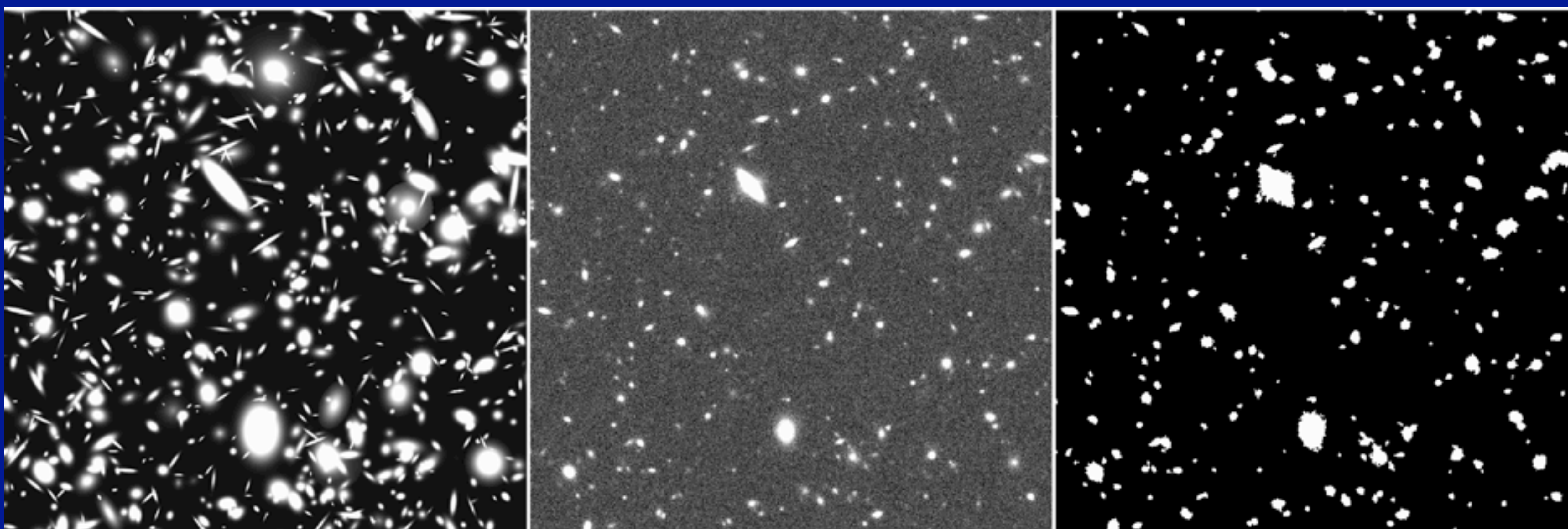


Millennium Run Observatory Workflow

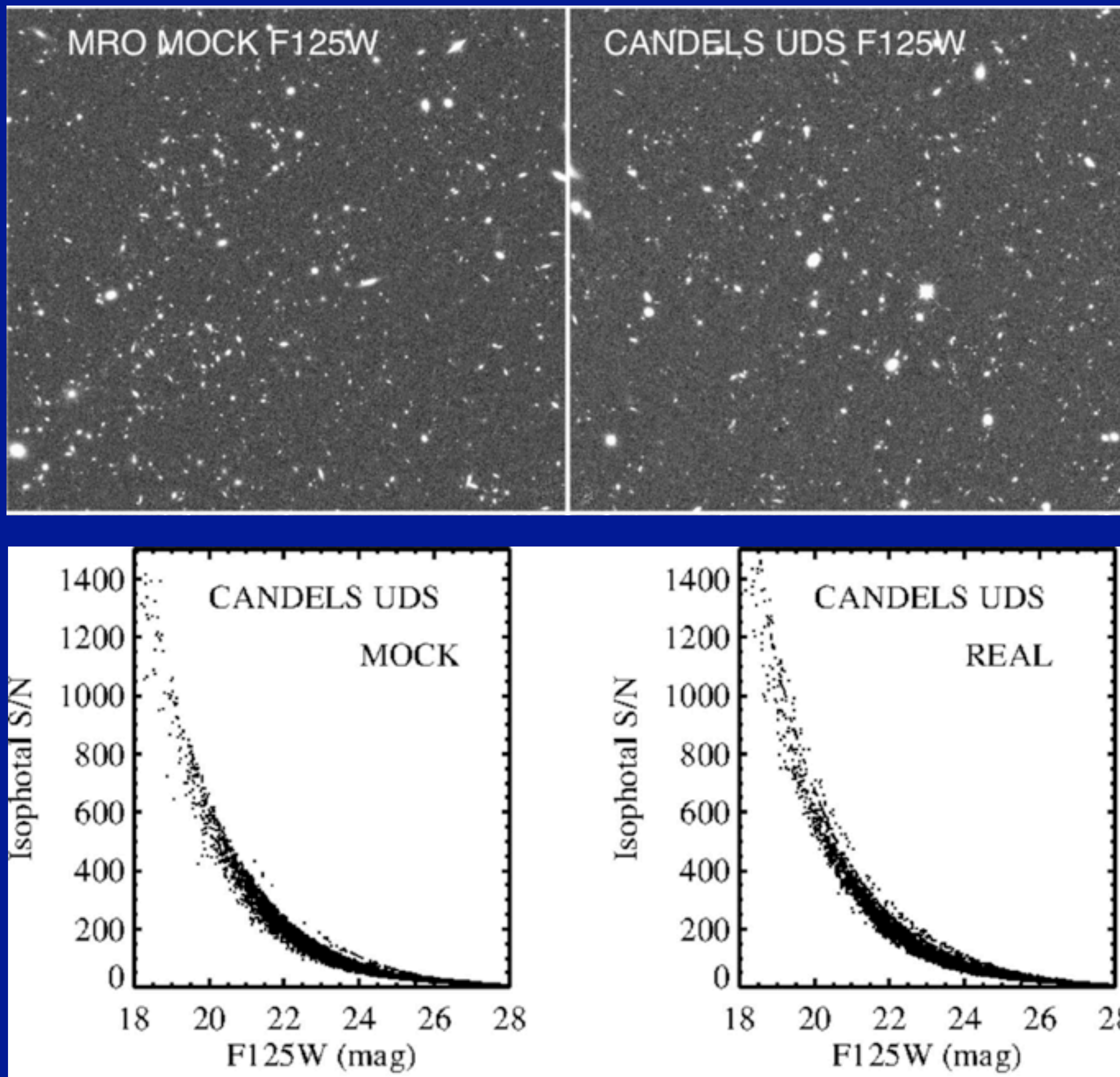


Source Extracting the Millennium Simulations...

perfect image **telescope image** **Source Extractor objects**



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



Max-Planck-Institut für Astrophysik

The Millennium Run Observatory

MRObs - Imaging Portal

Surveys Overview Table

Show 25 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*	v0.5
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*	v0.5
CFHT-LS Deep	Megacam u Megacam g Megacam r Megacam i Megacam z	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	v0.5
CFHT-LS Wide	Megacam u Megacam g Megacam r Megacam i Megacam z	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	v0.5
GOODS v2.0	HST/ACS F435W HST/ACS F625W HST/ACS F775W HST/ACS F850LP	BC03 M05	MADAU MEIKSIN INOUE-IWATA	WMAP1 WMAP7*	v0.5
	WFC3/UVIS F225W WFC3/UVIS F275W WFC3/UVIS F336W				

http://galformod.mpa-garching.mpg.de/mrobs/

Distribution of new kinds of MR Data

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The Millennium Run Observatory

Data Holdings - GOODS/ERS Survey

Synthetic Images

Show 25 entries

Search:

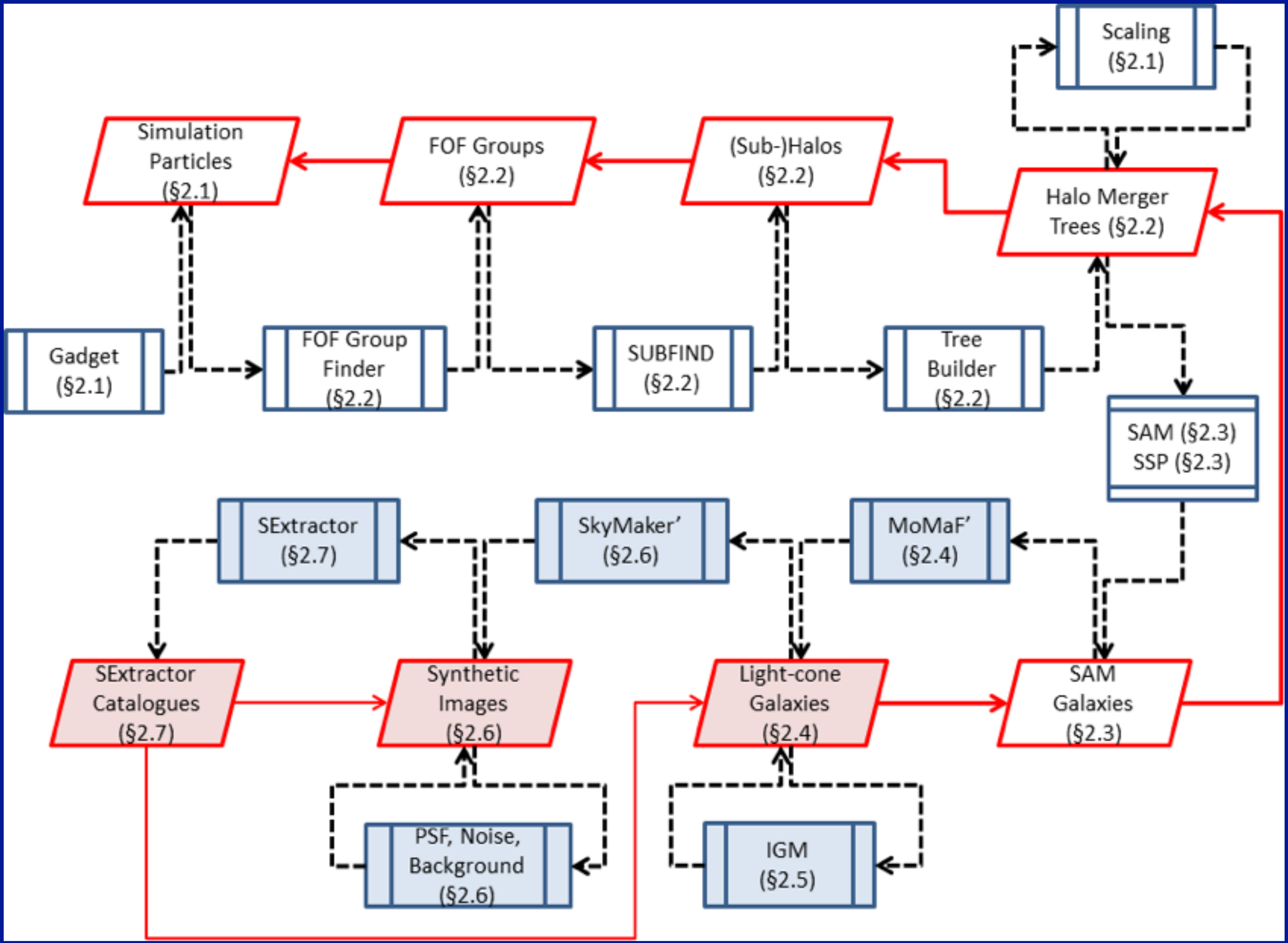
Cosmology	Lightcone	SSP	IGM	Survey	Filter	SQL	CSV	PRE	PSF	SCI
wmap1	MRObs.wmap1.BC03_001	bc03	madau	GOODS/ERS	hst_wfc3_uvis_wfc225	hst_wfc3_uvis_wfc225.sql	hst_wfc3_uvis_wfc225.csv	hst_wfc3_uvis_wfc225.fits	F225W_psf_127x127_v3.fits	hst_wfc3_uvis_wfc225_post.fits
wmap1	MRObs.wmap1.BC03_001	bc03	madau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

- Simulation Identifier: cosmology, SAM, SSP, lightcone, IGM, survey, filter

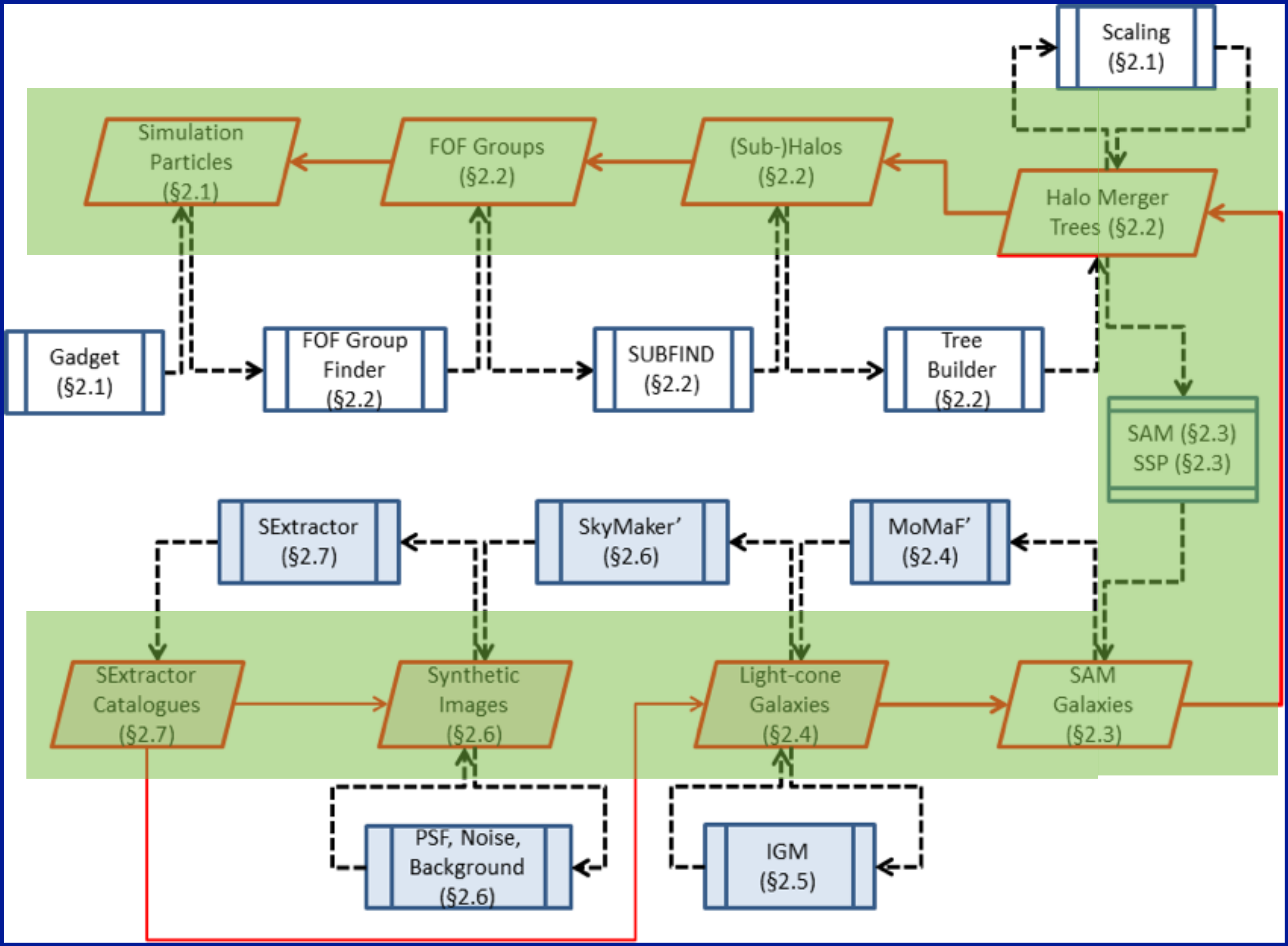
Example: WMAP1, Guo2010a, BC03, Henriques2012a.001, Madau, HUDF, B-band

- 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)

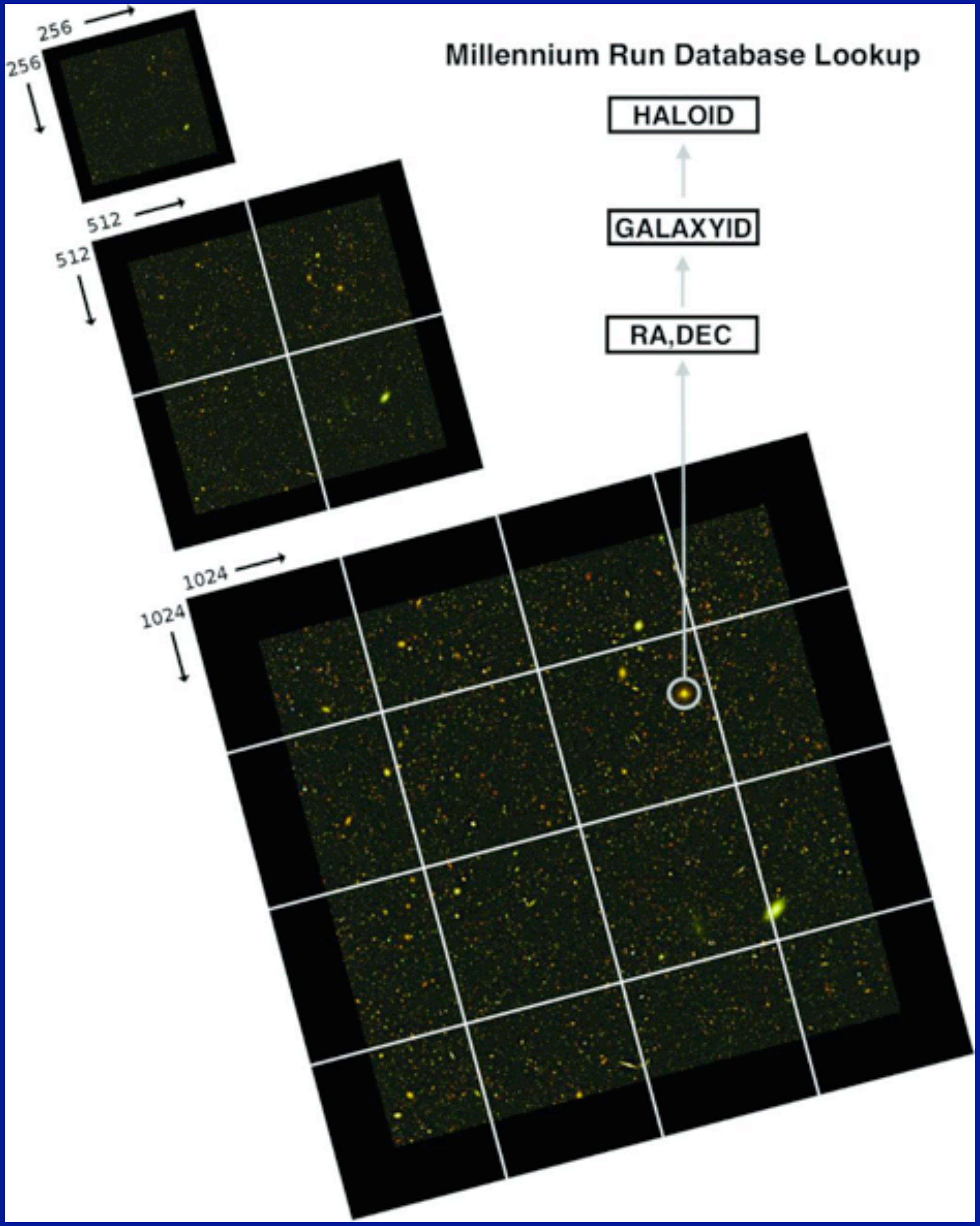
Millennium Run Observatory Workflow



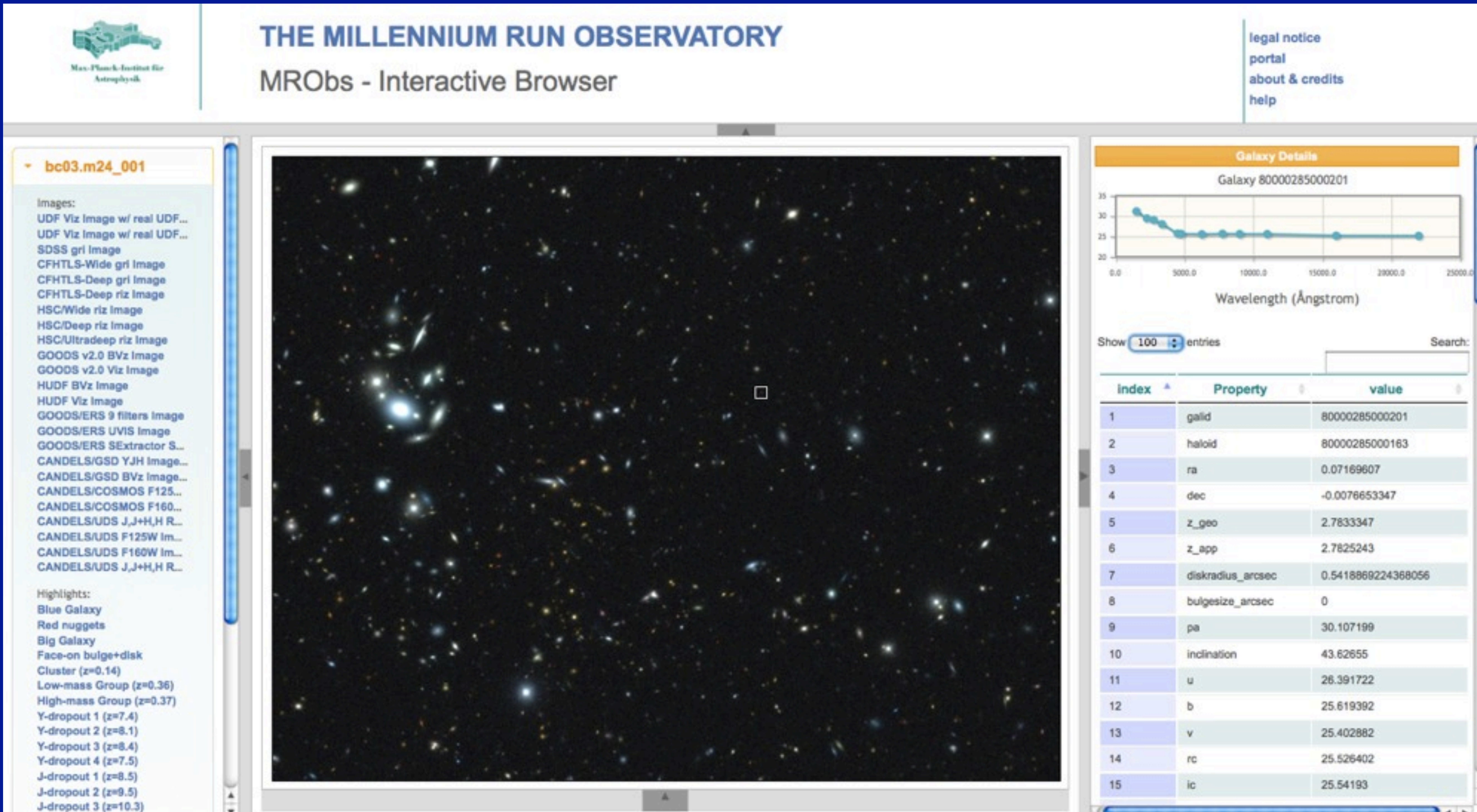
Millennium Run Observatory Workflow



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

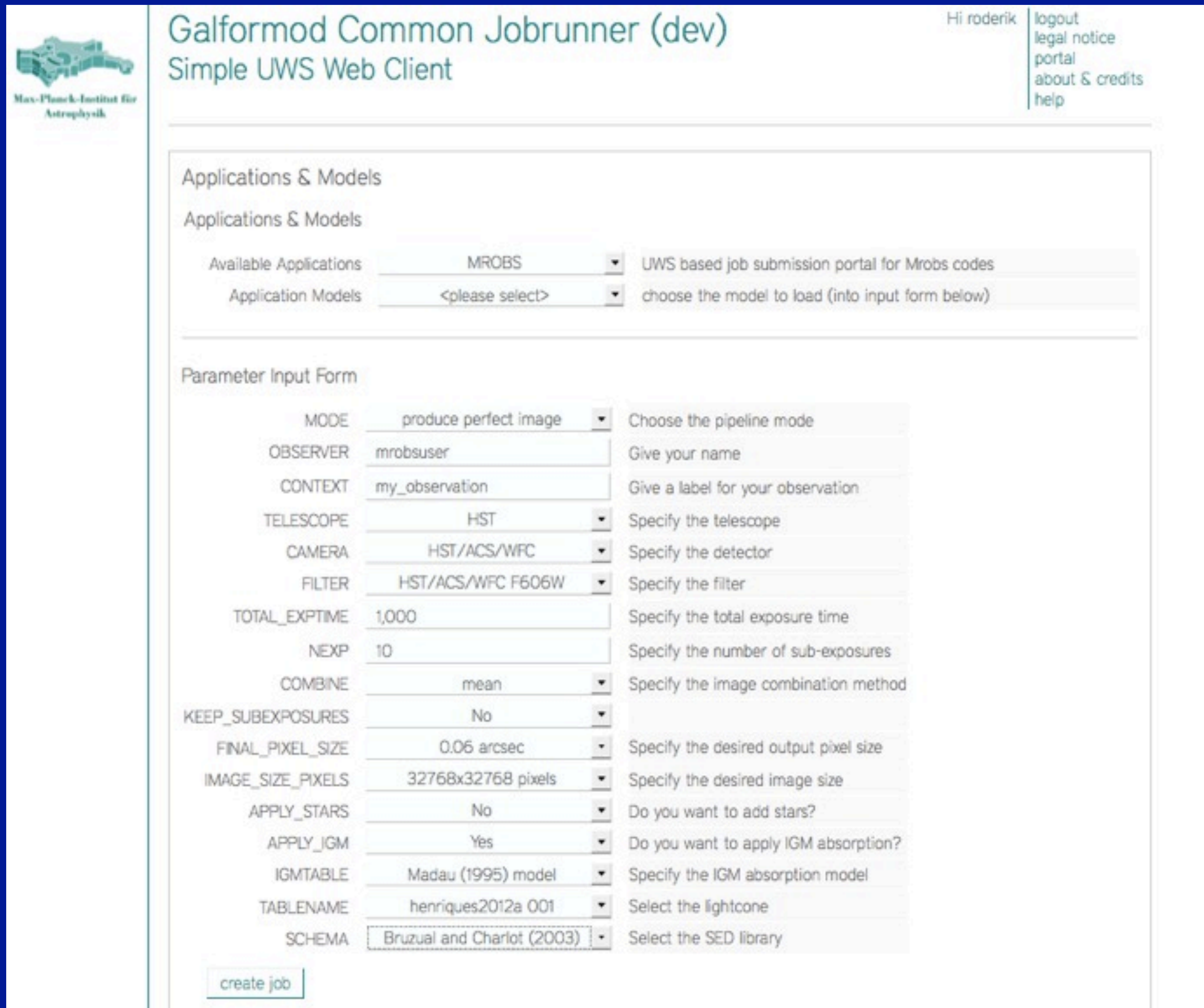


The MRObs browser is one way to explore those links



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

Create your own simulated observations from lightcones in the MRDB



(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