The Astrophysical Journal Supplement Series, 234:20 (15pp), 2018 February
https://doi.org/10.3847/1538-4365/aaa24c

Data Release of UV to Submillimeter Broadband Fluxes for Simulated Galaxies from the EAGLE Project

Peter Camps[1], Ana Trčka[1], James Trayford[2], Maarten Baes[1], Tom Theuns[2], Robert A. Crain[3], Stuart McAlpine[2], Matthieu Schaller[2], and Joop Schaye[4]

1. EAGLE: simulations
-Cosmological hydrodynamic simulations using GADGET3 (Tree-PM + SPH)
- Follow formation & evolution of galaxies
- Adopt subgrid recipes for radiative cooling, star & BH formation & feedback from stars and AGNs
(Schaye + 2015)

2.EAGLE: Public data release
➔ halo & galaxy catalogues
(McAlpine + 2016)
➔ particle data
(EAGLE Team 2017)

3.SKIRT (based on Baes + 2011)
- post-processing of galaxy data from EAGLE
- assign **dust** to star-forming gas particles
- Forward modelling: 3D radiative transfer
➔ Predict broadband fluxes from UV to sub-mm
(Camps + 2018)

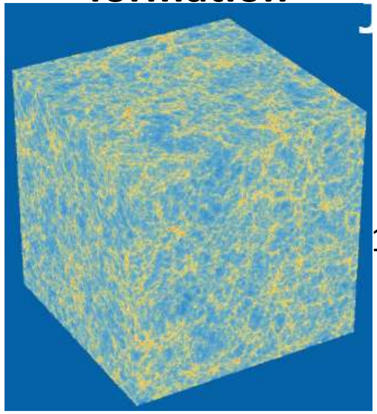
The EAGLE project: simulating the evolution and assembly of galaxies and their environments Schaye + 2015

Evolution and Assembly of GaLaxies and their Environments

- Volumes of 25 - 100 Mpc and zooms
- Particle mass $10^5 - 10^6\ M_\odot$ (smaller for zooms), resolves warm ISM
- Modern SPH GADGET3
- Includes feedback from stars and AGN (1 type each)
- Subgrid recipes depend only on local gas properties
- Hydro and cooling never turned off
- Winds develop without predetermined mass loading or velocity
- Stellar feedback efficiency calibrated to $z = 0$ mass function and galaxy sizes
- AGN feedback efficiency calibrated to $z = 0$ BH mass – stellar mass relation
- Many different models, spin offs

The formation of galaxies

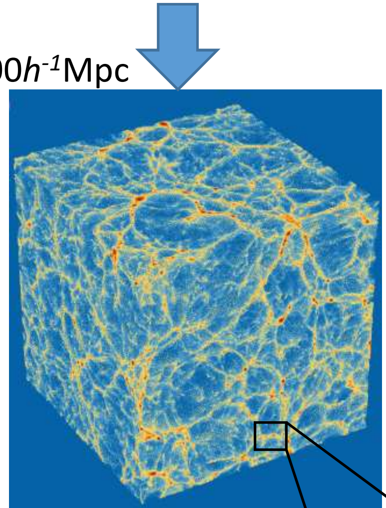
Large-scale structure formation



100h^{-1}Mpc

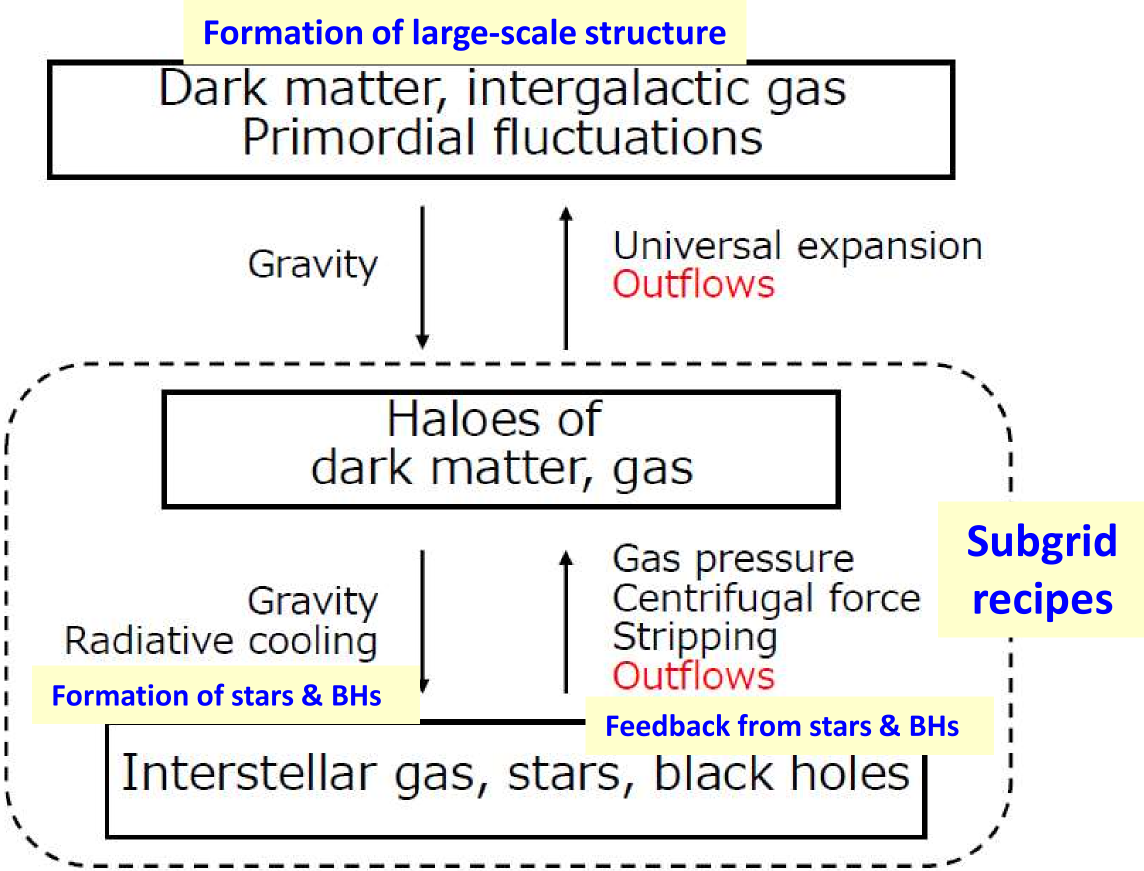
Z~127

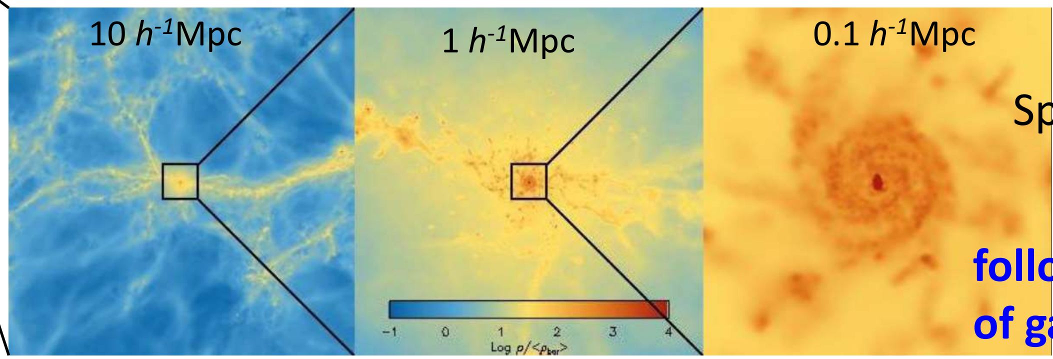
100h^{-1}Mpc



Z~0

follow the emergence of cosmic web





Spiral galaxy

follow the formation of galaxies

Schaye + 2015

6 set of simulations with GADGET 3 (N-body Tree-PM SPH code)

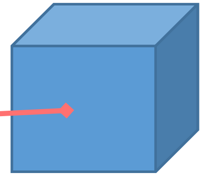
Identifier	L (cMpc)	N	m_g ($M_\odot$)	m_{dm} ($M_\odot$)	ϵ_{com} (ckpc)	ϵ_{phys} (pkpc)	$n_{H,0}$ (cm^{-3})
Ref-L0025N0376	25	2×376^3	1.81×10^6	9.70×10^6	2.66	0.70	0.67
Ref-L0025N0752	25	2×752^3	2.26×10^5	1.21×10^6	1.33	0.35	0.67
Recal-L0025N0752	25	2×752^3	2.26×10^5	1.21×10^6	1.33	0.35	0.25
Ref-L0050N0752	50	2×752^3	1.81×10^6	9.70×10^6	2.66	0.70	0.67
AGNdT9-L0050N0752	50	2×752^3	1.81×10^6	9.70×10^6	2.66	0.70	0.67
Ref-L0100N1504	100	2×1504^3	1.81×10^6	9.70×10^6	2.66	0.70	0.67

Plummer potential
with Softening length

-DM + Baryonic matter: gas, stars, BH
-from z=127 → to z=0
-LCDM cosmology:

Ω_Λ=0.693, Ω_m=0.307, Ω_b=0.04825, σ_8=0.8288, n_s=0.9611, H_0= 67.77 km/s/Mpc

-$\Delta x_{grid} = 33 - 66\ h^{-1}$ kpc,
but gravitational softening lengths, smoothing length $h << \Delta x_{grid}$

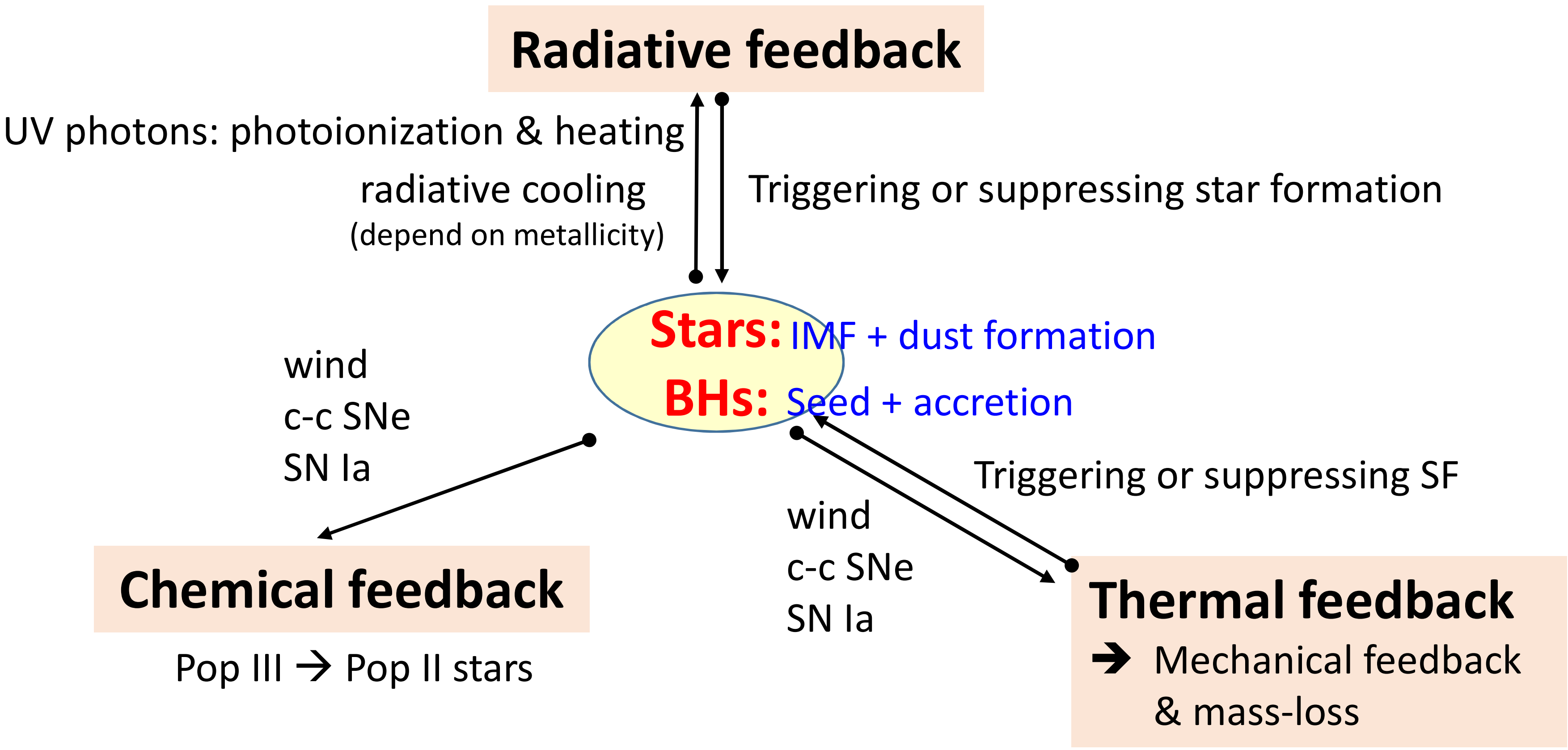


Δx_{grid}

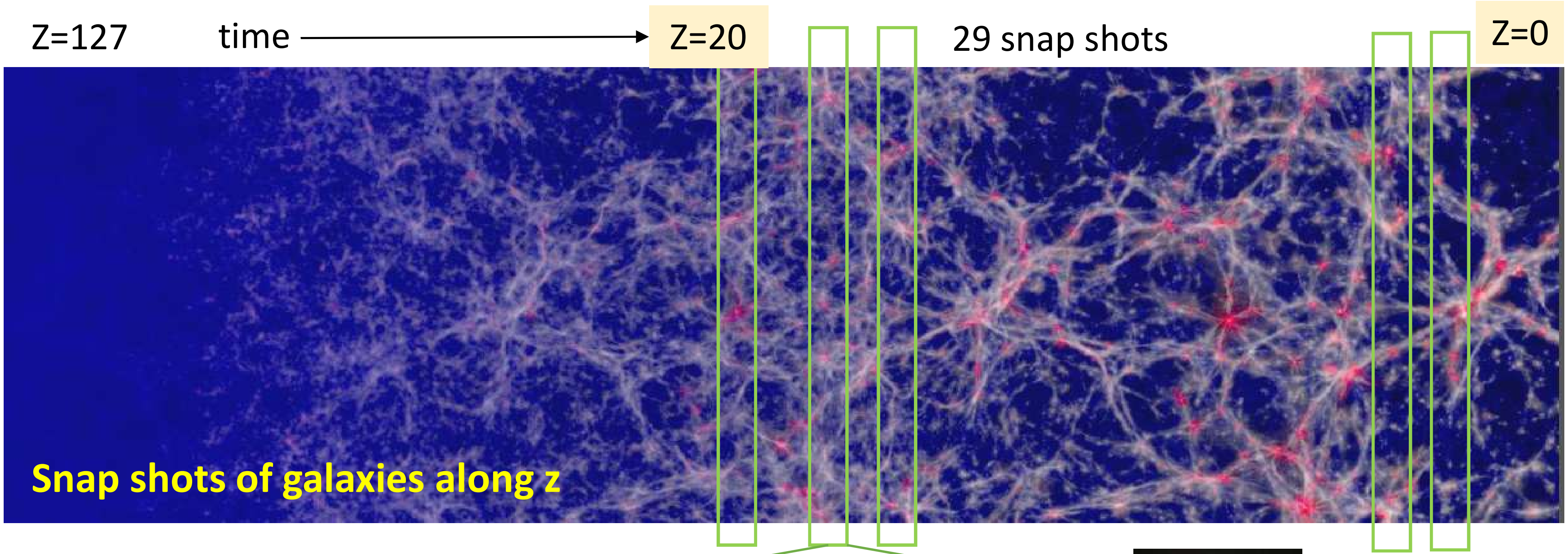
one cell

-subgrid physics model:
processes not resolved by the numerical scheme are implemented as subgrid source and sink terms.
→ Fine-turning of a set of free parameters
→ calibrated against observations:

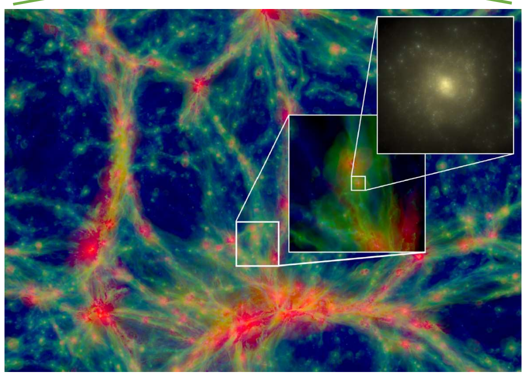
Subgrid recipes for feedback from stars & BHs



1 . stochastic star formation: Kennicutt-Schmidt relations
2. Initial Mass Function by Chabrier (2003) + Dust formation
3. Seed black hole: Bondi-Hoyle accretion + feedback (AGN heating)
4. radiative cooling and photoionization heating with temperature floor
5. stellar mass loss due to winds (massive stars, SN Ia, core collapse SN)
6. thermal energy feedback + chemical enrichment from star formation



Structured Query Language (SQL):
data retrieval tool



Properties of haloes and galaxies
-stellar mass, SFR, metallicity, merger trees (evolution)
-photomertic magnitudes & colors: SDSS u, g, r filters
-mock three-color gri images

Astronomy and Computing 15 (2016) 72–89

The EAGLE simulations of galaxy formation: Public release of halo and galaxy catalogues☆

S. McAlpine [a,*], J.C. Helly [a], M. Schaller [a], J.W. Trayford [a], Y. Qu [a], M. Furlong [a], R.G. Bower [a], R.A. Crain [b], J. Schaye [c], T. Theuns [a], C. Dalla Vecchia [d,e], C.S. Frenk [a], I.G. McCarthy [b], A. Jenkins [a], Y. Rosas-Guevara [f], S.D.M. White [g], M. Baes [h], P. Camps [h], G. Lemson [i]

EAGLE galaxy database

If you already have an account, follow this link to access the data or register via the form below.

Documentation can be found on the database itself or in the galaxy catalogue release paper.

The python examples from the release paper are available here:

- To connect to the database directly via Python here
- Galaxy stellar mass function example here.

Structured Query Language (SQL)
+ Python

EAGLE particle data

If you already have an account, the particle data can be accessed from this link. Registation is done via the form below.

The documentation accompanying the particle data can be downloaded in the data release paper.

The Python examples from the release paper are available below:

EAGLE Public Data Release

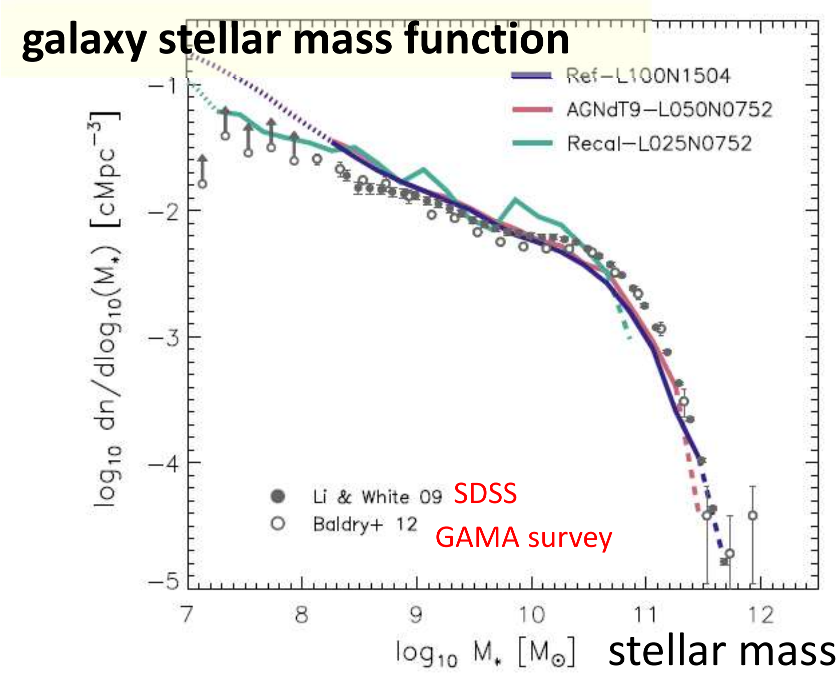
Welcome to the EAGLE public data release.

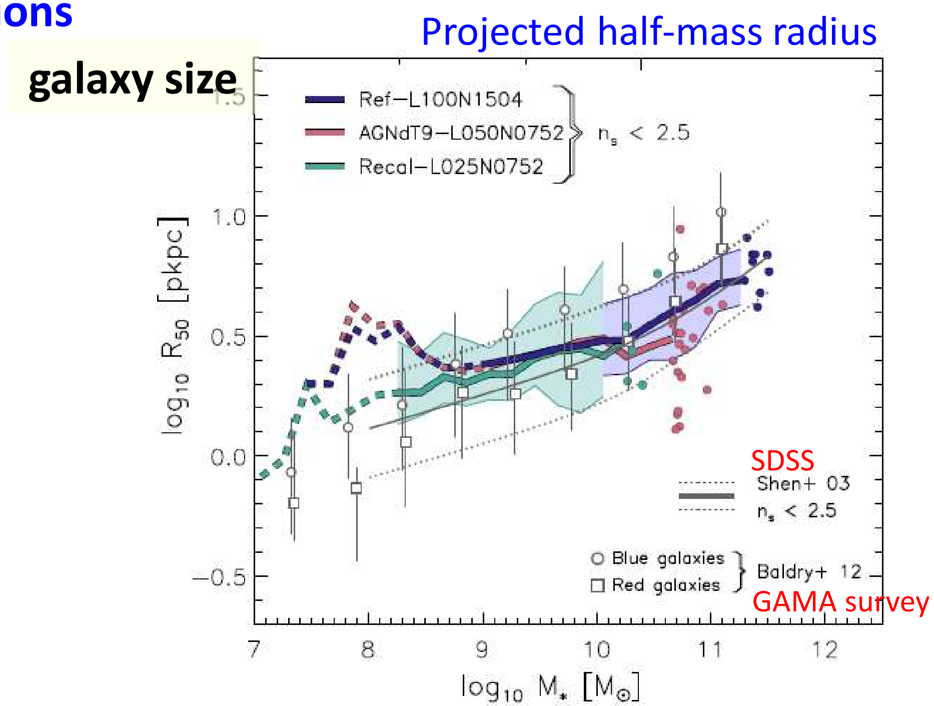
Below we provide access to the EAGLE public database, which contains galaxy properties (such as masses, star formation rates, luminosites and metallicities), merger histories and images for more than 1,000,000 simulated galaxies extracted from multiple simulations of various box sizes, numerical resolutions and physical models. Additionally, we also provide access to the particle data for each of these simulations.

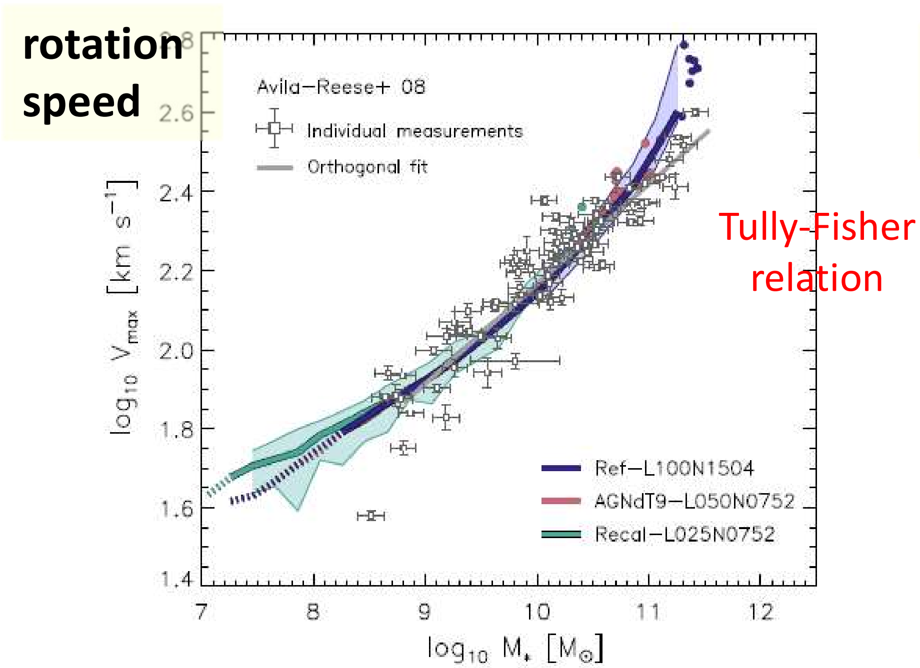
Access to both the database and particle data require only a single account, which you can register for below.

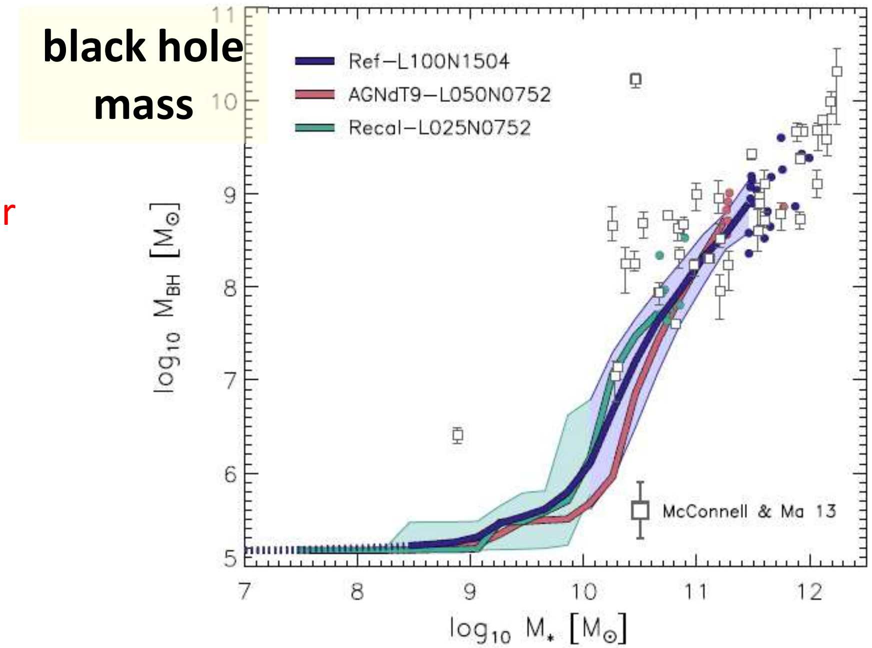
http://icc.dur.ac.uk/Eagle/database.php

Calibrating subgrid recipes against observations

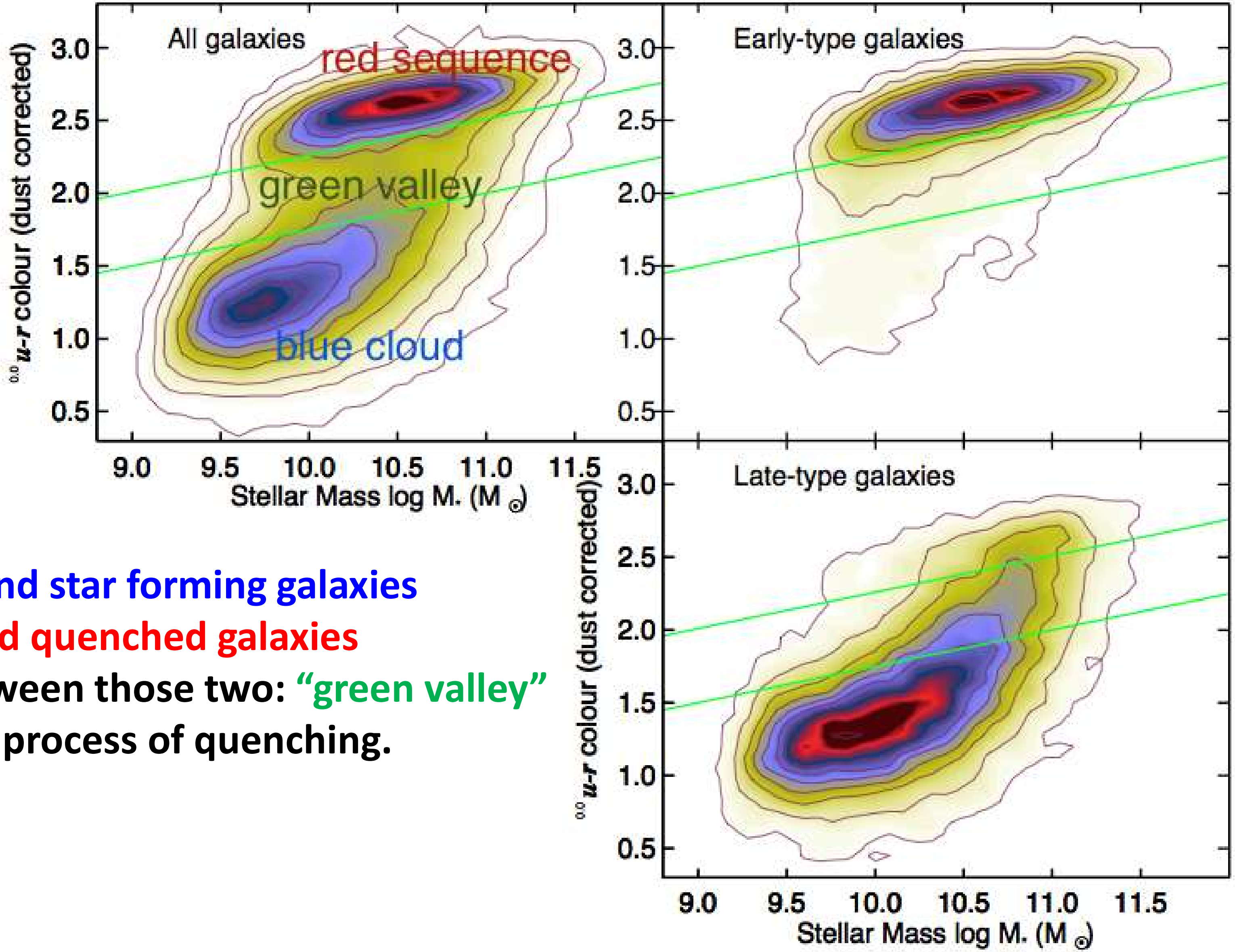








Observational Data: SDSS+GALEX+Galaxy Zoo data



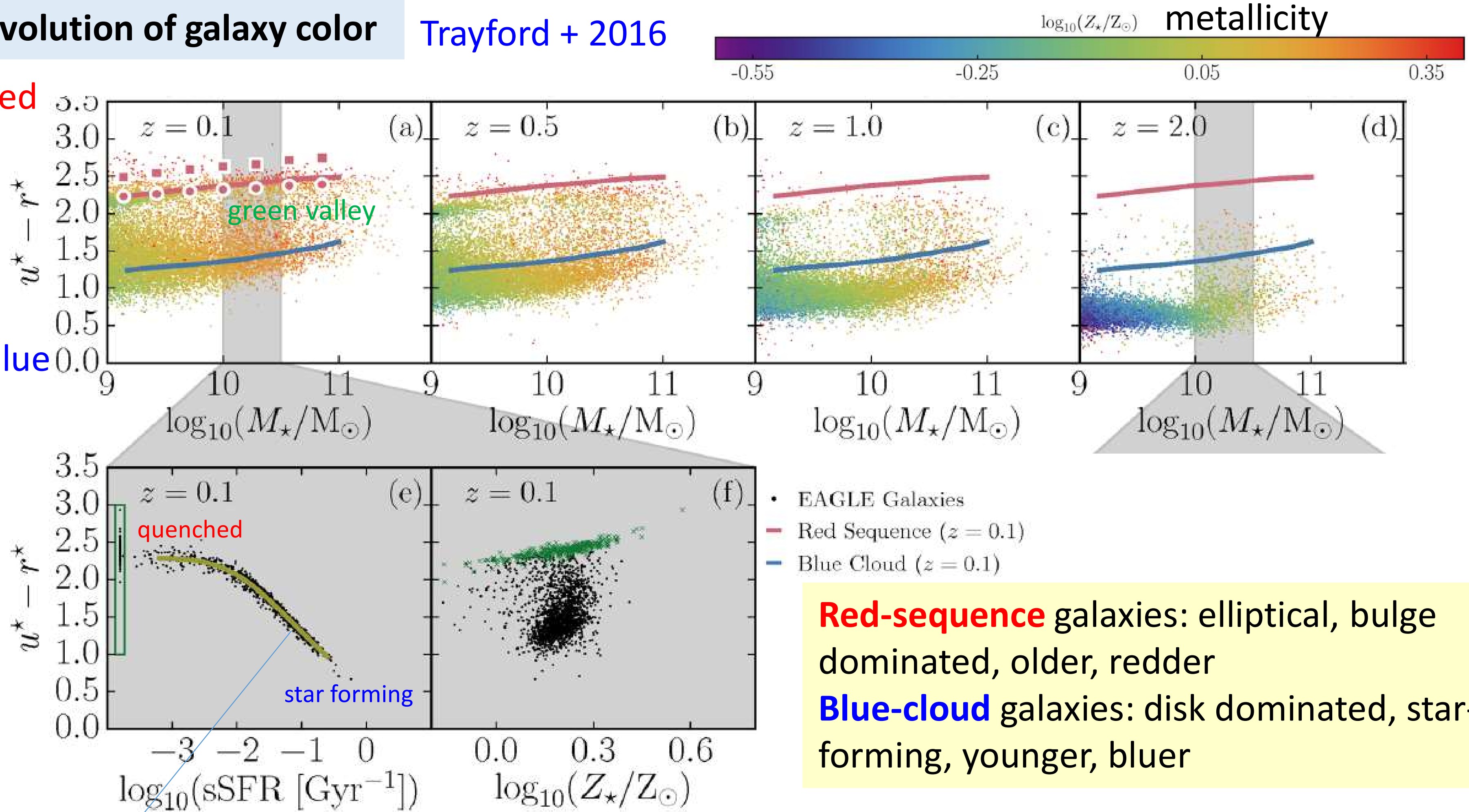
-blue and star forming galaxies

-red and quenched galaxies

-in between those two: "green valley" in the process of quenching.

Evolution of galaxy color

Trayford + 2016



Red-sequence galaxies: elliptical, bulge dominated, older, redder

Blue-cloud galaxies: disk dominated, star-forming, younger, bluer

-**Bimodality** in color at z=0.1 : red & blue sequences.

-Redder with increasing M*, as more massive galaxies are more **metal rich** and hence redder

-red sequence becomes bluer and less populated at higher z

-blue sequence becomes bluer with increasing z

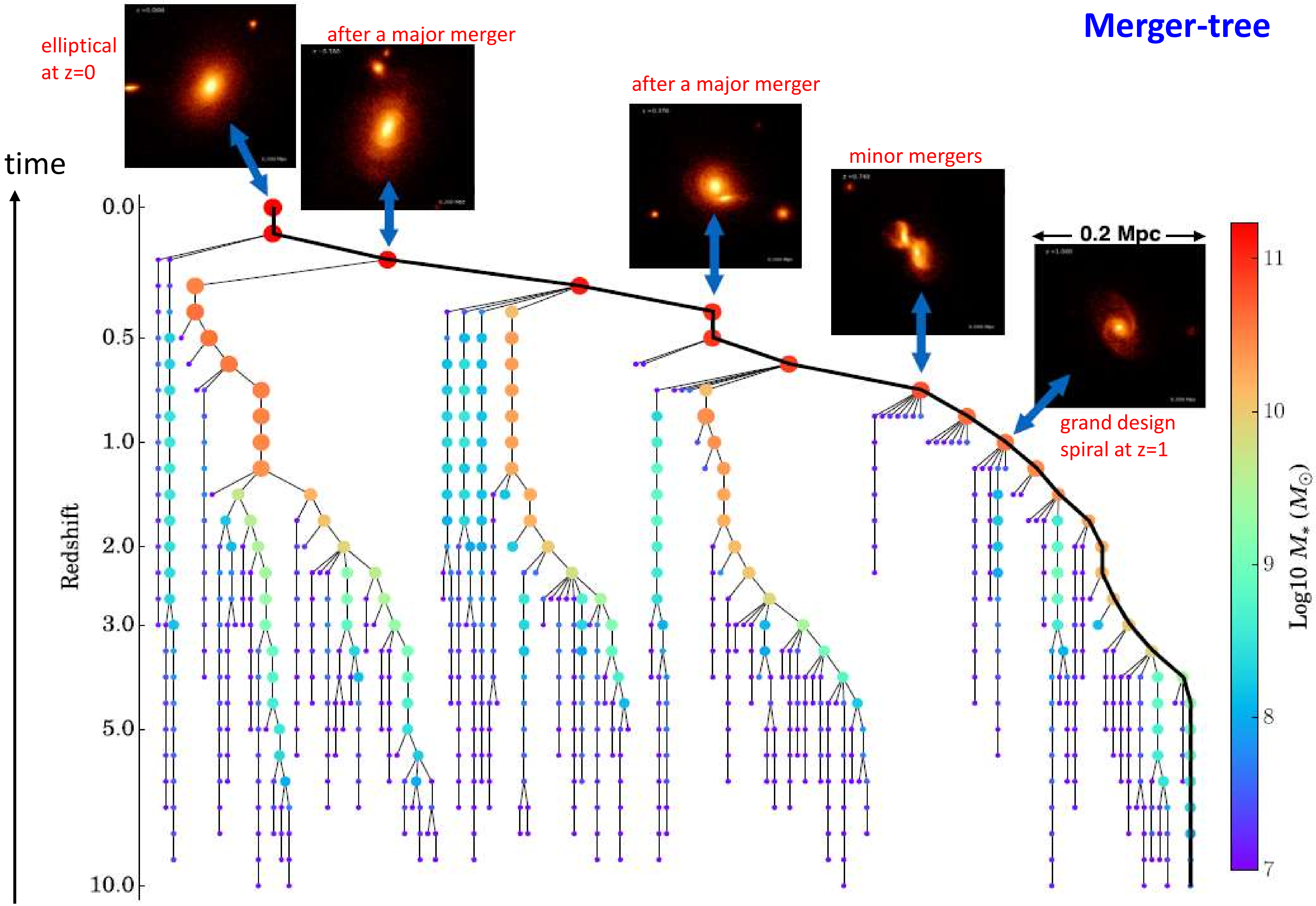
-bluer with higher SFR: strong (anti)correlation

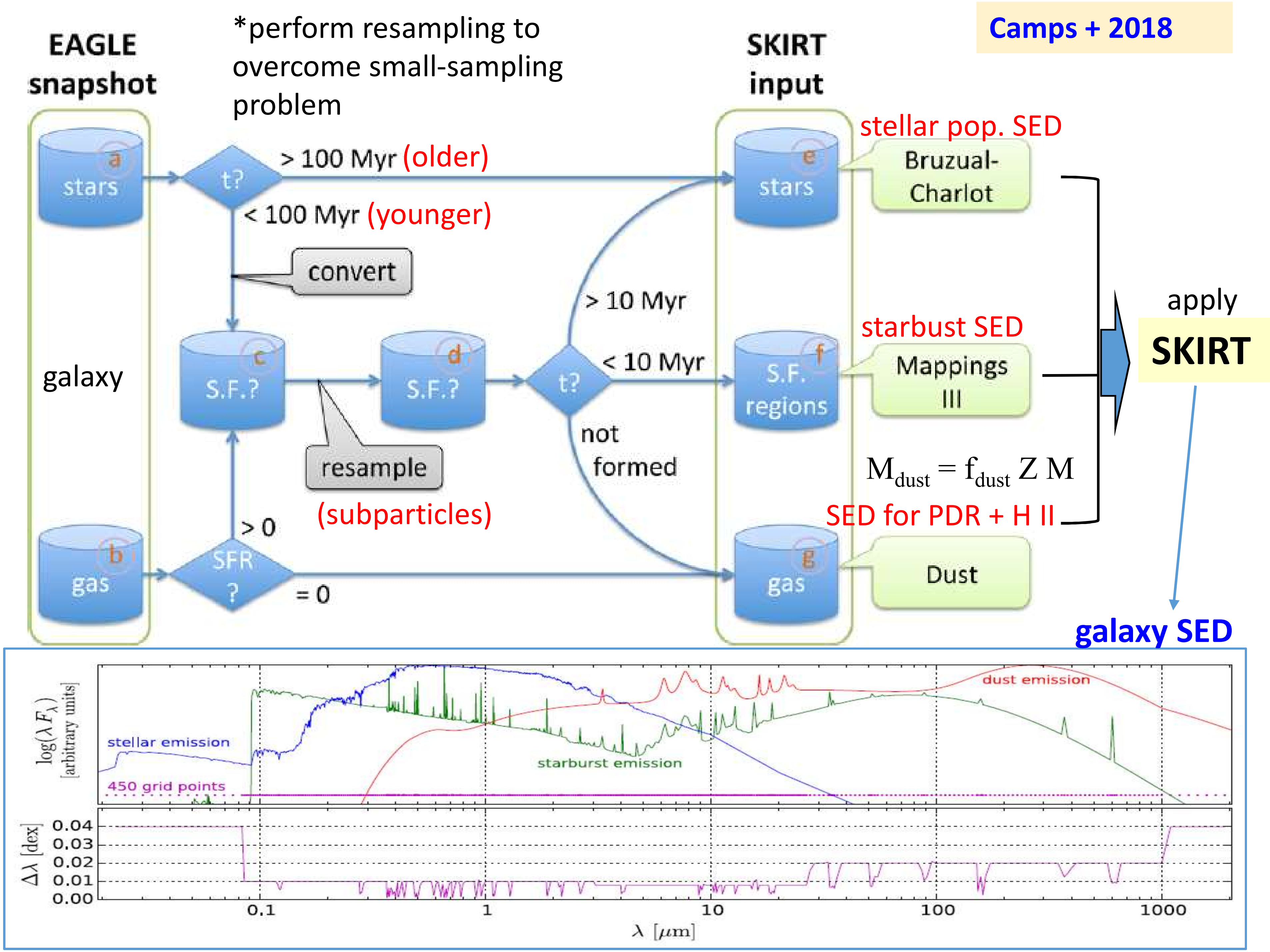
-it is not being easy being green: $\Delta t_{green} < 2$ Gyr

Following the evolution of galaxy properties with merger history

Qu + 2017

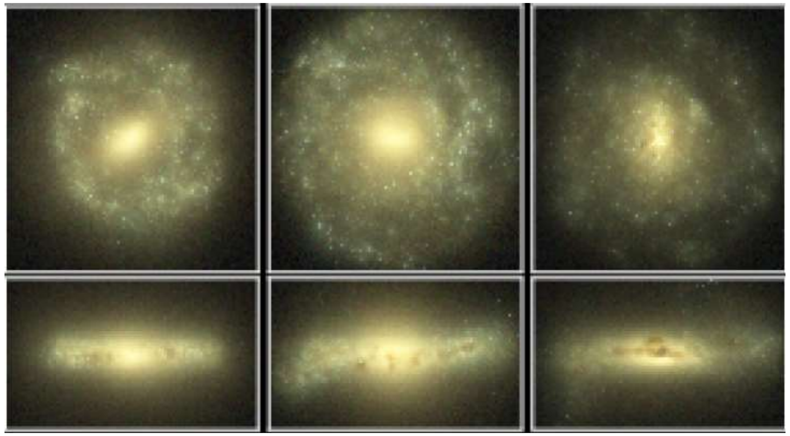
Merger-tree



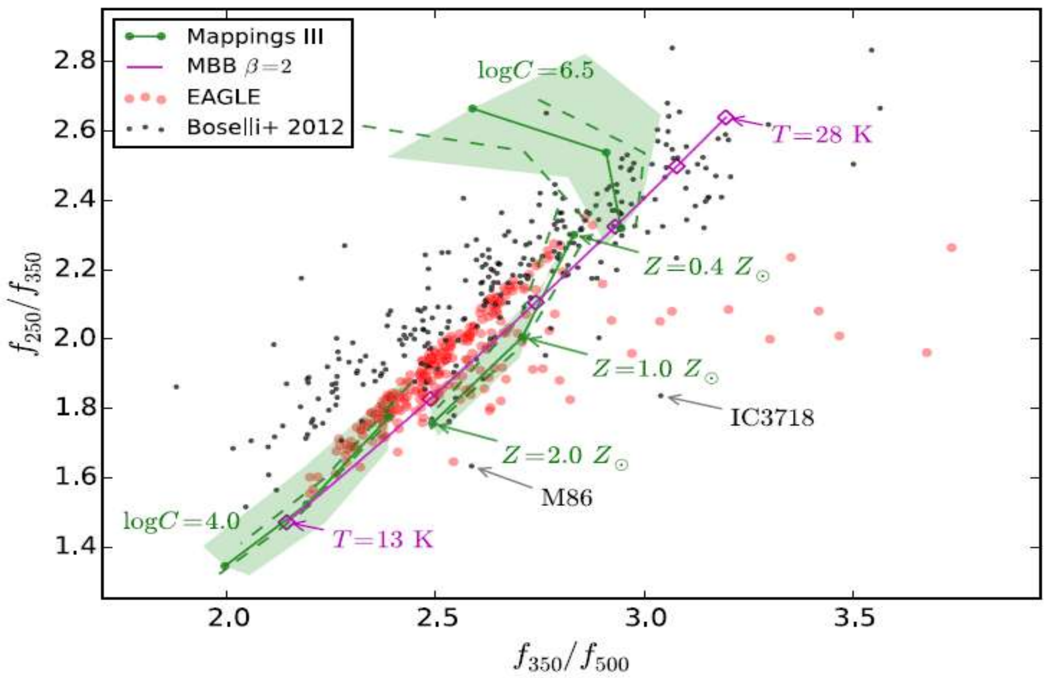

Camps + 2018
EAGLE snapshot
*perform resampling to overcome small-sampling problem
SKIRT input
stars
t?
> 100 Myr (older)
< 100 Myr (younger)
convert
stellar pop. SED
Bruzual-Charlot
galaxy
S.F.?
S.F.?
resample
(subparticles)
> 10 Myr
< 10 Myr
not formed
S.F. regions
starbust SED
Mappings III
apply
SKIRT
$M_{dust} = f_{dust} Z M$
SED for PDR + H II
gas
SFR ?
> 0
= 0
gas
Dust
galaxy SED
stellar emission
starburst emission
dust emission
450 grid points
$\log(\lambda F_\lambda)$ [arbitrary units]
$\Delta\lambda$ [dex]
λ [μm]

EAGLE Model	L (cMpc)	m_g ($M_\odot$)	Number of Galaxies with $M_* > 10^{8.5}\,M_\odot$		
			All	With Some Dust	With Resolved Dust
RefL0025N0752	25	2.26×10^5	8279	8096 (97.8%)	7819 (94.4%)
RecalL0025N0752	25	2.26×10^5	5954	5886 (98.9%)	5700 (95.7%)
RefL0025N0376	25	1.81×10^6	5742	5553 (96.7%)	3871 (67.4%)
RefL0050N0752	50	1.81×10^6	48,261	44,470 (92.1%)	31,422 (65.1%)
AGNdT9L0050N0752	50	1.81×10^6	48,278	44,601 (92.4%)	31,231 (64.7%)
RefL0100N1504	100	1.81×10^6	371,728	334,717 (90.0%)	236,346 (63.6%)
Total			488,242	443,323 (90.8%)	316,389 (64.8%)

- *UV-FIR Photometry*
- *UV-FIR Spectra*
- *Broad band FITS files*
- *IFU data cubes*



GALEX FUV/NUV (Morrissey et al. 2007); SDSS *ugriz* (Doi et al. 2010); 2MASS *JHK* (Cohen, Wheaton & Megeath 2003); *WISE* *W1*/*W2*/*W3*/*W4* (Wright et al. 2010); *Spitzer* MIPS 24/70/160 (Rieke et al. 2004); *Herschel* PACS 70/100/160 (Poglitsch et al. 2010); and *Herschel* SPIRE 250/350/500 for extended sources (Griffin et al. 2010).



Herschel SPIRE:250/350/500 μm

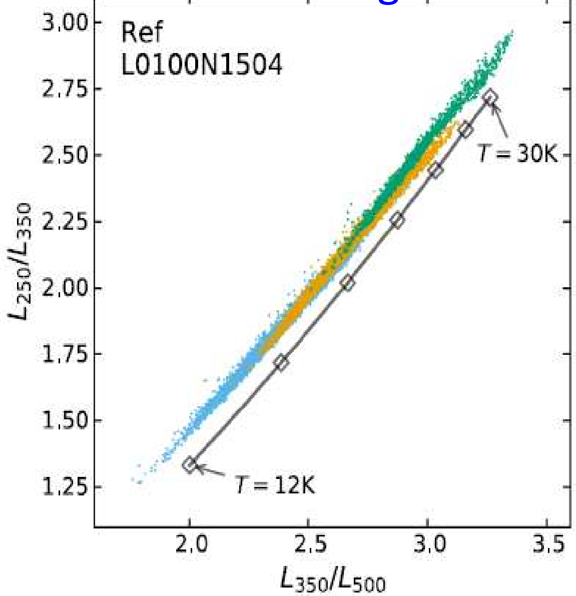
Mapping III template with different Z

Modified Black Body

EAGLE galaxies

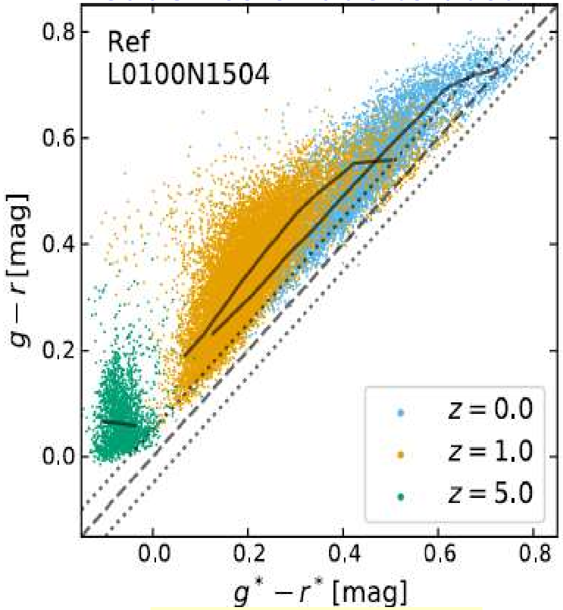
Herschel Reference Survey data

color-color diagram



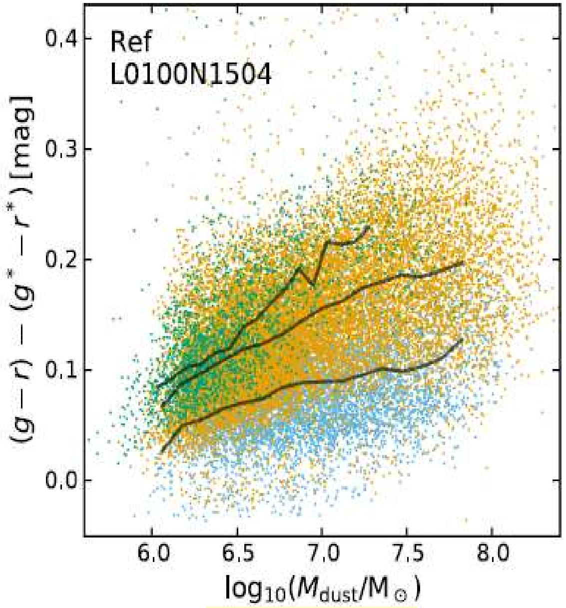
Herschel SPIRE:250/350/500 μm

Redden color due to dust



(intrinsic color)

(observed-intrinsic) color



(dust mass)

Evolution and Assembly of GaLaxies and their Environments

1. SIMULATION

MNRAS **446**, 521–554 (2015)

The EAGLE project: simulating the evolution and assembly of galaxies and their environments

Joop Schaye,[1★] Robert A. Crain,[1] Richard G. Bower,[2] Michelle Furlong,[2]

2. Galaxy Catalogues

Astronomy and Computing 15 (2016) 72–89

The EAGLE simulations of galaxy formation: Public release of halo and galaxy catalogues[☆]

S. McAlpine[a,*], J.C. Helly[a], M. Schaller[a], J.W. Trayford[a], Y. Qu[a], M. Furlong[a], R.G. Bower[a],

3. Revised Catalogues with Dust + Radiative Transfer

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 234:20 (15pp), 2018 February

Data Release of UV to Submillimeter Broadband Fluxes for Simulated Galaxies from the EAGLE Project

Peter Camps[1], Ana Trčka[1], James Trayford[2], Maarten Baes[1], Tom Theuns[2], Robert A. Crain[3], Stuart McAlpine[2], Matthieu Schaller[2], and Joop Schaye[4]

➔ EAGLE provides a powerful tool for understanding and interpreting a wide range of observation measurements.

No. of papers with “EAGLE” in the title since 2015: ~ 60

Query Results from the ADS Database
Selected and retrieved **60** abstracts.

#	Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1	2018MNRAS.tmp..578R Rahmati, Alireza; Oppenheimer, Benjamin D.	1.000 The metallicity distribution of HI systems in the EAGLE cosmological simulations	03/2018	A E X U
2	2018MNRAS.475.1288S Scholtz, J.; Alexander, D. M.; Harrison, C. M.; Rosario, D. J.; McAlpine, S.; Mullaney, J. R.; Stanley, F.; Simpson, J.; Theuns, T.; Bower, R. G.; and 3 coauthors	1.000 Identifying the subtle signatures of feedback from distant AGN using ALMA observations and the EAGLE hydrodynamical simulations	03/2018	A E F X D R C U
3	2018MNRAS.474.3746A Armitage, Thomas J.; Barnes, David J.; Kay, Scott T.; Bahé, Yannick M.; Dalla Vecchia, Claudio; Crain, Robert A.; Theuns, Tom	1.000 The Cluster-EAGLE project: velocity bias and the velocity dispersion-mass relation of cluster galaxies	03/2018	A E F X R U
4	2018MNRAS.474.3403T Tagore, Amitpal S.; Barnes, David J.; Jackson, Neal; Kay, Scott T.; Schaller, Matthieu; Schaye, Joop; Theuns, Tom	1.000 Reducing biases on H_0 measurements using strong lensing and galaxy dynamics: results from the EAGLE simulation	03/2018	A E F X R C U
5	2018ApJS..234...20C Camps, Peter; Trcka, Ana; Trayford, James; Baes, Maarten; Theuns, Tom; Crain, Robert A.; McAlpine, Stuart; Schaller, Matthieu; Schaye, Joop	1.000 Data Release of UV to Submillimeter Broadband Fluxes for Simulated Galaxies from the EAGLE Project	02/2018	A E F X R C U
6	2018MNRAS.473..380T Tescari, E.; Cortese, L.; Power, C.; Wyithe, J. S. B.; Ho, I.-T.; Crain, R. A.; Bland-Hawthorn, J.; Croom, S. M.; Kewley, L. J.; Schaye, J.; and 16 coauthors	1.000 The SAMI Galaxy Survey: understanding observations of large-scale outflows at low redshift with EAGLE simulations	01/2018	A E F X R S U
7	2018arXiv180108781B Barnes, Luke A.; Elahi, Pascal J.; Salcido, Jaime; Bower, Richard G.; Lewis, Geraint F.; Theuns, Tom; Schaller, Matthieu; Crain, Robert A.; Schaye, Joop	1.000 Galaxy Formation Efficiency and the Multiverse Explanation of the Cosmological Constant with EAGLE Simulations	01/2018	A X R U
8	2018AAS...23114904K Kulier, Andrea; Padilla, Nelson; Schaye, Joop; Crain, Robert; Schaller, Matthieu; Bower, Richard; Theuns, Tom; Paillas, Enrique	1.000 Examining the effect of galaxy evolution on the stellar-halo mass relation in the EAGLE simulation	01/2018	A U
9	2017MNRAS.472.3354D De Rossi, María Emilia; Bower, Richard G.; Font, Andreea S.; Schaye, Joop; Theuns, Tom	1.000 Galaxy metallicity scaling relations in the EAGLE simulations	12/2017	A E F X R C U
10	2017MNRAS.472L..45C Correa, Camila A.; Schaye, Joop; Clauwens, Bart; Bower, Richard G.; Crain, Robert A.; Schaller, Matthieu; Theuns, Tom; Thob, Adrien C. R.	1.000 The relation between galaxy morphology and colour in the EAGLE simulation	11/2017	A E F X R C U
11	2017MNRAS.472..919K Katsianis, A.; Blanc, G.; Lagos, C. P.; Tejos, N.; Bower, R. G.; Alavi, A.; Gonzalez, V.; Theuns, T.; Schaller, M.; Lopez, S.	1.000 The evolution of the star formation rate function in the EAGLE simulations: a comparison with UV, IR and Halpha observations from z ~ 8 to z ~ 0	11/2017	A E F X R C U
12	2017MNRAS.471.2856V Velliscig, Marco; Cacciato, Marcello; Hoekstra, Henk; Schaye, Joop; Heymans, Catherine; Hildebrandt, Hendrik; Loveday, Jon; Norberg, Peder; Sifón, Cristóbal; Schneider, Peter; and 7 coauthors	1.000 Galaxy-galaxy lensing in EAGLE: comparison with data from 180 deg^2 of the KiDS and GAMA surveys	11/2017	A E F X D R C U
13	2017MNRAS.471L..11D Desmond, Harry; Mao, Yao-Yuan; Wechsler, Risa H.; Crain, Robert A.; Schaye, Joop	1.000 On the galaxy-halo connection in the EAGLE simulation	10/2017	A E F X R C U
14	2017MNRAS.471.1088B Barnes, David J.; Kay, Scott T.; Bahé, Yannick M.; Dalla Vecchia, Claudio; McCarthy, Ian G.; Schaye, Joop; Bower, Richard G.; Jenkins, Adrian; Thomas, Peter A.; Schaller, Matthieu; and 3 coauthors	1.000 The Cluster-EAGLE project: global properties of simulated clusters with resolved galaxies	10/2017	A E F X R C S U
15	2017MNRAS.470.4434P Paillas, Enrique; Lagos, Claudia D. P.; Padilla, Nelson; Tissera, Patricia; Helly, John; Schaller, Matthieu	1.000 Baryon effects on void statistics in the EAGLE simulation	10/2017	A E F X R C U
16	2017MNRAS.470.1771A Artale, M. Celeste; Pedrosa, Susana E.; Trayford, James W.; Theuns, Tom; Farrow, Daniel J.; Norberg, Peder; Zehavi, Idit; Bower, Richard G.; Schaller, Matthieu	1.000 Small-scale galaxy clustering in the eagle simulation	09/2017	A E X R C U
17	2017MNRAS.470..771T Trayford, James W.; Camps, Peter; Theuns, Tom; Baes, Maarten; Bower, Richard G.; Crain, Robert A.; Gunawardhana, Madusha L. P.; Schaller, Matthieu; Schaye, Joop; Frenk, Carlos S.	1.000 Optical colours and spectral indices of z = 0.1 eagle galaxies with the 3D dust radiative transfer code skirt	09/2017	A E F X R C S U
18	2017arXiv170907577O Oppenheimer, Benjamin D.; Schaye, Joop; Crain, Robert A.; Werk, Jessica K.; Richings, Alexander J.	1.000 The multiphase circumgalactic medium traced by low metal ions in EAGLE zoom simulations	09/2017	A X R C U

The Illustris Simulation

$3 \times 1820^3 = 18.1 \times 10^9$
cells / particles / tracers

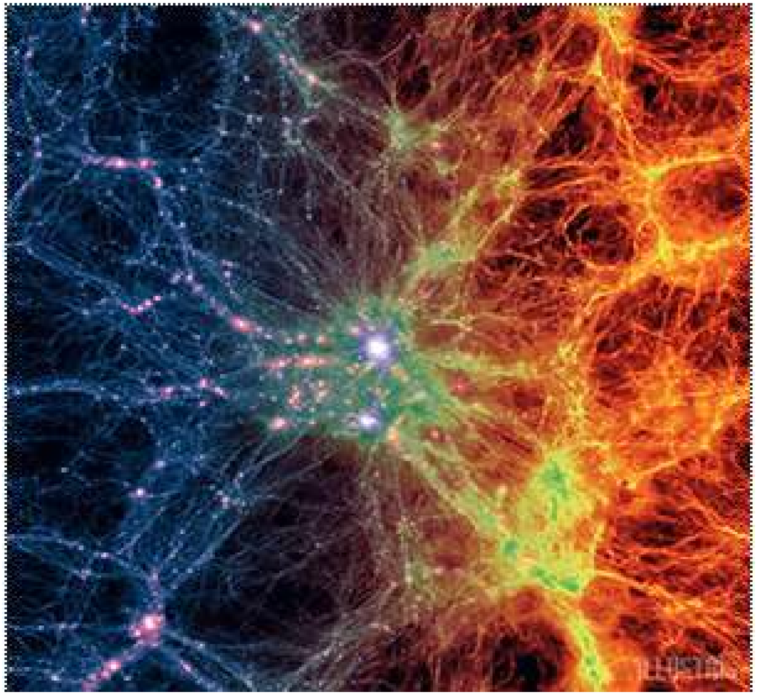
106.5 Mpc boxsize

$M_{\mathrm{baryon}} = 1.26 \times 10^5\ M_\odot$
$M_{\mathrm{dm}} = 6.26 \times 10^5\ M_\odot$

~50 pc smallest cell size

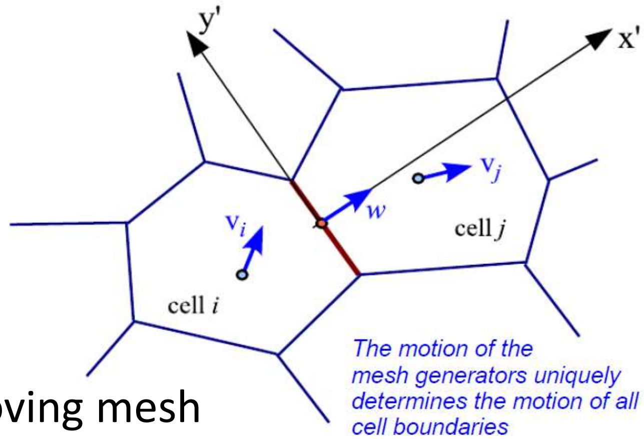
16 (+3) million CPU hours

www.illustris-project.org

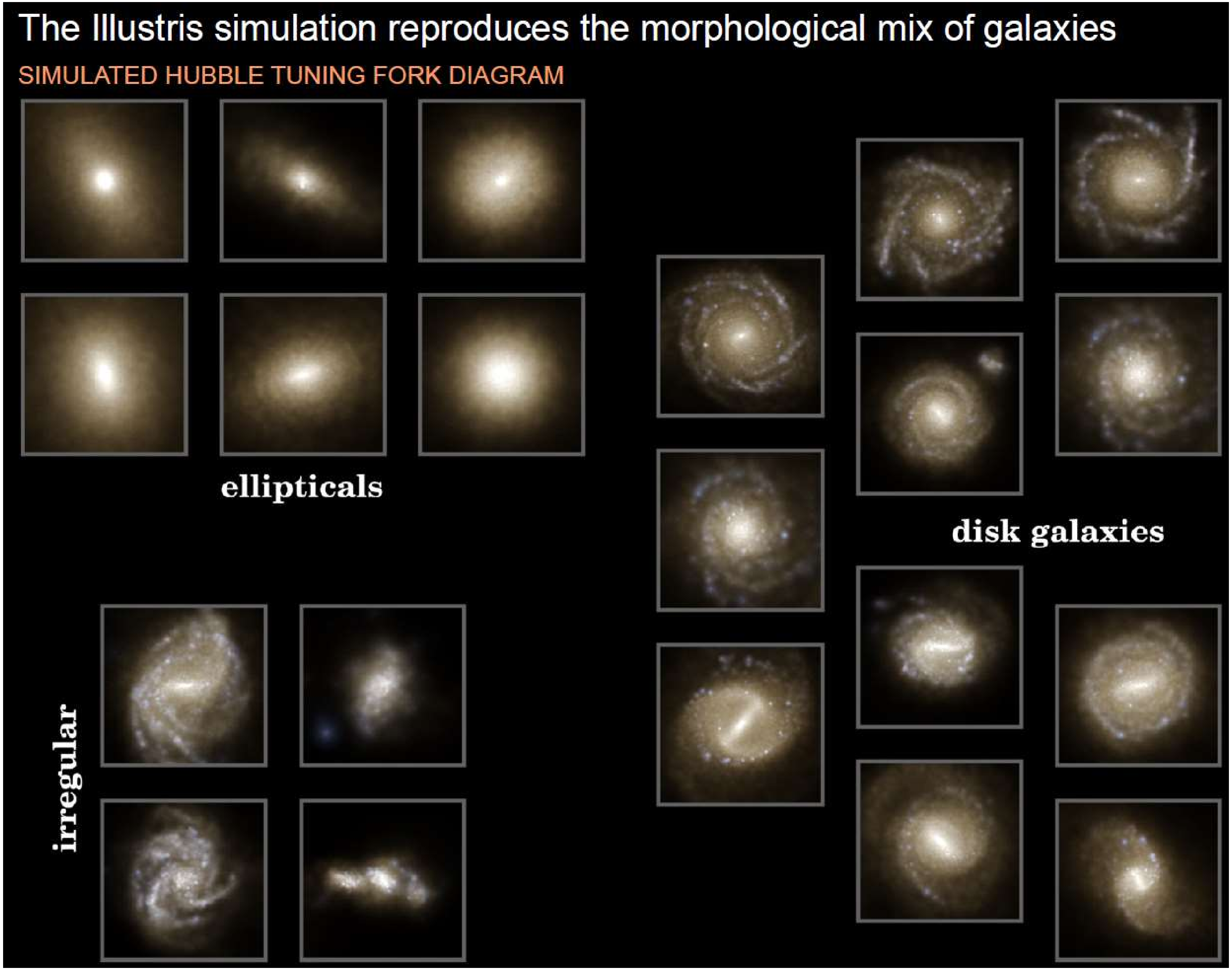


Large scale projection through the Illustris volume at z=0. Shows dark matter density (left) transitioning to gas density (right).

primordial & metal line cooling
+ self-shielding
stellar evolution
stellar feedback
gas recycling
chemical enrichment
black hole growth
black hole feedback:
quasar, radiative and radio bubbles



AREPO codel (Springel 2010): unstructured moving mesh


The Illustris simulation reproduces the morphological mix of galaxies
SIMULATED HUBBLE TUNING FORK DIAGRAM
ellipticals
disk galaxies
irregular