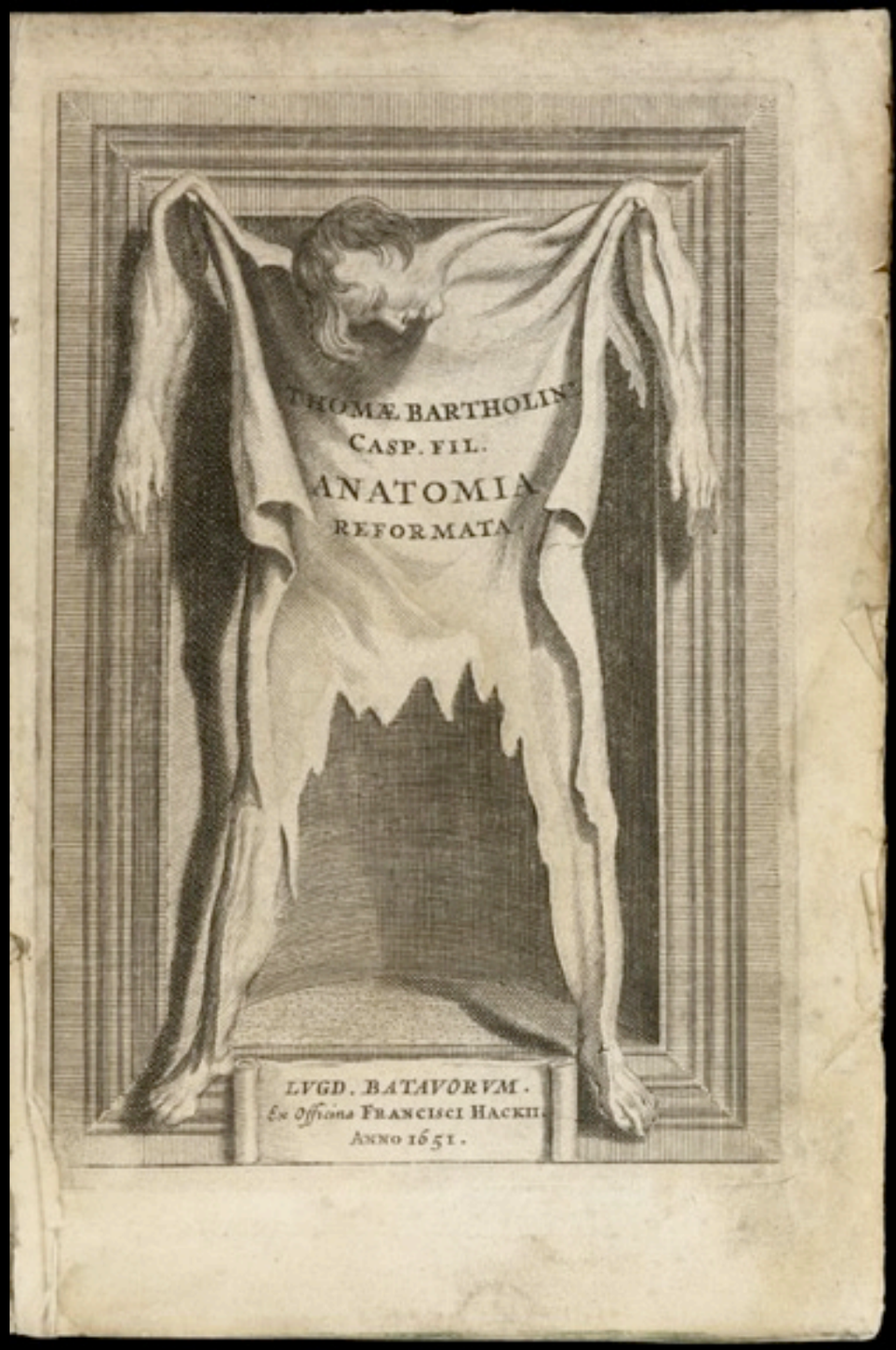
The Role of Galaxy Environment and Galaxy Assembly

Darren Crotonxxx
Centre for Astrophysics and Supercomputing
Swinburne University
dcroton@astro.swin.edu.au

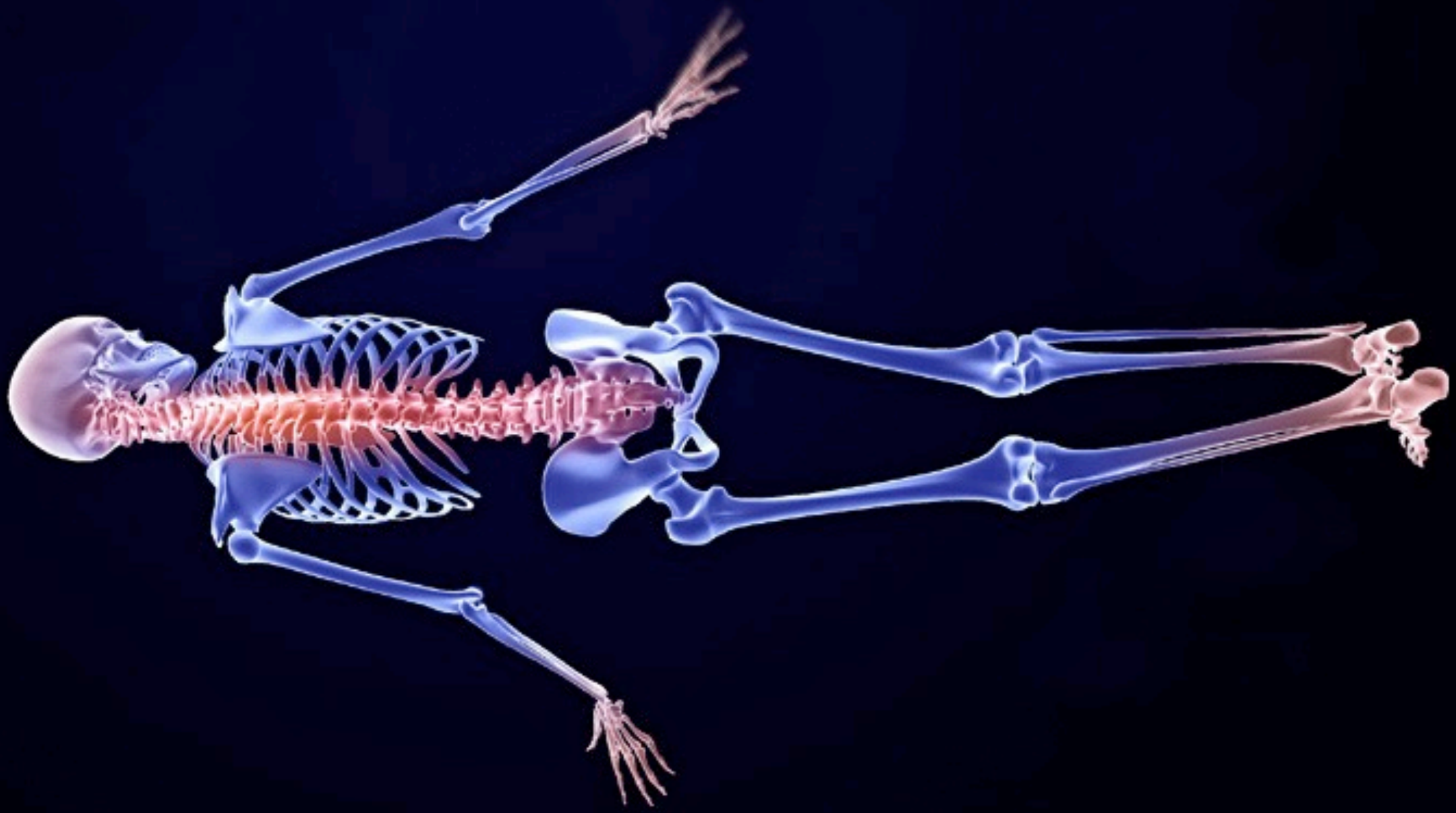
- Galaxy formation (re)primer (15 minutes)
- What is environment? (30 minutes)
- What can we learn from studying environment? (15 minutes)

Galaxy formation primer

The skeleton

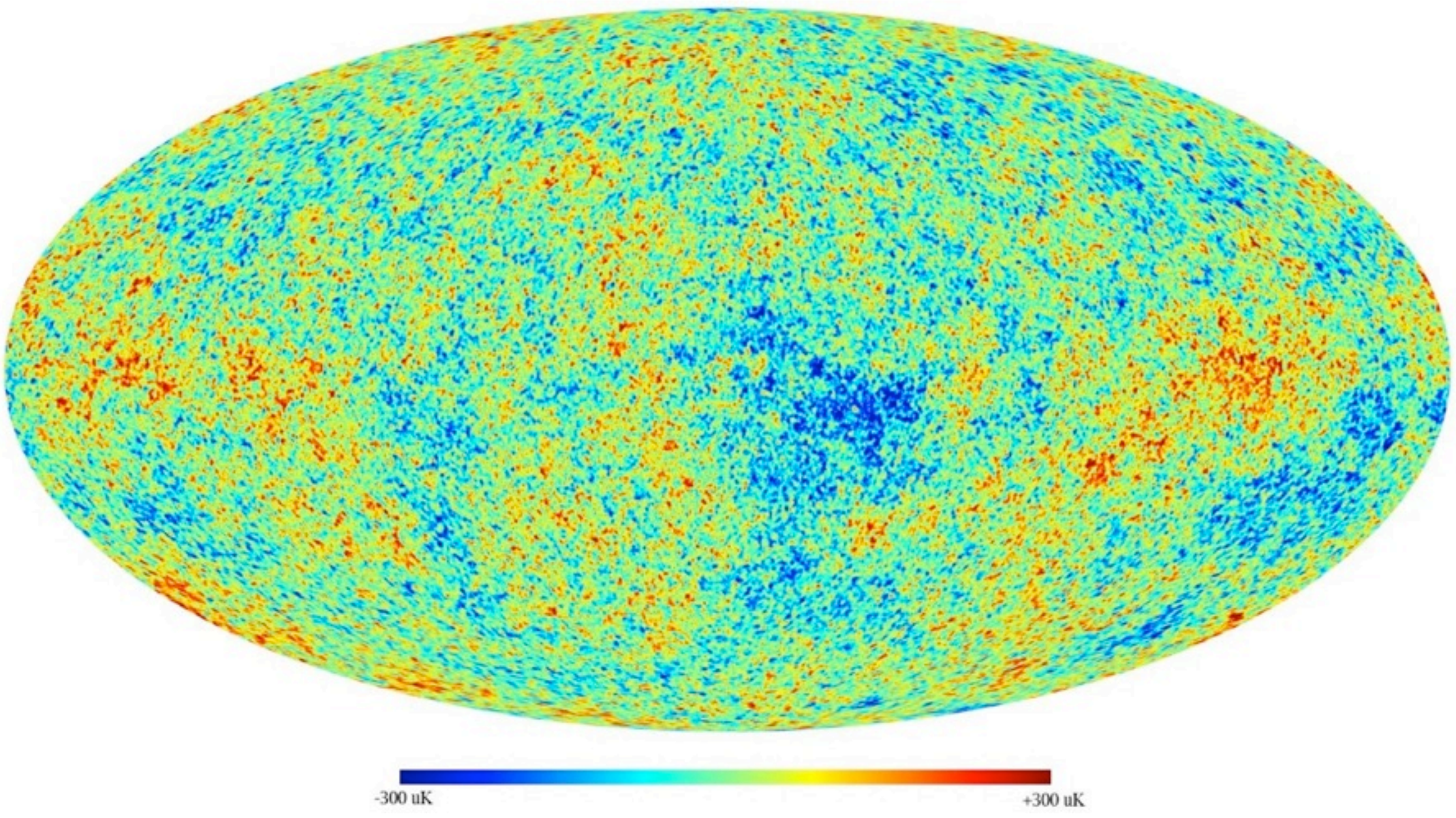


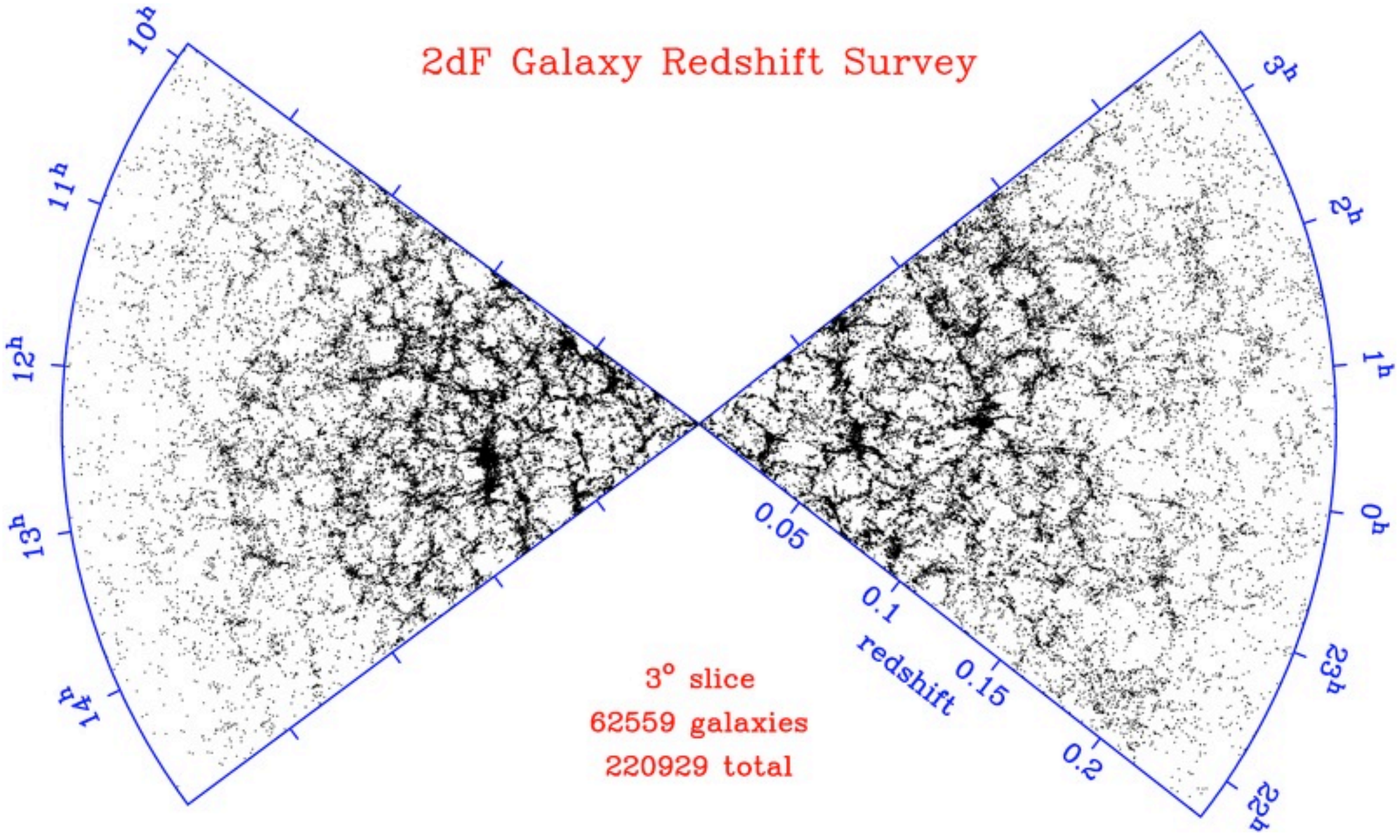
The flesh

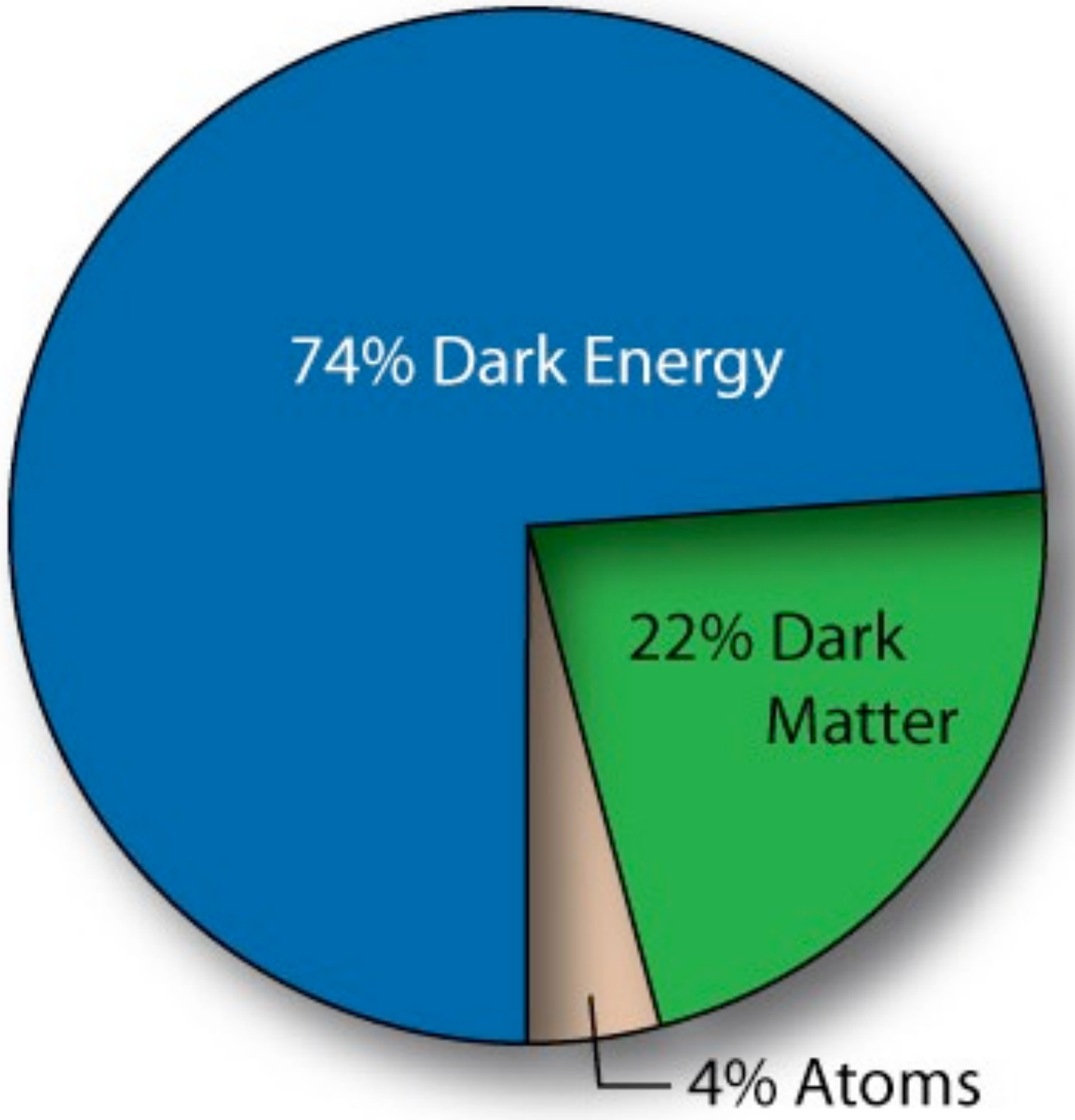


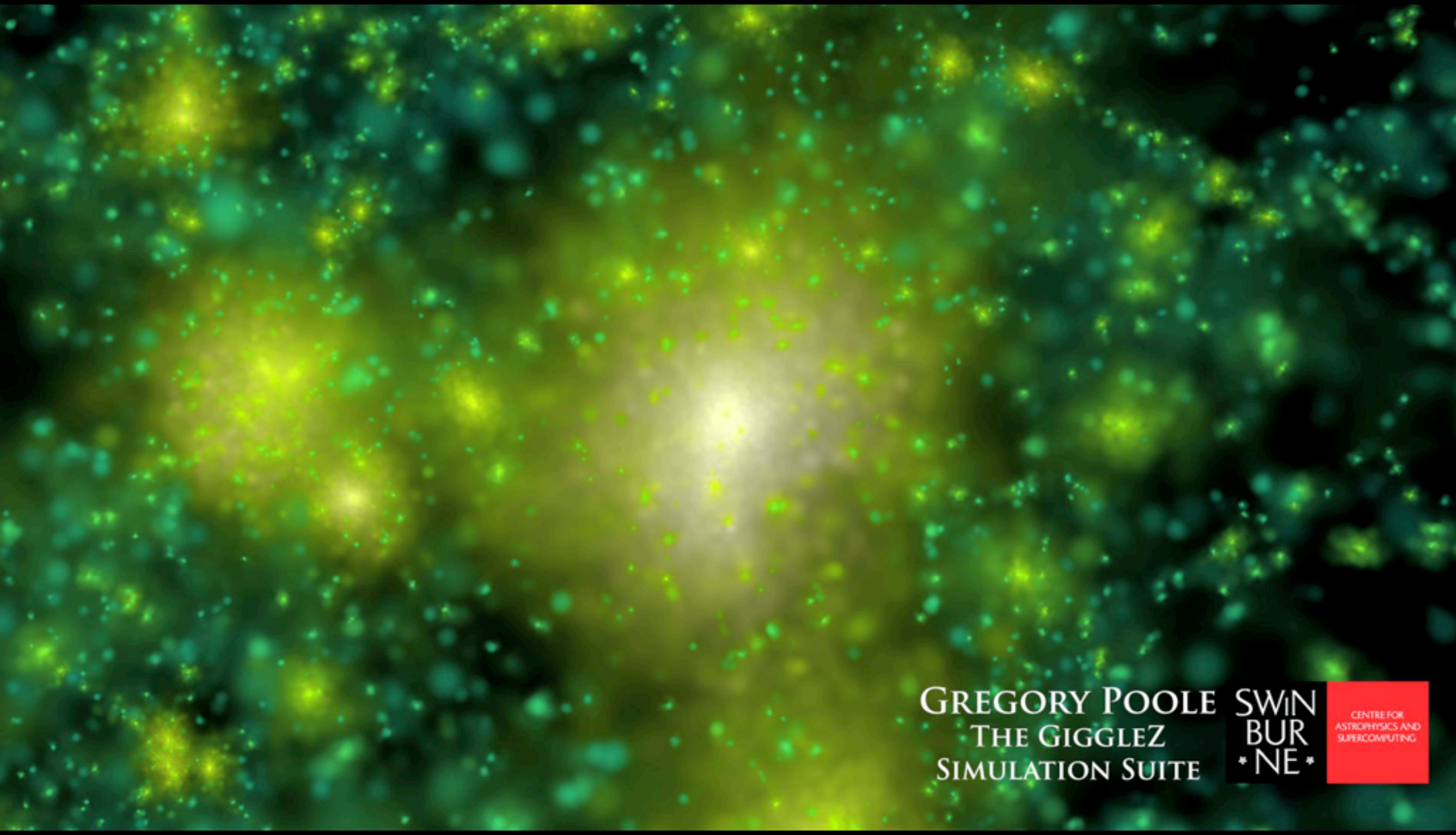
1. The skeleton: N-body simulations

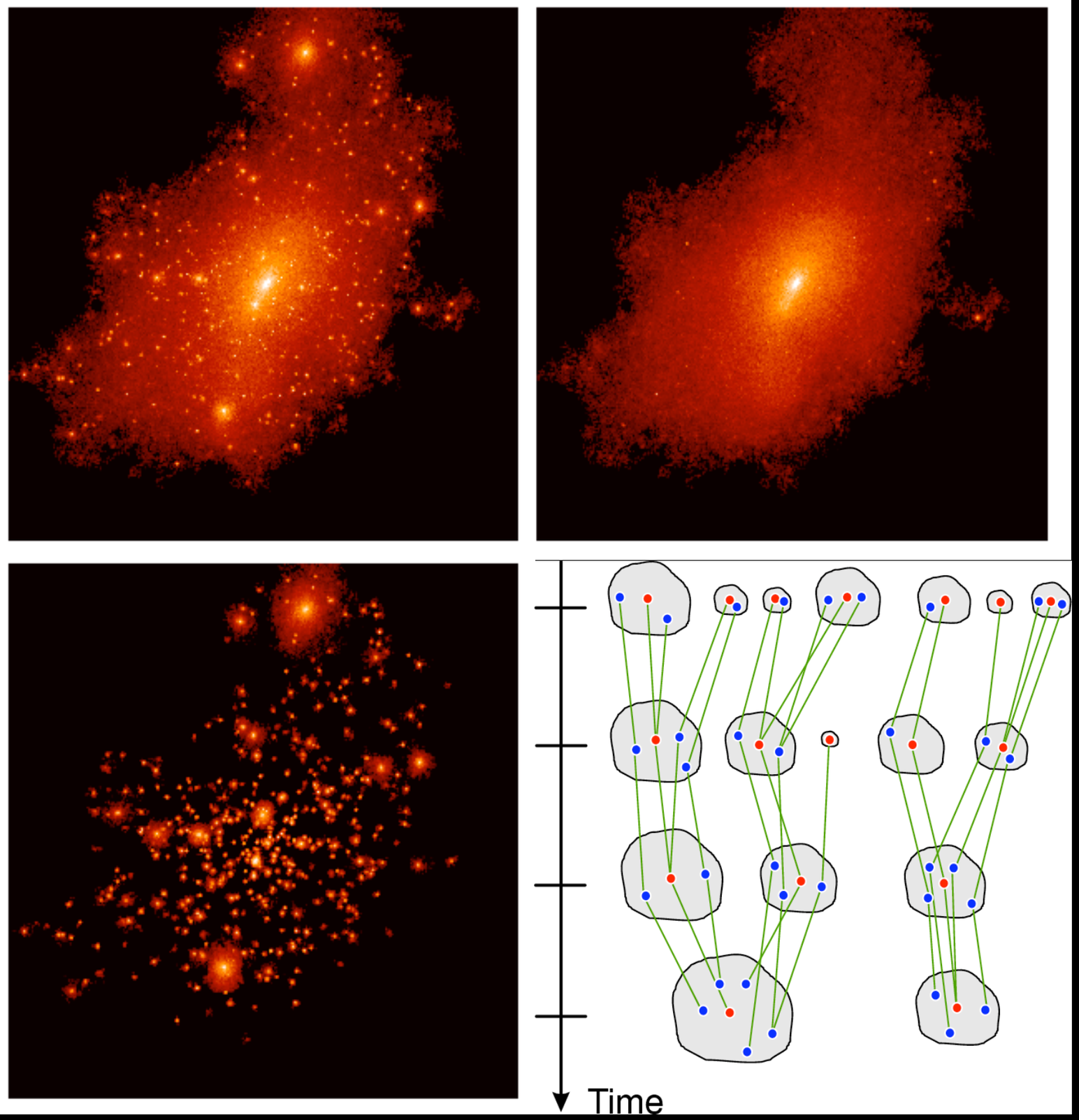
2. The flesh: interwoven analytic models of the physics of galaxy formation


-300 uK
+300 uK


2dF Galaxy Redshift Survey
10h
11h
12h
13h
14h
3h
2h
1h
0h
23h
22h
0.05
0.1
0.15
0.2
redshift
3° slice
62559 galaxies
220929 total

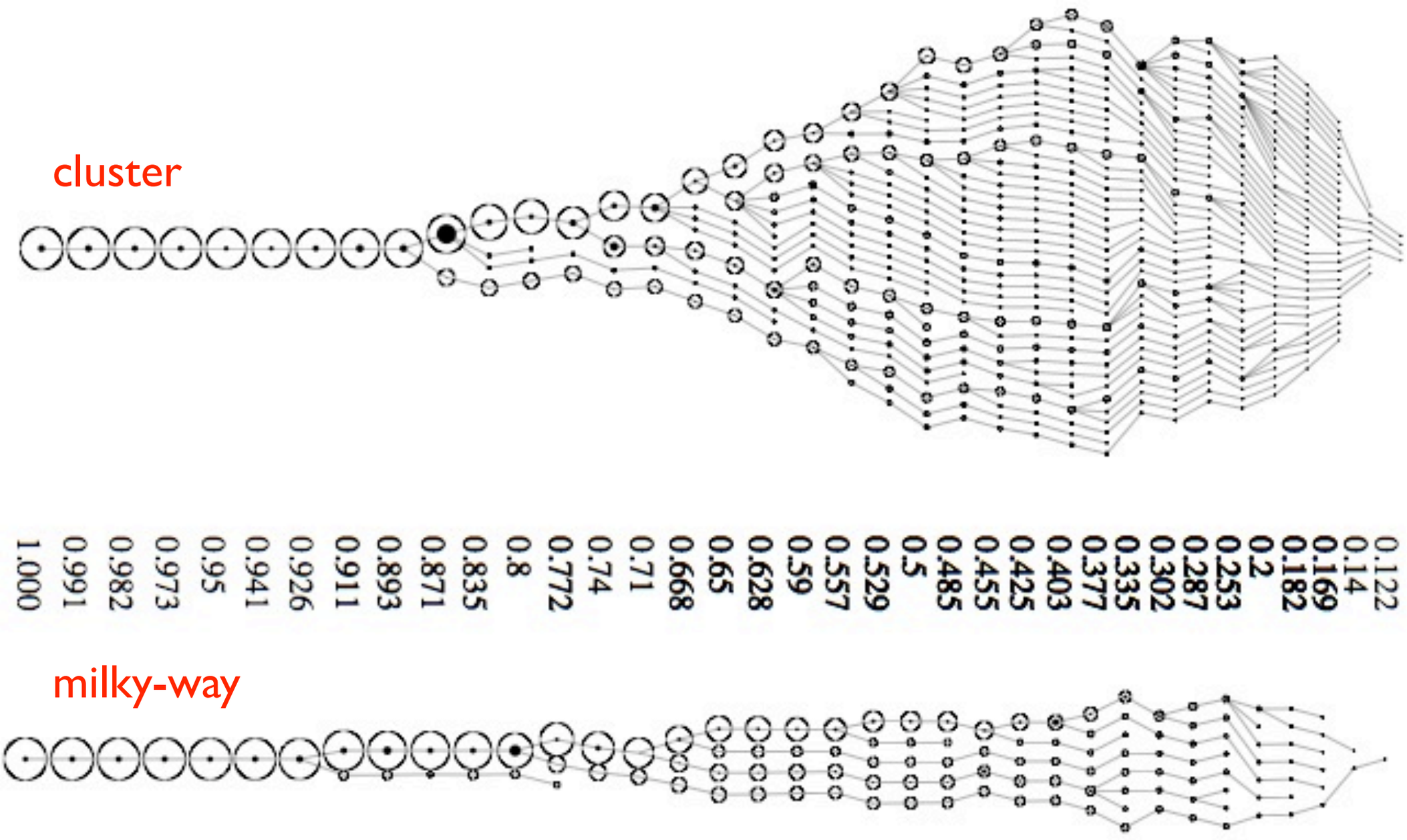

74% Dark Energy
22% Dark Matter
4% Atoms


Gregory Poole
The GiggleZ
Simulation Suite
SWIN
BUR
NE
CENTRE FOR
ASTROPHYSICS AND
SUPERCOMPUTING


Time

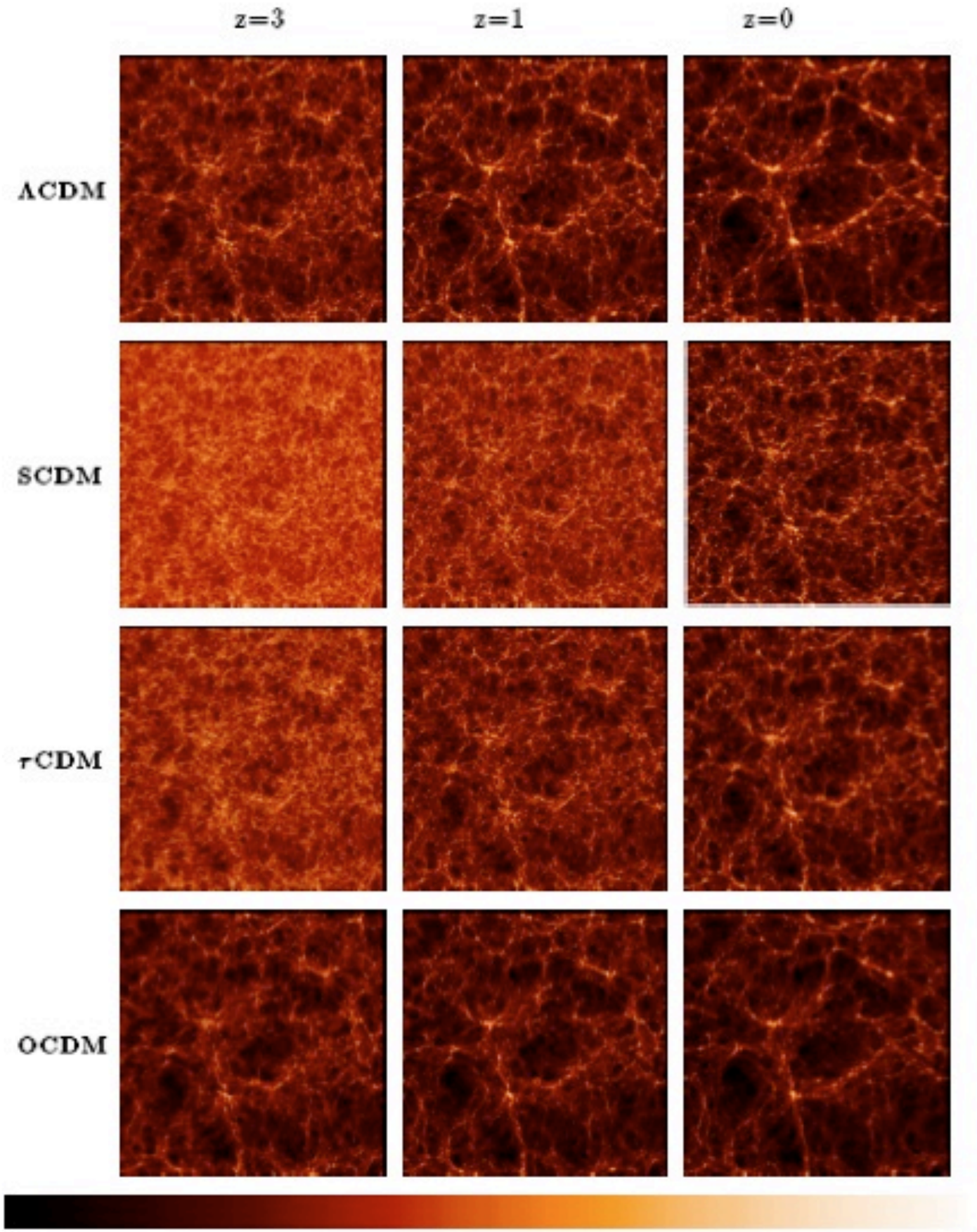
z=0 z=1 z=3 z=6

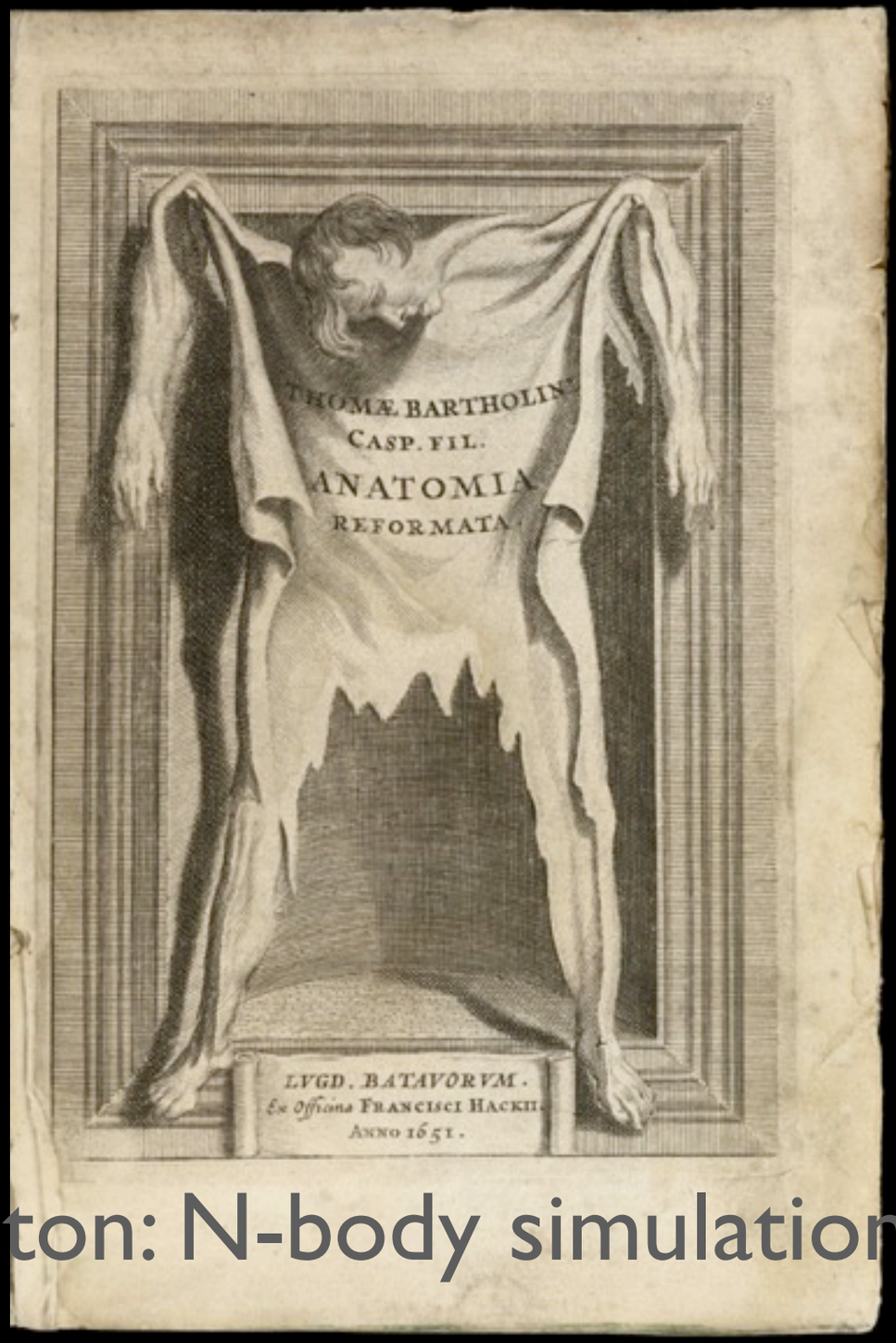
cluster



milky-way

Wechsler et al. 2002


z=3
z=1
z=0
ΛCDM
SCDM
τCDM
OCDM



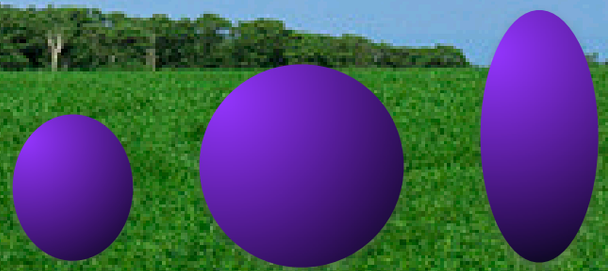
1. The skeleton: N-body simulations

2. The flesh: interwoven analytic models of the physics of galaxy formation

Alien invasion

height & shape,
density, pressure,
gravity, ...

flexibility, running,
jumping, ...

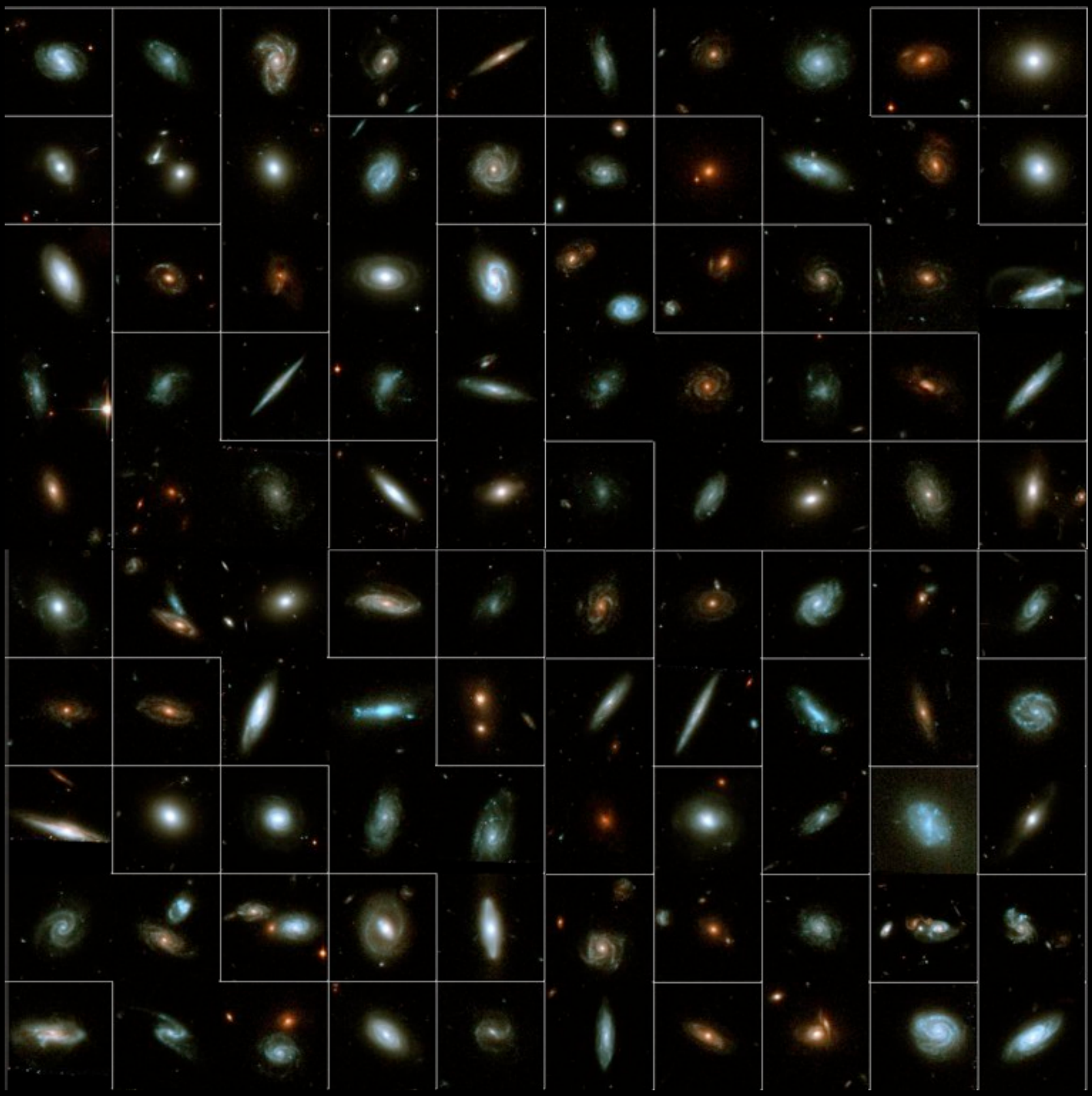


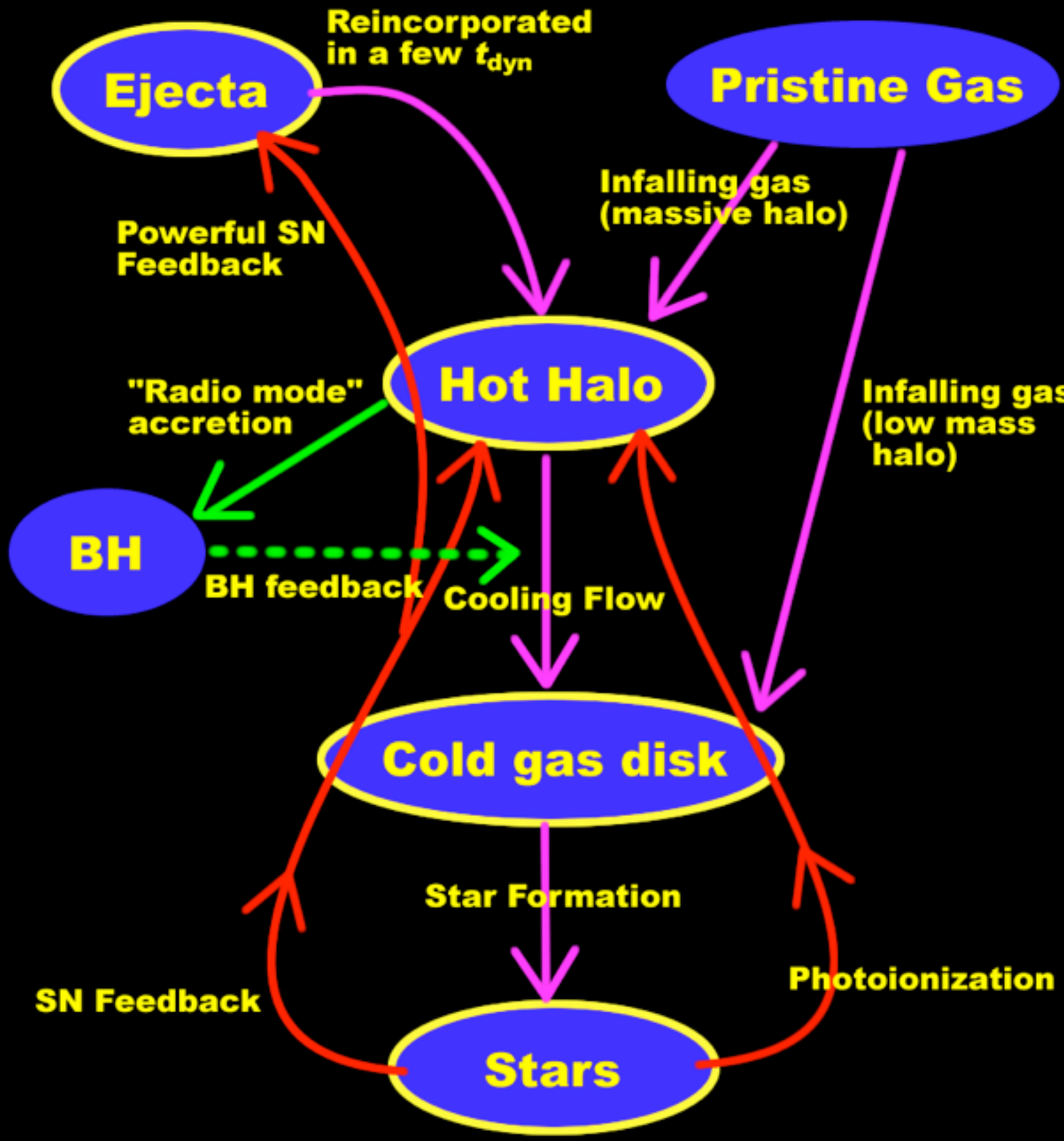
(human)

Our model is only as good as the questions we ask

For systems with infinite levels of complexity, our model can never be “correct”

GEMS (Rix et al. 2004)





- Schmidt law star formation
- SFR dependent SN winds
- satellite gas stripping
- morphological transformation
- assembly through mergers
- starbursts through mergers
- Magorrian relation BH growth
- jet & bubble AGN feedback

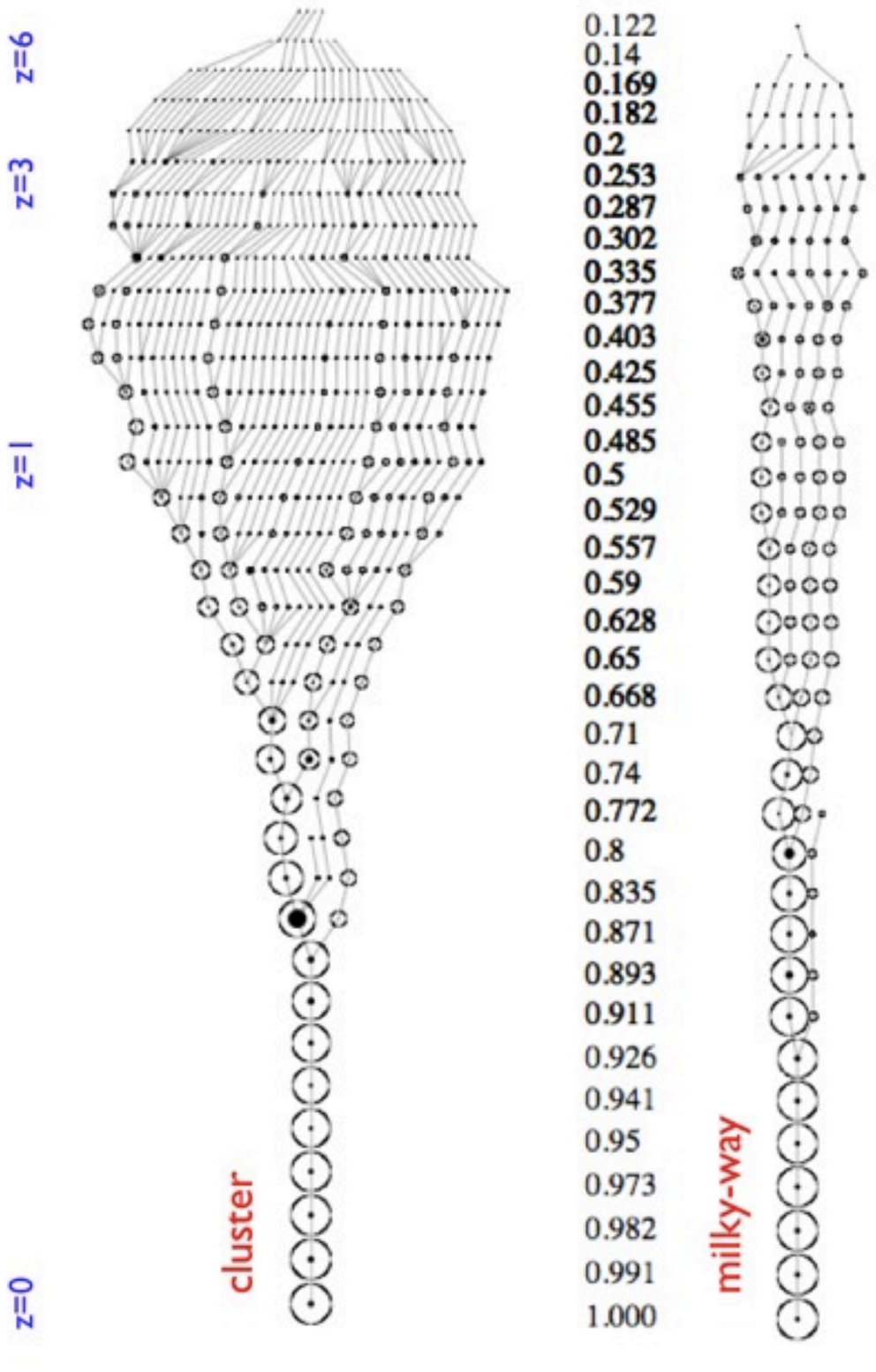
Croton et al. 2006

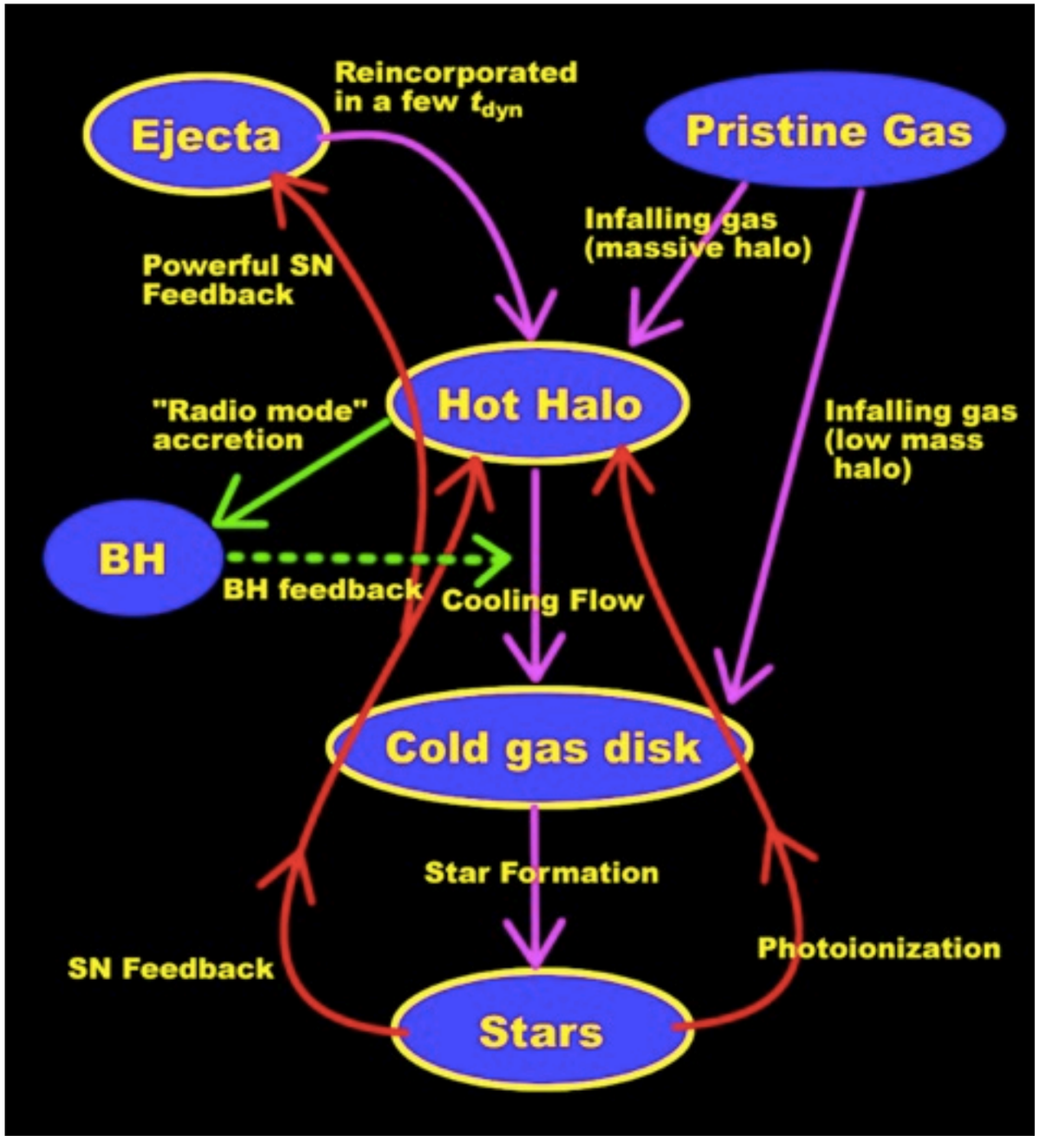
z=0 dark matter

125 Mpc/h

Remember:

Numerical Simulation + Analytic Simulation

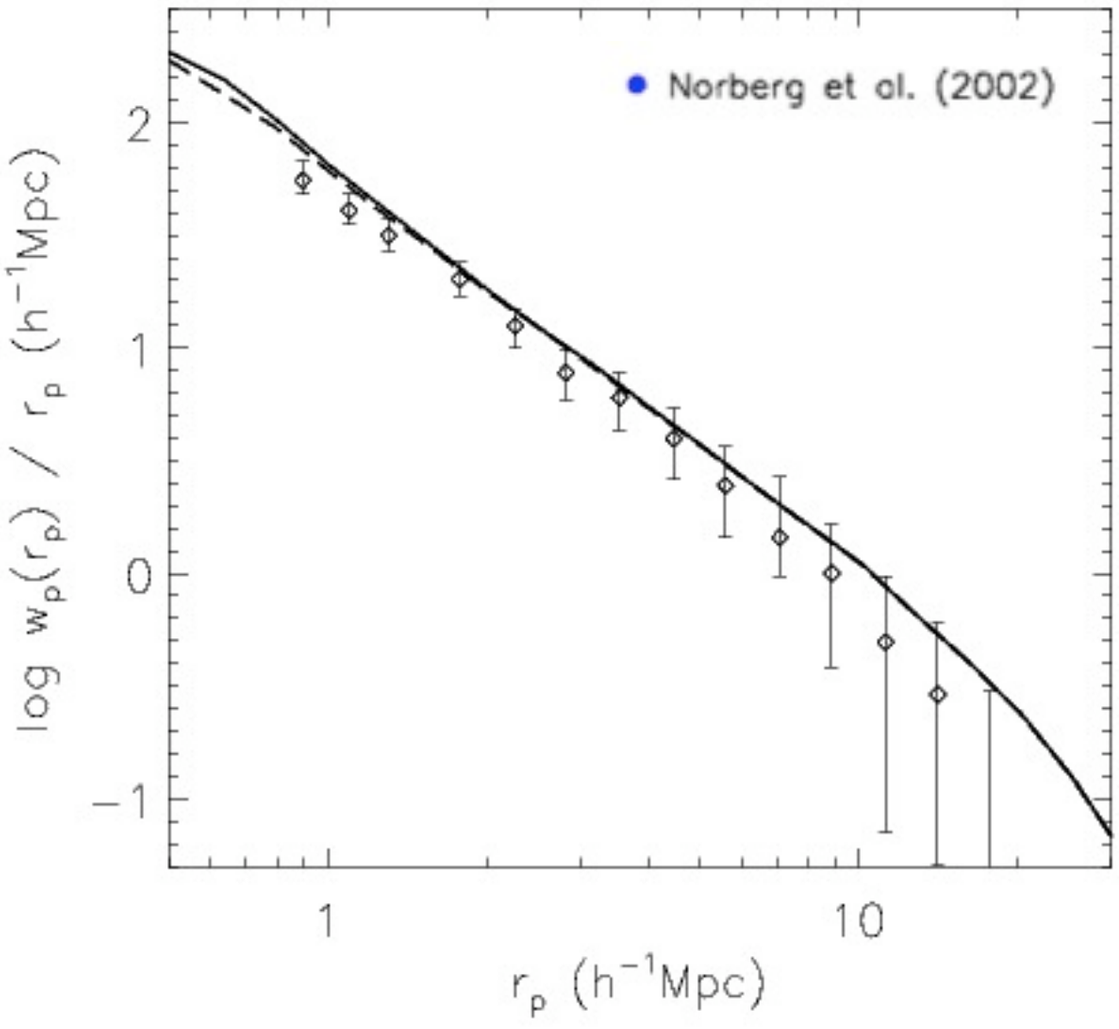




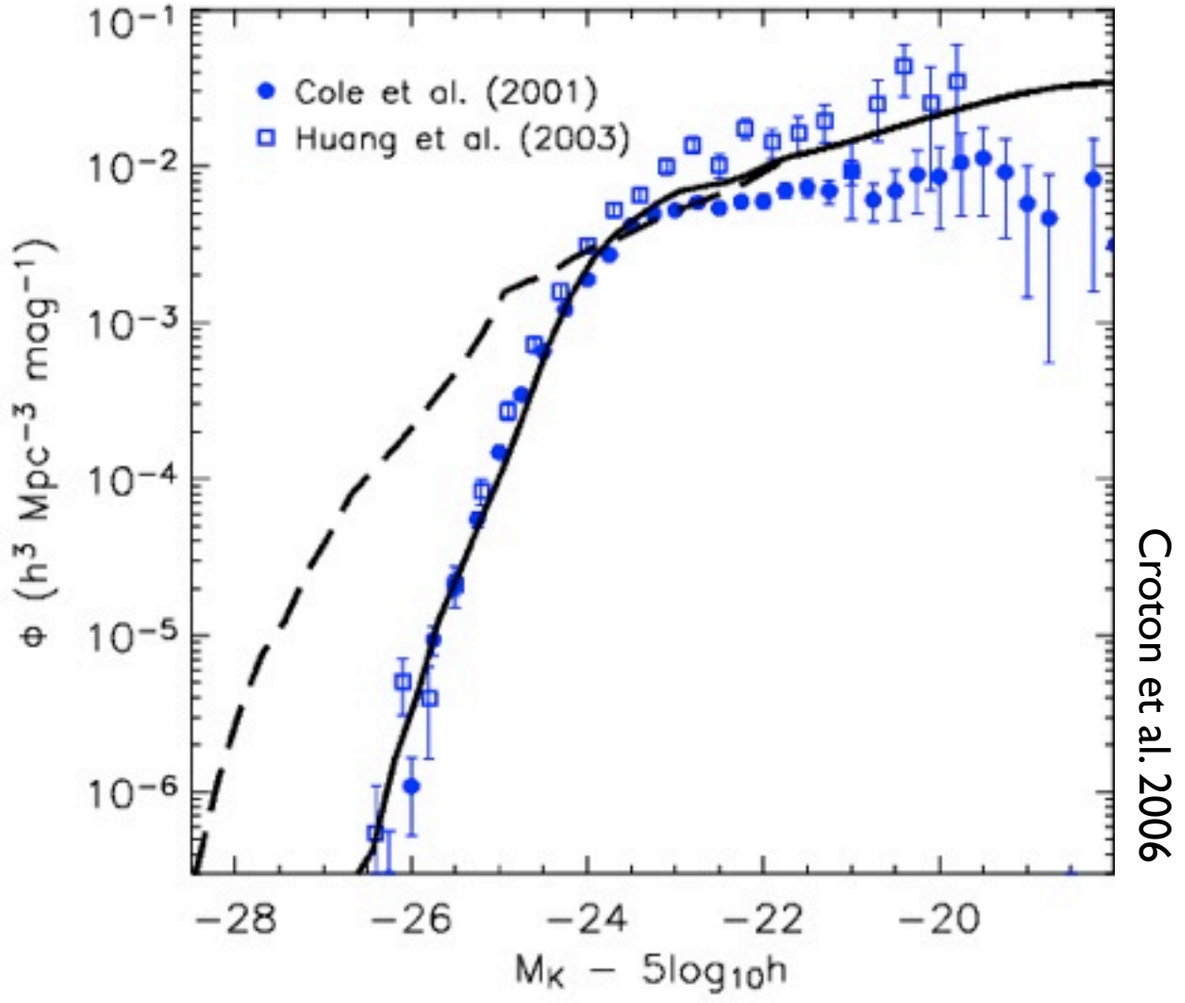
z=0 galaxy light

2 Mpc/h

Galaxy spatial and luminosity distributions



-clustering-

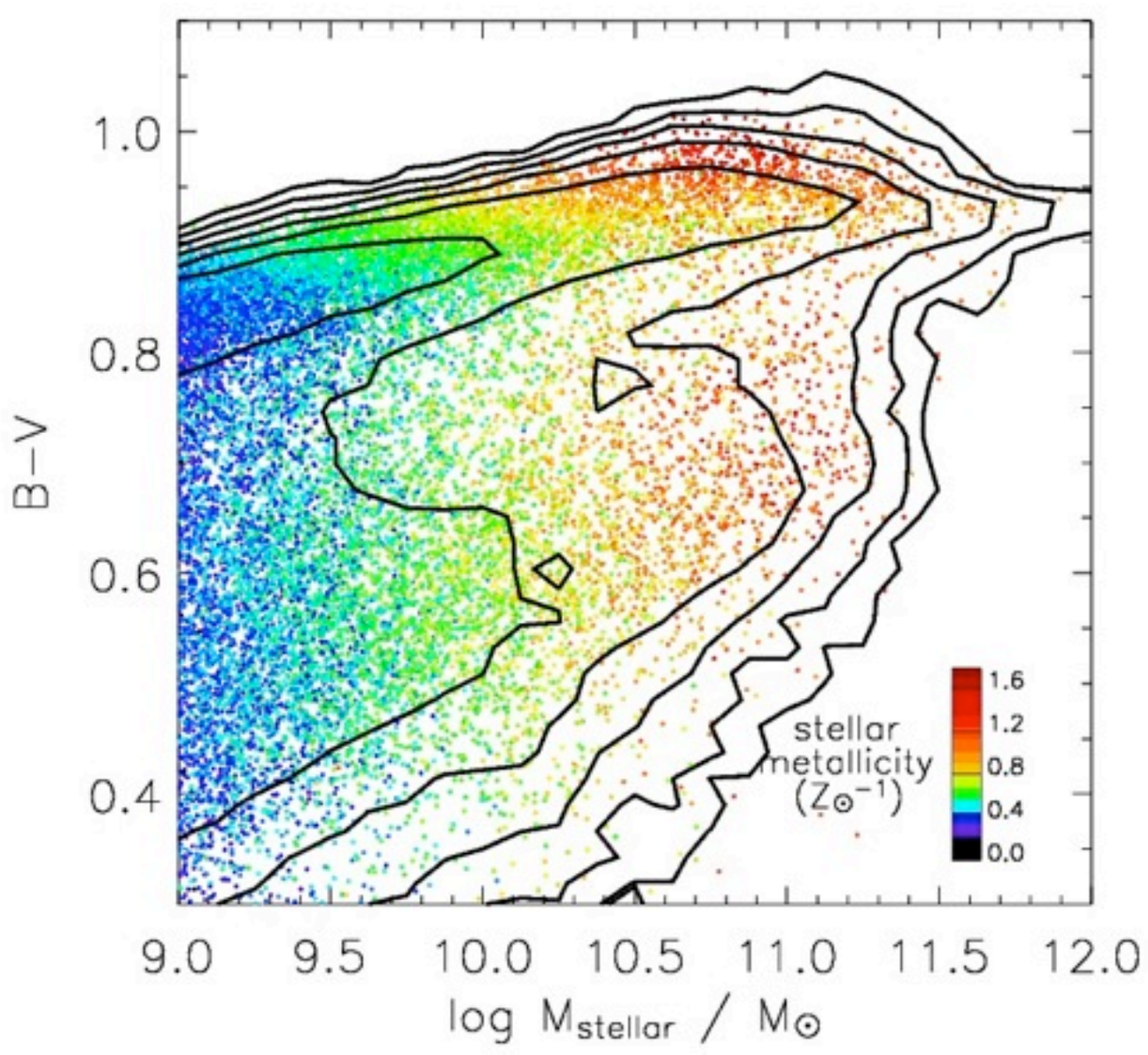


Croton et al. 2006

-luminosity function-

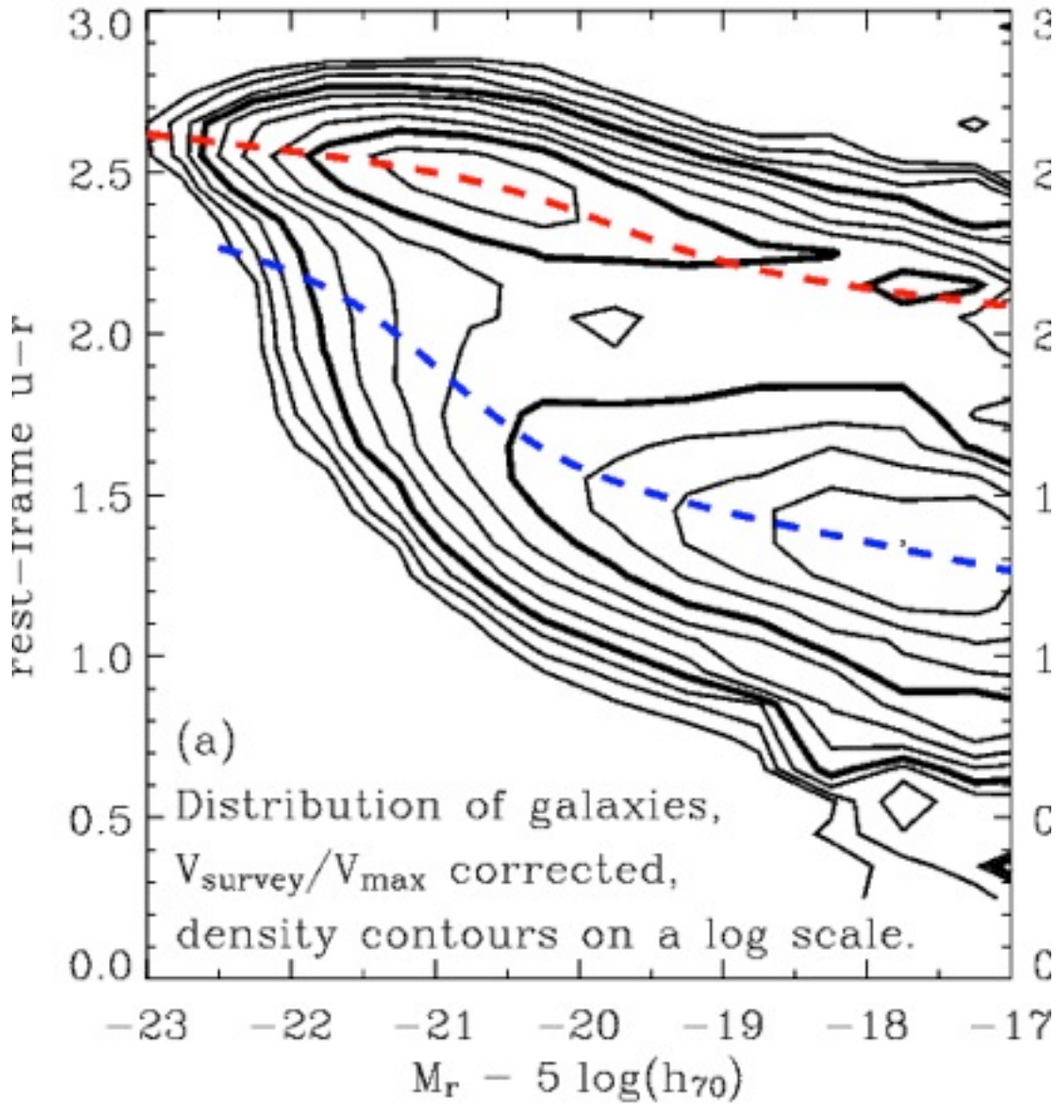
Galaxy colour distribution

Croton et al. 2006



-model-

Baldry et all. 2005

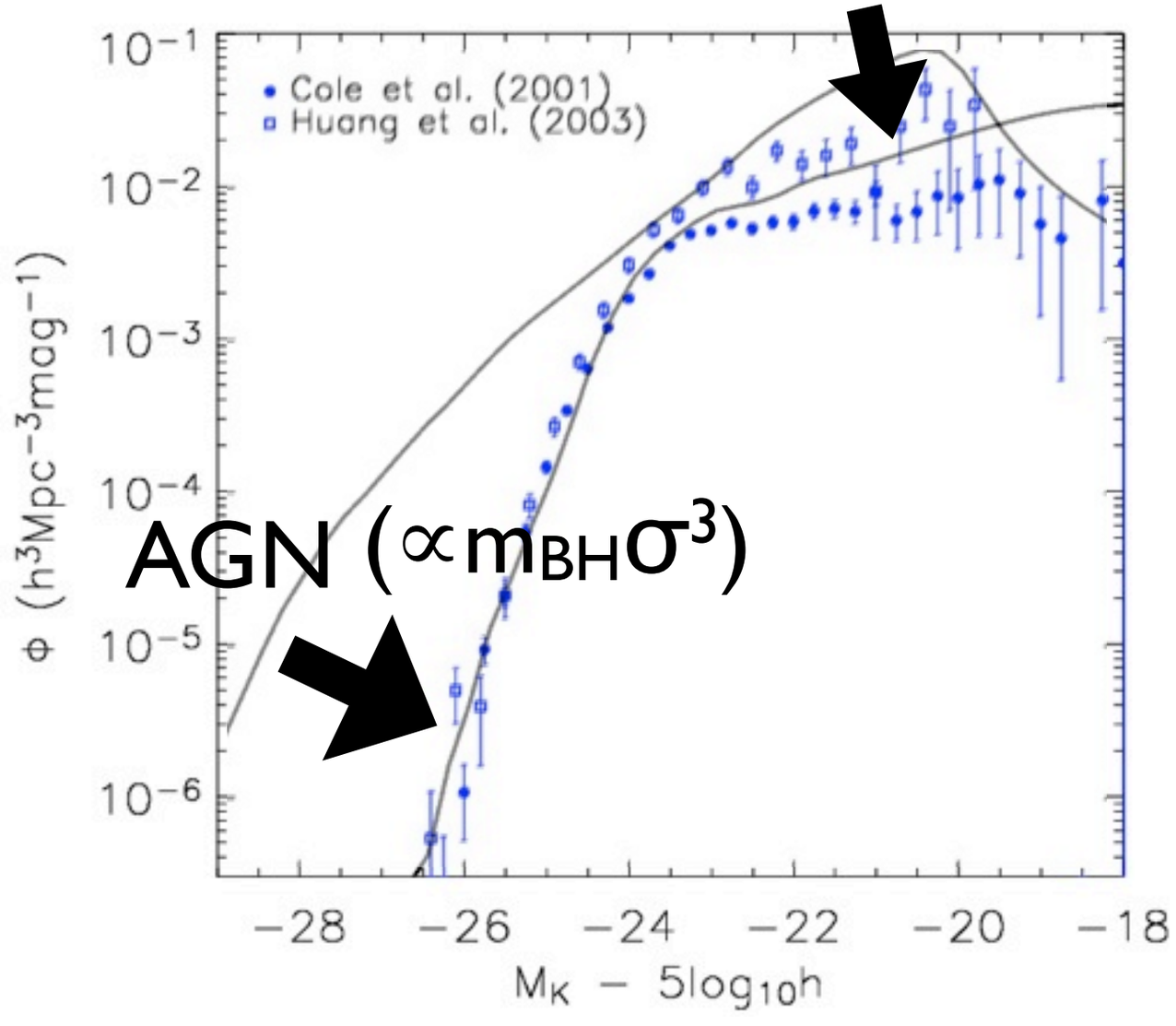


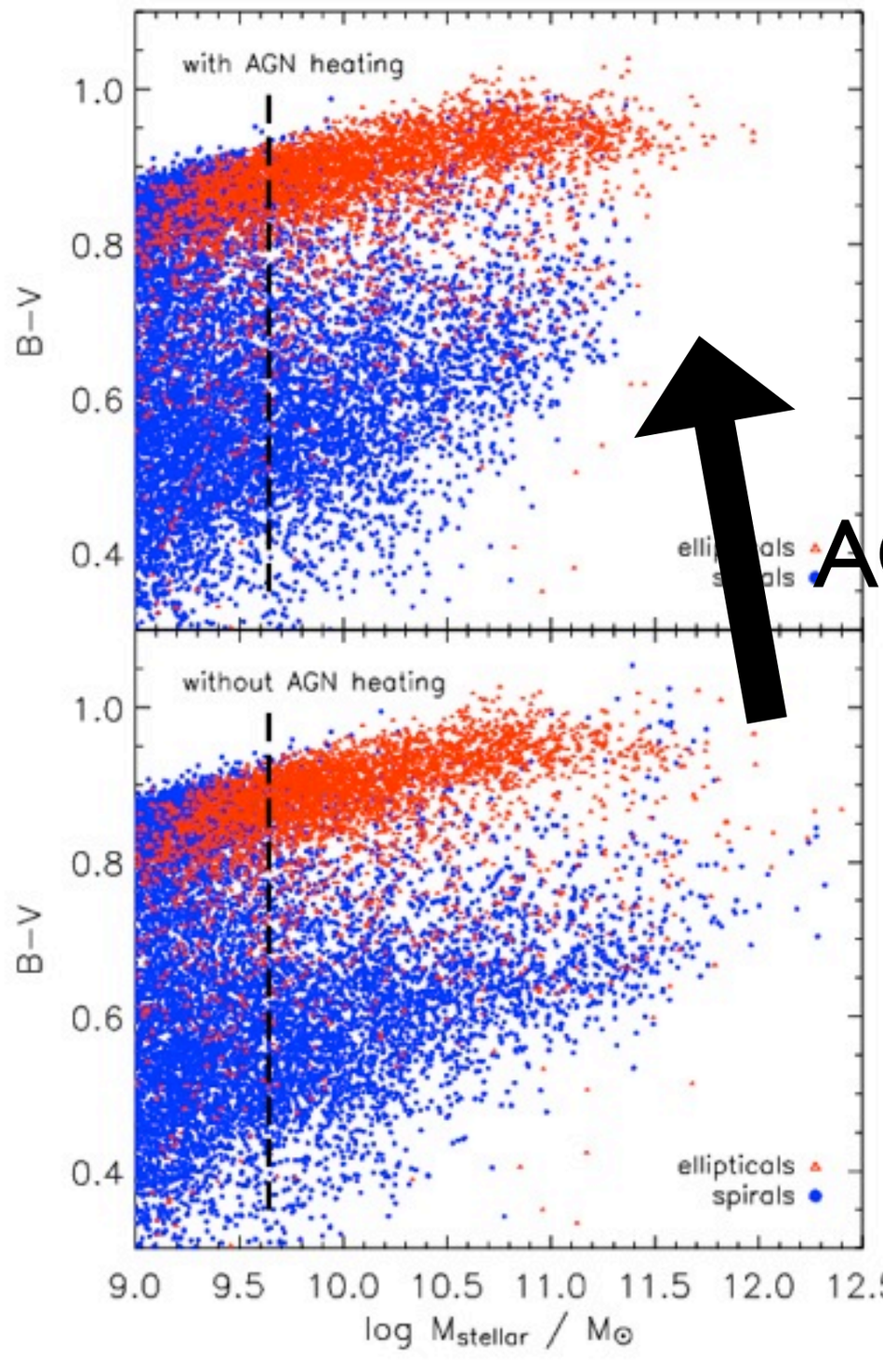
-SDSS-

Physical consequences

SN (∝SFR)

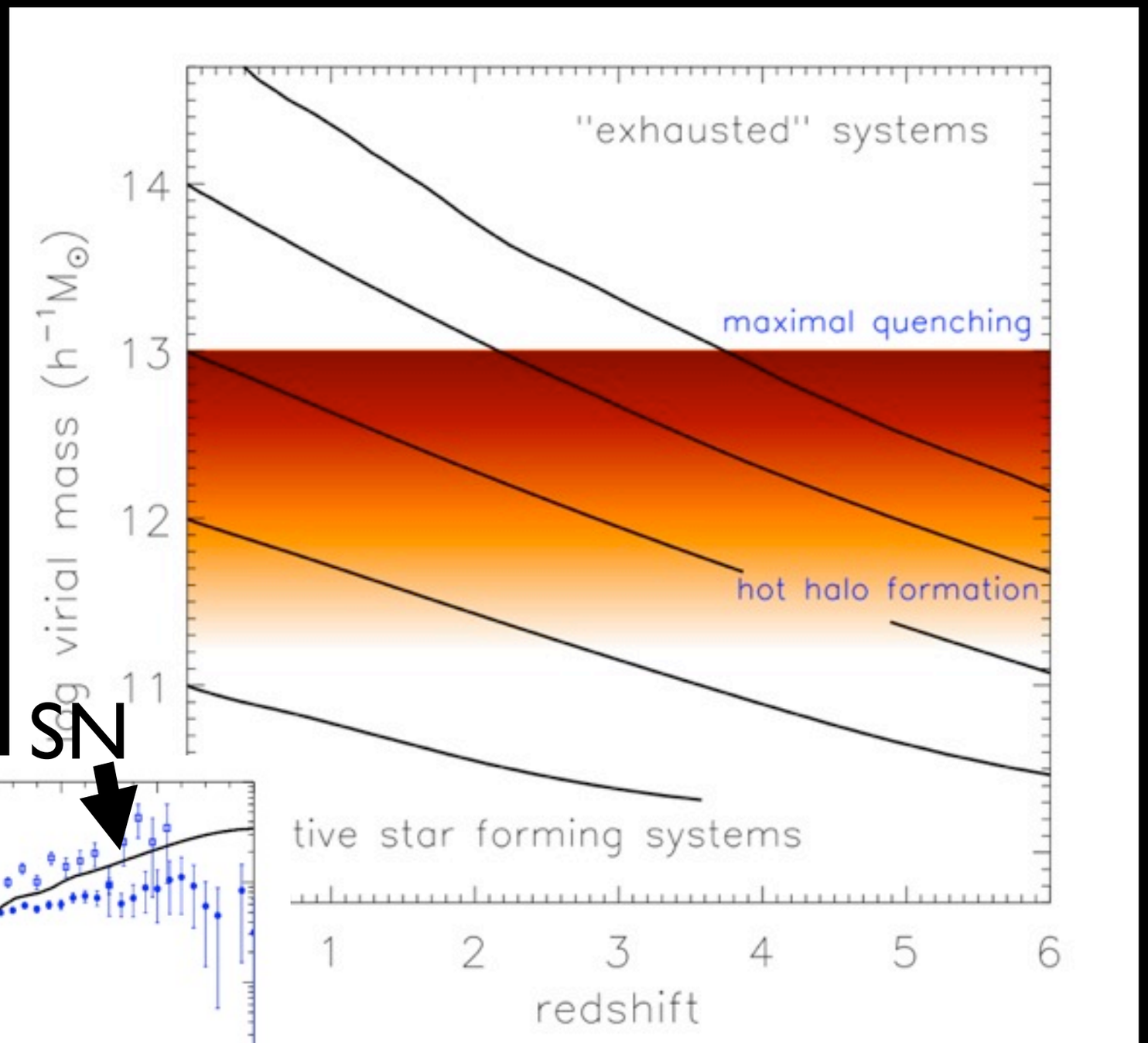
AGN ($\propto m_{BH}\sigma^3$)





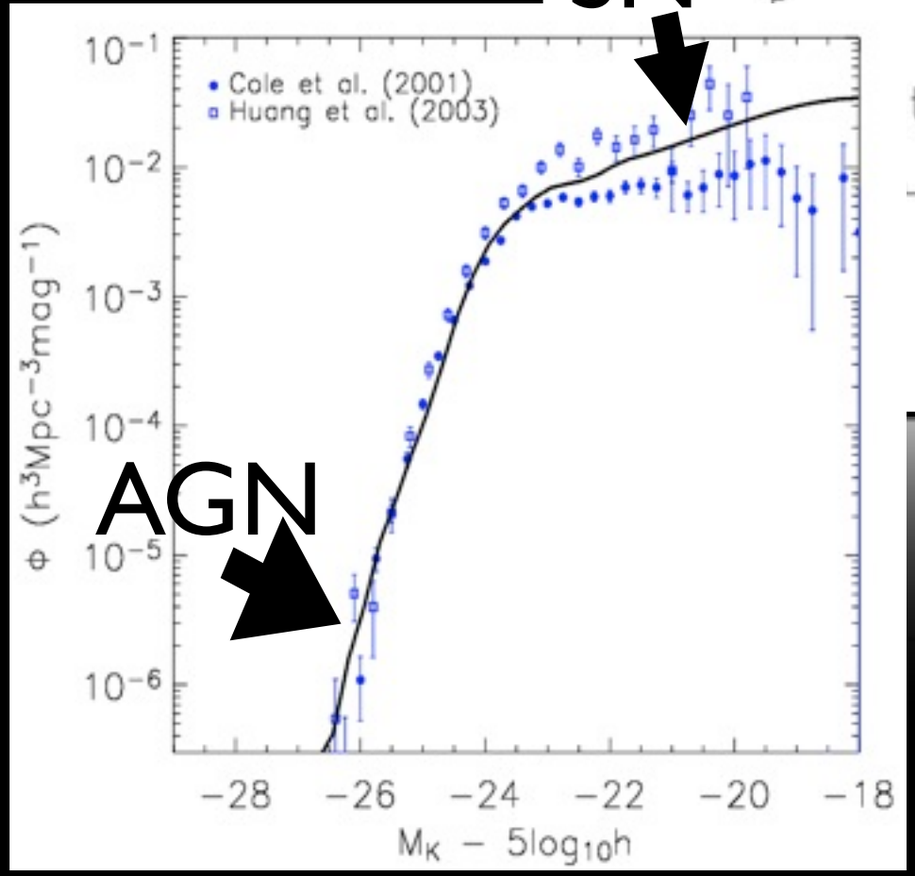
AGN

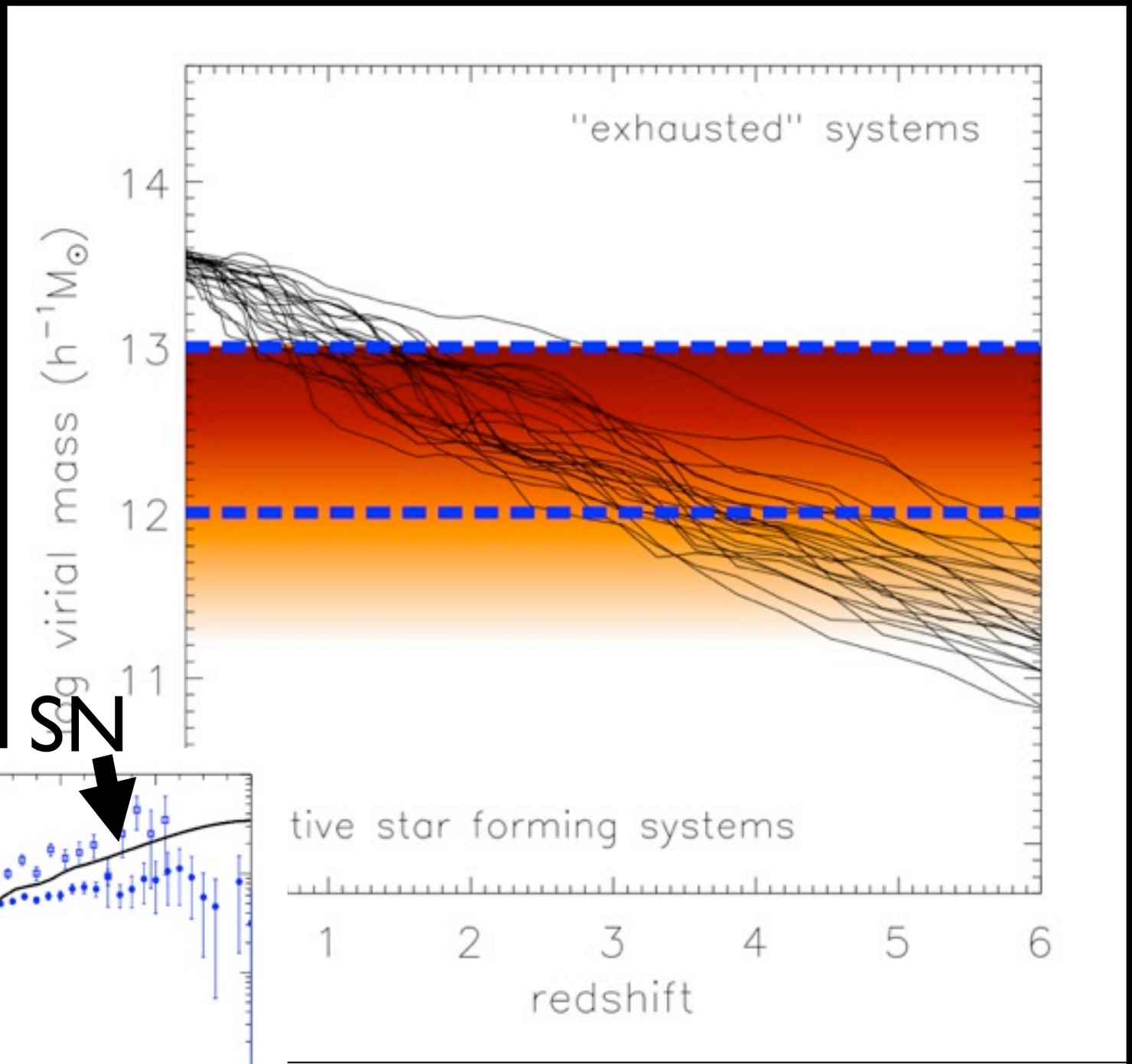
Croton et al. 2006


"exhausted" systems
maximal quenching
hot halo formation
tive star forming systems
14
13
12
11
g virial mass ($h^{-1}M_\odot$)
1
2
3
4
5
6
redshift

SN

AGN


Cole et al. (2001)
Huang et al. (2003)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Φ (h^3Mpc^{-3}mag^{-1})
−28
−26
−24
−22
−20
−18
$M_K - 5\log_{10}h$


"exhausted" systems
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log virial mass ($h^{-1}M_\odot$)
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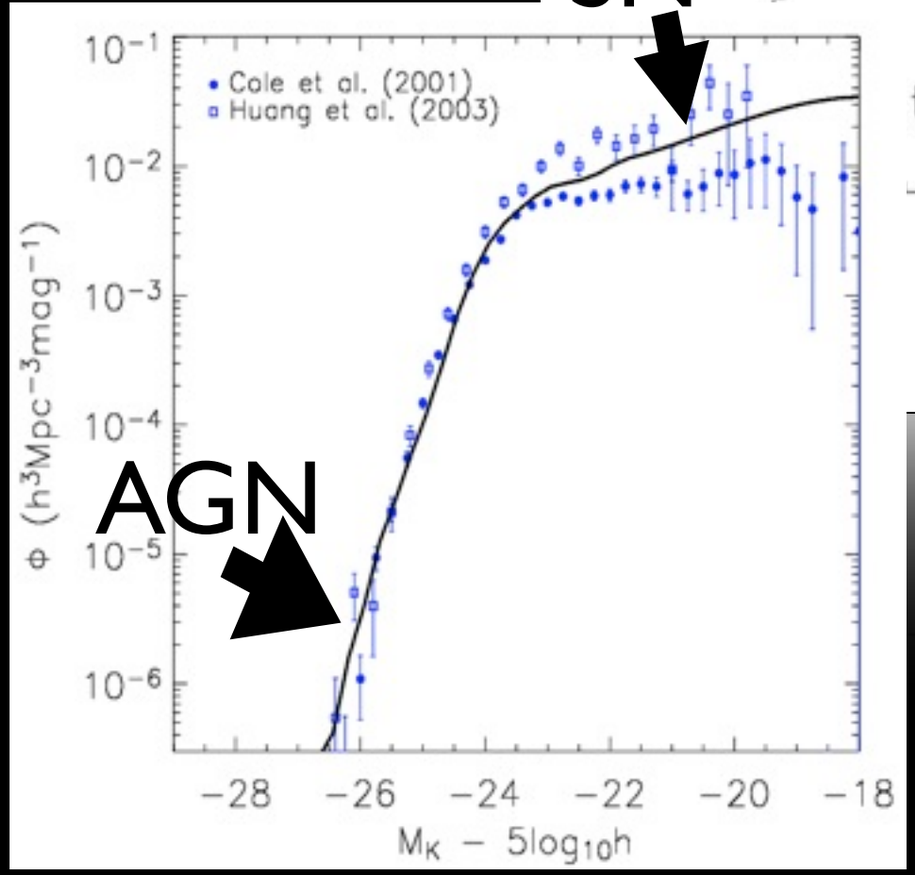
SN

AGN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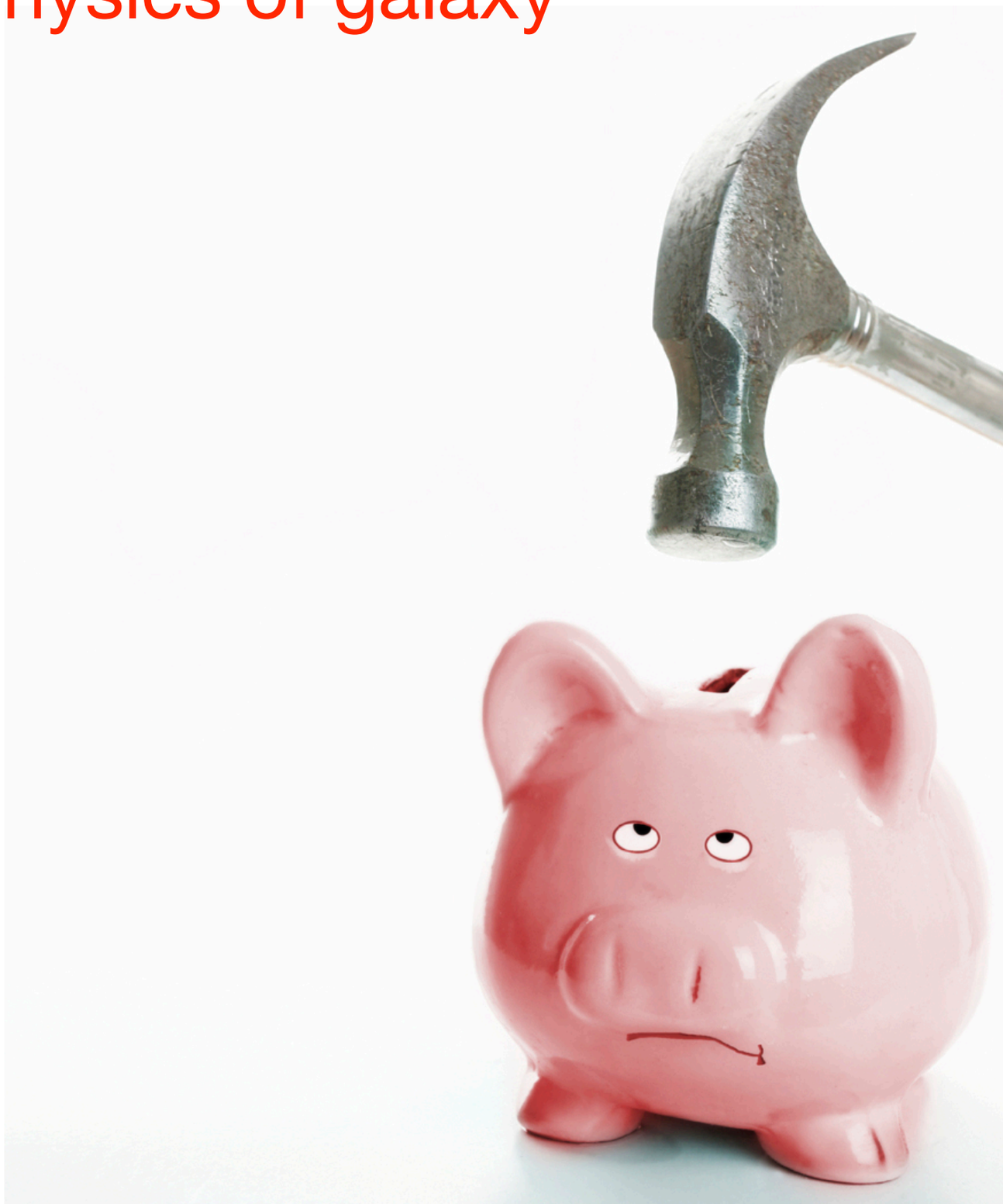
10^{-6}
Φ ($h^3Mpc^{-3}mag^{-1}$)
−28
−26
−24
−22
−20
−18
$M_K - 5\log_{10}h$

Why study environment?

Environment shapes the physics of galaxy formation

1. .
2. .
3. .
4. .
5. .
6. .
7. .
8. .
9. .
10. .



Environment shapes the physics of galaxy formation

1. Gas accretion
2. Gas removal
3. .
4. .
5. .
6. .
7. .
8. .
9. .
10. .

Environment shapes the physics of galaxy formation

1. Gas accretion
2. Gas removal

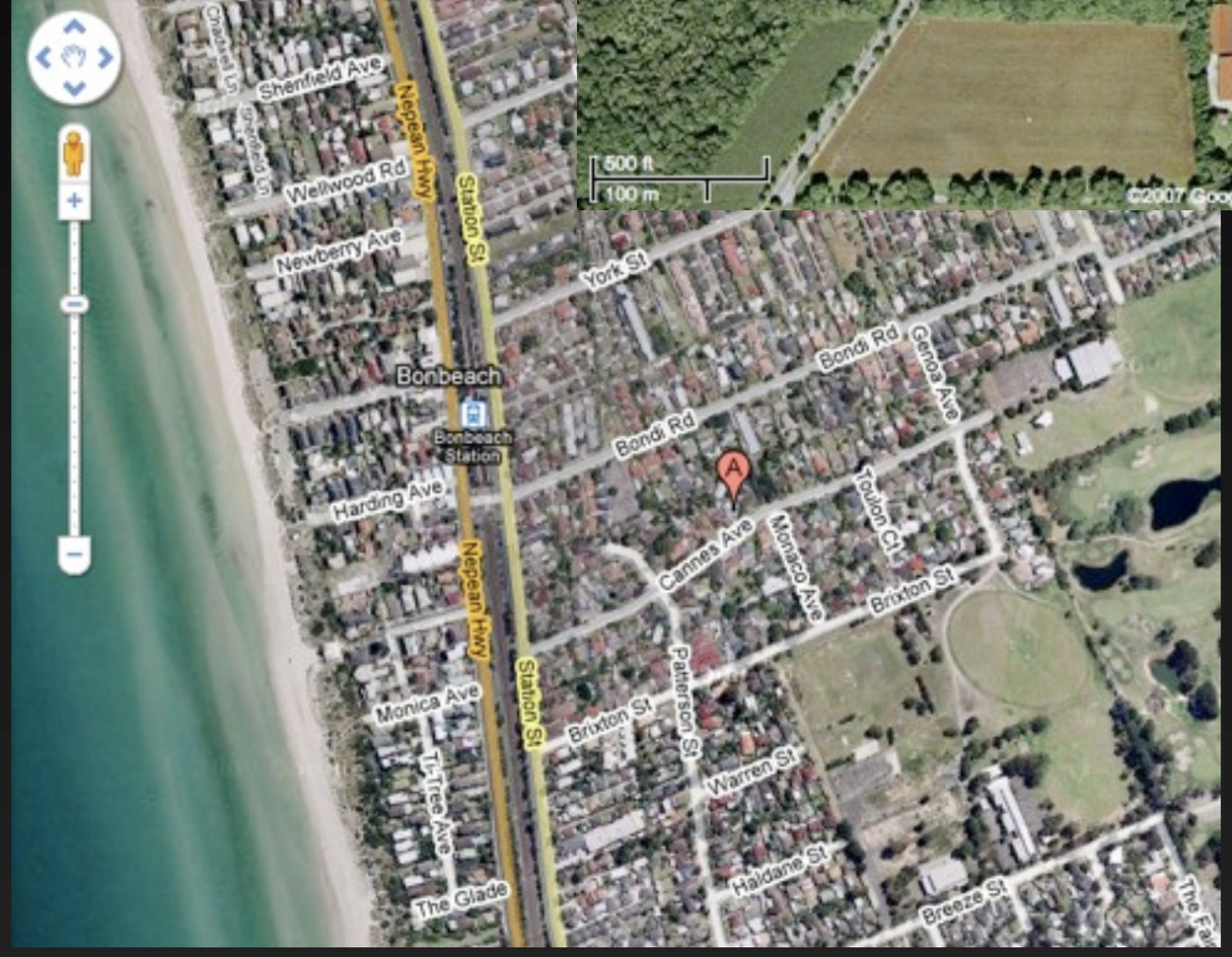
1. Galaxy mass and luminosity
2. Galaxy colour
3. Baryon (inc. metal) abundance
4. ...

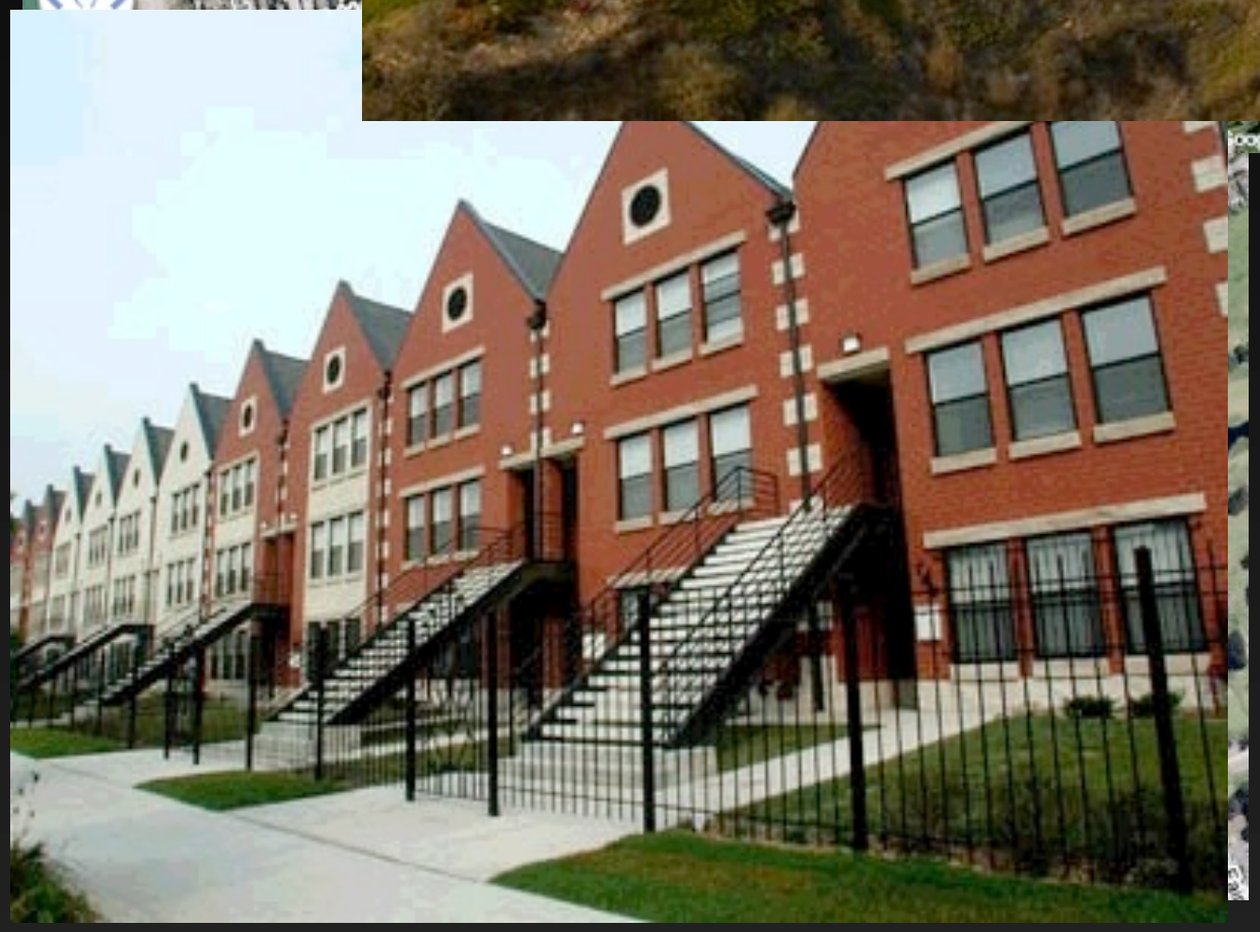
What is environment?

Munich

De ent

Mell ley





Defining environment
physical

"group" finders:

- close pairs, friends of friends, ...
- optimal linking length?
- won't find voids, but will identify isolated galaxies

Defining environment
physical

N’th nearest neighbour:

- what “N” is optimal?
- how to compare dense with sparse populations?

Defining environment

physical

fixed aperture:

- what kind of aperture (top-hat, Gaussian, ...)?
- smoothed on what scale?
- loss of information on smaller scales (e.g. halo radii typically <2Mpc)

Defining environment
physical

using the underlying structure itself:

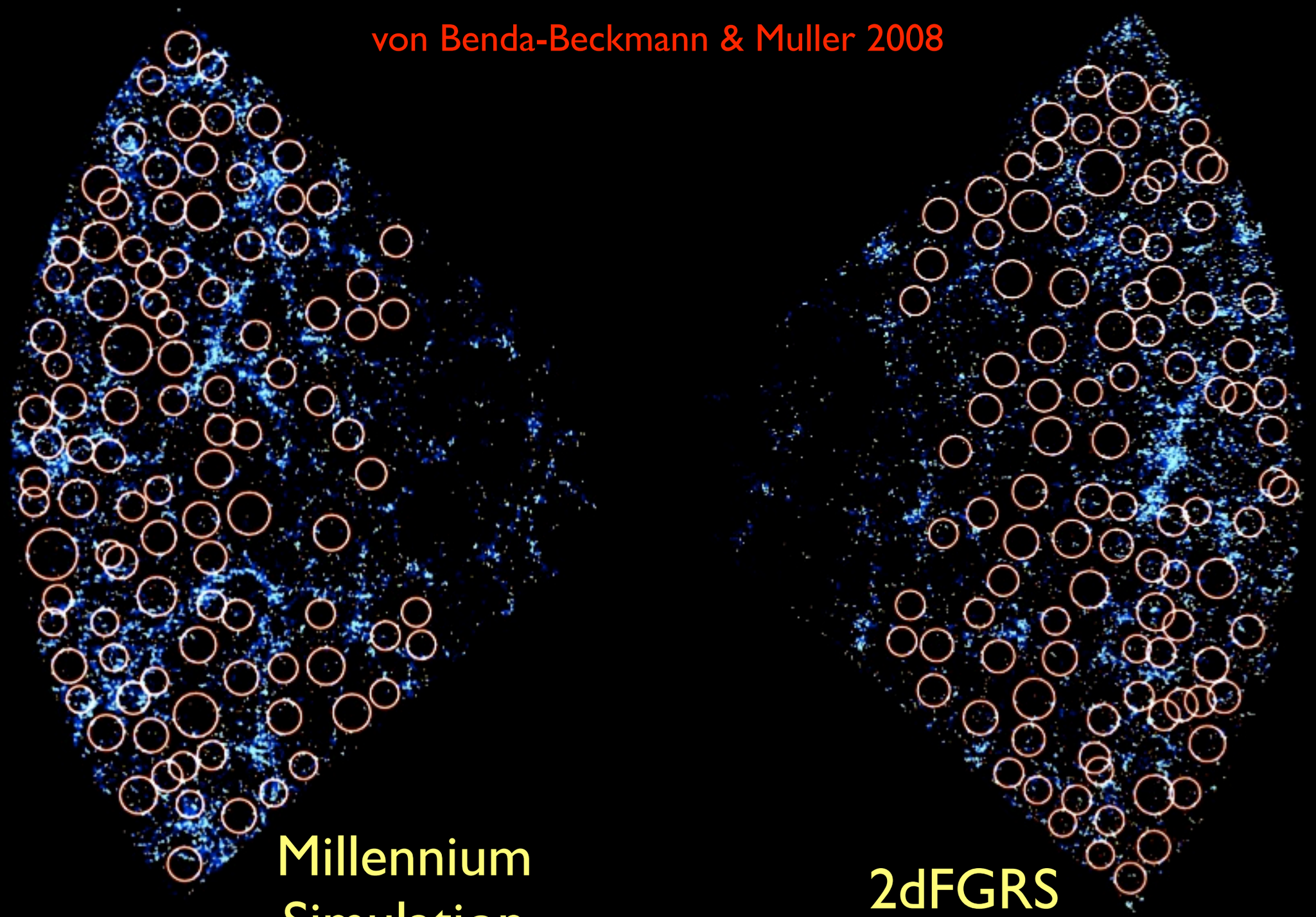
- halo mass (i.e. bound structures)
- the dark matter density field
- observation vs. theory
- dealing with bias

Defining environment
physical

voids:

- “void” galaxies vs. “wall” galaxies (e.g. Hoyle et al. 2005)
- maximal non-overlapping spheres (e.g. Patiri et al. 2006)
- grid based (e.g. Colberg et al. 2005)

von Benda-Beckmann & Muller 2008



Millennium Simulation

2dFGRS

Defining environment
physical

internal processes:

- galaxy interactions within a dark matter halo
- ram pressure stripping, strangulation, harassment, ...
- mostly important for satellite galaxies

Defining environment
statistical

the power of large numbers:

- 2-pt clustering - amplitude links to both environment and halo mass
- shape statistics - voids, filaments, sheets, clusters
- void statistics - voids can be just as clustered as clusters

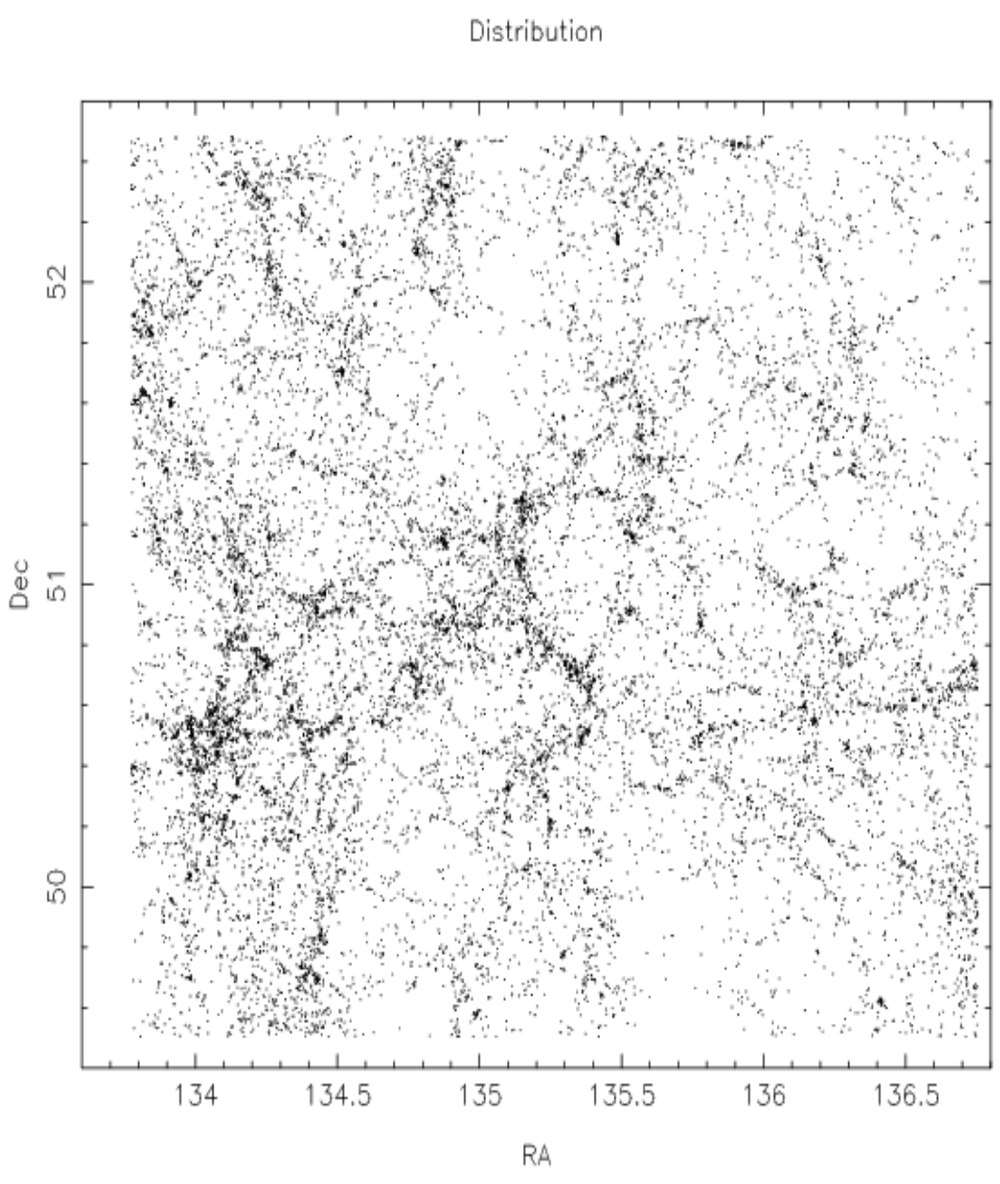
Defining environment

issues:

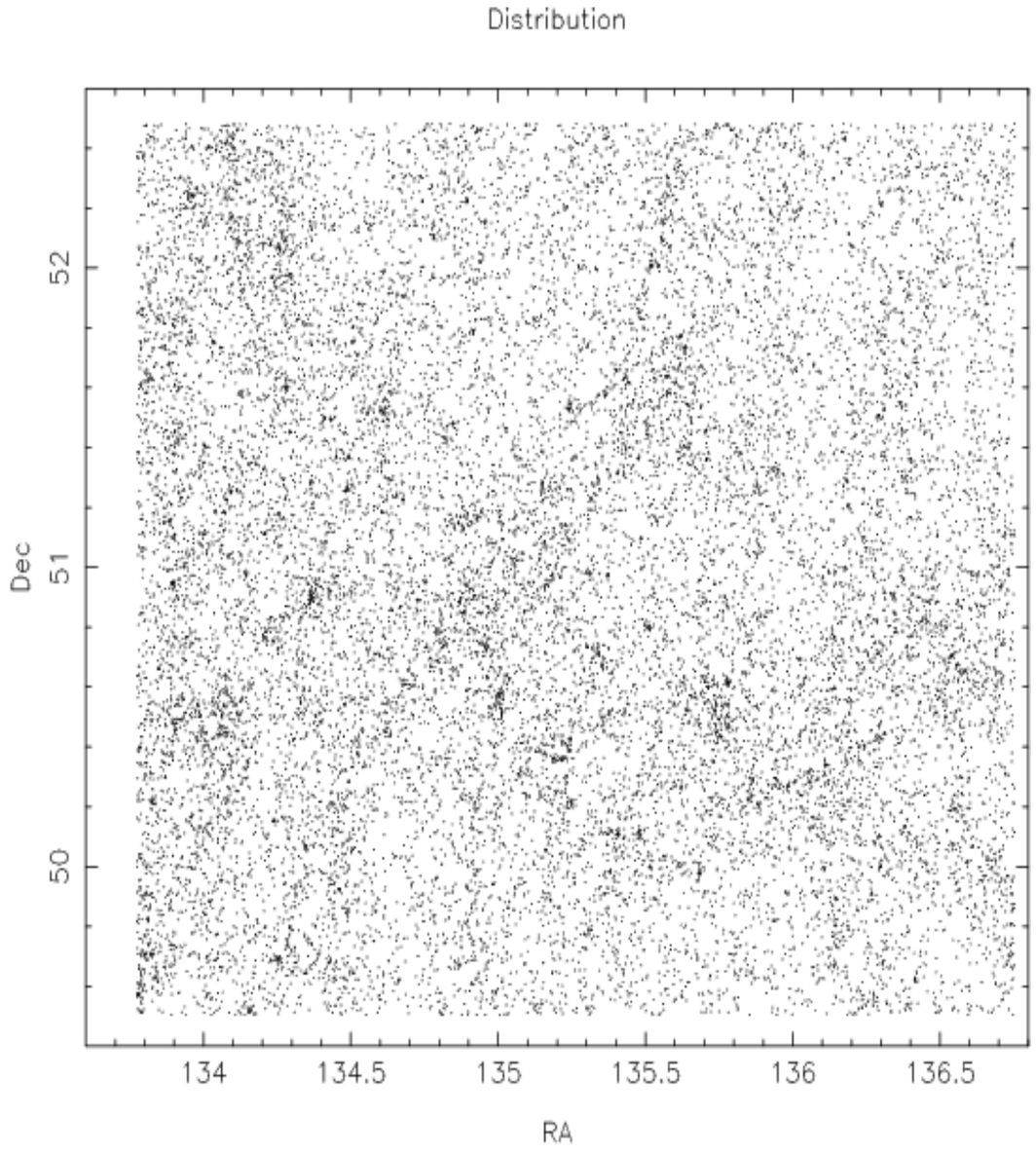
- 2D vs. 3D
- photometric vs. spectroscopic redshifts
- dealing with selection, incompleteness and volume effects
- how empty do you have to be to be a void (δ<-0.6, δ<-0.9)?
- comparing different environment and void measures

Projected large-scale structure at 0.98<z< 1.00
From Millennium Simulation

rms of δz = 0



rms of δz = 0.04



Dec

RA

Chuan-Chin Lai & Lihwai Lin

A comment on dark matter halos

Do we understand dark matter halos?

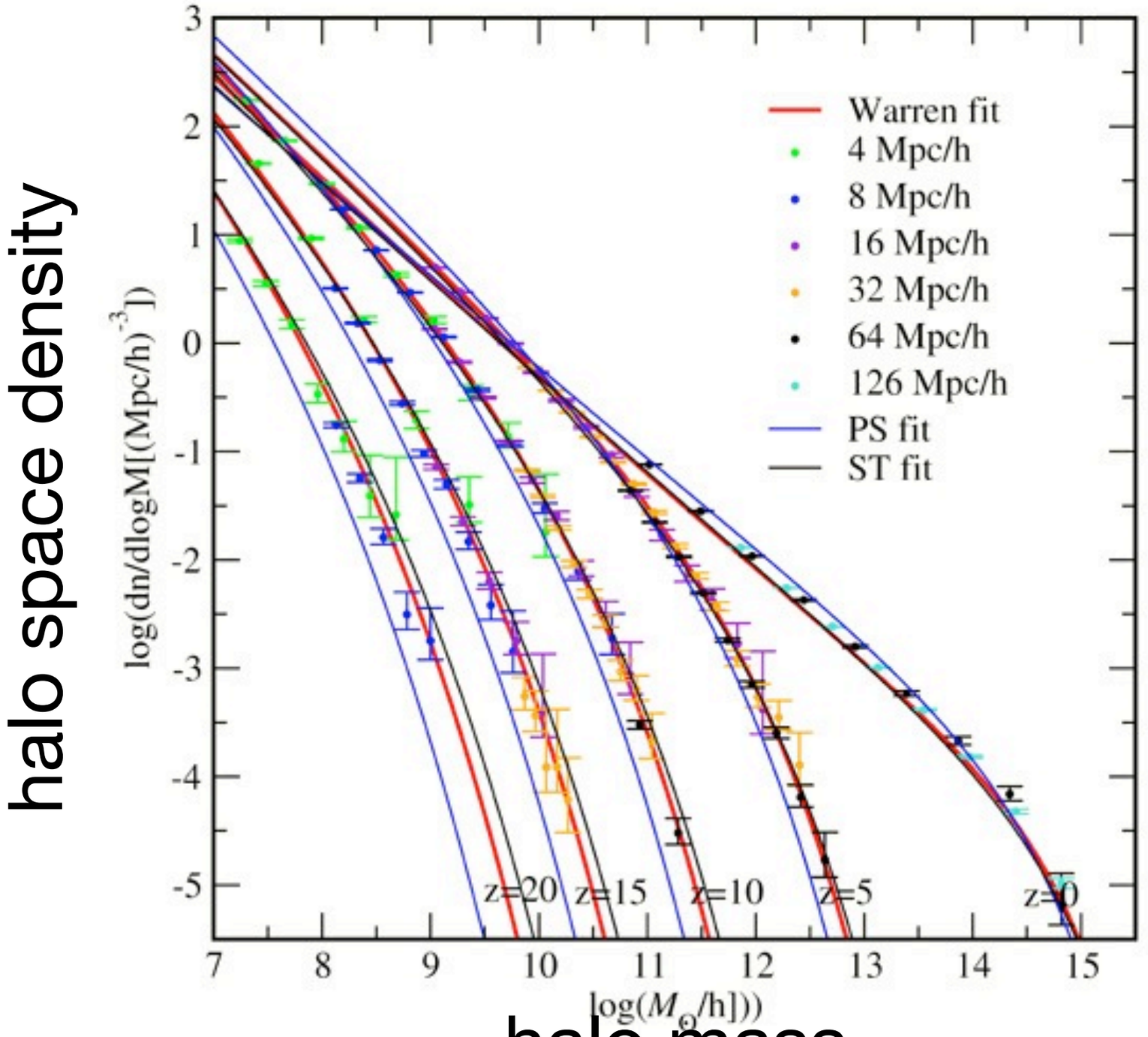
Press & Schechter 1974

Press-Schechter theory assumption:

1. Initial Gaussian density field.
2. Density perturbations $\delta > \delta_c$ on a given scale collapse into bound objects with mass M.
3. On different scales, one can extract the fractions of objects in different mass ranges.

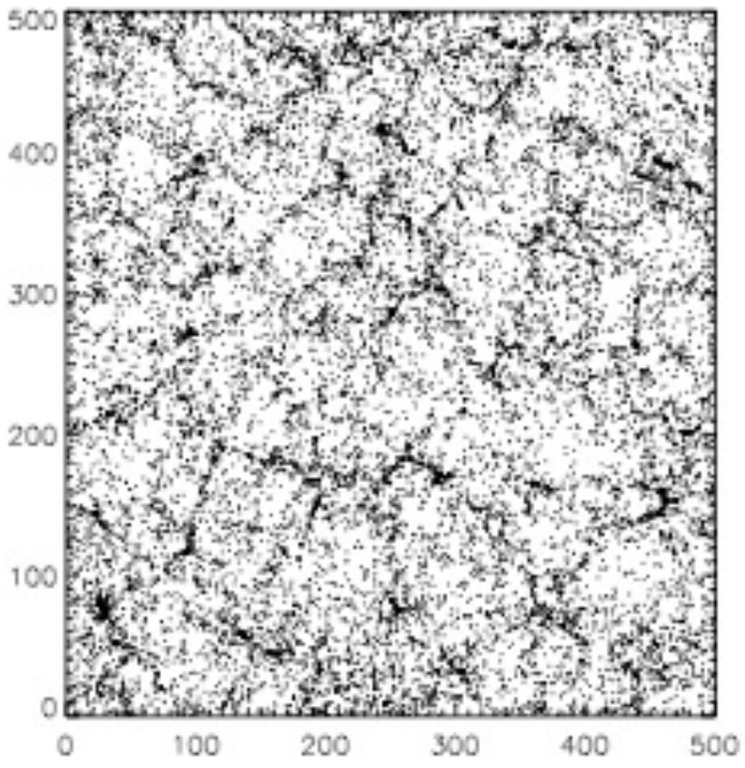
Do we understand dark matter halos?

Press & Schechter 1974



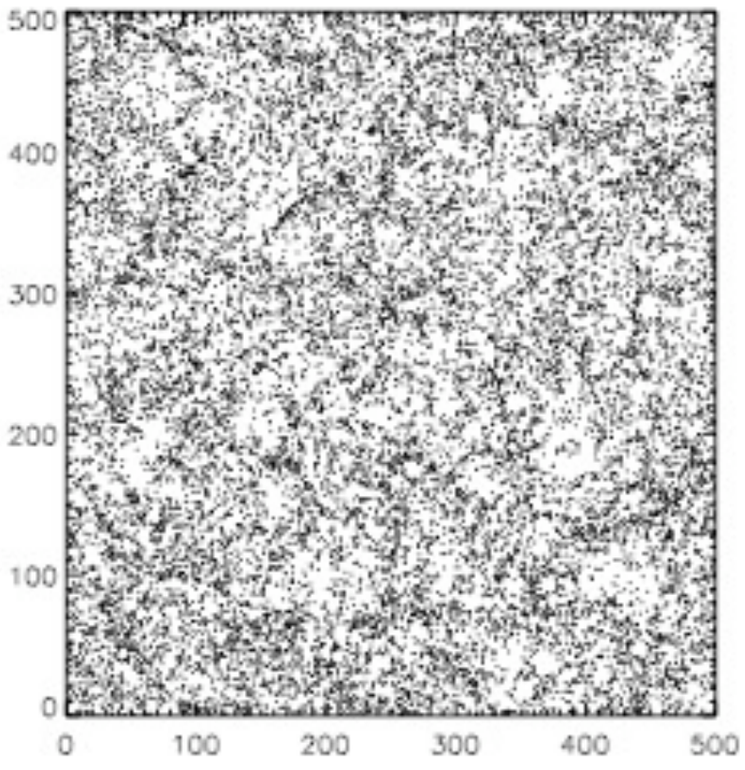
Do we understand dark matter halos?

Gao et al. 2005
(Croton et al. 2007)

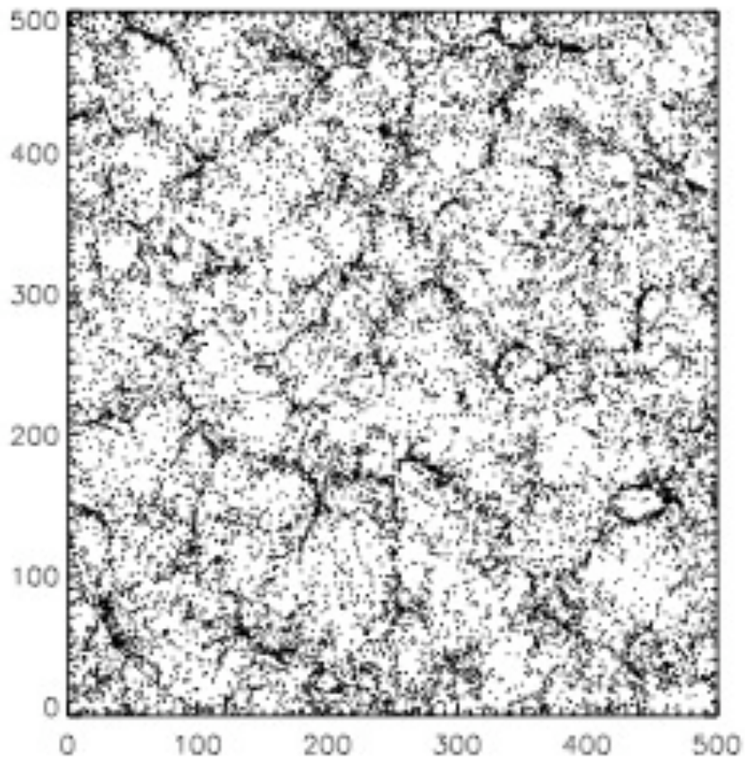


all $10^{11} M_{sun}$ halos

latest forming 20%



earliest forming 20%



Do we understand dark matter halos?

Gao et al. 2005
(Croton et al. 2007)

This is called “assembly bias”

Clearly halo (and hence galaxy) formation is more complicated than previously thought

Is there agreement?

apply multiple environment measures to a common mock catalogue:

1. How do different measures of environment compare?
2. How are our end results coloured by the environment measures we use?

Participants

- HongBae Ann (hbann@pusan.ac.kr)
- Ivan Baldry (ikb@astro.livjm.ac.uk)
- Betsy Barton (ebarton@uci.edu)
- Sarah Brough (sbrough@astro.swin.edu.au)
- Matthew Colless (colless@aao.gov.au)
- Chris Conselice (conselice@nottingham.ac.uk)
- Michael Cooper (cooper@as.arizona.edu)
- Nick Cowan (cowan@astro.washington.edu)
- Darren Croton (dcroton@astro.swin.edu.au) *<-point of contact*
- Sara Ellison (sara@beluga.phys.uvic.ca)
- Chiara Ferrari (ferrari@oca.eu)
- Anna Gallazzi (gallazzi@mpia-hd.mpg.de)
- Meghan Gray (Meghan.Gray@nottingham.ac.uk)
- Tom Hughes (Thomas.Hughes@astro.cf.ac.uk)
- Jorge Iglesias (jiglesia@iaa.es)
- Katarina Kovac (kovac@phys.ethz.ch)
- Tornado Li (tli@astro.swin.edu.au)
- Josep Maria Solanes (jm.solanes@ub.edu)
- Isabel Marquez (isabel@iaa.es)
- Jean-Christophe Mauduit (mauduit@oca.eu)
- Changbom Park (cbp@kias.re.kr)
- Sergey Pilipenko (spilipenko@asc.rssi.ru)
- Frazer Pearce (Frazer.Pearce@nottingham.ac.uk)
- Ravi Sheth (shethrk@physics.upenn.edu)
- Ramin Skibba (skibba@mpia-hd.mpg.de) *<-point of contact*
- Kim-Vy Tran (kimvy.tran@gmail.com)
- Arjen van der Wel (vdwel@mpia-hd.mpg.de)
- Michael Vogeley (vogeley@drexel.edu)
- Christian Wolf (cwolf@astro.ox.ac.uk)

The Millennium Simulation [edit]

The mock catalogue is constructed from the Millennium Simulation halo merger trees (Springel et al. 2005). The Millennium Simulation is a 10 billion particle dark matter simulation of structure formation in a (500Mpc/h)^3 box with halo mass resolution ~5x10^10Msun/h. The simulation assumes a WMAP1+2dFGRS cosmology with Omega_M=0.25, Omega_L=0.75, h=0.73 and sigma_8=0.9. The halo merger trees are publicly available at the German Astrophysical Virtual Observatory (GAVO).

Mock galaxy catalogue [edit]

From the merger tree at **z=0** we construct a local Universe mock galaxy catalogue using the halo occupation distribution (HOD) method described in Skibba & Sheth (2009). The mock is constrained to match the local SDSS luminosity function, colour-magnitude distribution, and 2-point clustering. Due to limitations in the methodology this match can only be made down to **M_r(cut)-5log(h)=-19**, which is where we cut the mock (it actually turns out to be slightly brighter than that).

The mock can be downloaded in two forms, in the original simulation cube or as a light cone. The cone has an opening angle of 90x90 degrees and a depth of 500Mpc/h.

Download mock cube (71Mb)

Download mock light cone (29Mb)

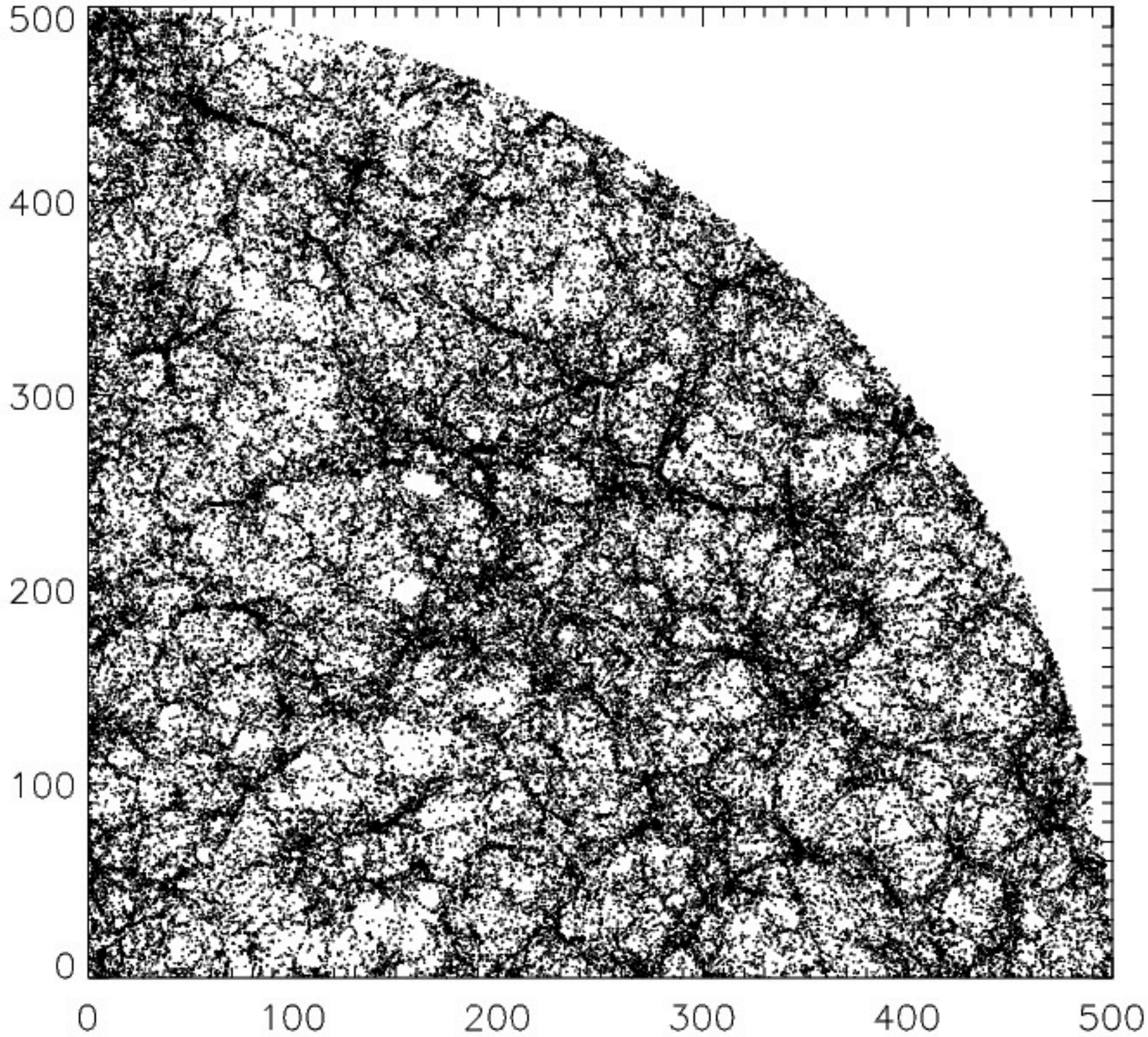
(note these are gzipped ascii files)

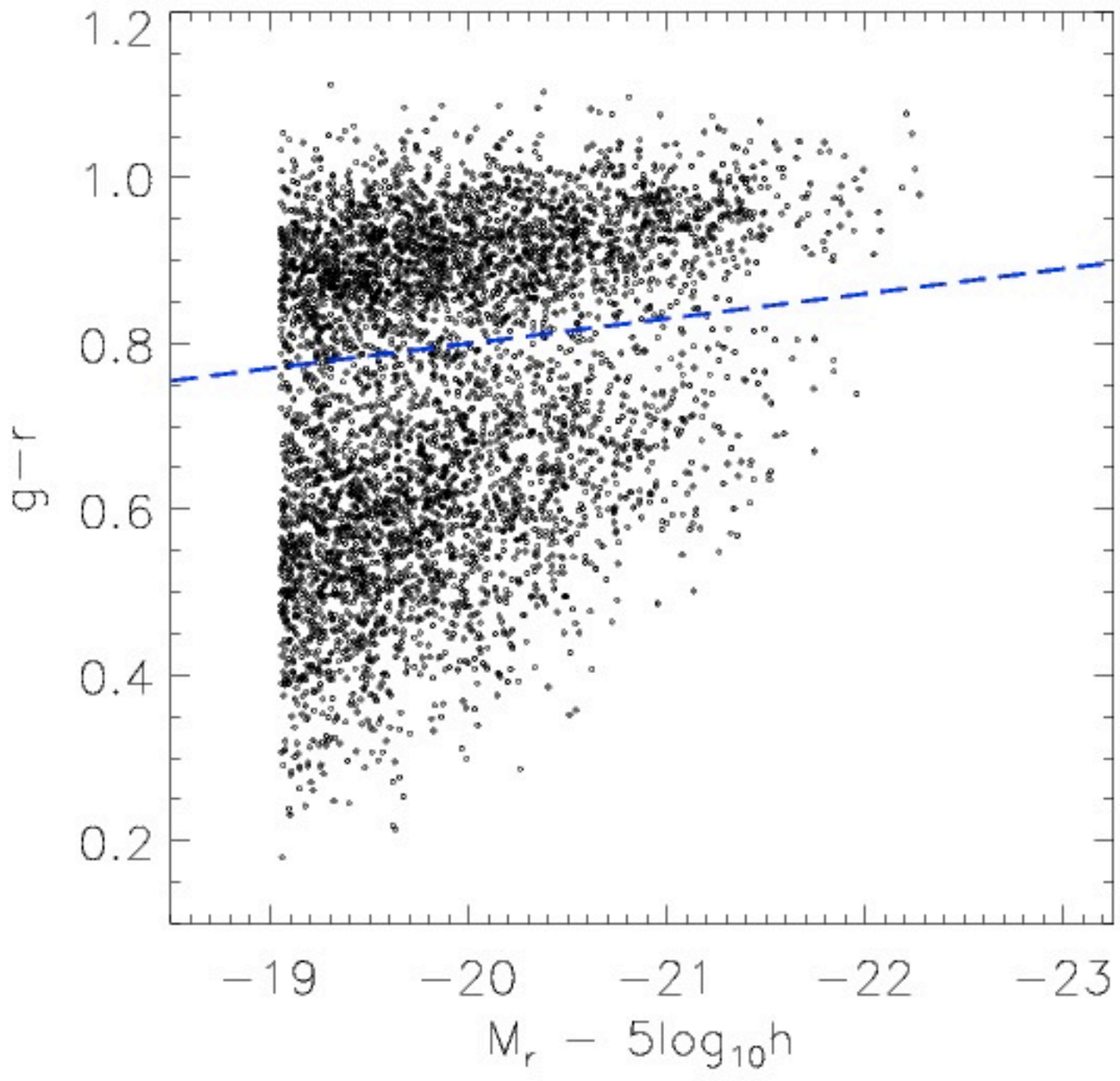
The following properties are available for each galaxy:

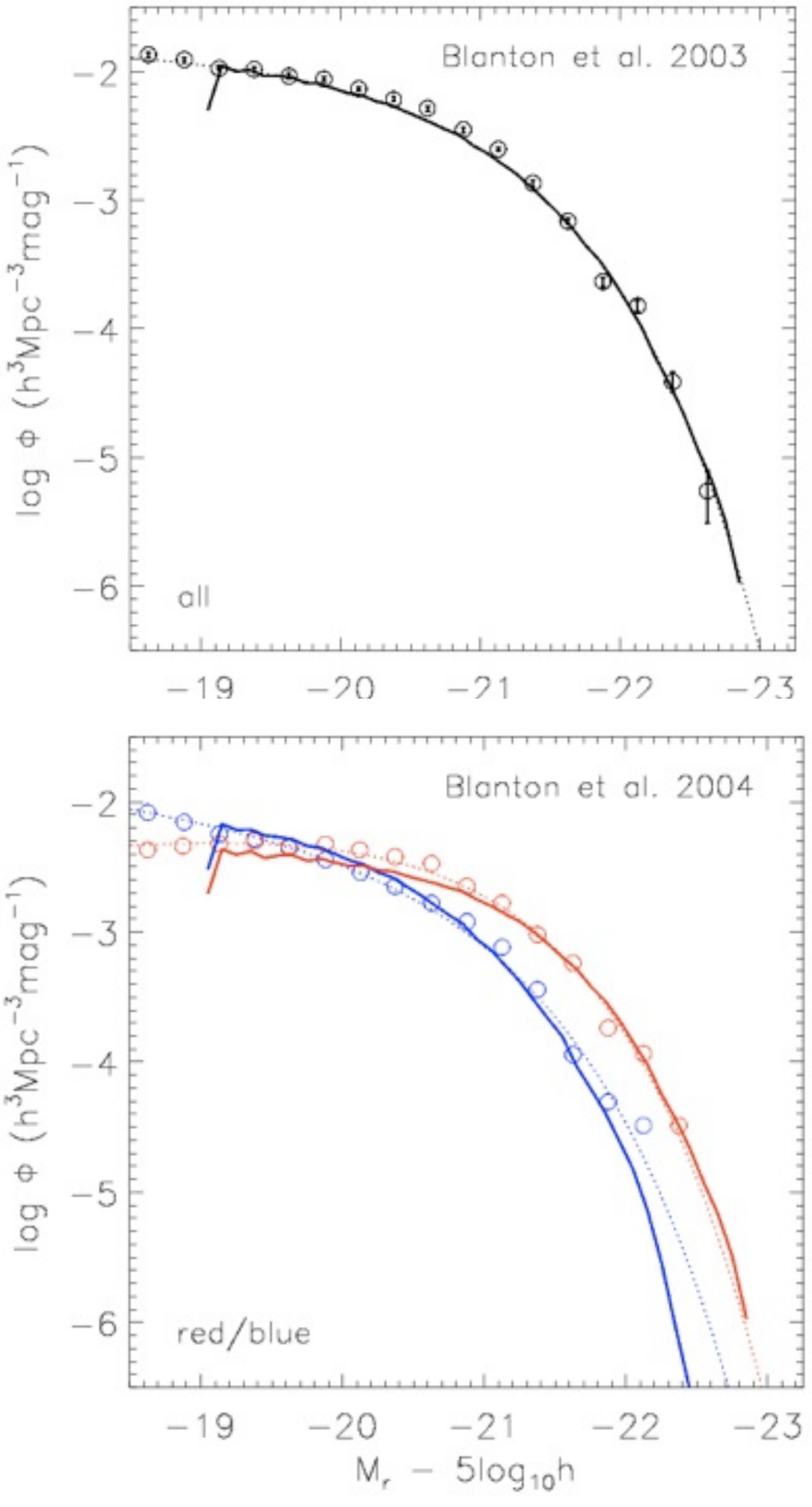
- *ID*: unique ID for each galaxy
- *x, y, z*: box co-ordinates in Mpc/h
- *z_red*: the redshift space distorted *z* box co-ordinate (use this instead of *z* to work in redshift space) in Mpc/h
- *ra, dec, distance*: cone co-ordinates in redshift space using radians and Mpc/h
- *M_r*: SDSS r-band absolute magnitude in units of -5logh (k-corrected to z=0.1)
- *g-r*: SDSS colour (k-corrected to z=0.1)
- *rank*: defined as 1 for centrals, 0 for satellites
- *M_vir*: the virial mass of the main halo of each galaxy in log units of Msun/h

Box columns: ID, x, y, z, z_red, M_r, g-r, rank, M_vir
Cone columns: ID, ra, dec, distance, M_r, g-r, rank, M_vir

Luminosity functions and colour-magnitude diagrams for the mock can be found here. 2-point correlation functions can be found here.


500
400
300
200
100
0
0
100
200
300
400
500

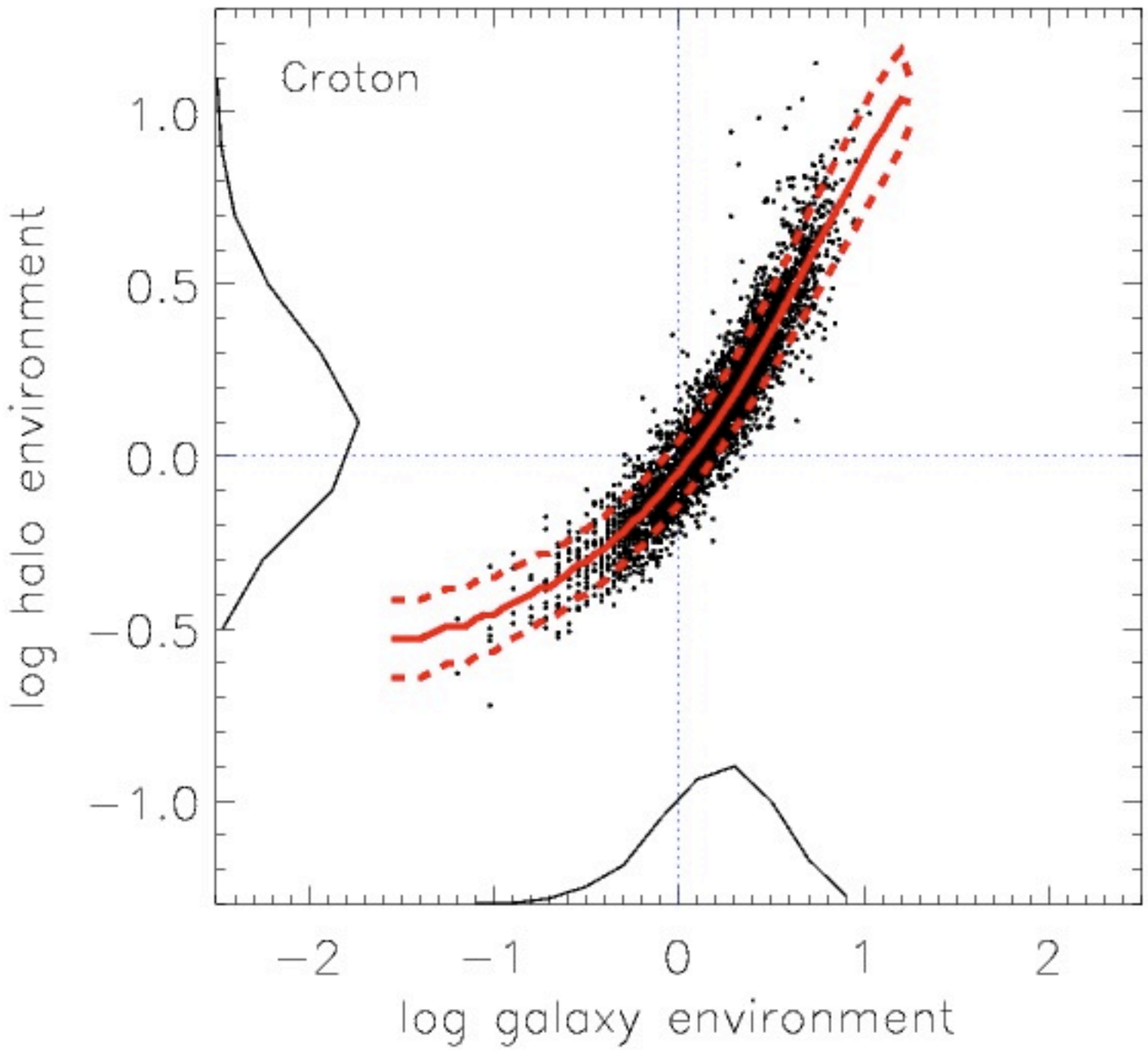




Skibba & Sheth 2009

Croton et al. 2005

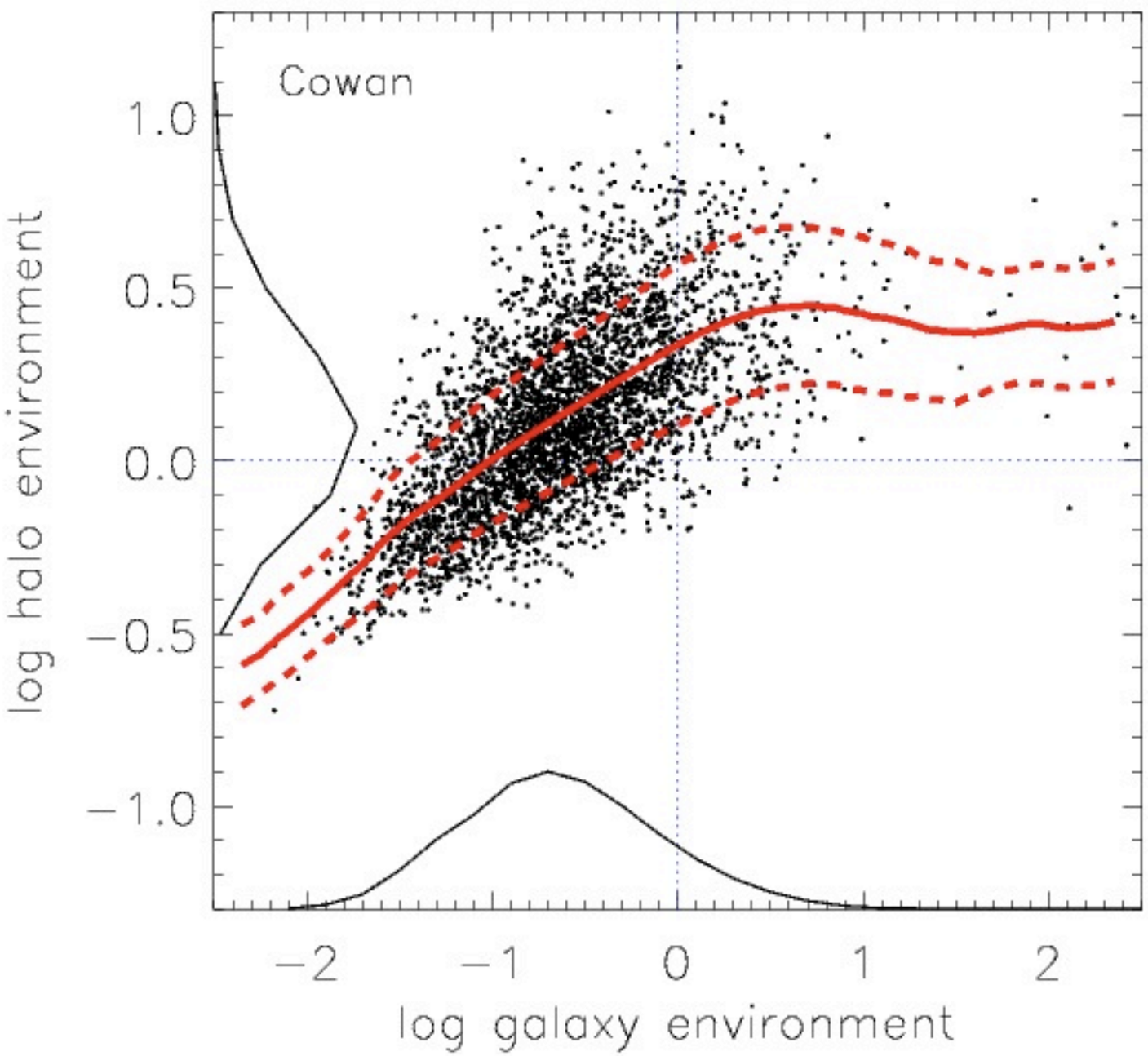
DM Gaussian smoothed $5h^{-1}$Mpc



top hat sphere $8h^{-1}$Mpc

Cowan & Ivezic 2008

DM Gaussian smoothed $5h^{-1}$Mpc



n'th nearest neighbour, n=9

...and the story continues in the next lecture...