

PART I:

Galaxy Formation Models

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PART I: Building synthetic universes

PART II: The universe in the cloud

The basics of how galaxies are built and evolve

The uses and limitations of galaxy models

The challenge of data access and delivery

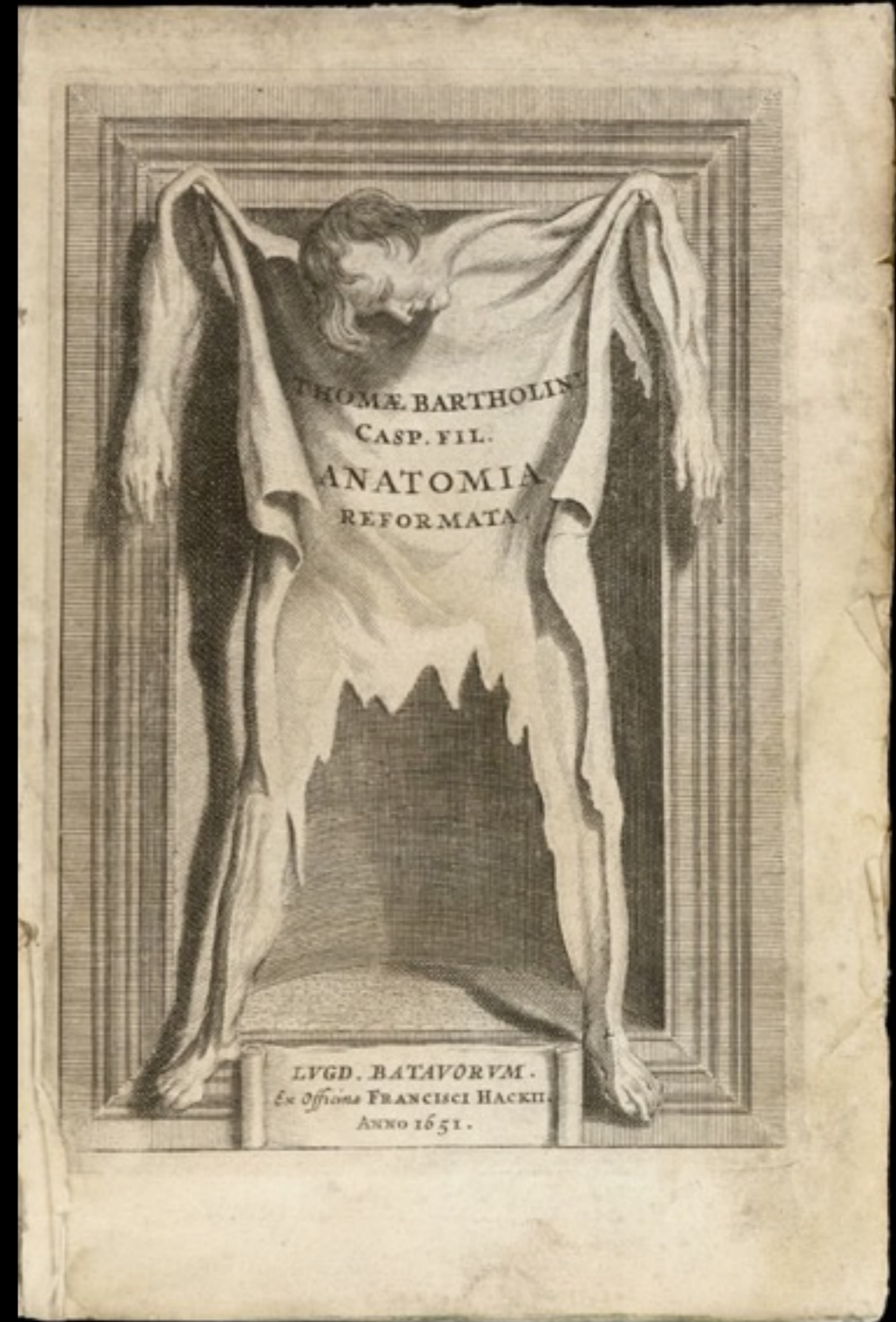
\$300 $z=1$
\$500 $z=2$
\$1000 $z=3$



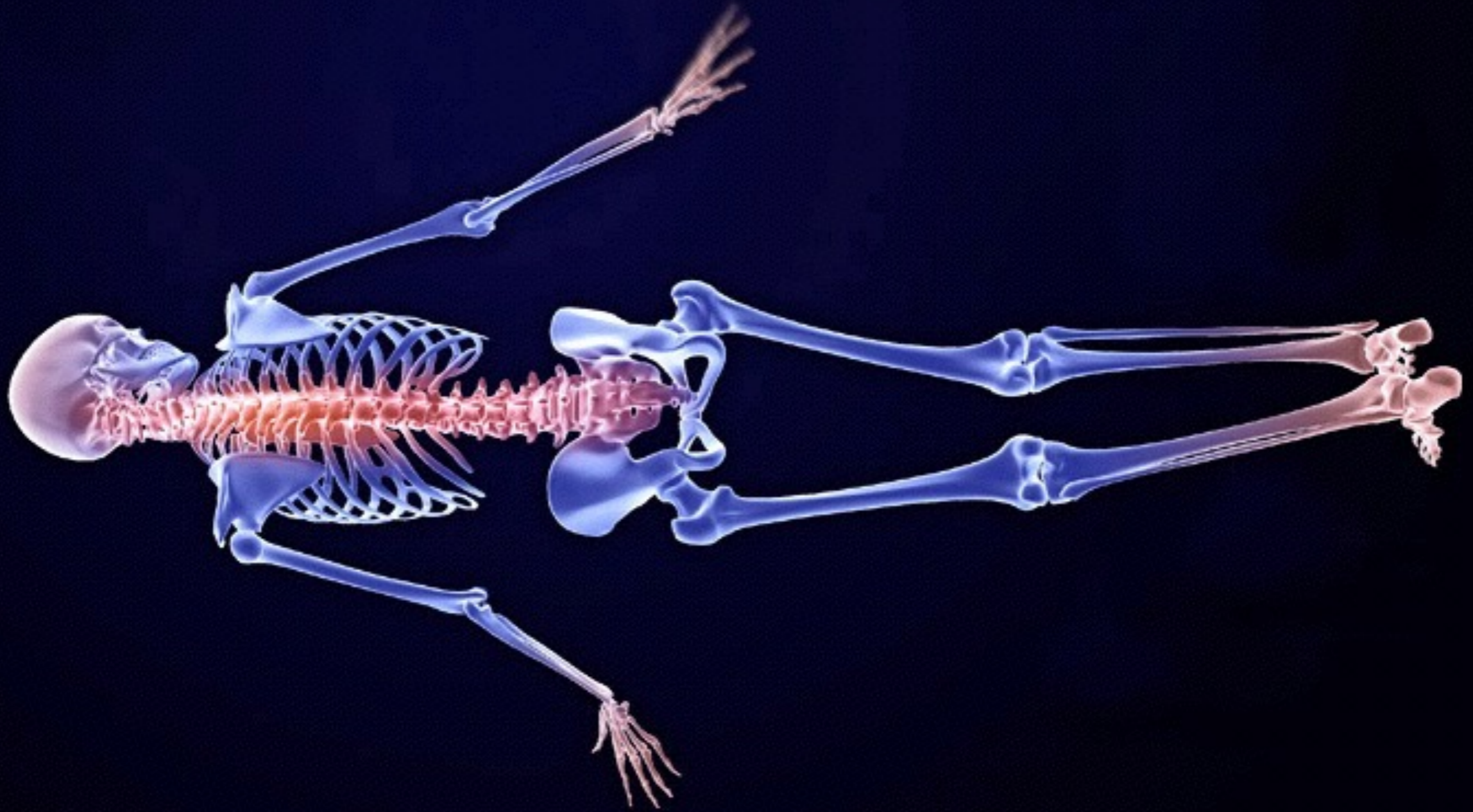
Galaxy formation primer



The skeleton

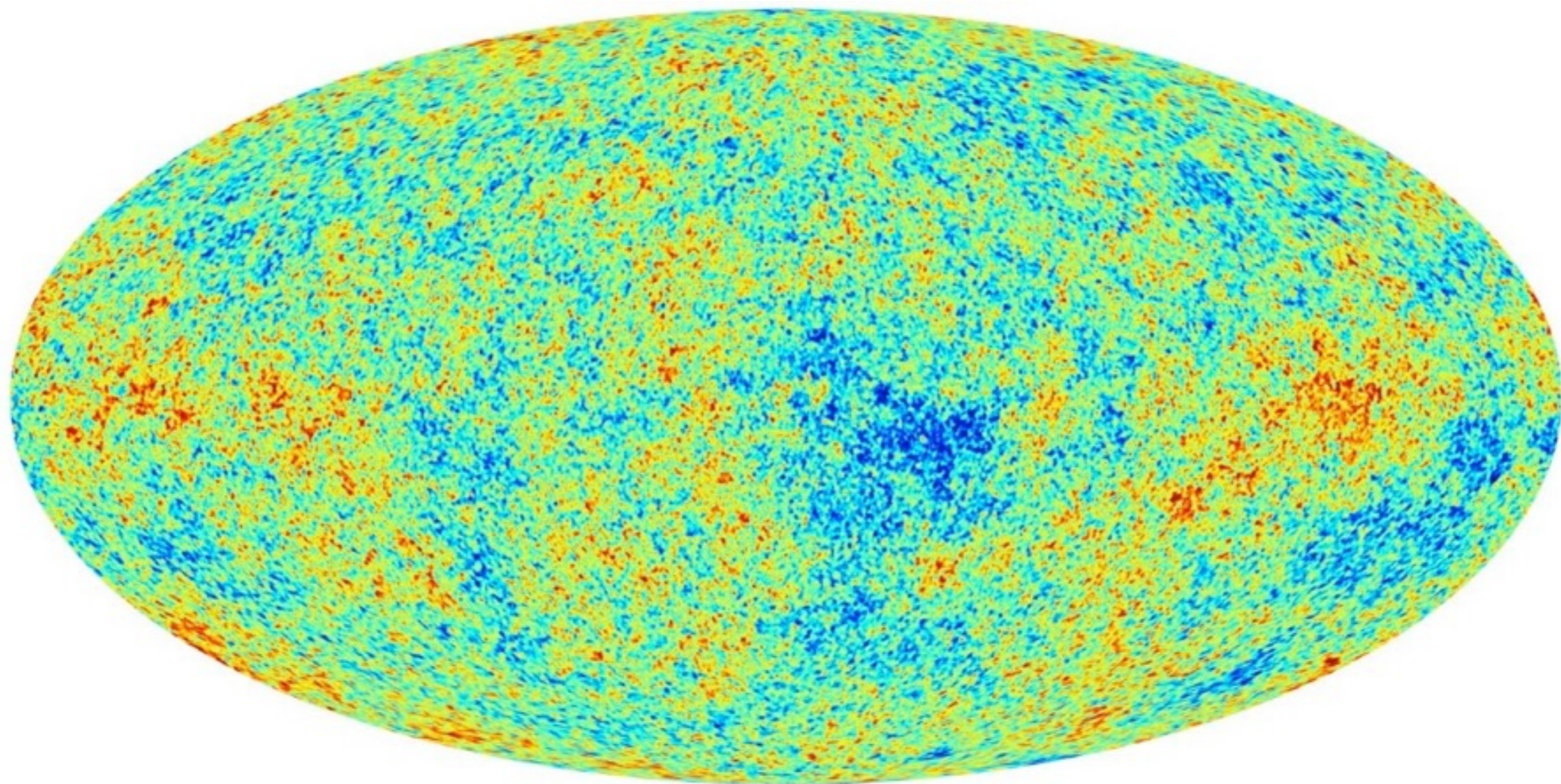


The flesh

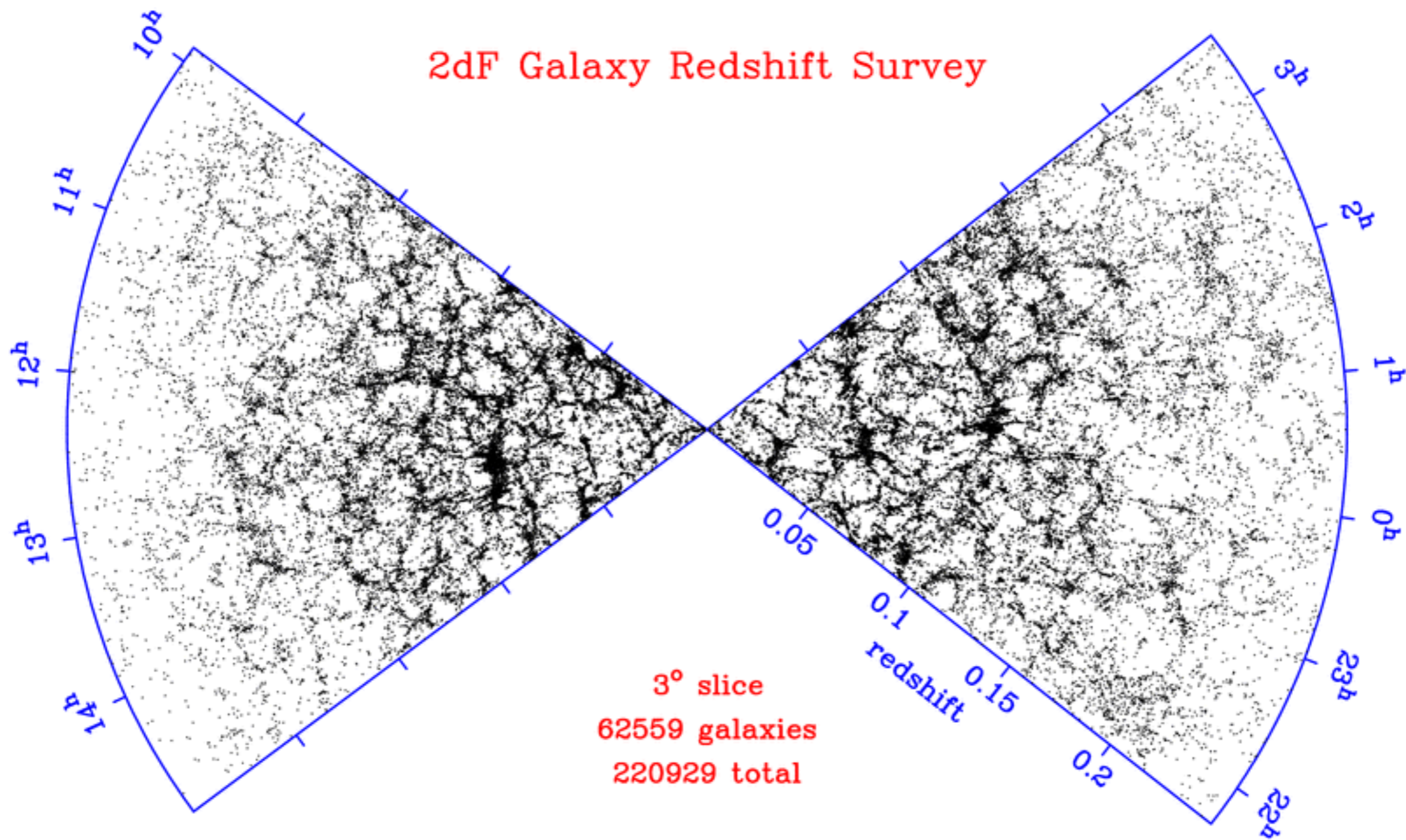


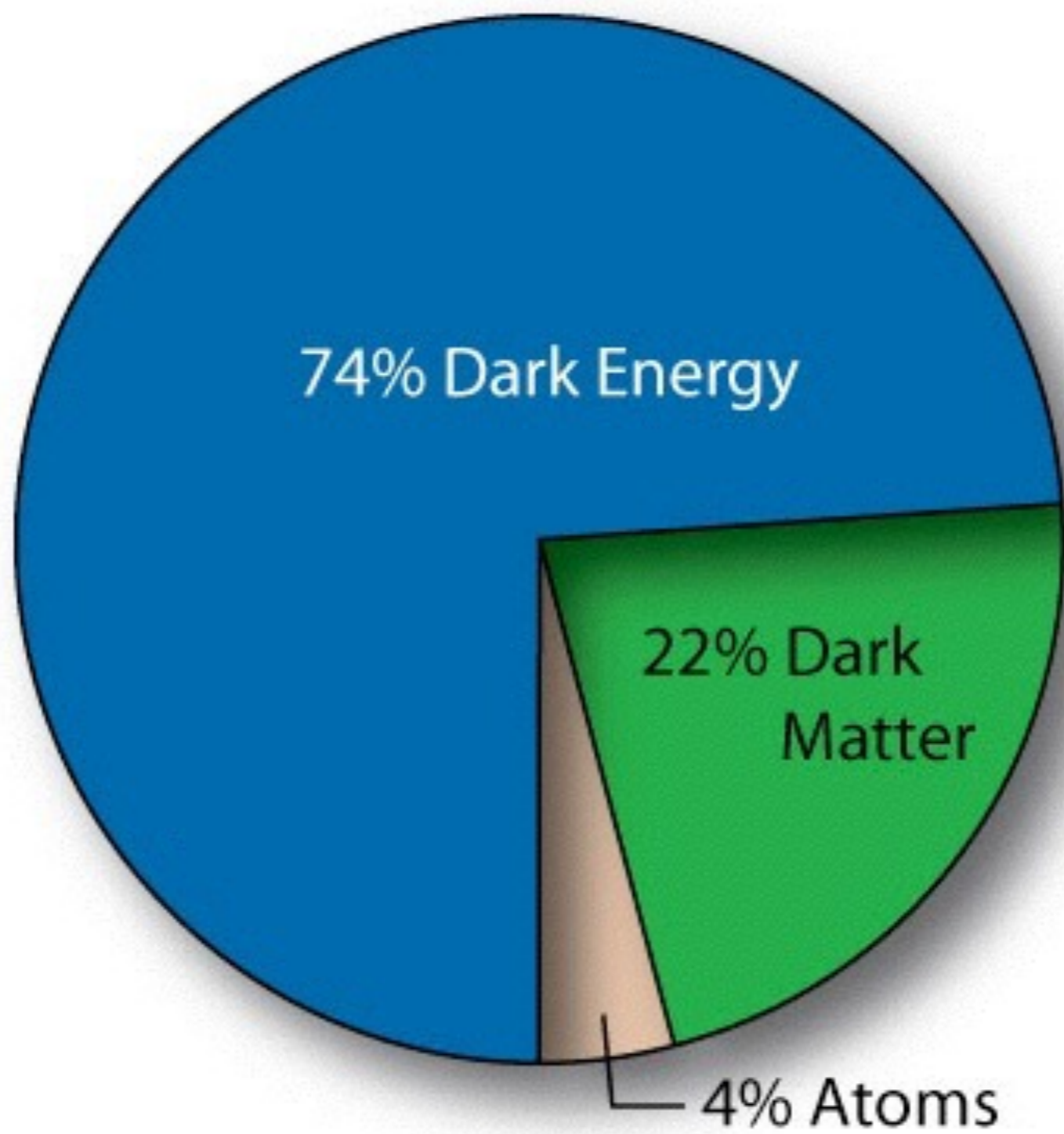
1. The skeleton: N-body simulations

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



2dF Galaxy Redshift Survey







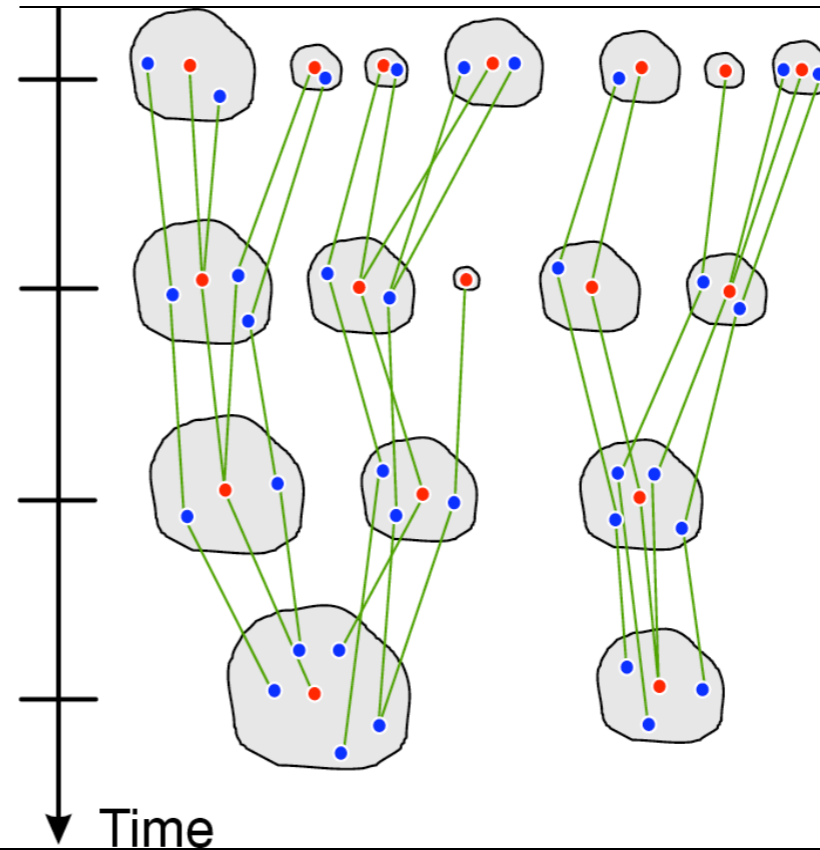
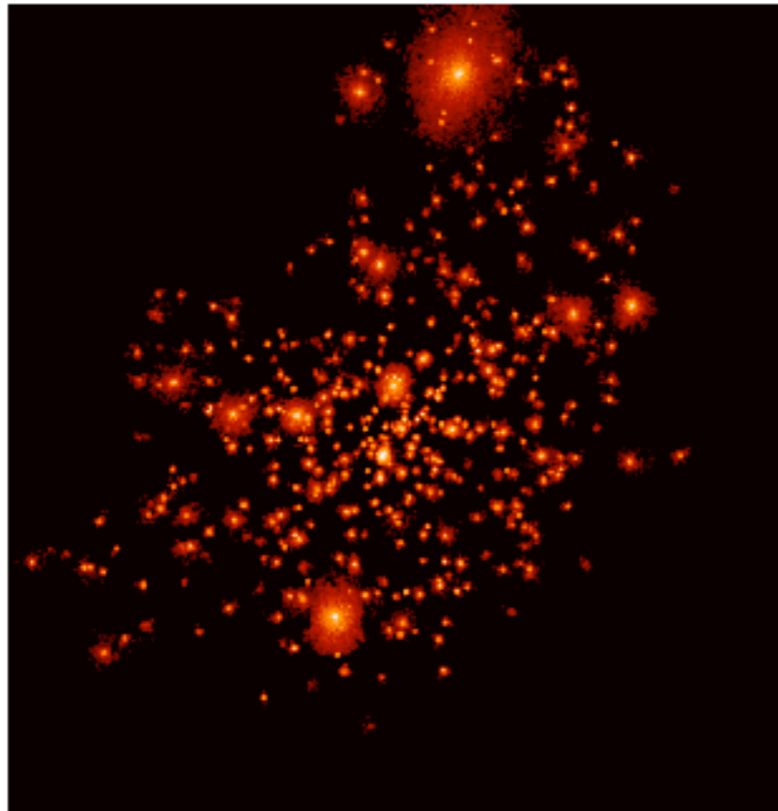
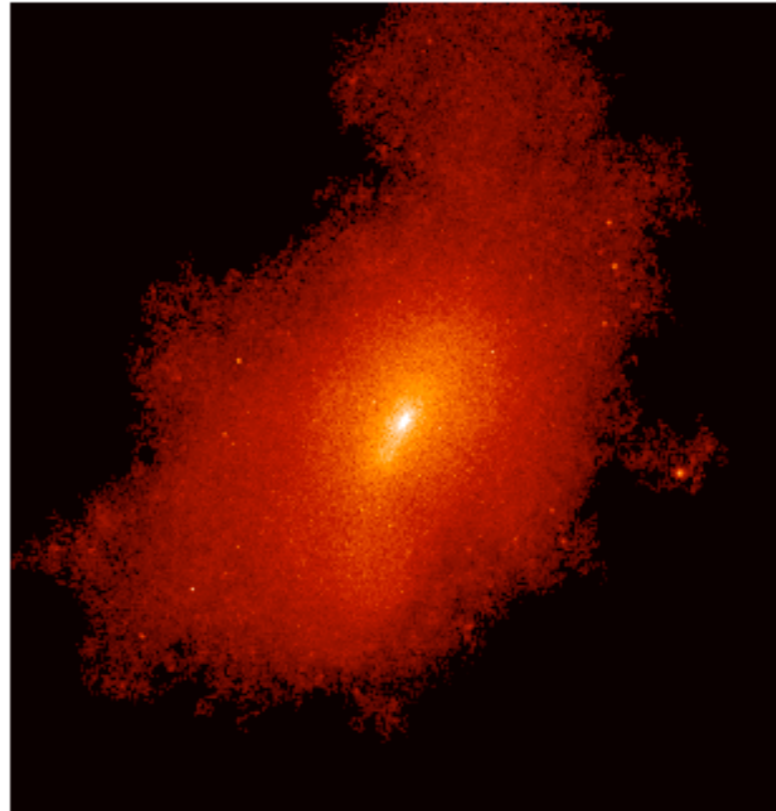
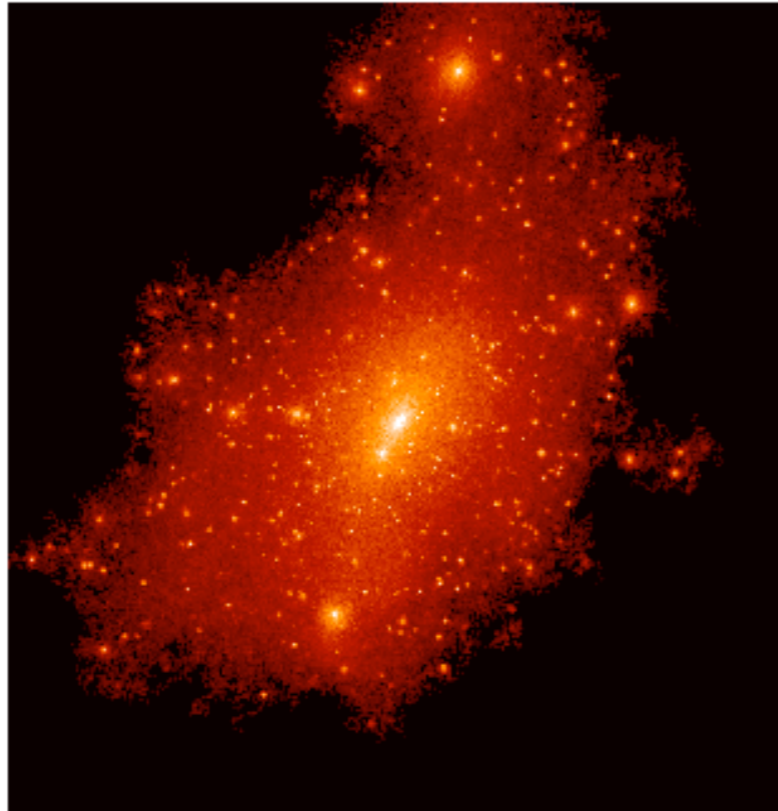




GREGORY POOLE
THE GIGGLEZ
SIMULATION SUITE

SWIN
BUR
NE

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SUPERCOMPUTING



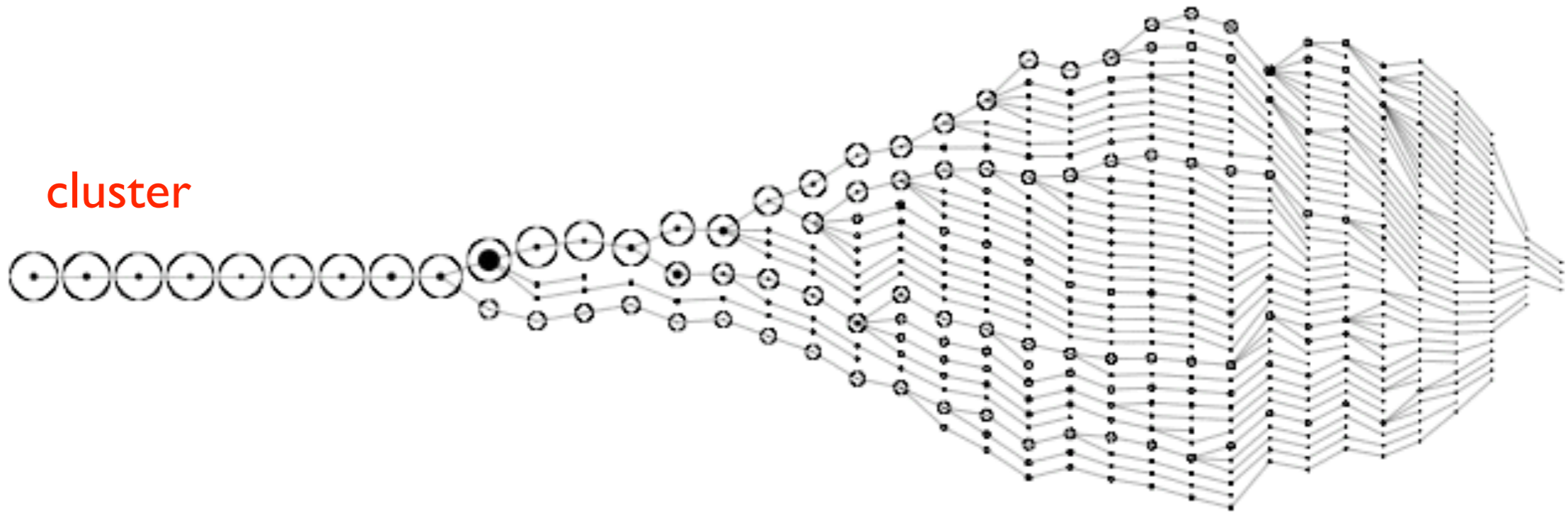
$z=0$

$z=1$

$z=3$

$z=6$

cluster

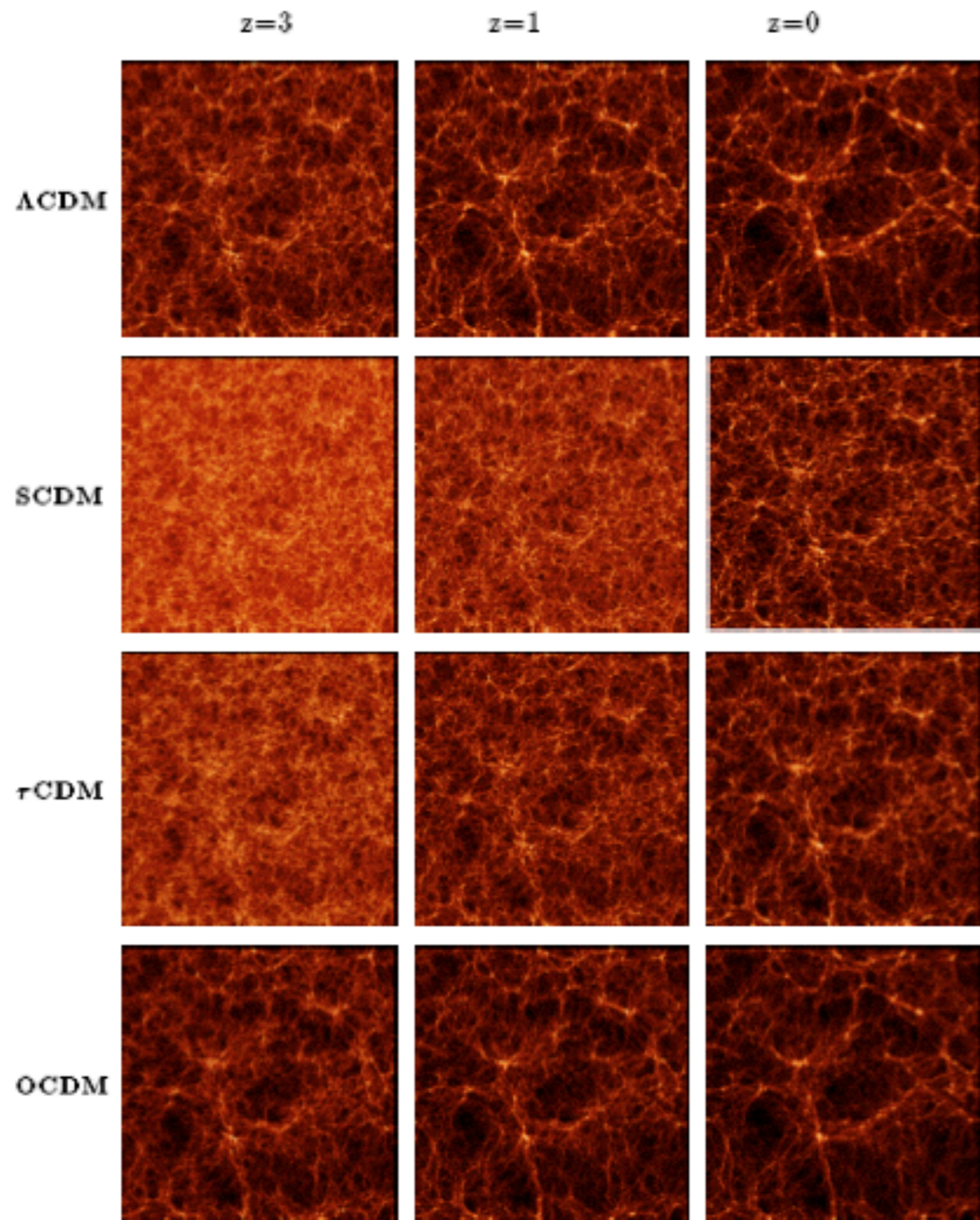


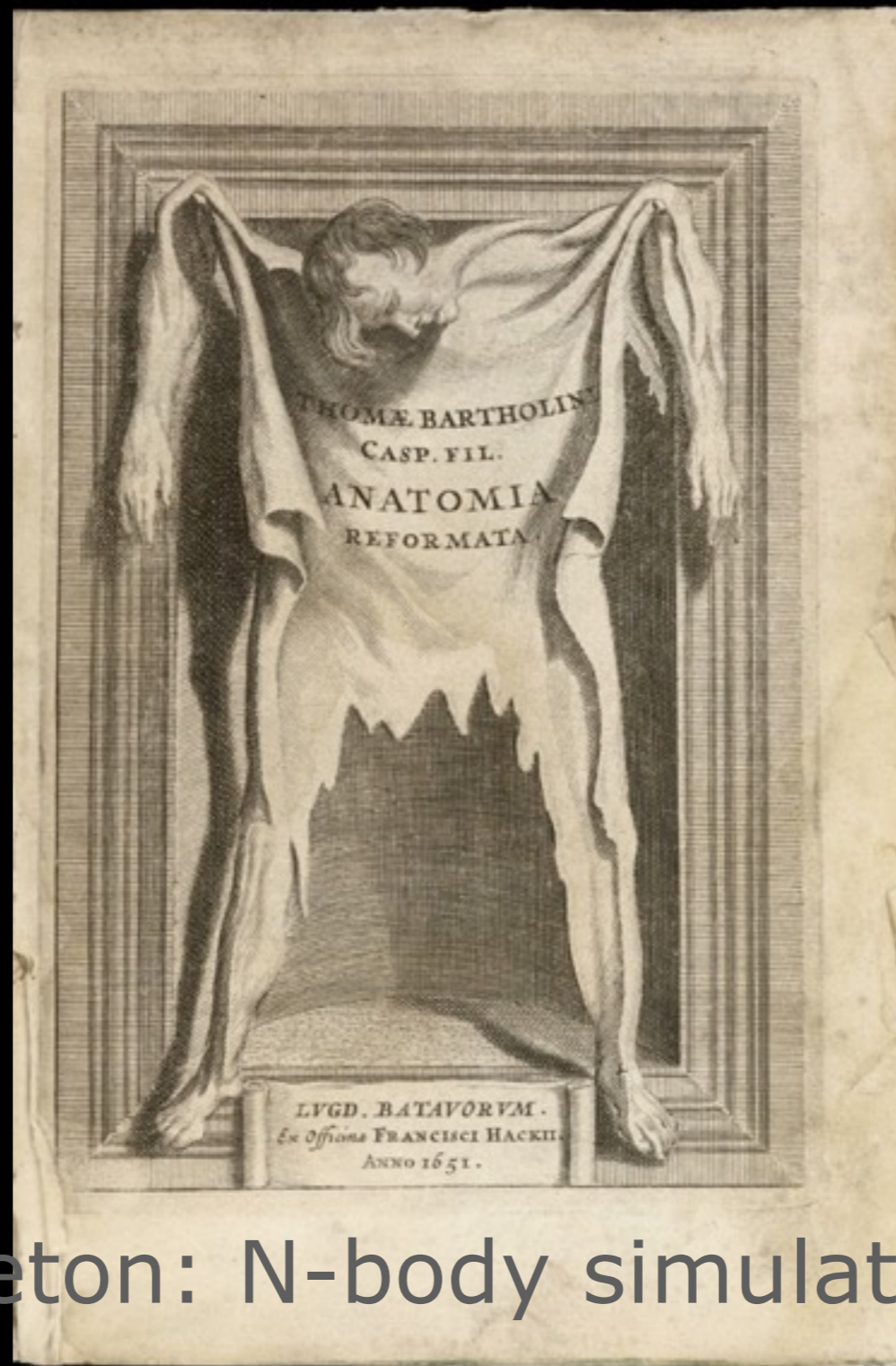
1.000
0.991
0.982
0.973
0.95
0.926
0.911
0.893
0.871
0.835
0.8
0.772
0.74
0.71
0.668
0.65
0.628
0.59
0.557
0.529
0.5
0.485
0.455
0.425
0.403
0.377
0.335
0.302
0.287
0.253
0.2
0.182
0.169
0.14
0.122

milky-way



Wechsler et al. 2002





1. The skeleton: N-body simulations

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

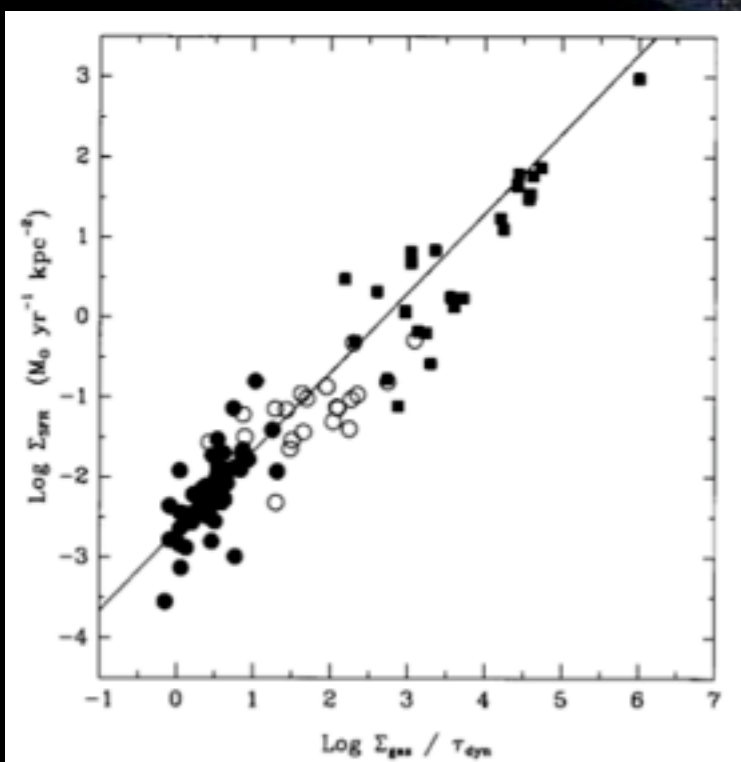
Galaxies, why we care ...

- highly non-linear evolution
- home of internal phenomena
- shaped by external influences



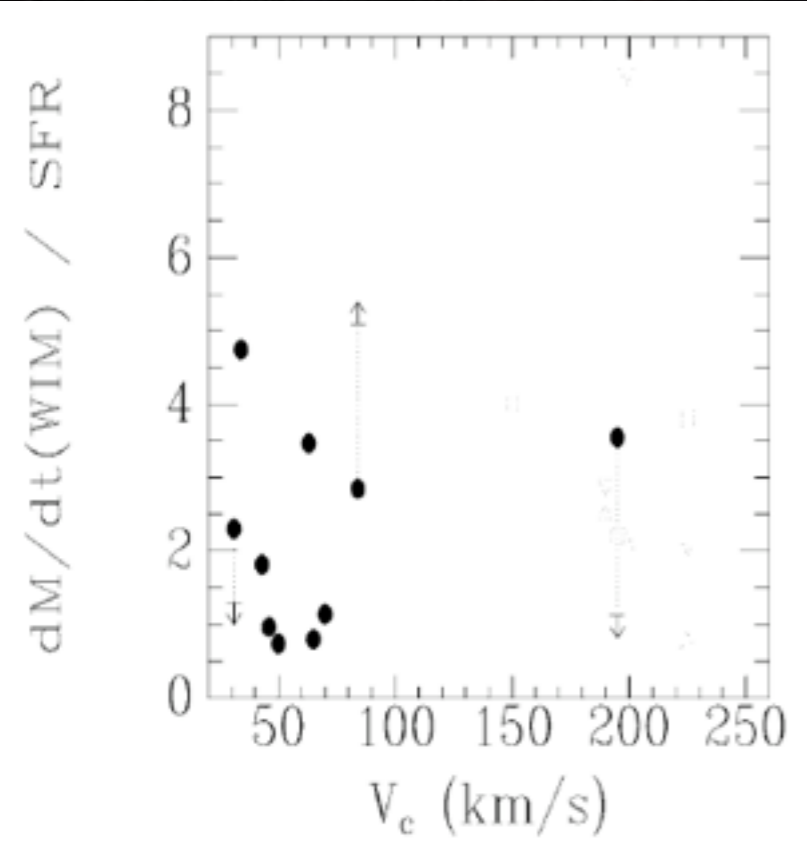
Star formation

Kennicutt 1998



M31

M82

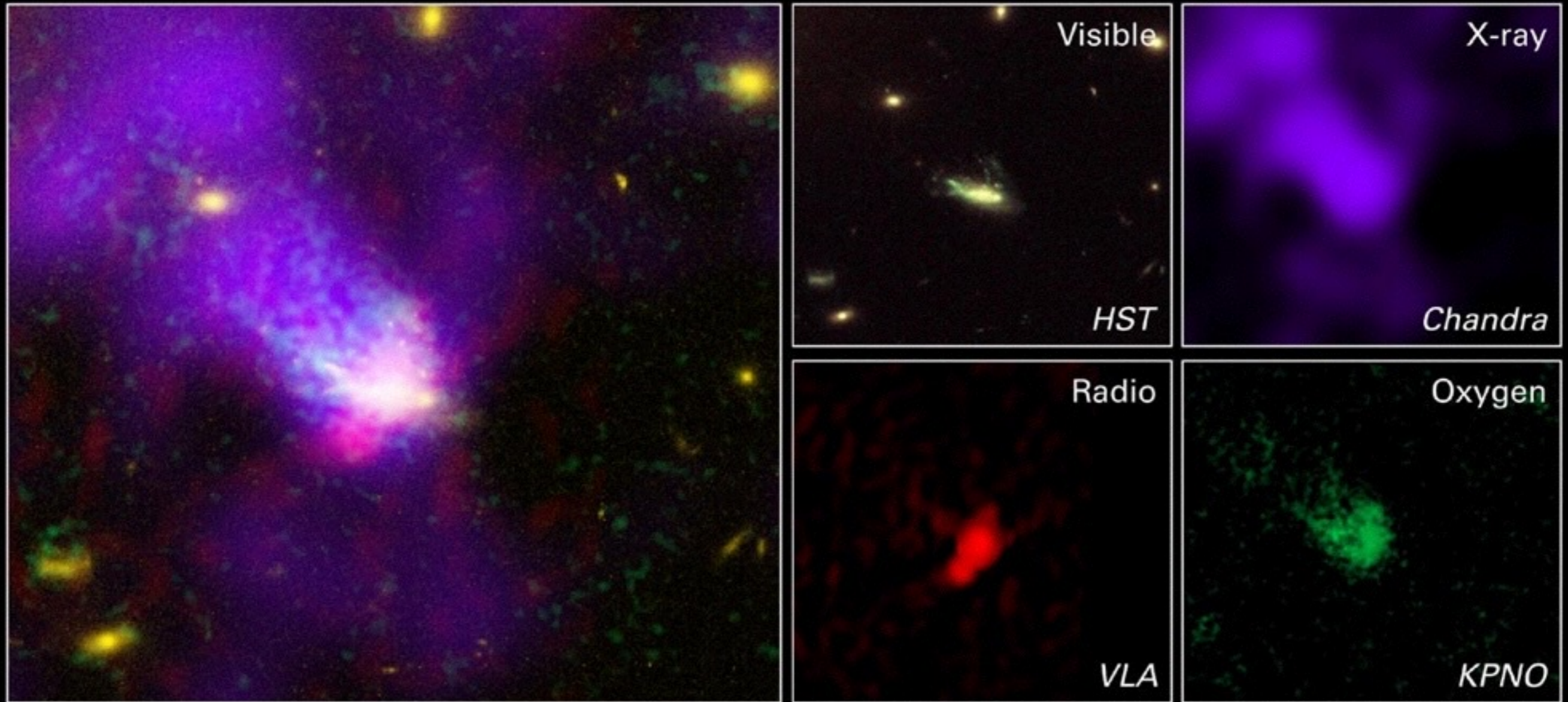


Martin 1999

Supernova feedback

Satellite galaxies

Galaxy C153 in Cluster Abell 2125



NASA, W. Keel (University of Alabama), F. Owen (National Radio Astronomy Observatory),
M. Ledlow (Gemini Observatory) and D. Wang (University of Massachusetts)

STScI-PRC04-02a

Morphological evolution



NGC 2207 & IC 2163

... and assembly



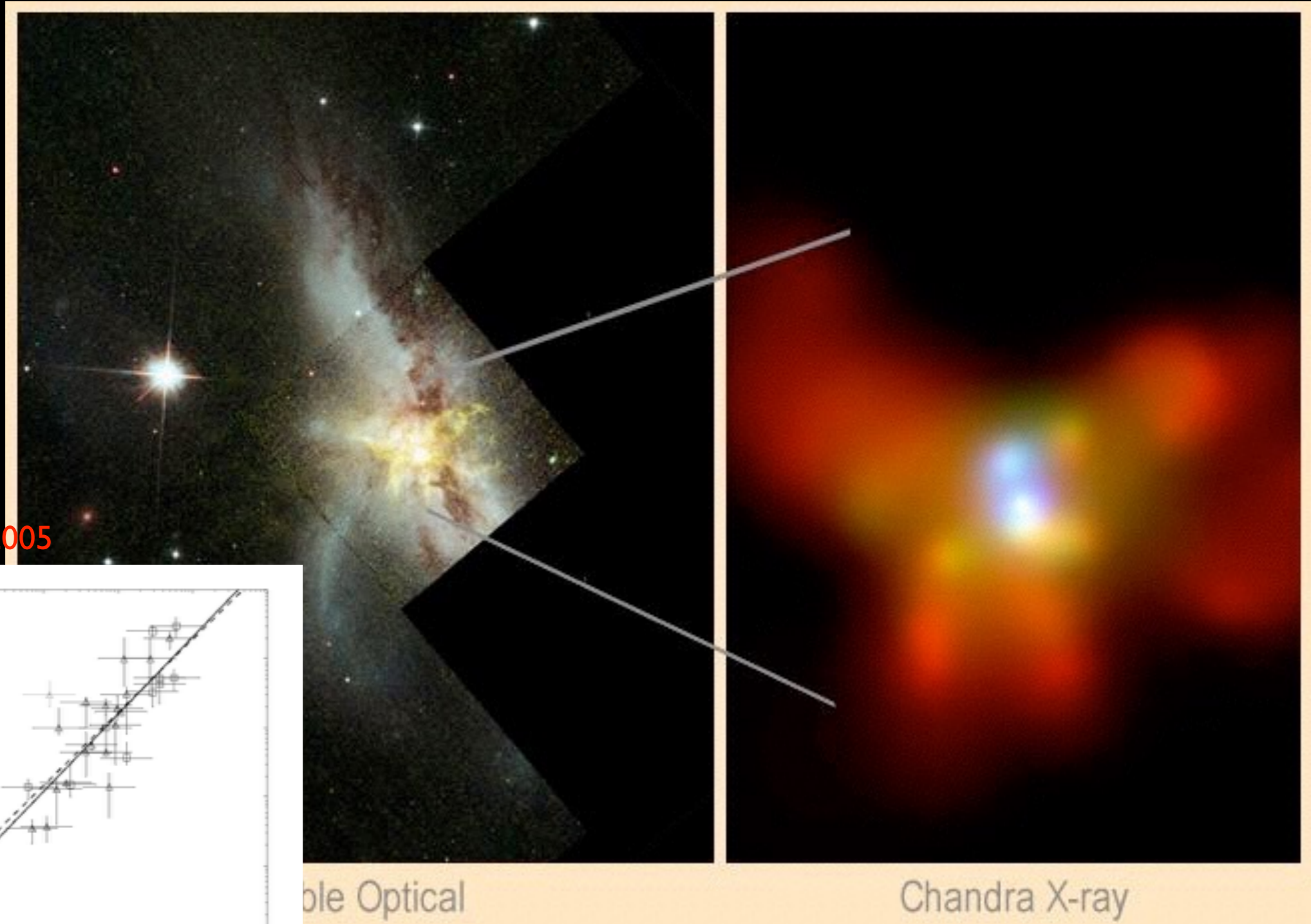
Seyfert's Sextet



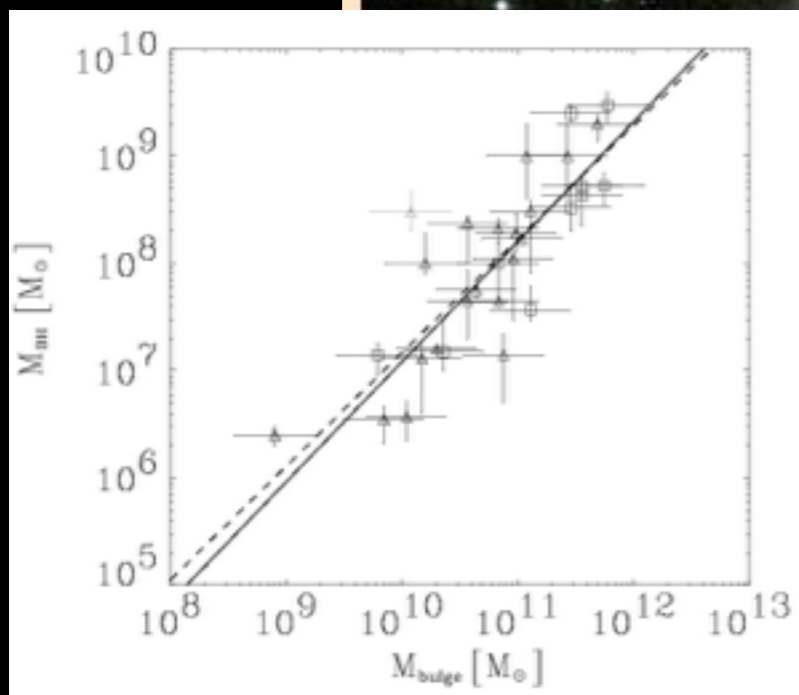
... and death

M87 (Virgo cluster)

Black holes



Haring & Rix 2005



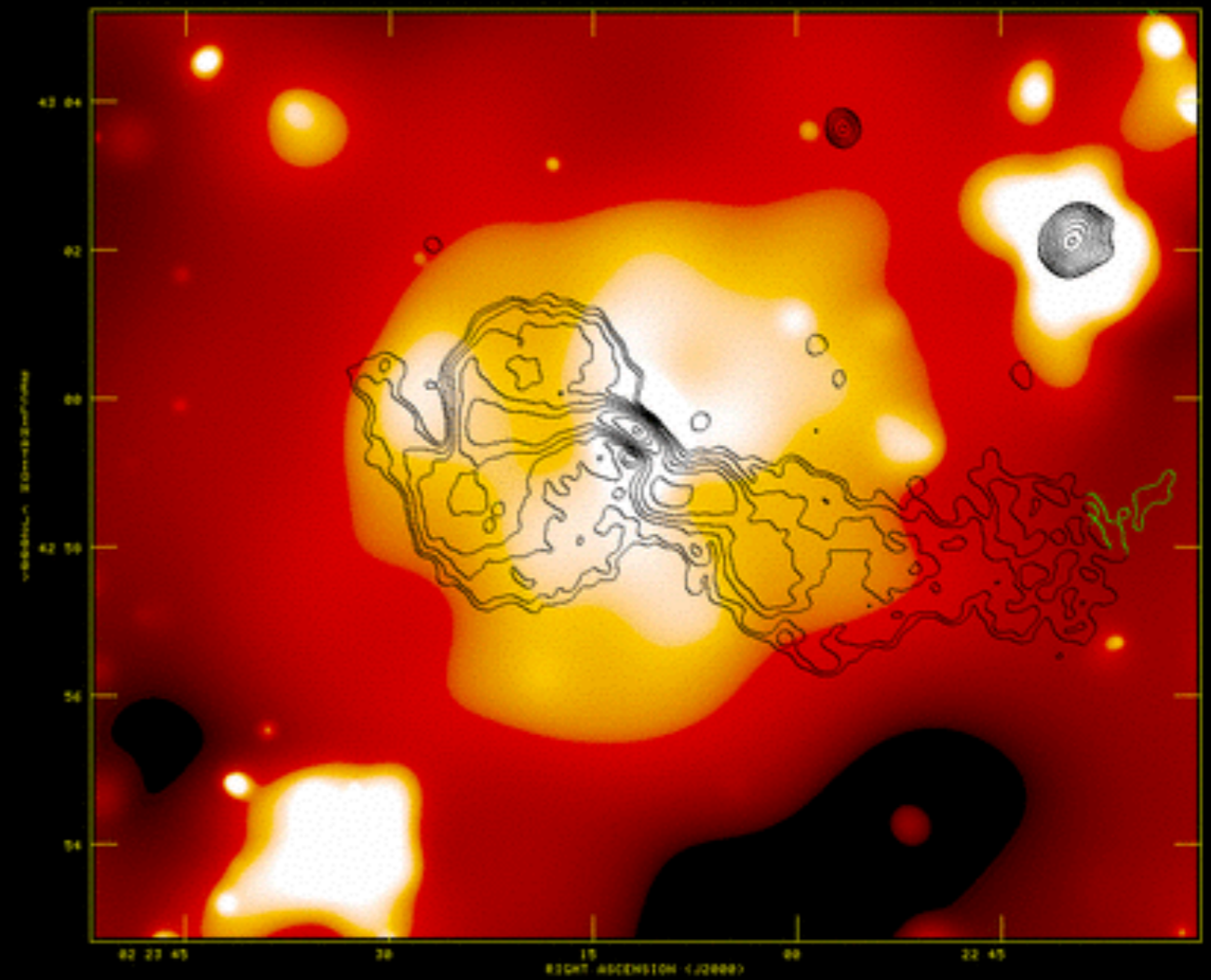
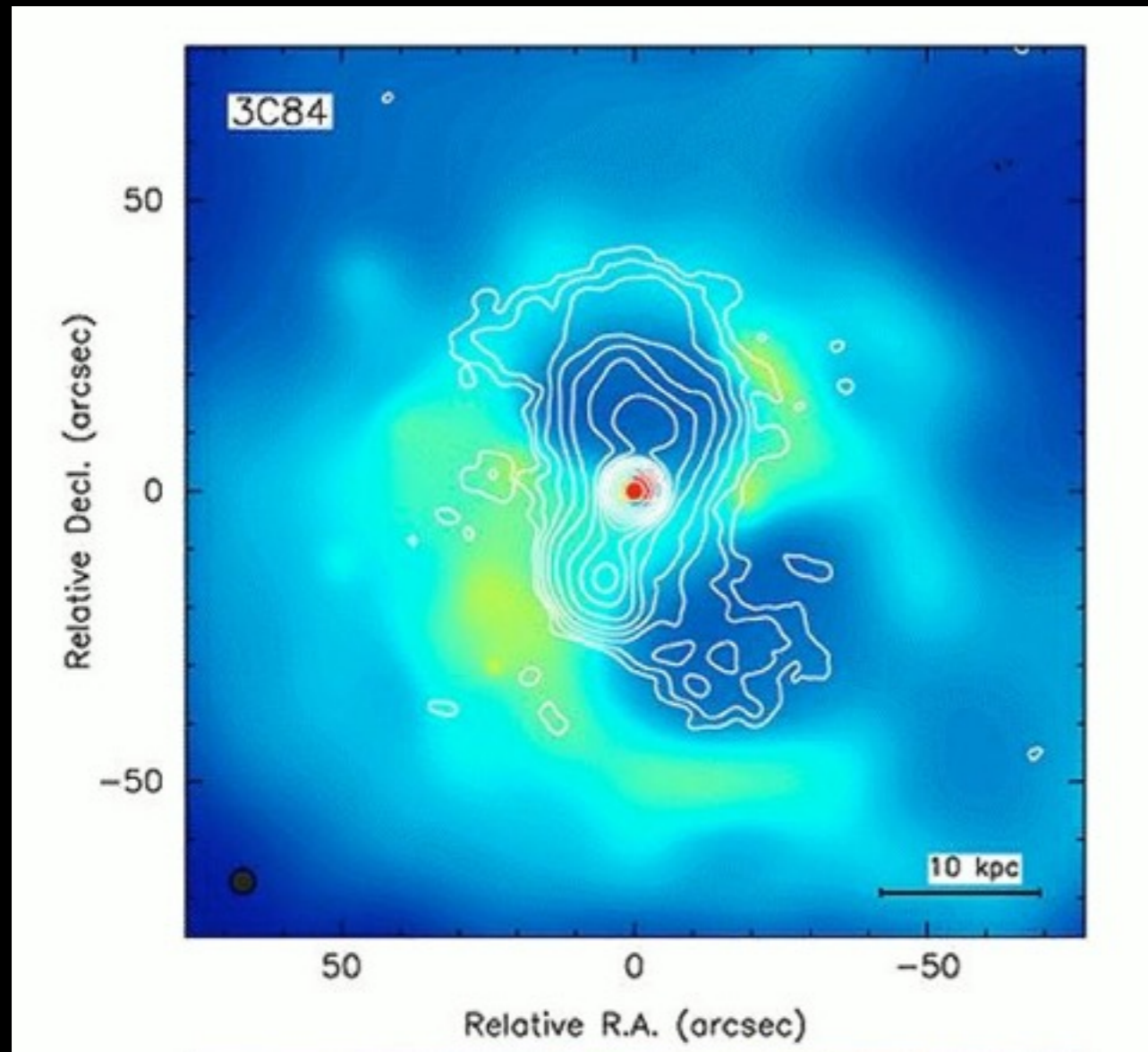
NGC 6240

AGN jets

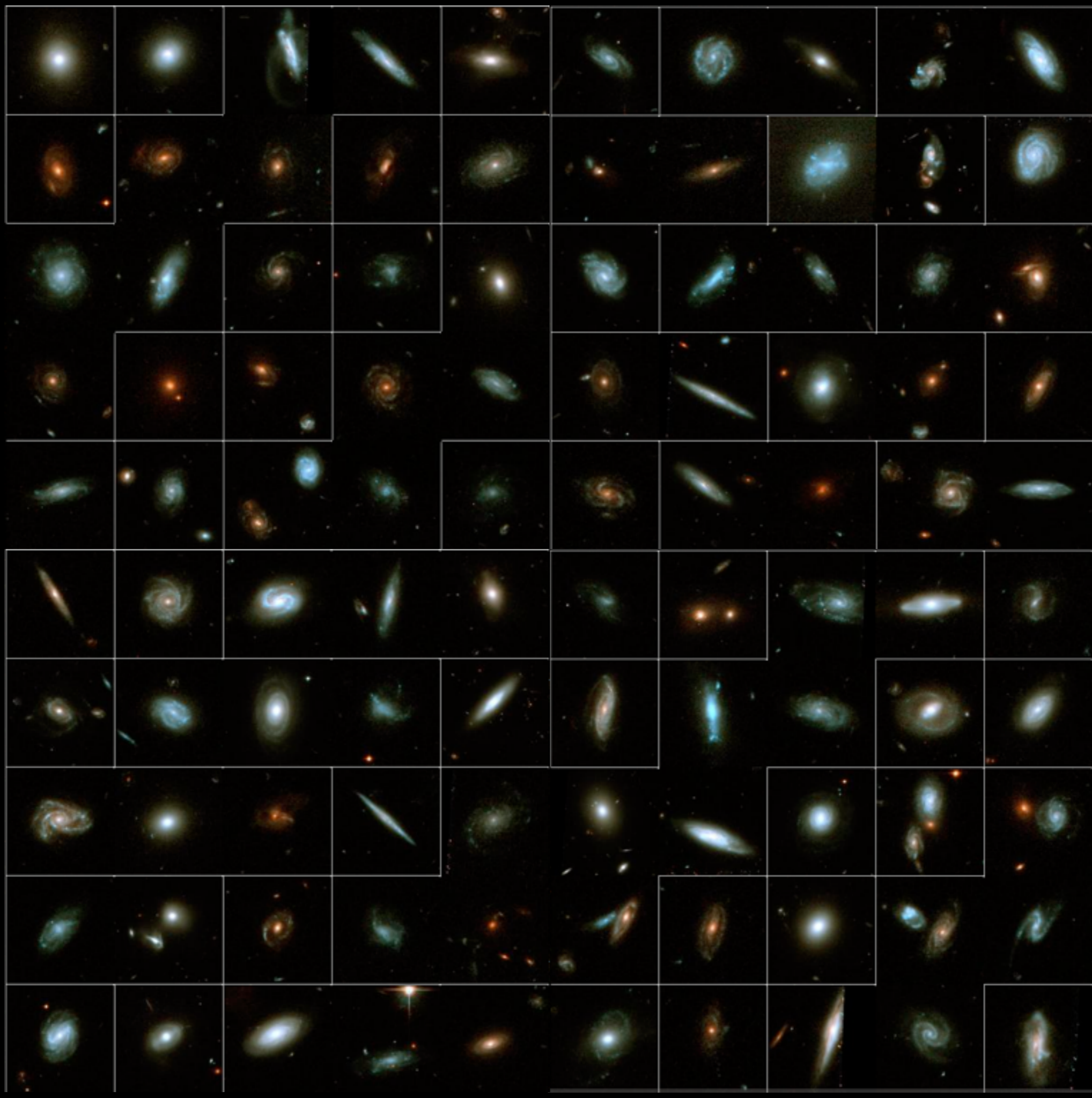
The image shows a deep-field astronomical observation of the galaxy M87. A bright, yellowish-white point source at the top left represents the active galactic nucleus (AGN). A long, curved, blueish-purple jet extends from the nucleus towards the bottom right of the frame. The background is a dark, reddish-brown color with numerous small, faint stars scattered throughout.

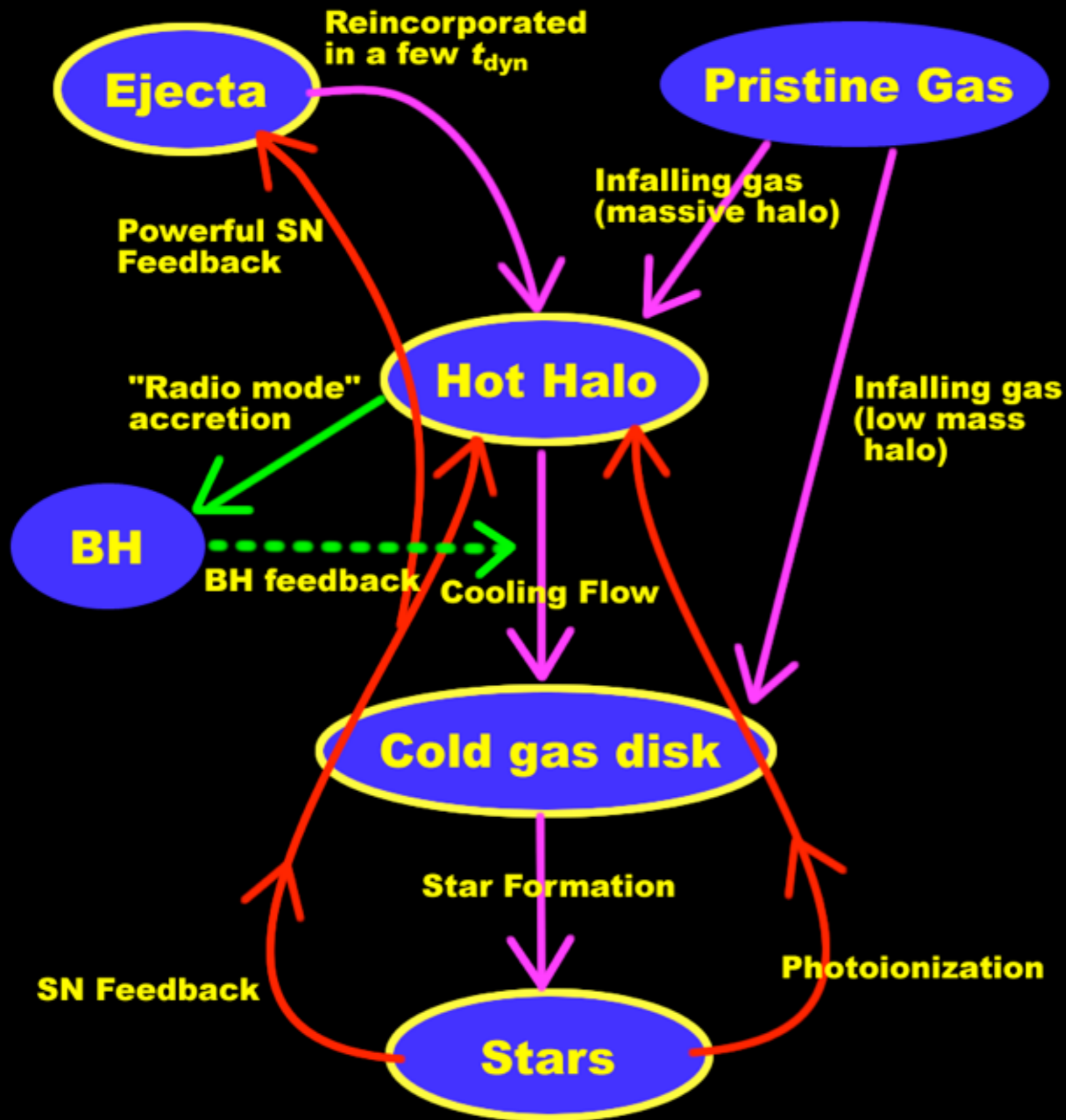
M87
(Virgo cluster)

AGN bubbles



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

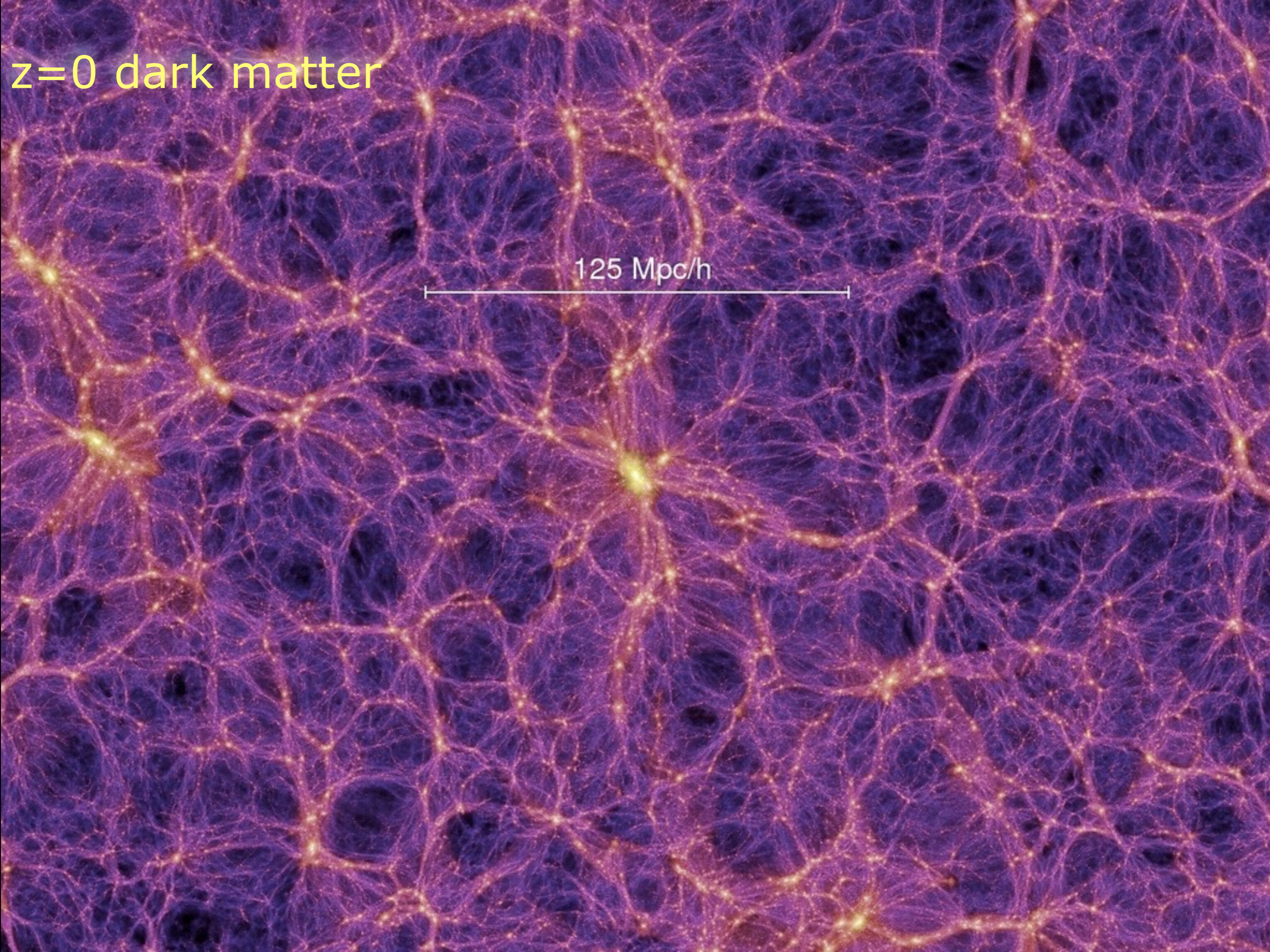
Semi-Analytic Galaxy Evolution (SAGE)

Parameter	Description	Value	C06 value	Fixed	Section(s)
$f_b^{(\text{cosmic})}$	(Cosmic) baryon fraction	0.17, 0.13	0.17	No	4, 5
z_0	Redshift when H II regions overlap	8.0	8.0	Yes	5
z_r	Redshift when the intergalactic medium is fully reionized	7.0	7.0	Yes	5
α_{SF}	Star formation efficiency	0.05	0.07	No	7
Y	Yield of metals from new stars	0.025	0.03	No	7
\mathcal{R}	Instantaneous recycling fraction	0.43	0.30	Yes	7, 8
ϵ_{disc}	Mass-loading factor due to supernovae	3.0	3.5	No	8
ϵ_{halo}	Efficiency of supernovae to unbind gas from the hot halo	0.3	0.35	No	8
k_{reinc}	Sets velocity scale for gas reincorporation	0.15	N/A	Yes	8
κ_{R}	Radio mode feedback efficiency	0.08	N/A	No	9.1
κ_{Q}	Quasar mode feedback efficiency	0.005	N/A	No	9.2
f_{BH}	Rate of black hole growth during quasar mode	0.015	0.03	No	9.2
f_{friction}	Threshold subhalo-to-baryonic mass for satellite disruption or merging	1.0	N/A	Yes	10
f_{major}	Threshold mass ratio for merger to be major	0.3	0.3	Yes	10

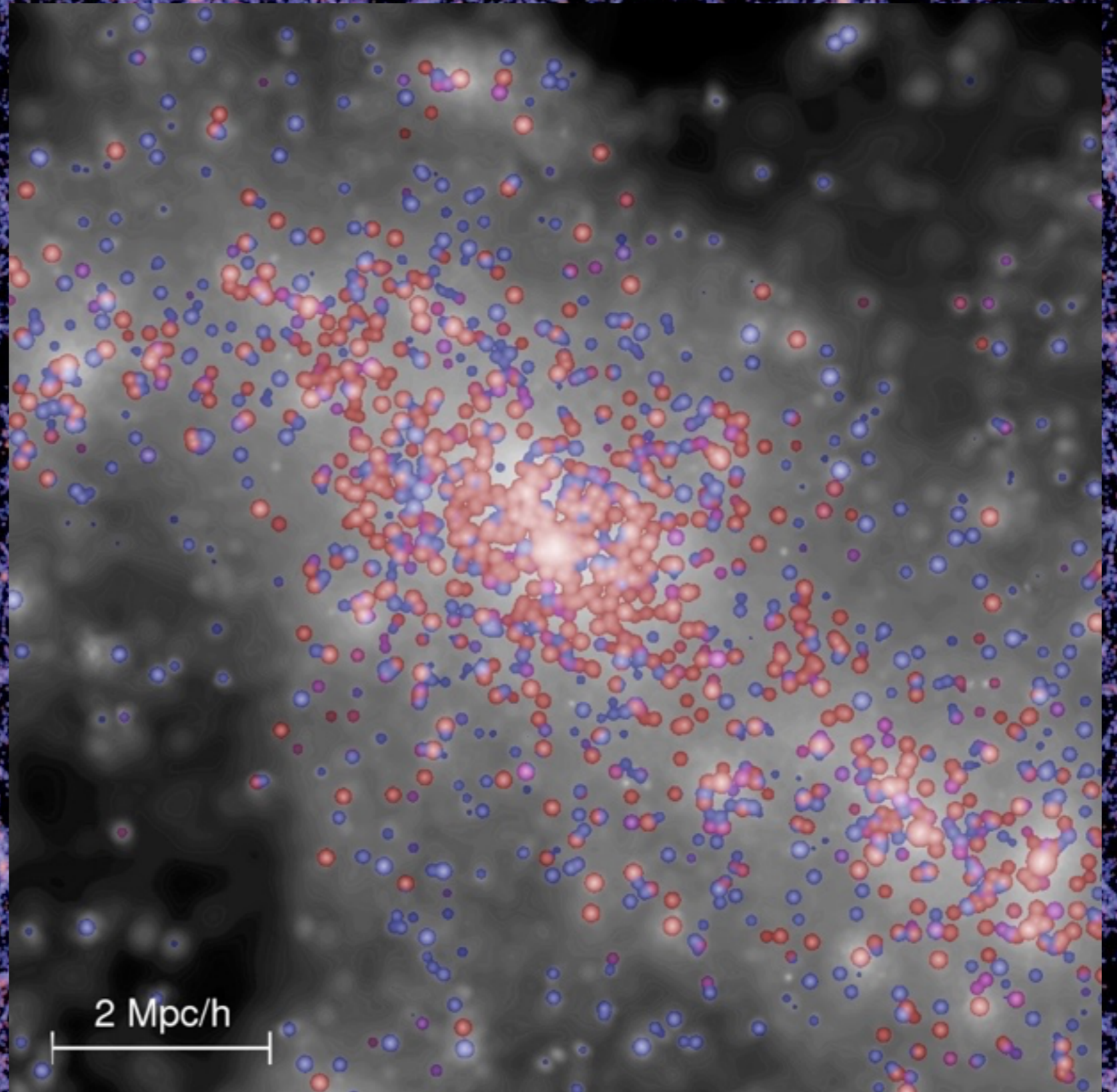
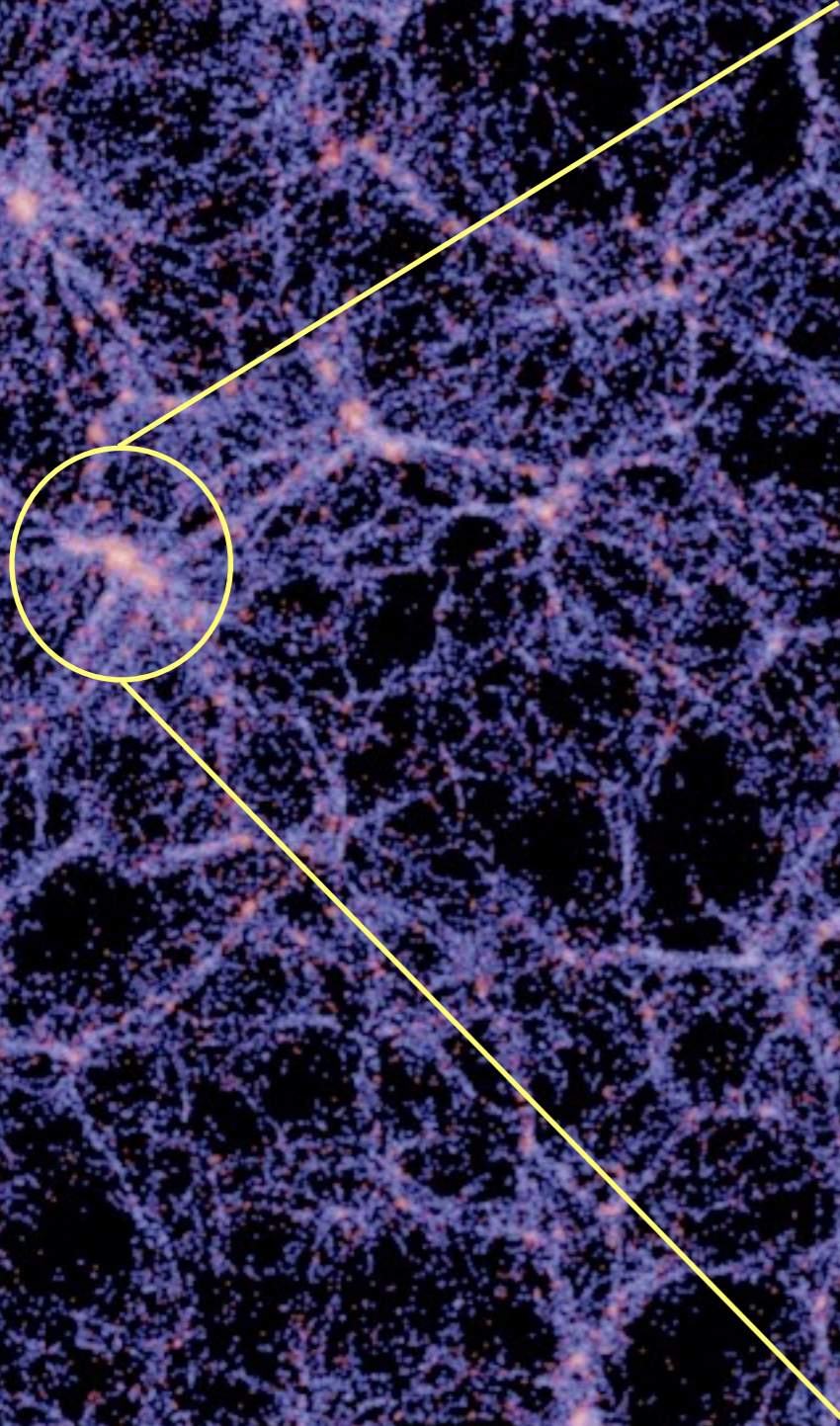
Croton et al. 2016

$z=0$ dark matter

125 Mpc/h



$z=0$ galaxy light

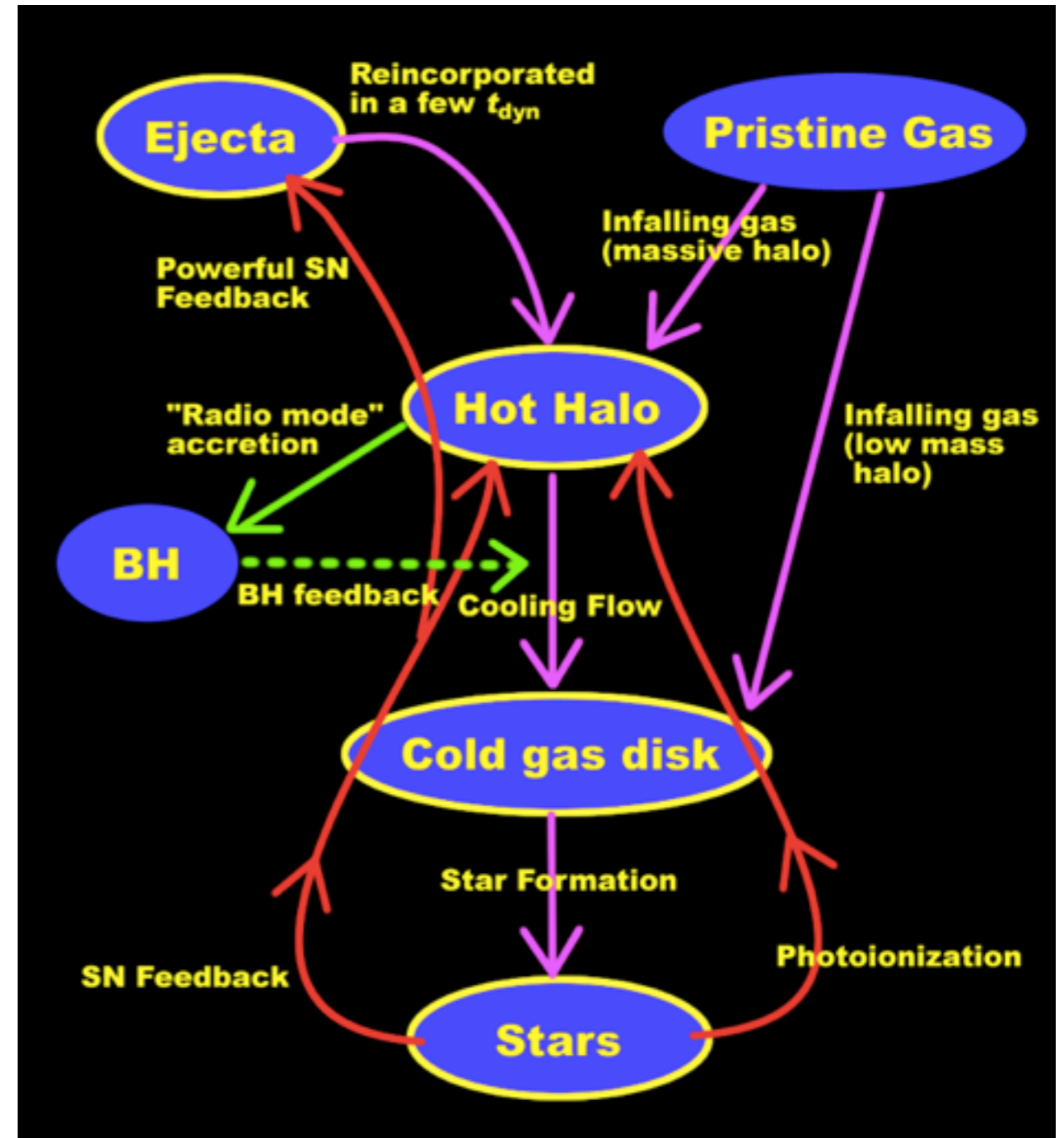
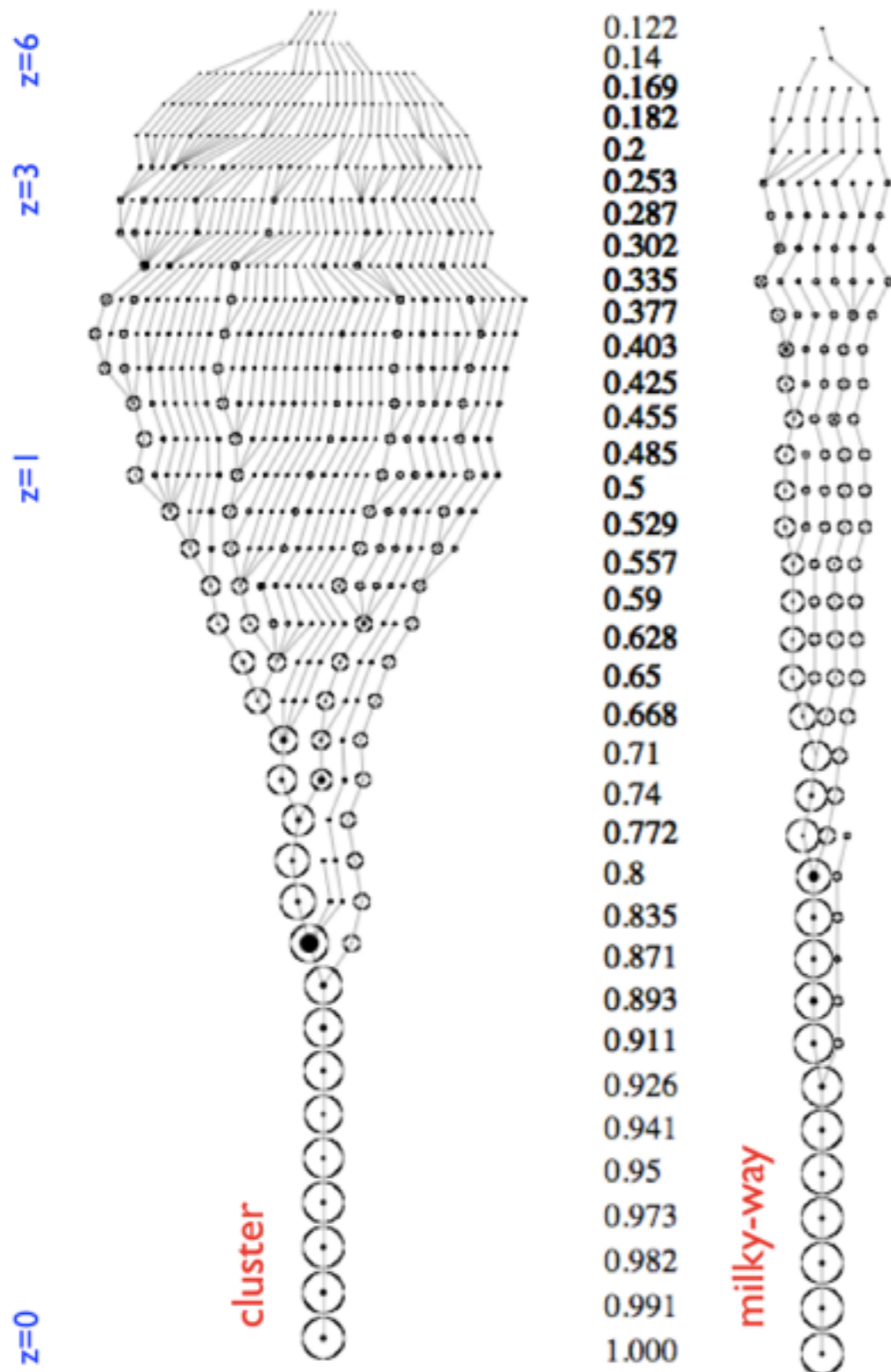


Remember:

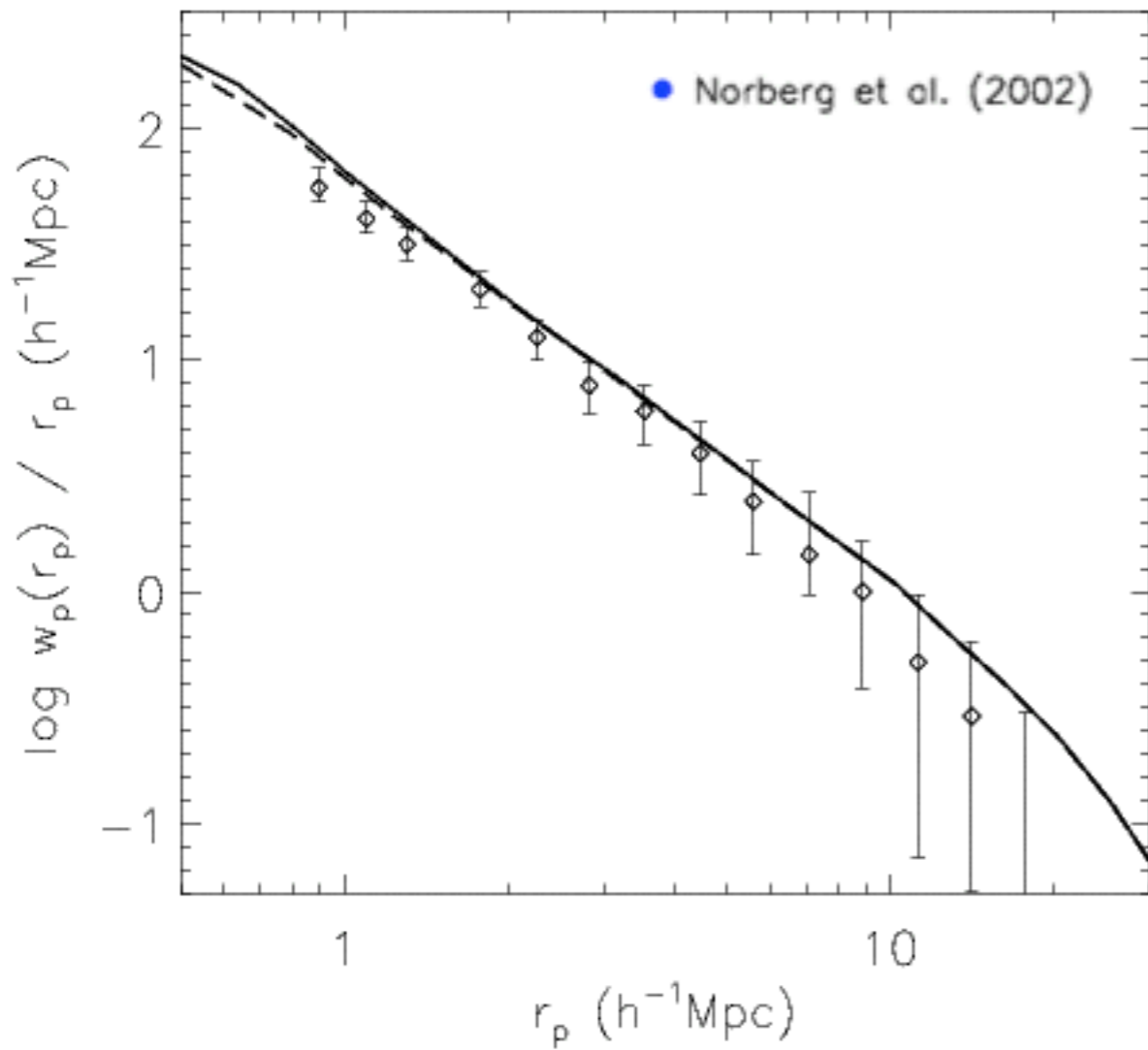
Numerical Simulation

+

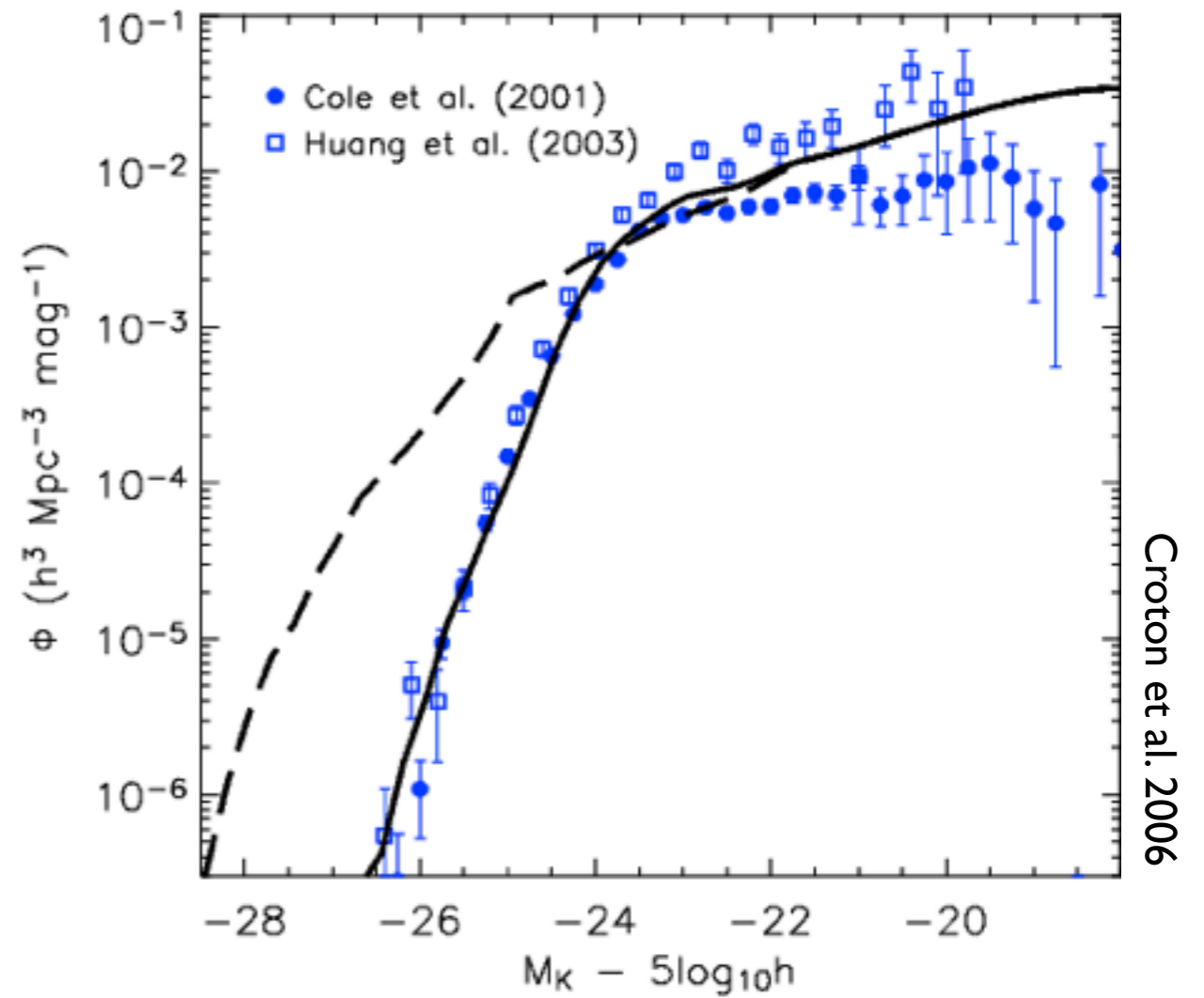
Analytic Simulation



Galaxy spatial and luminosity distributions



-clustering-

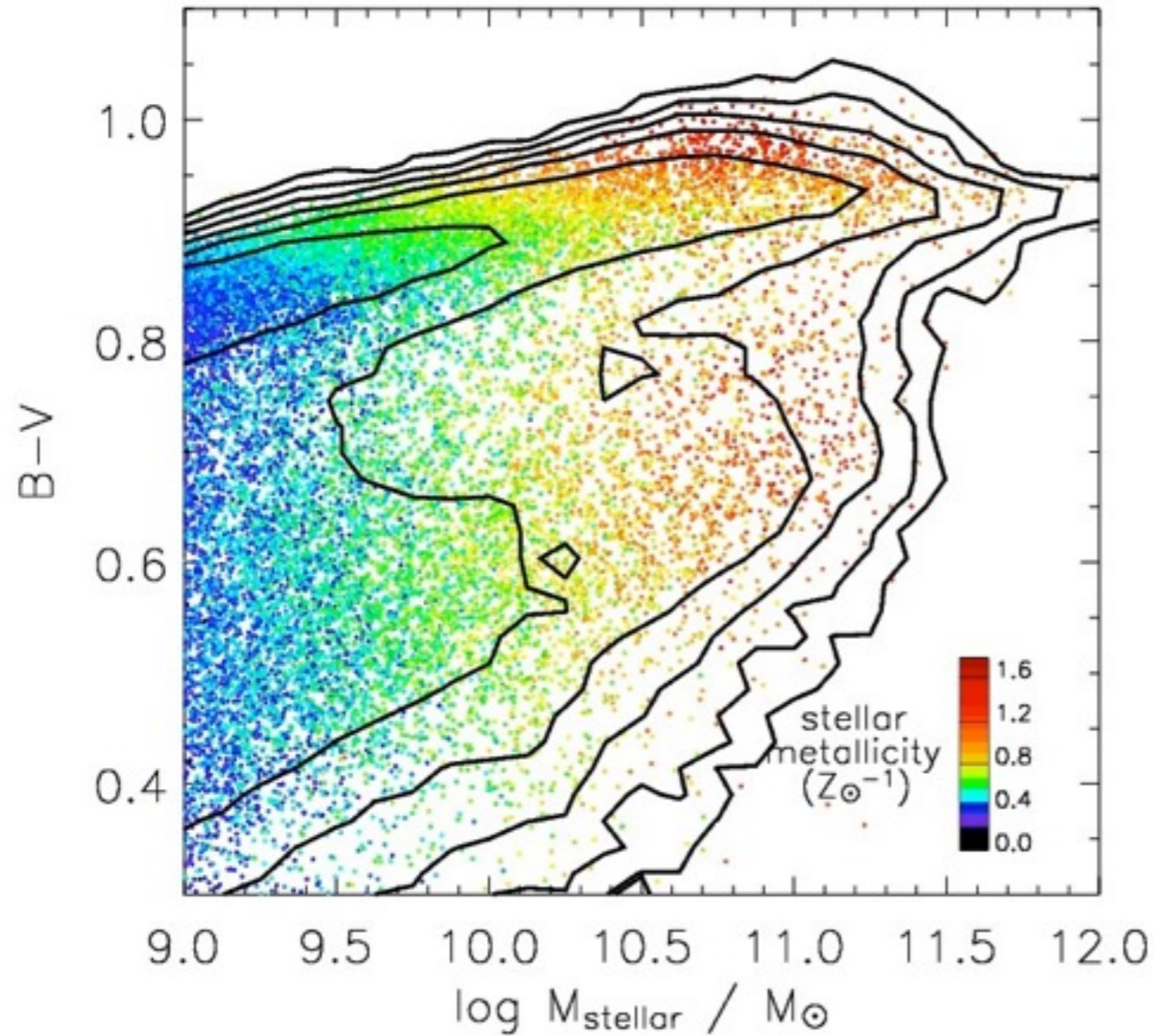


Croton et al. 2006

-luminosity function-

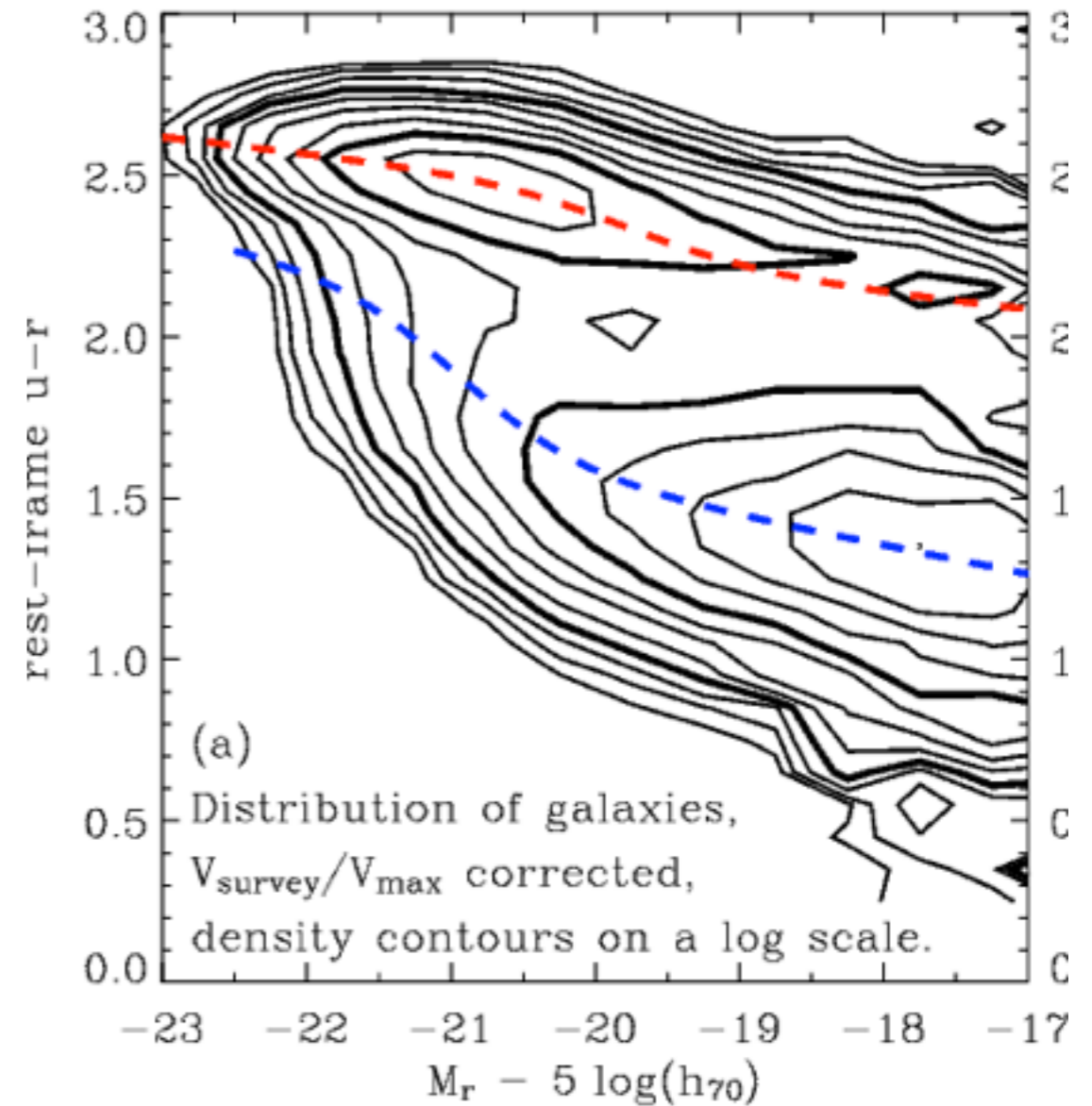
Galaxy colour distribution

Croton et al. 2006



-model-

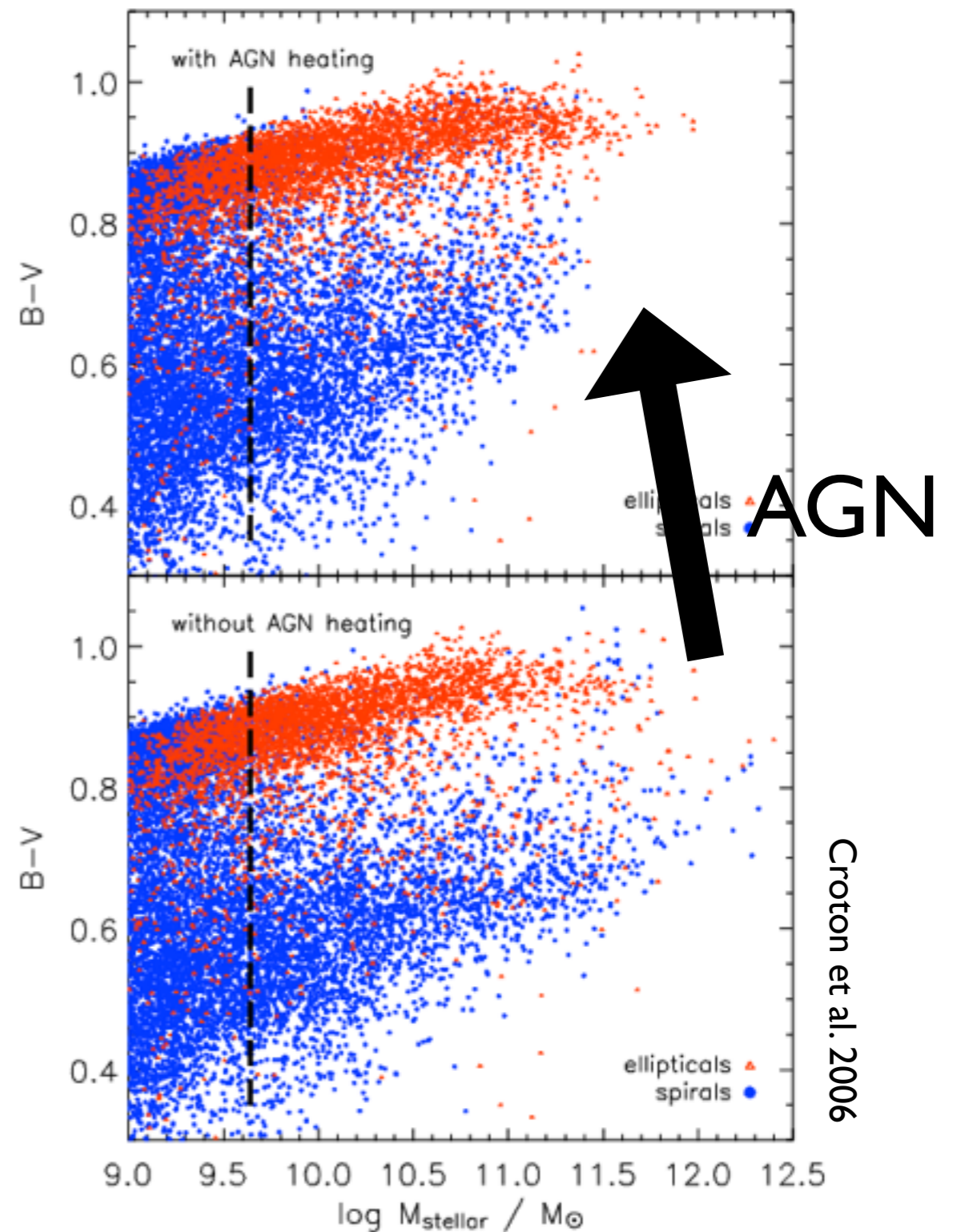
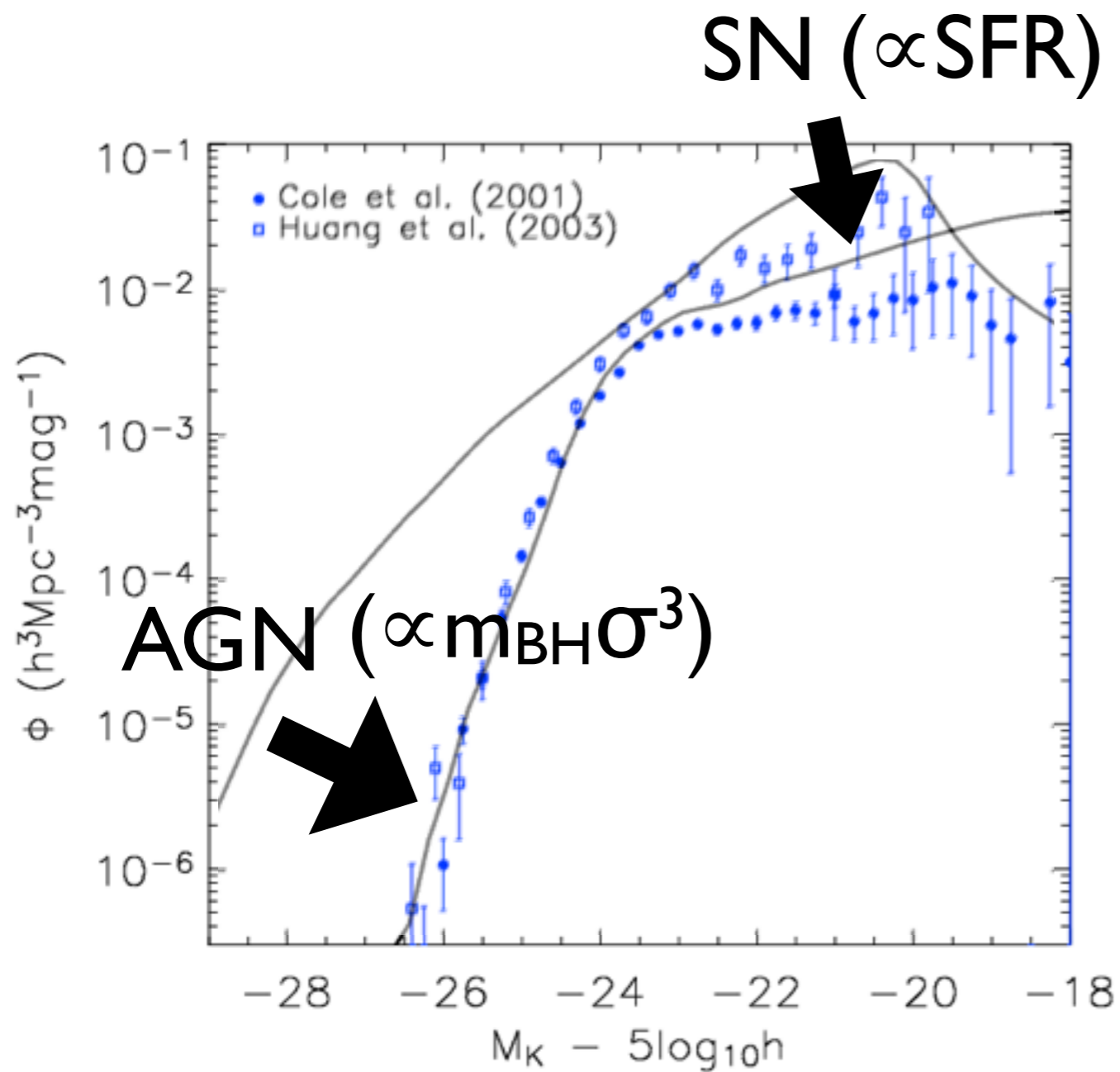
Baldry et al. 2005



(a)
Distribution of galaxies,
 $V_{\text{survey}}/V_{\text{max}}$ corrected,
density contours on a log scale.

-SDSS-

Physical consequences



Let's now look at some code...

CODE:

git clone <https://github.com/darrencroton/sage.git>

TREE FILES:

<http://supercomputing.swin.edu.au/data-sharing-cluster/mini-millennium-simulation/>