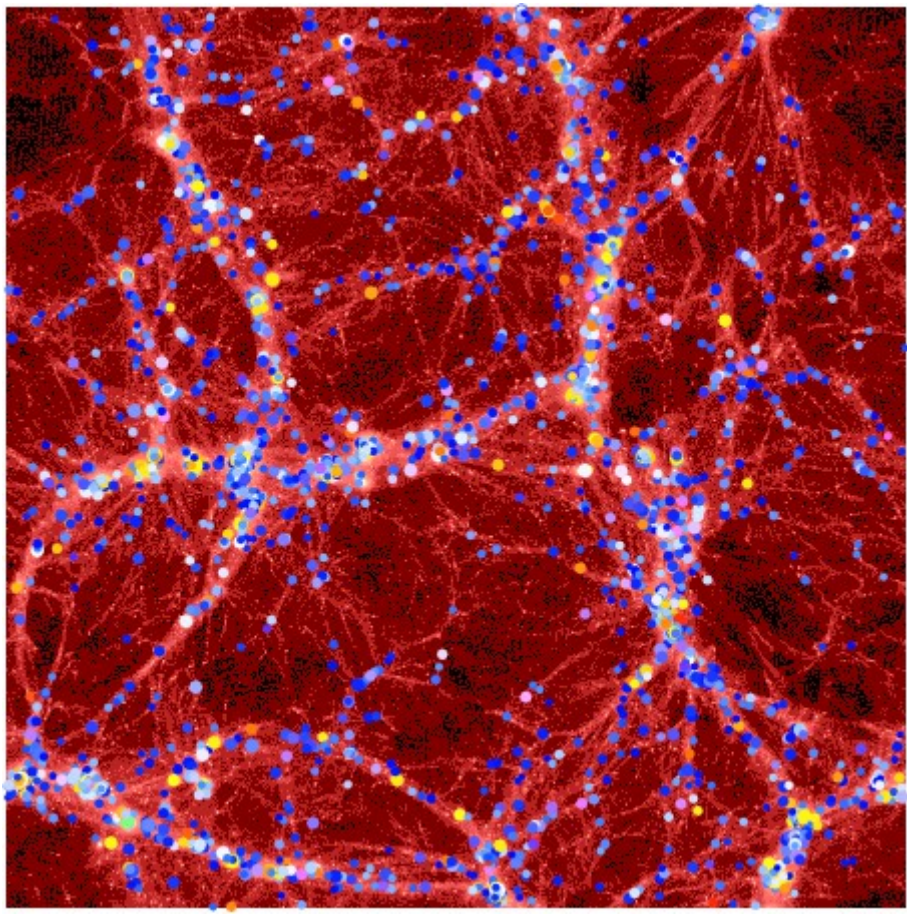
Prospects of the semi-analytic model of galaxy formation

masahiro@nagasaki-u.ac.jp

Masahiro Nagashima (Nagasaki U)
with M. Enoki, M.A.R. Kobayashi & T. Ishiyama

results and prospects of
out semi-analytic model of
galaxy formation

bulge formation – pseudo-bulge
and supermassive black holes



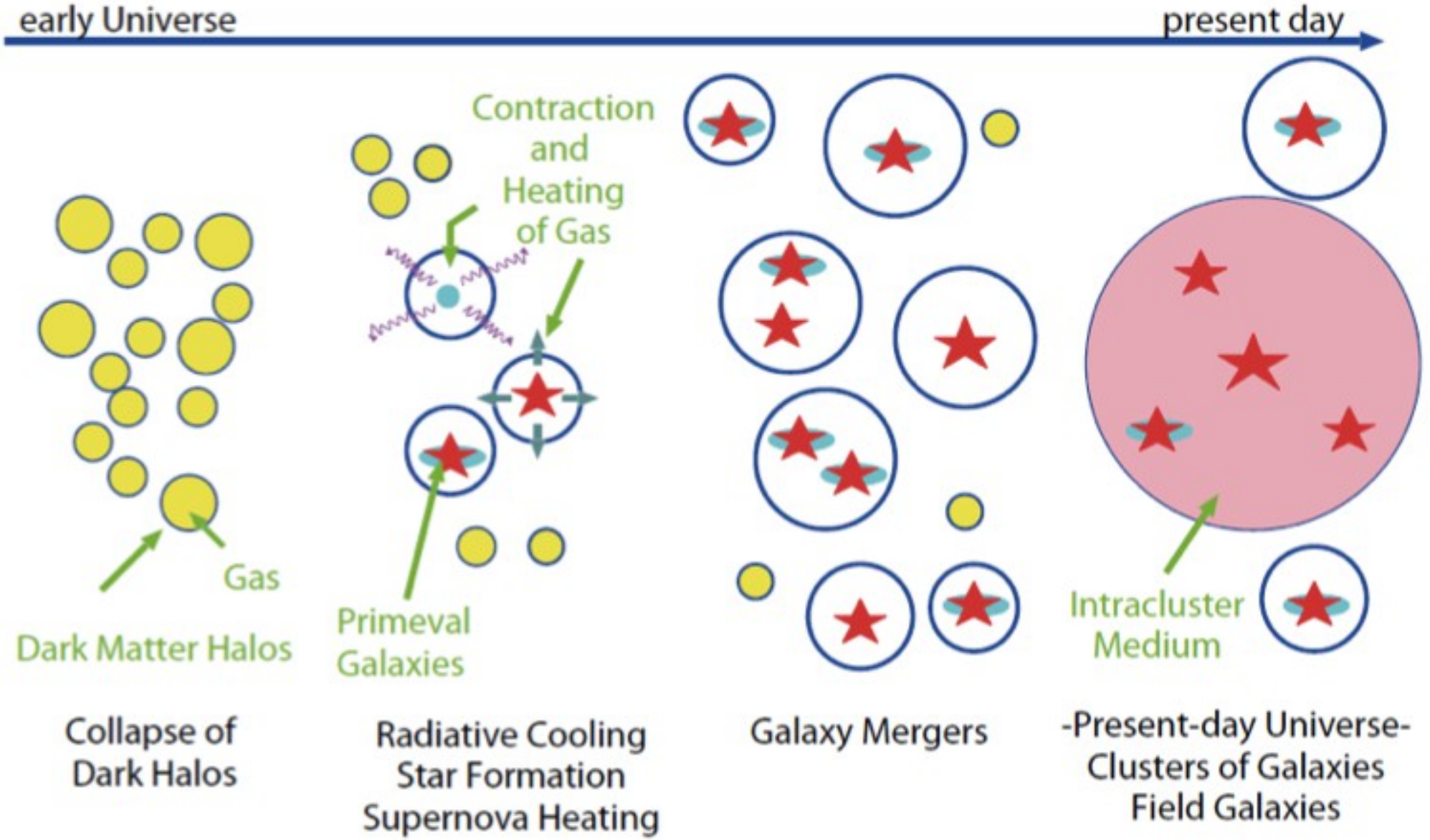
Numerical Galaxy Catalog

blue: dark matter
white: galaxies created by using a semi-analytic model of galaxy formation, "νGC (numerical galaxy catalog)" (Nagashima et al. 2005)

L=100Mpc box

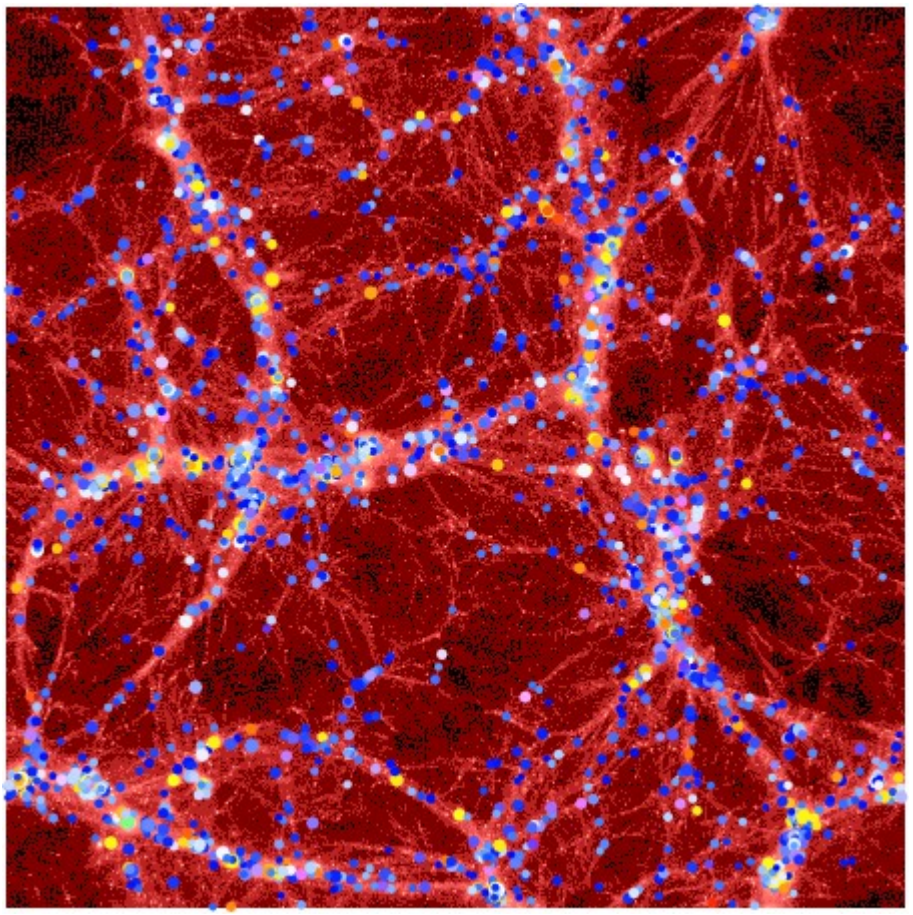
→see http://4d2u.nao.ac.jp/t/var/download/index.php?id=lss2

Galaxy Formation in the Hierarchical Clustering Scenario



Why SA models?

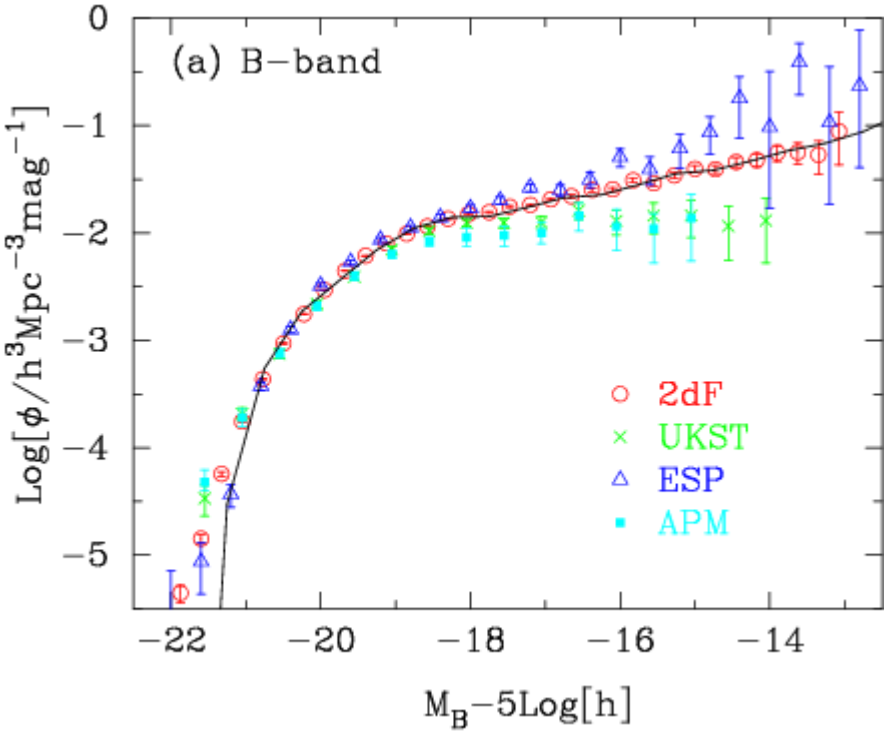
- Many galaxies can be realized
  - ~10^5 galaxies with $\phi \sim 10^{-1}h^3/Mpc^3$ in 100Mpc/h box
  - QSO's ϕ is much smaller than that of galaxies – need much larger boxes
  - direct comparison with observations: constructing mock catalogs
- High speed computation: we can run many models in wide parameter space
  - we can get physical understanding
- SA models have revealed that ΛCDM is not inconsistent with many observations
  - luminosity functions, amount of gas, two-point correlations, etc.
  - ways growing S/E galaxies based on hierarchical clustering scenario

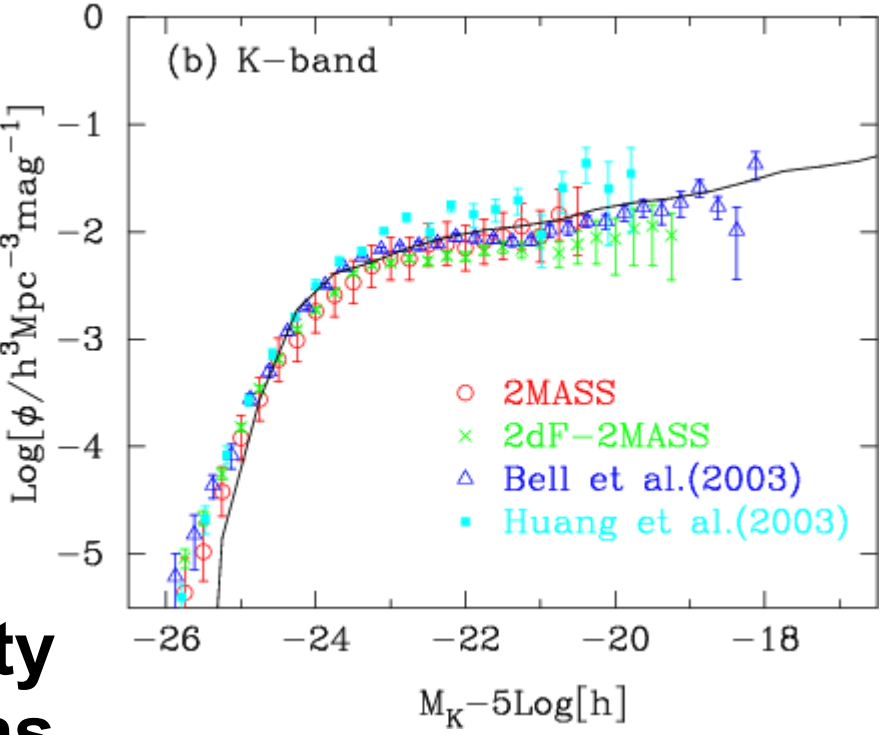


distributions of dark matter and galaxies

red scale: dark matter density

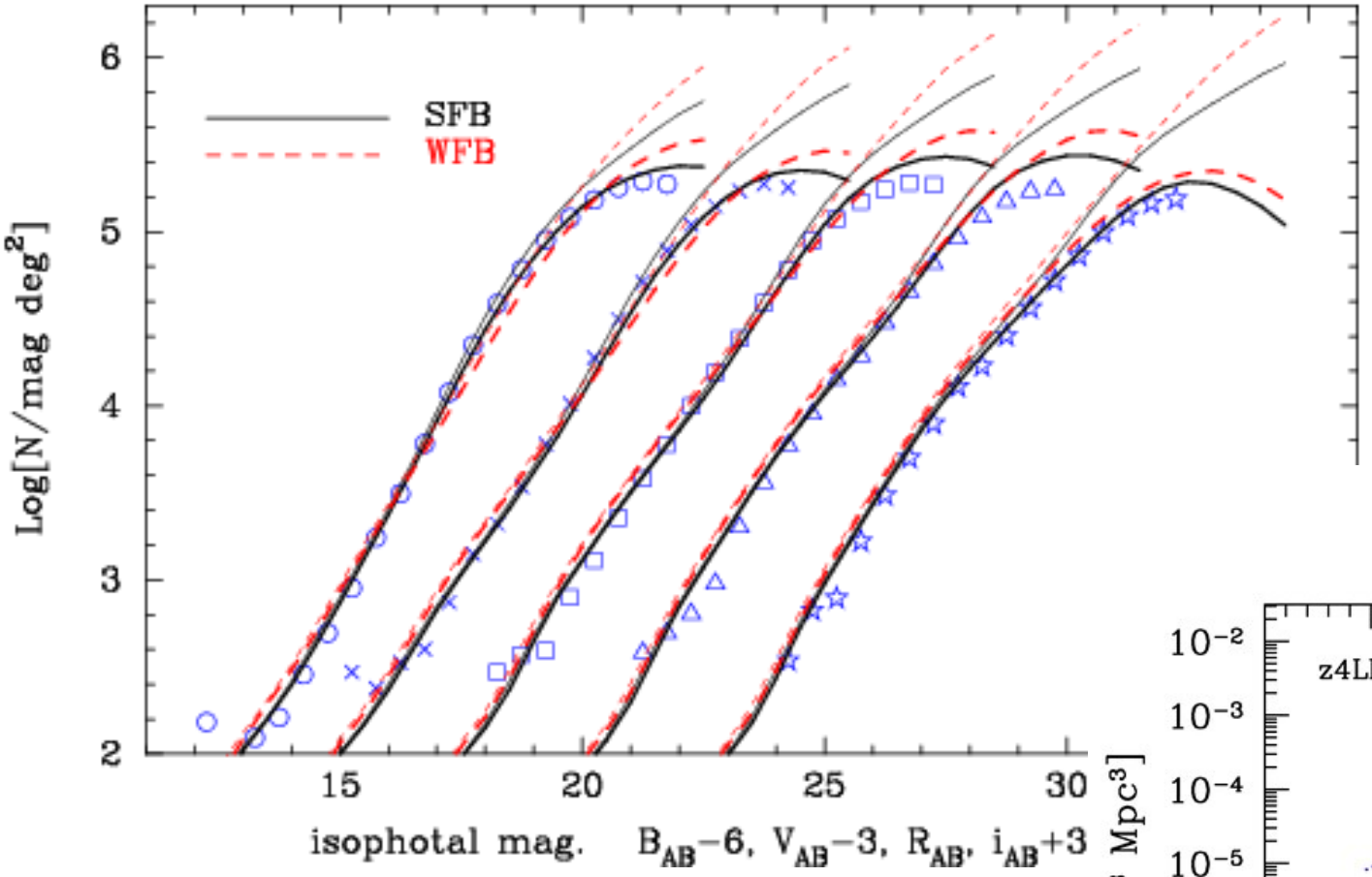
color circles: galaxies



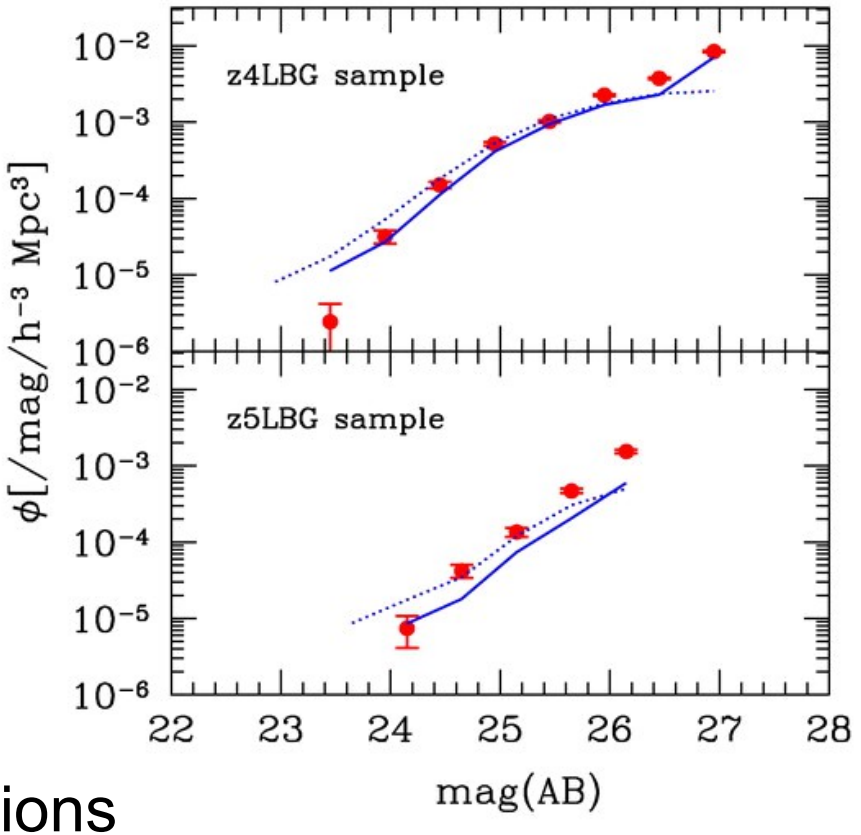


luminosity functions

Nagashima et al.(2005)



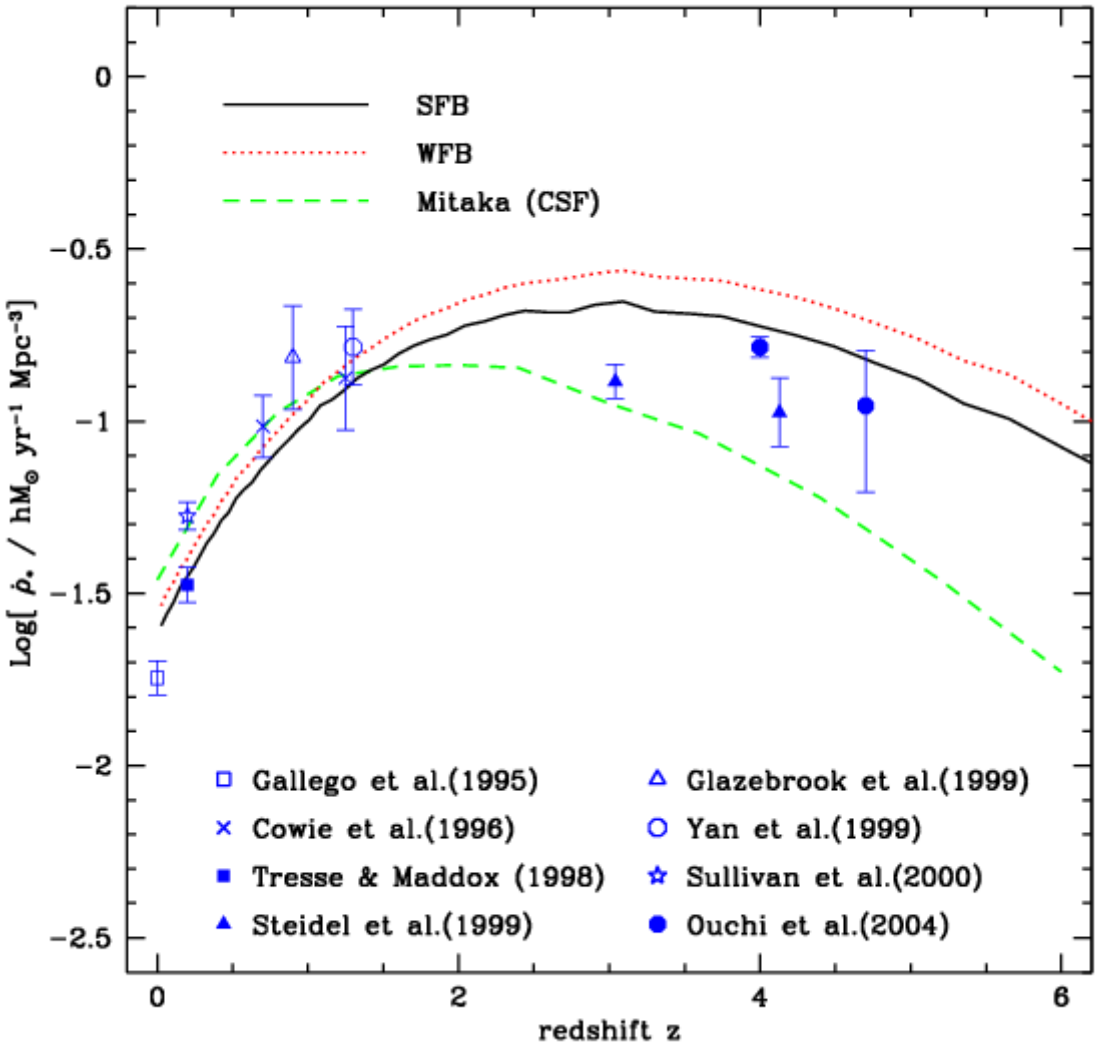
galaxy numver counts
compared with Subaru Deep Field
Nagashima et al.(2005)



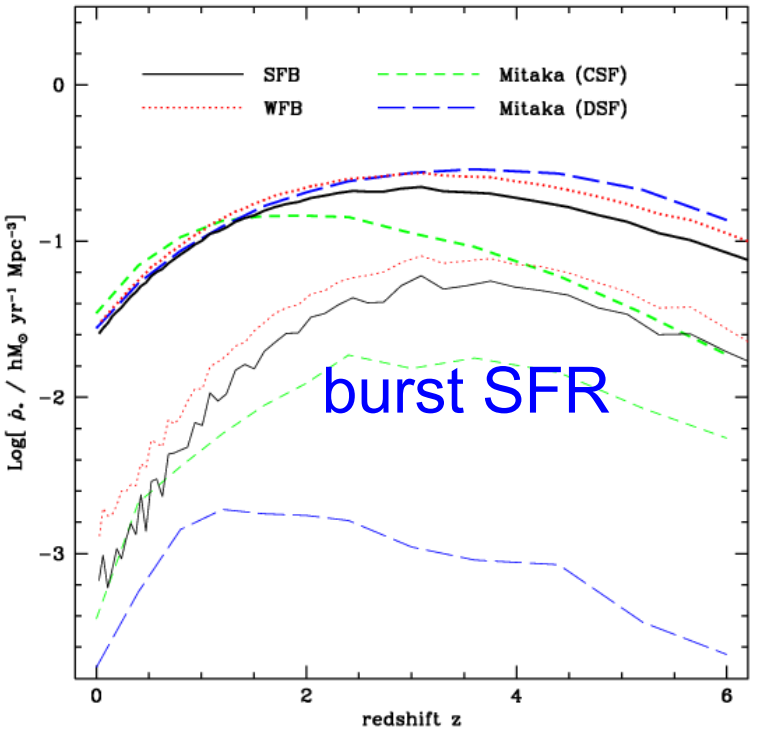
LBG luminosity functions
within Subaru Deep Field

Kashikawa et al.(2006)

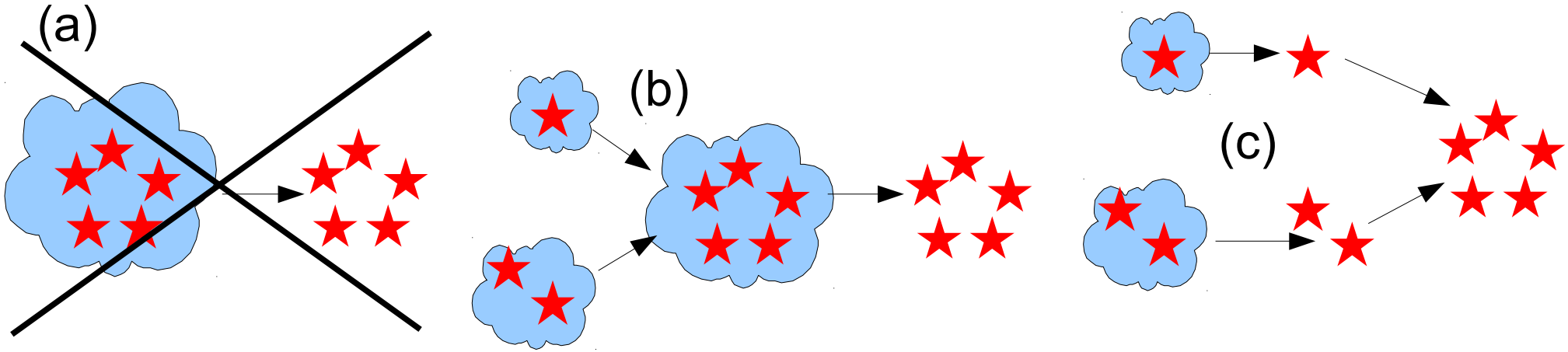
Cosmic Star Formation History



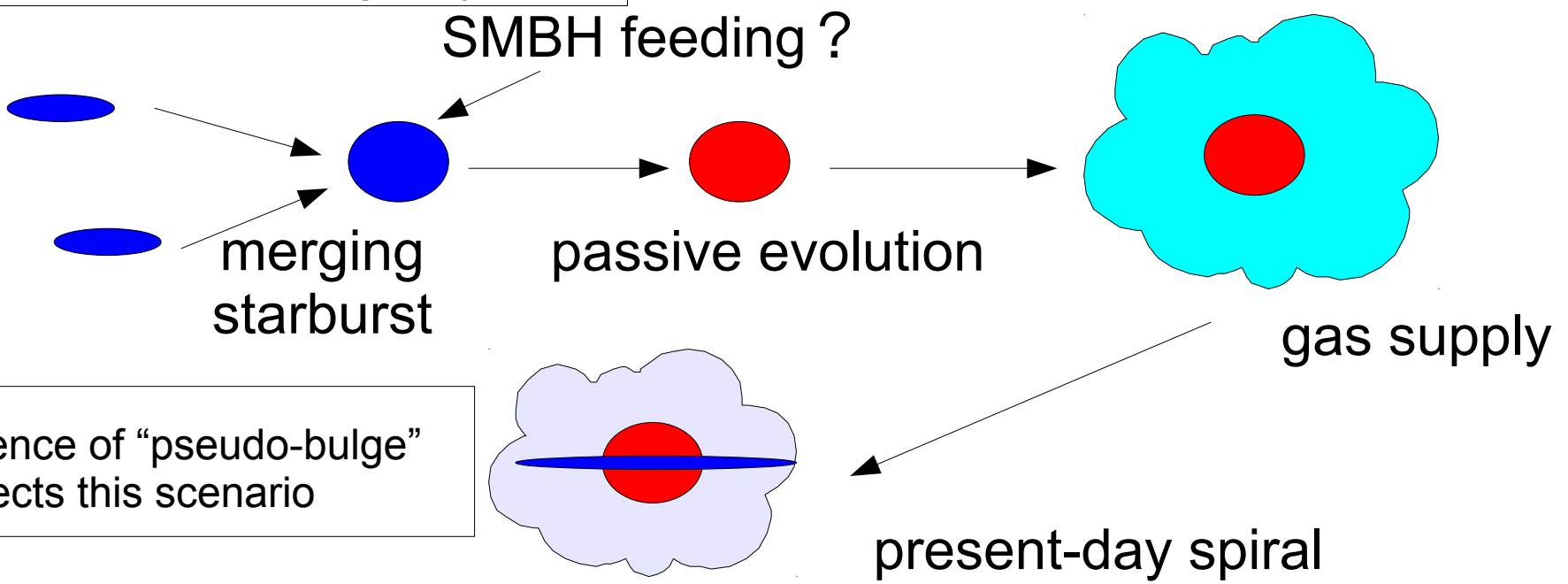
Nagashima, Yahagi, Enoki, Yoshii & Gouda (2005)



Elliptials: (b) and (c) are favourable, and (a) should be impossible because such large clouds cannot collapse at high redshift



Spirals: disk+bulge system



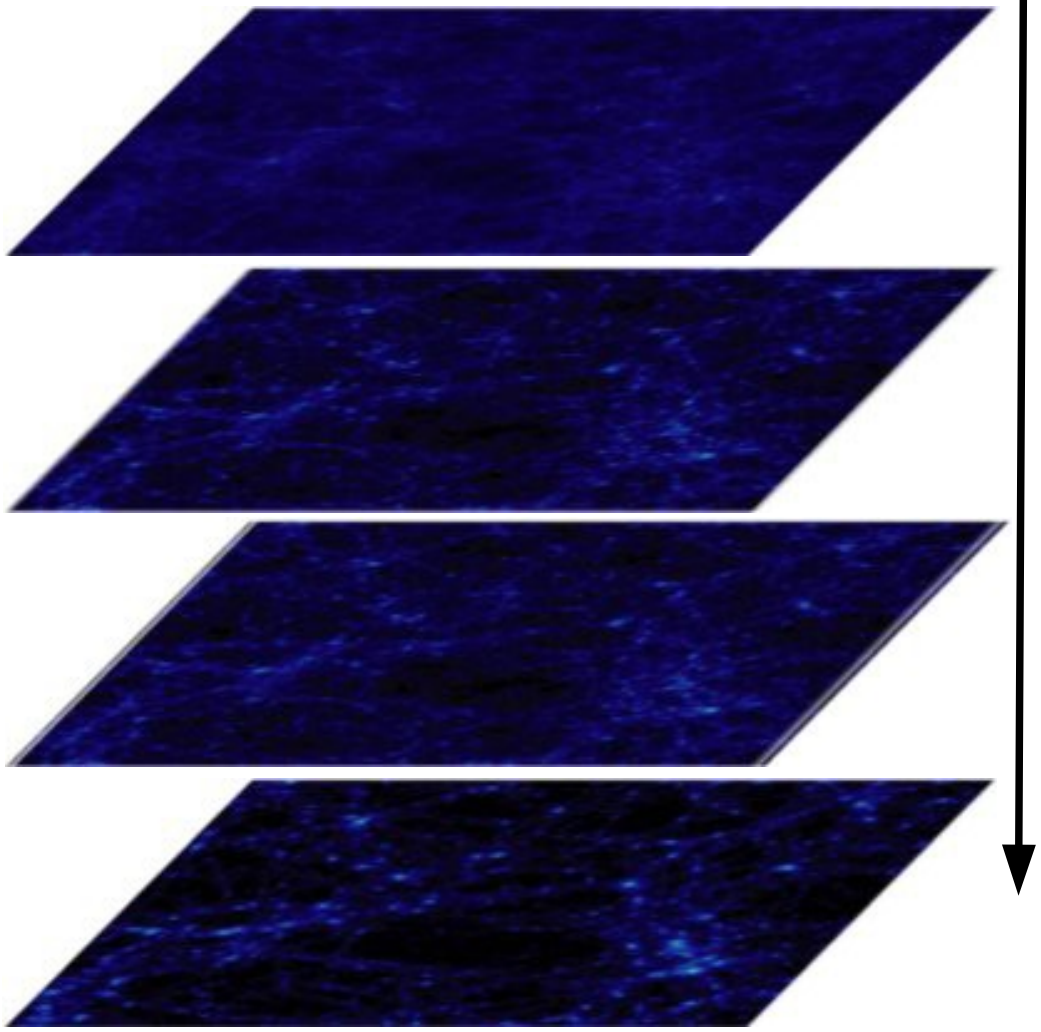
existence of “pseudo-bulge” suspects this scenario

Future Plan for N-body sim.

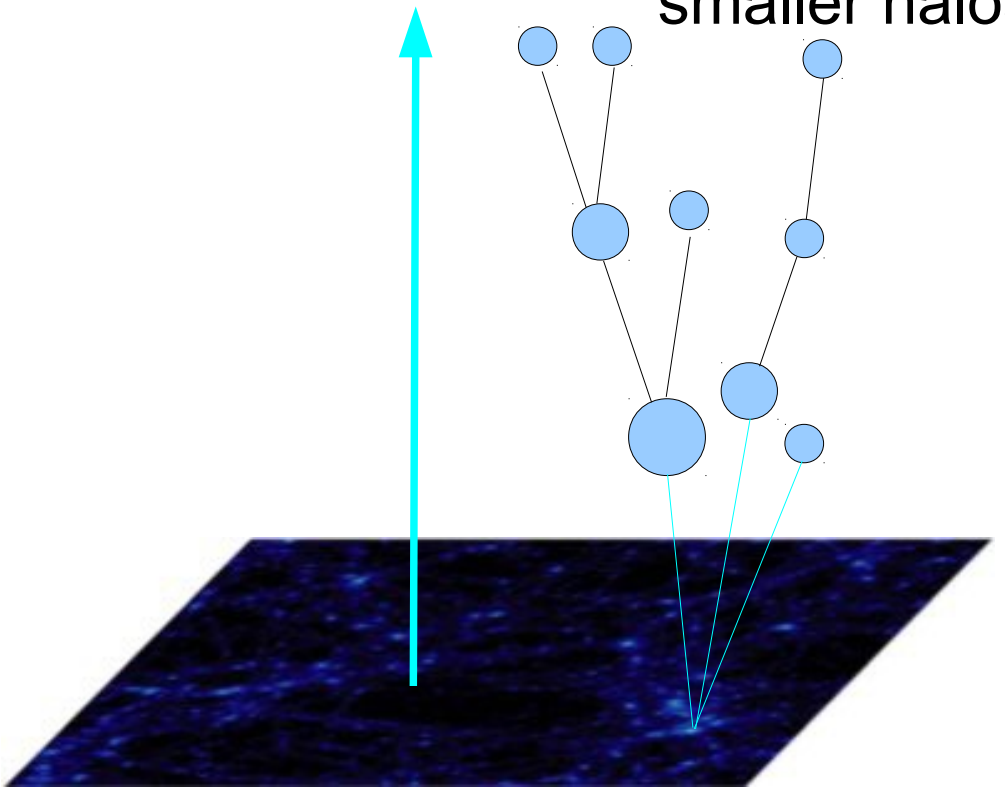
- published version (Yahagi):
  - $N=512^3$, $m_p=3\times10^8$Msun, L=70Mpc/h (140Mpc/h)
- current version (Ishiyama):
  - $N=2048^3$, $m_p=3\times10^8$Msun, L=280Mpc/h
  - Volume: $4^3=64$ times、QSO/AGN OK (it should be difficult to say something about spatial distribution)
- future prospects (Ishiyama): → Enoki's talk
  - L=560Mpc/h box
    - larger (8 times) volume, worse resolution
    - getting positions of halos at output redshift from N-body results, and using Extended Press-Schechter model, follow merging histories → hybrid model
  - Use of "K" computer (2013? ~ 2016?)
    - enables $N=4096^3$、8192^3 calculation

Image of hybrid model

N-body snapshots



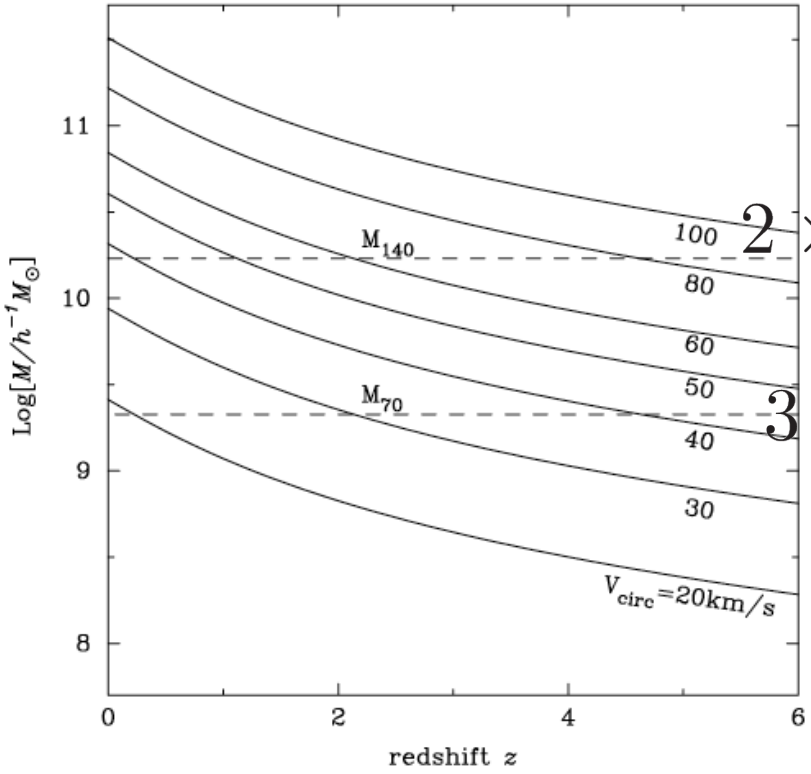
By using Extended Press-Schechter model, merging histories are constructed



low res., large box N-body sim.

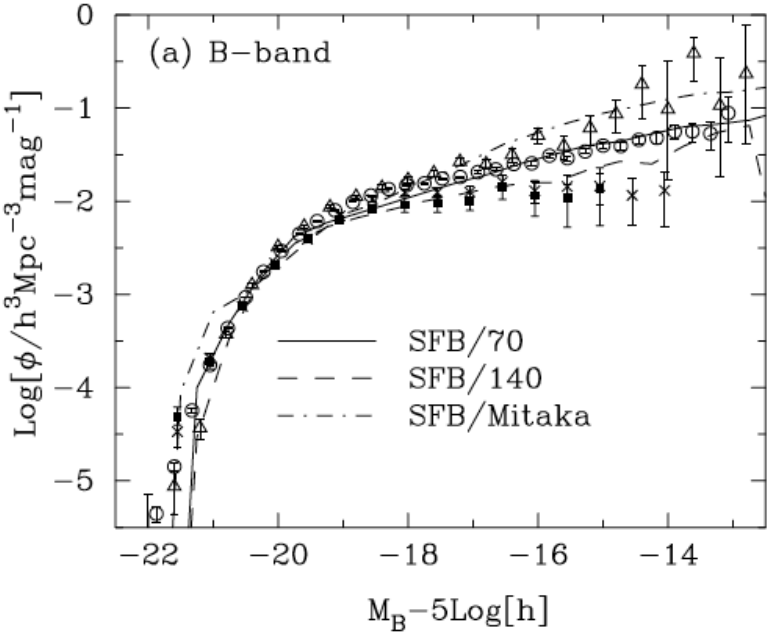
Resolution is matter

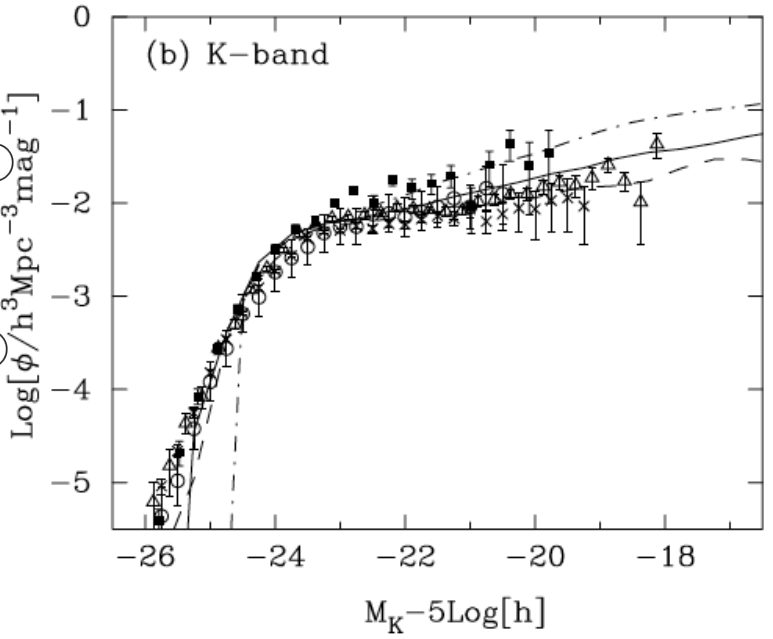
- Results depend on the minimum mass of halos: 3×10^{9}Msun vs 2×10^{10}Msun
- need resolve Jeans mass at z～2-3



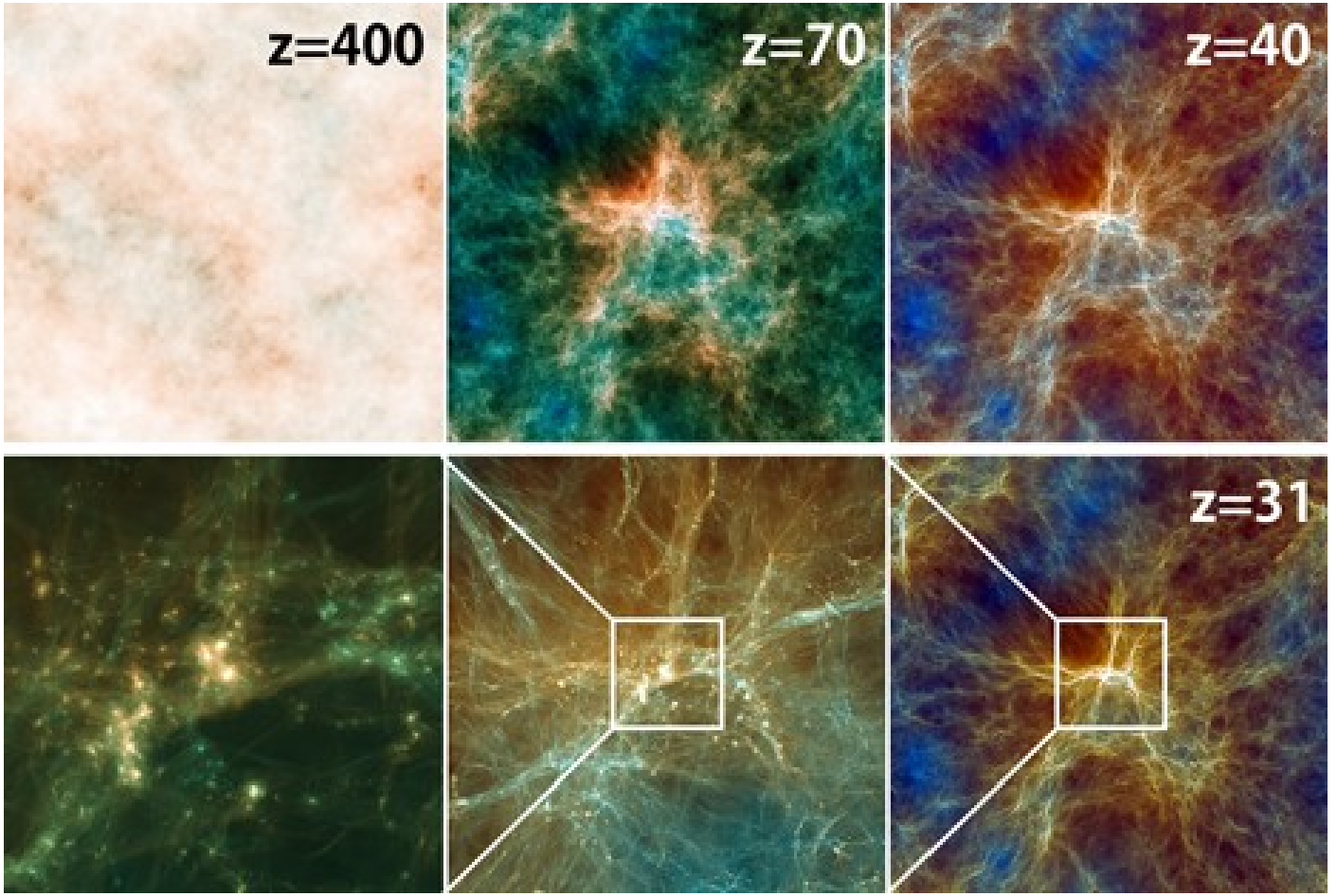
$2\times10^{10}M_{\odot}$

$3\times10^{9}M_{\odot}$





Gordon Bell Prize for “K” comp.



N=10740^3
Ishiyama, NItadori and Makino

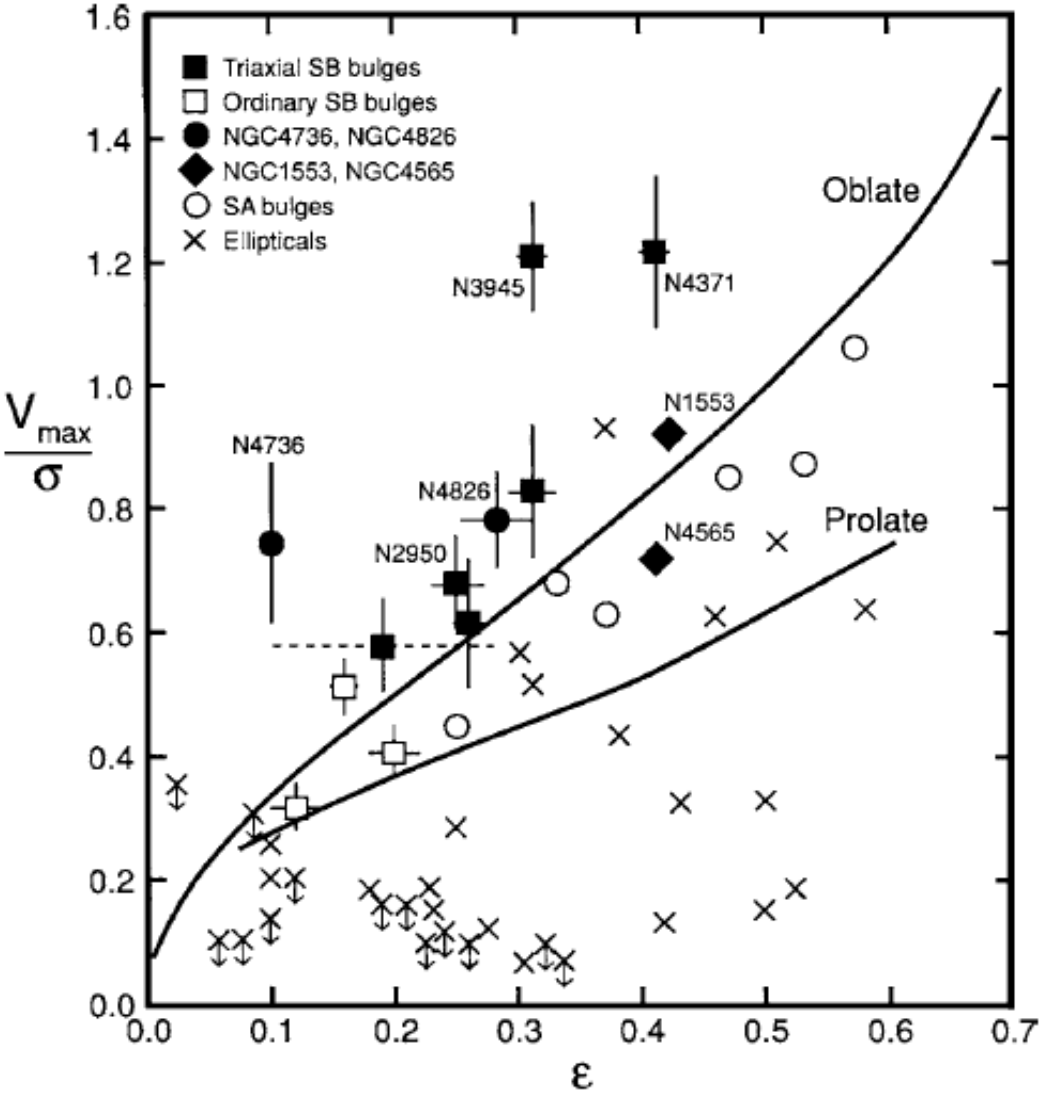
http://www.ccs.tsukuba.ac.jp/CCS/pr/media/gordonbell121116

Next Generation SA model

- $N=8192^3$ calculation enabes us:-
  - L=1120Mpc/h > 1Gpc/h !
  - to get 10^3 rare objects with $\phi \sim 10^{-6} h^3/Mpc^3$
    - spatial distribution can be discussed (2-point corr. fn.)
  - For L=70Mpc/h box, the minimum halo mass is down to $\sim 10^6 Msun$
    - we can attack galaxy formation BEFORE reionization
- It will finish by 2015-2016?
  - $N=4096^3$ calculation will finish by the end of 2013

Pseudo-bulge?

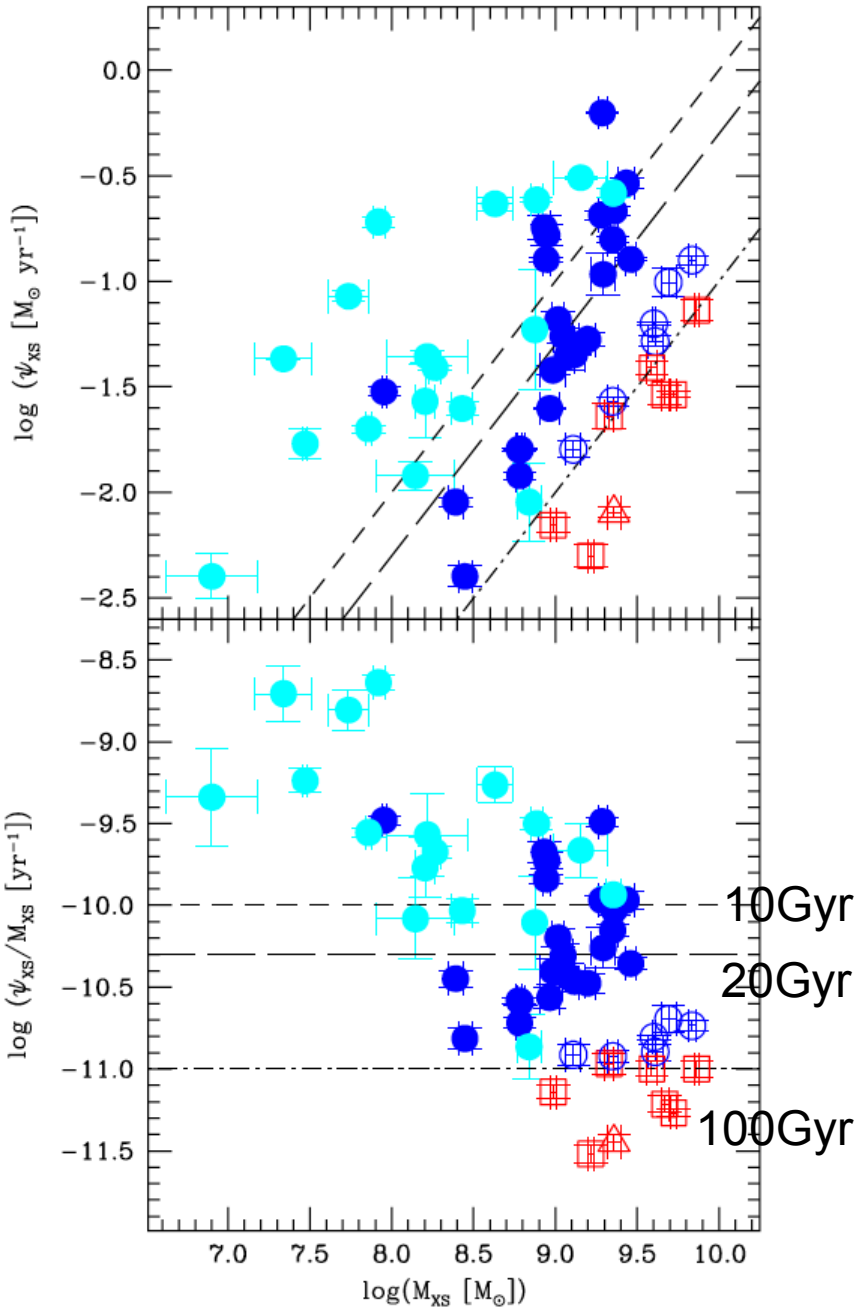
- some (most?) bulges seem to rotate
  - ↔ classical bulges
- it seems not to explain it by the major merger scenario
- "secular" evolution or disk instability may explain it? ⋯ rotating gas/stars in disks fall onto bulges, then bulges acquire anglar momenta



Kormendy & Kennicutt (2004)

Observations

- classical bulges have low SFR, and pseudo-bulges high.
- active pseudo-bulges have high SFRs, $M^*/\psi < 1/H \sim 10\mathrm{Gyr}$
  - secular evolution?
- inactive pseudo-bulges and classical bulges seem to stop SF activity at high z … starburst at high z?

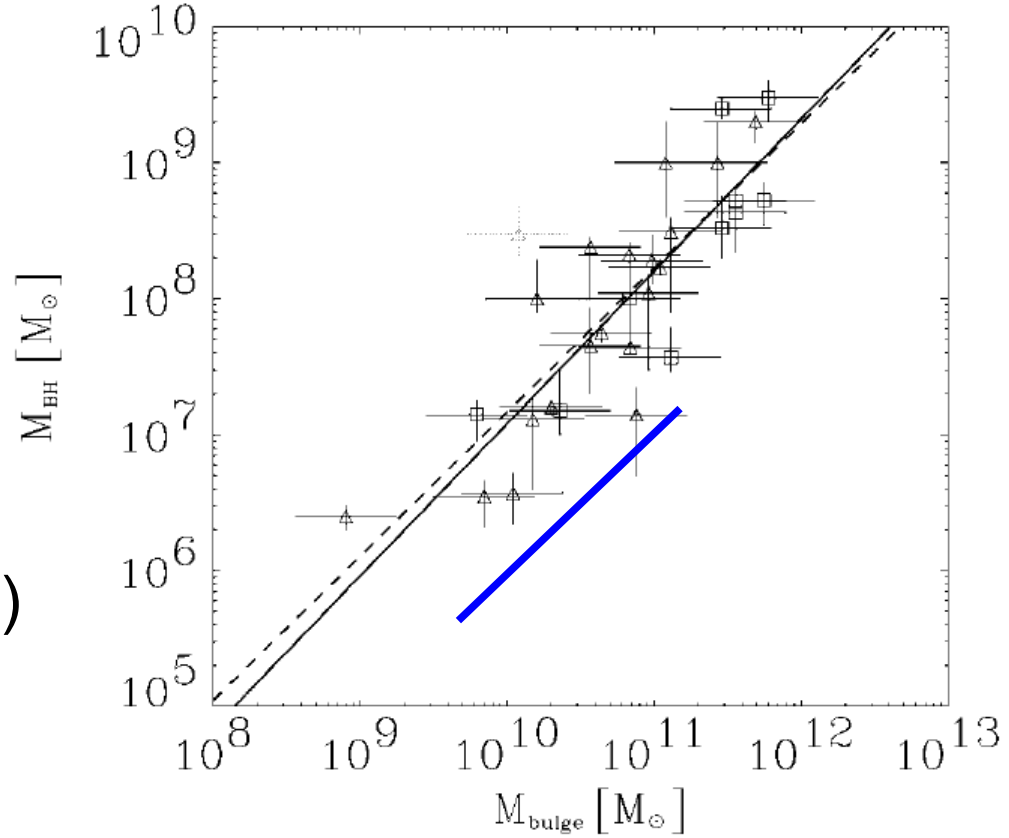


Fisher et al. (2009)

Gas accretion onto SMBHs

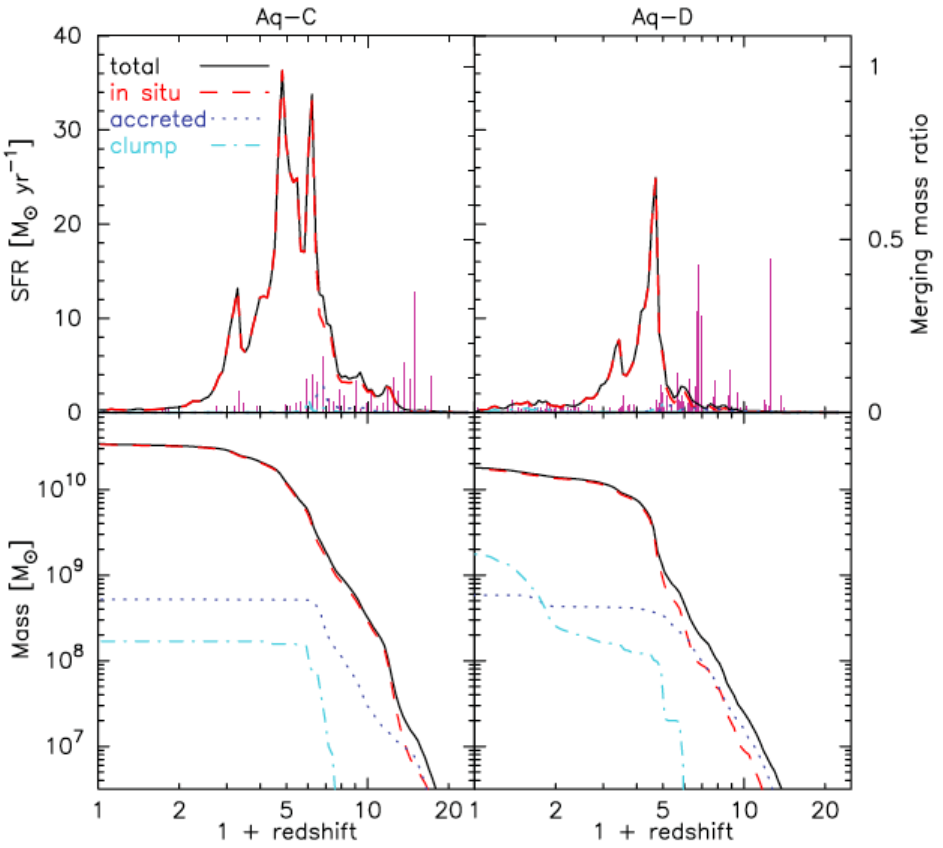
- gas accretes onto SMBH during major merger
  - the details will be shown in Enoki's talk
- if pseudo-bulges are formed via secular evolution?
  - it seems difficult for gas to accrete onto SMBHs
- M_{bulge}-M_{BH} relation must deviate for pseudo-bulge?

Häring & Rix (2004)



“initial” star burst for bulge?

- high-res. numerical simulations suggest that spirals at z=0 have experienced starburst making bulges at high z, which is NOT caused by major mergers – just like “initial starburst”
- Much gas having low angular momentum accretes and causes starburst
- the predicted SFRs are consistent with those of observed inactive pseudobulges



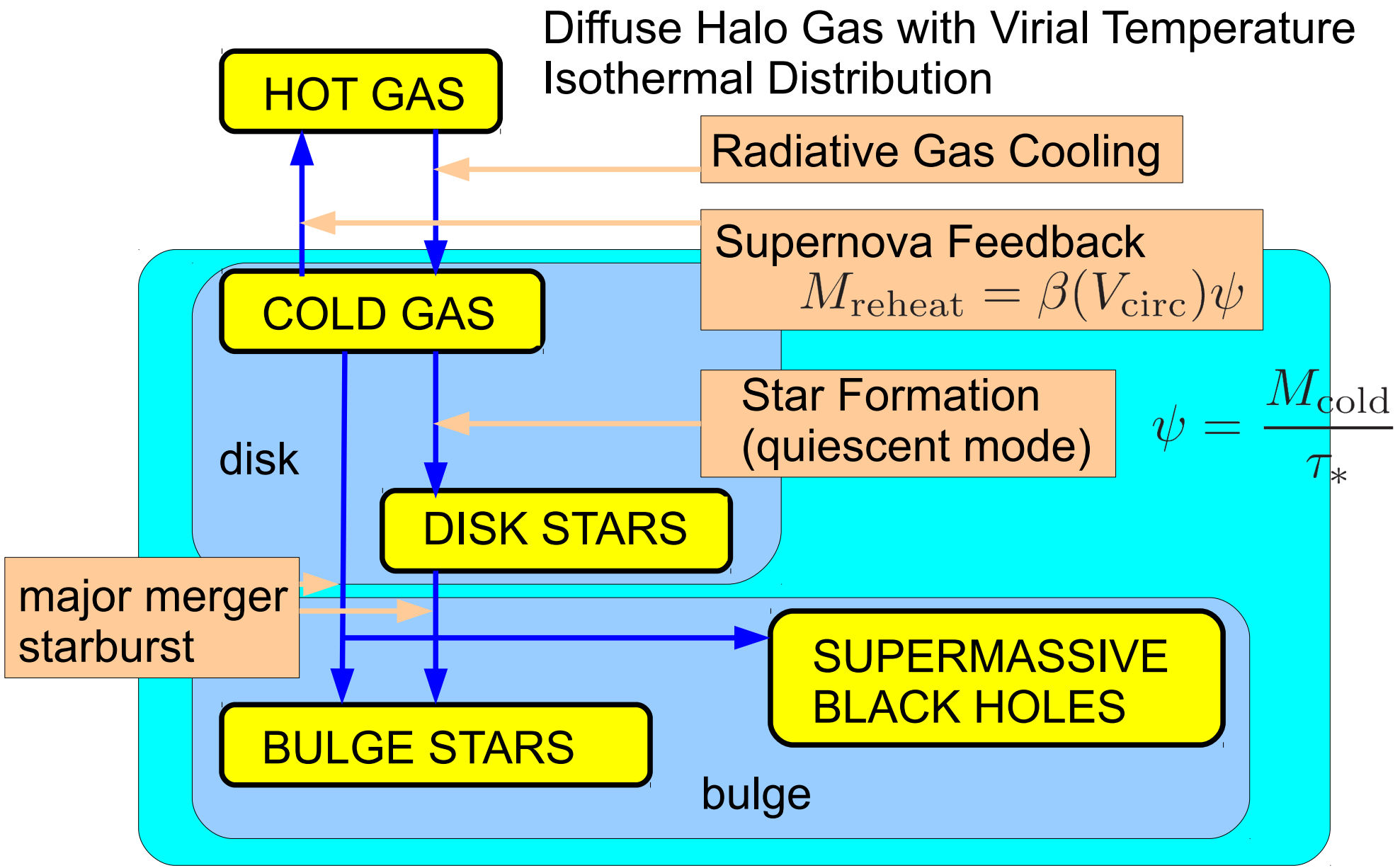
Okamoto (2012)

Can it make SMBHs?

Summary

- Next generation SA models will enable us to handle many QSO/AGNs enough to estimate QSO auto-correlation functions
  - utilizing “K” computer
- Bulge formation processes must be reconsidered – what can we learn from the HSC survey?

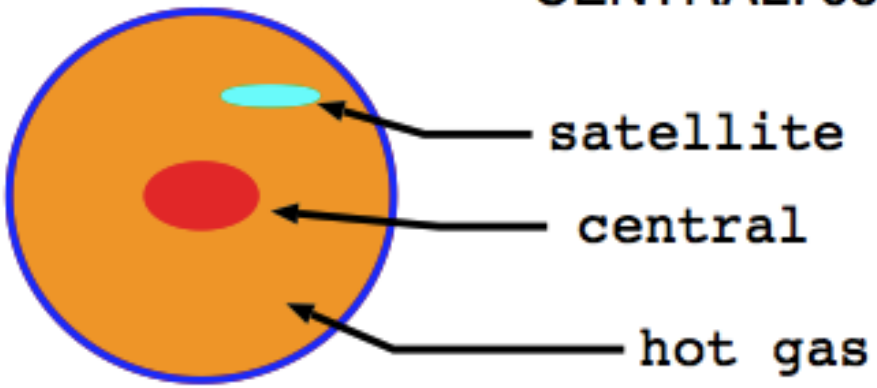
Evolutionary Cycle of Baryons



When dark halos merge:

- Hot gas components merge immediately
- Dividing galaxies into CENTRAL and SATELLITES

CENTRAL: central galaxy in the most massive progenito



Criteria of galaxy mergers:

$t_{elapse} > t_{fric}$ (dynamical friction time-scale) satellite-central merger

$\Delta t > t_{coll}$ (random collision) satellite-satellite merger

Types of mergers:

Merger of similar mass galaxies: STARBURST + BULGE FORMATION (MAJOR MERGER)

Otherwise: Smaller galaxy is incorporated into disk of larger galaxy (MINOR MERGER)