「 研究会「すばるHSCサーベイによるサイエンス」　2012.9.26-28

銀河・AGN形成に関する理論的課題

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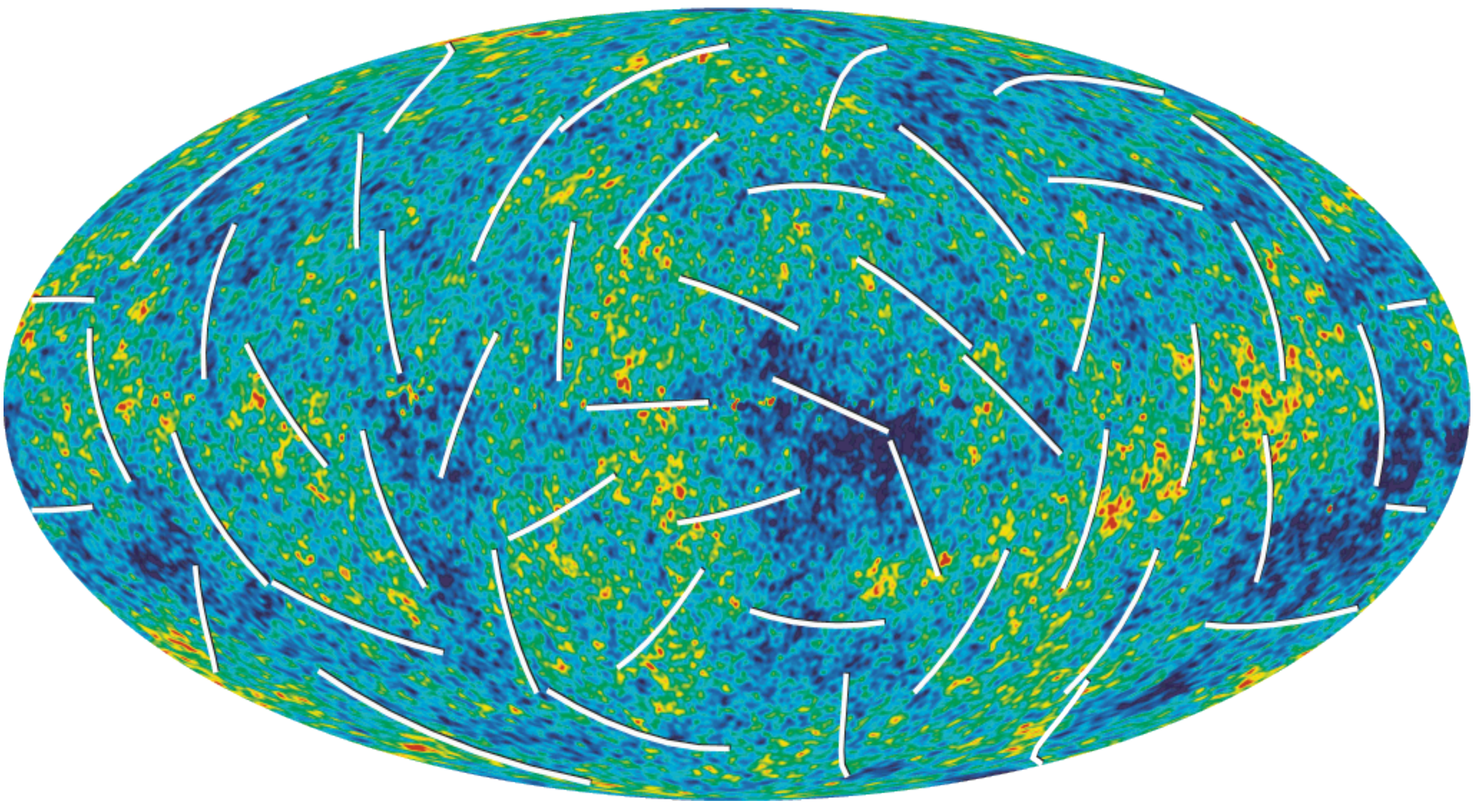
Cosmic Reionization

Missing light Problem
(電離源はどこに)

WMAP 7 Year

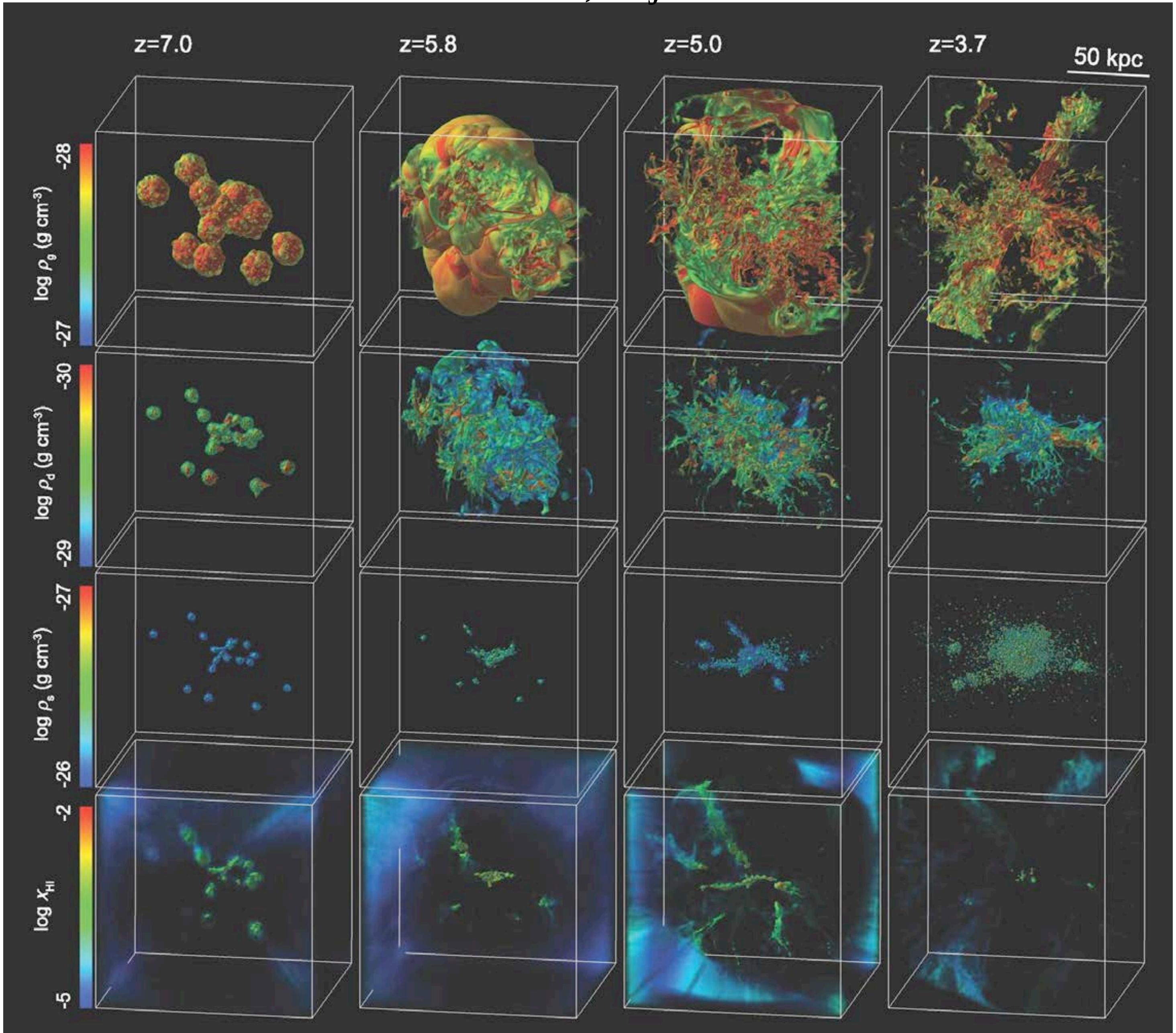
$$\tau_e = 0.087 \pm 0.0014$$

$$z_{reion} = 10.4 \pm 1.2$$



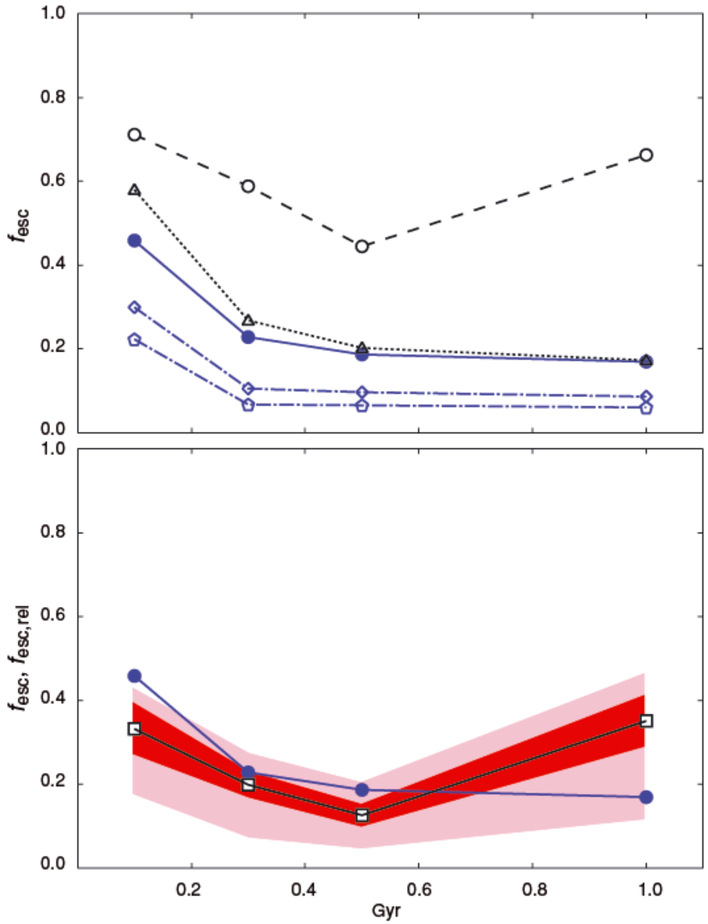
Radiation Transfer of Ionizing Photons in a Primordial Galaxy

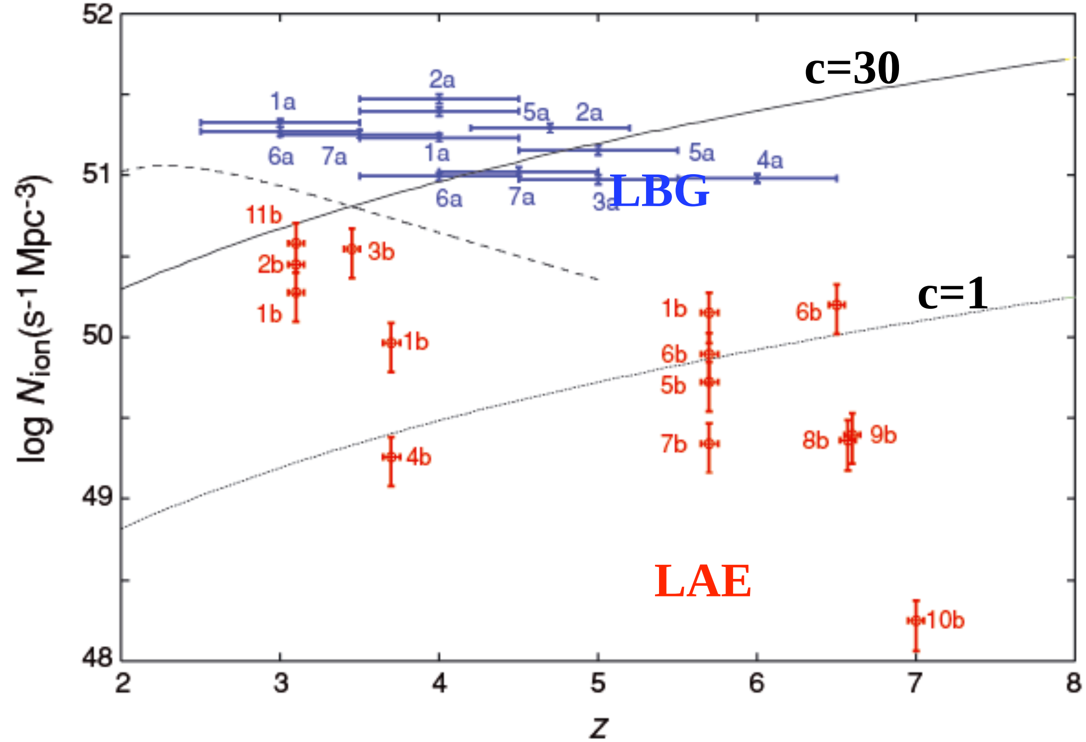
Mori & Umemura 2006, Yajima et al. 2009



LAE + LBG でも
z>6 の電離源が足りない！

Escape fraction of ionizing photons





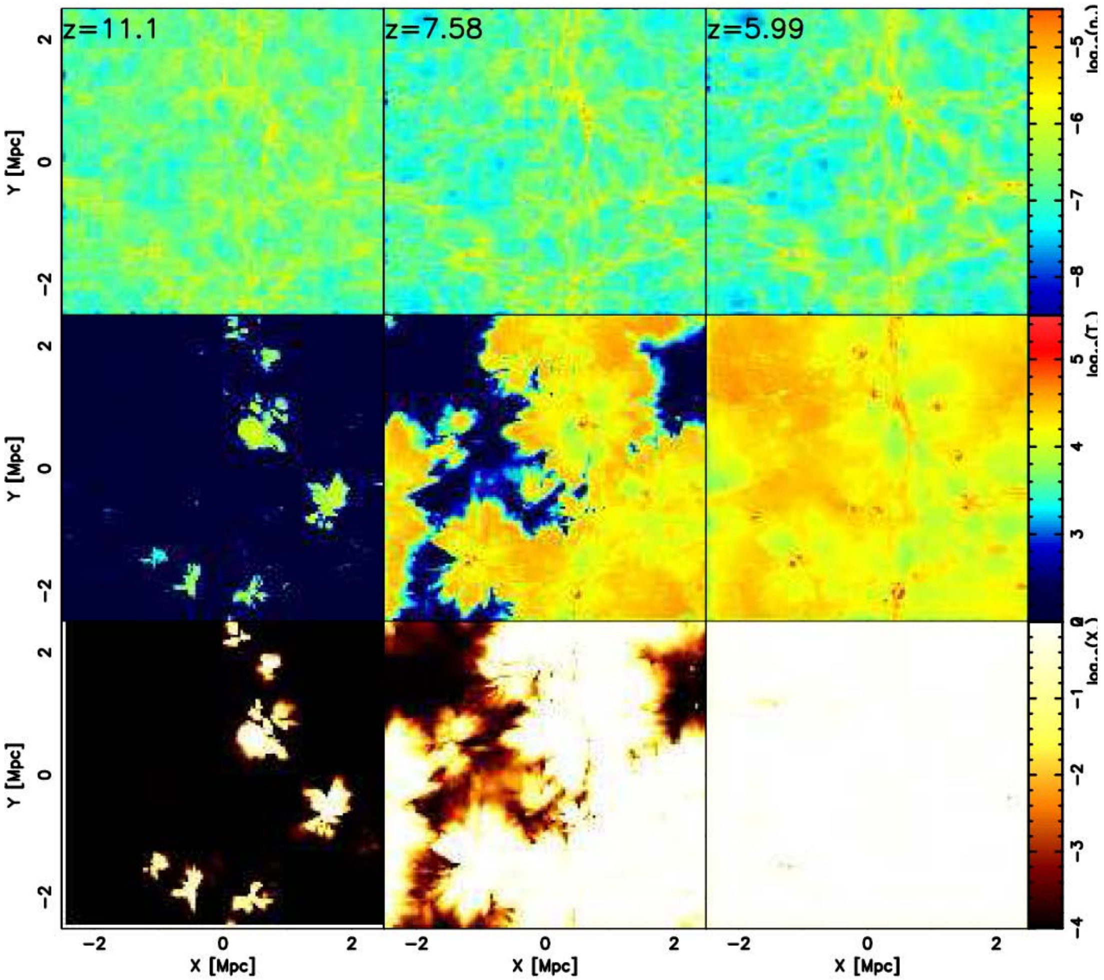
Yajima et al. 2009, MNRAS, 398, 715

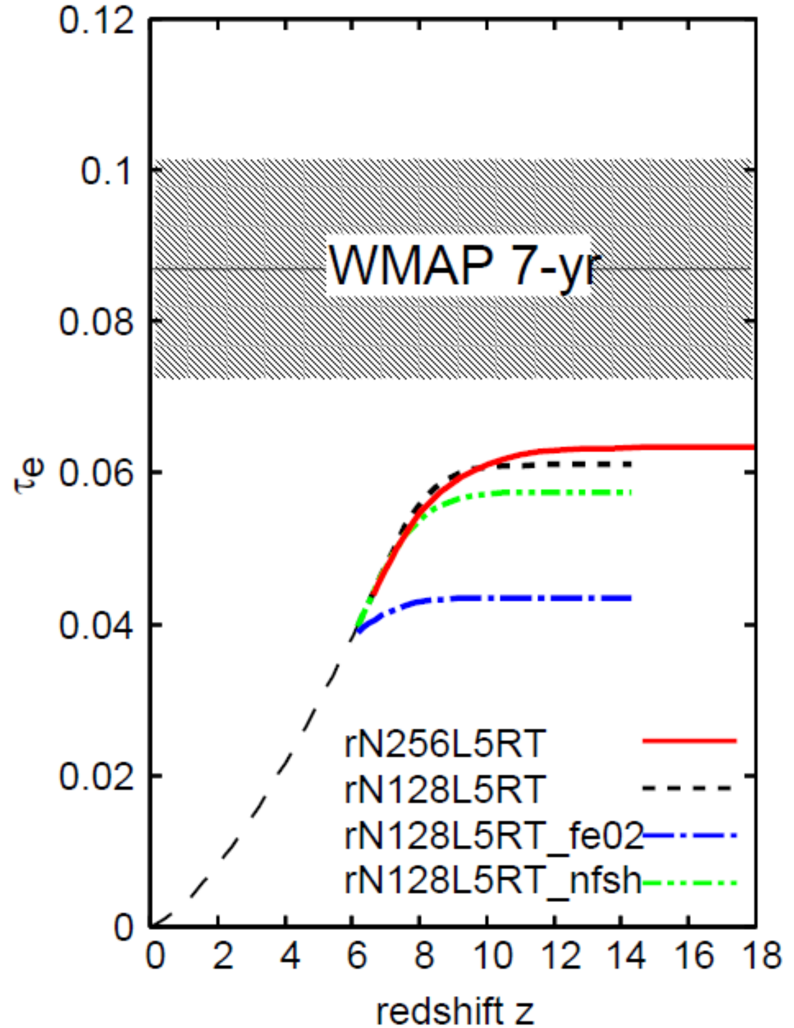
Figure 4. The evolution of emission rate of ionizing photons per comoving Mpc, $\dot{N}_{ion}$, as a function of redshift. The blue filled symbols represent the $\dot{N}_{ion}$ of LBGs derived from (1a) Steidel et al. (1999), (2a) Yoshida et al. (2006), (3a) Iwata et al. (2003), (4a) Bouwens et al. (2006), (5a) Ouchi et al. (2004), (6a) Sawicki & Thompson (2006) and (7a) Gabasch et al. (2004) with $\langle f_{esc} \rangle = 0.18$ which is the mean escape fraction at LBG phase. Open red symbols represent $\dot{N}_{ion}$ of LAEs derived from (1b) Ouchi et al. (2008), (2b) Kudritzki et al. (2000), (3b) van Breukelen, Jarvis & Venemans (2005), (4b) Fujita et al. (2003), (5b) Ajiki et al. (2003), (6b) Malhotra & Rhoads (2004), (7b) Rhoads et al. (2003), (8b) Kodaira et al. (2003), (9b) Taniguchi et al. (2005), (10b) Iye et al. (2006) and (11b) Gronwall et al. (2007) with $\langle f_{esc} \rangle = 0.35$ which is mean escape fraction at LAE phase. The horizontal and vertical error bars arise from the uncertainty of observations and the variation of escape fractions (LAE: $f_{esc} = 0.22$–0.47, LBG: $f_{esc} = 0.17$–0.19), respectively. The solid and dotted lines indicate the emission rate required to ionize the IGM with $C = 30$ and $C = 1$, respectively (Madau et al. 1999). The dashed line represents the emission rate evaluated by the QSO luminosity function shown in Madau et al. (1999).

Full RHD (Radiation Hydrodynamics) Simulation

SPH + UV radiation transfer + SNs

Hasegawa & Semelin 2012, MNRAS, in press





電離源が足りない！

Galaxy Formation

❖ 銀河形態起源問題

1) Primordial Ellipticals (Bulges)
2) Primordial Disks

❖ 銀河形成シミュレーションの問題

1)角運動量問題

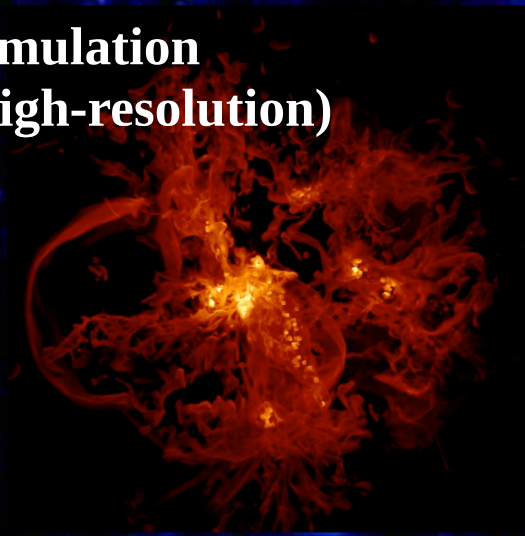
2)質量問題

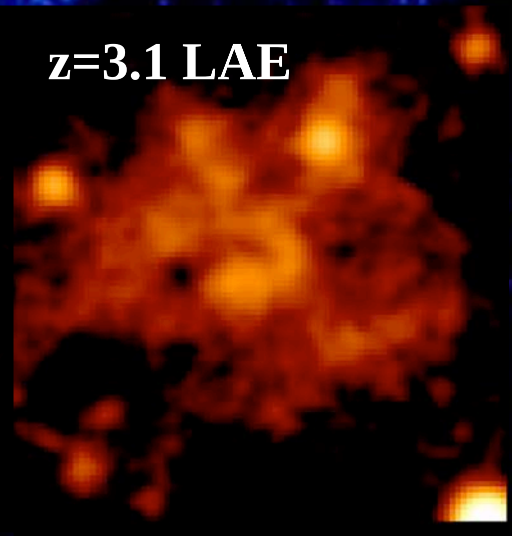
3) sub-clump (missing satellite) problem

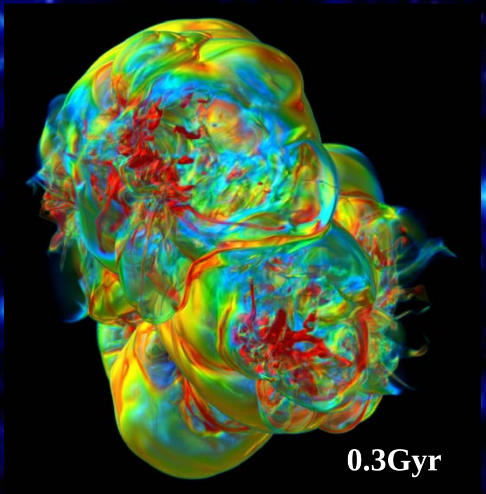
From Primeval Irregulars to Present-day Ellipticals

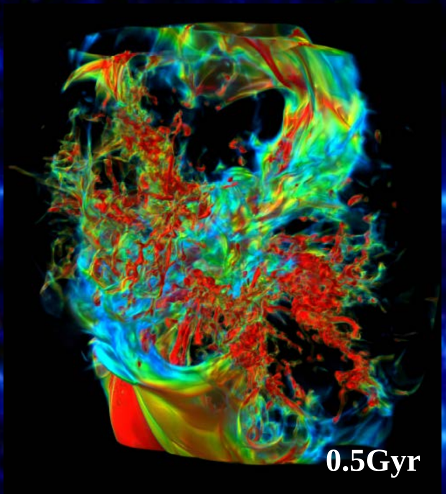
Mori and Umemura, 2006, Nature, 440, 644

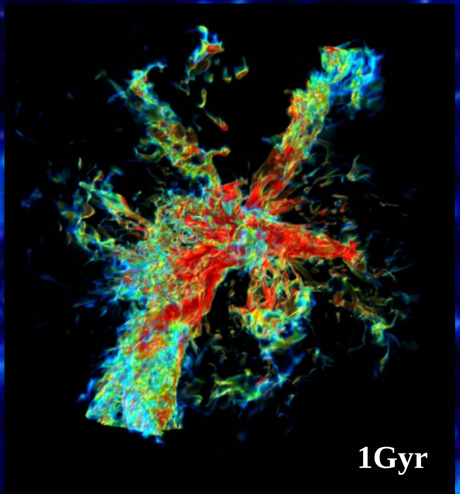
Total Mass: $10^{11}\ M_{\odot}$
Gas Mass: $1.3\times10^{10}\ M_{\odot}$
# of Subunits: 20
Box Size: 134 kpc
Grid Points: 1024^3

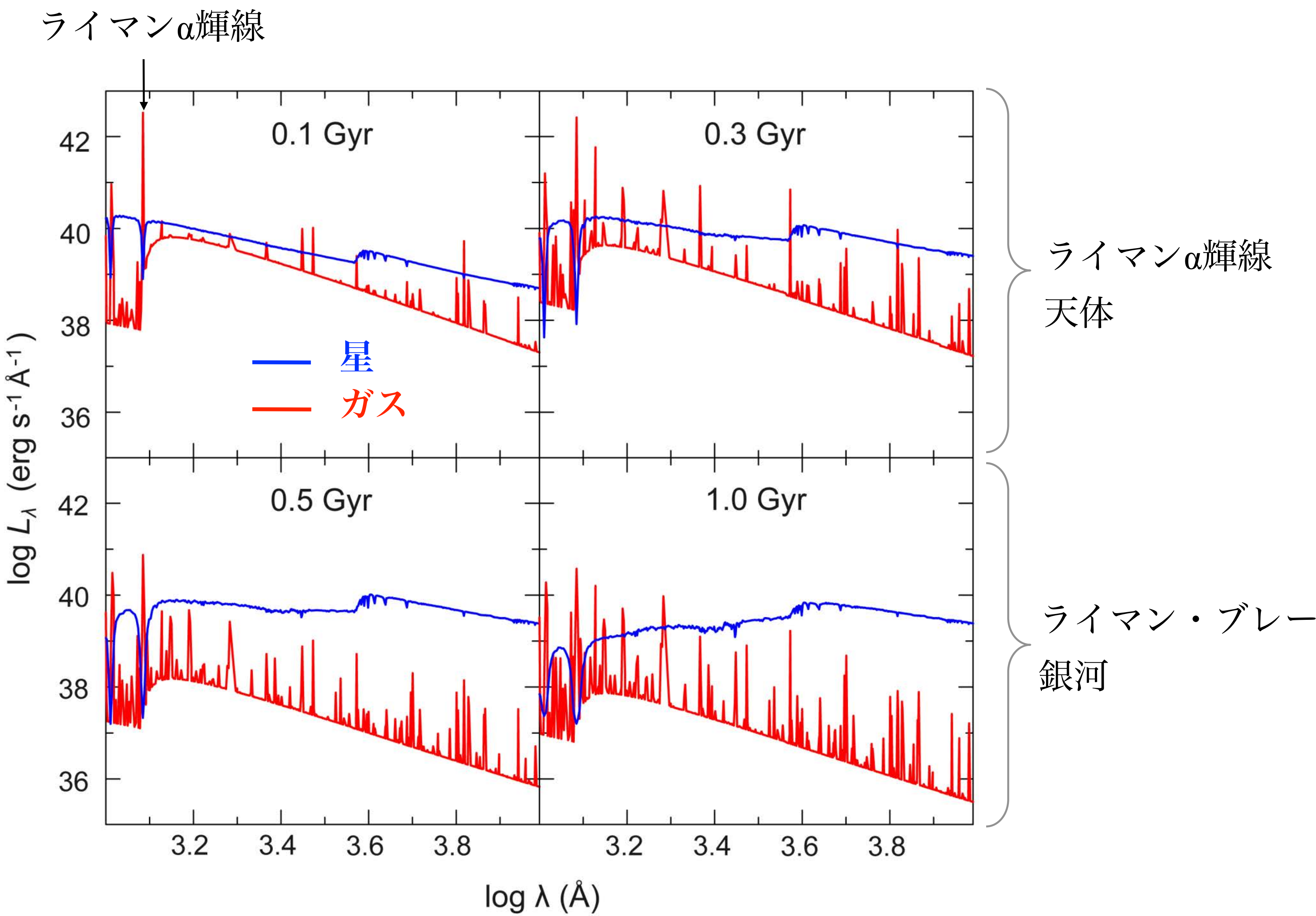




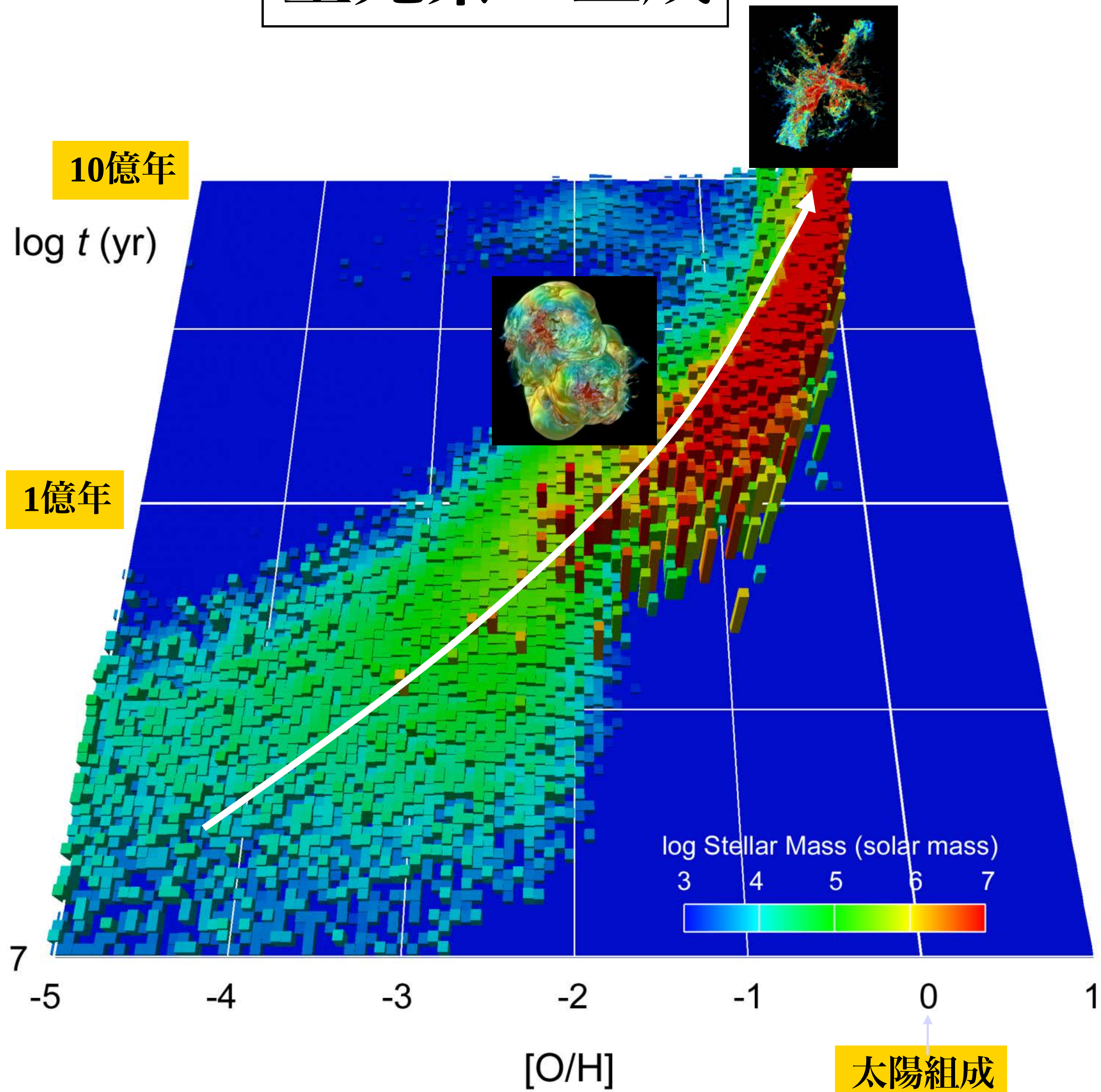






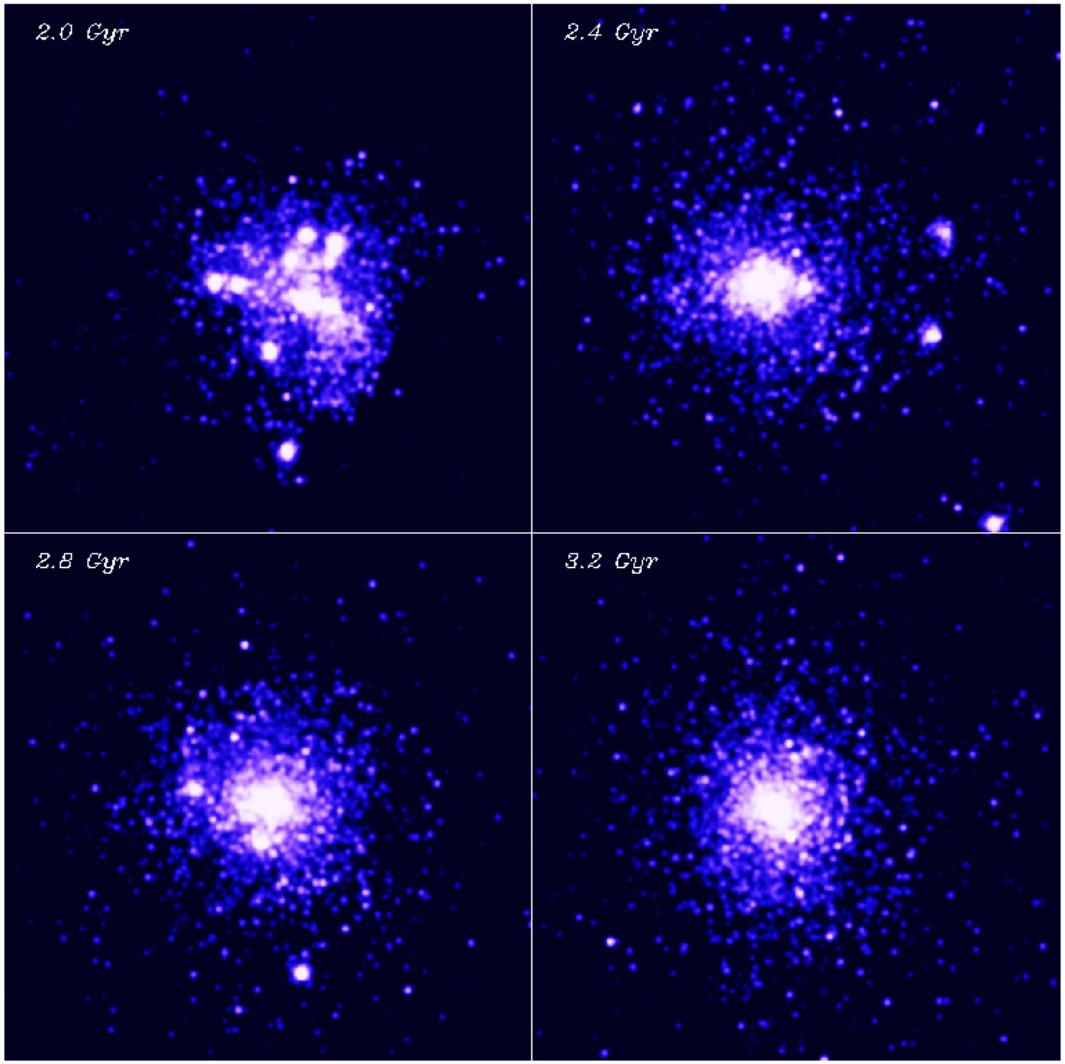

ライマンα輝線
0.1 Gyr
0.3 Gyr
0.5 Gyr
1.0 Gyr
星
ガス
log L_λ (erg s^{-1} Å^{-1})
log λ (Å)
42
40
38
36
3.2
3.4
3.6
3.8
ライマンα輝線
天体
ライマン・ブレー
銀河

重元素の生成



10億年
log t (yr)
1億年
7
-5
-4
-3
-2
-1
0
1
[O/H]
太陽組成
log Stellar Mass (solar mass)
3
4
5
6
7

Lyman α Emitters (LAE) Evolves into Elliptical Galaxies



The virializaion of the total system is almost completed 3 Gyrs.

The resultant system at 13 Gyrs (redshift z=0) :

Stellar mass: $M_{*}=1.1\times10^{10}\ M_{\odot}$

Central velocity dispersion: V_0=133 km s^{-1}

Effective radius: R_e=3.97 kpc

B-band mag.: M_B= -17.2

V-band mag.: M_V= -18.0

Color: U-V=1.15

V-K=2.85

These values are consistent with the properties of the present-day less-massive elliptical galaxies.

Disk Galaxy Evolution

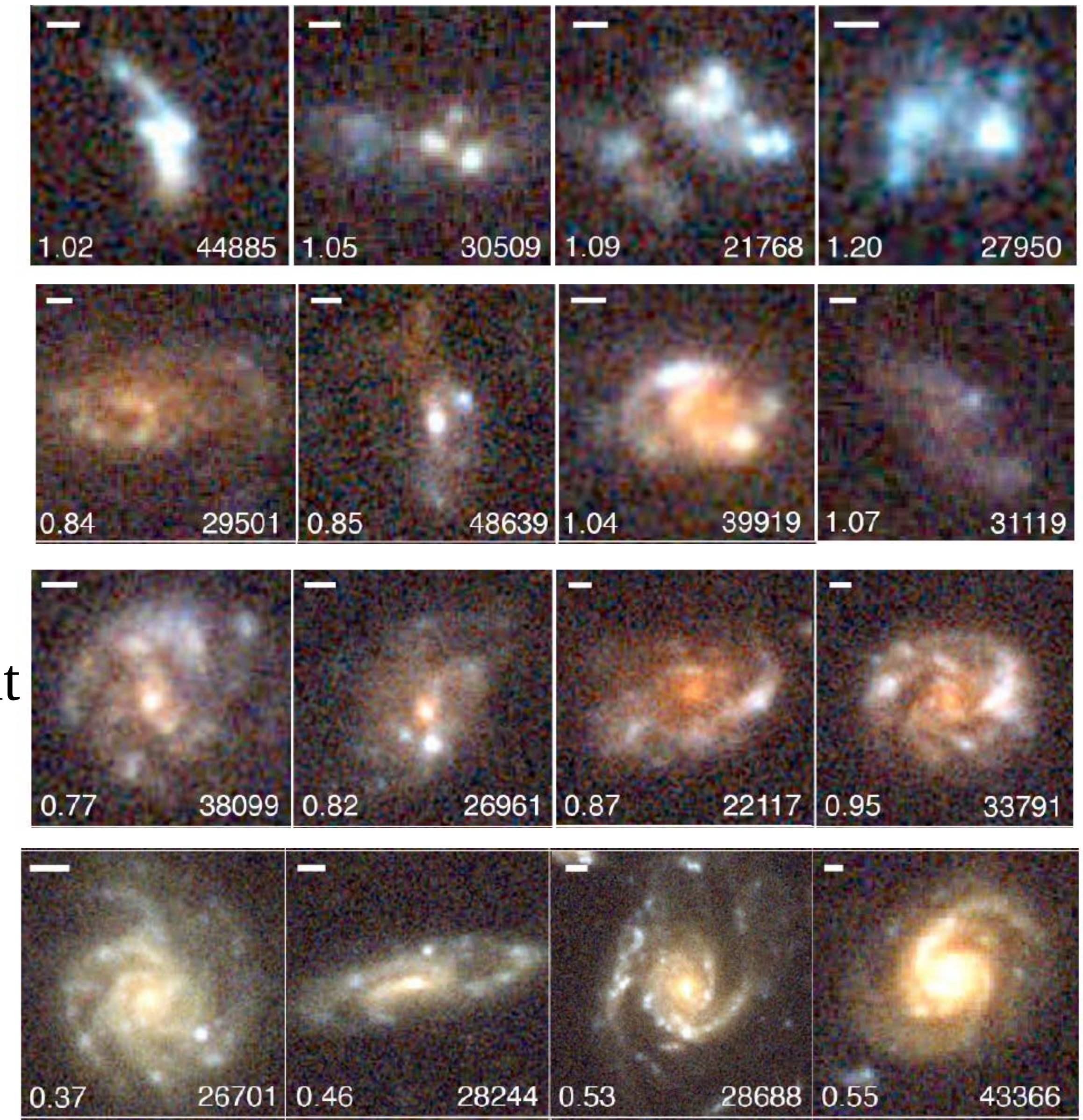
現在のdisk galaxy のprogenitor は？　thick-disk ×→ thin disk

Clump Clusters

Clumpy Galaxies

Flocculent Spirals

Spirals

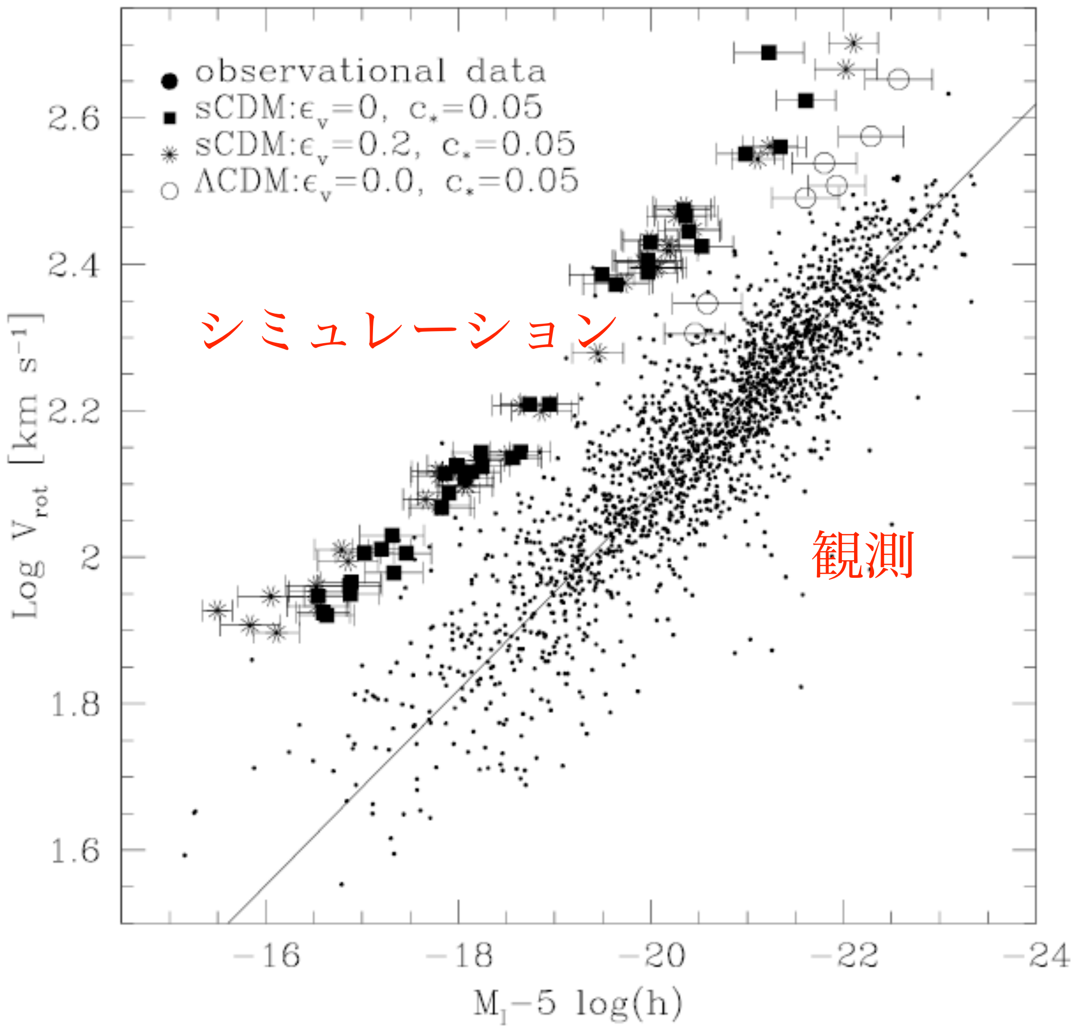


GOODS field

Elmegreen et al 2009

角運度量問題

Tully-Fisher 関係



Navarro & Steinmetz 2000

シミュレーション結果は，観測に比べて，システマティックに回転が速い

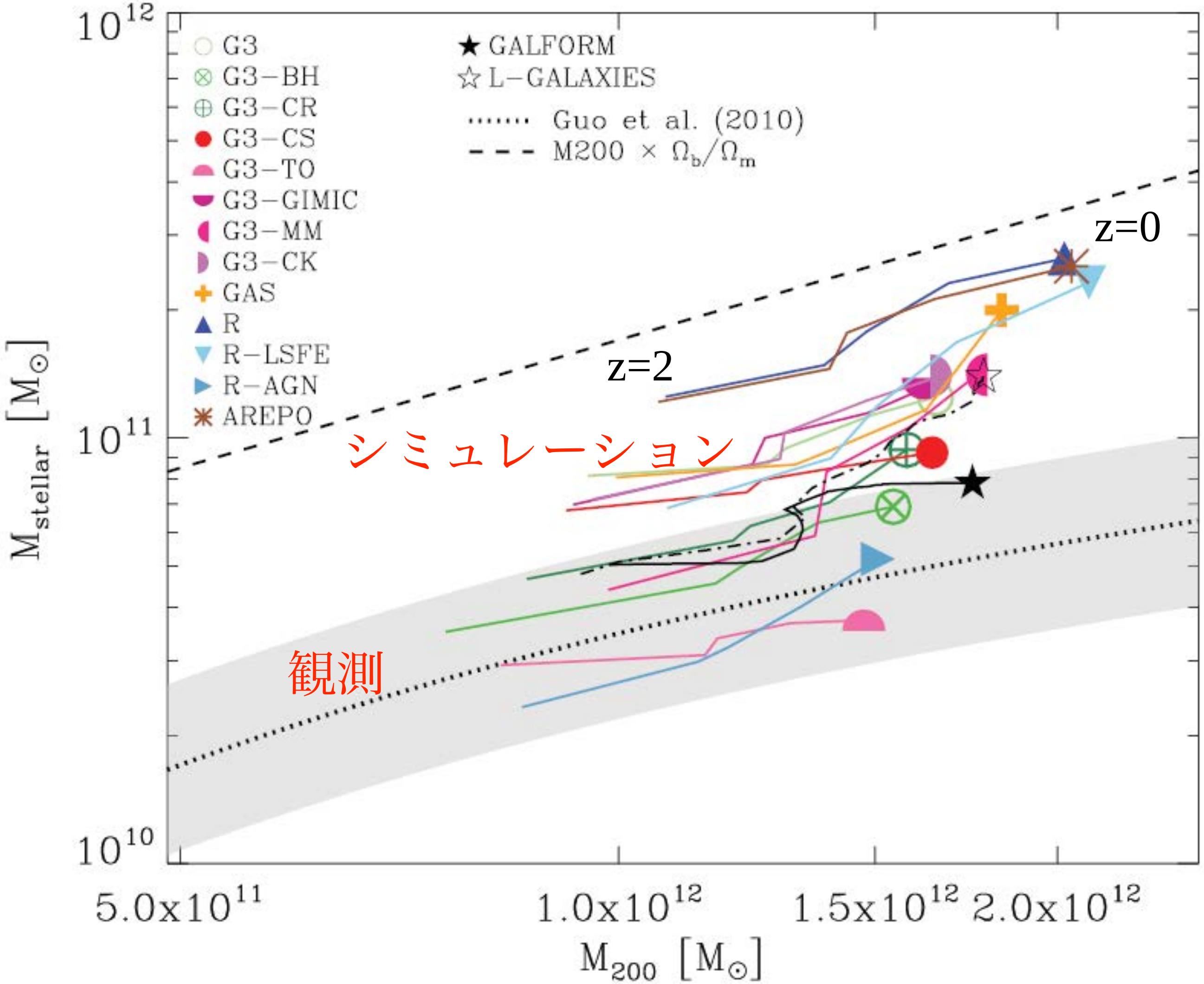
⇓

重たいバルジが出来すぎる

質量問題

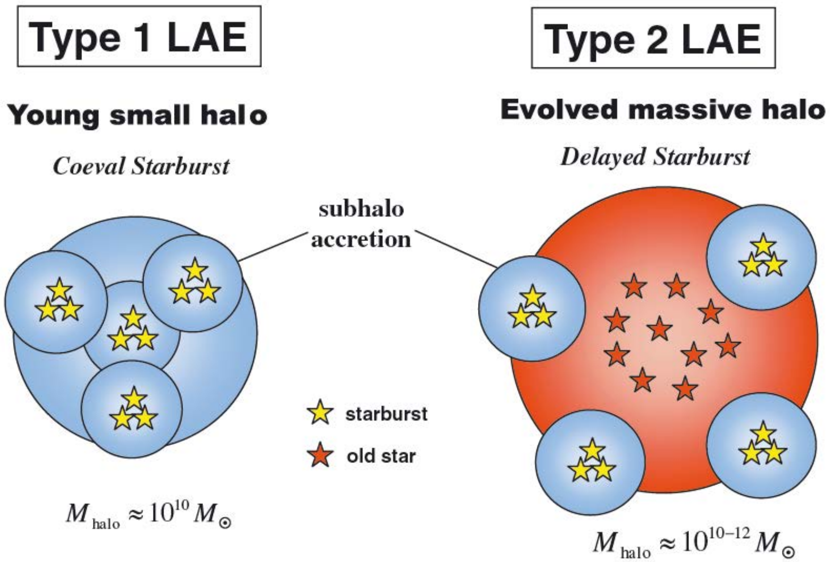
The Aquila comparison project: the effects of feedback and numerical methods on simulations of galaxy formation

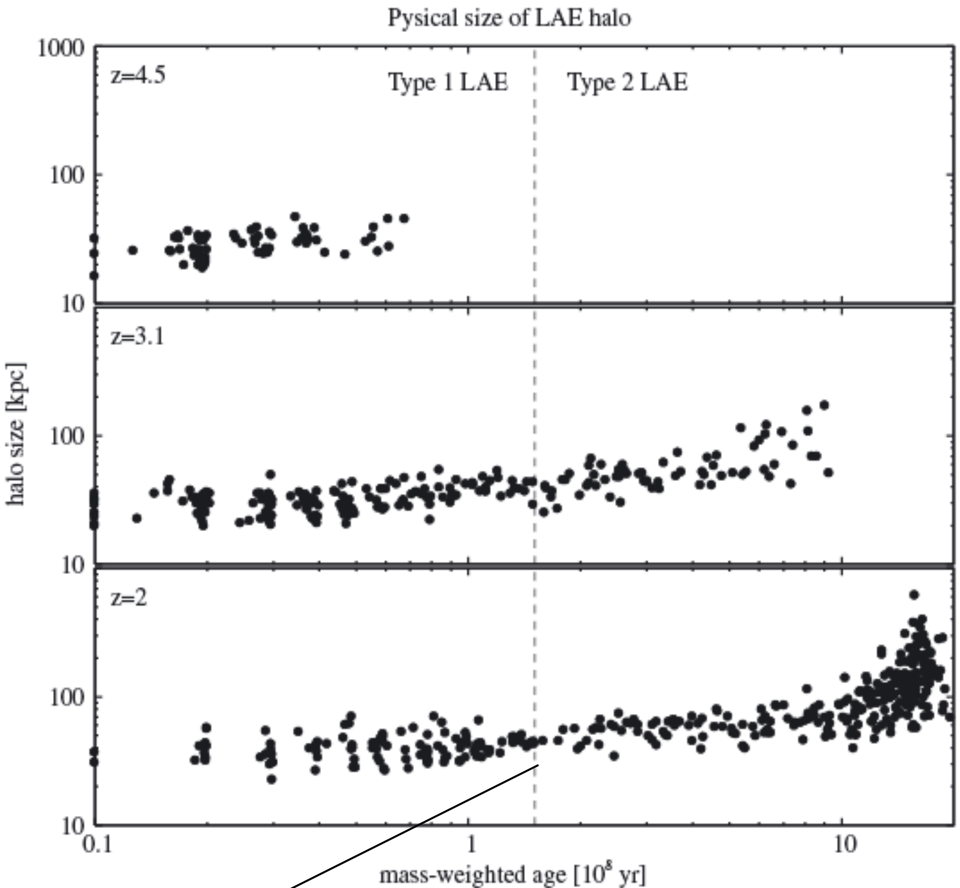
Scannapieco et al 2012



ダークハローの中で星になる割合が観測に比べて多すぎる

Two types of Lyman α emitters





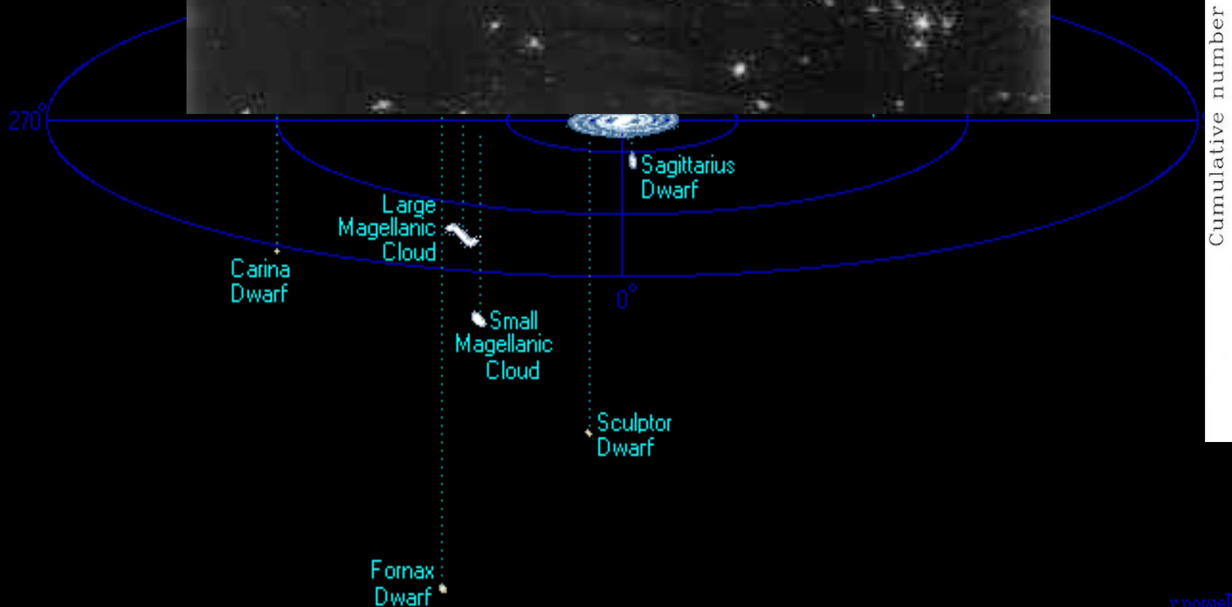
Shimizu & Umemura 2010

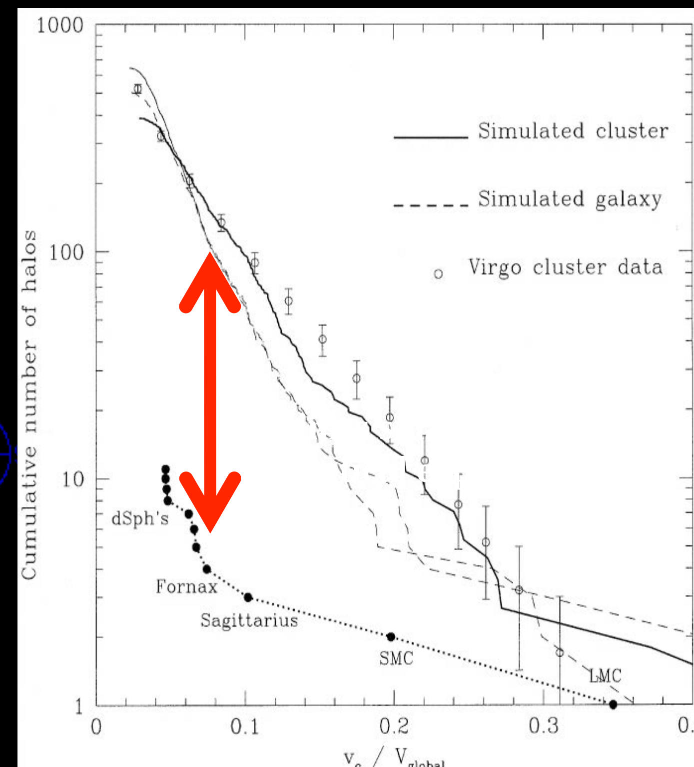
low-z LAEはSpiral を含む？

Missing Satellites Problem

J, 524, L19 $2 \times 10^{12} M_{\odot}$

Galac





Sub-clump (Missing satellite) Problem

① **UV フィードバック**

② **SN フィードバック**

③ **環境効果**

どれも，完全には成功していない

AGN GUT

Paradigm over 30 years

Problems

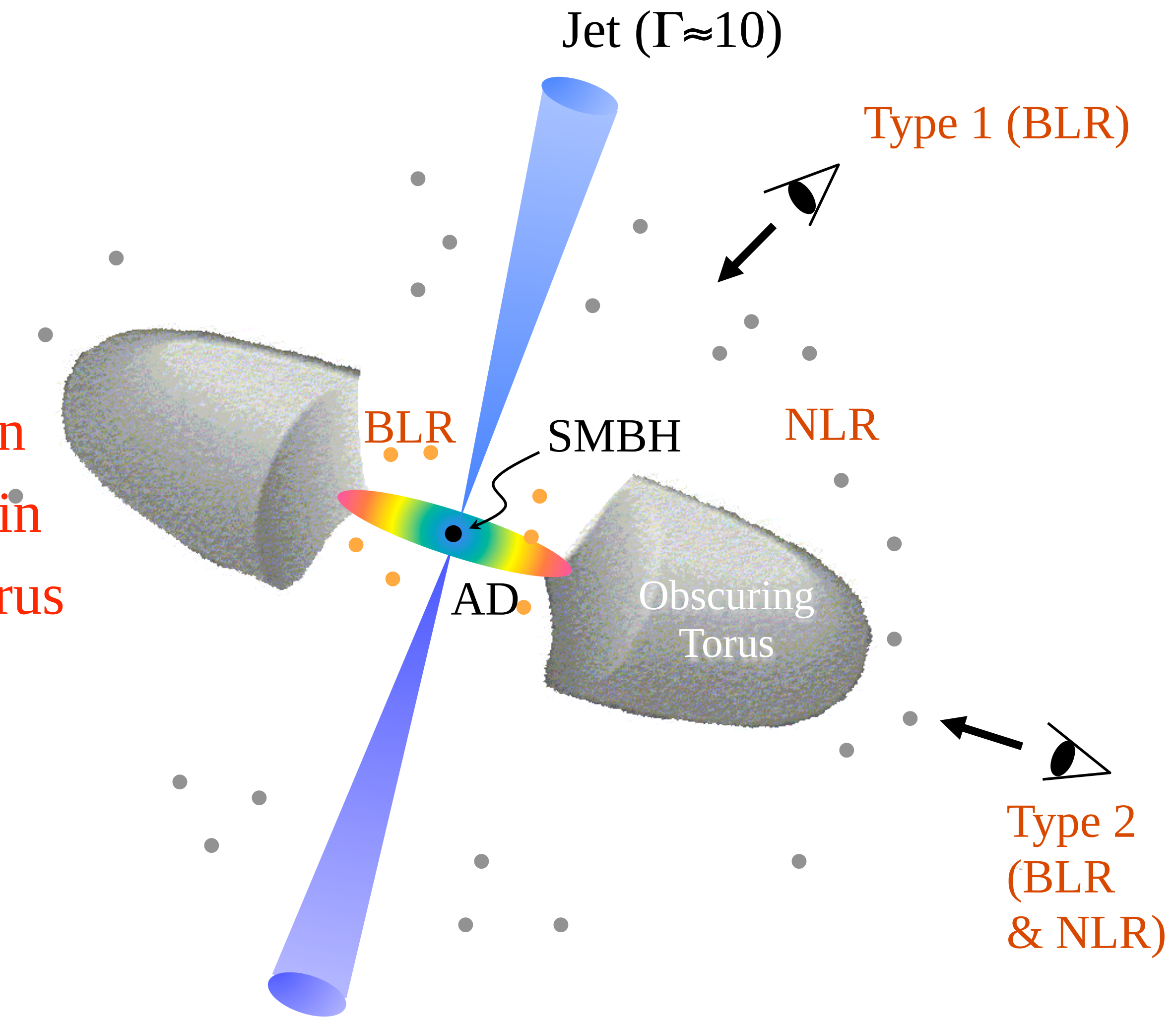
SMBH - formation

Accretion Disk - slim disk

Jet - acceleration, collimation

UFO - ultrafast outflow origin

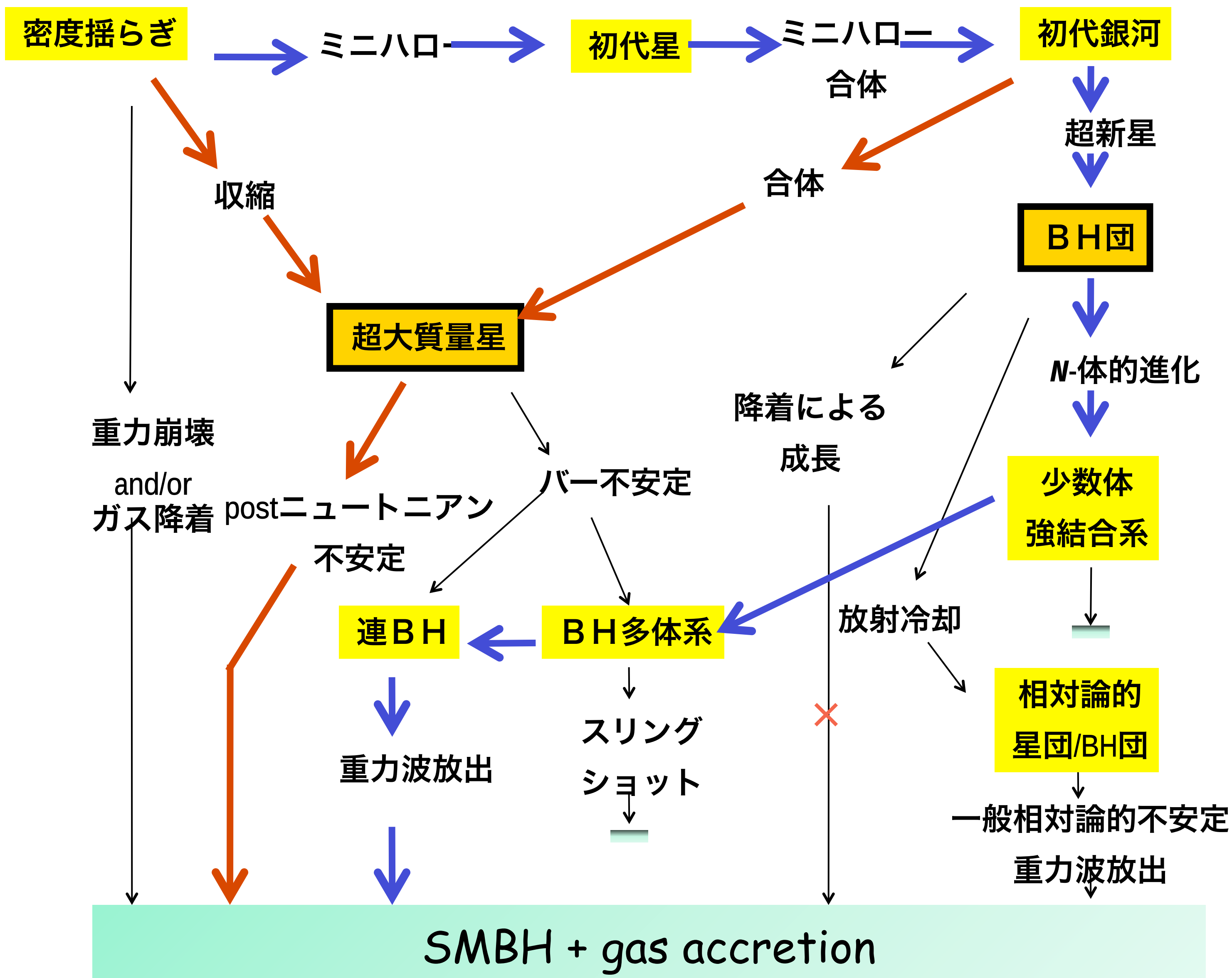
Obscuring torus - clumpy torus



BLR: Broad Line Regions, NLR: Narrow Line Regions

Cosmological Rees Diagram

by MU



QSO Luminosity Functionからの制限
Soltan's Argument (1982)

Integration of QSO LF

$$\Omega_{BH}(QSO) \approx 1.8 \times 10^{-6}$$

Yu & Tremaine 2002, MNRAS, 335, 965

$$\Omega_{BH}(QSO) \approx (2.4 - 4.8) \times 10^{-6}$$

Marconi et al. 2004, MNRAS, 351, 169

SMBH-bulge mass relation at z=0

$$\Omega_{BH}(bulge) \approx 2.1 \times 10^{-6}$$

⇓

QSO BHの最終フェーズはガスアクリーションで太った

ブラックホール形成と成長の課題

Seed BH

$M_{BH} = 10 - 10^5 M_\odot$

Supermassive star ($10^{4\text{-}5} M_\odot$)

SN/GRB remnant (Pop III remnant) ($30\text{-}100 M_\odot$)

ガス降着

N-body 過程

$M_{BH} = 10^6 M_\odot$

BH-bulge relation

ガス降着

N-body 過程

銀河との共進化

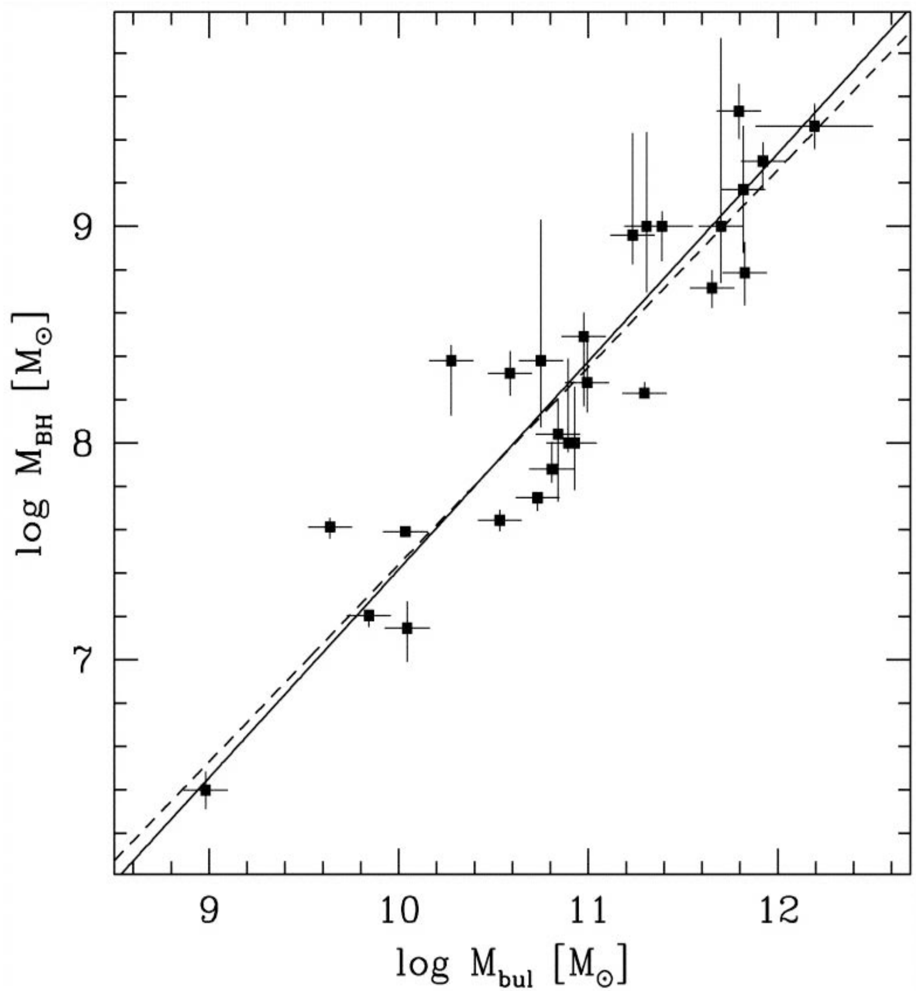
$t \approx 10^{7-9}$ yr

$M_{BH} = 10^{8-9} M_\odot$

超巨大BH－銀河バルジ関係
(マゴリアン関係)

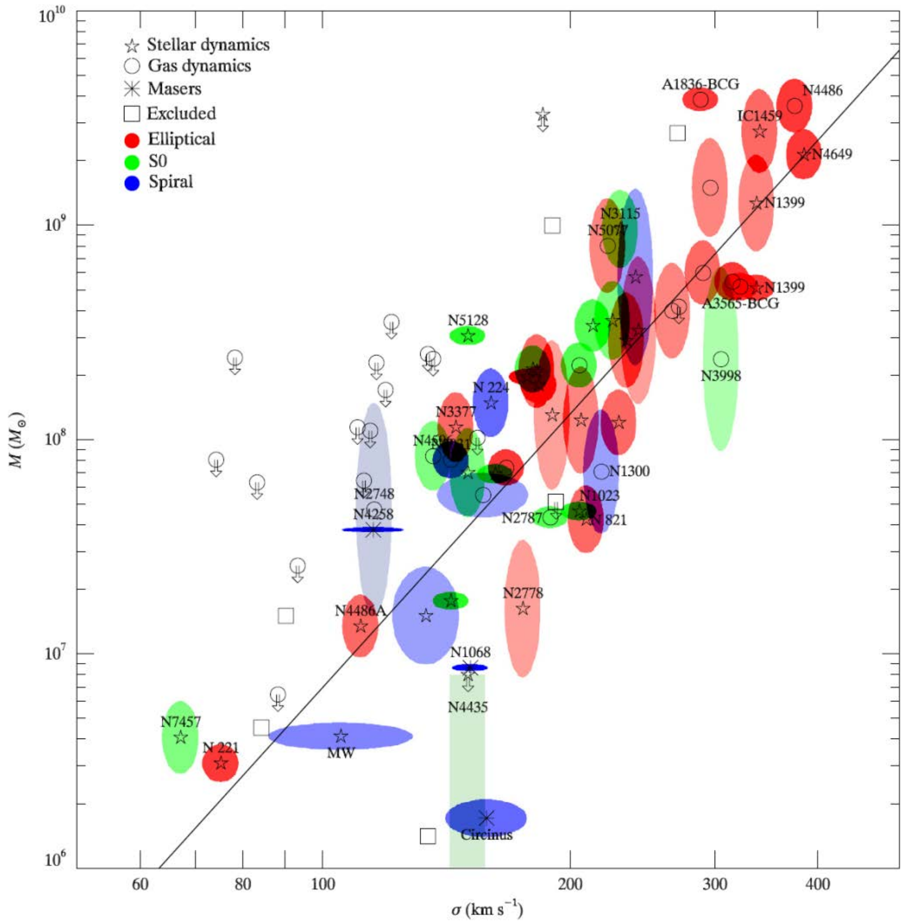
$M_{BH}/M_{bulge} \approx 0.001$

Marconi & Hunt 2003, ApJ, 589, 21



$M_{BH} \propto \sigma^{3.96 \pm 0.42}$

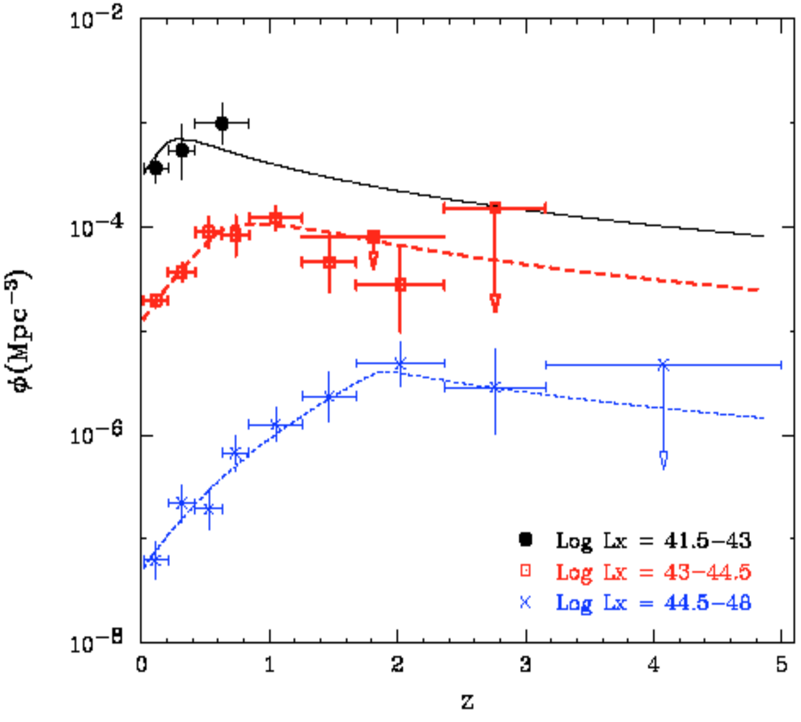
Gultekin et al. 2009, ApJ, 698, 198



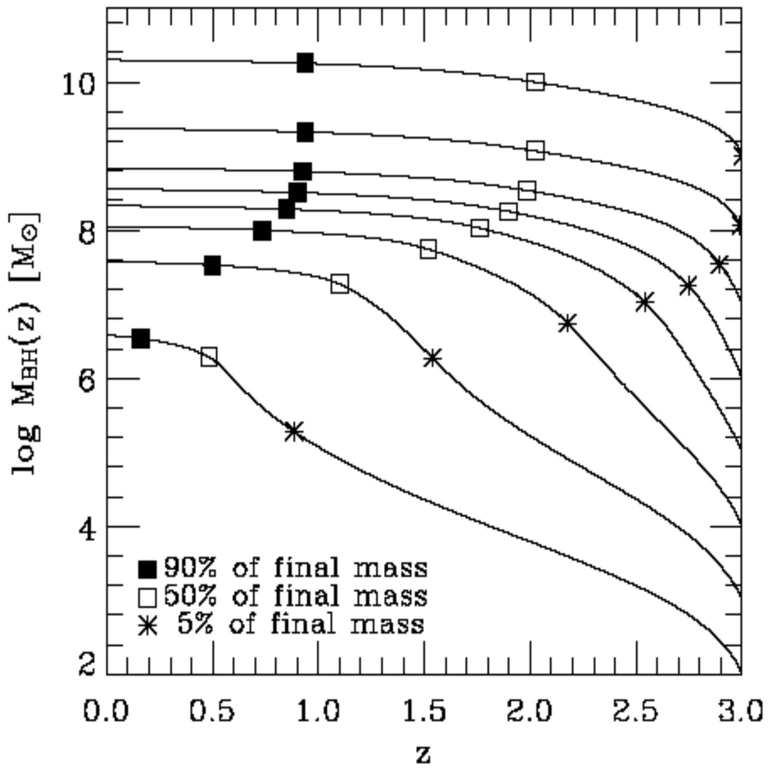
“Downsizing” in SMBH Formation

More massive BHs formed at higher redshifts.

Ueda et al. 2003, ApJ, 598, 886



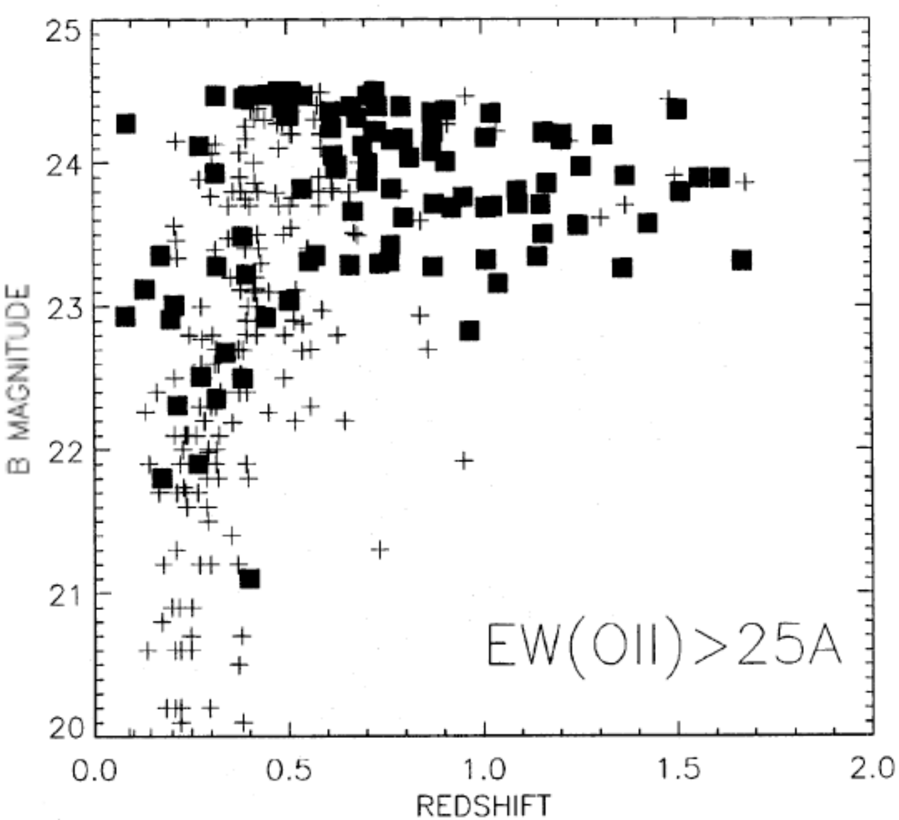
Marconi et al. 2004, MNRAS, 351, 169



“Downsizing” in Galaxy Formation

More massive galaxies formed at higher redshifts.

Cowie et al. 1996, AJ, 112, 839



Kodama et al. 2004, MNRAS, 350, 1005
SXDS(Subaru/*XMM–Newton* Deep Survey)

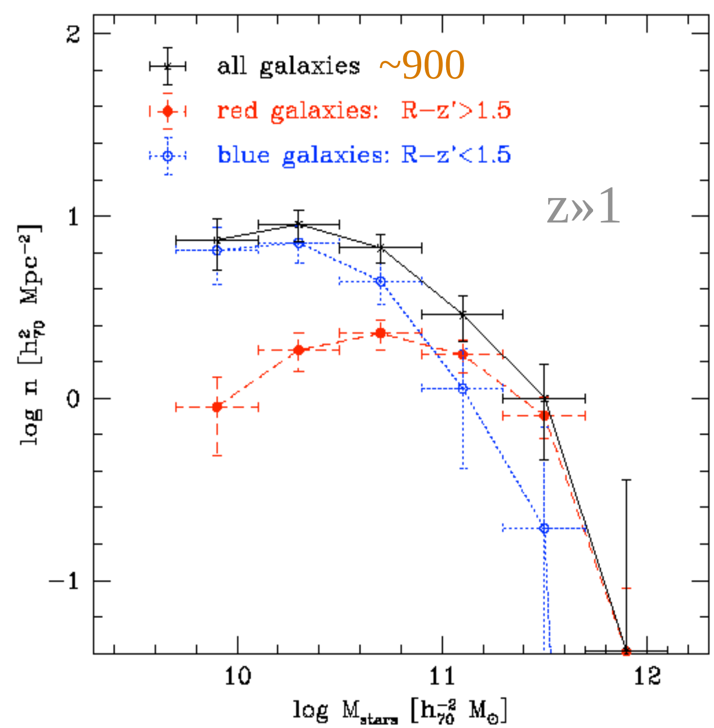


Figure 10. Field-corrected stellar mass functions for the $z \sim 1$ galaxies. The solid curve shows the total mass function, while dashed and dotted curves show the mass functions for red and blue galaxies, respectively, separated at $R - z' = 1.5$. The error bars shown here are purely Poissonian, and the errors due to field-to-field variation are shown later in Fig. 11.

超巨大ブラックホールのダウンサイジング

+

銀河のダウンサイジング

+

SMBH-bulge 関係

=

重いバルジほど昔星形成を終了した

Early-type galaxies formed earlier.

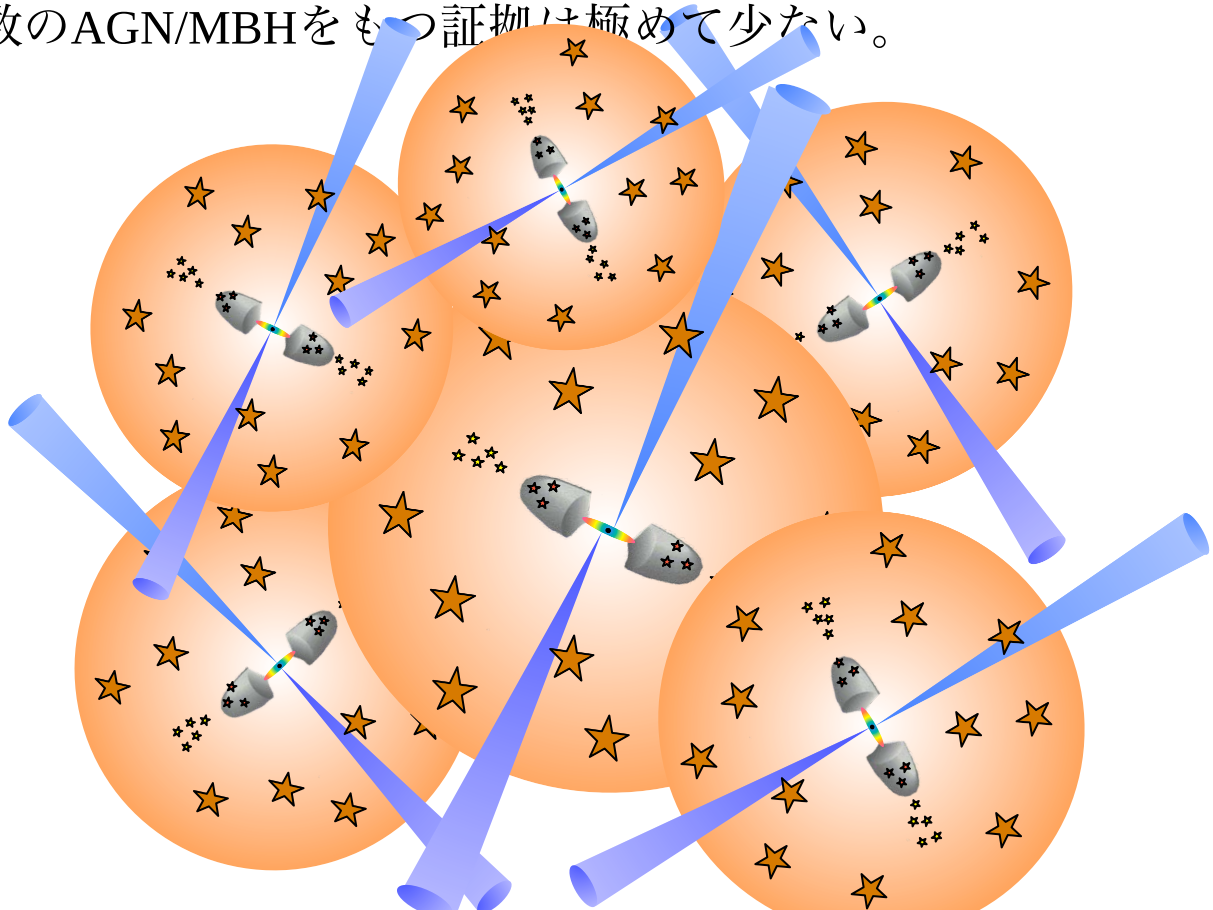
ハッブル銀河分類は物理的だった！？

CDM銀河形成論への挑戦

階層的天体形成とSMBH形成とのconsistency

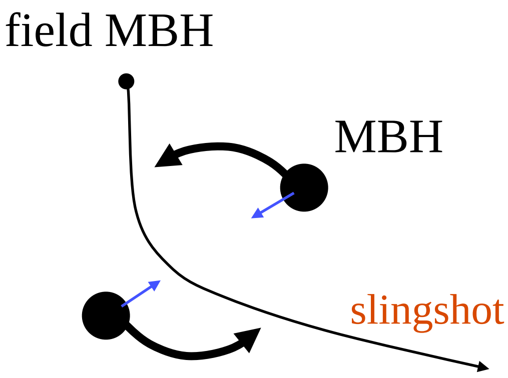
・銀河のbuilding block がMBHを持っているなら，原始銀河には複数のMBHがあるはず。

しかし，複数のAGN/MBHをもつ証拠は極めて少ない。



Successive Merger of Multiple Massive Black Holes in a Primordial Galaxy

Tanikawa & Umemura 2011, ApJ , 728, L31



MBH 10体系のシミュレーション

Infall by dynamical friction

⇓

a binary MBH + an interacting BH

⇓

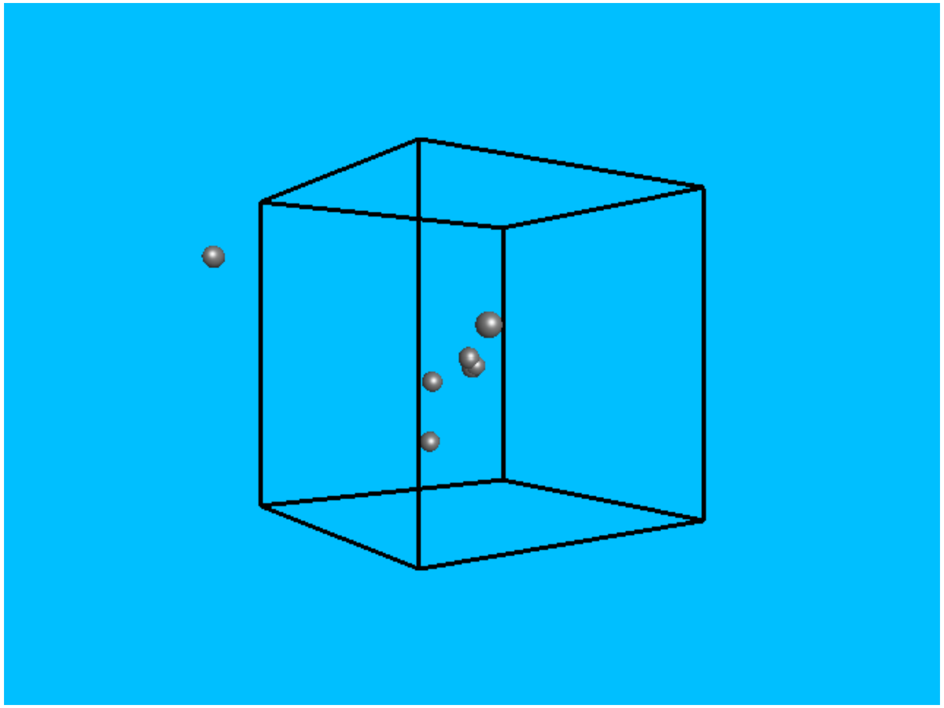
Binary hardening by slingshot
(three-body reaction)

⇓

Merger by gravitational wave

⇓

a half of MBHs merge



Kozai 機構は有効ではない

Successive Merger of Multiple Massive Black Holes in a Primordial Galaxy

Tanikawa & Umemura 2012, in prep

- Gravitational Wave Recoil
- Galactic Velocity Dispersion

Model	N_B	v_g [1]	v_{GW} [1]	v_{GW}/v_g	$m_{B,p}$ [2]	$m_{B,s}$ [1]	$N_{B,ej}$
$A_{0,1}$	10	350	0	0	4	3(e)	2
$A_{0,2}$	10	350	0	0	4	1	3
$A_{0,3}$	10	350	0	0	6	1	1
A_1	10	350	500	1.4	6	1	1
B_0	10	240	0	0	6	1	1
B_1	10	240	500	2.1	4	2(e)	2
C_0	10	180	0	0	5	1	1
C_1	10	180	200	1.1	3	2	1
D_0	10	120	0	0	3	1	2
BH0	0	–	–	–	–	–	–
BH2	2	–	–	–	–	–	–

[1] km/s
[2] initial MBH mass

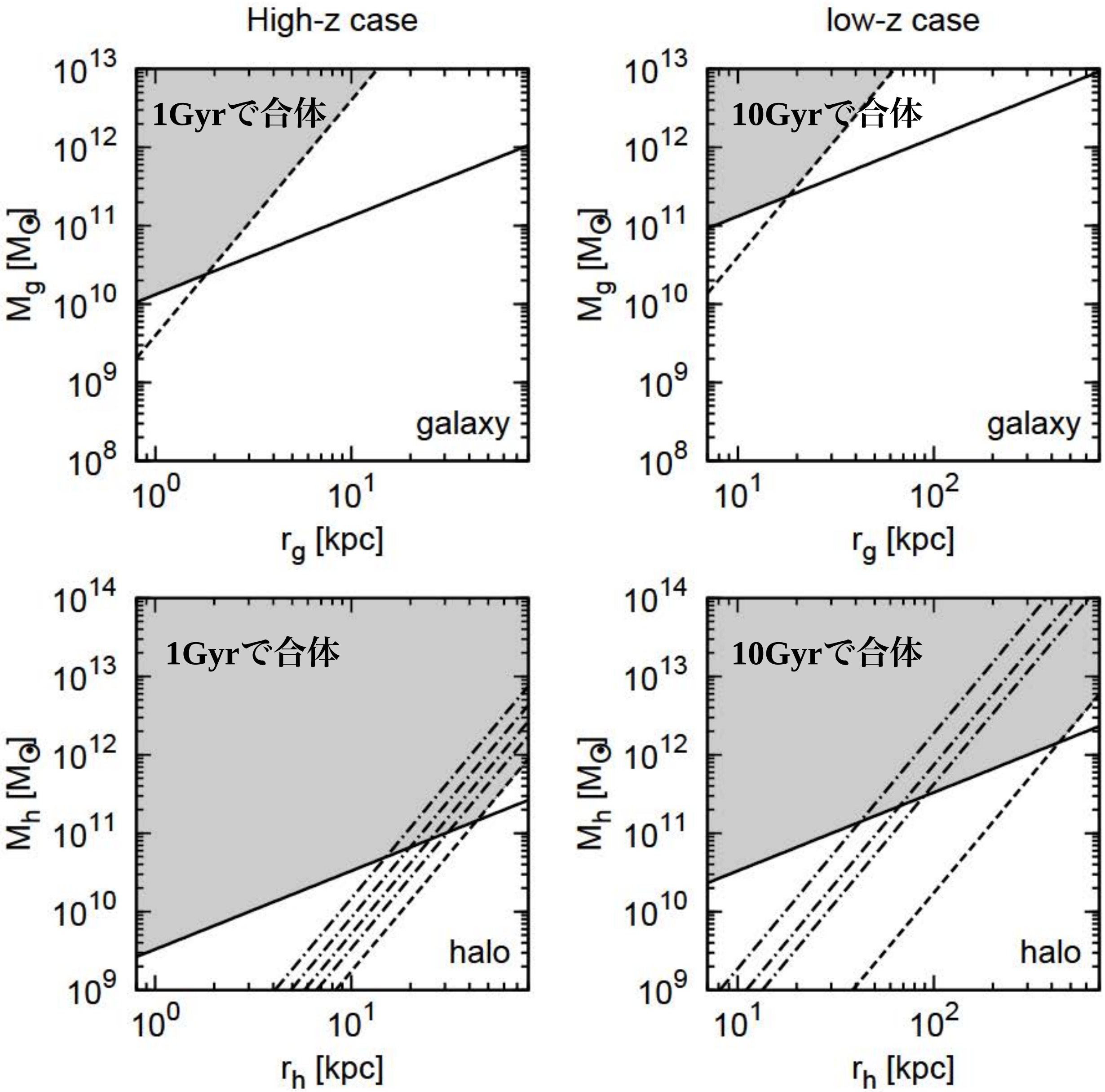
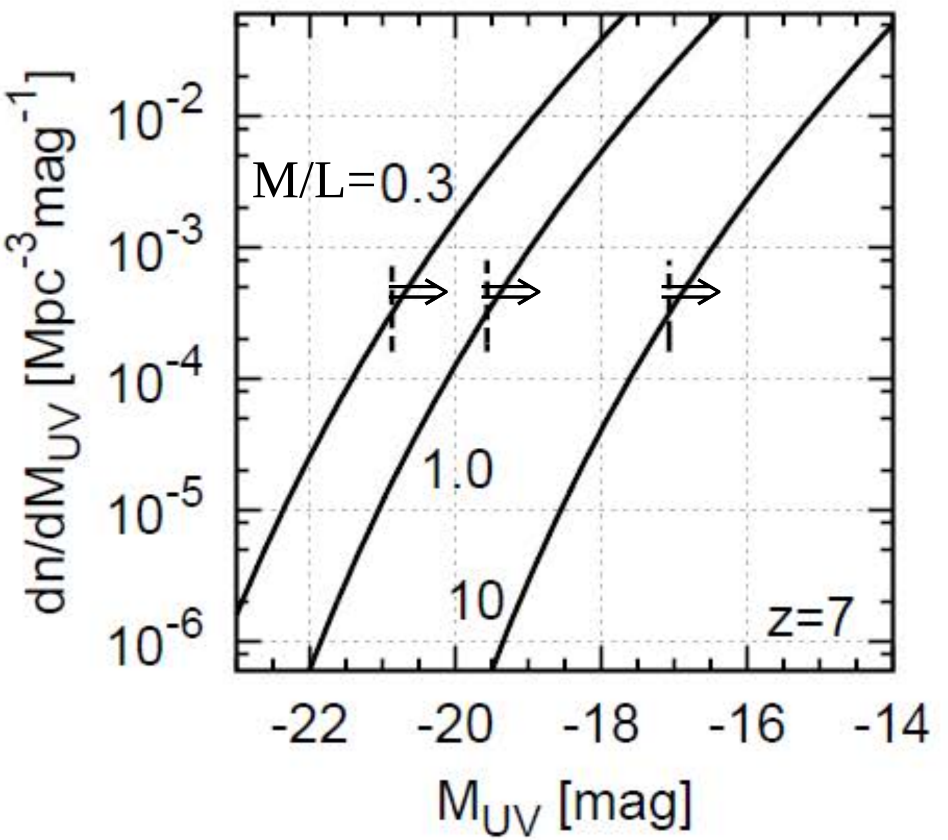


FIG. 1.— Mass and size of a galaxy (top panels) and halo containing the galaxy (bottom panels). In left and right panels, gray regions indicate the galaxy and halo in which MBHs merge within 1 Gyr and 10 Gyr, respectively. Dashed-dotted lines show mass and size of a halo formed at redshift $z = 15$, 10, 7, and 5 in the left bottom panel, and those of a halo formed at redshift $z = 3$, 1, and 0 in the right bottom panel.

一般相対論的N体計算によるブラックホール合体条件と観測との比較

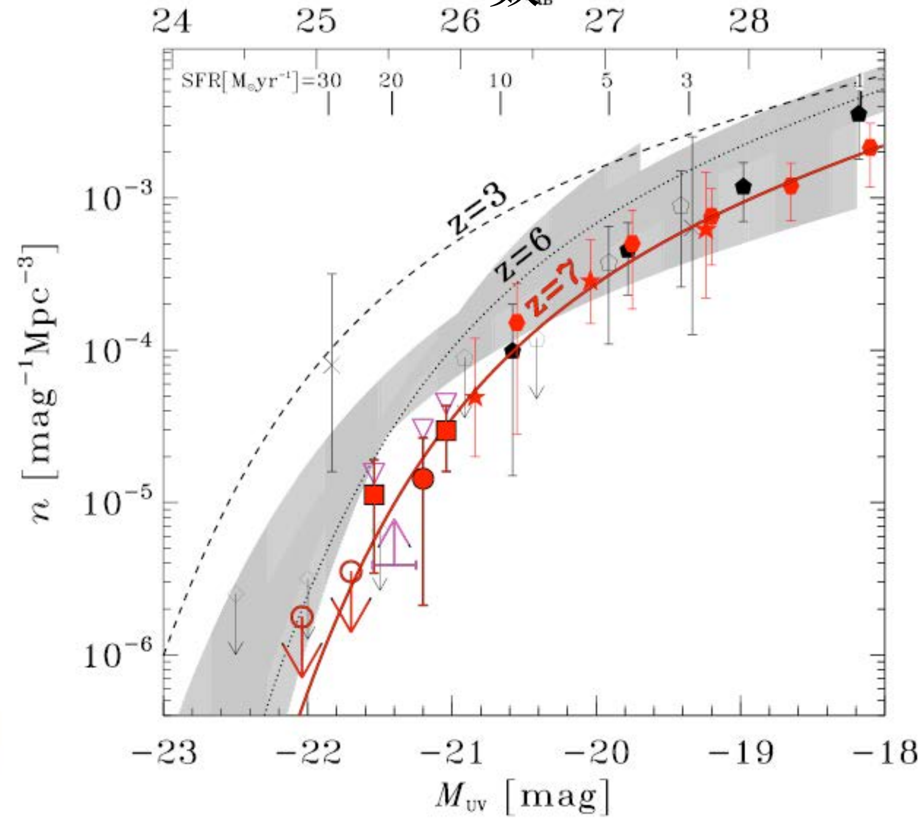
シミュレーションによって得られたブラックホール合体条件



線に付けられた数値は仮定した質量－光度比
縦の波線より左側で合体が可能

Tanikawa & Umemura 2012

z=7 ライマンαエミッターの光度関数



Ouchi et al. 2009

成長期のSMBHはどこに？

【１】　LBG, LAB, ERO, DRG, BzK, SMG, ULIRG, Radio Galaxies のいずれかに成長期のQSOがあるはず（?）

AGN fraction

↓
LBG 数％
BzK 2-3割
ULIRG ～5割　（Type I ULIRG）L_{IR} と共に増大

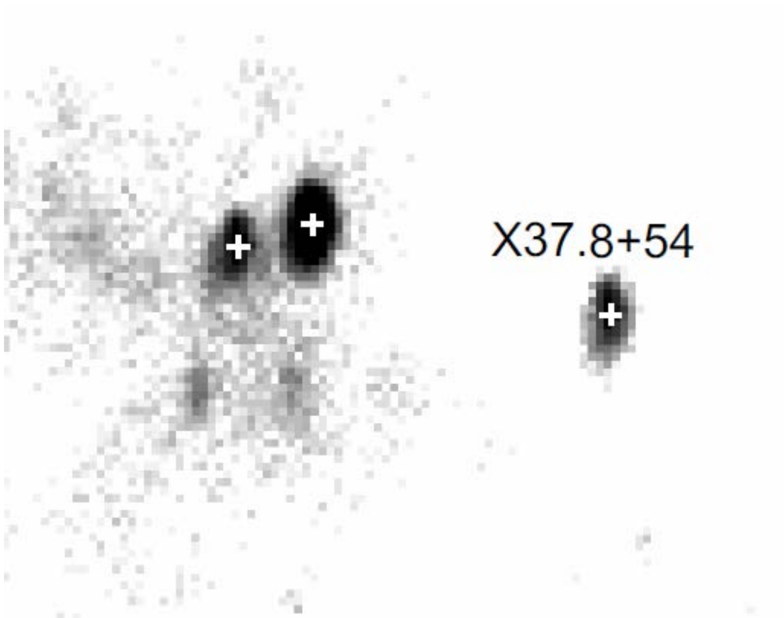
【２】　Off-center MBHs

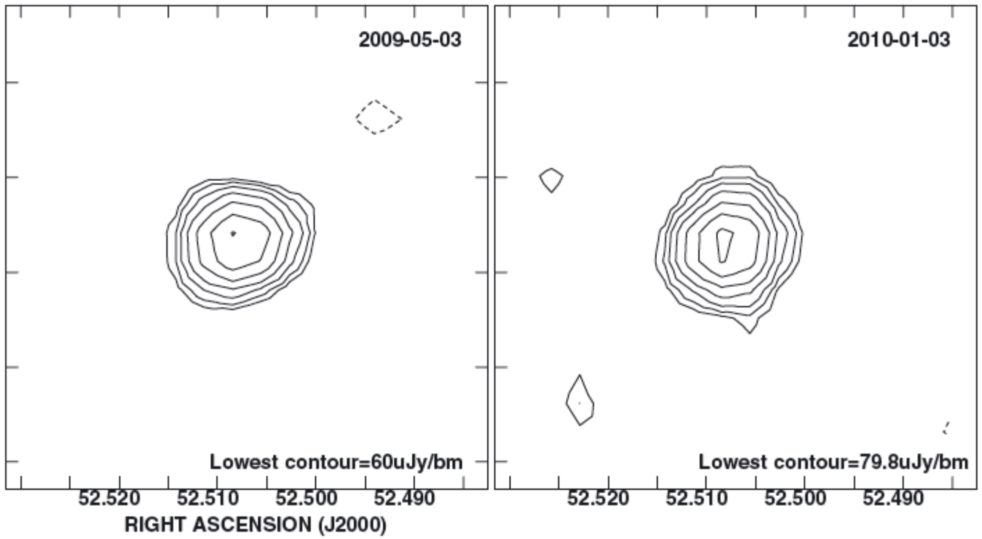
現在の銀河に中心外MBHがある？

近傍宇宙で

Off-center BHs in Bulgeless Galaxies

M82
Off-center ULXs (Jin+10, arXiv:1005.0469)
Radio sources (Muxlow+10, MNRAS, 404, L109)





Black Holes in Bulgeless Galaxies

M_{BH}=10^5–10^7M$_\odot$ for NGC3367

M_{BH}=10^4–10^6M$_\odot$ for NGC4536

M_{BH}>2´10^4M$_\odot$ for NGC4561

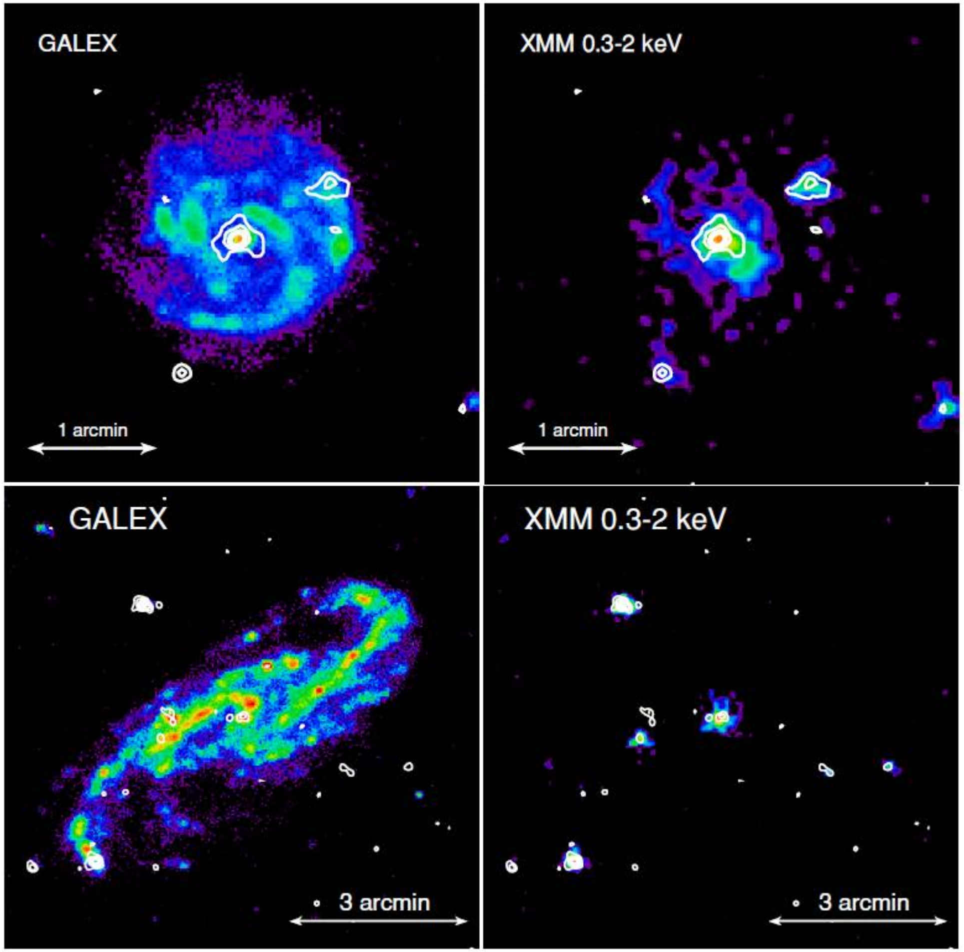


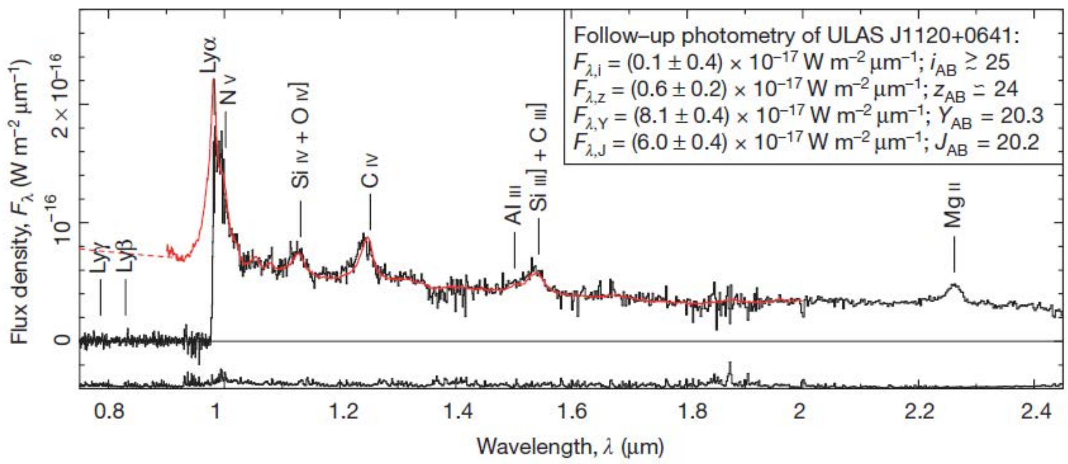
Figure 1. Images of NGC 3367 (top) and NGC 4536 (bottom) from *Galaxy Evolution Explorer* in the near-ultraviolet (left; from Gil de Paz et al. 2007) and smoothed *XMM-Newton* in the 0.3–2 keV energy range (right). Both panels show the smoothed *XMM-Newton* 2–10 keV image overlaid as contours with levels starting at 0.25 counts (smoothed), incremented in 0.25 steps. The smoothing of the *XMM-Newton* images used a Gaussian with kernel of radius = 4.″8 (3 pixels).

(A color version of this figure is available in the online journal.)

z=7.085 QSO

Mortlock et al. 2011, nature, 474, 616

L=6.3×10$^{13}L_{\odot}$ M_{BH}=2×10$^{9}M_{\odot}$ **Super-Eddigton Accretion**



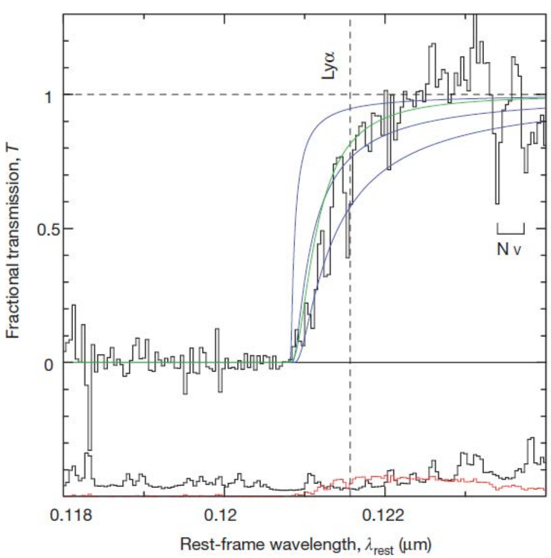


Figure 4 | Rest-frame transmission profile of ULAS J1120+0641 in the region of the Lyα emission line, compared to several damping profiles. The transmission profile of ULAS J1120+0641, obtained by dividing the spectrum by the SDSS composite shown in Fig. 1, is shown in black. The random error spectrum is plotted below the data, also in black. The positive residuals near 0.1230 µm in the transmission profile suggest that the Lyα emission line of ULAS J1120+0641 is actually stronger than average, in which case the absorption would be greater than illustrated. The dispersion in the Lyα equivalent width at a fixed C IV equivalent width of 13% quantifies the uncertainty in the Lyα strength; this systematic uncertainty in the transmission profile is shown in red. The blue curves show the Lyα damping wing of the intergalactic medium for neutral fractions of (from top to bottom) f_{HI} = 0.1, f_{HI} = 0.5 and f_{HI} = 1.0, assuming a sharp ionization front 2.2 Mpc in front of the quasar. The green curve shows the absorption profile of a damped Lyα absorber of column density $N_{HI} = 4 \times 10^{20}$ cm^{-2} located 2.6 Mpc in front of the quasar. These curves assume that the ionized zone itself is completely transparent; a more realistic model of the H I distribution around the quasar might be sufficient to discriminate between these two models[25,27]. The wavelength of the Lyα transition is shown as a dashed line; also marked is the N V doublet of the associated absorber referred to in the text.

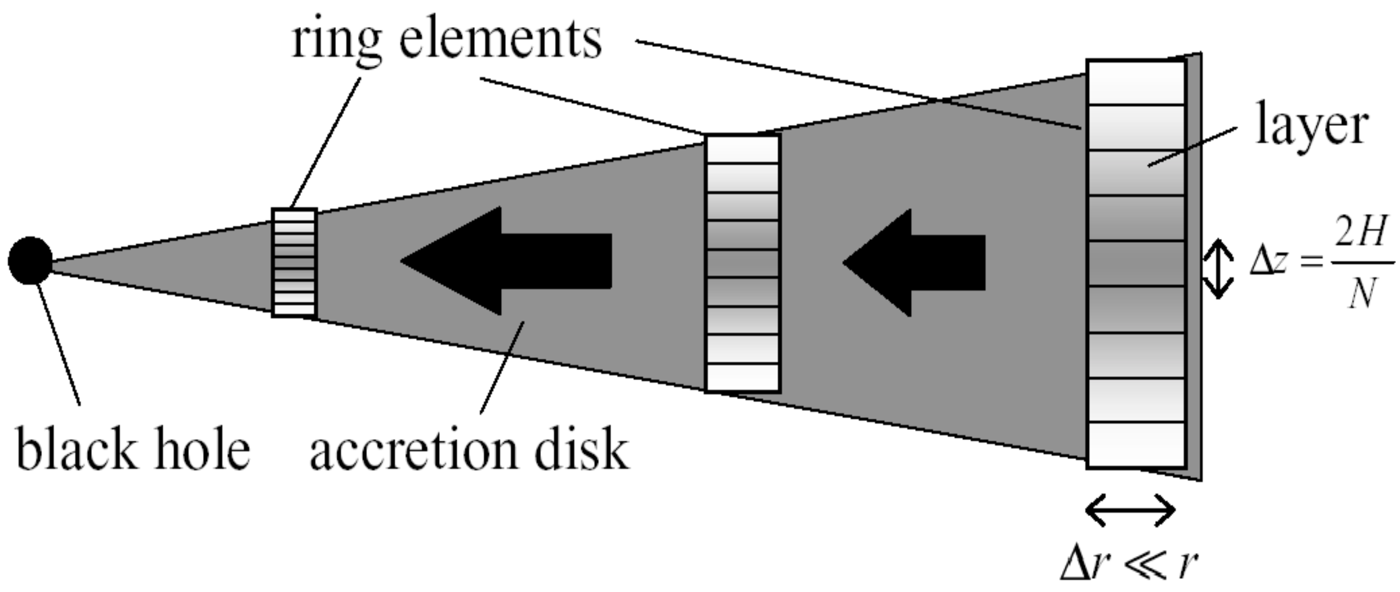
Photon Trapping in Slim Disk

Diffusion Approximation

Jaroszynski et al. 1980; Begelman & Meier 1982

Flux Limited Diffusion Approximation

Ohsuga, Mineshige, Mori & Umemura 2002



Luminosity of Slim Disk

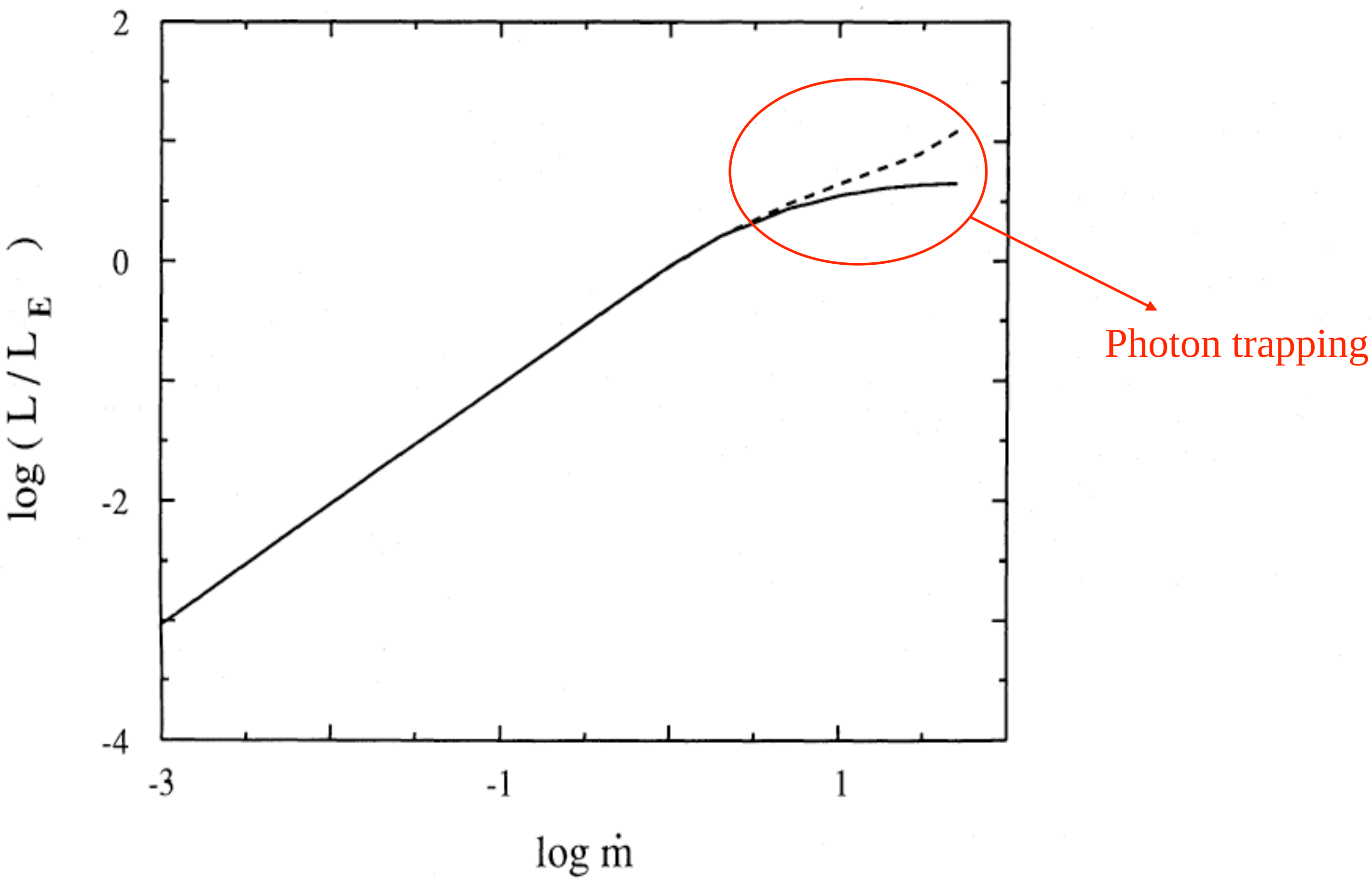
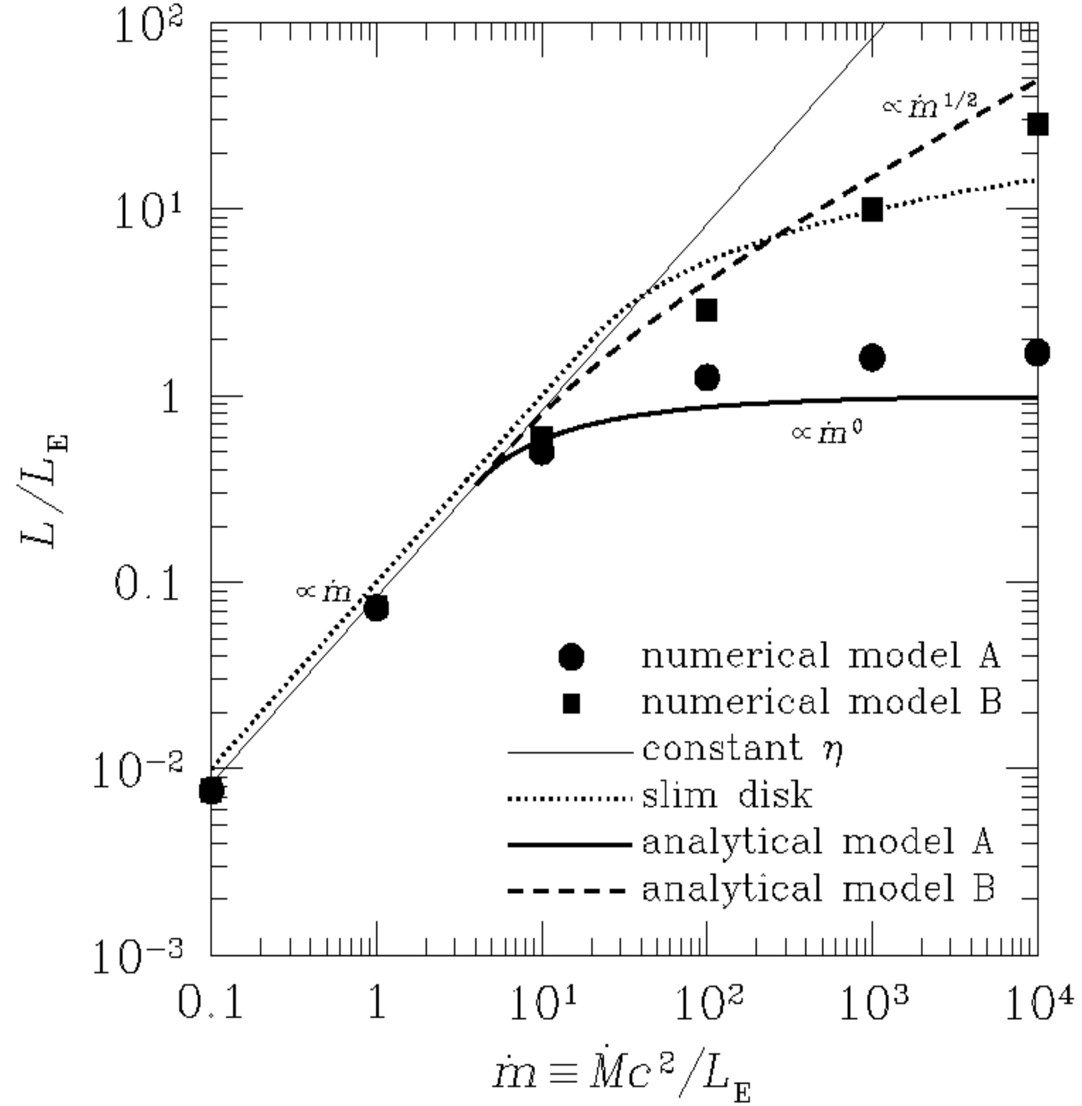


FIG. 1.—The total luminosity for slim disk models (*solid line*) in function of the accretion rate $\dot{m}$. The dashed line represents the rate of energy generation by viscous stresses. $\dot{m}$ is a accretion rate in terms of critical accretion rate, $\dot{M}_C = 64\pi GM/c\kappa_{es}$. All the models are computed with central black hole mass $M = 10M_\odot$, viscosity parameter $\alpha = 0.001$.

Abramowicz et al. 1988, ApJ, 332, 646

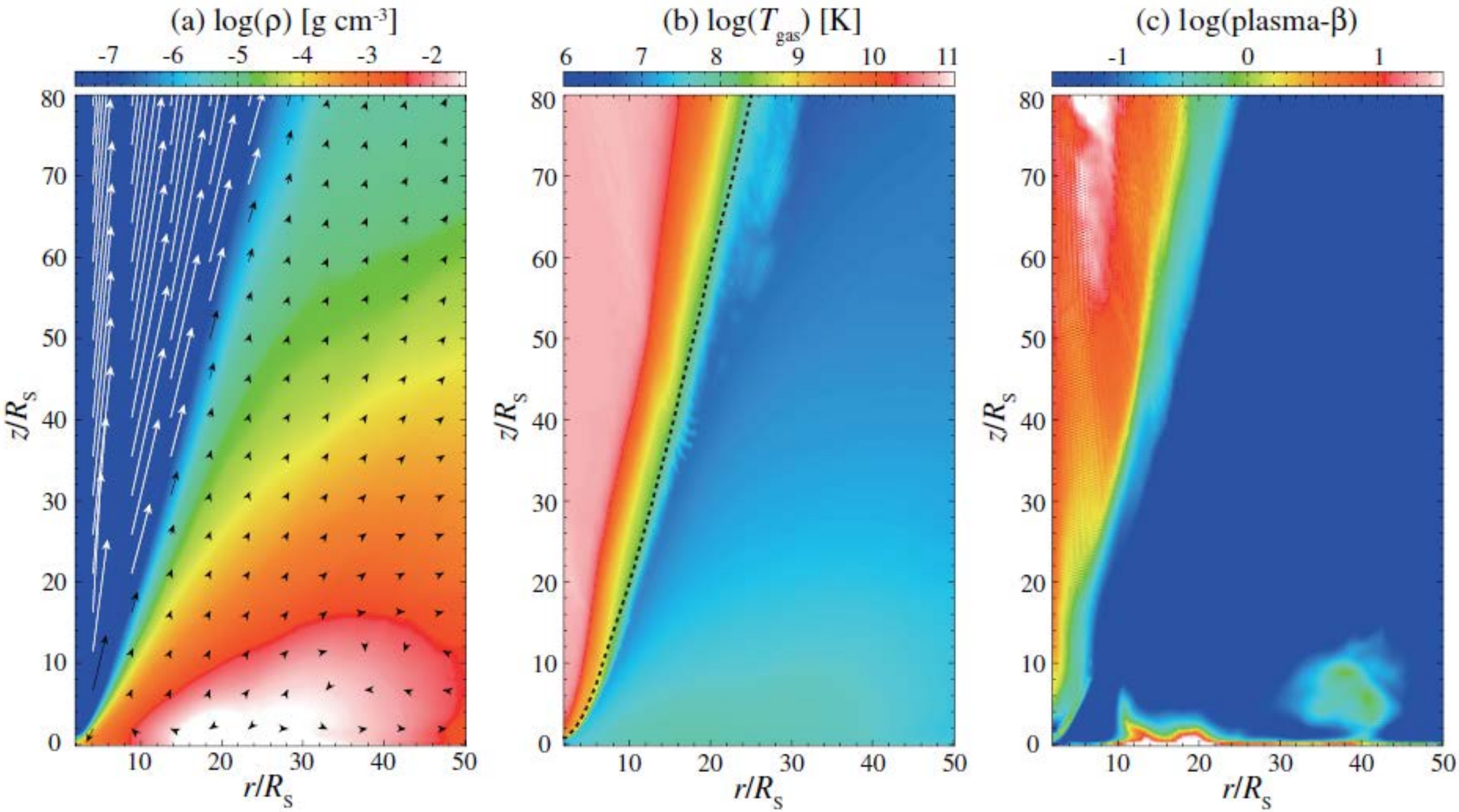


Ohsuga, Mineshige, Mori & Umemura 2002

Super-Eddington Acccretion & Outflow

Ohsuga & Mineshige 2011, ApJ, 736:2

2D Radiation Magneto-hydrodynamical simulation



Summary

宇宙再電離の課題

- Missing light 問題

銀河形成の課題

- 形態起源
- missing satellite 問題

AGNの課題

- SMBH の起源
- 質量降着（super-Eddington）