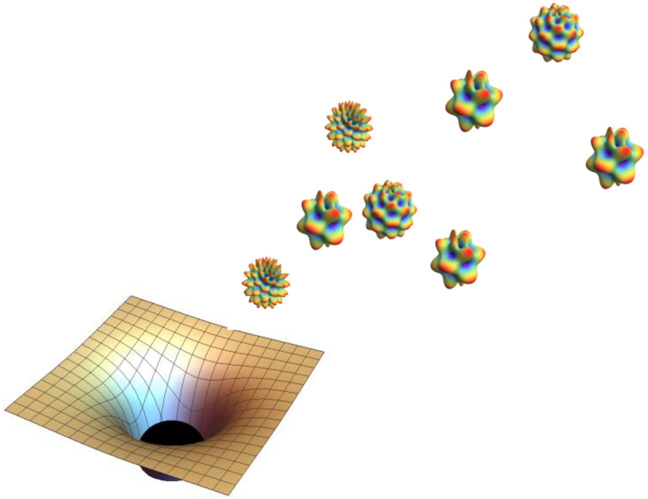
銀河進化 MM　2017June7@Osaka

銀河のダウンサイジング

―もし超重ブラックホールが先にできたら―



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1. Introduction – Cosmic Downsizing

Downsizing of galaxies:
Larger galaxies evolve faster (observation).

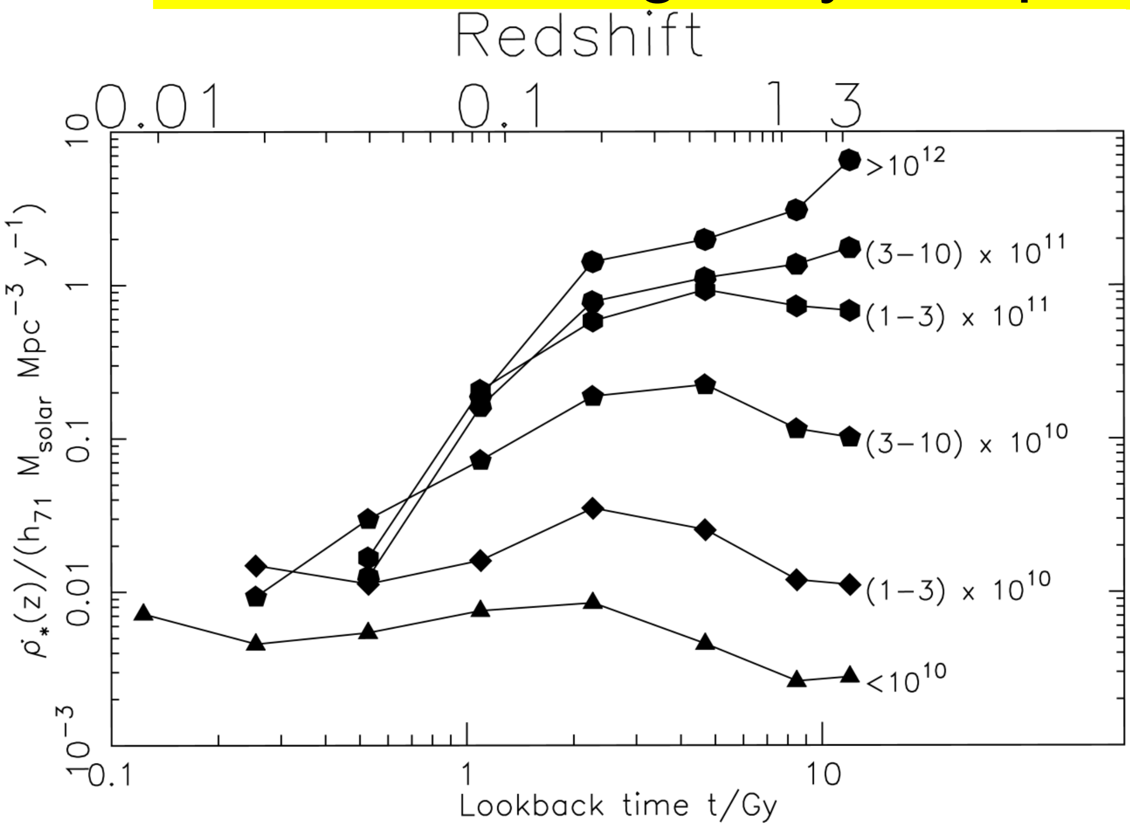
Similar to: stars, sparkling firework, nuclear fuel, …
Top-down as functional differentiation (機能分化)

Opposite to: lives, variable stars, LCDM cosmology (theory), …
Bottom-up as disordered aggregation (要素凝集)

→ galaxy formation as functional differentiation !

2. Various aspects of Cosmic Downsizing

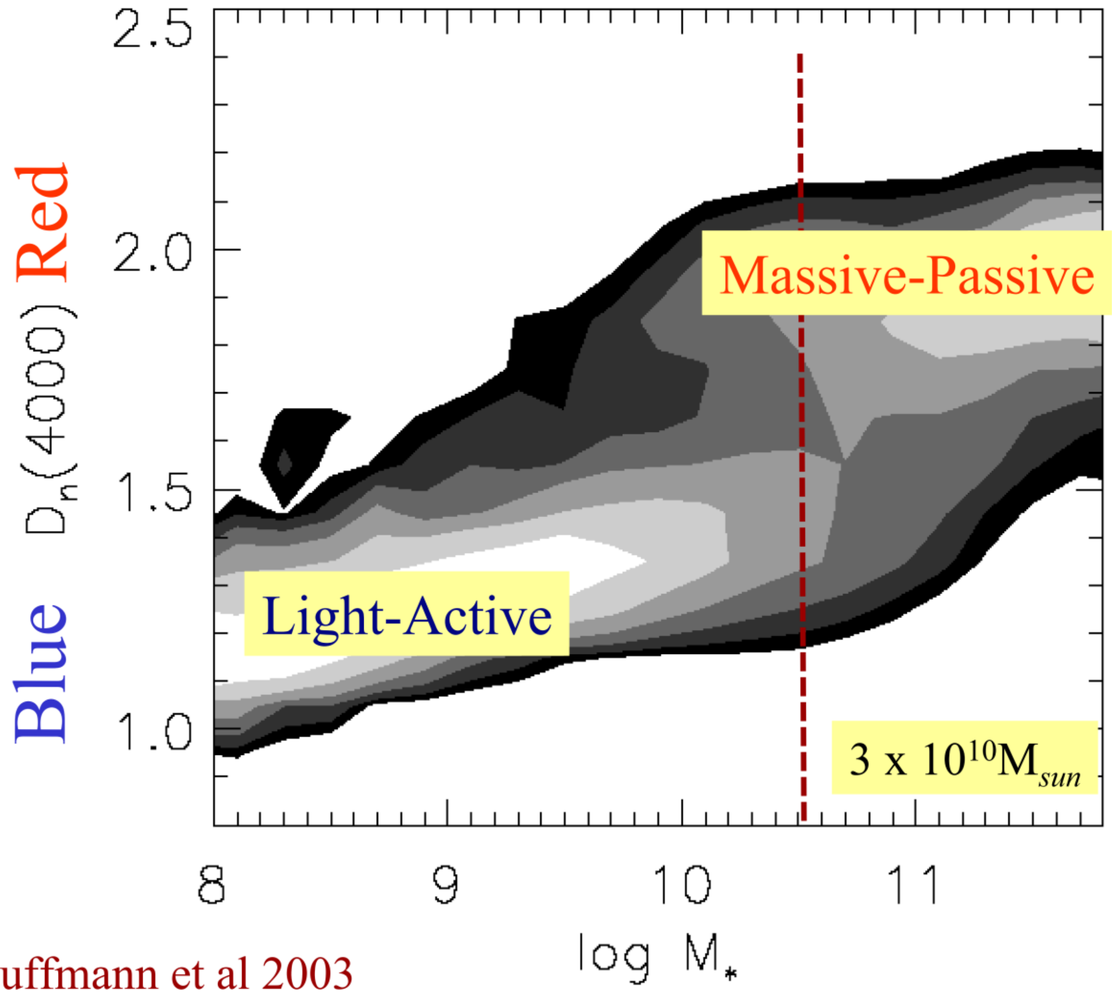
★ More massive galaxy completes the star formation fast.



Heavens et al. 2004

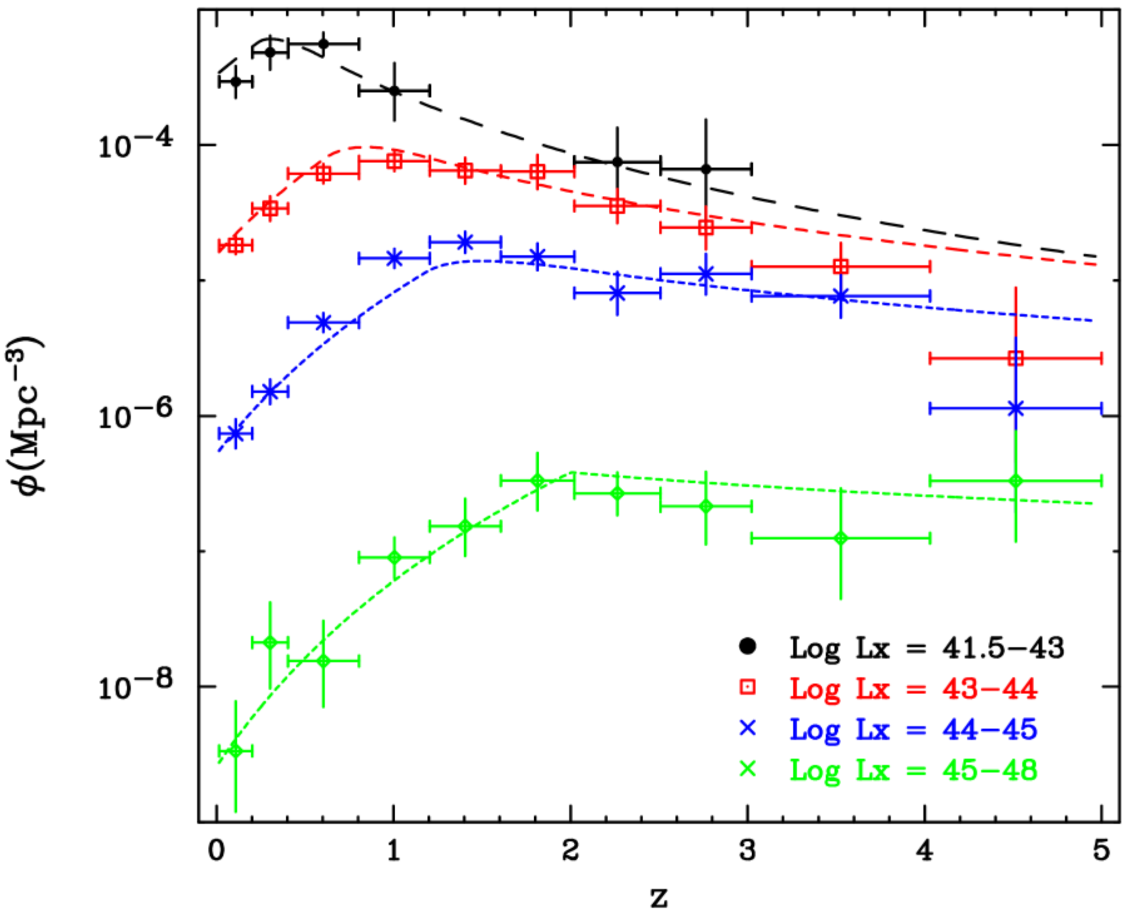
★ More massive galaxy is redder.

i.e. more massive galaxies host older stellar populations



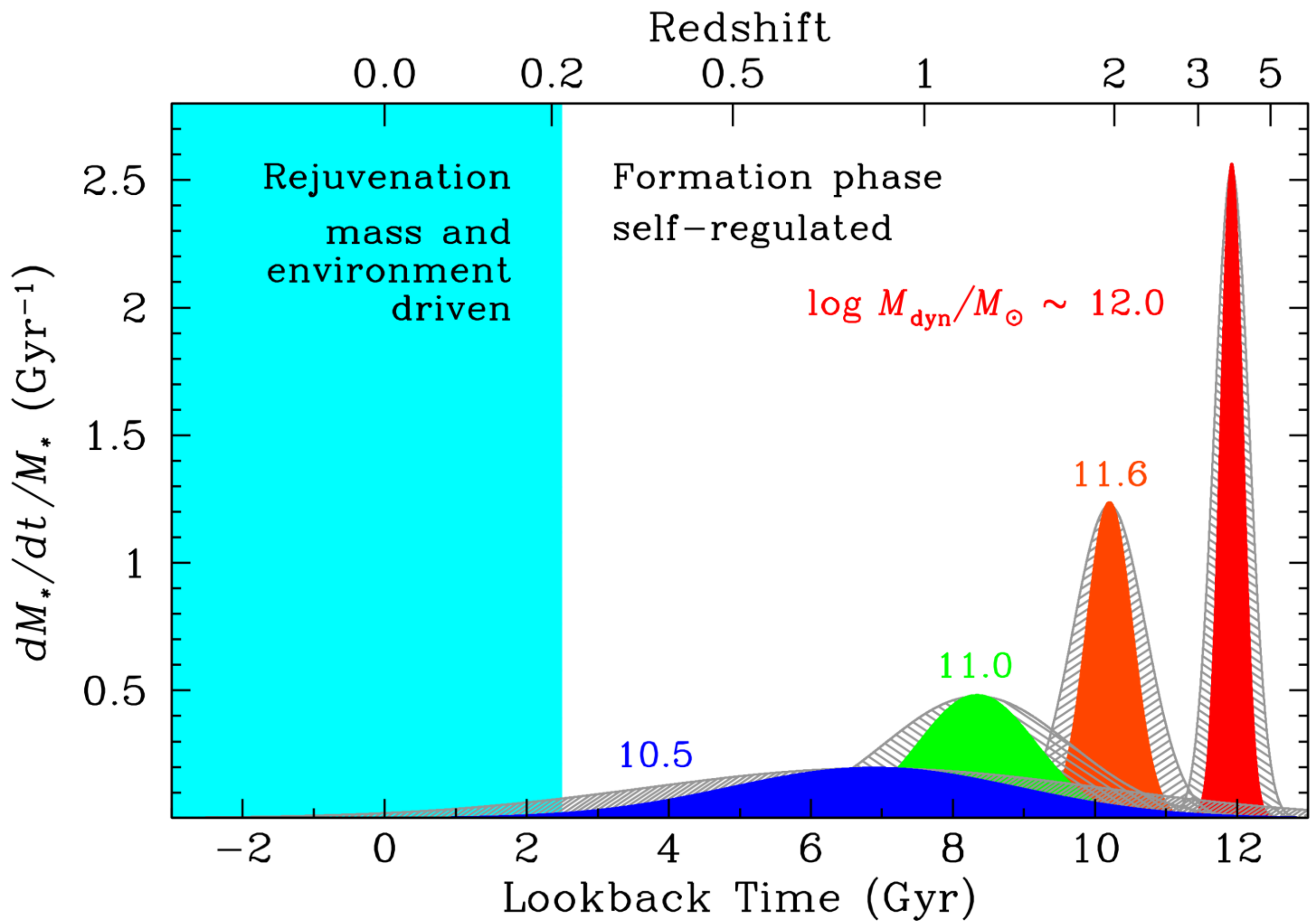
Kauffmann et al 2003

★ More luminous AGN peaked at higher z.
i.e. More massive BH formed earlier.



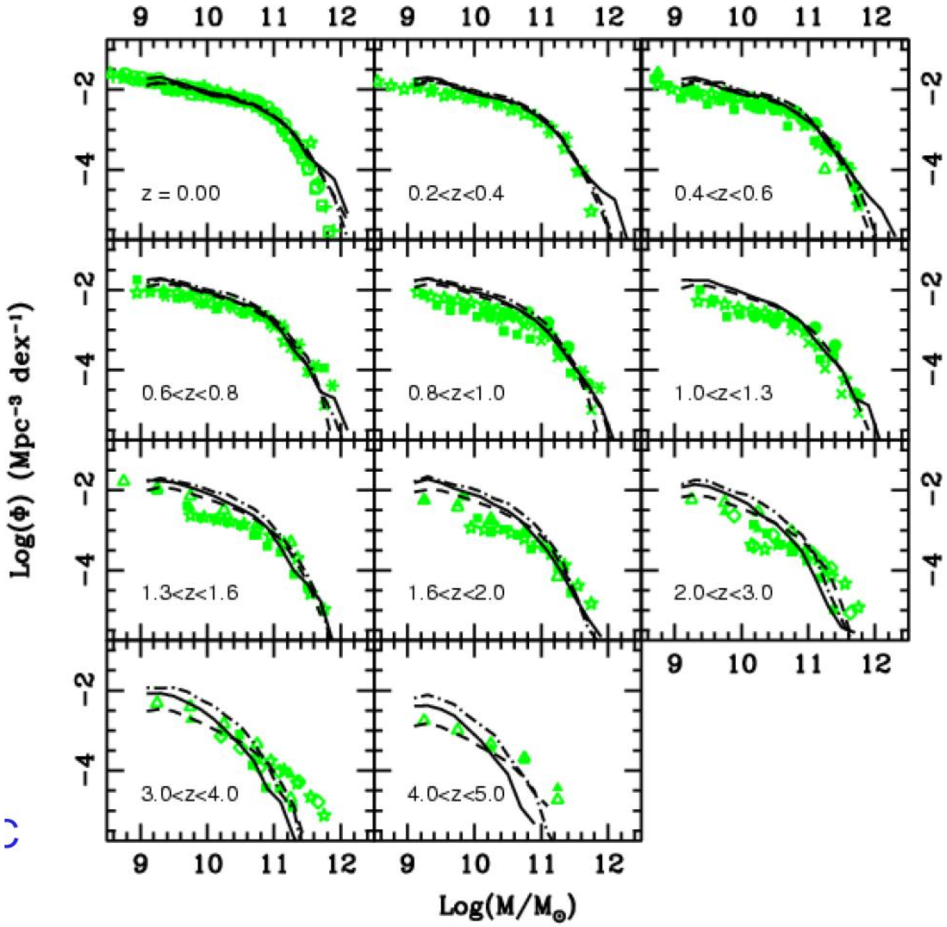
LADE (Aird+ 2010)

★ the mass of the typical SF galaxy grows with z.



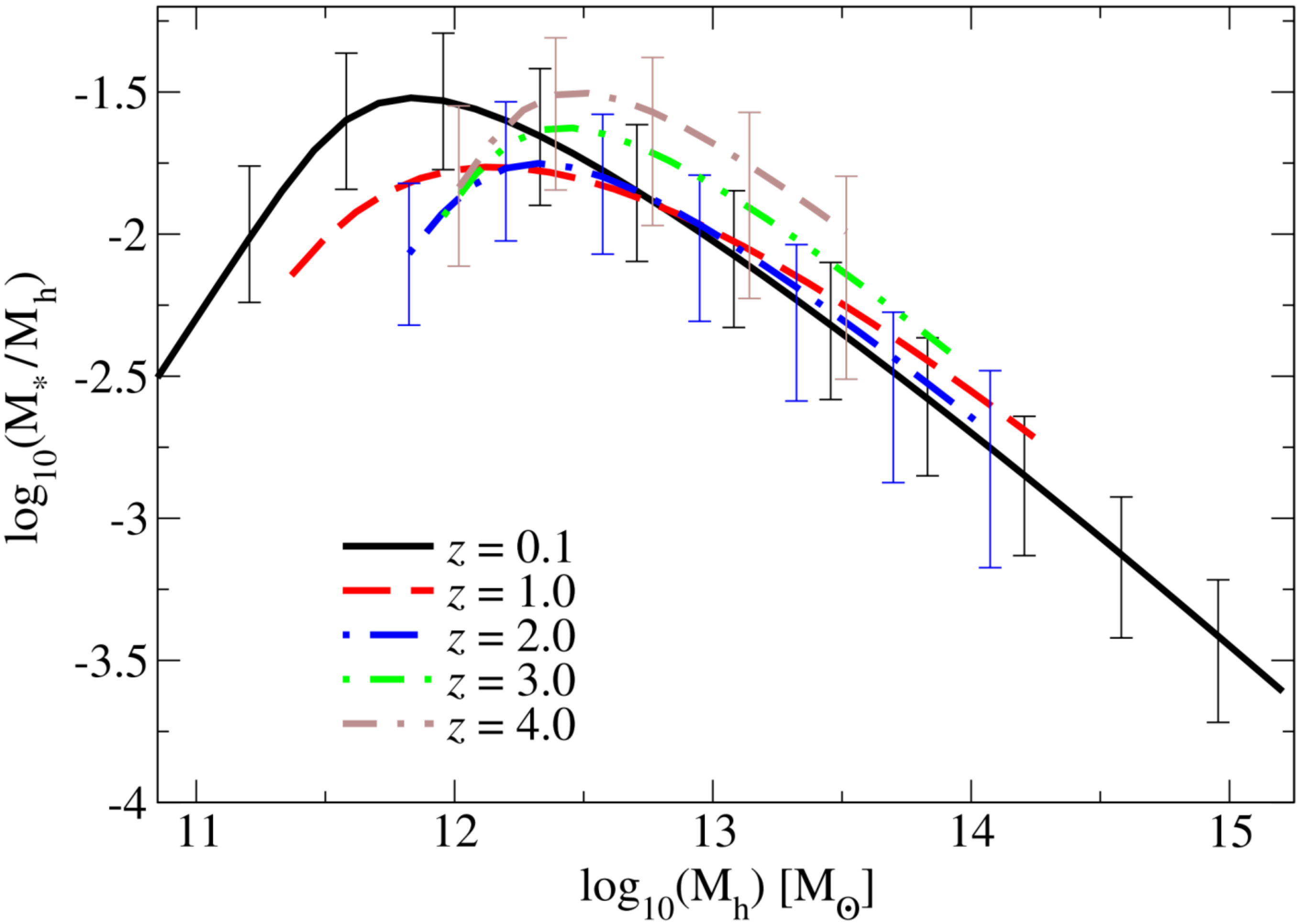
https://arxiv.org/abs/0912.0259v2

★ at z≲1, the number density of smaller galaxies evolves faster



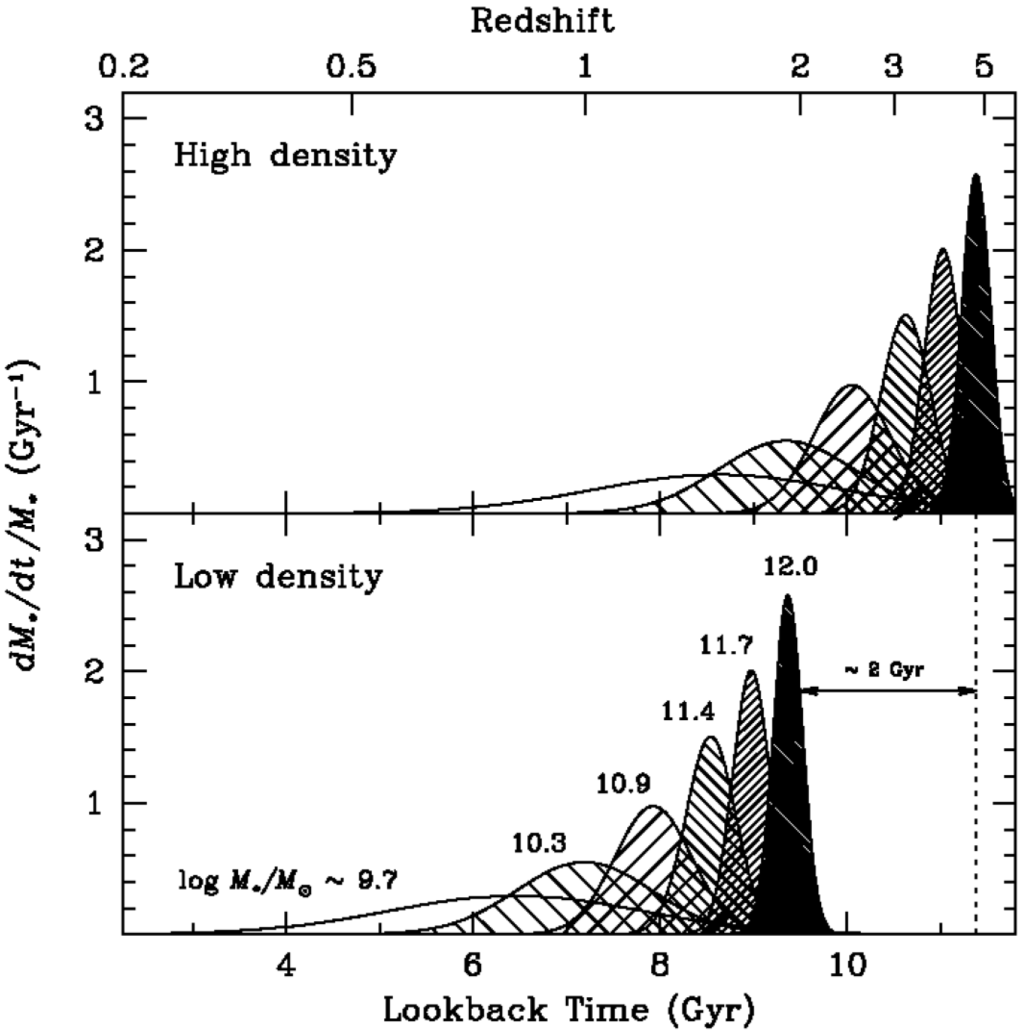
Fontanot et al. (2009)

★ More massive galaxy has higher M_* / M_h peaks earlier



Apj717 379 P. S. Behroozi 2010

★ Galaxies evolve faster in higher density environment



Thomas et al. (2005)

◆ DS from (L)CDM model?

Standard LCDM model:

- Small structures form first $\leftarrow$"C" i.e. pressure=0, $\lambda_J = 0$
- These DM halos ($10^6 M_\odot$) merge to form galaxies($10^{11} M_\odot$)

$\rightarrow$ Quite opposite to the Downsizing!

Any bias is needed for rapid merger w/o SF at $t \sim 0.8 Gy$

◆ DS from L(CDM) model

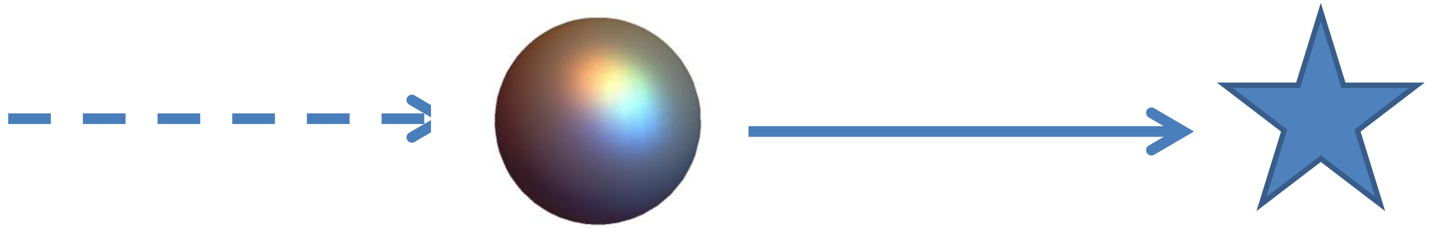
Natural solution is needed based on LCDM.

CDM…OK

L…?? Is it always uniform?

1. Unstable L model based on DE=BEC
   i.e. coherent classical field collapses into SMBH
2. SMBH form variety of galaxies.

$z \approx 10 - 20$



【Our assumption】 SMBH forms first and nurtures a galaxy

- Usually they are thought to have coevolved, but mature SMBH appeared too early:

$z = 6.3,\ M_{SMBH} = 12 \times 10^9 M_\odot$ Xue-BingWu et al., Nature14241 etc.

$z = 7,\ M_{SMBH} = 2.0 \times 10^9 M_\odot$ De Rosa et al.2014, ApJ, 790, 145 etc. etc.…

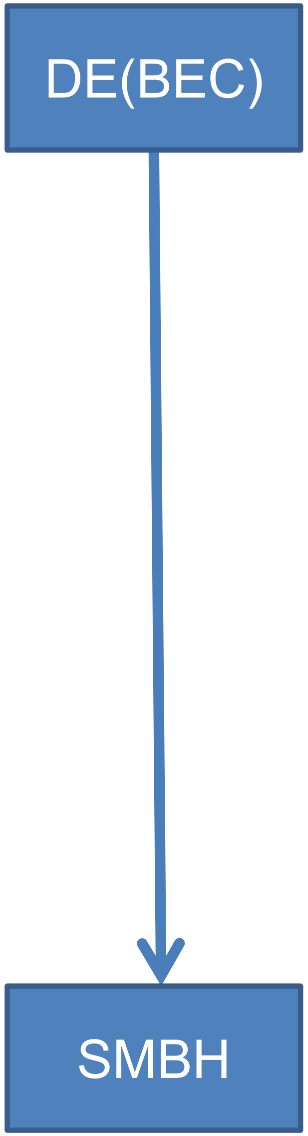
- Boson: If $M > M_{kaup} \equiv 0.633 \dfrac{\hbar c}{Gm} \approx \dfrac{{m_{pl}}^2}{m}$, collapse cannot be avoided.

- cf. critical phenomena of BH: Choptuik1993, Gundlach2007

$$M_{BH} \propto (p - p_*)^\gamma$$

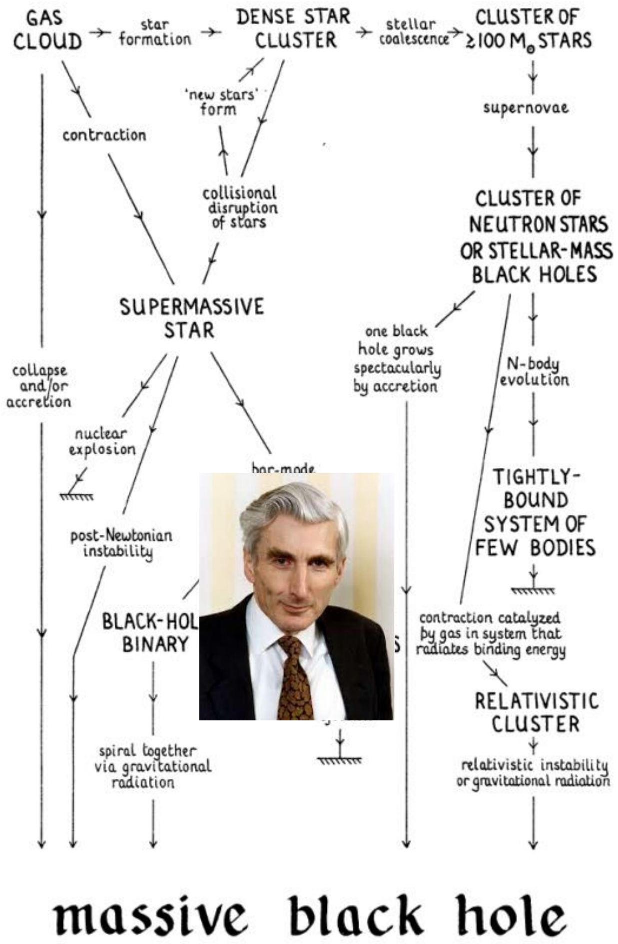
BEC easily collapses to form SMBH

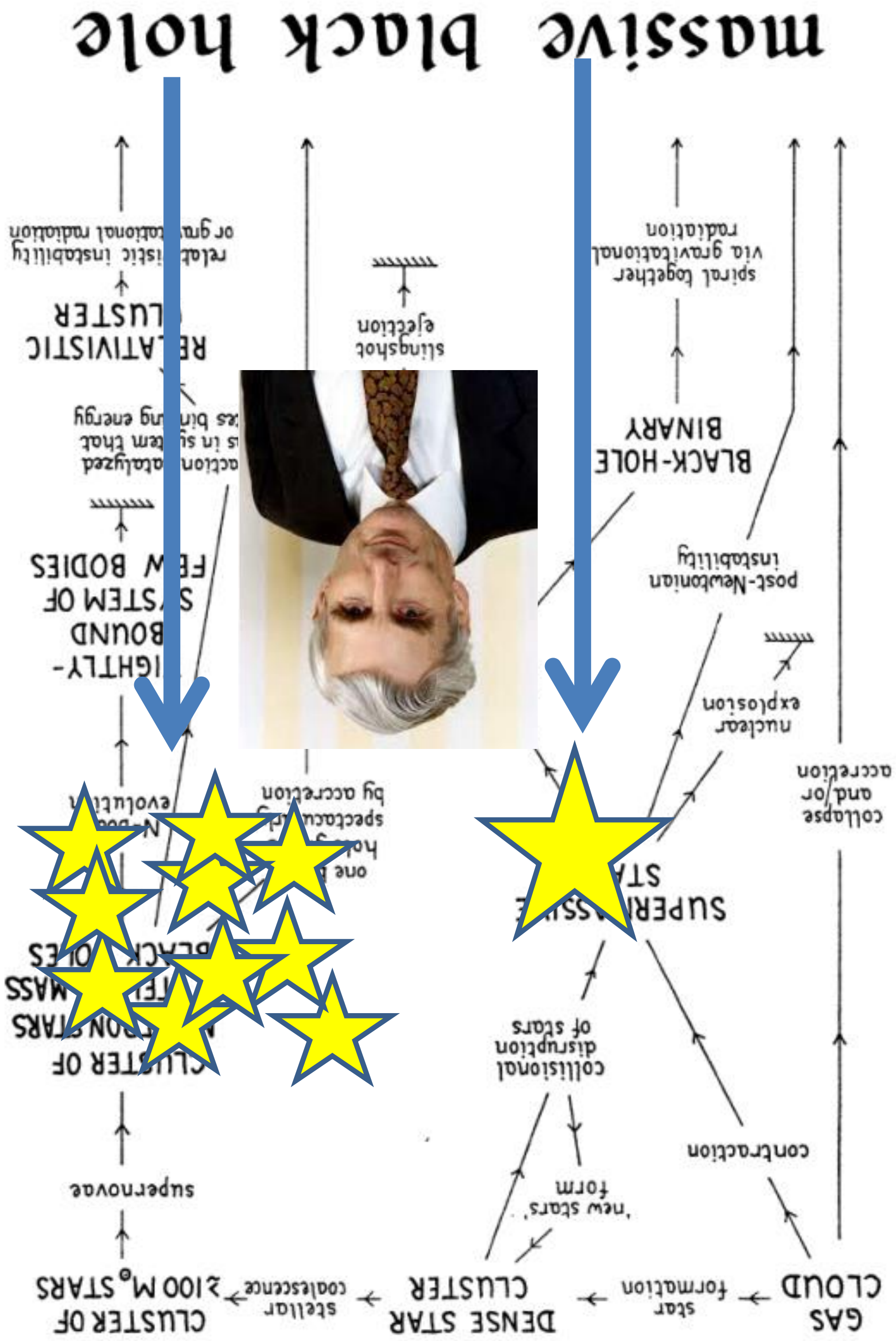
Updated Rees chart 2017



Rees chart 1978

How to make SMBH



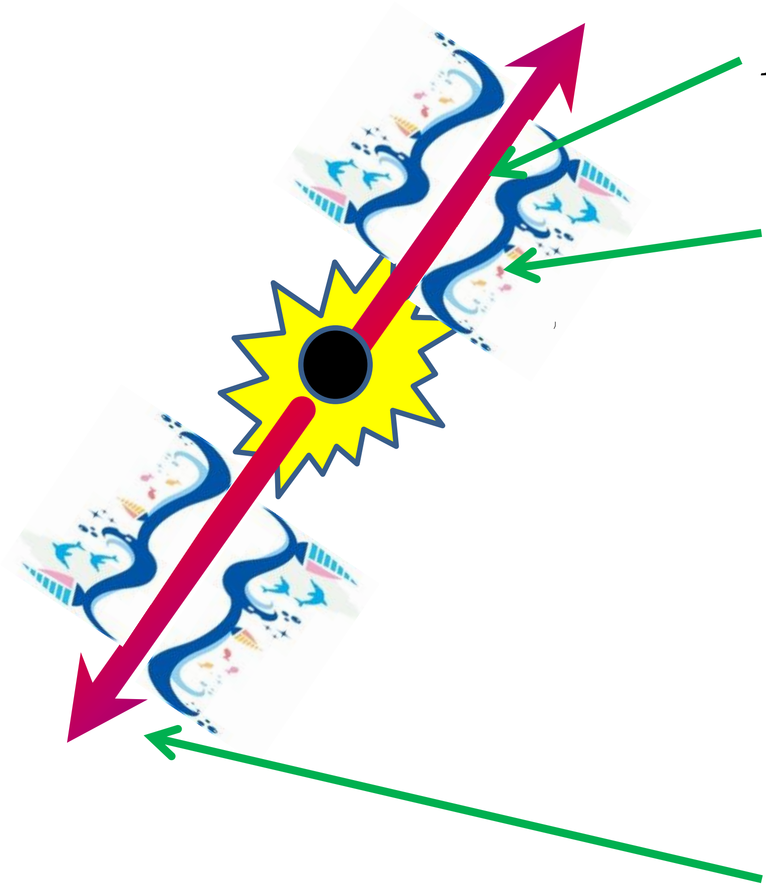


Reversed Rees chart

How the SMBH form stars and galaxies

Terribly Sorry, Prof. Rees!

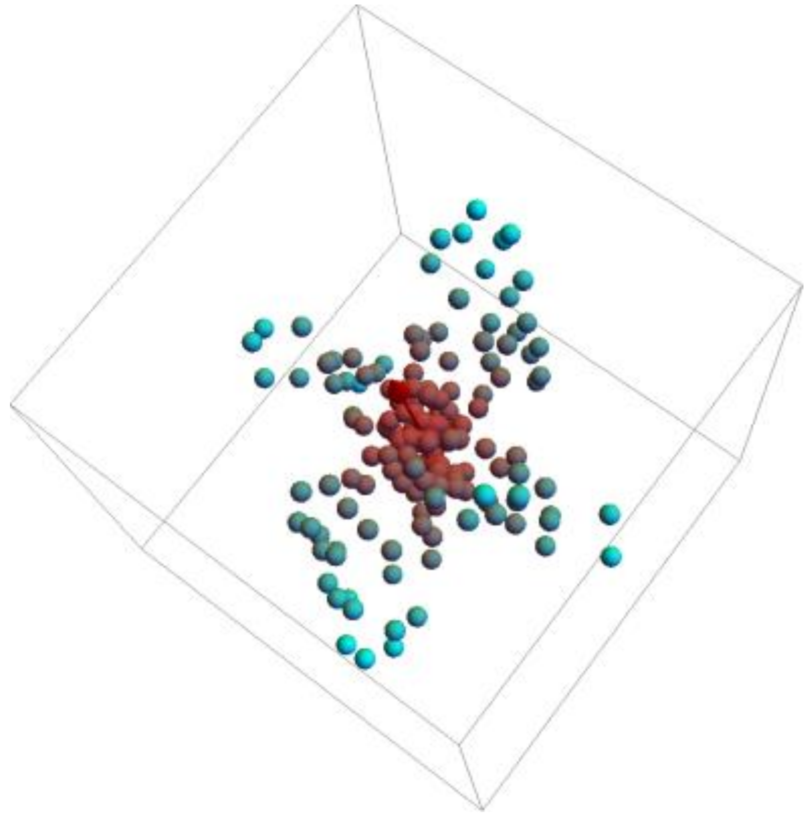
◆SMBH → Jet → Shock wave → SF (Inside the jet, hot)
→ Activates Jet



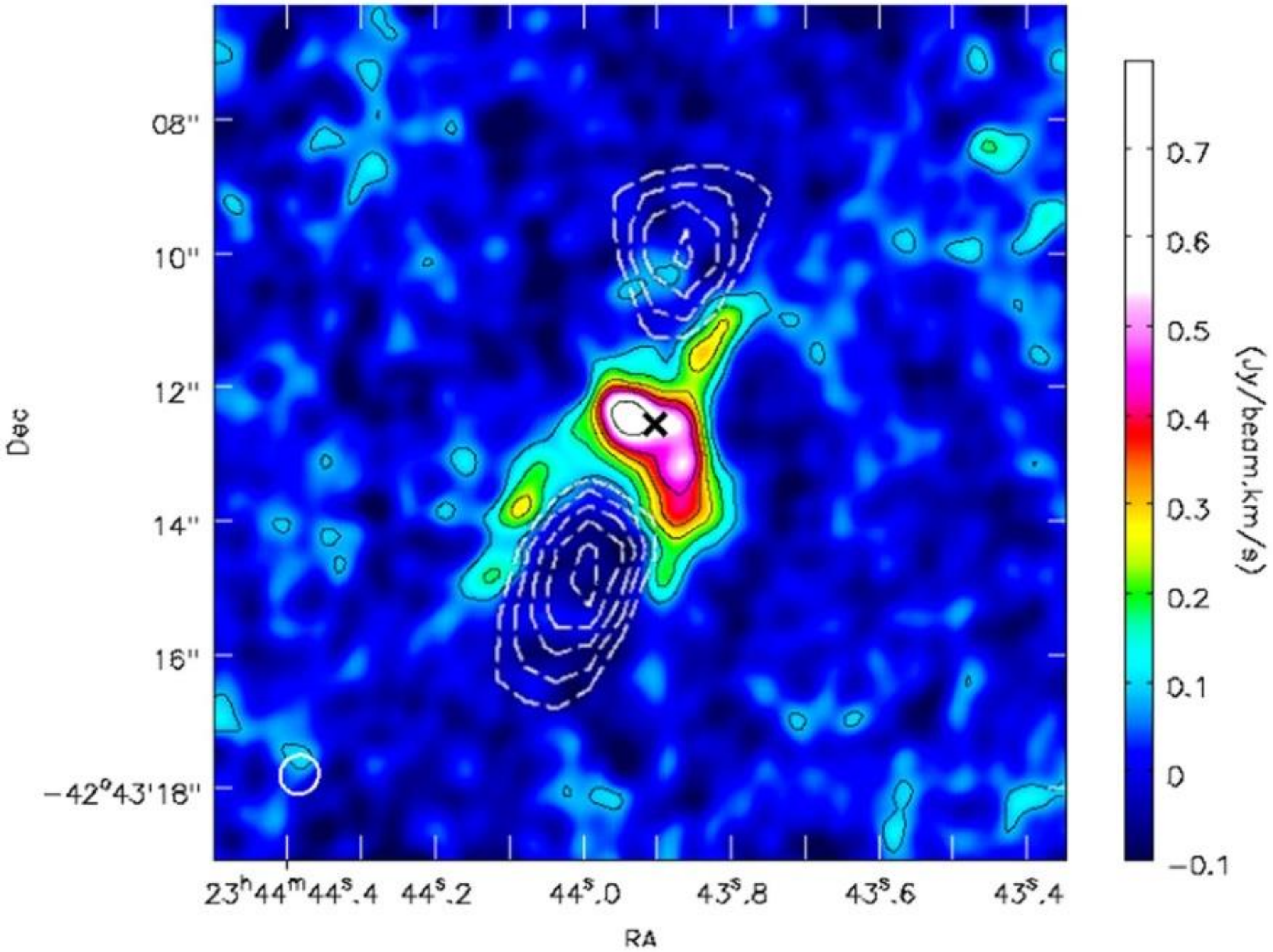
$$M_{BH} = \frac{f\kappa\sigma^5}{4\pi c G^2}$$ (energy balance)...prevent SF

$$M_{BH} = \frac{f\kappa\sigma^4}{4\pi G^2}$$ (pressure balance)...promote SF

GC？



⇒ SF Promotion & SF Obstruction coexist !



a galaxy in Fenix cluster
H. Russell, et al. 2017

CO(3-2) integrated intensity map (Cold gas)
&
X-ray cavities (McDonald et al. 2015).
(Hot gas)
Jet

3. SMBHFF model

- Our model:
  - Gas of amount G_i in the direction i ($i = 1, 2, 3..., N$ covers the whole sky) forms new stars with the rate μ, and falls toward the center, triggered by jet $\vec{J}$ from SMBH.
  - A part of them (of ratio λ) exerts torque on the SMBH yielding the shift of the jet direction.
  - New gas in that direction forms new stars that fall and exert further torque

$$\ddot{G}_i(t) = -\mu c_{conv} \left| \vec{J}(t) \right| G_i(t) - \dot{G}_i(t)$$

$$\dot{\vec{J}}(t) = -\lambda \vec{J}(t) \times \sum_i \dot{G}_i(t) - \kappa \vec{J}(t)$$

μ: SFR…environment

λ : acc rate…intrinsic

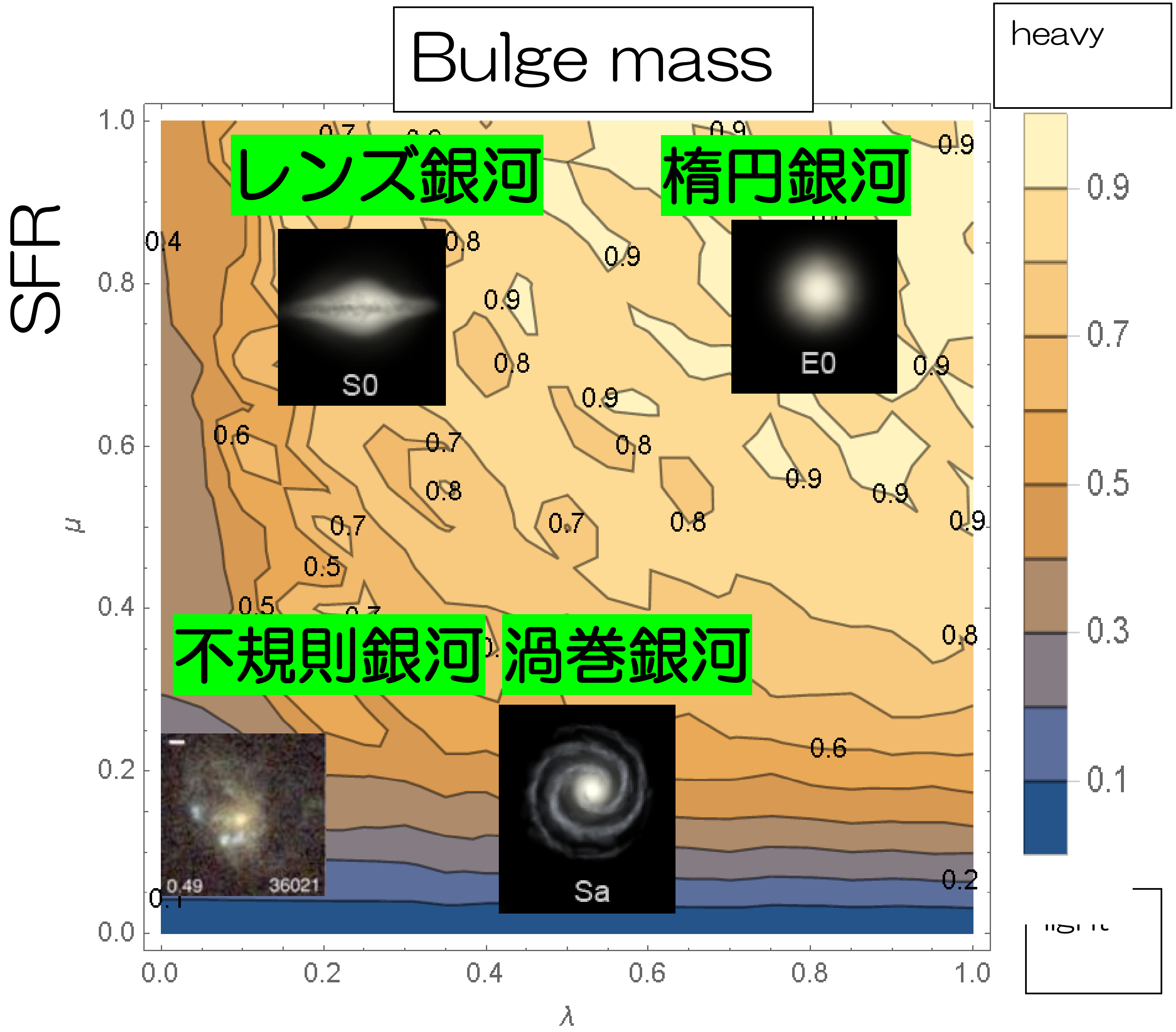
J-G, Feedback model

◆ variety of galaxies

Ellipticals:
…if gas exhausted
jetflippingElliptical.avi

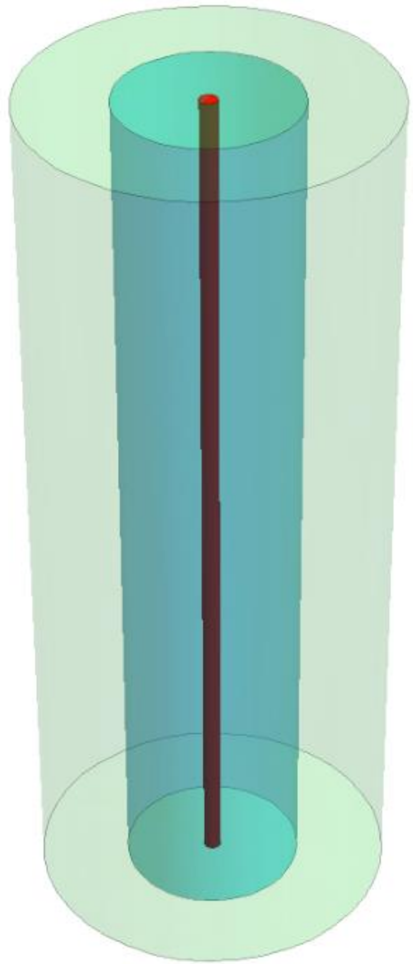
Spirals:
…if gas remains
jetflippingSpiral.avi

i.e.
Percolation
phase separation



4. Downsizing 1

- The SMBH emits energetic jet that is narrow and long.
- This jet heats up the ambient gas, which rapidly expands in almost the cylindrical symmetric form.
- Thus the gas forms a cylindrical shock wave which propagates outward.
- This shock wave compresses the ambient gas and triggers the star formation (momentum driven shock).



Shock wave from jet forms stars:

$$\frac{d(M_R \dot{R})}{dt} = -\frac{G M_R M_{gly}}{r^2} + \frac{\triangle l}{2 l_{max}} \frac{\eta L_{edd}}{c}$$

Where

$$M_R = \triangle l \ \sigma_R = \triangle l \ 2\pi \int_0^R \rho(R) R dR$$

$$\rho(r) = \rho_0 r^{-\alpha}$$

$$L_{edd} = \frac{4\pi G m_p M_{\mathrm{SMBH}} c}{\sigma_T} = \frac{3 c^5 G m_e^2 m_p M_{\mathrm{SMBH}}}{2 e^4 k_0^2}$$

cf. King 2003,2008

Assuming $\Delta t < t_{ff}$, the solution is

$$R\left(t\right)=\left(\frac{3}{4\pi}q\right)^{1/3}t^{2/3}$$

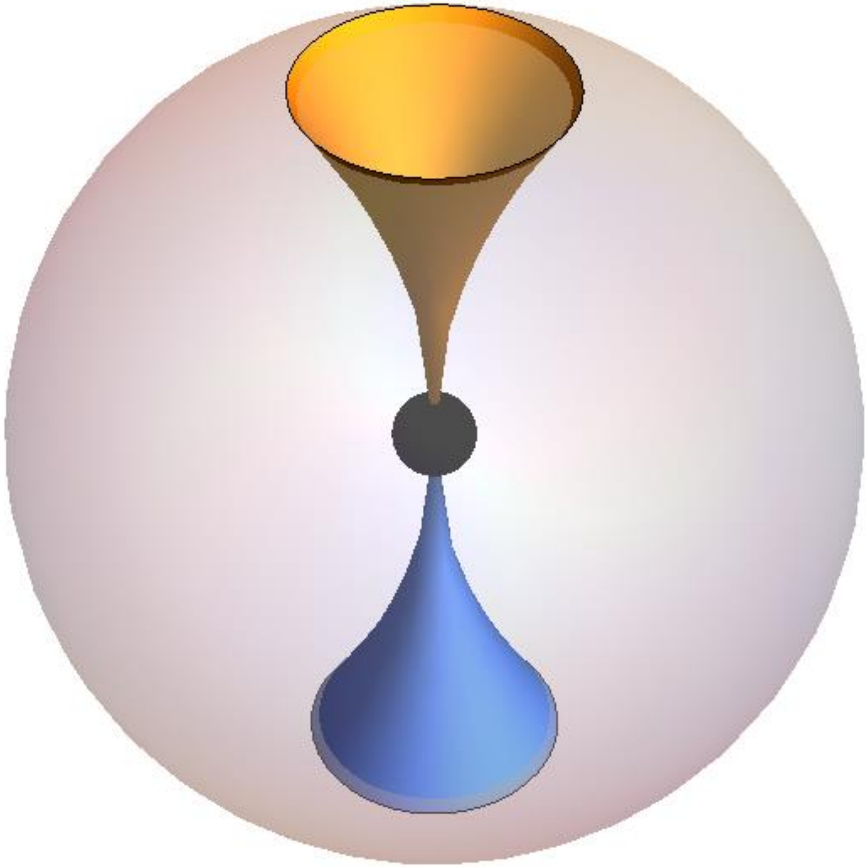
where $q \equiv \frac{\eta L_{edd} l^{\alpha}}{c\rho_0 l_{max}}$

The shock wave is assumed to stop when $v = v_S$

→ the time $t^* = \frac{2}{9\pi} q v_S^{-3}$ and

→ the radius:

$$\begin{aligned} R^* &= \frac{q}{3\pi v_S^2} \\ &= \left(\frac{16\pi}{3\left(3-\alpha\right)}\right)\eta R_{gly}\left(\frac{v_V}{v_S}\right)^2\left(\frac{m_p/\sigma_T}{M_{gly}/R_{gly}^2}\right) \\ &\times\left(\frac{M_{\rm SMBH}}{f\ M_{gly}}\right)\left(\frac{R_{gly}}{l_{max}}\right)\left(\frac{l}{R_{gly}}\right)^{\alpha} \end{aligned}$$



Suppose the stars forms within this region, then

$$SFR = \frac{1}{2\alpha + 1} \frac{q\rho_0 l_{max}^{2\alpha+1}}{l^{2\alpha} v_S}$$

From $t_{ev} SFR = f\ M_{gly}$,
Time scale of the evolution becomes:

$$t_{ev} = (2\alpha + 1)\,\frac{f\ M_{gly} v_S l^{2\alpha}}{q\rho_0 l_{max}^{2\alpha+1}}$$

This is almost independent of the galaxy size. This is NOT DS.

The failuer would be the lack of the feedback effect of the jet star formation.

Typical values:

$$R^* = \frac{2c^4\eta G l^2 m_e^3 R_{\rm gal} m_p M_{\rm SMBH}}{e^4 f k_0^2 k_B M_{\rm gal} T_{\rm gas} l_{\rm max}} = 0.57kpc$$

< galaxy size.

$\rightarrow$ Cylinder app. OK.

$$t^* = 0.95 \times 10^6 year$$

< $t_{ff} = 1.49 \times 10^7 year$

$\rightarrow$ gr. Neglected OK

$$MFSF = 5.46 \times 10^{-4}$$

$$SFR = 56.9 M_\odot / year$$

$$t_{ev} = 1.76 \times 10^9 year$$

Z=2.95

For

$$\alpha = 2,\ \eta = 1,\ f = 0.1,\ M_{SMBH} = 10^8 M_\odot,\ M_{gly} = 10^{12} M_\odot$$

$$l_{max} = l = R_{gly} = 10kpc,\ T_{gas} = 10^4 K$$

5. Downsizing 2 - rough estimate of feed back

$\ddot{G}_i = -\mu \left| \vec{J} \cdot \vec{n}_i \right| G_i$ yields the time scale of the gas depletion:

$\tau^{-2} \approx \mu J$ further, $\tau^{-1} \approx \sqrt{\mu J} \propto \begin{cases} \sqrt{\mu M_{BH}} \\ {\rho_{gas}}^{3/4} \sqrt{M_{\text{Bulge}}} \end{cases}$

(star formation rate $\mu \propto {\rho_{gas}}^{3/2}$ Schmit law) i.e.

1. Larger the galaxy/SMBH, more rapid formation.

2. Denser the environment, more rapid formation.

6. Downsizing 3 - numerical calculations

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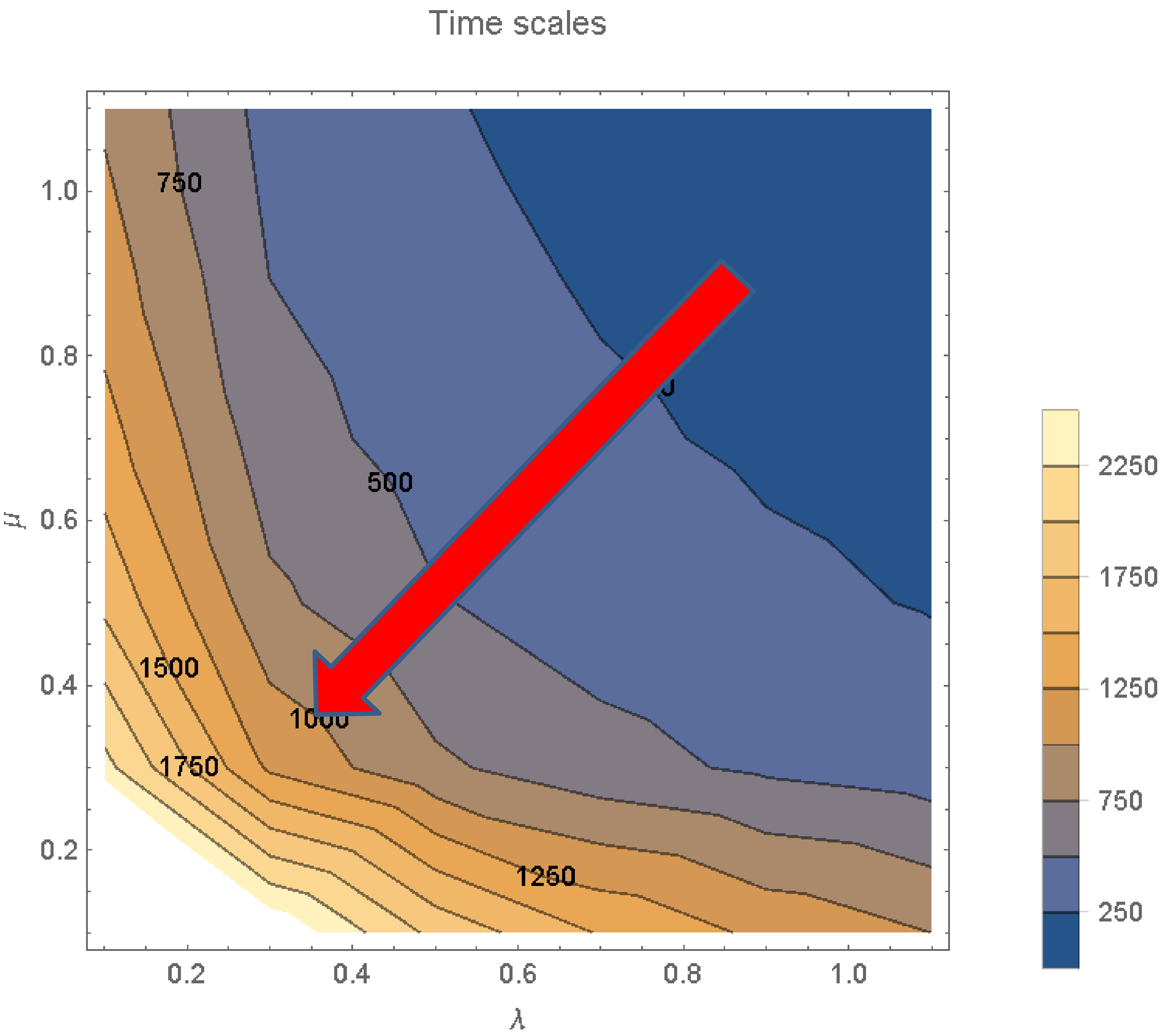
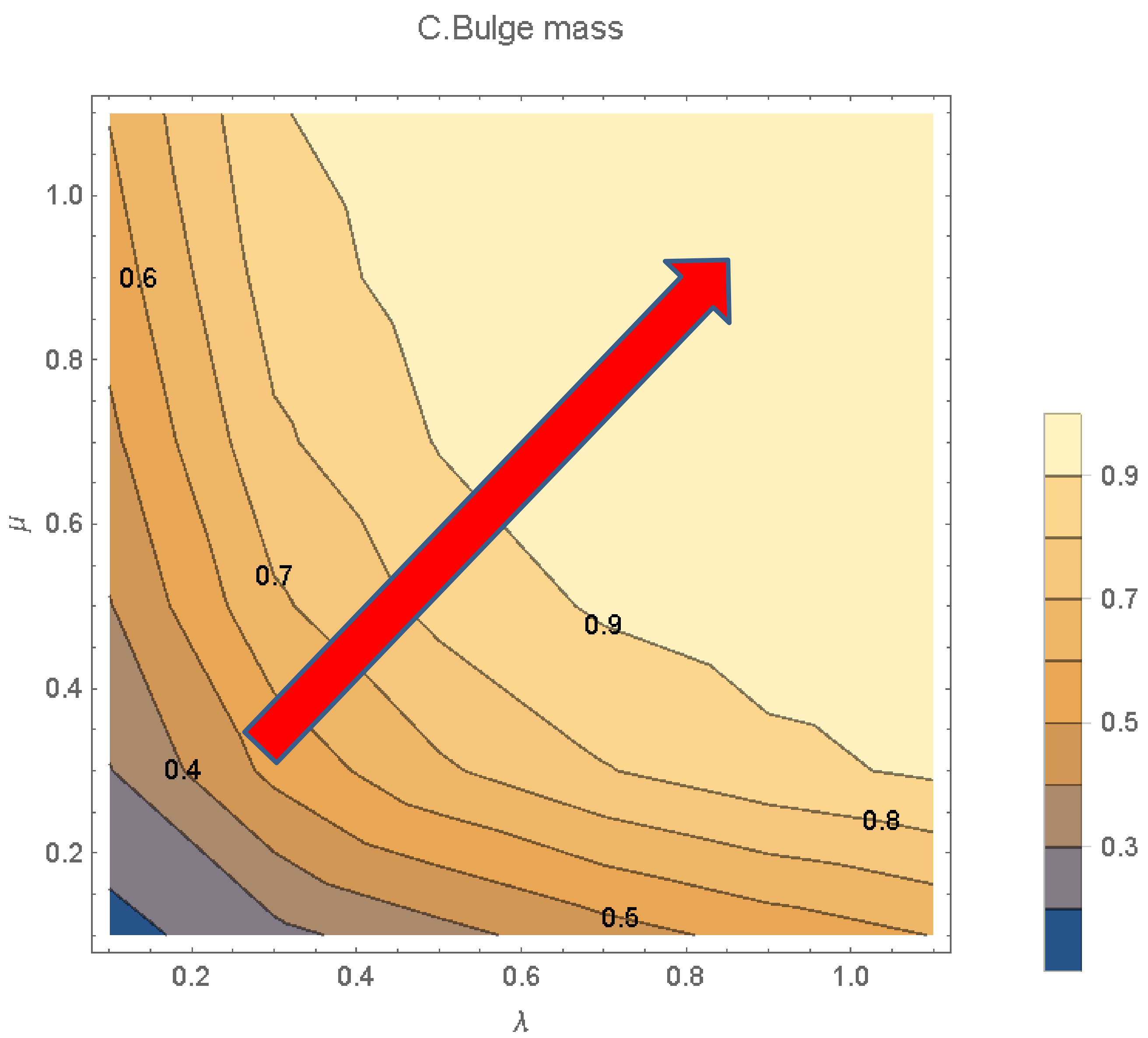
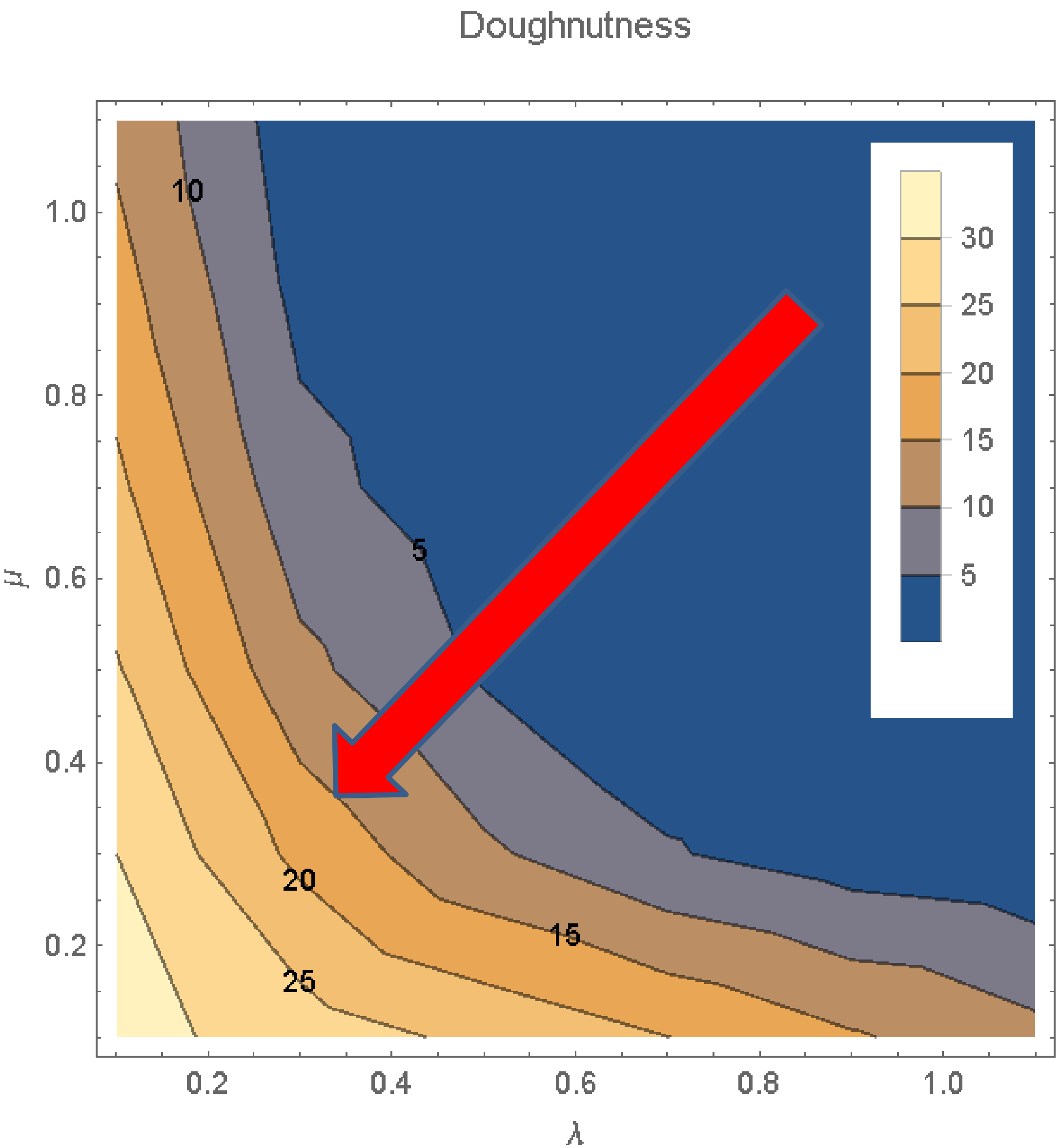




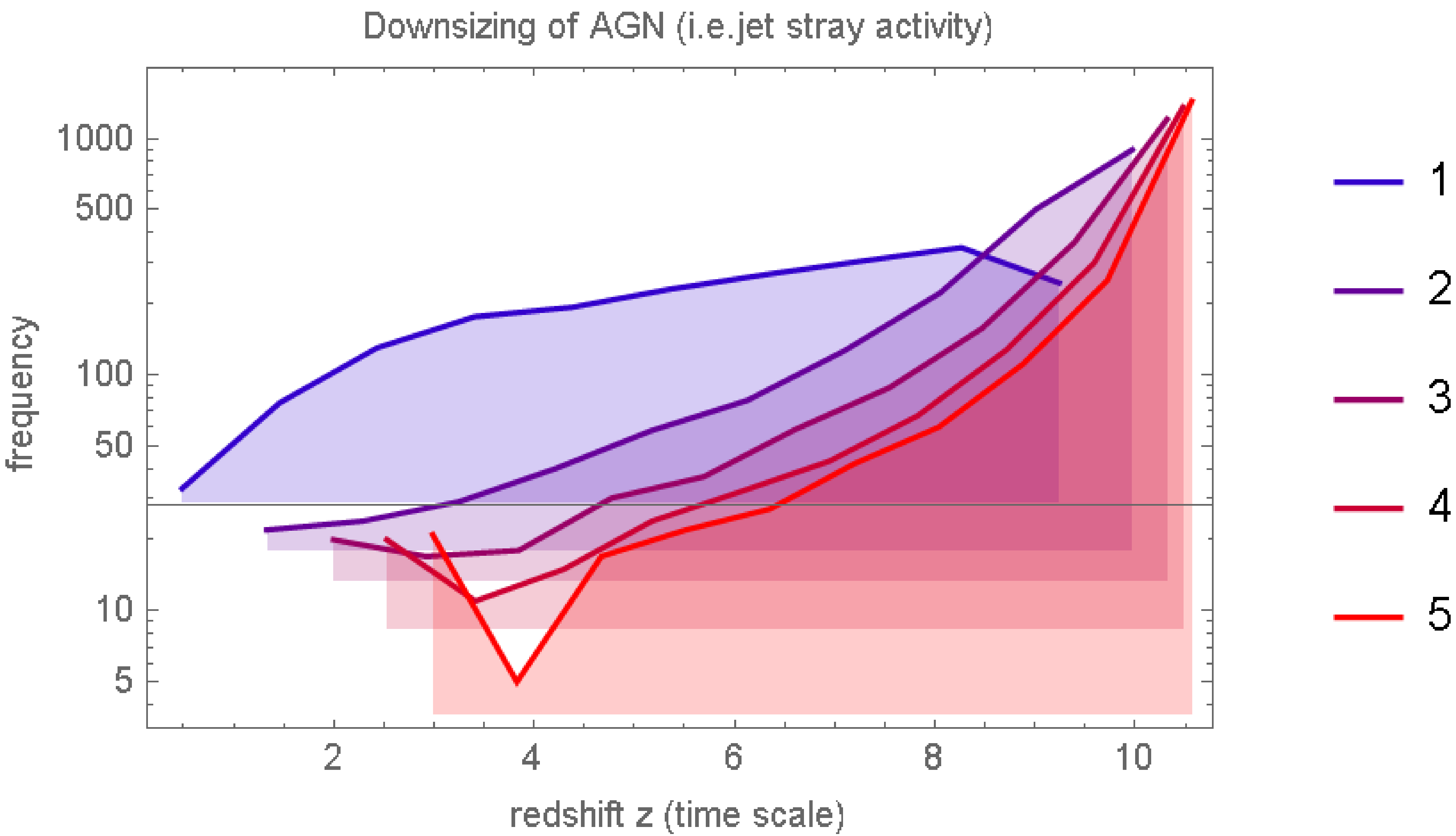
Time scale & Bulge mass → Larger galaxy evolves faster

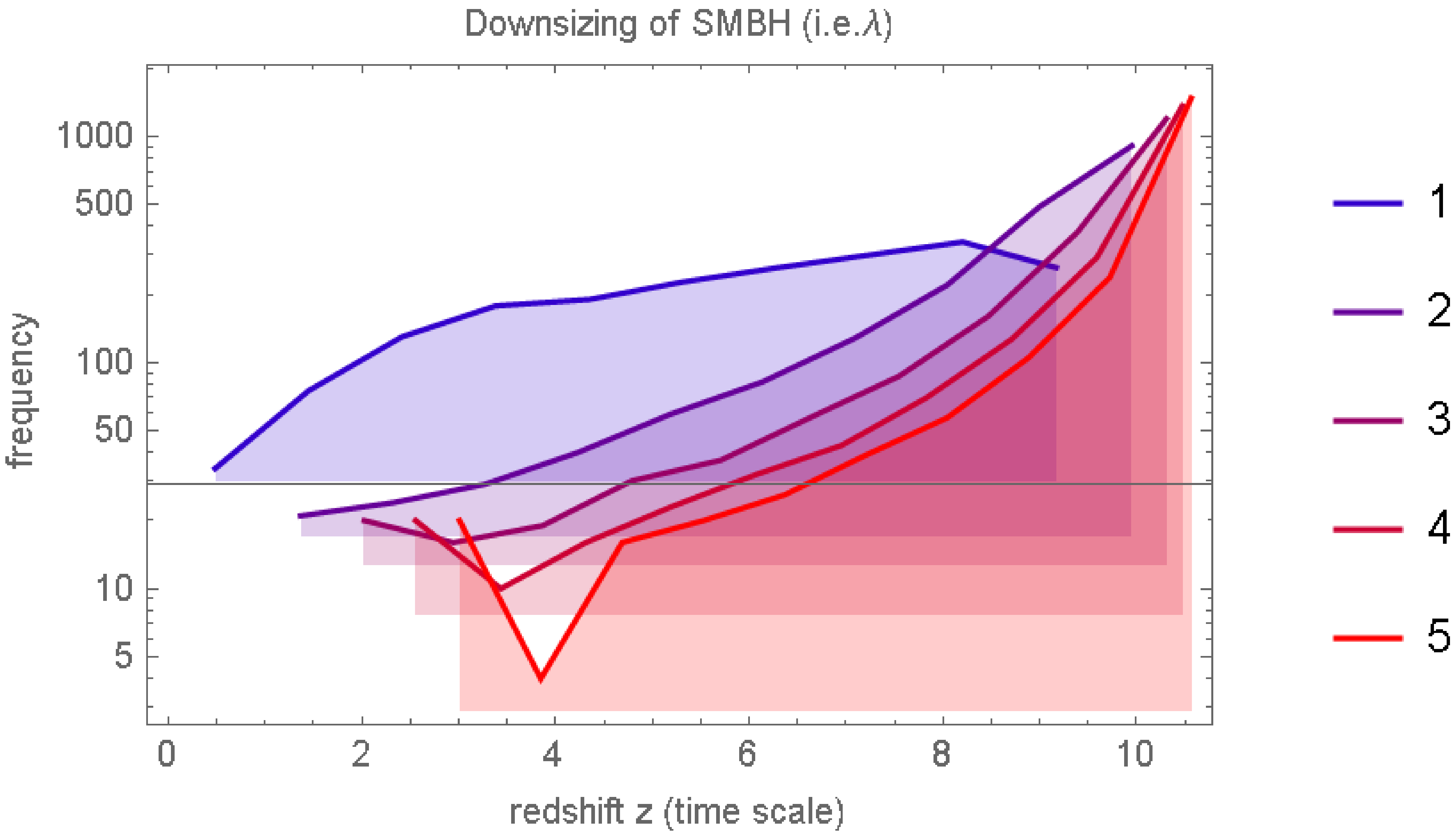


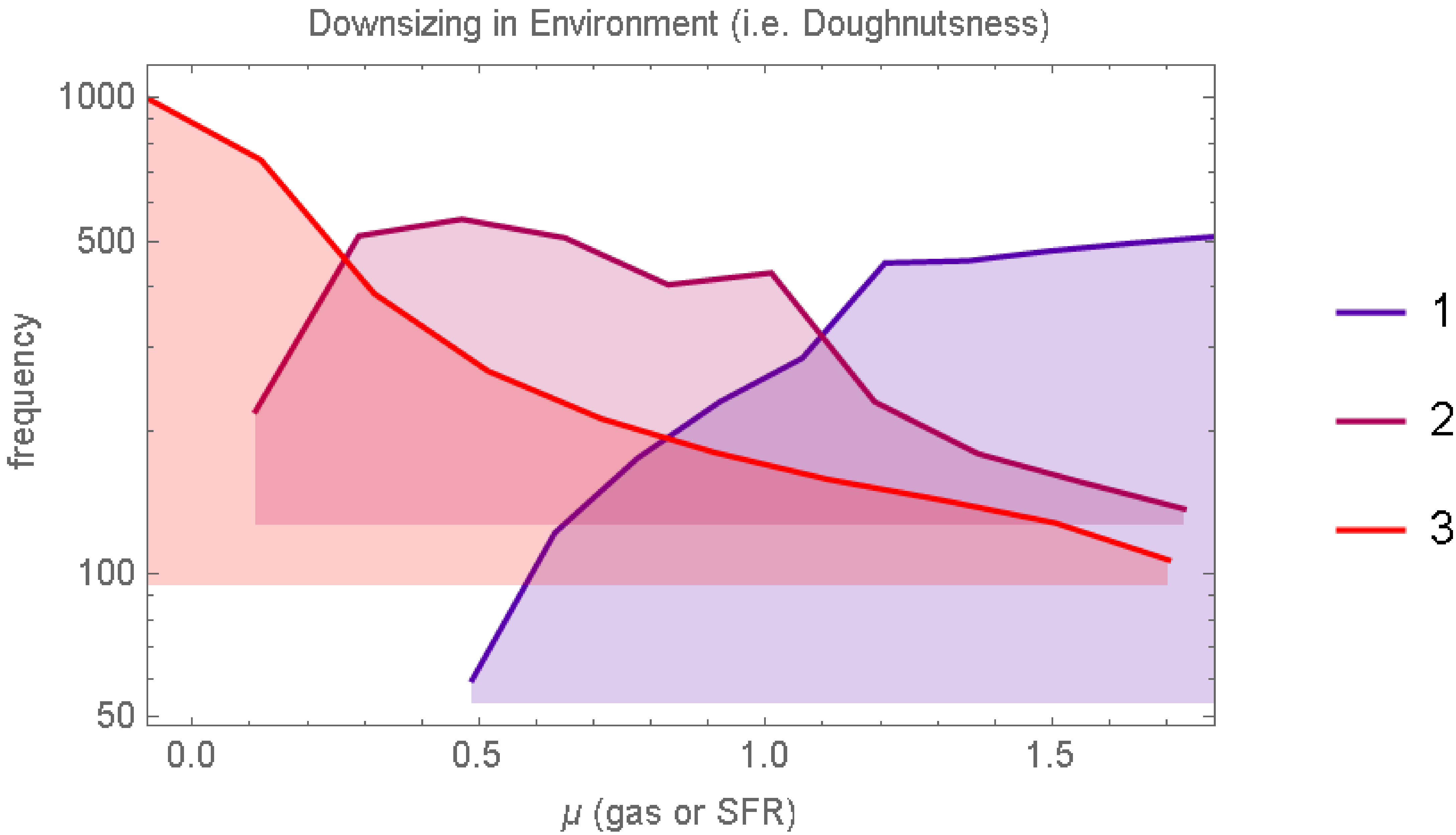
- larger j, μ, λ, means faster evolution.

- Elliptical evolves faster than Spiral.

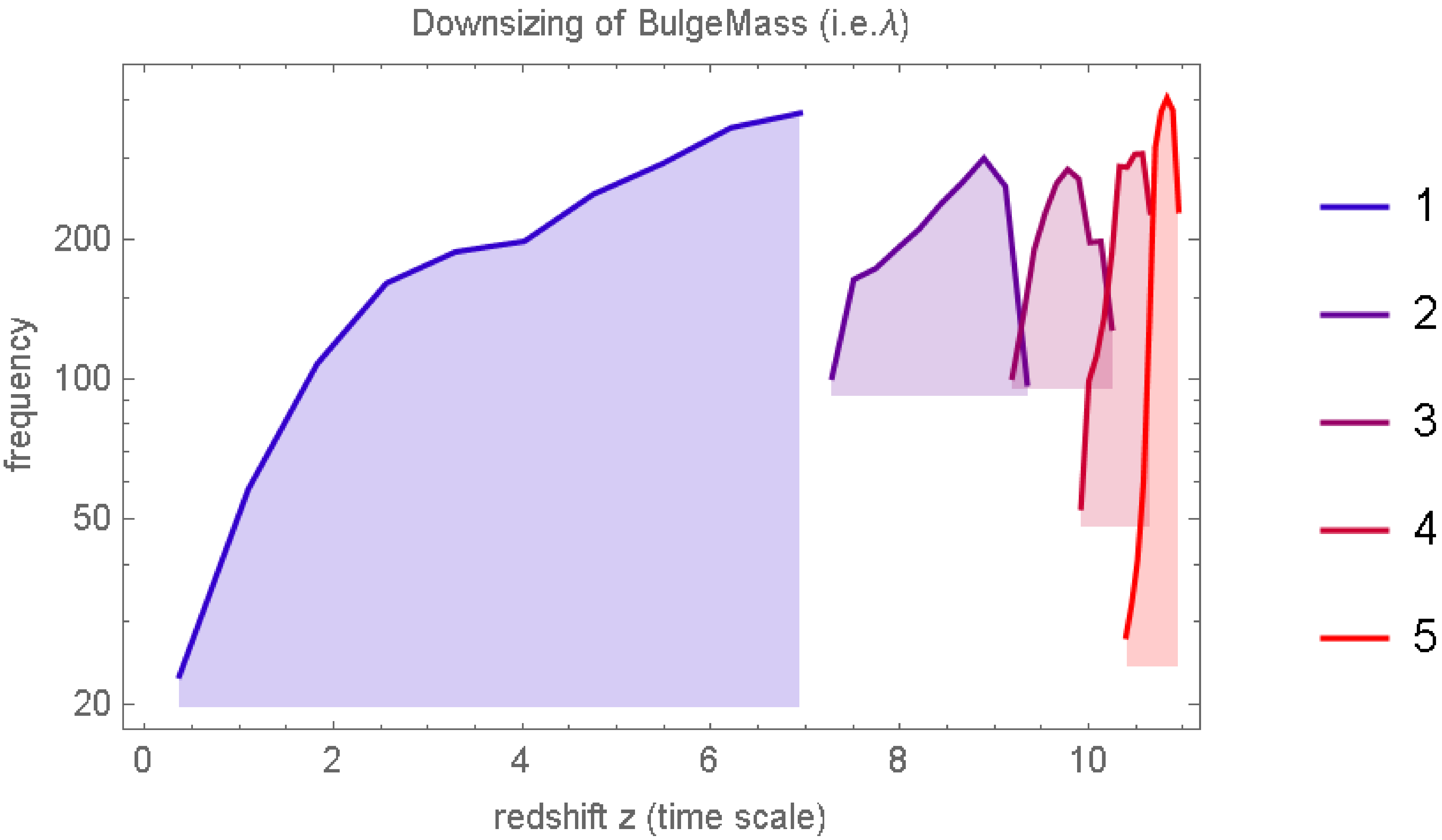
i.e. many colliding Spirals do not form Elliptical.


Downsizing of AGN (i.e.jet stray activity)
frequency
1000
500
100
50
10
5
2
4
6
8
10
redshift z (time scale)
1
2
3
4
5


Downsizing of SMBH (i.e.λ)
frequency
1000
500
100
50
10
5
0
2
4
6
8
10
redshift z (time scale)
1
2
3
4
5



Downsizing in Environment (i.e. Doughnutsness)
1000
500
100
50
frequency
0.0
0.5
1.0
1.5
μ (gas or SFR)
1
2
3


Downsizing of BulgeMass (i.e.λ)
frequency
200
100
50
20
0
2
4
6
8
10
redshift z (time scale)
1
2
3
4
5

7. Summary and prospects

【conclusions】

- galaxy formation based on primordial SMBH is possible

- “L”CDM model → DE field decays →SMBH→Jet→stars

- Downsizing is naturally associated with this model.

- Origin of DS is the strong feedback J ⇔ G

- Physics behind is the percolation phase separation: Ell&Sp…

- Numerical calculation is possible based on the minimal model.

【comments】basic problem for SMBH/galaxy/DS

1. Why SMBH rapid evolution at z=7?

   → *DE (if attractive BEC) can collapse to form SMBH*

2. Why there is no SMBH off center?

   → *a SMBH forms galaxy around it*

3. Why galaxies are symmetric for rotation-π?

   → *SMBH jet formed stars around it (momentum conservation)*

4. Why downsizing?

   → *jet activity (not merger) determines the time scale*