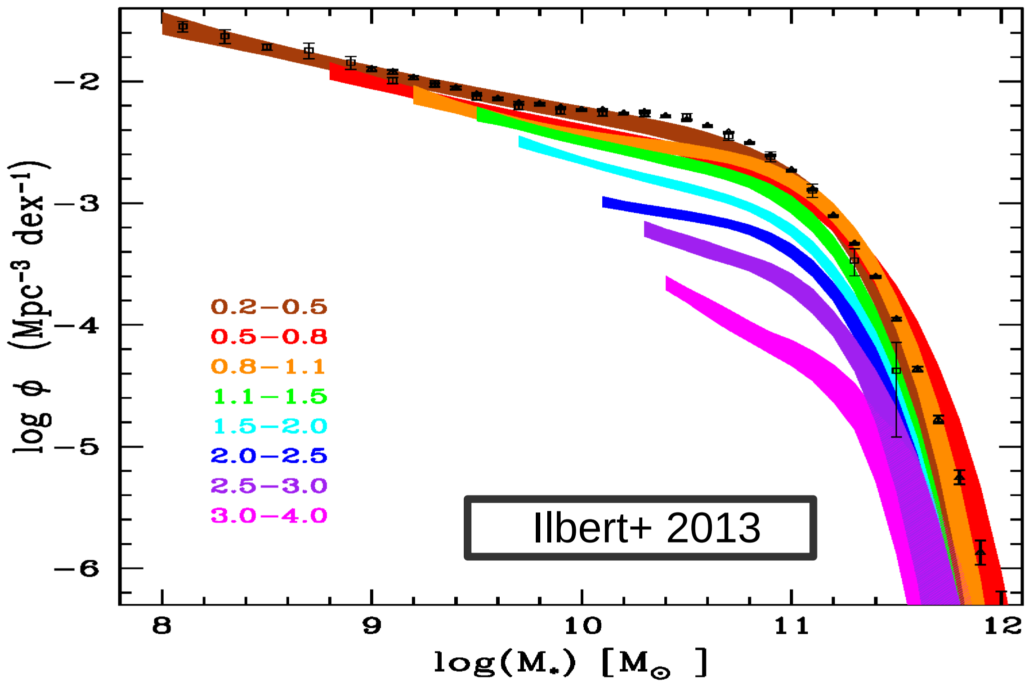
# AGN evolution from galaxy evolution viewpoint

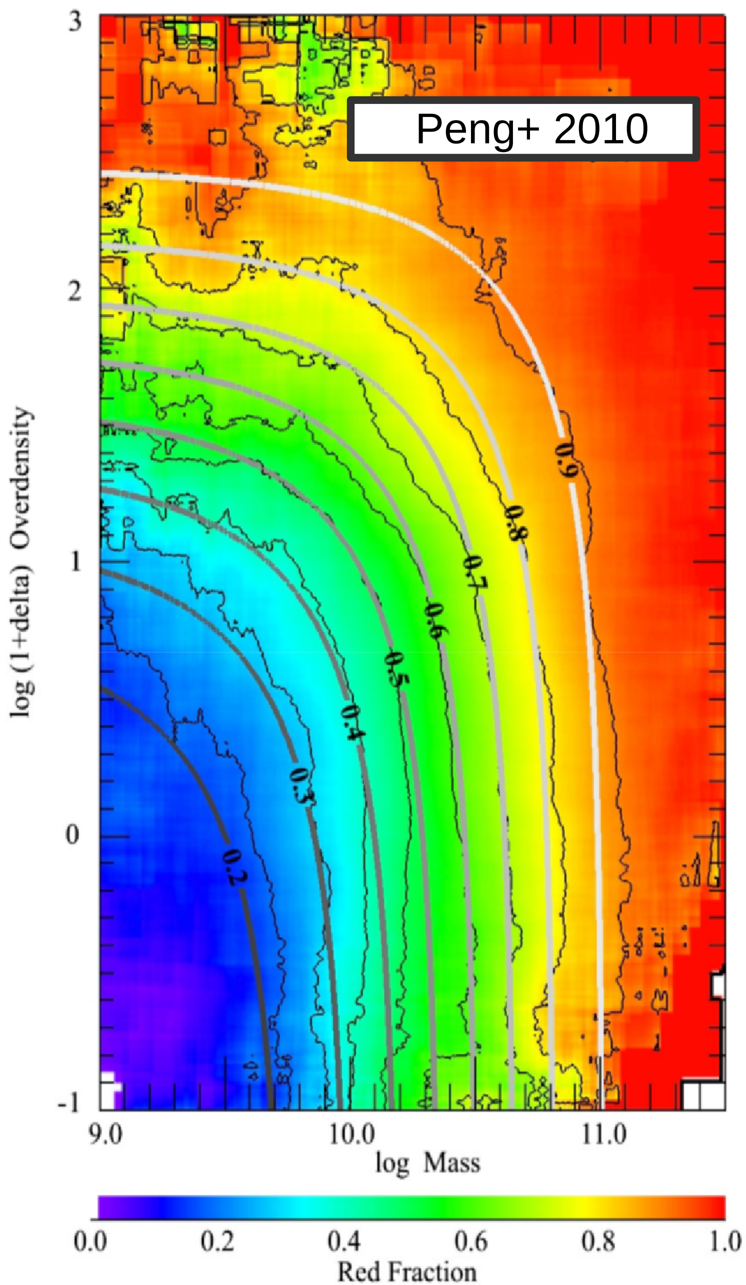
Neven Caplar, Simon J. Lilly, Benny Trakhtenbrot

ETH Zurich

# Motivation

- Great improvements in our knowledge of galaxy population



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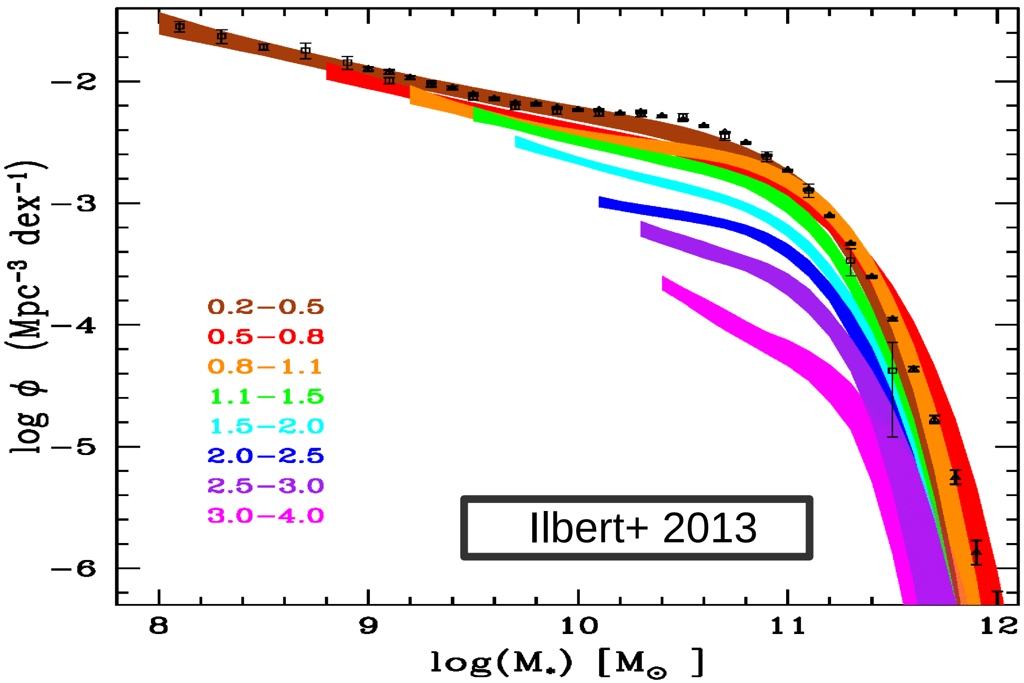
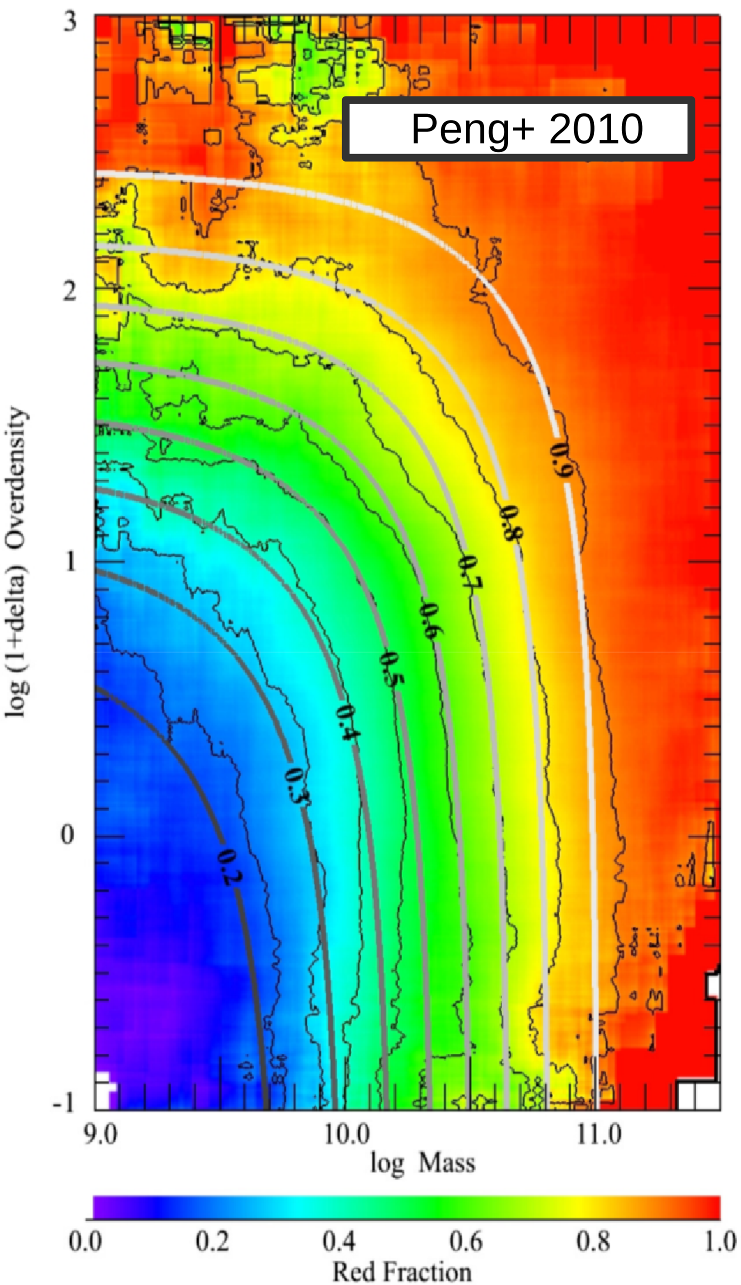
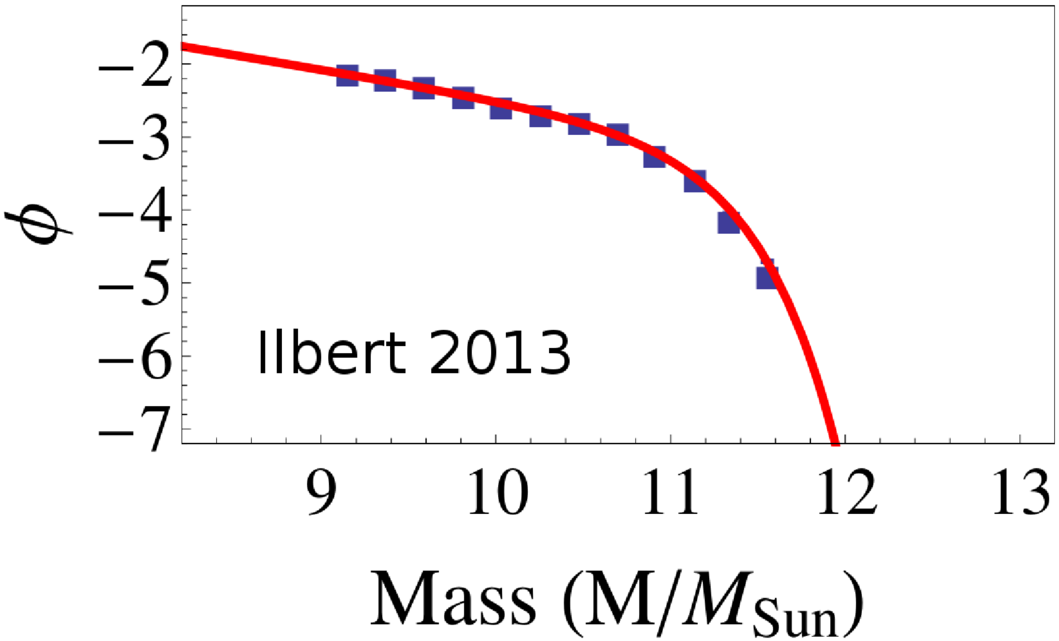


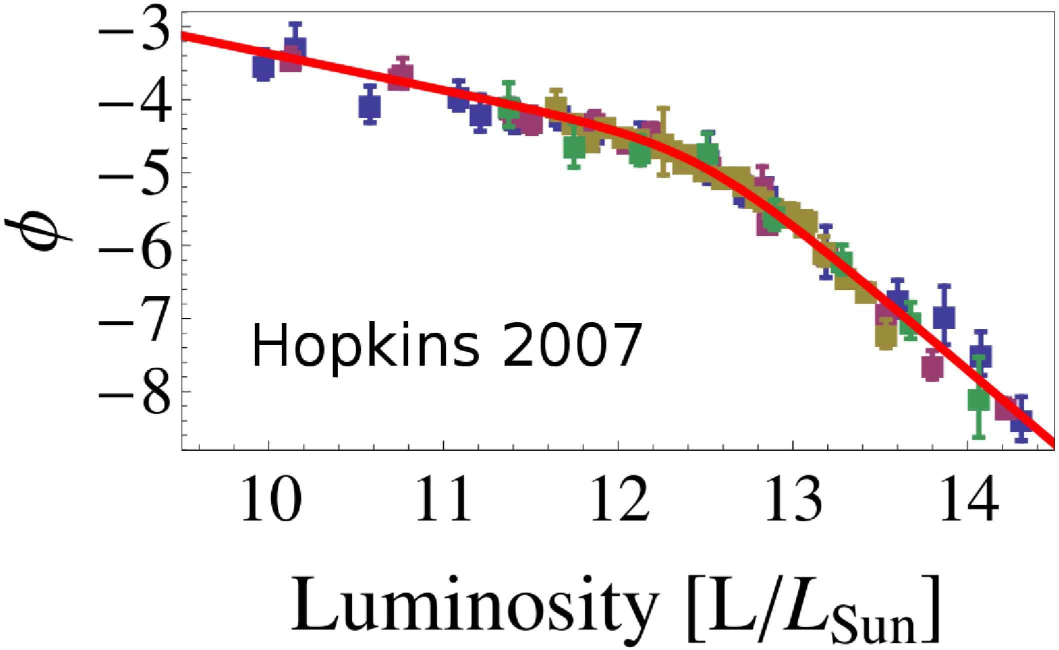




- We wish to describe AGN population with a model which is
  - Phenomenological
  - Analytical
  - Simple
  - Data driven

# Outline

- What we can learn just from evolution of quasar luminosity function
  - How do get connect quasar luminosity function and galaxy mass function
  - Redshift evolution of these functions
  - Connecting these evolutions
- Mass ratio ($m_{bh}/m_*$) evolution
  - Hints for mass evolution
  - Observational consequences



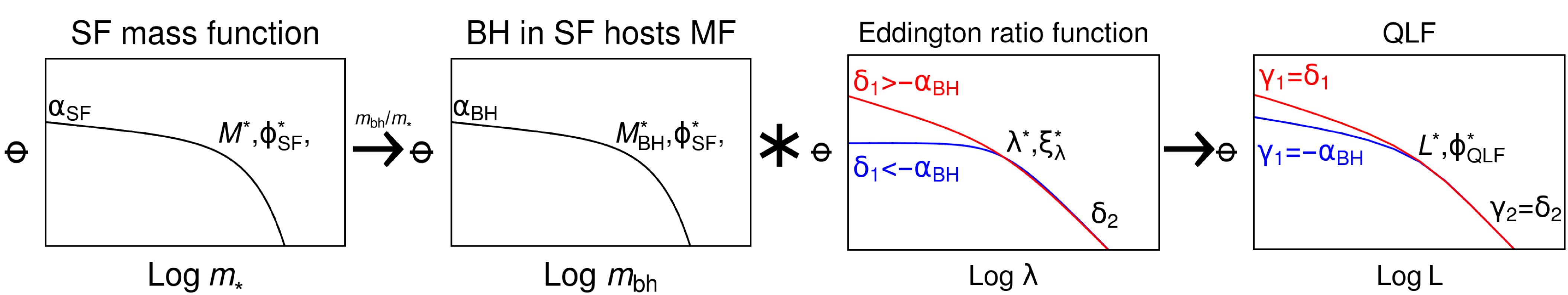



# Quasar luminosity function is convolution of galaxy mass function and Eddington ratio function

**Ansätze**

- Radiatively efficient AGNs are in star forming galaxies
- Distribution of Eddington ratio does not depend on the mass of the black hole
- Mass of central black hole proportional to stellar mass

- To make quasar luminosity function convolve
  - AGN mass function & Eddington ratio function



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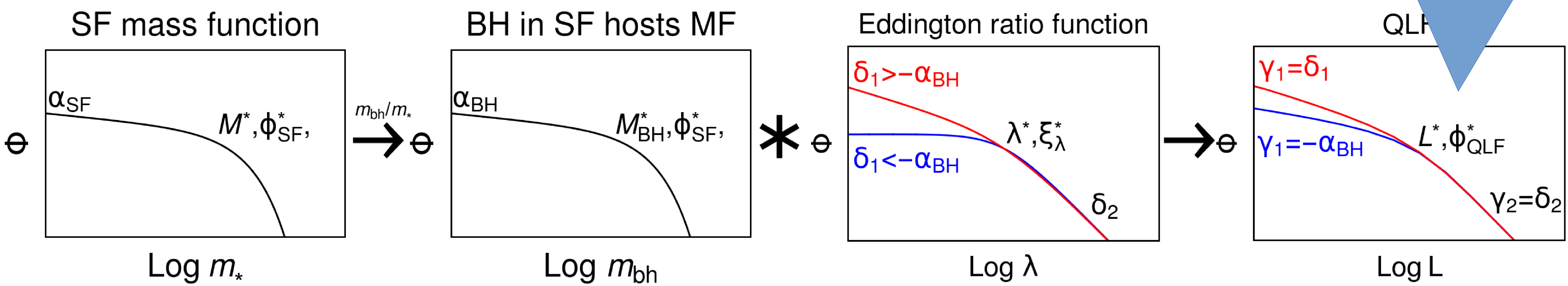

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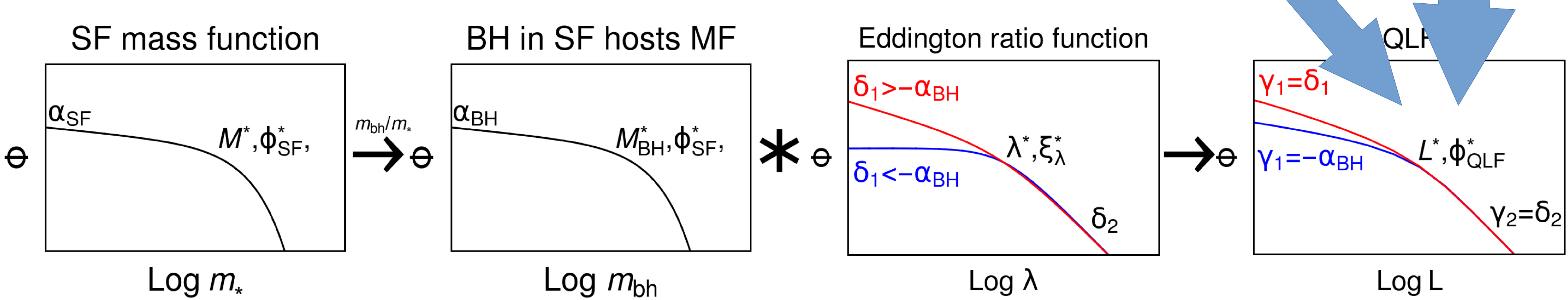
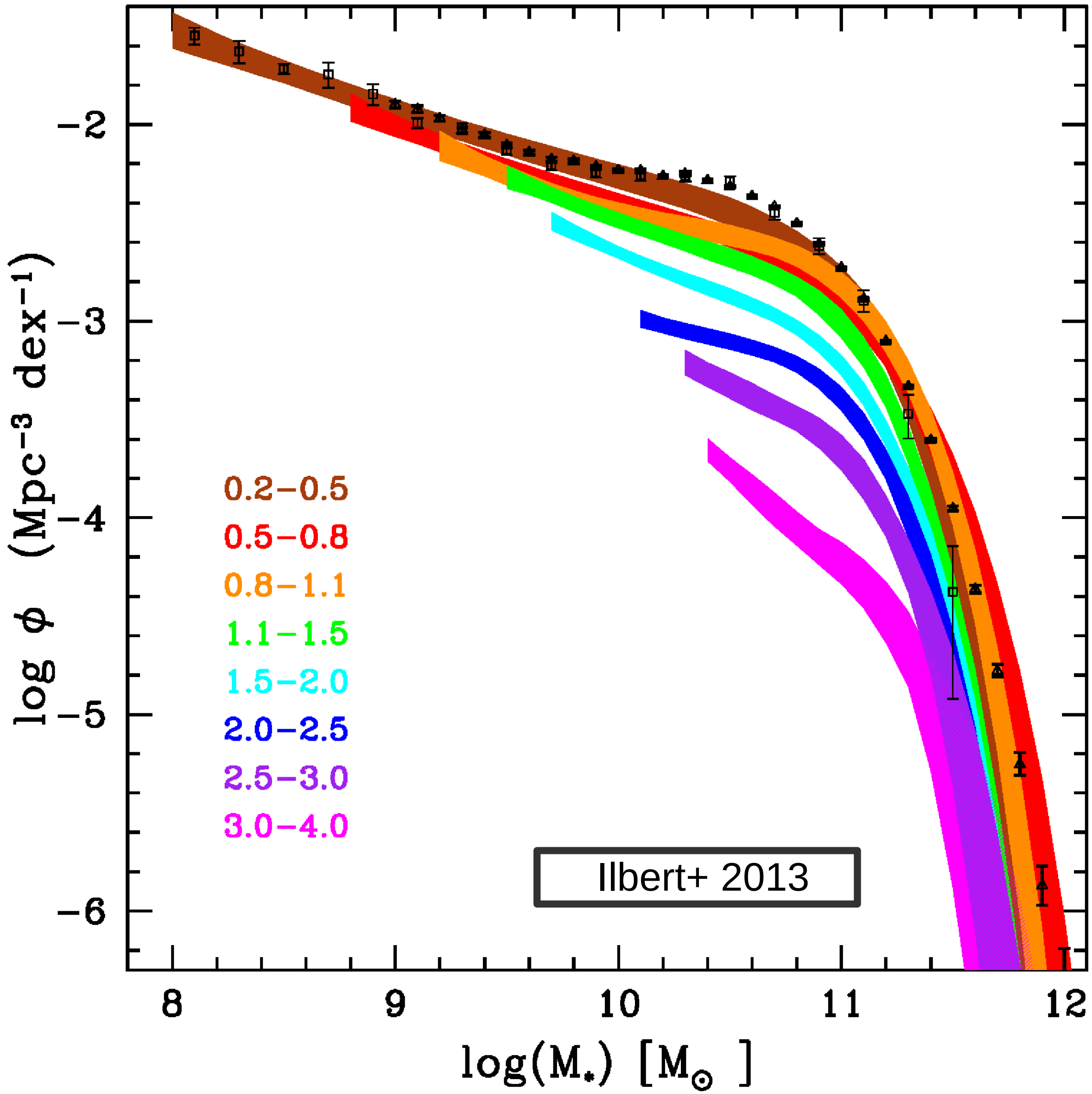


# M* of galaxies does not change

- Fit star-forming component with

$$\phi^*_{SF}\left(\frac{m}{M^*}\right)^{\alpha}\exp\left[\frac{-m}{M^*}\right]$$



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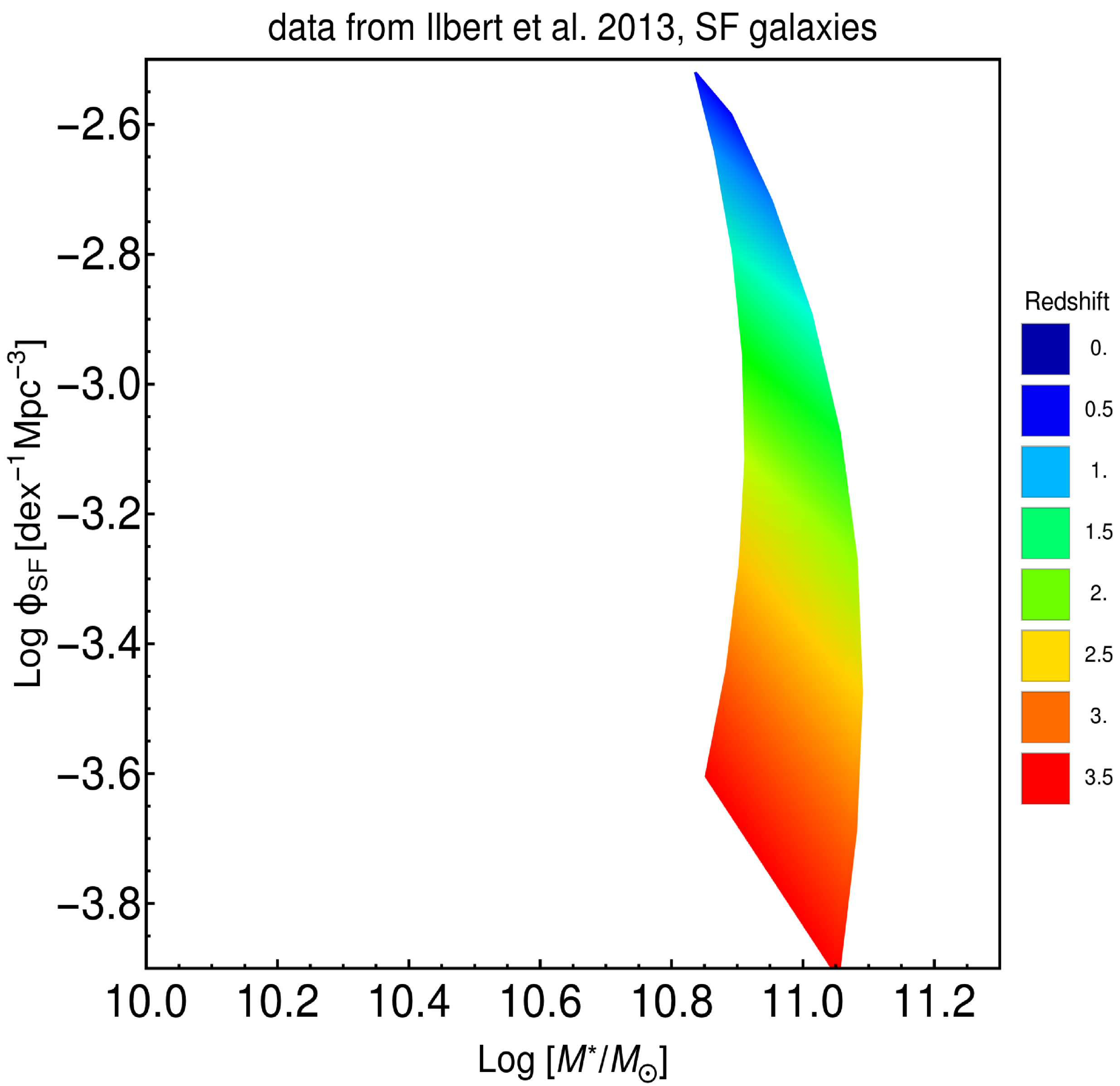

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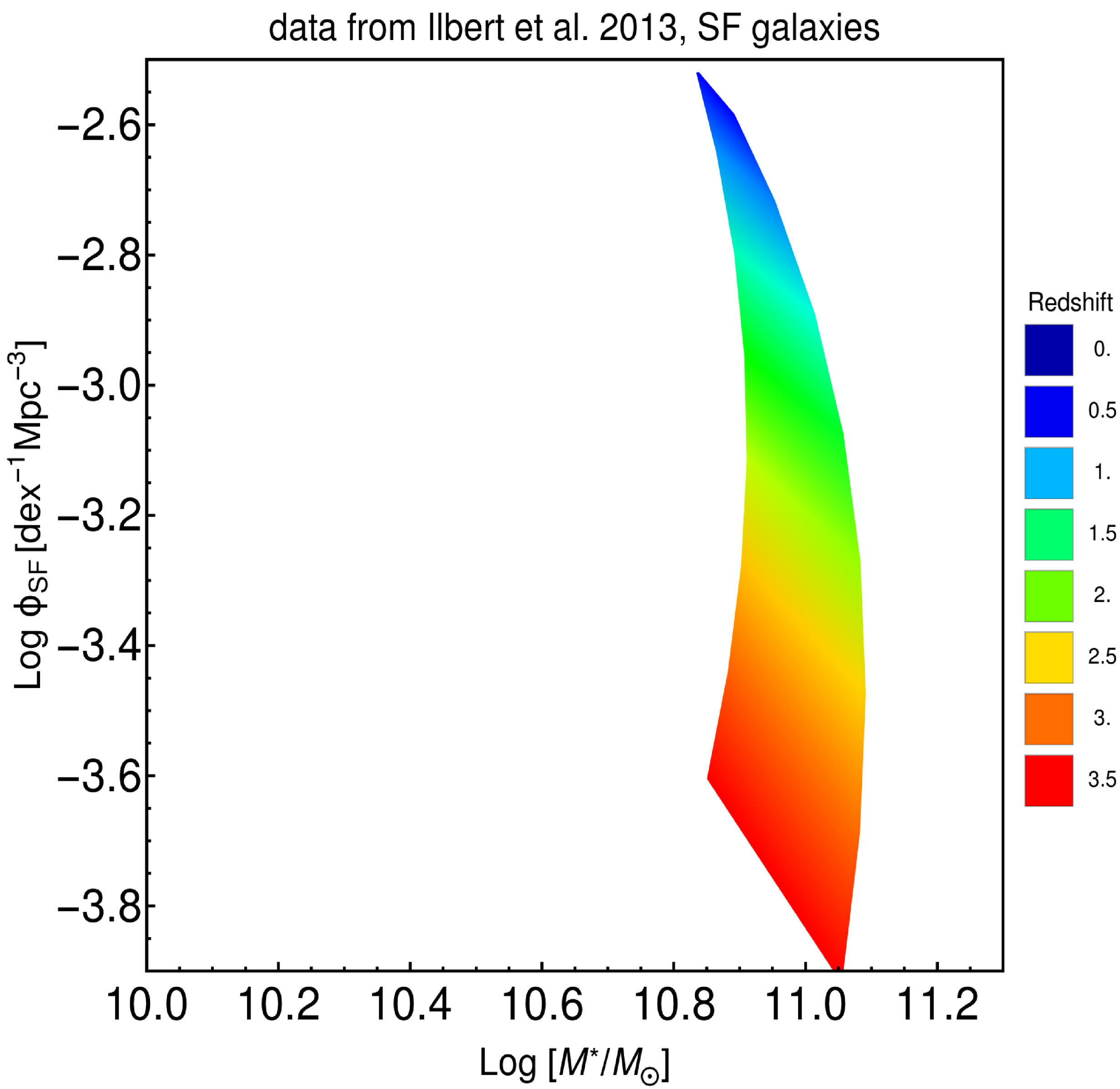

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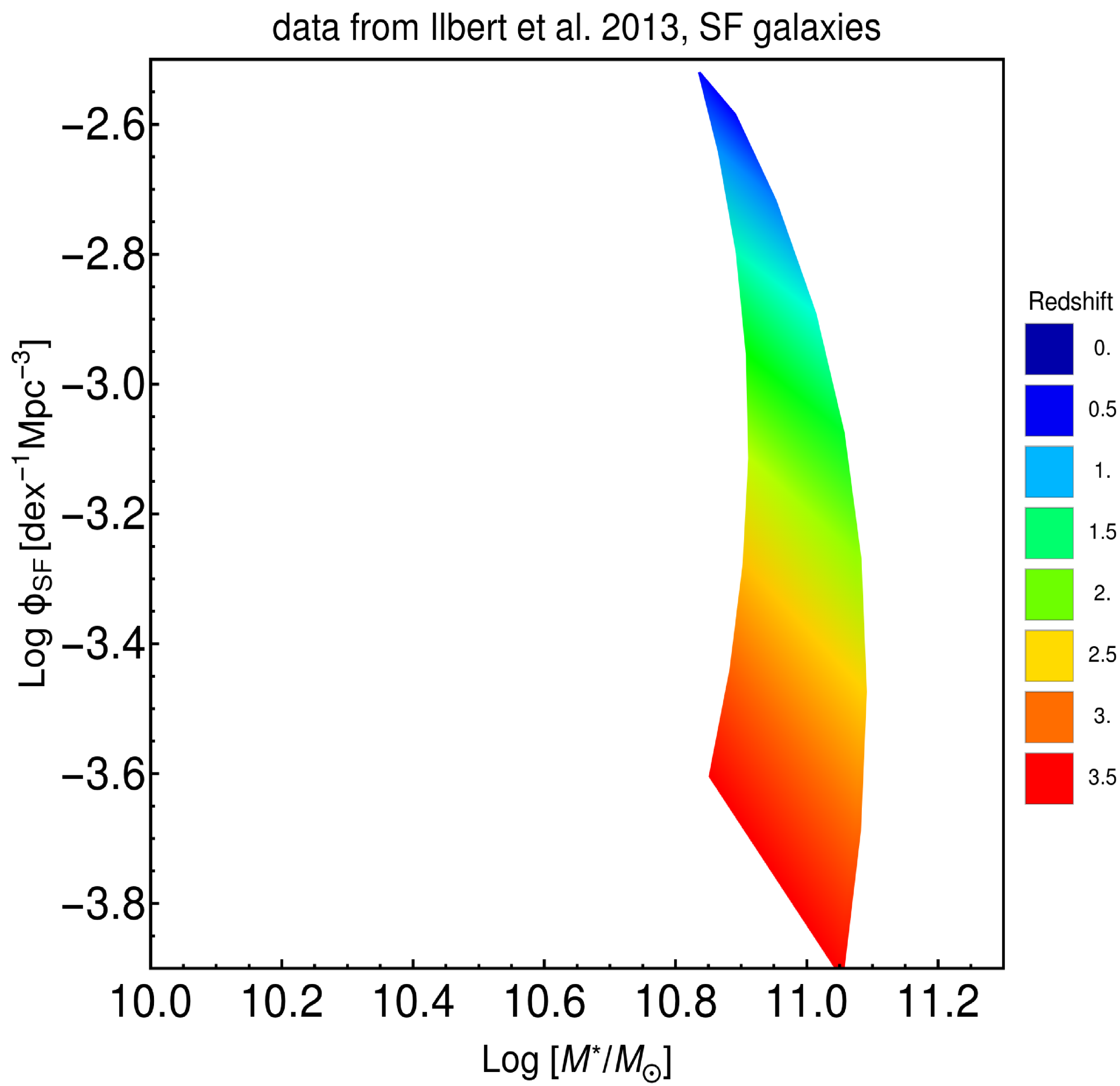
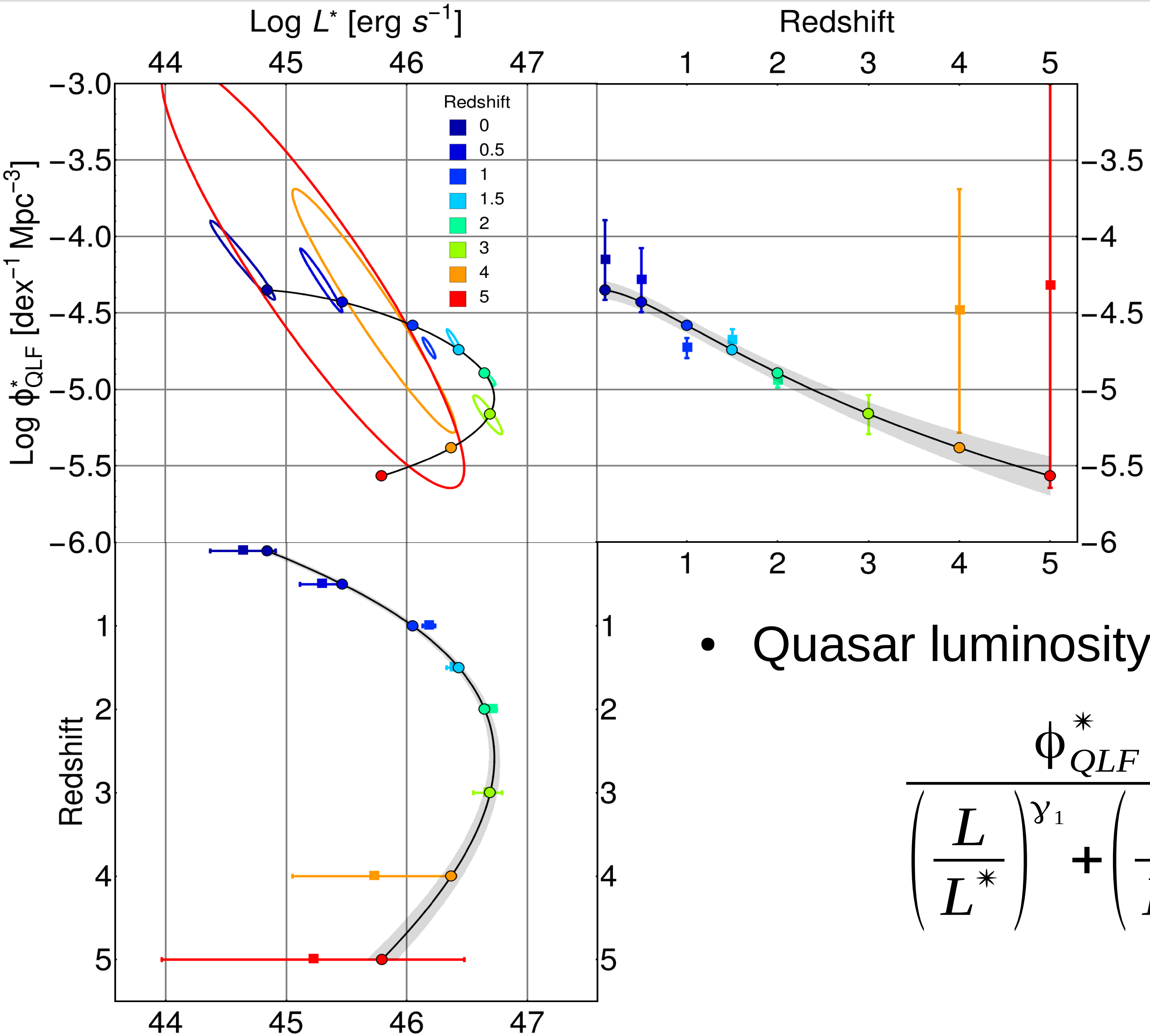
- Fit star-forming component with

$$\phi^*_{SF}\left(\frac{m}{M^*}\right)^{\alpha}\exp\left[\frac{-m}{M^*}\right]$$

- Minimal change of M* up to until at least z = 3
- Normalization change consistent with simple phenomenological model for galaxies (Peng+ 2010)



# Two interesting results from quasar luminosity function




- Quasar luminosity function

$$\frac{\phi^*_{QLF}}{\left(\frac{L}{L^*}\right)^{\gamma_1}+\left(\frac{L}{L^*}\right)^{\gamma_2}}$$

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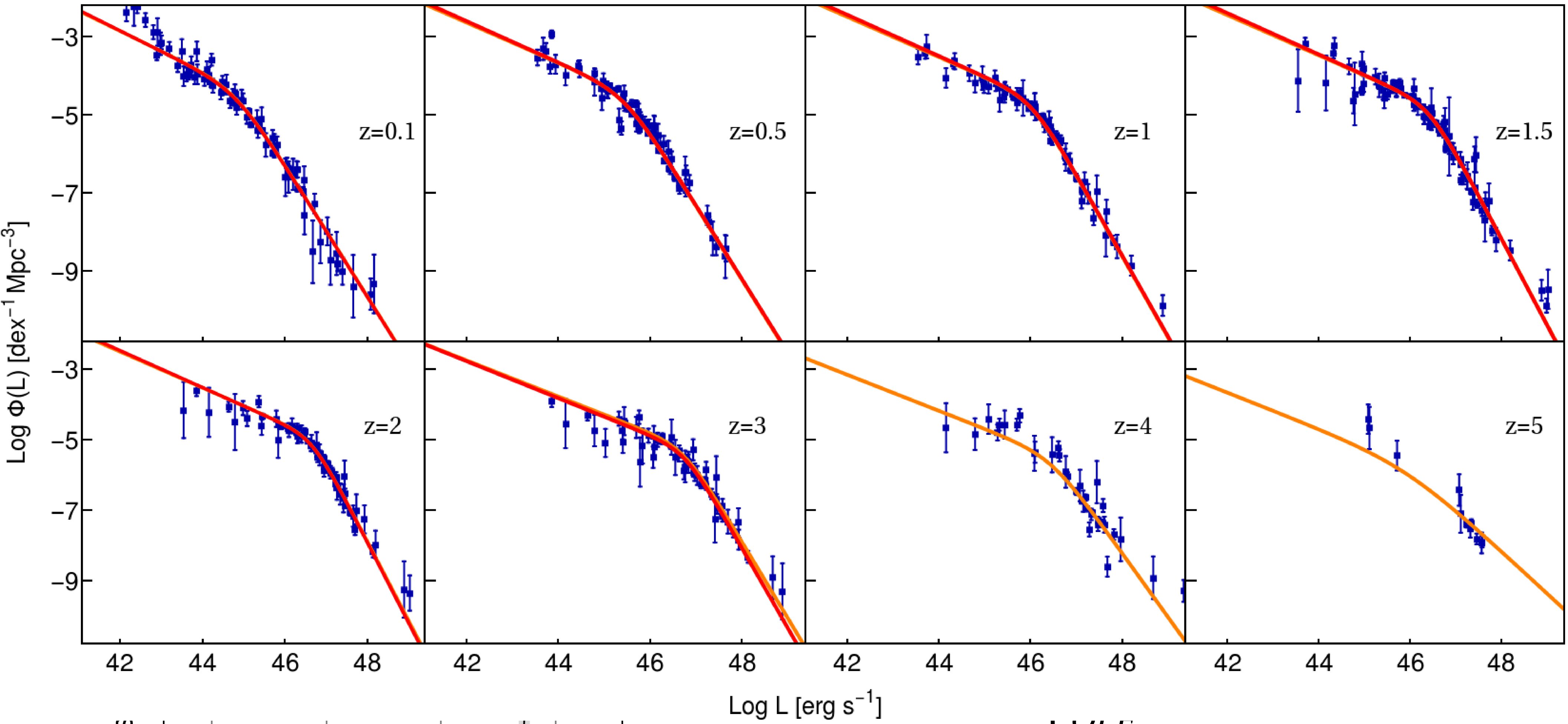


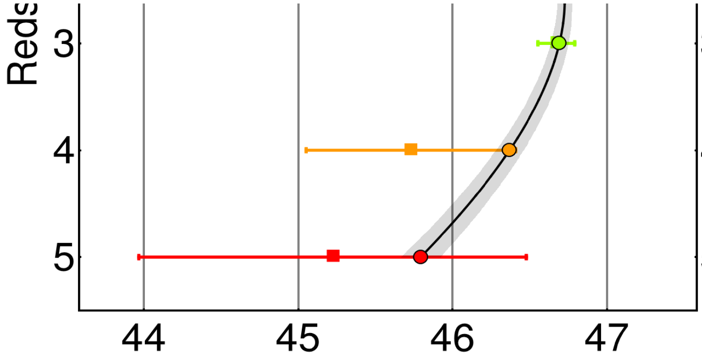


$$\frac{\Phi_{QLF}}{\left(\frac{L}{L^*}\right)^{\gamma_1}+\left(\frac{L}{L^*}\right)^{\gamma_2}}$$

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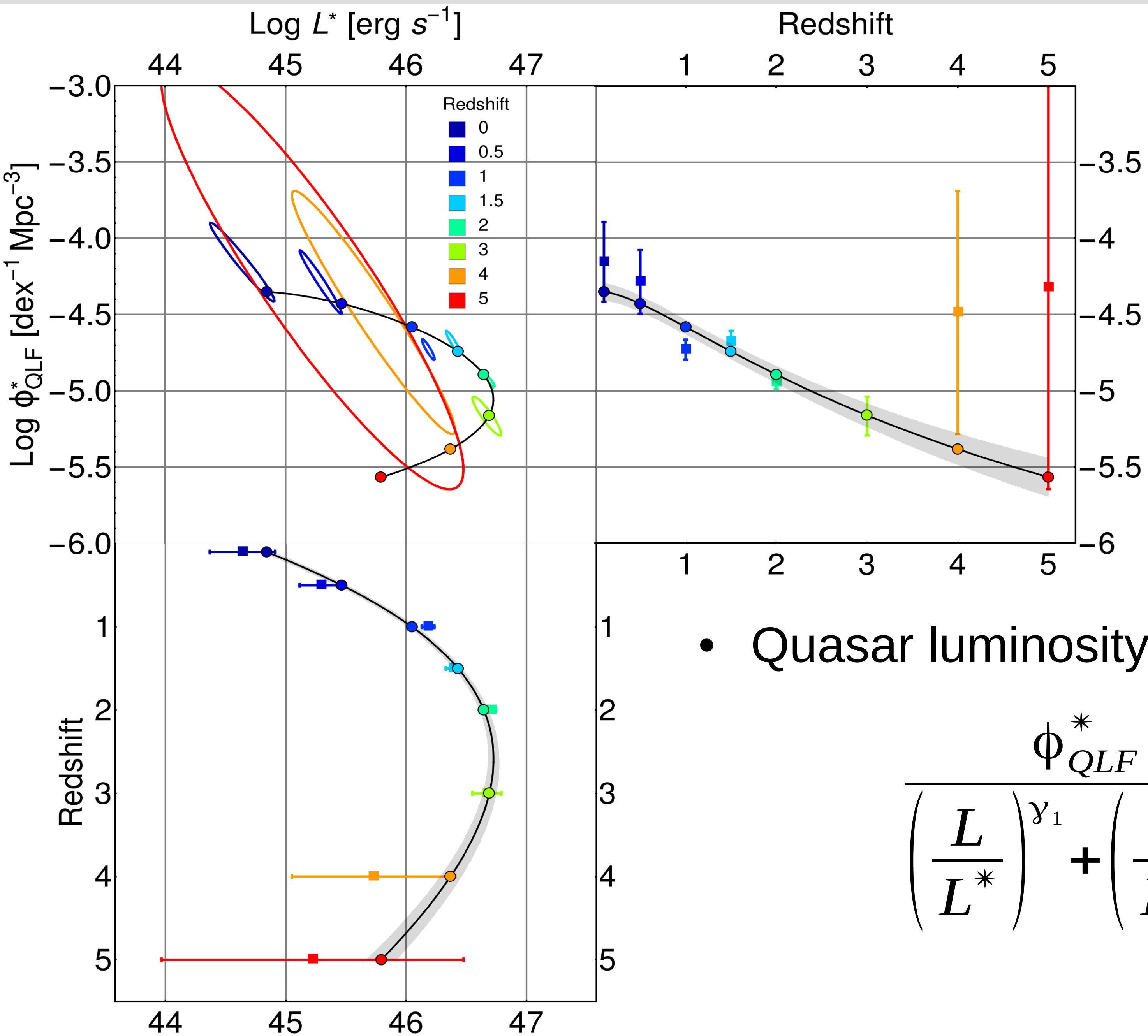


- Quasar luminosity function

$$\frac{\phi^*_{QLF}}{\left(\frac{L}{L^*}\right)^{\gamma_1} + \left(\frac{L}{L^*}\right)^{\gamma_2}}$$

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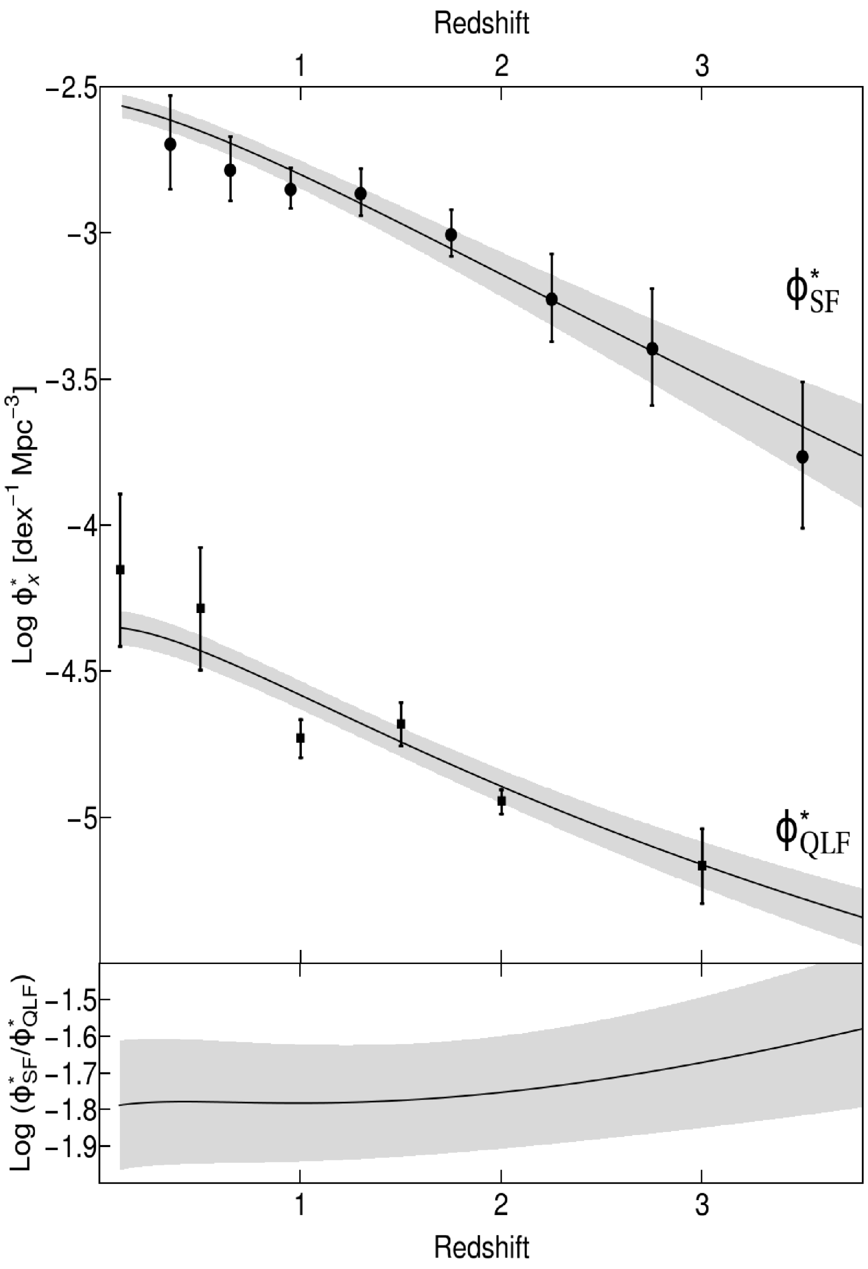


- Normalization of quasar luminosity function changes as normalization of star forming galaxies

$$\phi^*_{QLF} \propto \phi^*_{SF}\, \xi^*_{\lambda}$$

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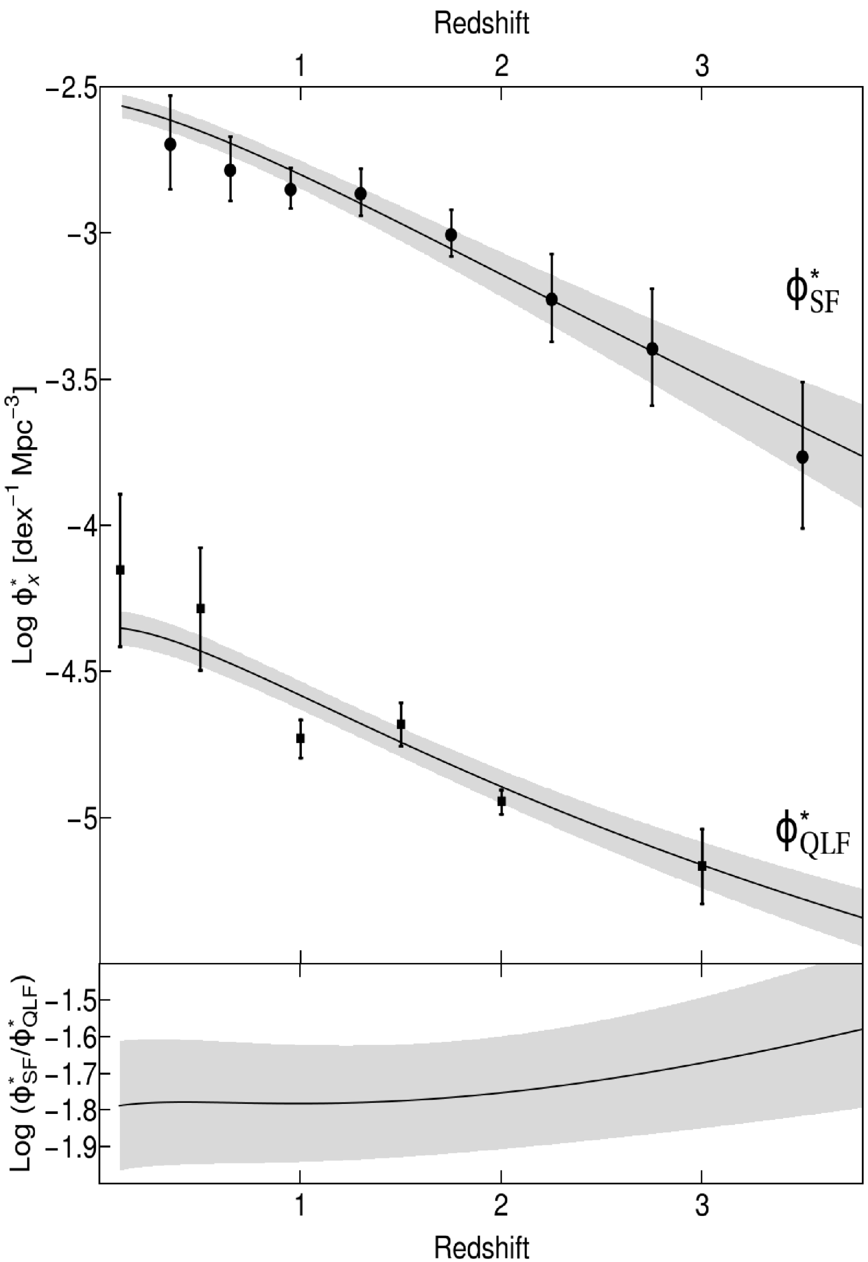


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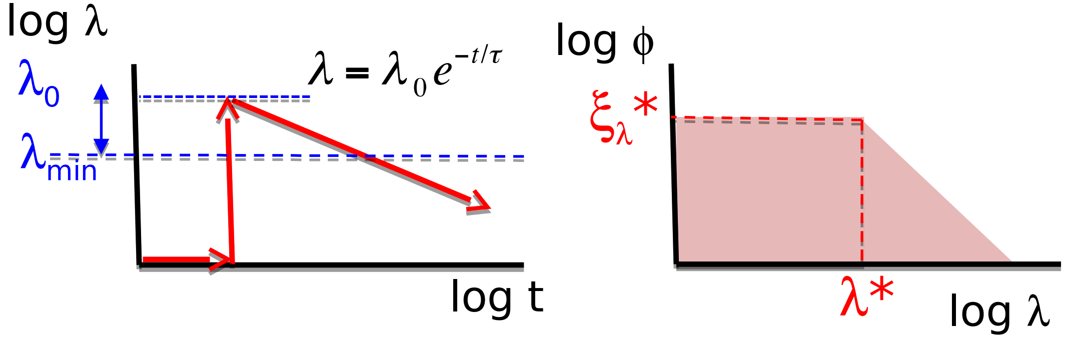
$$\phi^*_{QLF} \propto \phi^*_{SF}\, \xi^*_\lambda$$

- For example: in a "kick+decay" toy model
  - chance per unit time of kicking on, $\eta$,
  - a distribution of size of kicks at $\lambda_0 > \lambda_{min}$
  - exponential decay time constant $\tau$

$$\xi^*_\lambda = \eta\,\tau$$

- **Constant "duty cycle"**



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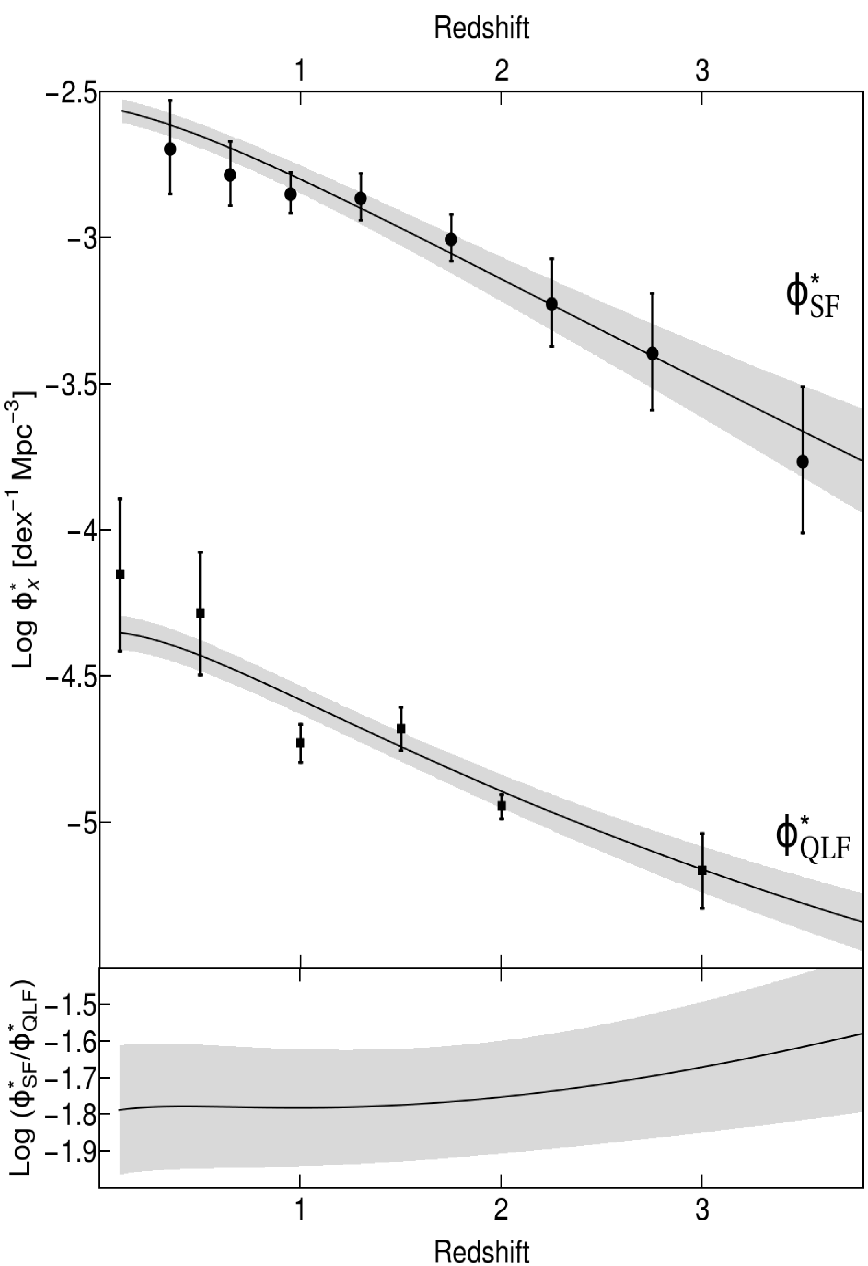


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$$\xi^*_\lambda = \eta\,\tau$$

- **Constant “duty cycle”**

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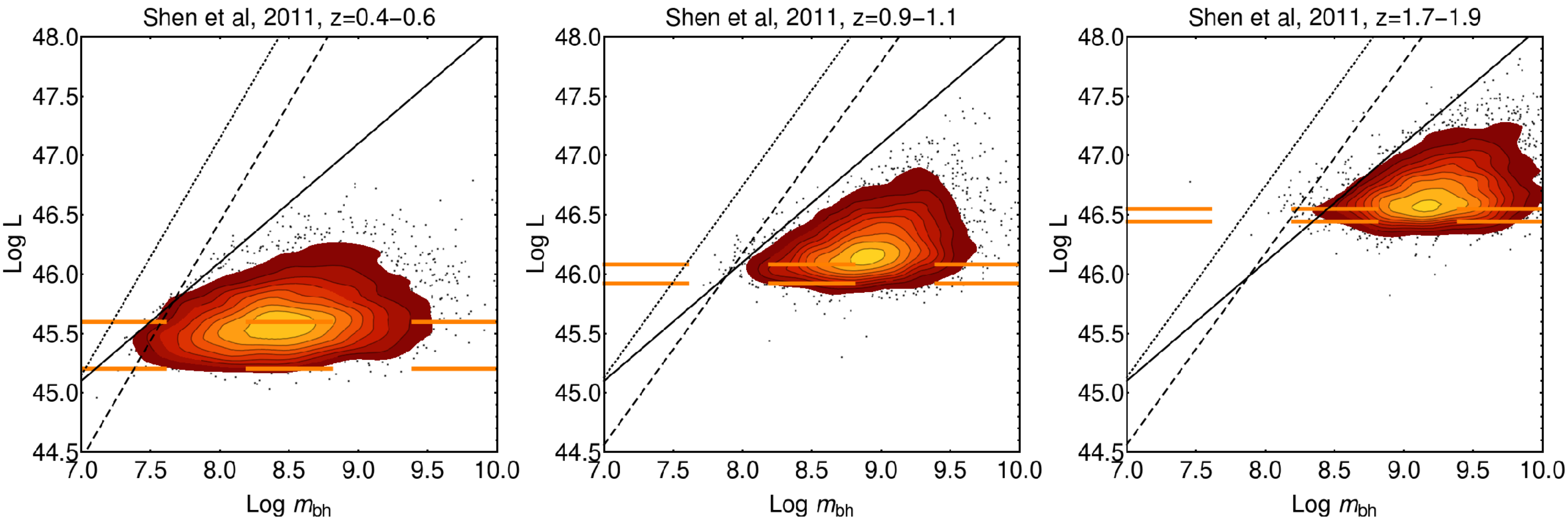
$$L^* \propto (1+z)^4 \qquad z<2$$

$$L^* \propto M^*\, m_{bh}/m_*\, \lambda^*$$

# Results from simulating mass-luminosity plane



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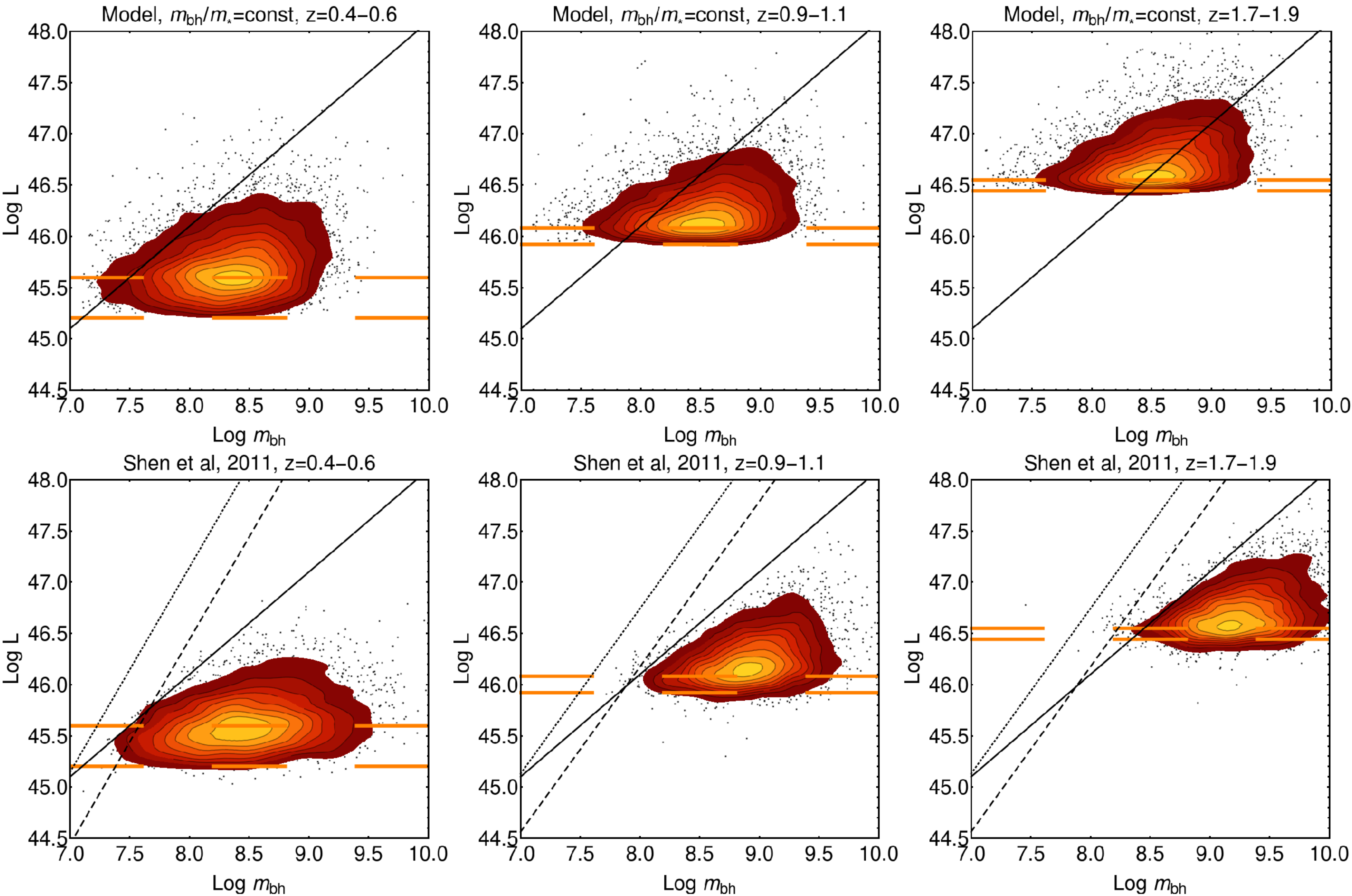

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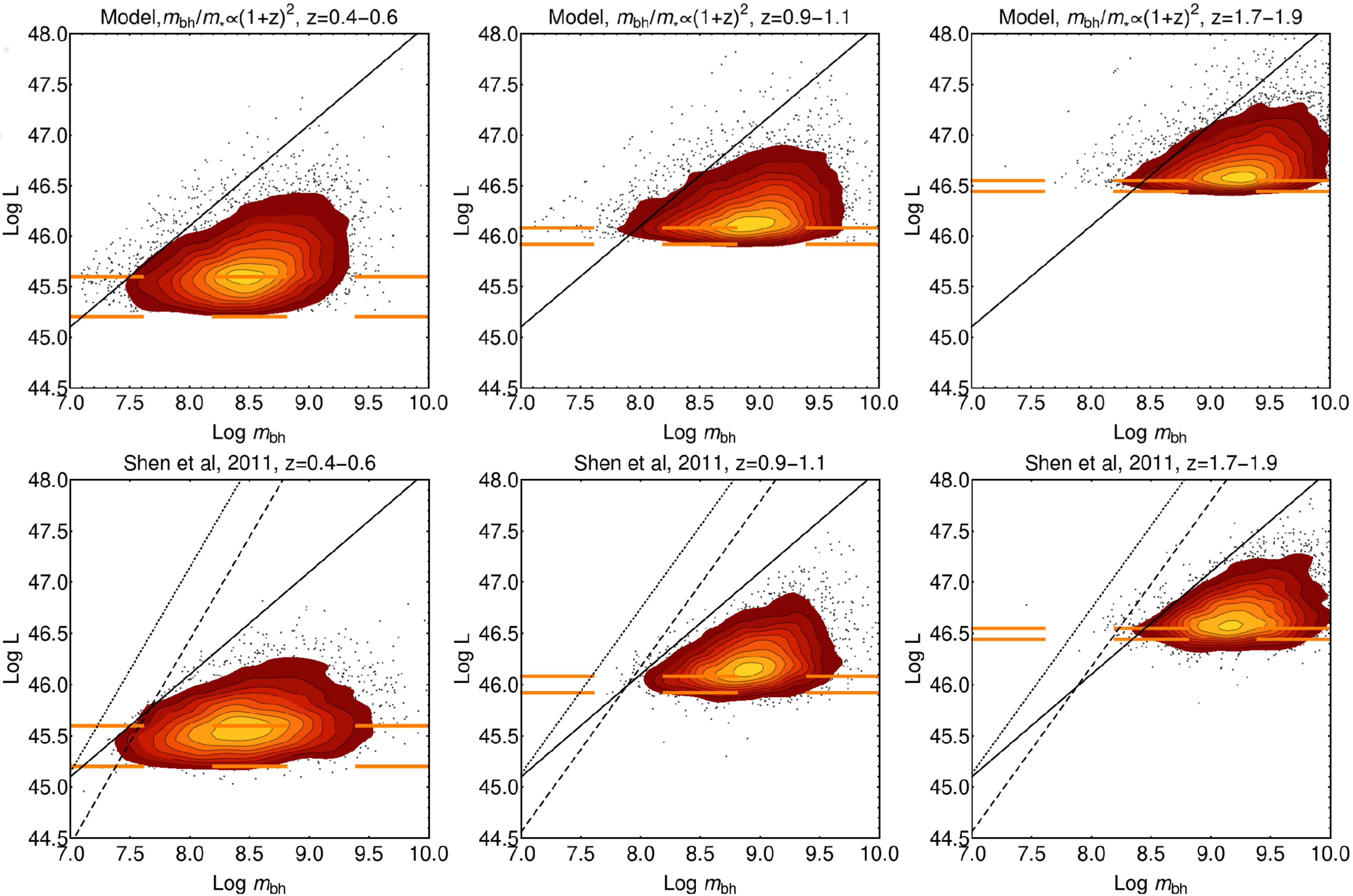
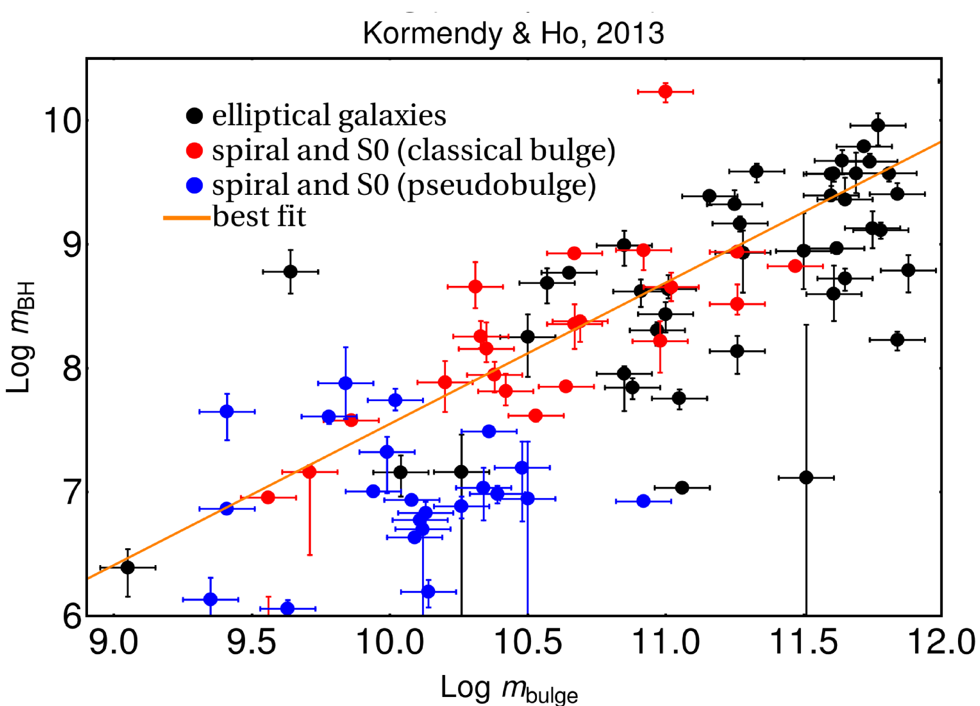


# Local relation is reproduced?



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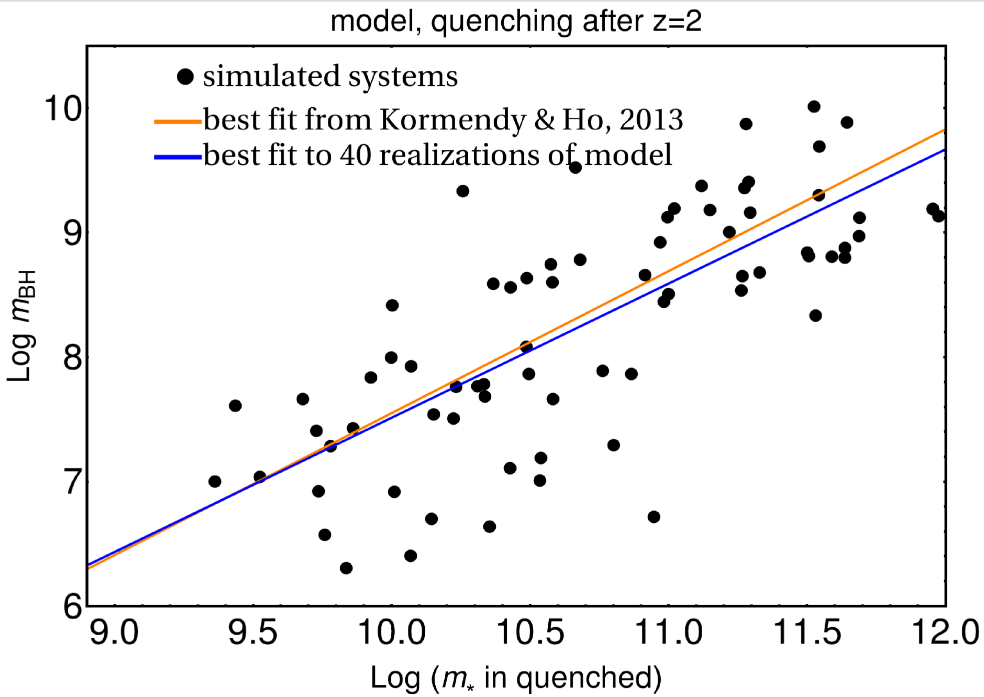


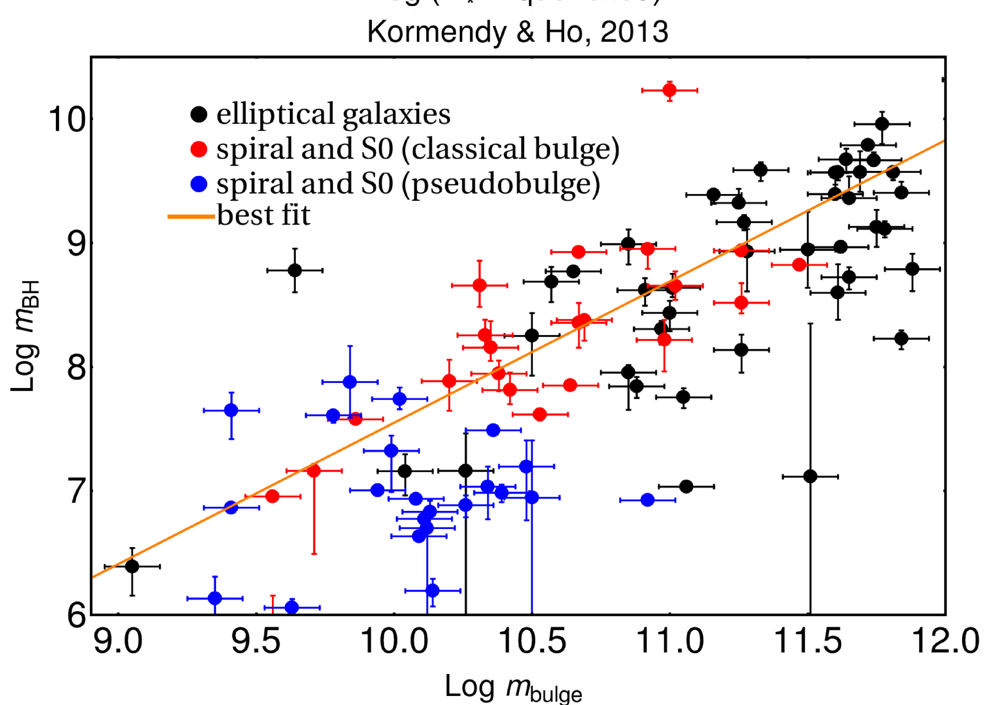

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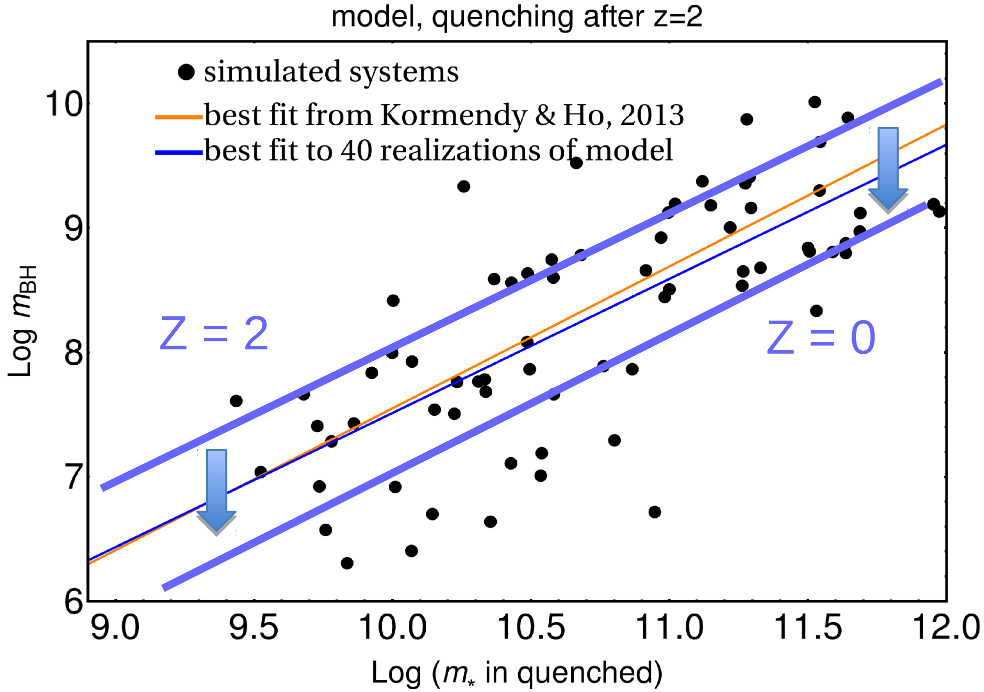
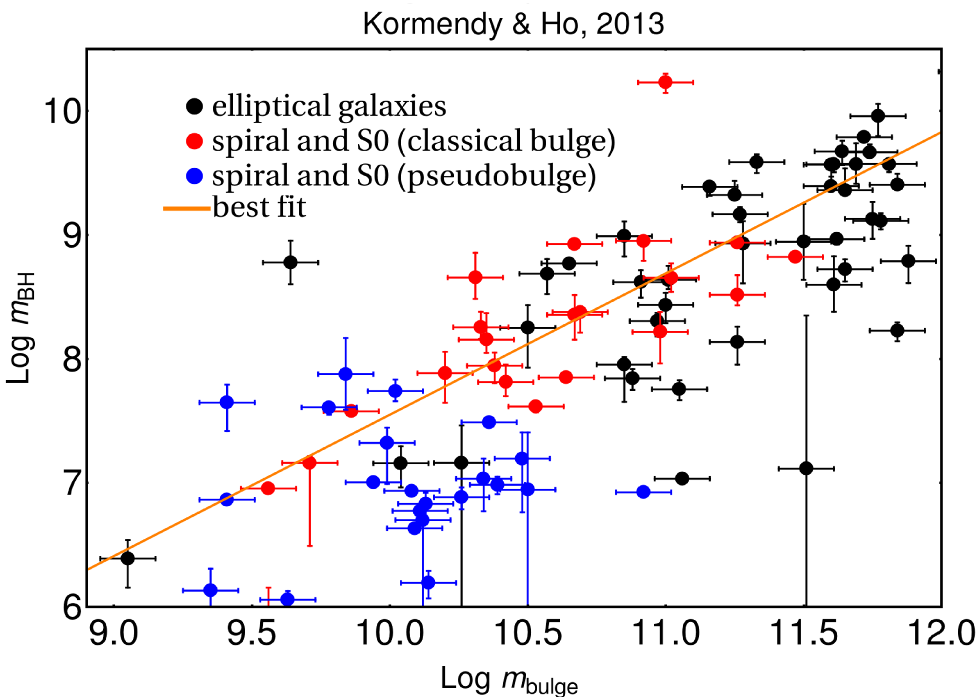
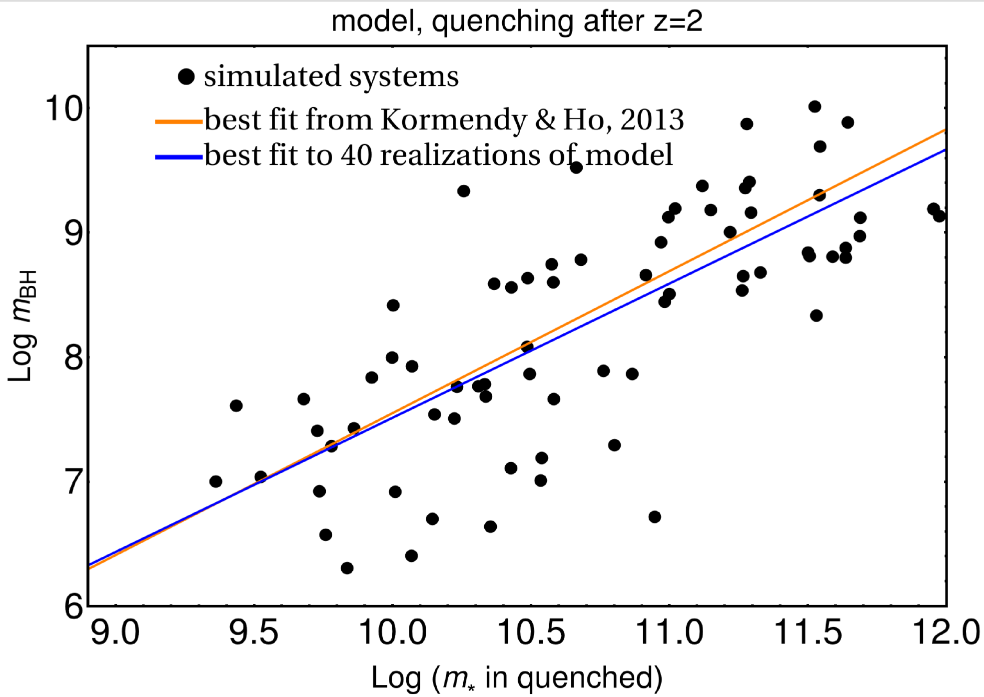
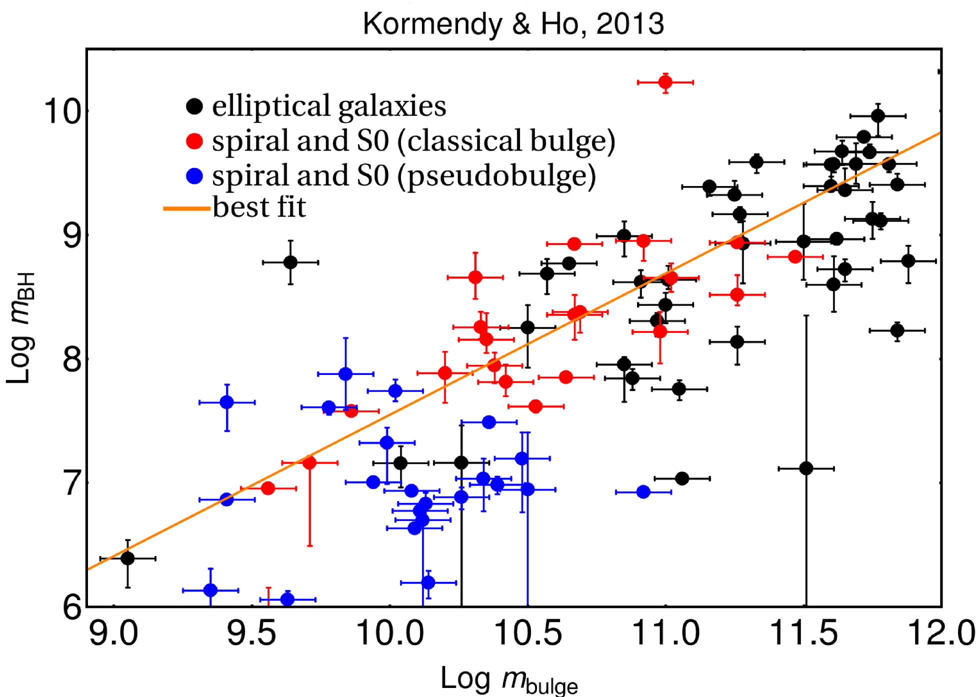



- Mean redshift of quenching for quenched galaxies we see today is at around redshift of 1 to 1.5.
- Galaxies which have quenched at low redshift will be below relation (pseudobulges?)
- Tilt in the relation

# Local relation is reproduced!




- At a given stellar mass, the size of star-forming galaxies scales roughly as $(1+z)^{-1}$
- $m_{bh} \propto 3 \cdot 10^8 \sigma_{200}^4$
- At a given galaxy mass $r \propto (1+z)^{-1} \Leftrightarrow \sigma^2 \propto (1+z)$

$$\frac{m_{bh}}{m_{star}} \propto (1+z)^2 \Leftrightarrow \frac{m_{bh}}{\sigma^4} = constant$$

- Constant $m_{bh}$ – sigma, virial relation, and size evolution of galaxies lead to evolution in $m_{bh}/m_*$

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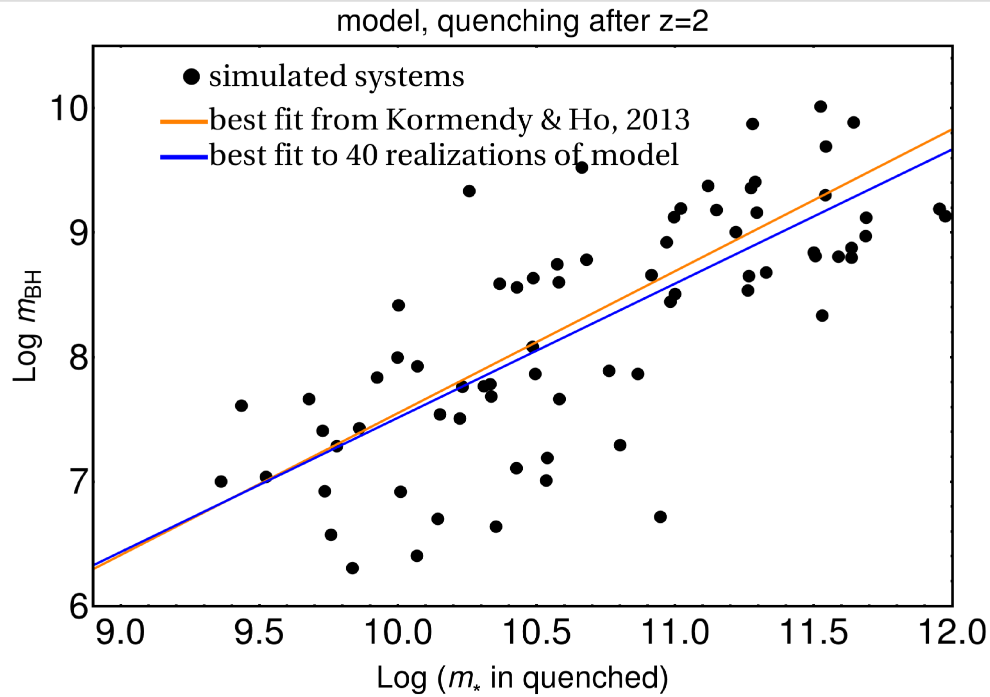


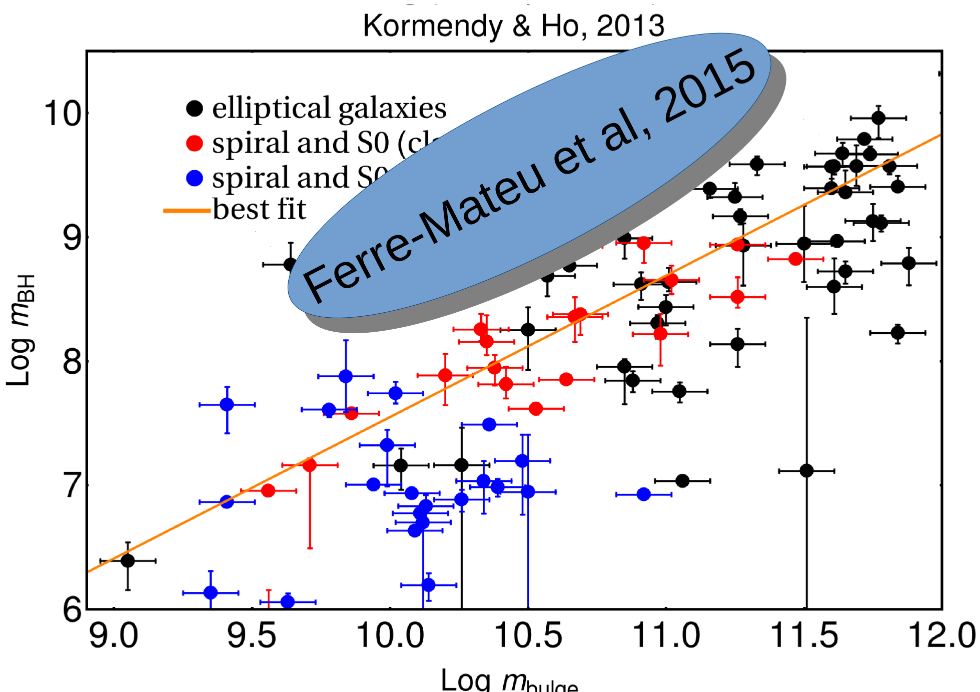


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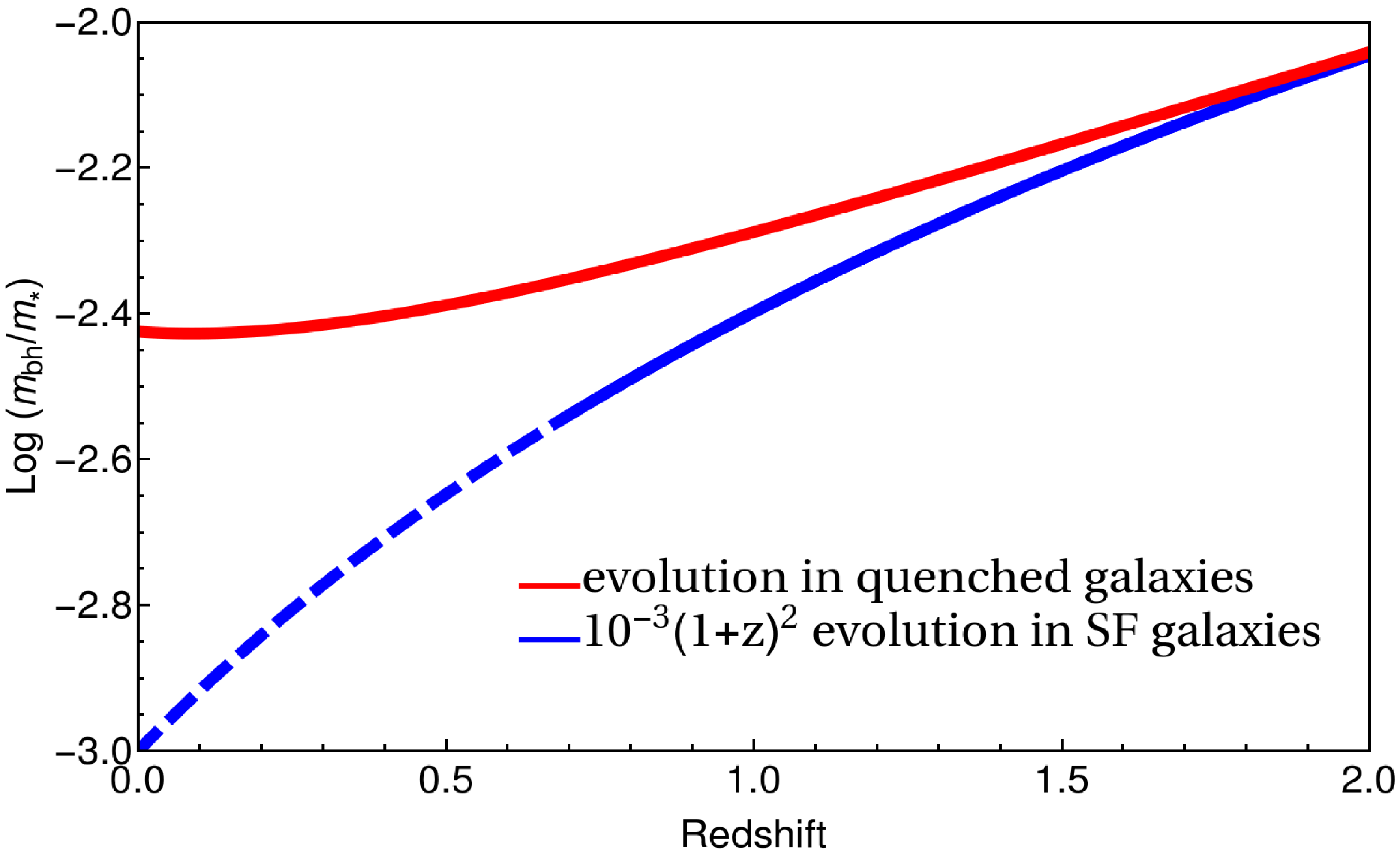
# Bias in measuring $m_{bh}/m_*$



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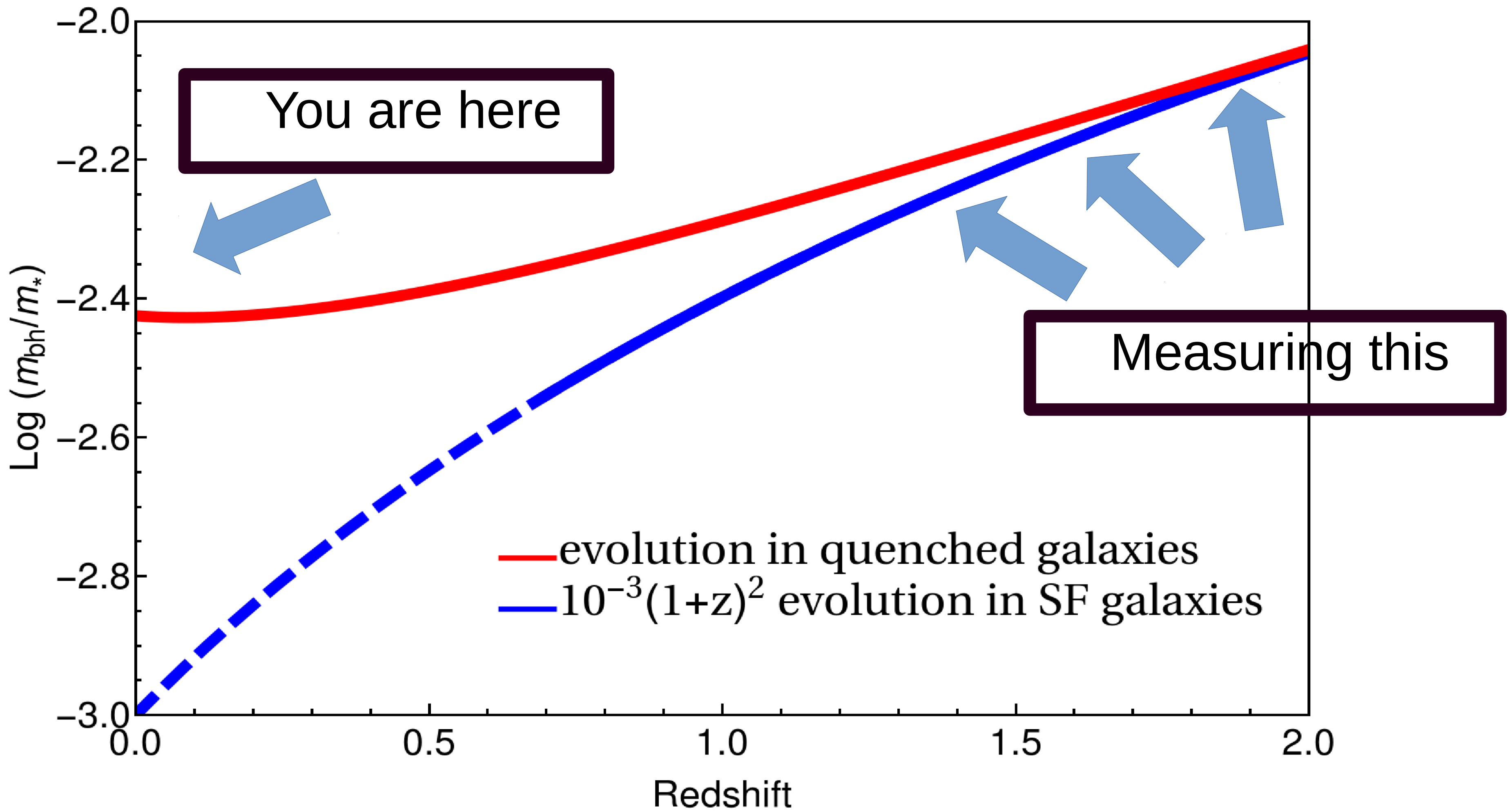

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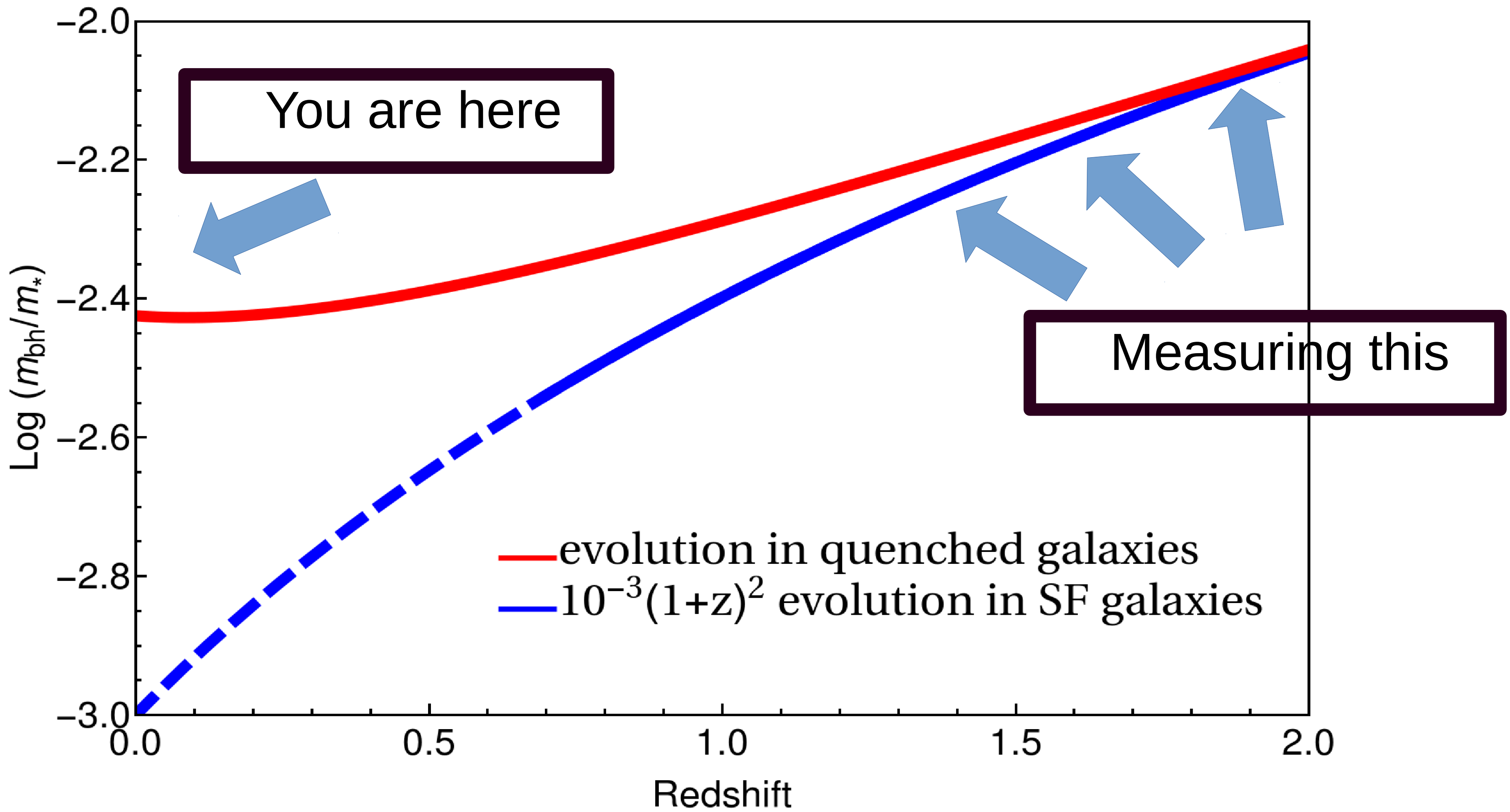
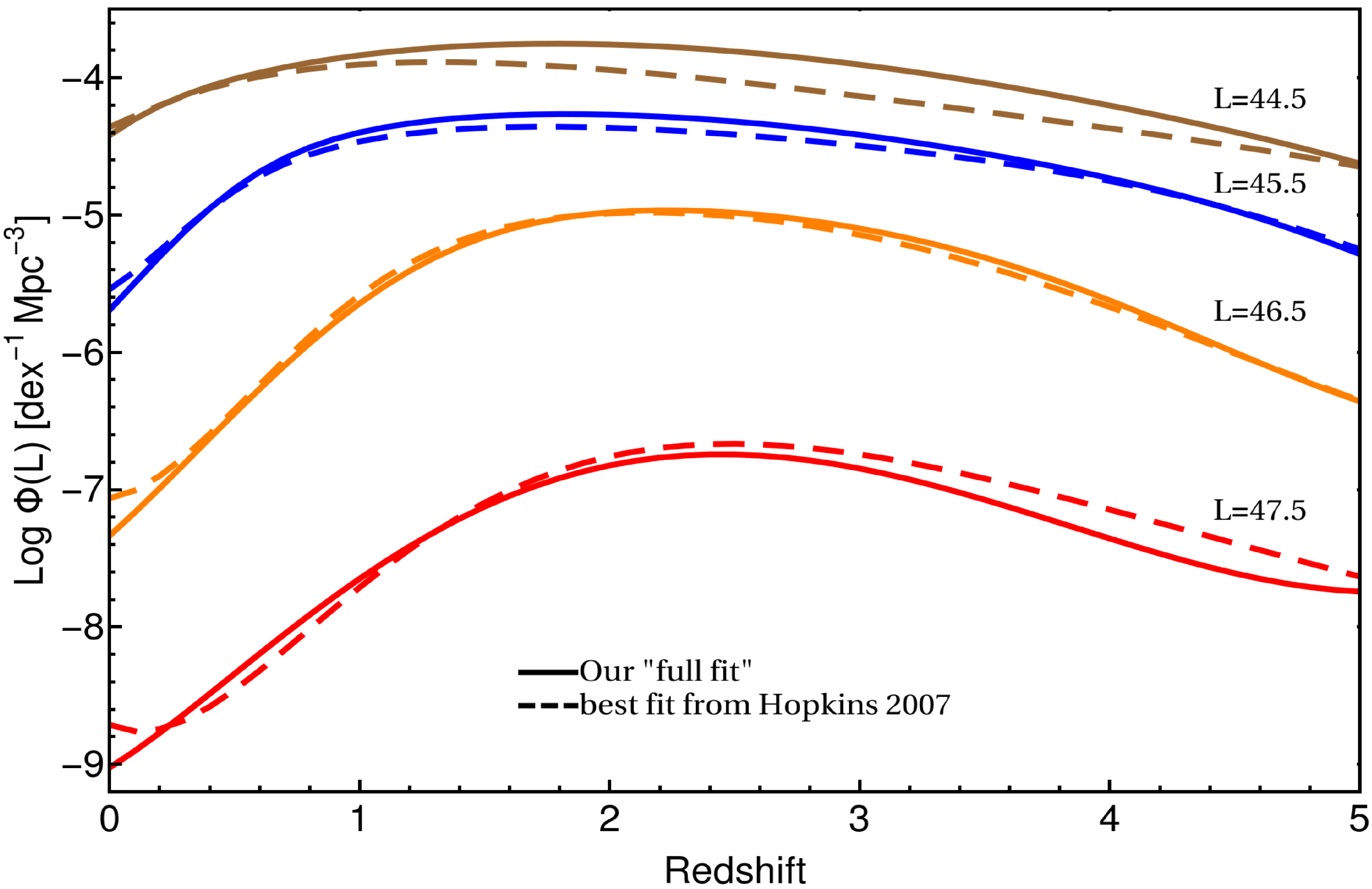



- Measuring mass ratio in star-forming systems and comparing to local relation is potentially very dangerous

# What/where is downsizing

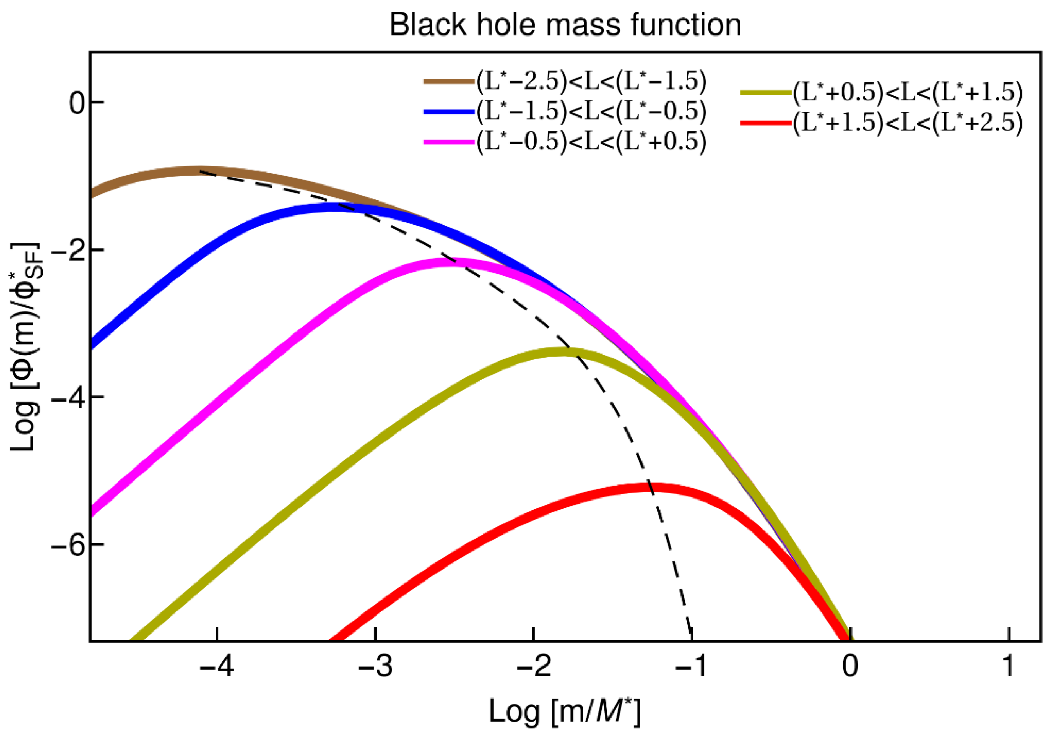


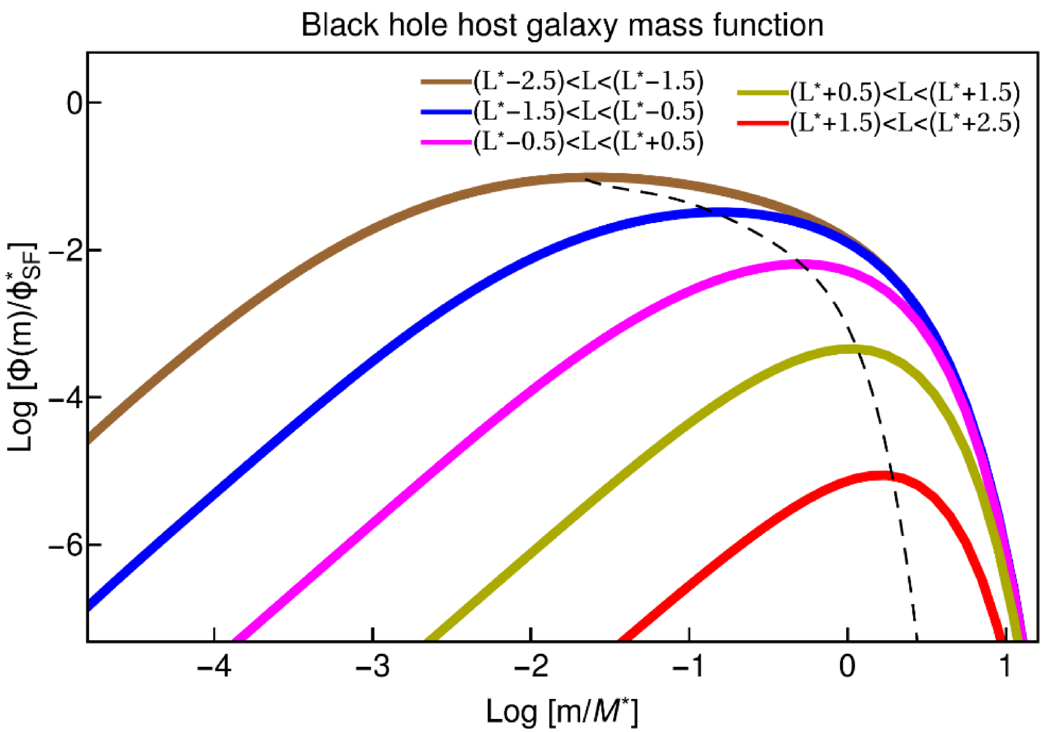

- “Downsizing” is reproduced even though Eddington ratio distribution is strictly mass-independent

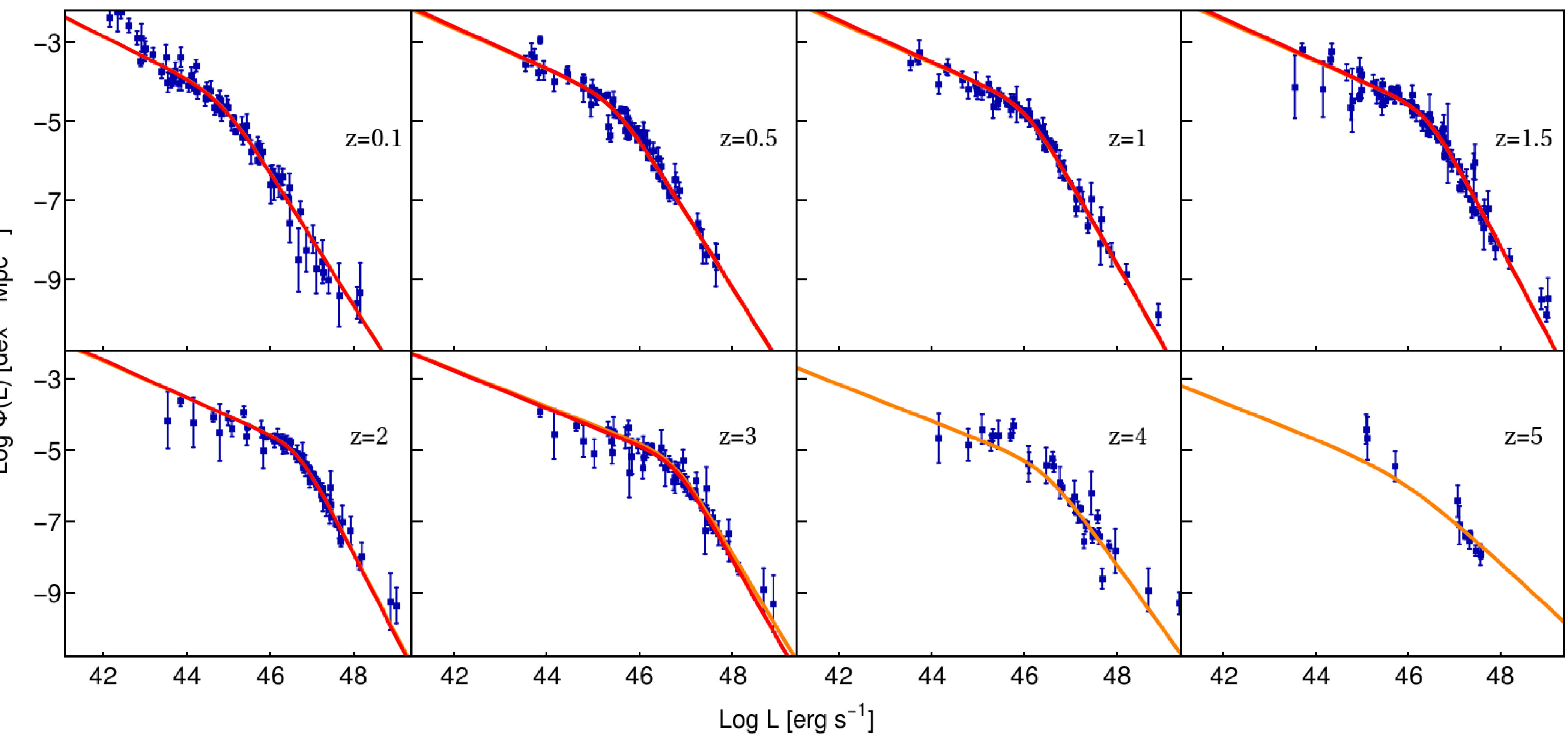
# Summary

- Simple global model combining galaxy mass function and quasar luminosity function leads to following conclusions
  - **Constant "duty cycle"** at characteristic Eddington ratio
    - Evolution of $\phi^*_{QLF}$ normalization of quasar luminosity function is consistent with $\phi^*_{SF}$ normalization of star-forming galaxies
  - **Evolution in the $m_{bh}/m_*$ relation** in star-forming galaxies
    - Evolution in L* can be due to evolution of $\lambda^*$ and/or $m_{bh}/m_*$
    - Non-evolving $m_{bh}/m_*$ disfavored by mass-luminosity plane
    - Local relation and measurements at higher redshift are satisfied by evolving relation
    - Size evolution in galaxies implies evolution in either $m_{bh}/m_*$ or mbh – sigma relation
    - Extreme caution when comparing black holes in star-forming and quenched galaxies

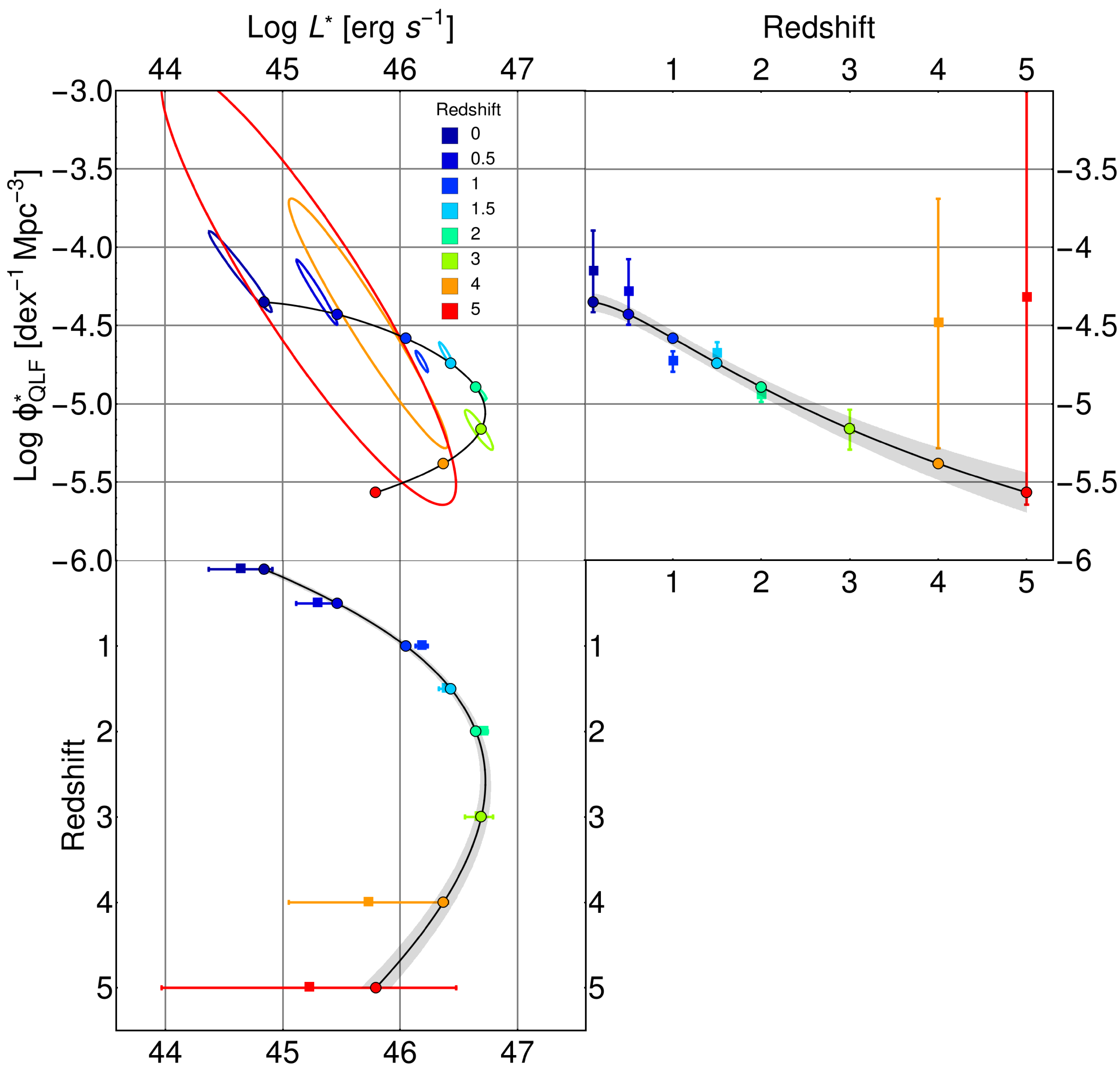
# Additional slides



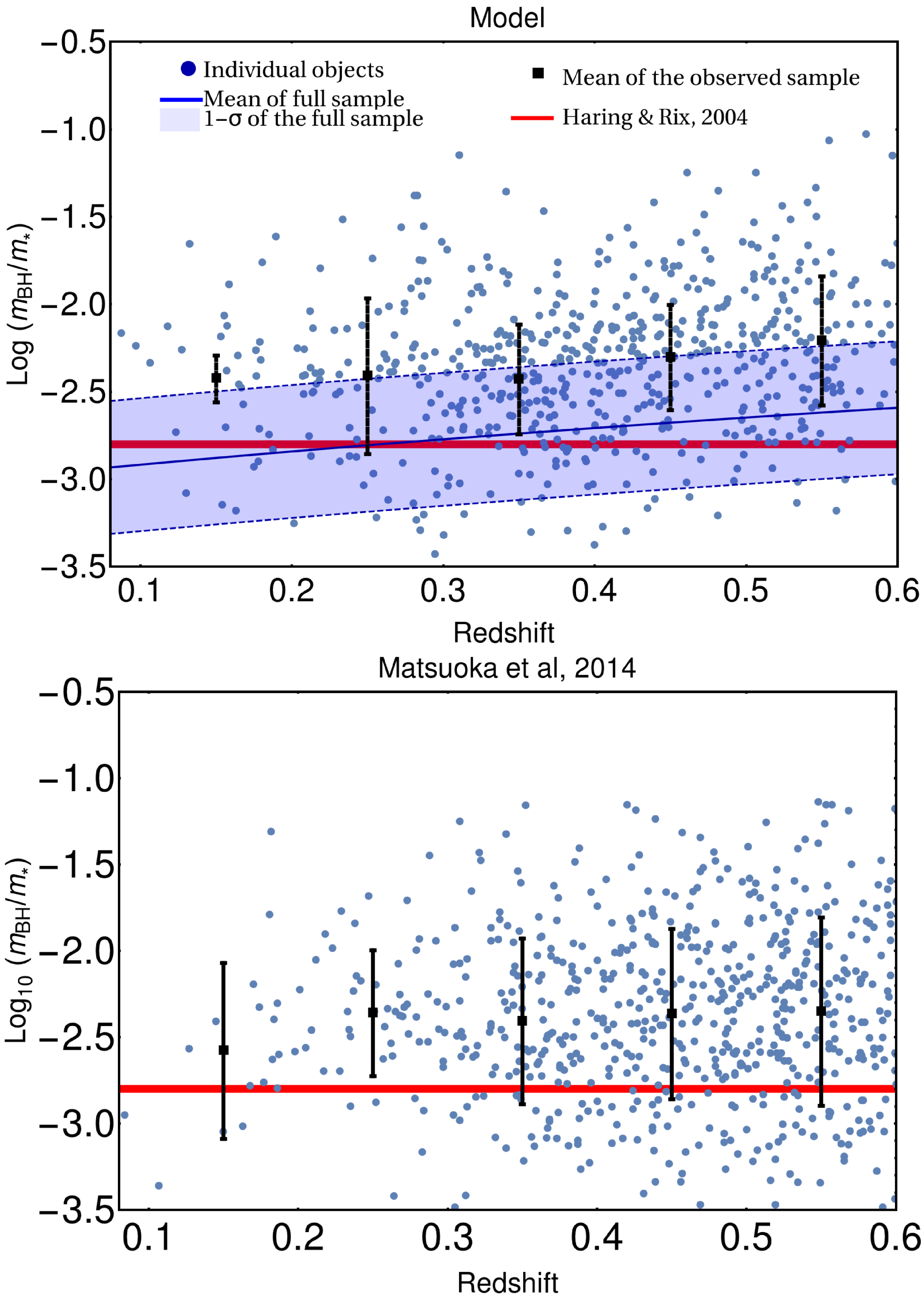





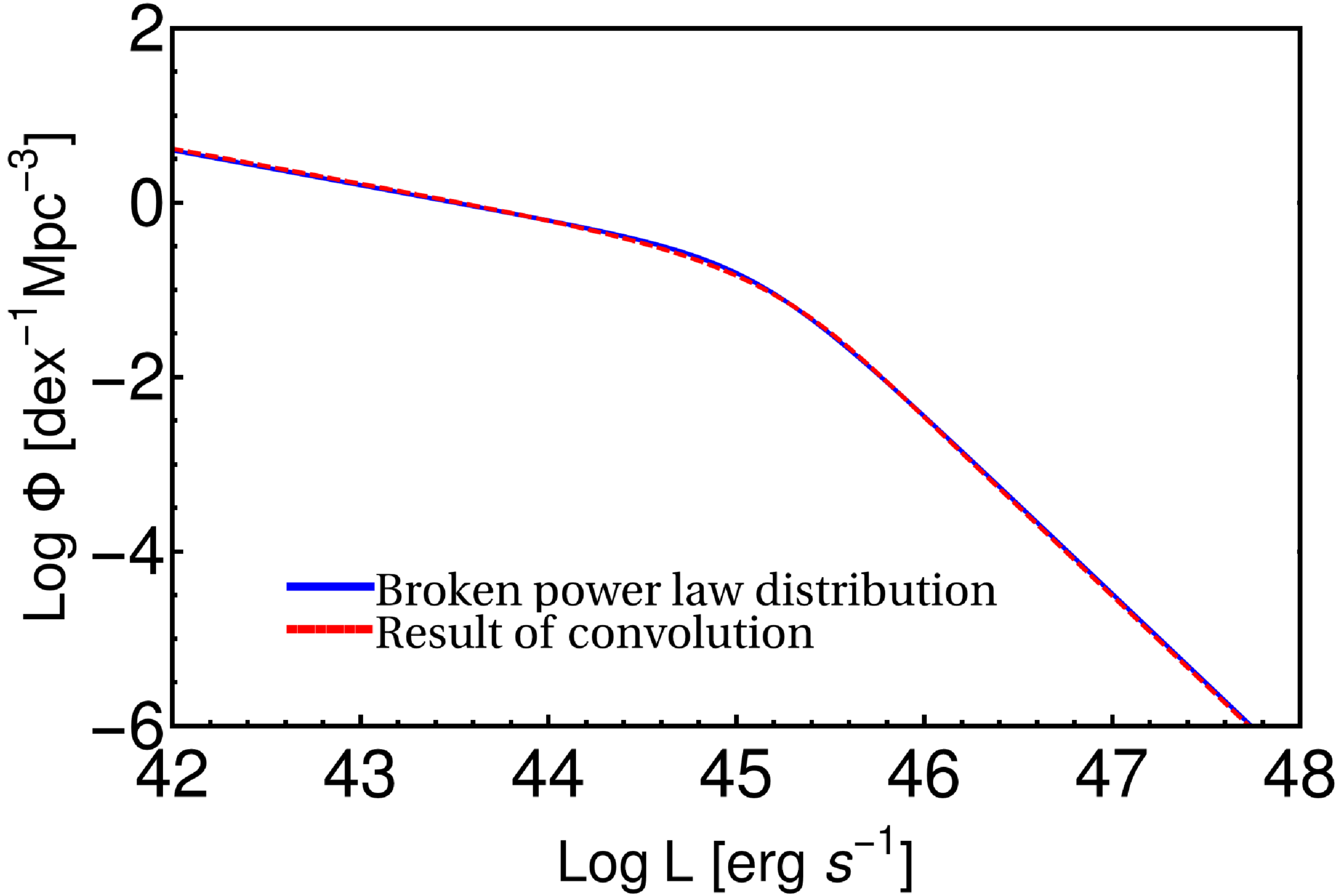
Log Φ(L) [dex⁻¹ Mpc⁻³]
Log L [erg s⁻¹]
z=0.1
z=0.5
z=1
z=1.5
z=2
z=3
z=4
z=5
-3
-5
-7
-9
42
44
46
48



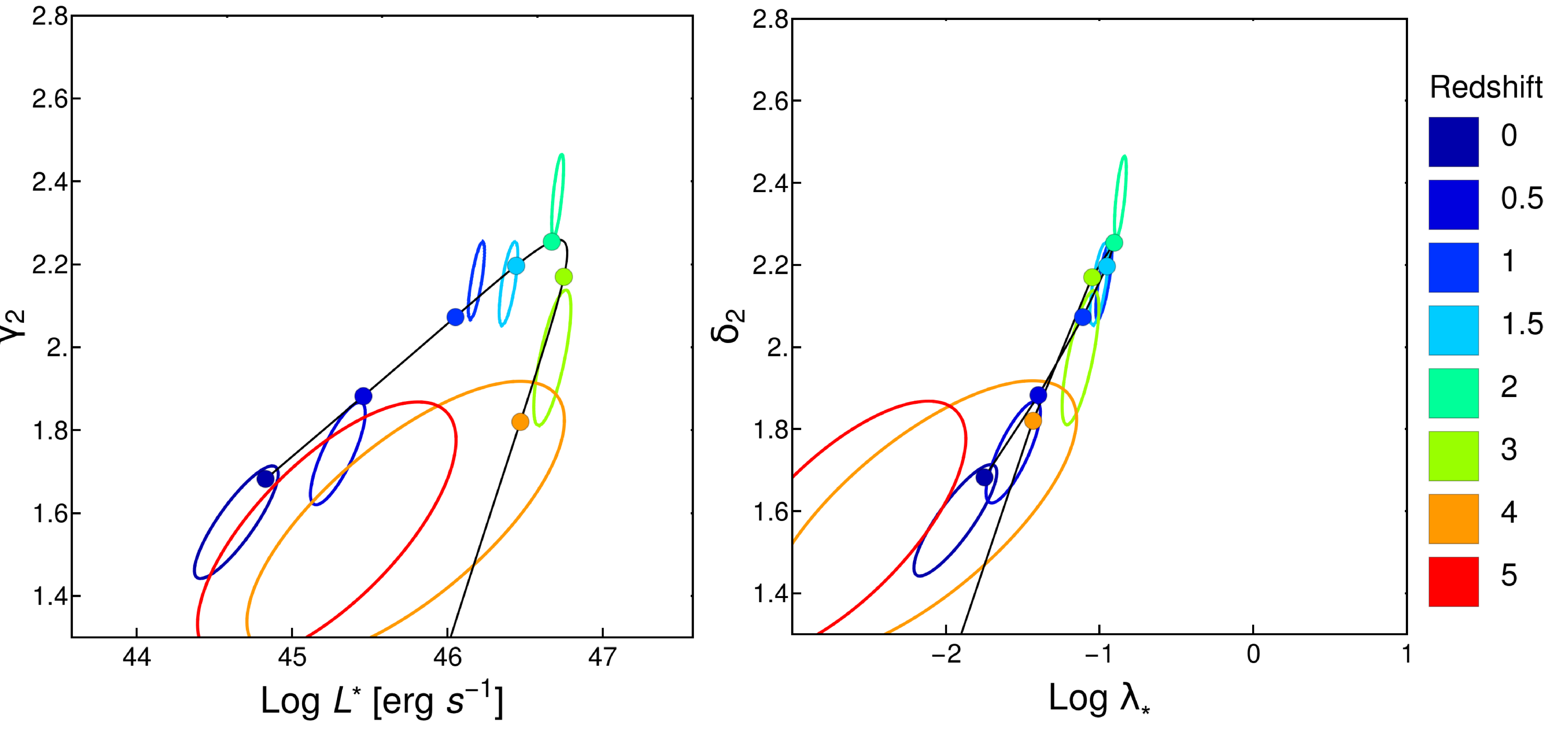
Log $L^*$ [erg $s^{-1}$]
Redshift
Log $\phi^*_{QLF}$ [dex$^{-1}$ Mpc$^{-3}$]
Redshift
0
0.5
1
1.5
2
3
4
5



Model
Individual objects
Mean of full sample
1−σ of the full sample
Mean of the observed sample
Haring & Rix, 2004
Log ($m_{BH}/m_*$)
Redshift
Matsuoka et al, 2014
$Log_{10}$ ($m_{BH}/m_*$)
Redshift
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
0.1
0.2
0.3
0.4
0.5
0.6



Log Φ [dex$^{-1}$Mpc$^{-3}$]
2
0
−2
−4
−6
42
43
44
45
46
47
48
Log L [erg $s^{-1}$]
Broken power law distribution
Result of convolution



γ2
Log L* [erg s−1]
δ2
Log λ*
Redshift
0
0.5
1
1.5
2
3
4
5