

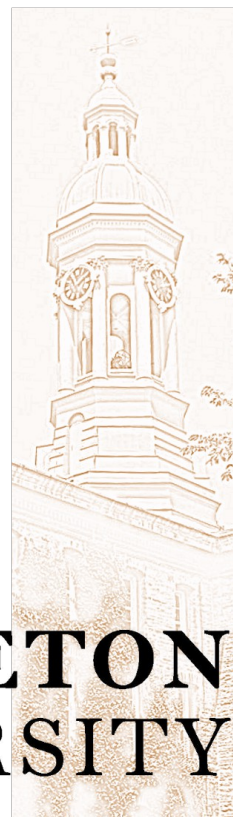
Evolution of the AGN Population in the Universe

Neven Caplar

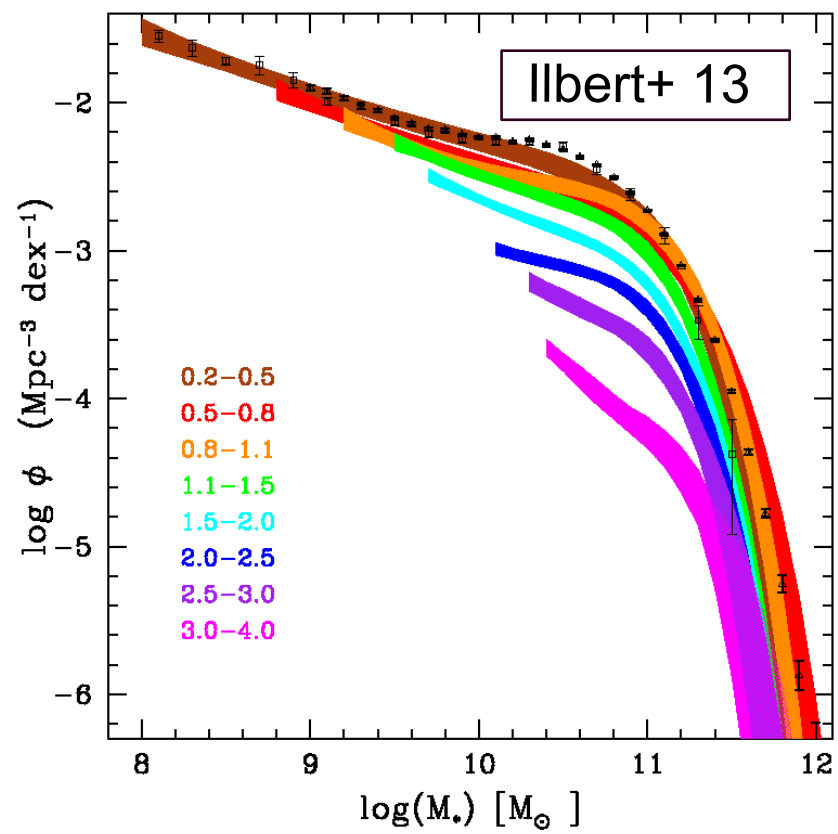
Simon Lilly, Benny Trakhtenbrot



**PRINCETON
UNIVERSITY**



Noeske+ 07



Reverse engineering approach

Basic idea: Identify key features of the observed galaxy and AGN populations and then explore *analytically* what they tell us, via the most basic continuity equations or via other simple relationships

$$\begin{aligned}\phi_{\text{red}}(t) &= \phi_{\text{blue}}(t_0) \frac{1}{-(1 + \alpha_s + \beta)} \frac{m}{M^*} \\ &\quad \times \int_{t_0}^t -(1 + \alpha_s + \beta) \text{sSFR}(t') e^{\int_{t_0}^t -(1 + \alpha_s + \beta) \text{sSFR}(t') dt'} dt' \\ &= \phi_{\text{blue}}(t_0) \frac{1}{-(1 + \alpha_s + \beta)} \frac{m}{M^*} e^{\int_{t_0}^t -(1 + \alpha_s + \beta) \text{sSFR}(t') dt'} \\ &= \phi_{\text{blue}}(t) \frac{1}{-(1 + \alpha_s + \beta)} \frac{m}{M^*}.\end{aligned}\tag{B4}$$

Peng+ 2010

Putting Equations (B2) and (B4) together gives

$$\begin{aligned}\frac{1}{\phi_{\text{red}}(t)} \frac{d\phi_{\text{red}}(t)}{dt} &= -\text{sSFR}(t)(1 + \alpha_s + \beta) \\ &= \frac{1}{\phi_{\text{blue}}(t)} \frac{d\phi_{\text{blue}}(t)}{dt} \\ \frac{d \ln \phi_{\text{red}}(t)}{dt} &= \frac{d \ln \phi_{\text{blue}}(t)}{dt}.\end{aligned}\tag{B5}$$

Peng+ 2012

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Observationally self-consistent

Constrains possible physical processes

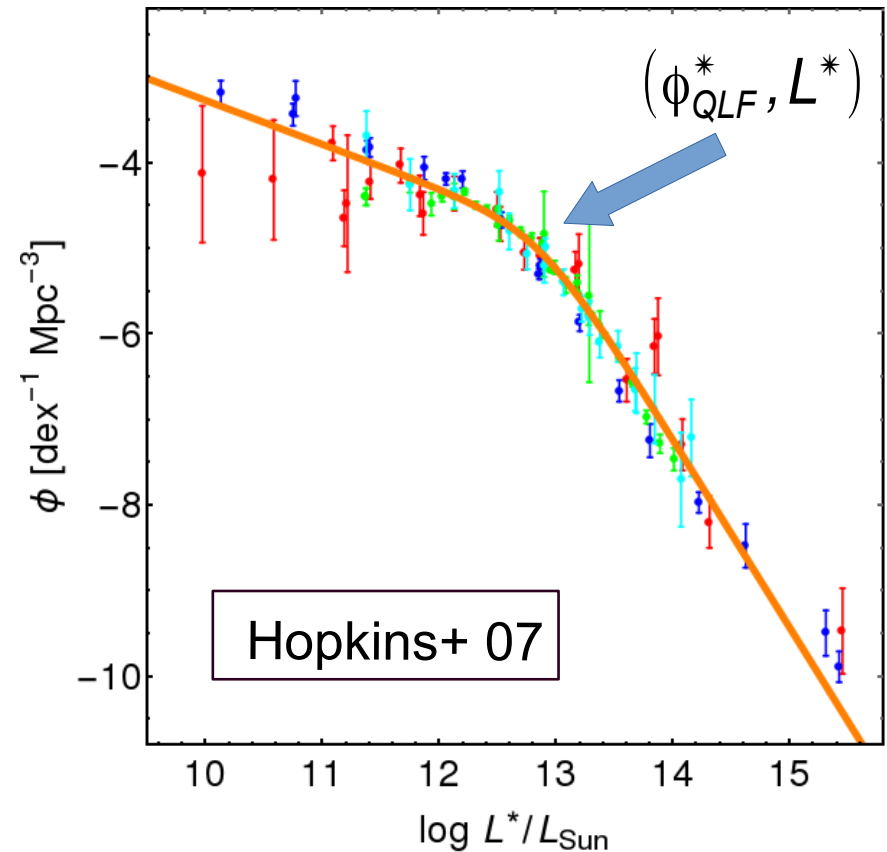
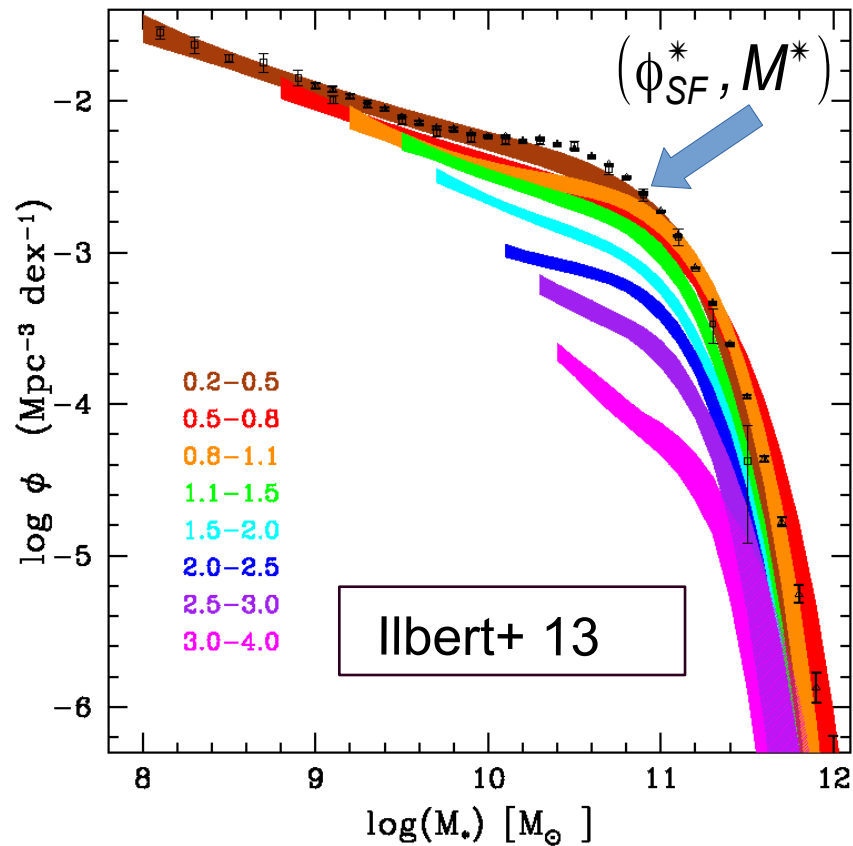
Reveals connections between different aspects of the problem

Highlights difficulties of establishing uniqueness and causality

Topics for which this approach has been used

- Quenching of star-formation in galaxies (Peng+ 10, Peng+ 12, Knobel+ 14)
- Gas-regulator control of star-formation (Lilly+ 13)
- Size and internal structure of galaxies (Lilly & Carollo 16)

Simplest observables in the Universe



- Galaxy mass function – number of galaxies per unit of mass
- Quasar luminosity function – number of quasars (AGN) per unit of luminosity

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

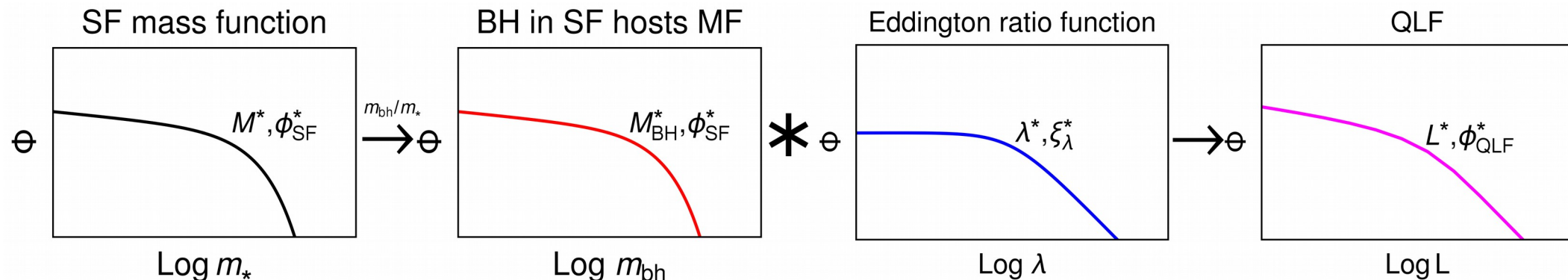
Ansätze - coexistence scenario

- Radiatively efficient AGN are in star forming systems
- Distribution of Eddington ratio does not depend on the mass of the central black hole
- Mass of central black hole proportional to stellar mass
- To make quasar luminosity function use
 - AGN mass function & Eddington ratio function

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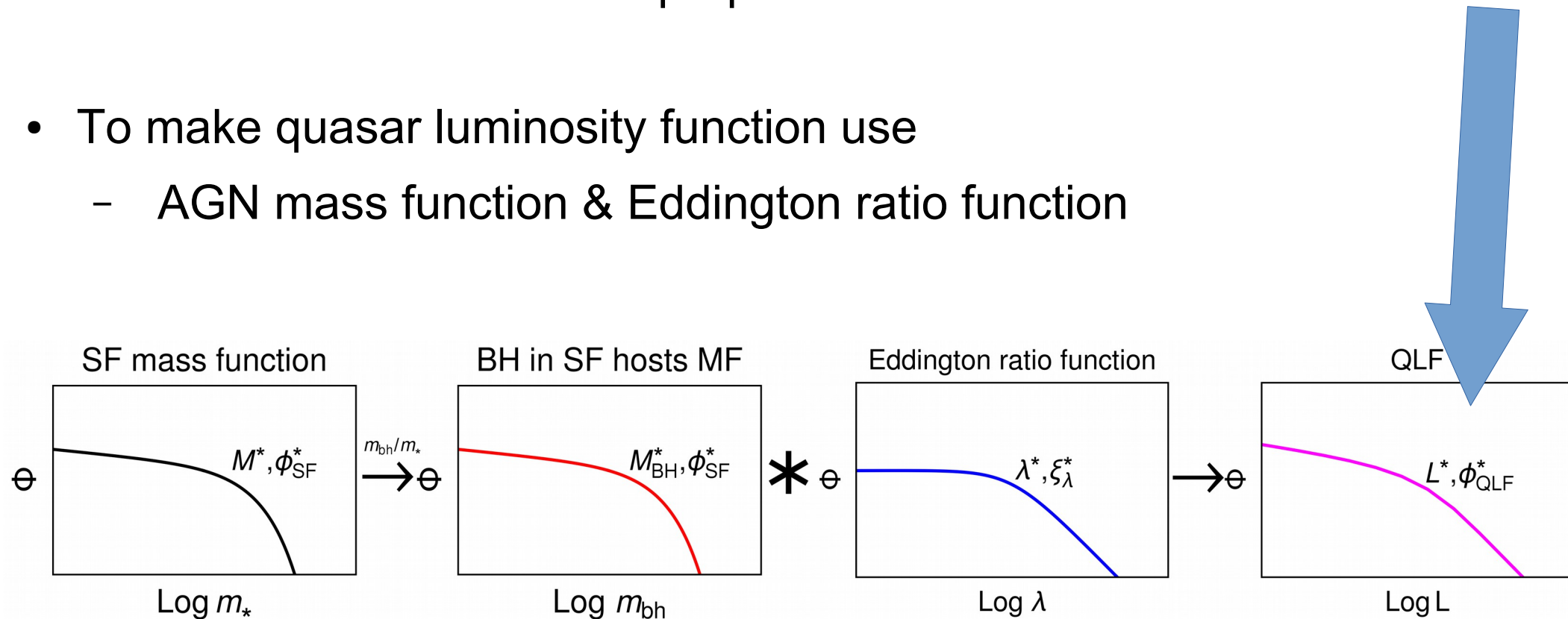


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$$L^* \propto M^* m_{bh} / m_* \lambda^*$$



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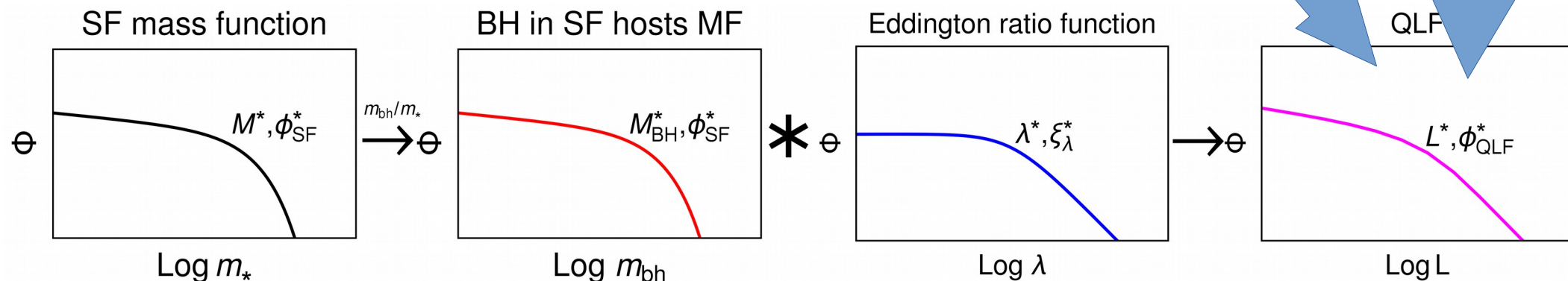
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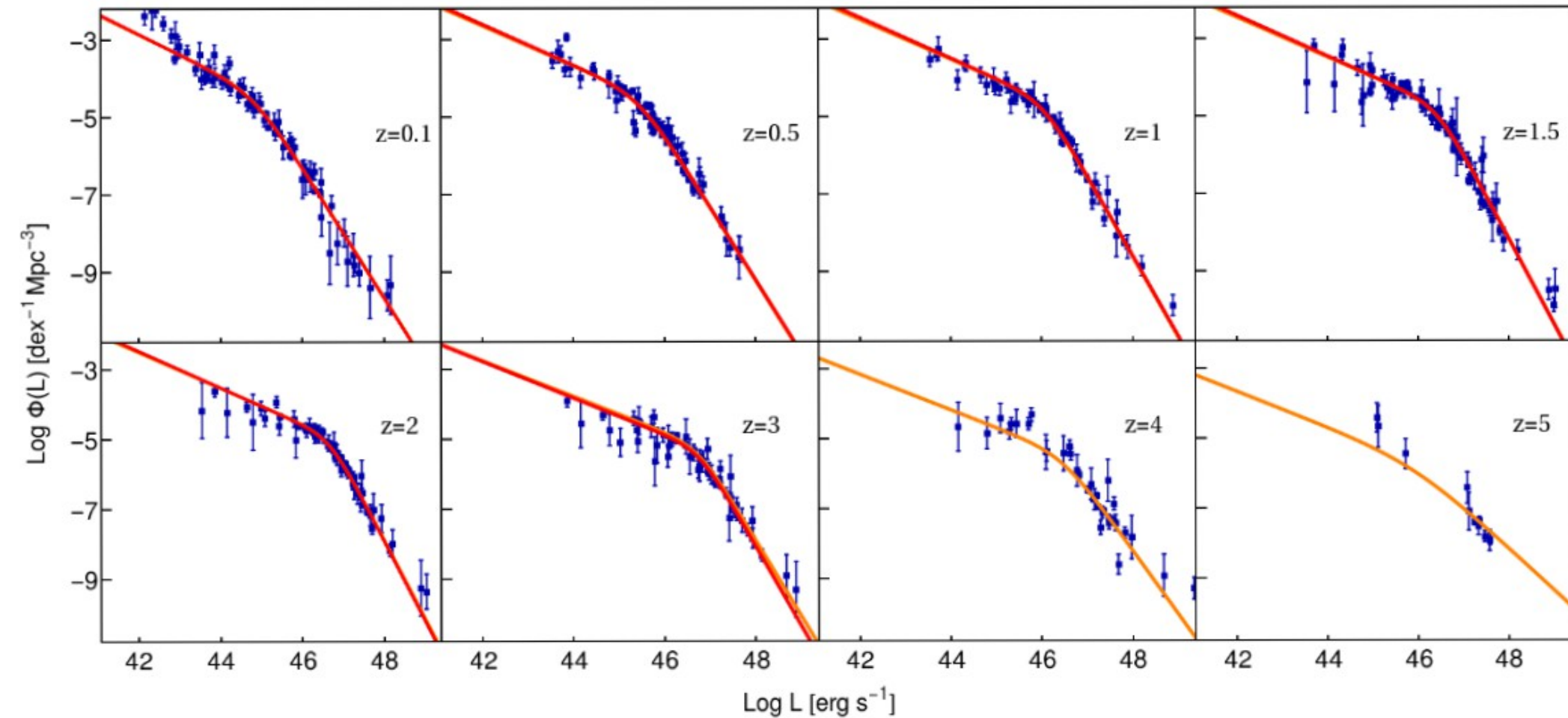
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$$\phi_{QLF}^* \propto \phi_{SF}^* \xi_{\lambda}^*$$

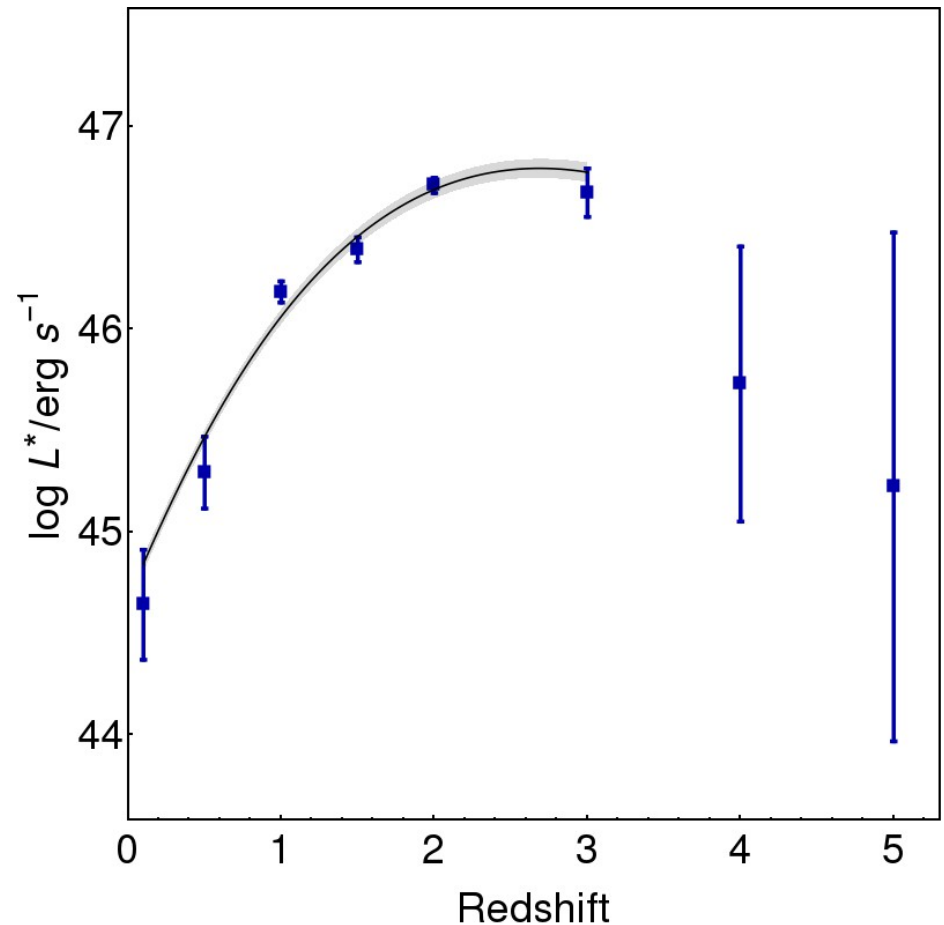


Two interesting results from quasar luminosity function



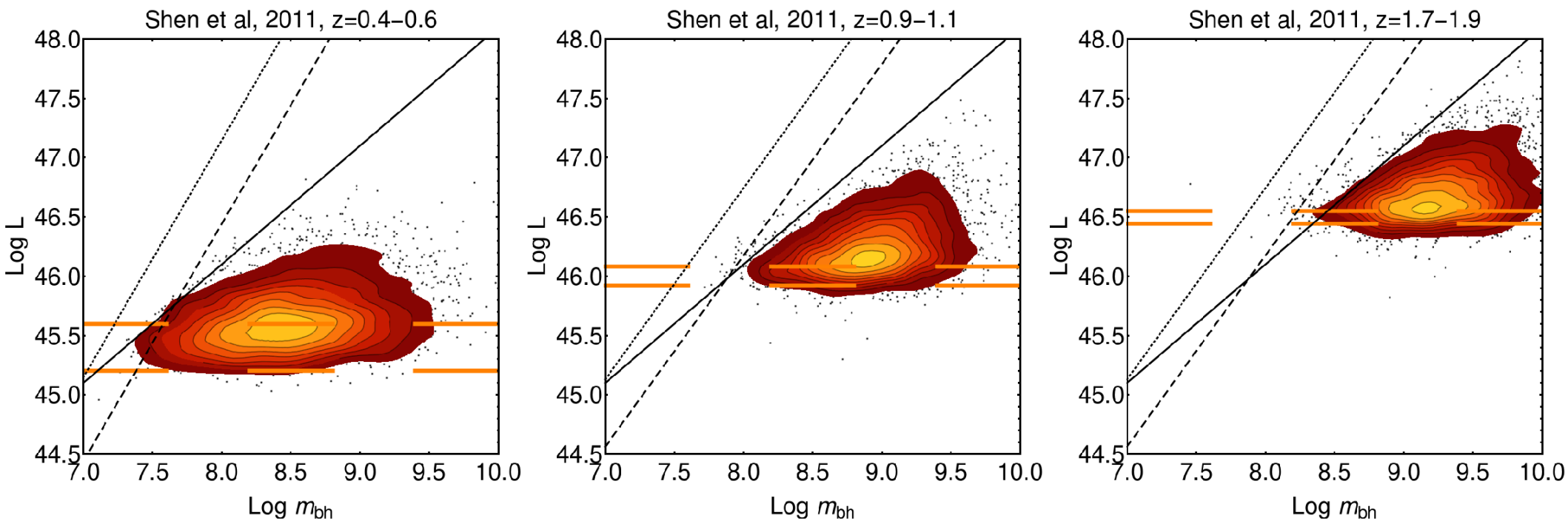
Hopkins+ 07, but also Aird+ 14, Ueda+ 15, Aird+ 18

Two interesting results from quasar luminosity function

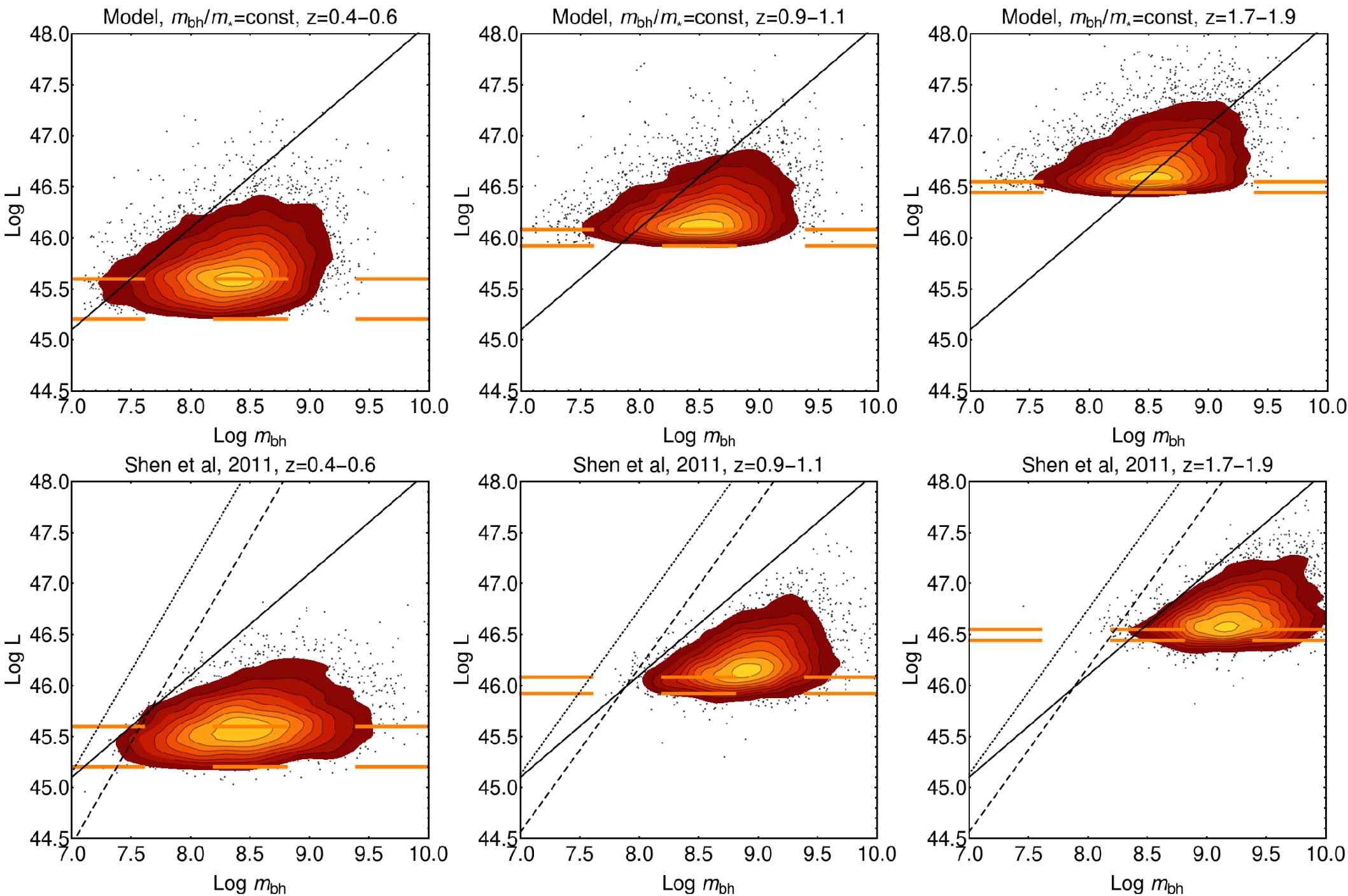


- Normalization of quasar luminosity function changes as normalization of star forming galaxies
- $L^* = (1 + z)^4, z < 2$
- $L^* \propto M^* m_{bh} / m_* \lambda^*$

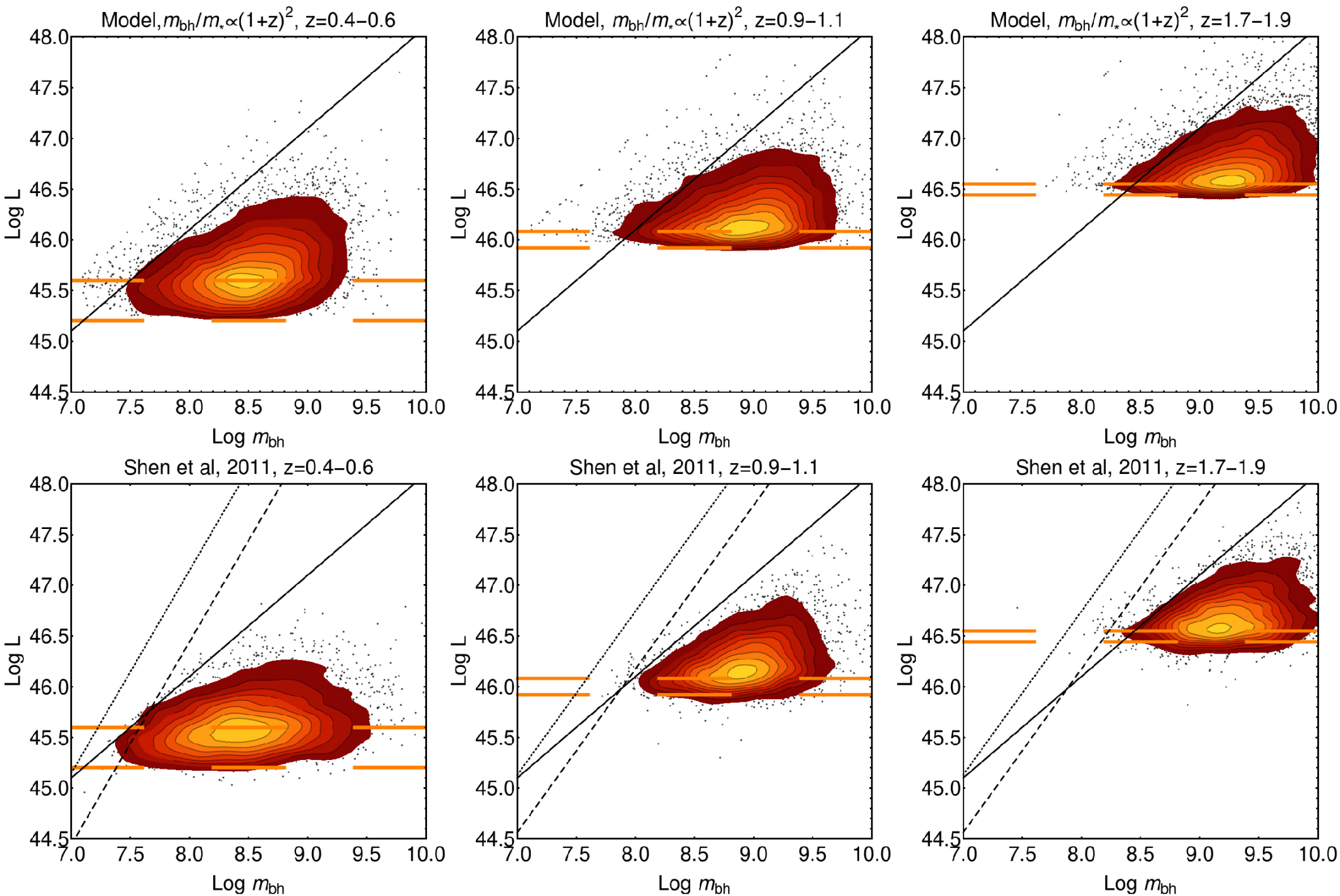
Results from simulating mass-luminosity plane



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What about local black hole – galaxy relation?

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Consequences of size evolution

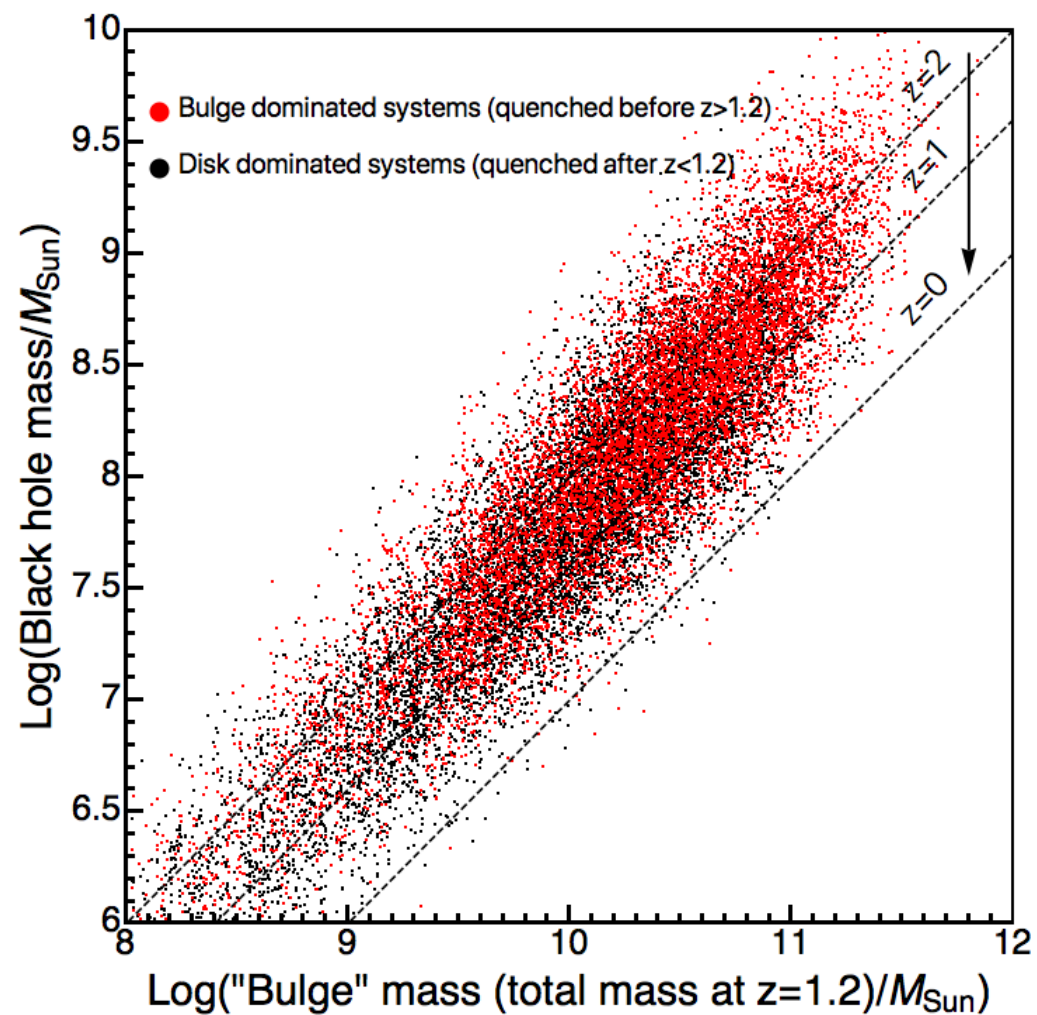
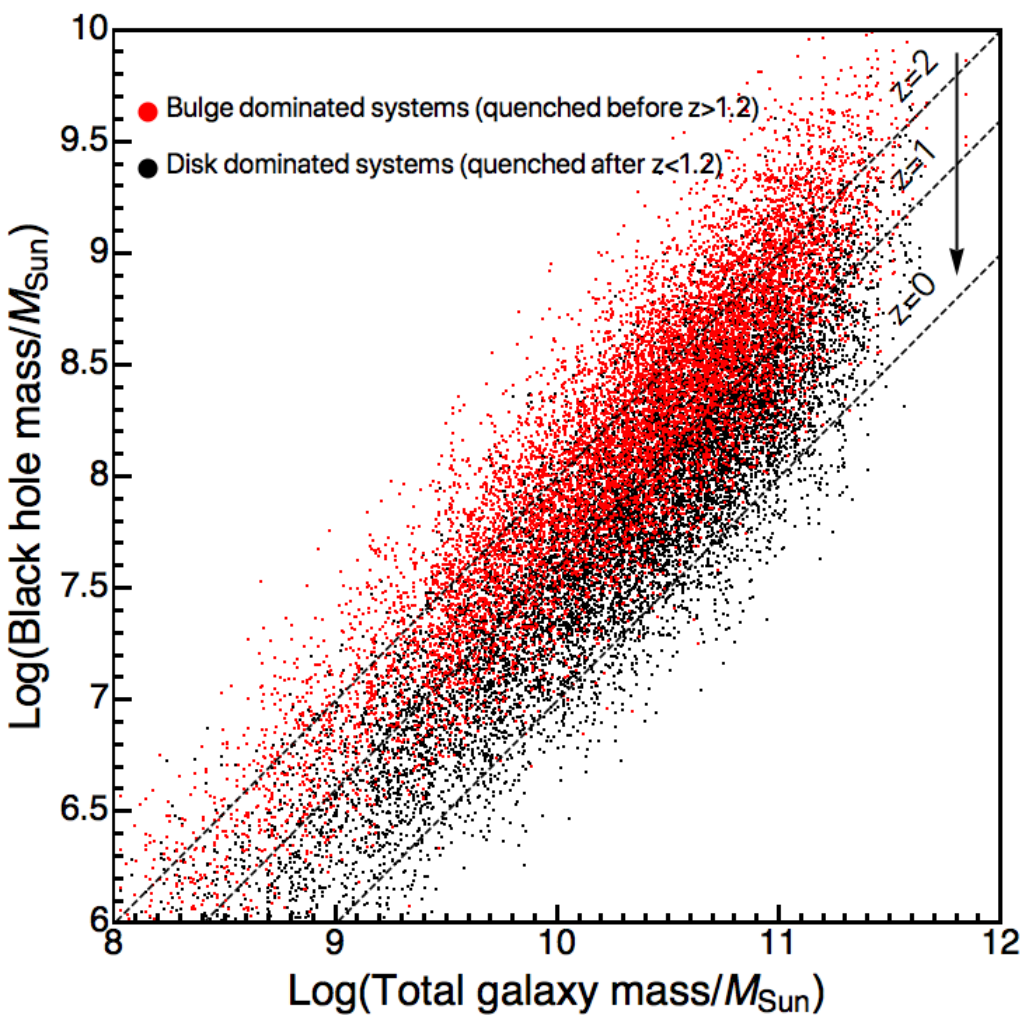
- Virial relation, Faber-Jackson and size evolution in galaxies implies evolution in either m_{bh}/m_* or $m_{bh} - \sigma$ relation
- redshift evolution in m_{bh}/m_* of $(1+z)^2$ leads to constant and tighter $m_{bh} - \sigma$ relation

$$r|_m \propto (1+z)^{-1} \Leftrightarrow \sigma^2|_m \propto (1+z)$$

$$m_{star} \propto \sigma^4 (1+z)^2$$

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

Consequences of size evolution

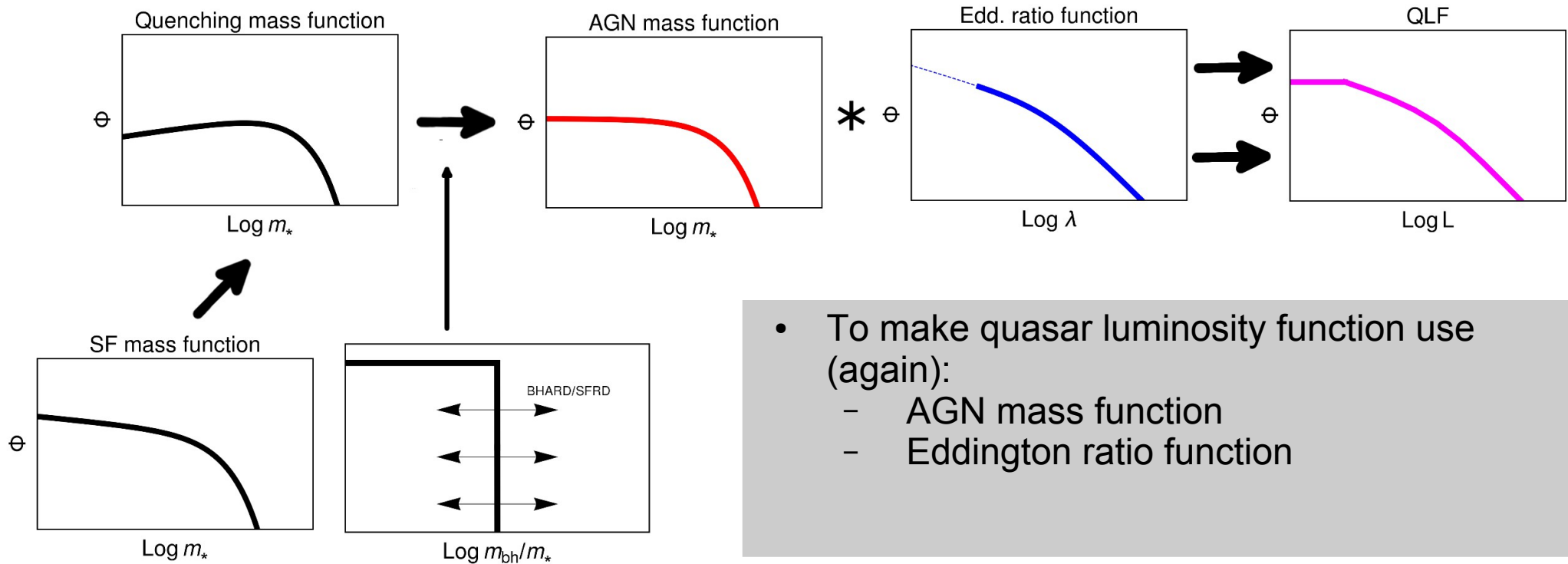


“The problem”

- Mass growth of galaxies and AGN does not support such a mass ratio evolution in the co-existence scenario considered until now

Quenching scenario

- Equations?

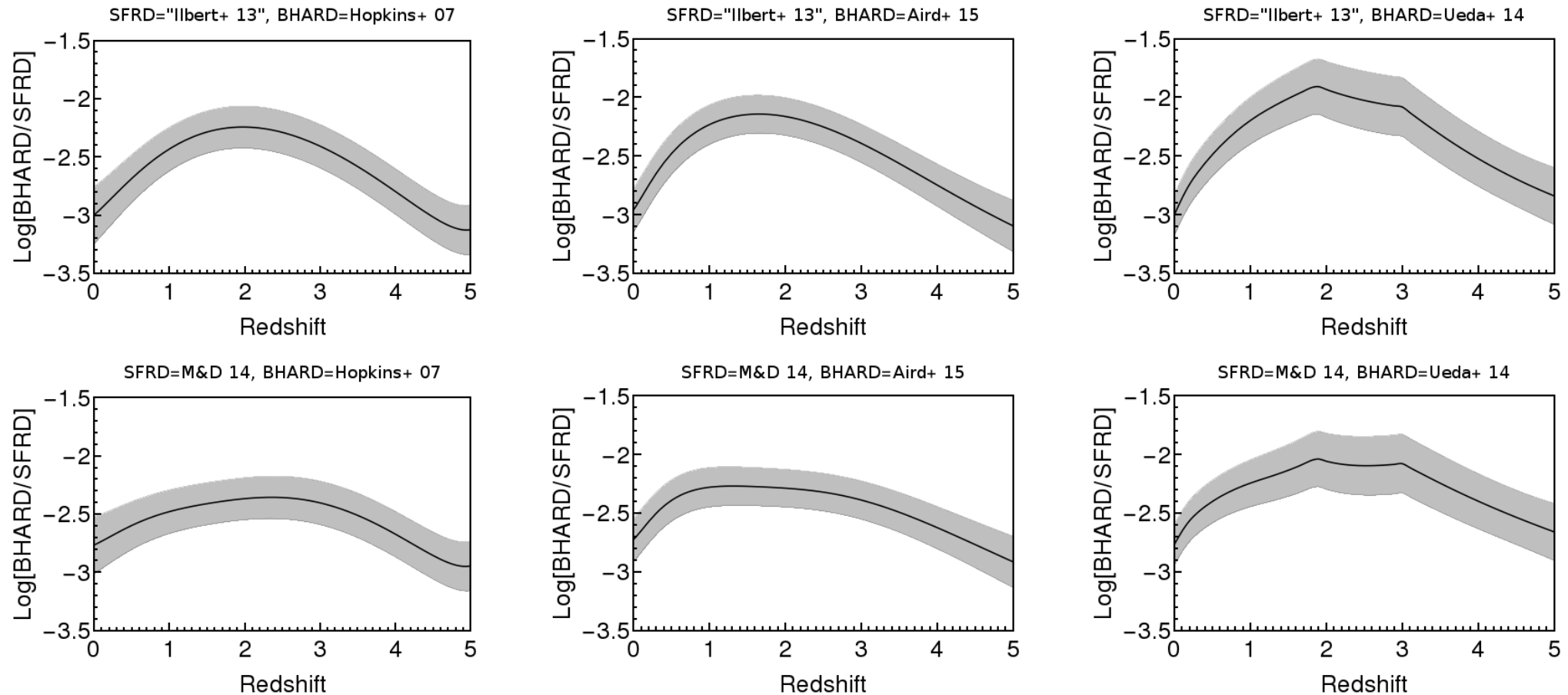


- To make quasar luminosity function use (again):
 - AGN mass function
 - Eddington ratio function

- Now – AGN activity connected with mass-quenching; black hole accretion happens in a single, almost delta-like burst

Naturally overcomes “the problem”- mass ratio responds instantly to the changes of the mass accretion rate

Evolution of AGN population in quenching scenario



- Mass ratio evolution is now an output of the model
- Mass ratio = BHARD/SFRD $\propto (1+z)^{1.5}$

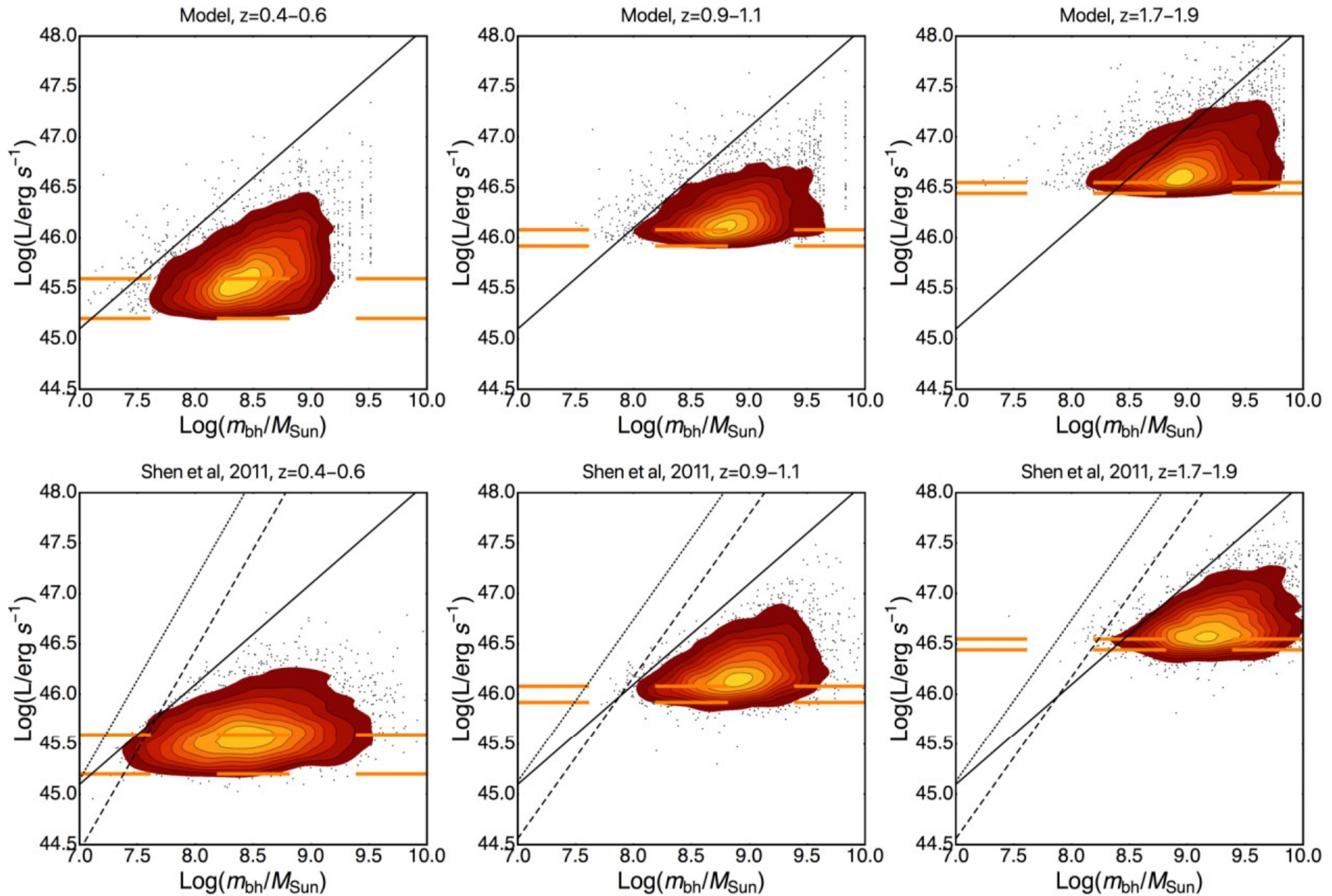
Evolution of AGN population in quenching scenario

- Eddington ratio = $\lambda^* = (SFRD/BHARD) \cdot (L^\square / M^\square)$
- Eddington ratio $\propto (1+z)^{2.5}$
- sSFR $\propto (1+z)^{2.5}$



$$\frac{\phi_{QLF}^*}{\phi_{SF}^*} = \frac{\lambda^*}{sSFR} = const$$

Evolution of AGN population in quenching scenario

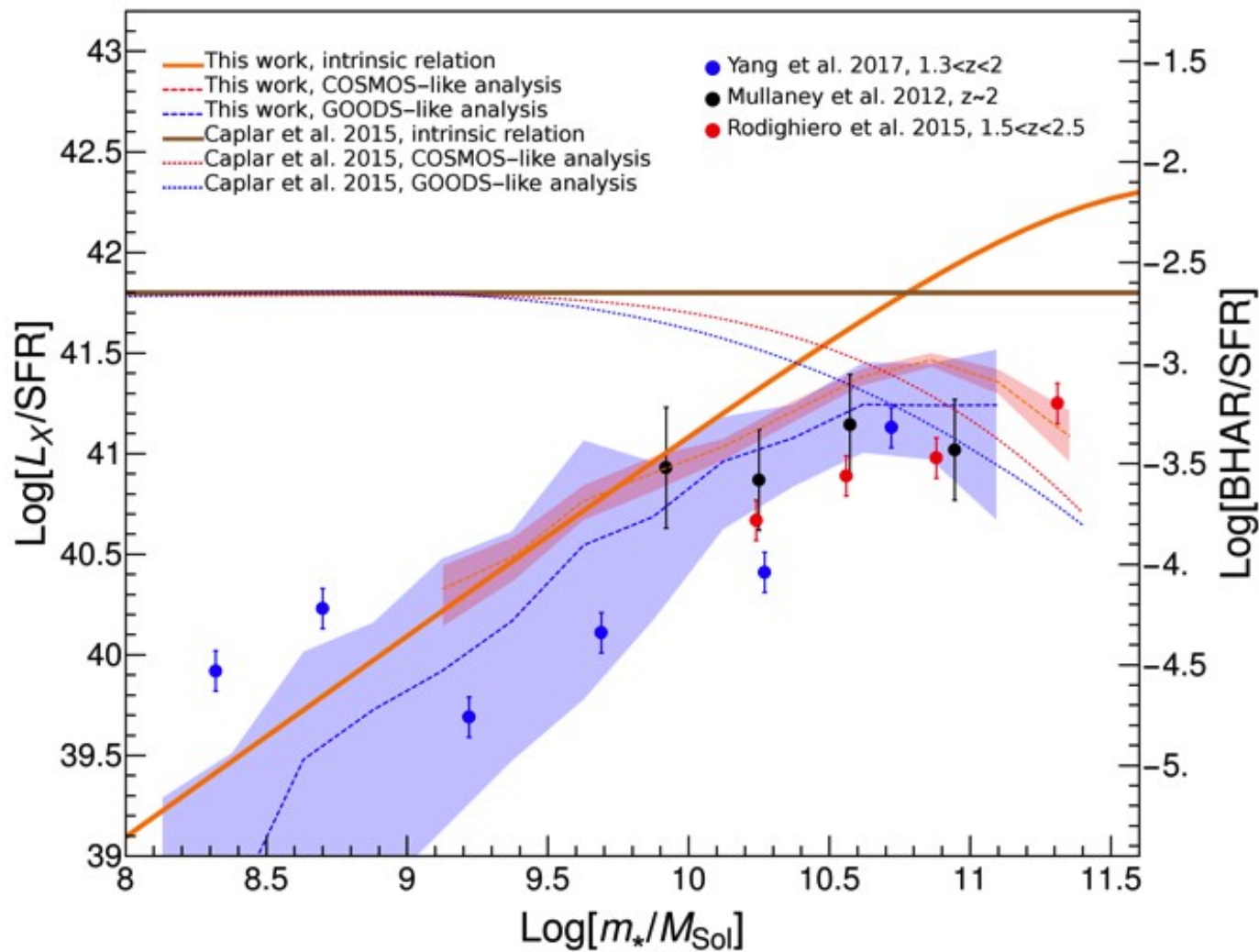


How to differentiate two scenarios

- The main difference = which galaxies host AGN
- Co-existence → All SF galaxies have equal chance to host an AGN
- Quenching → More massive SF galaxies have a great chance to host an AGN

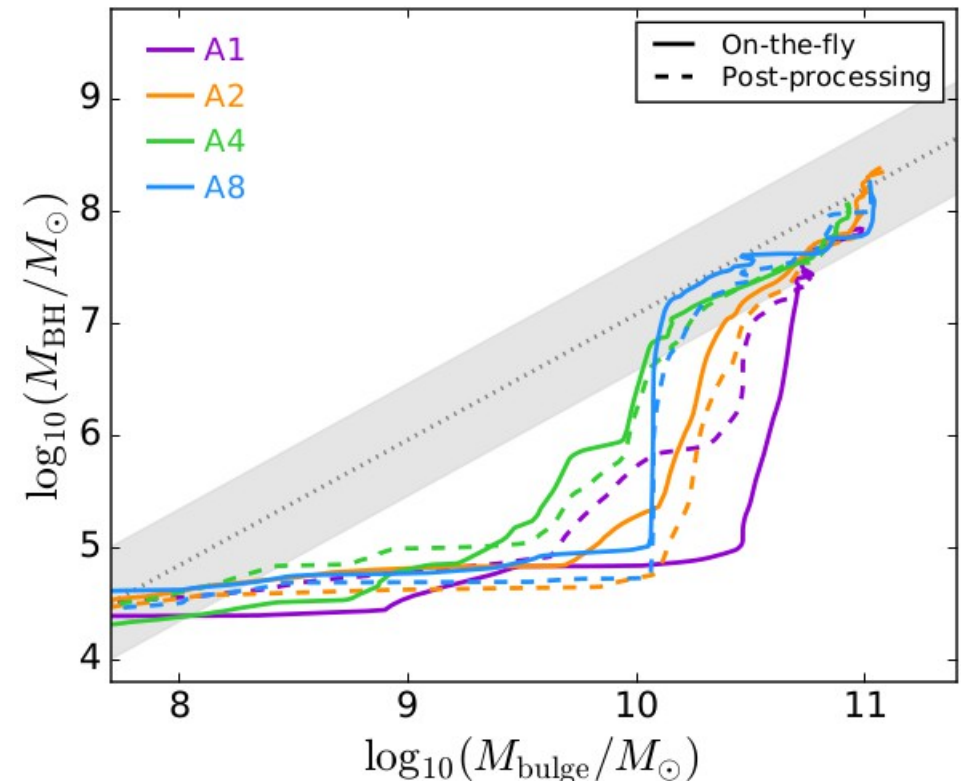
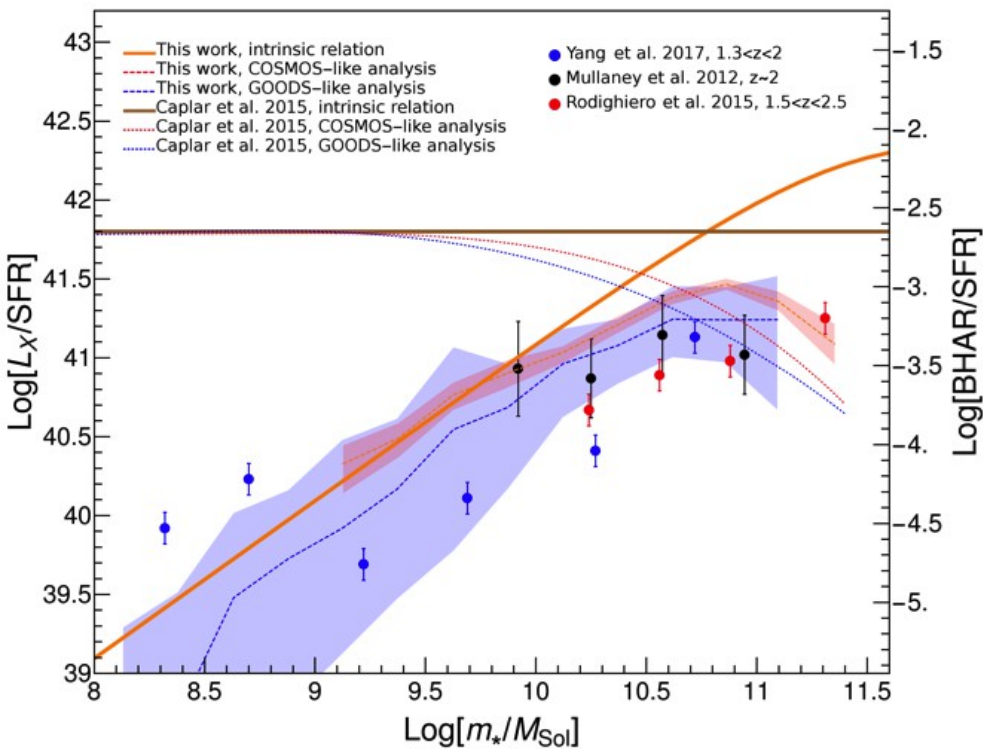
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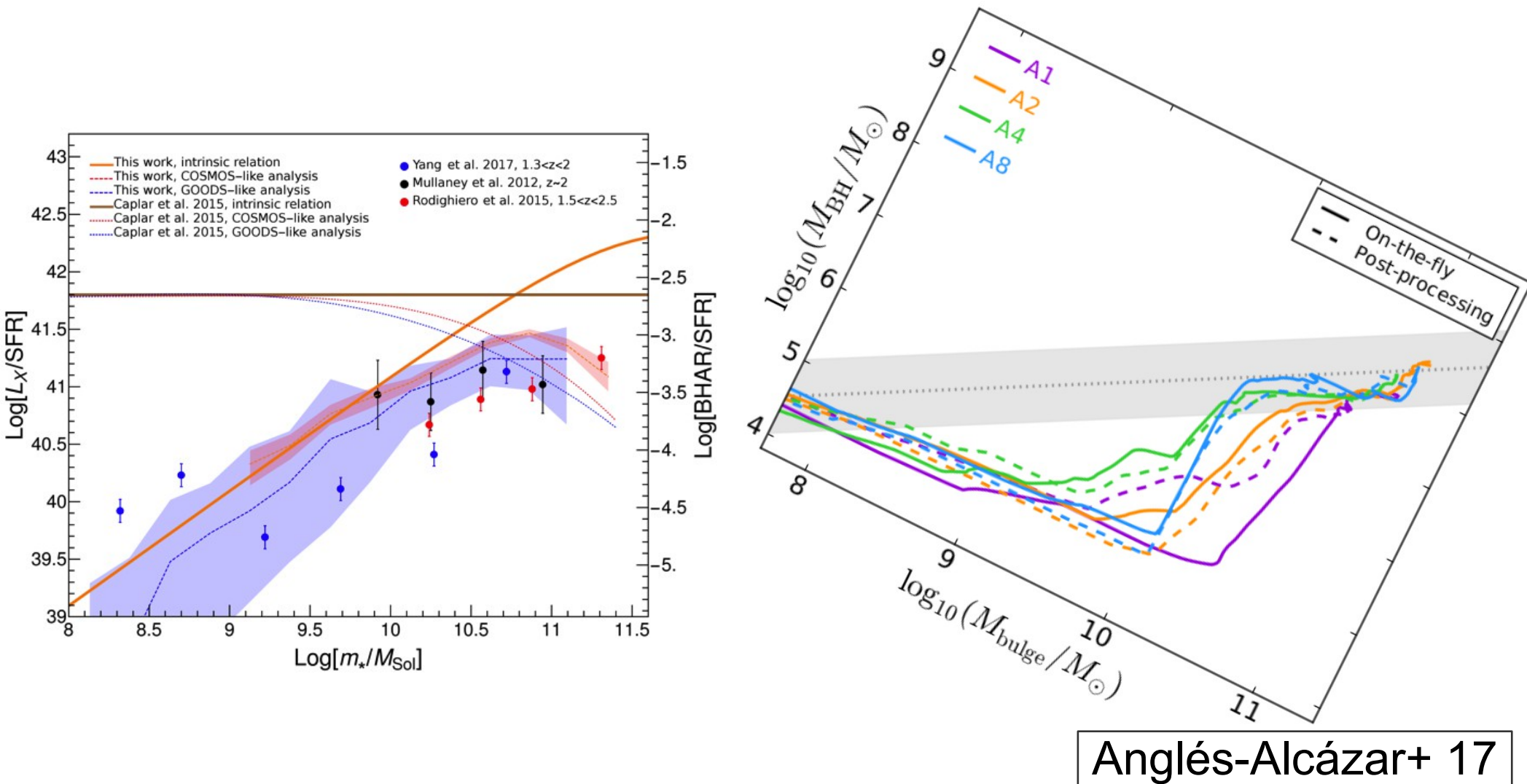
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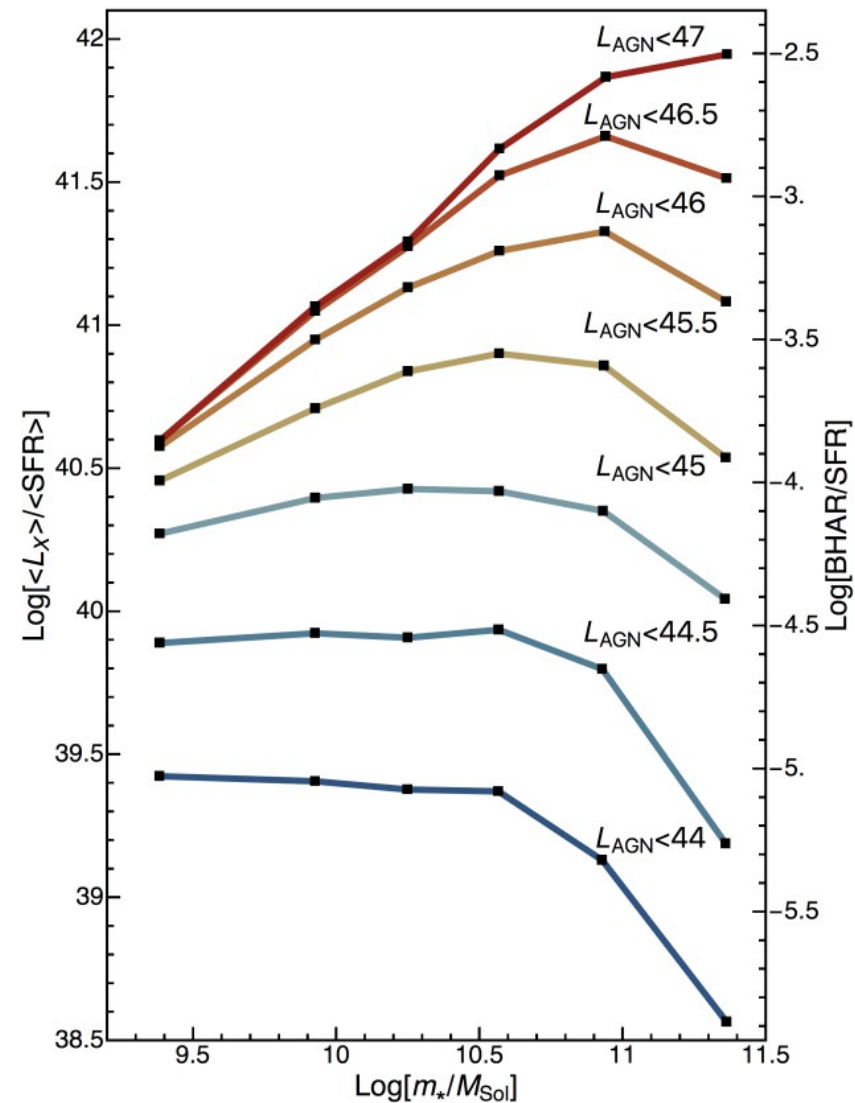
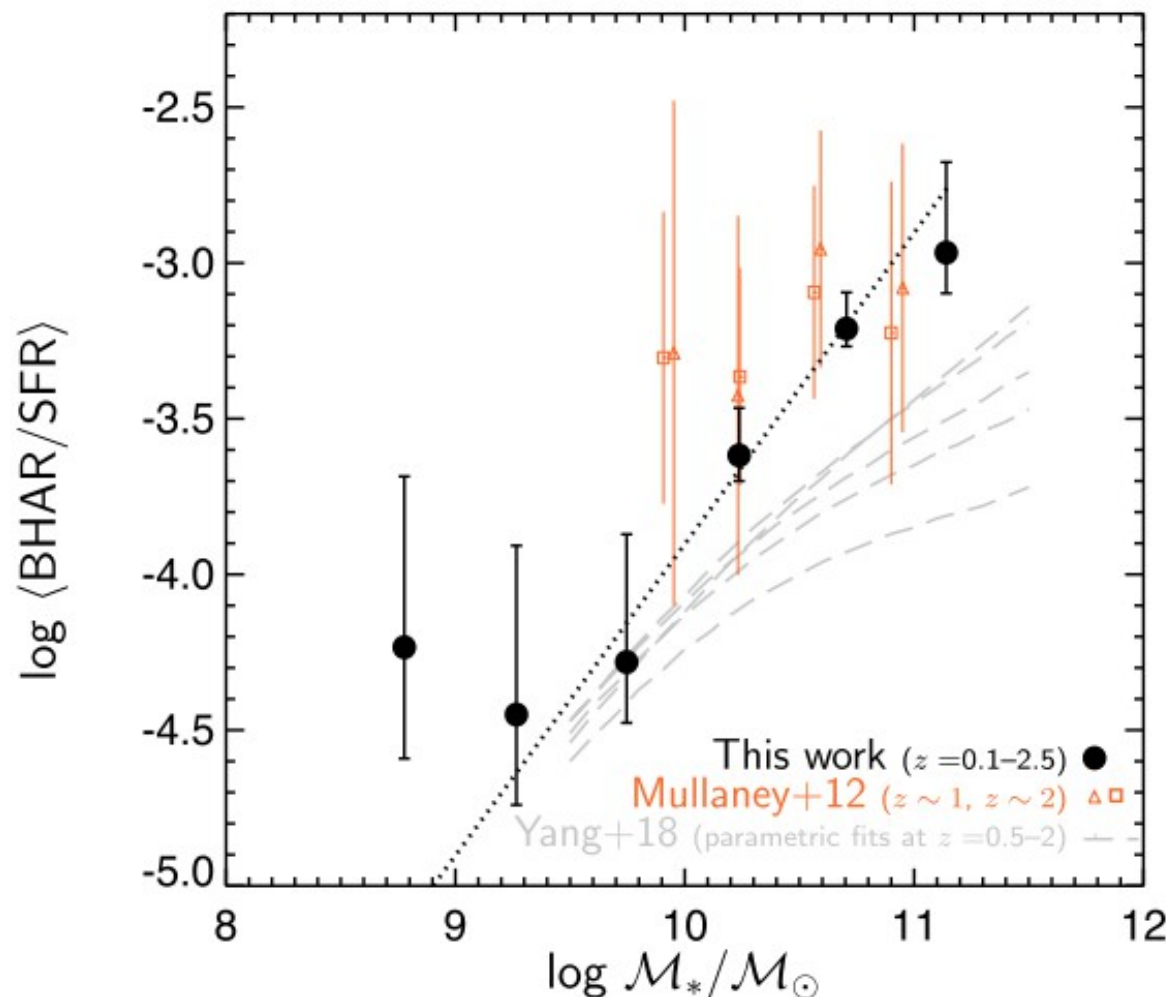
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Summary

- Simple global model combining galaxy mass function and quasar luminosity function leads to following conclusions
 - **Evolution in the m_{bh}/m_* relation** in star-forming galaxies
 - Non-evolving m_{bh}/m_* disfavored by mass-luminosity plane

Rewrite

- Scenario in which **AGN growth is connected with quenching of star-formation** self-consistently produces m_{bh}/m_* evolution, Edd. ratio evolution and normalization evolution as seen in observations.