Evolution of the AGN Population in the Universe – insights from galaxy evolution perspective

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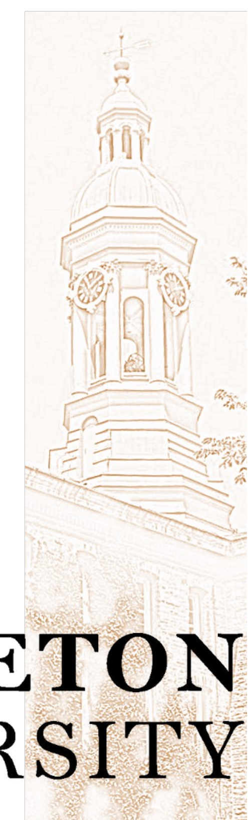
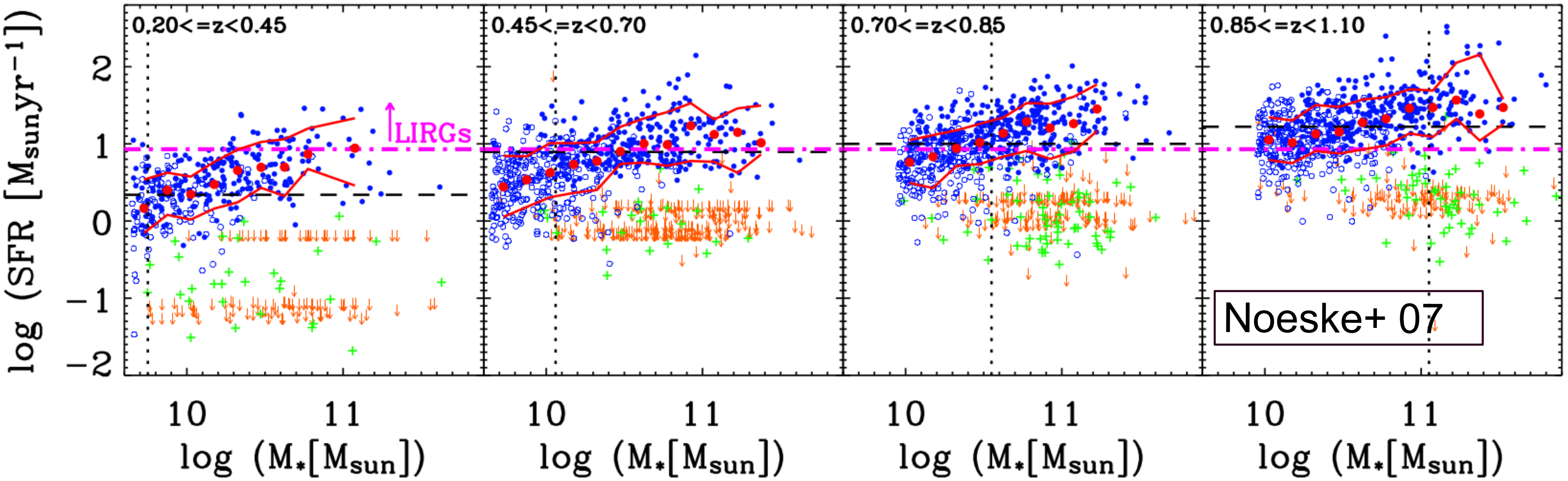
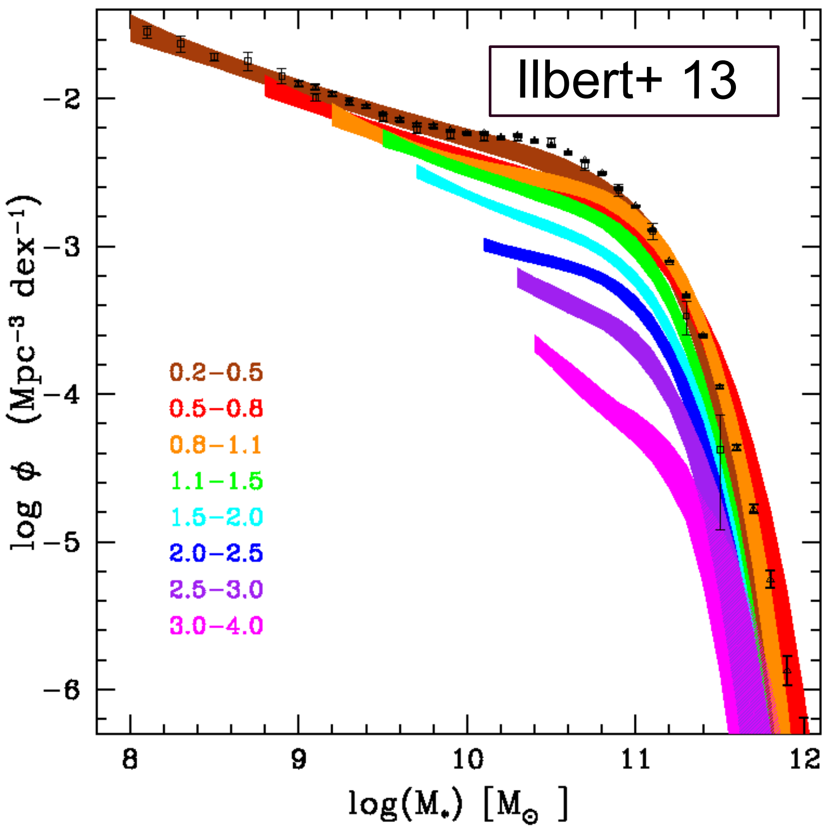
Simon Lilly, Benny Trakhtenbrot



PRINCETON UNIVERSITY



0.20<=z<0.45
0.45<=z<0.70
0.70<=z<0.85
0.85<=z<1.10
LIRGs
Noeske+ 07
log (SFR [Msunyr−1])
log (M*[Msun])



Ilbert+ 13
0.2−0.5
0.5−0.8
0.8−1.1
1.1−1.5
1.5−2.0
2.0−2.5
2.5−3.0
3.0−4.0
log φ (Mpc−3 dex−1)
log(M*) [M⊙]

Reverse engineering approach

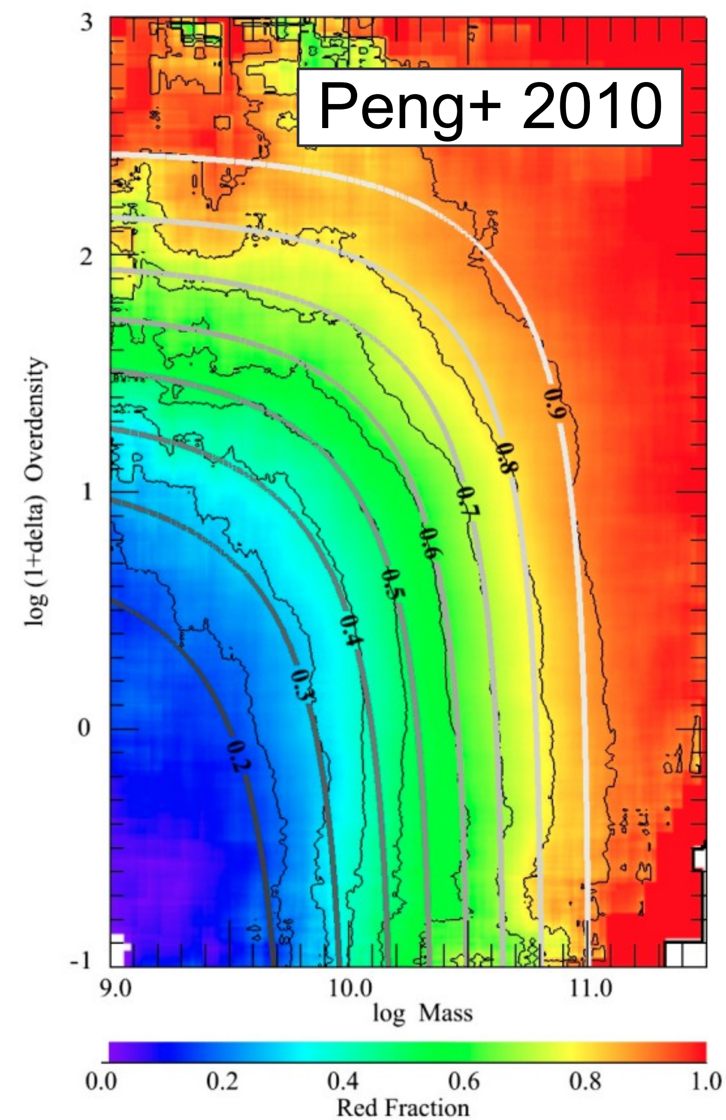
Basic idea: Identify key features of the observed galaxy and AGN <u>populations</u> and then explore *analytically* what they tell us, via the most basic continuity equations or via other simple relationships

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

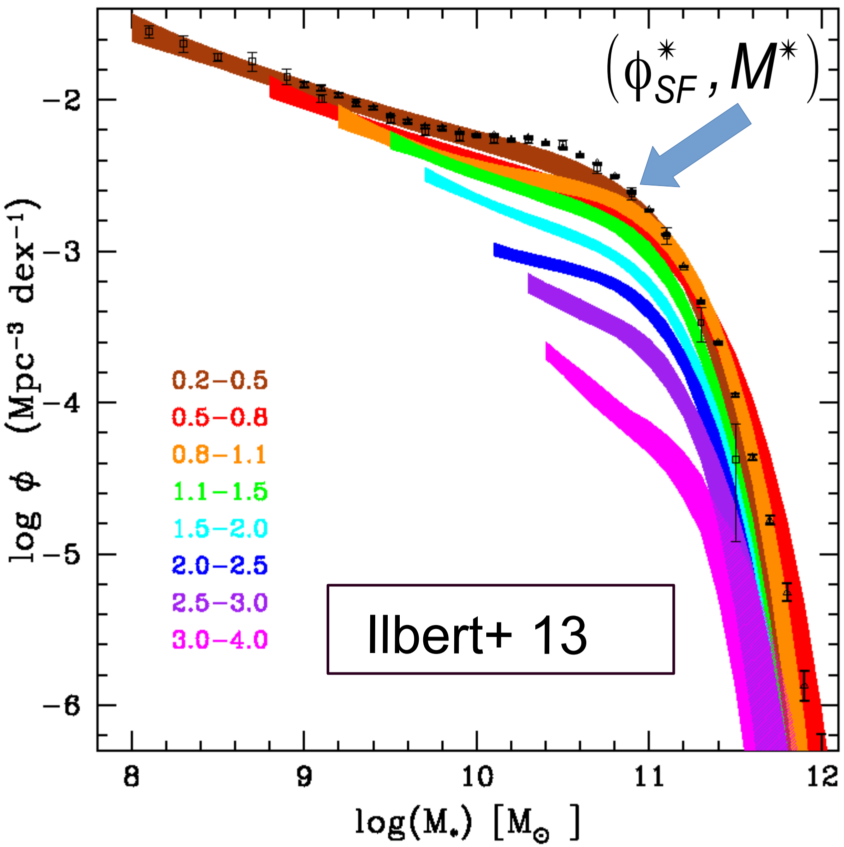
Putting Equations (B2) and (B4) together gives

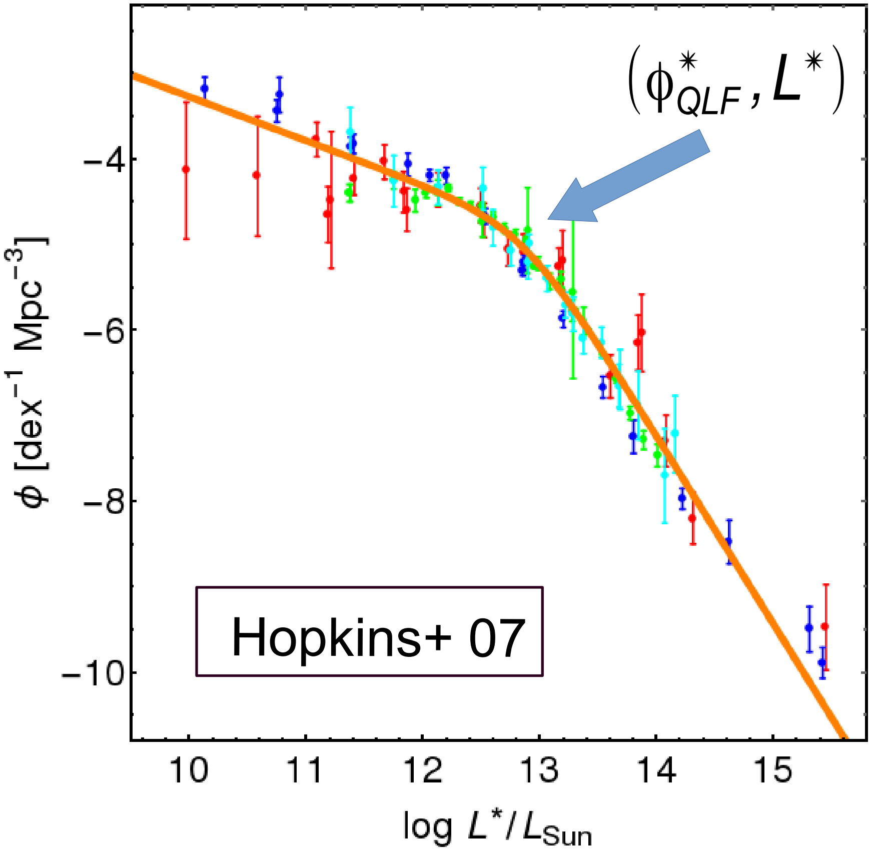
$$
\begin{aligned}
\frac{1}{\phi_{\rm red}(t)}\frac{d\phi_{\rm red}(t)}{dt} &= -\mathrm{sSFR}(t)(1+\alpha_s+\beta) \\
&= \frac{1}{\phi_{\rm blue}(t)}\frac{d\phi_{\rm blue}(t)}{dt} \\
\frac{d\ln\phi_{\rm red}(t)}{dt} &= \frac{d\ln\phi_{\rm blue}(t)}{dt}. \qquad \text{(B5)}
\end{aligned}
$$

Peng+ 2012



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 - coexistance 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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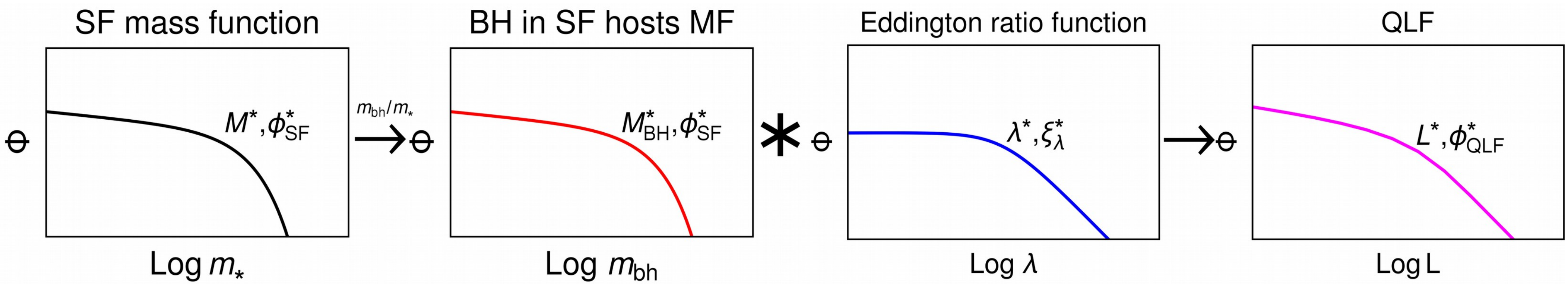

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$$\boxed{L^* \propto M^* m_{bh}/m_* \lambda^*}$$

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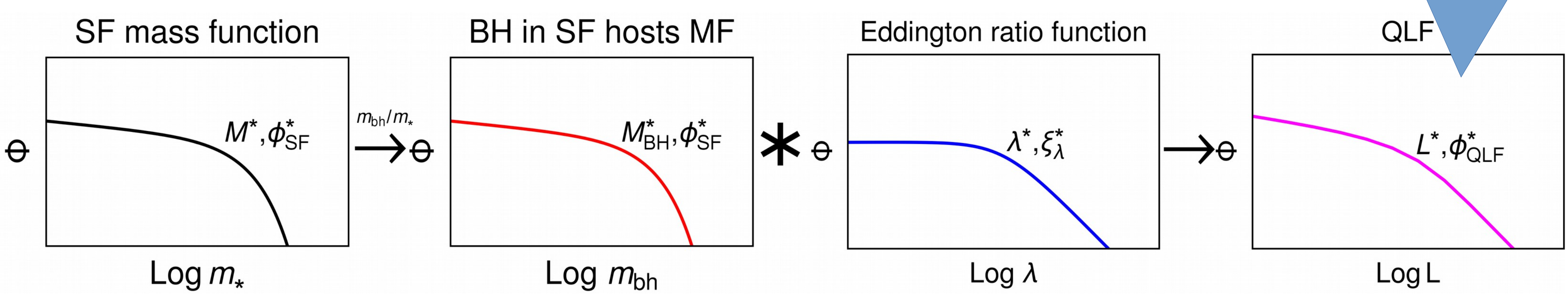

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$$\boxed{\phi^*_{QLF} \propto \phi^*_{SF}\, \xi^*_\lambda}$$

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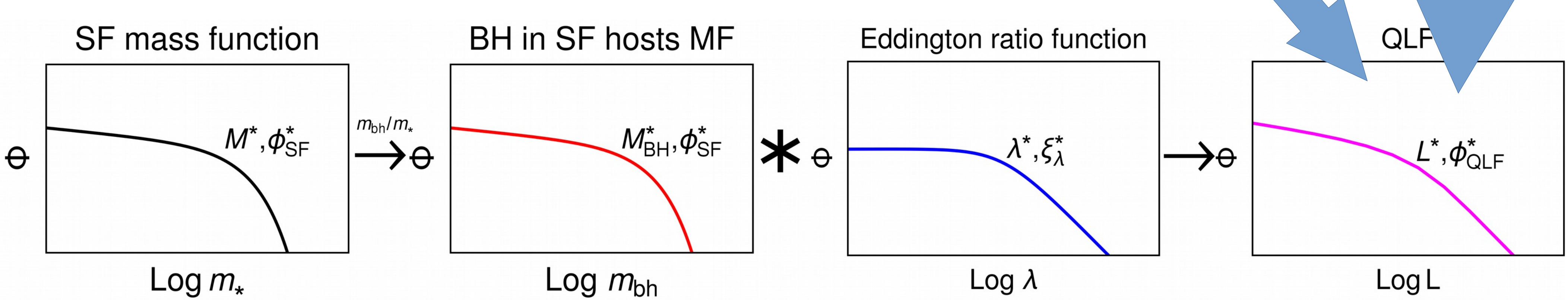
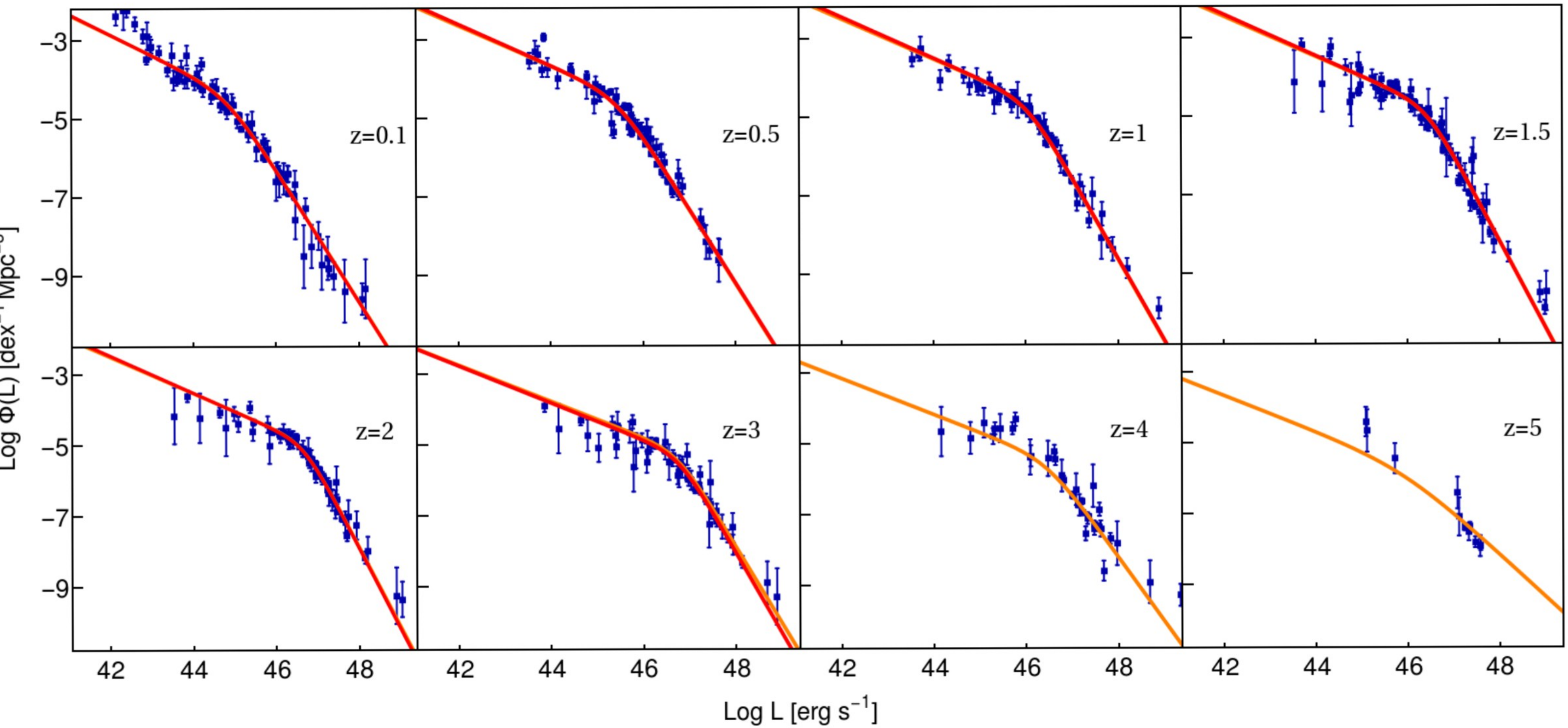


Two interesting results from quasar luminosity function



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

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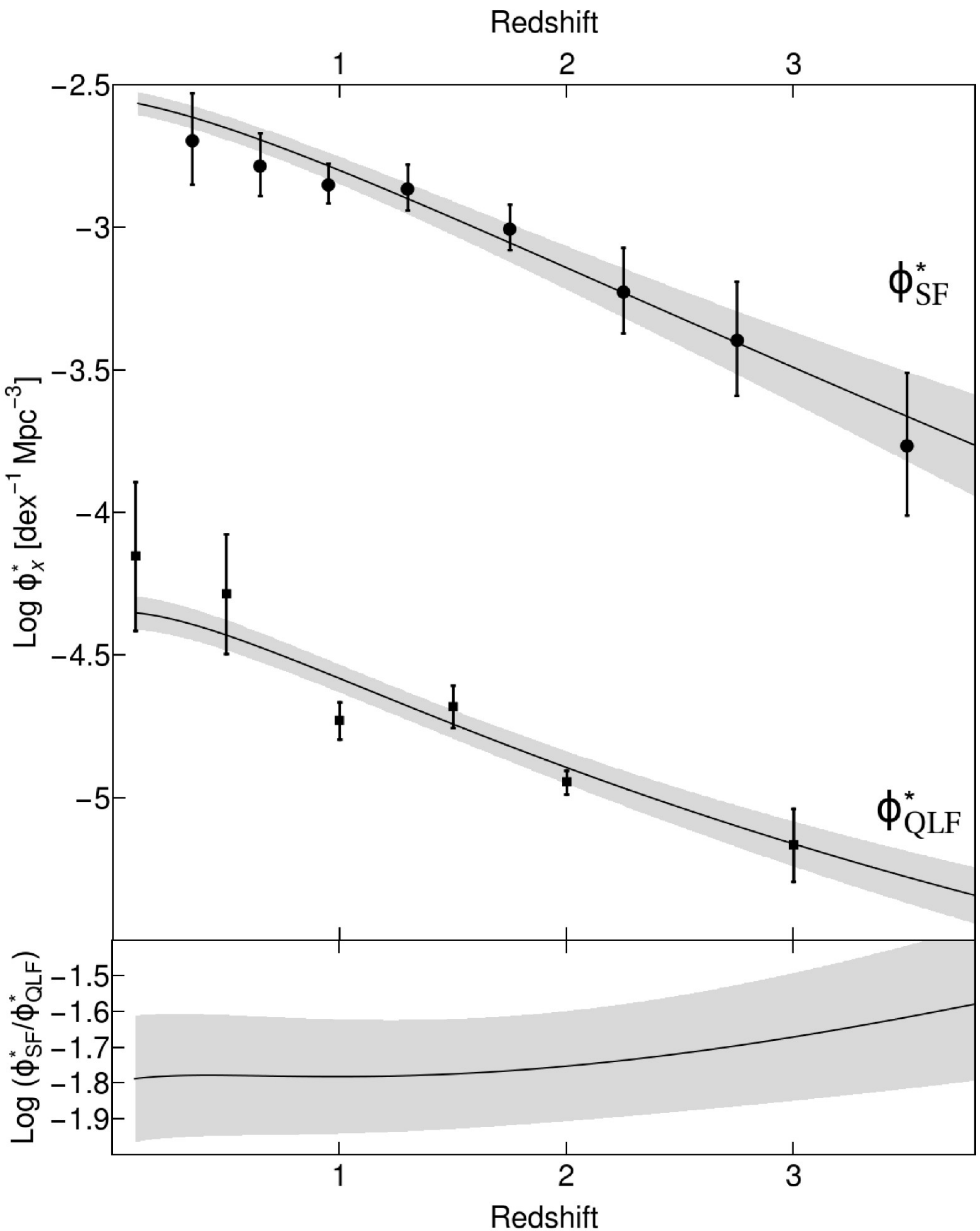
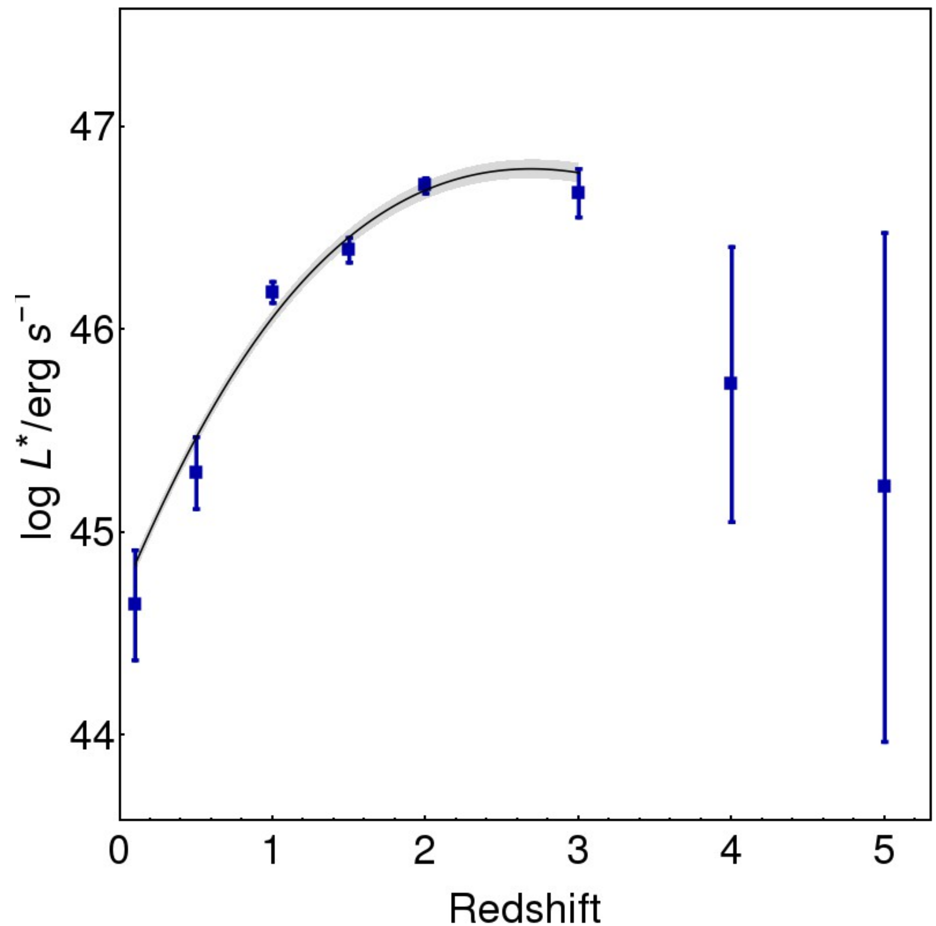
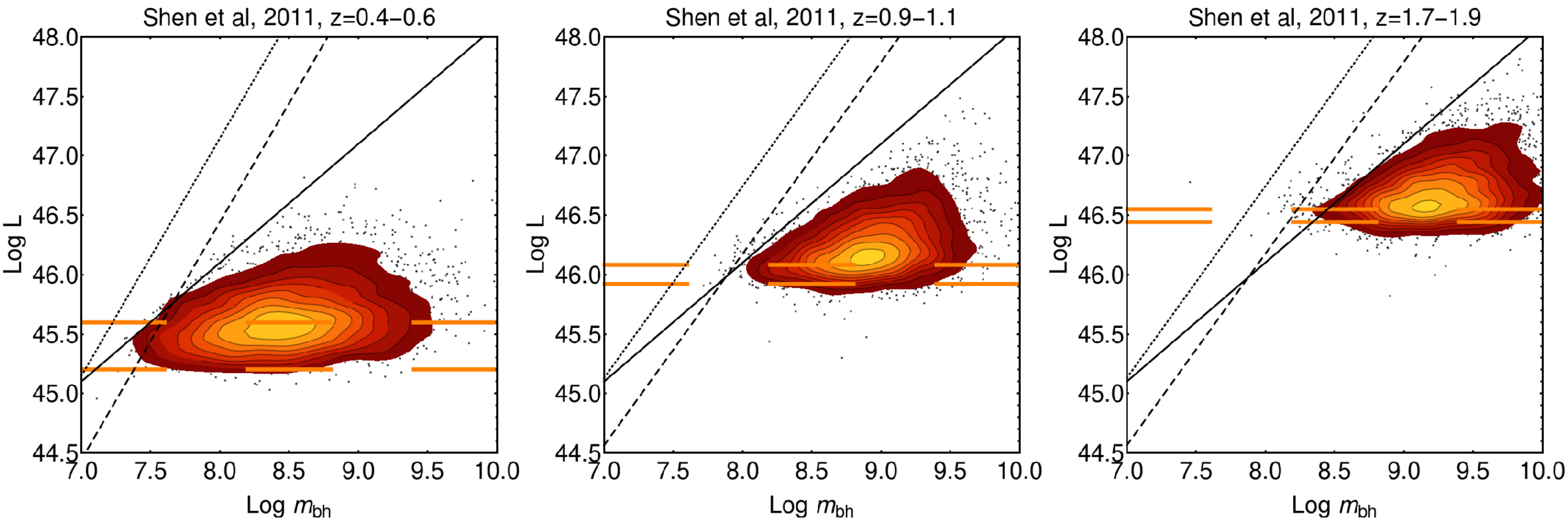




- Normalization of quasar luminosity function changes as normalization of star forming galaxies
- $L^* = (1+z)^4, z<2$
- $L^* \propto M^* m_{bh}/m_* \lambda^*$

Results from simulating mass-luminosity plane



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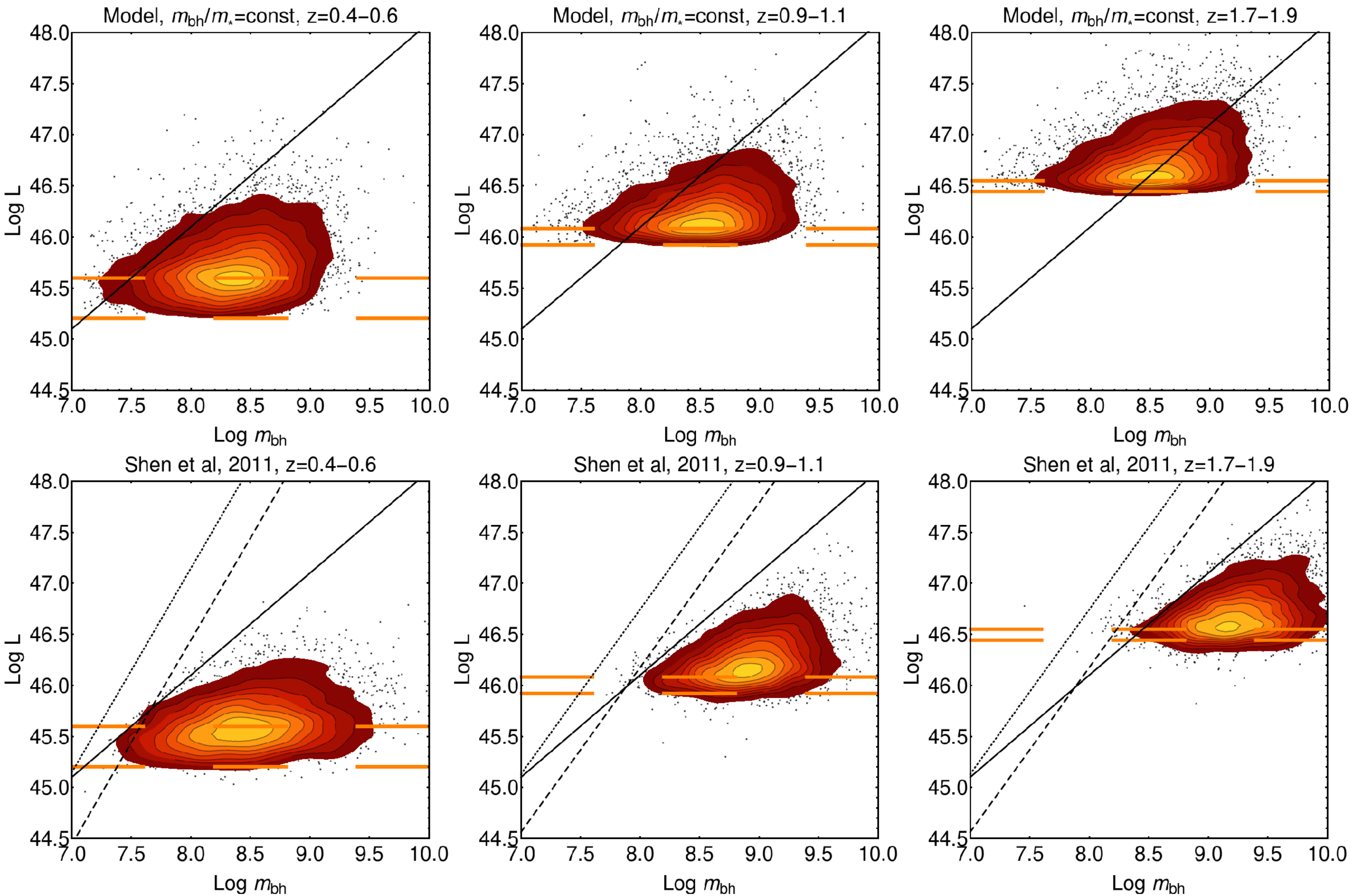

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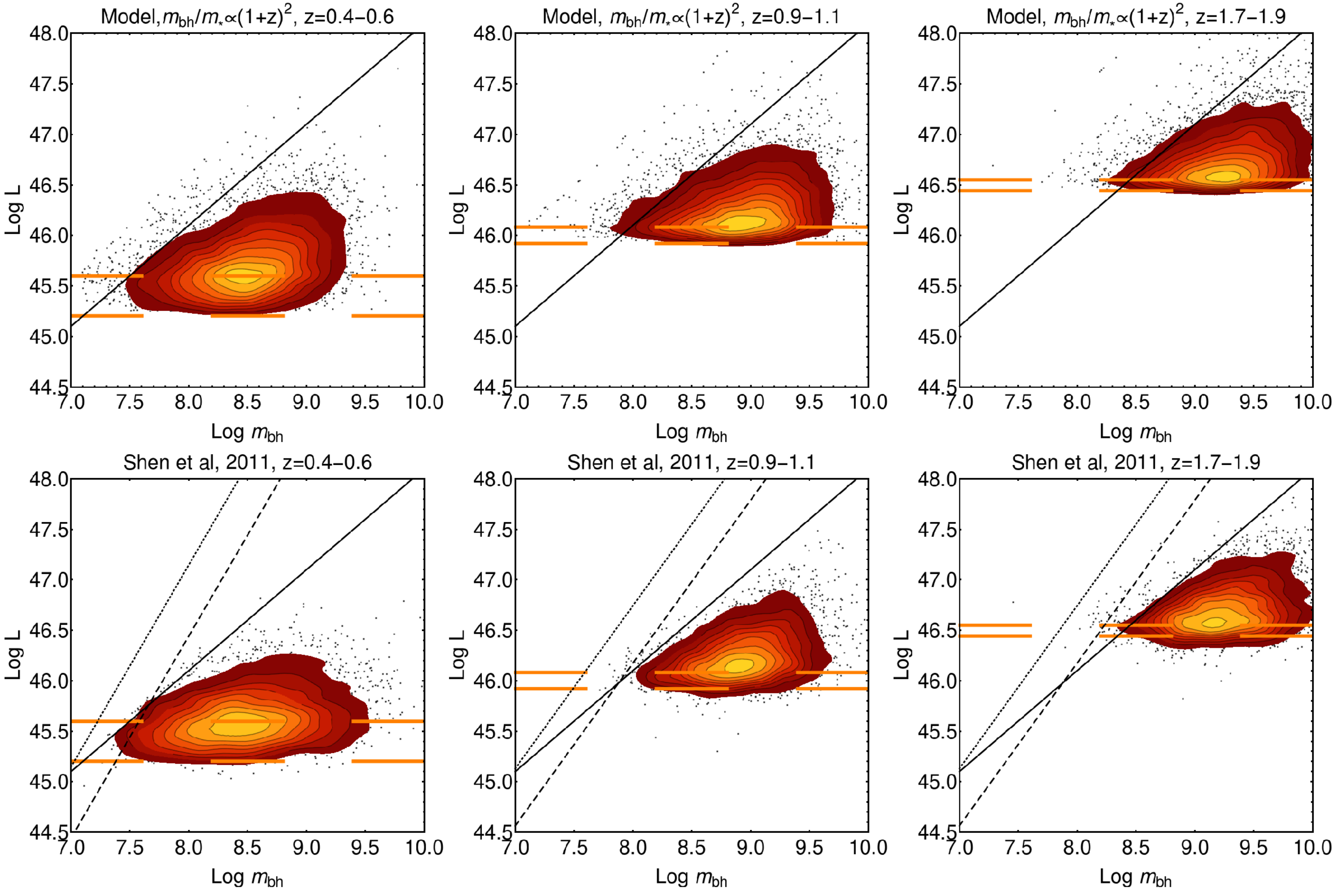
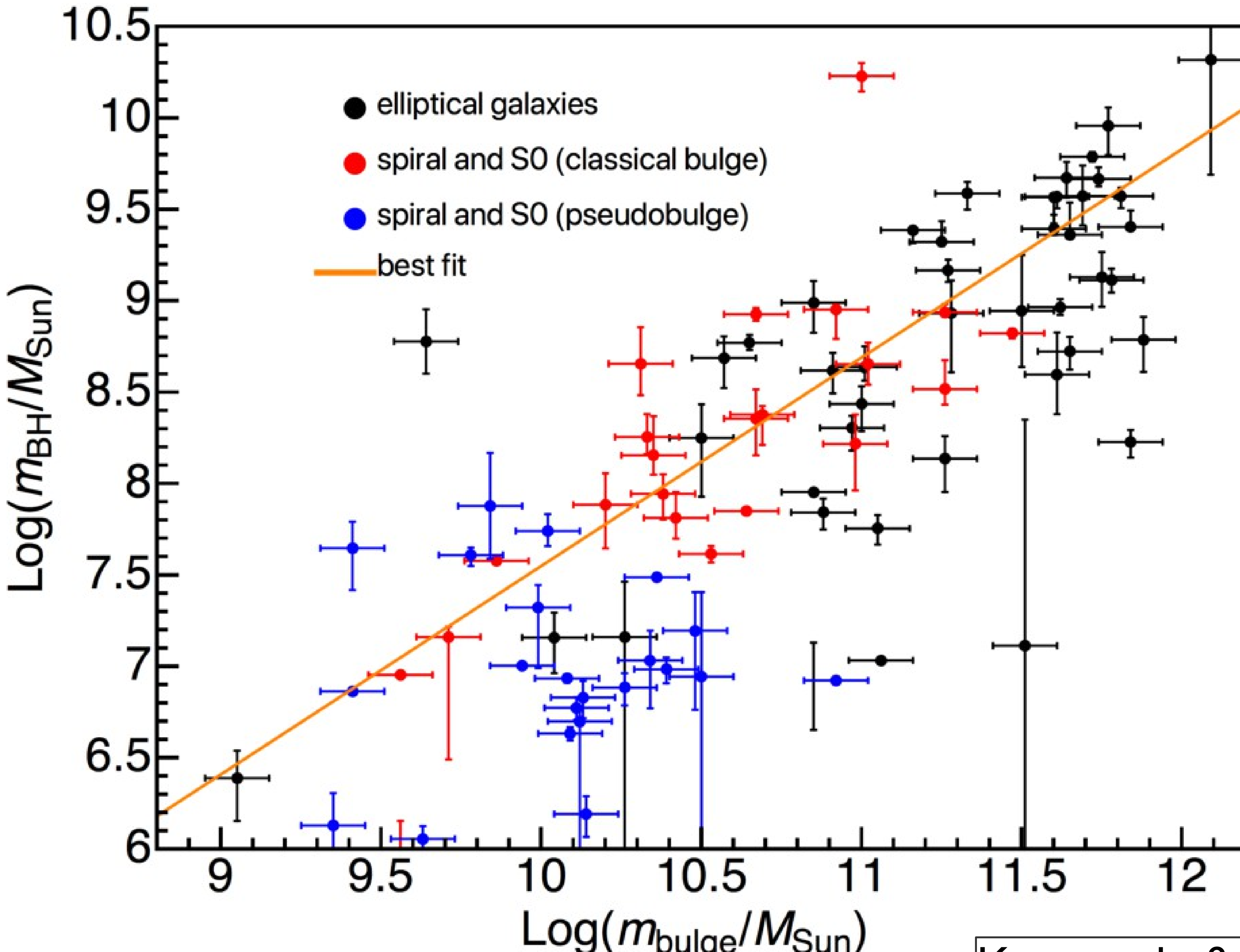


What about local black hole – galaxy relation?



Kormendy & Ho, 13

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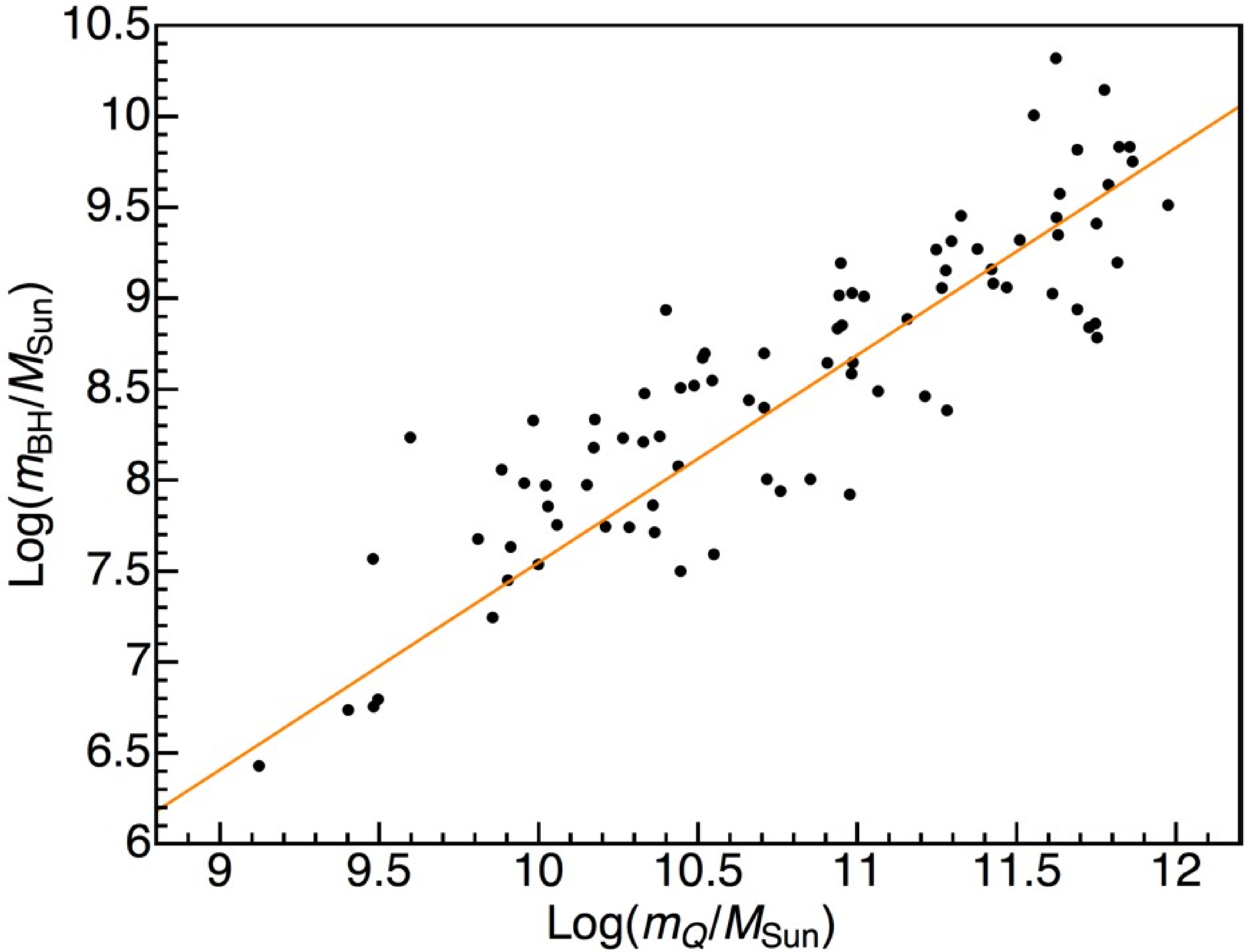
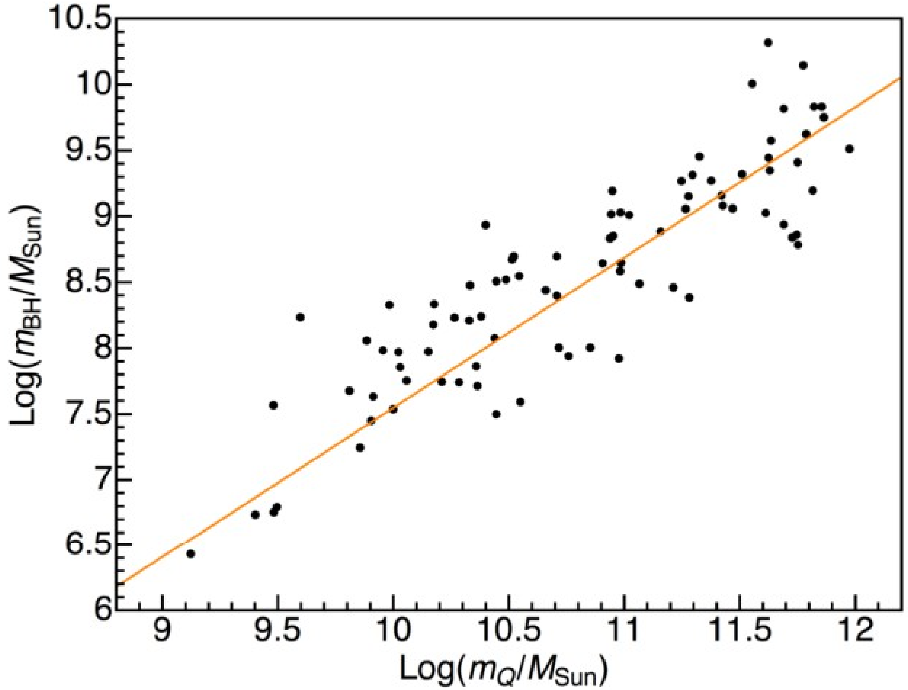
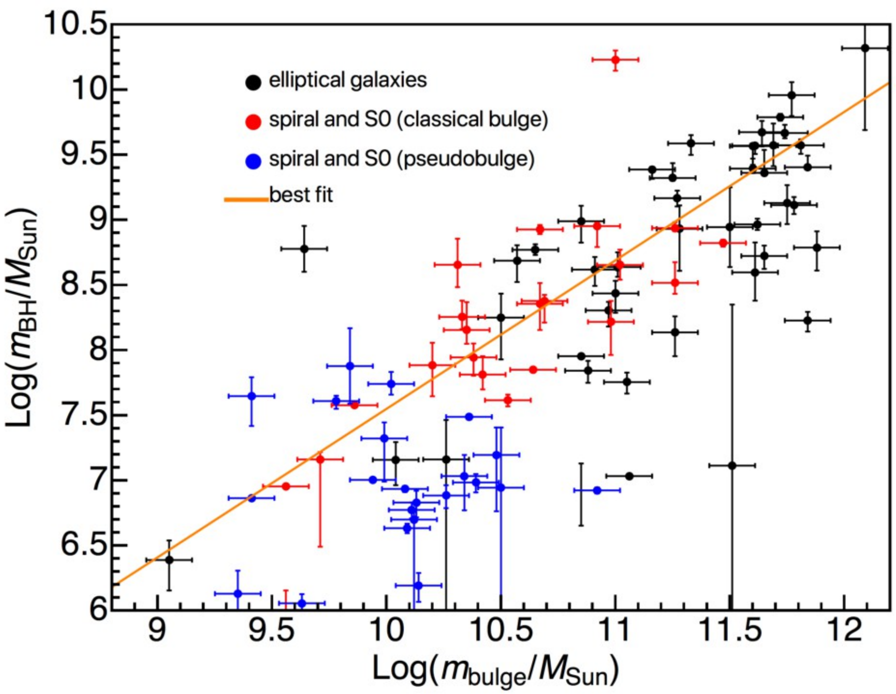


Consequences of size evolution





- Virial relation, Faber-Jackson and size evolution in galaxies implies evolution in either m_{bh}/m_* or m_{bh} – sigma relation

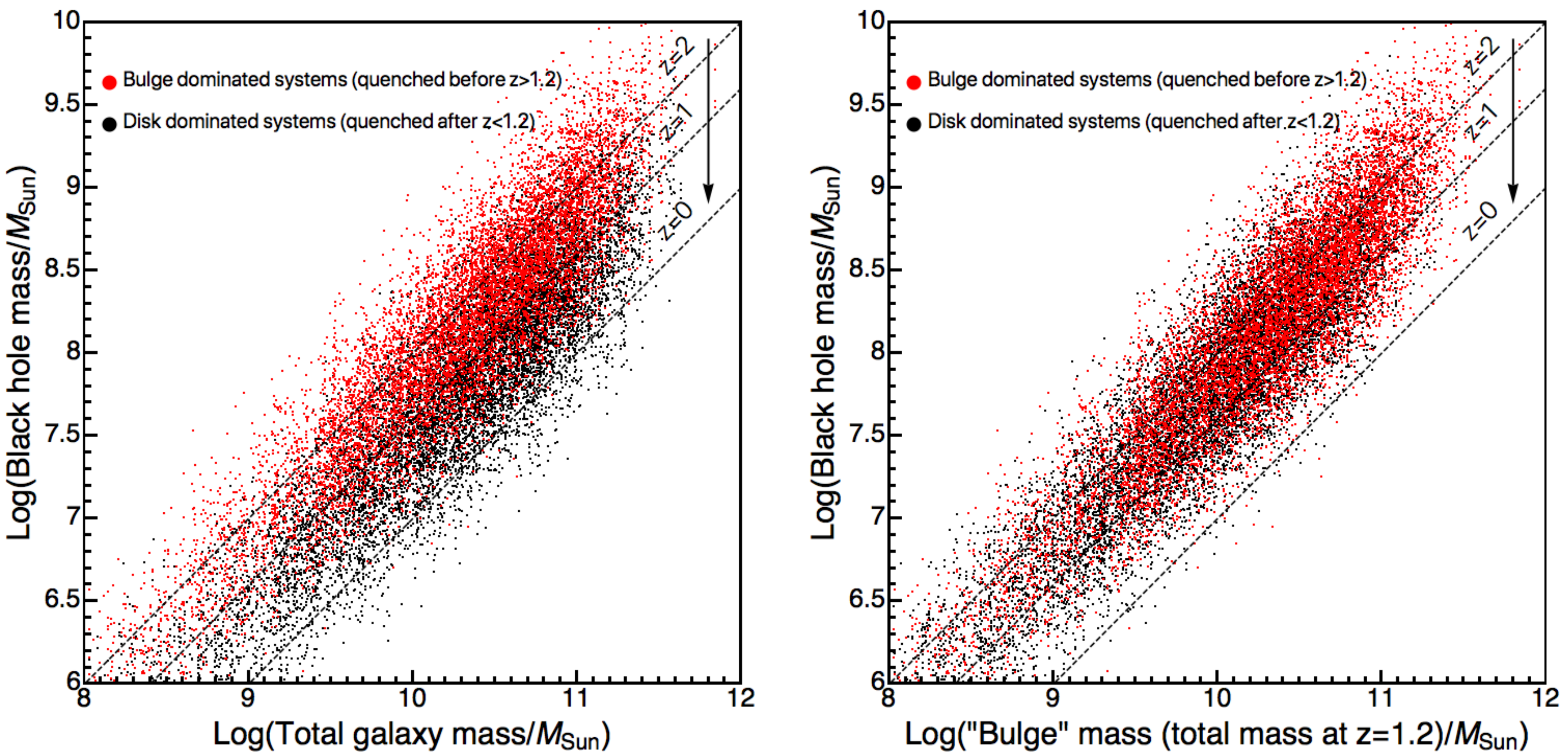
- redshift evolution in m_{bh}/m_* of $(1+z)^2$ leads to constant and tighter m_{bh} – sigma relation

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

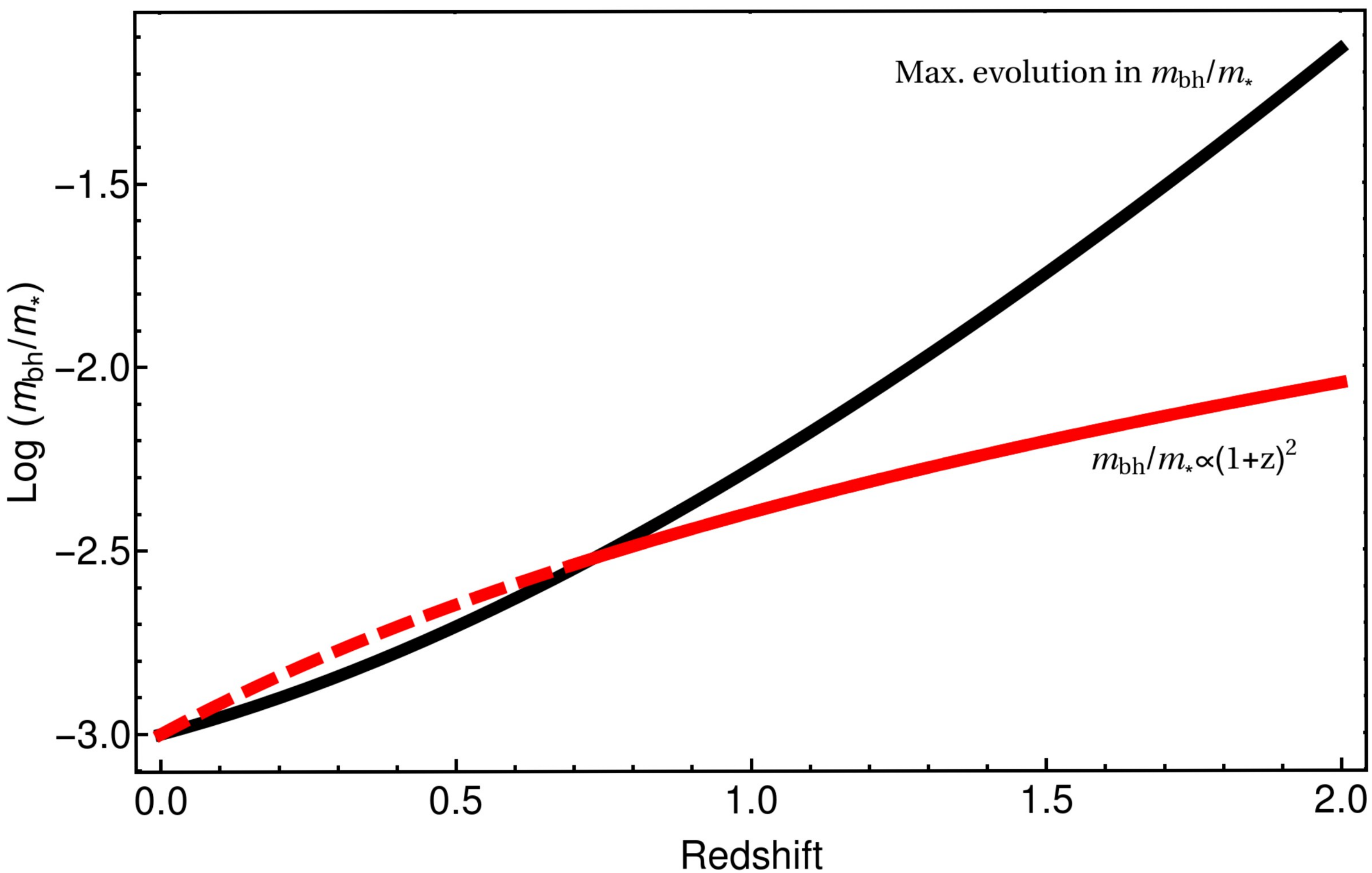
$$m_{star} \propto \sigma^4 (1+z)^2$$

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

Consequences of size evolution



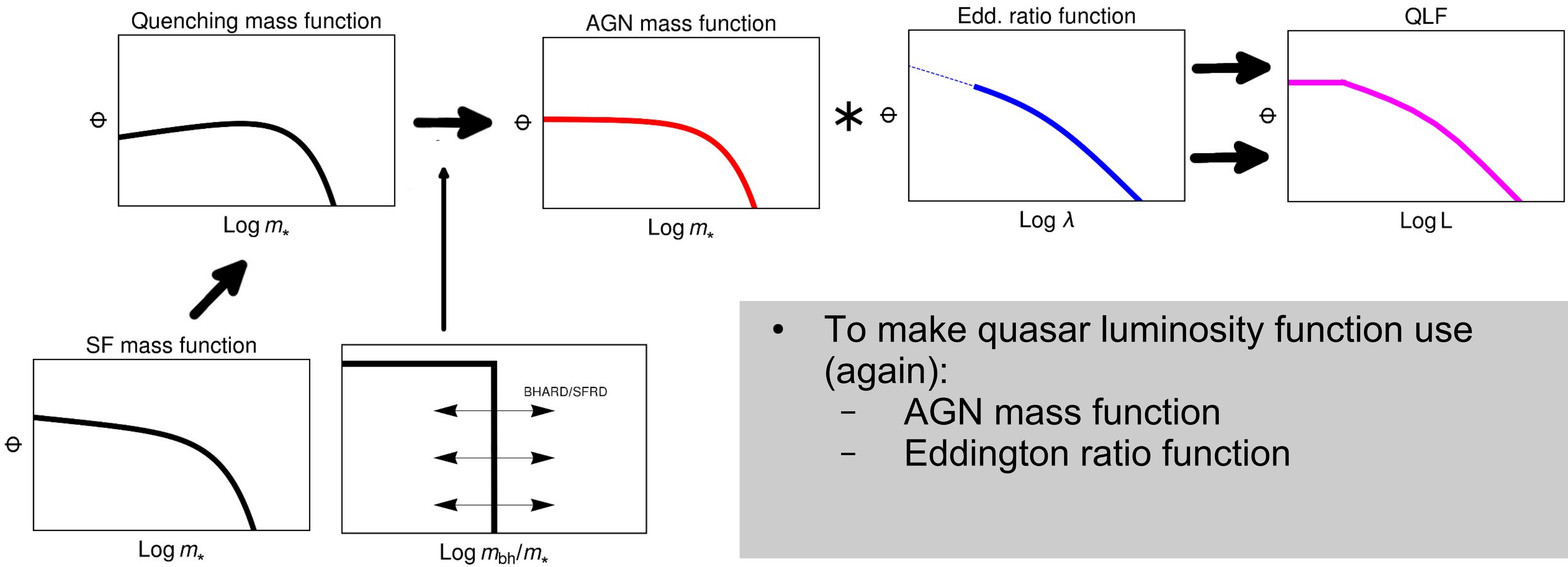
“The problem”



- 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?

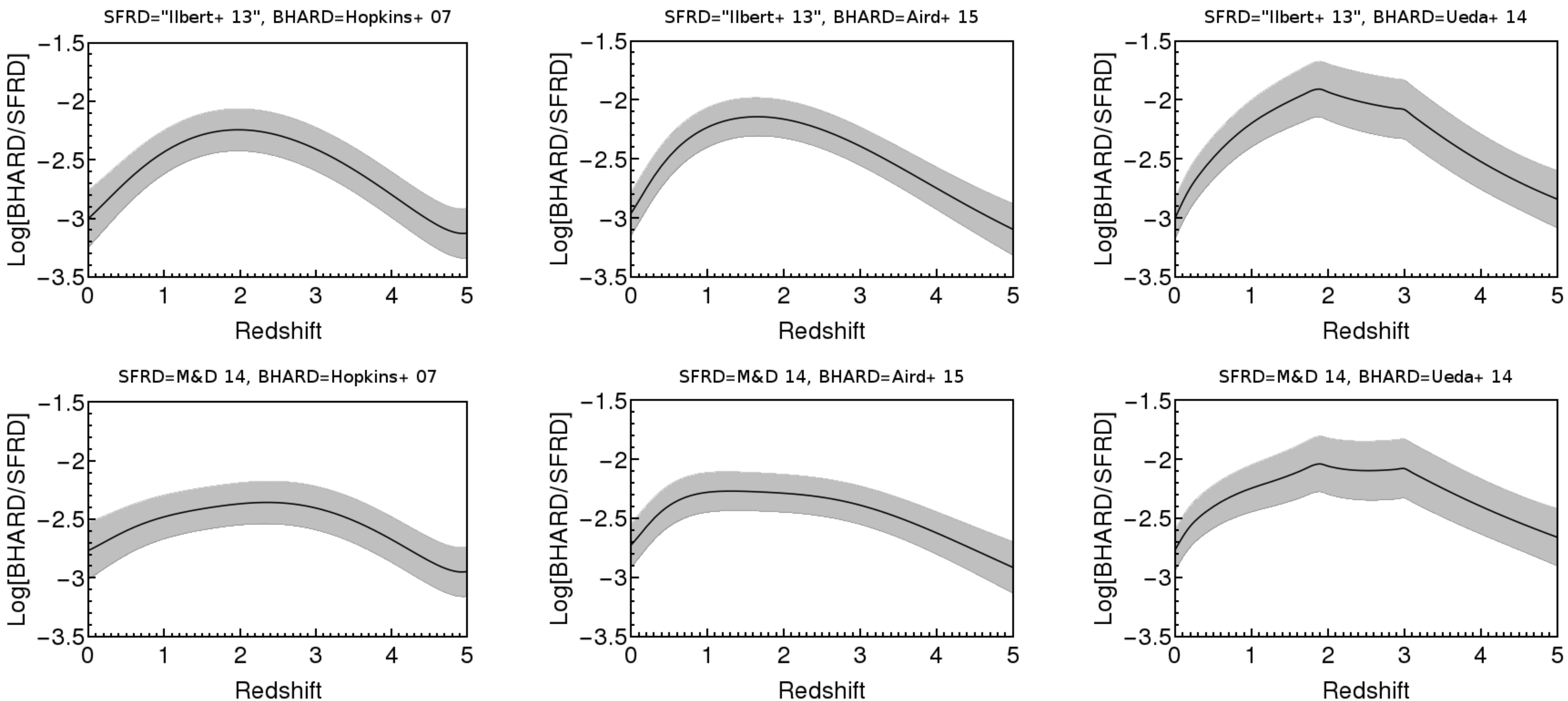


- To make quasar luminosity function use (again):
  - AGN mass function
  - Eddington ratio function

- 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 $\propto (1+z)^{1.5}$

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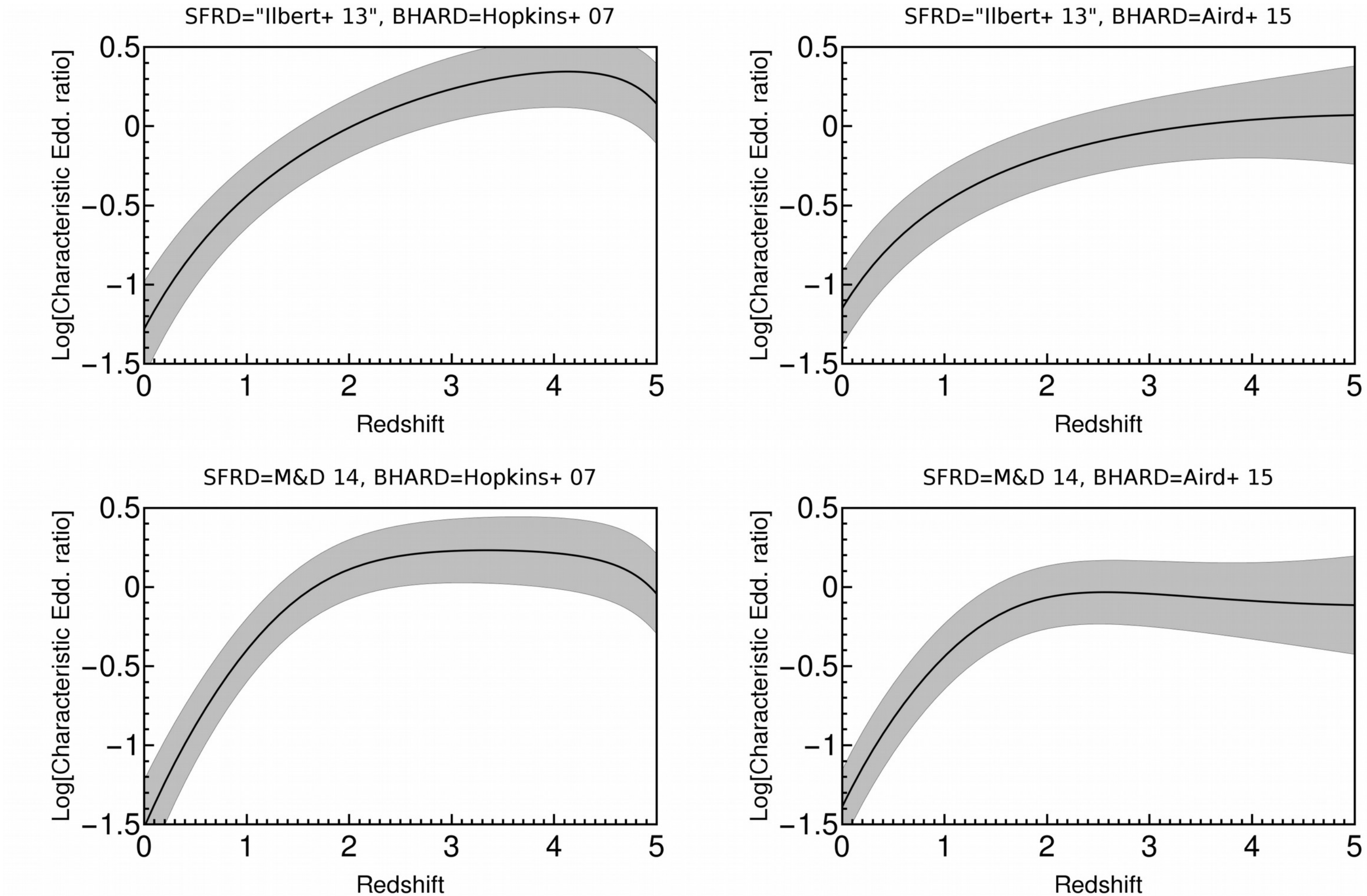
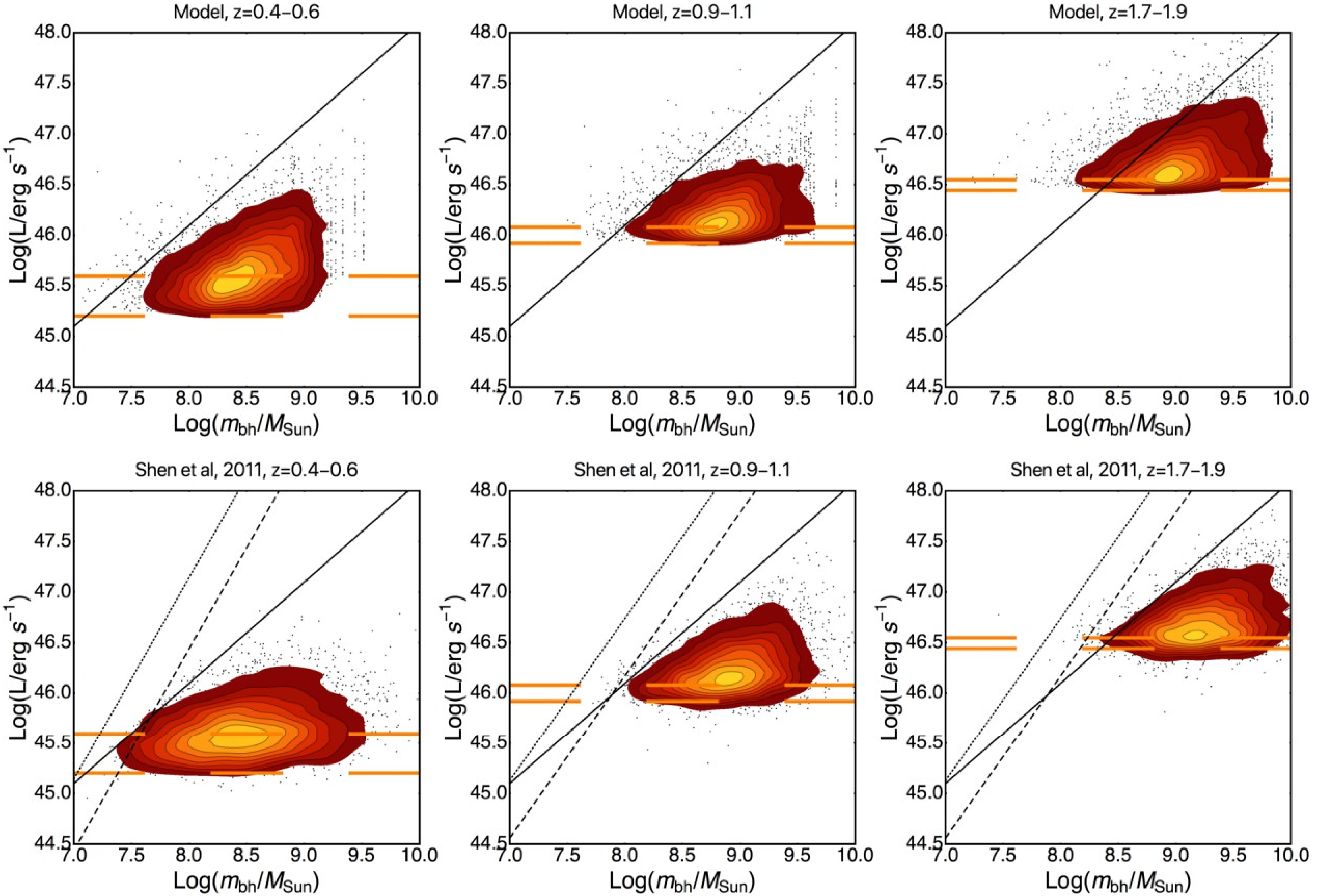


- Eddington ratio = $\lambda^* = (SFRD/BHARD)\cdot(L^*/M^*)$
- Eddington ratio $\propto (1+z)^{2.5}$
- sSFR $\propto (1+z)^{2.5}$

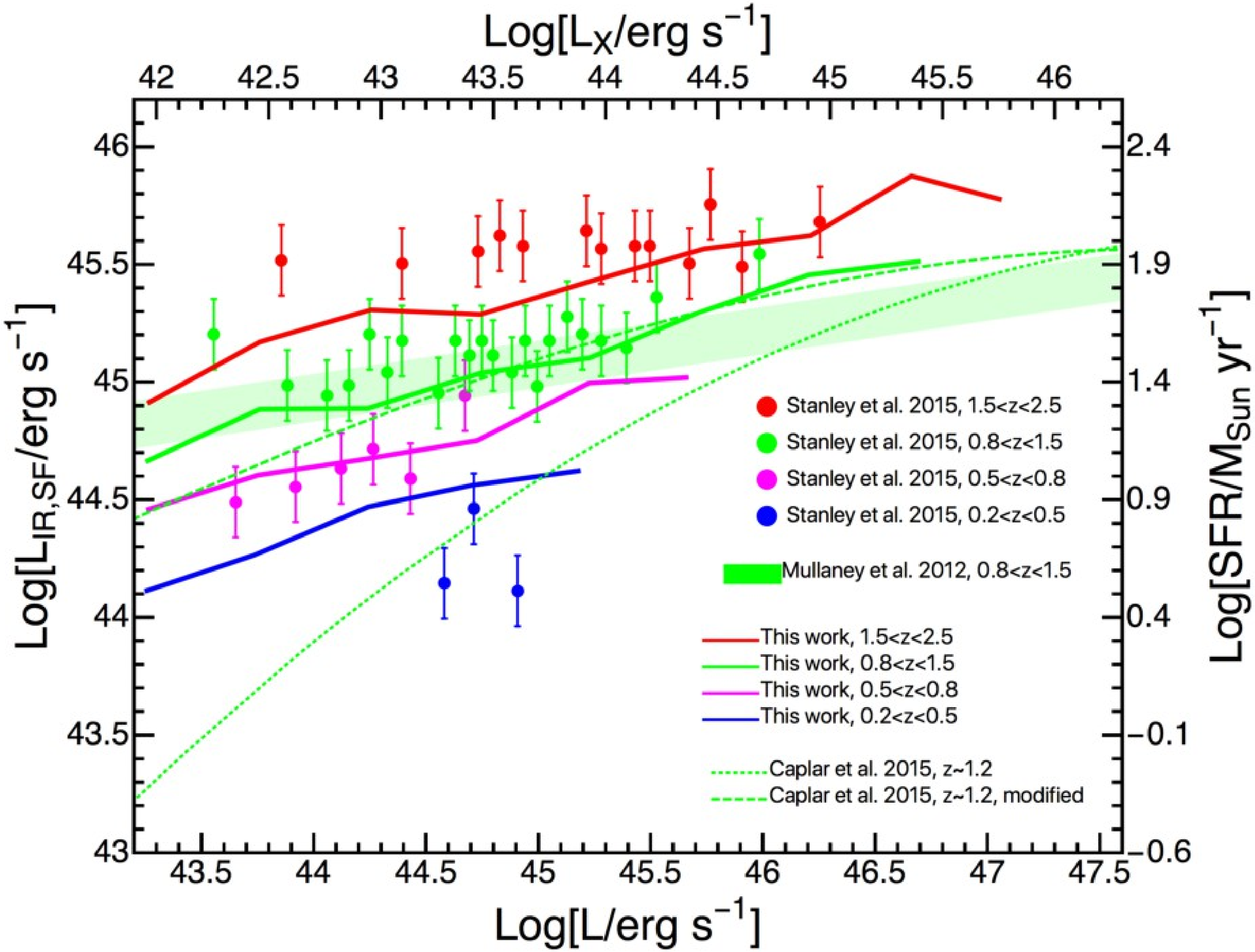
$$\frac{\phi^*_{QLF}}{\phi^*_{SF}} = \frac{\lambda^*}{sSFR} = const$$

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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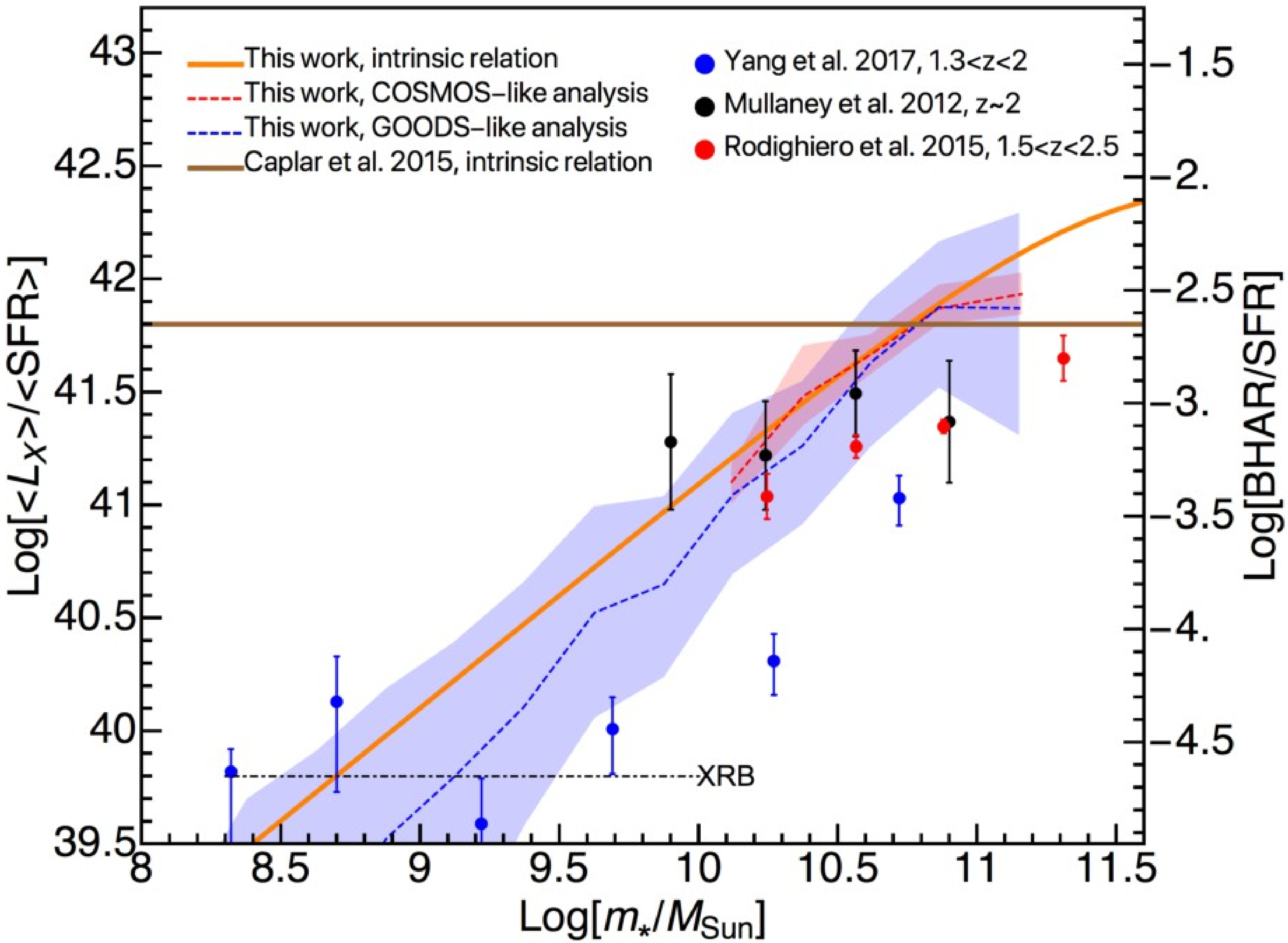

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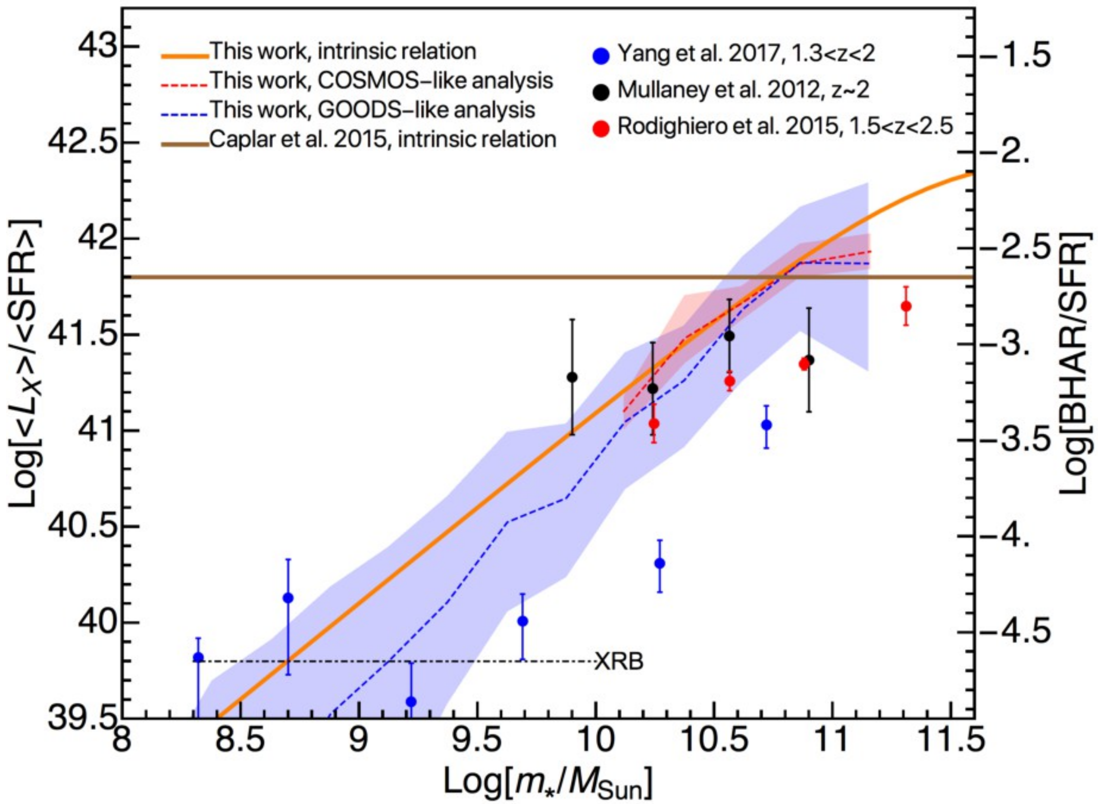

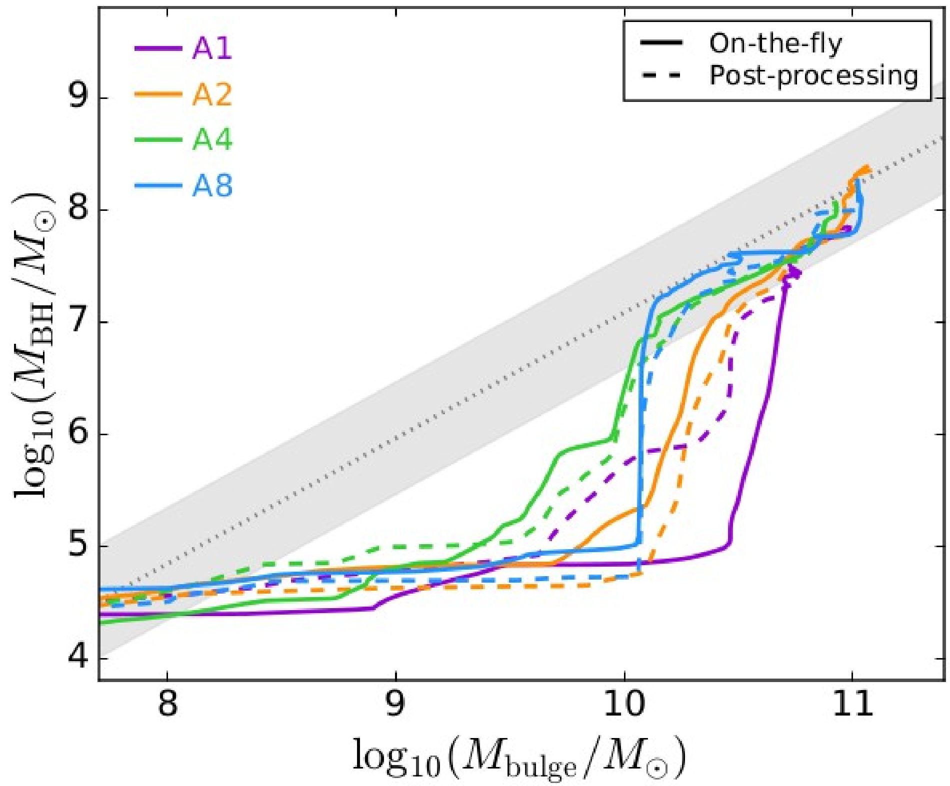

Anglés-Alcázar+ 17

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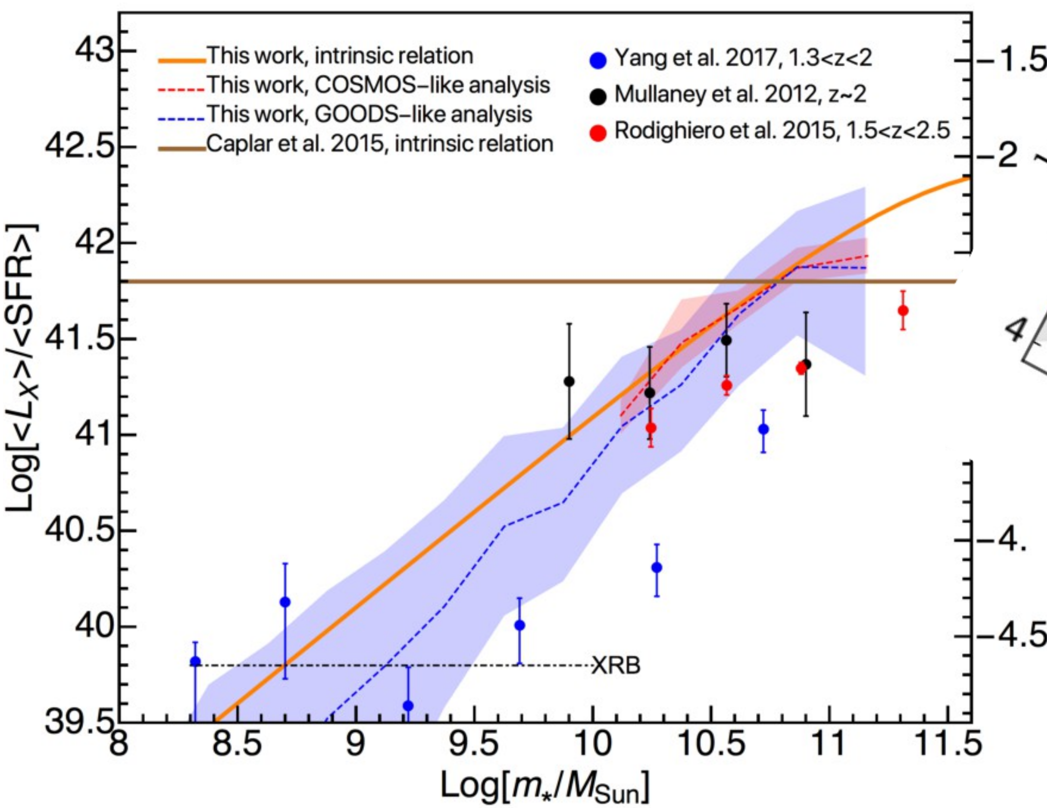

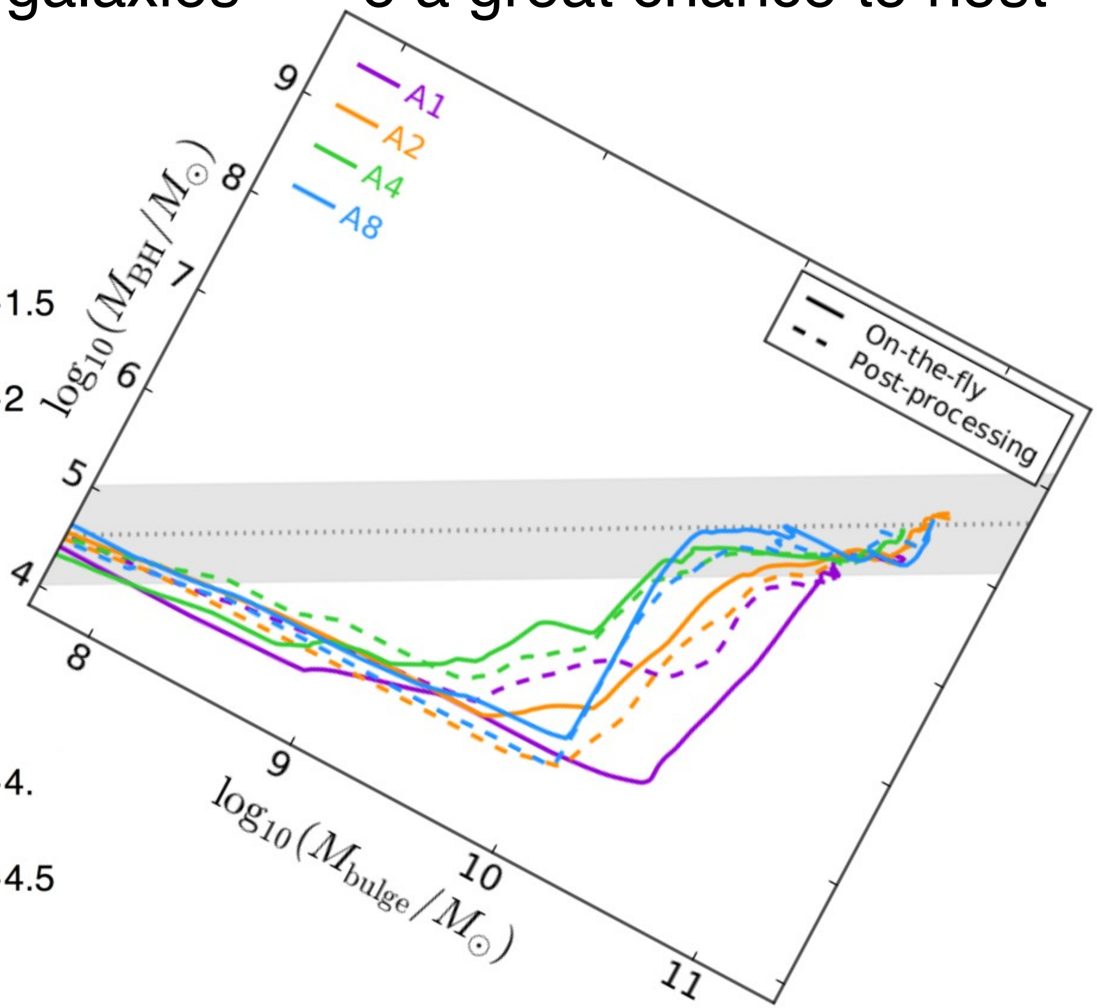

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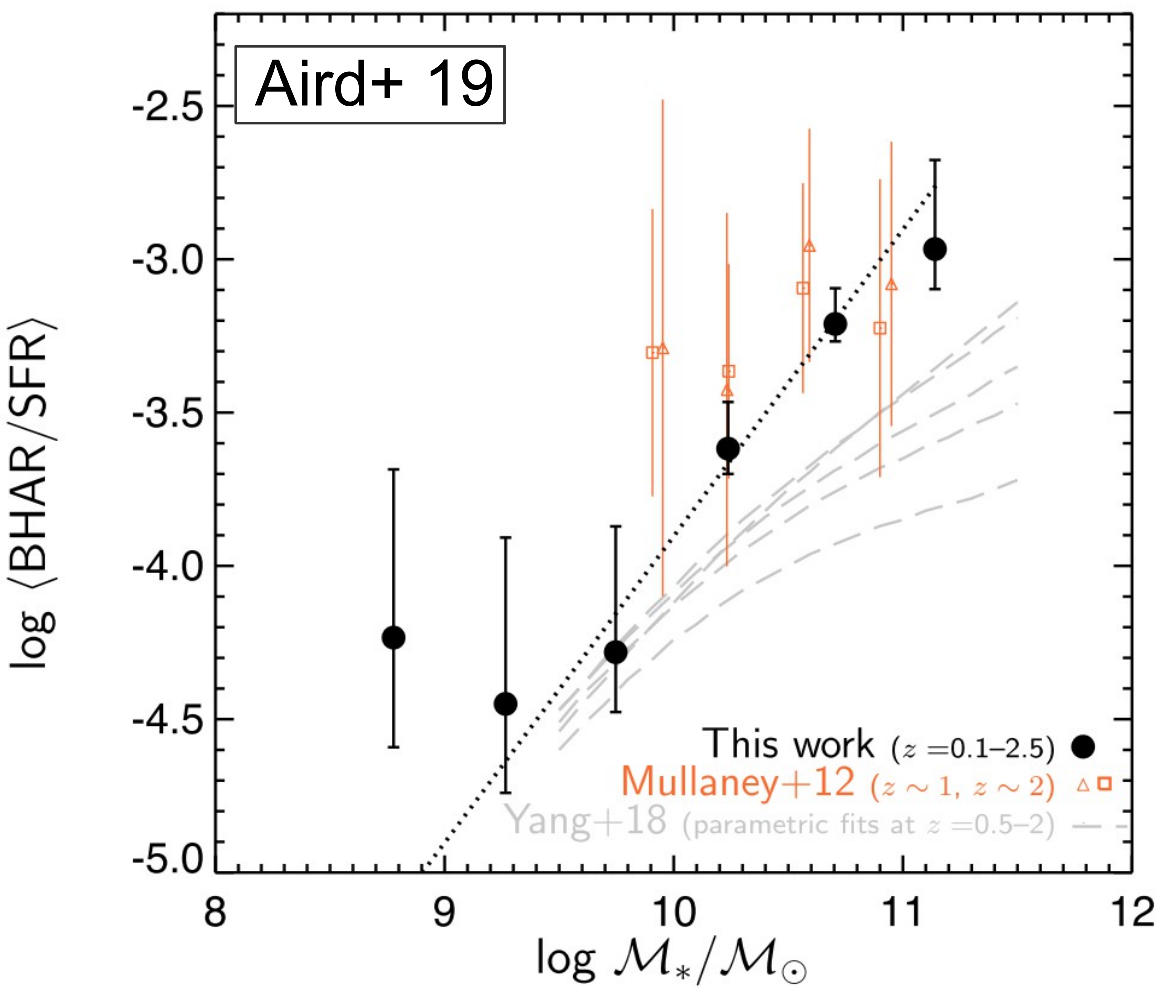

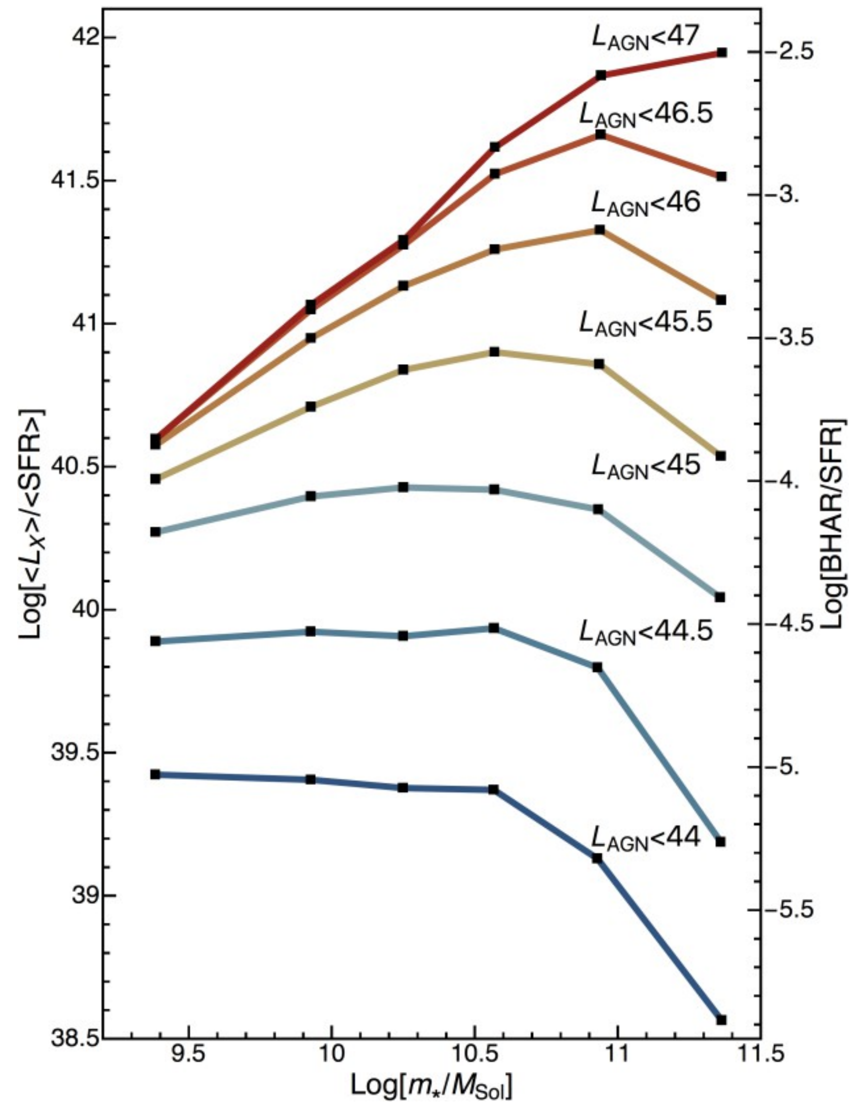

Summary

- 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
    - Evolving m_{bh}/m_* naturally explains number of observations (tight m_{bh}-sigma, m_{bh}/m_* observations at higher redshifts, compact galaxies with large m_{bh}...)
  - Scenario in which **AGN growth is connected with star-formation on long, cosmological, timescales** can not produce such an evolution in the m_{bh}/m_* relation.
  - 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.