

The background of the slide is a deep space image featuring the Milky Way galaxy. Overlaid on this are numerous translucent blue spheres of varying sizes, representing cosmic bubbles. One of these bubbles is larger and contains a glowing orange and yellow elliptical galaxy with a bright central core. In the bottom left corner, there is a silhouette of a radio telescope dish mounted on a structure, with its interior illuminated by a warm orange light. The overall color palette is dominated by the blues of the bubbles and the Milky Way, the oranges and yellows of the galaxy cores, and the dark blacks of the cosmic void.

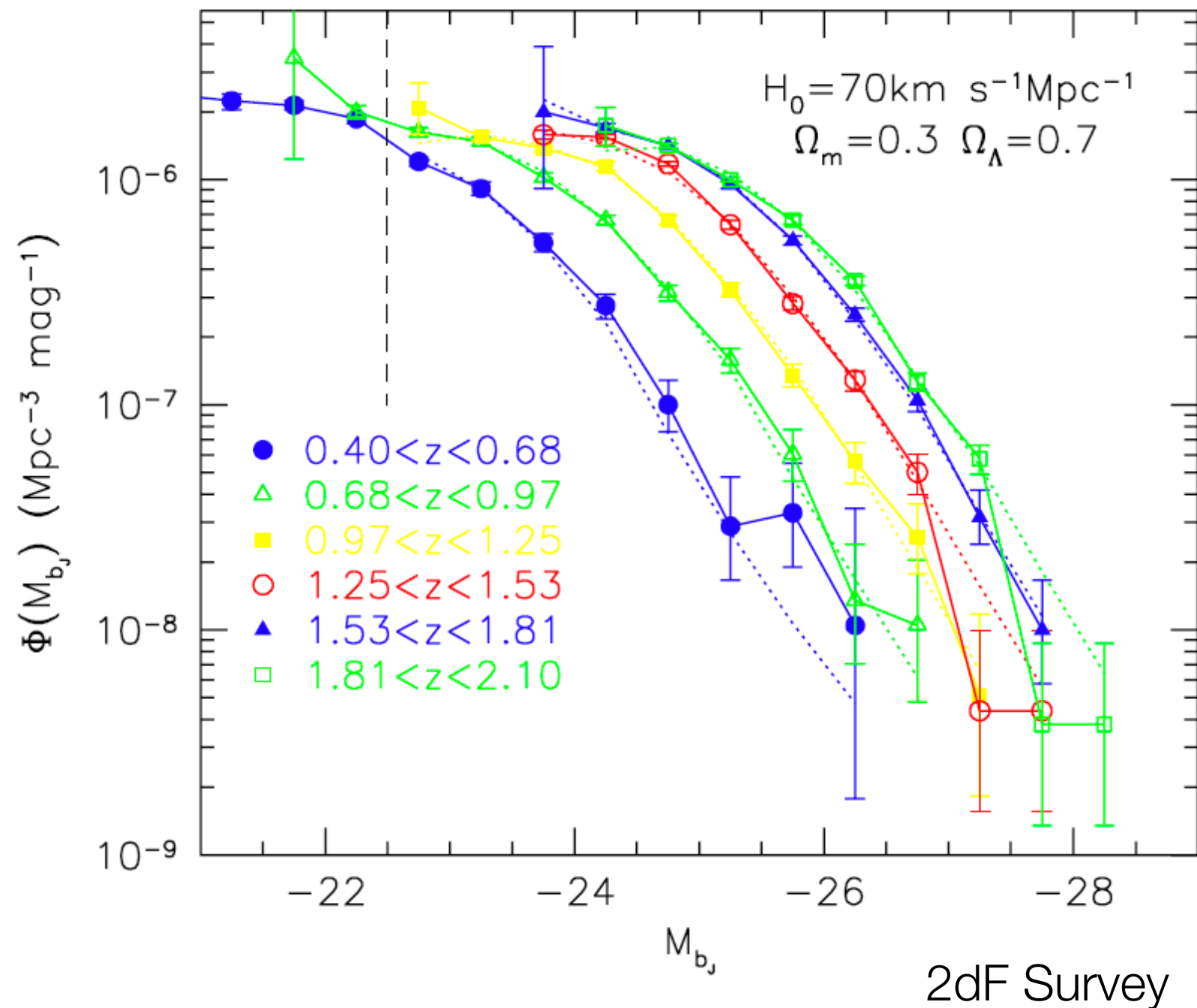
# Updated Observational Constraints on Quasar Bolometric Luminosity Function

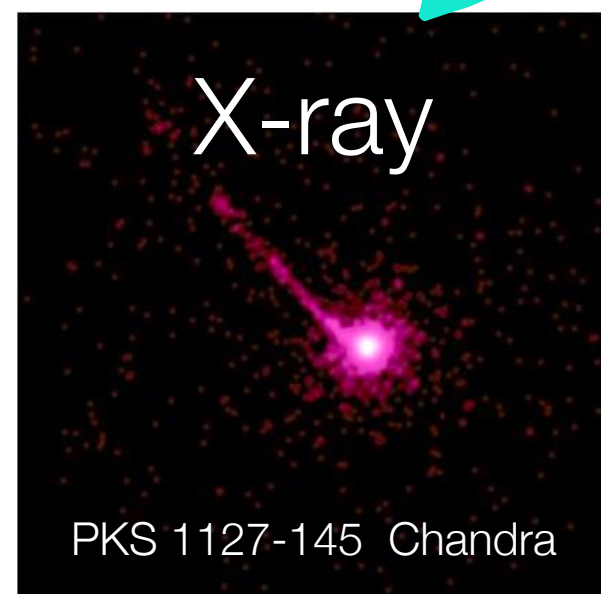
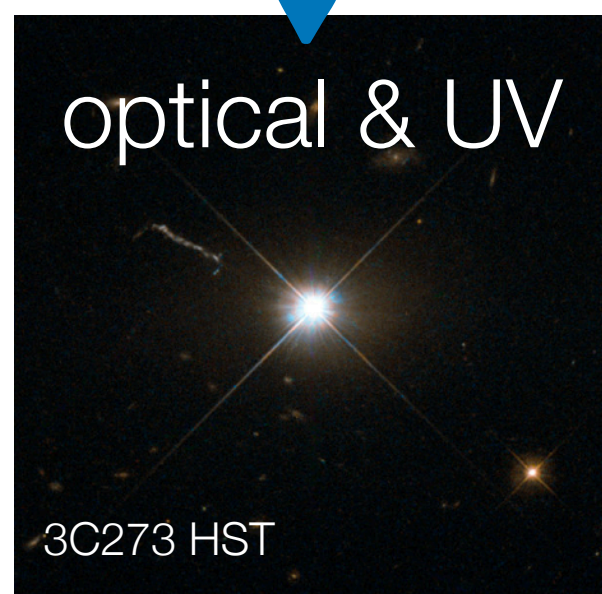
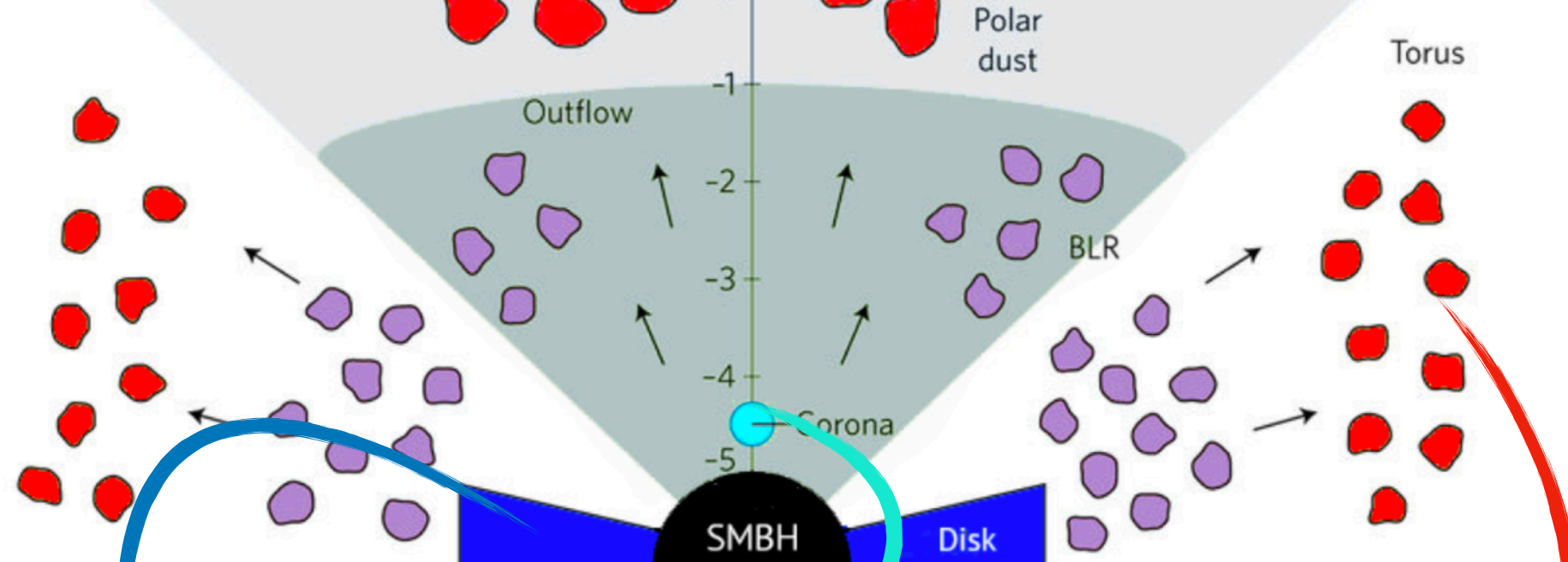
Xuejian(Jacob) Shen  
Caltech



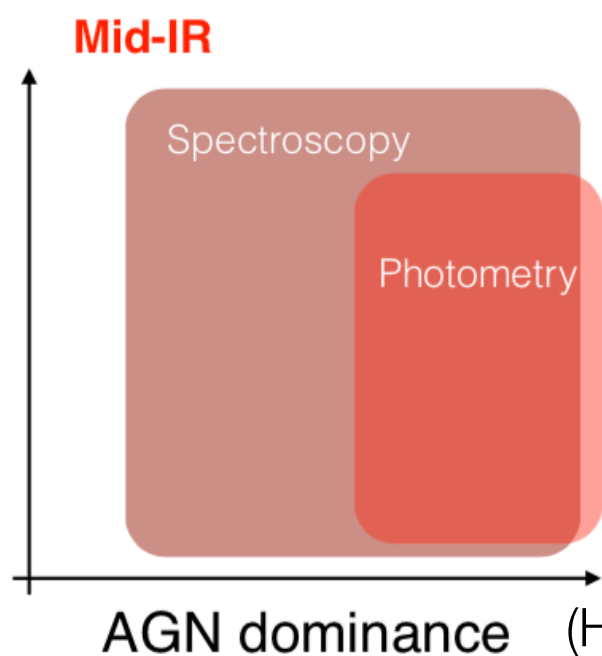
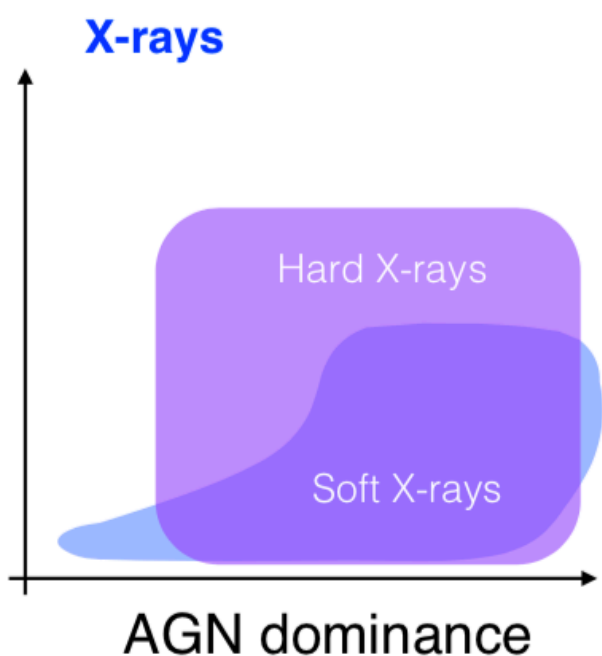
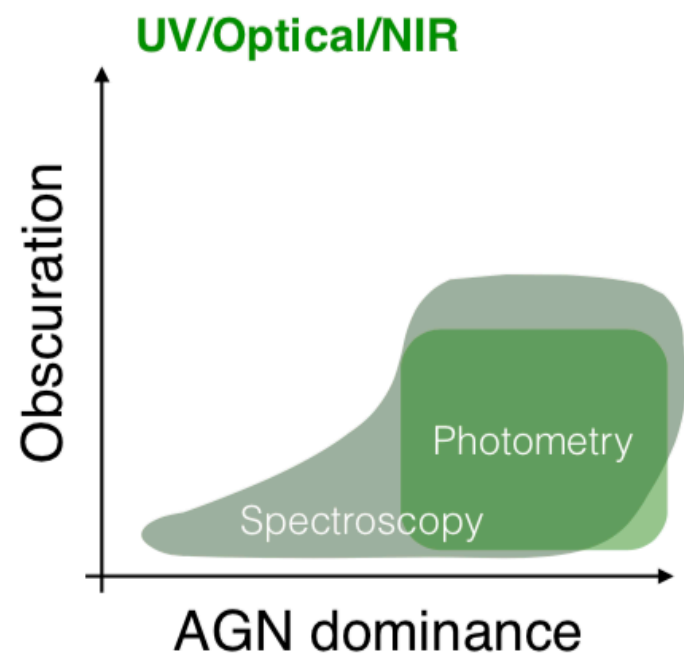
# Direct observable: luminosity functions

( comoving number density as a function of luminosity )





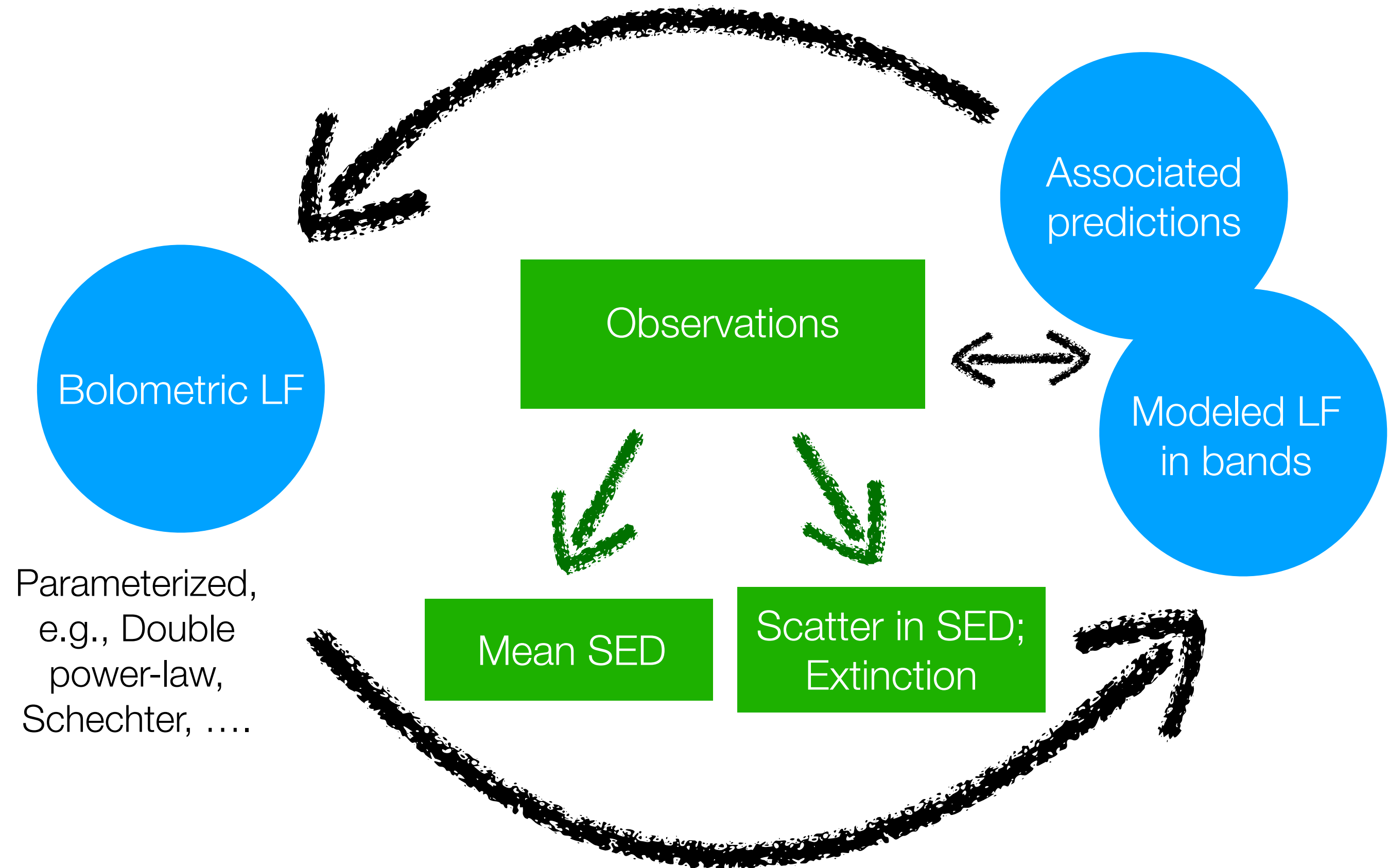
mid-IR



(Hickox+2018)

- Consistent with each other?
- Explain them simultaneously with a unified model ?
- Any physical properties of the quasars? e.g., bolometric luminosity, accretion rate

# The workflow

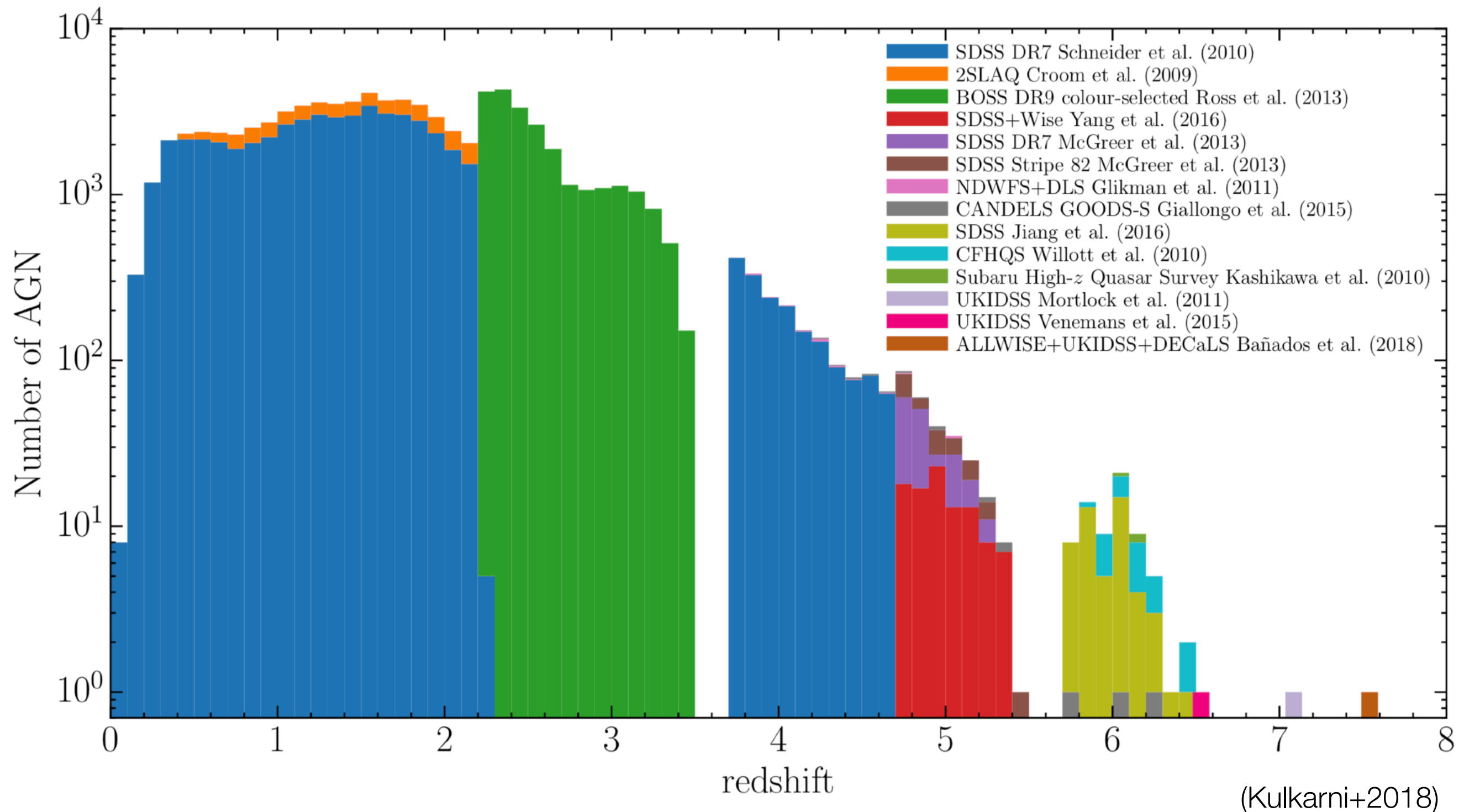


# Problems of the 2007 LF model

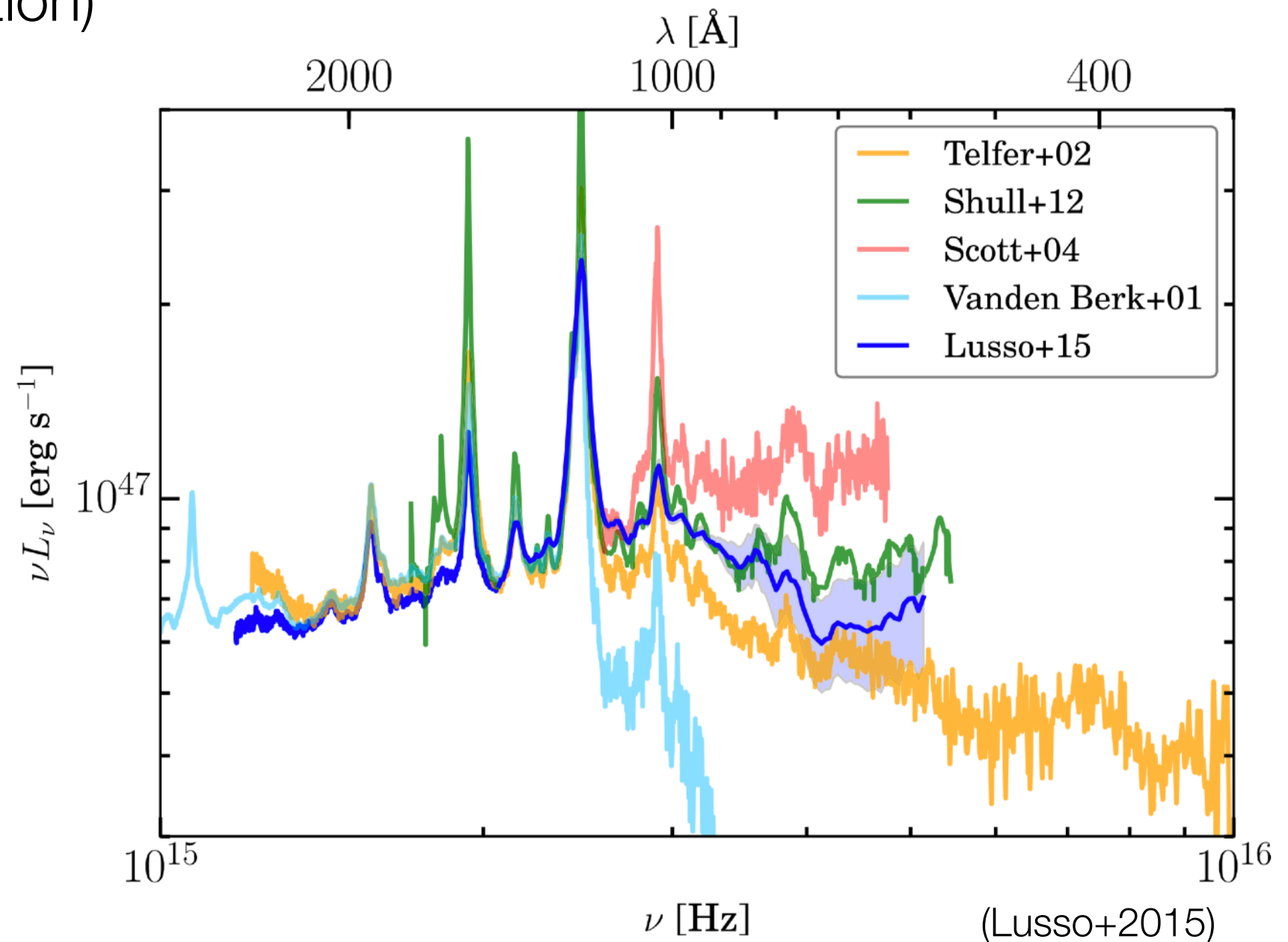
- Big uncertainty limited by data available by 2007 and inconsistent with recent measurement at  $z > \sim 3$
- Unphysical behaviors in the evolution of LF, e.g. extrapolating the model to  $z \sim 8$  leads to diverged integrated luminosity at bright end; an assumption that number density normalization is always constant

# Updates in the recent decade

- More data at high redshift



- New channels in ultra-hard Xray band, e.g. *NuSTAR*
- Updated SED
- Updated column density measurement (compton thick fraction)



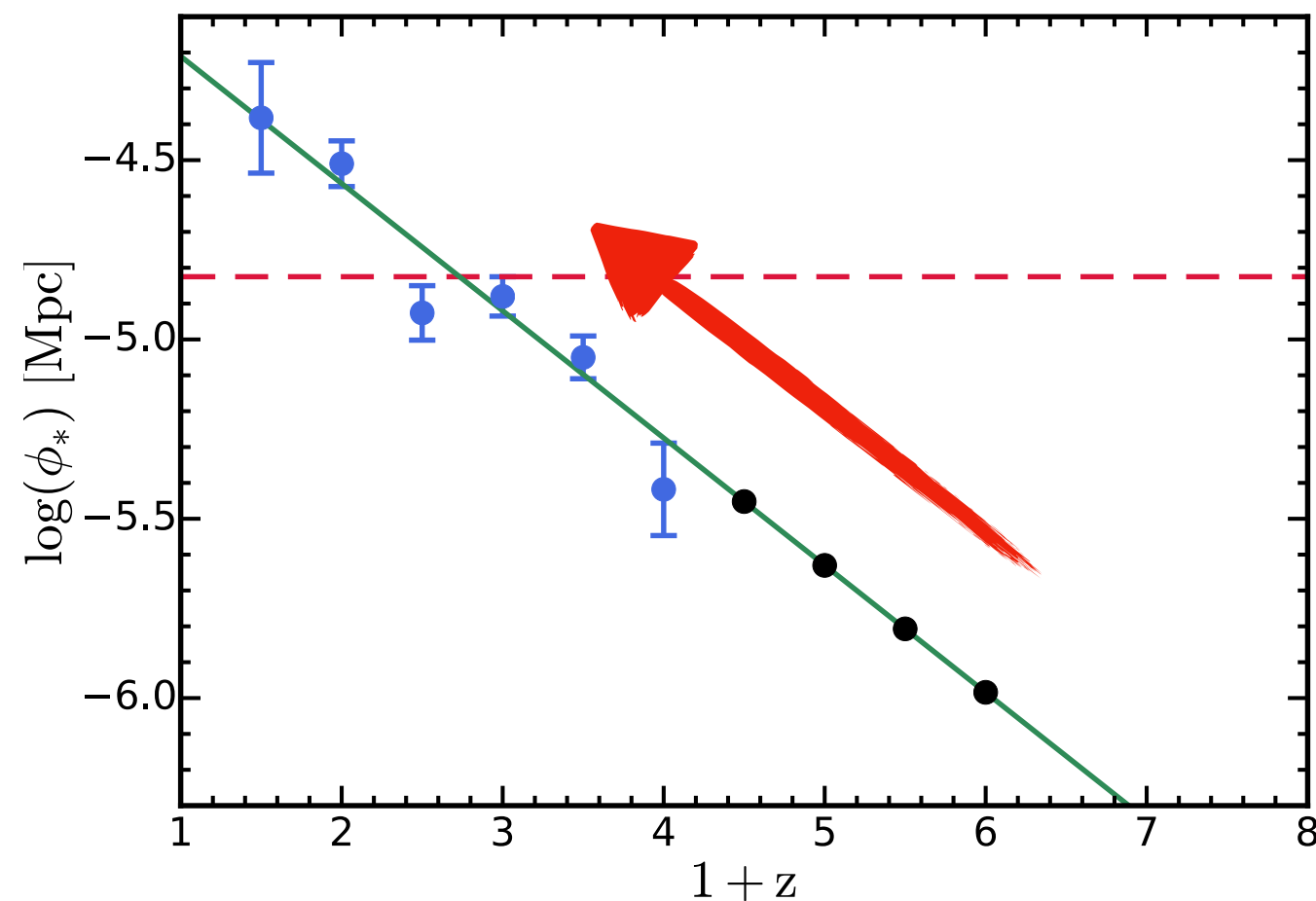


# Preliminary results

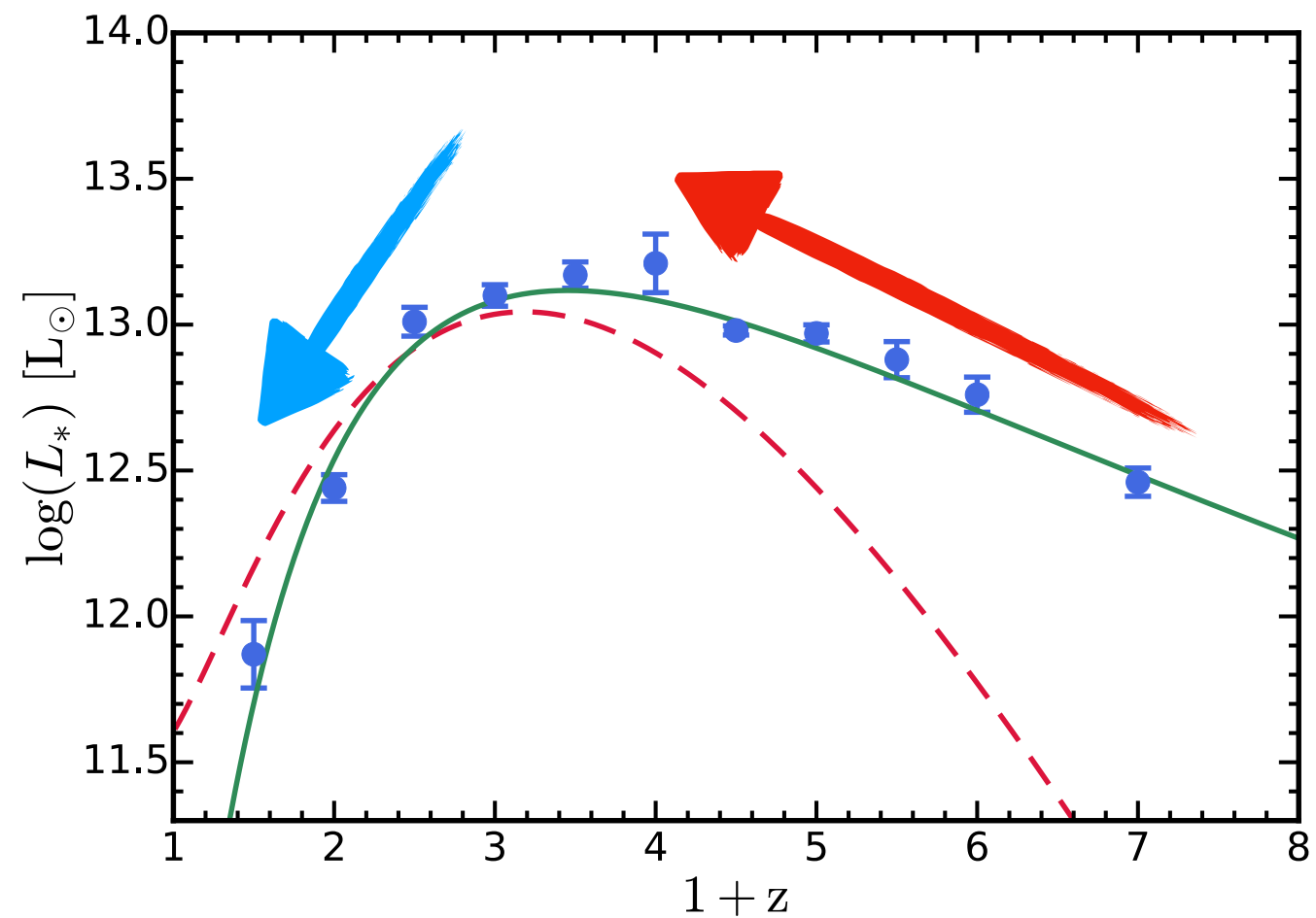
- A double-power law with redshift evolving parameters

$$\frac{d\phi}{d \log L}(z) = \frac{\phi_*(z)}{\left(\frac{L}{L_*(z)}\right)^{\gamma_1(z)} + \left(\frac{L}{L_*(z)}\right)^{\gamma_2(z)}}$$

- Number density normalization



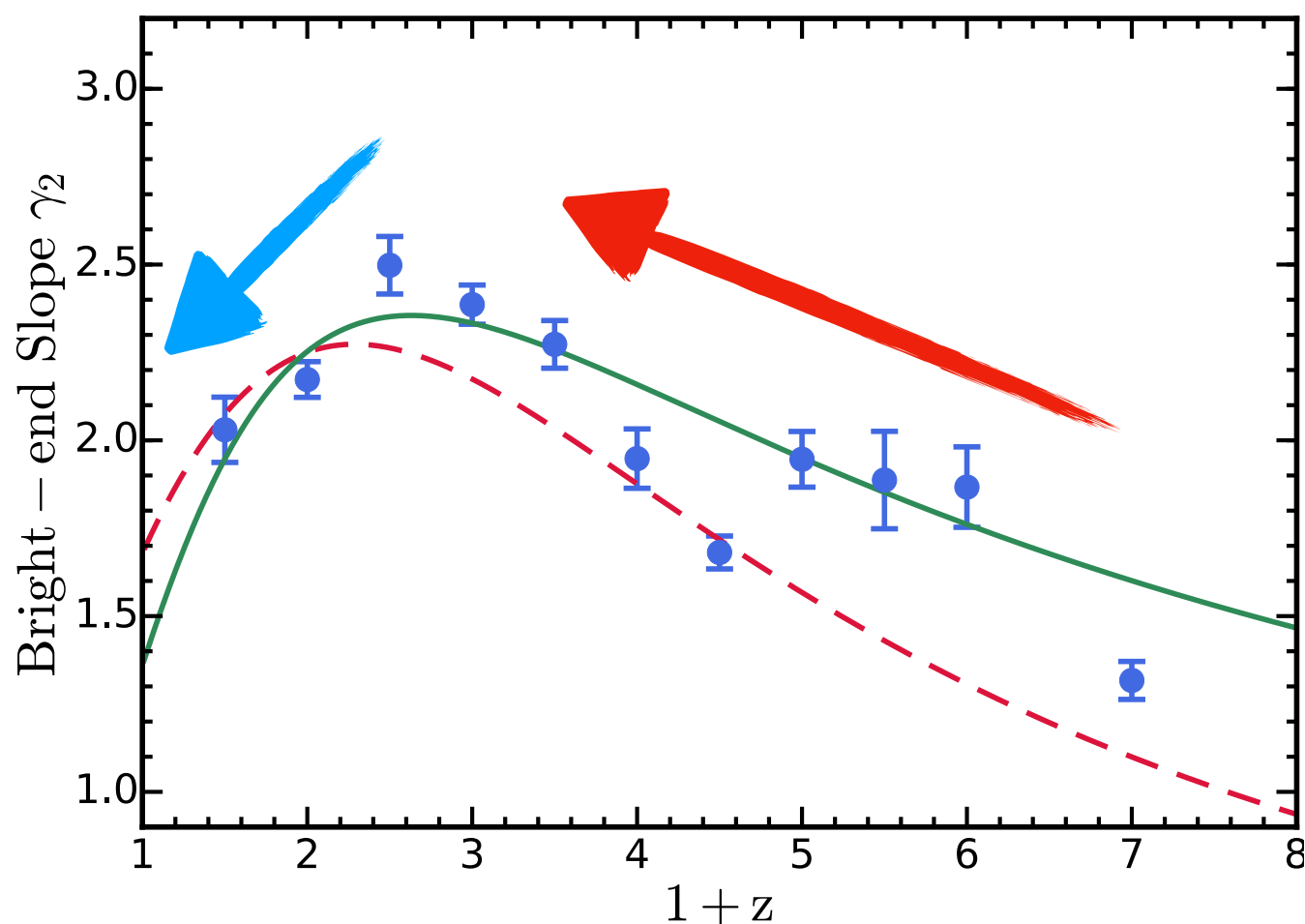
- Break luminosity



A double-power law shape evolution  
of bright-end slope; also peaks at  $z = 2$

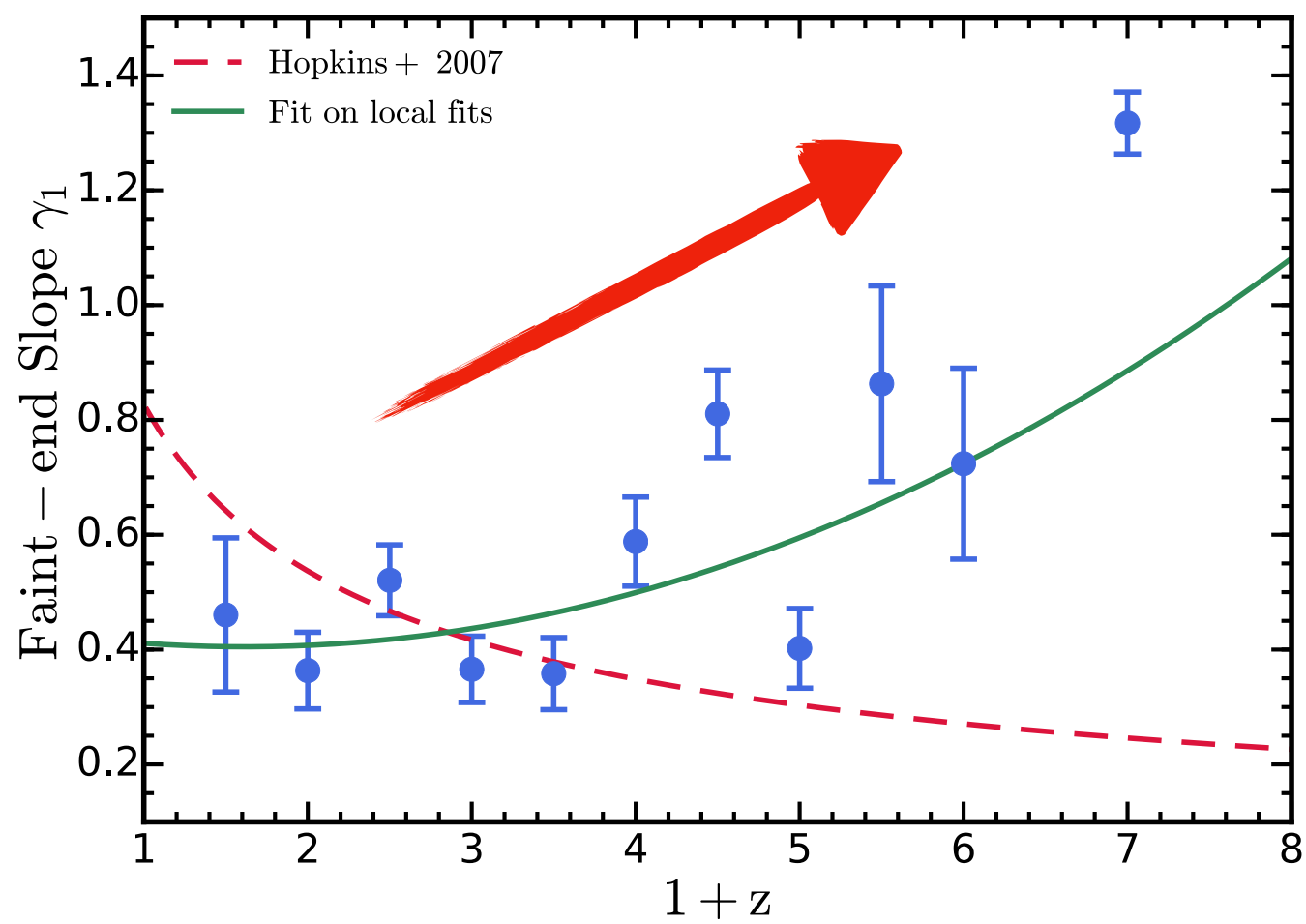
?

● Bright-end slope

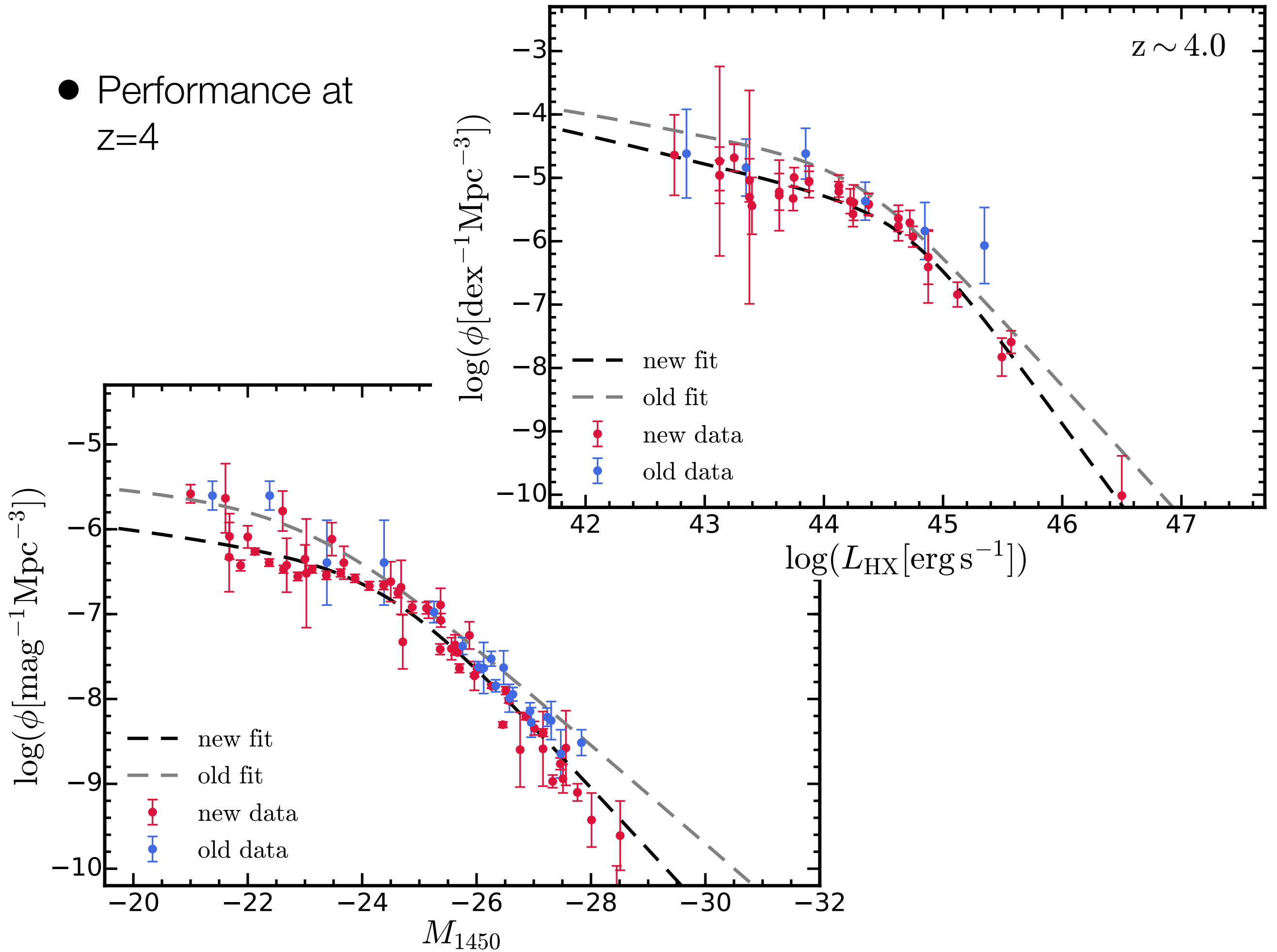


A steeper fainter-end slope towards  
higher redshift (similar trend as  
found in galaxy UVLF)

● Faint-end slope



● Performance at  
 $z=4$



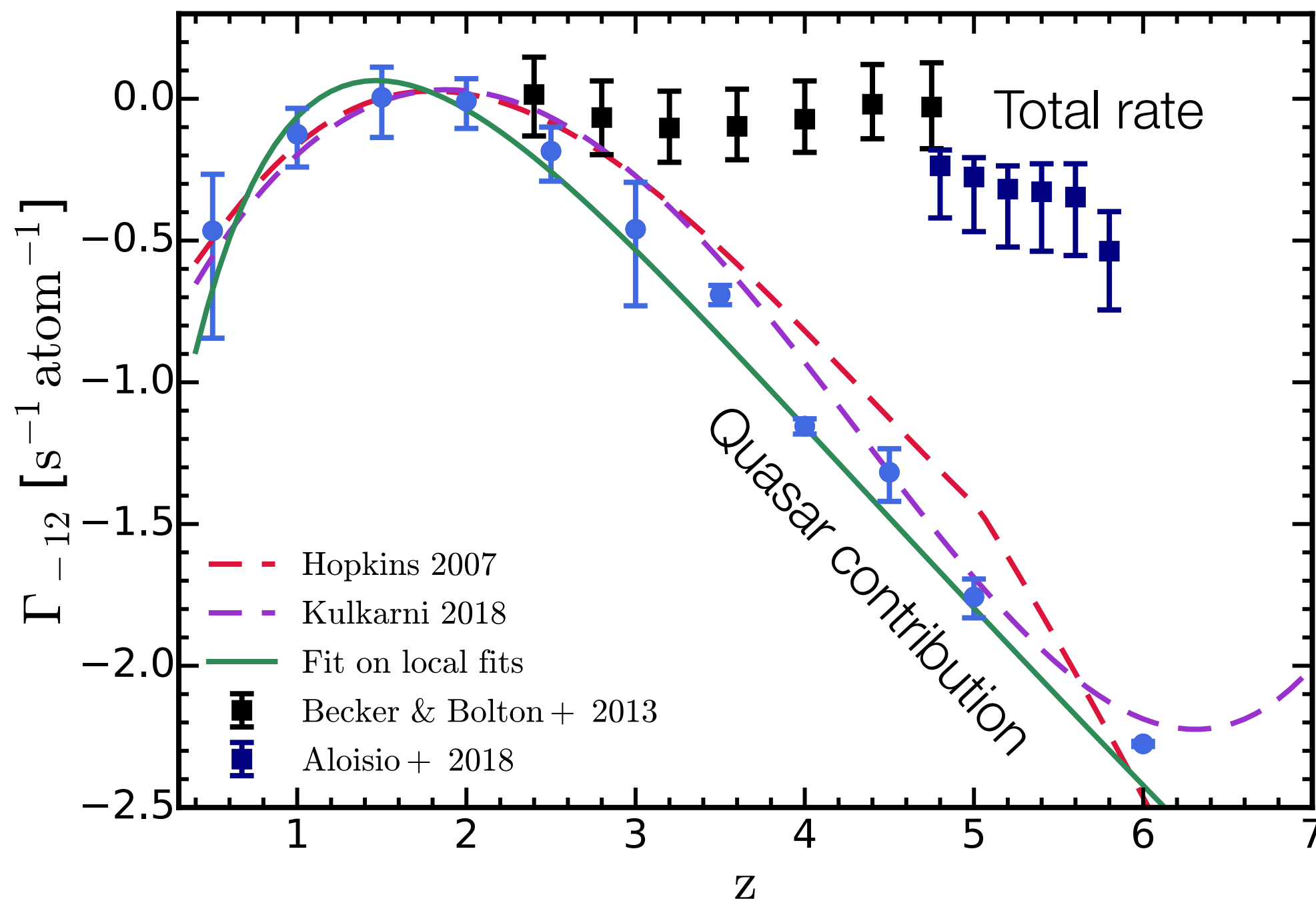


# Implications

- Ionizing photon production; quasar's role in reionization of hydrogen and helium
- SMBH growth history, especially at the dawn of first SMBHs
- Cosmic X-ray & IR background

# Ionizing Photon Production Rate

- Can quasars alone ionize the universe ?
- When did quasars' contribution to ionizing photons become important?



# Future

- Polish the pipeline (model, data)
- BH mass function?
- Connection with galaxy formation?