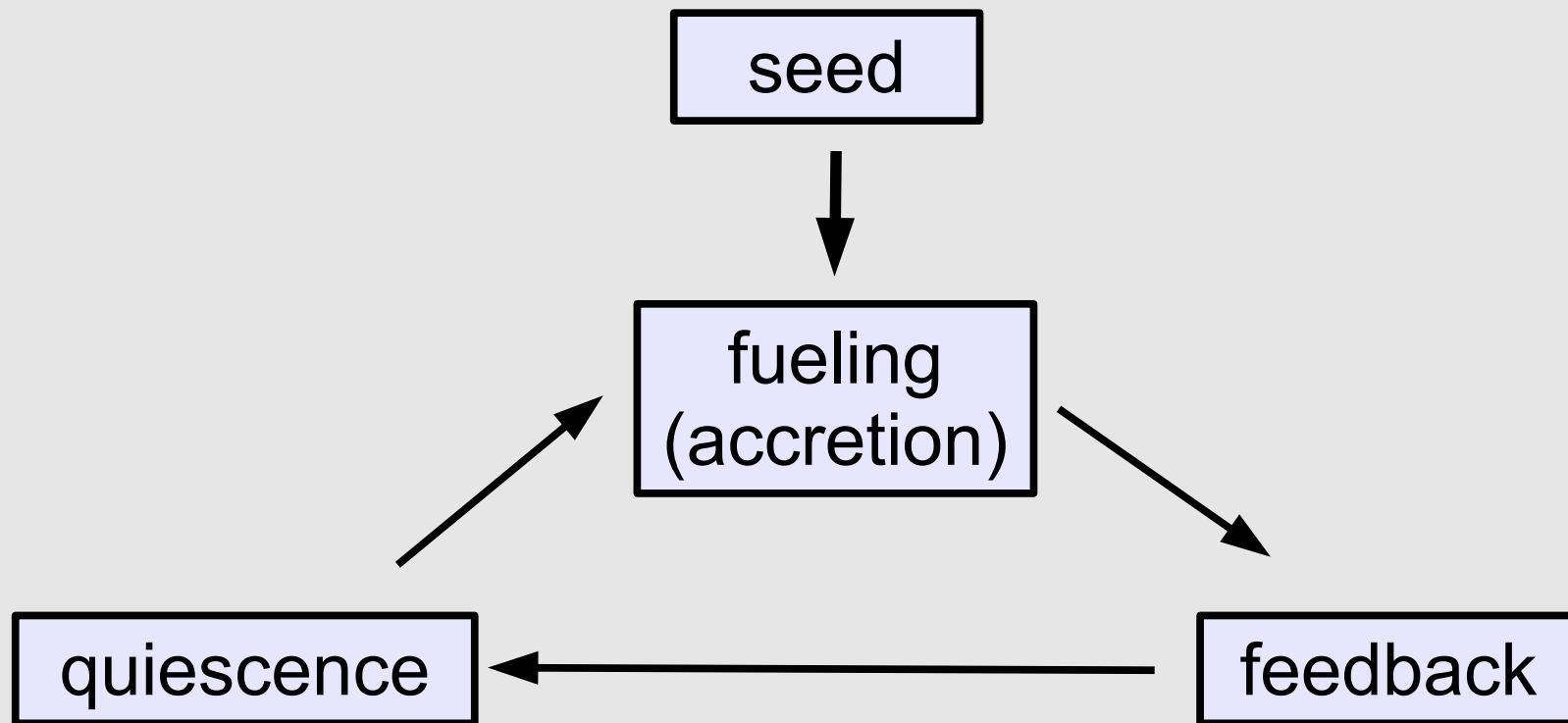


Quasar evolution at high redshift from optical surveys

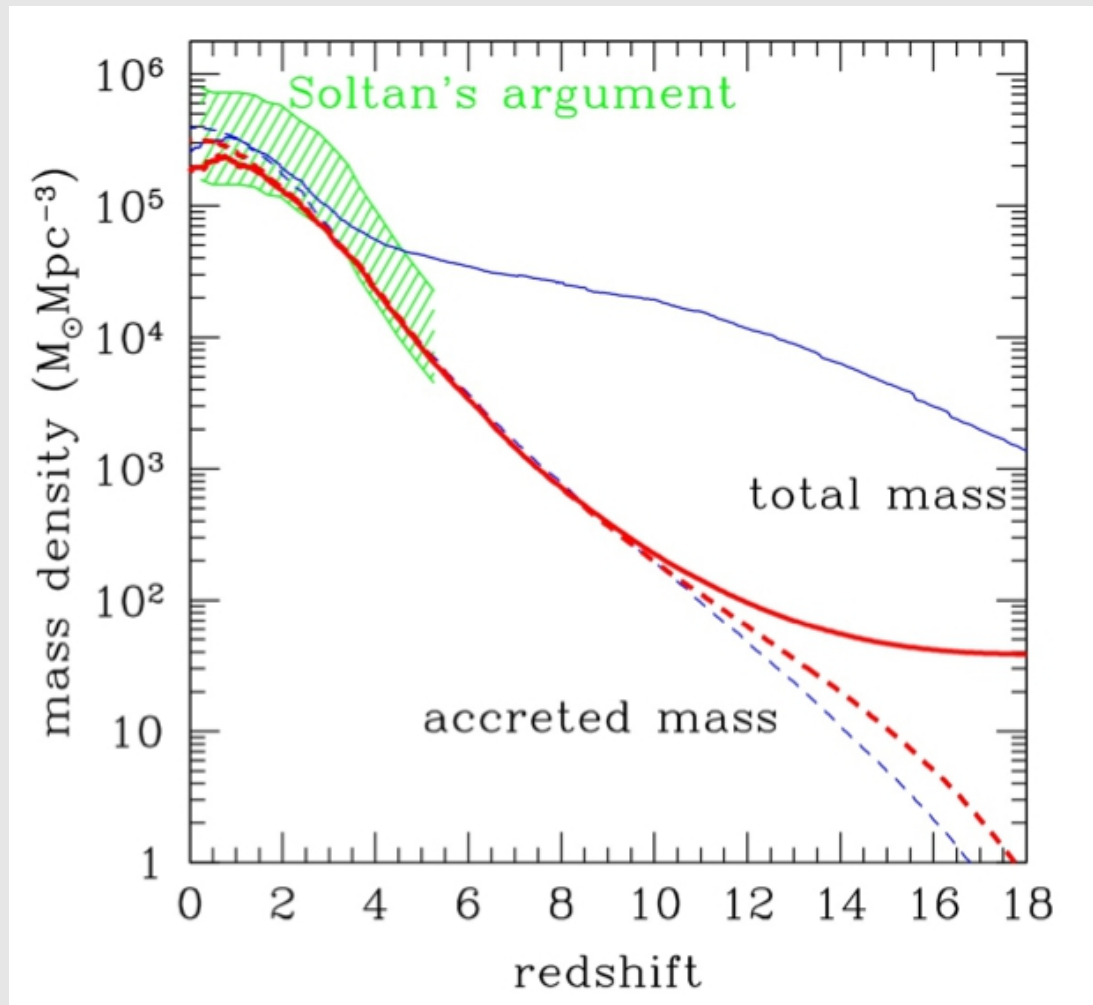
Ian McGreer (Steward Observatory)

Xiaohui Fan (Steward), Linhua Jiang (ASU),
Nic Ross, Martin White (LBNL,UCB),
Gordon Richards (Drexel), Michael Strauss (Princeton),
Zoltán Haiman (Columbia), Don Schneider (PSU)

quasar lifecycle



BHMF at high redshift

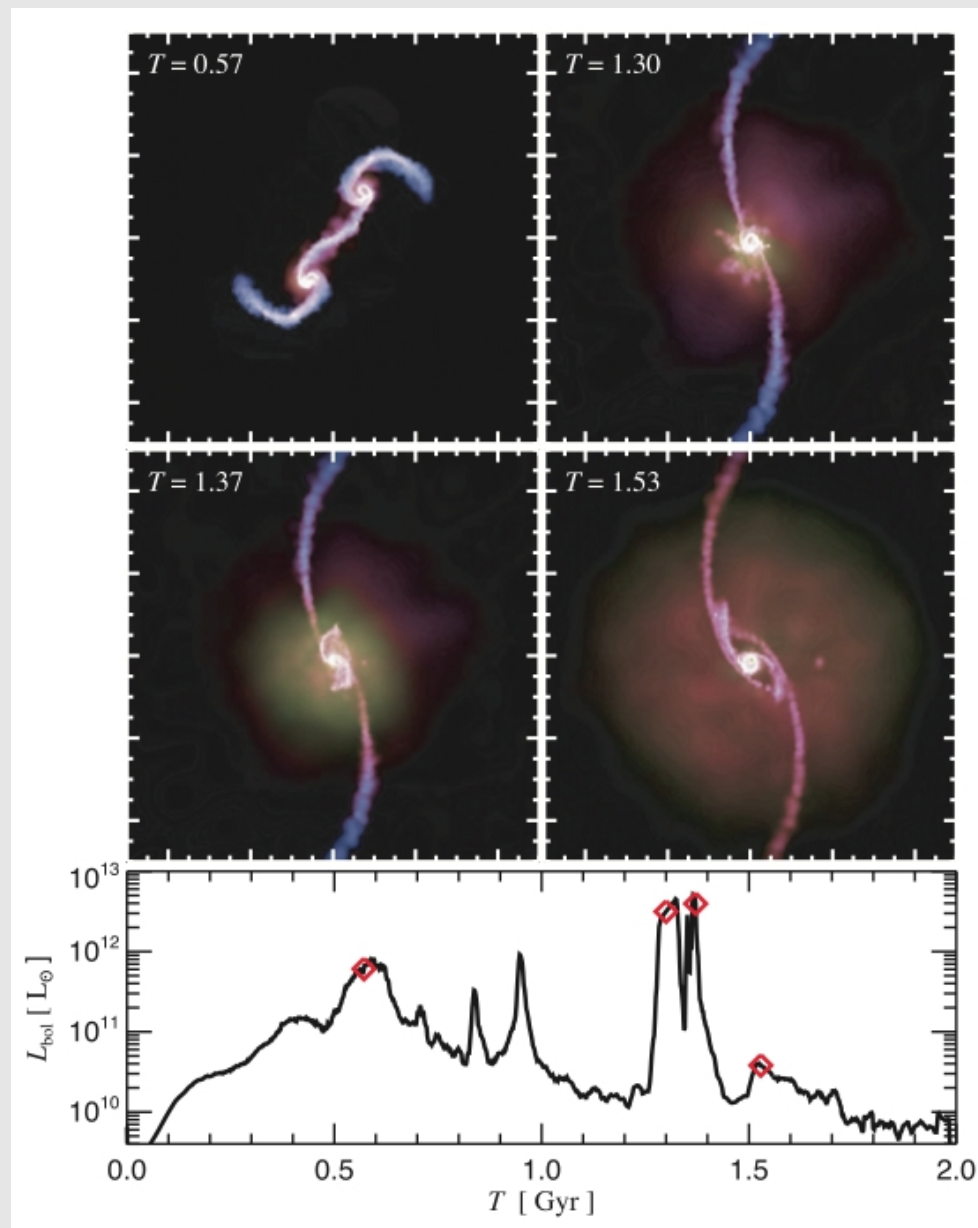


heavy seeds

light seeds

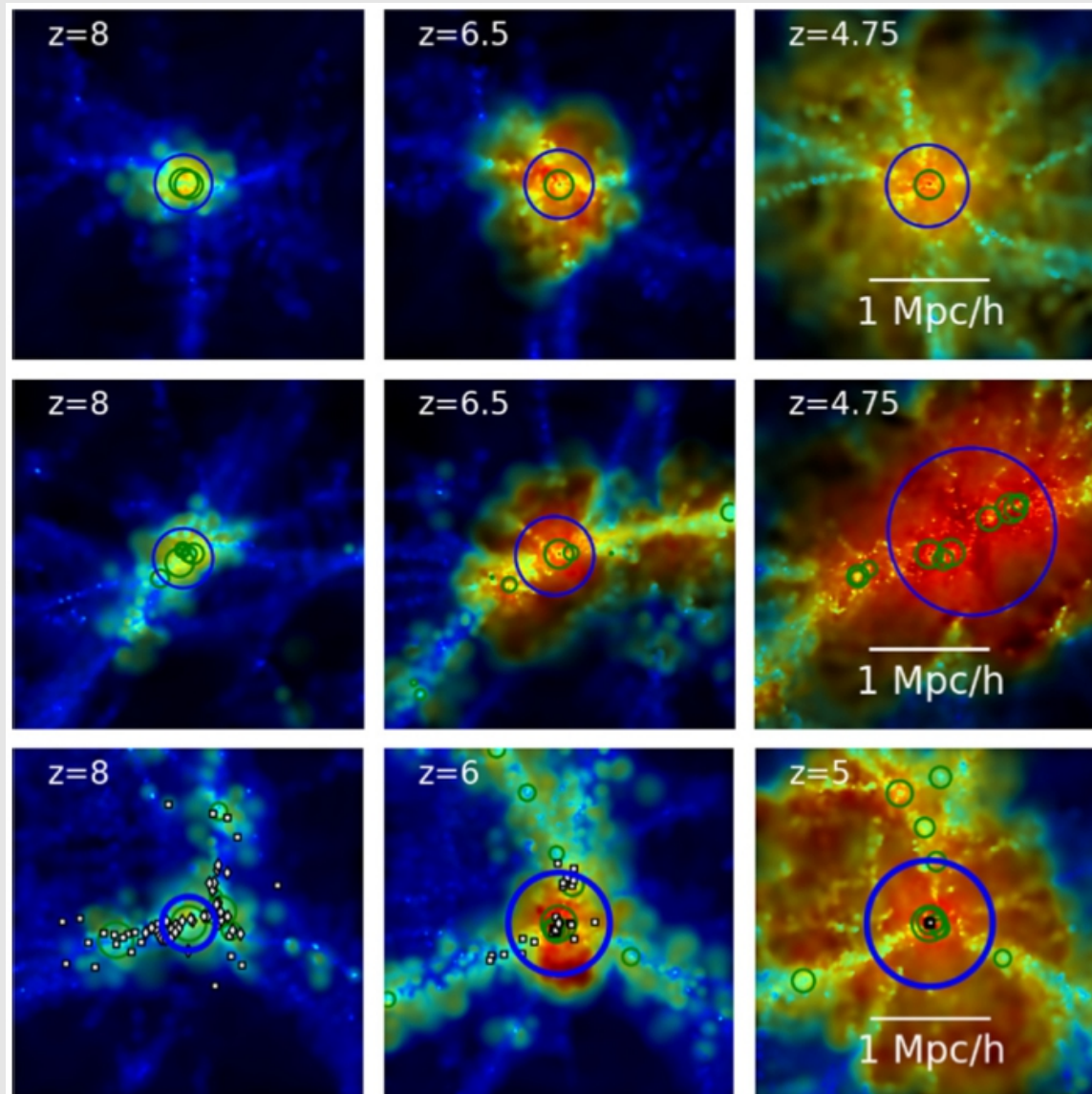
Volonteri 2010

fuel supply: gas-rich mergers



Hopkins+05

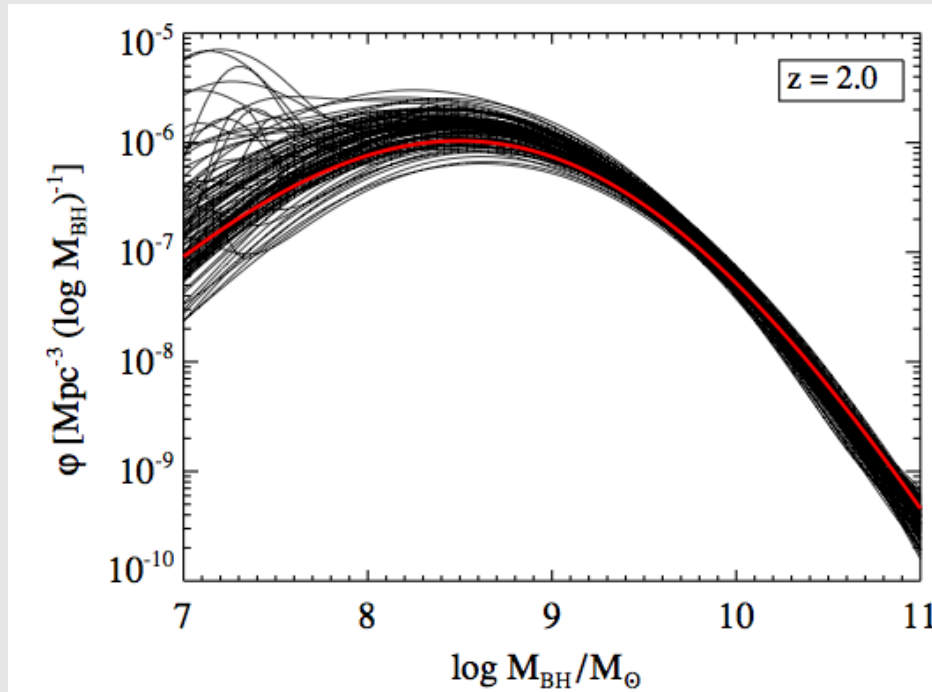
fuel supply: cold mode accretion



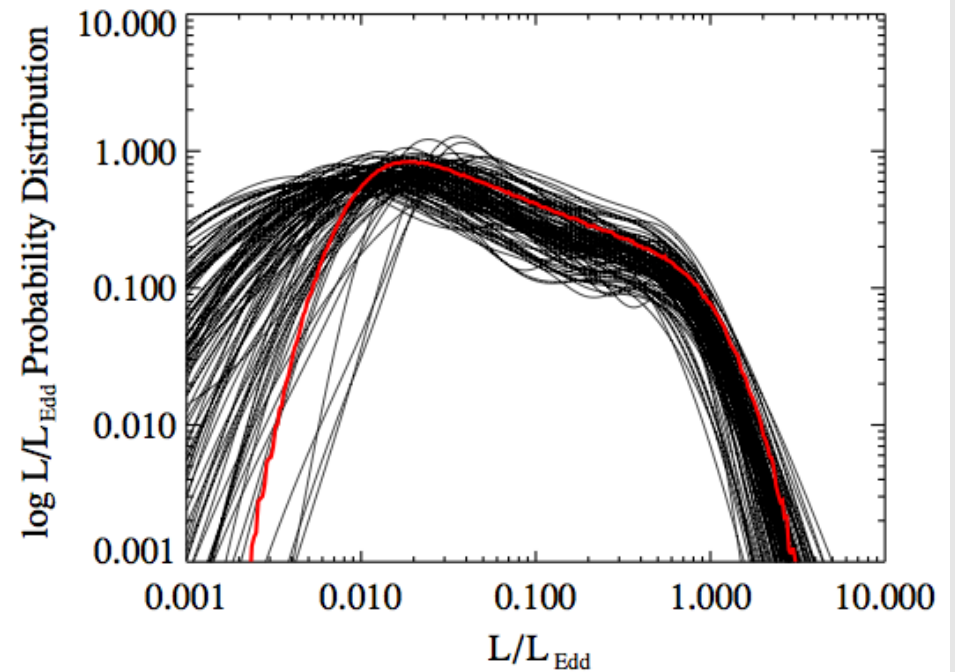
di Matteo+2012

The Quasar Luminosity Function

$$\Phi(L) =$$

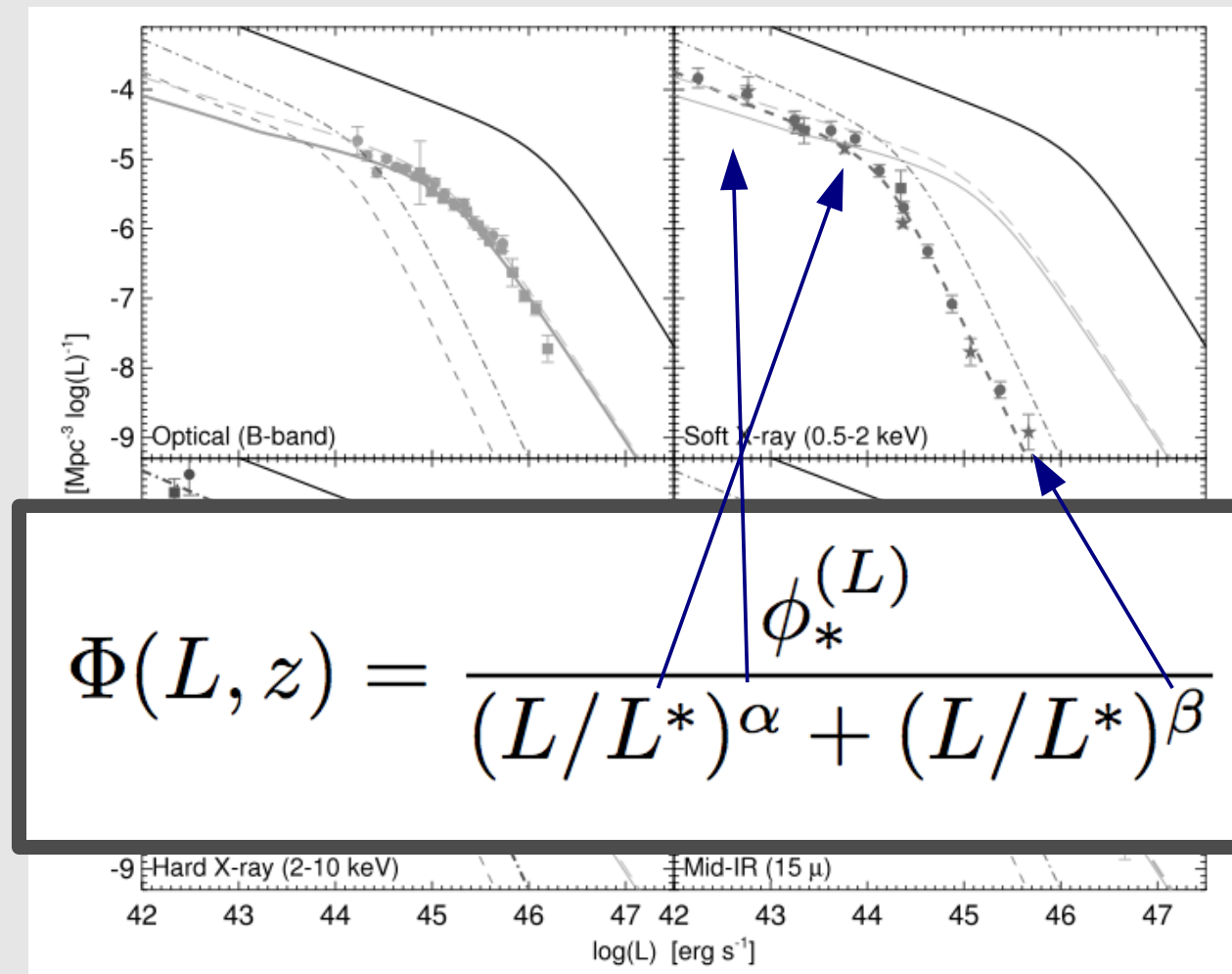


black hole mass function



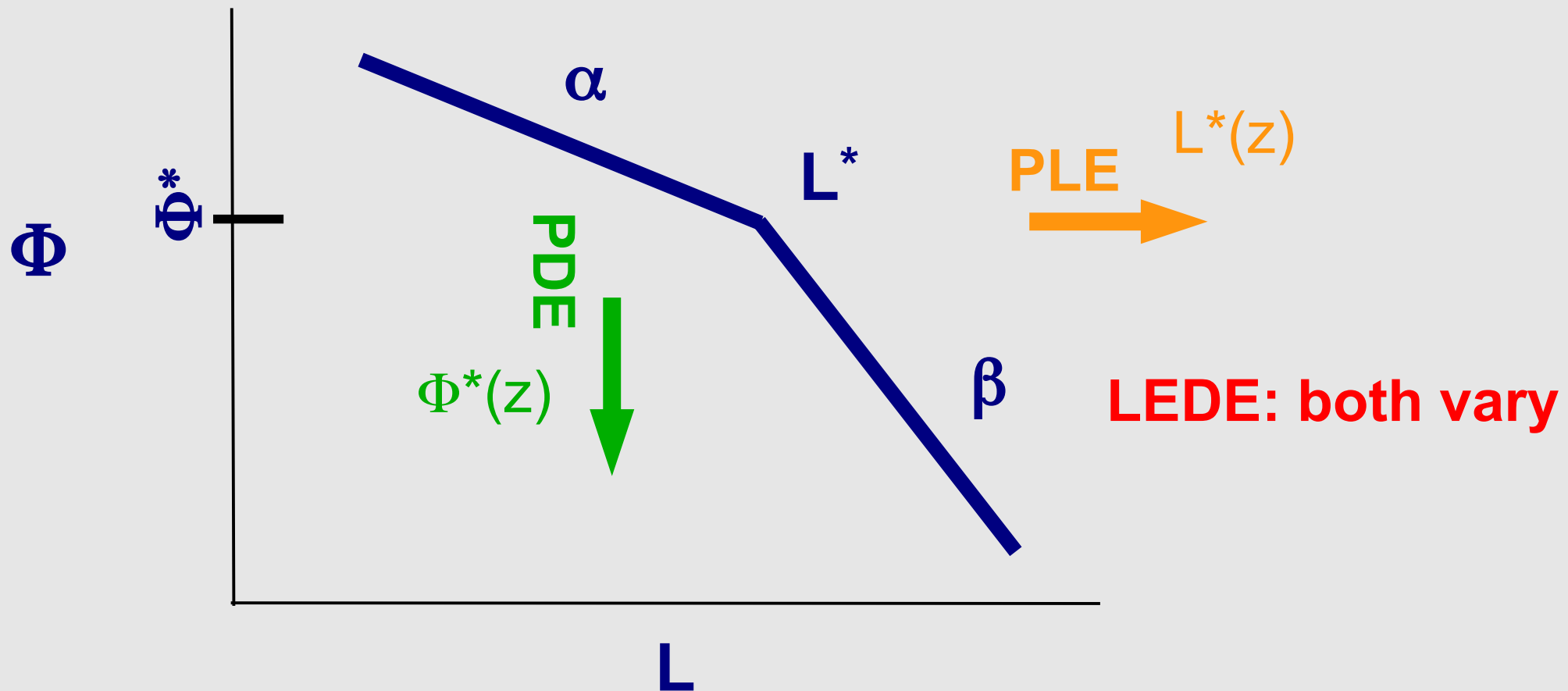
Eddington ratio
distribution

The Quasar Luminosity Function

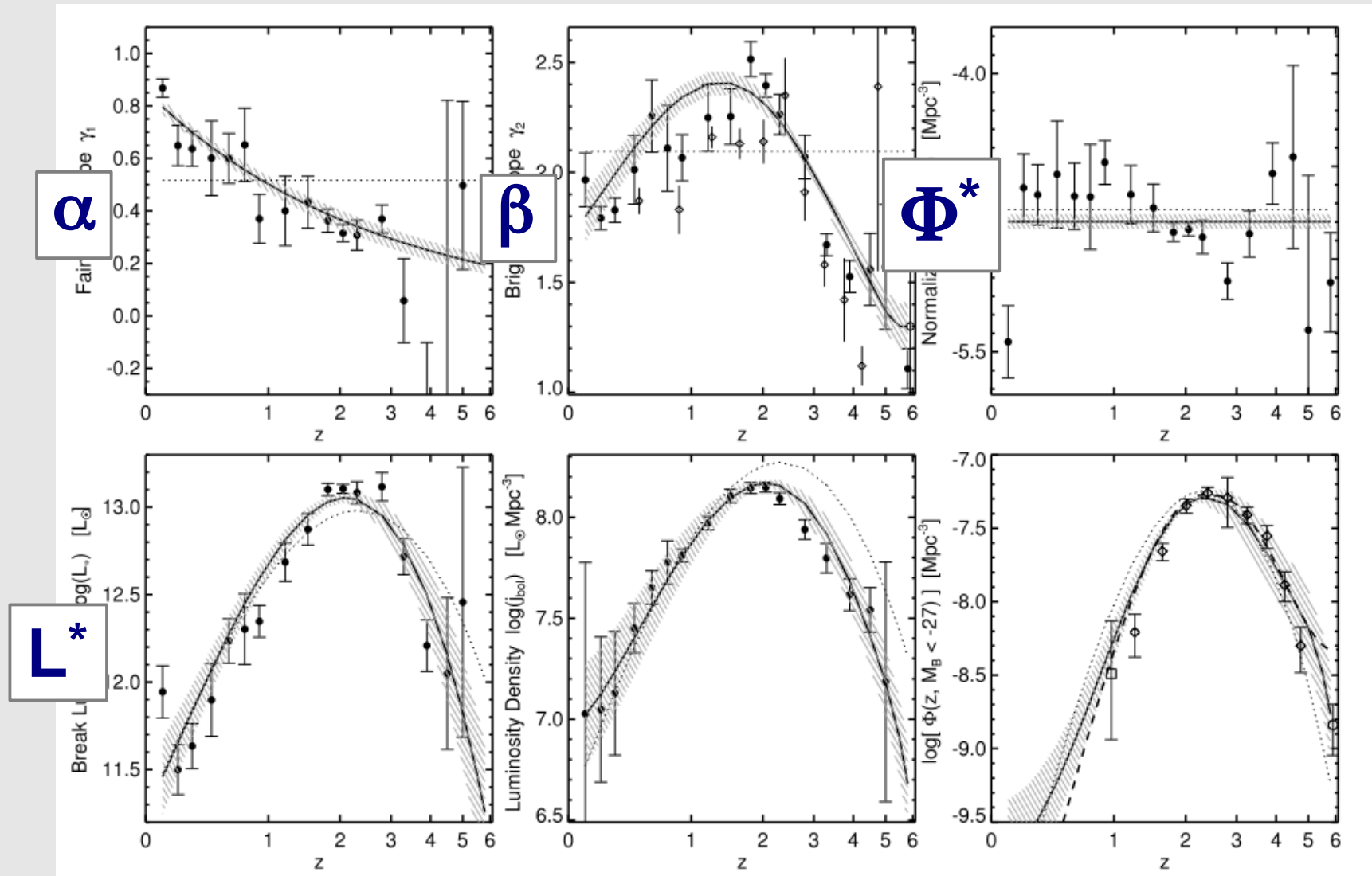


Hopkins, Richards & Hernquist 2007 (HRH07)

models for QLF evolution



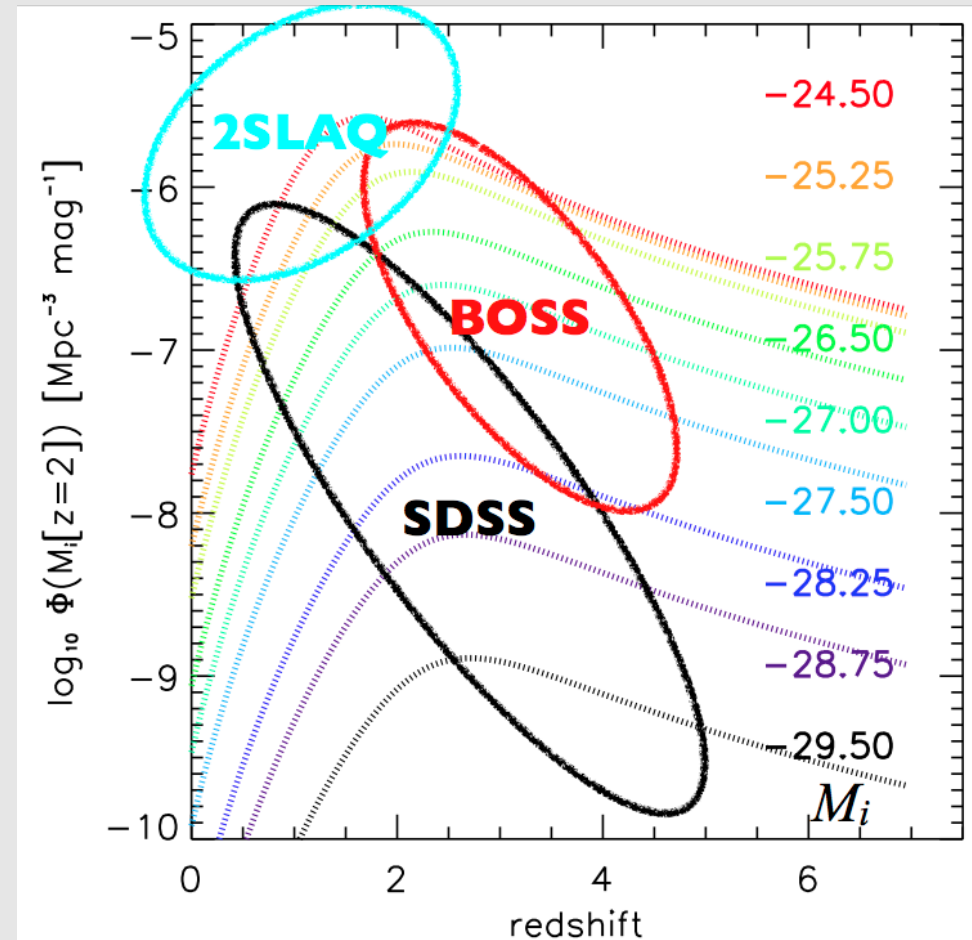
Evolution of QLF parameters



BOSS QLF

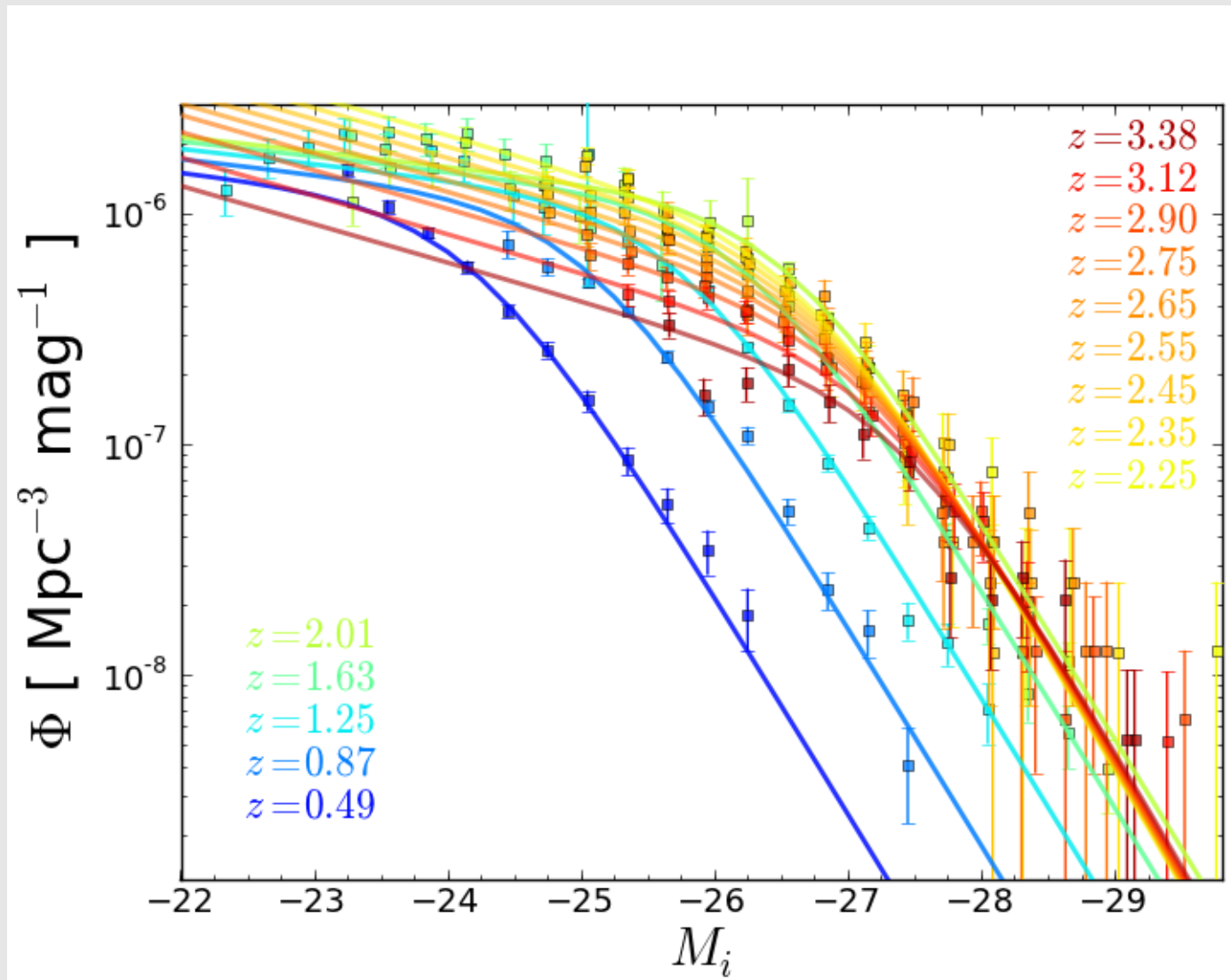
summary of BOSS quasars

- **DR9QLF** (*N. Ross, IDM, M. White, et al. 2013*)
 - 22,301 QSOs ($i < 21.8$)
 - 2236 deg^2
 - $2.2 < z < 3.5$
- **variability** (*Palanque-Delabrouille++2011,2012*)
 - Stripe 82 (220 deg^2 , 5500 QSOs $2.2 < z < 3.5$)
 - boss21 (15 deg^2 , 1900 QSOs $0.7 < z < 4$)

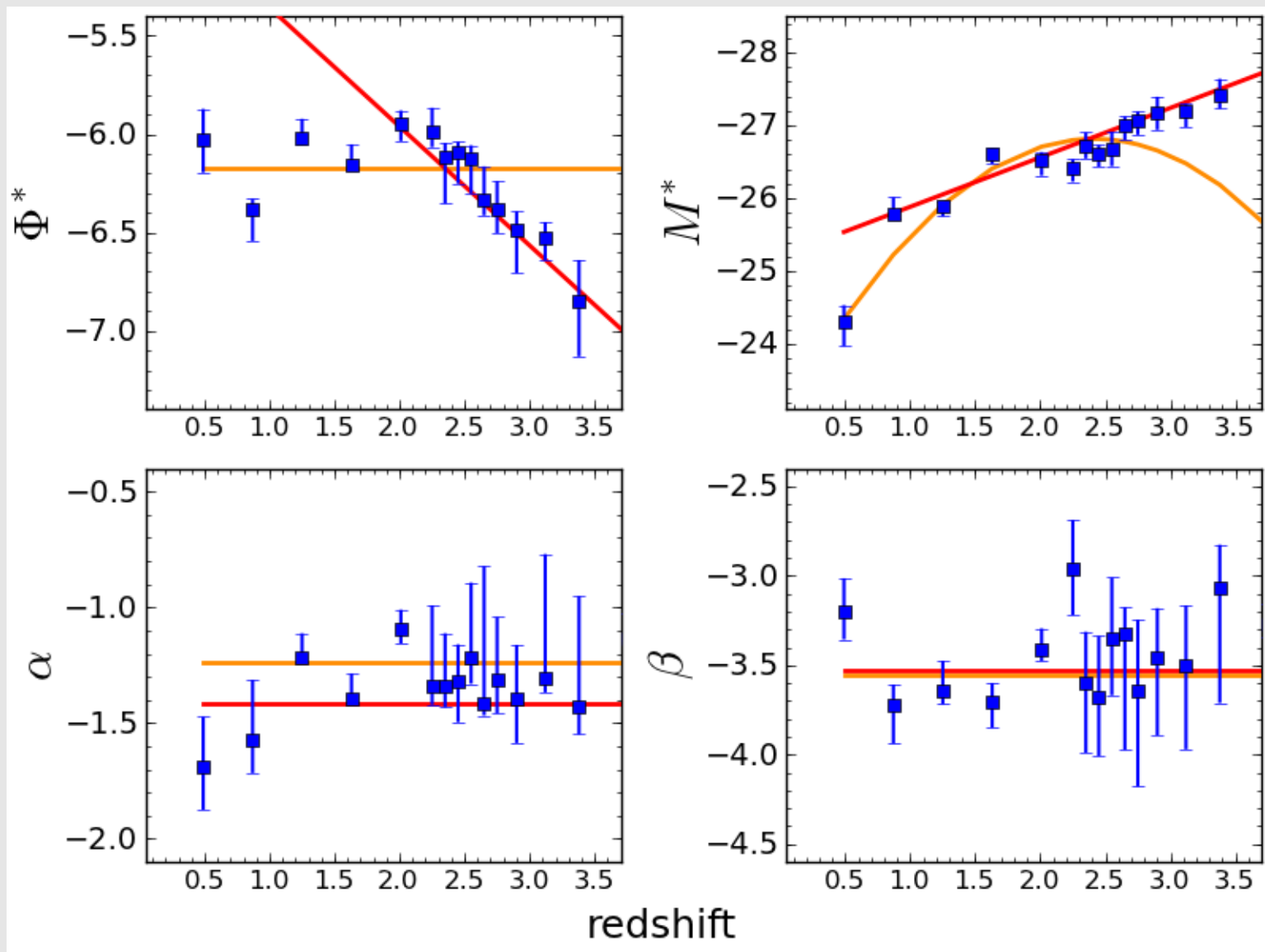


from N. Ross

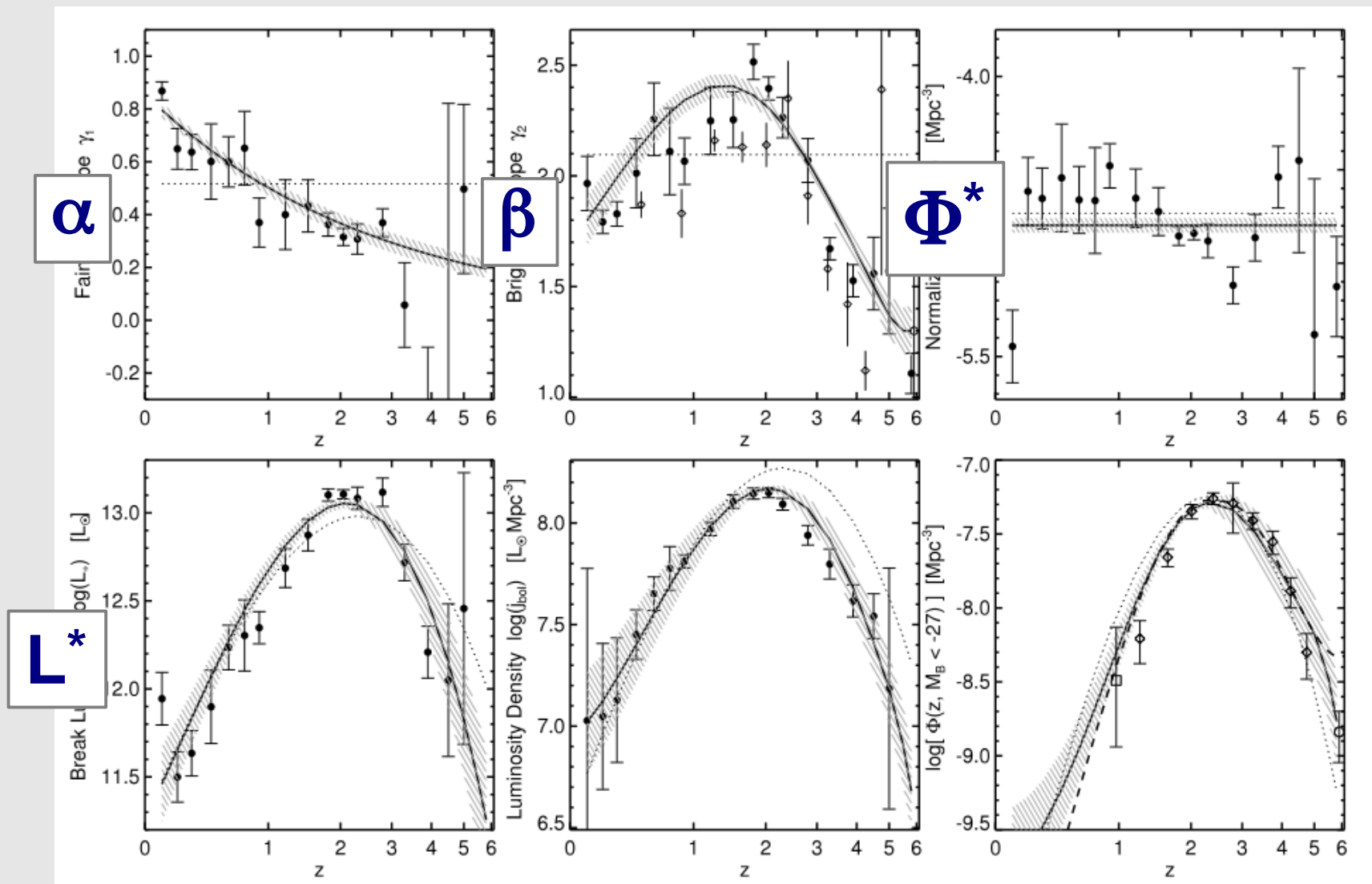
evolution with redshift



evolution of QLF parameters

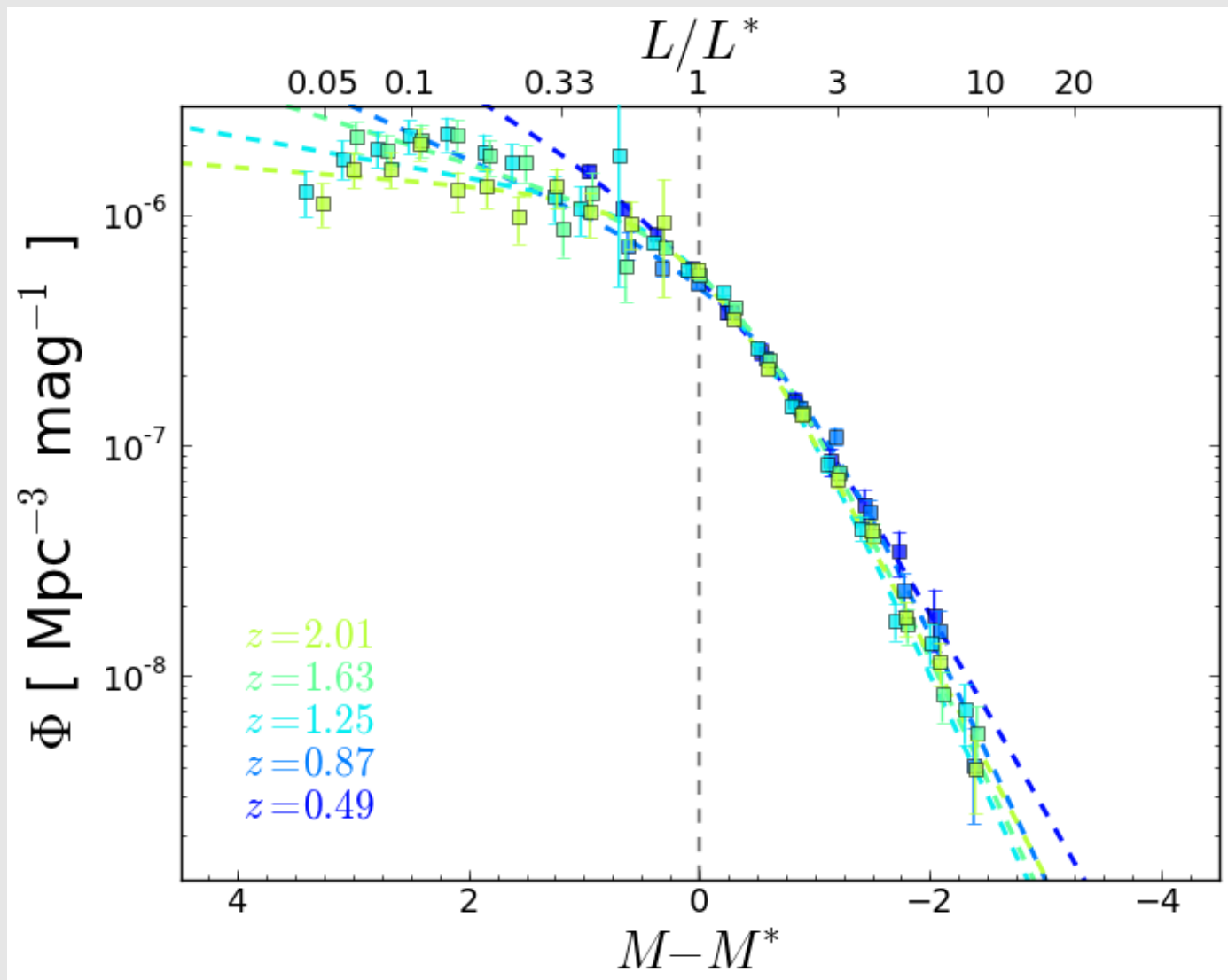


compare to HRH07

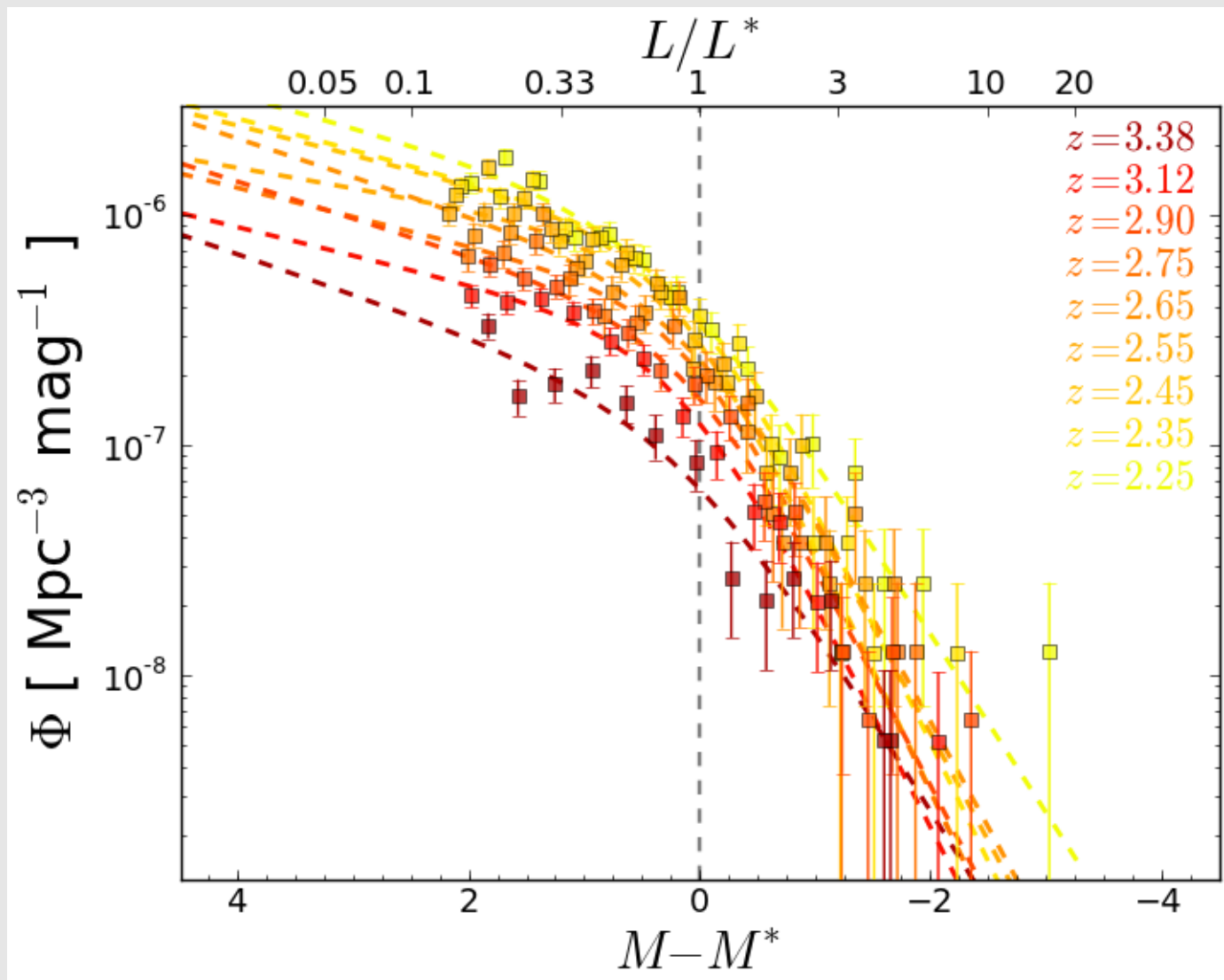


HRH07

evolution at low redshift ($z \leq 2$)

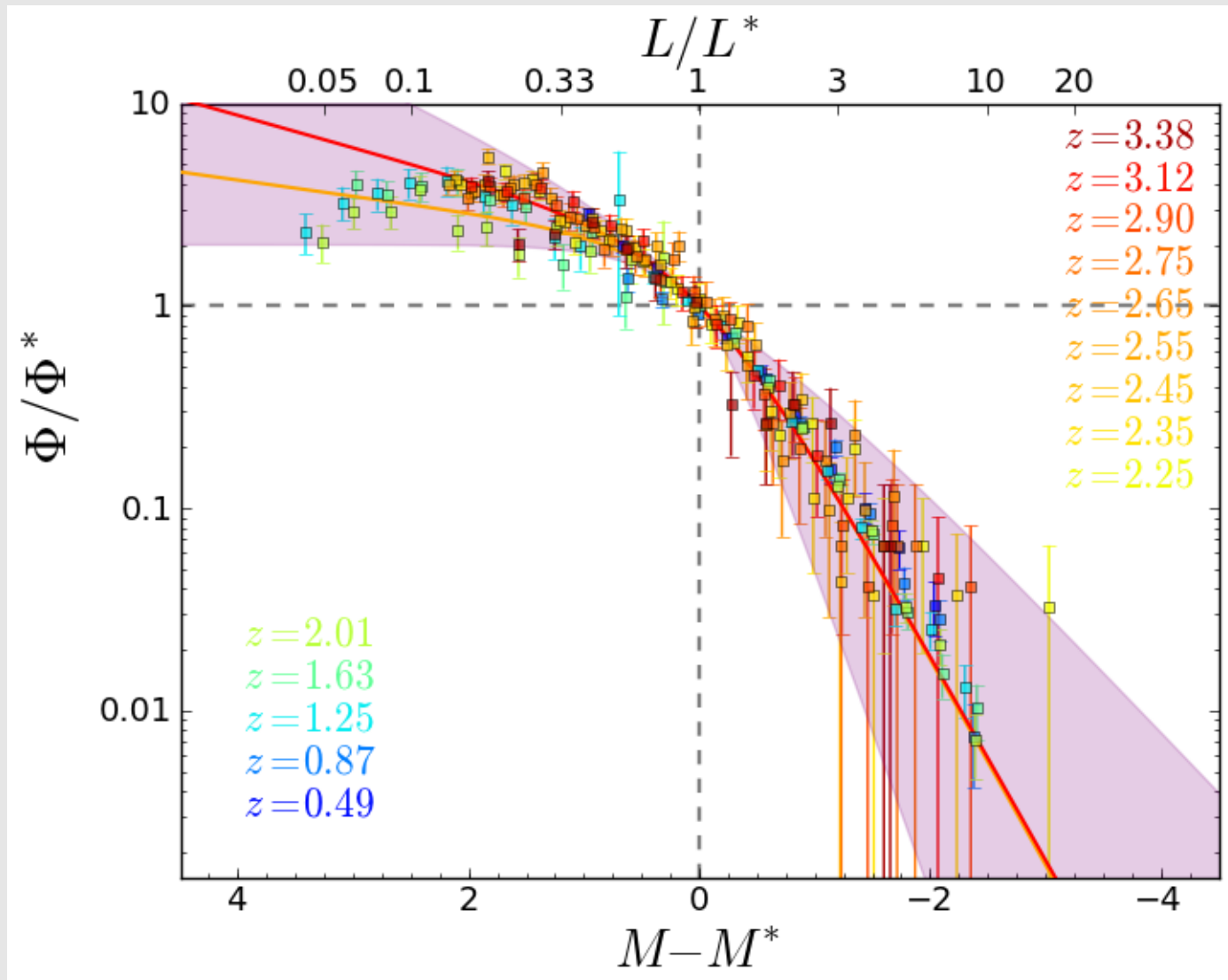


evolution at high redshift ($z > 2$)



evolution of shape (power-law slopes)

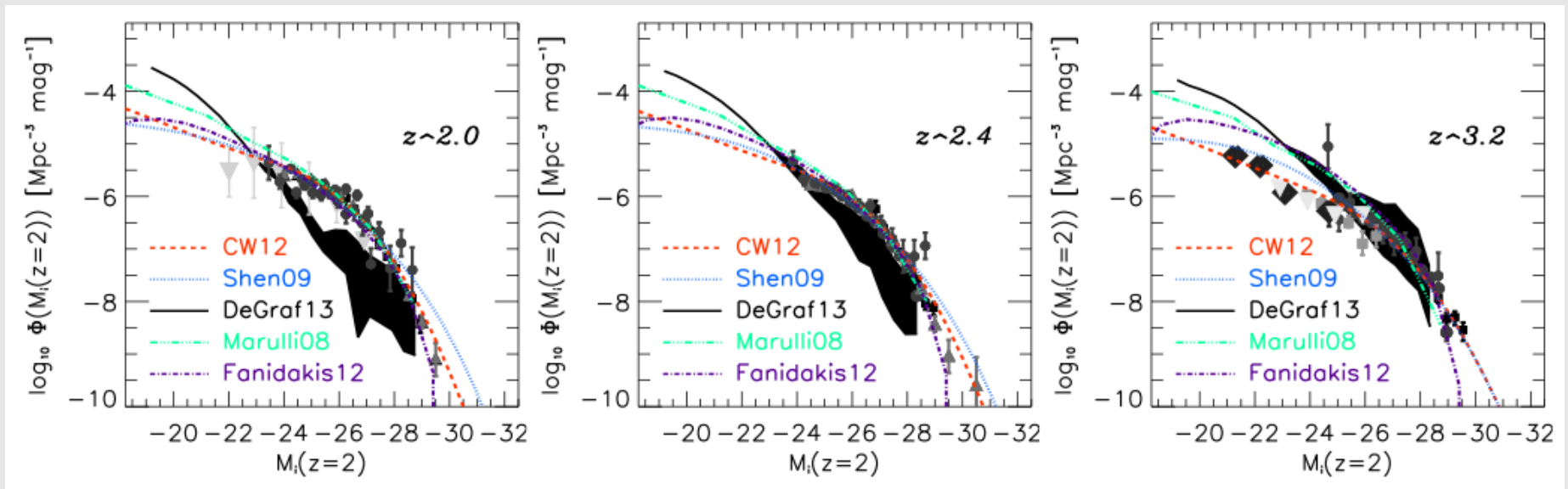
$\alpha = -1.4$
(-1.2)
(-1.6, -1.1)



PLE
LEDE

$\beta = -3.6$
(-4.5, -2.8)

comparison to theoretical models

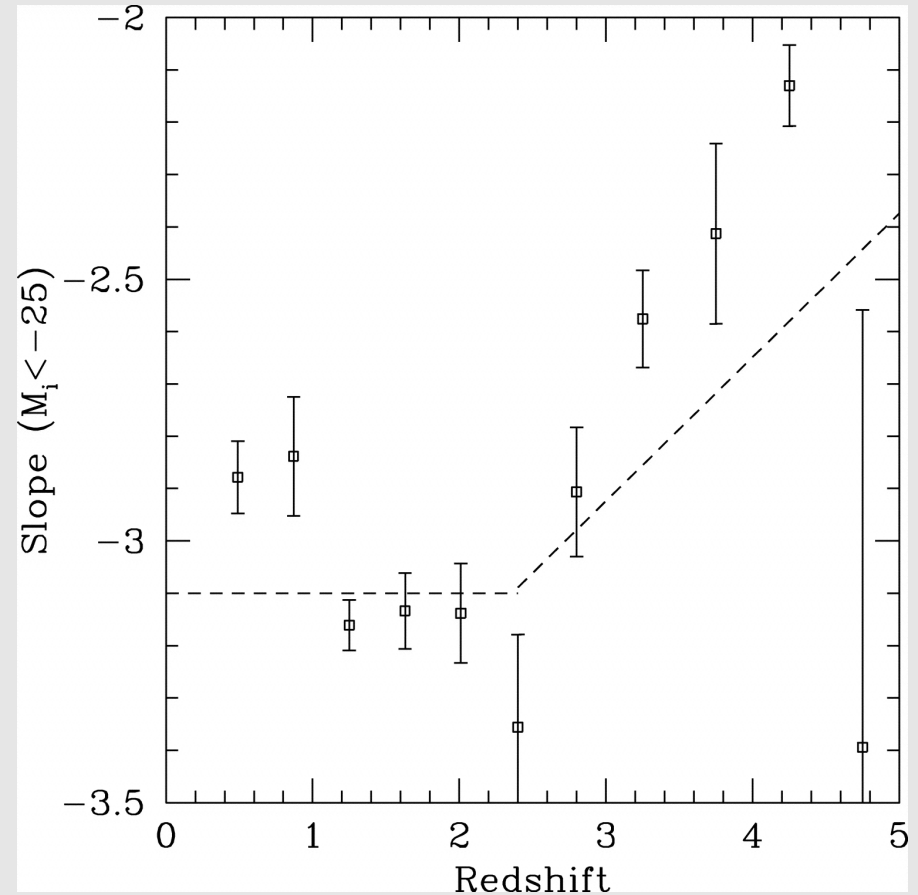


The $z \sim 5$ QLF from SDSS Stripe 82

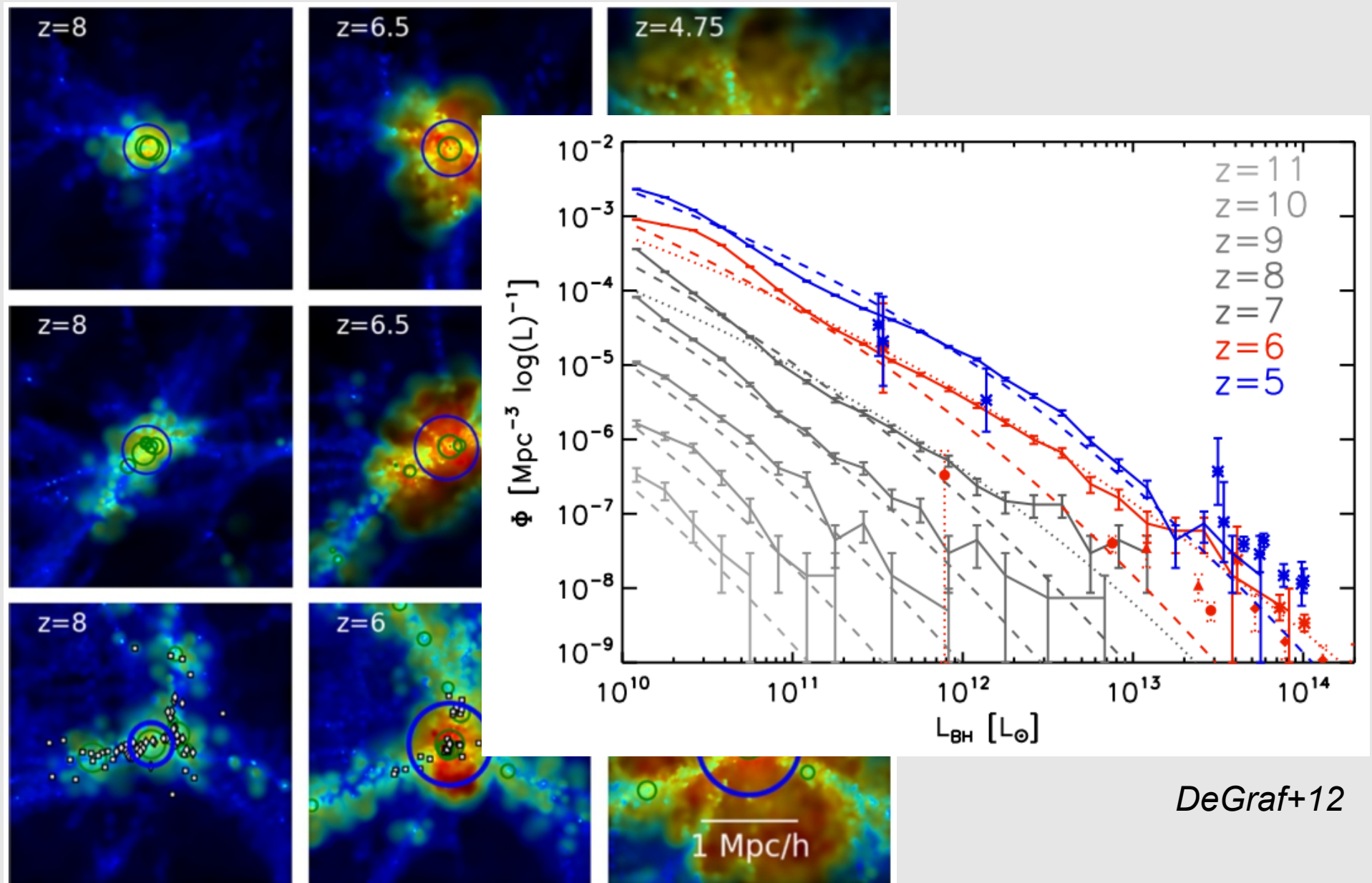
evolving slope

bright end slope flattens at
high- z (Schmidt, Schneider, &
Gunn 1995, Fan+01, Richards+06,
HRH07)

accretion mode?
feedback?

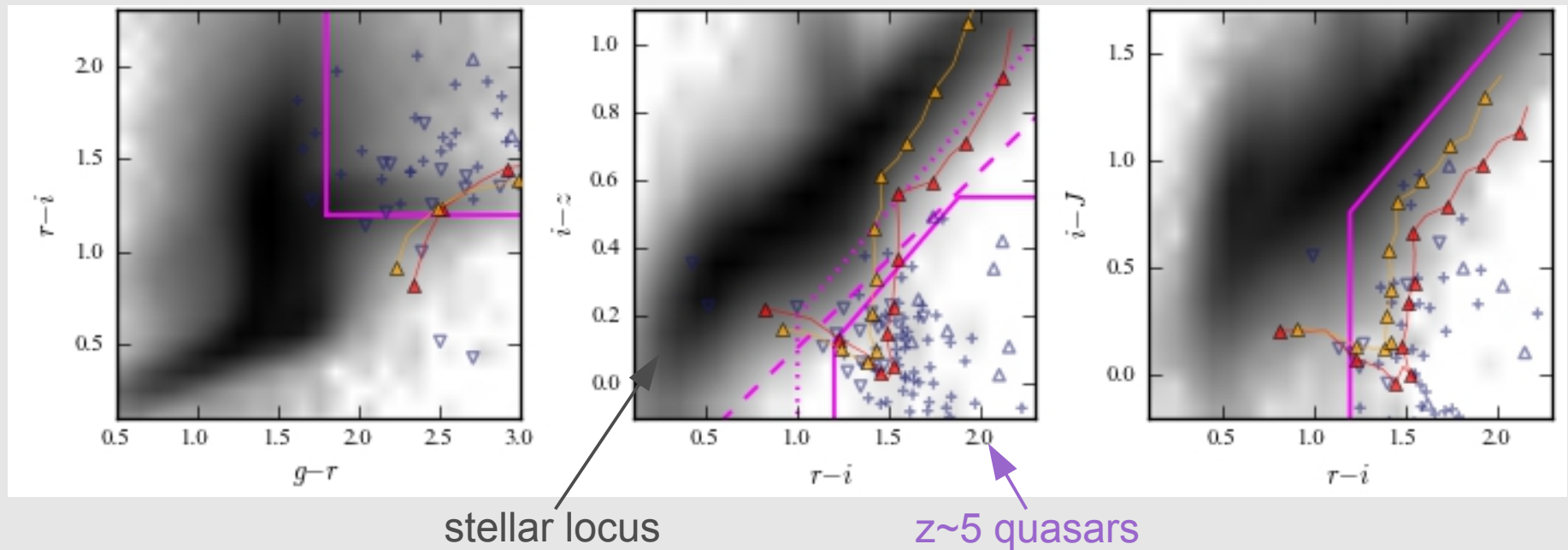


bright end evolution from cold stream model



selection from Stripe 82 coadds

coadded imaging is ~ 2 mag fainter than SDSS



simple color selection highly efficient & complete at $z \sim 5$

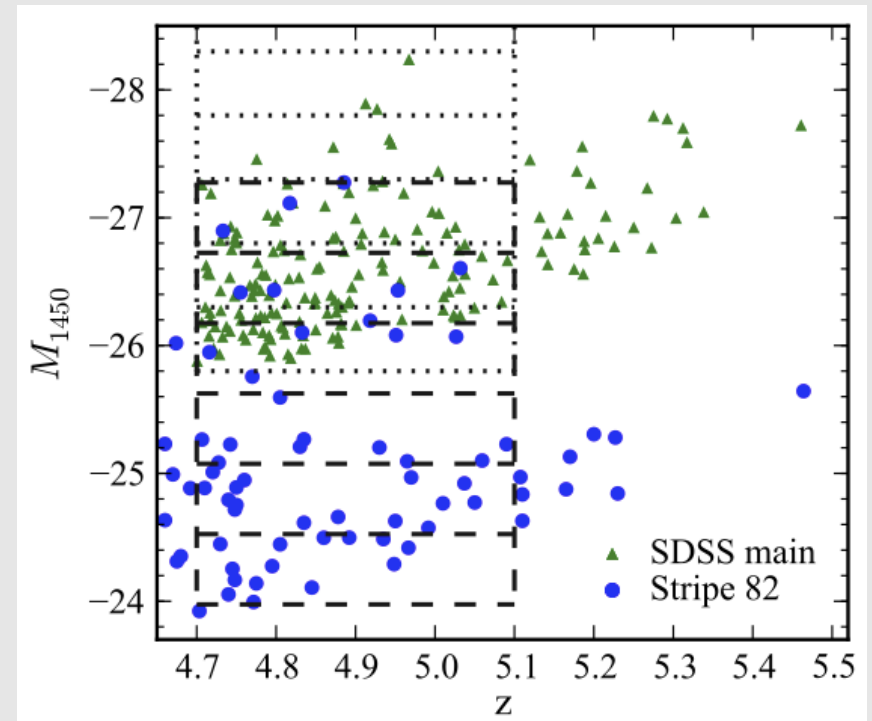
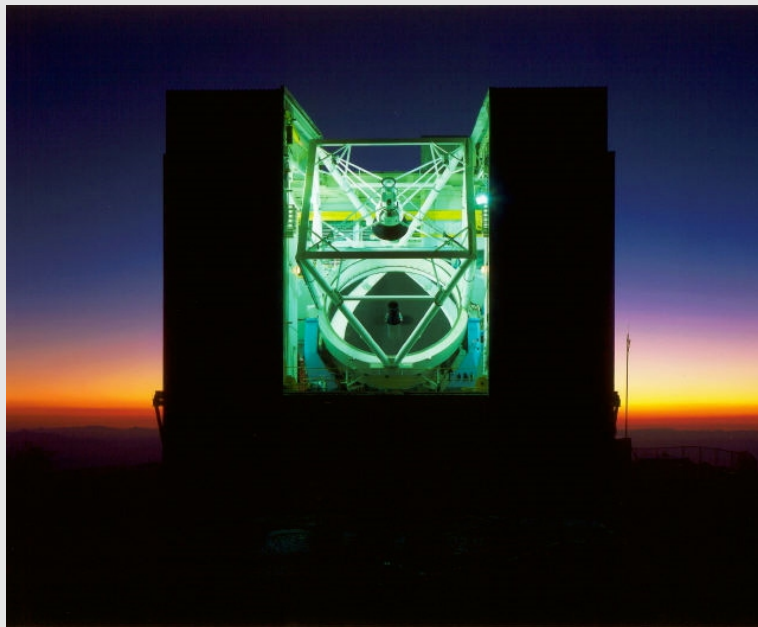
Stripe 82 $z \sim 5$ numbers

92 candidates

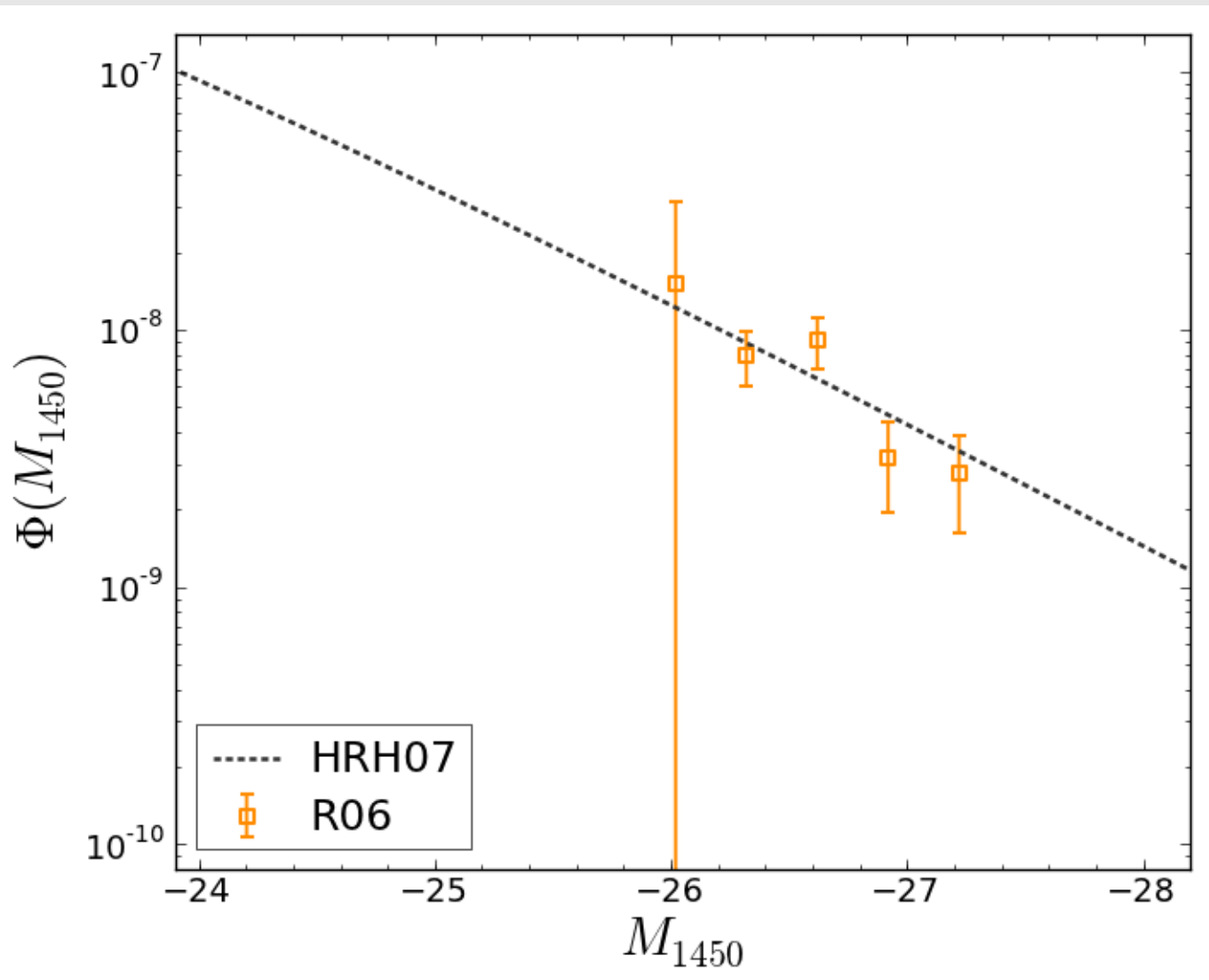
73 spectra

71 quasars

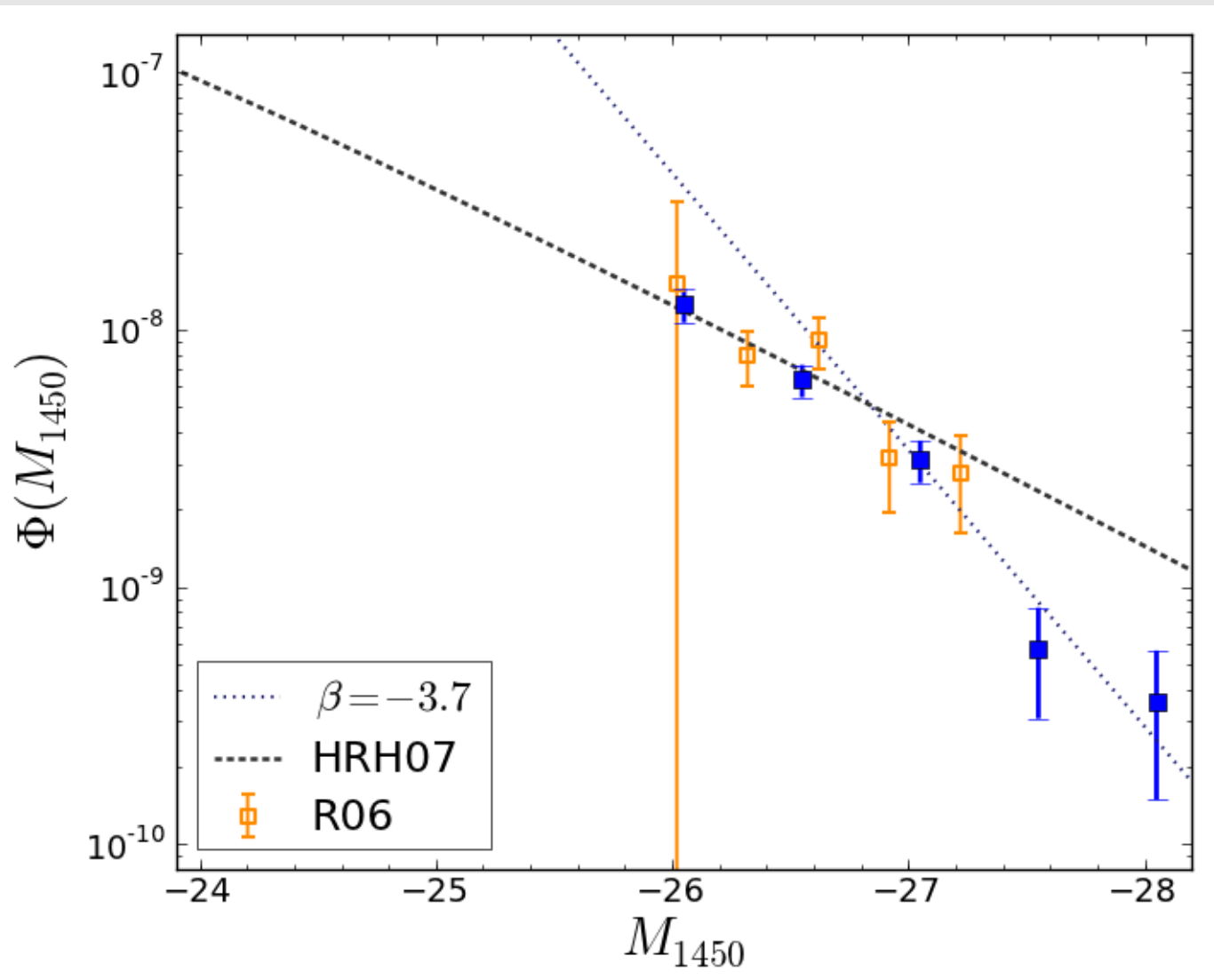
52 $4.7 < z < 5.1$



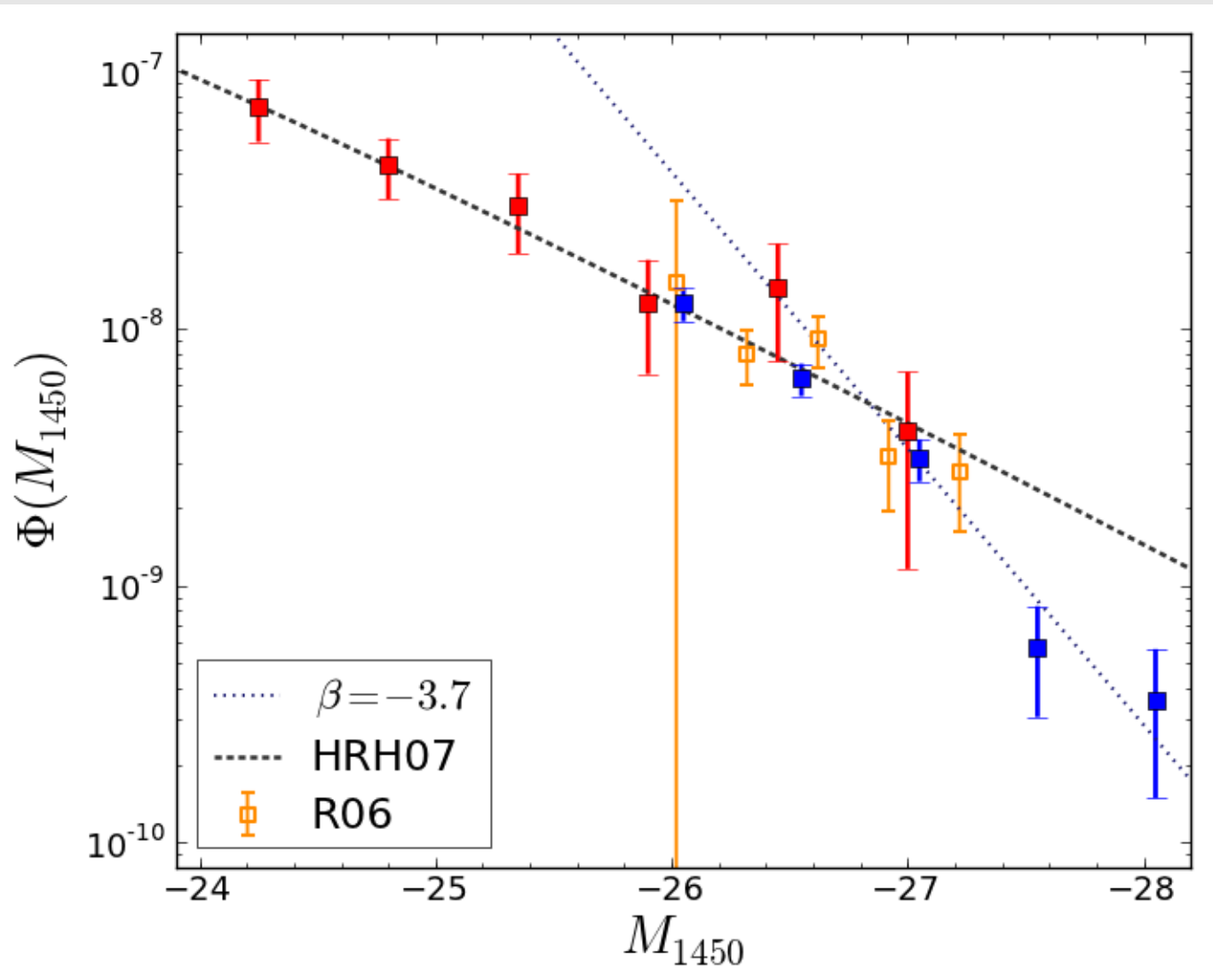
QLF shape at $z \sim 5$, SDSS DR3



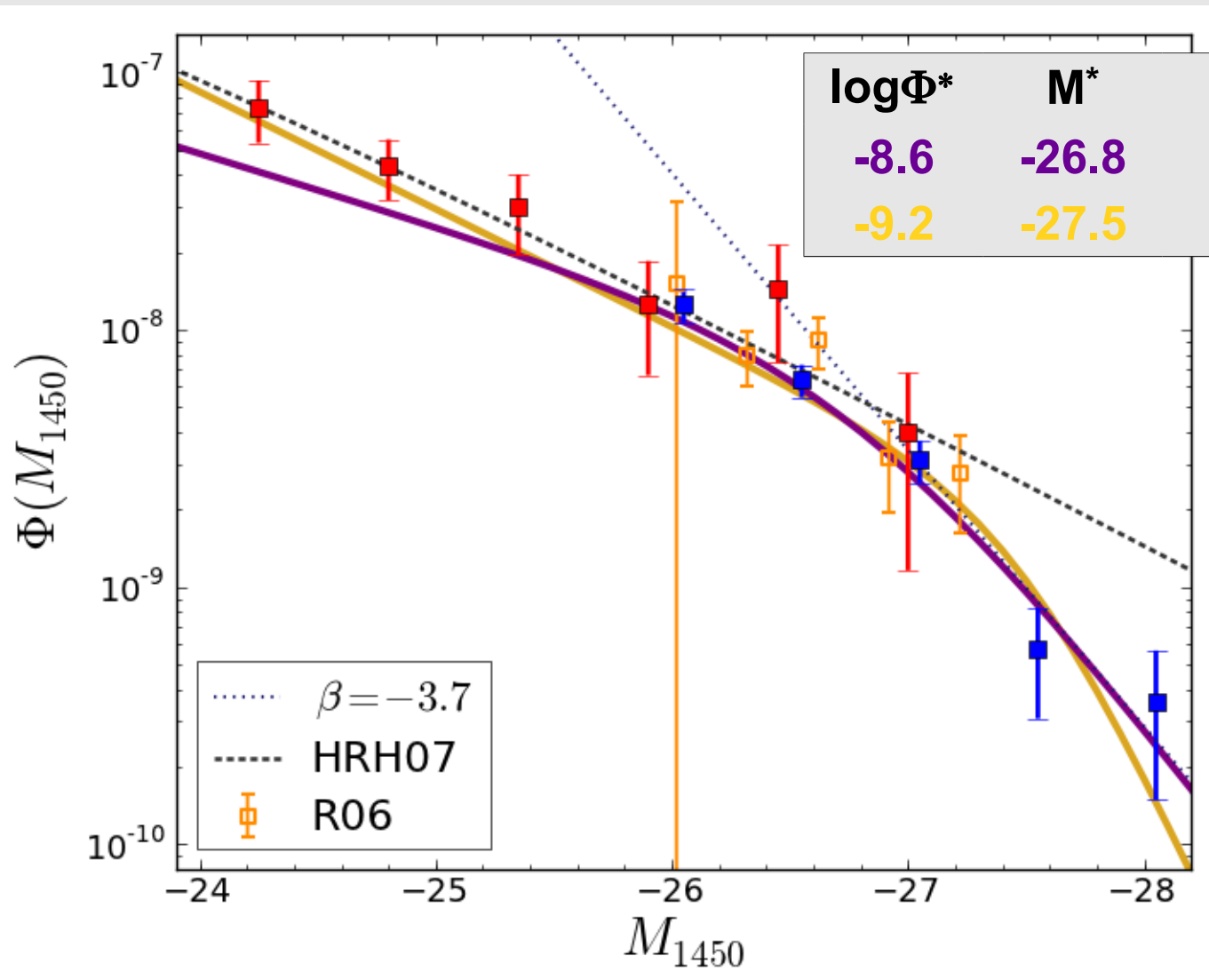
QLF shape at $z \sim 5$, SDSS DR7



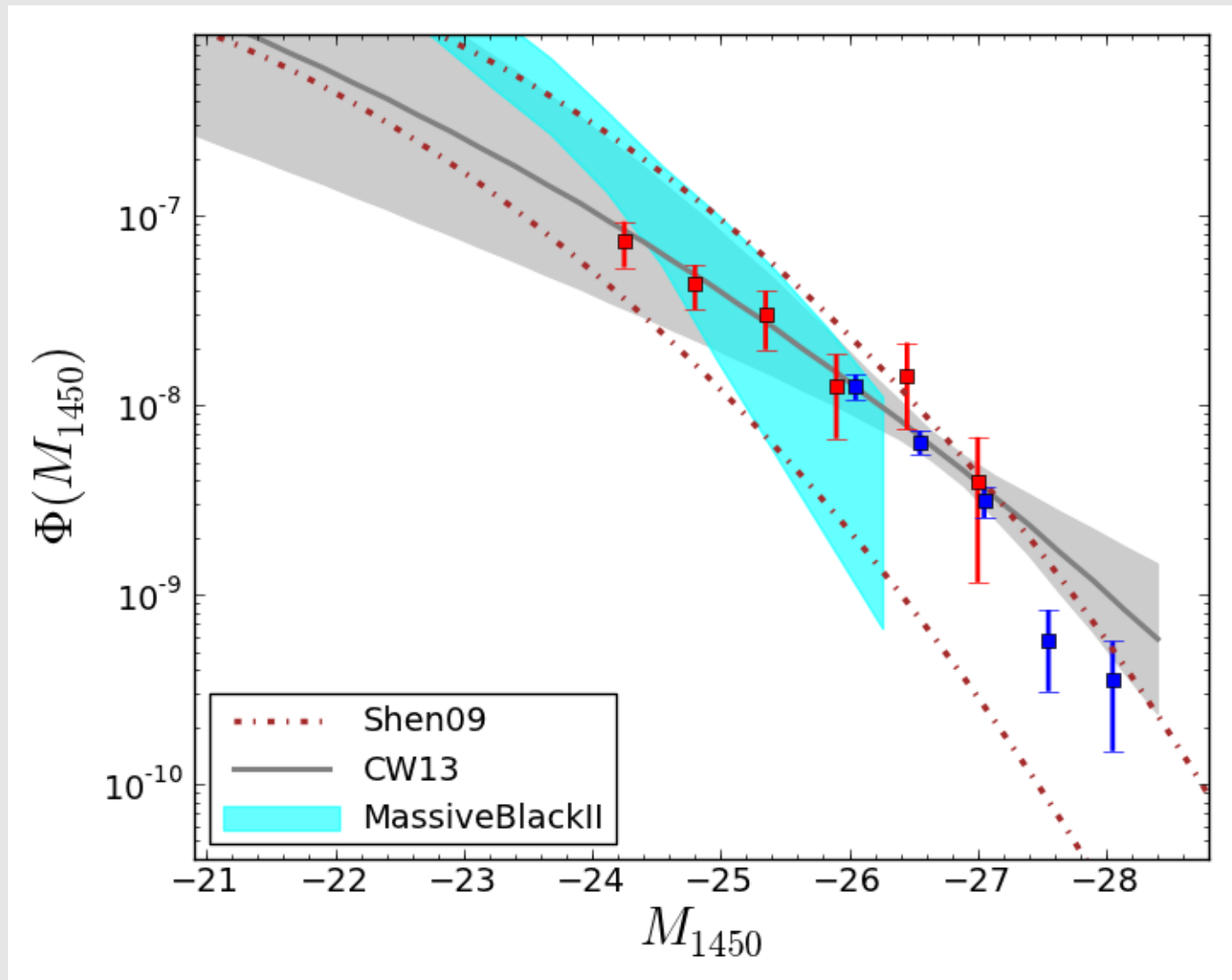
QLF shape at $z \sim 5$, Stripe 82



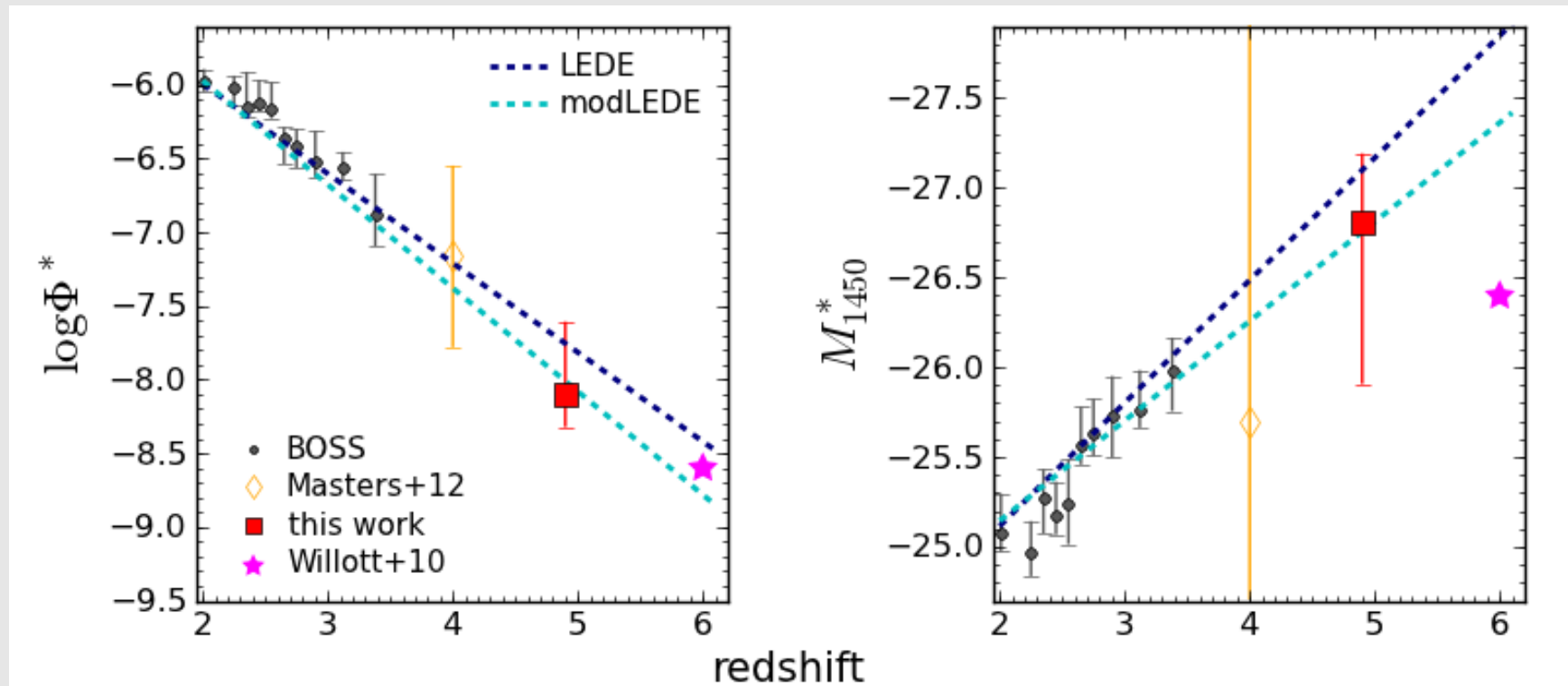
QLF shape at $z \sim 5$, model fits



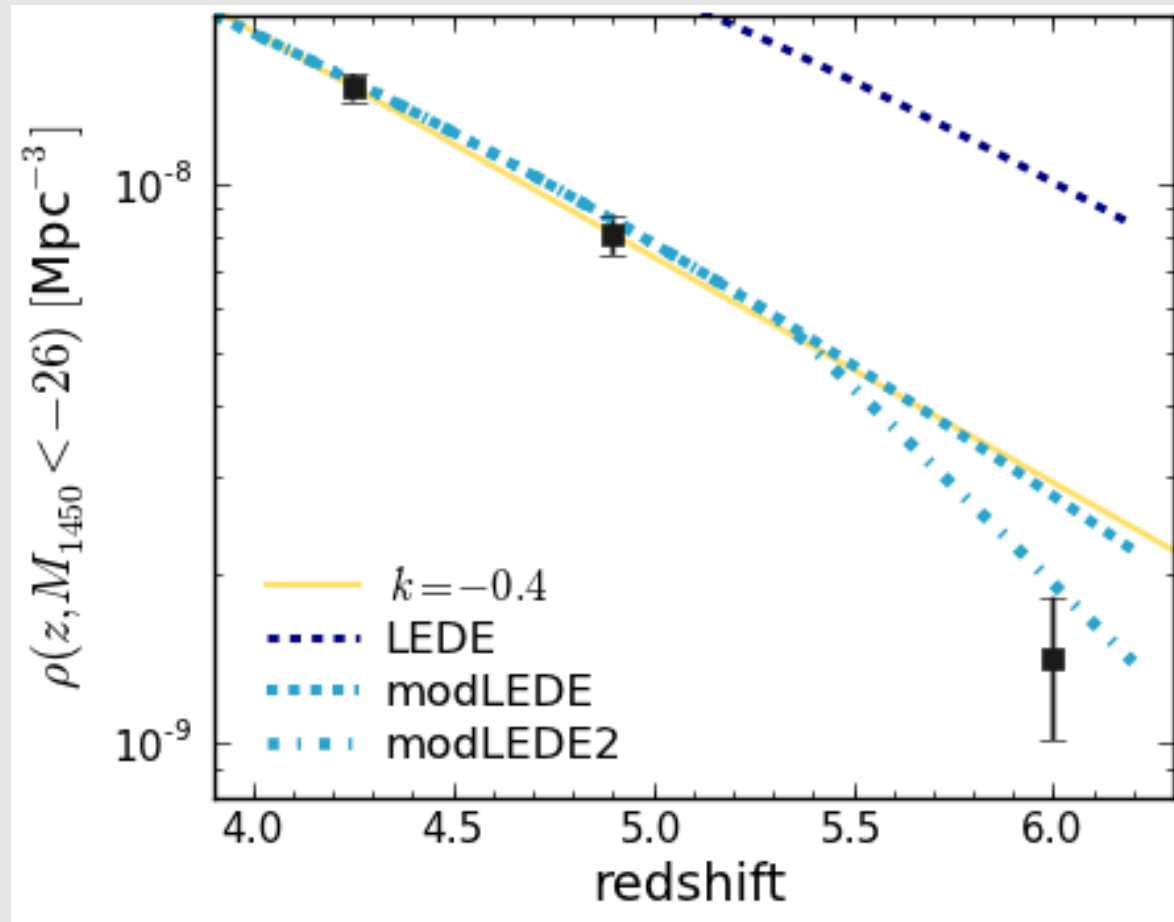
comparison to theoretical models



in the context of the BOSS LEDE model



acceleration evolution at $z > 6$?



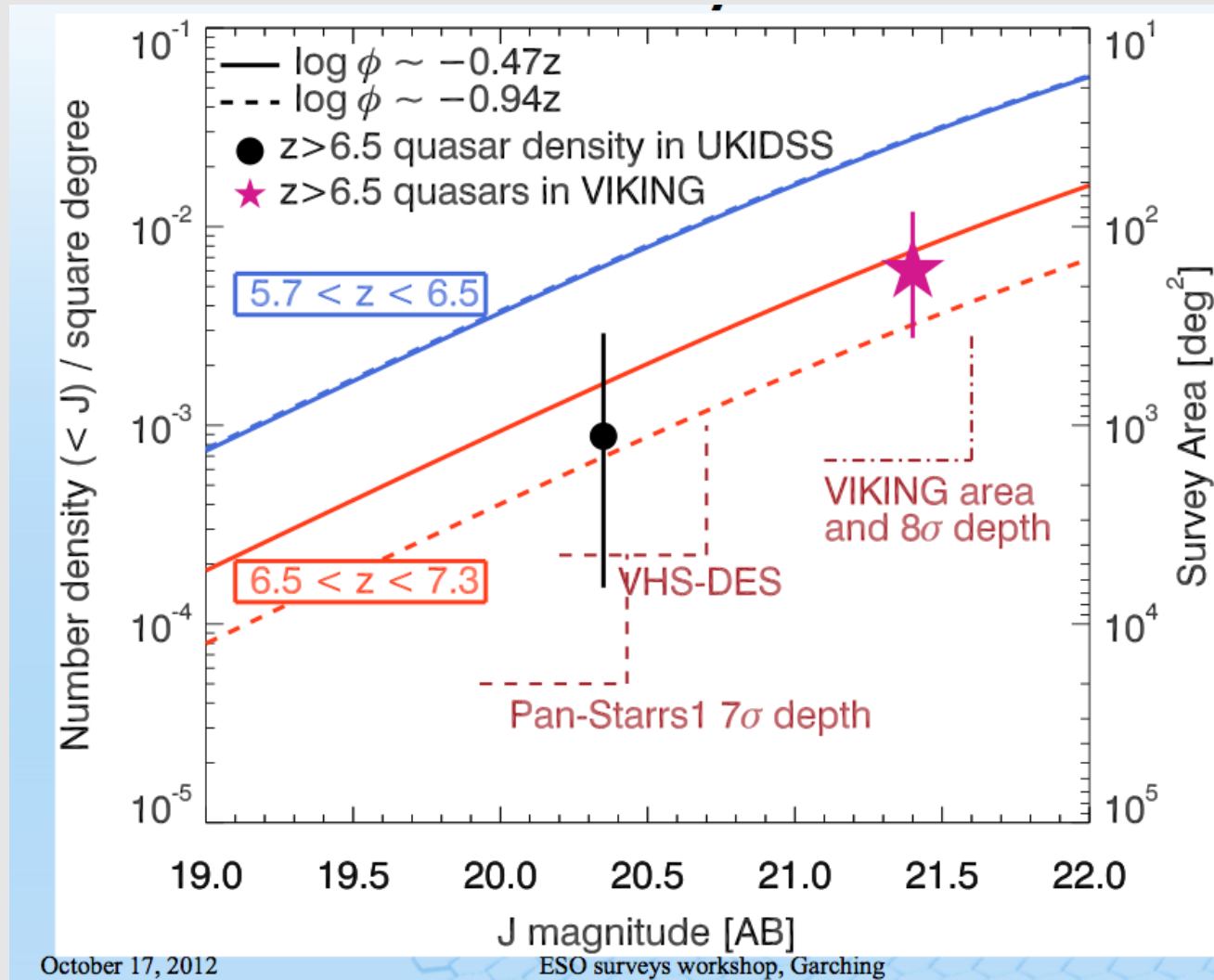
$$\log \rho \approx -0.7z$$

$$z = 5 \rightarrow 6$$

$$V_a = \int_{\Delta z} p(M_{1450}, z) \frac{dV}{dz} dz$$

$$\rho = \sum_i \frac{1}{V_a^i}, \quad \sigma(\rho) = \left[\sum_i \left(\frac{1}{V_a^i} \right)^2 \right]^{1/2}$$

... potentially seen in near-IR surveys

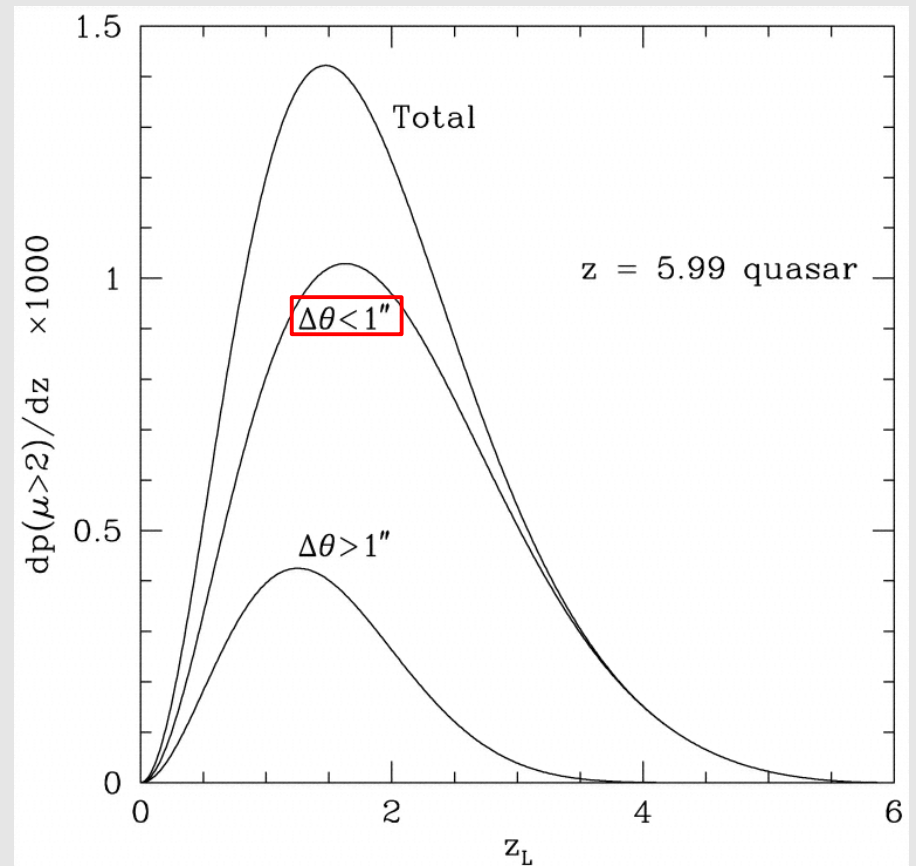
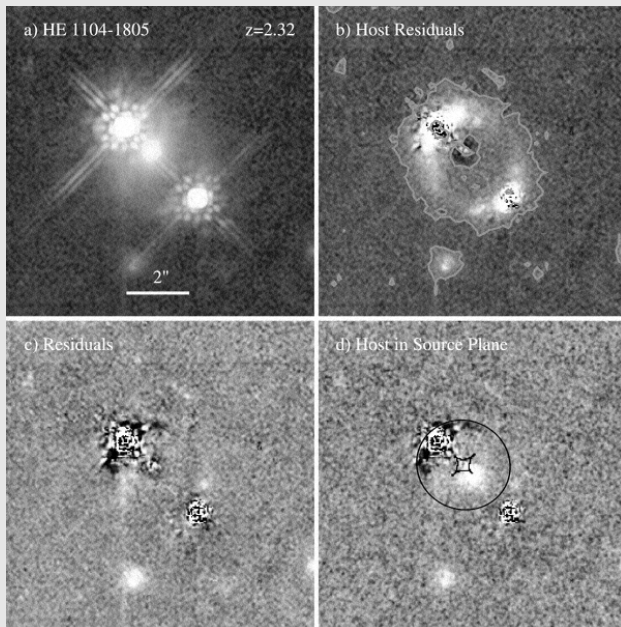


from B. Venemans

Constraints on the $z \sim 6$ QLF from an HST/WFC3 Snapshot Survey

motivation

- HST resolution
- biases (QLF, BH mass, near zones)
- host galaxies



Lensing model

Comerford, Haiman, & Schaye 2002

background lensing rate:

- DM Halo Mass function (Jenkins+01)
- baryonic cooling (Kochanek & White 2001)
- magnification PDF ($dp/d\mu$)

magnification bias (posterior lensed fraction)

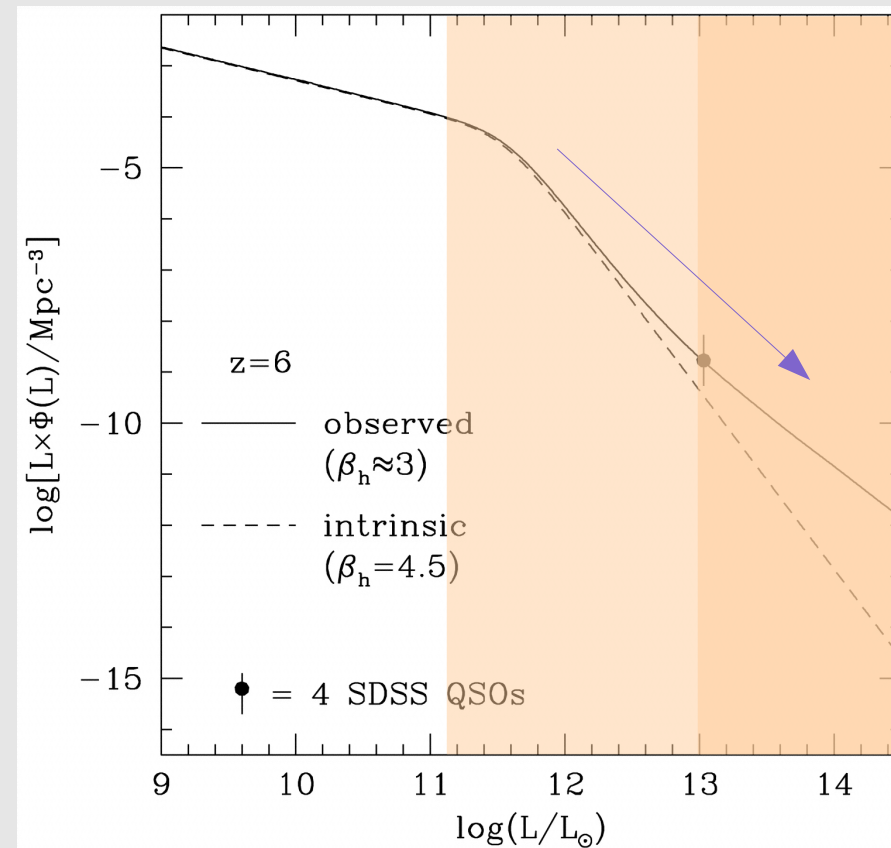
- QLF shape (break luminosity + bright-end slope)

lensing bias on observed QLF

$$\Phi_{\text{int}}(L) = \frac{\Phi_*/L_*}{(L/L_*)^{\beta_l} + (L/L_*)^{\beta_h}} . \quad (6)$$

$$\Phi_{\text{obs}}(L_{\text{obs}}, \mu_{\text{min}}) = \int_{\mu_{\text{min}}}^{\infty} d\mu \frac{dp}{d\mu} \Phi_{\text{int}}\left(\frac{L_{\text{obs}}}{\mu}\right) \frac{1}{\mu} . \quad (2)$$

$$dp/d\mu \propto \mu^{-3}$$

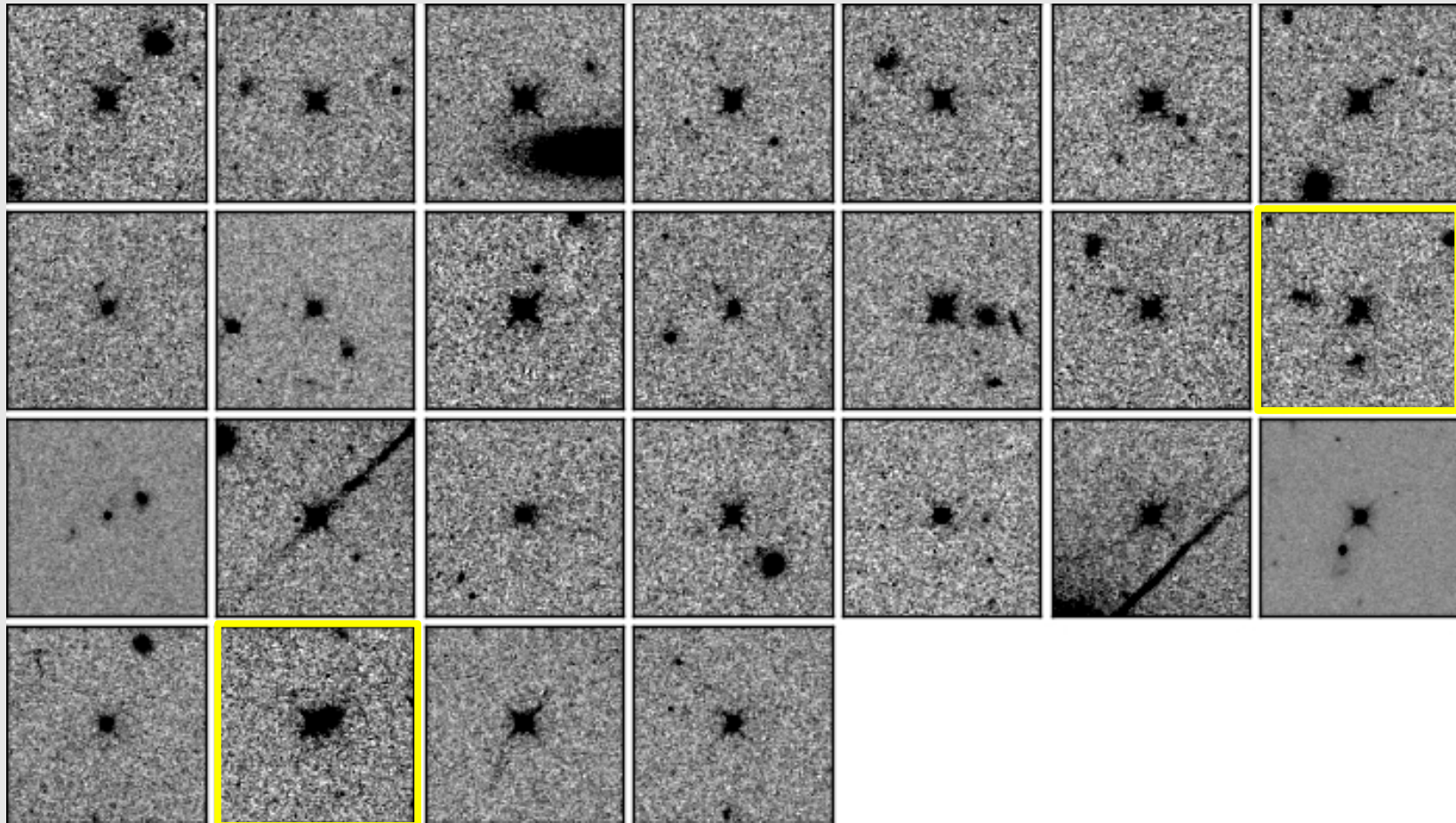


HST Snapshot sample

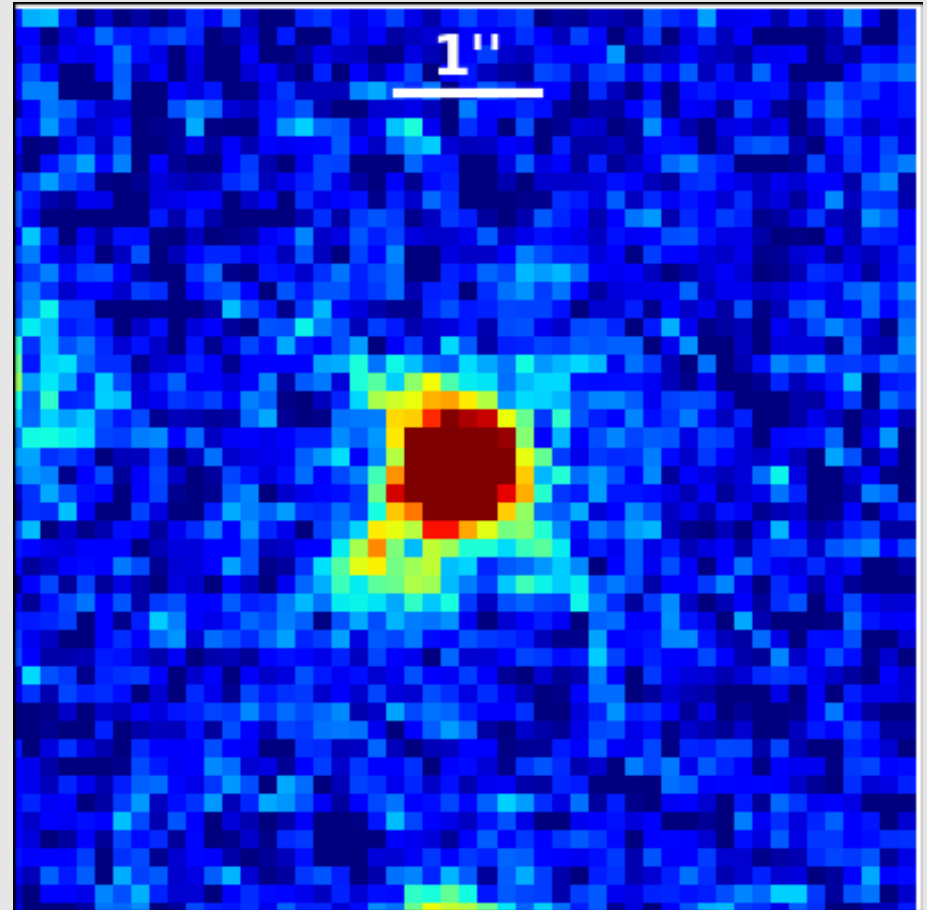
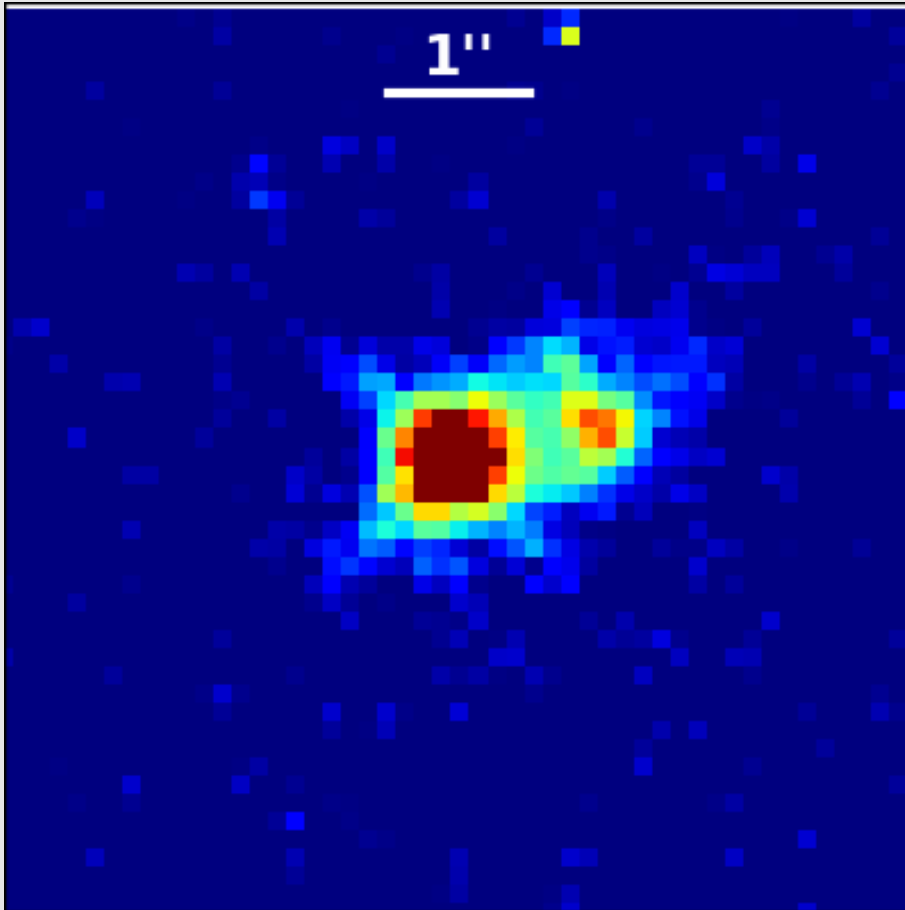
- > 60 quasars known at $z \geq 6$
- Divided into two samples:
 - $z_{AB} < 20.5$ 2x180s
 - $z_{AB} > 20.5$ 3x400s
- 29 observed (+ 8 archival)

Richards+04	ACS/HRC	F850LP	1200 s	4 QSOs
This work	WFC3/IR	F105W	360/1200 s	29 QSOs

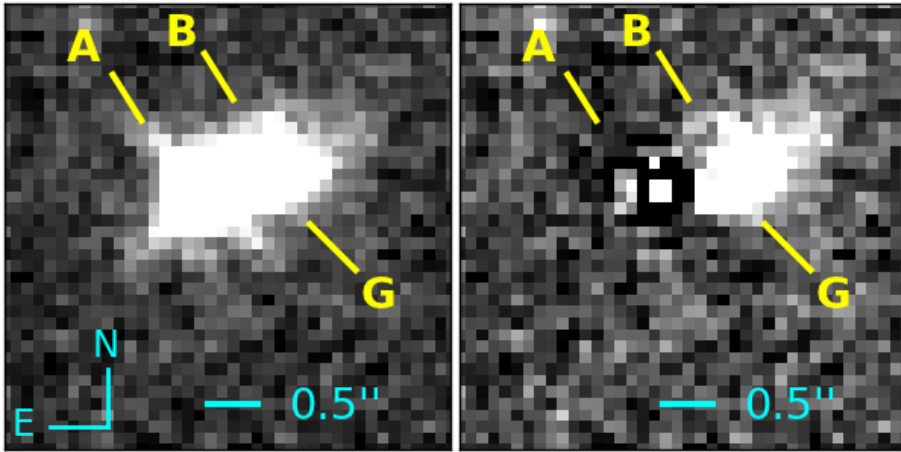
WFC3 Snapshot gallery



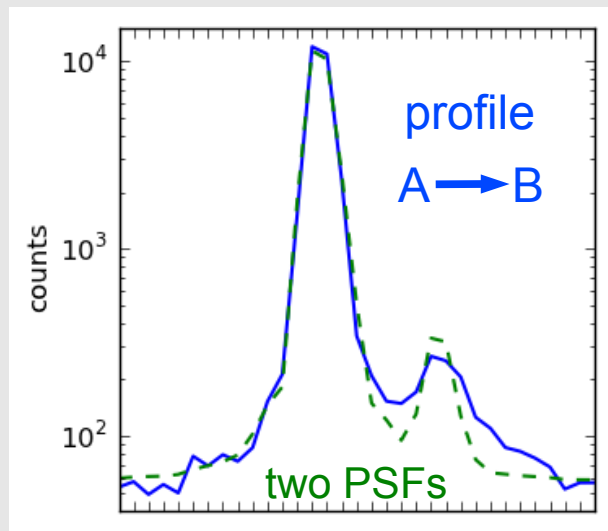
Two candidate lenses



J1602+4228

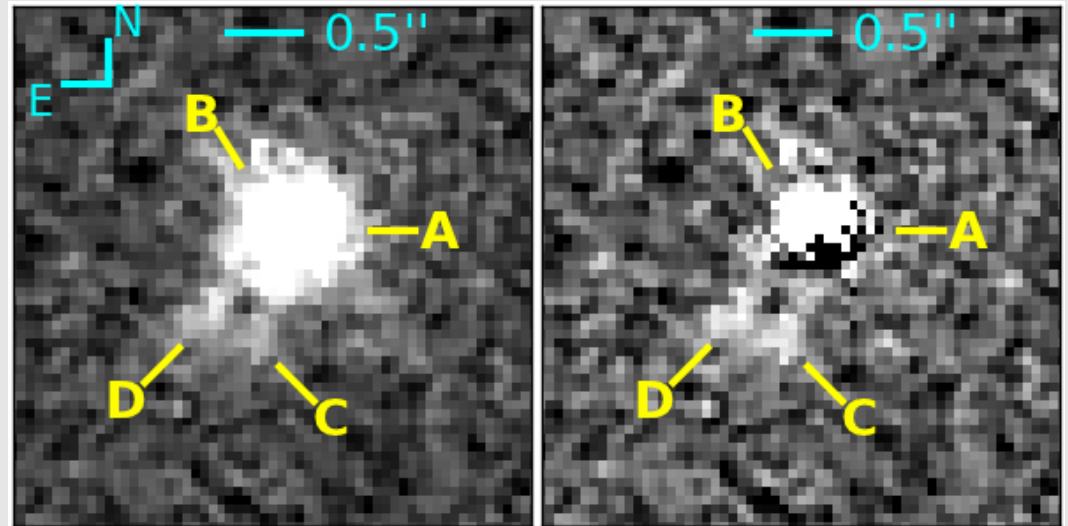


- SDSS (Fan et al. 2004)
- $z = 6.1$
- $z_{AB} = 19.9$
- two image lens + galaxy?
- awaiting confirmation

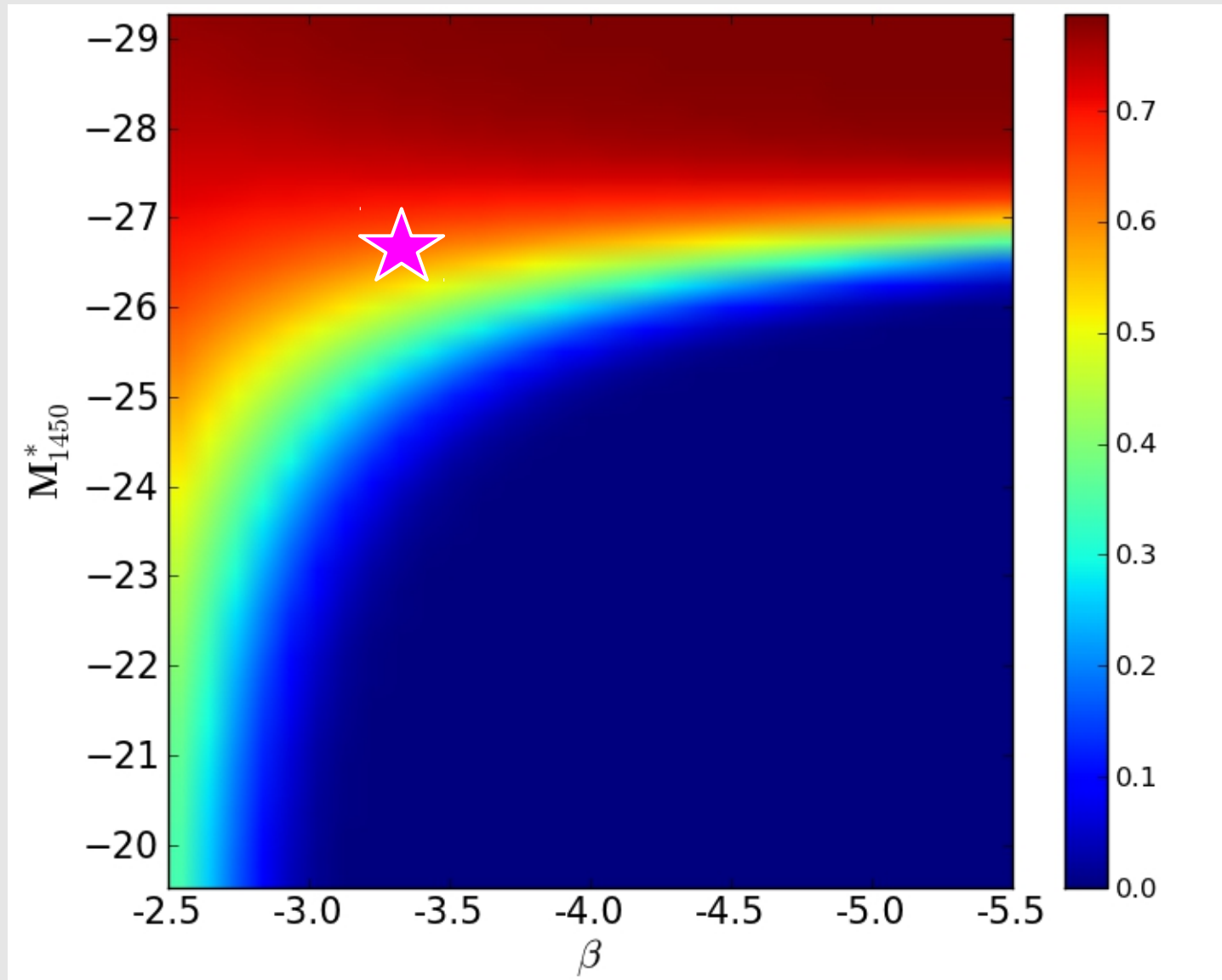


J0050+3445

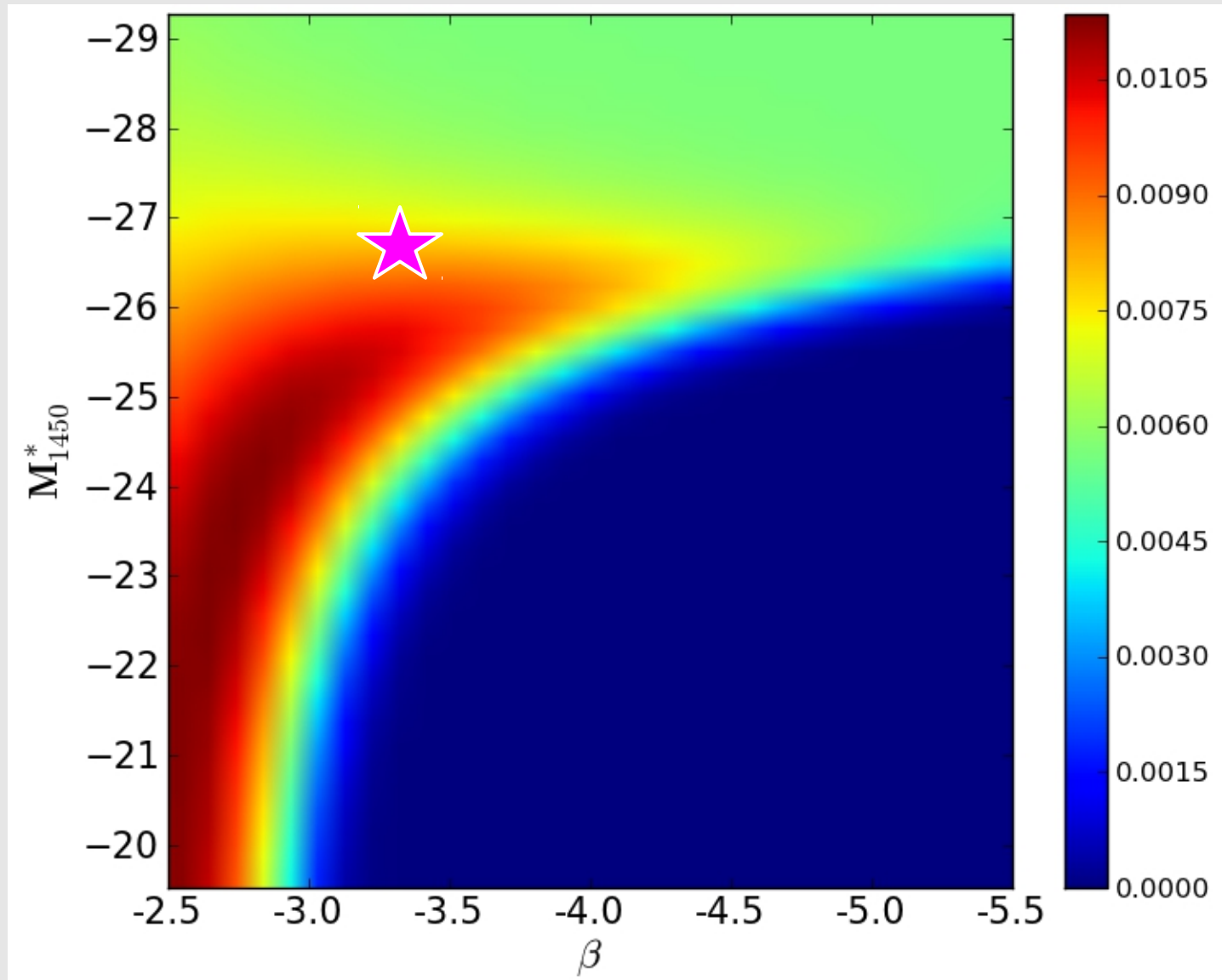
- CFHTQS (Willott et al. 2010)
- $z = 6.25$
- $z_{AB} = 20.5$
- 4 components? 3?
- Cycle 19 obtained
 - 3 orbits ACS-i
 - 2 orbits WFC3-Y



QLF constraints from 0 lenses

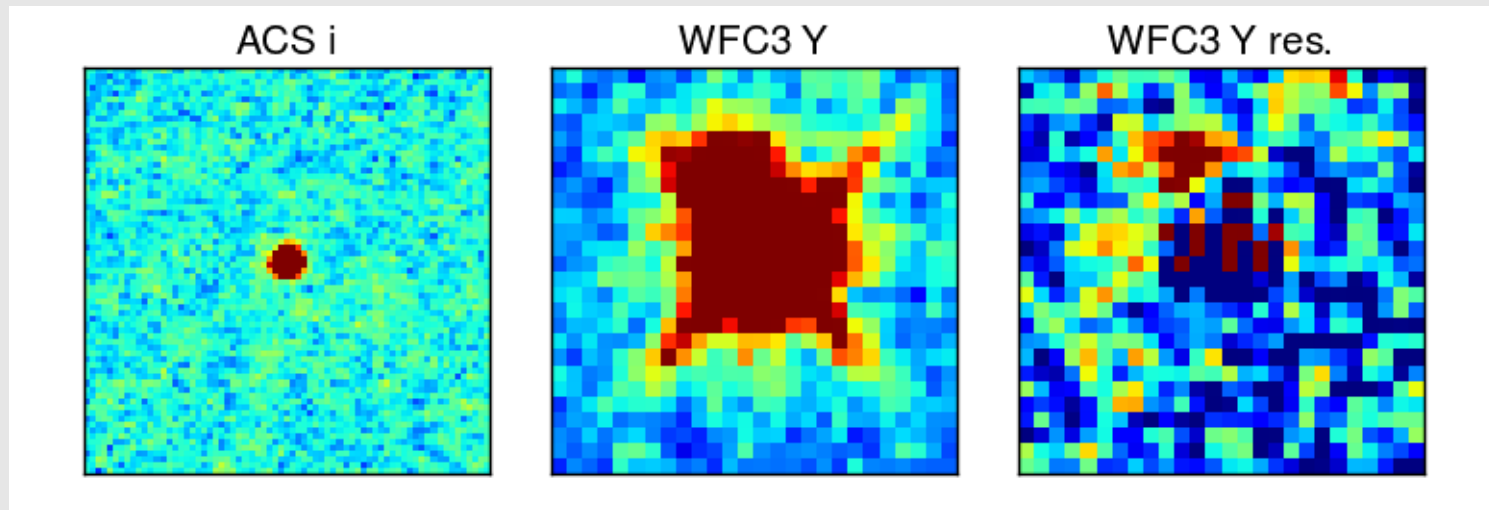


QLF constraints from 1 lens



aside on quasar fueling

J0050: ACS/i + WFC3/Y deep imaging



companion has F105W ~ 24.5 (i-dropout)

separation ~ 5 kpc

another close neighbor (from Stripe 82)

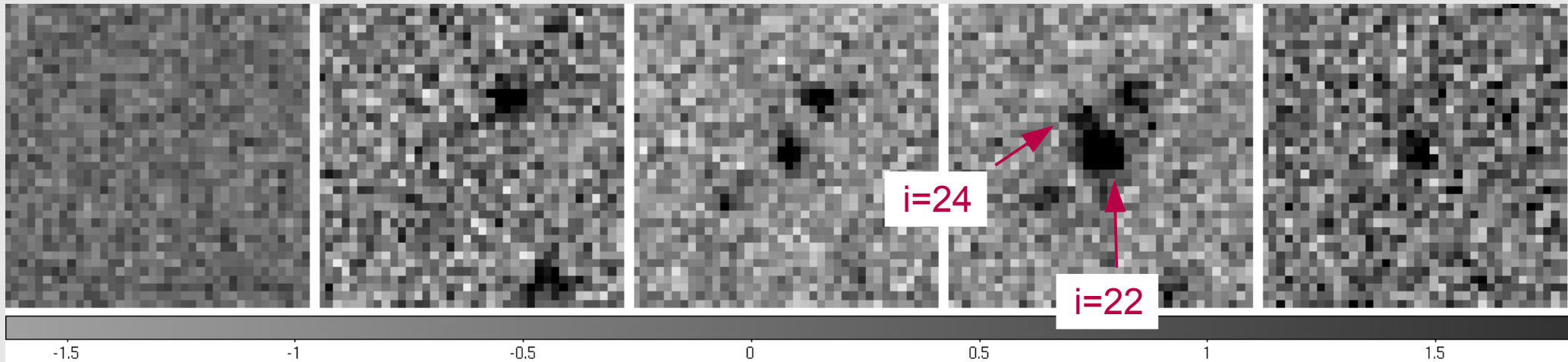
u

g

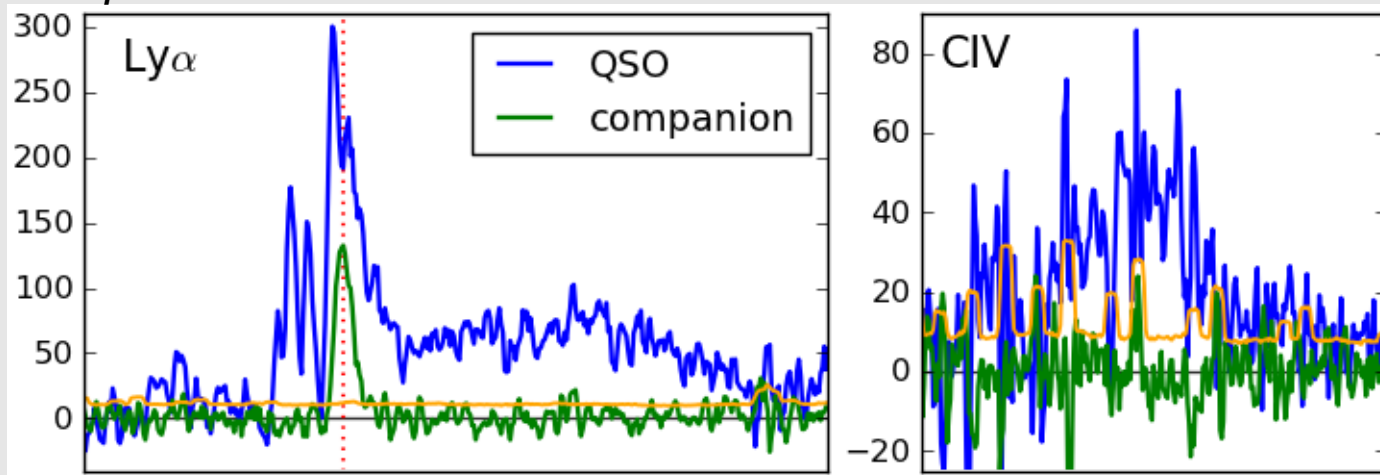
r

i

z



spectrum from LBT MODS



infalling?

separation ~ 12 kpc

FWHM(QSO) ~ 1200 km/s
companion ~ 350 km/s

$L(\text{Ly}\alpha) \sim 10^{44}$ erg/s

Summary

- PLE to LEDE transition at $z \sim 2$
- strong evolution in break luminosity
- weak bright end slope evolution
- low lensing rate at $z \sim 6$ also consistent with high break luminosity
- evidence for accelerated density evolution at $z > 6$