Measurement of the B-band Galaxy Luminosity function with Approximate Bayesian Computation

arXiv: 2001.07727

Luca Tortorelli

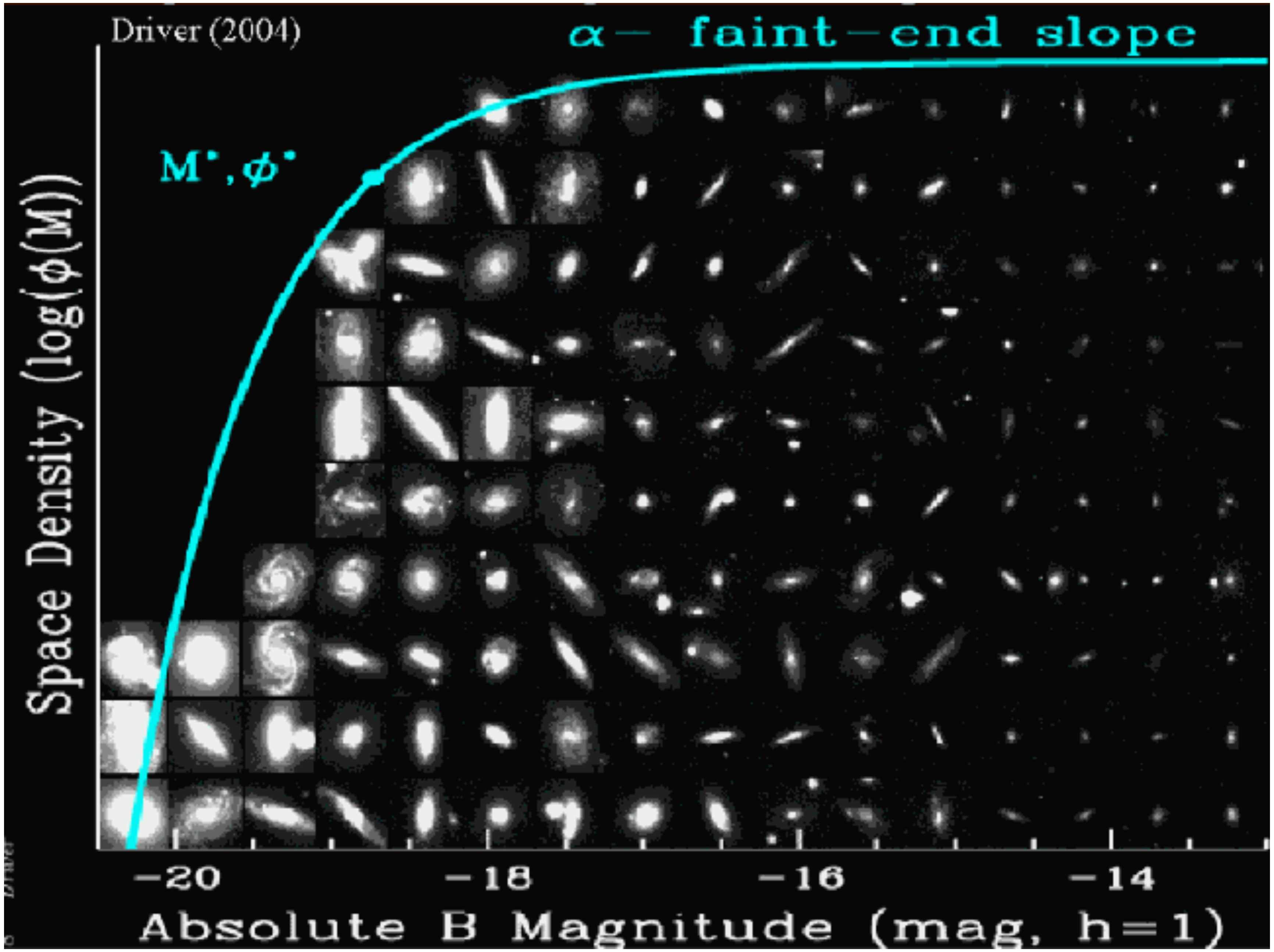
&

Martina Fagioli, Jörg Herbel, Adam Amara, Tomasz Kacprzak, Alexandre Refregier

IPA

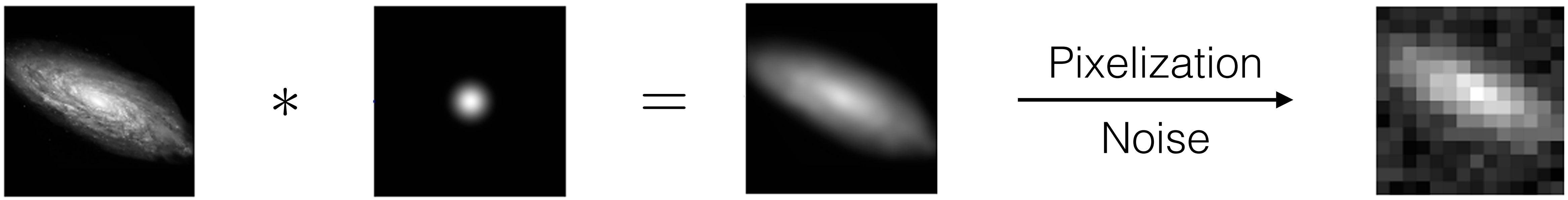
ETH zürich

The Galaxy Luminosity function

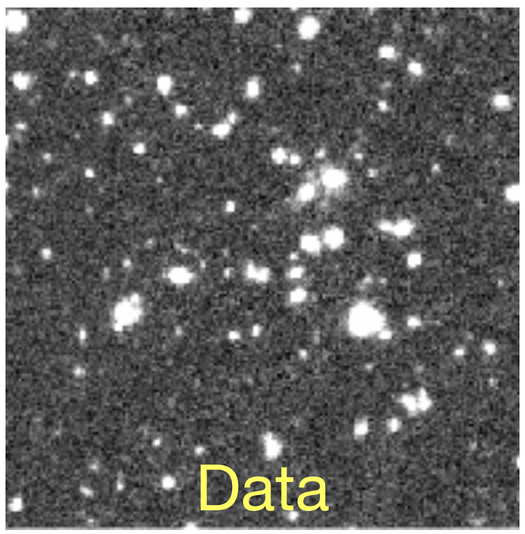


$\Phi(\mathrm{M}, \mathrm{z}) = $ Number of galaxies per unit volume per unit magnitude at redshift z

What is the Forward Modeling approach?



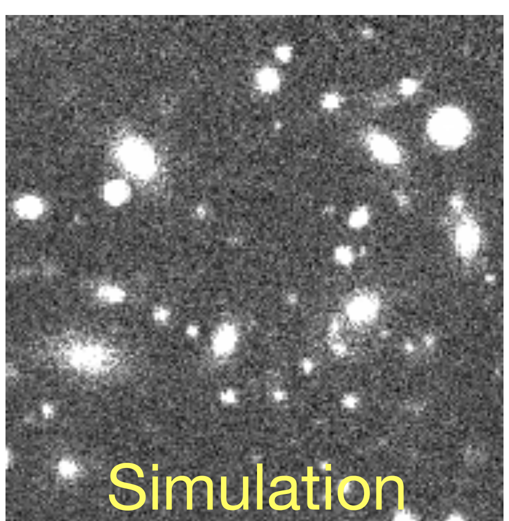
Bridle et al. 2009



Analysis → Selection cuts

Target sample

	Mag	Size	...
Obj 1	...	...	...
Obj 2	...	...	...
Obj 3	...	...	...
...	...	...	...



Analysis → Selection cuts

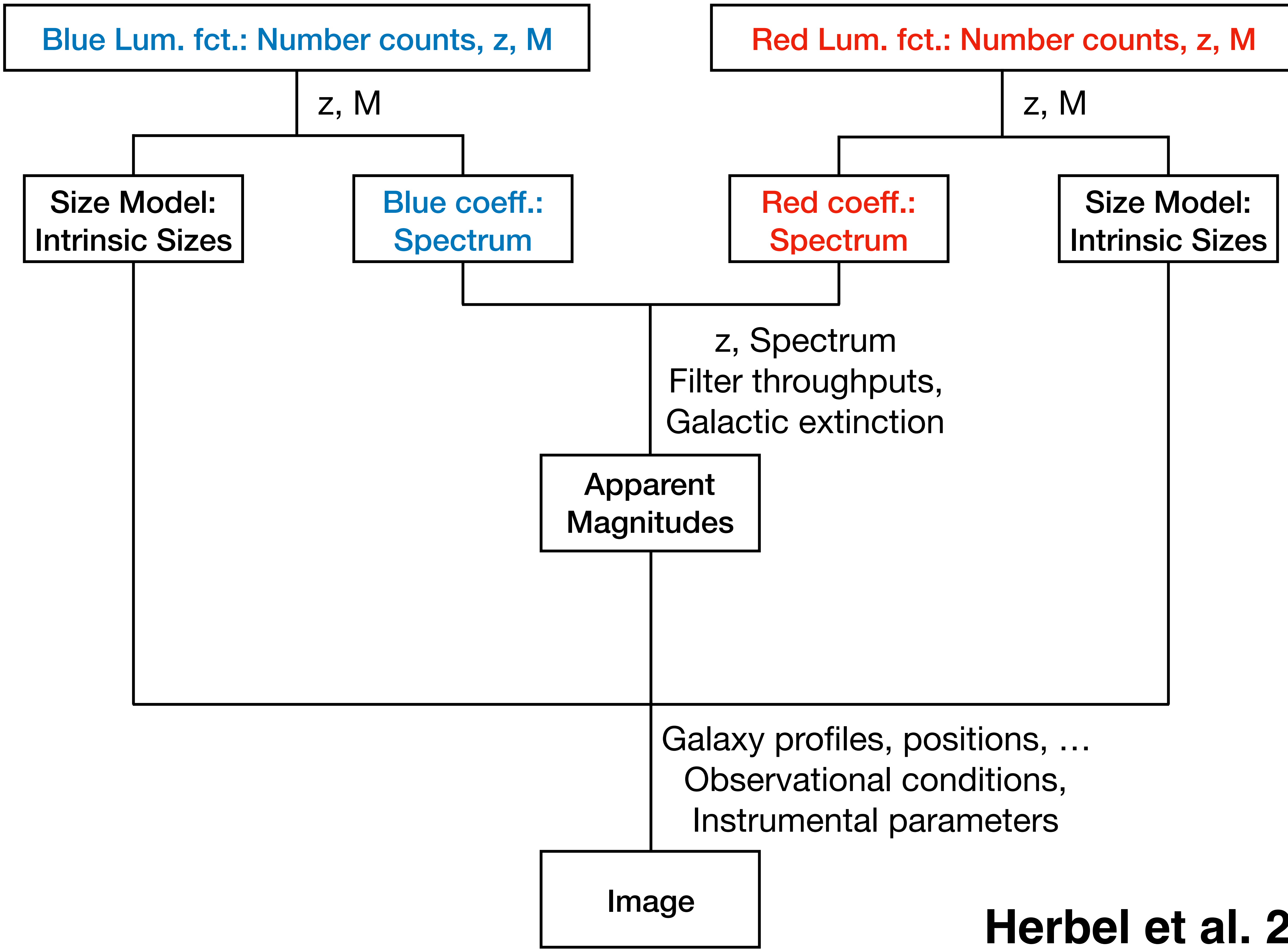
Simulated target sample

	Mag	Size	...
Obj 1	...	...	...
Obj 2	...	...	...
Obj 3	...	...	...
...	...	...	...

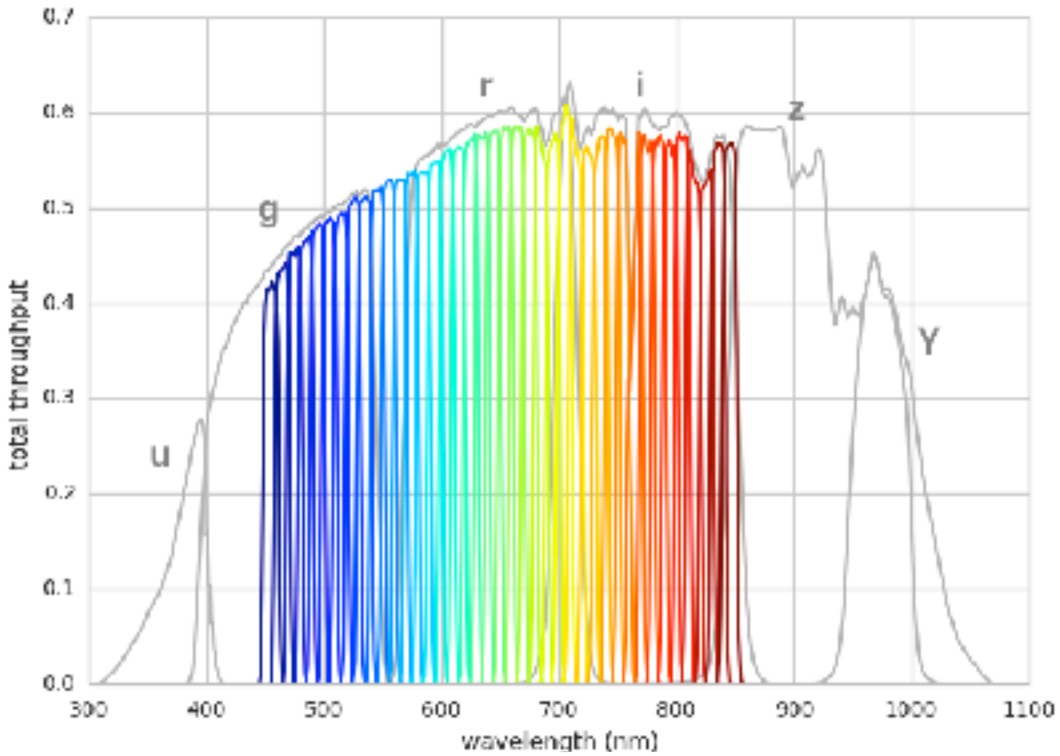
	z	...
Obj 1	...	...
Obj 2	...	...
Obj 3	...	...
...	...	...

Credits: Jörg Herbel

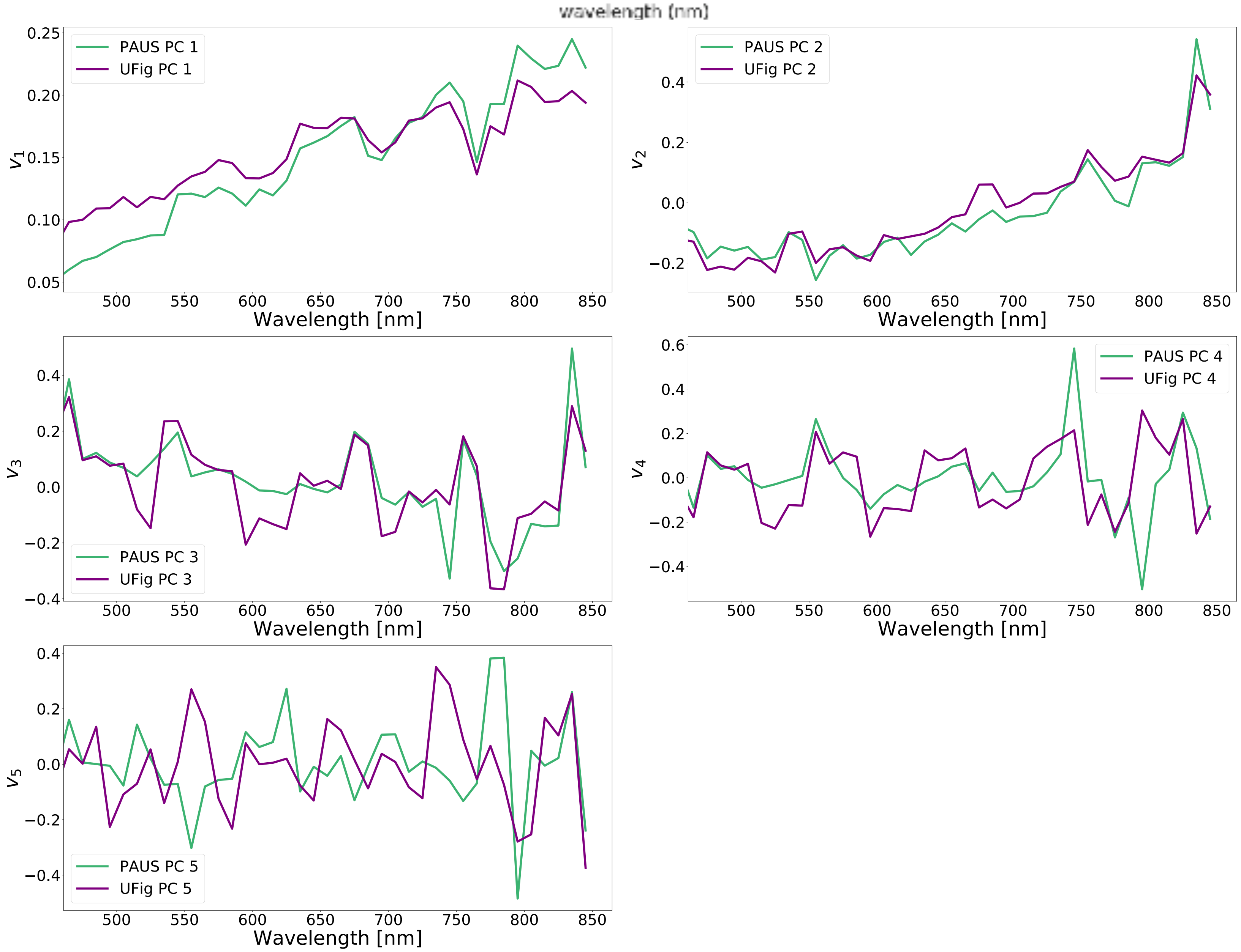
Galaxy population model in UFig

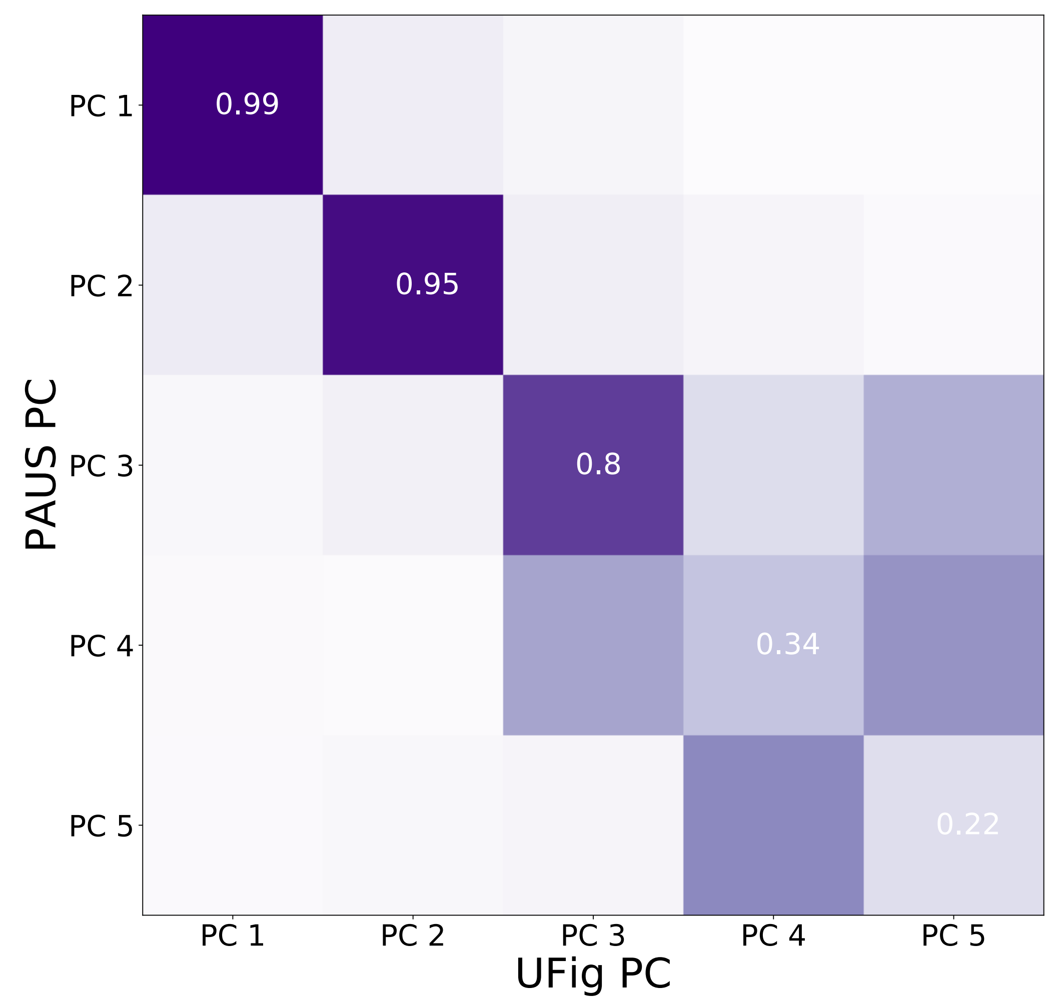


Herbel et al. 2017



Tortorelli et al. 2018





The ABC inference scheme

Calibration, but no likelihood for Bayesian Analysis

↓

Approximate Bayesian Computation (ABC).

$$p\left(\theta|y\right) \simeq p\left(\theta|\rho\left(x,y\right) \leq \epsilon\right)$$

ABC algorithm

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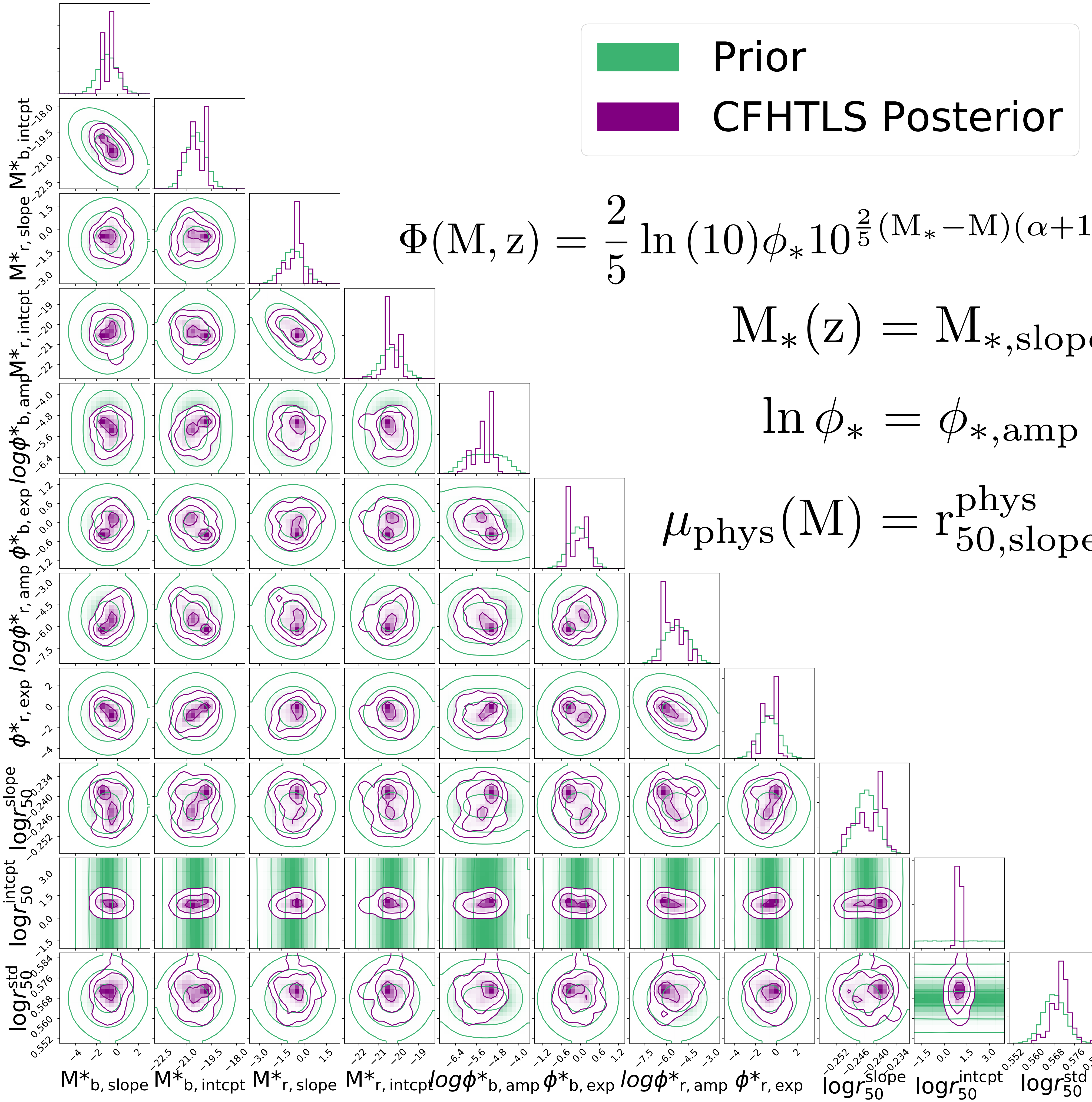
while $(\mathrm{p_{acc}} > \mathrm{p_{acc,min}})$ **do:**
  if T = 1 do:
    for i = 1 to N do:
      Sample $\theta^{*}_{\mathrm{i,T=1}}$ from pre-defined prior: $\theta^{*}_{\mathrm{i,T=1}} \sim \mathrm{p}(\theta)$
      Create dataset x from $\theta^{*}_{\mathrm{i,T=1}}$: $x \sim Model(\theta^{*}_{\mathrm{i,T=1}})$
      Set $\theta_{\mathrm{i,T=1}} = \theta^{*}_{\mathrm{i,T=1}}$
      Set $\rho_{\mathrm{i,T=1}} = \rho_{\mathrm{i,T=1}}(x,y)$
    end for
  else do:
    for i = 1 to N$'$ do:
      Sample $\theta^{*}_{\mathrm{i,T}}$ from $\mathrm{GMM}(\theta_{\mathrm{T-1}})$
      Create dataset x from $\theta^{*}_{\mathrm{i,T}}$: $x \sim Model(\theta^{*}_{\mathrm{i,T}})$
      Set $\theta_{\mathrm{i,T}} = \theta^{*}_{\mathrm{i,T}}$
      Set $\rho_{\mathrm{i,T}} = \rho_{\mathrm{i,T}}(x,y)$
    end for
    Set $\mathrm{p_{acc}} = \frac{1}{\mathrm{N'}} \sum_{\mathrm{k=1}}^{\mathrm{N'}} \mathbb{I}_{\rho_{\mathrm{i,T}} < \epsilon_{\mathrm{T-1}}}$
  Let $\epsilon_{\mathrm{T}} = \mathrm{Q}_{\rho^{(\mathrm{T})}}(\mathrm{q})$ the q-th percentile value of $\rho^{(\mathrm{T})}$, where $\rho^{(\mathrm{T})} = \{\rho_{\mathrm{i,T}}\}_{\mathrm{i=1,\dots,N'}}$
  Let $\{(\theta^{(\mathrm{T})}_{\mathrm{i}}, \rho^{(\mathrm{T})}_{\mathrm{i}})\} = \{(\theta_{\mathrm{i,T}}, \rho_{\mathrm{i,T}}) | \rho_{\mathrm{i,T}} \leq \epsilon_{\mathrm{T}}, \mathrm{i} = 1, \dots, \mathrm{N_{q,T}}\}$

Prior and Distance metrics

Parameter	Distribution	Prior
α (blue)	Fixed value	-1.3
α (red)	Fixed value	-0.5
$M^*_{B,slope}$ (blue)	Multivariate Normal	$\mu = -9.44 \times 10^{-1}$, $\sigma^2 = 8.29 \times 10^{-1}$
$M^*_{B,slope}$ (red)	Multivariate Normal	$\mu = -7.33 \times 10^{-1}$, $\sigma^2 = 5.30 \times 10^{-1}$
$M^*_{B,intcpt} - 5 \log h_{70}$ (blue)	Multivariate Normal	$\mu = -2.041 \times 10^{1}$, $\sigma^2 = 3.312 \times 10^{-1}$
$M^*_{B,intcpt} - 5 \log h_{70}$ (red)	Multivariate Normal	$\mu = -2.035 \times 10^{-1}$, $\sigma^2 = 2.968 \times 10^{-1}$
ϕ^*_{exp} (blue)	Multivariate Normal	$\mu = -5.66 \times 10^{-2}$, $\sigma^2 = 9.96 \times 10^{-2}$
ϕ^*_{exp} (red)	Multivariate Normal	$\mu = -6.97 \times 10^{-1}$, $\sigma^2 = 9.21 \times 10^{-1}$
$\ln \phi^*_{amp}$ / 10^{-3} h^3_{70} Mpc^{-3} mag^{-1} (blue)	Multivariate Normal	$\mu = -5.28 \times 10^{0}$, $\sigma^2 = 4.1 \times 10^{-1}$
$\ln \phi^*_{amp}$ / 10^{-3} h^3_{70} Mpc^{-3} mag^{-1} (red)	Multivariate Normal	$\mu = -5.28 \times 10^{0}$, $\sigma^2 = 6.5 \times 10^{-1}$
$r^{phys}_{50,slope}$	Multivariate Normal	$\mu = -2.4 \times 10^{-1}$, $\sigma^2 = 9.8 \times 10^{-6}$
$r^{phys}_{50,intcpt}$	Uniform	[-2, 4]
σ_{phys}	Multivariate Normal	$\mu = 5.7 \times 10^{-1}$, $\sigma^2 = 1.9 \times 10^{-5}$
$a_{i,0}$	Dirichlet $\times$ Uniform	[1., 1., 1., 1., 1.] $\times$ [5, 15]
$a_{i,1}$	Dirichlet $\times$ Uniform	[1., 1., 1., 1., 1.] $\times$ [5, 15]

Distance Metric	Label
Absolute difference in the number of detected galaxies	d_1
Random Forest distance with 21 summary statistics	d_2
Random Forest distance with 31 summary statistics	d_3
Maximum Mean Discrepancy distance on u^*, g', r', i', z' band properties	$d_{4,\ldots,7}$
Maximum Mean Discrepancy distance on u^*, g', i' band properties	$d_{8,\ldots,11}$
Maximum Mean Discrepancy distance on i' band magnitudes and redshift distributions	d_{12}
Magnitude histogram distance on u^*, g', r', i', z' bands separately	$d_{\{13,\ldots,17\}}$
Size histogram distance on u^*, g', r', i', z'bands separately	$d_{\{18,\ldots,22\}}$
Maximum value among all previously defined rescaled distances	$d_{23} = \max(\underline{d}_{\{1,\ldots,22\}})$
Maximum value between the rescaled MMD distance on 5 bands and the rescaled absolute difference	$d_{24,\ldots,27} = \max(\underline{d}_1, \underline{d}_{4,\ldots,7})$
Maximum value among the rescaled MMD distance and the rescaled magnitude histogram distance on 5 bands	$d_{28,\ldots,31} = \max(\underline{d}_{4,\ldots,7}, \underline{d}_{\{13,\ldots,17\}})$



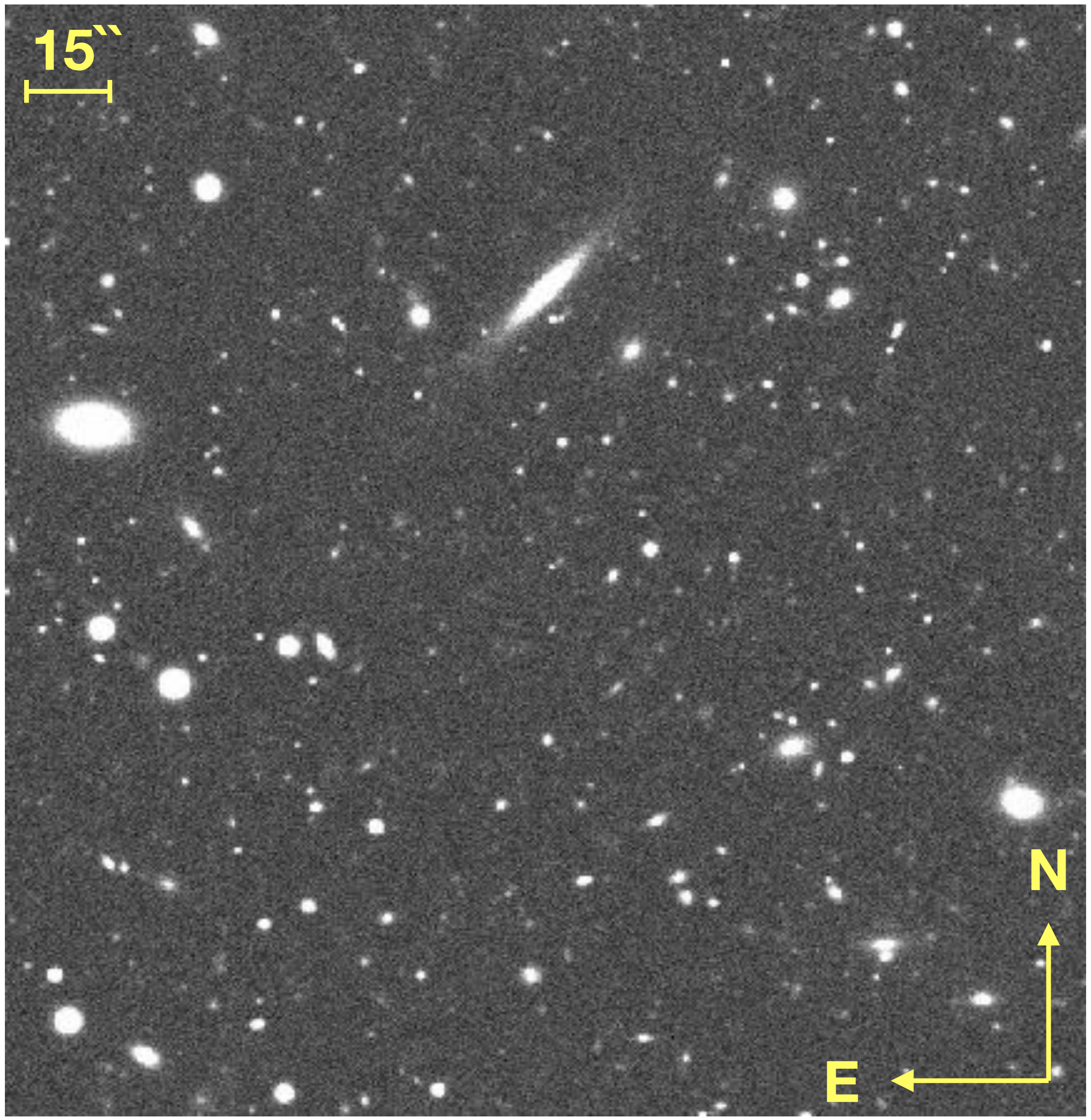
$$\Phi(\mathrm{M},\mathrm{z}) = \frac{2}{5}\ln(10)\phi_* 10^{\frac{2}{5}(\mathrm{M}_*-\mathrm{M})(\alpha+1)} \exp\left[-10^{\frac{2}{5}(\mathrm{M}_*-\mathrm{M})}\right]$$

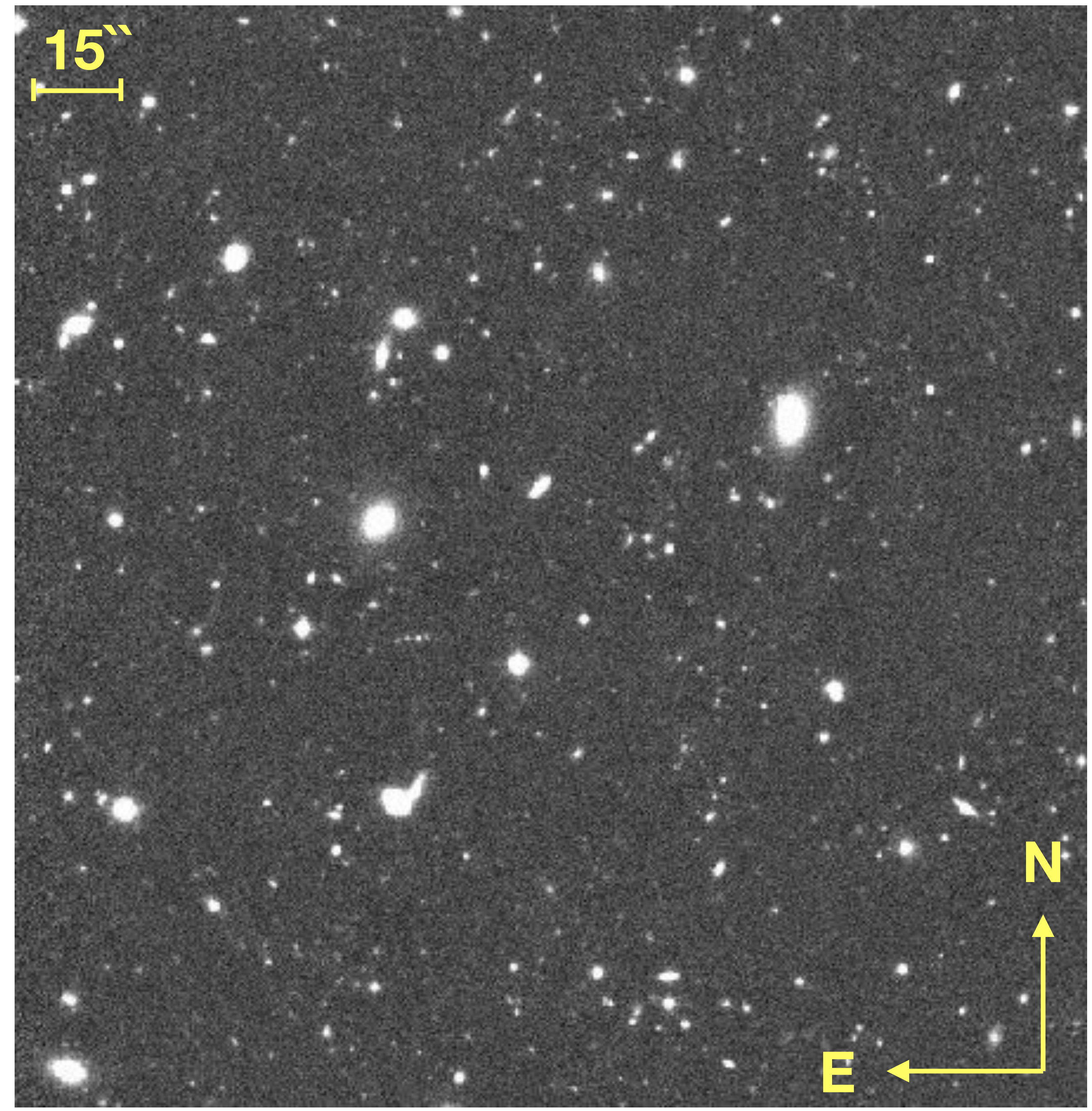
$$\mathrm{M}_*(\mathrm{z}) = \mathrm{M}_{*,\mathrm{slope}}\mathrm{z} + \mathrm{M}_{*,\mathrm{intcpt}}$$

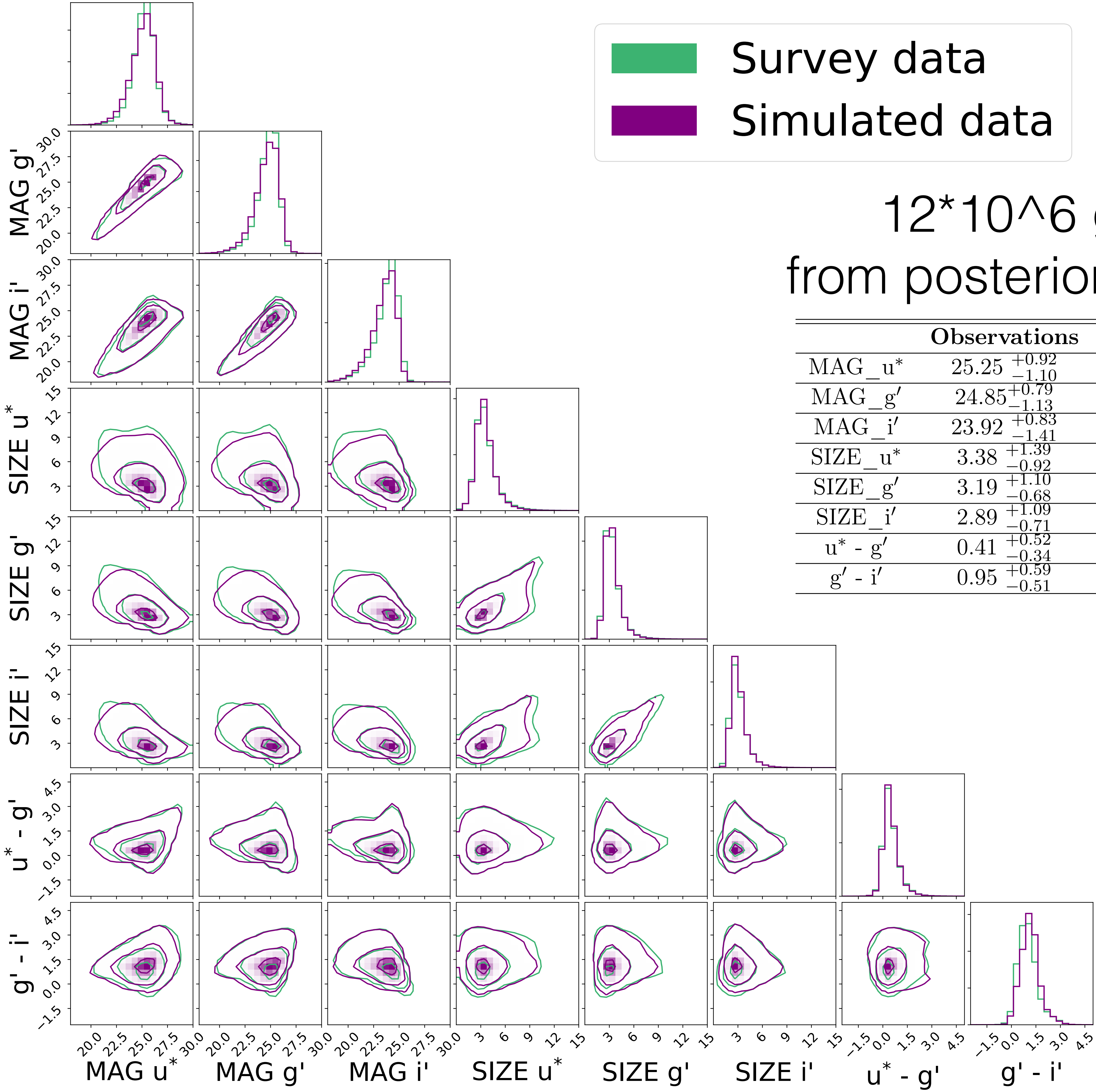
$$\ln\phi_* = \phi_{*,\mathrm{amp}} + \phi_{*,\mathrm{exp}}\ \mathrm{z}$$

$$\mu_{\mathrm{phys}}(\mathrm{M}) = \mathrm{r}^{\mathrm{phys}}_{50,\mathrm{slope}}\mathrm{M} + \mathrm{r}^{\mathrm{phys}}_{50,\mathrm{intcpt}}$$

Example images

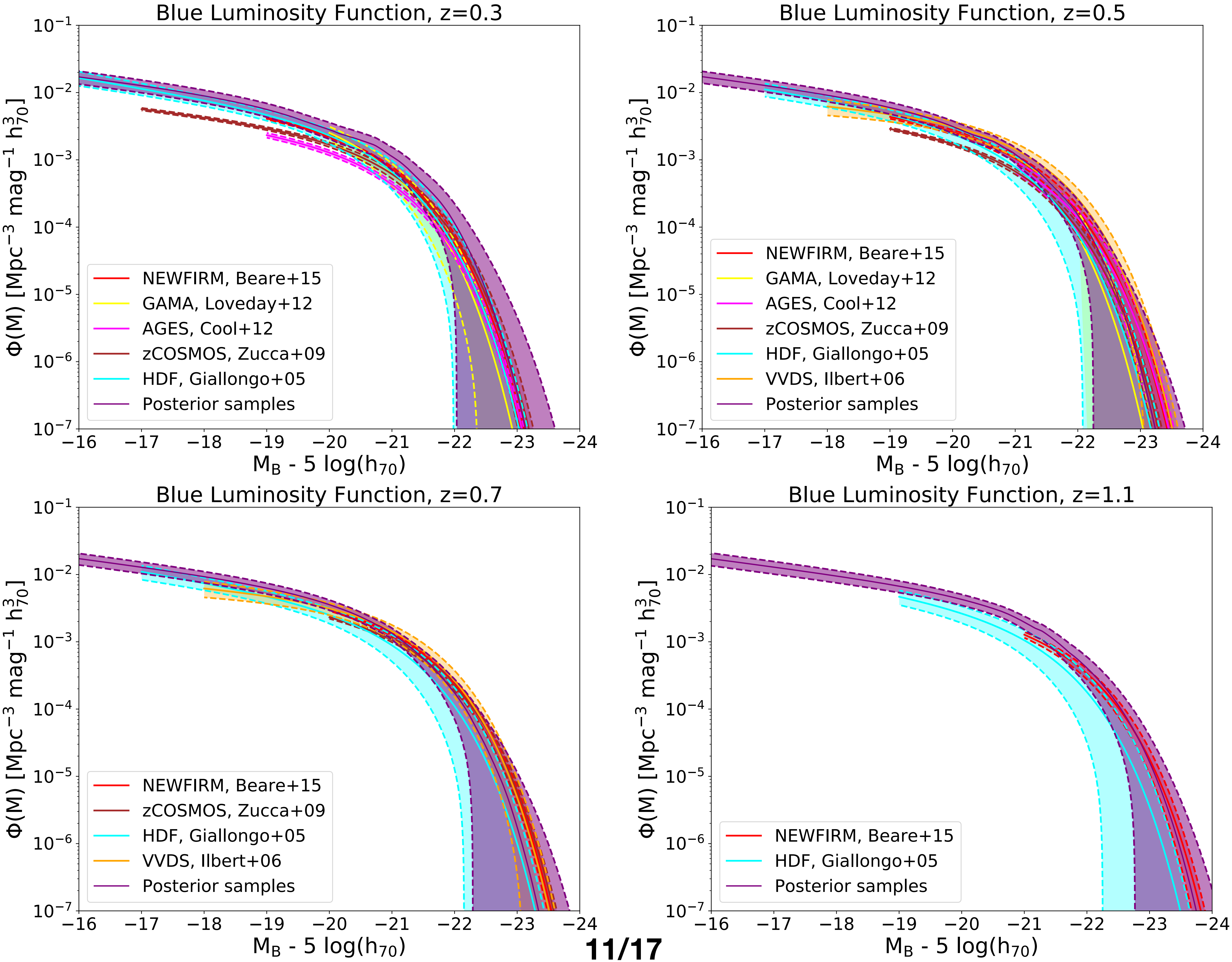




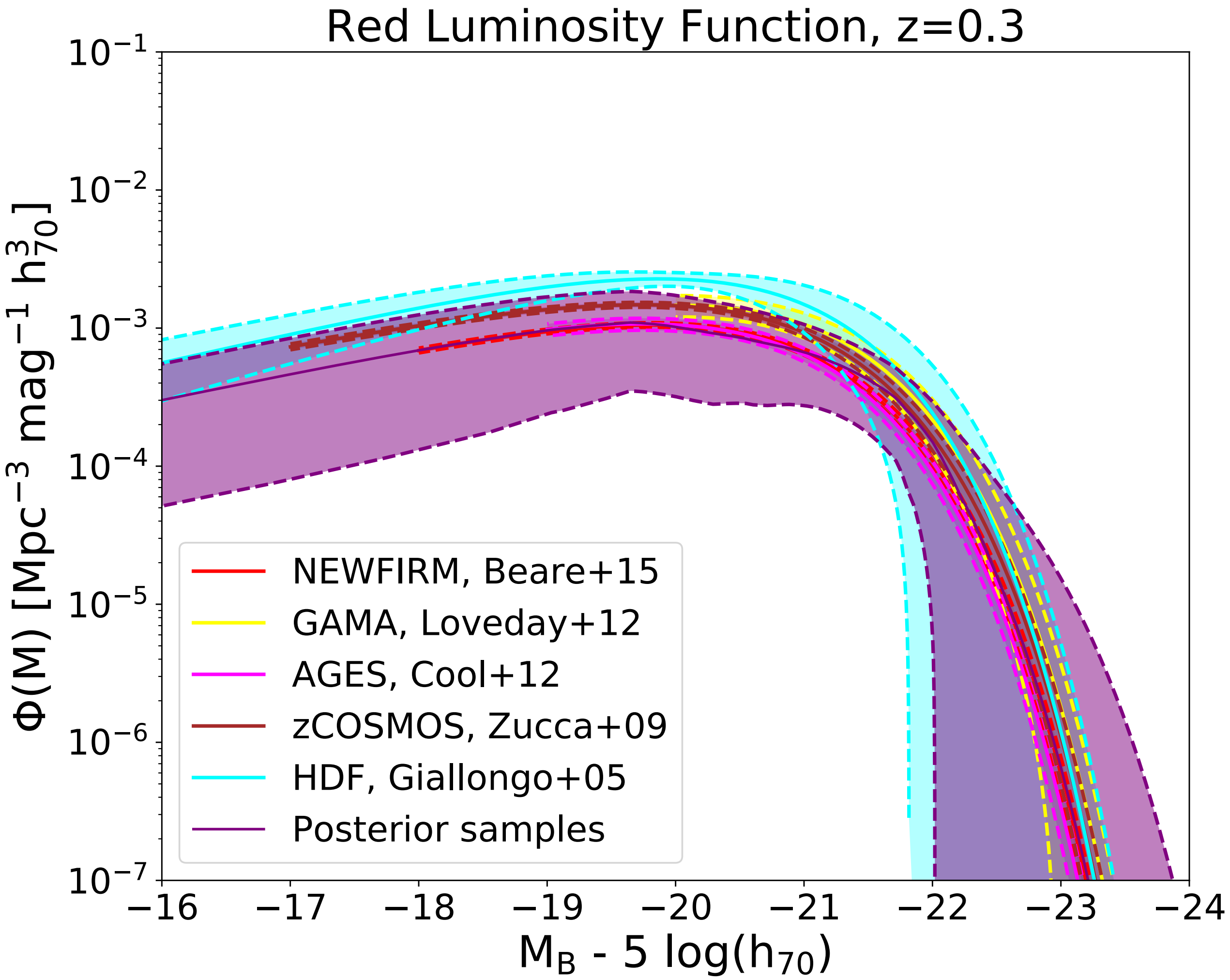


12*10^6 galaxies from posterior distribution

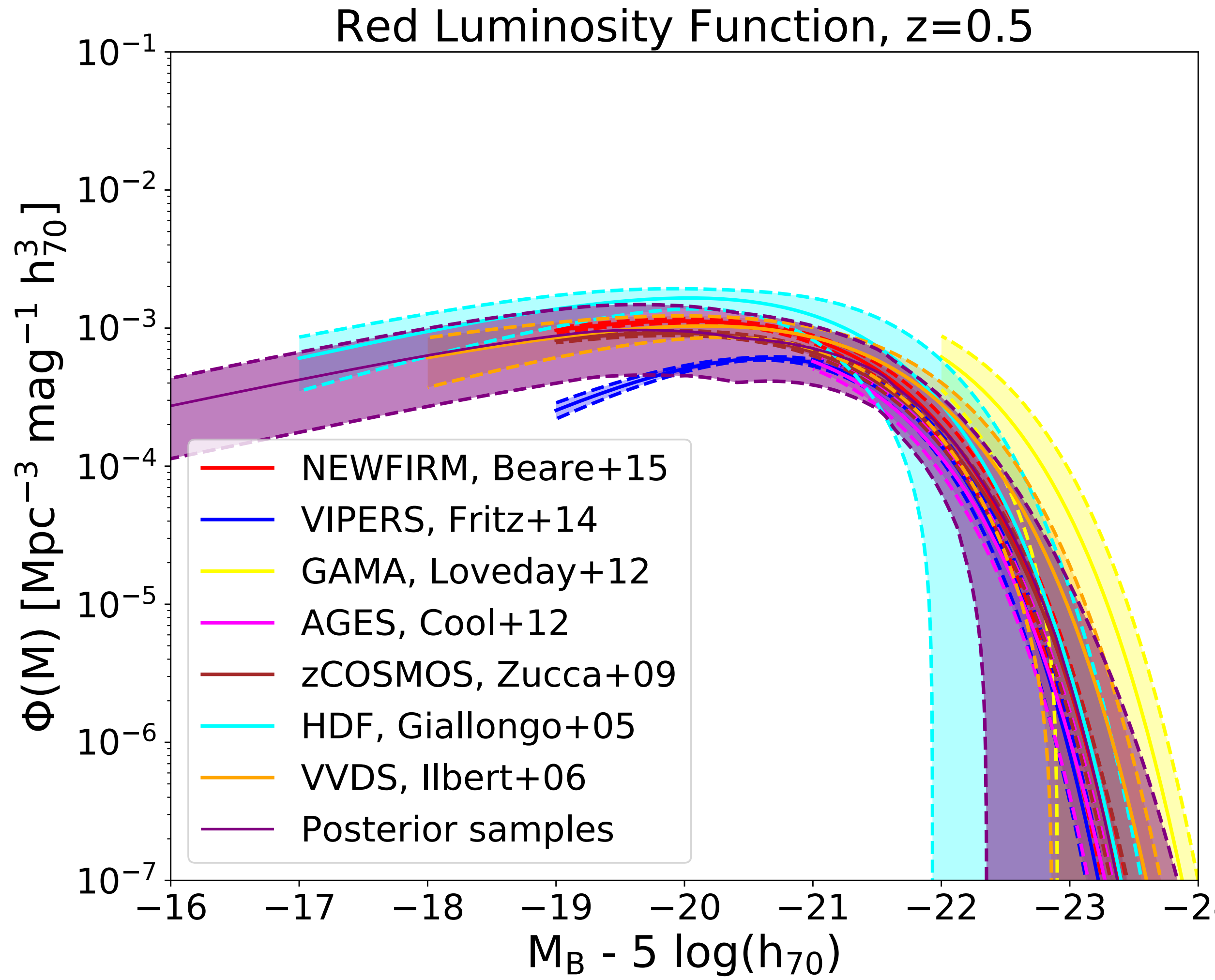
	Observations	Posterior simulations
MAG_u*	$25.25^{+0.92}_{-1.10}$	$25.21^{+1.02}_{-1.34}$
MAG_g′	$24.85^{+0.79}_{-1.13}$	$24.75^{+0.95}_{-1.34}$
MAG_i′	$23.92^{+0.83}_{-1.41}$	$23.66^{+0.91}_{-1.44}$
SIZE_u*	$3.38^{+1.39}_{-0.92}$	$3.40^{+1.23}_{-0.89}$
SIZE_g′	$3.19^{+1.10}_{-0.68}$	$3.23^{+1.01}_{-0.67}$
SIZE_i′	$2.89^{+1.09}_{-0.71}$	$2.94^{+1.02}_{-0.64}$
u* - g′	$0.41^{+0.52}_{-0.34}$	$0.42^{+0.49}_{-0.32}$
g′ - i′	$0.95^{+0.59}_{-0.51}$	$1.12^{+0.53}_{-0.53}$



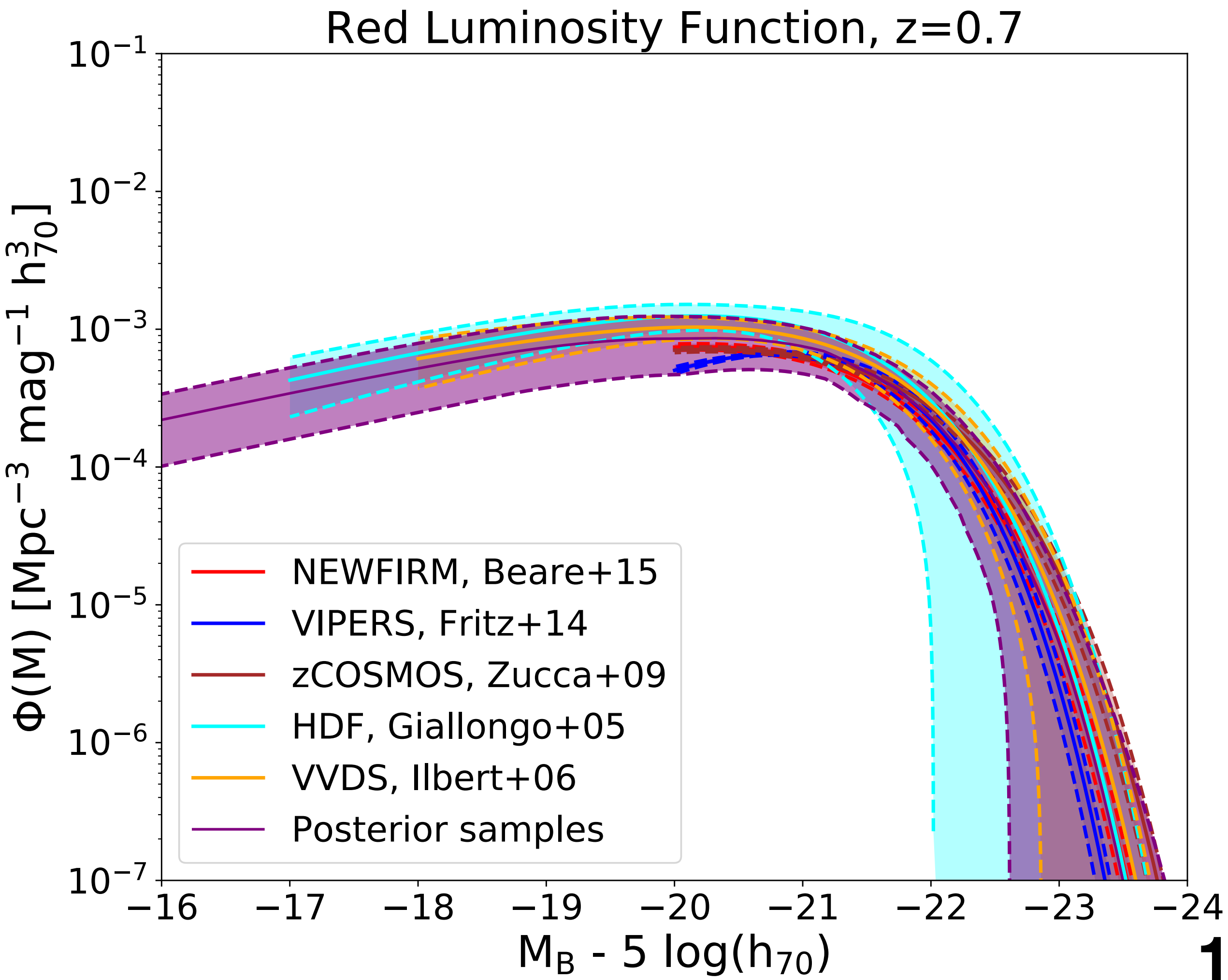
Blue Luminosity Function, z=0.3
Blue Luminosity Function, z=0.5
Blue Luminosity Function, z=0.7
Blue Luminosity Function, z=1.1
$\Phi(M)$ [Mpc^{-3} mag^{-1} h_{70}^{3}]
M_B - 5 log(h_{70})
NEWFIRM, Beare+15
GAMA, Loveday+12
AGES, Cool+12
zCOSMOS, Zucca+09
HDF, Giallongo+05
VVDS, Ilbert+06
Posterior samples



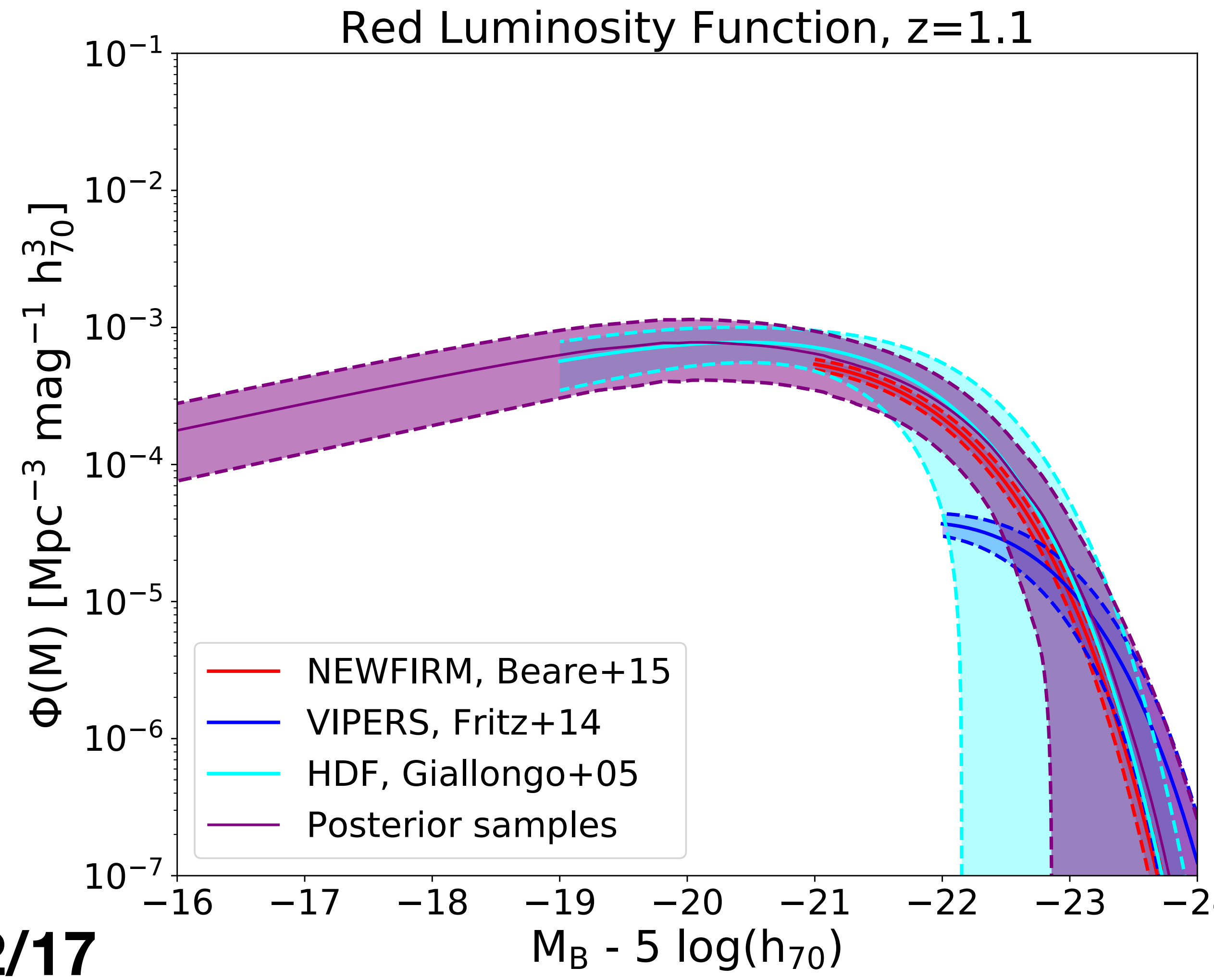
Red Luminosity Function, z=0.3
Φ(M) [Mpc⁻³ mag⁻¹ h³₇₀]
M_B - 5 log(h₇₀)
NEWFIRM, Beare+15
GAMA, Loveday+12
AGES, Cool+12
zCOSMOS, Zucca+09
HDF, Giallongo+05
Posterior samples



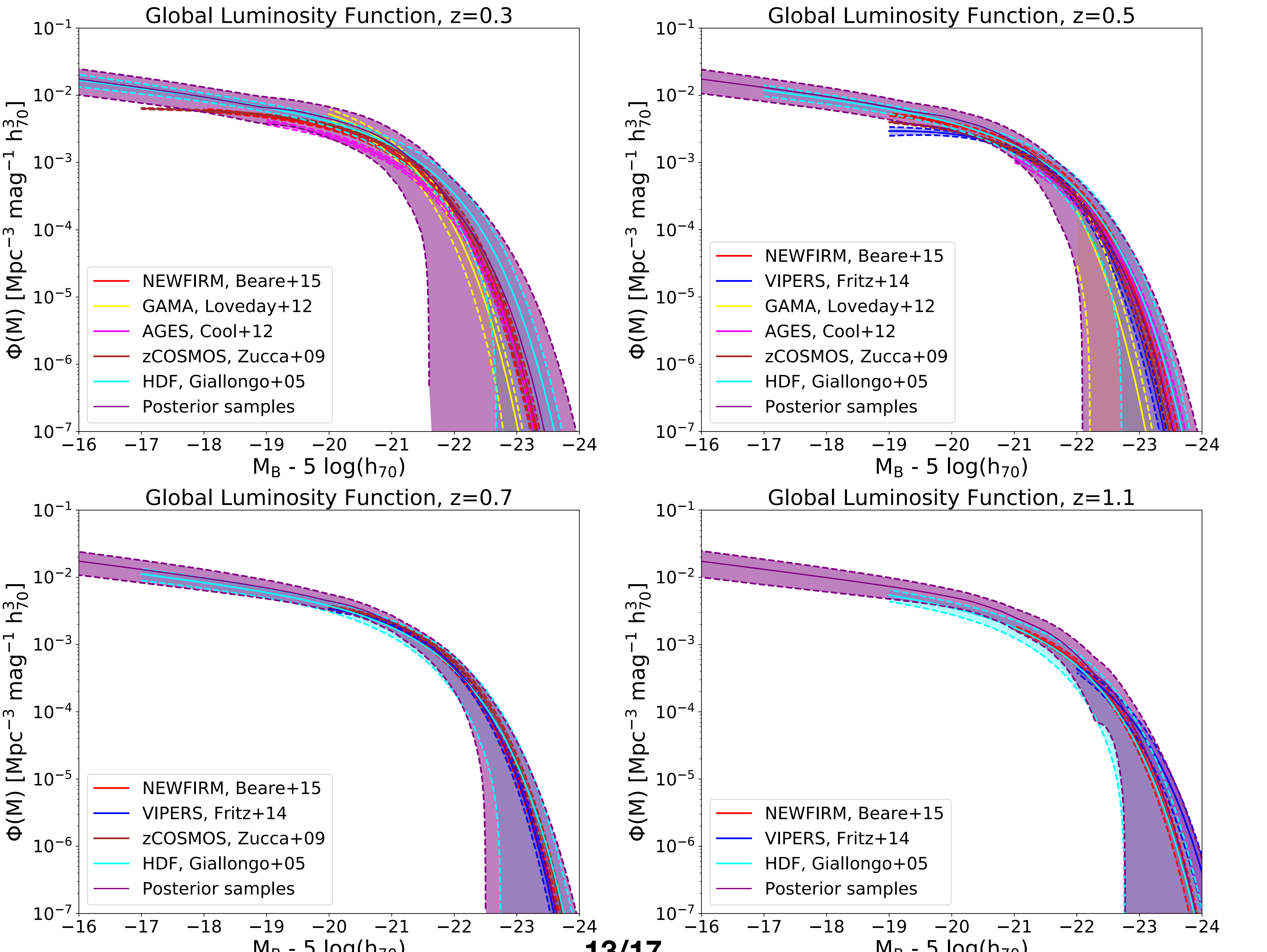
Red Luminosity Function, z=0.5
Φ(M) [Mpc⁻³ mag⁻¹ h³₇₀]
M_B - 5 log(h₇₀)
NEWFIRM, Beare+15
VIPERS, Fritz+14
GAMA, Loveday+12
AGES, Cool+12
zCOSMOS, Zucca+09
HDF, Giallongo+05
VVDS, Ilbert+06
Posterior samples

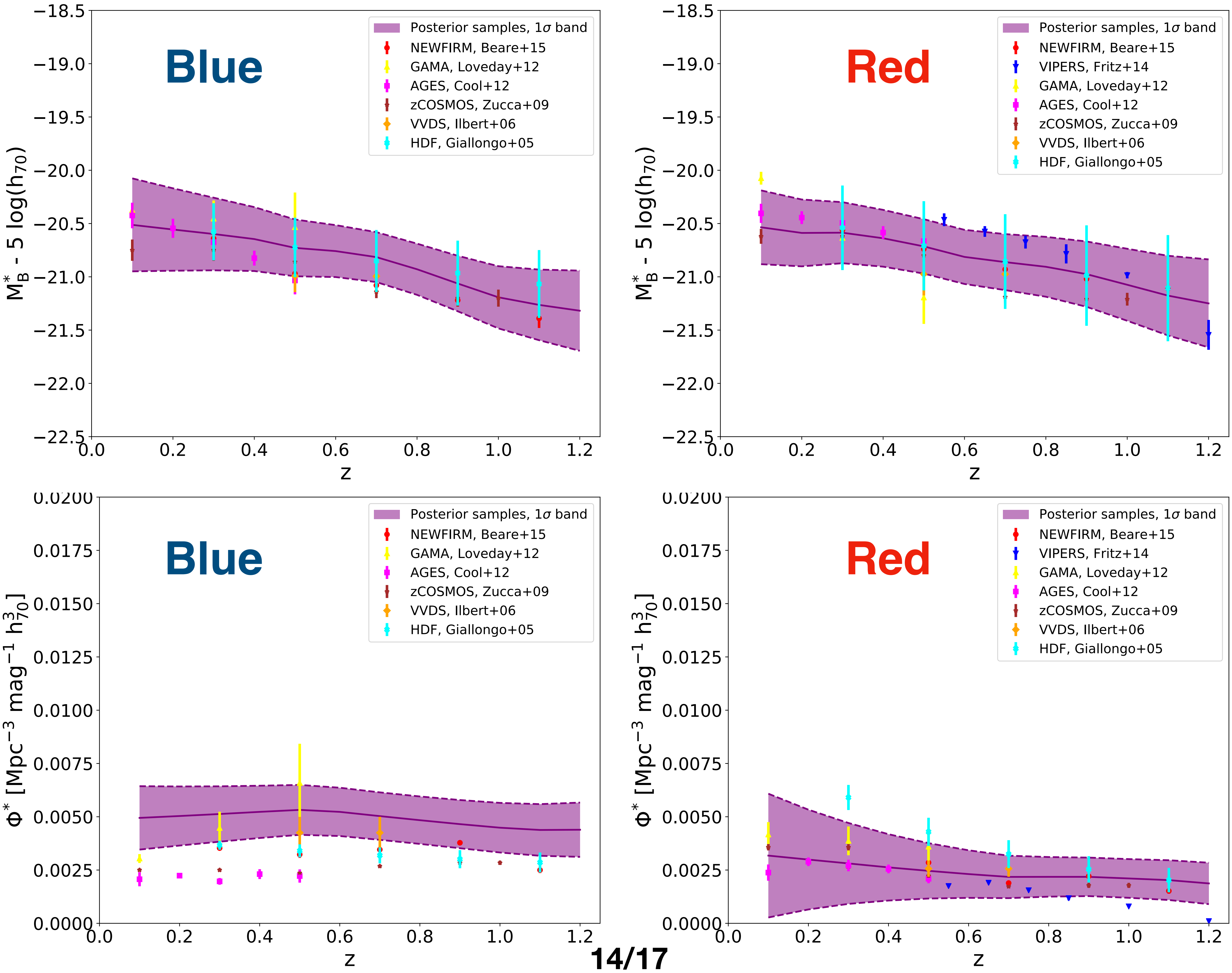


Red Luminosity Function, z=0.7
Φ(M) [Mpc⁻³ mag⁻¹ h³₇₀]
M_B - 5 log(h₇₀)
NEWFIRM, Beare+15
VIPERS, Fritz+14
zCOSMOS, Zucca+09
HDF, Giallongo+05
VVDS, Ilbert+06
Posterior samples

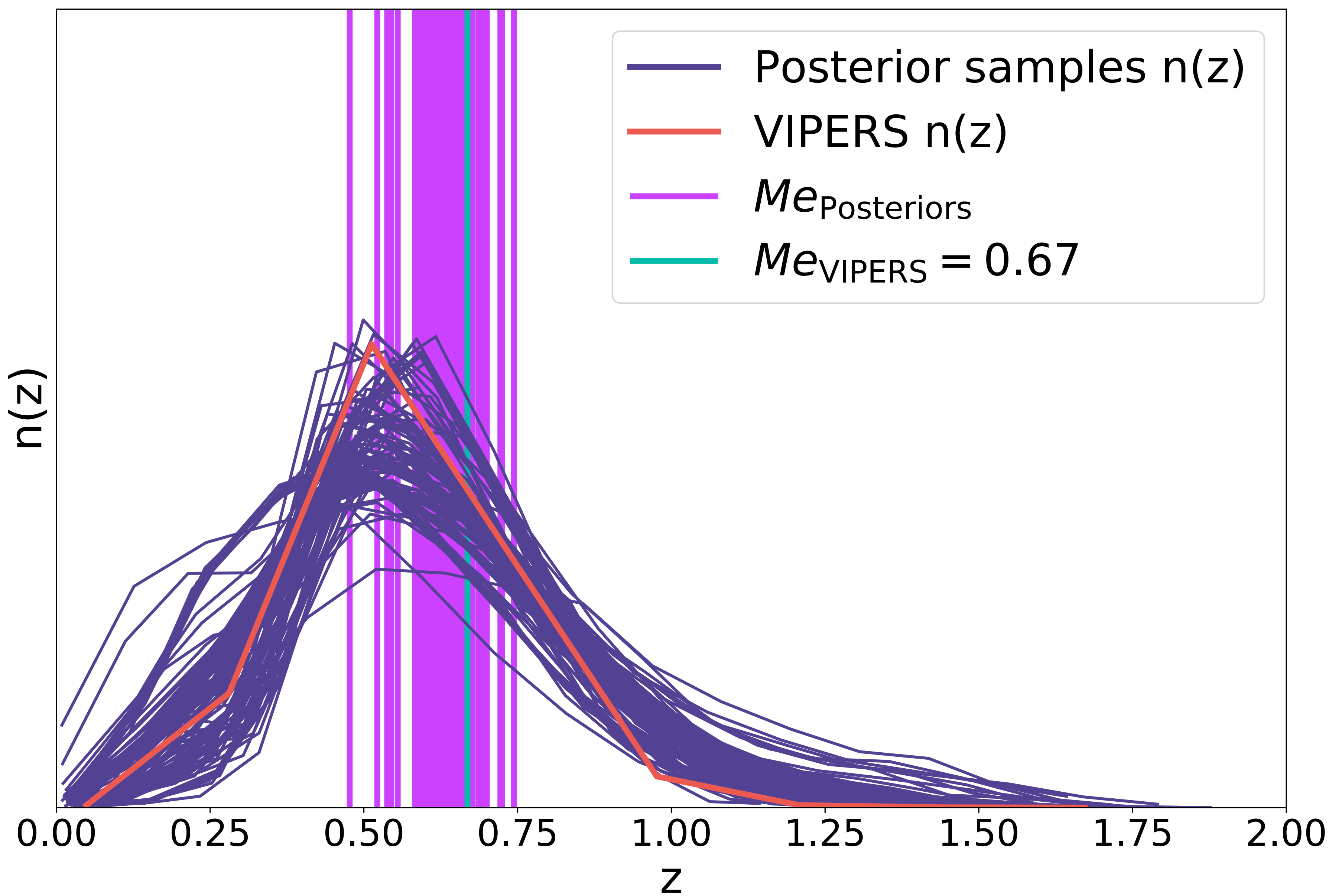


Red Luminosity Function, z=1.1
Φ(M) [Mpc⁻³ mag⁻¹ h³₇₀]
M_B - 5 log(h₇₀)
NEWFIRM, Beare+15
VIPERS, Fritz+14
HDF, Giallongo+05
Posterior samples

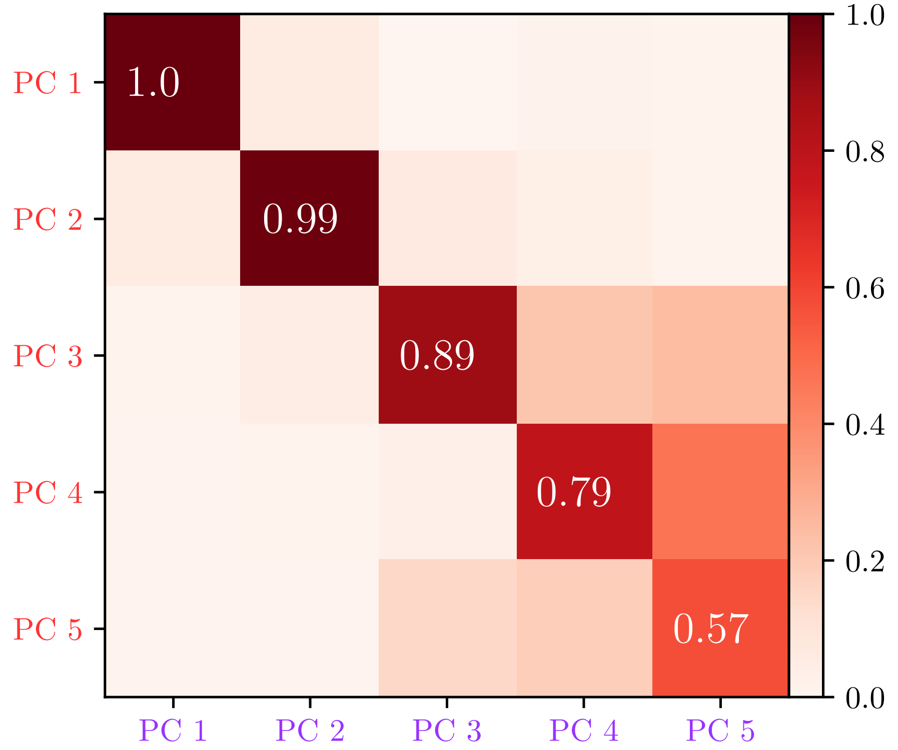

Global Luminosity Function, z=0.3
Global Luminosity Function, z=0.5
Global Luminosity Function, z=0.7
Global Luminosity Function, z=1.1
Φ(M) [Mpc^{-3} mag^{-1} h$^{3}_{70}$]
M$_B$ - 5 log(h$_{70}$)
NEWFIRM, Beare+15
VIPERS, Fritz+14
GAMA, Loveday+12
AGES, Cool+12
zCOSMOS, Zucca+09
HDF, Giallongo+05
Posterior samples

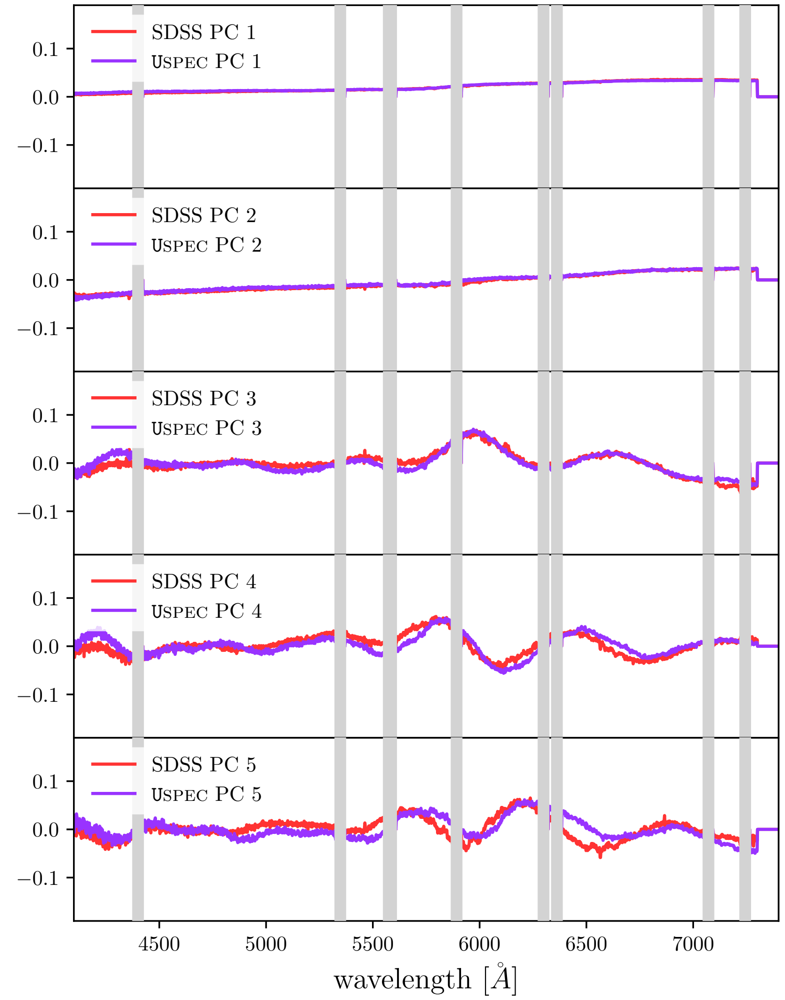

Blue
Red
Posterior samples, 1σ band
NEWFIRM, Beare+15
VIPERS, Fritz+14
GAMA, Loveday+12
AGES, Cool+12
zCOSMOS, Zucca+09
VVDS, Ilbert+06
HDF, Giallongo+05
M^*_B - 5 log(h_{70})
Φ^* [Mpc^{-3} mag^{-1} h^3_{70}]
z

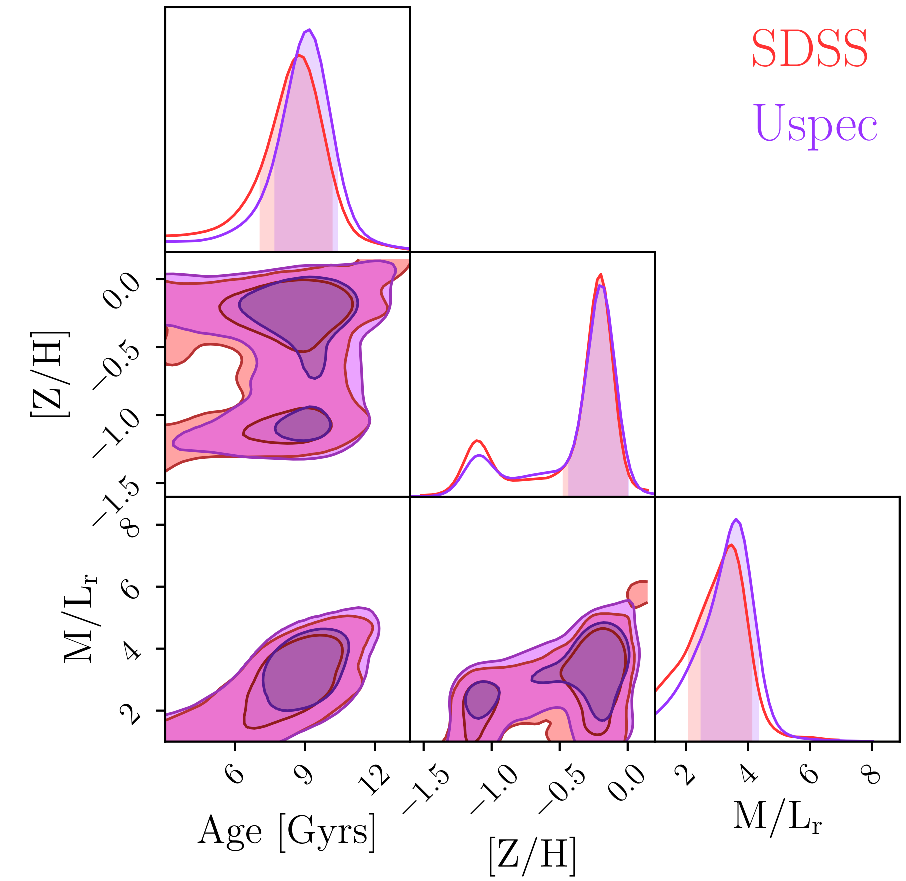
Redshift distribution n(z) for VIPERS



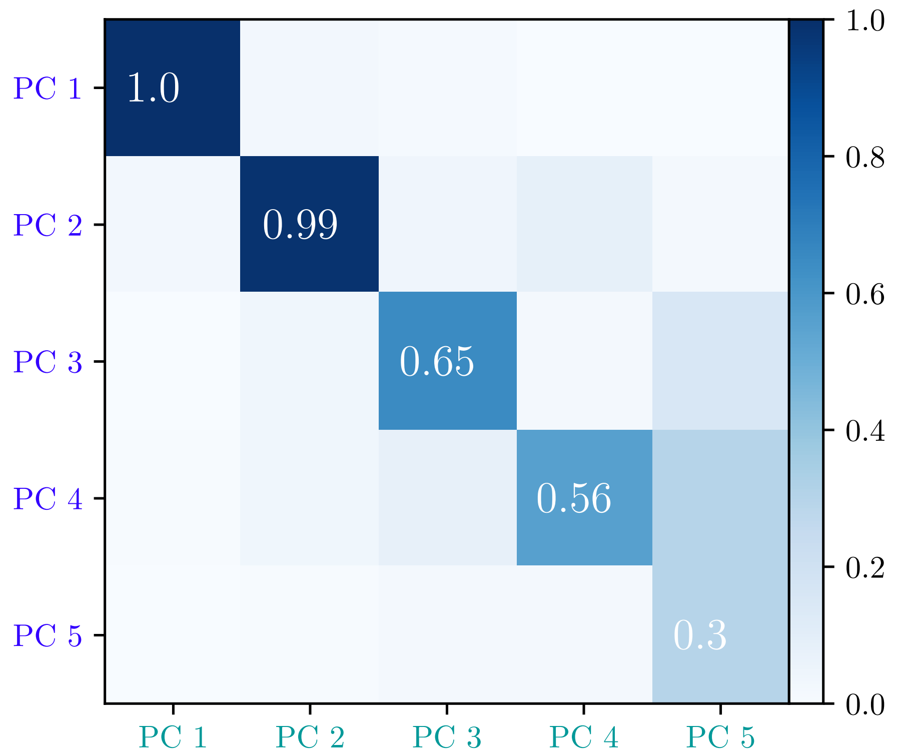
SDSS CMASS

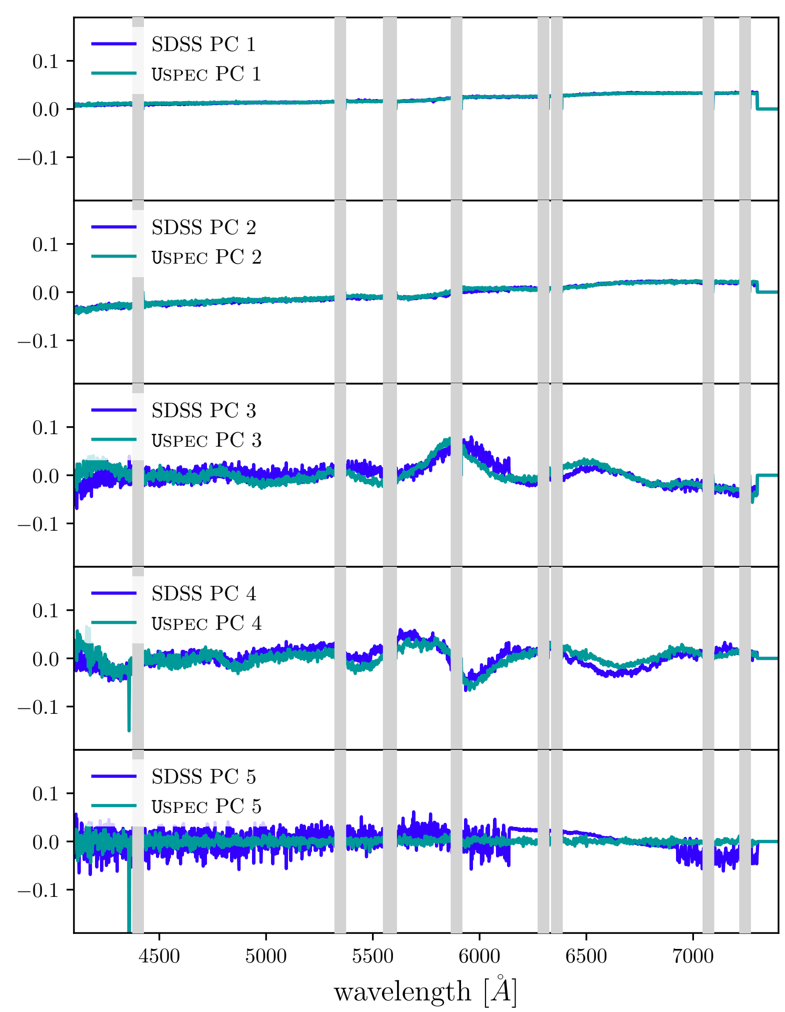


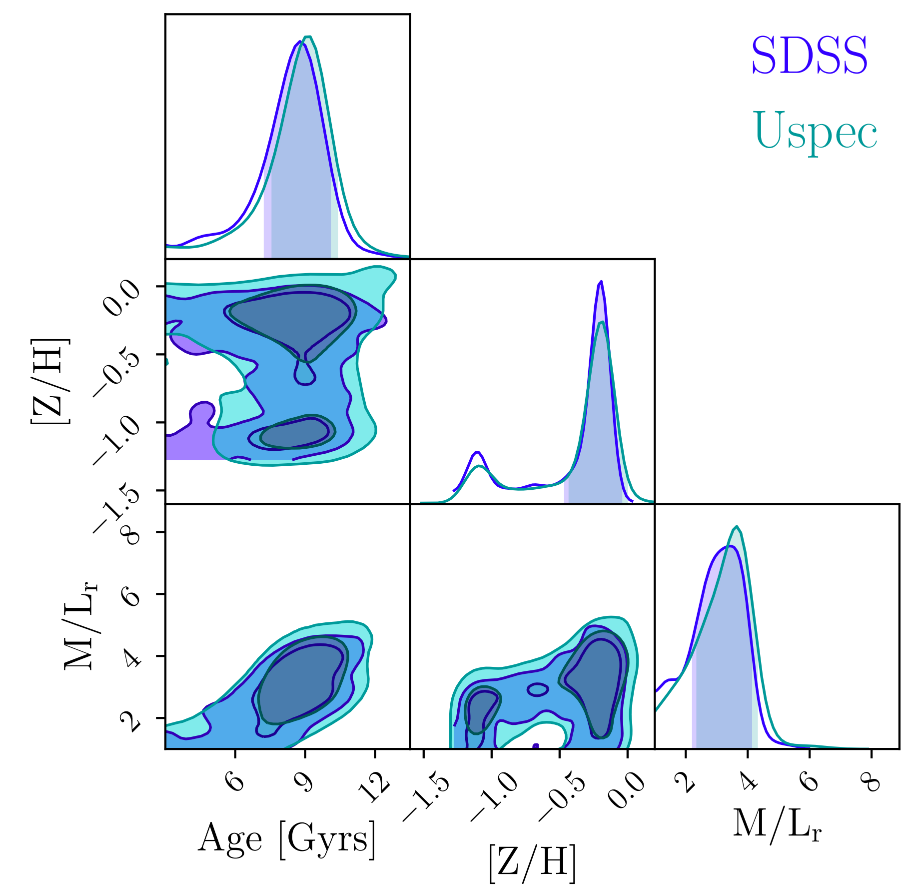




SDSS CMASS SPARSE







Fagioli, Tortorelli et al. 2020, arXiv:2002.04039

Conclusions

- For $M_B - 5 \log h_{70} > -21$, at all redshifts, the number density at fixed absolute magnitude of blue galaxies is greater than that of red galaxies.
- M^* for blue galaxies fades more than that for red galaxies from $z = 1$ to $z = 0.1$.
- Φ^* for blue galaxies stay roughly constant between $z = 0.1$ and $z = 1$.
- Φ^* for red galaxies decreases by 35% in the same redshift range.
- The number density of blue galaxies at M^* is always higher than the red one.