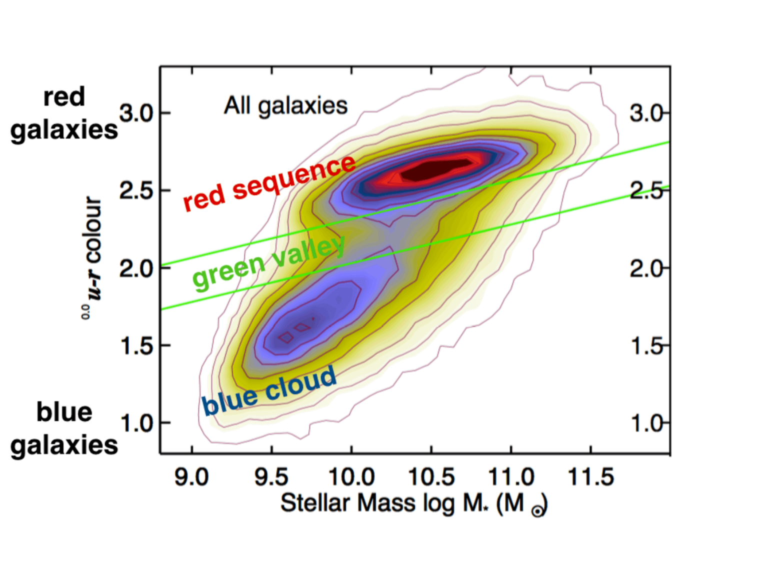
Forward modeling TDE detection rates in various galaxy types



Schawinski+ 2014

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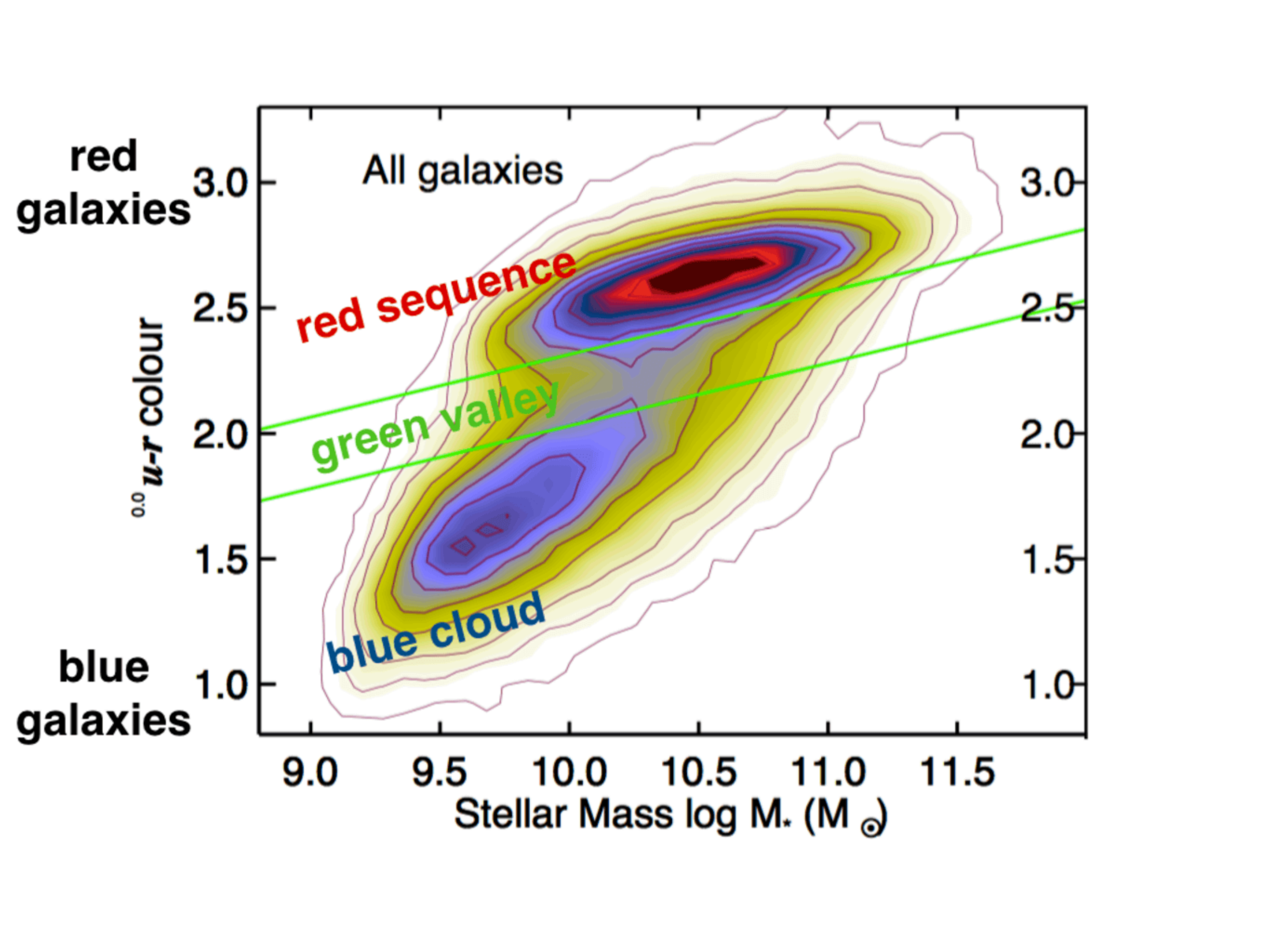
ZTF nuclear transient team

Some open questions in TDE demographics

- Are we finding TDEs at the overall rate we expect from dynamical calculations of stellar disruption rates? (selection effects?)
- Why do we seem to be finding TDEs at especially high rates in rare galaxy types? (selection effects?)

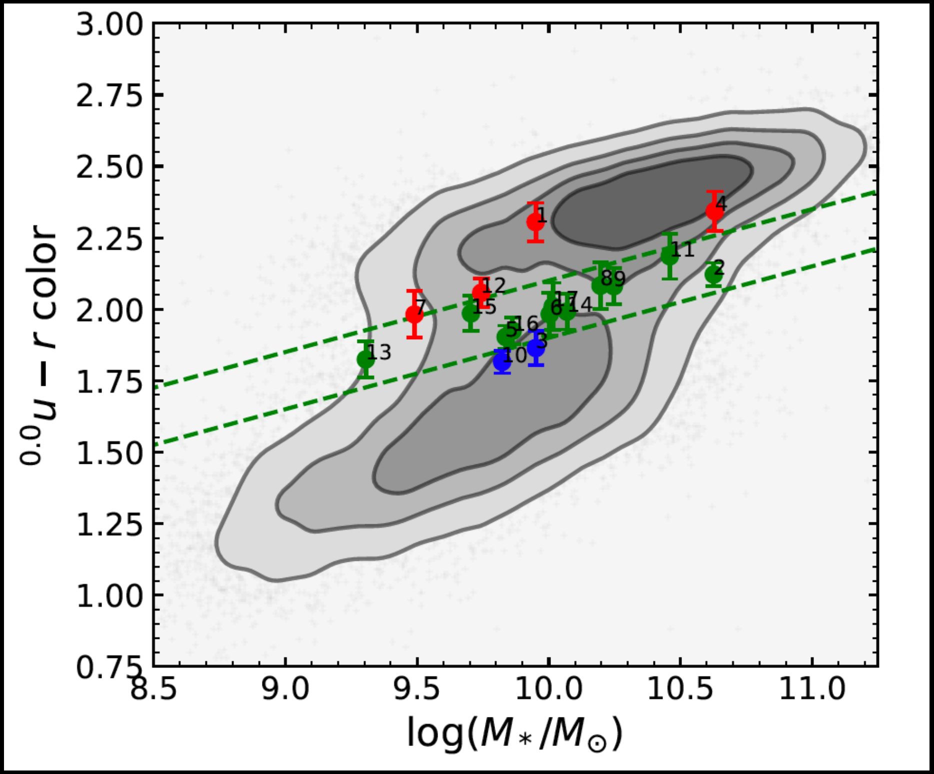
Galaxy bi-modality



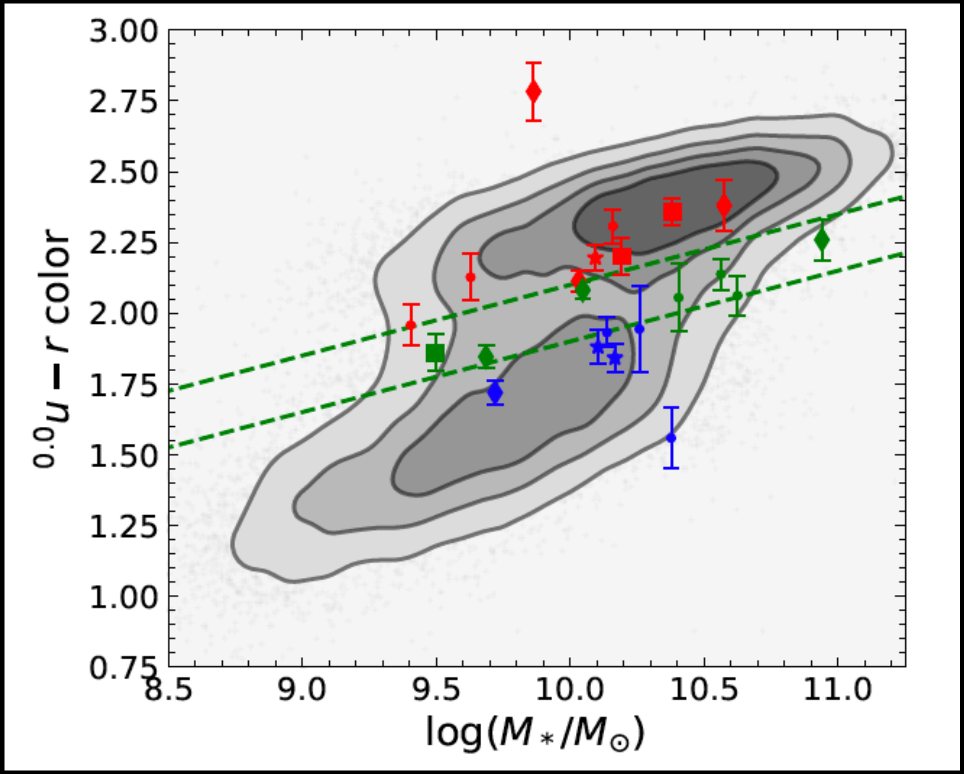
Schawinski+ 2014

ZTF TDEs in the green valley

ZTF

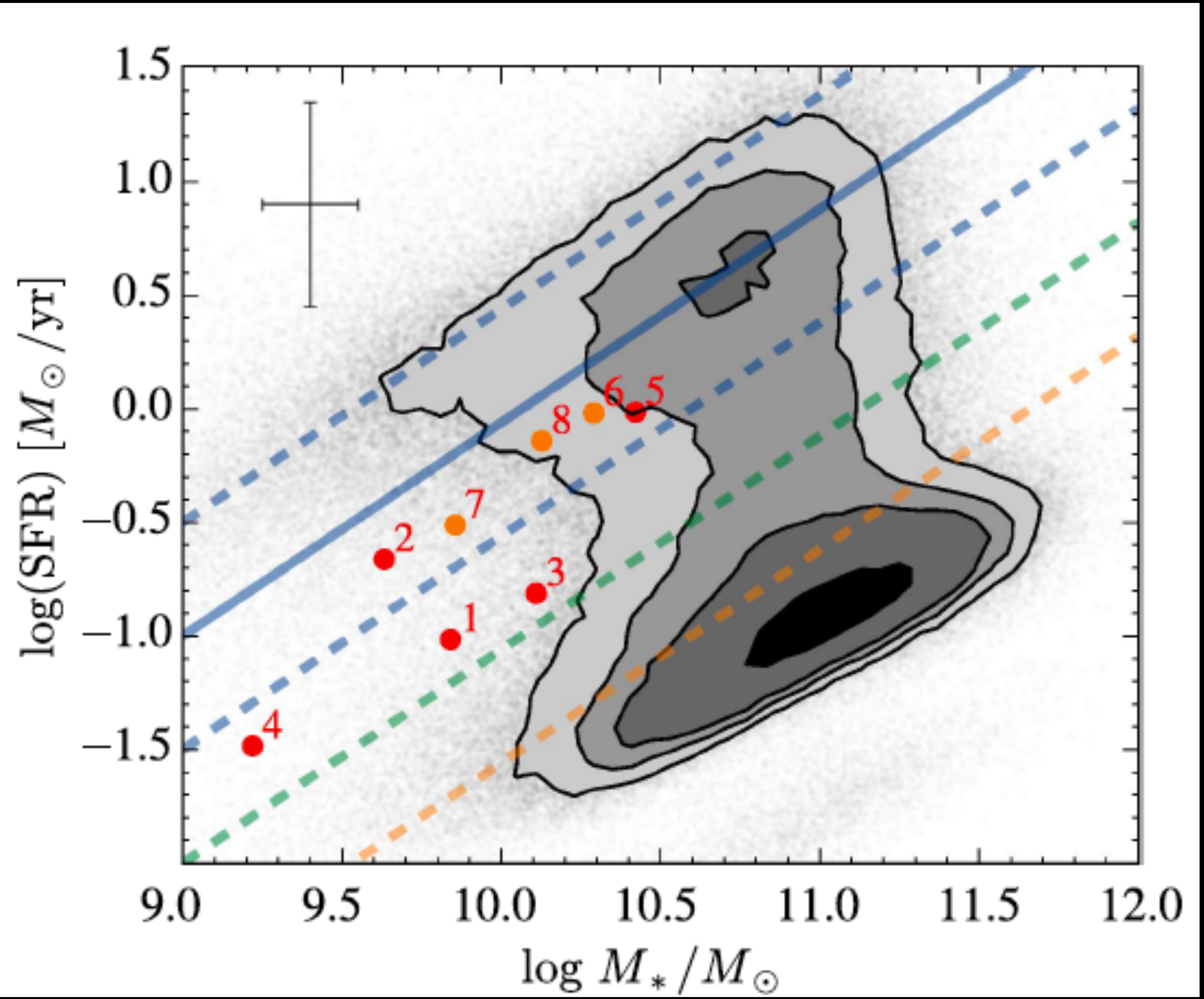


Previous surveys



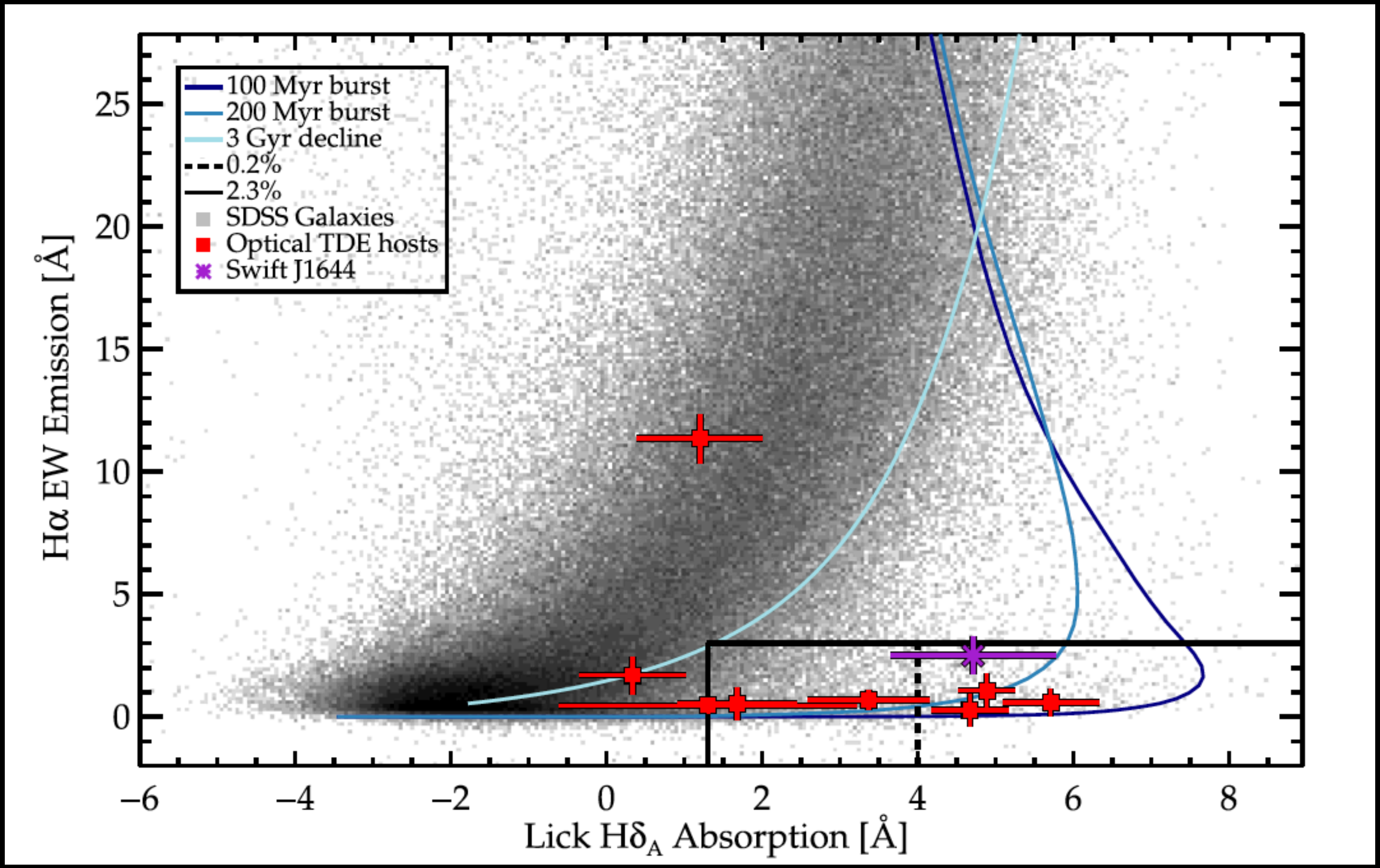
van Velzen et al 2020 (figures by Erica Hammerstein)

Past TDEs in the green valley



Law-Smith+ 2017

"E + A" galaxies (type of post-starburst galaxy)



French, Arcavi & Zabludoff 2016

Forward model TDE detection rates and how they depend on host galaxy properties

Catalog of galaxy hosts → Disruption rate in each galaxy → UV/optical luminosity function of flares → Survey selection criteria

Forward model TDE detection rates and how they depend on host galaxy properties

Dust obscuration from host

Catalog of galaxy hosts

Disruption rate in each galaxy

UV/optical luminosity function of flares

Survey selection criteria

Synthetic galaxy catalogue

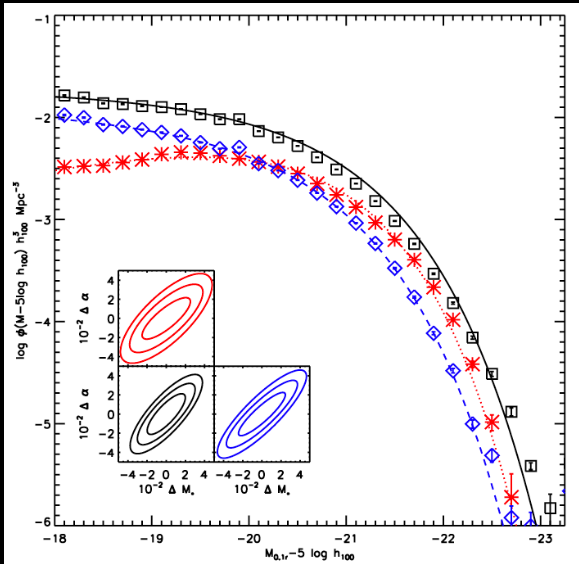
Van Velzen 2018

Table 5
Columns of the Synthetic Galaxy Catalog

Column Name	Unit	Comments
z		Redshift
ra	deg	R.A. (of original galaxy)
dec	deg	Decl. (of original galaxy)
mass	$M_\odot$	Total galaxy mass from NYU-VAGC based on *ugrizJHK* photometry
B300	yr^{-1}	Specific SFR over the past 300 Myr from NYU-VAGC based on *ugrizJHK* photometry
B1000	yr^{-1}	Specific SFR over the past Gyr from NYU-VAGC based on *ugrizJHK* photometry
sSFR	yr^{-1}	Specific SFR from the MPA-JHU catalog (their specsfr_fib_p50 column)
BT		Bulge-to-total ratio based on Lackner & Gunn (2012) measurements in the *r* band
r50_kpc	kpc	Effective radius based on Sérsic fit from NYU-VAGC
sersic_n		Sérsic index from NYU-VAGC
sigma	km s^{-1}	Velocity dispersion as estimated using the virial theorem (Equation (6))
sigma_SDSS	km s^{-1}	Velocity dispersion from SDSS pipeline (as reported in the NYU-VAGC)
sigma_SDSS_err	km s^{-1}	Uncertainty on sigma_SDSS
MBH_sigma	$M_\odot$	Black hole mass as estimated from the velocity dispersion (Equation (8))
MBH_bulge	$M_\odot$	Black hole mass as estimated from the bulge mass (Equation (8))
m_r	AB mag	Apparent magnitude in the *r* band
M_r	AB mag	Absolute magnitude in the *r* band (*k*-corrected)
m_g	AB mag	Apparent magnitude in the *g* band
M_g	AB mag	Absolute magnitude in the *g* band (*k*-corrected)

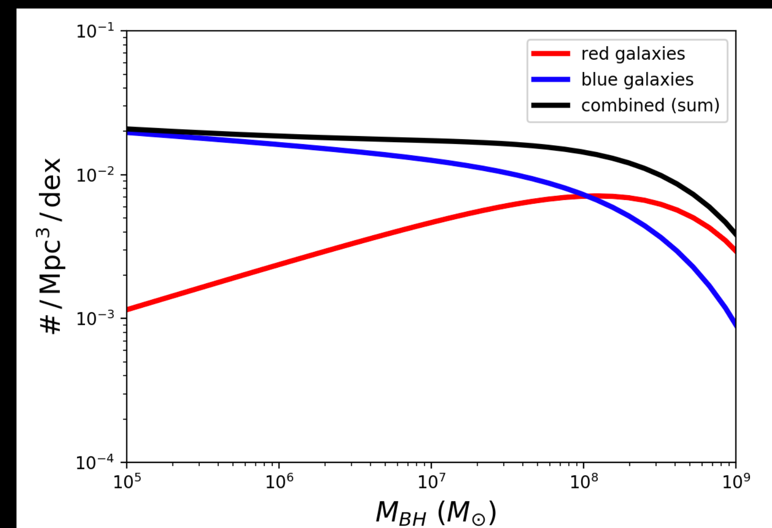
~ 6 million galaxies ($m_r <$ 22 on 100 square degrees of sky)

Galaxy LFs (with two color bins)

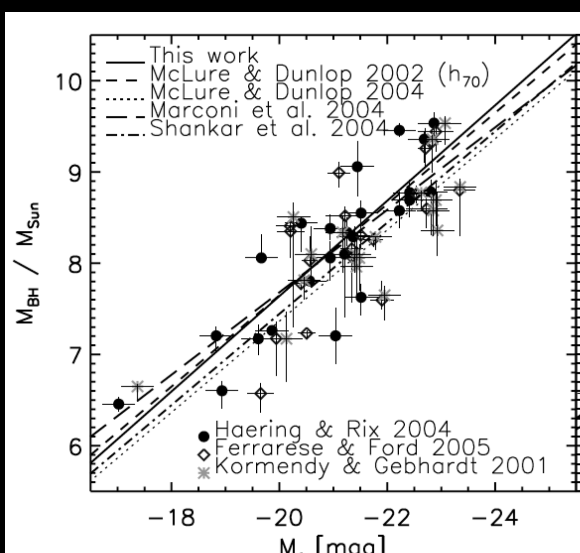


Cool+ 2012

SMBH mass function (two color bins)



M_{BH} - L_{bulge} relation



Tundo+ 2017

Bulge/total ratios

(also z – dependence for everything)

Some galaxy properties that influence TDE rate

- Black hole mass
  - Hills mass
  - Size of sphere of influence
- Stellar surface brightness profile, which encodes information about stellar orbits
- Overall density of stars in nucleus

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Hills mass

For a given $M_\star$ (and $R_\star$), there is a mass limit M_H such that if M_{BH}> Mhills, the star is tidally disrupted inside the BH event horizon

$$M_H = M_\star^{-1/2}\left(\frac{c^2 R_\star}{2G}\right)^{3/2} \simeq 1\times 10^8 M_\odot \left(\frac{R_\star}{R_\odot}\right)^{3/2}\left(\frac{M_\star}{M_\odot}\right)^{-1/2}.$$

Hills 1975; equation taken from Stone+ 2018

This, combined with the present-day mass function in the galaxy (related to IMF) puts limits on rate of potentially visible flares

Disruption rate depends on stellar surface brightness profile

"Nuker γ" – inner power-law of surface-brightness profile

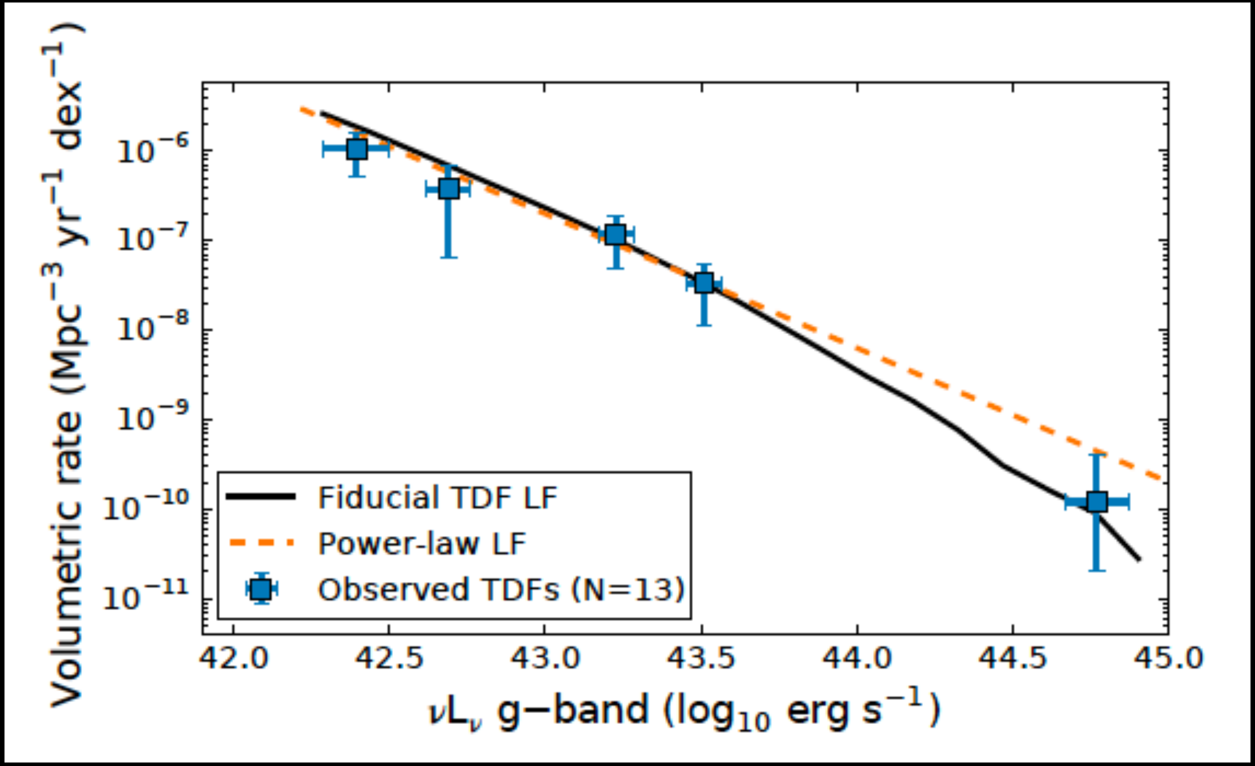
$$\dot{N}_{\rm TDE} \propto \gamma^{0.705}$$

Stone & Metzger 2016

γ can be estimated from Sersic index n and galaxy half-light radius

UV/optical flare luminosity function

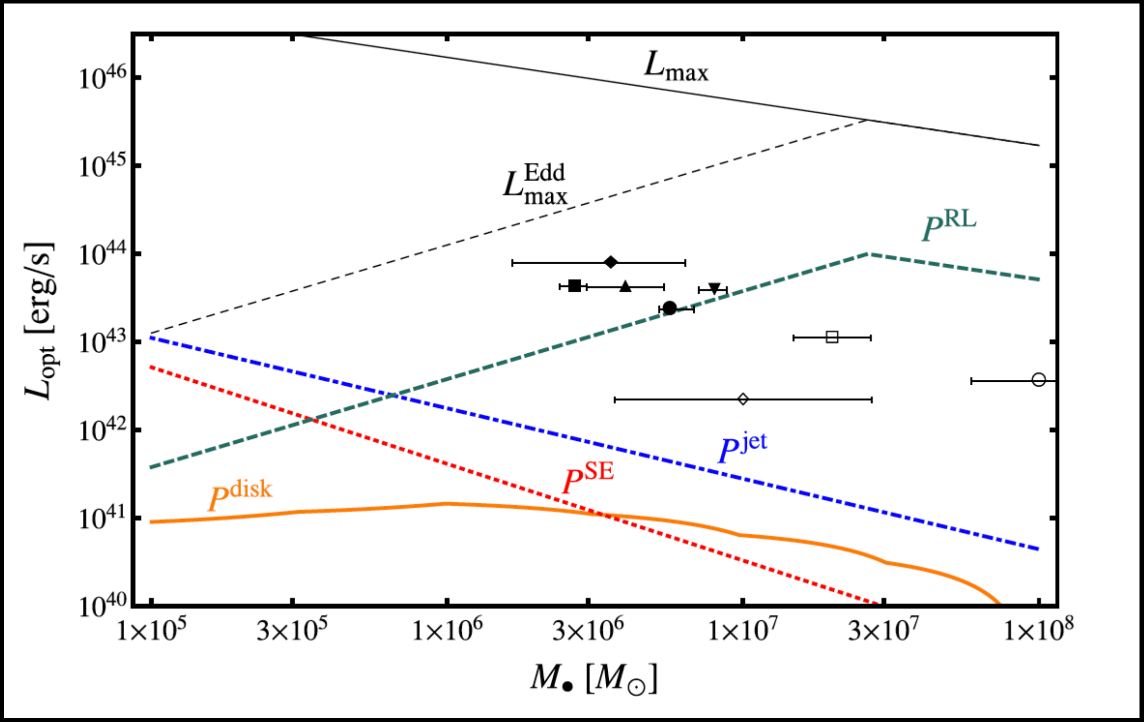
$$\frac{\partial N_{\rm TDE}}{\partial V_c\,\partial t\;\partial\log_{10}L} \propto L^{-1.5}$$



van Velzen 2018

Bounds on flare luminosity function

Well-defined limits on *maximum* peak luminosity



Stone & Metzger 2016

Limit on the faint end is trickier: for now, iPTF16fnl

Survey selection (to match ZTF)

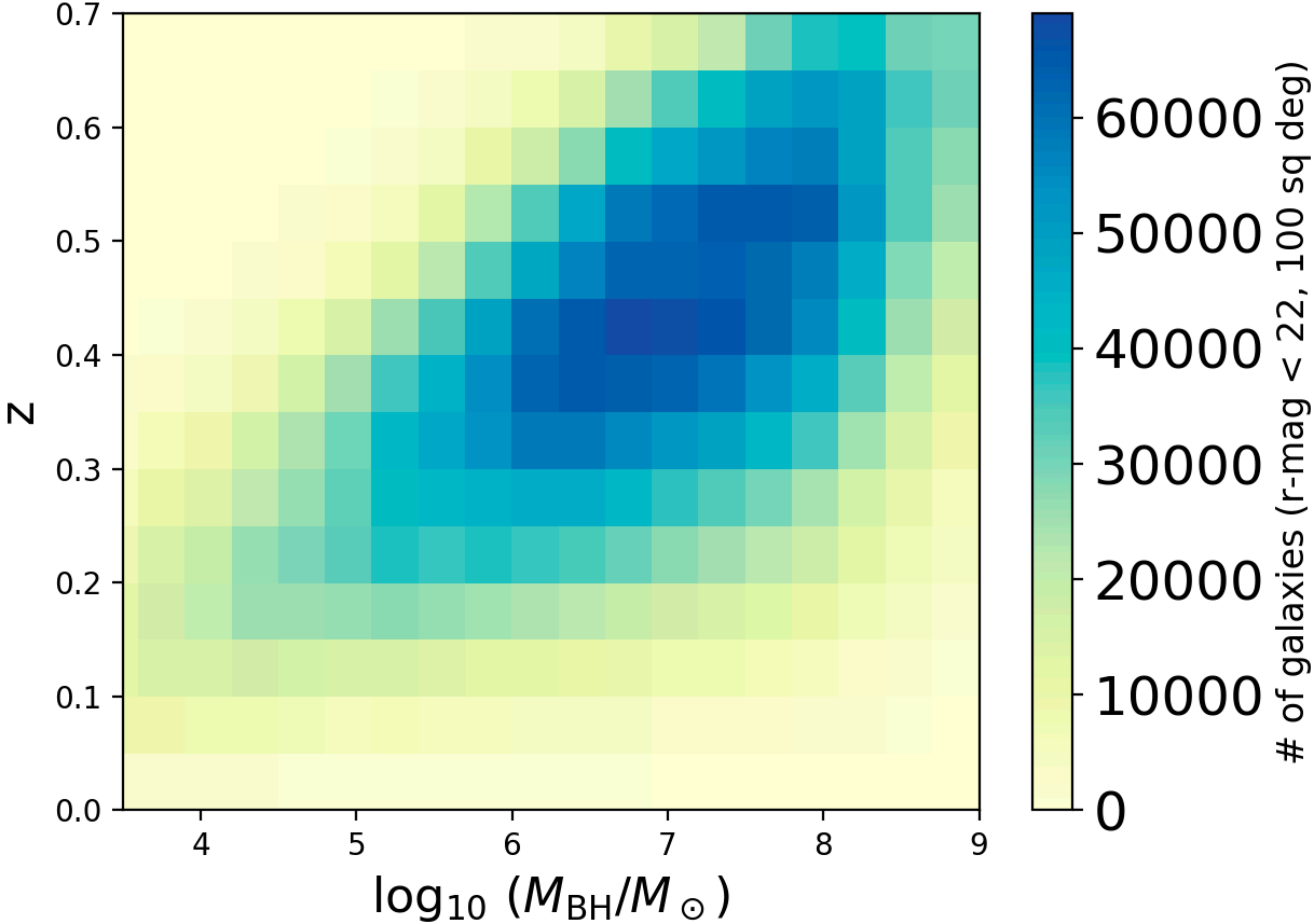
- For detection:
  - Require peak m_g, m_r < 19
  - Require peak $m_g - m_r < 0$
  - Require peak flux of transient to be brighter than host PSF light + 0.5 mags in all bands
- Survey area (15,000 deg^2) and duration (1.5 years) used to set the normalization of mock detection rates

Procedure

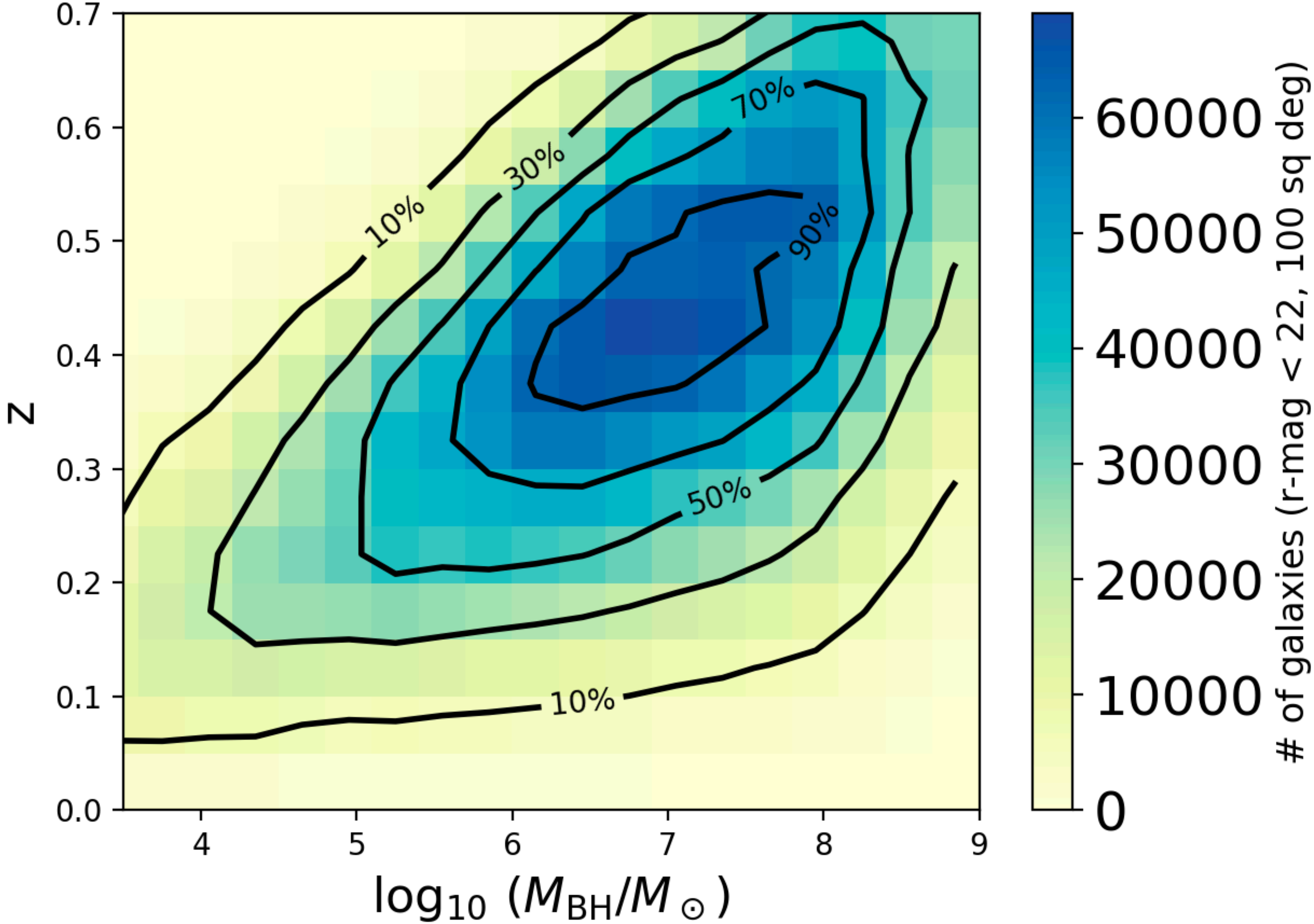
- For each galaxy in the mock catalogue:
  - use the galaxy properties (Nuker γ) to set overall rate normalization
  - Generate 5000 random disruptions
    - Sample the galaxy stellar mass function, and determine whether there is direct capture (i.e. account for Hills mass)
    - For stars that disrupt outside the event horizon, sample flare bolometric luminosity and temperature
    - Determine whether the flare would be detected by survey
  - Use these to compute detection rate for flares from the galaxy, and probability distributions of the properties of observed flares
- Bin results for all galaxies

Results

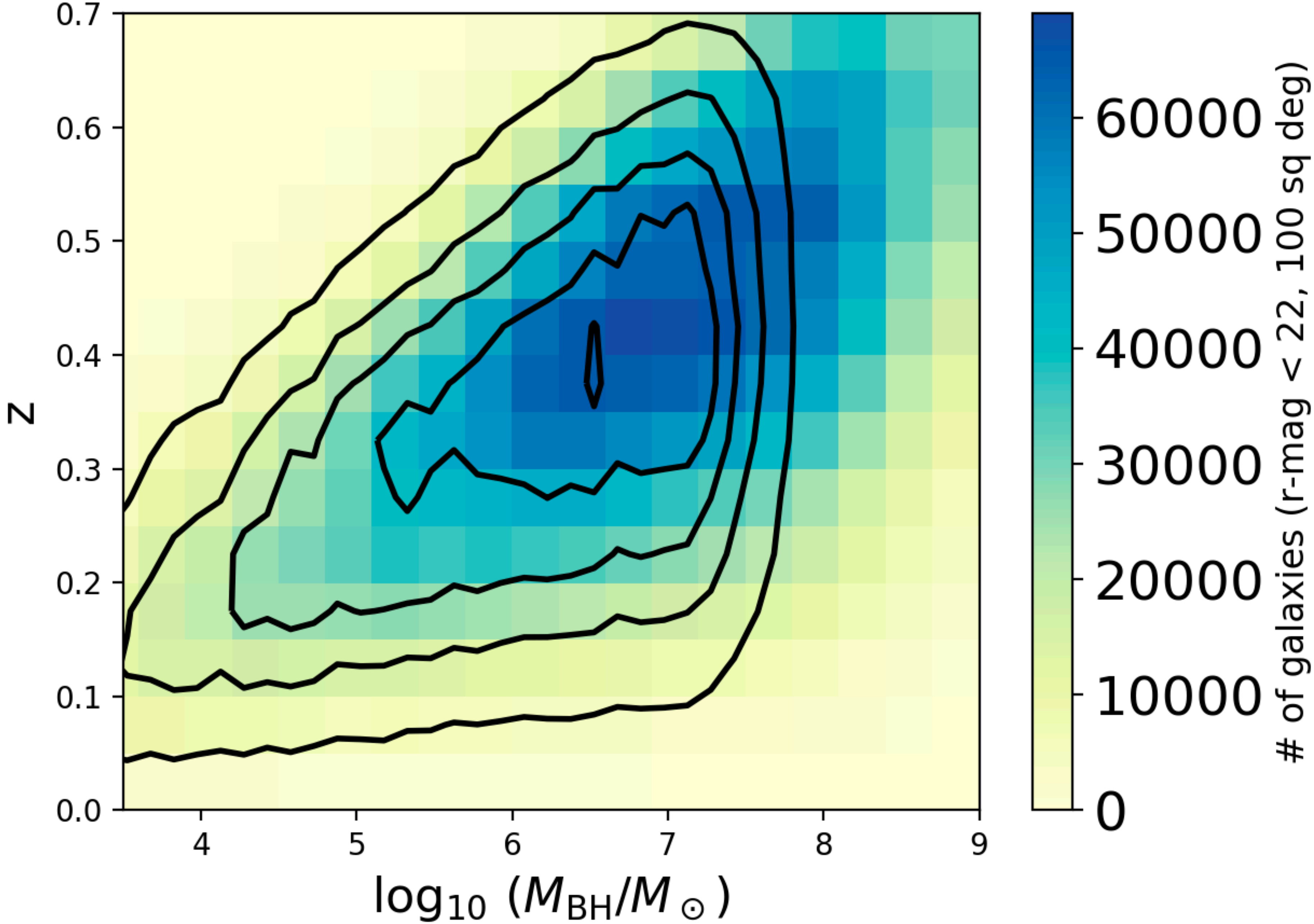
Number of galaxies in flux-limited survey



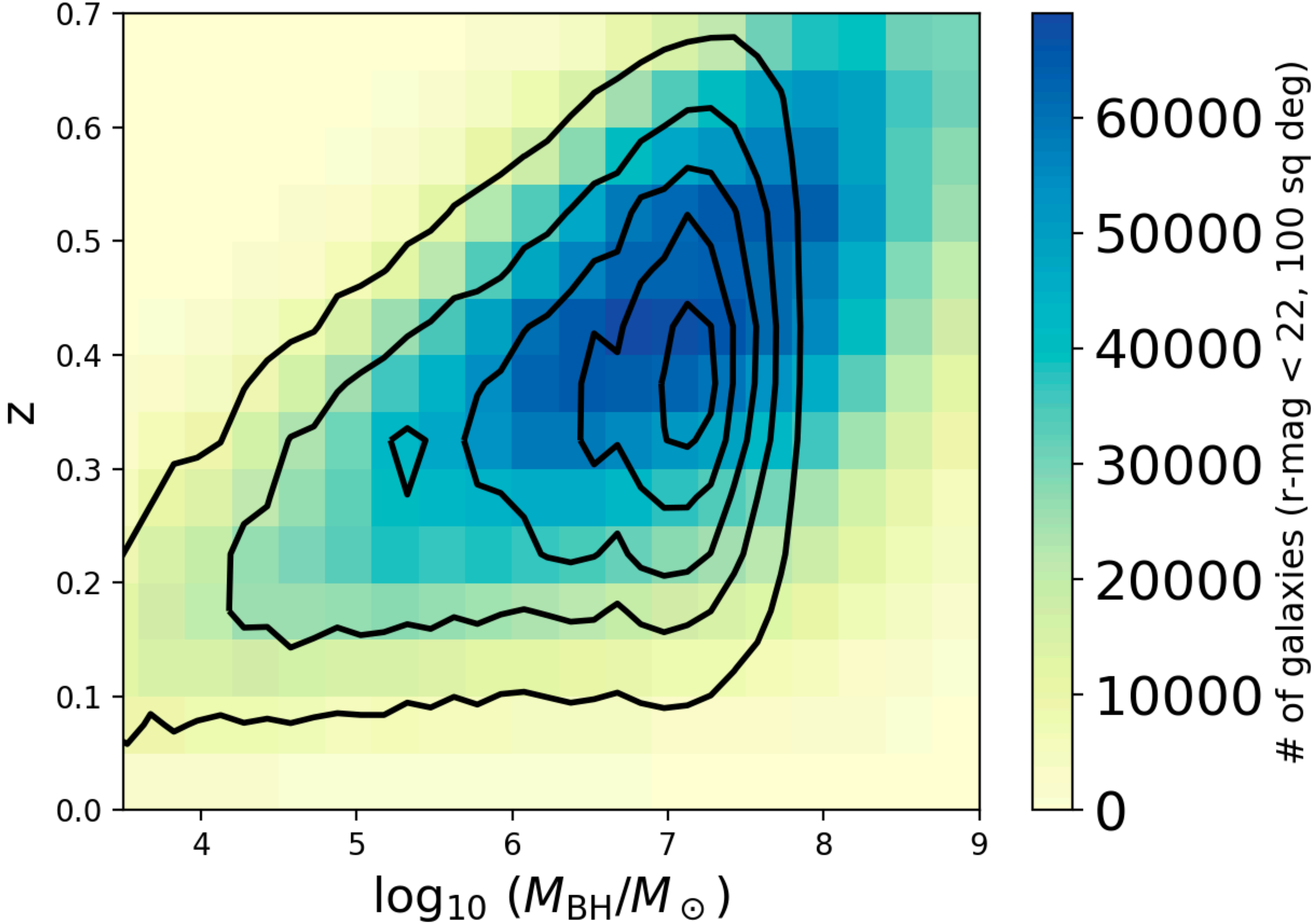
If the TDE rate were the same in every galaxy



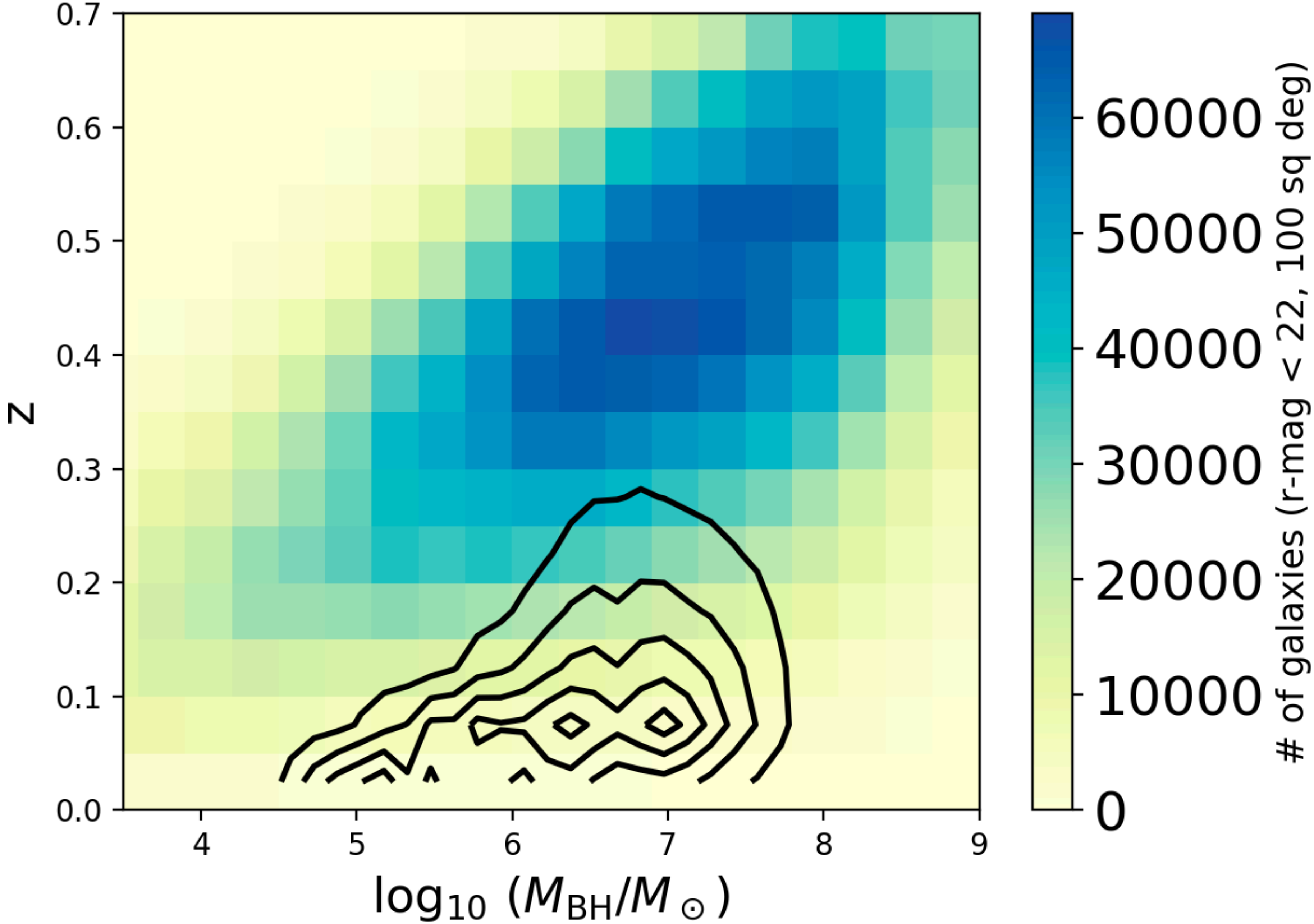
Account for Hills mass



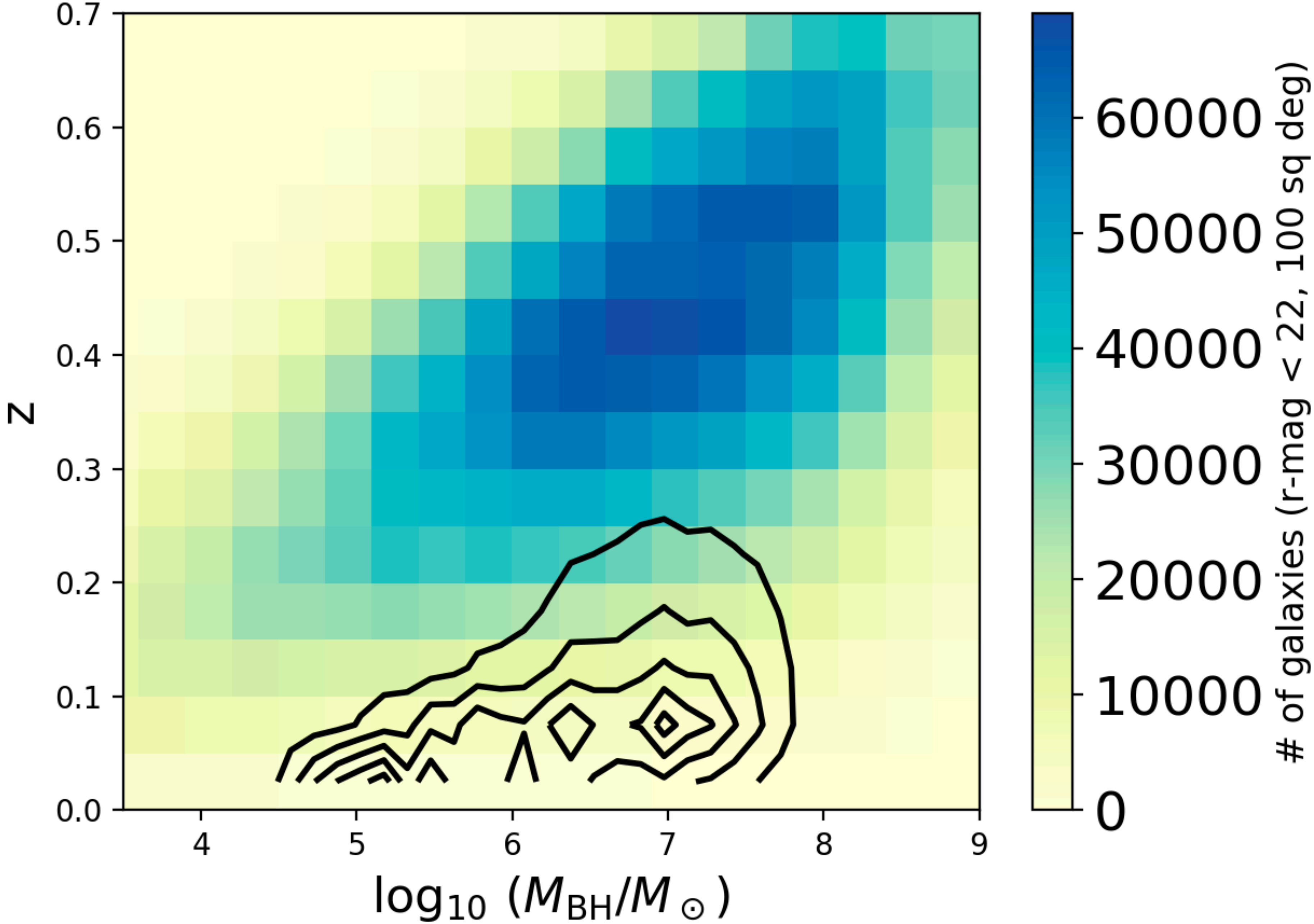
Account for Hills mass and Nuker γ



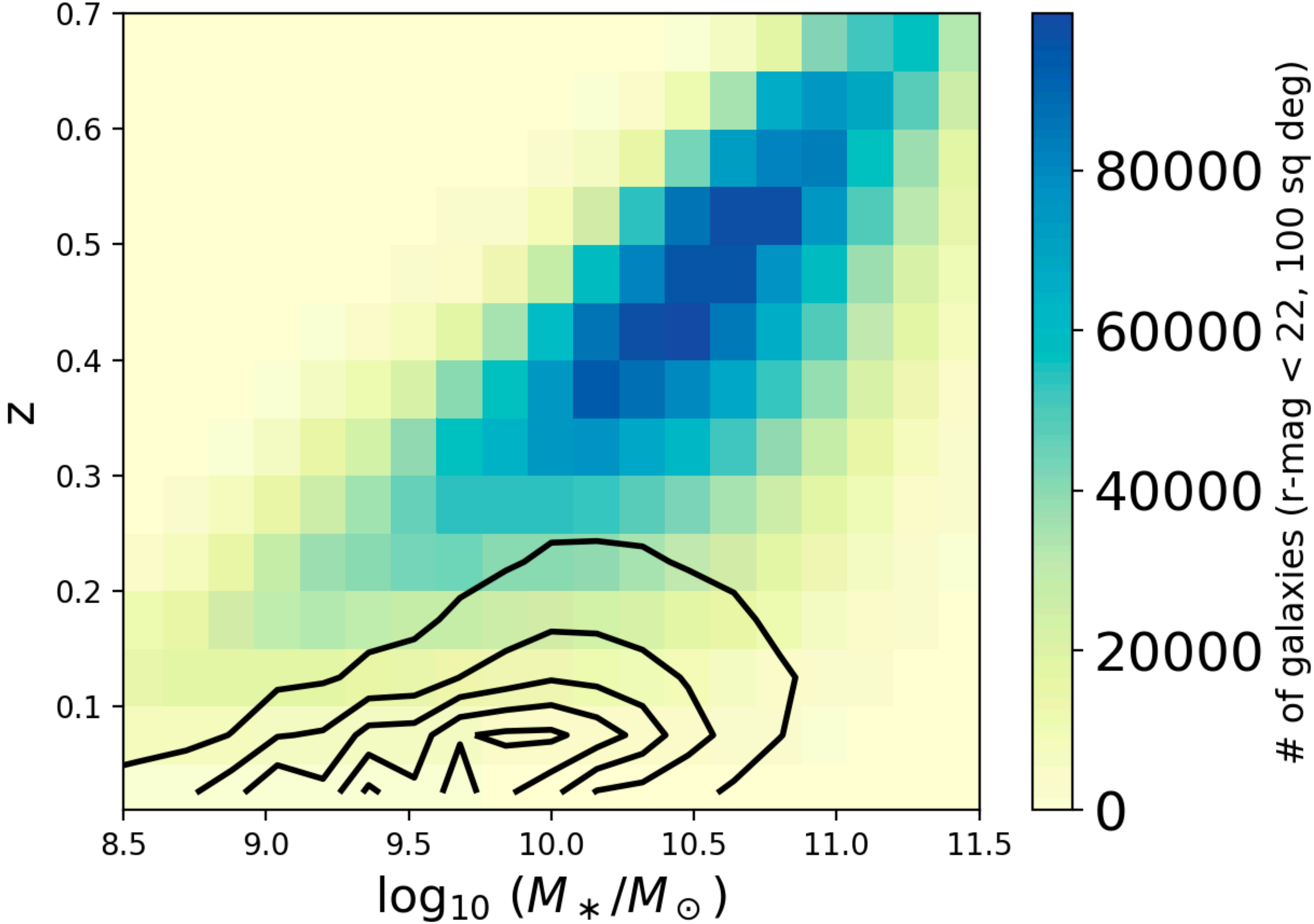
Apply survey selection cuts on flux



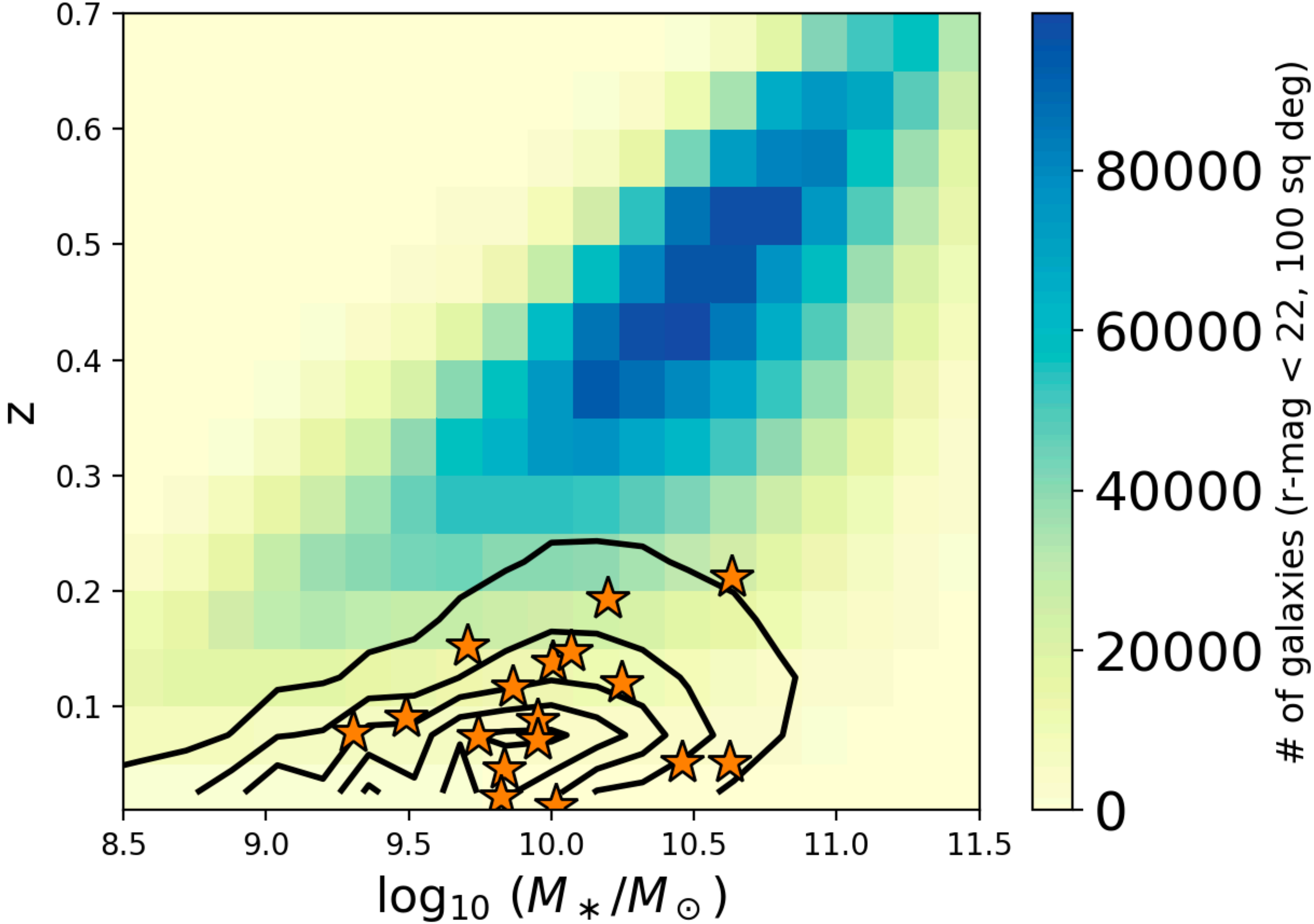
Account for dust obscuration in host



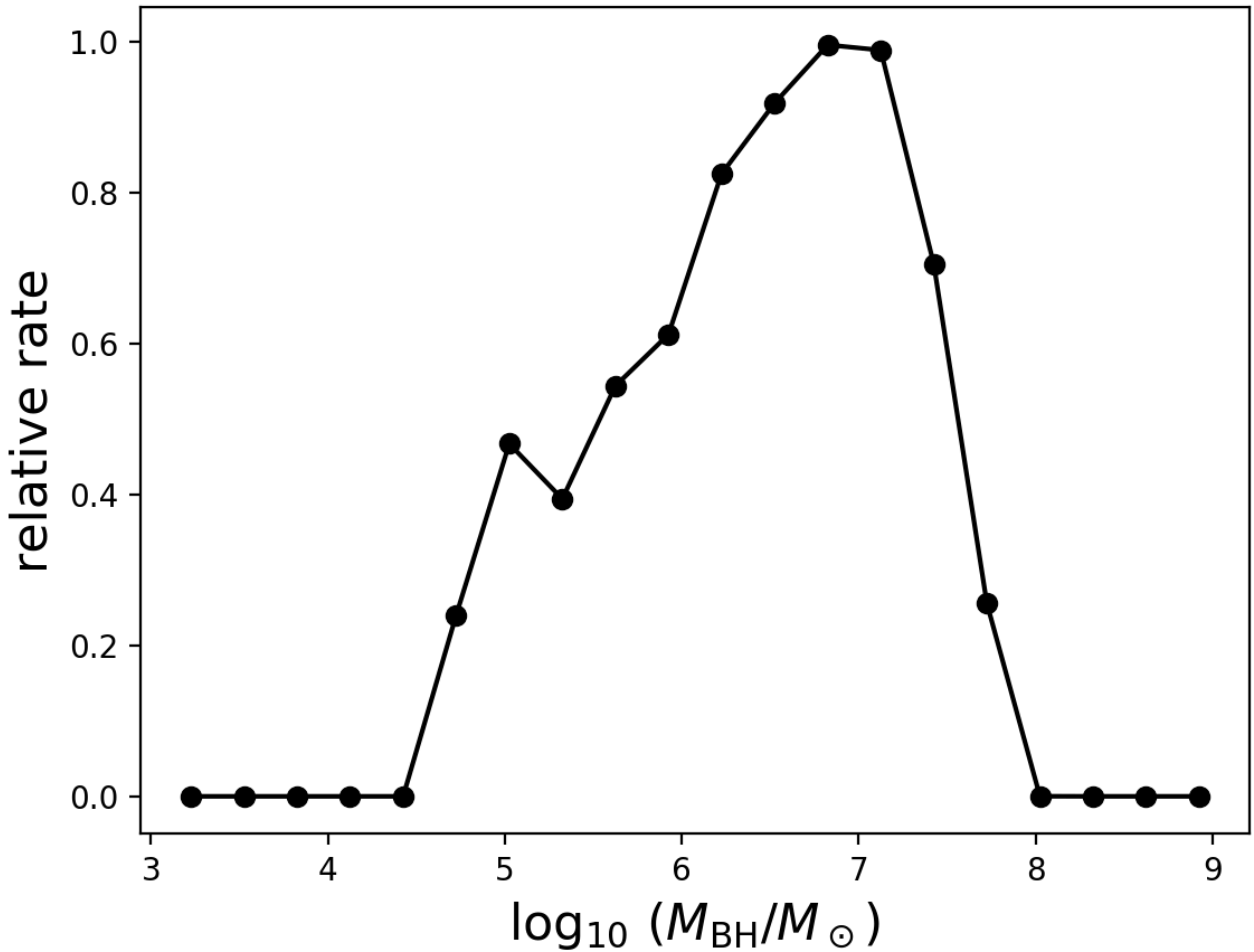
Consider galaxy M_* instead of M_{BH}



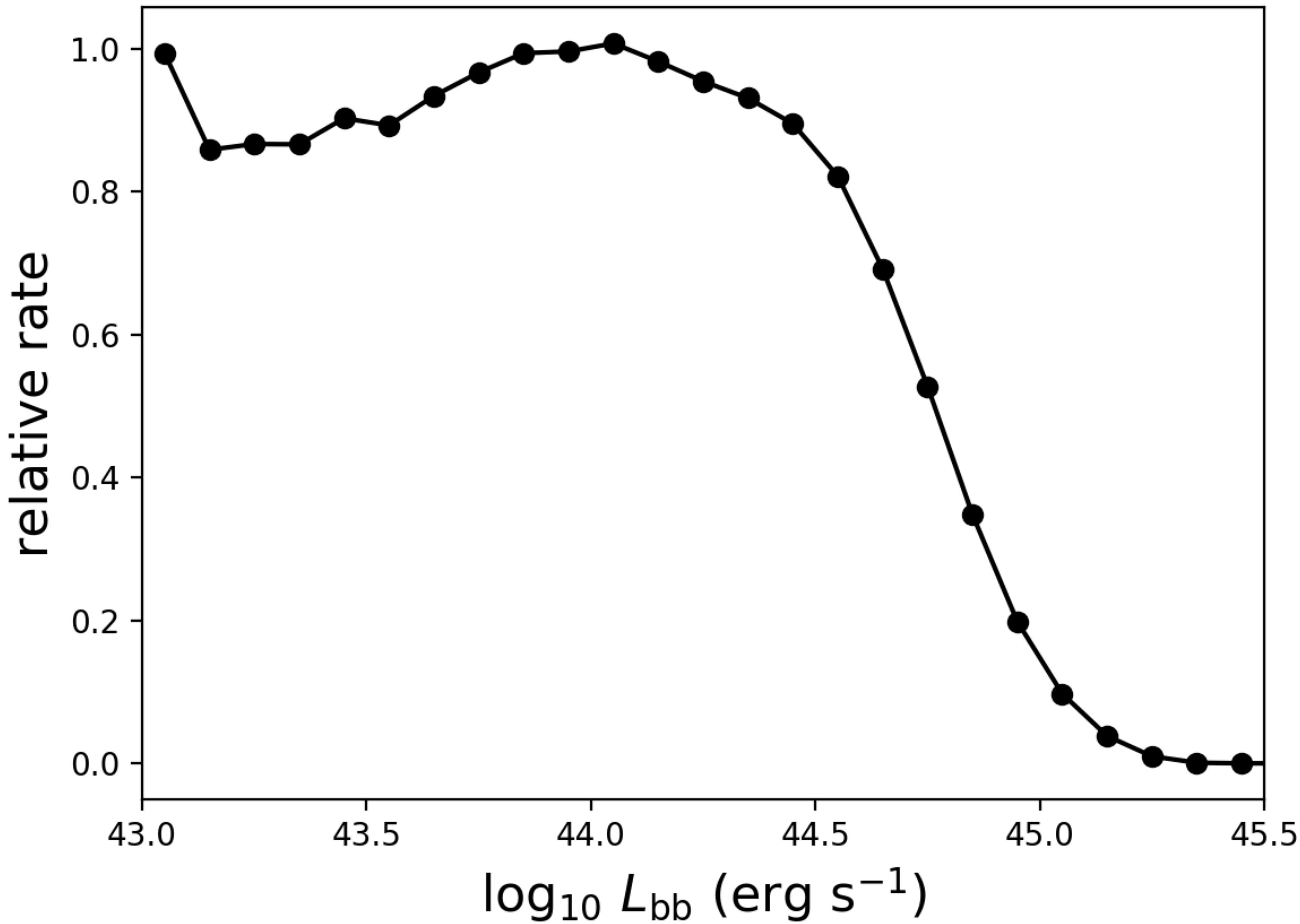
Compare with ZTF detections



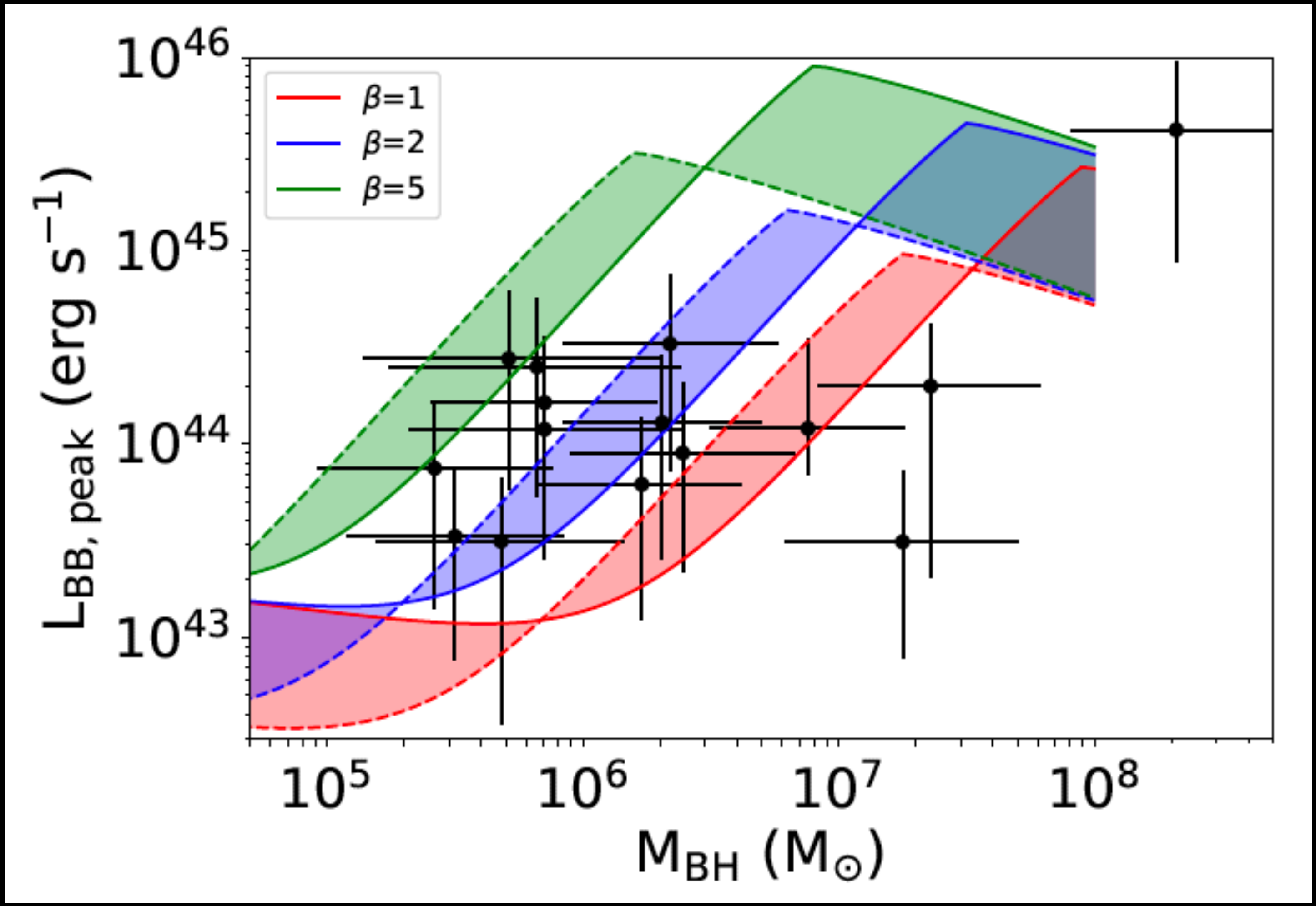
Mock distribution of observed BH masses



Mock observed UV/opt peak luminosity distribution

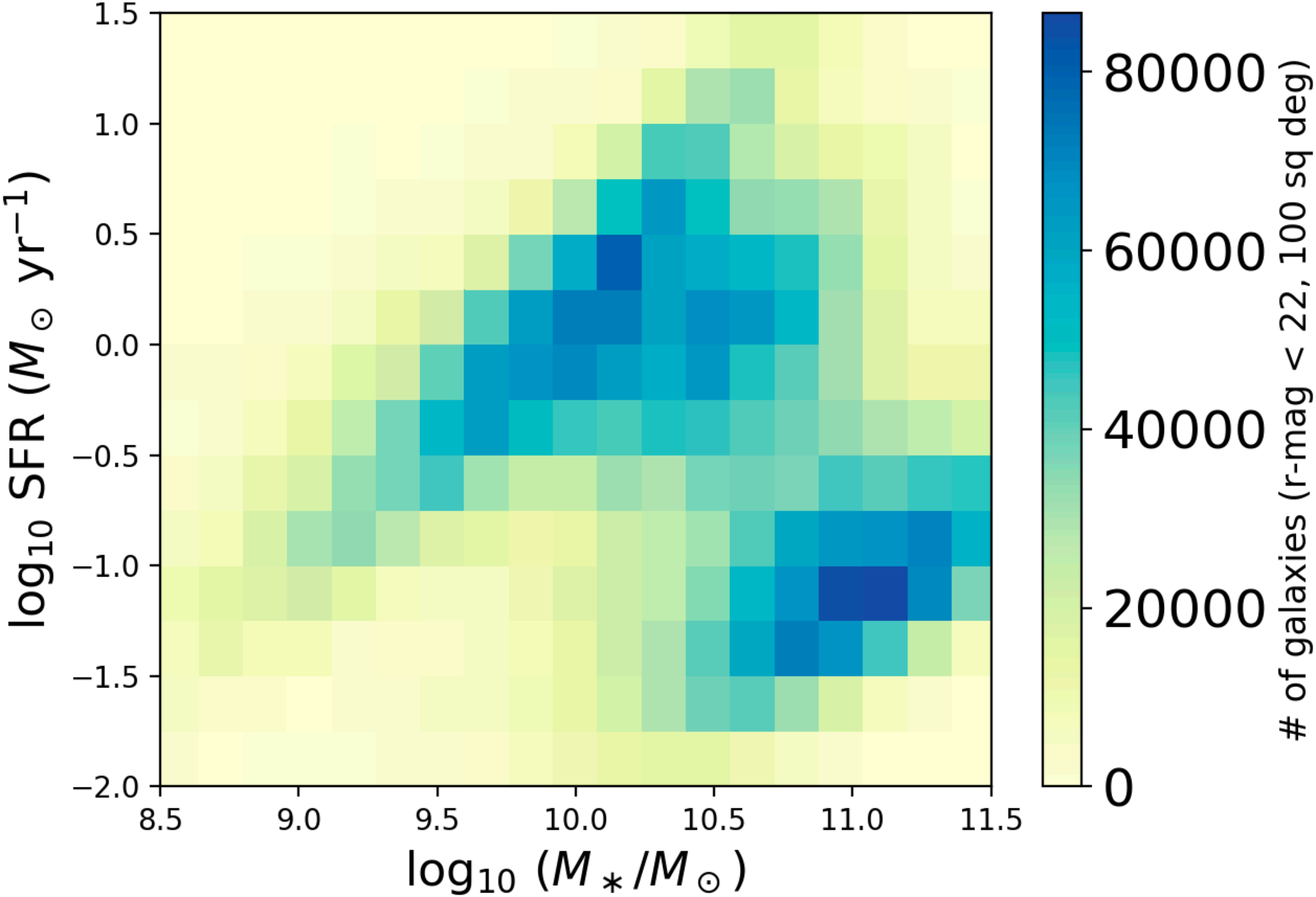


Compare with past surveys

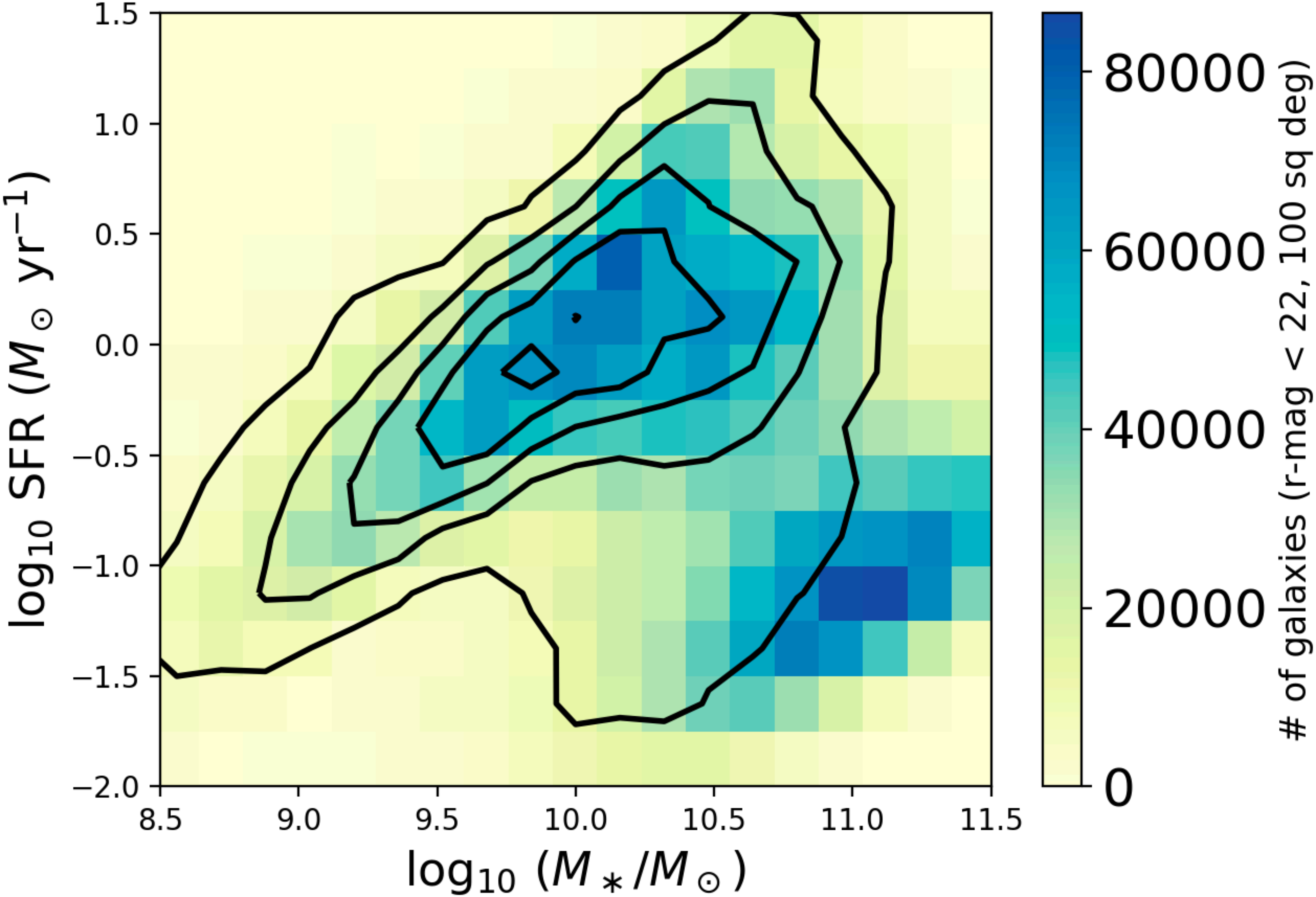


Wevers+ 2019

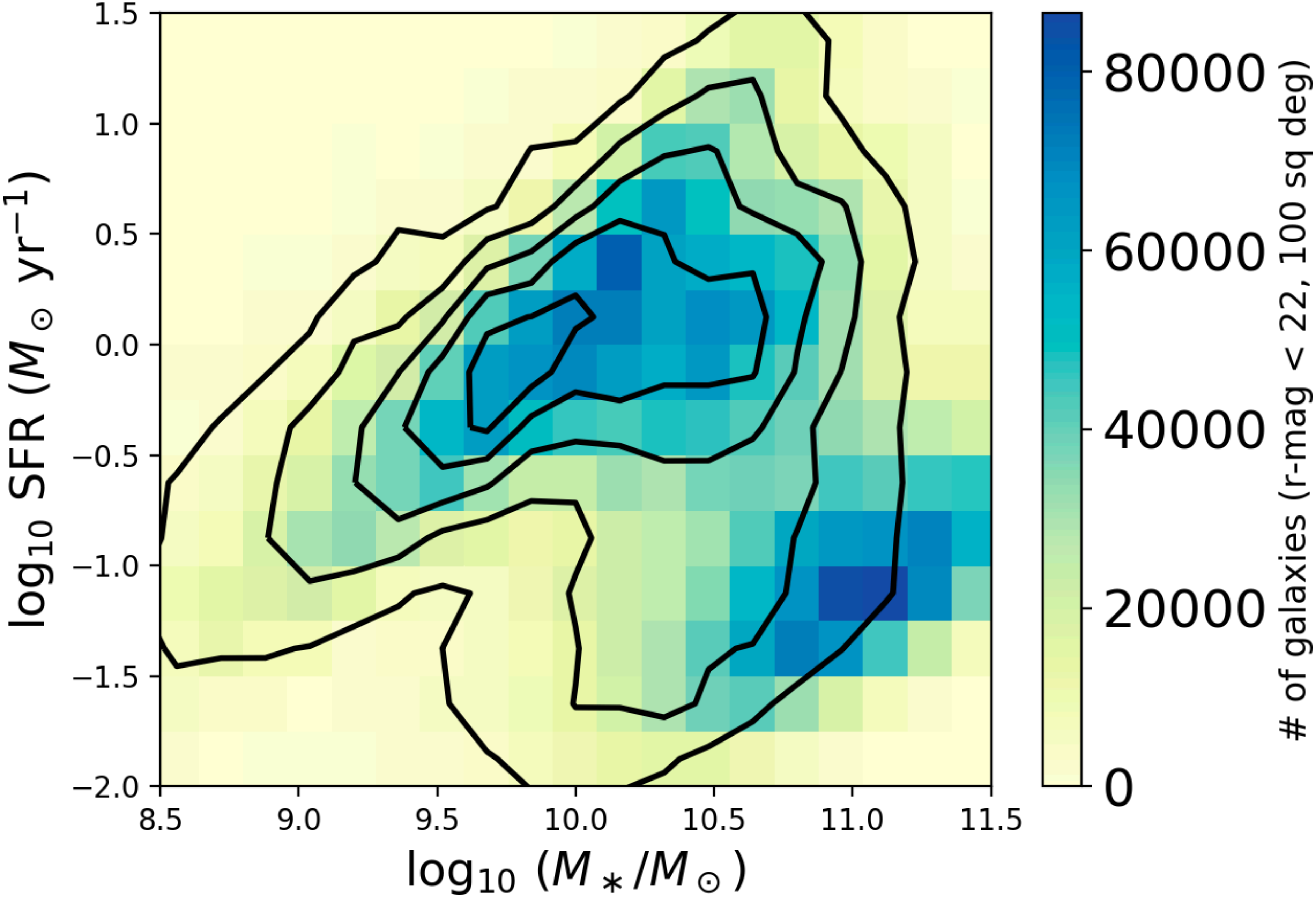
Number of galaxies in flux-limited survey



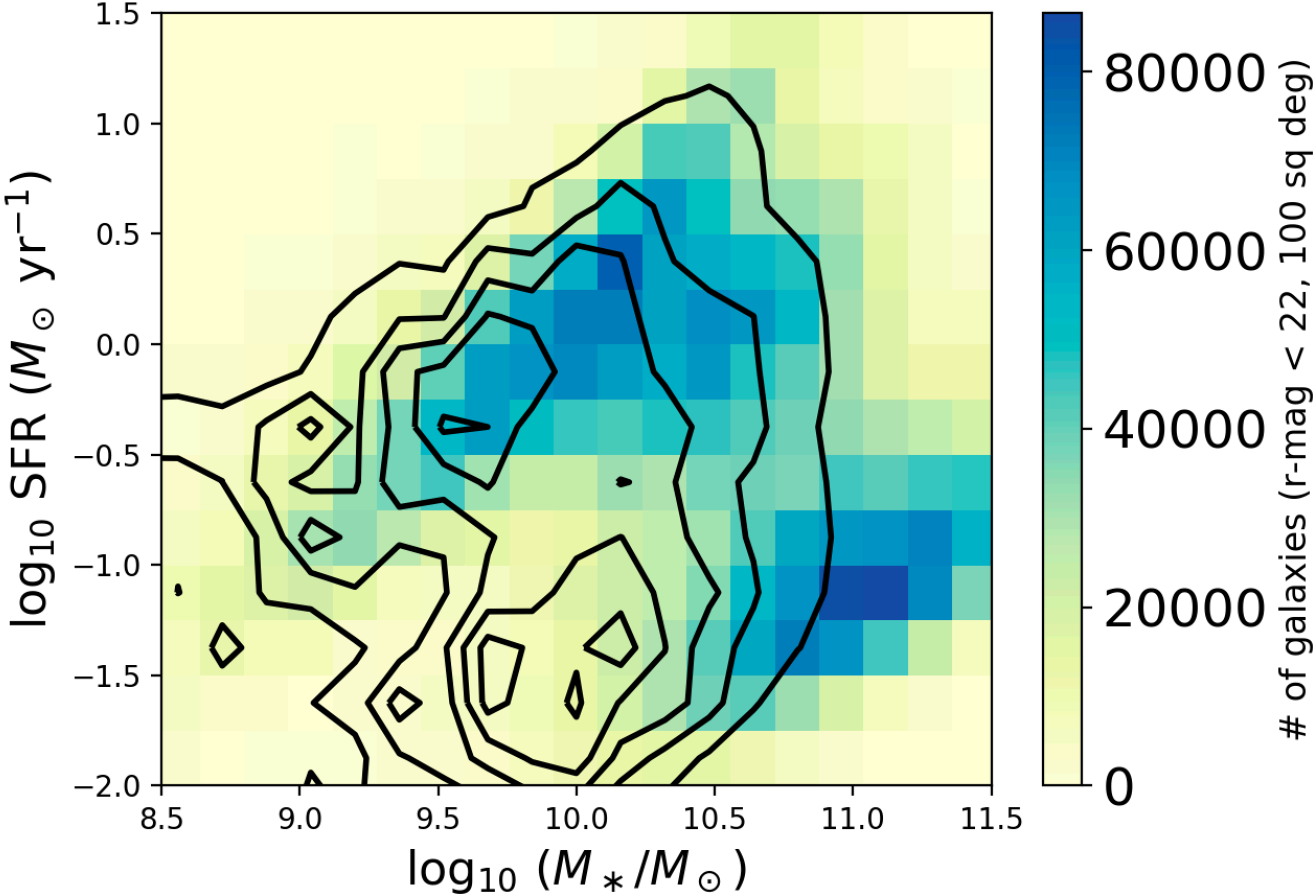
Account for Hills mass



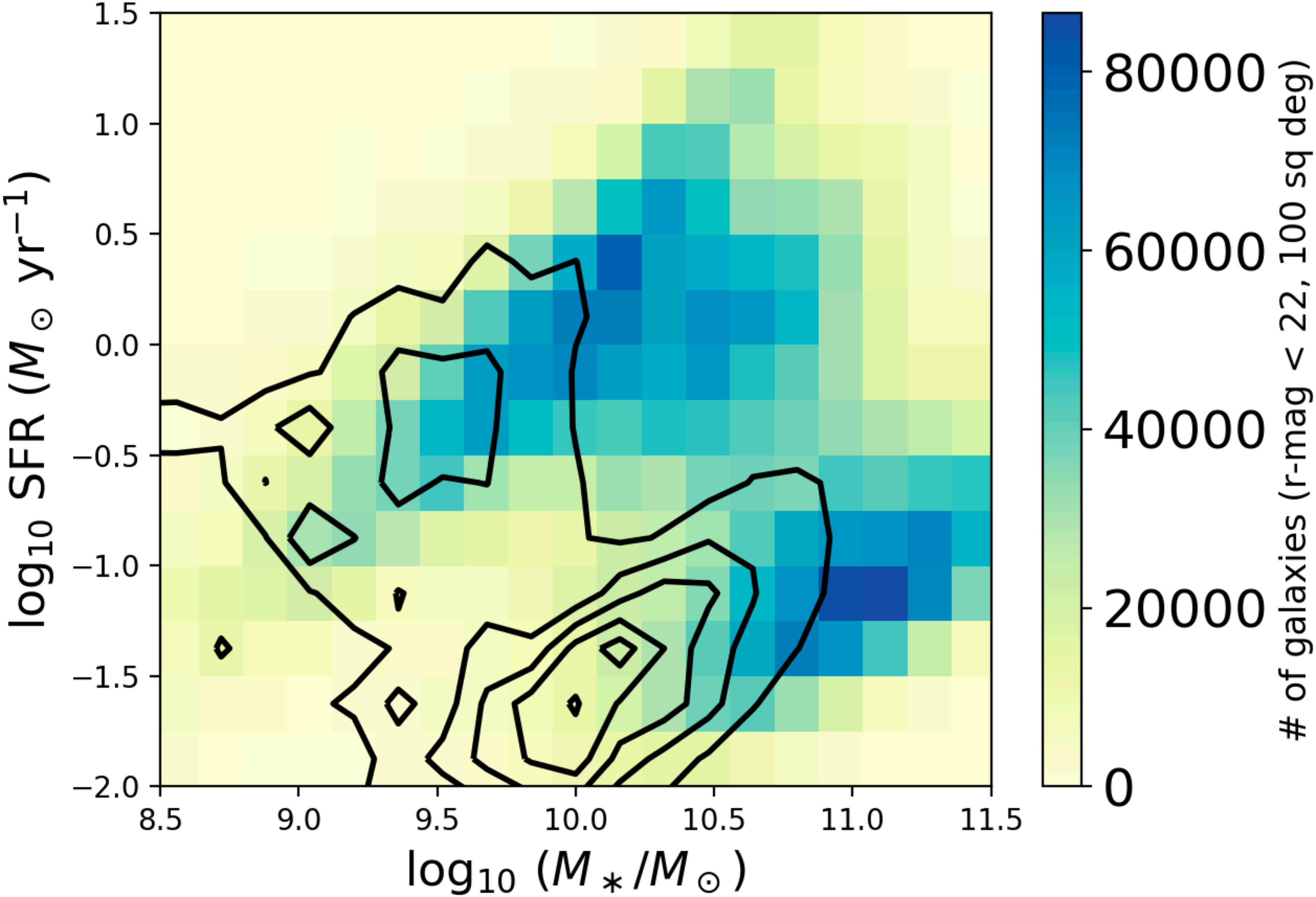
Account for Hills mass and Nuker γ



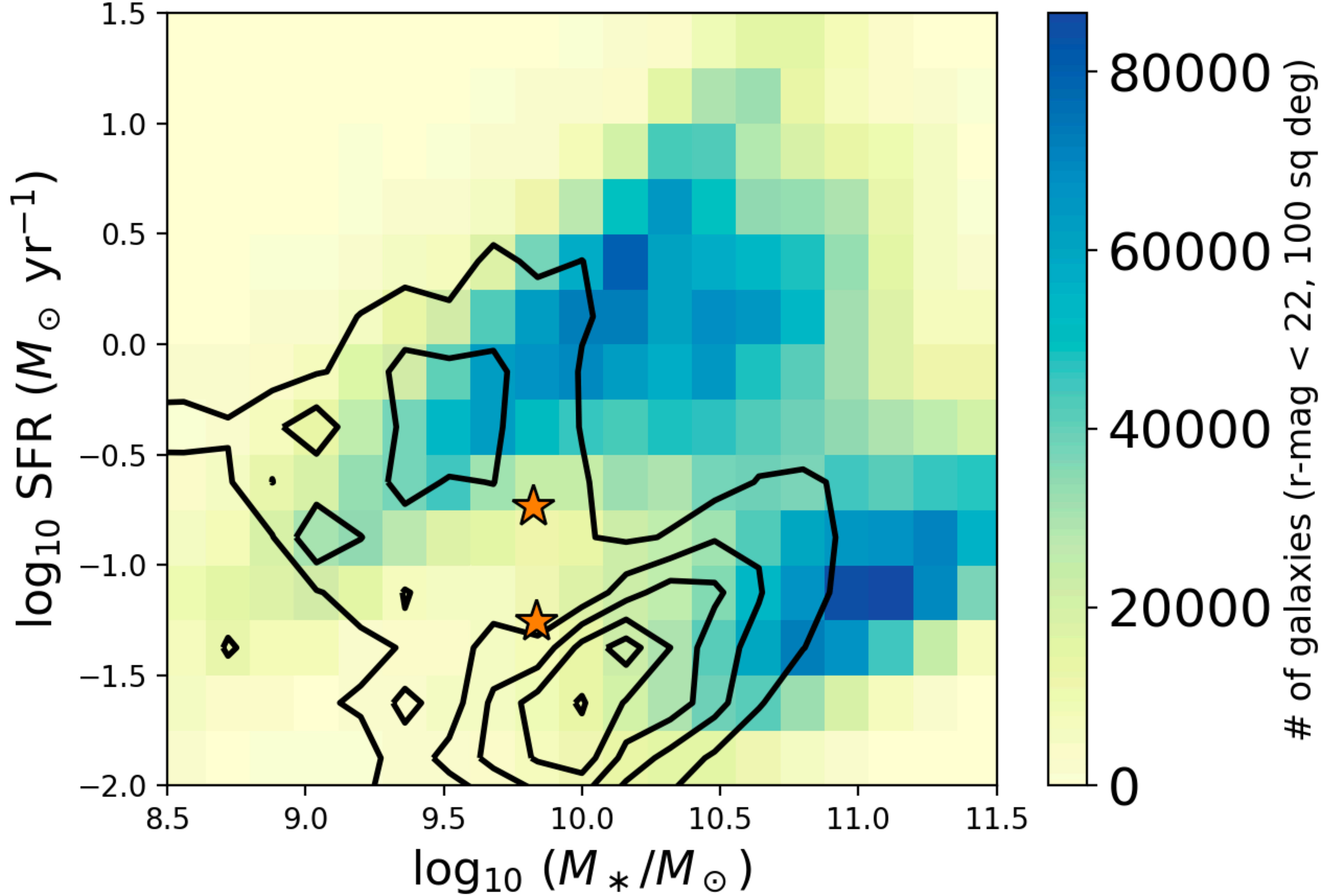
Apply survey selection cuts on flux



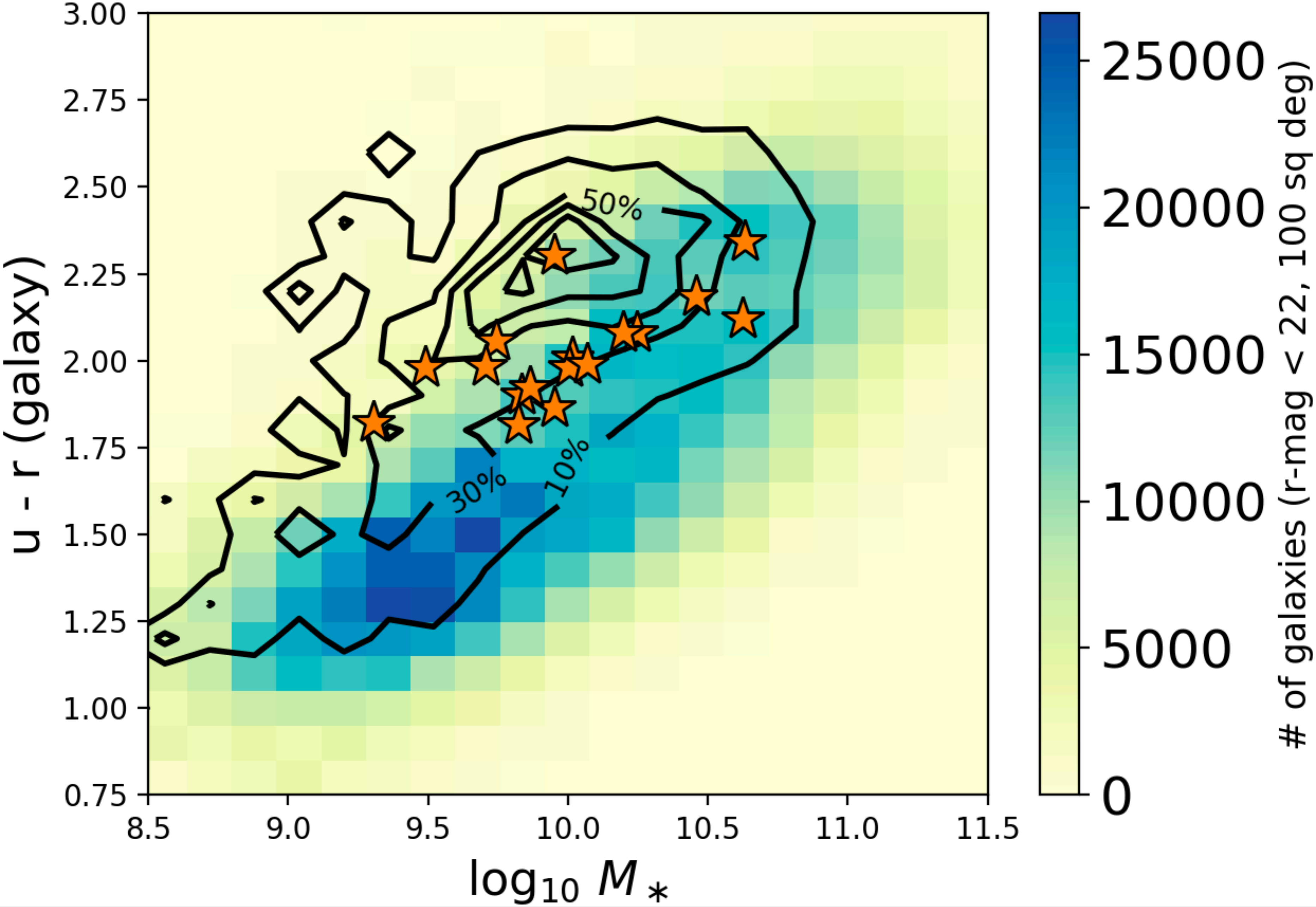
Account for dust obscuration in host



Plot ZTF hosts with existing SFR measurements



Results galaxy u - r



Conclusions

- The over-representation of TDEs detected in the green valley and lower mass red galaxies is partially reproduced in forward modelling using standard assumptions…
- … but only if we account for what we know about dust in star-forming galaxies, and how that should affect detection efficiency
- We expect to be missing at least half the flares that are intrinsically bright enough to be detectable because they are obscured by dust or because they don’t stand out enough against the light of their host
- The modeling favors slightly more quiescent galaxies than the real observations, and higher black hole masses
- We now have a tool to predict TDE detections in various galaxy populations, which is adaptable and can be applied to future surveys