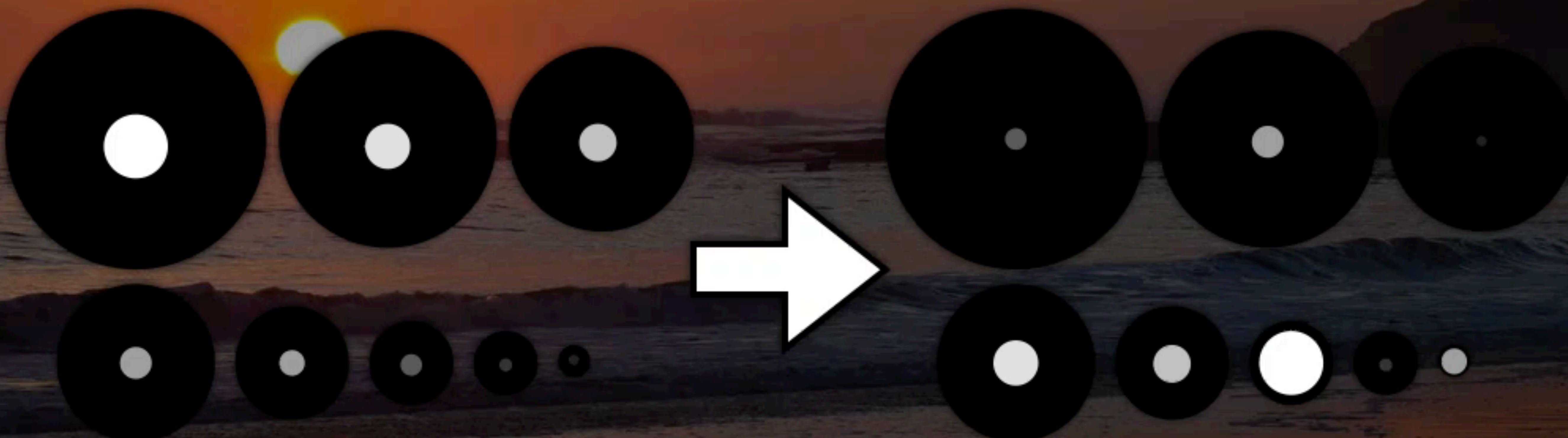
Scatter Carefully:

Constraining the faint end of the halo-galaxy connection with the Local Group

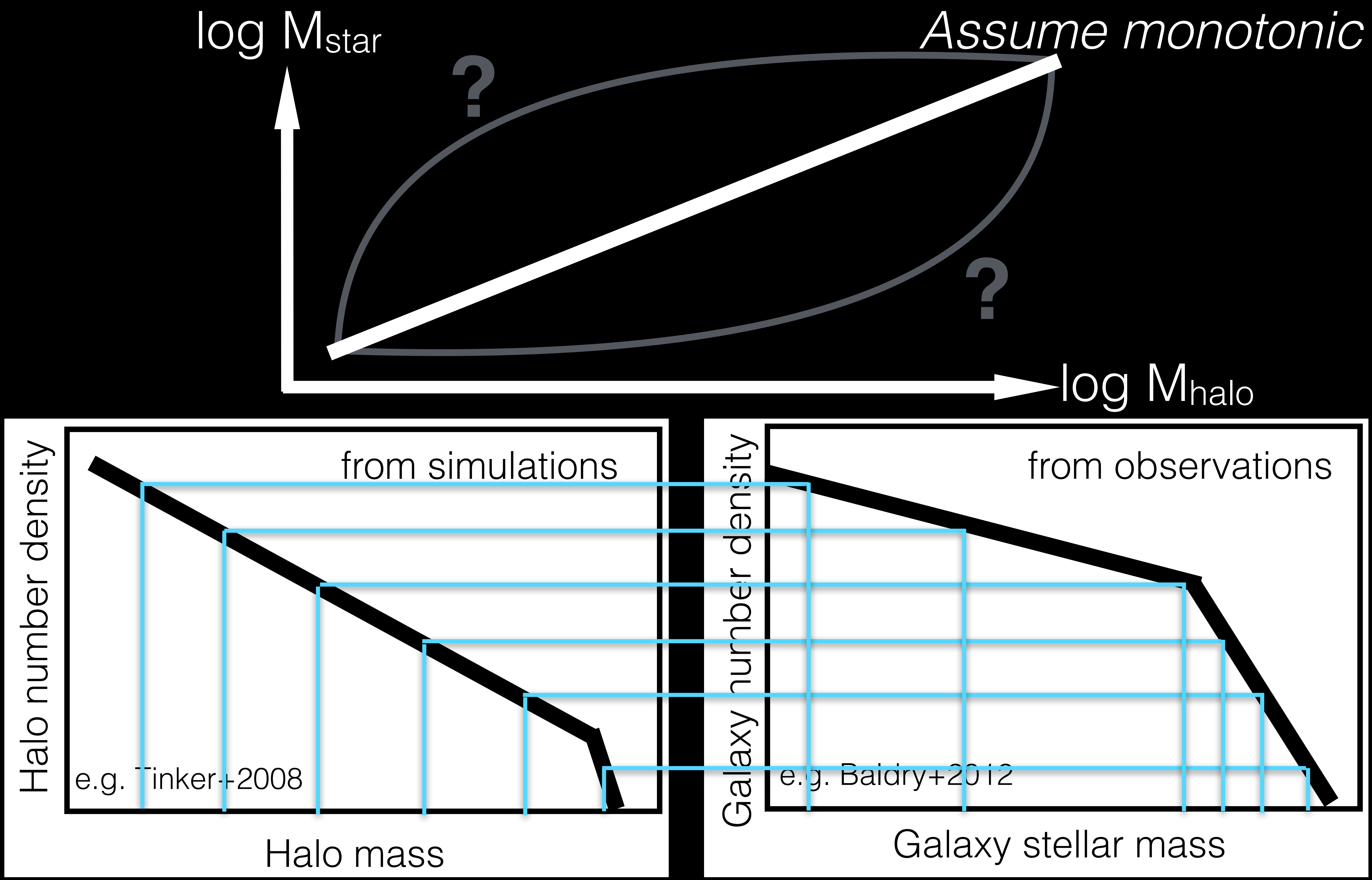


Shea Garrison-Kimmel

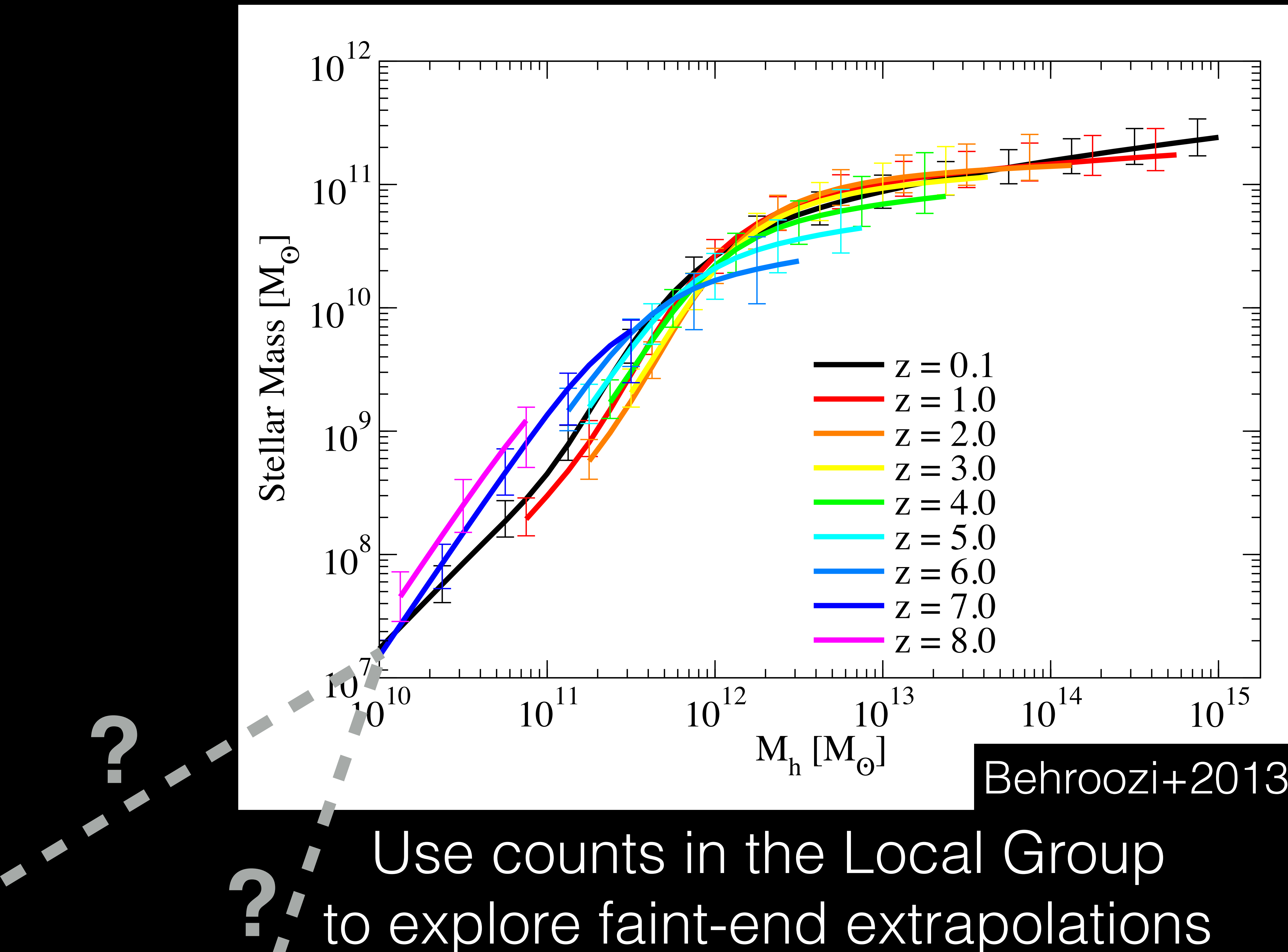
Caltech

with Emma Bardwell (Case Western), James Bullock (UC Irvine), and Mike Boylan-Kolchin (Texas)

Abundance matching



Abundance matching



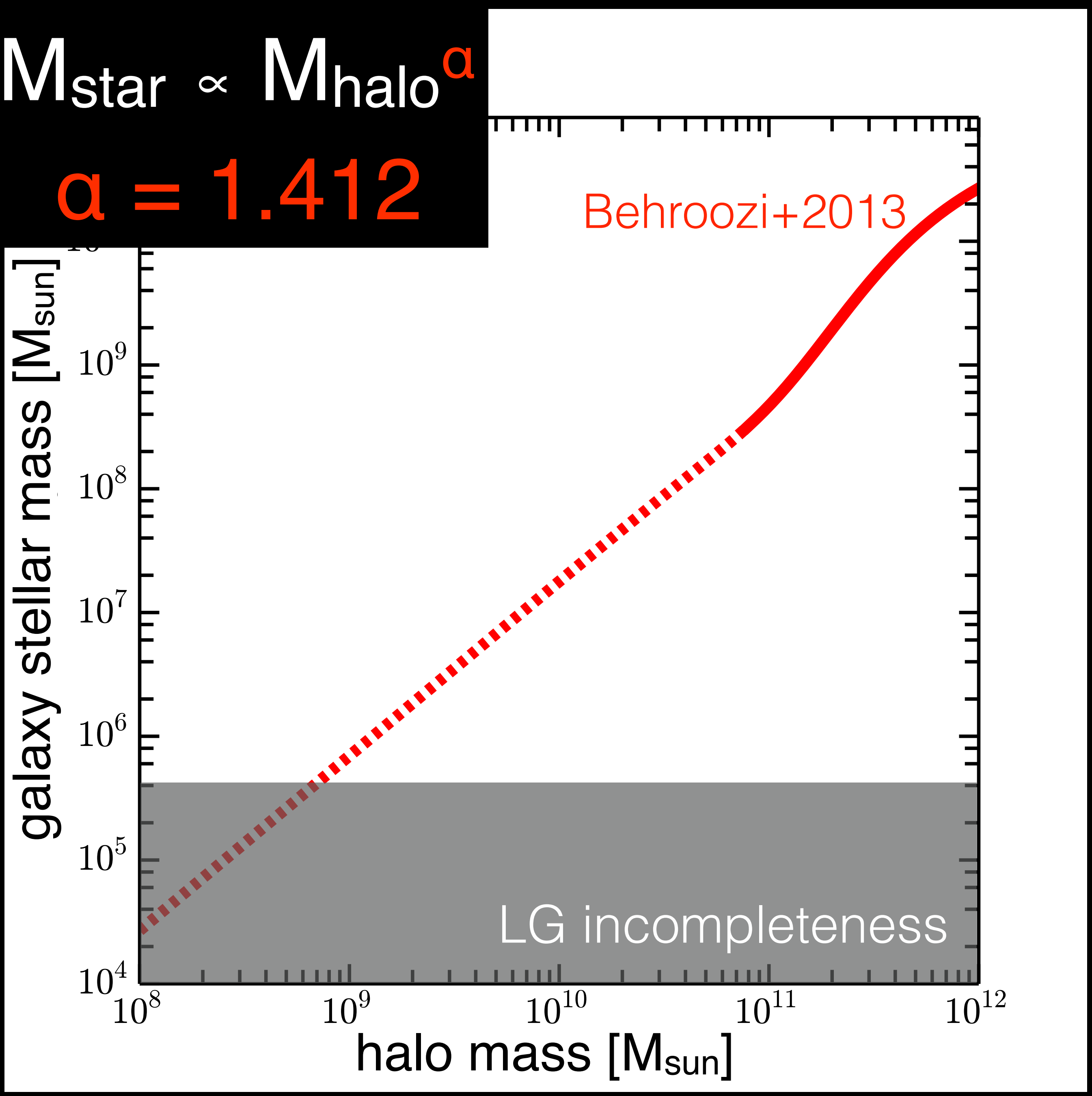
Behroozi+2013

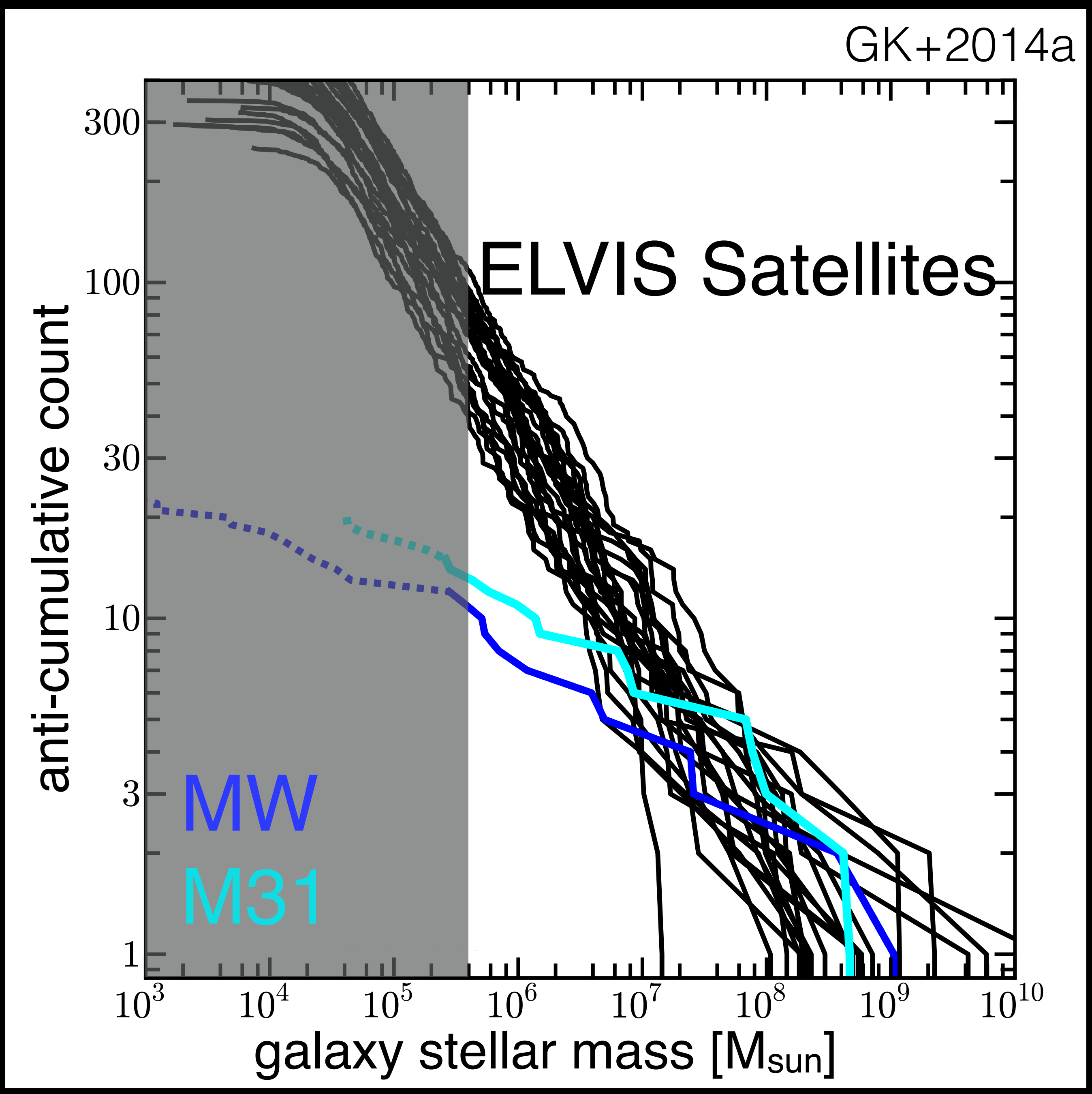
Use counts in the Local Group
to explore faint-end extrapolations

Abundance matching in the LG

$M_{star} \propto M_{halo}^{\alpha}$

$\alpha = 1.412$



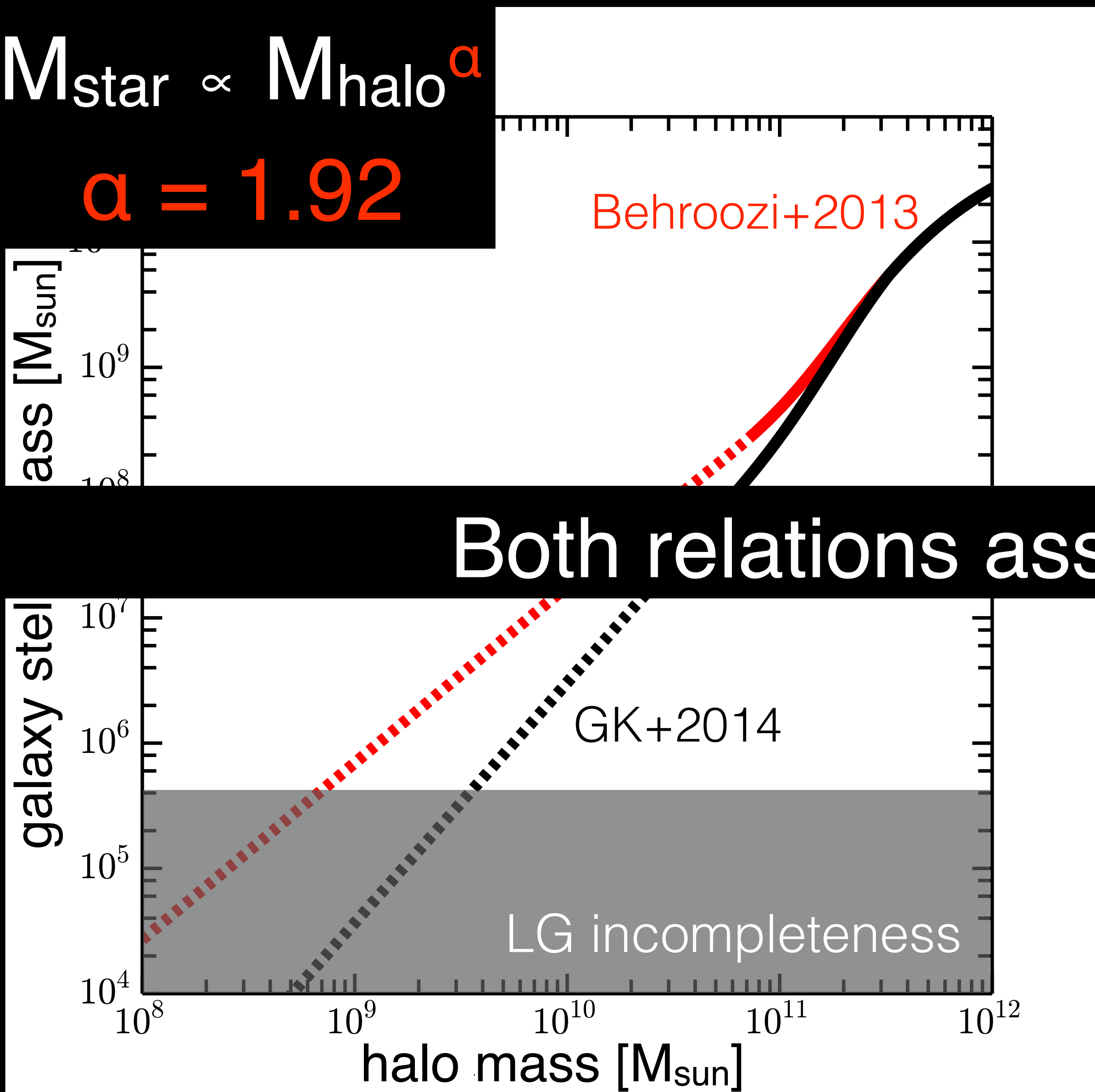


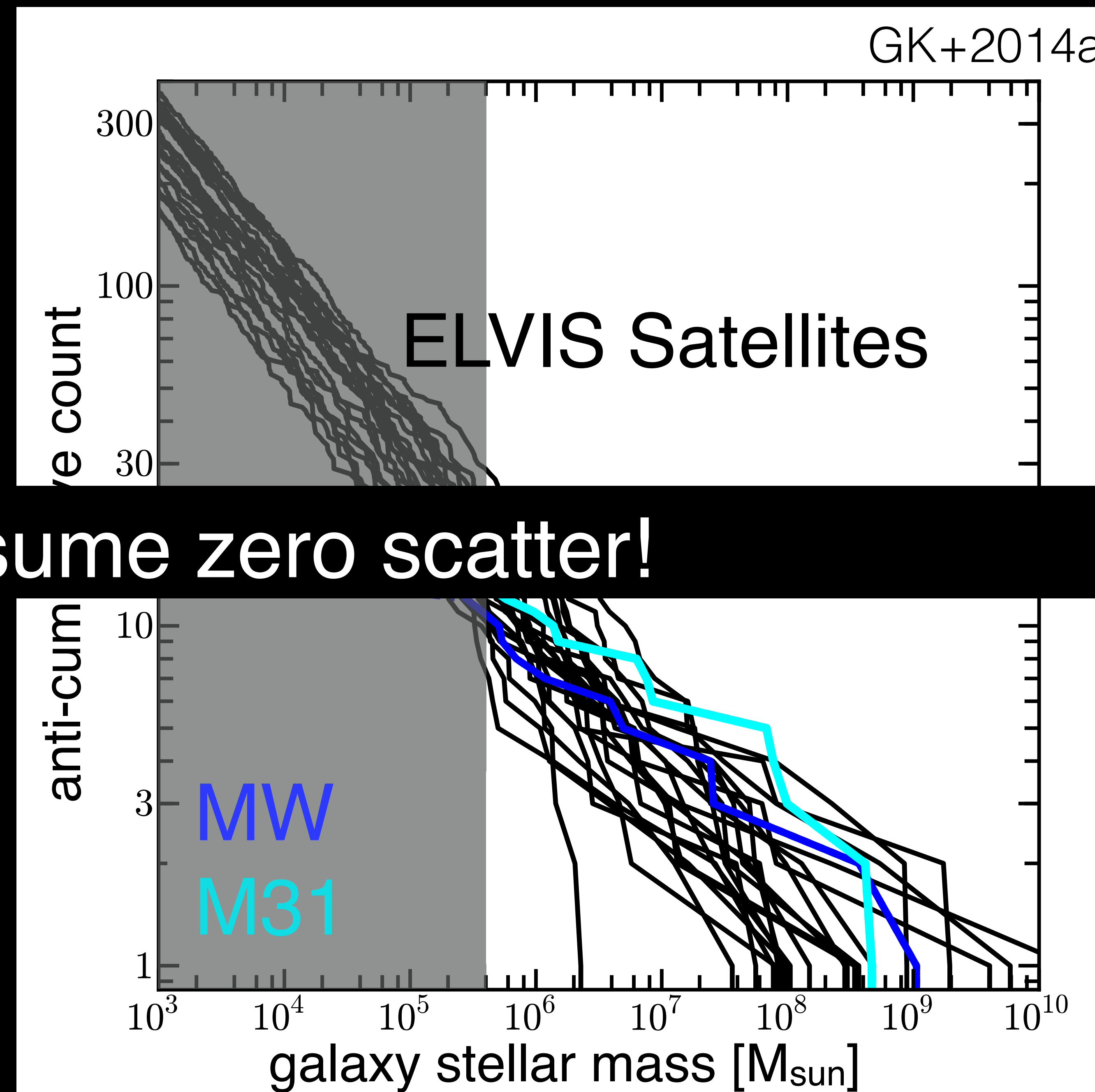
Behroozi+2013 AM predicts too many faint galaxies in the LG when applied to LG-like simulations

Abundance matching in the LG

$M_{star} \propto M_{halo}^{\alpha}$

$\alpha = 1.92$





Both relations assume zero scatter!

Modified Behroozi+2013 using a steeper low-mass slope (Baldry+2012) agrees well

But we know scatter exists at higher masses…

What is the scatter at the low mass end?

Can we constrain it with the LG?

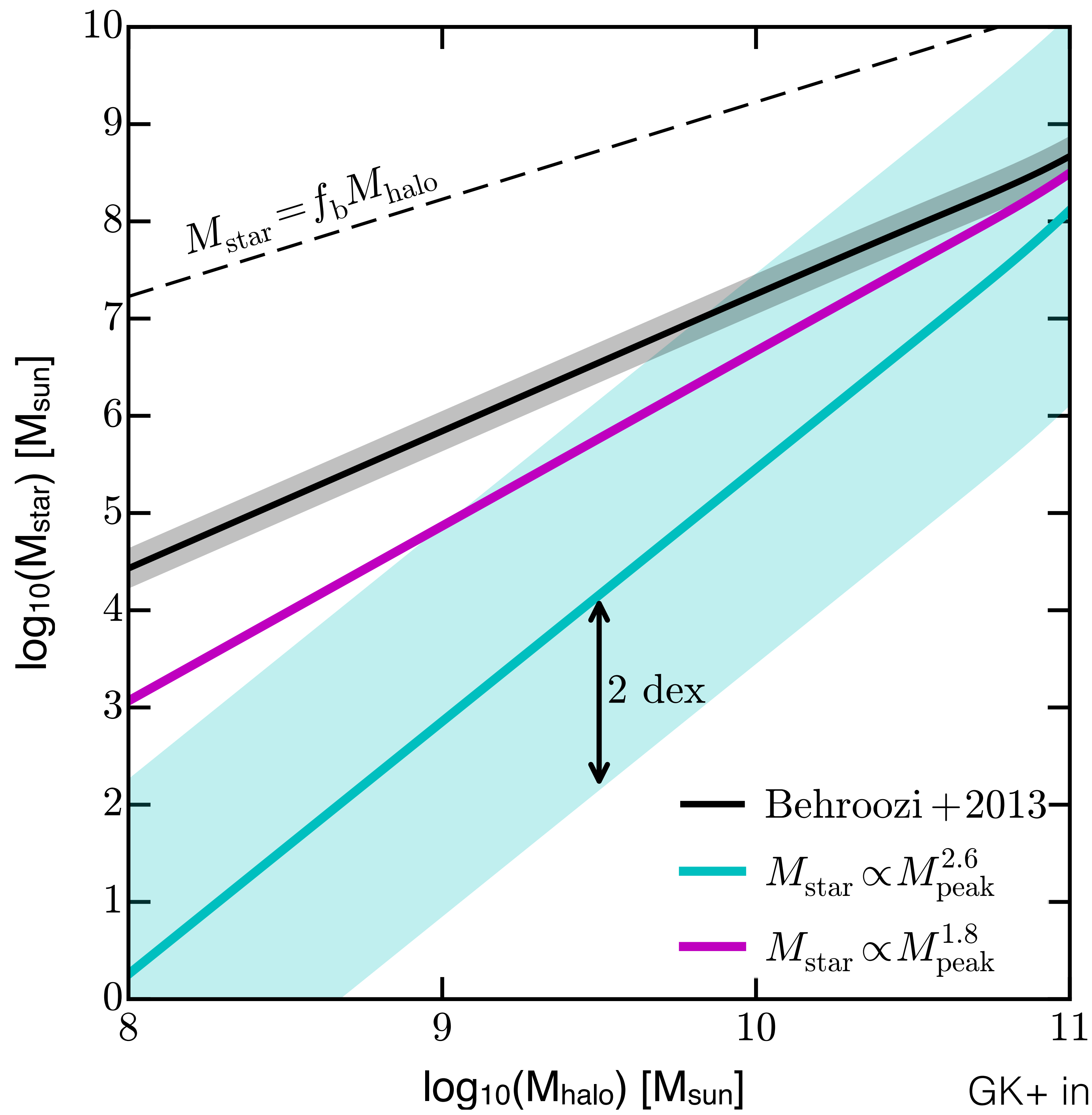
What are the implications of large scatter?

e.g., on extant problems in ΛCDM?

Can the scatter suggested by simulations be correct?

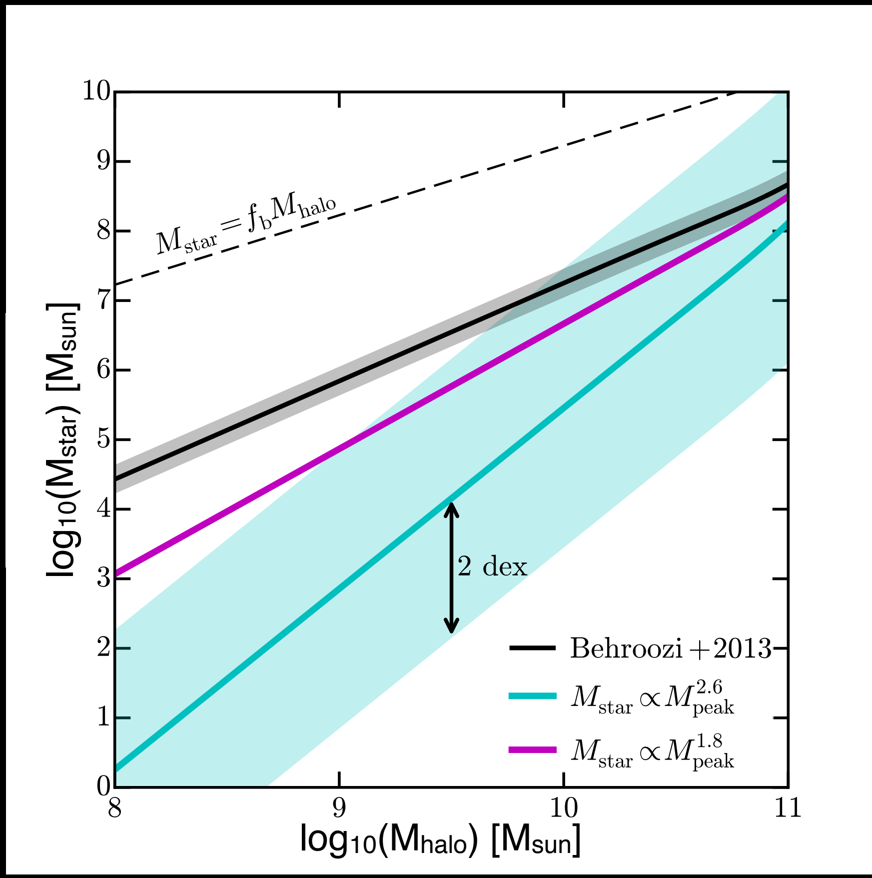
Will it correctly predict the LG?

The impact of scatter on mass functions

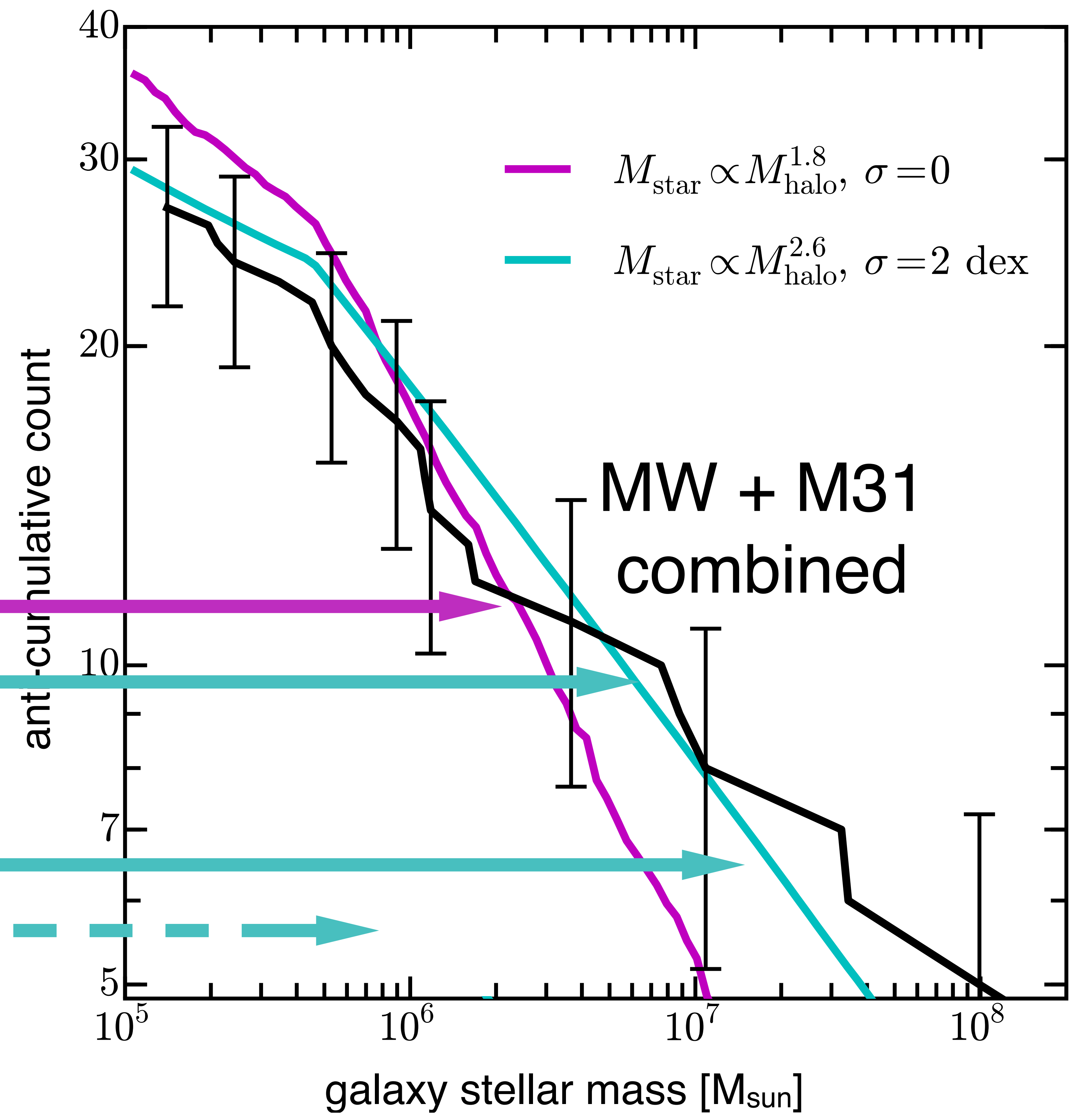


GK+ in prep

The impact of scatter on mass functions



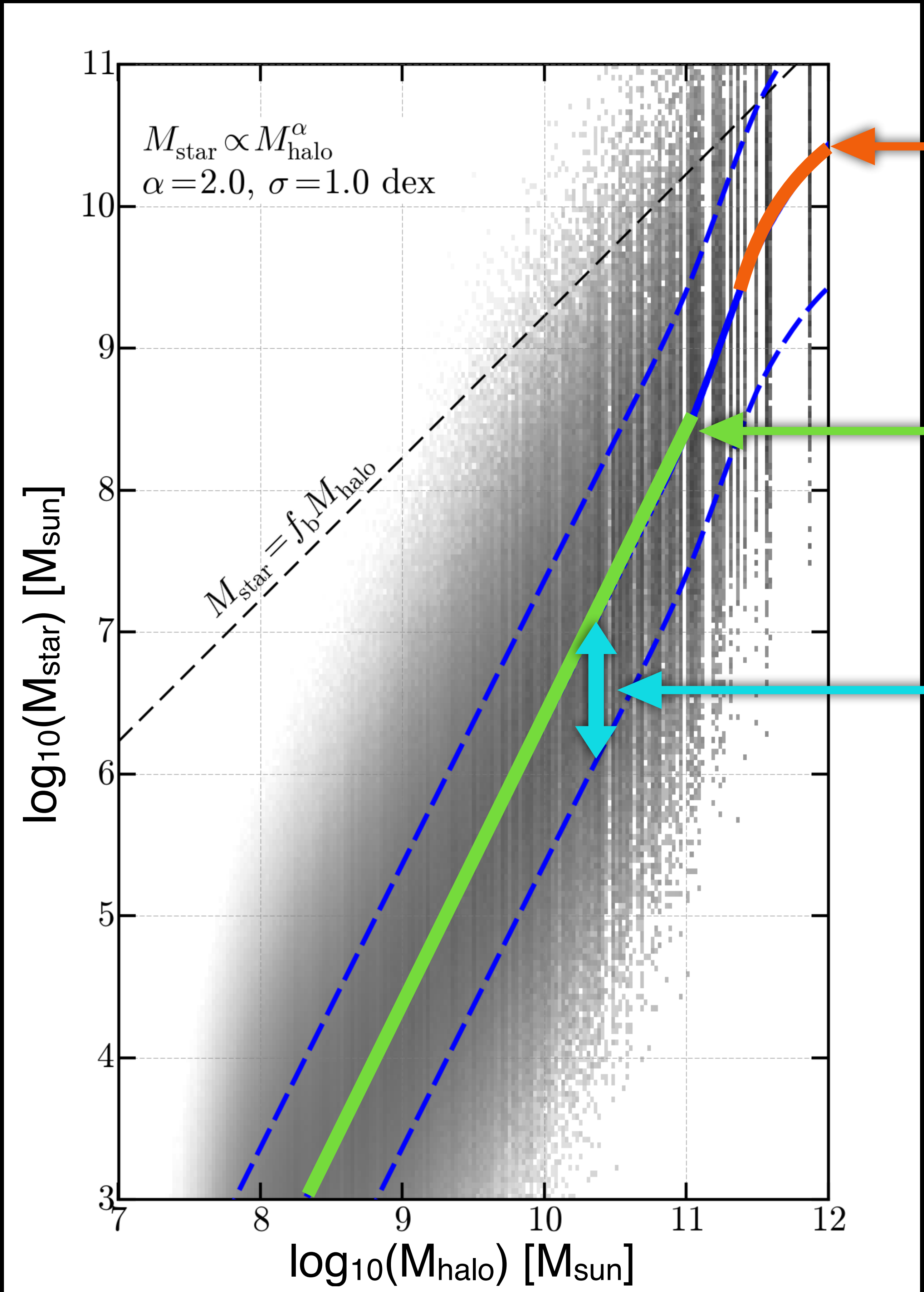
GK+ in prep



Different slope and scatter

Same slope, different scatter

More realistic AM: adding scatter



Pegged to Behroozi+2013

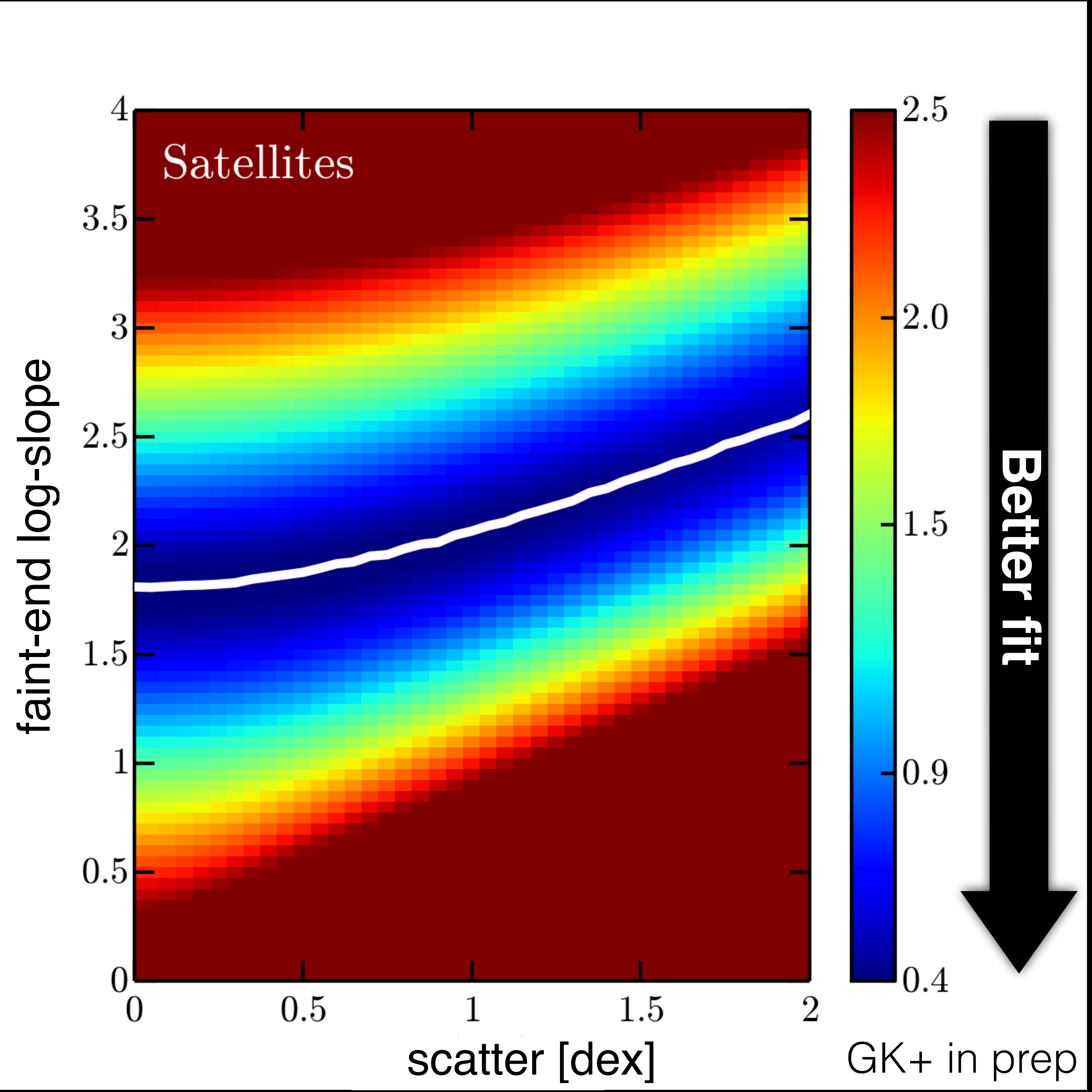
Low mass ($M_{\rm halo} \lesssim 10^{11} M_{\rm sun}$) log-slope α allowed to vary freely

Assume symmetric, log-normal scatter, which also varies freely
(quoted σ is one standard deviation)

Tested many models for assigning stellar mass to halos (one-sided or variable scatter, $M_{\rm star} < f_{\rm b} M_{\rm halo}$, cut-offs in star formation, etc.)

All yield qualitatively similar results!

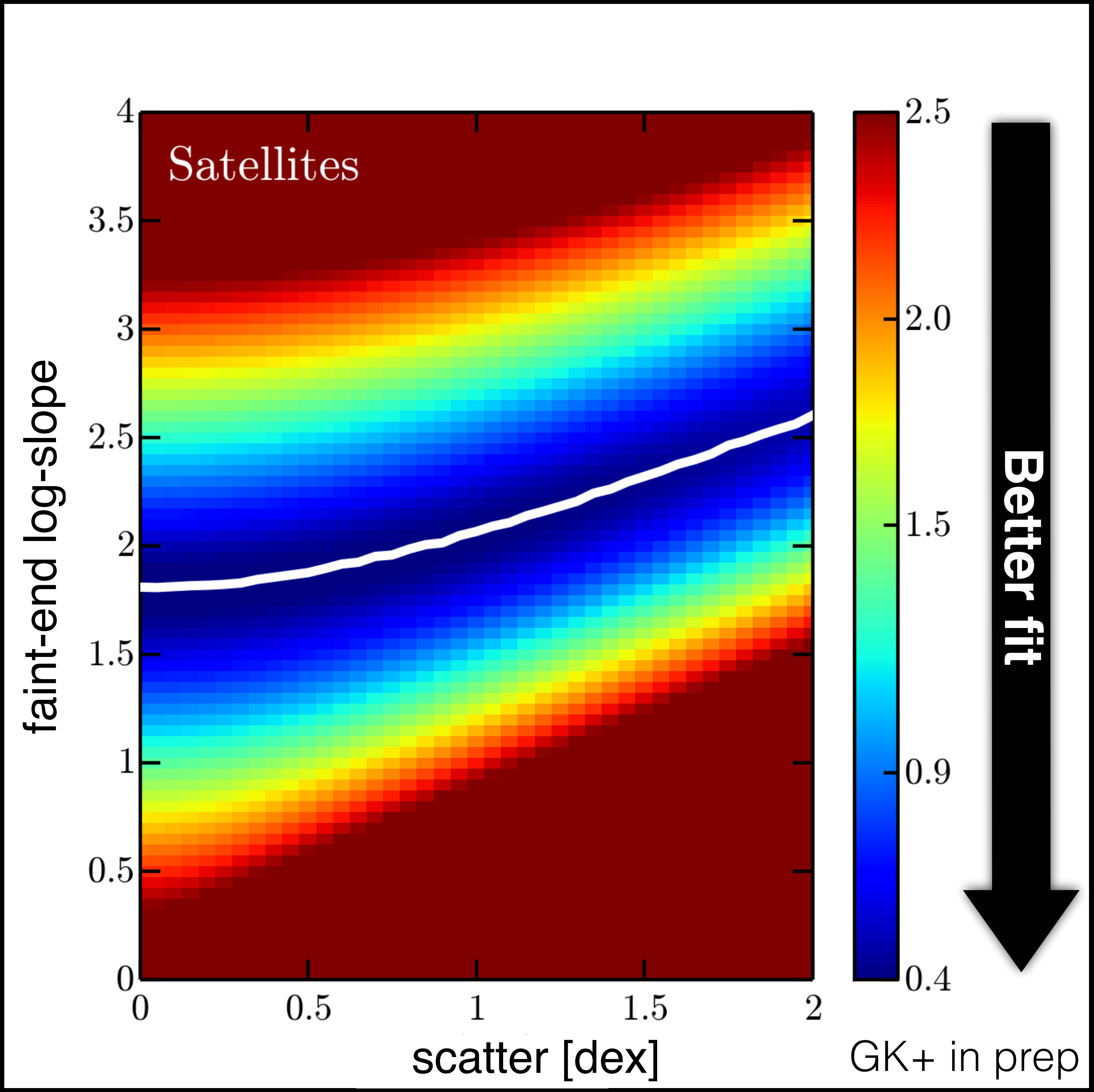
Scatter and slope are degenerate



Averaged over 24 systems, each with 500 realizations

⇒ **12,000 realizations per combination of σ and α**

Scatter and slope are degenerate



Qualitatively identical results using the Local Field

Effects of large σ: too-big-to-fail

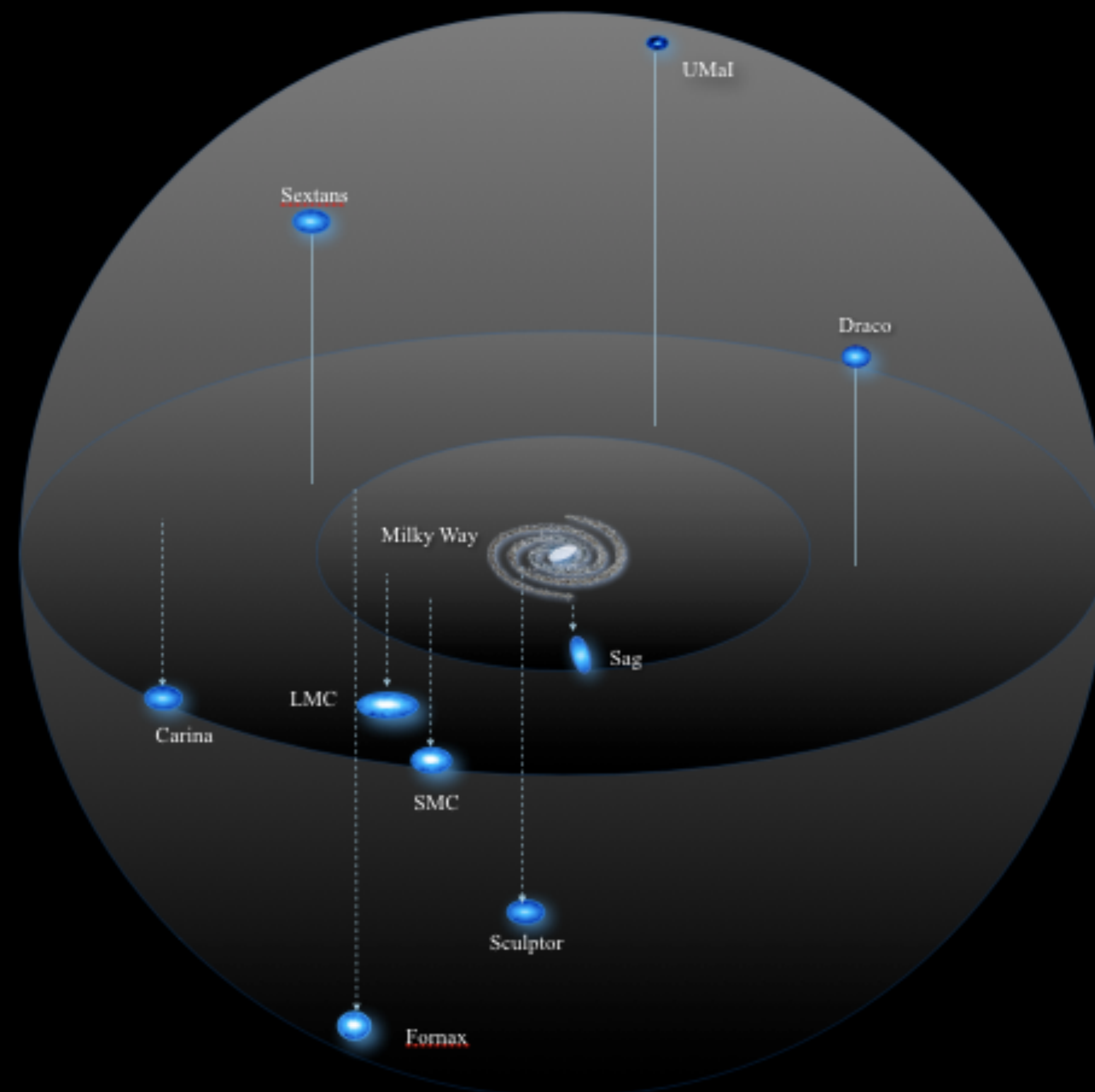
What is too-big-to-fail?

Theory: $N_{subhalos} \gg 1000$

Klypin et al. 1999; Moore et al. 1999; Kauffmann et al. 1993

What is too-big-to-fail?

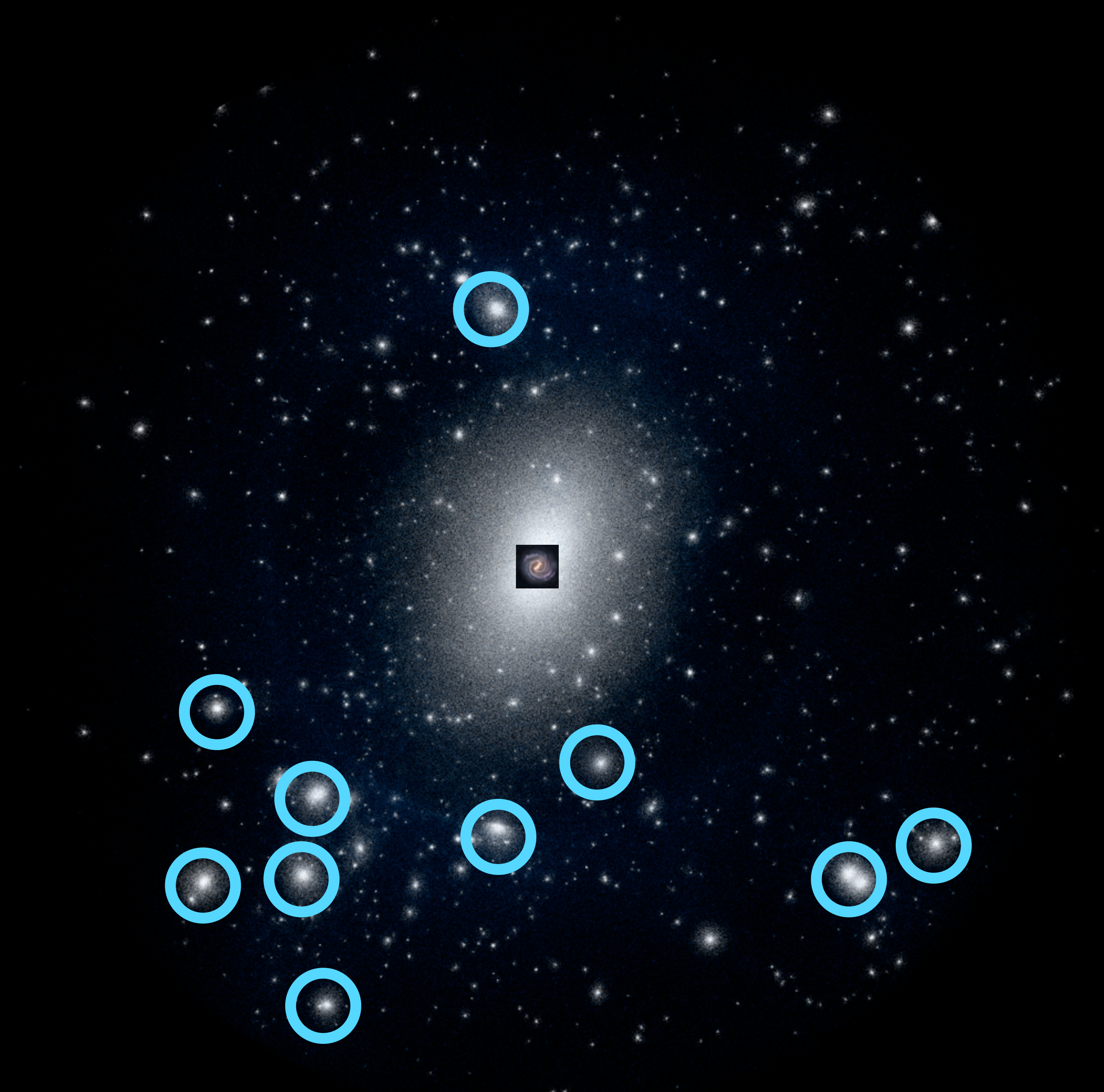
Theory: $N_{subhalos} \gg 1000$

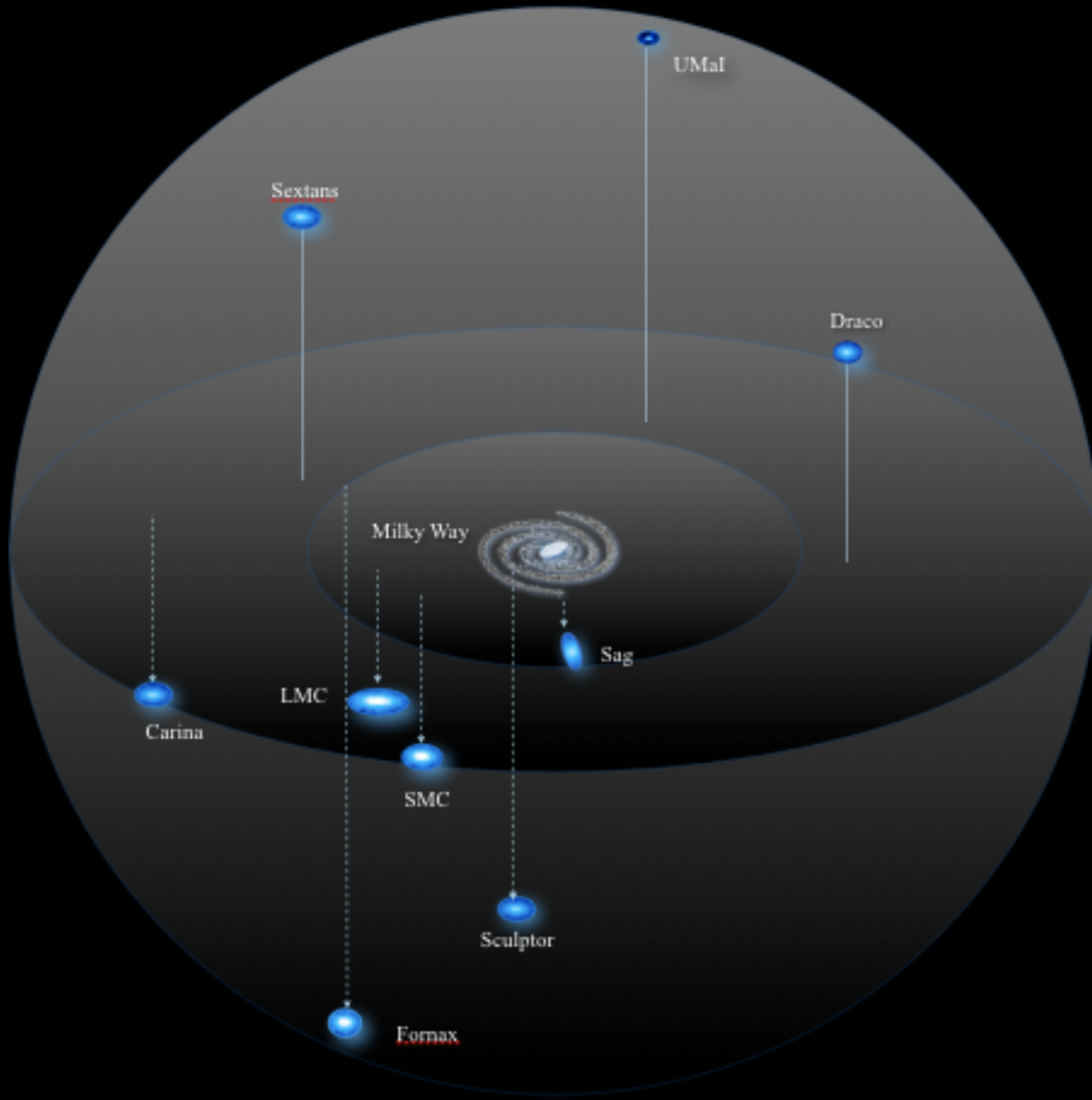


Observations: $N_{galaxies} \sim 10$

Klypin et al. 1999; Moore et al. 1999; Kauffmann et al. 1993

What is too-big-to-fail?

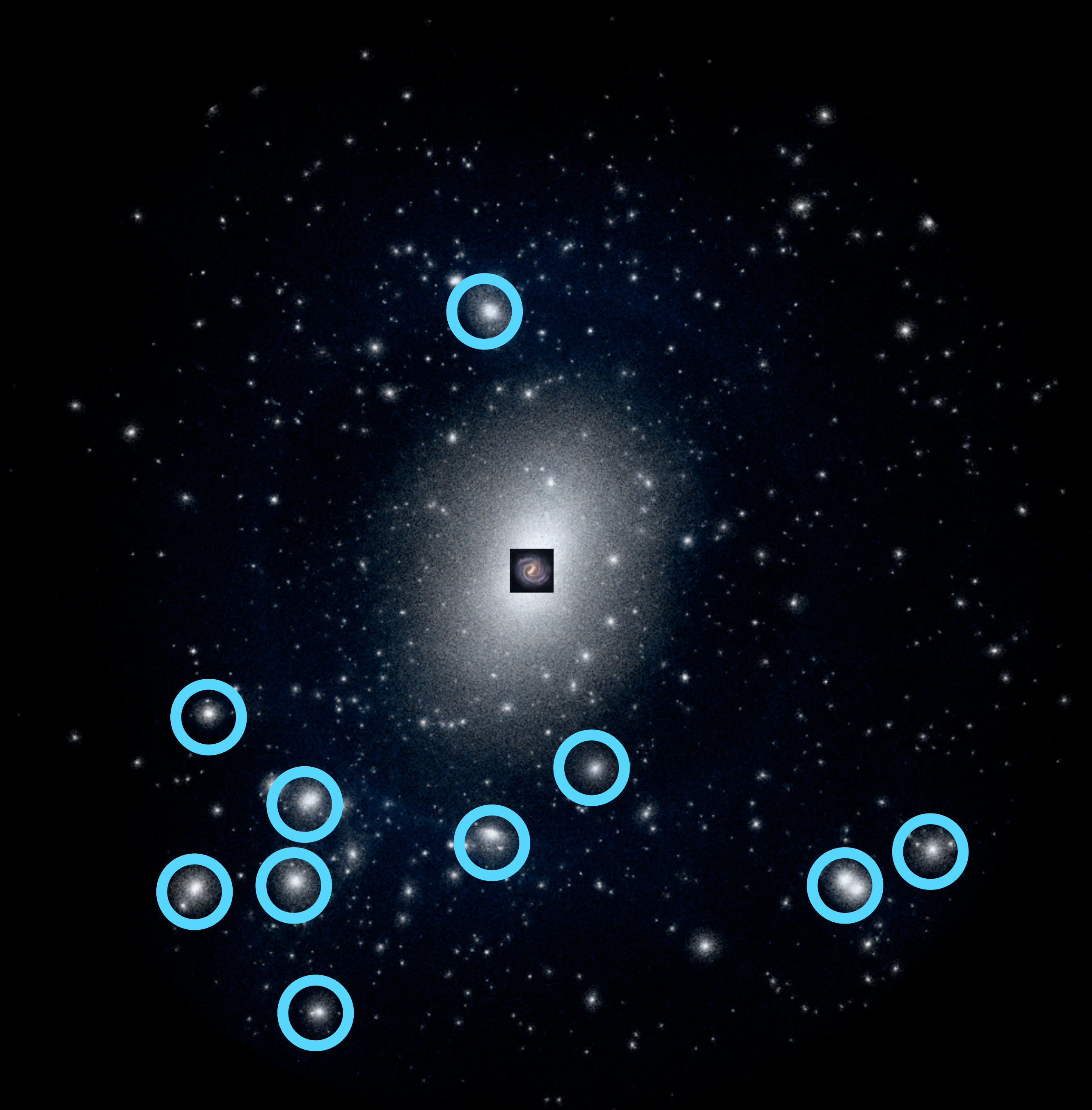


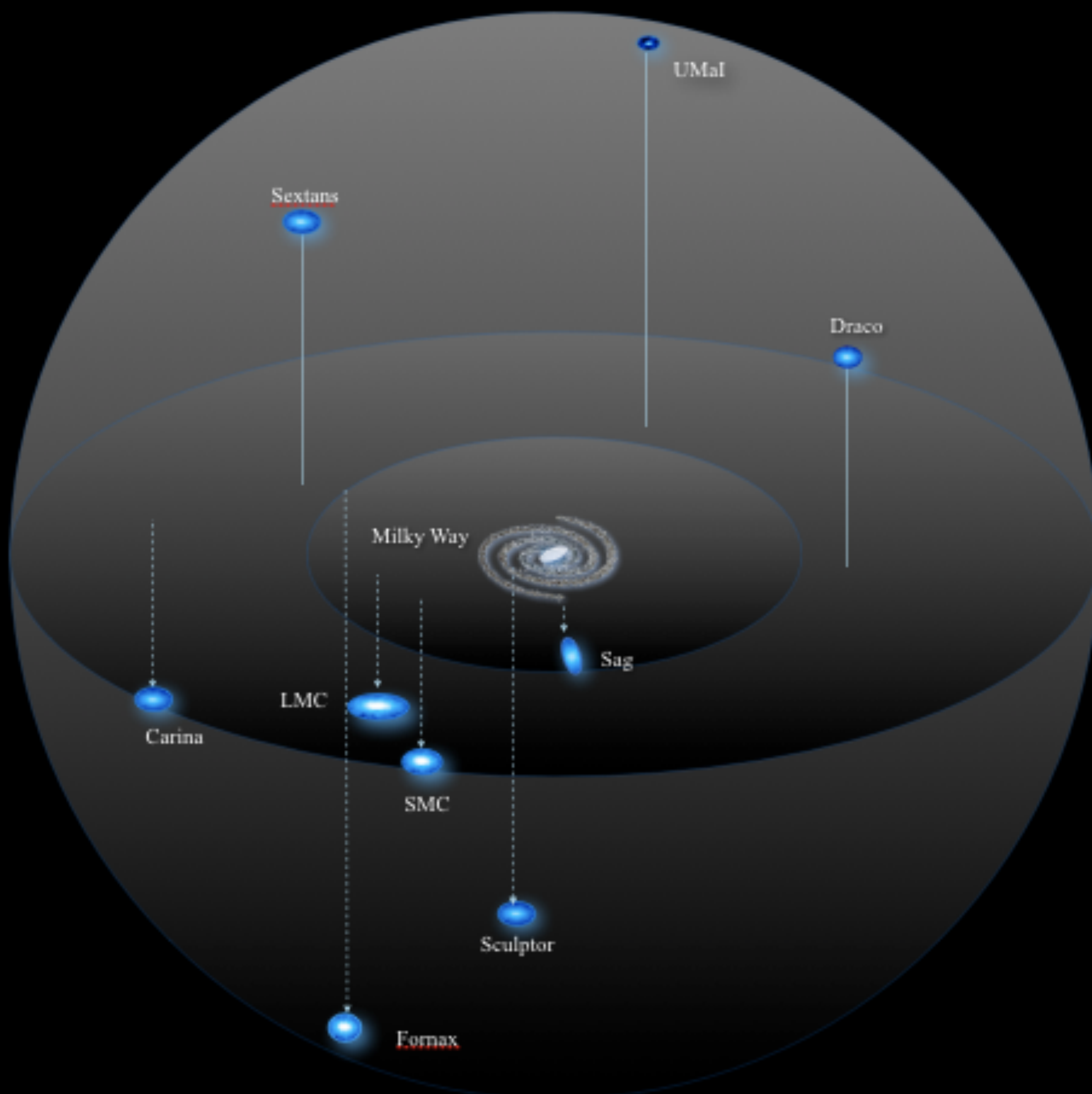


Obvious solution: only the largest clumps form stars and host galaxies

Klypin et al. 1999; Moore et al. 1999; Kauffmann et al. 1993

What is too-big-to-fail?



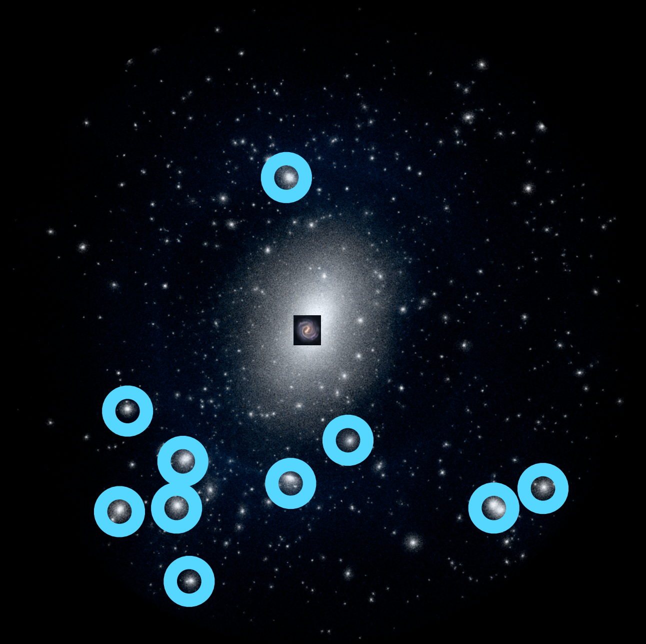


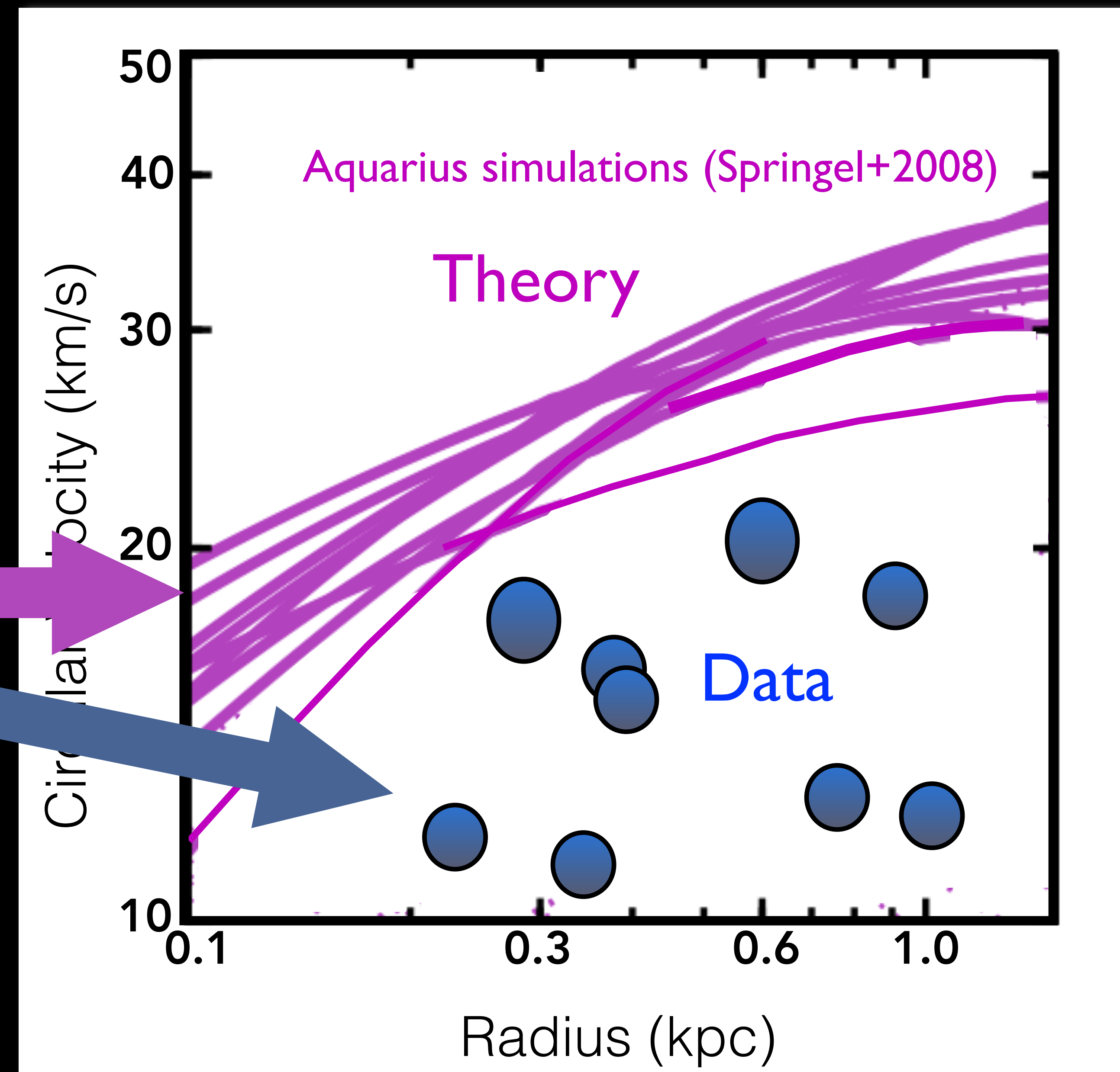
Does this actually work?

Klypin et al. 1999; Moore et al. 1999; Kauffmann et al. 1993

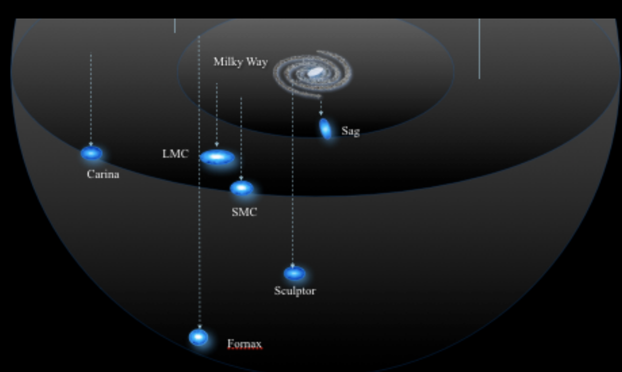
What is too-big-to-fail?

$$V_{\rm circ}(r) = \sqrt{\frac{GM(<r)}{r}}$$





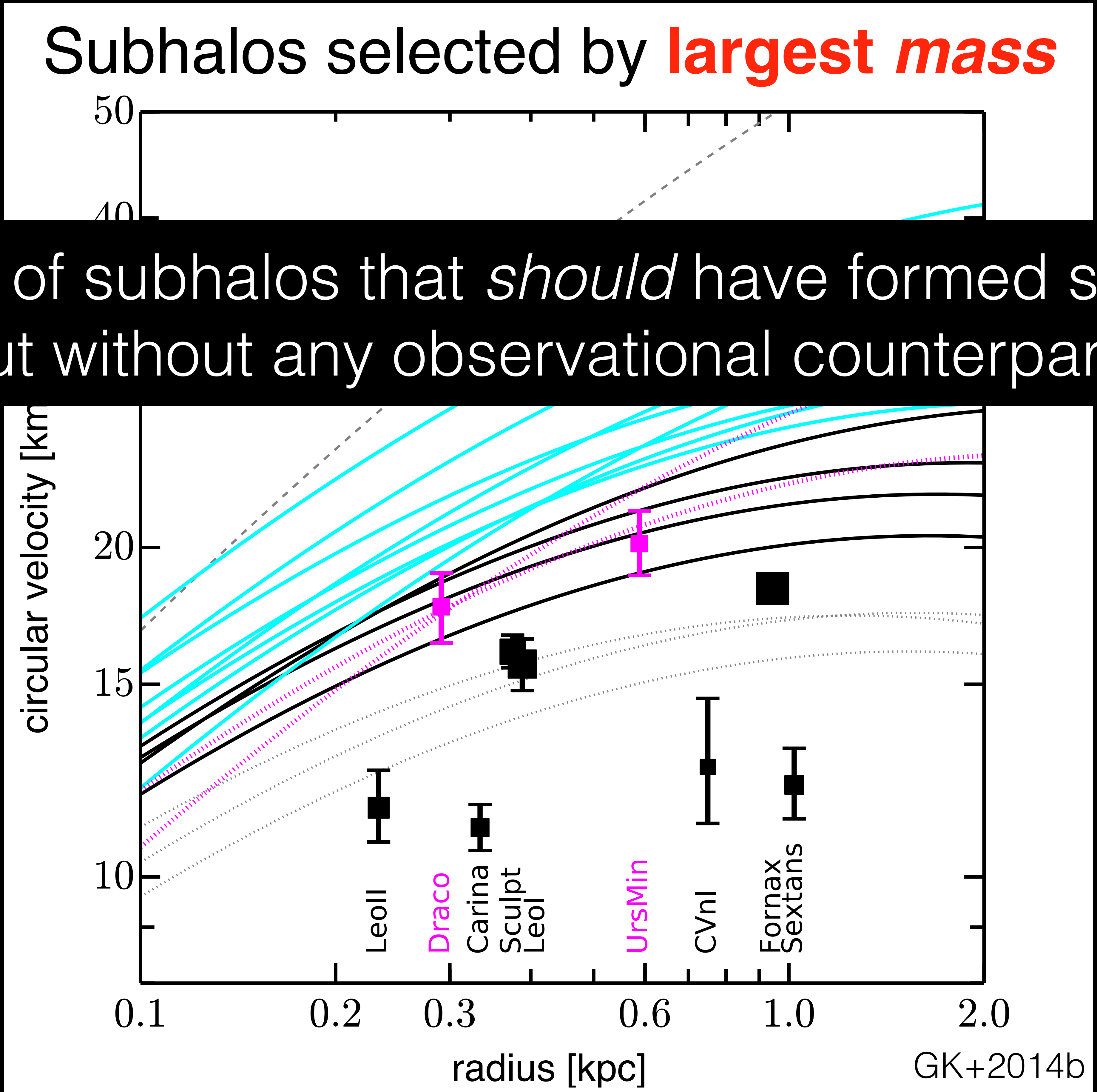
Massive subhalos are **too dense** to match the data



Does this actually work?

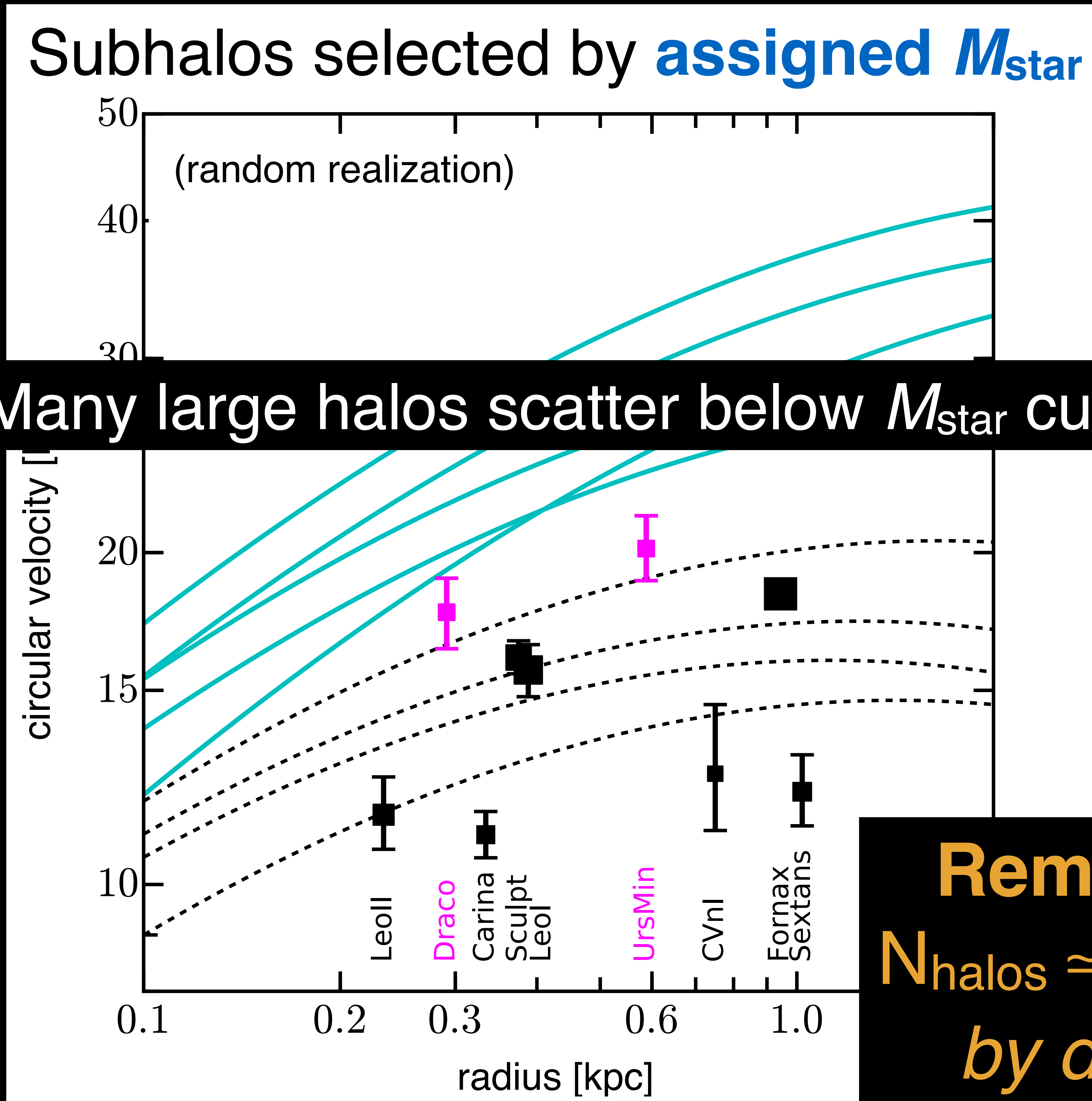
Boylan-Kolchin+2011,2012

Too big to fail



Lots of subhalos that *should* have formed stars,
but without any observational counterparts

TBTF with large scatter



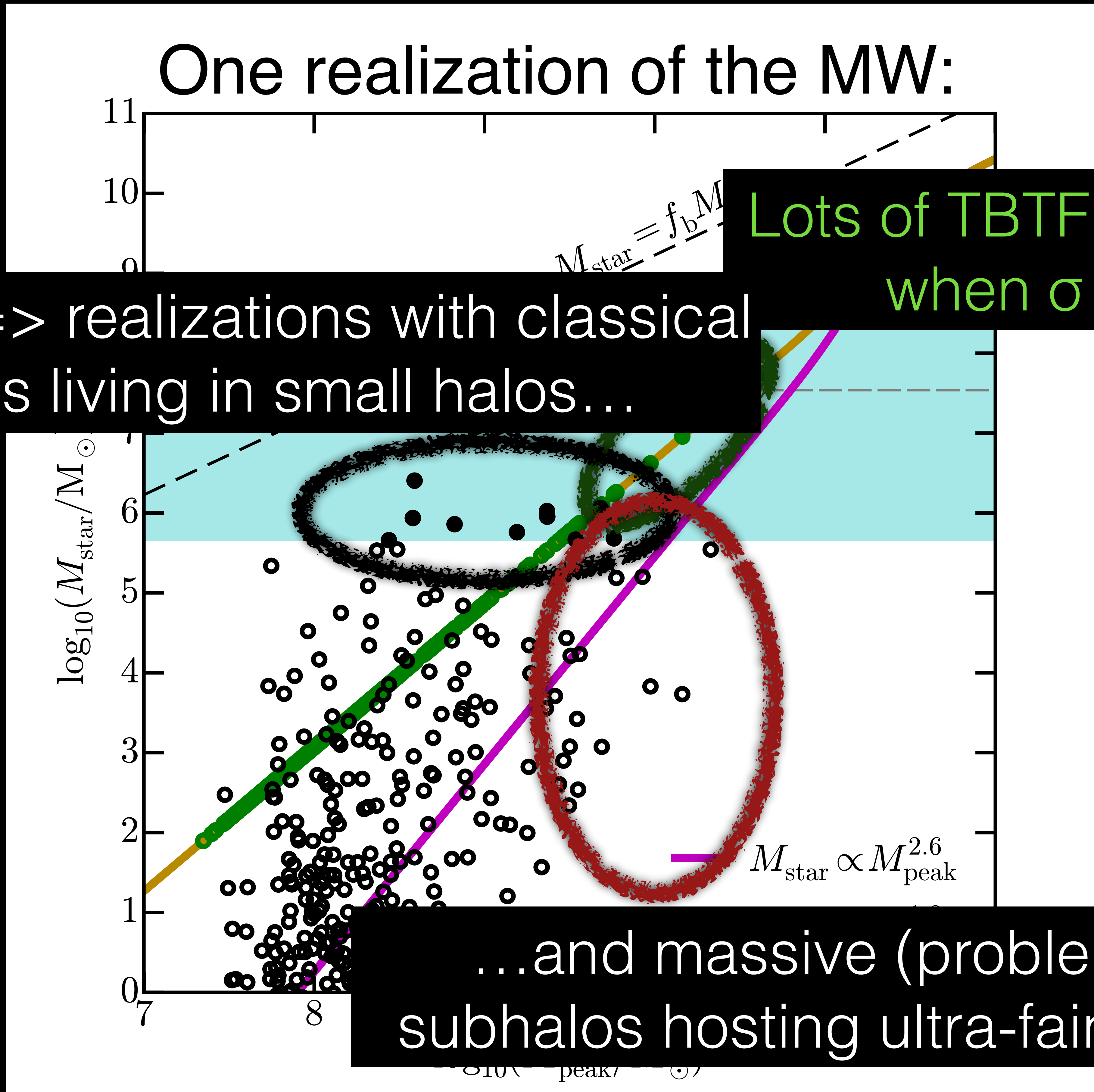
Many large halos scatter below M_{star} cut!

Reminder:

$N_{halos} \simeq N_{galaxies}$

by design

TBTF with large scatter

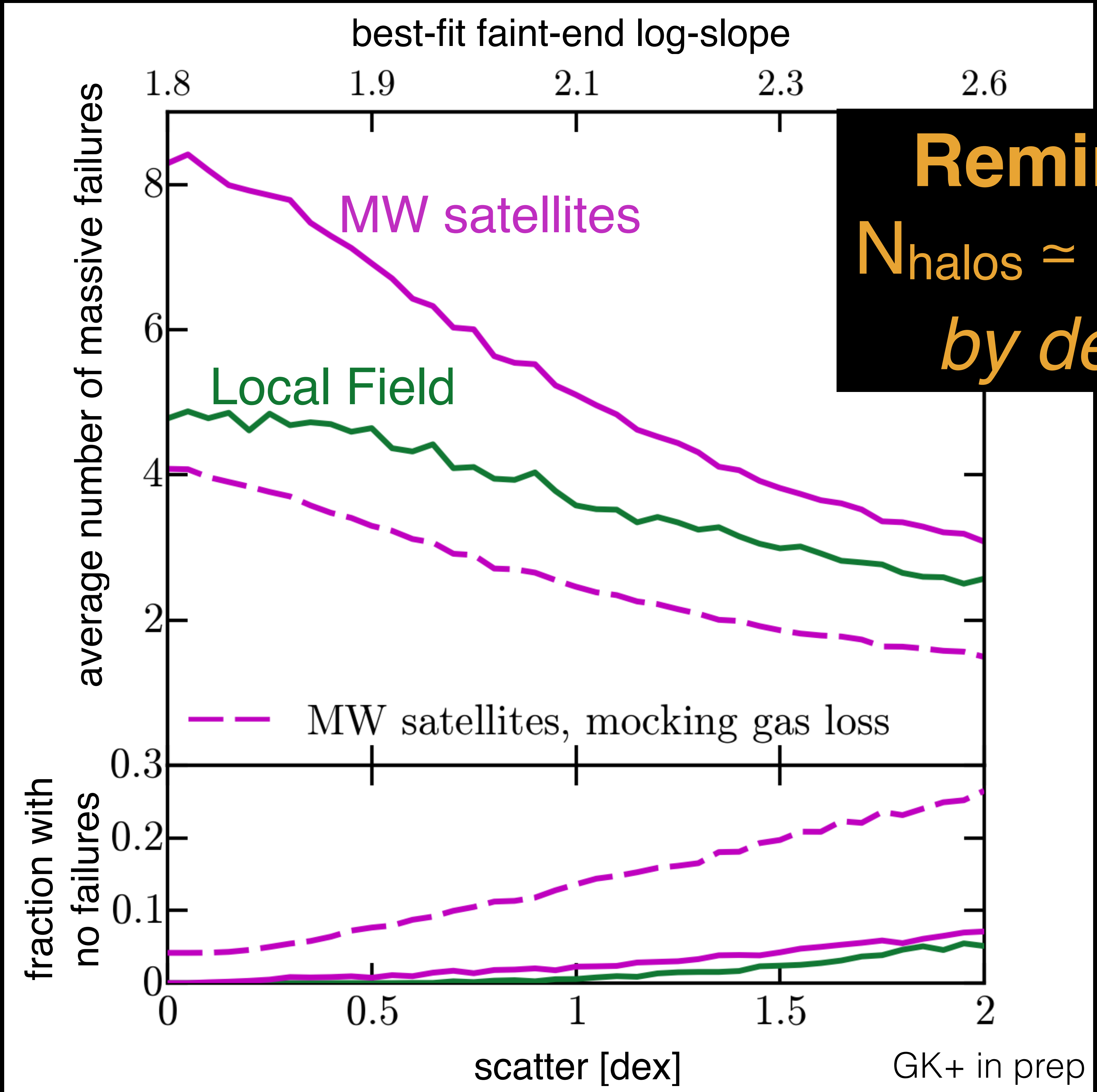


Lots of TBTF systems when σ = 0

Large σ => realizations with classical dSphs living in small halos…

…and massive (problematic) subhalos hosting ultra-faint dwarfs

TBTF with large (constant) scatter

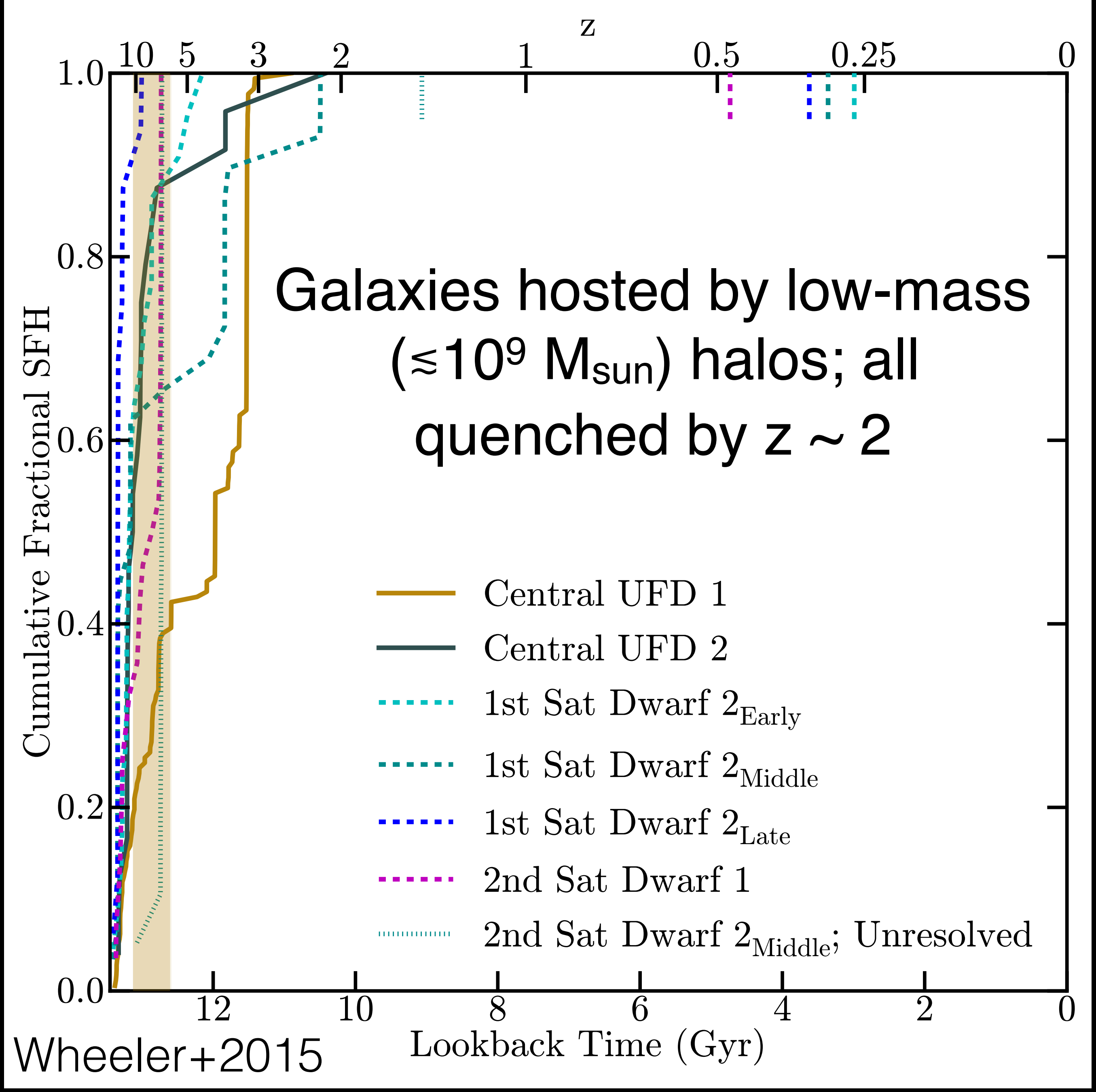


Reminder:
$N_{halos} \simeq N_{galaxies}$
by design

Observational evidence for large scatter?

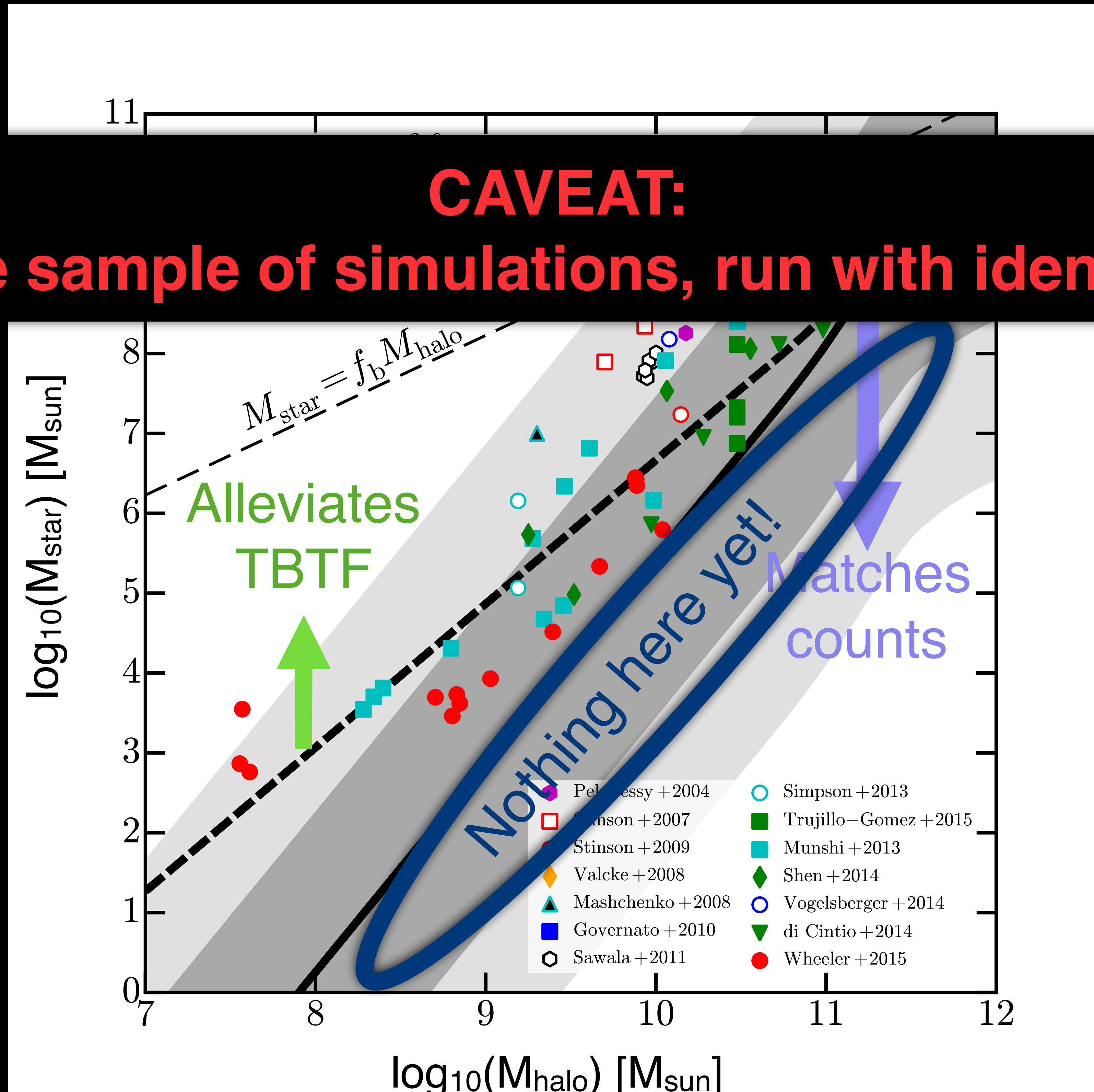
Direct measurements of M_{halo} impossible; indirect hints?

Unquenched, faint galaxies?



With large scatter, some faint galaxies live in massive halos, which are resistant to reionization quenching

Theoretical evidence for large scatter?



CAVEAT:

Need a large sample of simulations, run with identical physics

Ultra-high resolution simulations fail to reproduce the downward scatter necessary to avoid overproducing counts in the LG

Conclusions

Scatter in M_{star} - M_{halo} boosts galaxy counts at fixed M_{star}

Require a rapid fall-off to avoid overproducing LG dwarfs:
simulations should not trace Behroozi+13 if they exhibit scatter

Large scatter eliminates TBTF from ~25% of realizations by assigning the massive, problematic subhalos ultra-faints

Very difficult to directly test hypothesis that σ ~ 2 dex, but clues may exist in star formation histories or internal dynamics

No theoretical evidence yet (but need more sims!)