A Comprehensive Assessment of the Too-Big-to-Fail Problem

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Acknowledgments:

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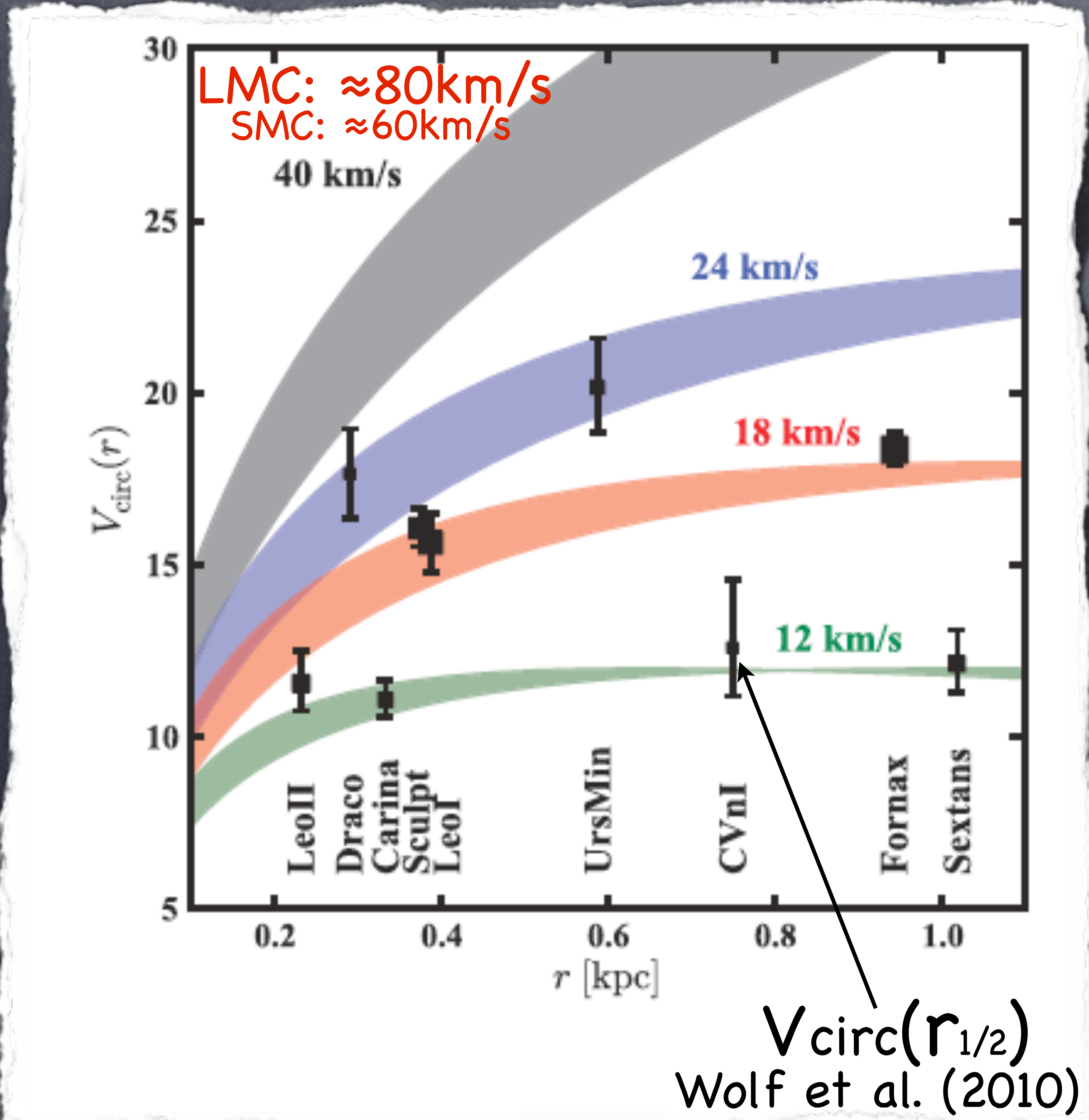
Outline

- What is "Too Big To Fail" (TBTF) ?
- Semi-analytical model of dark matter subhaloes
- Severity of TBTF

TBTF

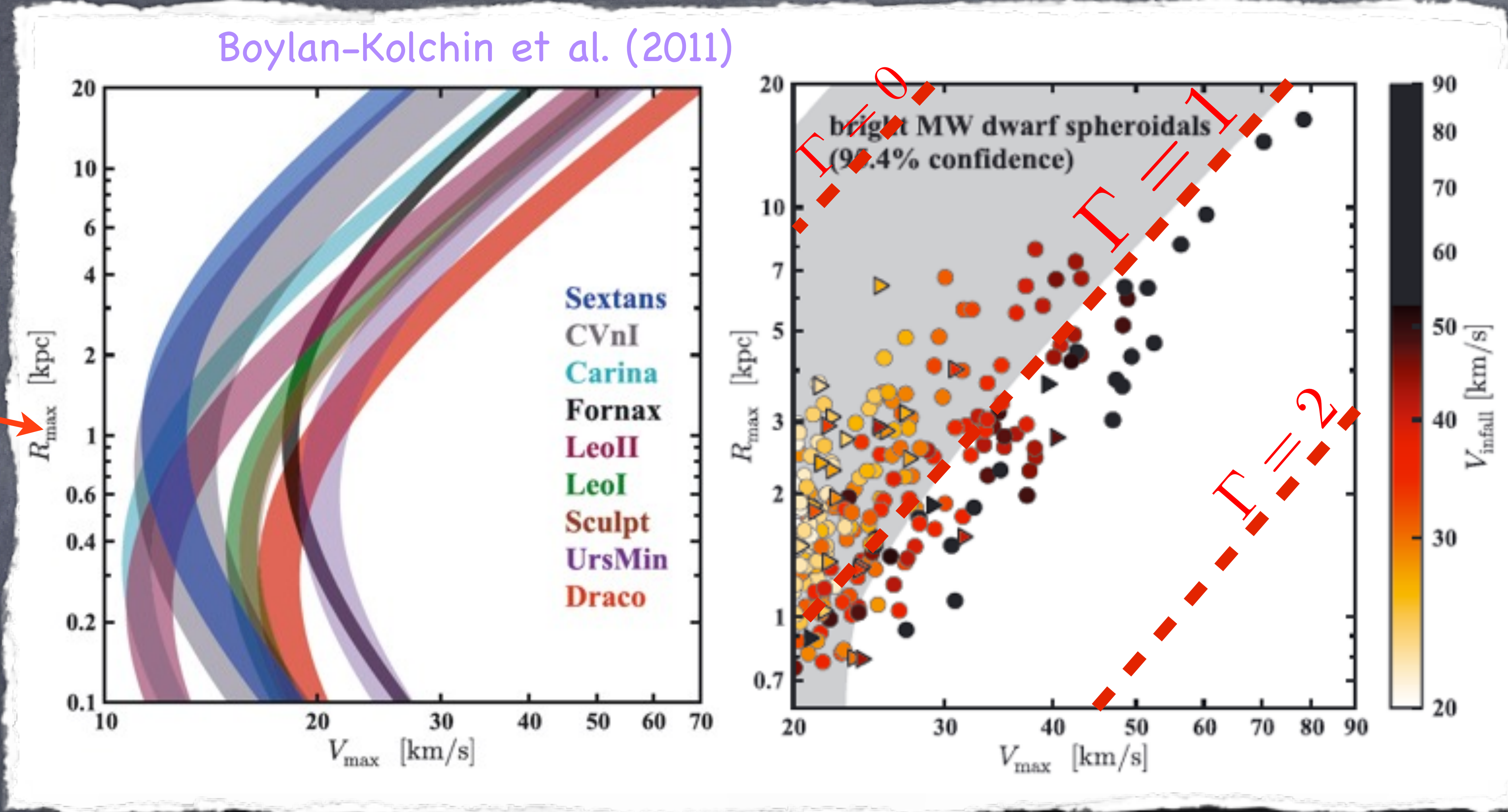


Boylan-Kolchin et al. (2012)

- Formulation I:
  - simulation: order of 10 subhaloes with V_{max}>25km/s
  - MW dSphs: V_{max}≤25km/s
  - "massive subhalo" formulation
- Formulation II:

  a V_{max} gap between ≈60km/s and ≈25km/s

Formulation III:



Rmax: the radius at which Vcirc(r) reaches Vmax

subhalo density proxy $\Gamma \equiv 1 + \log(0.0014 V_{\rm max}^{2.2}/R_{\rm max})$
Purcell & Zentner (2012)

the most massive subhaloes are too dense ($\Gamma_{\rm max} > 1$) to be consistent with MW dSphs ($\Gamma < 1$)

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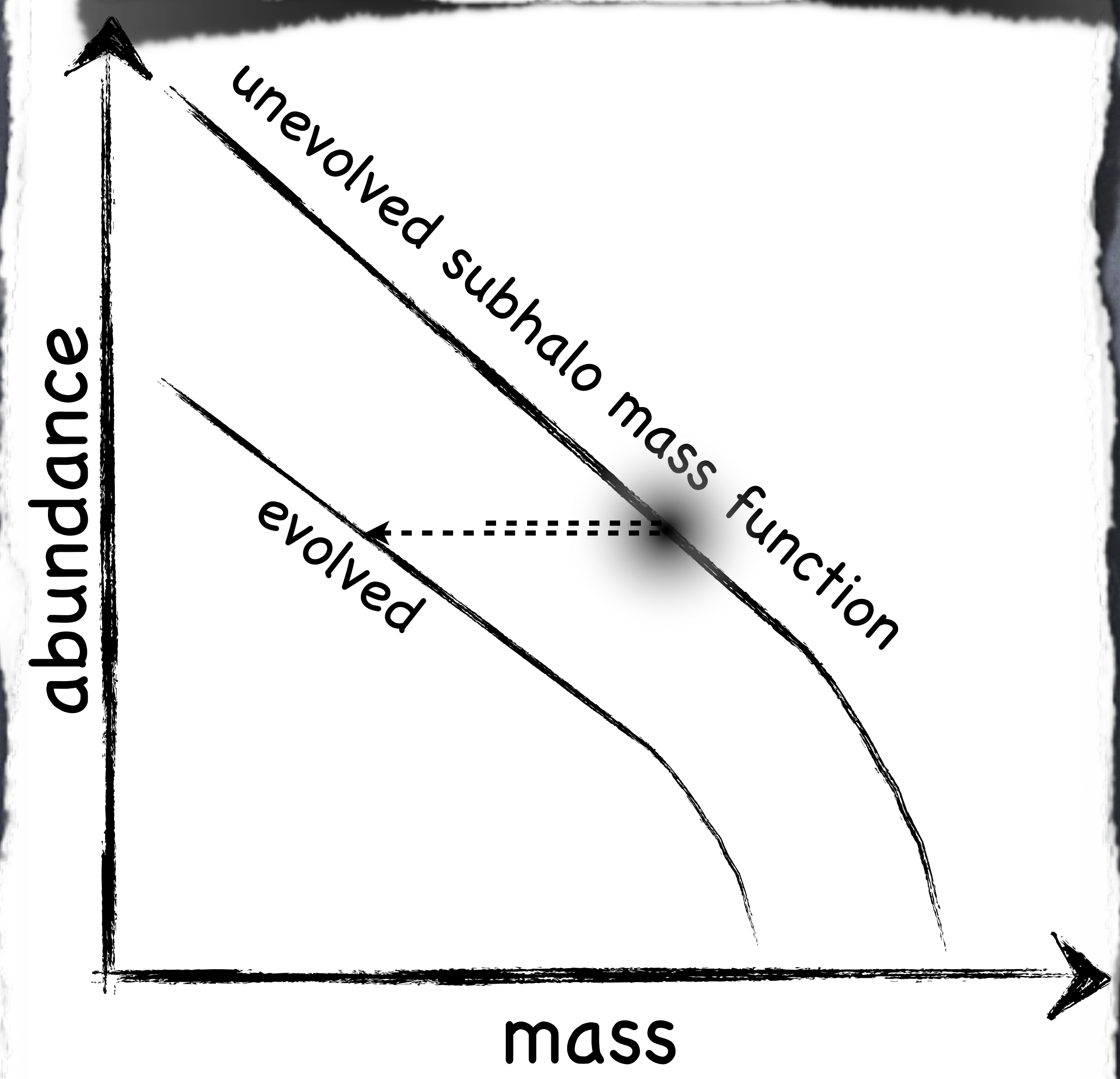
Merger Tree (EPS)

Jiang & van den Bosch (2014a)

Parkinson et al. (2008): $\frac{\mathrm{d}N}{\mathrm{d}m}(m, z|M_0, z_0)\,\mathrm{d}m$



For more about subhalo evolution:

Jiang & van den Bosch (2014b)

arXiv:1403.6827

mass evolution:

$$\dot{m} = -\mathcal{A}\frac{m}{\tau_{\rm dyn}}\left(\frac{m}{M}\right)^{0.07}$$

- $P(\mathcal{A})$: log-normal
- reflects variance in orbital properties & halo concentrations

disruption:

$$m_{\rm dis} = m_{\rm acc}(<\alpha \times r_{\rm s,acc})$$

- $P(\alpha)$: log-normal
- $\bar{\alpha} = \bar{\alpha}(m_{\rm acc}/M_{\rm acc})$

stucture evolution:

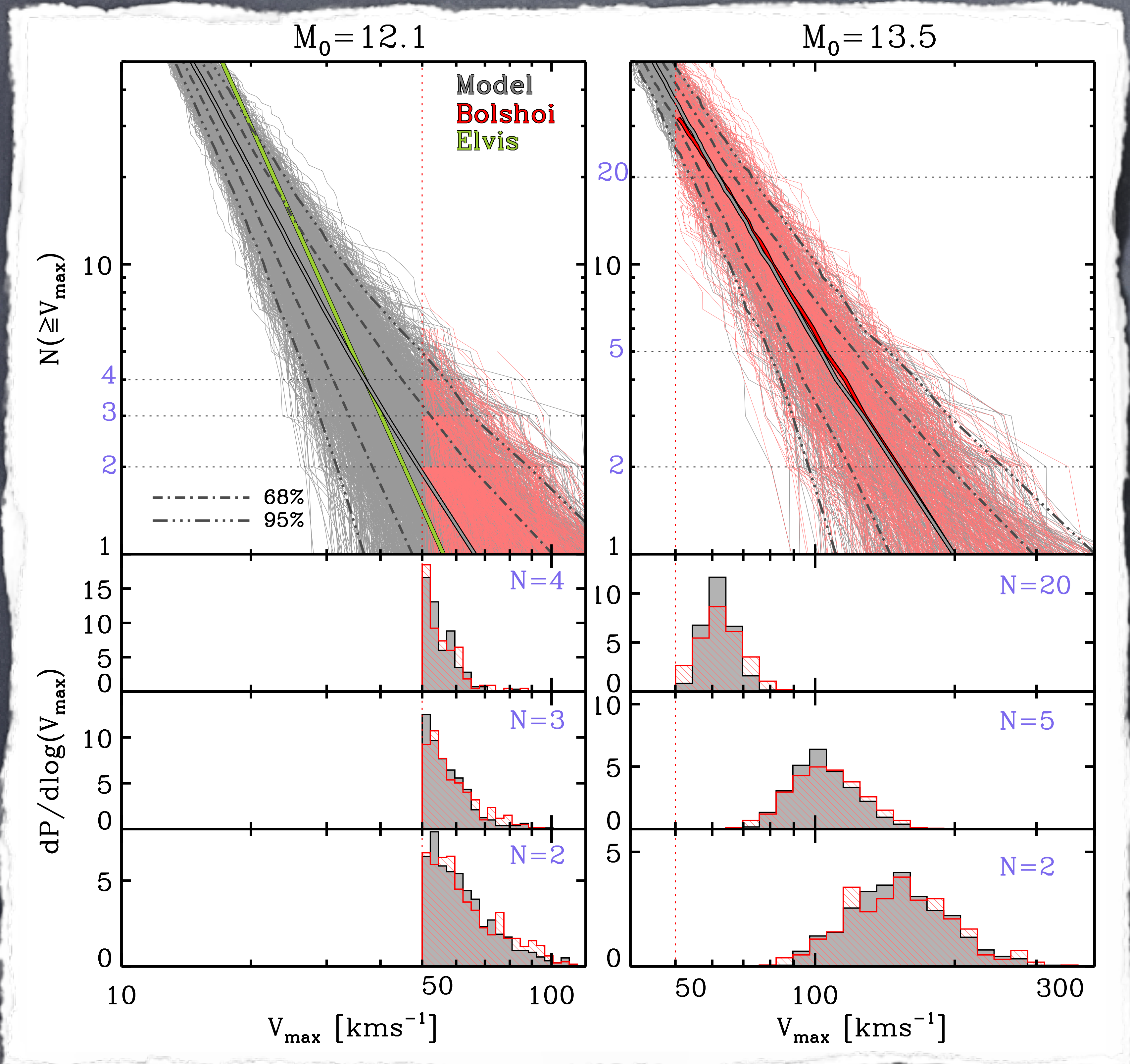
$$V_{\max} = V_{\rm acc} \times f(m/m_{\rm acc})$$

Penarrubia et al. (2010)

$$V_{\rm acc} = g(m_{\rm acc}, c_{\rm acc})$$

Zhao et al. (2009)

Model: Accurate Halo-to-Halo Variance



- **benchmark:**
  Bolshoi simulation
  441 $M_0 = 10^{13.5\pm0.05} h^{-1} M_\odot$
  1986 $M_0 = 10^{12.10\pm0.01} h^{-1} M_\odot$
- **model:**
  500 $M_0 = 10^{13.5} h^{-1} M_\odot$
  2000 $M_0 = 10^{12.1} h^{-1} M_\odot$

Jiang & van den Bosch, submitted to MNRAS

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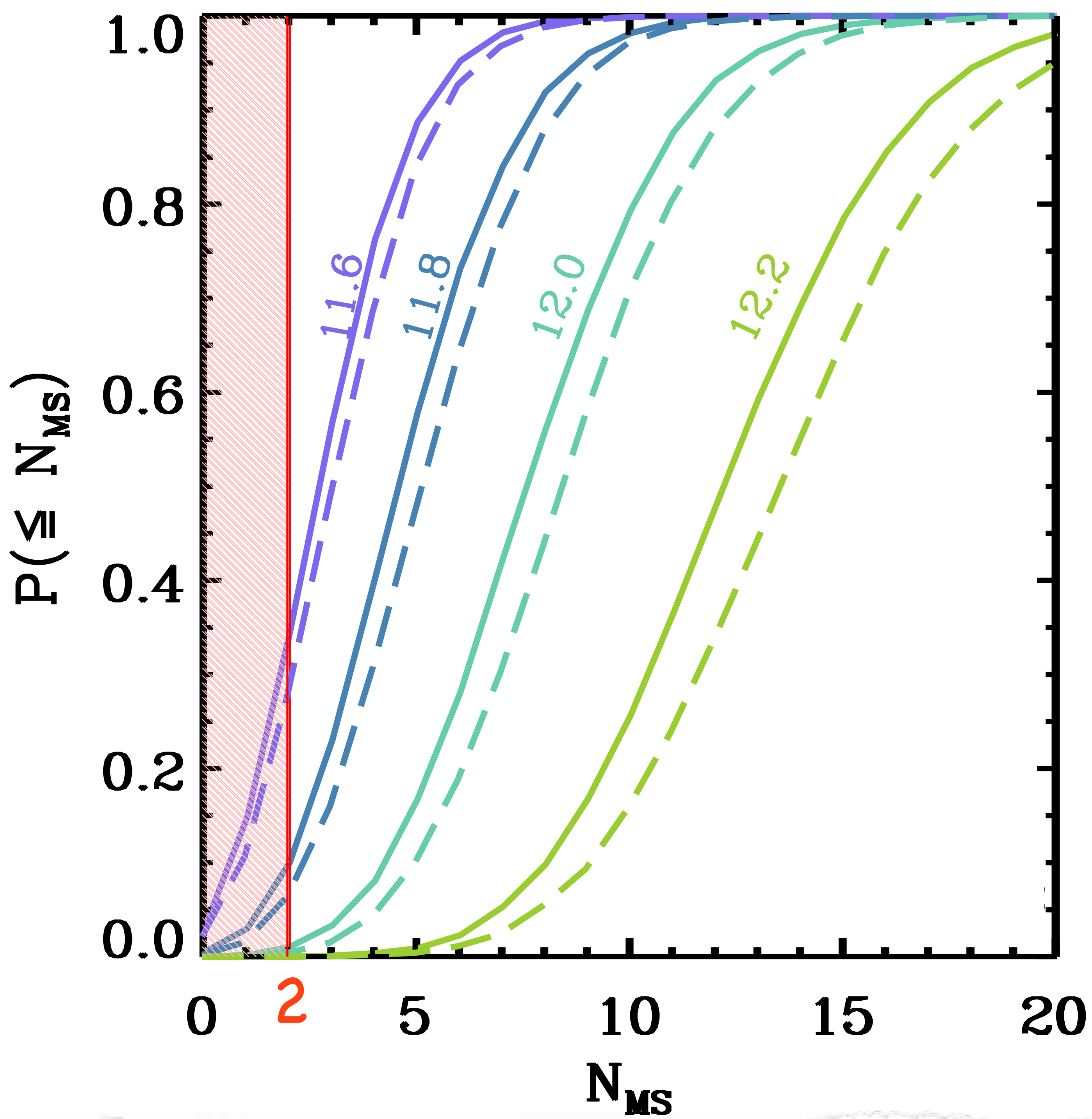
"Massive Subhalo" Count



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- definition:

$$V_{\rm acc} > 30{\rm kms}^{-1}$$
$$V_{\rm max} > 25{\rm kms}^{-1}$$

- MW has 2 MSs
- Wang et al. (2012): lower MW halo mass ==> significantly lower number of MSs
- Contemporary MW halo mass constraint:

$$M_0 \in [10^{11.7}, 10^{12.2}]h^{-1}M_\odot$$

Kafle et al. (2014)

- 10,000 realizations for each halo mass

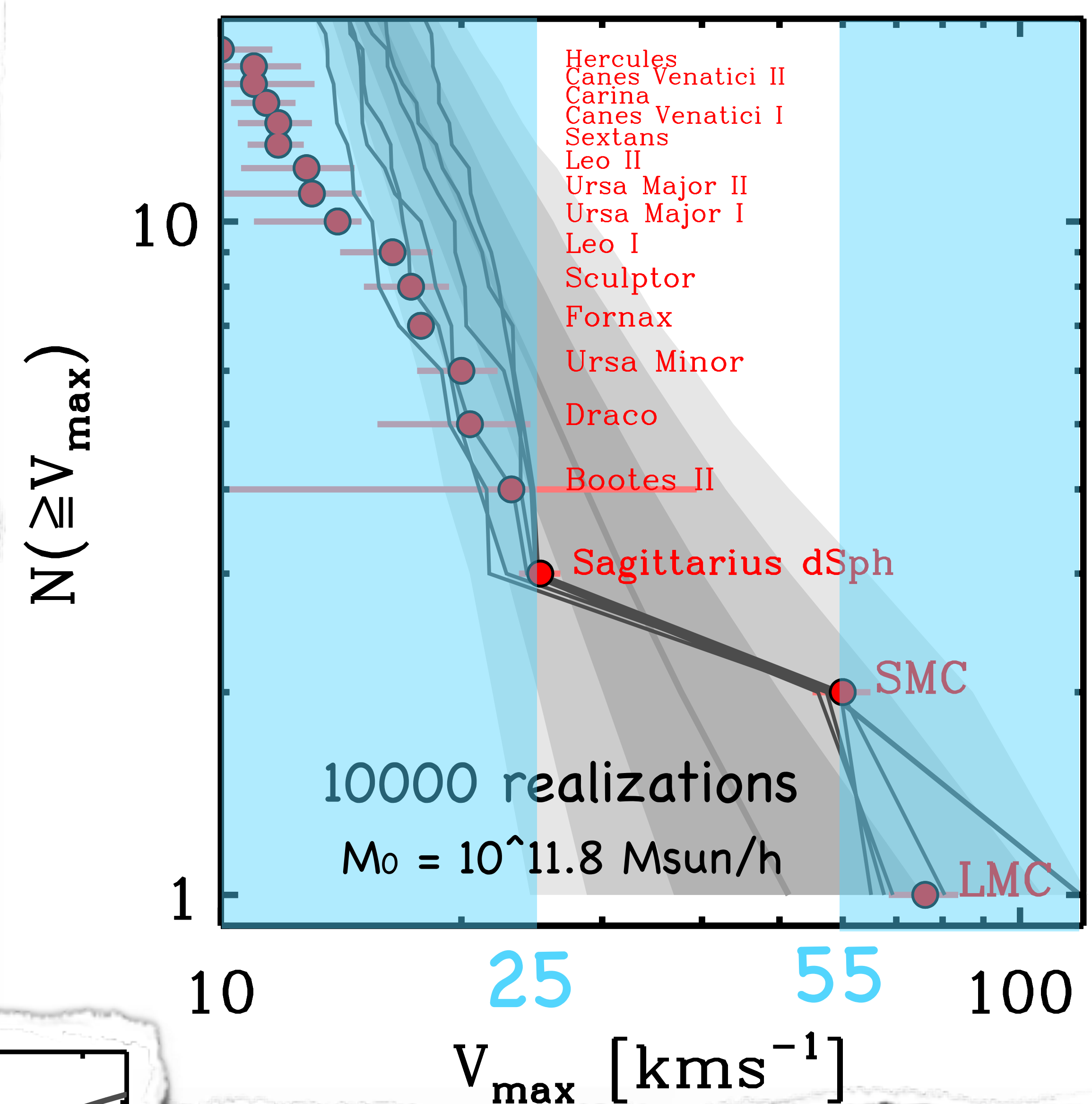
Vmax Gap

- Vmax (estimates) for MW satellites from
  - Kuhlen et al. (2010)
  - Boylan-Kolchin et al. (2012)
  - Kallivayalil et al. (2013)
- for MW satellites with no published Vmax, use

MacConnachie (2012)

$$V_{\rm max} = 2.2\sigma_{\rm LOS,\star}$$

Rashkov et al. (2012)



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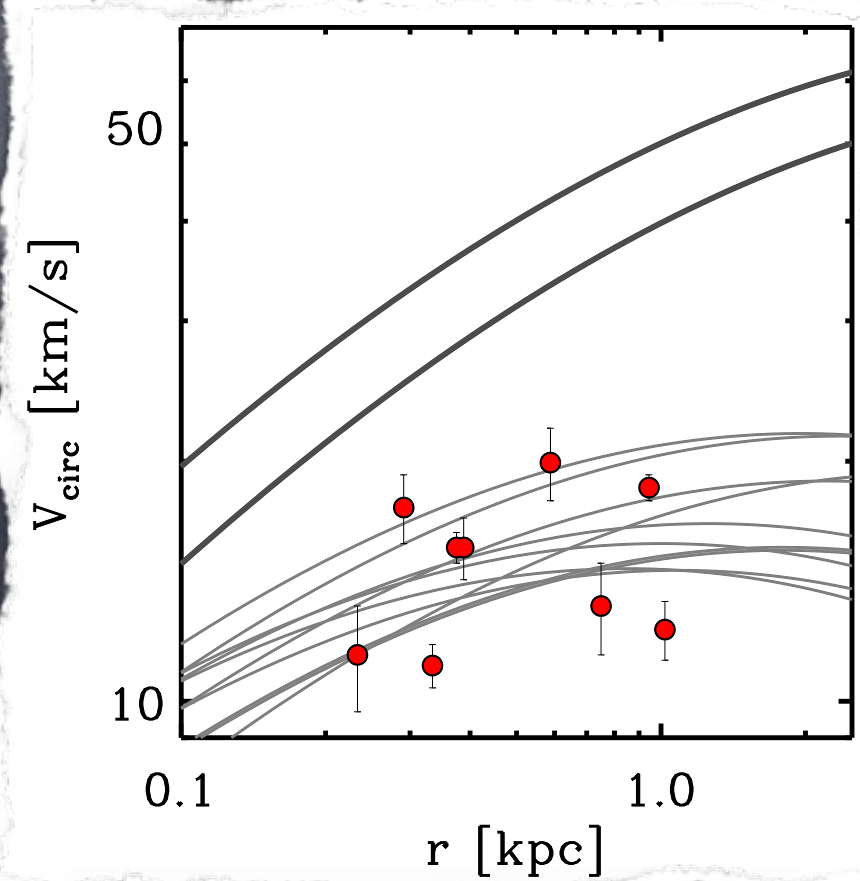
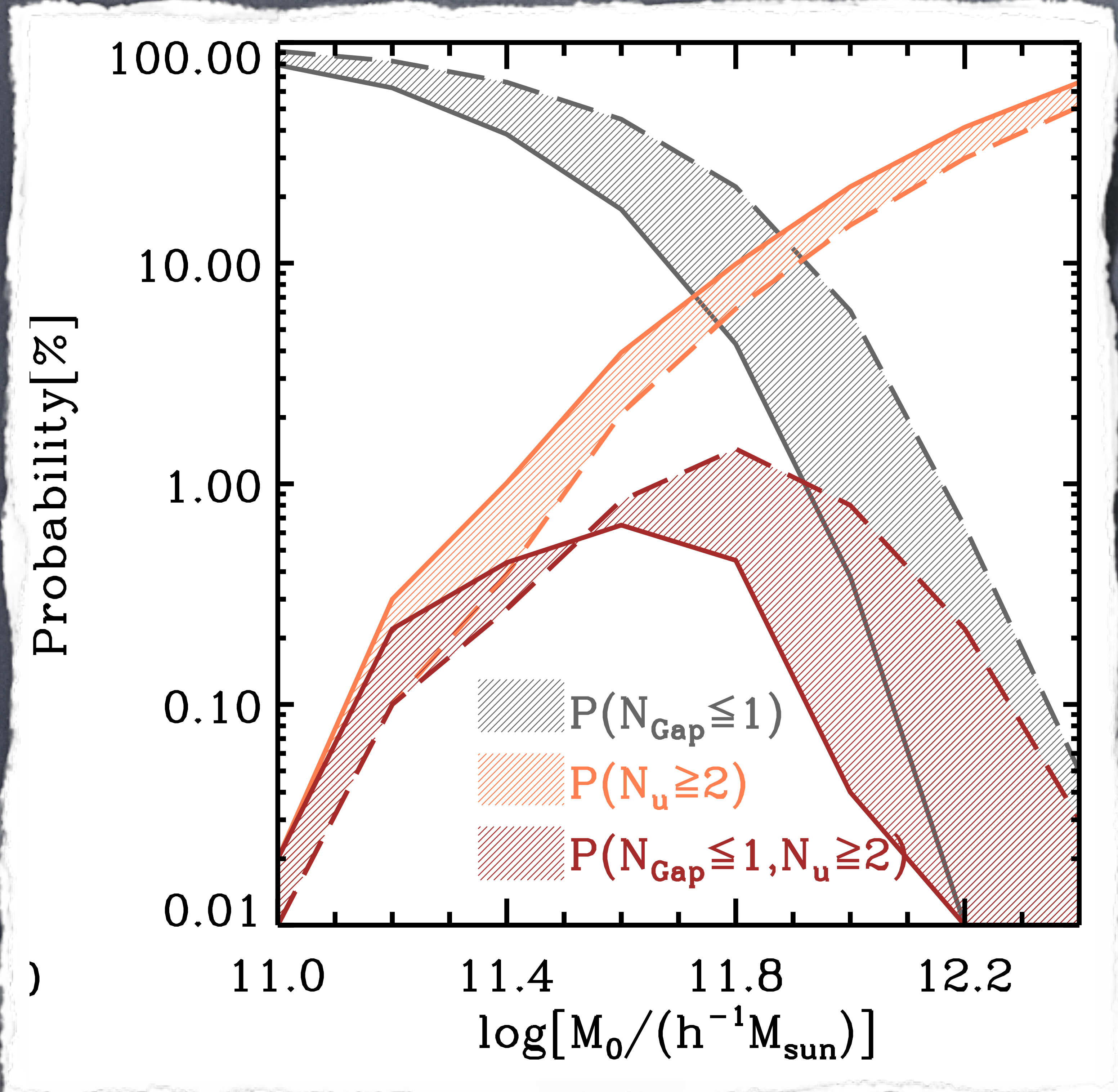


$$V_{\rm circ}(r|R_{\rm max}, V_{\rm max}, \alpha)$$

Einasto shape parameter, typically 0.18 (Aquarius)

MW-consistent fraction as a function of halo mass

- 10,000 realizations for each halo mass



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- NGap ≤ 1

(number of subhaloes in the gap ≤1)

$V_{\max} \in [25, 55]\mathrm{kms}^{-1}$

or

$V_{\max} \in [30, 60]\mathrm{kms}^{-1}$

- Nu ≥ 2

(number of MC analogs ≥2)

$V_{\max} > 55\mathrm{kms}^{-1}$

or

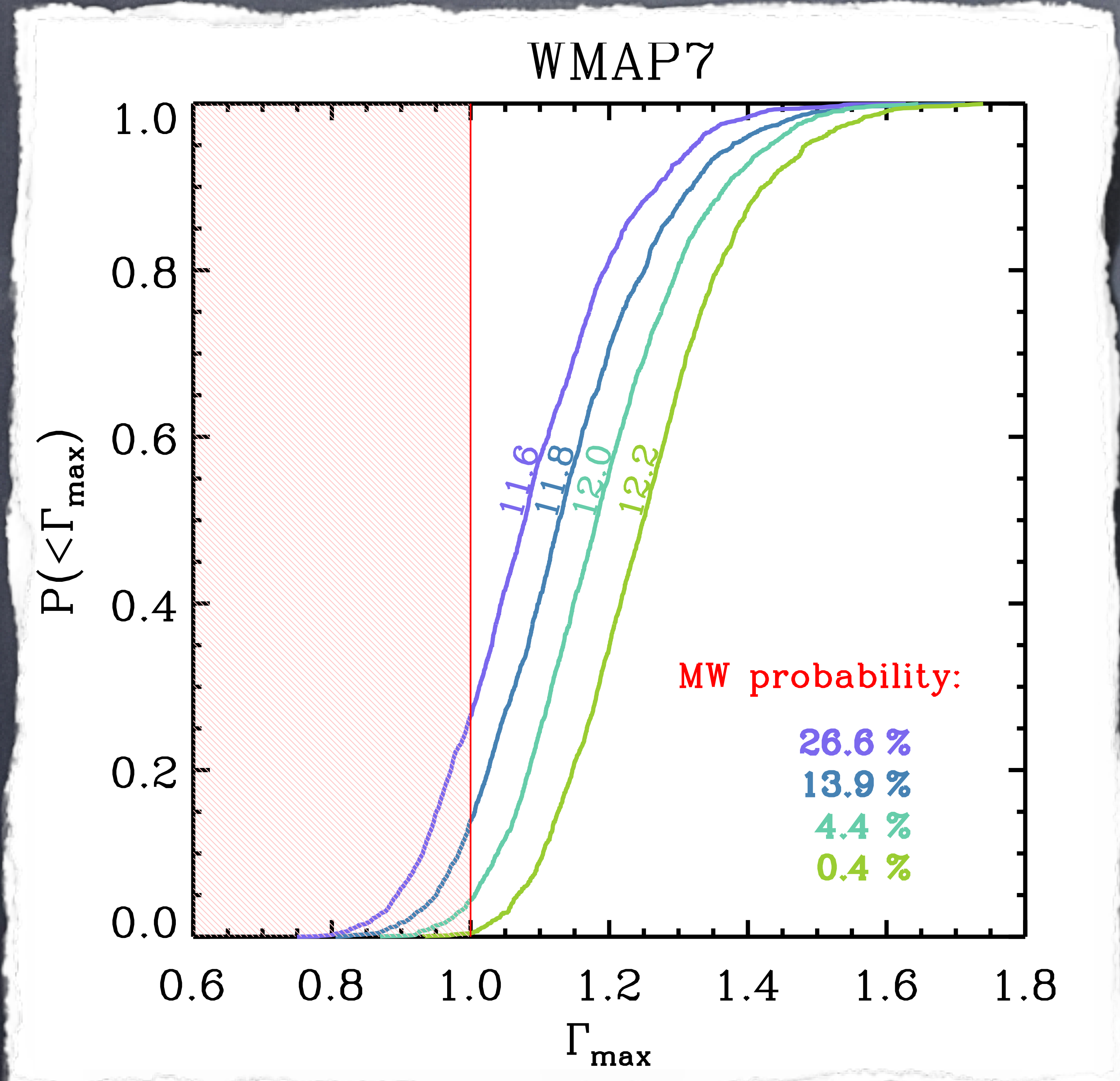
$V_{\max} > 60\mathrm{kms}^{-1}$

- NGap ≤ 1 & Nu ≥ 2

- probability of having MW-consistent Vmax Gap: always <1%

Subhalo Density

- recap: MW-consistent <==> $\Gamma_{\rm max} < 1$



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- also can be alleviated by lowering MW halo mass
- sensitive to cosmology change

WMAP7
$$(\Omega_{\rm m}, \sigma_8) = (0.266, 0.801)$$
Planck
$$(\Omega_{\rm m}, \sigma_8) = (0.318, 0.834)$$

- cosmology comes in mainly via Rmax

Summary

- If TBTF is the missing massive subhaloes:
  - MW-consistent fraction <1% for MW-size haloes (M_0=12.0)
  - reconcilable by lowering MW halo mass, MW-consistent fraction ≥10% for M_0=11.8
  - not very sensitive to cosmology (WMAP7 versus Planck)
- If TBTF is the massive subhaloes being too dense:
  - MW-consistent fraction <5% for MW-size haloes (M_0=12.0)
  - reconcilable by lowering MW halo mass, MW-consistent fraction ≈10% for M_0=11.8 (WMAP7)
  - very sensitive to cosmology: ≈3% for M_0=11.8 (Planck)
- If TBTF is a V_{max} Gap:
  - MW-consistent fraction always <1%, irrespective of MW halo mass or cosmology

Why semi-analytical model? Why not simulations ?

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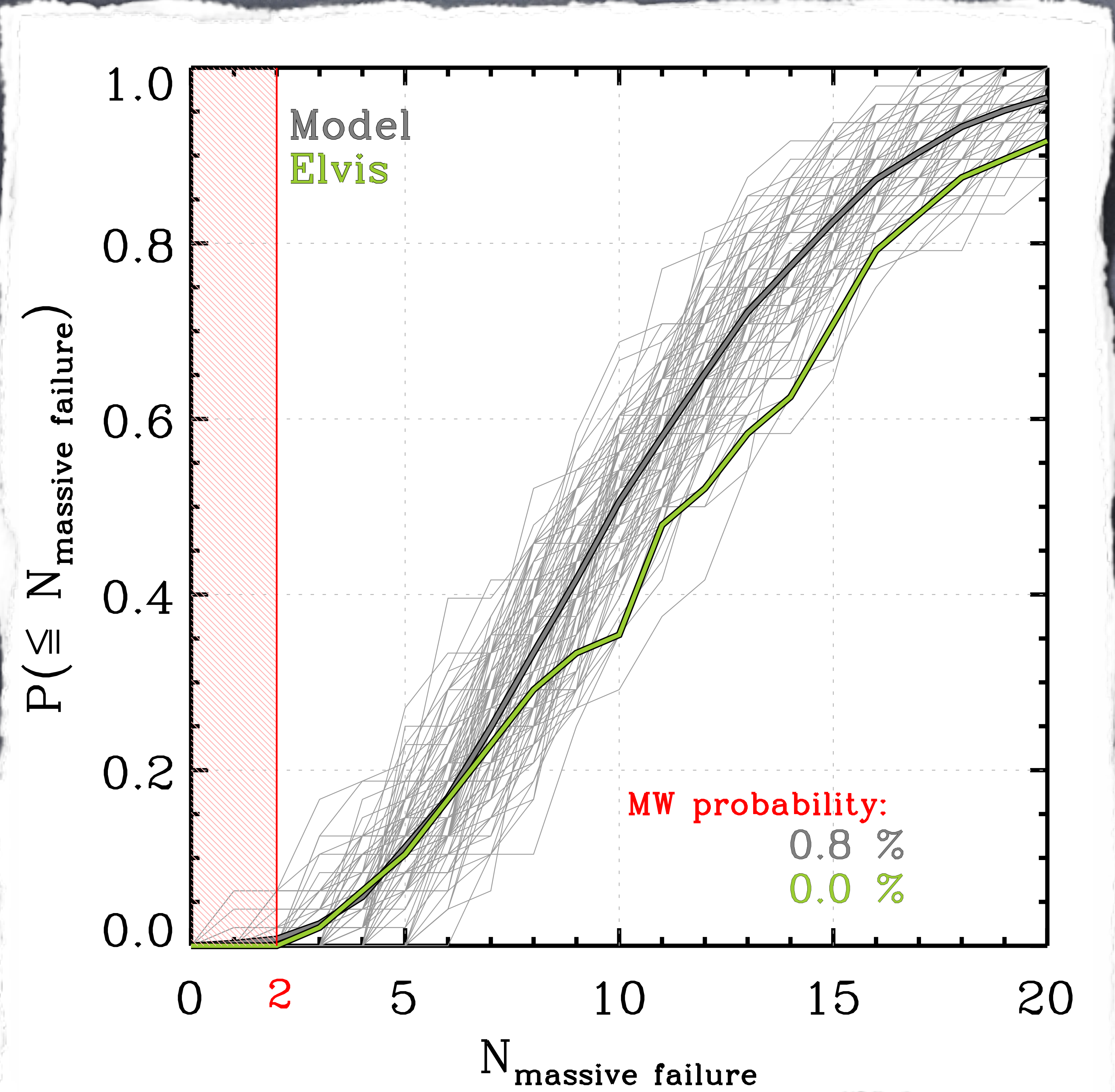

- **ELVIS:**
  48 haloes
  $M_0 = 10^{12.08\pm0.23} h^{-1} M_\odot$
- **Model:**
  4800 realizations of ELVIS-size haloes
  ⇕
  100 mock ELVIS suites