Competition between infectors leads to heterogeneous transmission patterns in homogeneous populations

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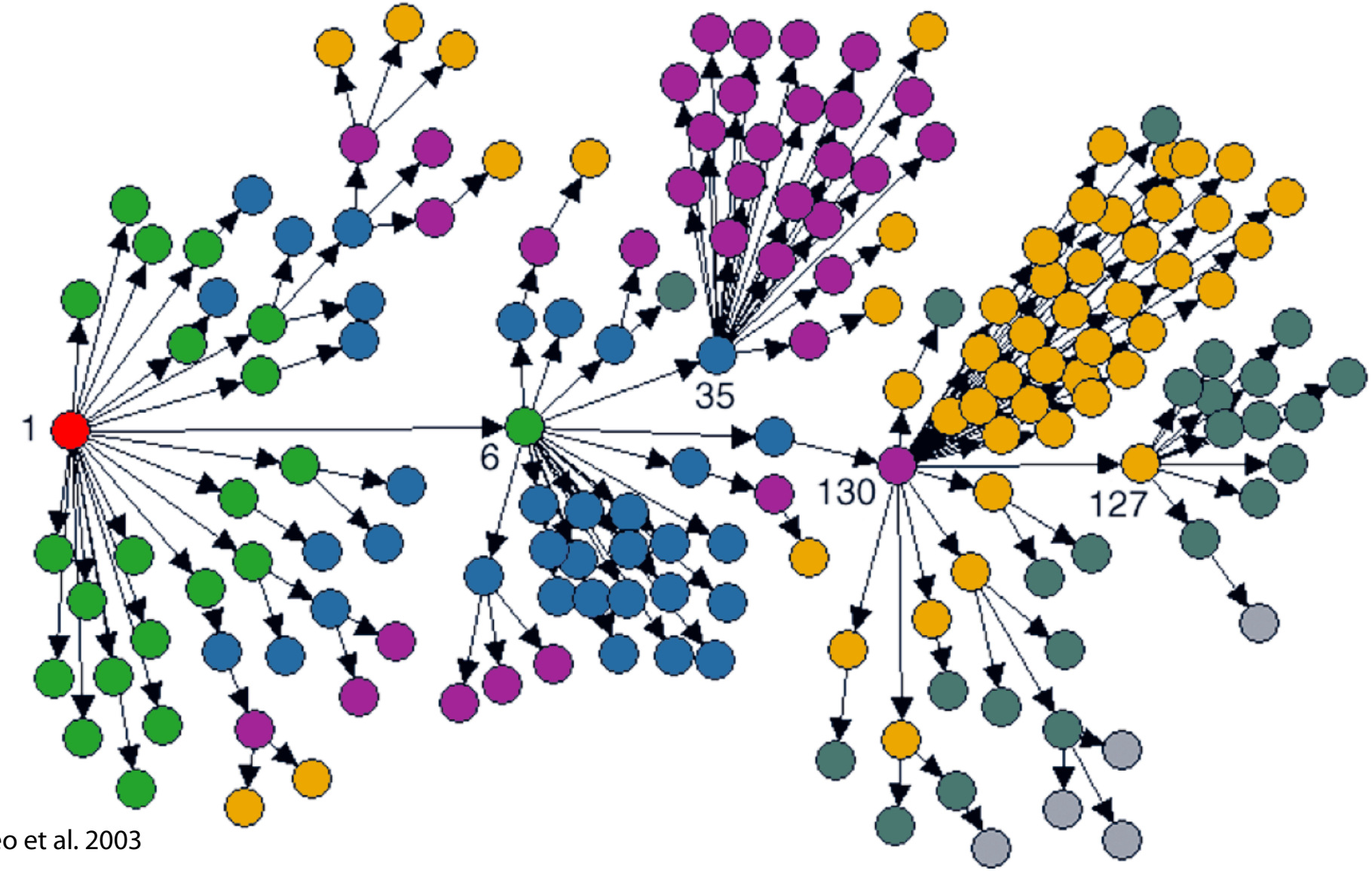
Resource Competition Arises Throughout Epidemiology

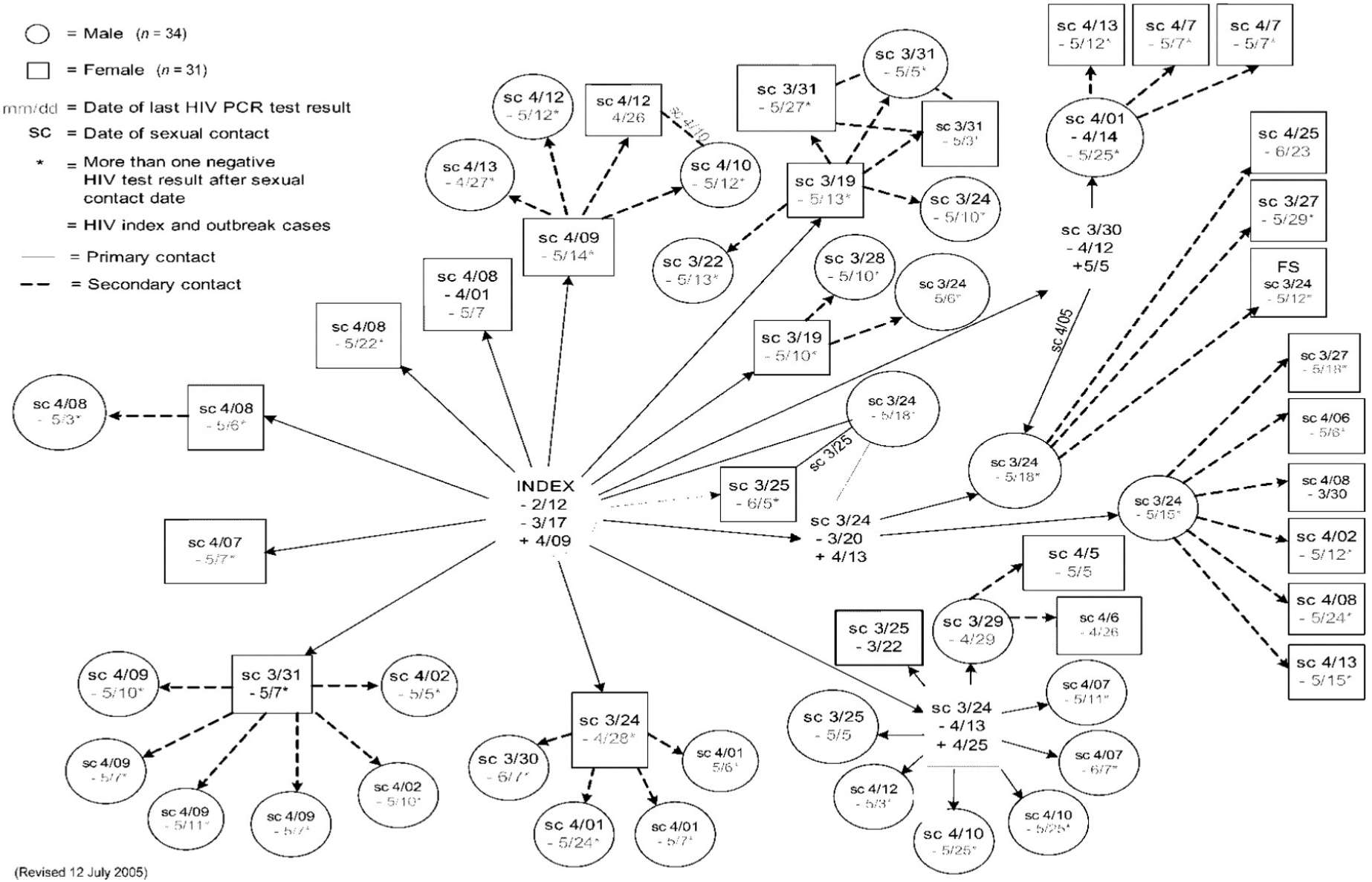
- For hosts and vectors
- For viral infections
- For therapies/treatment
- For susceptibles

Robust Observed Phenomenon: Heterogeneities in Transmission → SARS



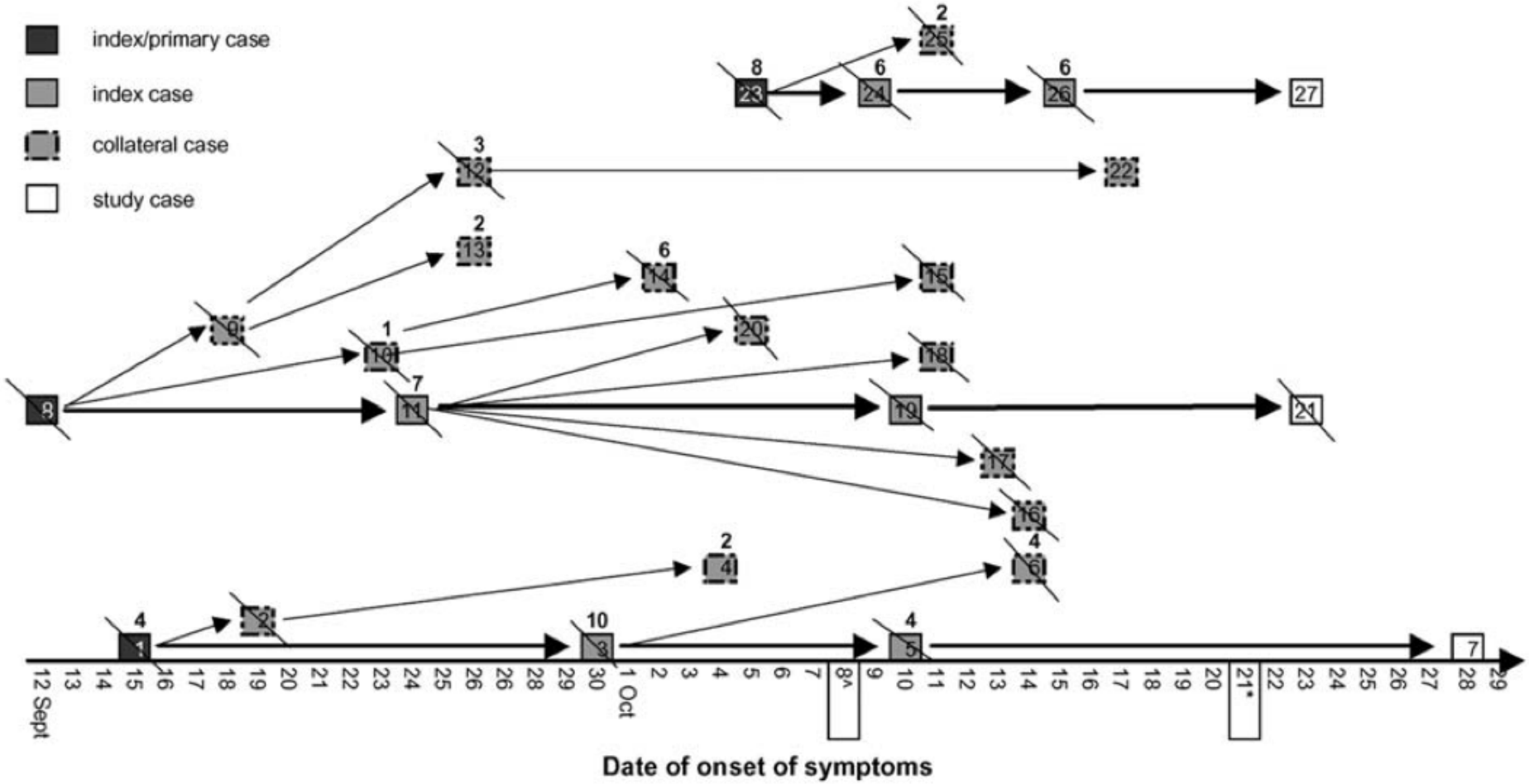
Leo et al. 2003

Heterogeneities in Transmission → HIV



Taylor et al. 2007

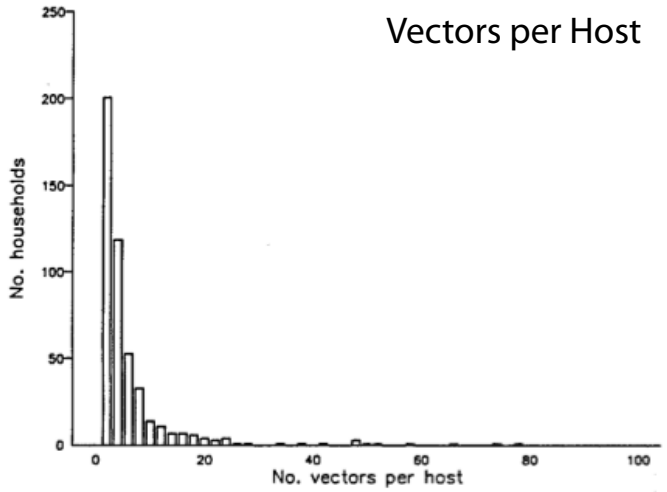
Heterogeneities in Transmission → Ebola



Francescont et al. 2003

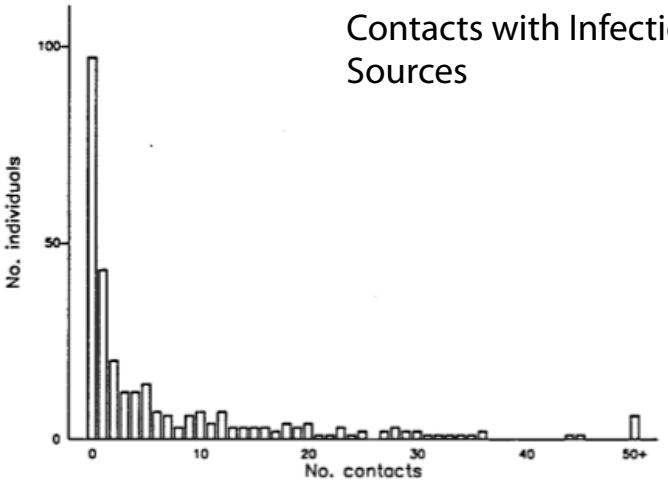
Superspreading Events and the 20/80 Rule

(a)



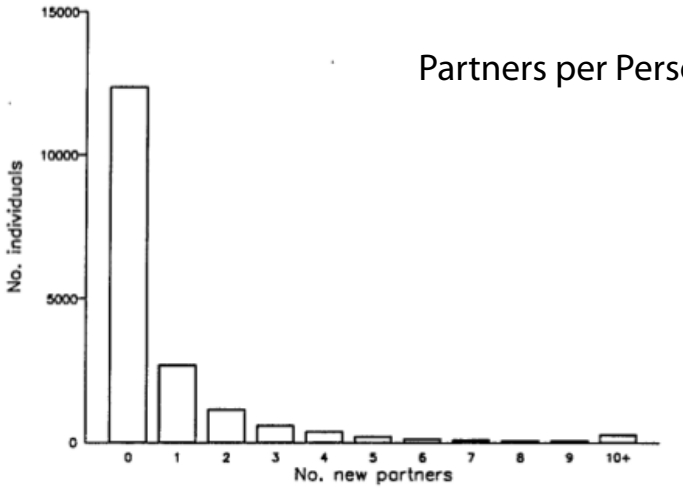
Vectors per Host

(b)



Contacts with Infectious Sources

(c)



Partners per Person

Heterogeneities in Transmission were Quantified a Few Years Ago as Over-dispersion in Numbers of Transmissions

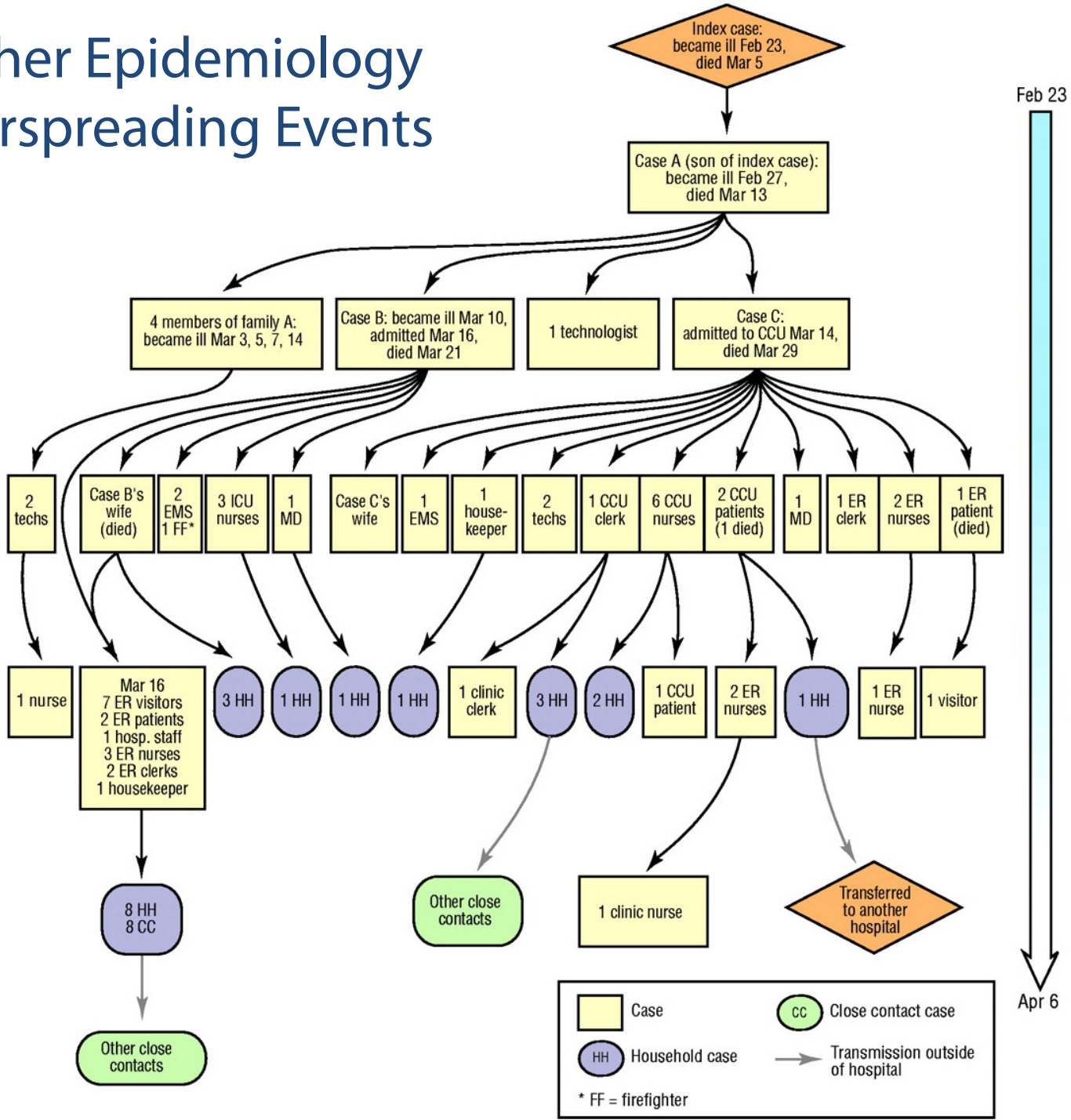
Vol 438|17 November 2005|doi:10.1038/nature04153 nature

LETTERS

Superspreading and the effect of individual variation on disease emergence

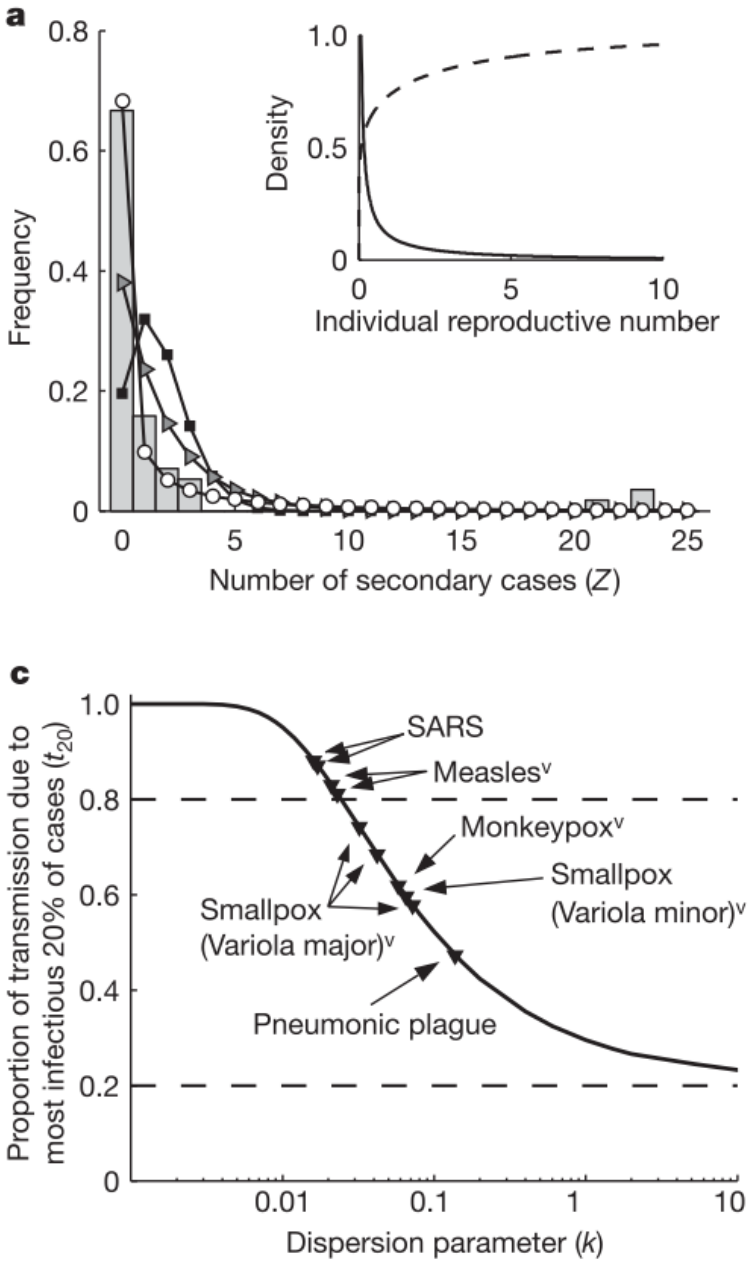
J. O. Lloyd-Smith[1,2], S. J. Schreiber[3], P. E. Kopp[4] & W. M. Getz[1]

Using Shoe-leather Epidemiology To Identify Superspreading Events

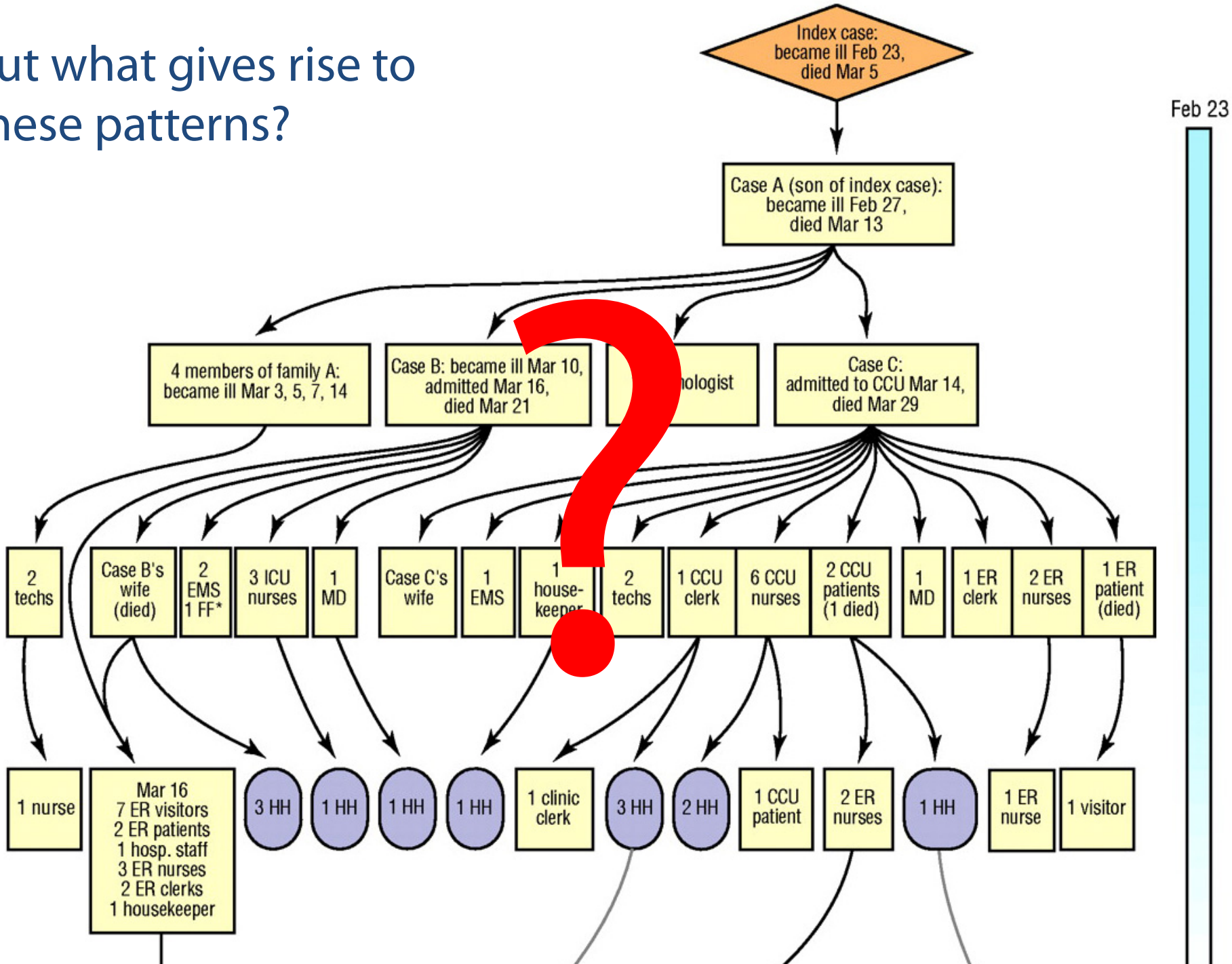


Varia et al. 2003

Superspreading Events Do Exist…

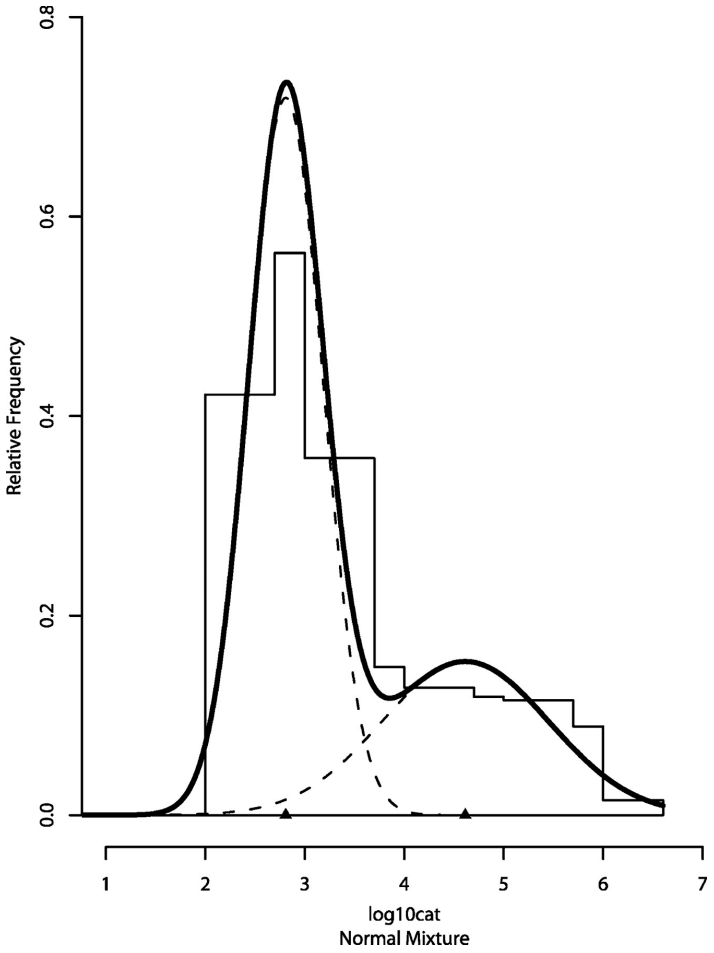


But what gives rise to these patterns?



Varia

Are they Due to Biological Differences between Individuals?



Chase-Topping et al. 2007

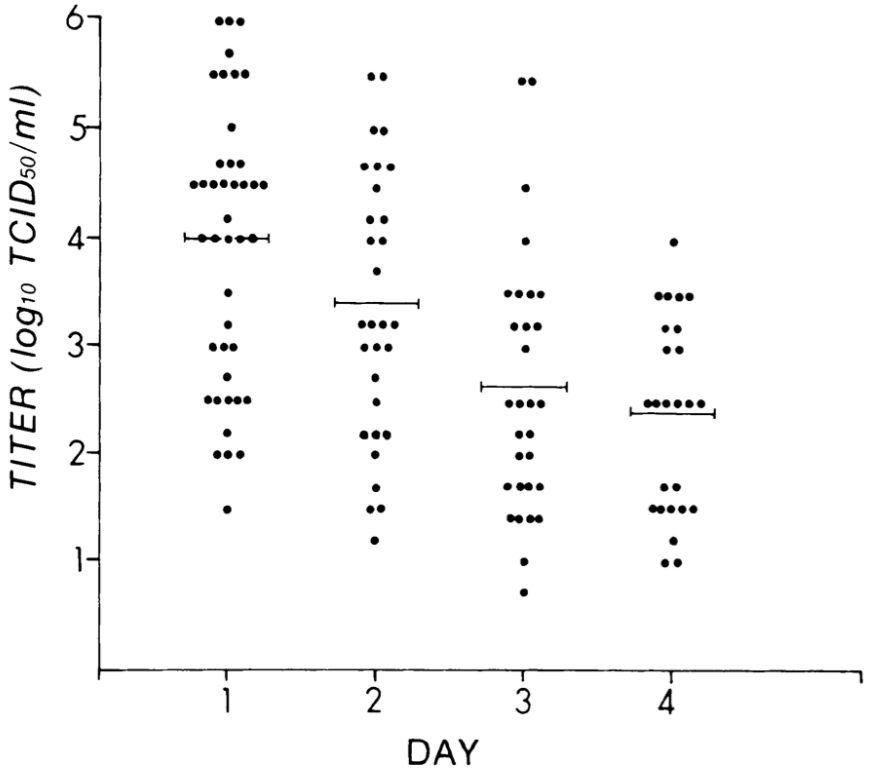
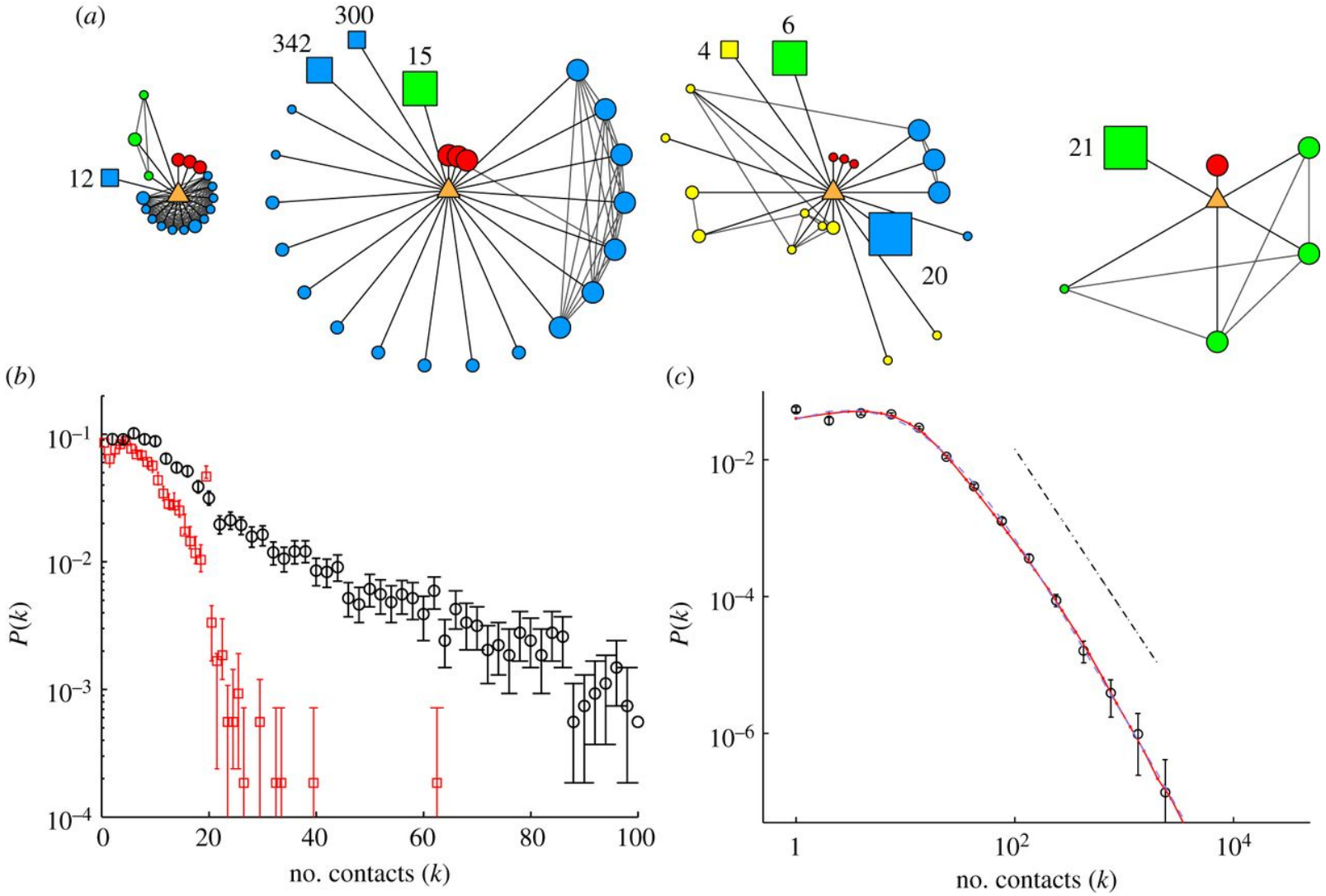


Figure 1. The quantities of influenza B virus (in $\log_{10}$

Hall et al. 1979

Social Differences between Individuals?



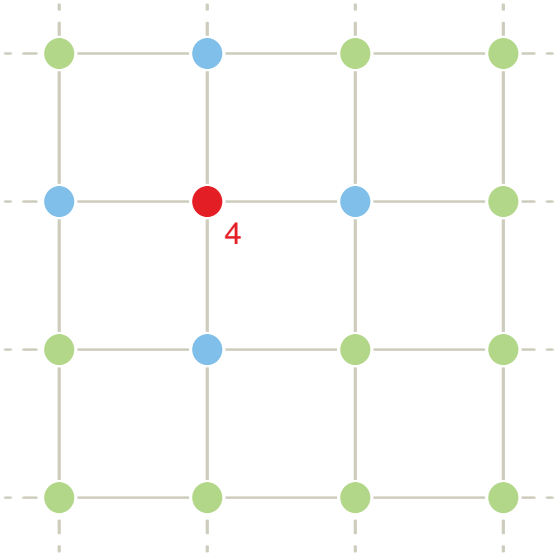
Danon et al. 2012

Heterogeneous transmission is endogenous to the infection process itself.

Due to…

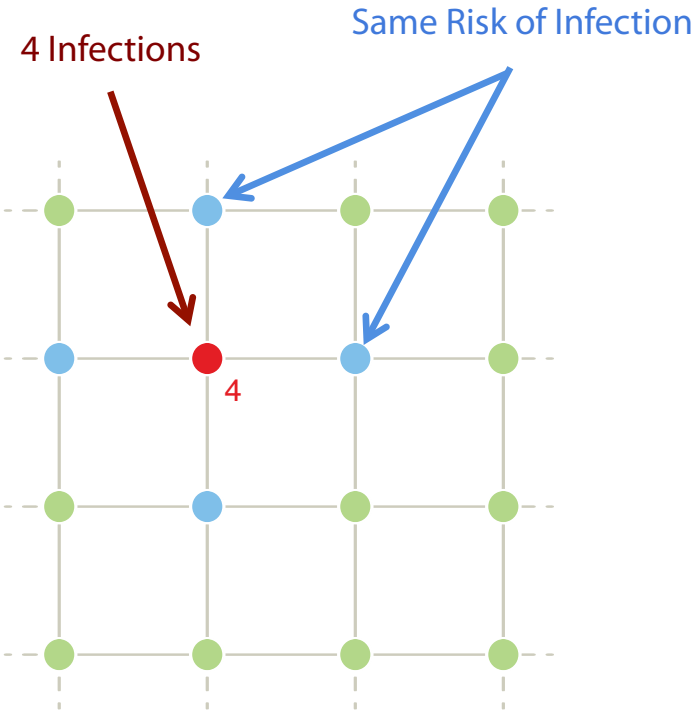
Competition for Susceptibles

Competition For Susceptibles



All else being equal (biological susceptibility/transmissibility, social contacts), we see differences in numbers of secondary cases and infection risk.

Competition For Susceptibles



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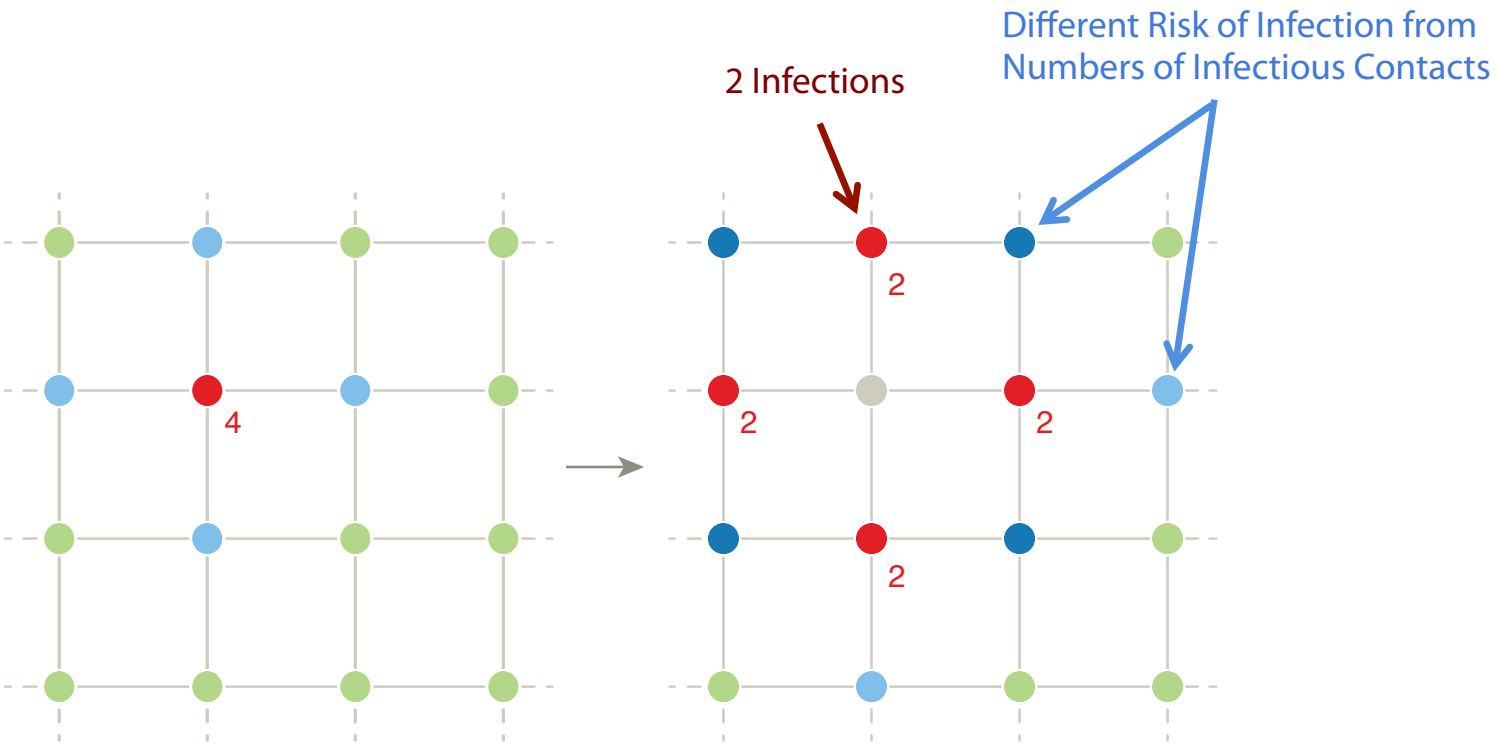

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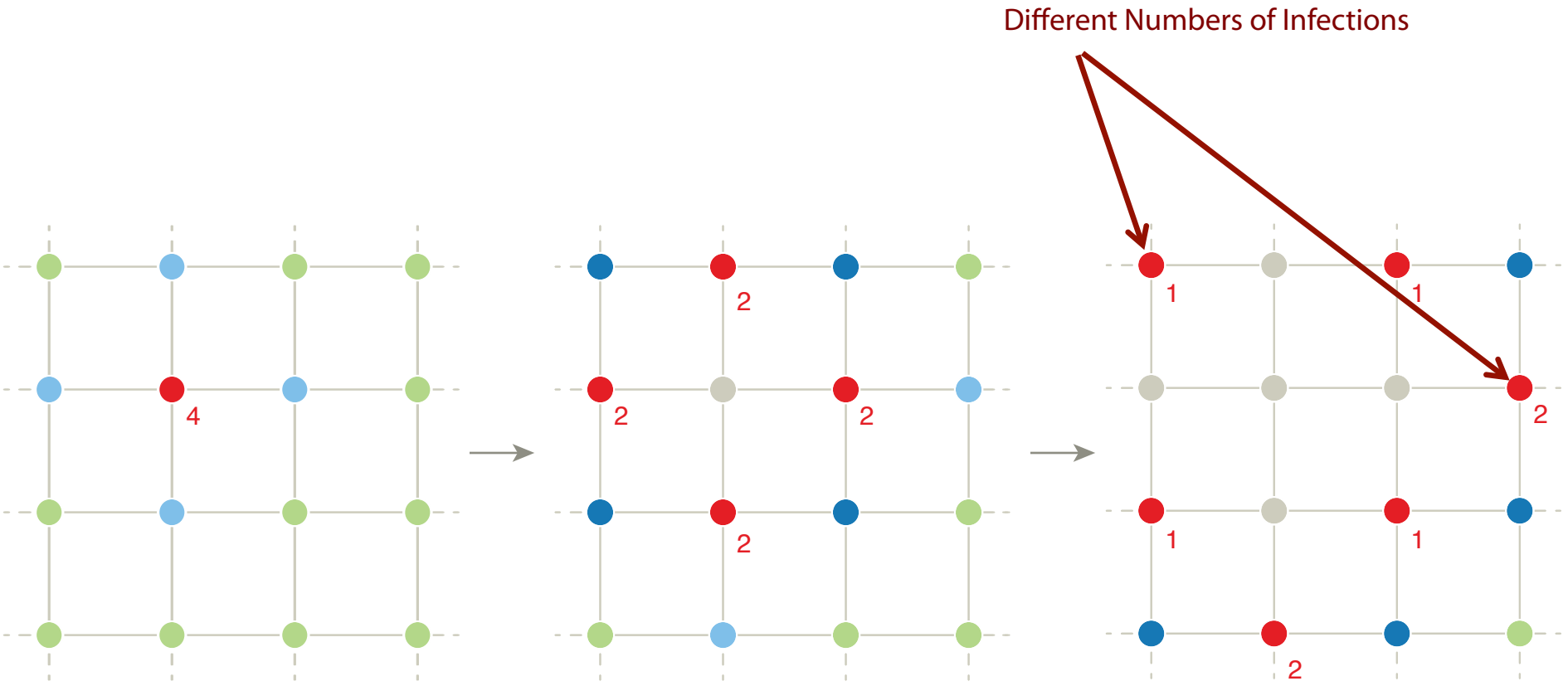

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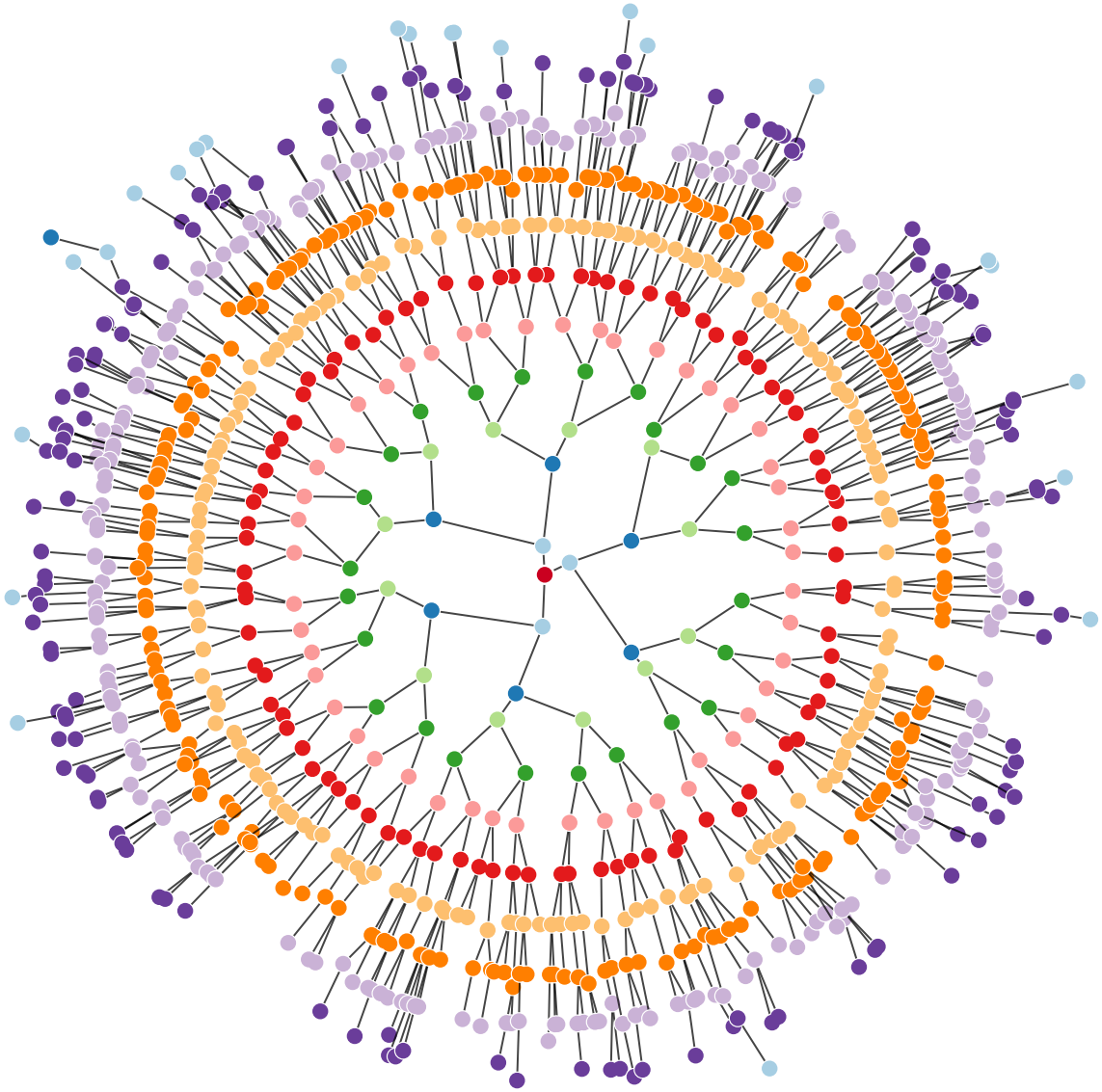
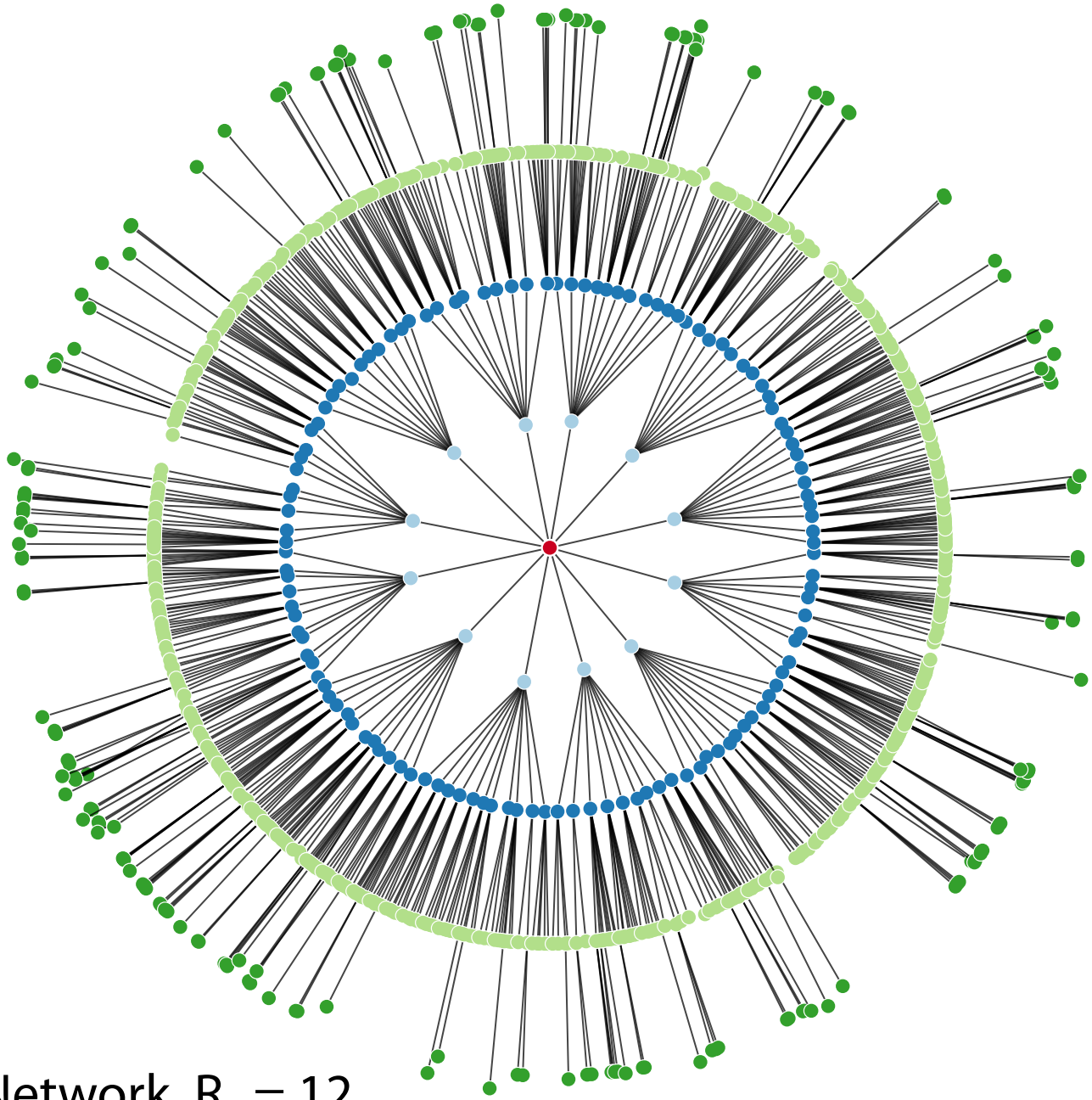
We Conducted Simulations of Competition for Susceptibles

- **Network-based** simulations with various degree distributions
  - **Uniform**
  - **Poisson** (exponential random, or NB with $k = \infty$)
  - **Negative Binomial**, multiple dispersion parameters, k
- **Deterministic Infection** (infect *all* susceptible contacts)
- **Non-overlapping latent and infectious periods** (discrete generations of transmission)
- Various **estimation techniques** for NB dispersion
- **Population immunity** approximated by changing percent susceptible (immune landscape)

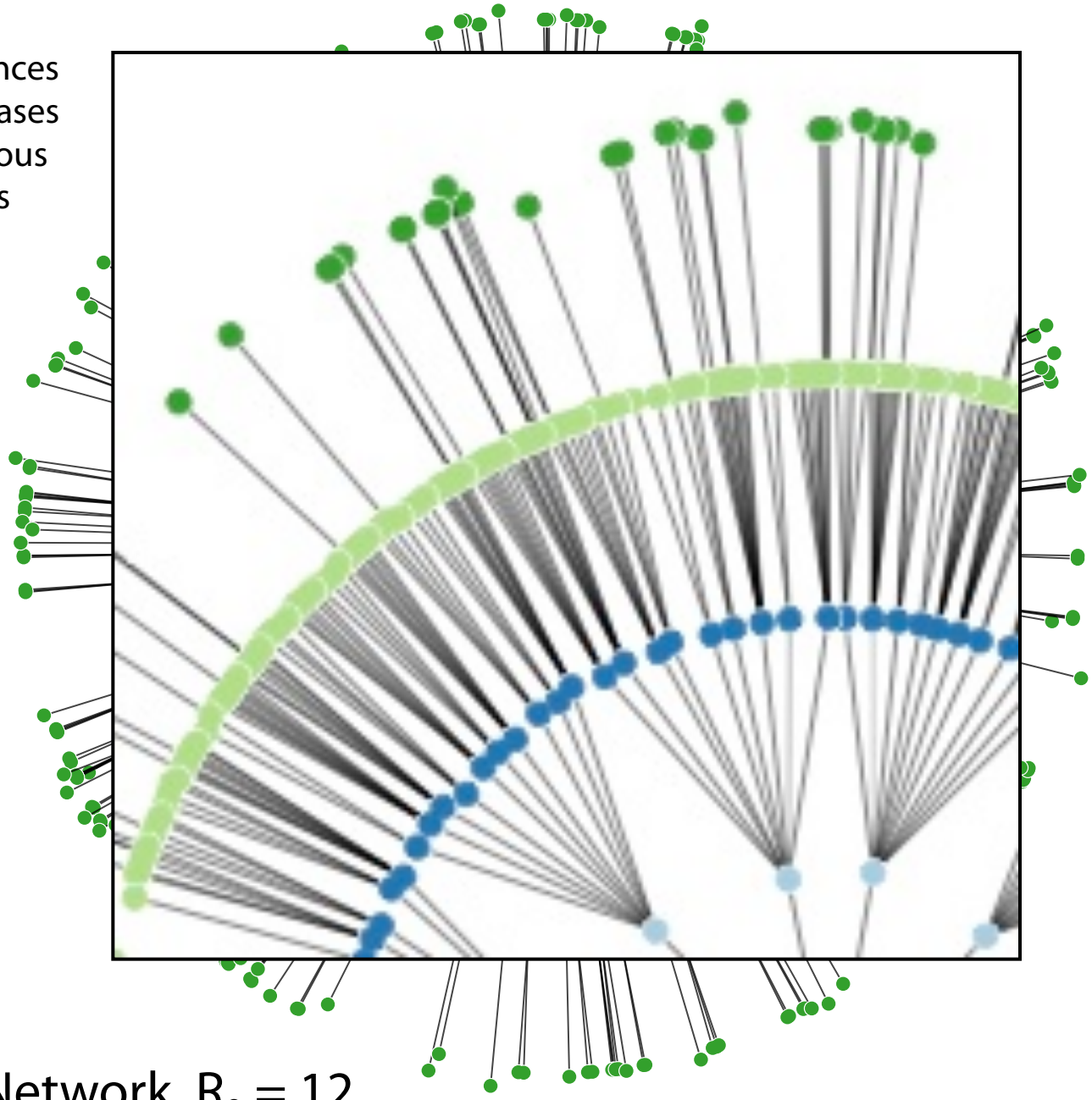


Uniform Network, $R_0 = 3$



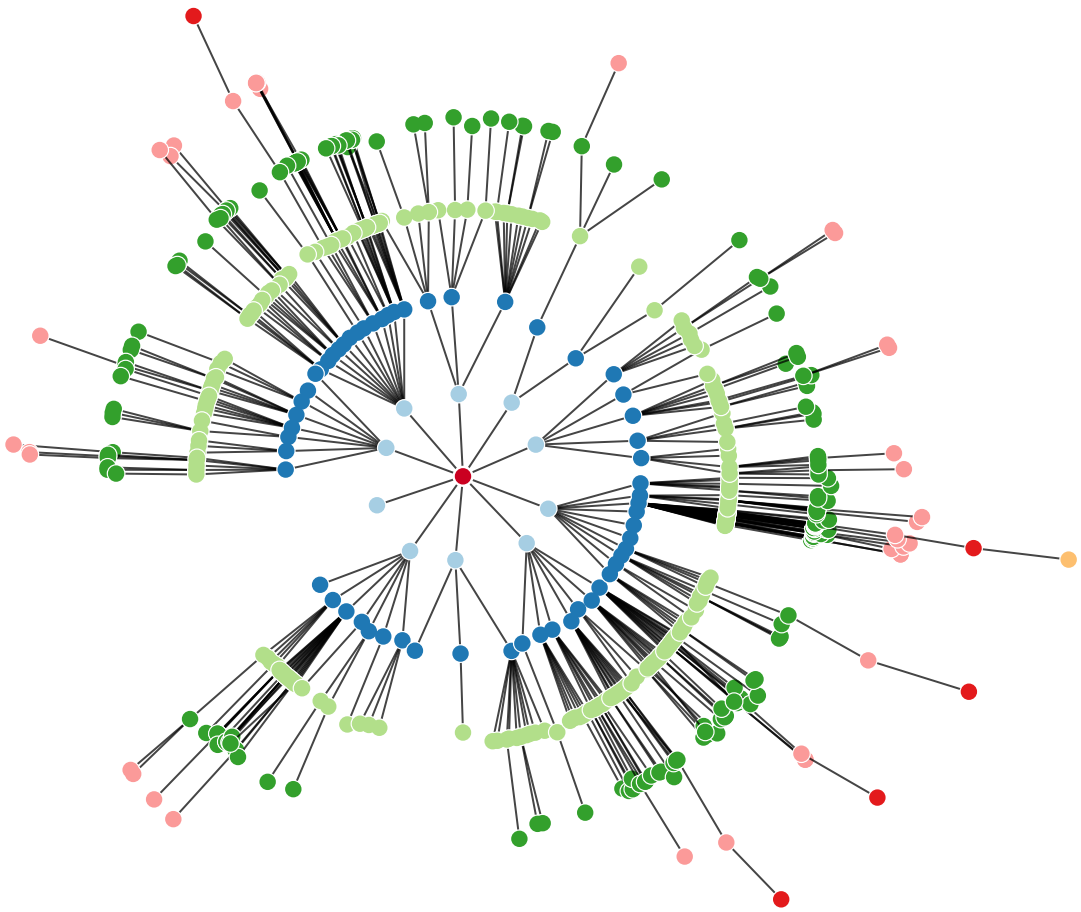
Uniform Network, $R_0 = 12$

We see differences in secondary cases in homogeneous populations

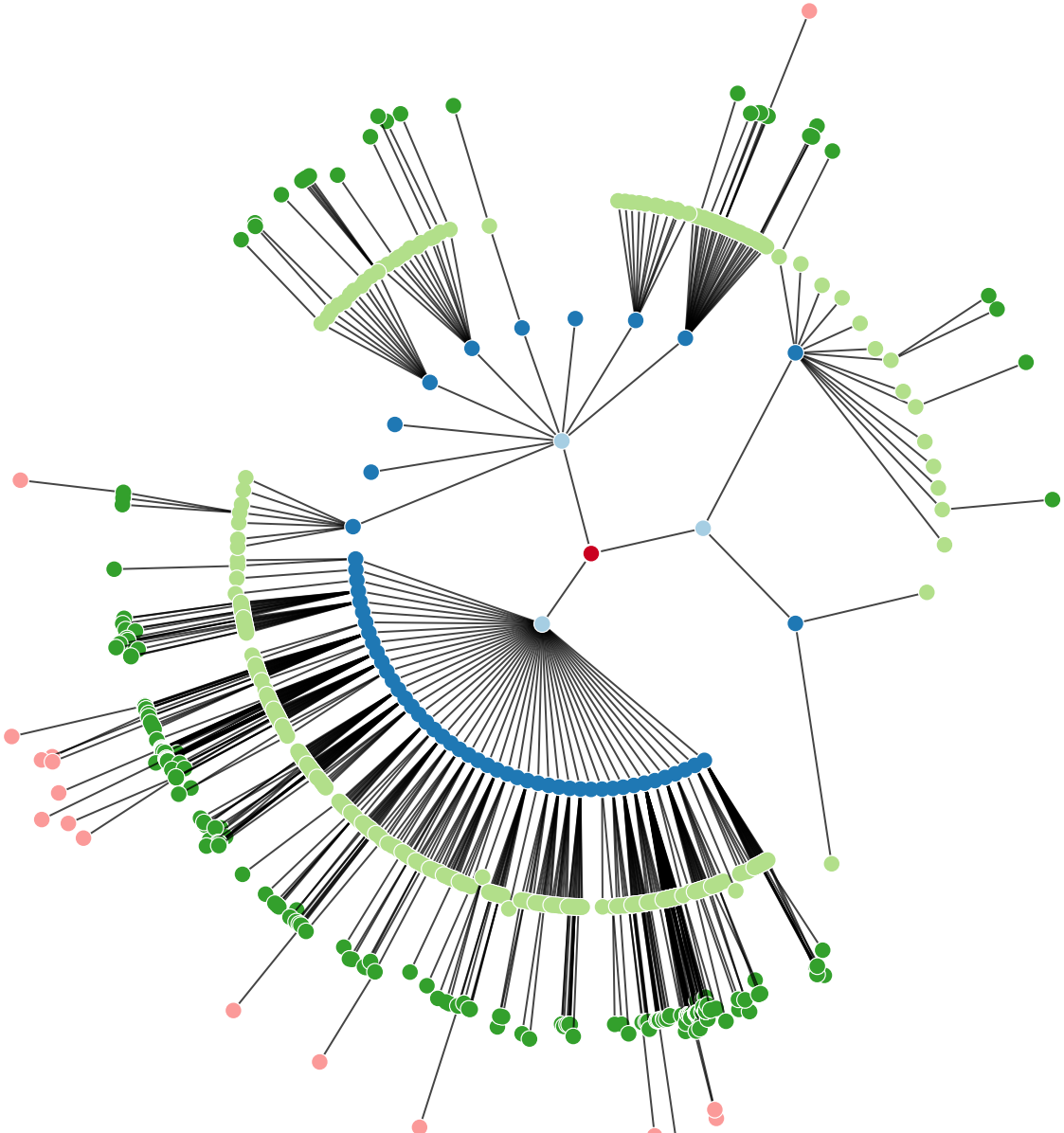


Uniform Network, $R_0 = 12$

We see more heterogeneities in transmission as we introduce heterogeneity in the network.

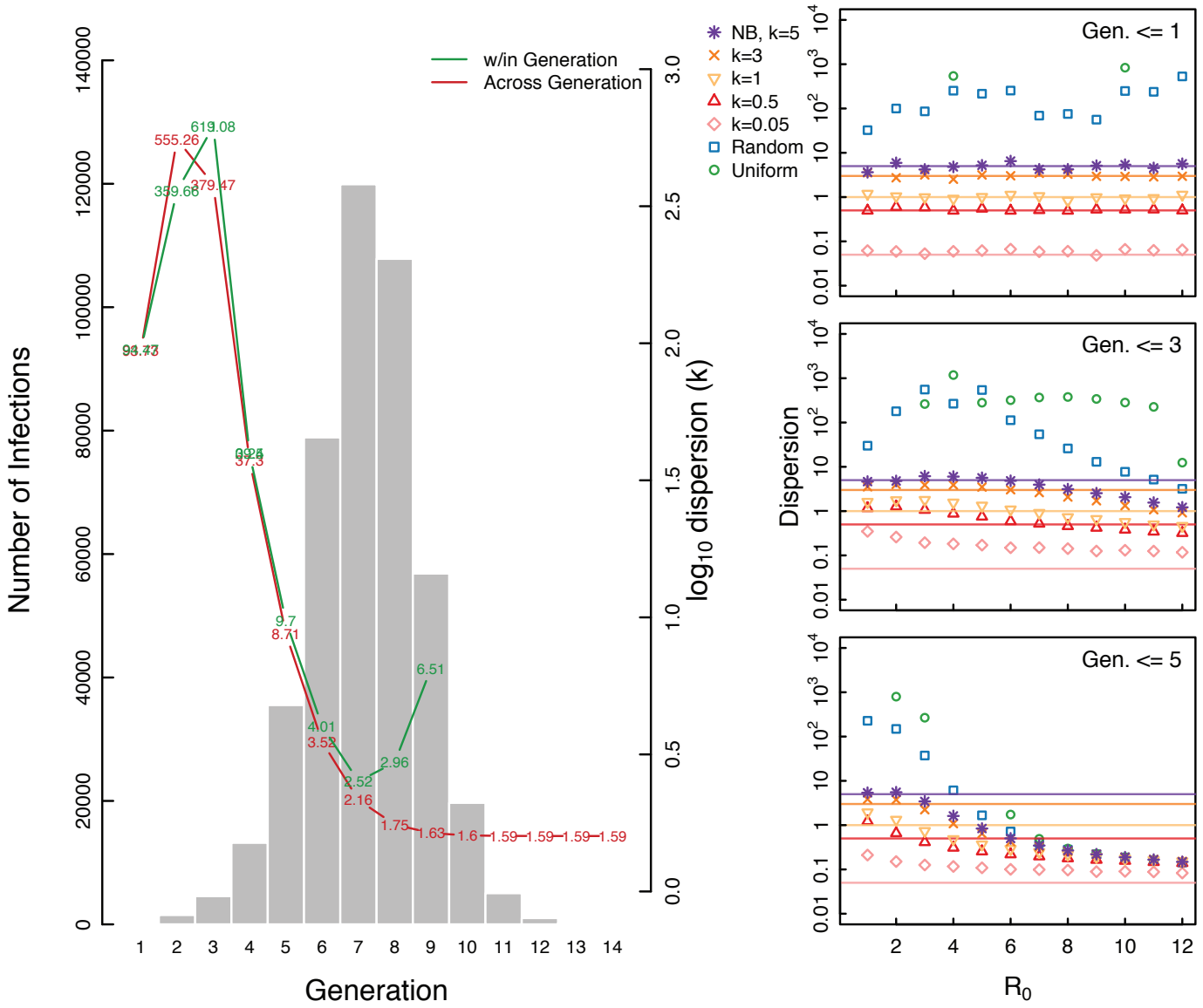


Negative Binomial Network, $R_0 = 3$, k=0.5



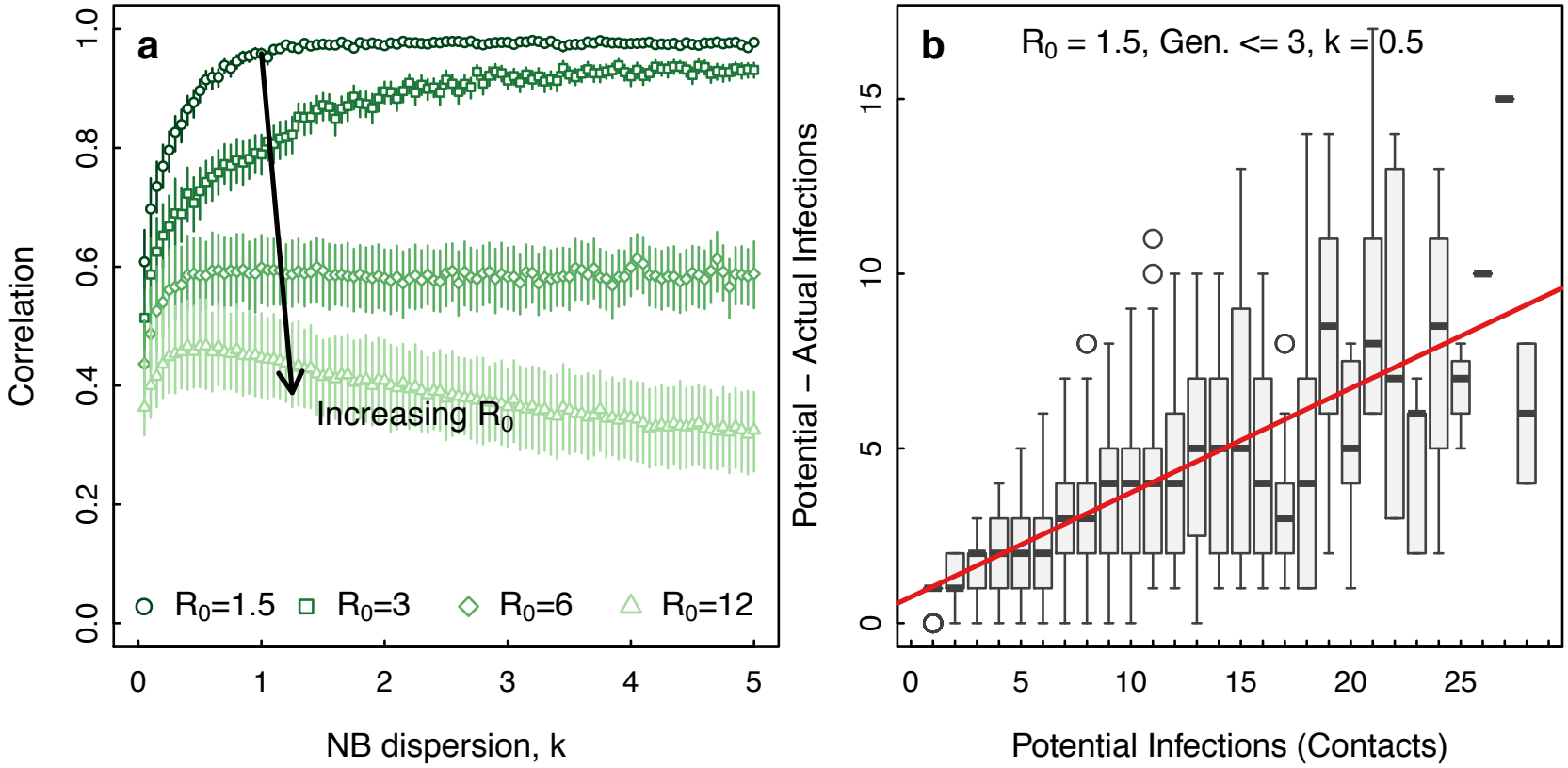
Negative Binomial Network, $R_0 = 12$, k=0.5

Observed Over-dispersion in Secondary Cases In Simulations



Can We Identify Superspreaders?

No! Correlation between actual infections and potential infections (susceptible contacts) is low due to competition for susceptibles!



Lessons

- Biologic & Social variation exist, but…
- Heterogeneity is **endogenous** to the transmission process itself
  - **Competition for susceptibles**
- Current estimates of heterogeneity miss this
- Targeted control **may be ineffective** due to low correlation between contacts and actual infections …
- **New methods** are needed to accurately estimate individual-level heterogeneity in transmission