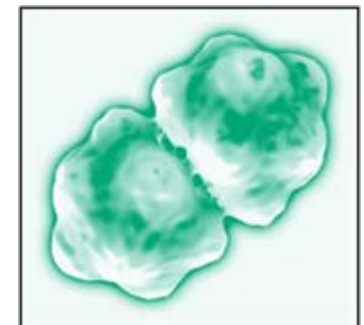
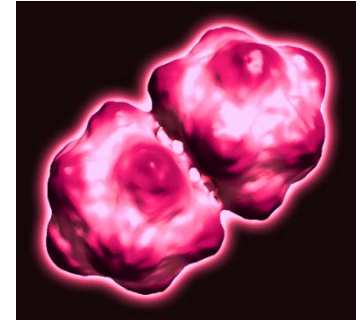


Estimation de la valeur sélective (fitness) de 2 souches virales et modélisation du rôle des co-infections dans leur coexistence

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Introduction

Co-occurrence of two species in a common niche

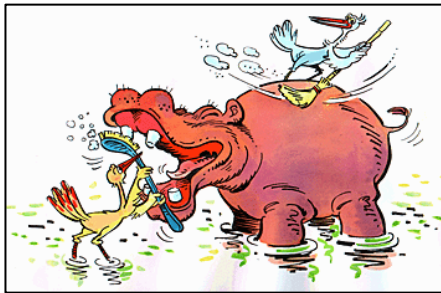


- Competition => competitive exclusion



- Coexistence:

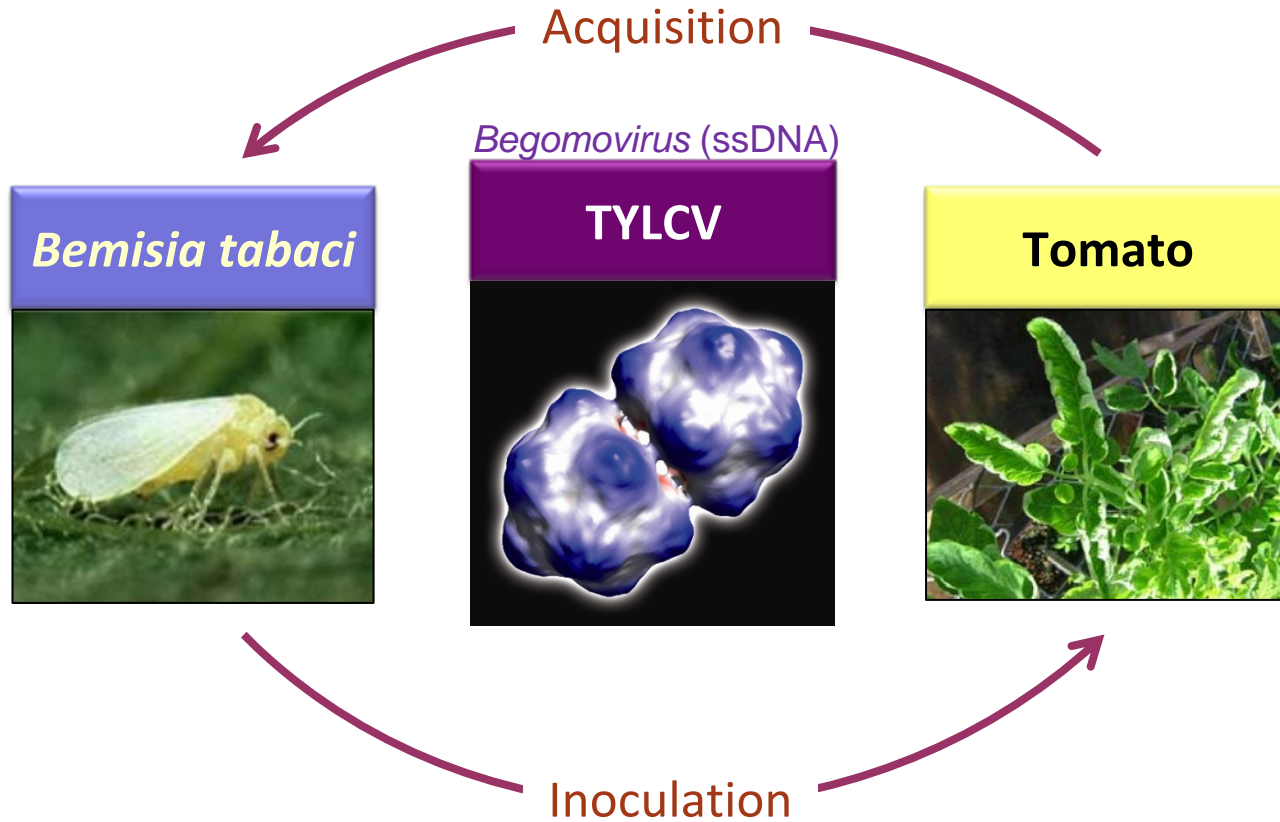
- commensalism (unilateral facilitation)
- co-operation (mutualistic interactions)
- ...



What happens in the field when a virus strain is introduced in a niche occupied by another strain of the same virus?

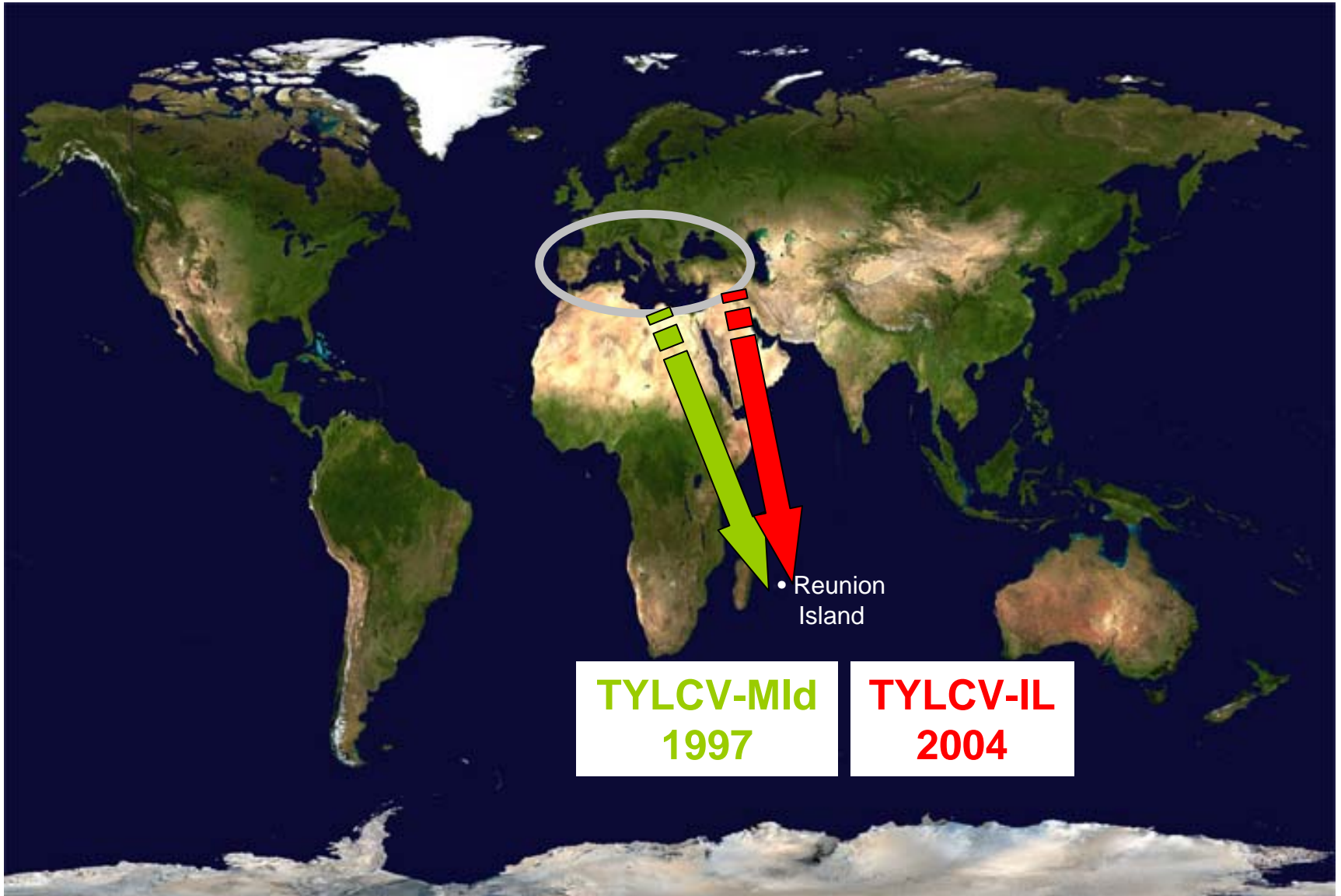
Introduction

Tomato yellow leaf curl virus (TYLCV)



Introduction

Tomato yellow leaf curl virus (TYLCV)

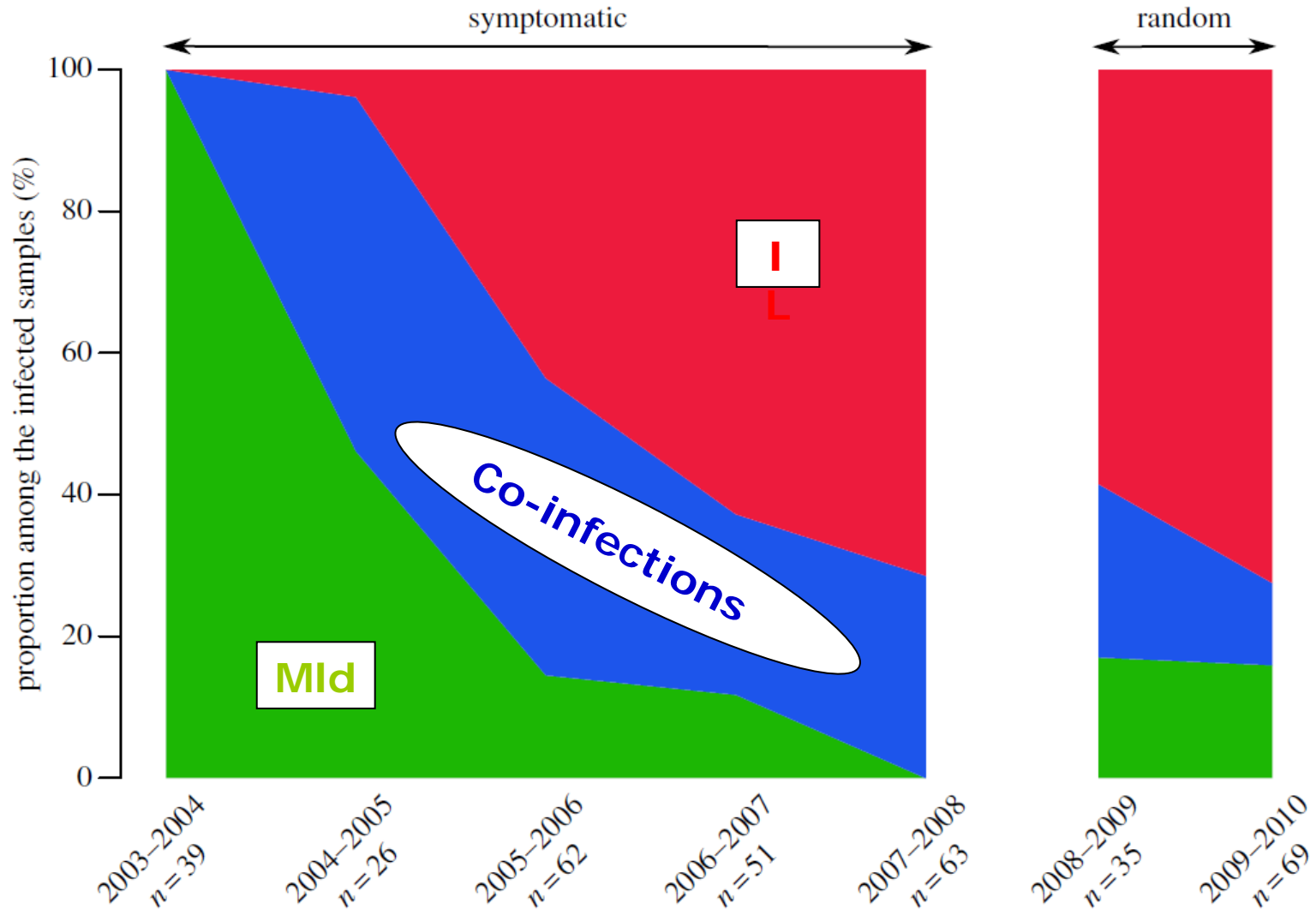


Introduction

- In the long term, should we expect coexistence or competitive exclusion?
 - Relative fitness of the 2 strains?
 - Fitness effects of co-infections?
- Background information / model hypotheses:
 - Tomato is cultivated throughout the year
 - Infected plants stay alive in the field
 - We only consider changes in genotypes frequencies
 - This is not a model on the evolution of virulence (despite the names of the 2 strains)

Relative fitness of the 2 strains

Inference from epidemiological data



Rapid displacement of the resident M1d by IL

Relative fitness of the 2 strains

- Population exponential growth rate: r $N(t) = N_0 \cdot e^{r \cdot t}$
- Progeny size per individual: R_0
- Relative fitness:

➤ $r_I - r_M$?

➤ r_I / r_M ???

$$\frac{N_I}{N_M} = \frac{N_{0,I}}{N_{0,M}} e^{(r_I - r_M) \cdot t}$$

➤ $R_{0,I} - R_{0,M}$???

➤ $R_{0,I} / R_{0,M}$?

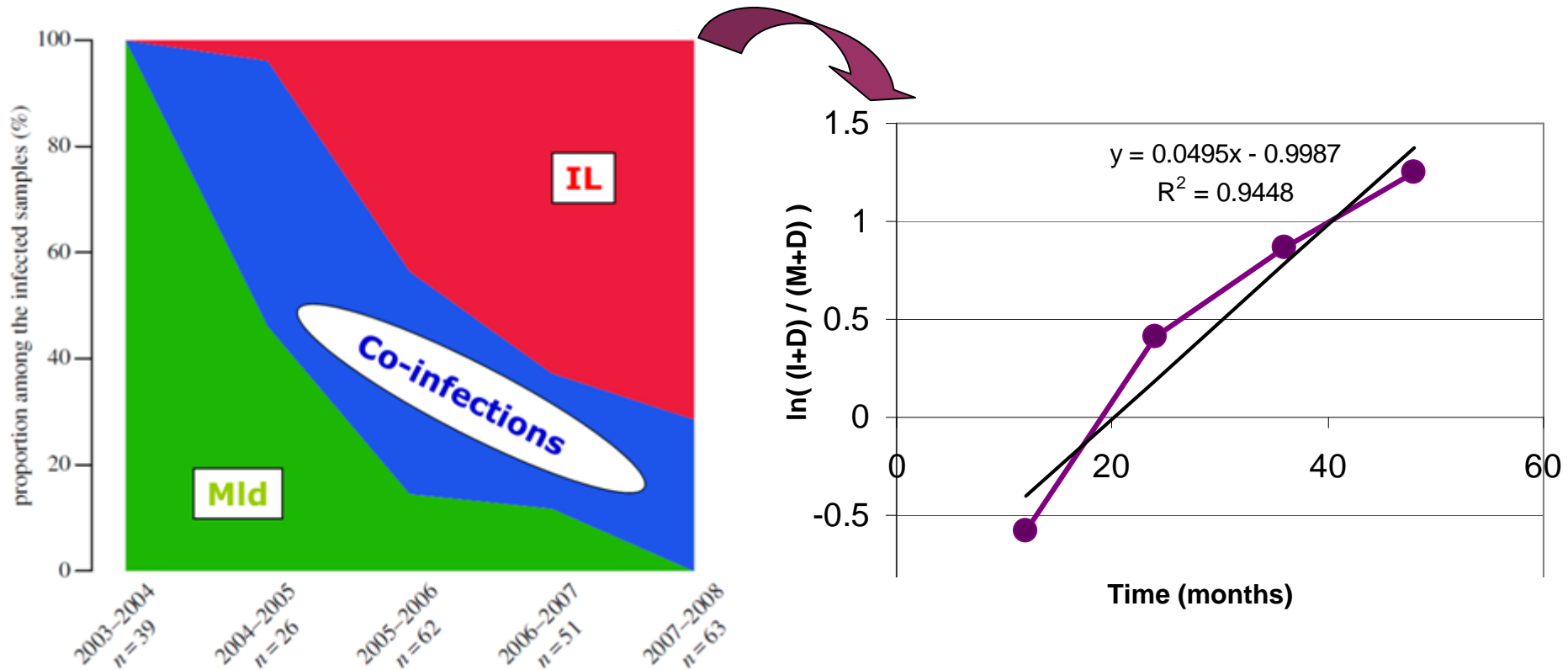
$$r \approx \frac{\ln(R_0)}{g} \Rightarrow r_I - r_M \approx \frac{\ln(R_{0,I}) - \ln(R_{0,M})}{g}$$

$$r_I - r_M \approx \frac{1}{g} \cdot \ln\left(\frac{R_{0,I}}{R_{0,M}}\right)$$

Relative fitness of the 2 strains

Inference from epidemiological data

$$\ln\left(\frac{I+D}{M+D}\right)_{t=t} = \ln\left(\frac{I+D}{M+D}\right)_{t=0} + \textcircled{s} \times t$$

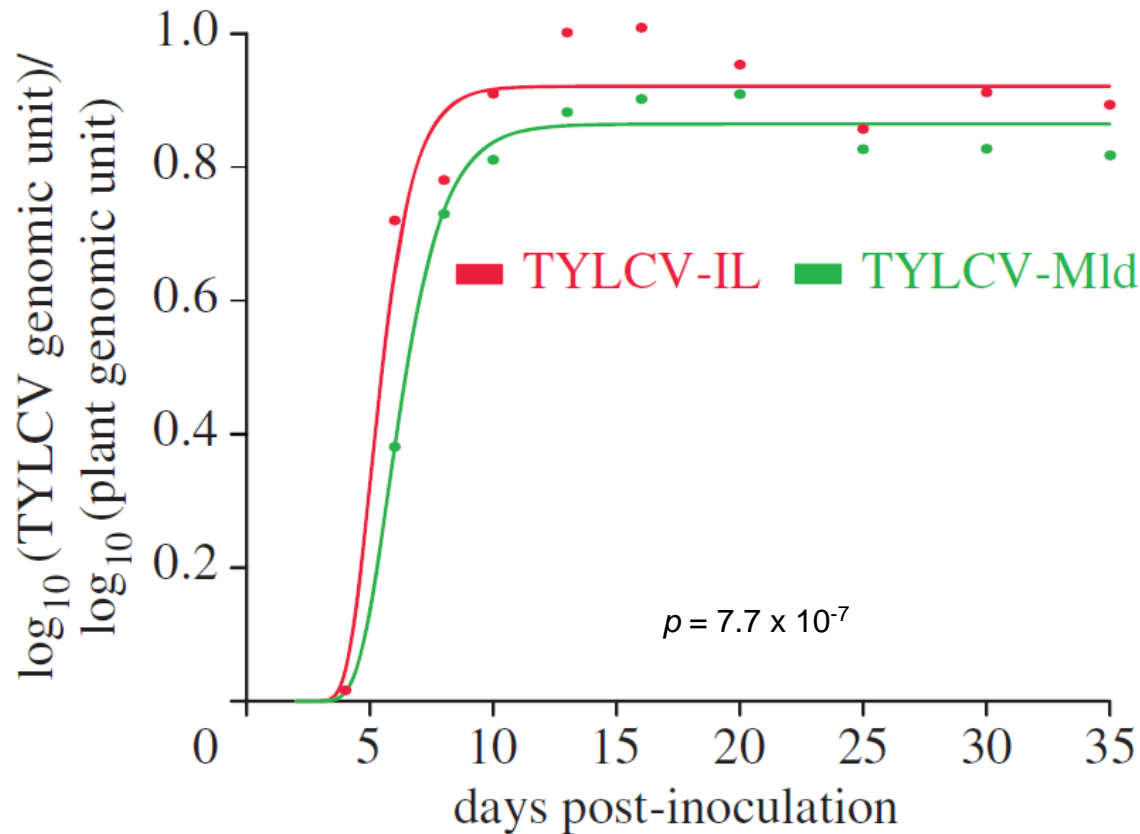


IL has a selective advantage $s = 0,049$ (month⁻¹)

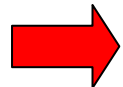
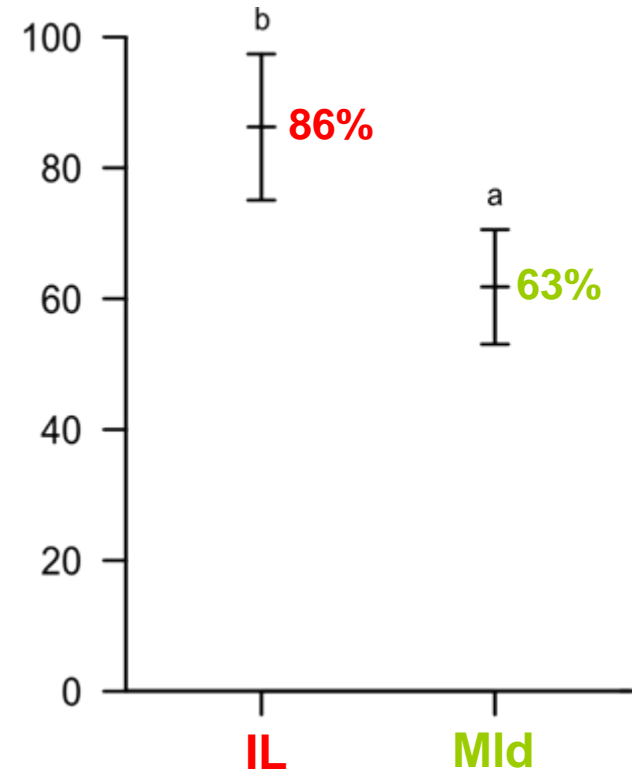
Relative fitness of the 2 strains

Inference from single-infection experiments

Within-plant virus accumulation



Transmission rate (% per vector)



Two classical proxies for virus fitness explain the displacement of Mld by IL

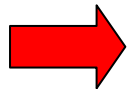
Relative fitness of the 2 strains

Inference from single-infection experiments

$$R_0 = \frac{ma^2 \beta_{p \rightarrow v} \beta_{v \rightarrow p}}{\gamma_v \gamma_p} \longrightarrow \frac{R_{0,I}}{R_{0,M}} = \frac{\beta_{I,p \rightarrow v} \beta_{I,v \rightarrow p}}{\beta_{M,p \rightarrow v} \beta_{M,v \rightarrow p}}$$

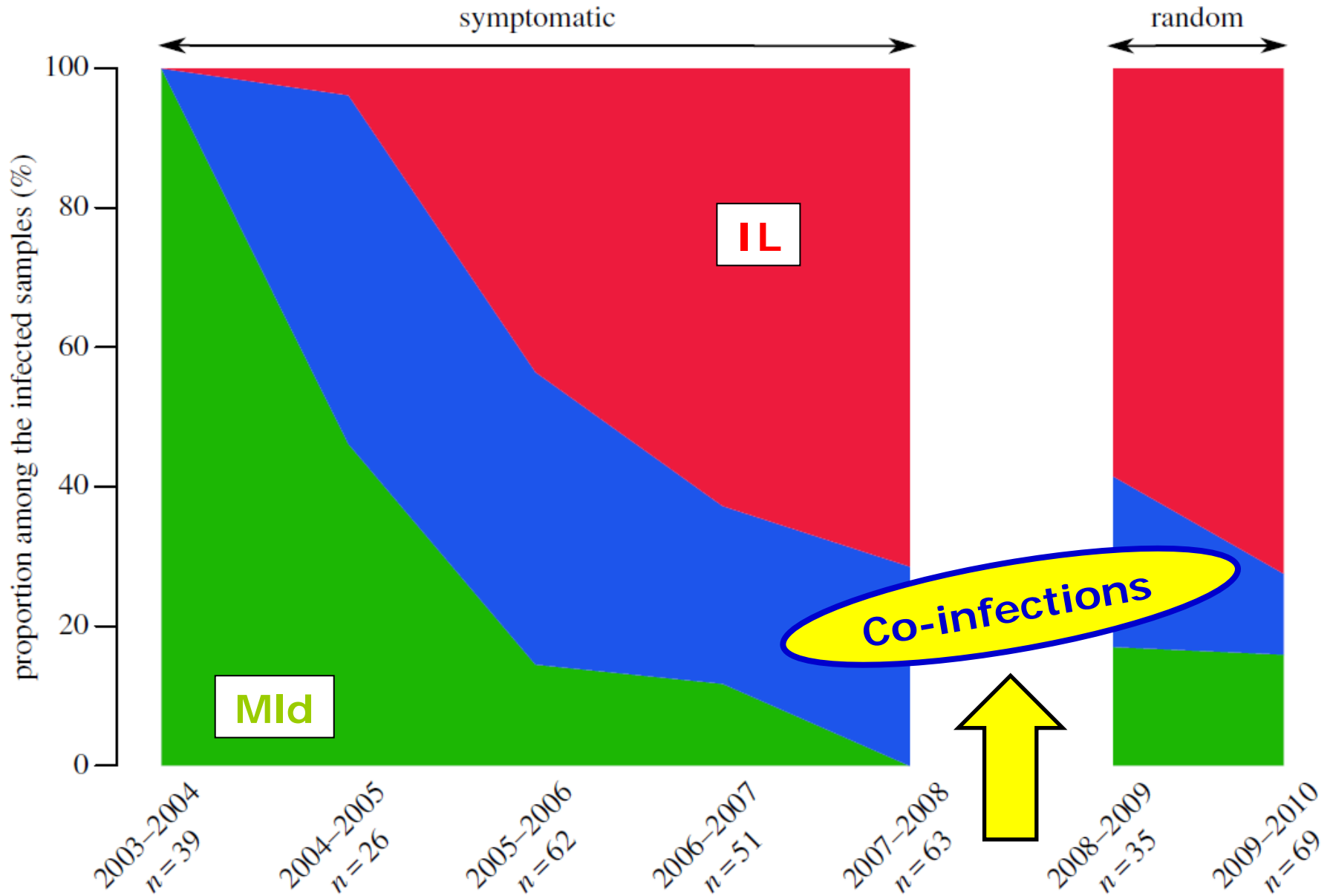
- P [transmission (IL)] = 0.865
- P [transmission (Mld)] = 0.633

$$\left. \begin{array}{l} P \text{ [transmission (IL)]} = 0.865 \\ P \text{ [transmission (Mld)]} = 0.633 \end{array} \right\} \frac{R_{0,I}}{R_{0,M}} = \frac{0.865}{0.633} = 1.37$$



Fitness(IL) = 1.37 x Fitness(Mld) per generation

Fitness effects of co-infections

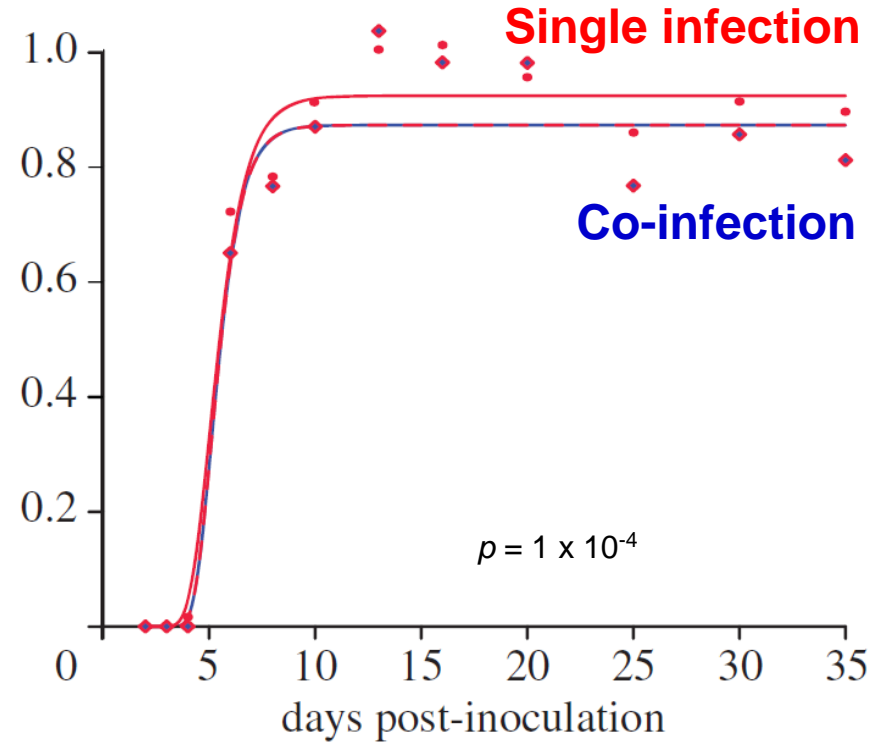
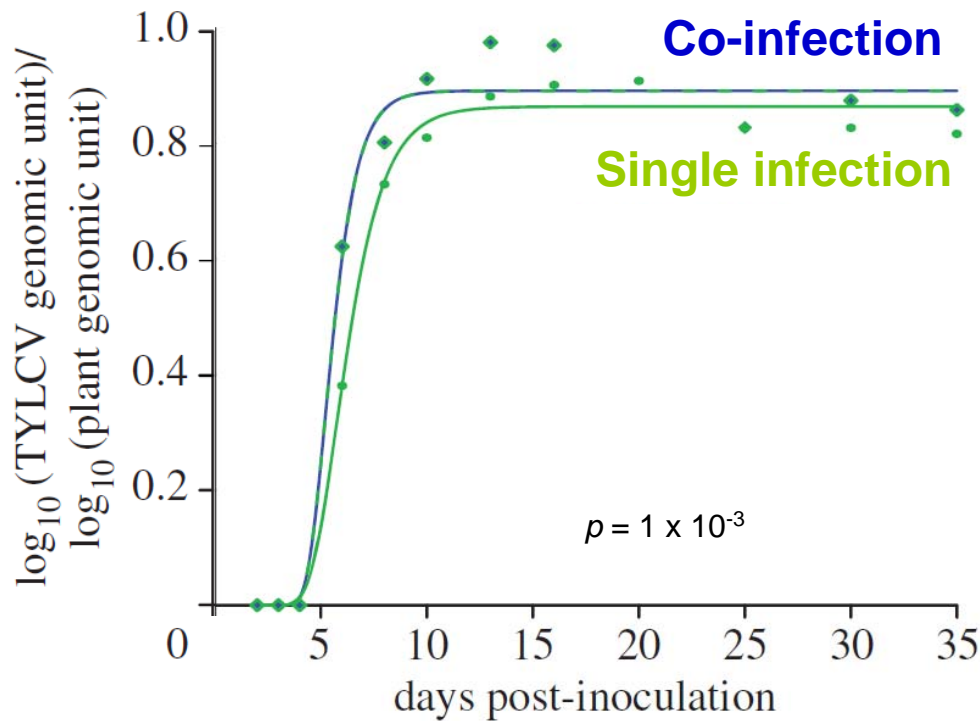


Fitness effects of co-infections

Within-plant viral accumulation

Mld strain

IL strain



In co-infection:

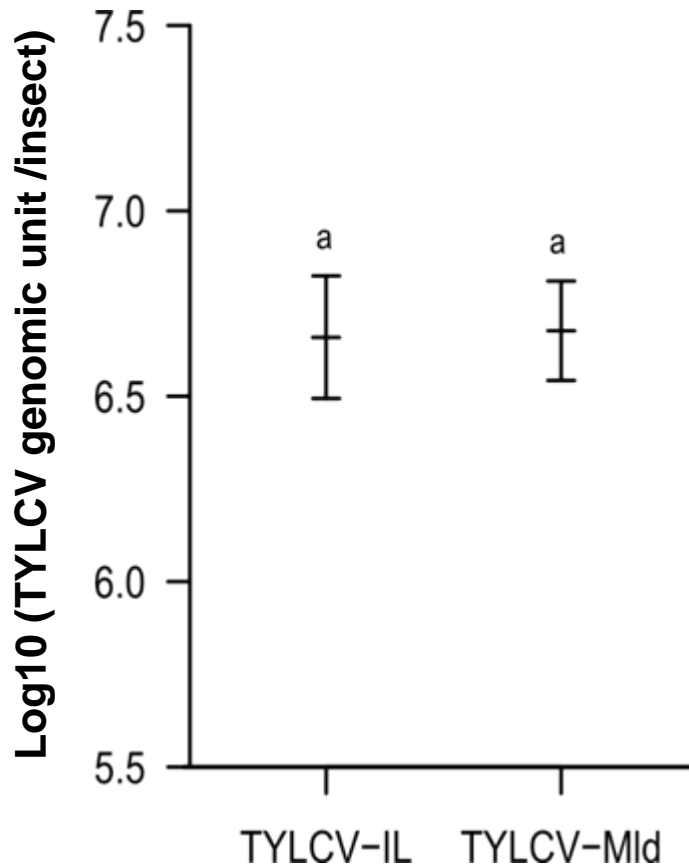
→ **Mld** viral load increases

→ **IL** viral load decreases

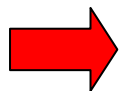
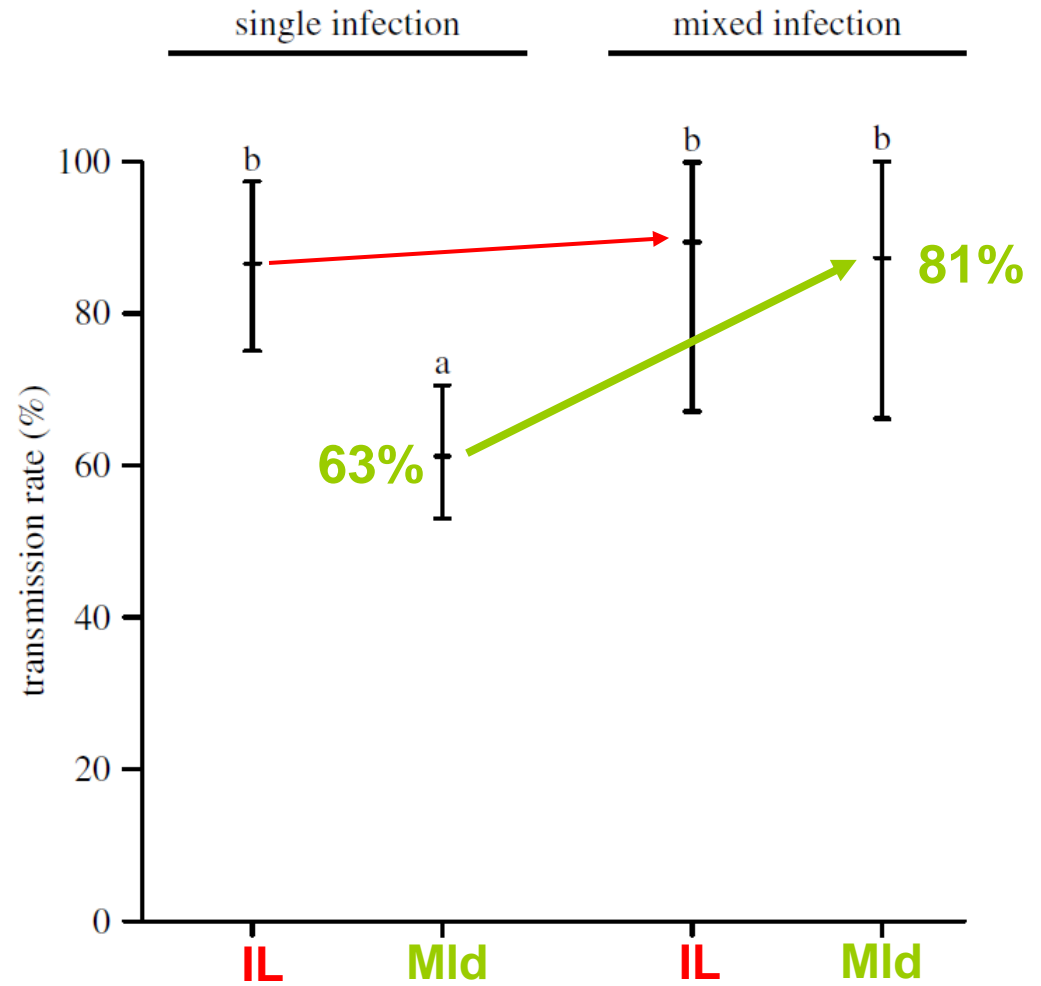
→ **Mld** and **IL** accumulate to similar levels

Fitness effects of co-infections

Viral load in the vector (single infection)



Transmission rate



Co-infections benefit Mld without affecting IL

Long-term dynamics with co-infections

Epidemiological model parameterized with experimental transmission rates

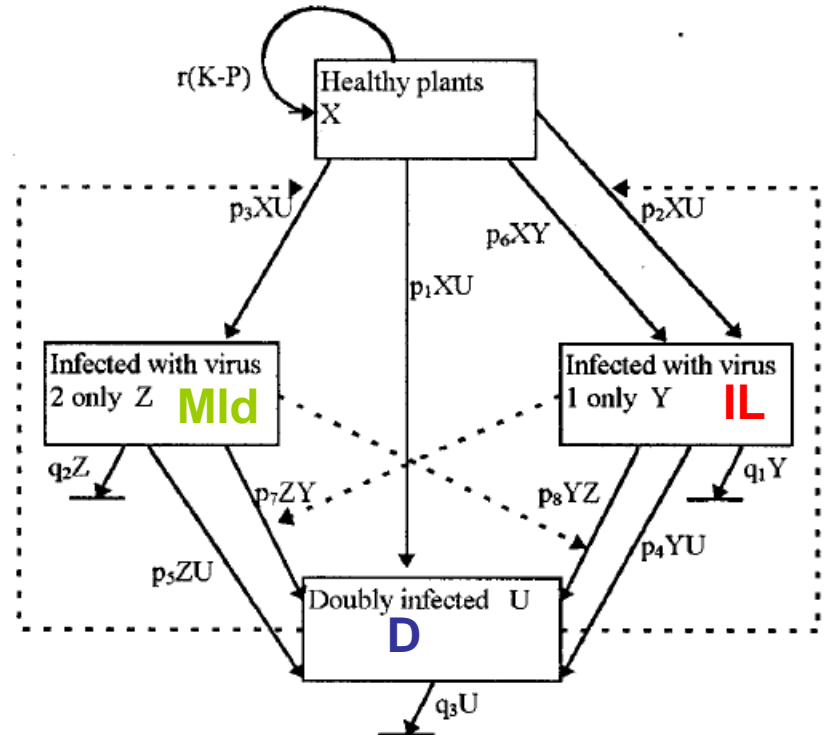
Extinction



Co-existence



What fate for the **Mld** strain?



(Zhang et al, *Phytopathology*, 2000)

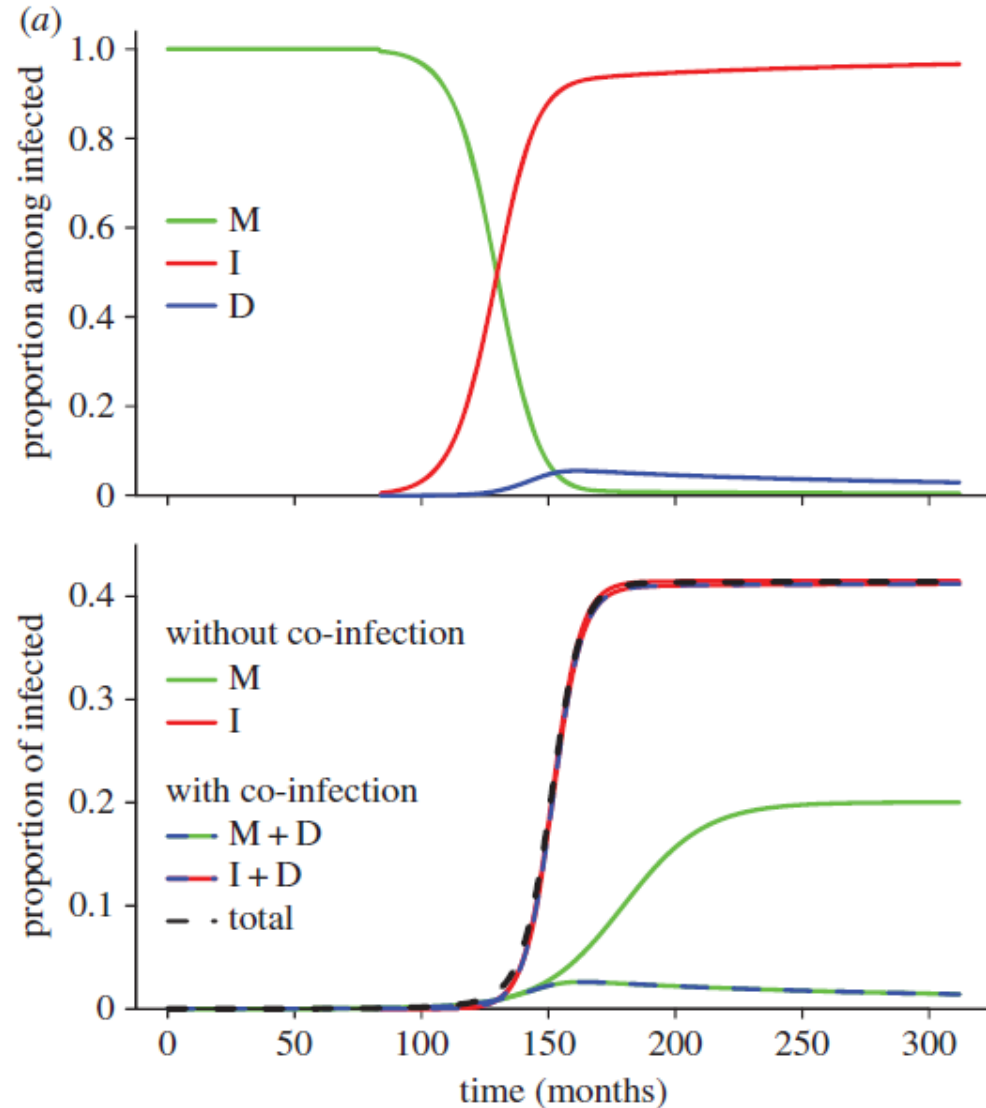
$$\begin{cases} dH / dt = \mu(1-H) - r_M MH - r_I IH - (r_{D \rightarrow M} + r_{D \rightarrow I} + r_{D \rightarrow D}) DH \\ dM / dt = r_M MH + r_{D \rightarrow M} DH - r_I IM - (r_{D \rightarrow I} + r_{D \rightarrow D}) DM - \mu M \\ dI / dt = r_I IH + r_{D \rightarrow I} DH - r_M MI - (r_{D \rightarrow M} + r_{D \rightarrow D}) DI - \mu I \\ dD / dt = r_{D \rightarrow D} DH + r_M MI + r_I IM + (r_{D \rightarrow I} + r_{D \rightarrow D}) DM + (r_{D \rightarrow M} + r_{D \rightarrow D}) DI - \mu D \end{cases}$$

Long-term dynamics with co-infections

Hypothesis: IL has reached the carrying capacity of the plant



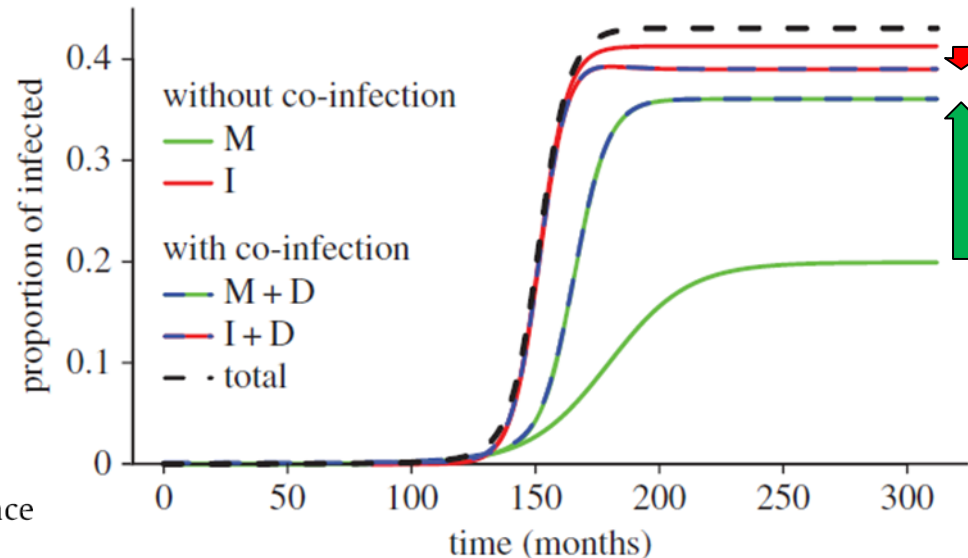
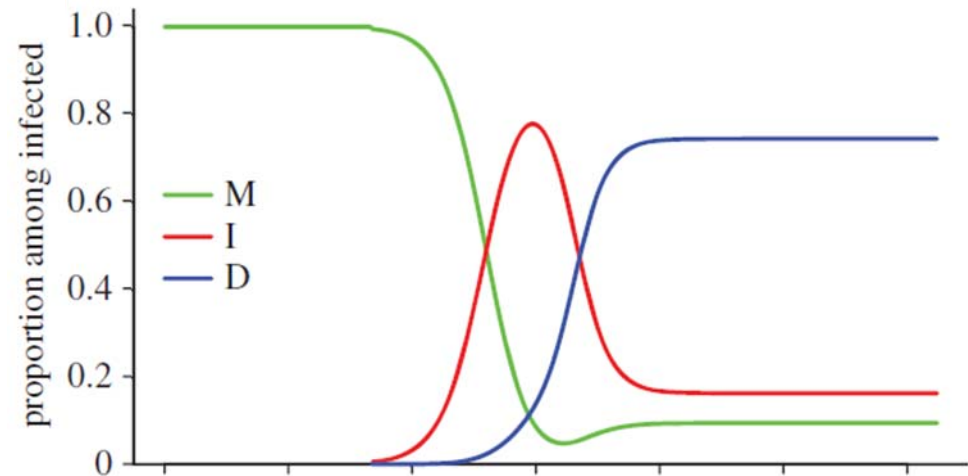
- No long-term coexistence
- **IL** overcompetes **M** and **D**



Long-term dynamics with co-infections

Epidemiological model parameterized with experimental transmission rates

- Long-term coexistence enabled by co-infection
- **M** gains a lot but **I** loses little
- More disease than with **I** only
- Qualitative results are robust



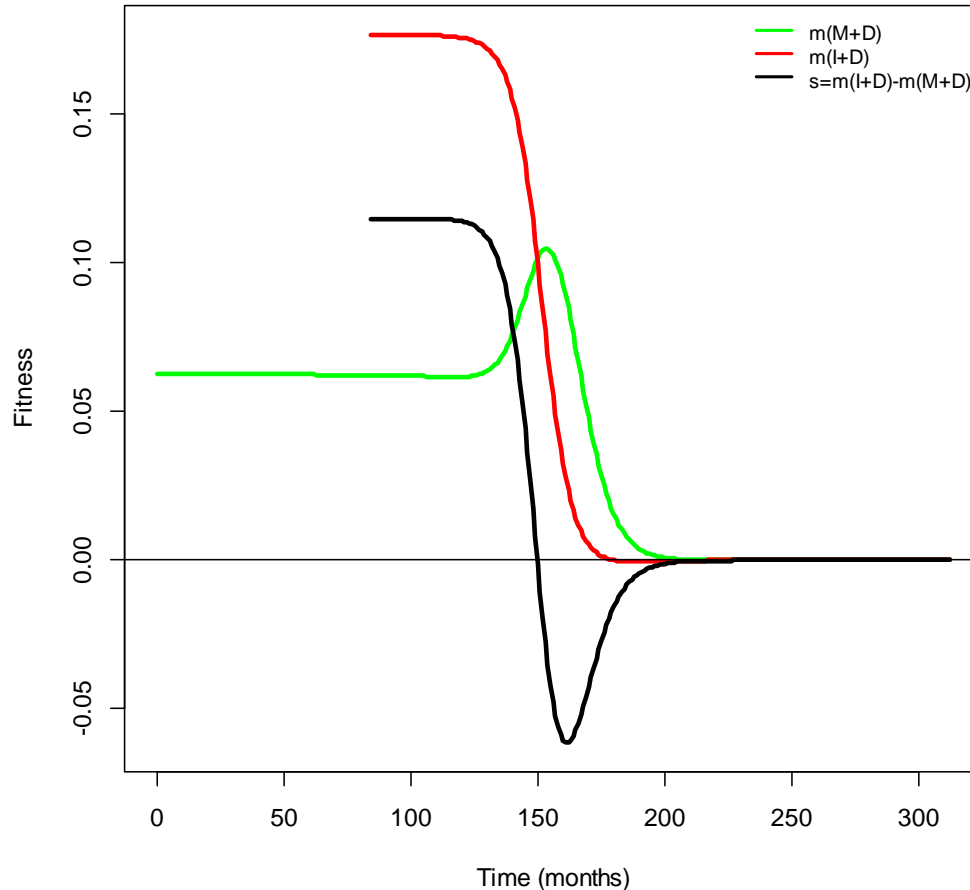
Journal of Theoretical Biology 265 (2010) 377–388

Asymmetrical over-infection as a process of plant virus emergence

Frédéric Fabre^{a,*}, Joël Chadœuf^b, Caroline Costa^a, Hervé Lecoq^a, Cécile Desbiez^a

Long-term dynamics with co-infections

Fitness dynamics



$$s = \frac{d \ln(RR)}{dt}$$

$$s = \frac{d(I+D)/dt}{I+D} - \frac{d(M+D)/dt}{M+D}$$

- The fitness of the **MId** strain increases with the frequency of co-infected hosts
- In the long run, both strains have the same fitness

Take-home messages

- A rare documented case of:
 - unilateral facilitation
 - inference of fitness difference from field data
- Co-infections play a crucial role:
 - allowing coexistence of 2 strains
 - increasing the risk of emergence of a new recombinant TYLCV strain
- Importance of measuring fitness in single AND mixed infections
- Importance of using the transmission rate as a fitness proxy

Reference

Péréfarres F, Thébaud G, Lefeuvre P, Chiroleu F, Rimbaud L, Hoareau M, Reynaud B, Lett J-M. (2014) *Proceedings of the Royal Society B* 281: 20133374.