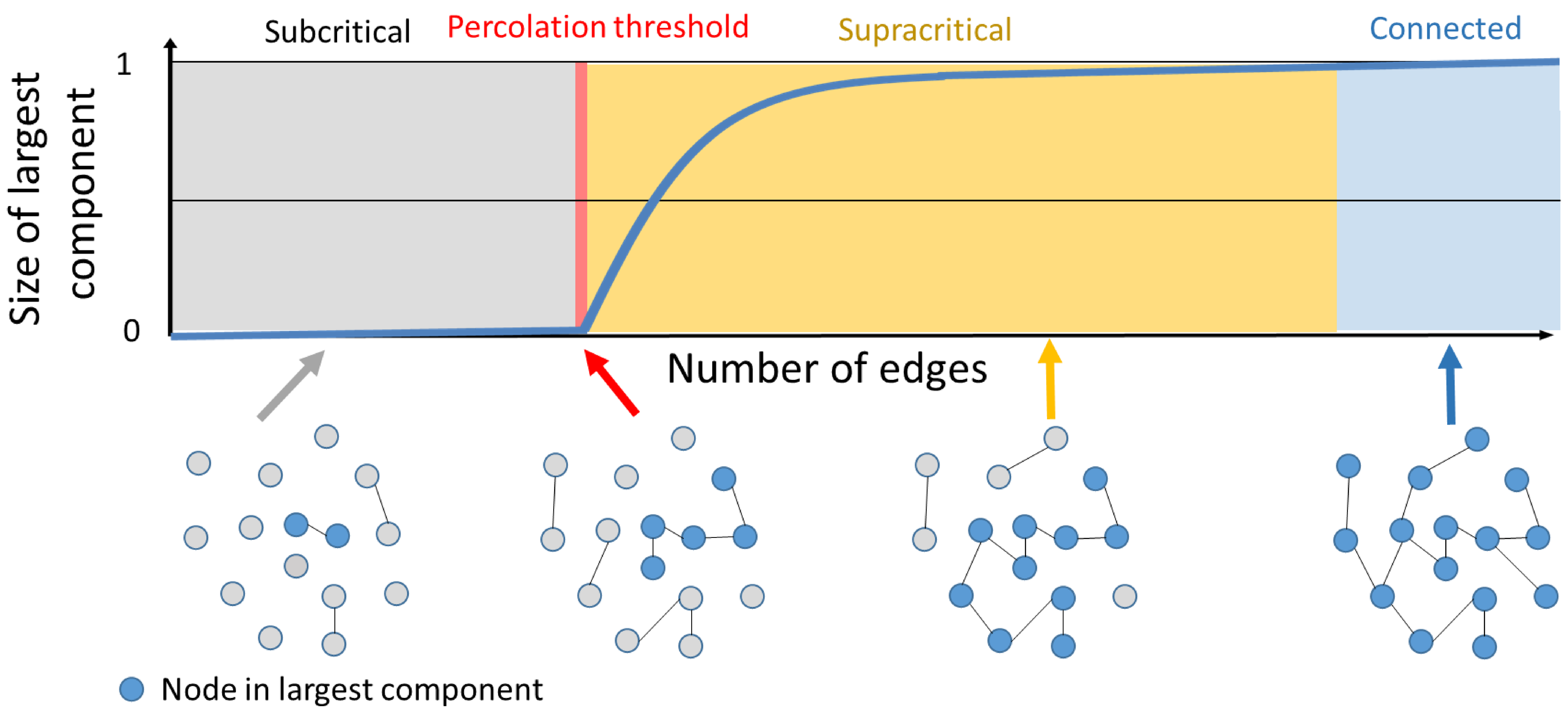
The percolation of metabolism and bacterial lifestyle and evolvability

Germán Plata, PhD & Dennis Vitkup, PhD

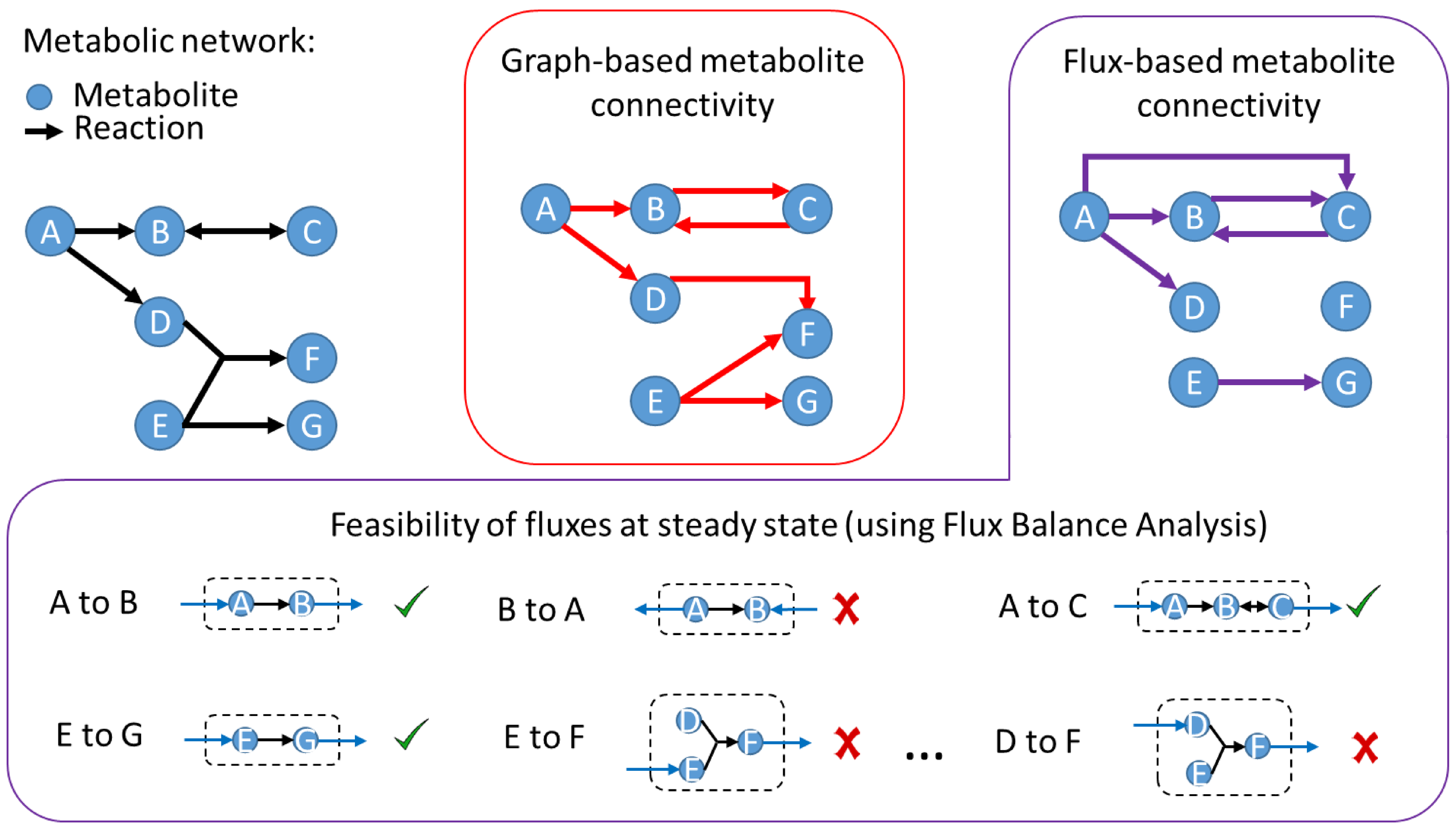
Department of Systems Biology, Columbia University Medical Center, New York, NY 10032, **gap2118@cumc.columbia.edu**

A percolation process describes the changes in the connectivity of a network as nodes or edges are removed



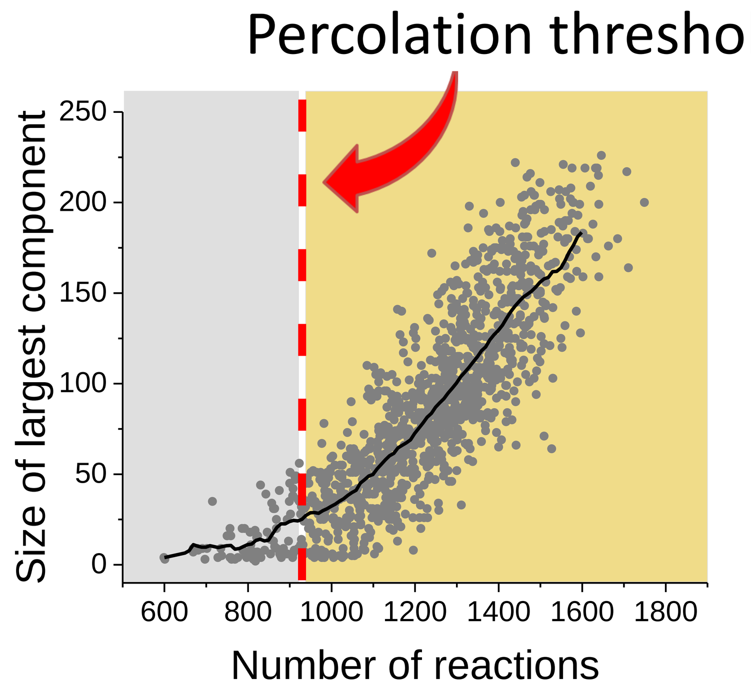
Can metabolic network diversity across bacteria be seen as a percolation process? If so, **what are its consequences for microbial physiology, ecology and evolution?**

Defining metabolic network connectivity



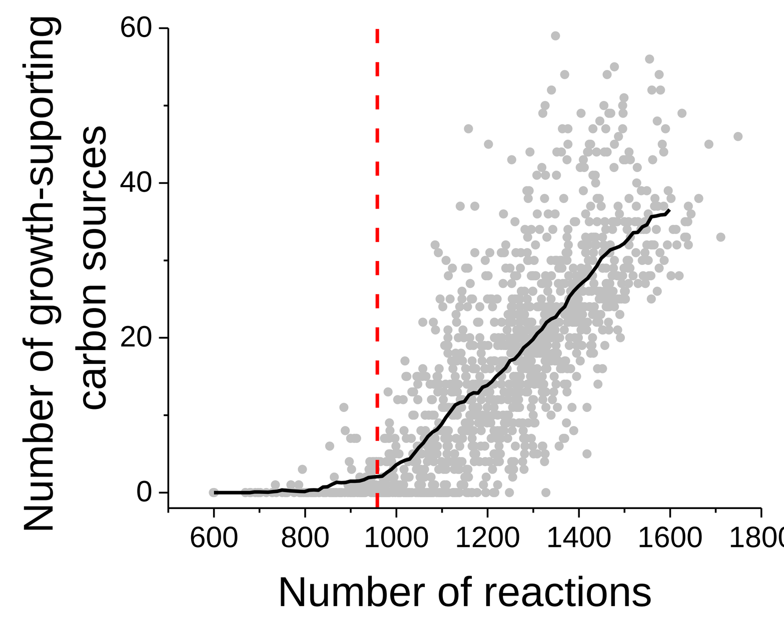
- Metabolic networks were defined based on the ability of mass (carbon) to flow between metabolites (right)
- 1,181 networks were obtained from Kbase, each from a different bacterial genus

A percolation transition in metabolism

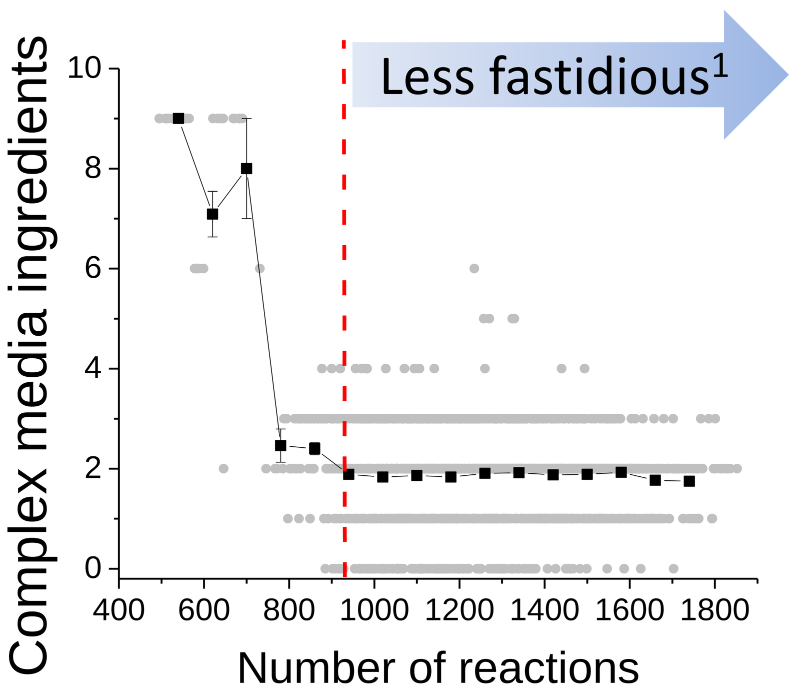


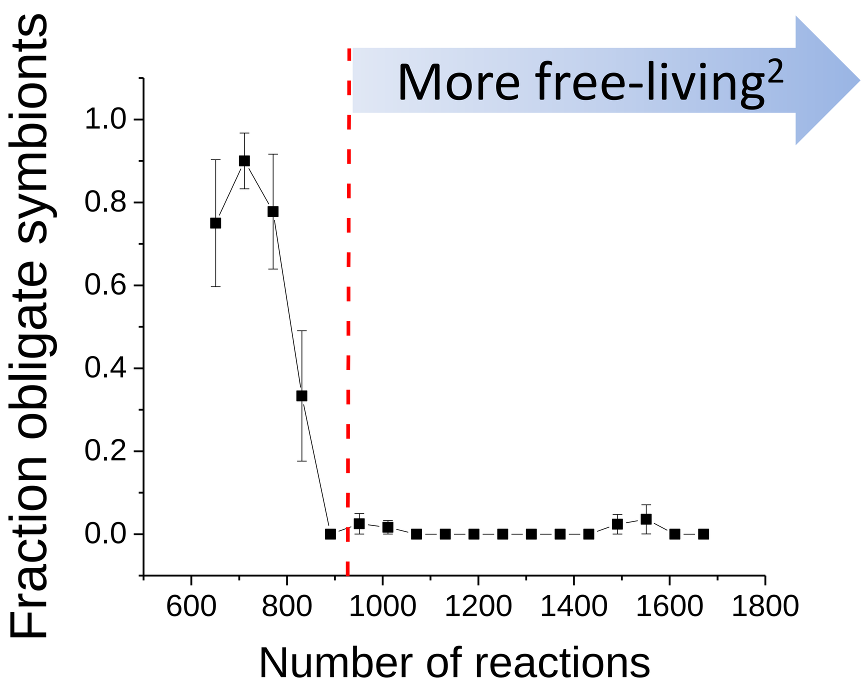
Each dot represents the metabolic network of a different bacterium

How many carbon sources support growth?



Critical threshold at **~900 reactions or ~2,000 genes**

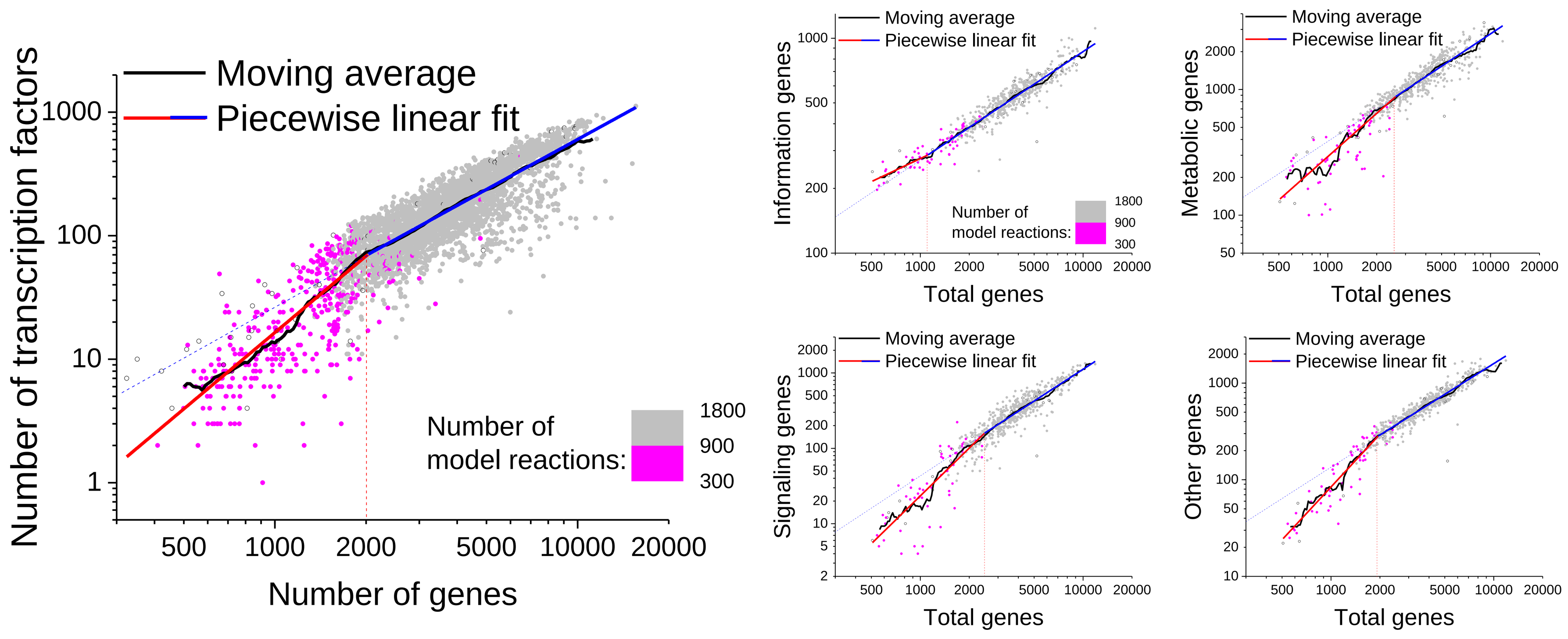




Obligate parasitic or symbiotic lifestyles are common below the percolation threshold

[1] Known growth media: komodo.modelseed.org [2] Lifestyle classification: Burstein et al. 2015. Nat Commun. **6**, 8493

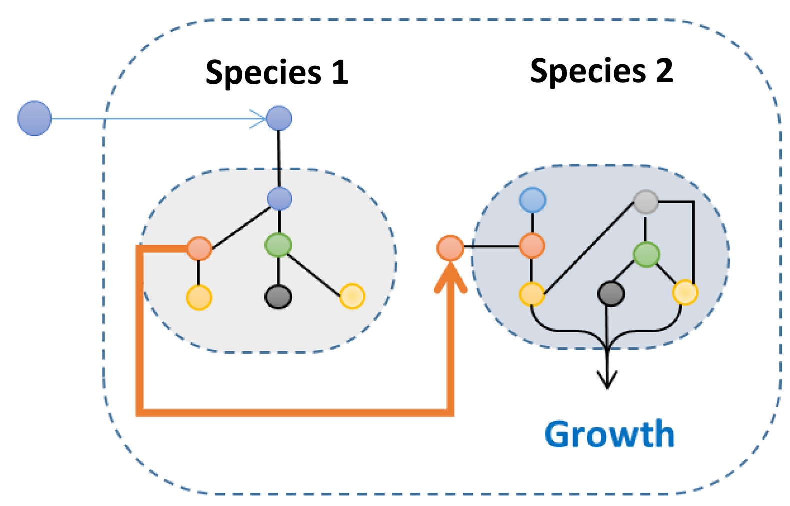
Impact on genome architecture

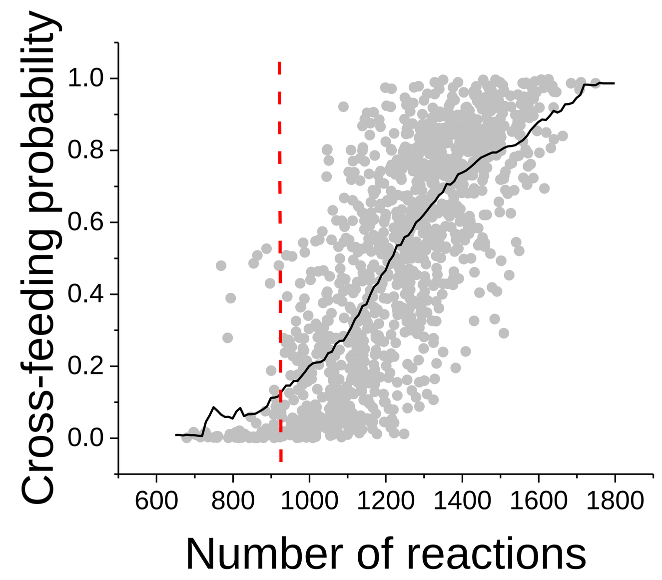


Condition-specific genes are lost more rapidly with decreasing genome size below percolation threshold

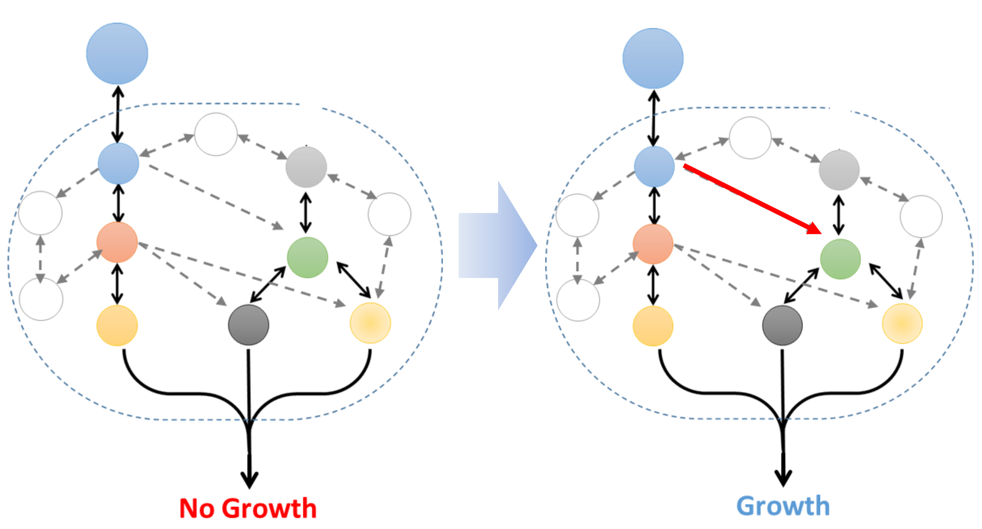
Species interactions and evolvability

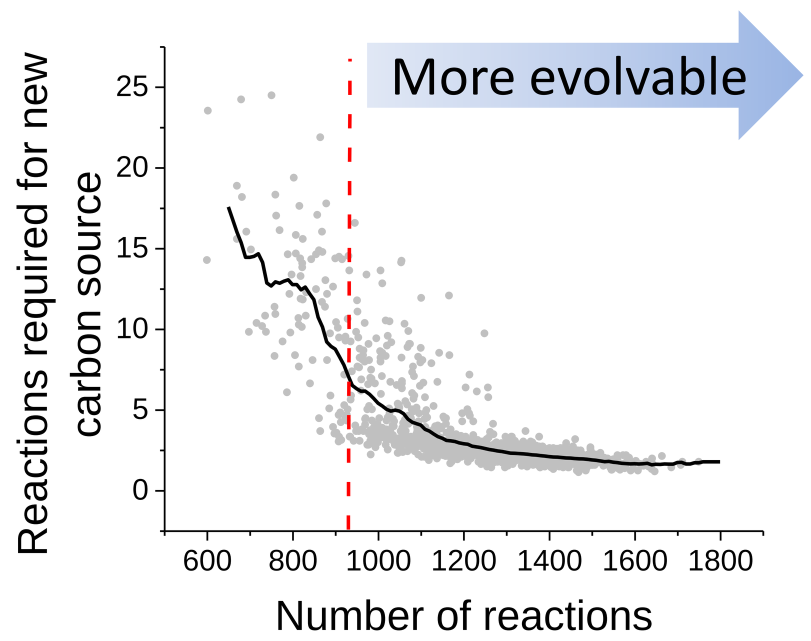
How likely is one species to benefit from metabolic by-products of another?



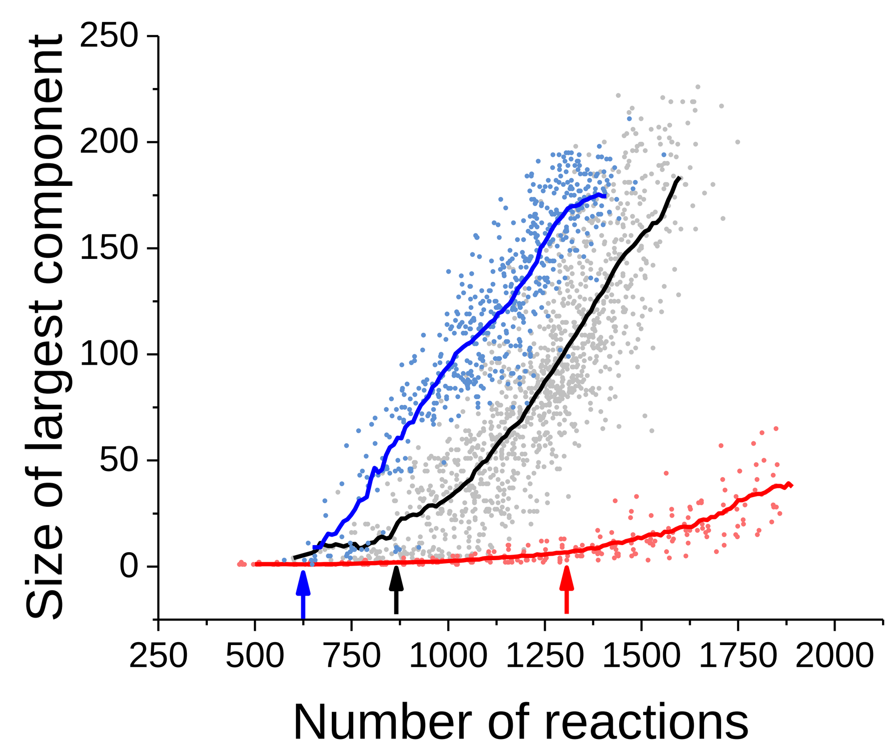


How many additional reactions are needed to grow on a new carbon source?





Percolation in random networks



Real networks from 1,181 bacterial species

Random networks, same probability per reaction.

Optimal networks, least number of reactions per carbon source supporting growth.

Arrows indicate percolation thresholds

Bacterial evolution avoids metabolic networks that are large and disconnected or small and connected.

Conclusions

- Differences in the connectivity of bacterial metabolic networks can be described as a percolation process
- Species with less than ~2,000 genes tend to be more fastidious, less easily evolvable, and less likely to cross-feed with a randomly chosen bacterium
- Differences are explained by metabolite interconversions supported by the giant component present in larger metabolic networks

Funding: National Institute of General Medical Sciences GM079759 to DV