Will a time-varying complex system be stable?

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Young Seminars SIFS — November 12th 2026

References

Will a time-varying complex system be stable?
FF et al.
arxiv 2026

Generalized Lotka-Volterra systems with time-correlated stochastic interactions
Suweis et al.
Physical Review Letters 2024

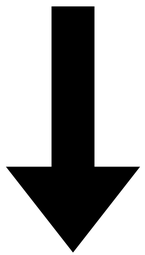
Where to invest?

emerging market

or

developed market

depends on risk tolerance



complexity vs stability

Broad motivation

- Does complexity increase or decrease stability?
- Empirically: complexity increases stability
- Mechanistically: unclear
  - ✅ redundancy, risk mitigation, …
  - ❌ more degrees of freedom, cascading failures, …

Stability

- Perturbations δx_i follow

$$\delta \dot{x}_i = \sum_{j=1}^{N} M_{ij}\, \delta x_j$$

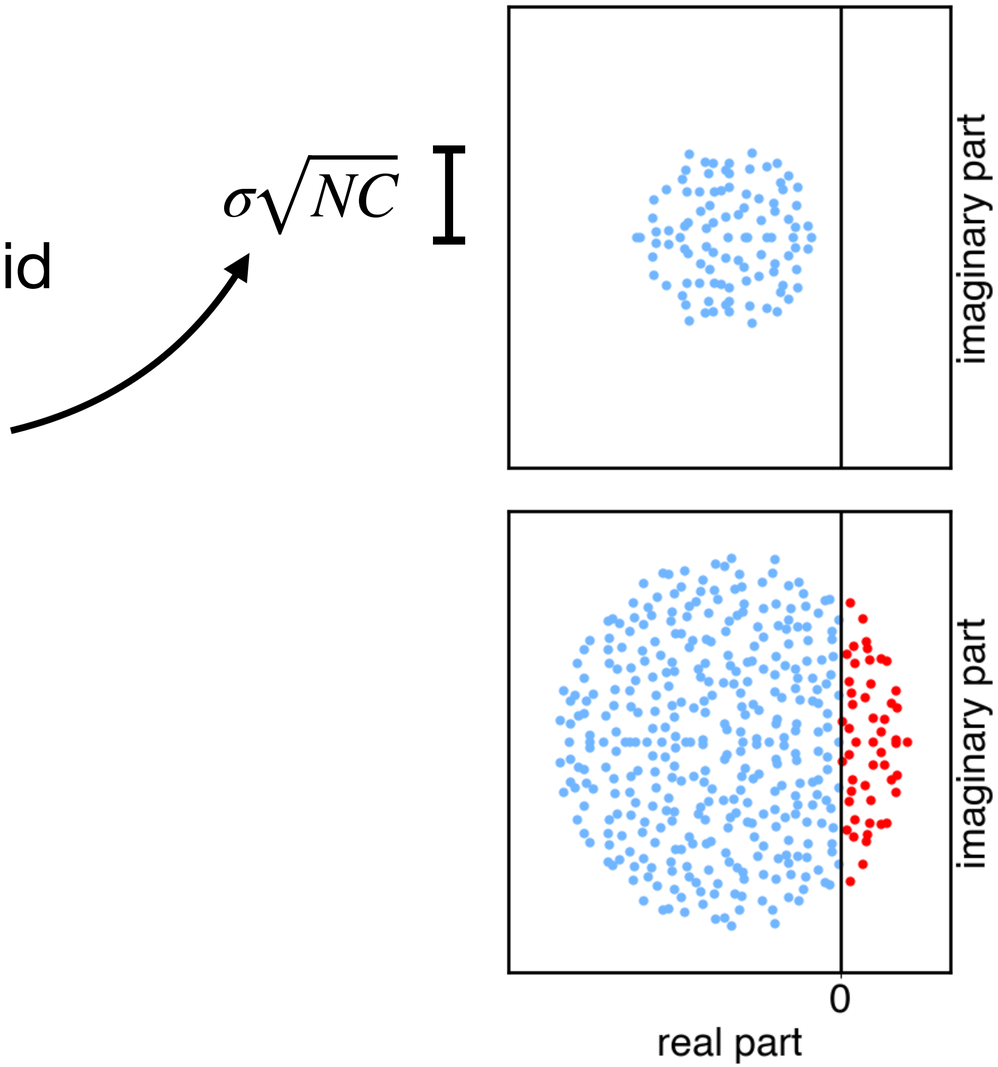
- Stability: all eigenvalues have negative real part
- How to proceed?

May's approach

- self-regulation $M_{ii} = -1$
- interactions M_{ij} zero or random iid

- Eigenvalues: circle centered at -1
- System stable if "complexity"

$$\sigma\sqrt{NC} < 1$$



May - Nature 1972

Complexity-stability paradox

- Theory: complex systems are unstable
- Empirics: complex systems are stable
- Random interactions: null model
- Add specific features to study impact on stability
- Many complexity-stability bounds obtained, but…

Sompolinsky et al. - PRL 1988
Allesina, Tang - Nature 2012
Moran, Bouchaud - PRE 2019
Hatton et al. - Science 2024

Complex systems are time-varying

- Interactions are time-dependent
  - 💡 agents update strategies
  - 🧠 neural connections adapt
  - 🦜 species interactions fluctuate

Does time-variability improve or hinder stability?

Challet, Zhang - Physica A 1997
Ushio et al. - Nature 2018
Magee, Grienberger - Ann. Rev. Neur. 2020

Dynamical stability

- Generic non-autonomous dynamics

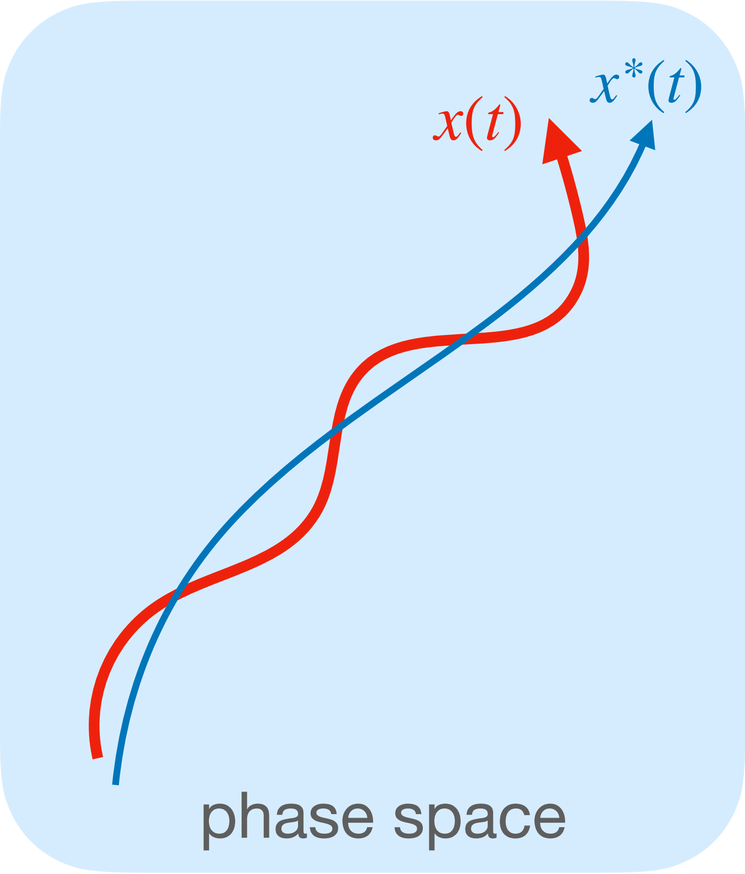
$$\dot{x}_i(t) = f_i(x(t), t)$$

- Reference state $f_i(x^*(t), t) = 0$

- Perturbations $\delta x(t) = x(t) - x^*(t)$ follow

$$\delta\dot{x}_i(t) = \sum_{j=1}^{N} M_{ij}(t)\, \delta x_j(t) + h_i(t)$$

- Dynamic stability: δx bounded

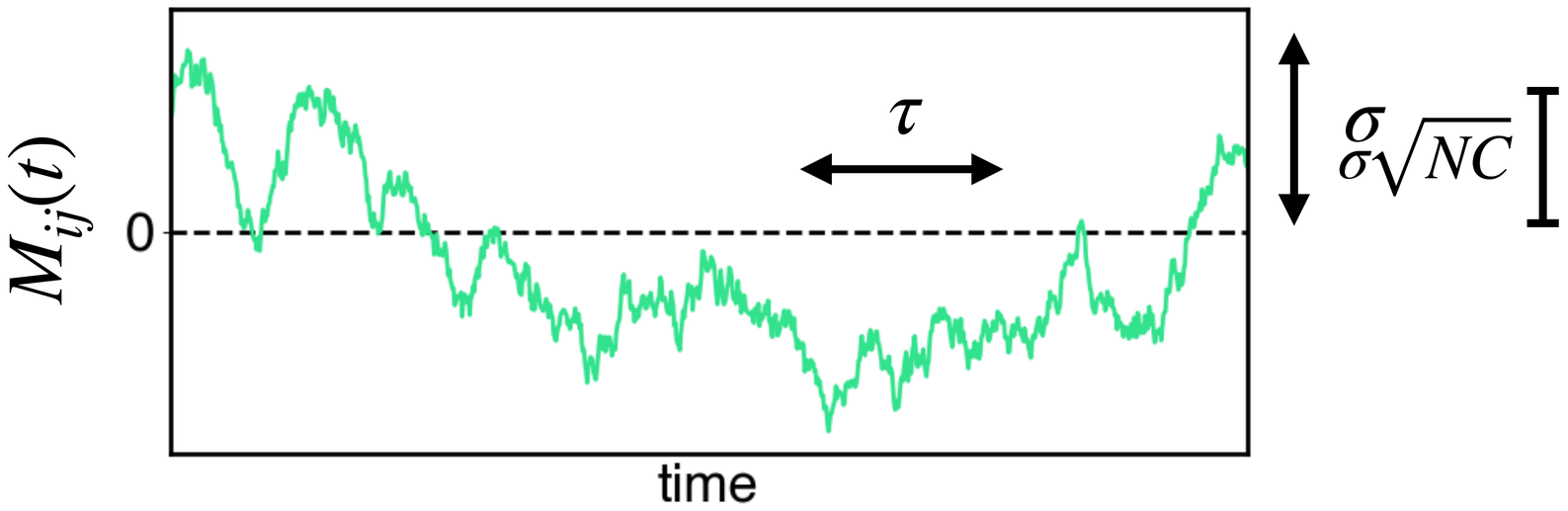


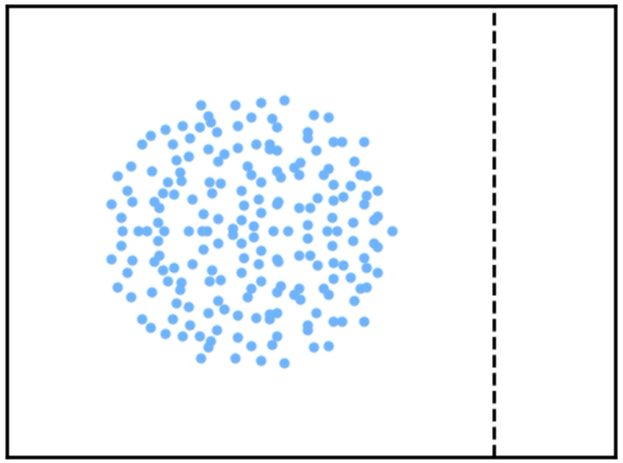
FF et al. - arxiv 2026

Dynamical May's approach

$$\delta\dot{x}_i(t) = \sum_{j=1}^{N} M_{ij}(t)\,\delta x_j(t) + h_i(t)$$

- Interactions: iid OU processes
- Fixed-time spectrum of $M_{ij}(t)$ same as before





FF et al. - arxiv 2026

Dynamical May's approach

$$\delta\dot{x}_i(t) = \sum_{j=1}^{N} M_{ij}(t)\,\delta x_j(t) + h_i(t)$$

stable stationary state

diverging solutions

FF et al. - arxiv 2026

Solution

1. Write mean-field equation (DMFT)

$$\delta\dot{x}_0(t) = -\delta x_0(t) + R\eta(t) + h(t)$$

2. Find closed equation for $C(t) = \langle \delta x_0(t)\delta x_0(0)\rangle$

$$-\ddot{C}(t) + \left[1 - R^2 e^{-t/\tau}\right] C(t) = \rho^2 e^{-t/\tau}$$

3. Solve it

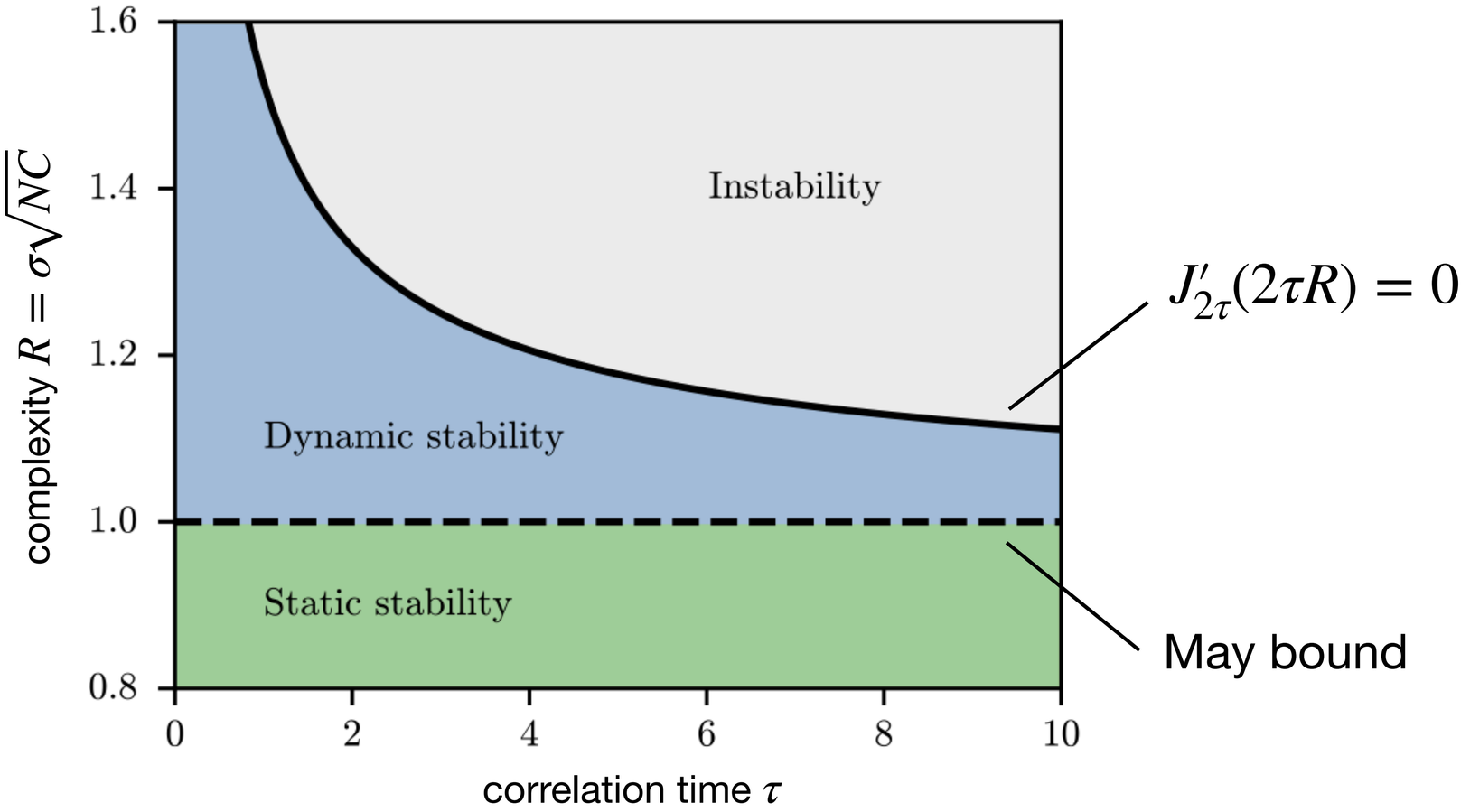
4. Evaluate $C(0)$ to find stationary variance

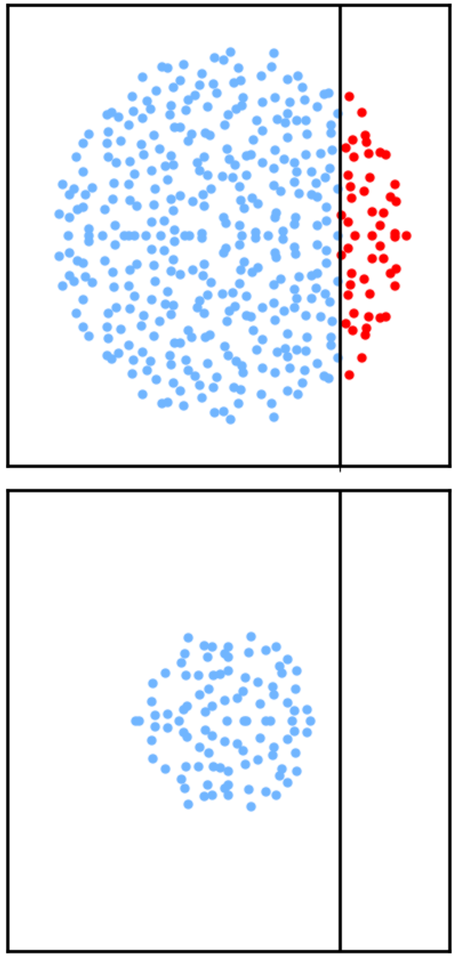
5. Look when it diverges

$$J'_{2\tau}(2\tau R) = 0$$

FF et al. - arxiv 2026

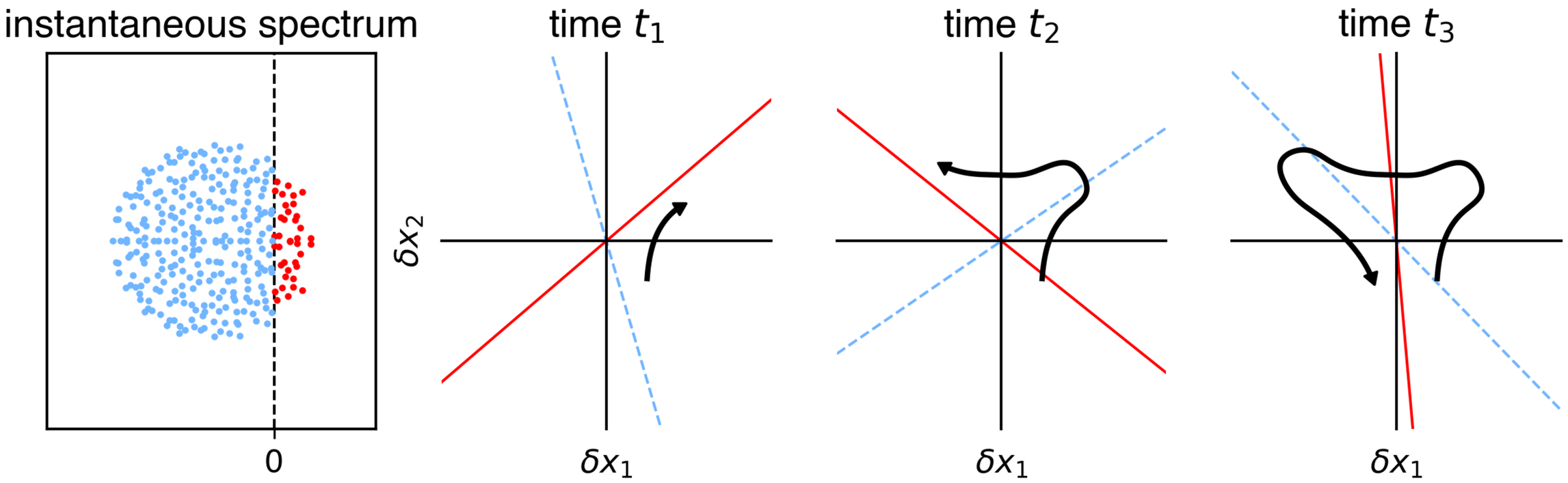
Solution





FF et al. - arxiv 2026

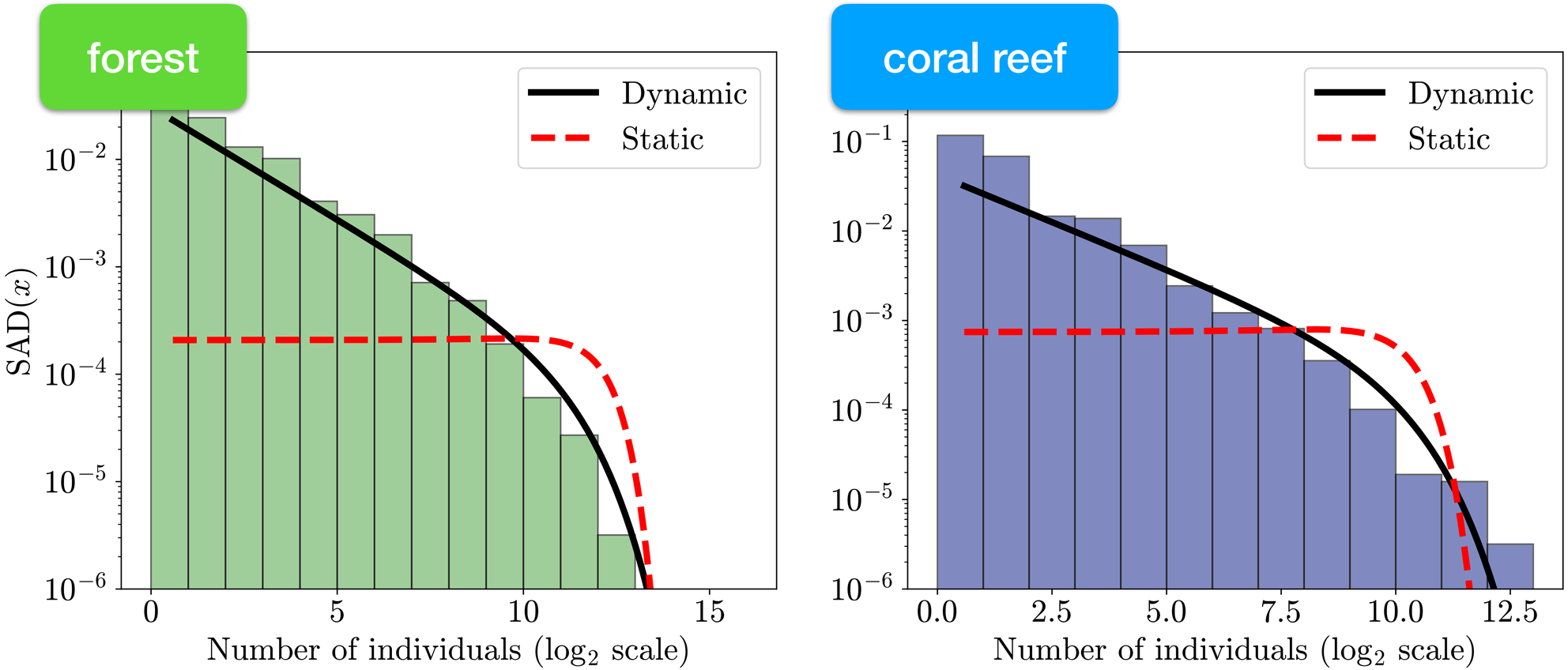
Stabilization mechanism



FF et al. - arxiv 2026

Data

random Lotka-Volterra



Suweis, FF et al. - PRL 2024

Takeaways

New framework:
random matrix theory + stochastic processes

Will a time-varying complex system be stable?

Yes!

Time-variability enhances stability



static criteria: uninformative

random time-variability!

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Thank you for your attention!

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