

# Non-Markovianity hinders Quantum Darwinism

arXiv:1412.3316



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Turku Cathedral

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Turku  
Univ



Are certain properties of the environment  
influencing the emergence of a classical  
objective reality?



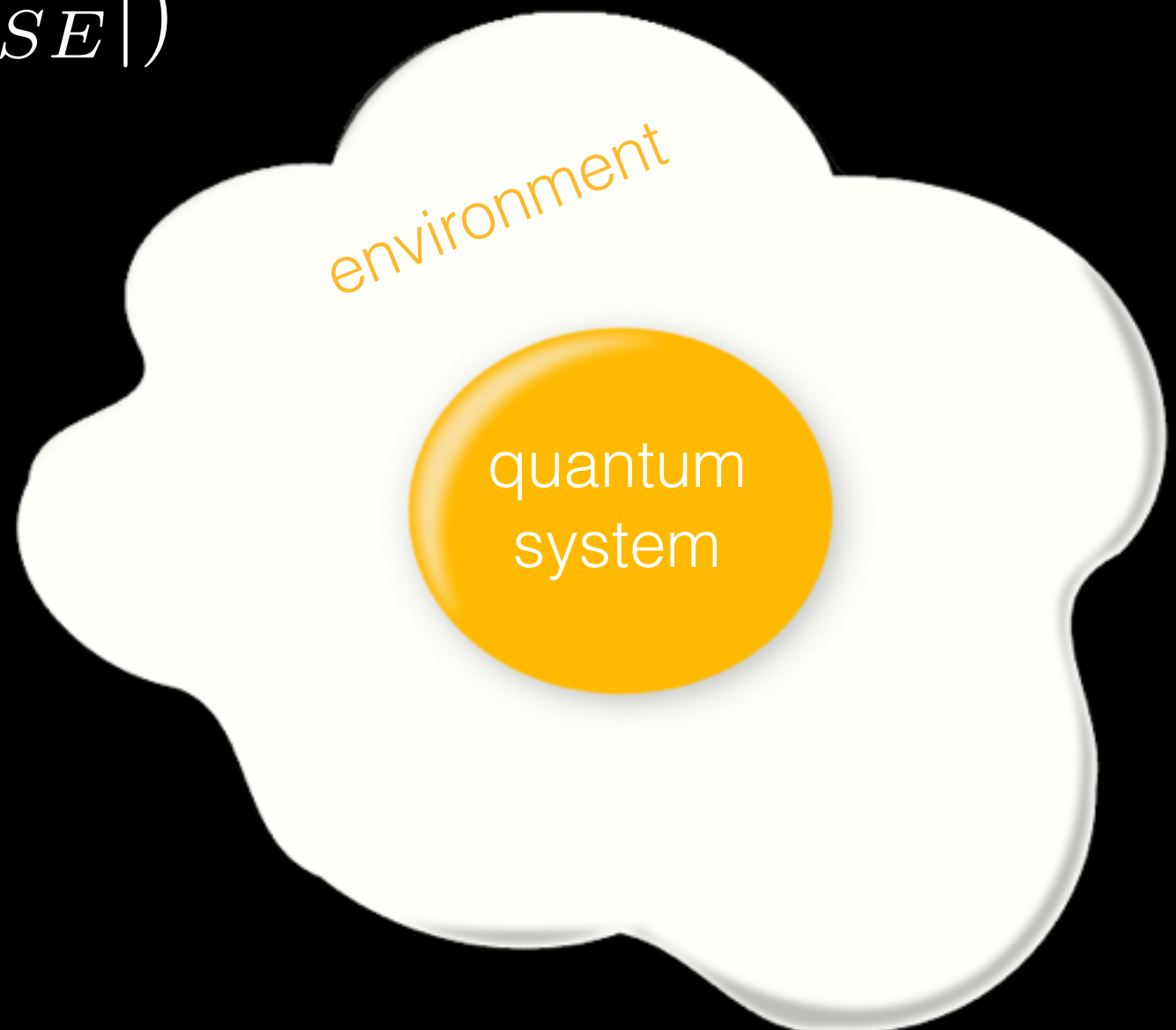
A pair of red curtains is pulled back to reveal a black stage. The curtains are tied back with gold-colored rings. The stage is empty, and the text "Quantum Darwinism" is centered on the stage.

# Quantum Darwinism

# Quantum Darwinism

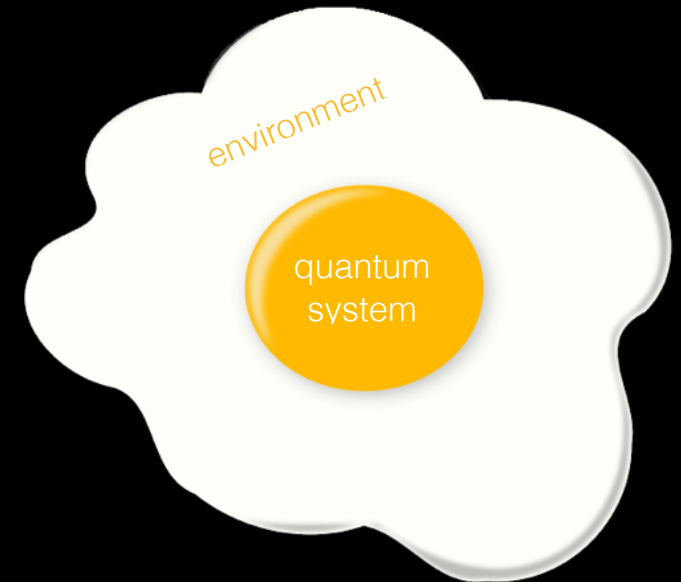
Open quantum systems

$$\rho_S = \text{Tr}_E(|\Psi_{SE}\rangle\langle\Psi_{SE}|)$$



# Quantum Darwinism

Pointer states and einselection



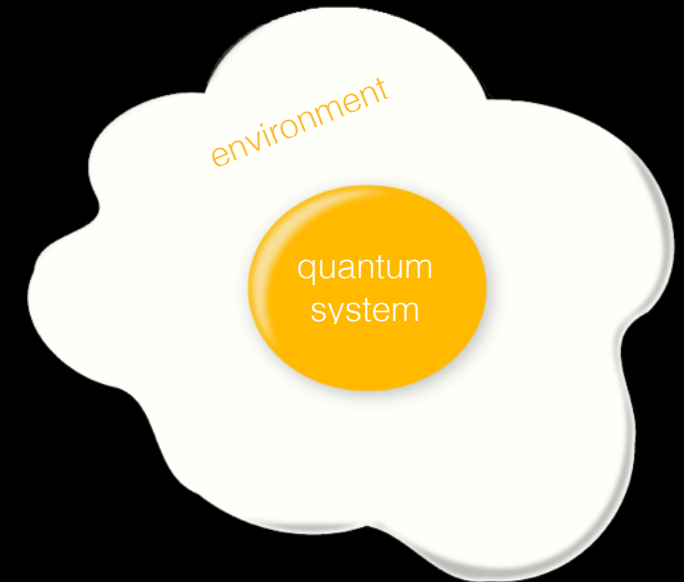
$$H = H_S + H_E + H_I$$

$$H_I = S \otimes E$$

Pointer states are eigenstates of  $S$

# Quantum Darwinism

Pointer states and einselection



System

quantum harmonic oscillator

$\omega_S$

Environment

quantum harmonic oscillators

$\omega_k$

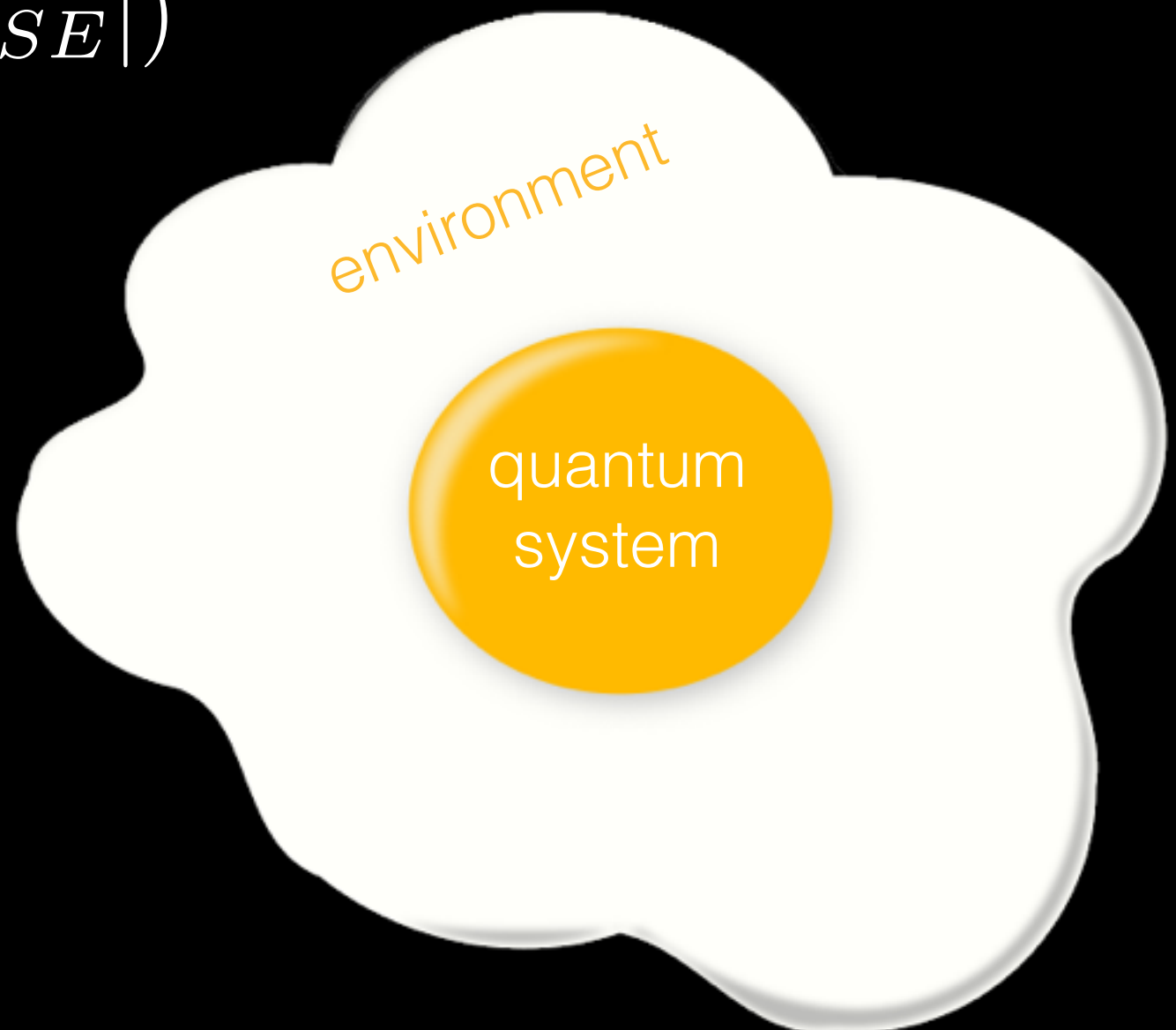
Interaction

$$- \kappa x_S \sum_{k=1}^N c_k x_k$$

# Quantum Darwinism

Environment as a witness

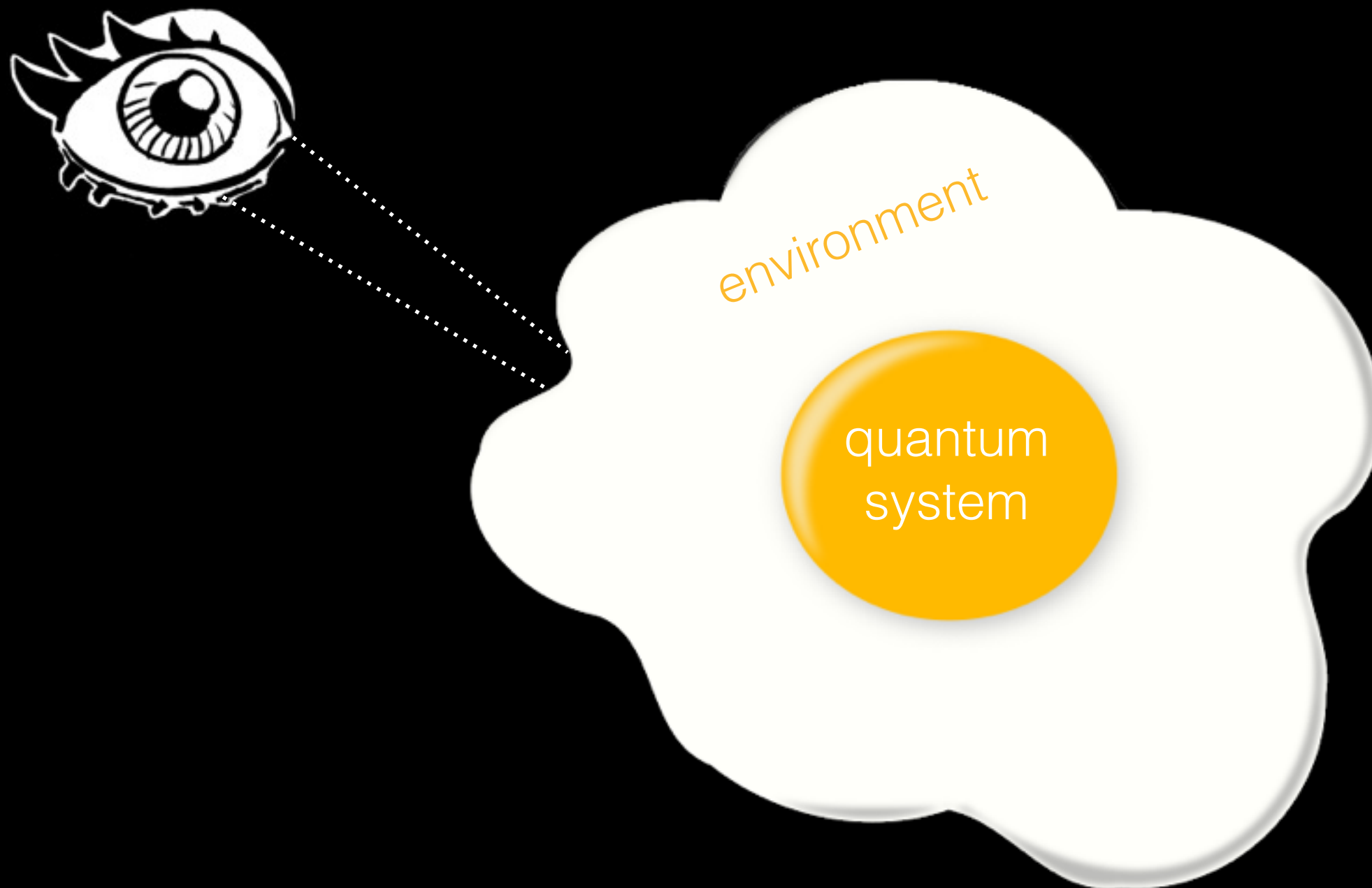
$$\rho_S = \text{Tr}_E(|\Psi_{SE}\rangle\langle\Psi_{SE}|)$$





# Quantum Darwinism

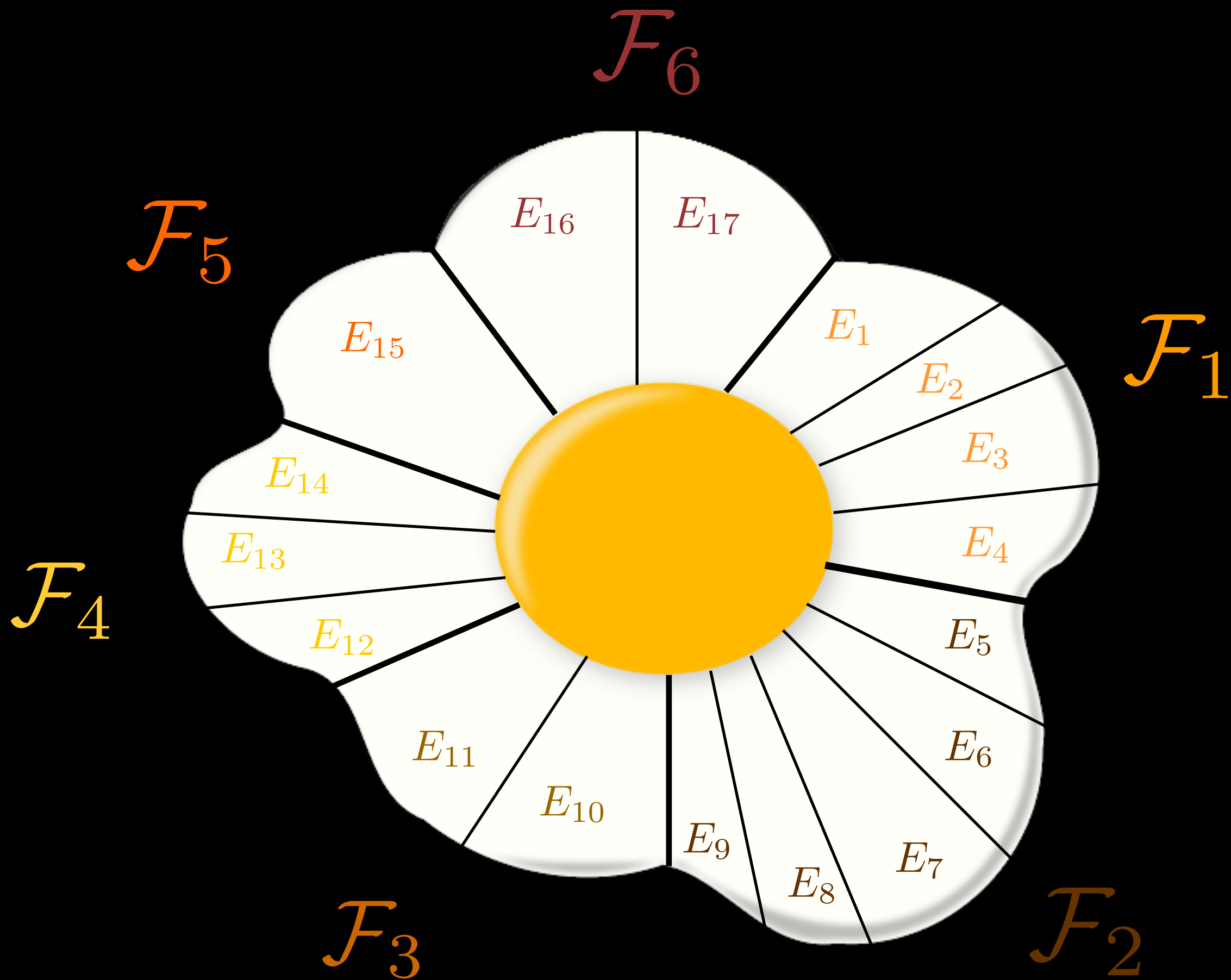
Environment as a witness

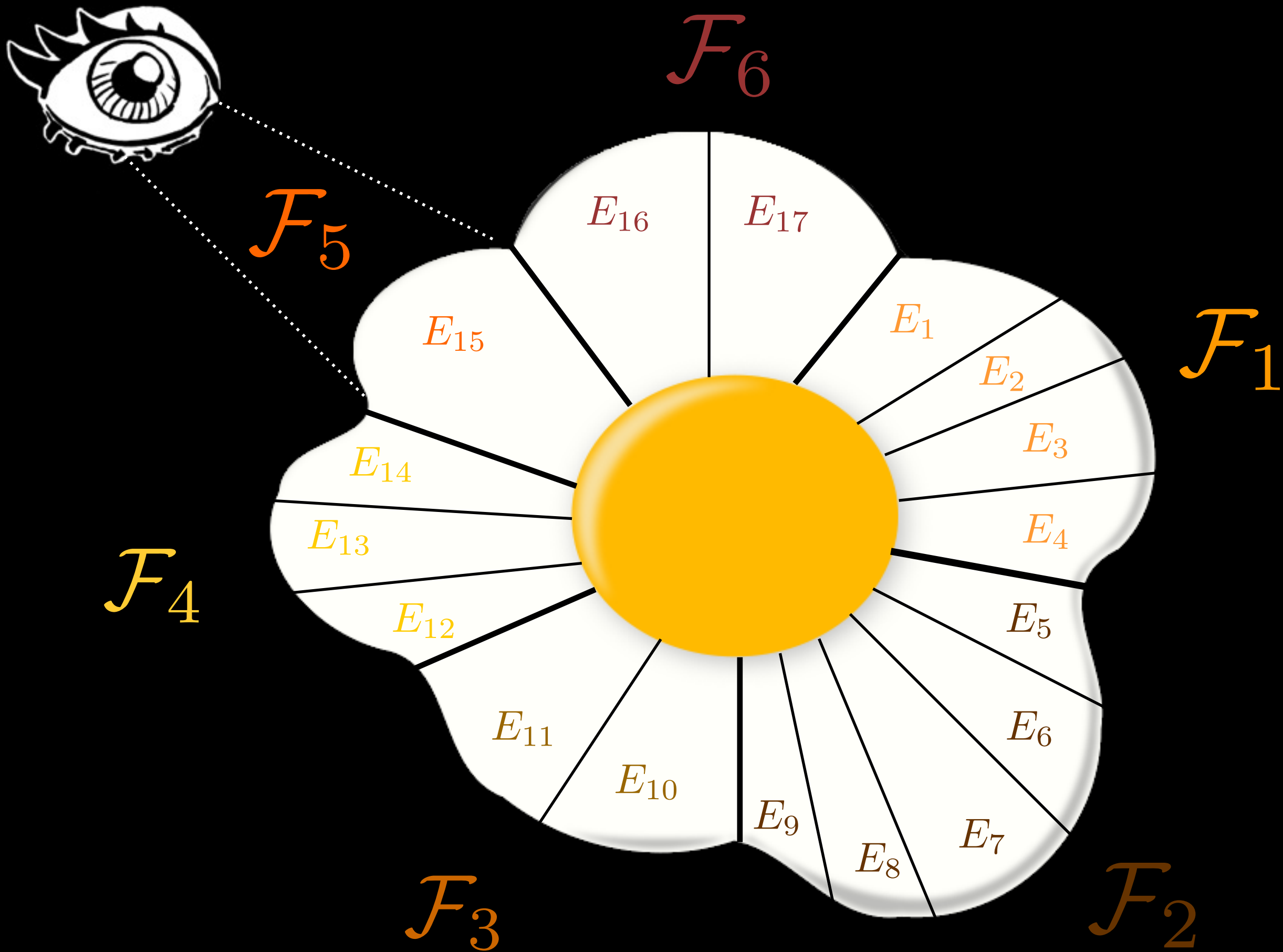


# The **essence** of **Quantum** **Darwinism**

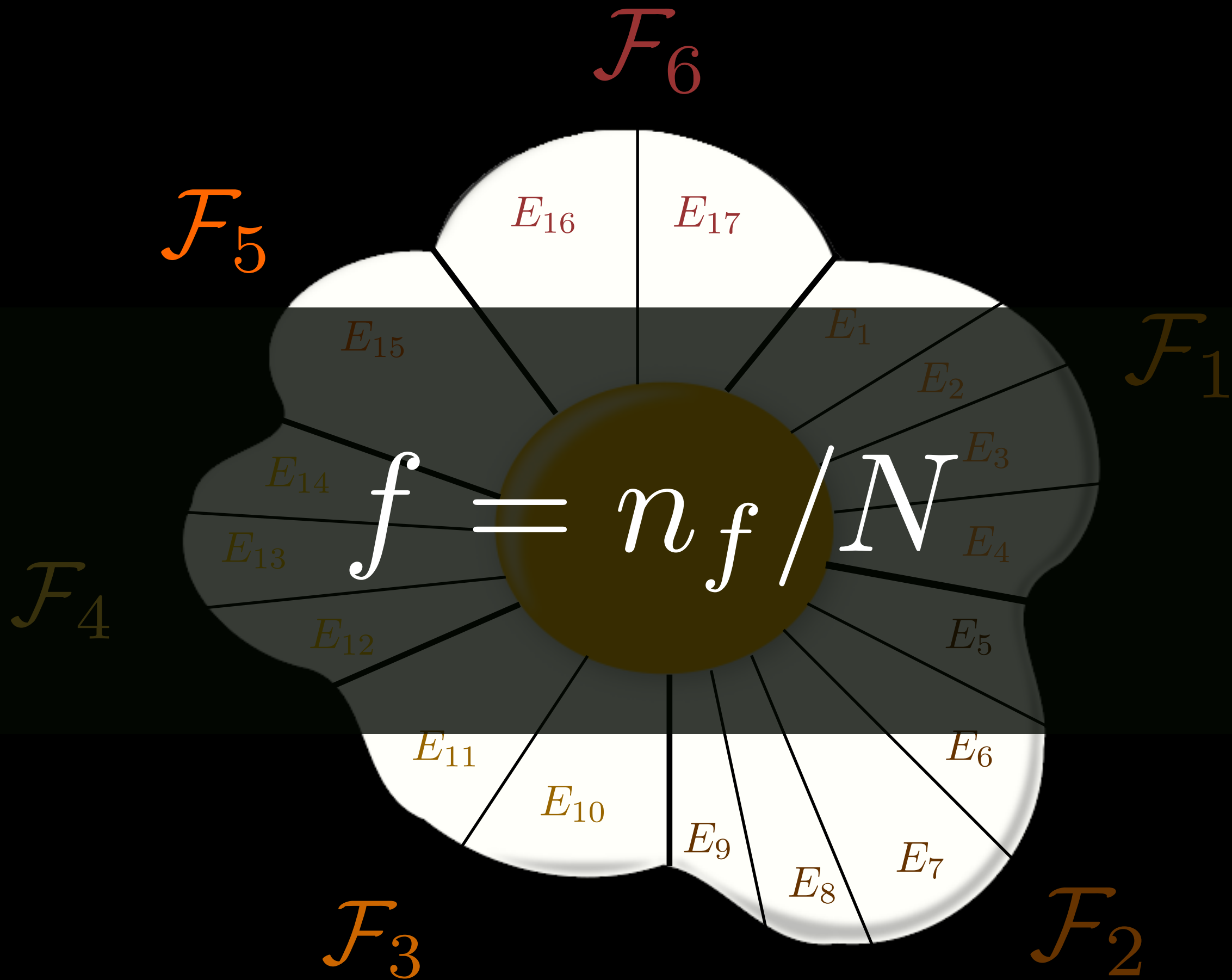
only states that produce **multiple**  
**imprints in the environment** can be  
found out from small fragments of E

the origin of the emergent classicality is  
therefore not just the *survival of the  
fittest states* but their **ability to deposit  
multiple copies of themselves** to the  
environment









# CENTRAL QUESTION

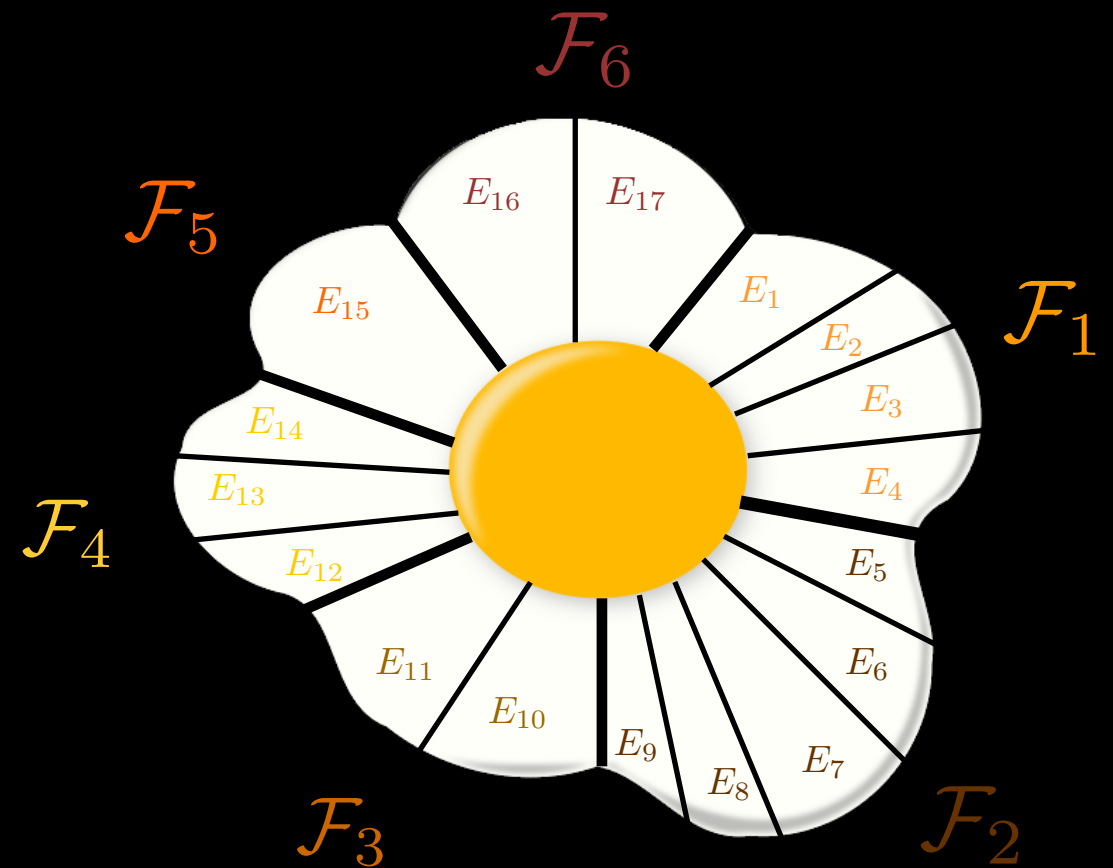
Which fraction  $f$  of the environment does one need to sample if the goal is to find out about the system?

# Quantum Darwinism

quantum mutual information

$$I(S : \mathcal{F}) = H_S + H_{\mathcal{F}} - H_{S\mathcal{F}}$$

$$H_S = H_{\mathcal{F}} = H_{S\mathcal{F}}$$



$$I(S : \mathcal{F}) = H_S + H_{\mathcal{F}} - H_{S\mathcal{F}} = H_S$$

an apparatus can fully reveal the state of the system

$$I(S : \mathcal{F}) = H_S + H_{\mathcal{F}} - H_{S\mathcal{F}}$$

$$I(S : \mathcal{F}) = 0 \quad \text{no correlations}$$

$$I(S : \mathcal{F}) = H_S \quad \begin{array}{l} \text{classical} \\ \text{correlations} \end{array}$$

$$I(S : \mathcal{F}) = 2H_S \quad \text{entanglement}$$



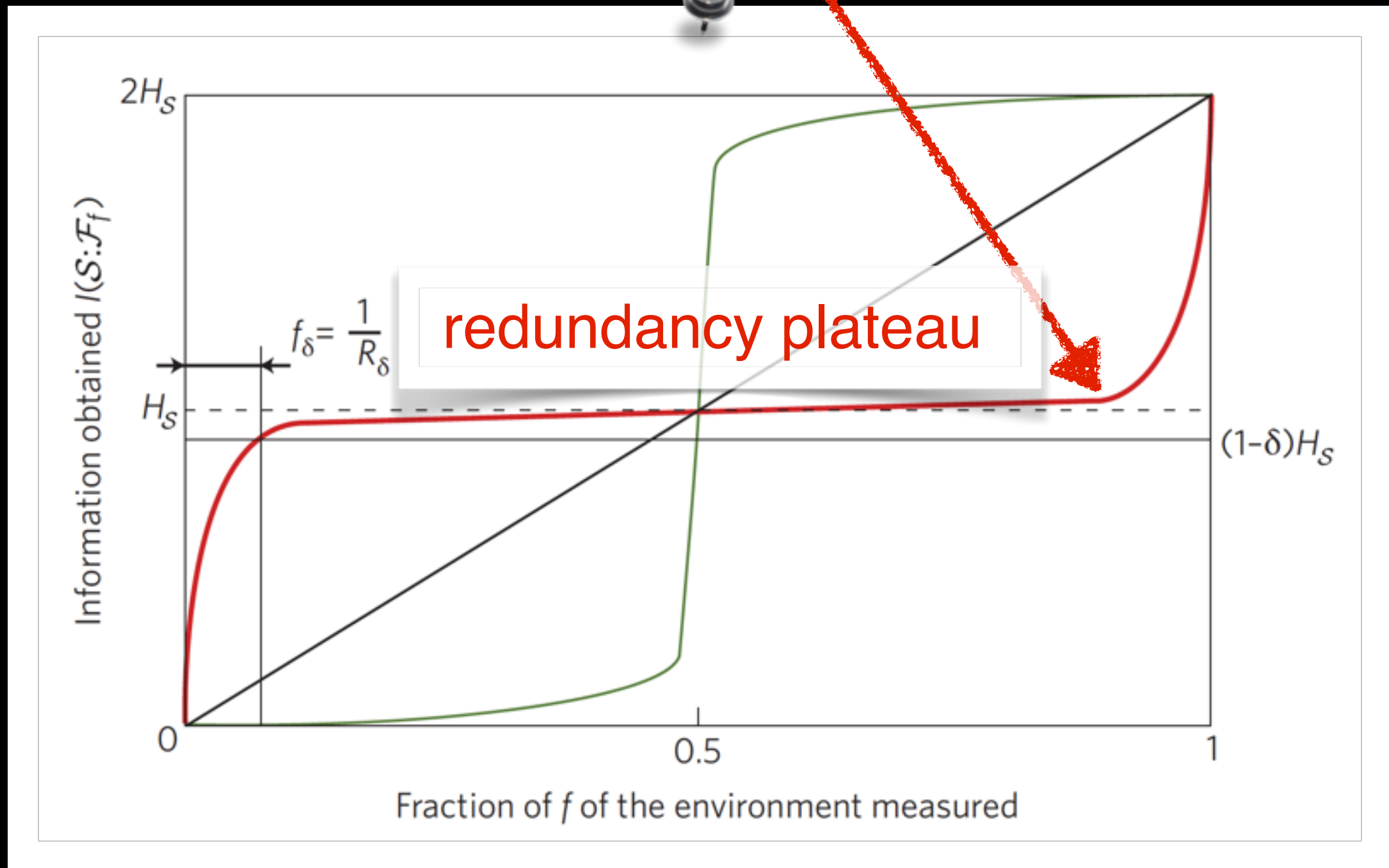
# Quantum Darwinism

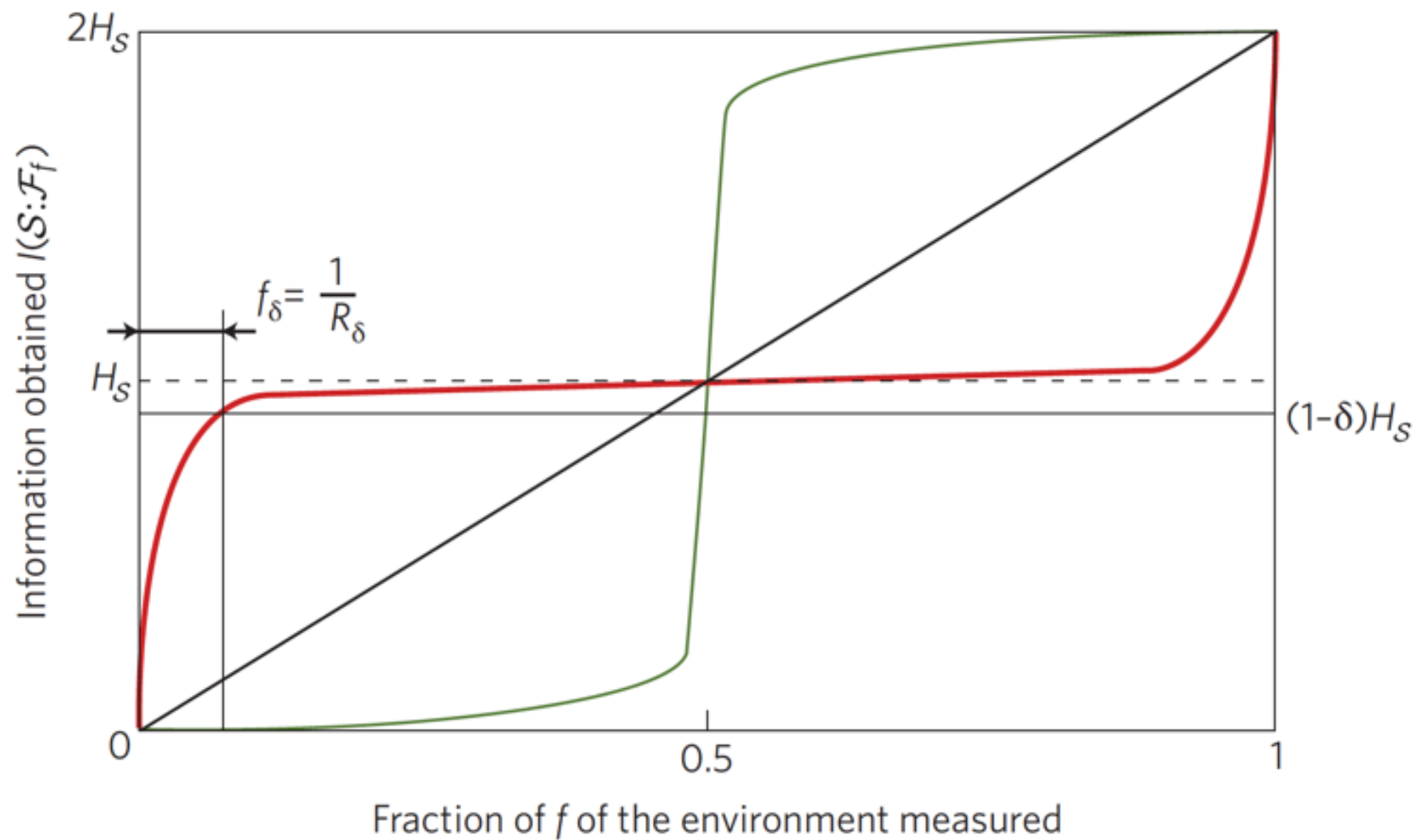
quantum mutual information

$$I(S : \mathcal{F}) = H_S + H_{\mathcal{F}} - H_{S\mathcal{F}}$$

$$f = n_f / N$$


mutual information of states which have decohered, indicating emergence of classical objective reality





## REDUNDANCY

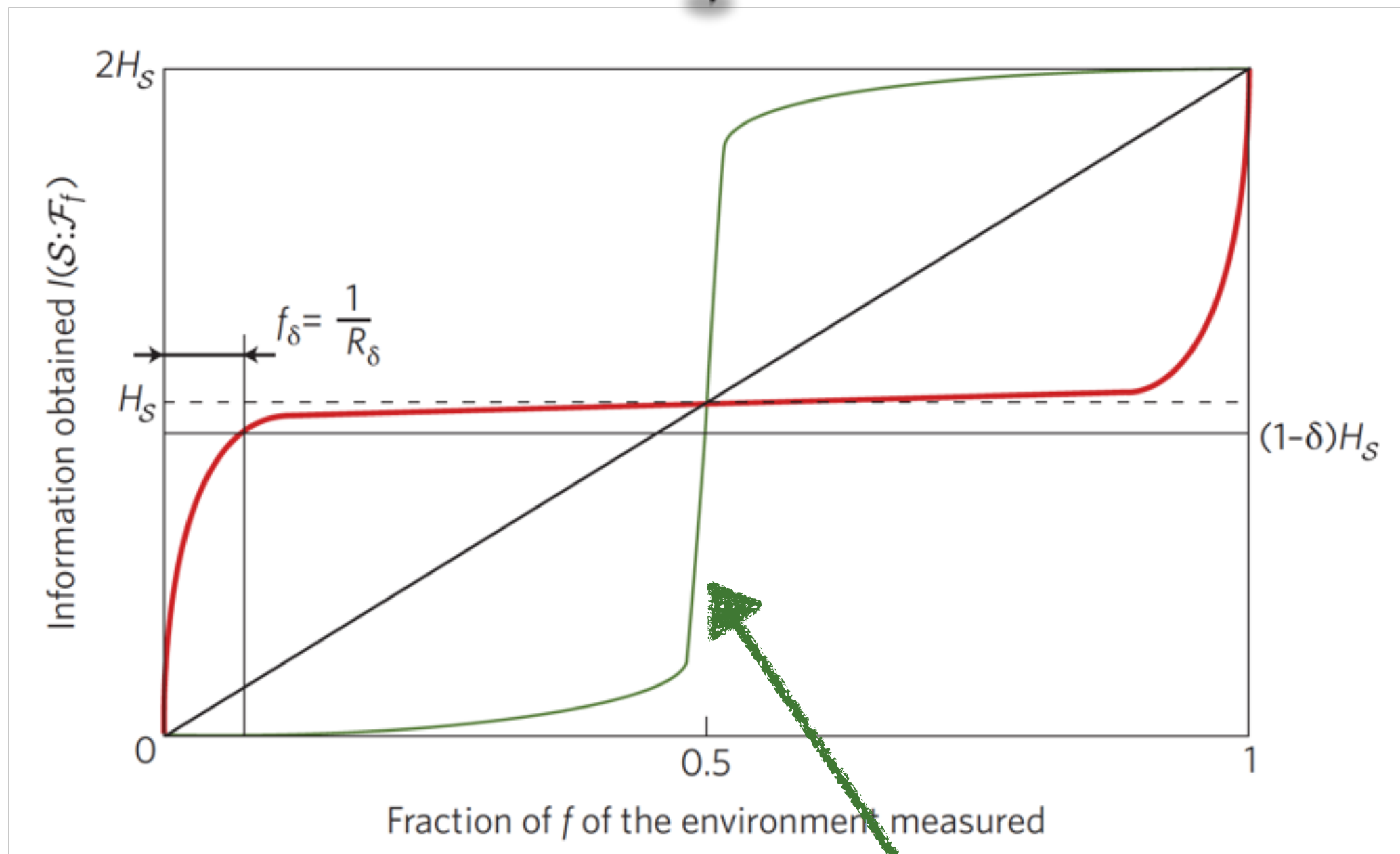
$$R_\delta = 1/f_\delta$$

$$(1 - \delta)H_S$$

## REDUNDANCY

$$R_\delta = 1/f_\delta \qquad (1 - \delta)H_S$$

high values of redundancy imply objectivity



mutual information of randomly selected states



The image features a black background framed by red curtains on the left and right sides. The curtains are pulled back, revealing the central area where the text is located. The text "Non-Markovianity" is written in a bold, sans-serif font. The word "Non" is in red, and the rest of the word is in white.

# **Non-Markovianity**

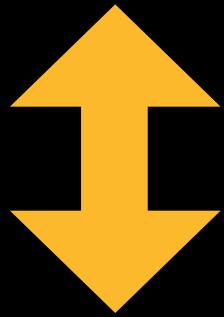
**Markovian**

**non-Markovian**

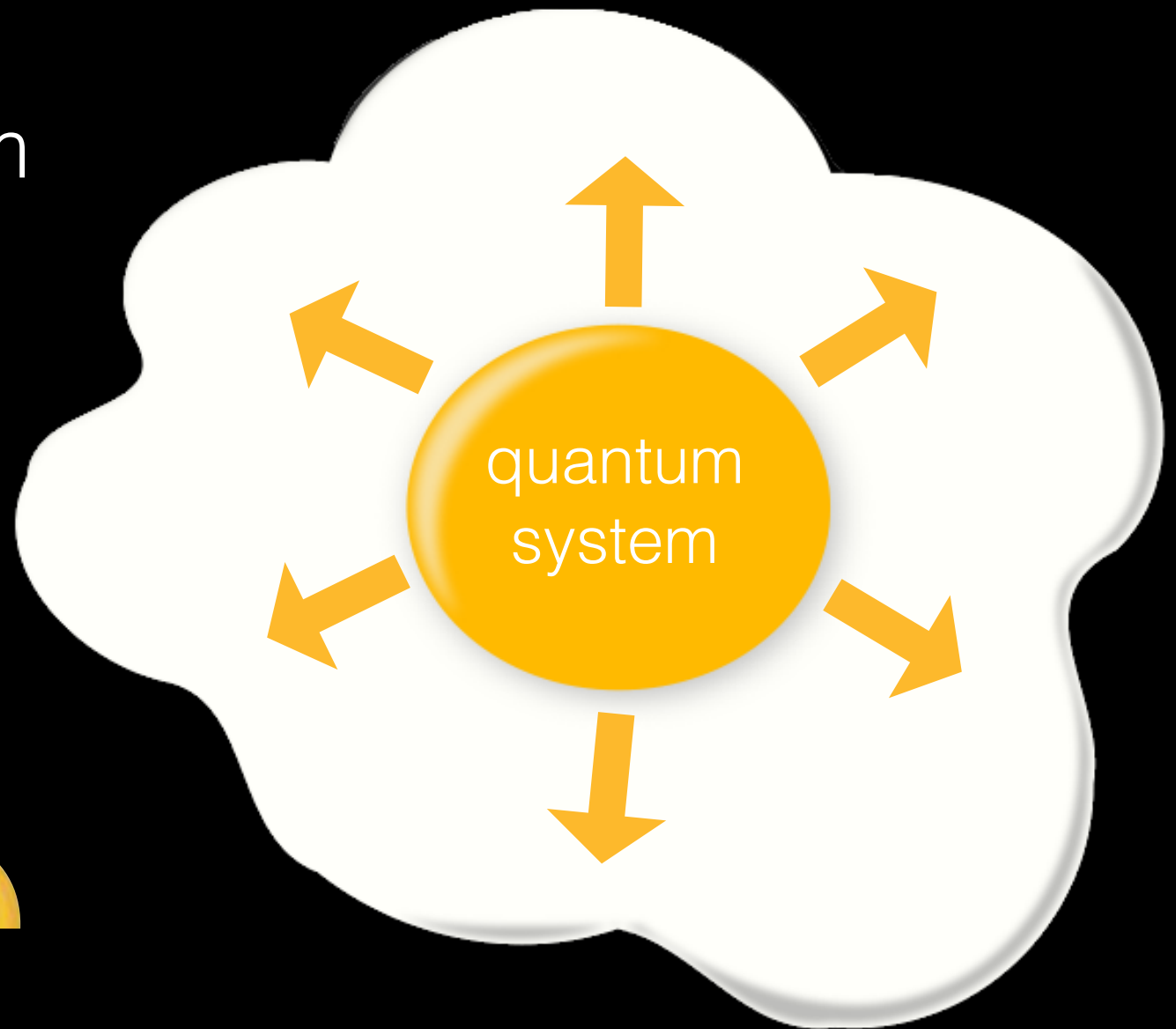
# Open systems dynamics

Information flow

Information on the system



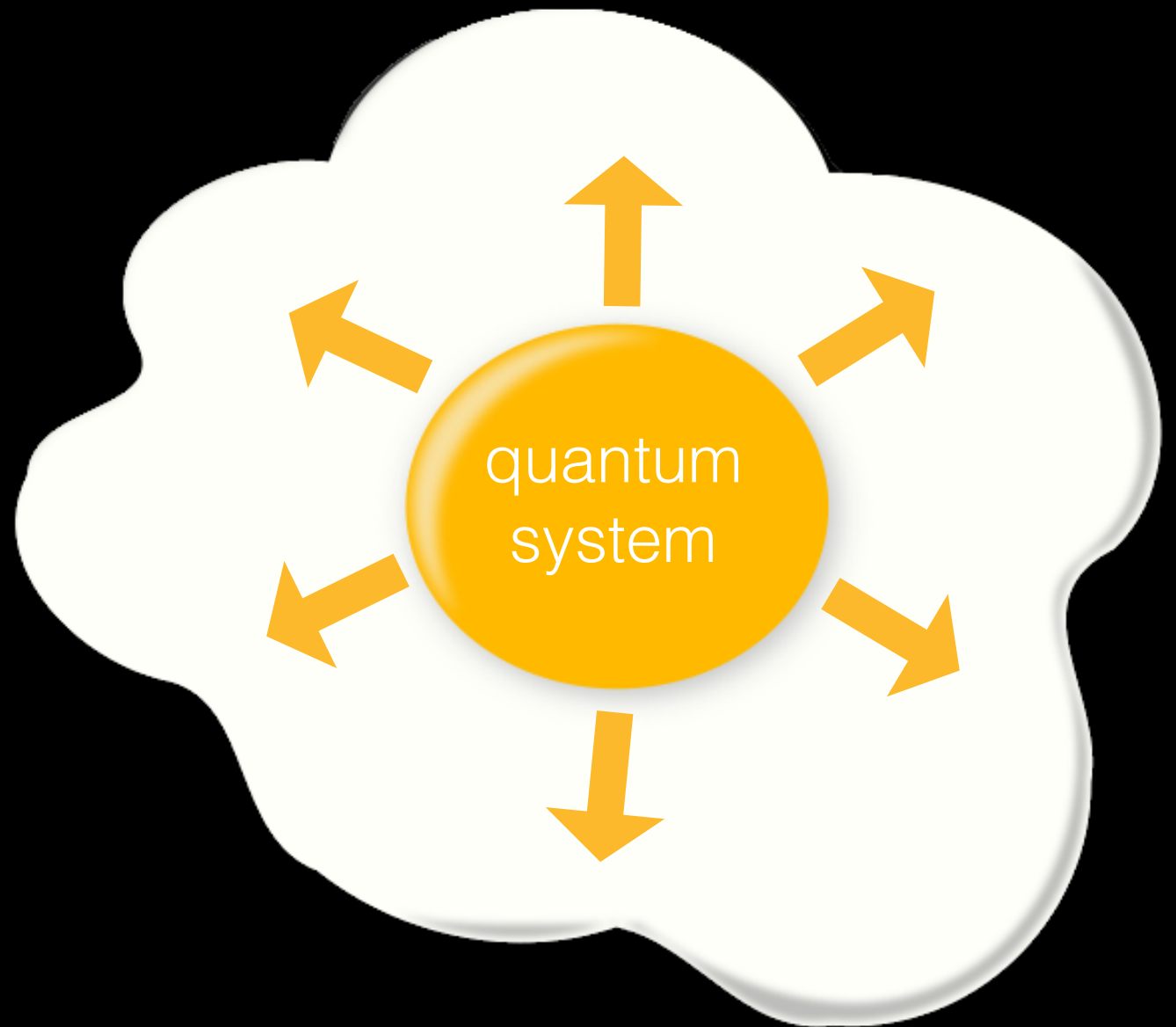
Distinguishability  
between pairs of states



# Markovian dynamics

Information flow

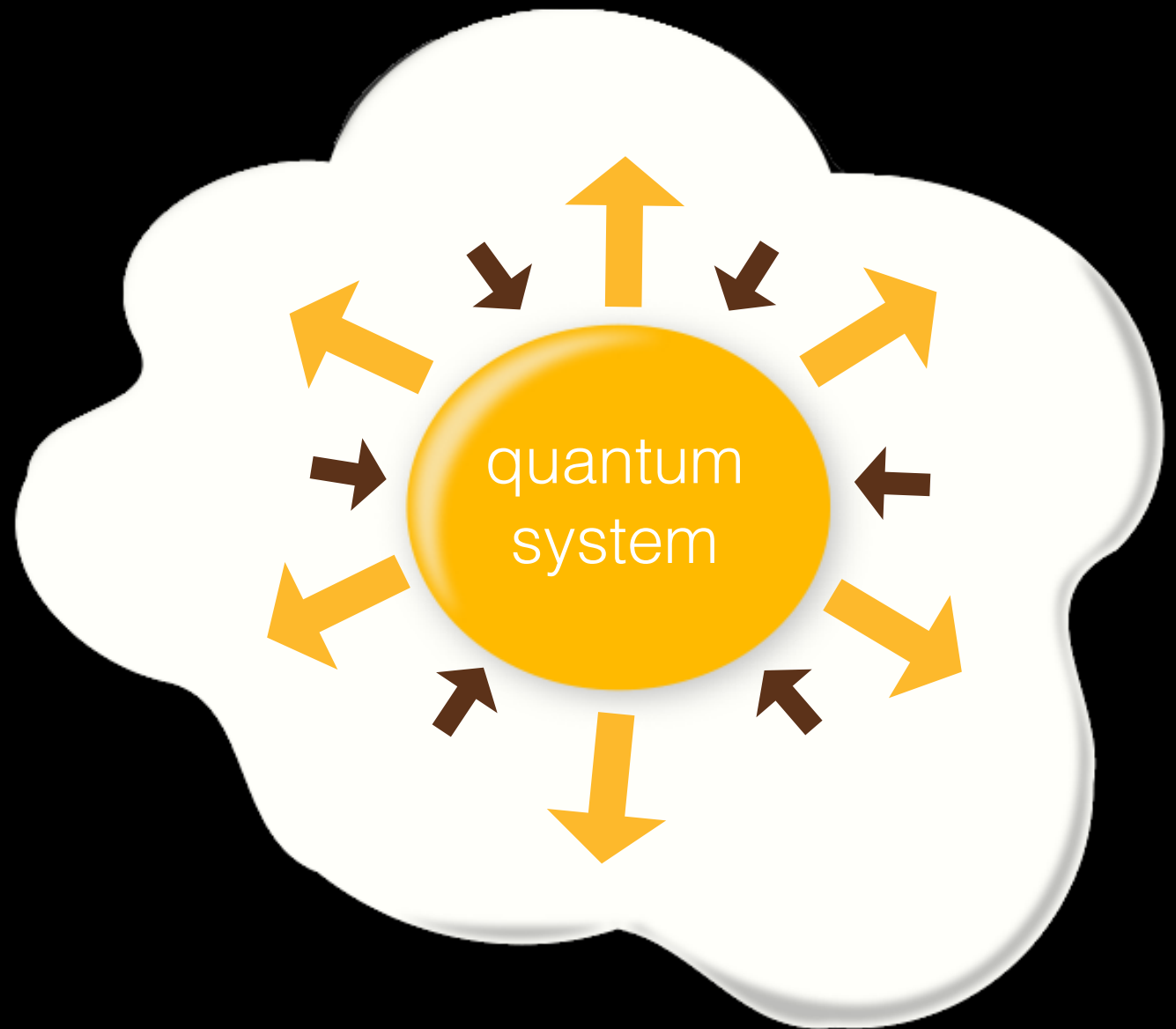
Information is continuously and **monotonically** lost into the environment



# Non-Markovian dynamics

Information flow

**Information flow back**  
due to memory effects  
and strong system-  
environment  
correlations





# Quantum Brownian Motion

System

quantum harmonic oscillator

$$\omega_S$$

Environment

quantum harmonic oscillators

$$\omega_k$$

Interaction

$$- \kappa x_S \sum_{k=1}^N c_k x_k$$

# Non-Markovianity measure

CV systems

## FIDELITY

$$F(\rho_1, \rho_2) = \text{Tr} \sqrt{\sqrt{\rho_1} \rho_2 \sqrt{\rho_1}}$$

Bures distance

$$\mathcal{D}_F(\rho_1, \rho_2) = \sqrt{2 - 2\sqrt{F(\rho_1, \rho_2)}}$$

$$\mathcal{N} = \max_{\rho_1, \rho_2} \int_{dF/dt < 0} -\frac{dF(\rho_1, \rho_2)}{dt} dt$$

The image features a black background framed by red curtains on the left and right sides. The curtains are tied back with gold-colored rings. In the center of the black area, the text "The Connection" is displayed in a bold, sans-serif font. The word "The" is colored red, and the word "Connection" is colored white.

# **The Connection**

Does Quantum Darwinism  
depend on the Markovian/  
non-Markovian character of  
the dynamics?

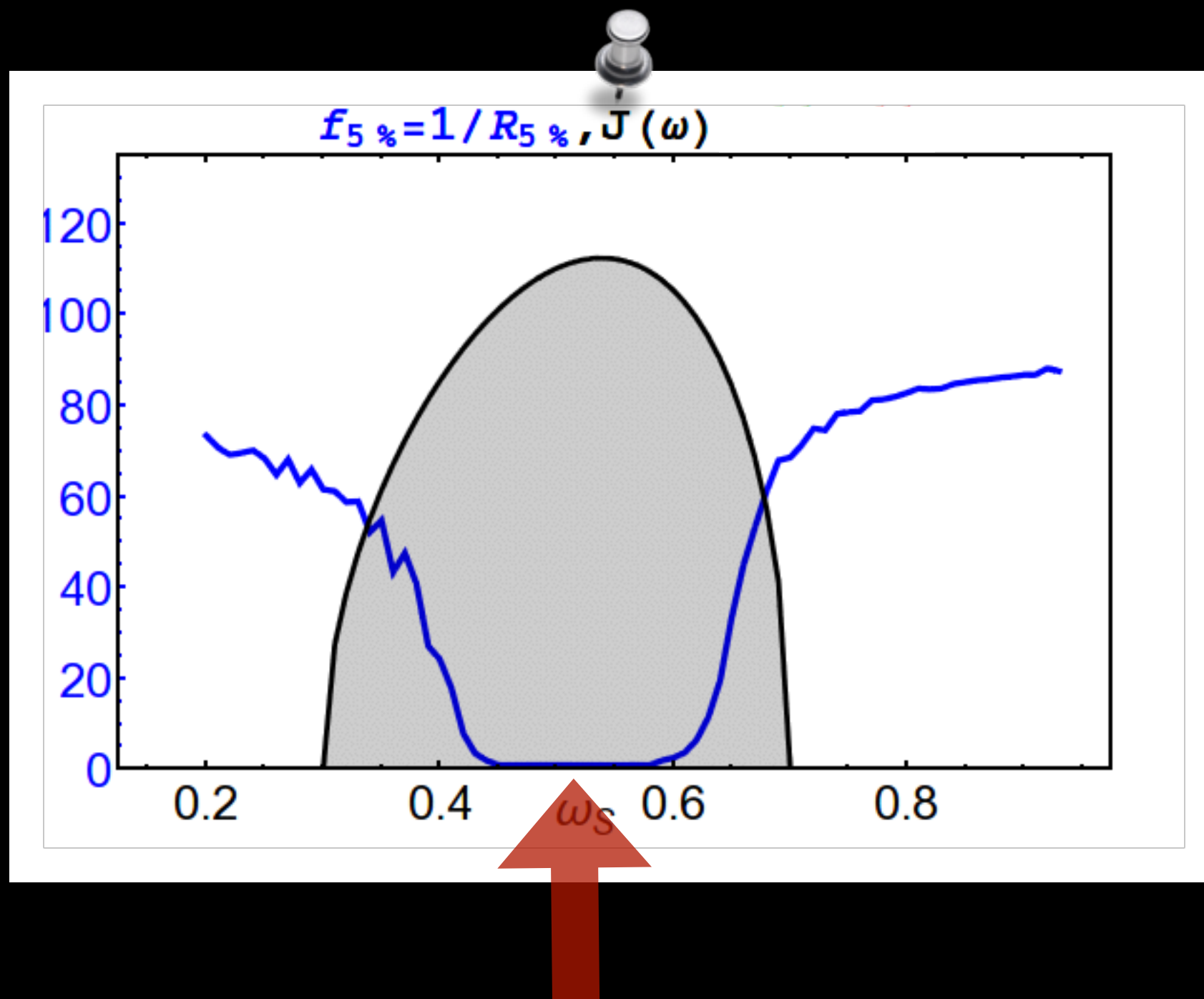


## REDUNDANCY

$$R_\delta = 1/f_\delta \qquad (1 - \delta)H_S$$

high values of redundancy imply objectivity

low values of the fraction  $f_\delta$  imply objectivity

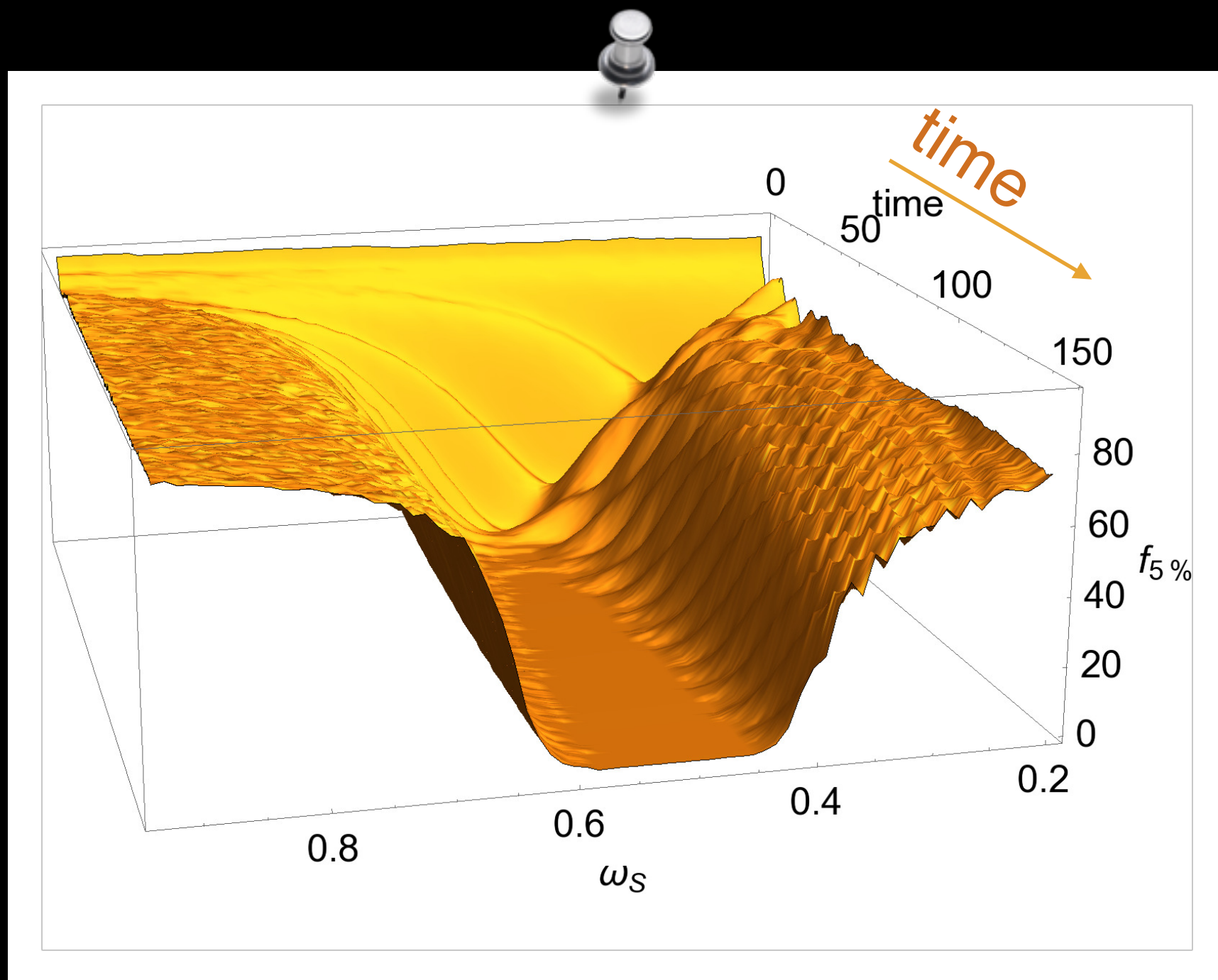


emergence of a classical objective reality

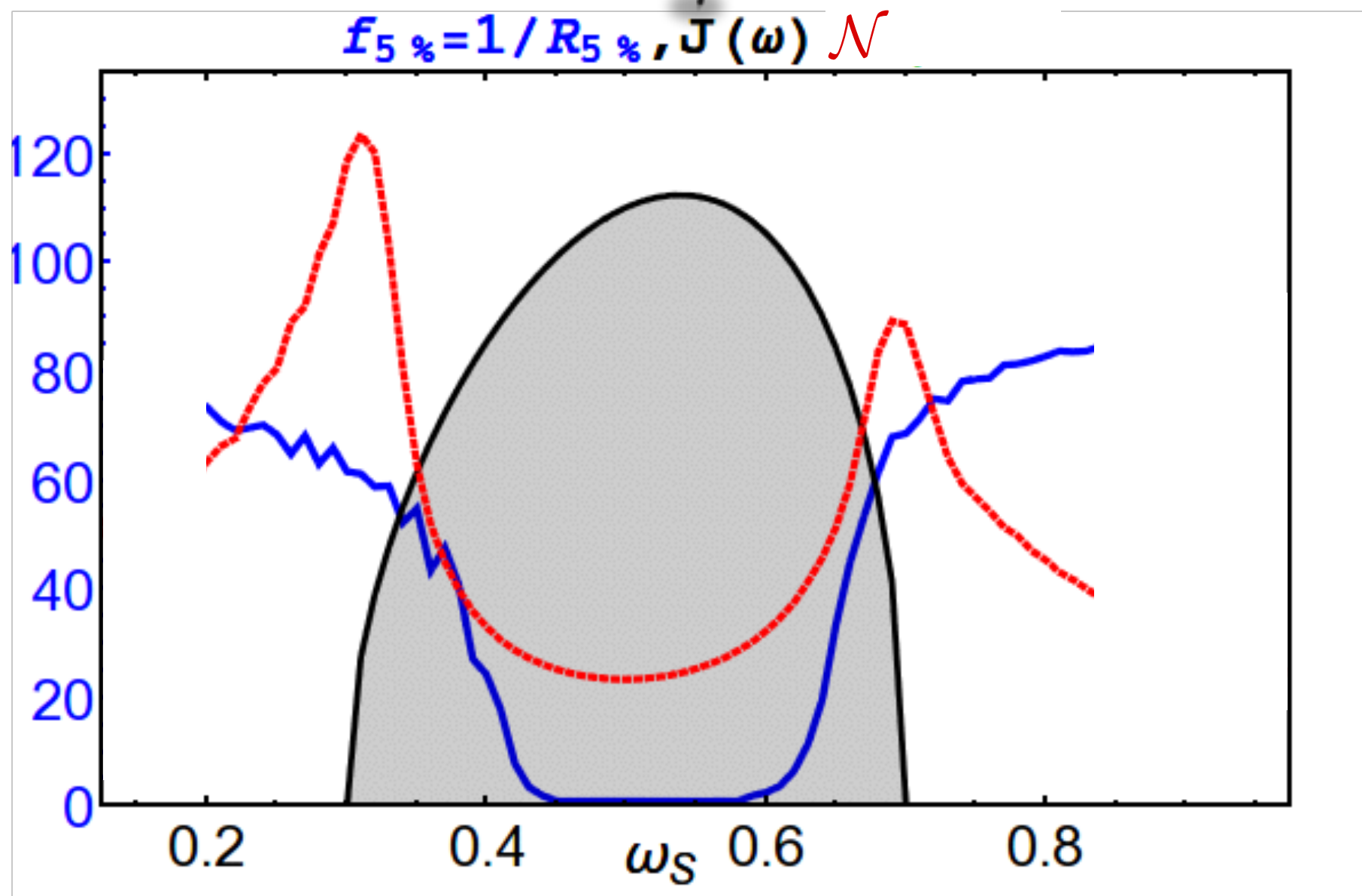


# Quantum Darwinism

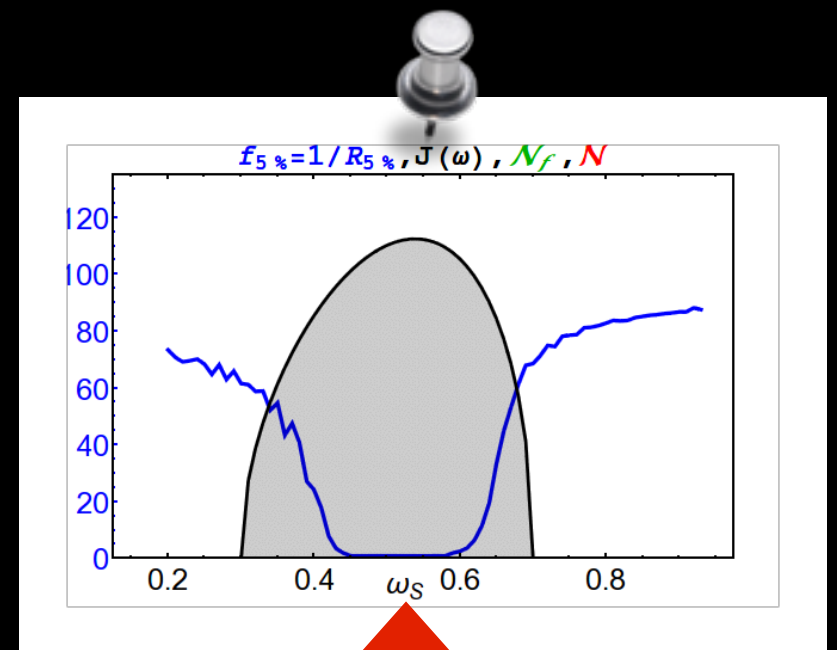
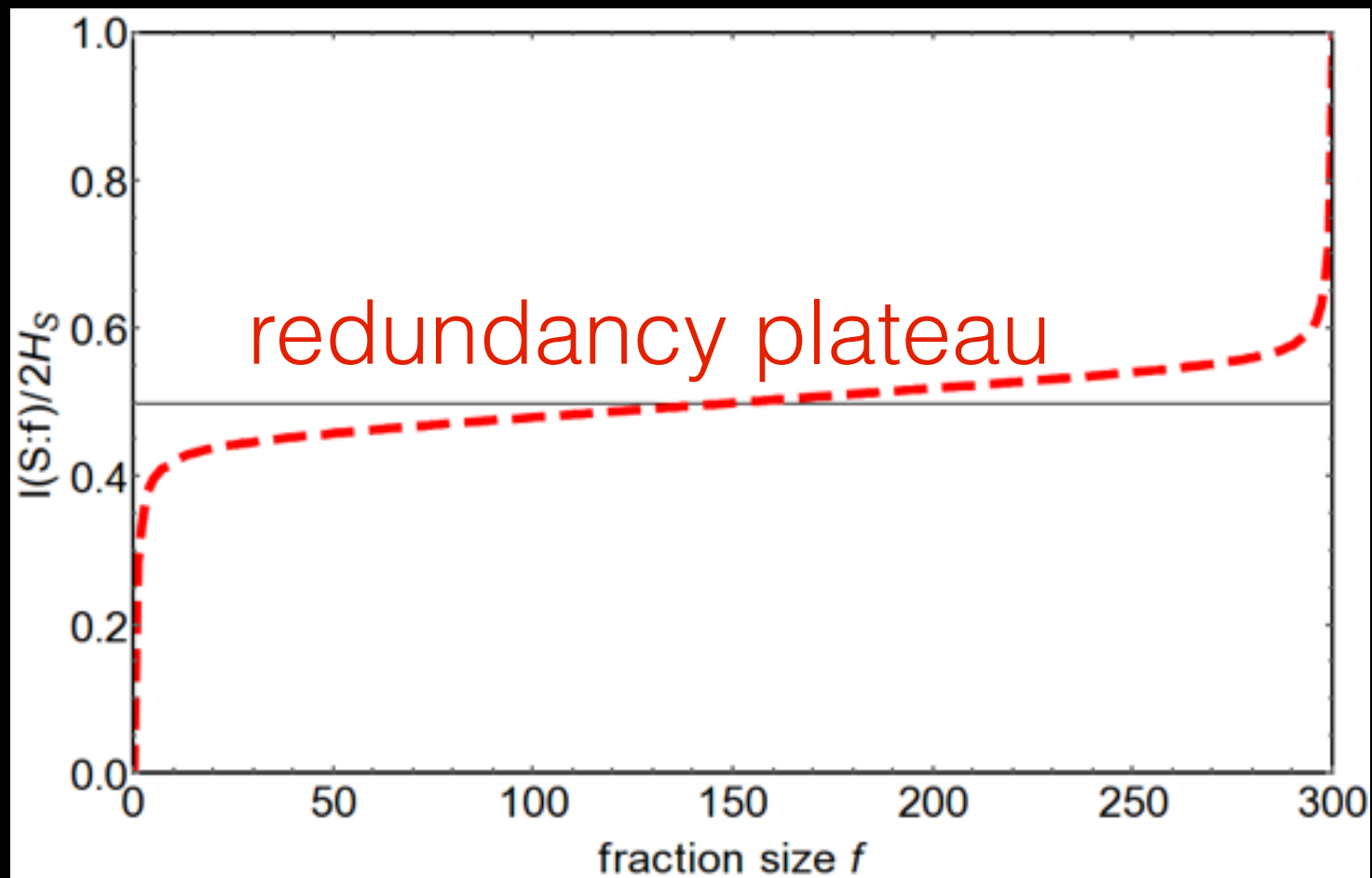
The movie





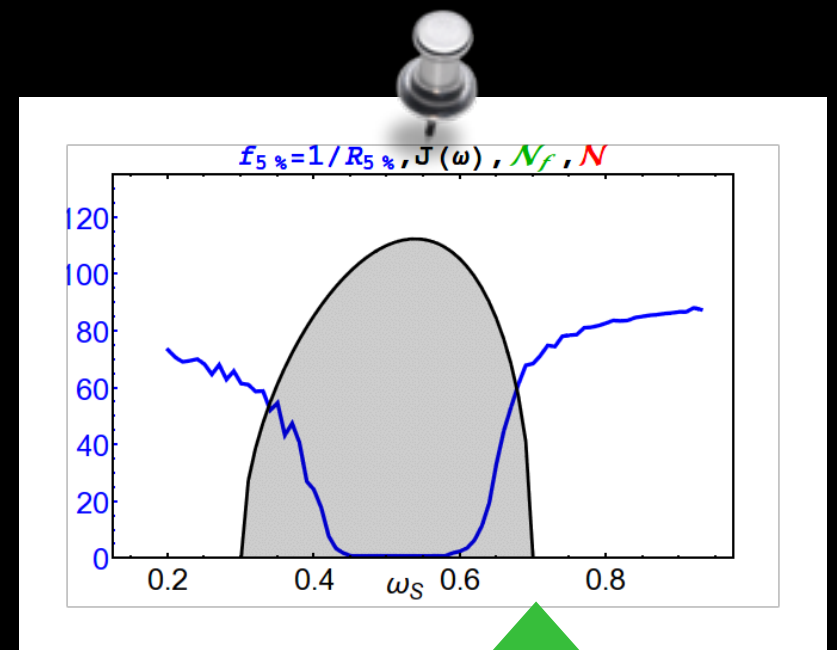
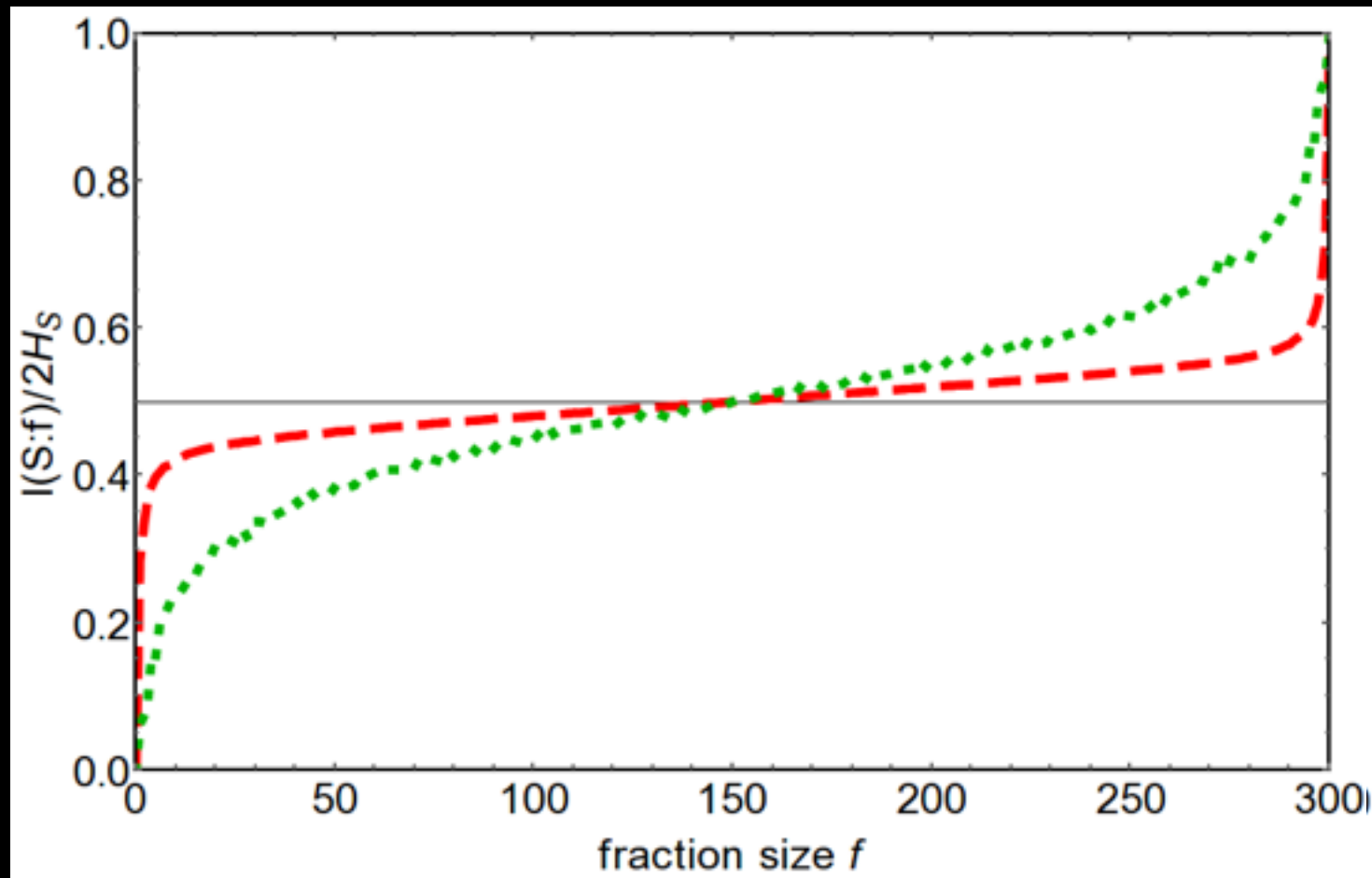


$t=40$  (a.u.)



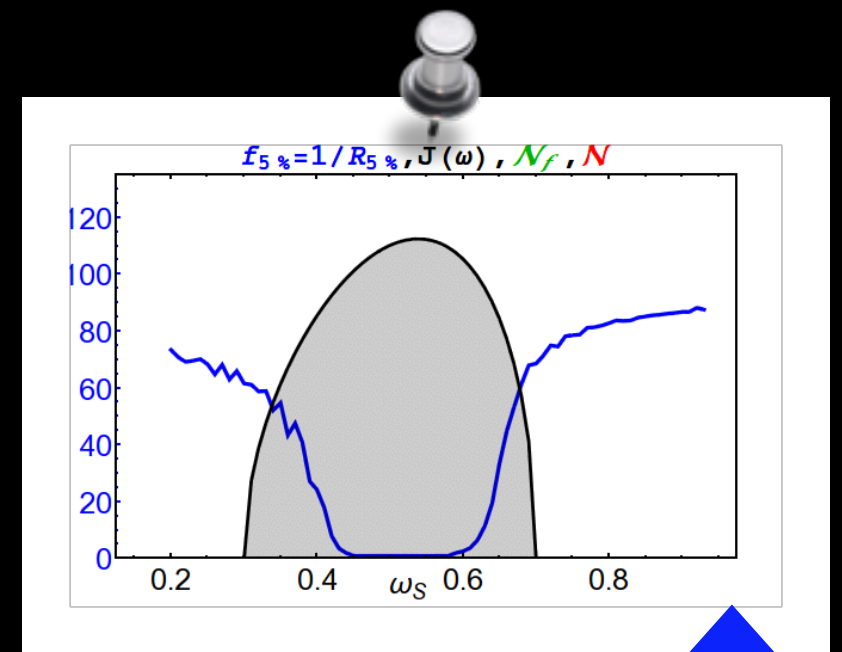
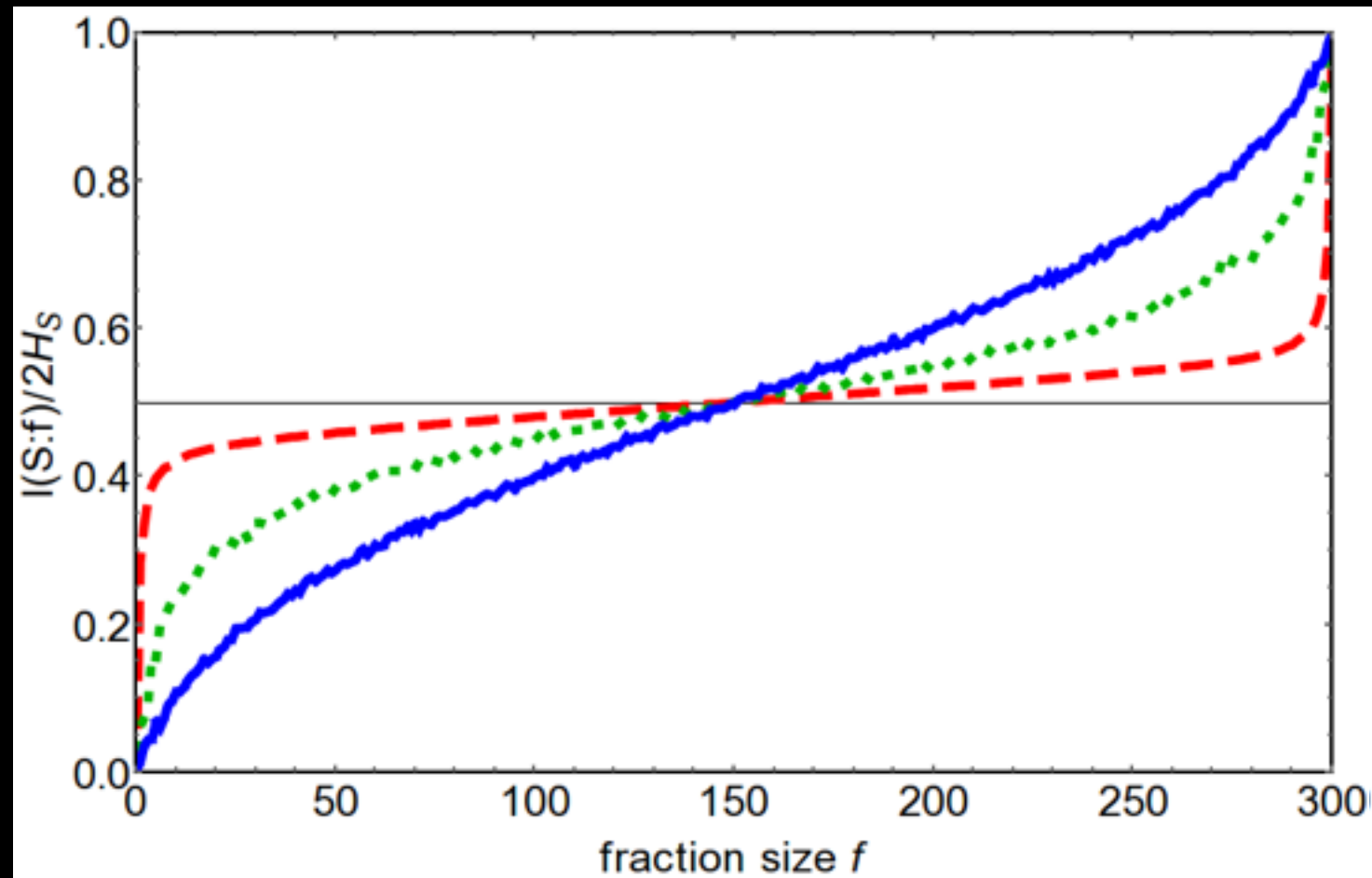
$$\omega_S = 0.5$$

$t=40$  (a.u.)



$\omega_S = 0.7$

$t=40$  (a.u.)



$\omega_S = 1$

A pair of red curtains is pulled back to reveal a black stage. The curtains are tied back with gold-colored rings. The stage is empty, and the text is centered on it.

# **The Future**

Conjectures and Speculation

**Non-Markovianity, the lack of a  
measurement scheme interpretation,  
and the absence of objectification**





Funding:



[www.tcqp.fi](http://www.tcqp.fi)



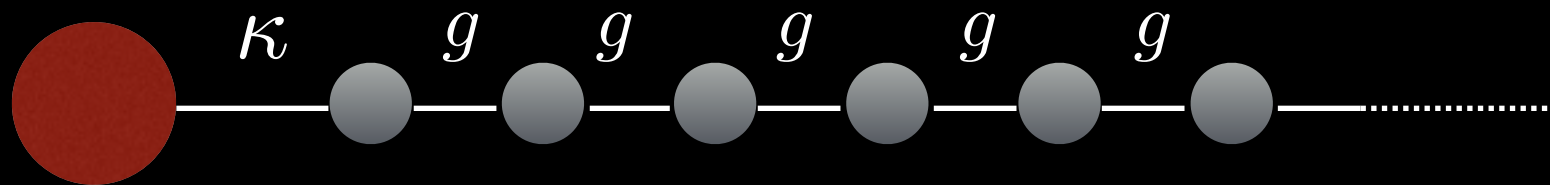
[www.openquantum.co.uk](http://www.openquantum.co.uk)



Tampere  
University

# The spectral density

Rubin model



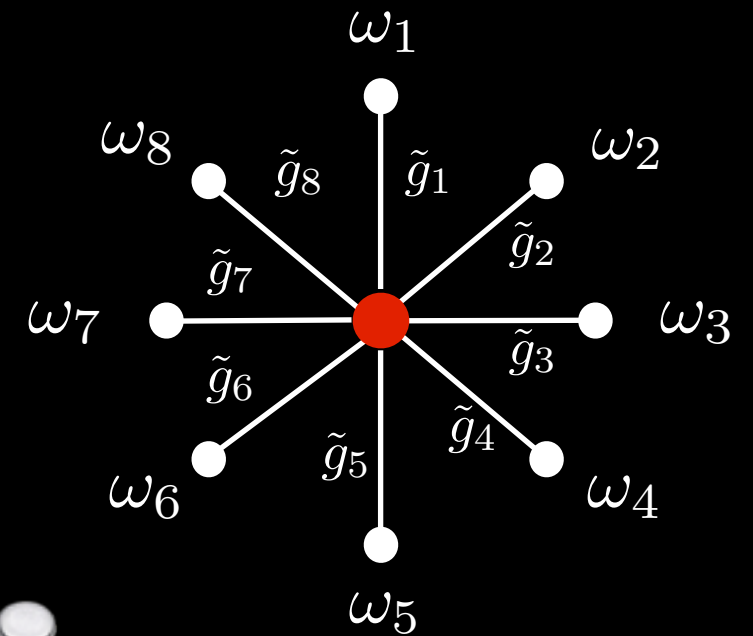
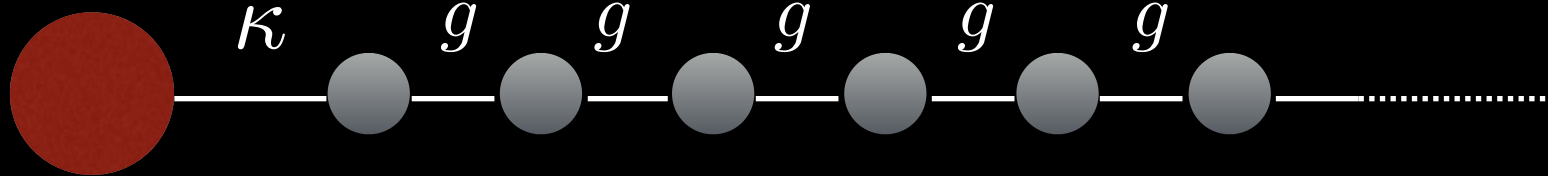
$$J(\omega) = \kappa \sqrt{\omega^2 - \omega_0^2} \sqrt{\omega_R^2 - \omega^2}$$

$$\omega_R = \sqrt{\omega_0^2 + 4g}$$

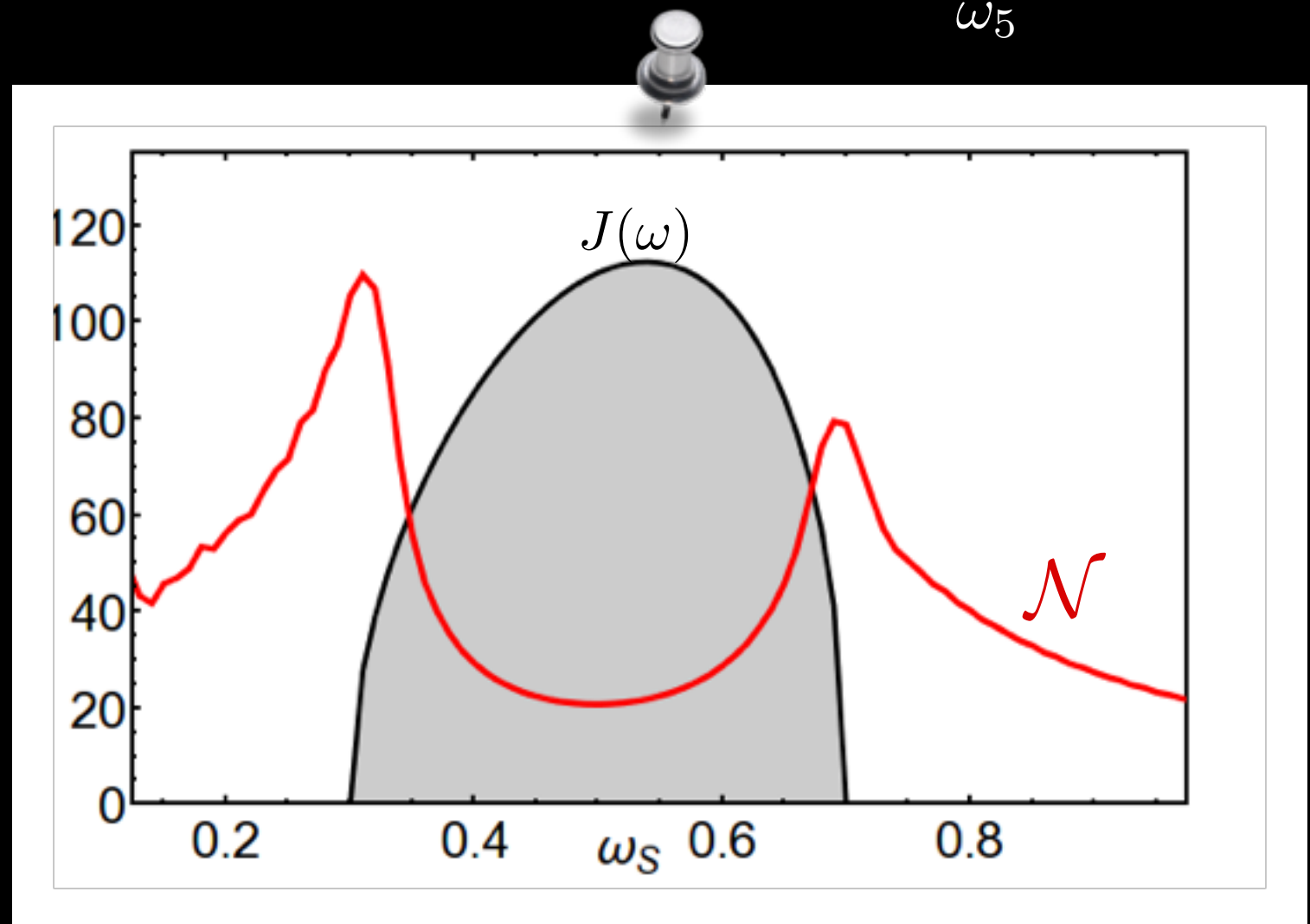


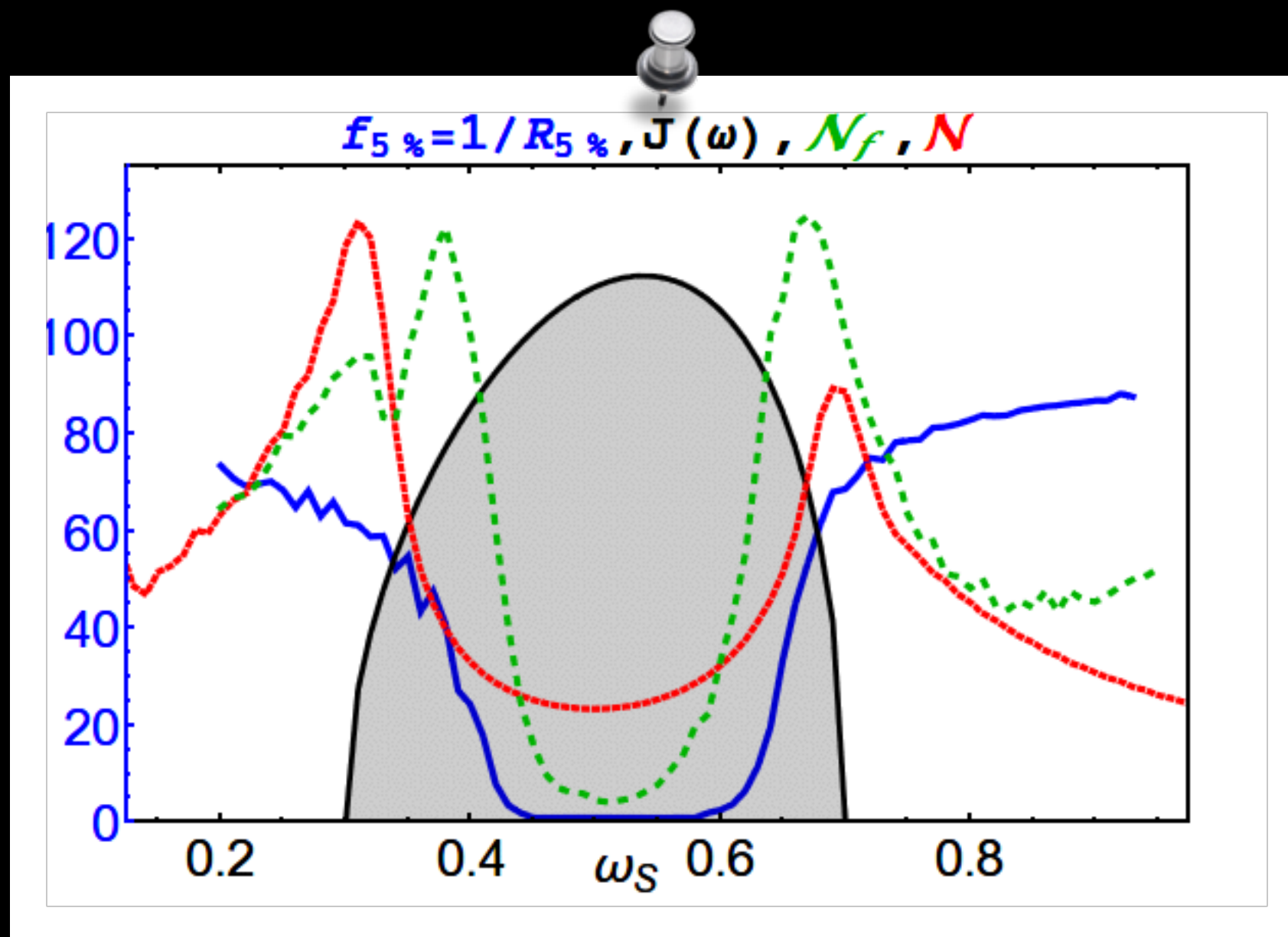
# Non-Markovianity

Rubin model



$$J(\omega) = \sum_{k=1}^N \frac{\tilde{g}_k^2}{\omega_k} \delta(\omega - \omega_k)$$





$$\mathcal{N}_f = \int_{df/dt > 0} \frac{df}{dt} dt$$

non-monotonicity of  
redundancy