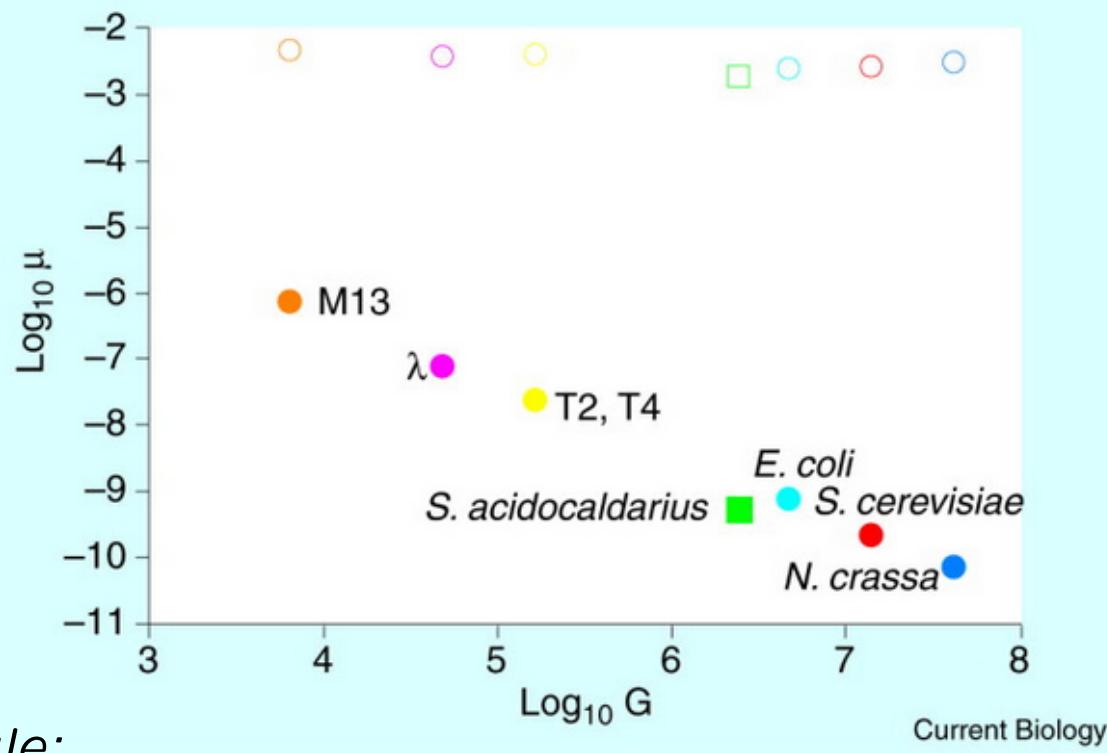


**Prebiotic evolution:**  
**Circumventing Information threshold(?)**

*emergence of higher levels of selection*

# Information threshold - any observational evidence?



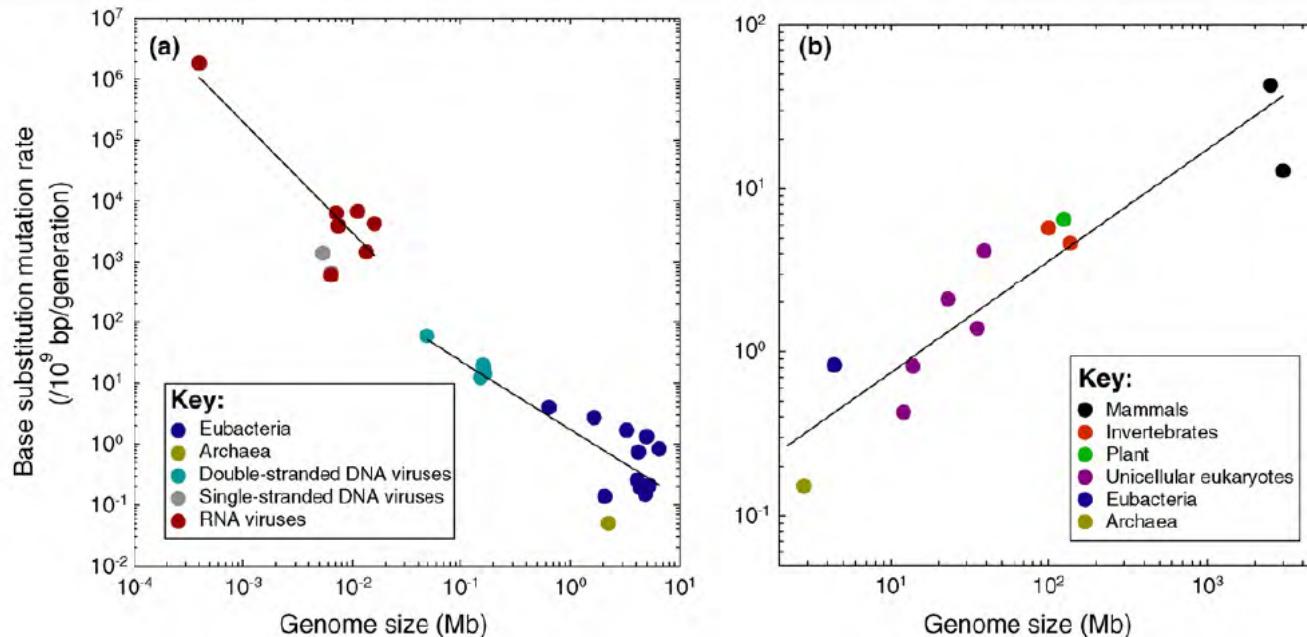
Drake's rule:

constant (BUT LOW!) per genome mutation rate

mutation rate “evolved” property  
(cf Sulfolobus in very harsh environment)

Sniegowski “Evolution: constantly avoiding mutation” current biology 2001

# Information threshold - any observational evidence?

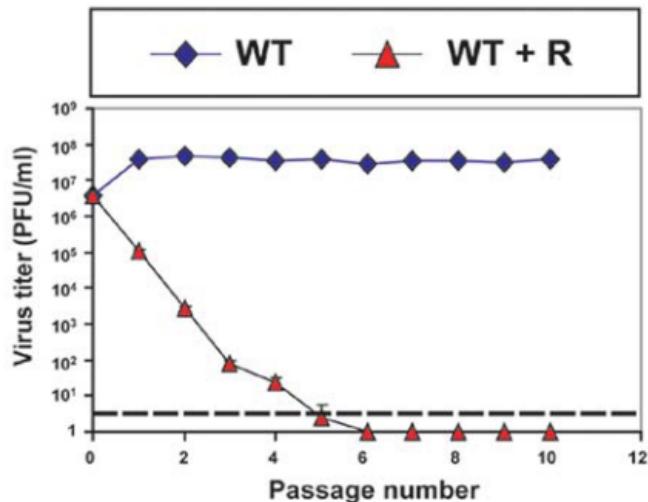


TRENDS in Genetics

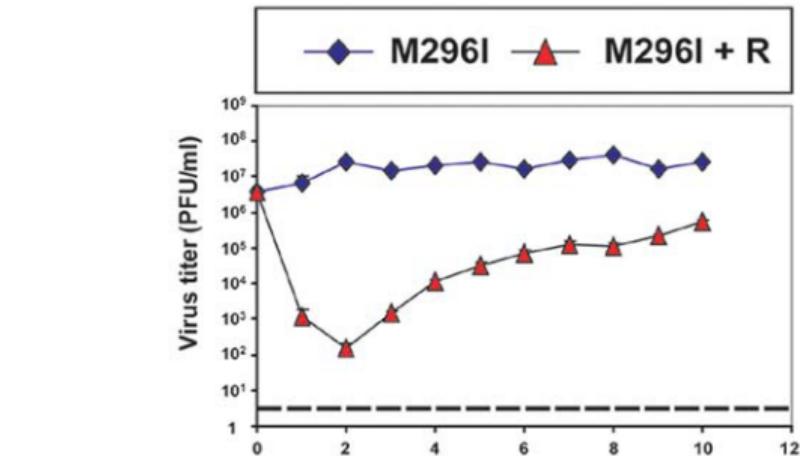
retaining low mutation rates impossible in eukaryotes because of small population sizes? ("above" error threshold?)

# experimental evidence of error threshold (?)

e.g. Perales C, Agudo R, Domingo E. PLOS-one 2009



WT extinction by mutagenesis



mutant resistant to mutagen  
(mutation in RNAddep RNA pol.)

# Eigen's paradox - Catch 22

*for more info we need better replication  
for better replication we need more info*

## How to 'solve' or 'circumvent' information threshold?

---

Did we ask the wrong question?

Did we use the wrong model?

Only little information needed for higher quality replication?

2(3) main directions to try to circumvent problem

“more replicators”      “more RNA in replicators”

BOTH

FIRST

more replicators: ecosystem based solution

Hypercycles (Eigen's original solution)

*Emergence of higher levels of selection*

## First attempt to circumvent information threshold: Hypercycles, Eigen and Schuster

---

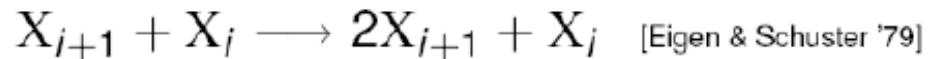
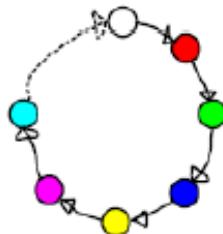
If one replicator has too little information - use many  
However beyond the many of the quasispecies: evolved and  
coordinately optimized.

*Specific catalysis of reactions*

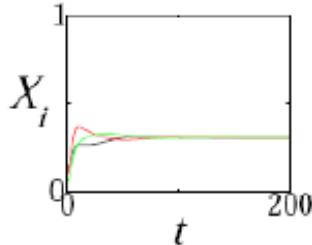
$$dX_i/dt = a_i X_i + b_i X_i X_j - \Omega_i$$

- (no mutations): look at 'ecosystem'
- ONLY stable topology: cycle

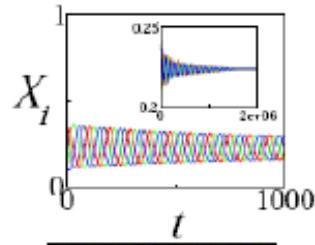
# Hypercycle properties



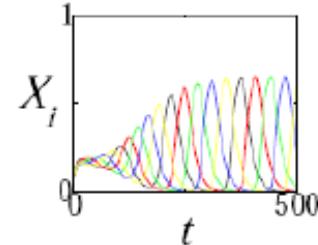
■ 3-member



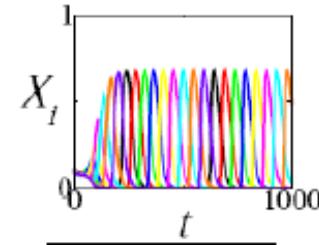
■ 4-member



■ 5-member



■ 9-member



- Selection LOCAL on amount of catalysis received
- growth and contraction of cycles

HOWEVER

- Once only selection/survival of the first
- NO selection for GIVING catalysis: Parasites

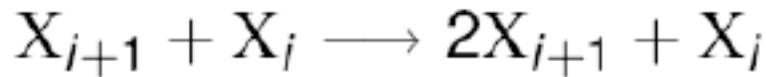
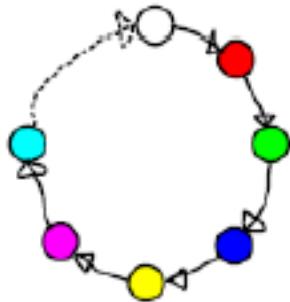
# **Nothing in biology makes sense except ....**

---

- .....in the light of Evolution (*Dobzhansky 1973*)
- .....in the light of CA (s.l.)
  - .....local interactions
  - .....micro-macro transitions
  - .....non-linear dynamics etc.
  - ....."simple rules – > complex behavior"

*nothing in biology makes sense except in the light of Both*  
*9*

# Hypercycle model (Eigen and Schuster '79): cycle only possible topology

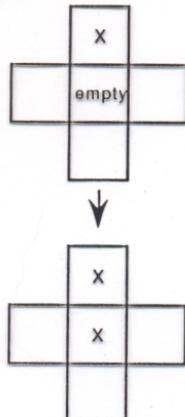


$$dX_i/dt = a_i X_i + b_i X_i X_j - \Omega_i$$

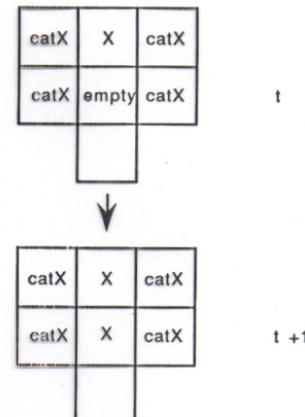
A. decay



B. replication



C. catalysed replication



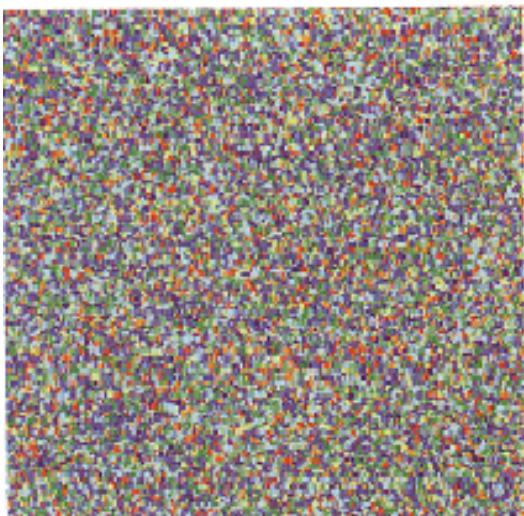
CA model:  
1992

Boerlijst and Hogeweg

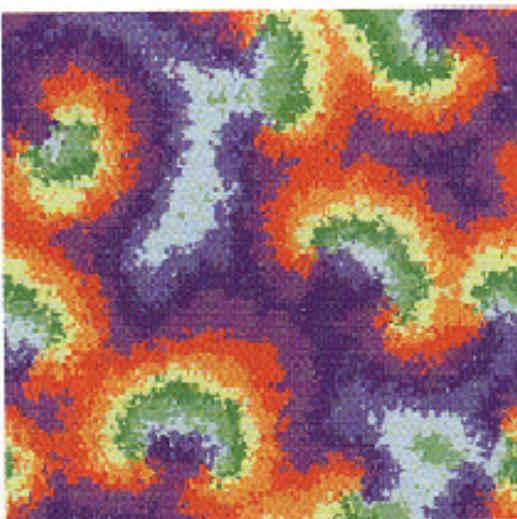
## Spiral waves: generic patterns in oscillating systems

---

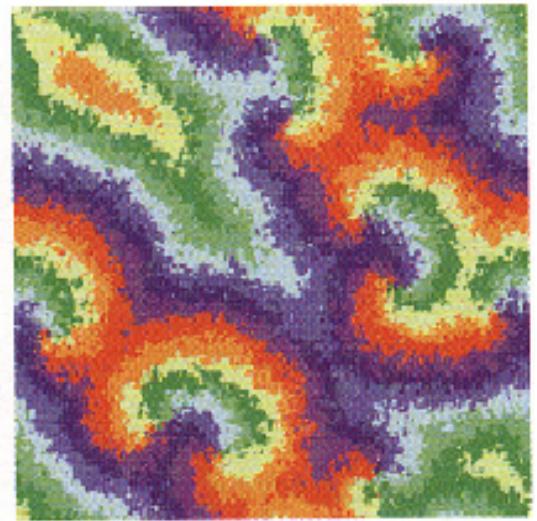
1A



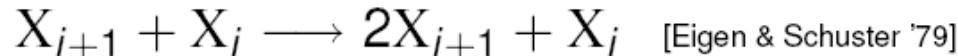
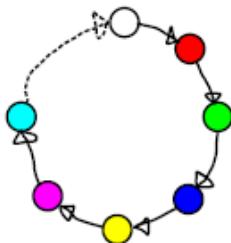
1B



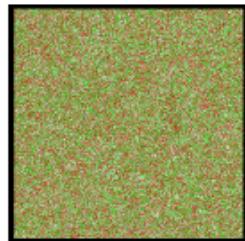
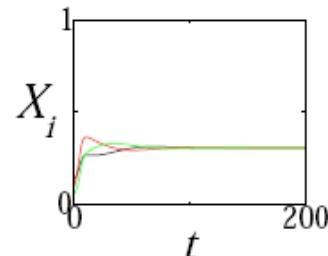
1C



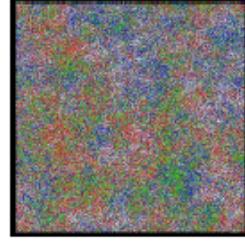
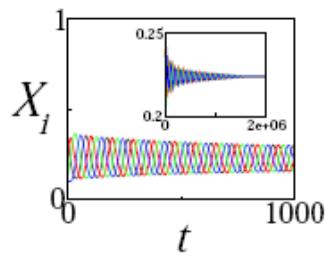
# Hypercycle model prototype of multilevel selection



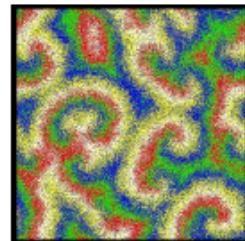
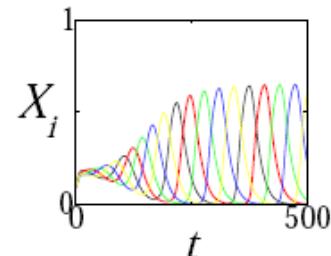
■ 3-member



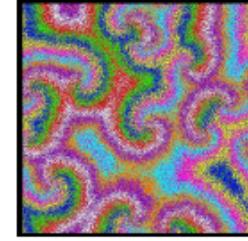
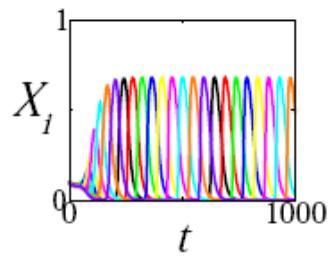
■ 4-member



■ 5-member



■ 9-member



chaotic waves ( $N=4$ )

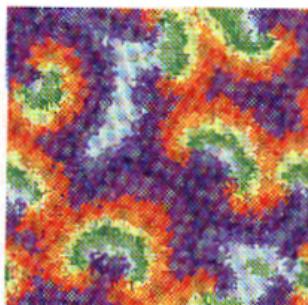
stable spiral waves ( $N > 5$  (9))

# PARASITE INVASIONS AND EXTINCTION

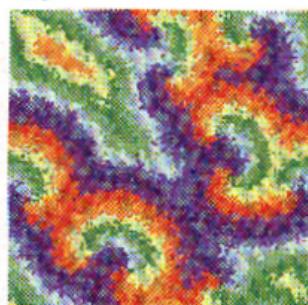
1A



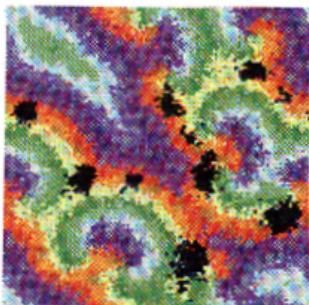
1B



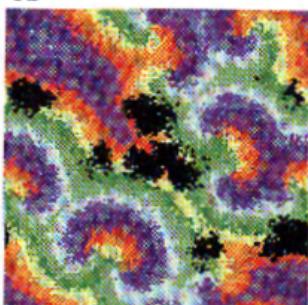
1C



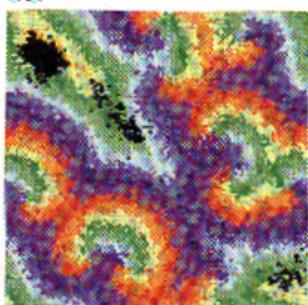
3A



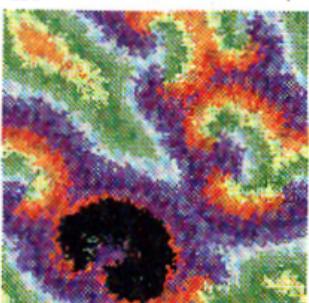
3B



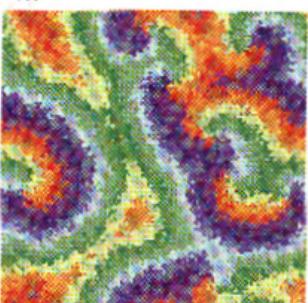
3C



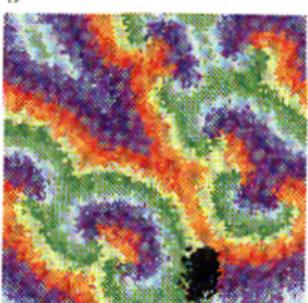
4A



4B

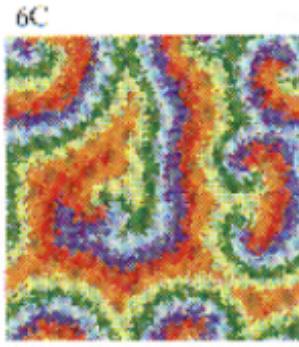
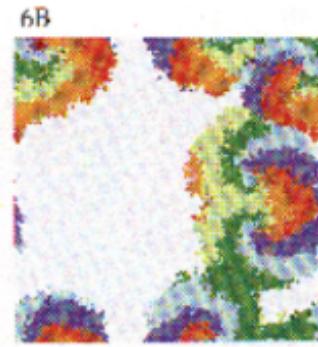
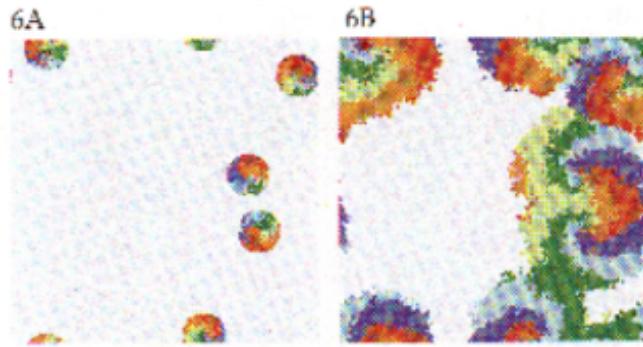


5

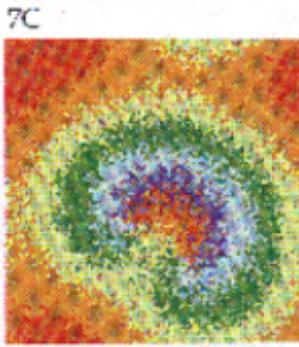
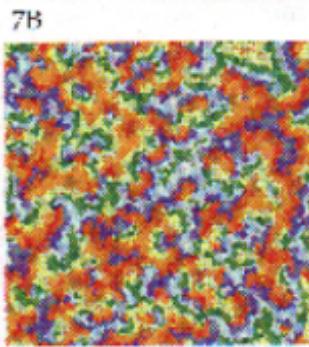
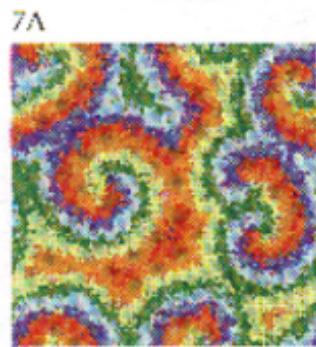


## spiral dynamics

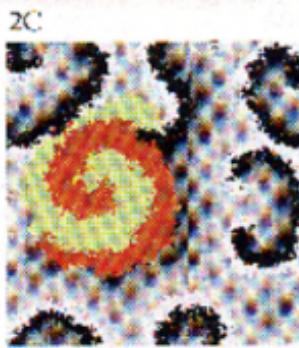
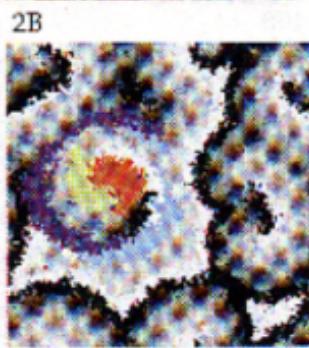
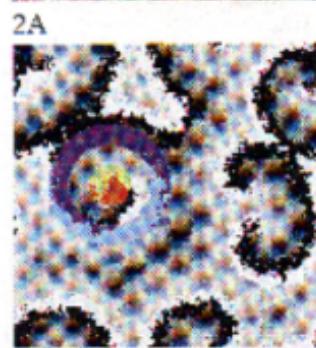
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regrowth from core



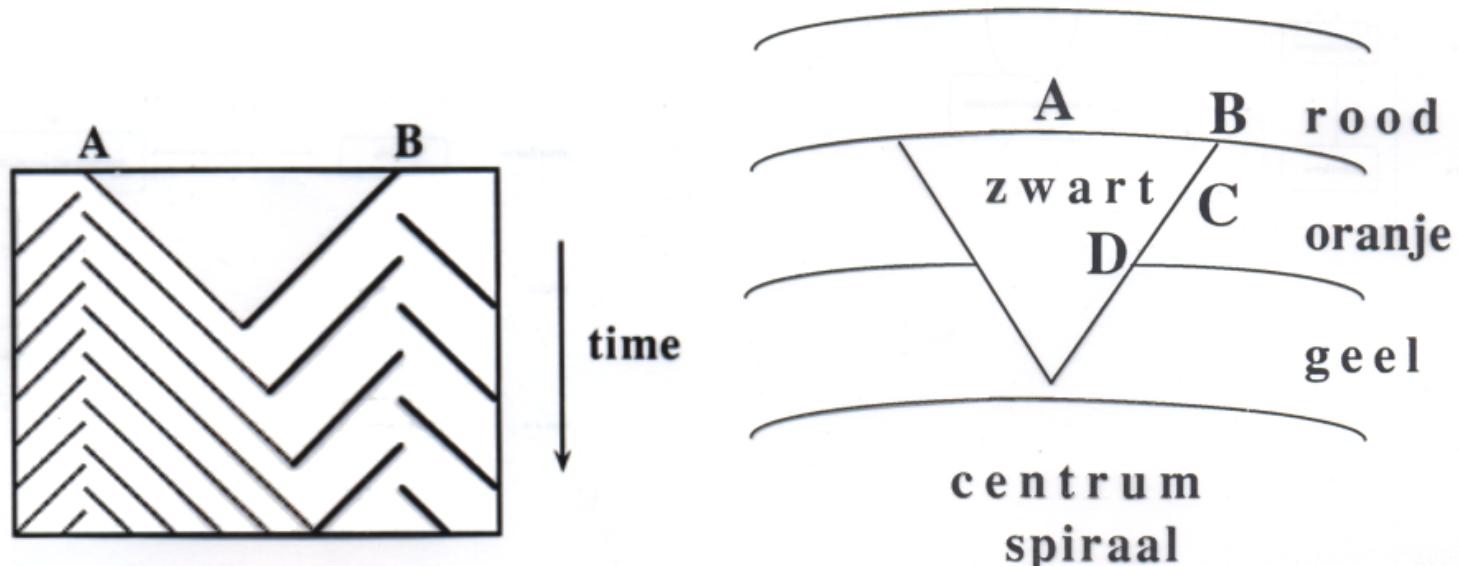
diffusion (low, none, high)



'inclusive fitness'

## Properties of Spirals

---

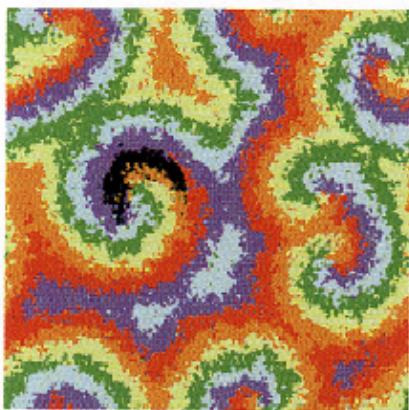


- **Faster Rotating Spirals:** Take over the domain of slower rotating ones
- **Core of Spiral:** produces all offsprings in long run

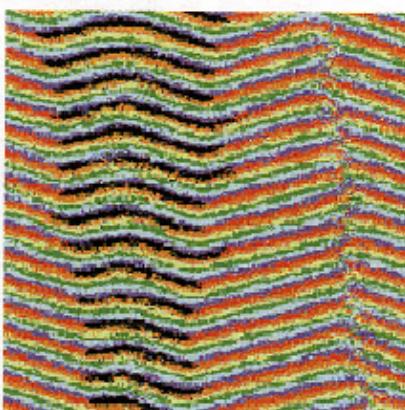
## positive selection for early death

---

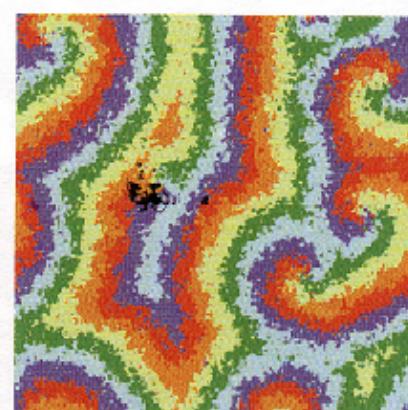
12A



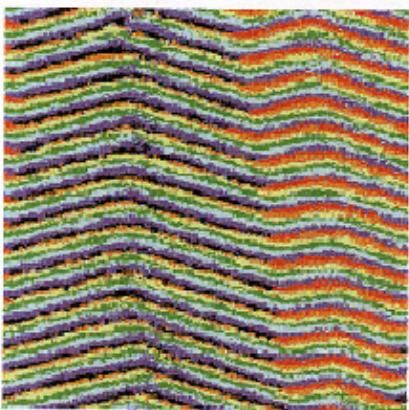
12B



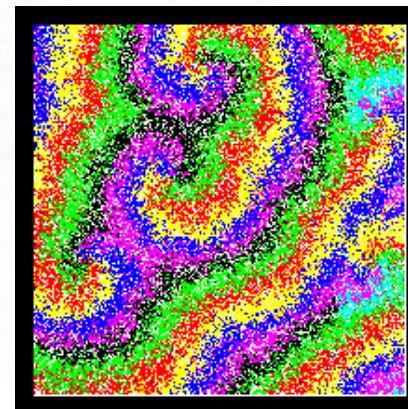
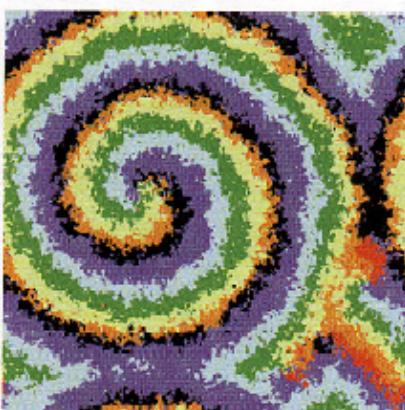
12C



12D



12E



## Selection for higher decay

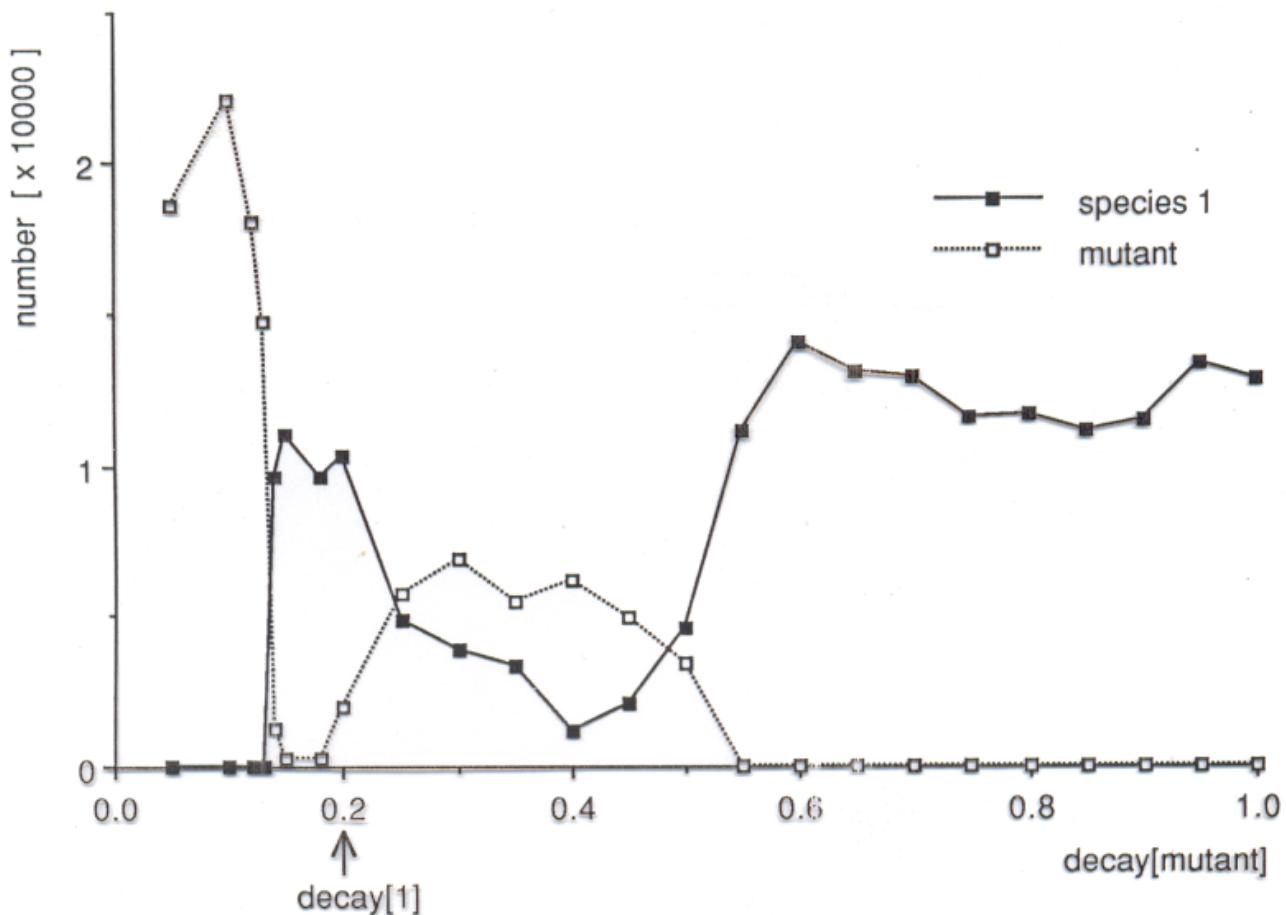
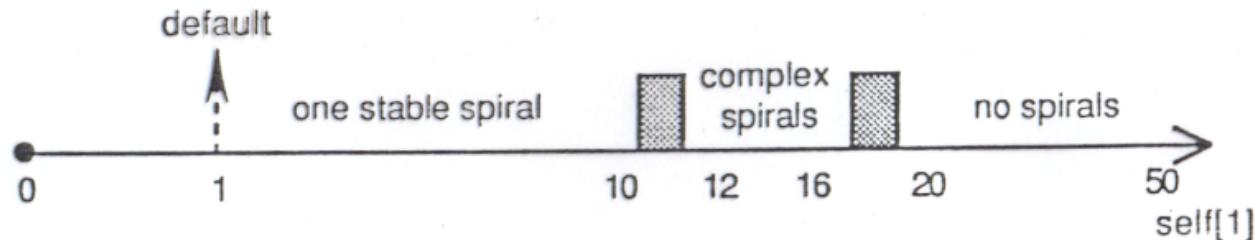


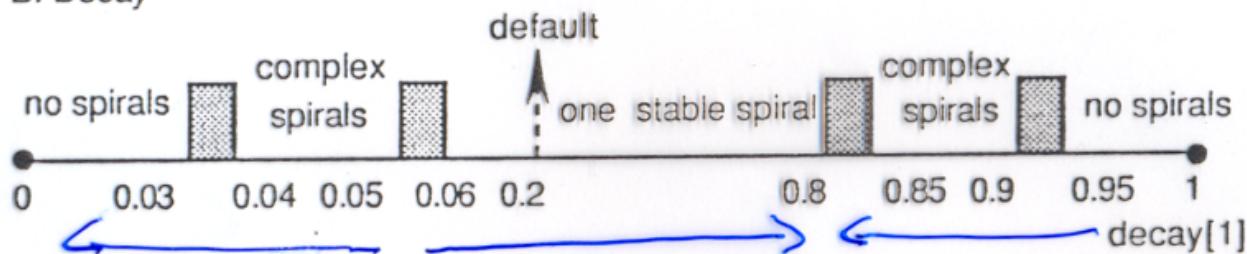
FIGURE 6 Number of molecules 4000 timesteps after infection with a decay mutant (Boerlijst & Hogeweg)

# Spirals and the Edge of Chaos

## A. Selfreplication



## B. Decay



## C. Catalytic support

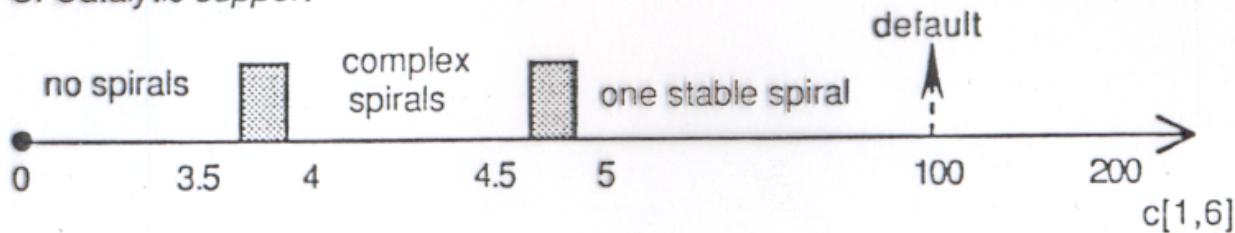


FIGURE 3 Stability results for various parameters of species 1, after 1000 timesteps.

## Conclusion

**Hypercycle properties: in spatial model  
everything differs from well mixed system**

---

- Limitcycle → spiral wave patters ( $>> 5$  stabiel)
- CAN be resistent to strong parasites
- Local interactions –> Selection non Local
- Not “once only selection”
- Spiral waves enslave molecules
- Positive selection for: early death, giving catalysis
- evolution towards ‘edge of chaos’ ('border of order')

## Multilevel evolution

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## **Did we solve the Information threshold problem?**

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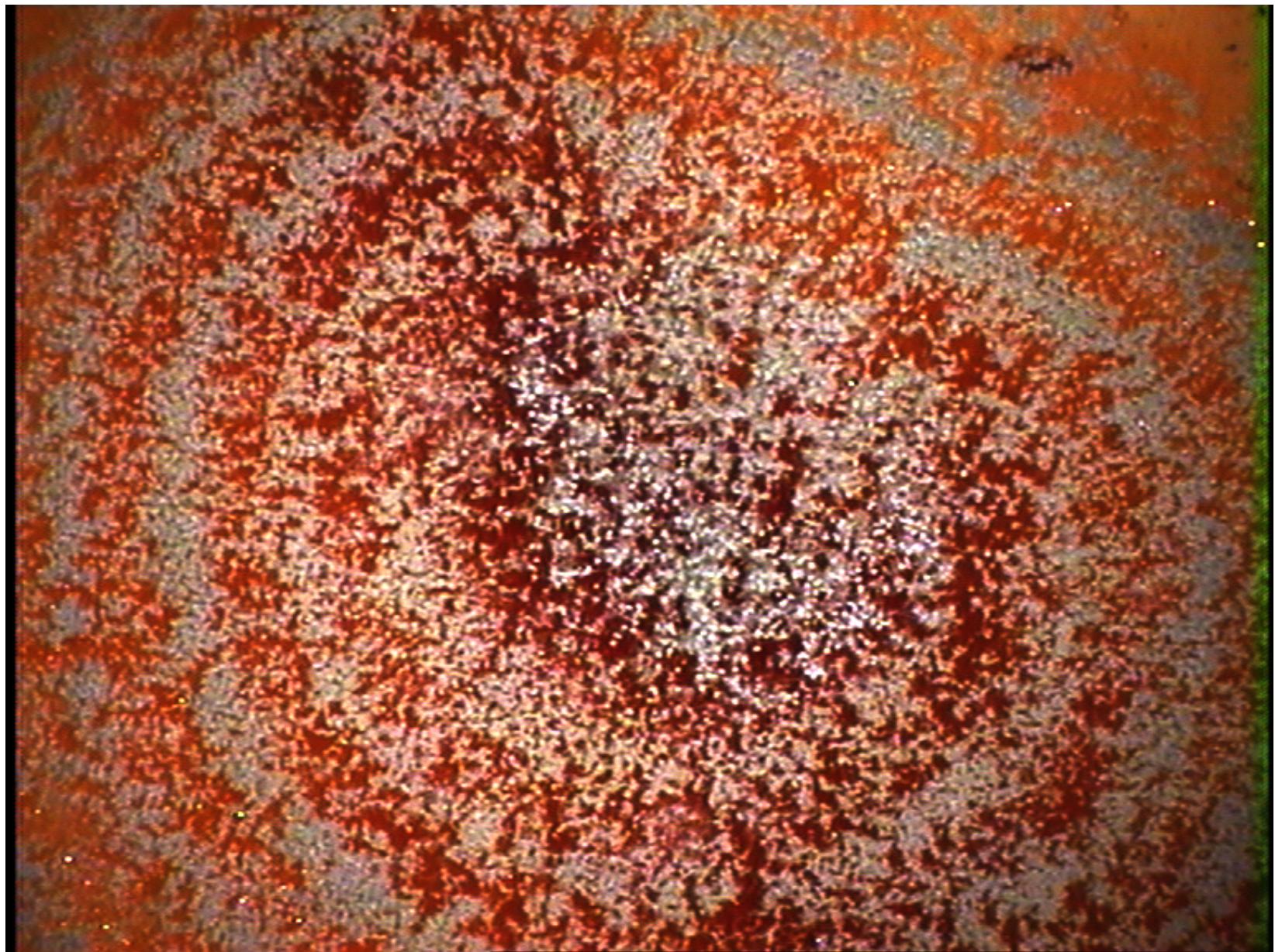
**NO.....**

because in PDE hypercycles not resistant to parasites?...NO

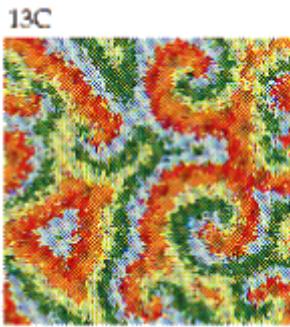
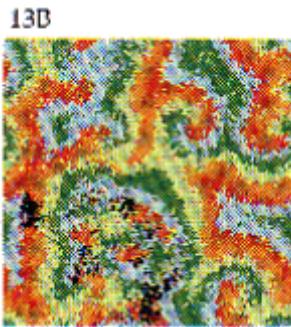
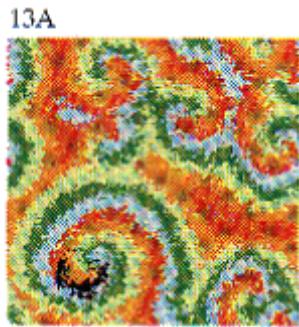
because spirals do not exist?.... NO



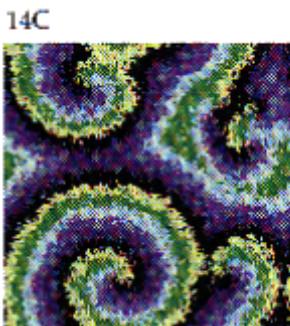
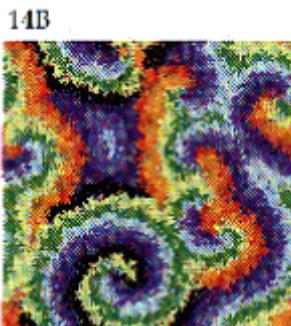
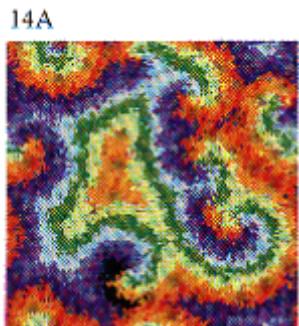




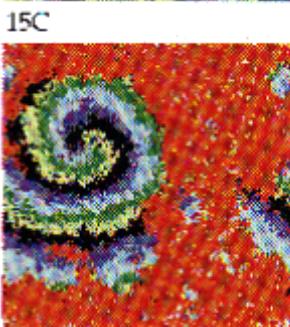
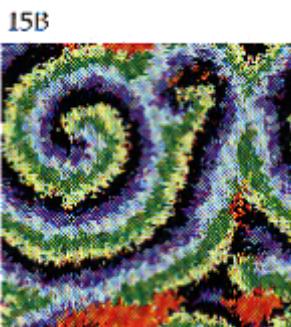
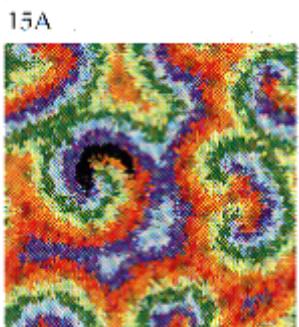
## Shortcut mutants



$5 -> 4 \Rightarrow 5$

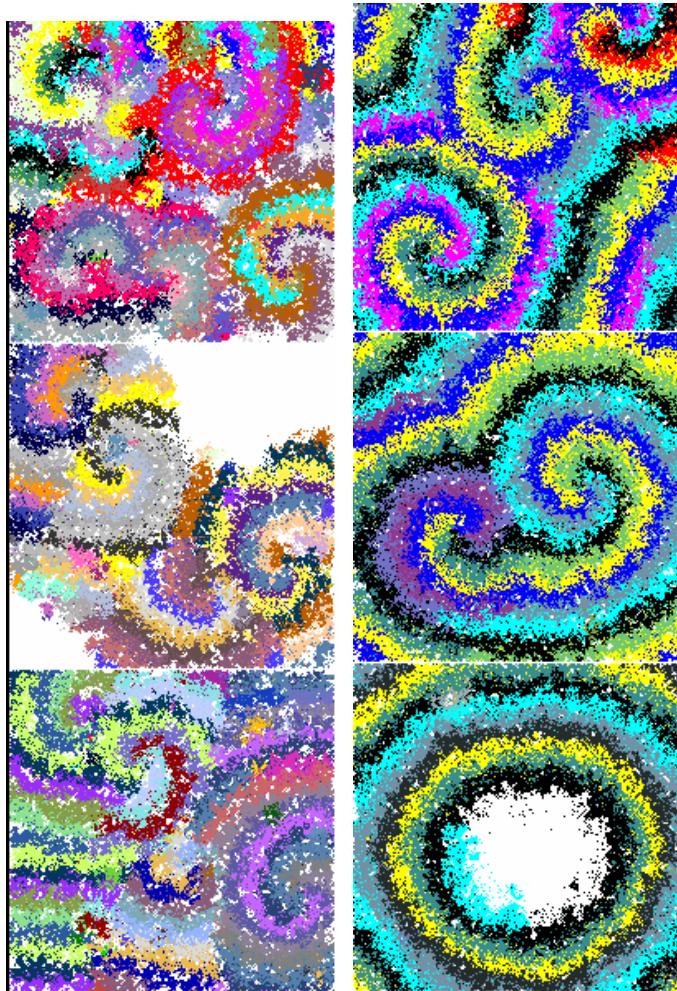


$7 -> 6 \Rightarrow 6$



$6 -> 5 \Rightarrow //$

. !!STUDIED SO FAR ONLY AS ECOSYSTEM WITH INVASIONS!!



: Limited stability of Spatial Hypercycle **with mutations!**