Leiden Institute of Physics

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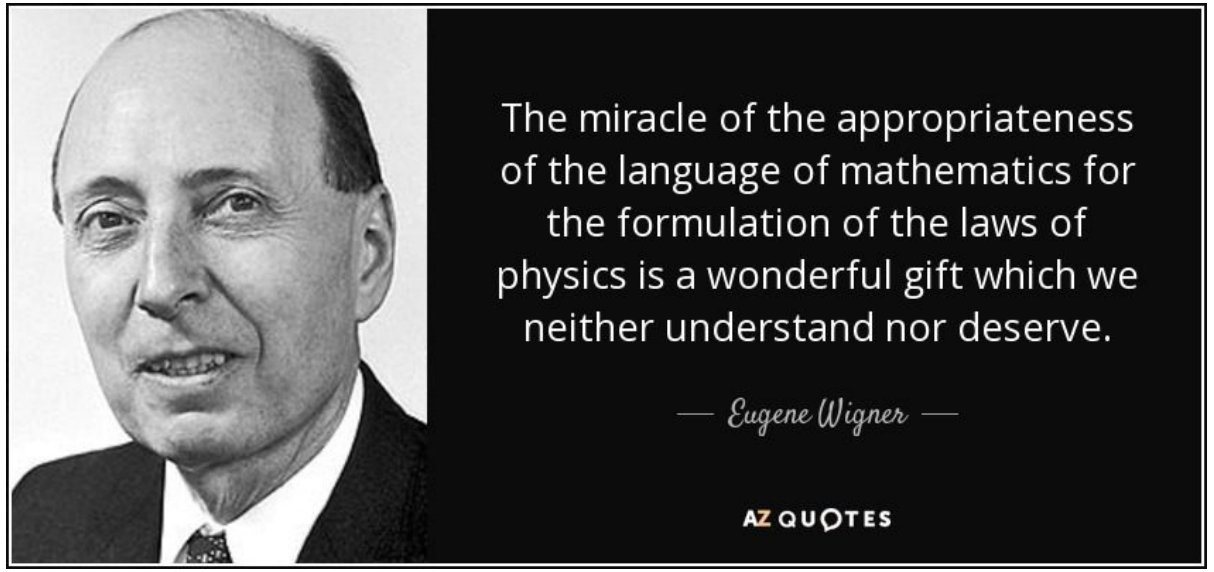
INSTITUUT LORENTZ

The Unreasonable Effectiveness of Mathematics for the moonshot programme

Wim van Saarloos

The Unreasonable Effectiveness of Mathematics in the Natural Sciences

Eugene Wigner



Eugene Wigner, 1960

Personal background

- Theoretical physicist
- PhD at Leiden University (Netherlands) 1982
- Researcher AT&T Bell Labs USA 1982-1990
- Professor of Physics in Leiden 1991-2009, 2017-
- Director Physics organization FOM 2010-2016
- Since June 2018: president of the

  Royal Netherlands Academy of Arts and Sciences

Universiteit Leiden

AT&T Bell Laboratories

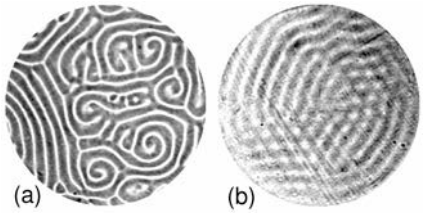
Universiteit Leiden

FOM

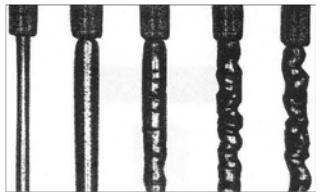
KONINKLIJKE NEDERLANDSE AKADEMIE VAN WETENSCHAPPEN

Scientific background

- Pattern formation in non-equilibrium systems



- Coherent structures in the Complex Ginzburg Landau eq.
- Granular media



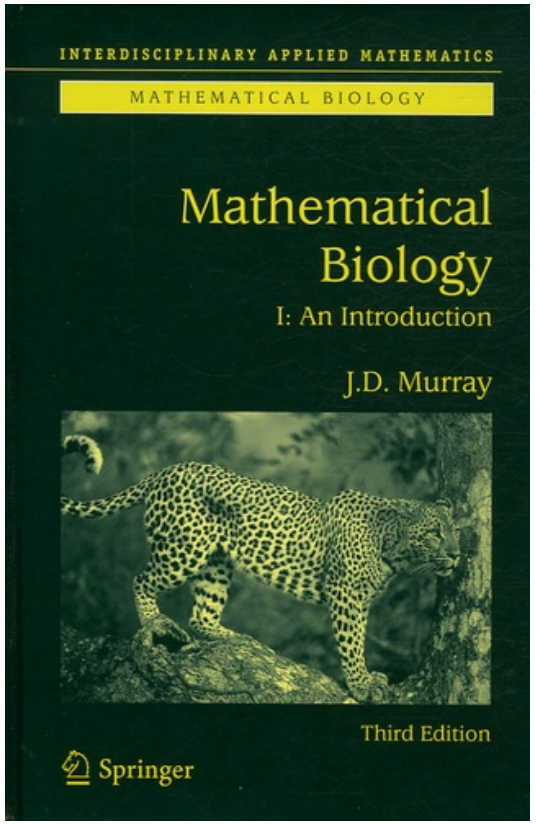
- Instabilities in flow
- *Front propagation into unstable systems (1988-2004)*
- Lorentz center

  Co-founder and director 1997-2009

Example: front propagation into unstable states

Since 1932: Fisher equation of population dynamics

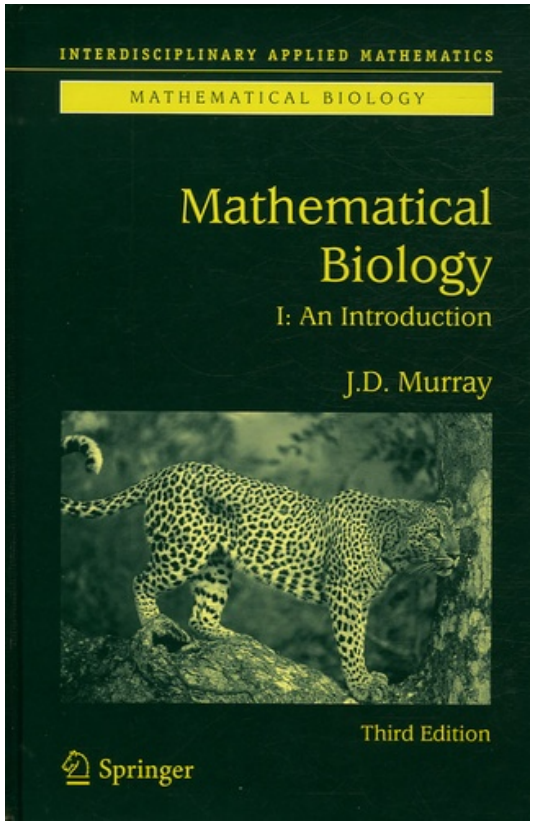
$$\partial_t u = \partial_x^2 u + u - u^3$$



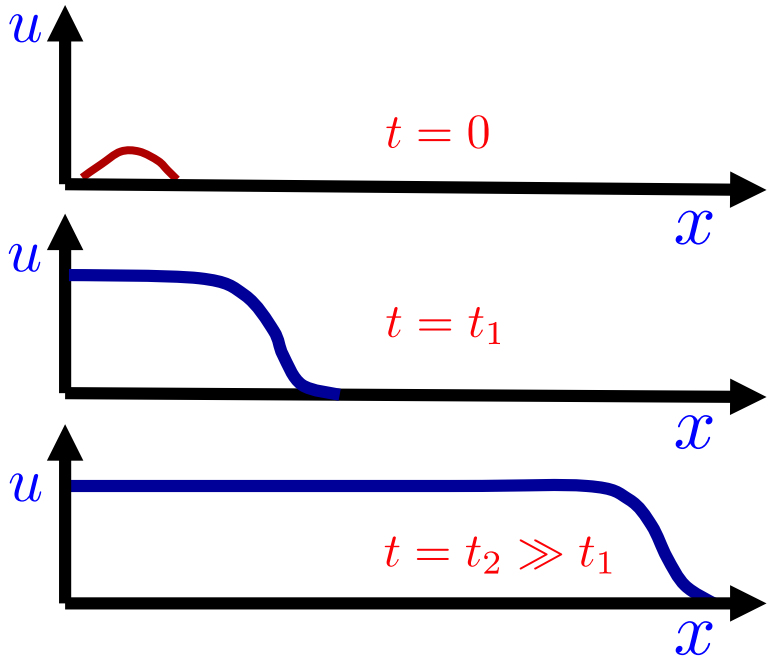
Murray, J.D.(2002), Mathematical Biology -Volume 1, An Introduction 3rd edition, New York, Springer,ISBN-10:0387952233

Example: front propagation into unstable states

Since 1932: Fisher equation of population dynamics



$$\partial_t u = \partial_x^2 u + u - u^3$$



Front speed an important ingredient of many problems

Problem has a long history in mathematics

$$\partial_t u = \partial_x^2 u + u - u^3$$

Aronson & Weinberger (1978) + Bramson (1983) proved for the

asymptotic front speed:

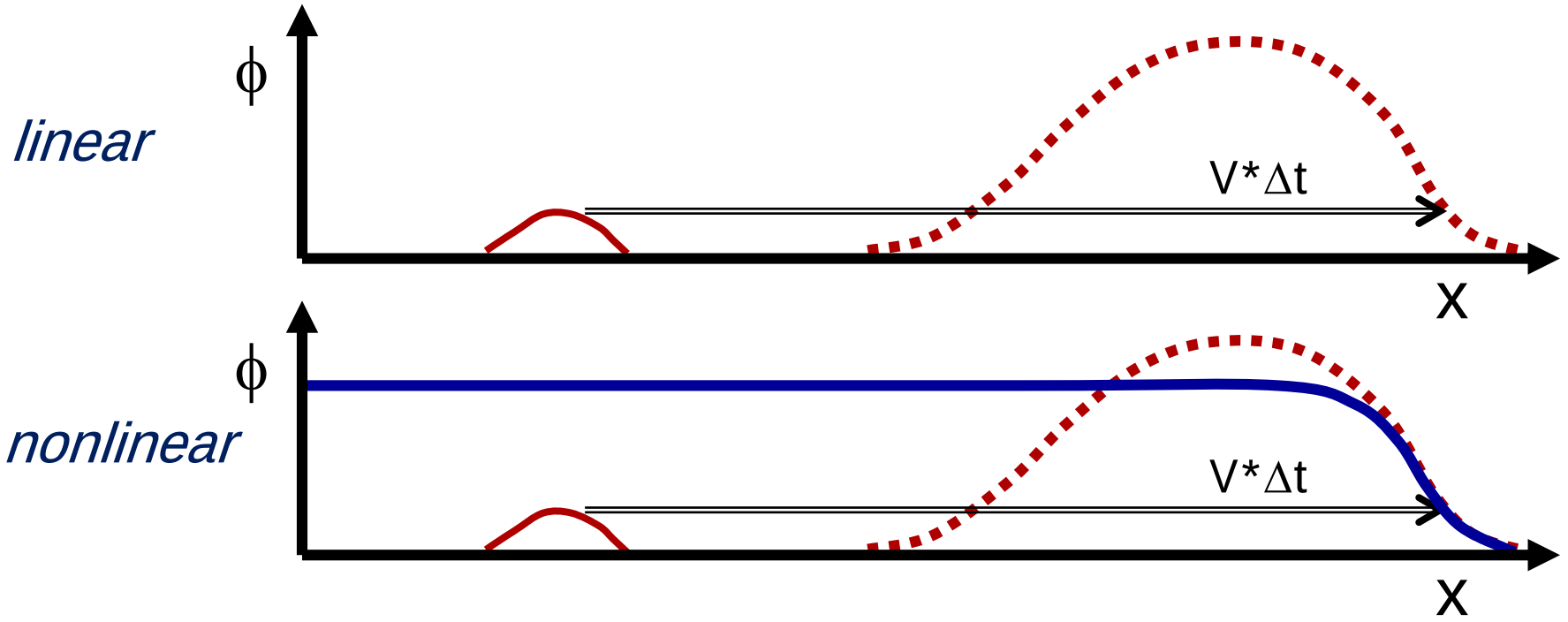
$$v(t) = 2 - \frac{3}{2t} + \cdots$$

for sufficiently localized initial conditions

Linear spreading velocity v*

Idea from Plasma Physics!

According to the *linear dynamics* already a small perturbation grows out and spreads!



My insight: there is a large class of *'pulled'* fronts which have

$$v(t\to\infty) = v^*$$

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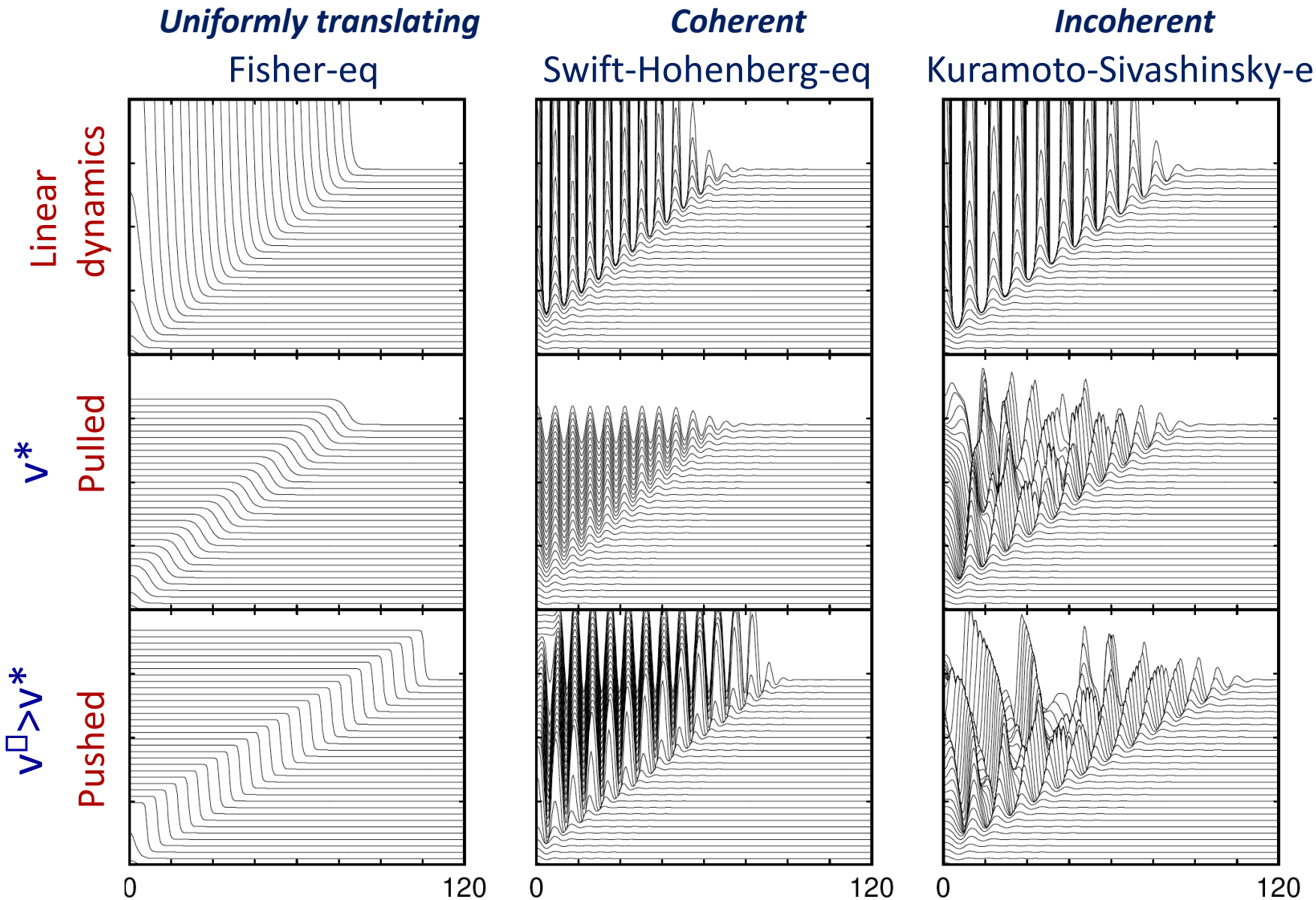
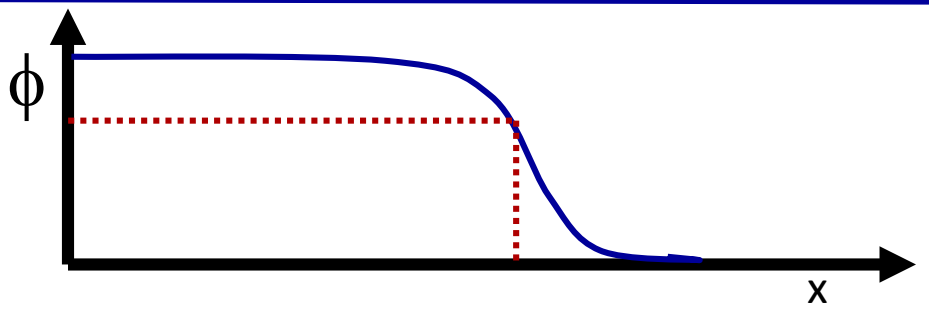
Illustration of the general scenario



Exact but non-rigorous result for 'pulled fronts'

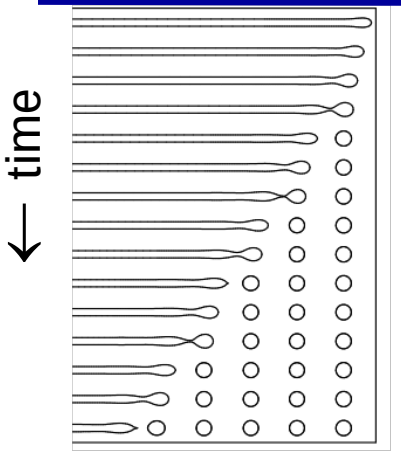
Universal slow relaxation of front velocity and shape:



$$v(t) = v^* - \frac{3}{2\lambda^* t} + \frac{3\sqrt{\pi}}{2(\lambda^*)^2 t^{3/2}} \mathrm{Re}\frac{1}{\sqrt{D}} + \cdots$$

- Independent of initial conditions *[provided <exp(-λ*x)]*
- Independent of at what level one tracks front position
- Independent of form of the nonlinearities and form of the equation (as long as front is pulled)
- All coefficients are known, even in complicated (relevant!) cases
- Also holds for pattern forming fronts!

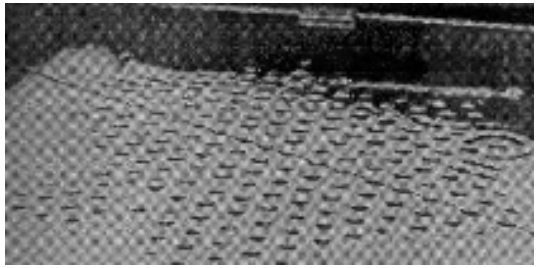
Examples of such fronts abound in nature



Propagating Rayleigh inst.

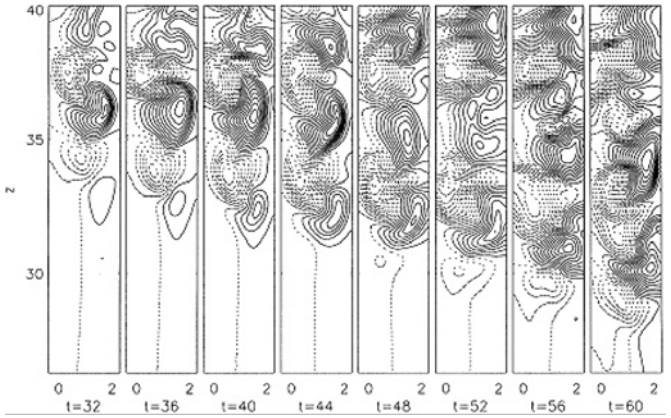
Powers *et al.*

Propagating Rayleigh-Taylor instability



Limat *et al.*

Schumacher and Eckhardt



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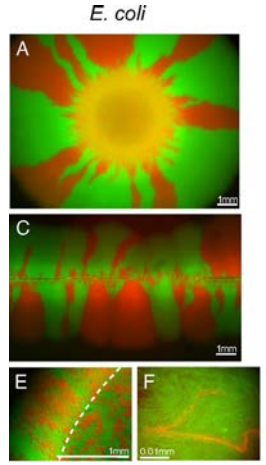
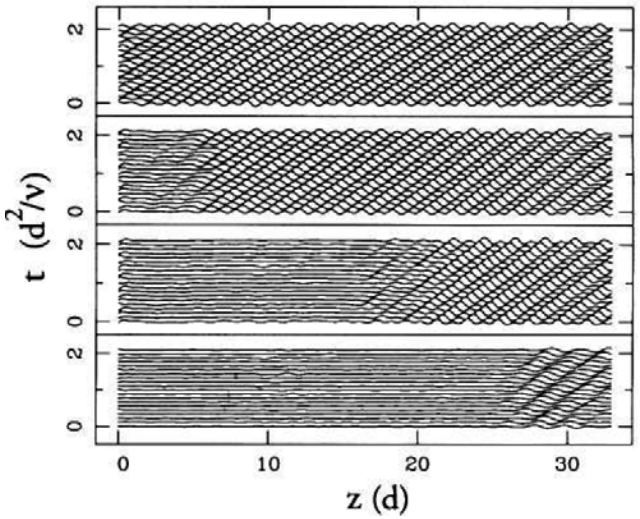
Turbulent front (Couette)

Genetic drift

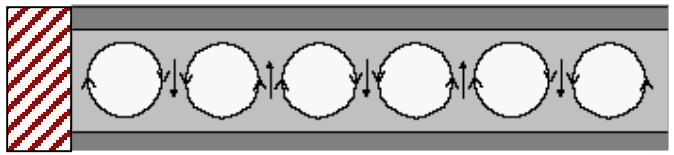


Hallatschek *et al.*

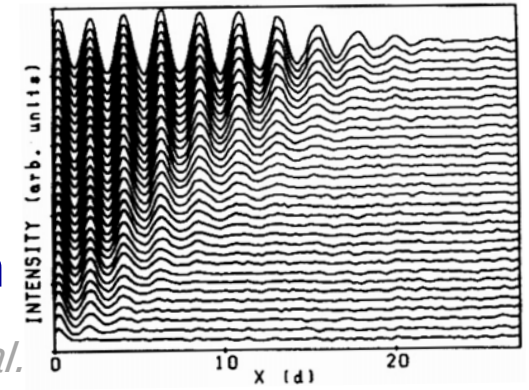


Taylor-Couette cell with throughflow

Babcock *et al.*

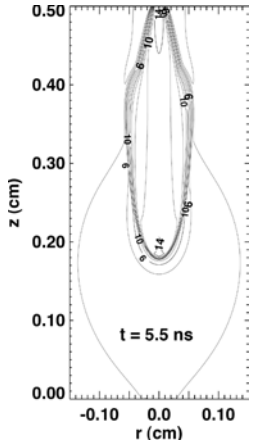


Front in Rayleigh-Bénard convection



Fineberg *et al.*

Plasma's



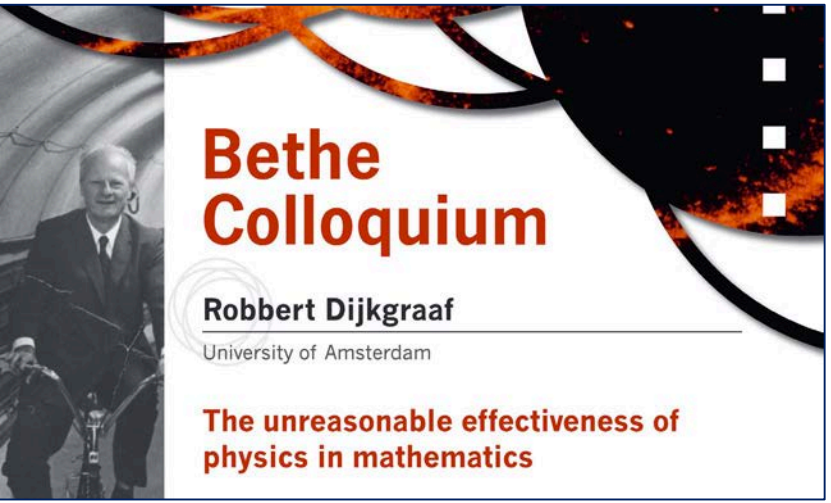
Ebert *et al.*

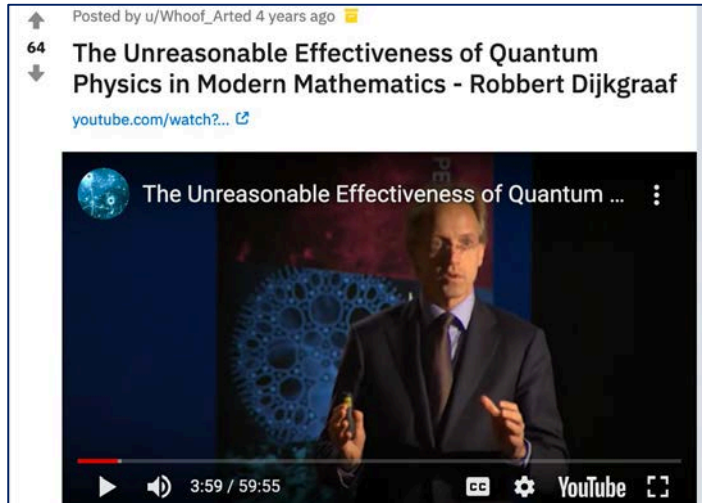
nLab

The Unreasonable Effectiveness of Physics in the Mathematical Sciences

In view of the developments in theoretical physics from about the the 1980s, and in reference to Eugene Wigner's famous phrase of the *The Unreasonable Effectiveness of Mathematics in the Natural Sciences*, Atiyah-Dijkgraaf-Hitchin 10 wrote this:

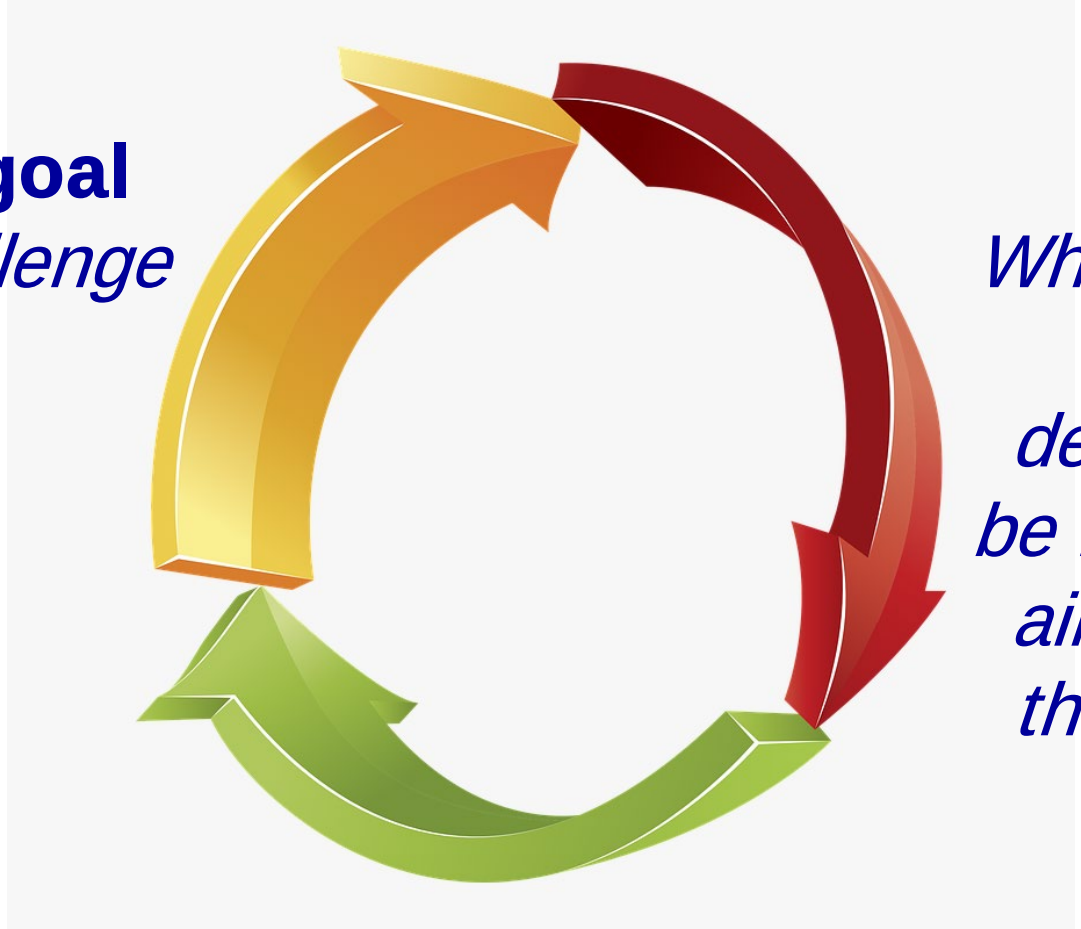
> But over the past 30 years [1980s- 2010s] a new type of interaction has taken place, probably unique, in which physicists, exploring their new and still speculative theories,have stumbled across a whole range of mathematical "discoveries". These are derived by physical intuition and heuristic arguments, which are beyond the reach, as yet, of mathematical rigour, but which have withstood the tests of time and alternative methods. There is great intellectual excitement in these mutual exchanges.





Applied math is more than applying math....

Moonshot goal
Problem, challenge



Model building
What is a proper model & mathematical description, what can be ignored, what do we aim at, have we seen this structure before?

Mathematics
solution, approximation, simulation

Moonshot goals: *unreasonable effectiveness of mathematics*

1. **“brain-machine interfaces, feedback/ feedforward of the five senses, and technology for real-time transmission”**

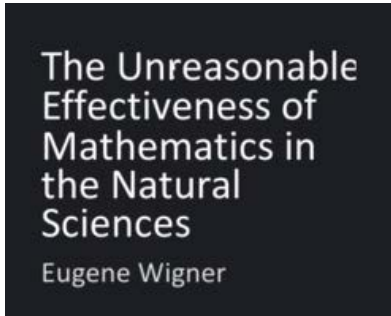
2. **“biological functions such as the nervous system and related tissues of large amounts of information”**

3. **“Deep Learning”, “reduce the power consumption of devices and help discover optimal architectures”, “feedback in robots-environment interaction”**

4. **“greenhouse gas reduction technologies”, “resources and materials circulation”, “resource-saving technologies”**

5. **”cutting-edge technologies such as AI, robotics, and biotechnology with use of natural organisms like soil microbes, optimizing the entire process of food value-chain”**

6. **“quantum sciences and technologies”, “quantum memory, general-purpose quantum computers, quantum relay technologies, quantum networks”**



Science

The Lorentz Center, established in 1997 is an (inter)national center for international workshops in all scientific disciplines. Its guiding philosophy is that innovative research thrives on *interactions* between creative researchers: Lorentz Center workshops focus on initiating and stimulating interactions and new collaborations between (groups of) researchers.

- High scientific quality;
- **All fields of research (initially natural sciences)**
- Multidisciplinary, with a strong embedding in the mono-disciplines
- typically one week and about 30-40 junior & senior participants
- About 80 workshops with in total 3000 participants per year

Concept

- **Openness & ample time for discussions.**
- *All participants know each other by the end of the meeting*
- Discuss present projects, not already published ones ...
- Diversity in all aspects (seniority, national/international, gender, culture)
- **Support in developing ideas** into successful workshops
- Care for all practical matters:

You do the research, we do the rest

and the moonshot programme

- Center has successfully ‘exported’ the concept of 1-week workshops for small groups of active researchers beyond the fields of astronomy, computer science, mathematics and physics
- The Lorentz Center has realized – and demonstrated – that the concept of stimulating active collaborations in the setting of 1-week workshops is pre-eminently suitable for establishing viable multidisciplinary connections, collaborations and communities
- Lorentz Center concept ideally suited to put mathematic at the heart of the Moonshot programme and to stimulate collaborations