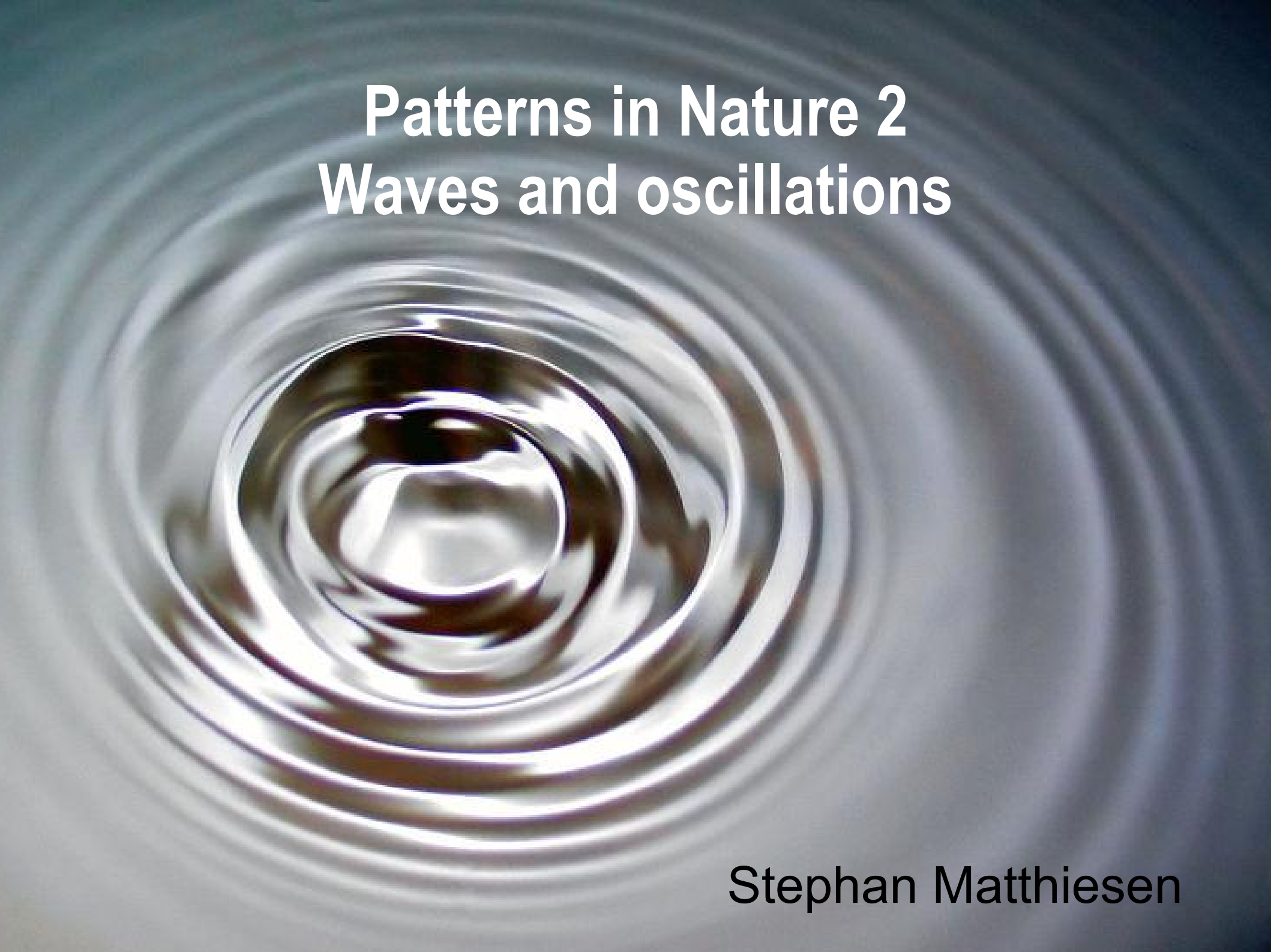


Patterns in Nature 2
Waves and oscillations

Stephan Matthiesen

Order from chaos
Mechanisms in comparison

- Well-informed leader
- Building by blueprint
- Following a recipe
- Templates

Usually, several of these mechanisms interact.

The instructions are “external”.

Stygmergy

Modifying the process through feedback from the emerging pattern.

Examples:

- A cook tasting the dish and modifying the recipe.
- Tourists going into the pub where there is already a crowd.

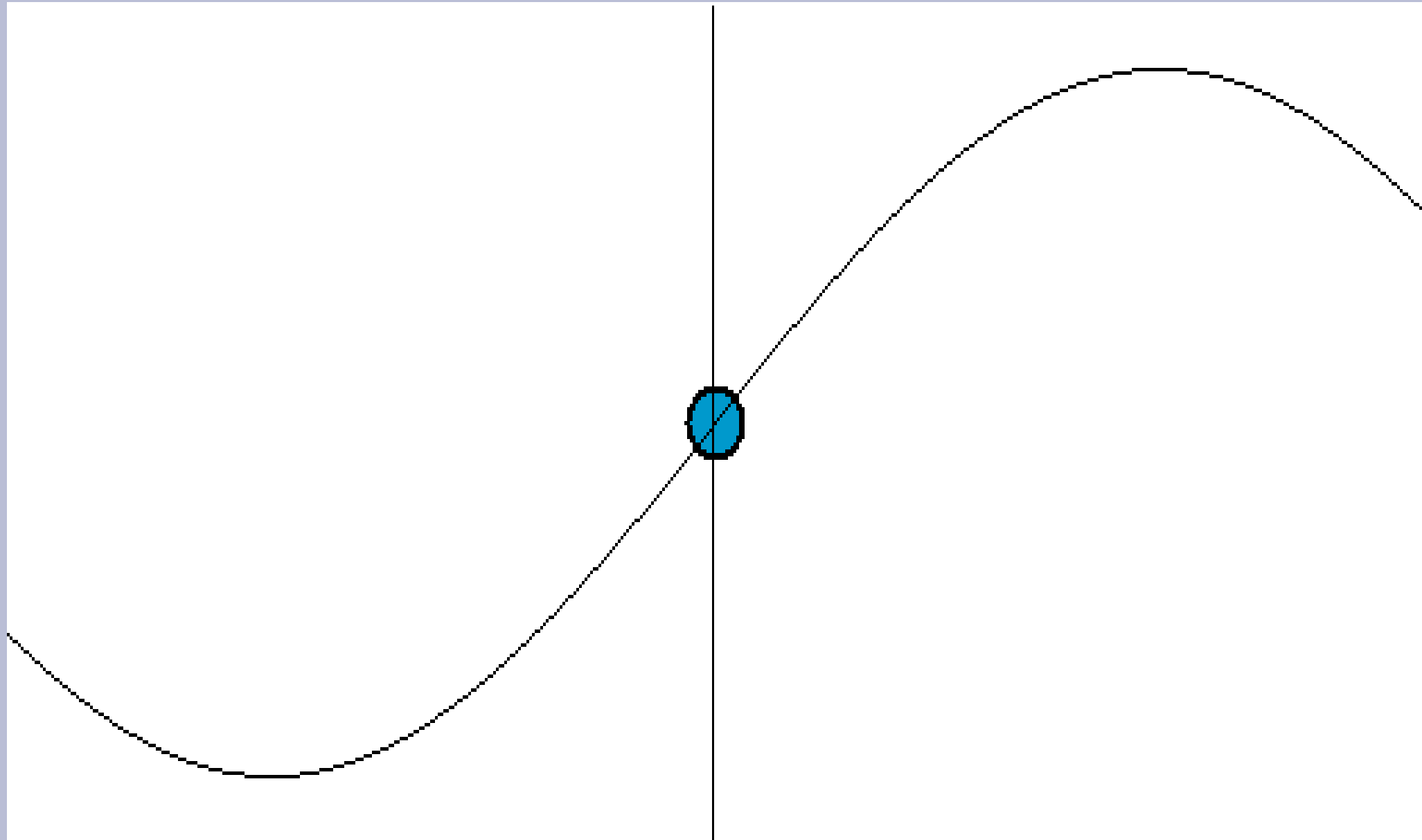
Self-organization Definition

Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern. (Camazine et al 2001, p. 8)

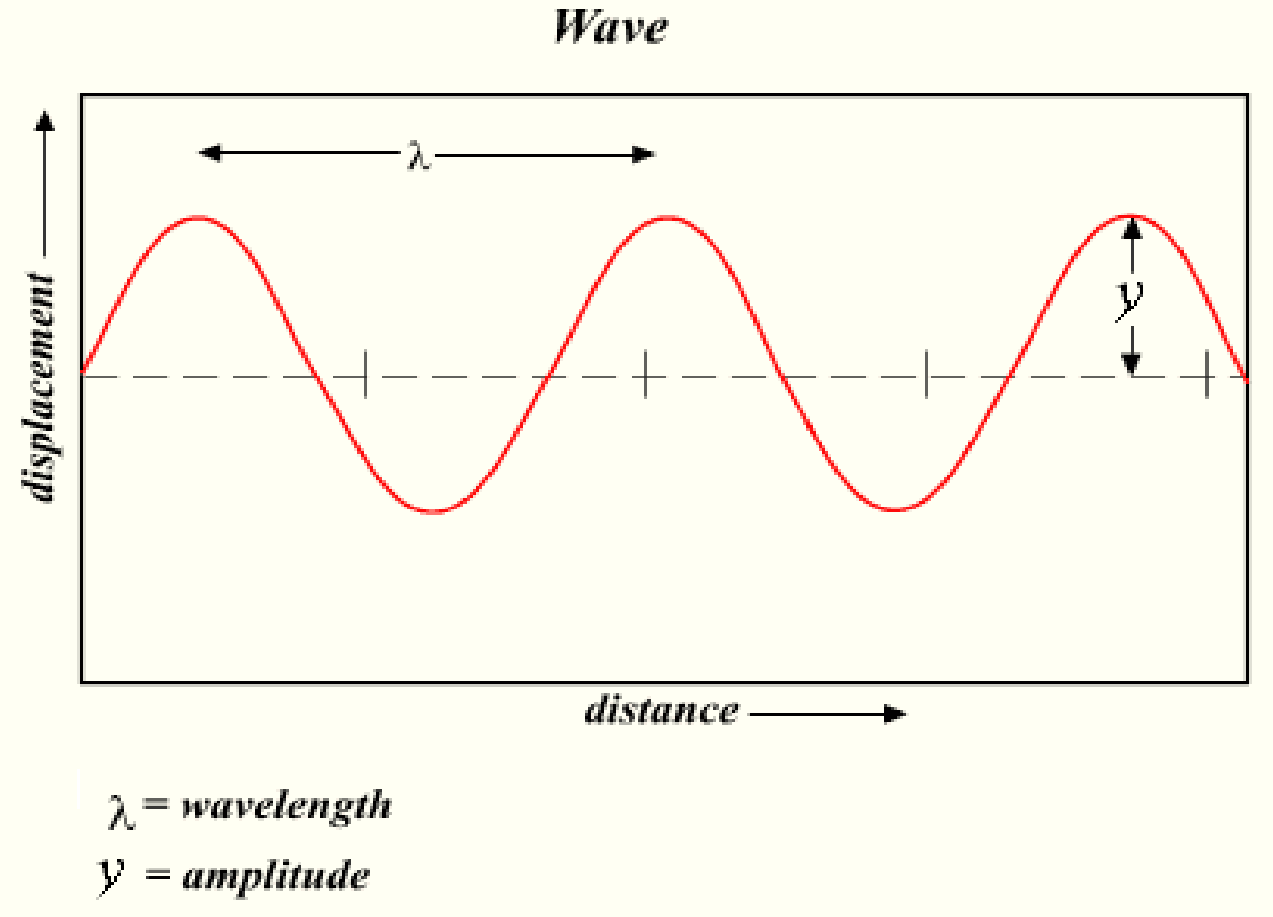
Oscillations

- Displacement
- Restoring force

Waves



Wave terminology

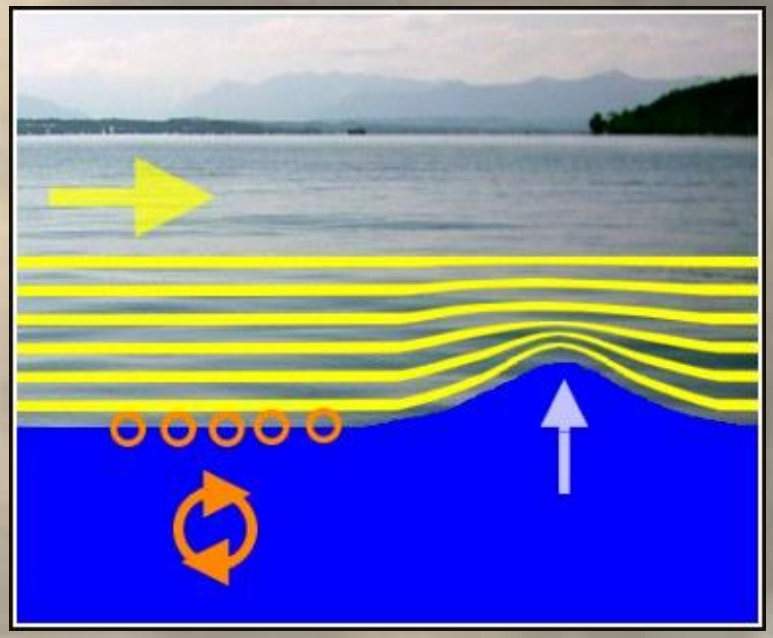


- amplitude
- wavelength λ
- period T
- frequency f (=1/T)
- speed c (=λ*f)

Types of waves

- Mechanical waves:
  - Longitudinal waves
  - Transversal waves
- Electromagnetic waves
  - Radiowaves
  - Light
  - Etc.
- Quantum phenomena
  - Wave particle dualism

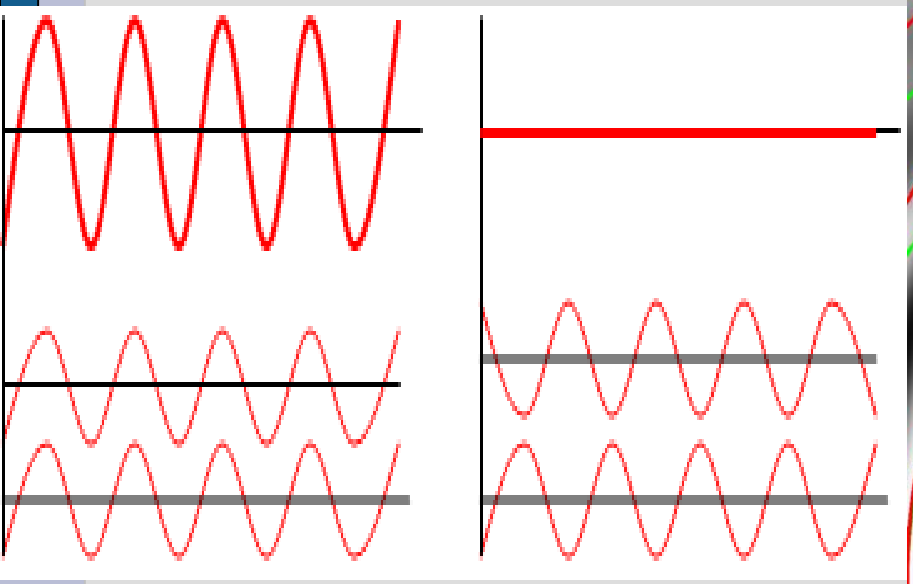
Wind and waves

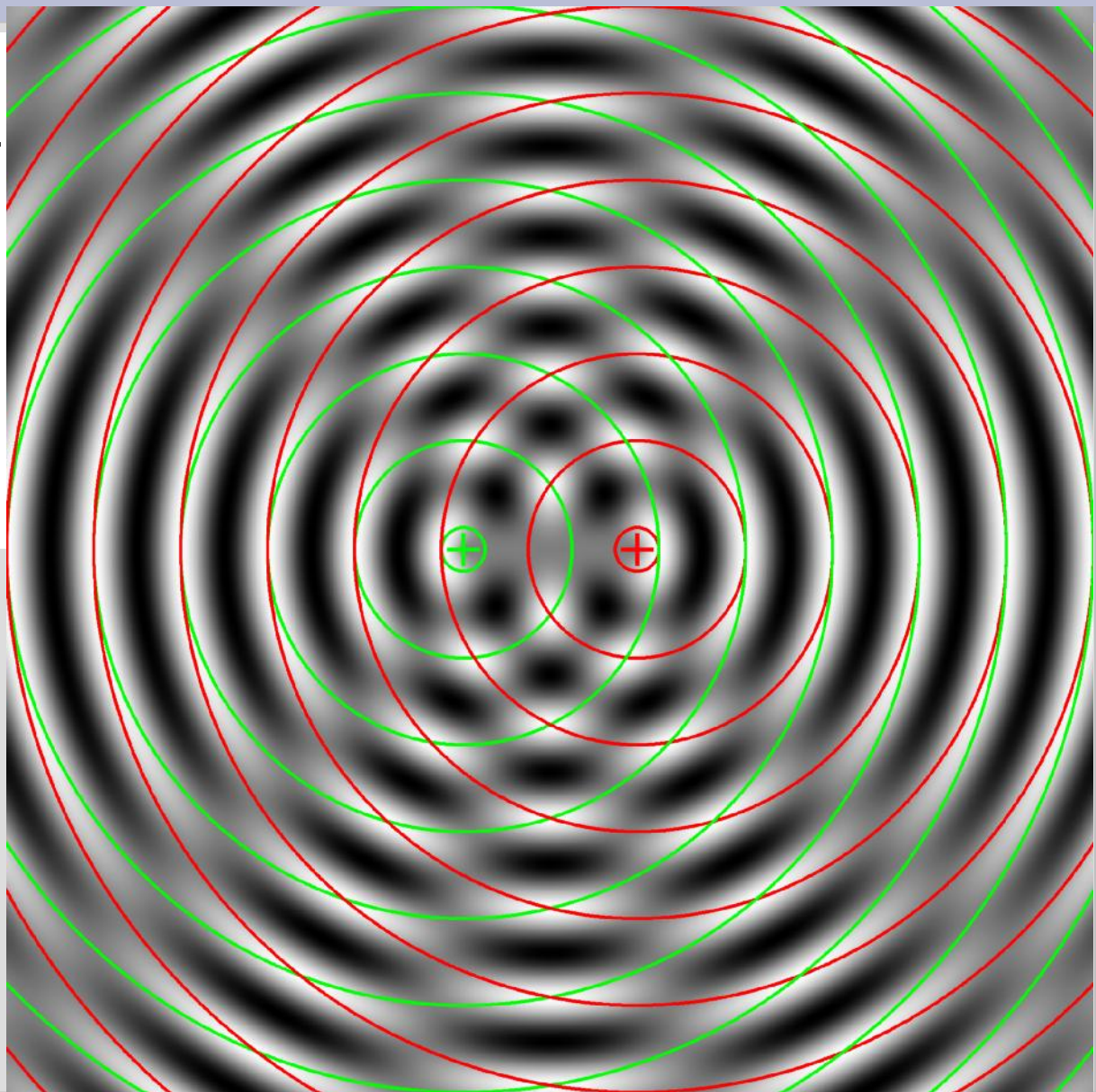


- Waves parallel to the beach
- Usually long wavelengths (swell)

Waves: Superposition

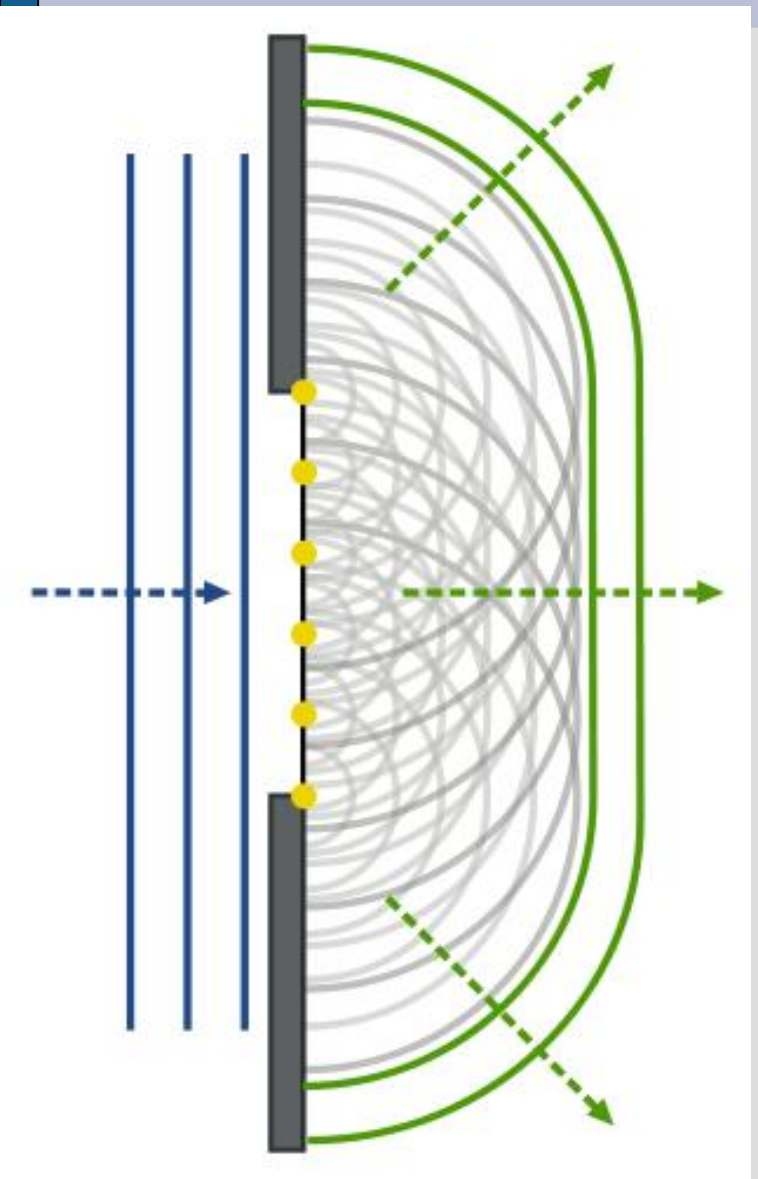
Waves: Interference

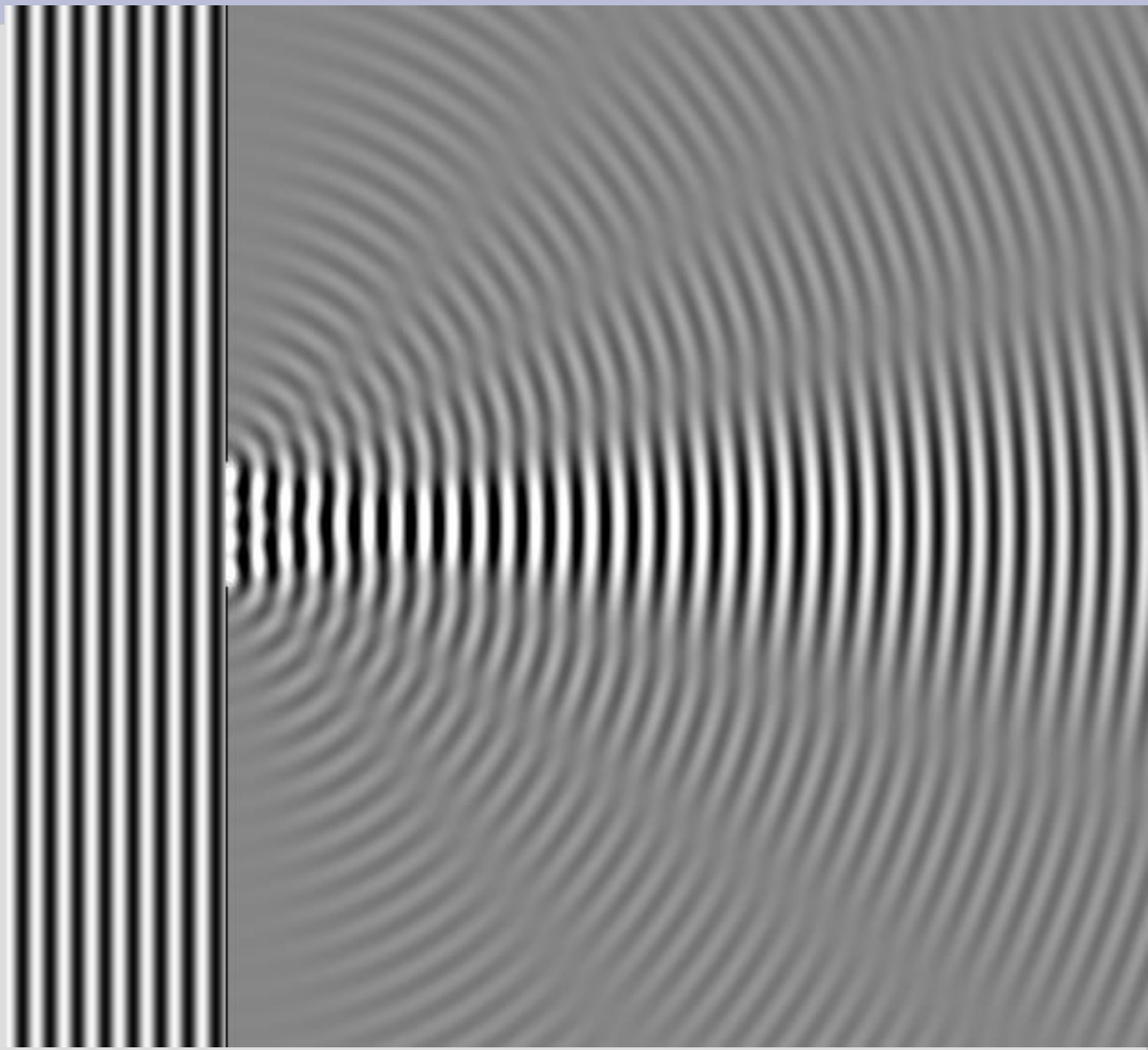




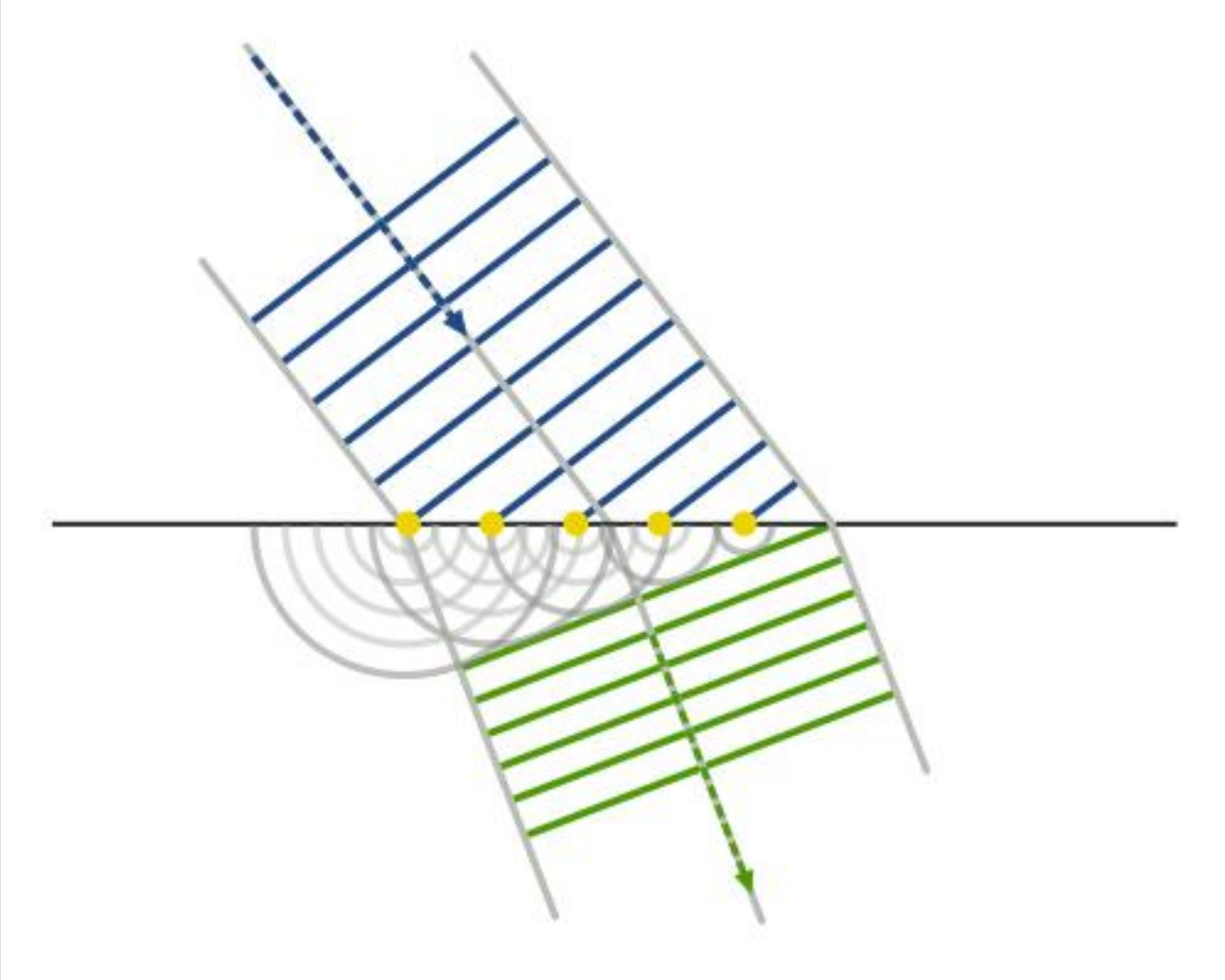
Images: Wikipedia

Waves: Diffraction





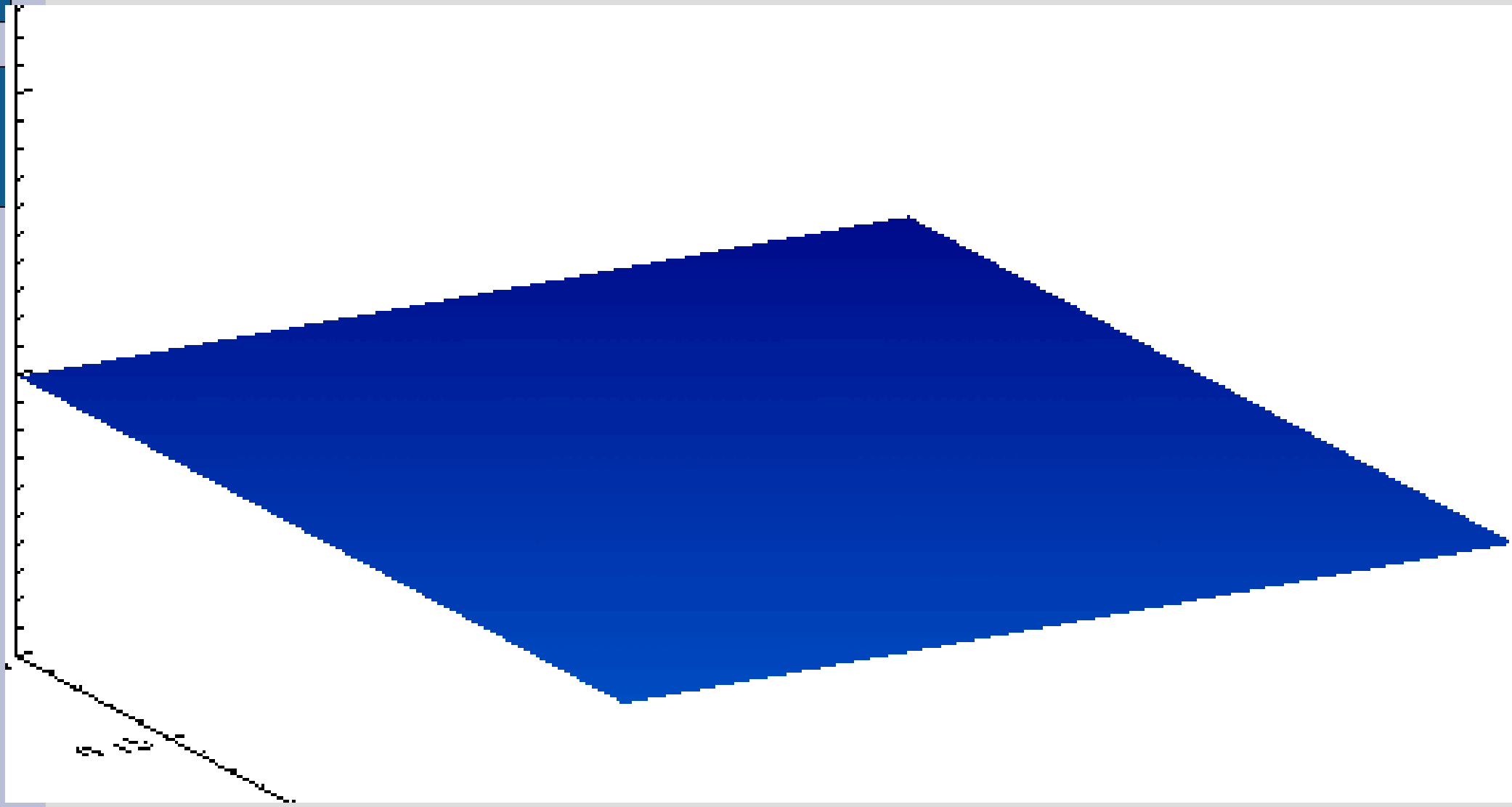
Waves: Refraction



Characteristics of waves

- **Superposition** – when waves meet, the total displacement is the sum of the displacements
- **Interference** – superposition of waves to form a new wave pattern
- **Diffraction** – (circular) spreading from entering a hole of comparable size to their wavelengths
- **Reflection** – direction change from hitting a reflective surface
- **Refraction** – direction change from entering a new medium (with different wave speed)
- **Dispersion** – splitting up by frequency

Characteristics of waves



Characteristics of waves

- **Reflection** – direction change from hitting a reflective surface
- **Refraction** – direction change from entering a new medium
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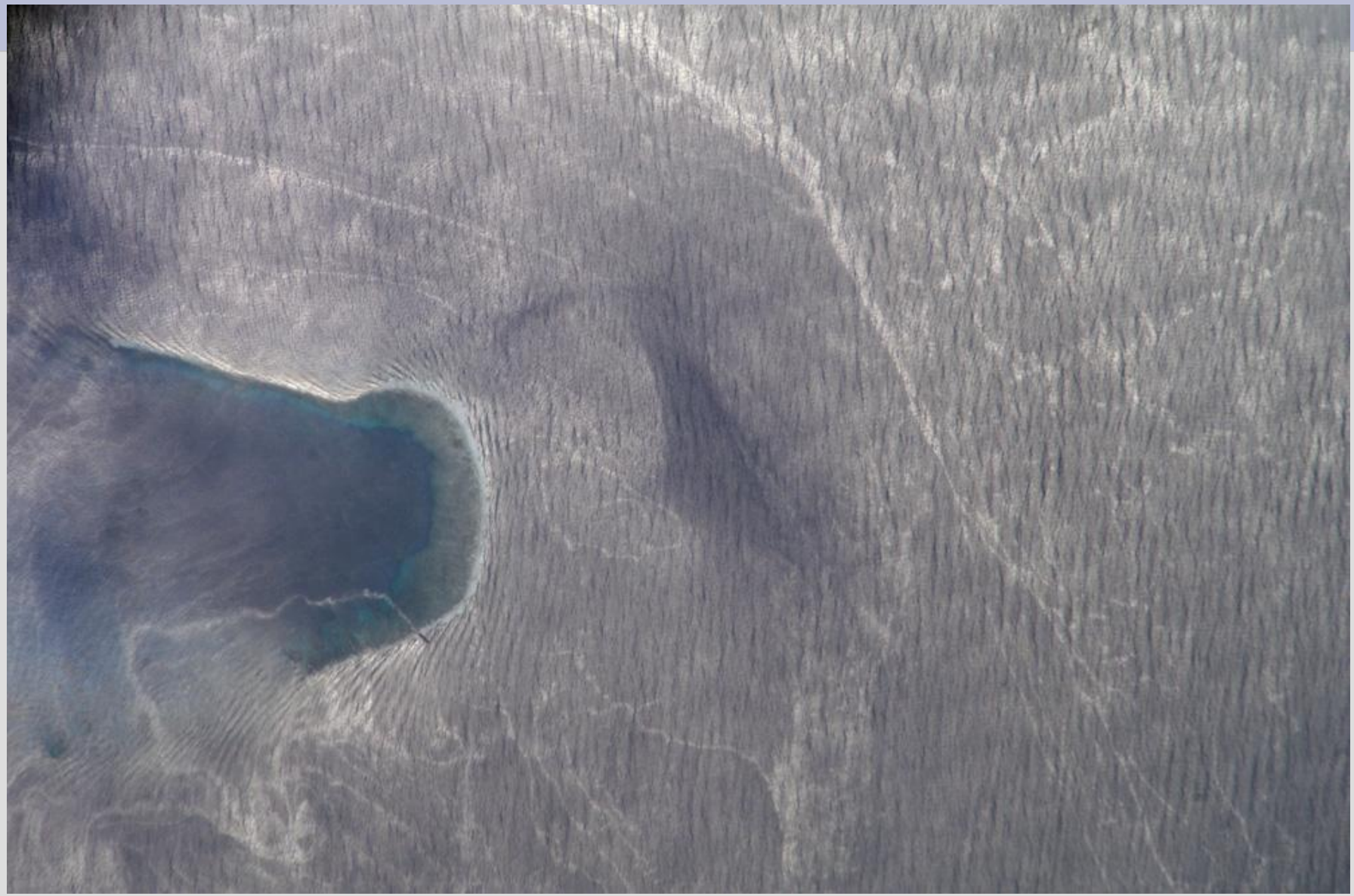
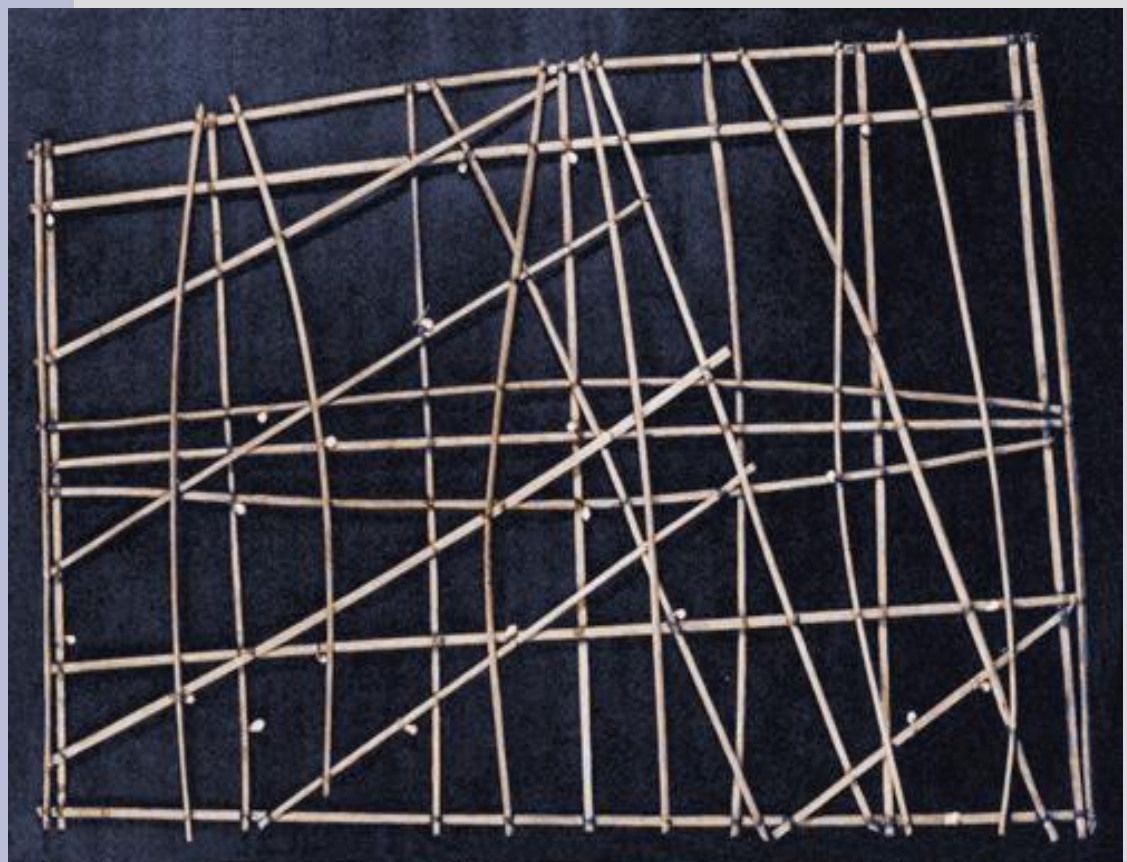
Ocean waves

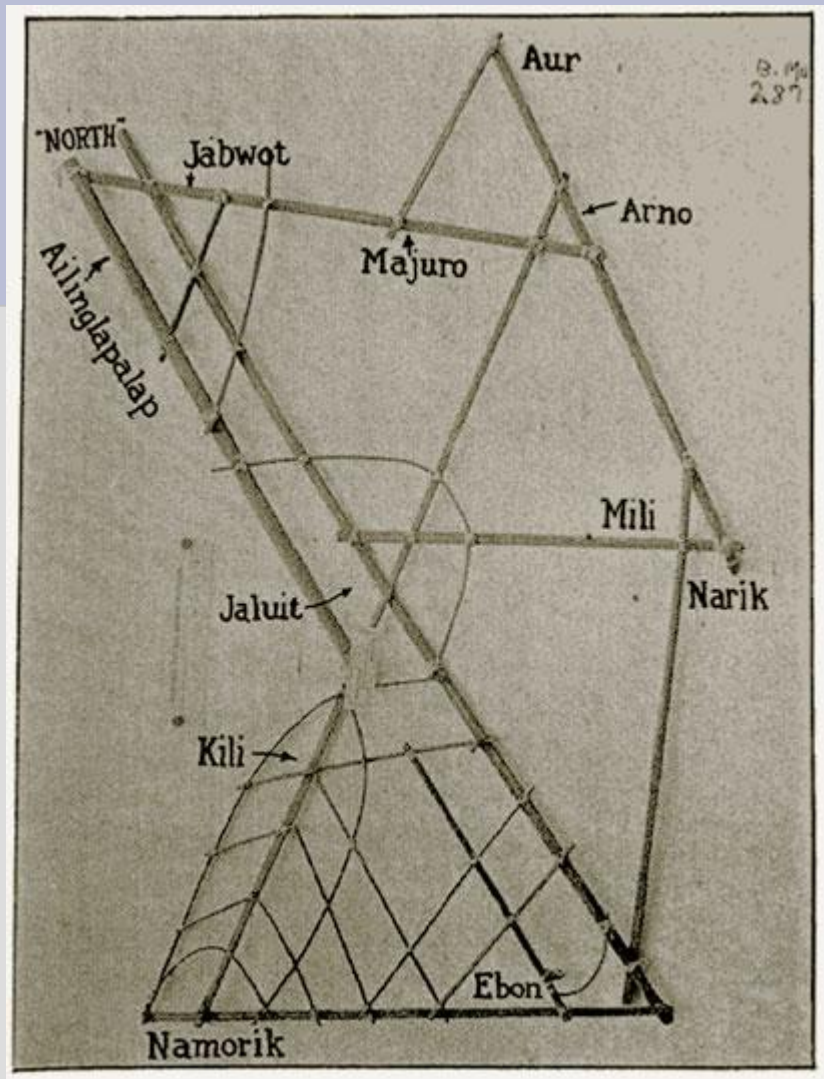


Imge: NASA (http://earthobservatory.nasa.gov/IOTD/view.php?id=6981)

Polynesian “stick chart”

- navigational aids
- record the wave patterns around islands

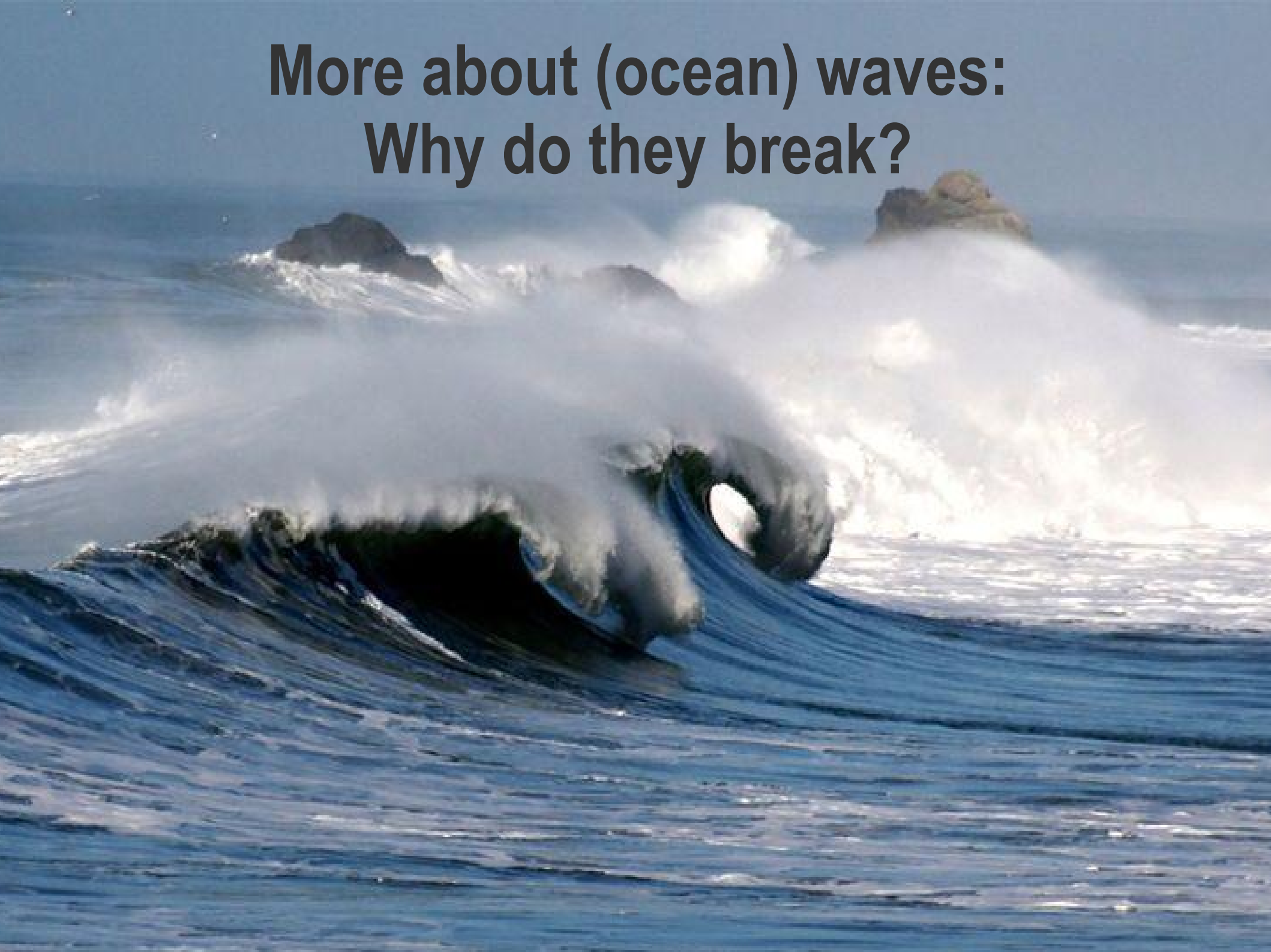




Images:
http://thenonist.com/index.php/thenonist/permalink/stick_charts/

See also:
Wikipedia: Marshall Islands Stick Chart

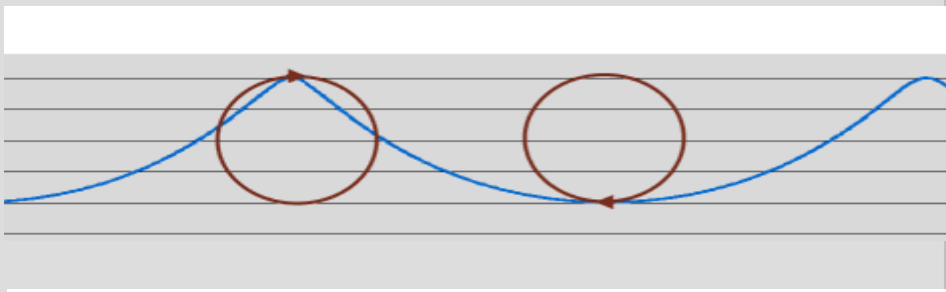
More about (ocean) waves: Why do they break?

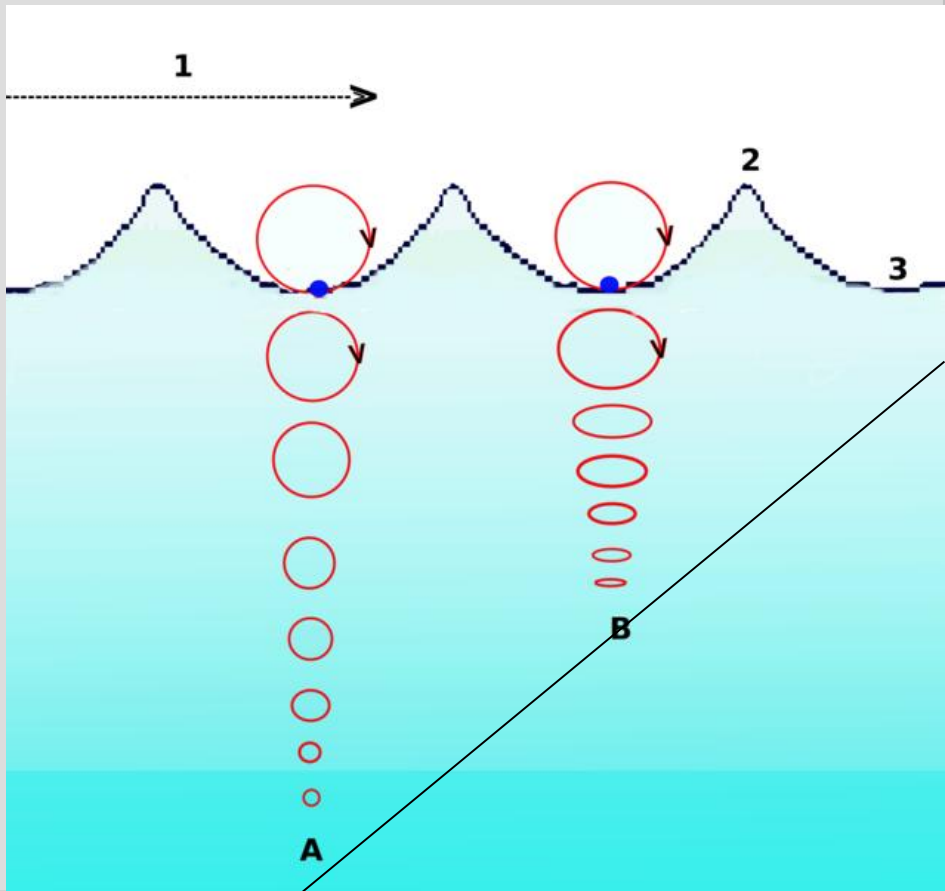


Deep and shallow water waves

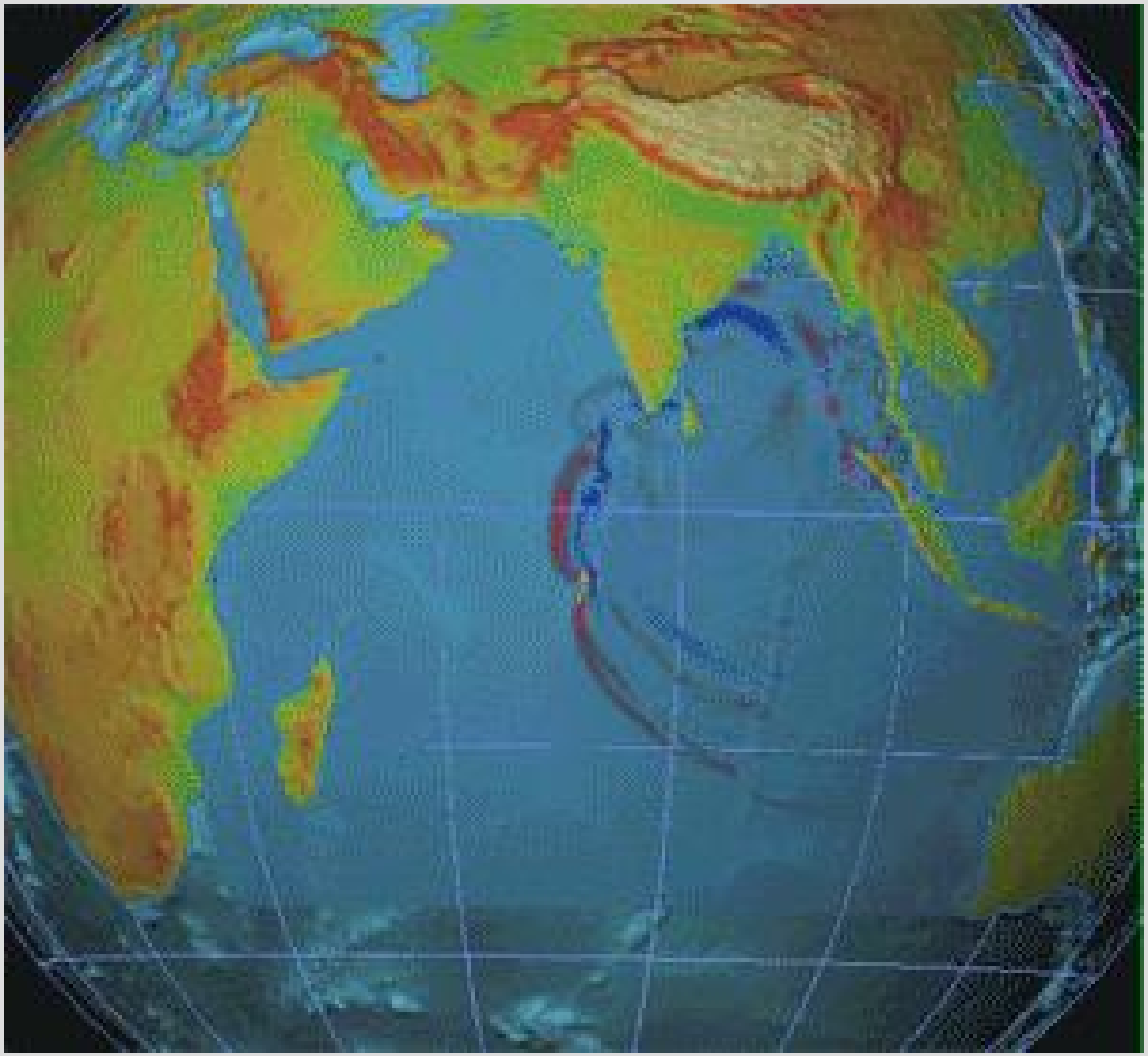
- **Deep water**
  (depth > ½ wavelength): speed is proportional to the square root of the wavelength
- **Shallow water**
  speed proportional to the square root of the water depth

$$c = \sqrt{\frac{g\lambda}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)}$$





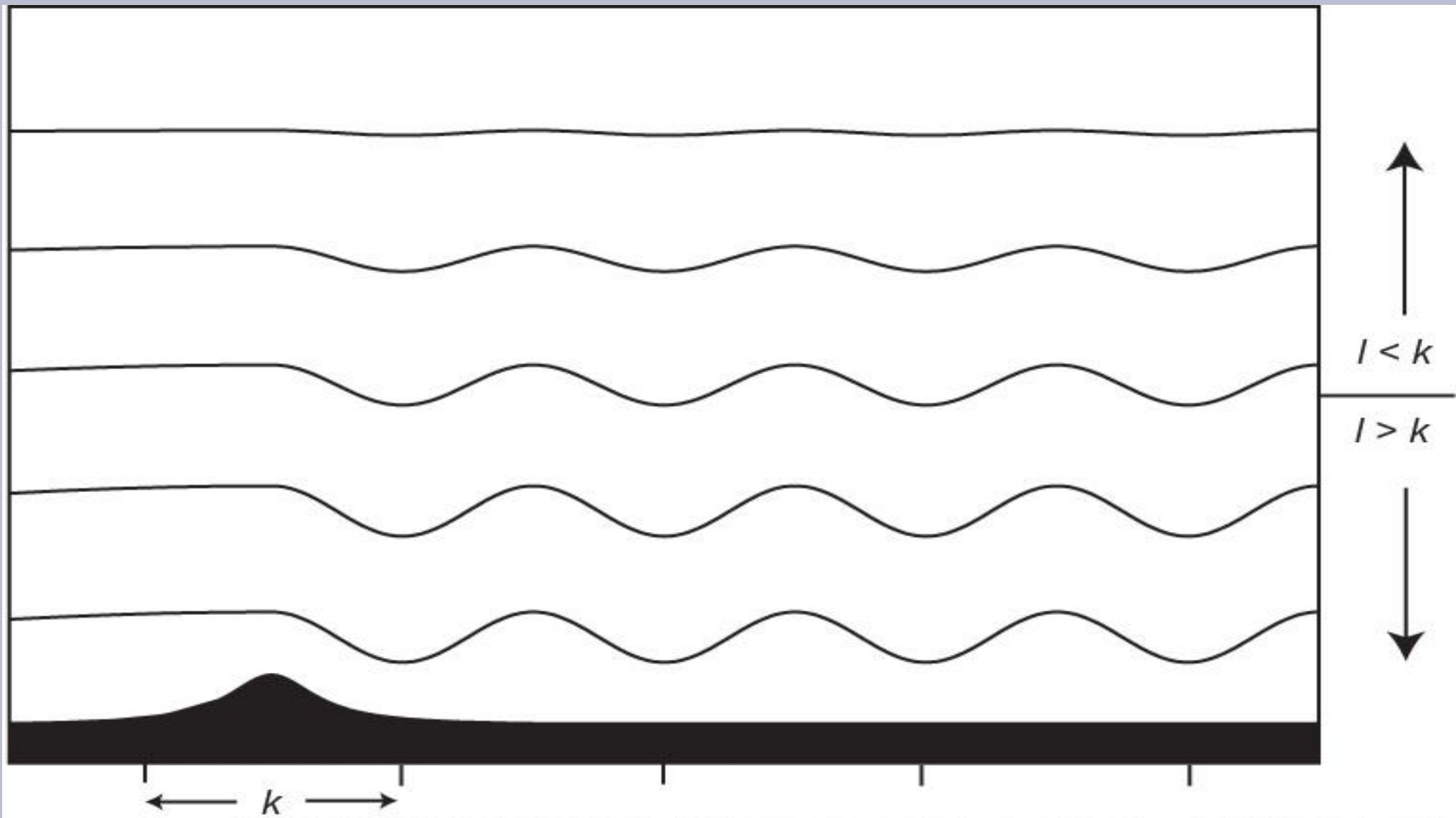
Tsunamis



- wave length: 100-500 km
- period: 1 hour
- wave speed up to 800 km/h (500 mph)

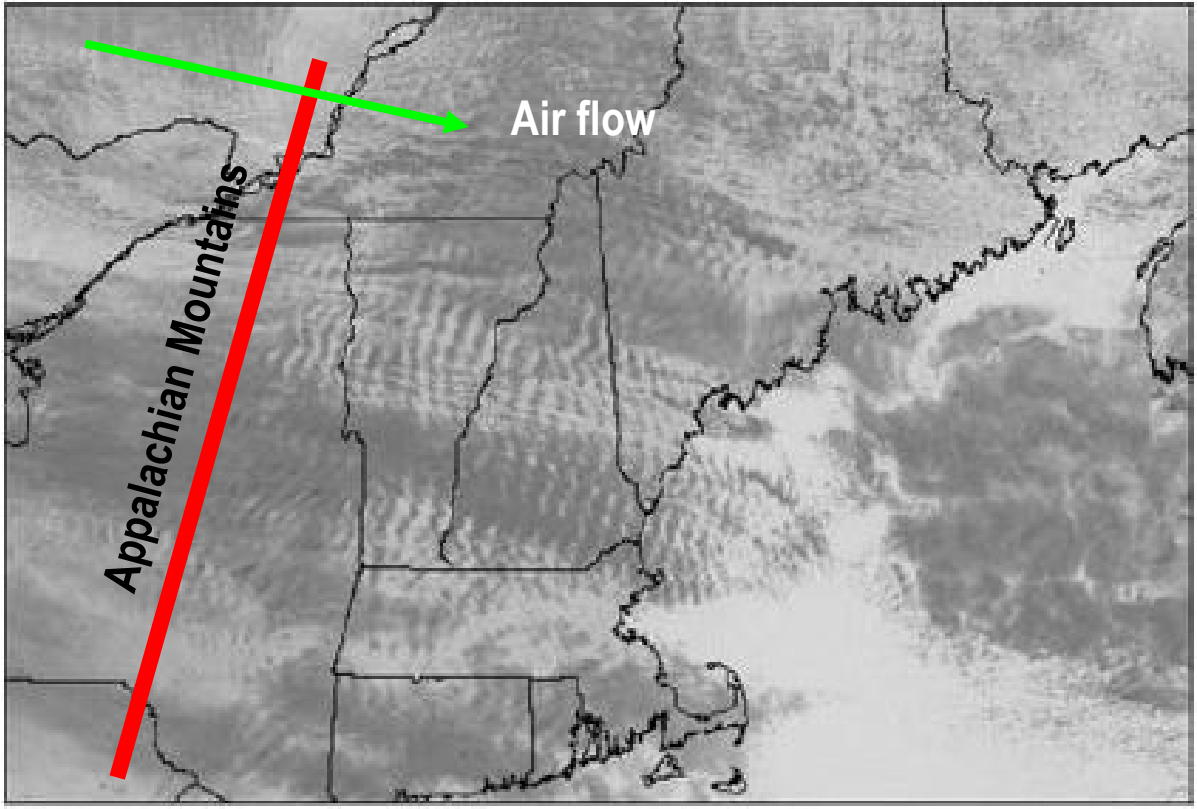
Animation: http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake

Atmospheric Waves

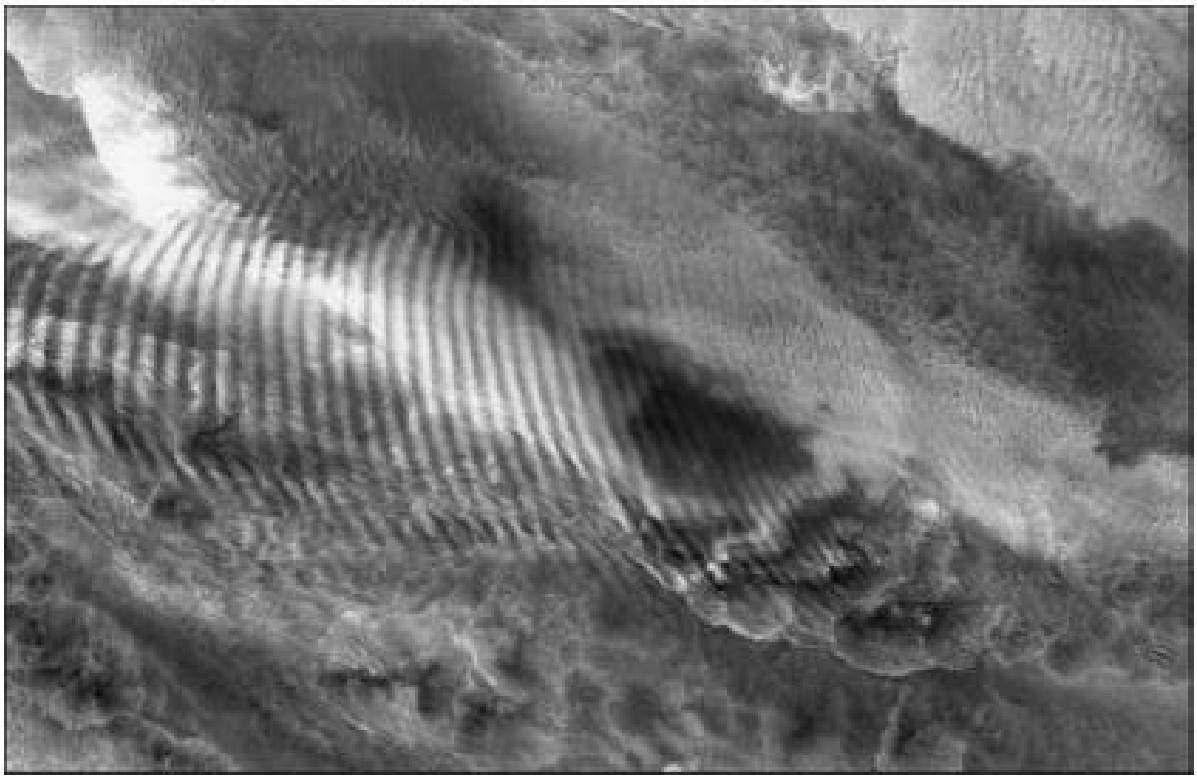


Gravity Waves

NE USA
Waves excited by mountains
Wavelength ~20km



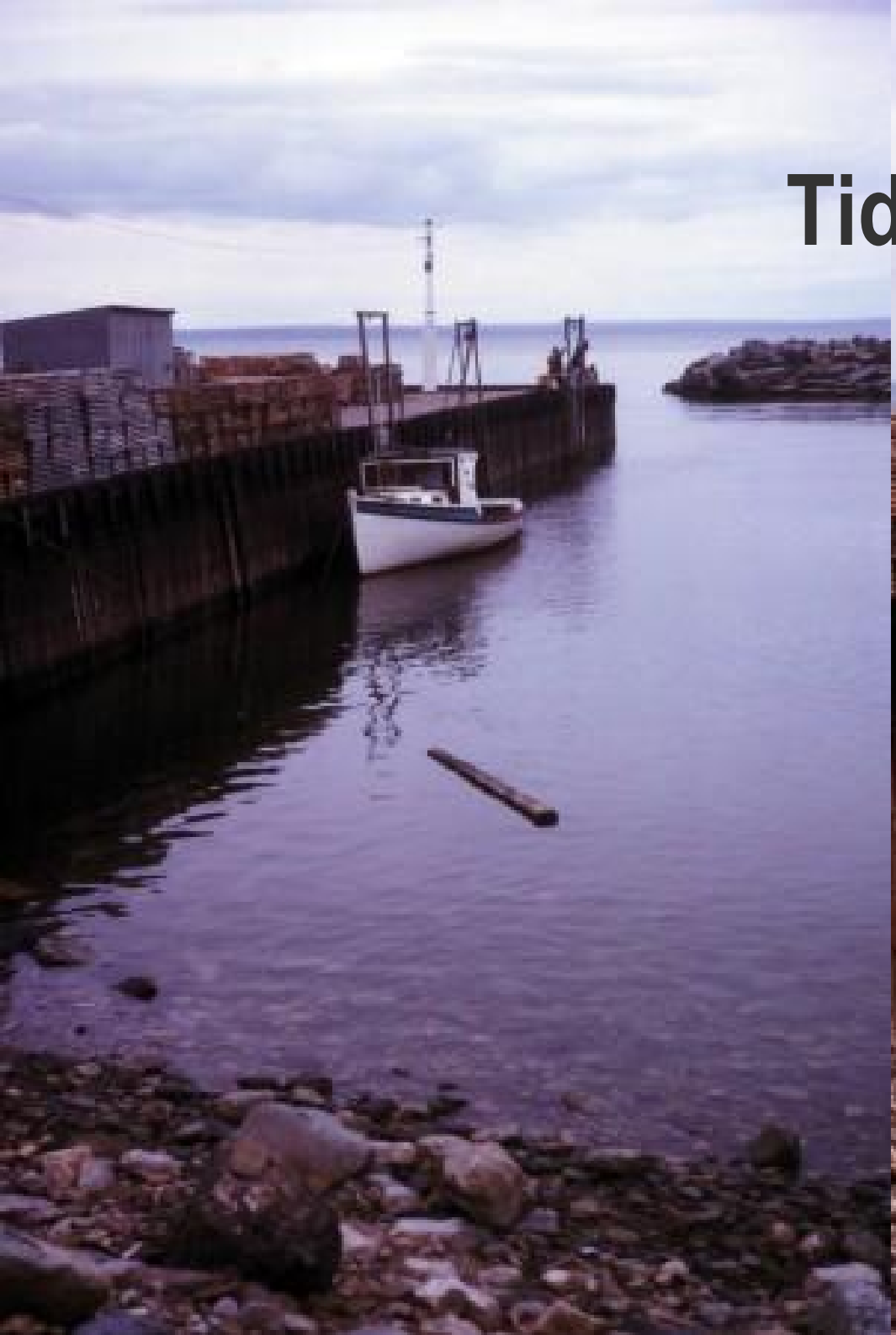
Indian Ocean
Probably triggered by
large thunderstorms



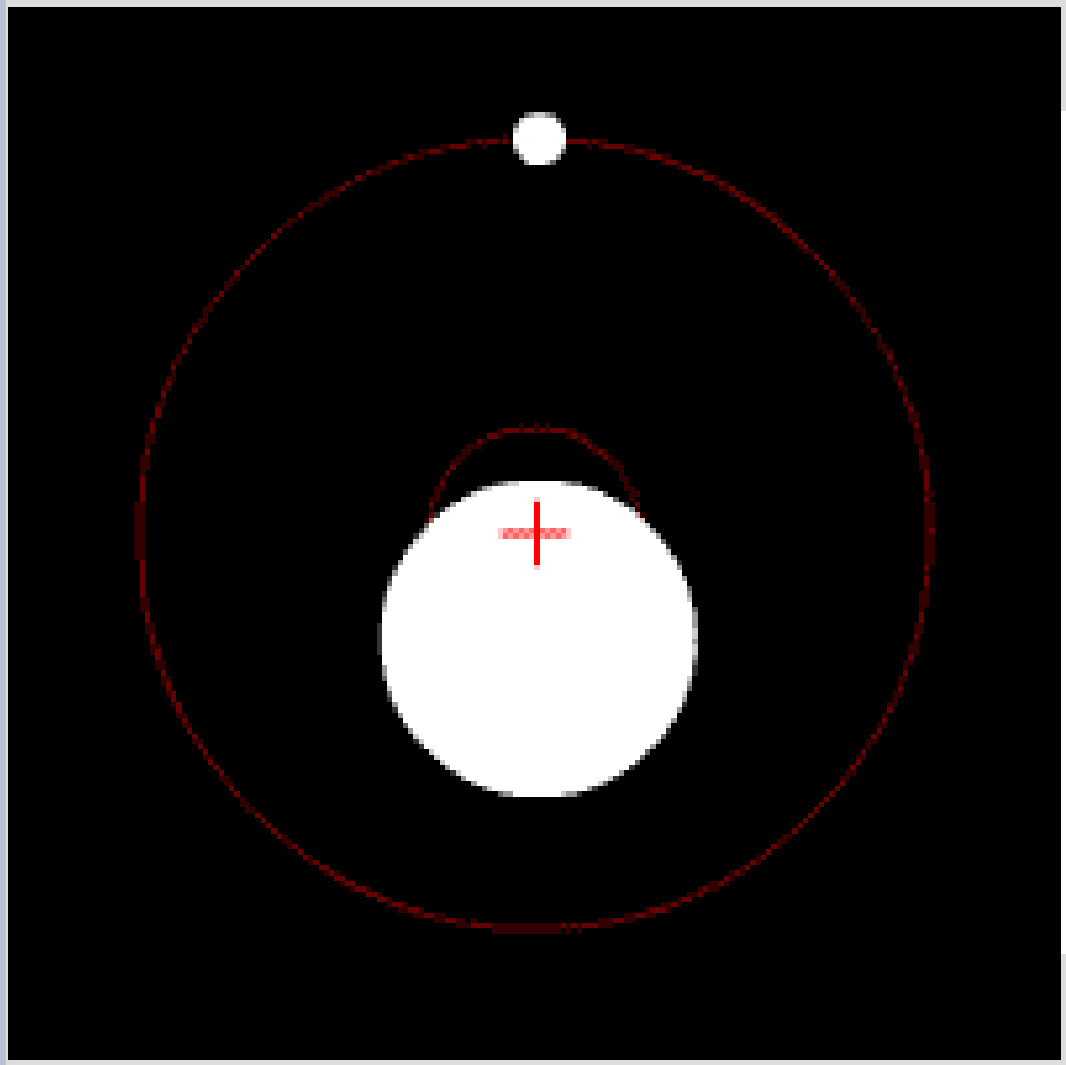

Finland

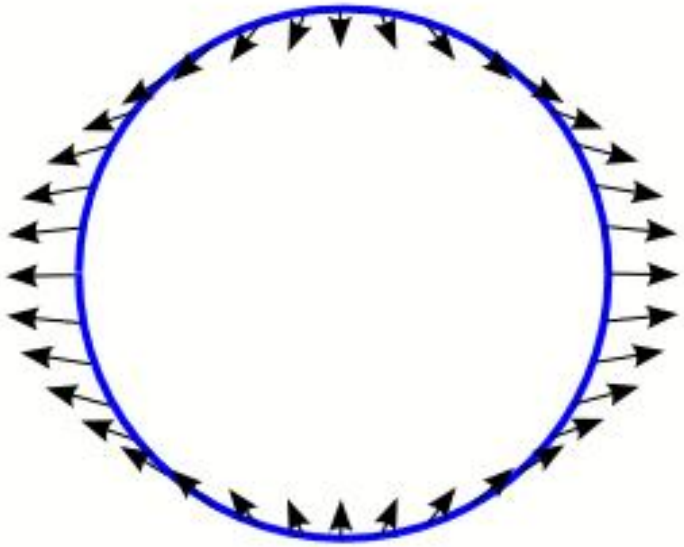
Lenticular clouds (image: www.wetter-foto.de)

Tides

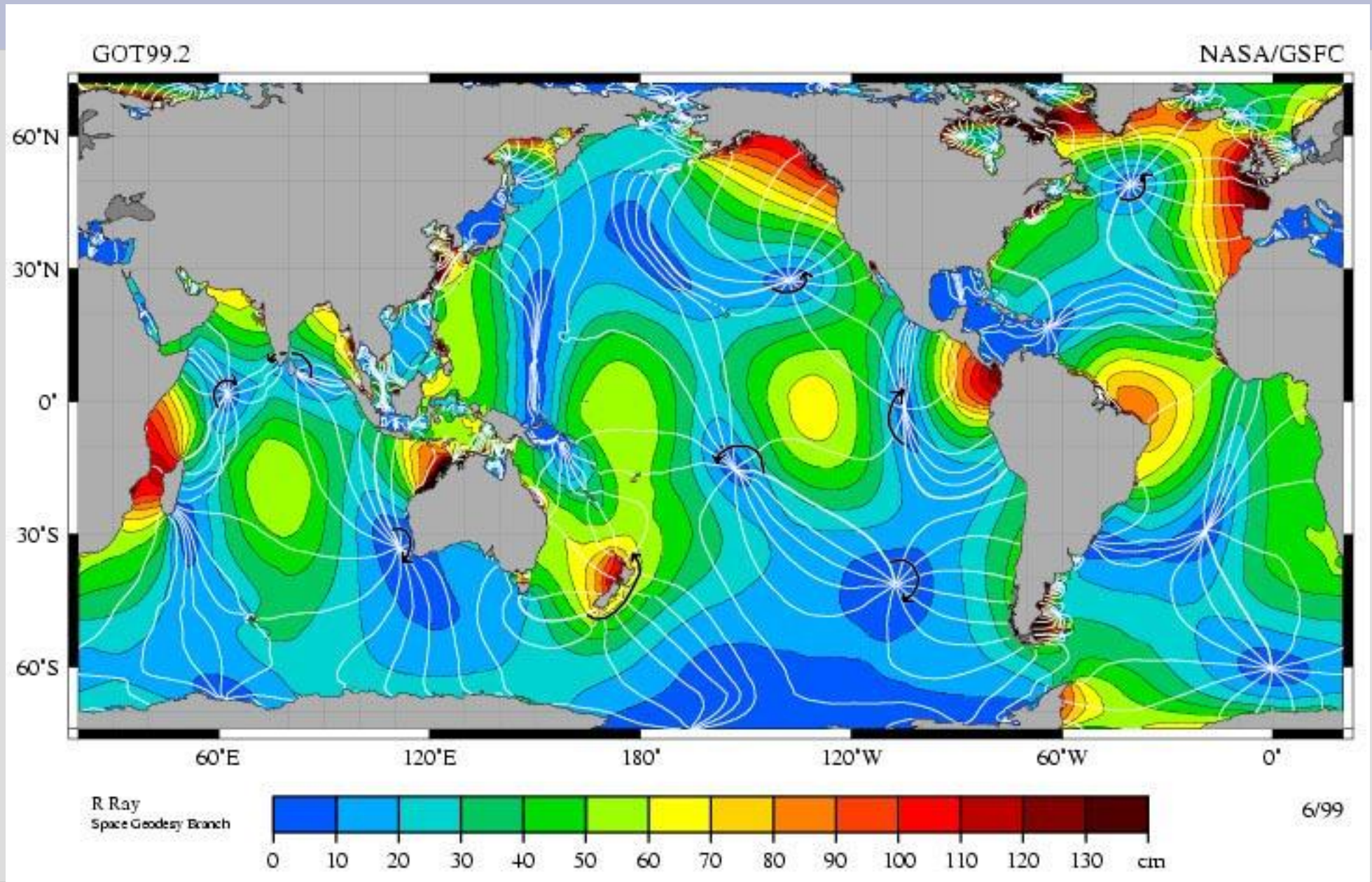


Tidal forces





Resonance: Dynamical tides

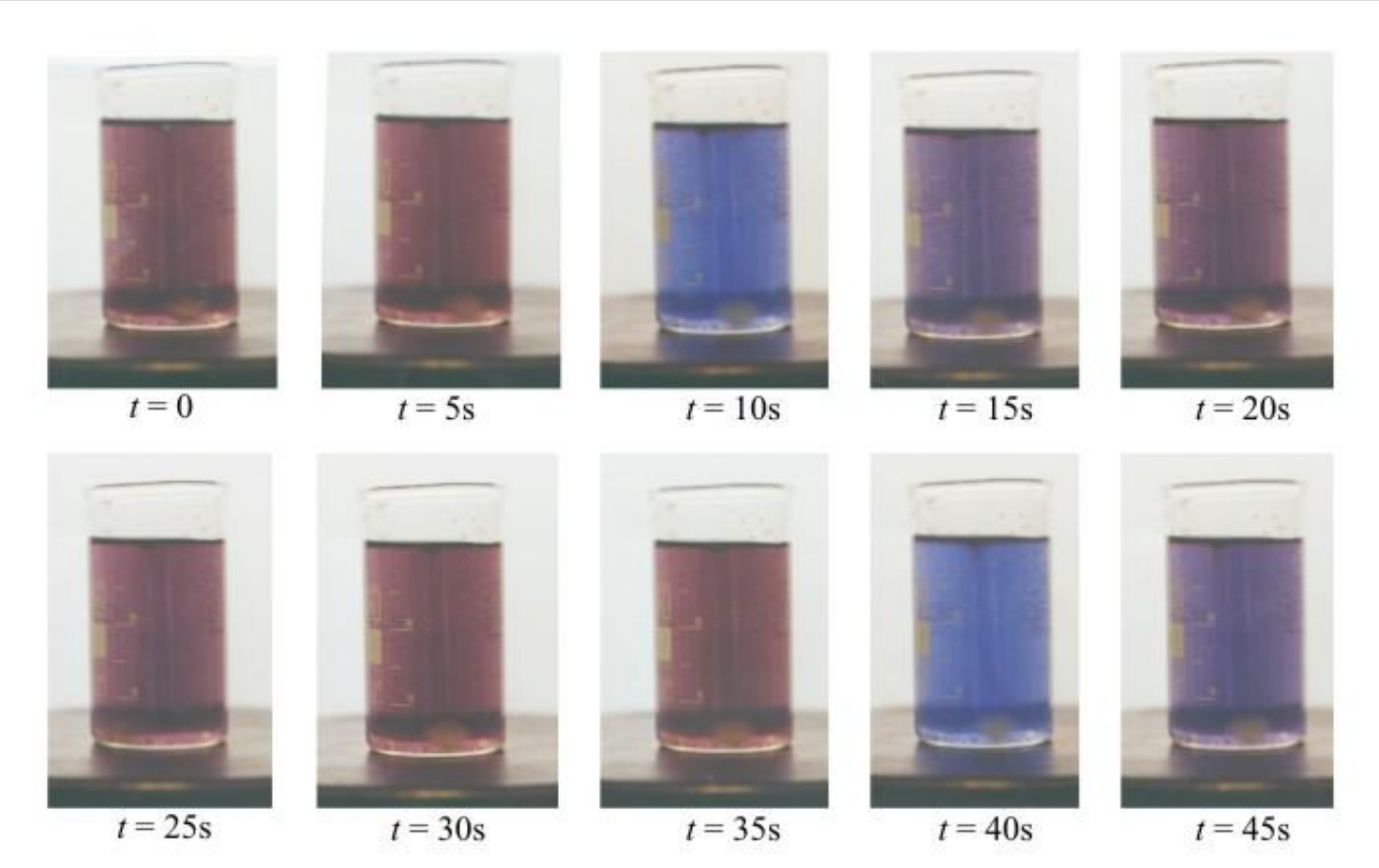


A different type of oscillation

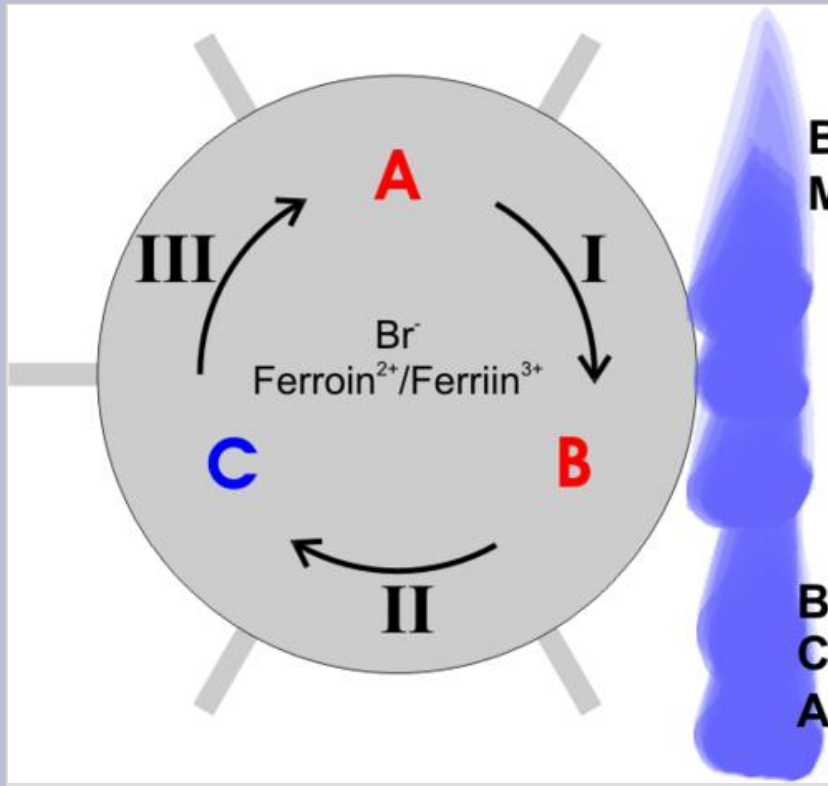
- Video at:
  http://uk.youtube.com/watch?v=5bho96R1sK4

Chemical Oscillations: The Belousov-Zhabotinsky reaction

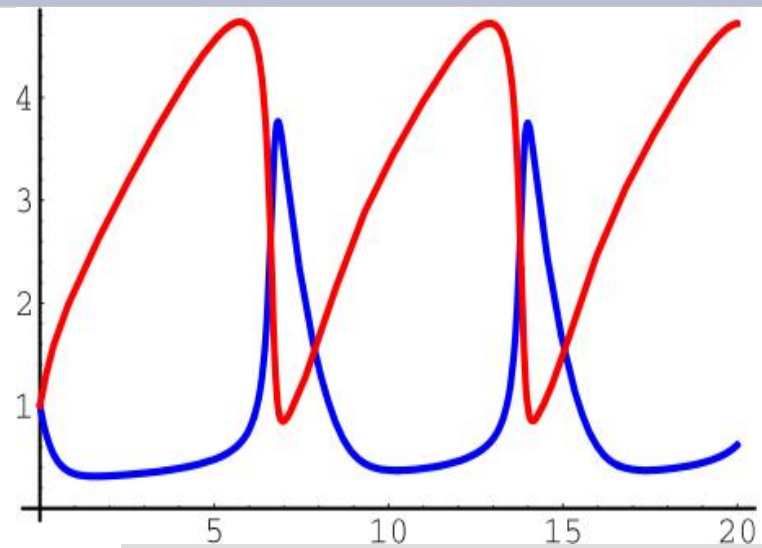
- discovered in the 1950s by Boris Belousov
- investigated from 1961 by Anatoli Zhabotinsky



The BZ reaction



Bromat (BrO_3^-)
Malonsäure
(HMal)

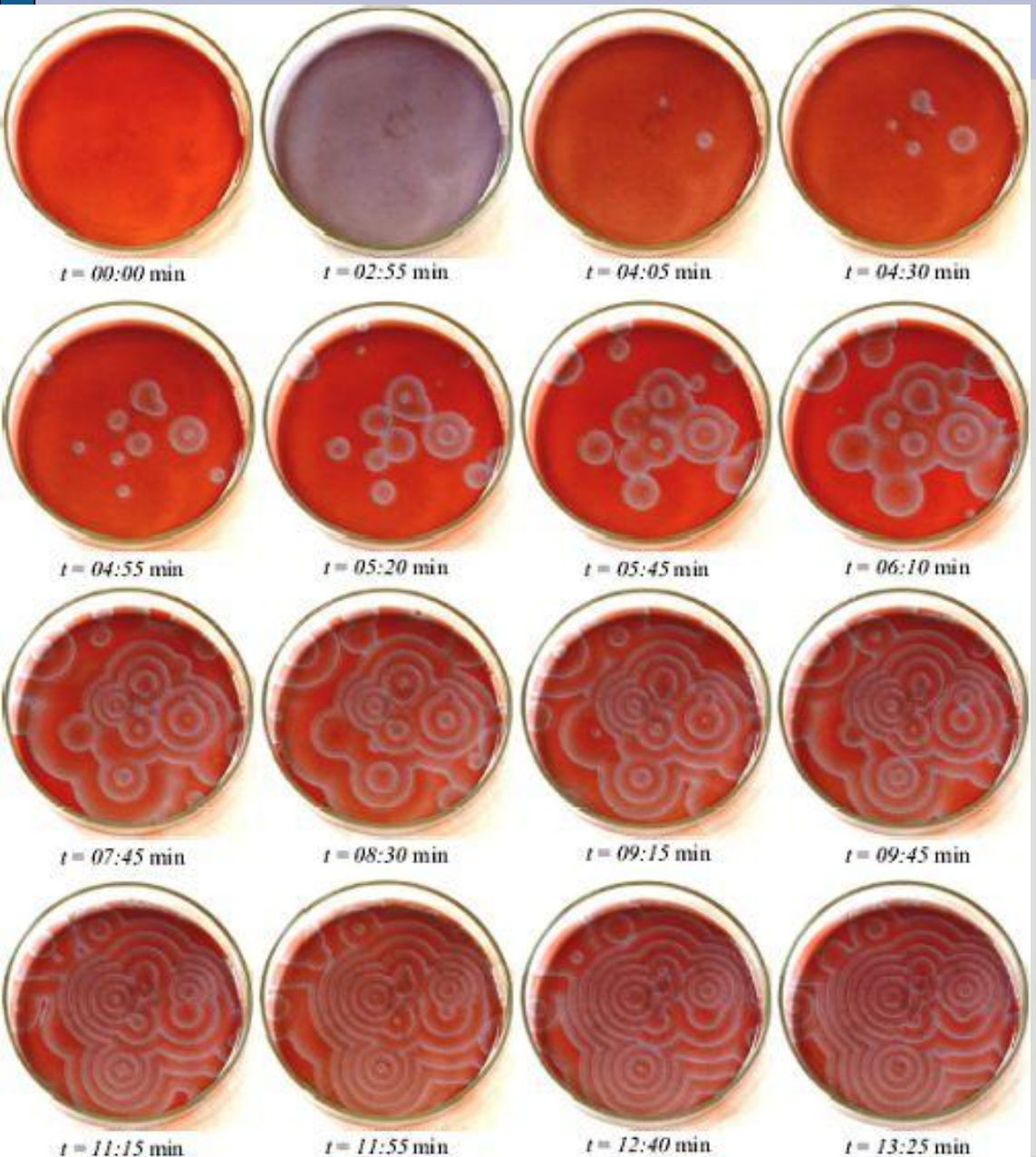


Brommalonsäure (HBrMal)
CO_2
Ameisensäure (HCOOH)

I	$2\ Br^- + BrO_3^- + 3\ H^+ + 3\ "H_2Mal"$	$\rightarrow 3\ "HBrMal" + 3\ H_2O$
II	$BrO_3^- + 4\ Ferroin^{2+} + "H_2Mal" + 5\ H^+$	$\rightarrow 4\ Feriin^{3+} + "HBrMal" + 3\ H_2O$
III	$4\ Feriin^{3+} + "HBrMal" + 2\ H_2O$	$\rightarrow 4\ Ferroin^{2+} + HCOOH + 2CO_2 + 5\ H^+ + Br^-$
IV	$3\ BrO_3^- + 5\ "H_2Mal" + 3\ H^+$	$\rightarrow 3\ "HBrMal" + 2\ HCOOH + 4\ CO_2 + 5\ H_2O$

Reaction II is inhibited by Br-

Spatial patterns from BZ



Video:
http://uk.youtube.com/watch?v=bH6bRt4XJcw

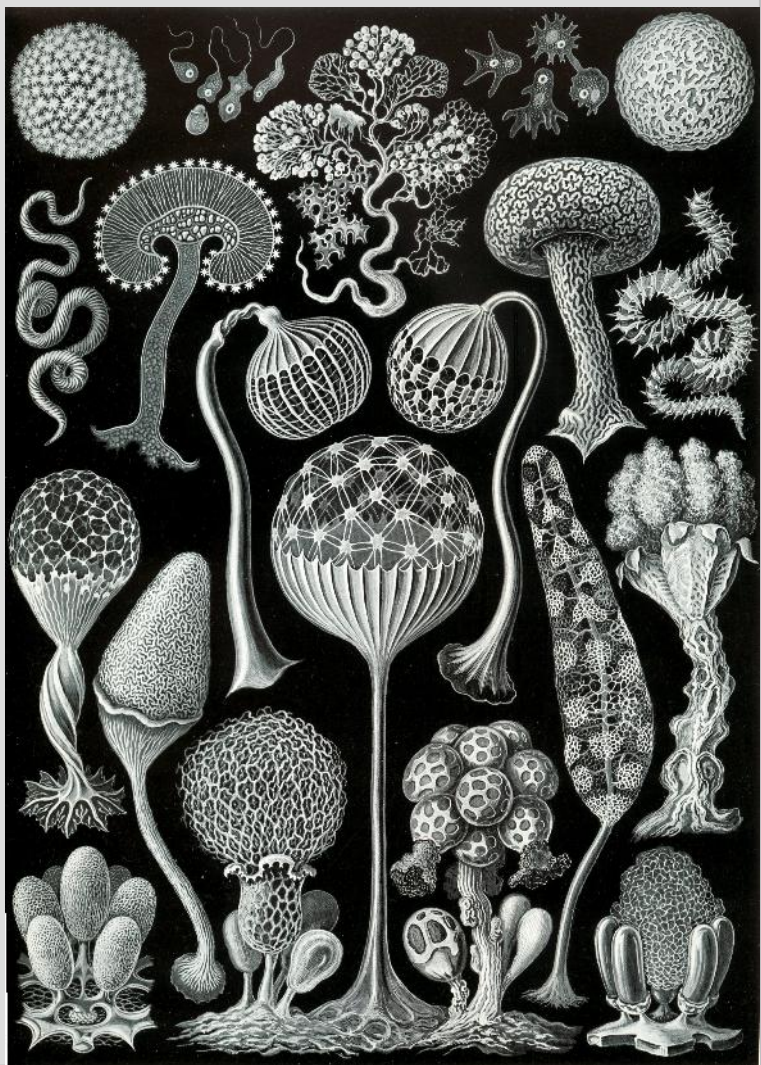
(image: http://jkrieger.de/bzr/inhalt.html)

Excitation waves

- Mechanism: Excitation with latency
- Tend to develop spiral patterns
- Compared to „normal“ waves:
  - No reflection
  - No superposition, but extinction

Slime mold

- Amoeba-like single cells
- Can form Plasmodia with many nuclei
- Differentiate into Fruiting bodies



Slime mold videos

- Slime mold on wood: http://vimeo.com/371660
- Amoeba coming together: http://www.youtube.com/watch?v=hpHpBHJZQvU
- Spiral waves: http://www.youtube.com/watch?v=OX5Yiz38fgY
- Streaming protoplasmic strands: http://www.youtube.com/watch?v=leKI3Cv9YYw
- Forming Fruiting Bodies: http://www.youtube.com/watch?v=Ne_KWY9RpTg

Excitation waves in slime mold

- cAMP: cyclic adenosine monophosphate
- Spiral waves of cAMP induce:
  - (a) Cell movement
  - (b) onset of cell streaming
  - (c) development of stream morphology

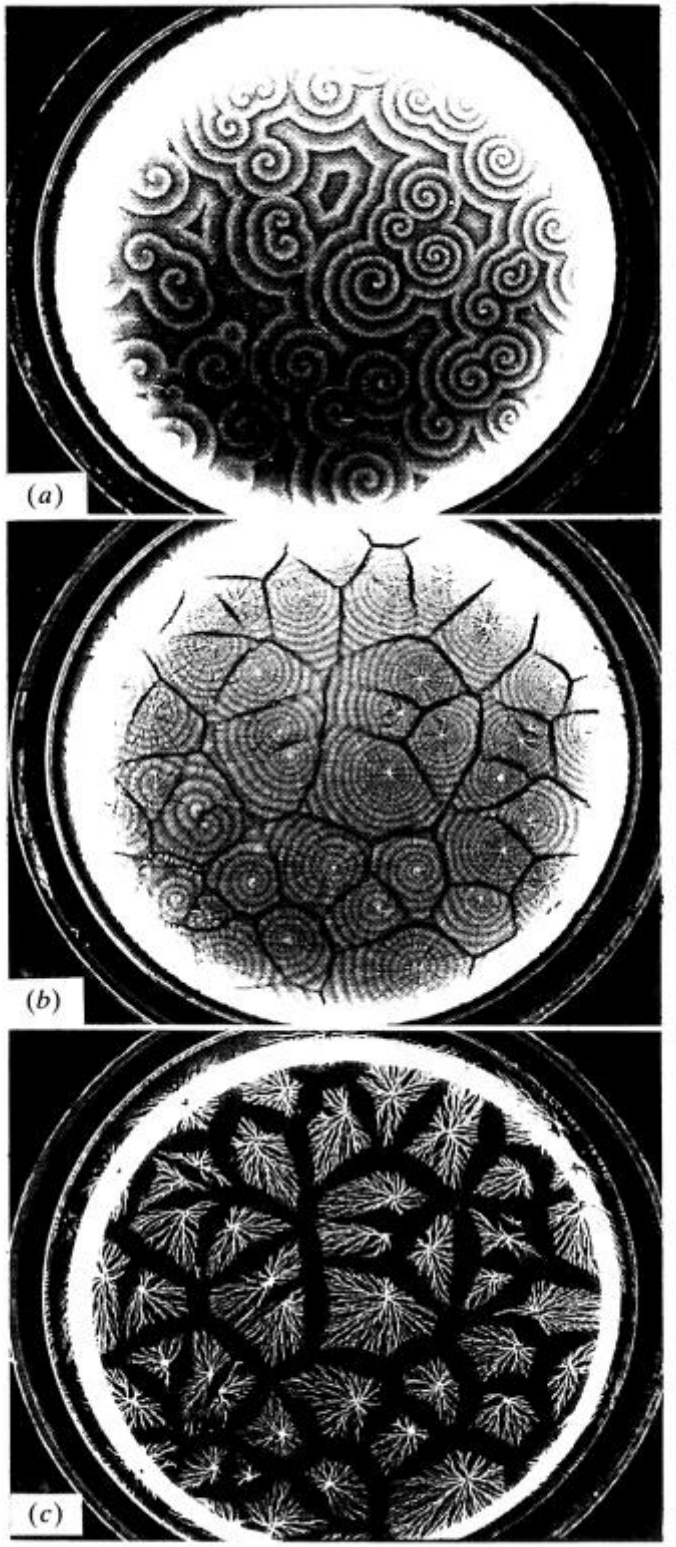
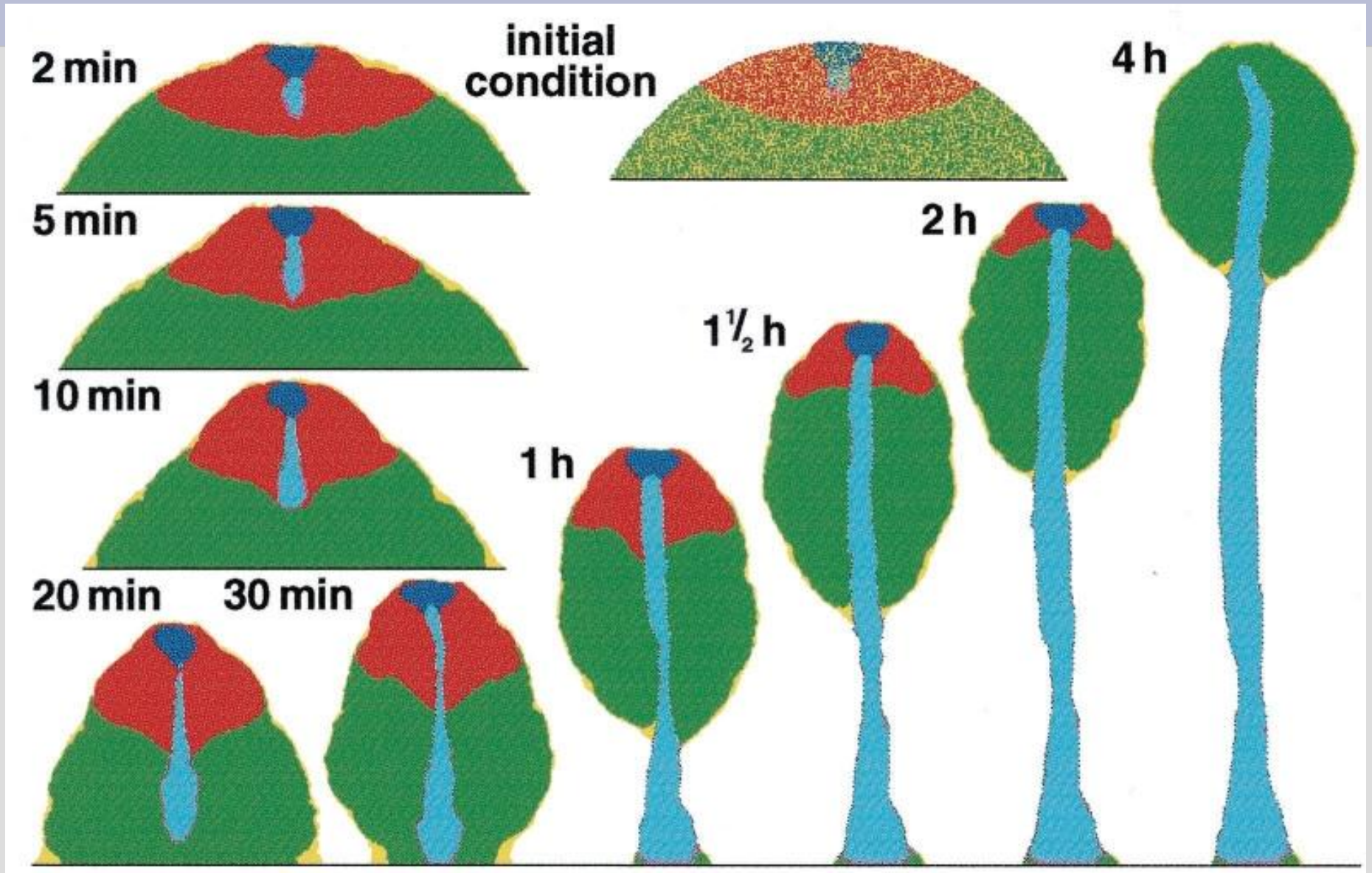


Figure 1. Aggregation of *Dictyostelium discoideum* on an agar

Höfer 1995

Fruiting body formation



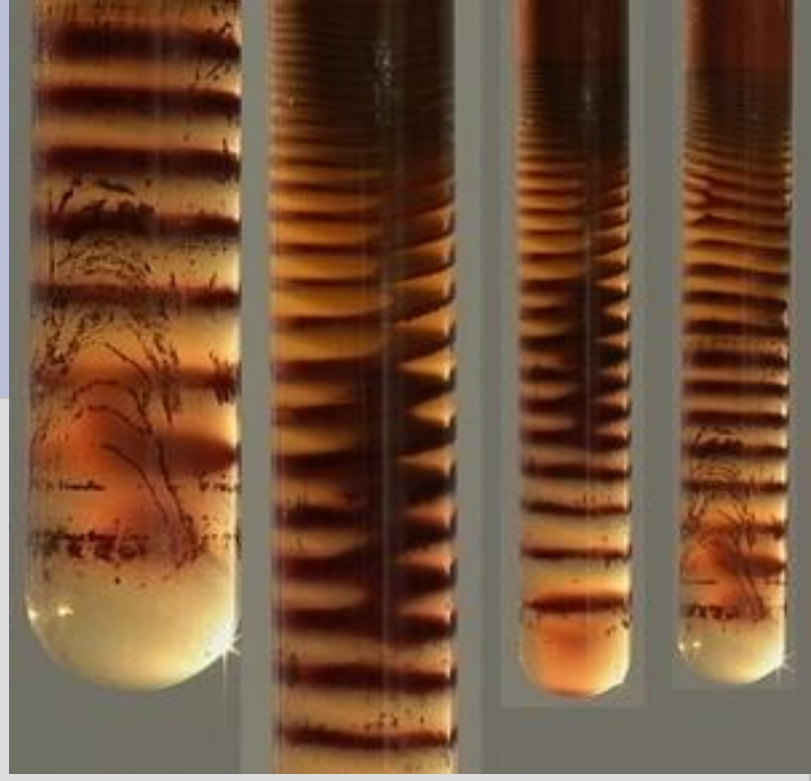
Maree&Hogeweg 2001

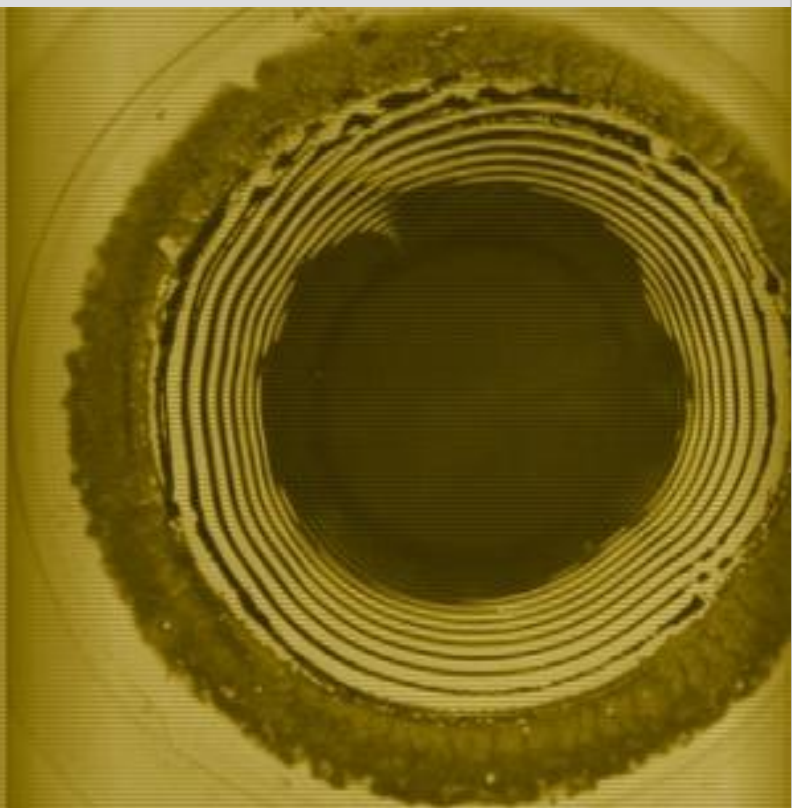
Other examples of excitation waves

- Calcium waves in frog spawn
- Heart
  - Normal heartbeat
  - arrhythmia
- Brain – Epilepsia
- Epidemics

Liesegang phenomenon

- discovered in 1896 by Raphael Eduard Liesegang





Agates

Summary: Two types of waves

- „Normal“ waves - restoring force
  - Mechanical
  - Electromagnetic
  - Quantum physics
- Excitation waves – excitation&latency
  - Chemical phenomena
  - Biological phenomena

Patterns in Nature
Outline

1. Introduction
2. Waves and oscillations
3. Regularity and chaos
4. Animal cooperation
5. Spatial patterns
6. Aggregation and growth processes
7. Cellular automata
8. Fractals
9. Miscellaneous topics
10. Concluding session

Literature

- Ball, Philip (2001): *The self-made tapestry. Pattern formation in nature.* Chapter 3.
- Ball, Philip (2009): *Flow*.
- Adam, John (2003): *Mathematics in Nature. Modeling Patterns in the Natural World.* Chapter 7.

Homework: What's this and how does it form?

Hint:Photos taken in Mid-December at just below 0°C after a few humid days