

The background of the slide is a close-up photograph of concentric ripples on a body of water. The ripples are centered in the lower-left quadrant and spread outwards towards the top and right edges. The water surface is dark, and the ripples create a series of bright, curved lines that catch the light, giving a sense of depth and movement. The overall tone is cool and scientific.

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.

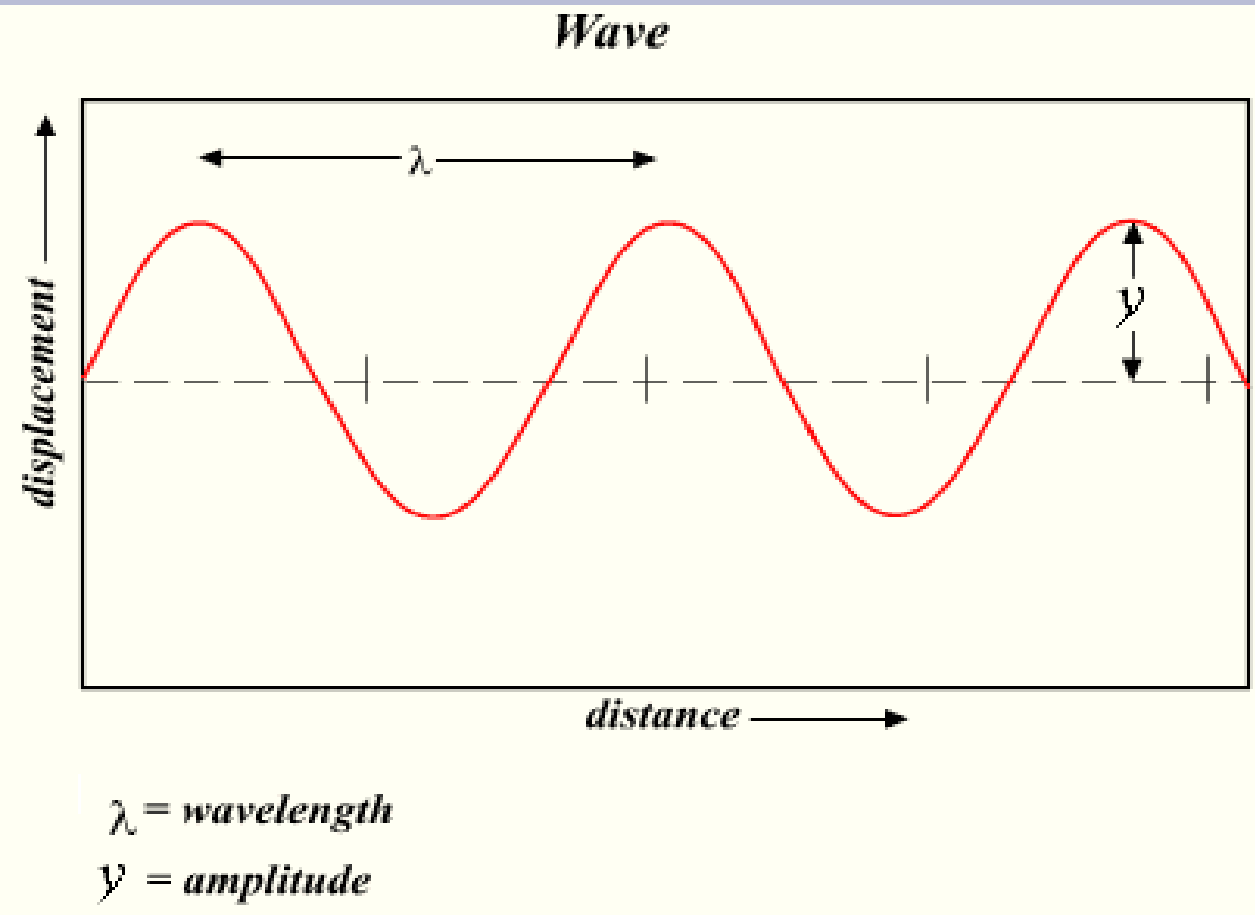
Self-organization Definition

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

Wave terminology

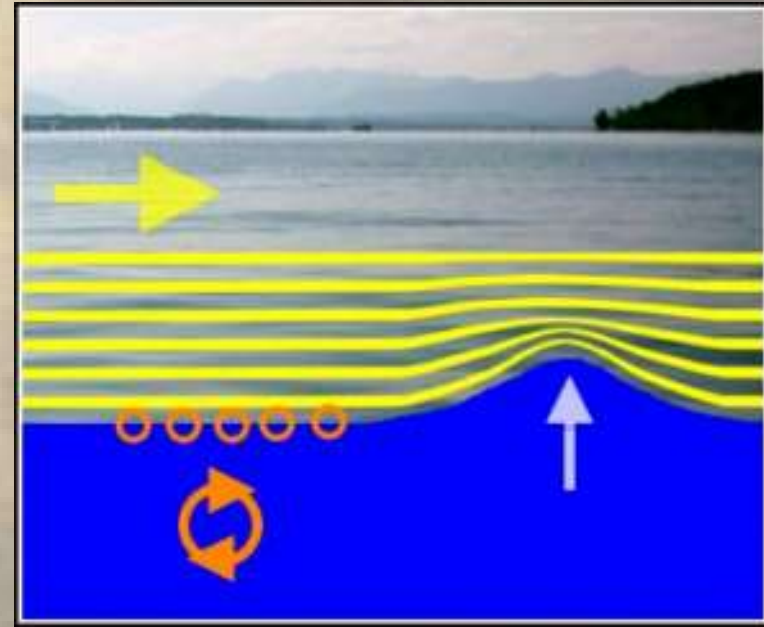


- amplitude
- wavelength λ
- period T
- frequency f ($=1/T$)
- speed c ($=\lambda*f$)

Types of waves

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

Wind and waves



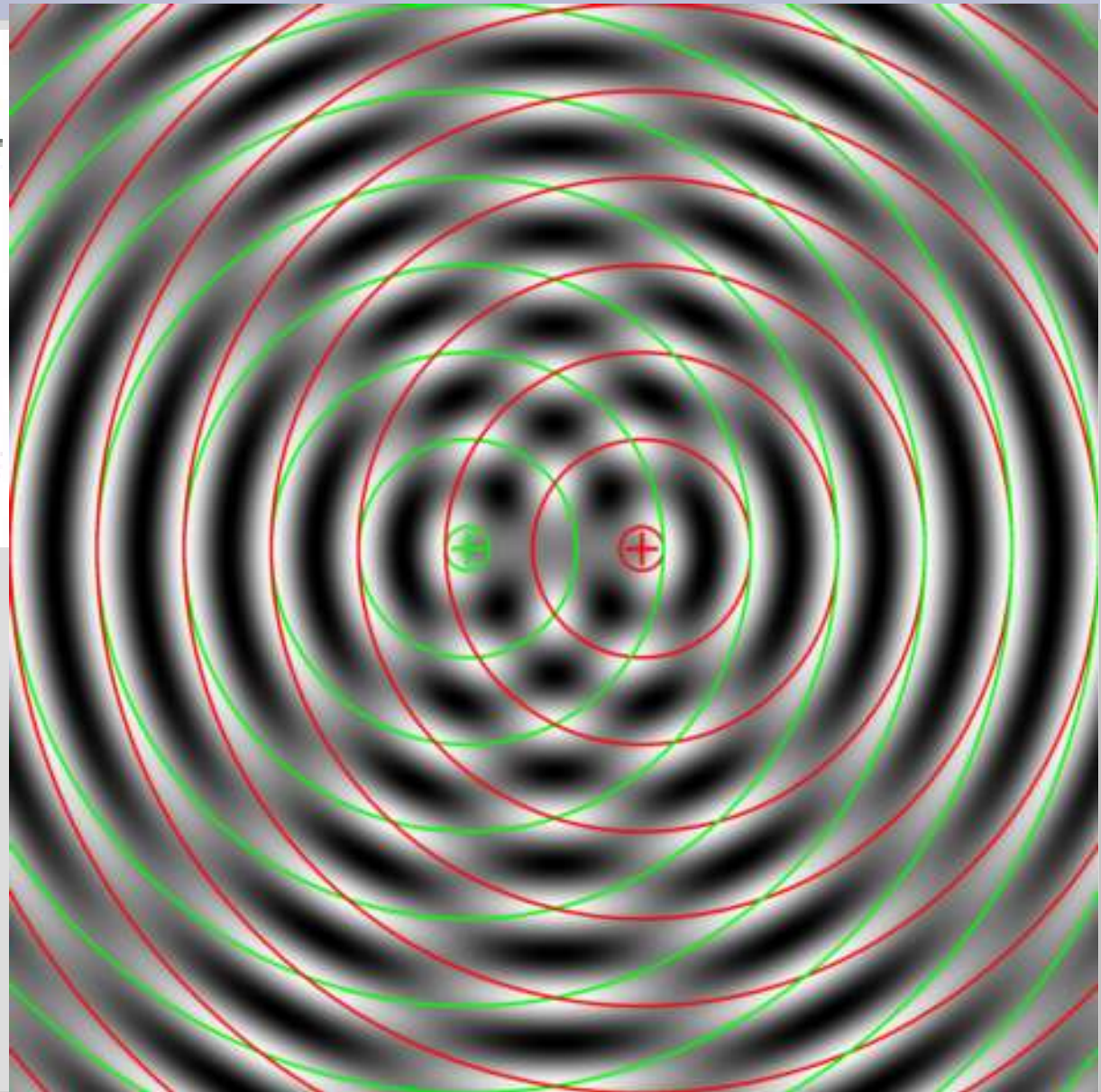
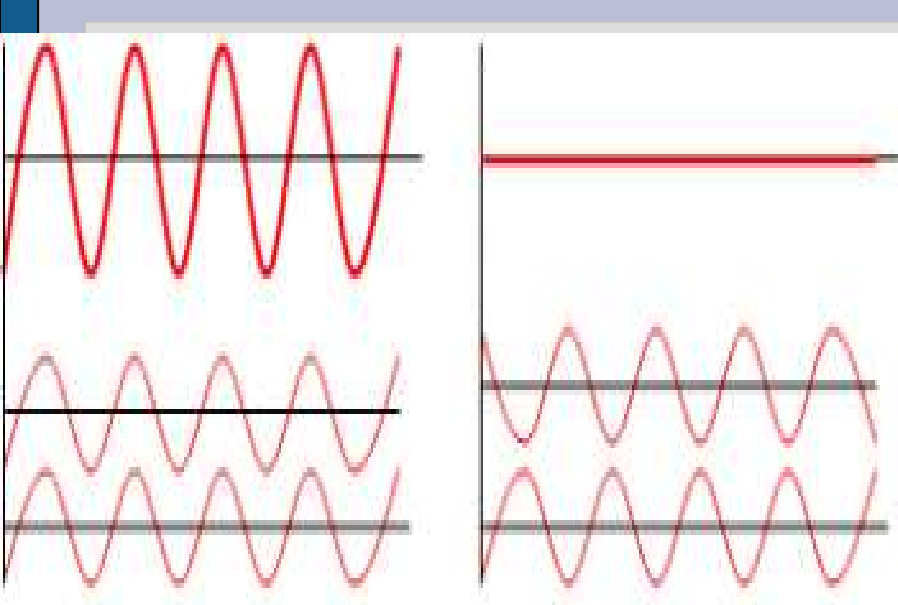


- Waves parallel to the beach
- Usually long wavelengths (swell)

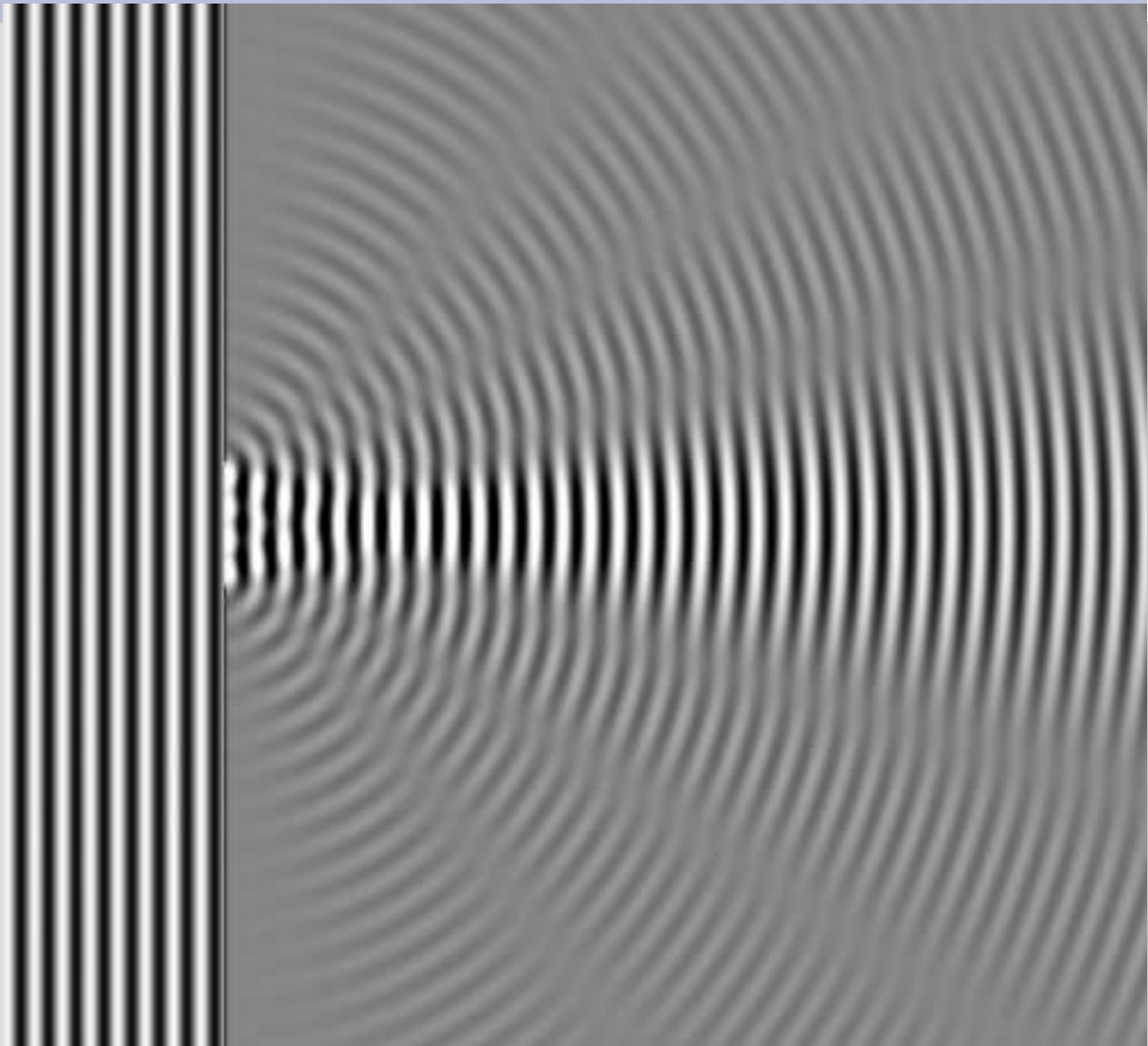
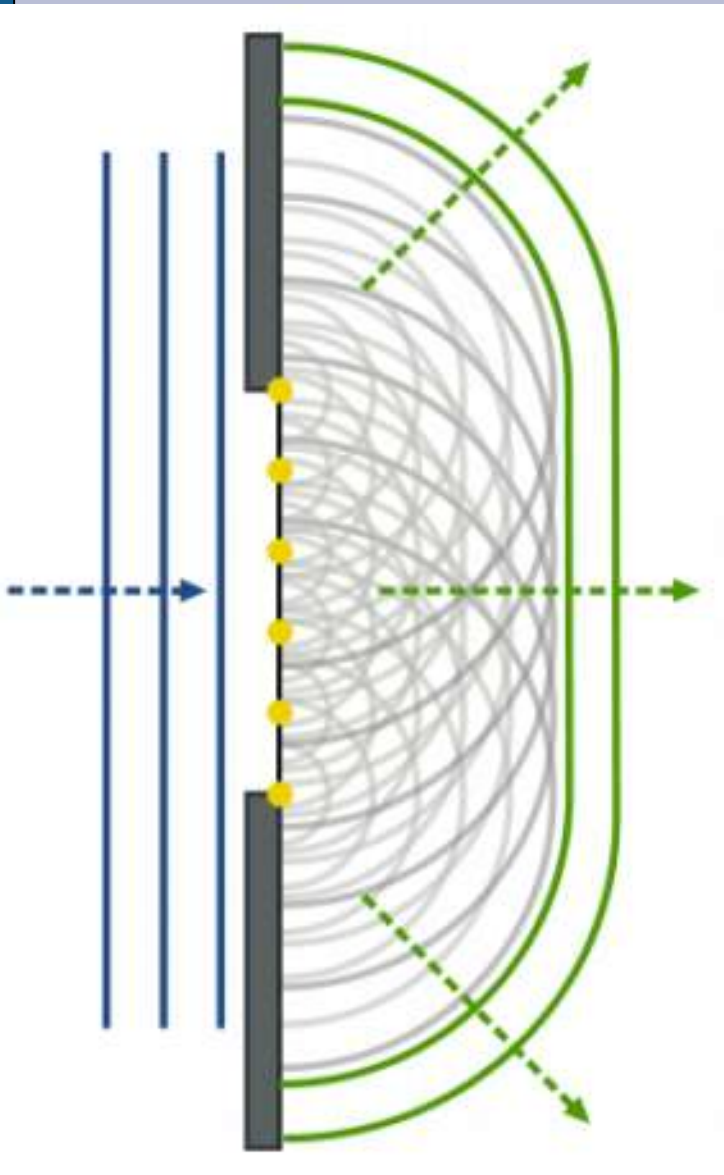
Waves: Superposition



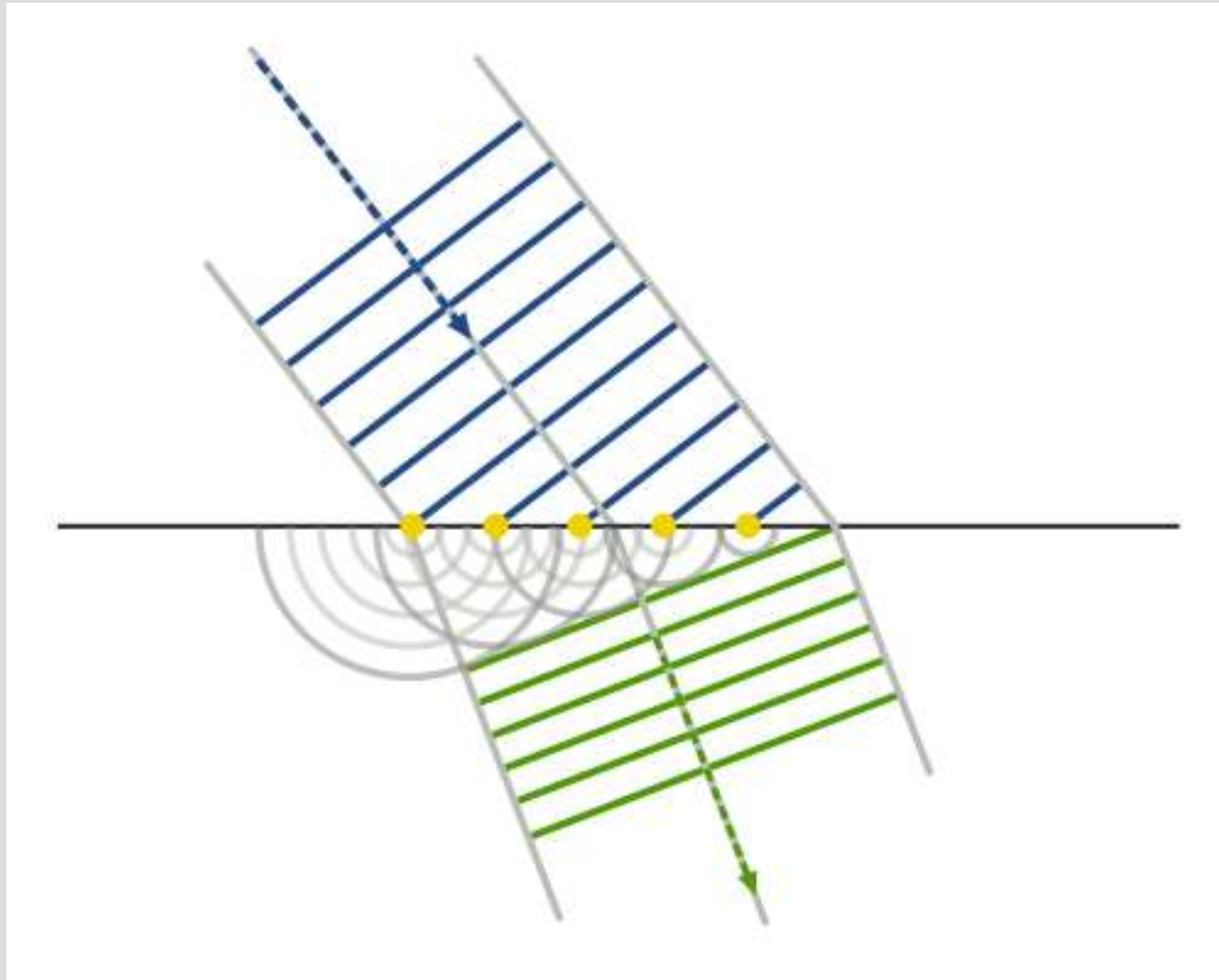
Waves: Interference



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

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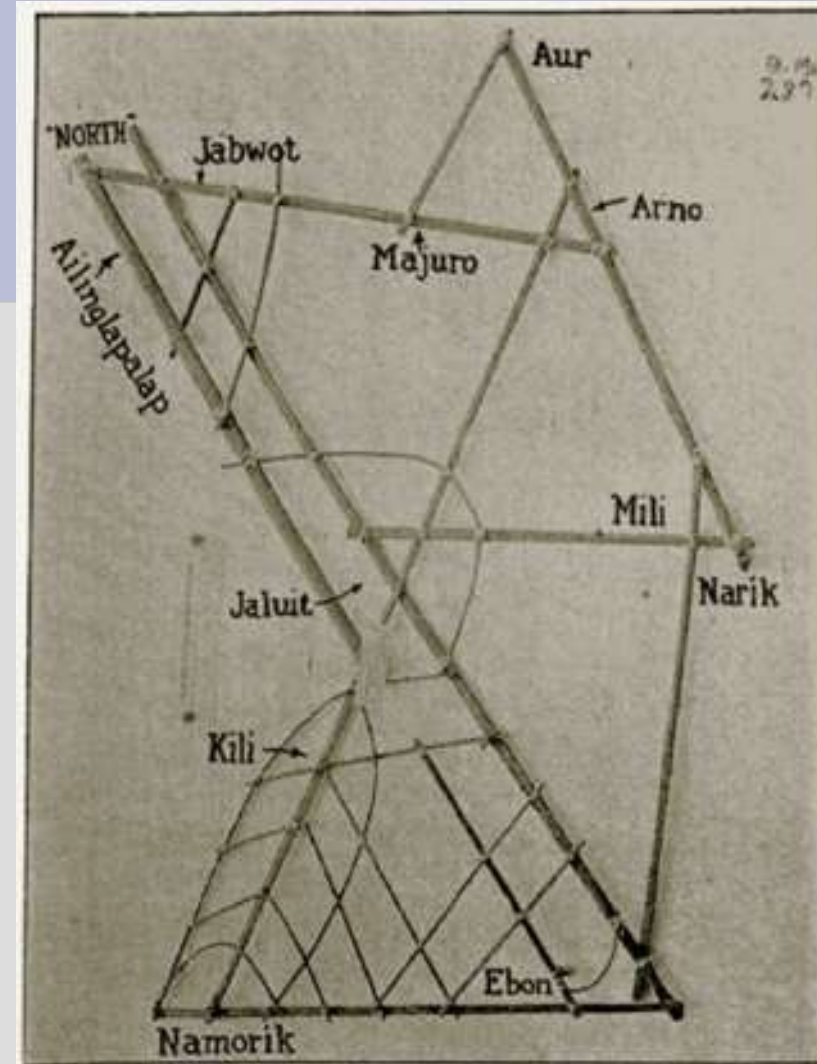
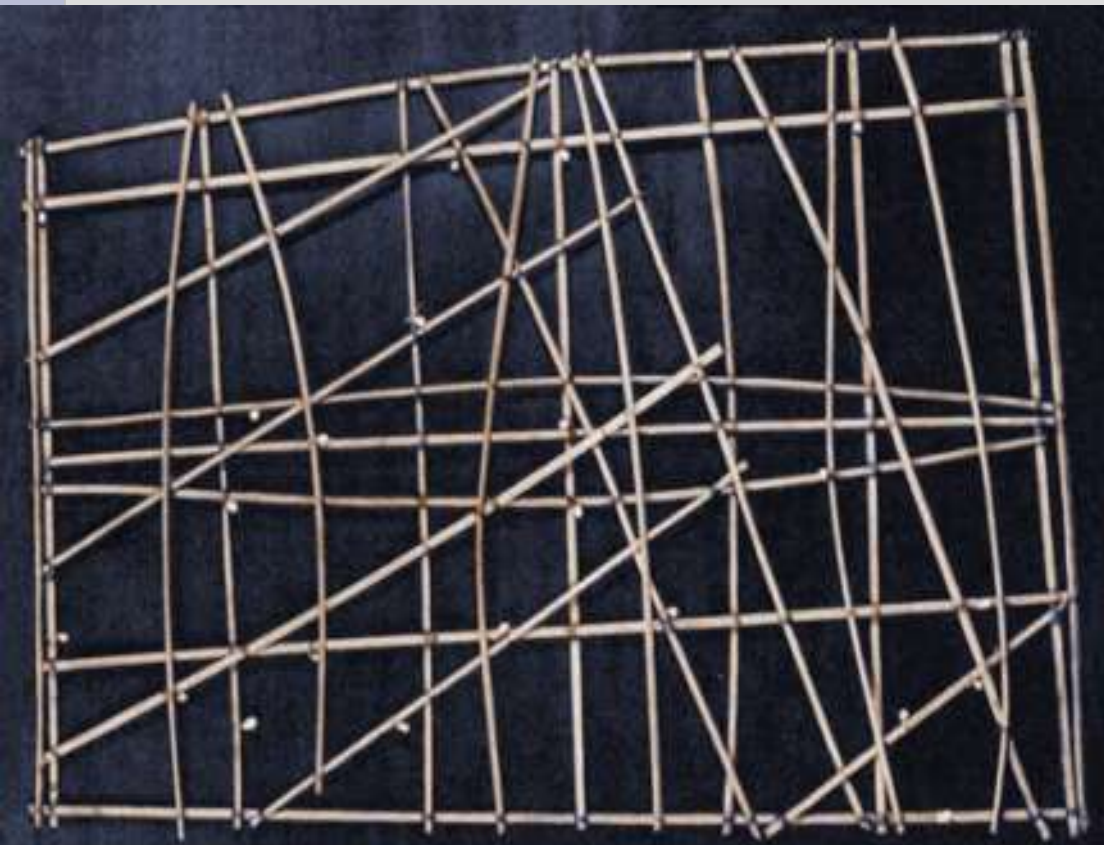
Ocean waves



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

Polynesian “stick chart”

- navigational aids
- record the wave patterns around islands



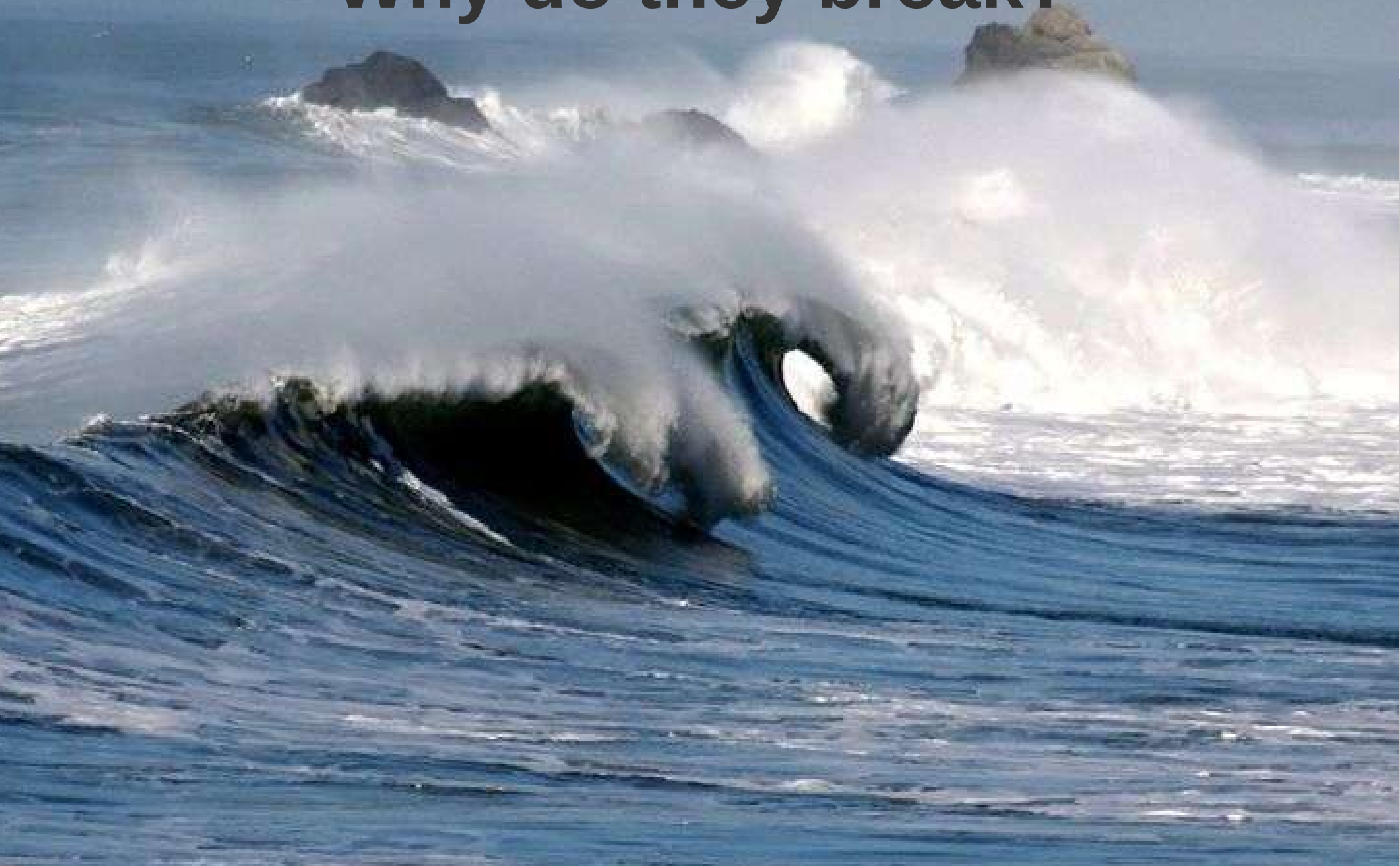
Images:

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

See also:

Wikipedia: Marshall Islands Stick Chart

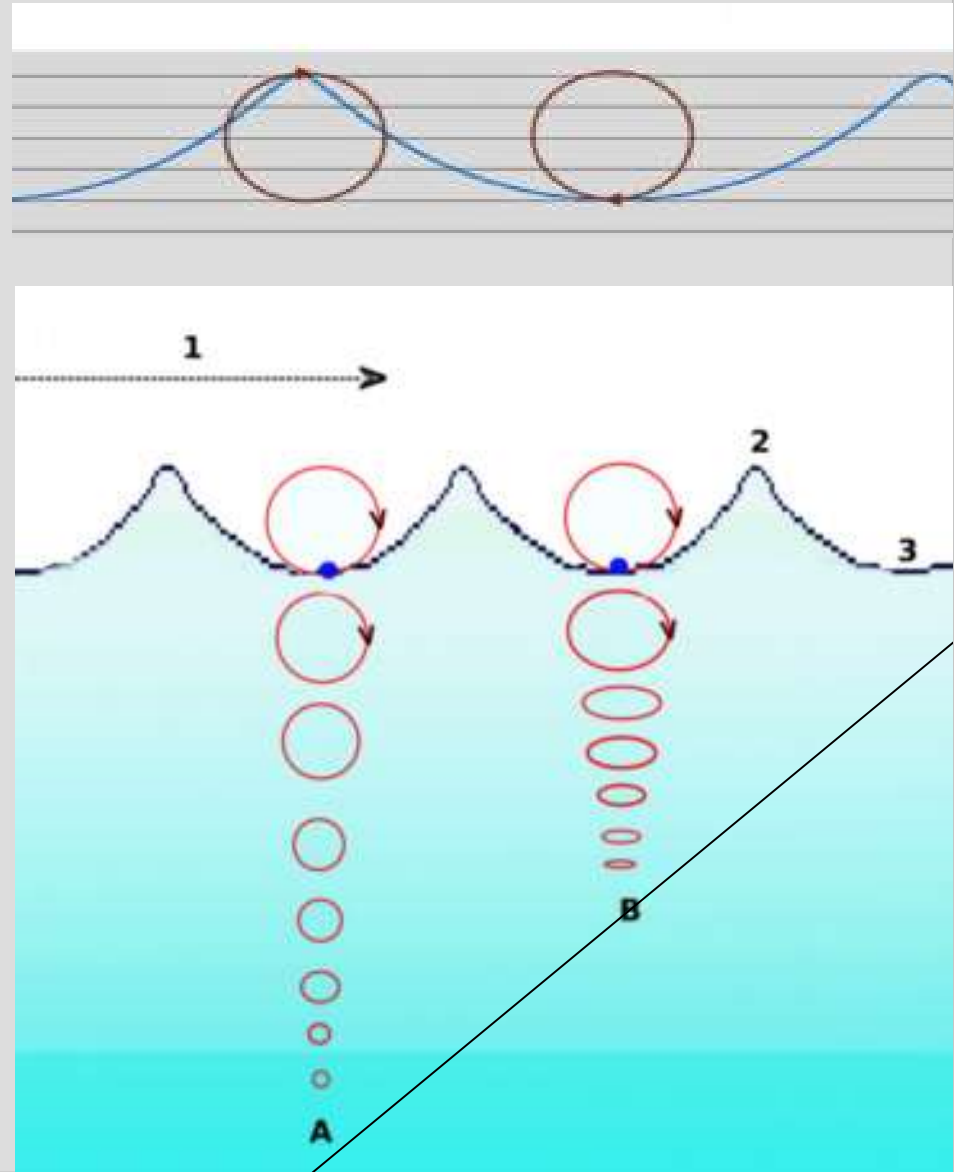
More about (ocean) waves: Why do they break?



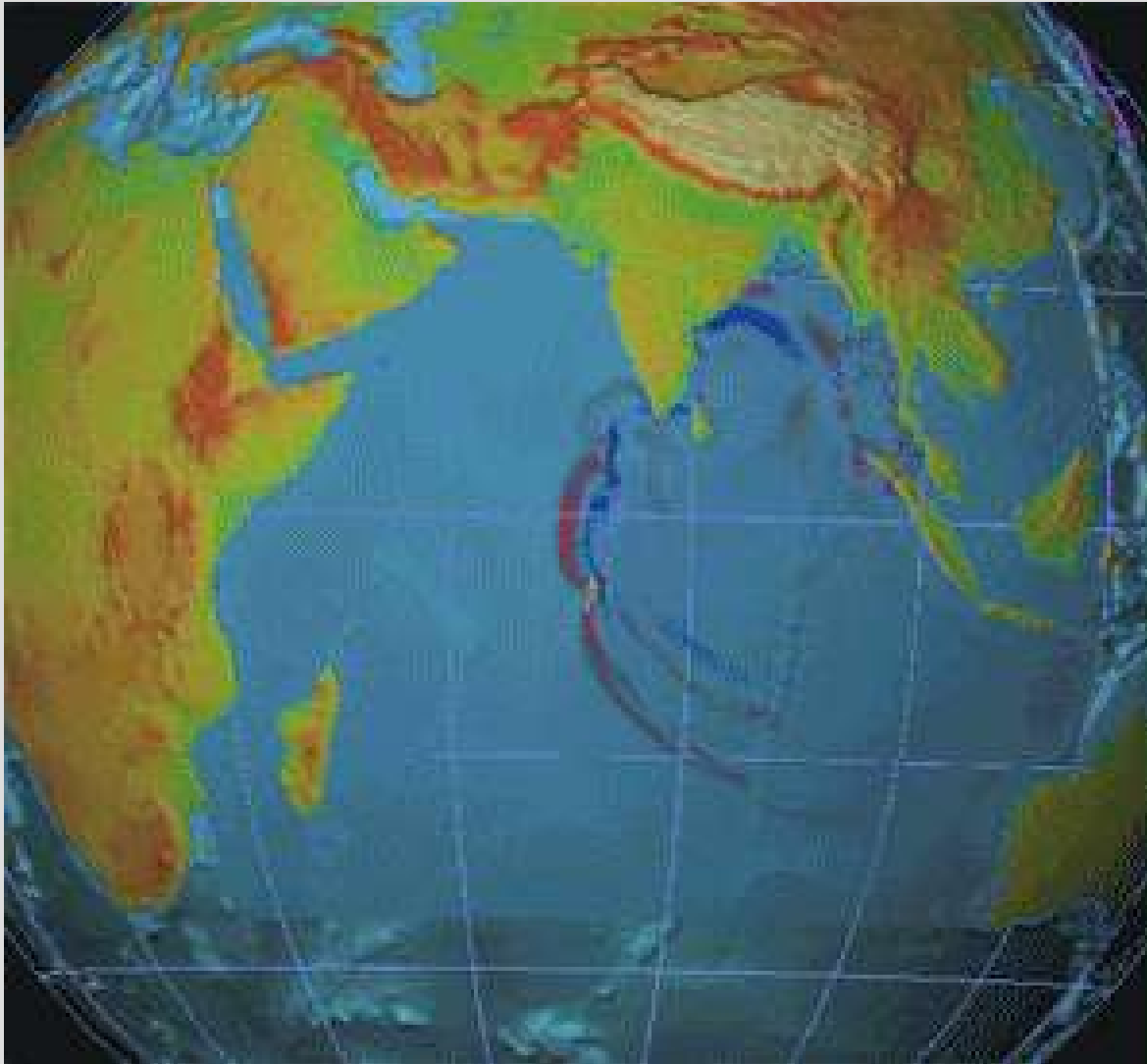
Deep and shallow water waves

- **Deep water**
(depth $> \frac{1}{2}$ 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

Tsunamis

Videos from NOAA-PMEL:

<http://www.youtube.com/user/NOAAPMEL>

(also linked from my website, see:

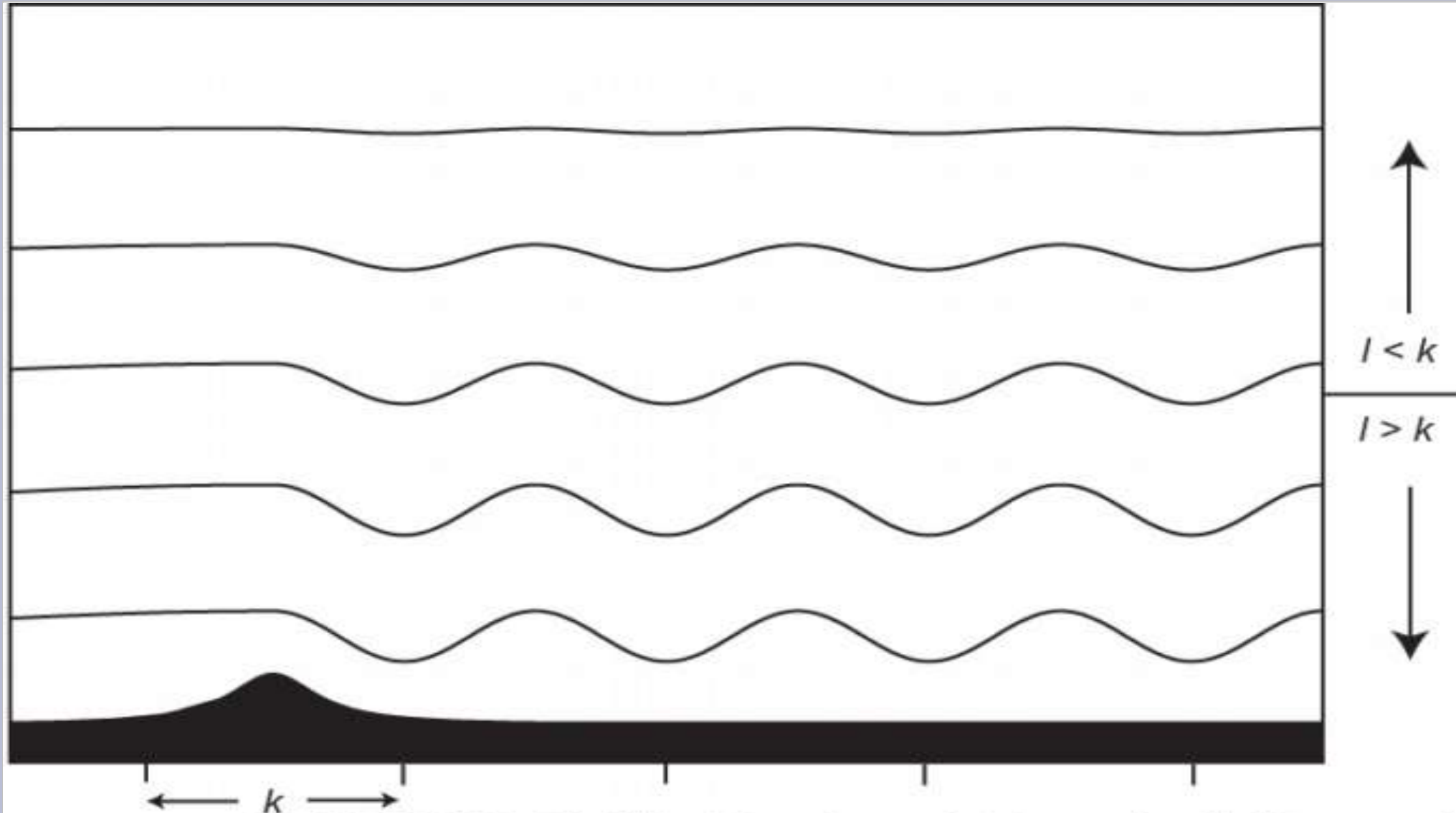
www.stephan-matthiesen.de/en/material)

7 Dec 2012 Honshu (Japan)

11 March 2011 Honshu (Japan)

26 December 2004 Indian Ocean

Atmospheric Waves

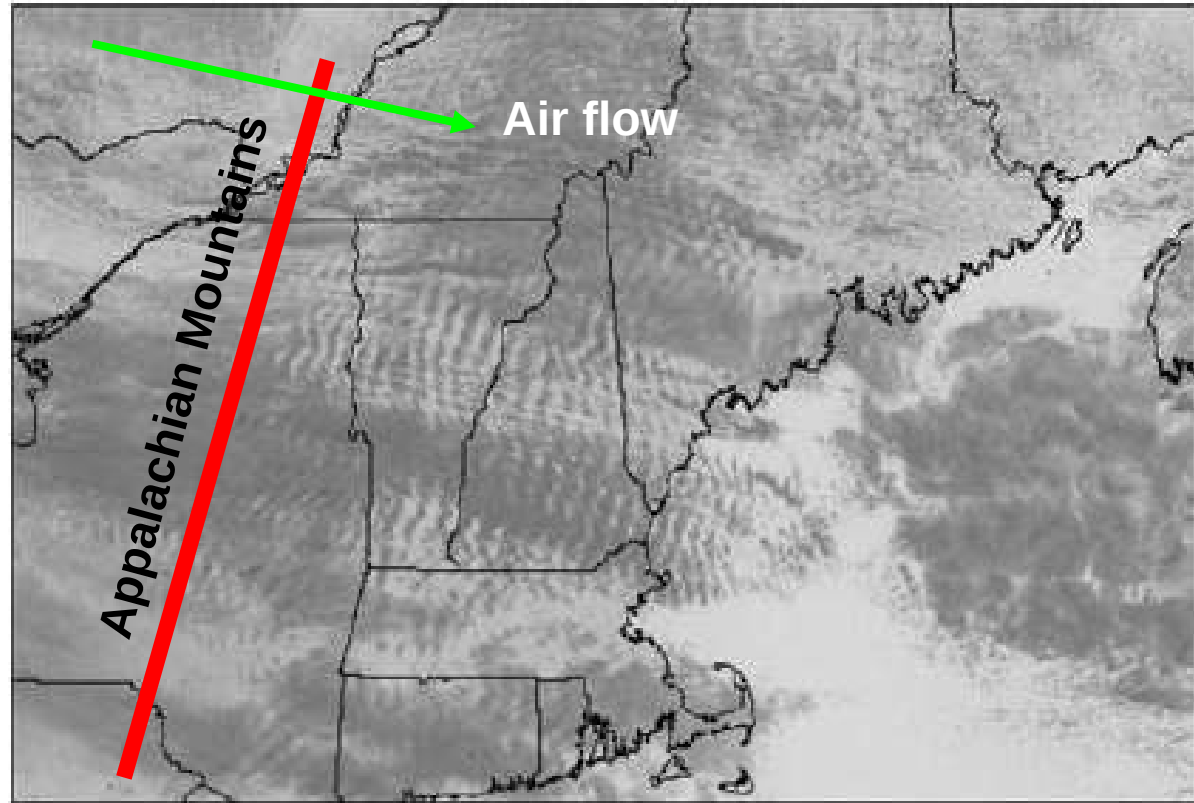


Gravity Waves

NE USA

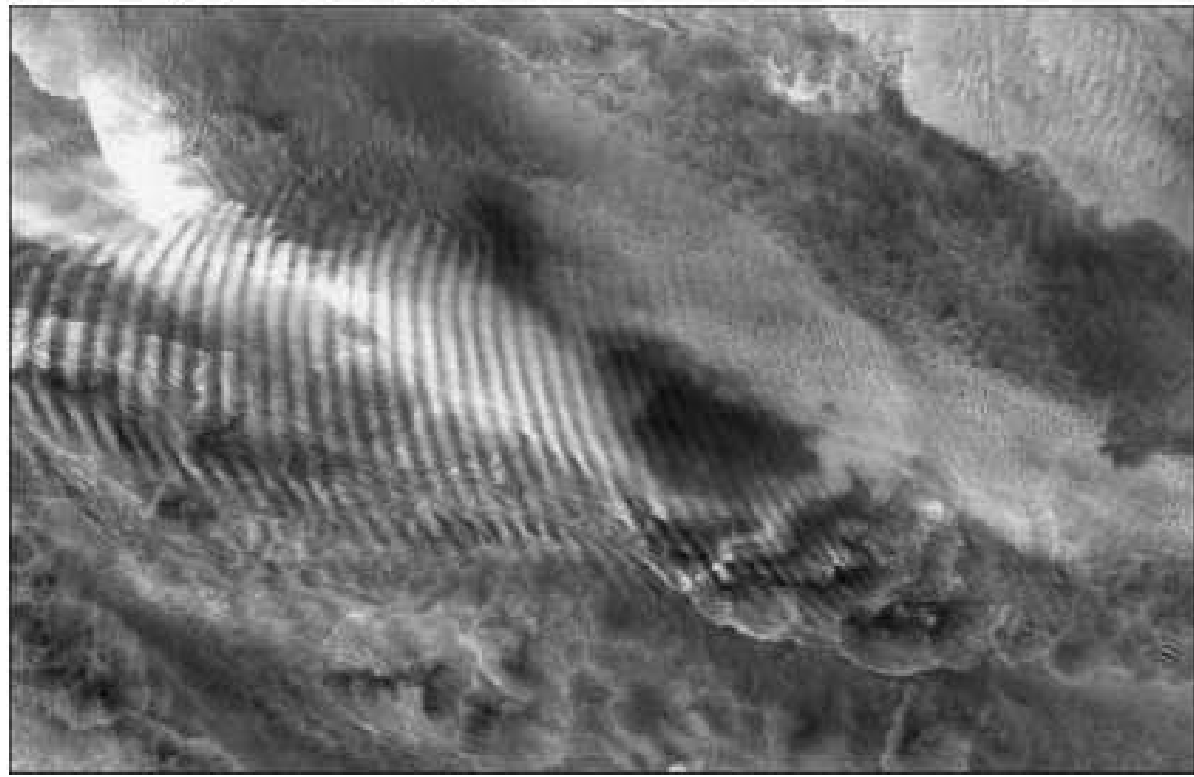
Waves excited by mountains

Wavelength $\sim 20\text{km}$



Indian Ocean

Probably triggered by
large thunderstorms







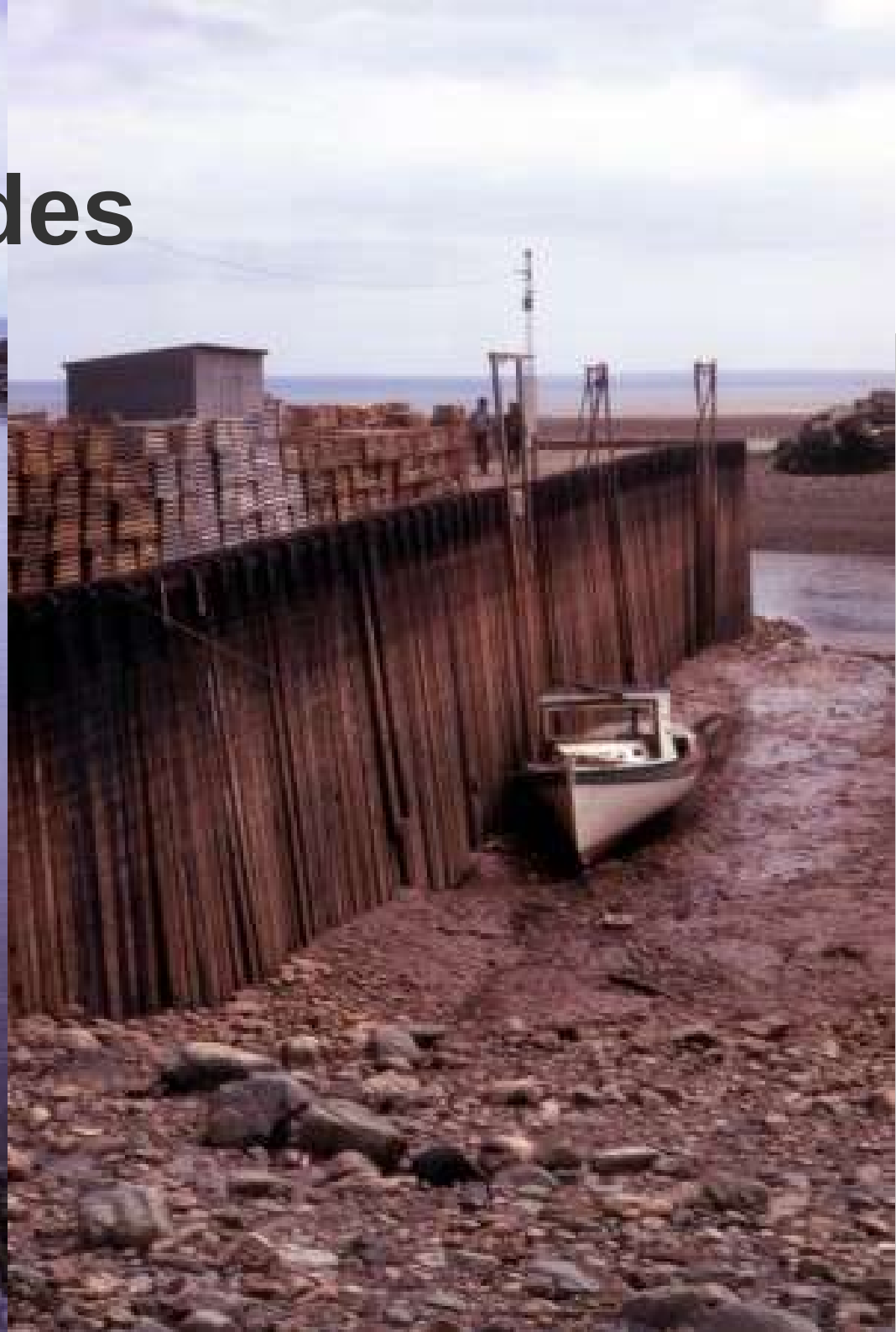
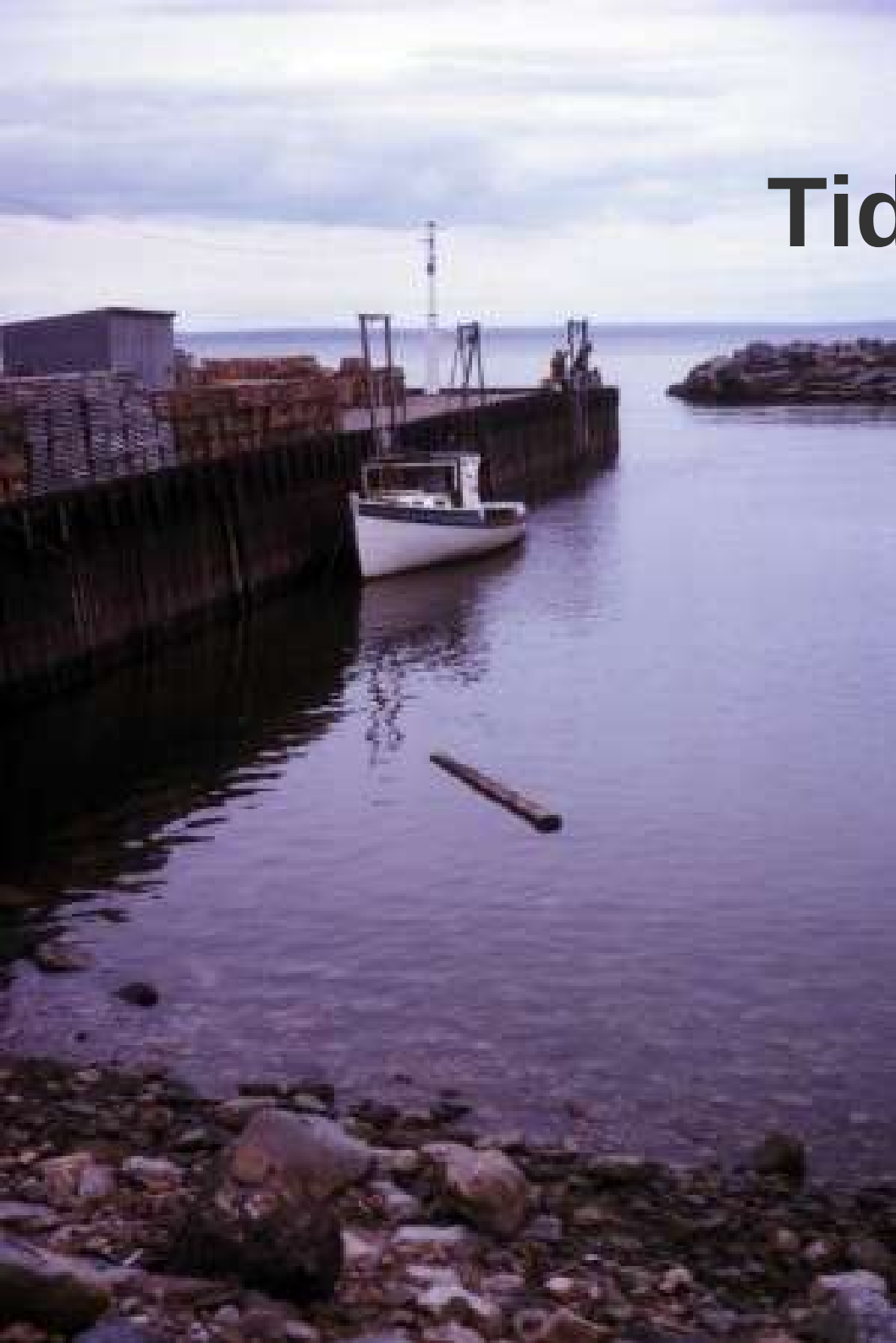
Finland



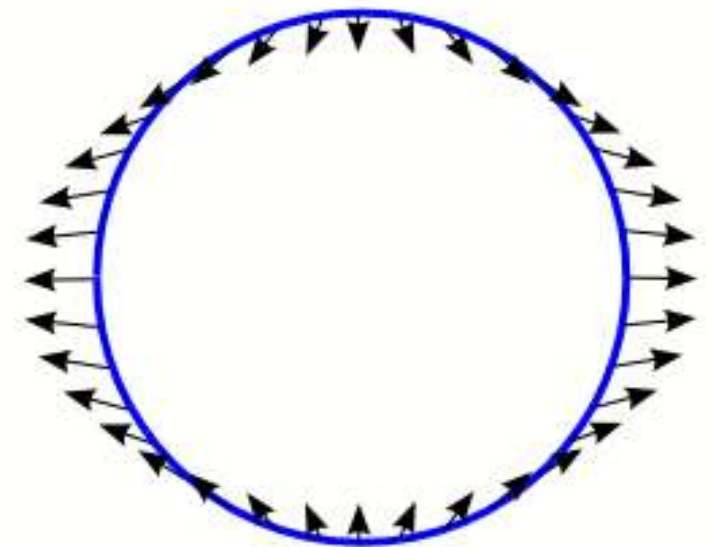
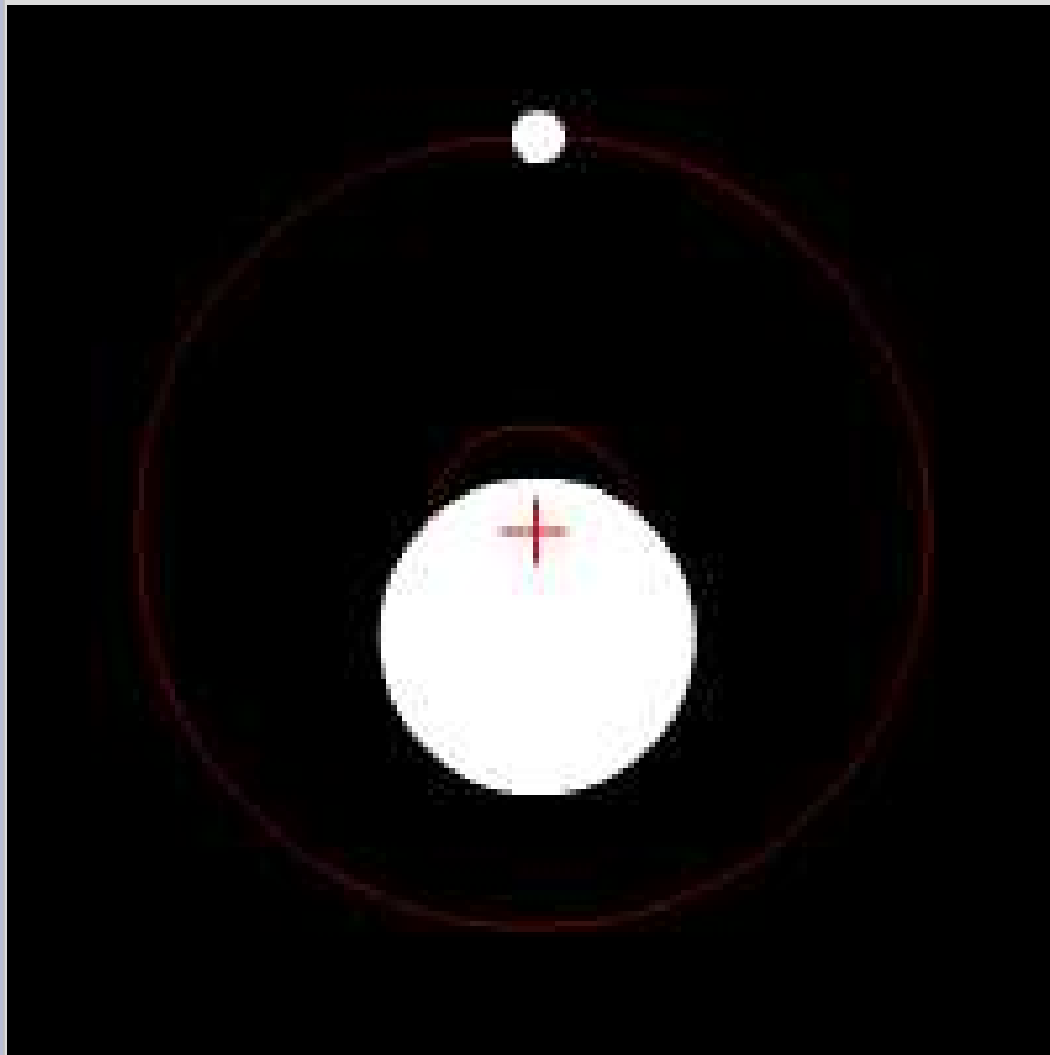
Lenticular clouds (image: www.wetter-foto.de)



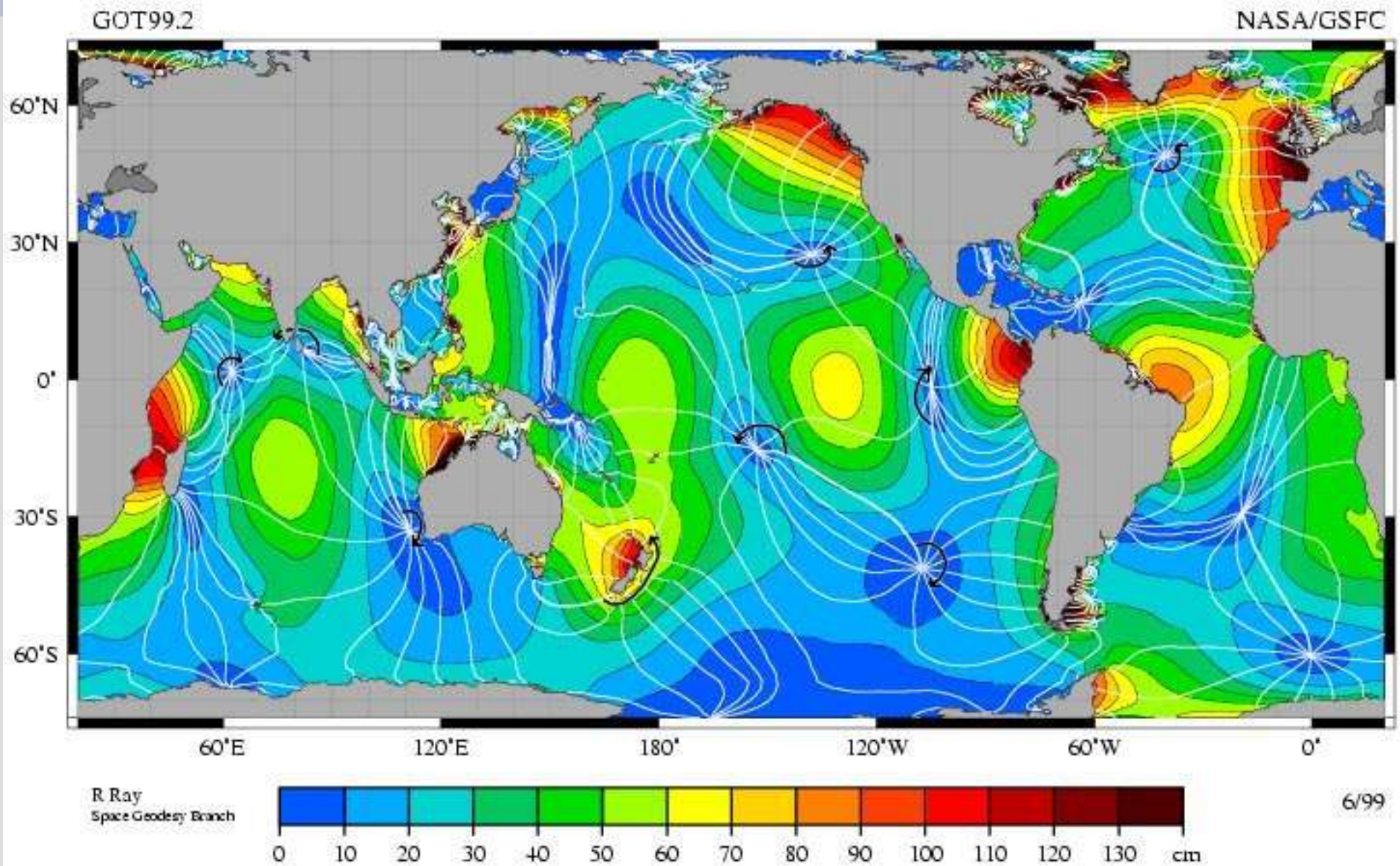
Tides



Tidal forces



Resonance: Dynamical tides



A different type of oscillation

Video at:

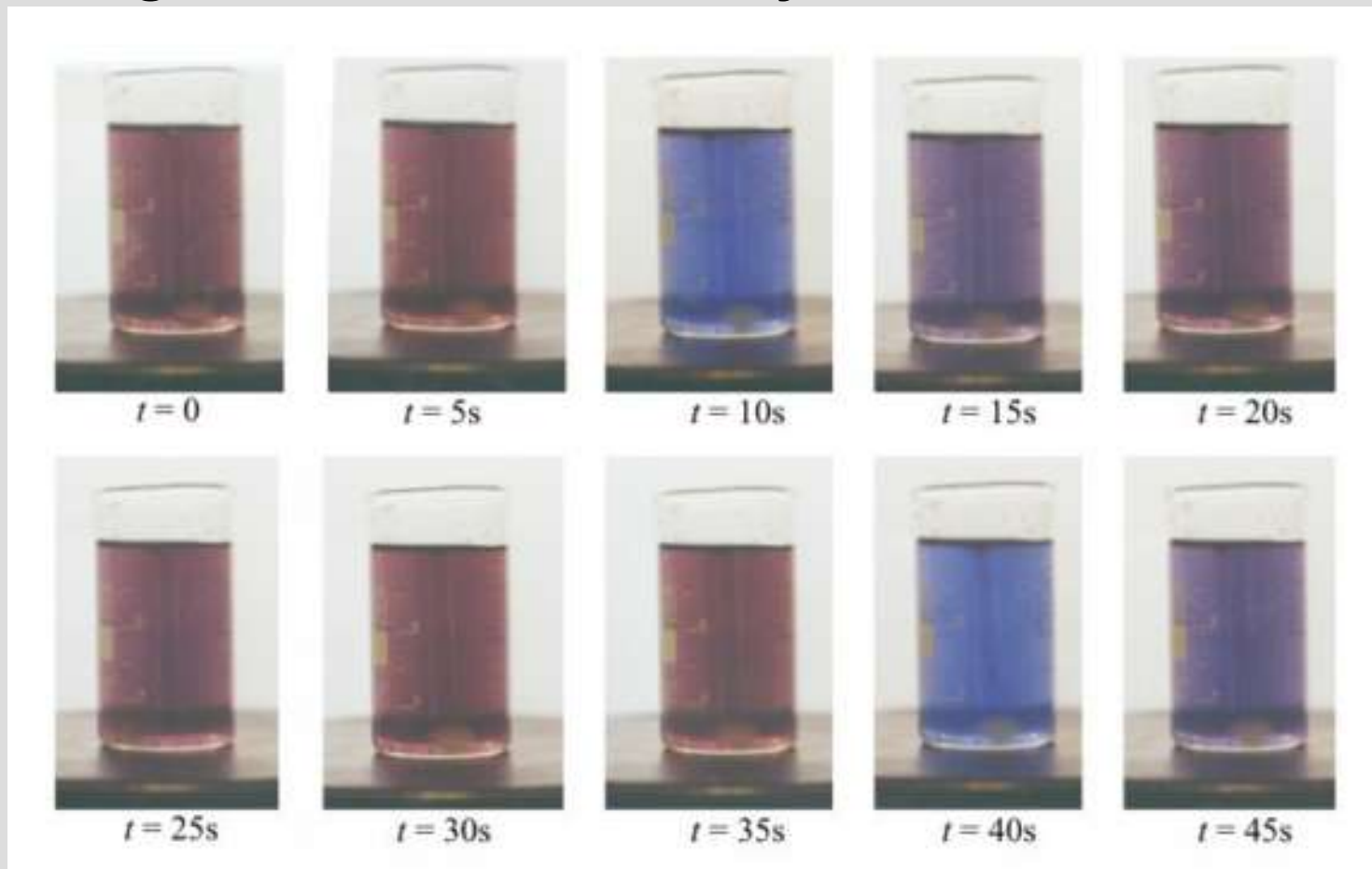
<http://uk.youtube.com/watch?v=5bho96R1sK4>

(also linked from

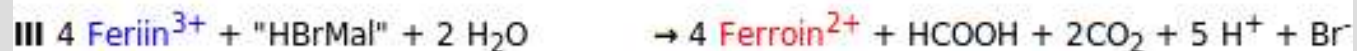
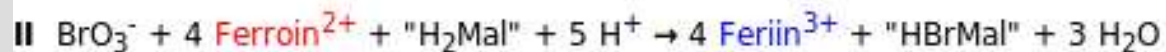
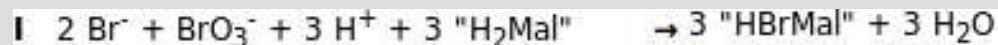
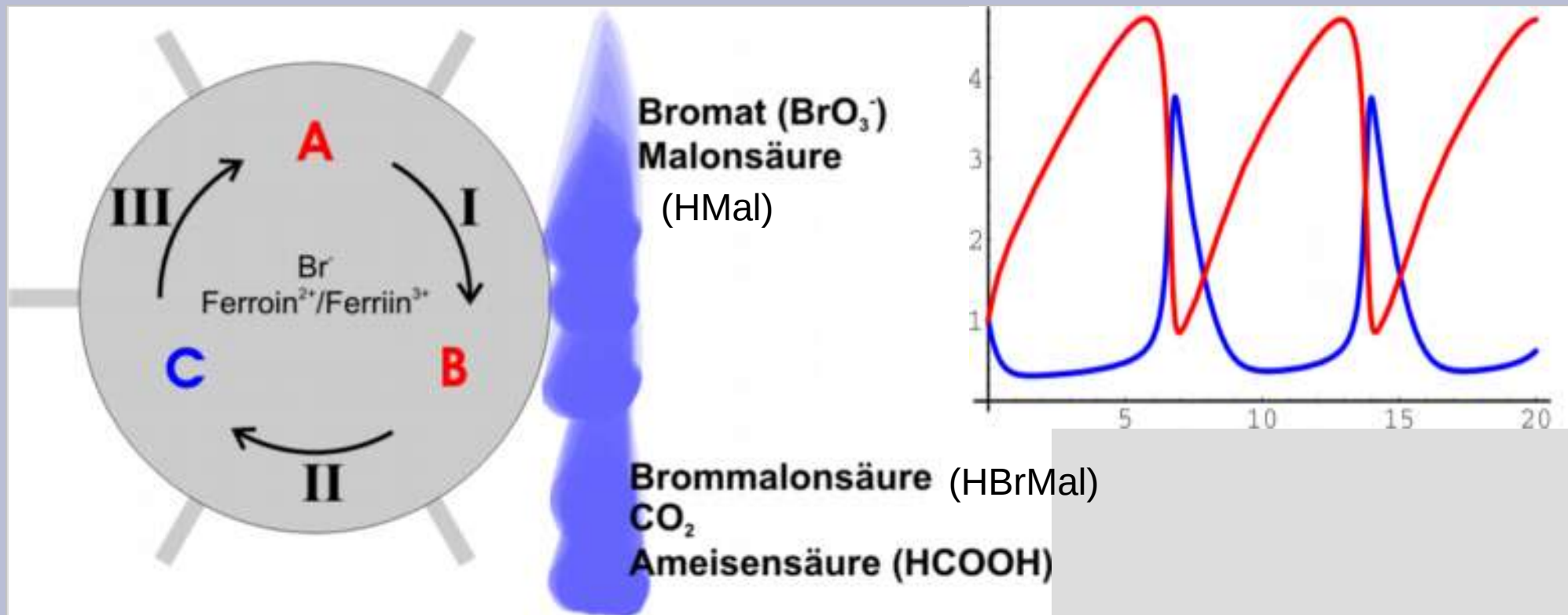
www.stephan-matthiesen.de/en/material)

Chemical Oscillations: The Belousov-Zhabotinsky reaction

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



The BZ reaction



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

(Videos also linked from
<http://www.stephan-matthiesen.de/en/material/>)

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:

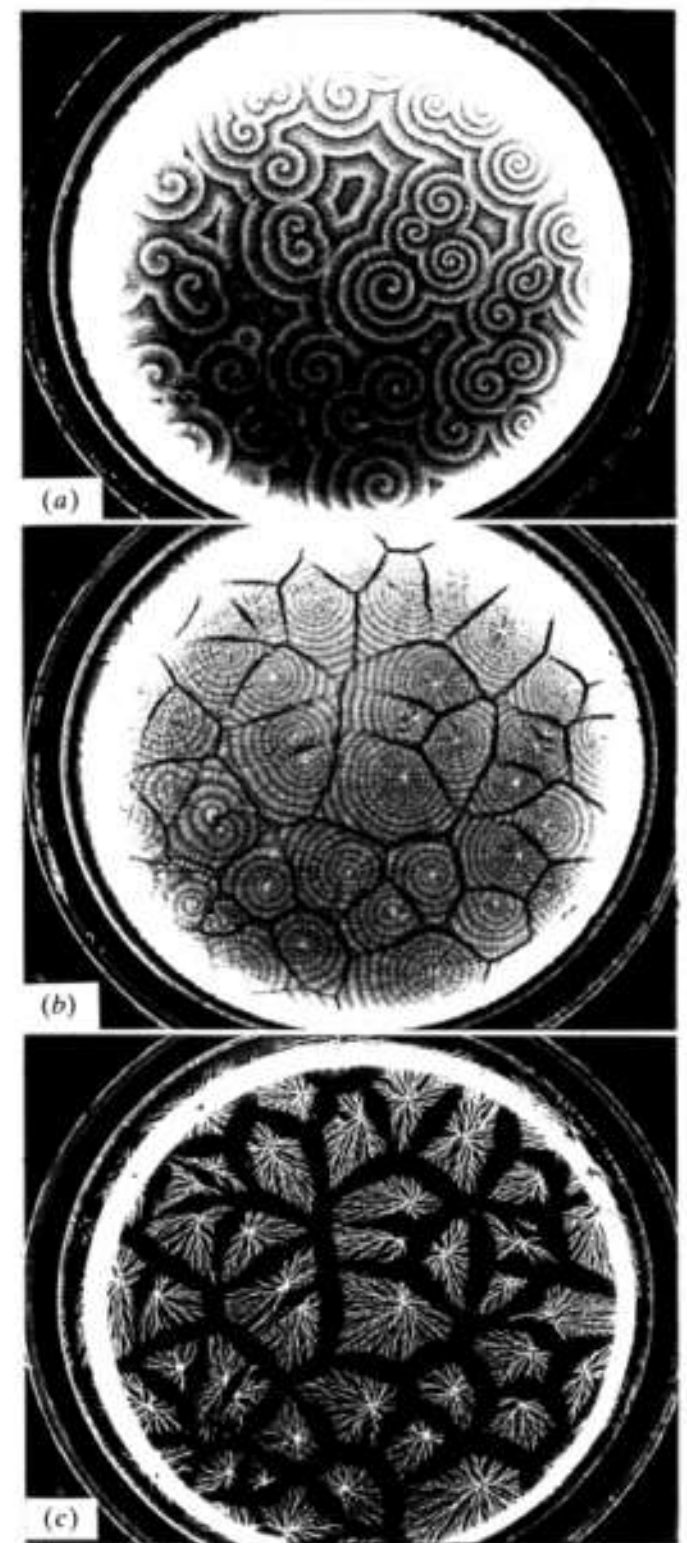
<http://www.youtube.com/watch?v=leKI3Cv9YYw>

Forming Fruiting Bodies:

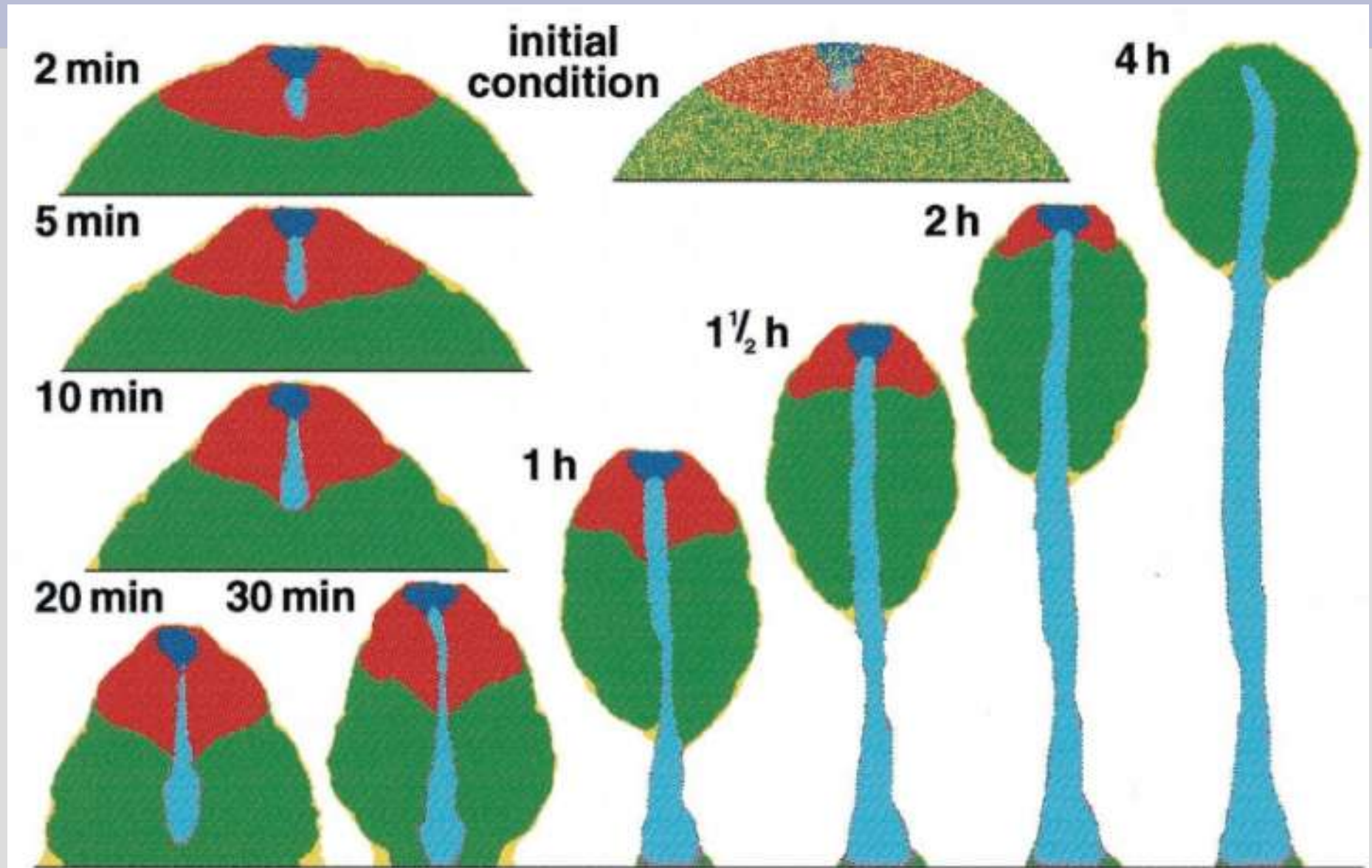
http://www.youtube.com/watch?v=Ne_KWY9RpTg

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



Fruiting body formation

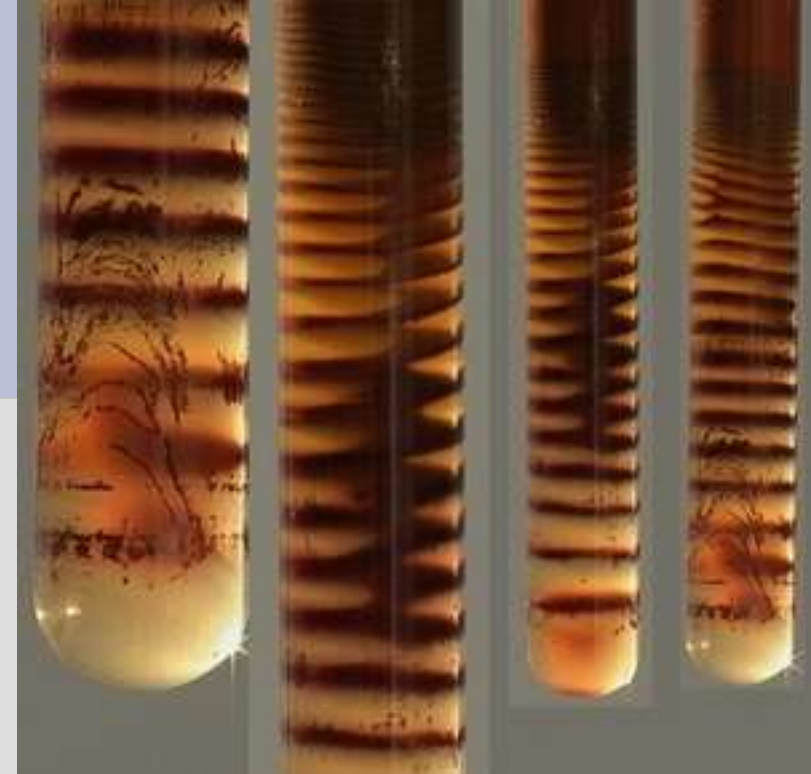


Other examples of excitation waves

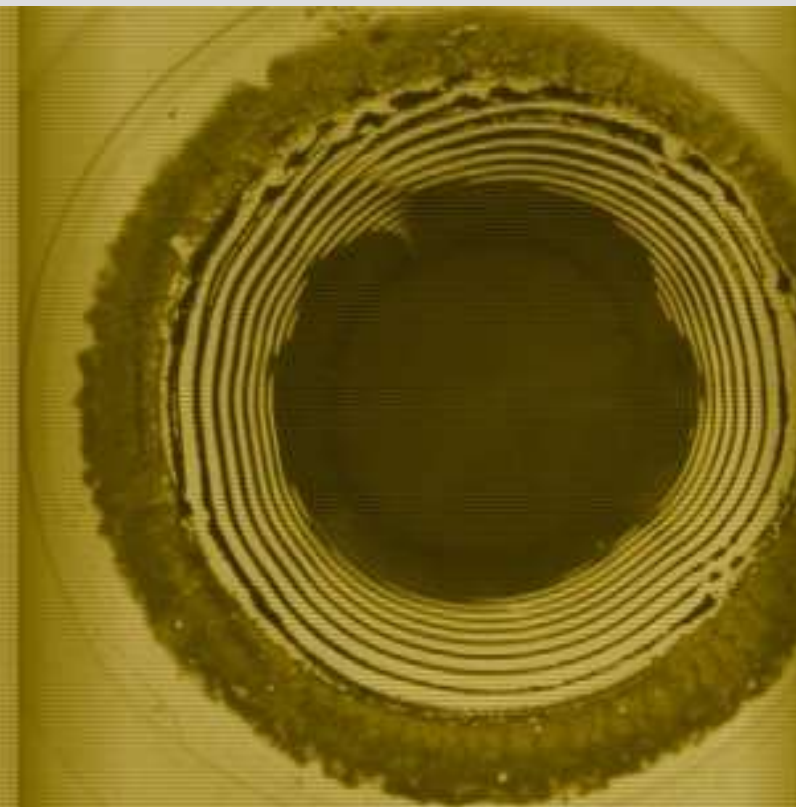
- Calcium waves in frog spawn
- Heart
 - Normal heartbeat
 - arrhythmia
- Brain – Epilepsia
- Epidemics

Liesegang phenomenon

- discovered in 1896 by Raphael Eduard Liesegang



R. E. 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

