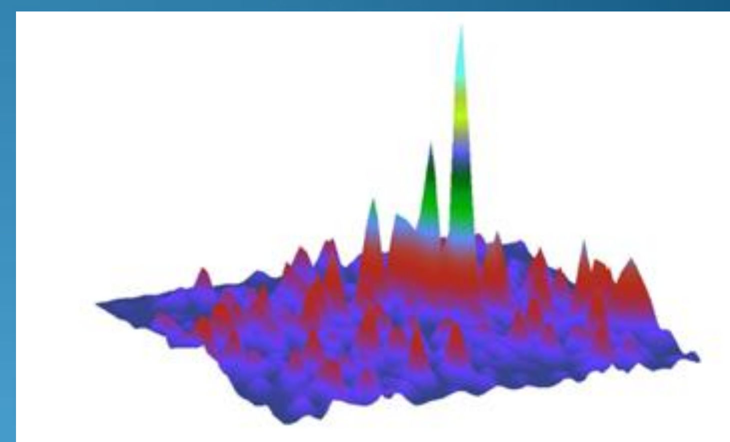
Going Rogue

From "The Great Wave of Translation"
to Rogue Ocean Waves



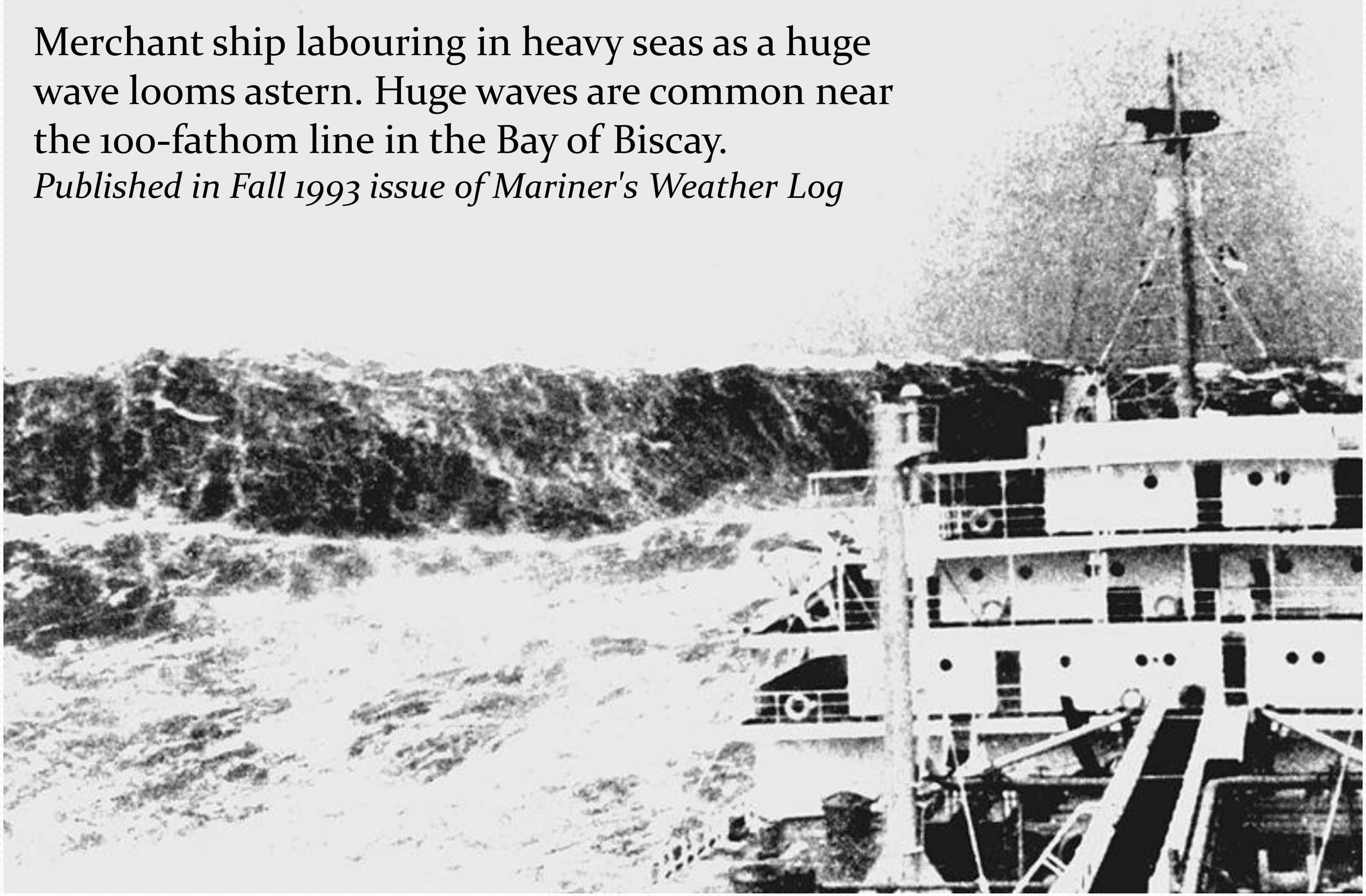
Dr. Russell Herman,
Physics and Physical Oceanography,
Mathematics and Statistics

Outline

- Freak/Rogue waves
- Great Wave of Translation
- History of nonlinear waves and solitons
- Emergence of rogue wave research

Fig. 4. A small-scale rogue wave in the nearshore of Harilaid (the Island of Saaremaa, western Estonia, the Baltic Sea) in September 2007. The total wave height is about 1 m. It is formed from about 30 cm high waves in about 2 m deep water.

Bay of Biscay, France - 1940

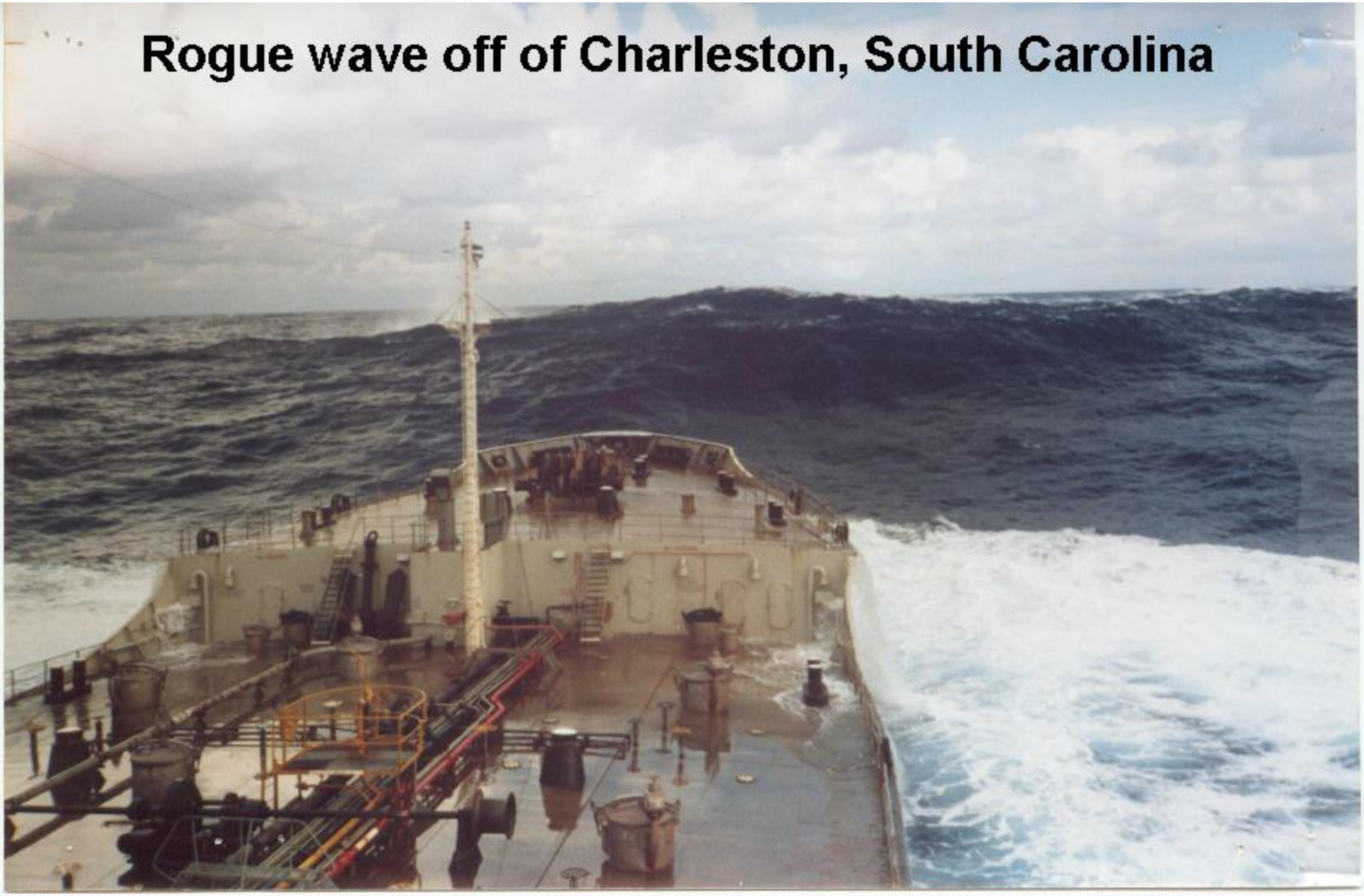


Merchant ship labouring in heavy seas as a huge wave looms astern. Huge waves are common near the 100-fathom line in the Bay of Biscay.
Published in Fall 1993 issue of Mariner's Weather Log

http://en.wikipedia.org/wiki/File:Wea00800,1.jpg

Bering Sea - 1979

NOAA Ship Discoverer gets pounded by monster wave in the Bering Sea. This picture was taken in 1979.



http://www.opc.ncep.noaa.gov/perfectstorm/index.shtml

Rogue Wave Incidents

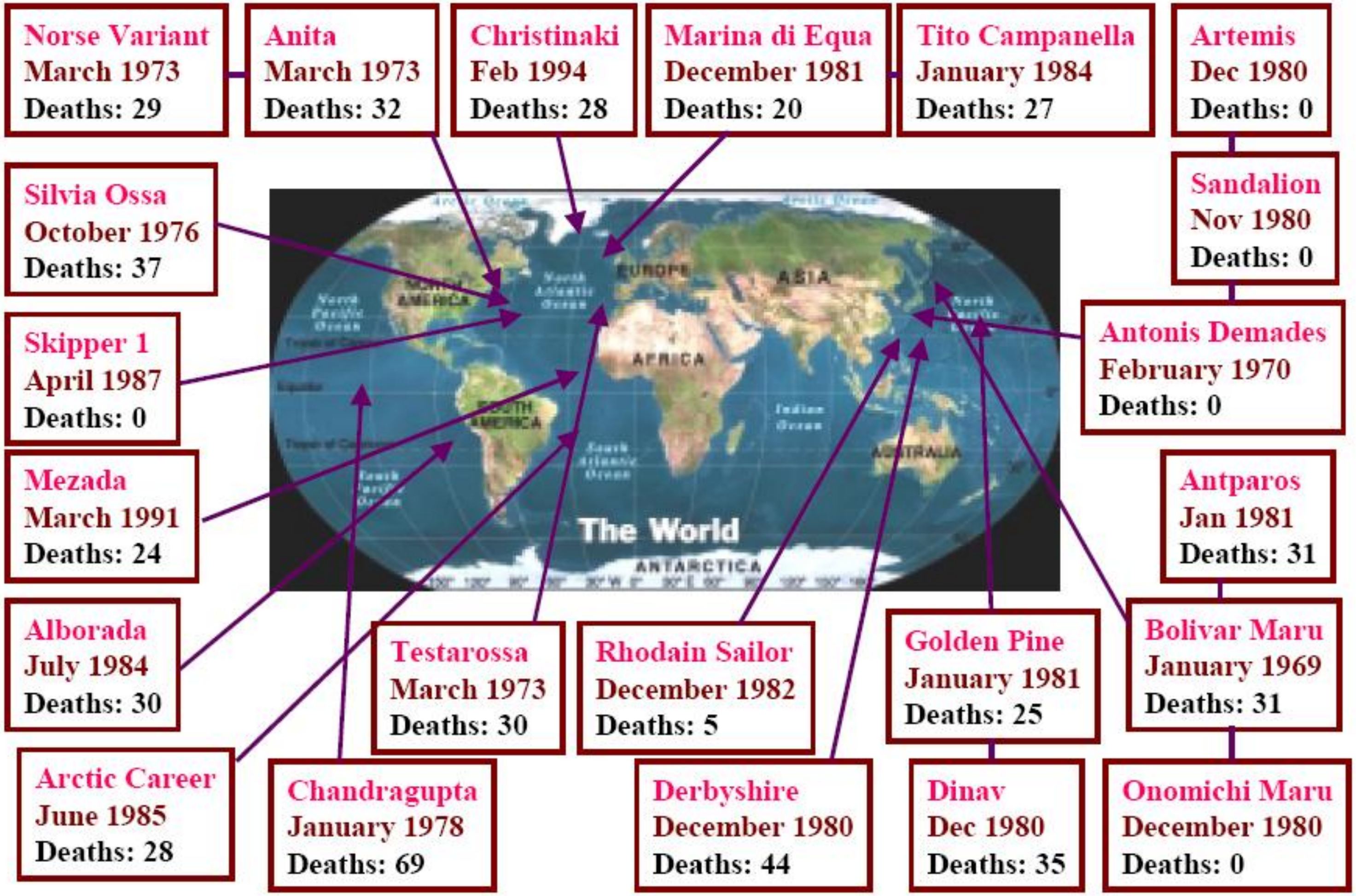
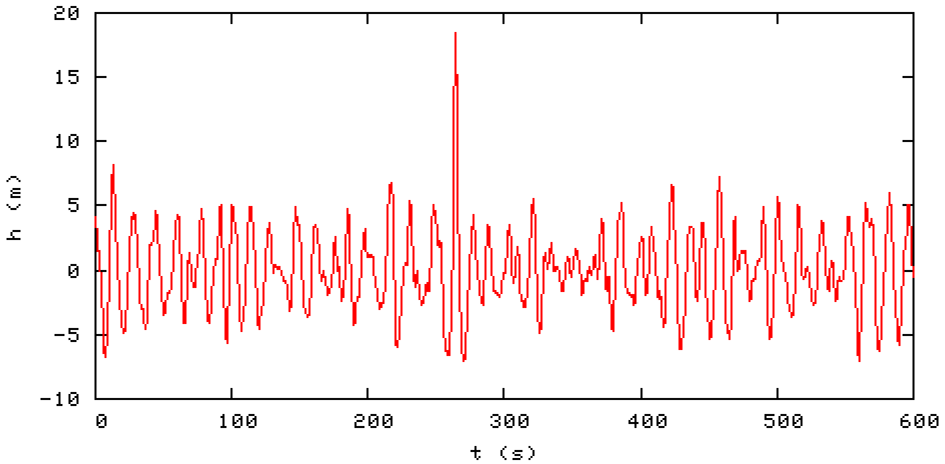


Figure 2.1. Statistics of the super-carrier collision with rogue waves for 1968-1994

http://hal.archives-ouvertes.fr/docs/00/00/03/52/PDF/Rogue_wave_V1.pdf

Draupner Wave – Jan 1, 1995

- Oil platform in the central North Sea
- Minor damage
- Read by a laser sensor.
- During wave heights of 12 m (39 ft),
    - Freak wave - max height of 25.6 m (84 ft)
    - (peak elevation was 18.5 m (61 ft)).
- Estimated – 1 in 200,000 wave (P. Taylor).

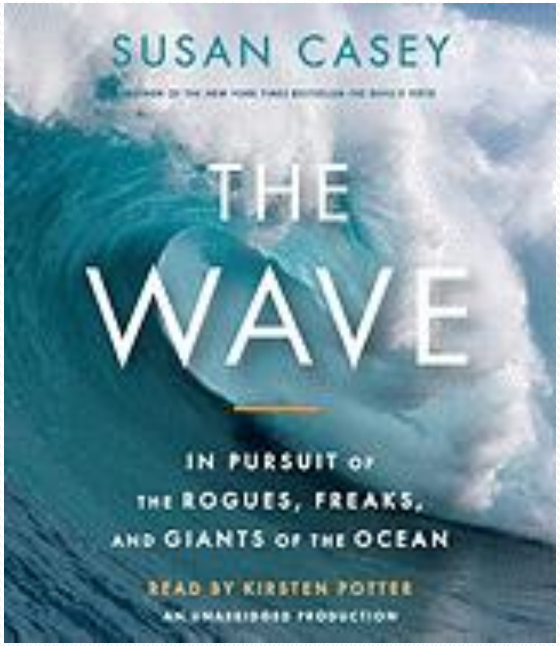


Crabbing Boat Video

60' Rogue Wave smashes Crabbing boat in the Bering Sea.

http://www.youtube.com/watch?v=l_8hOai9hGQ

Susan Casey – *The Wave*



Interviews with Charlie Rose and Jon Stewart in 2010

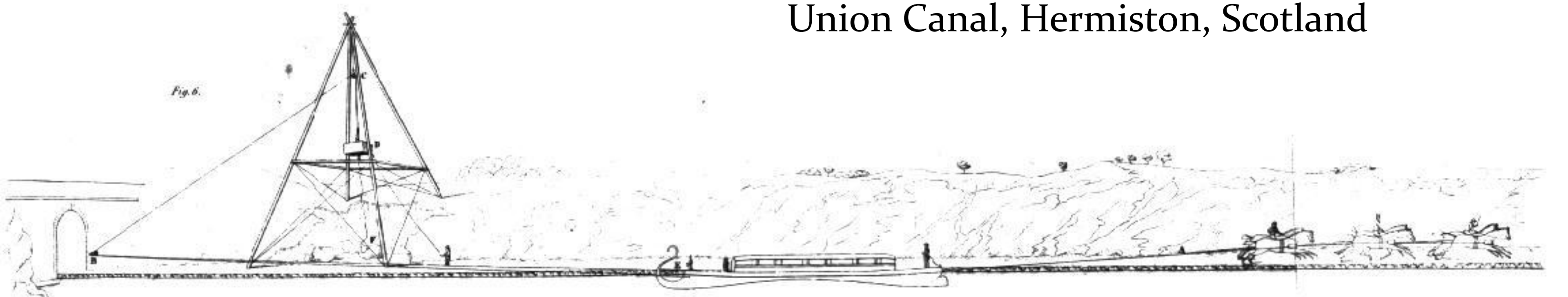
Susan Casey – *The Wave*

http://youtu.be/anXkV6jGvgE

Great Wave of Translation - 1834

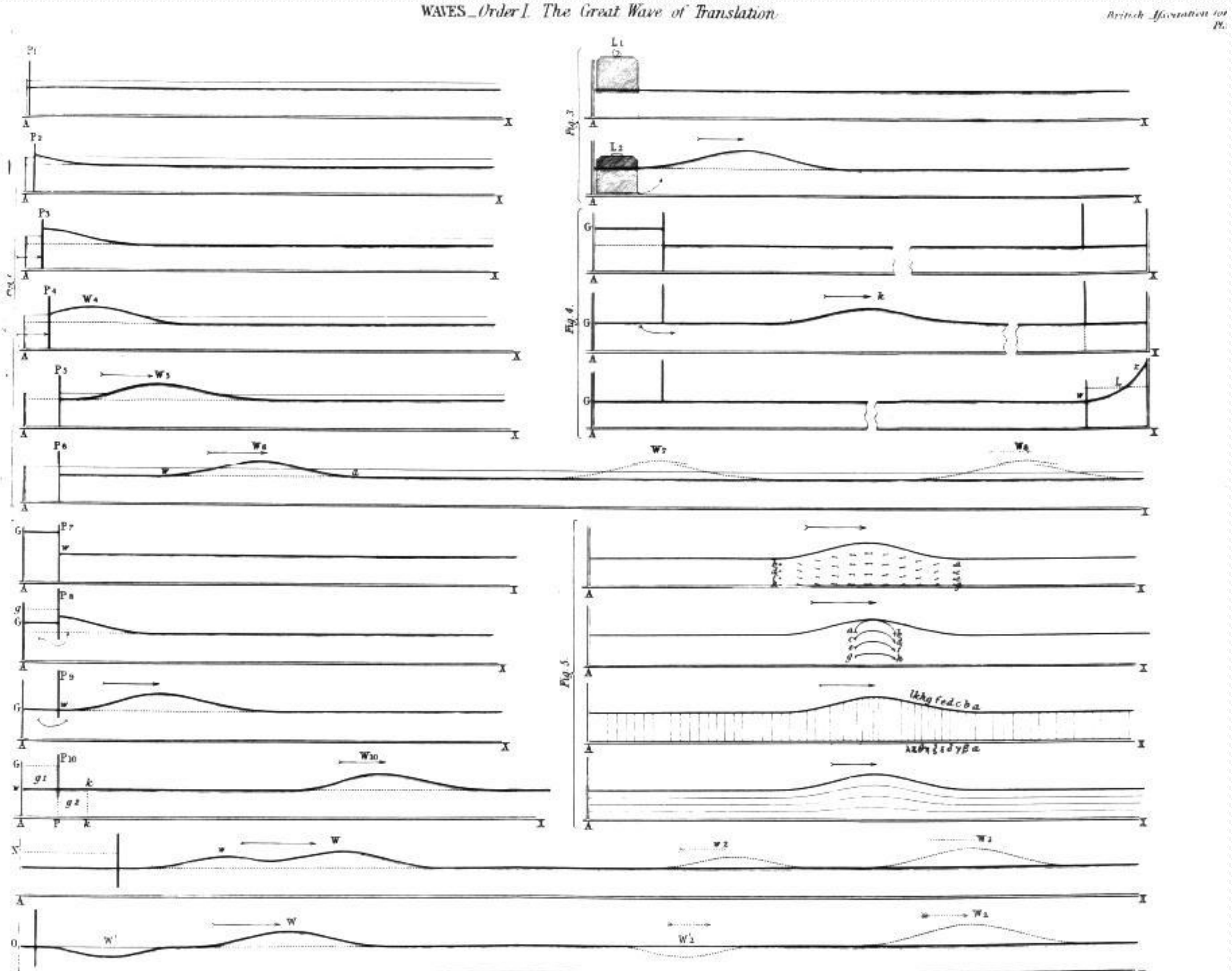
"I was observing the motion of a boat which was rapidly drawn along a narrow channel by a pair of horses, when the boat suddenly stopped—not so the mass of water in the channel which it had put in motion; it accumulated round the prow of the vessel in a state of violent agitation, then suddenly leaving it behind, rolled forward with great velocity, assuming the form of a large solitary elevation, a rounded, smooth and well-defined heap of water, which continued its course along the channel apparently without change of form or diminution of speed. I followed it on horseback, and overtook it still rolling on at a rate of some eight or nine miles an hour [14 km/h], preserving its original figure some thirty feet [9 m] long and a foot to a foot and a half [300–450 mm] in height. Its height gradually diminished, and after a chase of one or two miles [2–3 km] I lost it in the windings of the channel. Such, in the month of August 1834, was my first chance interview with that singular and beautiful phenomenon which I have called the Wave of Translation." – John Scott Russell

Union Canal, Hermiston, Scotland



http://www.ma.hw.ac.uk/~chris/canal.jpg

John Scott Russell



1808-1882
Engineer
Edinburgh

Used 30’ tank

$v^2 = g(h+a)$

http://www.ma.hw.ac.uk/~chris/scott_russell.html

Re-enactment – July 12, 1995

Union Canal, Scott Russell Aqueduct

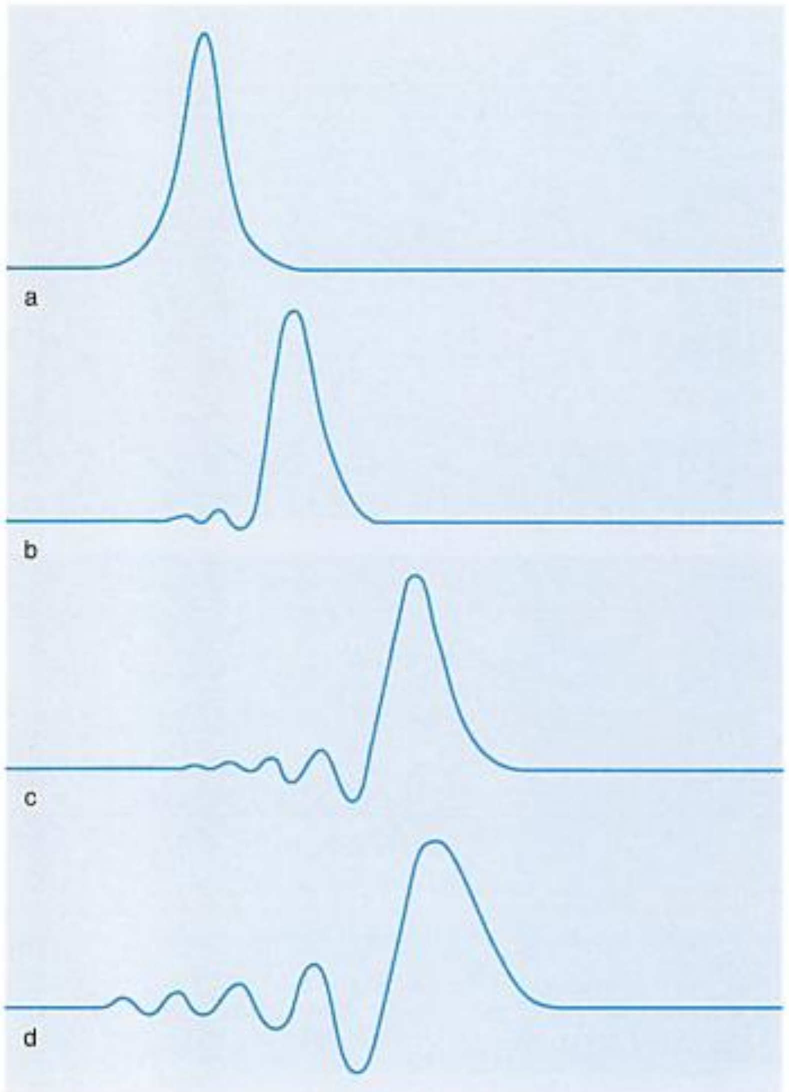
http://apachepersonal.miun.se/~tomnil/solitoner/solipic.htm

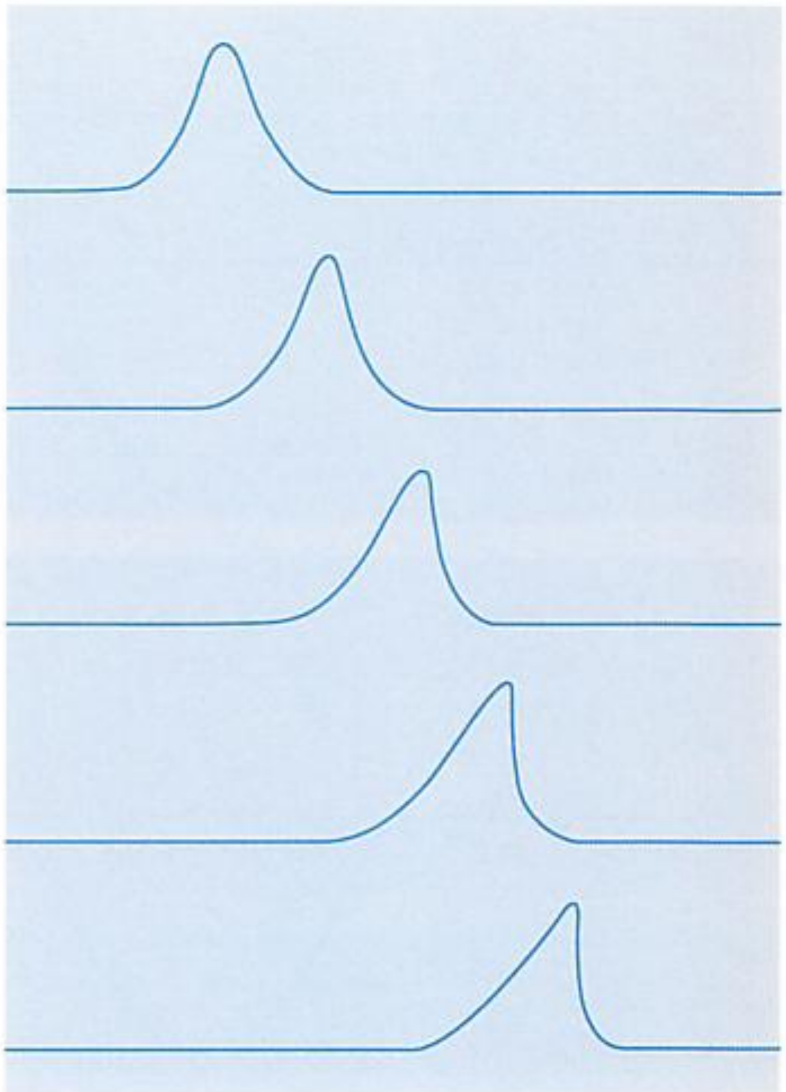
50 Years of Controversy

George Biddle Airy (1801-1892)

Sir George Gabriel Stokes (1819-1903)

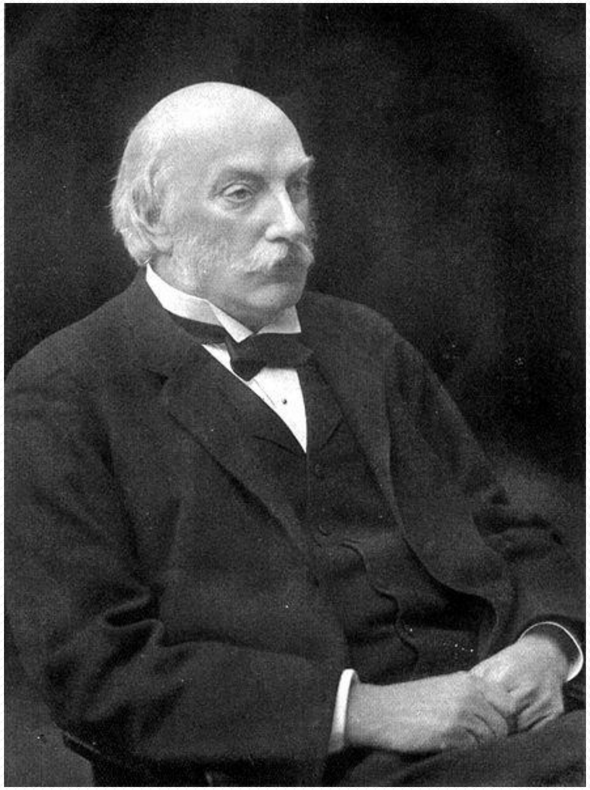
Dispersion vs Nonlinearity





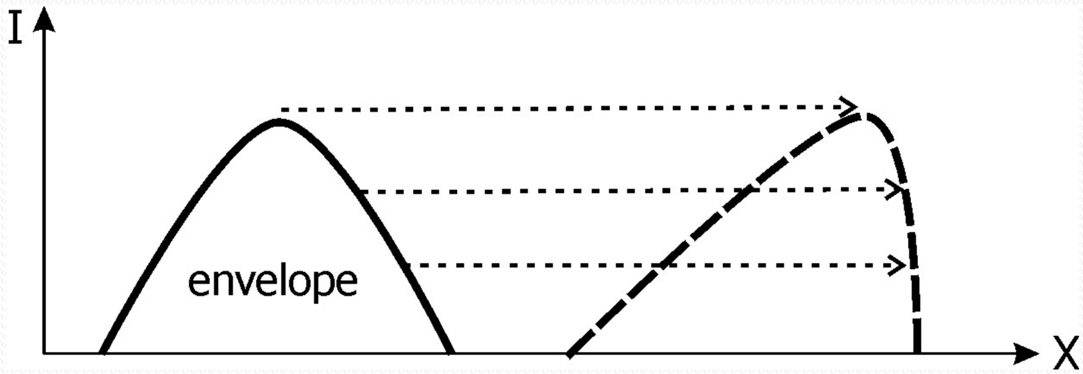
1870's – Nonlinear Theory/Solution

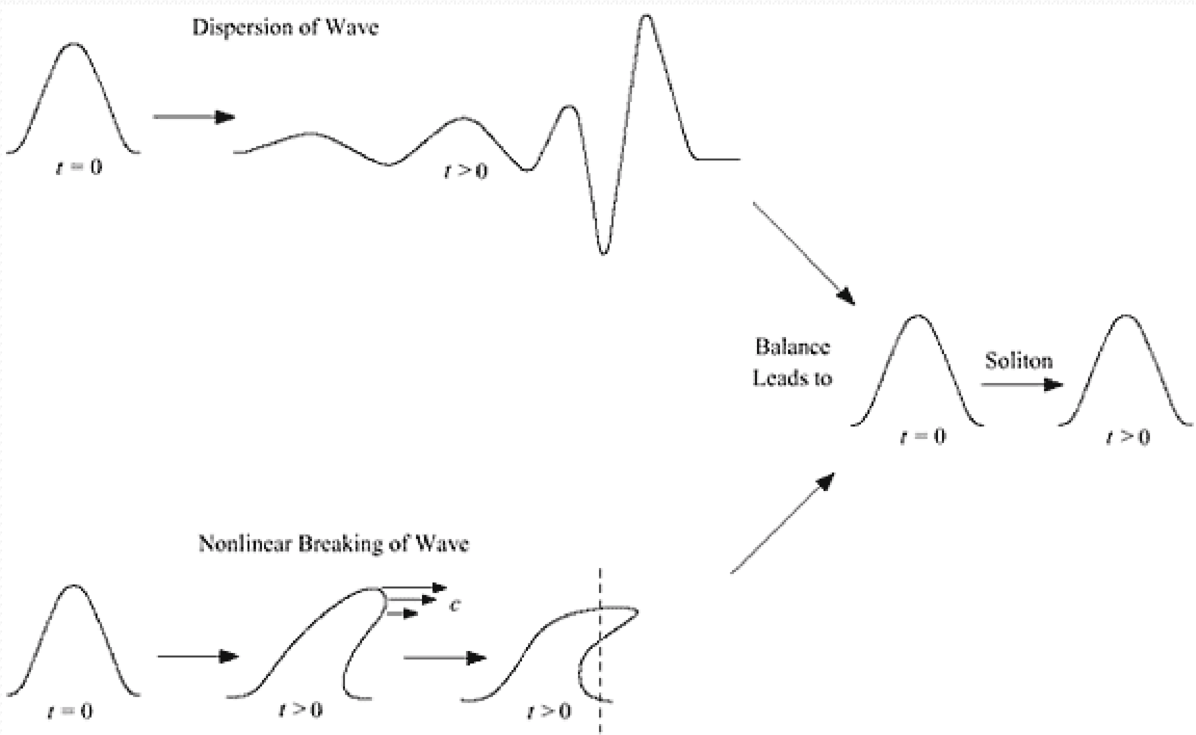
Joseph Valentin Boussinesq (1842-1929)

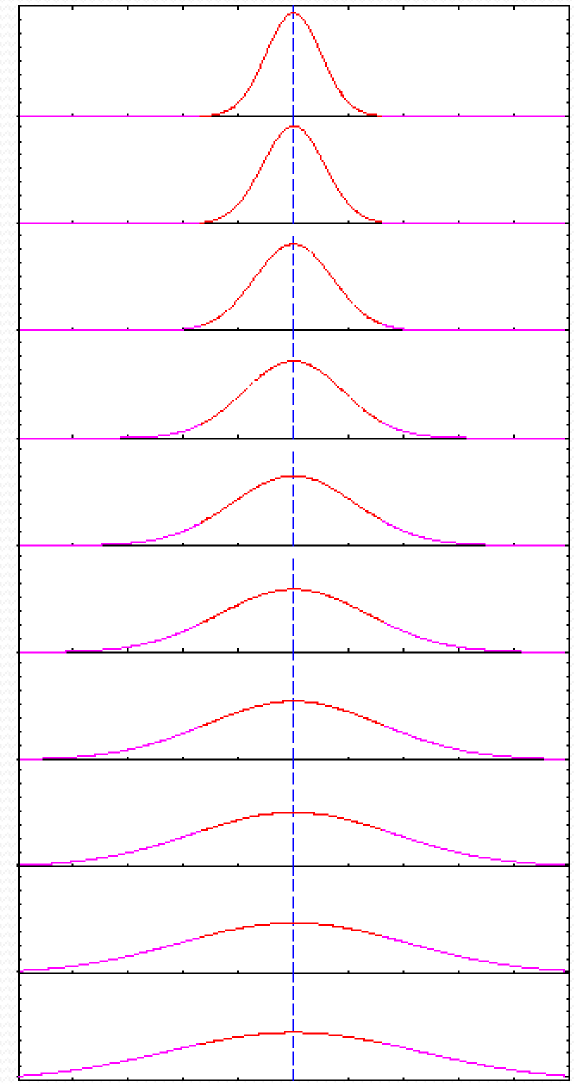


Lord Rayleigh
(John William Strutt, 1842-1919)

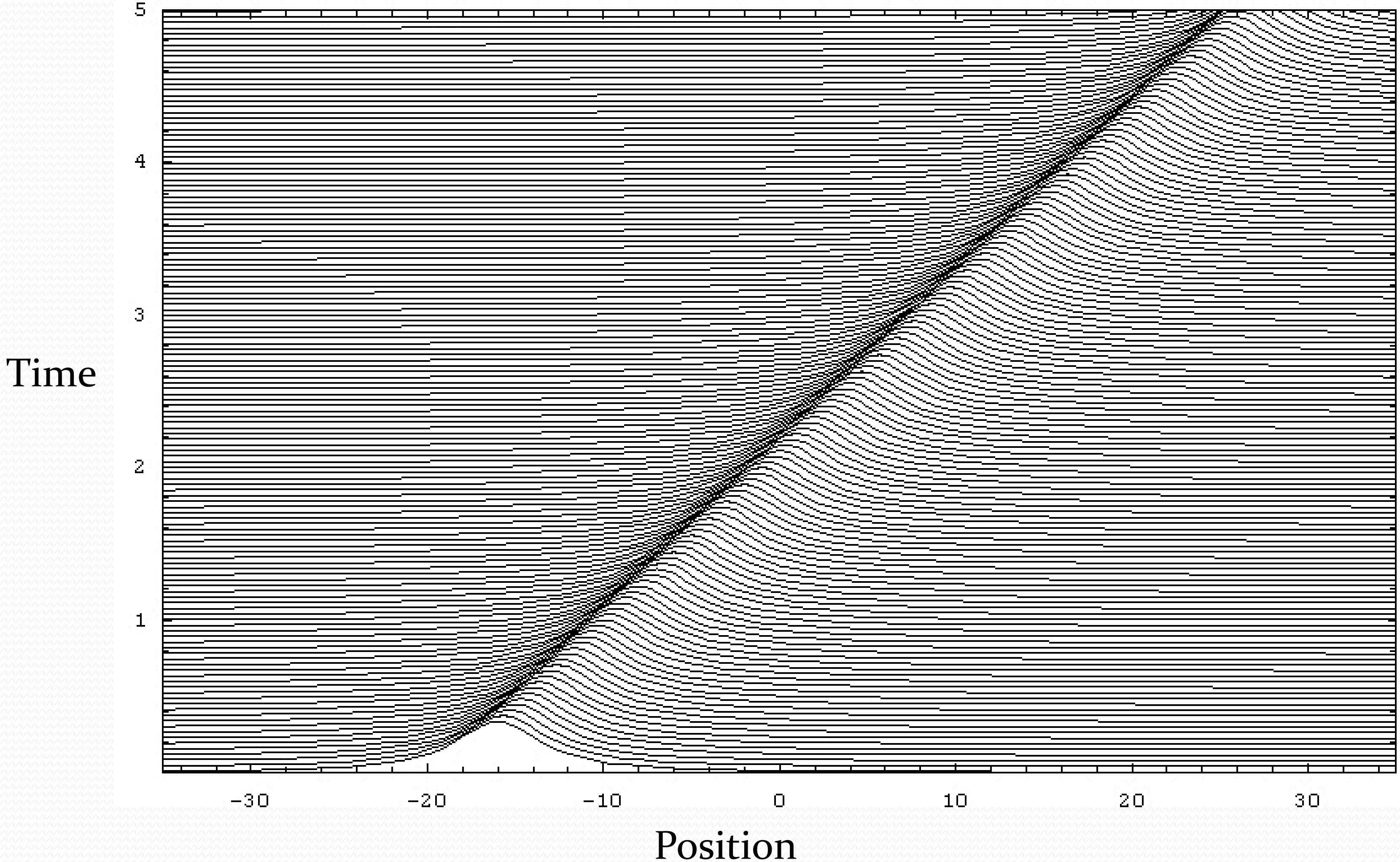
Finding the Balance







Time Evolution of Wave

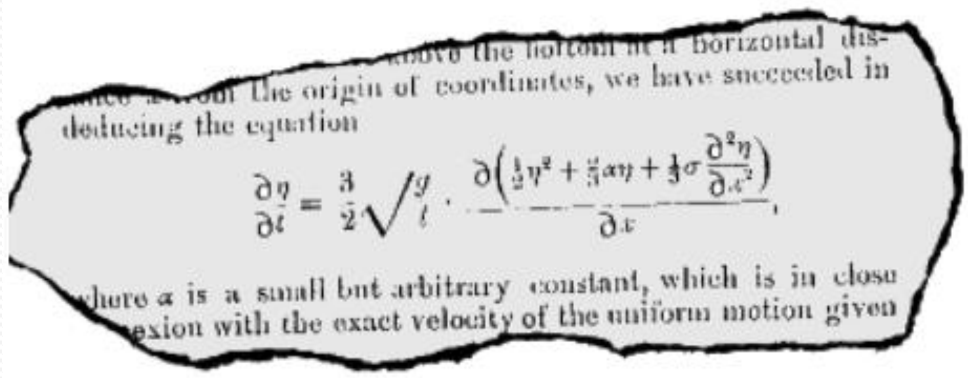


Soliton Experiment

http://www.youtube.com/watch?v=SknvLa8qEuo&feature=related

Korteweg-de Vries Equation - 1895

Diederik Johannes Korteweg
(1848-1941)



... the bottom at a horizontal dis-
... the origin of coordinates, we have succeeded in
deducing the equation

$$\frac{\partial \eta}{\partial t} = \frac{3}{2}\sqrt{\frac{g}{l}} \cdot \frac{\partial\left(\frac{1}{2}\eta^2 + \frac{2}{3}\alpha\eta + \frac{1}{3}\sigma\frac{\partial^2\eta}{\partial x^2}\right)}{\partial x},$$

where α is a small but arbitrary constant, which is in close
...exion with the exact velocity of the uniform motion given

$$u_t + uu_x + u_{xxx} = 0$$

Gustav de Vries
(1866-1934)

Fluid Equations

Navier–Stokes Equations

3 – dimensional – unsteady

Coordinates: (x,y,z) Time : t Density: ρ Pressure: p Reynolds Number: Re

Velocity Components: (u,v,w) Stress: τ Heat Flux: q Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum:

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Total Energy – Et:

$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z}$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

Lorenz – 1963 – Weather Model

The Butterfly Effect

Lorenz Equations

$$\frac{dx}{dt} = \sigma\,(y(t) - x(t))$$

$$\frac{dy}{dt} = -y(t) - x(t)\,z(t) + \rho x(t)$$

$$\frac{dz}{dt} = x(t)\,y(t) - \beta z(t)$$

Constants : $\sigma = 3;\ \rho = \dfrac{268}{10};\ \beta = 1$ **(These values determine the behavior of the trajectory)**

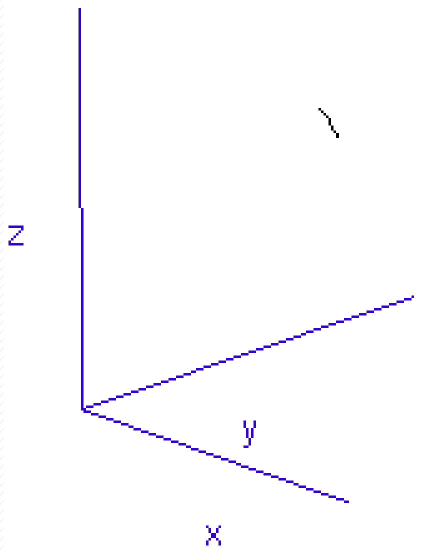
Initial Conditions : $x(t) = 0;\ y(t) = 1;\ z(t) = 0$

$x(t) \rightarrow$ **amplitude of convective currents**

$y(t) \rightarrow$ **temperature difference between rising and falling air currents**

$z(t) \rightarrow$ **normal temperature deviation**

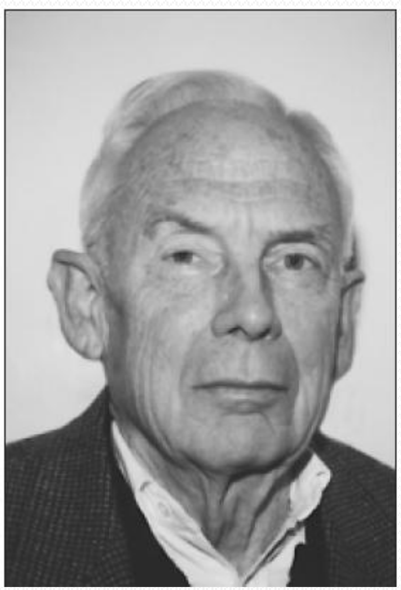
$t \rightarrow$ **time step**

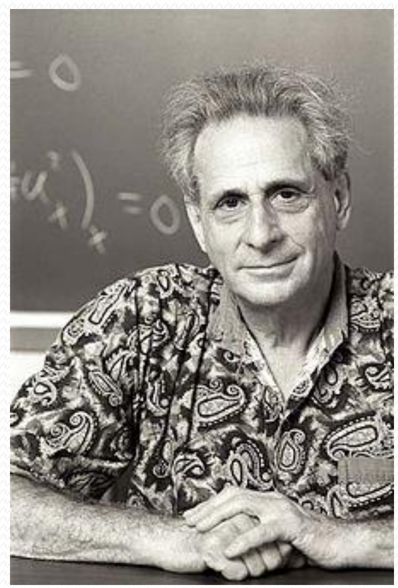
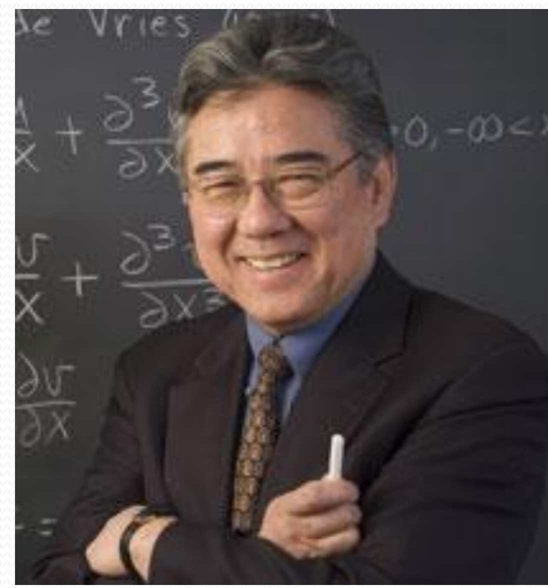


The KdV Resurgence – 1960's

Gardner, Greene, Kruskal, Miura – 1965

- Fermi, Pasta, Ulam Problem – 1954
- Coined term "soliton"
- Started a revolution



The Age of Computing

HISTORIC PHOTOS

Los Alamos scientisits Paul Stern (left) and Nick Metropolis playing chess with the MANIAC computer 1951

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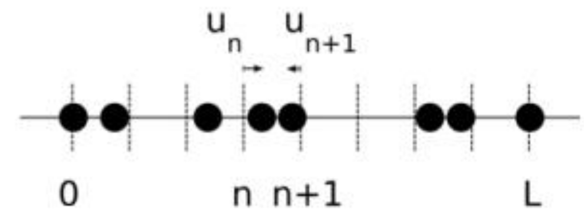
By 1956, mathematician and atomic bomb designer Stanislaus Ulam at Los Alamos programmed the Lab's MANIAC computer to play chess on a 6 x 6 chess board. This early program was easily beaten by average players.

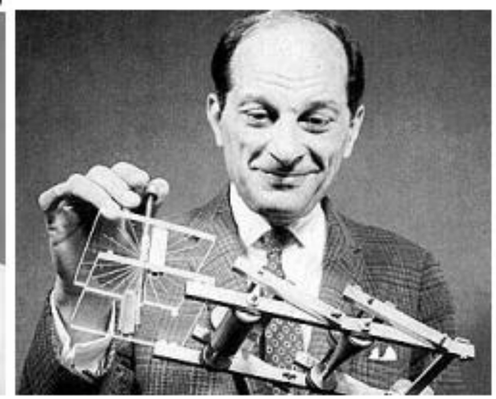
Fermi, Pasta, Ulam (FPU) Problem

Los Alamos 1955 report making beginning of nonlinear physics and the age of computer simulations

- Simulated 1D chain of masses linked by springs with weak nonlinear term.
- Linear interactions - energy of a single vibration mode remains in that mode
- Nonlinear term allows energy transfer between modes.
- Surprising behavior: The energy does not drift toward the equipartition predicted by statistical physics but periodically returns to the original mode.

And Mary Tsingou Menzel! - 2008





GGKM - Soliton Interactions

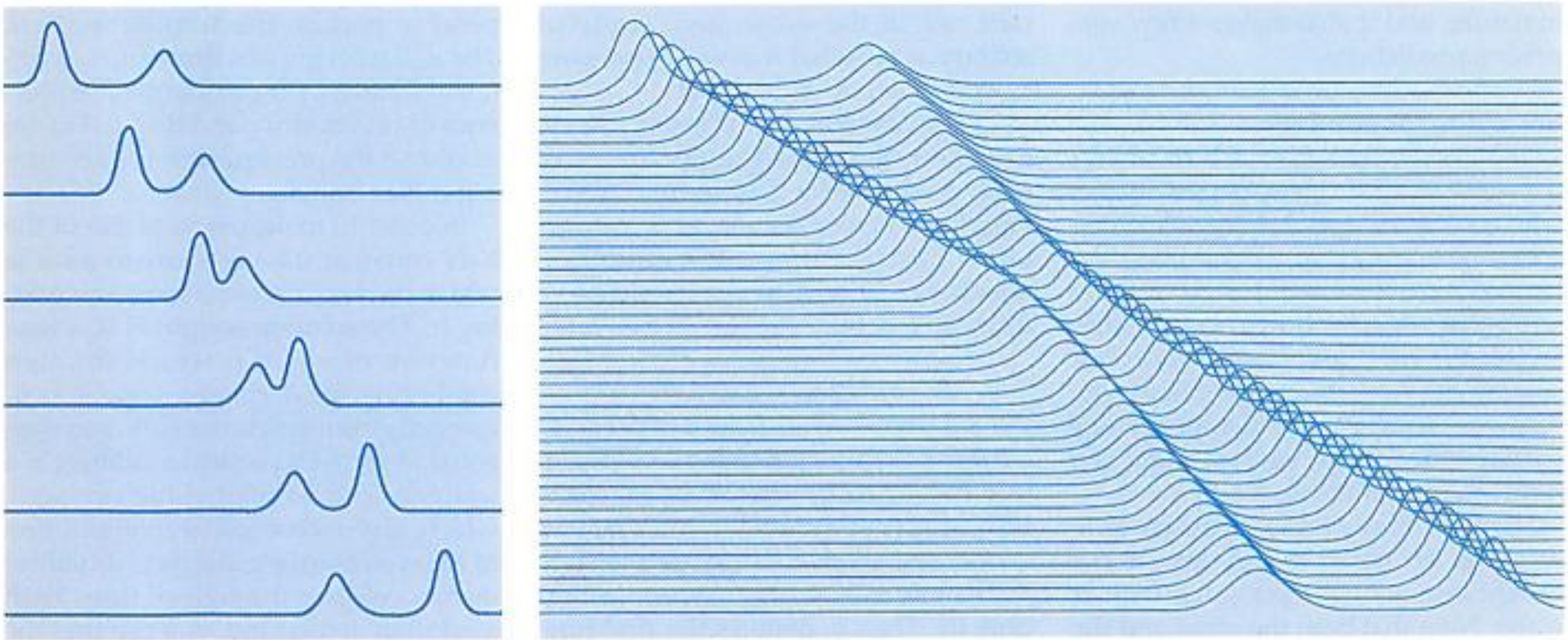
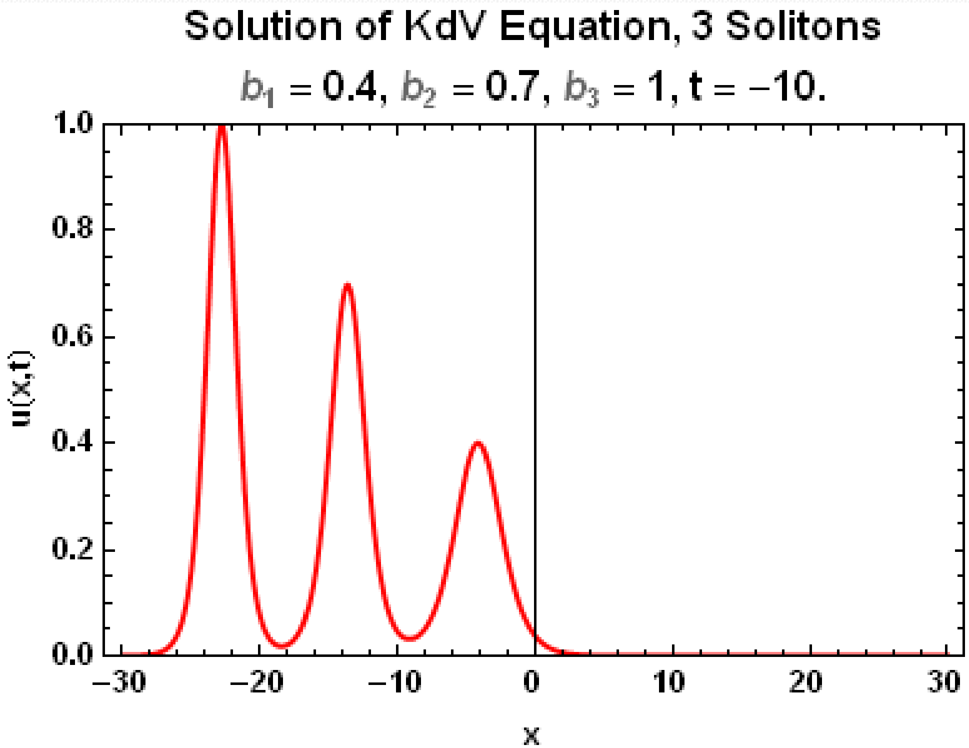
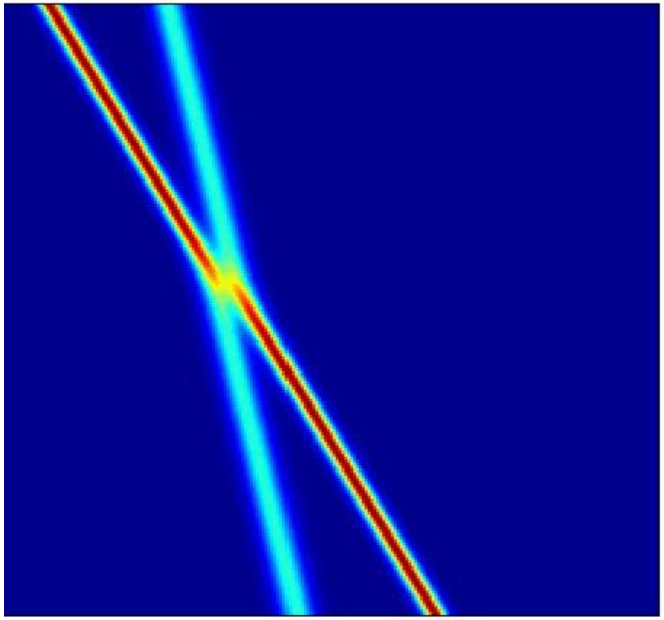


Figure 6. Solitons are solitary waves that emerge from a collision with their original shape, speed and size. If two solitons of different amplitudes are moving in the same direction *(left)*, the taller wave travels faster and eventually overtakes the shorter wave. But after the collision, the two solitons appear just as they did before the interaction. The only change is in the relative phase of the two waves: The taller, faster wave is pushed slightly forward, and the shorter, slower solitary wave is retarded slightly. The phase change is best depicted by arranging tracings of the waves such that the y-axis is time and the x-axis is position in space *(right)*.

Solitons – Elastic Collsions

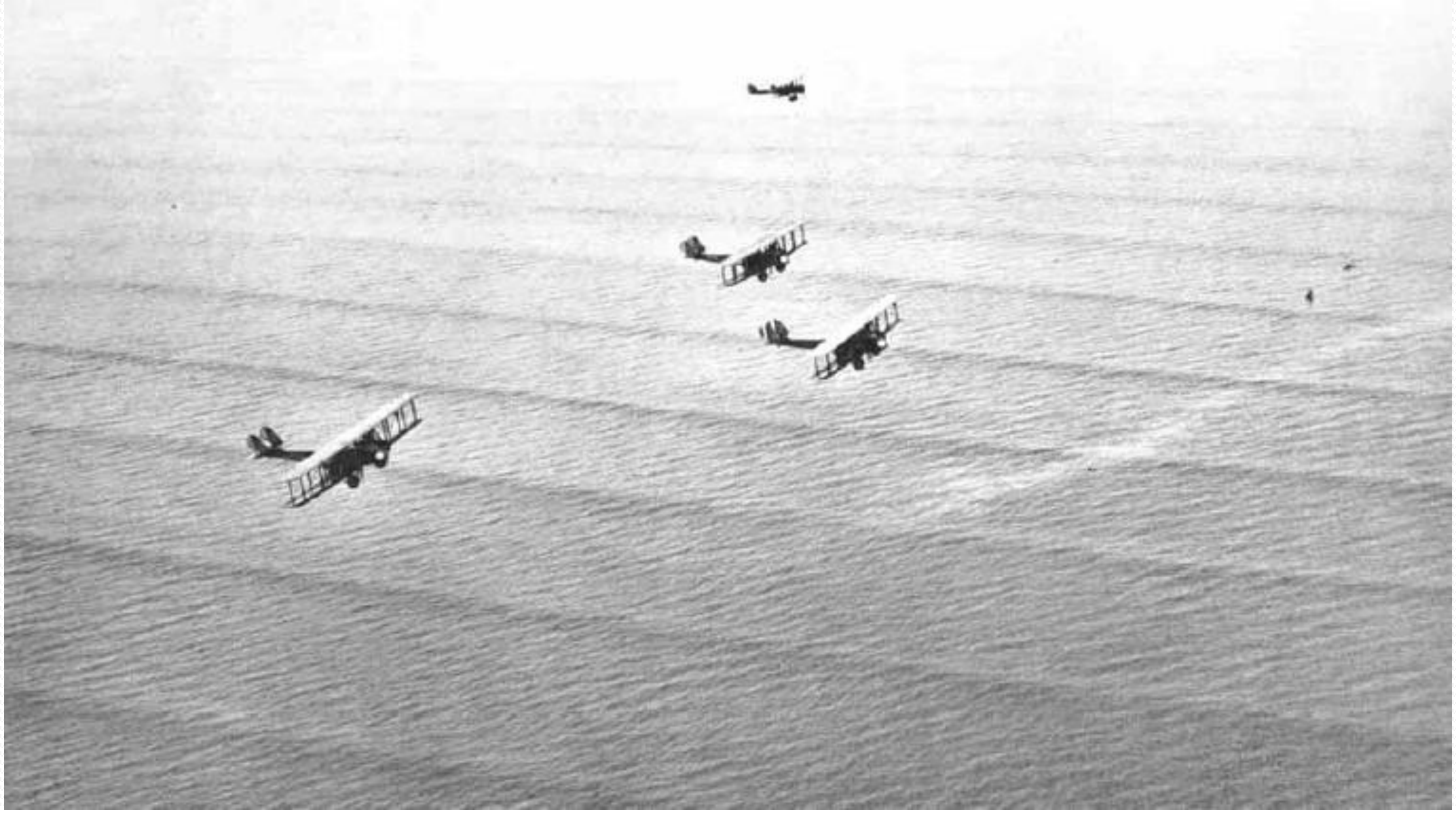




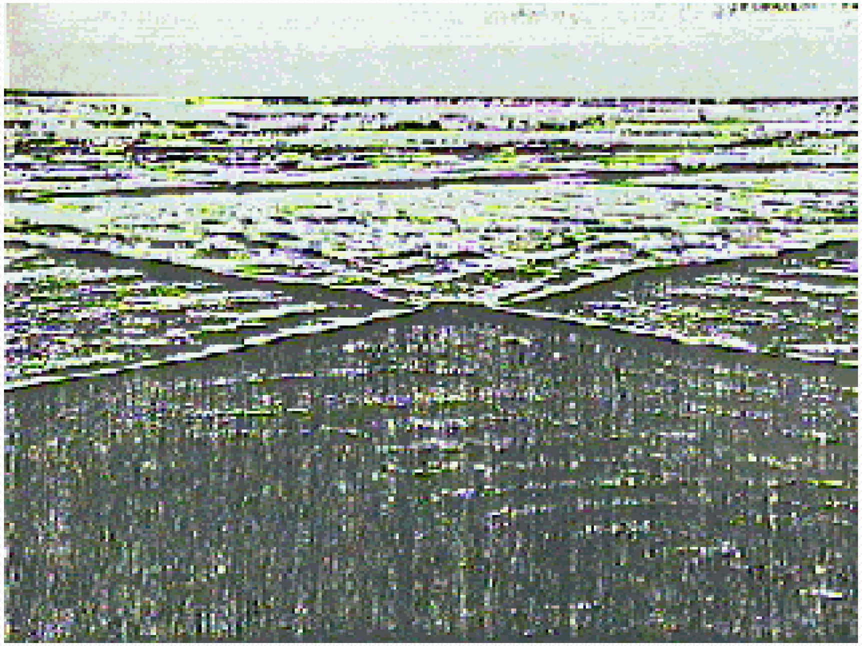
http://www.scholarpedia.org/article/Soliton

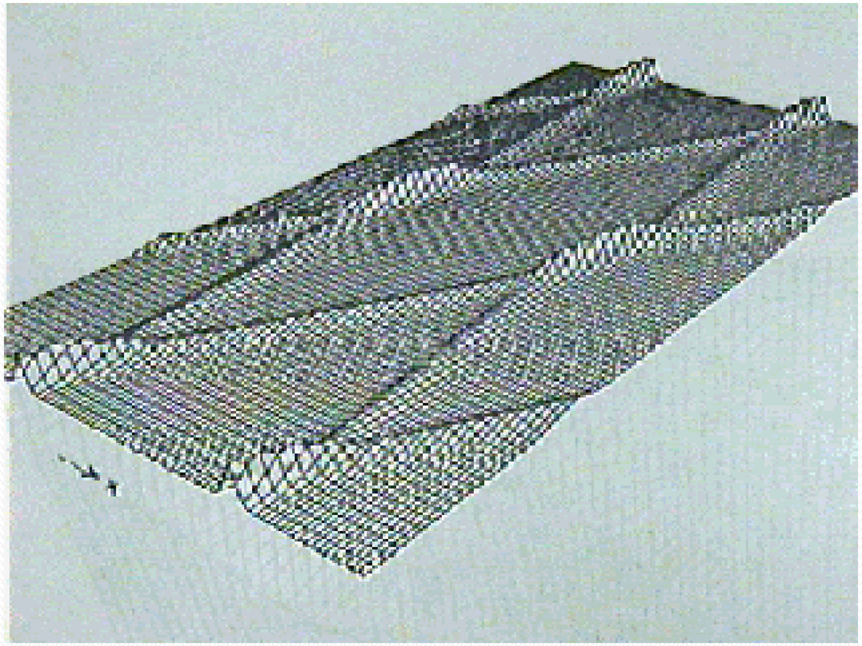
Cnoidal Waves

US Army bombers flying over near-periodic swell in shallow water, close to the Panama coast (1933).



Two-Dimensional Waves





Internal Waves

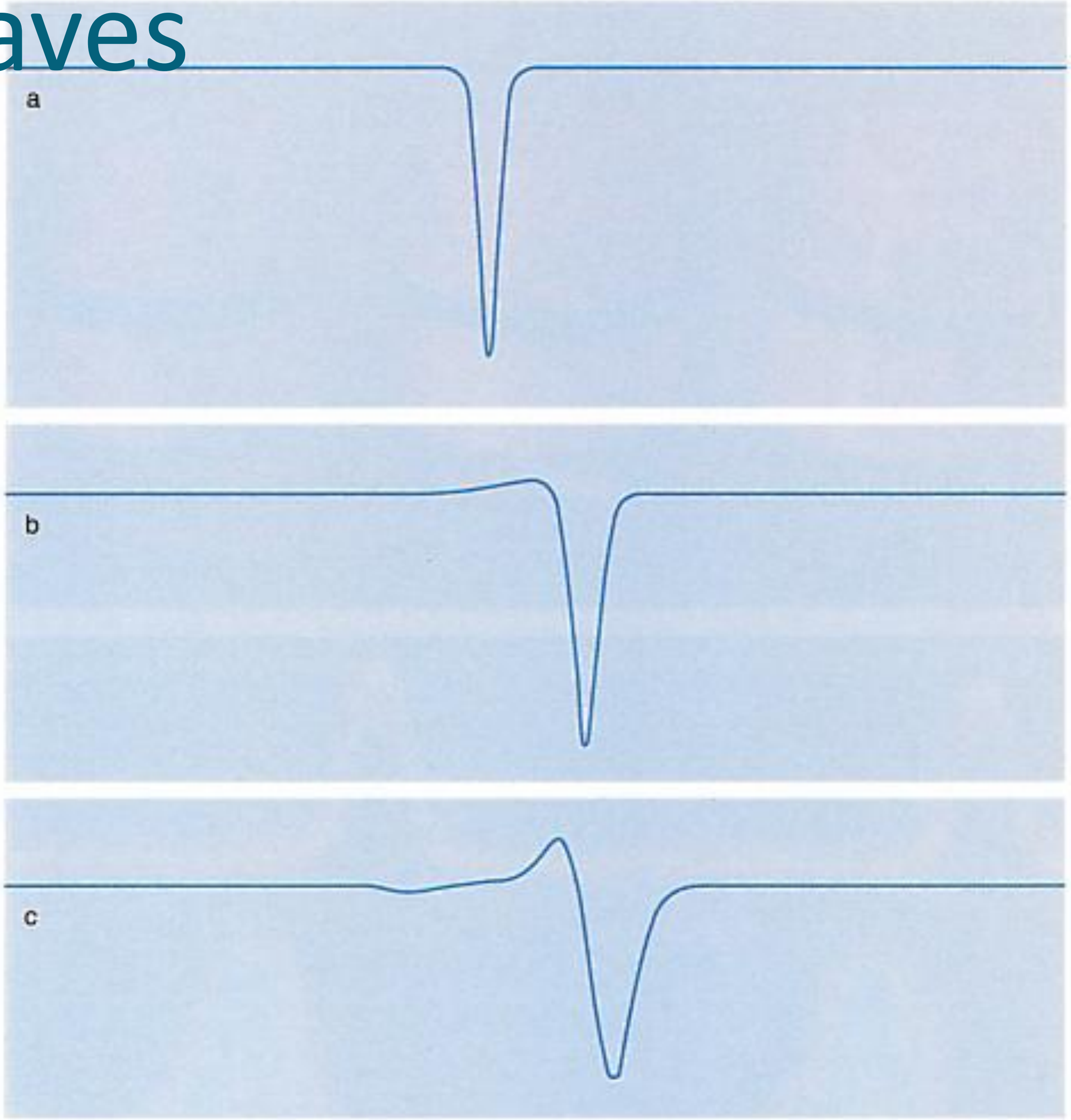
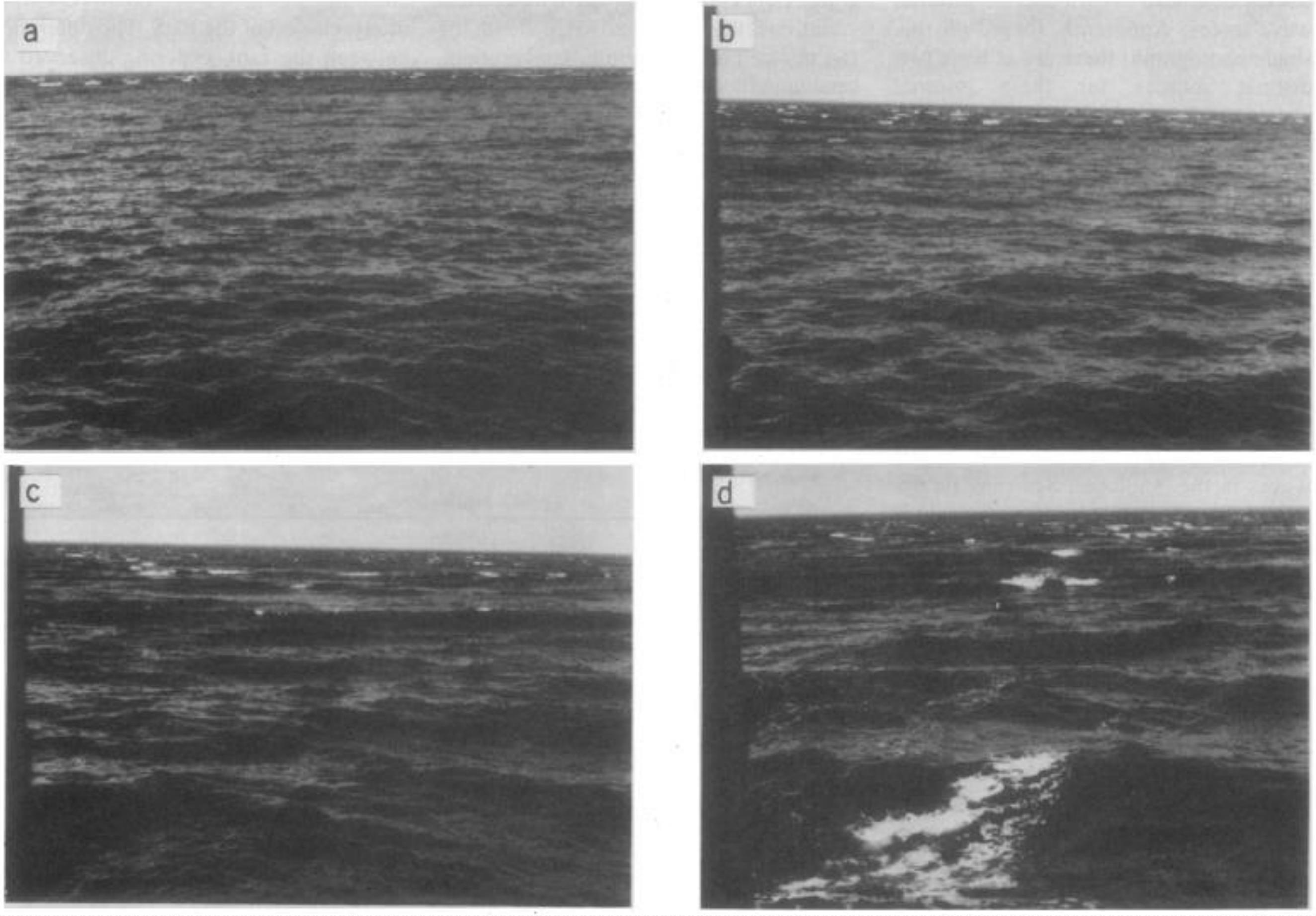


Figure 9. Internal solitary waves, of the kind observed in the Andaman Sea, can be modeled mathematically with the Korteweg-de Vries (KdV) equation, a hydrodynamic wave equation with weakly dispersive and weakly nonlinear terms. The wave travels along a thermal boundary between warmer and cooler water. It begins as a downward, finger-like excursion of warm water *(a)*, traveling into progressively shallower water. As the water depth decreases, the nonlinear term in the KdV equation becomes very small, and the wave disperses, becoming shorter and broader. At the same time, some water is forced backward, creating an elevated shelf behind the wave *(b)*. At a given depth—called the turning point—the nonlinear term becomes zero, and the wave is purely dispersive *(c)*. Beyond the turning point, however, the nonlinear term begins to increase, but it has reversed in sign. This creates a new solitary wave, but one that extends upward *(d)*. The original solitary wave disappears through dispersion *(e)*, and the new solitary wave races away *(f)*.

Rip Waves

Osborne and Burch - *Science*, New Series, Vol. 208, No. 4443 (May 2, 1980), pp. 451-460



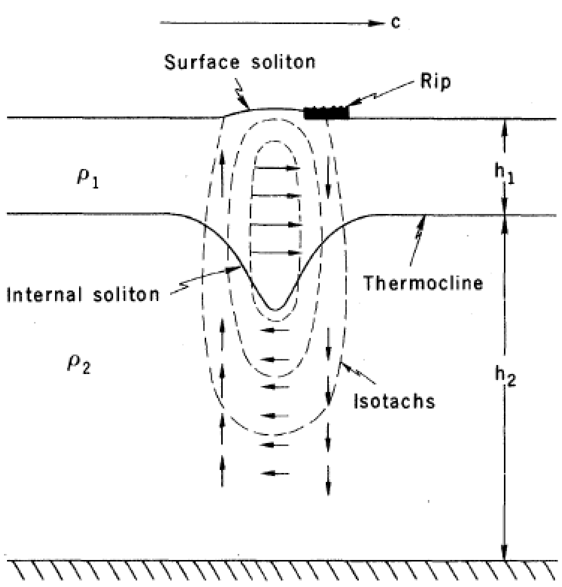


Fig. 3. An internal soliton in a two-layer fluid of finite depth is a wave of depression when $h_1 < h_2$. Dashed lines are lines of constant water particle speed (isotachs); the arrows indicate the magnitude and direction of the water particles. A small surface soliton of amplitude $\sim (\rho_2 - \rho_1)\eta_0$ accompanies the internal soliton (*35*). The approximate location of the surface rips, as observed in our Andaman Sea measurements, is also shown.

Internal

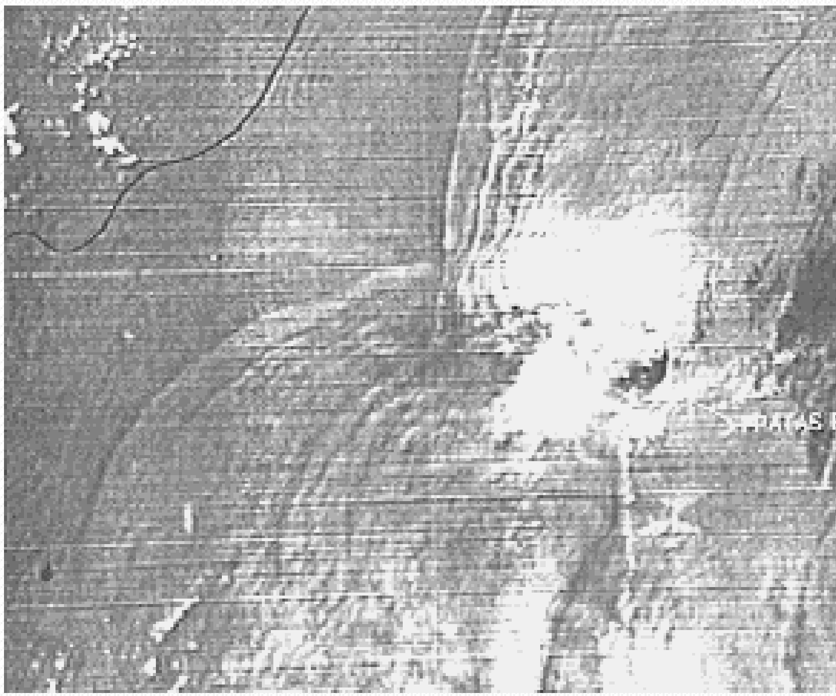
About the Authors

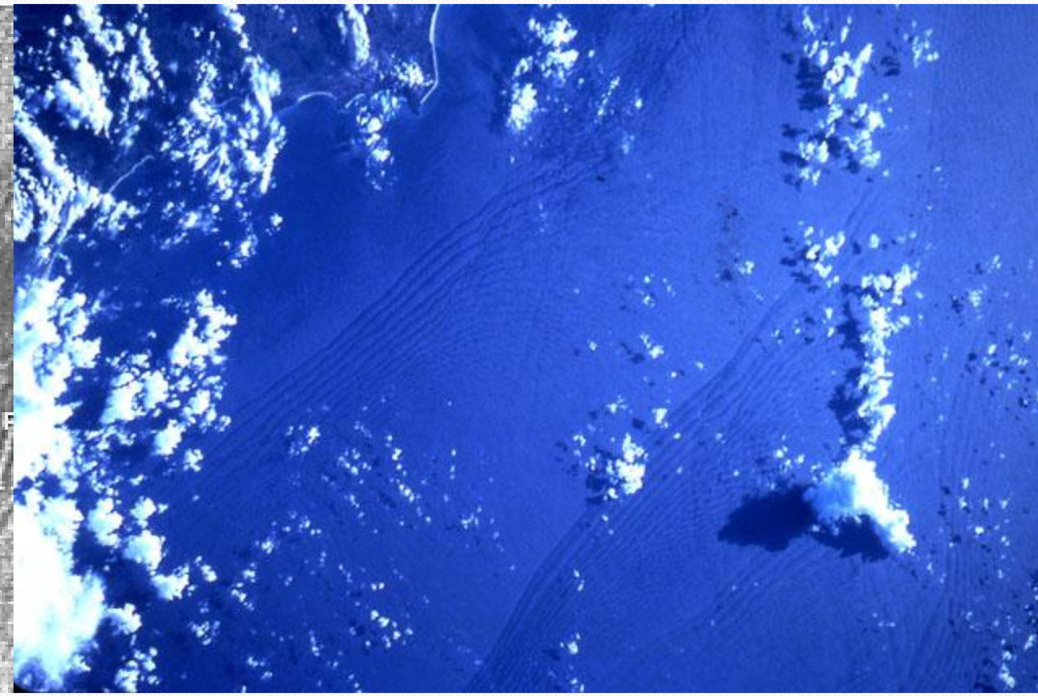
Martin Goff, CSci CMarSci MIMarEST, Senior

Dr Gus Jeans CSci CMarSci MIMarEST, Consultancy

Figure 1. Parallel bands on the surface of the Andaman Sea, near Thailand, have been explained as a by-product of solitary waves within the sea. The bands are seen here in a photograph made from earth's orbit during the Apollo-Soyuz joint mission. Solitary waves are single undulations that travel great distances without changing in size, shape or speed. The striations visible on the Andaman Sea are surface manifestations of internal solitary waves that travel at the thermal boundary between the cooler deep water and the warmer upper water. The wave is a downward extension of the warm water into the cool water. The internal disturbance appears on the surface in bands, sometimes more than 100 kilometers in length, which are called rips, because sailors attributed them to uncharted shoals. (Photograph courtesy of the Johnson Space Center.)

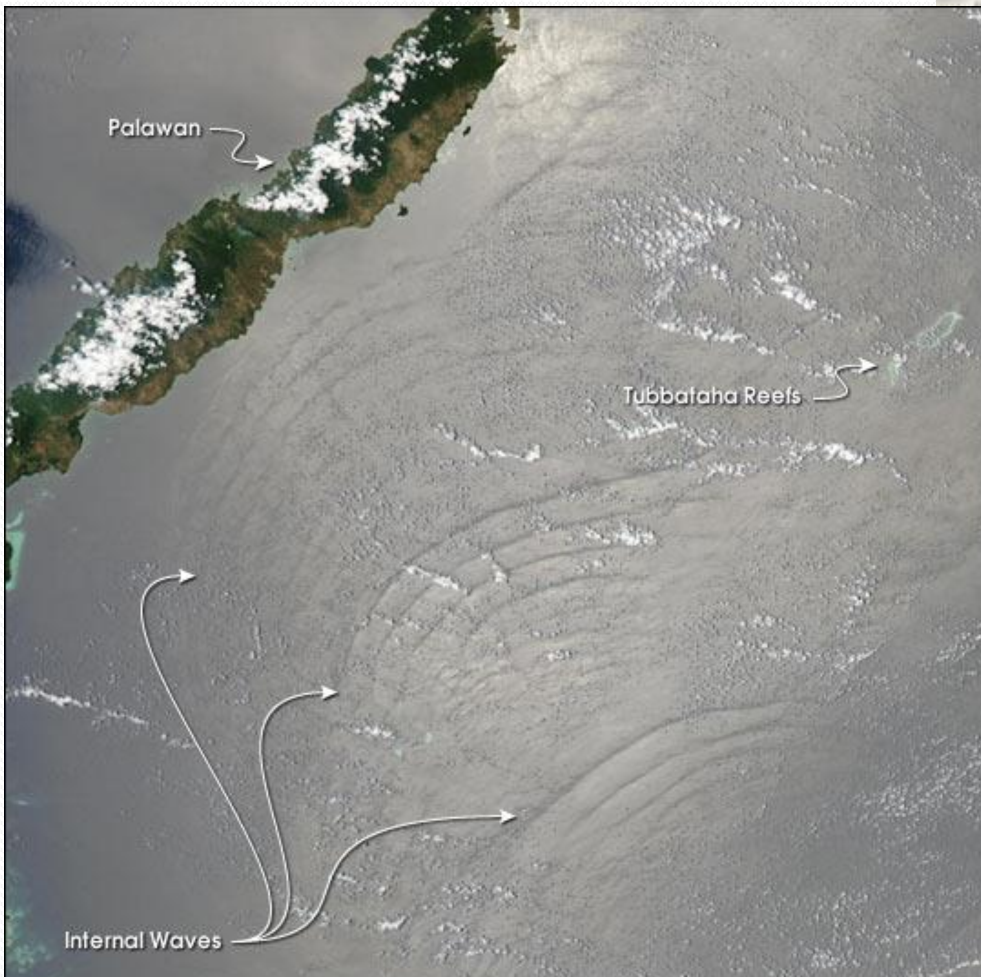
Pratas Reef/ South China Sea





http://www.lpi.usra.edu/publications/slidesets/oceans/oceanviews/slide_18.html

Sulu Sea


Palawan
Tubbataha Reefs
Internal Waves


MONGOLIA
GOBI DESERT
Ürümqi
Baotou
Beijing
Shenyang
NORTH KOREA
Pyongyang
Seoul
SOUTH KOREA
Pusan
Dalian
Tianjin
Jinan
Taiyuan
Qingdao
Yellow Sea
Sea of Japan
JAPAN
Tokyo
Yokohama
Nagoya
Osaka
Fukuoka
Lanzhou
Xi'an
Zhengzhou
Nanjing
Shanghai
CHINA
Wuhan
Hangzhou
Chengdu
Changsha
Chongqing
Nanchang
East China Sea
Okinawa
RYUKYU ISLANDS (JAPAN)
Tropic of Cancer
Taipei
Taiwan
Lhasa
Everest
BHUTAN
Thimphu
Guiyang
Kunming
Guangzhou
Hong Kong S.A.R.
Macau S.A.R.
Nanning
Dhaka
Chittagong
Mandalay
BURMA
Hanoi
Haiphong
LAOS
Vientiane
Rangoon
Hue
THAILAND
Bangkok
VIETNAM
CAMBODIA
Phnom Penh
Ho Chi Minh City
Gulf of Thailand
Andaman Sea
ANDAMAN ISLANDS (INDIA)
NICOBAR ISLANDS (INDIA)
South China Sea
SPRATLY ISLANDS
Philippine Sea
Luzon
Manila
PHILIPPINES
Cebu
Mindanao
Davao
Sulu Sea
Celebes Sea
Bandar Seri Begawan
BRUNEI
MALAYSIA
Kuala Lumpur
Medan
Singapore
SINGAPORE
Borneo
Pontianak
Equator
Celebes
Makassar
Banda Sea
Sumatra
Palembang
INDONESIA
Jakarta
Java Sea
Surabaya
Semarang
Bandung
Java
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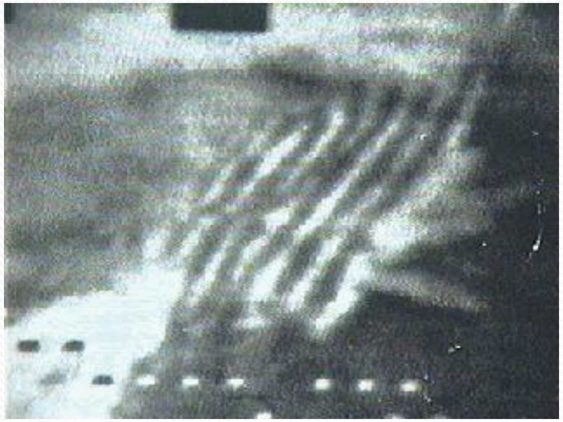
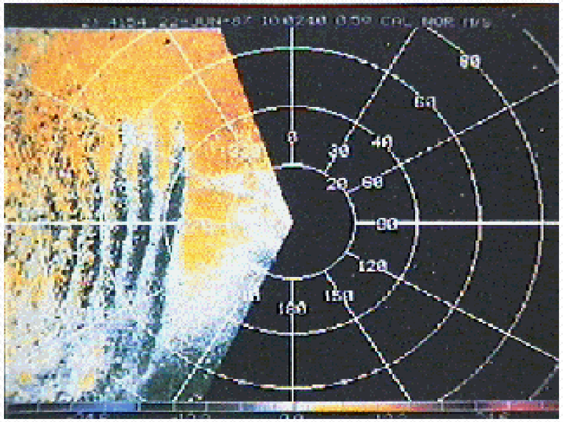
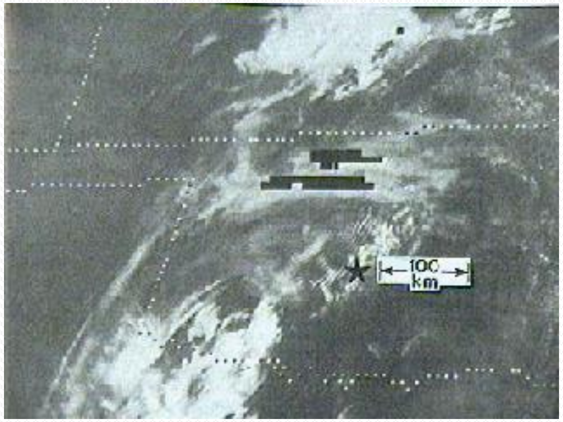
Atmospheric Solitons

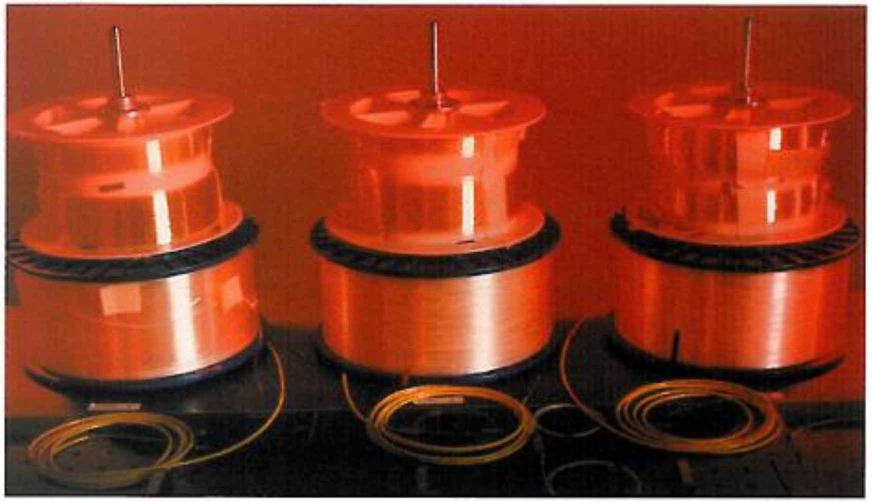






Optical Communications

Nonlinear Schrodinger Equation



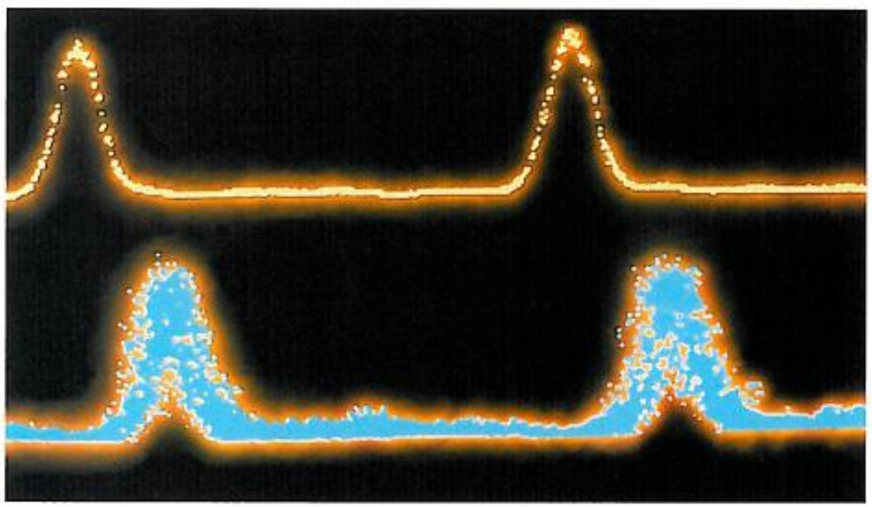


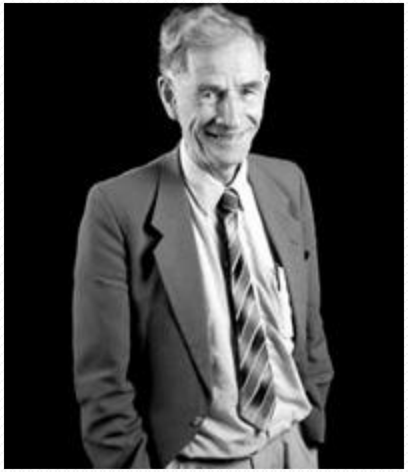
Figure 10. Fiber-optic communications could be enhanced by encoding information in solitons. Investigators at AT&T Bell Laboratories have been experimenting with soliton propagation since they first transmitted one through an optical fiber in 1980. Here the oscilloscope trace of a series of solitons is shown before *(yellow trace)* and after *(blue trace)* traveling 10,000 kilometers in an optical fiber. The pulses show little tendency to dispersion.

1973 Hasegawa Tappert predicted optical solitons and use in communications
1987, the first experimental observation of the propagation in an optical fiber.
1988, Mollenauer and his team transmitted soliton pulses over 4,000 kilometers.
1991, Bell Labs team transmitted solitons error-free at 2.5 gigabits over more than 14,000 kilometers.
1998, Georges and his team demonstrated a data transmission of 1 terabit per second (1,000,000,000,000 units of information per second).
2001, the practical use of solitons became a reality when Algety Telecom deployed submarine telecommunications equipment in Europe carrying real traffic using John Scott Russell's solitary wave.

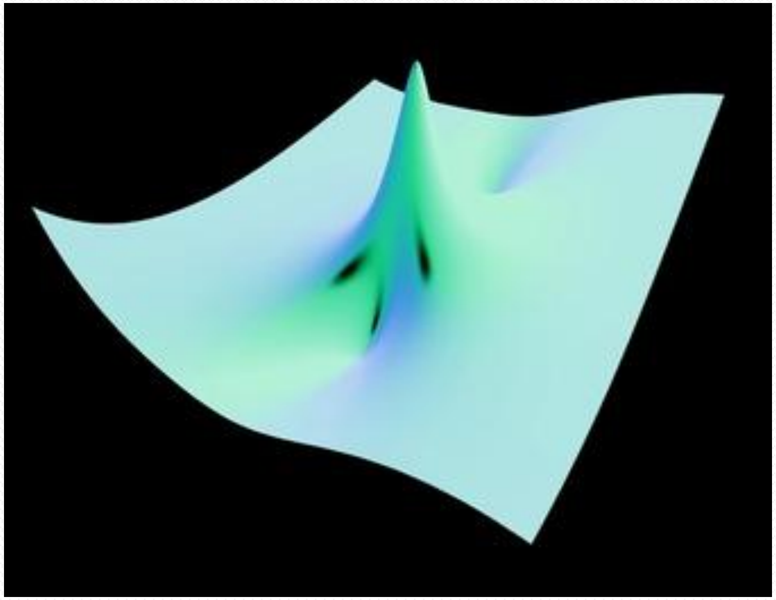
Peregrine Soliton

1983 – Peregrine predicted spatio-temporal evolution of an NLS soliton

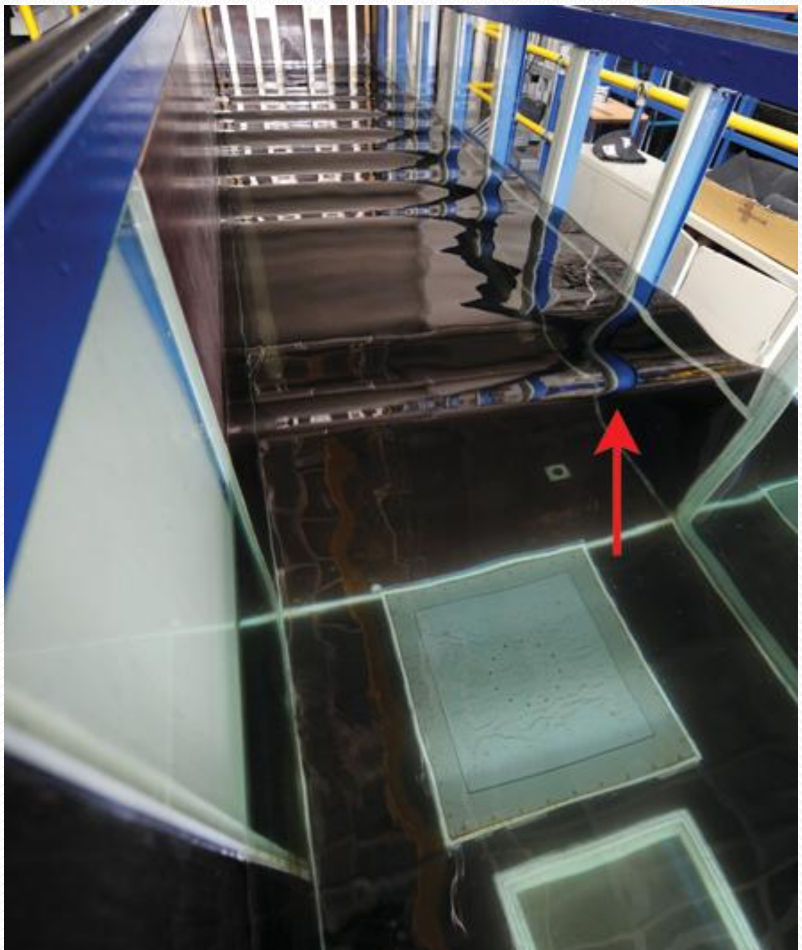
20 years later – used as protypical example of rogue waves – in water and in optics.



Howell Peregrine (1938 –2007)



Rogue Waves – 2010



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Rogue waves captured

Re-creating monster swells in a tank helps explain their origin

By Devin Powell
June 18th, 2011; Vol.179 #13 (p. 12)

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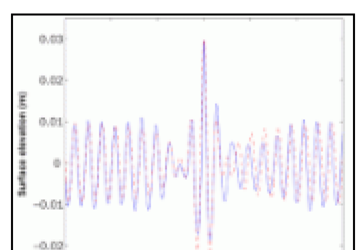
Wave gauges in a water tank spot the peak of a tiny rogue wave.
Amin Chabchoub

Freak waves that swallow ships whole have been re-created in a tank of water. Though these tiny terrors are only centimeters high, a devilishly difficult mathematical equation describing their shape may help to explain the origins of massive rogue waves at sea..

Sailors have long swapped stories about walls of water leaping up in the open ocean — even in calm water — without warning or obvious cause. But for centuries, rogue waves were little more than talk; no one had ever measured one with scientific instruments.

Then on New Year's Eve of 1995, a laser on an oil rig off Norway's coast recorded one of these rare events: a wave 26 meters from bottom to top, flanked by deep troughs on either side.

This wave and others measured since look like breather waves, says Amin Chabchoub, a mathematician at the Hamburg University of Technology in Germany. A breather wave is an anomaly in a series of waves that sucks in the energy of its neighbors and puffs itself up to a great height.



The nonlinear interactions that allow for this energy theft were described by mathematician Howell Peregrine in 1983. His solutions of nonlinear Schrödinger equations showed that pulselike waves called Peregrine solitons can pop out of sine waves under certain conditions.

… The Research Continues

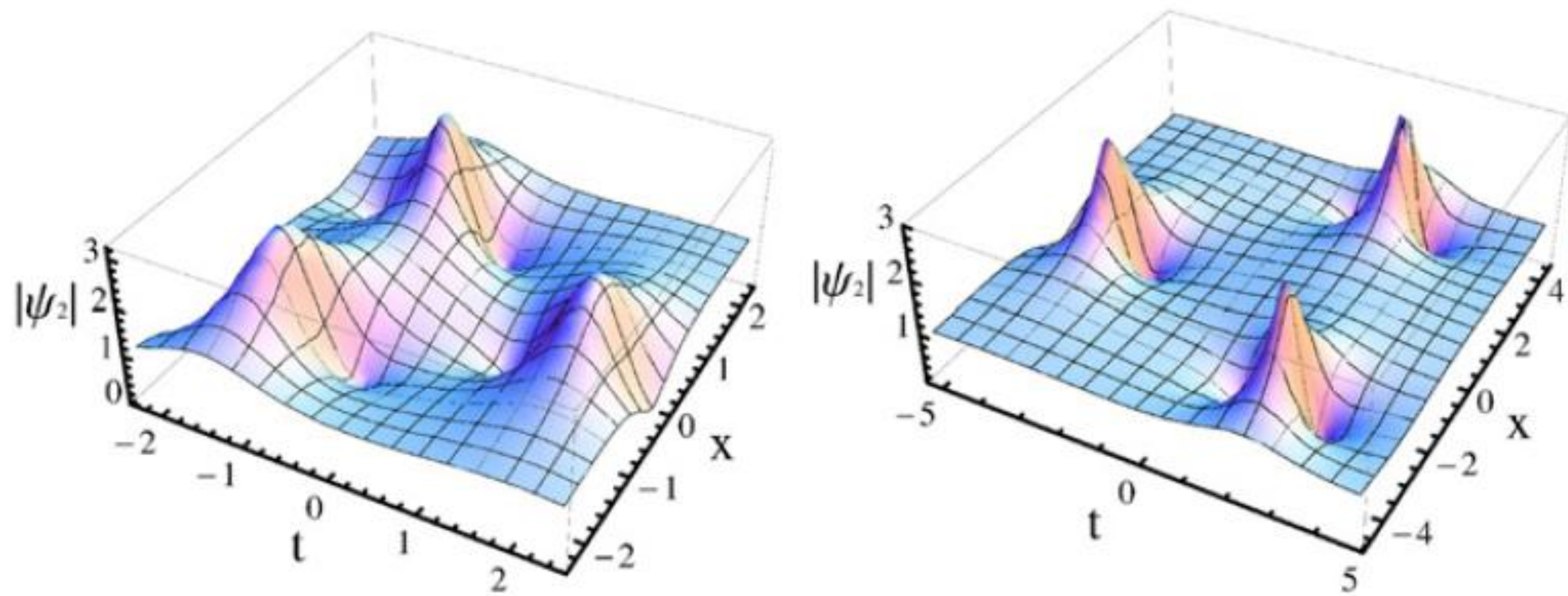


Fig. 3. Rogue wave triplets. Parameters (a) $\gamma = 20$ and $\beta = 40$; (b) $\gamma = 100$ and $\beta = -400$.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