From Nature to Plasma Physics

Waleed Moslem
Port Said University
The British University

Aim of the lecture

- How the scientific research was developed
- Learn how to think.....not what to think
- General outline to the school lectures
- Nature observation in plasma physics

Outline

- Soliton
- Cnoidal
- Tsunami
- Envelope soliotn
- Rogue wave
- Mach Cones
- Wakefield
- Water droplet
- St. Elmo's fire
- AGN
- Sun & Stars
- Lightning
- Kelvin–Helmholtz
- Rayleigh–Taylor

Why Nature?

- Nature → (Matter & Motion & Energy & Force….) → Physics → How the Universe Behaves
- Why? Development of new products → Improvement/development our modern-day society

Why Waves?

What is the importance to study waves in plasma?

(a) Plasma fingerprints appear in wave emissions. Thus, they are useful in faraway or unavailable plasma observation. They can serve as diagnostic tools.

(b) Plasma waves are essential for several processes, including energy transfer, ionospheric loss, particle acceleration, lightning, and heating.

Soliton

- In 1834, while conducting experiments to determine the most efficient design for canal boats, he discovered a phenomenon that he described as the **wave of translation**
- Stable – Large distances – Speed(size) – Width(depth) – Never merge – Splits into two waves

John Scott Russell
(1808-1882)

Soliton, cont.

REPORT

OF THE

FOURTEENTH MEETING

OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT YORK IN SEPTEMBER 1844.

LONDON:

JOHN MURRAY, ALBEMARLE STREET.

1845.

Report on Waves. *By* J. SCOTT RUSSELL, *Esq., M.A., F.R.S. Edin., made to the Meetings in* 1842 *and* 1843.

Members of Committee { Sir JOHN ROBISON*, *Sec. R.S. Edin.* / J. SCOTT RUSSELL, *F.R.S. Edin.* }

A PROVISIONAL Report on this subject was presented to the Meeting held at Liverpool in 1838, and is printed in the Sixth Volume of the Transactions. That report was a partial one. It states that "the extent and multifarious nature of the subjects of inquiry have rendered it impossible to terminate the examination of all of them in so short a time; but it is their duty to report the progress which they have made, and the partial results they have already obtained, leaving to the reports of future years such portions of the inquiries as they have not yet undertaken."

The first of these subjects of inquiry is stated to have been "to determine the varieties, phænomena and laws of waves, and the conditions which affect their genesis and propagation."

It is this branch of the duty of the Committee which forms the subject of the present report. Ever since the date of that report, it has happened that the author of this has been so fully pre-occupied by inevitable duty, that it was not in his power to indulge much in the pleasures of scientific inquiry; and as the active part of the investigation necessarily devolved upon him, it was not practicable to continue the series of researches on the ample and systematic scale originally designed, so soon as he had anticipated, so that the former report has necessarily been left in a fragmentary state till now.

But I have never ceased to avail myself of such opportunities as I could contrive to apply to the furtherance of this interesting investigation. I have now fully discussed the experiments which the former report only registered. I have repeated the former experiments where their value seemed doubtful, I have supplemented them in those places where examples were wanting. I have extended them to higher ranges, and where necessary to a much larger scale. In so far as the experiments have been repeated and more fully discussed, they have tended to confirm the conclusions given in the former report, as well as to extend their application.

The results here alluded to are those which concern especially the velocity and characteristic properties of the solitary wave, that class of wave which the writer has called the great wave of translation, and which he regards as the primary wave of the first order. The former experiments related chiefly to the mode of genesis, and velocity of propagation of this wave. They led to this expression for the velocity in all circumstances,

$$v = \sqrt{g(h+k)},$$

k being the height of the crest of the wave above the plane of repose of the fluid, h the depth throughout the fluid in repose, and g the measure of gravity. Later discussions of the experiments not only confirm this result, but are themselves established by such further experiments as have been recently instituted, so that this formerly obtained velocity may now be regarded as the phænomenon characteristic of the wave of the first order.

The former series of experiments also contained several points of research not published in the former report, because not sufficiently extended to be of

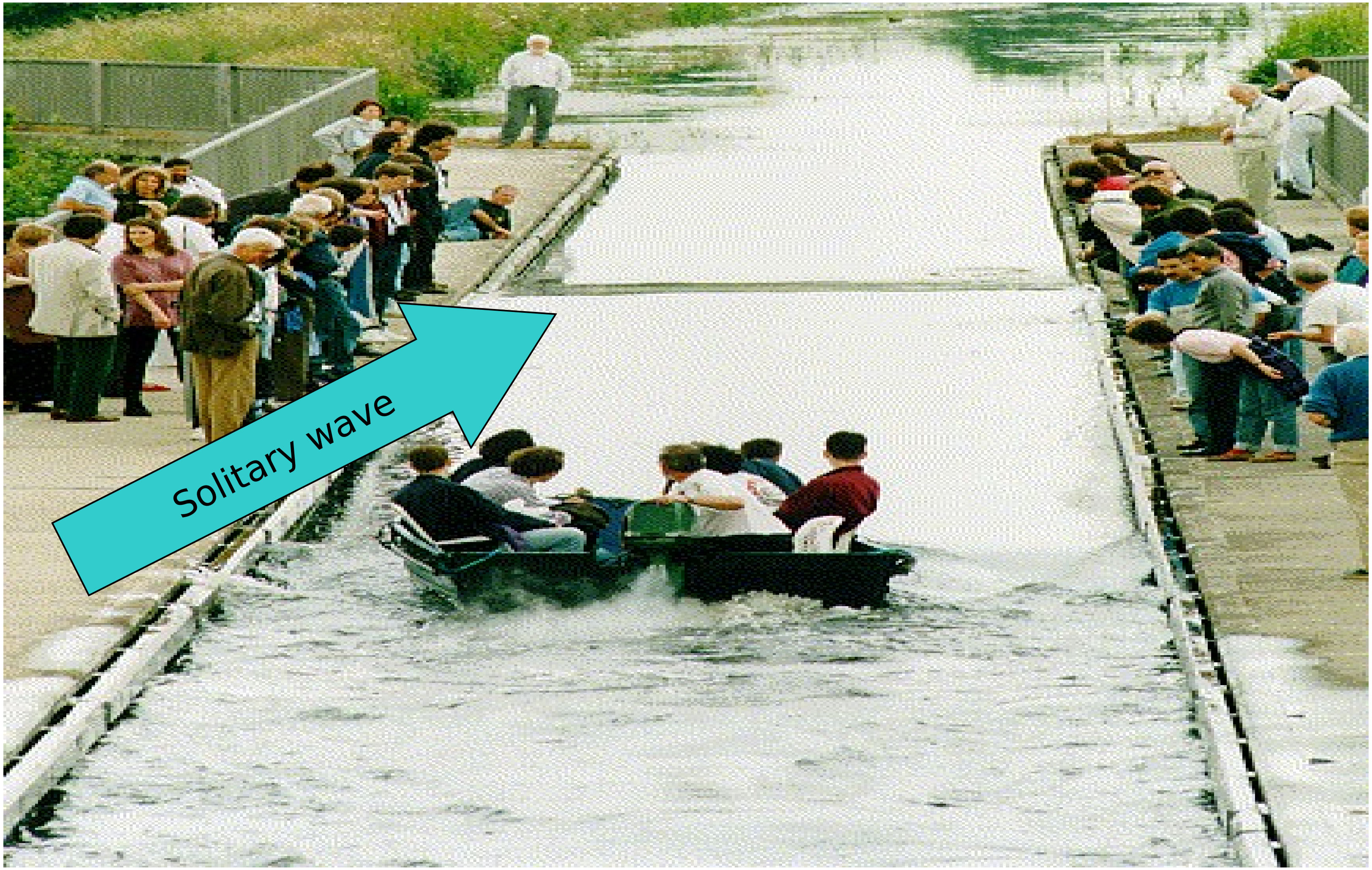
* I cannot allow these pages to leave my hands without expressing my deep regret that the death of Sir John Robison has suddenly deprived the Association of a zealous and distinguished office-bearer, and myself of a kind friend. In all these researches the responsible duties were mine, and I alone am accountable for them; but in forwarding the objects of the investigation I always found him a valuable counsellor and a respected and cordial cooperator.

Soliton, cont.

J. S. Russell Aqueduct

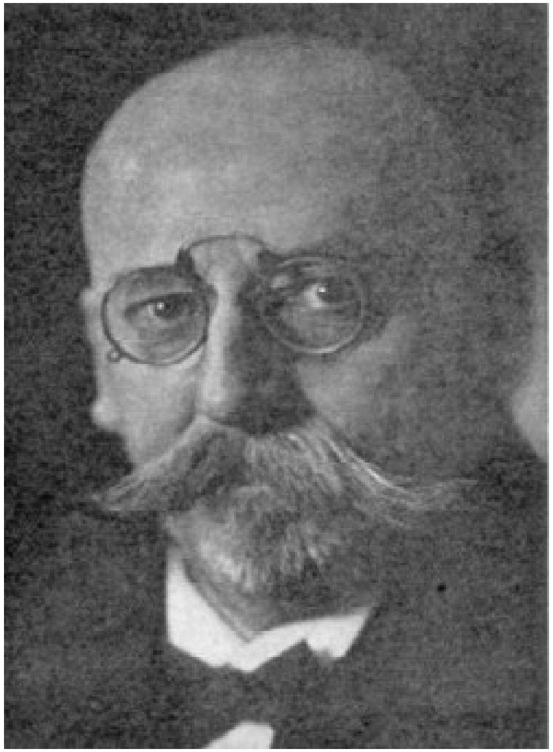
- 89.3 m long
- 4.13 m wide
- 1.52 m deep

Soliton, cont.



Soliton, cont.

Diederik Johannes Korteweg
(1848 – 1941)



Gustav de Vries
(1866 – 1934)

Soliton, cont.

$$\frac{\partial u}{\partial t} + \alpha u \frac{\partial u}{\partial x} + \beta \frac{\partial^3 u}{\partial x^3} = 0$$

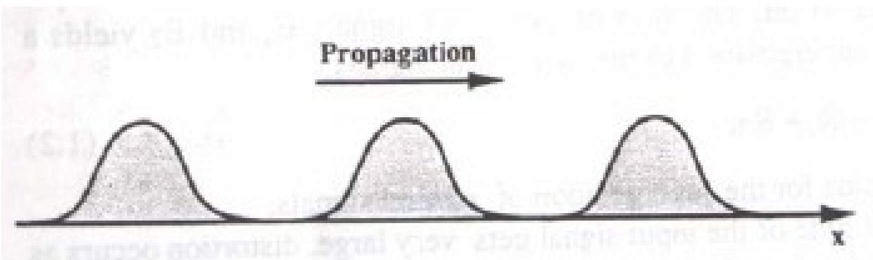
Nonlinearity

Dispersion

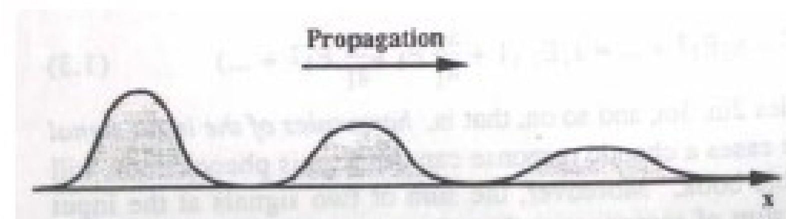
Korteweg-de Vries Equation
(1895)

Soliton, cont.

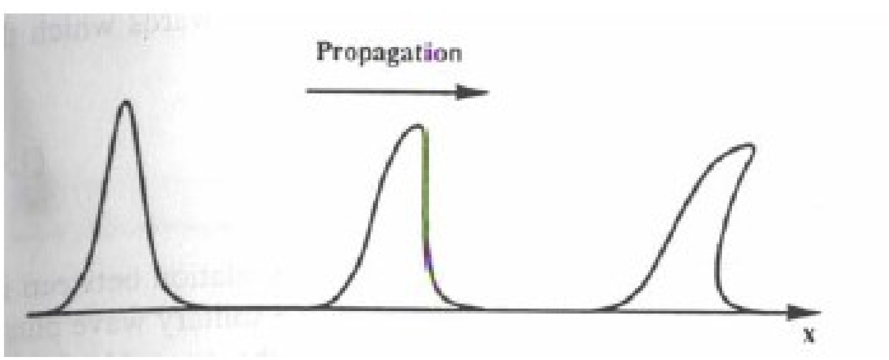
Linear & Nondispersive



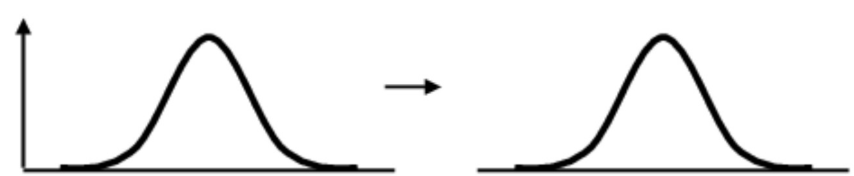
Linear & Dispersive



Nonlinear & Nondispersive



Nonlinear & Dispersive



Soliton, cont.

- Zabusky & Kruskal (1965) $\rightarrow$ numerically $\rightarrow$ solutions seemed to decompose at large times into a collection of "solitons"
- Soliton in: shallow-water waves, plasma, crystal lattice, biology, optical fiber
- Movie1 and Movie2

Soliton, cont.

VOLUME 17, NUMBER 19 PHYSICAL REVIEW LETTERS 7 NOVEMBER 1966

PROPAGATION OF ION-ACOUSTIC SOLITARY WAVES OF SMALL AMPLITUDE

Haruichi Washimi and Tosiya Taniuti
Institute of Plasma Physics, Nagoya University, Nagoya, Japan
(Received 5 August 1966)

VOLUME 25, NUMBER 1 PHYSICAL REVIEW LETTERS 6 JULY 1970

FORMATION AND INTERACTION OF ION-ACOUSTIC SOLITONS*

H. Ikezi,† R. J. Taylor,‡ and D. R. Baker
Department of Physics, University of California, Los Angeles, California 90024
(Received 11 May 1970)

Cnoidal

- Korteweg and de Vries → 1895 → KdV Eq.
- Jacobi elliptic function *cn*, which is why they are coined *cnoidal* waves
- In the limit of infinite wavelength → the cnoidal wave becomes a solitary wave.
- Surface water waves & Ion-acoustic waves in plasma physics & Optical fiber & Graphene-based superlattice & Solids & Traffic flow.......etc

Cnoidal, cont.

Cnoidal, cont.

PROCEEDINGS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

On cnoidal waves and bores

By T. B. Benjamin
Department of Engineering, University of Cambridge

and M. J. Lighthill, F.R.S.
Department of Mathematics, University of Manchester

(*Received* 13 *February* 1954)

Journal of the Physical Society of Japan, Vol. 46, No. 6, June, 1979

Propagation of Ion Acoustic Cnoidal Wave

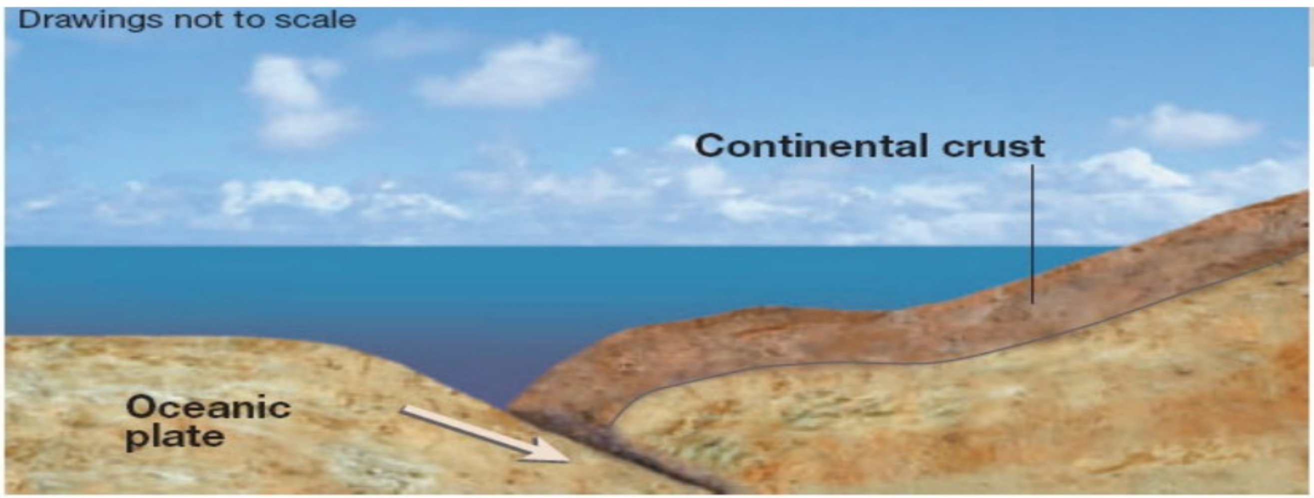
Kimiaki Konno, Teruo Mitsuhashi†
and Yoshi H. Ichikawa††

Department of Physics, College of Science and Technology,
Nihon University, Tokyo
†*Shiroyama Senior High School, Shiroyama, Kanagawa*
††*Institute of Plasma Physics, Nagoya University, Nagoya*

(Received February 5, 1979)

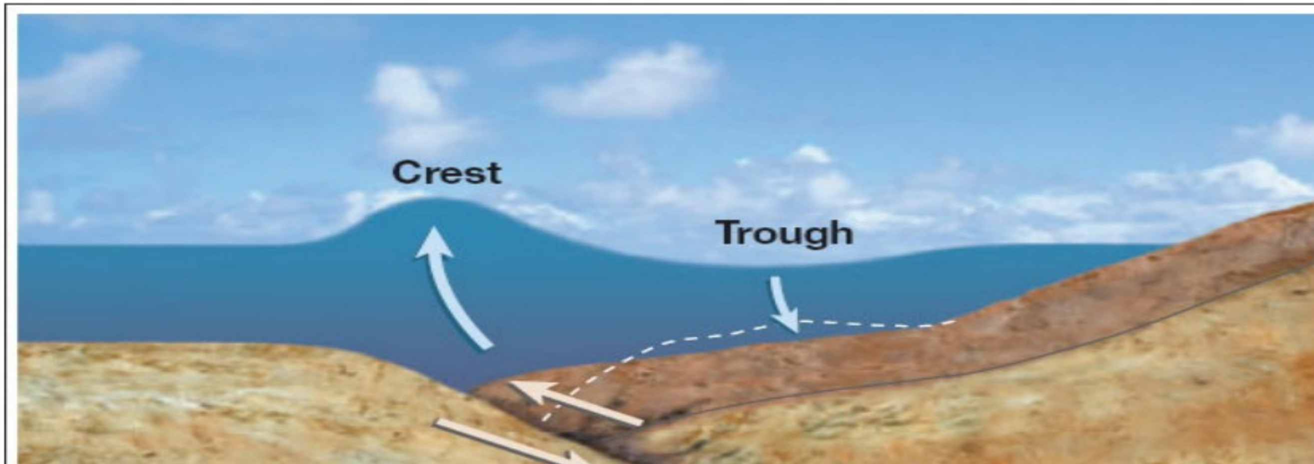
Tsunami

- What do you do if you're at the beach and the sea is receding farther than usual?



1 Before the earthquake

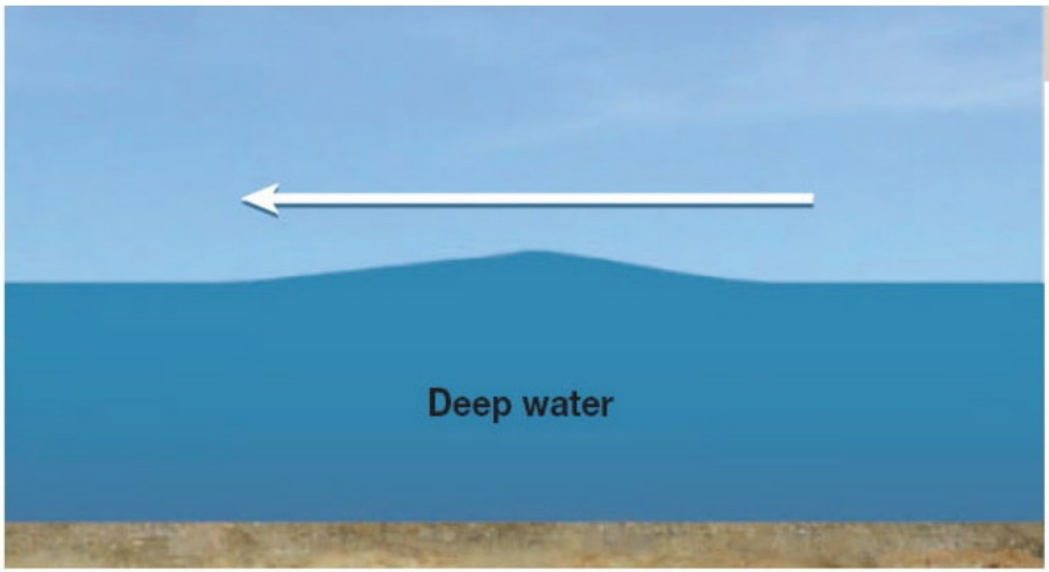
The plate holding the Indian Ocean was sliding under the continental plate (holding Indonesia and much of Asia) at about 6 cm per year. The continental crust was bent thanks to the constant pressure of collision.



2 During the quake

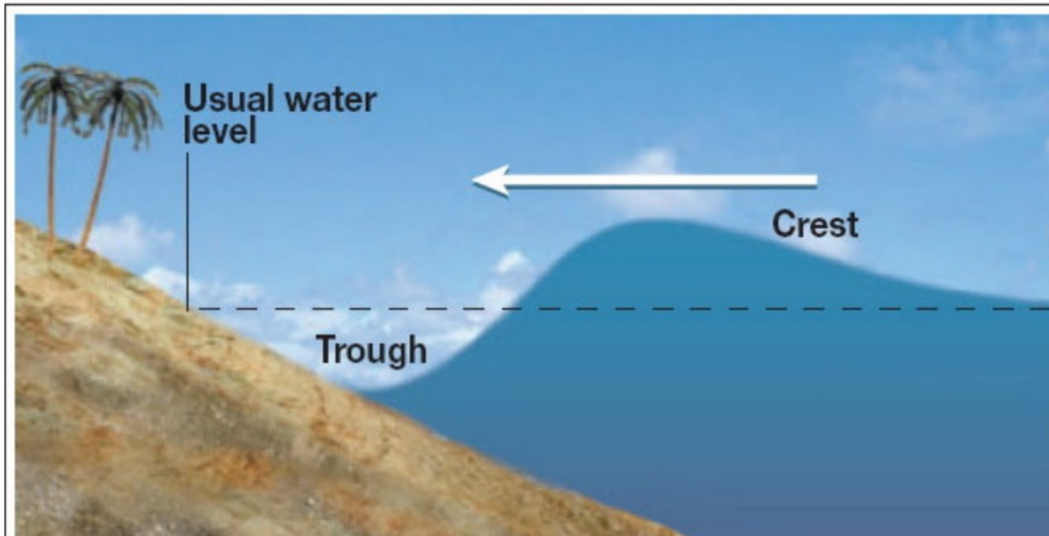
The fault ruptured violently, allowing the continental crust to unbend and causing portions of the sea floor to move up or down by several metres. The water above the fault responded in kind, creating a wave crest and trough.

Tsunami, cont.



3 The wave travels

One wave crashed towards the nearby shore of Indonesia. Another barrelled westwards at about 800 km per hour in deep water, with a wavelength of 100 km and an average wave height of just tens of centimetres.



4 Collision

When the wave entered shallow waters, it slowed to tens of kilometres per hour, its wavelength shortened to about 5 km, and its height is thought to have soared to more than ten metres. The trough of the wave often hits before the crest (as shown).

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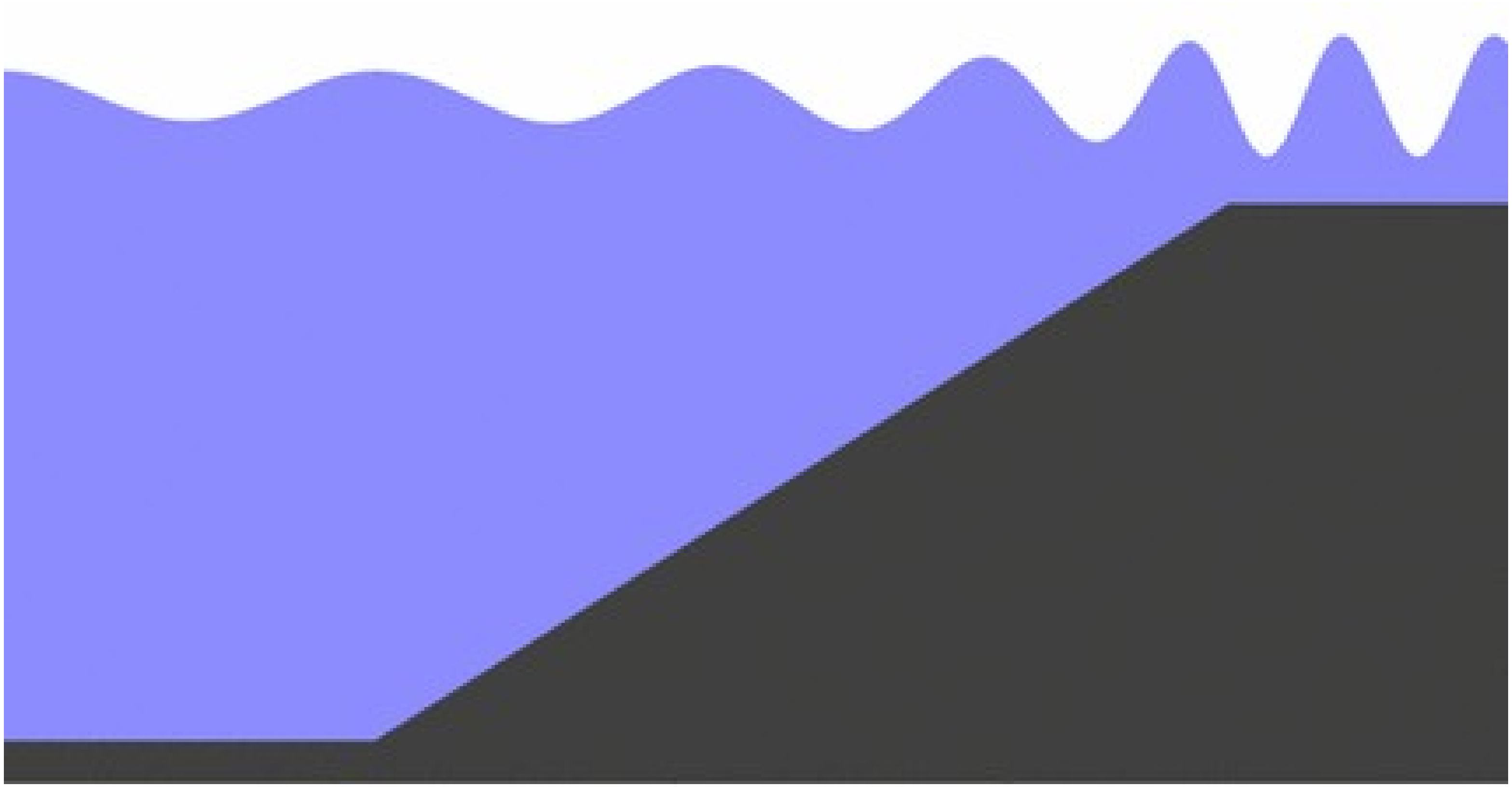
Tsunami, cont.



Movie

Tsunami, cont.

- **Mathematics** predicting to reduce their dangers
- **Modeling** ocean tsunami wave creation and propagation
- Clarifying tsunami wave **characteristics**
- **Engineers** design early warning systems

Tsunami, cont.

A Letters Journal Exploring the Frontiers of Physics

November 2009

EPL, 88 (2009) 45001
doi: 10.1209/0295-5075/88/45001

www.epljournal.org

Steepening of solitons (tsunami effect) in complex plasmas

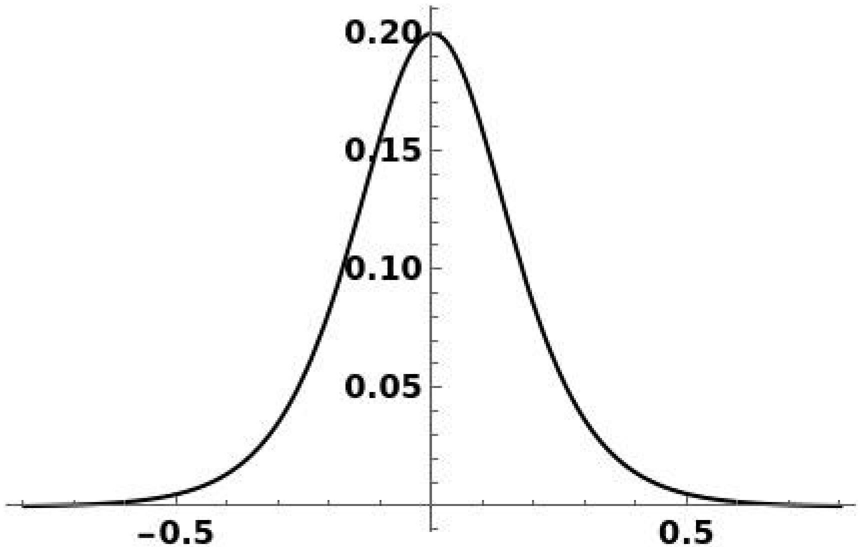
C. Durniak[1(a)], D. Samsonov[1], S. Zhdanov[2] and G. Morfill[2]

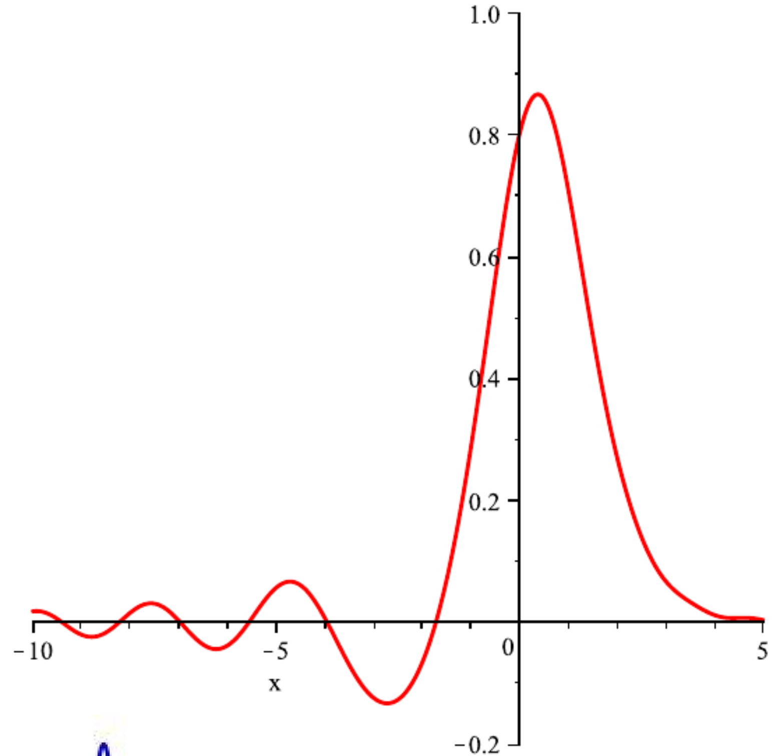
IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 39, NO. 11, NOVEMBER 2011

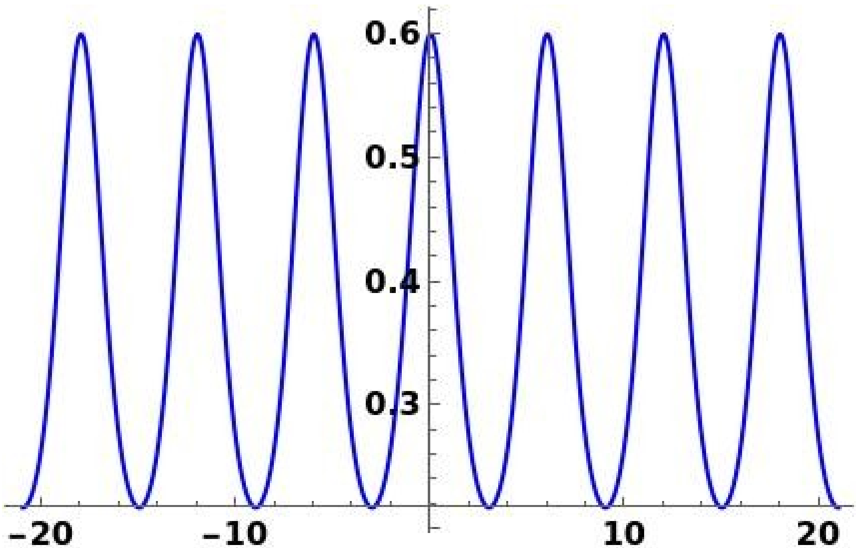
Tsunami in a Complex (Dusty) Plasma

D. Samsonov, C. Durniak, S. Zhdanov, and G. Morfill

Soliton & Cnoidal & Tsunami



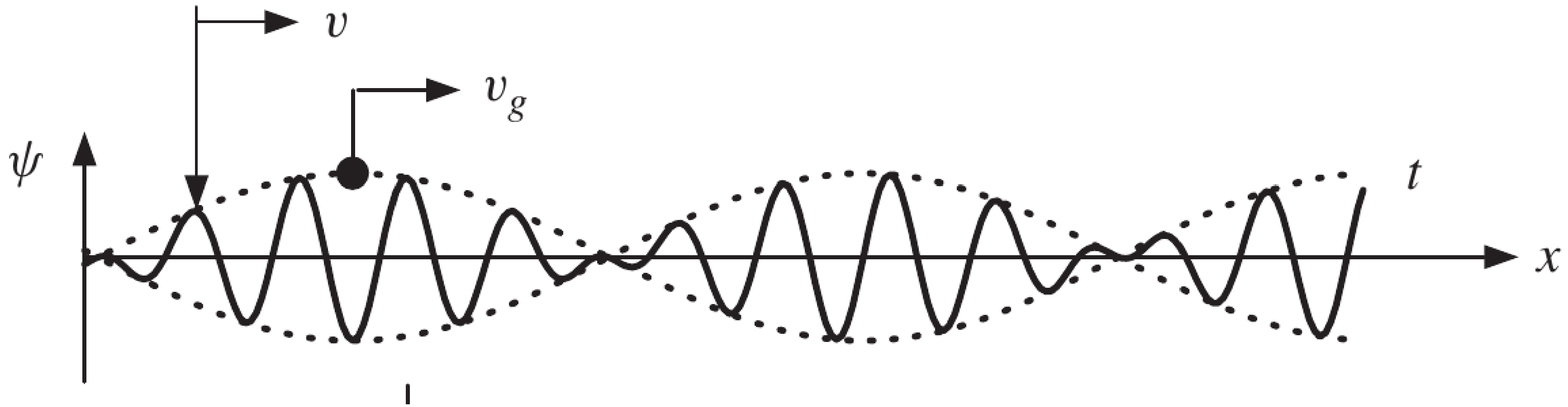




Envelope Soliotn

$$\psi_1 = A\cos(k_1 x - \omega_1 t), \qquad \psi_2 = A\cos(k_2 x - \omega_2 t)$$

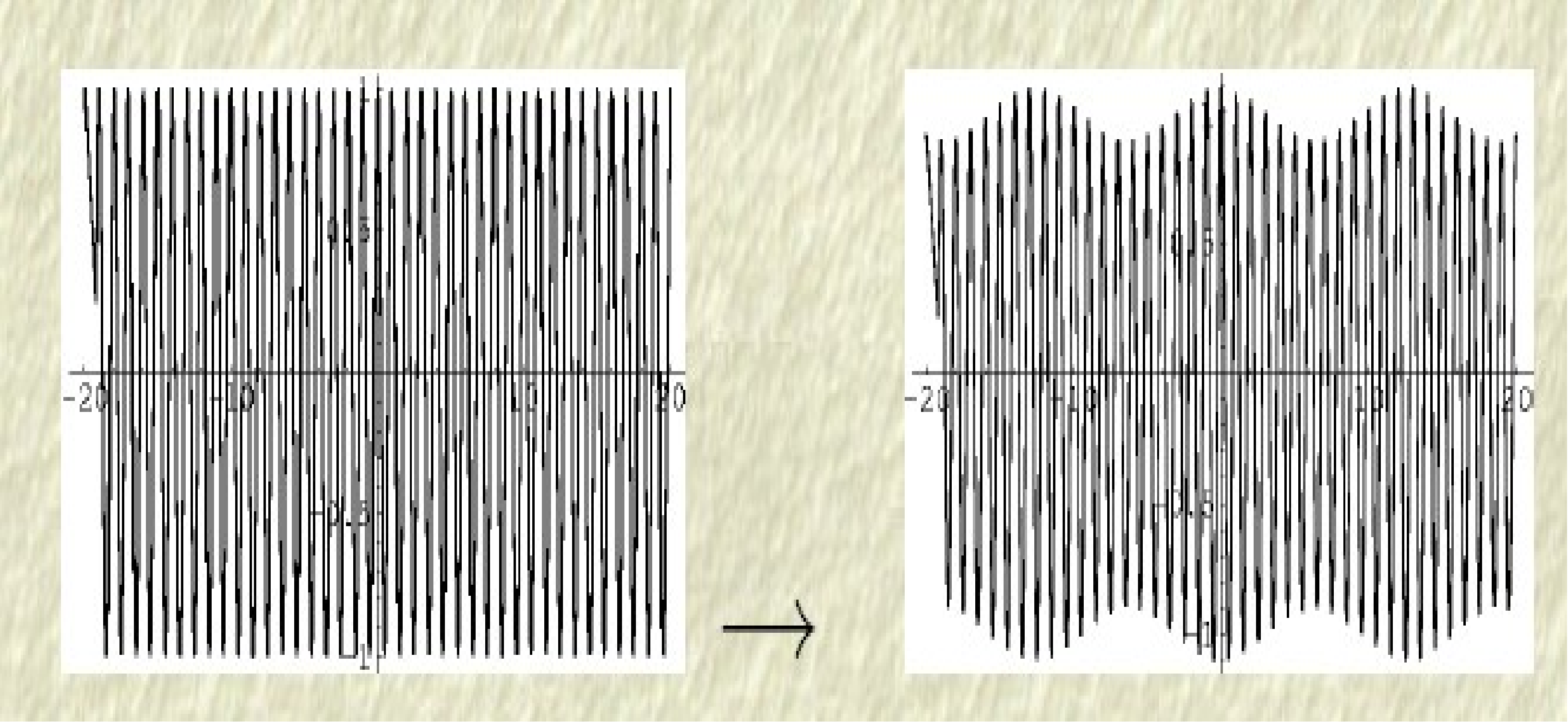
$$\psi = A(x, t)\cos(k_o x - \omega_o t)$$



Movie

Envelope Soliotn, cont.

- The amplitude of the harmonic wave may vary in space and time
- **Time scales. How many time scales?**

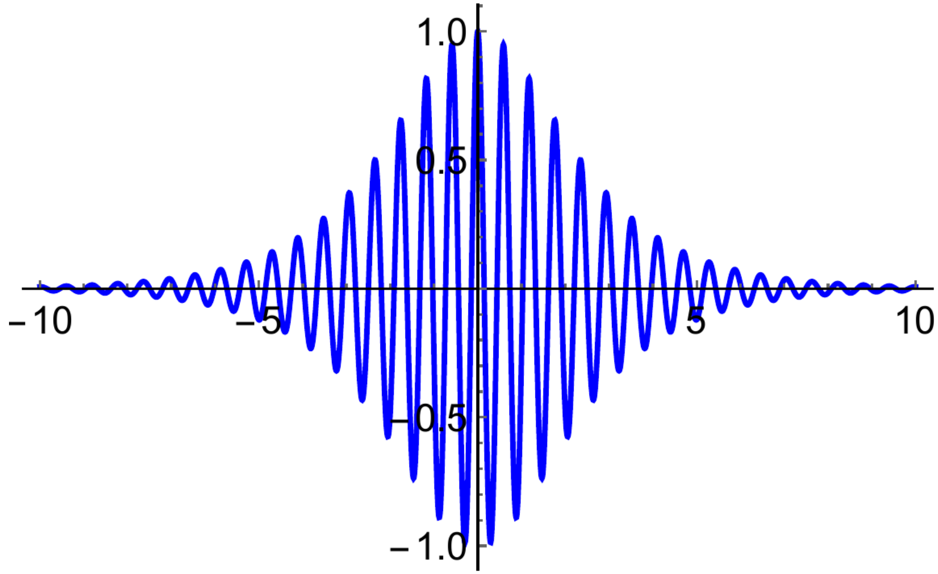


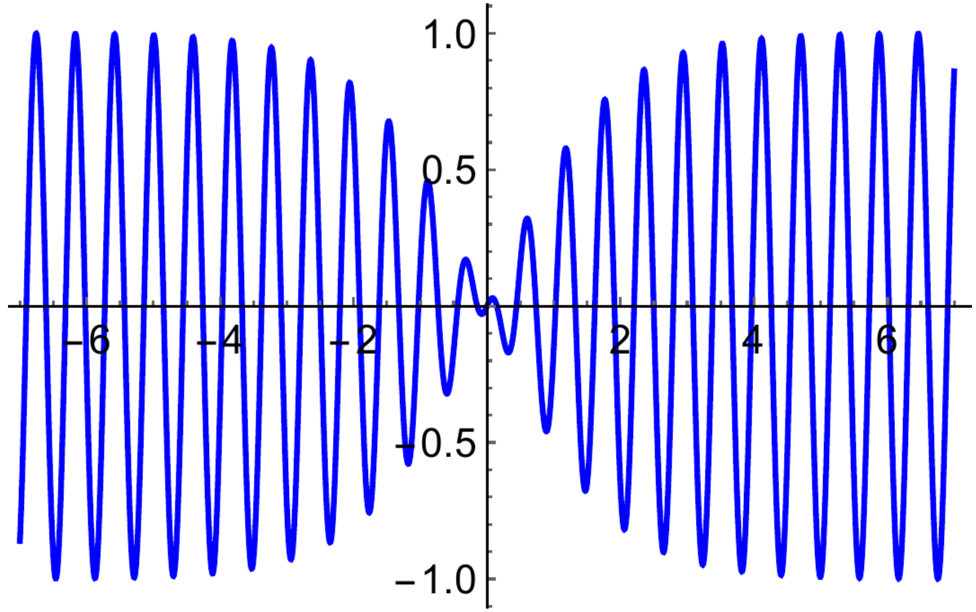
Envelope Soliotn, cont.

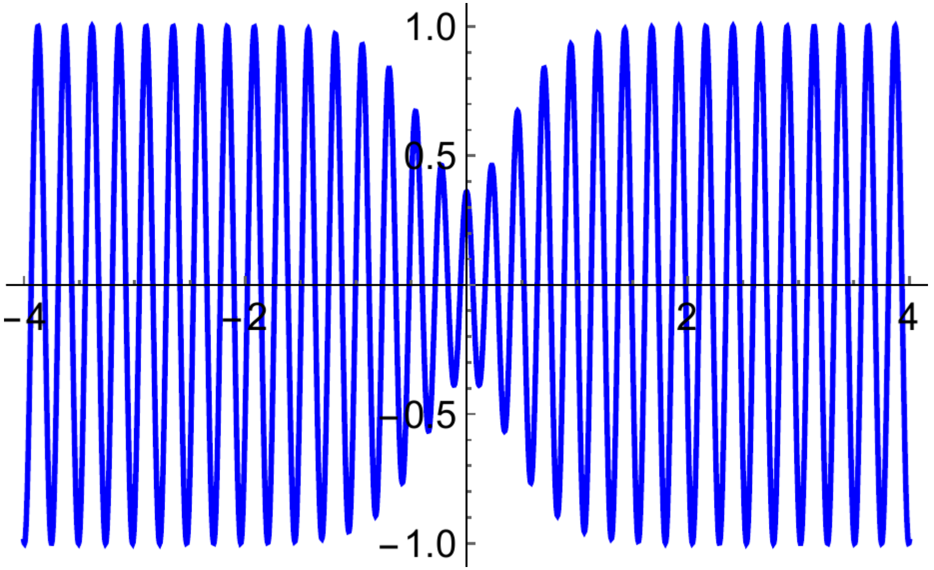
- This modulation due to nonlinearity may be strong enogh to lead to the formation of envelope soliton
- Three forms of envelope: bright, dark, and Gray
- Evloution equation → Nonlinear Schrödinger Eq.

$$\boxed{i\frac{\partial \psi}{\partial \tau} + P\frac{\partial^2 \psi}{\partial \zeta^2} + Q\left|\psi\right|^2 \psi = 0}$$

Envelope Soliotn, cont.







Envelope Soliotn, cont.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN, Vol. 27, No. 5, NOVEMBER, 1969

A Nonlinear Theory of Two-Stream Instability

Tsuguhiro WATANABE

PERTURBATION METHODS

ALI HASAN NAYFEH

Professor of Engineering Science and Mechanics
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

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Envelope Soliotn, cont.

J. Plasma Physics (1975), *vol.* 14, *part* 2, *pp.* 353–364

Ion-acoustic solitons excited by a single grid

By S. WATANABE

J. Plasma Physics (1976), *vol.* 15, *part* 1, *pp.* 67–81

Effect of wave–particle interaction on recurrence of a nonlinear ion wave

By S. WATANABE

Envelope Soliotn, cont.

- 1973: Akira Hasegawa of AT&T Bell Labs was the first to suggest that envelope solitons could exist in optical fibers
- 1973: Robin Bullough made the first mathematical report of the existence of optical solitons → suggest its application in optical telecommunications
- 1987: Emplit et al. made the first experimental observation of the propagation of a dark soliton, in an optical fiber
- 1970's: Starting the Nonlinear Plasma Physics Era

Rogue wave

Freak waves

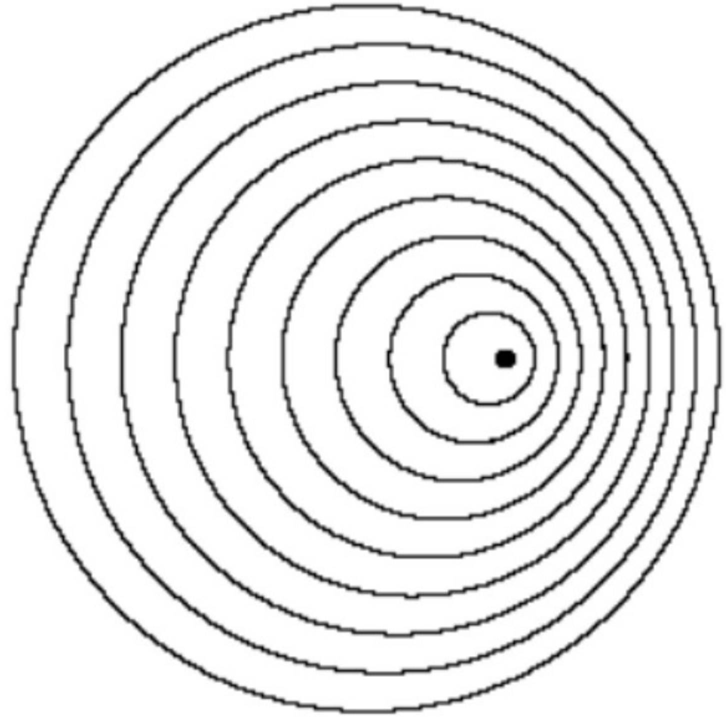
Rogue waves

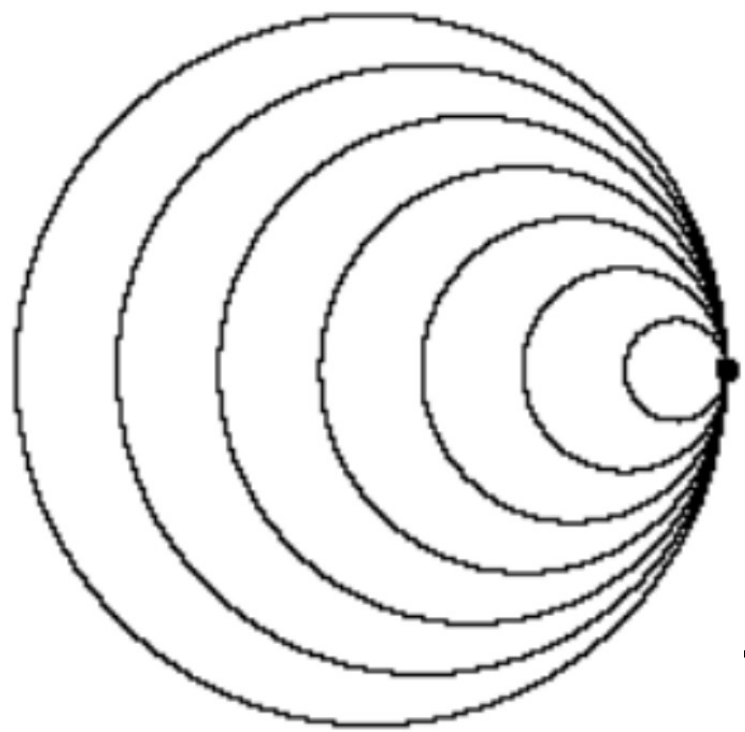
Giant waves

Extreme waves

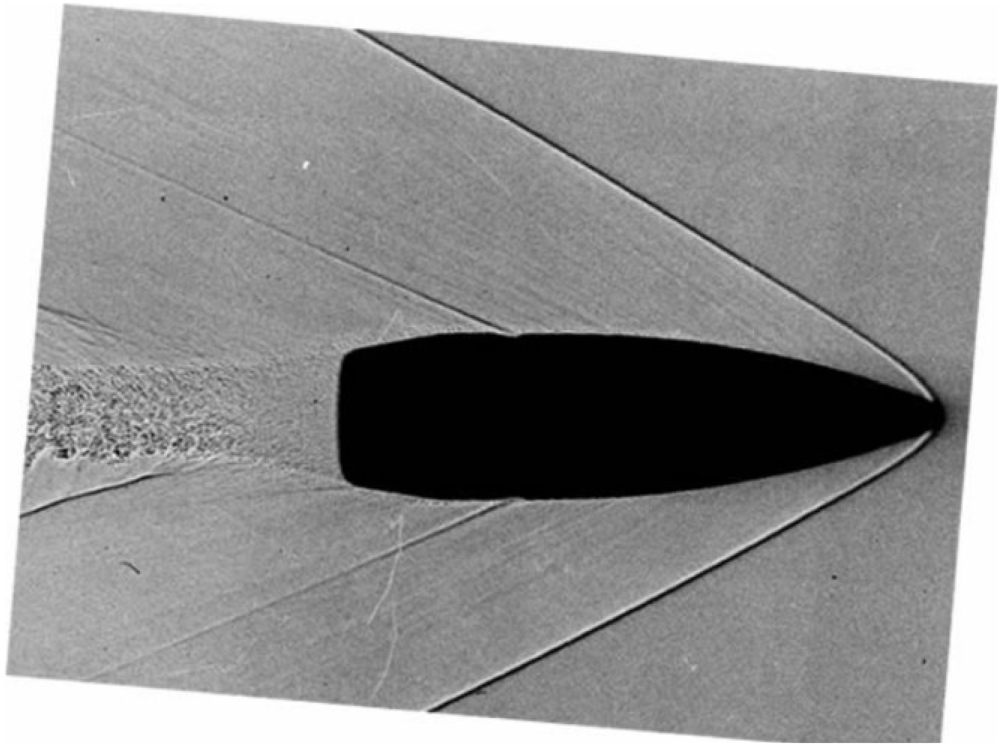
Mach Cones

- When an object moves through the air it pushes the air in front of it away, creating a pressure wave.
- This pressure wave travels away from the object at the speed of sound.
- If the object itself is travelling at the speed of sound then these pressure waves build up on top of each other to create a shock wave





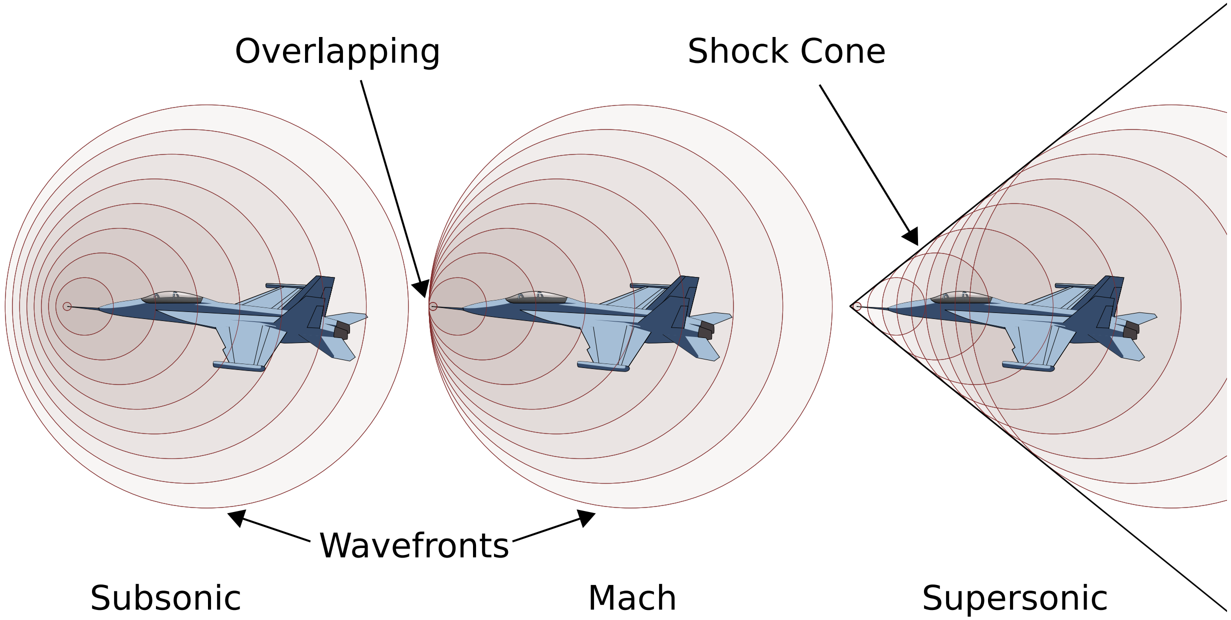
Mach Cones, cont.



In the photograph above the Mach cone angle is 28° and therefore the bullet must have been travelling at Mach 2.1 or 720 metres per second (assuming the speed of sound is 340 m/s).

$$\mu = \sin^{-1}\left(\frac{1}{M}\right)$$

Mach Cones, cont.



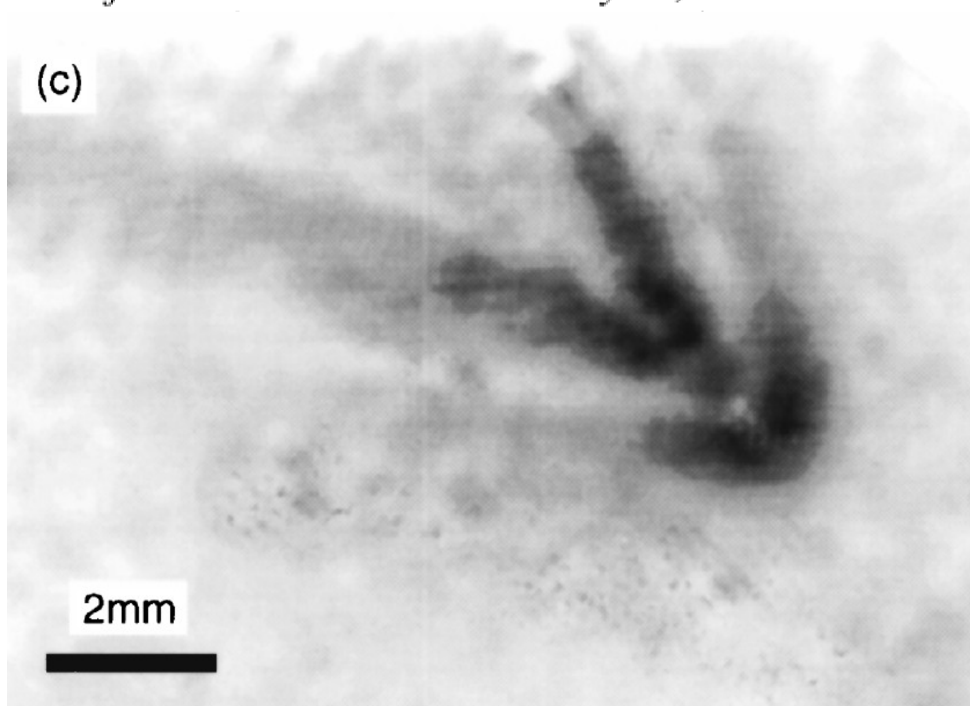
Mach Cones, cont.

VOLUME 83, NUMBER 18 PHYSICAL REVIEW LETTERS 1 NOVEMBER 1999

Mach Cones in a Coulomb Lattice and a Dusty Plasma

D. Samsonov, J. Goree,* Z. W. Ma, and A. Bhattacharjee
Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

H. M. Thomas and G. E. Morfill
Max Planck Institut für extraterrestrische Physik, 85740 Garching, Germany



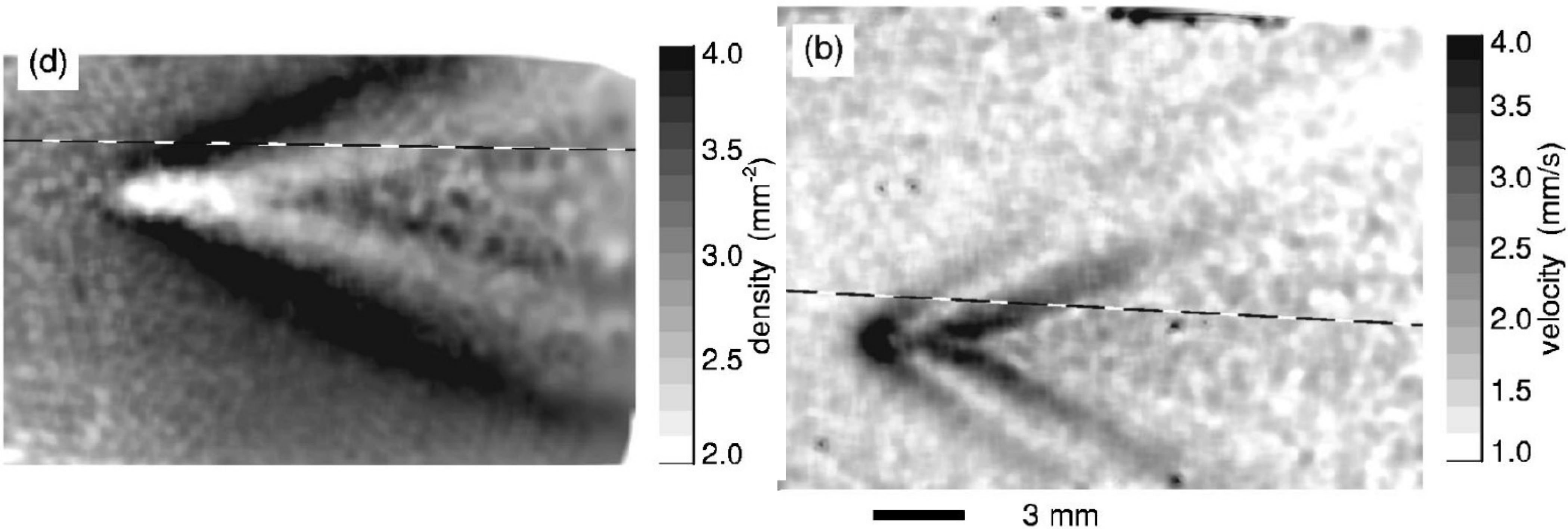
Mach Cones, cont.

PHYSICAL REVIEW E VOLUME 61, NUMBER 5 MAY 2000

Mach cone shocks in a two-dimensional Yukawa solid using a complex plasma

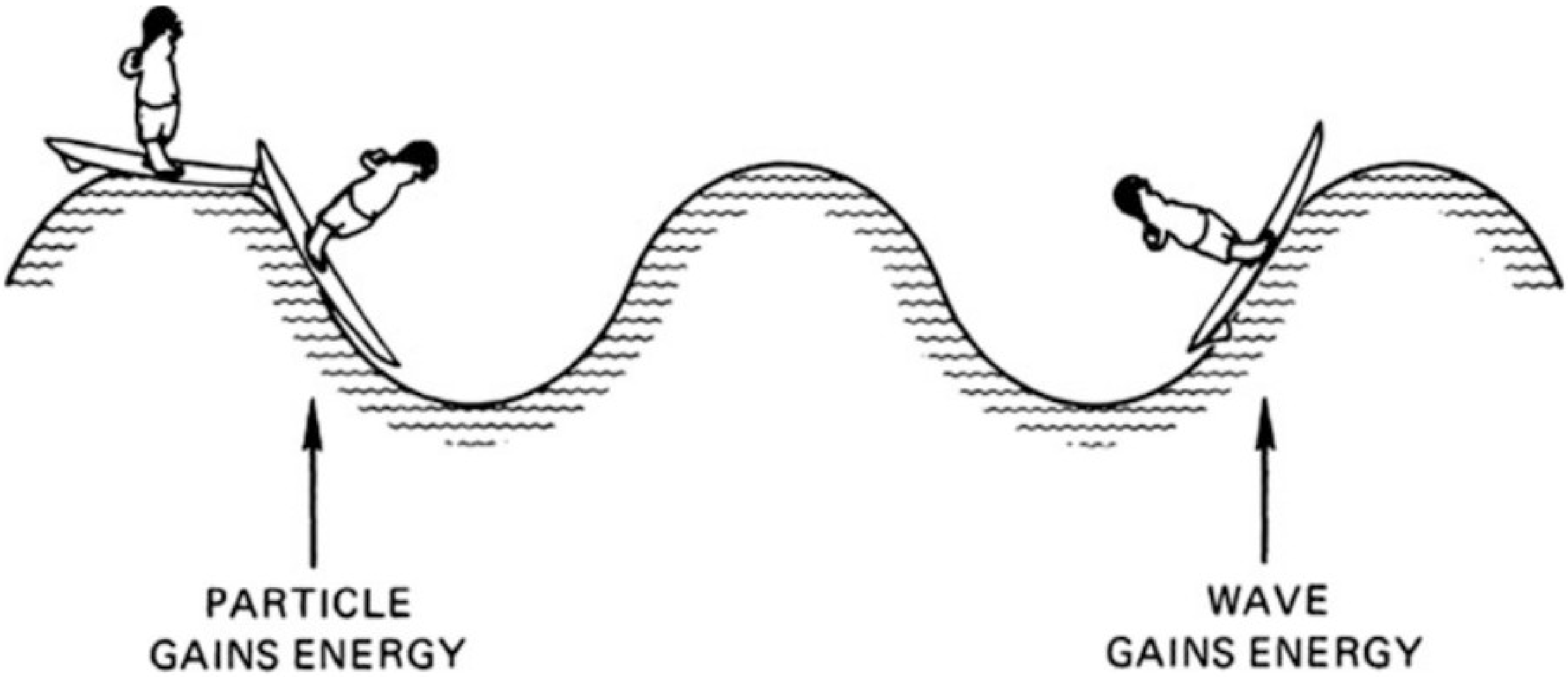
D. Samsonov* and J. Goree†
Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

H. M. Thomas and G. E. Morfill
Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse, 85740 Garching, Germany



Wakefield

- In 1979 John Dawson, in a paper with T. Tajima, proposed that Landau damping effect could be used to accelerate particles
- In plasma, there are electrons both faster and slower than the wave.

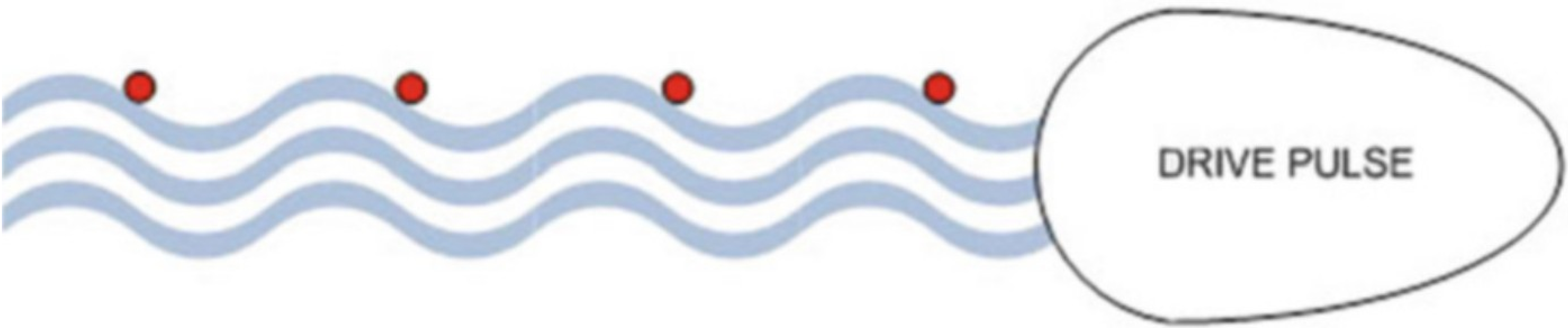


Wakefield, cont.

Wakefield, cont.

Wakefield, cont.

- There were two early ideas on plasma accelerators: *beatwave* and *wakefield*.

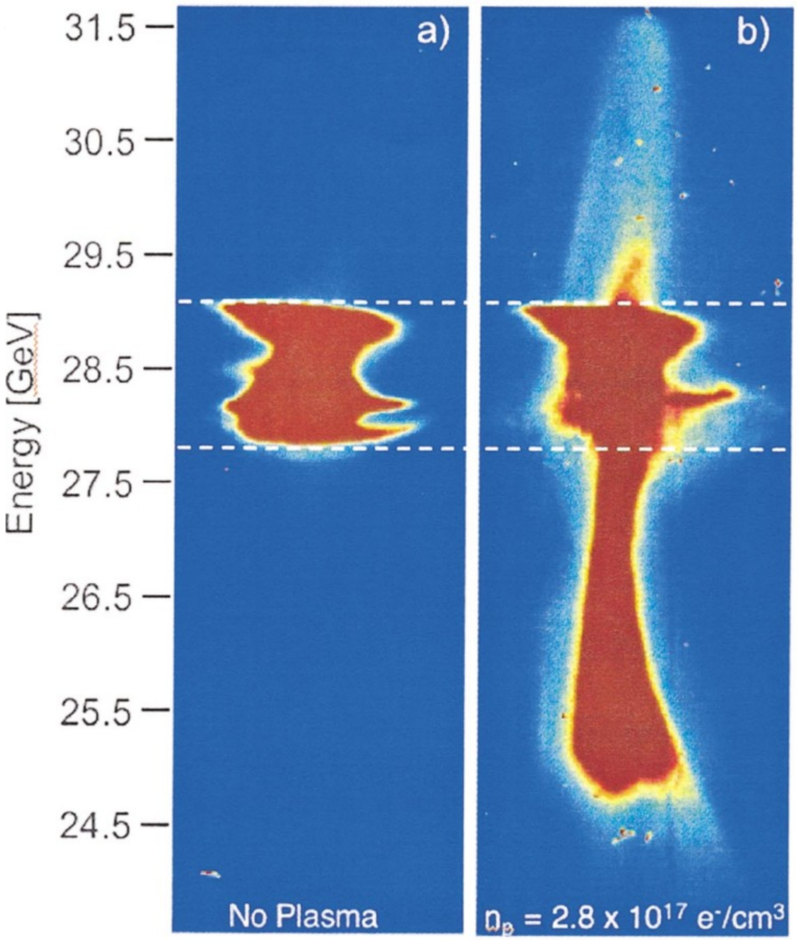


Wakefield, cont.

PRL 95, 054802 (2005) PHYSICAL REVIEW LETTERS week ending 29 JULY 2005

Multi-GeV Energy Gain in a Plasma-Wakefield Accelerator

J. Decker,[1] S. Deng,[3] P. Emma,[1] C. Huang,[2] R. H. Iverson,[1] D. K. Johnson,[2]
Lu,[2] K. A. Marsh,[2] W. B. Mori,[2] P. Muggli,[3] C. L. O'Connell,[1] E. Oz,[3]
R. H. Siemann,[1] and D. Walz[1]



a) No Plasma → Only electron beam with 1 GeV energy.

b) 10 cm long lithium plasma → the core of the electron bunch has lost energy driving the plasma wake while particles in the back of the bunch have been accelerated to 2.7 GeV

Wakefield, cont.

Phys. Fluids, Vol. 28, No. 7, July 1985

Attractive potential between resonant electrons

M. Nambu and H. Akama

College of General Education, Kyushu University, Ropponmatsu, Fukuoka 810, Japan

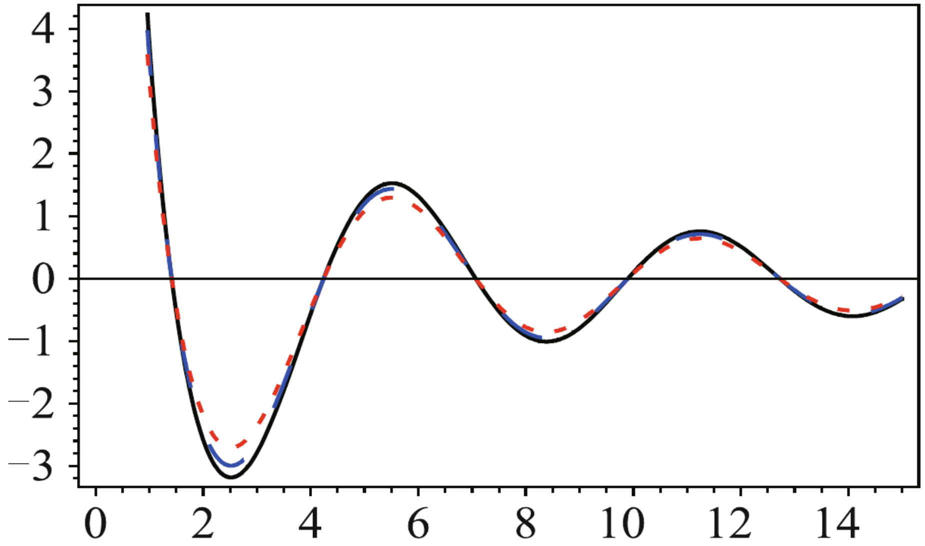
Physics Letters A 203 (1995) 40–42

Attractive forces between charged particulates in plasmas

Mitsuhiro Nambu, Sergey V. Vladimirov [1], Padma K. Shukla [2]

The charged particles having the same polarity can attract each other...!!

Wakefield, cont.



- **Vph ~ Cs**
- Appearing long-range **oscillatory wakefield**
- The background **positive ions are trapped** in the negative part of the oscillatory wake potential.
- The **negative charges are attracted** to each other as they are **glued by positive ions** in a linear chain

Outline

- Soliton
- Cnoidal
- Tsunami
- Envelope soliotn
- Rogue wave
- Mach Cones
- Wakefield
- Water droplet
- St. Elmo's fire
- AGN
- Sun & Stars
- Lightning
- Kelvin–Helmholtz
- Rayleigh–Taylor

Water droplet

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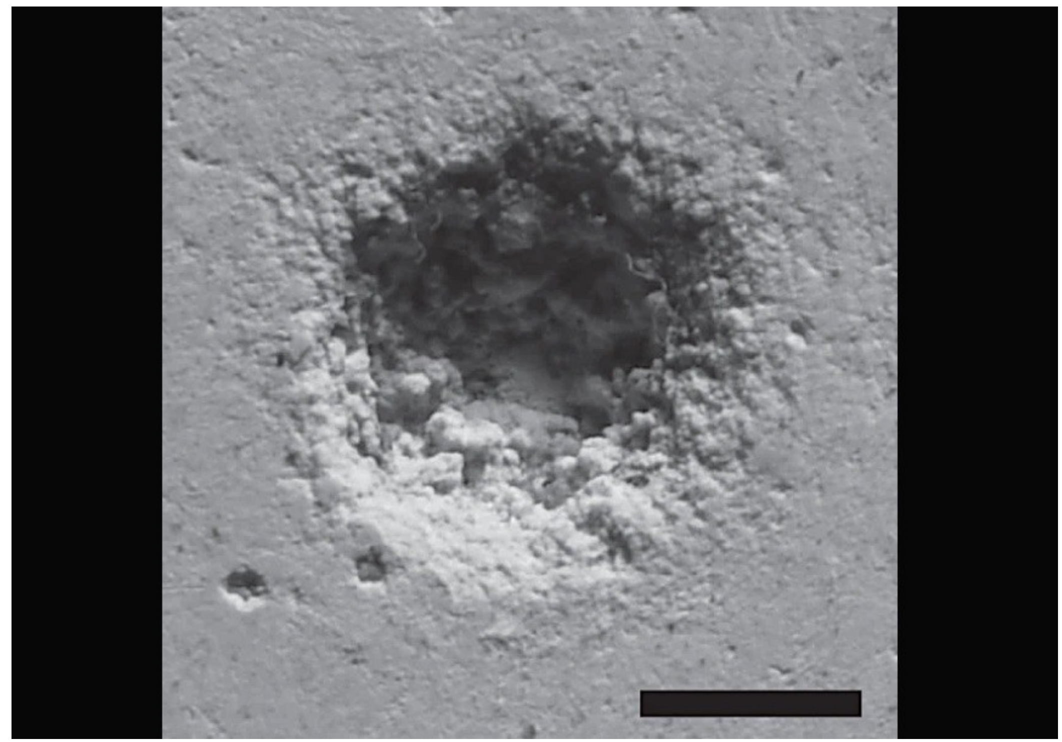
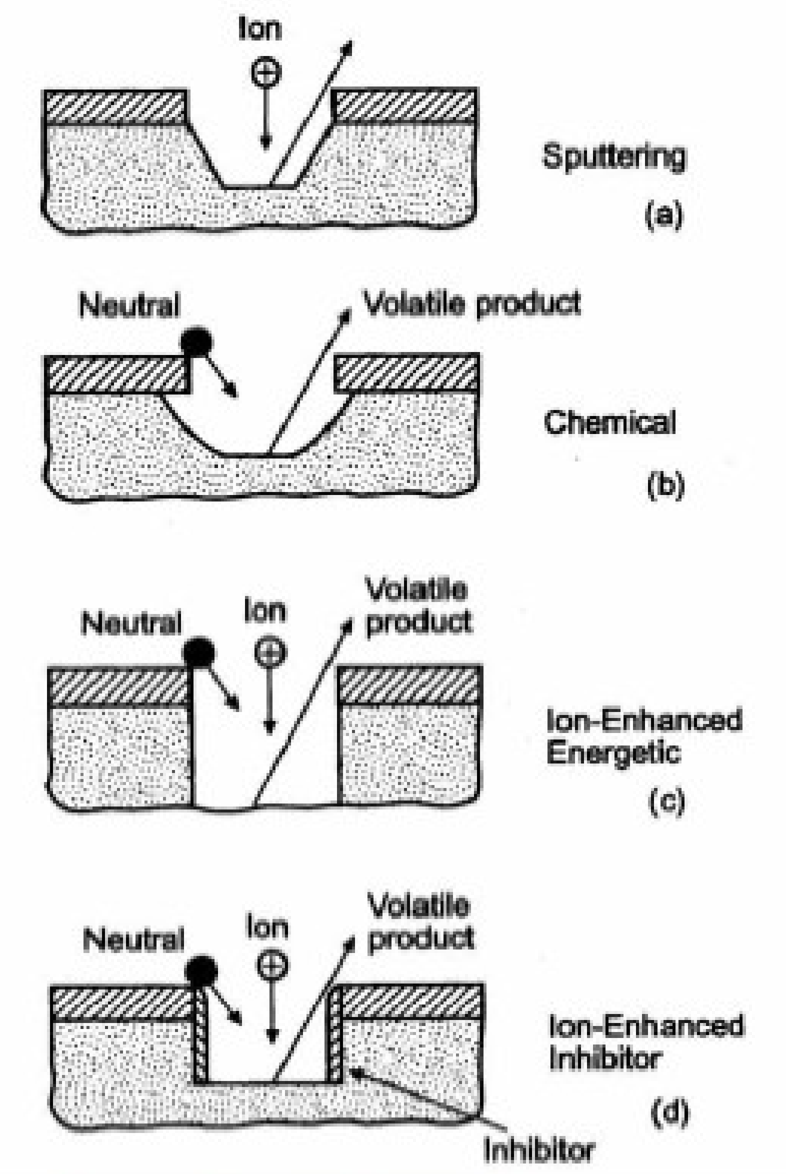
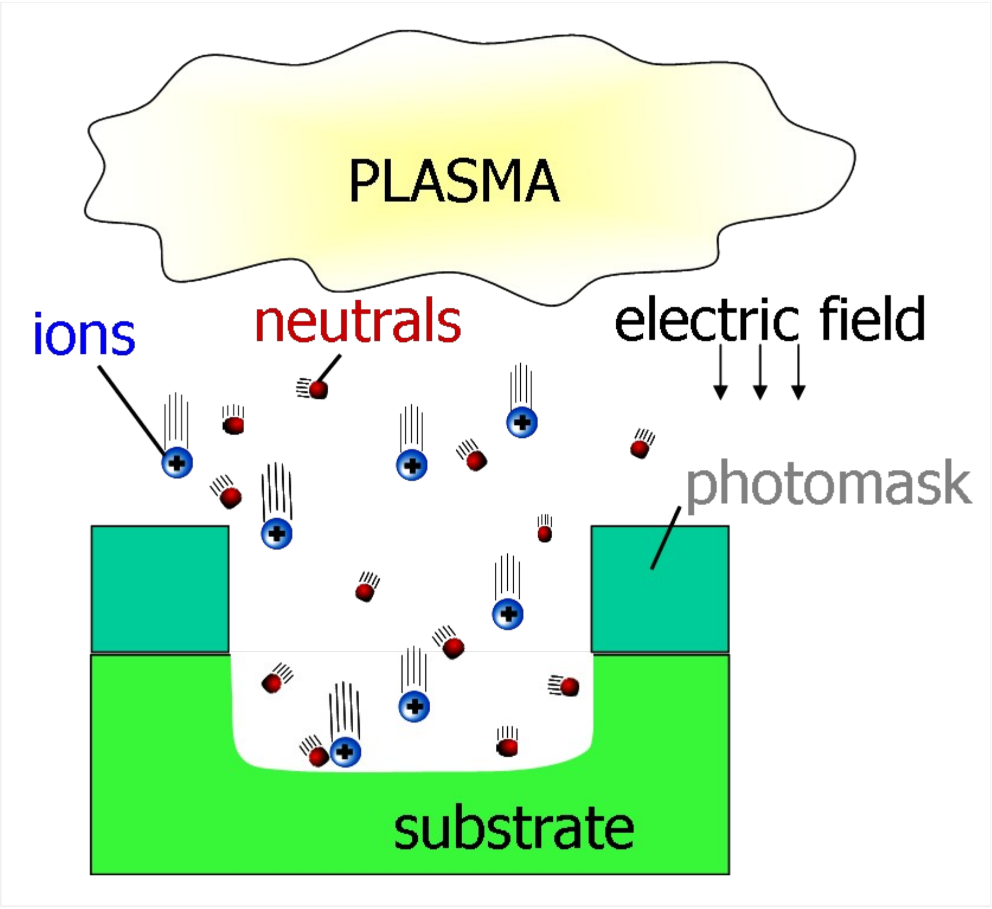
Water droplet, cont.



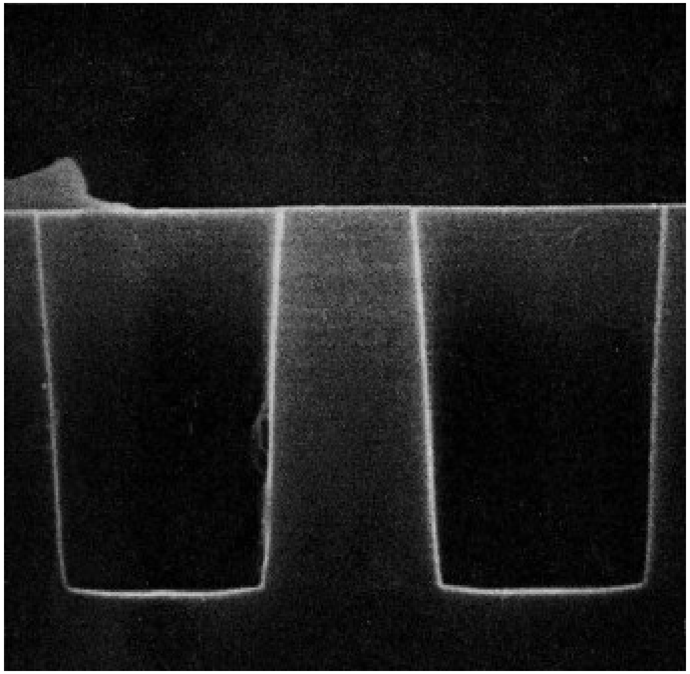
Water droplet, cont.

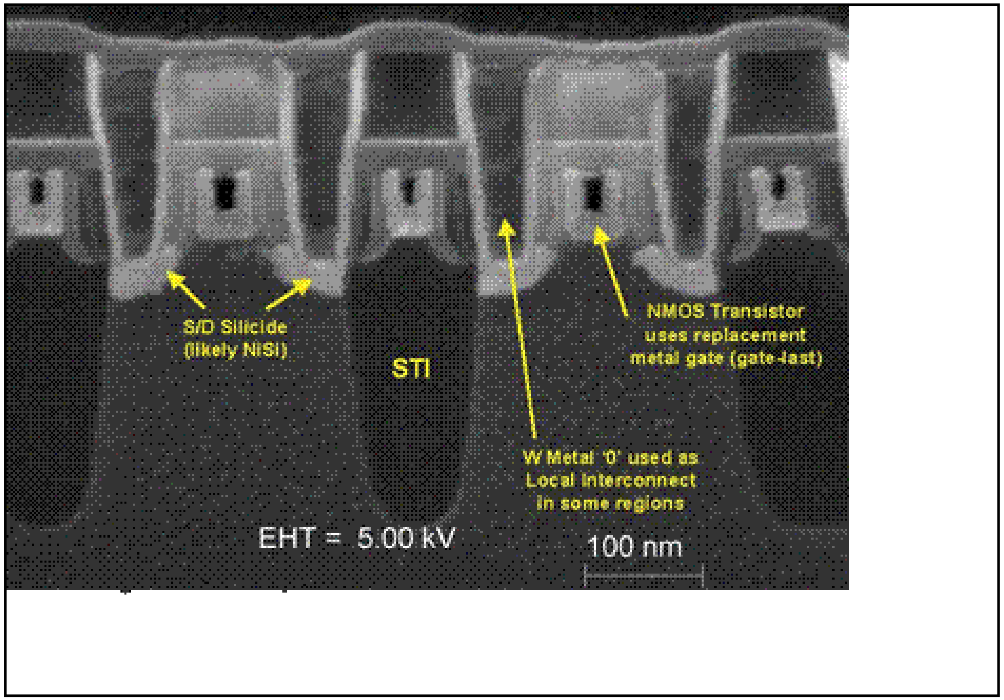


Plasma Etching, (1989) p.93



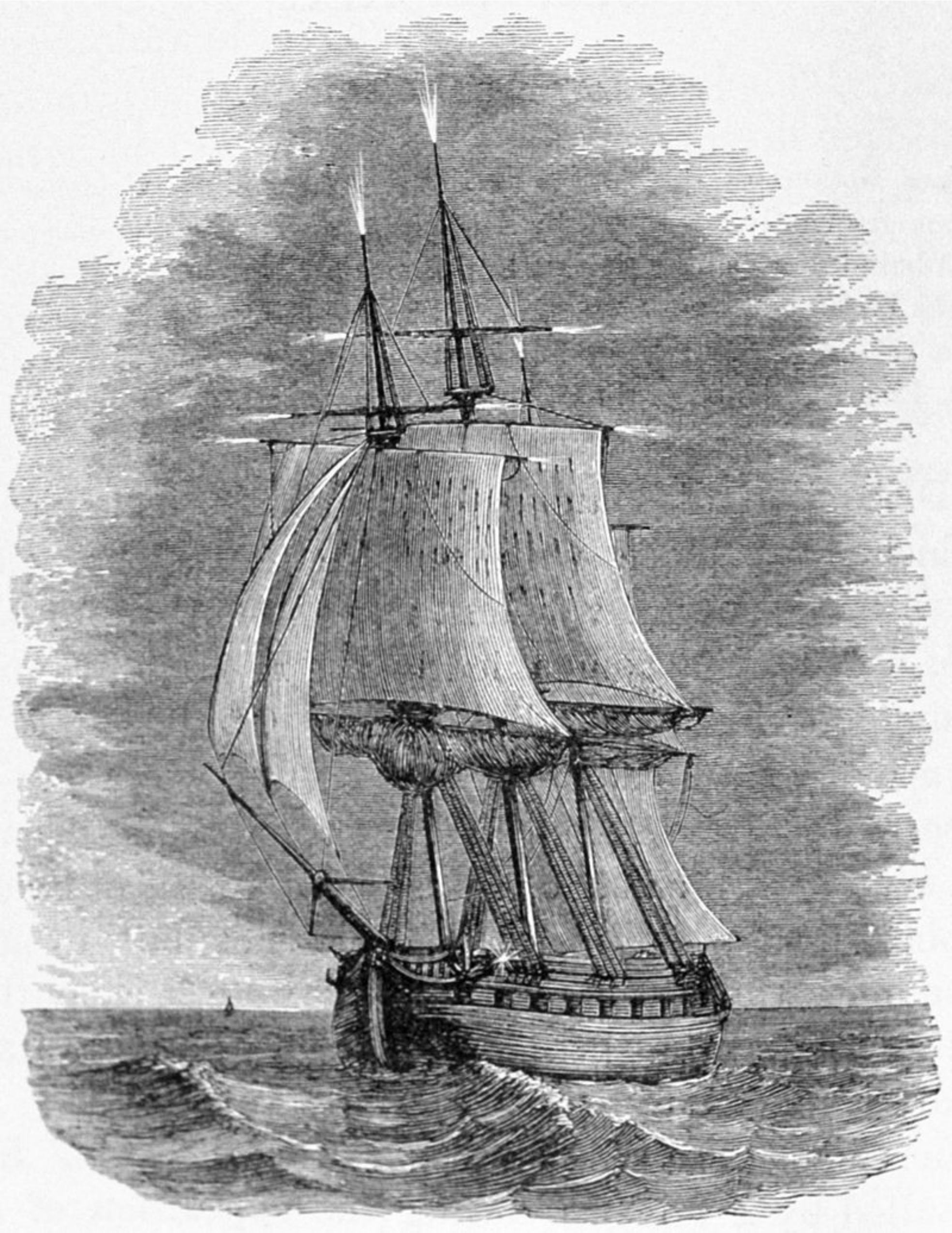
Water droplet, cont.





St. Elmo's fire

- Blue or violet ball with a hissing sound that constitutes Saint Elmo's fire is different from fire and lightning.
- Ship mast should start St. Elmo's fire, airplane wing...



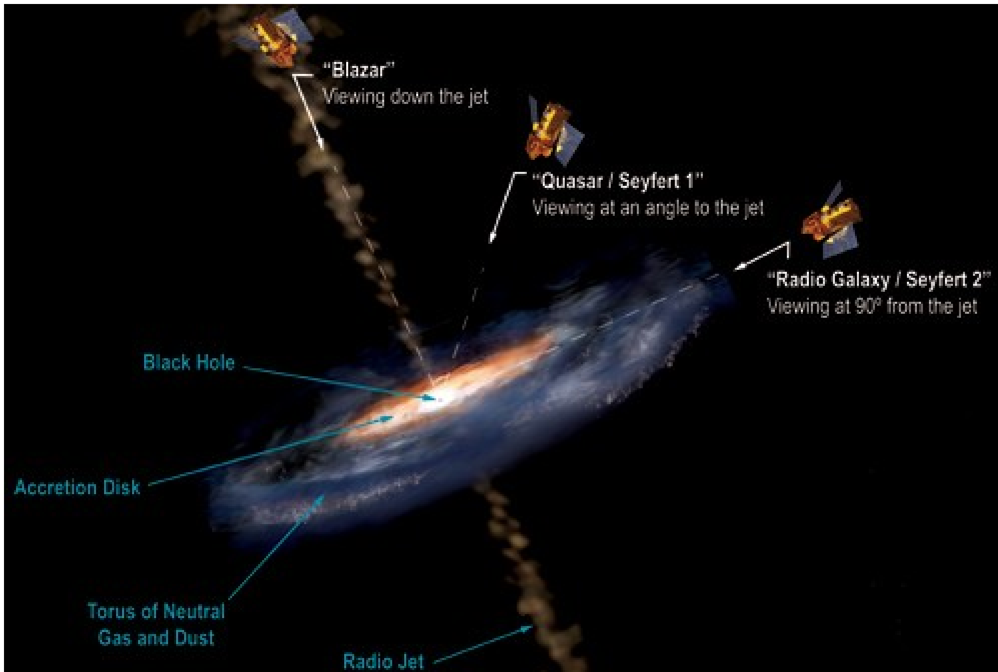
St. Elmo's fire, cont.

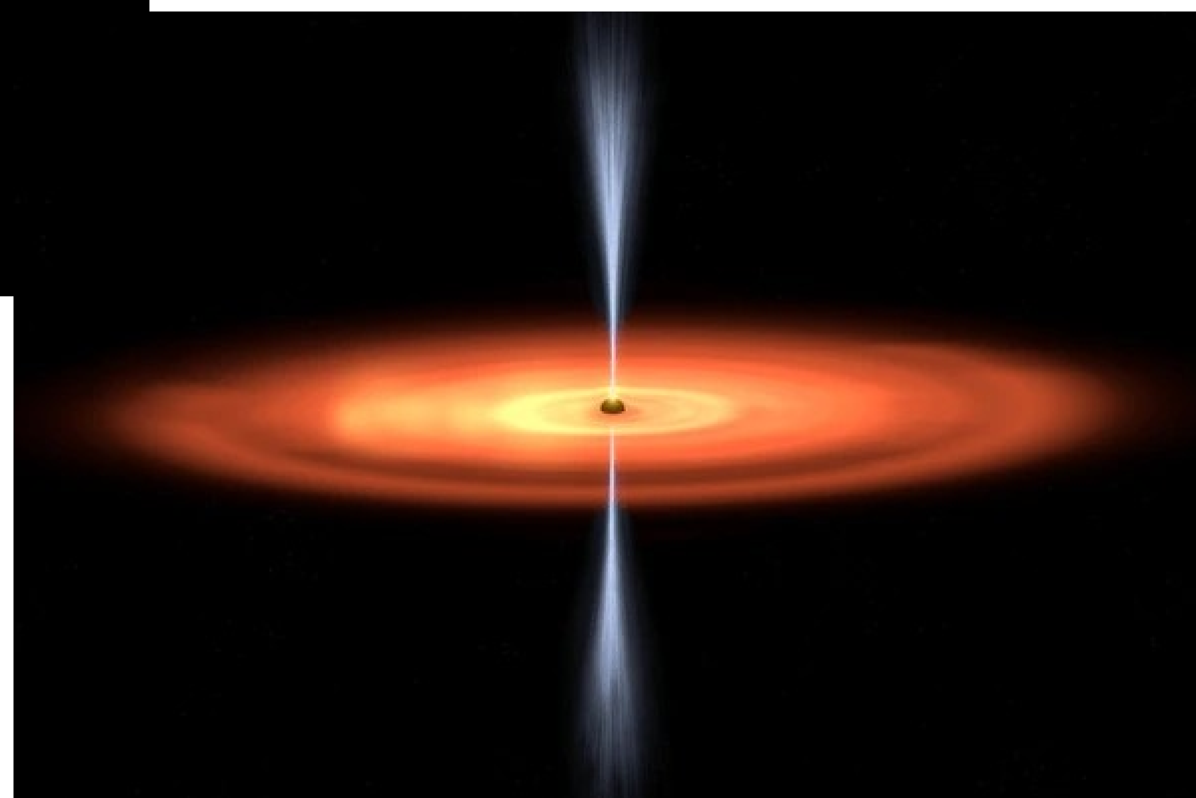
Movie

St. Elmo's fire, cont.

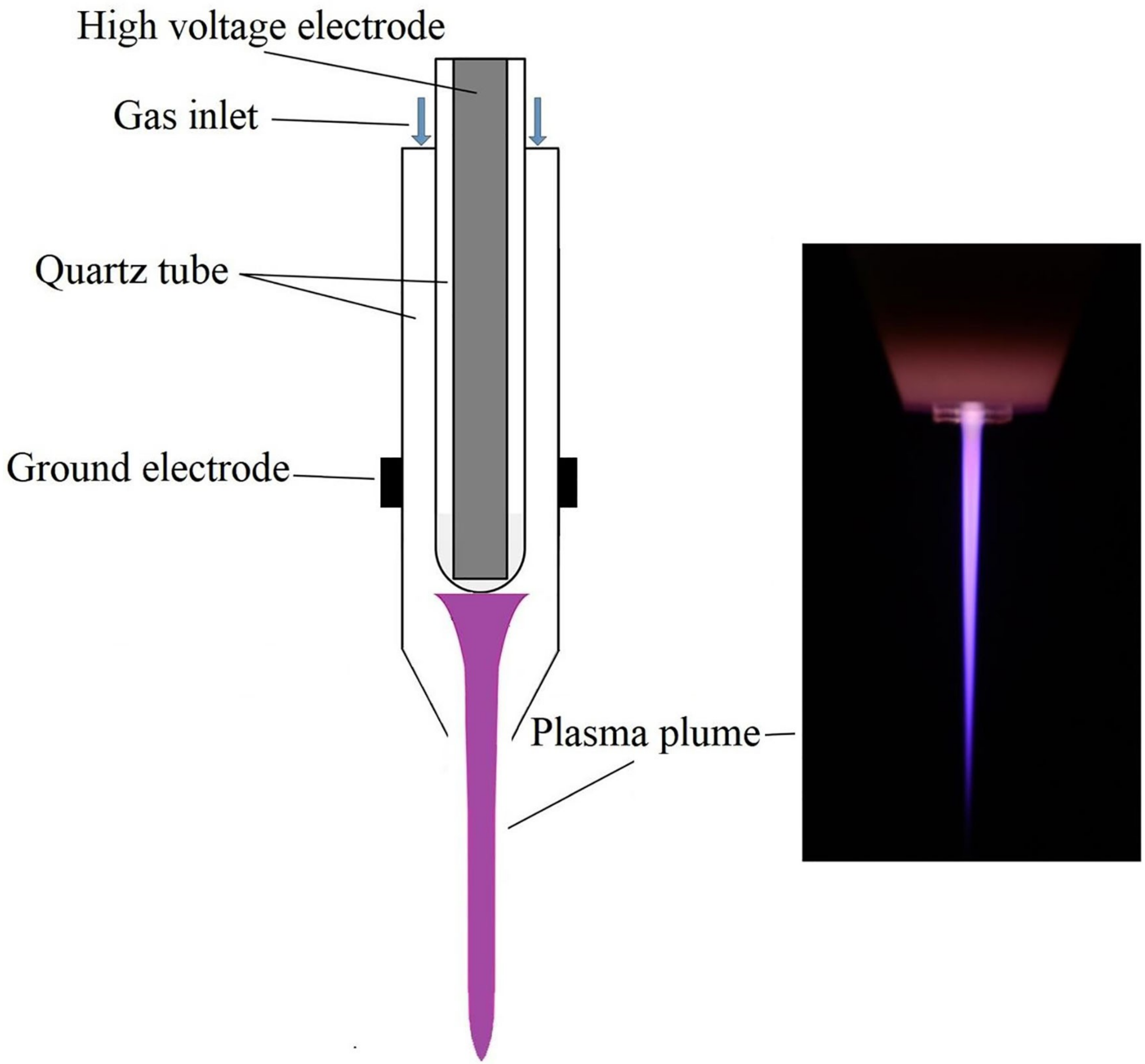
- Gas glows with proton clusters and electrons under high voltage
- Air is good electrical insulation. If a metal rod's end has a high electric field, air molecules nearby are ionized and charges flow off
- These "corona discharges" light softly in the dark. The St. Elmo fire is a corona discharge. It's not lightning
- Mast seems like fire but does not burn
- Low temperature plasma

Active Galactic Nuclei





Active Galactic Nuclei, cont.



Active Galactic Nuclei, cont.

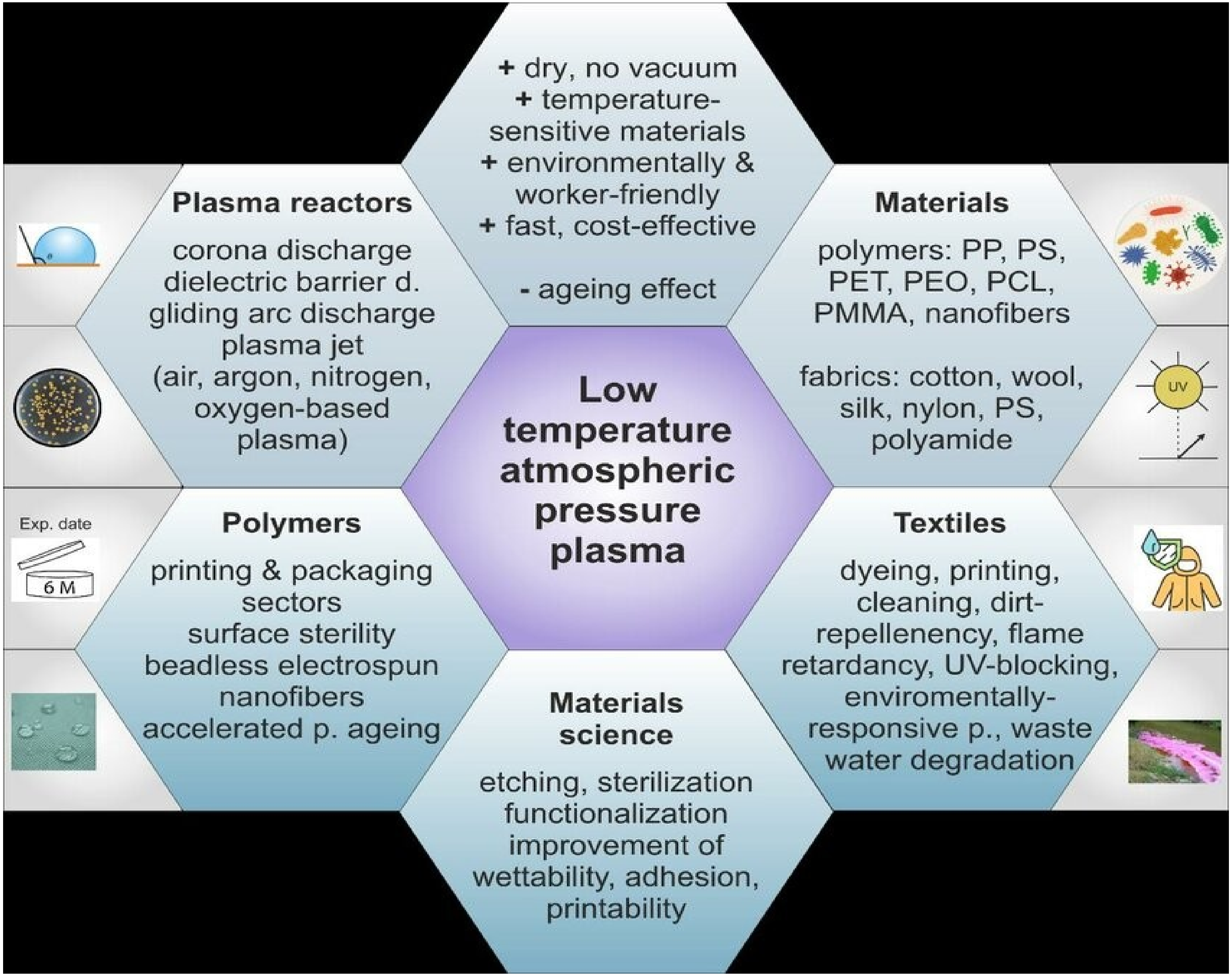
Wound Healing: Suppurated Burns

Plasma
Technologies, Inc

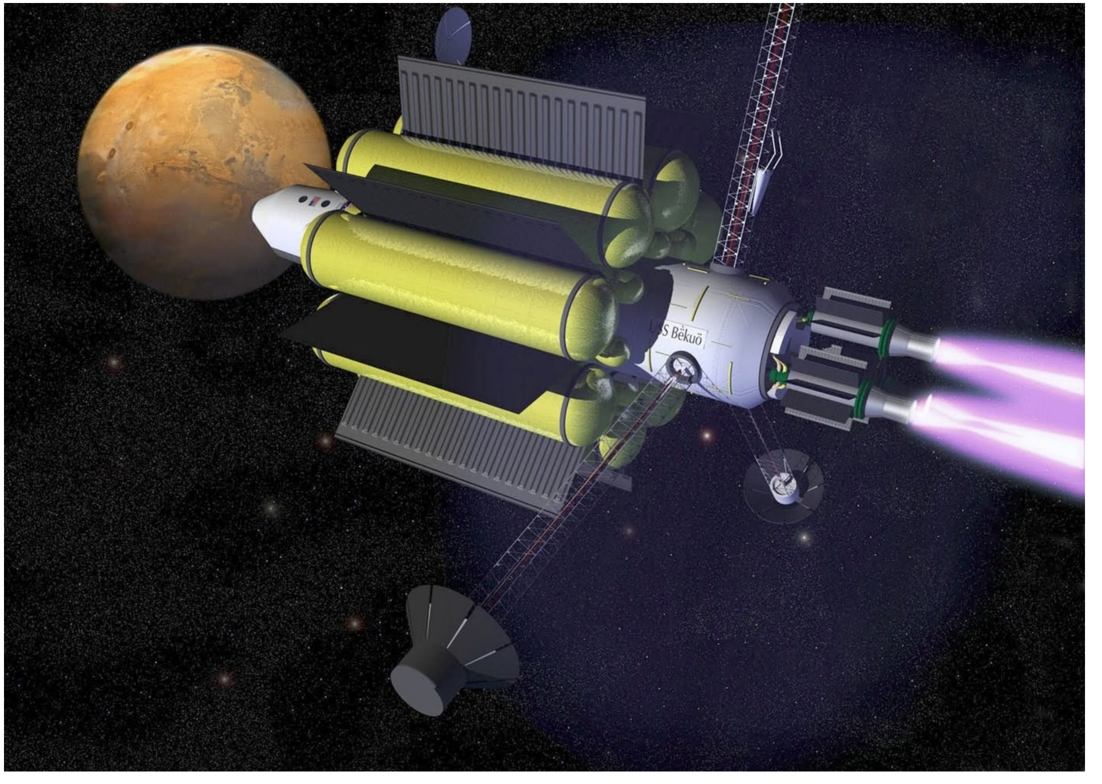
Wound Healing: Trophic Venous Ulcers

Broad Necrotic Suppurated Ulcer (Diabetic Peripheral Neuropathy)

Active Galactic Nuclei, cont.



Active Galactic Nuclei, cont.

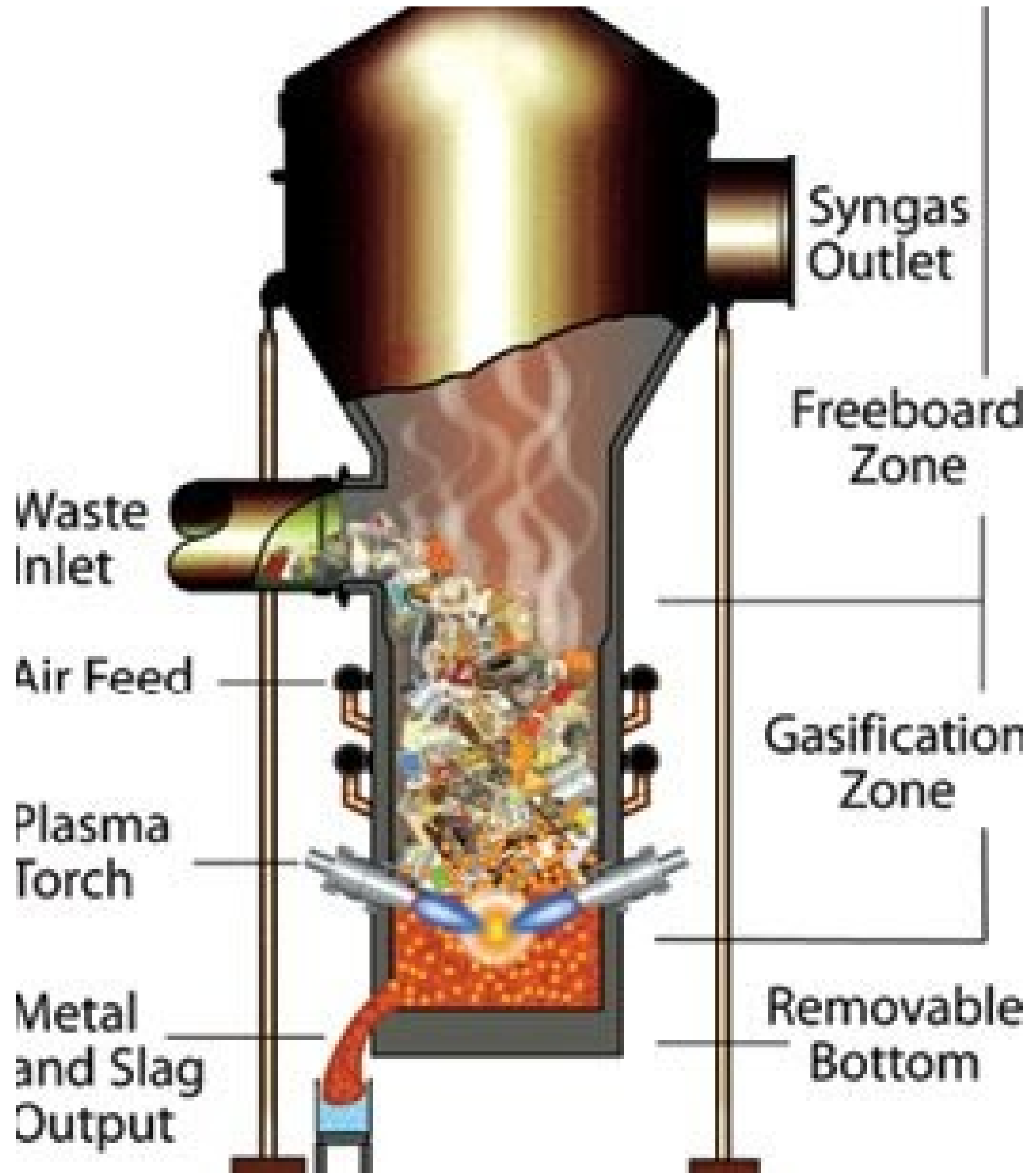


Plasma thruster

Sun & Stars

China artificial sun

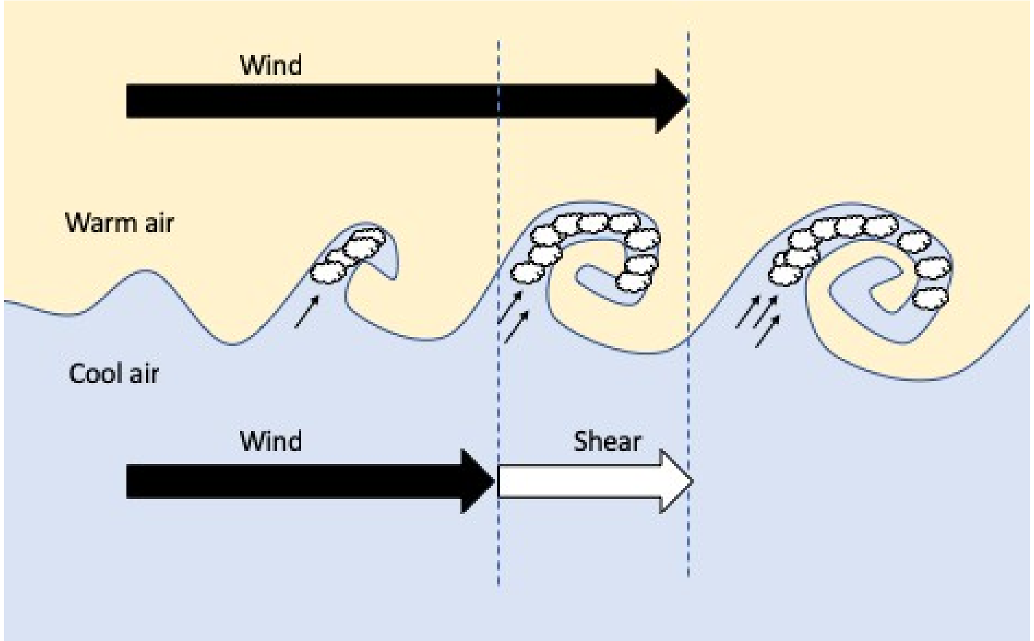
Lightning



- Plasma arc recycling
- Movie

Kelvin–Helmholtz

- Velocity shear in a single continuous fluid
- Velocity difference across the interface between two fluids



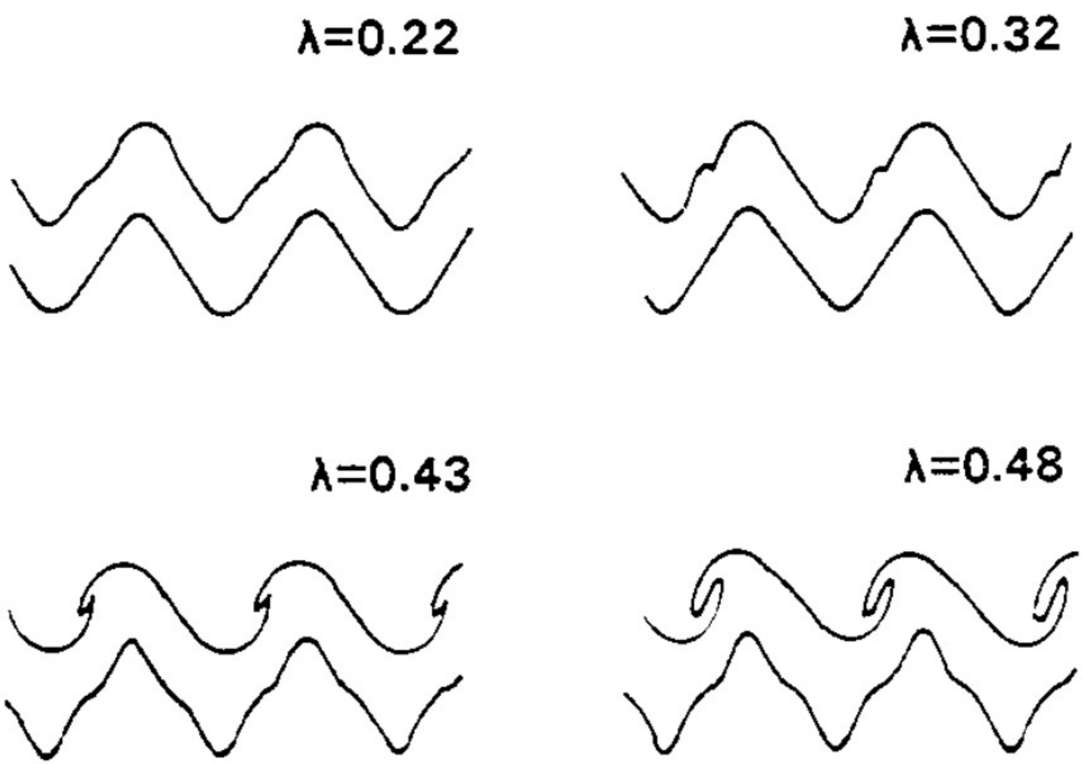
Movie

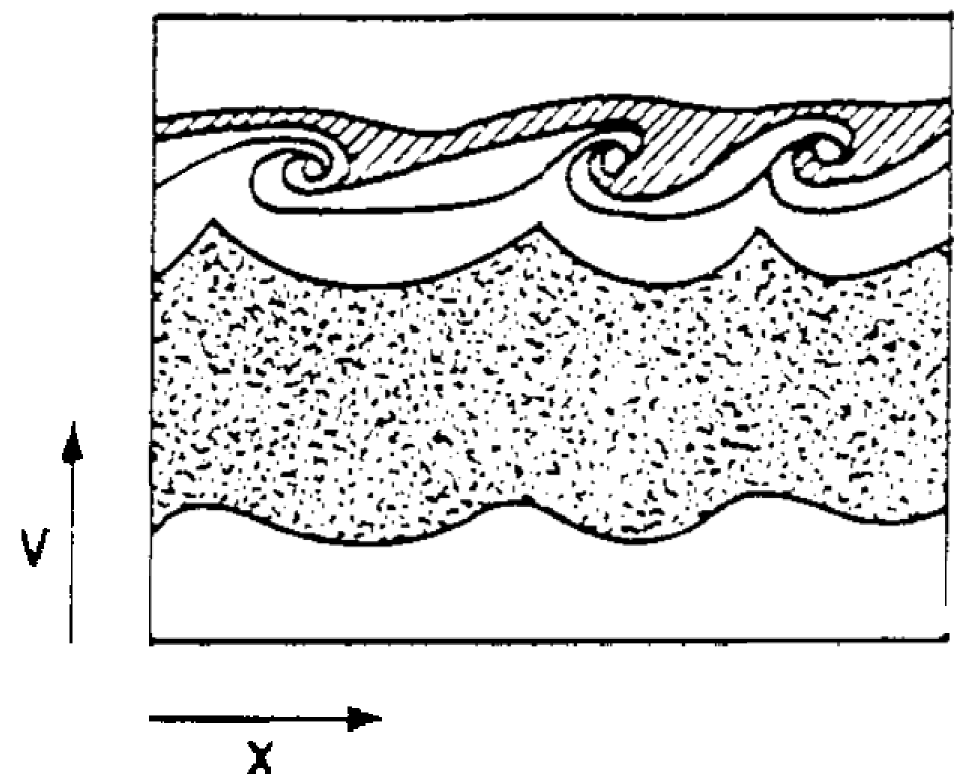
Kelvin–Helmholtz, cont.

Plasma Physics and Controlled Fusion, Vol. 28, No. 10, pp. 1549 to 1558, 1986

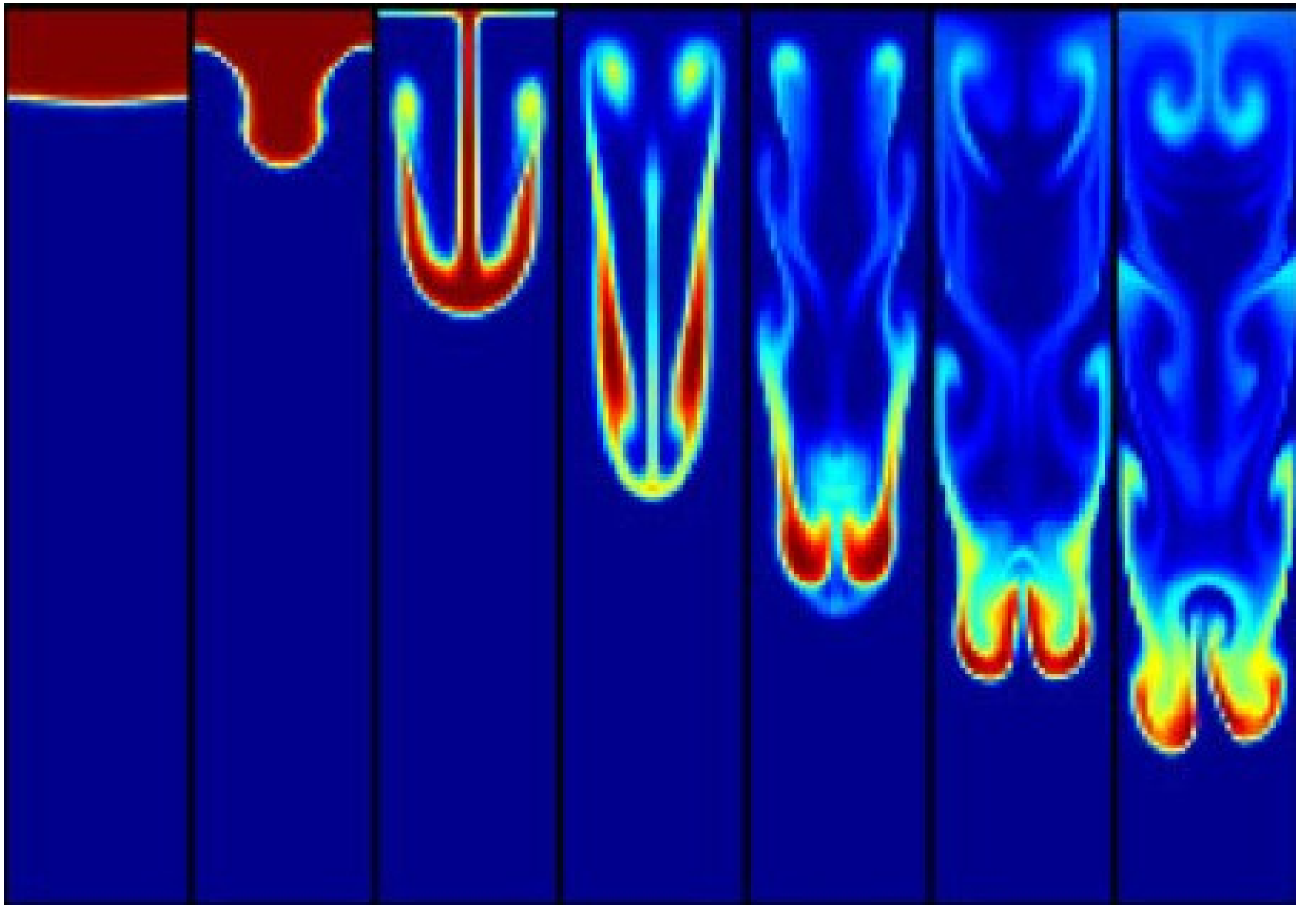
THE NON-LINEAR TWO-STREAM PROBLEM—A NEW APPROACH

S. K. EL-LABANY* and G. ROWLANDS



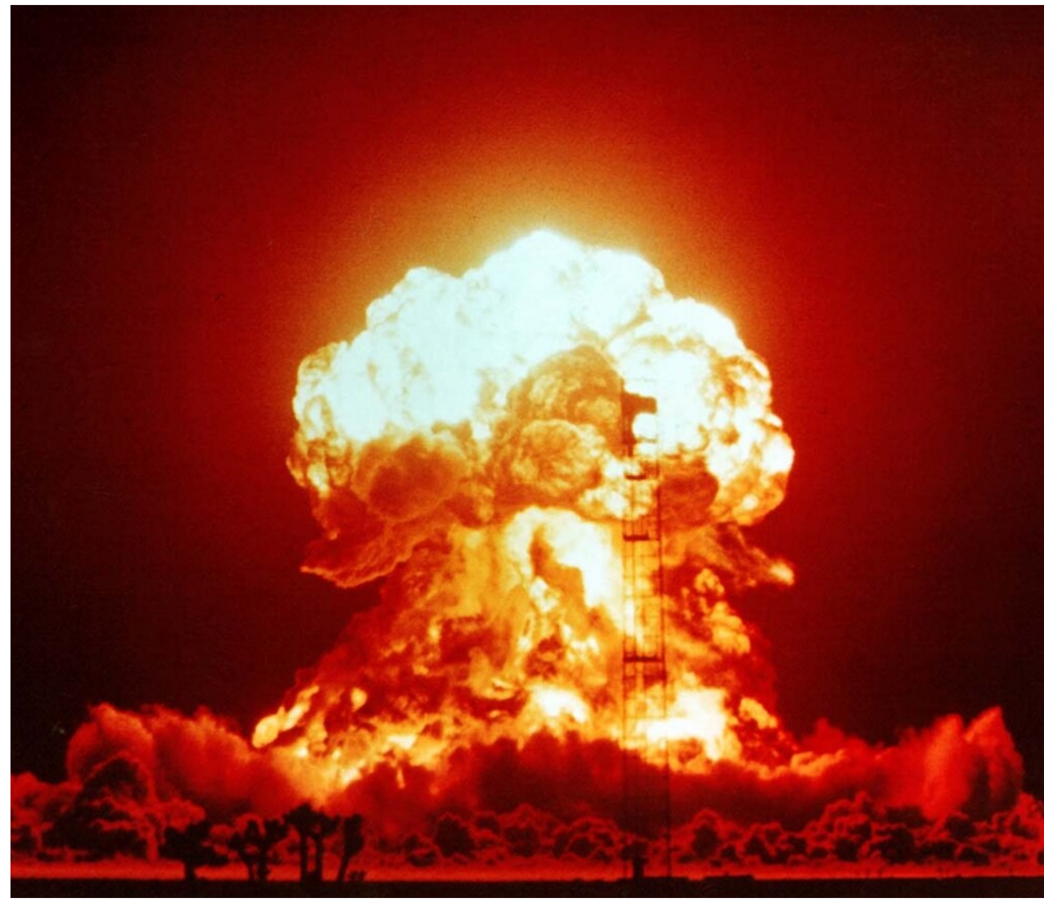


Rayleigh–Taylor

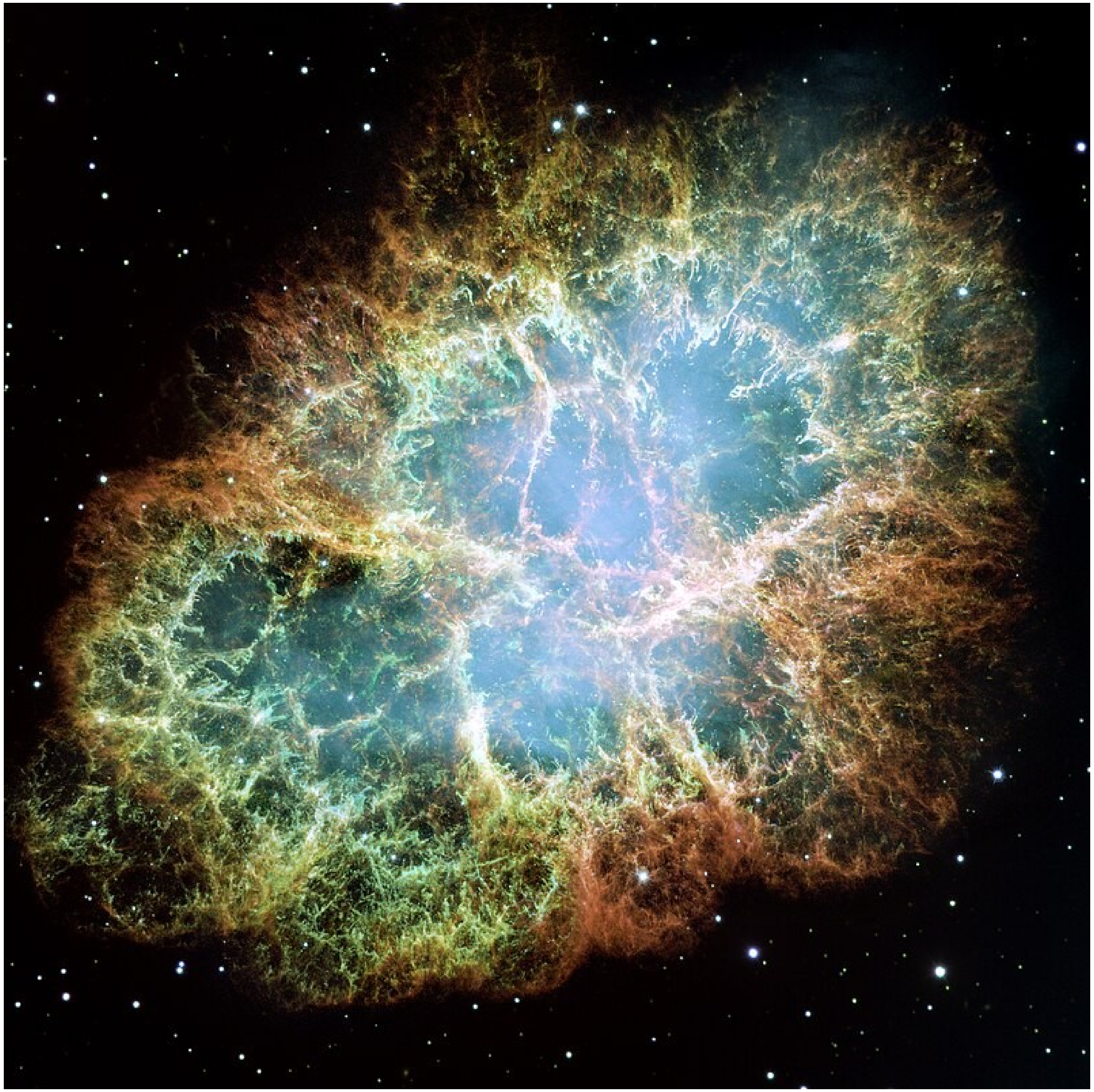


When the lighter fluid is pushing the heavier fluid

Rayleigh–Taylor, cont.



Rayleigh–Taylor, cont.

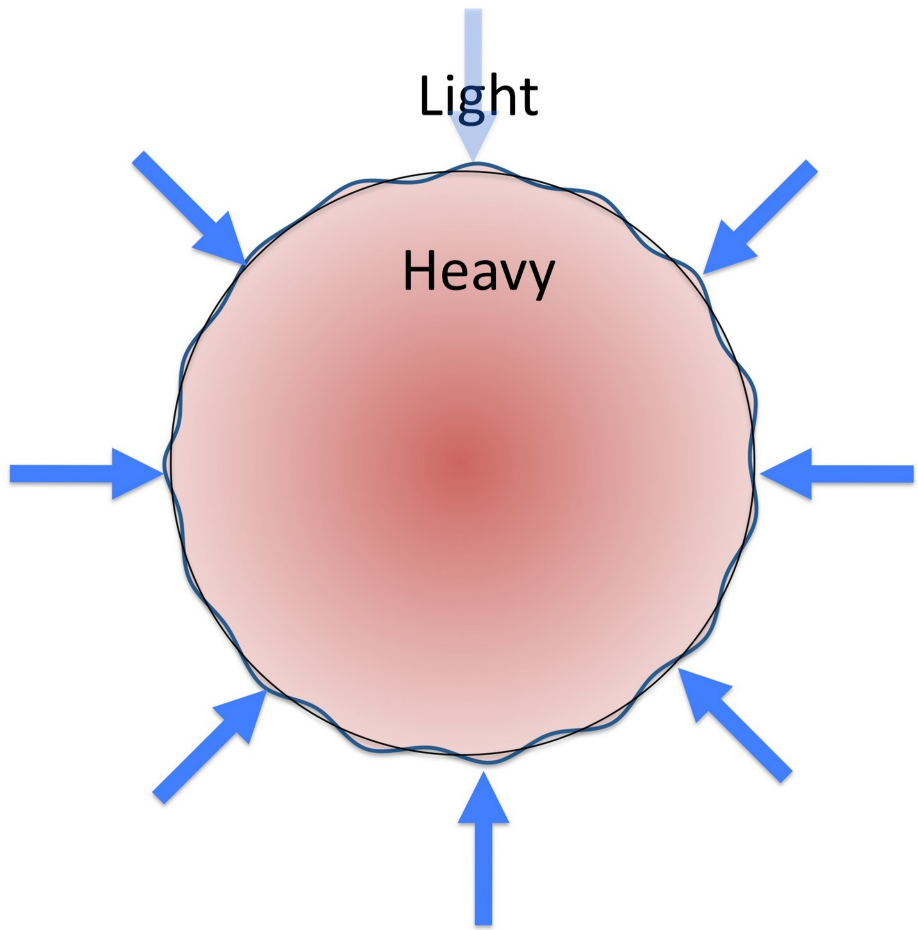


Rayleigh–Taylor, cont.

Inertial confinement fusion

Rayleigh–Taylor, cont.

Inertial confinement fusion



Finally...

Time for Questions…!!