

FINAL REPORT ON :

NON-LINEAR WAVES IN CONTINUOUS MEDIA

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I am happy to report that this project has been a big success.

For over 10 years the DOE [Division of Materials Sciences and Engineering] has funded our research program on the overarching theme of spontaneous energy focusing phenomena. These effects occur when a nonlinear macroscopic system is excited so as to drive it far from equilibrium. The subsequent relaxation to equilibrium does not occur smoothly but instead is accompanied by the formation of structured domains where the energy density is highly concentrated. A signature example is picosecond sonoluminescence [1] wherein a smooth sound wave has its energy density focused by 12 orders of magnitude to generate a clock-like string of picosecond flashes of ultraviolet light.

Our earlier work on solitons [2] demonstrated how uniform surface waves break up into stable localized structures. Our experimental work on turbulence produced photos of localized structures lying many standard deviations outside the range of gaussian statistics[3]. This effect is referred to as intermittency.

Our recent work on friction finds its motivation in those theories of sonoluminescence which invoke frictional electricity. In its most common form this is the generation of a spark when we touch a doorknob after walking over a carpet. Our reading of the literature on this subject indicated that frictional electricity like sonoluminescence is not understood. So to probe triboelectrification we set up a modern version of an experiment performed by Bernoulli in 1700. Here sparking is caused by the rubbing of glass against mercury. We indeed observed flashes of light which were accompanied by events of stick-slip friction at the interface between the mercury and glass. Furthermore, we found that a very slow relative motion of 1mm/second created repetitive macroscopic picosecond discharges wherein electrons are accelerated to at least 1% of the speed of light[4].

Following up on the Bernoulli-Picard effect we wondered if electrification played a role in ordinary friction and if friction itself might be another example of an energy focusing effect. Indeed we found that dry friction is due to the spontaneous formation of atomic/molecular bonds at the interface of two materials brought into contact. Bond formation provides for the stick in stick-slip friction. When the external force is great enough to rupture the bonds the interface slips. Thus the averaged normal force applied to an interface is focused down to the level of individual bonds where quantum mechanics comes into play in determining the properties of friction in macroscopic systems[5,6,7]. A typical applied

stress is about 1bar whereas the focused stress at the bonds which spontaneously form at the interface is about 1Megabar. This stress is so great that it locally distorts the interface and leads to spot cold welding between surfaces in contact. And as these cold welds grow the change in stiffness of the junction displays quantum jumps which we have observed even when the bodies in contact have macroscopic dimensions [7].

The intellectual thrust for all the advances mentioned above has been seeded by the Division of Materials Sciences and Engineering. We believe that our efforts have generated favorable science based publicity for Basic Energy Science. The Principal Investigator has been invited to give colloquia at each of the top 20 universities at least once. The New York Times has written 3 science articles based on our effort on sonoluminescence and the mercury light. Nature has written a news-story about our work on solitons [8] and more recently a news-story about our work on cold welding [9]. Our recent success in scaling up sonoluminescence to pulses with a peak power of 1/2Watt [10] has just been reported by Physics Today[11], and a presentation to the Acoustical Society of America [12] about megakelvin sonoluminescing bubbles has been picked up by Business Week [13]. Additional news articles about our work in Nature, Science, etc. could be cited.

#### DOE References

1-B.P. Barber, S. Putterman; Observation of Synchronous Picosecond Sonoluminescence, Nature 352, 318 (1991). Other recent papers supported by the DOE are :S.J. Putterman, K. Weninger, Sonoluminescence: How Bubbles Turn Sound into Light, Ann Rev Fluid Mech. 32,445 (2000). K. Weninger, C. Camara, S. Putterman, Observation of Bubble Dynamics within Luminescent Cavitation Clouds: Sonoluminescence at the Nanoscale, Physical Review E63,016310 (2000). S.Putterman, P.G.Evans, G.Vazquez, K.Weninger, Is There a Simple Theory of Sonoluminescence, Nature 409, 782 (2001).

2- Observation of Envelope Solitons in Solids, with J. Wu, J. Wheatley, and I. Rudnick, Phys. Rev. Lett., 59, 2744 (1987) Observation of a Kink Soliton on the Surface of a Liquid," with B. Denardo, W. Wright and A. Larraza, Phys. Rev. Lett., 64, 1518 (1990) "Observation of Localized Structures in Nonlinear Vibratory Lattices: Domain Walls and Kinks," with Bruce Denardo, B. Galvin, A. Greenfield, A. Larraza, W. Wright, Physical Review Letters 68, 1730 (92).

- 3- Imaging of Intermittency in Ripple-Wave Turbulence," with William Wright, R. Budakian, and D. Pine; *Science* 278, 1609, (1997).
- 4-R.Budakian,K.Weninger, R.A.Hiller, S.J. Putterman, Picosecond Discharges and Stick-Slip Friction at a Moving Interface of Mercury and Glass, *Nature* 391, 266 (1998).
- 5-R.Budakian, S.J. Putterman, Correlation Between Charge Transfer and Stick-Slip Friction at a Metal Insulator Interface, *Phys. Rev. Lett.* 85, 1000 (2000). R. Budakian, S.J. Putterman, Real Time Imaging of Two-Dimensional Charge on Dielectric Surfaces, *Rev. Sci. Instr.* 71, 444 (2000).
- 6-R. Budakian, S.J. Putterman, Time Scales for Cold Welding and the Origins of Stick-Slip Friction, *Phys. Rev.* B65, 235429 (2002)
- 7-R.Budakian, S.J. Putterman, Force Detection Using a Fiber Optic Cantilever, *Appl. Phys. Lett.* 81,2100 (2002)
- 8- P.L. Christiansen, *Naure*, 323, 12 (1988).
- 9-Phill Ball,Spot Welds Stick Sliding Metals, *Nature* 15 March 2002, [nature.com/nsu/020311/020311-11.html](http://nature.com/nsu/020311/020311-11.html)
- 10- C.K. Su, C. Camara, B. Kappus S.J. Putterman, Cavitation Luminescence in a Water Hammer: Upscaling Sonoluminescence" *Physics of Fluids* 15, 1457 (2003).
- 11-Physics news Update #635 May 1, 2003, P. Schewe ed; and, *Physics Today* July 2003, p.9.
- 12-S.Putterman, C. Camara, B. Kappus, C.K.Su, What are the Limits of Energy Focusing in Sonoluminescence? *J. Acoust. Soc. Am* 113,2193 (2003). C. Camara, S. Putterman, E. Kirilov, Sonoluminescence from a Single Bubble Driven at 1MHz, *Phys. Rev. Lett.* 92, 124301 (2004).
- 13- *Business Week* May 19, 2003.