AS-TEXONO/05-02
December 15, 2004

NSC Research Proposal (2005-2006)
on
Studies of the Emissions of High Energy Radiations and Other Fundamental Processes in Sonoluminescence

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(operating under the framework of the TEXONO Collaboration [2])

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Abstract & Summary [3]

Recent claims of sonoluminescence-induced nuclear fusion have induced much interest in this subject. There are still many unknowns in this newly discovered phenomenon such that there are much room for research topics and surprises. The experimental high energy physics group of the Academia Sinica has initiated a research program in this area, which is pursued in conjunction to our mainstream particle physics program. We have already acquired the basic techniques and enhanced our capabilities on some of them, based on our experience with the advanced high energy physics experimentation. An inter-disciplinary team of expertise has been co-ordinated to work coherently on this problem. In particular, we have successfully devised methods to observe and measure the emissions of ultra-violet radiations and soft x-rays. This article surveys the progresses already achieved, as well as the current status and plans. It serves as supporting document to our NSC proposal.

[3] Following suggestions from the NSC convener, funding request for our mainstream TEXONO neutrino physics program is submitted as a separate proposal.

1 Introduction

An introductory survey on the history and physics of Single-Bubble Sonoluminescence(SL), as well as our proposed strategies and research directions, can be referred to our previous document AS-TEXONO/03-02, available at

http://hepmail.phys.sinica.edu.tw/~texono/TEXT/TEXONO/texono0302.pdf .

A list of references [1] were also included.

Since 2003, the ORNL experiment published a more detailed paper [2] putting the neutron detection in firmer footing. Meanwhile, we identified another possible research direction: measurement of the angular correlations in SL to perform an HBT measurement (à la heavy ion physics) to probe the intrinsic spatial structures of SL emissions [3].

It is worth-noting that by pursuing a multi-disciplinary subject beyond typical expertise of the high energy physics group, we are adding much vigor and flexibilities to our research program. We notice that such table-top projects are attractive to students, and they will learn many of the advanced particle physics experimental techniques along the way. Researchers from other fields find such subjects closer to their expertise and are willing to explore scenario of working with us. We believe that such projects will, at the end, enhance our versatilities and capabilities in our mainstream particle physics program. The experience is so far positive, and will serve as a reference if we may wish to get involved – indeed to launch and to take lead – in other multi-disciplinary subjects in the future.

2 Team and Tasks-Sharing

We have built up an multi-disciplinary team to pursue the subject *in the high energy physics style.* The main groups and their respective tasks are :

1. **Academia Sinica (AS):**
   The AS particle physics group is the mastermind behind the concerted program. They are responsible for acquiring – and enhancing – the many necessary tools, and is the base laboratory for the program on the studies of ultra-violet emissions in SL through the the detection of fluorescence lights (FL). Funding is provided by the NSC and ASIoP. Nanjing University Ph.D. student Jia-Qi Lu stations at AS to pursue his thesis on this subject. Another student, Feng-Kai Lin (NTHU), completed his Master thesis on this in 2004 (the first thesis for this program) and remains at AS as research assistant.

2. **China Institute of Atomic Energy (CIAE):**
   It is an officially supported program in CIAE. The first goal is to "repeat the Oak Ridge Experiment". There are well-established in-house facilities on neutron generators and detectors. The group is in close contact with groups from Institute of Acoustics, Chinese Academy of Science, for consultation on the generation of high acoustic pressure.

3. **Optics and Lasers Groups :**
   A undergraduate from National Tsing Hua University is setting up at the NTHU optics lab (courtesy of Prof. J.T. Shy) to master the skills on laser optics towards reproducing the Mie scattering measurements. The optics team from National Central University, under Prof. T.S. Yih (NCU), is responsible for spectral analysis. Meanwhile, the optics laboratory at National Chung-Cheng University (NCCU), under Prof. J.L. Tang, is pursuing ps-grade timing spectroscopy for SL pulses.

4. **Theorists Contacts:**
   Contacts have been established with theorists who have worked on the subject before: Profs. C. Yuan (ASIAA, Taiwan), M.C. Chu (CU, Hong Kong), and Y. An (THU, China). They provided many suggestions to the research directions and clarified many fine points along the way.

The AS group is organizing their activities of the Taiwan groups and provides the necessary equipment and expertise know-how for setting up SL at the various laboratories. Regular contacts are maintained with the CIAE groups, with meetings at Beijing twice a year to review the status on both sides.

3 Research Directions & Status

The research program can be categorized as follows:

1. **Learning the Basic Skills and Developing the Essential Tools (AS):**
   We have already mastered the basic skills. Standard SL conditions can be robustly produced in spherical and cylindrical flasks. Gas and liquid handling system have been built. Advanced electronics, data acquisition, analysis and monitoring tools have been developed, including GHz digital oscilloscope readout, VME readout on multi-event ADCs, automatic monitoring and feedback software via LabView, data analysis packages in the event-by-event mode with ROOT. A LabView-based feedback system is now being constructed to ensure stability of SL emissions over time.

An future goal will be to build a VME data acquisition framework incorporating FADC, ADC and TDCs to provide maximum information for every event, followed by event-by-event analysis with ROOT. With this tool, one can perform "rare event" studies, rather than measuring the parameters statistically done up to now. To this end, we will install VME-GHz FADC into the data acquisition system.

It should be noted that developing these advanced techniques for concrete applications provide an excellent platform for training students to the sophistications of in high energy physics instrumentations.

2. **Detection of High-Energy Photon Emissions in SL (AS,NCU):**

   SL is expected to produce ultra-violet (UV) radiations, but these have not been experimental observed due to the self-absorption in water. By adding a chemical quinine to water, we successfully generate fluorescence light (FL) emissions, as demonstrated by the signals observed with a cosmic rays telescope. The primary UV emissions in SL are re-converted to the detectable FL light. The signature for SL+FL emissions, as compared to pure SL emissions in pure water, include changes in (a) emissions spectra – FL has a stronger green component, and (b) emission pulse shape – FL is slower. We have observed the pulse shape distortion, as displayed in Figure 1. Comparing to pure SL in water and pure FL with cosmic-ray trigger, a best fit to the function $y = \alpha$ SL + β FL can decouple the two components (α, β). The next tasks will be to quantify the effects, by establishing an energy scale to both components. Once this is performed, we can test the Black-Body radiation model – or assuming it is correct, derive the temperature of the SL emission source, an important parameter to understand the underlying physics.

   We are improving on and extending the measurement (AS) and will measure the optical spectra emissions (NCU). Completion of the work would merit a high-quality publication.

3. **Repeating the Neutron Detection Experiment (CIAE):**

   The CIAE team will repeat the ORNL neutron experiment. The original experiment operated at an acoustic pressure of 15 atm, as compared to 1.2-1.5 atm for standard SL. This is the technical hurdle we have to overcome. Contacts are made with the Institute of Acoustics (part of the Chinese Academy of Science) at Beijing, and prototype flasks and piezo-electric oscillators for high acoustic pressures are being produced. The other ingredients of the the experiment are ready and available at CIAE. We can certainly enhance the neutron detection sensitivities and accuracies through the pulse shape discrimination and time-of-flight techniques, standard in neutron physics.

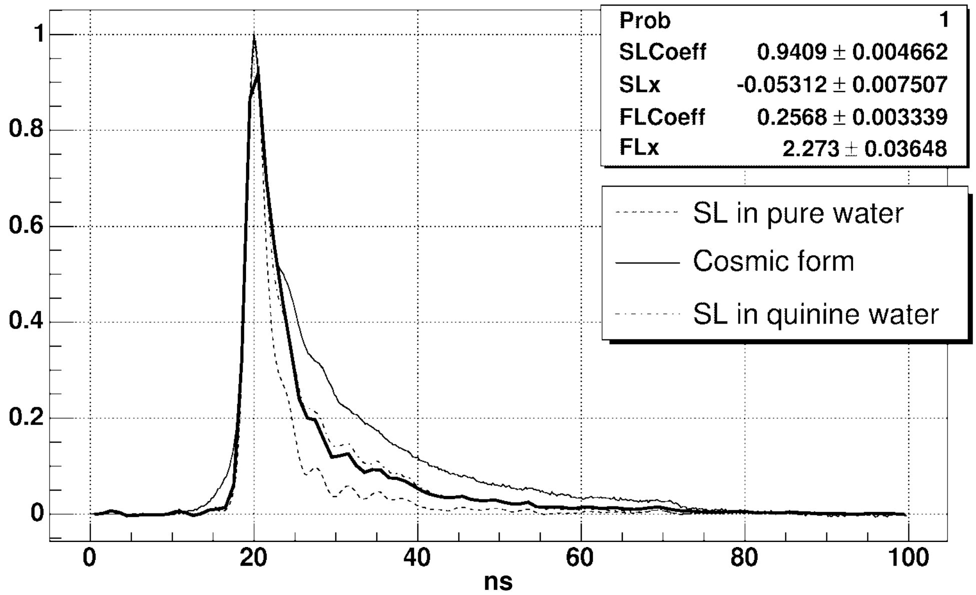

Figure 1: Measured pulse shapes in SL processes with a GHz digital scope. Different thin lines represent pulse shape for exclusive SL in pure water, predominantly FL in cosmic ray, and SL+FL in SL processes. The bold solid line is a best fit to the SL+FL measured curve.

4. **Fast ps-timing Spectroscopy and Angular Correlation Studies (AS, NCCU):**

   Emissions of SL light is a 10-100 ps phenomenon. The exact time-scale and fine-structures can shed light to the underlying physics and help to differentiate models. It is, however, not well-measured. We are interested to proceed along this direction from the known "femto-second laser spectroscopy" techniques. The opto-electronics group from NCCU is pursuing this.

   Hanbury-Brown-Twiss (HBT) interferometry has been used in studying internal dynamics of stars and in heavy ion collisions. Spatial-and-temporal correlations of SL emissions with HBT analysis have been studied theoretically [3] as means to probe the dimensions and distributions of the SL light source – an important problem. Several experimental groups are pursuing this but without success yet. The key experimental challenge is to devise methods for a "ps timing-filter" to the correlated events. Our ps-timing spectroscopy project, if successful, will put us in favorable positions in this direction.

Overall in the 2005-06 period, our goals will be complete the Phase-1 for the SL+FL project towards a publication, make significant advances in the neutron experiment, and have put techniques for the fast-timing project on firming footing. We expect once the SL+FL techniques are established, there will be many detail structures in SL phenomena that can be studied, and hence new projects will be initiated.

4 Request of this Proposal

We request funding support for the AS-based parts of the program discussed in Section 3. These include: (a) chemicals and piezo-electric ceramics, (b) 2 GHz VME FADC modules, to be incorporated into the DAQ system, (c) PMT with GaAs photo-cathode, which provide more uniform response in the optical 400 nm to 700 nm range, compared to the standard Bi-alkaline photo-cathode. On the manpower side, we request one R.A. position to participate in this program at AS. Support for attendance in international meeting in ultra-sonics will also be necessary to further enhance the impact of our work.

The CIAE-based part (neutron detection) are supported mostly by various agencies in China. We request only travel support for the team to make trips to Beijing to participate in collaboration meetings and to share data taking duties.

The NCCU-based part (ps-timing) will be spear-headed by the NCCU group, which will submit an independent proposal to request funding support on this program.

References

[1] See AS-TEXONO/03-02 for a full list of references on many of the background materials.

[2] R.P. Taleyarkhan et al., Phys. Rev. **E 69**, 036109 (2004).

[3] Y. Hama, T. Kodama, and S. Padula, Phys. Rev. **A 56**, 2233 (1997); C. Slotta and U. Heinz, Phys. Rev. **E 58**, 526 (1998).