SHOCK SYNTHESIS OF PRE-BIOTIC MOLECULES III: PROBING THE PRESSURES. M. C. Price[1], V. Spathis[1], J. D. Tandy[2], P. J. Wozniakiewicz[1], J. New[3] and L. S. Alesbrook[1], [1]School of Physical Sciences, University of Kent, Canterbury, CT2 7NH, UK, (E-mail: v.spathis@kent.ac.uk), [2]School of Human Sciences, London Metropolitan University, London, N7 8DB, UK, [3]Space Sciences Lab., University of California, Berkeley, CA 94720, USA.

Introduction: The use of light gas guns, and similar technologies, to emulate the high speed impacts that occur throughout the Solar System is a well-developed skill dating back to the 1940s. However, direct measurement of the high pressures (and temperatures) that occur on these very short timescales is difficult and computer simulations are therefore commonly employed to model these events. Such computer simulations predict peak pressures of the order of GPa lasting for timescales of ~µsec (depending on the size/velocity of the impactor, and the composition of the target and impactor). Validating the output of such codes is vitally important to establish confidence that the results for simulations of metre-to-km size impactors (where experiments cannot be performed) are accurate. Such results are necessary in order to understand the physical conditions that occur during these impacts within the Solar System, and how these extreme conditions can modify the materials (both target and impactor) involved.

Methodology: Although PVDF sensors, which are widely available and low-cost, have been used for many years to measure impact-induced strain and to give accurate timing of impact events (e.g. [1], [2], [3]), it is difficult to accurately relate the strains measured to peak pressures. Recently, however, low-cost sensors have become available (*Tekscan's* range of "Flexiforce" sensors) whose output is a quasi-static resistance, as opposed to a charge pulse, thus making it possible to build a sensor whose output scales directly with pressure. This sensor also has a fast response (of order of microseconds), is cheap (a few tens of dollar/pounds/euros) making it effectively disposable and therefore ideal for embedding in ice/water/granular targets where sensors could easily be damaged/destroyed. In order to reduce the sensitivity of the sensor so that peak pressures of the order of GPa could be sensed, without saturating the output, the sensor was embedded in epoxy (*Struers*' "EpoTek", Fig. 1). After embedding, the sensors were calibrated using a tensometer so that quasi-static pressure versus electrical resistance (and temperature) curves could be generated. These curves are used to calibrate the measured resistances prior to applying the FFT.

Preliminary Ice Impact Experiment: Currently of great interest is the shock synthesis of complex organic and pre-biotic molecules from simple icy compounds, and the conditions under which such organics are (or are not) synthesised.

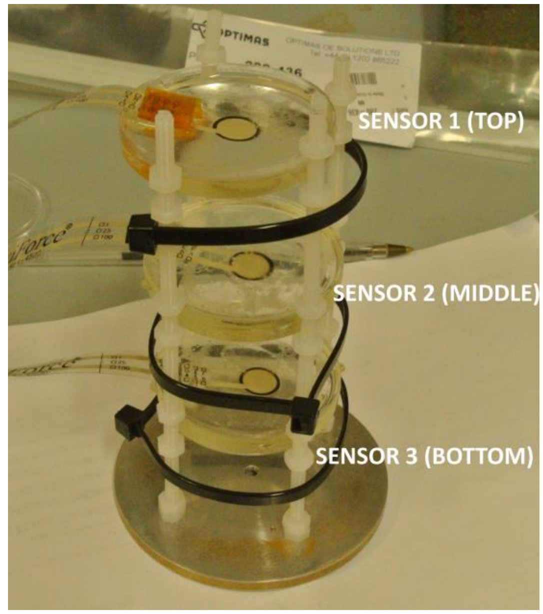

Fig. 1: Prototype sensor stack of three embedded "Flexiforce" sensors prior to immersion in a NaCl and ammonium sulfate brine solution and freezing to -120°C. The entire stack is approximately 150 mm in height.

For our initial experiment to test the sensors we immersed the sensor stack into a solution of 10g of NaCl and 10g of $(NH_4)_2(SO_4)$ dissolved in 1 litre of HPLC grade water. The solution was then frozen to approximately -120 °C before being impacted with a 3 mm diameter Al sphere at 5.98 km s^{-1} using the Uni. of Kent's light gas-gun facility. NaCl and $(NH_4)_2(SO_4)$ were selected to approximate the surface composition of icy worlds, such as Europa [4, 5] and Enceladus [6 and refs therein], where pre-biotic molecules (such as amino acids – accepted to be necessary for the emergence of life) could potentially have been/are being formed from impacts. We have had previous success in synthesising amino acids from simple ice mixtures [7], and very recently had indications of the formation of isoleucine from a frozen glycine solution [8–V. Spathis, these proceedings]. However, currently, the results are generally binary in nature: "have we?" or "haven't we?". In order to get a more quantitative measure of the process we set out on a co-ordinated program to investigate the pressures (and temperatures, [9]) experienced during such an experiment.

Experimental Results: The sensor data had to be post-processed after the impact to account for the non-instantaneous response of the sensors. Although fast, the sensors have a rise time of ~5-20 microseconds (we refer to this as the 'measured sensor response', S_r) which smears out the actual impact response and lowers the measured peak pressure. However, as we know that the actual impact response should be almost discontinuous, we can deconvolve the measured instrument response, S_r, with the recorded data, R_r, to give the actual impact response, A_r, and thus the peak pressure. Mathematically:

$$R_r = S_r * A_r$$

To perform the deconvolution, the measured data, R_r, and A_r are fast-Fourier-transformed and then the FFTs divided to give the FFT of the real pulse. In essence, the slower detector response is acting as a low pass filter attenuating the higher frequency components of the Fourier transform and leading to a smearing out of the real pulse. The inverse transform can then be plotted, which gives Fig. 2 below.

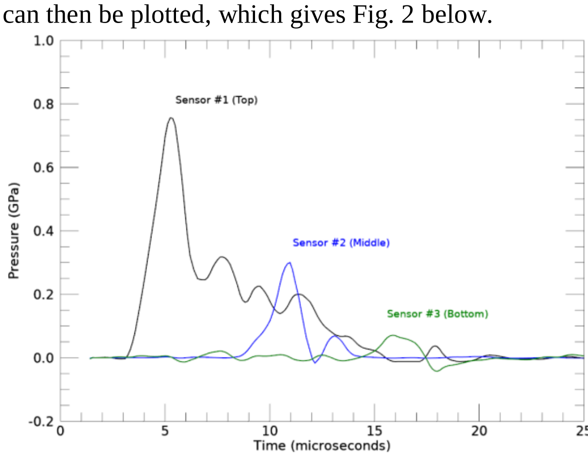

Fig. 2: Restored and calibrated pressure data from the sensor stack. 3 mm Al sphere into brine ice at 5.98 km/sec.

Hydrocode modelling: Hydrocode modelling (using Ansys' AUTODYN) was also undertaken to compare the data from the pressure sensors to the output from the simulation. Modelling ice is notoriously difficult, but many attempts have been made [e.g. 10 - 13]. Here we use a simple ice model with a Tillotson [14] equation-of-state and a very simple Von Mises strength model. We acknowledge that there are significant differences between pure water ice, and the $NaCl/(NH_4)_2SO_4$ ice mixture used in this experiment, however, the current goal is not to achieve a 100% match, but to see if there is a first-order agreement between the pressures and temporal scales. Comparison of Fig. 2 and Fig. 3 shows good agreement with similar peak pressures

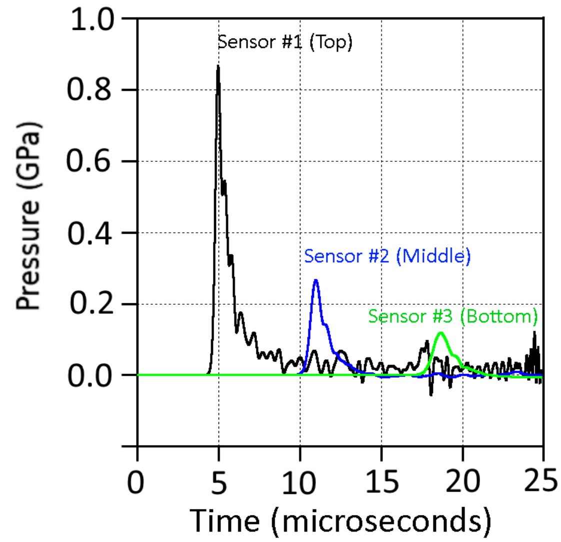

Fig. 3: AUTODYN output of the impact experiment using Tillotson ice model. Same axes as Fig. 2.

and decay time times (although the sampling rate on the experimental system needs to be increased).

Conclusions and Future Work: We have developed, and demonstrated, a novel, prototype system that can be used to measure GPa pressures on μ-sec time-scales. Coupled with the high-speed temperature monitoring system that we are also developing [9], we now have a suite of in situ probes that open up a new dimension in shock synthesis experiments.

Funding is being sought to improve upon, and further develop, the prototype systems. Significantly these will quantitatively constrain the pressures and temperatures required for synthesis, which is vitally important for understanding the potential origin of organics on the surface of any impacted body.

Acknowledgments: The authors thank the STFC, UK, for funding this work (grant code: ST/S000348/1).

References: **[1]** Tuzzolino A. J. et al. (1996). *Adv. Space Res.*, 17, 12, 123. **[2]** Hirai T. et al. (2014). *PSS.*, 100, 87. **[3]** Tang E. J. et al. (2019). *Adv. Space Res.*, 63, 8, 2410. **[4]** Martins Z. et al. (2013). *Nat. Geoscience*, 6, 1045. **[5]** Pappalardo P et al. (2009). *Uni. of Arizona Space Science Series – "Europa"*, 283. **[6]** Hibbitts C. A. et al. (2019), *Icarus*, 326, 37. **[7]** Schenk P. M. et al. (2018). *Uni. of Arizona Space Science Series – "Enceladus"*, 129. **[8]** Spathis V. et al. (2021a). *LPSC LII, Abstract #1623*. **[9]** Spathis V. et al. (2021b). *LPSC LII, Abstract #1625*. **[10]** Carney K. S. et al. (2006). *J. of Solids & Structures*, 43, 7820. **[11]** Senft L. E. & Stewart S. T. (2007). *J. Geo. Res.*, 112, E11. **[12]** Fendyke S. et al. (2013). *Adv. Space. Res.*, 52, 705. **[13]** Haghighipour N. et al. (2018). *Ap. J.*, 855: 60. **[14]** Tillotson J. H. (1962). *General Atomic Report*, GA-3216.