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Preliminary results on the EOS of water in the Megabar range

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1 INTRODUCTION

The mantle of Neptune and Uranus is mainly constituted by "ice layers" containing water, methan and ammonia. The magnetic field of both planets, as measured by the probe Voyager 2, is larger than what was expected and asymetrical, hence originates from the conductiity of those layers. The range of temperature and pressure in the ice layers is of 0.2 to 6 Mbar and 2,000 K to 8,000 K. Estimations of the minimum conductivity capable of sustaining the magnetic field by dynamo effect give about 200 $(\Omega.\text{cm})^{-1}$. Recent calculations predict a transition from electrolyte to metal in this regime for water and ammonia [1]. Yet no measure has so far confirmed its existence.

We describe here the first experiment measuring the equation of state (EOS) of water with laser driven shock waves in the range of pressure 1-10 Mbar. This technique of measurement has been much improved in recent years [2] and has become a reliable tool for high pressure physics. [3] The experiments were conducted at the Commissariat à l'Énergie Atomique in Limeil, France.
Our goals are to obtain new experimental points for the EOS of water in the Megabar range, as well as to estimate the conductivity in this range of pressure.

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2 SET-UP

The experiments are based on the impedance mismatch method, where the shock velocity is measured in two different materials, one of which used as a reference. We choose Aluminium, as its EOS is well known up to 40 Mbar. [4]

We used a beam of the PHEBUS laser (cf. fig. 1) in the green ($\lambda = 0.526$ μm), optically smoothed with a Kinoform Phase Plate (K.P.P.) The focal spot was 900 x 600 μm^2 and we used a square pulse of duration 4 ns, obtaining a maximal intensity of 1.4 10^{14} $W.cm^{-2}$.
A probe beam ($\lambda = 1.064$ μm) with a longer duration (10 ns) and very little energy (a few mJ) was reflected on the rear-side of the target and sent to two VISAR (Velocity Interferometer Systems for Any Reflector) [5] which measure the velocity of the target.
To resolve the ambiguity on the initial shift of the fringes at the shock arrival [6], we used two VISAR with different sensitivities coupled with streak cameras. Assuming that water is metallised, the probe beam crosses "cold" water and gets reflected on the shock front. The sensitivities of the VISAR are of 15.9 $km.s^{-1}$ and 5.3 $km.s^{-1}$ per fringe respectively. To image the rear-side of the target, we used a relaying system to avoid vignetting (i.e. a luminosity drop on the borders of the image).
A third streak camera was used to record the target self-emission (VDC).
The target consists of an Aluminium step and a cell filled with water (cf. fig. 2). To minimize preheating of the target, a layer of plastic (CH) was added in front; finaly, a very thin Al foil was placed to avoid laser

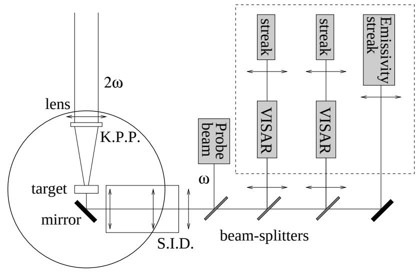

Figure 1: *Set-up. The power laser beam ($\lambda = 0.526$ μm) is optically smoothed by a KPP and focused on the target; a probe beam ($\lambda = 1.064$ μm) is reflected on its rear side and analysed by two VISAR; the emissivity of the target is recorded by a third diagnostic.*

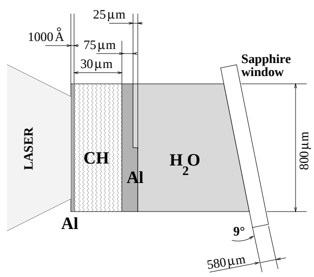

Figure 2: *Target. The interface between Al and Water is made of a 25 μm step.*

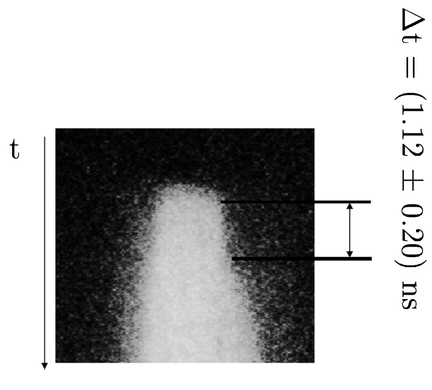

Figure 3: *Target self-emission. We measure the transit time of the shock in the Al step.*

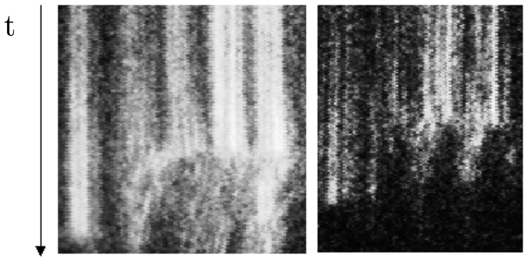

Figure 4: *Images from the VISAR : we can measure the fringe shift, get an independent measurement of the shock transit time in the Al step, and measure the reflectivity of the target.*

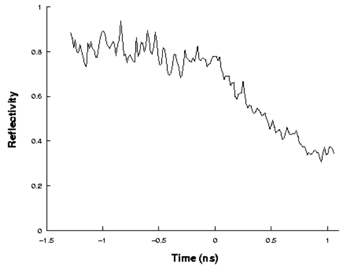

Figure 6: *Reflectivity of the target measures from the images of fig. 4. Initialy, the reflecty decreases because of a small preheating of the target. It seems to stabilize further around the value 0.3.*

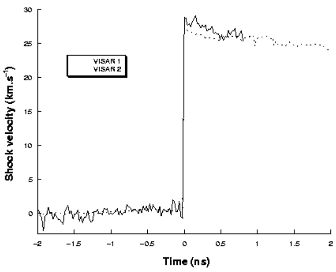

Figure 5: *Shock velocity profile measured with the VISARS from the images of fig. 4. The shock is stationnary.*

shine-through at early times.

The transit time Δt of the shock in the Aluminium step is measured with the VDC : when the shock breaks through, Al begins to emit, and a visible signal is detected. This measurement can be confirmed with the VISAR (cf. fig.s 3 and 4). Hence, knowing the height of the step (and assuming that the shock is stationnary – cf. fig. 5), the shock velocity in Al can be calculated. The shock velocity in water is measured by the fringe shift on the VISAR (cf. fig. 4).

3 RESULTS

The results for the EOS are shown on fig. 8 with other data [7, 8, 9, 4].
With the measurement of the reflectivity (cf. fig. 6) and a simple electromagnetic model, we can evaluate the electronic conductivity of water (cf. fig. 7). It is found to be an order of magnitude higher than the extrapolation of measurements [7, 9, 10]. It shows that water reached a state with a high density of free electrons.
For the shot at 10 Mbar (cf. fig. 8), the reflectivity is more difficult to measure, and too close to 1 to allow the estimation of the conductivity. We can only say that $\sigma \geq 10^4 (\Omega.\mathrm{cm})^{-1}$.

4 CONCLUSIONS

The results presented here are the first measurement of the EOS of water with laser driven shock waves. This method proved to be a reliable tool for this measurement. However, the error bars are large, and we need to get new data.
We evidenced a high electronic conductivity at P $\simeq$ 3 Mbar and (T = 2.6 eV.

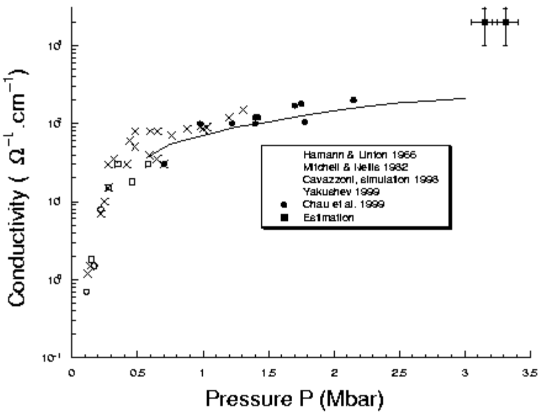

Figure 7: *Estimation of the electronic conductivity and comparison with measurements [7, 10, 9]. The curve is the* ab initio *calculation of Cavazzoni [1]. The temperature for the two shots is about 2.6 eV.*

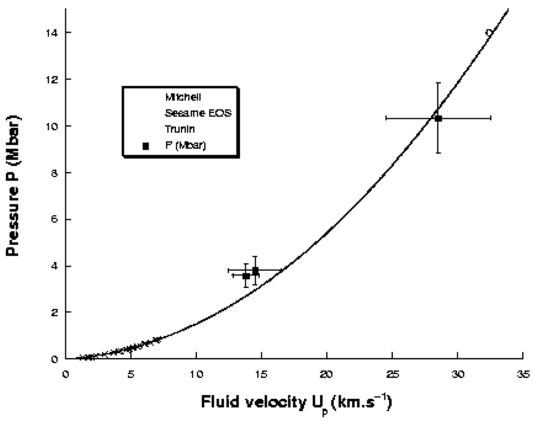

Figure 8: *Points on the EOS compared with the SESAME table [4] and existing experimental data [7, 8, 9].*

ACKNOWLEDGMENTS

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References

[1] C. Cavazzoni *et al. Science* **283**, pp. 44–46, 1999.

[2] M. Koenig *et al. Phys. Rev. Lett.* **74**(12), pp. 2260–2263, 1995.

[3] Y. Zeldovich and Y. Raizer, Academic Press, New York, 1967.

[4] "SESAME : Report LA-UR-92-3407." Los Alamos National Laboratory, 1992.

[5] P. Celliers *et al. Applied Phys. Lett.* **73**, pp. 1320–1322, September 1998.

[6] R. Trunin *Phys.-Usp.* **37**(11), pp. 1123–45, 1994.

[7] A. Mitchell and W. Nellis *Journal of Chemical Physics* **76 (12)**, pp. 6273–6281, 1982.

[8] A. Mitchell *et al.* in *Proc. VIIth AIRAPT Conf.*, No. II, European Physical Society, Pergamon, (Oxford), 1980.

[9] Chau *et al.* 1999.

[10] V. Yakushev in *AIRAPT conf.*, 1999.