National Aeronautics and Space Administration

Laboratory Electrical Conductivity Measurements for Exploring Ocean Worlds

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Program: FY22 R&TD Topics
Strategic Focus Area: Solar System characteristics and origin of life

Objectives:
Obtain electrical conductivity data needed to interpret magnetic observations of extraterrestrial oceans, to salinity and pressure.

Background:

Geophysical measurements can reveal the interior properties of icy ocean worlds. Such measurements can point to the presence and temporal variability of fluids and gases, thus identifying potential habitable niches for life. The thickness and geodynamics of different ice phases, and the depth of the ocean, determine the conditions under which life might exist. The global fluxes of chemical energy must be understood in terms of a world's interior structure and evolution. Such a global picture is necessary for quantifying the types of life and amounts of biomass that might be supported. Interpreting the results from magnetic induction measurements assumes good knowledge of the electrical conductivity of the solutions, but available electrical conductivity data do not cover the range of possible conditions. Currently available data generally extend to a maximum concentration of 30 parts per thousand (ppt), with no consideration for the effects of high pressure. Coverage at temperatures other than 25°C is less reliable. Salinities of ocean worlds can extend well beyond 30ppt, and pressures in the largest oceans can reach 1GPa (10,000 bar).

Approach and Results:

Newly commissioned JPL Simulator for Icy World Interiors (SIWI) to measure electrical conductivity σ up to 700 MPa from -20 to 20°C to the solubility of NaCl and $MgSO_4$.
Corrosion resistant Ti electrodes with optimized geometry in PTFE sample containment package suitable for high-pressure measurements. Container sealed with a nitrile finger cot.

Implemented software and hardware for pressure and temperature readout and control.
Through analyses based on our own simulations of Europa's magnetic induction [1], we identified the needed precision of measurements better than 1% in the range 0.1 wt% (Figure 1).
Available measurements at 1 atm [2,3] have repeatability in this range, but only for T > 5°C.
Measurements at high pressure and high salinity [4,5] (1-10 wt%) are in the range 10-15%.
Galileo constraints on Europa's salinity are consistent with the broad range considered here [6].
Preliminary measurements in NaCl solutions and NIST-traceable standard KCl solutions at 1 atmosphere. The use of NIST standards and cross calibration will be essential to achieving the desired accuracy (Figure 2).

Molecular dynamics (MD) simulations to predict the conductivity behaviors of NaCl solutions.
Also used in recently published work by Pan et al. (2021) [5].
Our analyses demonstrate that MD simulations do not provide the needed precision.
Representations of water's behavior appear to better match conductivity trends in different regimes of pressure and temperature.
We believe that MD simulations will provide useful insights into the trends of our measurements.
Main insight at present is that their application in previously published work was not effective.

Our analysis and understanding of electrical conductivity data relevant to ocean worlds was as employed, related to this
project, in a recent publication in the journal Geophysical Research Letters led by Julie Castillo-Rogez [A].

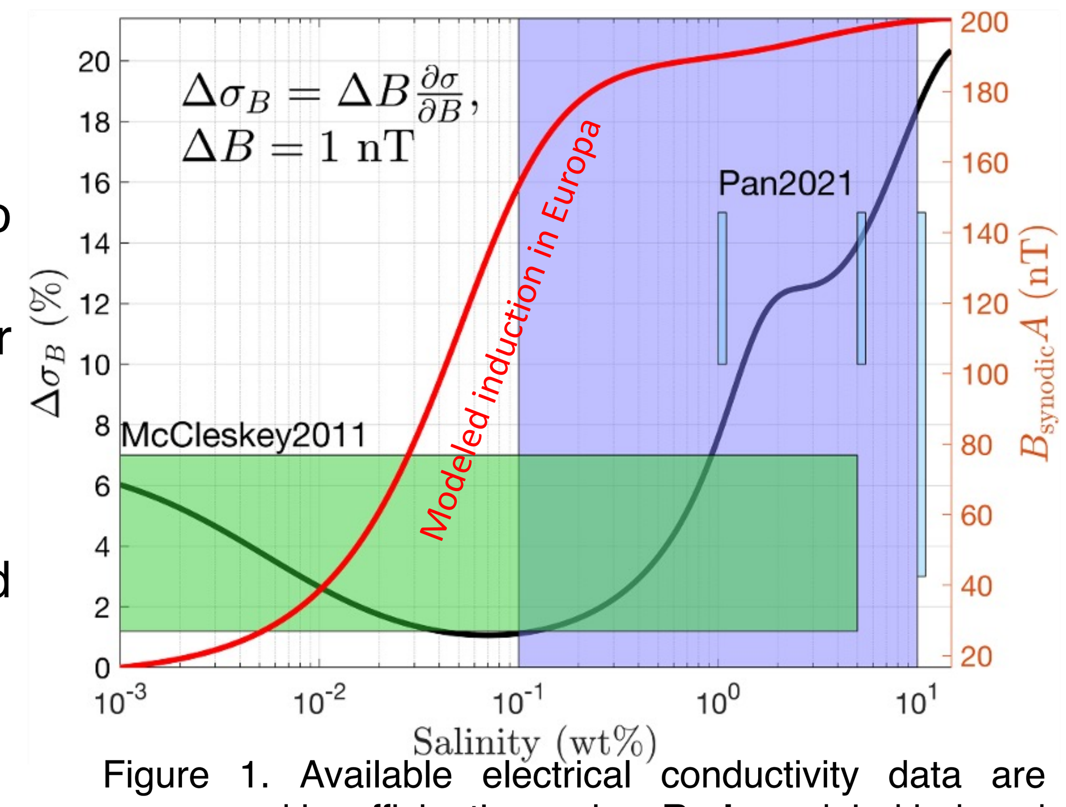

Figure 1. Available electrical conductivity data are sparse and insufficiently precise. **Red:** modeled induced magnetic field strength at Europa vs salinity (conductivity). **Cyan and green rectangles:** assessed uncertainties for published measurements [1,2, respectively]. **Large shaded region to the right:** salinities inferred from Galileo measurements [3]. **Black:** needed precision of conductivity measurements corresponding to a 1 nT uncertainty in the induced field. More sensitive measurements are needed, especially around 0.1 wt%.

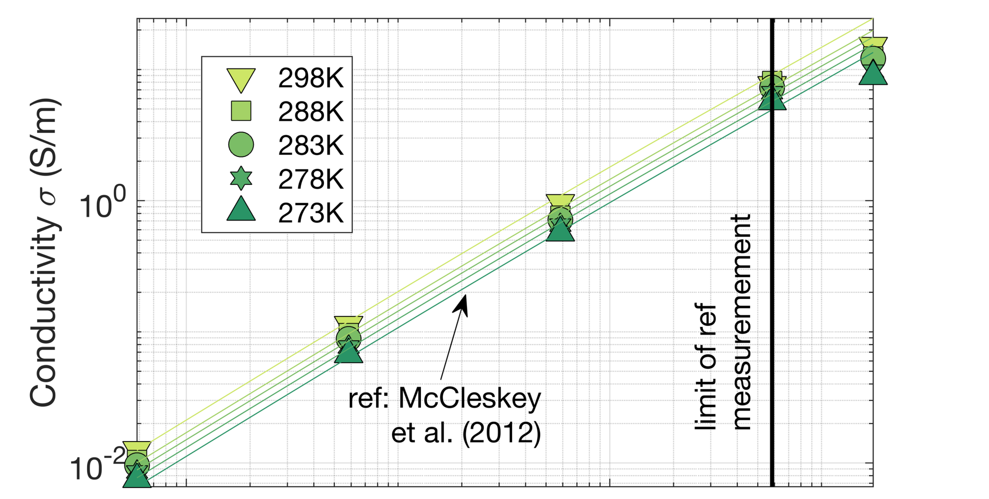

Figure 2. Measurements in NaCl solutions at room pressure, compared with the assessed state of the art [2]. Improved precision will be obtained by cross-calibrating with NIST-traceable standard solutions and using Ti electrodes that are less susceptible to corrosion (Au was used here).

Significance/Benefits to JPL and NASA:

Significant progress toward establishing a verified approach to obtaining the data needed to interpret magnetic induction measurements by Europa Clipper, JUICE, and future ice giants missions. To our knowledge, other efforts to measure in the relevant range of conductivities are inadequate. Our modeling approach gives us a distinct advantage when proposing because we can demonstrate the application of our laboratory data to simulated magnetic induction measurements in highly realistic models of ocean worlds.

References:

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[2] McCleskey, R. B. (2011). Electrical conductivity of electrolytes found in natural waters from (5 to 90) ◦C. Journal of Chemical & Engineering Data, 56(2):317–327.
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[4] Pan, Y., Yong, W., and Secco, R. A. (2020). Electrical conductivity of aqueous mag- nesium sulfate at high pressure and low temperature with application to Ganymede's subsurface ocean. Geophysical Research Letters, 47(21).
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[6] Hand, K. and Chyba, C. (2007). Empirical constraints on the salinity of the europan ocean and implications for a thin ice shell. Icarus, 189(2):424–438.

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Publications:

[A] Castillo-Rogez, J. C., Daswani, M. M., Glein, C. R., Vance, S. D., and Cochrane, C. J. (2022). Contribution of non-water ices to salinity and electrical conductivity in ocean worlds. Geophysical Research Letters, 2021GL097256.

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