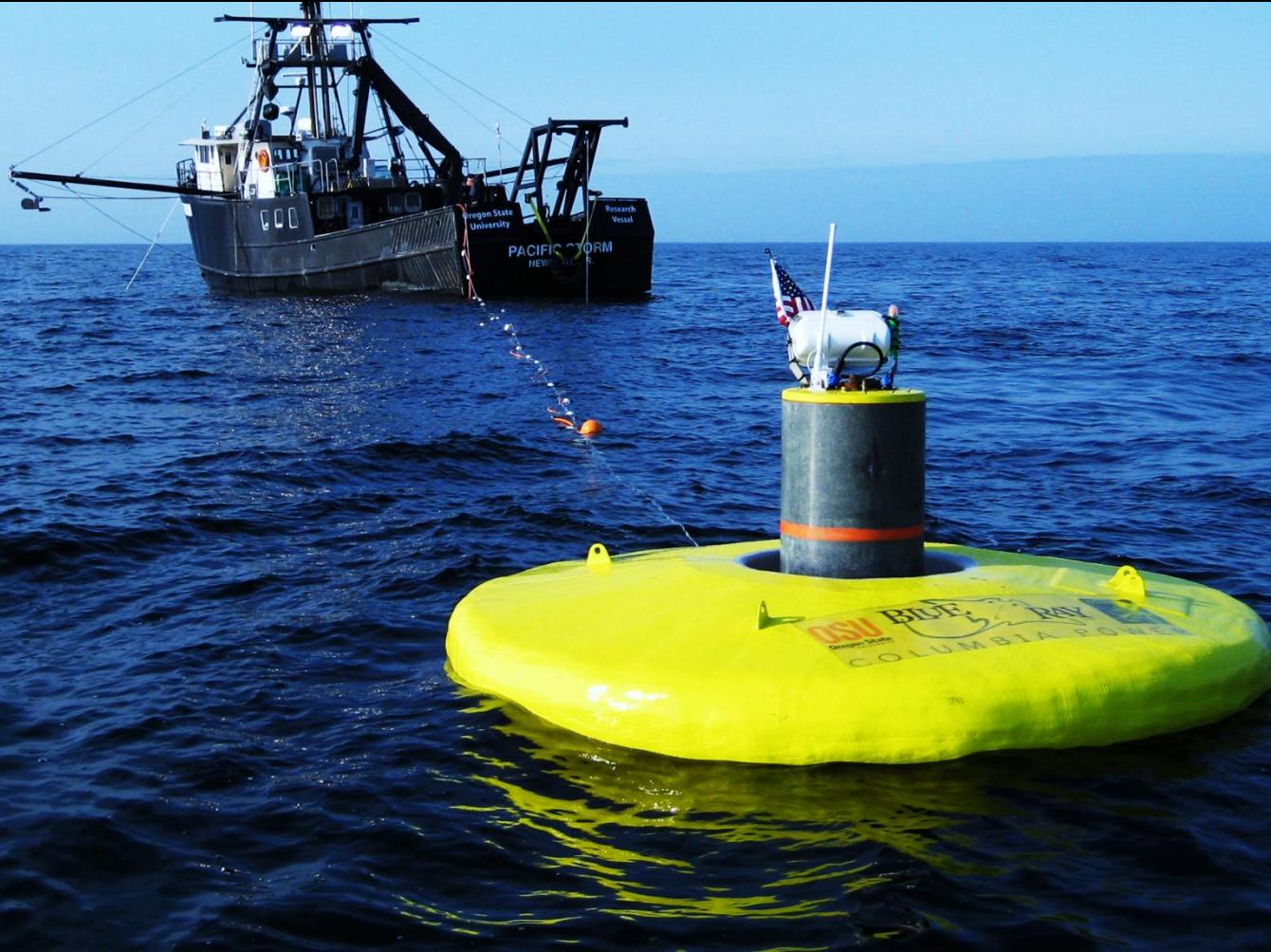
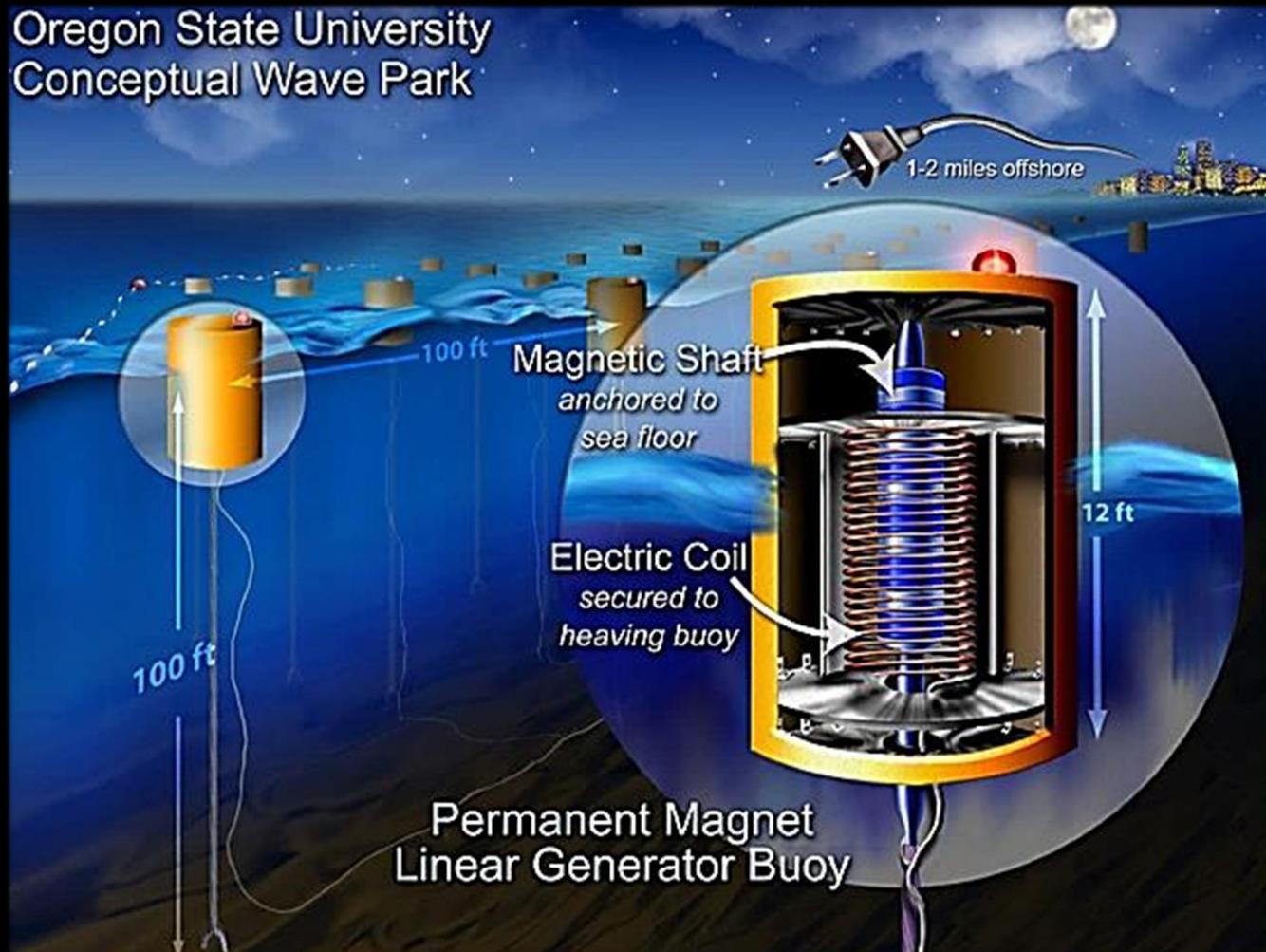


Wave Energy Power Transmission Lines: Electric and Magnetic Field Propagation

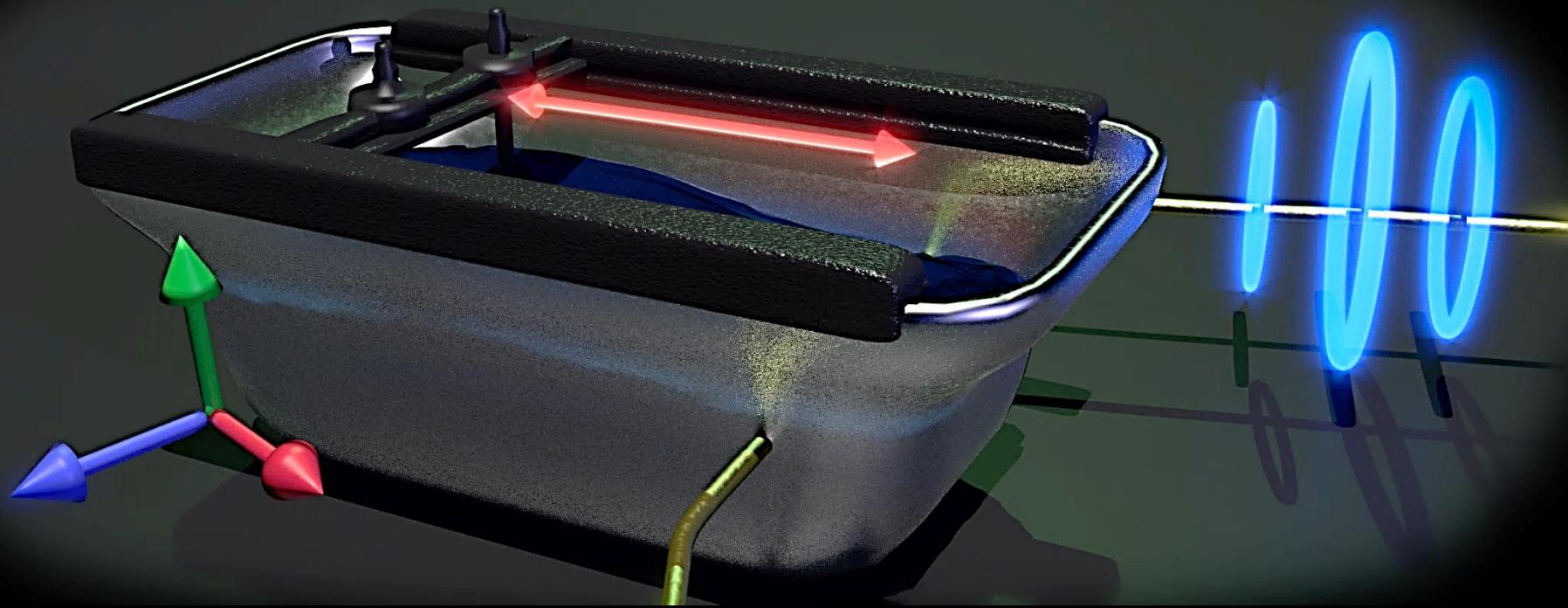
Jordan Pommerenck, Justin Pommerenck, Annette von Jouanne, Alexandre Yokochi



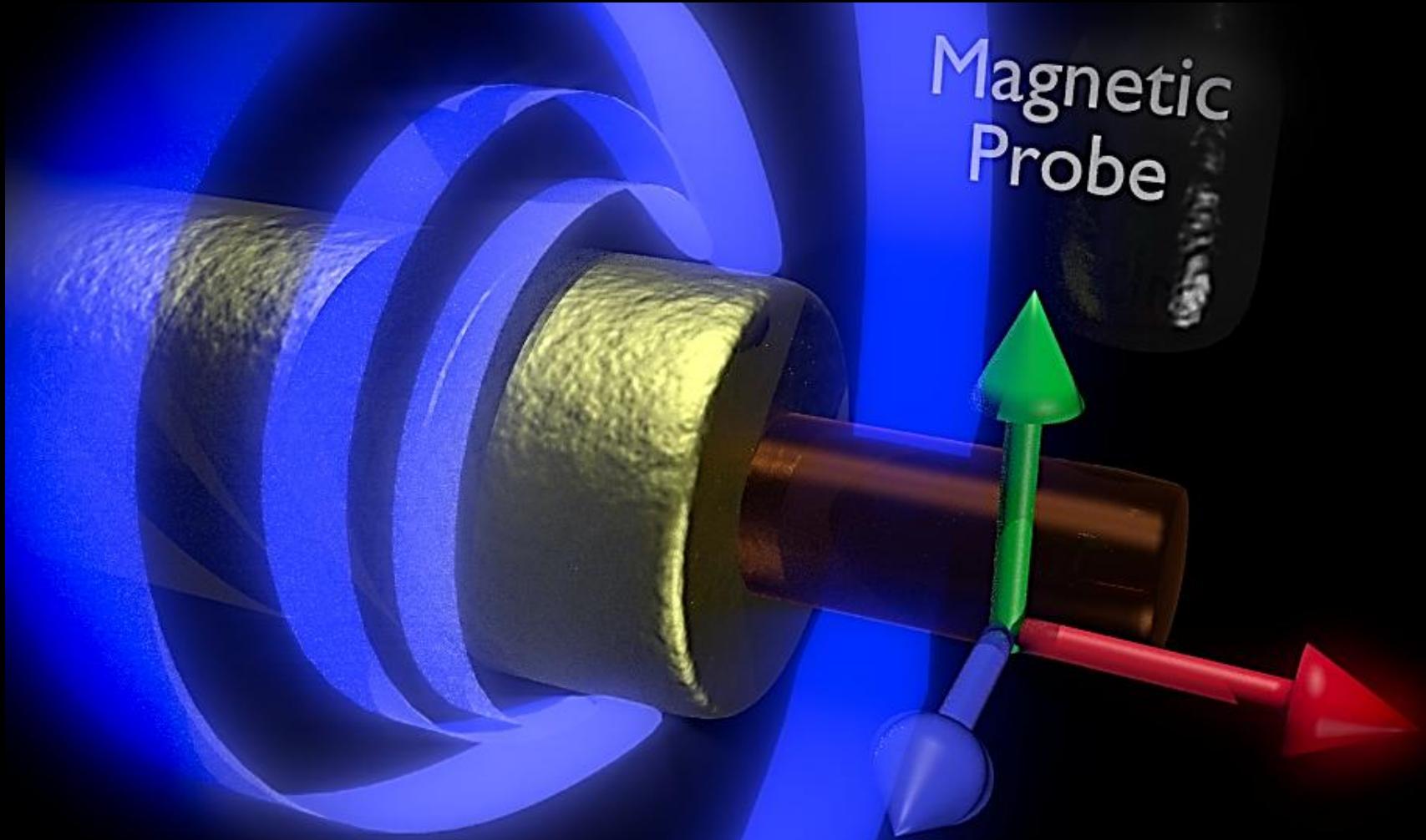
Experimental Background



Experimental Setup



Measuring B_ϕ



Modelling B_ϕ

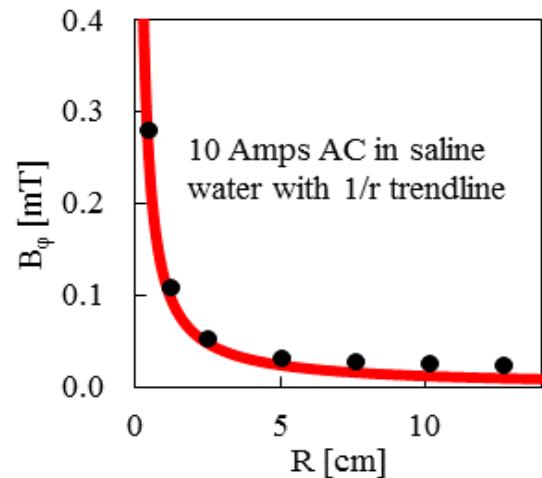
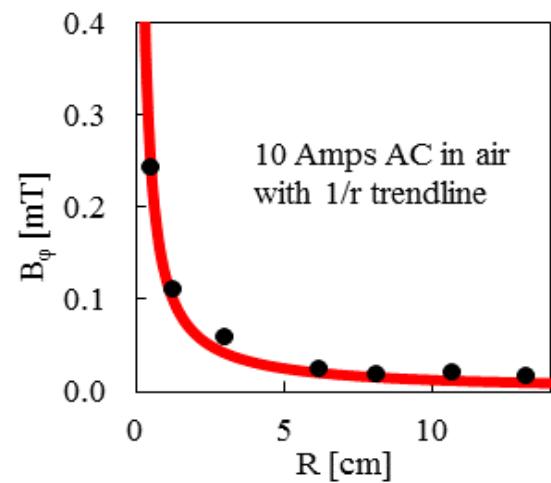
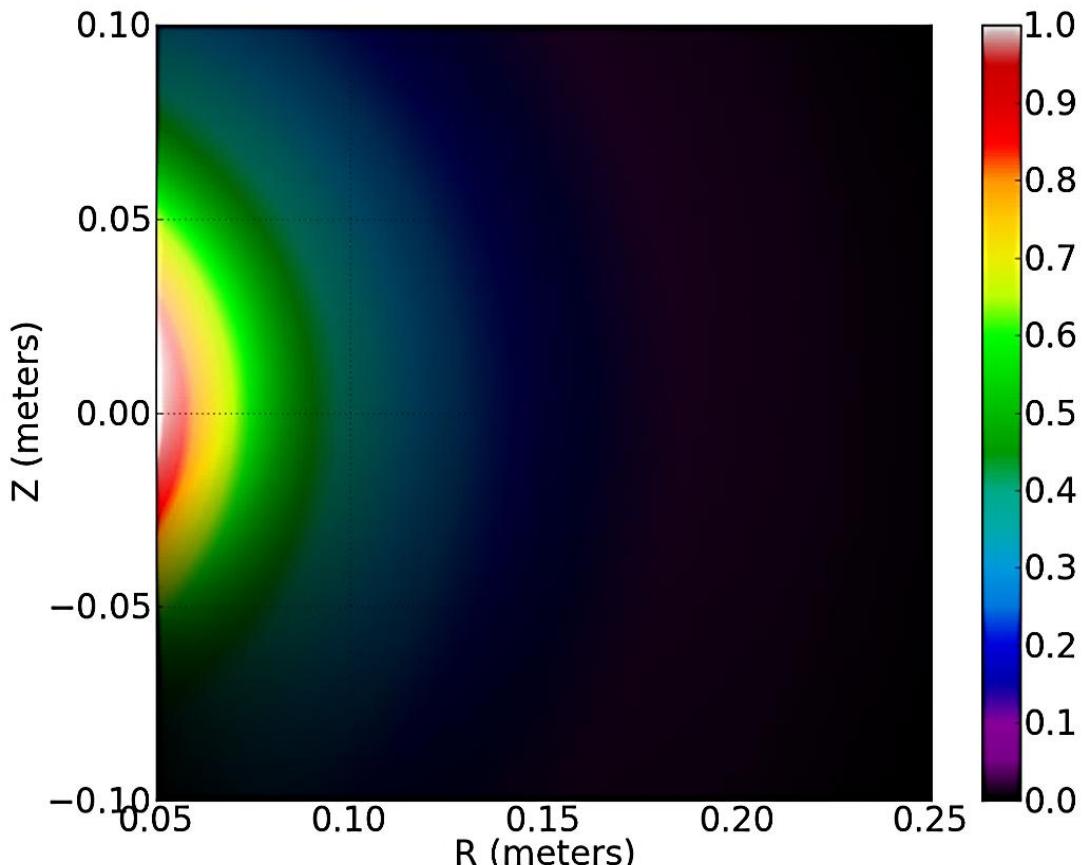
Ampere's Circuital Law can be written in integral or differential form via Stokes theorem (Time independent).

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} \quad \oint_C \mathbf{B} \cdot d\ell = \mu_0 \iint_S \mathbf{J} \cdot d\mathbf{S} = \mu_0 I_{\text{enc}}$$

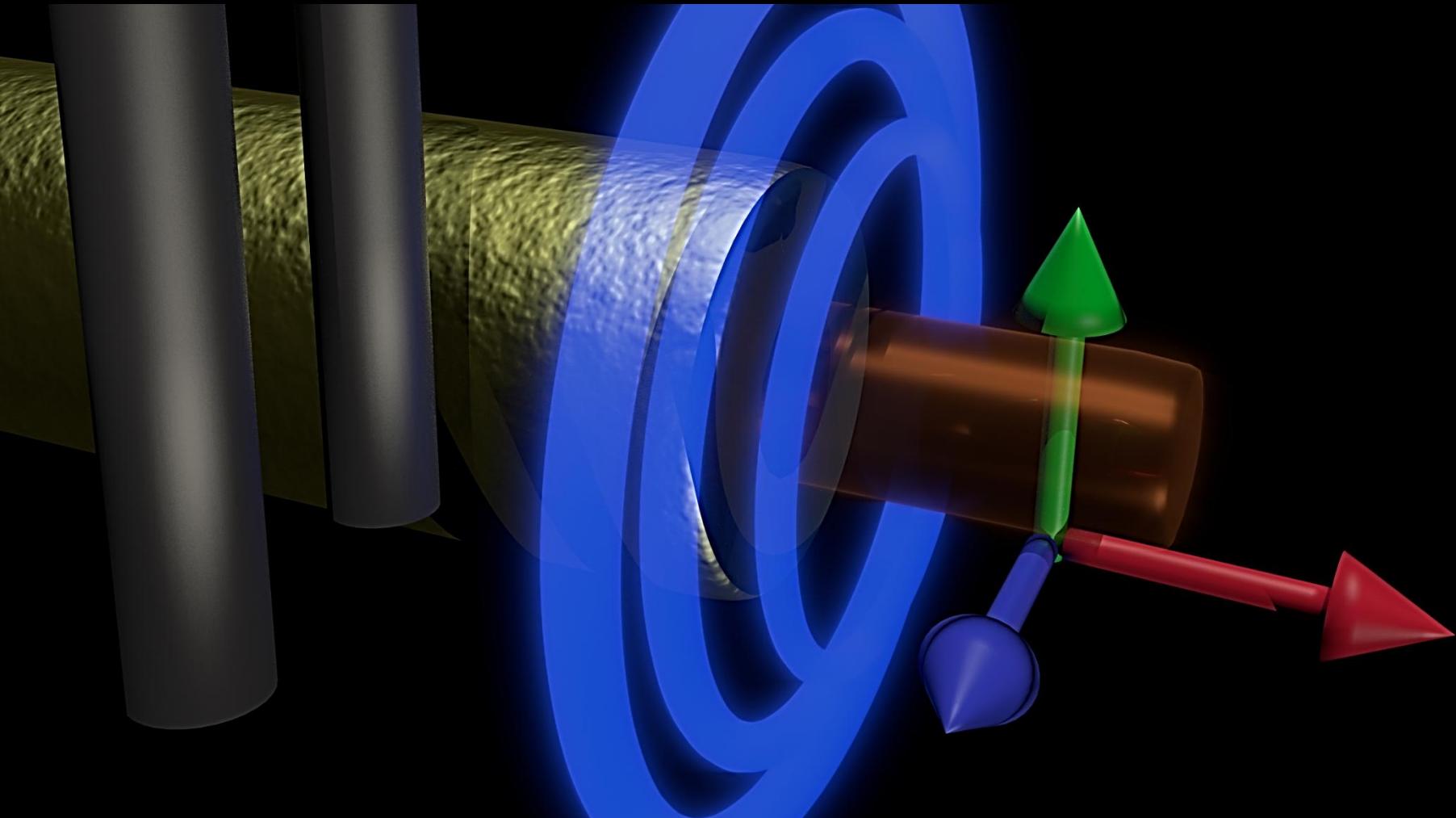
By integrating around the closed loop C, the expression below is obtained.

$$\frac{B_\phi}{I} = e^{i\omega t} \frac{\mu_0}{2\pi R}$$

Modelling B_ϕ



Measuring E_R



Modelling E_R

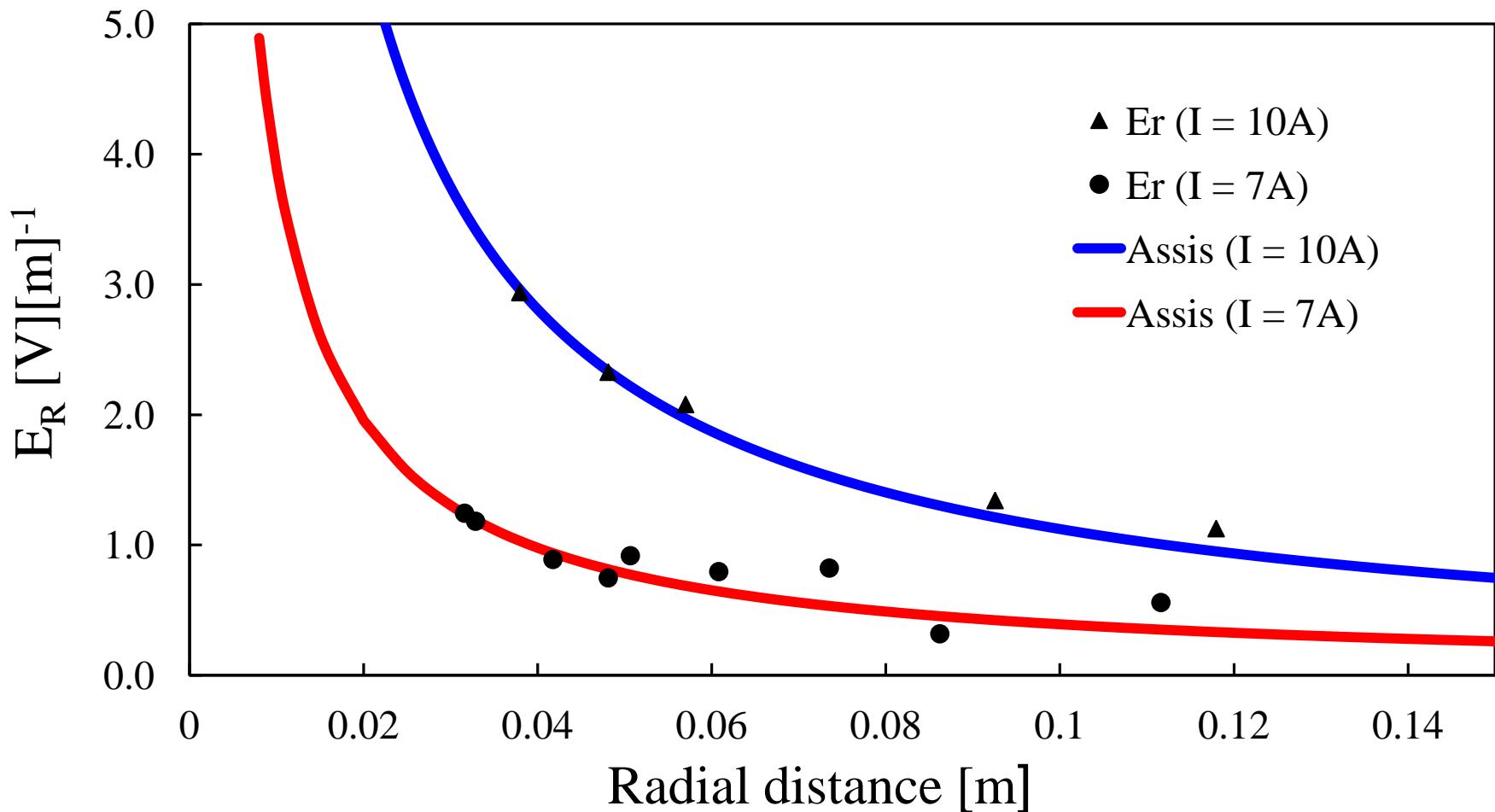
Gauss's Law can be written in integral or differential form via the divergence theorem.

$$\oint_S \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0} \quad \nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \quad E_R = \frac{\lambda}{2\pi\epsilon_0 R}$$

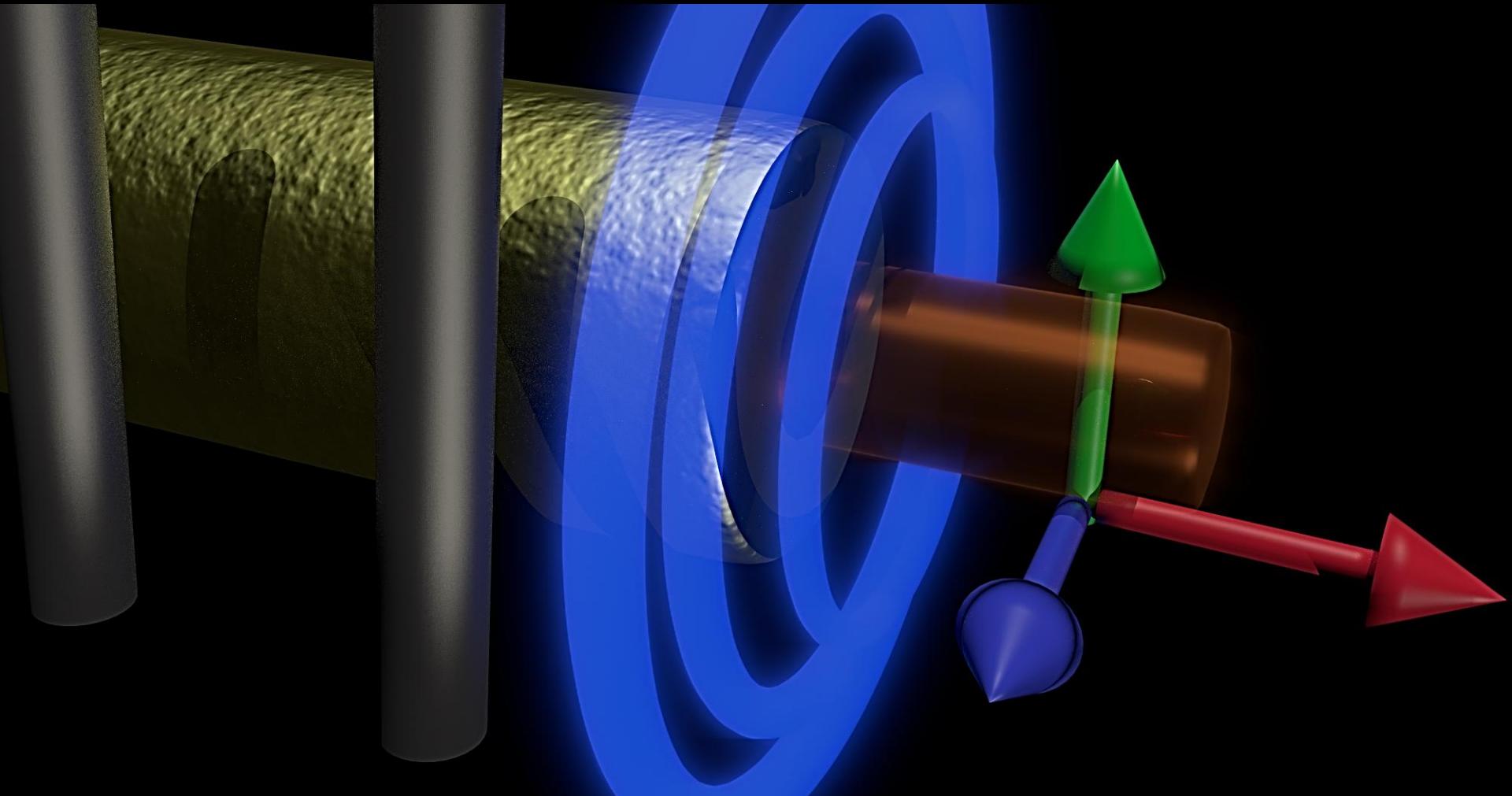
A model by Assis allows the charge to be calculated.

$$Q_B = 2\pi a L \sigma_B \quad \sigma_B = \epsilon_0 \left(\frac{\Omega I + 2\phi_R}{2a \ln(L/a)} \right) \quad \frac{E_R}{I} = \frac{L/\sigma \pi a^2}{2R \ln(L/a)}$$

Modelling E_R



Measuring E_z



Modelling E_Z

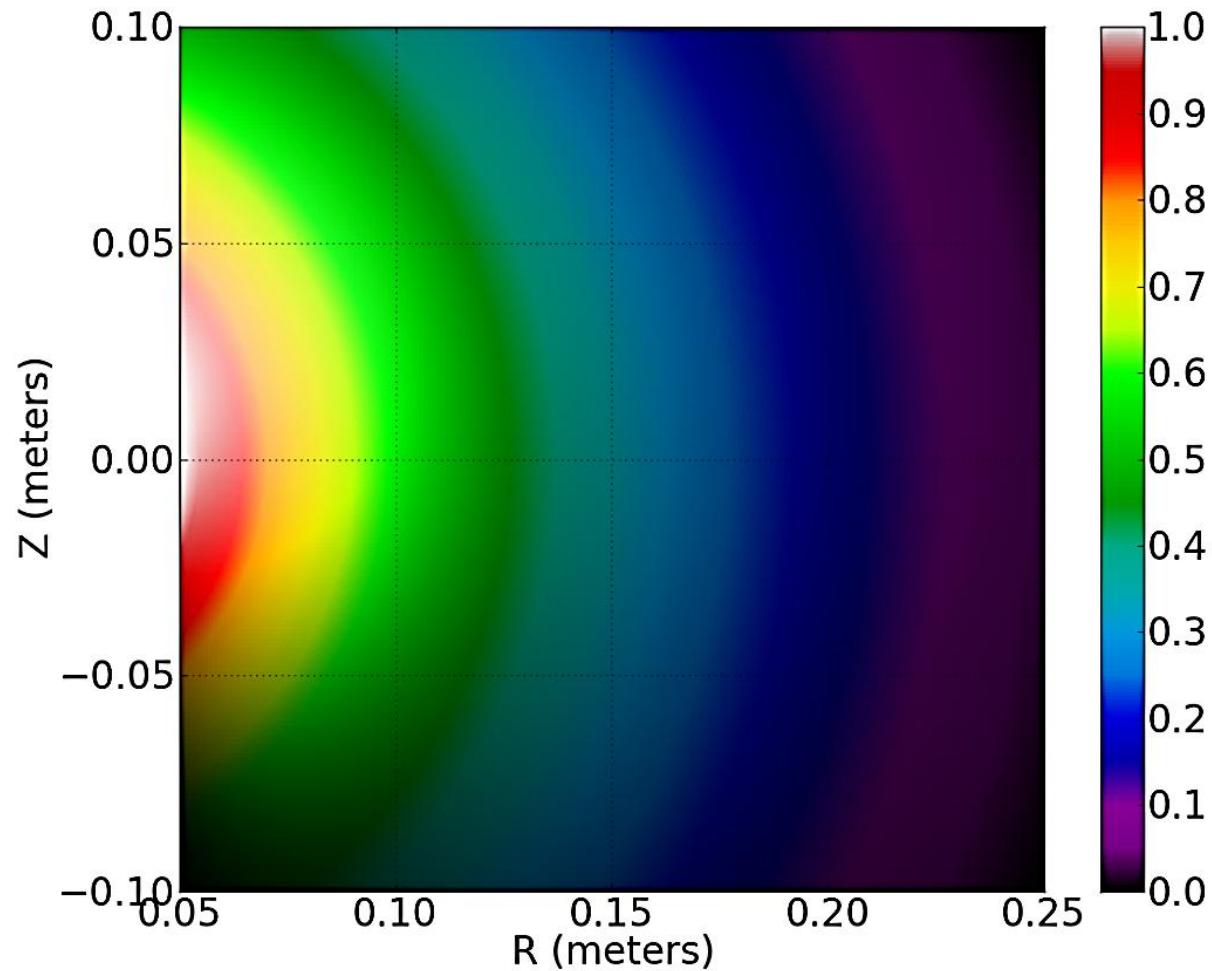
The Maxwell-Faraday equation can be written in differential form and the magnetic field theory can be inserted.

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad \frac{B_\phi}{I} = e^{i\omega t} \frac{\mu_0}{2\pi R}$$

The induced electric field discussed by Gauthier and Shakur in the 80s is shown below.

$$\frac{E_z}{I} = -i\omega e^{i\omega t} \frac{\mu_0}{2\pi} \ln\left(\frac{R}{a}\right) + K \quad \tilde{\frac{E_z}{I}} = -\frac{\mu_0 \omega}{2\pi} \ln\left(\frac{R}{a}\right) + K$$

Modelling E_Z



Modelling E_Z

The Hertz vector formulation is another method of recasting the problem in terms of potentials.

$$\Pi_z = \frac{I}{4\pi\sigma} \int_{\ell_1}^{\ell_2} \frac{e^{-\gamma r}}{r} d\ell \quad \gamma = (i\mu\omega\sigma)^{1/2}$$

The Hertz vector in terms of the scalar and vector potentials.

$$\begin{aligned}\phi &= -\nabla \cdot \Pi & \mathbf{A} &= \mu\epsilon \frac{\partial \Pi}{\partial t} \\ \mathbf{E} &= -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t} & \mathbf{B} &= \nabla \times \mathbf{A}\end{aligned}$$

Modelling E_Z

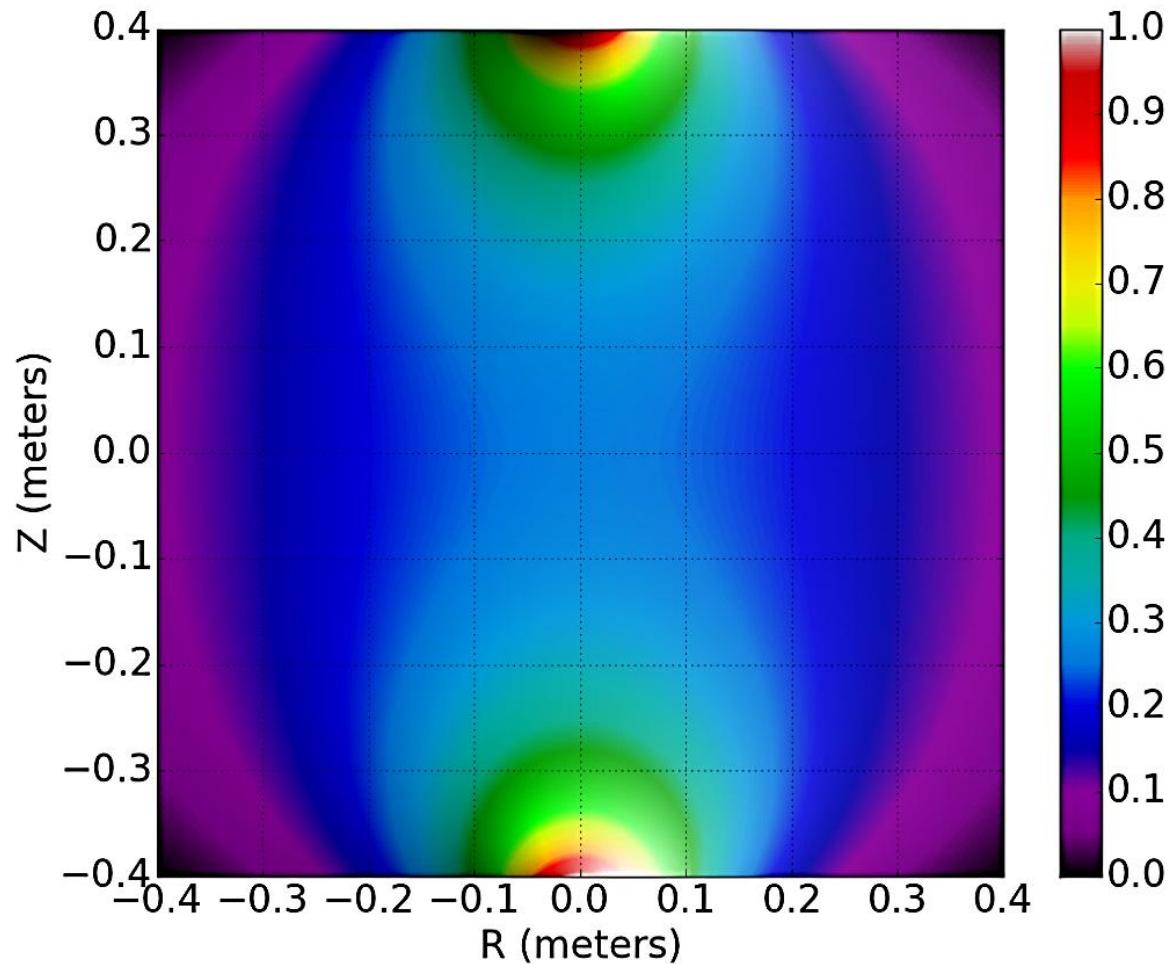
The electric and magnetic fields can now be written in terms of a single ‘super potential’ the Hertz vector.

$$\mathbf{E} = -\gamma^2 \boldsymbol{\Pi} + \nabla \nabla \cdot \boldsymbol{\Pi} \quad \mathbf{B} = \mu \sigma \nabla \times \boldsymbol{\Pi}$$

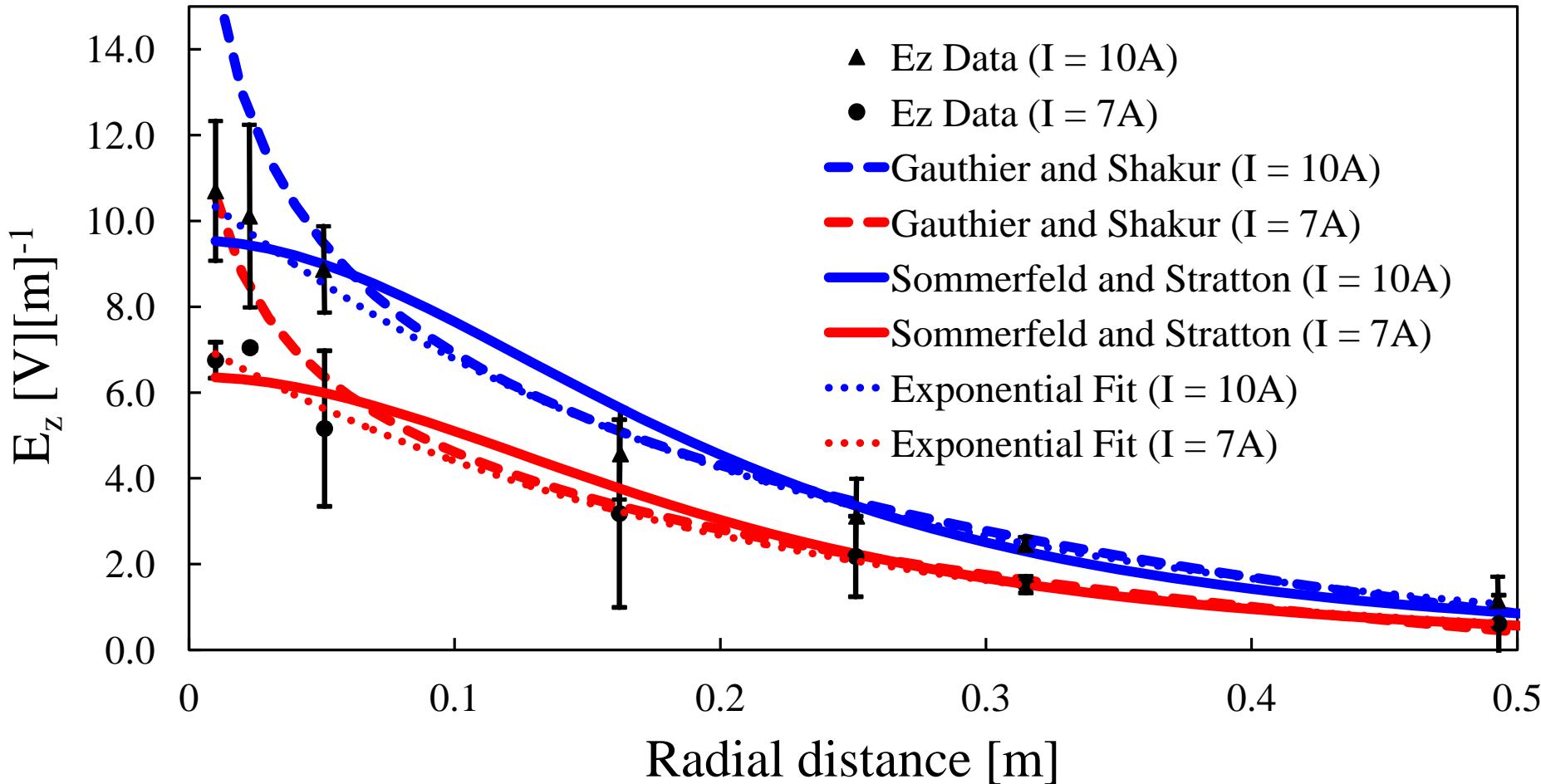
The electric field can be written in analytical form.

$$\begin{aligned} \frac{E_z}{I} &= \frac{i\mu\omega}{4\pi} \left[\sinh^{-1}\left(\frac{\ell_2 - z}{\rho}\right) - \sinh^{-1}\left(\frac{\ell_1 - z}{\rho}\right) \right] \\ &+ \frac{z - \ell_1}{4\pi\sigma r_1^3} - \frac{z - \ell_2}{4\pi\sigma r_2^3} \end{aligned}$$

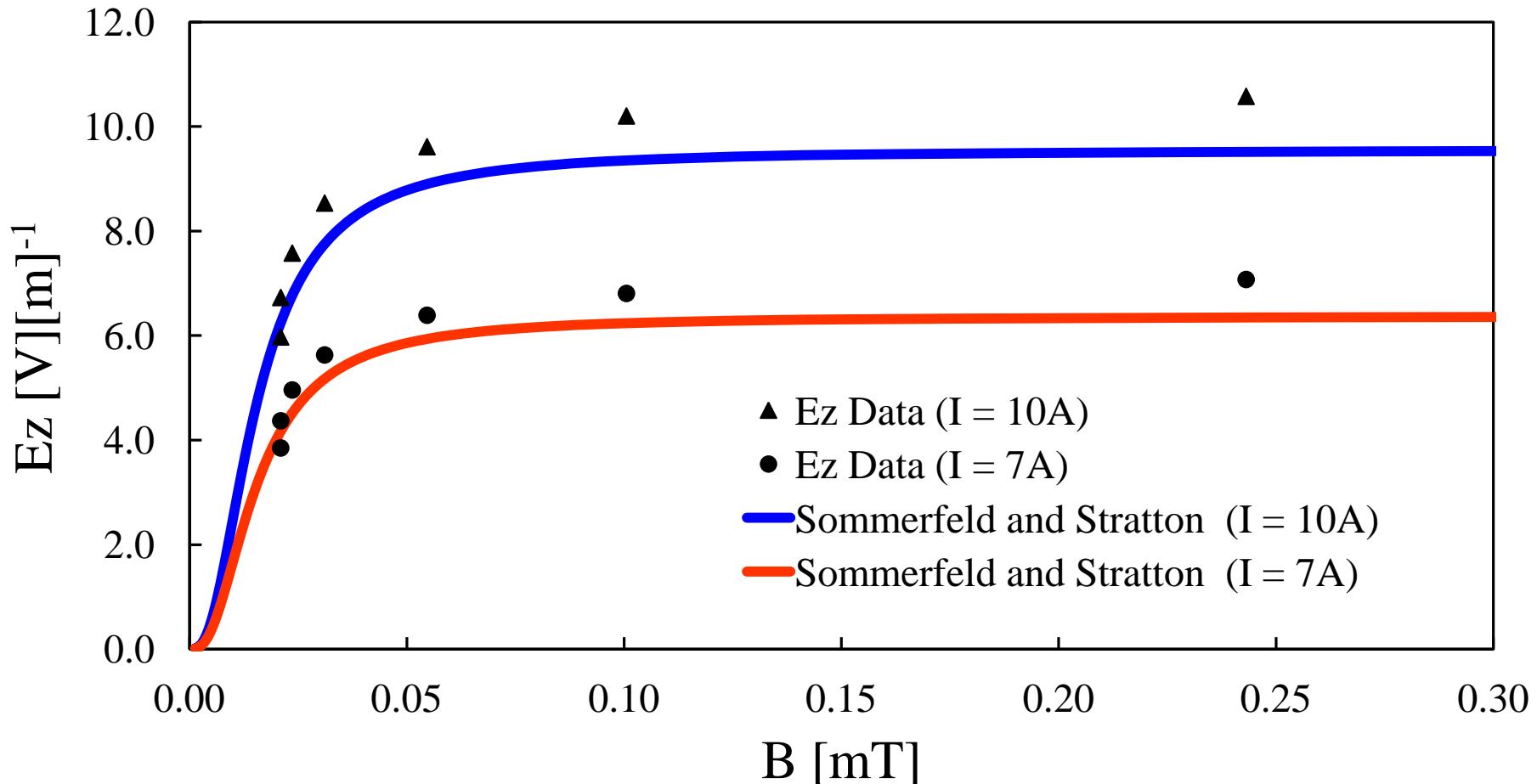
Modelling E_Z



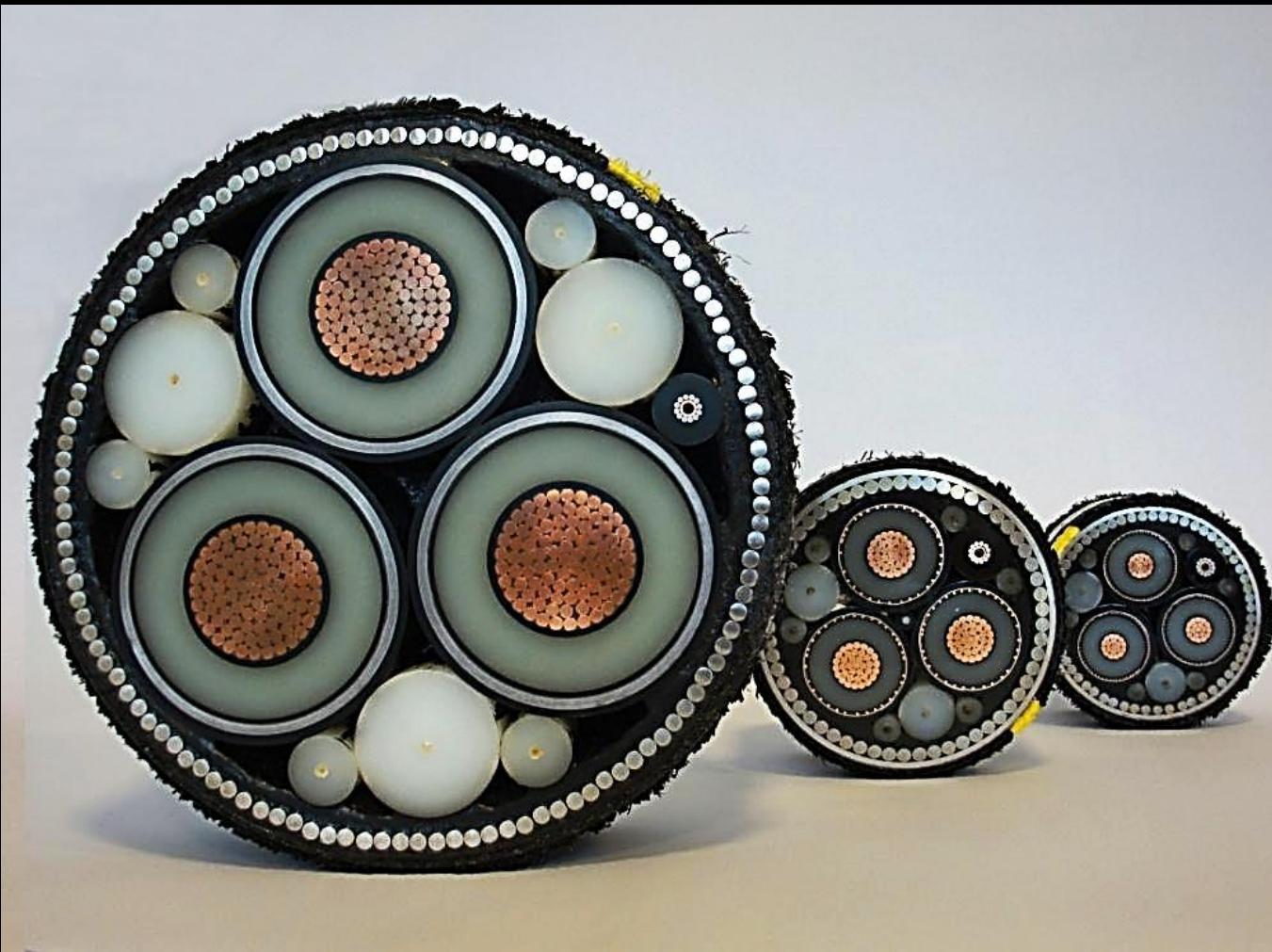
Modelling E_z



Correlation E_z and B_φ



Future Work



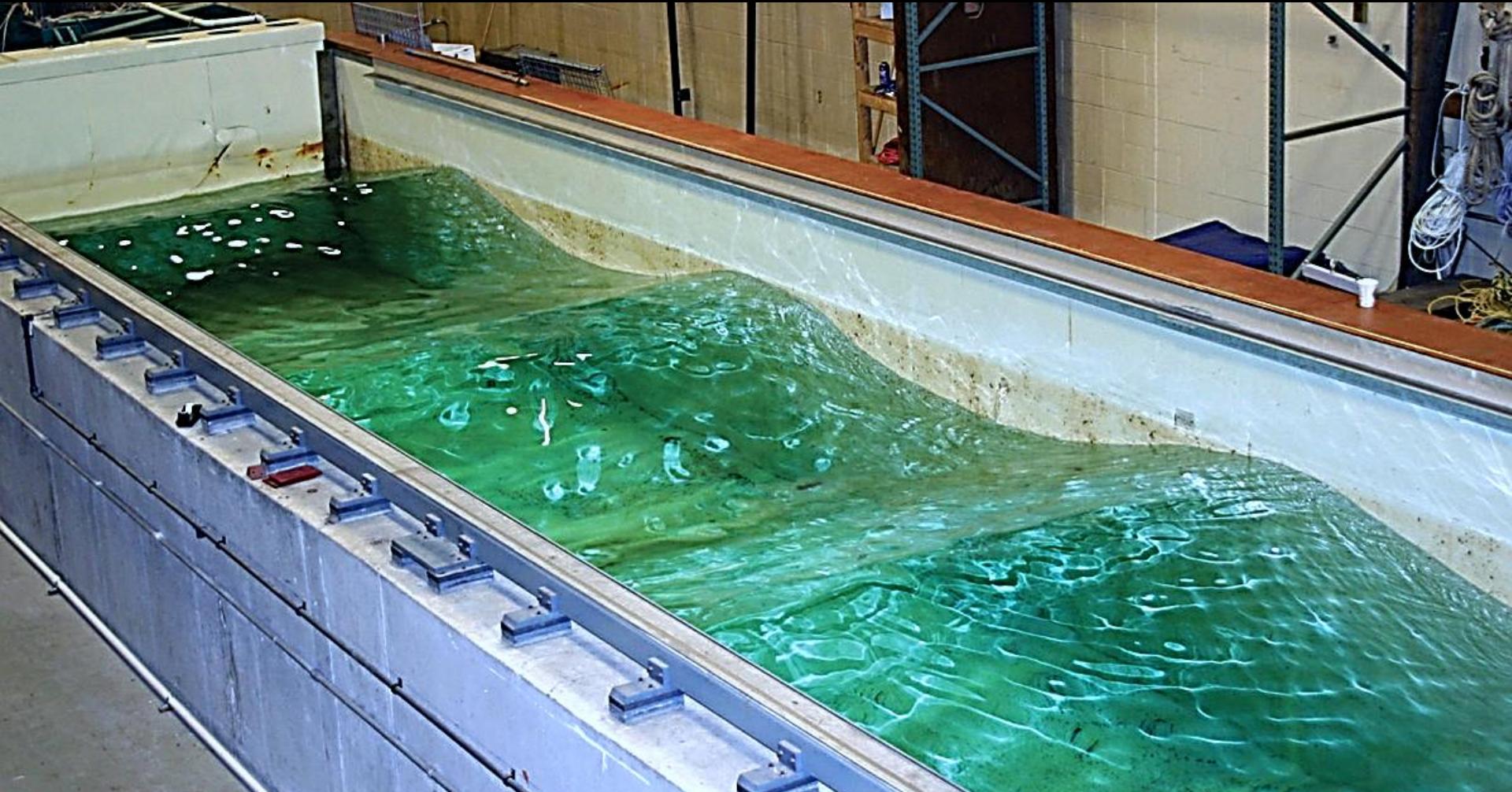
Explore electromagnetic fields generated by three phase transmission cables in a controlled system.

Examine the effects of frequency and current on the electromagnetic fields.

Construct a larger system and explore behavior. Use an actuator to input controlled wave pulses in the system.

Derive a predictive model using first principles.

Future Work



Future Work

Explore the effects of boundary conditions. Does the confined system impact the electromagnetic measurements at the boundaries?

Measure the electromagnetic fields with the tri-axial cable buried under various ocean floor materials. Explore field behavior at the boundary between ocean floor materials and seawater.

Thank you all very much for your attention!

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July 25, 2014

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