Locally-resonant wave energy converter

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OERC Symposium 2018

What is wave energy?

- A form of marine renewable energy (MRE)

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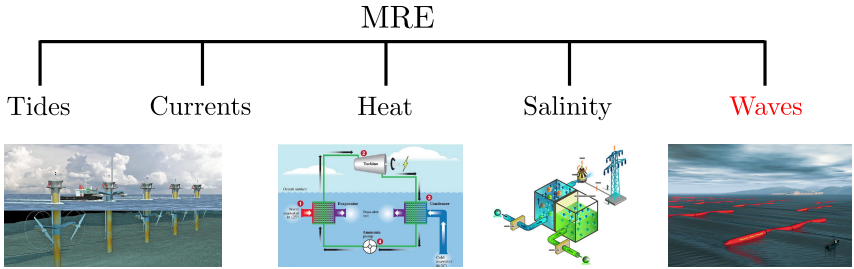

What is wave energy?

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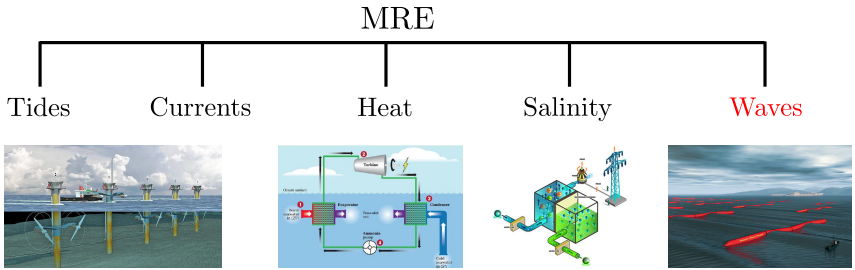


- Converts ocean wave mechanical energy to electrical energy, e.g. with a turbine.
- A device extracting wave energy is called a wave energy converter (WEC).

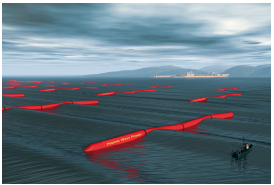
WEC technology

- Point absorber

WEC technology

- Point absorber

- Attenuator



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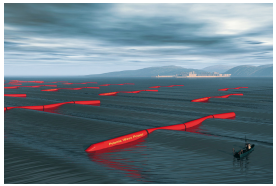
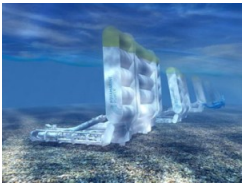


- Wave surge converter



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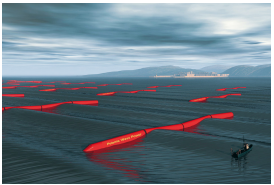

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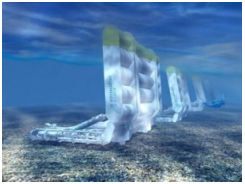
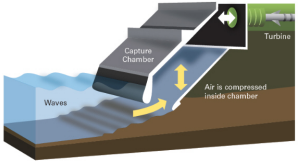


- Oscillating water column (OWC)



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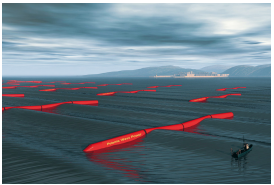

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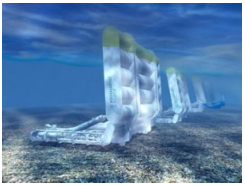

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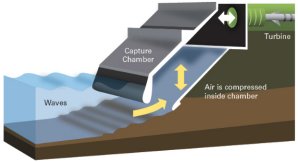
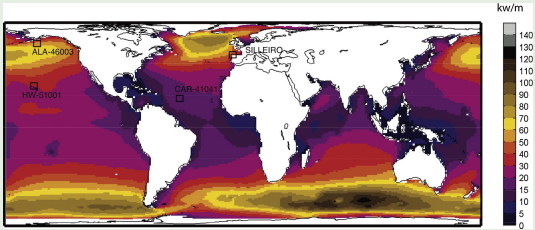


and more ...

Wave energy resources

International

- ∼20,000 TW h/yr on world's coastline[1].



[1] Reguero et al., 2015, *Applied Energy*.
[2] Stevens et al., 2005, *Water & Atmosphere*.

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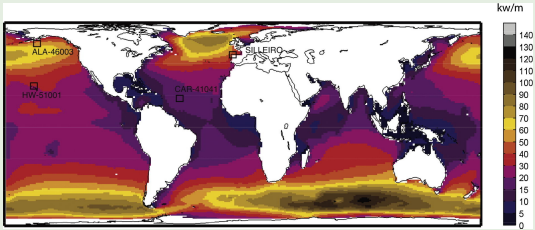

- Intensification of winds is expected to further increase available wave power, especially in the Southern Ocean.

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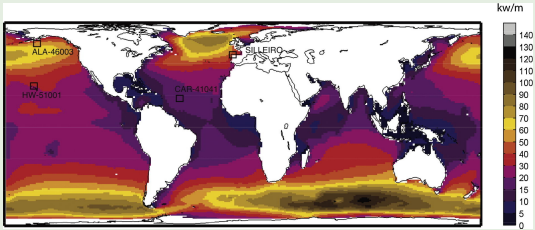

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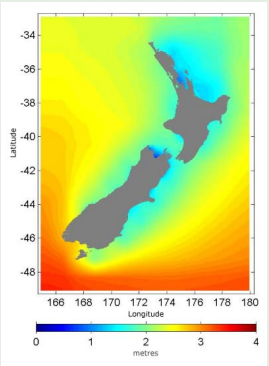
NZ

- 25 kW per metre of coastline[2].



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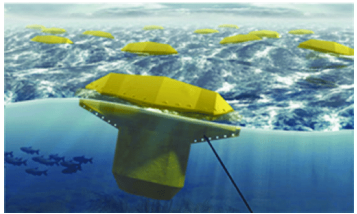
Wave energy farms

- Capacity of individual WECs currently limited ($\sim$O(100–1000) kW).
- Commercial developments looking at large scale farms (100–1000 MW) composed of hundreds of WECs.



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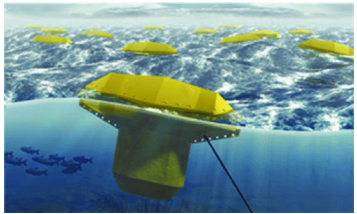
- **Goal**: Maximise power absorption through wave interference (park effect[3])



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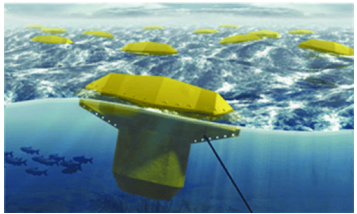

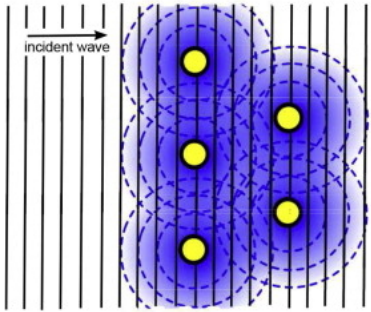

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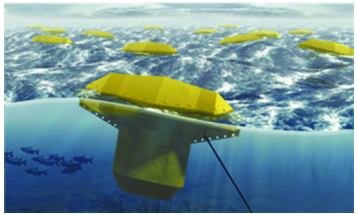

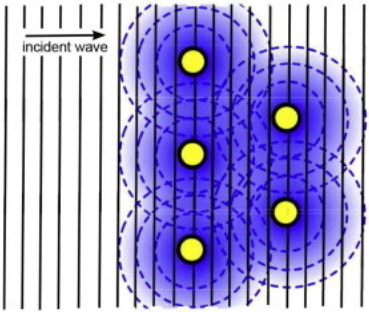

$$q_{\text{factor}}(\omega) = \frac{P_{\text{array}}(\omega)}{N \times P_{\text{single}}(\omega)}.$$

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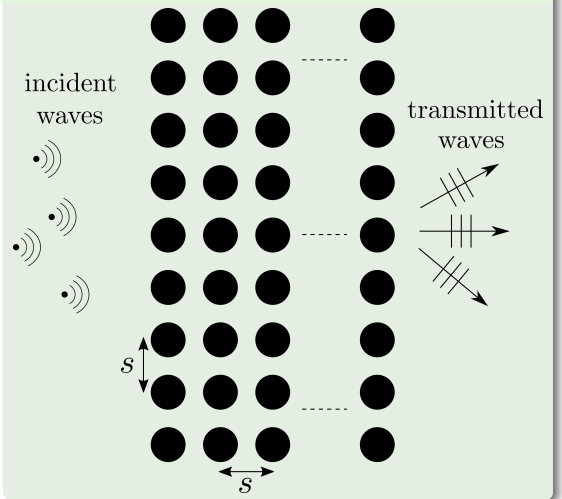
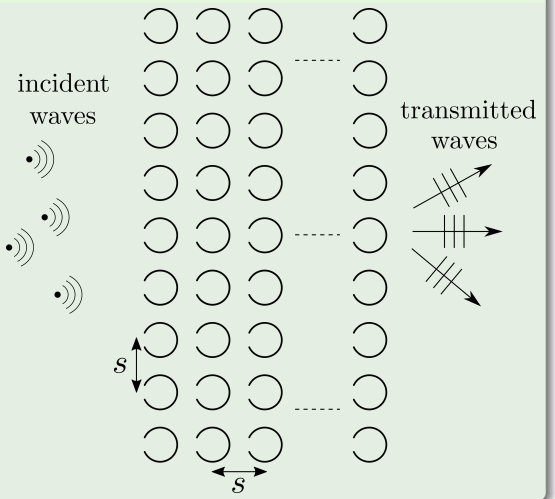
Motivation: sonic crystals

Hard cylinders



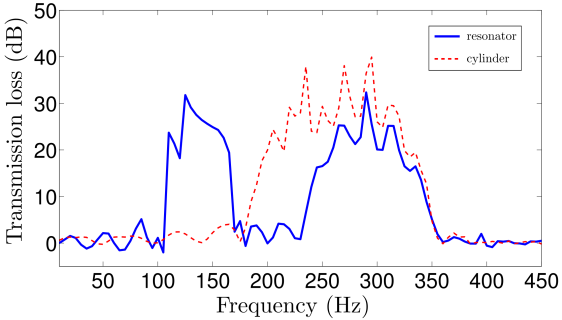
Split-ring resonators



Motivation: band gaps

Simulation parameters[4]

- 5×51 array
- radius $0.2\,\mathrm{m}$
- angle $45°$
- spacing $0.6\,\mathrm{m}$
- frequency sweep: $f = 10$–$450\,\mathrm{Hz}$



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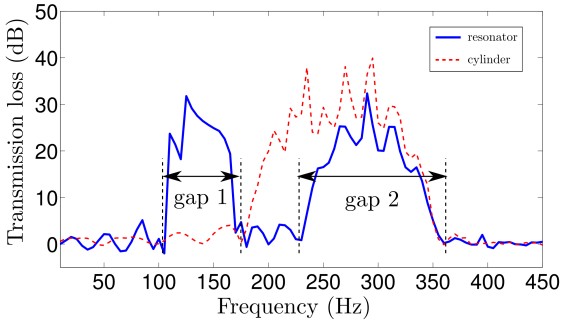

Band gaps

- Gap 1: Helmholtz resonance (split-ring geometry)
- Gap 2: Bragg resonance (periodic arrangement)

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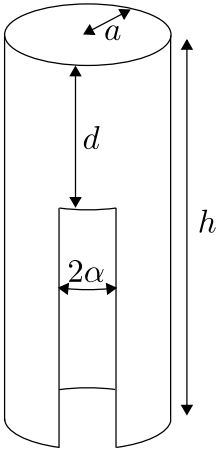
A new concept of OWC

Features

- Fixed, rigid cylindrical shell
- Bottom-mounted and surface-piercing structure
- Opening connecting interior and exterior domains



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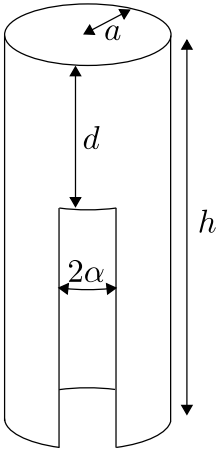

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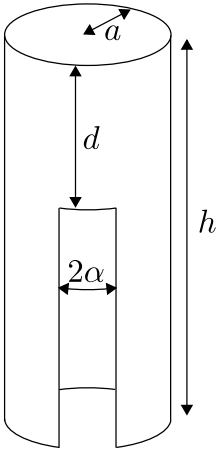

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Features

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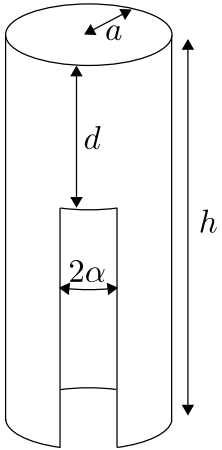
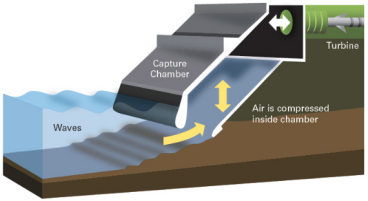
- Low-frequency resonance (Helmholtz)
- Wave interaction problem can be solved using semi-analytical mathematical techniques!

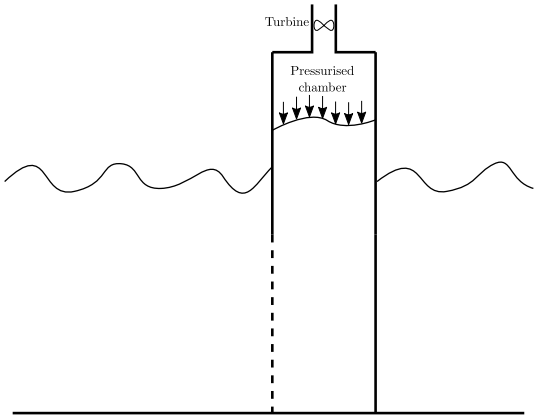


Oscillating water column (OWC) models

Uniform pressure model

- Internal surface condition: free surface
- Power take-off (PTO): through turbine motion
- Tuning: air pressure in chamber

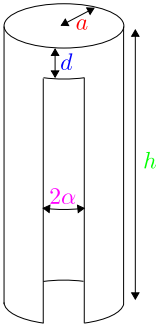




Simulation — example without PTO

Parameters

- $h = 10\,\text{m}$, $a = 1\,\text{m}$, $d = 5\,\text{m}$, $\alpha = \pi/8$
- $f = 0.38\,\text{Hz}$ ($\lambda \approx 10\,\text{m}$)



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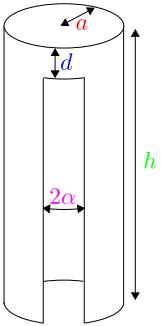

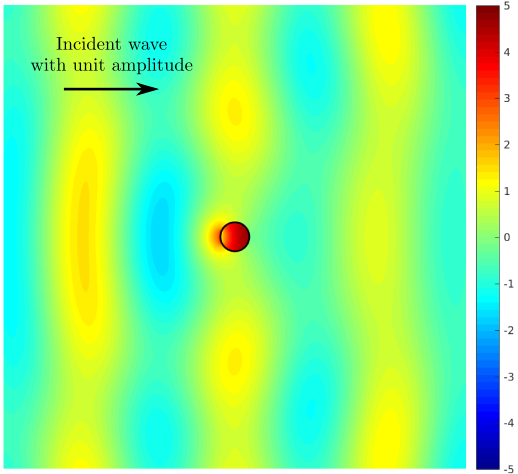

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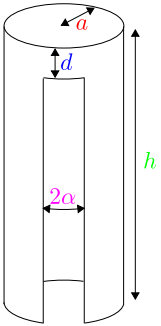
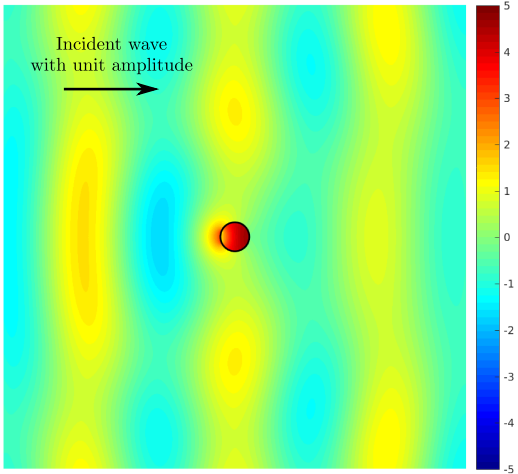




Link to animation

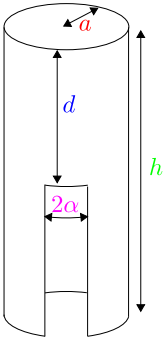
Our WEC — $d = 5\,\mathrm{m}$ (no PTO)

Parameters

- $h = 10\,\mathrm{m}$, $a = 1\,\mathrm{m}$, $d = 5\,\mathrm{m}$
- α varies
- $f = 0.01$–$1\,\mathrm{Hz}$

Output

- Scattering cross-section σ measures magnitude of resonance.



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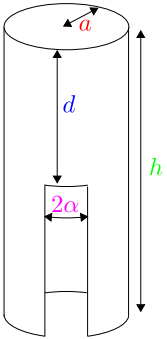

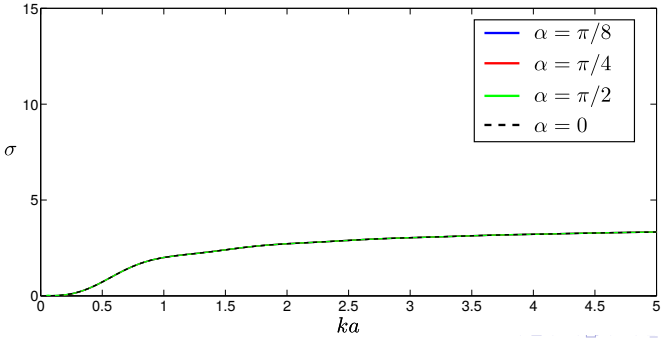

Our WEC — $d = 3\,\mathrm{m}$ (no PTO)

Parameters

- $h = 10\,\mathrm{m}$, $a = 1\,\mathrm{m}$, $d = 3\,\mathrm{m}$
- α varies
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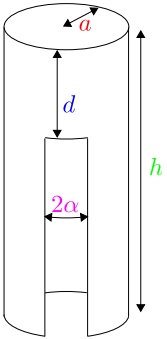

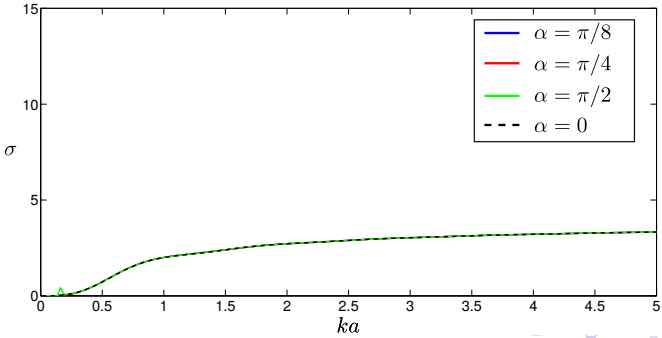

Our WEC — $d = 1\,\mathrm{m}$ (no PTO)

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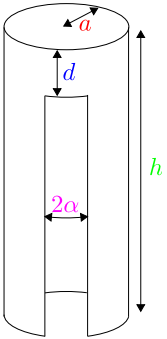

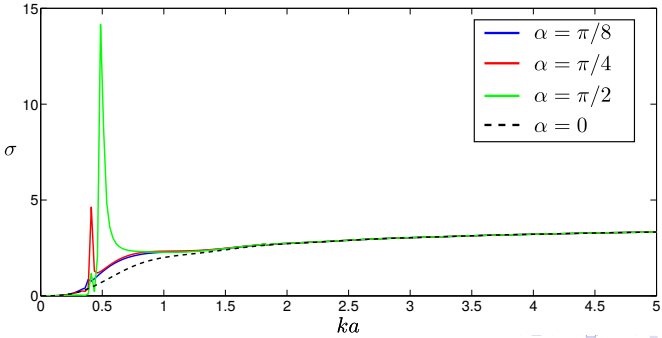

Our WEC — $d = 0.5\,\mathrm{m}$ (no PTO)

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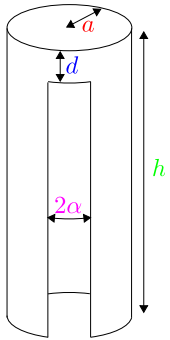

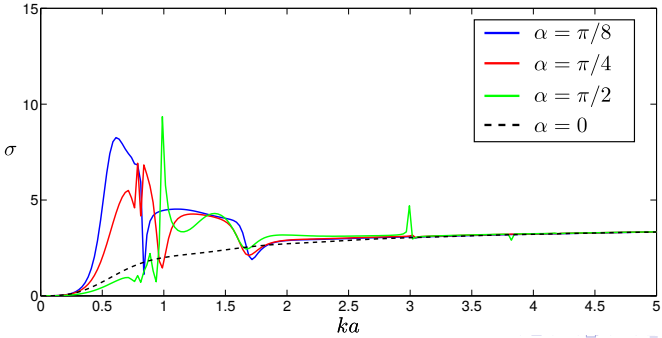

Wrap-up

Future research

- Resonance analysis
- Couple to PTO
- WEC farms
- More realistic geometry/fluid
- Experiments in wave basin

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THANK YOU!