An integrable sector of the membrane

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M-theory as membrane theory

- Membranes are only understood well in special limits or subsectors.
- Examples include:
  - double-dimensional reduction to type IIA strings,
  - matrix models in flat or toroidal backgrounds,
  - holography in $AdS_4 \times S^7 \leftrightarrow$ ABJM.

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→ **Are there at least integrable subsectors?**

Yes!

Bosonic membrane

$$S \sim \int \mathrm{d}^3\sigma \sqrt{-\gamma}\left(\gamma^{MN}\partial_M X^\mu \partial_N X^\nu g_{\mu\nu} + \epsilon^{KLM}\partial_K X^\mu \partial_L X^\nu \partial_M X^\rho C_{\mu\nu\rho} - \frac{1}{2}\right)$$

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- g, C: background metric and 3-form field

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Goal: find a decoupling limit ($\gamma_{MN} \to \eta_{MN}$) so that the effective dynamics becomes classically integrable.

Overview

- Review: the MZW model
- A decoupling limit for world-volume gravity
- Deriving the MZW model from a toy-model membrane
- Embedding into 11d supergravity and associated non-Lorentzian limit

The MZW model

- A classically integrable 2+1-dimensional non-Lorentzian field theory

[Manakov/Zakharov ’81 /Ward ’87]

Action $$S_{MZW} = T_0 \int \left(\frac{1}{2} tr(j \wedge \star\, j + \frac{1}{3} \sigma^y tr(j \wedge [j,j])\right)$$

$$g : \Sigma \to G, \qquad j = g^{-1} dg$$

Equations of motion $$d \star j - [j,j] \wedge v = 0$$

- $v = \mathrm{d}\sigma^y$ is a fixed $3d$ one-form that breaks Lorentz invariance.
- $y = 0$ timelike: Manakov/Zakharov, $y = 1,2$ spacelike: Ward

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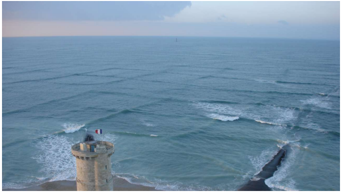

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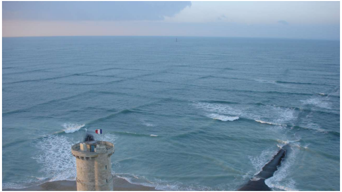

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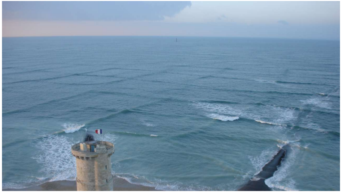

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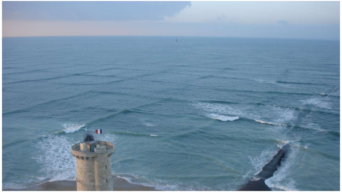
One of the rare interacting integrable field theories in 3 dimensions.



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Setup

- Consider the membrane on

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‚longitudinal‘ space
with metric scale R

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Choose an appropriate limit for R, R̄, ω and T_0

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Finite leading order dynamics requires a **simultaneous scaling** of the membrane tension, and metric scales $R, \bar{R}$, (+ assumptions on F_4).

$$\omega \to \infty, \qquad \bar{R}/(R\omega) \to 0, \qquad T \sim T_0/(\bar{R}^2 R\, \omega)$$

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[Blair/Zinnato ,21]

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- **singular limit:** does not commute with reparameterisations (e.g. choice of static gauge)

The MZW model from the membrane: toy model

Choosing $M_H = \mathrm{Lie\ group}\ G$, and an appropriate F_4

$$ds^2 = R^2 \eta_{MN} d\mathrm{x}^M d\mathrm{x}^N + \bar{R}^{\,2} \kappa_{ab} e^a(x^n) e^{\mathrm{b}}(x^n)$$

$$F_4 = -R\bar{R}^{\,2} f_{abc} e^a \wedge e^b \wedge e^c \wedge v$$

with Maurer-Cartan one-forms e^a, Killing form κ_{ab}. and structure constants f_{ab}

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Tranversal fluctuations follow MZW dynamics: $\boxed{S_H = S_{MZW}}$

under $\omega \to \infty$, $\bar{R}/(R\omega) \to 0$, $\quad T \sim T_0/(\bar{R}^{\,2} R\, \omega)$

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$\mathbb{R}_t$ T^2

longitudinal

$$F = 2R\bar{R}^2\big(Vol(AdS_3) + Vol(S_3)\big) \wedge \mathrm{d}z$$

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- Truncation to membrane fluctuations around $(\mathbb{R}_t \times T^2) \times \mathrm{SU}(2)$

$\rightarrow$ **SU(2) MZW model.**

outlook

- MZW conserved charges and solitons on the membrane?
- holographic dual of membranes in $AdS_3 \times S^3 \times T^5$?
- **generalisations:**
  - *supermembrane* (super MZW model?)
  - *homogeneous spaces*
    (gauged MZW model, a la gauged WZW?)
  - *deformations* (re-introducing dispersive KP term?)
- MZW line soliton scattering, quantisation, …

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