Fractons, dipole symmetry breaking and gravity

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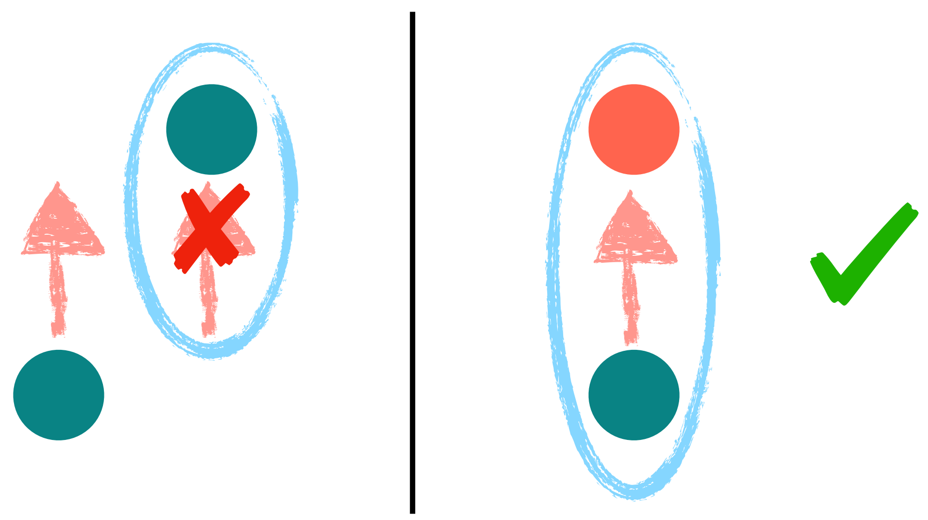
In a nutshell

Fractons: excitations with reduced mobility



Charges cannot move: *fractons*

Bound states of dipoles can freely move

Motivation

- Challenge longstanding beliefs in QFT (UV/IR mixing).
- Construction of quantum field theories with dipole symmetry.
- Coupling to curved background geometries.
- Spontaneous breaking of coordinate dependent symmetries.
- Connections of fractons and gravity.

Realization of dipole symmetry

Dipole symmetry $\longrightarrow$ **immobility** constraints: ω^2=0.

The current conservation equation:

$$\partial_\mu J^\mu = \dot{\rho} + \partial_i \partial_j J^{ij} = 0$$

$$Q_0 = \int d^d x \rho, \qquad Q_1^i = \int d^d x x^i \rho$$

Coupling to A_0 and A^{ij} (symmetric),

$$S = \int d^{d+1}x \left(A_0 \rho + A_{ij} J^{ij} \right)$$

[Pretko '16]

with gauge transformations

$$\delta A_0 = -\partial_0 \lambda_0, \quad \delta A_{ij} = \partial_i \partial_j \lambda_0$$

Realization of dipole symmetry

Linear realization of dipole symmetry for scalar ϕ :

$$\phi \to e^{i(\lambda_0 + \vec{\lambda}_1 \vec{x})}\phi \quad \longrightarrow \quad \mathscr{L} = |\partial_0\phi|^2 + |\partial_i\phi|^2 - g\,|\phi\partial_i\partial_j\phi - \partial_i\phi\partial_j\phi|^2 + \ldots$$

[Pretko '18]

Gauging the monopole $\lambda_0 \to \lambda_0(t, x)$,

$$\phi\partial_i\partial_j\phi - \partial_i\phi\partial_j\phi \to e^{2i\lambda_0}\left(\phi\partial_i\partial_j\phi - \partial_i\phi\partial_j\phi + (i\partial_i\partial_j\lambda_0)\phi^2\right)$$

We need to introduce A_{ij} such that

$$A_{ij} \to A_{ij} + \partial_i\partial_j\lambda_0, \qquad \phi\partial_i\partial_j\phi - \partial_i\phi\partial_j\phi - iA_{ij}\phi^2$$

Problems when coupling to curved background geometries, due to not gauge invariant terms!

A different realization

The tool

$$\text{MDMA}: \quad i[P_i, Q_1^j] = \delta_i^j Q_0 \,.$$

[K. T. Grosvenor, C. Hoyos, F. Peña Benítez, and P. Surówka '21]

Generators: **translations** P_i, **monopole** charge Q_0 and **dipole** charge Q^i_1.

Consequences

Ordinary **vector gauge fields** →

- Construct an "ordinary" covariant derivative D_μ.
- No obstruction to introducing quadratic derivative terms in the action.
- Couple to generic curved background geometries.

Dipole symmetry breaking

Having D_μ,

$$\mathscr{L} = \sum_n |D_\mu \phi_n|^2 + V\left(\phi_n^\dagger \phi_n\right) .$$

By means of standard techniques, **e.o.m.** with dipole symmetry breaking.

The **NG mode**

$$\mathscr{L}_{NG}^{1-loop} = \frac{V_x^2}{240\pi \tilde{m}_\phi^4}\left(10\tilde{m}_\phi^2(\partial_t\theta)^2 - (\partial_x\partial_t\theta)^2 + (\partial_t^2\theta)^2\right) .$$

With emergent subsystem symmetry: $\theta(t,x) \to \theta(t,x) + f(x)$.

Moreover: $\omega^2 = 0.$

Fractonic NG mode!

Results and open questions

Spontaneous dipole symmetry breaking with or without concomitant monopole breaking → fractonic NG.

[CHMW, Goldstone physics, hydrodynamics, gravity…**]**

Dipole-conserving models with bosonic and fermionic matter.

Dipole symmetry breaking

Sensitivity to the details of the symmetry realization. Might not be a universal effective description.

Couple the model to **dynamical gauge fields** for the monopole and dipole symmetries.

Extend the analysis to **higher dimensions**.

Thank you for your attention!