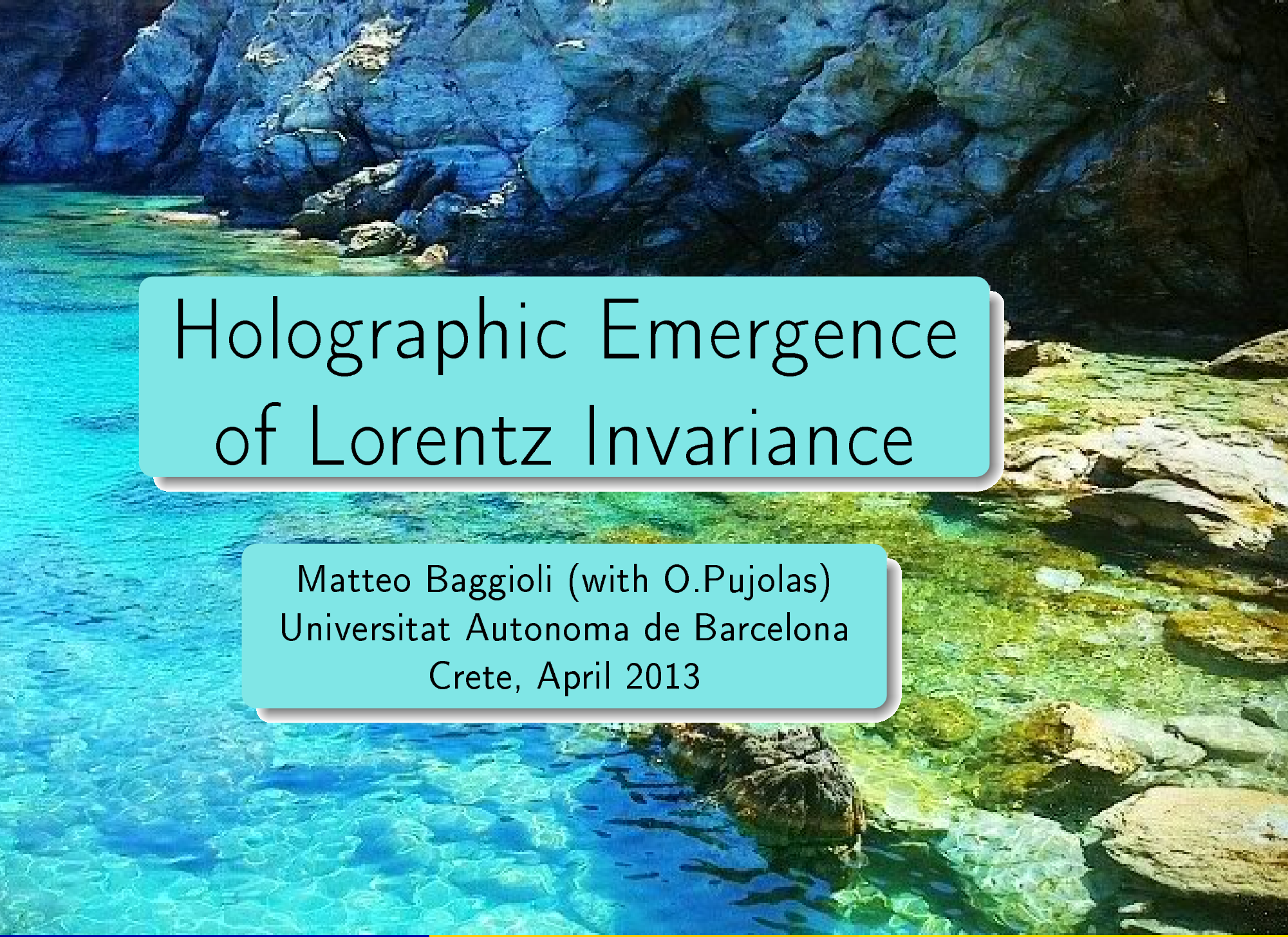

Holographic Emergence of Lorentz Invariance

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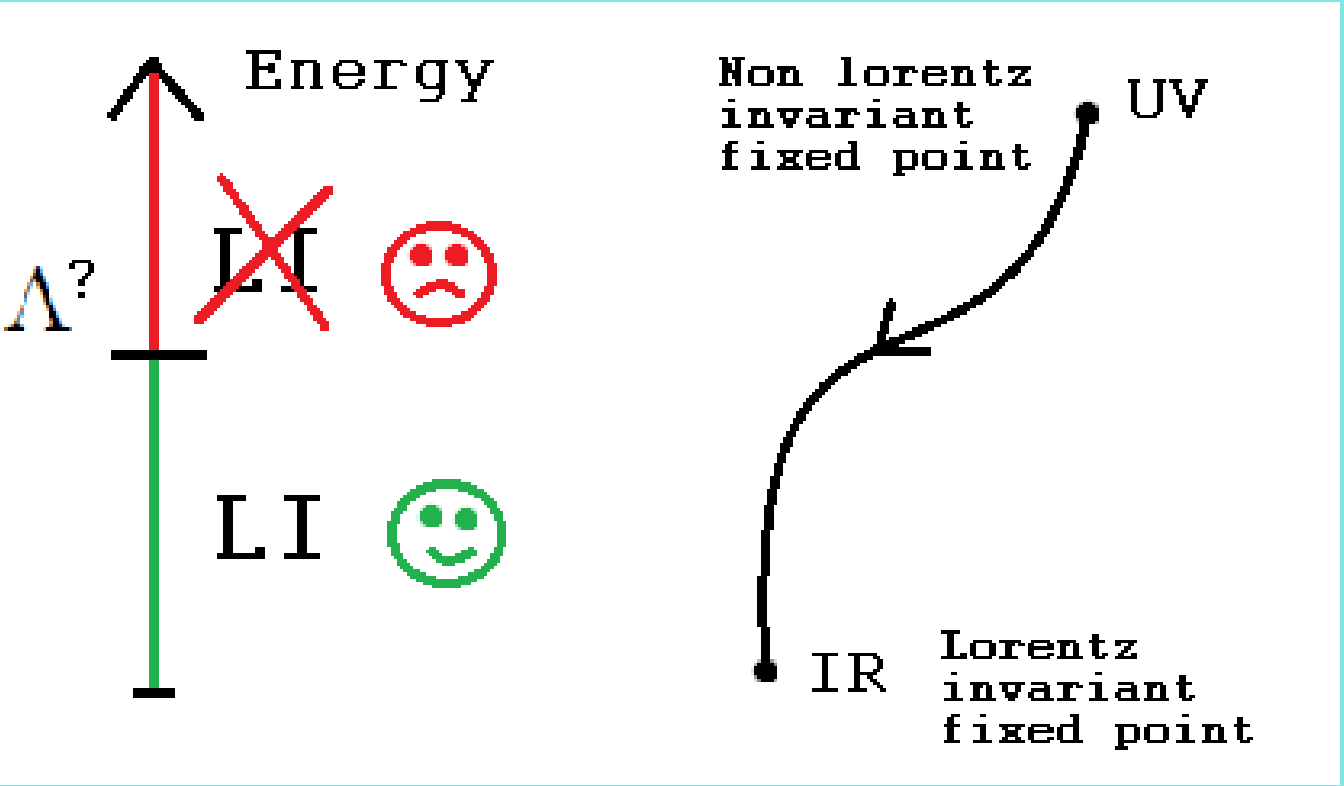
Crete, April 2013

Emergence of Lorentz Invariance

Is Lorentz Invariance really fundamental . . . ?

IDEA (Nielsen-Chadha 1982):

Lorentz Invariance broken in UV and emergent in IR



Lorentz invariant fixed point is IR attractive

Emergence of Lorentz Invariance

Why accept and study this possibility:

- **Horava-Lifshitz gravity $\Longrightarrow$ renormalizable theory of quantum gravity?**
- **Emergent Lorentz invariance in CM systems like Graphene**
- Exact Lorentz invariance cannot completely be experimentally tested since the Lorentz group is non-compact, why trust it?
- Boost invariance $\Longrightarrow$ QFT UV divergences
  LV $\Longrightarrow$ possible way to solve them?

Why be scared:

- LI tested at 10^{-21} accuracy!

Holographic Mechanism for Emergence of Lorentz Invariance:Strong coupling dynamics

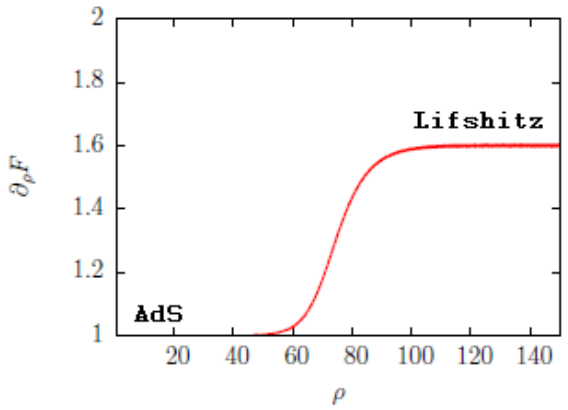
Lifshitz flow: the gravity side...

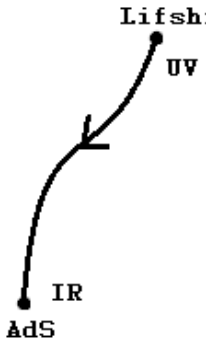
Lifshitz geometry $\longrightarrow$ gravity dual of Non Relativistic CFT (Kachru, Liu, Mulligan,2008)

$$ds^2 = L^2(-r^{2z}dt^2 + r^2 d\vec{x}^2 + \frac{dr^2}{r^2}) : t \to \lambda^z t,\ x \to \lambda x,\ r \to \frac{r}{\lambda} \qquad z \neq 1$$

Flows between Lifshitz and AdS

- Background: Einstein-Proca= gravity + massive spin1 field
- Domain wall geometry interpolating between Lifshitz and AdS (Gregory,Braviner,Ross,2011):





Domain wall solution

$$ds^2 = L^2\left(-e^{2F(r)}dt^2 + e^{2D(r)}\frac{dr^2}{r^2} + r^2\sum_{i=1}^{d-1}dx_i^2\right)$$

$$A = \alpha(r)\, e^{F(r)}dt,$$

Lifshitz: $F = z\ln r,\ D = 0,\ \alpha = L\sqrt{\frac{2(z-1)}{z}}$

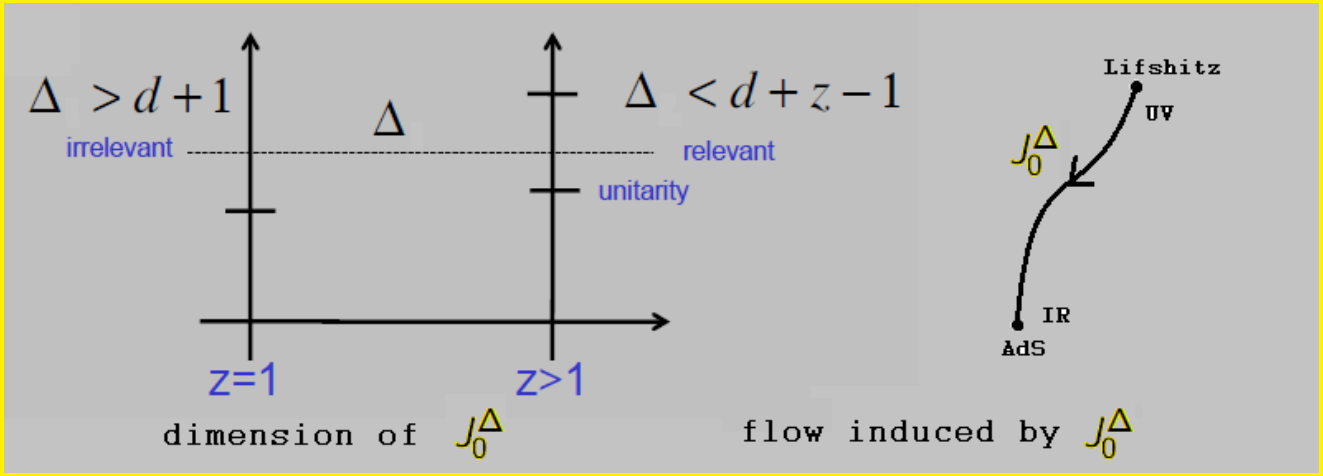
AdS: $z \to 1$ limit

Holographic Mechanisms for Emergence of Lorentz Invariance

Lifshitz flow: the CFT side...

CFT side:

- Lifshitz $\Longleftrightarrow$ Lifshitz CFT
- Lifshitz Flow $\Longleftrightarrow$ CFT deformed by relevant spin 1 operator J_0^Δ flow into IR to a CFT with an irrelevant operator



Idea:

Can we implement similar flow induced by spin 2 operators??

Holographic RG flow between Lifshitz and AdS

Lifshitz and spin 2 fields . . .

First step:

Is Lifshitz a solution of (Gravity + massive spin 2 field) (Buchbinder et al;2000) ??

- With only minimal couplings Lifshitz is not a solution.
- Adding non-minimal couplings Lifshitz can be a solution with diagonal spin 2 field.
- Puzzle: For both Spin1 and Spin2 case Lifshitz is a solution only if massive fields scale like Lifshitz metric!?

Second step:

Does a spin 2 operator relevant in UV and irrelevant in IR which can implement flow exist???

Outlook

Answers:

- Emergence of LI can make consistent LV at high energy !
- Mechanisms for emergence of LI exist !
- Holographic flows can explain this emergence !

Questions and future directions:

- Understand these flows and find more ones?
- Study emergence of LI in other ways (ex. Lifshitz Brane,Singh 2013)
- Understand the puzzle about Lifshitz solution (spinX field generalization...)?
- Link this picture with emergence of LI in CM (ex.Graphene)?
- Resolve Lifshitz singularities through these flows ?
- C-theorem for Lifshitz?
- Is this framework applicable to D-Wave Superconductors?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