Analogue Black-Hole Horizons

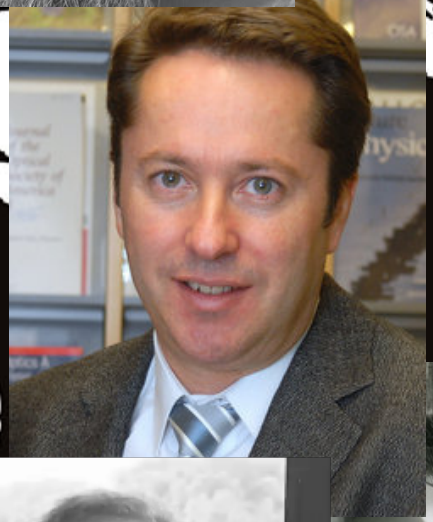
Carlos Barceló
Instituto de Astrofísica de Andalucía, CSIC

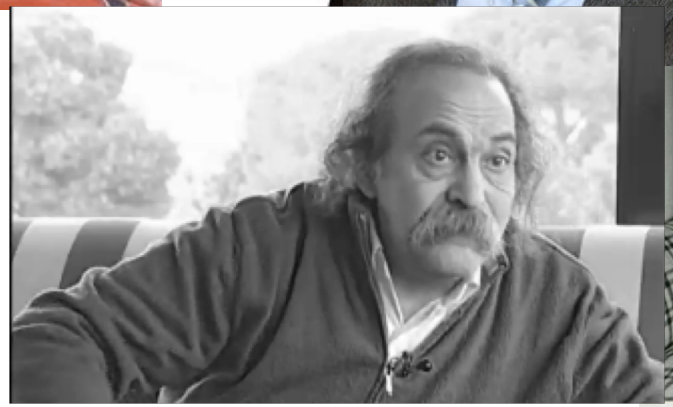
Travelling through Pedro's universes, 3-5 Dic. 2018

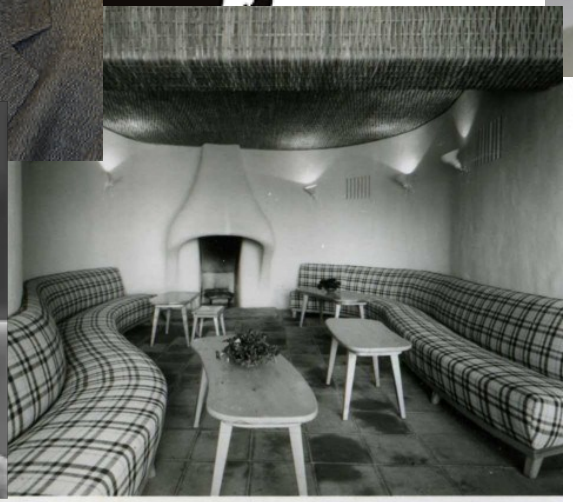
In memoriam of Pedro F. González

Based on: Insight Progress Report, Nature Physics (soon to appear)

Analogue gravity: inception of an idea in my mind







Outline

_ Analogue gravity horizons

_ Theoretical vs experimental verifications

_ More developed experimental efforts

- Gravity waves in water flows
- Bose-Einstein condensates (BEC)
- Non-linear optical systems

_What are we learning from the gravitational side?

Analogue gravity horizons, I

_ Unruh's idea:

Scalar field in a background spacetime

acoustic waves in a moving fluid

(Credit: Yan Nascimbene copying Unruh)

- Strict formal analogy at low energies
- Any horizon should Hawking radiate (as Hawking's effect is kinematic)
- Well controlled deviations at high energies, in the form of modified dispersion relations

Analogue gravity horizons, II

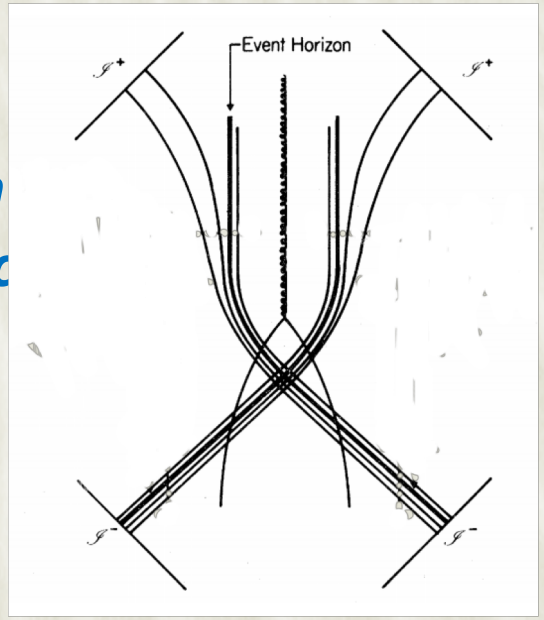
_ Horizons act as magnifying glasses

- Positive side: a unique opportunity to look into the Planck realm
- Negative side: lost of confidence in e.g. Hawking's prediction

_ The trans-Planckian problem

Modes contributing to Hawking radiation at late times have trans-Planckian frequenc close to the horizon

_Analogue systems are well suited to analyze this problem



Analogue gravity horizons, III

_ The most paradigmatic investigation: Does analogue horizons really produce Hawking radiation?

_People has investigated the potential impact of high-energy physics on the Hawking process, both theoretically and experimentally

_ Essentially two main types of modified dispersion relations: superluminal and subluminal

_ There are system essentially quantum and others essentially classical: spontaneous vs stimulated Hawking effects

Theoretical vs experimental verifications, I

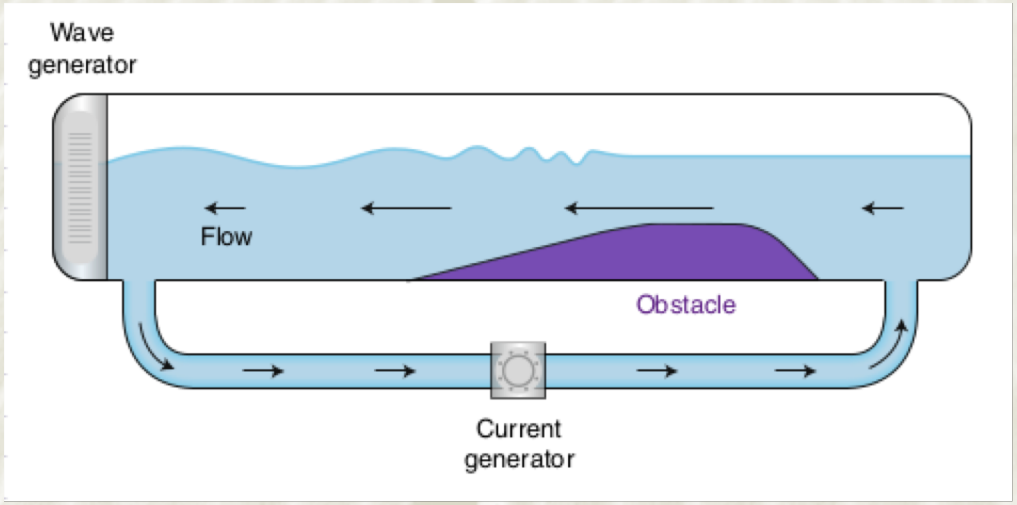
- **In an empirical science, one has to always look for experimental verifications**
  - **Do long-lived horizons exist?**
  - **Do they emit Hawking radiation?**
- **Not foreseeable observation of Hawking radiation in its real astrophysical setting**
- An analogue-experiment verification would partially alleviate this situation
- Again, experiments and not just theory: do simplifications, approximations and additional factors matter?
- We should be even more demanding than with a non-analogue verification

Theoretical vs experimental verifications, II

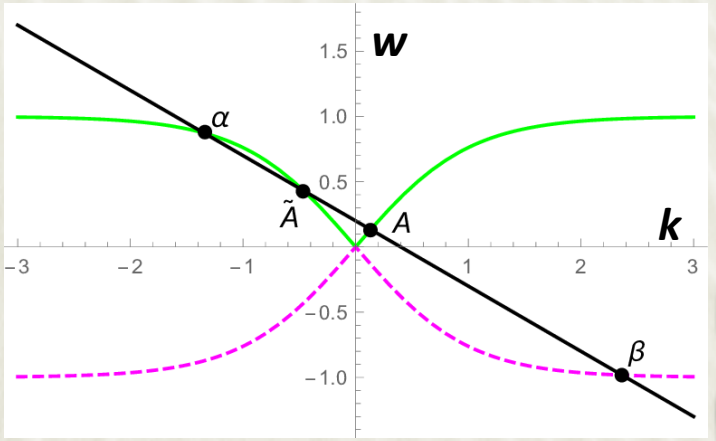
_ From this perspective, although a lot of progress has been made, I would not answer Unruh's question "Has Hawking radiation been already measured?" in the affirmative just yet

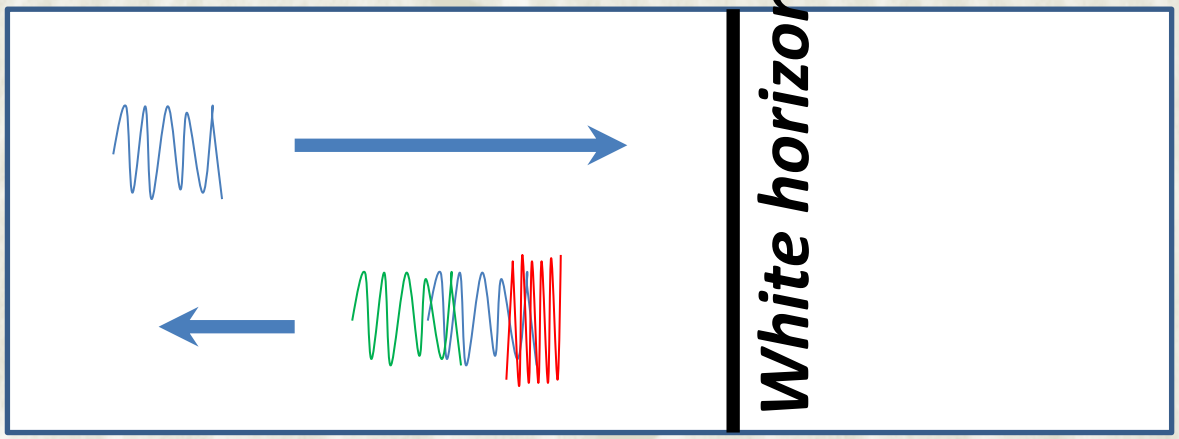
- **Stimulated does not imply spontaneous**
- **Under dispersion the distinction between spontaneous and stimulated is blurred**

Gravity waves in water flows, I

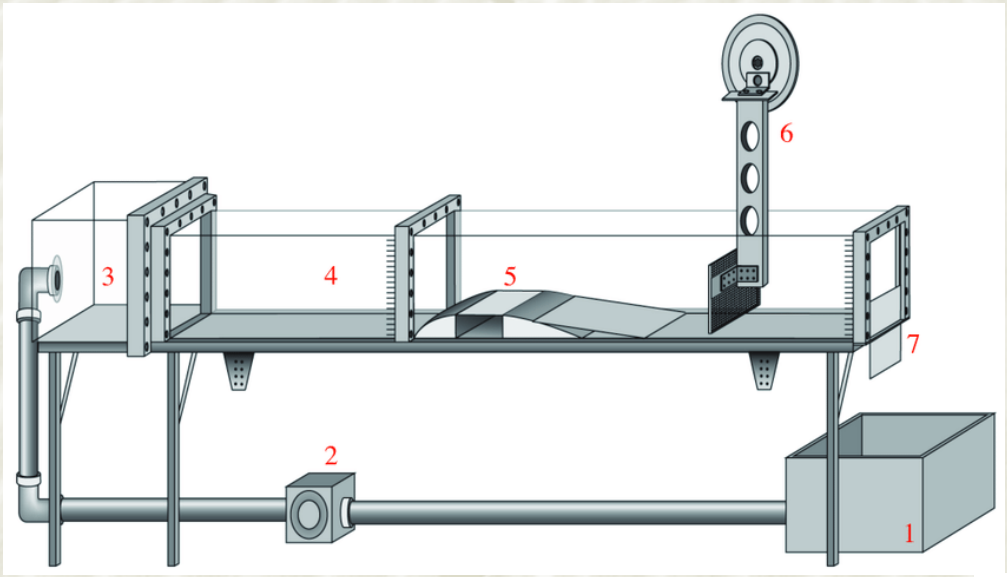


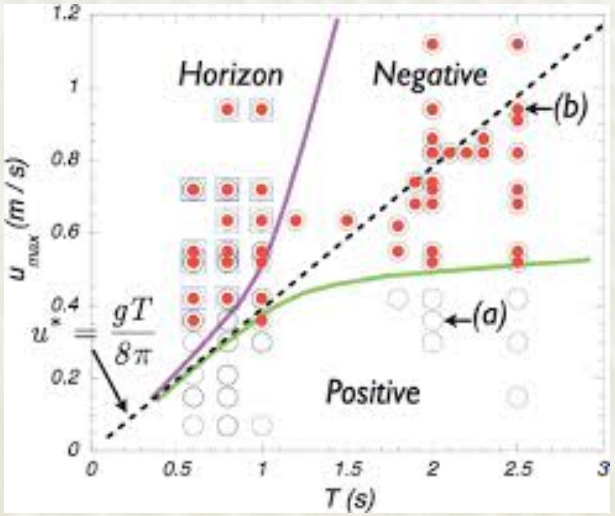
$$(w-vk)^2 = gk \tanh(hk)$$



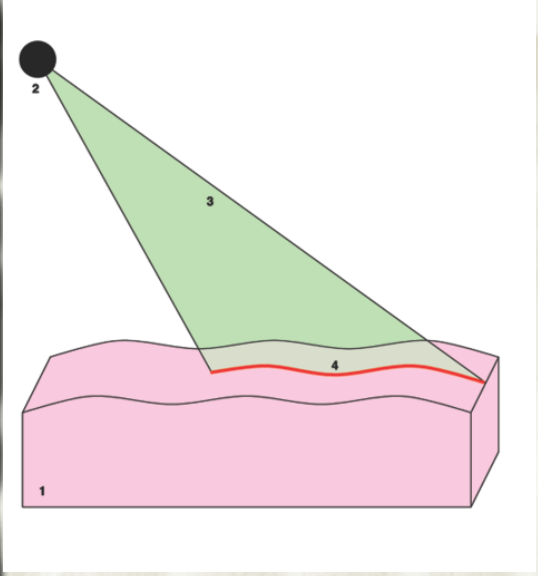


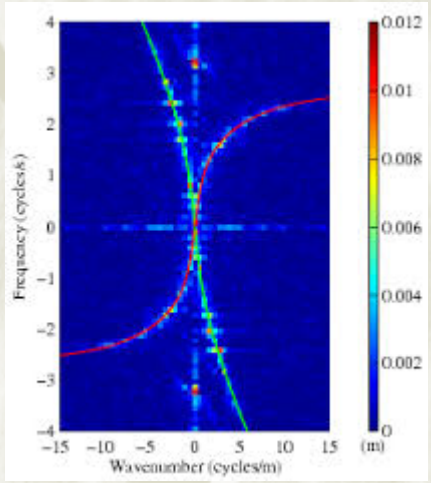
Gravity waves in water flows, II

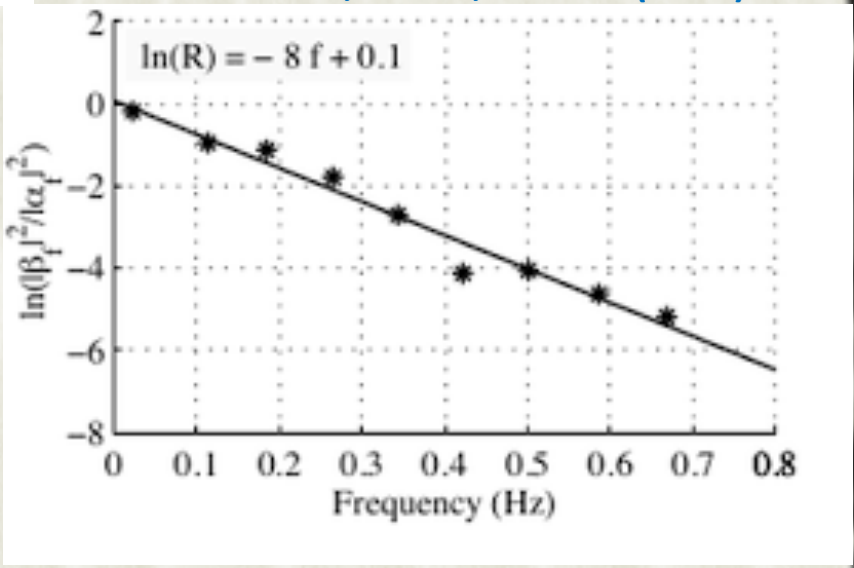




Rousseaux et al, NJP10, 053015 (2008)







Weinfurtner et al, PRL106, 021302(2011)

Gravity waves in water flows, III

_ Negative mode mixing has been observed

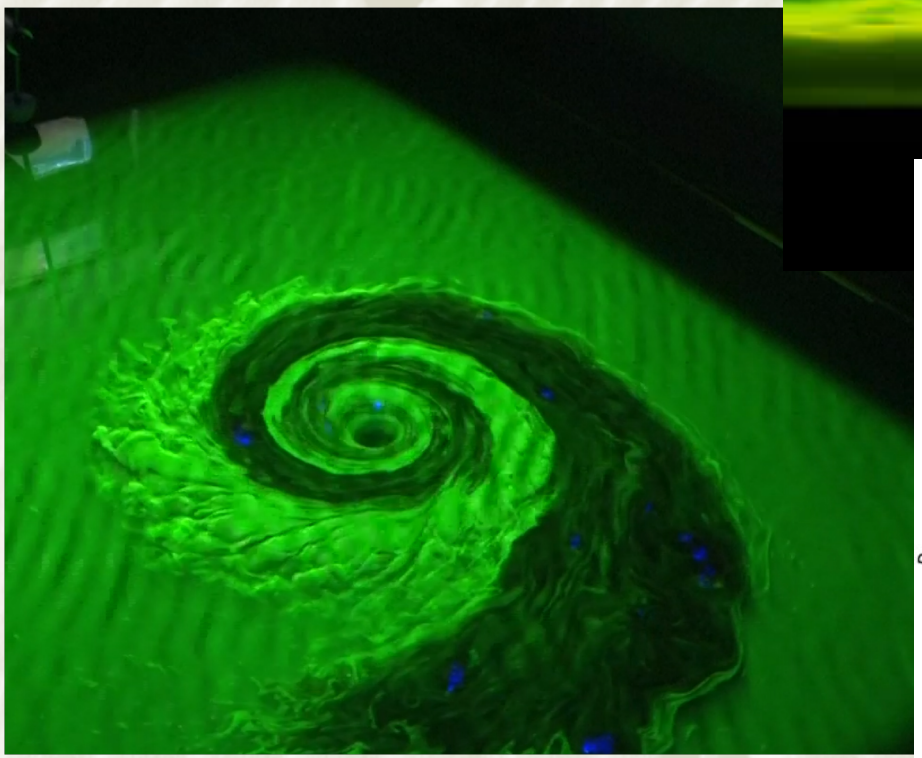
_ In both experiments the flows where subcritical for most of the frequency range

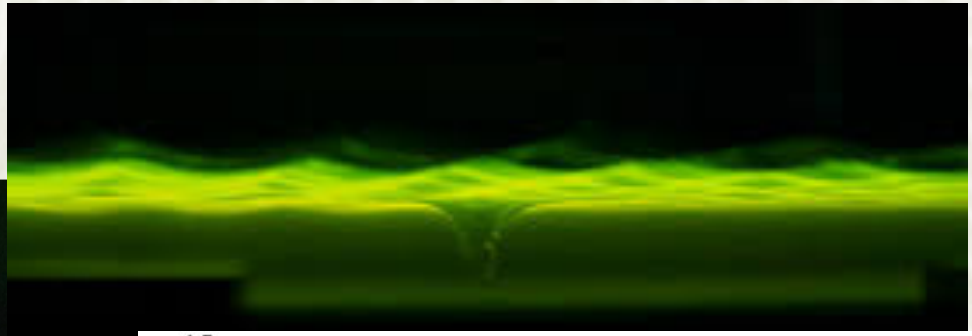
_ It is not clear that the exponential factor has a horizon origin

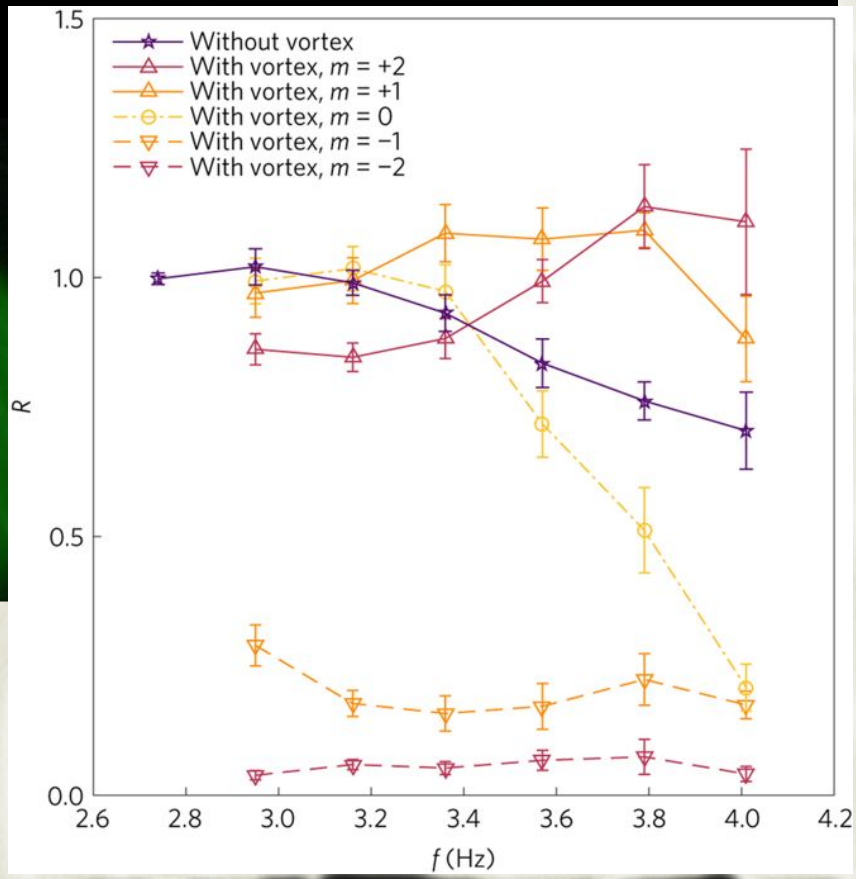
_ At least part of the effect seem s to come from a subcritical to subcritical transition

_ In any case, the system is classical (stimulated process) **so one has to look for quantum systems to obtain real spontaneous Hawking radiation**

Gravity waves in water flows, III: superradiance



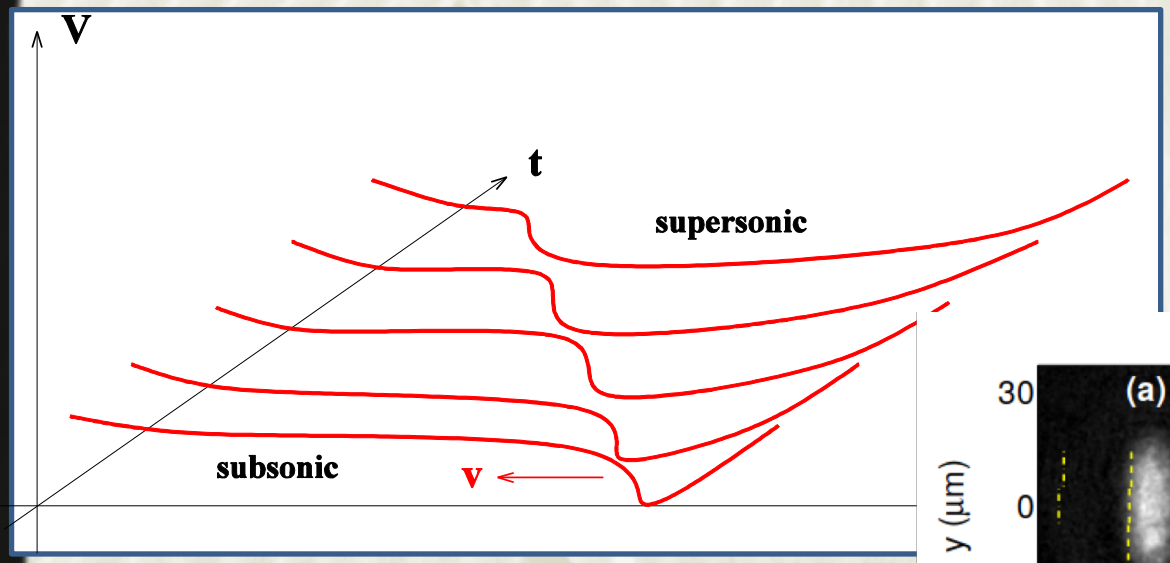


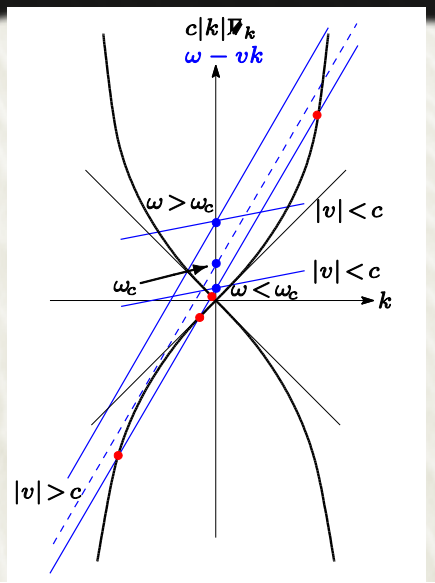


Torres et al, Nature Physics 13, 833 (2017)

Bose-Einstein condensates, I

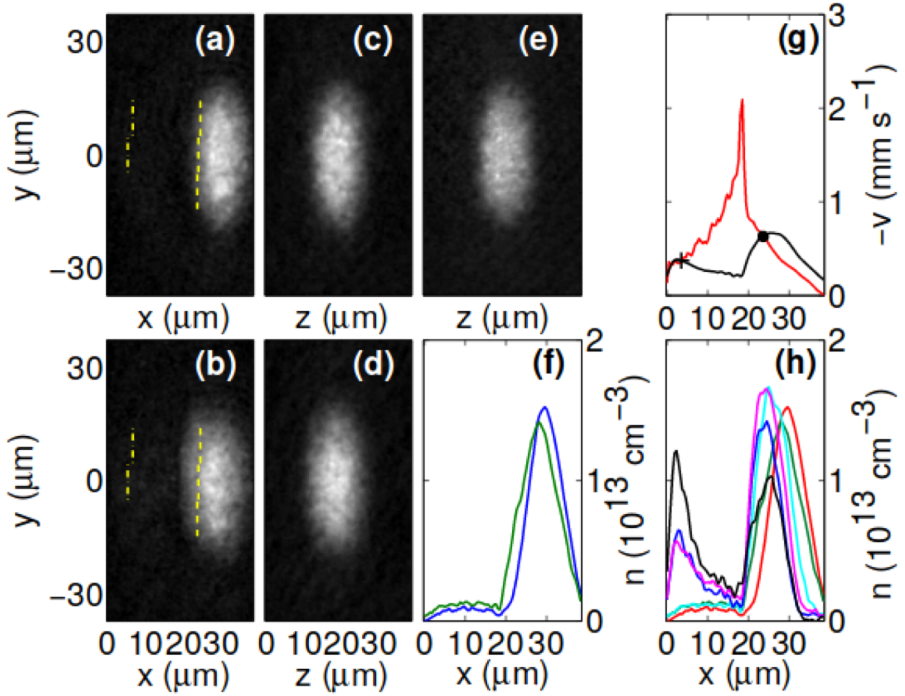
_ A horizon in a BEC





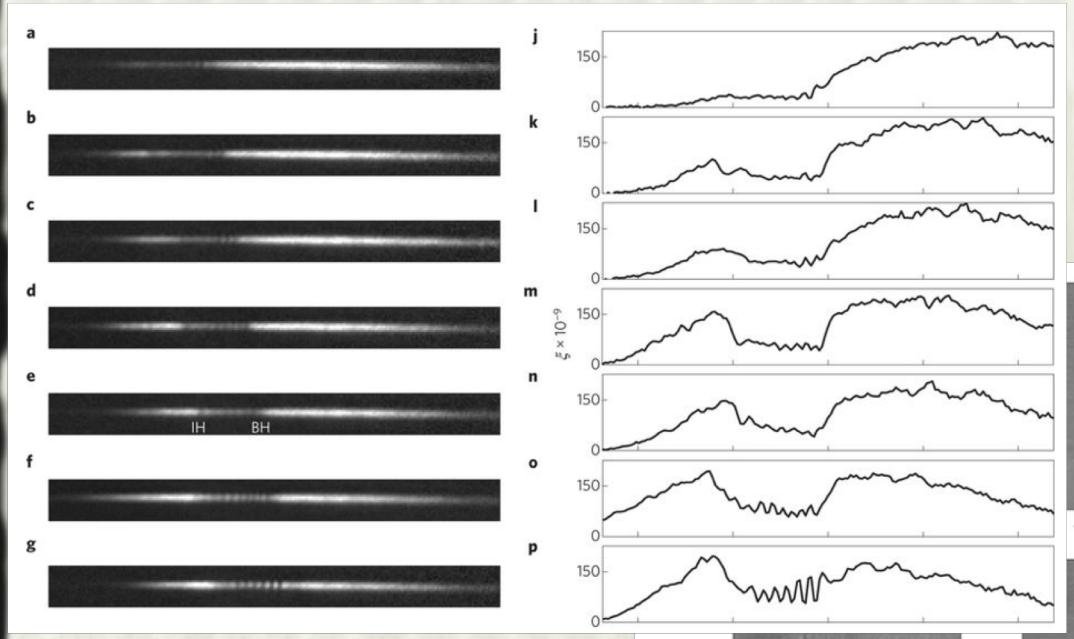
Lahav et al PRL105, 240401(2010)

$$(w-vk)^2 = k^2 + k^4 {}_0^2/k$$

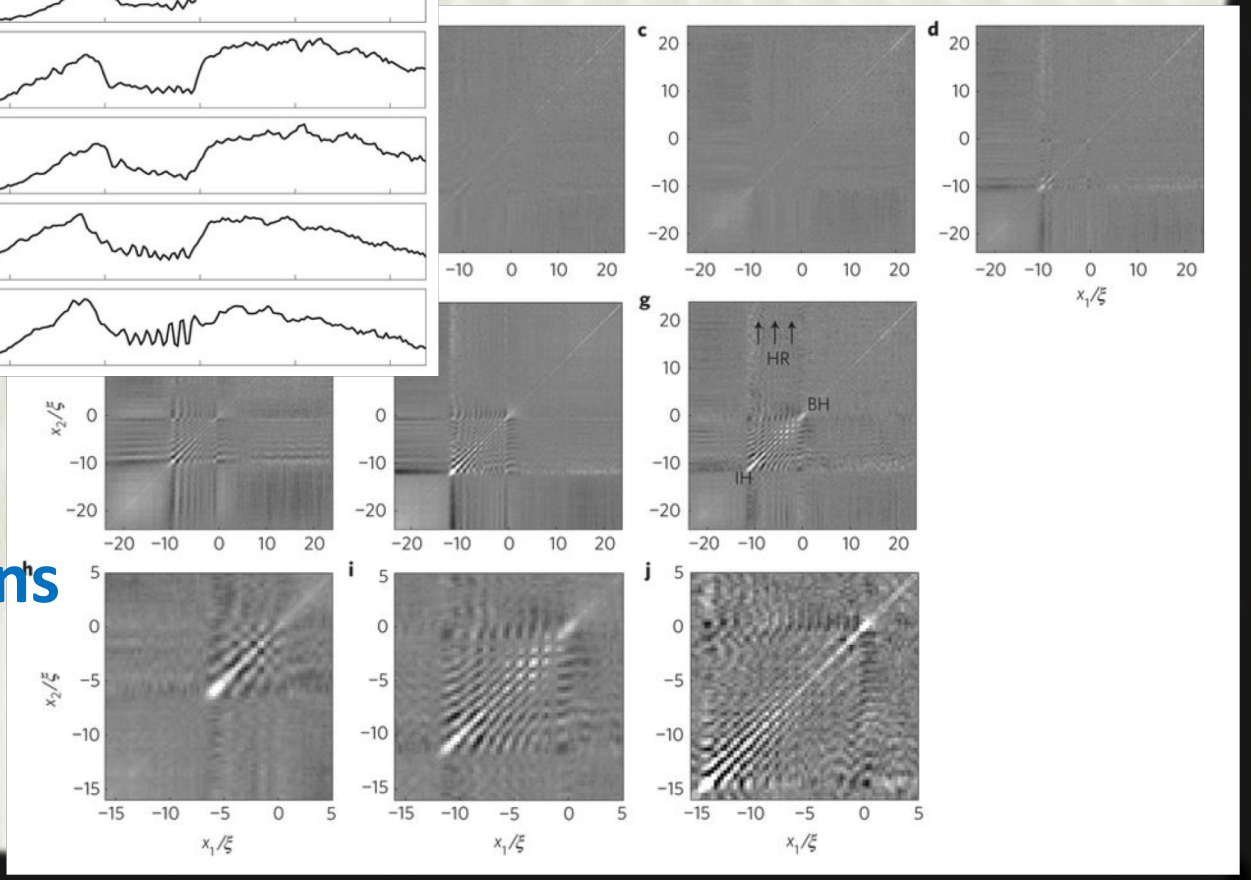


Bose-Einstein condensates, II

_ A black-hole laser in a BEC

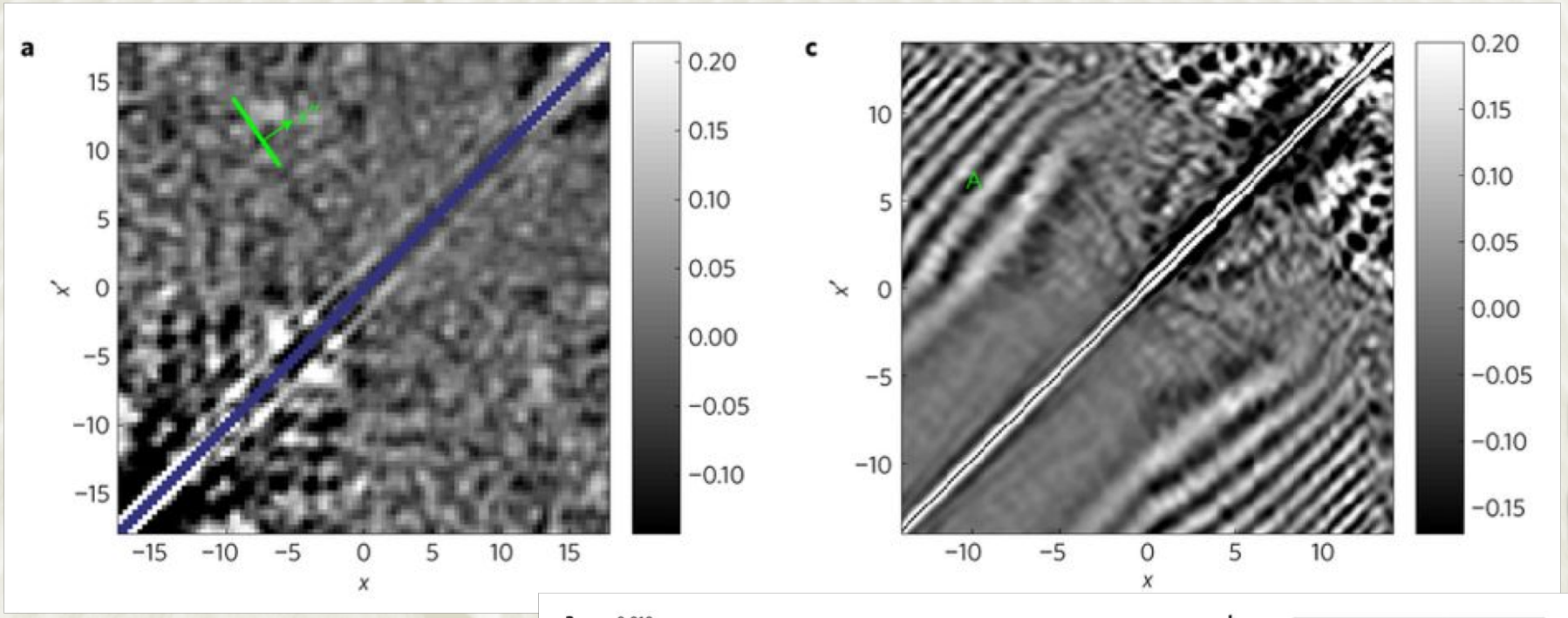


Steinhauer, Nature Phys. 10, 864(2014)

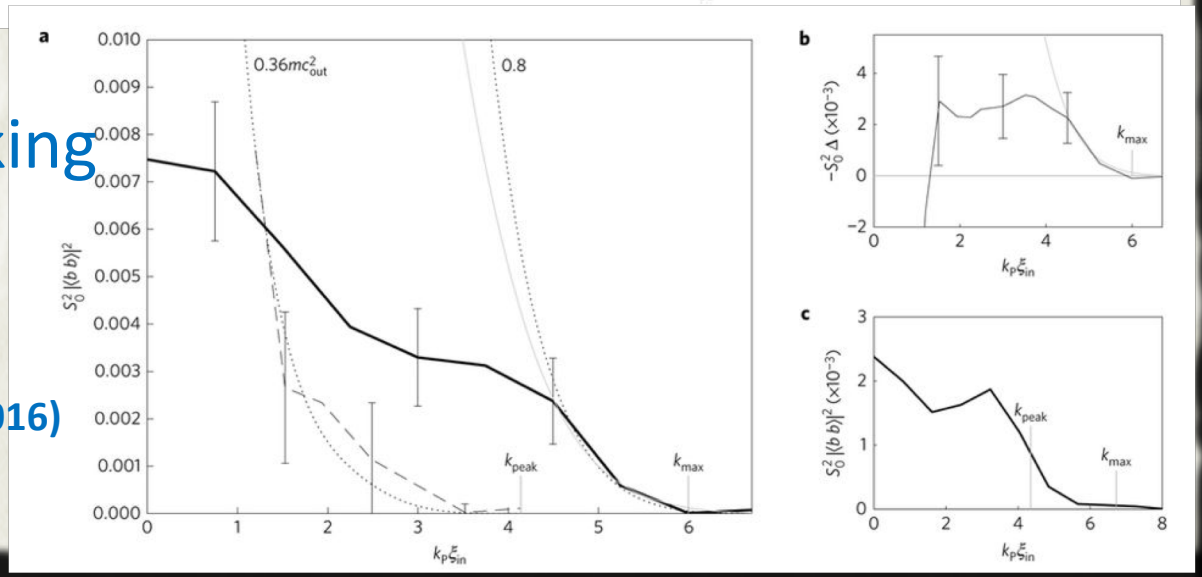


_ Two-point **correlation functions**

Bose-Einstein condensates, III



_ Spontaneous Hawking **emission in a BEC**



Steinhauer, Nature Phys. 12 , 959(2016)

Bose-Einstein condensates, IV

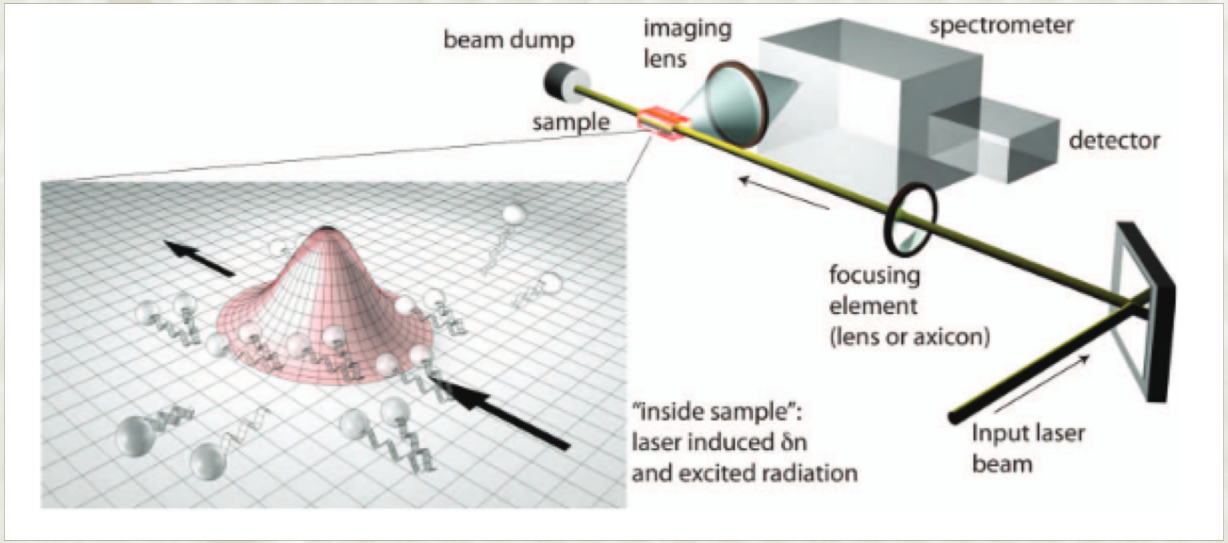
_ The main problem with these results is that it appears possible to reproduce then using just the Gross-Pitaevskii equation (classical equation)

_ What is the real trigger of the observed dynamical behaviour ? (classical or quantum perturbations)

Non linear optical systems, I

_ Ultra-short laser pulses

Belgiorno et al PRL104, 140403 (2010)

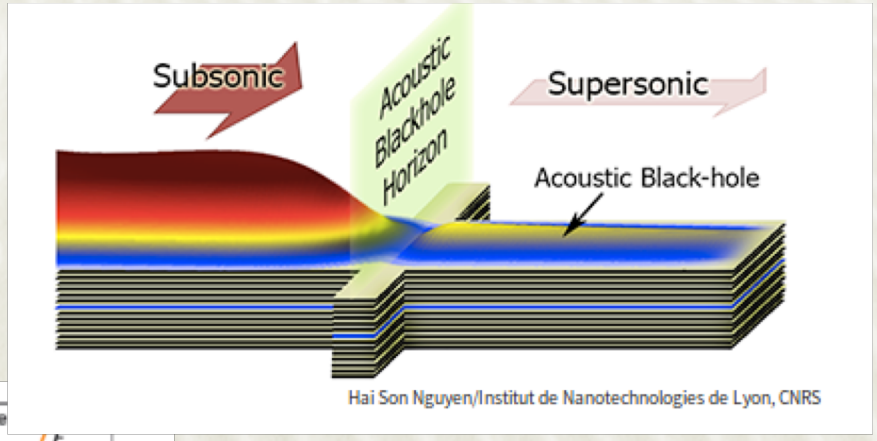


_ They observe emission in the relevant superluminal window

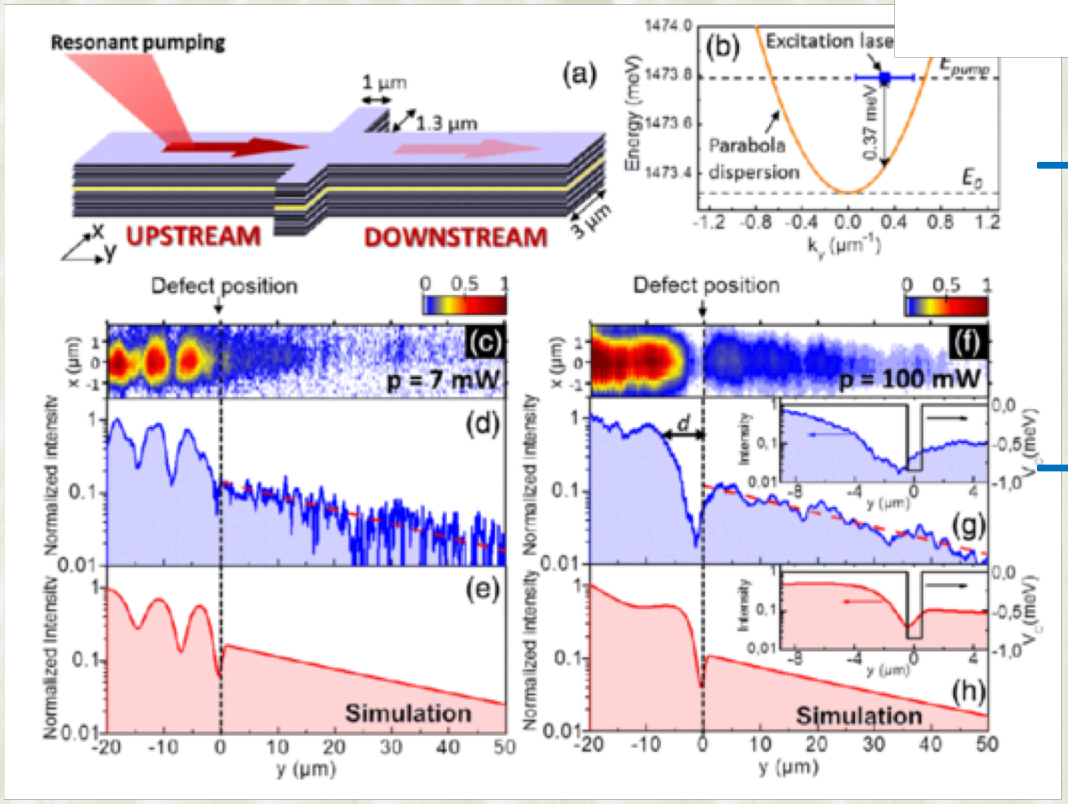
_ With hindsight the emission seems to have a different origin

Non linear optical systems, II

_ Quantum fluids of light



Nguyen et al Nature Phys. 10, 864(2014)



_ One can create proper **single and stationary horizons**

_ Bigger Hawking temperatures

What are we learning?, I

_ The challenge to observe Hawking-like radiation in specific laboratory systems is helping to reach new levels of understanding of those specific systems

_ But, what are learning from the gravitational side ?

What are we learning?, II

_Once a long-lived horizon is established, there is a high probability that it would radiate in a Hawking-like manner, regardless of the specific high-energy physics involved

- **Condition 1: $E_P >> k_B T$**
- **Condition 2: Deep enough potential well ($w >> k_B T$)**

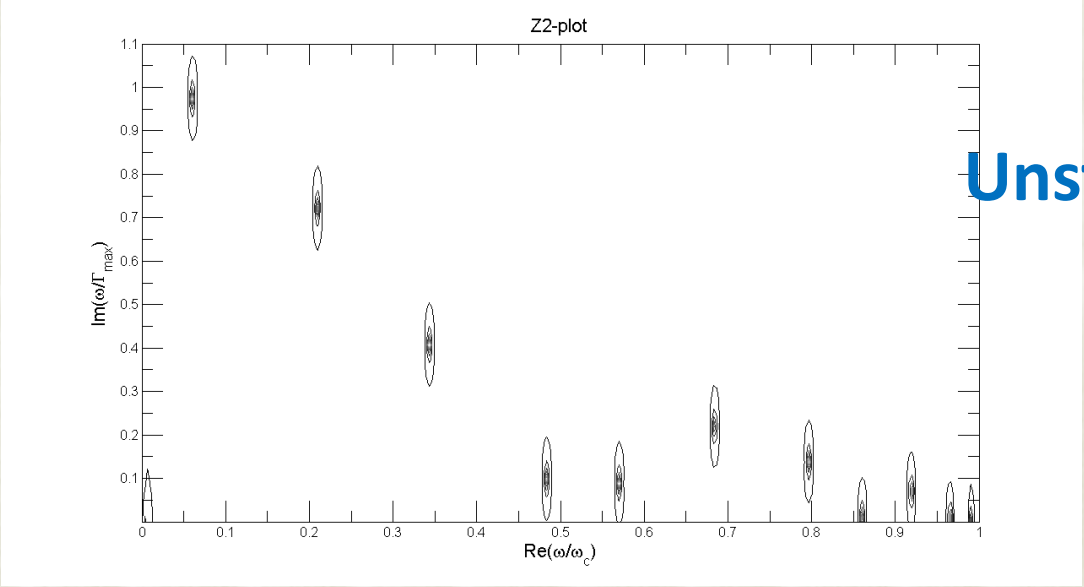
_However, with the same logic, the natural presence of long-lived horizons appears very much dependent on the high-energy characteristics

What are we learning?, III

_Under superluminal dispersion relations the singularity inside a black hole can affect the external region

_Any reflection in the internal region would make a system with a long-lived horizon unstable

_The dynamics would try to get rid of the horizon



Unstable quasinormal frequencies

Barbado-Barceló-Garay JHEP11,112(2011)

nada más...

Gracías Pedro for so many things