Title: Physics Through the Looking-Glass

Speakers: Puttarak Jai-akson

Collection: Young Researchers Conference

Date: June 22, 2022 - 11:45 AM

URL: https://pirsa.org/22060060

Abstract: In 1965, Lévy-Leblond introduced the ultra-relativistic cousin of the Poincaré symmetry and named it the Carrollian symmetry after Lewis Carroll (the pseudonym of the author of Alice's adventures in Wonderland and Through the Looking-Glass). It can be seen as the counterpart of the non relativistic Galilean symmetry. Since then, Carrollian symmetry has become an active research topic in various fields, ranging from field theories, hydrodynamics, and more recently, gravity and black holes. In this talk, I will give an introductory review of the Carrollian symmetry and Carrollian physics, especially focusing on the emergence of Carrollian hydrodynamics in gravity and black holes

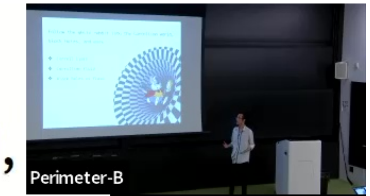
Running Through Time (Alina Chau/ Disney)

Physics Through the Looking Glass

Puttarak Jai-akson

Young Researchers Conference @ PI
June 22, 2022

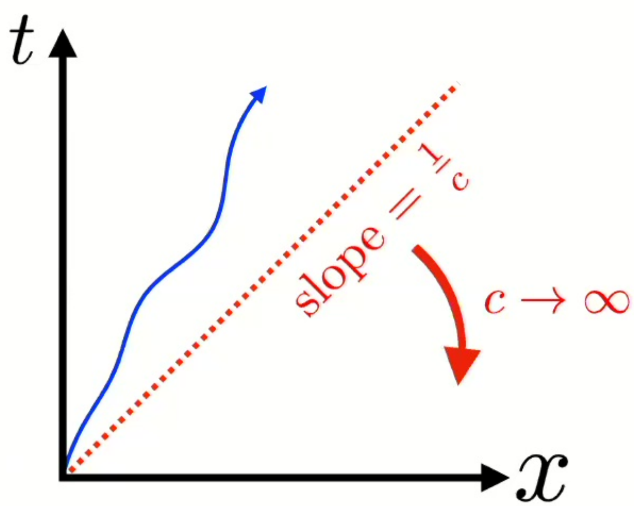
Follow the white rabbit into the Carrollian world, black holes, and more



- ✤ Carroll limit
- ✤ Carrollian fluid
- ✤ Black holes vs fluid

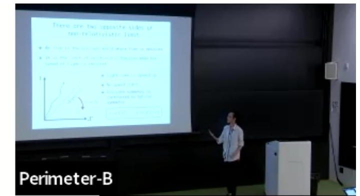
There are two opposite sides of non-relativistic limit

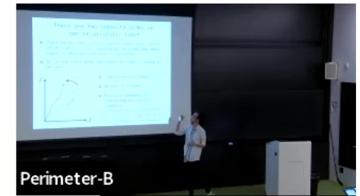
- We live in the Galilean world where time is absolute
- It is the limit of relativistic theories when the speed of light is infinite



- Light-cone is opened up
- No speed limit
- Poincaré symmetry is contracted to Galilei symmetry

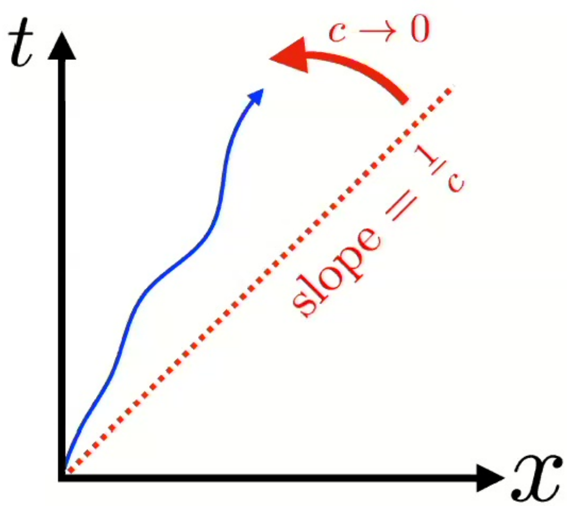
$$\boxed{t \to t'(t) \qquad x \to x'(t,x)}$$





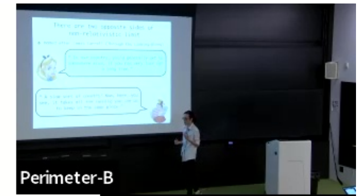
There are two opposite sides of non-relativistic limit

- There exists the Carroll limit (ultra-local, ultra-relativistic), first studied by Lévy-Leblond, when space is absolute but time is relative
- It is the limit when the speed of light is taken to be zero



- Light-cone is closed
- Motion is frozen
- Poincaré symmetry is contracted to Carroll symmetry

$$\boxed{t \to t'(t, x) \qquad x \to x'(x)}$$



There are two opposite sides of non-relativistic limit

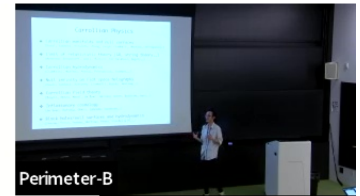
- Named after Lewis Carroll (Through the Looking-Glass)

" In our country, you'd generally get to somewhere else, if you ran very fast for a long time "

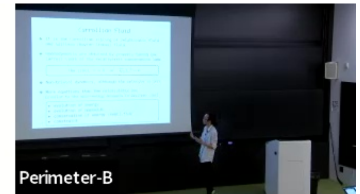
" A slow sort of country! Now, here, you see, it takes all the running you can do to keep in the same place "

Carrollian Physics

- Carrollian manifolds and null surfaces
  (Duval, Gibbons, Horvathy, Zhang, Leigh, Ciambelli, Marteau, Petropoulos,)
- Limit of relativistic theory (GR, string theory,…)
  (Henneaux, Bergshoeff, Gomis, Rollier, ter Veldhuis, Bagchi,…)
- Carrollian hydrodynamics
  (Ciambelli, Marteau, Petkou, Petropoulos, Siampos,…)
- Null infinity an Flat space holography
  (Duval, Gibbons, Horvathy, Ciambelli, Bagchi, Hartong,…)
- Carrollian field theory
  (Bagchi, Mehra, Nandi, de Boer, Hartong, Obers, Banerjee, Basu,…)
- Inflationary cosmology
  (de Boer, Hartong, Obers, Sybesma, Vandoren,…)
- Black holes/null surfaces and hydrodynamics
  (Thorne, Price, Donnay, Marteau, Penna, Freidel & PJ,…)



Carrollian Fluid



- It is the Carrollian sibling of relativistic fluid and Galilean (Navier-Stokes) fluid

- Hydrodynamics are obtained by properly taking the Carroll limit of the relativistic conservation laws

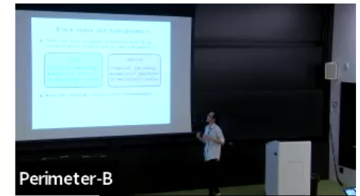
The Limit $c \to 0$ of $\nabla_b T_a{}^b = 0$

- Non-trivial dynamics, although the velocity is zero

- More equations than the relativistic one
(similar to the mass-energy decouple in Galilean case)

  - evolution of energy
  - evolution of momentum
  - conservation of energy (heat) flux
  - constraint

Black holes and hydrodynamics

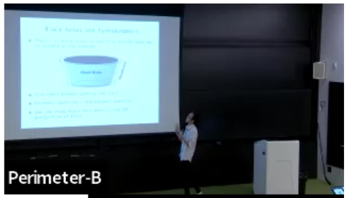


- There are many evidences displaying underlying correspondence between gravity and hydrodynamics

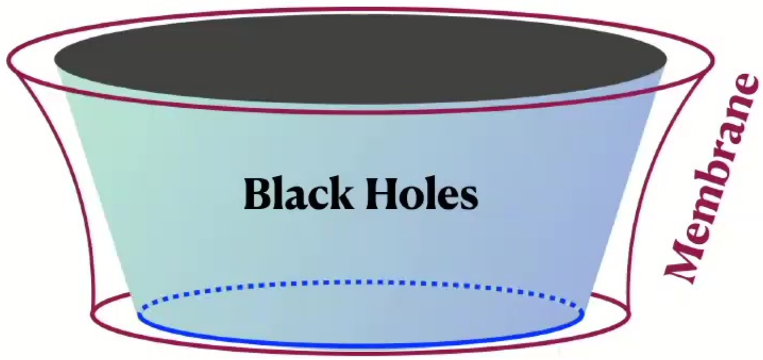
Fluid	Gravity
Classical low-energy dynamics of particle on macroscopic scales	Classical low-energy dynamics of spacetime on macroscopic scales

- Membrane paradigm, fluid-gravity correspondence,…

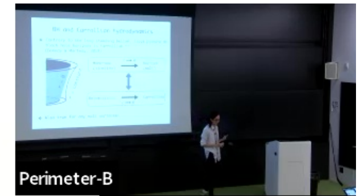
Black holes and hydrodynamics



- Physics of black holes as seen from outside observers is encoded at the membrane

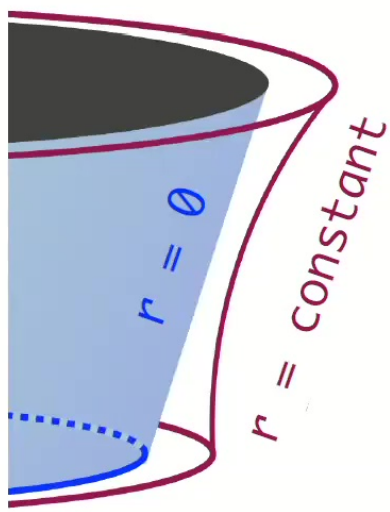


- Dictionary between gravity and fluid
- Einstein equations = hydrodynamic equations
- One can study black hole physics from the perspective of fluid



BH and Carrollian hydrodynamics

- Contrary to the long-standing belief, fluid picture at black hole horizons is Carrollian !!
  (Donnay & Marteau, 2019)

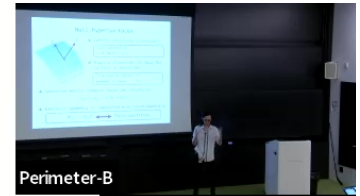


Membrane (timelike) $\xrightarrow{r \to 0}$ Horizon (null)

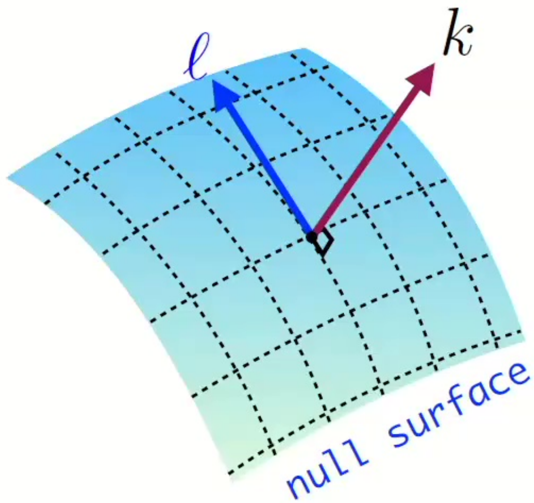
$\Updownarrow$

Relativistic $\xrightarrow[c \to 0]{}$ Carrollian

- Also true for any null surfaces!



Null hypersurfaces



- Carroll structures (intrinsic)

null vector	ℓ^a
2-d metric	q_{ab}

- Rigging structures (to hang the surface in spacetime)

Transverse vector	k^a
normal 1-form	n_a

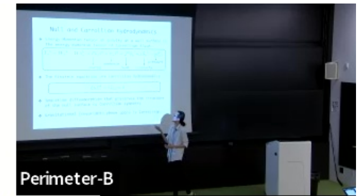
- Spacetime metric connects these two structures

$$g_{ab} = q_{ab} + \ell_a k_b + k_a n_b$$

- Extrinsic geometry is identified with fluid quantities

$$\boxed{W_a{}^b = D_a \ell^b \longleftrightarrow \text{Fluid quantities}}$$

Null and Carrollian hydrodynamics



- Energy-Momentum tensor of gravity at a null surface is the energy-momentum tensor of Carrollian fluid

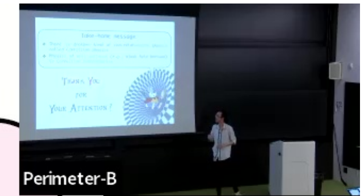
$$\boxed{T_a{}^b = W_a{}^b - W\delta_a^b = \underbrace{\mathcal{E}k_a\ell^b}_{\text{energy}} + \underbrace{\pi_a\ell^b}_{\text{momentum}} + \underbrace{\mathcal{J}^b k_a}_{\text{heat}} + (\underbrace{\mathcal{S}_a{}^b}_{\text{viscosity}} - \underbrace{p\delta_a^b}_{\text{pressure}})}$$

- The Einstein equations are Carrollian hydrodynamics

$$\boxed{D_b T_a^b = G_{\ell a} = 0}$$

- Spacetime diffeomorphism that preserves the structure of the null surface is Carrollian symmetry

- Gravitational (covariant) phase space is Carrollian



Take-home message

- There is another kind of non-relativistic physics called Carrollian physics
- Physics of null surfaces (e.g., black hole horizon) is Carrollian hydrodynamics

THANK YOU

FOR

YOUR ATTENTION !