

Title: Physics Through the Looking-Glass

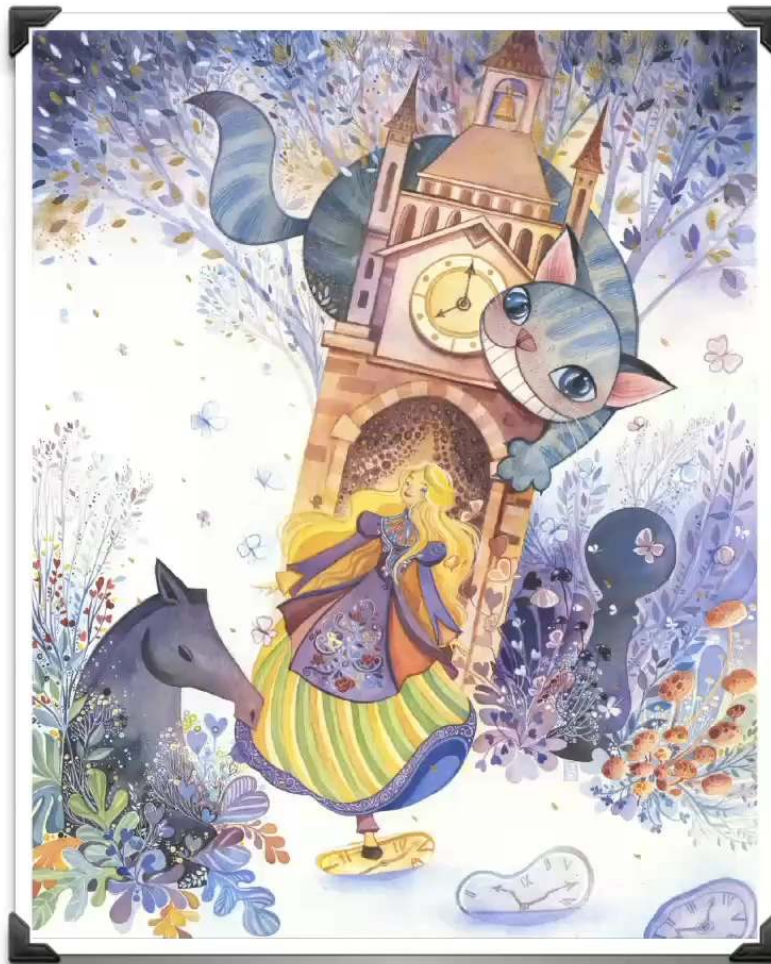
Speakers: Puttarak Jai-akson

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

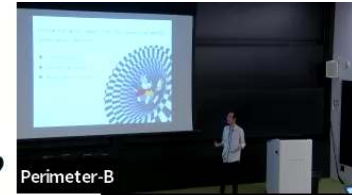
Puttarak Jai-akson

Young Researchers Conference @ PI  
June 22, 2022



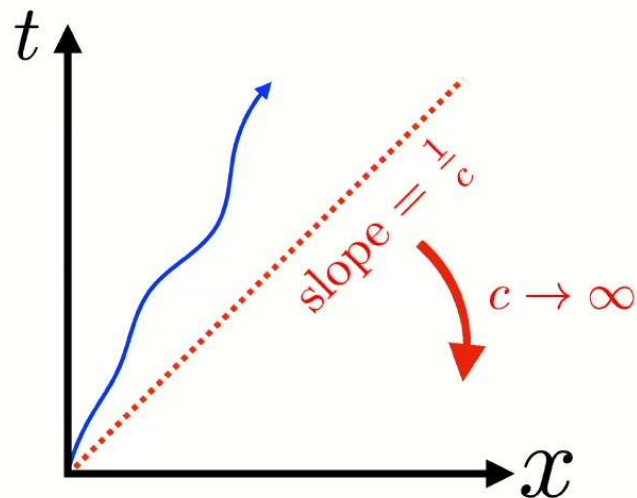
Follow the white rabbit into the **Carrollian** world,  
**black holes**, and more

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



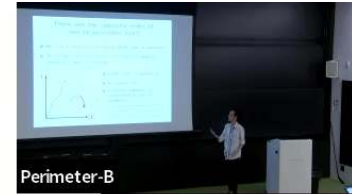
# There are two opposite sides of non-relativistic limit

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



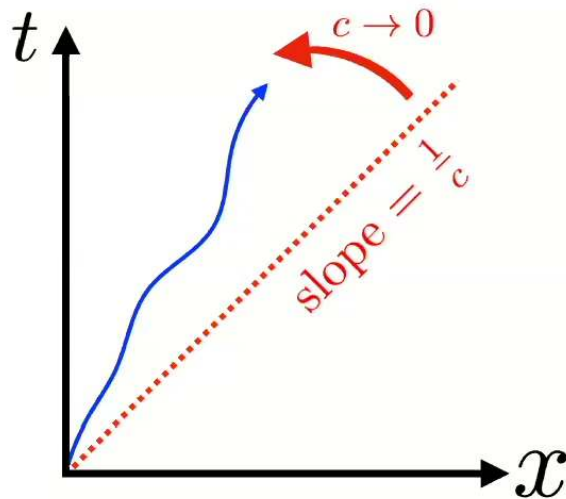
- ♣ Light-cone is opened up
- ♣ No speed limit
- ♣ Poincaré symmetry is contracted to **Galilei symmetry**

$$t \rightarrow t'(t) \quad x \rightarrow x'(t, x)$$



## 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**

$$t \rightarrow t'(t, x) \quad x \rightarrow x'(x)$$



# 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, Marateau, Petropoulos,)
- ❖ Limit of relativistic theory (GR, string theory,...)  
(Henneaux, Bergshoeff, Gomis, Rollier, ter Veldhuis, Bagchi,...)
- ❖ Carrollian hydrodynamics  
(Ciambelli, Marateau, Petkou, Petropoulos, Siampos,...)
- ❖ Null infinity and 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, Marateau, 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

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

- ❖ 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



Perimeter-B

# Black holes and hydrodynamics

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

## Fluid

Classical low-energy dynamics of **particle** on macroscopic scales

## Gravity

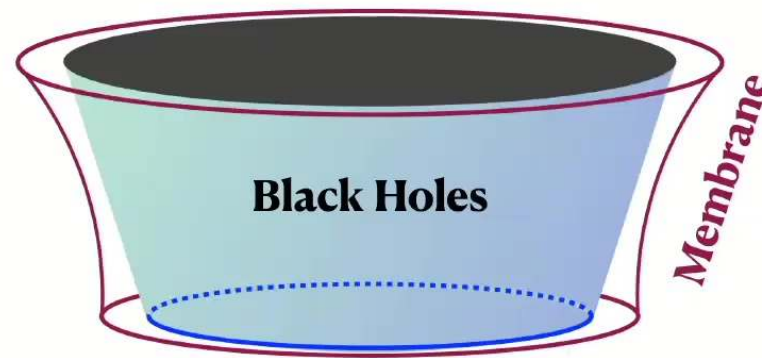
Classical low-energy dynamics of **spacetime** on macroscopic scales

- ❖ **Membrane paradigm**, fluid-gravity correspondence,...



# Black holes and hydrodynamics

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



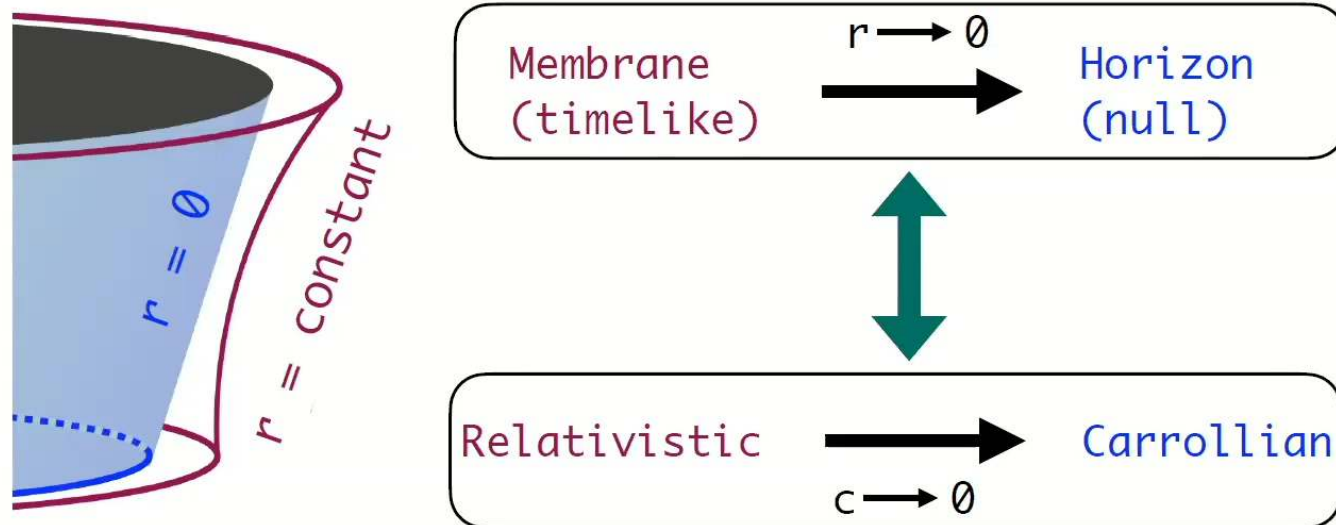
- ❖ Dictionary between gravity and fluid
- ❖ Einstein equations = hydrodynamic equations
- ❖ One can study black hole physics from the perspective of fluid



# BH and Carrollian hydrodynamics

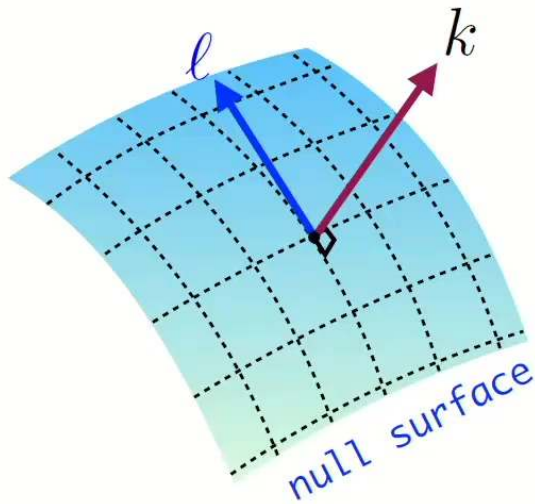


- ❖ Contrary to the long-standing belief, fluid picture at black hole horizons is Carrollian !!  
(Donnay & Marteau, 2019)



- ❖ Also true for any null surfaces!

# Null hypersurfaces



- ❖ Carroll structures (intrinsic)

$\text{null vector } \ell^a$   
 $\text{2-d metric } q_{ab}$

- ❖ Rigging structures (to hang the surface in spacetime)

$\text{Transverse vector } k^a$   
 $\text{normal 1-form } n_a$

- ❖ 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

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



# Null and Carrollian hydrodynamics

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

$$T_a{}^b = W_a{}^b - W\delta_a^b = \mathcal{E}k_a\ell^b + \pi_a\ell^b + \mathcal{J}^bk_a + (\mathcal{S}_a{}^b - p\delta_a^b)$$

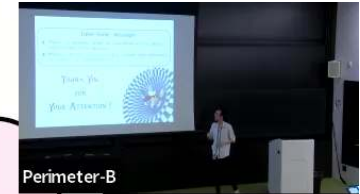
↓                      ↓                      ↓                      ↓                      ↓  
energy                      momentum                      heat                      viscosity                      pressure

- ❖ The Einstein equations are Carrollian hydrodynamics

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

- ❖ 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 !

