

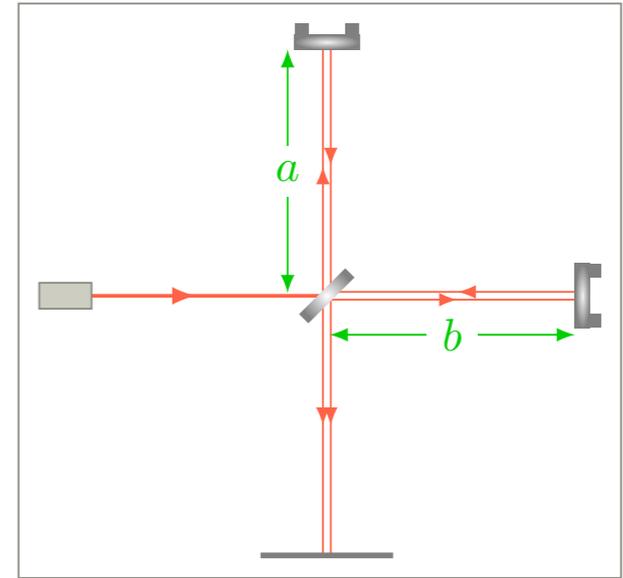
# Física IV

1º dezembro

Relatividade restrita

# Relatividade restrita

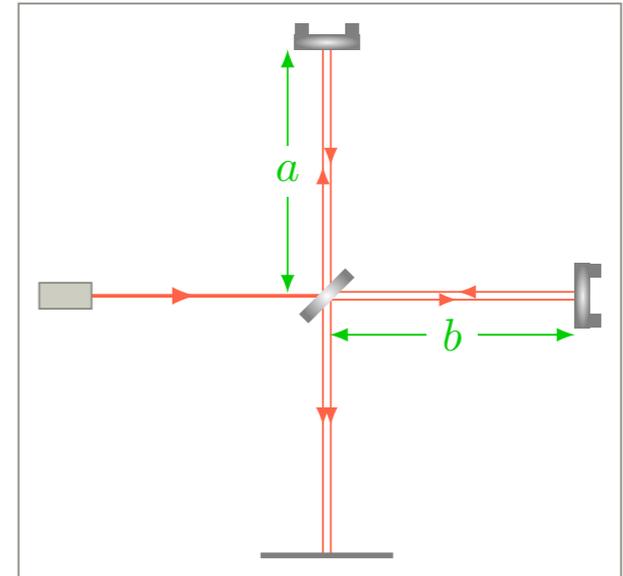
## Hipótese de Einstein



Velocidade da luz é  $c$  em qualquer sistema de referências

# Relatividade restrita

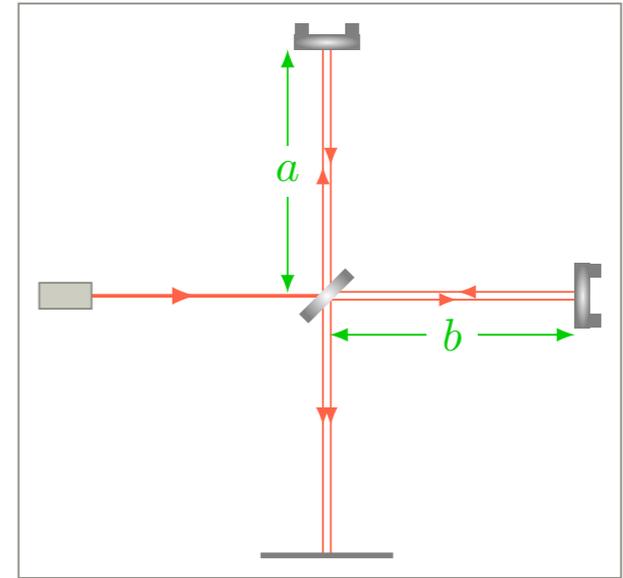
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# Relatividade restrita

## Hipótese de Einstein



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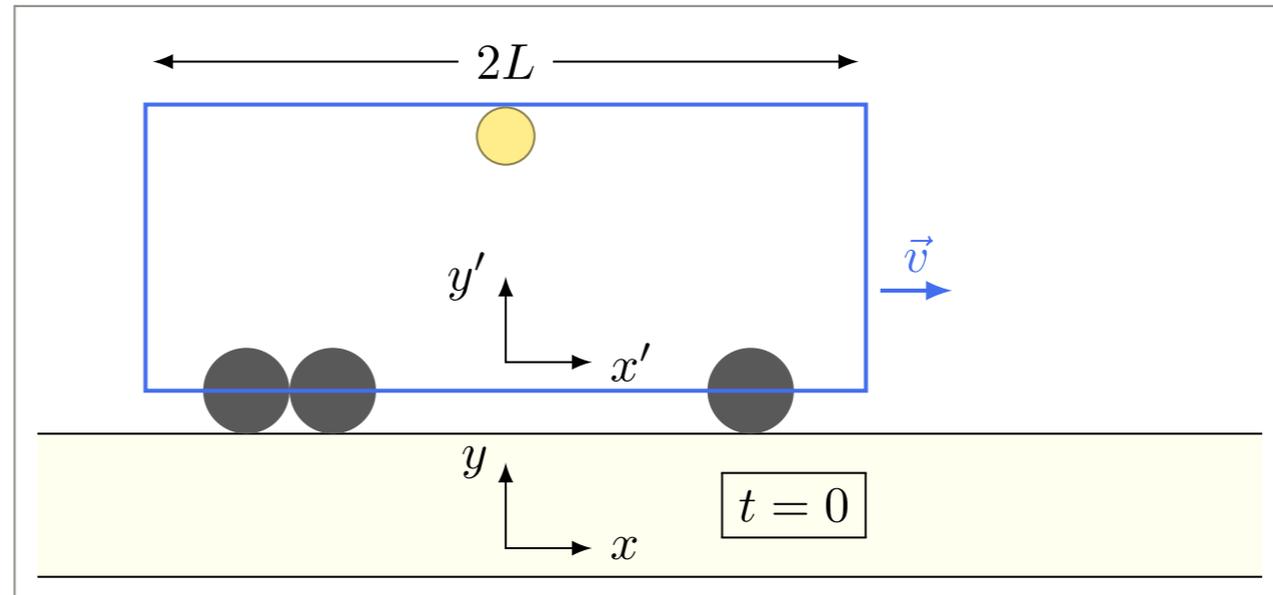


Consequências?

# Relatividade restrita

## Hipótese de Einstein

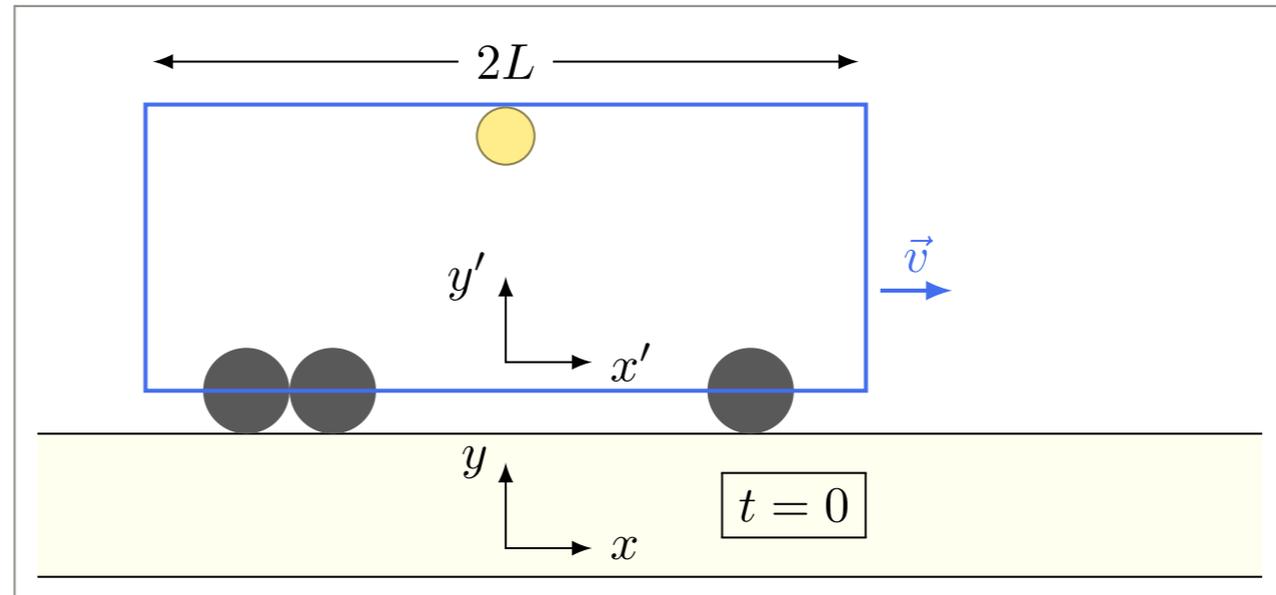
Luz se acende, no meio do ônibus



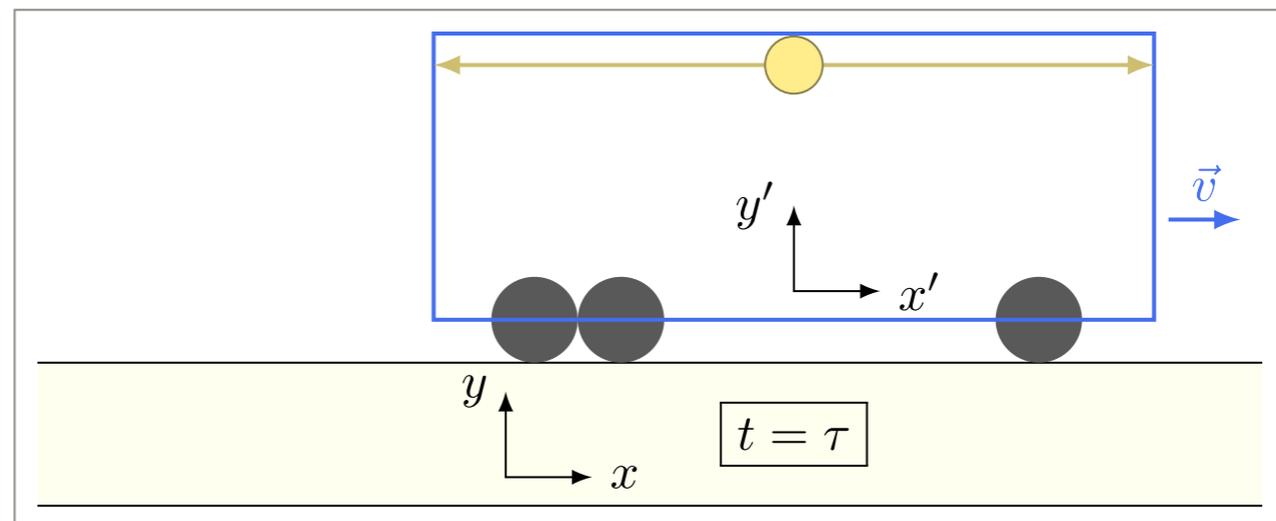
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## Hipótese de Einstein

Luz se acende, no meio do ônibus

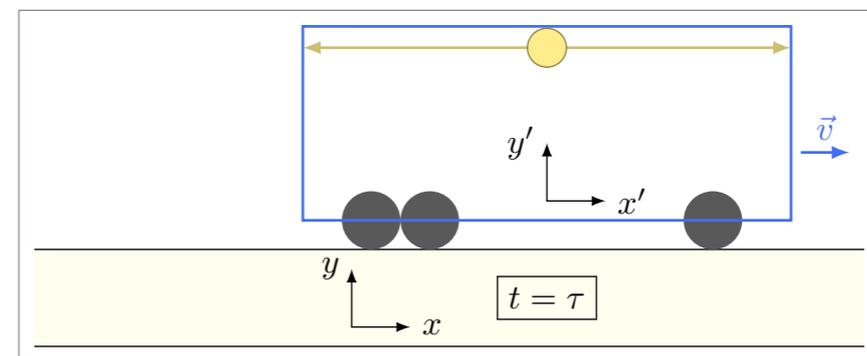
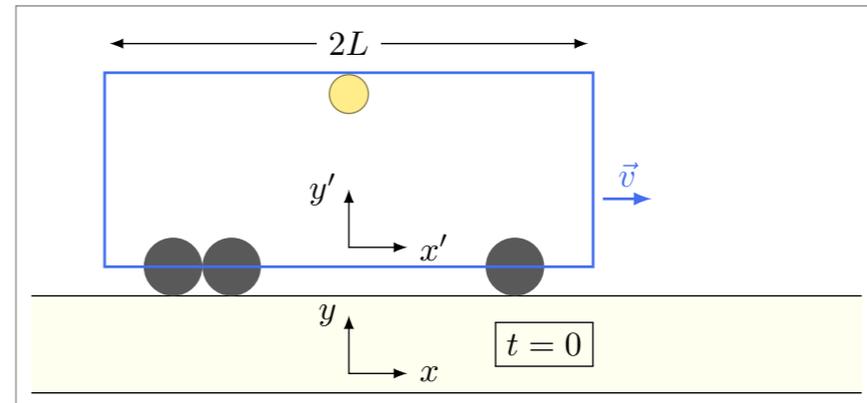
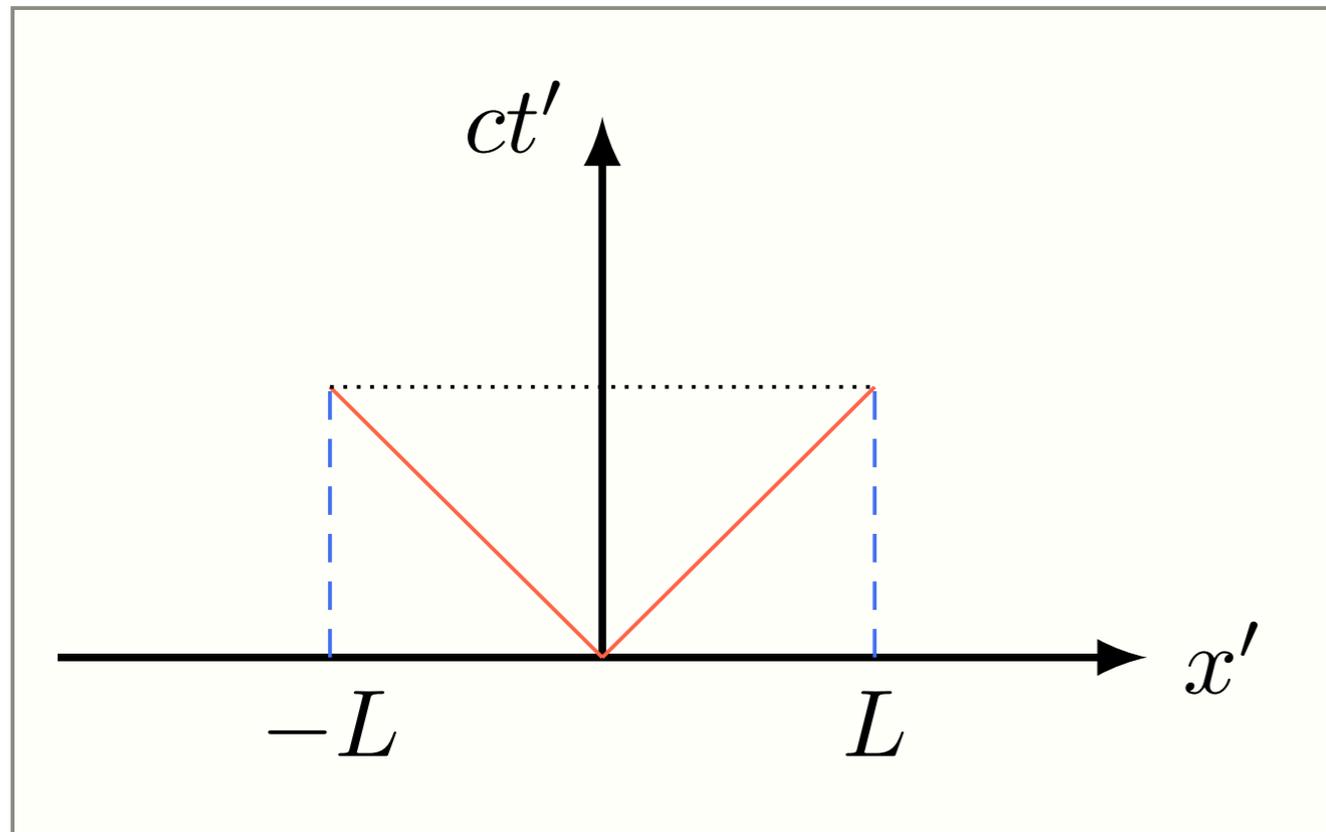


Luz chega às extremidades



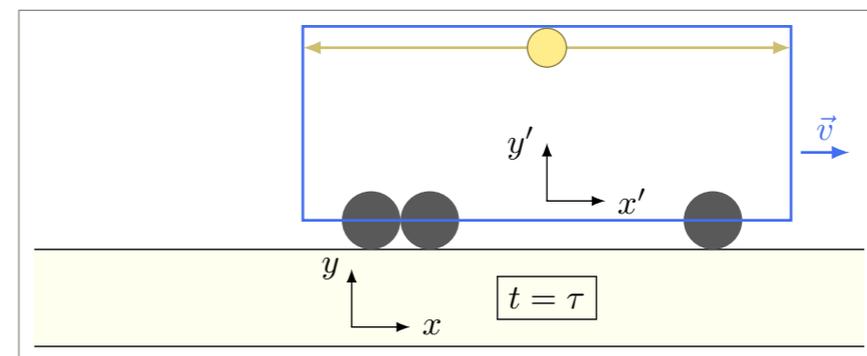
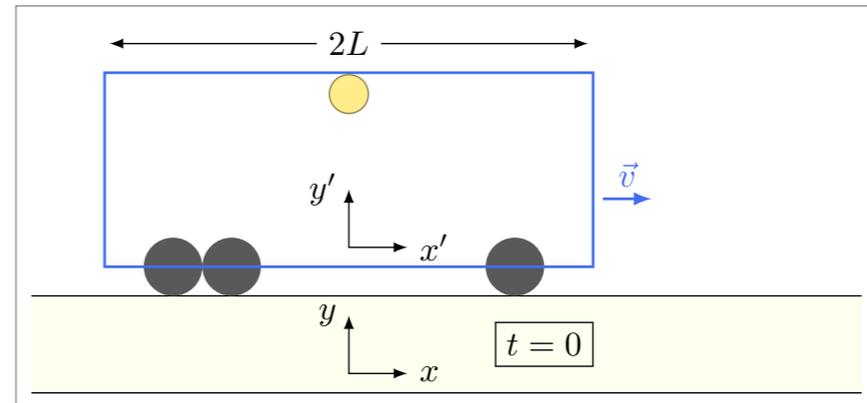
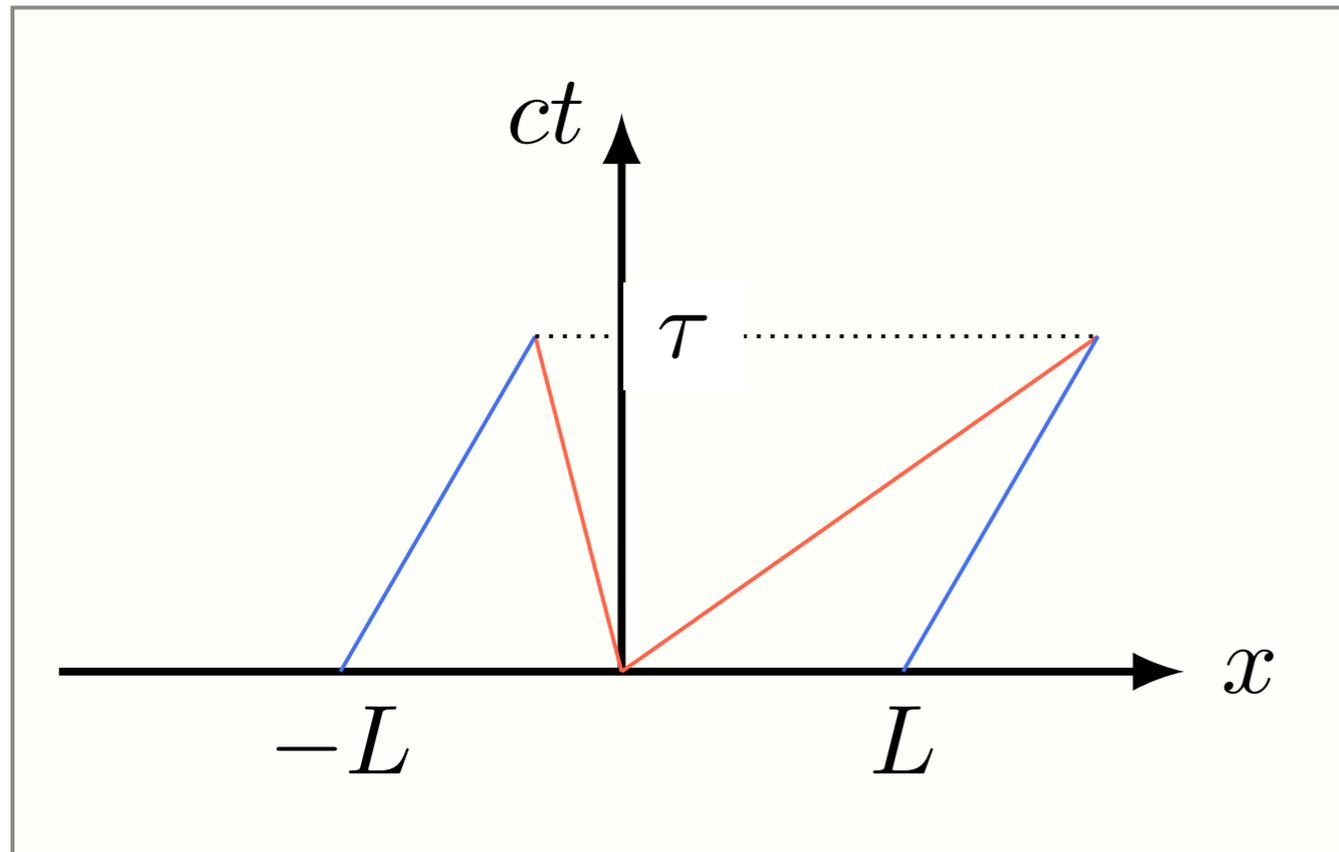
# Relatividade restrita

## Hipótese de Einstein



# Relatividade restrita

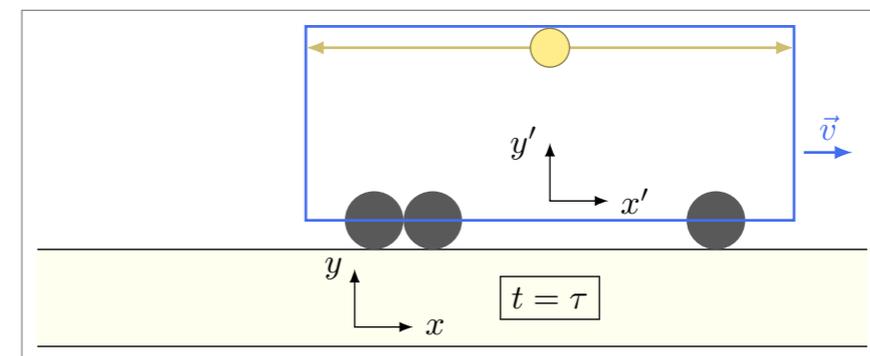
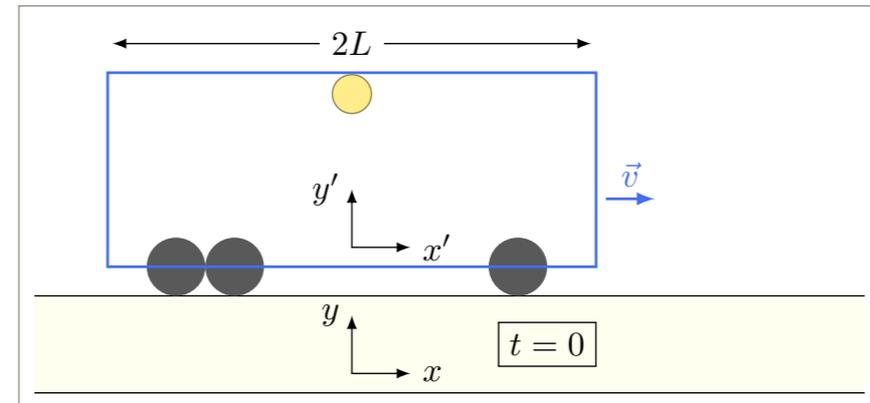
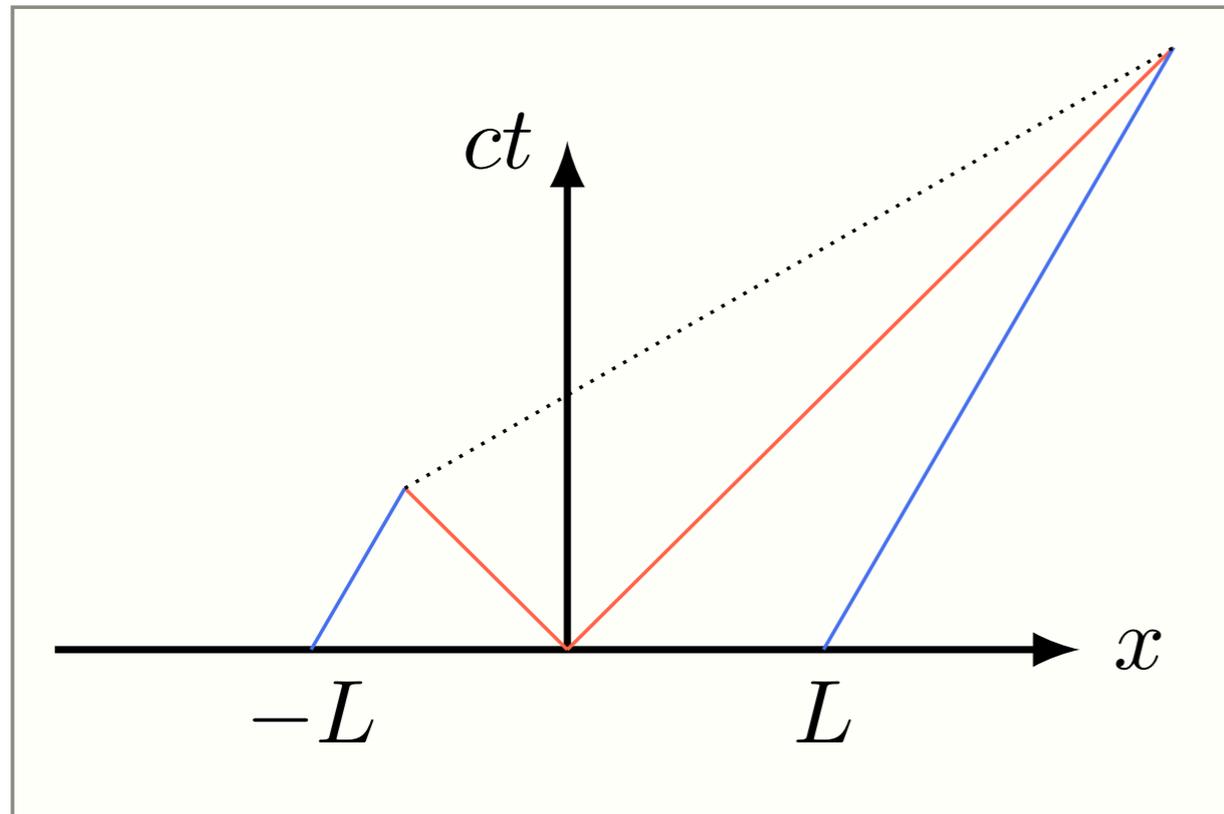
## Hipótese de Einstein



Galileu

# Relatividade restrita

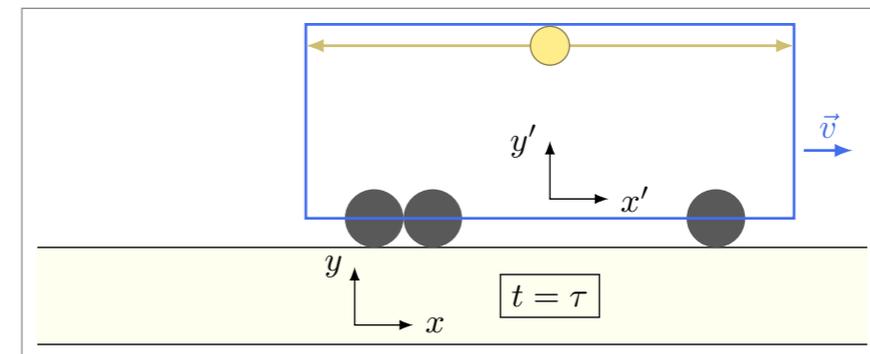
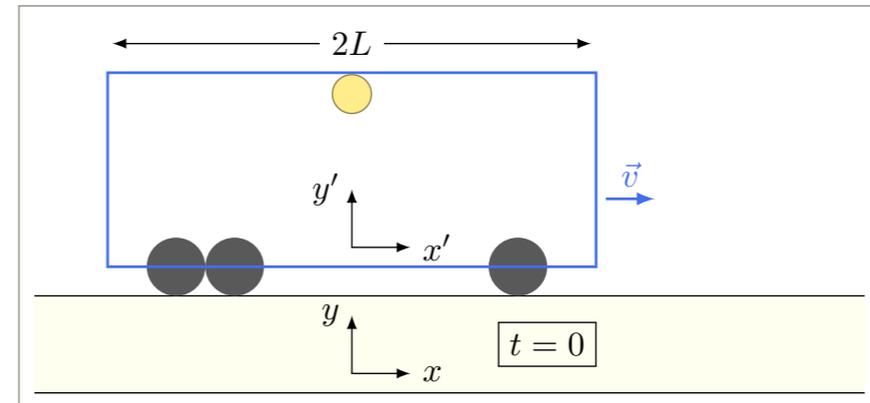
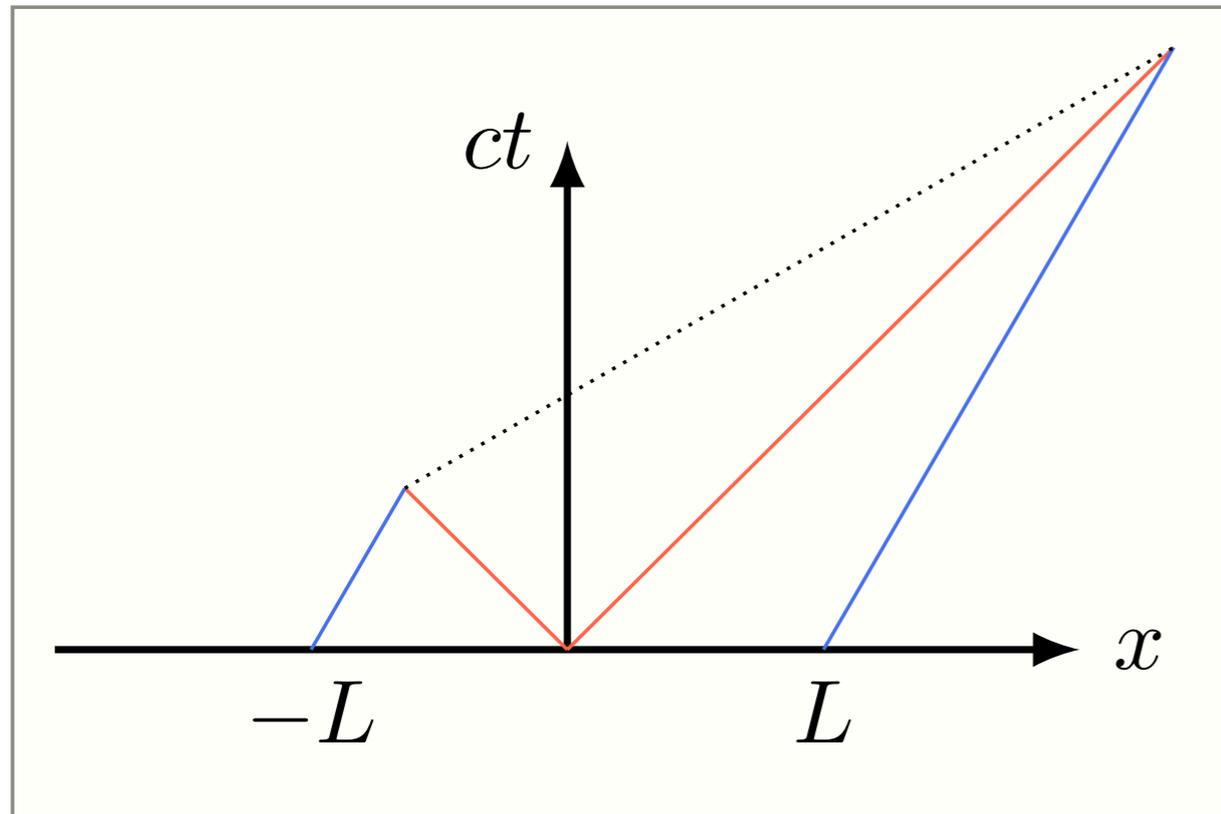
## Hipótese de Einstein



Einstein

# Relatividade restrita

## Hipótese de Einstein

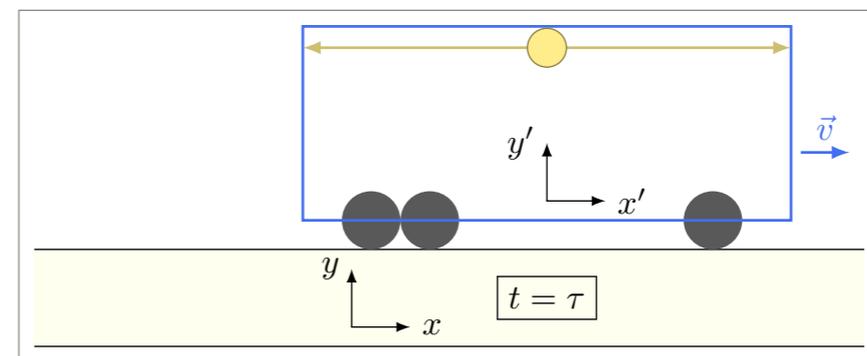
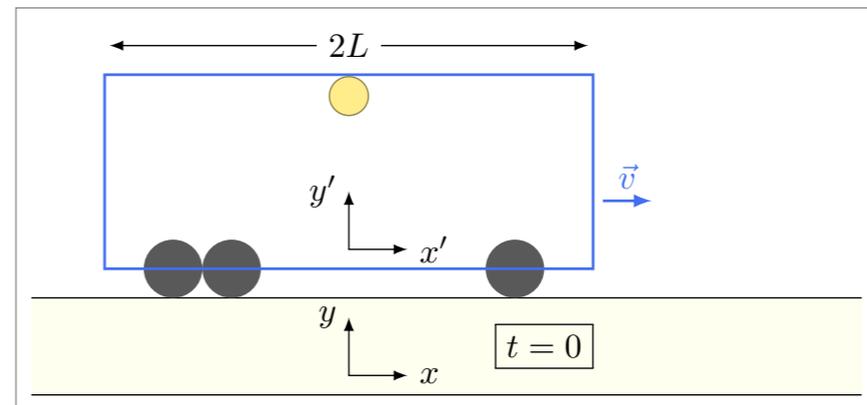
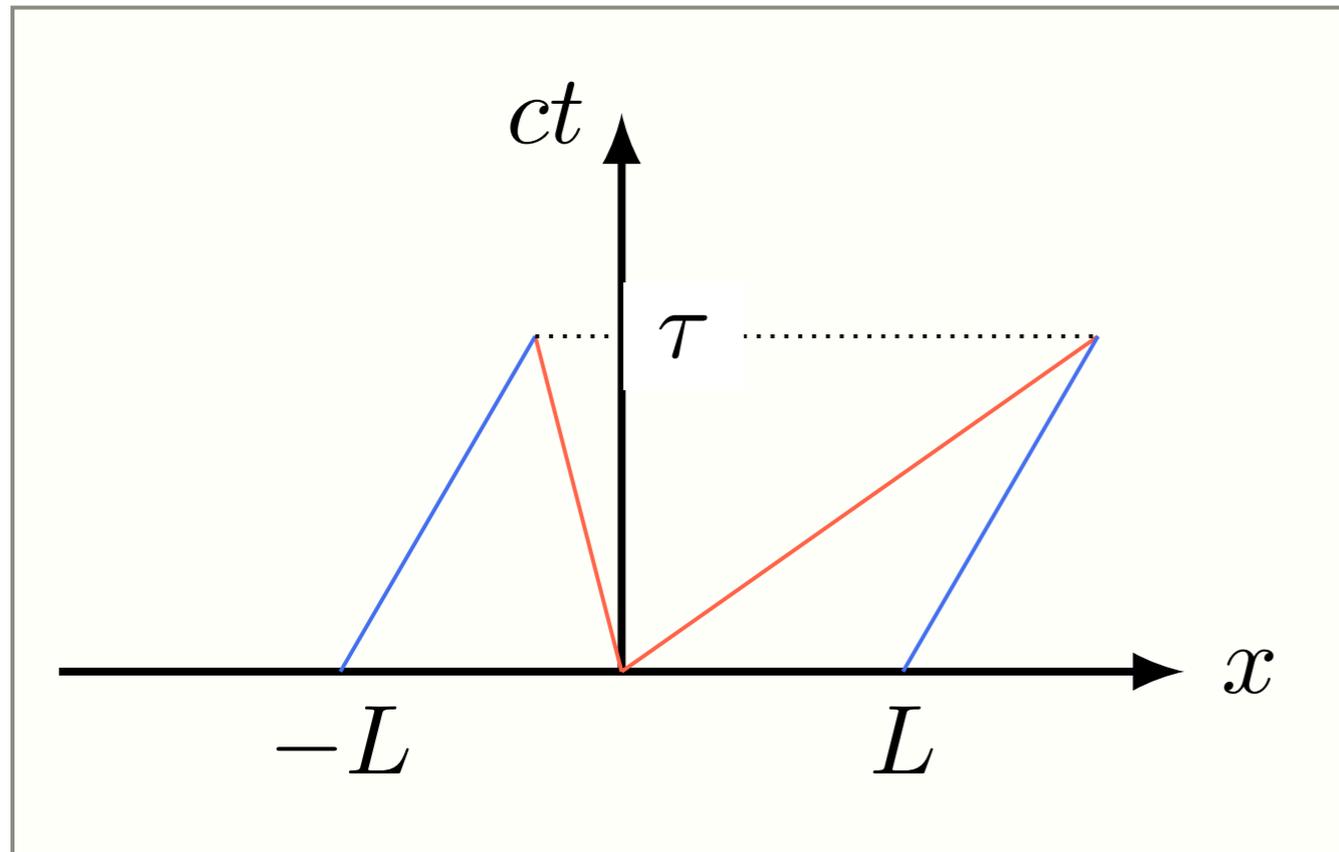


Einstein

Tempo depende do sistema de referências

# Relatividade restrita

## Transformação de coordenadas



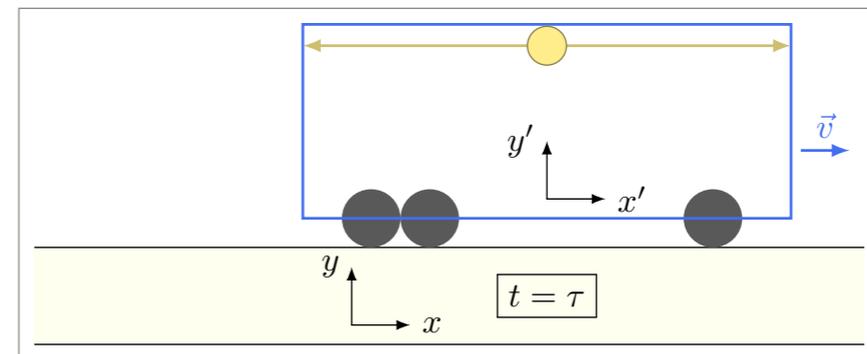
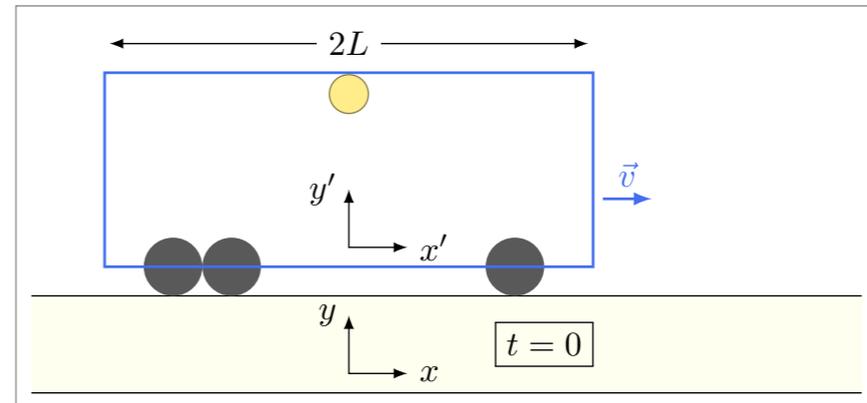
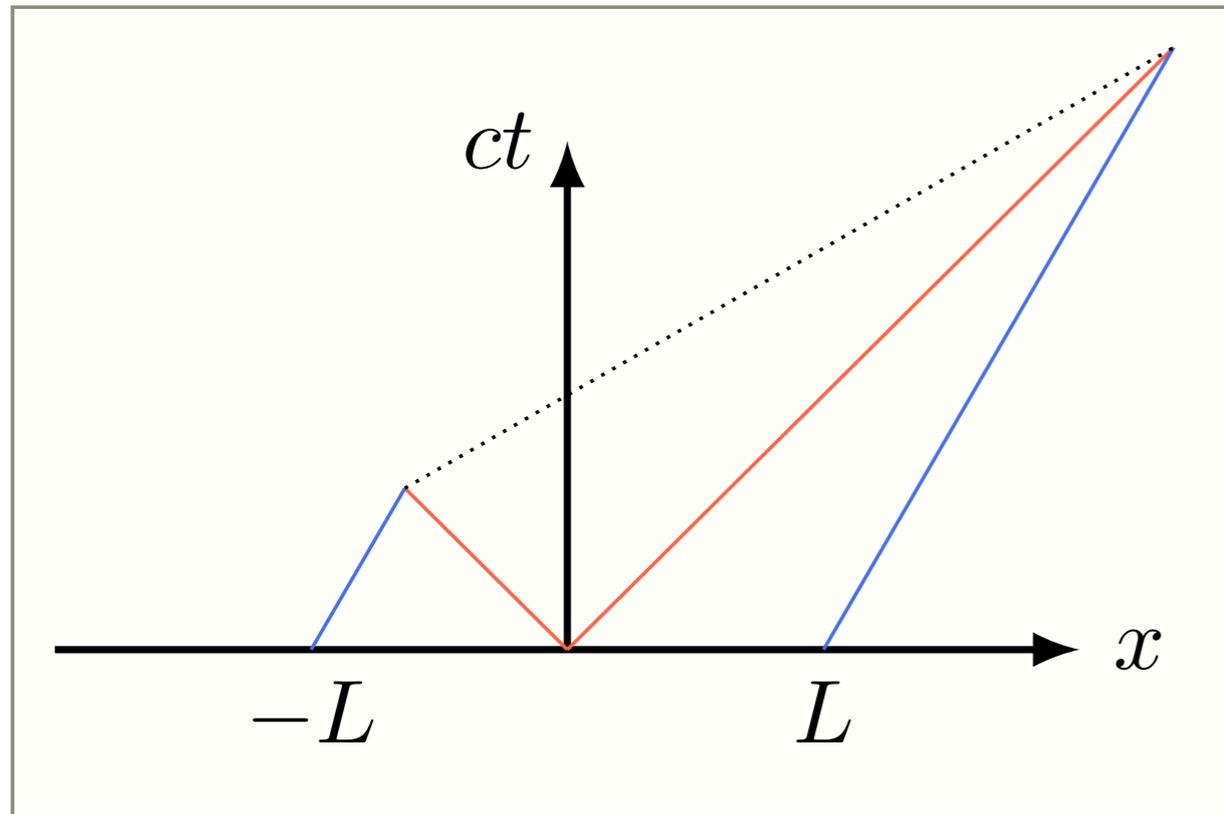
Galileu

$$x' = x - vt \quad t' = t$$

$$\begin{bmatrix} t' \\ x' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -v & 1 \end{bmatrix} \begin{bmatrix} t \\ x \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas

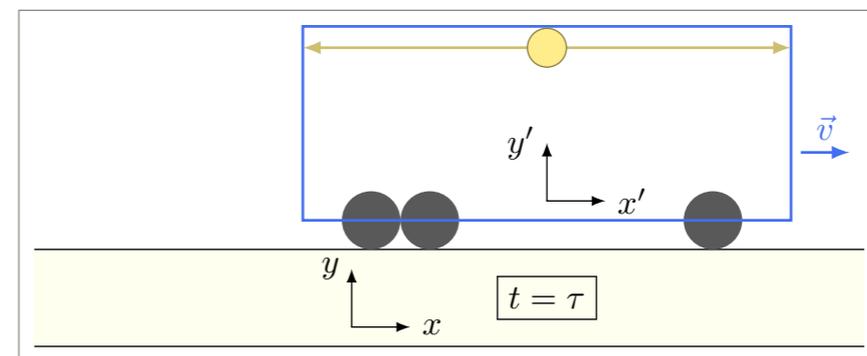
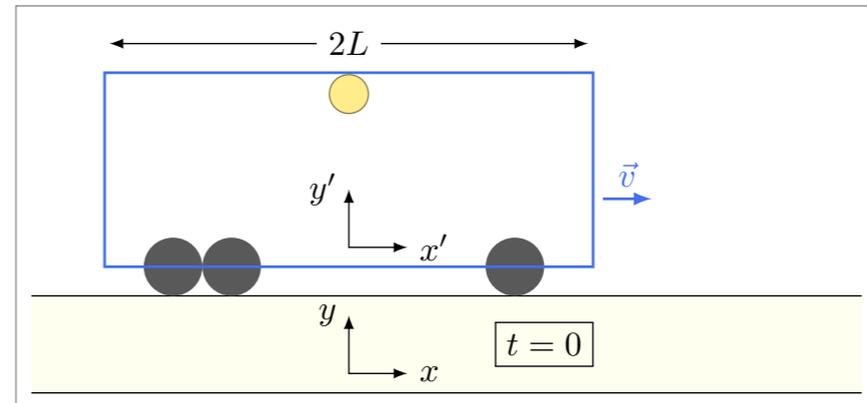
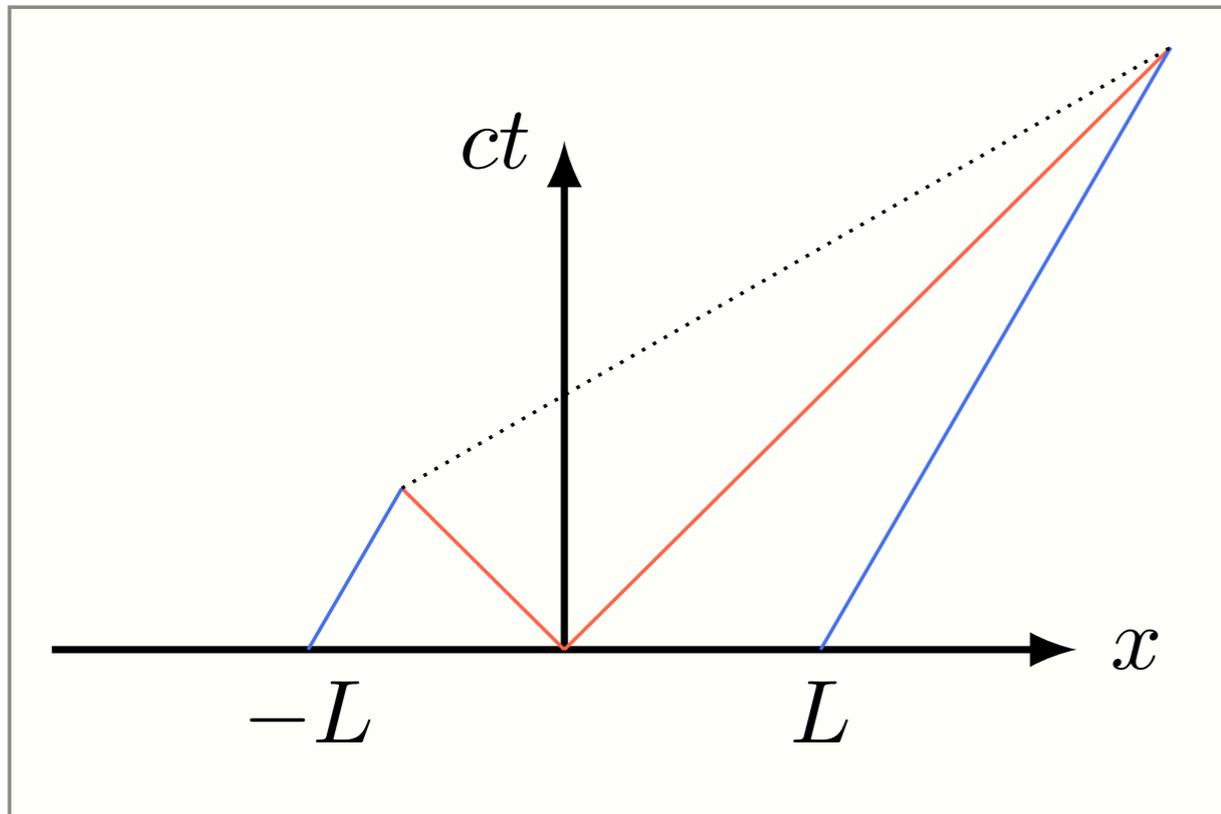


Einstein

$$\begin{bmatrix} t' \\ x' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} t \\ x \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas



Einstein

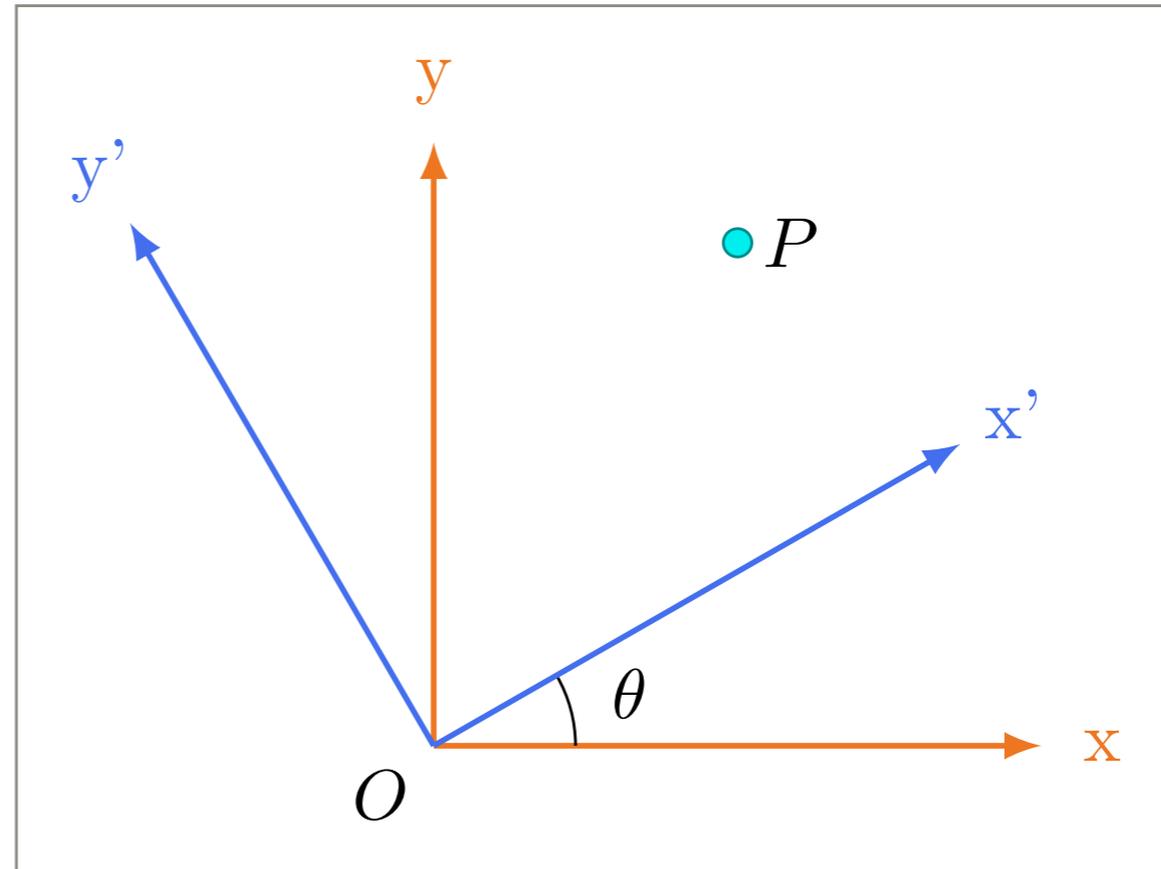
$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

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# Relatividade restrita

## Transformação de coordenadas

$$\begin{bmatrix} y' \\ x' \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} y \\ x \end{bmatrix}$$



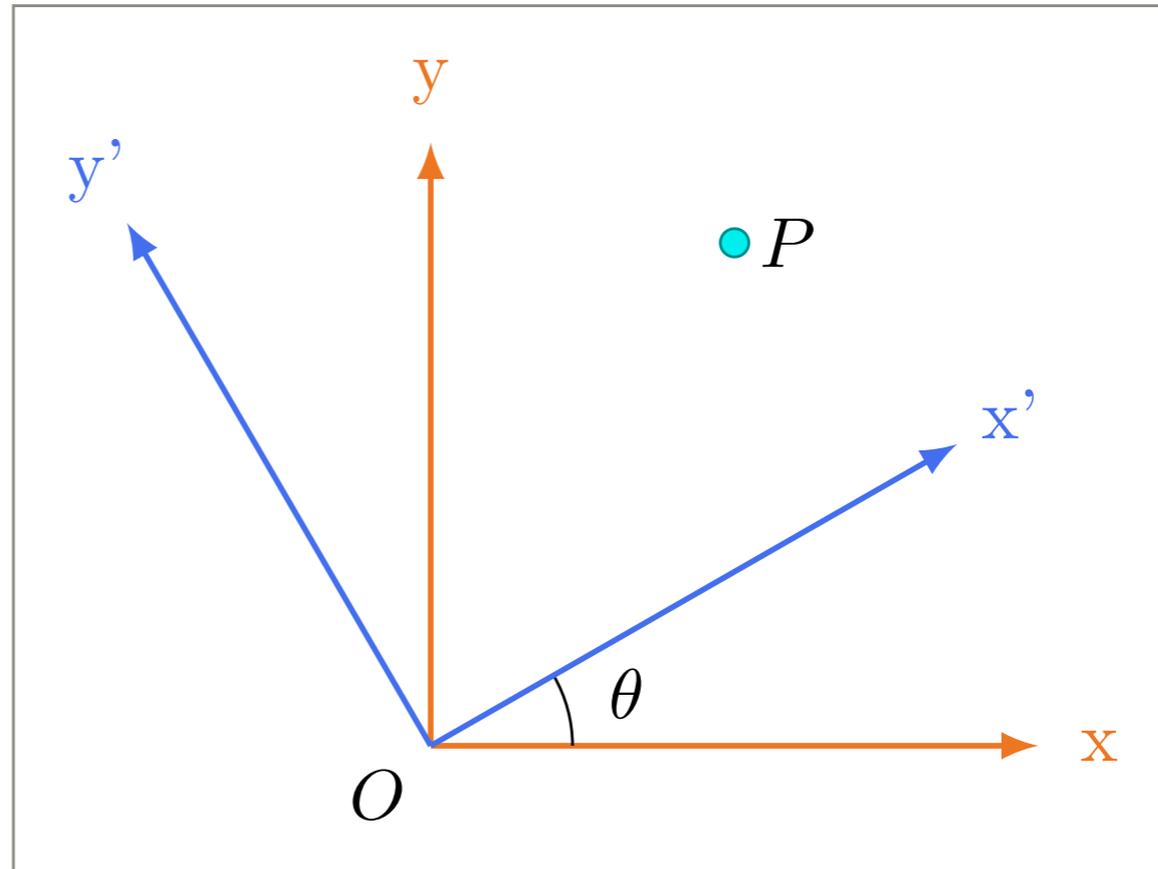
$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas

$$\begin{bmatrix} y' \\ x' \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} y \\ x \end{bmatrix}$$

$$\begin{bmatrix} y' & x' \end{bmatrix} = \begin{bmatrix} y & x \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}$$



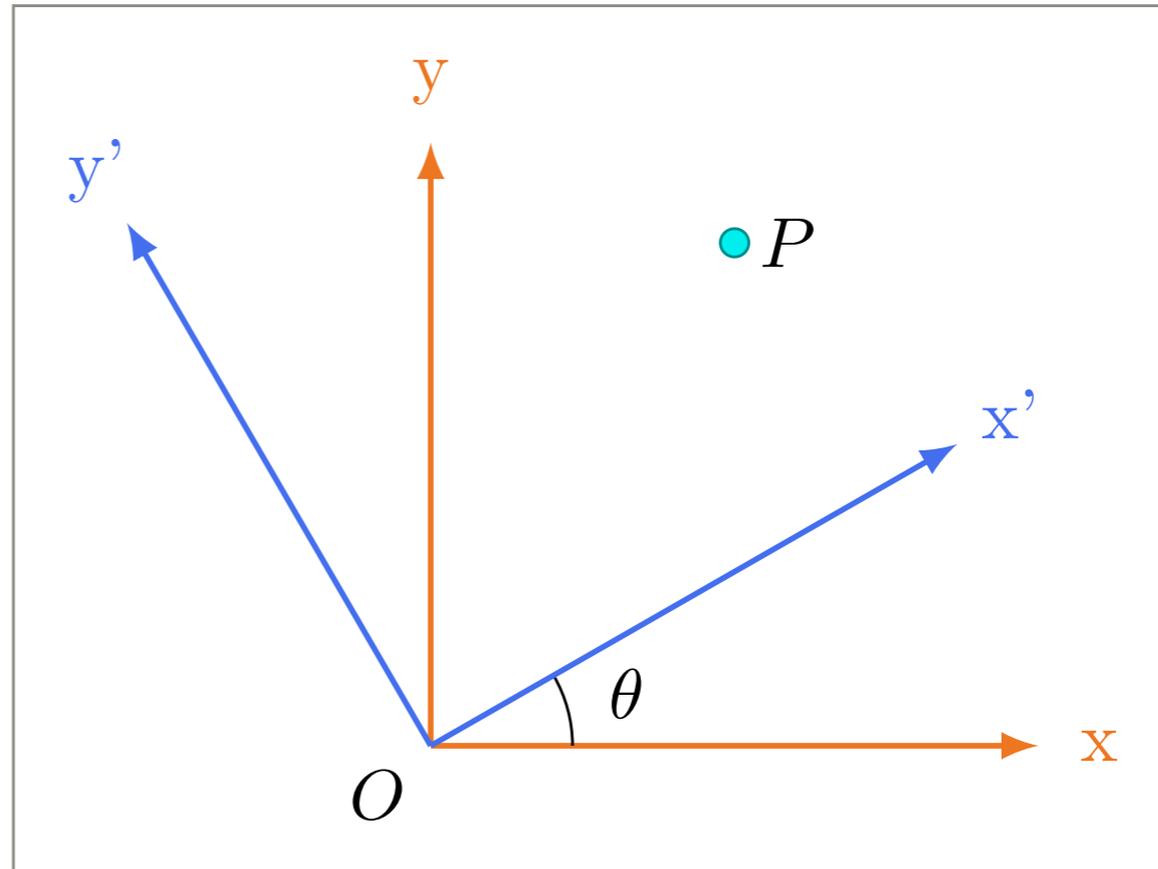
$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas

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$$\begin{bmatrix} y' & x' \end{bmatrix} = \begin{bmatrix} y & x \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}$$



$$\begin{bmatrix} y'^2 + x'^2 \end{bmatrix} = \begin{bmatrix} y & x \end{bmatrix} \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} y \\ x \end{bmatrix}$$

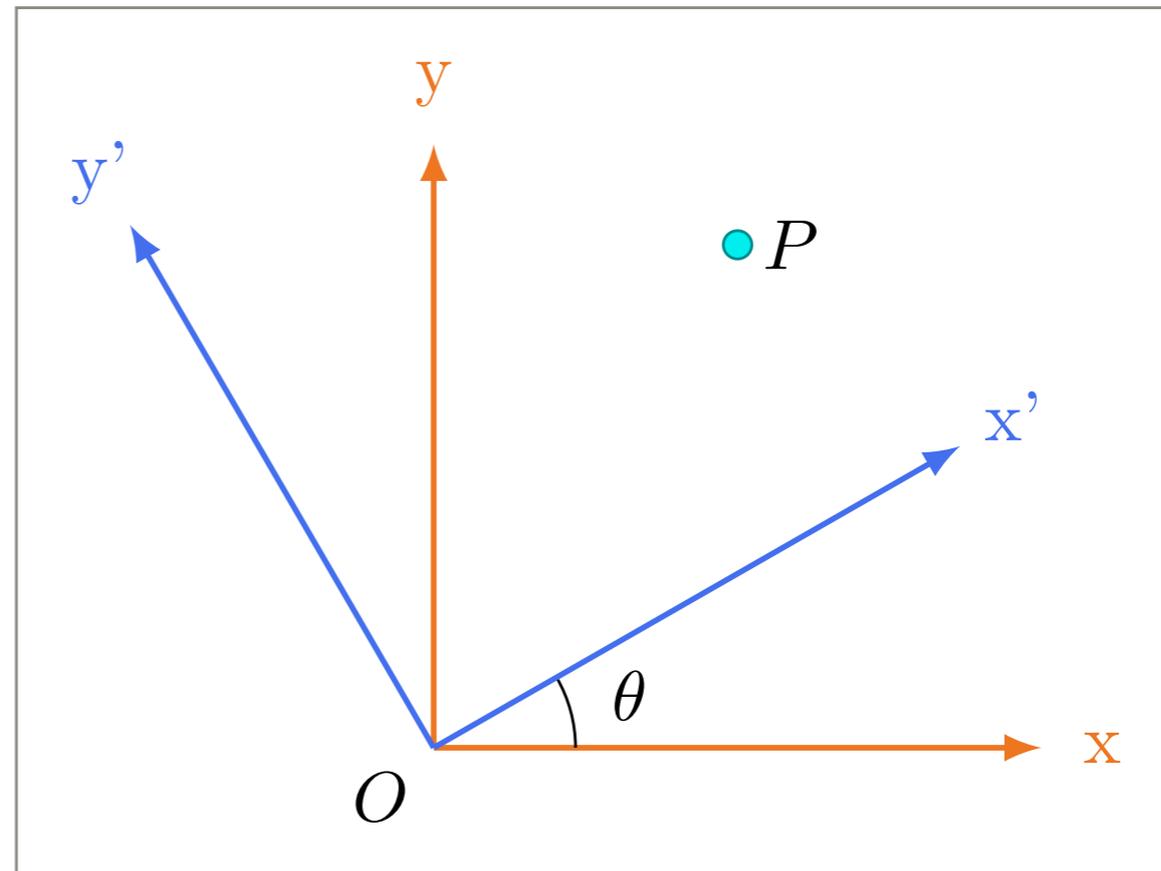
$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas

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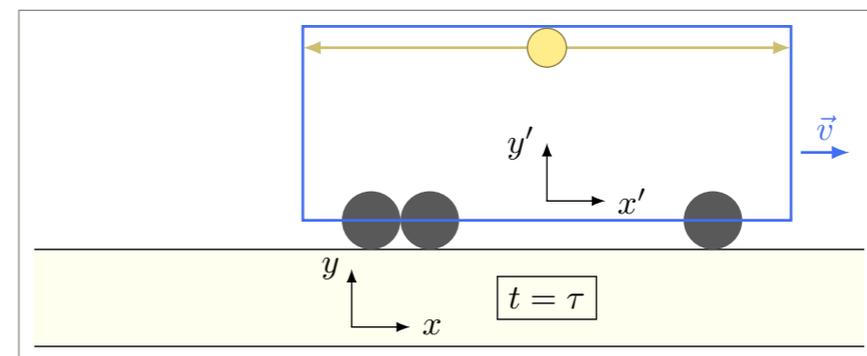
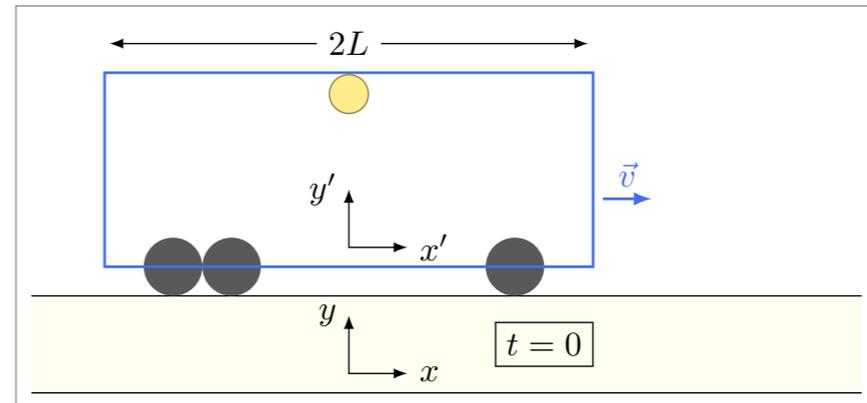
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$$\begin{bmatrix} y'^2 + x'^2 \end{bmatrix} = \begin{bmatrix} y^2 + x^2 \end{bmatrix}$$

# Relatividade restrita

## Transformação de coordenadas

$$\begin{bmatrix} ct' \\ x' \end{bmatrix} \stackrel{?}{=} \begin{bmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

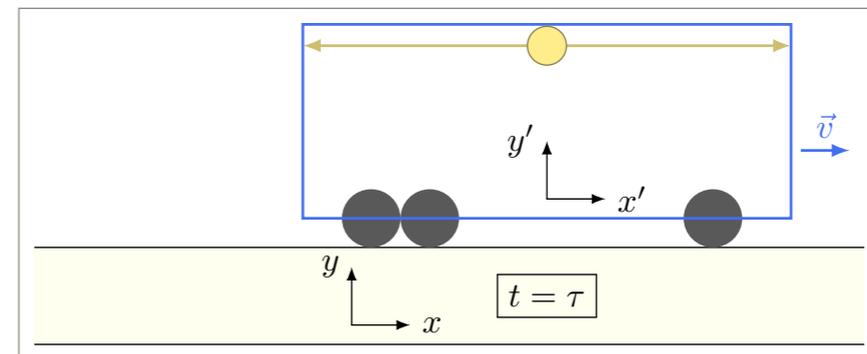
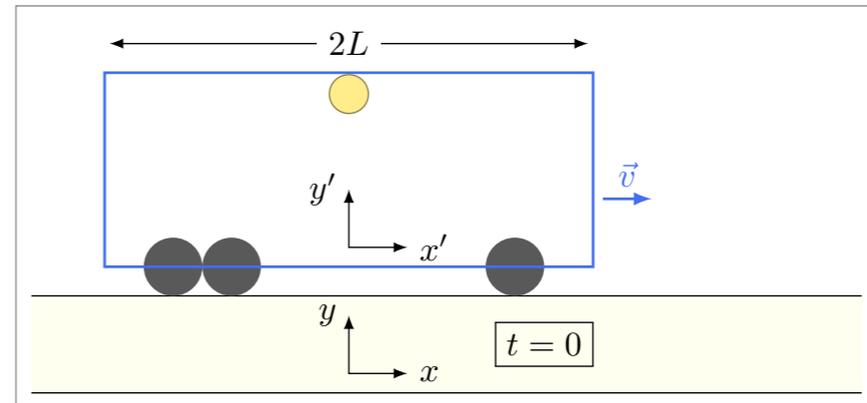


# Relatividade restrita

## Transformação de coordenadas

$$\begin{bmatrix} ct' \\ x' \end{bmatrix} \stackrel{?}{=} \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

$$\Rightarrow c^2 t'^2 + x'^2 = c^2 t^2 + x^2$$



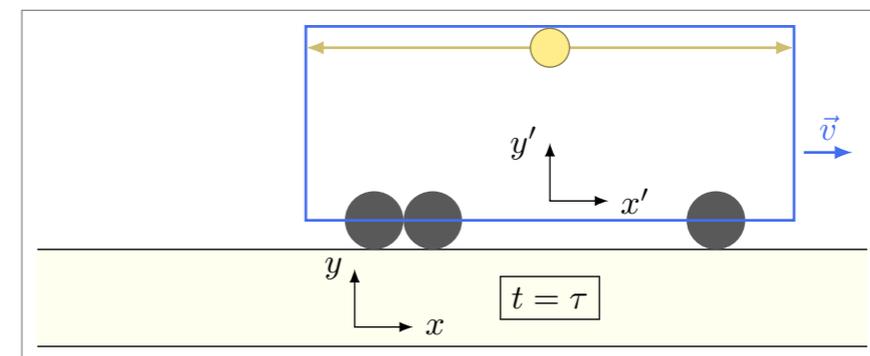
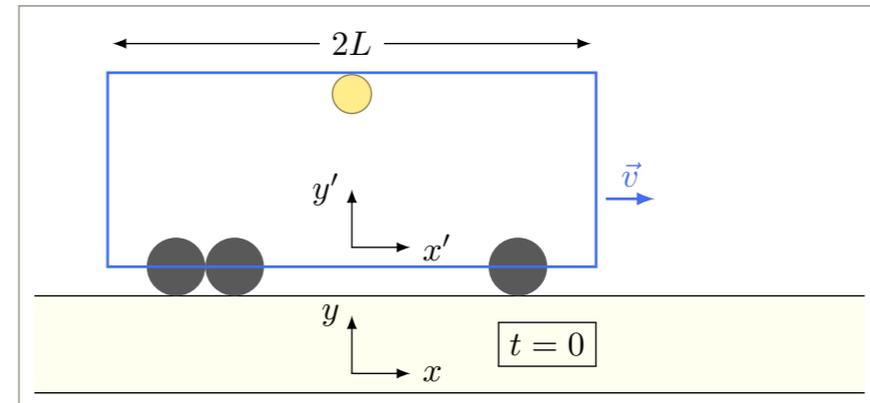
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$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$

$$\Rightarrow -c^2 t'^2 + x'^2 = -c^2 t^2 + x^2 \quad \text{😊}$$

$$\alpha = ?$$



# Relatividade restrita

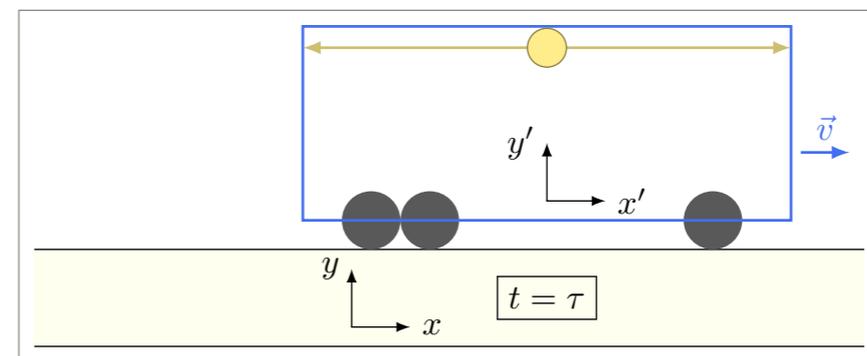
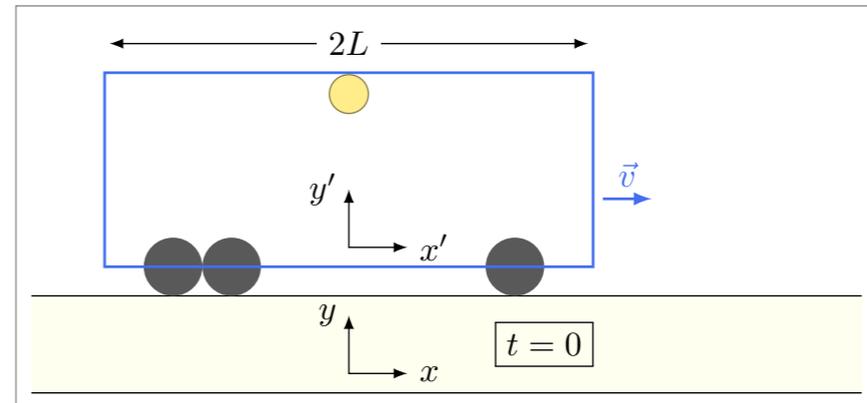
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$$\alpha = ?$$

$$\text{Caso especial} \quad x = vt \Rightarrow x' = 0$$



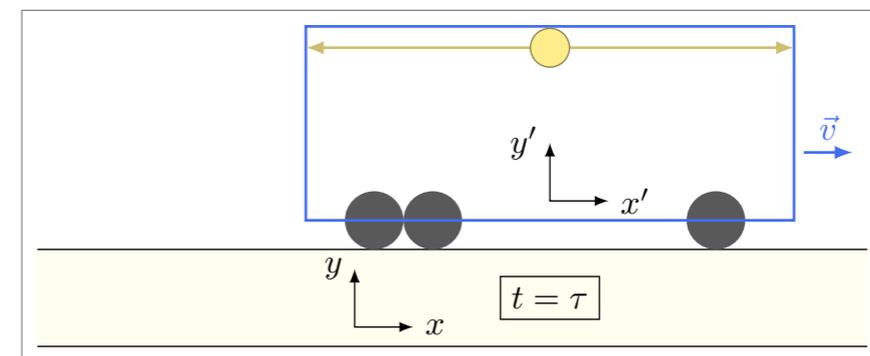
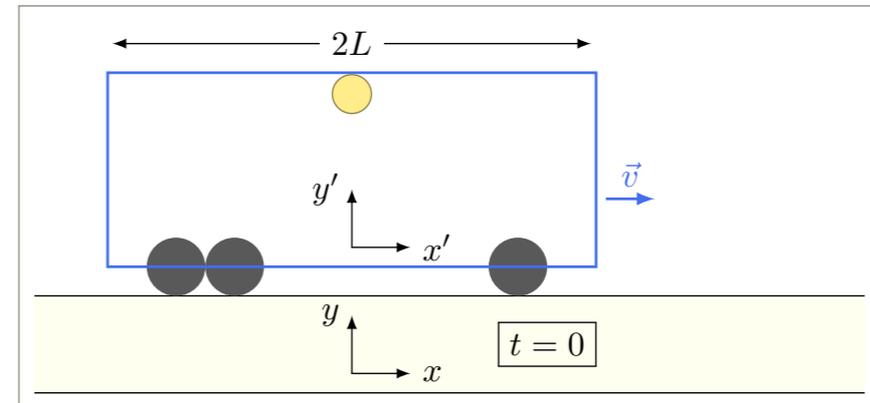
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$$\Rightarrow -c^2 t'^2 + x'^2 = -c^2 t^2 + x^2 \quad \text{😊}$$

$\alpha = ?$



**Caso especial**  $x = vt \Rightarrow x' = 0$

$$\begin{bmatrix} ict' \\ 0 \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ict \\ vt \end{bmatrix}$$

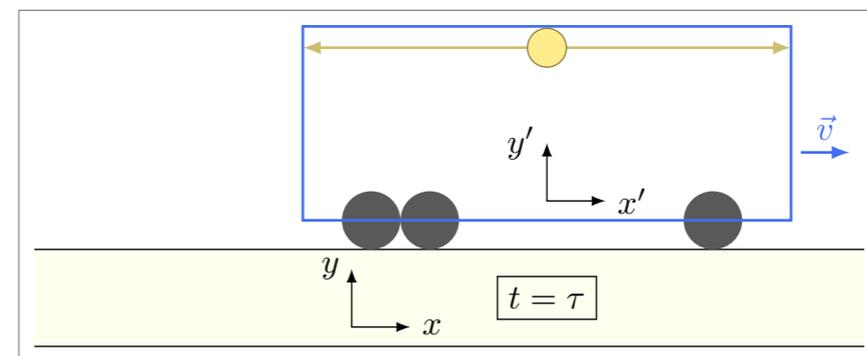
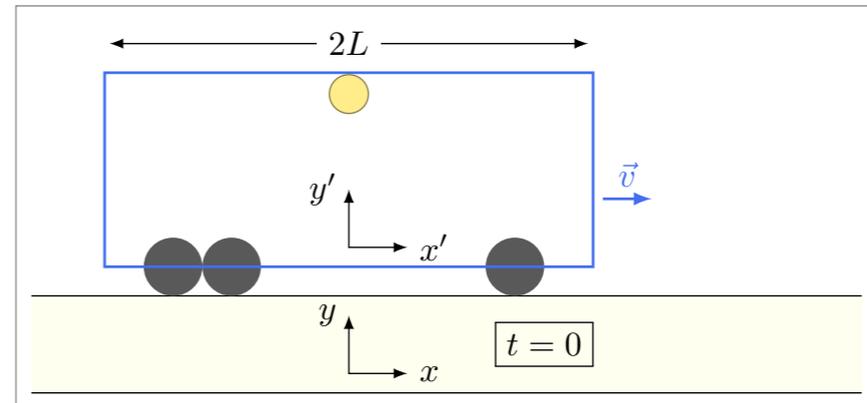
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$$\alpha = ?$$



**Caso especial**  $x = vt \Rightarrow x' = 0$

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$$\Rightarrow 0 = ict \sin \alpha + vt \cos \alpha$$

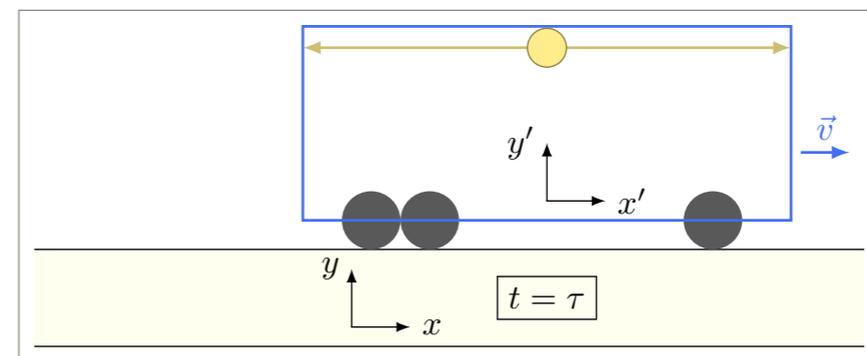
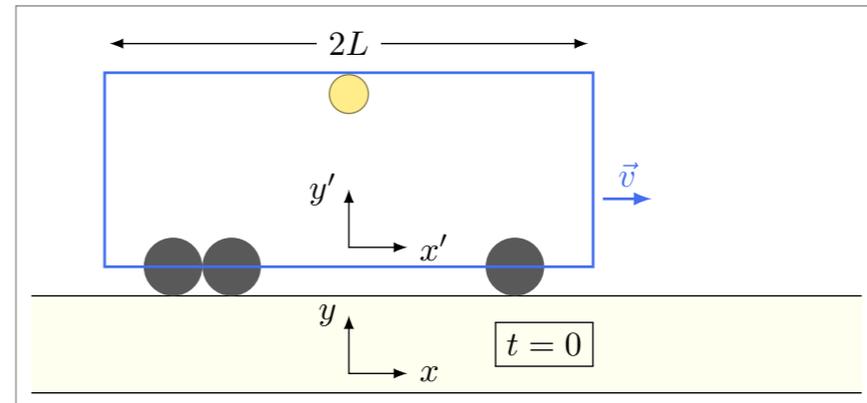
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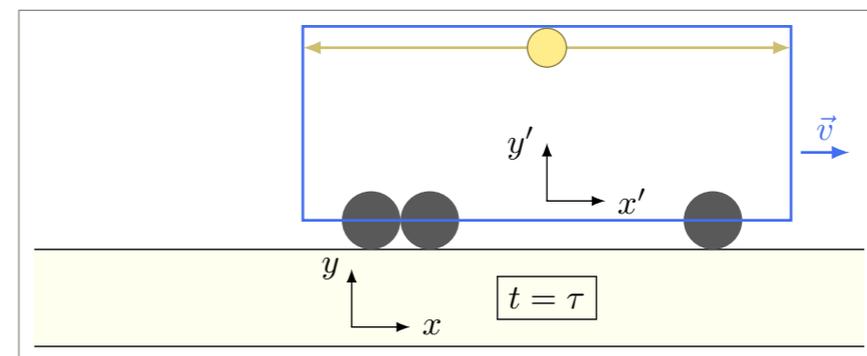
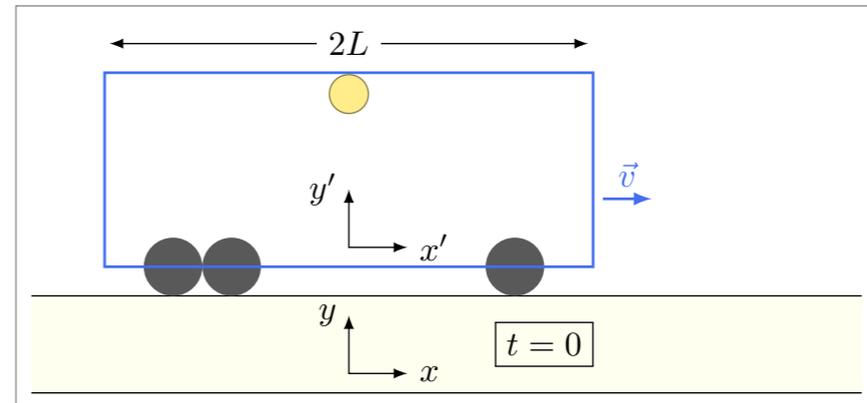
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$$\begin{bmatrix} ict' \\ x' \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ict \\ x \end{bmatrix}$$

$$0 = ict \sin \alpha + vt \cos \alpha$$

$$\tan \alpha = -i \frac{v}{c}$$



# Relatividade restrita

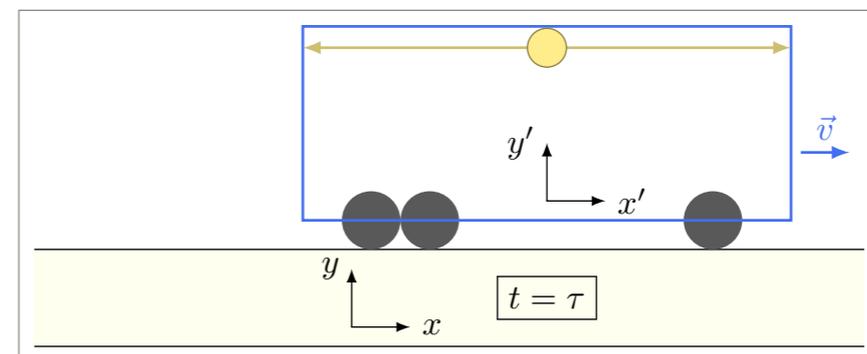
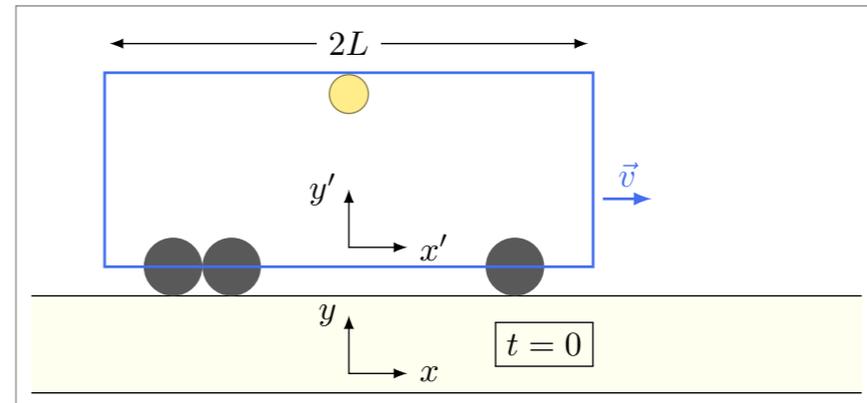
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$$0 = ict \sin \alpha + vt \cos \alpha$$

$$\tan \alpha = -i \frac{v}{c}$$

$$\cos \alpha = \frac{1}{\sqrt{1 + \tan^2 \alpha}}$$



# Relatividade restrita

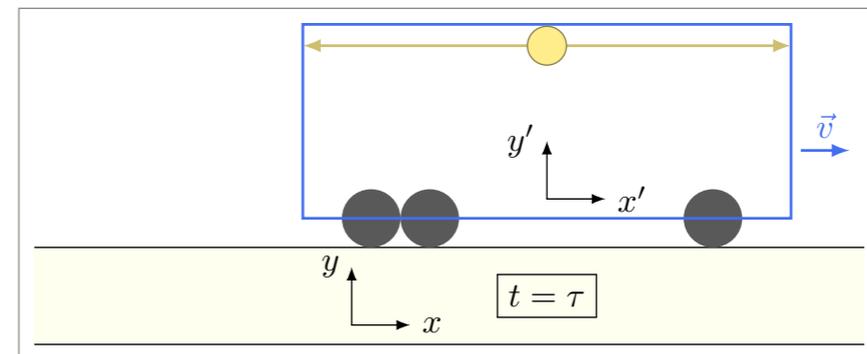
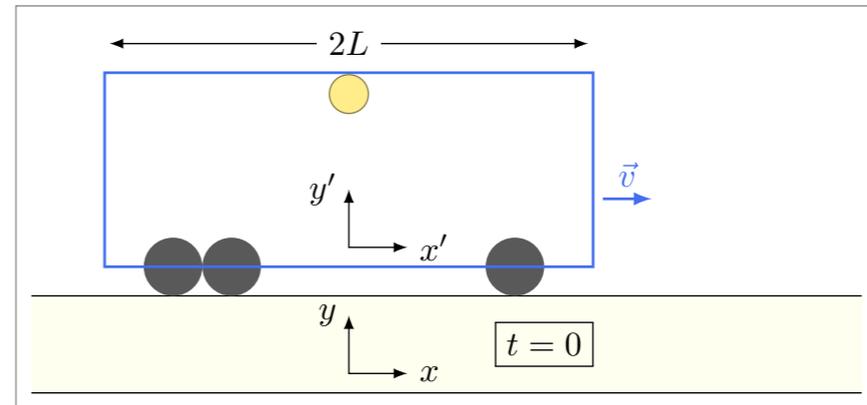
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$$0 = ict \sin \alpha + vt \cos \alpha$$

$$\tan \alpha = i \frac{v}{c}$$

$$\cos \alpha = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$



# Relatividade restrita

## Transformação de coordenadas

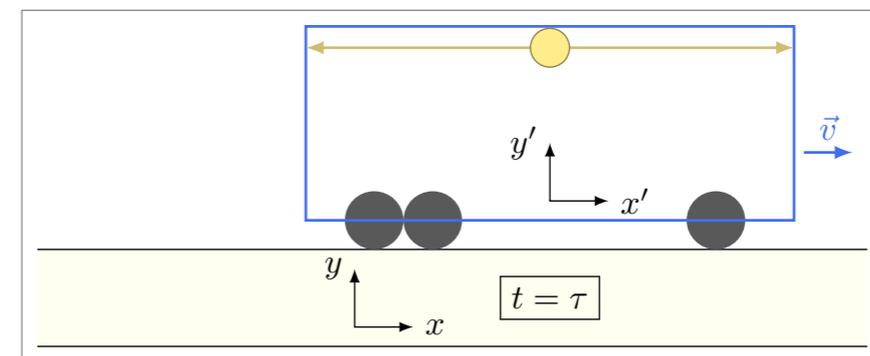
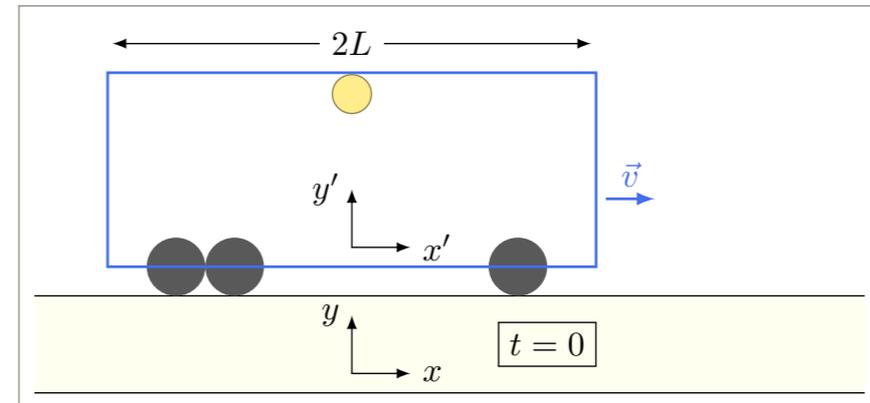
$$\begin{bmatrix} ict' \\ x' \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} ict \\ x \end{bmatrix}$$

$$0 = ict \sin \alpha + vt \cos \alpha$$

$$\tan \alpha = i \frac{v}{c}$$

$$\cos \alpha = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

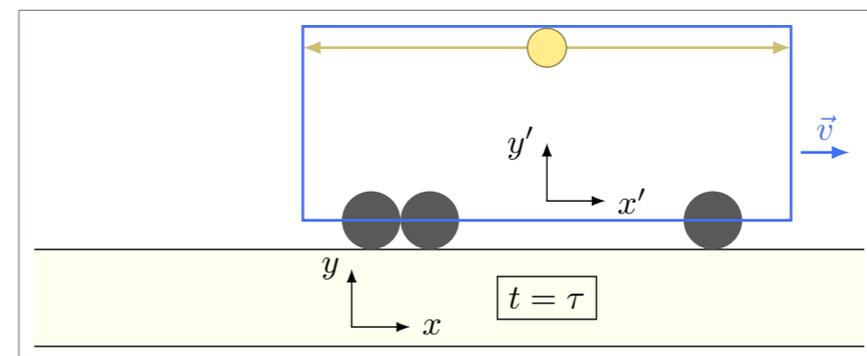
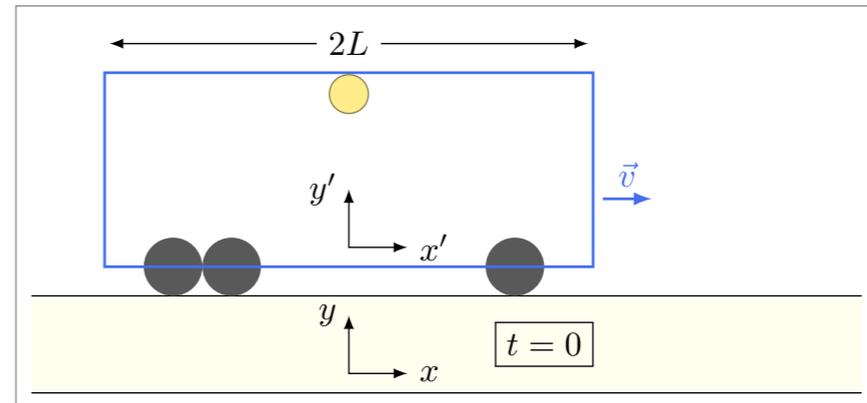
$$\sin \alpha = i \frac{v/c}{\sqrt{1 - \frac{v^2}{c^2}}}$$



# Relatividade restrita

## Transformação de Lorentz

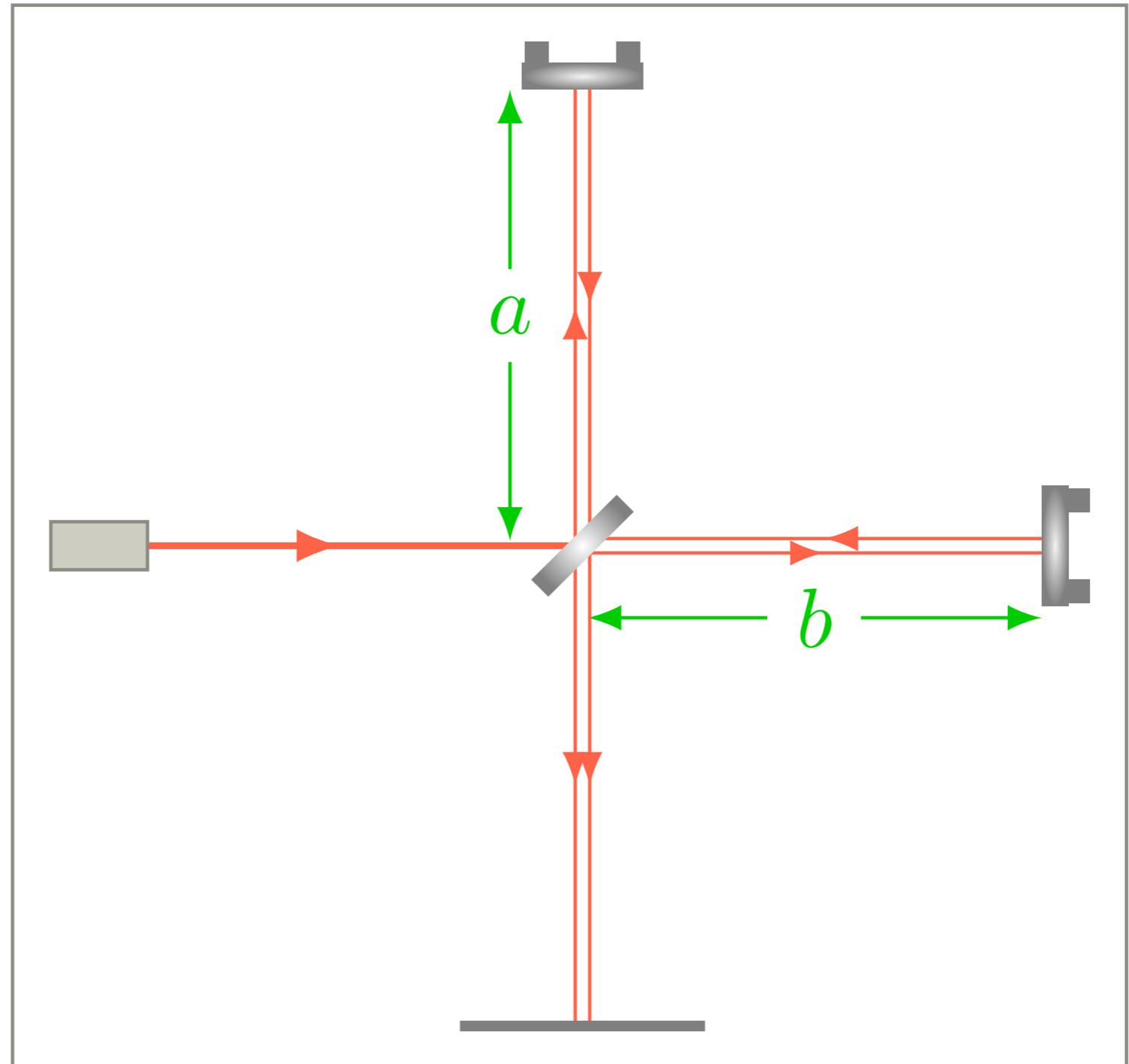
$$\begin{bmatrix} ct' \\ x' \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} & -\frac{v/c}{\sqrt{1-\frac{v^2}{c^2}}} \\ \frac{v/c}{\sqrt{1-\frac{v^2}{c^2}}} & \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \end{bmatrix} \begin{bmatrix} ct \\ x \end{bmatrix}$$



# Relatividade restrita

## Experiência de Michelson e Morley

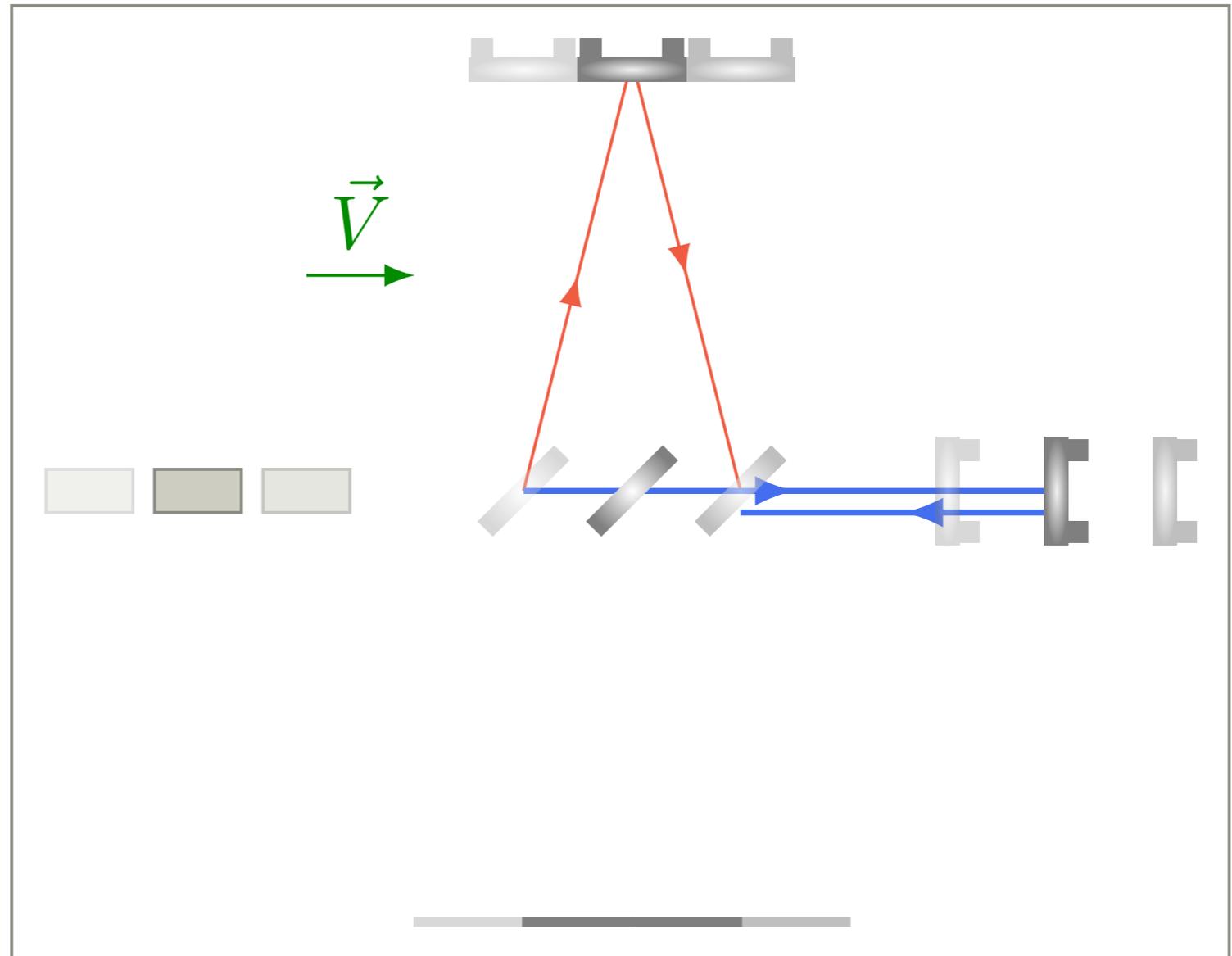
Qual é a  
velocidade do  
éter?



# Relatividade restrita

## Experiência de Michelson e Morley

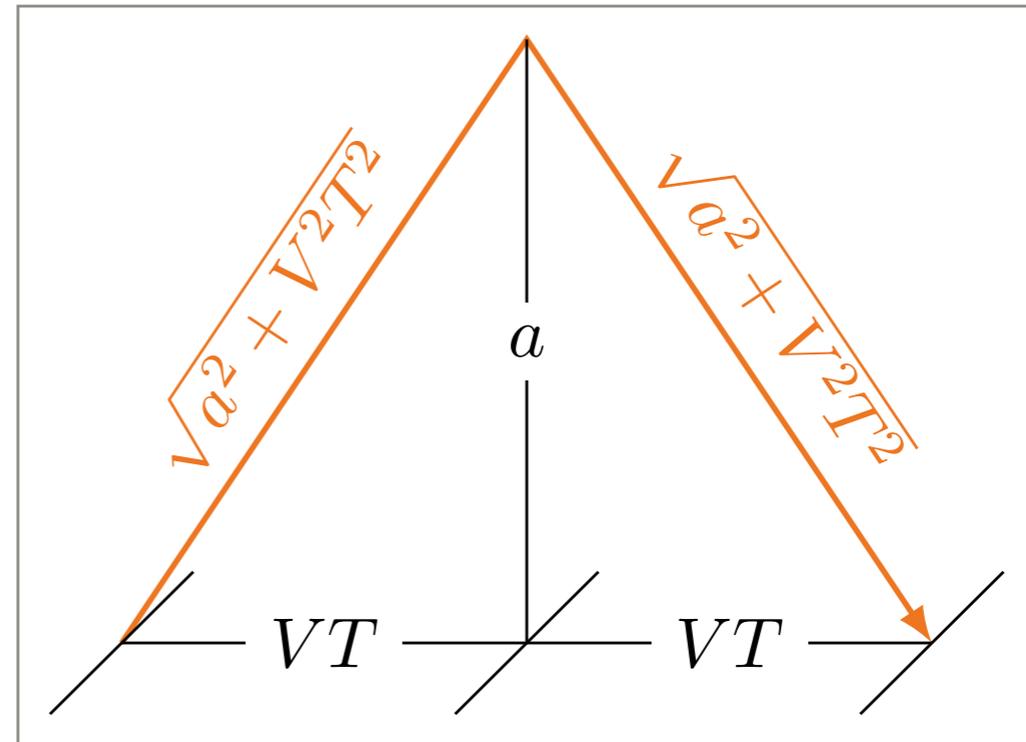
Qual é a  
velocidade da  
Terra no éter?



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