Relatividade e Gravitação

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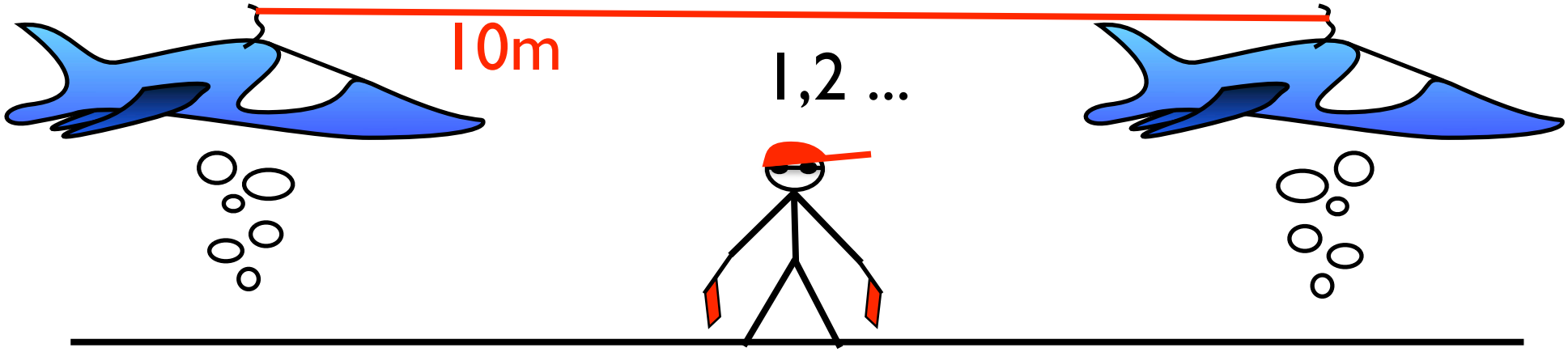
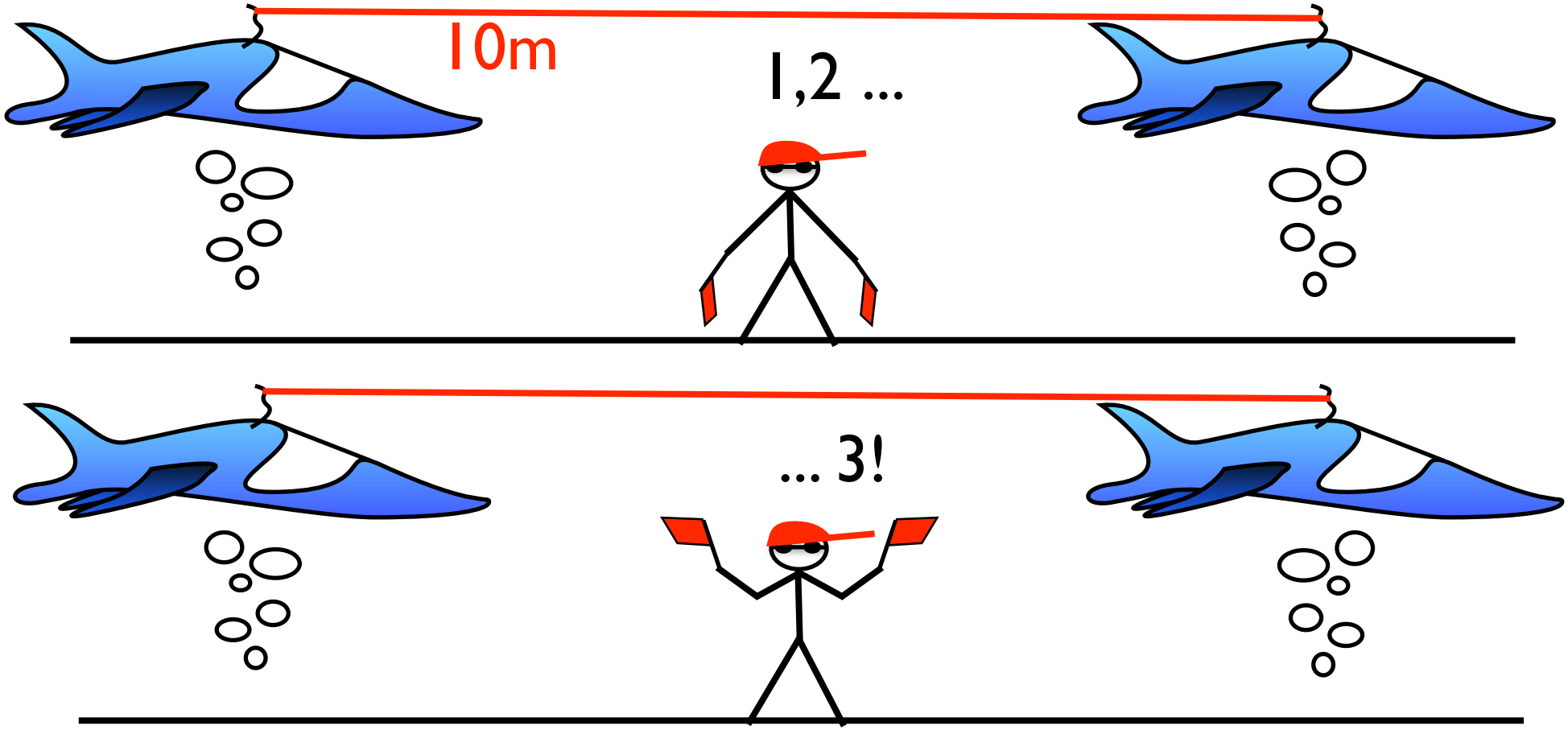
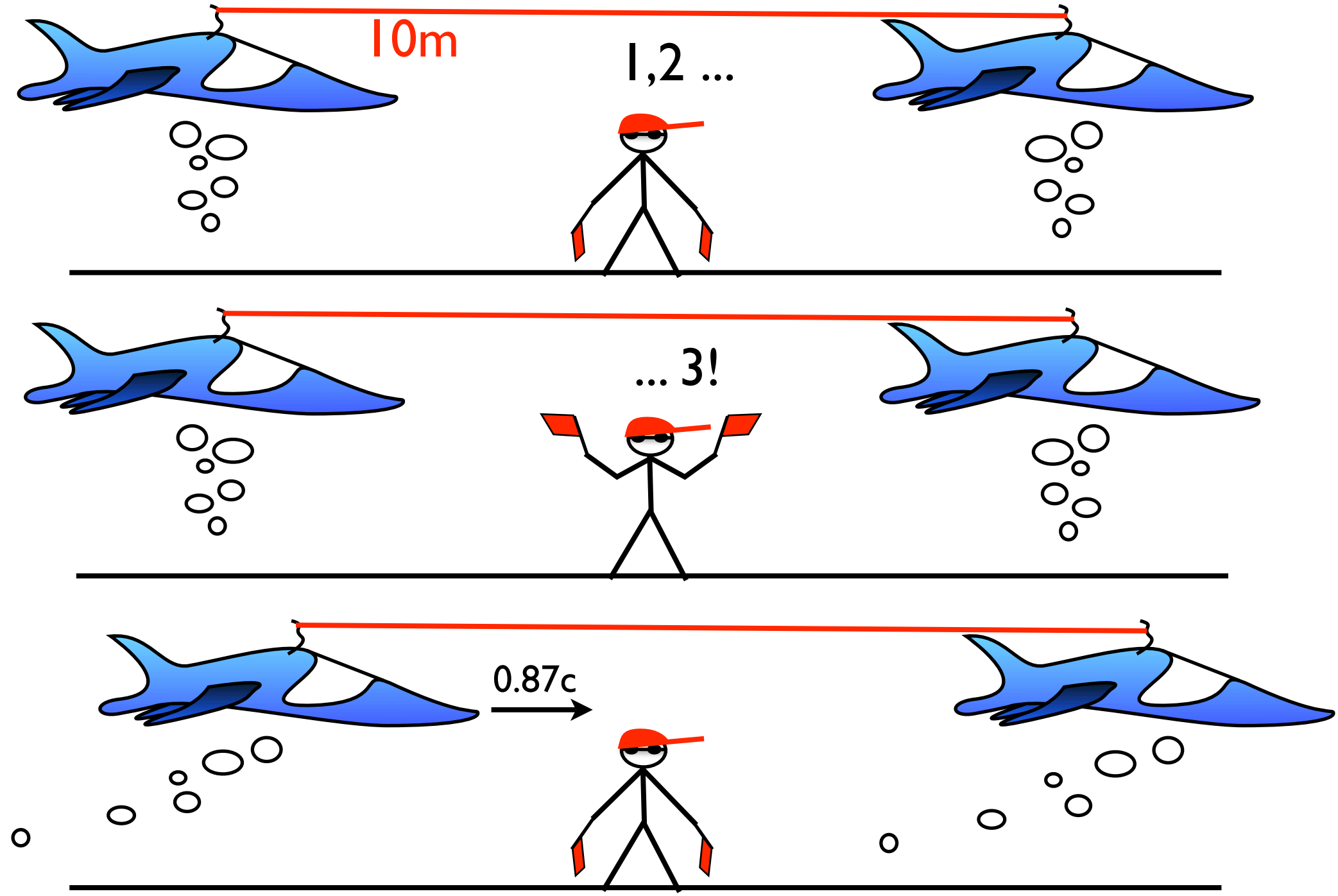
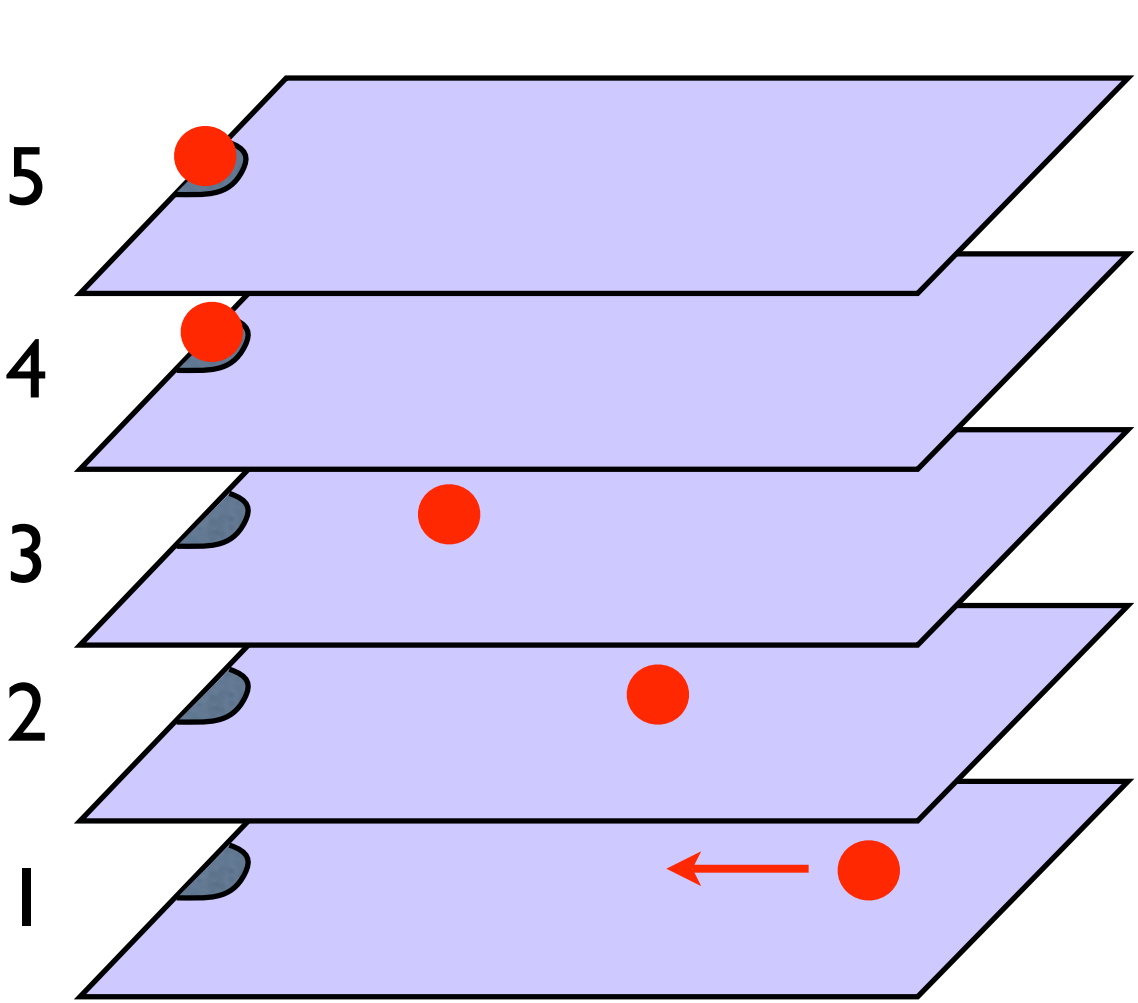
South American Institute for Fundamental Research

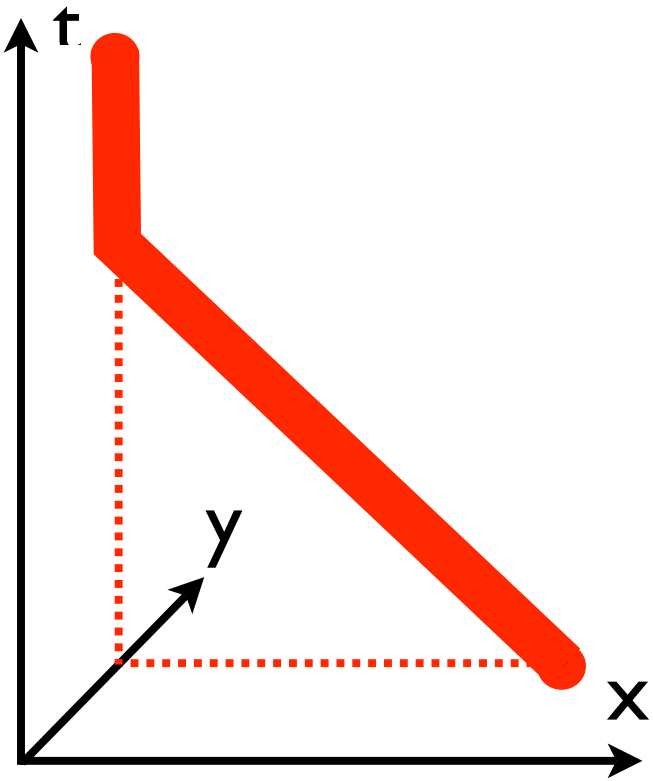

10m
1,2 ...

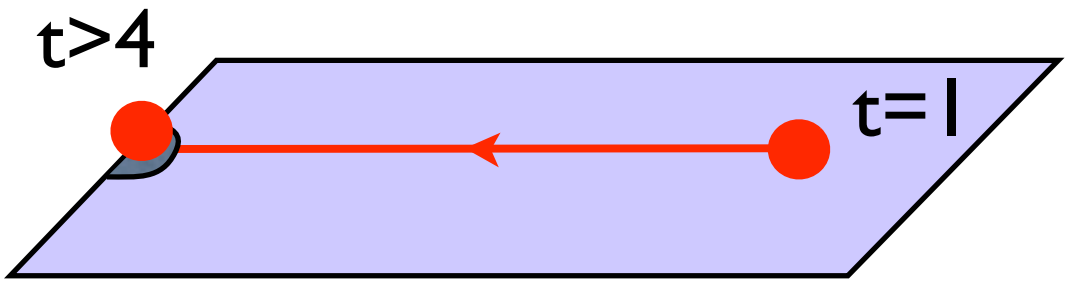

10m
1,2 ...
... 3!

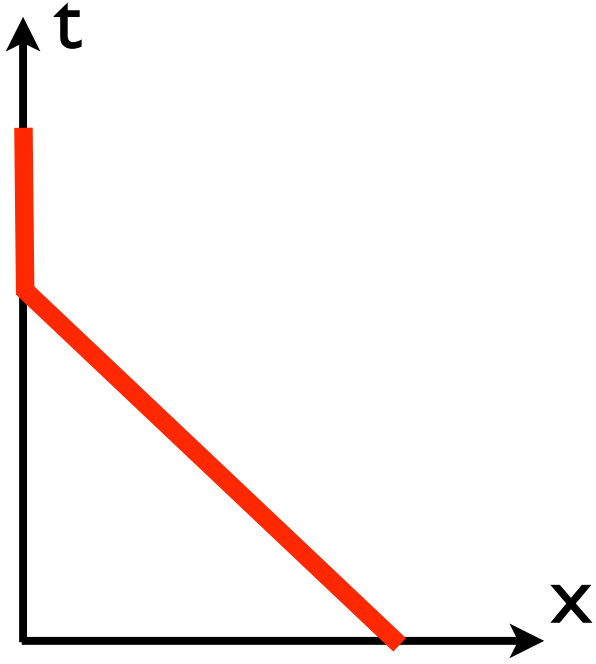

10m
1,2 ...
... 3!
0.87c

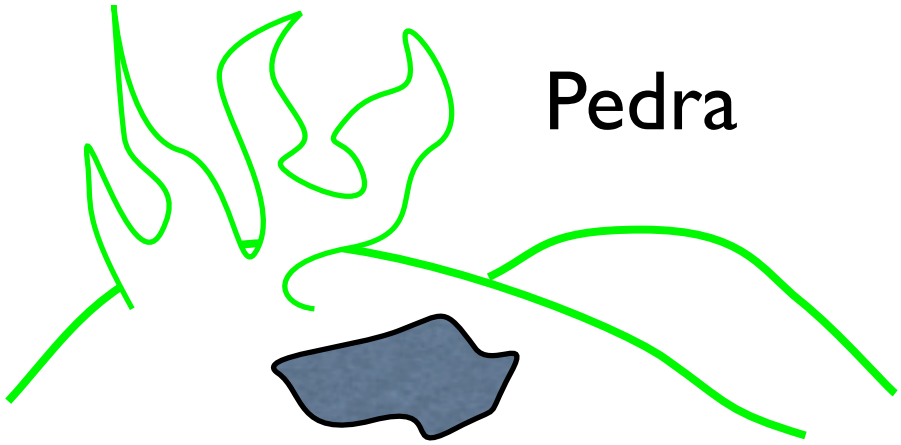
Diagramas de Espaço-Tempo

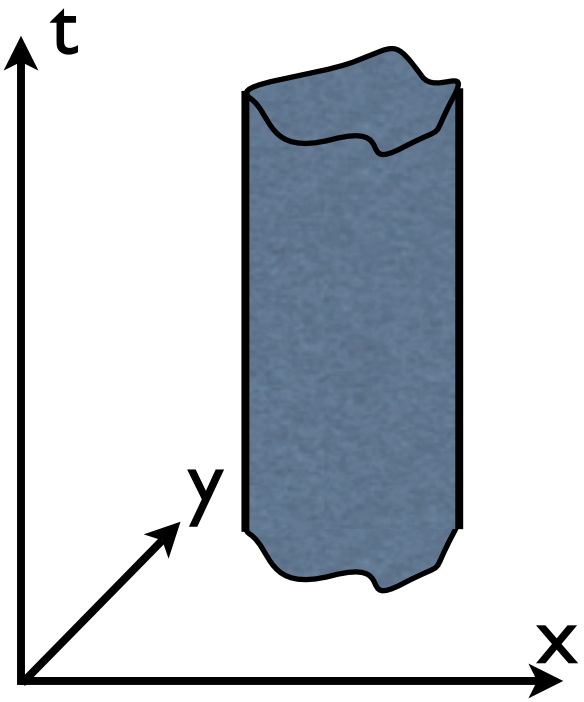

5
4
3
2
1


t
y
x

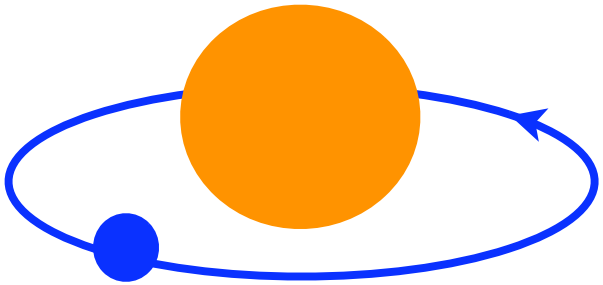

t>4
t=1

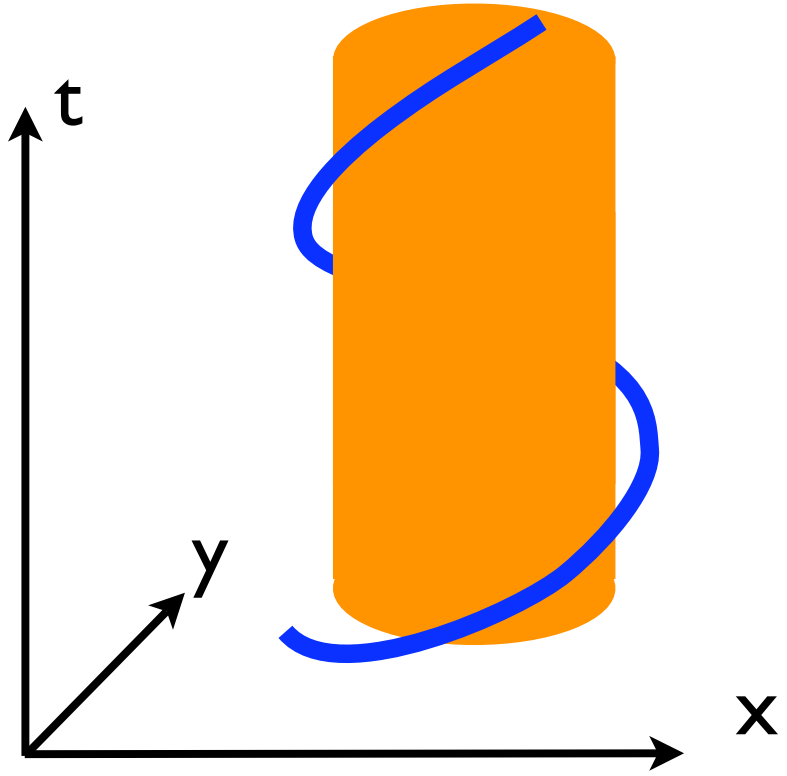

t
x





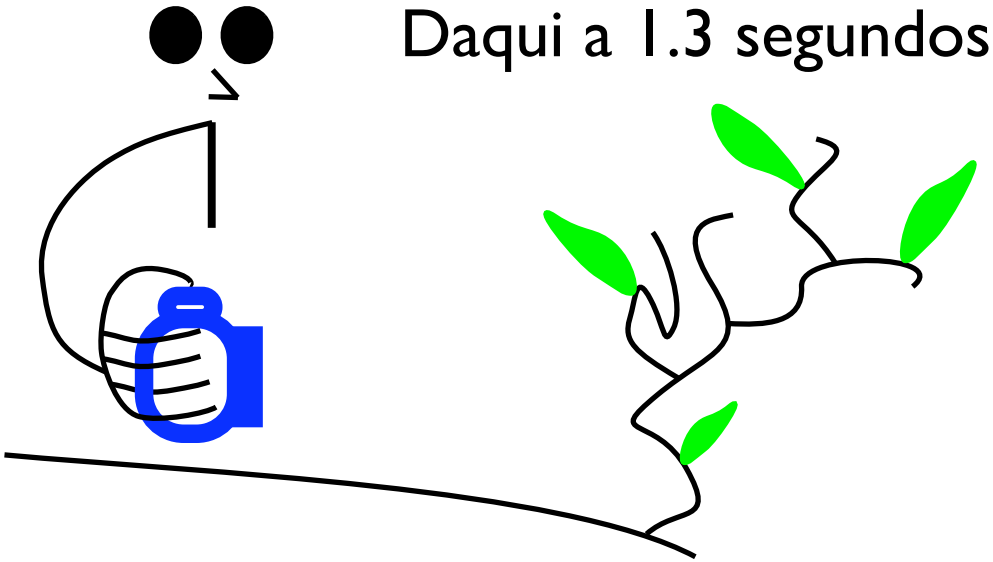
Planeta à volta de um Sol

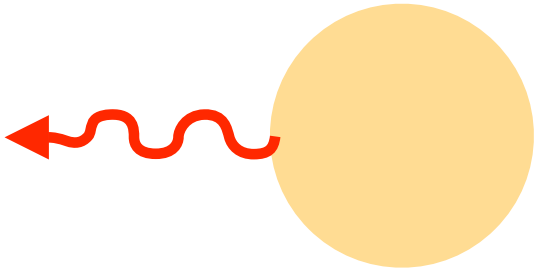




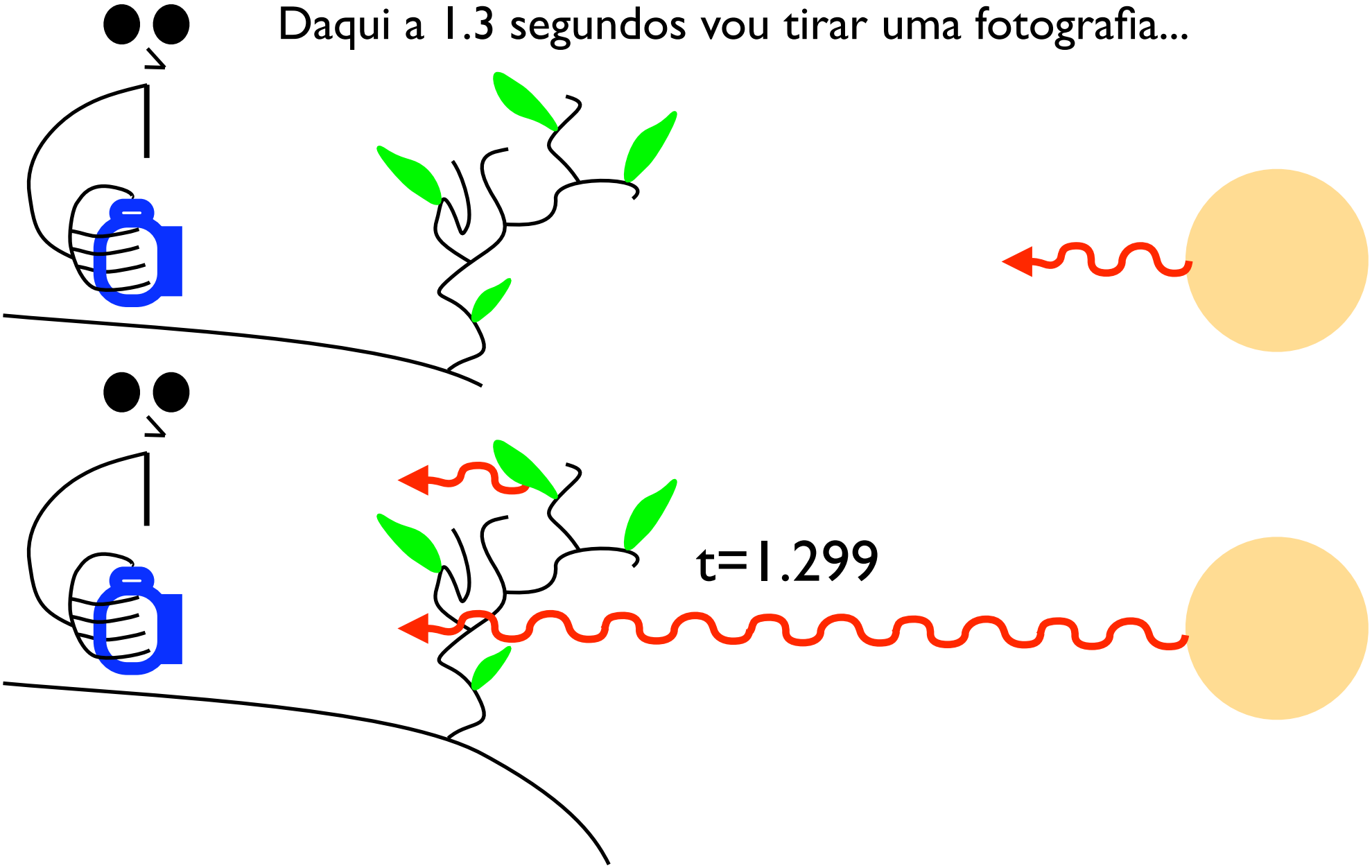
Velocidade da Luz

Daqui a 1.3 segundos vou tirar uma fotografia...

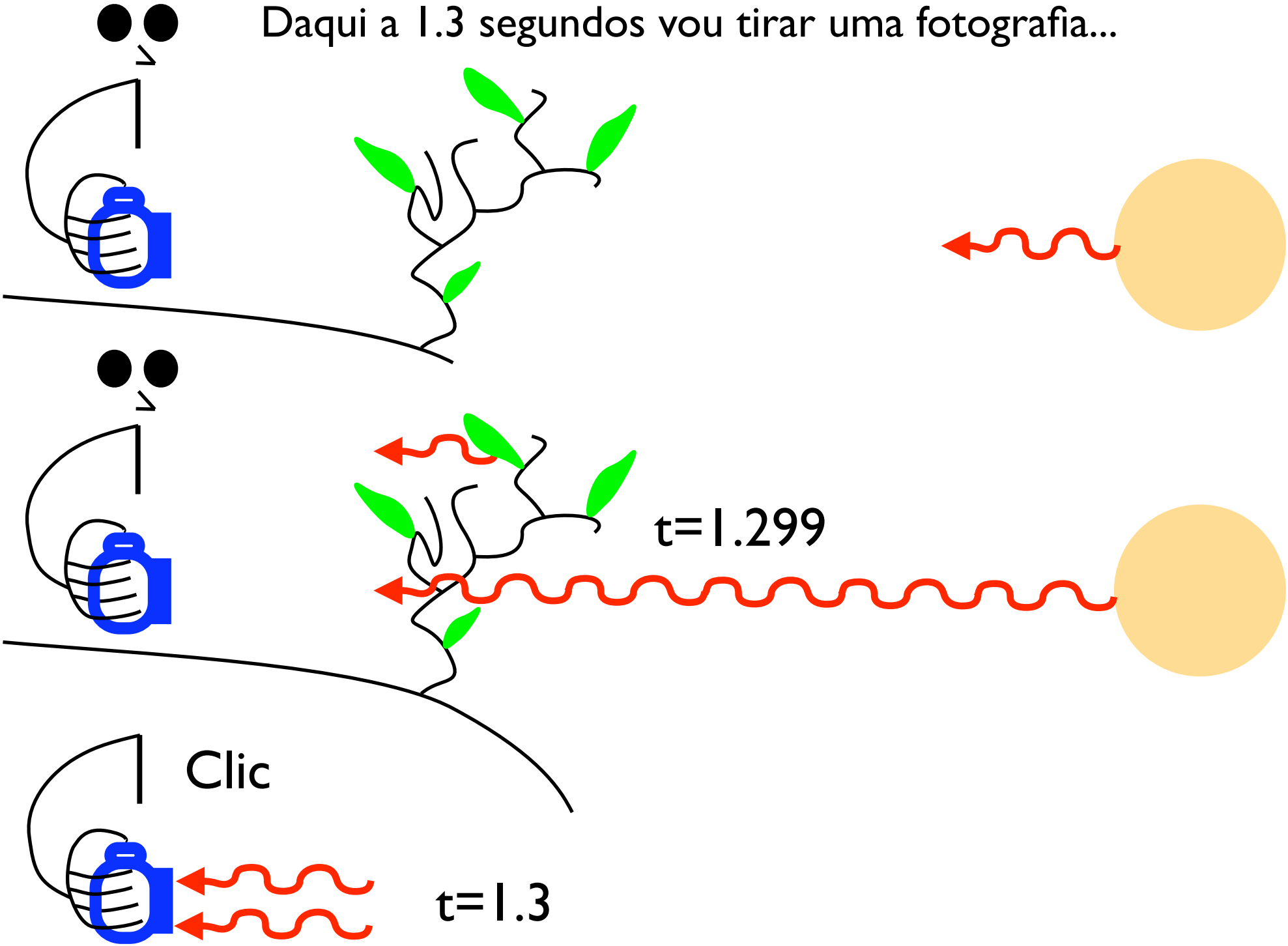




Daqui a 1.3 segundos vou tirar uma fotografia...



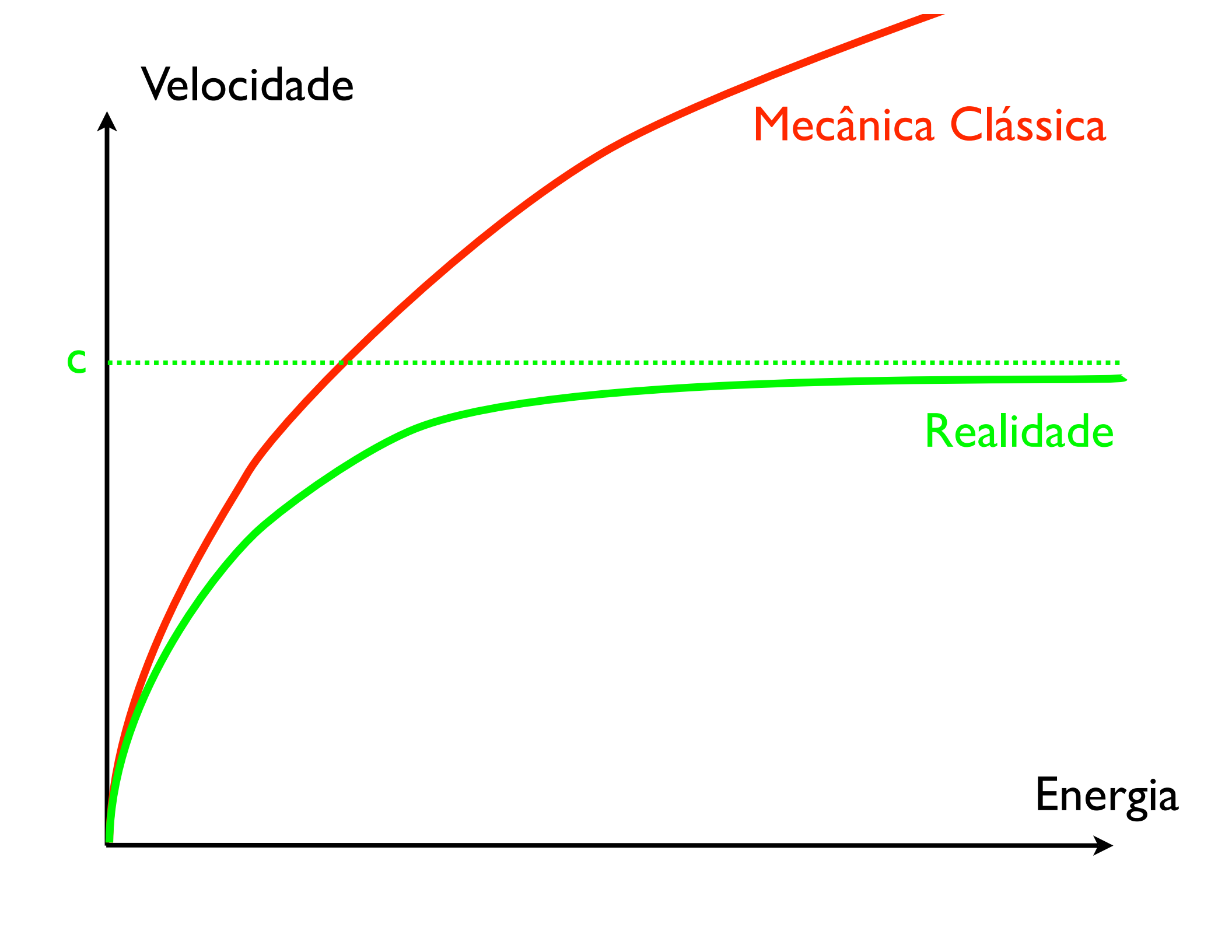
Daqui a 1.3 segundos vou tirar uma fotografia...



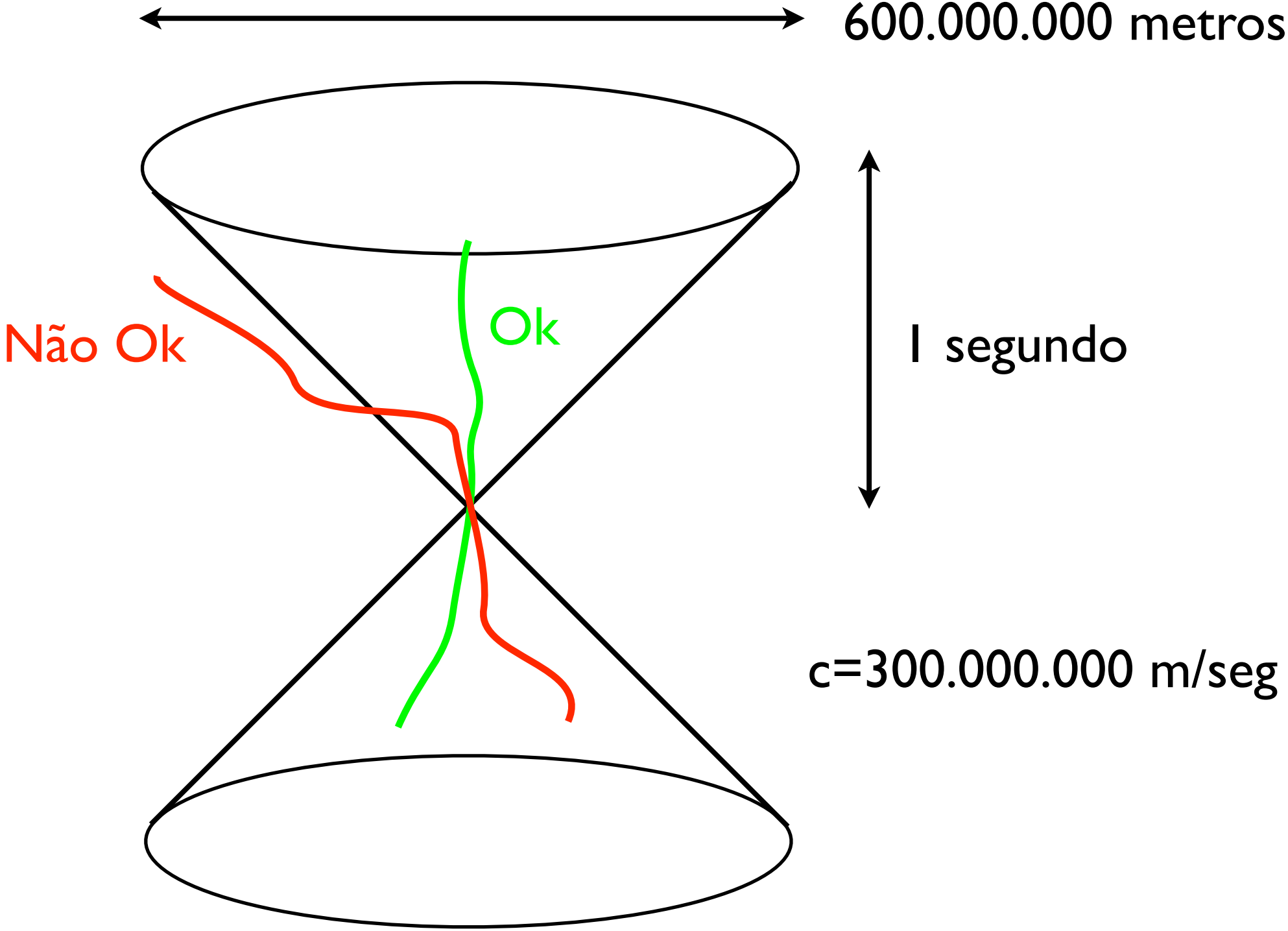
Fotografia

Lua há 1.3 segundos atrás

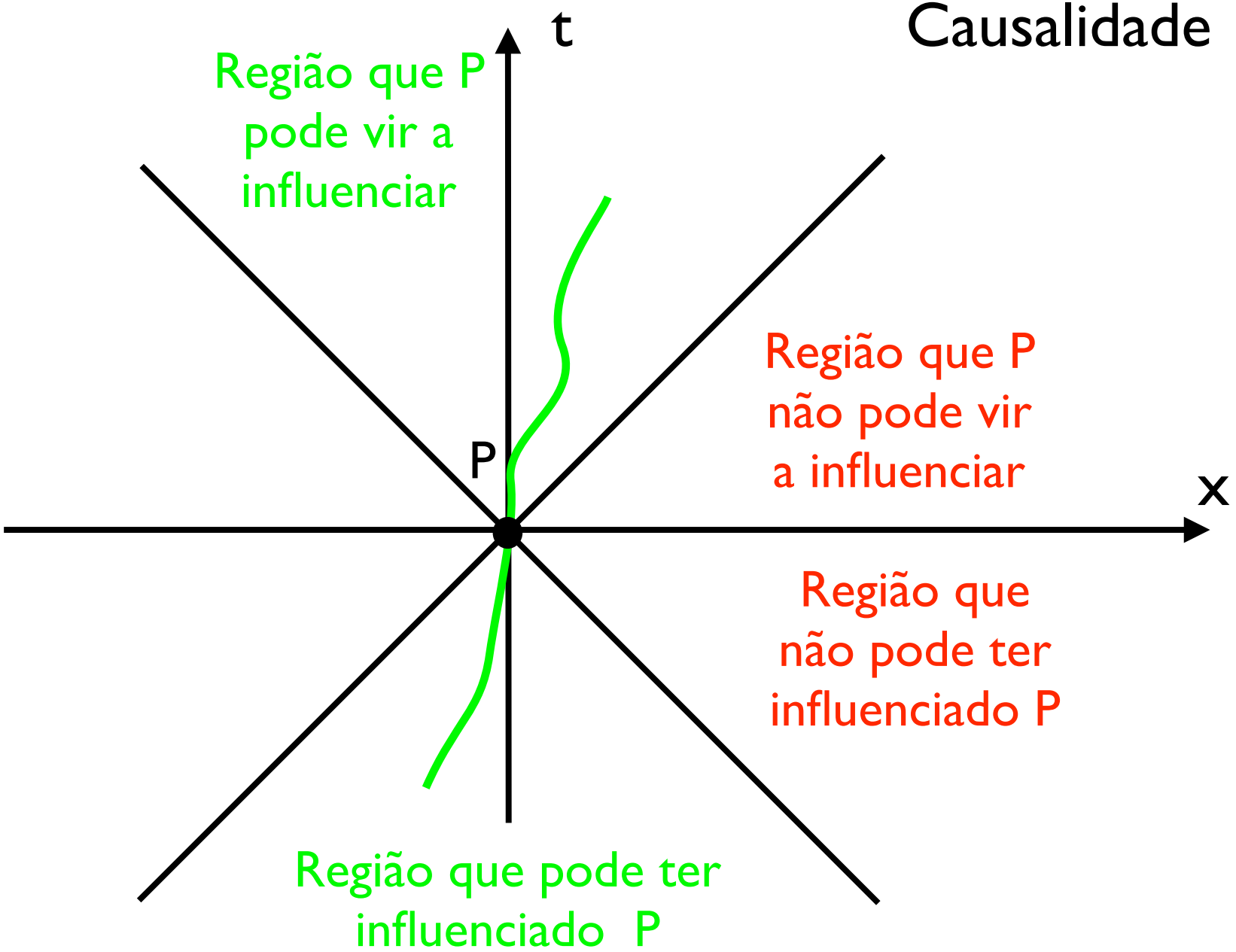
Planta há milionésimos de segundos

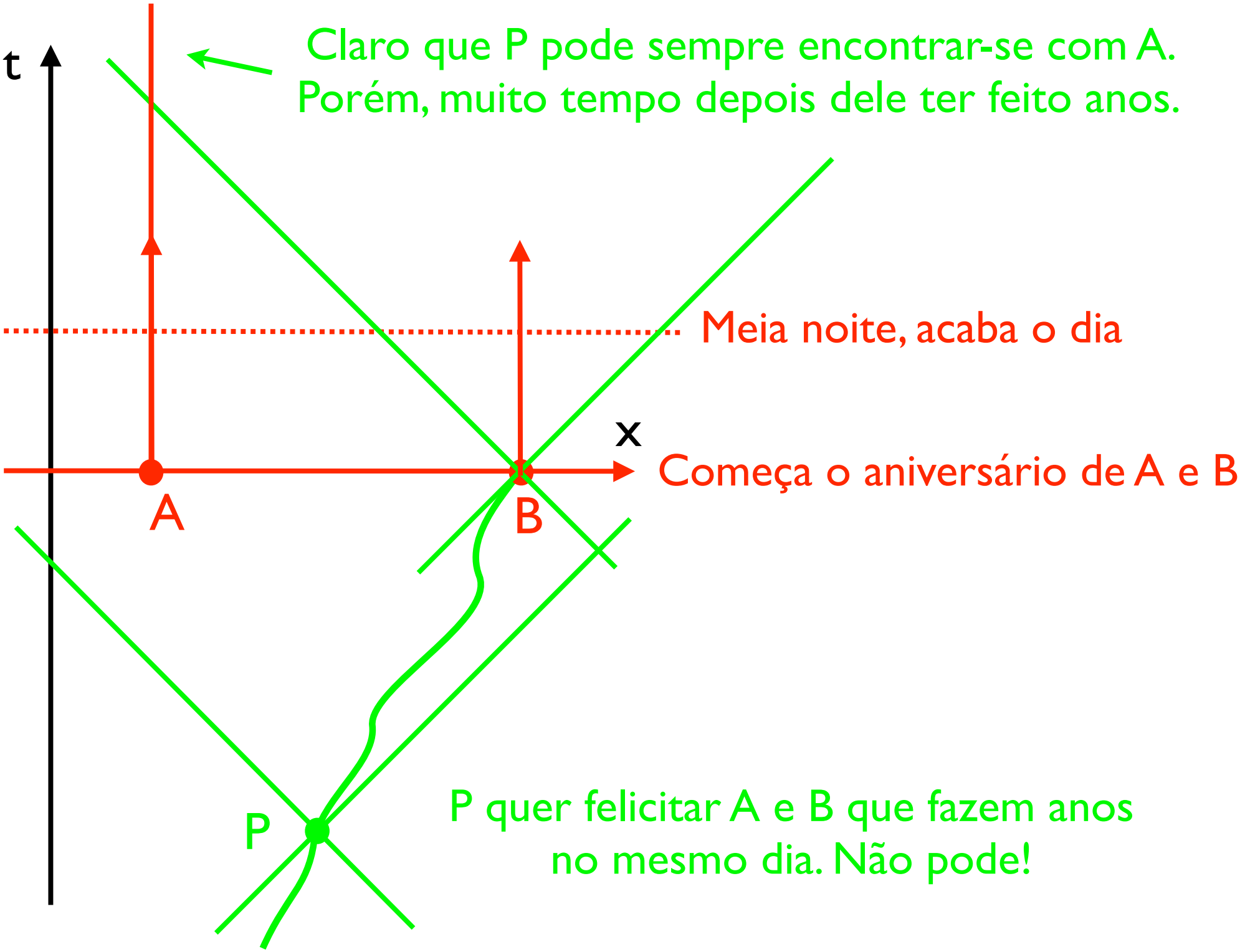

Velocidade
Mecânica Clássica
c
Realidade
Energia

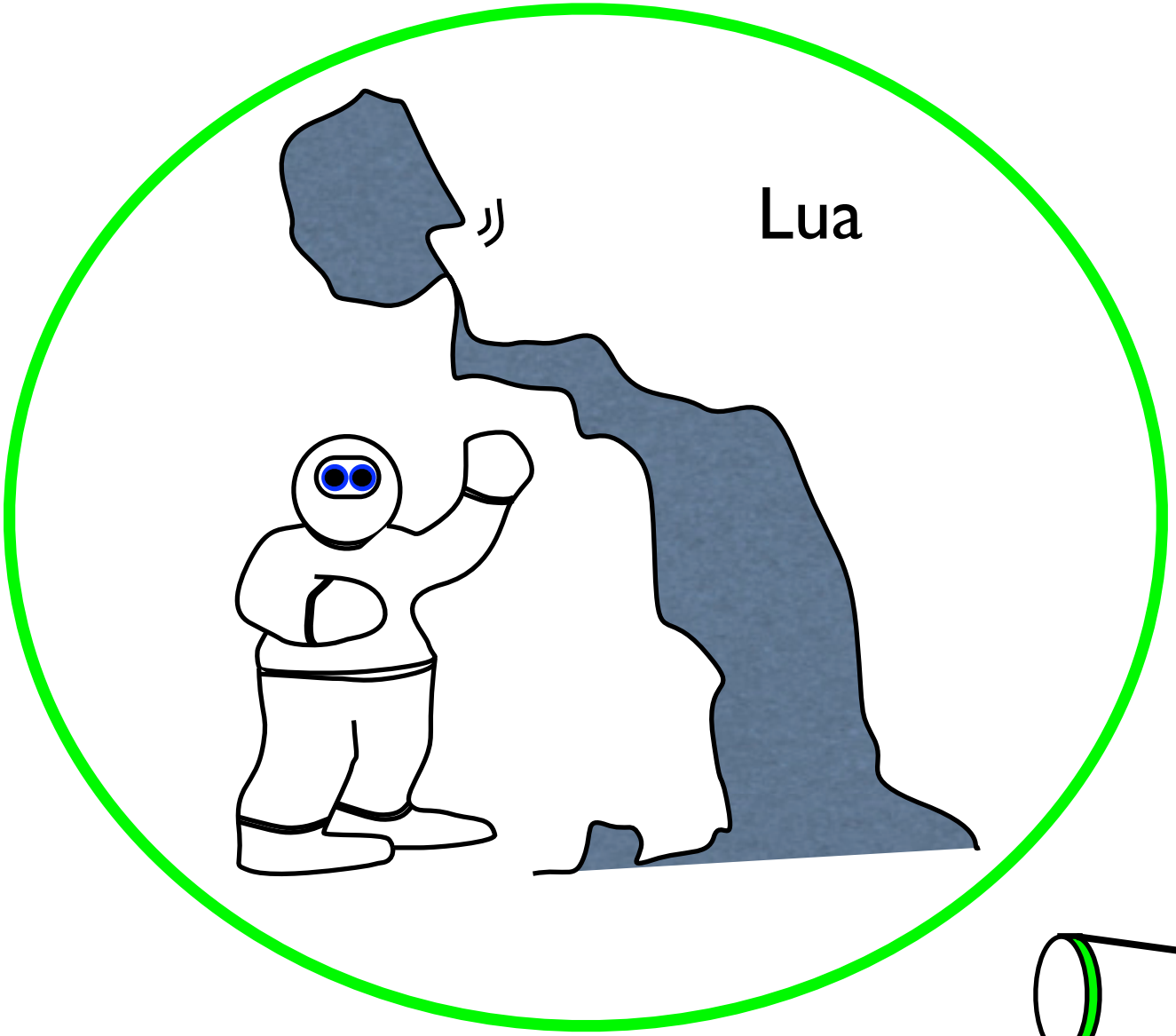
Cone de Luz


600.000.000 metros
Não Ok
Ok
1 segundo
c=300.000.000 m/seg

Causalidade

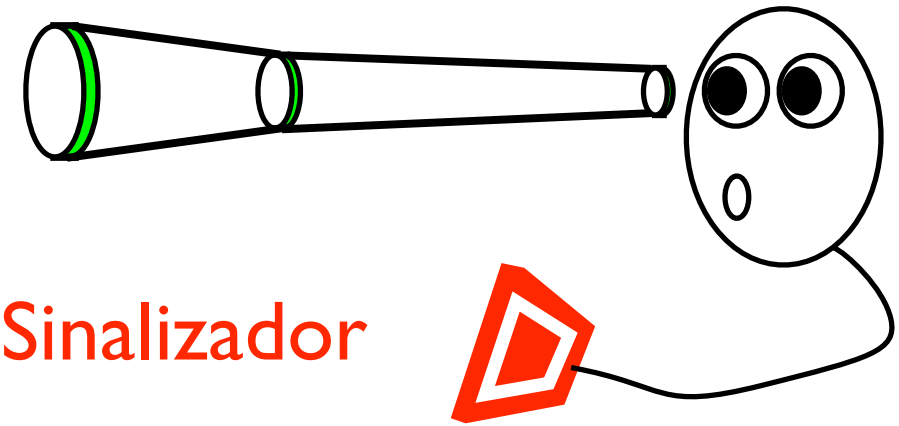



t
x
A
B
P
Claro que P pode sempre encontrar-se com A.
Porém, muito tempo depois dele ter feito anos.
Meia noite, acaba o dia
Começa o aniversário de A e B
P quer felicitar A e B que fazem anos
no mesmo dia. Não pode!

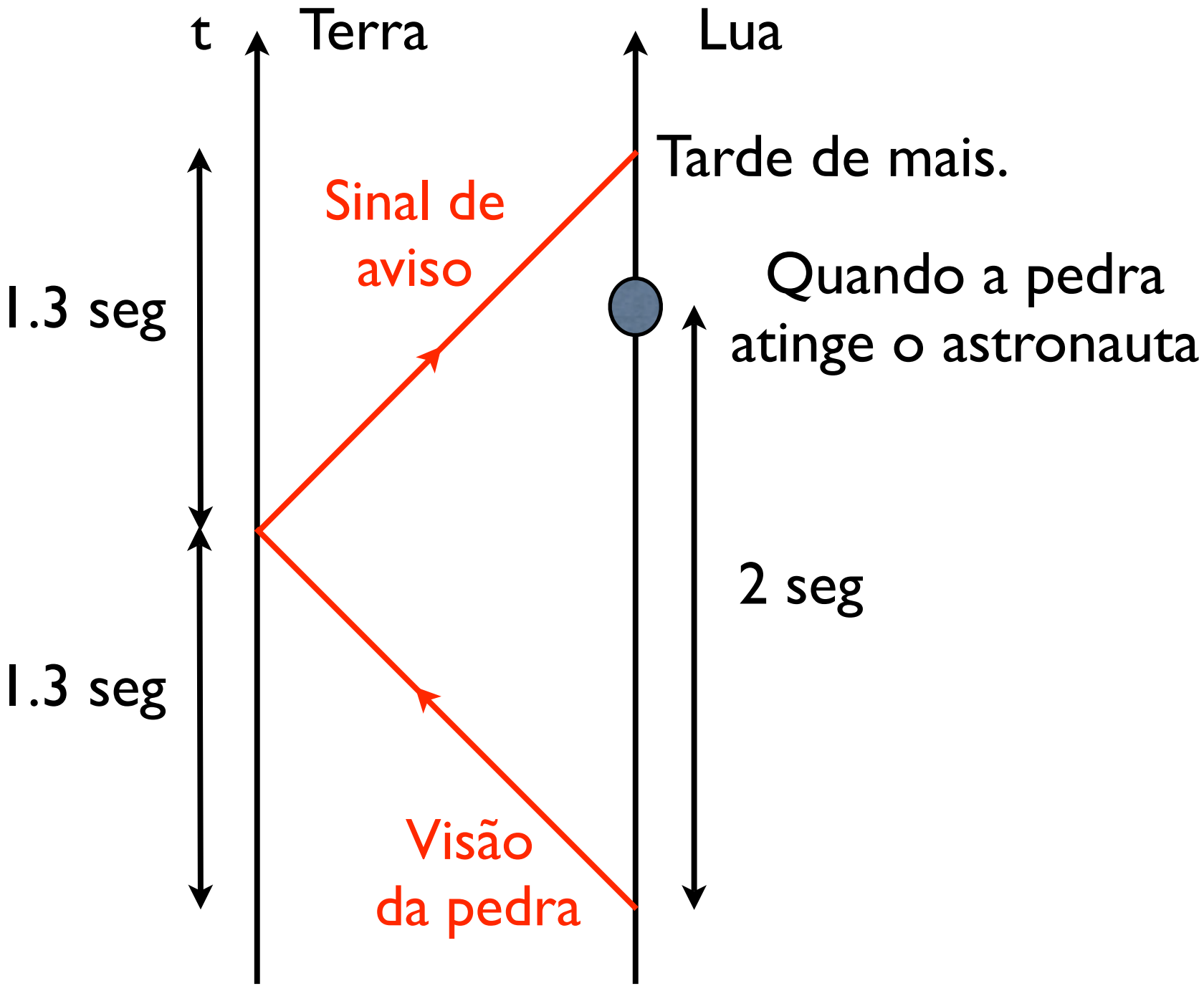


Terra

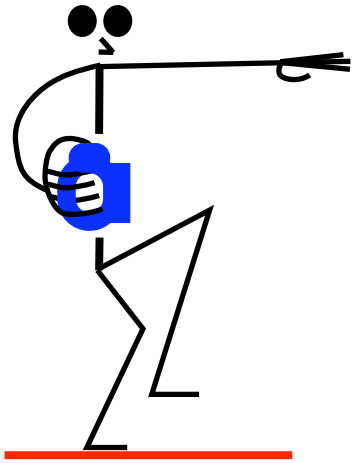
A pedra demorará 2 segundos a cair-lhe em cima mas como eu vejo o passado...

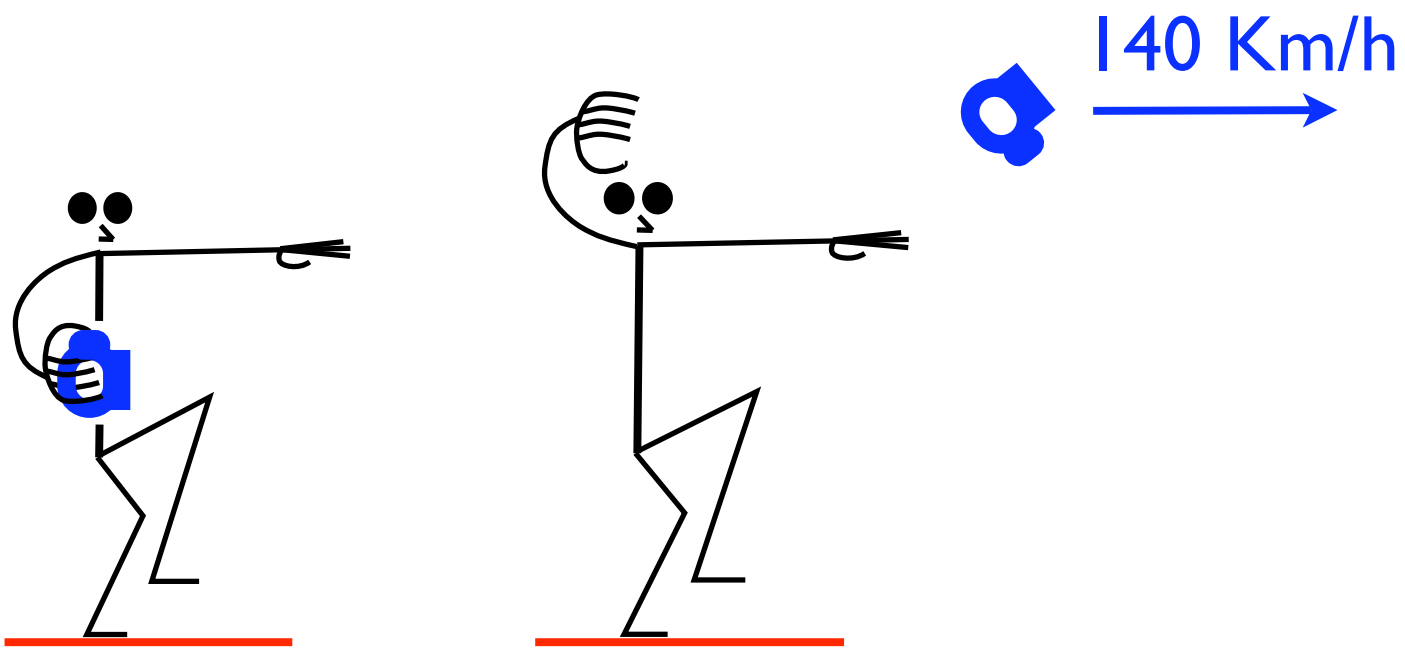


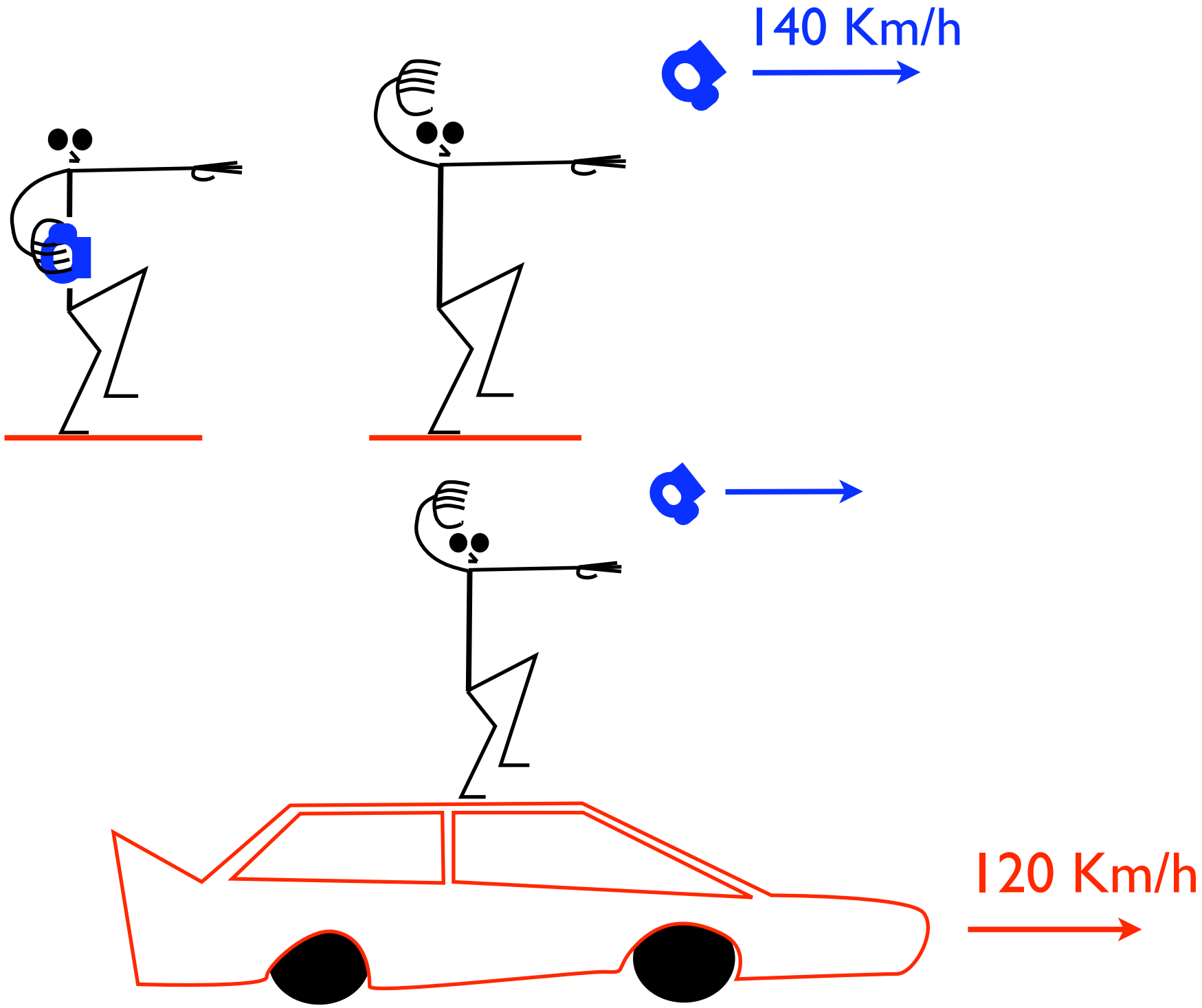
Sinalizador

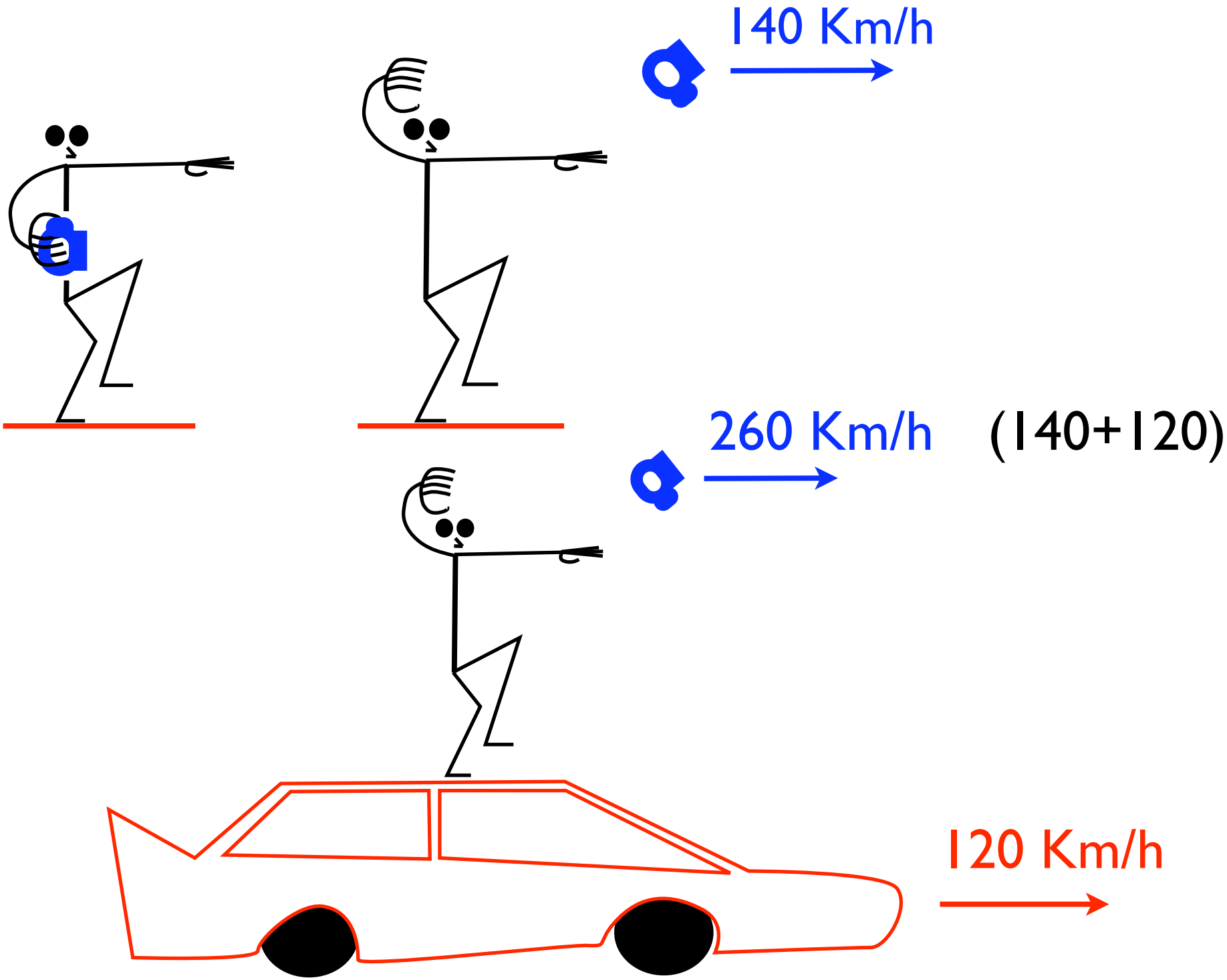

t
Terra
Lua
Tarde de mais.
Sinal de
aviso
1.3 seg
Quando a pedra
atinge o astronauta
2 seg
1.3 seg
Visão
da pedra

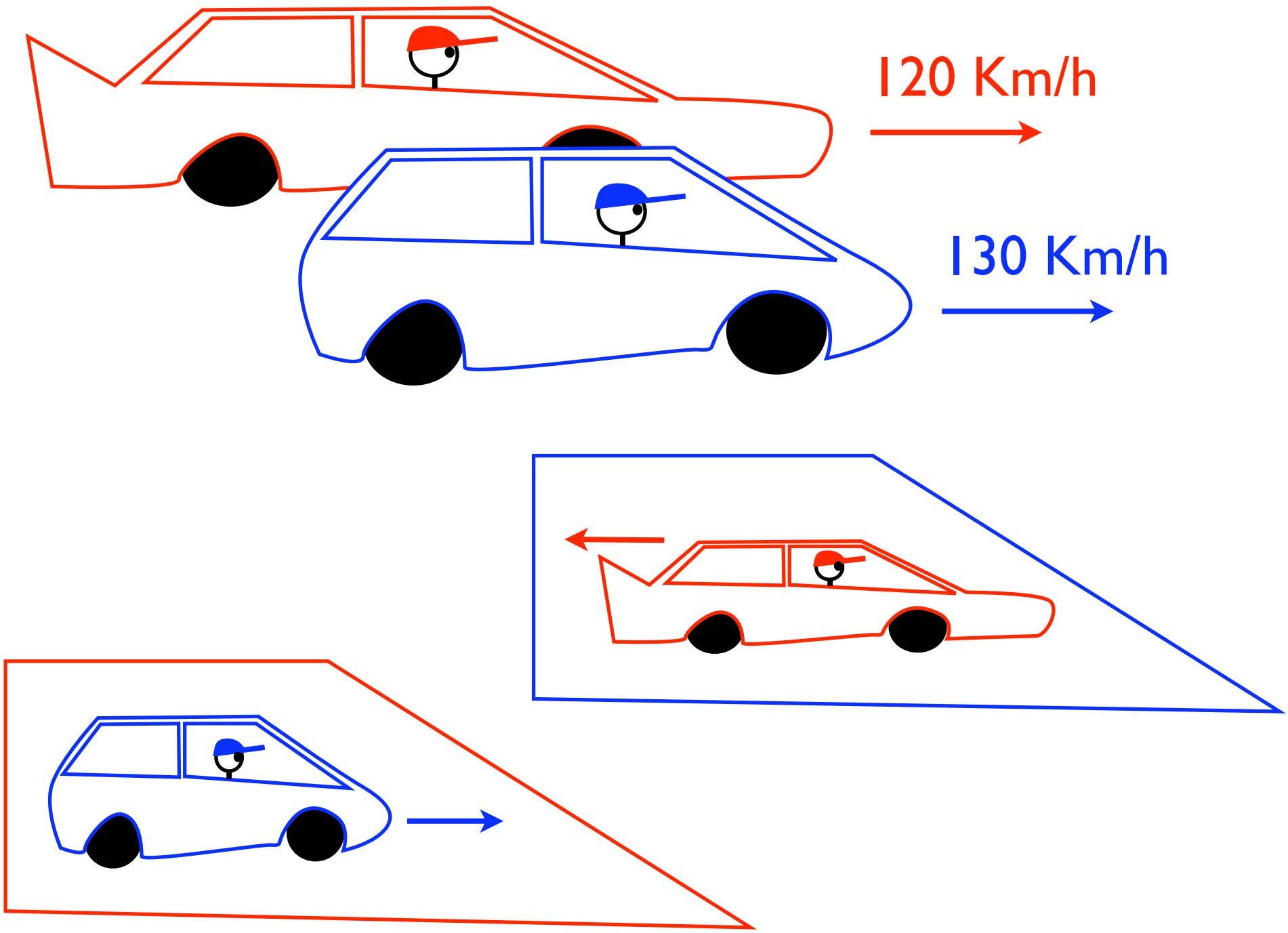
Adição de velocidades

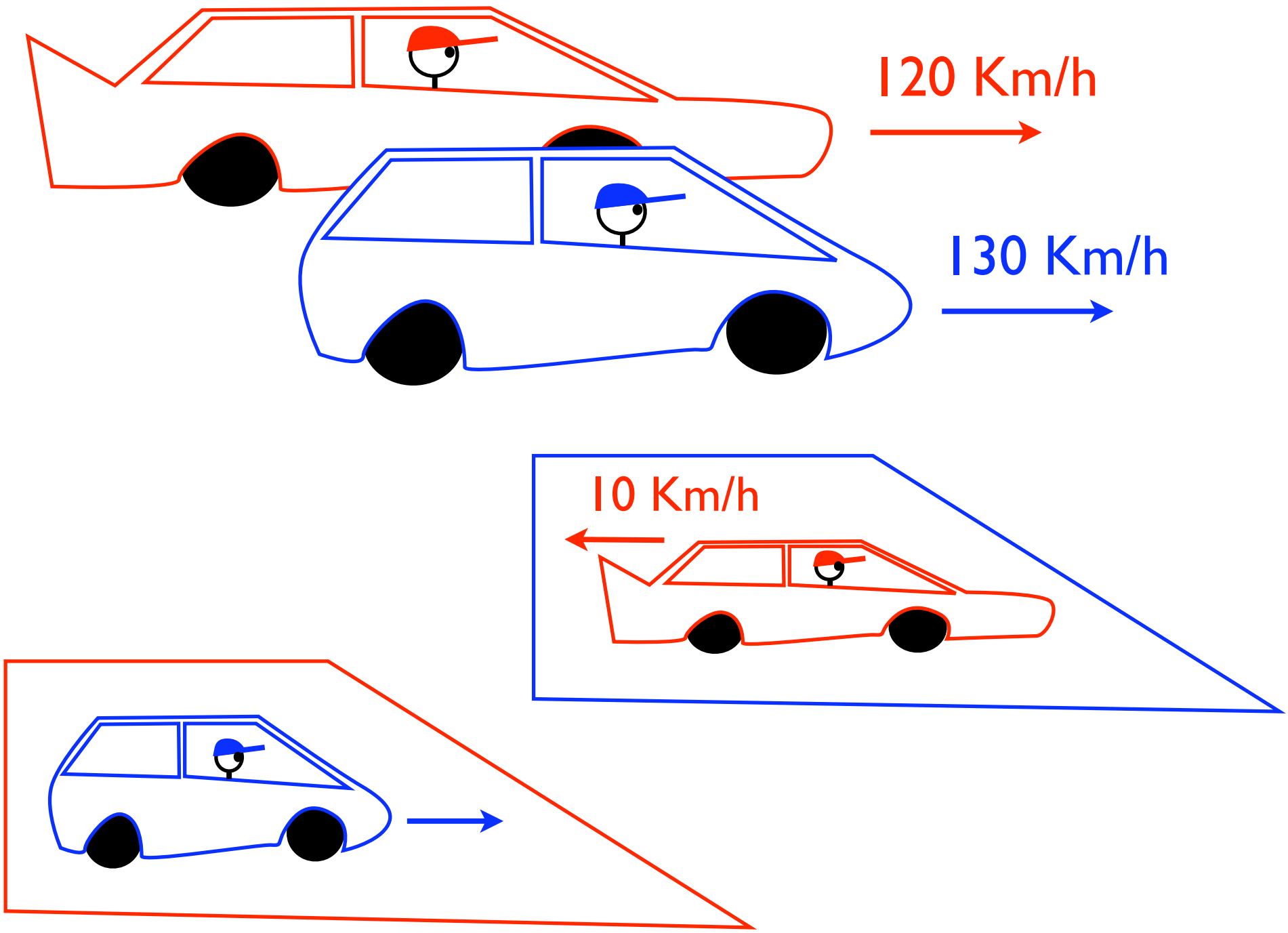


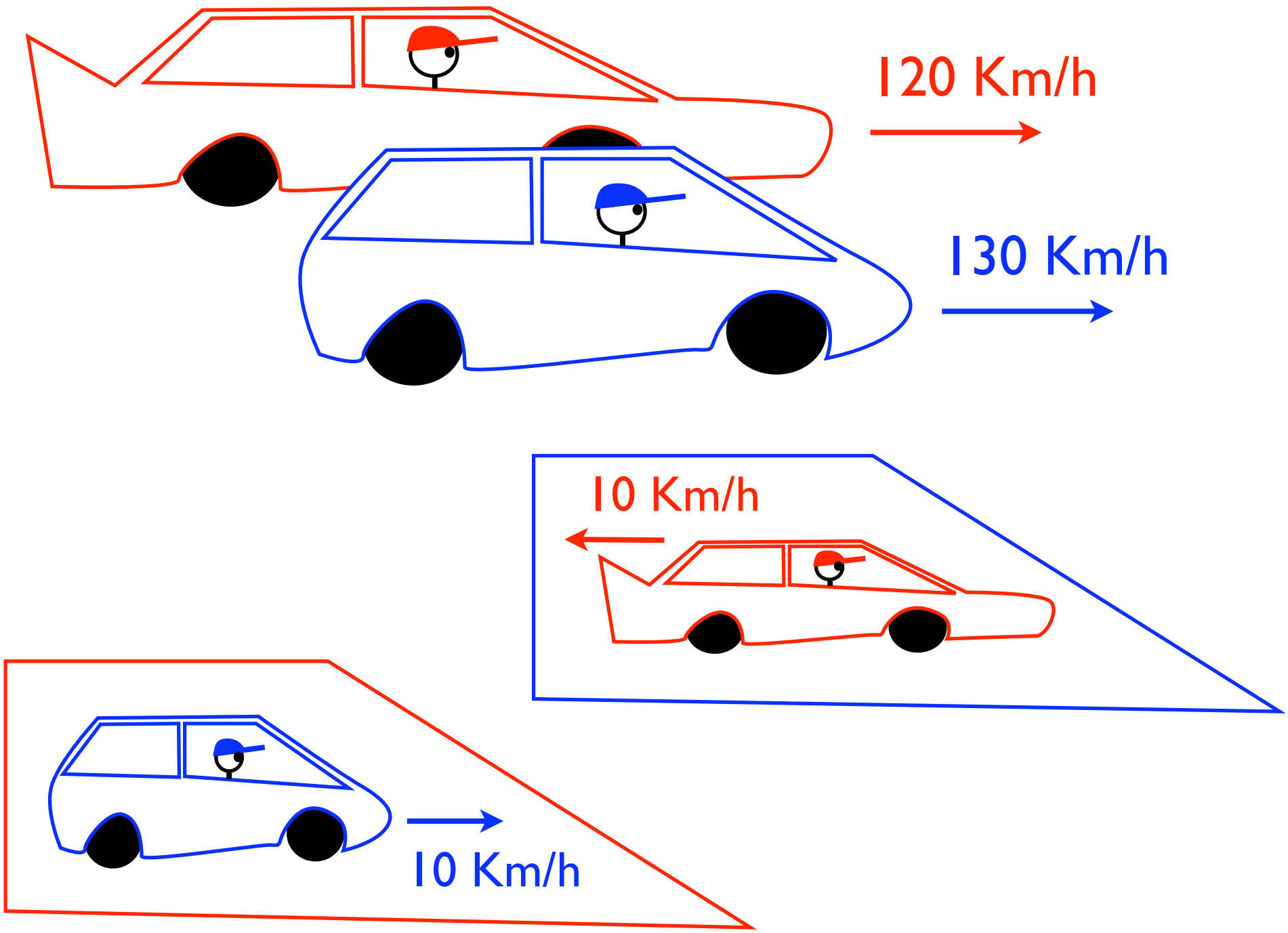

140 Km/h

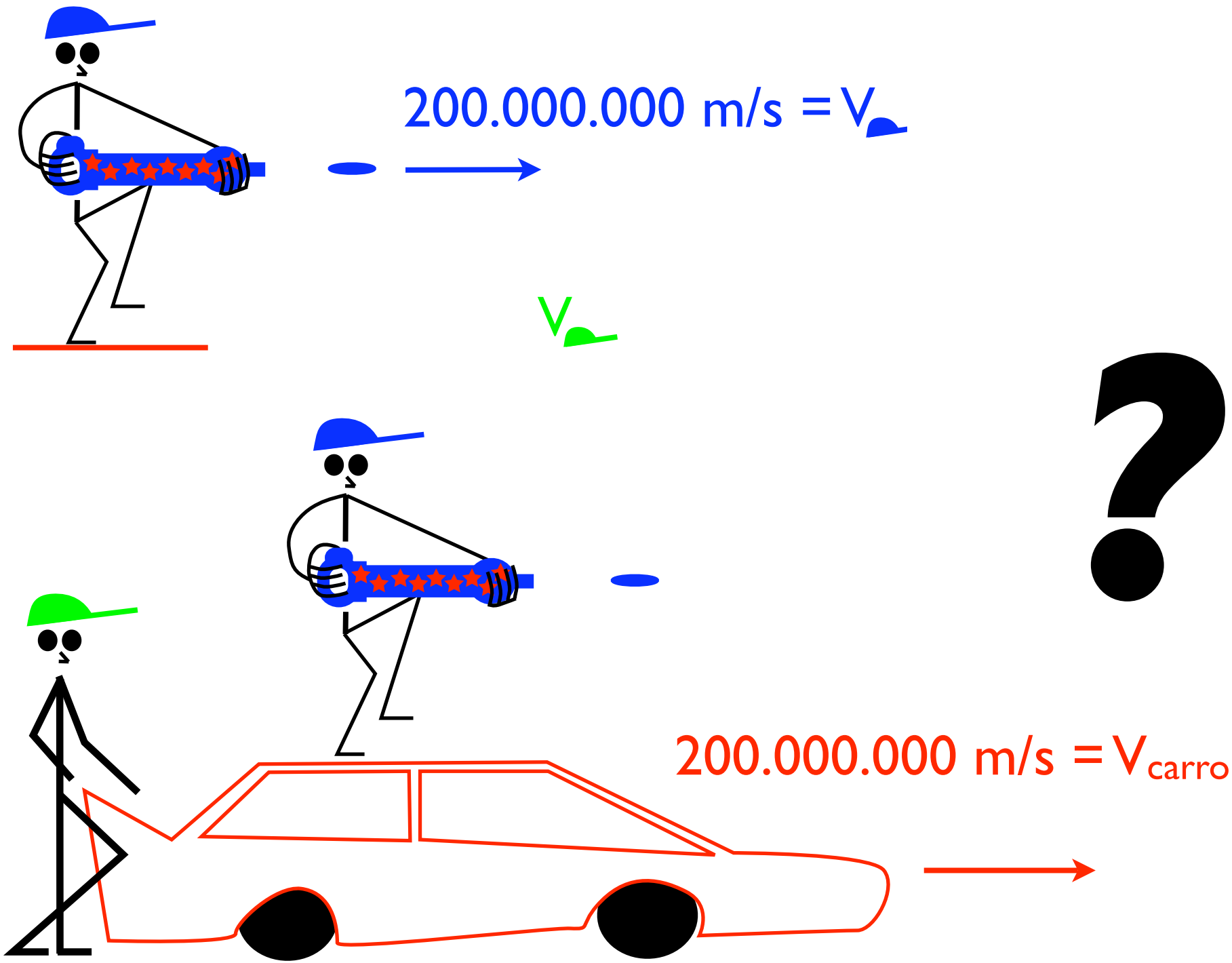

140 Km/h
120 Km/h

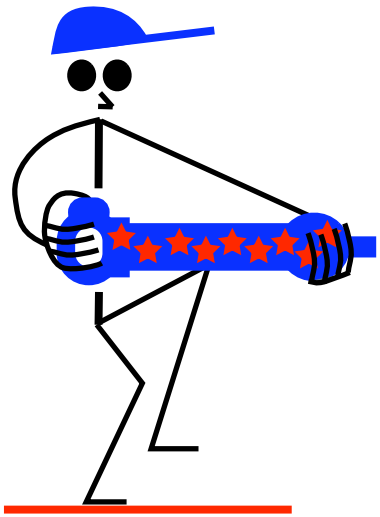

140 Km/h
260 Km/h
(140+120)
120 Km/h


120 Km/h
130 Km/h


120 Km/h
130 Km/h
10 Km/h


120 Km/h
130 Km/h
10 Km/h
10 Km/h


200.000.000 m/s = V
V
?
200.000.000 m/s = V carro



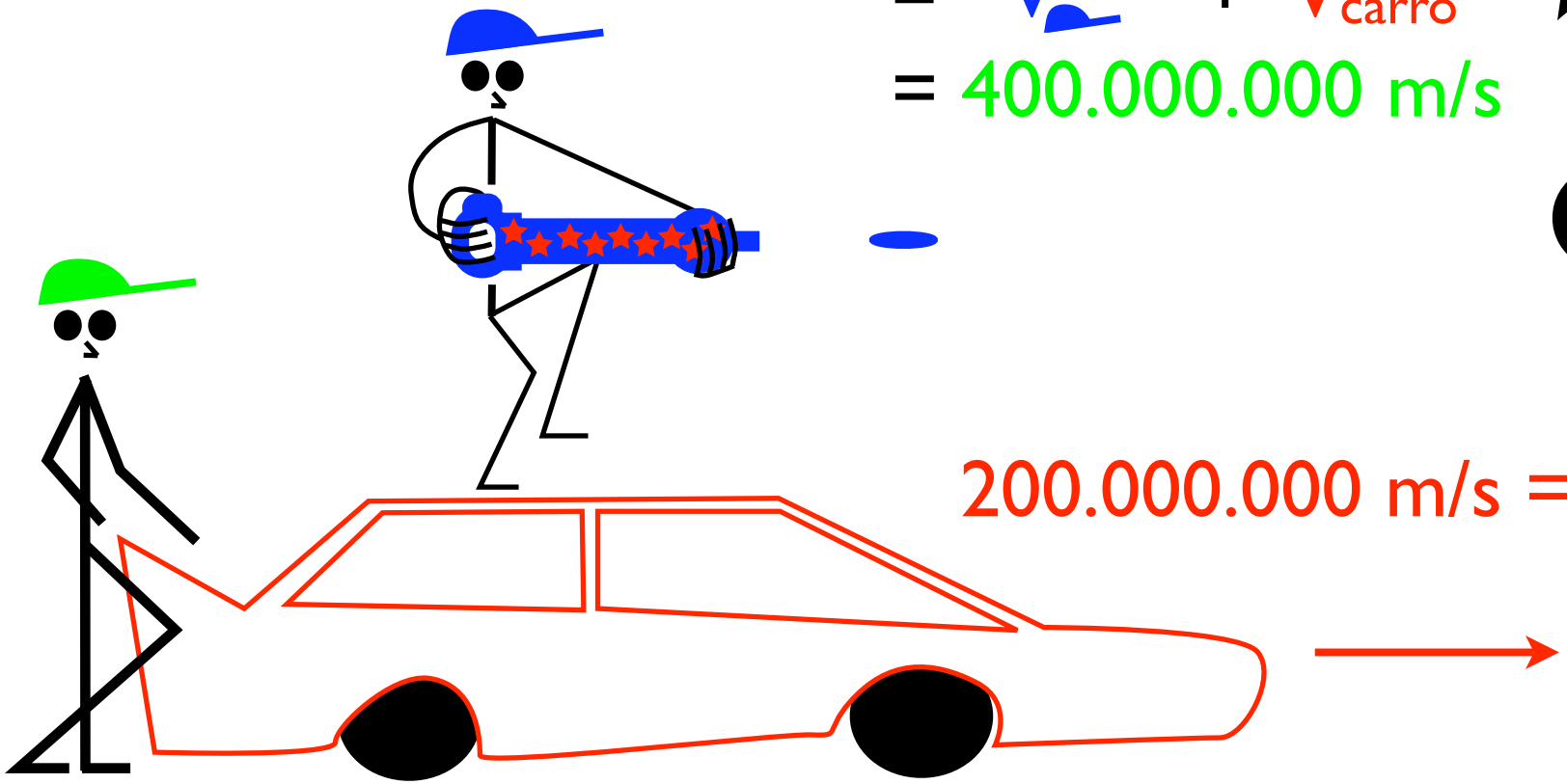
200.000.000 m/s = $V_{\text{[illegible]}}$

$V_{\text{[illegible]}}$ = 200.000.000 + 200.000.000

= $V_{\text{[illegible]}}$ + V_{carro}

= 400.000.000 m/s

?



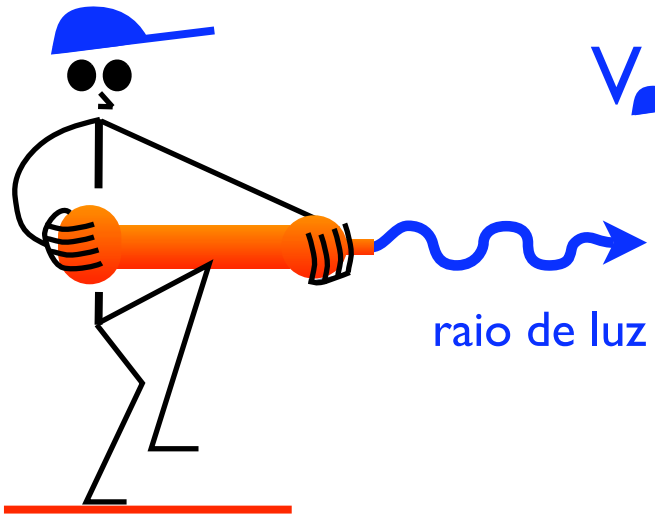
200.000.000 m/s = V_{carro}

Não!

400.000.000 m/s > 300.000.000 m/s = c

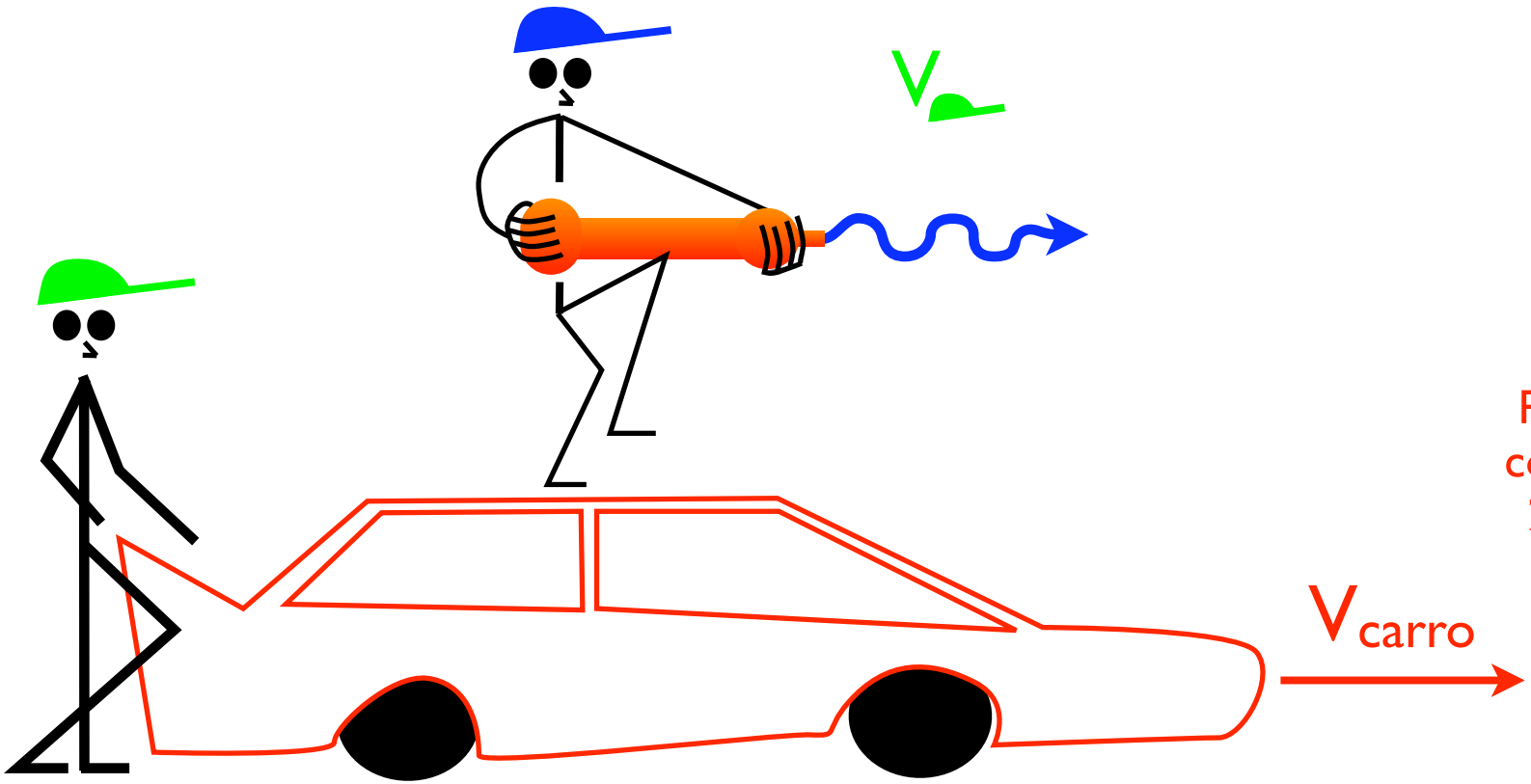
O cálculo que parecia normal tem um erro de pelo menos 100.000.000 m/s !

O Postulado

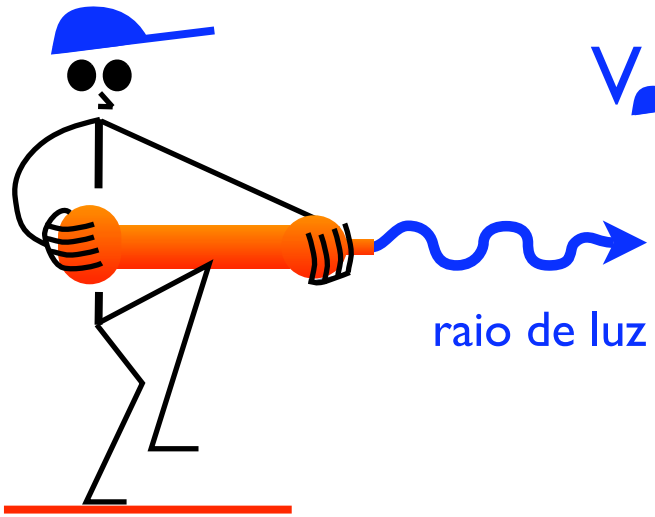


V_{luz} = 300.000.000 m/s = c

raio de luz



Pode ser qualquer coisa, (por exemplo 200.000.000 m/s)

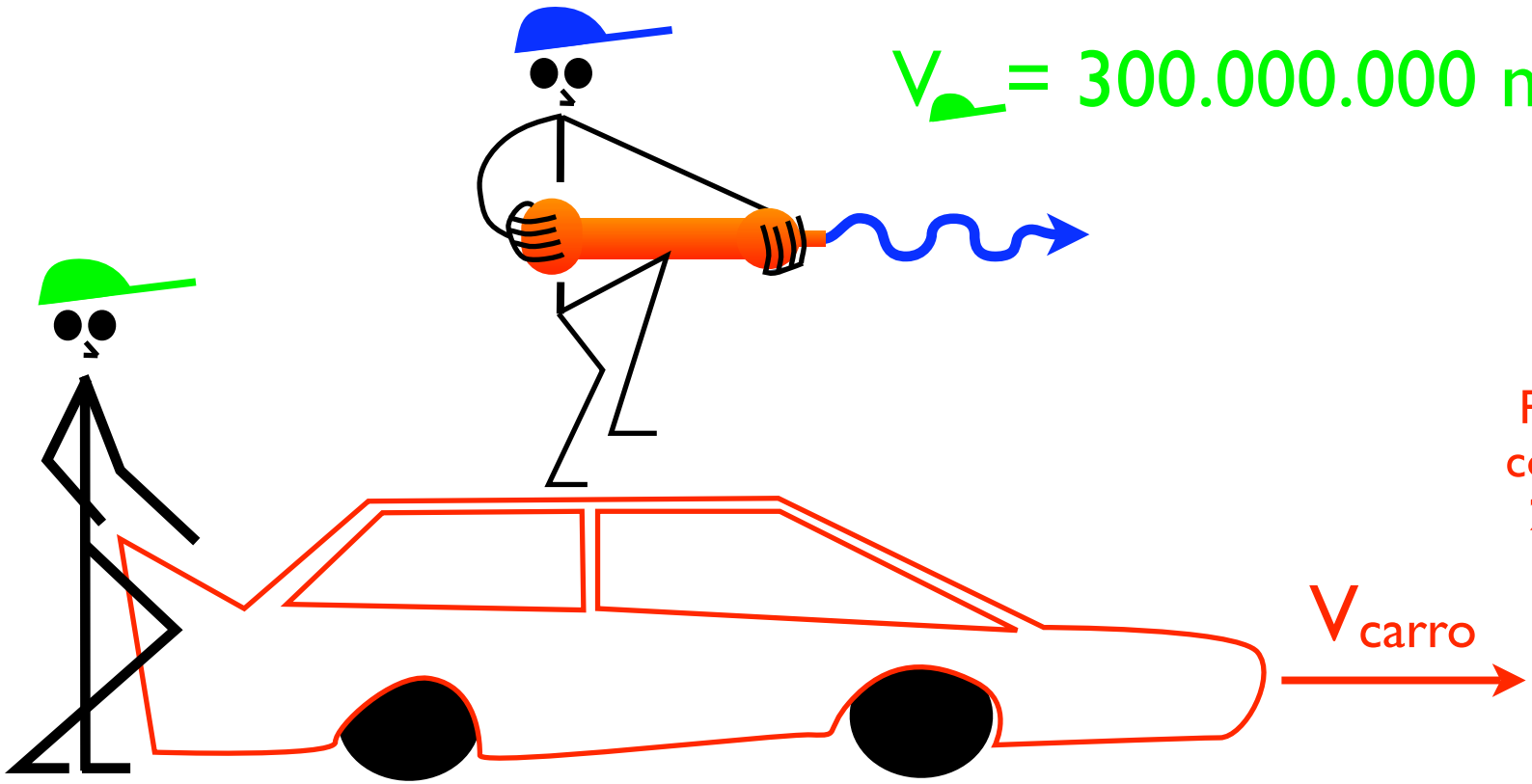


$V_{\text{luz}} = 300.000.000 \text{ m/s} = c$

raio de luz

Independentemente da velocidade do carro

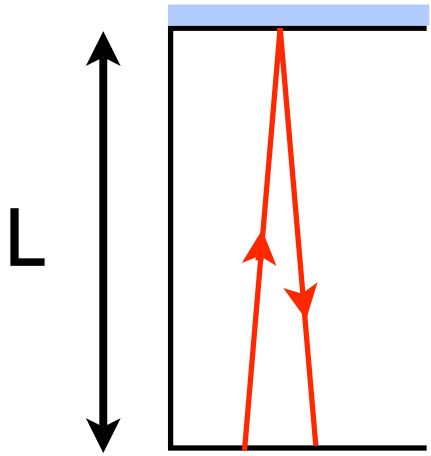
$V_{\text{luz}} = 300.000.000 \text{ m/s} = c$



Pode ser qualquer coisa, (por exemplo 200.000.000 m/s)

V_{carro}

Dilatação do Tempo



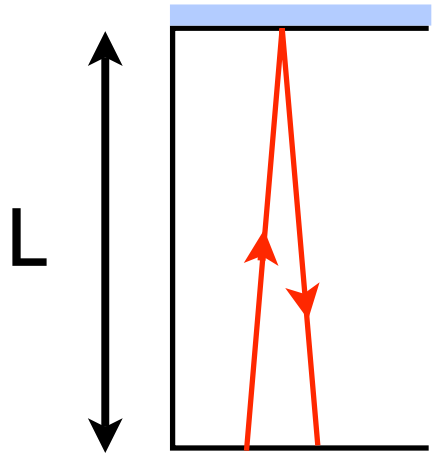
Relógio de luz

$$t = \frac{2L}{c}$$

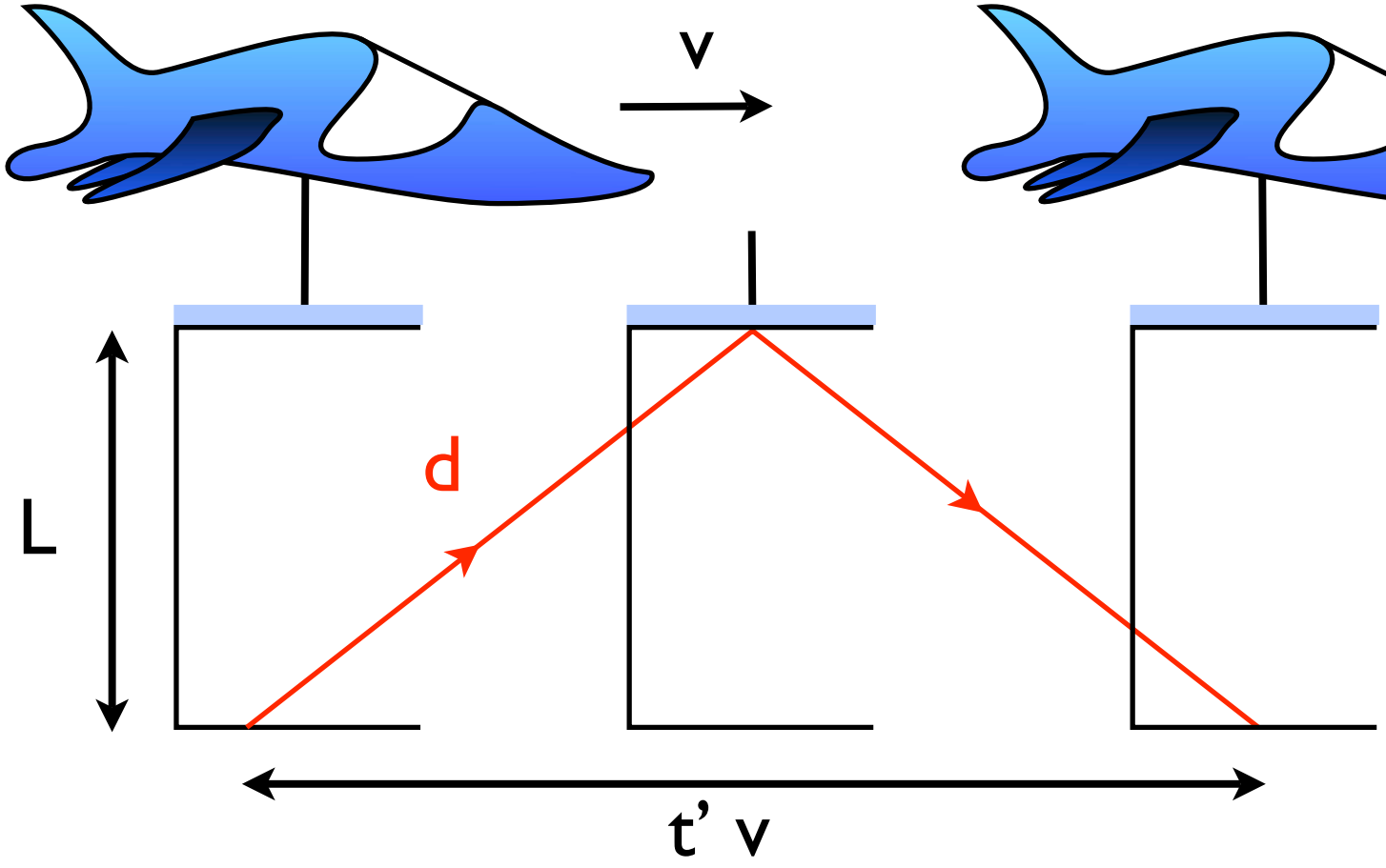
velocidade = $\frac{\text{distância}}{\text{tempo}}$

Relógio de luz

velocidade = $\frac{\text{distância}}{\text{tempo}}$



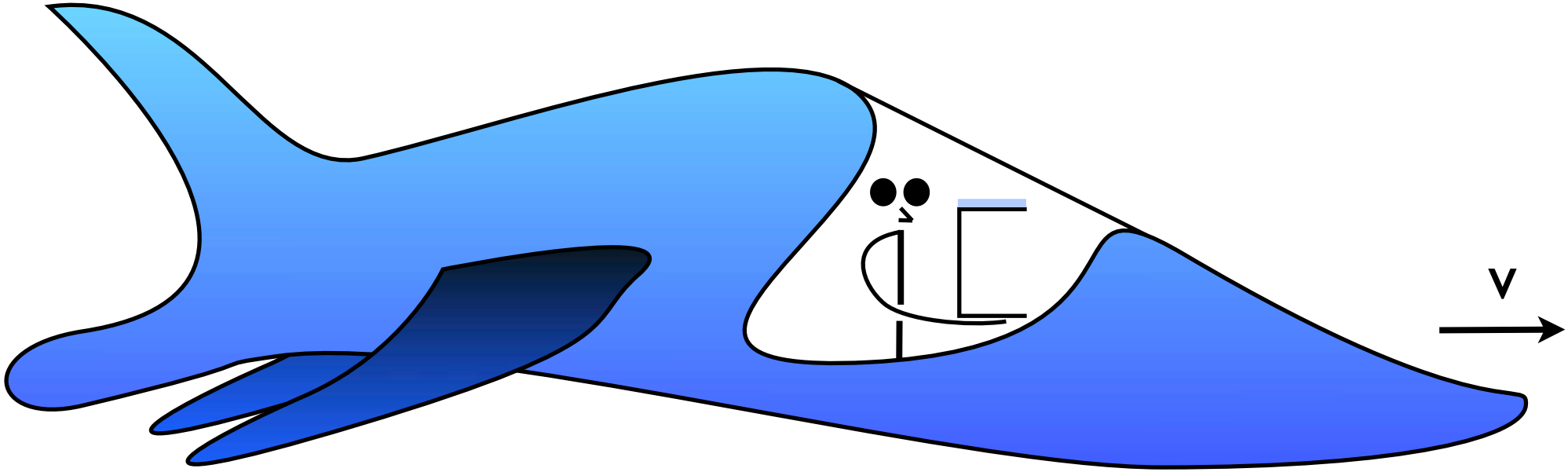
$$t = \frac{2L}{c}$$



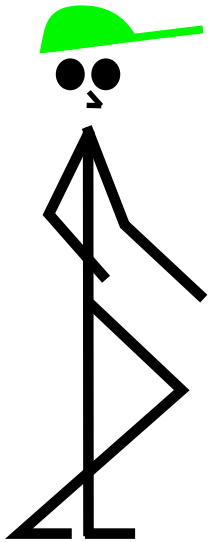
$$t' = \frac{2d}{c}$$

$$d^2 = L^2 + \left(\frac{t'v}{2}\right)^2$$

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

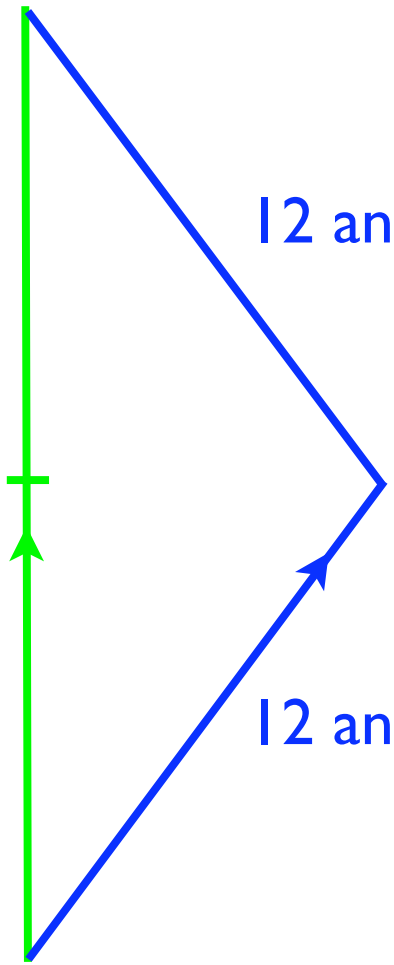


t' , o tempo medido por alguém em **terra**,
é **maior** do que
t , o tempo medido por alguém na **nave**



$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

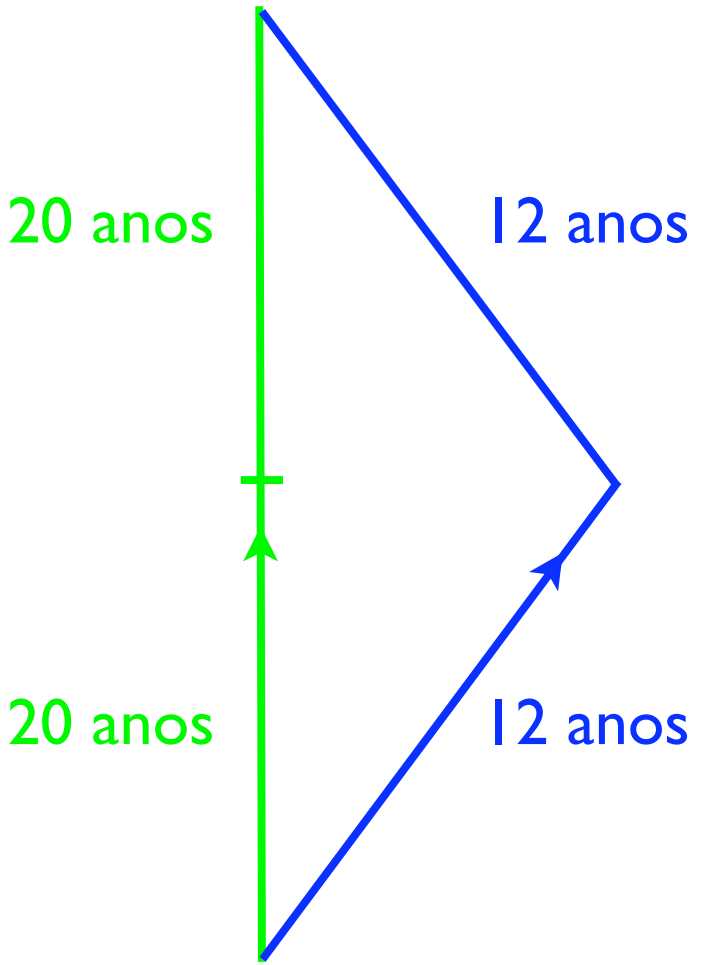
Se eu, na nave, a 240.000.000 m/s (0.8c), jogar um jogo de xadrez de 120 minutos, um espectador, na terra, dirá que o jogo demorou 200 minutos.



V = 0.8c

12 anos a afastar e
12 anos a aproximar

Se eu, na nave, a 240.000.000 m/s (0.8c), jogar um jogo de xadrez de 120 minutos, um espectador, na terra, dirá que o jogo demorou 200 minutos.

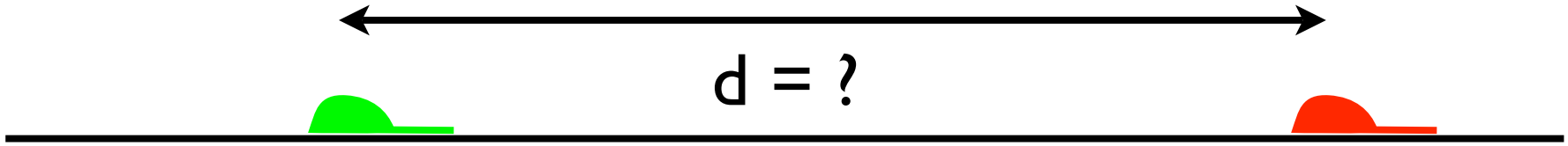


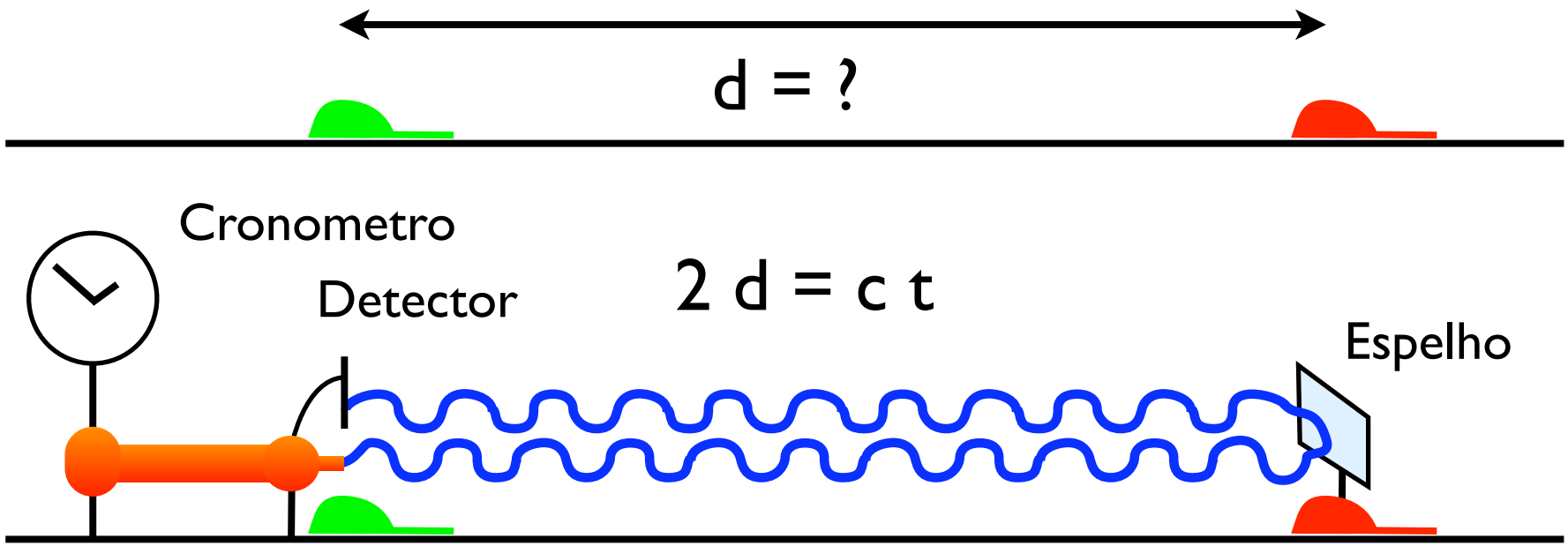
V = 0.8c

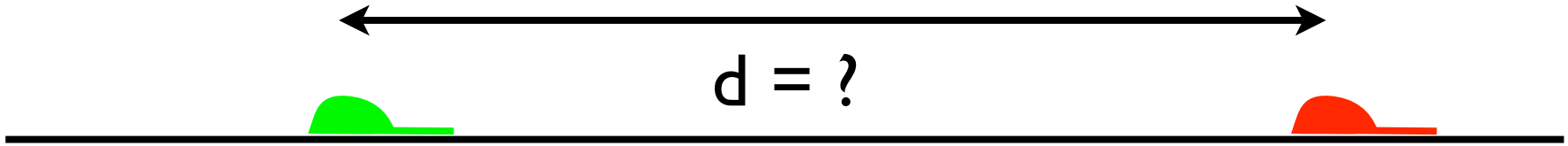
12 anos a afastar e
12 anos a aproximar

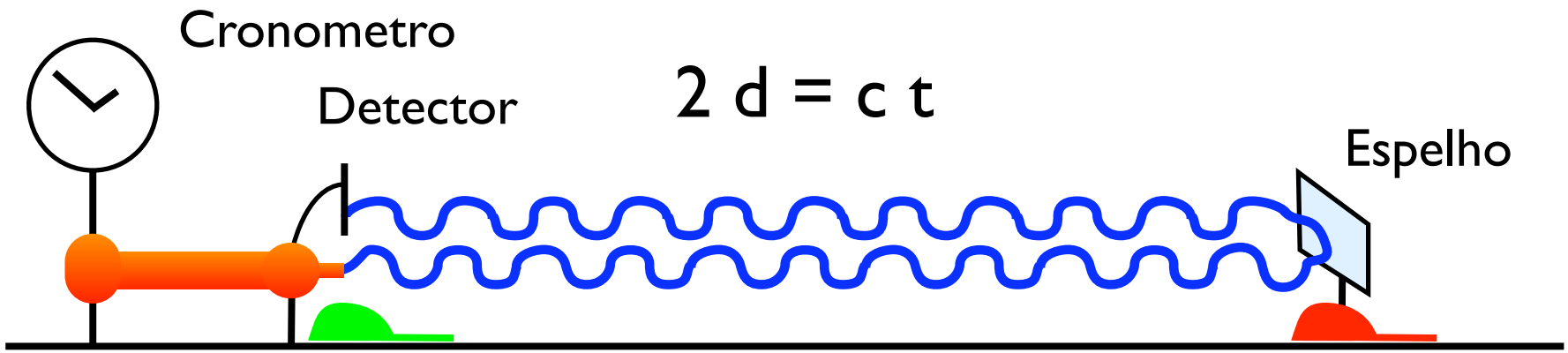
Dois gémeos com 17 anos. Um fica na Terra. Quando o outro regressa tem 41 anos enquanto que o que ficou tem 57!

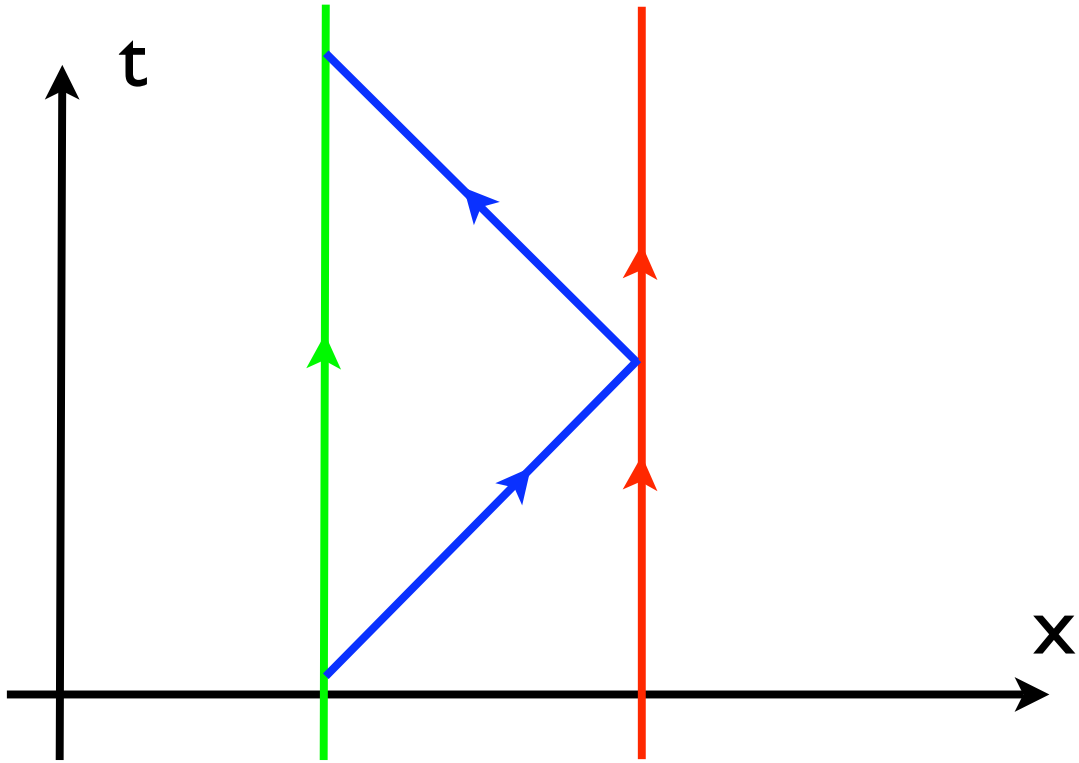
Distâncias e Simultaneidade

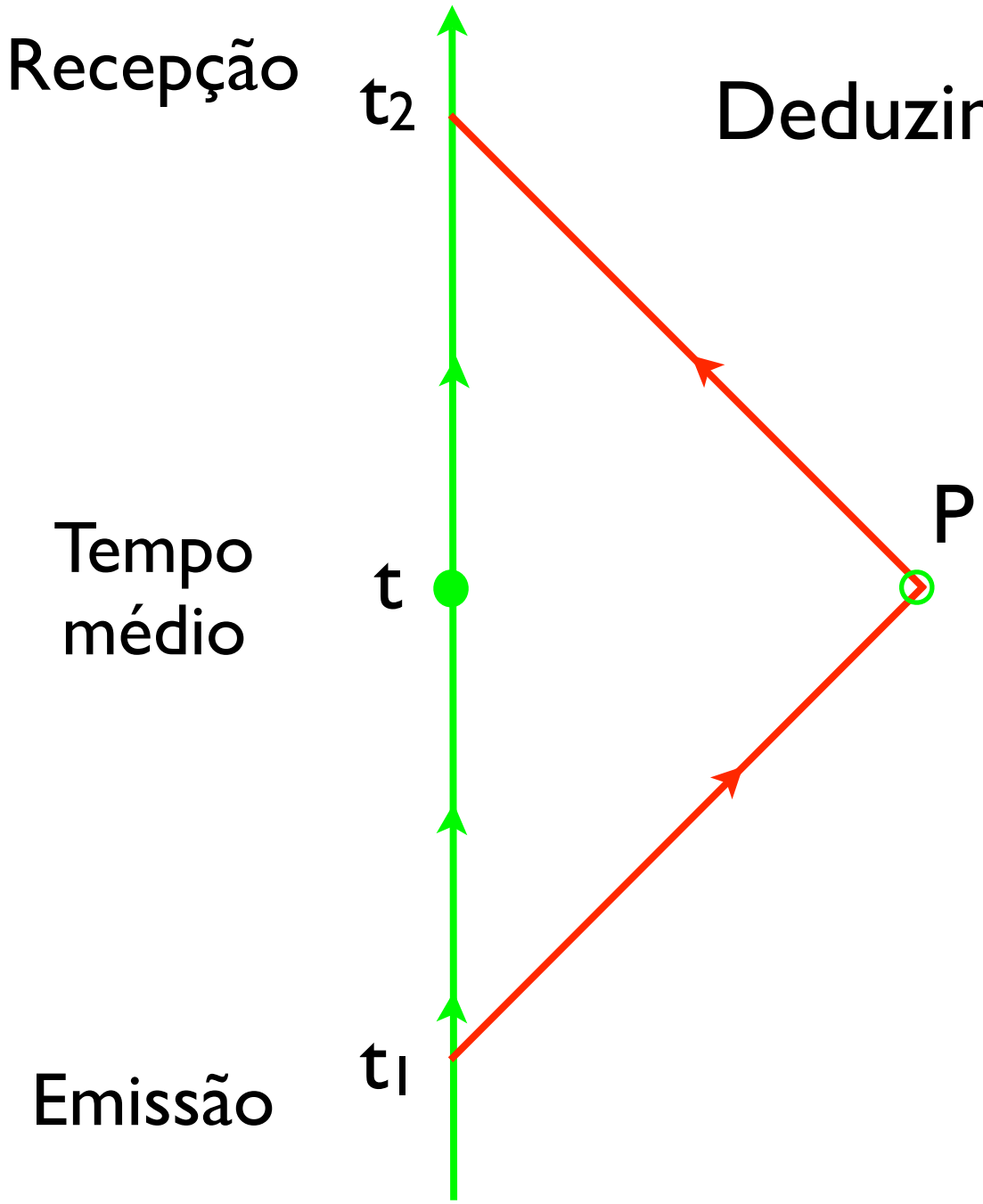

d = ?


d = ?
Cronometro
Detector
2 d = c t
Espelho


d = ?


Cronometro
Detector
2 d = c t
Espelho


t
x

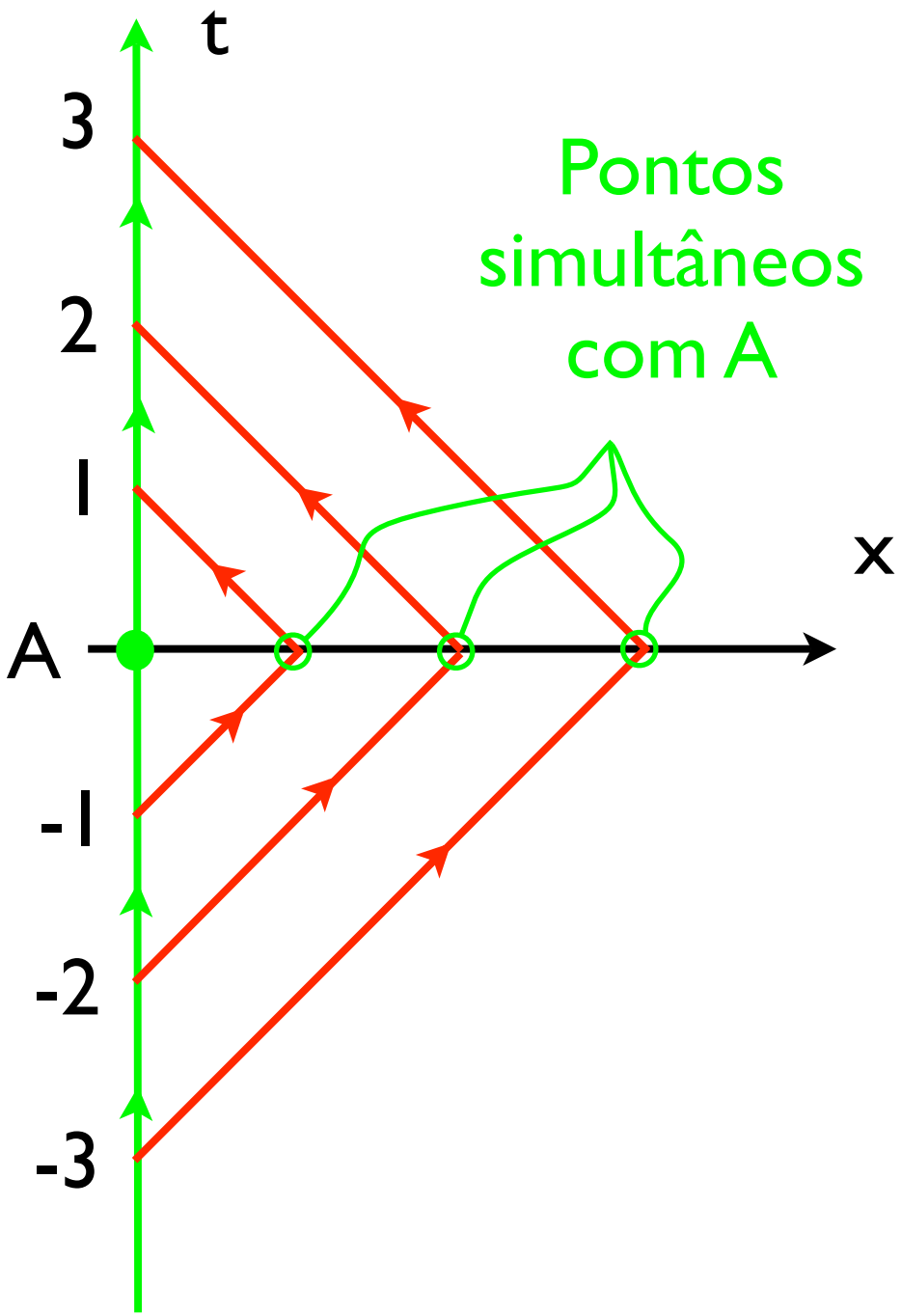


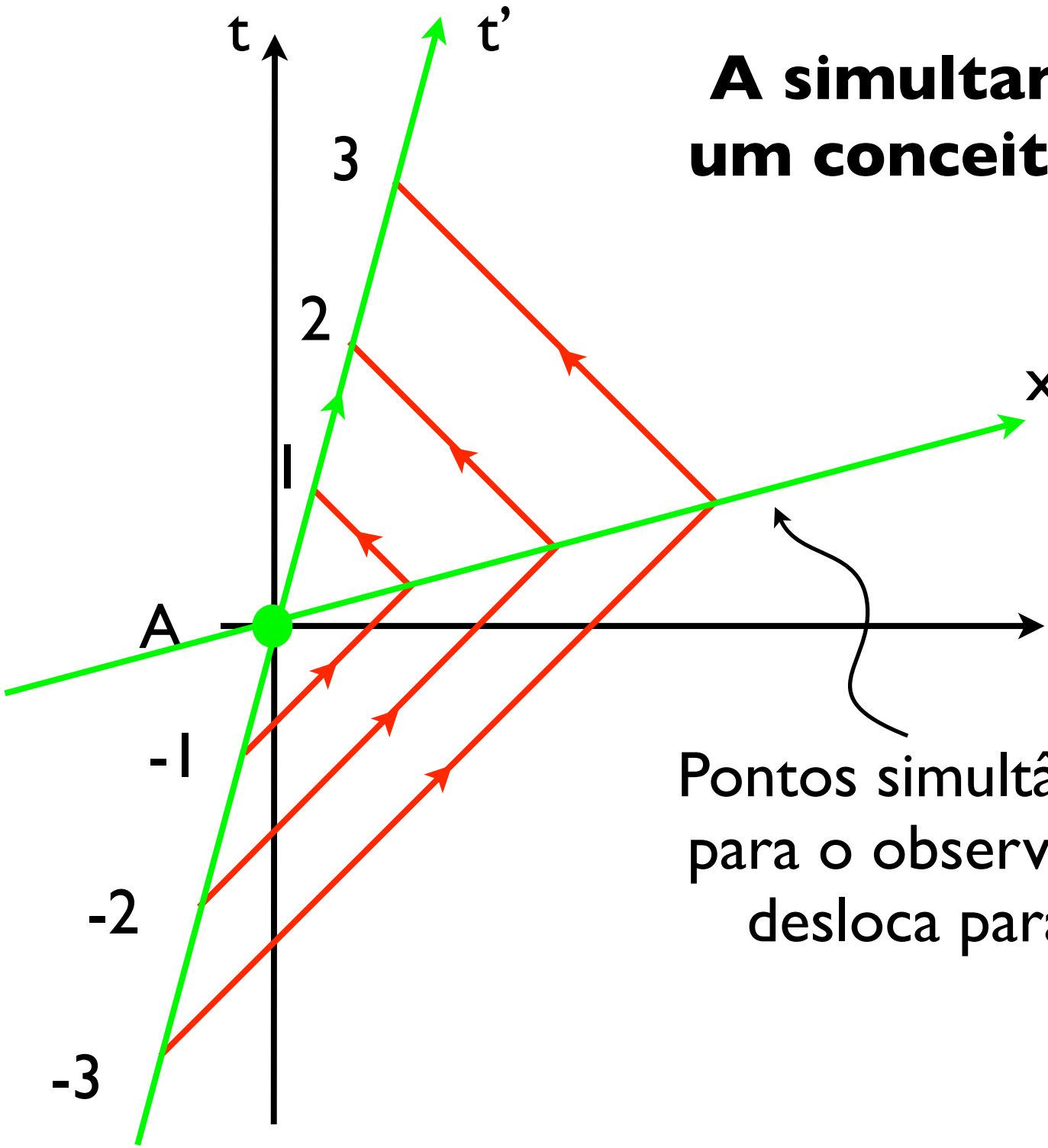
Deduzimos que P ocorreu no instante de tempo

$$t = t_1 + \frac{t_2 - t_1}{2} = \frac{t_1 + t_2}{2}$$

na posição

$$x = \frac{t_2 - t_1}{2}\, c$$

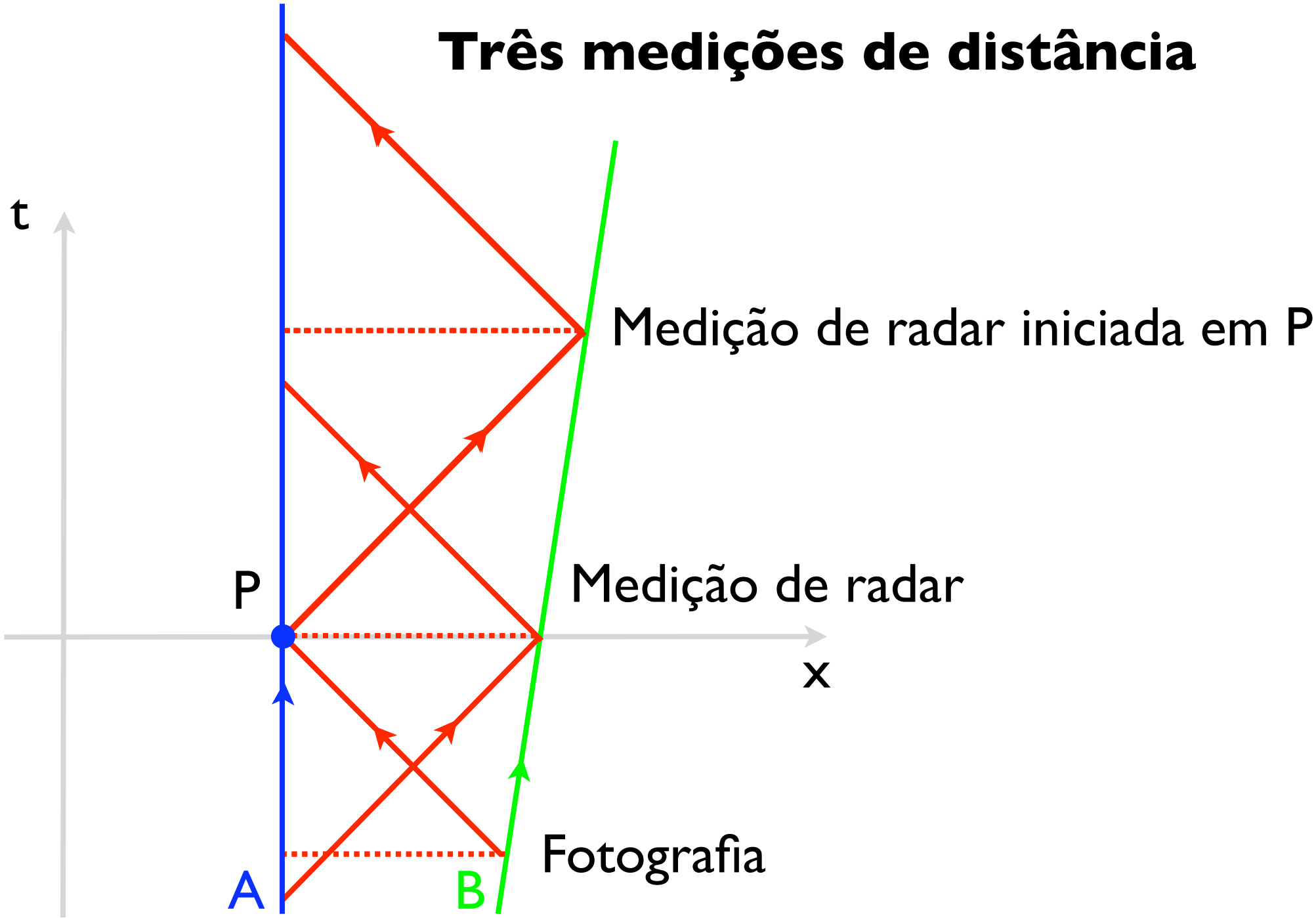

t
3
2
1
A
-1
-2
-3
x
Pontos
simultâneos
com A



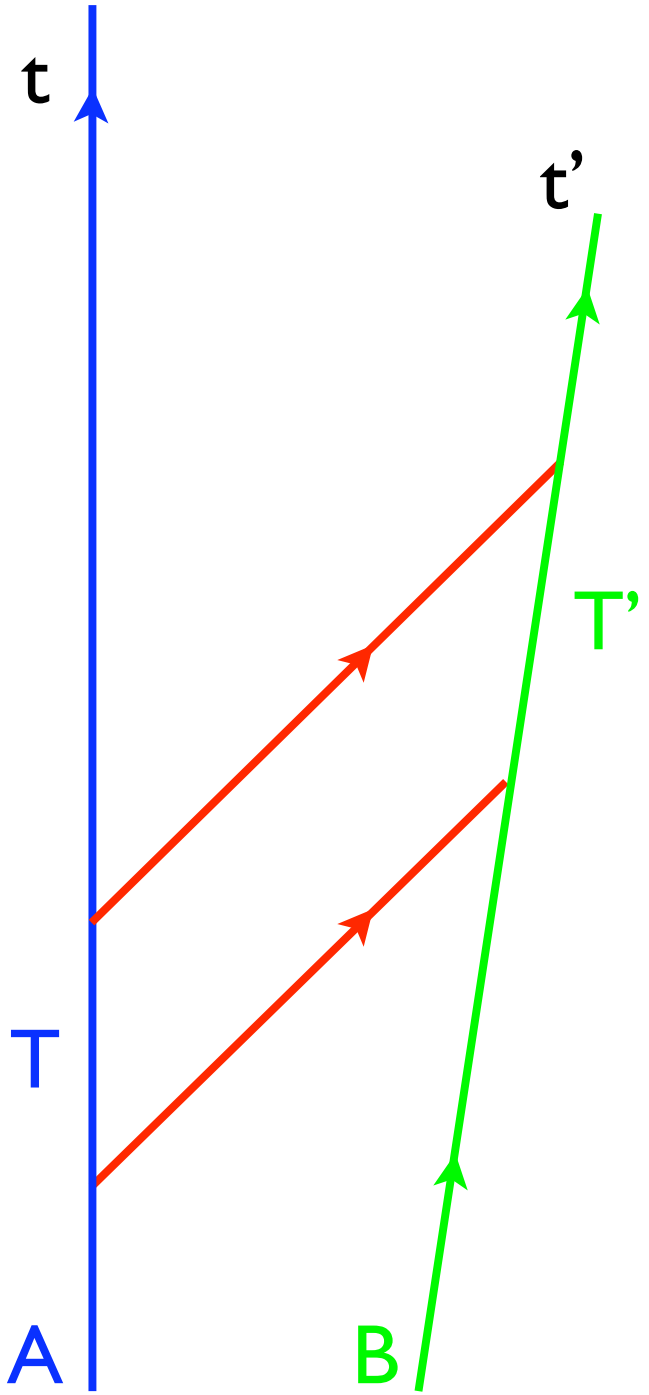
A simultaneidade é um conceito relativo

Pontos simultâneos com A para o observador que se desloca para a direita

Três medições de distância



Cálculo K



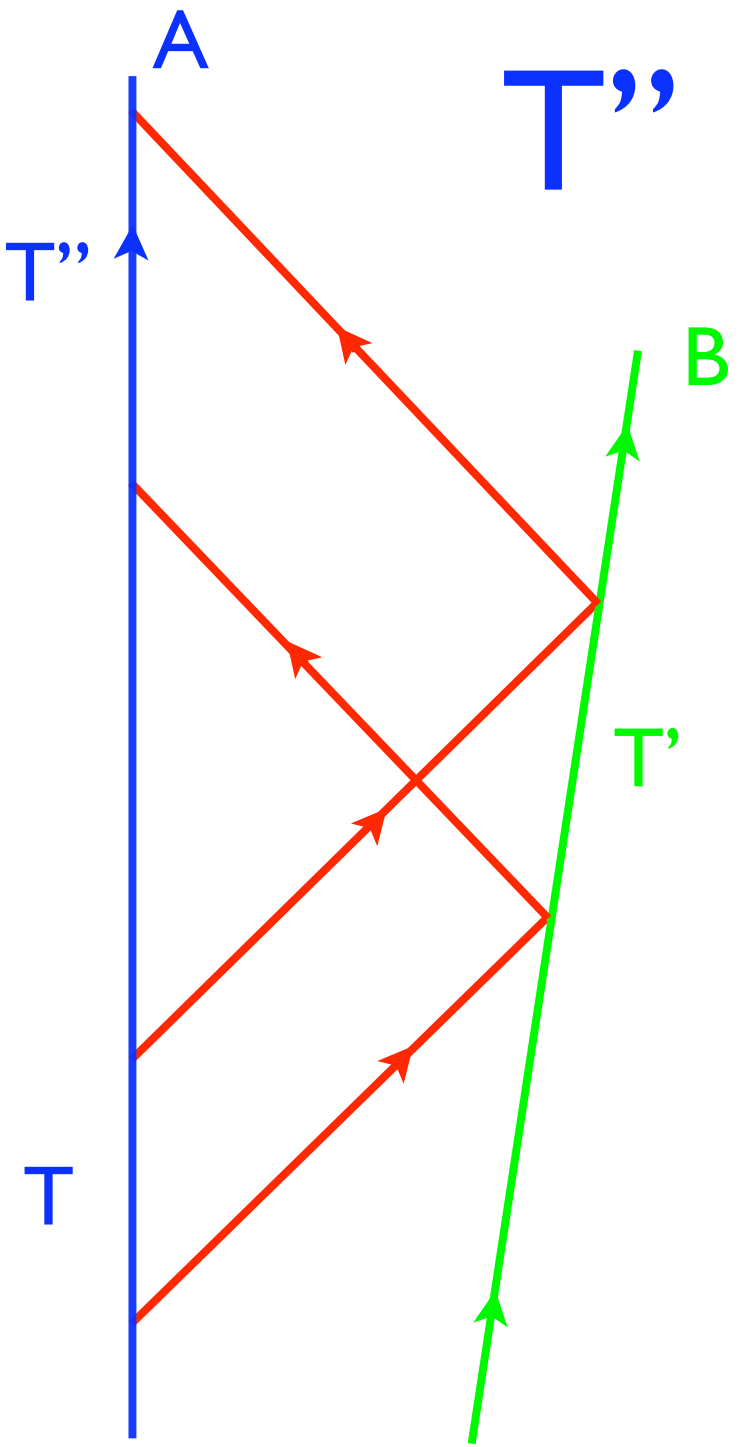
$$T' = K\,T$$

ou, melhor,

$$T_B = K_{BA}\,T_A$$

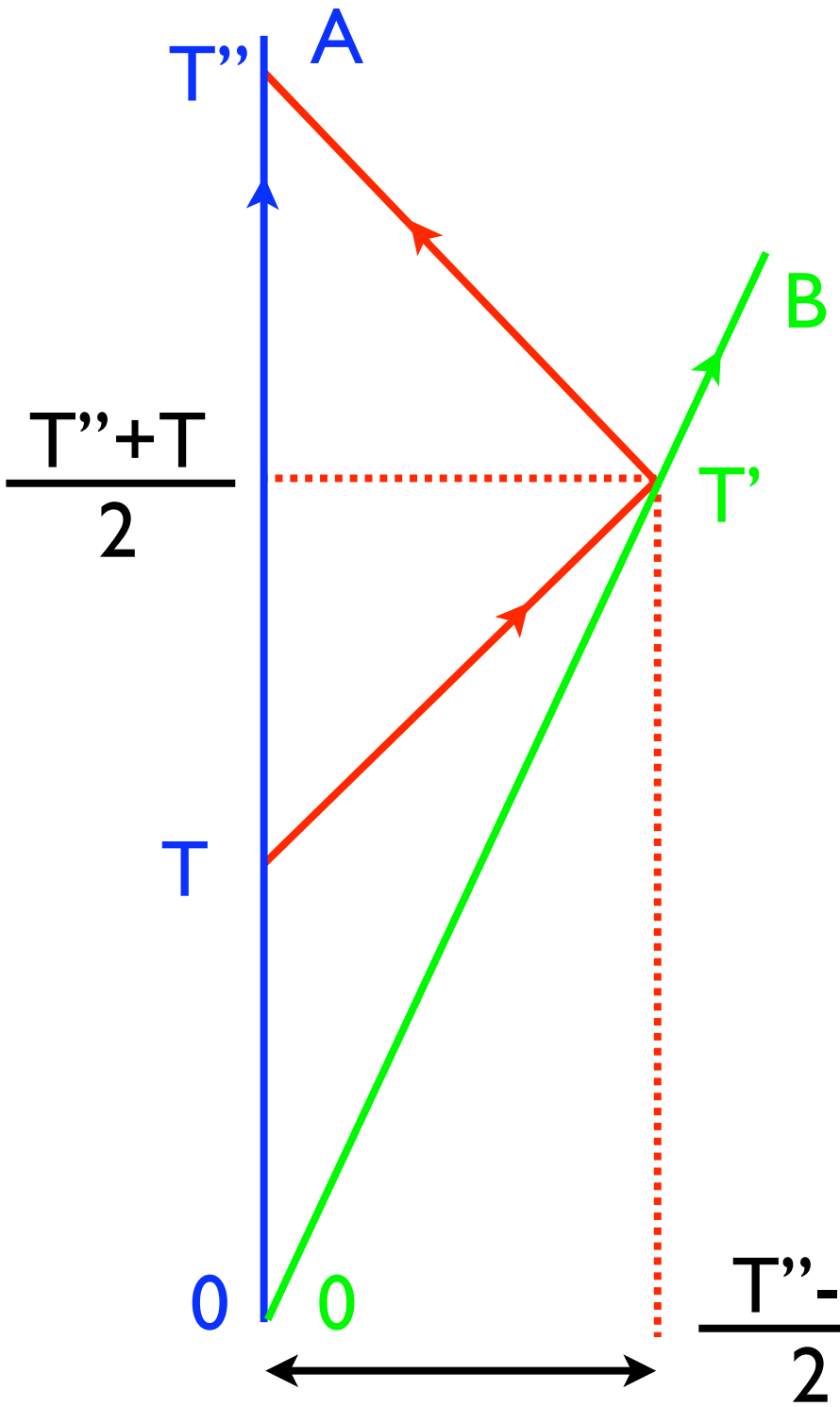
Princípio da Relatividade:

$$K_{AB} = K_{BA} = K$$



$$T'' = KT' = K(K\,T)$$

$$T'' = K^2\,T$$

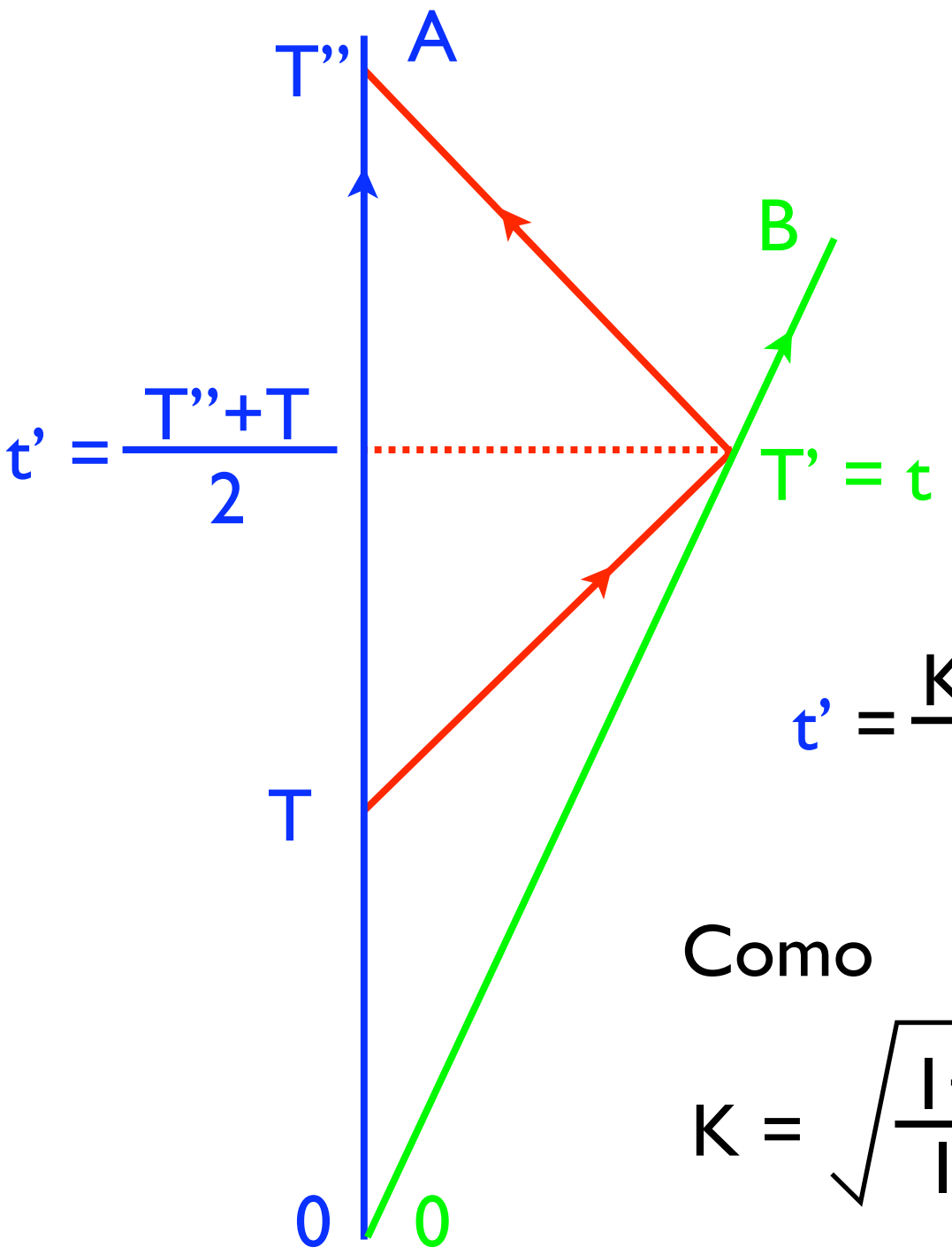


$$V = \frac{\frac{T''-T}{2}}{\frac{T''+T}{2}} c = \frac{K^2 T - T}{K^2 T + T} c$$

$$\frac{V}{c} = \frac{K^2 - 1}{K^2 + 1}$$

$$K = \sqrt{\frac{1+V/c}{1-V/c}}$$

Dilatação do Tempo



$T' = KT$ OK

$T'' = KT'$ OK

$t' = \frac{K^2 + 1}{2} T$ OK

$t' = \frac{K^2 + 1}{2K} t$ nada normal

Como

$K = \sqrt{\frac{1+V/c}{1-V/c}}$,

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Palavras chave

- Diagramas de Espaço-Tempo
- Velocidade da Luz
- Cone de Luz
- Adição de velocidades
- Postulado
- Dilatação do Tempo
- Distâncias e Simultaneidade
- Cálculo K
- Dilatação do Tempo

Imagens chave