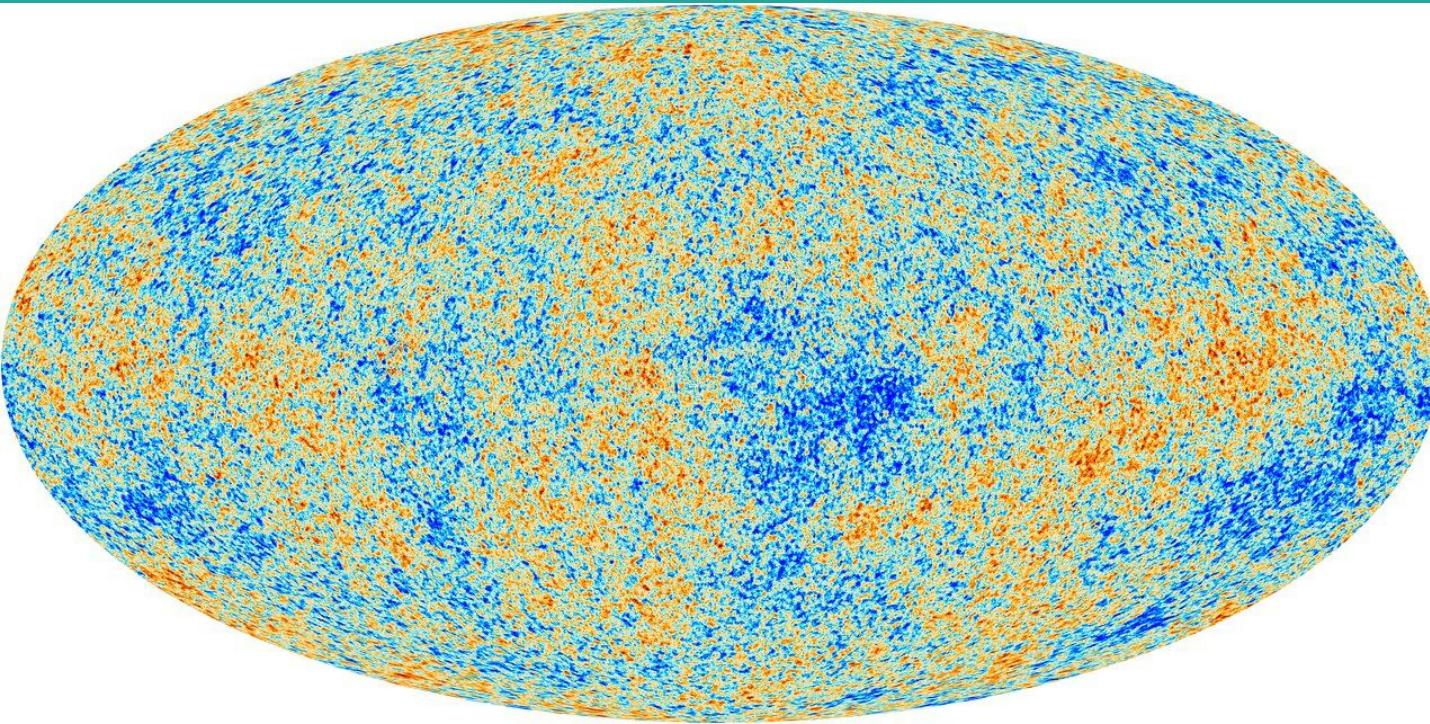
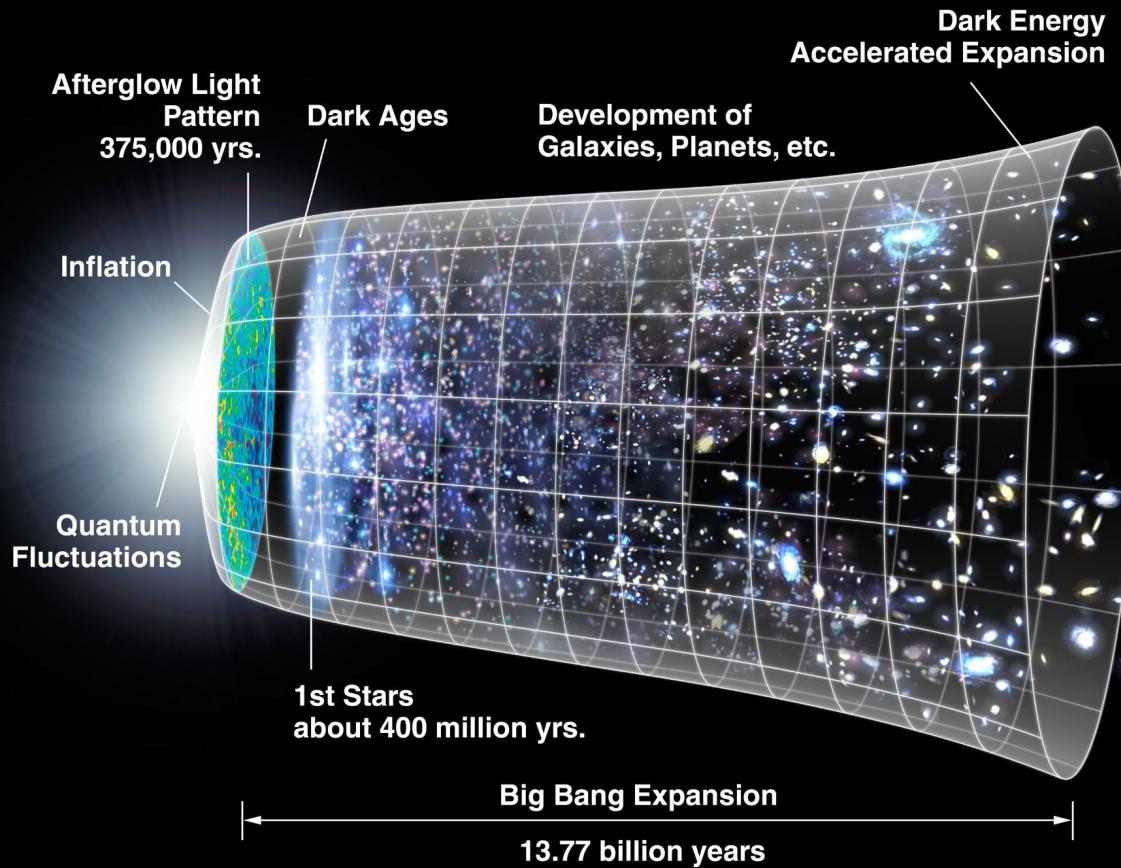


Introdução à Cosmologia: evolução dos conceitos e pesquisa



Lucas
James Faga

como chegamos aqui?





Vale a pena
fazer esse
curso man?

por que?

objetivos

1. primeiro contato com
cosmologia

não objetivos

por que?

objetivos

não objetivos

1. primeiro contato com
cosmologia
2. foco na complexidade e impacto
dos conceitos

por que?

objetivos

não objetivos

1. primeiro contato com cosmologia
2. foco na complexidade e impacto dos conceitos
3. visão ampliada sobre linhas de pesquisa e como elas dialogam

por que?

objetivos

1. primeiro contato com cosmologia
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3. visão ampliada sobre linhas de pesquisa e como elas dialogam

não objetivos

1. não vamos ensinar relatividade geral em 5 dias

por que?

objetivos

1. primeiro contato com cosmologia
2. foco na complexidade e impacto dos conceitos
3. visão ampliada sobre linhas de pesquisa e como elas dialogam

não objetivos

1. não vamos ensinar relatividade geral em 5 dias
2. não vamos substituir um curso formal de Cosmologia Física

por ~~euro~~²

Advinha qual deles fez o curso

1. prime
cosmo
2. foco n
dos co
3. visão
pesqu



elatividade
um curso
a Física

#Darkbites

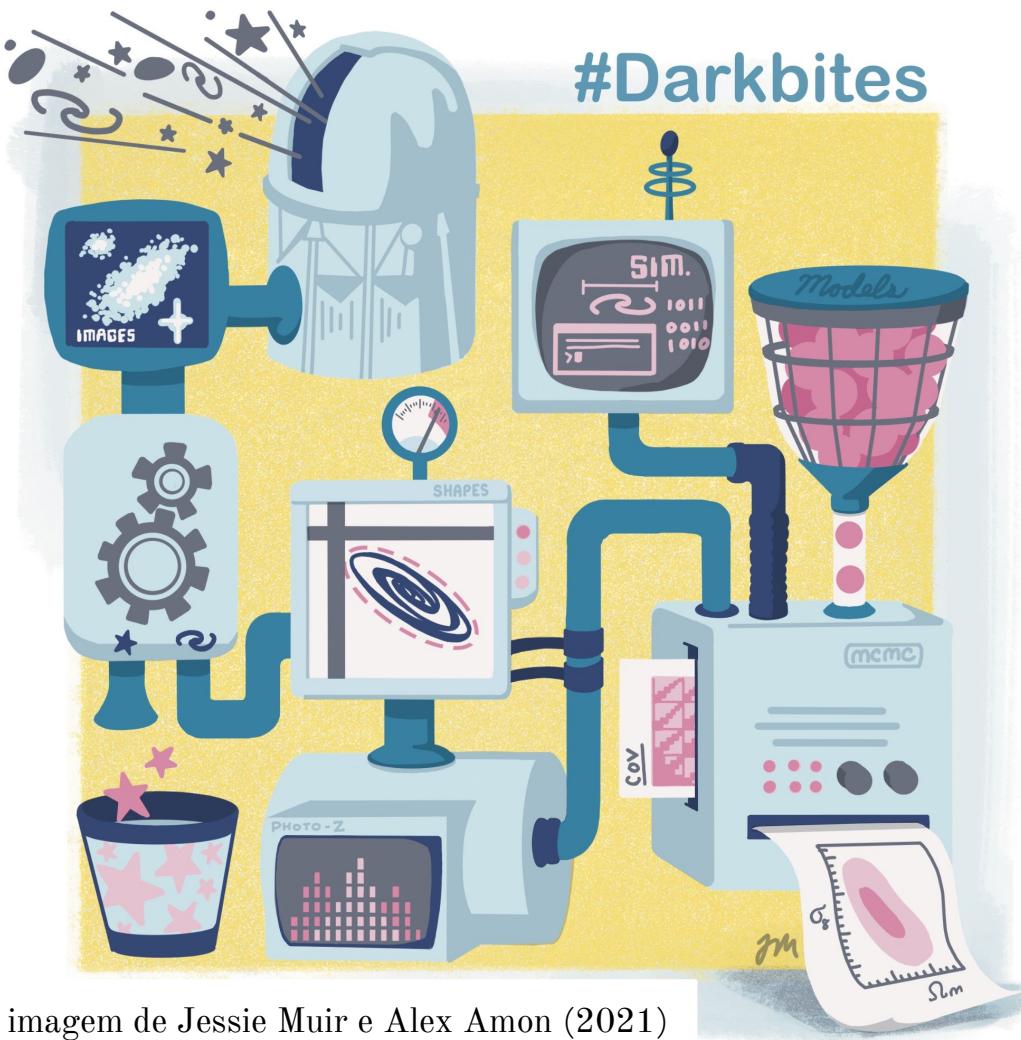


imagem de Jessie Muir e Alex Amon (2021)

instrumentação

observação

tratamento de dados

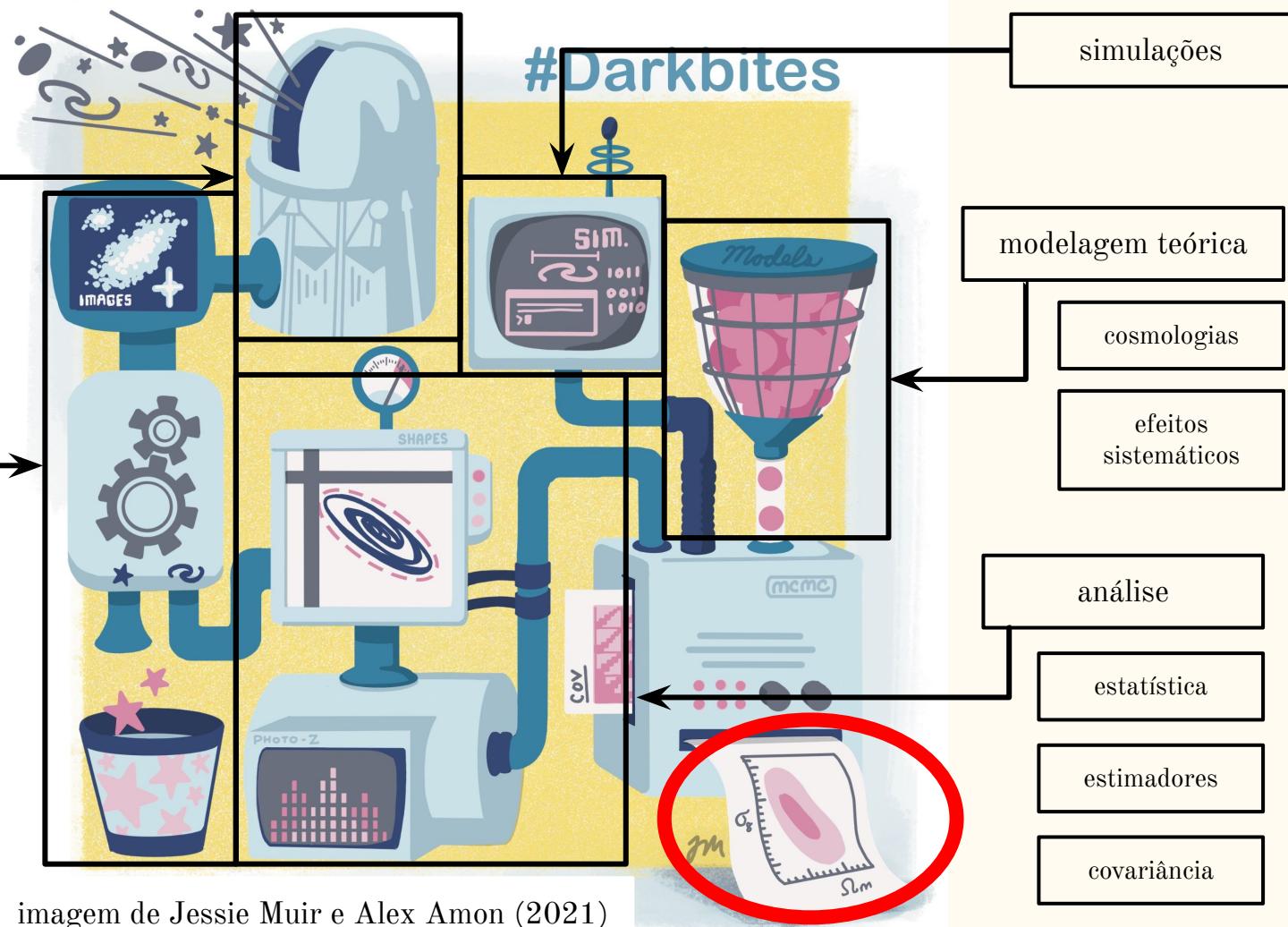


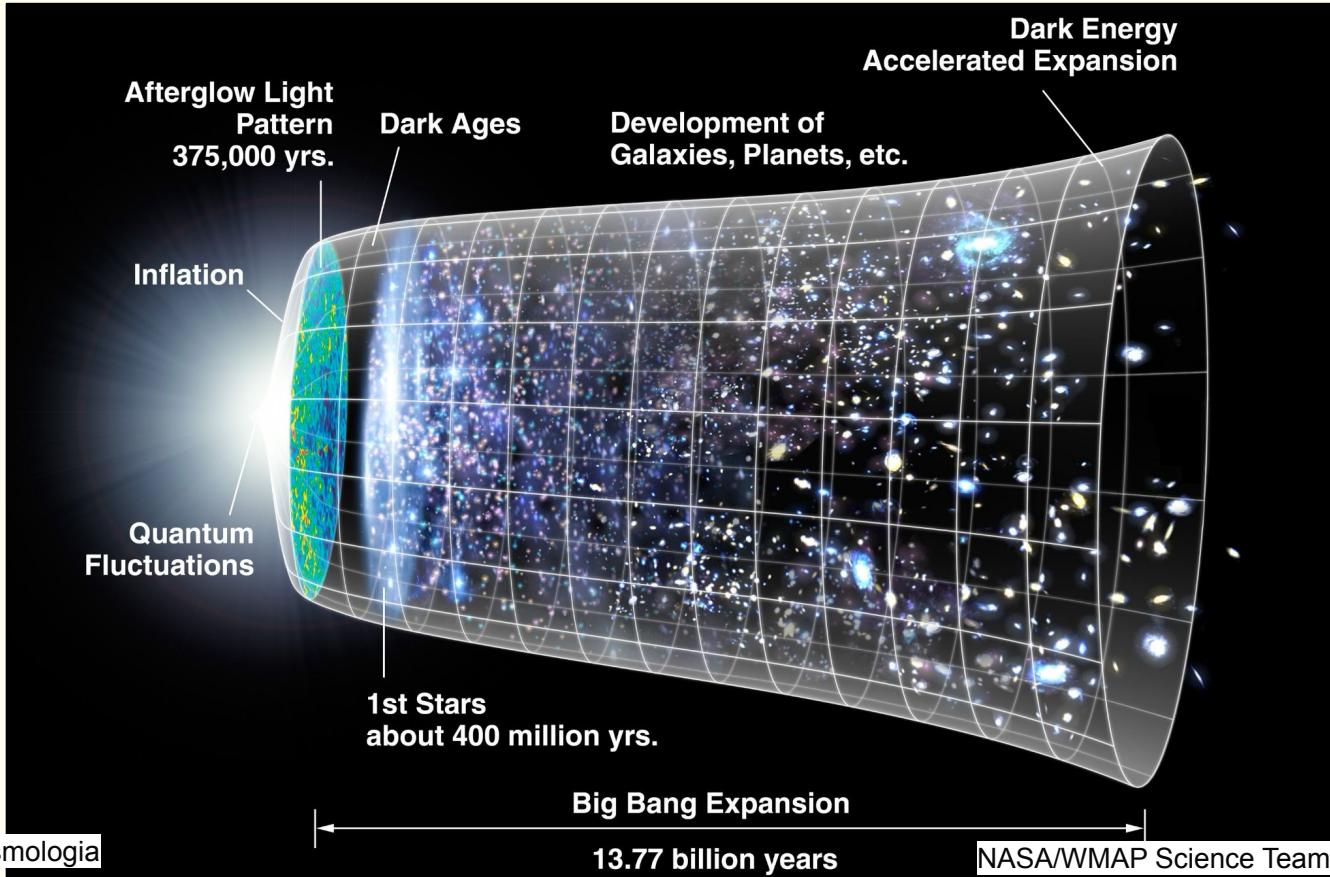
imagem de Jessie Muir e Alex Amon (2021)

O que são cosmologias?

São teorias do mundo. Da ordem do mundo, do movimento no mundo, no espaço e no tempo, no qual a humanidade é apenas um dos muitos personagens em cena.

Cosmologias definem o lugar que os humanos ocupam no cenário total [...]

Na vida cotidiana, essas concepções orientam, dão sentido, permitem interpretar acontecimentos e ponderar decisões.

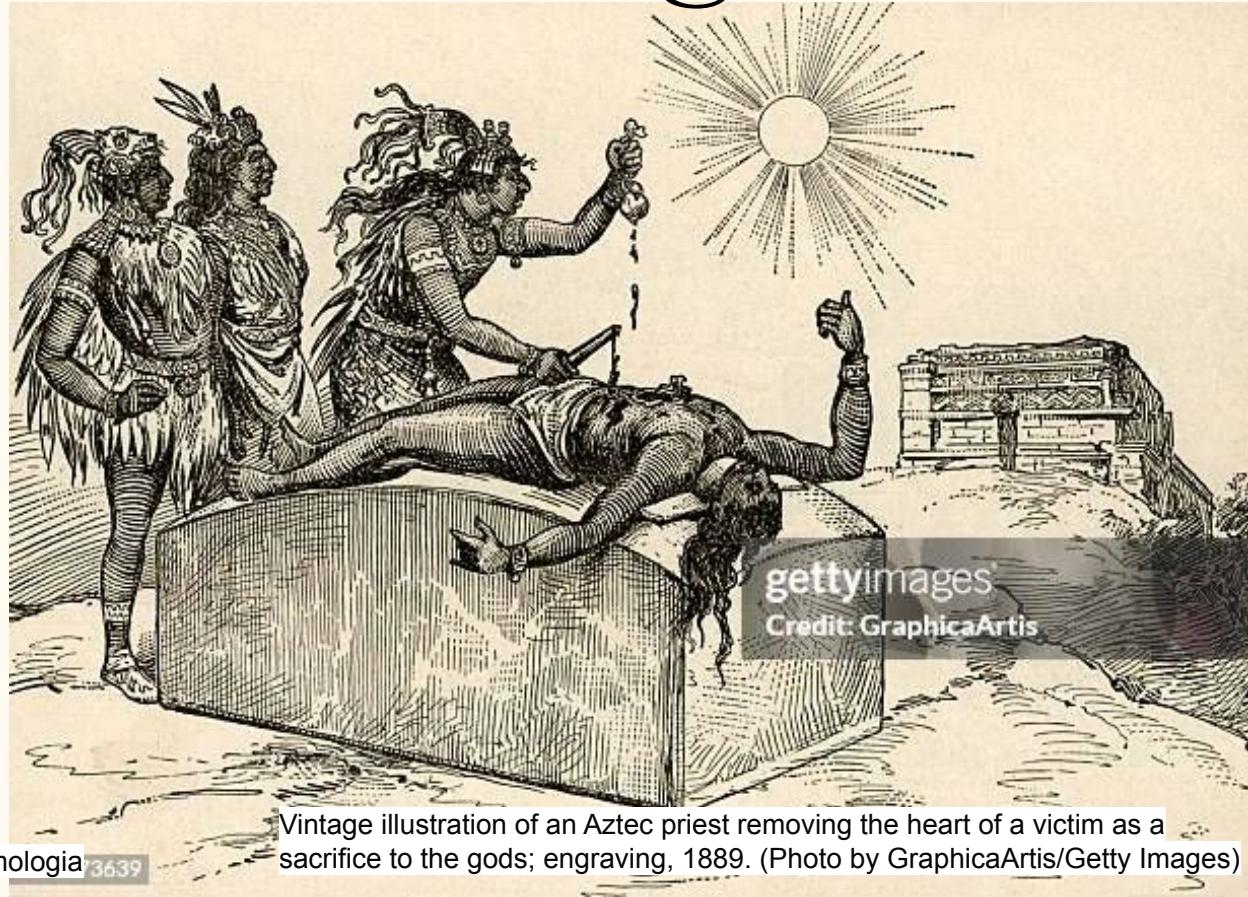


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São teorias do mundo. Da ordem do mundo, do movimento no mundo, no espaço e no tempo, no qual a humanidade é apenas um dos muitos personagens em cena.

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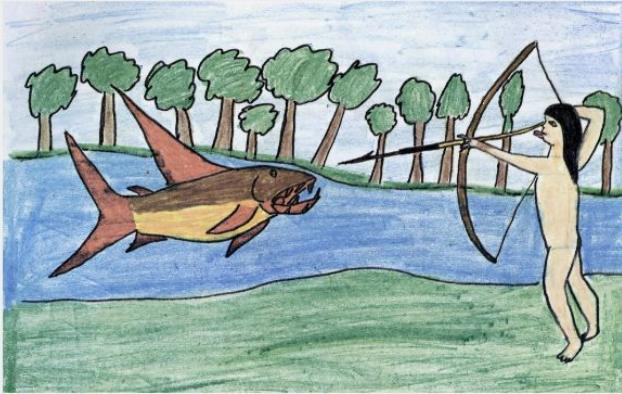
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Vintage illustration of an Aztec priest removing the heart of a victim as a sacrifice to the gods; engraving, 1889. (Photo by GraphicaArtis/Getty Images)

Cosmo logias br

Povos Jê



Tempty Suiá, retirado do mito /Como Aconteceu Antes dos Brancos Chegarem. Fonte: Livro de História / Professores Indígenas do Parque Indígena do Xingu. Vol. 1. São Paulo: Instituto Socioambiental; Brasília: MEC, 1998(p.03).

Entre povos da família lingüística Jê, o cosmos é concebido como habitado por diferentes humanidades - a subterrânea, a terrestre, a subaquática e a celeste – que existem desde sempre. O tempo das origens é o da indiferenciação e da desordem, da convivência e da interpenetração daqueles domínios. Astros, como o Sol e a Lua, são gêmeos primordiais que vivem aventuras na terra e aqui deixam o seu legado, antes de partirem para sua morada eterna. Nos mitos Jê, há

referências explícitas às atividades de subsistência e às práticas sociais de modo geral. Instituições sociais – a nomeação dos indivíduos, a guerra, o xamanismo... – têm no mito descritas as suas origens e exposta a sua essência.

cosmo logias br

Povos do Alto Rio Negro



Cobra Grande pintada sobre maloca no Alto Rio Negro. Foto: Beto Ricardo

Por contraste, caberia mencionar, a região do alto rio Negro, o noroeste amazônico, morada de povos de língua Tukano. No início dos tempos, antepassados míticos criaram o mundo que, antes, não existia. Das entradas de uma cobra grande ancestral, que fazia o percurso do rio, saíram, em pontos precisos daquele percurso, os primeiros antepassados de cada um dos vários povos da região,

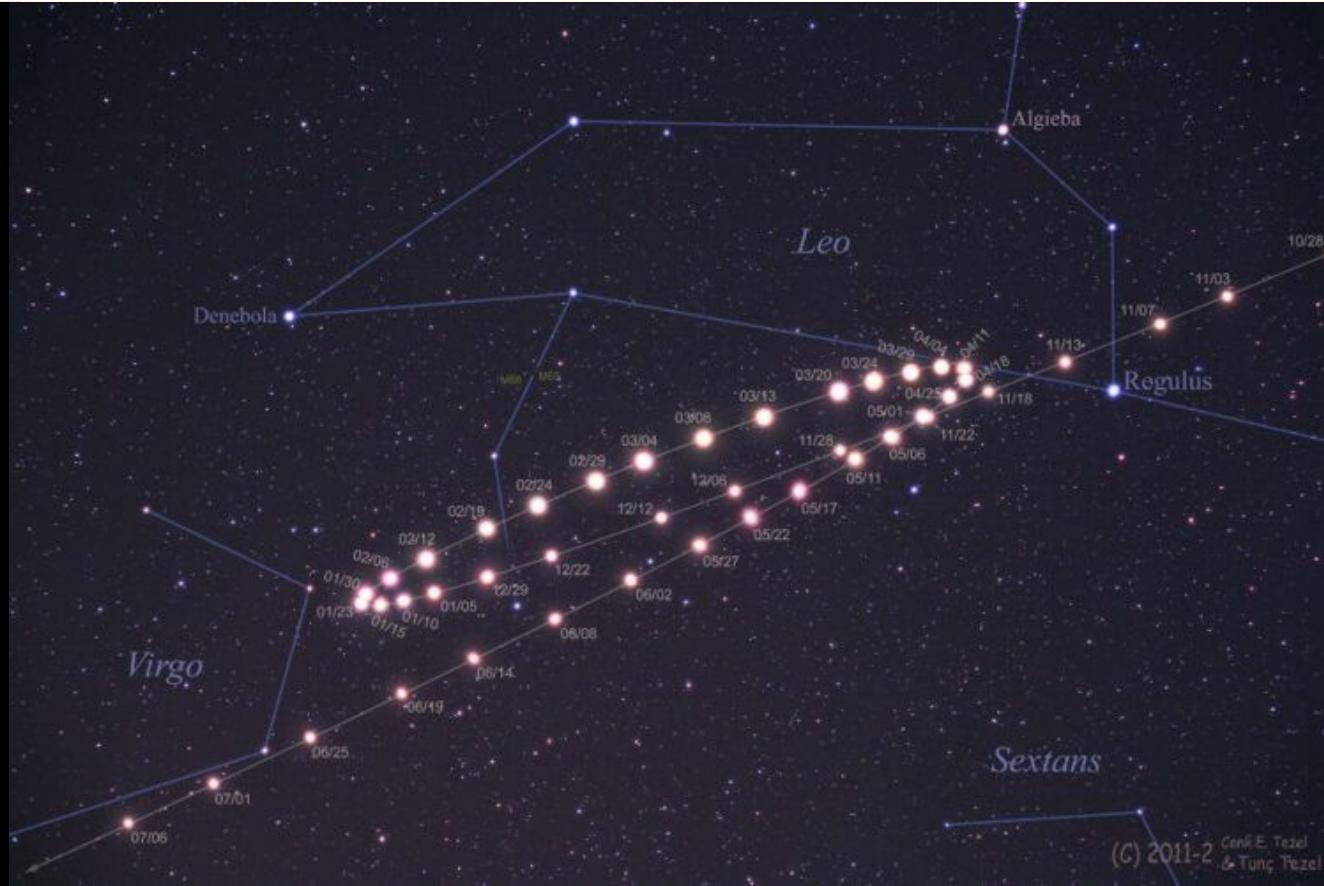
determinando, assim, seus respectivos territórios, suas atribuições específicas e um padrão hierarquizado de relacionamento entre eles.

Em muitas cosmologias, as relações entre humanos e os demais seres são pensadas através da idéia da predação, numa metáfora que simbólica e logicamente aproxima caça, guerra, sexo e comensalidade. Ainda no alto rio Negro, o xamã parece estar encarregado de garantir que fluxos e volumes de energia vital compartilhada por humanos e animais mantenham-se em níveis adequados. Exageros na matança de animais deflagrariam, como contrapartida, epidemias e malefícios entre os homens, provocados por espíritos protetores dos animais. Um equilíbrio vital nas lembranças e o convívio com a idéia da morte são experiências diárias na apreciação e na condução da vida.

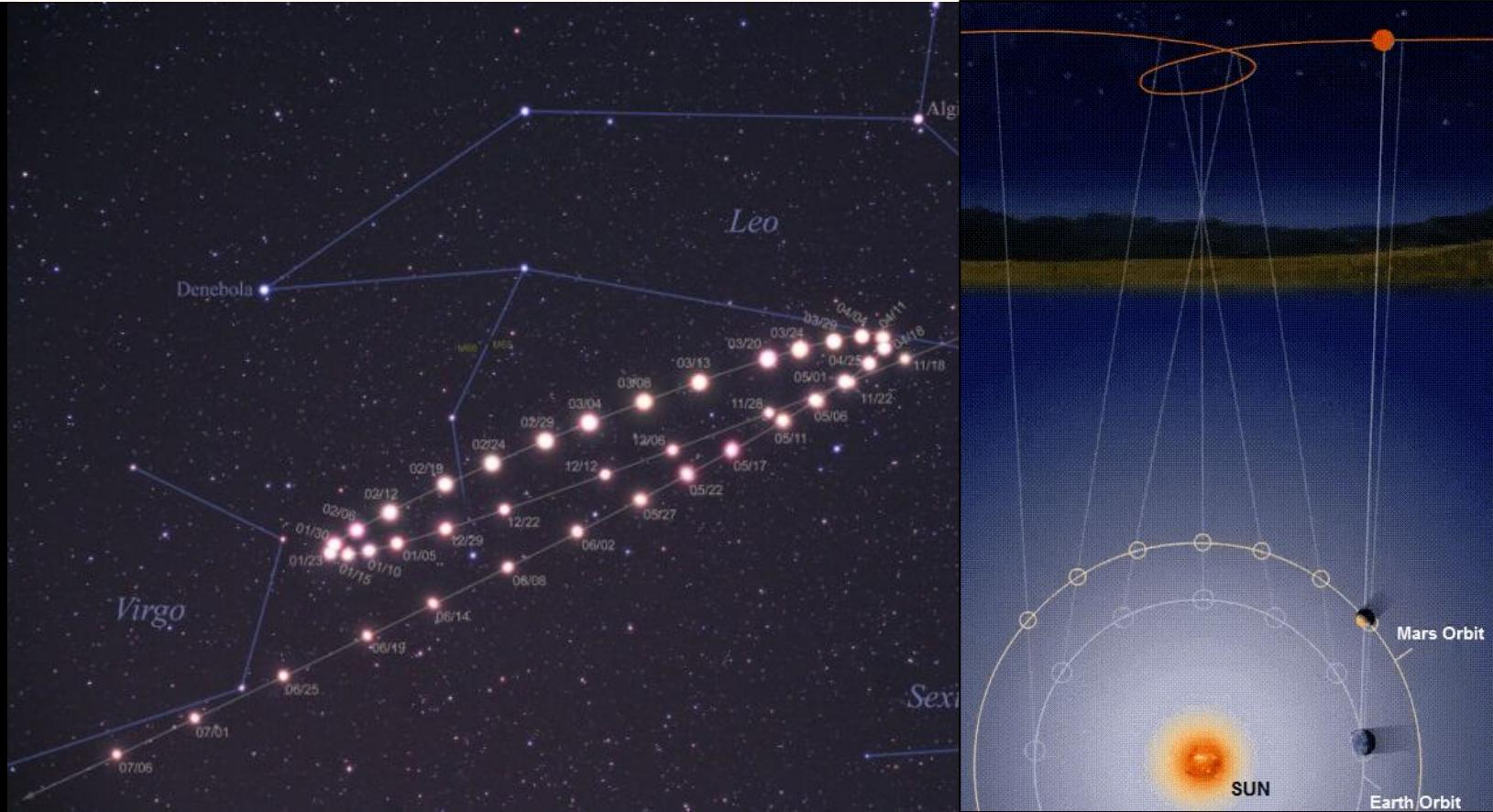
Parte 1

Universos-ilhas, relatividade e implicações cosmológicas

revolução copernicana

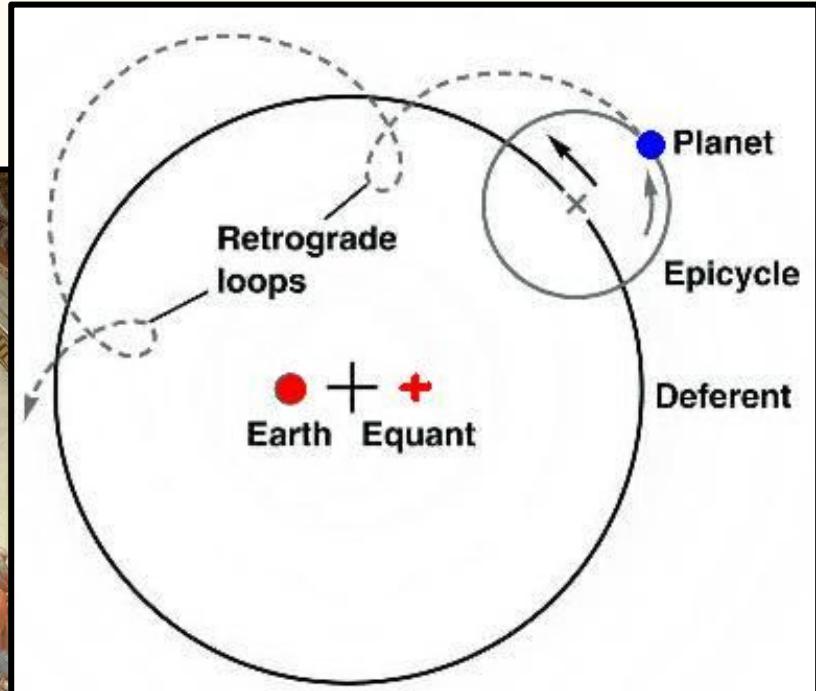


revolução copernicana



revolução copernicana

(séc II)

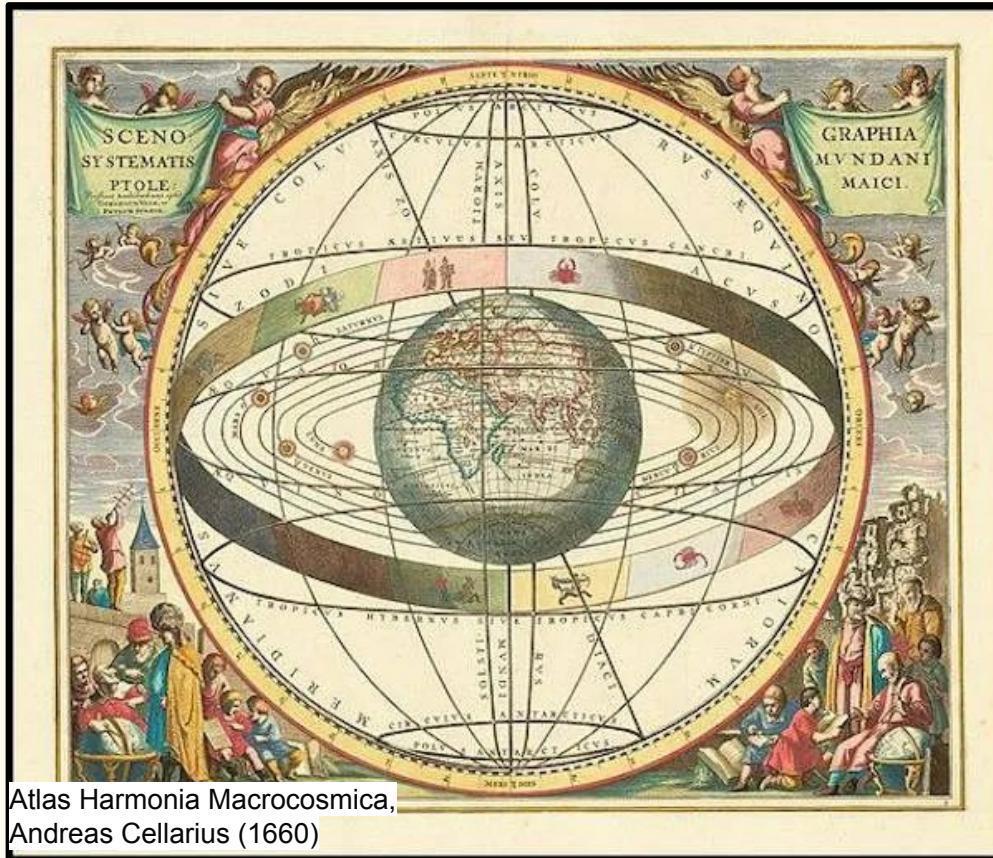


A escola de Atenas,
Rafael (1509)

revolução copernicana

(séc II)

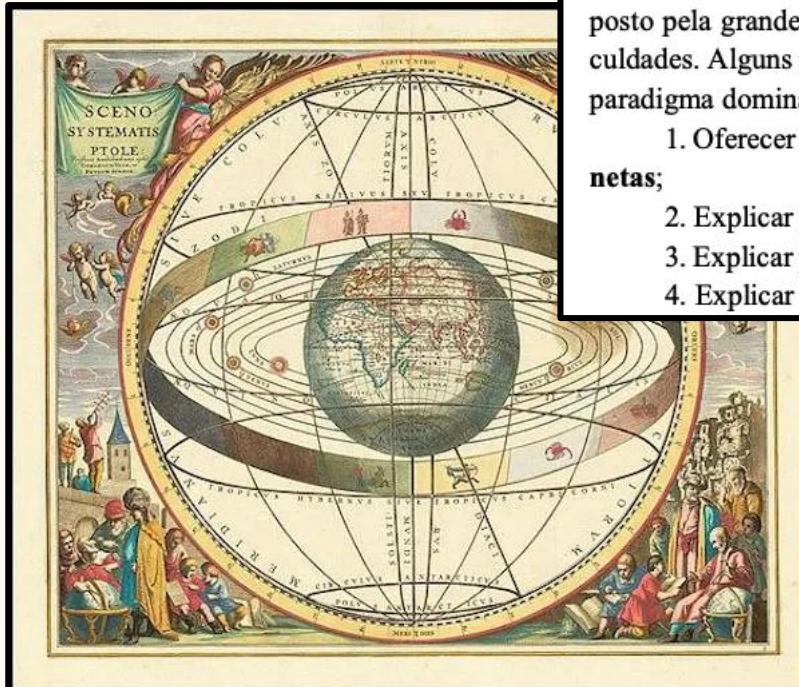
(séc XVI)



revolução copernicana

(séc II)

(séc XVI)



Atlas Harmonia Macrocosmica,
Andreas Cellarius (1660)

5.1. A proposta de Nicolau Copérnico

À época de Copérnico o sistema aristotélico-ptolomaico, apesar de aceito e imposto pela grande maioria dos estudiosos de astronomia, enfrentava uma série de dificuldades. Alguns problemas não podiam ser resolvidos dentro das condições dadas pelo paradigma dominante. Eis alguns deles:

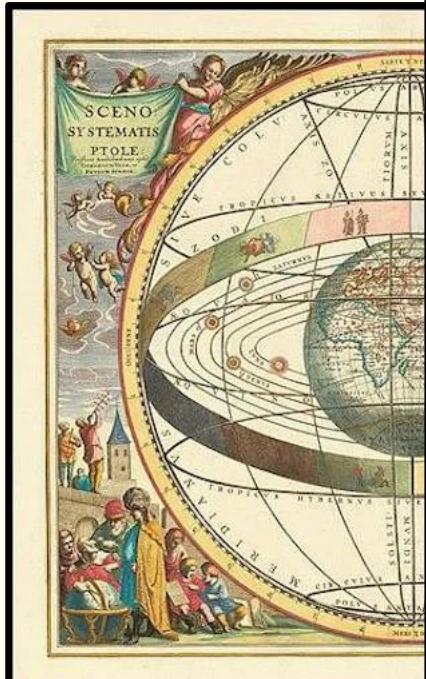
1. Oferecer uma explicação convincente sobre o **movimento retrógrado dos planetas**;
2. Explicar porque Vênus e Mercúrio sempre são vistos nas proximidades do Sol;
3. Explicar porque Marte, Júpiter e Saturno podiam ser vistos em oposição ao Sol;
4. Explicar a ordem de afastamento dos planetas com relação ao Sol.

Notas de aula de gravitação, João Zanetic (2019)

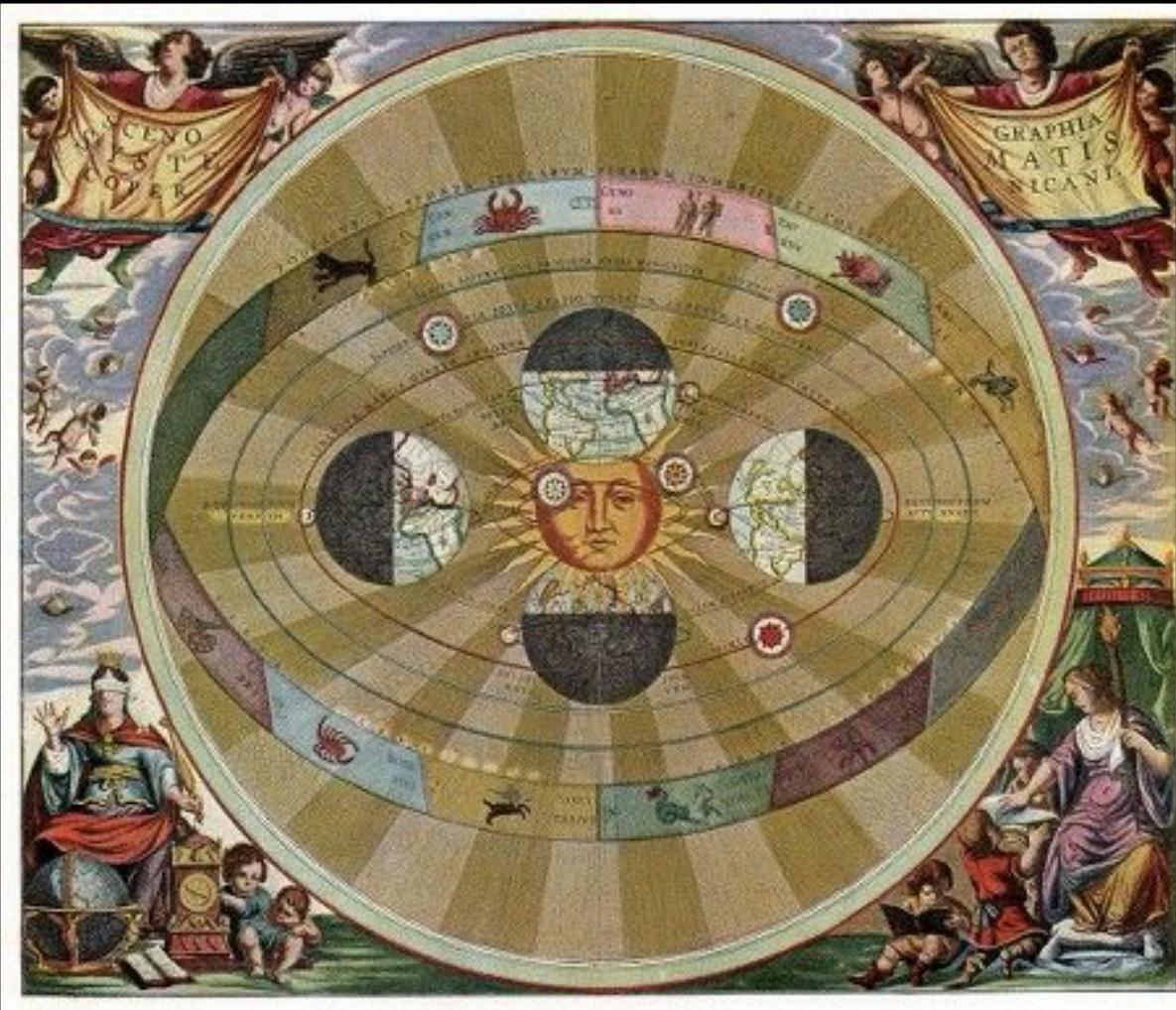
revolução

(séc II)

(séc XVI)



Atlas Harmonia Macrocosmica,
Andreas Cellarius (1660)

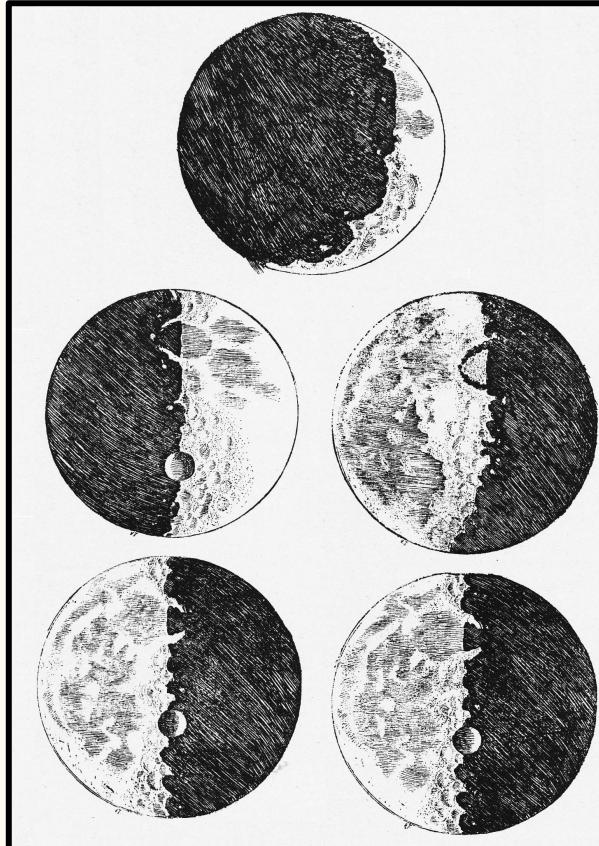


estruturação da ciência

(séc II)

(séc XVI)

(séc XVII)



Observações Jovianas			
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3. mês		** O *	
2. febr.		O * *	*
3. mês		O * *	
3. Ho. 5.		* O *	
4. mês		* O **	
6. mês		** O *	
8. mês H. 13.		*** O	
10. mês		* * * O *	
11.		* * O *	
12. H. 4. mês		* O *	
13. mês		* ** O *	
14. febr.		* * O *	

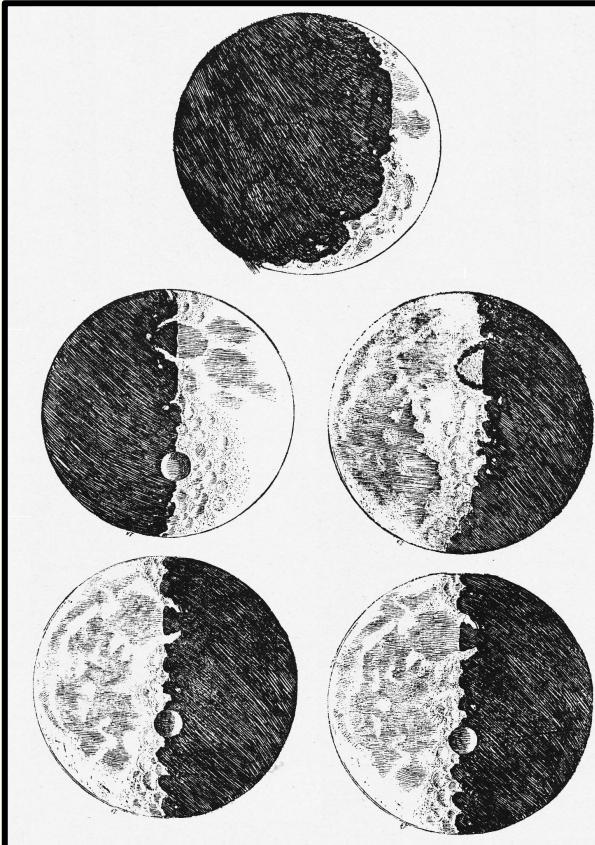
Observações de
Galileu Galilei (1564 – 1642)

estruturação da ciência

(séc II)

(séc XVI)

(séc XVII)



"Enquanto Galileu se limita a interpretar com a ajuda de esquemas geométricos precisos as manchas lunares como indicadores do relevo, Kepler salta imediatamente mais adiante a imaginar selenitas, a conjecturar qual seria a constituição corporal e inclusive a explicar-nos seus planos urbanísticos (...) Inclusive vaticina viagens espaciais, e em seu postumamente publicado, *Sonho*, oferece-nos uma verdadeira obra de ficção científica."¹⁷⁵

6. manc.	*	*	O	*
8. manc. H. 17.	*	*	*	O
10. manc.	*	*	*	O
11.	*	*	O	*
12. H. queijo:	*		O	*
13. manc.	*	*	O	*
14. casc.	*	*	O	*

Considerações sobre Descartes,
Alexandre Koyré (1980)

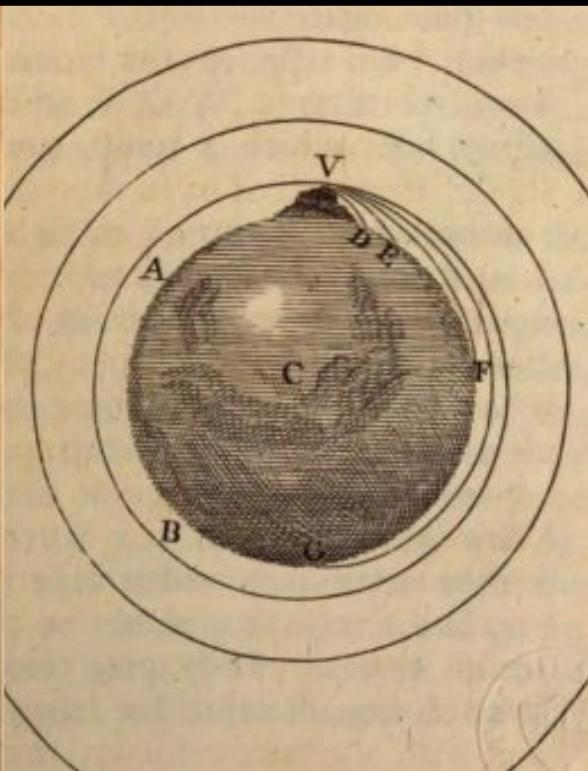
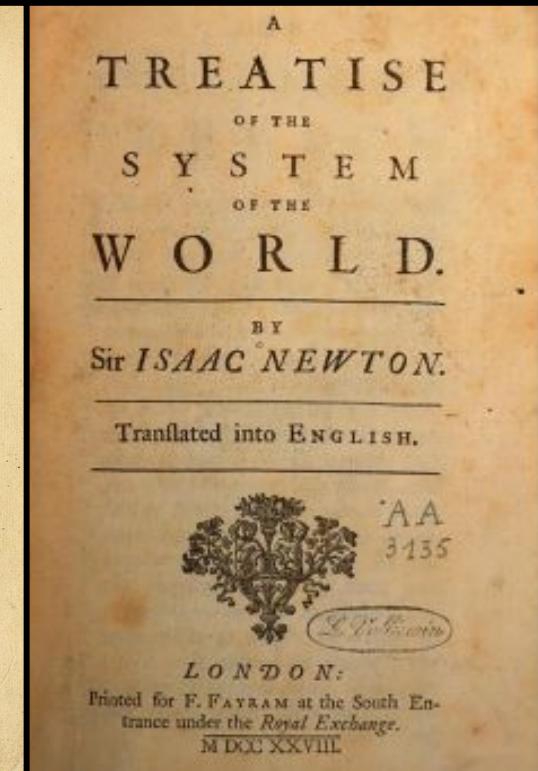
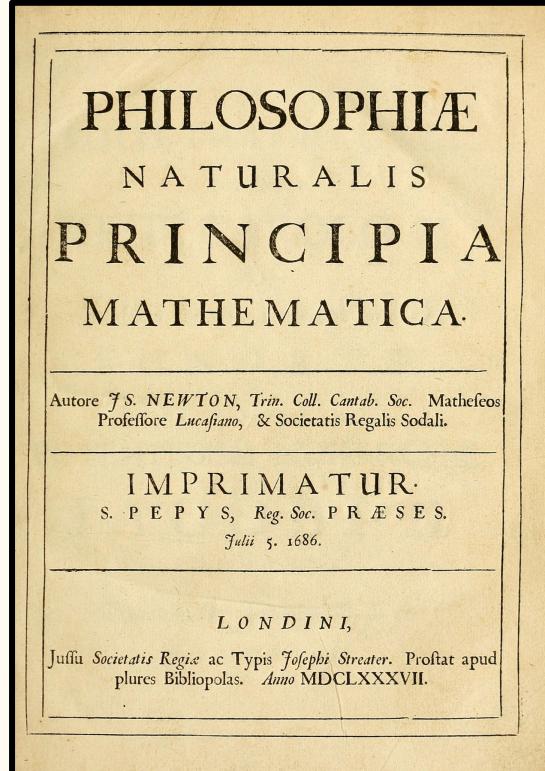
Observações de
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estruturação da ciência

(séc II)

(séc XVI)

(séc XVII)

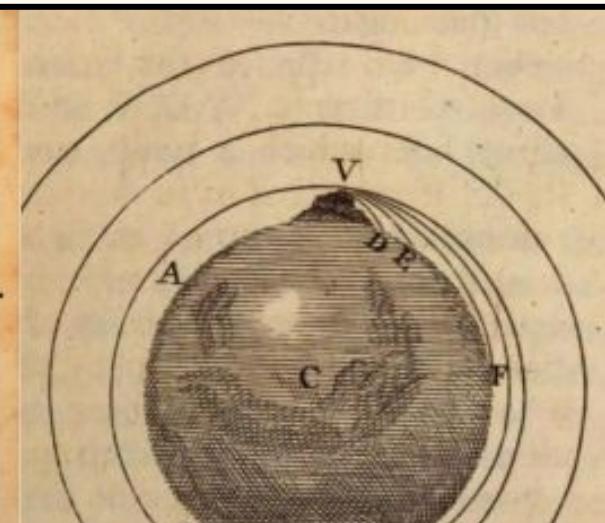
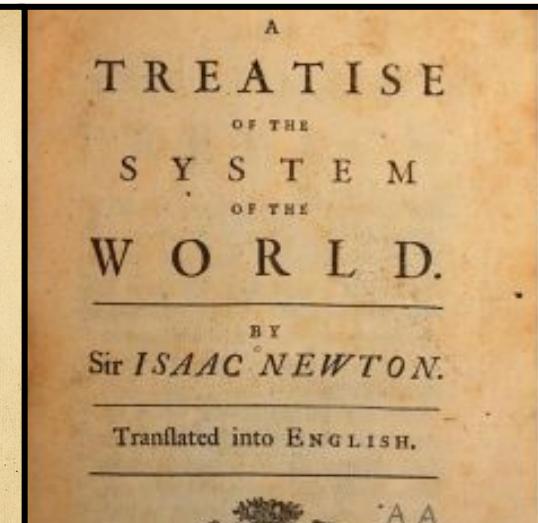
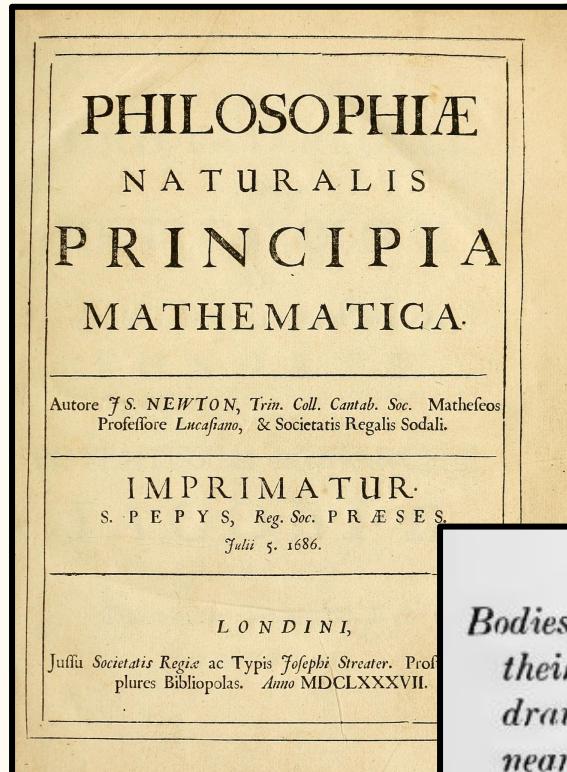


estruturação da ciência

(séc II)

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(séc XVII)

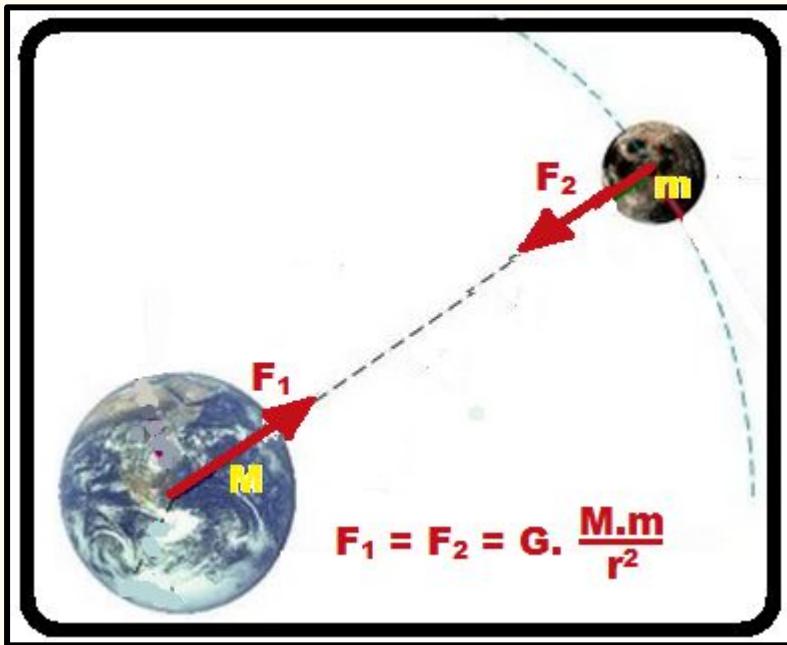


PROPOSITION LXV. THEOREM XXV.

Bodies, whose forces decrease in a duplicate ratio of their distances from their centres, may move among themselves in ellipses; and by radii drawn to the foci may describe areas proportional to the times very nearly.

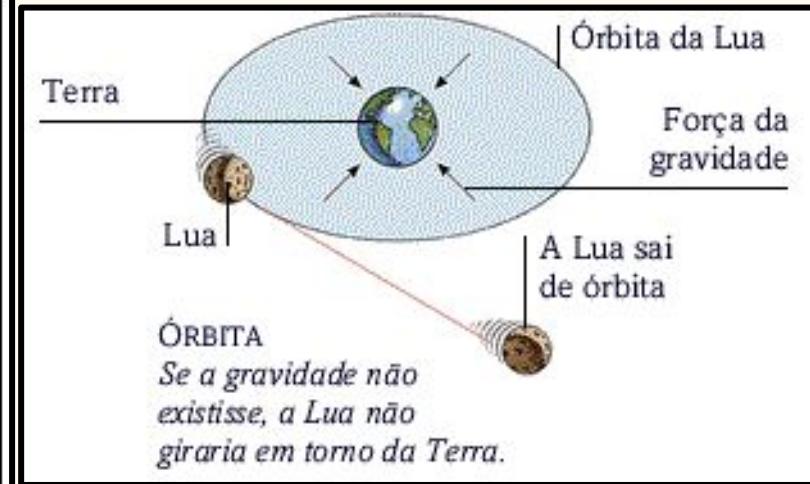
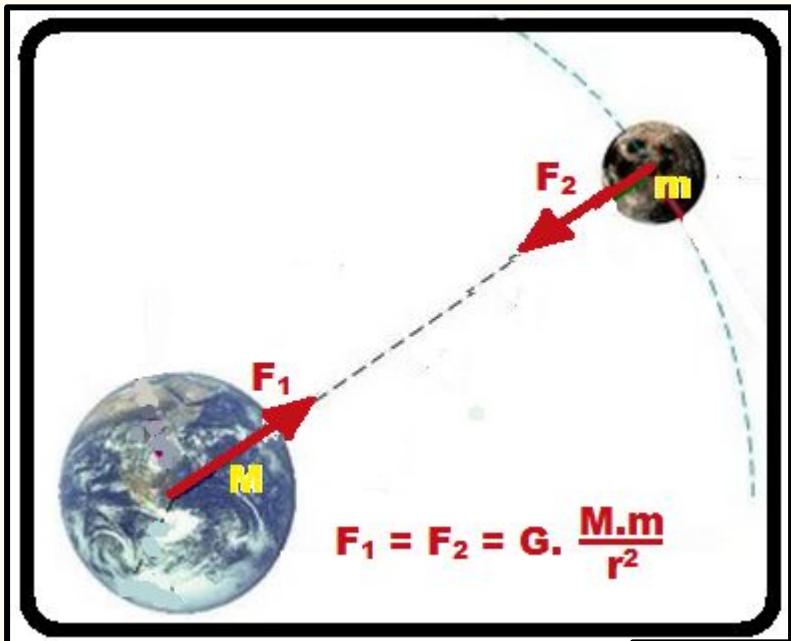
estruturação da ciência

(séc II)
(séc XVI)
(séc XVII)



estruturação da ciência

(séc II)
(séc XVI)
(séc XVII)



"I have not yet been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses (hypotheses non fingo)."

???

Principia,
Isaac Newton (1713)

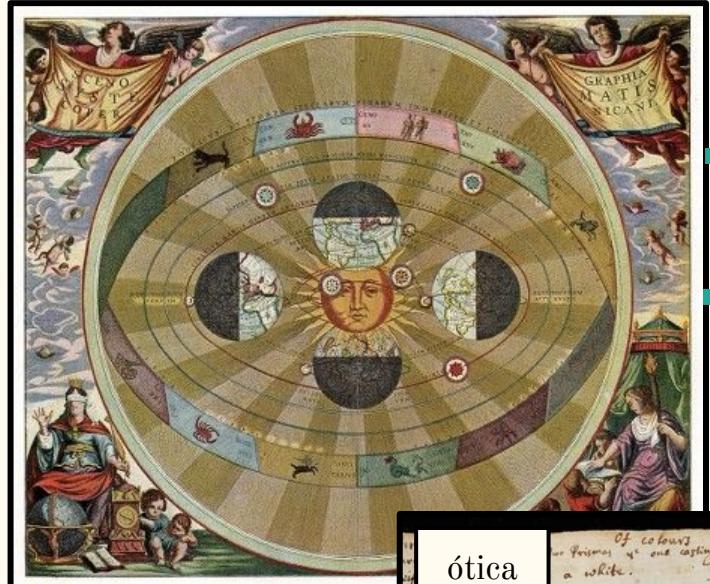
estruturação da ciência

(séc II)

(séc XVI)

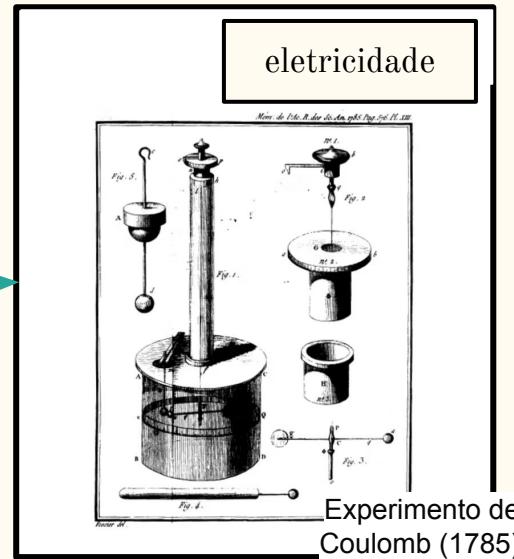
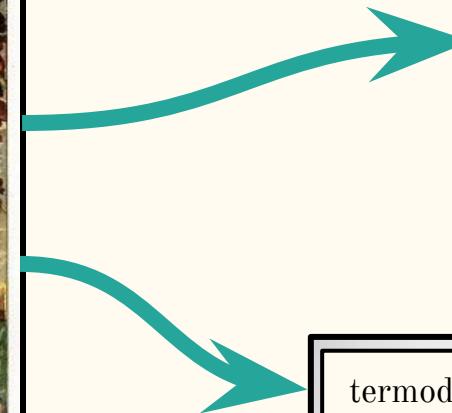
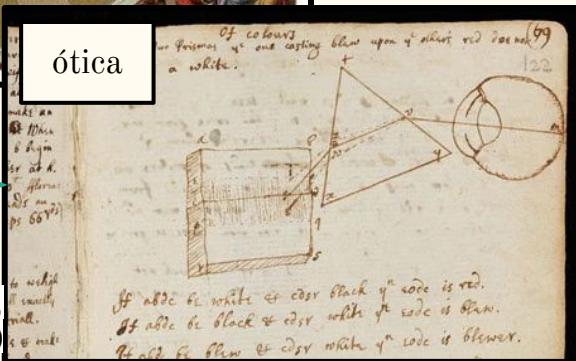
(séc XVII)

(séc XVIII)



Principia,
Isaac Newton (1713)

ótica



eletrocidade

Experimento de Coulomb (1785)

termodinâmica



Primeira locomotiva (1804)

estruturação da ciência

(séc II)

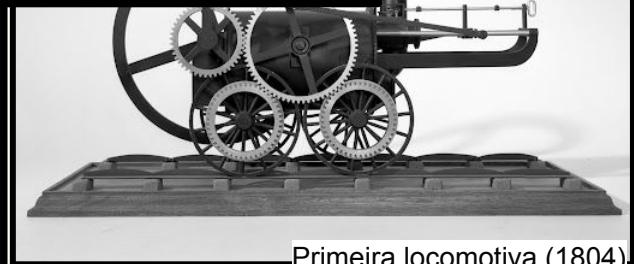
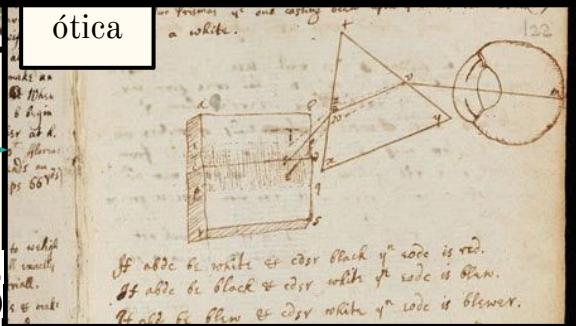
(séc XVI)

(séc XVII)

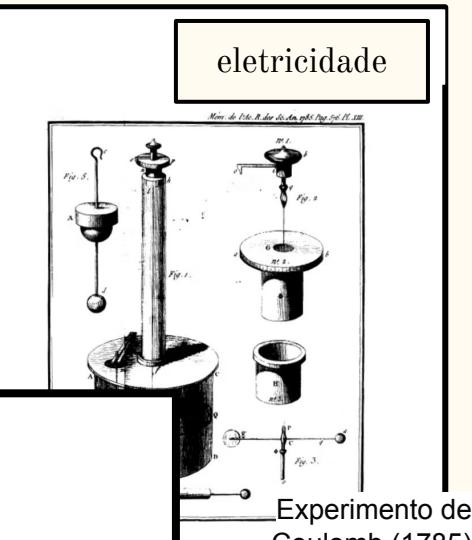
(séc XVIII)



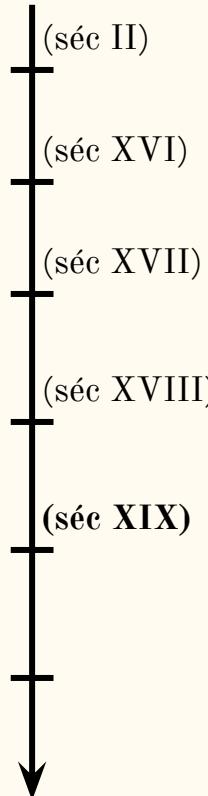
Principia,
Isaac Newton (1713)



Primeira locomotiva (1804)



eletromagnetismo



$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t}$$

[A Dynamical Theory of the Electromagnetic Field](#),

James Clerk Maxwell (1865)

eletromagnetismo

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

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Between these twenty quantities we have found twenty equations, viz.

Three equations of Magnetic Force (B)

“ Electric Currents (C)

“ Electromotive Force (D)

“ Electric Elasticity (E)

“ Electric Resistance (F)

“ Total Currents (A)

One equation of Free Electricity (G)

“ Continuity (H)

These equations are therefore sufficient to determine all the quantities which occur in them, provided we know the conditions of the problem. In many questions, however, only a few of the equations are required.

[A Dynamical Theory of the Electromagnetic Field](#)

James Clerk Maxwell (1865)

eletromagnetismo

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

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$$\nabla \times$$

$$\nabla \times$$

$$c^2 \ dt$$



Between these twenty quantities we have found twenty equations, viz.

Three equations of Magnetic Force (B)

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„ Electromotive Force (D)

„ Electric Elasticity (E)

„ Electric Resistance (F)

„ Total Currents (A)

One equation of Free Electricity (G)

„ Continuity (H)

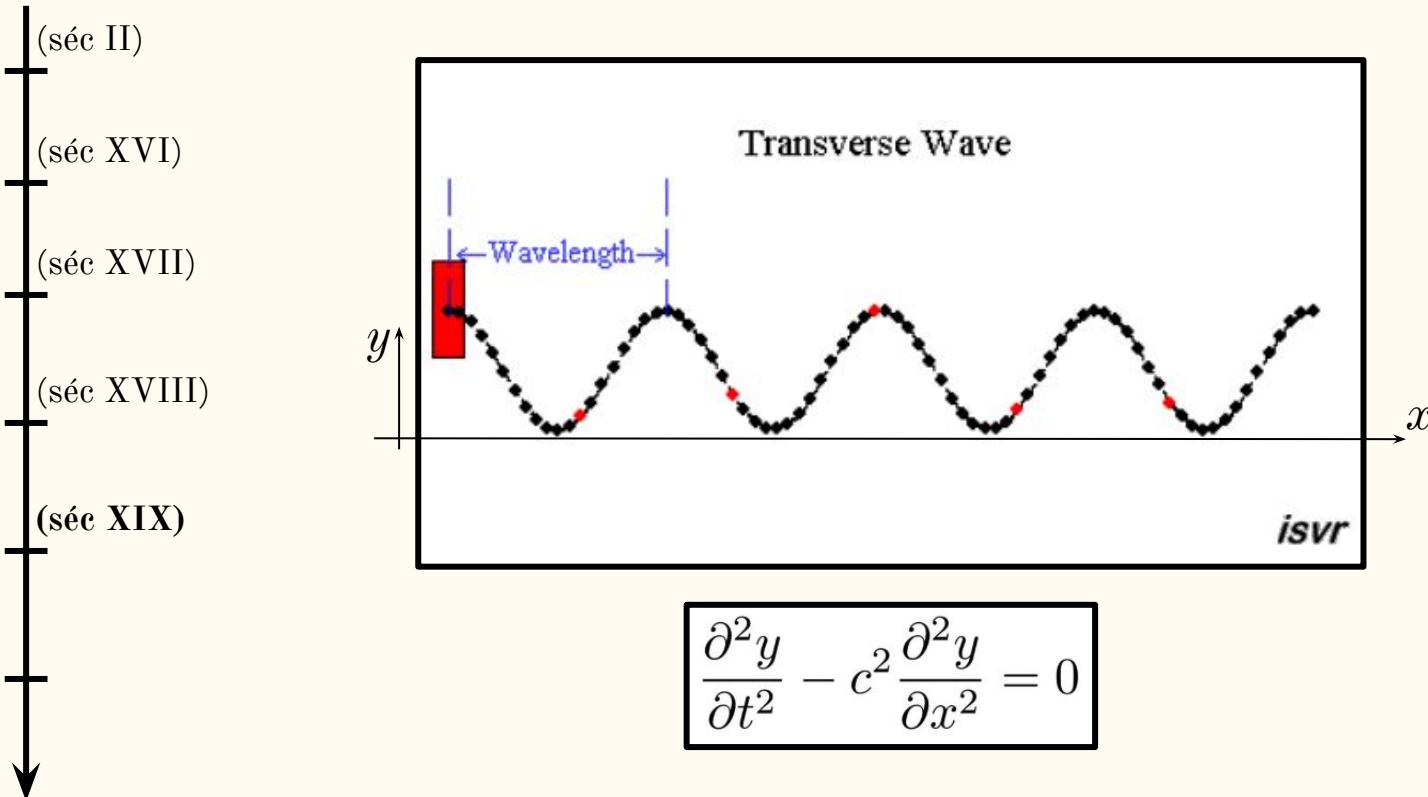


JP

De um lado estavam os defensores do uso dos quatérnions e de outro os defensores da análise vetorial. A análise vetorial como conhecemos hoje não existia no tempo de Maxwell e foi inventada por Gibbs e Heaviside independentemente, em parte devido à inspiração de Maxwell e, como discutiremos, teve suas origens no método rival dos quatérnions. Estes últimos negam qualquer influência dos quatérnions

[A Escolha De Uma Ferramenta Matemática Para a Física: O Debate Entre Os Quatérnions e a Álgebra Vetorial De Gibbs e Heaviside,](#)
Cibelle Celestino Silva (2004)

união: ótica e eletromag



união: ótica e eletricidade

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

In regions of space where there is no charge or current, Maxwell's equations read

$$\left. \begin{array}{ll} \text{(i)} & \nabla \cdot \mathbf{E} = 0, \\ \text{(ii)} & \nabla \cdot \mathbf{B} = 0, \\ \text{(iii)} & \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}, \\ \text{(iv)} & \nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}. \end{array} \right\} \quad (9.40)$$

They constitute a set of coupled, first-order, partial differential equations for \mathbf{E} and \mathbf{B} . They can be decoupled by applying the curl to (iii) and (iv):

$$\nabla \times (\nabla \times \mathbf{E}) = \nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E} = \nabla \times \left(-\frac{\partial \mathbf{B}}{\partial t} \right)$$

$$= -\frac{\partial}{\partial t} (\nabla \times \mathbf{B}) = -\mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2},$$

$$\nabla \times (\nabla \times \mathbf{B}) = \nabla(\nabla \cdot \mathbf{B}) - \nabla^2 \mathbf{B} = \nabla \times \left(\mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$

$$= \mu_0 \epsilon_0 \frac{\partial}{\partial t} (\nabla \times \mathbf{E}) = -\mu_0 \epsilon_0 \frac{\partial^2 \mathbf{B}}{\partial t^2}.$$

Or, since $\nabla \cdot \mathbf{E} = 0$ and $\nabla \cdot \mathbf{B} = 0$,

$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2}, \quad \nabla^2 \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{B}}{\partial t^2}.$$

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8 \text{ m/s},$$

união: ót

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

In regions of space where the

$$(i) \quad \nabla \cdot \mathbf{E} = 0$$

$$(ii) \quad \nabla \cdot \mathbf{B} = 0$$

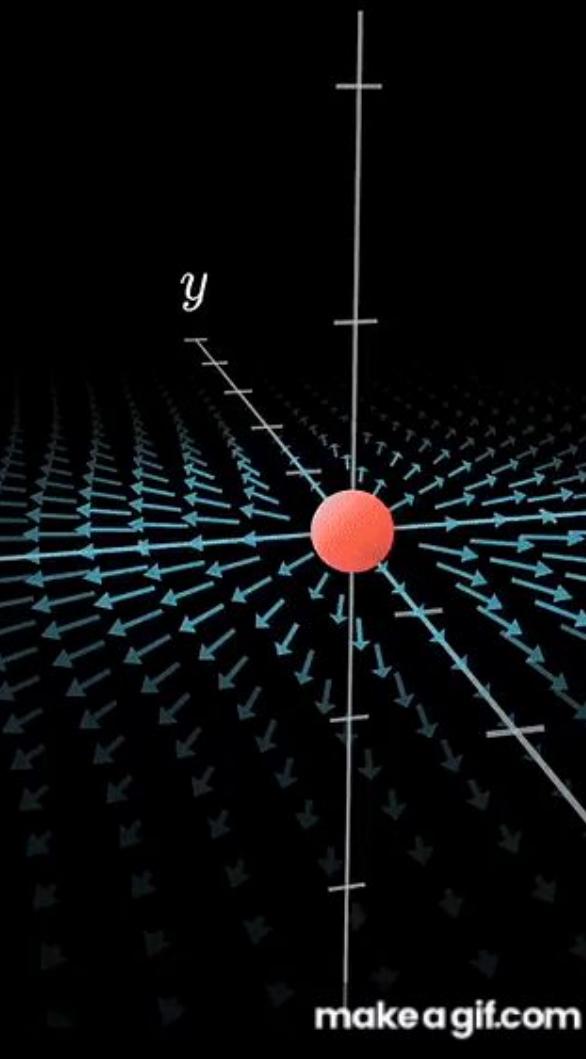
They constitute a set of coupled equations for the fields \mathbf{E} and \mathbf{B} . They can be decoupled by using the vector identity

$$\nabla \times (\nabla \times \mathbf{E})$$

$$\nabla \times (\nabla \times \mathbf{B})$$

Or, since $\nabla \cdot \mathbf{E} = 0$ and $\nabla \cdot \mathbf{B} = 0$,

Introduction to Electrodynamics
David Griffiths (1981)

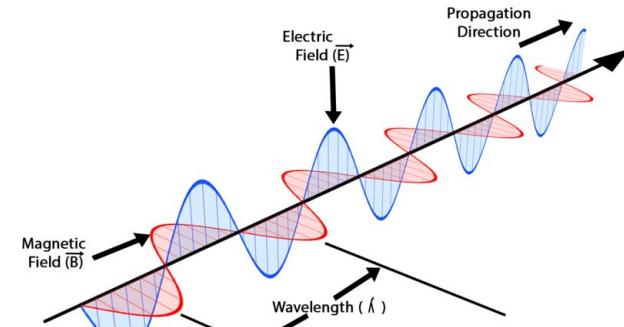


romag

$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2}, \quad \nabla^2 \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{B}}{\partial t^2}.$$

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8 \text{ m/s},$$

Electromagnetic Wave



união: ótica e eletromag

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

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They constitute a set of coupled, first-order, partial differential equations for \mathbf{E} and \mathbf{B} . They can be decoupled by applying the curl to (iii) and (iv):

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$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2}, \quad \nabla^2 \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{B}}{\partial t^2}.$$

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8 \text{ m/s},$$



which happens to be precisely the velocity of light, c . The implication is astounding: Perhaps light *is* an electromagnetic wave.⁴ Of course, this conclusion does not surprise anyone today, but imagine what a revelation it was in Maxwell's time! Remember how ϵ_0 and μ_0 came into the theory in the first place: they were constants in Coulomb's law and the Biot-Savart law, respectively. You measure them in experiments involving charged pith balls, batteries, and wires—experiments having nothing whatever to do with light. And yet, according to Maxwell's theory, you can calculate c from these two numbers.

Or, since $\nabla \cdot \mathbf{E} = 0$ at

Introduction to Electrodynamics
David Griffiths (1981)

união: ótica e eletromag

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

By the electromagnetic experiments of MM. WEBER and KOHLRAUSCH *,

$$v=310,740,000 \text{ metres per second}$$

is the number of electrostatic units in one electromagnetic unit of electricity, and this, according to our result, should be equal to the velocity of light in air or vacuum.

The velocity of light in air, by M. FIZEAU's † experiments, is

$$V=314,858,000;$$

according to the more accurate experiments of M. FOUCAULT ‡,

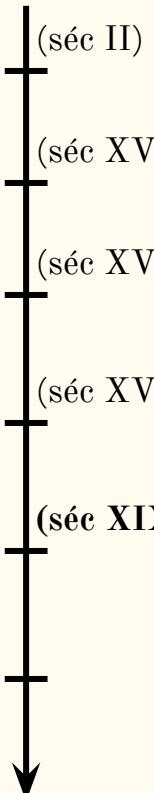
$$V=298,000,000.$$

The velocity of light in the space surrounding the earth, deduced from the coefficient of aberration and the received value of the radius of the earth's orbit, is

$$V=308,000,000.$$

(97) Hence the velocity of light deduced from experiment agrees sufficiently well with the value of v deduced from the only set of experiments we as yet possess. The

união: ótica e eletromag



(séc II)

(séc XVI)

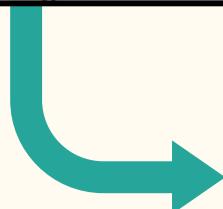
(séc XVII)

(séc XVIII)

(séc XIX)

The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws.

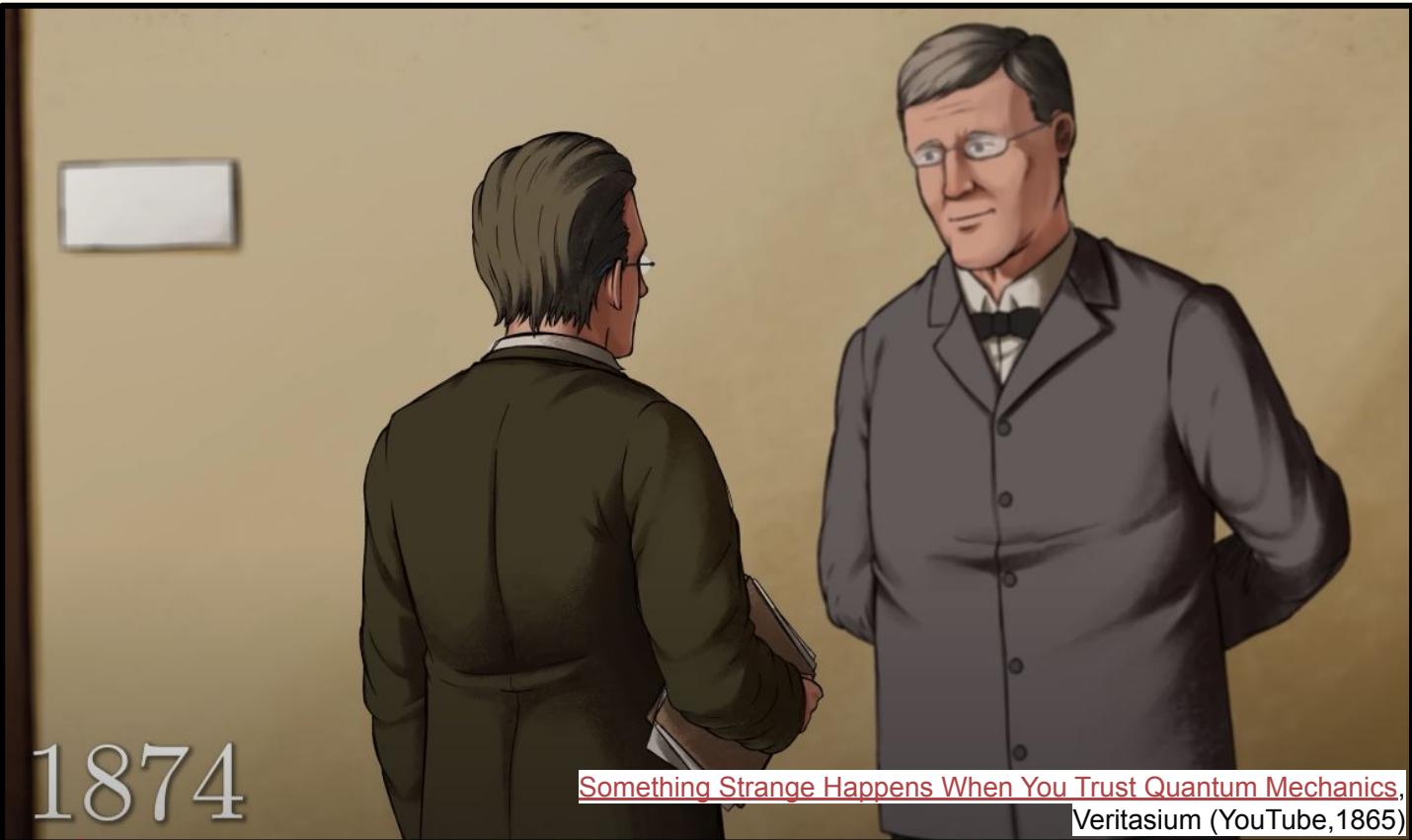
[A Dynamical Theory of the Electromagnetic Field](#),
James Clerk Maxwell (1865)



... mas de qual referencial estamos falando?

física quase completa...

(séc II)
(séc XVI)
(séc XVII)
(séc XVIII)
(séc XIX)



Something Strange Happens When You Trust Quantum Mechanics,
Veritasium (YouTube, 1865)

física quase completa...

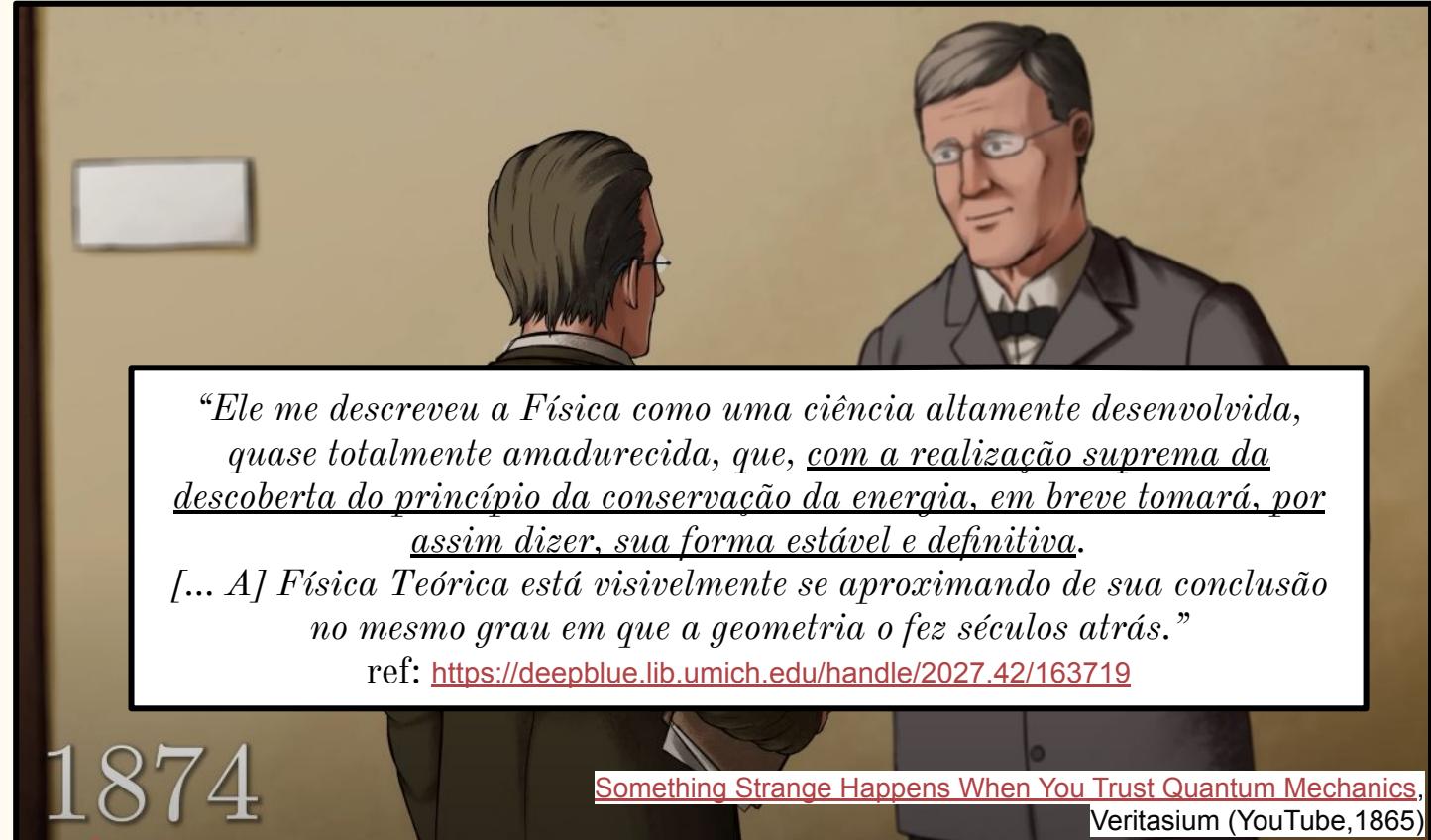
(séc II)

(séc XVI)

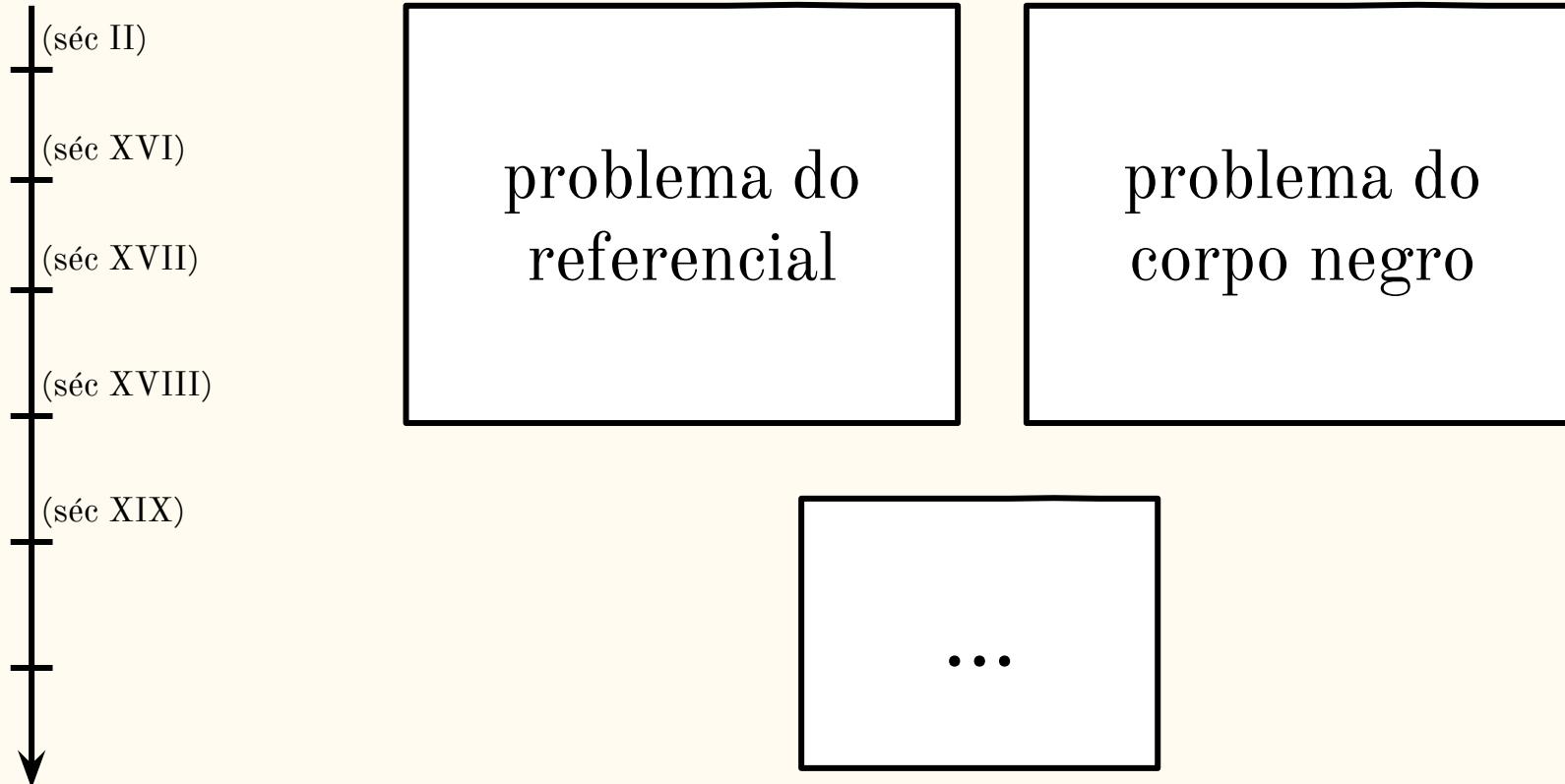
(séc XVII)

(séc XVIII)

(séc XIX)

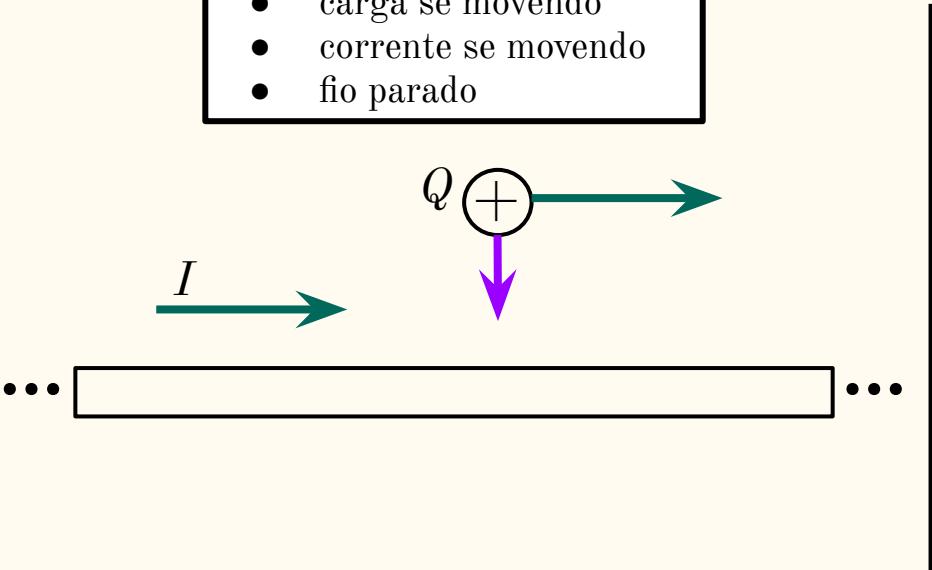
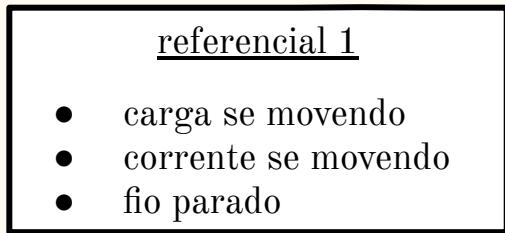


só faltam alguns detalhes...



problema do referencial

(séc XIX)

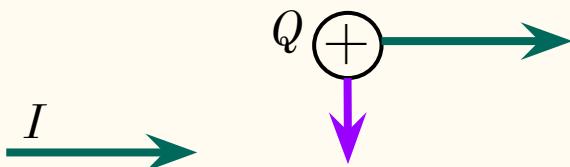


problema do referencial

(séc XIX)

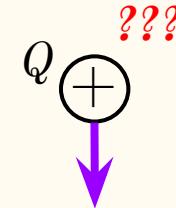
referencial 1

- carga se movendo
- corrente se movendo
- fio parado



referencial 2

- carga parada
- corrente parada
- fio se movendo

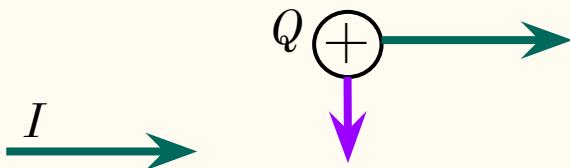


problema do referencial

(séc XIX)

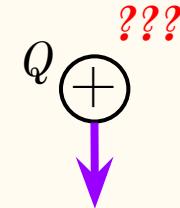
referencial 1

- carga se movendo
- corrente se movendo
- fio parado



referencial 2

- carga parada
- corrente parada
- fio se movendo



$$x = \frac{x' + vt'}{\sqrt{1 - \frac{v^2}{c^2}}} \quad t = \frac{t' + \frac{vx'}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Lorentz: cargas
aparentes?

“o experimento mais
importante da física”



relatividade especial

2 postulados

1. *As leis pelas quais os estados dos sistemas físicos sofrem mudanças não são afetadas, quer essas mudanças de estado sejam referidas a um ou outro dos dois sistemas de coordenadas em movimento translacional uniforme.*
2. *A luz é sempre propagada no espaço vazio com uma velocidade definida, que é independente do estado de movimento do corpo emissor.*

relatividade especial

1.1.3 Coordinates and Metric

Defining contravariant coordinates

$$x^\mu = (x^0, x^1, x^2, x^3) = (ct, x, y, z), \quad (1.23)$$

the line element ds

$$\begin{aligned} ds^2 &= dx^2 + dy^2 + dz^2 - c^2 dt^2 = -(dx^0)^2 + (dx^1)^2 + (dx^2)^2 + (dx^3)^2 \\ &= \eta_{\mu\nu} dx^\mu dx^\nu \end{aligned} \quad (1.24)$$

defines the metric $\eta_{\mu\nu}$

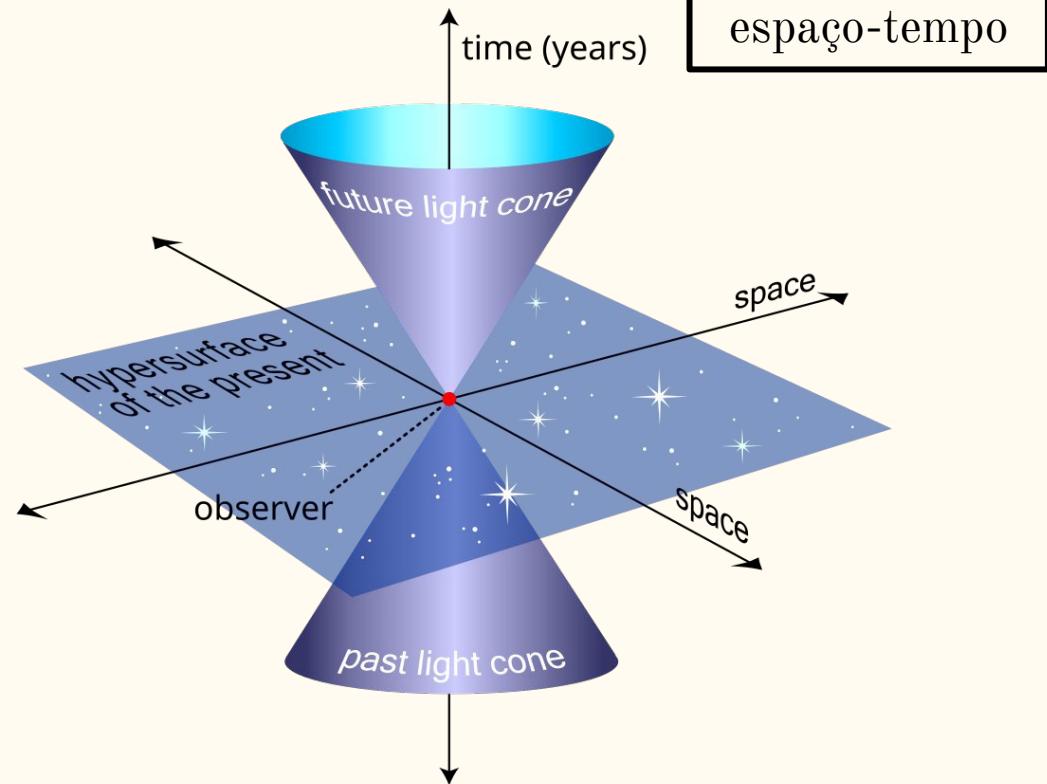
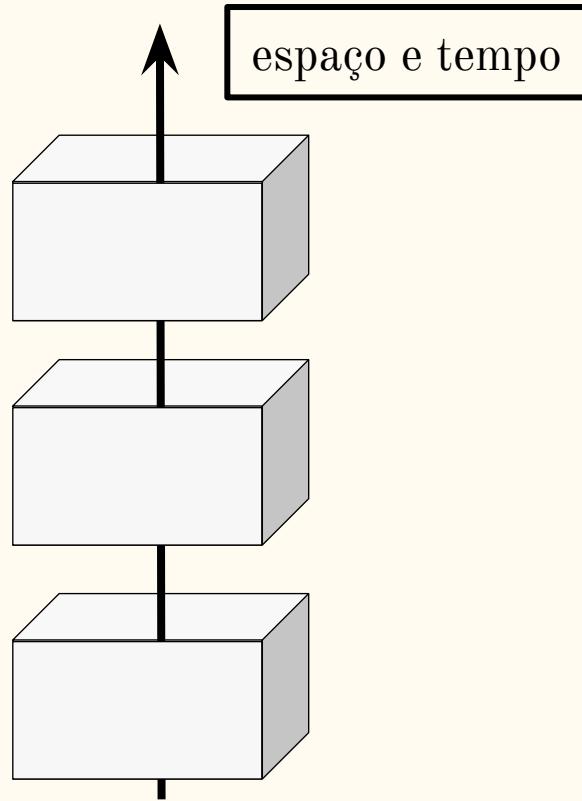
$$\eta_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \quad (1.25)$$

1.1.5 Invariance of the Line Element: Lorentz Boosts

Consider an inertial frame K and another K' that moves relative to K with speed v in the x direction. For simplicity we may assume that the two frames coincide initially, i.e. at $t = t' = 0$ we have $x = x' = 0$. For both frames c is the same, so considering the trajectory of a light ray, we have that the line element s is null in both frames

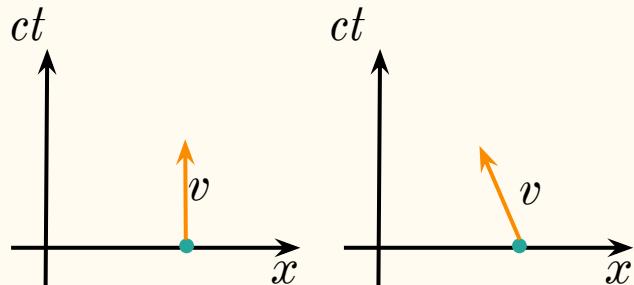
$$s^2 = x^2 + y^2 + z^2 - c^2 t^2 = 0 = x'^2 + y'^2 + z'^2 - c^2 t'^2 = s'^2 \quad (1.30)$$

relatividade especial

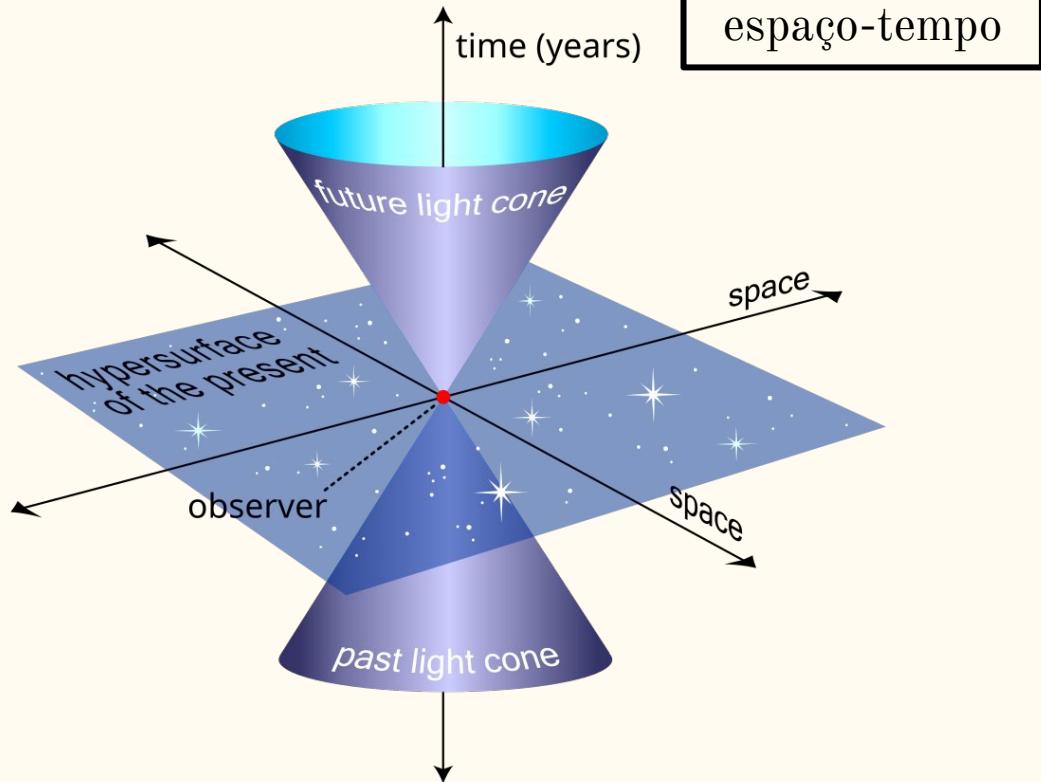


relatividade especial

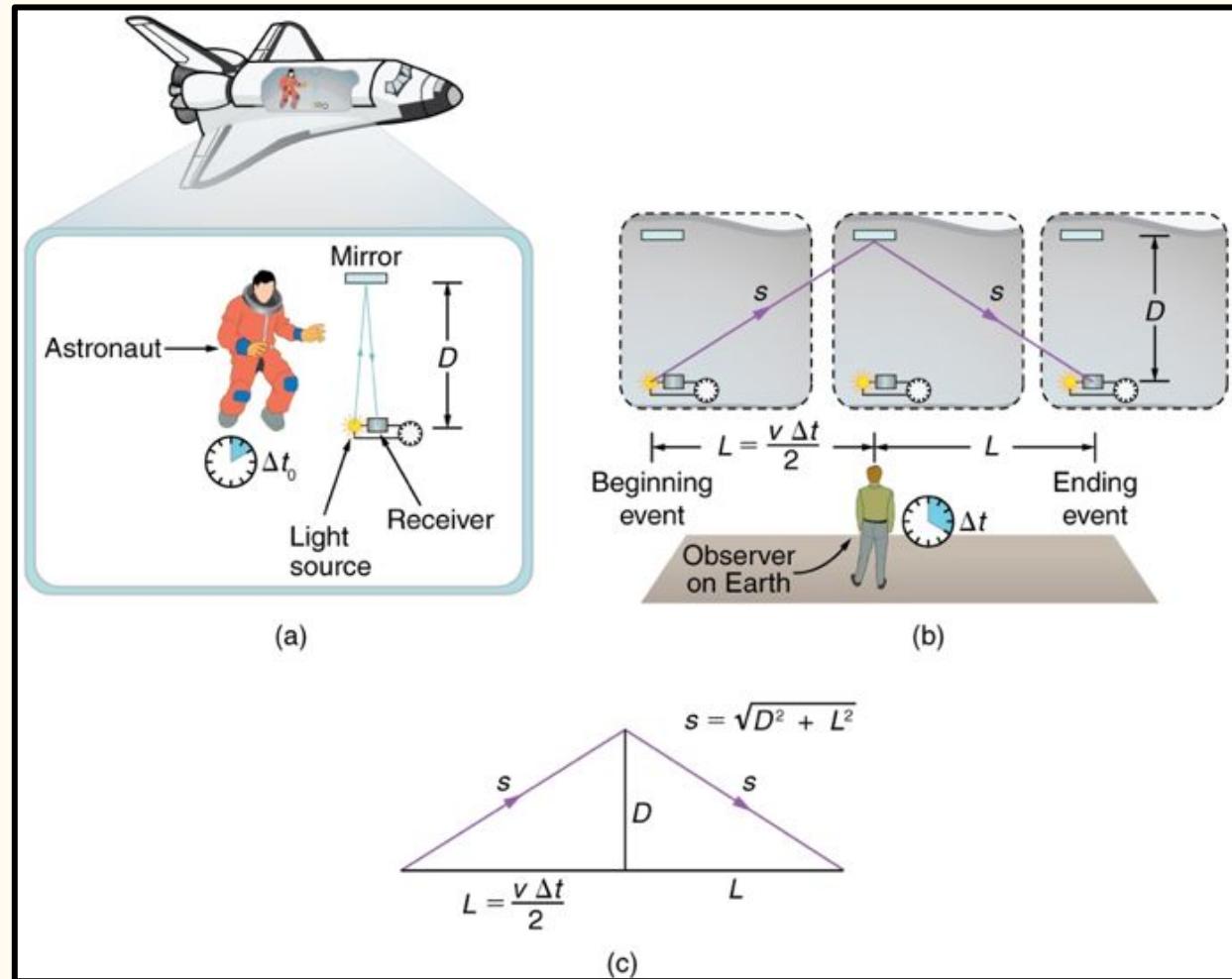
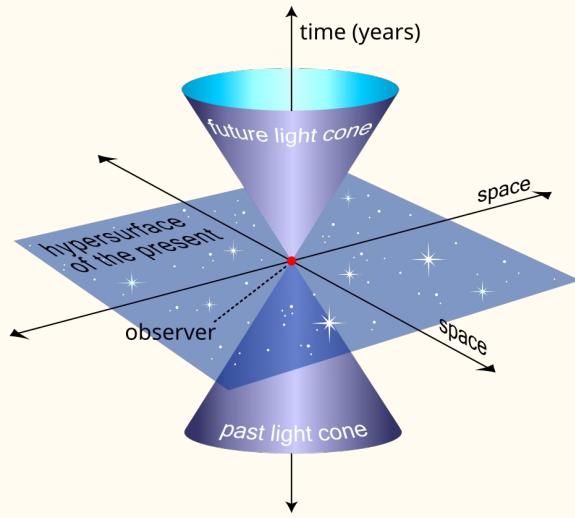
“sempre estamos na velocidade da luz no espaço-tempo”



quadrvetor da velocidade é normalizado para $U = (c, 0, 0, 0)$



réguas e relógios



relatividade especial

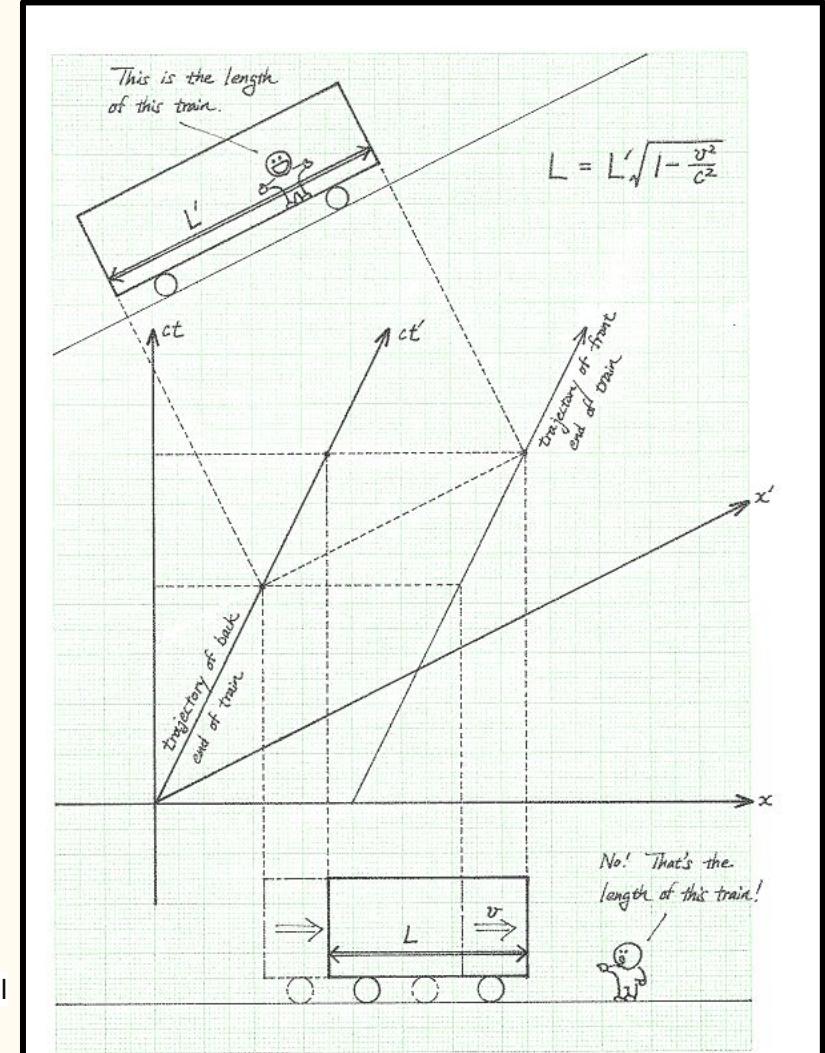
o que é um comprimento?

*é a distância dos dois cantos de um objeto
realizada **no mesmo instante de tempo***

*mas o conceito de simultaneidade depende do
observador!*

$$L = L' \sqrt{1 - \frac{v^2}{c^2}}$$

Fonte: <https://www1.phys.vt.edu/~takeuchi/relativity/notes/section13.html>



relatividade especial

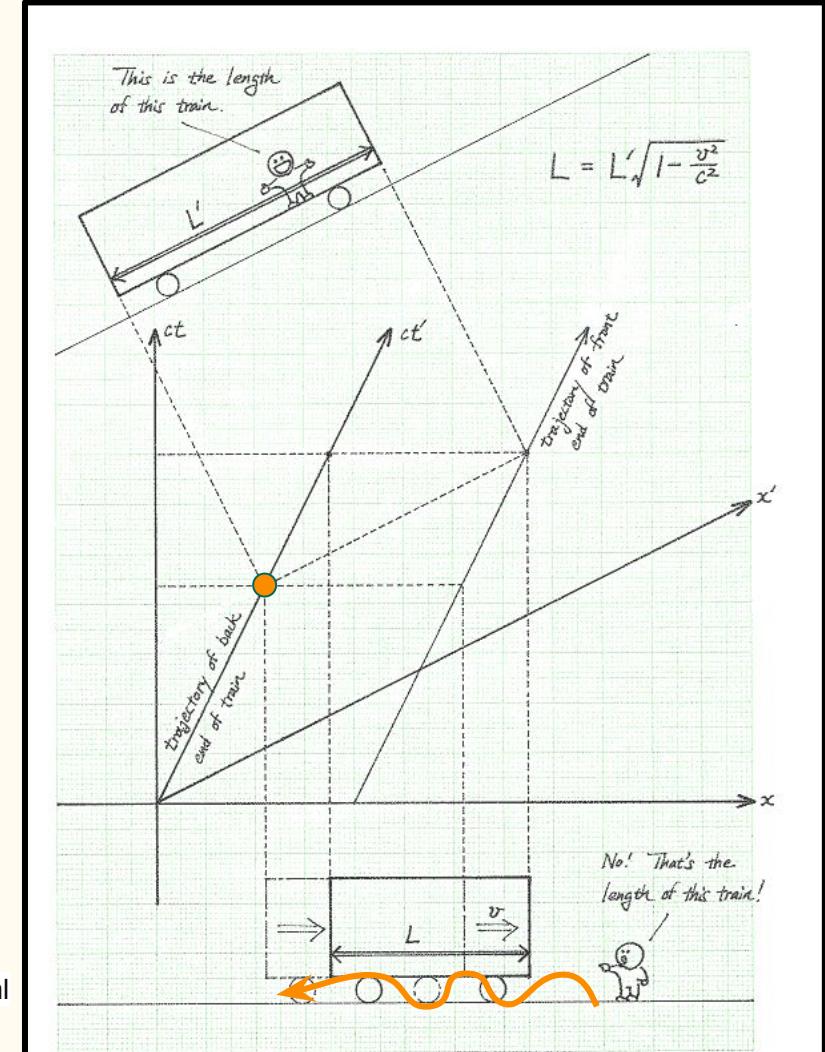
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relatividade especial

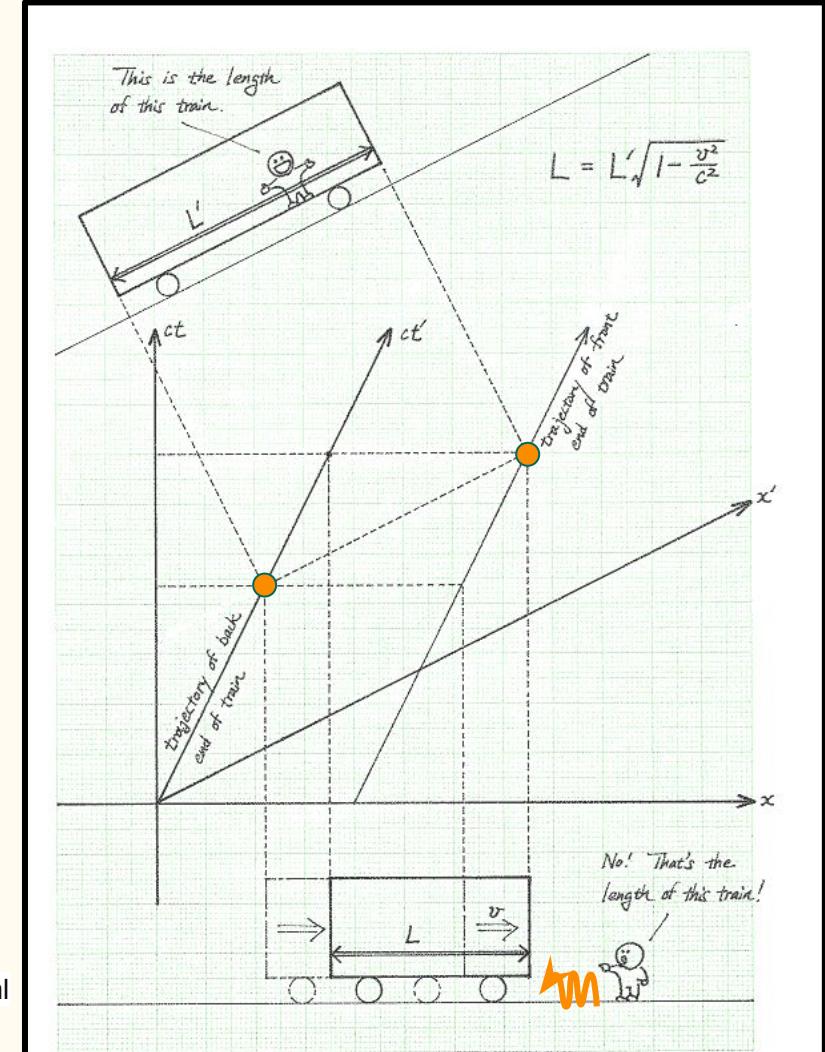
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relatividade especial

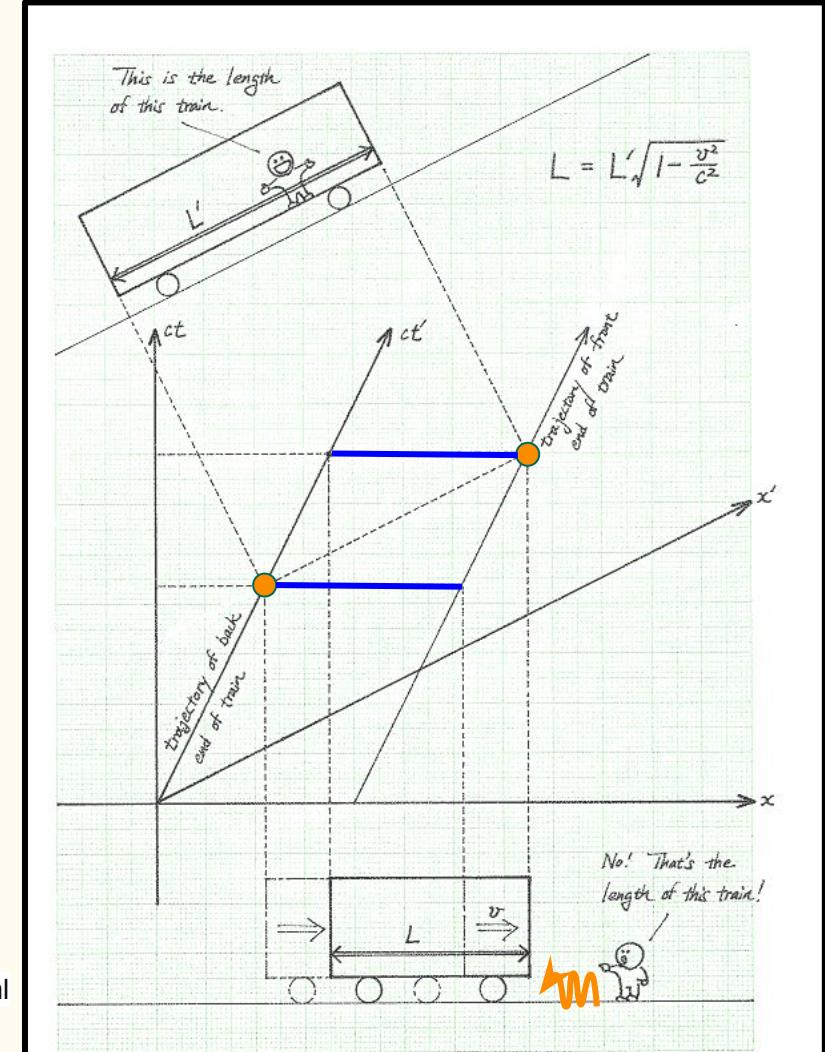
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$$L = L' \sqrt{1 - \frac{v^2}{c^2}}$$

Fonte: <https://www1.phys.vt.edu/~takeuchi/relativity/notes/section13.html>



relatividade especial

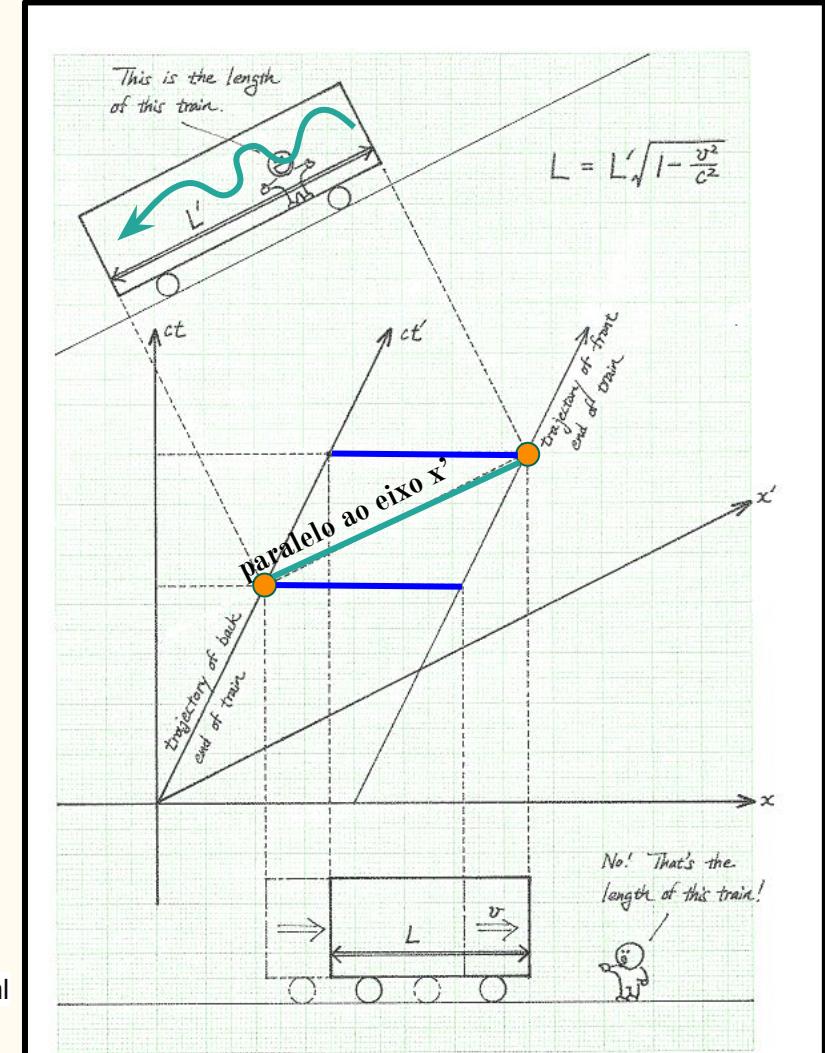
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Fonte: <https://www1.phys.vt.edu/~takeuchi/relativity/notes/section13.html>



revisitando o
problema do
referencial



mas nem tudo foi resolvido

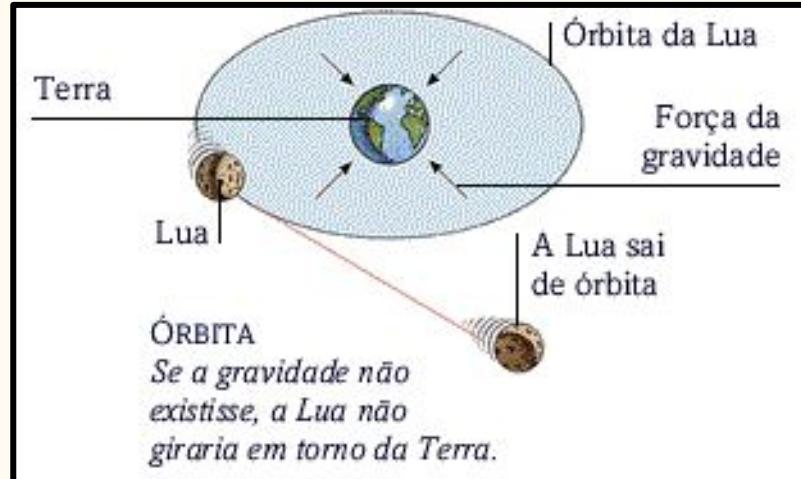
1. Como a gravidade entra no jogo?

Newton a formulou como uma interação instantânea e disse nada sobre sua natureza.

2. Relatividade especial resolve para

“referenciais inerciais” (mais precisamente, não acelerados).

Como generalizar?



“I have not yet been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses (hypotheses non fingo).”

???

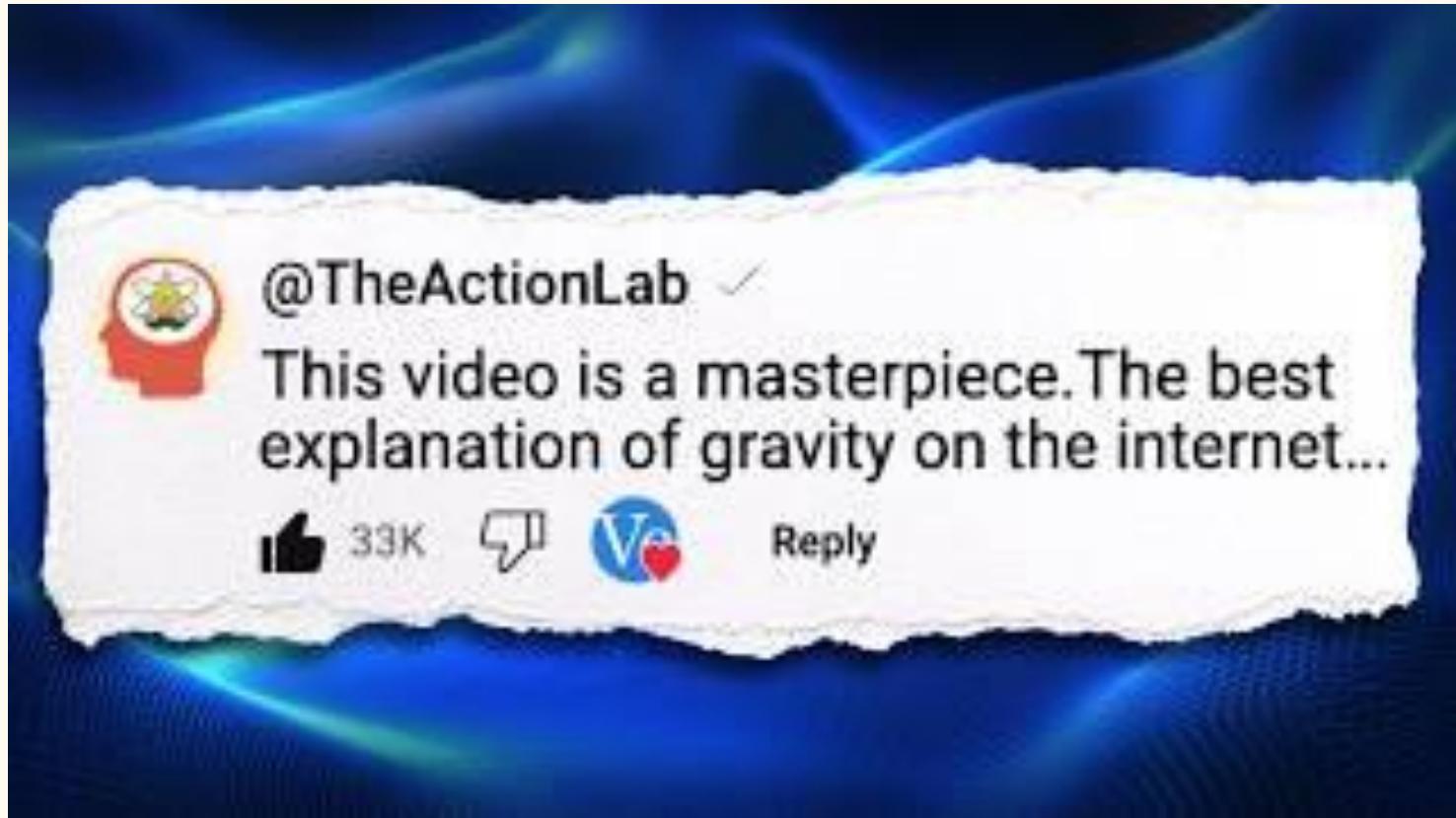
Principia,
Isaac Newton (1713)

pensamento mais feliz do Einstein

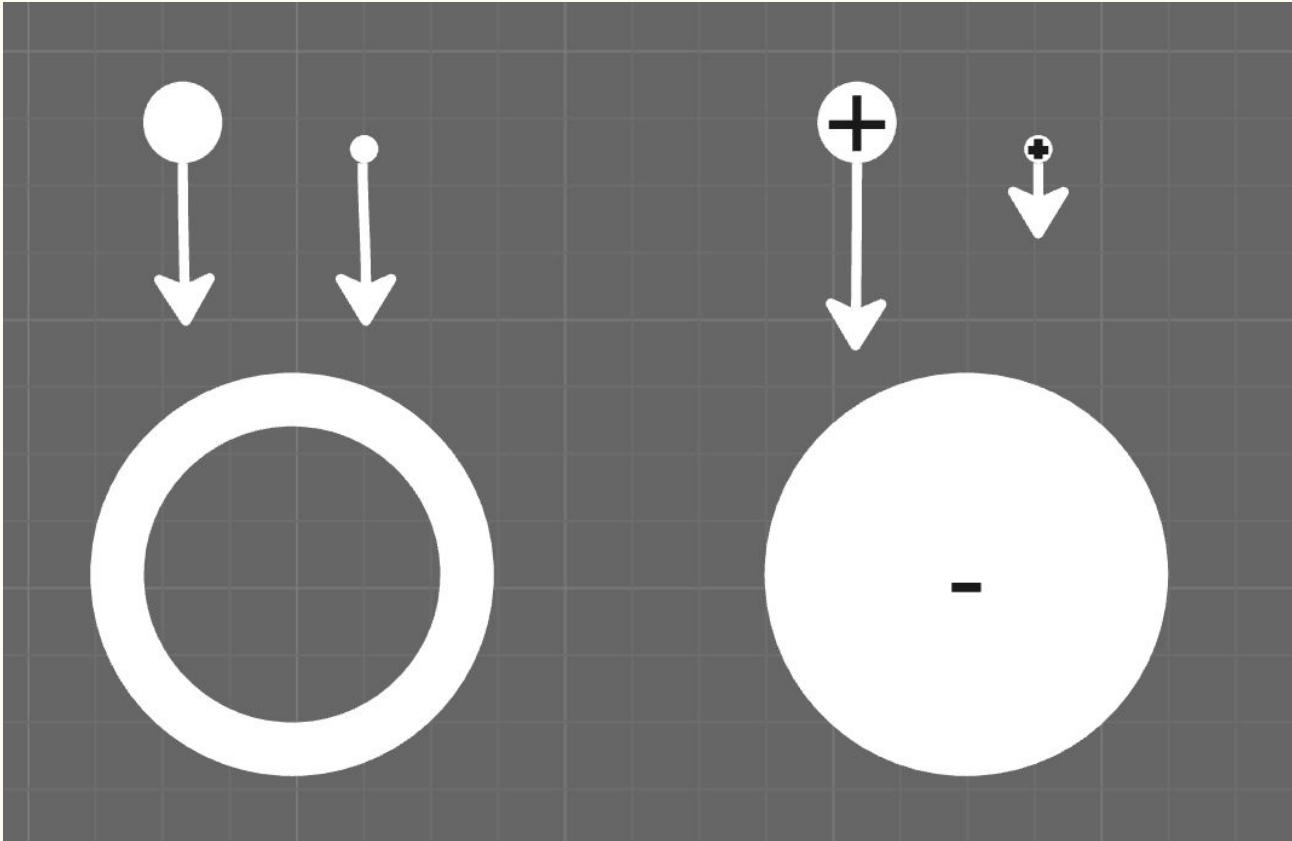
*Literalmente um
pensamento
intrusivo
imaginando um
trabalhador caindo
de um prédio.*



princ. da equivalência



princ. da equivalência



equação de Einstein

curvatura do
espaço-tempo

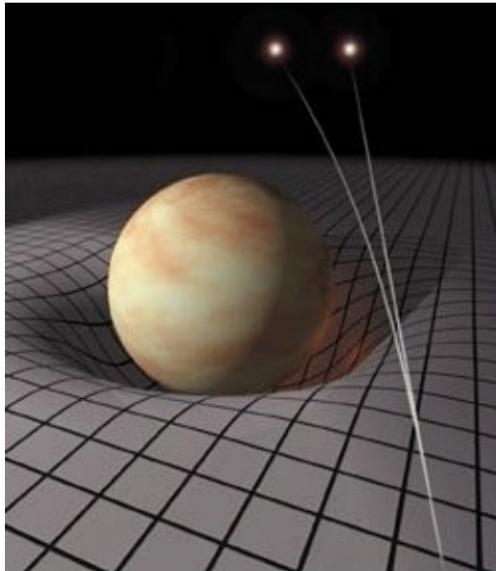
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

matéria e
energia

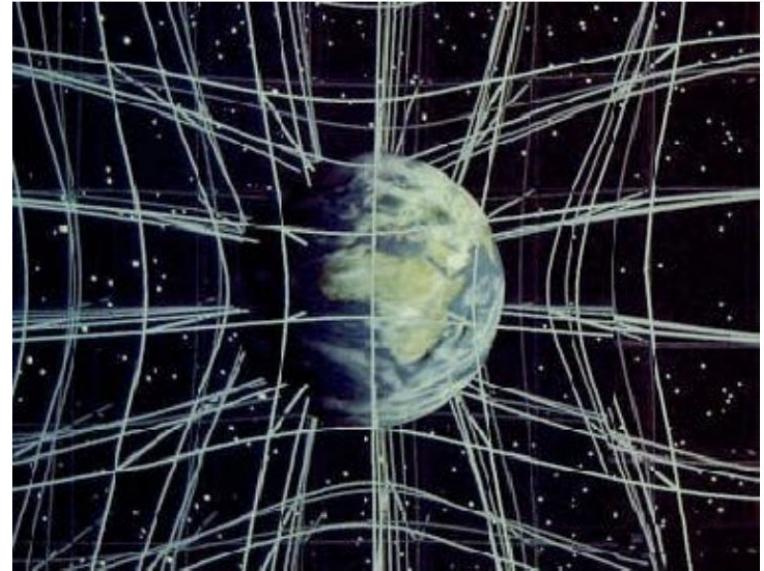
$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

réguas e relógios

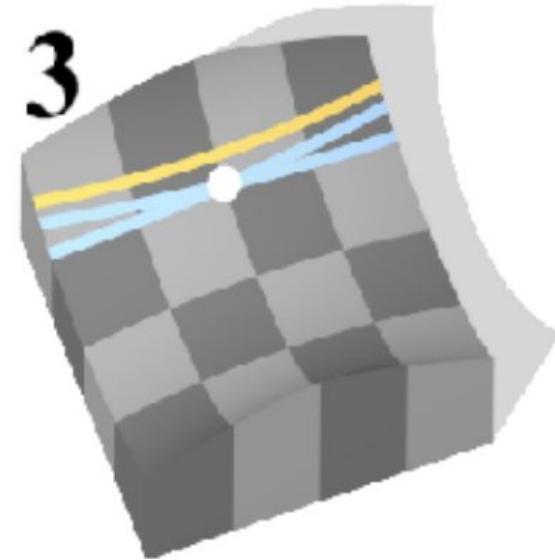
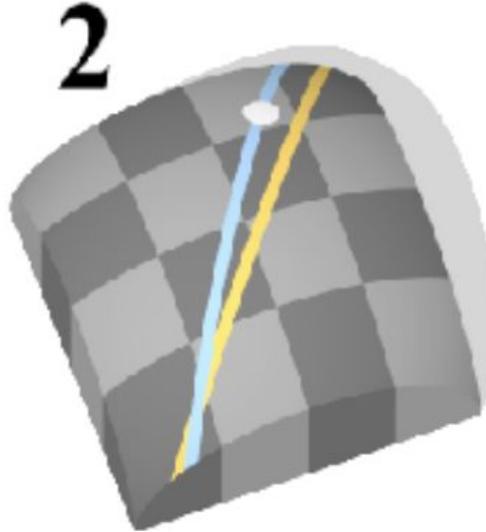
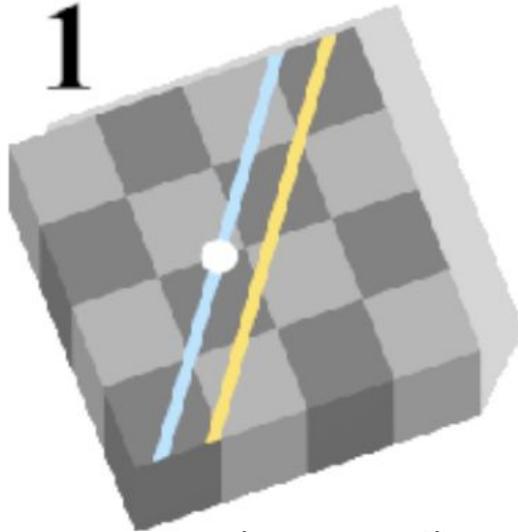
it both causes the motions of bodies...



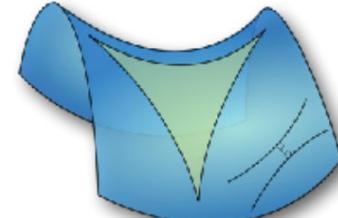
and it is affected by them.



régulas e relógios



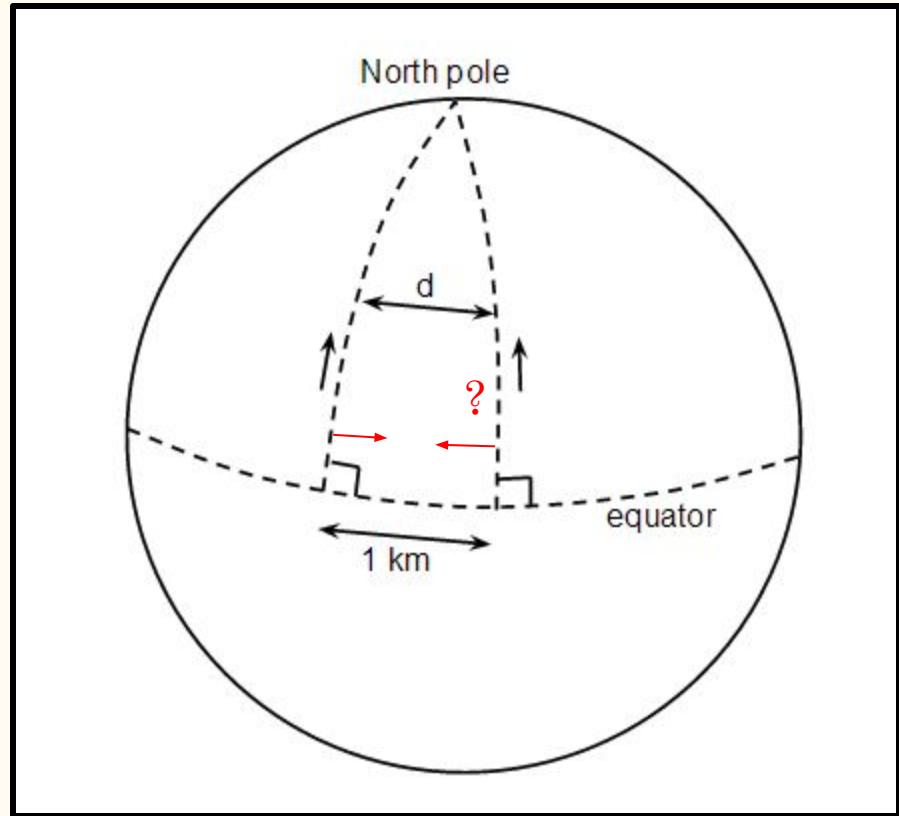
- On the surface of the hyperboloid, given a point and a line, there are many (infinite!) lines parallel to the given line that pass through the point!
- In this space, the sum of the interior angles of a triangle is $< 180^\circ$!



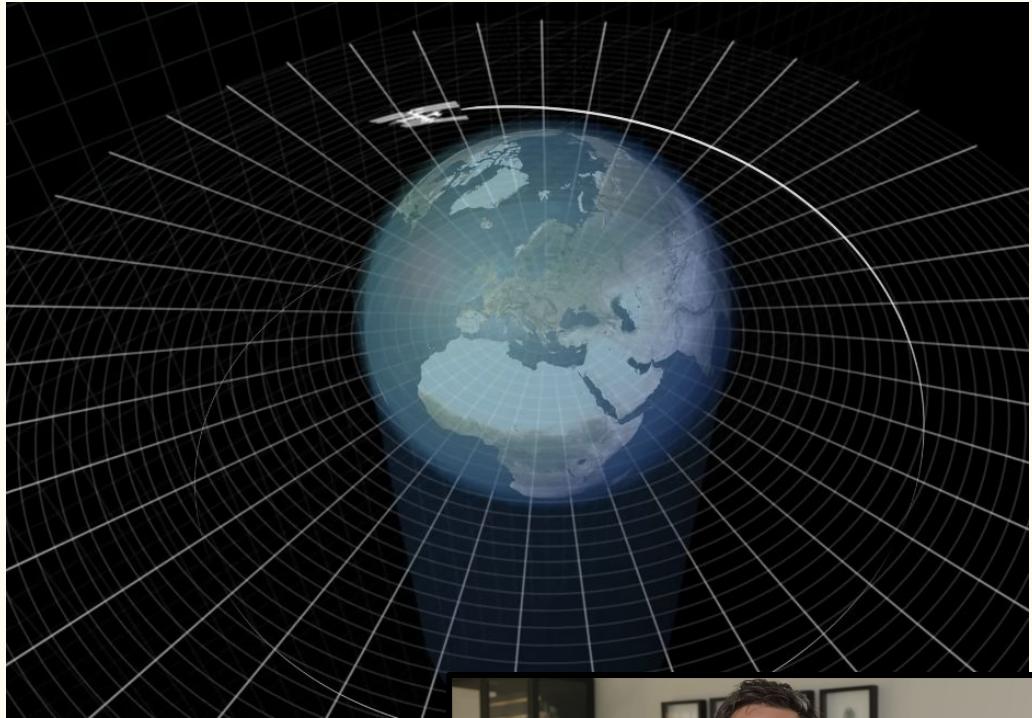
geodésicas,
inércia e
ilusão da
gravidade



geodésicas, inércia e ilusão da gravidade



geodésicas, inércia e ilusão da gravidade



What Everyone Gets Wrong About Gravity,
Veritasium (YouTube, 2021)

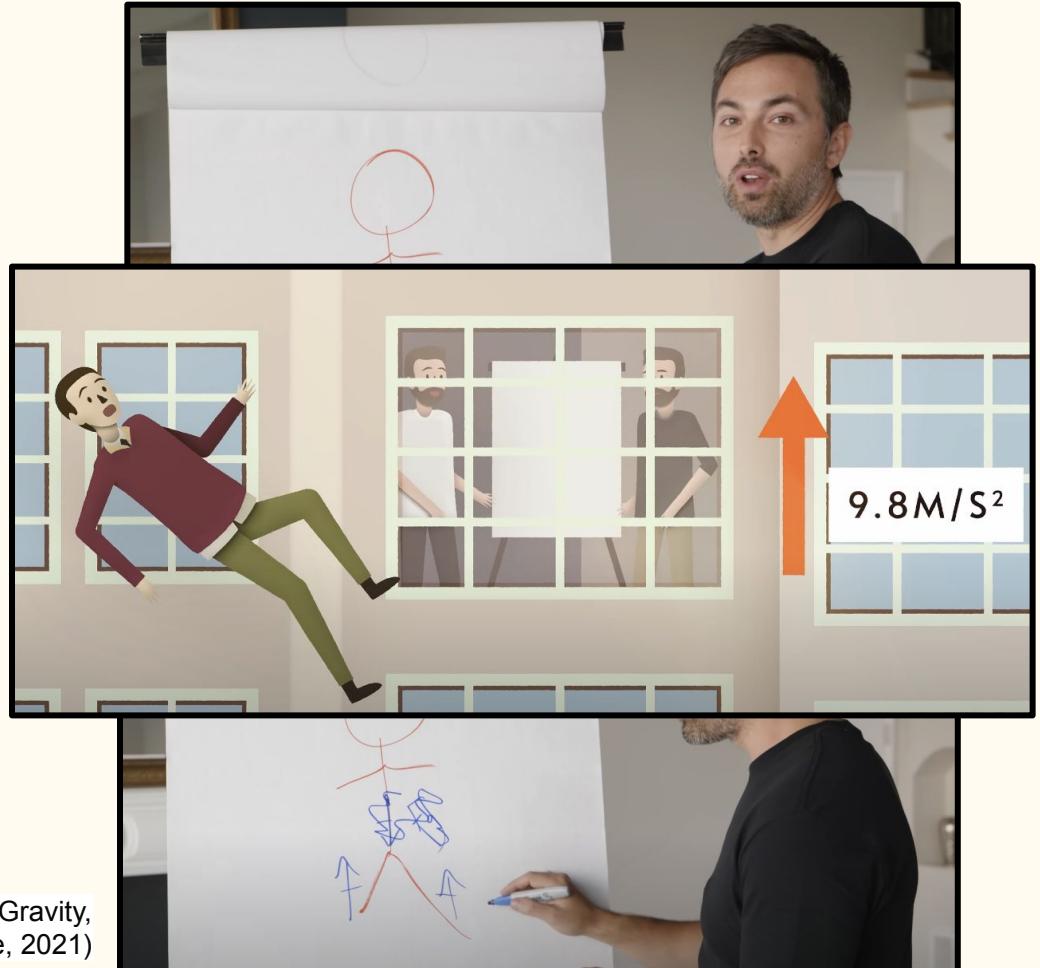


geodésicas, inércia e ilusão da gravidade

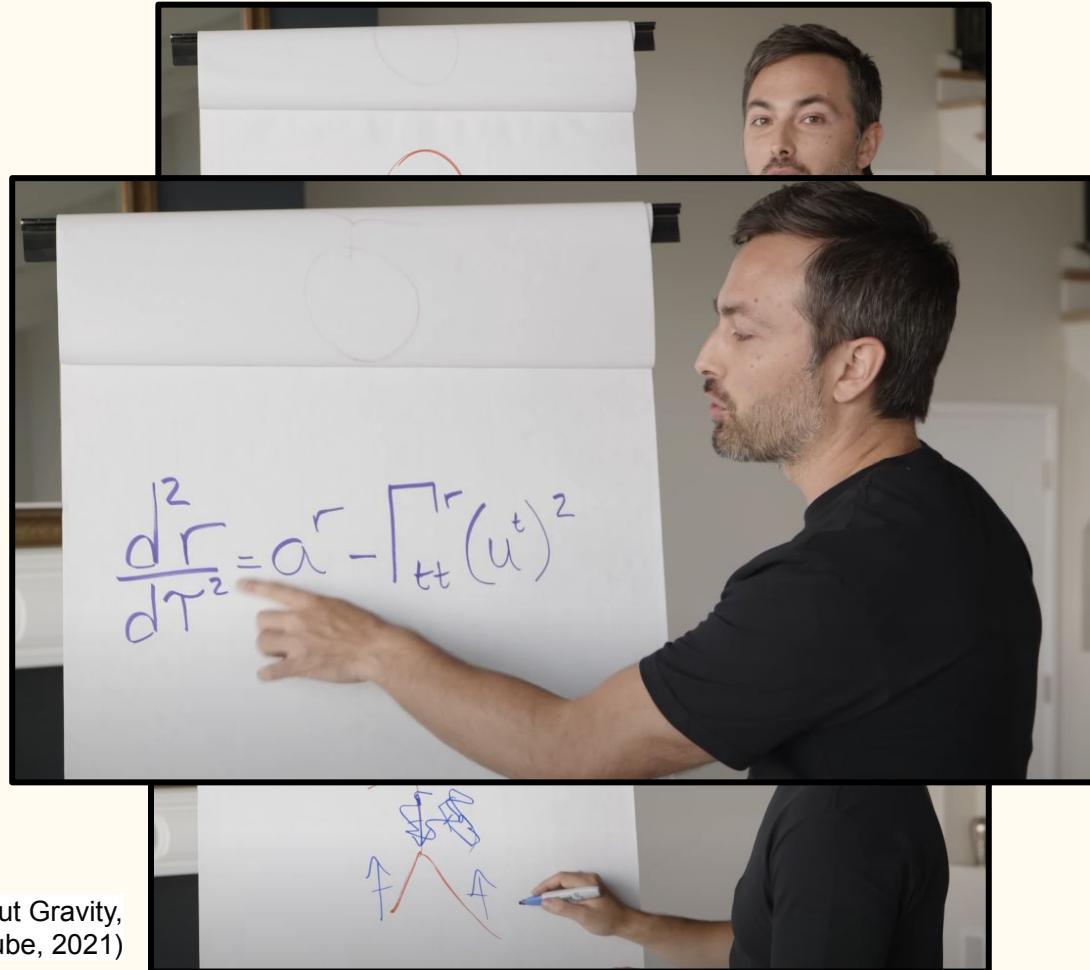
What Everyone Gets Wrong About Gravity,
Veritasium (YouTube, 2021)



geodésicas, inércia e ilusão da gravidade

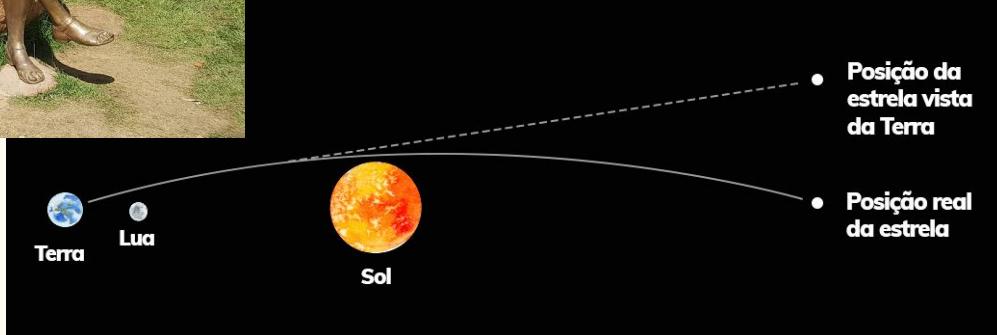


geodésicas, inércia e ilusão da gravidade



What Everyone Gets Wrong About Gravity,
Veritasium (YouTube, 2021)

teste em Sobral



teste do avião

Around-the-World Atomic Clocks: Predicted Relativistic Time Gains

Abstract. During October 1971, four cesium beam atomic clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicts that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40 ± 23 nanoseconds during the eastward trip, and should have gained 275 ± 21 nanoseconds during the westward trip. The observed time differences are presented in the report that follows this one.

Table 1. Predicted relativistic time differences (nsec).

Effect	Direction	
	East	West
Gravitational	144 ± 14	179 ± 18
Kinematic	-184 ± 18	96 ± 10
Net	-40 ± 23	275 ± 21

relatividade especial

$$\tau - \tau_0 = - (2R\Omega v + v^2) \tau_0 / 2c^2$$

relatividade geral

$$\tau - \tau_0 = [gh/c^2 - (2R\Omega v + v^2)/2c^2] \tau_0$$

pesquisa: geometry split



$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

A Test of the Standard Cosmological Model with Geometry and Growth

Uendert Andrade^{a,b,1} , Dhayaanbajagane^{b,c,d} , Rodrigo von Marttens^a , Dragan Huterer^{b,c,e} and Jailson Alcaniz^a

^aObservatório Nacional, Rio de Janeiro, RJ 20921-400, Brazil

^bDepartment of Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109-1040

^cLeinweber Center for Theoretical Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109-1040

^dDepartment of Astronomy and Astrophysics, University of Chicago, 5640 S. Ellis Ave, Chicago, IL 60637

^eMax-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany

E-mail: uendertandrade@on.br, dhayaanbajagane@umich.edu,
rodrigovonmarttens@gmail.com, huterer@umich.edu, alcaniz@on.br

pesquisa: gravidade modificada

Explaining the observed cosmic acceleration of the background expansion of the Universe will likely require yet unknown physics. Assuming General Relativity is the correct gravity theory up to the largest scales, one is forced to introduce a new form of energy with negative pressure, dubbed dark energy, in order to create the gravitational repulsion necessary to produce acceleration.

On the other hand, if we allow for General Relativity to be modified on cosmologically interesting scales, it may be possible to explain cosmic acceleration from such modification. The simplest modification of gravity is the cosmological constant, which can also be viewed as a form of dark energy, depending on which side of the Einstein's equations it is introduced. Other possibilities include the addition of extra dimensions to which only gravity leaks, therefore becoming weaker at large scales, as well as more phenomenological modifications to the Einstein-Hilbert action.

<https://fma.if.usp.br/~mlima/research/modgrav/modgrav.html>

pesquisa: quintessence

Early dark energy constraints with late-time expansion marginalization

João Rebouças,^a Jonathan Gordon,^b Diogo H. F. de Souza,^a
Kunhao Zhong,^b Vivian Miranda,^b Rogerio Rosenfeld,^a Tim Eifler^c
and Elisabeth Krause^{c,d}

^aInstituto de Física Teórica da Universidade Estadual Paulista and ICTP South American Institute for Fundamental Research,

R. Dr. Bento Teobaldo Ferraz, 271, Bloco II, Barra-Funda - São Paulo/SP, Brasil

^bC. N. Yang Institute for Theoretical Physics, Stony Brook University,
Stony Brook, NY 11794, USA

^cDepartment of Astronomy and Steward Observatory, University of Arizona,
933 N Cherry Ave, Tucson, AZ 85719, USA

^dDepartment of Physics, University of Arizona,
1118 E Fourth Str, Tucson, AZ, 85721-0065, USA

E-mail: joao.reboucas@unesp.br

Abstract. Early dark energy (EDE) is an extension to the Λ CDM model that includes an additional energy density contribution near recombination. The model was proposed to reduce the tension between the measurements of the Hubble constant H_0 from the cosmic microwave background (CMB) and from the local cosmic distance ladder. Some analyses in the recent literature have shown intriguing hints for EDE. However, this model increases the tension in the derived clustering of galaxies (as measured by the so-called S_8 parameter) between CMB and large scale structure (LSS) measurements. This new tension limits the contribution of EDE during recombination, and thus its effect on the Hubble tension. In this work, we investigate whether the inclusion of a general, smooth late-time dark energy modification can increase back the EDE contribution when LSS data is included in the analysis. In order to generalize the late expansion with respect to the Λ CDM model, we substitute the cosmological constant by a late dark energy fluid model with a piecewise constant equation of state $w(z)$ in redshift bins. We show that, when analysing this generalized model with combinations of CMB, LSS and type Ia supernovae data from several experiments no significant changes on S_8 and EDE parameter constraints is found. The contribution to the EDE fraction constraint with late-time expansion marginalization is $f_{\text{EDE}} = 0.067^{+0.019}_{-0.027}$ using 3 redshift bins, with similar results for 5 and 10 redshift bins. This work shows that in order to solve simultaneously the Hubble and S_8 tensions, one needs a mechanism for increasing the clustering of matter at late times different from a simple change in the background evolution of late dark energy.

pesquisa: quintessence

ear
late

Jo  o
Kunh
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^aInstit
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R. Dr

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Stony

^cDepar
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E-ma

The Structure of Structure Formation Theories

Wayne Hu and Daniel J. Eisenstein

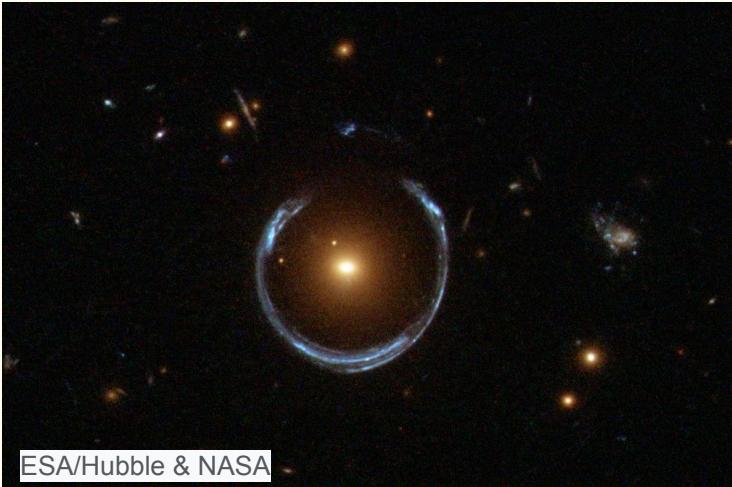
Institute for Advanced Study, Princeton, NJ 08540

We study the general structure of models for structure formation, with applications to the reverse engineering of the model from observations. Through a careful accounting of the degrees of freedom in covariant gravitational instability theory, we show that the evolution of structure is completely specified by the stress history of the dark sector. The study of smooth, entropic, sonic, scalar anisotropic, vector anisotropic, and tensor anisotropic stresses reveals the origin, robustness, and uniqueness of specific model phenomenology. We construct useful and illustrative analytic solutions that cover cases with multiple species of differing equations of state relevant to the current generation of models, especially those with effectively smooth components. We present a simple case study of models with phenomenologies similar to that of a Λ CDM model to highlight reverse-engineering issues. A critical-density universe dominated by a single type of dark matter with the appropriate stress history can mimic a Λ CDM model exactly.

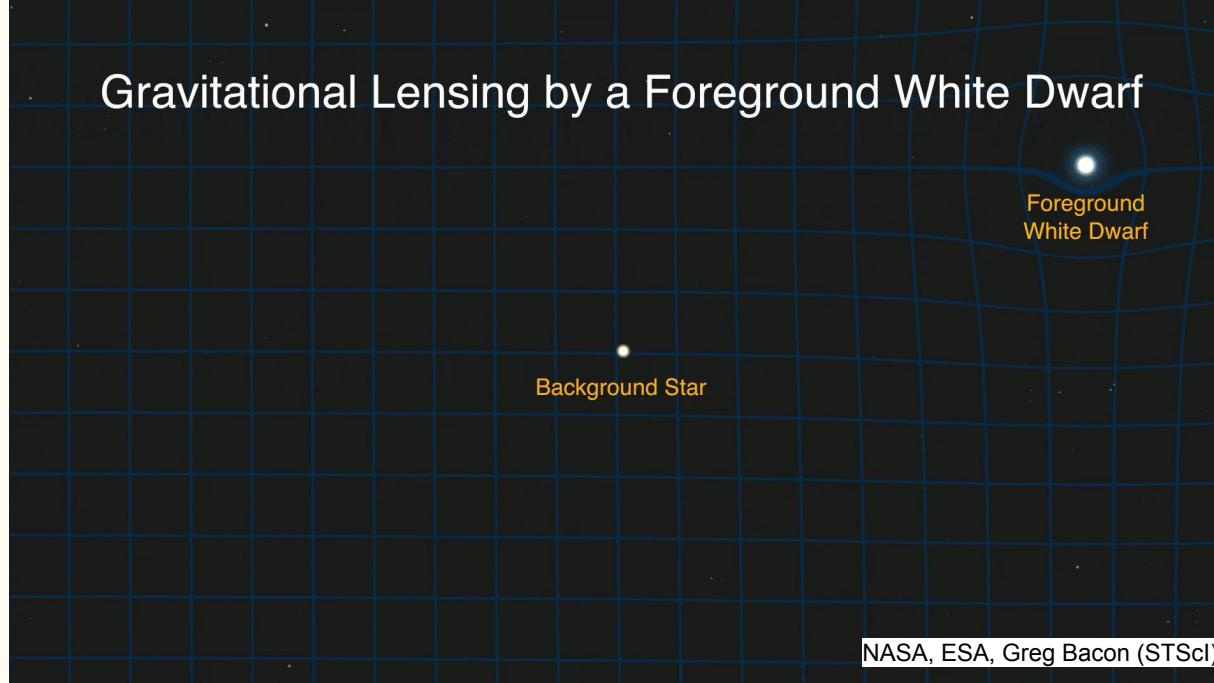
includes
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itute the
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del with
no signif-
the EDE
using 3
order to

solve simultaneously the Hubble and S_8 tensions, one needs a mechanism for increasing the clustering of matter at late times different from a simple change in the background evolution of late dark energy.

pesquisa: lenteamento gravitacional



pesquisa: lenteamento gravitacional

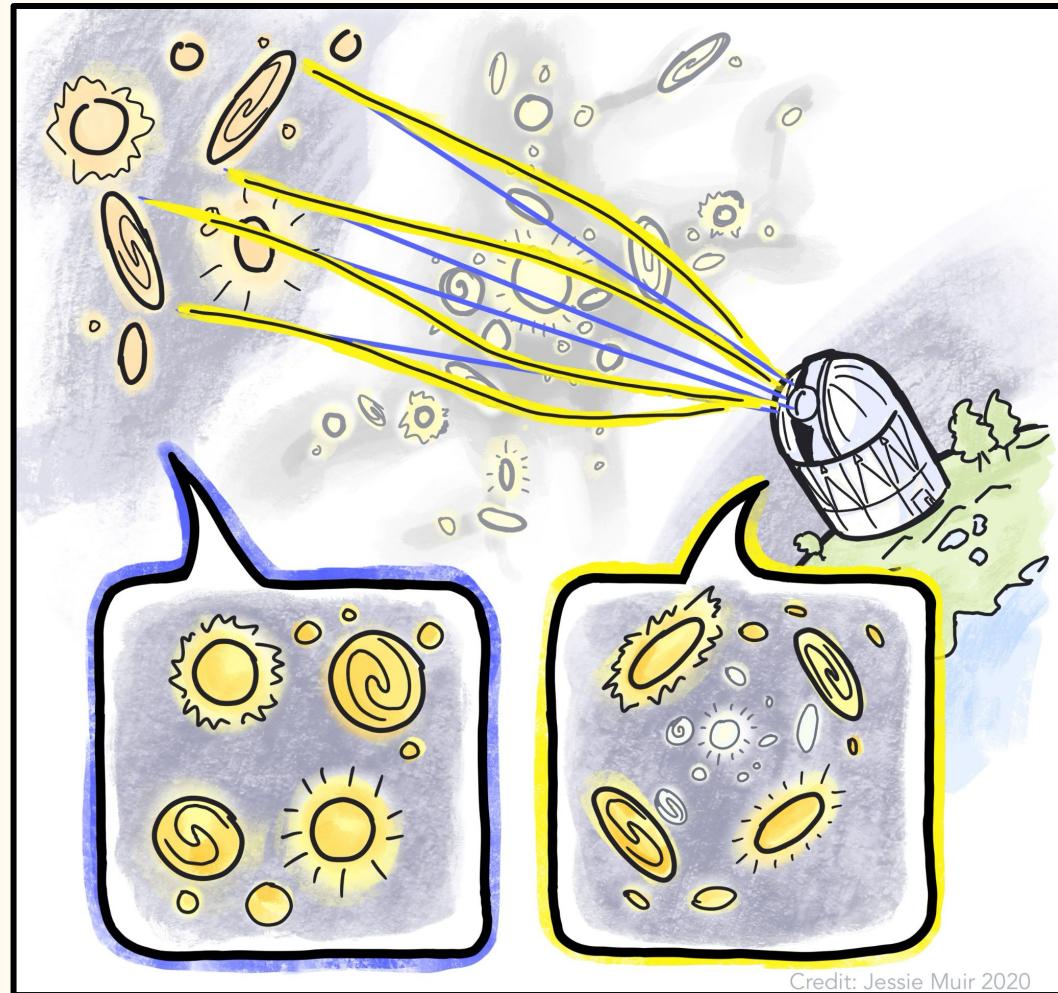


pesquisa: lenteamento gravitacional

IFUSP
IFT
IAG
UEL
UnB

...

imagem de Jessie Muir (2021)



Credit: Jessie Muir 2020