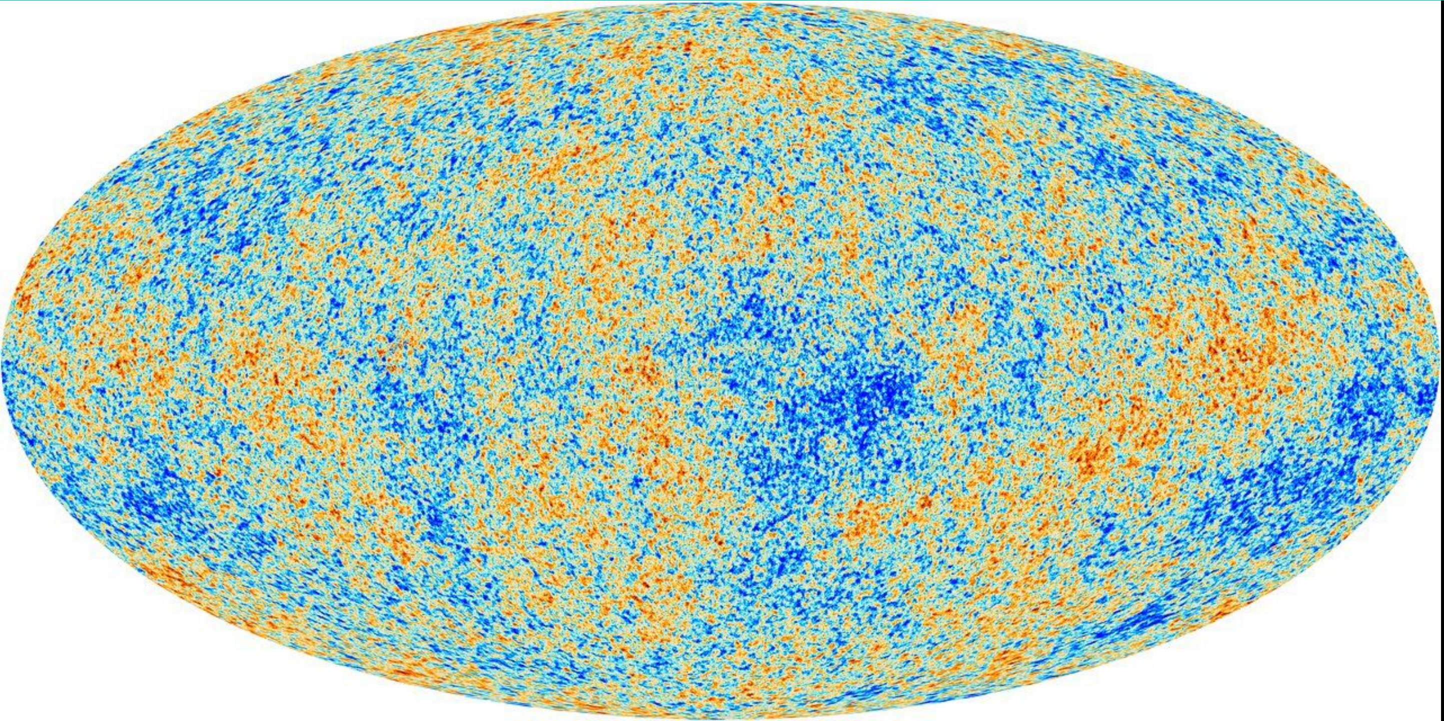
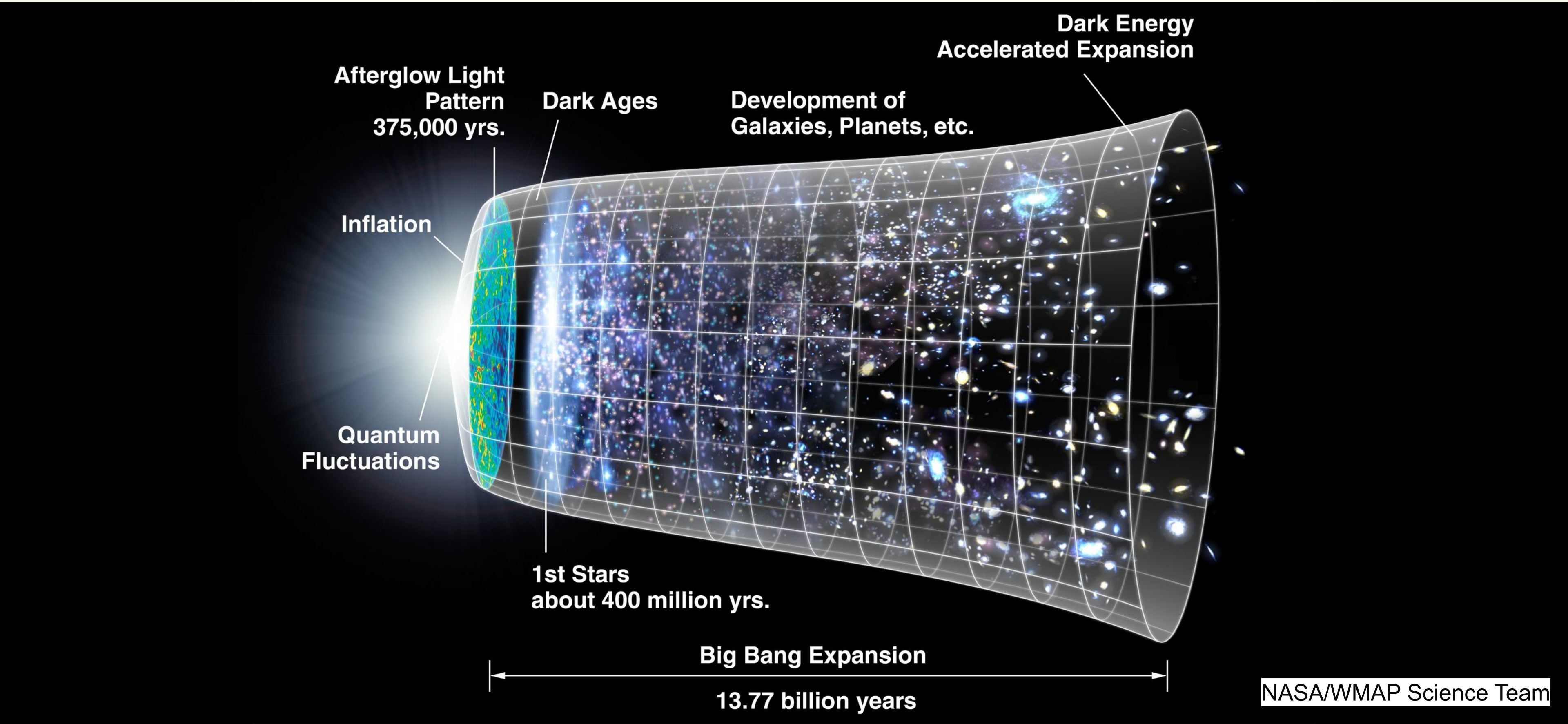
Introdução à Cosmologia: evolução dos conceitos e pesquisa



Lucas
James Faga

como chegamos aqui?



NASA/WMAP Science Team

Vale a pena fazer esse curso man?

por que?

objetivos

1. primeiro contato com cosmologia

não objetivos

por que?

objetivos

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

não objetivos

por que?

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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

por que?

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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 que?

1. prime … elatividade
   cosmo
2. foco n …
   dos co … um curso
3. visão … a Física
   pesqu

imagem de Jessie Muir e Alex Amon (2021) instrumentação

observação

tratamento de dados

imagem de Jessie Muir e Alex Amon (2021)

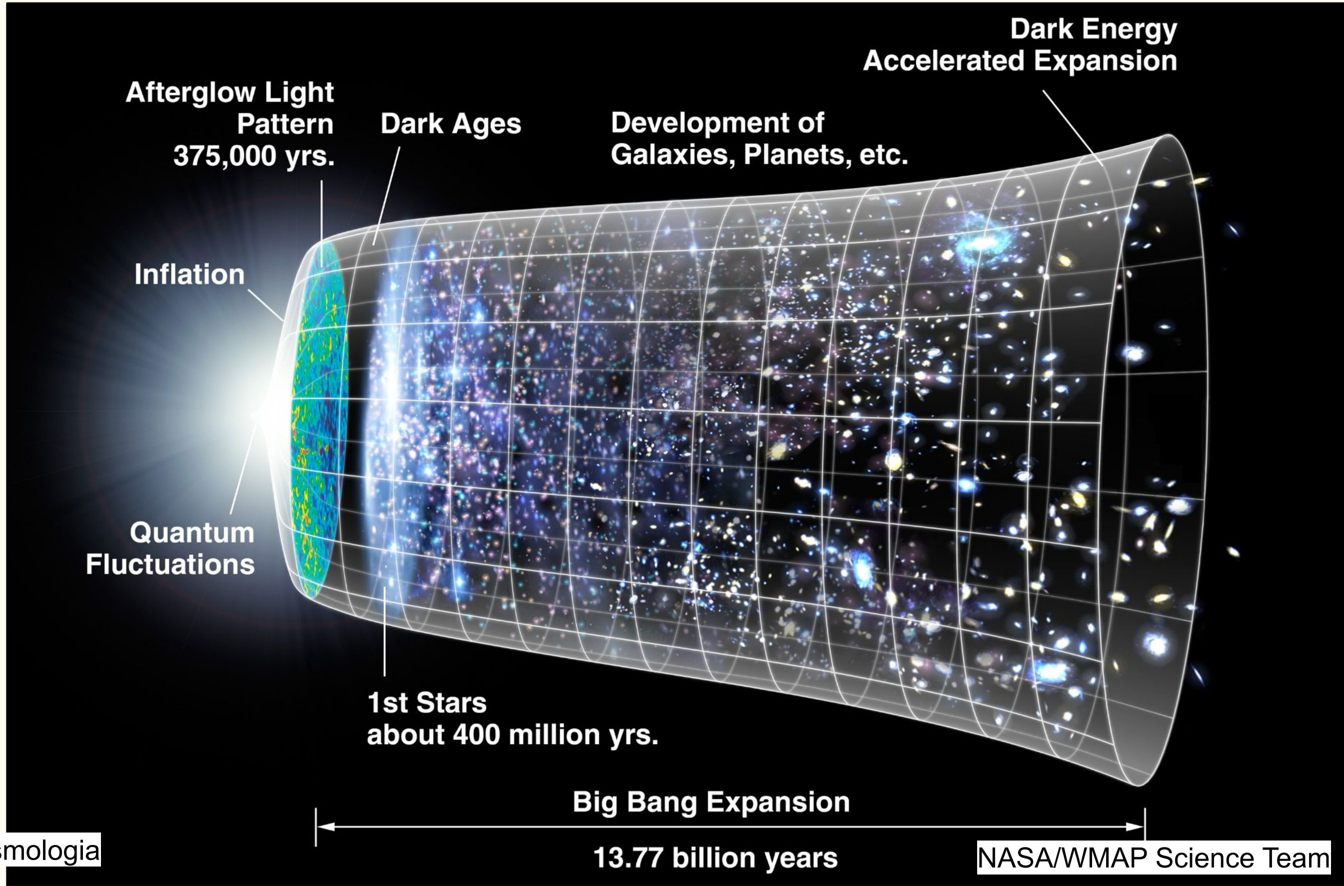
o que são cosmologias?

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.

Projeto Povos Indígenas no Brasil
https://pib.socioambiental.org/pt/Mitos_e_cosmologia



NASA/WMAP Science Team

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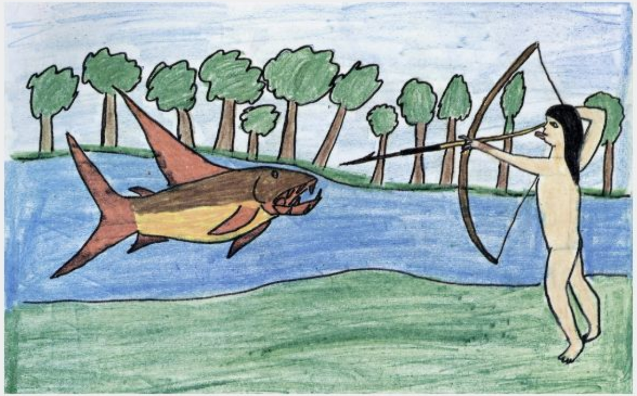
Vintage illustration of an Aztec priest removing the heart of a victim as a sacrifice to the gods; engraving, 1889. (Photo by GraphicaArtis/Getty Images)

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.

Projeto Povos Indígenas no Brasil
https://pib.socioambiental.org/pt/Mitos_e_cosmologia

cosmo logias br

Projeto Povos Indígenas no Brasil
https://pib.socioambiental.org/pt/Mitos_e_cosmologia

Povos do Alto Rio Negro

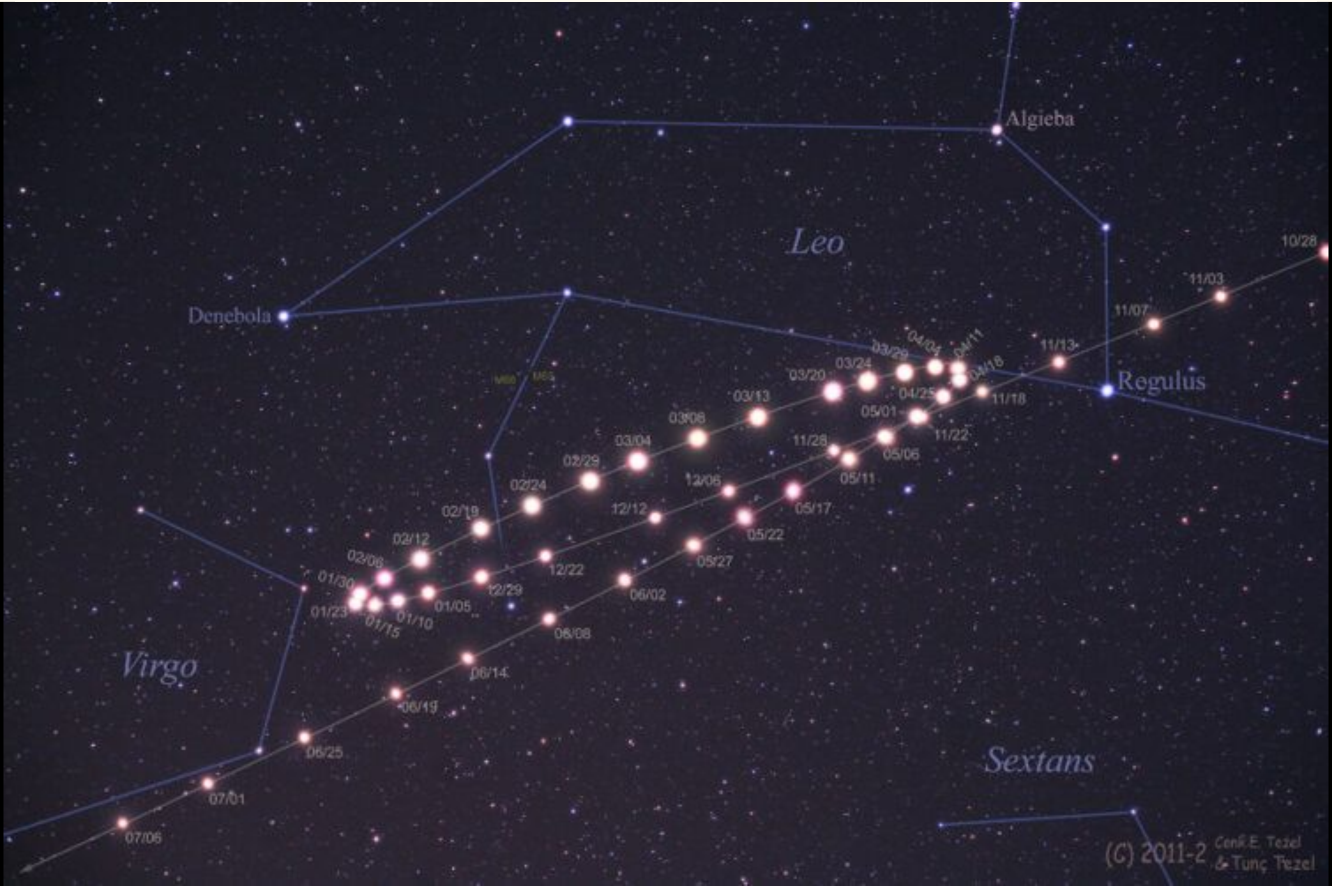
Cobra Grande pintada sobre maloca no Alto Rio Negro. Foto: Beto Ricardo

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 entranhas 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.

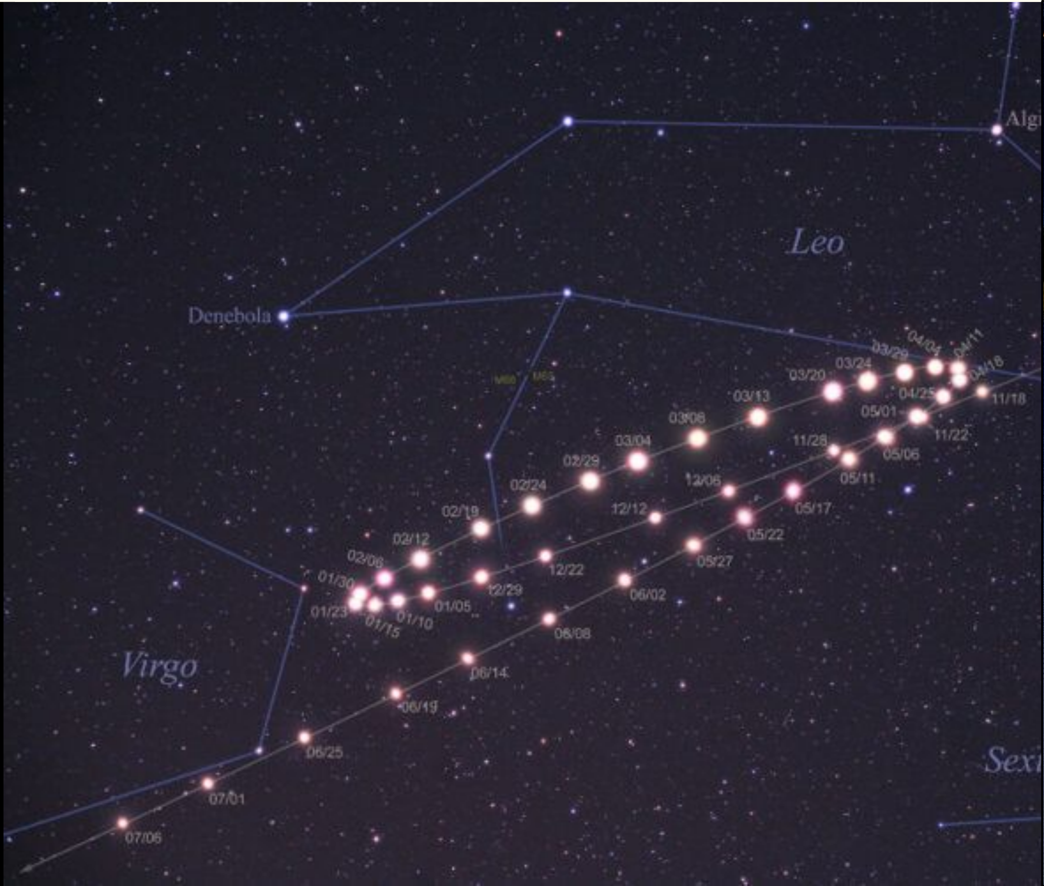
Em muitas cosmologias, as relações entre humanos e os demais seres são pensadas através da idéia da predação, numa metáfora que simbólica e logicamente aproxima caça, guerra, sexo e comensalidade. Ainda no alto rio Negro, o xamã parece estar encarregado de garantir que fluxos e volumes de energia vital 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.

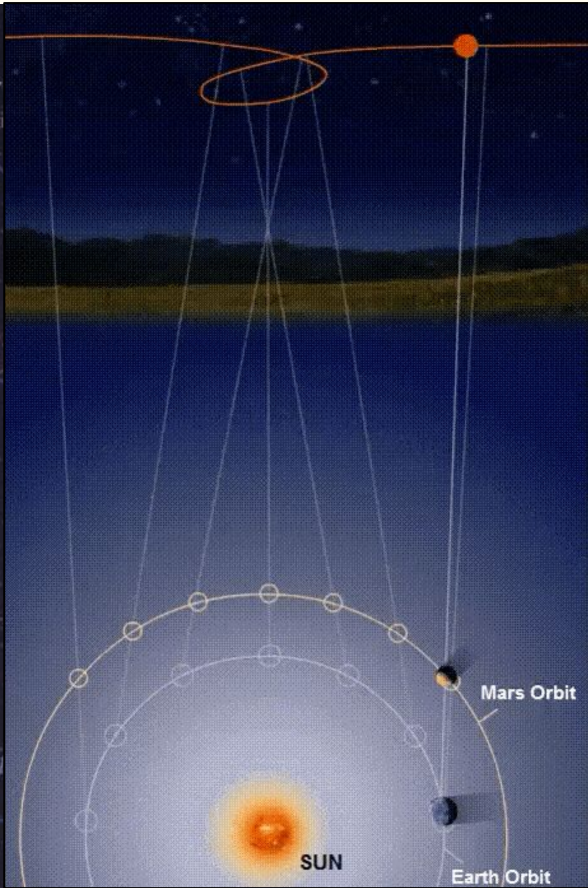
Parte 1
Universos-ilhas, relatividade e implicações cosmológicas

revolução copernicana



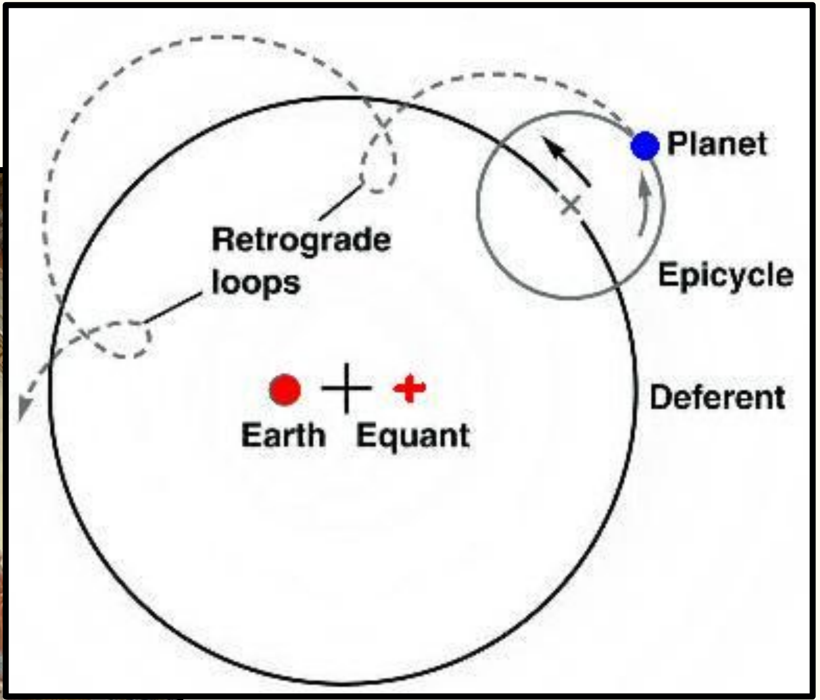
revolução copernicana





revolução copernicana

(séc II)

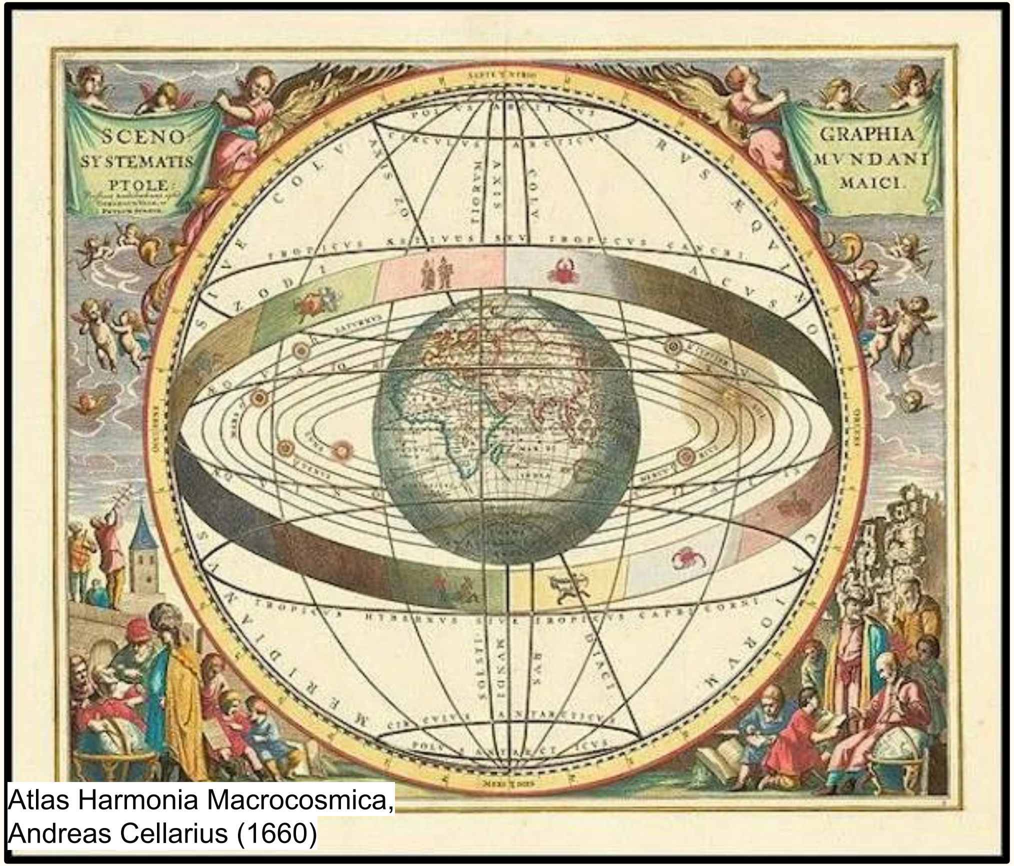


A escola de Atenas, Rafael (1509)

revolução copernicana

(séc II)

(séc XVI)

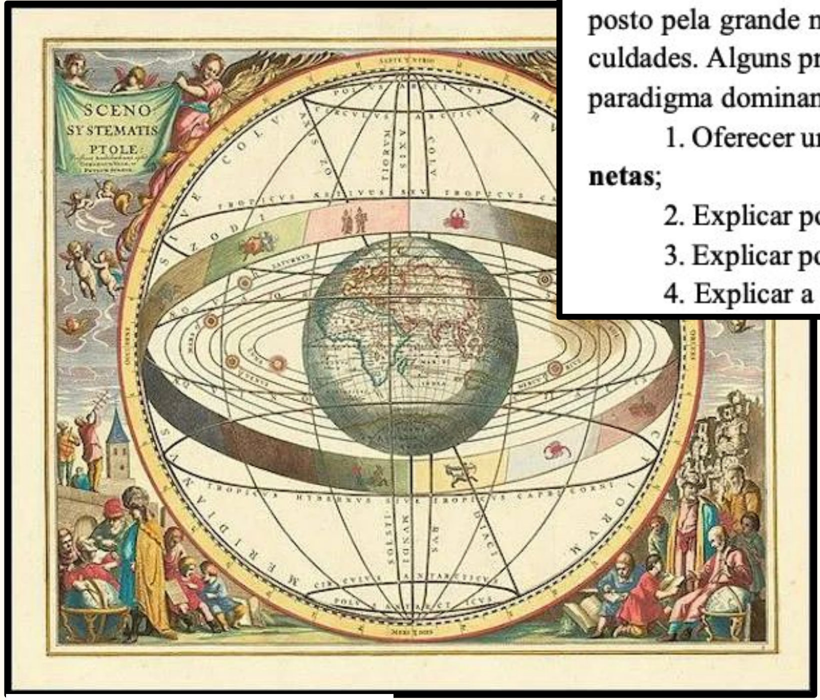


Atlas Harmonia Macrocosmica,
Andreas Cellarius (1660)

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:

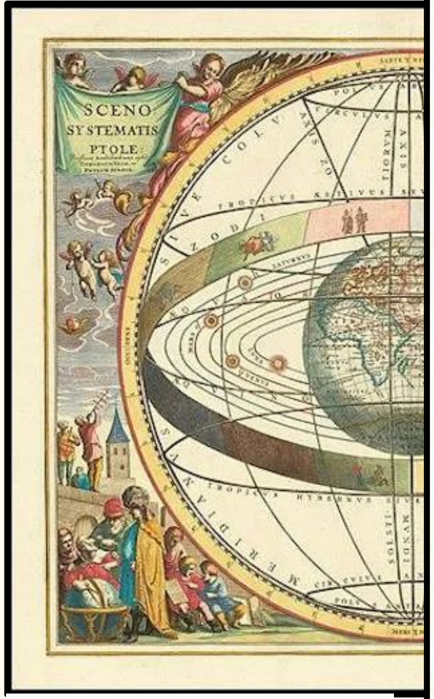
1. Oferecer uma explicação convincente sobre o **movimento retrógrado dos planetas**;
2. Explicar porque Vênus e Mercúrio sempre são vistos nas proximidades do Sol;
3. Explicar porque Marte, Júpiter e Saturno podiam ser vistos em oposição ao Sol;
4. Explicar a ordem de afastamento dos planetas com relação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

Notas de aula de gravitação, João Zanetic (2019)

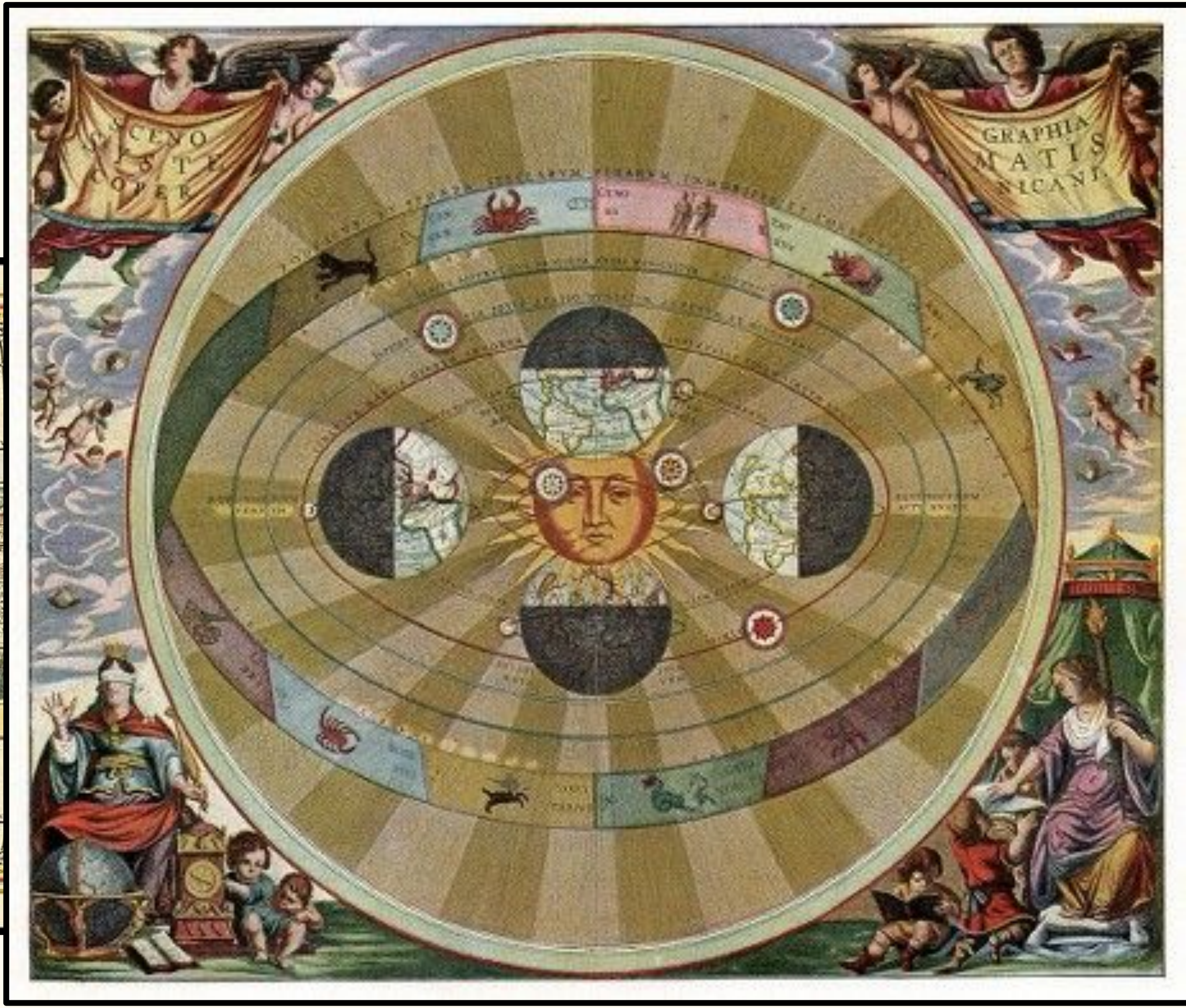
revolução

(séc II)

(séc XVI)



Atlas Harmonia Macrocosmica,
Andreas Cellarius (1660)

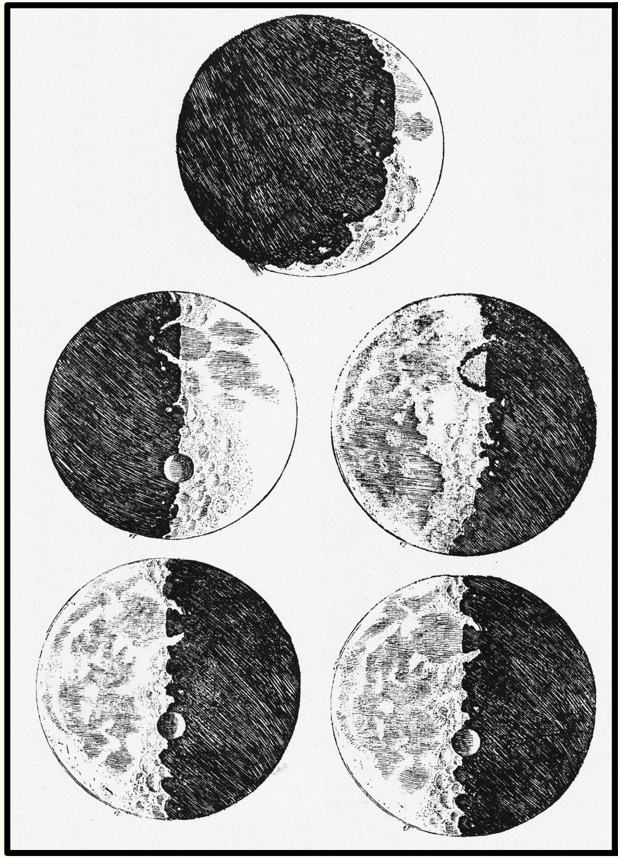


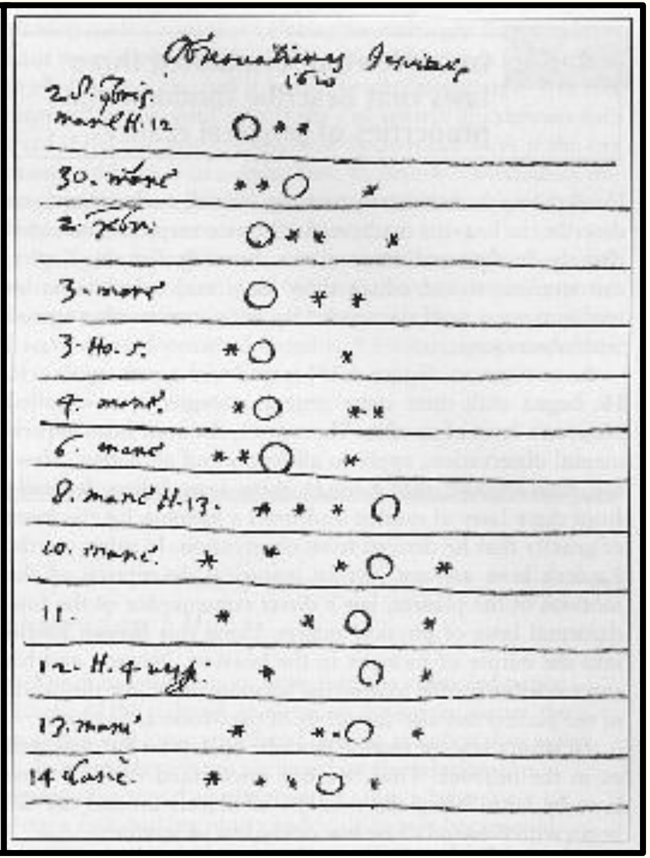
estruturação da ciência

(séc II)

(séc XVI)

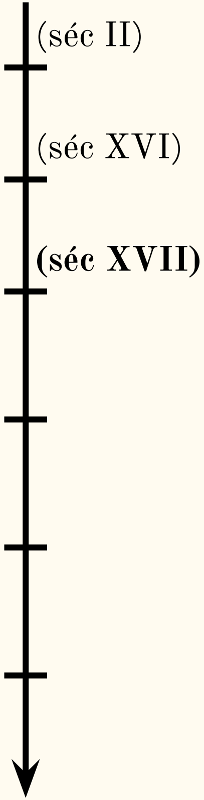
(séc XVII)

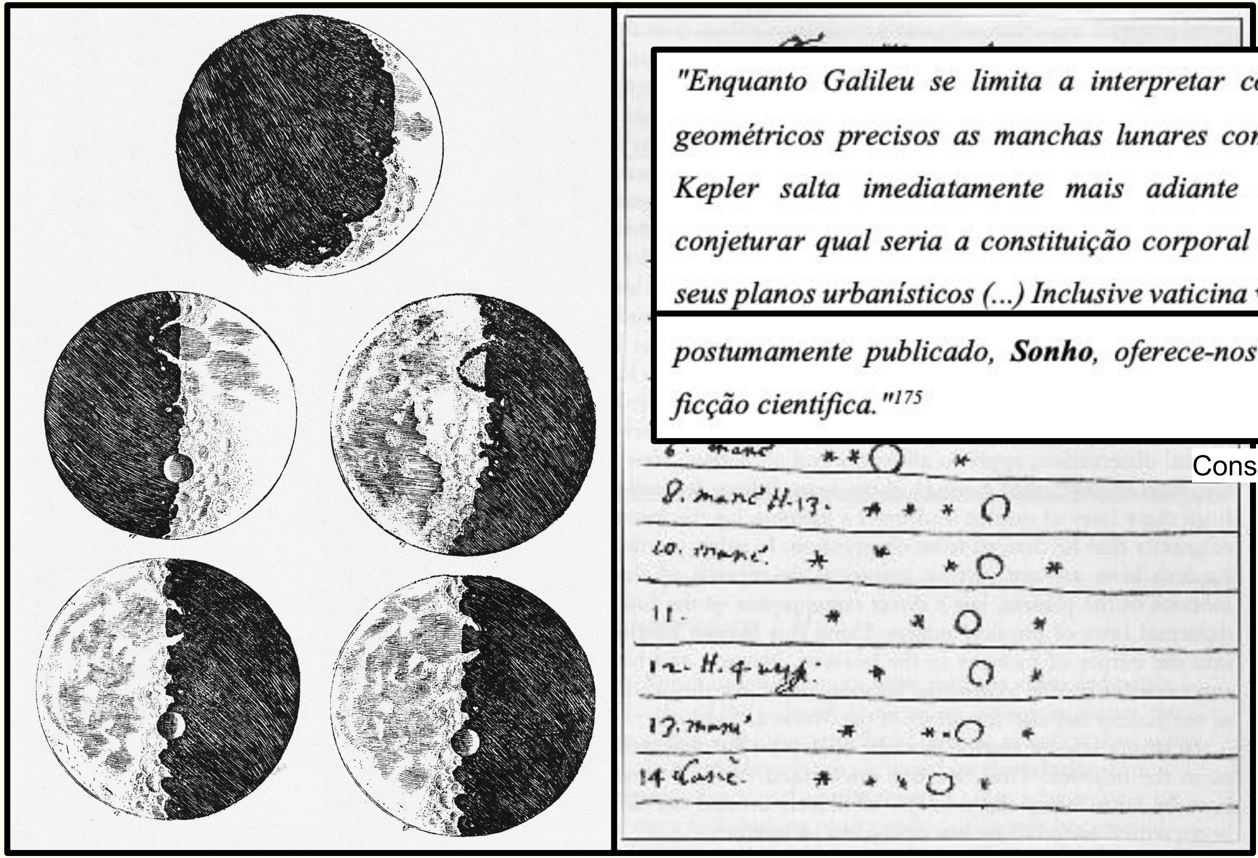




Observações de
Galileu Galilei (1564 – 1642)

estruturação da ciência





"*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 conjeturar 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]

Considerações sobre Descartes,
Alexandre Koyré (1980)

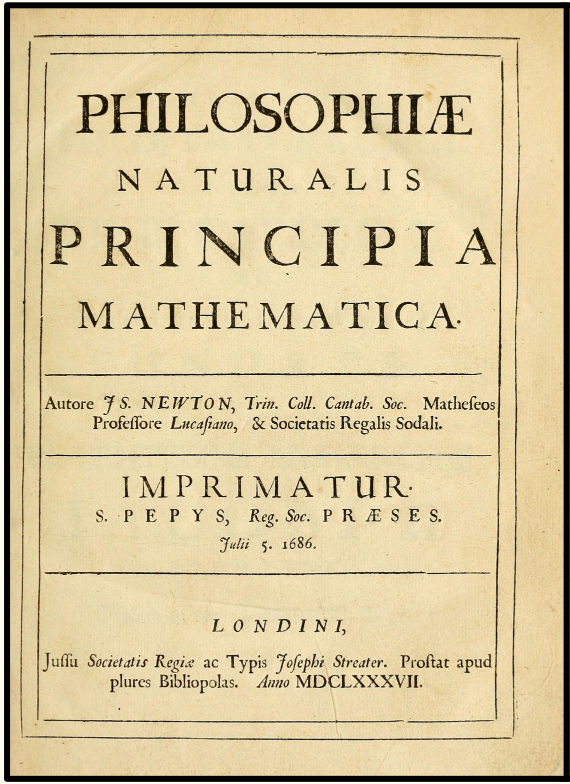
Observações de
Galileu Galilei (1564 – 1642)

estruturação da ciência

(séc II)

(séc XVI)

(séc XVII)



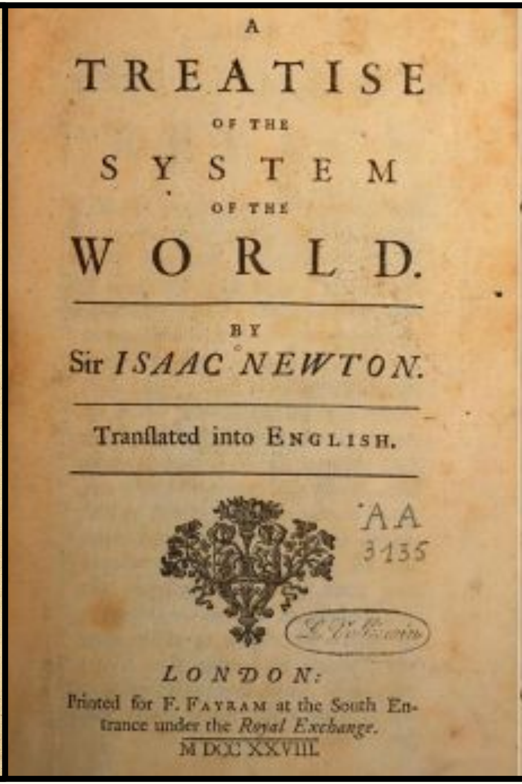
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

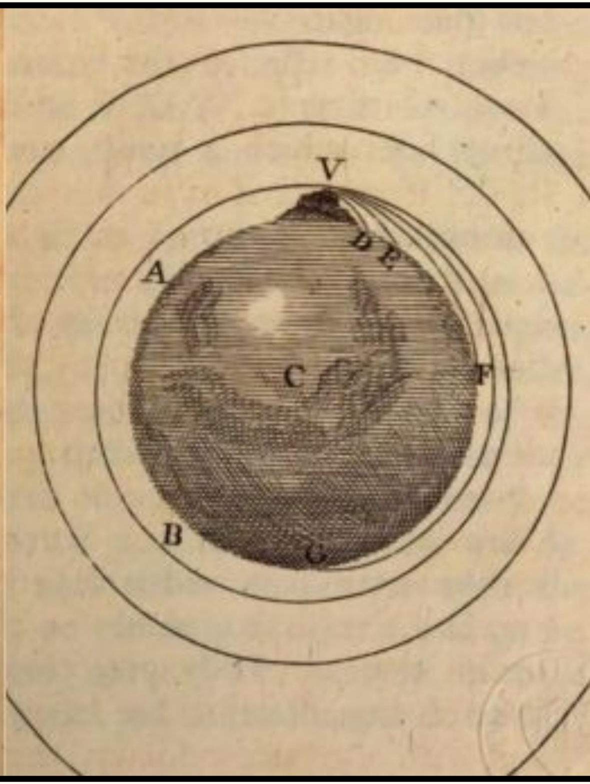


A
TREATISE
OF THE
SYSTEM
OF THE
WORLD.

BY
Sir *ISAAC NEWTON*.

Translated into ENGLISH.

LONDON:
Printed for F. FAYRAM at the South Entrance under the *Royal Exchange*.
MDCCXXVIII.



estruturação da ciência

(séc II)

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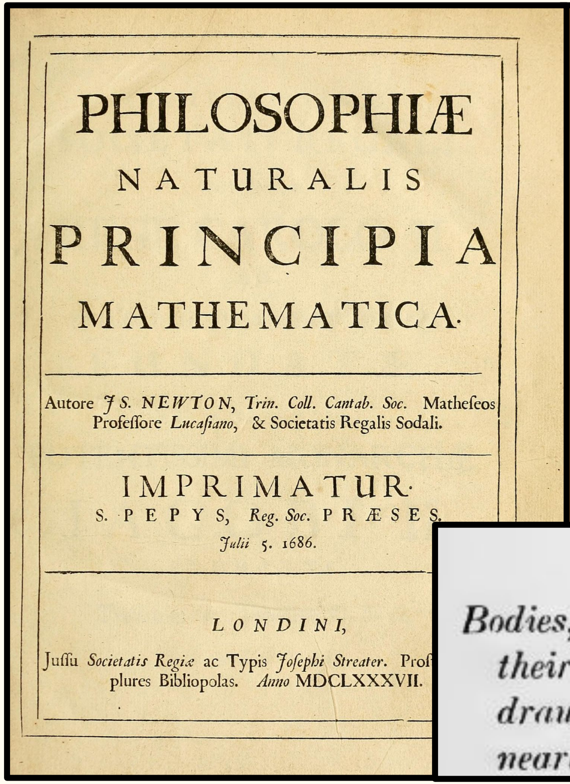
(séc XVII)



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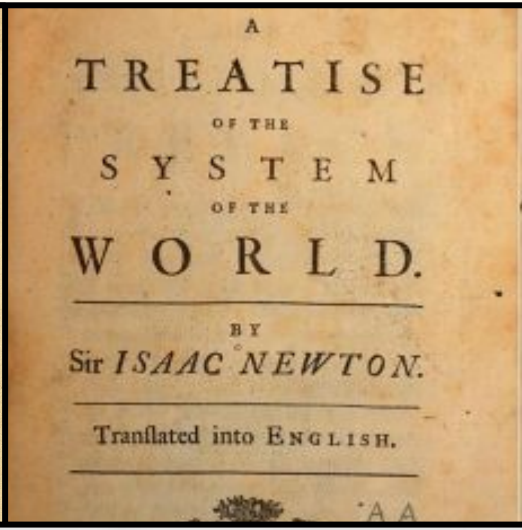

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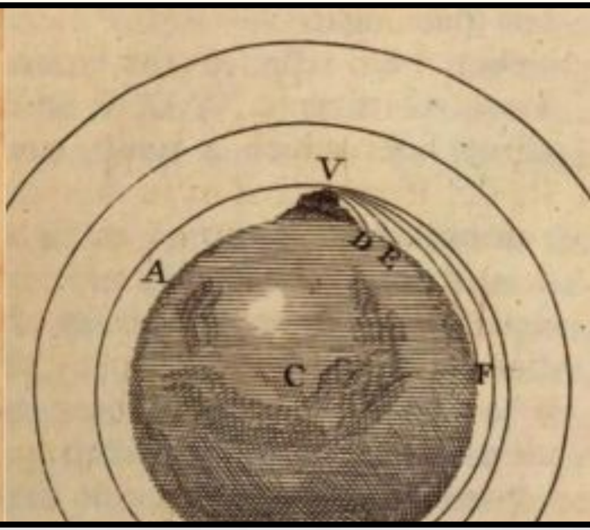
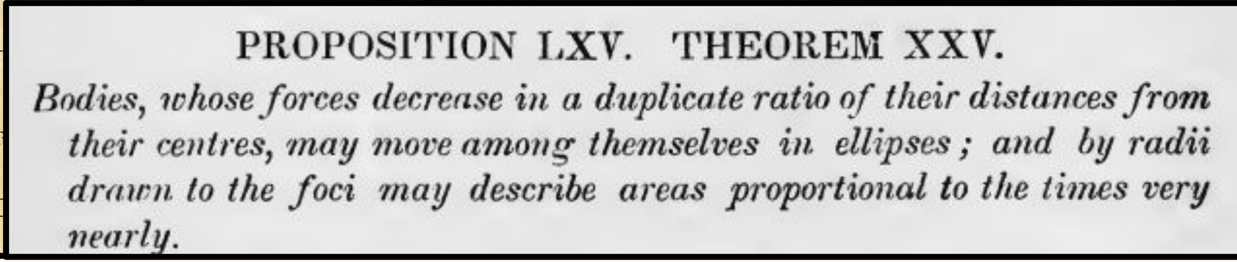




PROPOSITION LXV. THEOREM XXV.

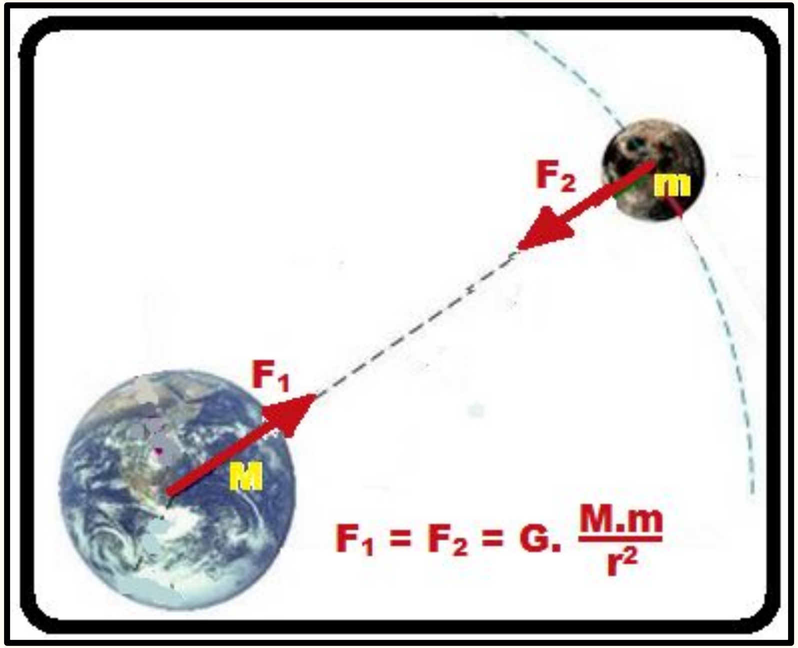
Bodies, whose forces decrease in a duplicate ratio of their distances from their centres, may move among themselves in ellipses; and by radii drawn to the foci may describe areas proportional to the times very nearly.

estruturação da ciência

(séc II)

(séc XVI)

(séc XVII)



estruturação da ciência

(séc II)

(séc XVI)

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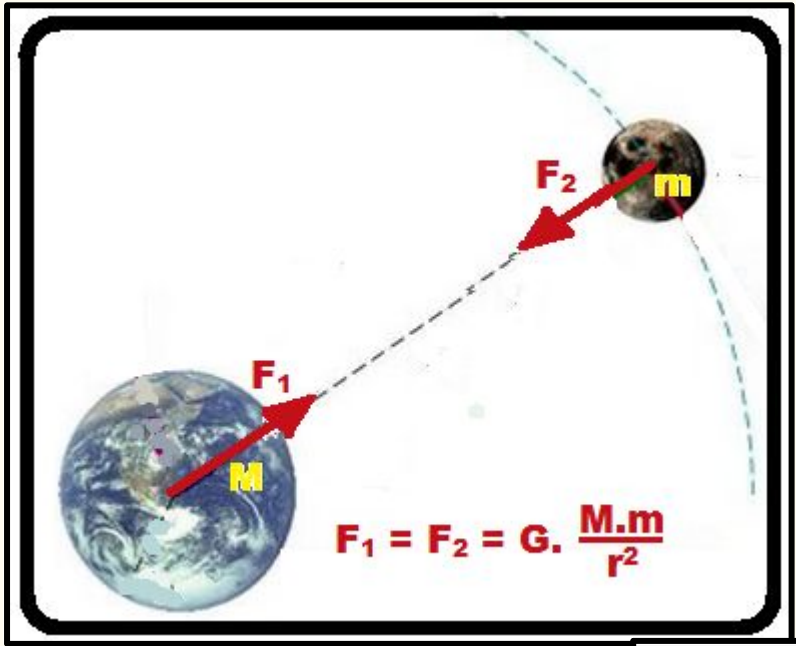
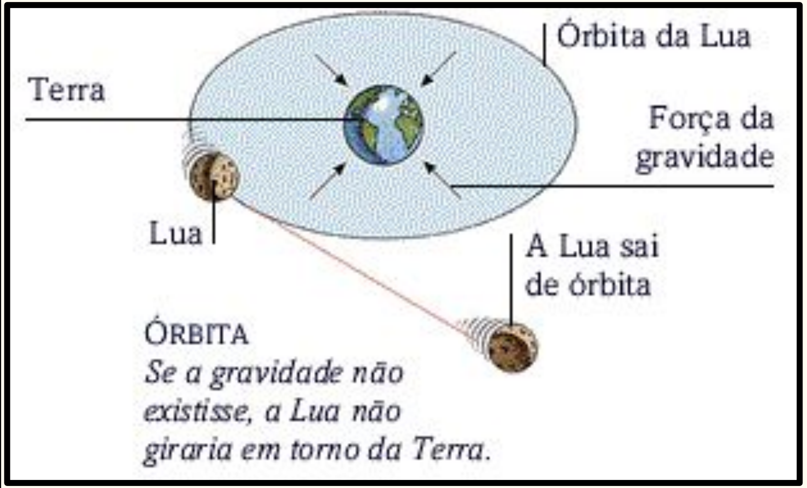




"I have not yet been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses (hypotheses non fingo)." ???

Principia,
Isaac Newton (1713)

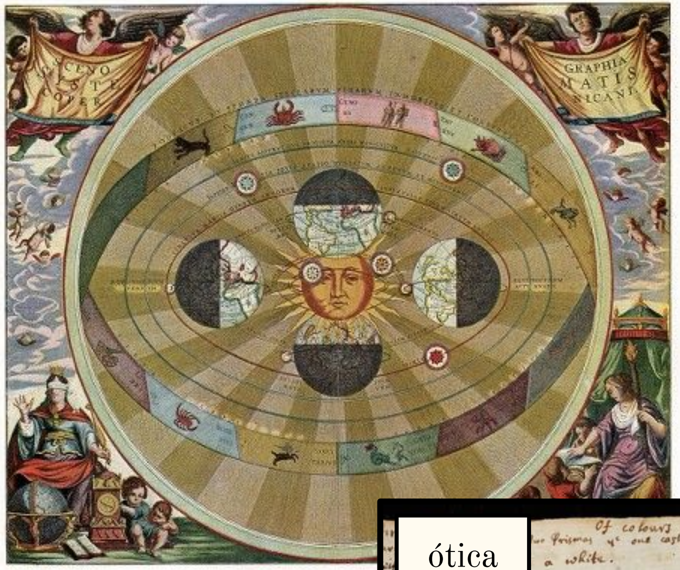
estruturação da ciência

(séc II)

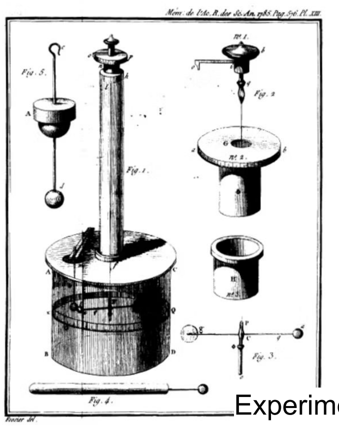
(séc XVI)

(séc XVII)

(séc XVIII)



eletricidade

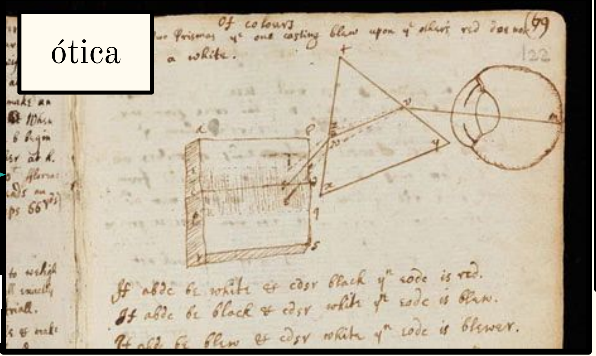


Experimento de Coulomb (1785)

termodinâmica

Primeira locomotiva (1804)

ótica



Principia,
Isaac Newton (1713)

estruturação da ciência

(séc II)

(séc XVI)

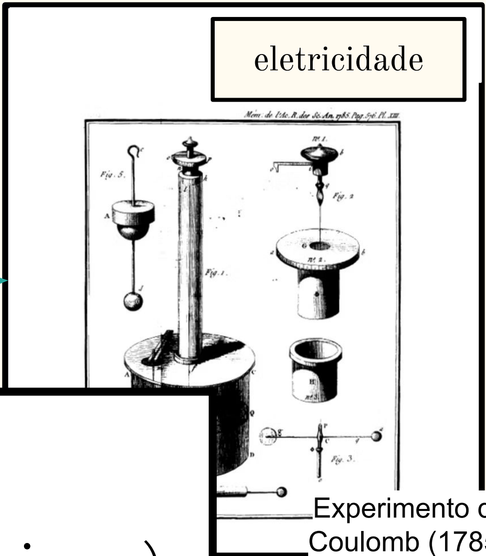
(séc XVII)

(séc XVIII)

Revolução científica

Revolução filosófica (iluminismo, positivismo)

Revolução socioeconômica



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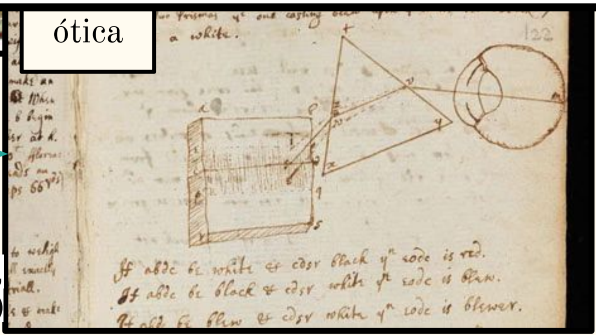
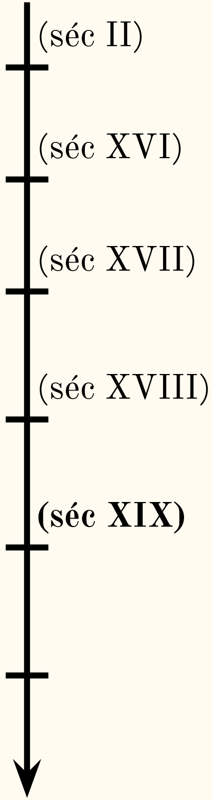


Principia,
Isaac Newton (1713)

Primeira locomotiva (1804)

eletromagnetismo



$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

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

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

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

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

eletromagnetismo

(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

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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)

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,, Continuity	. . . .	(H)

*

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

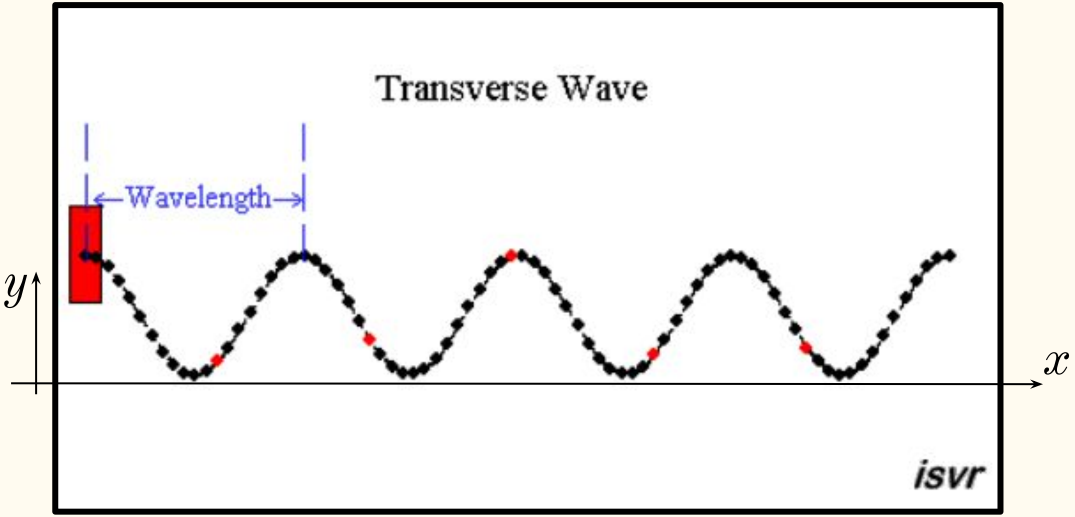
(séc II)

(séc XVI)

(séc XVII)

(séc XVIII)

(séc XIX)



$$\boxed{\frac{\partial^2 y}{\partial t^2} - c^2 \frac{\partial^2 y}{\partial x^2} = 0}$$

união: ótica e eletromag

(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

$$\left.\begin{array}{llll}\text{(i)} & \nabla\cdot\mathbf{E}=0, & \text{(iii)} & \nabla\times\mathbf{E}=-\dfrac{\partial\mathbf{B}}{\partial t},\\[2ex] \text{(ii)} & \nabla\cdot\mathbf{B}=0, & \text{(iv)} & \nabla\times\mathbf{B}=\mu_0\epsilon_0\dfrac{\partial\mathbf{E}}{\partial t}.\end{array}\right\} \tag{9.40}$$

They constitute a set of coupled, first-order, partial differential equations for **E** and **B**. They can be *de*coupled 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 $\nabla\cdot\mathbf{B}=0$,

Introduction to Electrodynamics,
David Griffiths (1981)

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

$$\boxed{v=\frac{1}{\sqrt{\epsilon_0\mu_0}}=3.00\times10^8\ \mathrm{m/s},}$$

união: ót romag

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

In regions of space where t

(i) $\nabla \cdot$

(ii) $\nabla \cdot$

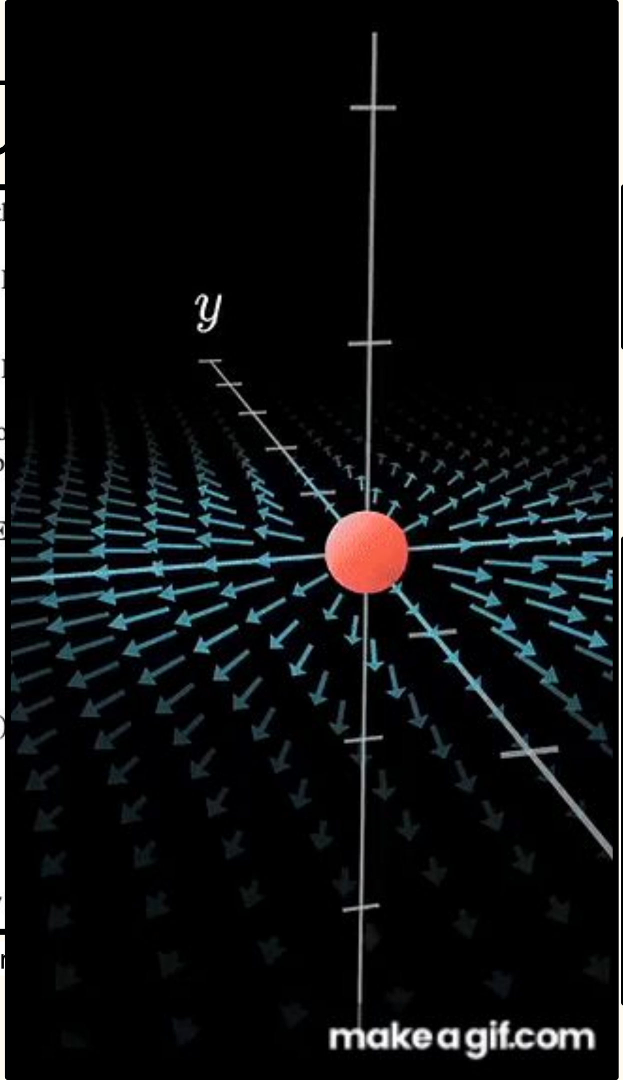
They constitute a set of co
and $\mathbf{B}$. They can be *de*coup

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

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

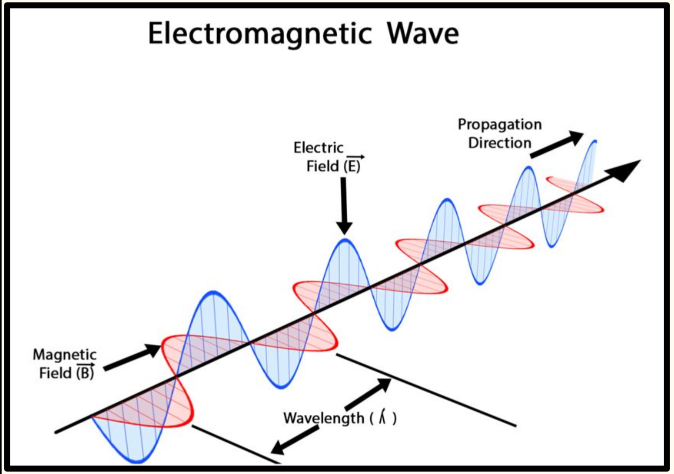
Or, since $\nabla \cdot \mathbf{E} = 0$ and ∇

Introduction to Electrody
David Griffiths (1981)



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

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



união: ótica e eletromag

(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

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

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

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

$\nabla\times(\nabla$

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

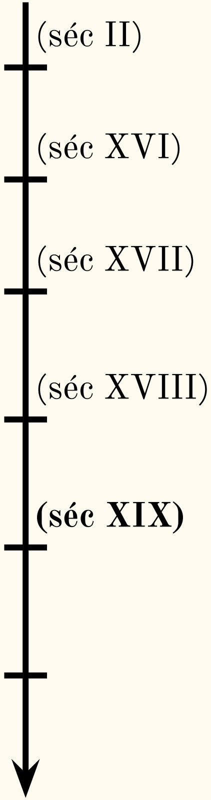
Introduction to Electr
David Griffiths (1981

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

$$v=\frac{1}{\sqrt{\epsilon_0\mu_0}}=3.00\times10^8\ \text{m/s},$$

* 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.

união: ótica e eletromag



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

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

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...

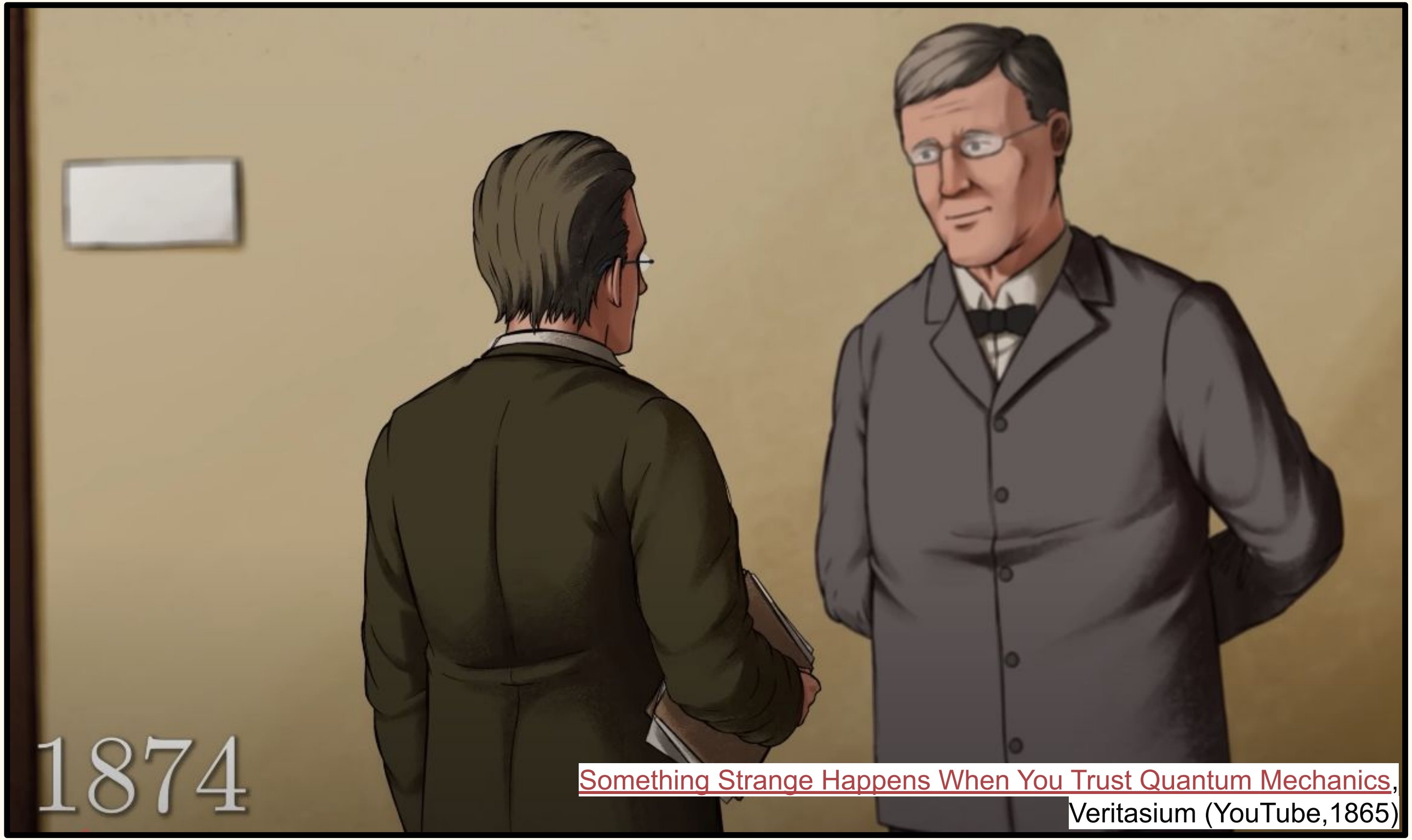
(séc II)

(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)

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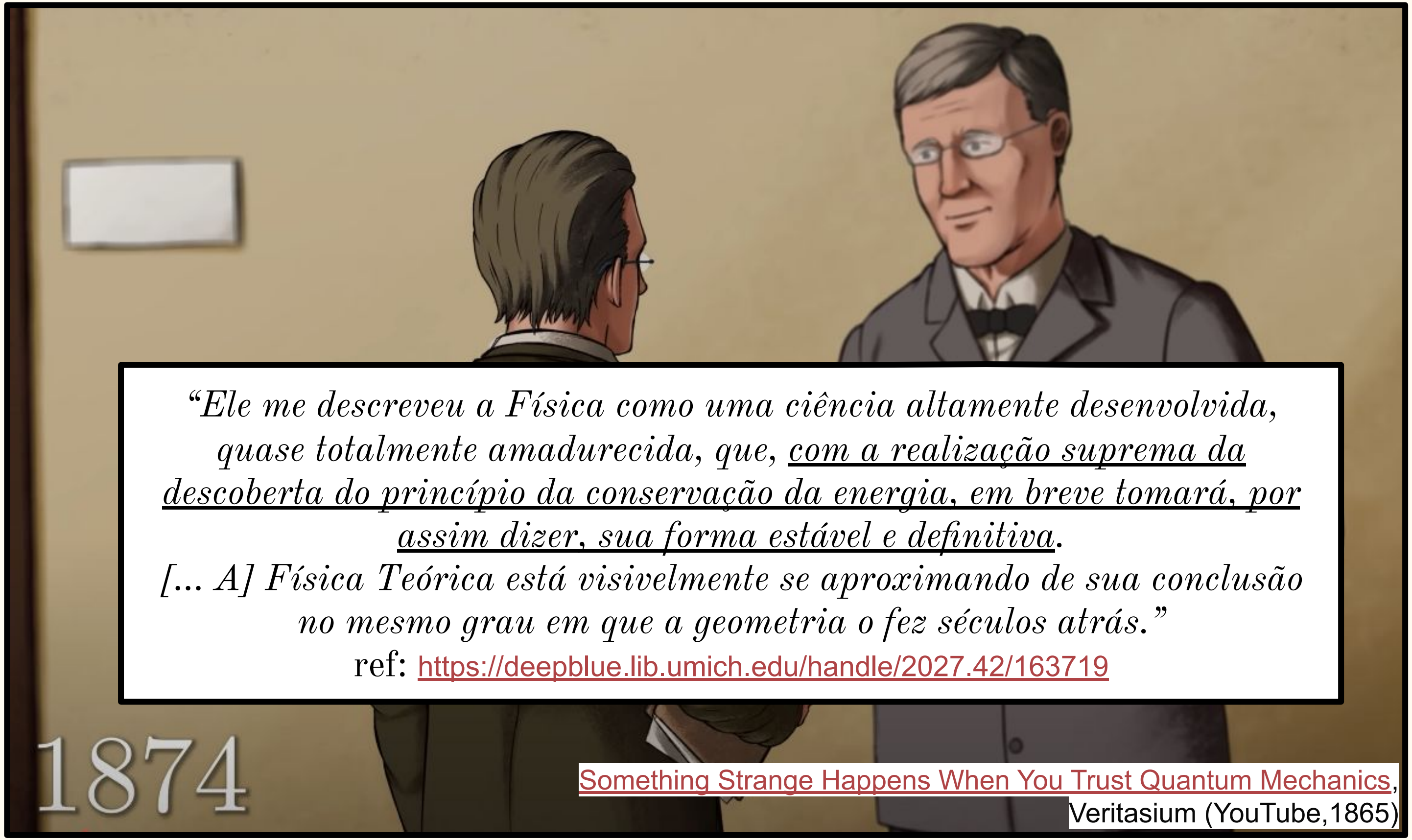
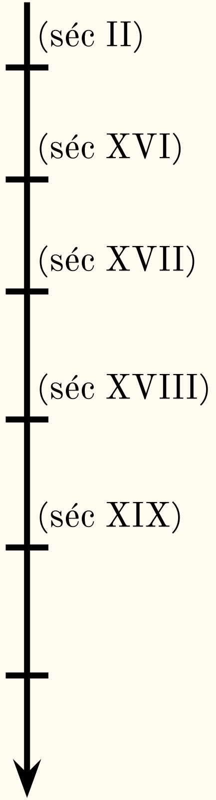
(séc XIX)



"Ele me descreveu a Física como uma ciência altamente desenvolvida, quase totalmente amadurecida, que, com a realização suprema da descoberta do princípio da conservação da energia, em breve tomará, por assim dizer, sua forma estável e definitiva.
[... A] Física Teórica está visivelmente se aproximando de sua conclusão no mesmo grau em que a geometria o fez séculos atrás."
ref: https://deepblue.lib.umich.edu/handle/2027.42/163719

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

só faltam alguns detalhes...



problema do referencial

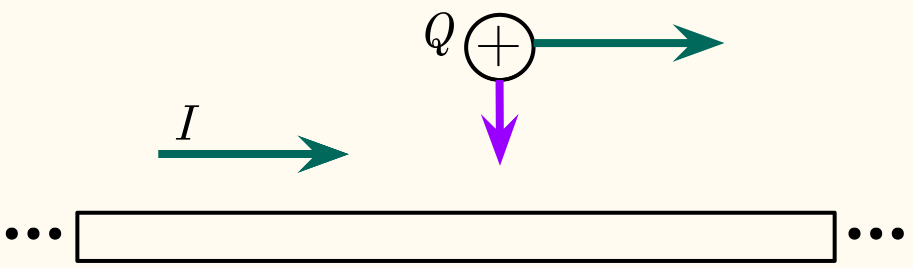
problema do corpo negro

...

problema do referencial (séc XIX)

referencial 1

- carga se movendo
- corrente se movendo
- fio parado



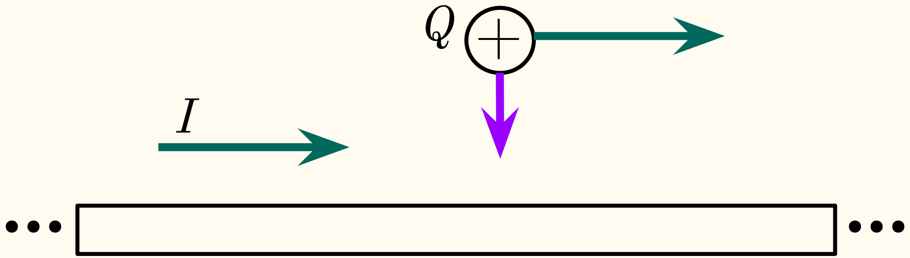
problema do referencial (séc XIX)

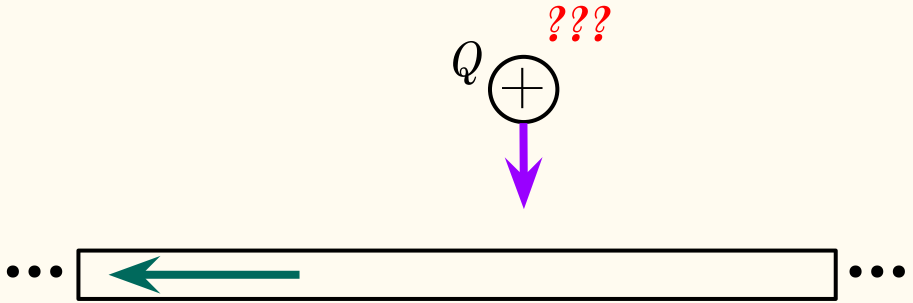
<u>referencial 1</u>

- carga se movendo
- corrente se movendo
- fio parado

<u>referencial 2</u>

- carga parada
- corrente parada
- fio se movendo





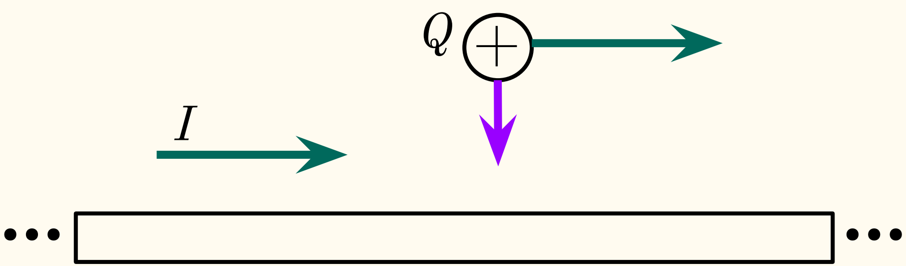
problema do referencial (séc XIX)

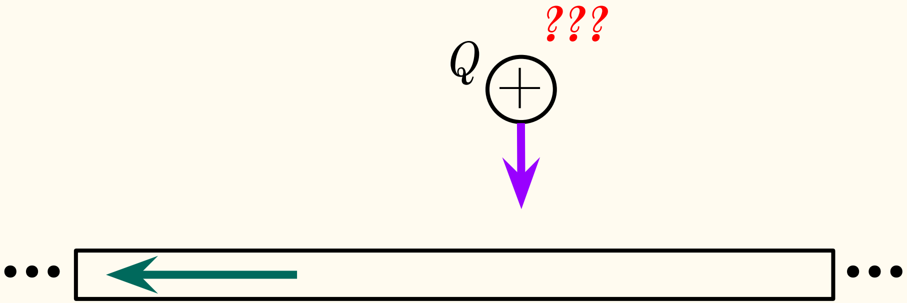
referencial 1

- carga se movendo
- corrente se movendo
- fio parado

referencial 2

- carga parada
- corrente parada
- fio se movendo





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

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

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

the line element ds

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

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

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

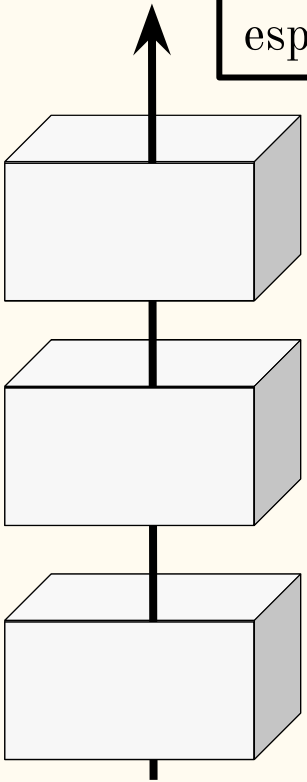
1.1.5 Invariance of the Line Element: Lorentz Boosts

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

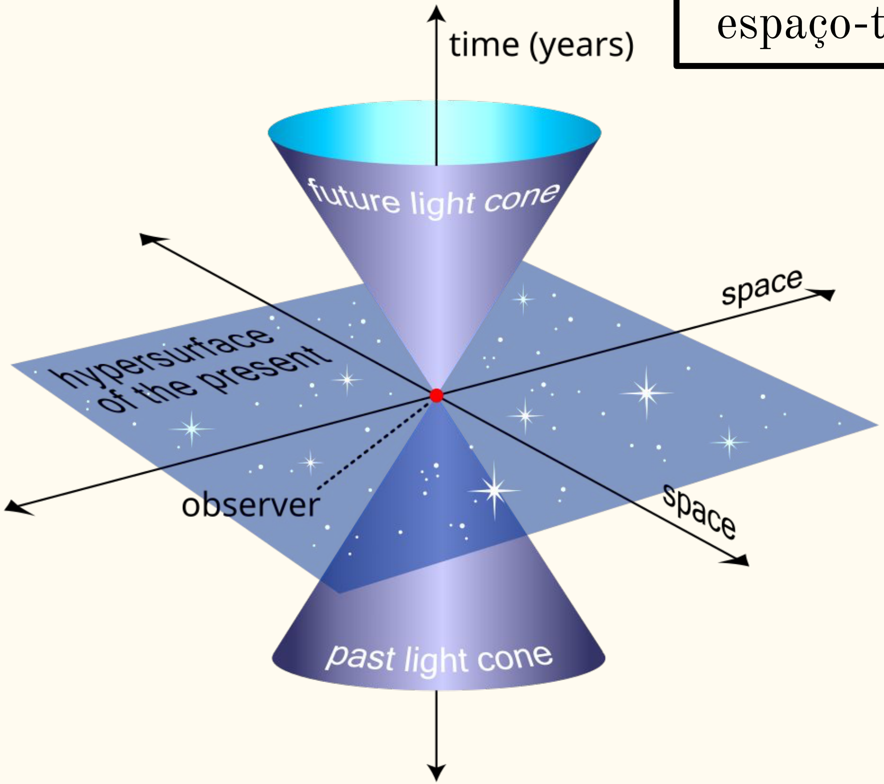
$$s^2 = x^2 + y^2 + z^2 - c^2t^2 = 0 = x'^2 + y'^2 + z'^2 - c^2t'^2 = s'^2 \tag{1.30}$$

relatividade especial

espaço e tempo

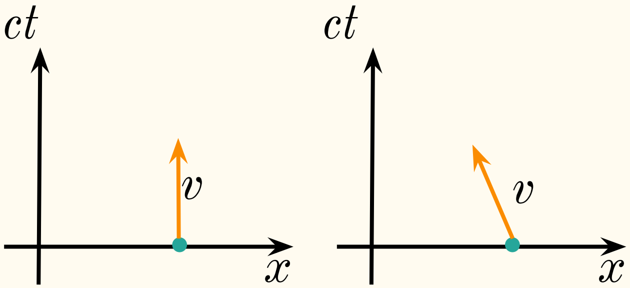


espaço-tempo



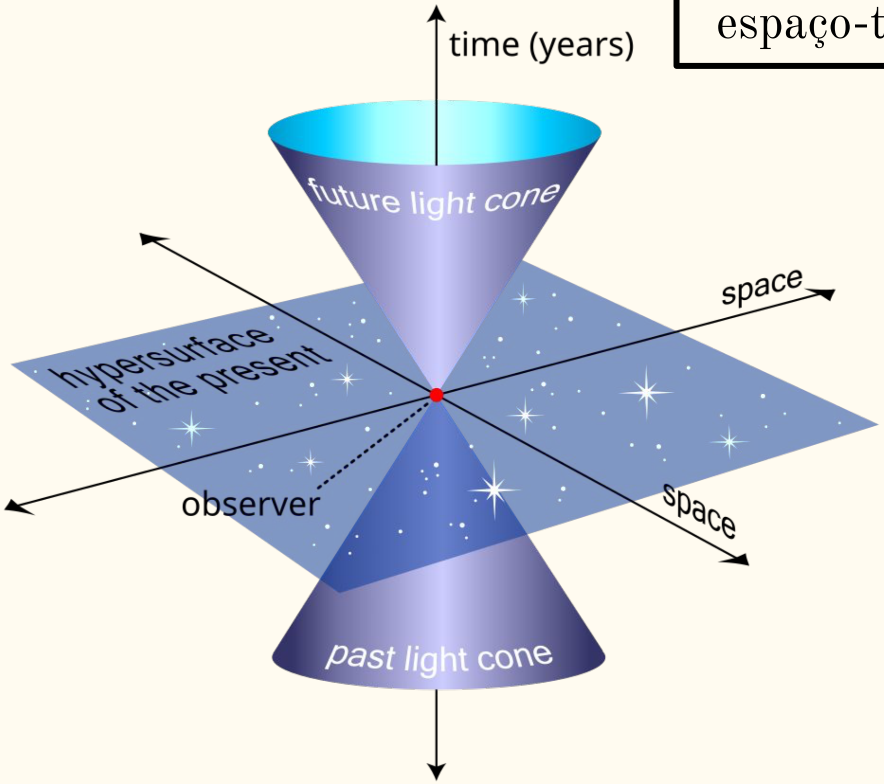
relatividade especial

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

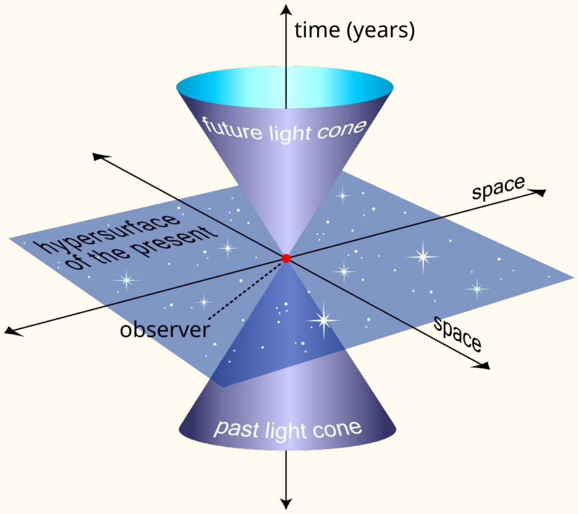


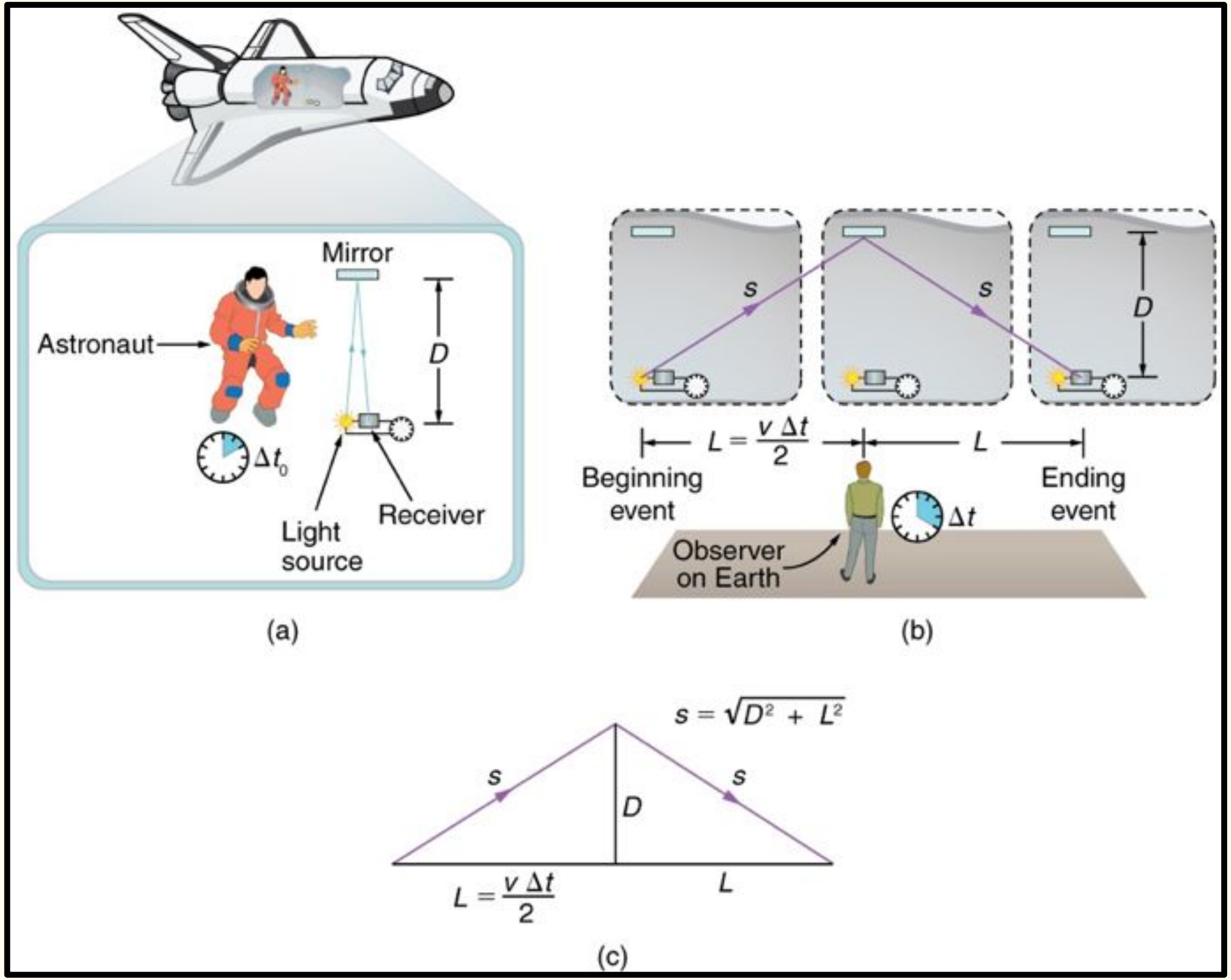
quadrivetor da velocidade é normalizado para
$U = (c, 0, 0, 0)$

espaço-tempo



réguas e relógios





relatividade especial

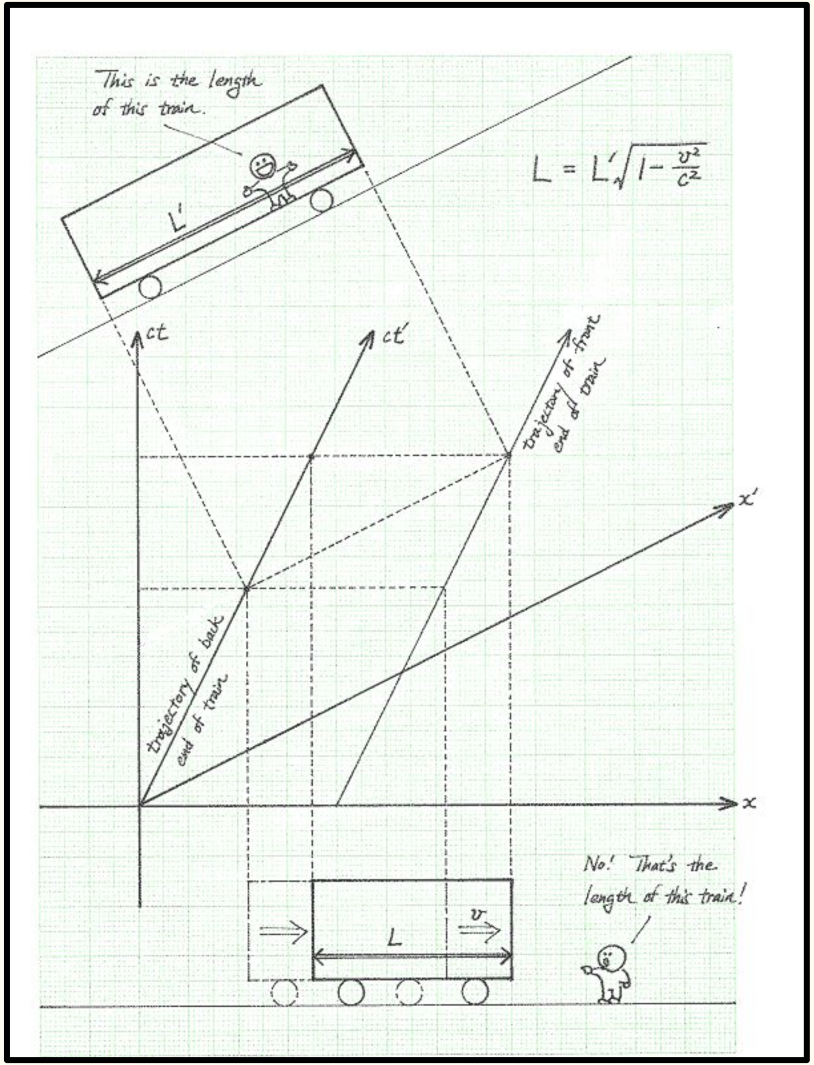
o que é um comprimento?

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



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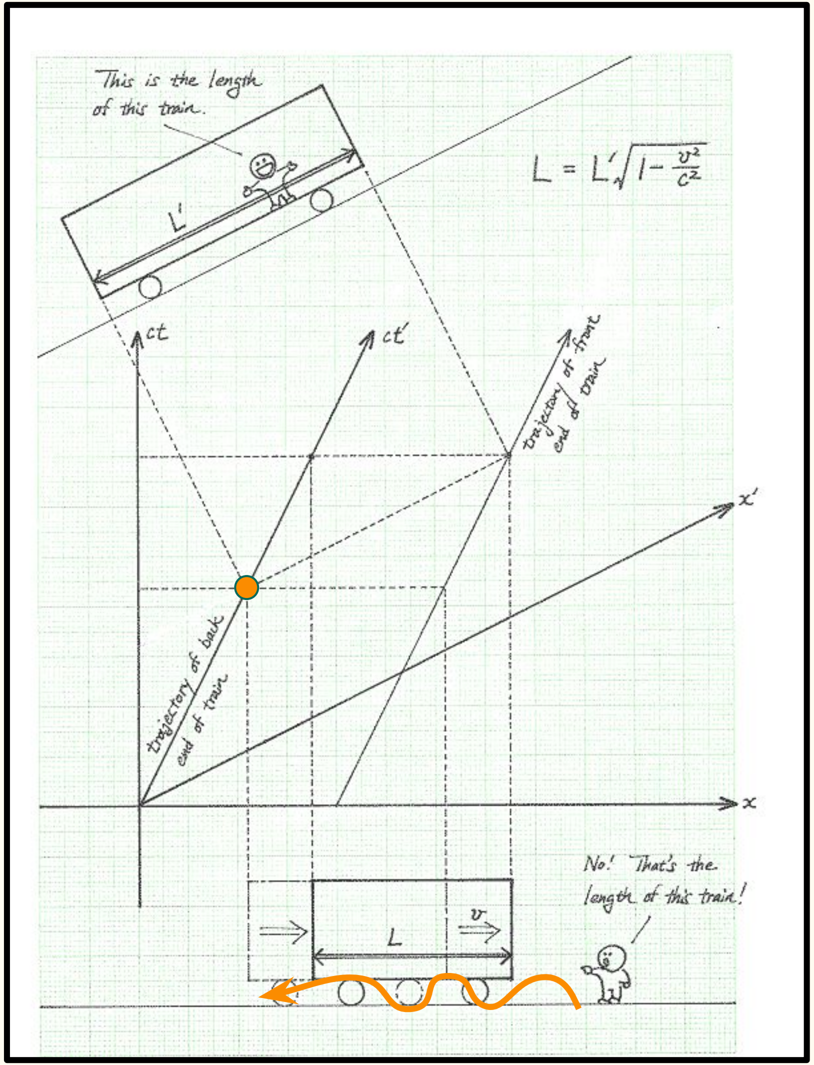

relatividade especial

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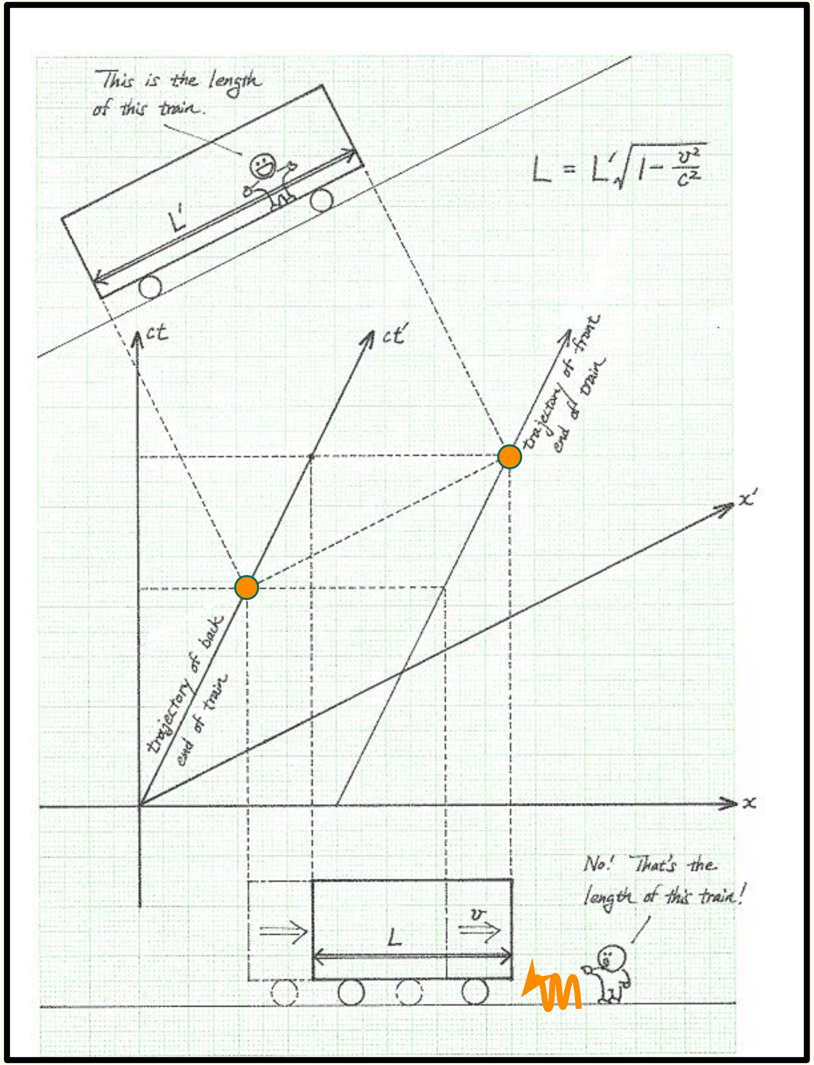

relatividade especial

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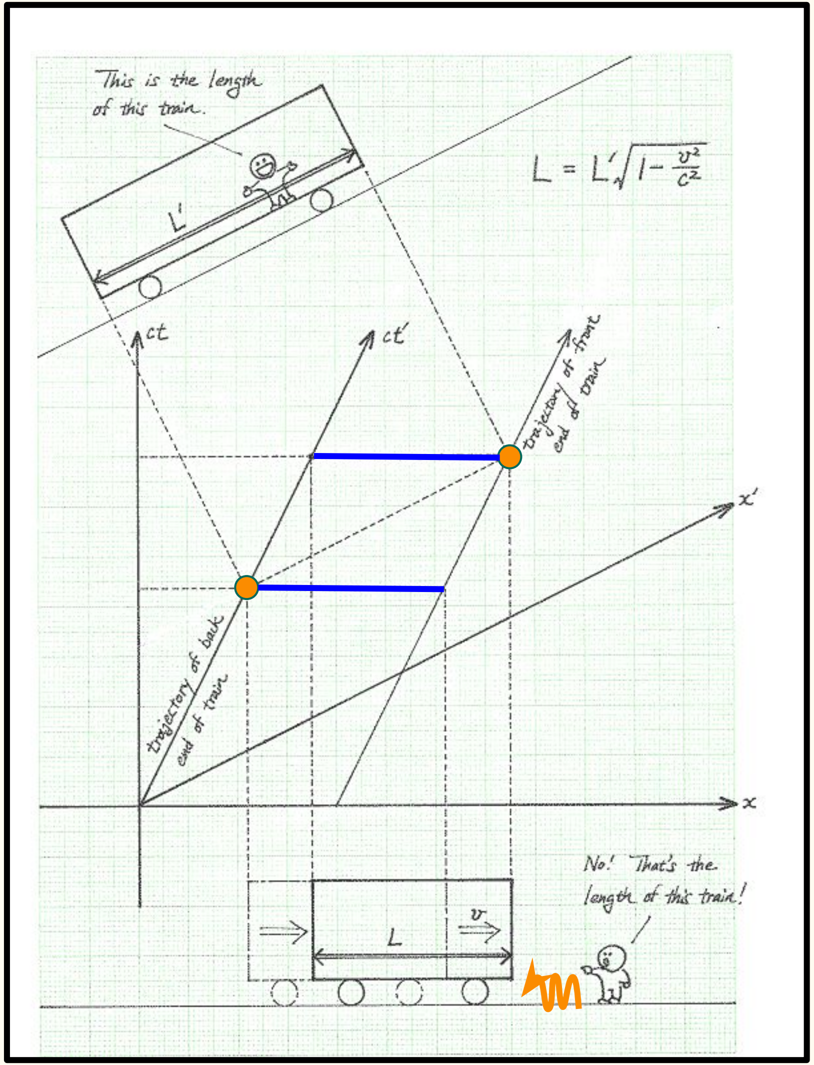

relatividade especial

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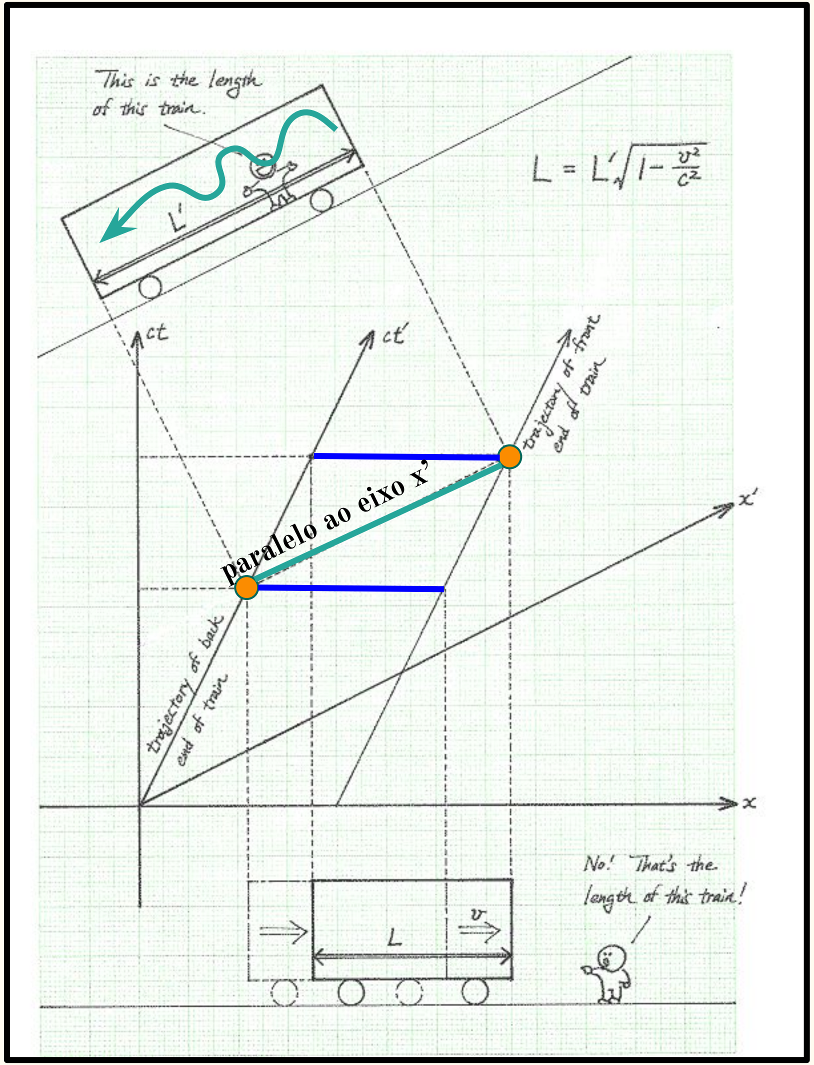
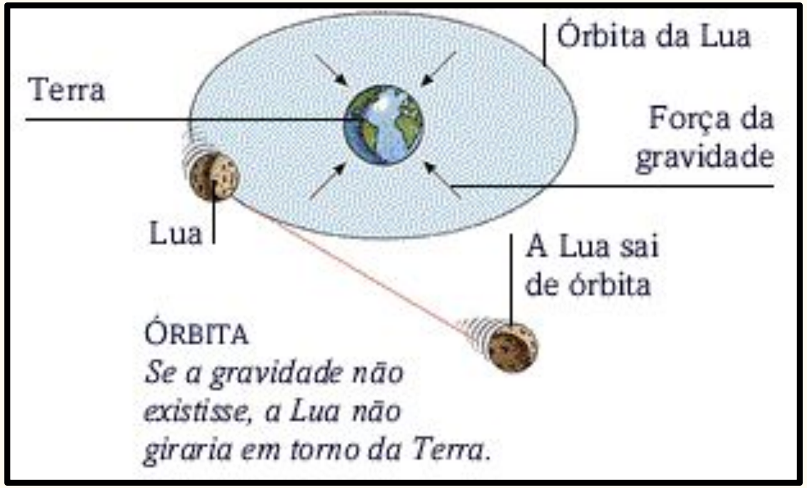


revisitando o problema do referencial

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)."* ???

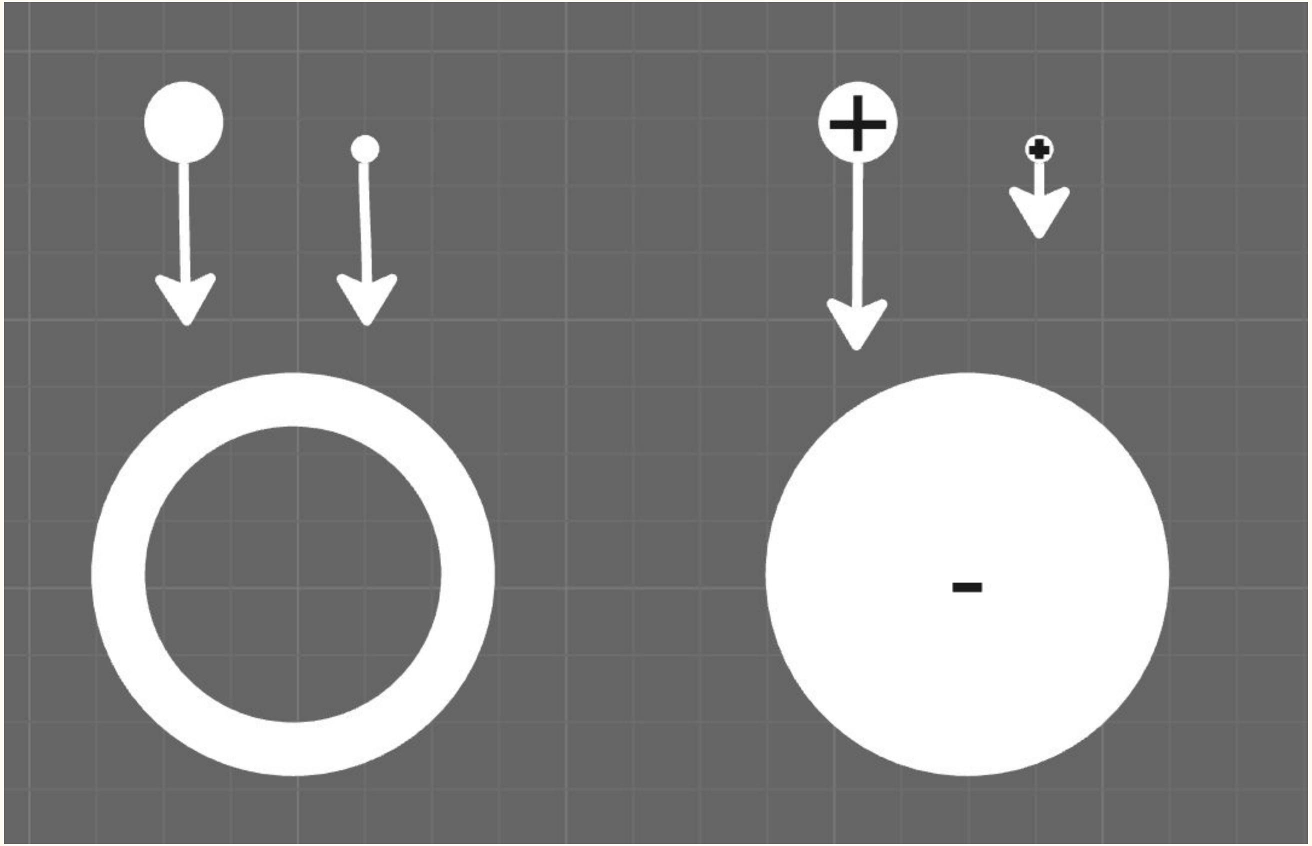
Principia,
Isaac Newton (1713)

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

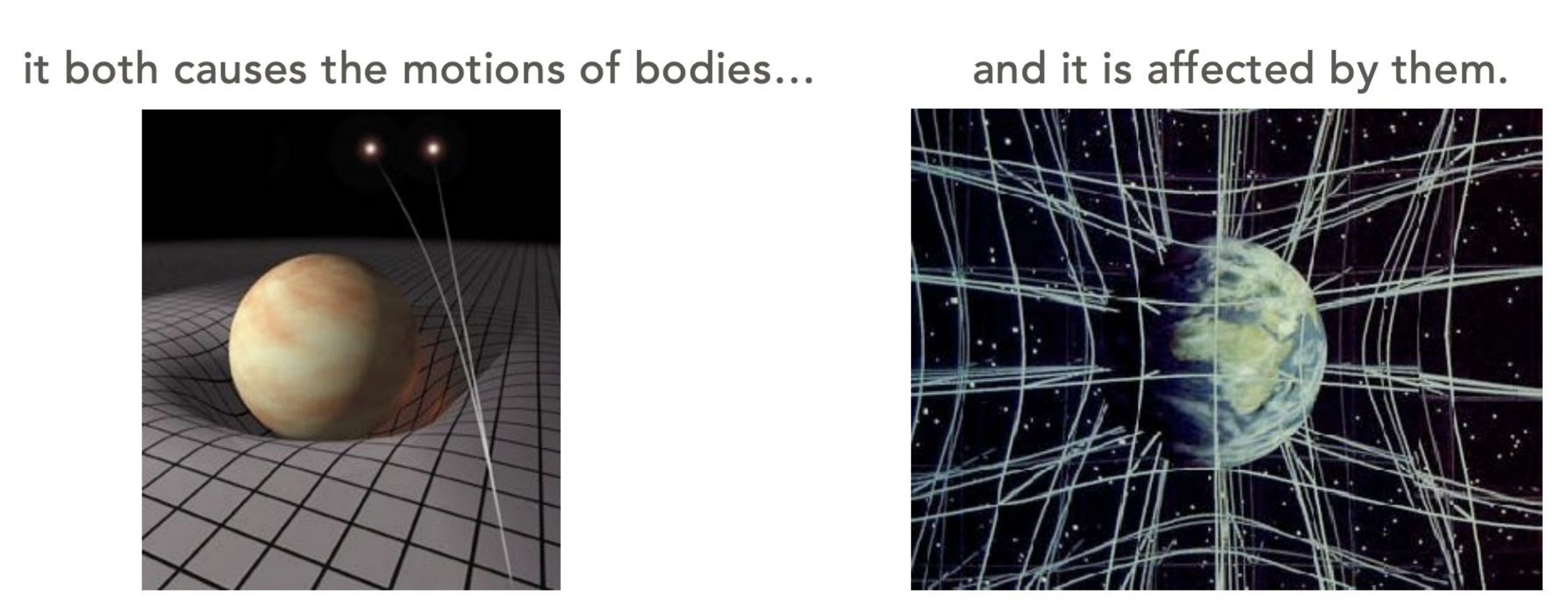
curvatura do espaço-tempo

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

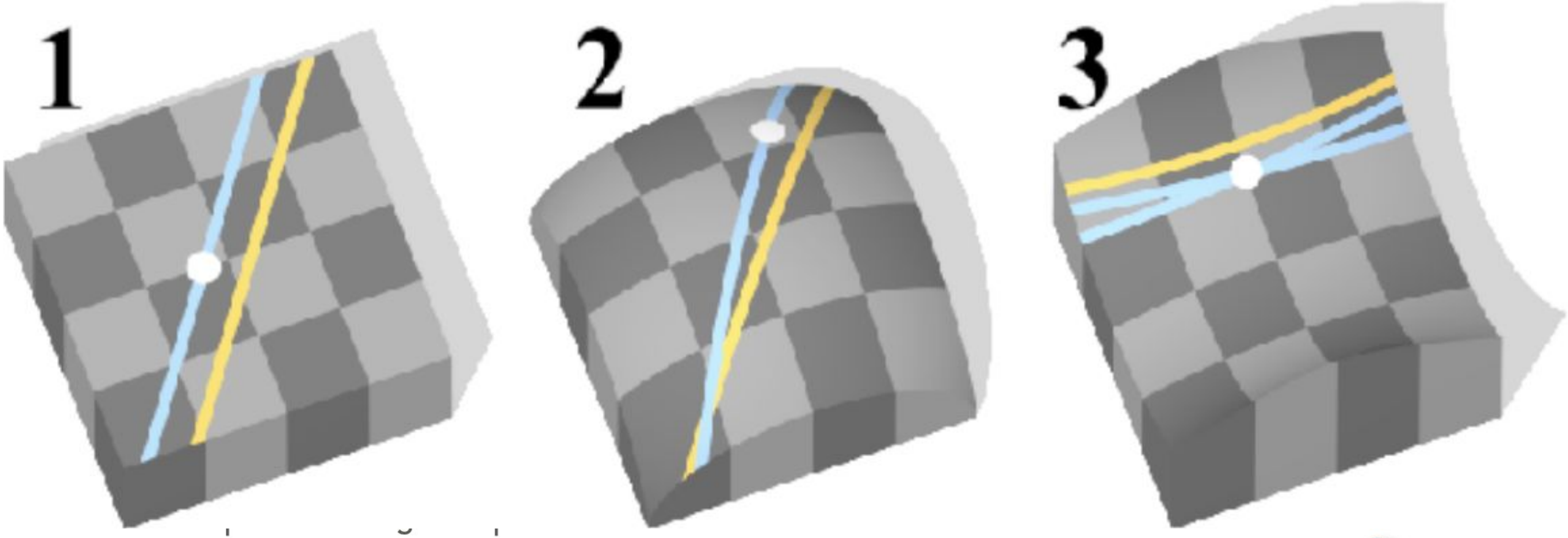
matéria e energia

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

réguas e relógios

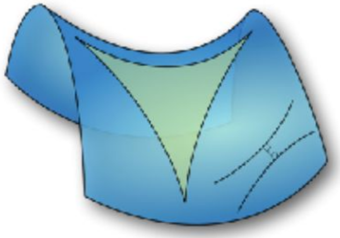


réguas e relógios

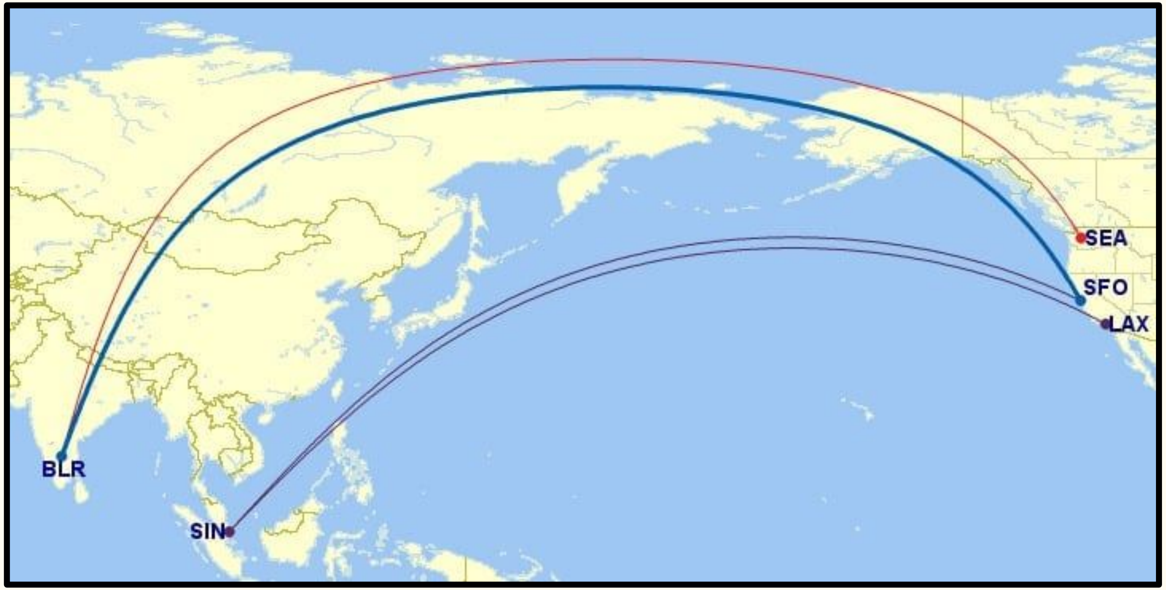


- On the surface of the hyperboloid, given a point and a line, there are many (infinite!) lines parallel to the given line that pass through the point!

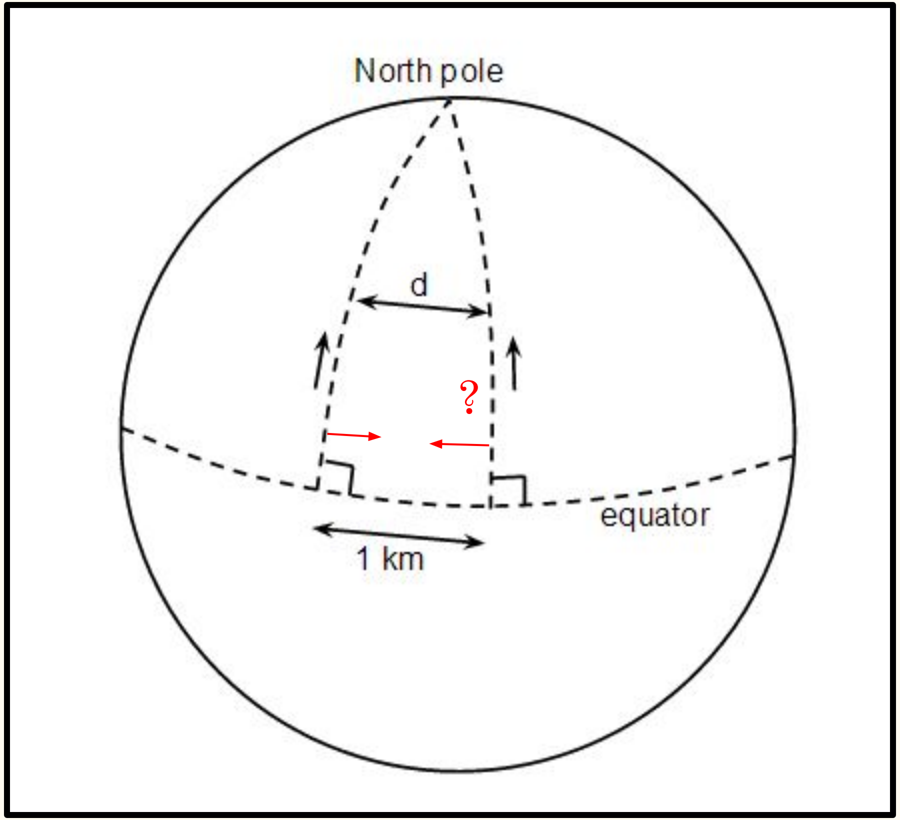
- In this space, the sum of the interior angles of a triangle is < 180º !



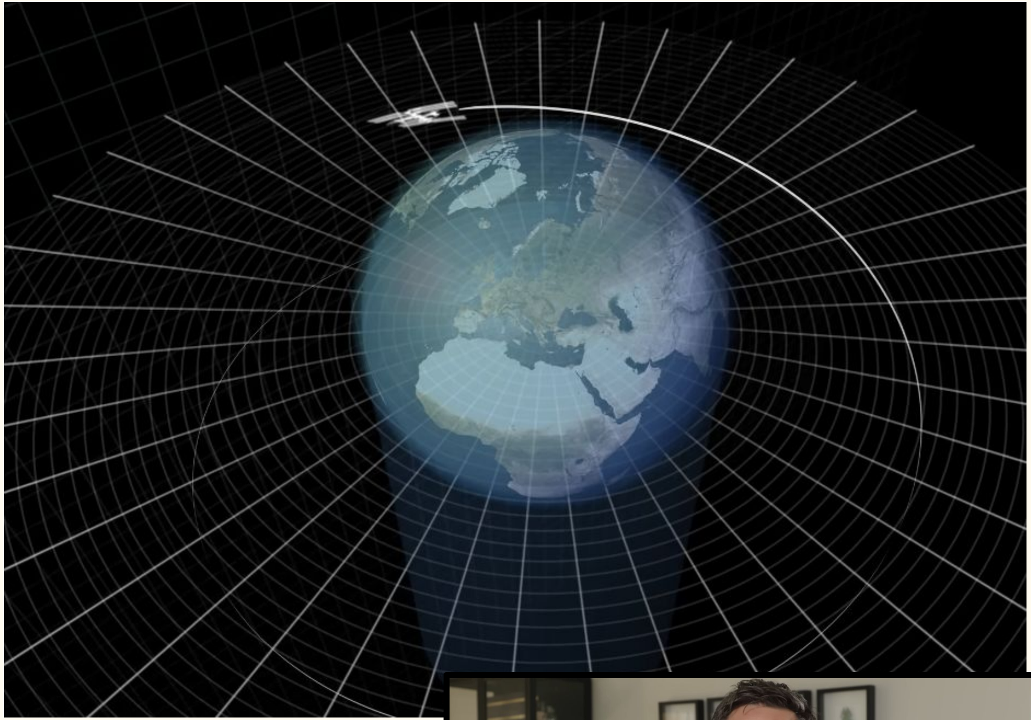
geodésicas, inércia e ilusão da gravidade

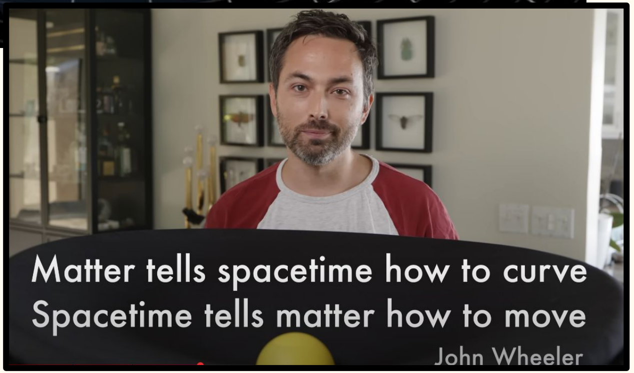


geodésicas, inércia e ilusão da gravidade



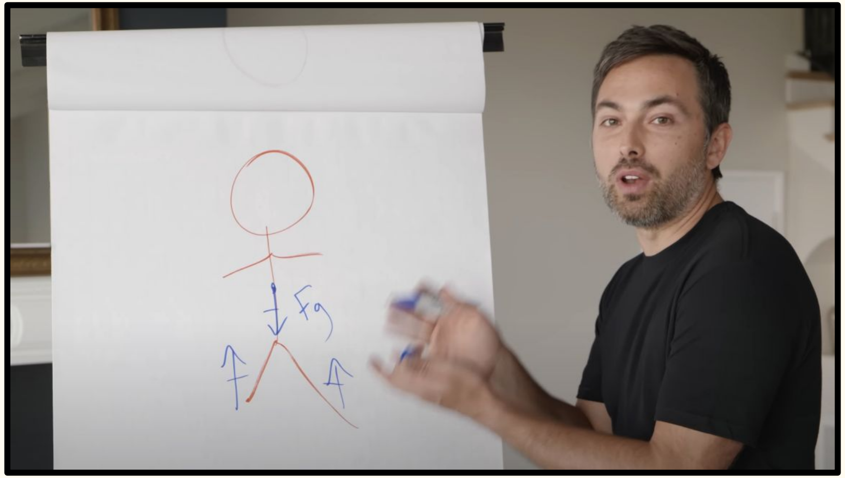
geodésicas, inércia e ilusão da gravidade

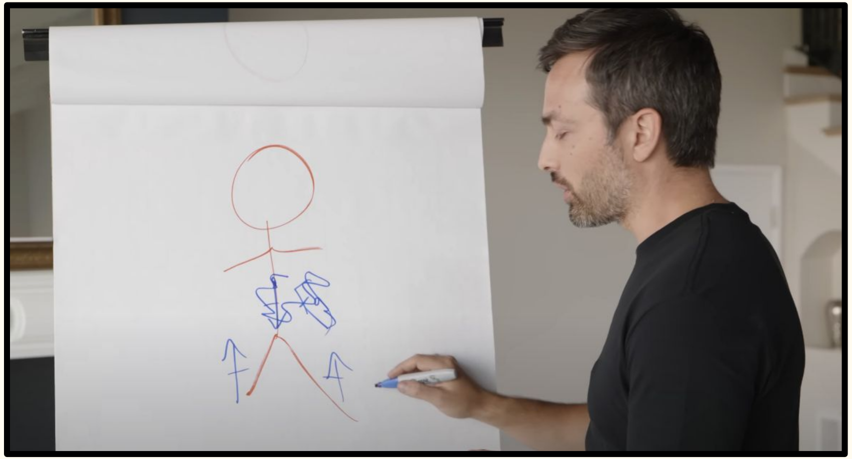




What Everyone Gets Wrong About Gravity,
Veritasium (YouTube, 2021)

geodésicas, inércia e ilusão da gravidade





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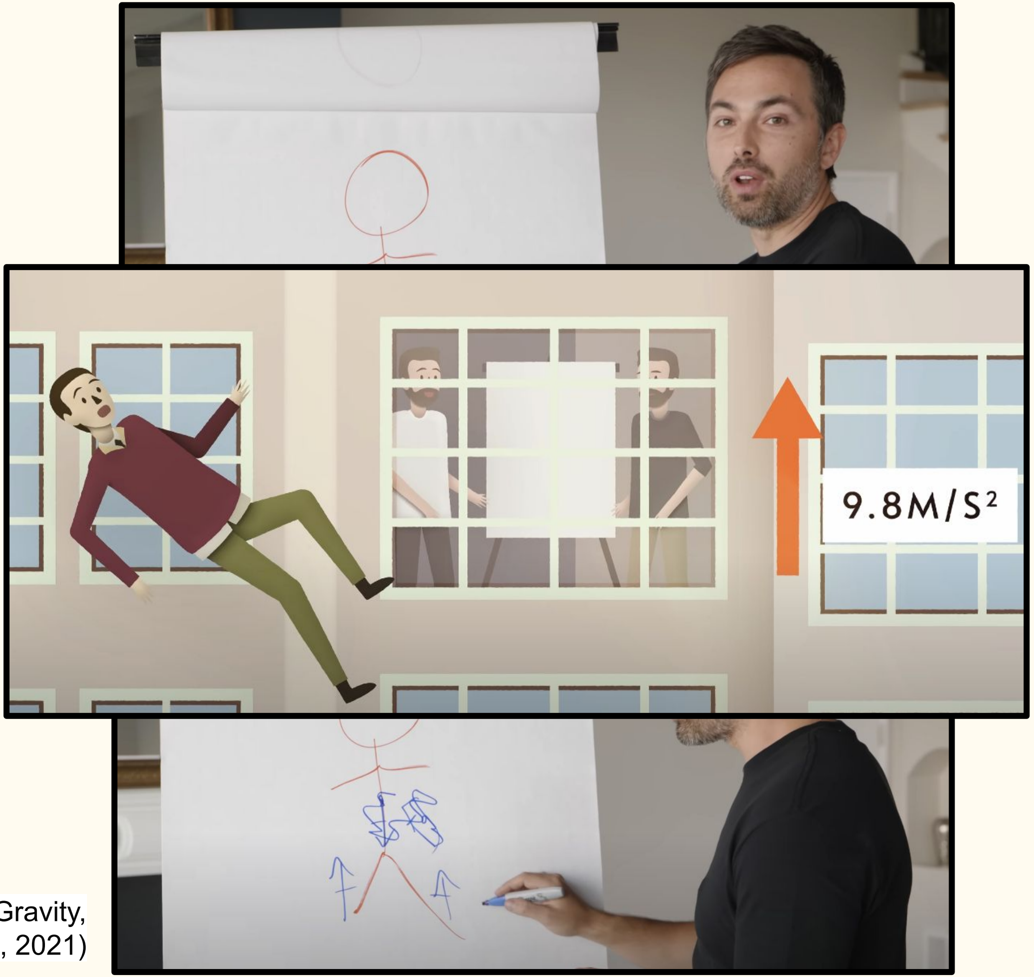

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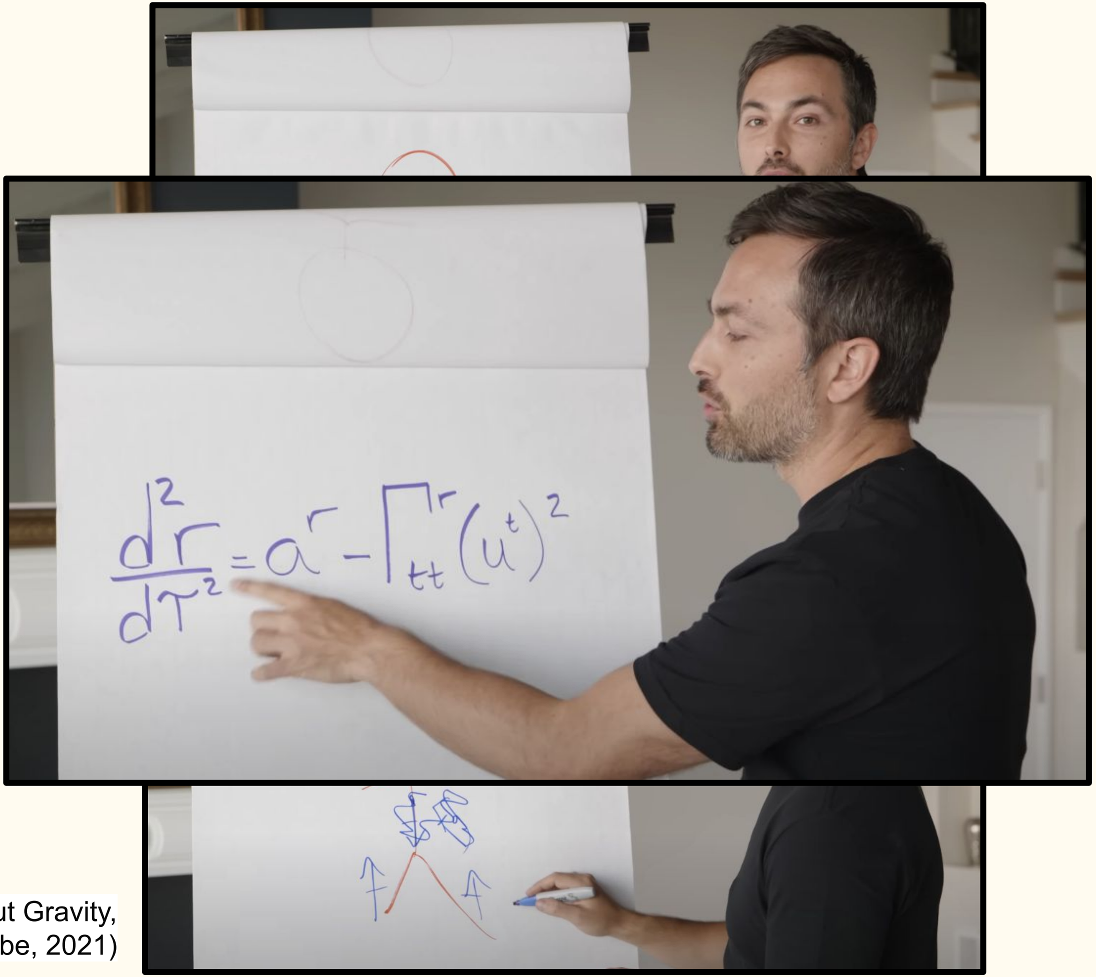
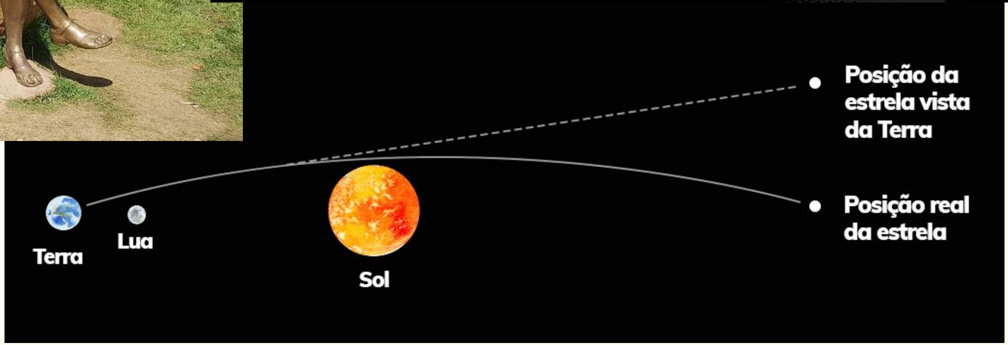


What Everyone Gets Wrong About Gravity,
Veritasium (YouTube, 2021)

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

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

Around-the-World Atomic Clocks: Predicted Relativistic Time Gains, J. C. Hafele e Richard E. Keating (1972)

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], Dhayaa Anbajagane[b,c,d], Rodrigo von Marttens[a], Dragan Huterer[b,c,e] and Jailson Alcaniz[a]

[a]Observatório Nacional, Rio de Janeiro, RJ 20921-400, Brazil
[b]Department of Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109-1040
[c]Leinweber Center for Theoretical Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109-1040
[d]Department of Astronomy and Astrophysics, University of Chicago, 5640 S. Ellis Ave, Chicago, IL 60637
[e]Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany

E-mail: uendertandrade@on.br, dhayaa@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]

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Abstract. Early dark energy (EDE) is an extension to the ΛCDM 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 ΛCDM 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 $f_{\mathrm{EDE}} = 0.067^{+0.019}_{-0.027}$ 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

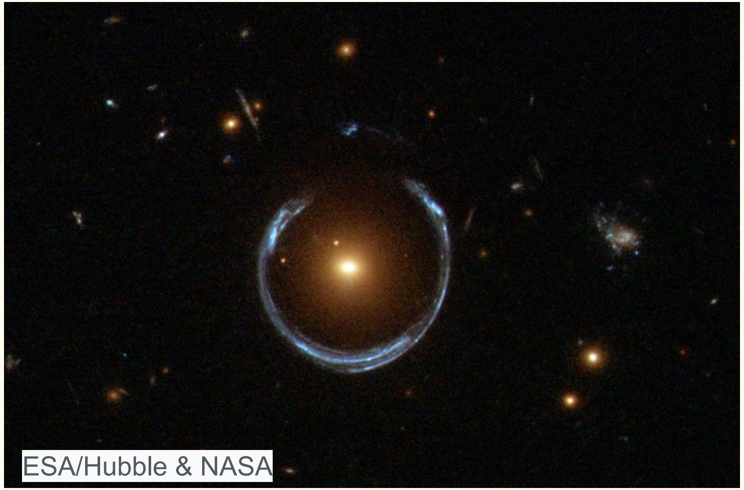
The Structure of Structure Formation Theories

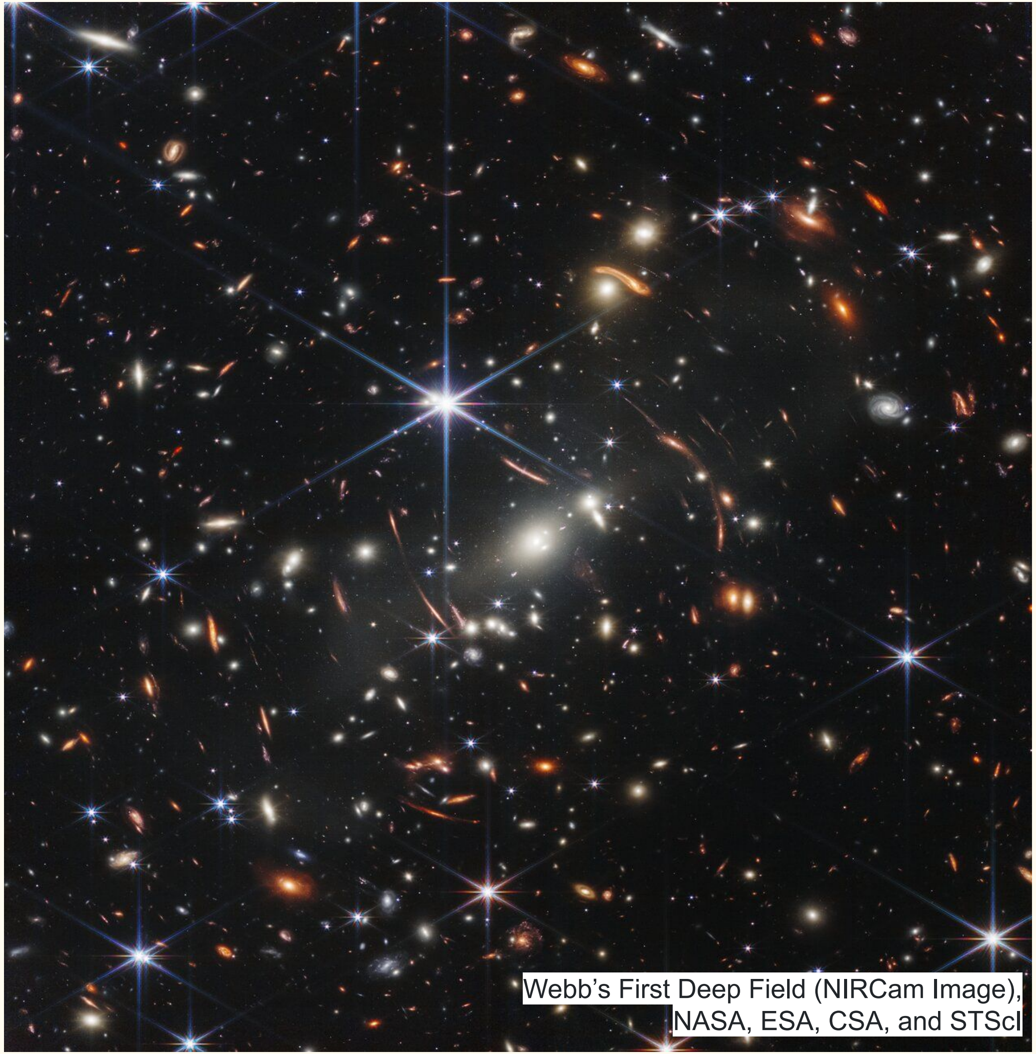
Wayne Hu and Daniel J. Eisenstein
Institute for Advanced Study, Princeton, NJ 08540

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 ΛCDM 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 ΛCDM model exactly.

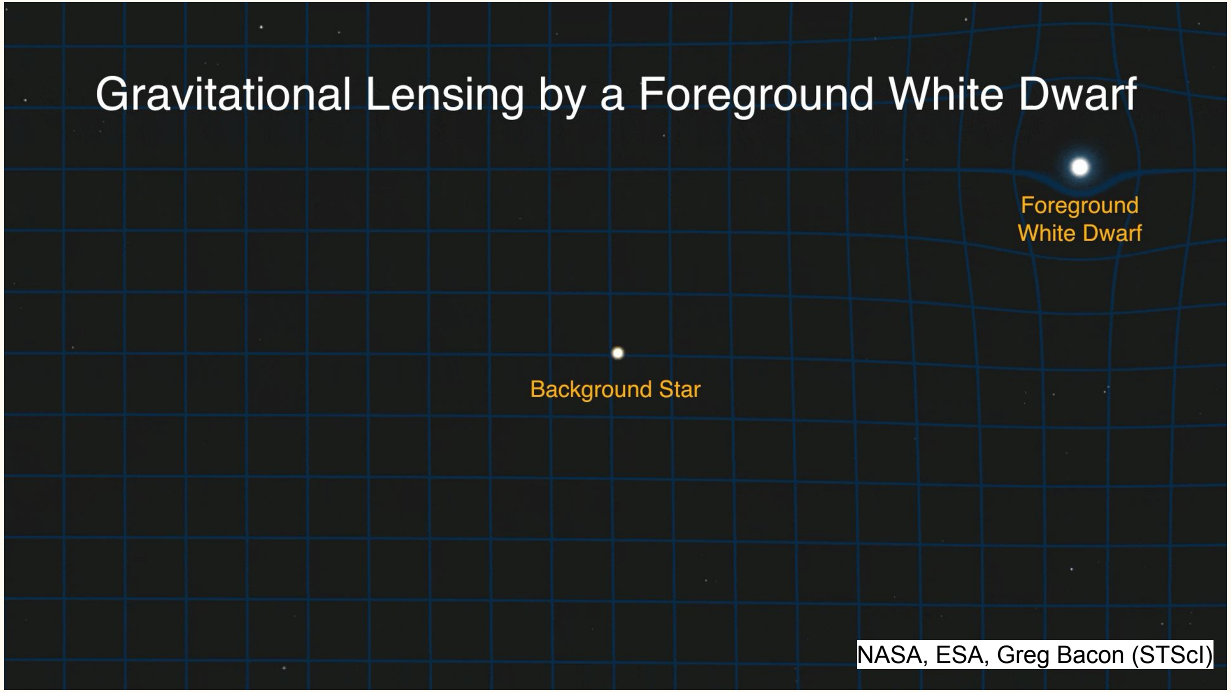
solve simultaneously the Hubble and S_8 tensions, one needs a mechanism for increasing the clustering of matter at late times different from a simple change in the background evolution of late dark energy.

pesquisa: lenteamento gravitacional





pesquisa: lenteamento gravitacional



pesquisa: lenteamento gravitacional

IFUSP
IFT
IAG
UEL
UnB
...

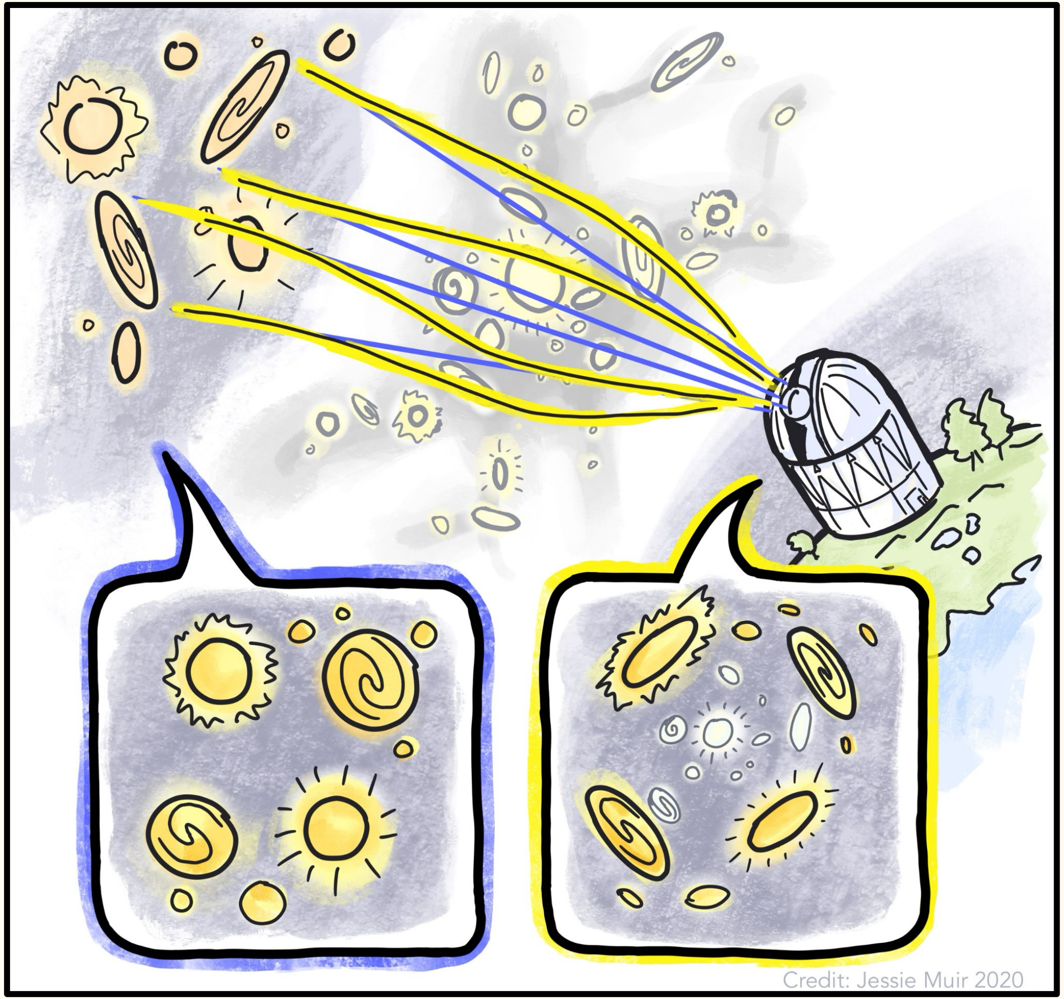


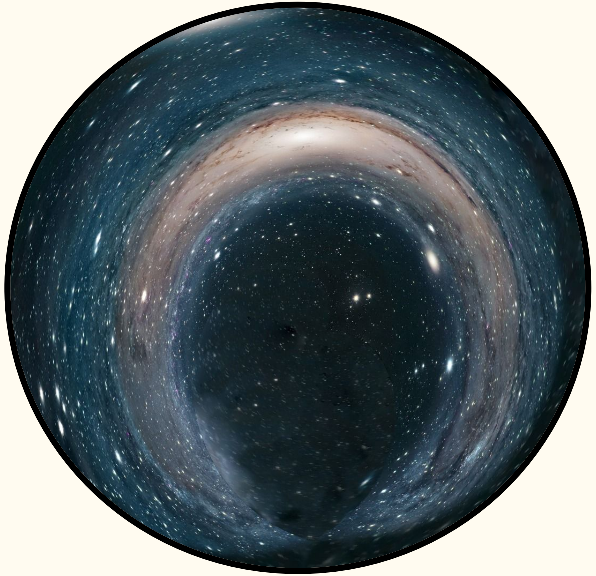
imagem de Jessie Muir (2021)

Parte 2

Cefeidas, distâncias e a expansão do universo

o universo de Einstein

o universo de Einstein



simetria esférica

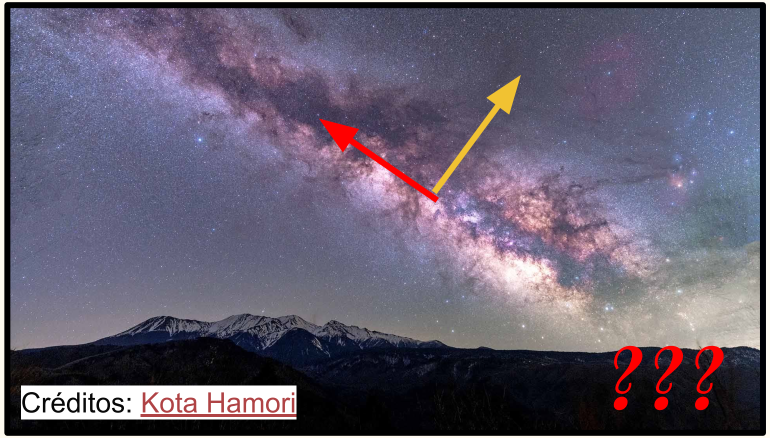
1ª solução cosmológica

§ 3. The Spatially Finite Universe with a Uniform Distribution of Matter

According to the general theory of relativity the metrical character (curvature) of the four-dimensional space-time continuum is defined at every point by the matter at that point and the state of that matter. Therefore, on account of the lack of uniformity in the distribution of matter, the metrical structure of this continuum must necessarily be extremely complicated. But if we are concerned with the structure only on a large scale, we may represent matter to ourselves as being uniformly distributed over enormous spaces, so that its density of distribution is a variable function which varies

There is a system of reference relatively to which matter may be looked upon as being permanently at rest. With respect to this system, therefore, the contravariant energy-tensor $T^{\mu\nu}$ of matter is, by reason of (5), of the simple form

$$\left.\begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho \end{matrix}\right\} \quad . \quad . \quad . \quad (6)$$

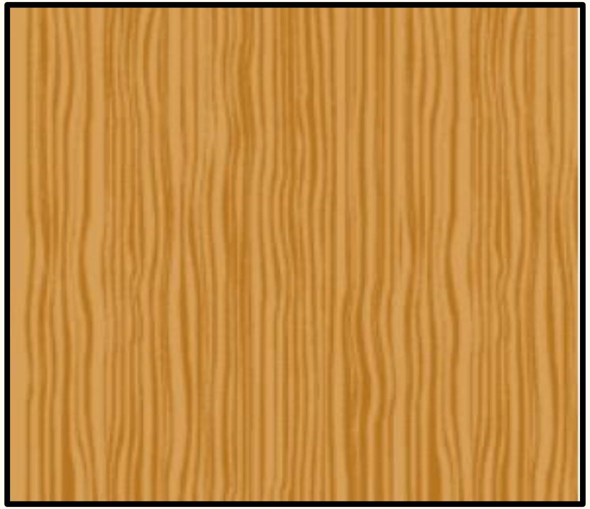


Créditos: Kota Hamori

Cosmological Considerations on the General Theory of Relativity, Albert Einstein (1917)

homogeneidade e isotropia

✅ homogêneo
✅ isotrópico



✅ homogêneo
❌ isotrópico

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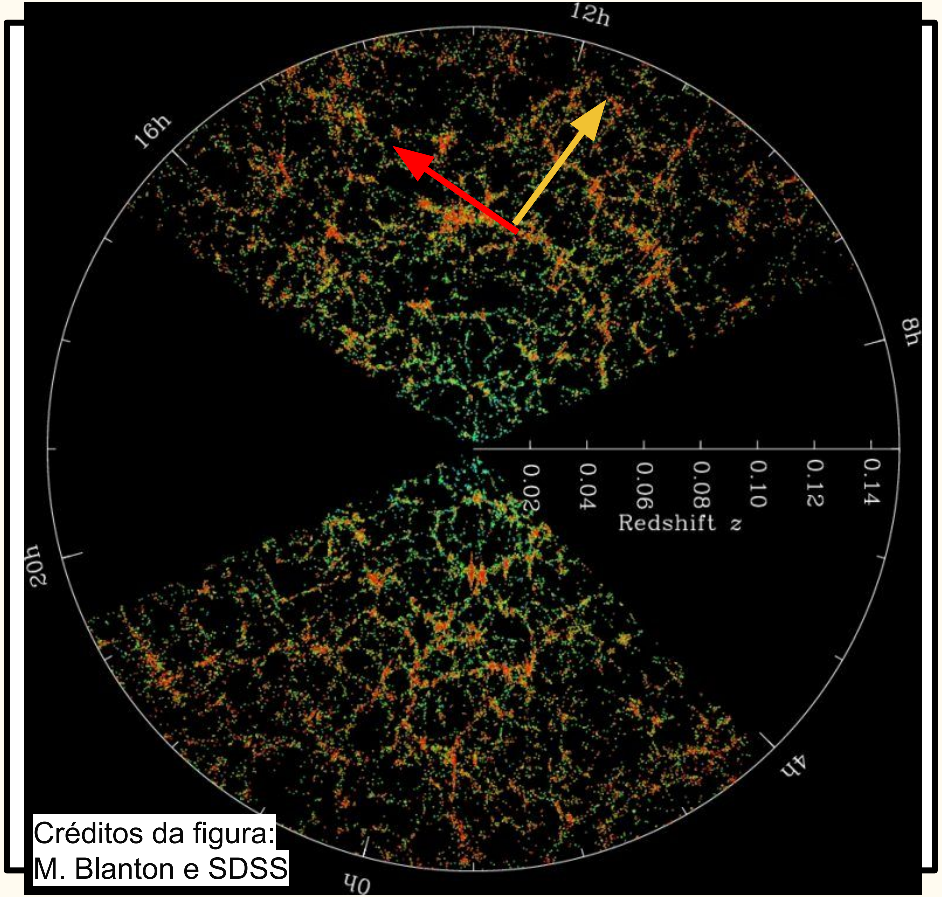
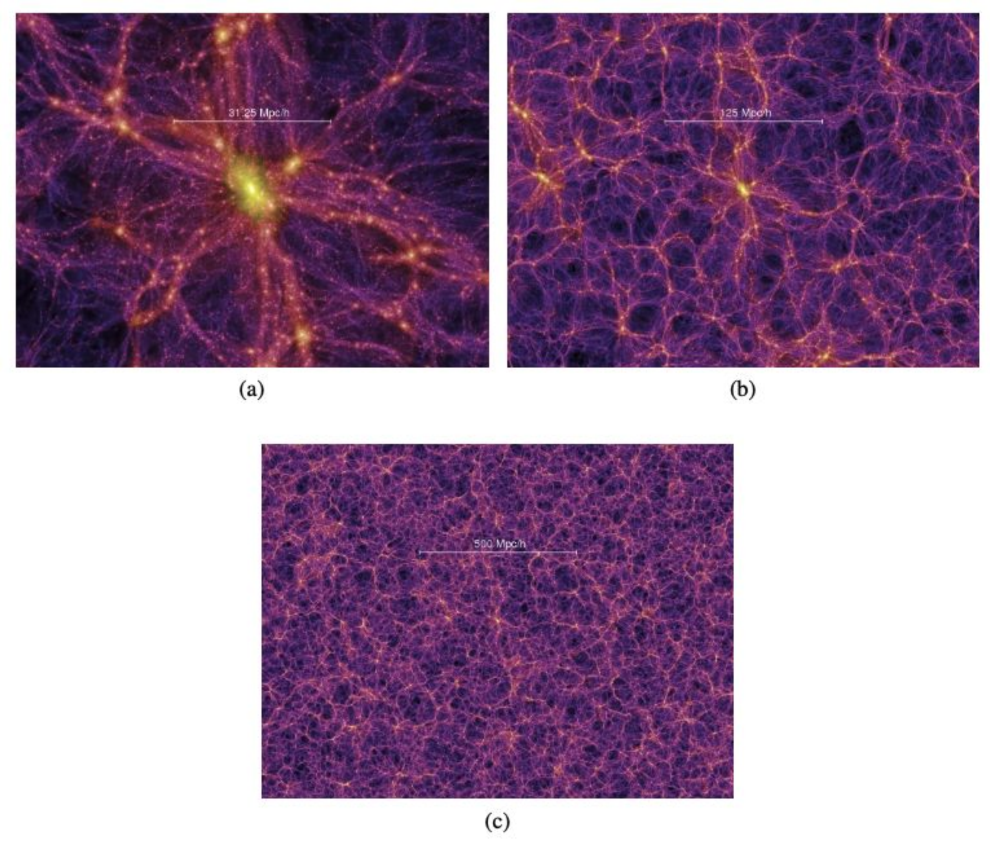
homogeneidade e isotropia



Introduction to Cosmology,
Barbara Ryden (2006)

homogeneidade e isotropia



1ª solução cosmológica

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

$$g_{44} = 1 \quad . \quad . \quad . \quad . \quad (7)$$

Further, as always with static problems, we shall have to set

$$g_{14} = g_{24} = g_{34} = 0 \quad . \quad . \quad . \quad (8)$$

space-time universe is also given us. For the potential $g_{\mu\nu}$, both indices of which differ from 4, we have to set

$$g_{\mu\nu} = -\left(\delta_{\mu\nu} + \frac{x_\mu x_\nu}{R^2 - (x_1^2 + x_2^2 + x_3^2)}\right) \quad . \quad (12)$$

constante

There is a system of reference relatively to which matter may be looked upon as being permanently at rest. With respect to this system, therefore, the contravariant energy-tensor $T^{\mu\nu}$ of matter is, by reason of (5), of the simple form

$$\left.\begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho \end{matrix}\right\} \quad . \quad . \quad . \quad (6)$$

Cosmological Considerations on the General Theory of Relativity, Albert Einstein (1917)

1ª solução cosmológica

My proposed field equations of gravitation for any chosen system of co-ordinates run as follows :—

$$\left.\begin{aligned} G_{\mu\nu} &= -\kappa(T_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}T), \\ G_{\mu\nu} &= -\frac{\partial}{\partial x_\alpha}\{\mu\nu, \alpha\} + \{\mu\alpha, \beta\}\{\nu\beta, \alpha\} \\ &\quad + \frac{\partial^2 \log\sqrt{-g}}{\partial x_\mu \partial x_\nu} - \{\mu\nu, \alpha\}\frac{\partial \log\sqrt{-g}}{\partial x_\alpha} \end{aligned}\right\} \quad (13)$$

The system of equations (13) is by no means satisfied when we insert for the $g_{\mu\nu}$ the values given in (7), (8), and (12), and for the (contravariant) energy-tensor of matter the values indicated in (6). It will be shown in the next paragraph how this calculation may conveniently be made. So

Cosmological Considerations on the General Theory of Relativity,
Albert Einstein (1917)

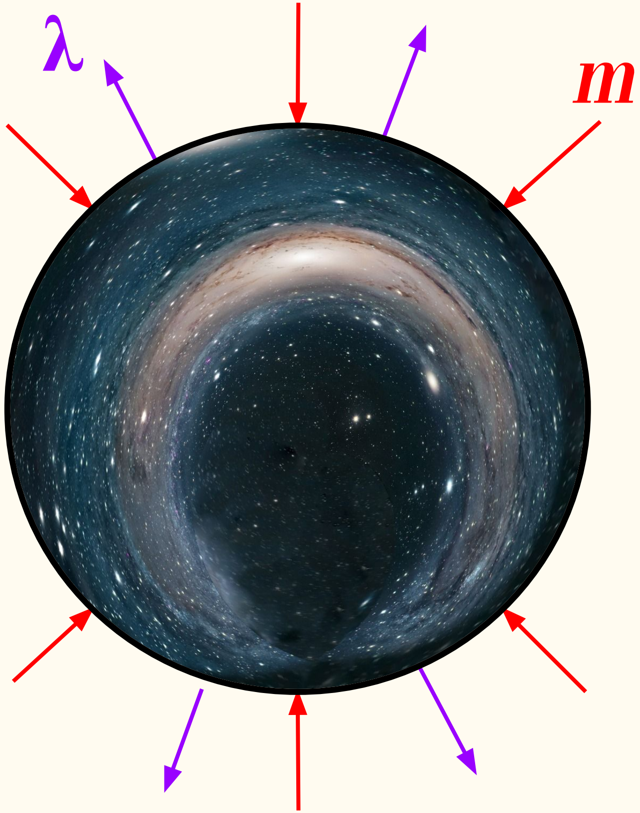
1ª solução cosmológica

constante cosmológica

unknown, without destroying the general covariance. In place of field equation (13) we write

$$G_{\mu\nu} - \lambda g_{\mu\nu} = -\kappa\left(T_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} T\right) \quad . \quad . \quad (13a)$$

will not here be discussed. In order to arrive at this consistent view, we admittedly had to introduce an extension of the field equations of gravitation which is not justified by our actual knowledge of gravitation. It is to be emphasized, however, that a positive curvature of space is given by our results, even if the supplementary term is not introduced. That term is necessary only for the purpose of making possible a quasi-static distribution of matter, as required by the fact of the small velocities of the stars.



tamanho do cosmos

Na época, cosmos = Via Lactea

Distância do diâmetro angular não ajudava

fim do séc XVIII	contagem de estrelas em diferentes direções	~mil anos-luz
fim do séc XIX	paralaxe, estimativa da magnitude aparente das estrelas	~mil a 100 mil anos-luz
início do séc XX	velas padrão • aglomerados globulares estrelas variáveis	~100 mil anos-luz

universos-ilhas

Credit: G. W. Ritchey, 1910, ApJ 32, Plate IV

universos-ilhas

nebulosa espiral

vs

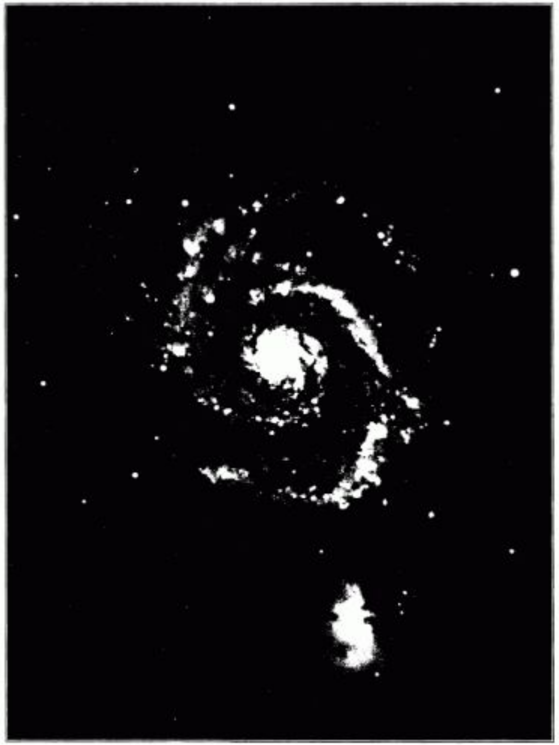
outra galáxia

Algumas referências:

- Hubble's Announcement of Cepheids in Spiral Nebulae, Berendzen, R. & Hoskin, M. (1967)
- site da Nasa sobre o Grande Debate

PLATE IV

South



SPIRAL NEBULA *Messier 51 Canum Venaticorum*

Photographed with 60-Inch Reflector on Seed 23 plate, February 7 and 8, 1910

Exposure $3^h\ 55^m$. Enlargement from negative 6.4 diameters. Scale: 1 mm = 4."2

Credit: G. W. Ritchey, 1910, ApJ 32, Plate IV

universos-ilhas

nebulosa espiral

Harlow Shapley

vs

outra galáxia

Heber Curtis

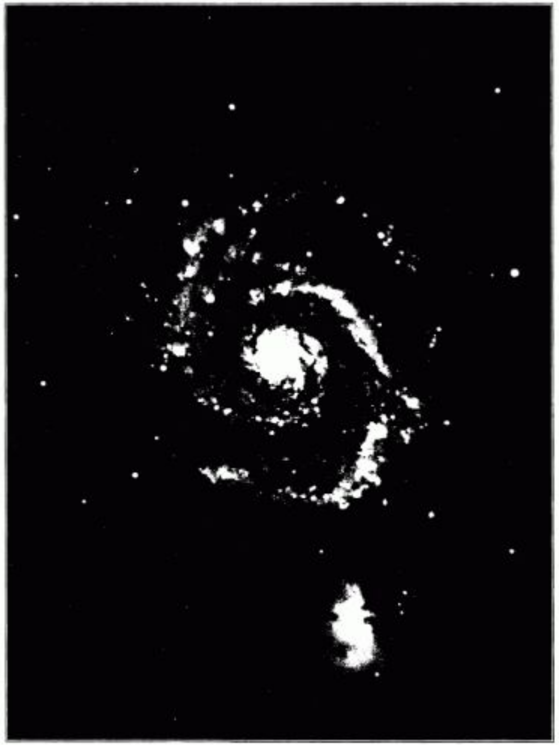
[link da fofoca]

Algumas referências:

- Hubble's Announcement of Cepheids in Spiral Nebulae, Berendzen, R. & Hoskin, M. (1967)
- [site da Nasa sobre o Grande Debate]

PLATE IV

South



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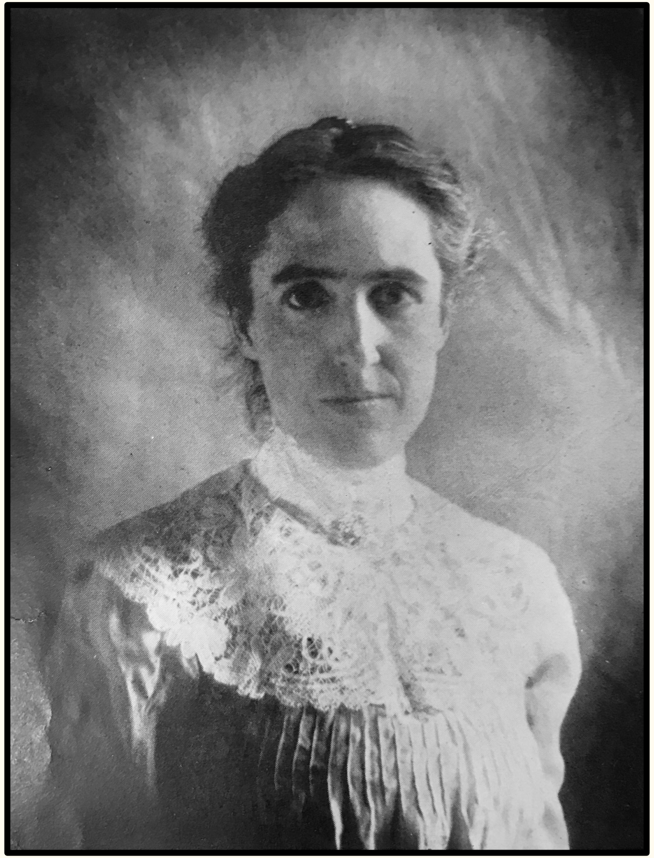
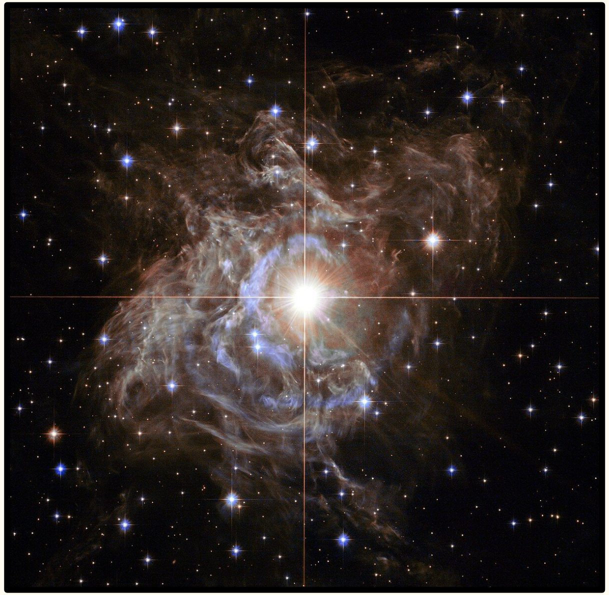
Credit: [G. W. Ritchey, 1910, ApJ 32, Plate IV]

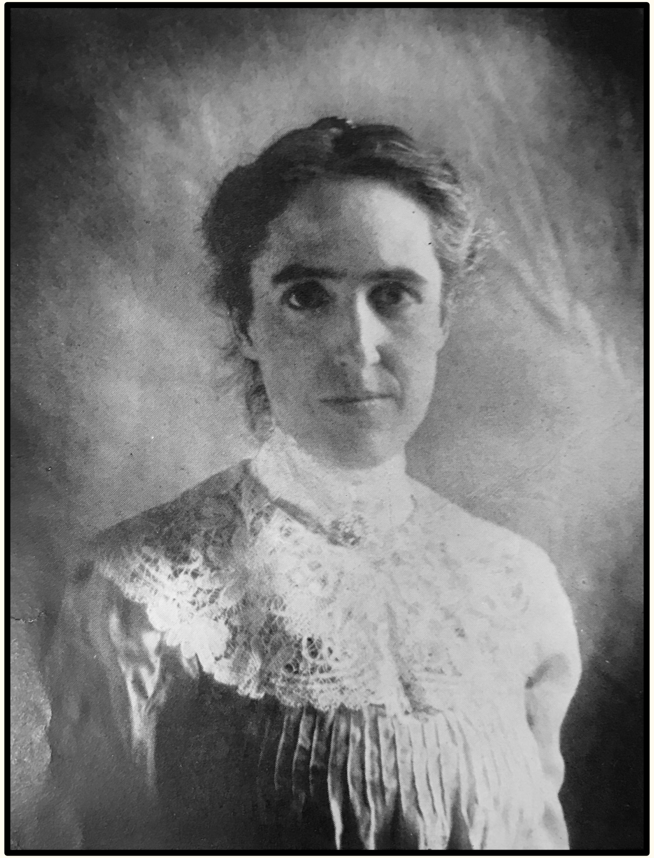
Henrietta Leavitt

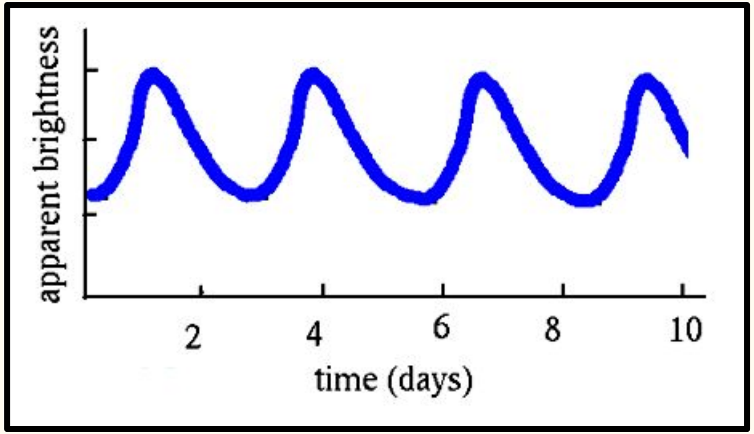




- Observações na Grande Nuvem de Magalhães (1912)
- Estrelas variáveis (como RR Lyrae de Shapley)
- Mais brilhantes

Henrietta Leavitt





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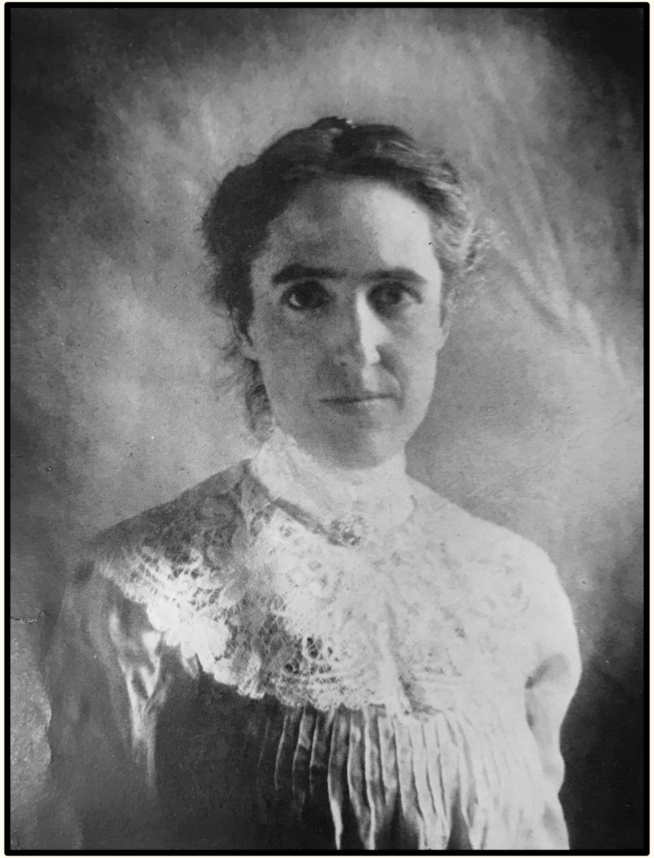

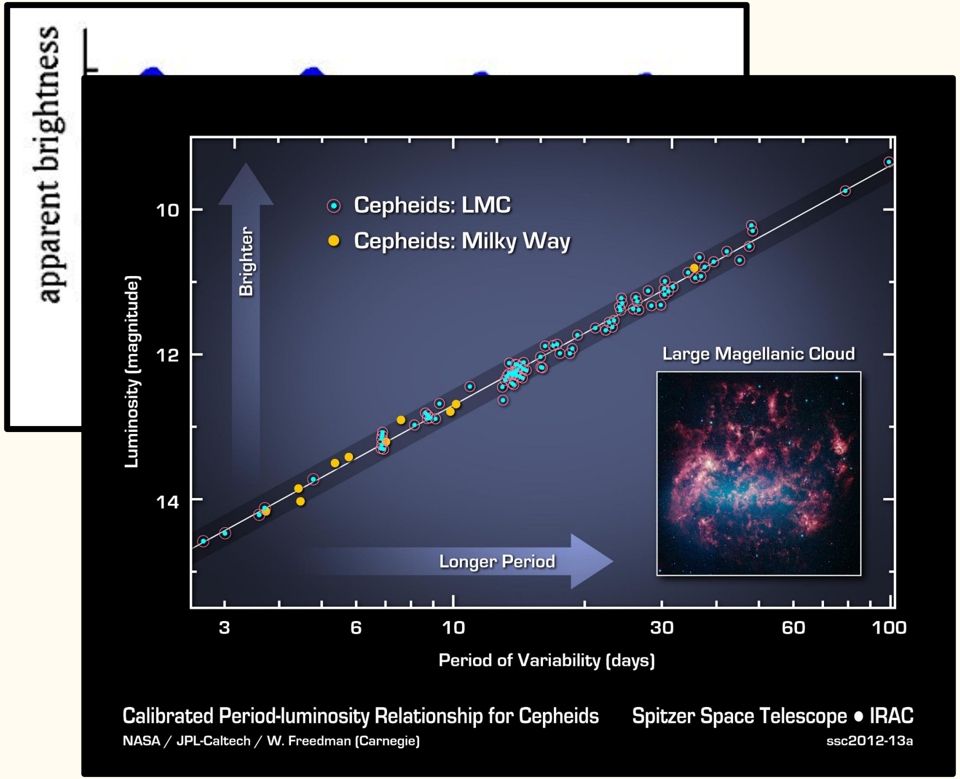

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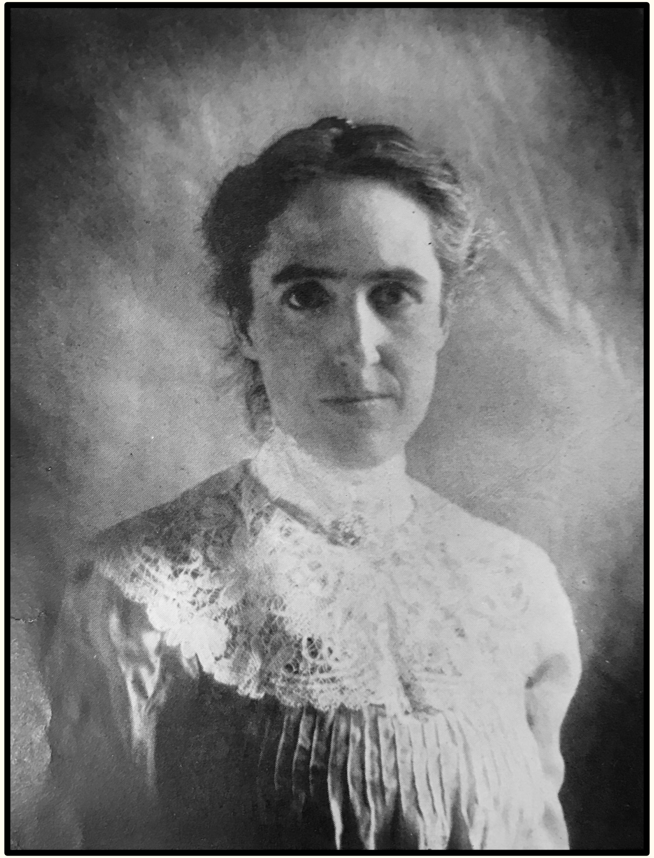
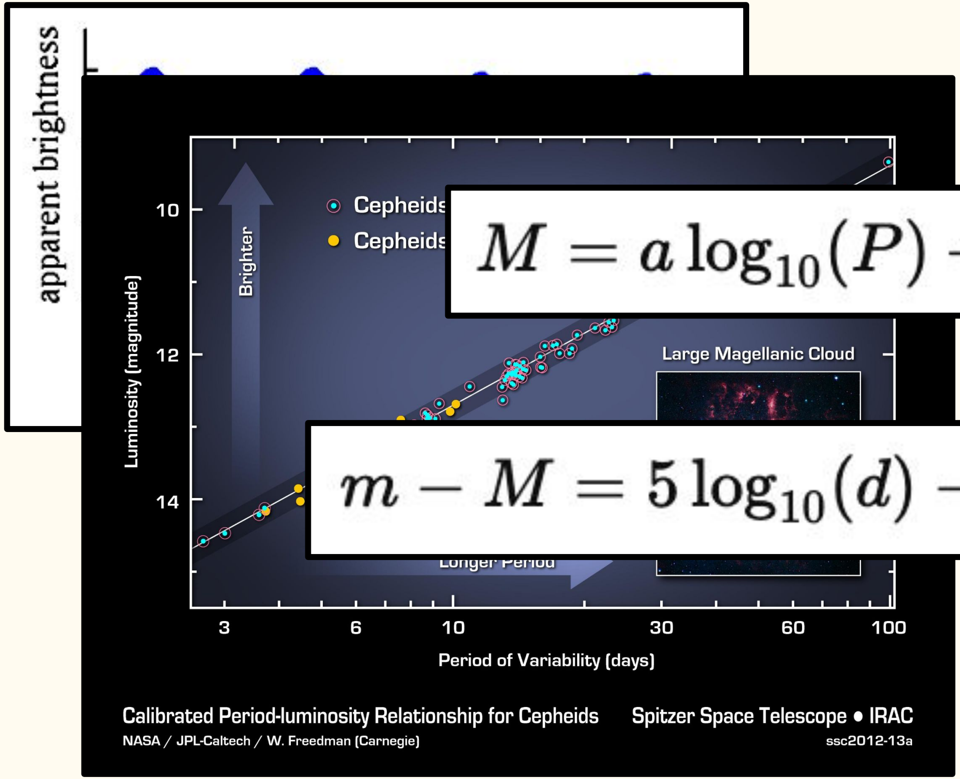
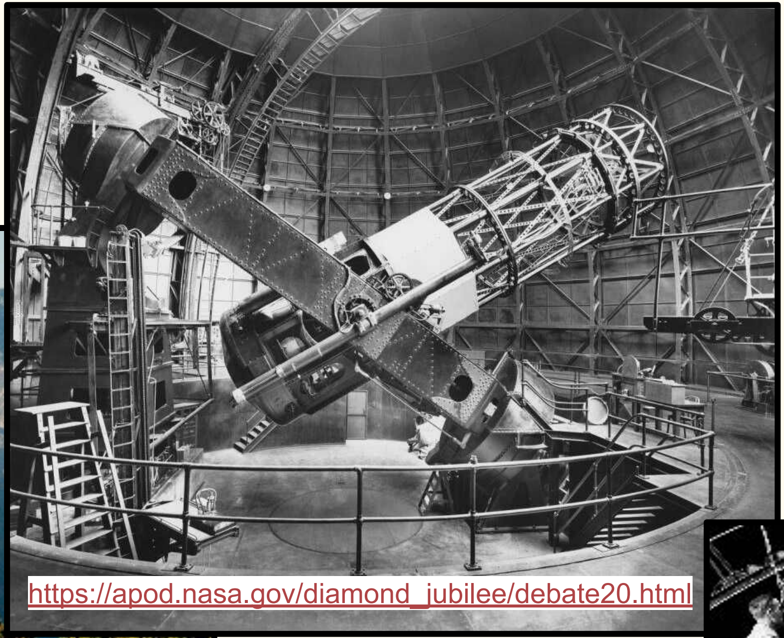




$$M = a\log_{10}(P) + b$$

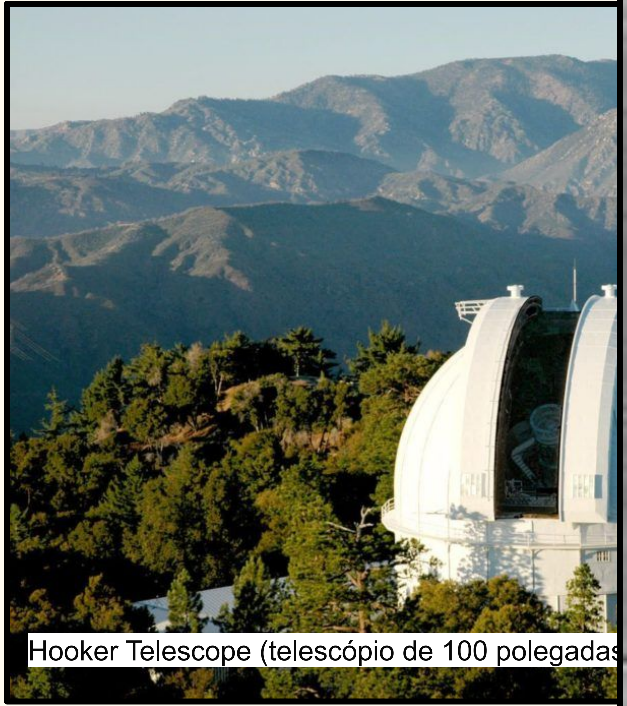
$$m - M = 5\log_{10}(d) - 5$$

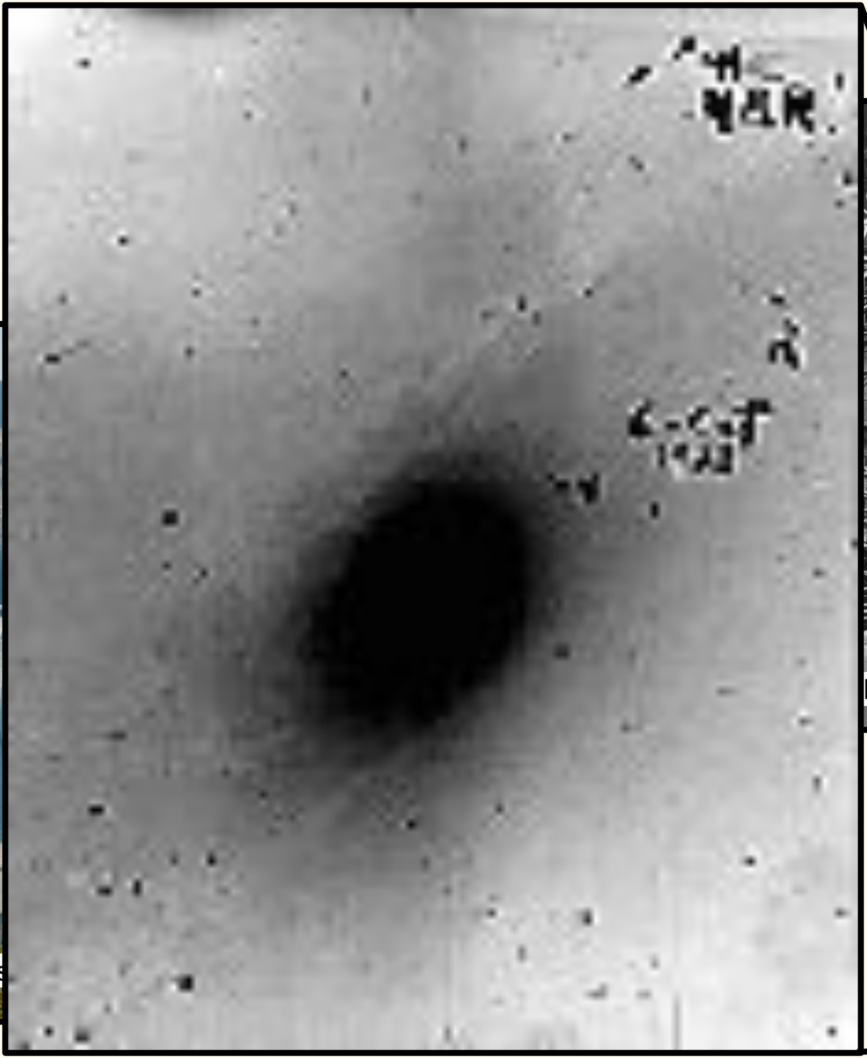
Hubble


https://apod.nasa.gov/diamond_jubilee/debate20.html


Hooker Telescope (telescópio de 100 polegadas) no Monte Wilson

Hubble

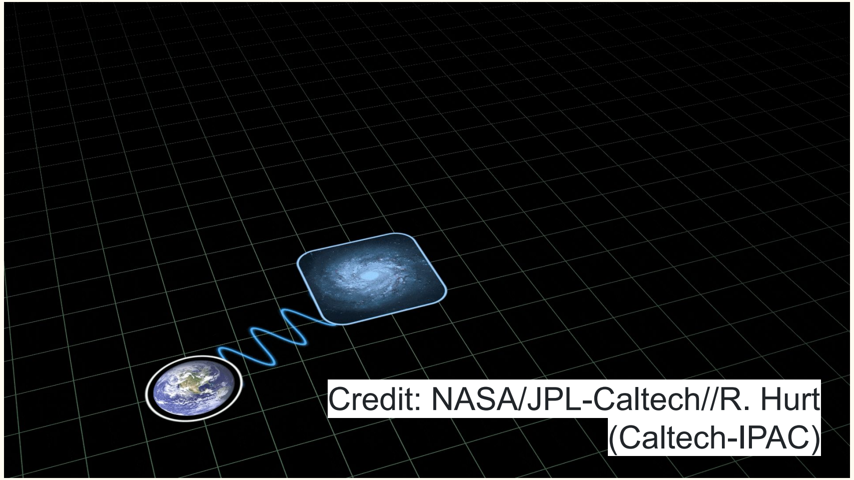

Hooker Telescope (telescópio de 100 polegadas




html

expandindo a(s) galáxia(s)

1. *usar cefeidas para calcular distâncias de outras nebulosas espirais*
2. *estudar o comportamento delas, como a **velocidade***



redshift** (ou avermelhamento)**:

"efeito doppler" das ondas eletromagnéticas

$$\boxed{z = \frac{\lambda_{\text{obs}} - \lambda_0}{\lambda_0}}$$

expandindo a(s) galáxia(s)

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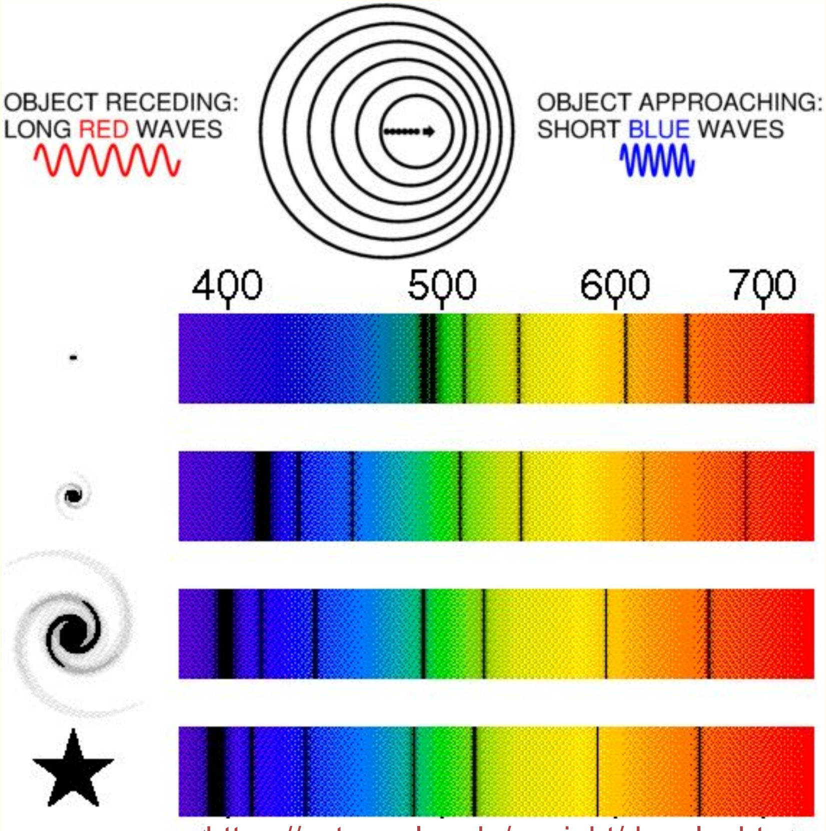
redshift *(ou avermelhamento)****:***

"efeito doppler" das ondas eletromagnéticas

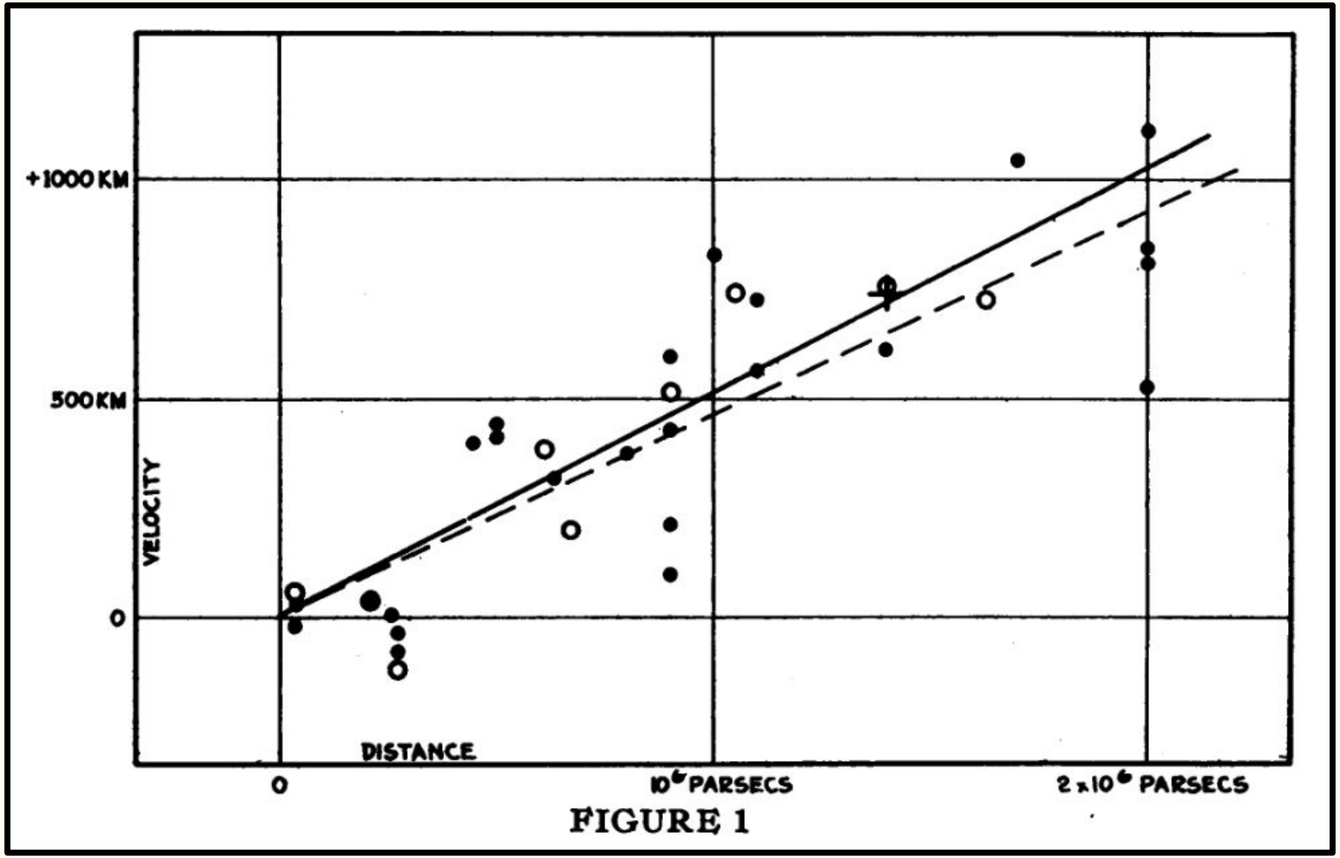
$$\boxed{z = \frac{\lambda_{\rm obs} - \lambda_0}{\lambda_0}}$$

$$\boxed{v \approx cz}$$



https://astro.ucla.edu/~wright/doppler.htm

diagrama de Hubble



$$\boxed{v = H_0 d}$$

$$[H_0] = \frac{[v]}{[d]} = \frac{km}{s}\frac{1}{Mpc} = \frac{km/s}{Mpc}$$

“For this reason it is thought premature to discuss in detail the obvious consequences of the present results.”

A relation between distance and radial velocity among extra-galactic nebulae,
Edwin Hubble (1929)

Friedmann

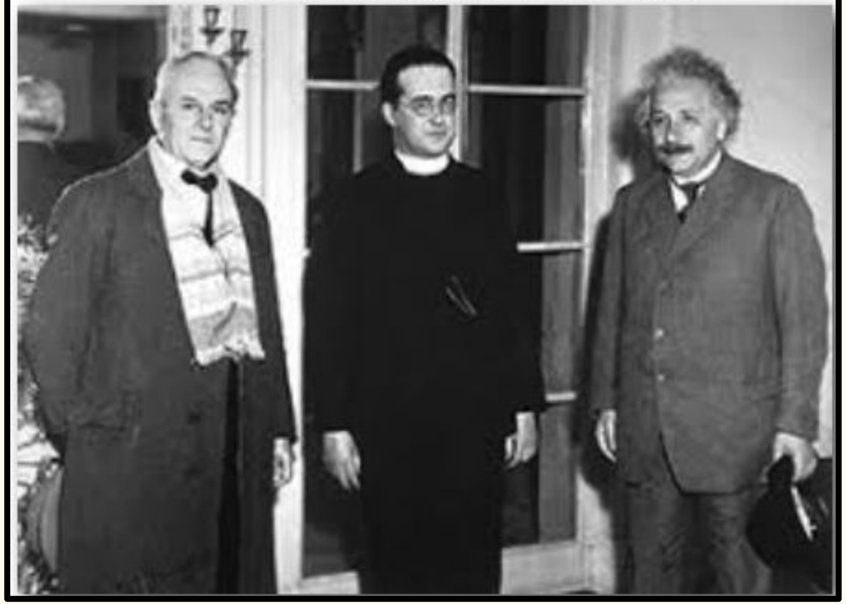
Lemaître

Robertson

Walker

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

Hubble , Lemaître , Einstein



Friedmann

Lemaître

Robertson

Walker

$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & a^2(t) & 0 & 0 \\ 0 & 0 & a^2(t) & 0 \\ 0 & 0 & 0 & a^2(t) \end{pmatrix}$$

$$T^{\mu}{}_{\nu} = \begin{pmatrix} -\rho & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix}$$

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

Friedmann

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

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{kc^2}{a^2} = \frac{8\pi G}{3}\rho + \frac{\Lambda c^2}{3}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda c^2}{3}$$

entendendo $a(t)$

$$d(t) = a(t)d_0$$

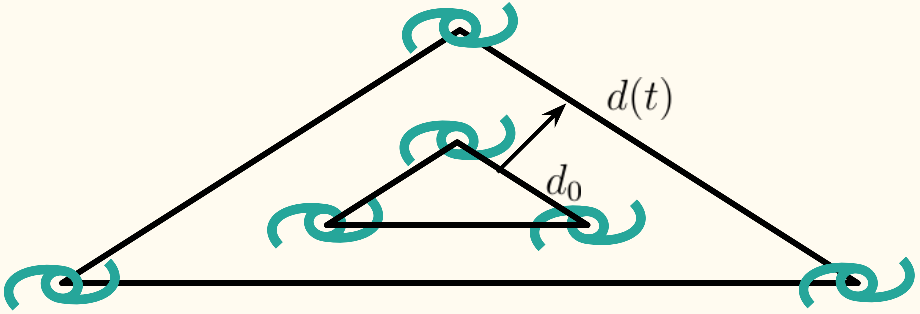
$$\dot{d}(t) = \dot{a}(t)d_0$$

$$v = \dot{a}(t)d_0$$

$$\frac{v}{d} = \frac{\dot{a}}{a}\frac{d_0}{d_0}$$

$$v = \frac{\dot{a}}{a}d$$

$$v = H(t)d$$



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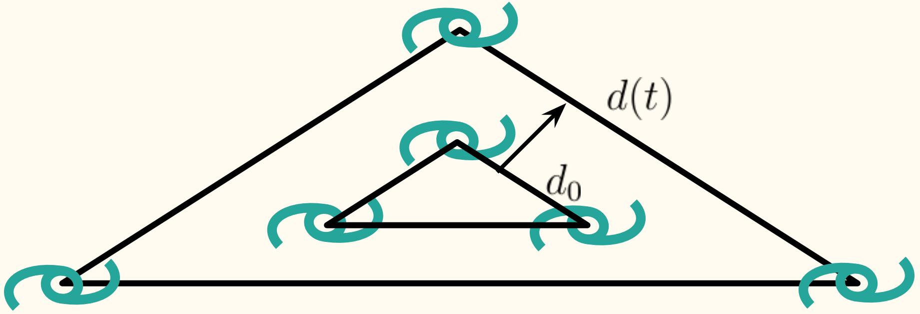

$$\boxed{H(t) \equiv \frac{\dot{a}(t)}{a(t)}}$$

parâmetro de Hubble

entendendo $a(t)$

$$d(t) = a(t)d_0$$

$$\dot{d}(t) = \dot{a}(t)d_0$$

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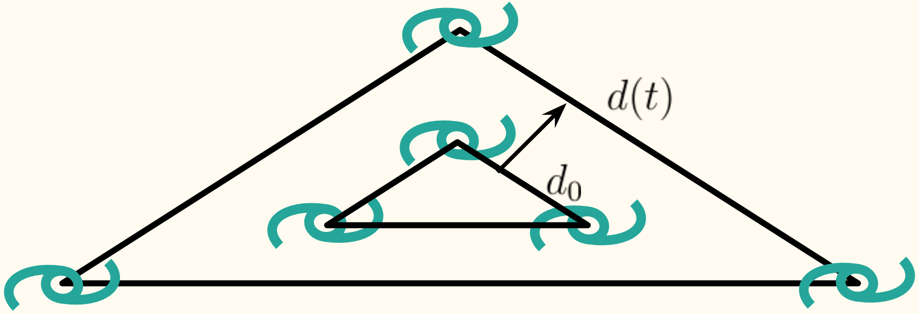
$$v = \frac{\dot{a}}{a}d$$

$$v = H(t)d$$



$$\boxed{H(t) \equiv \frac{\dot{a}(t)}{a(t)}}$$

parâmetro de Hubble

$$\boxed{H(t_0) \equiv H_0 \sim 70km/s/Mpc}$$

hoje em dia

universo observável e idade

1. E se d for grande o suficiente para que $v = c$?

$$c = H_0 D_H$$

$$D_H = \frac{c}{H_0}$$

$$D_H = \frac{3 \cdot 10^5 km/s}{70 km/s/Mpc} = 4 \cdot 10^3 Mpc = 4 Gpc$$

universo observável e idade

1. E se d for grande o suficiente para que $v = c$?

$$c = H_0 D_H$$
$$D_H = \frac{c}{H_0}$$
$$D_H = \frac{3 \cdot 10^5 km/s}{70 km/s/Mpc} = 4 \cdot 10^3 Mpc = 4Gpc$$

2 Qual o tempo que a luz leva para percorrer essa distância?

$$\begin{aligned} T_H &= \frac{D_H}{c} \\ &= \frac{c}{cH_0} \\ &= \frac{1}{H_0} \\ &= \frac{1}{70 km/s/Mpc} = \frac{1}{70} \frac{1}{3,24 \cdot 10^{-20} s{-}1} = 4,4 \cdot 10^{-17} s \\ &= 14 Gyr \end{aligned}$$

universo observável e idade

1. E se d for grande o suficiente para que $v = c$?

$$c = H_0 D_H$$
$$D_H = \frac{c}{H_0}$$
$$D_H = \frac{3 \cdot 10^5 km/s}{70 km/s/Mpc} = 4 \cdot 10^3 Mpc = 4Gpc$$

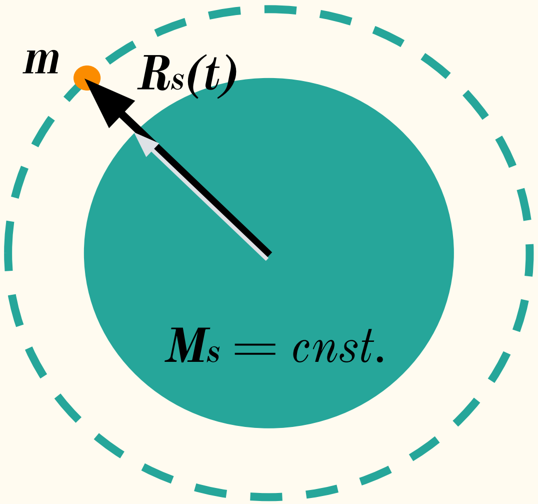
2. Qual o tempo que a luz leva para percorrer essa

Qual o problema com essas contas??

$$= \frac{c}{cH_0}$$
$$= \frac{1}{H_0}$$
$$= \frac{1}{70km/s/Mpc} = \frac{1}{70}\frac{1}{3,24 \cdot 10^{-20} s^-1} = 4,4 \cdot 10^{-17} s$$
$$= 14Gyr$$

FLRW “newtoniano”

$$\boxed{F = -\frac{GM_s m}{R_s^2(t)}}$$



FLRW “newtoniano”

$$\boxed{F = -\frac{GM_s m}{R_s^2(t)}}$$

$$\frac{d^2 R_s}{dt^2} = -\frac{GM_s}{R_s^2(t)}$$

Multiplicando ambos os membros por dR_s/dt e integrando, obtemos:

$$\frac{1}{2}\left(\frac{dR_s}{dt}\right)^2 = \frac{GM_s}{R_s(t)} + U$$, sendo U uma constante de integração.

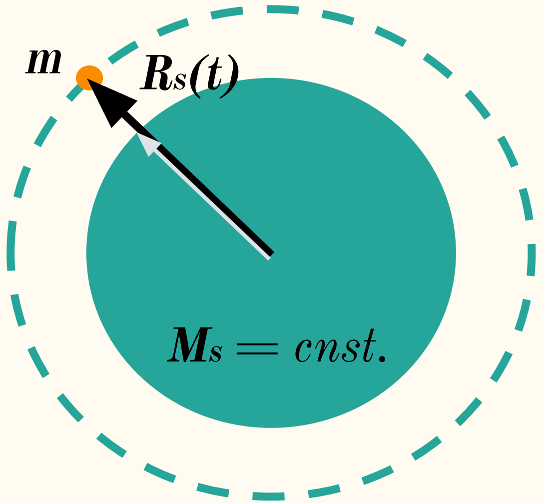
Energia cinética por unidade de massa

Energia potencial gravitacional por unidade de massa

FLRW "newtoniano"

$$\boxed{\frac{1}{2}\left(\frac{dR_s}{dt}\right)^2 = \frac{GM_s}{R_s(t)} + U}$$

a soma dessas duas grandezas se conserva para uma massa na superfície da esfera, enquanto e esfera se expande ou se contrai



FLRW “newtoniano”

$$\boxed{\frac{1}{2}\left(\frac{dR_s}{dt}\right)^2 = \frac{GM_s}{R_s(t)} + U}$$

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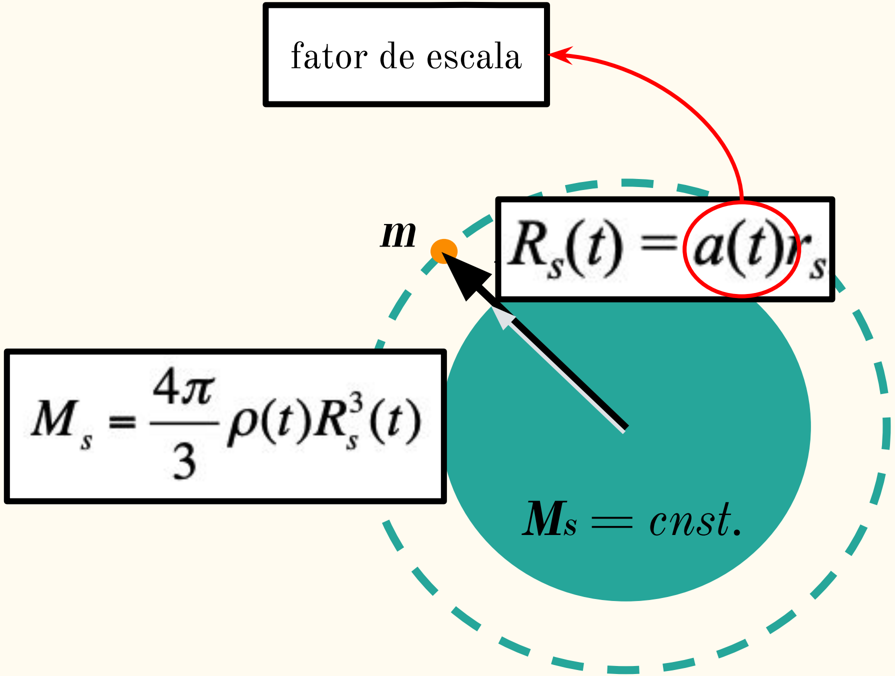
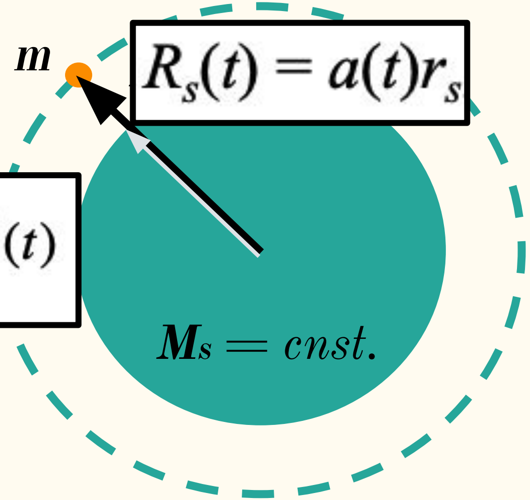


FLRW “newtoniano”

$$\frac{1}{2}\left(\frac{dR_s}{dt}\right)^2 = \frac{GM_s}{R_s(t)} + U \quad \rightarrow \quad \frac{1}{2} r_s^2 \dot{a}^2 = \frac{4\pi}{3} G r_s^2 \rho(t) a^2(t) + U$$

a soma dessas duas grandezas se conserva para uma massa na superfície da esfera, enquanto e esfera se expande ou se contrai

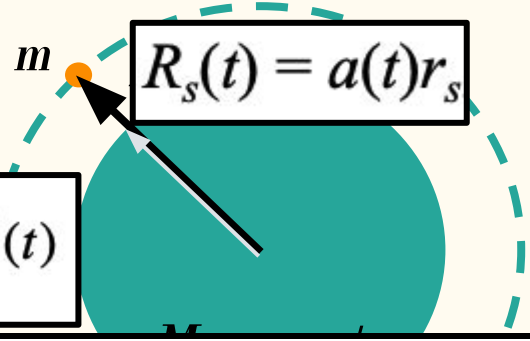
$$M_s = \frac{4\pi}{3}\rho(t) R_s^3(t)$$



FLRW “newtoniano”

$$\frac{1}{2}\left(\frac{dR_s}{dt}\right)^2 = \frac{GM_s}{R_s(t)} + U \quad \rightarrow \quad \frac{1}{2} r_s^2 \dot{a}^2 = \frac{4\pi}{3} G r_s^2 \rho(t) a^2(t) + U$$

a soma dessas duas grandezas se conserva para uma massa na superfície da esfera, enquanto e esfera se expande ou se contrai



$$M_s = \frac{4\pi}{3} \rho(t) R_s^3(t)$$

Dividindo os membros por $r_s^2 a^2/2$ $\Rightarrow$ $\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3} \rho(t) + \frac{2U}{r_s^2} \frac{1}{a^2(t)}$

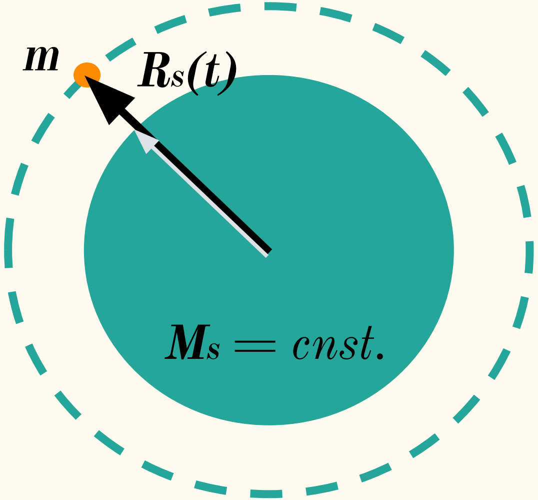
FLRW "newtoniano"

densidade $\rho(t)$ → energia relativística $E^2 = m^2c^4 + p^2c^2$

$\frac{2U}{r_s^2}$ → $-kc$

1ª equação de Friedmann

$$\boxed{\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{kc}{a^2(t)}}$$



FLRW "newtoniano"

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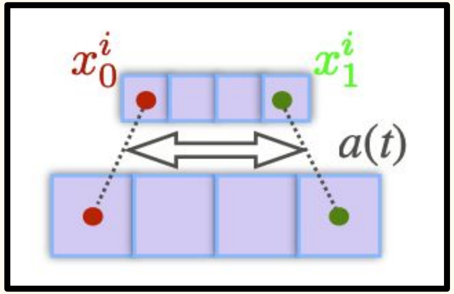
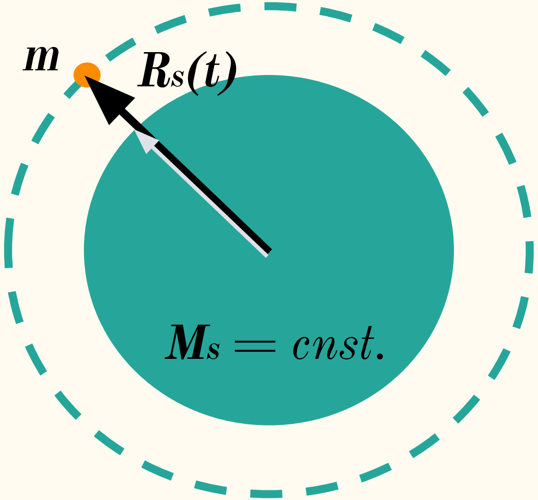
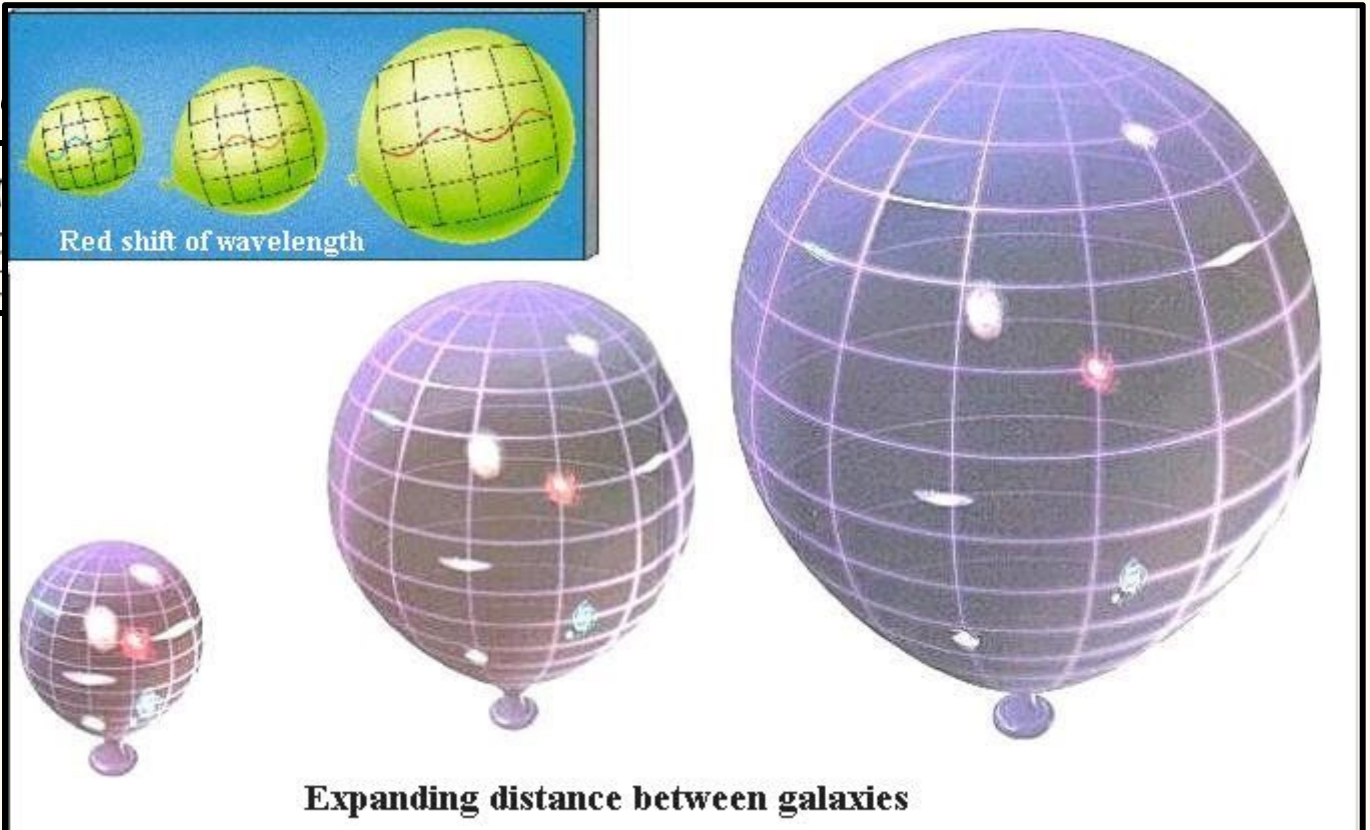




FLRW “newtoniano”

1ª equação

$$\boxed{\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi}{3}}$$



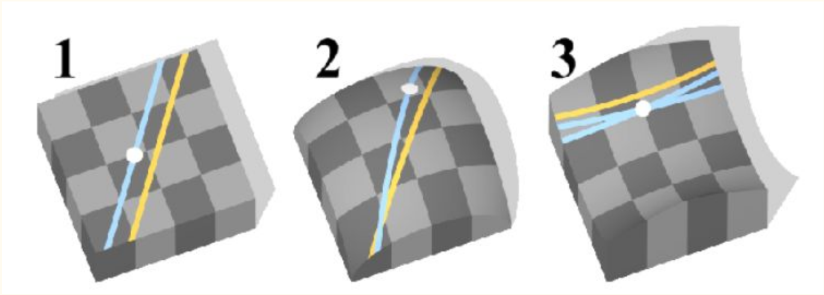
https://universe-review.ca/R15-17-relativity08.htm

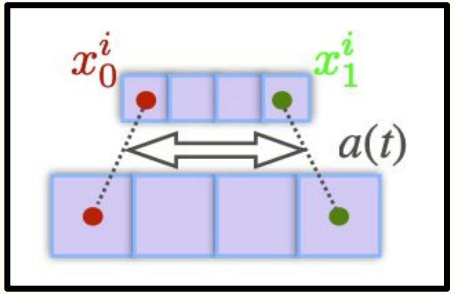
FLRW "newtoniano"

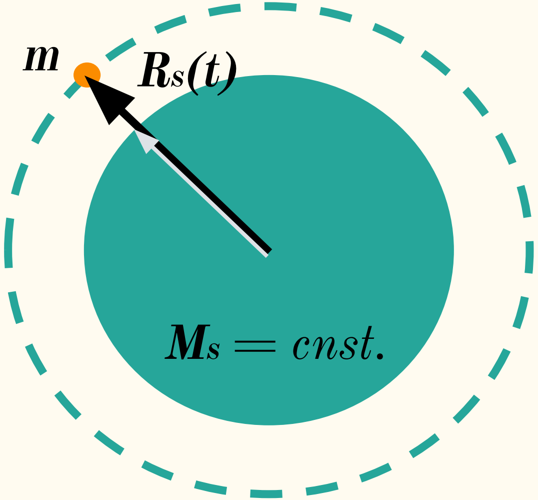
1ª equação de Friedmann

$$\boxed{\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{kc}{a^2(t)}}$$

$$\begin{cases} \mathrm{k} = +1 & \text{(curvatura positiva)} \\ \mathrm{k} = -1 & \text{(curvatura negativa)} \\ \mathrm{k} = 0 & \text{(geometria plana)} \end{cases}$$







FLRW “newtoniano”

1ª equação de Friedmann

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{kc}{a^2(t)}$$

mas

$$\begin{aligned}\rho(t) &= \rho_m(t) + \rho_r(t) + \rho_\Lambda(t) + \ldots \\ &= \frac{\rho_{m,0}}{a^3(t)} + \frac{\rho_{r,0}}{a^4(t)} + \rho_{\Lambda,0} + \ldots\end{aligned}$$

$$H(t) \equiv \frac{\dot{a}}{a}$$

FLRW "newtoniano"

1ª equação de Friedmann

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{kc}{a^2(t)}$$

mas

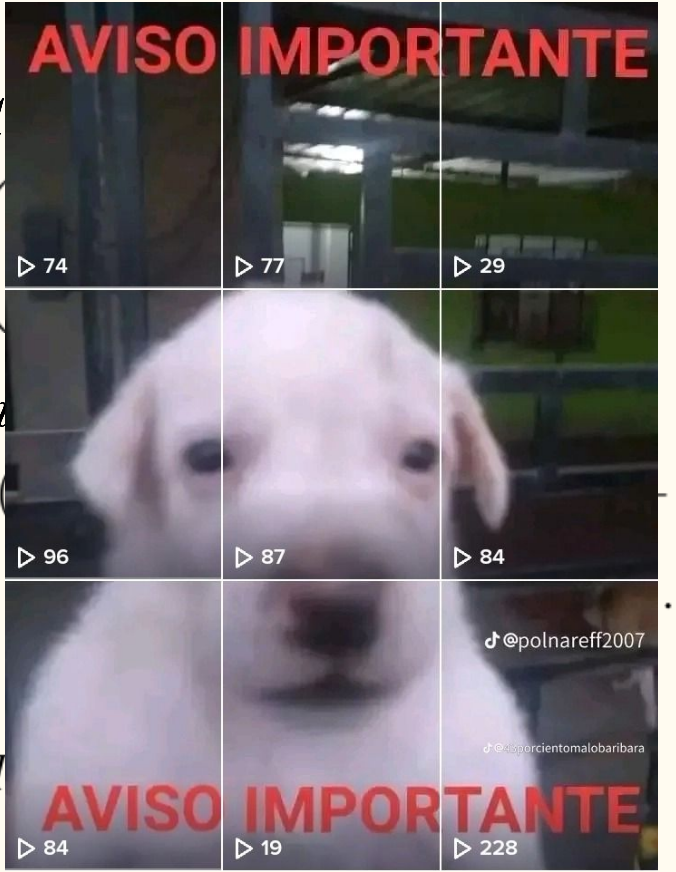
$$\rho(t) = \rho_m(t) + \rho_r(t) + \rho_\Lambda(t) + \dots$$
$$= \frac{\rho_{m,0}}{a^3(t)} + \frac{\rho_{r,0}}{a^4(t)} + \rho_{\Lambda,0} + \dots$$

$$H(t) \equiv \frac{\dot{a}}{a}$$

$$H^2(t) = \frac{8\pi G}{3}\left(\frac{\rho_{m,0}}{a^3(t)} + \frac{\rho_{r,0}}{a^4(t)} + \rho_{\Lambda,0}\right) - \frac{kc}{a^2(t)}$$

$$\boxed{H^2(t) = H_0^2\left(\frac{\Omega_m}{a^3(t)} + \frac{\Omega_r}{a^4(t)} + \Omega_\Lambda + \frac{\Omega_k}{a^2(t)}\right)}$$

FLRW "newtoniano"



$$H^2(t) = \frac{8\pi G}{3}\left(\frac{\rho_{m,0}}{a^3(t)} + \frac{\rho_{r,0}}{a^4(t)} + \rho_{\Lambda,0}\right) - \frac{kc}{a^2(t)}$$

$$\boxed{H^2(t) = H_0^2\left(\frac{\Omega_m}{a^3(t)} + \frac{\Omega_r}{a^4(t)} + \Omega_\Lambda + \frac{\Omega_k}{a^2(t)}\right)}$$

átomo primordial de Lemaître

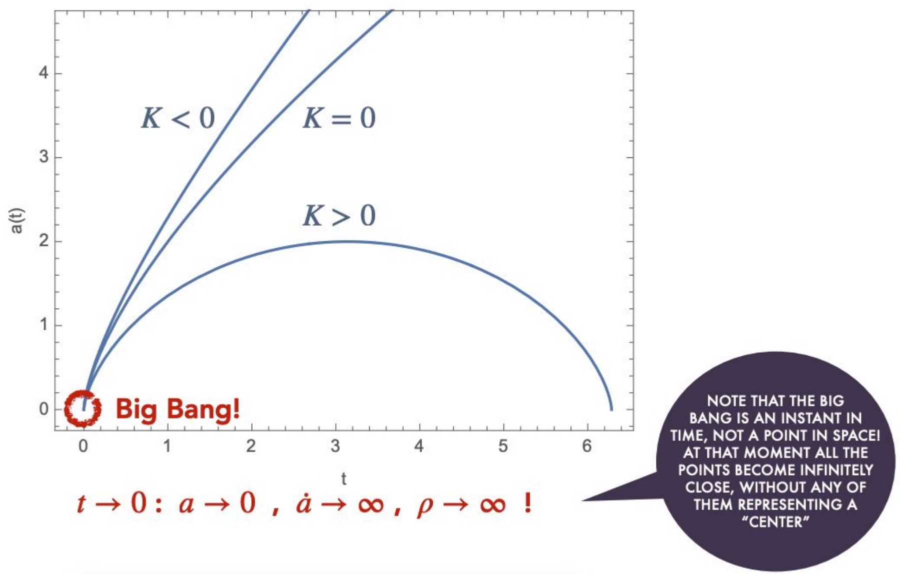
$$H^2(t) = H_0^2\left(\frac{\Omega_m}{a^3(t)} + \frac{\Omega_r}{a^4(t)} + \Omega_\Lambda + \frac{\Omega_k}{a^2(t)}\right)$$

$$\rho_{cr} = \frac{3H_0^2}{8\pi G}$$

$$\Omega_i = \frac{\rho_{i,0}}{\rho_{cr}}$$

$$\Omega - 1 = \frac{ck}{H_0^2}$$

- The ***general solution*** (for all K) is shown in the plot below



distâncias cosmológicas

1. Não medimos distâncias, **inferimos** porque elas dependem de um modelo cosmológico

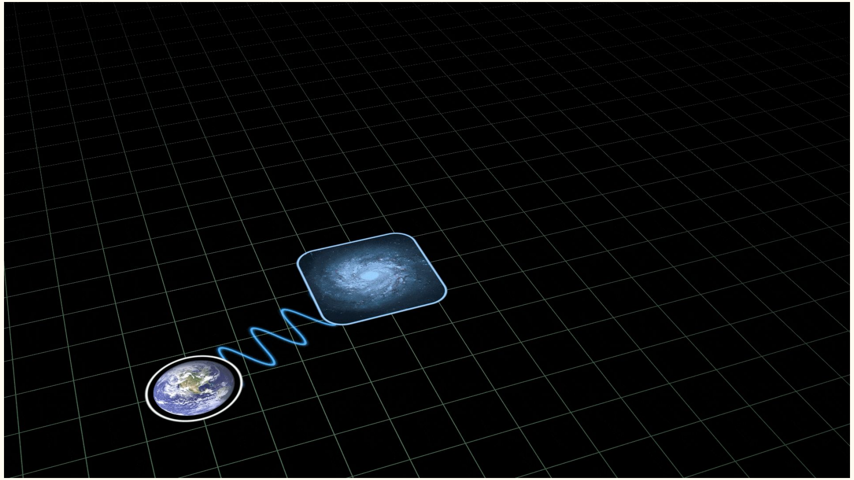
2. distância ⇄ redshift
   distância ⇄ fator de escala
   saber distância = saber a cosmologia

3. distância física

   distância comóvel

   distância diâmetro-angular

   distância luminosidade



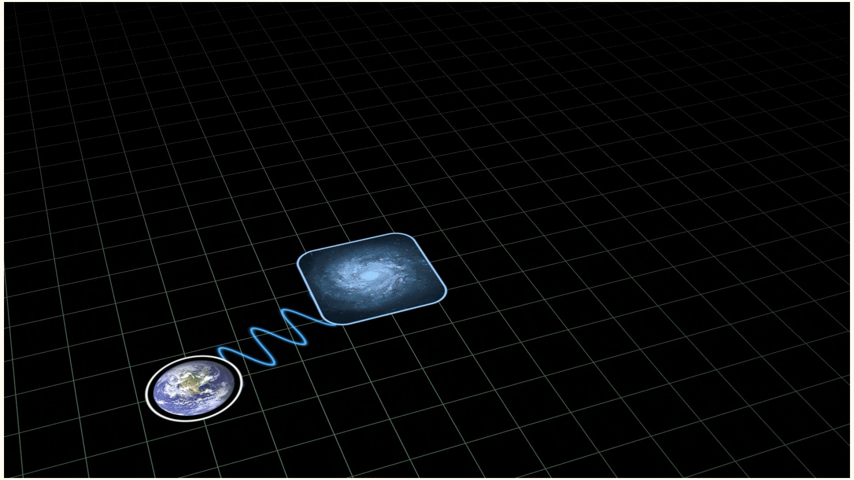
Credit: NASA/JPL-Caltech//R. Hurt (Caltech-IPAC)

hoje:	$a = 1$ e $z = 0$
big bang:	$a = 0$ e $z =$ infinito

distância **comóvel**

A distância entre Terra e galáxia aumenta, mas a quantos "quadradinhos" de distância elas estão?

$$D_c \equiv c\int_{t_0}^{t}\frac{dt}{a(t)}$$
$$= c\int_{a}^{1}\frac{da}{a^2H(a)}$$
$$= c\int_{0}^{z}\frac{dz}{H(z)}$$



Credit: NASA/JPL-Caltech//R. Hurt (Caltech-IPAC)

hoje:	$t = t_0$,	$a = 1$ e $z = 0$
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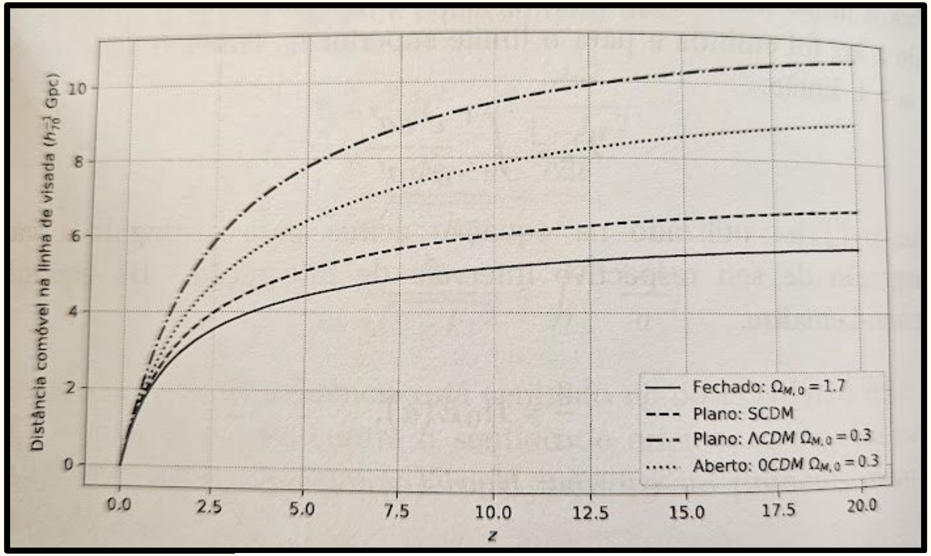


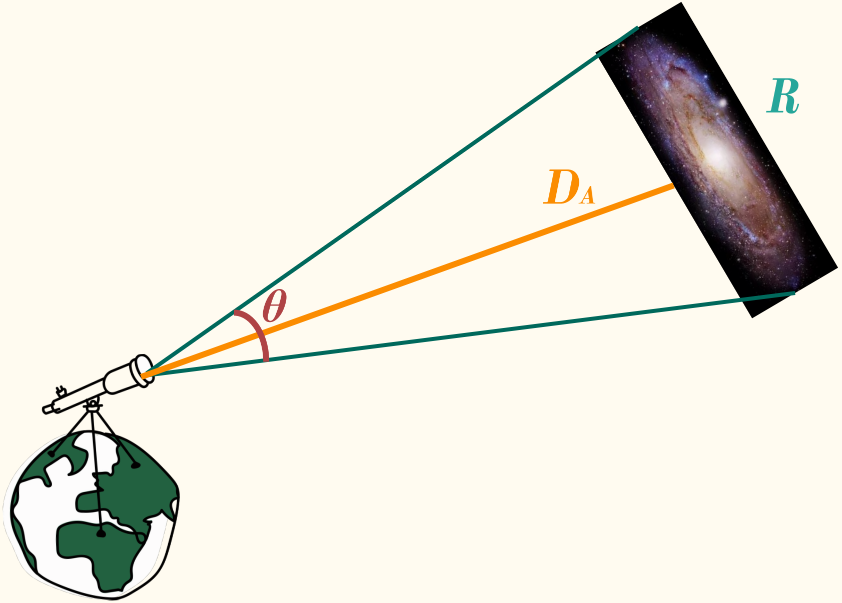
Introdução à Cosmologia, um curso de graduação, A. Zabot (2023)

hoje:	$t = t_0$,	$a = 1$ e $z = 0$
big bang:	$t = 0$,	$a = 0$ e $z =$ infinito

distância **diâmetro angular**

Se sabemos o tamanho de um objetos, inferimos sua distância pelo ângulo que ele forma no céu

$$D_A = \frac{R}{\theta}$$

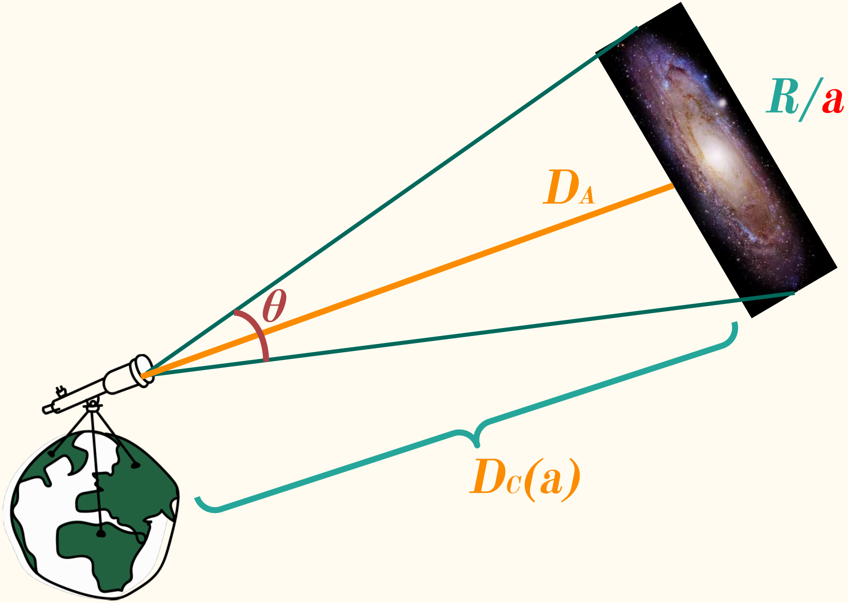


hoje:	$t = t_0$,	$a = 1$ e $z = 0$
big bang:	$t = 0$,	$a = 0$ e $z =$ infinito

distância **diâmetro angular**

Se sabemos o tamanho de um objetos, inferimos sua distância pelo ângulo que ele forma no céu

$$\underbrace{\underset{\boxed{\text{físico}}}{D_A = \frac{R}{\theta}} \qquad \underset{\boxed{\text{comóvel}}}{\theta = \frac{R/a}{D_C(a)}}}$$



hoje:	$t = t_0$,	$a = 1$ e $z = 0$
big bang:	$t = 0$,	$a = 0$ e $z =$ infinito

distância **diâmetro angular**

Se sabemos o tamanho de um objetos, inferimos sua distância pelo ângulo que ele forma no céu

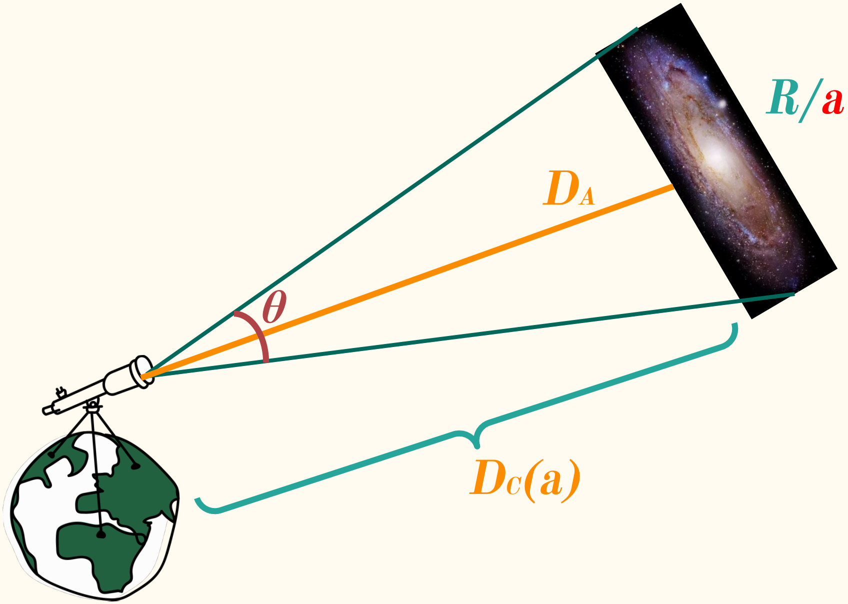
$$\underbrace{\boxed{D_A = \frac{R}{\theta}}_{\text{físico}} \qquad \underbrace{\theta = \frac{R/a}{D_C(a)}}_{\text{comóvel}}}$$

físico

comóvel

$$\boxed{D_A = aD_C = \frac{D_C}{1+z}}$$

*para um universo plano



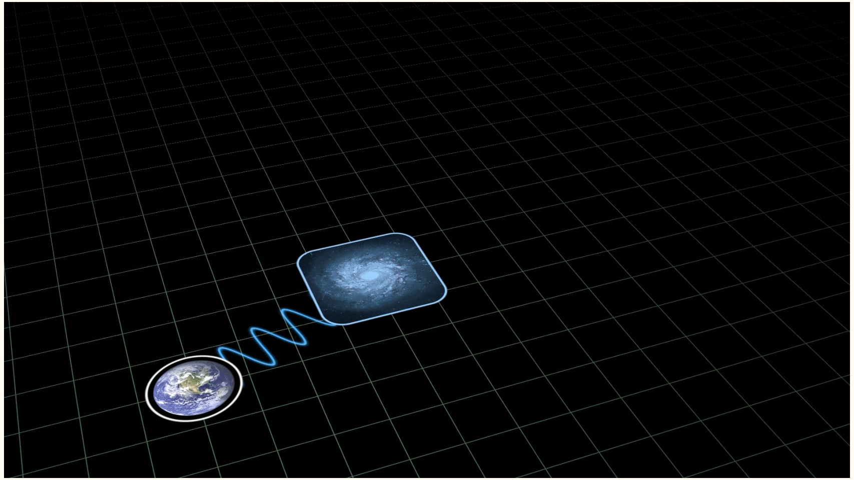
hoje:	$t = t_0$,	$a = 1$ e $z = 0$
big bang:	$t = 0$,	$a = 0$ e $z =$ infinito

distância **luminosidade**

$$\lambda_e = \frac{\lambda_o}{1+z} = a\lambda_o \qquad a \equiv \frac{1}{1+z}$$

$$E = hf = \frac{hc}{\lambda} \qquad T \propto \frac{1}{f} \propto \lambda$$

$$v = \lambda f$$



Credit: NASA/JPL-Caltech//R. Hurt (Caltech-IPAC)

hoje: $t = t_0$, $a = 1$ e $z = 0$
big bang: $t = 0$, $a = 0$ e $z =$ infinito

distância luminosidade

$$\lambda_e = \frac{\lambda_o}{1+z} = a\lambda_o \qquad a \equiv \frac{1}{1+z}$$

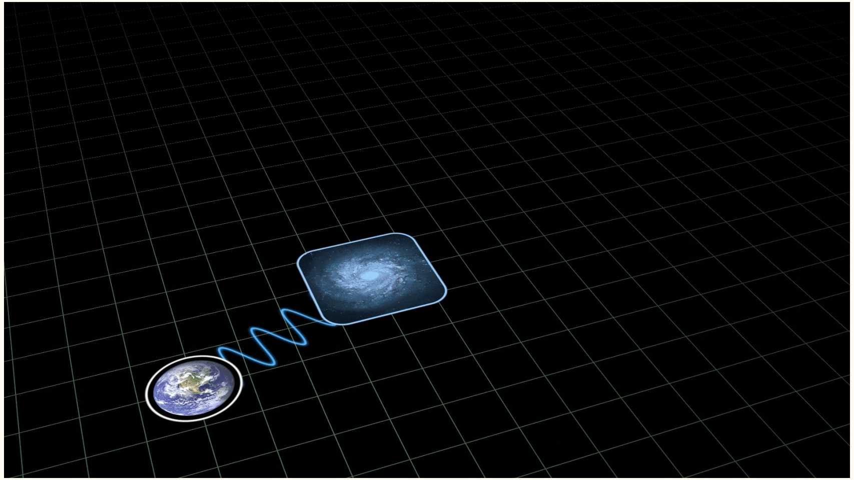
$$E = hf = \frac{hc}{\lambda} \qquad T \propto \frac{1}{f} \propto \lambda$$

$$v = \lambda f$$

$$L = \frac{energia}{tempo} \qquad E_e = E_o(1+z) \qquad T_e = \frac{T_o}{1+z}$$

$$\frac{L_o}{L_e} = \frac{T_e}{E_e}\frac{E_o}{T_o} = \frac{1}{(1+z)^2}$$

$$\boxed{F = \frac{L}{4\pi d^2} \Rightarrow F_o = \frac{F_e}{(1+z)^2} = \frac{L_e}{4\pi(1+z)^2 D_c^2}} \Rightarrow D_L \equiv (z+1)D_C = \frac{D_C}{a}$$



Credit: NASA/JPL-Caltech//R. Hurt (Caltech-IPAC)

distâncias cosmológicas

$$
\left\{
\begin{aligned}
D_c &\equiv c\int_{t_0}^{t}\frac{dt}{a(t)} \\
&= c\int_{a}^{1}\frac{da}{a^2H(a)} \\
&= c\int_{0}^{z}\frac{dz}{H(z)} \\
D_A &= aD_C = \frac{D_C}{1+z} \\
D_L &\equiv (z+1)D_C = \frac{D_C}{a}
\end{aligned}
\right\}
$$

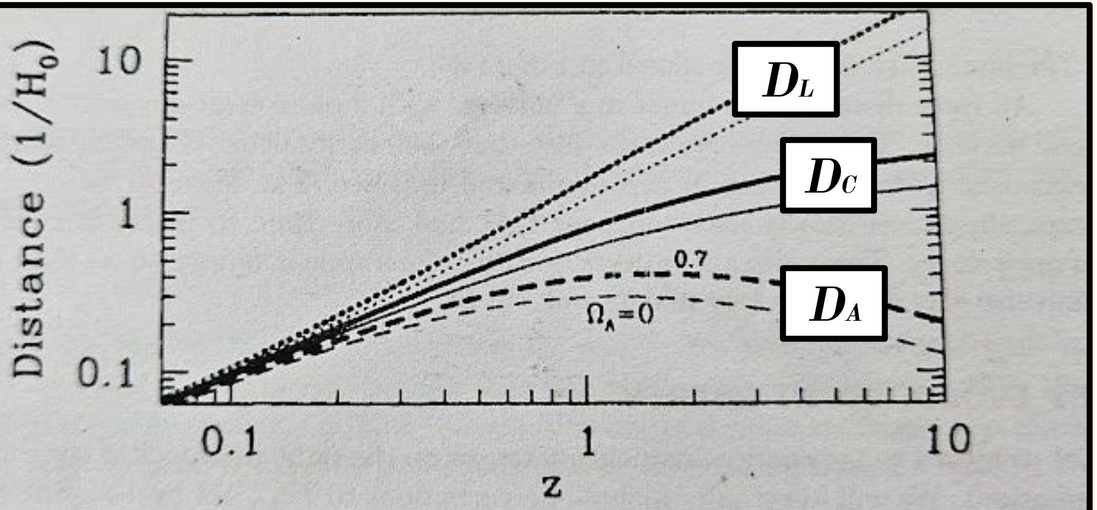


Figure 2.3. Three distance measures in a flat expanding universe. From top to bottom, the luminosity distance, the comoving distance, and the angular diameter distance. The pair of lines in each case is for a flat universe with matter only (light curves) and 70% cosmological constant Λ (heavy curves). In a Λ-dominated universe, distances out to fixed redshift are larger than in a matter-dominated universe.

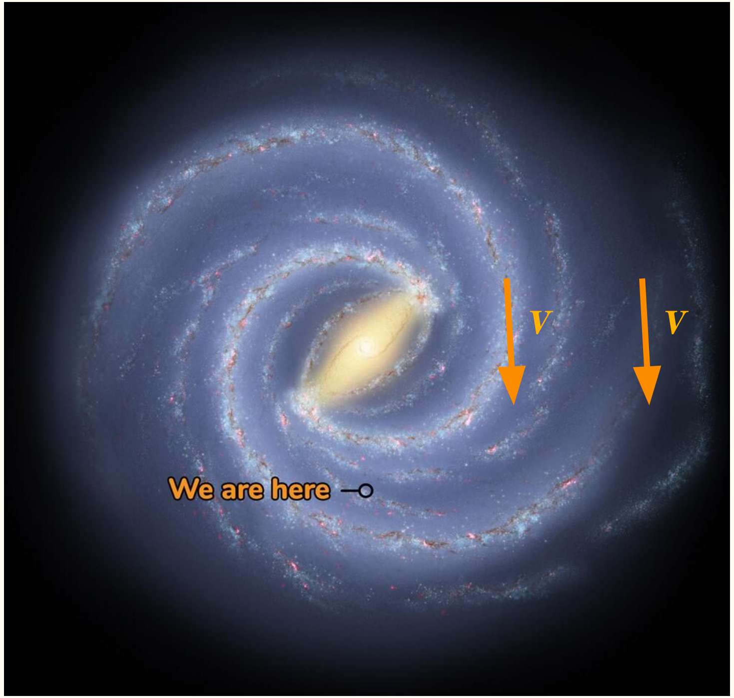
matéria escura?

1. Em 1930, Fritz Zwicky analisa por meio de **paralaxe vs distância luminosidade** que galáxias em aglomerados estão se movendo muito rápido para ainda estarem “em órbita”.
2. Conclui que deve ter ~5–6x mais matéria do que pode ver, mas medidas são muito imprecisas para serem conclusivas
3. Denomina essa matéria ausente de **matéria escura**

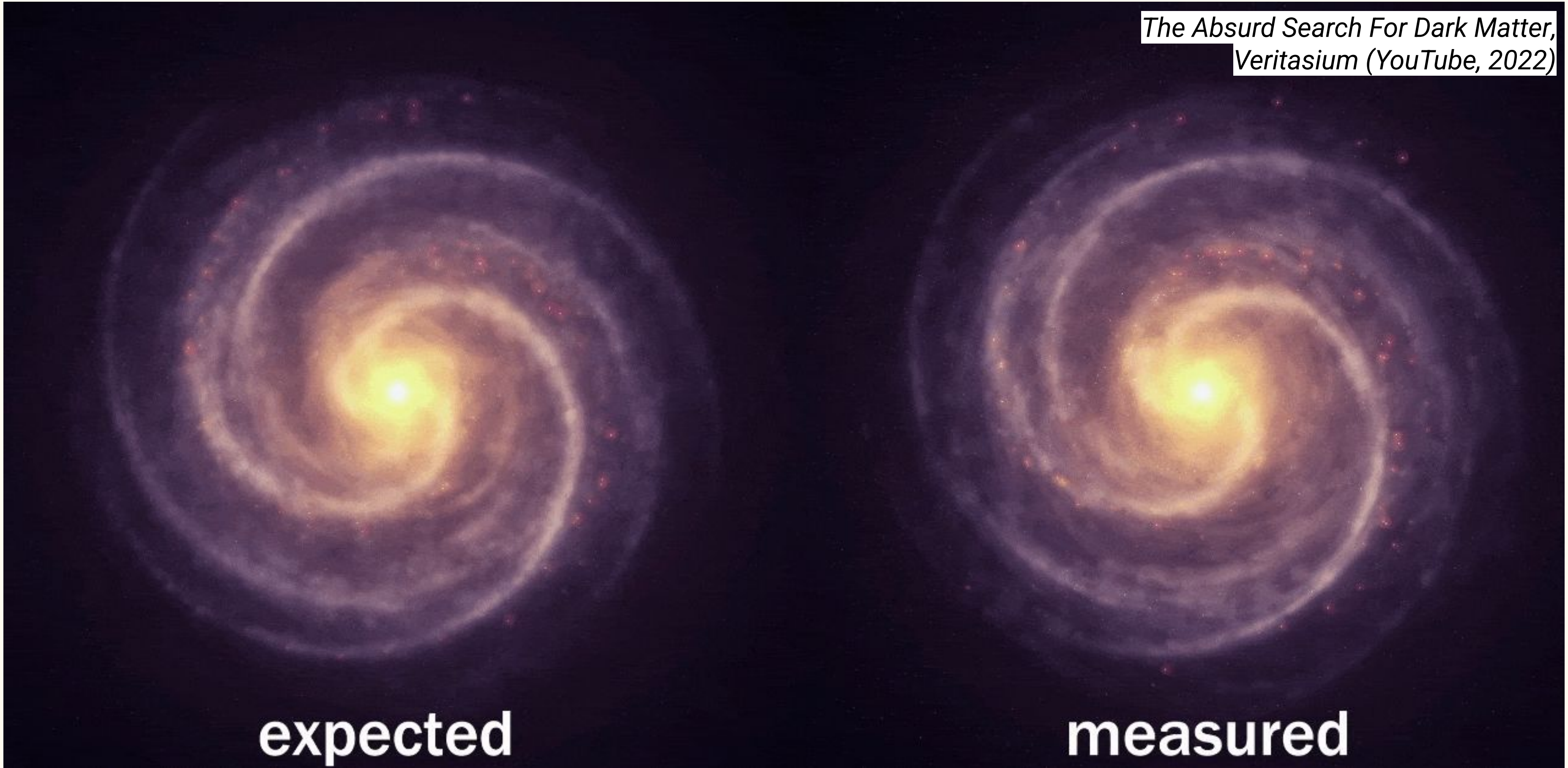
Dark Matter: Crash Course Astronomy #41, Crash Course (YouTube, 2016)

Vera Rubin (1960)

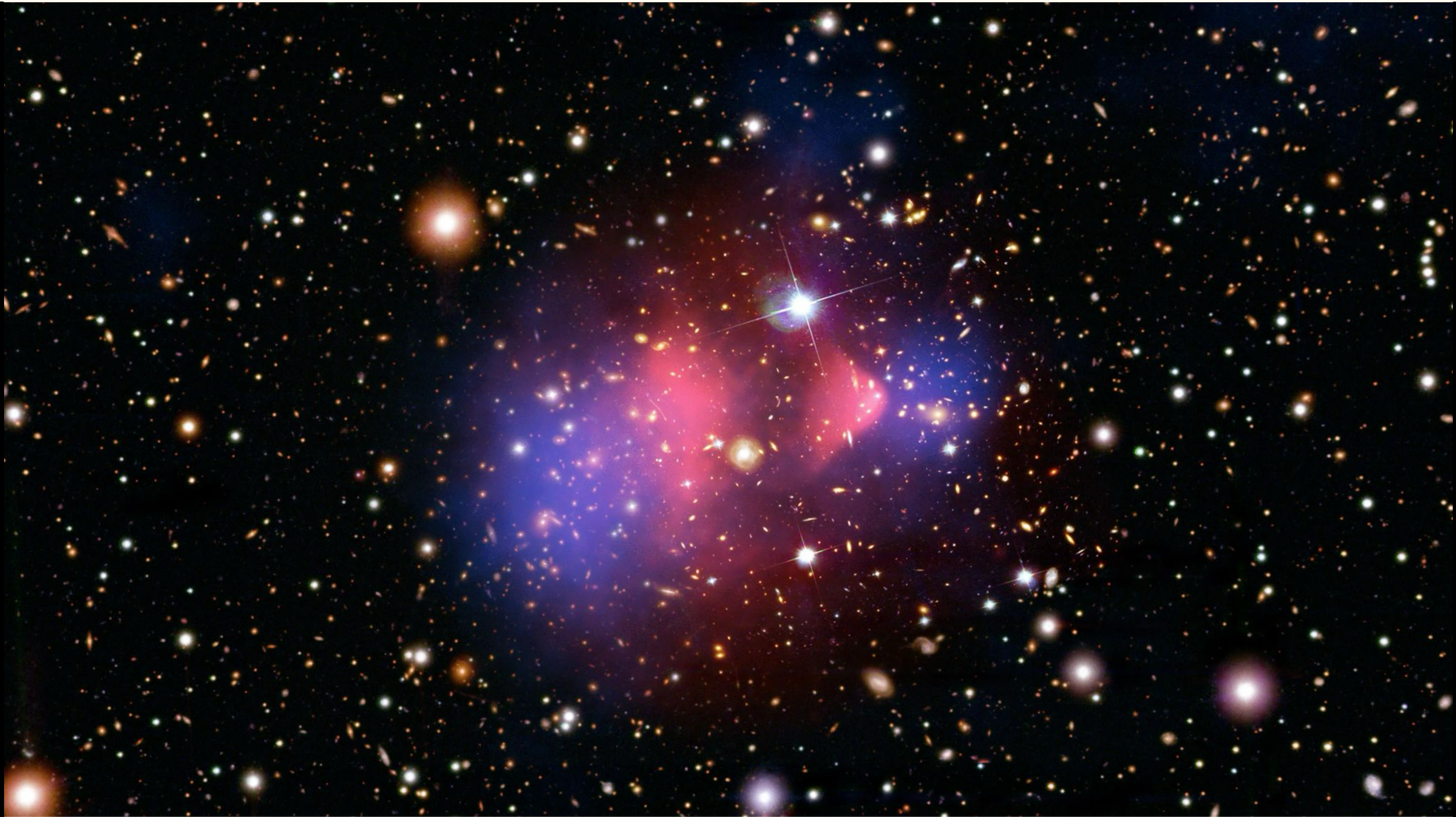
velocidade peculiar



Vera Rubin (1960)



bullet cluster



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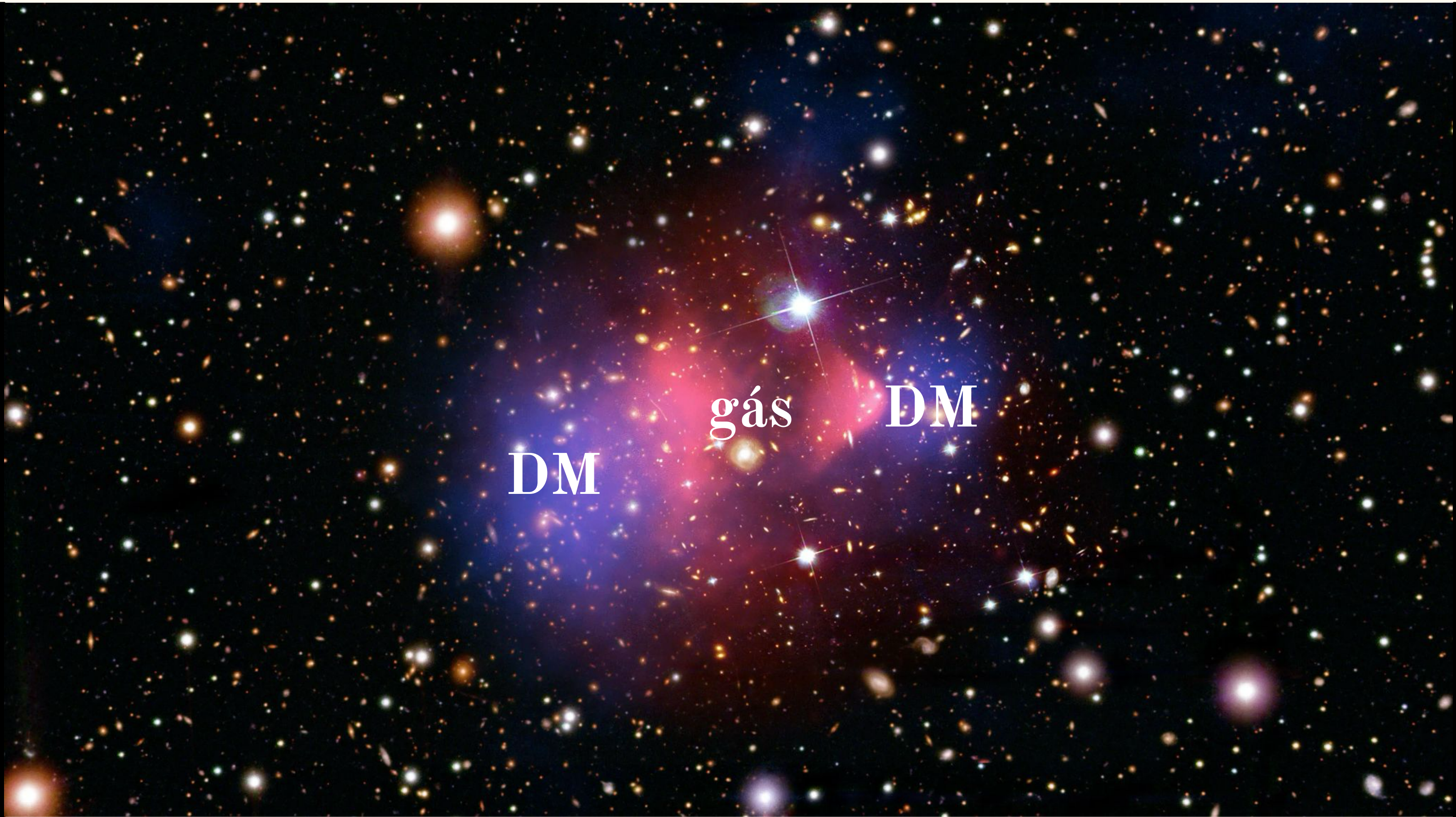

matéria escura

matéria escura

pesquisa

Enhancing weak lensing redshift distribution characterization by optimizing the Dark Energy Survey Self-Organizing Map Photo-z method

A. Campos[1,2]*, B. Yin[3], S. Dodelson[1,2], A. Amon[4,5], A. Alarcon[6,7], C. Sánchez[8], G. M. Bernstein[8], G. Giannini[9,10], J. Myles[11], S. Samuroff[12], O. Alves[13], F. Andrade-Oliveira[13], K. Bechtol[14], M. R. Becker[6], J. Blazek[12], H. Camacho[15,16,17], A. Carnero Rosell[15,18,19], M. Carrasco Kind[20,21], R. Cawthon[22], C. Chang[23,9], R. Chen[3], A. Choi[24], J. Cordero[25], C. Davis[26], J. DeRose[27], H. T. Diehl[28], C. Doux[8,29], A. Drlica-Wagner[9,23,28], K. Eckert[8], T. F. Eifler[30,31], J. Elvin-Poole[32], S. Everett[30], X. Fang[31,33], A. Ferté[34], O. Friedrich[5], M. Gatti[8], D. Gruen[35], R. A. Gruendl[20,21], I. Harrison[36], W. G. Hartley[37], K. Herner[28], H. Huang[31,38], E. M. Huff[30], M. Jarvis[8], E. Krause[31], N. Kuropatkin[28], P.-F. Leget[26], N. MacCrann[39], J. McCullough[26], A. Navarro-Alsina[40], S. Pandey[8], J. Prat[41,23], M. Raveri[42], R. P. Rollins[25], A. Roodman[26,34], R. Rosenfeld[43,15], A. J. Ross[44], E. S. Rykoff[34,26], J. Sanchez[45], L. F. Secco[9], I. Sevilla-Noarbe[46], E. Sheldon[17], T. Shin[47], M. A. Troxel[3], I. Tutusaus[48], T. N. Varga[49,50,51], R. H. Wechsler[26,52,34], B. Yanny[28], Y. Zhang[53], J. Zuntz[54], M. Aguena[15], J. Annis[28], D. Bacon[55], S. Bocquet[35], D. Brooks[56], D. L. Burke[26,34], J. Carretero[10], F. J. Castander[7,57], M. Costanzi[58,59,60], L. N. da Costa[15], J. De Vicente[46], P. Doel[56], I. Ferrero[61], B. Flaugher[28], J. Frieman[9,28], J. García-Bellido[62], E. Gaztanaga[7,55,57], G. Gutierrez[28], S. R. Hinton[63], D. L. Hollowood[64], K. Honscheid[44,65], D. J. James[66], K. Kuehn[67,68], M. Lima[15,69], H. Lin[28], J. L. Marshall[70], J. Mena-Fernández[71], F. Menanteau[20,21], R. Miquel[10,72], R. L. C. Ogando[73], M. Paterno[28], M. E. S. Pereira[74] A. Pieres[15,73], A. A. Plazas Malagón[26,34], A. Porredon[46,75], E. Sanchez[46], D. Sanchez Cid[46], M. Smith[76], E. Suchyta[77], M. E. C. Swanson[21], G. Tarle[13], C. To[44], V. Vikram[78], and N. Weaverdyck[27,33]

DES Collaboration

pesquisa

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optimizing the Dark Energy S

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L. N. da Costa[15], J. De Vicente[46], P. D
Bellido[62], E. Gaztanaga[7,55,57], G. Gutier
D. J. James[66], K. Kuehn[67,68], M. Li
F. Menanteau[20,21], R. Miquel[10,72], R. L.
A. A. Plazas Malagón[26,34], A. Porredon[46
M. E. C. Swanson[21], G. Tarle[13], C. To[44],
DES Collaboration

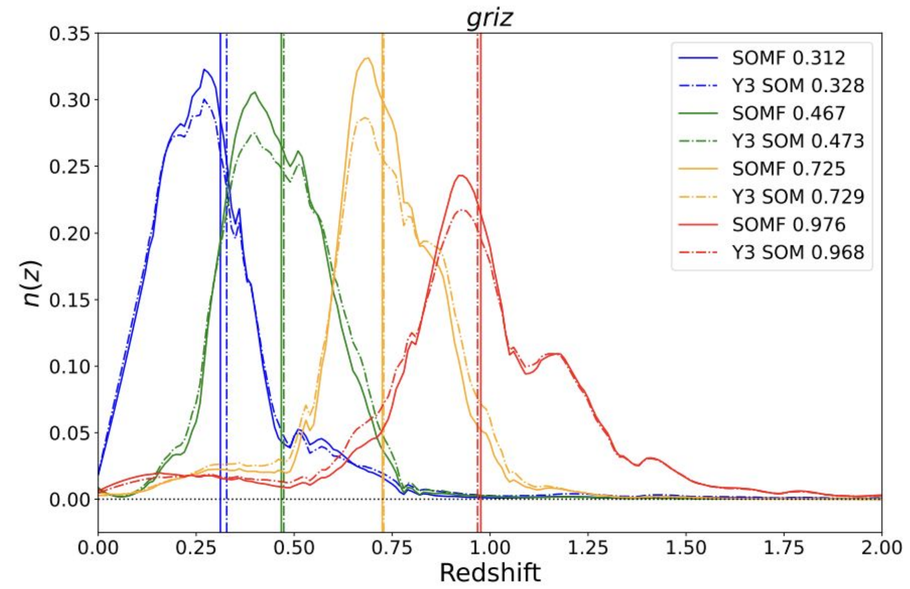


Figure 6. Photometric redshift distribution obtained from the *griz* bands, using the Y3 SOM (dot-dashed line) and the SOMF algorithm (filled line). The two methods show good agreement regarding the shape of each bin, and their mean redshifts values, shown in the legend on the top right. However, the addition of the *g*-band further emphasizes the ability of SOMF to produce better defined bins.

pesquisa

Observationally Determining the Properties of Dark Matter

Wayne Hu*, Daniel J. Eisenstein, and Max Tegmark†
Institute for Advanced Study, Princeton, NJ 08540

Martin White
Departments of Astronomy and Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801

Determining the properties of the dark components of the universe remains one of the outstanding challenges in cosmology. We explore how upcoming CMB anisotropy measurements, galaxy power spectrum data, and supernova (SN) distance measurements can observationally constrain their gravitational properties with minimal assumptions on the theoretical side. SN observations currently suggest the existence of dark matter with an exotic equation of state $p/\rho \lesssim -1/3$ that accelerates the expansion of the universe. When combined with CMB anisotropy measurements, SN or galaxy survey data can in principle determine the equation of state and density of this component separately, regardless of their value, as long as the universe is spatially flat. Combining these pairs creates a sharp consistency check. If $p/\rho \gtrsim -1/2$, then the clustering behavior (sound speed) of the dark component can be determined so as to test the scalar-field "quintessence" hypothesis. If the exotic matter turns out instead to be simply a cosmological constant ($p/\rho = -1$), the combination of CMB and galaxy survey data should provide a significant detection of the remaining dark matter, the neutrino background radiation (NBR). The gross effect of its density or temperature on the expansion rate is ill-constrained as it is can be mimicked by a change in the matter density. However, anisotropies of the NBR break this degeneracy and should be detectable by upcoming experiments.

pesquisa

"The 'Dark' Universe May Be Full of Strange Interactions"

"The light and fuzzy side of dark matter"

"Relieving the Hubble tension with Early Dark Energy"

"If dark matter is fuzzy, then how fuzzy is it? - A gravitational lens has the answer"

"[In a Monster Star's Light, a Hint of Darkness"]

https://www.elisagmferreira.com/

ABOUT ME

I am an Assistant Professor at the Kavli IPMU. Until 2024 I was also a professor at the Institute of Physics of the University of São Paulo. I received my PhD from McGill University.

My field of research is in the interface between cosmology, astrophysics, and high energy physics. My work focuses mostly on studying the dark sector. I am mostly worried about dark matter, focusing on ultra-light dark matter. I am also interested in the late expansion of the universe, studying the phenomenology of dark energy. I also study several topics in early universe cosmology, including the initial singularity, the early evolution of the universe, and reheating. Testing those models using the current observational probes and new observational windows is also part of my research.

I am a Serrapilheira Institute grantee since 2021.

pesquisa:

Testando modelos de matéria escura ultra-leve com levantamentos astrofísicos
Fernanda Lima
Raul Abramo
Elisa Ferreira

A matéria escura constitui cerca de 85\% da densidade de matéria do universo. Contudo, sua natureza fundamental ainda é desconhecida, representando uma grande lacuna no nosso entendimento do universo. Há muitos modelos para essa componente elusiva. A matéria escura ultra-leve (ULDM), ou os axions ultra-leves (ULA), são os candidatos a matéria escura mais leves, e, dada sua microfísica bem motivada e rica fenomenologia, se tornaram um dos principais candidatos a matéria escura. Neste projeto, queremos usar os mais recentes levantamentos astrofísicos para vincular propriedades físicas de ULDM.

pesquisa:

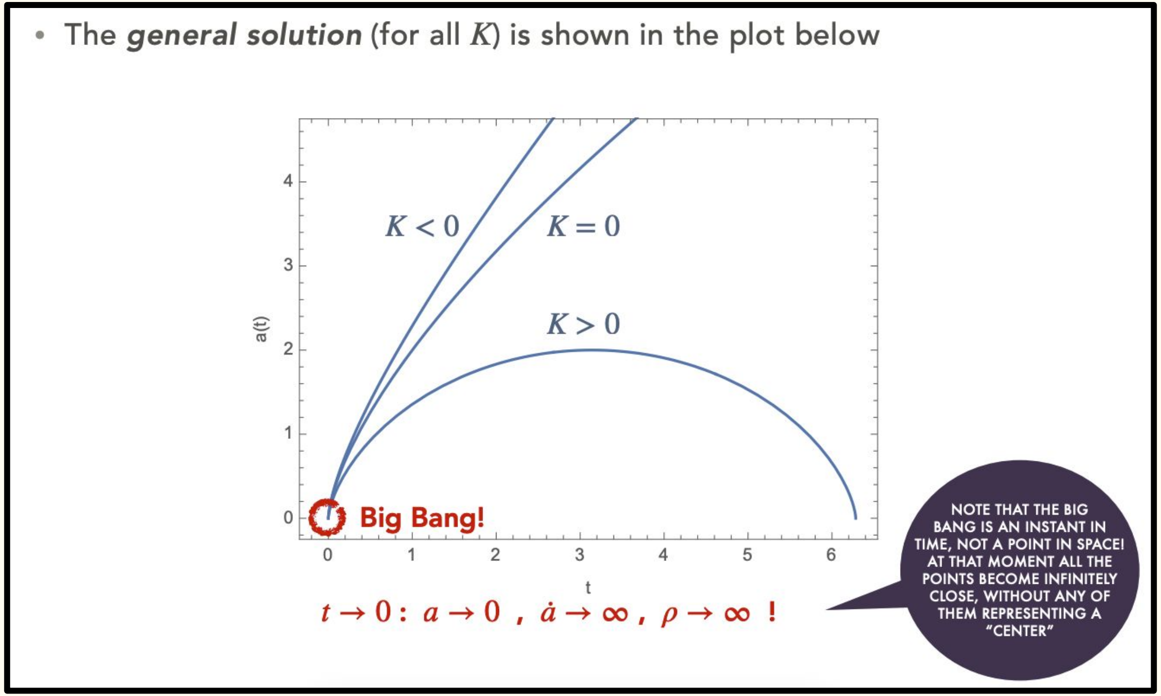

Observations
from 21 cm hydrogen
Pioneira
Expected from visible disk
Matéria Escura
20
30
40
50
1000 ly)
Dra. Ivone Albuquerque


09.09
quinta-feira
16h00
Prof. Enrico Bertuzzo
IFUSP
PORTALS TO THE
DARK WORLD
colóquio
IFUSP

Parte 3

Universo primordial e tardio: como medir e analisar

átomo primordial de Lemaître



átomo primordial de Lemaître

The Beginning of the World from the Point of View of Quantum Theory.

Sir Arthur Eddington[1] states that, philosophically, the notion of a beginning of the present order of Nature is repugnant to him. I would rather be inclined to think that the present state of quantum theory suggests a beginning of the world very different from the present order of Nature. Thermodynamical principles from the point of view of quantum theory may be stated as follows: (1) Energy of constant total amount is distributed in discrete quanta. (2) The number of distinct quanta is ever increasing. If we go back in the course of time we must find fewer and fewer quanta, until we find all the energy of the universe packed in a few or even in a unique quantum.

Now, in atomic processes, the notions of space and time are no more than statistical notions; they fade out when applied to individual phenomena involving but a small number of quanta. If the world has begun with a single quantum, the notions of space and time would altogether fail to have any meaning at the beginning; they would only begin to have a sensible meaning when the original quantum had been divided into a sufficient number of quanta. If this suggestion is correct, the beginning of the world happened a little before the beginning of space and time. I think that such a beginning of the world is far enough from the present order of Nature to be not at all repugnant.

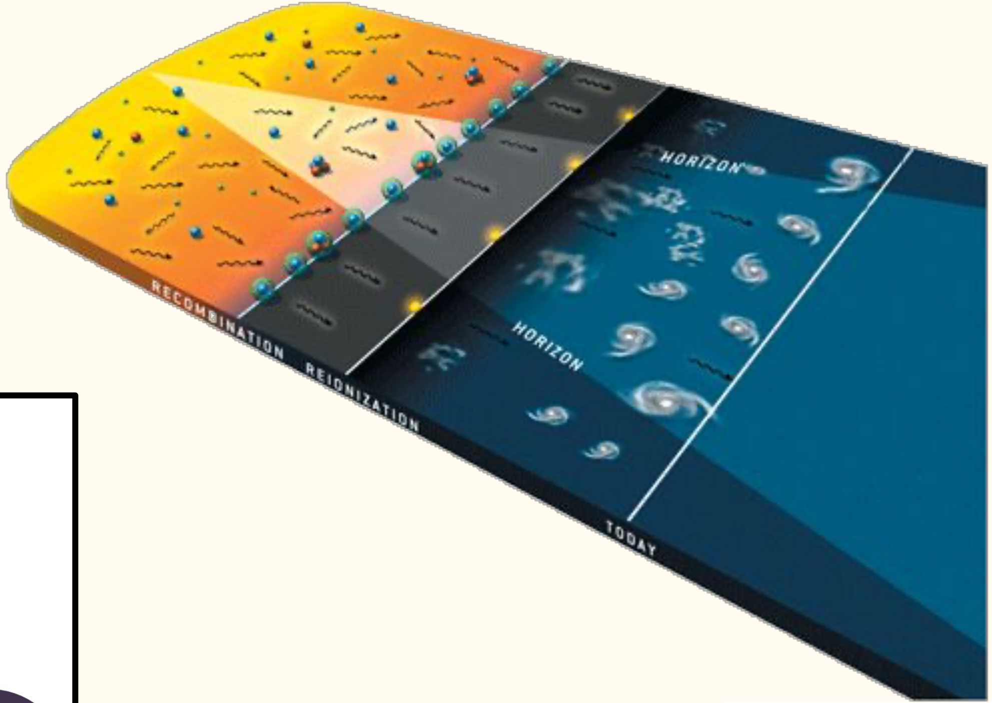
It may be difficult to follow up the idea in detail as we are not yet able to count the quantum packets in every case. For example, it may be that an atomic nucleus must be counted as a unique quantum, the atomic number acting as a kind of quantum number. If the future development of quantum theory happens to turn in that direction, we could conceive the beginning of the universe in the form of a unique atom, the atomic weight of which is the total mass of the universe. This highly unstable atom would divide in smaller and smaller atoms by a kind of super-radioactive process. Some remnant of this process might, according to Sir James Jeans's idea, foster the heat of the stars until our low atomic number atoms allowed life to be possible.

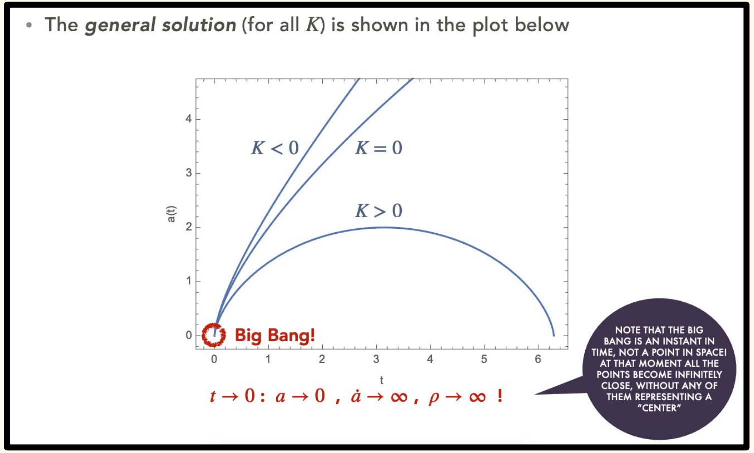
Clearly the initial quantum could not conceal in itself the whole course of evolution; but, according to the principle of indeterminacy, that is not necessary. Our world is now understood to be a world where something really happens; the whole story of the world need not have been written down in the first quantum like a song on the disc of a phonograph. The whole matter of the world must have been present at the beginning, but the story it has to tell may be written step by step.

G. Lemaître.
40 rue de Namur,
Louvain.

It may be difficult to follow up the idea in detail as we are not yet able to count the quantum packets in every case. For example, it may be that an atomic nucleus must be counted as a unique quantum, the atomic number acting as a kind of quantum number. If the future development of quantum theory happens to turn in that direction, we could conceive the beginning of the universe in the form of a unique atom, the atomic weight of which is the total mass of the universe. This highly unstable atom would divide in smaller and smaller atoms by a kind of super-radioactive process. Some remnant of this process might, according to Sir James Jeans's idea, foster the heat of the stars until our low atomic number atoms allowed life to be possible.

big bang e implicações





Créditos: Wayne Hu

debate:
big bang vs estático

1940s – Gamow, Alpher, Herman: Nucleosynthesis & radiation

George Gamow (with Ralph Alpher and Robert Herman) reframed Lemaître's idea in physical terms:

- The early universe was a **hot, dense plasma** of nucleons, electrons, and photons.
- **1948**: Alpher and Gamow publish the famous "α–β–γ" paper (with Hans Bethe's name added as a pun). They predict the formation of light elements (hydrogen, helium) in the hot early universe.
- Alpher & Herman also predict the existence of a **cosmic background radiation** at a few kelvins, the cooled remnant of the hot early stage.

1950s – Competing with Steady State theory

- **Fred Hoyle, Hermann Bondi, and Thomas Gold** propose the **Steady State model** (1948): the universe has no beginning, matter is continuously created as it expands.
- Fred Hoyle mockingly coins the term **"Big Bang"** in a 1949 BBC radio broadcast.
- Through the 1950s, many astronomers preferred steady state, since it avoided a cosmic beginning and seemed more philosophically satisfying.

debate:
big bang vs estático

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George G ... emaître's
idea in ph

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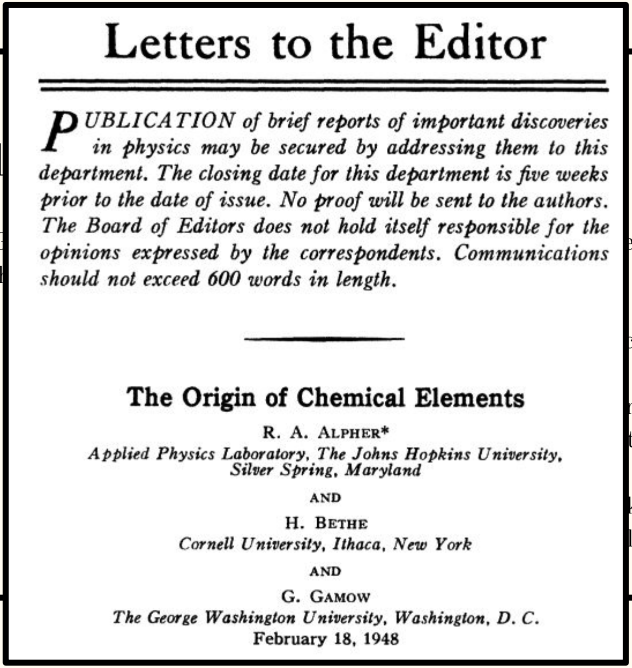
- ... **kground** ... ly stage.



Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length.

The Origin of Chemical Elements

R. A. Alpher*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

AND

H. Bethe
Cornell University, Ithaca, New York

AND

G. Gamow
The George Washington University, Washington, D. C.

February 18, 1948

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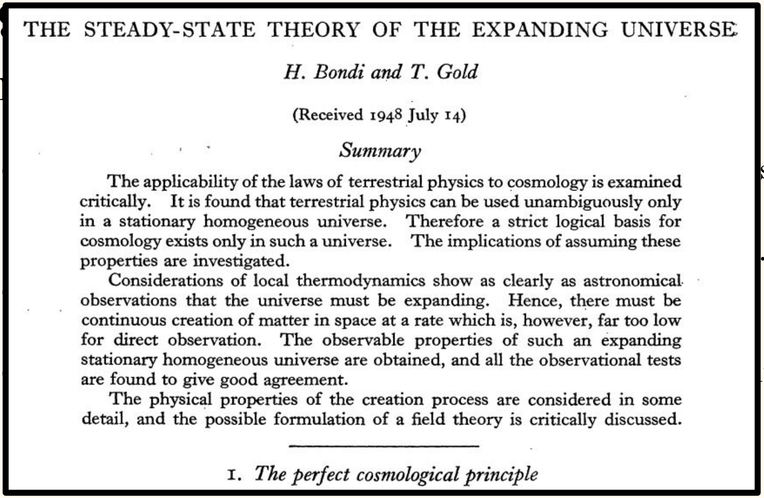


THE STEADY-STATE THEORY OF THE EXPANDING UNIVERSE

H. Bondi and T. Gold

(Received 1948 July 14)

Summary

The applicability of the laws of terrestrial physics to cosmology is examined critically. It is found that terrestrial physics can be used unambiguously only in a stationary homogeneous universe. Therefore a strict logical basis for cosmology exists only in such a universe. The implications of assuming these properties are investigated.

Considerations of local thermodynamics show as clearly as astronomical observations that the universe must be expanding. Hence, there must be continuous creation of matter in space at a rate which is, however, far too low for direct observation. The observable properties of such an expanding stationary homogeneous universe are obtained, and all the observational tests are found to give good agreement.

The physical properties of the creation process are considered in some detail, and the possible formulation of a field theory is critically discussed.

1. *The perfect cosmological principle*

universo estático

1. *The perfect cosmological principle*

1.1. The unrestricted repeatability of all experiments is the fundamental axiom of physical science. This implies that the outcome of an experiment is not affected by the position and the time at which it is carried out. A system of cosmology must be principally concerned with this fundamental assumption and, in turn, a suitable cosmology is required for its justification. In laboratory physics we have become accustomed to distinguish between conditions which can be varied at will and the inherent laws which are immutable.

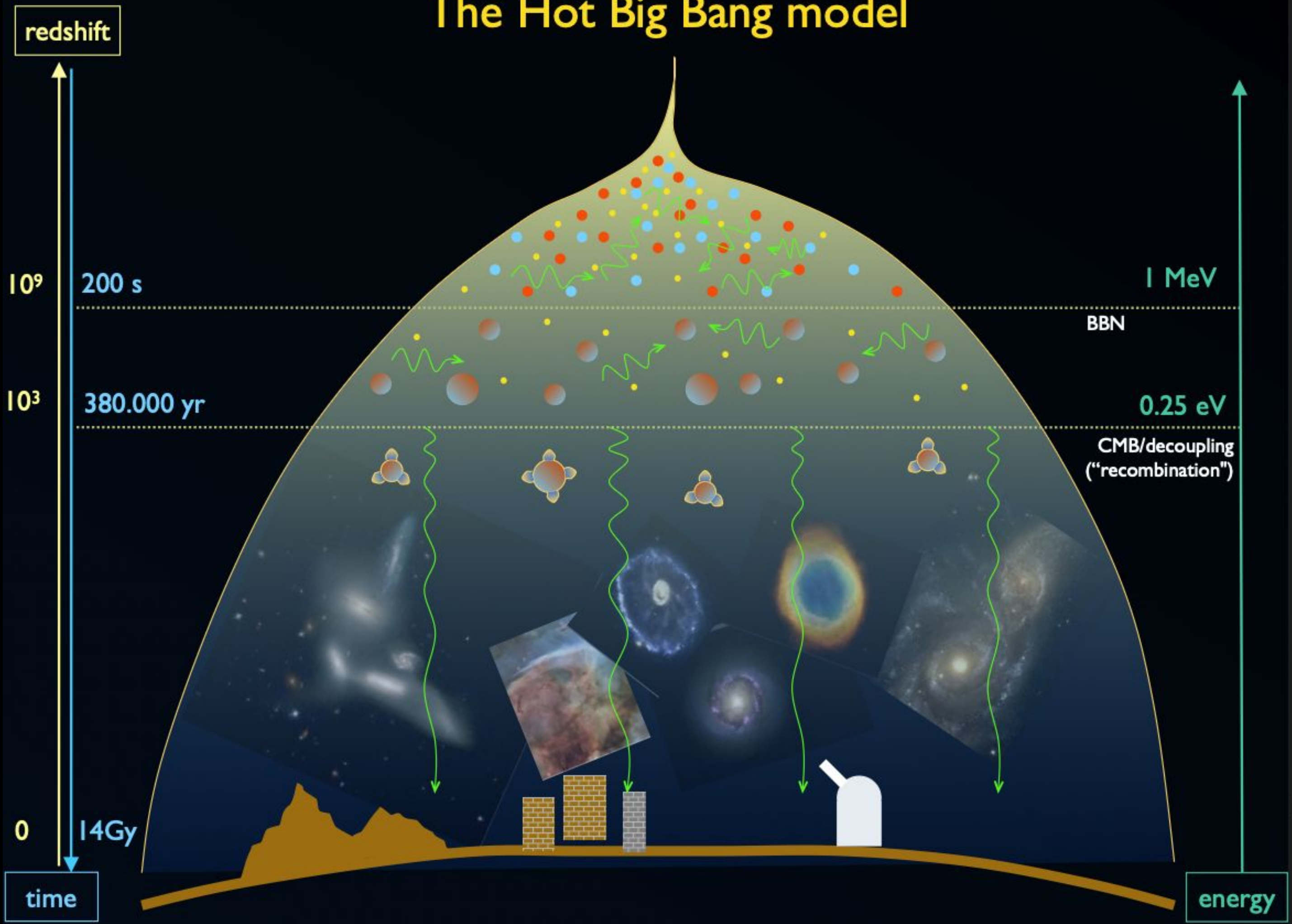
We do not claim that this principle must be true, but we say that if it does not hold, one's choice of the variability of the physical laws becomes so wide that cosmology is no longer a science. One can then no longer use laboratory physics without relying on some arbitrary principle for their extrapolation.

But if the perfect cosmological principle is satisfied in our universe then we can base ourselves confidently on the permanent validity of all our experiments and observations and explore the consequences of the principle. Unless and until any

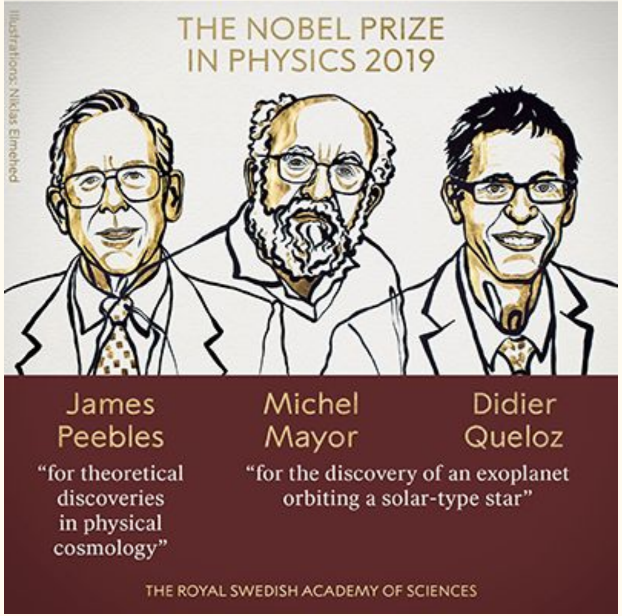
https://academic.oup.com/mnras/article/108/3/252/2603423?login=false

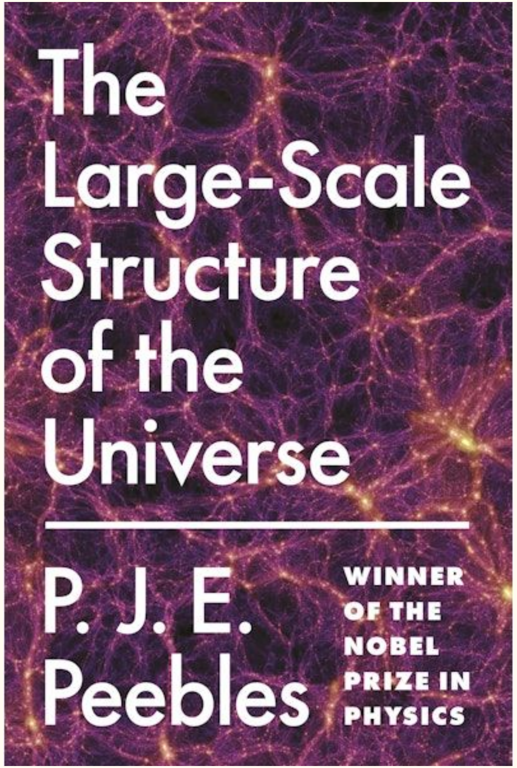
medida acidental da RCF

The Hot Big Bang model

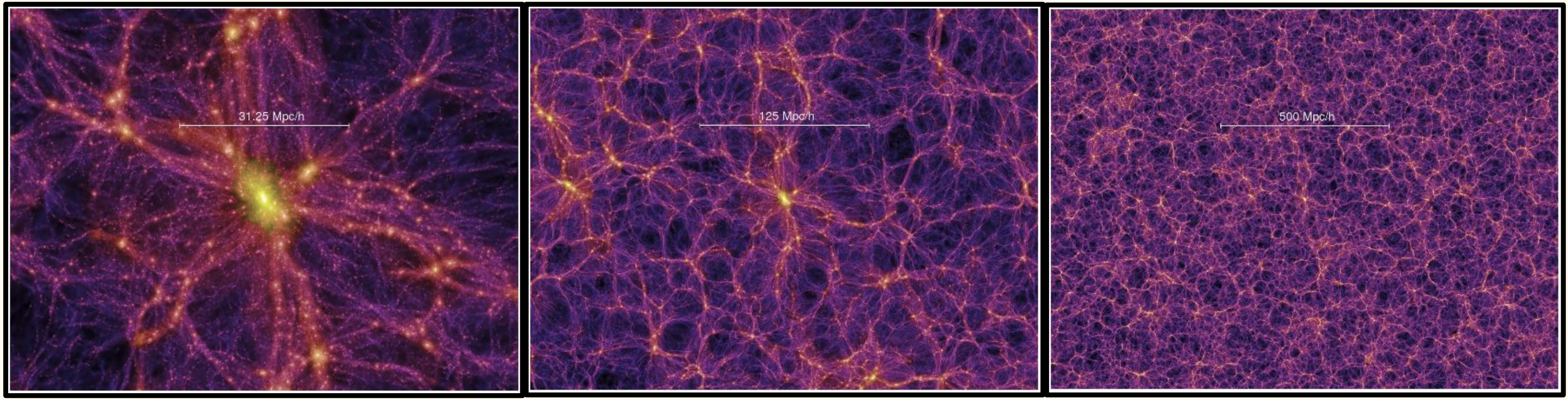


Peebles e as funções de correlação





hipótese de amostras honestas



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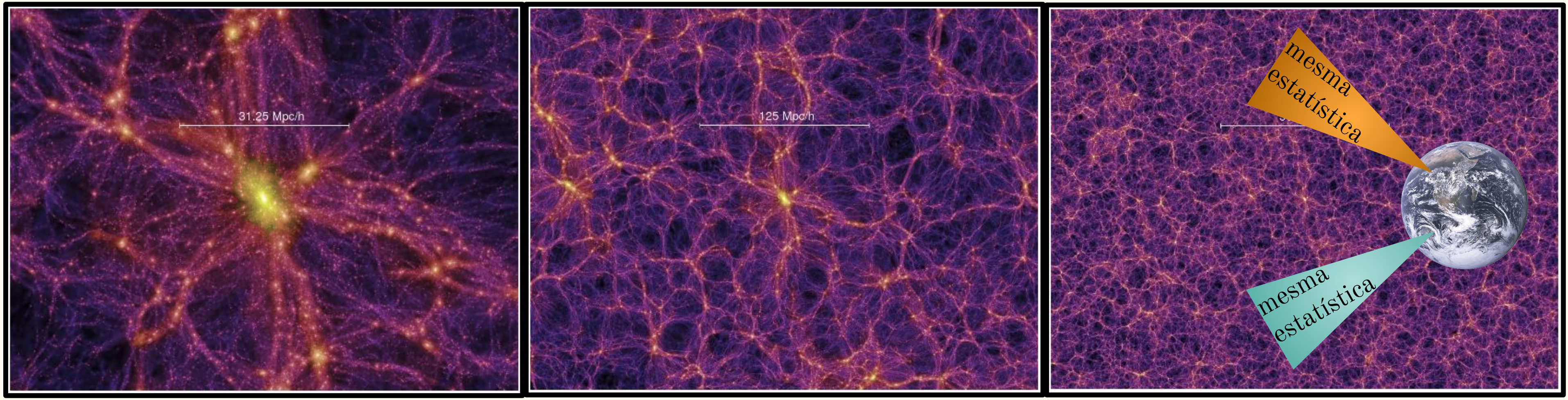
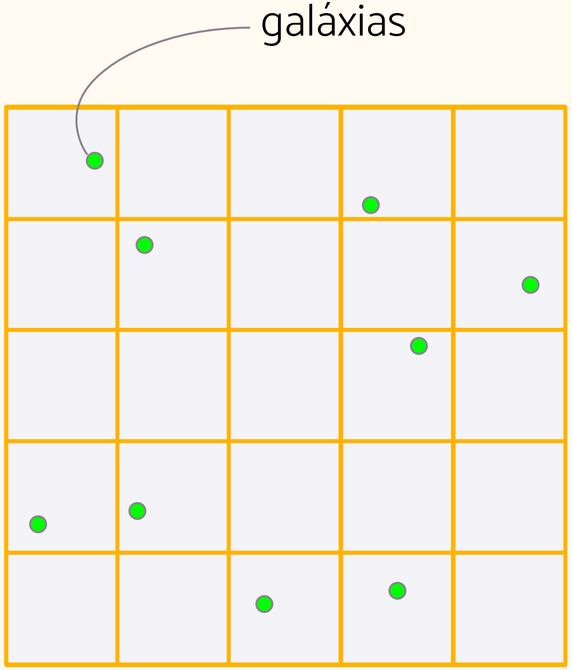
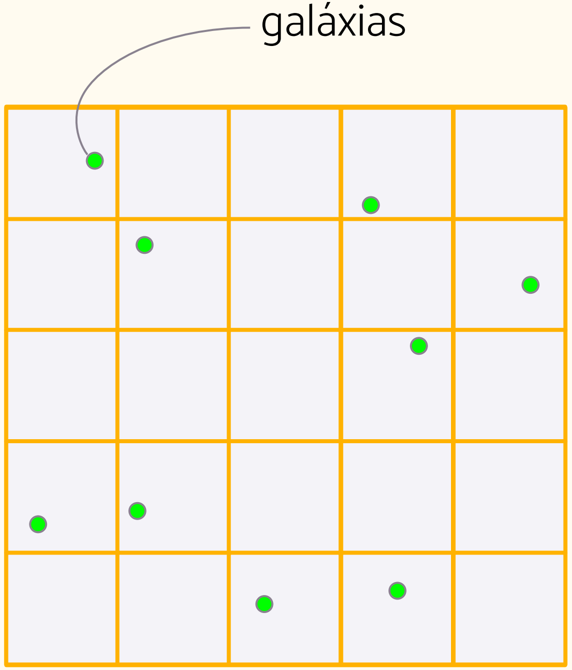
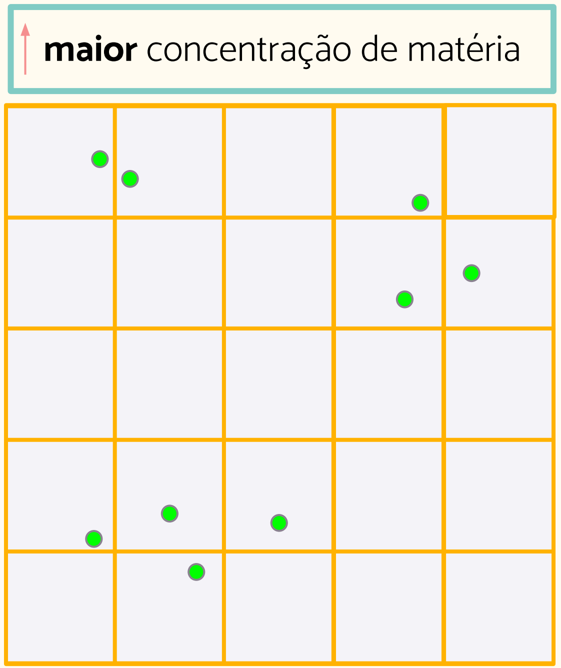


expansão e posições

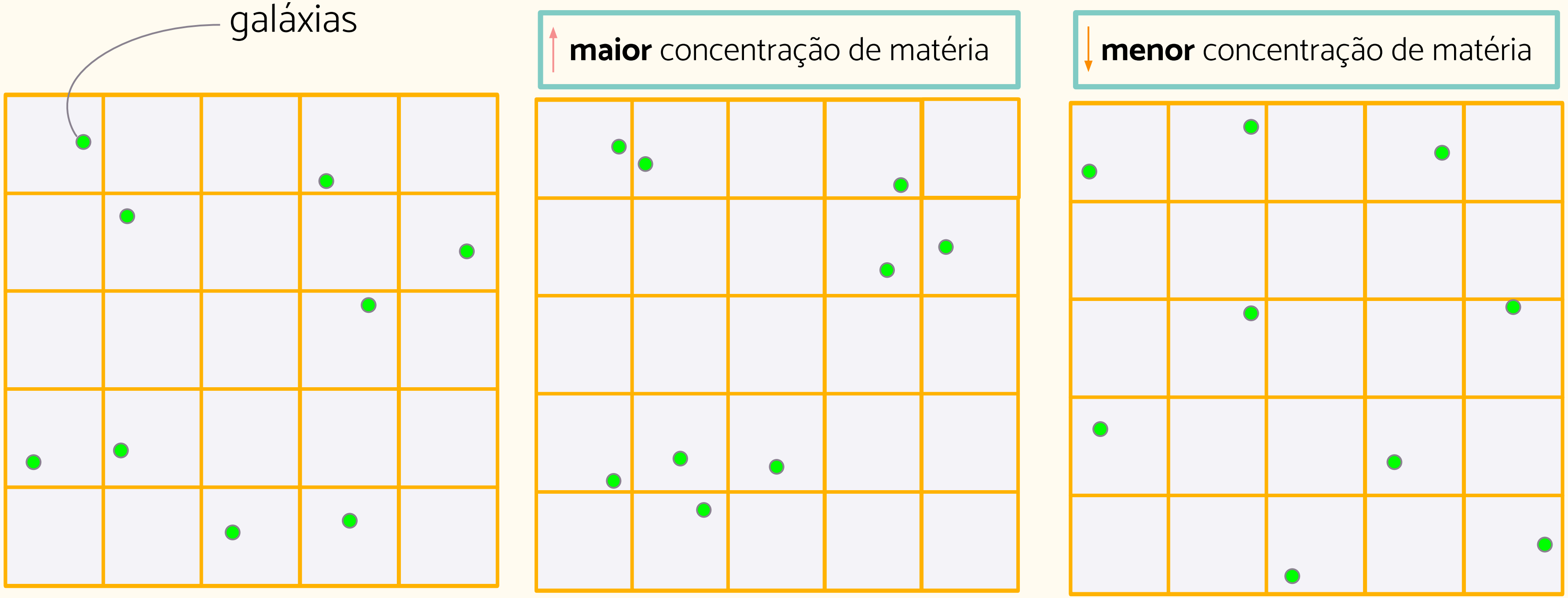


expansão e posições





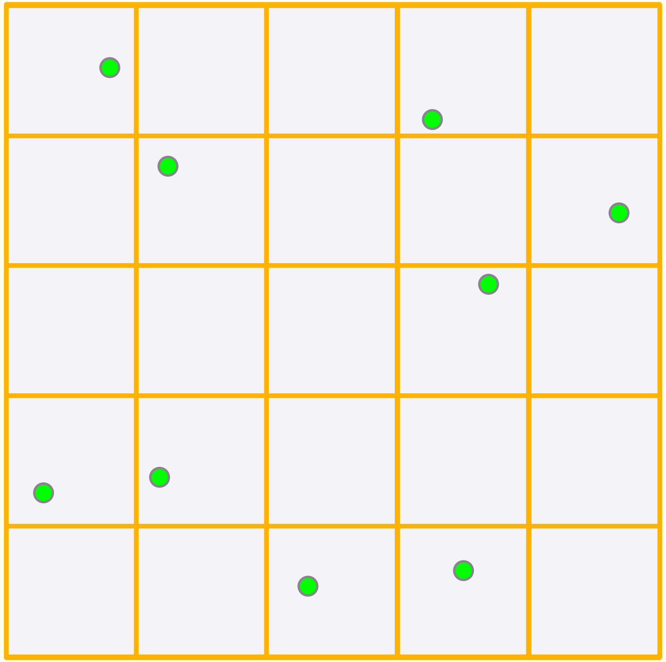
expansão e posições



função de correlação de 2pt

A probabilidade de encontrarmos uma galáxia em uma unidade de volume é

$$P = \bar{n}\delta V$$



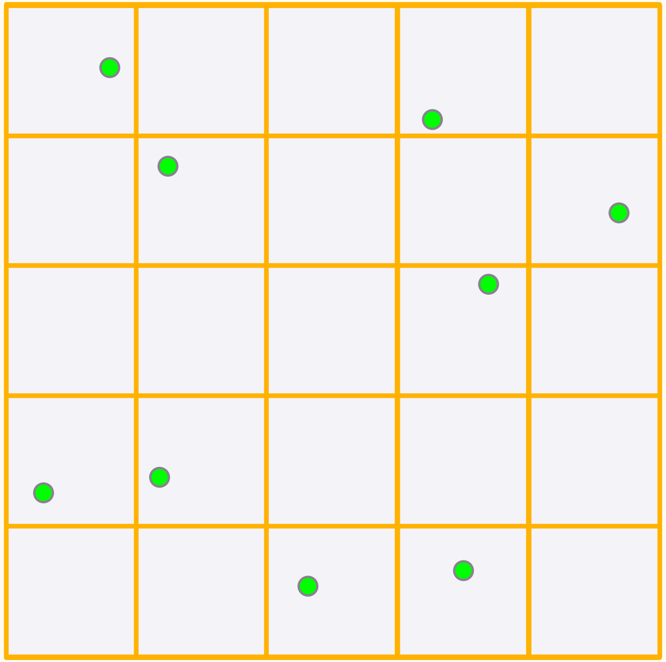
função de correlação de 2pt

A probabilidade de encontrarmos uma galáxia em uma unidade de volume é

$$P = \bar{n}\delta V$$

Se a distribuição for de Poisson, a probabilidade de sortearmos dois volumes a uma distância $r_{12} = |\vec{r_2} - \vec{r_1}|$ e encontrarmos duas galáxias é

$$P_{12} = \bar{n}^2 \delta V_1 \delta V_2$$



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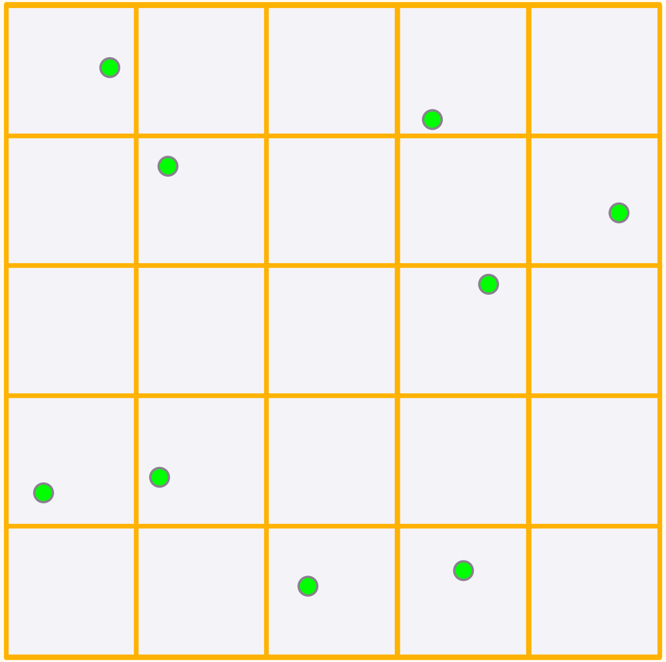
$$P_{12} = \bar{n}^2 \delta V_1 \delta V_2$$

Se o campo não for de Poisson, o **excesso de probabilidade** é definido como a **função de correlação de 2 pontos** $\xi(r_{12})$

$$P_{12} = \bar{n}^2 \delta V_1 \delta V_2 (1 + \xi(r_{12}))$$



função de correlação de 2pt

Essa mesma função de correlação é usada num caso parecido, com diferença sutil. A probabilidade condicionada de encontrar uma galáxia num volume δV_2 dado que exista uma galáxia no volume δV_1 é

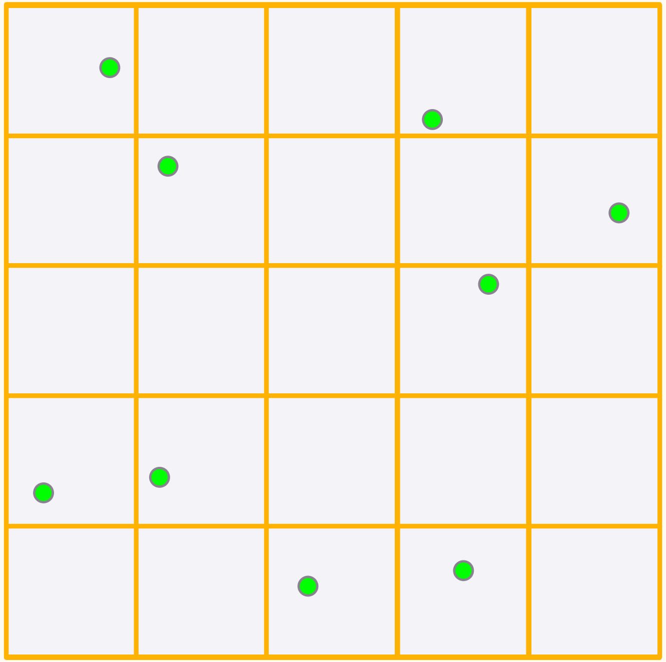
$$\delta P(2|1) = \bar{n}\delta V_2(1 + \xi(r_{12})) \tag{3.2.5}$$

ou, colocando a mesma questão de outra maneira, a probabilidade de uma galáxia escolhida aleatoriamente tenha uma vizinha a uma distância r no volume δV é de

$$\delta P = \bar{n}\delta V(1 + \xi(r)). \tag{3.2.6}$$

Para saber qual é a quantidade média de galáxias vizinhas a uma distância r, basta integrar no volume desejado. Se esta expressão convergir, pode-se estimar o número médio de galáxias em um aglomerado, por exemplo.

$$\langle N \rangle = \frac{4}{3}\pi r^3 \bar{n} + \bar{n}\int_0^r \xi(r)dV. \tag{3.2.7}$$



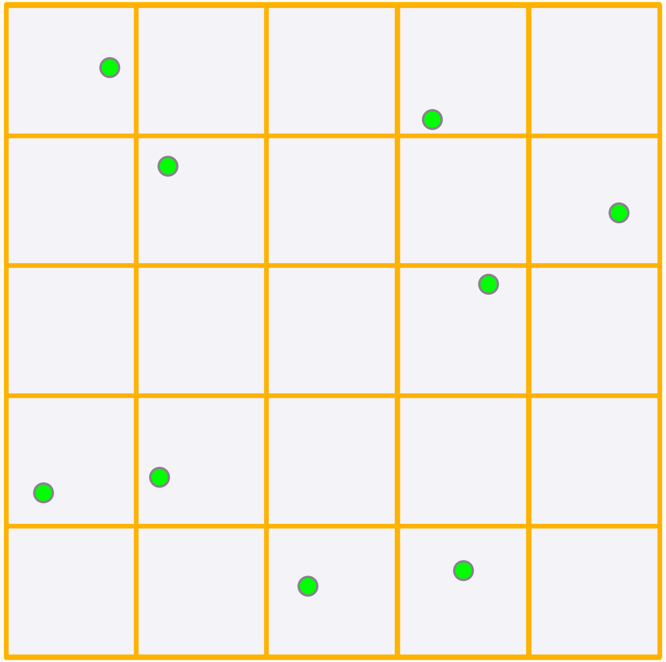
função de correlação de 2pt

O excesso de probabilidade $\xi(r)$ que aparece na equação (3.2.6) pode ser entendido como a covariância do campo de contraste de densidade de galáxias. Para ver isso, se o número de galáxias dentro de um volume δV_1 for escrito como a densidade numérica média mais uma sobredensidade $n_1 = \bar{n}(1+\delta_1)$, então, similarmente ao que foi feito na equação 3.2.4, a probabilidade de encontrarmos uma galáxia em δV_1 e outra em um volume δV_2 a uma distância r_{12} é de

$$\begin{aligned} \delta P_{12} &= (n_1 \delta V_1)(n_2 \delta V_2) \\ &= \bar{n}^2 \delta V_1 \delta V_2 (1+\delta_1)(1+\delta_2). \end{aligned} \tag{3.2.8}$$

Assim, se tirarmos a média de todos os pares de volume infinitesimal a uma distância r_{12} obtemos a probabilidade de encontrarmos duas galáxias quaisquer a uma distância r_{12} uma da outra

$$\begin{aligned} \langle \delta P(r_{12}) \rangle &= \bar{n}^2 \delta V_1 \delta V_2 \langle 1+\delta_1+\delta_2+\delta_1\delta_2 \rangle \\ &= \bar{n}^2 \delta V_1 \delta V_2 (1+\langle \delta_1 \delta_2 \rangle), \end{aligned} \tag{3.2.9}$$



função de correlação de 2pt

$$\xi(r) = \langle \delta(x+r)\delta(x) \rangle - \langle \delta(x+r) \rangle \langle \delta(x) \rangle$$
$$= \langle \delta(x+r)\delta(x) \rangle.$$

caracteriza as “não-aleatoriedades”

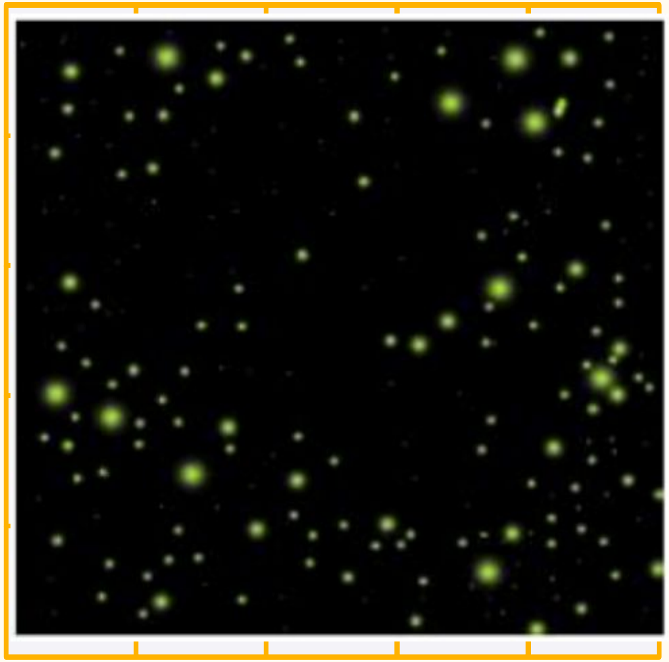
mesmas “não-aleatoriedades” do universo primordial

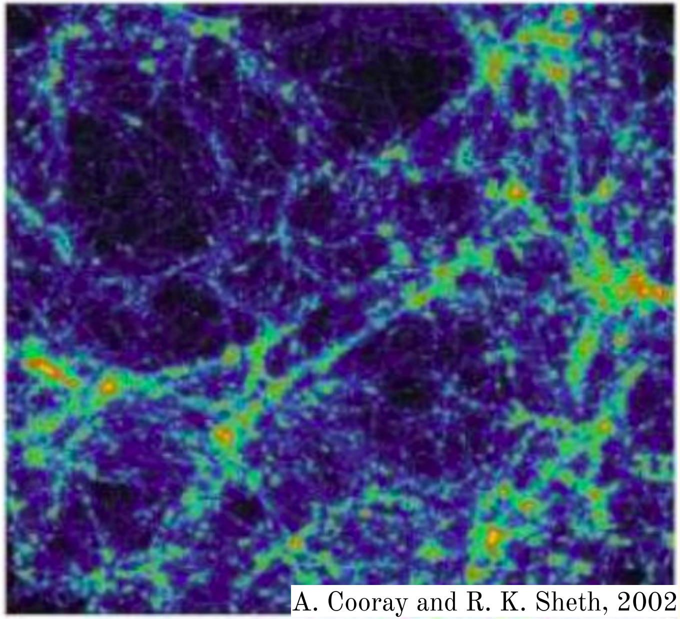
6 parâmetros do modelo ΛCDM

$H_0, \Omega_{CDM}, \Omega_b, \Omega_r$

A_s, n_s

campo de galáxias



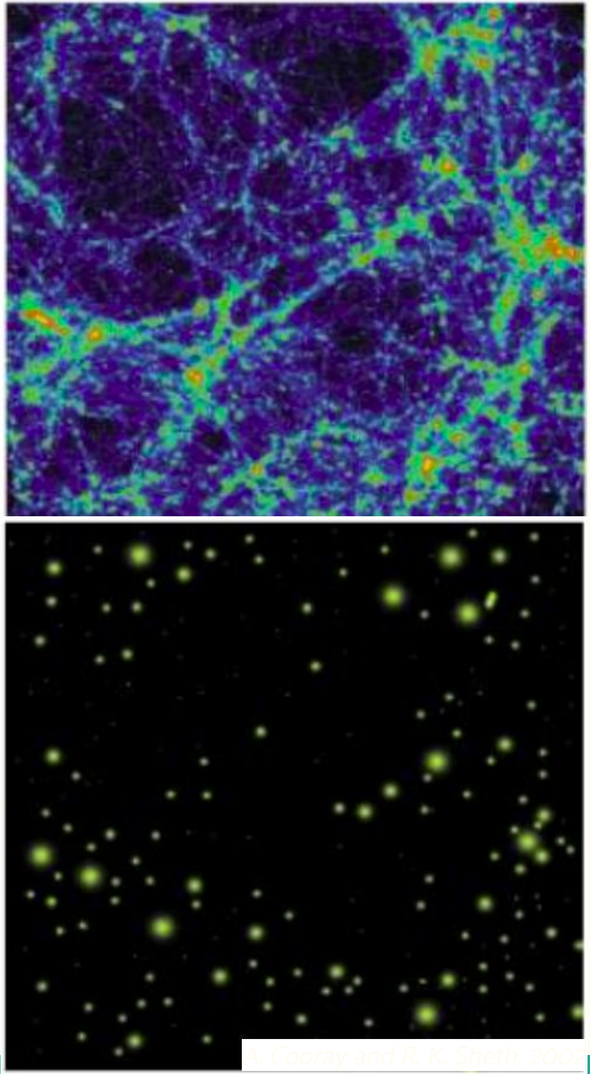


A. Cooray and R. K. Sheth, 2002

campo de galáxias

O campo de matéria pode ser definido pelo **contraste de densidade**

$$\delta(\vec{x}) \equiv \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}}$$



campo de galáxias

O campo de matéria pode ser definido pelo **contraste de densidade**

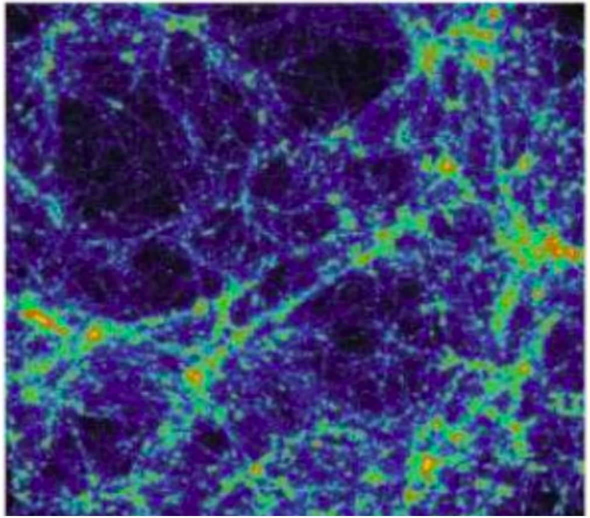
$$\delta(\vec{x}) \equiv \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}}$$

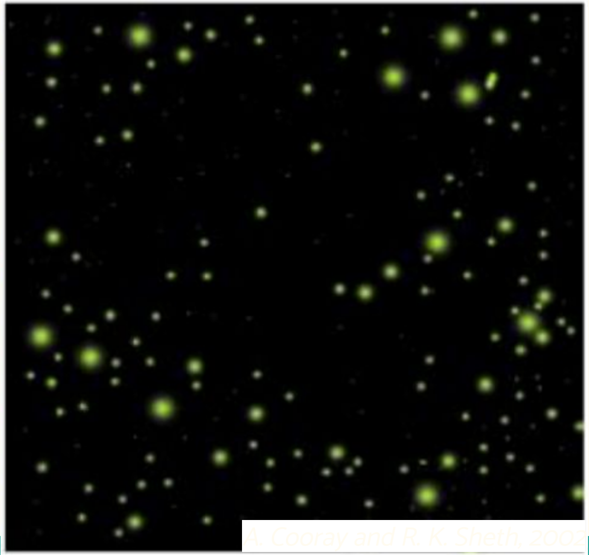
E o campo de galáxias por um contraste de densidade discreto

$$\delta_g^i \equiv \frac{n_i - \bar{n}}{\bar{n}}$$

O **viés de galáxia** conecta esses dois contrastes

$$\delta_g = b(z)\delta$$





A. Cooray and R. K. Sheth, 2002

transformada de Fourier

espectro de potência da matéria

A função de correlação do campo de galáxias é

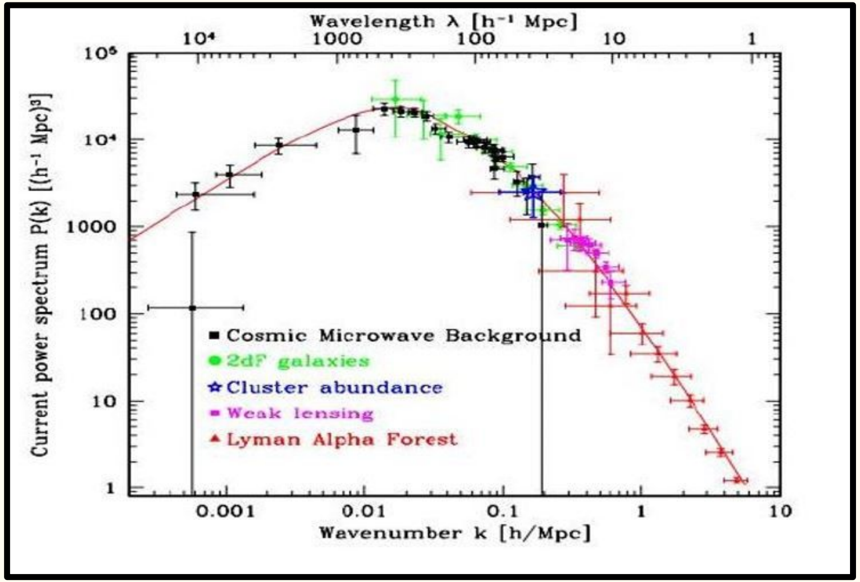
$$\xi_{gg}(r) = \langle \delta_g(\vec{x} + \vec{r})\delta_g(\vec{r}) \rangle$$

Aplicando a transformada de Fourier, obtemos o espectro de potência

$$\langle \delta_g(\vec{k})\delta_g^*(\vec{k}')\rangle = (2\pi)^3 \delta_D(\vec{k} - \vec{k}')P_{gg}(k)$$

Que se conecta ao espectro de potência da matéria total pelo viés de galáxia

$$P_{gg}(k) \longleftrightarrow P(k)$$



espectro de potência da matéria

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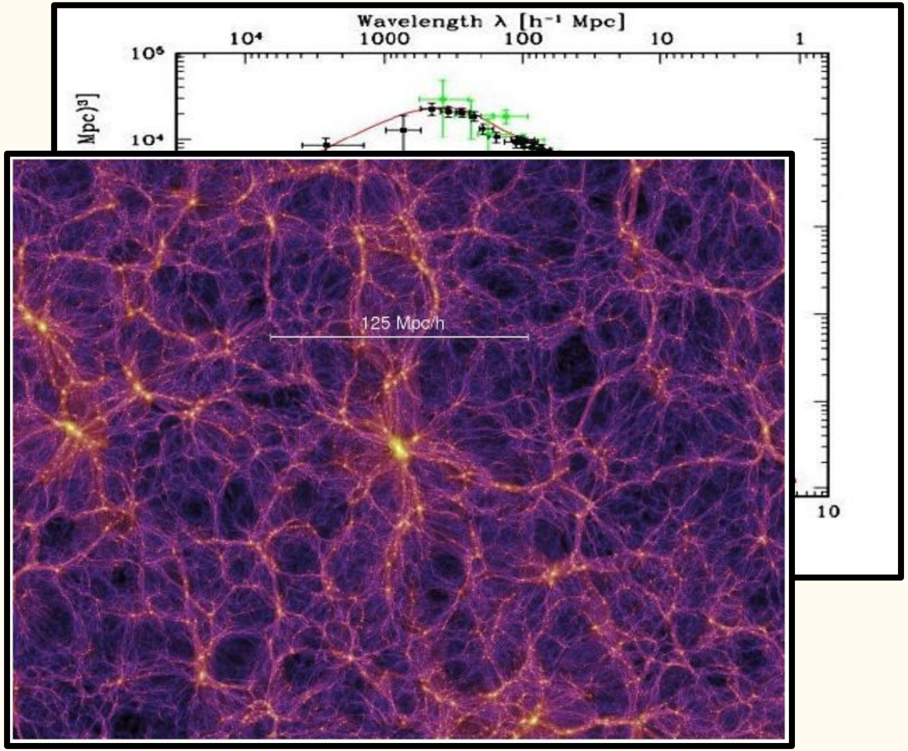


inferência de toda história do universo

STATISTICAL ANALYSIS OF CATALOGS OF EXTRAGALACTIC OBJECTS.
III. THE SHANE-WIRTANEN AND ZWICKY CATALOGS*

P. J. E. PEEBLES
Joseph Henry Laboratories, Physics Department, Princeton University

AND

M. G. HAUSER
Physics Department, California Institute of Technology

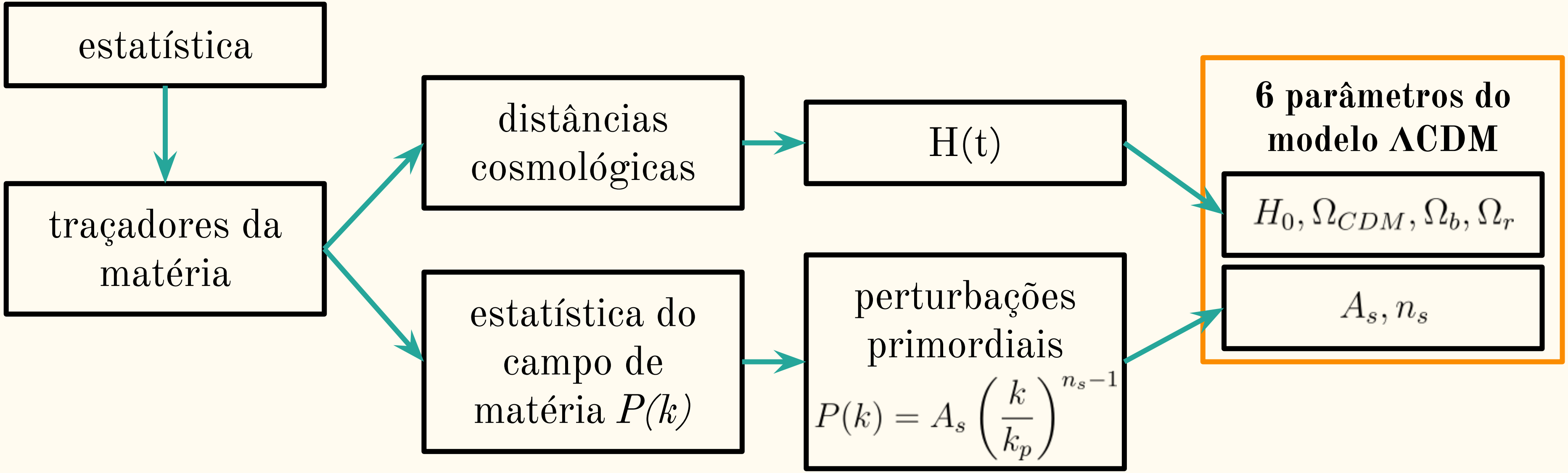
Received 1973 July 16

ABSTRACT

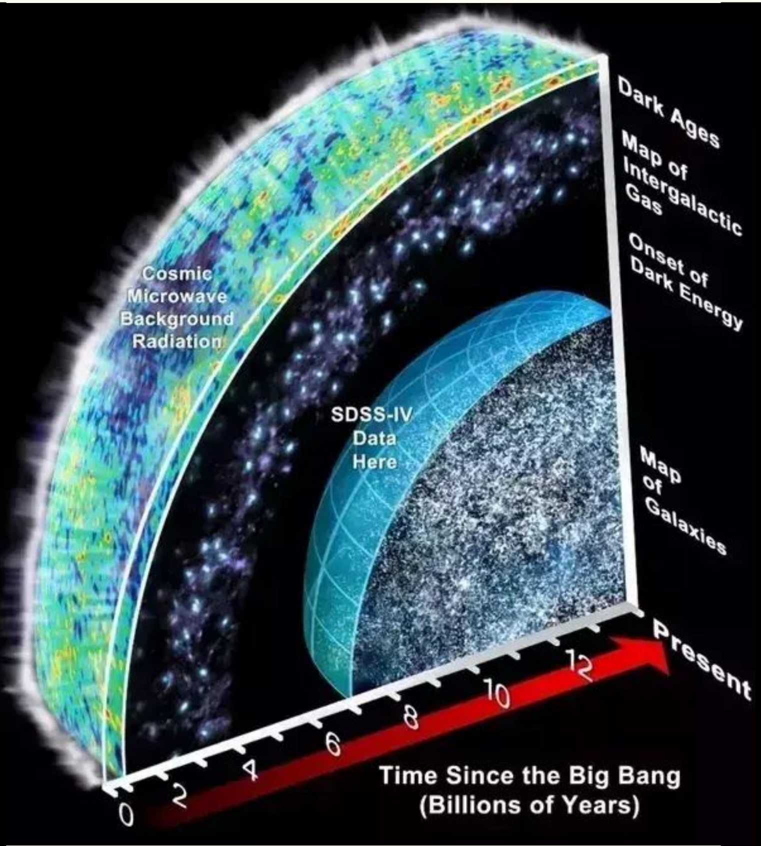
We present a statistical investigation of clustering in the galaxy catalogs compiled by Zwicky *et al*. and by Shane and Wirtanen. We estimate the covariance and power spectrum of the angular distributions. We find that the region of space surveyed in the Zwicky Catalog acts like a "fair sample of the Universe," in the sense that the statistical nature of the clustering revealed by this catalog is found mirrored at smaller angular scales in the deeper survey of Shane and Wirtanen. We find that the spatial correlation of galaxies as mapped in these surveys is quite small for separations greater than about $20h^{-1}$ Mpc (h = Hubble's constant in units of 100 km s^{-1} Mpc^{-1}). Although this estimate is uncertain because of the uncertainty in the galaxy luminosity function, the correlation length for galaxies seems to fall clearly below the corresponding quantity for the distribution of the rich clusters of galaxies.

Subject headings: galaxies, clusters of

inferência de toda história do universo



radiação cósmica de fundo



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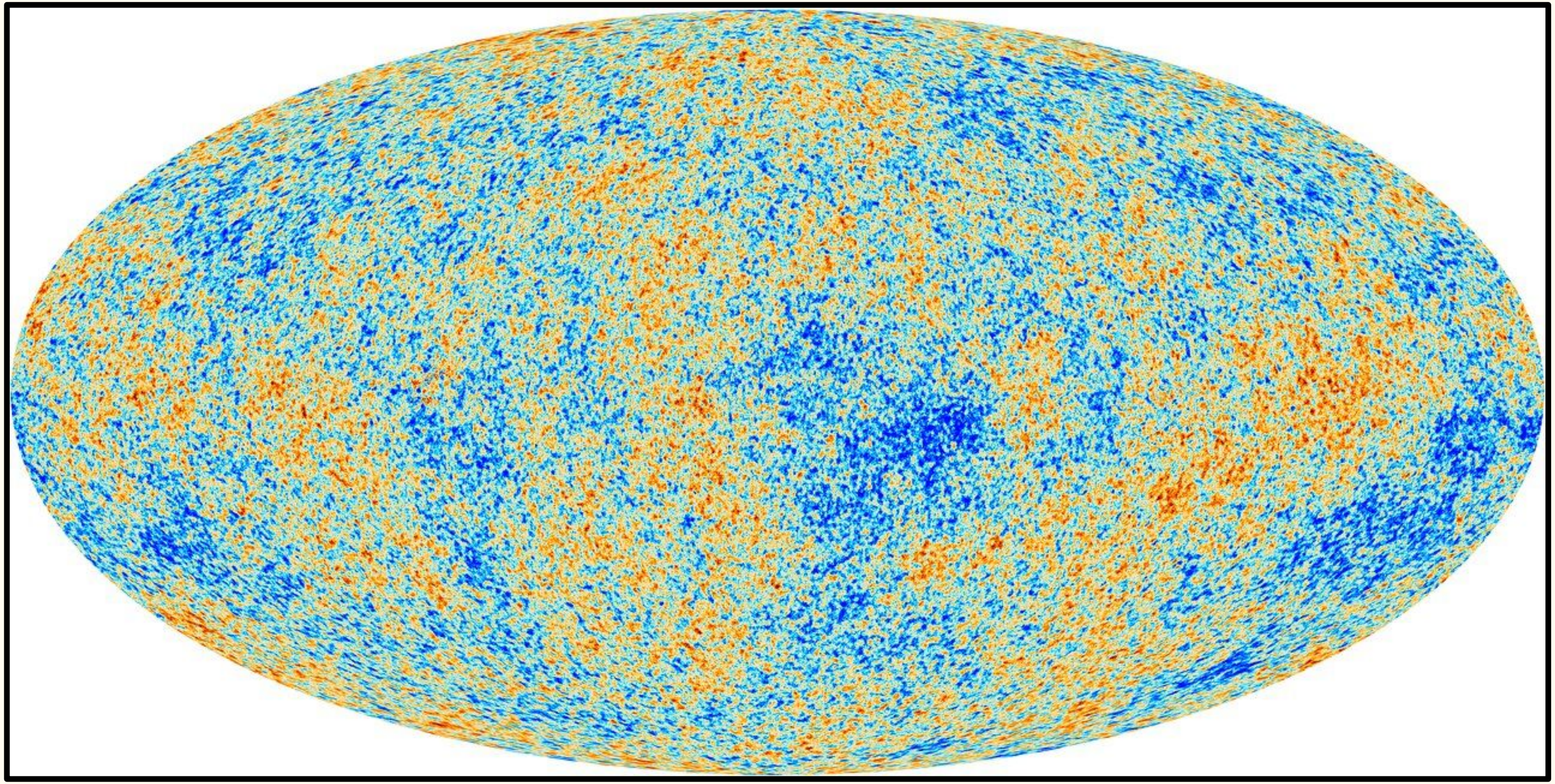
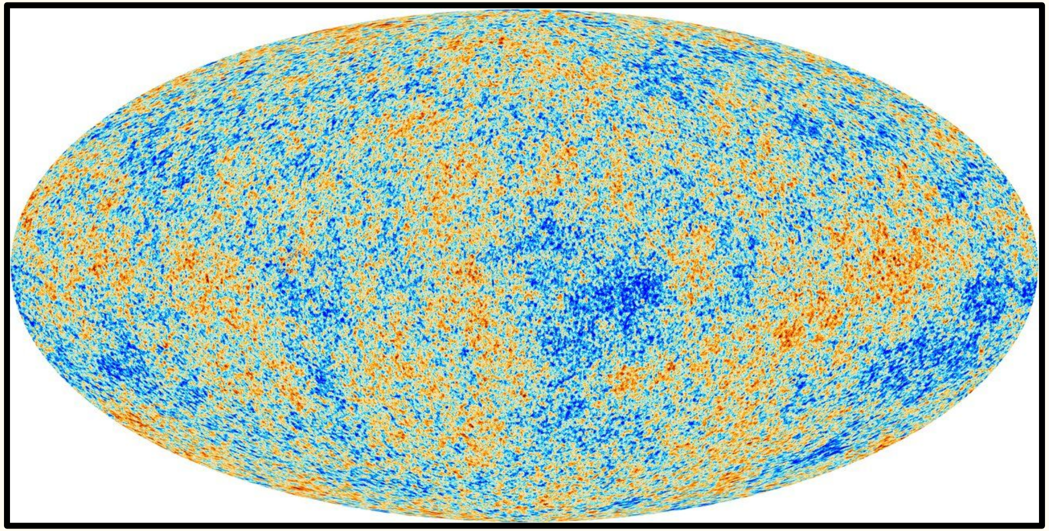
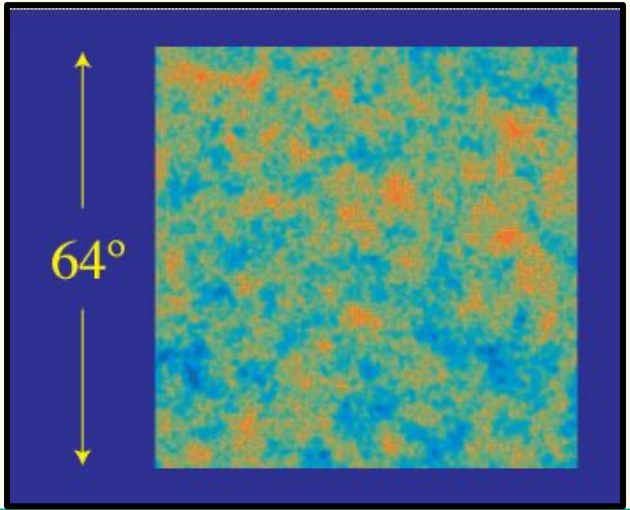
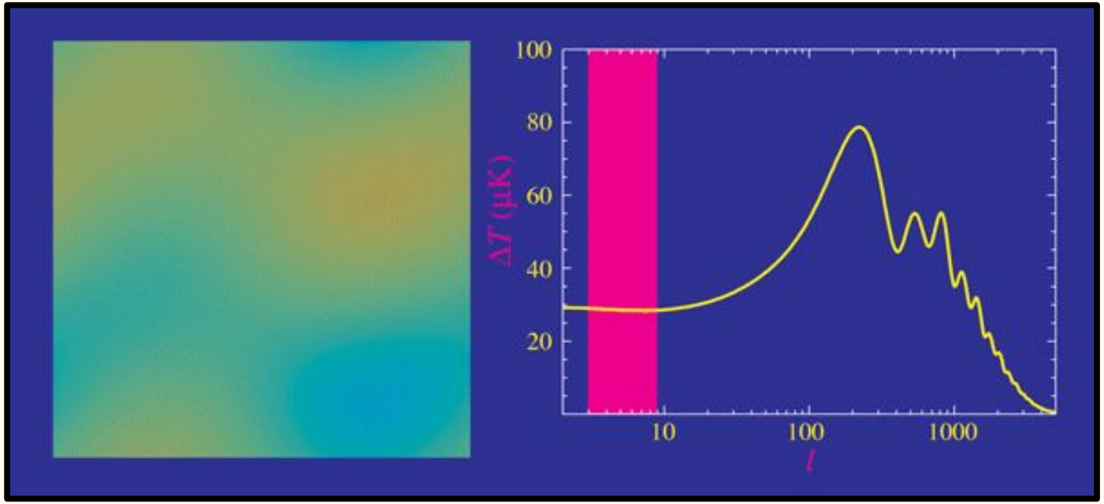
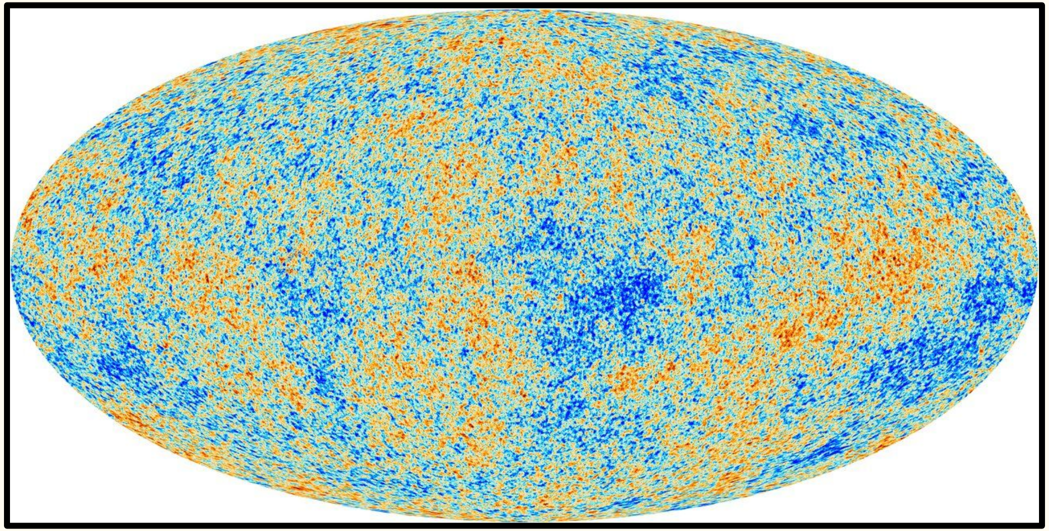
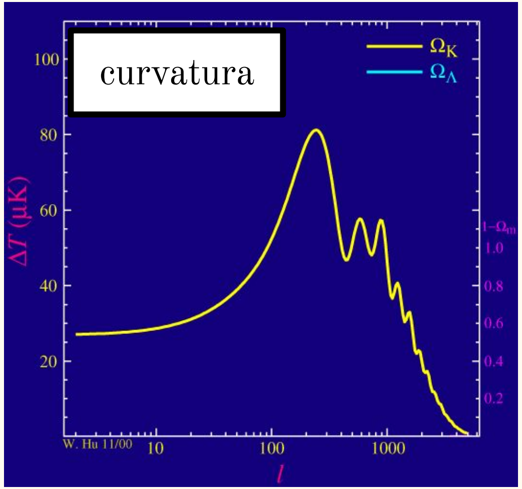


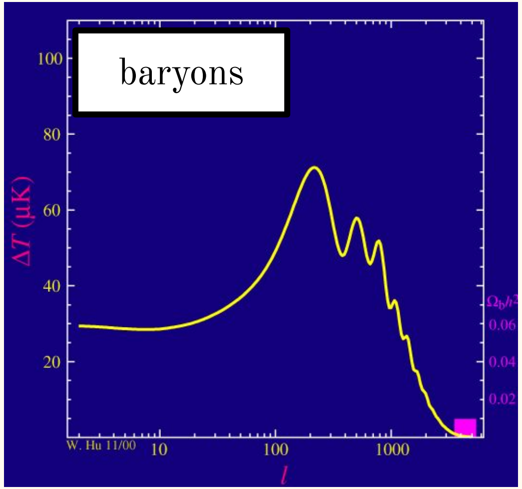



64°


100
80
60
40
20
ΔT (μK)
10
100
1000
l




curvatura
Ω_K
Ω_Λ
ΔT (μK)
$1-\Omega_m$
W. Hu 11/00
l


baryons
ΔT (μK)
$\Omega_b h^2$
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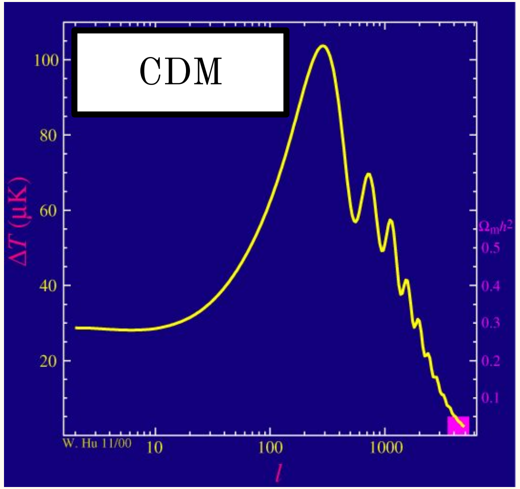
CDM
ΔT (μK)
$\Omega_m h^2$
W. Hu 11/00
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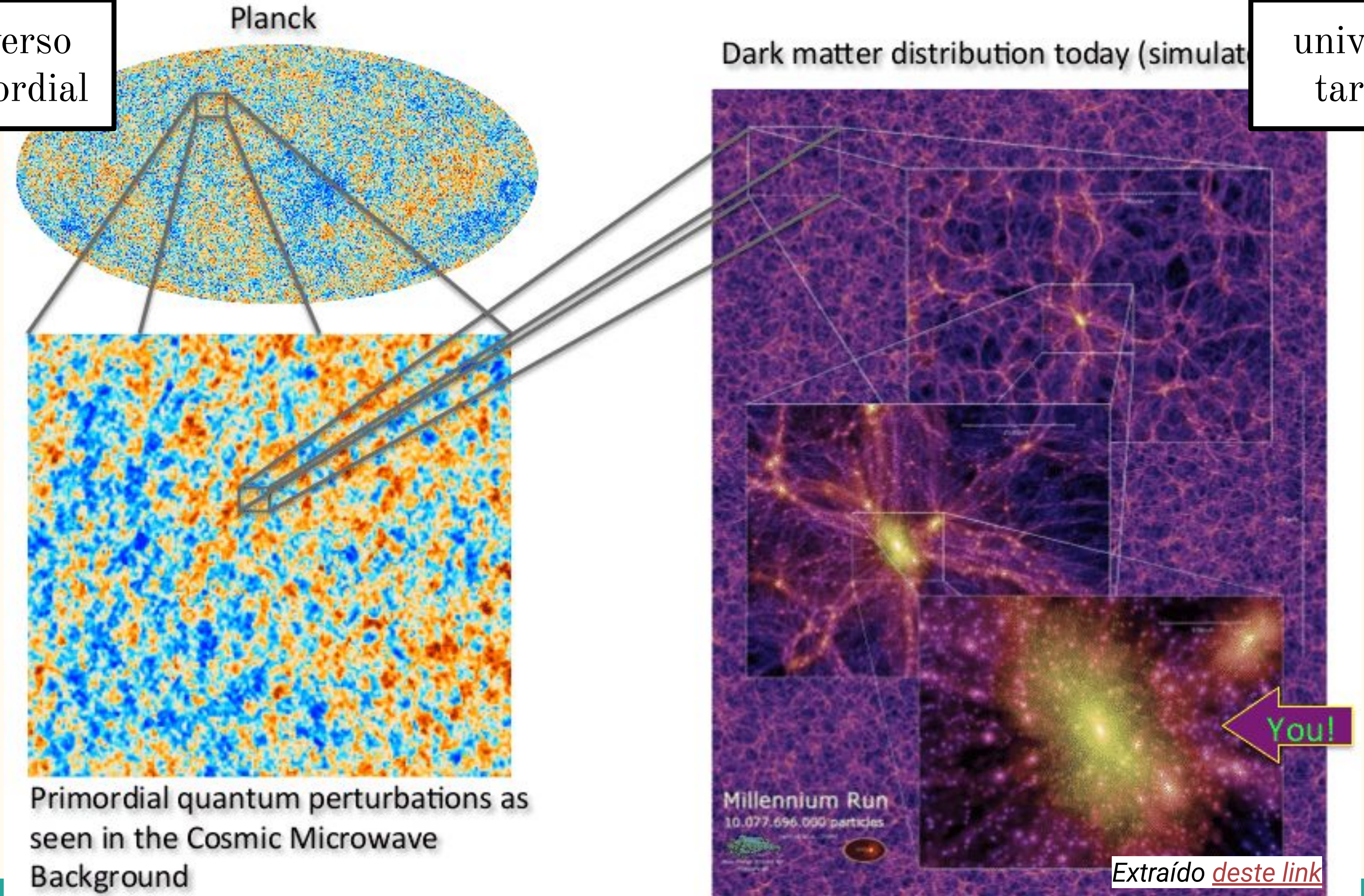
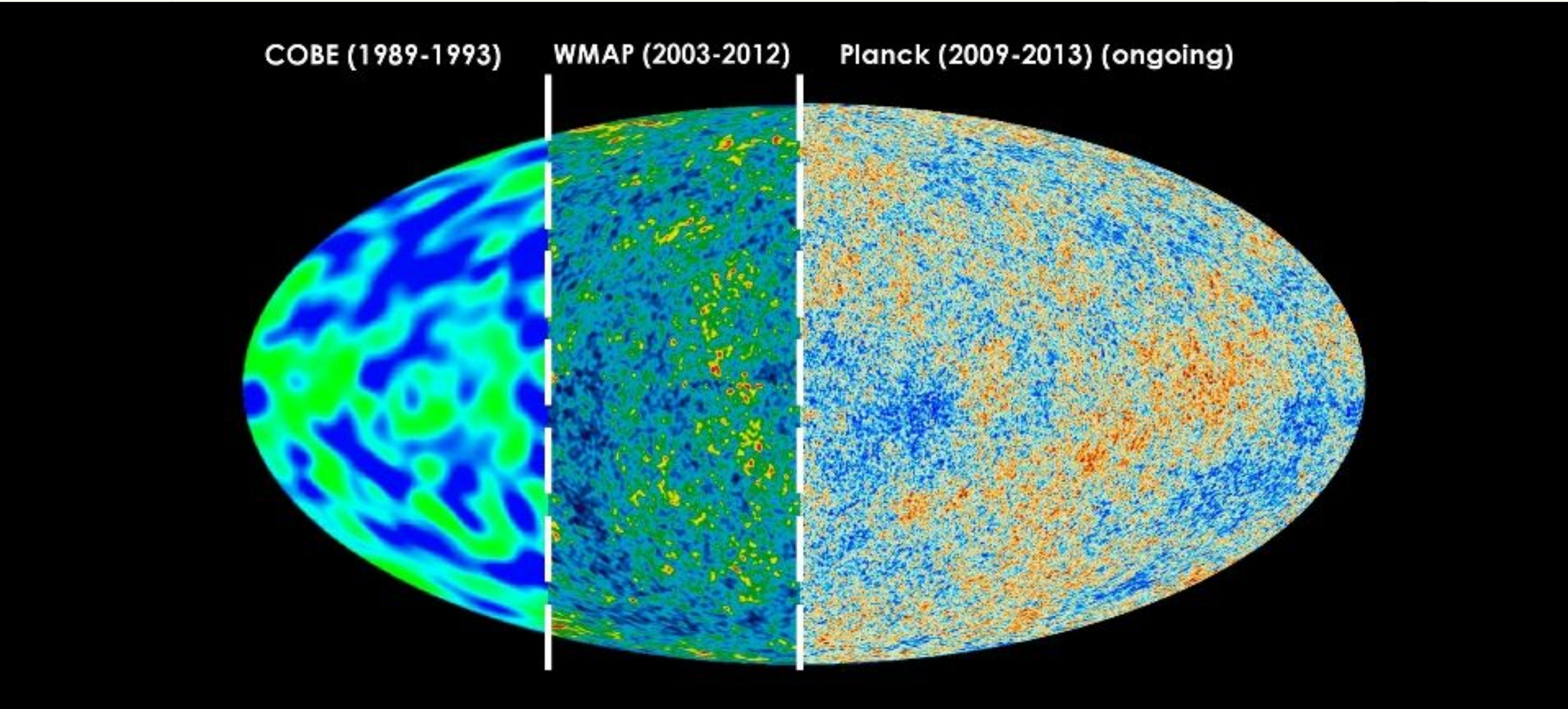
universo primordial

universo tardio

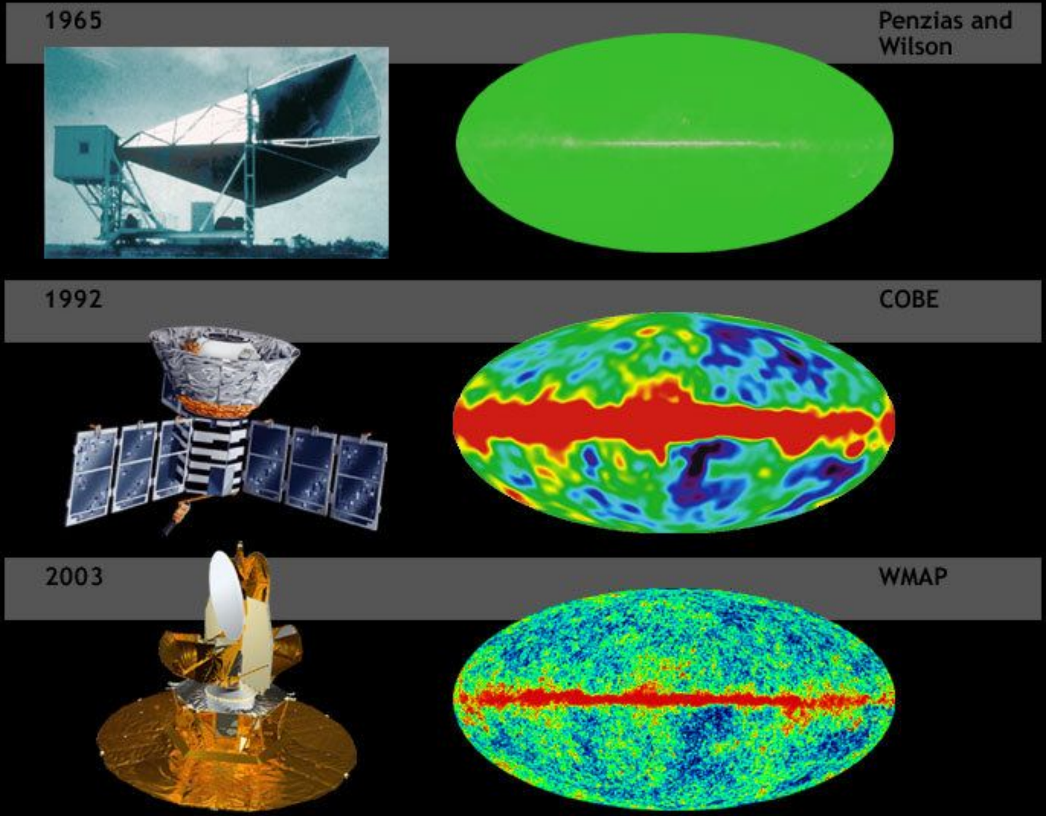


Extraído deste link

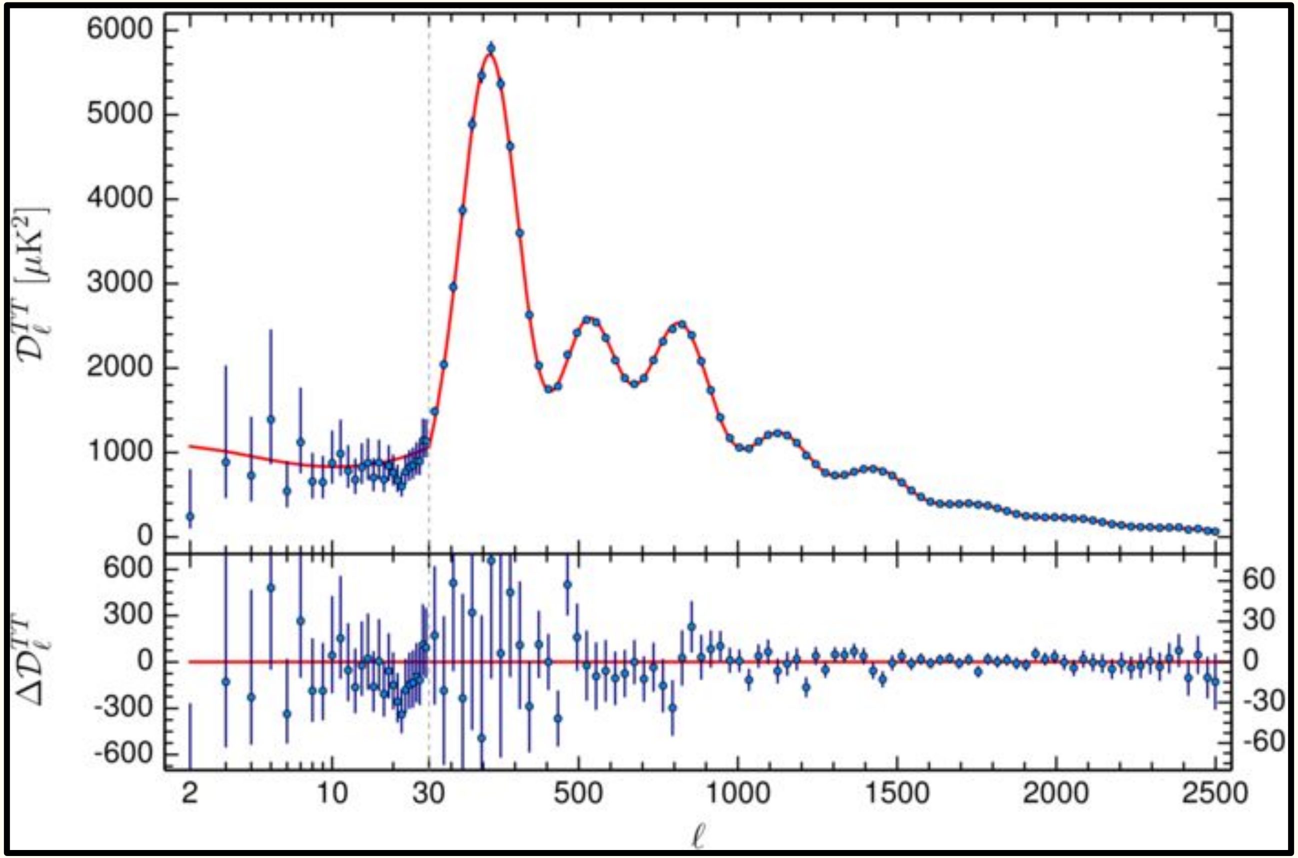
medida da RCF (ou CMB)



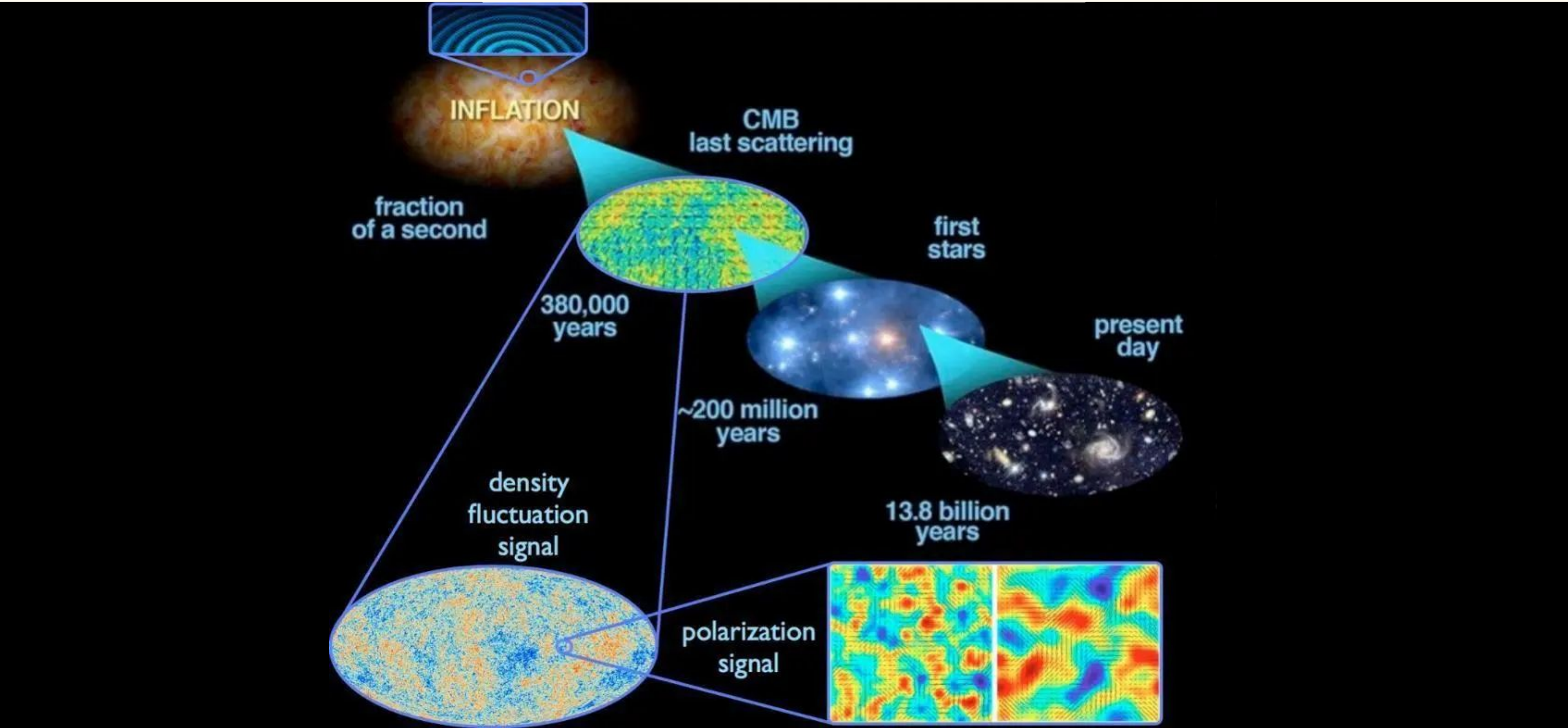
medida da RCF (ou CMB)



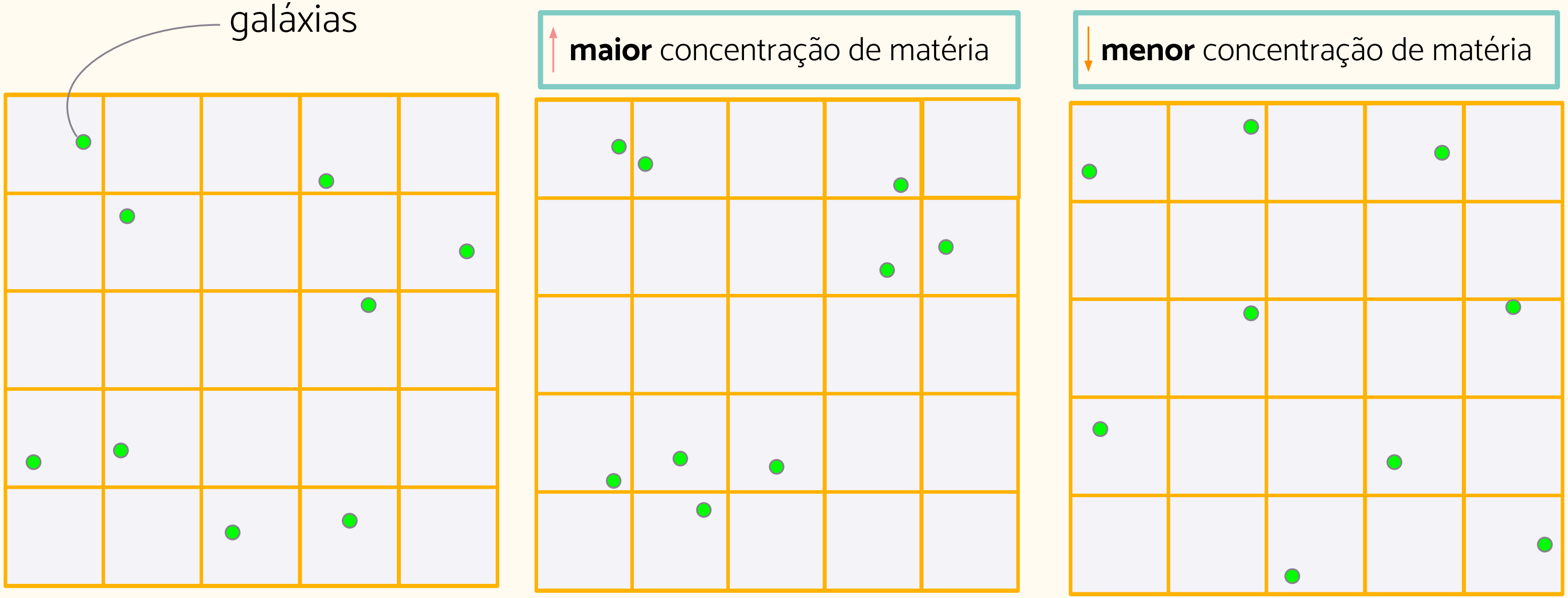
medida da RCF (ou CMB)



formação de estrutura



análise de 3x2pt



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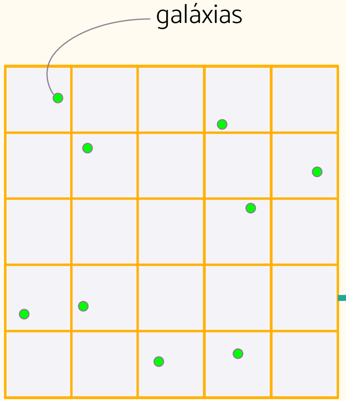
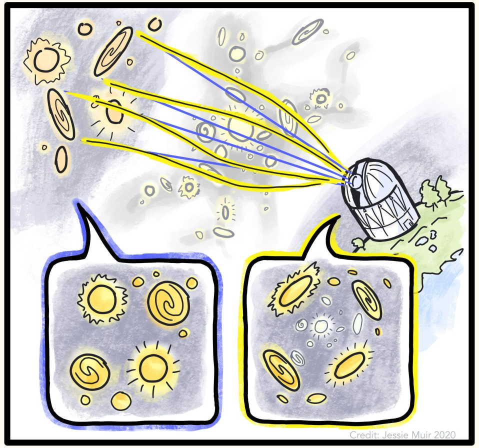
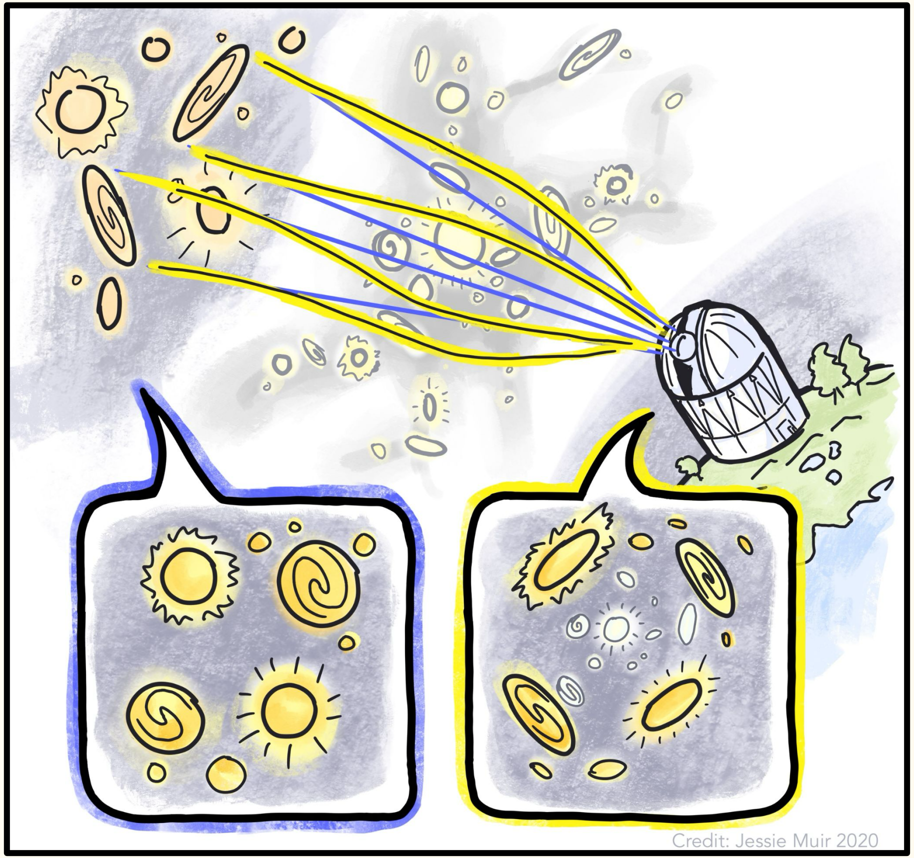


aglomeramento
de galáxias

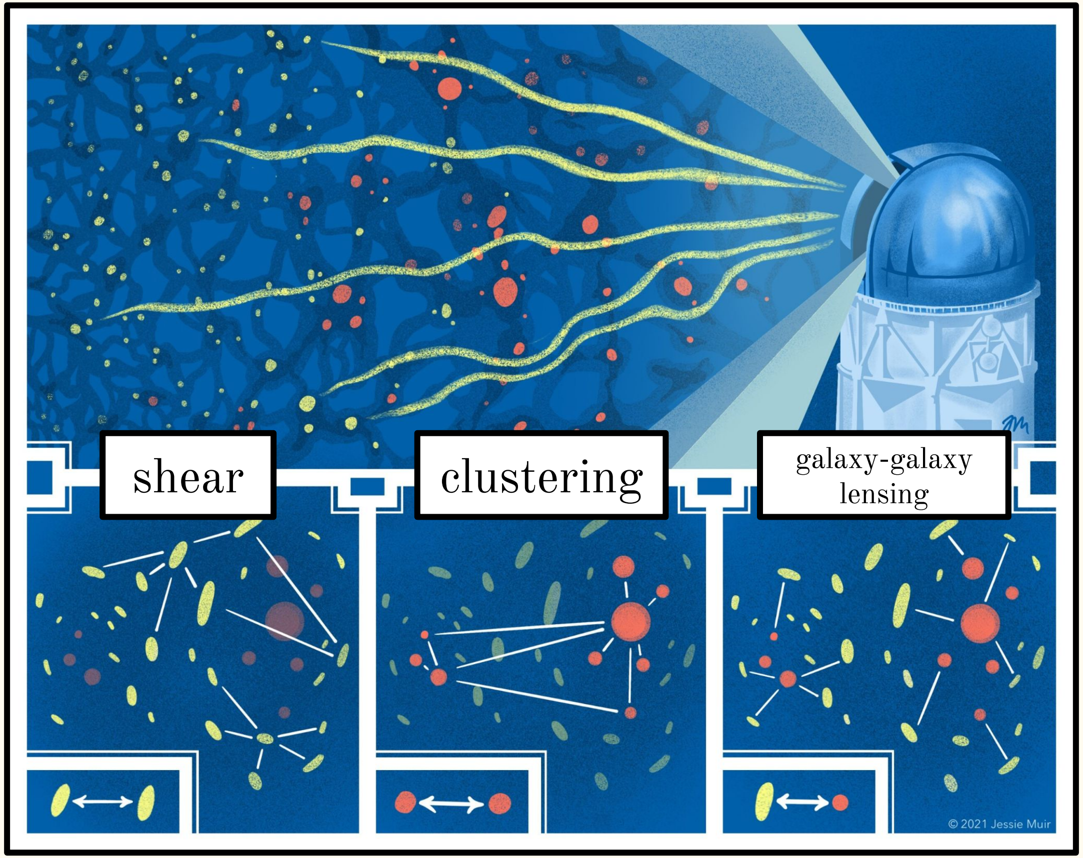
lenteamento
gravitacional



análise de 3x2pt



análise de 3x2pt



análise de 3x2pt

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

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Dark energy survey year 3 results: cosmology from galaxy clustering and galaxy–galaxy lensing in harmonic space

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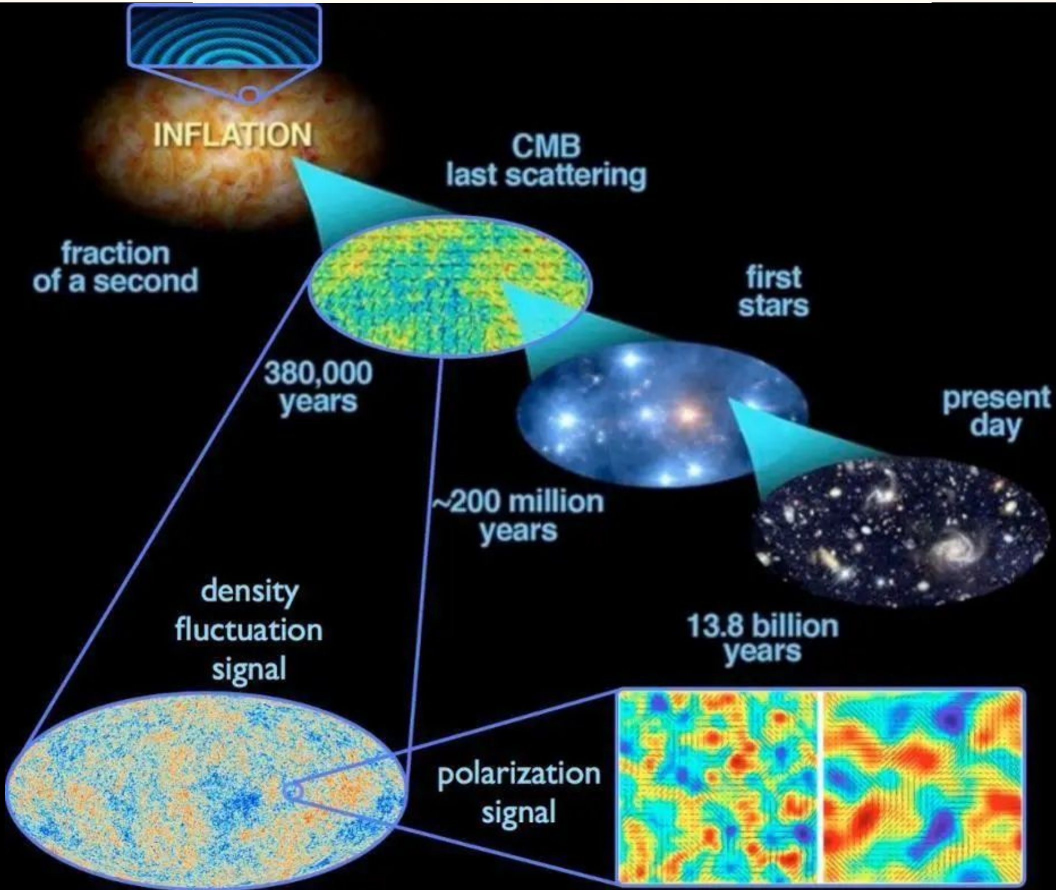
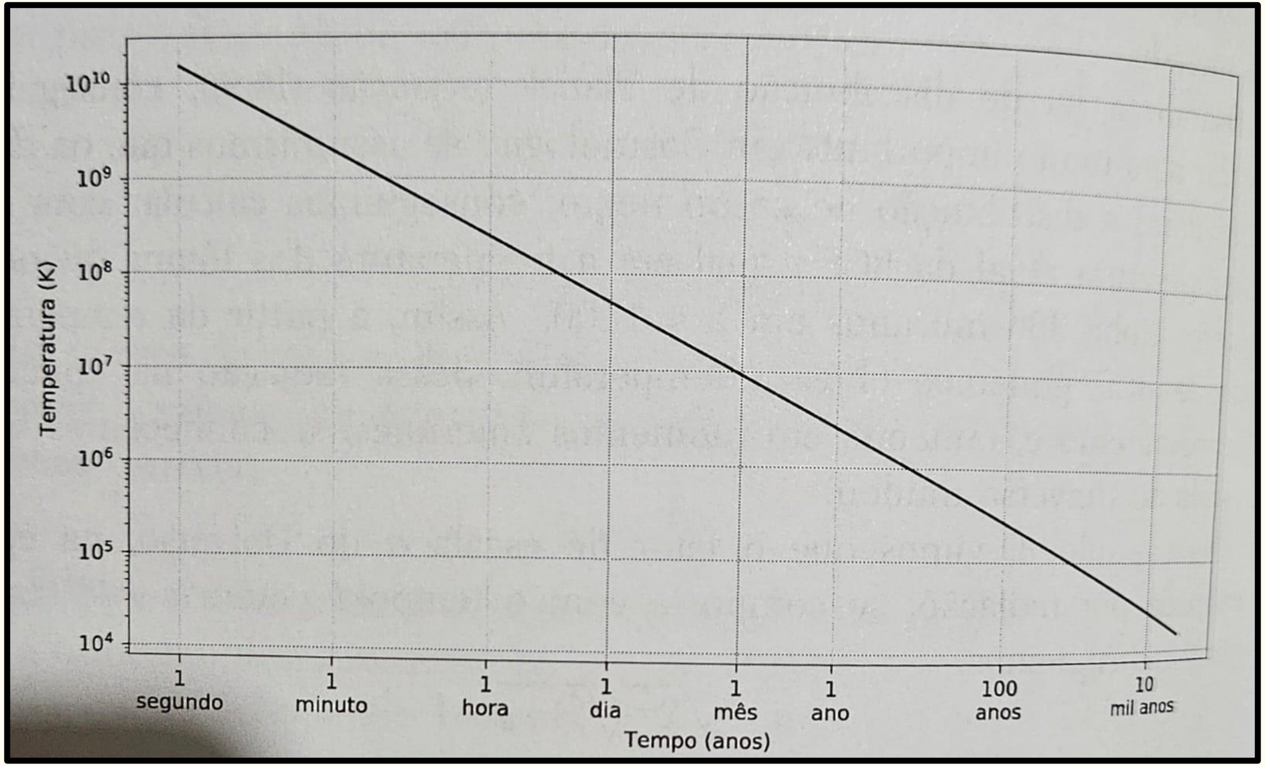
Parte 4

Aceleração cósmica e o futuro do universo

formação de estrutura



nucleossíntese



Introdução à Cosmologia Moderna,
A. Zabot

nucleossíntese

3.1.3 A Brief History of the Universe

Table 3.1 lists key events in the thermal history of the universe:

- **Baryogenesis.*** Relativistic quantum field theory requires the existence of anti-particles. This poses a slight puzzle. Particles and anti-particles annihilate through processes such as $e^+ + e^- \to \gamma + \gamma$. If initially the universe was filled with equal amounts of matter and anti-matter then we expect these annihilations to lead to a universe dominated by radiation. However, we do observe an overabundance of matter (mostly baryons) over anti-matter in the universe today. Models of *baryogenesis* try to derive the observed baryon-to-photon ratio

$$\eta_b \equiv \frac{n_b}{n_\gamma} \sim 10^{-9} , \tag{3.1.11}$$

  from some dynamical mechanism, i.e. without assuming a primordial matter-antimatter asymmetry as an initial condition. Although many ideas for baryogenesis exist, none is singled out by experimental tests. We will not have much to say about baryogenesis in this course.

Baumann lectures

nucleossíntese

- **Neutrino decoupling.** Neutrinos only interact with the rest of the primordial plasma through the weak interaction. The estimate in (3.1.10) therefore applies and neutrinos decouple at 0.8 MeV.

- **Electron-positron annihilation.** Electrons and positrons annihilate shortly after neutrino decoupling. The energies of the electrons and positrons gets transferred to the photons, but not the neutrinos. In §3.2.4, we will explain that this is the reason why the photon temperature today is greater than the neutrino temperature.

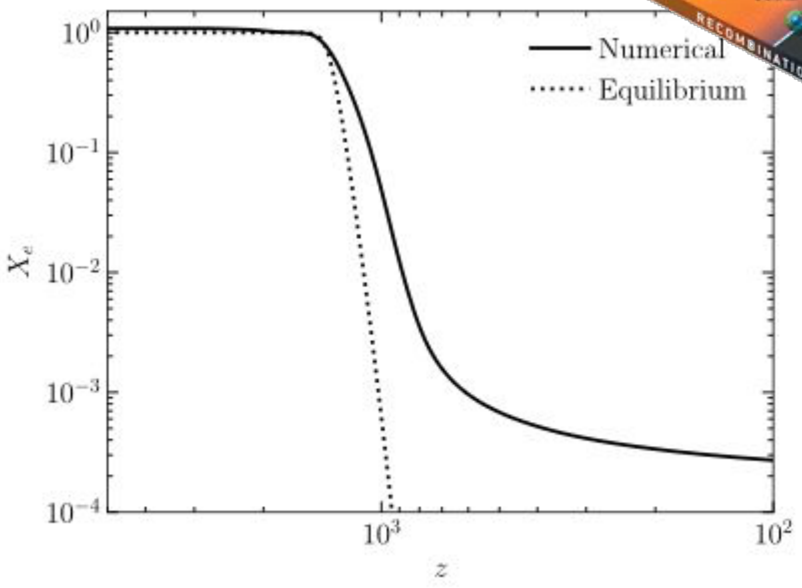
- **Big Bang nucleosynthesis.** Around 3 minutes after the Big Bang, the light elements were formed. In §3.3.4, we will study this process of *Big Bang nucleosynthesis* (BBN).

- **Recombination.** Neutral hydrogen forms through the reaction $e^- + p^+ \to \mathrm{H} + \gamma$ when the temperature has become low enough that the reverse reaction is energetically disfavoured. We will study *recombination* in §3.3.3.

- **Photon decoupling.** Before recombination the strongest coupling between the photons and the rest of the plasma is through Thomson scattering, $e^- + \gamma \to e^- + \gamma$. The sharp drop in the free electron density after recombination means that this process becomes inefficient and the photons decouple. They have since streamed freely through the universe and are today observed as the *cosmic microwave background* (CMB).

Baumann lectures

recombinação



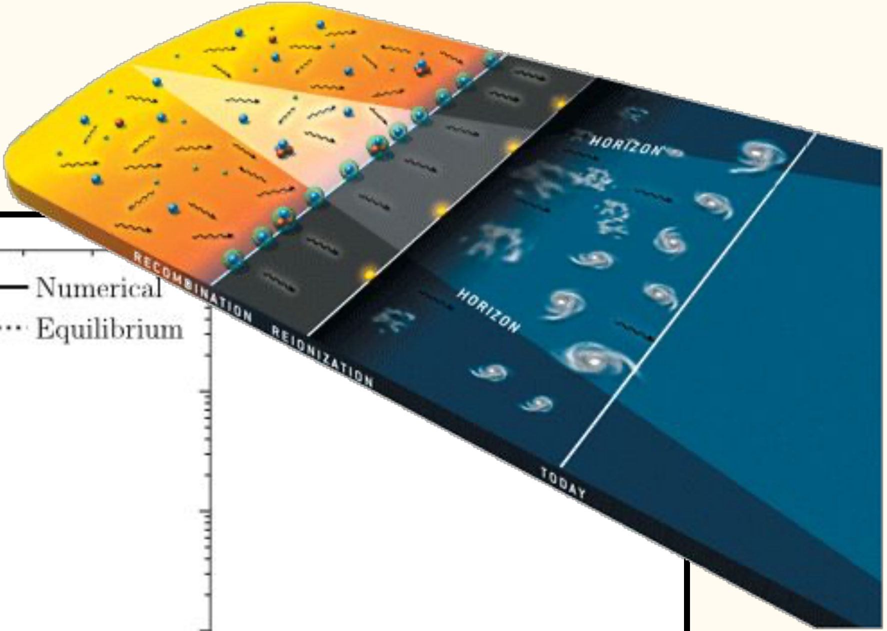


FIGURE 4.4 Free electron fraction as a function of redshift. The solid line shows the full numerical solution in the fiducial cosmology (given by the CLASS code), while the dotted line is the equilibrium result (the Saha approximation,

Modern Cosmology, S. Dodelson (2023)

problemas em aberto

problema do horizonte

problema da planicidade

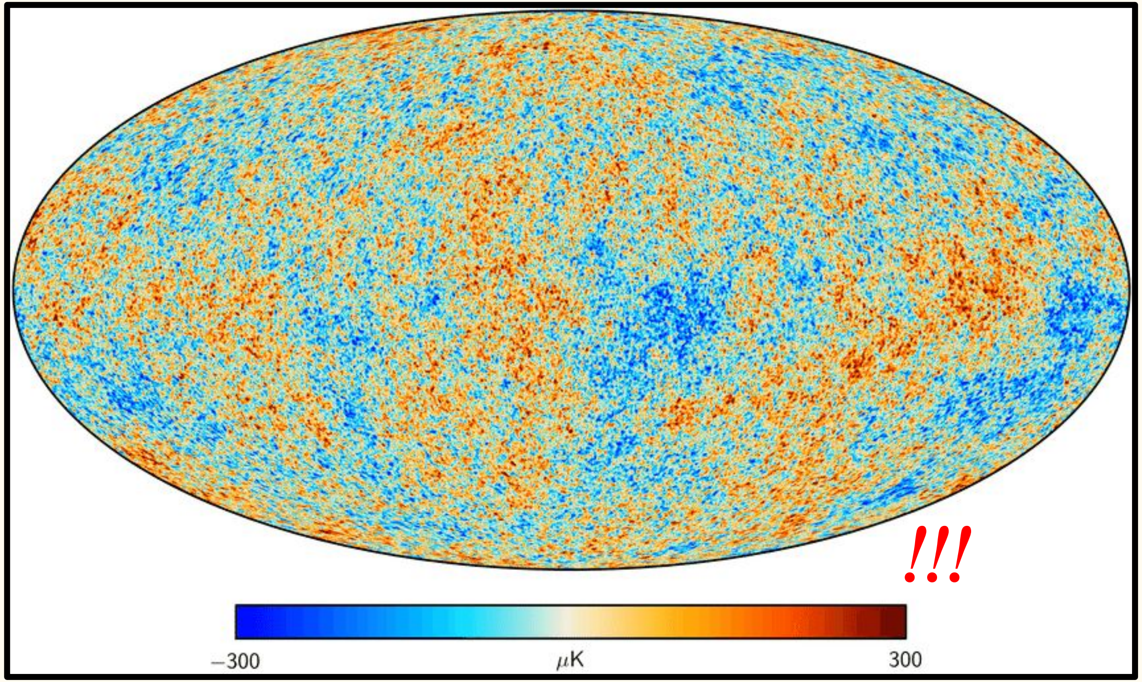
problema do monopolo magnético

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético

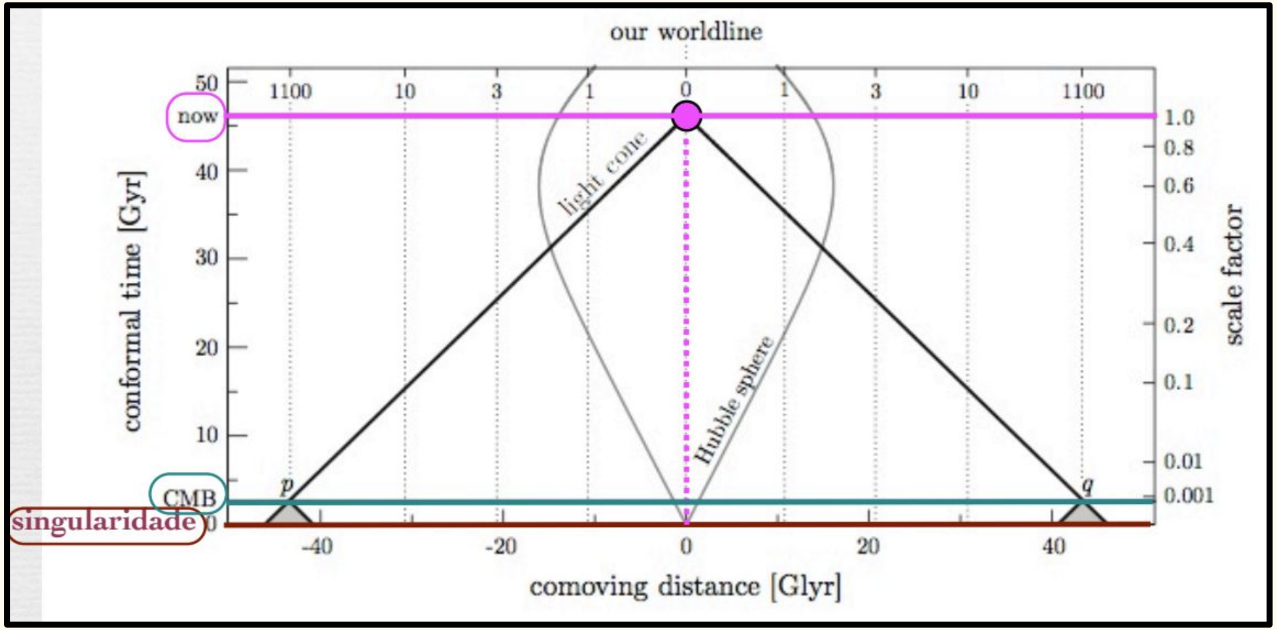


problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético



Fundamentos de Cosmologia Aula 10, C. Wuensche, Inpe

Pontos separados por uma distância própria maior do que a distância de Hubble,

$$d_H(t_0) \equiv c/H_0$$

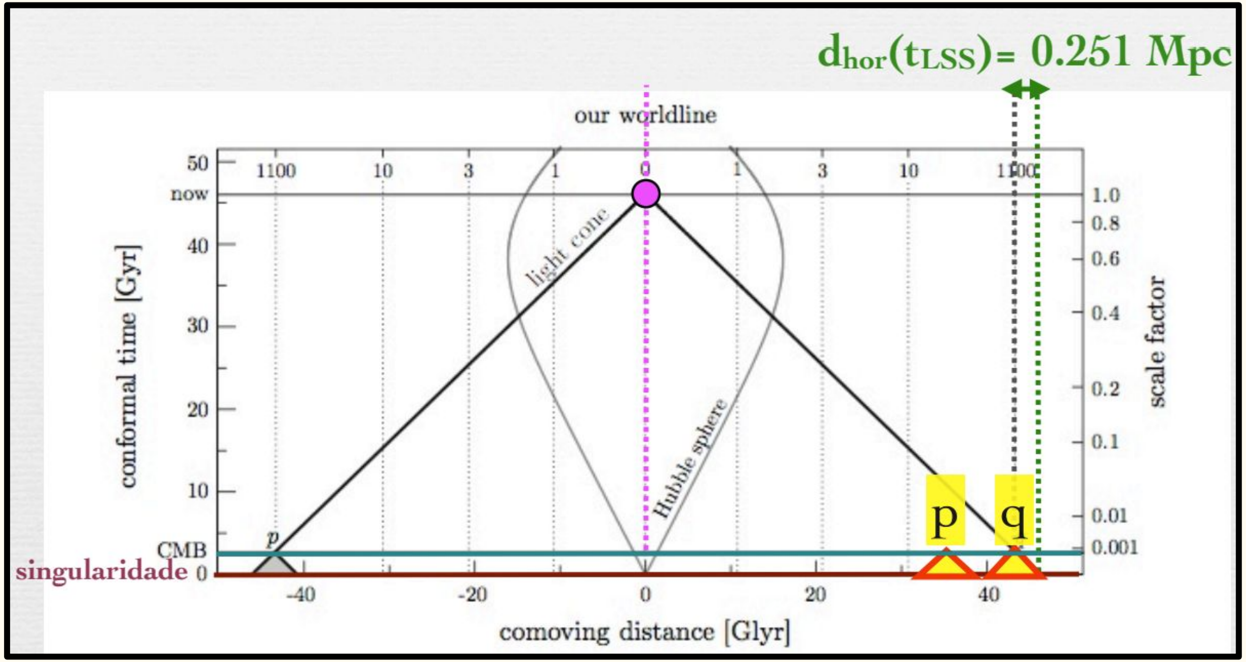
apresentam velocidades de recessão maiores do que a da luz.

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético



Fundamentos de Cosmologia Aula 10, C. Wuensche, Inpe

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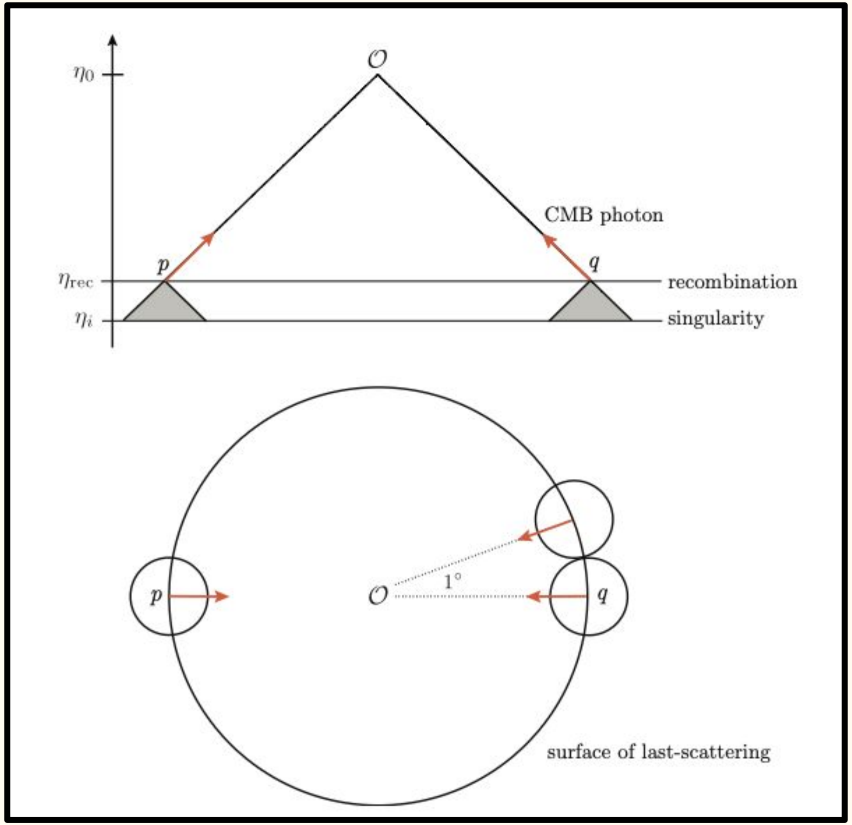
problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético



Baumann lectures

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético

O Universo hoje é aproximadamente plano e, no passado, era ainda mais próximo de ser plano.

Por que?

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético

Eq. de Fridmann $$1 - \Omega(t) = -\frac{\kappa c^2}{R_0^2 a(t)^2 H(t)^2} \qquad (1)$$

hoje (a=1) $$1 - \Omega_0 = -\frac{\kappa c^2}{R_0^2 H_0^2} \qquad (2)$$

CMBR e SNIa $$|1 - \Omega_0| \leq 0.005 \qquad \Rightarrow R_0 \geq \frac{14c}{H_0}$$

Por que $\Omega_0 \approx 1$?

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético

$$a_{rm} \approx 2.9 \times 10^{-4} \longrightarrow |1 - \Omega|_{rm} \leq 2 \times 10^{-6}$$

$$a_{nuc} \approx 3.6 \times 10^{-9} \longrightarrow |1 - \Omega|_{nuc} \leq 7 \times 10^{-16}$$

$$a_P \approx 2 \times 10^{-32} \longrightarrow |1 - \Omega|_P \leq 2 \times 10^{-62}$$

Para mudar a massa do Sol por esse fator, seria necessário adicionar / remover um vigésimo de um elétron.

Se $|1 - \Omega|_{nuc}$ tivesse sido de uma parte em um milhão (ao invés de 1 em um quatrilhão), o Universo teria colapsado em um Big Crunch ou expandido em um Big Chill em apenas algumas décadas.

problemas em aberto

problema do horizonte

problema da planicidade

problema do monopolo magnético

Para entender ainda melhor a questão, podemos utilizar uma analogia que está no livro de (Schneider , 2015): se jogarmos um objeto no ar, ele poderá levar alguns segundos até atingir o solo. Quanto maior a velocidade inicial de lançamento, mais tempo o objeto ficará no ar. Para aumentarmos o tempo de voo, precisamos aumentar a velocidade inicial, por exemplo, usando um canhão. Se quisermos que o objeto volte somente após um dia, devemos usar um foguete para lançá-lo. Mas, se a velocidade do foguete exercer a velocidade de escape da Terra de 11,2 km/s, o objeto sairá do campo gravitacional terrestre e nunca mais irá retornar para o solo. Analogamente, podemos pensar na velocidade de escape como a densidade crítica do Universo.

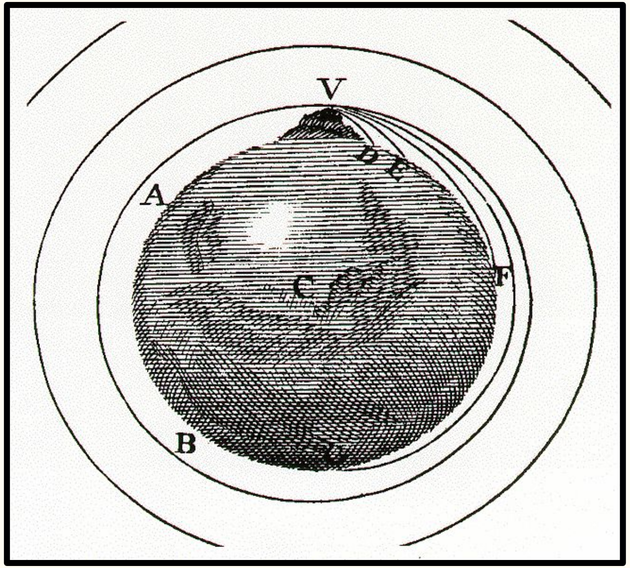
Quando dizermos que o Universo está em sua densidade crítica, significa que o Universo nasceu muito especial, porque caso ele tenha nascido com densidade abaixo da densidade crítica, ele teria se expandido e crescido muito rápido. Neste cenário, não haveria tempo para se formar as estruturas que constituem esse Universo e não estaríamos vendo da forma como ele é hoje: com estrelas, galáxias, aglomerado de galáxias etc. Para um Universo que apresenta densidade muito acima da densidade crítica, temos um Universo que se expande e colapsa muito rápido e, provavelmente, não estaríamos aqui estudando Cosmologia neste momento.

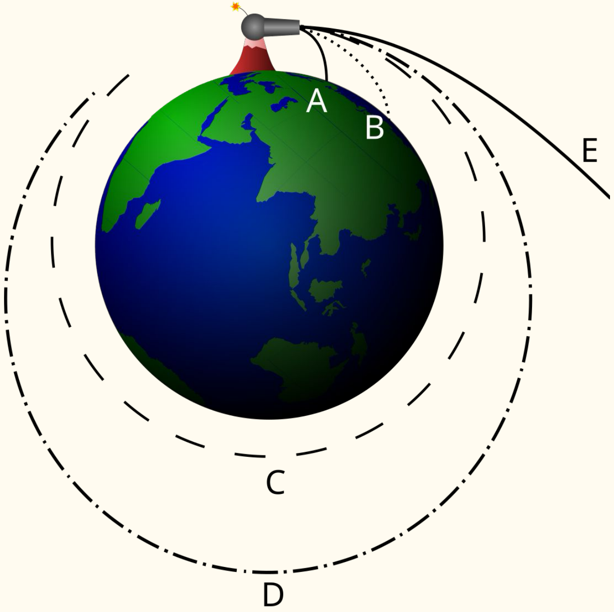
problemas em aberto

problema do horizonte

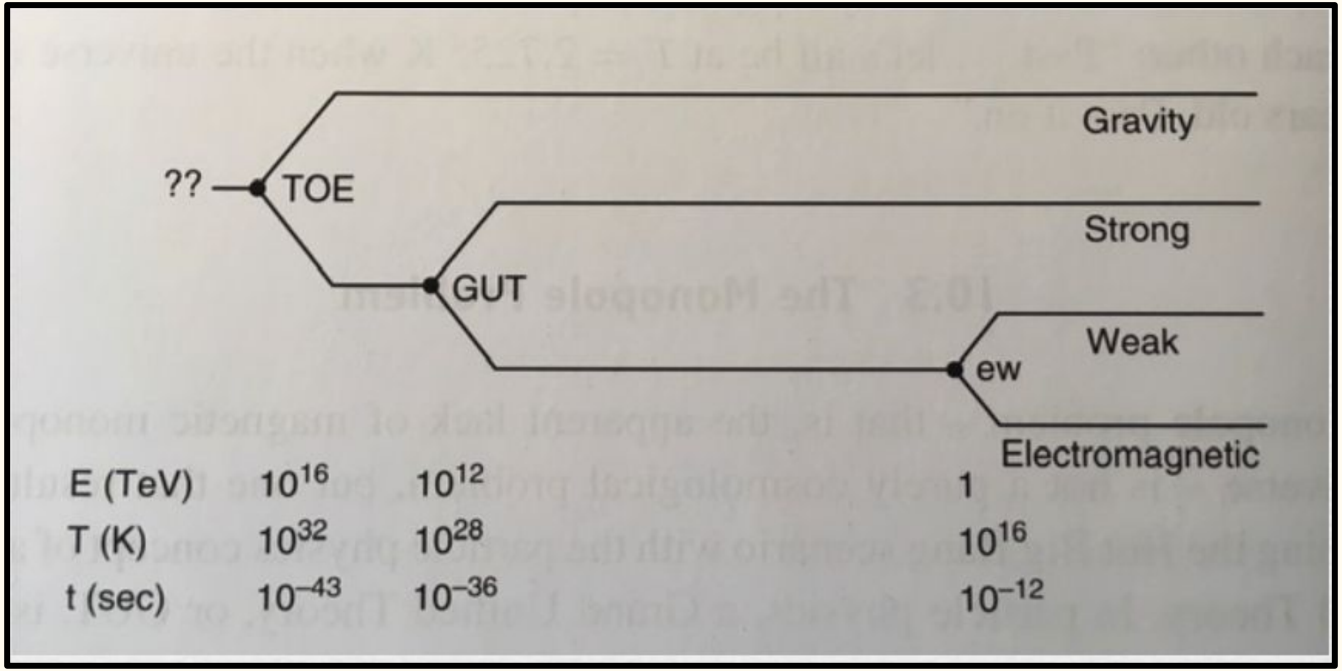
problema da planicidade

problema do monopolo magnético





problema do monopolo



Fundamentos de Cosmologia Aula 10, C. Wuensche, Inpe

problema do monopolo

Uma das previsões do GUT é que o Universo teria passado por uma **transição de fase** quando $T < T_{GUT}$.

Transição de fase: fenômeno associado com perda espontânea de simetria do sistema quando sua temperatura cai abaixo de um certo valor.

Ex:

A água é líquida para T > 273 K: moléculas de H2O são orientadas randomicamente gerando simetria rotacional em torno de qualquer ponto (isotropia).

Quando T < 273 K, a água passa por uma transição de fase (de líquida para sólida), com perda da simetria rotacional, gerando um cristal anisotrópico, com eixos preferenciais de simetria.

Fundamentos de Cosmologia Aula 10, C. Wuensche, Inpe

problema do monopolo

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Transição de fase: fenômeno associado com perda espontânea de simetria do sistema quando sua

De forma análoga:

Ocorre uma perda de simetria quando o Universo percorre a transição de fase do GUT em $t_{GUT} \sim 10^{-36}$ s.

Em $T > T_{GUT}$, havia uma simetria entre as forças **nuclear forte** e **eletrofraca.**

Em $T < T_{GUT}$, a simetria é espontaneamente perdida e essas forças desacoplam e começam a ter propriedades diferentes.

Aula 10,
che, Inpe

problema do monopolo

De for

Ocorr

em t_{GU}

GUT

monopolos magnéticos (*M*)

Energia de repouso dos *M* criados na fase de transição do GUT:

$$m_M c^2 \sim E_{\mathrm{GUT}} \sim 10^{12}\ \mathrm{TeV}$$

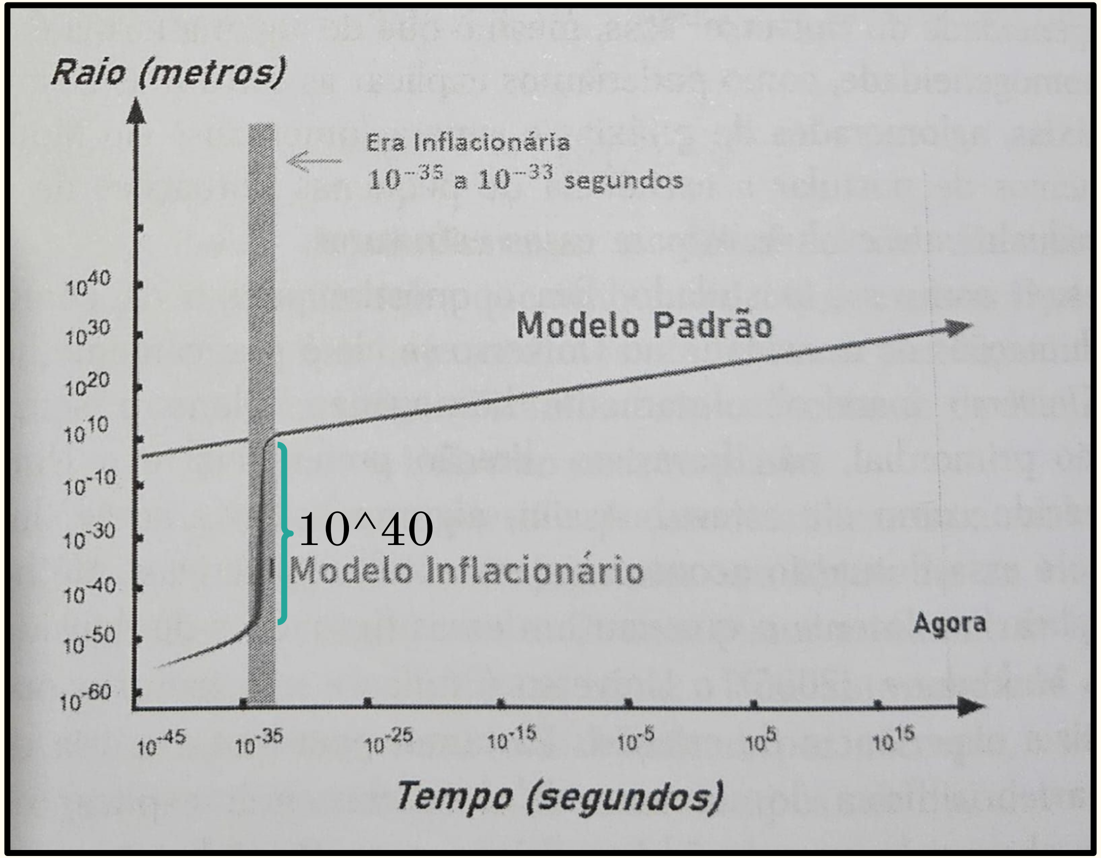
(comparável a 1 ng ~ massa de uma bactéria)

Em T > T_{GUT}, havia uma simetria entre as forças **nuclear forte** e **eletrofraca.**

Em T < T_{GUT}, a simetria é espontaneamente perdida e essas forças desacoplam e começam a ter propriedades diferentes.

Aula 10,
che, Inpe

teoria da inflação (1980)



Introdução à Cosmologia Moderna, A. Zabot

teoria da inflação (1980)

assumindo que o universo primordial seja dominado por um "energia de vácuo" temporária $p \approx -p$, originária do potencial de energia de um suposto campo inflaton

$$\left(\frac{H}{H_0}\right)^2 = \Omega_\Lambda$$

$$\frac{\dot{a}}{a} = H_0\sqrt{\Omega_\Lambda}$$

$$\int \frac{da}{a} = \int H_0\sqrt{\Omega_\Lambda}dt$$

$$\therefore a \propto e^{\chi t}$$

teoria da inflação (1980)

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$$\therefore a \propto e^{\chi t}$$

hom. + iso.

horizonte causal

$$d = c\int \frac{dz}{H(z)} = \frac{c}{H_0\sqrt{\Omega_\Lambda}} \int_{-\infty}^{t_{infl.}} dz$$

$$\rightarrow \infty$$

perturbações

Se tomarmos o tamanho de uma galáxia e dividi-lo por um fator de 10^{40}, estaremos em uma ordem menor do que um núcleo atômico. Considerando que ϕ seja o diâmetro da Via Láctea em metros, temos:

$$\frac{\phi}{10^{40}} \approx \frac{9,46 \times 10^{20}\ \text{m}}{10^{40}} \approx 9,46 \times 10^{-20}\ \text{m}, \tag{27.19}$$

e sendo assim, estamos na ordem de 10^{-19}m, ou seja, em escalas quânticas. Então, as flutuações que deram origem às galáxias foram flutuações quânticas em um Universo que se expandiu e as aumentou de um fator de 10^{40} vezes de tamanho. Dessa forma, a Inflação liga as grandes estruturas do Universo ao mundo quântico.

Introdução à Cosmologia Moderna, A. Zabot

teoria da inflação (1980)

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$$\int \frac{da}{a} = \int H_0\sqrt{\Omega_\Lambda}dt$$

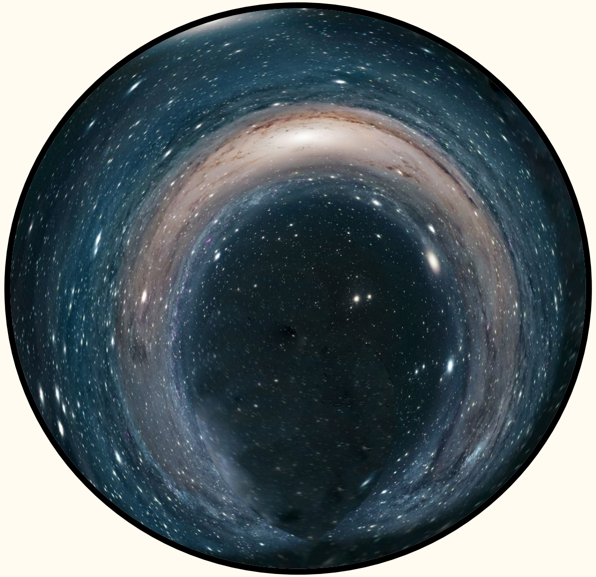
$$\therefore a \propto e^{\chi t}$$

planicidade

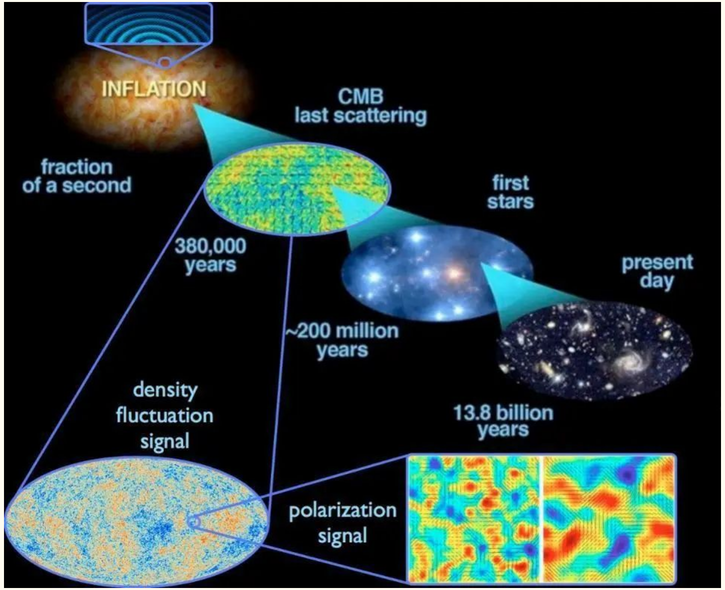
“Imagine que o nosso universo observável está sobre uma esfera e, de repente, essa esfera aumenta 10^40 vezes de raio. Logo, a curvatura que era percebida por nós não mais o será devido à grande expansão.”

Introdução à Cosmologia Moderna,
A. Zabot

ciência de precisão

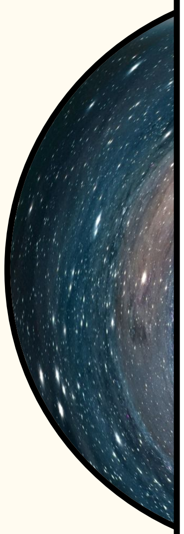


1ª metade do século XX



2ª metade do século XX

ciênci



A SURVEY OF GALAXY REDSHIFTS. V. THE TWO-POINT POSITION AND VELOCITY CORRELATIONS

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Received 1982 August 5; accepted 1982 October 12

ABSTRACT

We describe the results of a study of the two-point correlations in the 14.5 m_B CfA redshift survey. We use the distance information provided by the redshifts to estimate the two-point spatial correlation function $\xi(r)$ in a way that is designed to be unbiased by peculiar velocities. The results agree well with what has been found from the deeper angular distributions. In the fiducial model $\xi(r)=(r_0/r)^\gamma$ with $\gamma=1.77$ we find $r_0=5.4\pm0.3\ h^{-1}$ Mpc ($H_0=100\ h$ km s^{-1} Mpc^{-1}). At $r \gtrsim 10\ h^{-1}$ Mpc, $\xi(r)$ seems to steepen and may in fact be negative at $20 \lesssim hr \lesssim 40$ Mpc. In existing n-body simulations $\xi(r)$ is poorly modeled by a power law, with more power on small scales and less power on large scales than the data. This confirms the visual impressions that the n-body clusters are too compact and the clusters too homogeneously distributed relative to the data.

The rms line of sight peculiar velocity difference $\sigma(r_p)$ of correlated galaxy pairs seen projected at separation r_p is clearly detected at $hr < 5$ Mpc. The results fit quite well to a power law,

$$\sigma(r_p) = 340 \pm 40 (hr_p/1\ \text{Mpc})^{(0.13\pm0.04)}\ \text{km s}^{-1},$$

at 10 kpc $\lesssim hr_p \lesssim 1$ Mpc. The slow variation of σ with r_p would not be expected on scales $r_p < 300$ kpc unless the matter is considerably less concentrated than the light of bright galaxies. The mass could be in dark halos extending to this scale. Alternatively the mass could be clustered like the galaxies if matter loosely associated with the fainter galaxies deleted in our analysis carries the bulk of the mass density, so that M/L is a decreasing function of luminosity. We argue that the available evidence tends to favor the latter picture. We derive the cosmological density parameter $\Omega = 0.2\ e^{\pm 0.4}$ for the component of matter clustered with the galaxy distribution on scales $\leqslant 1\ h^{-1}$ Mpc.

Subject headings: cosmology — galaxies: clusters of — galaxies: redshifts

ciência de precisão

🟤 Pre–Modern Era (1930s–1970s) — catalogs & counts

- **1932 – Shapley & Ames Catalog** (~1,250 bright galaxies, morphology & positions).
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First direct maps of the 3D galaxy distribution.

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Bigger samples + computers make statistical analysis possible.

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Atenção: Recomenda-se discrição na leitura, lista gerada pelo ChatGPT

supernovas

THE ASTRONOMICAL JOURNAL, 116:1009–1038, 1998 September

OBSERVATIONAL EVIDENCE FROM SUPERNOVAE FOR AN ACCELERATING UNIVERSE AND A COSMOLOGICAL CONSTANT

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Received 1998 March 13; revised 1998 May 6

supernovas

4. COSMOLOGICAL IMPLICATIONS OF TYPE Ia SUPERNOVAE

4.1. *Cosmological Parameters*

Distance estimates from SN Ia light curves are derived from the luminosity distance,

$$D_L = \left(\frac{\mathscr{L}}{4\pi\mathscr{F}}\right)^{1/2} , \tag{1}$$

where $\mathscr{L}$ and $\mathscr{F}$ are the SN's intrinsic luminosity and observed flux, respectively. In Friedmann-Robertson-Walker cosmologies, the luminosity distance at a given redshift, z, is a function of the cosmological parameters. Limiting our consideration of these parameters to the Hubble constant, H_0, the mass density, Ω_M, and the vacuum energy density (i.e., the cosmological constant), Ω_Λ (but see Caldwell, Dave, & Steinhardt 1998; Garnavich et al. 1998a, 1998b for other energy densities), the luminosity distance is

$$D_L = cH_0^{-1}(1+z)|\Omega_k|^{-1/2} \operatorname{sinn}\left\{|\Omega_k|^{1/2} \times \int_0^z dz[(1+z)^2(1+\Omega_M z) - z(2+z)\Omega_\Lambda]^{-1/2}\right\} , \tag{2}$$

where $\Omega_k = 1 - \Omega_M - \Omega_\Lambda$ and sinn is sinh for $\Omega_k \geq 0$ and sin for $\Omega_k \leq 0$ (Carroll et al. 1992). For D_L in units of megaparsecs, the predicted distance modulus is

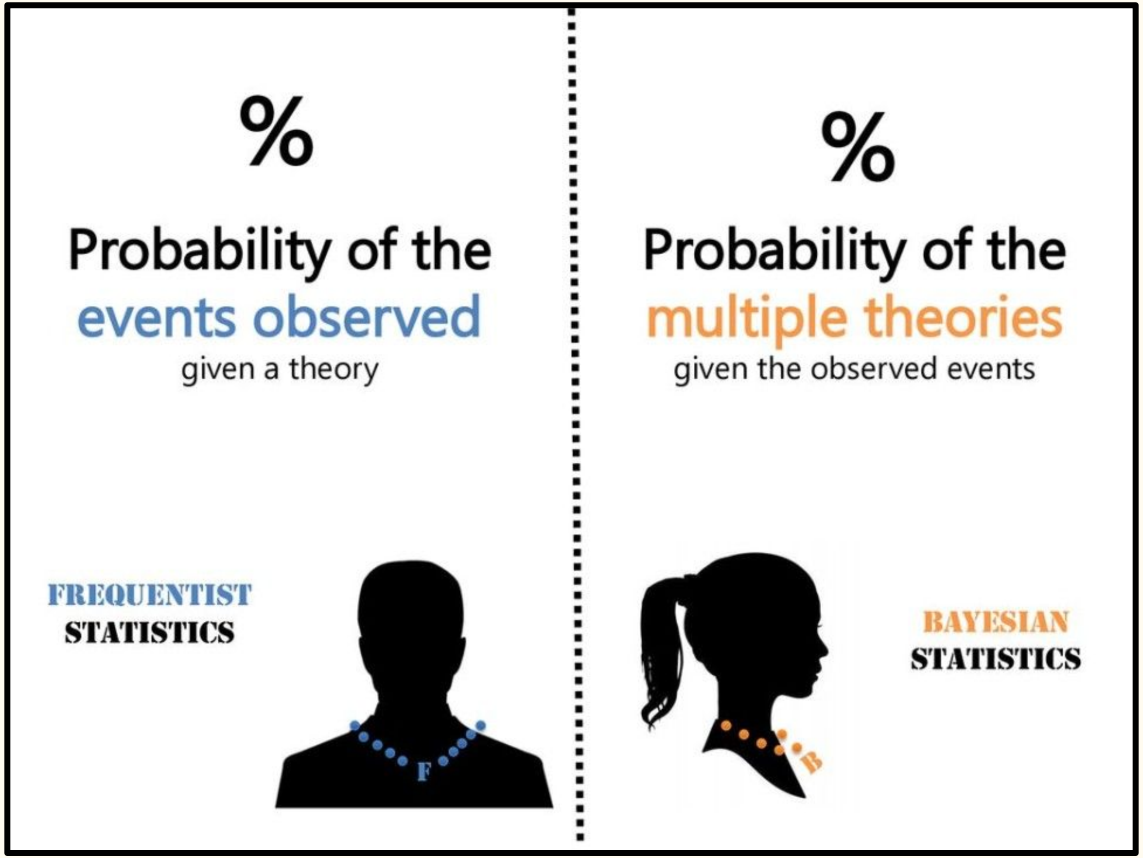
$$\mu_p = 5 \log D_L + 25 . \tag{3}$$

Using the data described in § 2 and the fitting methods of § 3, we have derived a set of distances, $\boldsymbol{\mu}_0$, for SNe with $0.01 \leq z \leq 0.97$. The available set of high-redshift SNe includes nine well-observed SNe Ia, six sparsely observed SNe Ia, and SN 1997ck ($z = 0.97$), whose light curve was well observed but lacks spectroscopic classification and color measurements. The Hubble diagrams for the nine well-observed SNe Ia plus SN 1997ck, with light curve distances calculated from the MLCS method and the template approach, are shown in Figures 4 and 5. The likelihood for the cosmological parameters can be determined from a χ^2 statistic, where

$$\chi^2(H_0, \Omega_M, \Omega_\Lambda) = \sum_i \frac{[\mu_{p,i}(z_i; H_0, \Omega_m, \Omega_\Lambda) - \mu_{0,i}]^2}{\sigma_{\mu_{0,i}}^2 + \sigma_v^2} \tag{4}$$

and σ_v is the dispersion in galaxy redshift (in units of distance moduli) due to peculiar velocities. This term also includes the uncertainty in galaxy redshift. We have calculated this χ^2 statistic for a wide range of the parameters H_0, Ω_M, and Ω_Λ. We do not consider the unphysical region of

análise bayesiana



análise bayesiana

$$P(\vec{\theta}|\vec{D}, H) = \frac{P(\vec{D}|\vec{\theta}, H)P(\vec{\theta}|H)}{P(\vec{D}|H)}.$$

análise bayesiana

Posterior

Vamos então entender cada probabilidade separadamente. $P(\vec{\theta}|\vec{D}, H)$ é denominado probabilidade posterior: a chance de, dado o modelo H, seu conjunto de parâmetros $\vec{\theta}$ conseguir descrever as medidas $\vec{D}$ que foram feitas também a partir desse modelo; essa é a probabilidade em que estamos interessados, da qual extrairemos os vínculos cosmológicos.

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análise bayesiana

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Na prática, entretanto, o que nós conseguimos calcular é a verossimilhança $P(\vec{D}|\vec{\theta}, H)$: a probabilidade das medidas $\vec{D}$ terem acontecido, dado que o universo é regido pelo modelo H com parâmetros $\vec{\theta}$.

Verossimilhança

$$\boxed{P(\vec{\theta}|\vec{D}, H)} = \frac{\boxed{P(\vec{D}|\vec{\theta}, H)}\,P(\vec{\theta}|H)}{P(\vec{D}|H)}.$$

análise bayesiana

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Verossimilhança

$$\boxed{P(\vec{\theta}|\vec{D}, H)} = \frac{\boxed{P(\vec{D}|\vec{\theta}, H)}\boxed{P(\vec{\theta}|H)}}{P(\vec{D}|H)}.$$

Prior

Essas duas probabilidades estão necessariamente conectadas pela probabilidade a priori $P(\vec{\theta}|H)$, ou simplesmente *prior*, que carrega a informação prévia que temos sobre os parâmetros do modelo H antes de termos feito as medidas $\vec{D}$. Perceba que, por definição, portanto, o *prior* é uma probabilidade subjetiva, no sentido de que ele depende da informação individual que se possui do modelo: se não há informação prévia, pode-

resultados

The likelihood for the cosmological parameters can be determined from a χ^2 statistic, where

$$\chi^2(H_0, \Omega_M, \Omega_\Lambda) = \sum_i \frac{[\mu_{p,i}(z_i; H_0, \Omega_m, \Omega_\Lambda) - \mu_{0,i}]^2}{\sigma^2_{\mu 0,i} + \sigma^2_v} \quad (4)$$

$$p(H_0, \Omega_m, \Omega_\Lambda \mid \boldsymbol{\mu}_0) = \frac{p(\boldsymbol{\mu}_0 \mid H_0, \Omega_m, \Omega_\Lambda)p(H_0, \Omega_m, \Omega_\Lambda)}{p(\boldsymbol{\mu}_0)}, \quad (5)$$

where $\boldsymbol{\mu}_0$ is our set of distance moduli (Lupton 1993). Since we have no prior constraints on the cosmological parameters (besides the excluded regions) or on the data, we take $p(H_0, \Omega_m, \Omega_\Lambda)$ and $p(\boldsymbol{\mu}_0)$ to be constants. Thus, we have for the allowed region of $(H_0, \Omega_m, \Omega_\Lambda)$

$$p(H_0, \Omega_m, \Omega_\Lambda \mid \boldsymbol{\mu}_0) \propto p(\boldsymbol{\mu}_0 \mid H_0, \Omega_m, \Omega_\Lambda). \quad (6)$$

The normalized PDF comes from dividing this relative PDF by its sum over all possible states,

$$p(H_0, \Omega_m, \Omega_\Lambda \mid \boldsymbol{\mu}_0) = \frac{\exp(-\chi^2/2)}{\int_{-\infty}^{\infty} dH_0 \int_{-\infty}^{\infty} d\Omega_\Lambda \int_0^{\infty} \exp(-\chi^2/2) d\Omega_M}, \quad (10)$$

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$$p(H_0, \Omega_m, \Omega_\Lambda \,|\, \mu_0) = \frac{p(\mu_0 \,|\, H_0, \Omega_m, \Omega_\Lambda) p(H_0, \Omega_m, \Omega_\Lambda)}{p(\mu_0)}, \quad (5)$$

where μ_0 is our set of distance moduli (Lupton 1993). Since we have no prior constraints on the cosmological parameters (besides the excluded regions) or on the data, we take $p(H_0, \Omega_m, \Omega_\Lambda)$ and $p(\mu_0)$ to be constants. Thus, we have for the allowed region of $(H_0, \Omega_m, \Omega_\Lambda)$

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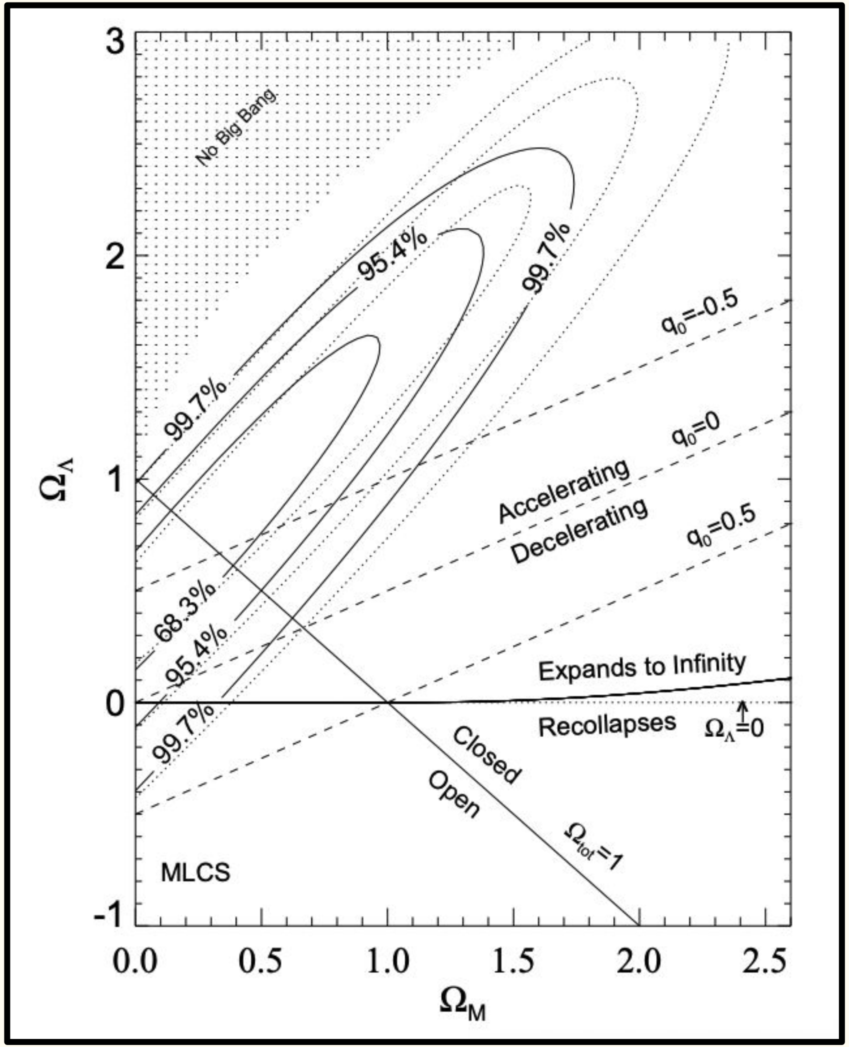
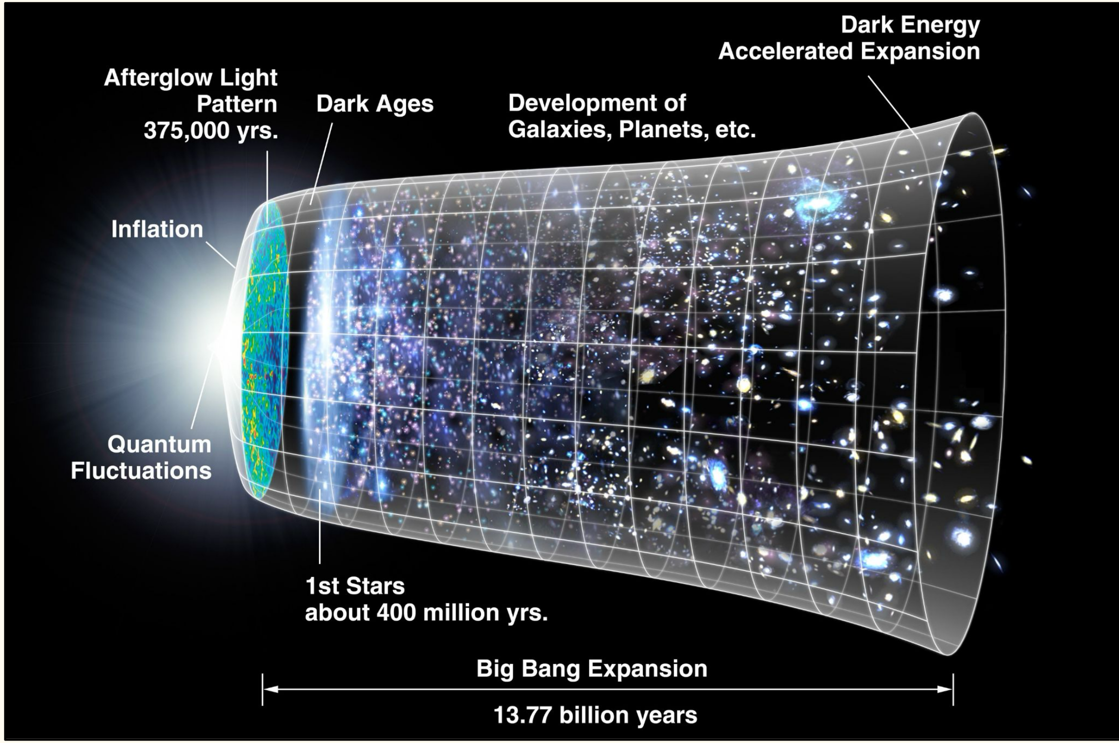


expansão acelerada

1. cosmos até então: $\Omega_m > 1$
   - slow down
   - big crunch
2. nascimento do ΛCDM
3. $[\Omega_\Lambda = 0.7, \Omega_{CDM} = 0.25, \Omega_b = 0.05]$
4. nascimento do DETF



Dark Energy Task Force

1. Esforço dos Estados unidos de planejar a situação
   a. Department of Energy (DOE) +
   b. National Science Foundation (NSF)

2. Estratégia de múltiplos observáveis:
   a. Supernovas
   b. Oscilação Acústica de Baryons (ou BAO)
   c. Lenteamento gravitacional fraco
   d. Aglomerações de galáxias
   e. Radiação Cósmica de Fundo

3. Métrica quantitativa para investigar a equação estado da energia escura

$$w \equiv \frac{p}{\rho} \begin{cases} \Lambda\text{CDM:} \\ w = -1 \\ \\ w\text{CDM:} \\ w(a) = w_0 + w_a(1-a) \end{cases}$$

Dark Energy Task Force

REPORT OF THE

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Gary Bernstein, University of Pennsylvania
Robert Cahn, Lawrence Berkeley National Laboratory
Wendy L. Freedman, Carnegie Observatories
Jacqueline Hewitt, Massachusetts Institute of Technology
Wayne Hu, University of Chicago
John Huth, Harvard University
Marc Kamionkowski, California Institute of Technology
Edward W. Kolb, Fermi National Accelerator Laboratory and The University of Chicago
Lloyd Knox, University of California, Davis
John C. Mather, Goddard Space Flight Center
Suzanne Staggs, Princeton University
Nicholas B. Suntzeff, Texas A&M University

Dark energy appears to be the dominant component of the physical Universe, yet there is no persuasive theoretical explanation for its existence or magnitude. The acceleration of the Universe is, along with dark matter, the observed phenomenon that most directly demonstrates that our theories of fundamental particles and gravity are either incorrect or incomplete. Most experts believe that nothing short of a revolution in our understanding of fundamental physics will be required to achieve a full understanding of the cosmic acceleration. For these reasons, the nature of dark energy ranks among the very most compelling of all outstanding problems in physical science. These circumstances demand an ambitious observational program to determine the dark energy properties as well as possible.

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Fortunately, the extraordinary scientific challenge of the dark energy has generated outstanding ideas for an observational program that can greatly impact our understanding. A properly executed dark energy program should have as its goals to

1. Determine as well as possible whether the accelerating expansion is consistent with a cosmological constant.
2. Measure as well as possible any time evolution of the dark energy.
3. Search for a possible failure of general relativity through comparison of the effect of dark energy on cosmic expansion with the effect of dark energy on the growth of cosmological structures like galaxies or galaxy clusters.

Dark Energy Task Force

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Using our figure of merit, we evaluated ongoing and future dark energy studies in four areas represented in the white papers. These are based on observations of Baryon Acoustic Oscillations, Galaxy Clusters, Supernova, and Weak Lensing.

One of our main findings is that no single technique can answer the outstanding questions about dark energy: combinations of at least two of these techniques must be used to fully realize the promise of future observations. Already there are proposals for major, long-term (Stage IV[1]) projects incorporating these techniques that have the promise of increasing our figure of merit by a factor of ten beyond the level it will reach with the conclusion of current experiments. What is urgently needed is a commitment to fund a program comprised of a selection of these projects. The selection should be made on the basis of critical evaluations of their costs, benefits, and risks.

Dark Energ

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Our recommendations are based on the results of our modeling. They are discussed in detail in Section V. In summary, they are

I. We strongly recommend that there be an aggressive program to explore dark energy as fully as possible, since it challenges our understanding of fundamental physical laws and the nature of the cosmos.

II. We recommend that the dark energy program have multiple techniques at every stage, at least one of which is a probe sensitive to the growth of cosmological structure in the form of galaxies and clusters of galaxies.

III. We recommend that the dark energy program include a combination of techniques from one or more Stage III projects designed to achieve, in combination, at least a factor of three gain over Stage II in the DETF figure of merit, based on critical appraisals of likely statistical and systematic uncertainties.

IV. We recommend that the dark energy program include a combination of techniques from one or more Stage IV projects designed to achieve, in combination, at least a factor of ten gain over Stage II in the DETF figure of merit, based on critical appraisals of likely statistical and systematic uncertainties. Because JDEM, LST, and SKA all offer promising avenues to greatly improved understanding of dark energy, we recommend continued research and development investments to optimize the programs and to address remaining technical questions and systematic-error risks.

V. We recommend that high priority for near-term funding should be given as well to projects that will improve our understanding of the dominant systematic effects in dark energy measurements and, wherever possible, reduce them, even if they do not immediately increase the DETF figure of merit.

VI. We recommend that the community and the funding agencies develop a coherent program of experiments designed to meet the goals and criteria set out in these recommendations.

pesquisa

THE HUBBLE CONSTANT FROM SN REFSDAL

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(Accepted 2018-01-17)

Submitted to ApJL

ABSTRACT

Hubble Space Telescope observations from December 11 2015 detected the expected fifth counter image of SN Refsdal at
the time delay predictions from numerous models with the measured value derived by Kelly
a in the light curve of the SN Refsdal, and find a best value for $H_0 = 64^{+9}_{-11}$ km s^{-1} Mpc^{-1}
with predictions from CMB and recent weak lensing data + BAO + BBN (from the DES
onstraint on H_0 derived from time delays between multiple lensed SN images, and the first
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imaged SNe will allow derivation of competitive constraints on H_0.

Parte 5

Estado da arte e futuro da pesquisa

pesquisas

Atenção: Recomenda-se discrição na leitura, lista gerada pelo ChatGPT

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Bigger samples + computers make statistical analysis possible.

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🟡 Third Generation (2000s) — precision cosmology

Massive surveys that enabled robust cosmological parameter constraints.

- **2000–2008 – Sloan Digital Sky Survey (SDSS-I/II)** (~1M galaxies, ~100k quasars; revolutionized LSS, BAO, galaxy evolution studies).
- **2005–2013 – WiggleZ Survey** (~200,000 galaxies; measured BAO at higher redshift).
- **2005–2009 – VVDS & DEEP2** (deep galaxy redshift surveys out to $z > 1$).

🟣 Fourth Generation (2010s) — dark energy era

Surveys designed explicitly to constrain dark energy via BAO, weak lensing, supernovae.

- **2008–2014 – BOSS (Baryon Oscillation Spectroscopic Survey, SDSS-III)** (~1.5M galaxies; BAO detection with percent-level precision).
- **2013–2019 – eBOSS (SDSS-IV)** (~2M galaxies + quasars, extended to $z \sim 2$).
- **2013–2019 – Dark Energy Survey (DES)** (deep imaging, 300M galaxies, lensing + BAO).

🔴 Fifth Generation (2020s) — next level precision, wide + deep

Ongoing or just launched surveys, aiming for sub-percent constraints on cosmology.

- **2021–present – DESI (Dark Energy Spectroscopic Instrument)** (targeting ~40M galaxies & quasars; largest spectroscopic survey ever).
- **2020s – Euclid (ESA space mission, launched 2023)** (weak lensing + spectroscopy of ~1.5B galaxies).
- **2020s – Rubin Observatory LSST** (10-year imaging survey, billions of galaxies, time-domain cosmology).
- **Roman Space Telescope (mid-2020s planned)** (high-resolution imaging & spectroscopy, dark energy & structure formation).

pesquisas

Atenção: Recomenda-se discrição na leitura, lista gerada pelo ChatGPT

🟤 **Pre–Modern Era (1930s–1970s) — catalogs & counts**

- **1932 – Shapley & Ames Catalog** (~1,250 bright galaxies, morphology & positions).
- **1954 – Shane & Wirtanen Lick Survey** (galaxy counts from photographic plates, first statistical map).
- **1961–68 – Zwicky Catalog of G**
- **1970s – Peebles et al.** use these functions).

🔵 **First Generation Redshift S**

First direct maps of the 3D galaxy dis

- **1977–82 – CfA Redshift Survey** voids, the CfA Great Wall).
- **1980s – Perseus–Pisces survey**
- **1980s – ESO/Southern Sky surv**

🟢 **Second Generation (1990s**

Bigger samples + computers make statistical analysis possible.

- **1995–2002 – Las Campanas Redshift Survey (LCRS)** (~26,000 galaxies, key for power spectrum studies).
- **1990s – IRAS Point Source Redshift Survey (PSCz)** (~15,000 galaxies; first all-sky IR redshift survey).
- **1996–2001 – 2dF Galaxy Redshift Survey (2dFGRS)** (~220,000 galaxies; measured power spectrum, clustering, redshift-space distortions).

🟡 **Third Generation (2000s) — precision cosmology**

Massive surveys that enabled robust cosmological parameter constraints.

- **2000–2008 – Sloan Digital Sky Survey (SDSS-I/II)** (~1M galaxies, ~100k quasars; revolutionized LSS, BAO, galaxy evolution studies).

igher redshift).

1).

supernovae.

-III) (~1.5M galaxies; BAO

$z \sim 2$).

s, lensing + BAO).

eep

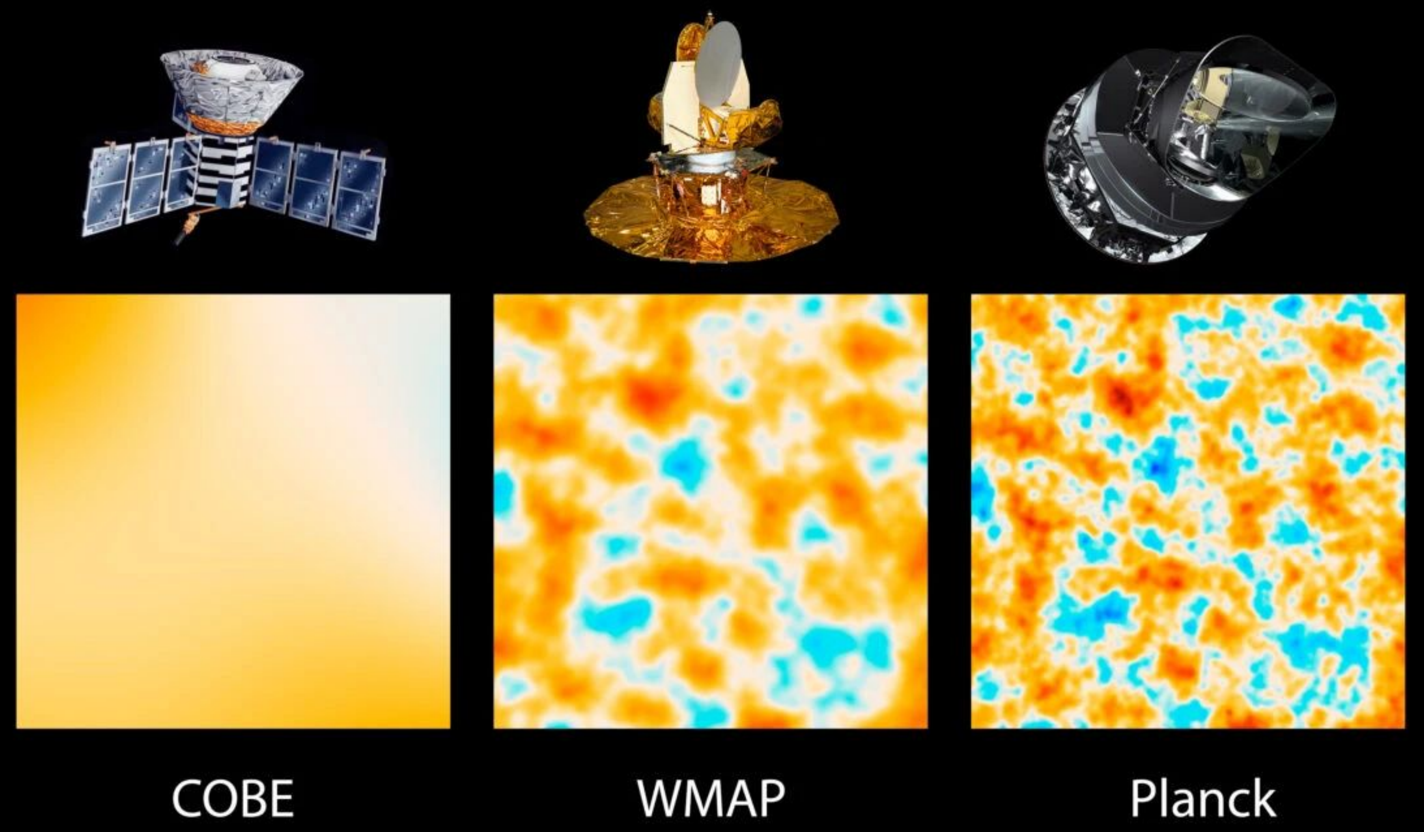
smology.

- **2021–present – DESI (Dark Energy Spectroscopic Instrument)** (targeting ~40M galaxies & quasars; largest spectroscopic survey ever).
- **2020s – Euclid (ESA space mission, launched 2023)** (weak lensing + spectroscopy of ~1.5B galaxies).
- **2020s – Rubin Observatory LSST** (10-year imaging survey, billions of galaxies, time-domain cosmology).
- **Roman Space Telescope (mid-2020s planned)** (high-resolution imaging & spectroscopy, dark energy & structure formation).

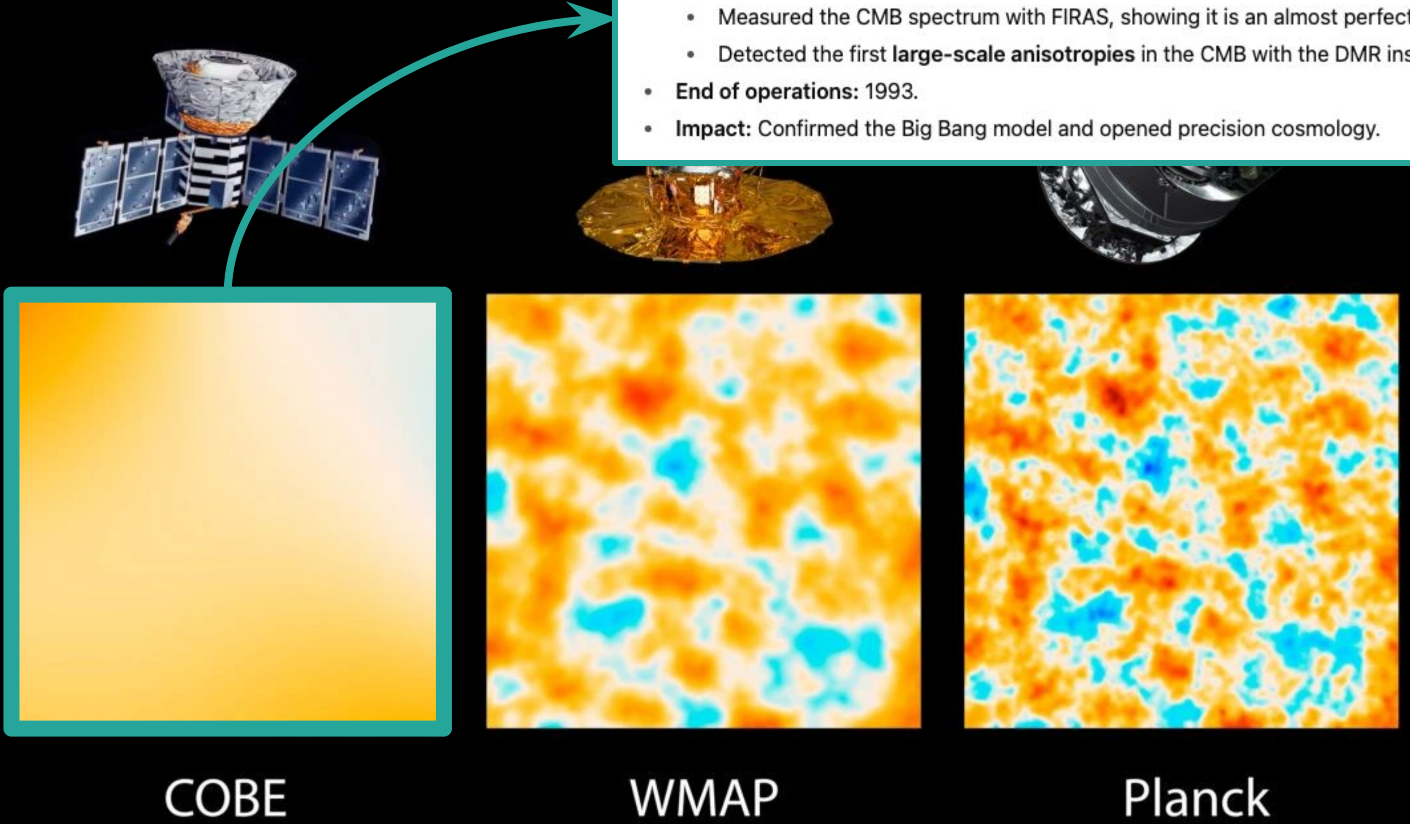
✅ Generational summary

1. **1930s–70s:** Catalogs & counts (Shapley–Ames, Zwicky, Shane–Wirtanen).
2. **1980s:** First 3D maps (CfA).
3. **1990s:** Larger samples, first parameter fits (LCRS, 2dF, IRAS).
4. **2000s:** SDSS era → BAO & precision cosmology.
5. **2010s:** Dark energy–focused (BOSS, eBOSS, DES).
6. **2020s:** Next-gen precision cosmology (DESI, Euclid, Rubin, Roman).

universo primordial



universo primordial



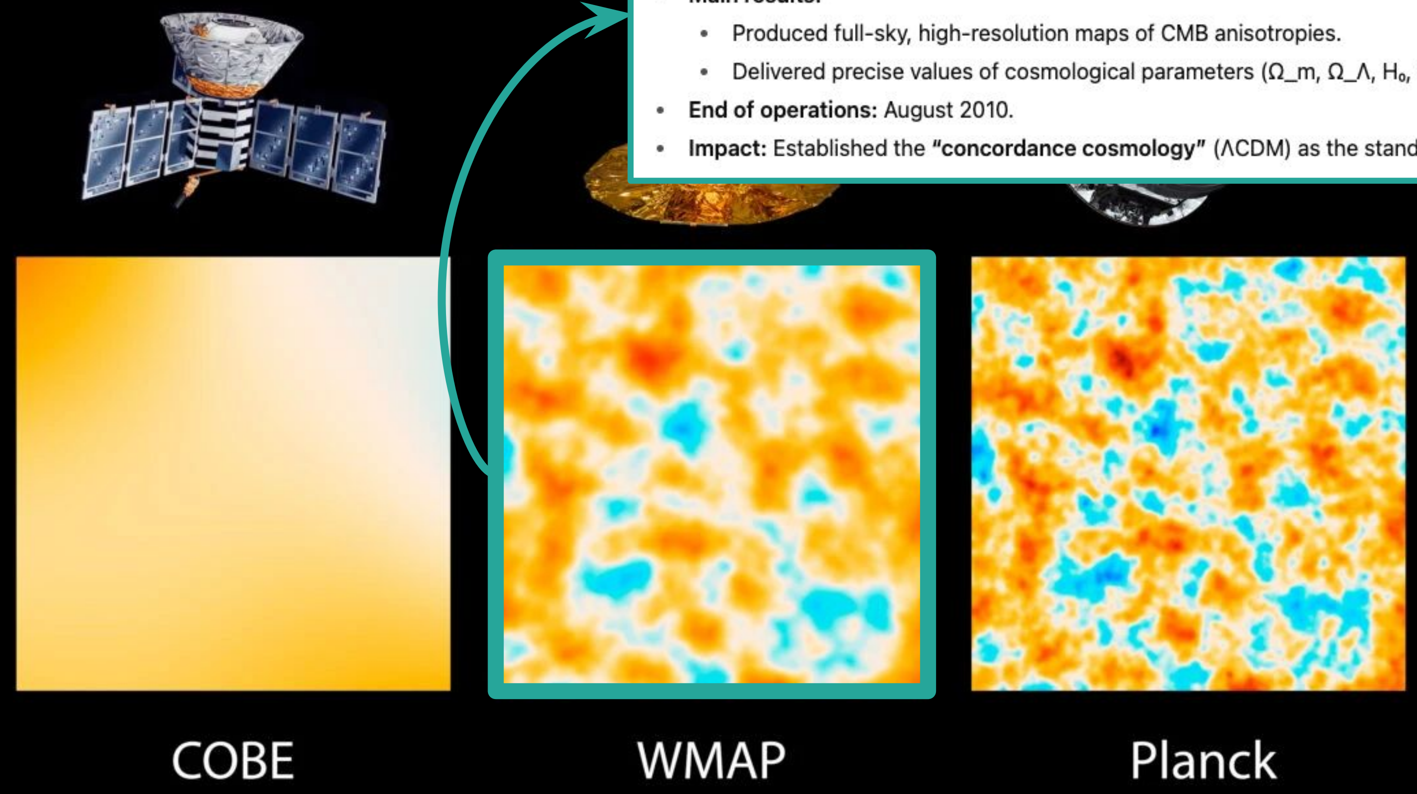
COBE (Cosmic Background Explorer)

- **Launch:** 18 November 1989 (NASA).
- **Main results:**
  - Measured the CMB spectrum with FIRAS, showing it is an almost perfect blackbody (1990).
  - Detected the first **large-scale anisotropies** in the CMB with the DMR instrument (1992).
- **End of operations:** 1993.
- **Impact:** Confirmed the Big Bang model and opened precision cosmology.

universo primordial

WMAP (Wilkinson Microwave Anisotropy Probe)

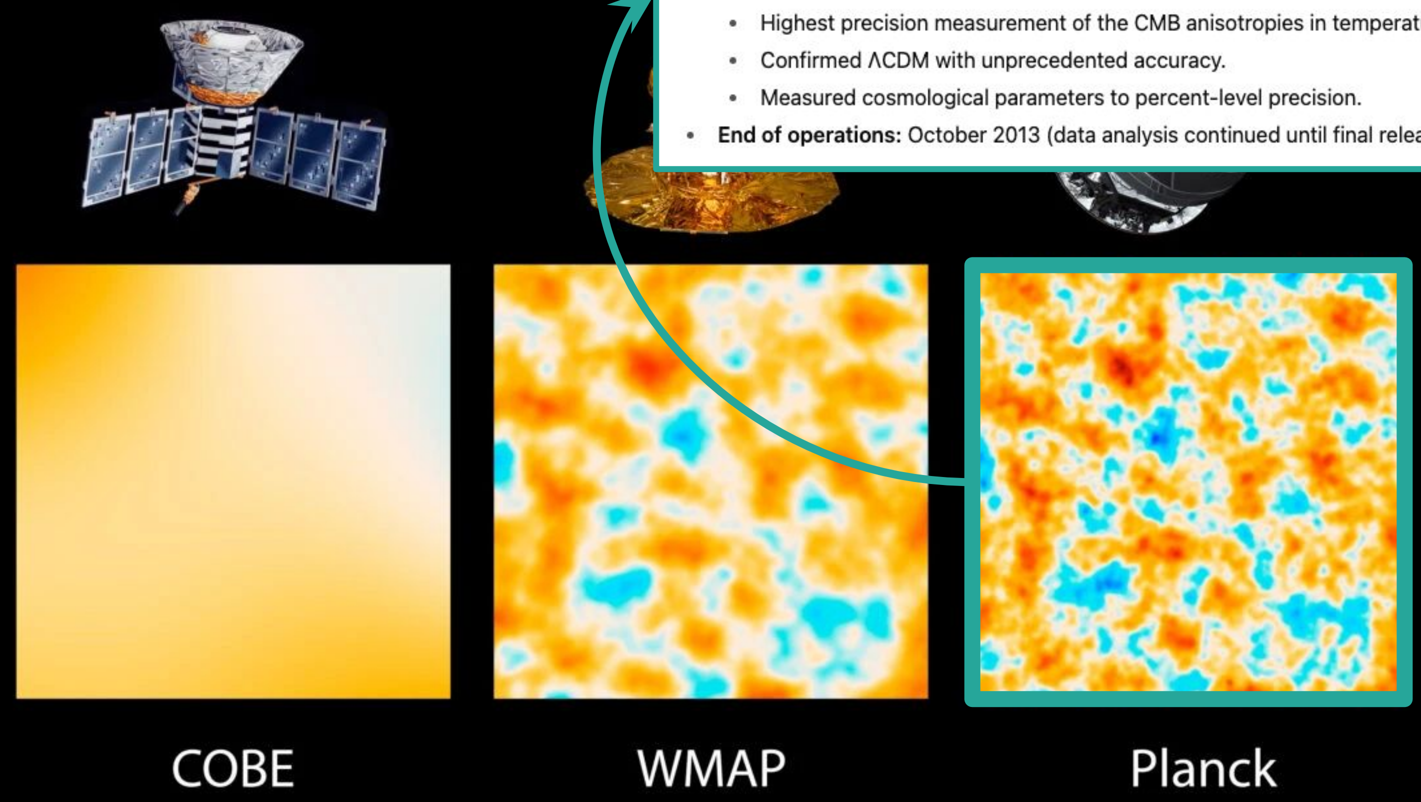
- **Launch:** 30 June 2001 (NASA).
- **First results:** 2003.
- **Main results:**
  - Produced full-sky, high-resolution maps of CMB anisotropies.
  - Delivered precise values of cosmological parameters (Ω_m, Ω_Λ, H_0, age of the Universe).
- **End of operations:** August 2010.
- **Impact:** Established the **"concordance cosmology"** (ΛCDM) as the standard model.



universo prin

Planck (ESA, with NASA participation)

- **Launch:** 14 May 2009.
- **First data release:** 2013 (CMB temperature anisotropy).
- **Final data release:** 2018.
- **Main results:**
  - Highest precision measurement of the CMB anisotropies in temperature and polarization.
  - Confirmed ΛCDM with unprecedented accuracy.
  - Measured cosmological parameters to percent-level precision.
- **End of operations:** October 2013 (data analysis continued until final release).



universo prin

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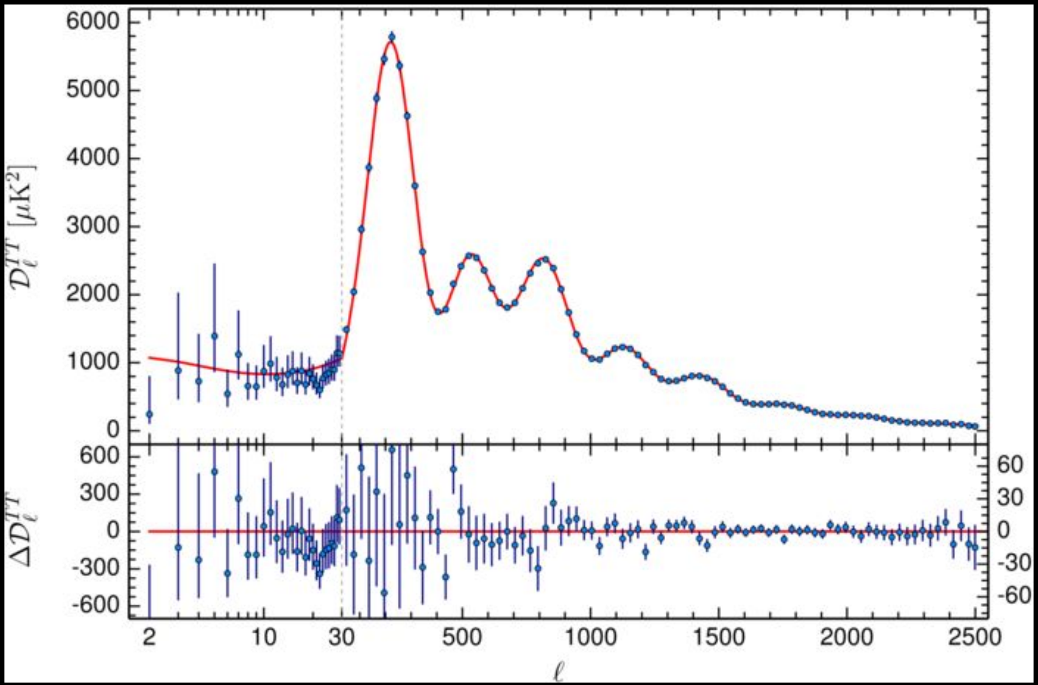
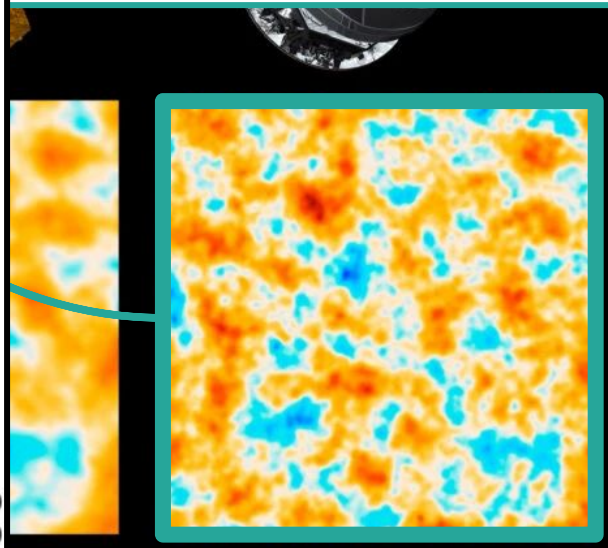
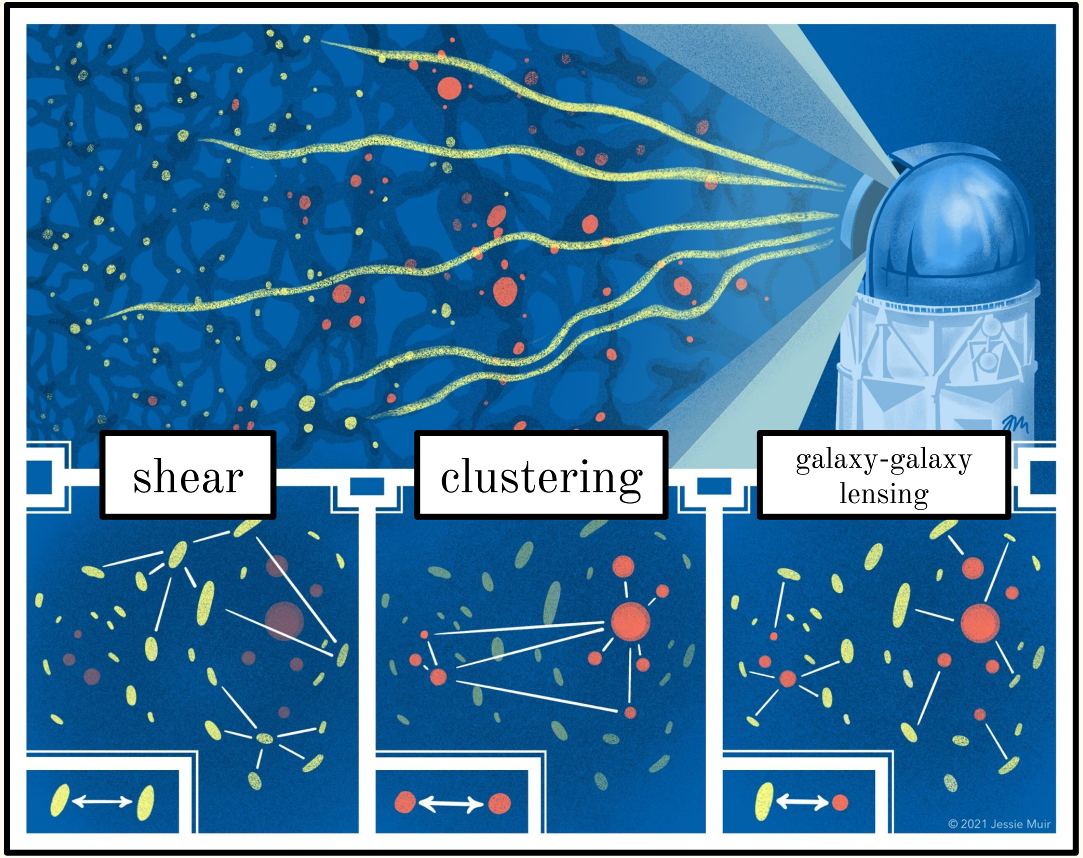




Planck

universo tardio



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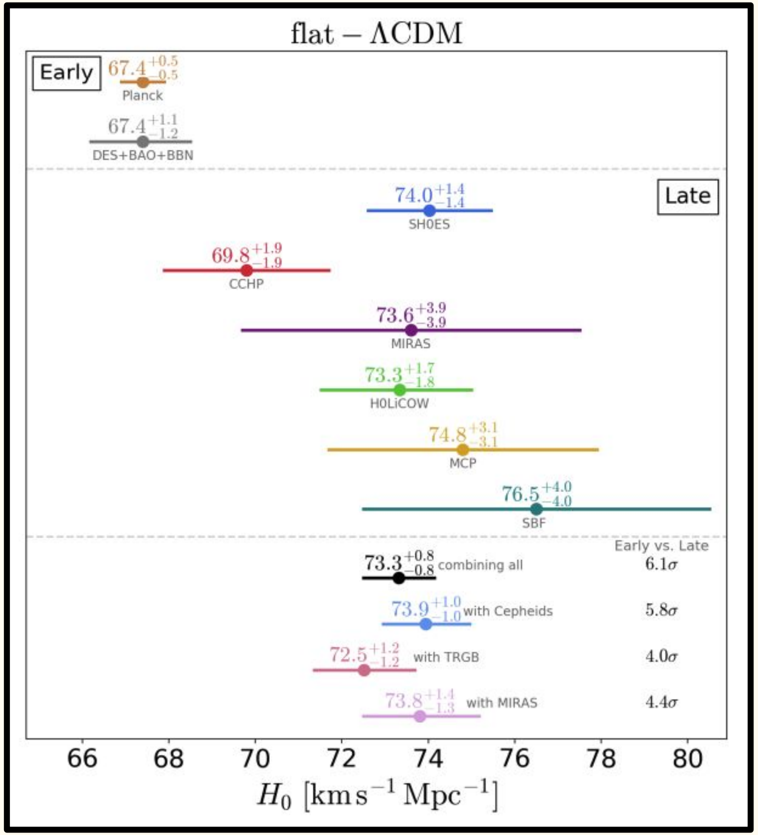
tensão de Hubble



Tensions between the Early and the Late Universe
Kavli Institute for Theoretical Physics, July 2019
Verde, L., Treu, T., Riess, A.G.

Tensions between the Early and the Late Universe

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Abstract. The standard cosmological model successfully describes many observations from widely different epochs of the Universe, from primordial nucleosynthesis to the accelerating expansion of the present day. However, as the basic cosmological parameters of the model are being determined with increasing and unprecedented precision, it is not guaranteed that the same model will fit more precise observations from widely different cosmic epochs. Discrepancies developing between observations at early and late cosmological time may require an expansion of the standard model, and may lead to the discovery of new physics. The workshop "Tensions between the Early and the Late Universe" was held at the Kavli Institute for Theoretical Physics on July 15-17 2019 † to evaluate increasing evidence for these discrepancies, primarily in the value of the Hubble constant as well as ideas recently proposed to explain this tension. Multiple new observational results for the Hubble constant were presented in the time frame of the workshop using different probes: Cepheids, strong lensing time delays, tip of the red giant branch (TRGB), megamasers, Oxygen-rich Miras and surface brightness fluctuations (SBF) resulting in a set of six new ones in the last several months. Here we present the summary plot of the meeting that shows combining any three independent approaches to measure H_0 in the late universe yields tension with the early Universe values between 4.0σ and 5.8σ. This shows that the discrepancy does not appear to be dependent on the use of any one method, team, or source. Theoretical ideas to explain the discrepancy focused on new physics in the decade of expansion preceding recombination as the most plausible. This is a brief summary of the workshop.

próxima geração

Legacy
Survey of
Space and
Time

https://rubinobservatory.org/explore/skyviewer/skysynth-sonification-about

Dark
Energy
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Instrument

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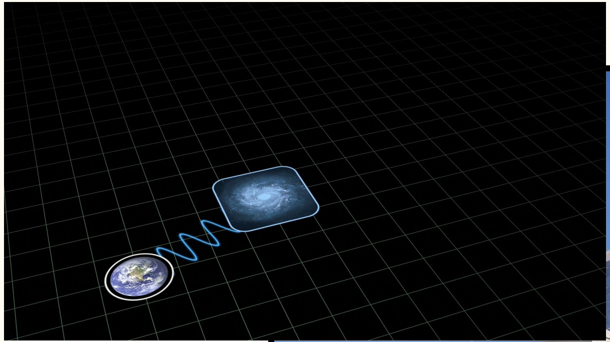
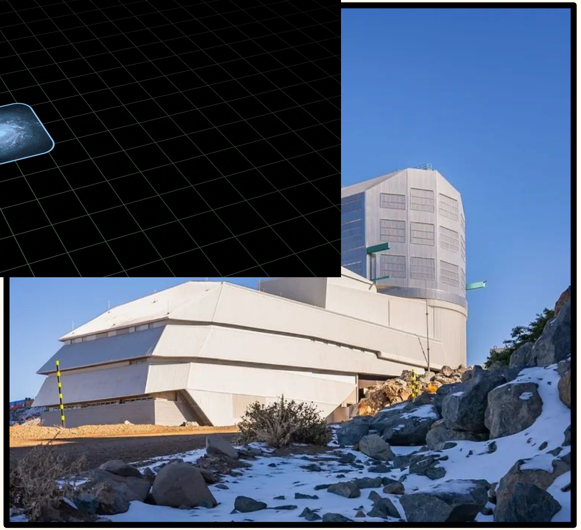
próxima geração





Legacy
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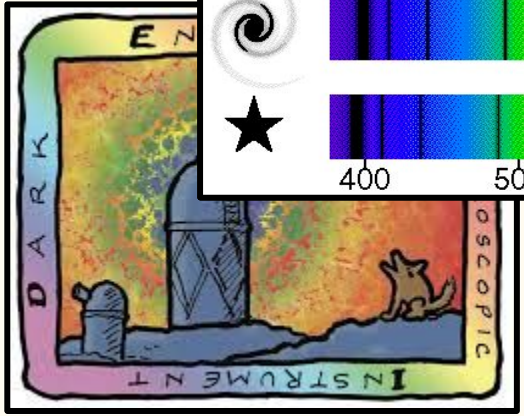

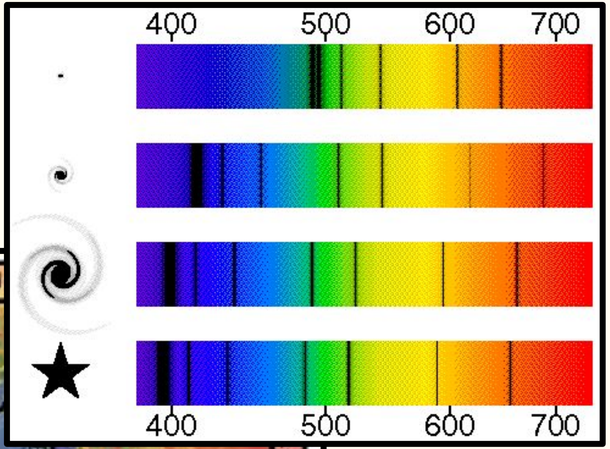

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https://www.desi.lbl.gov/

cosmologia com simulações

Mimicking the halo–galaxy connection using machine learning

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ABSTRACT

Elucidating the connection between the properties of galaxies and the properties of their hosting haloes is a key element in galaxy formation. When the spatial distribution of objects is also taken under consideration, it becomes very relevant for cosmological measurements. In this paper, we use machine-learning techniques to analyse these intricate relations in the IllustrisTNG300 magnetohydrodynamical simulation, predicting baryonic properties from halo properties. We employ four different algorithms: *extremely randomized trees*, *K-nearest neighbours*, *light gradient boosting machine*, and *neural networks*, along with a unique and powerful combination of the results from all four approaches. Overall, the different algorithms produce consistent results in terms of predicting galaxy properties from a set of input halo properties that include halo mass, concentration, spin, and halo overdensity. For stellar mass, the Pearson correlation coefficient is 0.98, dropping down to 0.7–0.8 for specific star formation rate (sSFR), colour, and size. In addition, we apply, for the first time in this context, an existing data augmentation method, *synthetic minority oversampling technique for regression with Gaussian noise* (SMOGN), designed to alleviate the problem of imbalanced data sets, showing that it improves the overall shape of the predicted distributions and the scatter in the halo–galaxy relations. We also demonstrate that our predictions are good enough to reproduce the power spectra of multiple galaxy populations, defined in terms of stellar mass, sSFR, colour, and size with high accuracy. Our results align with previous reports suggesting that certain galaxy properties cannot be reproduced using halo features alone.

https://academic.oup.com/mnras/article/514/2/2463/6595312?login=false

Robust Field-level Likelihood-free Inference with Galaxies

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Abstract

We train graph neural networks to perform field-level likelihood-free inference using galaxy catalogs from state-of-the-art hydrodynamic simulations of the CAMELS project. Our models are rotational, translational, and permutation invariant and do not impose any cut on scale. From galaxy catalogs that only contain 3D positions and radial velocities of $\sim$1000 galaxies in tiny $(25\,h^{-1}\mathrm{Mpc})^3$ volumes our models can infer the value of Ω_m with approximately 12% precision. More importantly, by testing the models on galaxy catalogs from thousands of hydrodynamic simulations, each having a different efficiency of supernova and active galactic nucleus feedback, run with five different codes and subgrid models—IllustrisTNG, SIMBA, Astrid, Magneticum, SWIFT-EAGLE—we find that our models are robust to changes in astrophysics, subgrid physics, and subhalo/galaxy finder. Furthermore, we test our models on 1024 simulations that cover a vast region in parameter space—variations in five cosmological and 23 astrophysical parameters—finding that the model extrapolates really well. Our results indicate that the key to building a robust model is the use of both galaxy positions and velocities, suggesting that the network has likely learned an underlying physical relation that does not depend on galaxy formation and is valid on scales larger than $\sim 10\,h^{-1}$ kpc.

https://iopscience.iop.org/article/10.3847/1538-4357/acd1e2

cosmologia com simulações

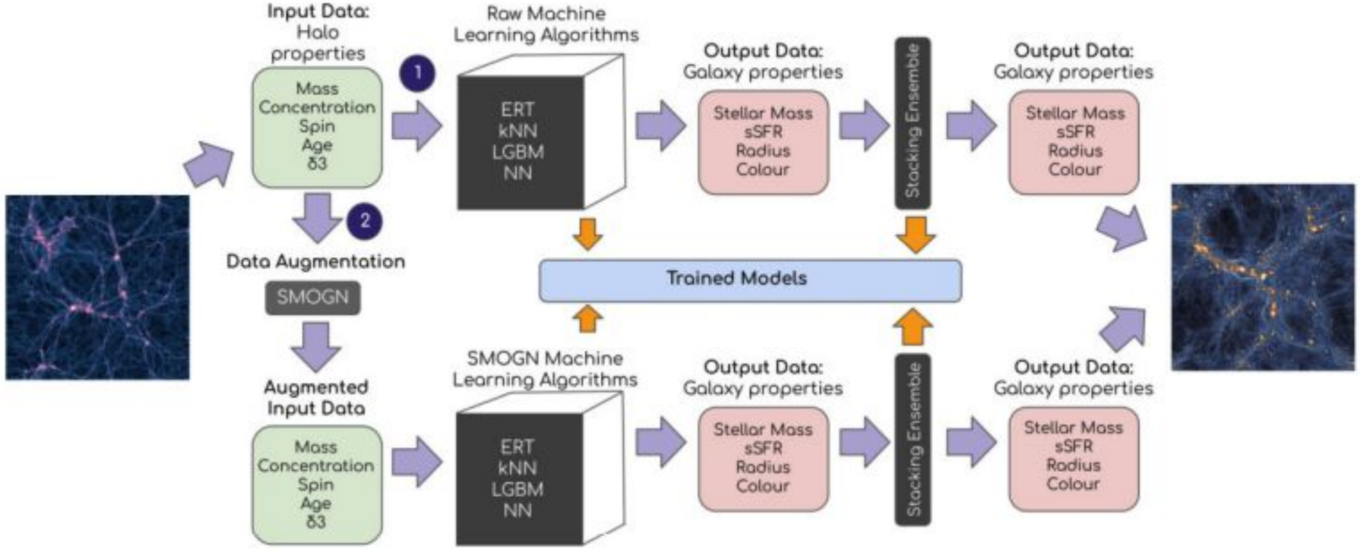

Figure 1. A schematic summary of the methodology is followed in this analysis. First, a data pre-selection is performed in order to generate the input data set. Once this initial catalogue is constructed, our method takes two different paths: in Path 1 (top panel), several ML algorithms are applied (ERT, kNN, LGBM, and NN) to the input data set; these are the 'raw' models. A separate approach, which employs the SMOGN data augmentation technique, is shown in Path 2 (bottom panel). Subsequently, the same ML methods are applied to the SMOGN input data set. Both paths result in trained models for the galaxy properties. Finally, we have also implemented a stacking ML technique separately for each path, where all ML methods for the corresponding path are combined. The final output data set comprises our predictions for the galaxy properties under analysis.

extensões de ΛCDM

Dark Energy Survey Year 3 Results: Constraints on extensions to ΛCDM with weak lensing and galaxy clustering

(DES Collaboration)

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(DES Collaboration)

https://arxiv.org/pdf/2207.05766

extensões de ΛCDM

Dark Energy Survey Year 3 Results: Constraints on extensions to ΛCDM with weak lensing and galaxy clustering

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D. Thomas,[9] C. To,[46] A. Troja,[76,2] M. A. Troxel,[33] I. Tu
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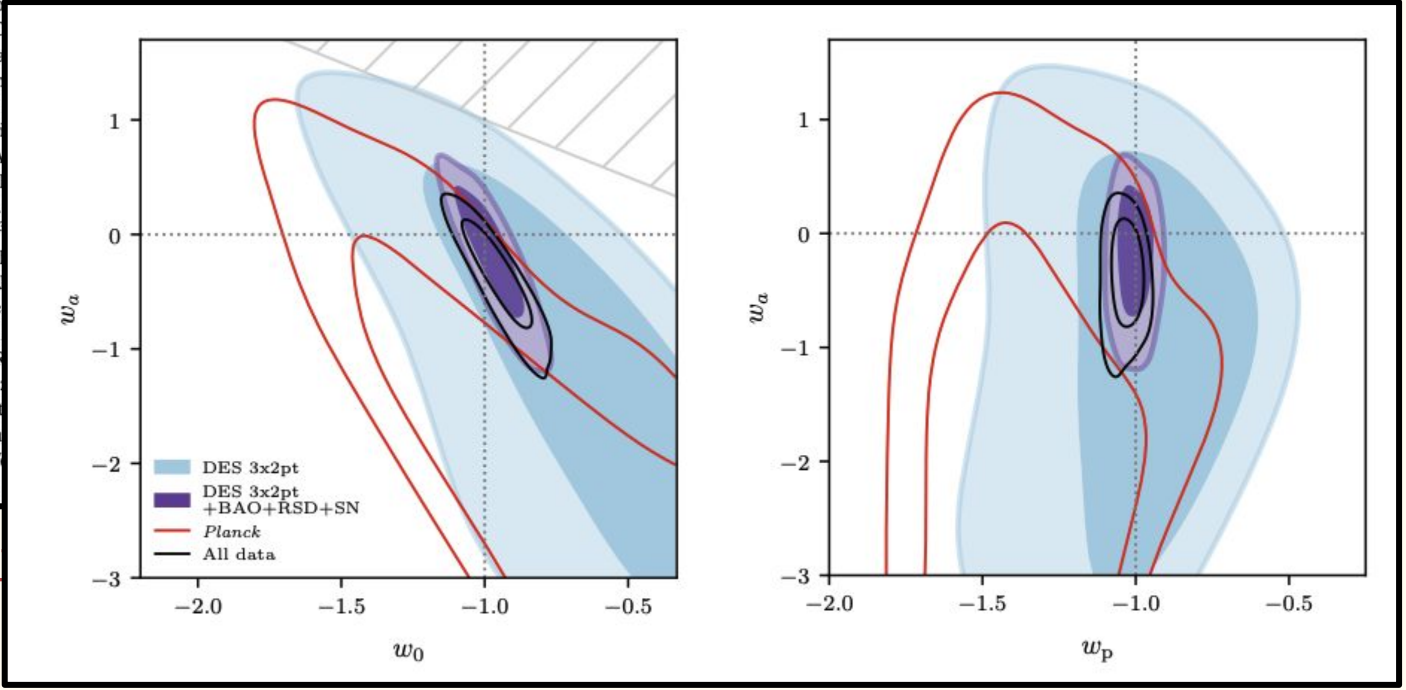

https://arxiv.org/pdf/2207.05

blinding

https://arxiv.org/pdf/2404.07282

Validating the Galaxy and Quasar Catalog-Level Blinding Scheme for the DESI 2024 analysis

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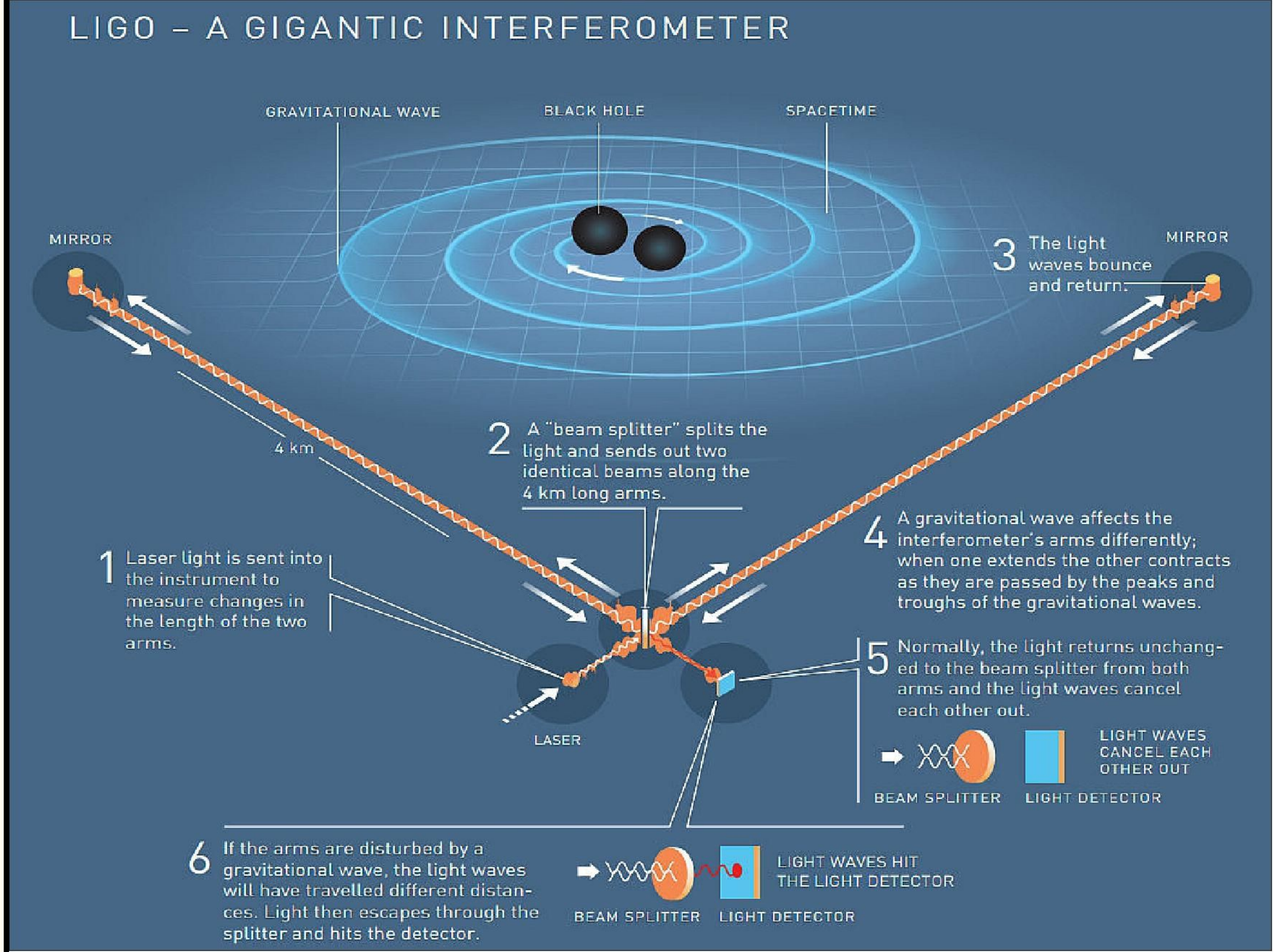

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THE ELECTROMAGNETIC COUNTERPART OF THE BINARY NEUTRON STAR MERGER LIGO/VIRGO GW170817. I.
DISCOVERY OF THE OPTICAL COUNTERPART USING THE DARK ENERGY CAMERA

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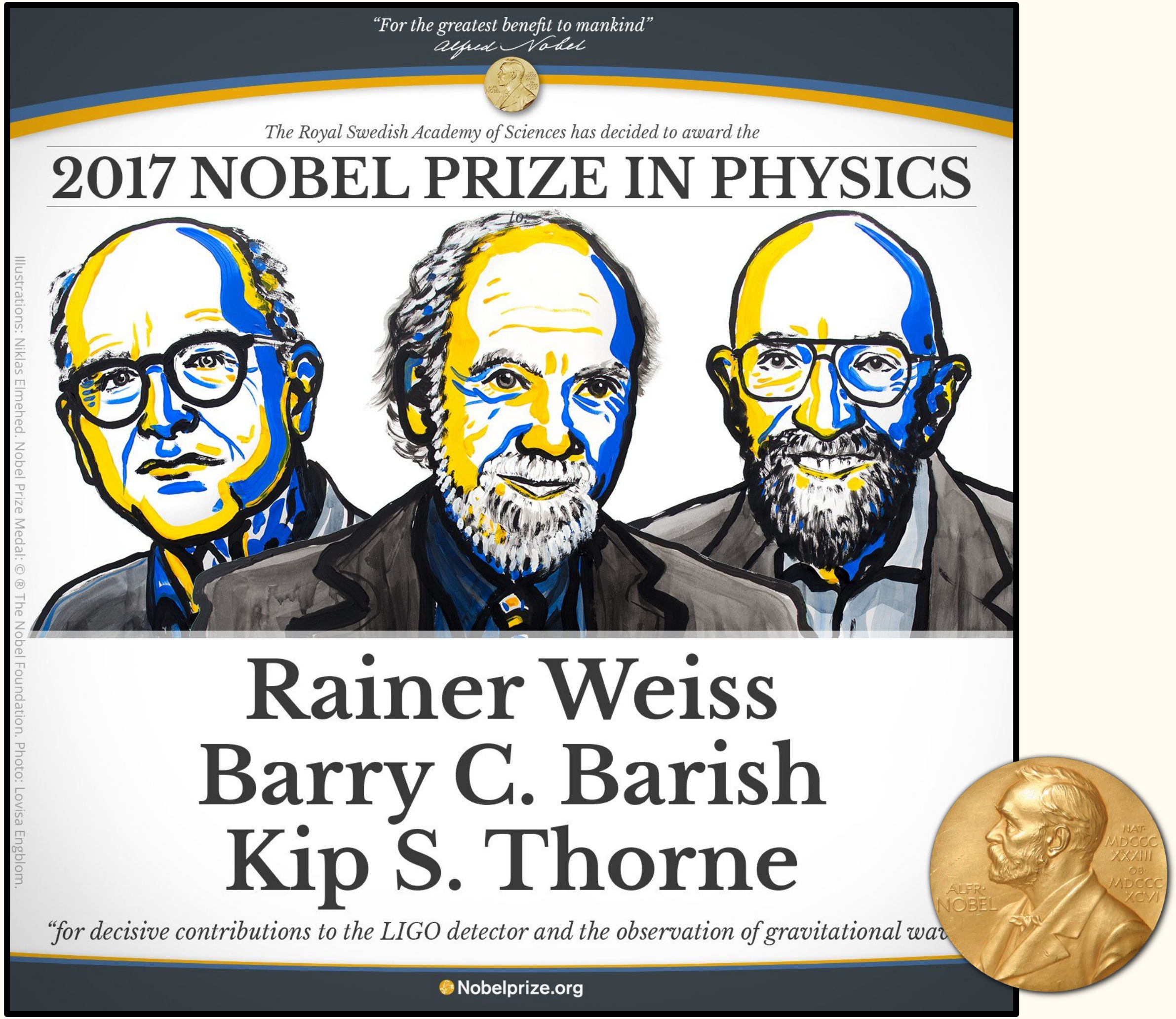

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