O LADO ESCURO DO UNIVERSO

Pedro Abreu
LIP/IST, Lisboa
Escola de Profs no CERN em Língua Portuguesa 2019

(Heinrich Wilhelm Olbers, 1823)

- Porque é que o Universo é escuro?

E porque era isto um paradoxo?

Se o Universo é infinito e eterno (e com uma densidade de estrelas ±uniforme), então todas as linhas de visão deveriam terminar na superfície de uma estrela.

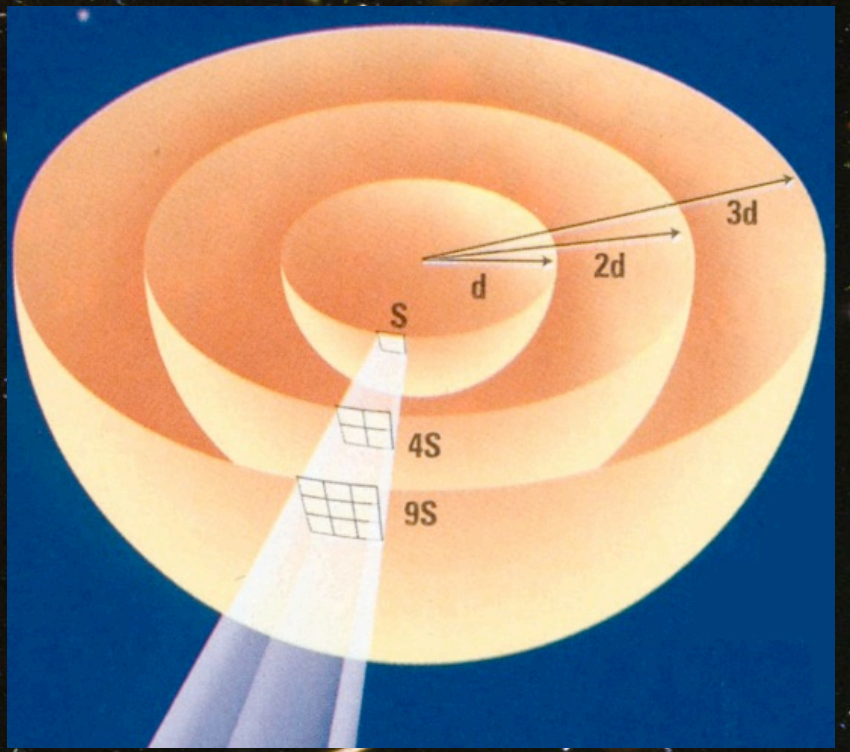
Formalmente:

Cada camada contribui com nº estrelas ~ r^2
A luz diminui de intensidade com ~$1/r^2$
Contribuição de luz de cada camada = constante

O Céu deveria ser cheio de luz

Consequência:

O UNIVERSO NÃO PODE SER INFINITO E ETERNO!

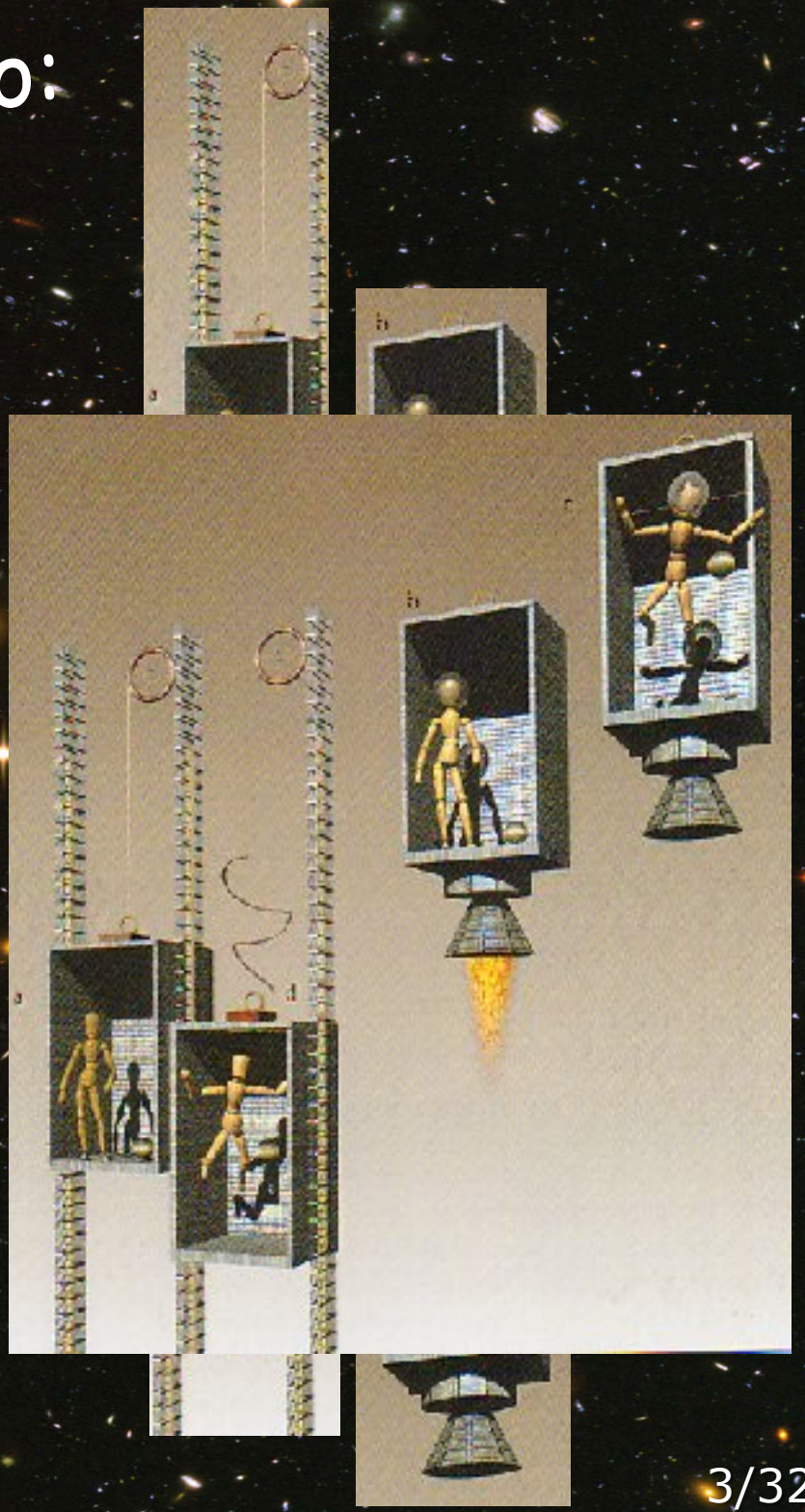


Uma teoria para o Universo:

Relatividade Geral (1915 !)

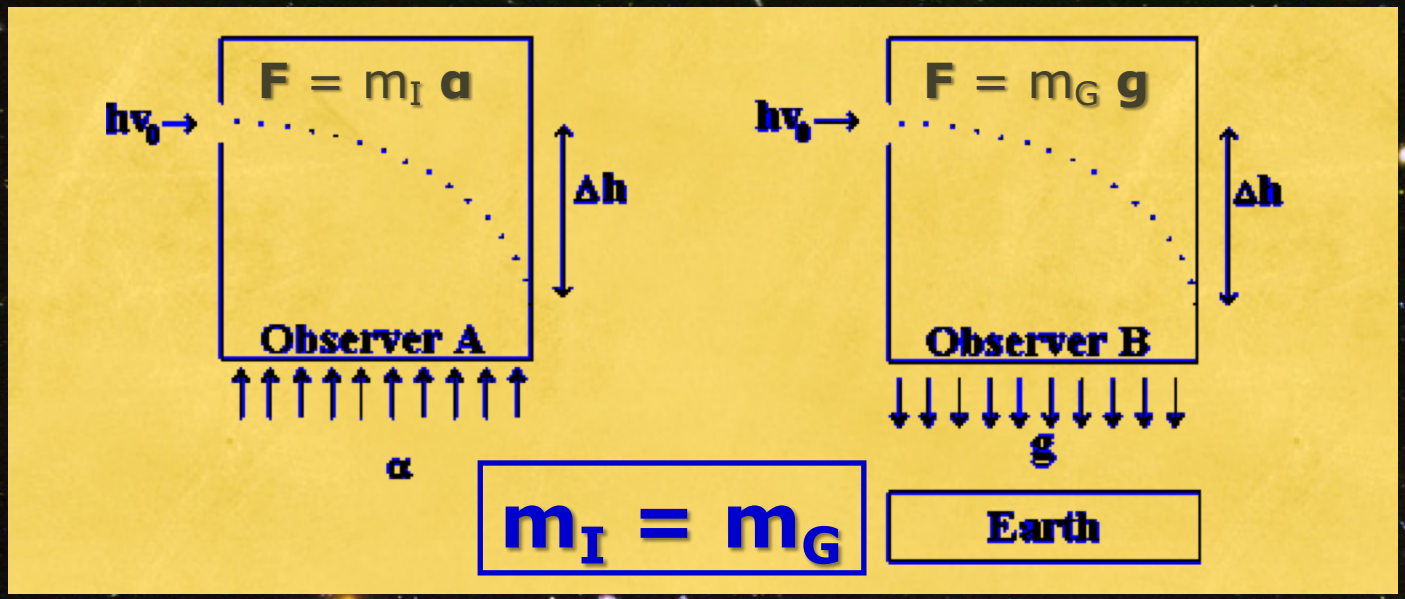
Não se pode realizar nenhuma experiência, de qualquer natureza, que nos permita distinguir um referencial acelerado e um referencial sujeito à gravidade!

Então e se ligar uma **lanterna** ?!



Princípio de Equivalência

1907



Massa Inercial = Massa Gravítica

Aceleração = Gravitação

"A Ideia mais feliz da minha vida" (Albert Einstein)

A Teoria da Relatividade Geral

O caminho mais curto no espaço-tempo é definido pela trajetória dos raios de luz.

Elevador acelerado: luz segue uma trajectória parabólica

Campo Gravítico: raios de luz são curvados!

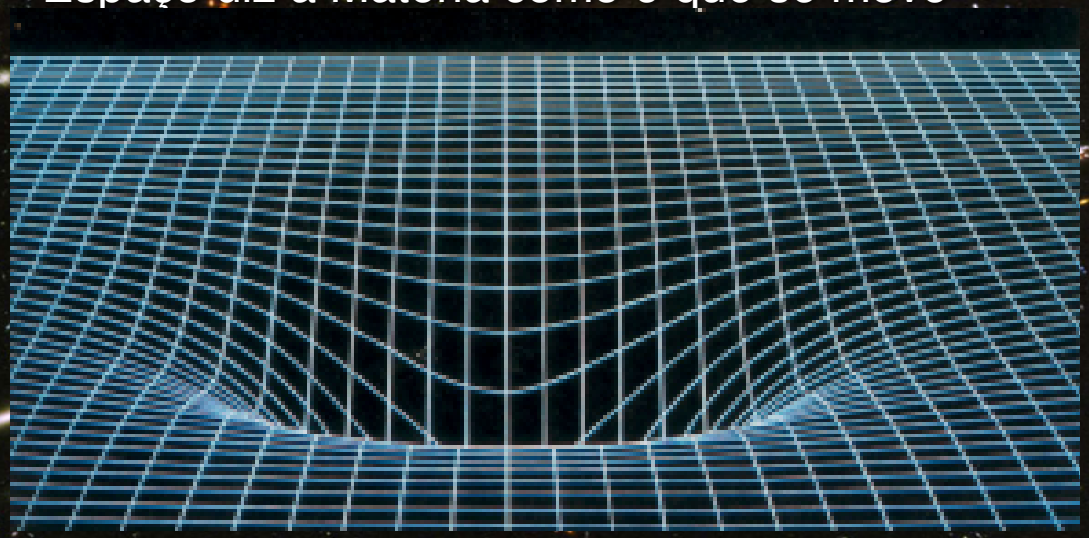
Espaço e Tempo são curvos!

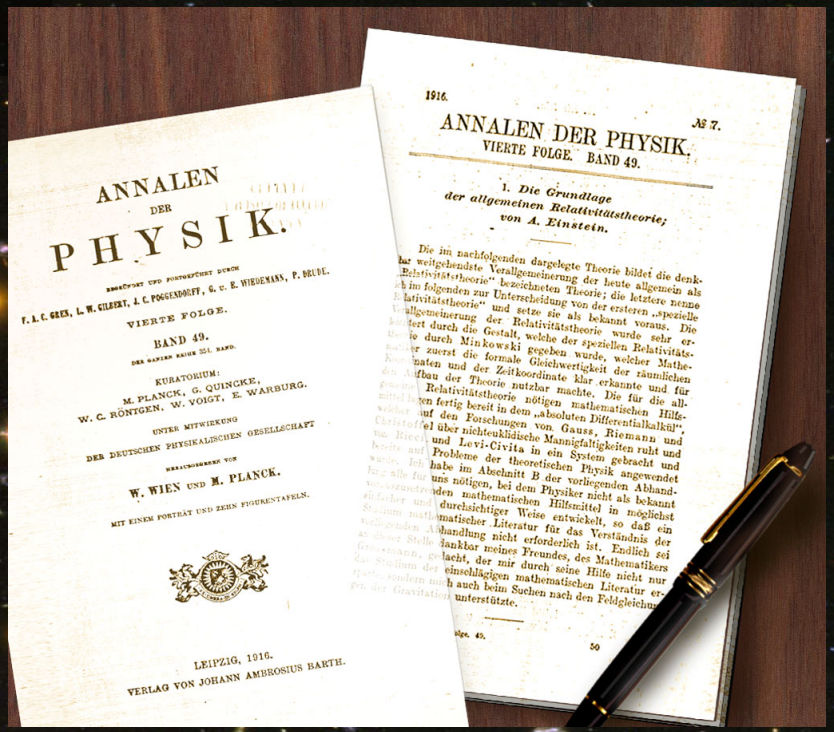
Albert Einstein (1912-15) : Relatividade Geral

$$G\mu\nu = 8\pi T\mu\nu \cdot G/c^4$$

Matéria diz ao Espaço como se curva

Espaço diz à Matéria como é que se move





Einstein 1917:

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

↓

(Constante Cosmológica)

$$R_{\eta\eta} = -\frac{2a^2\frac{\partial\psi}{\partial\delta}\cot\theta}{\delta\psi} + \frac{2ac\frac{\partial\psi}{\partial\eta}\cot\theta}{\delta\psi} + \frac{a\frac{\partial c}{\partial\eta}\cot\theta}{\delta} - \frac{\frac{\partial a}{\partial\eta}c\cot\theta}{\delta} - \frac{a\frac{\partial a}{\partial\theta}\cot\theta}{d} - \frac{2a^2\frac{\partial^2\psi}{\partial\theta^2}}{d\psi}$$

$$- \frac{a\frac{\partial a}{\partial\theta}c\frac{\partial c}{\partial\theta}}{2d^2} - \frac{a\frac{\partial a}{\partial\eta}b\frac{\partial c}{\partial\theta}}{2d^2} - \frac{a\frac{\partial b}{\partial\eta}c\frac{\partial c}{\partial\eta}}{2d^2} - \frac{a^2\frac{\partial b}{\partial\theta}\frac{\partial c}{\partial\eta}}{2d^2} + \frac{a\frac{\partial a}{\partial\eta}\frac{\partial b}{\partial\theta}c}{4d^2} - \frac{a\frac{\partial a}{\partial\theta}\frac{\partial b}{\partial\eta}c}{4d^2}$$

$$- \frac{2a^2\left(\frac{\partial\psi}{\partial\theta}\right)^2}{\delta\psi^2}$$

$$+ \frac{ab\frac{\partial b}{\partial\eta}c\frac{\partial\psi}{\partial\eta}}{\delta^2\psi} + \frac{\frac{\partial a}{\partial\eta}b^2c\frac{\partial\psi}{\partial\eta}}{\delta^2\psi} - \frac{a^2b\frac{\partial b}{\partial\theta}\frac{\partial\psi}{\partial\eta}}{\delta^2\psi} - \frac{a\frac{\partial a}{\partial\theta}b^2\frac{\partial\psi}{\partial\eta}}{\delta^2\psi} + \frac{\frac{\partial d}{\partial\eta}\frac{\partial d}{\partial\theta}}{4d^2} - \frac{\frac{\partial a}{\partial\theta}c\frac{\partial d}{\partial\theta}}{4\delta d}$$

$$- \frac{3a\frac{\partial a}{\partial\theta}\frac{\partial\psi}{\partial\theta}}{\delta\psi} -$$

$$+ \frac{a\frac{\partial b}{\partial\eta}\frac{\partial d}{\partial\theta}}{4\delta d} - \frac{\frac{\partial^2 d}{\partial\eta\partial\theta}}{2d} - \frac{\frac{\partial b}{\partial\eta}c\frac{\partial d}{\partial\eta}}{4\delta d} + \frac{\frac{\partial a}{\partial\theta}b\frac{\partial d}{\partial\eta}}{4\delta d} - \frac{\frac{\partial c}{\partial\eta}\frac{\partial c}{\partial\theta}}{\delta} + \frac{\frac{\partial a}{\partial\theta}\frac{\partial c}{\partial\theta}}{2\delta}$$

$$R_{\eta\theta} = -\frac{2}{}$$

$$+ \frac{a^2\frac{\partial a}{\partial\theta}b}{\delta^2\psi}$$

$$+ \frac{c\frac{\partial^2 c}{\partial\eta\partial\theta}}{\delta} + \frac{\frac{\partial b}{\partial\eta}\frac{\partial c}{\partial\eta}}{2\delta} - \frac{\frac{\partial^2 b}{\partial\eta^2}c}{2\delta} - \frac{\frac{\partial^2 a}{\partial\theta^2}c}{2\delta} - \frac{\frac{\partial a}{\partial\eta}\frac{\partial b}{\partial\theta}}{4\delta} + \frac{\frac{\partial a}{\partial\theta}\frac{\partial b}{\partial\eta}}{4\delta}$$

$$- \frac{2}{}$$

$$+ \frac{ac\frac{\partial d}{\partial\theta}}{\delta d\psi}$$

$$+ \frac{ab\frac{\partial c}{\partial\eta}\frac{\partial c}{\partial\theta}}{\delta^2} - \frac{\frac{\partial a}{\partial\eta}bc\frac{\partial c}{\partial\theta}}{2\delta^2} - \frac{a\frac{\partial a}{\partial\theta}b\frac{\partial c}{\partial\delta}}{2\delta^2} - \frac{a\frac{\partial b}{\partial\delta}c\frac{\partial c}{\partial\eta}}{2\delta^2} - \frac{ab\frac{\partial b}{\partial\eta}\frac{\partial c}{\partial\eta}}{2\delta^2} + \frac{a\frac{\partial a}{\partial\theta}\frac{\partial b}{\partial\theta}c}{4\delta^2}$$

$$- \frac{}{}$$

$$+ \frac{2a^2b\frac{\partial c}{\partial\theta}\frac{\partial\psi}{\partial\eta}}{\delta^2\psi} -$$

$$+ \frac{2ab}{}$$

$$+ \frac{a\left(\frac{\partial b}{\partial\eta}\right)^2c}{4\delta^2} + \frac{\frac{\partial a}{\partial\eta}b\frac{\partial b}{\partial\eta}c}{4\delta^2} + \frac{\left(\frac{\partial a}{\partial\theta}\right)^2bc}{4\delta^2} + \frac{a\frac{\partial a}{\partial\eta}b\frac{\partial b}{\partial\theta}}{4\delta^2} - \frac{a\frac{\partial a}{\partial\theta}b\frac{\partial b}{\partial\eta}}{4\delta^2}$$

$$+ \frac{}{}$$

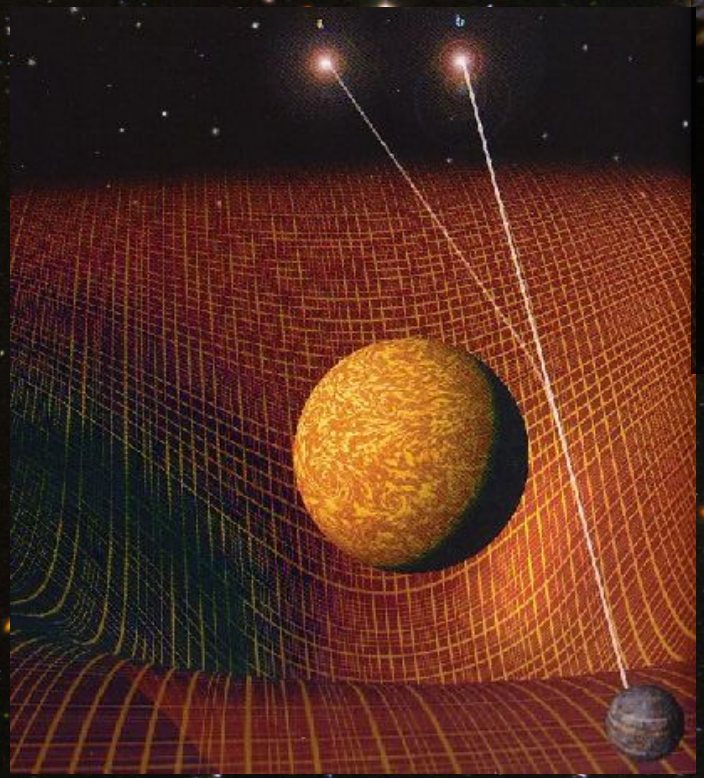
$$+ \frac{}{}$$

$$R_{\theta\theta} = -\frac{2ab\frac{\partial\psi}{\partial\theta}\cot\theta}{\delta\psi} + \frac{2bc\frac{\partial\psi}{\partial\eta}\cot\theta}{\delta\psi} - \frac{\frac{\partial d}{\partial\theta}\cot\theta}{d} - \frac{c\frac{\partial c}{\partial\theta}\cot\theta}{\delta} + \frac{\frac{\partial b}{\partial\eta}c\cot\theta}{2\delta} + \frac{a\frac{\partial b}{\partial\delta}\cot\theta}{2\delta}$$

$$+ \frac{2b}{}$$

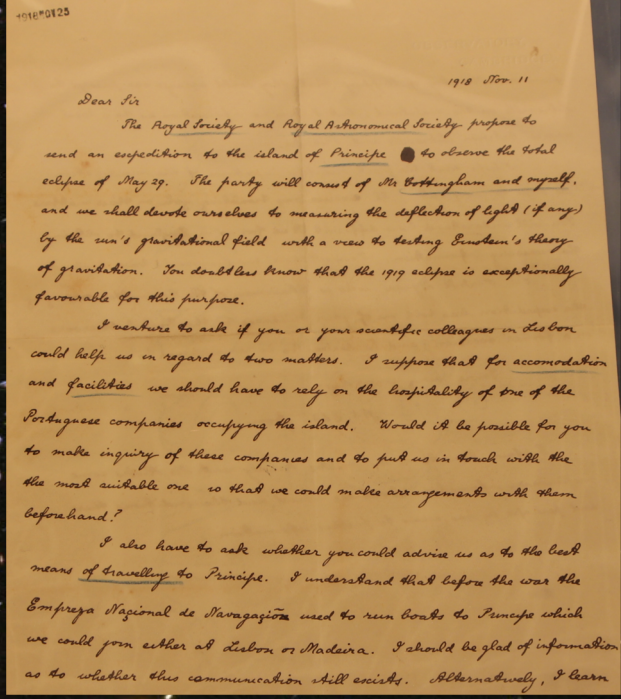
$$- \frac{2ab\frac{\partial^2\psi}{\partial\theta^2}}{\delta\psi} - \frac{2\frac{\partial^2\psi}{\partial\theta^2}}{\psi} - \frac{2ab\left(\frac{\partial\psi}{\partial\theta}\right)^2}{\delta\psi^2} + \frac{6\left(\frac{\partial\psi}{\partial\theta}\right)^2}{\psi^2} + \frac{4bc\frac{\partial\psi}{\partial\eta}\frac{\partial\psi}{\partial\theta}}{\delta\psi^2} - \frac{ab\frac{\partial d}{\partial\delta}\frac{\partial\psi}{\partial\theta}}{\delta d\psi}$$

A Luz desviada pelo Sol (1919 !)



Confirmado por
Sir Arthur Eddington
Ilha do Príncipe,
29 de Maio de 1919

(resultado idêntico e
simultâneo em Sobral, Brasil)



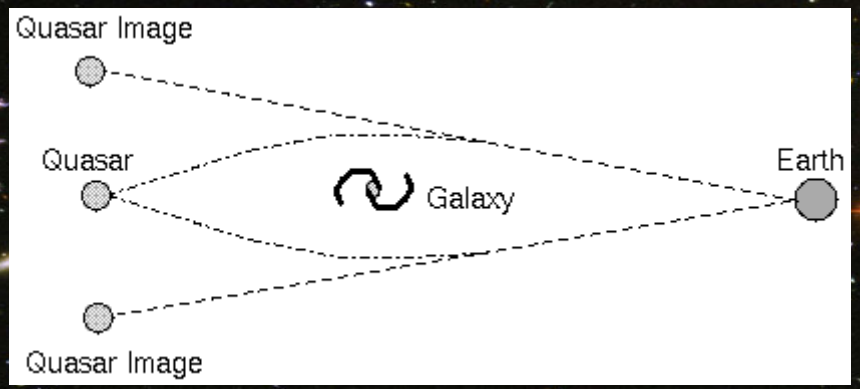
1918 Nov. 11

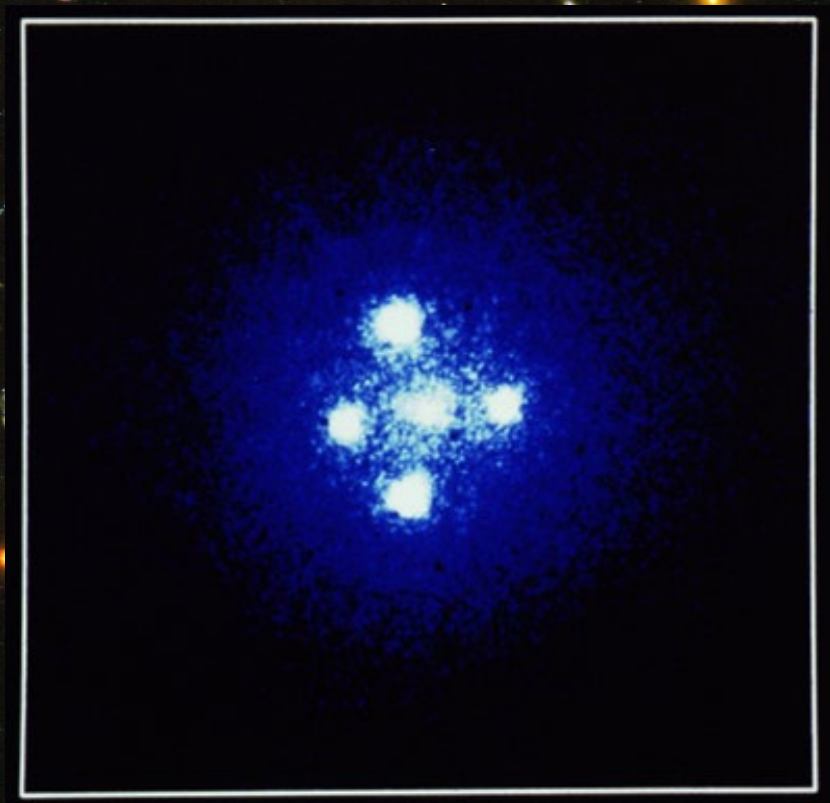
Dear Sir

The Royal Society and Royal Astronomical Society propose to send an expedition to the island of Principe to observe the total eclipse of May 29. The party will consist of Mr Cottingham and myself, and we shall devote ourselves to measuring the deflection of light (if any) by the sun's gravitational field with a view to testing Einstein's theory of gravitation. You doubtless know that the 1919 eclipse is exceptionally favourable for this purpose.

I venture to ask if you or your scientific colleagues in Lisbon could help us in regard to two matters. I suppose that for accomodation and facilities we should have to rely on the hospitality of one of the Portuguese companies occupying the island. Would it be possible for you to make inquiry of these companies and to put us in touch with the the most suitable one so that we could make arrangements with them beforehand?

I also have to ask whether you could advise us as to the best means of travelling to Principe. I understand that before the war the Empreza Nazional de Navagaçion used to run boats to Principe which we could join either at Lisbon or Madeira. I should be glad of information as to whether this communication still exists. Alternatively, I learn



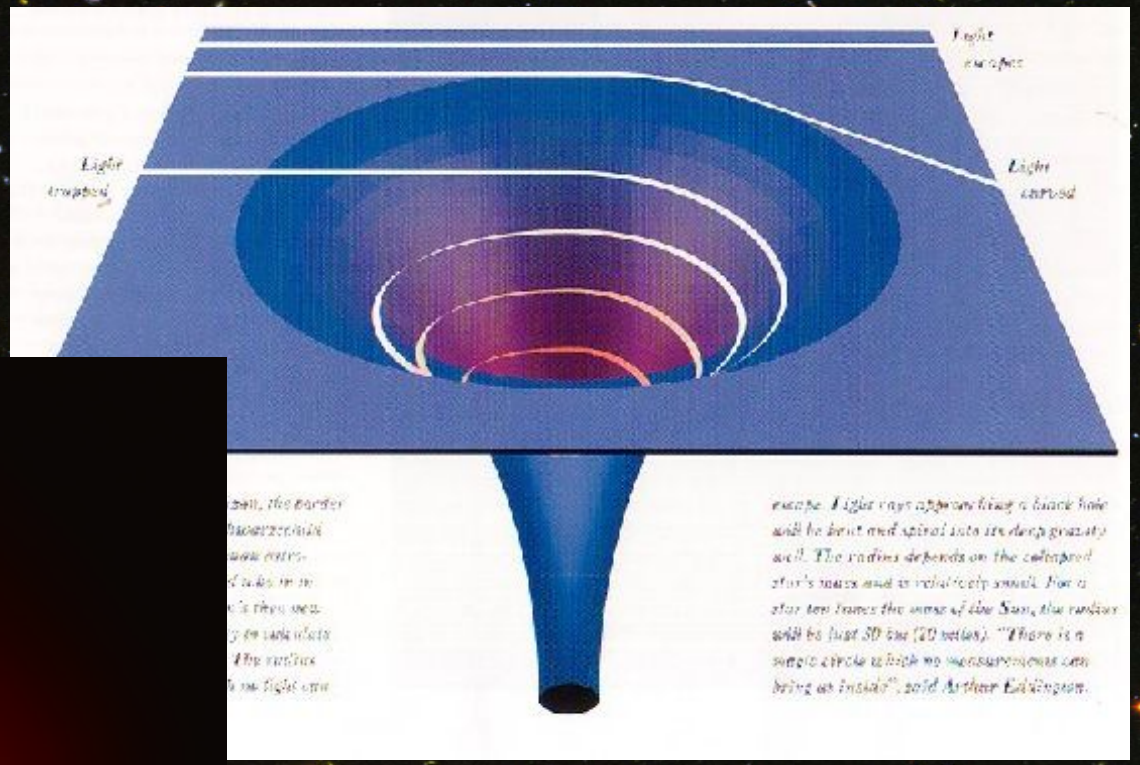


Gravitational Lens G2237+0305

Caso limite: Buraco Negro

John Mitchell (1728)

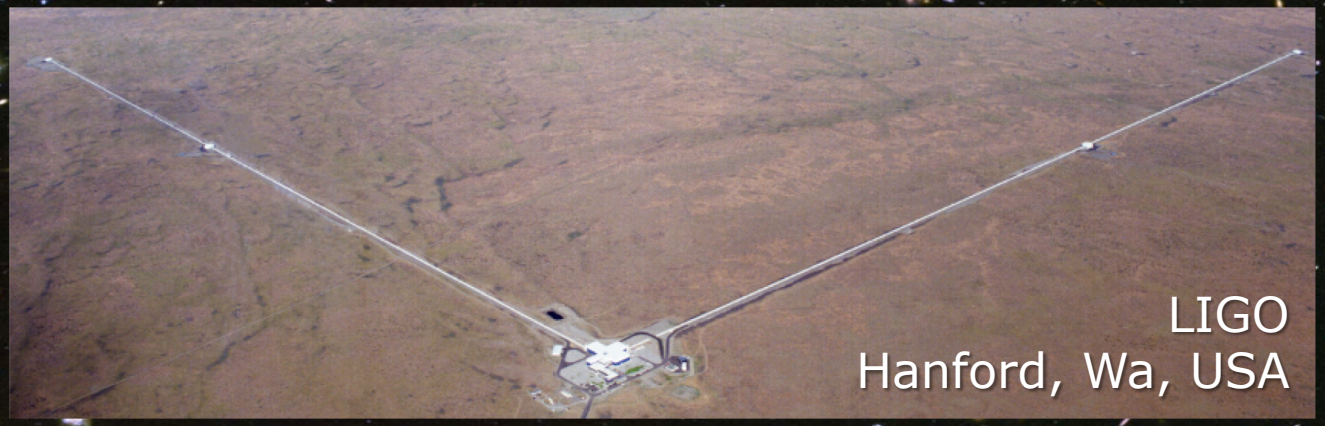
$$v_{esc} = \sqrt{\frac{2G_N M}{r}} > c$$

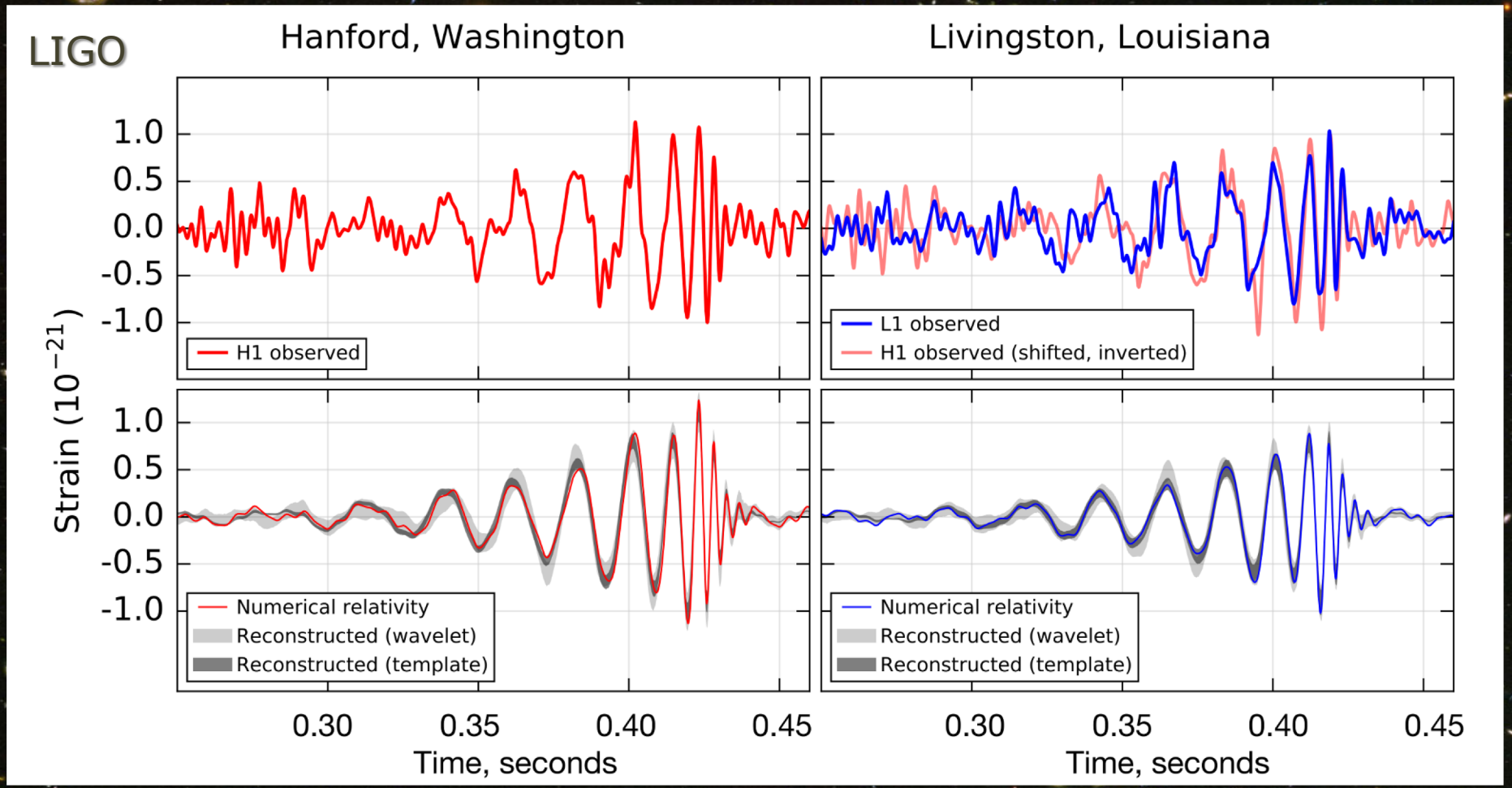


$$r_S = \sqrt{\frac{2G_N M}{c^2}}$$

Ondas Gravitacionais

LIGO (USA)
Virgo/EGO (Itália/França)

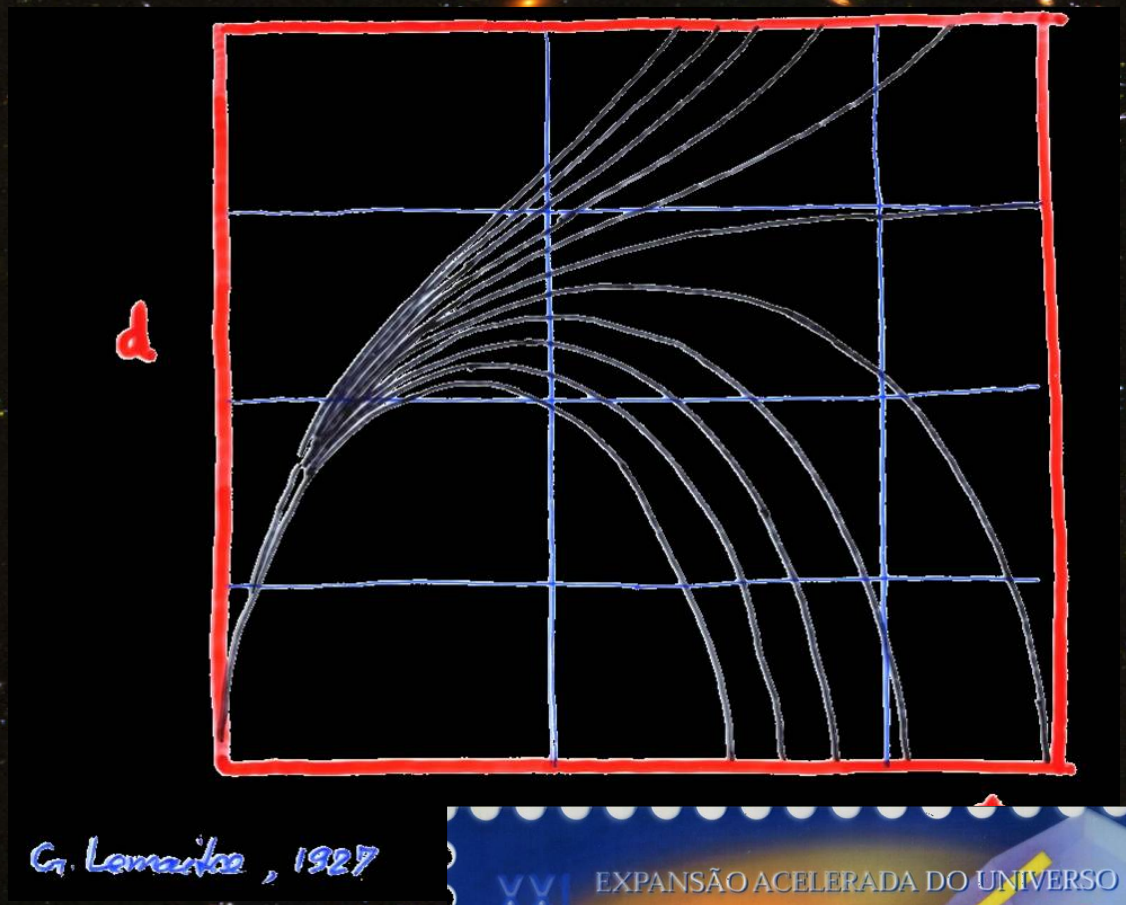


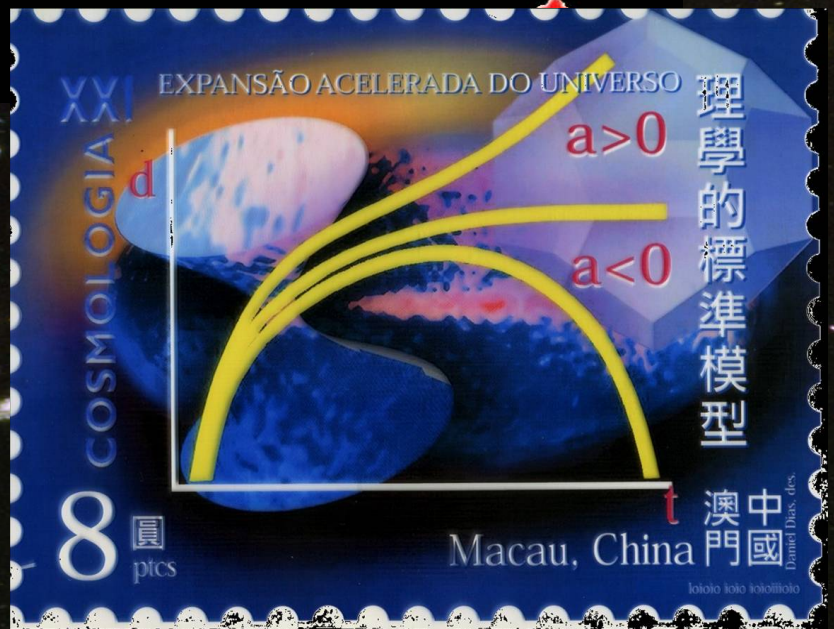


https://youtu.be/Zt8Z_uzG71o

https://youtu.be/ZD4TXK4wQgU

EXPANSÃO DO UNIVERSO!

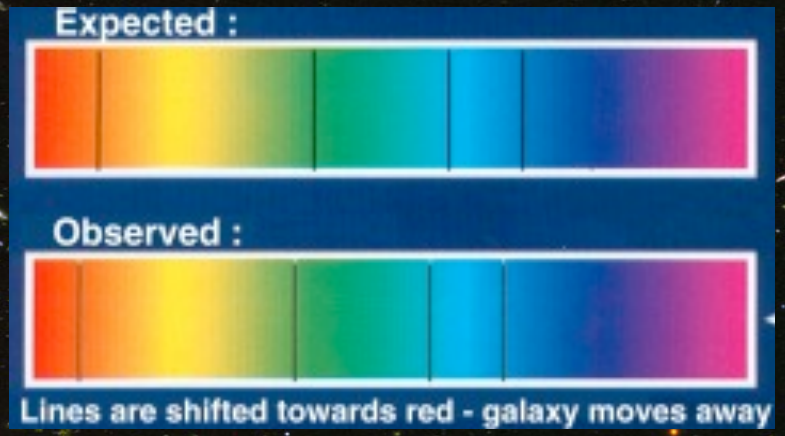




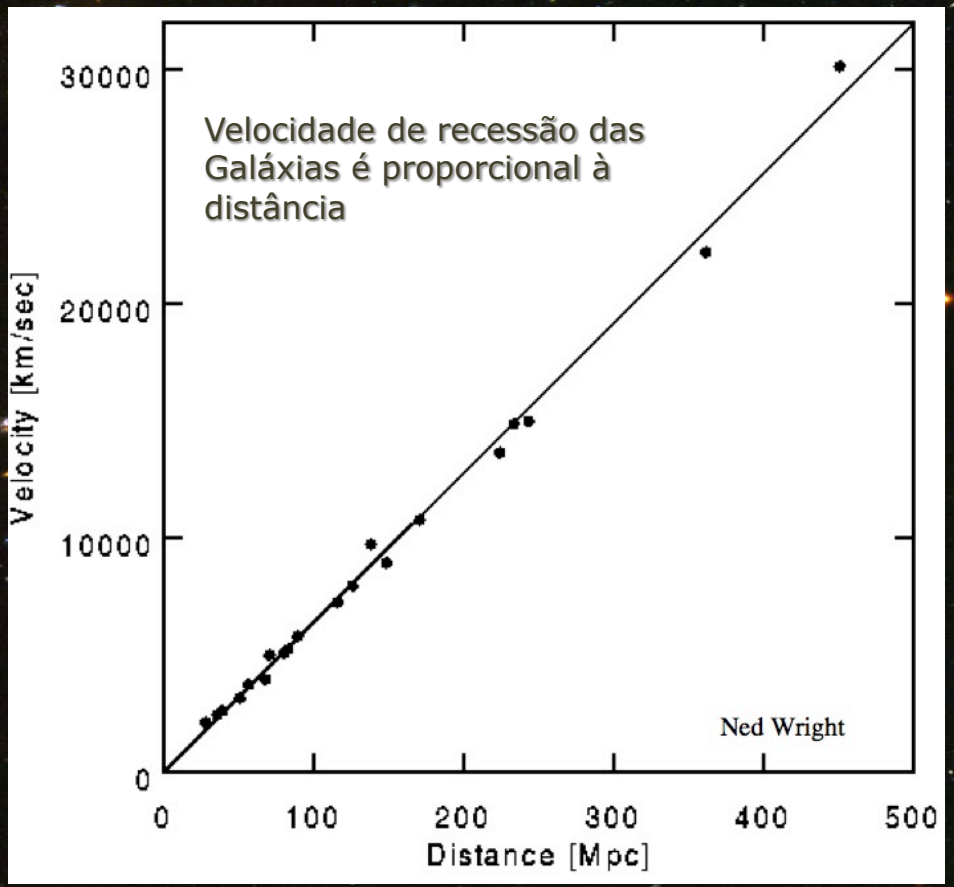
George Lemaitre (1927)

Todo o Universo Expande!
Um ‘átomo primordial quente’ ?

EXPANSÃO DO UNIVERSO!

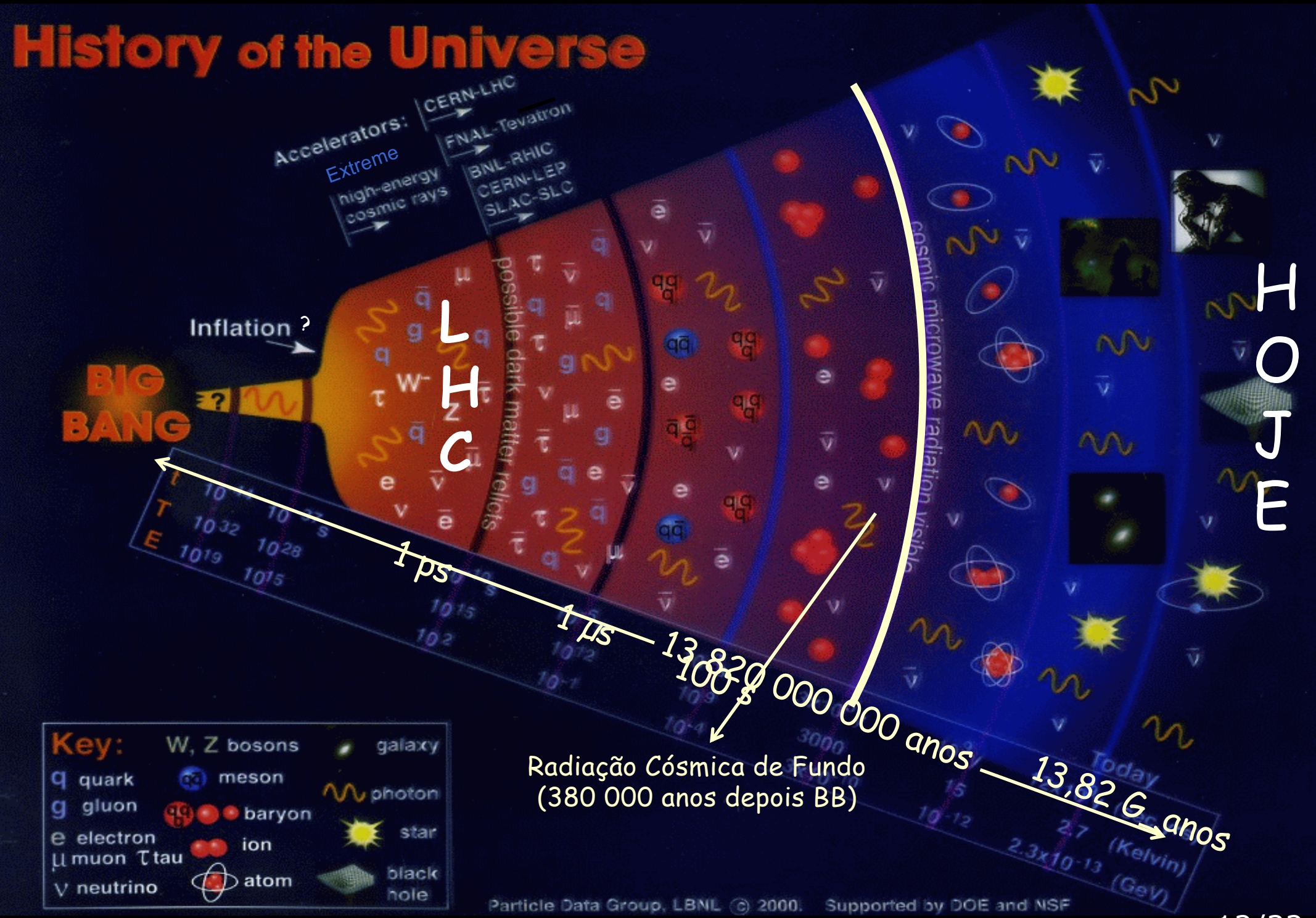


Edwin Hubble (1929)
Mt. Palomar telescope



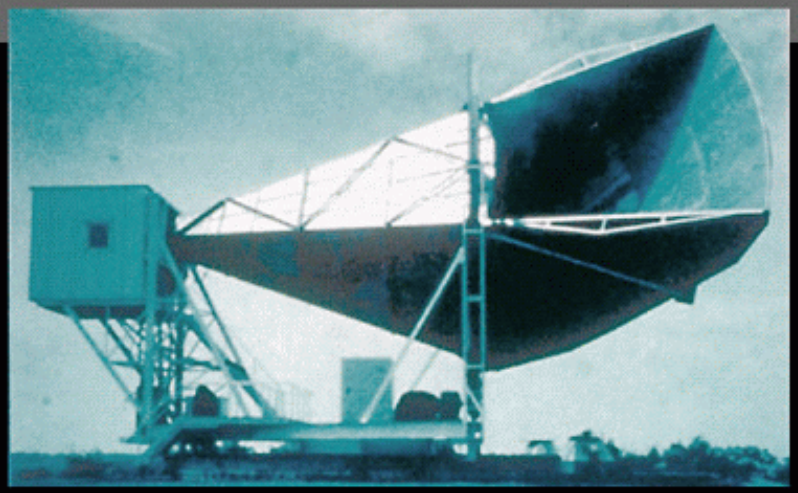
Einstein afirma:

a constante cosmológica = 'o meu maior erro'

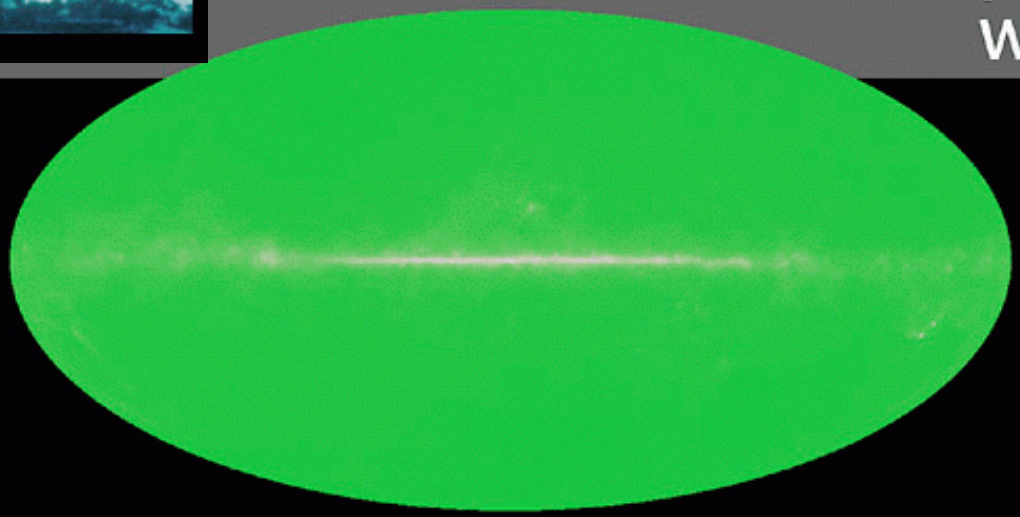

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
Extreme
high-energy
cosmic rays
Inflation ?
BIG BANG
?
LHC
possible dark matter relics
cosmic microwave radiation visible
HOJE
1 ps
1 μs
100 s
13 820 000 000 anos
13,82 G anos
Radiação Cósmica de Fundo
(380 000 anos depois BB)
Today
3000
2.7 (Kelvin)
2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
galaxy
photon
star
black hole
Particle Data Group, LBNL © 2000. Supported by DOE and NSF

A Radiação Cósmica de Fundo

1965

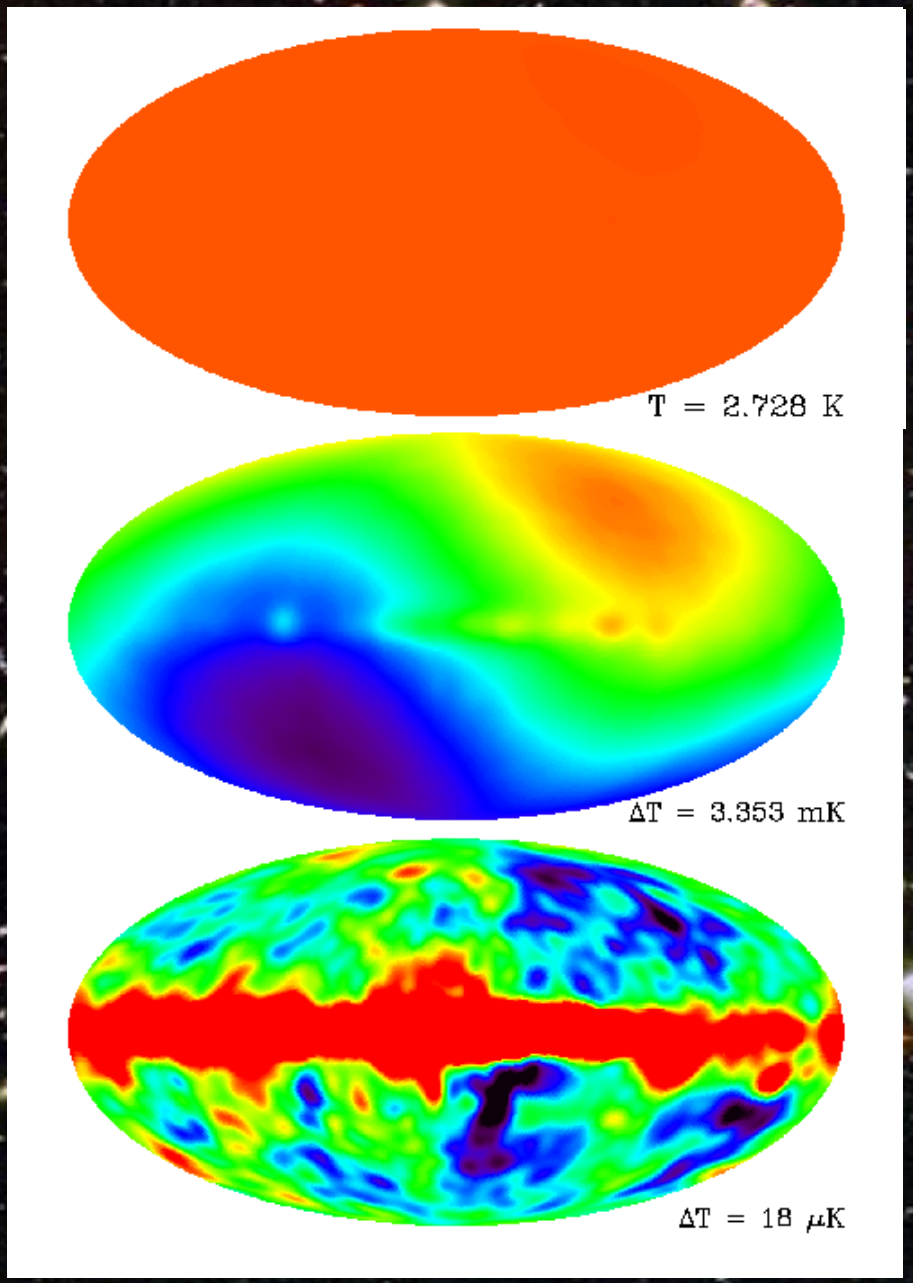


Penzias and Wilson



Prémio Nobel 1978

Estudo da Radiação Cósmica de Fundo (COBE)
(Prémio Nobel 2006)



T= 2.725 K **Penzias & Wilson, Prémio Nobel 1965**

ΔT= 3.3 mK (0,0033 K)

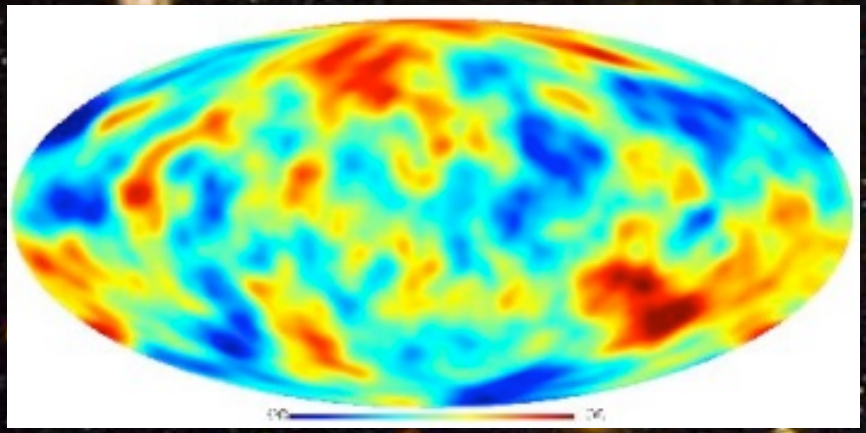
(depois da subtracção do fundo comum)

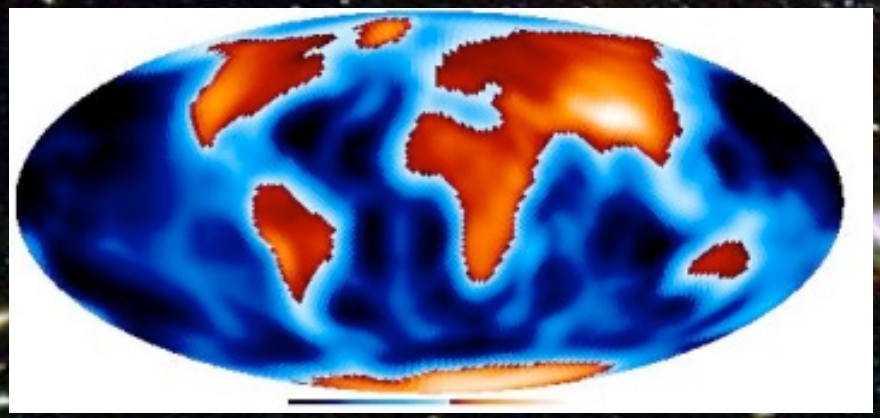
Δ T= 18 μK (0,000 018 K)

(depois de corrigido para o mov. Terra)

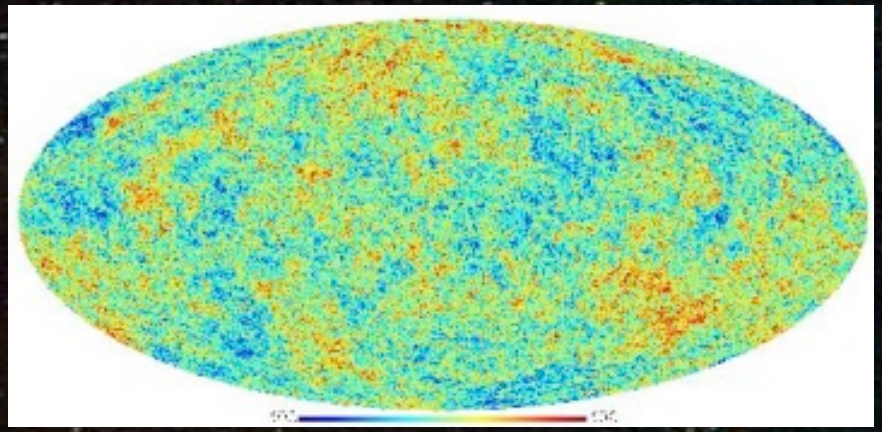
WMAP (2003): uma observação mais precisa

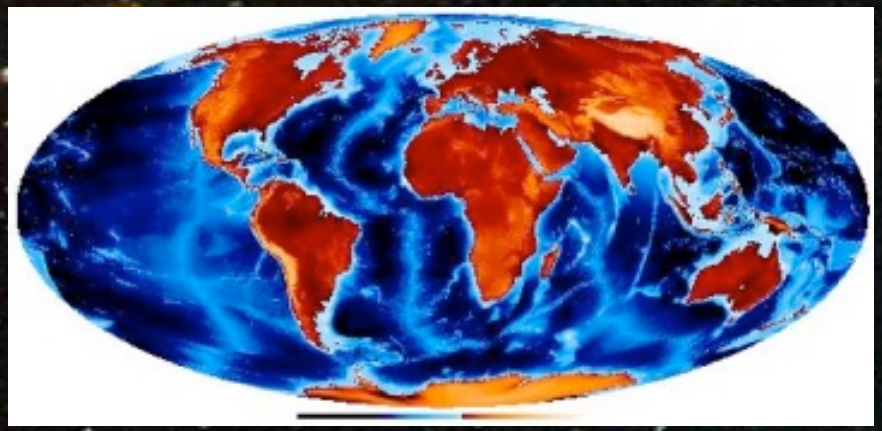
COBE
(7 degree resolution)



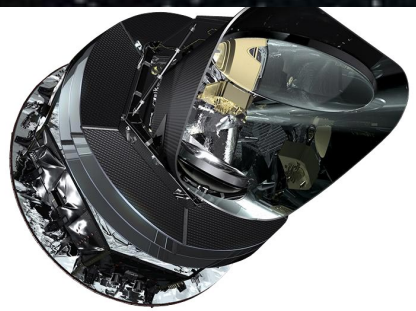


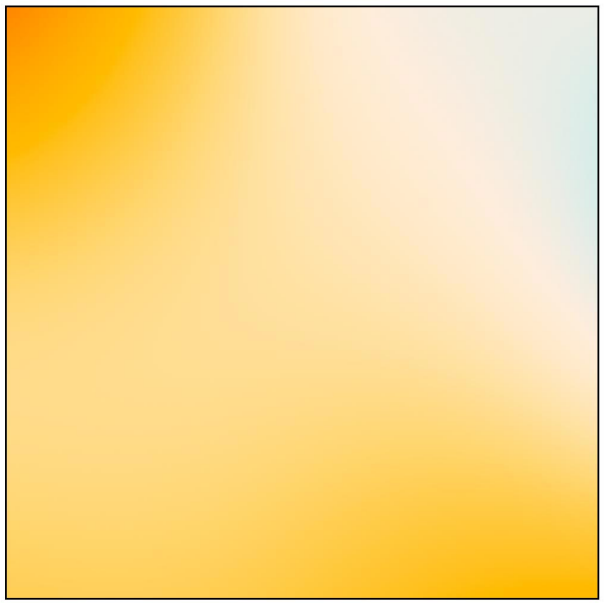
WMAP
(0.25 degree resolution)

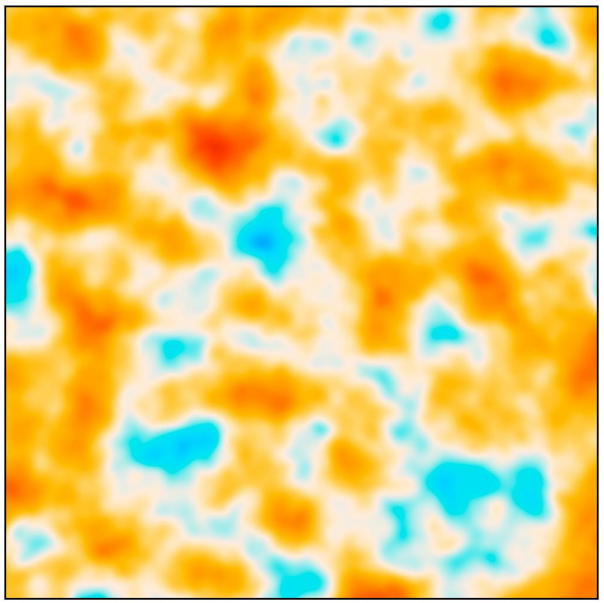


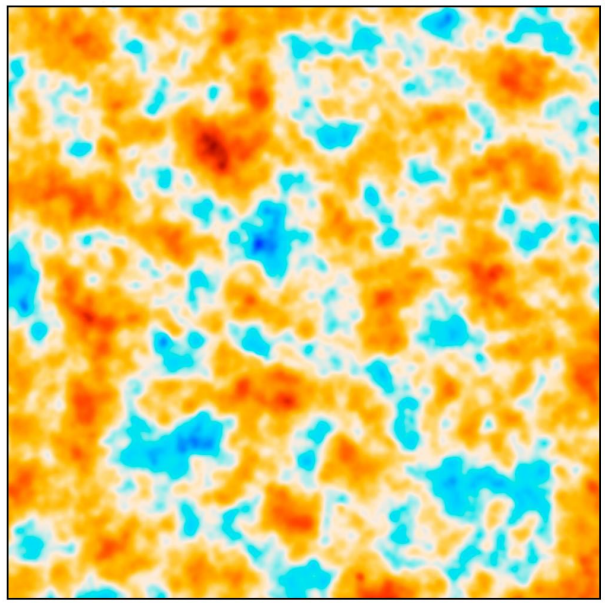


PLANCK (2013): uma observação AINDA mais precisa









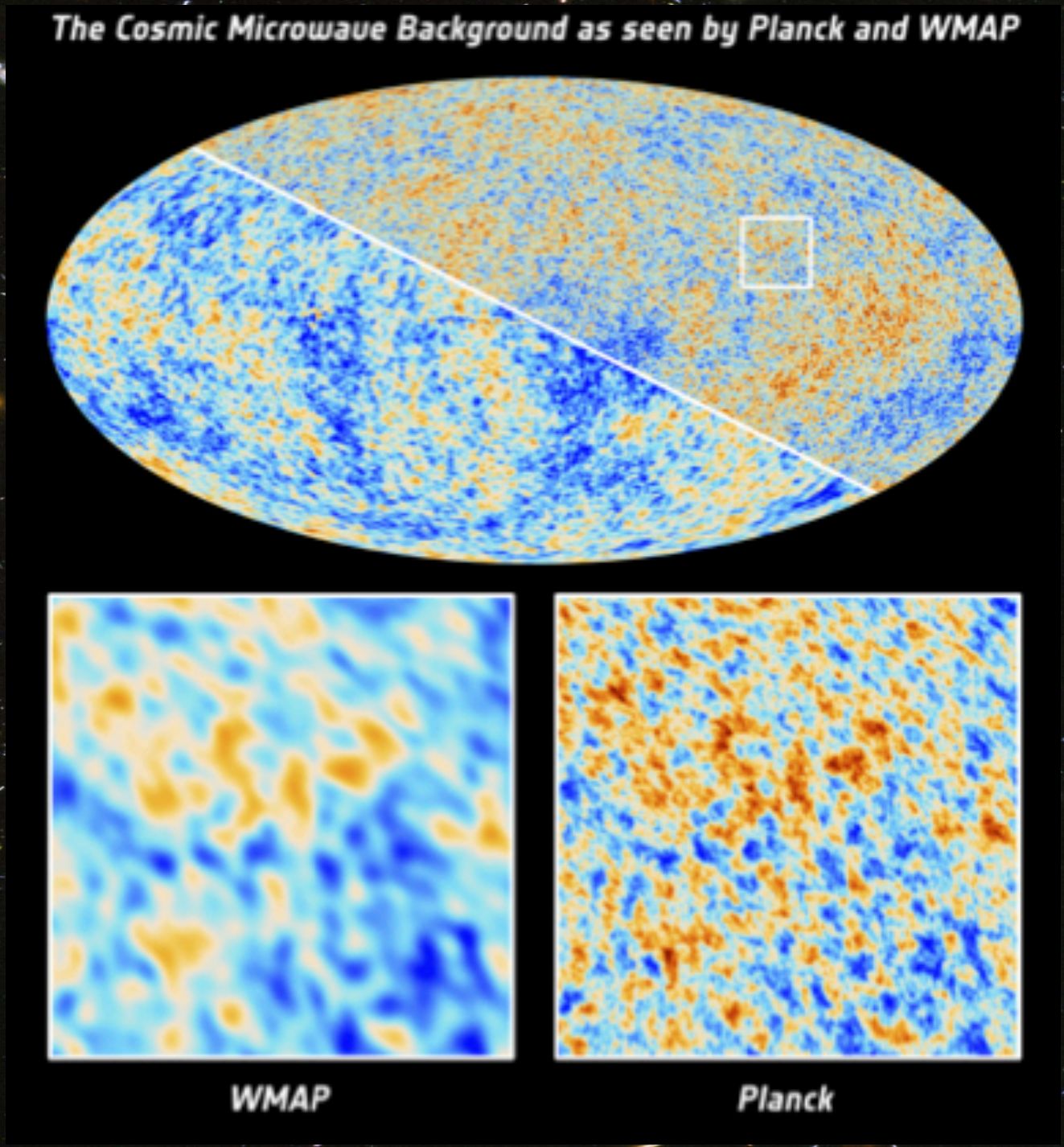
COBE
1990

WMAP
2003

Planck
2013

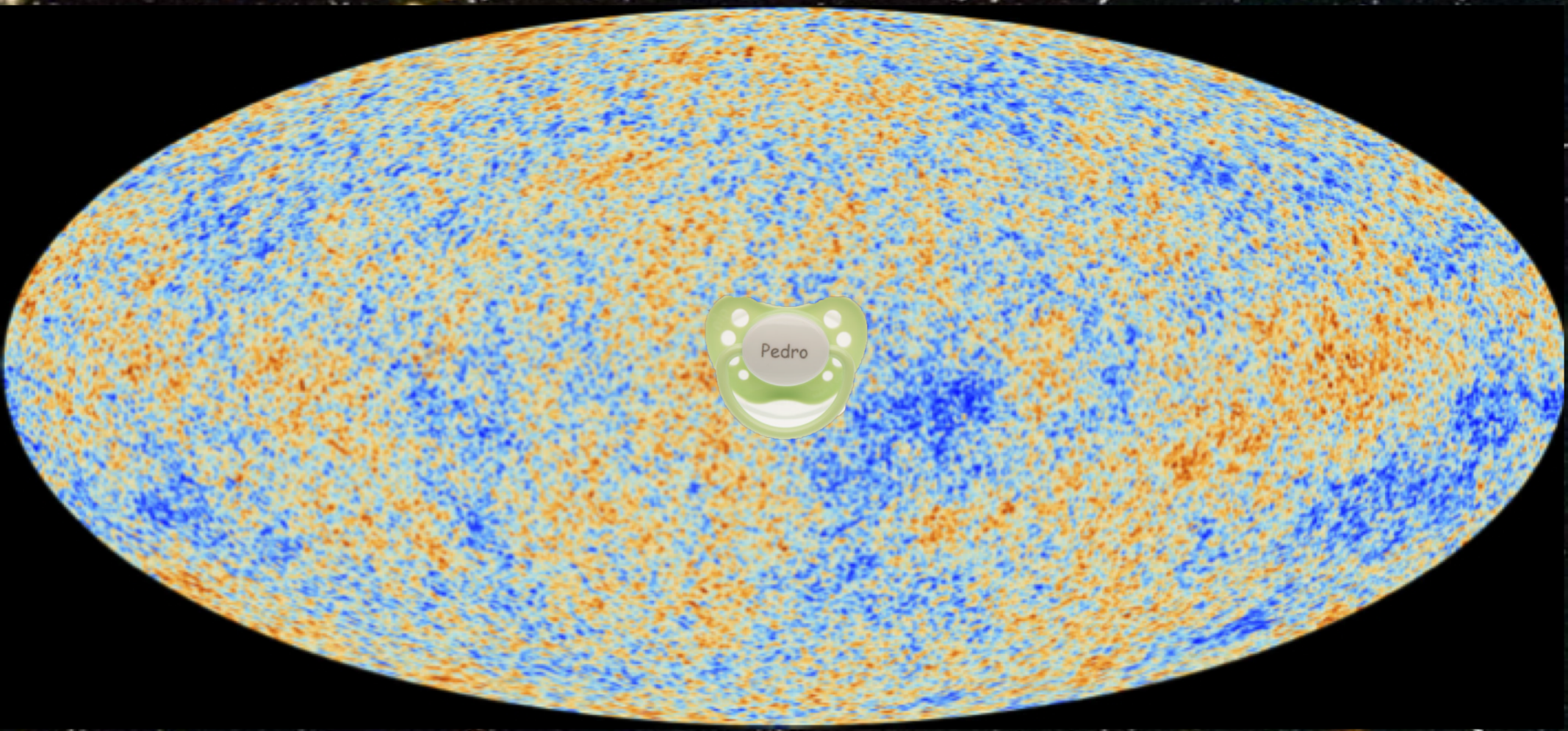
PLANCK (2013):

uma observação
AINDA
mais precisa

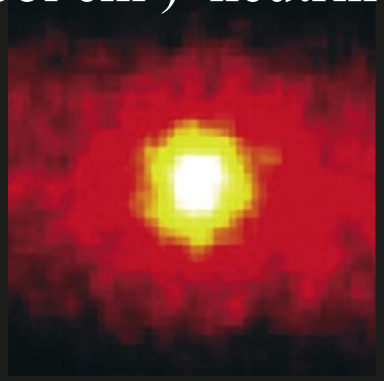


PLANCK (2013)

Uma fotografia do Universo bébé (idade de 380 000 anos)



(Sol em) neutrinos



Raios Cósmicos de Energia Extrema

O UNIVERSO INVISÍVEL

Ótico

InfraVerm.

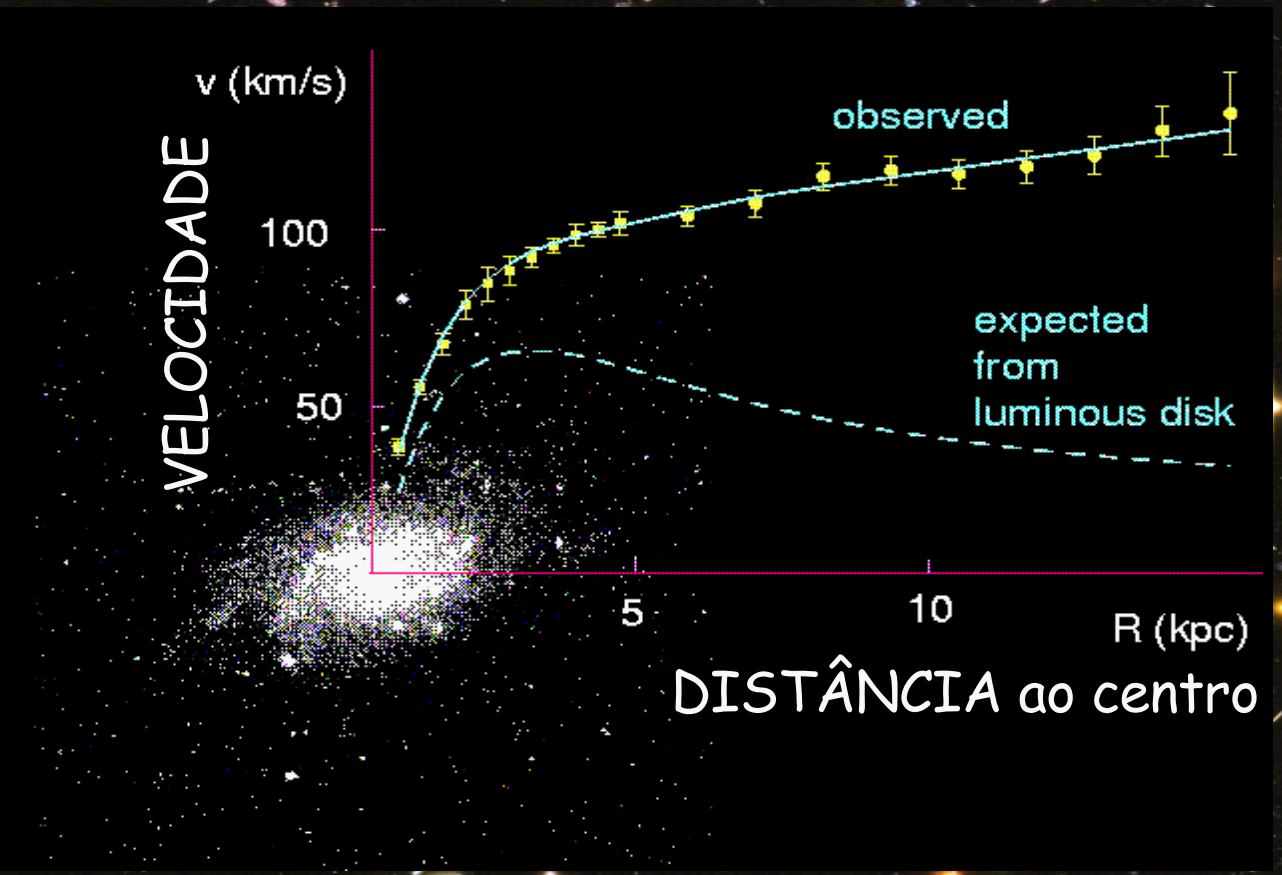
UltraVioleta

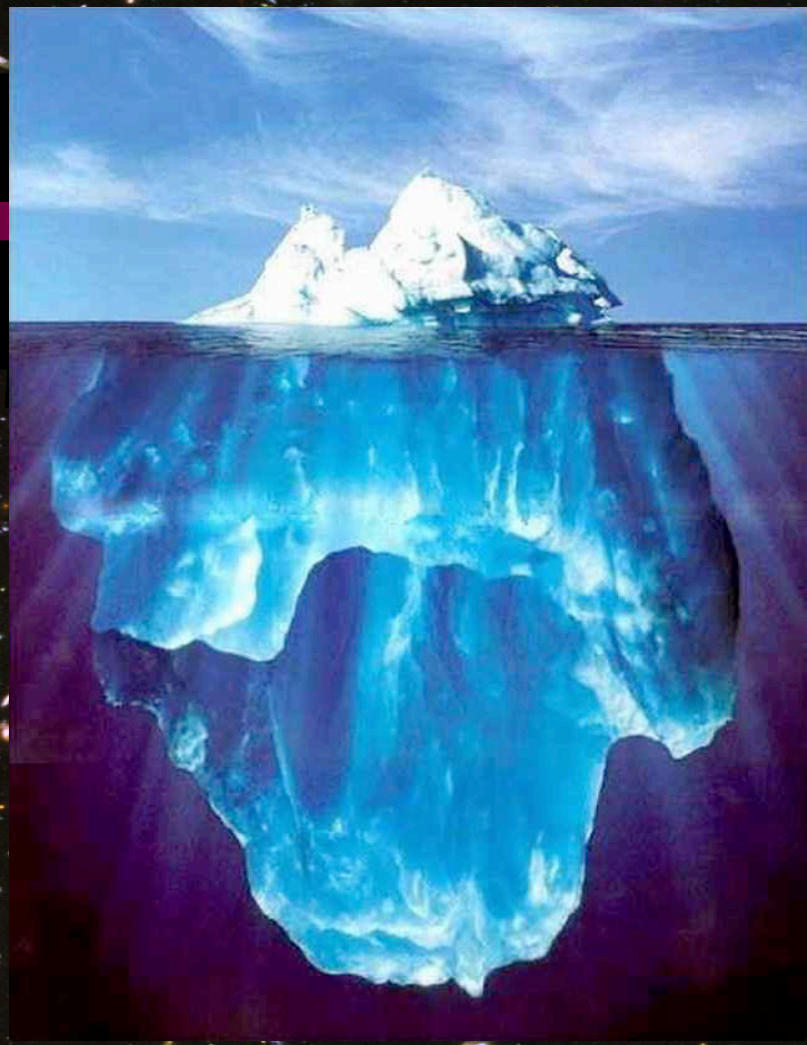
Raios-X

Ondas Rádio

pedro abreu - ao Encontro do Infinito...

O Problema da Matéria Escura

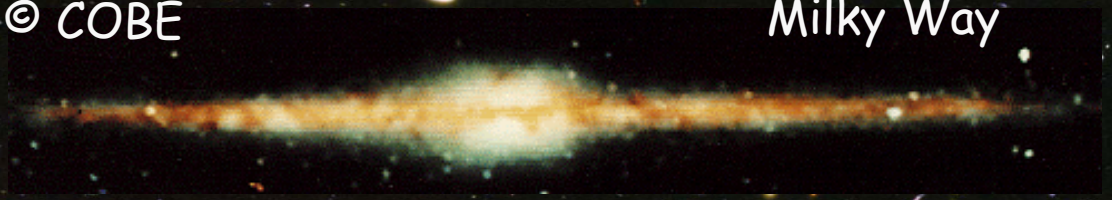


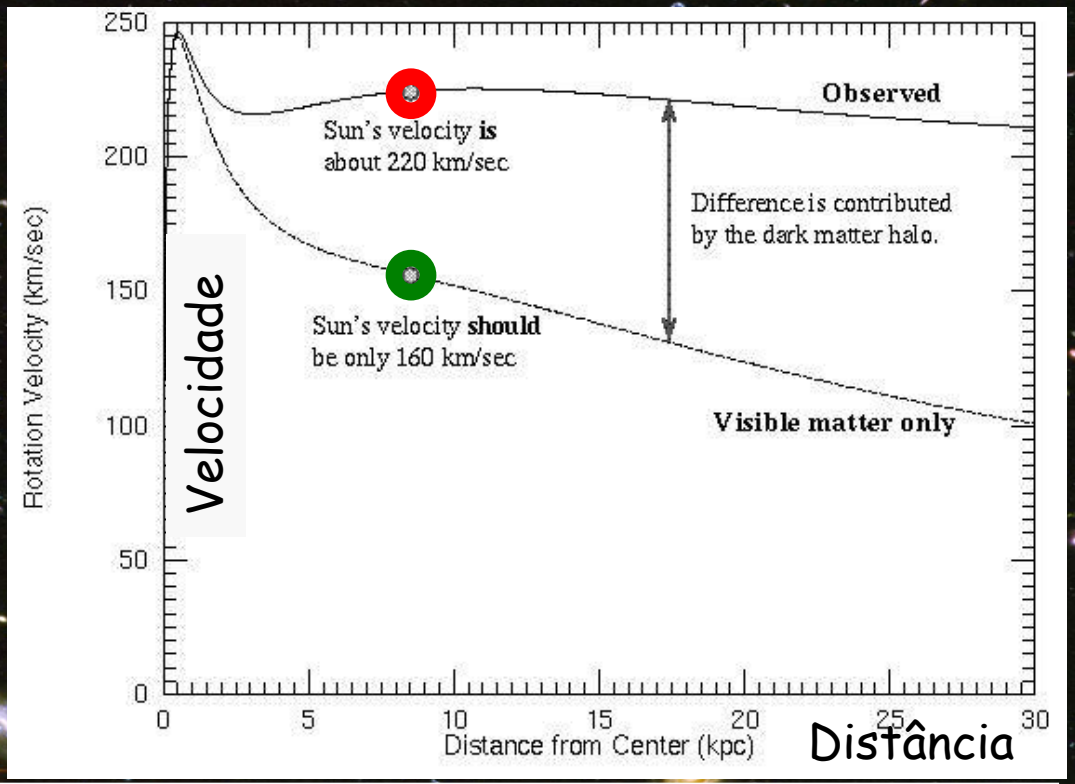


©A.De Angelis

Maior fracção de massa não brilha! O que será?!

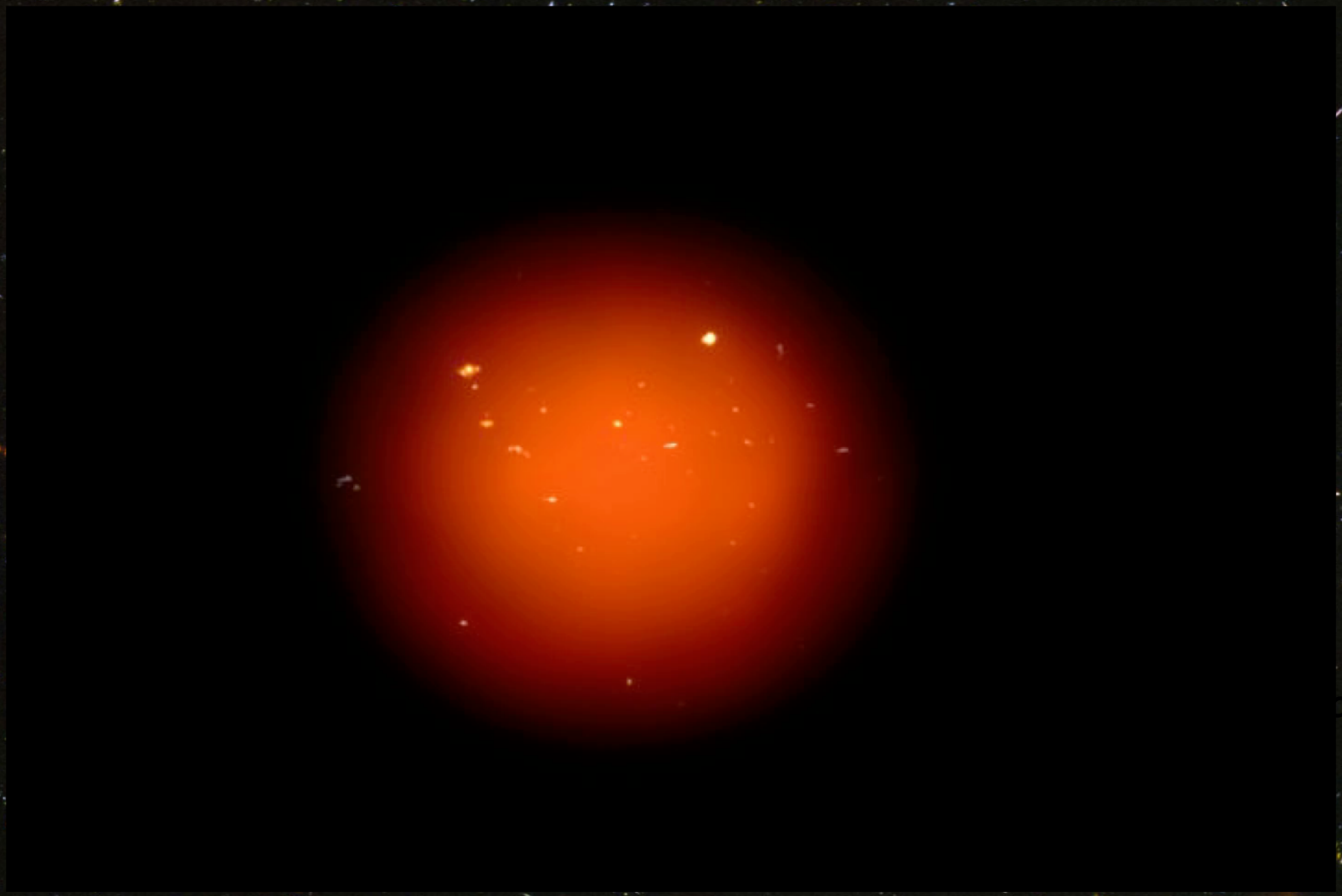
Matéria escura na Via Láctea!





- Distribuída na Galáxia, não agrupada!
- Nenhuma forma de matéria conhecida!

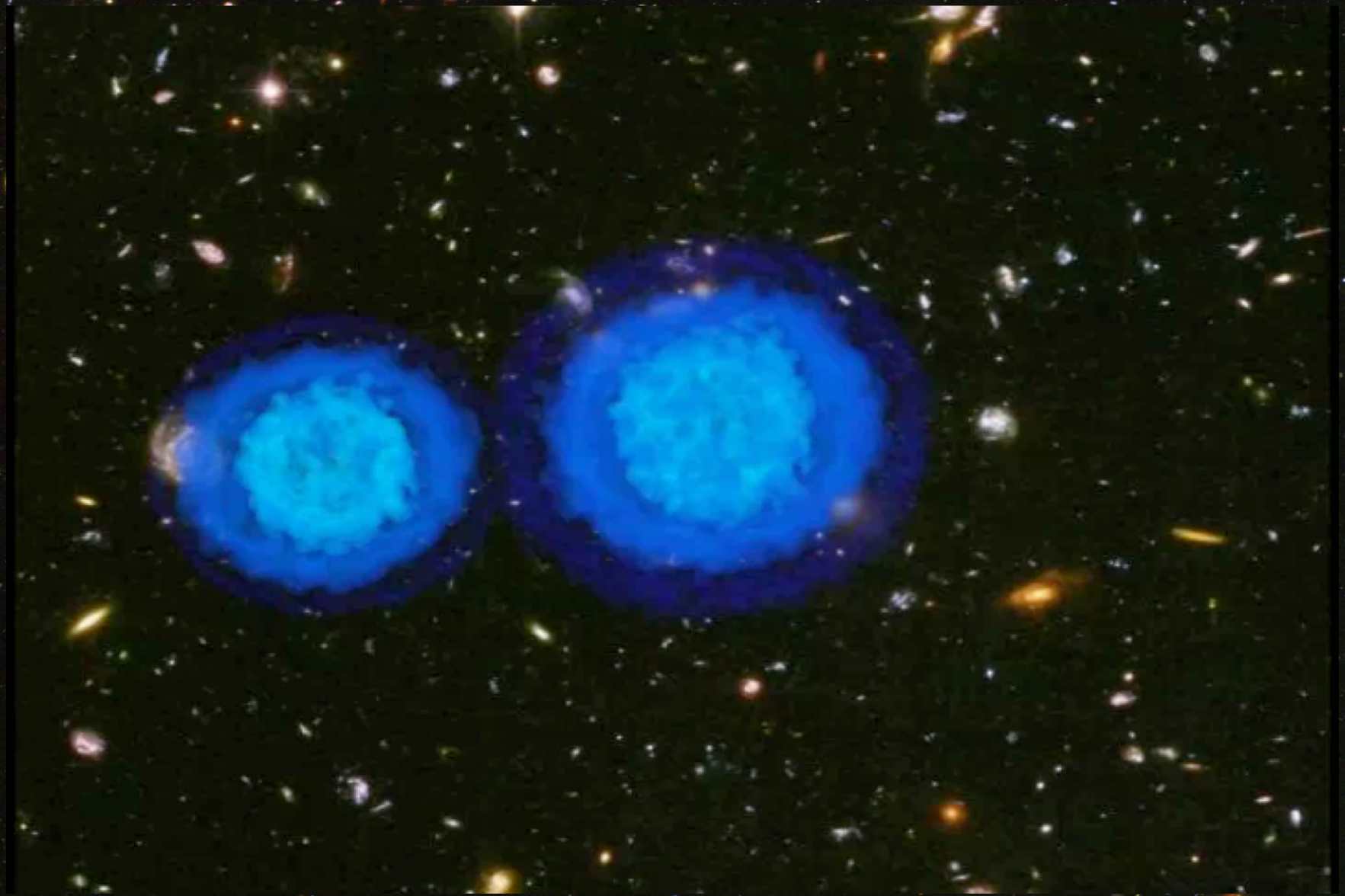
Matéria Escura
na colisão de Aglomerados de Galáxias



Matéria Escura na Colisão de Aglomerados de Galáxias

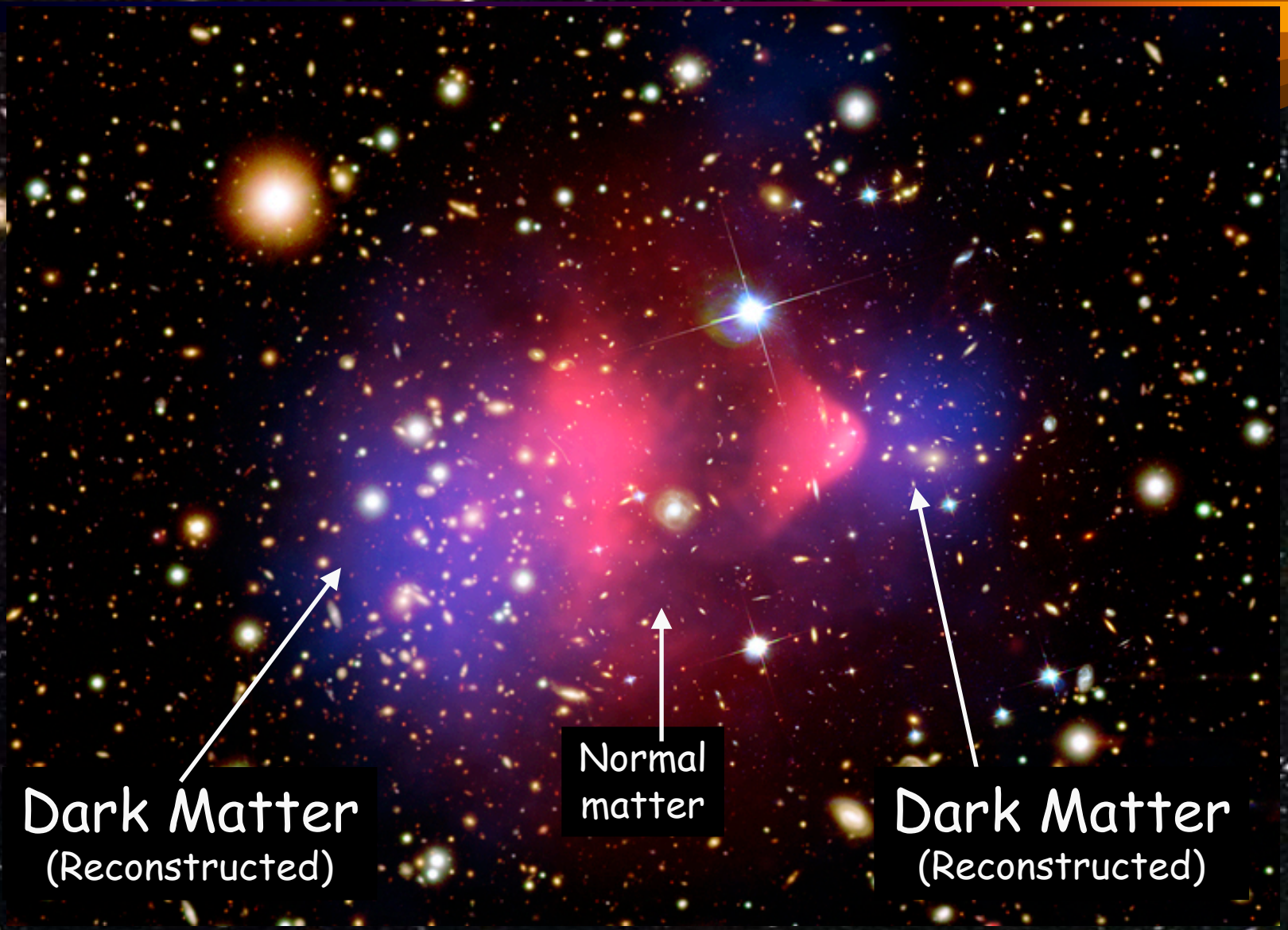
© CHANDRA X-RAY OBSERVATORY

A formação do Bullet Cluster



© CHANDRA X-RAY OBSERVATORY

Matéria Escura na Colisão de Aglomerados de Galáxias

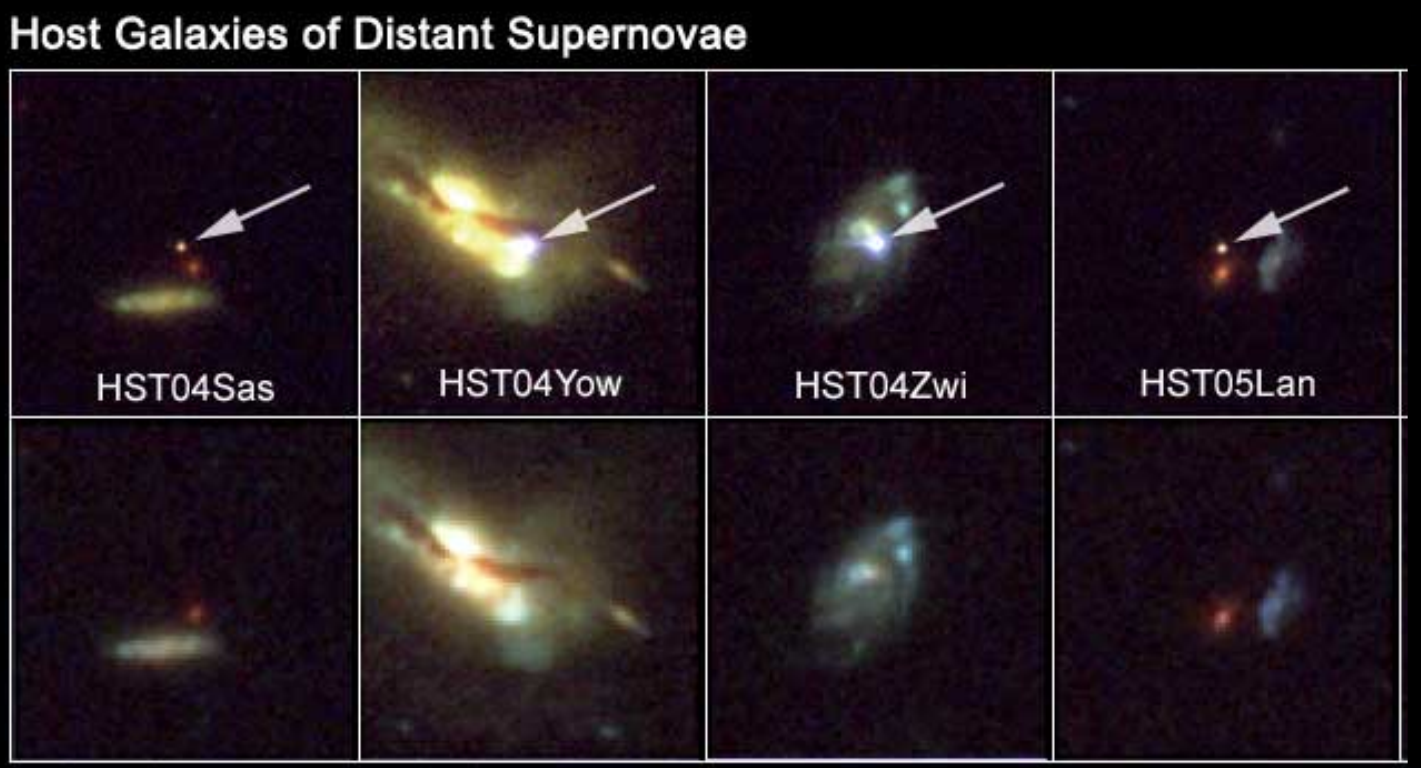


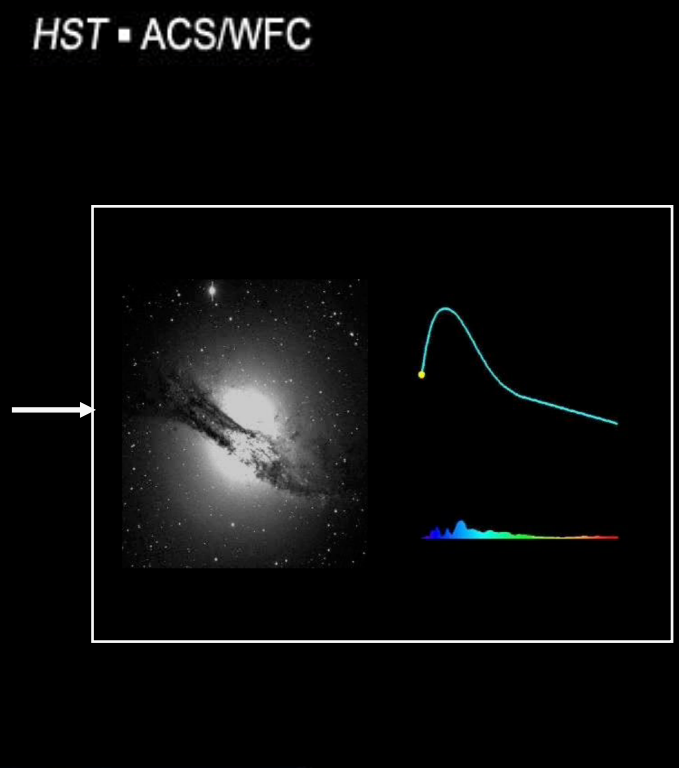
© CHANDRA X-RAY OBSERVATORY

O Problema da 'Energia Escura'

Cientistas estudam supernovae distantes para medir a evolução da expansão do Universo.

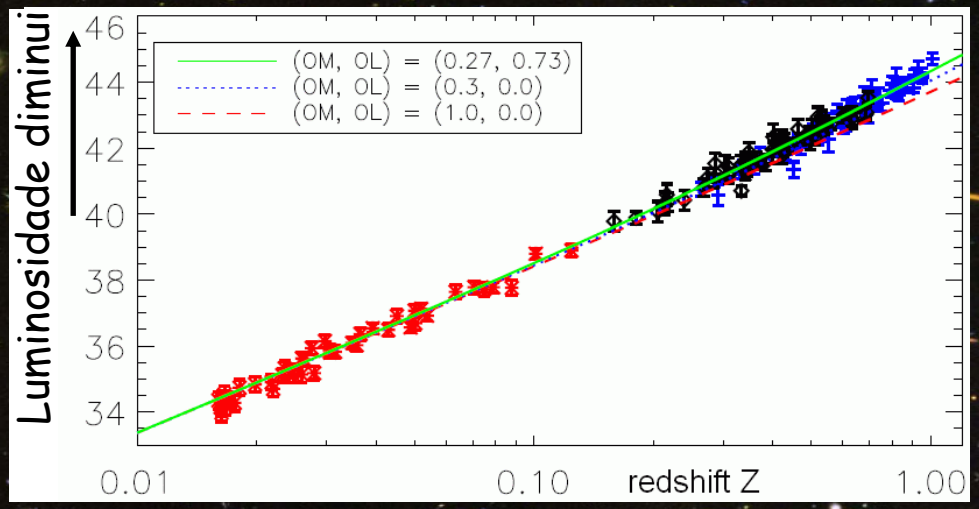
Esperavem que a taxa de expansão diminuísse desde o Big-Bang.



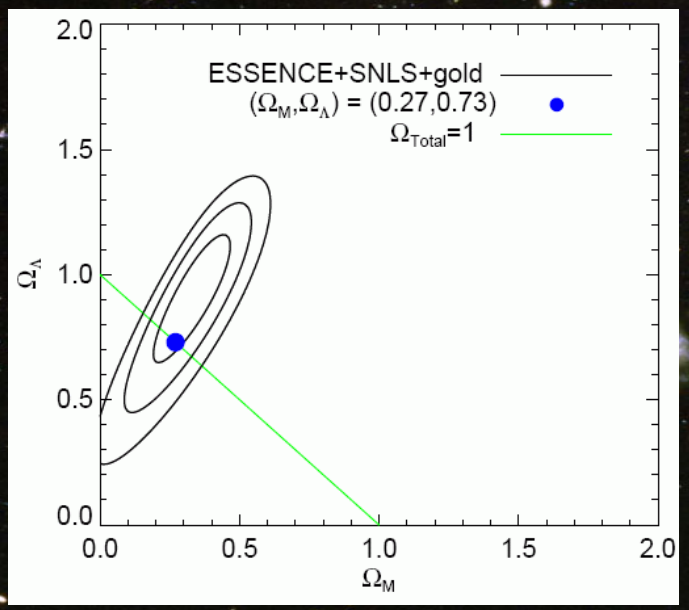


...socorro!!!

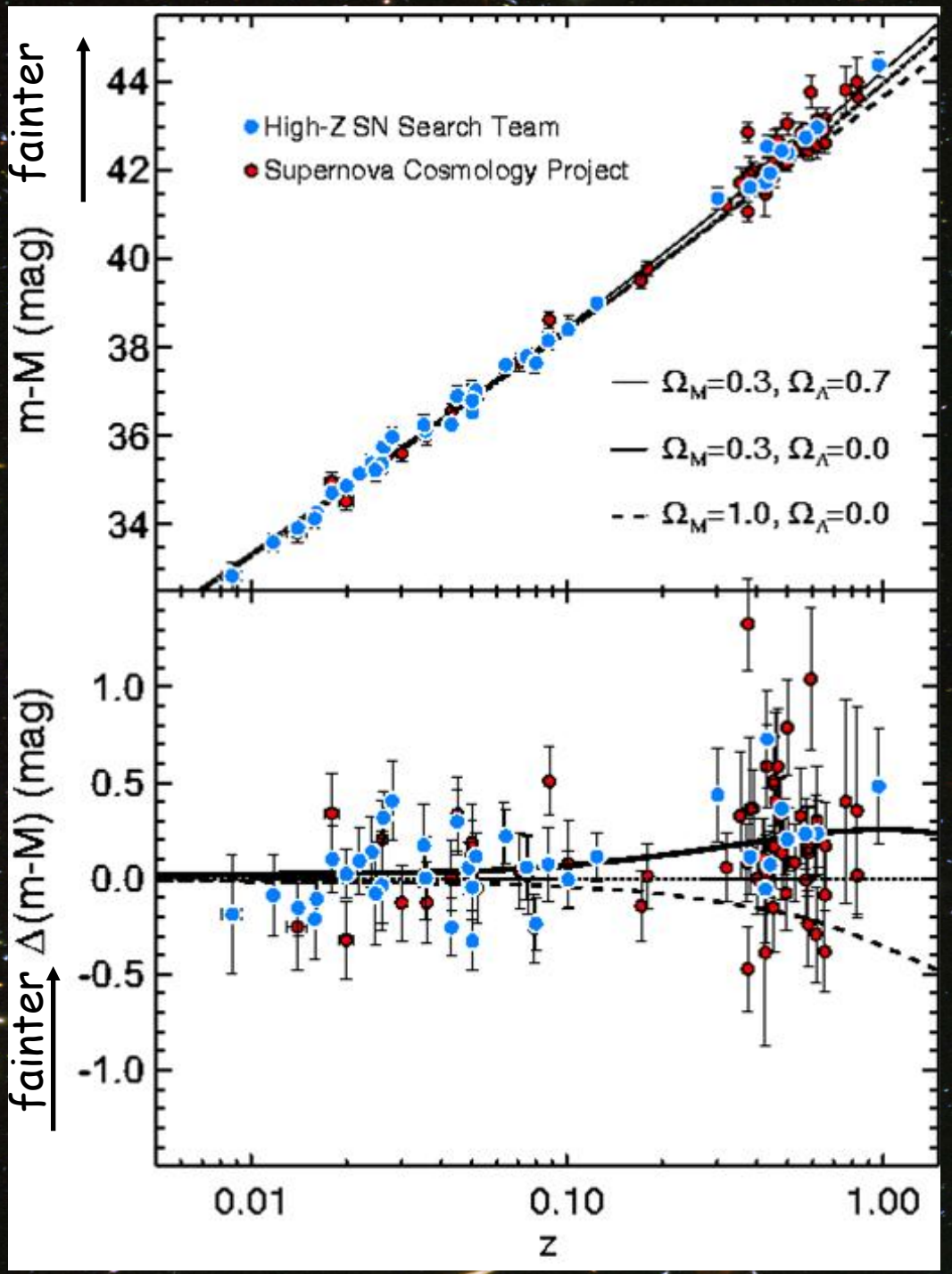
E mais recentemente:



Densidade Não-Matéria .vs. Densidade Matéria

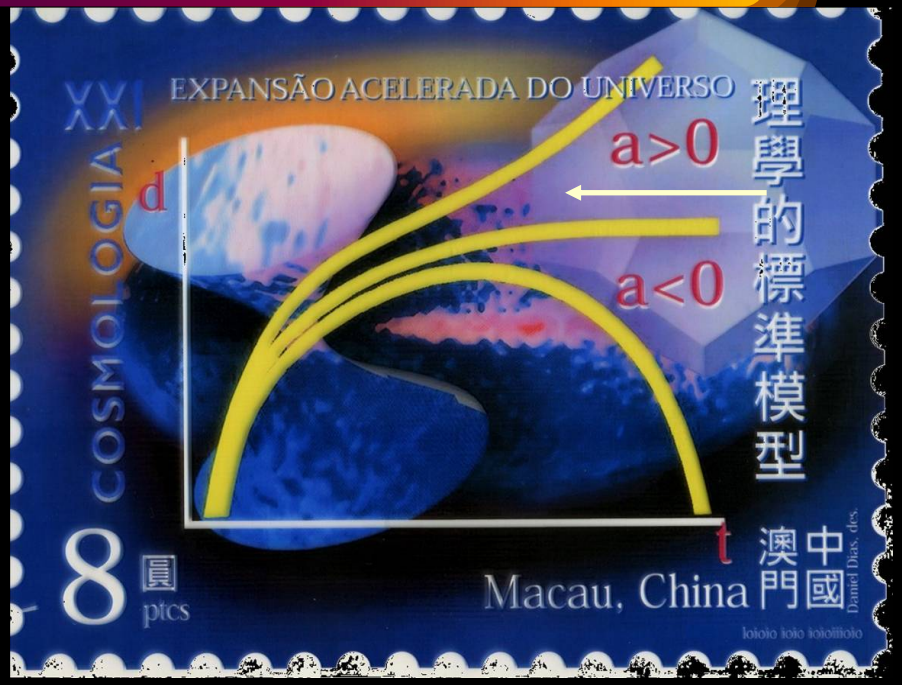


s/ efeito



Oops…não está a diminuir!

- A Expansão do Universo está acelerando!!!



- Algo se está a sobrepôr à gravidade

- Cientistas chamam-lhe 'Energia Escura'

De que é que feito o Universo?!

Energia Escura
Matéria Escura
Matéria Ordinária

©2013 PLANCK

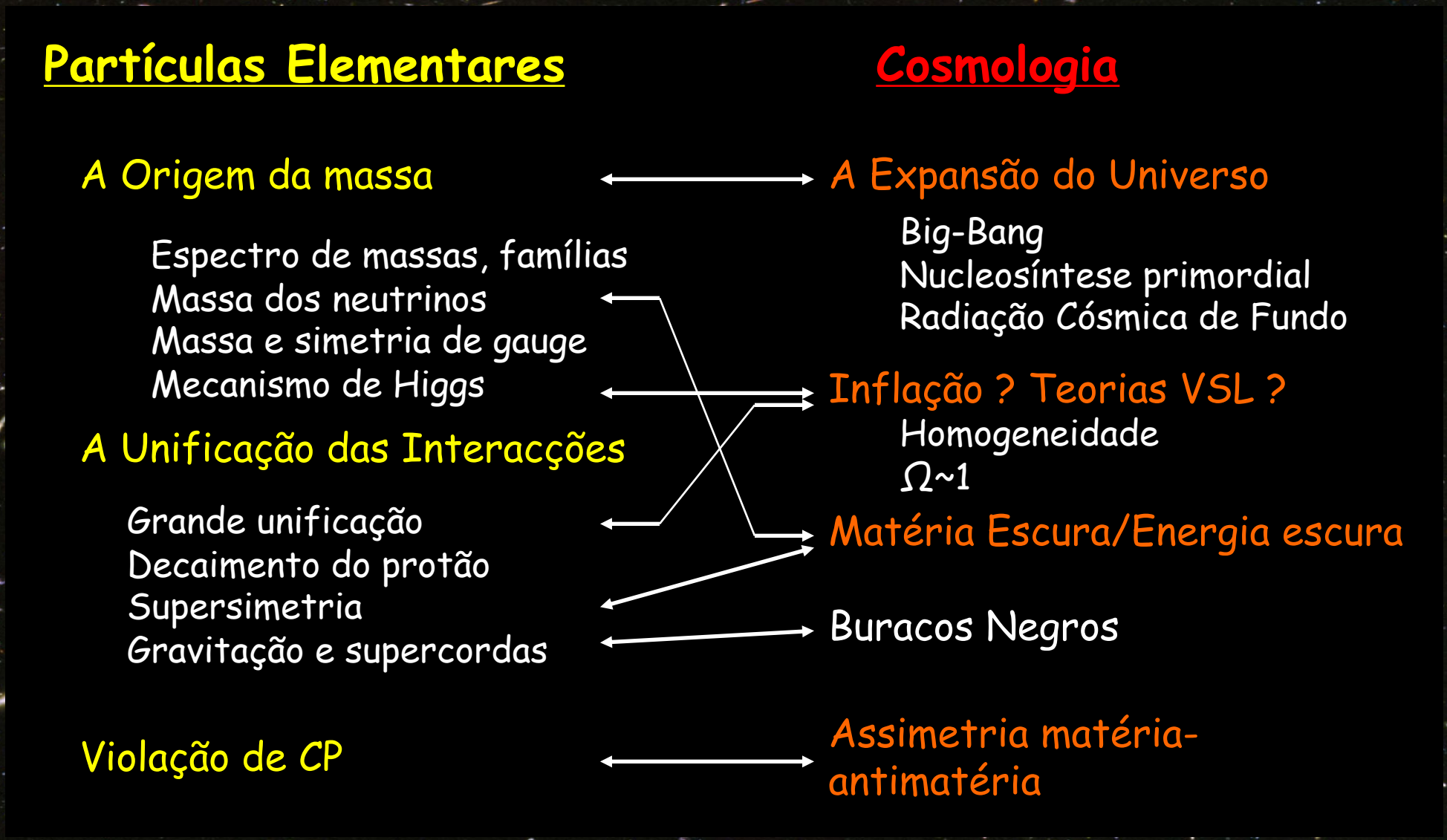
Como poderá o LHC ajudar?

- Encontrar **Supersimmetria**, se existir:
  o melhor candidato para a Matéria Escura será a partícula supersimétrica mais leve, estável e produzida em grandes quantidades no Big Bang

- Encontrando **W**eakly **I**nteractive **M**assive **P**articles:
  se existirem = Matéria Escura

- Encontrando dimensões extra (>=5D), etc!

Conclusões


Partículas Elementares
Cosmologia
A Origem da massa
A Expansão do Universo
Big-Bang
Nucleosíntese primordial
Radiação Cósmica de Fundo
Espectro de massas, famílias
Massa dos neutrinos
Massa e simetria de gauge
Mecanismo de Higgs
Inflação ? Teorias VSL ?
Homogeneidade
Ω~1
A Unificação das Interacções
Grande unificação
Decaimento do protão
Supersimetria
Gravitação e supercordas
Matéria Escura/Energia escura
Buracos Negros
Violação de CP
Assimetria matéria-antimatéria

Obrigado pela v/ atenção

Albert Einstein [P.N.1921]: (Com o conhecimento...)
"*podemos olhar para o Universo como se não existissem milagres.*
Mas também podemos olhar para o Universo como se tudo fosse um milagre!"