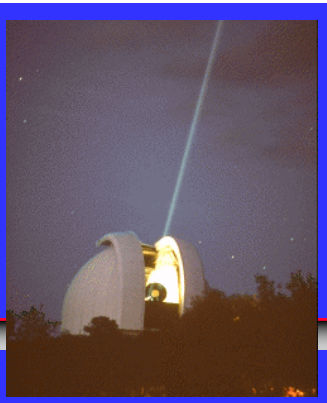
O Universo é Finito!



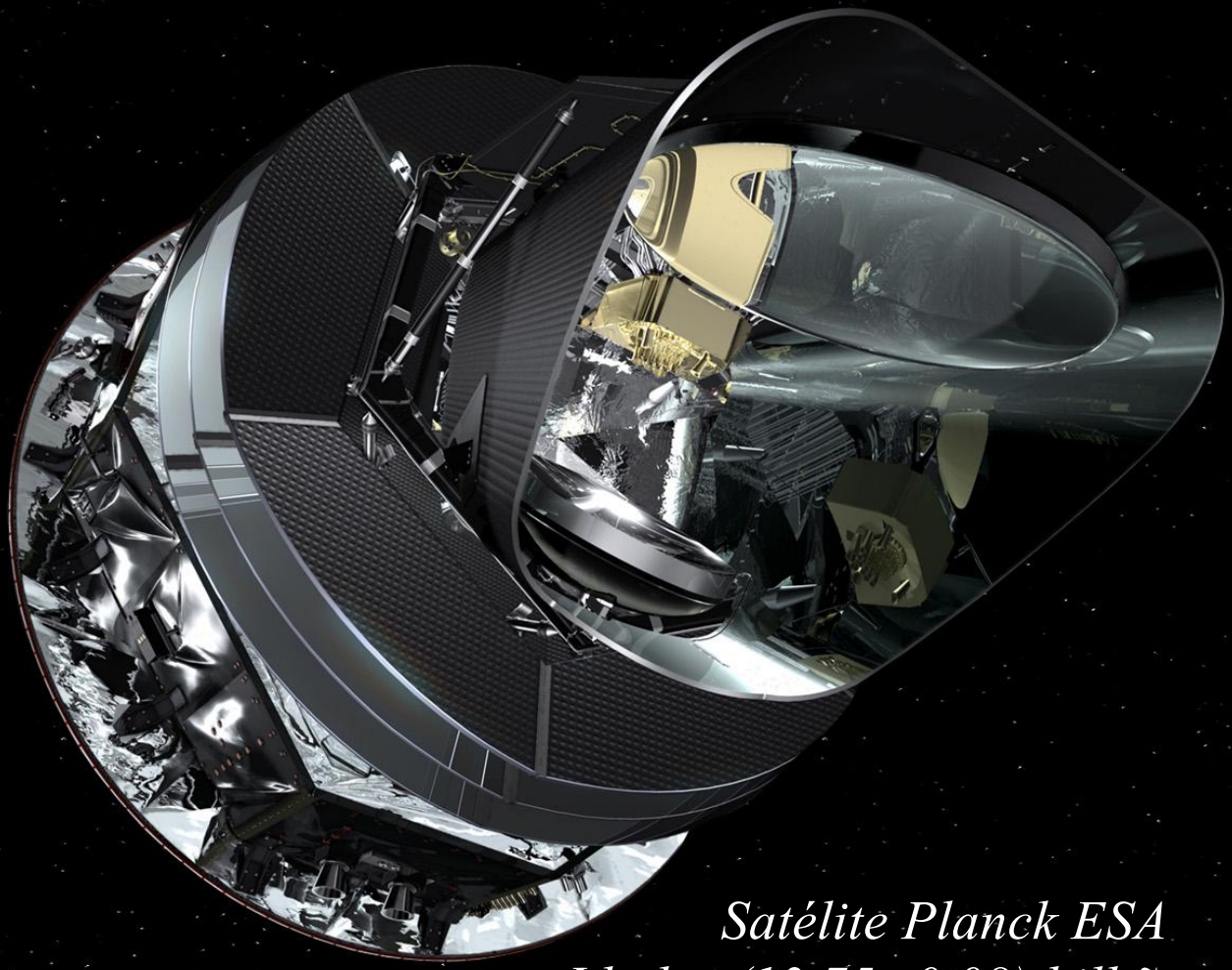
- Kepler de Souza Oliveira Filho
- Departamento de Astronomia
- UFRGS

A&A 594, A1 (2016)
DOI: 10.1051/0004-6361/201527101

Volume 594 (October 2016) A&A, 594 (2016) A1

Astronomy & Astrophysics
Special feature

Planck 2015 results



Satélite Planck ESA
Idade=(13,75±0,08) bilhões anos

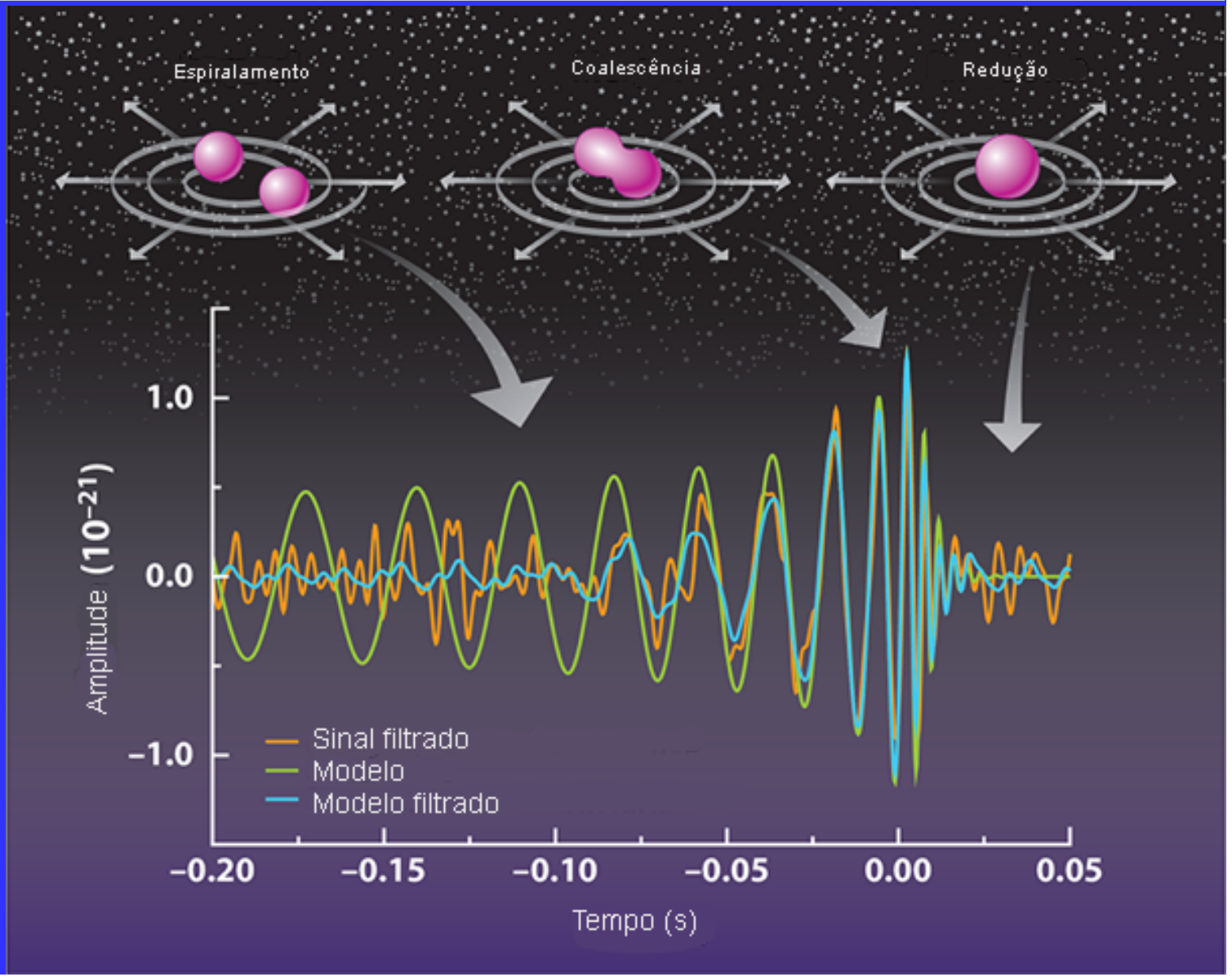
LIGO 14 set 2015

Colisão de BNs

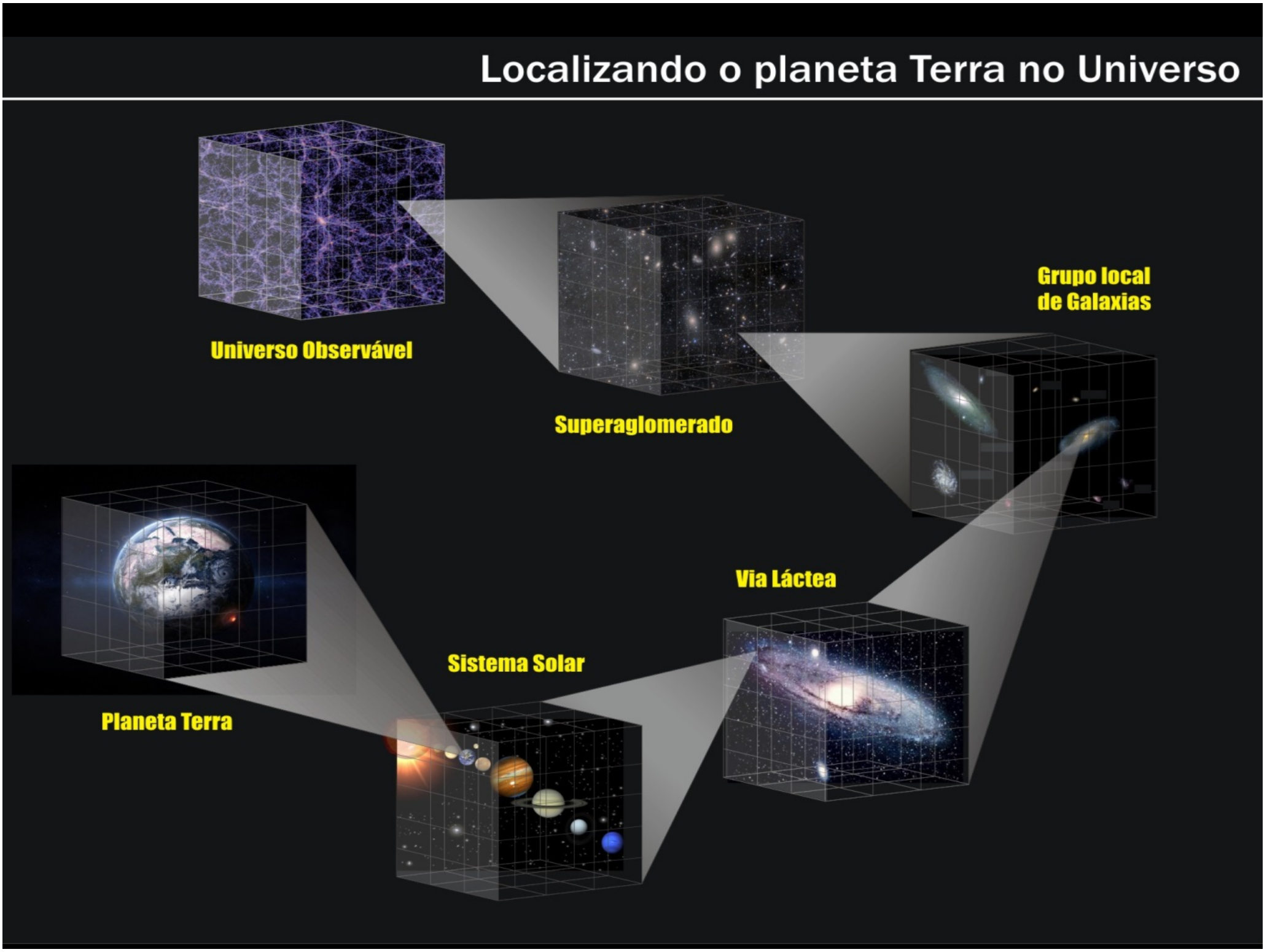
34 ± 4 e

30 ± 4 M_{sol}

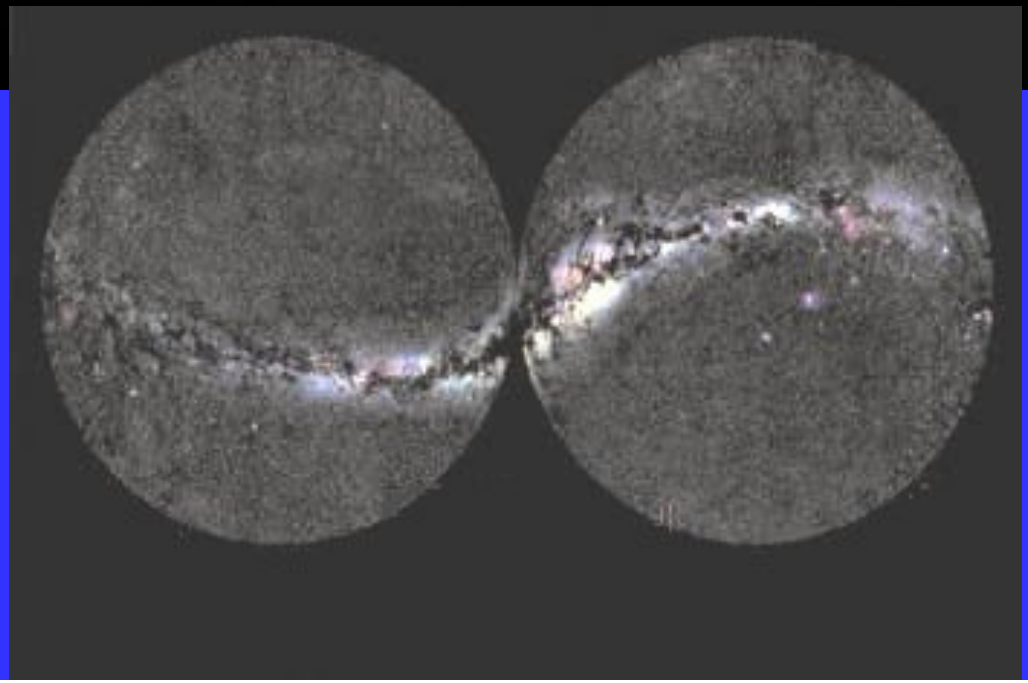
1,3 bilhões de anos-luz



Localizando o planeta Terra no Universo



A Via Láctea

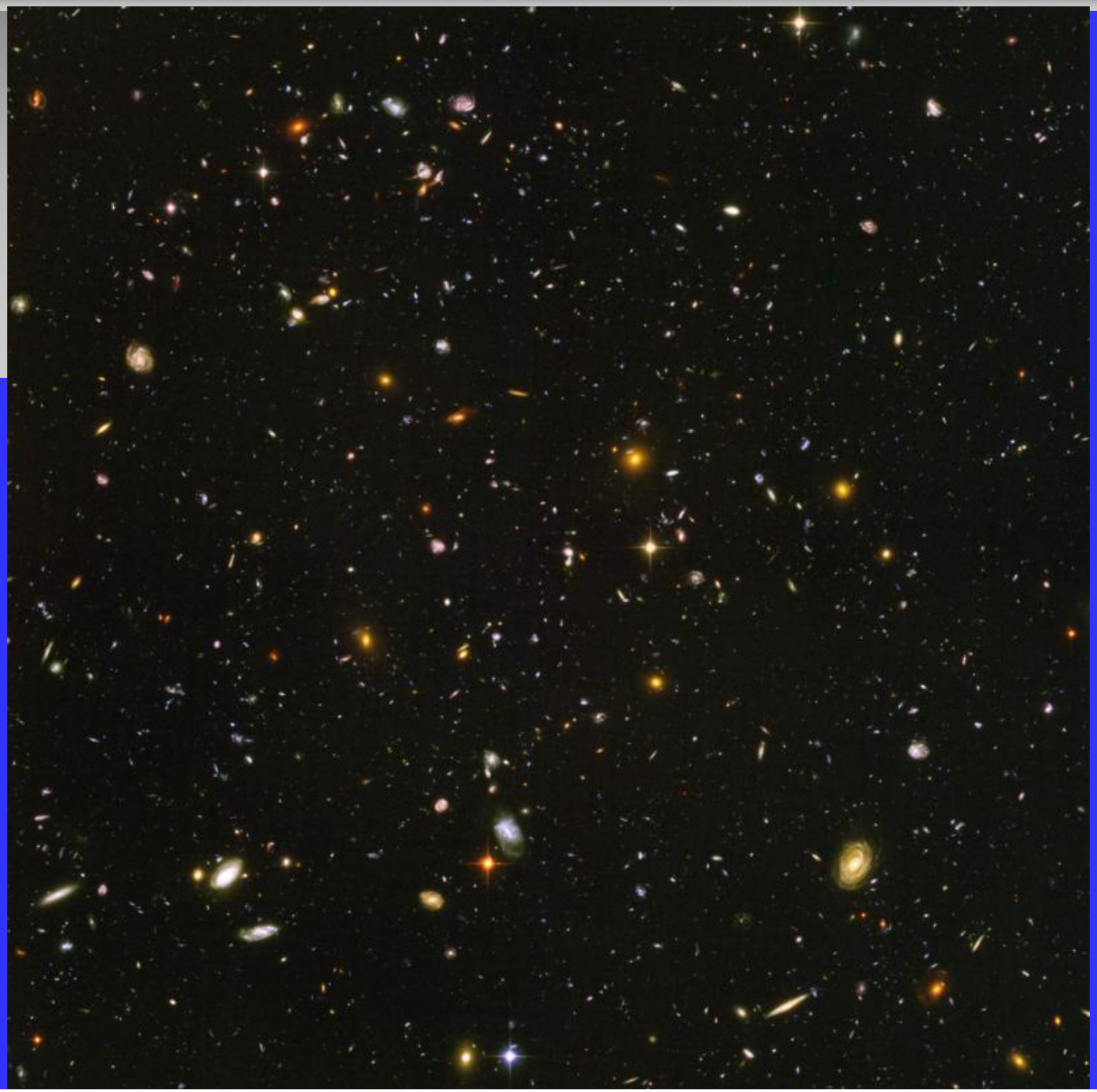


Galileo 1610

SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuperà se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumvolutis; quos, neminem in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

O céu é escuro!
Exposições longas com o Telescópio Espacial

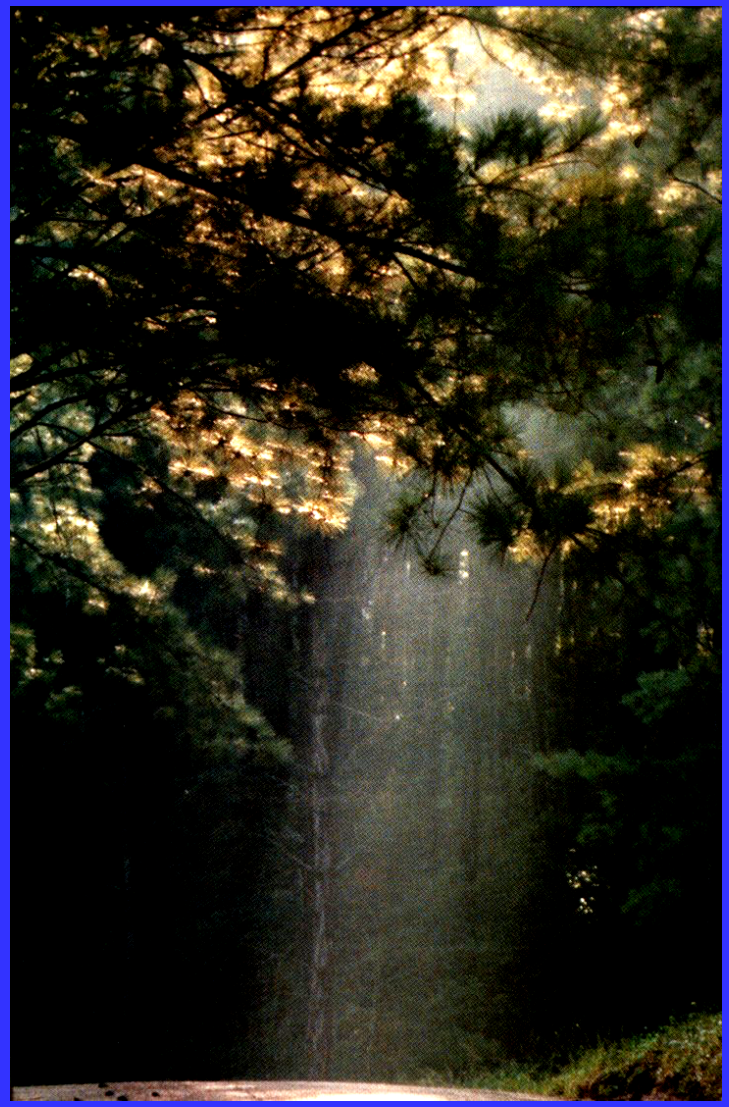


Norte

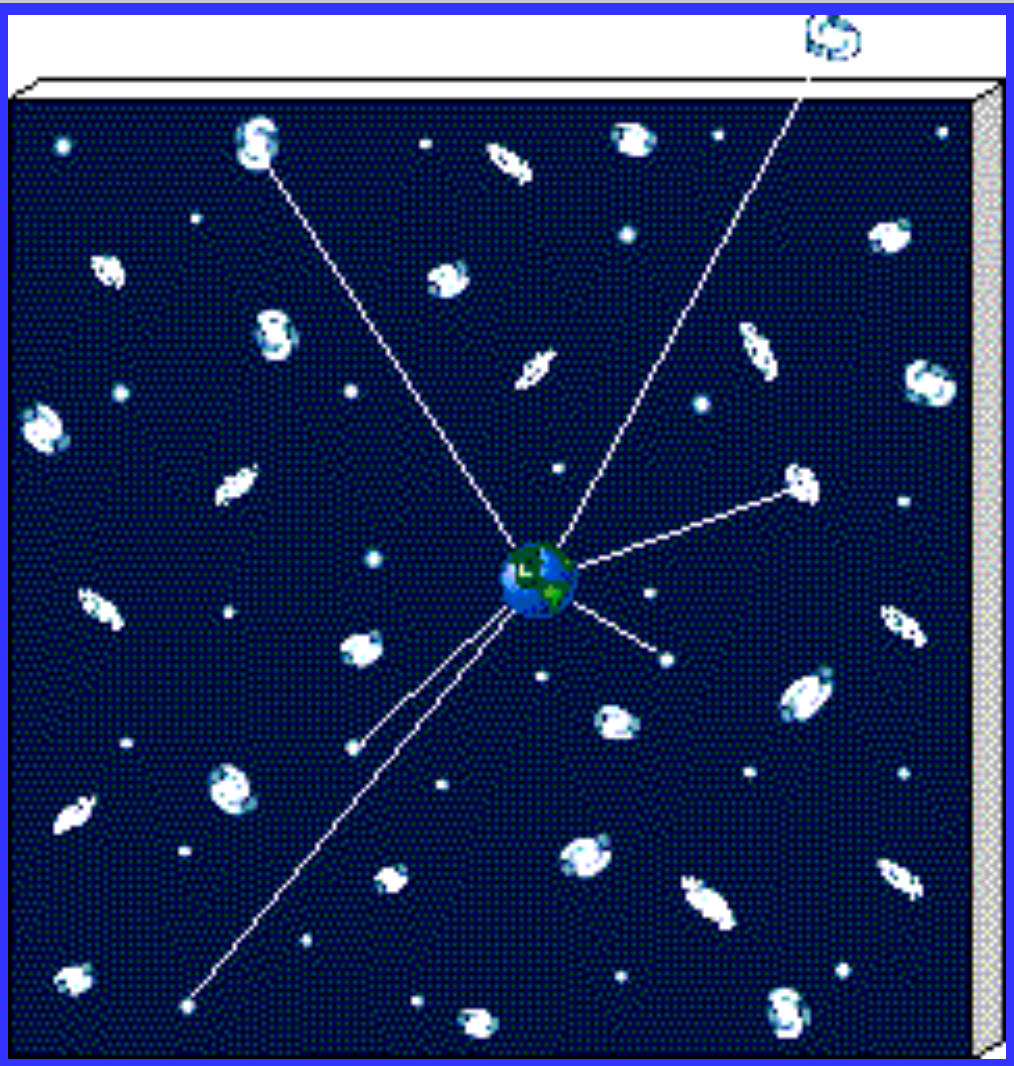
2 semanas

2004

Floresta de árvores

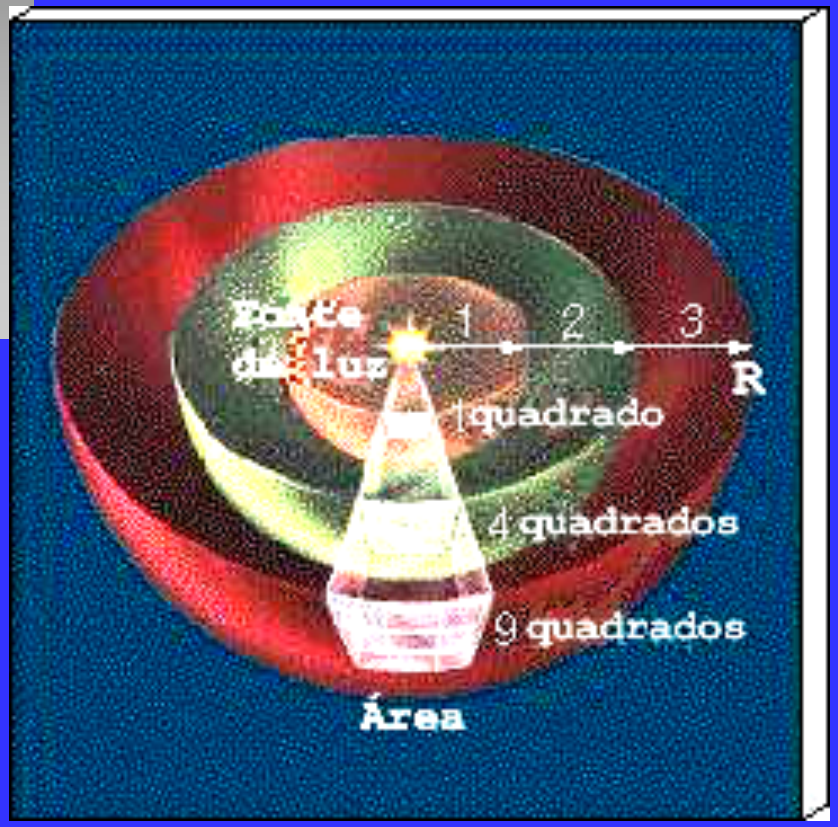


Paradoxo de Olbers



Heinrich Wilhem Mattäus Olbers (1826)

Céu seria brilhante se universo infinito



$$\text{Área} = 4\pi R^2$$

$$\text{Brilho} = \frac{\textbf{Intensidade}}{4\pi R^2}$$

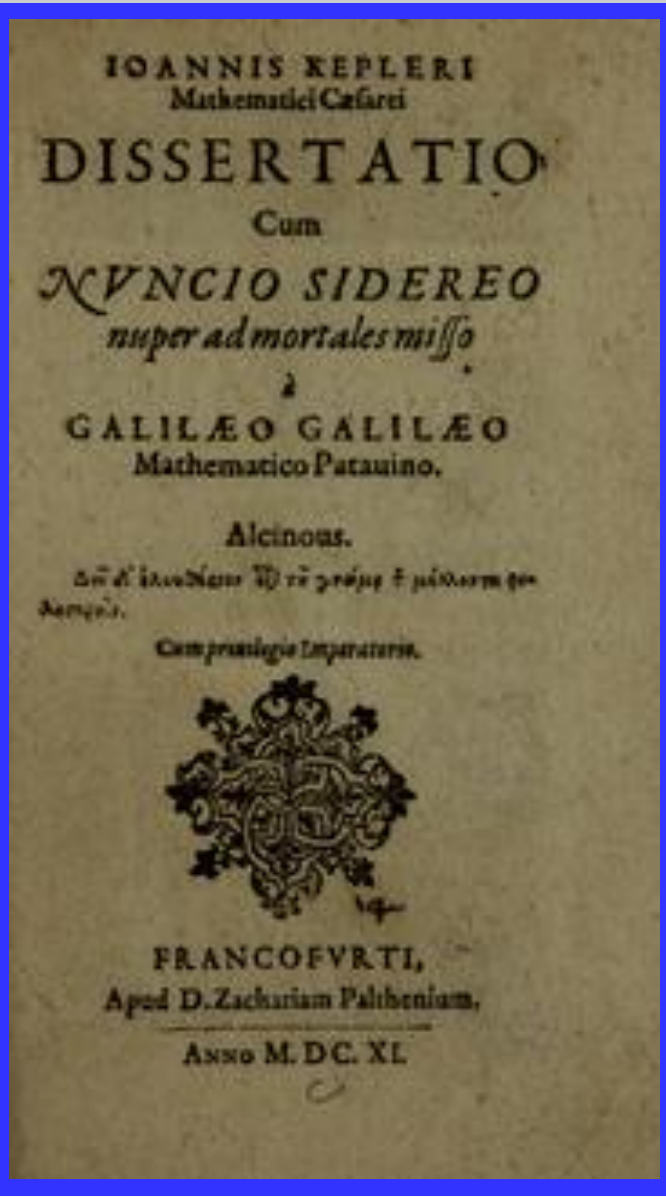
(de uma estrela)

$$\Delta\text{Volume} = 4\pi R^2 \Delta r$$

$$\text{Brilho} = \textbf{Intensidade}$$

(do céu)

Johannes Kepler 1610



IOANNIS KEPLERI
Mathematici Cæsarei

DISSERTATIO

Cum

NVNCIO SIDEREO

nuper ad mortales misso

à

GALILÆO GALILÆO
Mathematico Patauino.

Alcinous.

Cum priuilegio Imperatorio.

FRANCOFVRTI,
Apud D. Zachariam Palthenium.

Anno M. DC. XL

Solução do Paradoxo

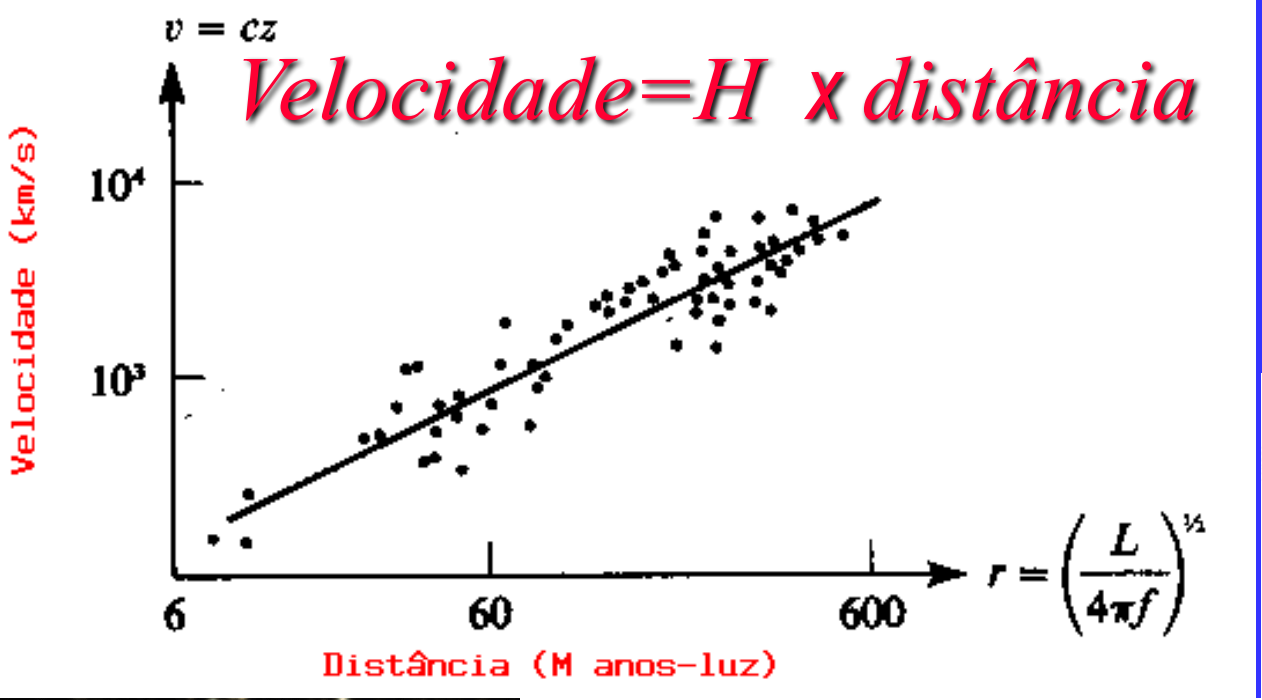
- Se estrelas têm raio médio de $R=700\,000$ km → seção reta $\sigma=\pi R^2$
- Se a separação média entre as estrelas é de $r=4$ a.l. → seção reta $\Sigma=\pi r^2$
- O número mínimo de estrelas necessárias para cobrir todo o céu: $N=(\pi r^2)/(\pi R^2) = 3\times10^{15}$ **estrelas**
- Se a densidade média das estrelas é $n=1/(4\ \text{a.l.})^3$, pode-se obter a distância d mínima necessária para acumular o número acima de estrelas:

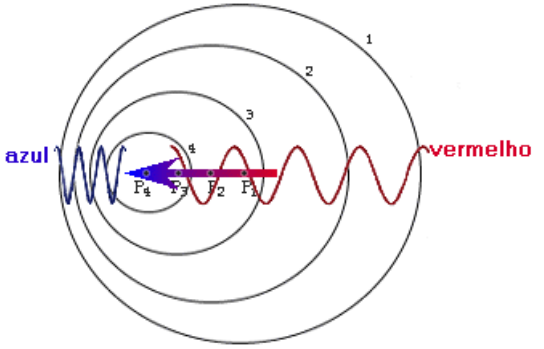
$$N = nV = n\Sigma d = n\pi r^2 d$$

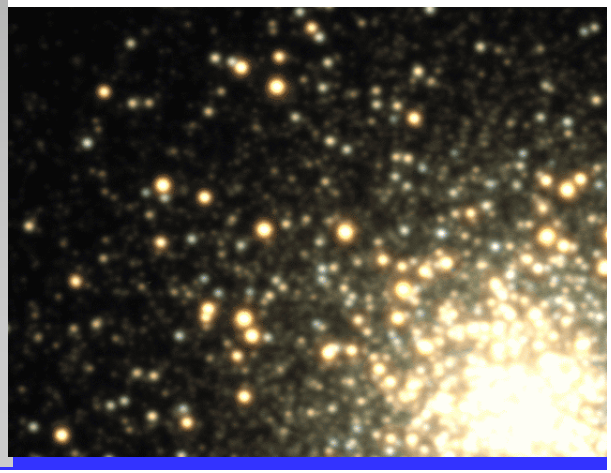
$$d = \frac{N}{n\pi r^2} = \frac{3\times10^{15}}{\frac{1}{(4a.l.)^3}\pi(4a.l.)^2} = 4\times10^{15}\,a.l.$$

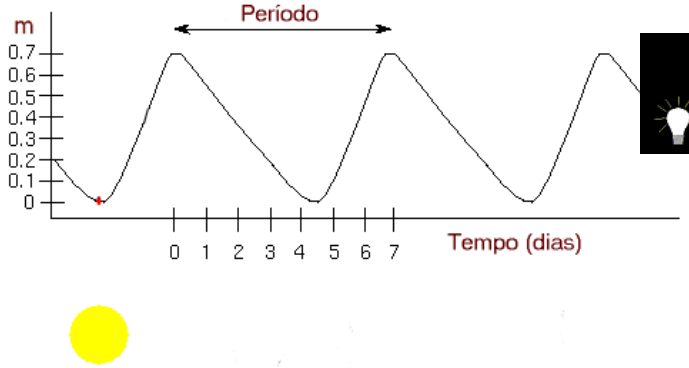
- A distância 4×10^{15} **a.l.** é **300 000** vezes maior do que o raio observável do Universo **(13,7 bilhões de a.l.)!**
- **Conclusão: o Universo é escuro à noite porque seu raio observável é menor do que o necessário para acumular o número de estrelas suficientes para tornar todo o céu brilhante!**

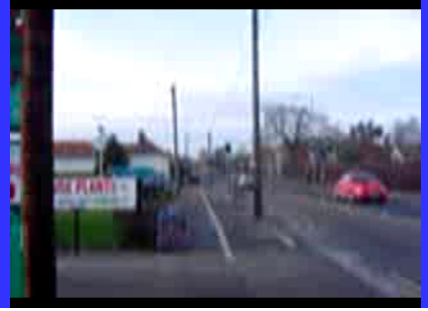
Edwin Hubble 1929



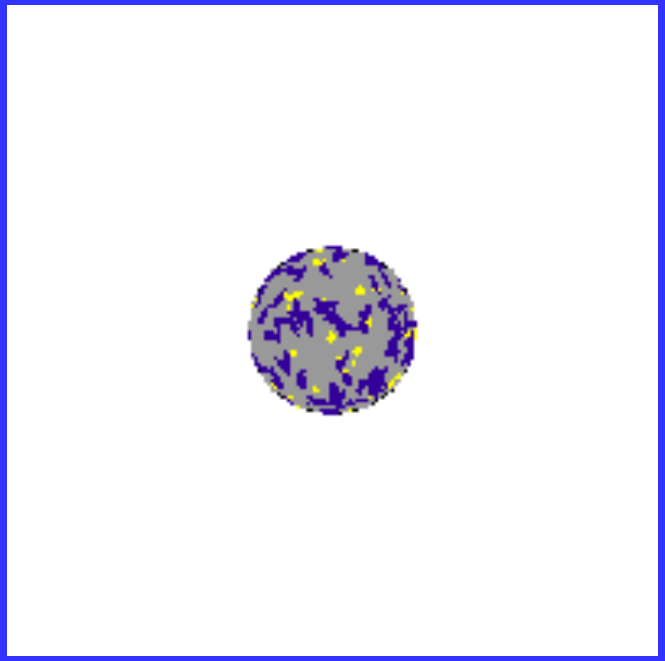


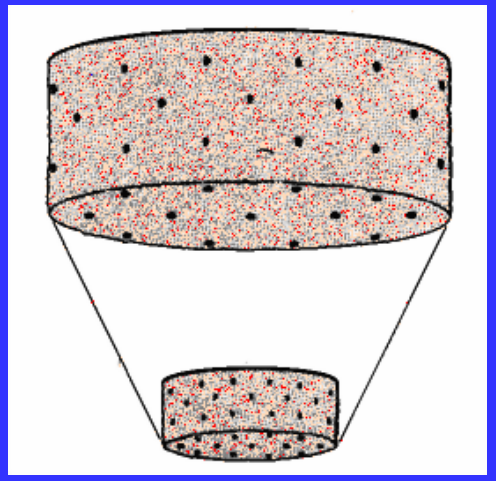






Expansão da Lei de Hubble: v=H d





t_2

t_1

Modelo do bolo de passas:

Num tempo t_i=0, as distâncias das passas em relação a uma passa de referência são:

passa A: d_i= 1 cm

passa B: d_i= 3 cm

passa C: d_i= 4 cm

Após 1 hora, o bolo dobra de tamanho, e as distâncias entre as passas serão:

passa A: d_f= 2 cm

passa B: d_f= 6 cm

passa C: d_f= 8 cm

Portanto as velocidades são:

passa A: v=1 cm/h

passa B: v=3 cm/h

passa C: v=4 cm/h

Velocidade em função de suas distâncias, reta com

H = (1cm/h)/2cm = (3cm/h)/6cm = (4cm/h)/8cm = 0,5/h

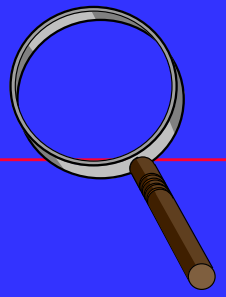
T=1/H=2h

Expansão

Velocidade=H x distância

Velocidade= distância/Tempo

Tempo = 1/H

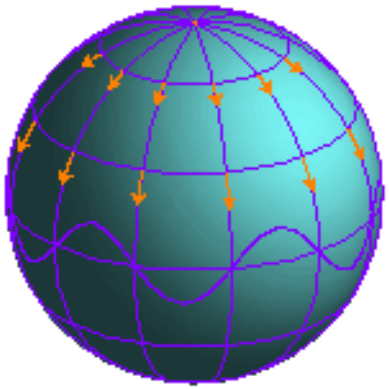


H = 72 km/s/Mpc ➡ *Tempo= 13 bilhões de anos*

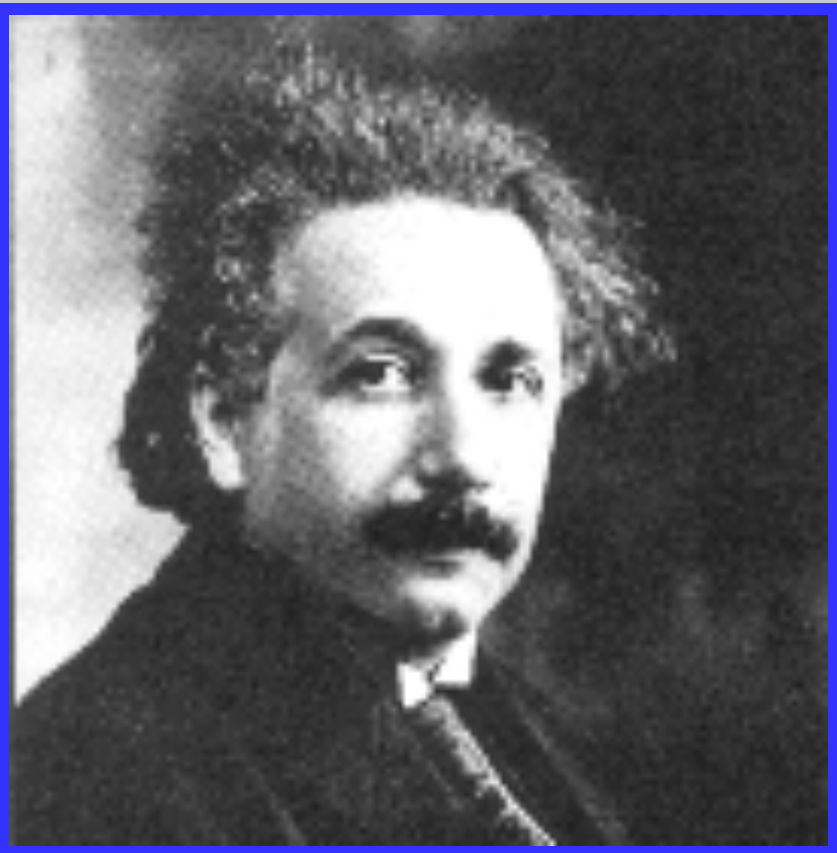
1 Mpc = 3,26 M anos-luz = 3 x 10^{19} km

Big Bang

Expansão



Albert Einstein



$V_{max} = c$

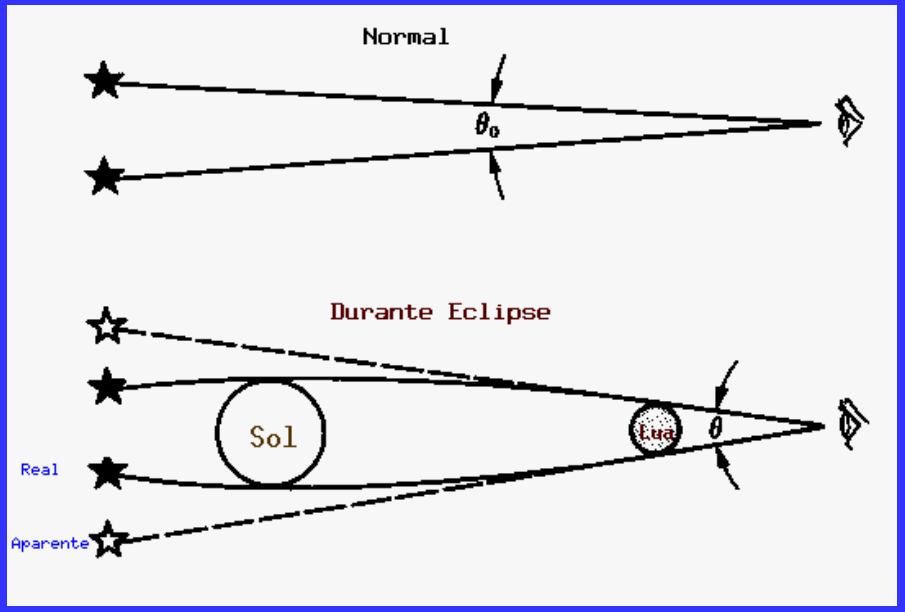
c =300 000 km/s

$$G_{ij} = \frac{8\pi G}{c^2} T_{ij}$$

1916 Teoria da Relatividade Geral

Relatividade Geral: Espaço = K x Energia-Momentum

Relatividade Geral



Desvio da luz pelo campo gravitacional

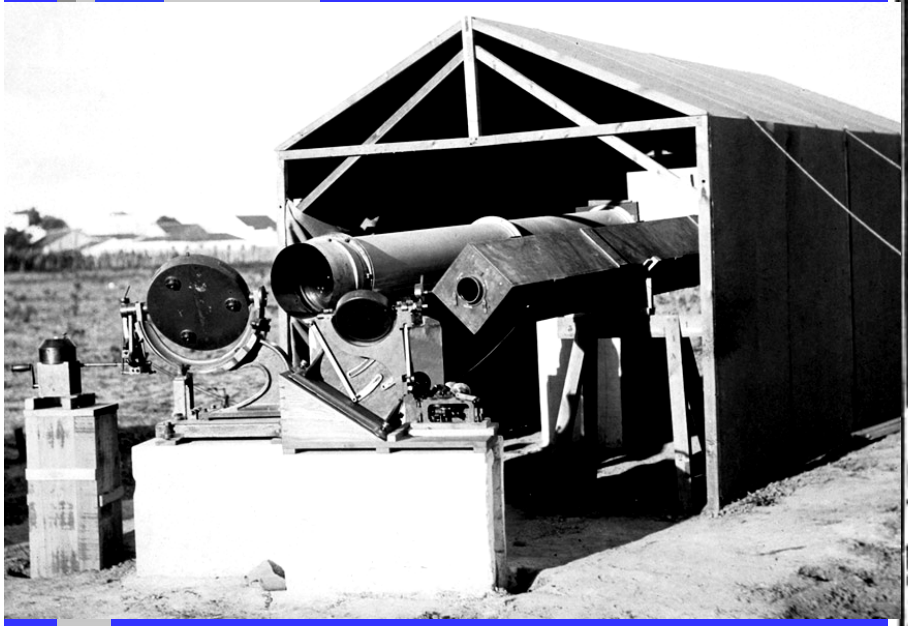
$$\theta - \theta_0 = \frac{1{,}7 \text{ segundos de arco}}{\Delta}$$

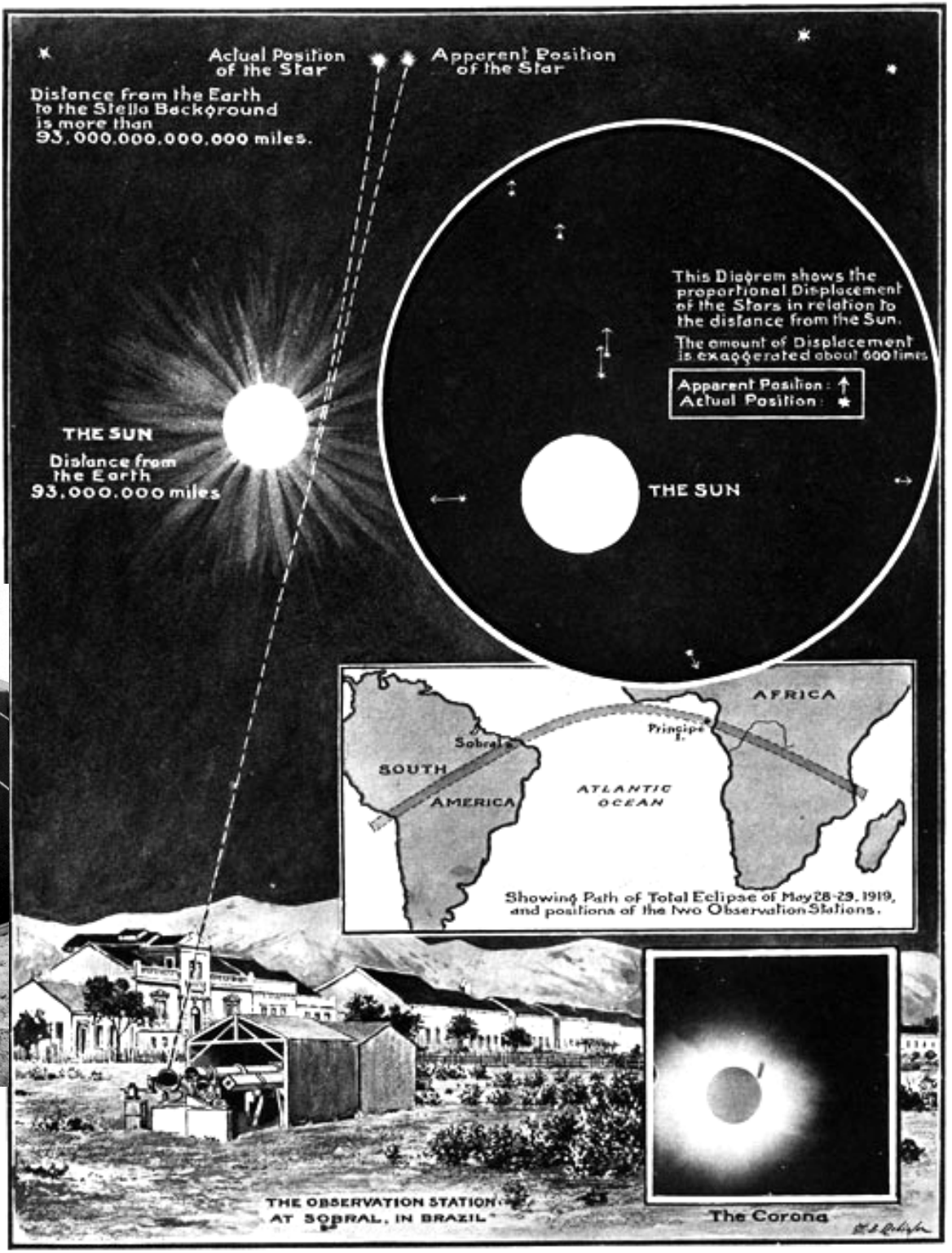
$$E_{fóton} = h f = m_{equivalente}\, c^2$$

$$F = -\frac{GMm}{r^2}$$

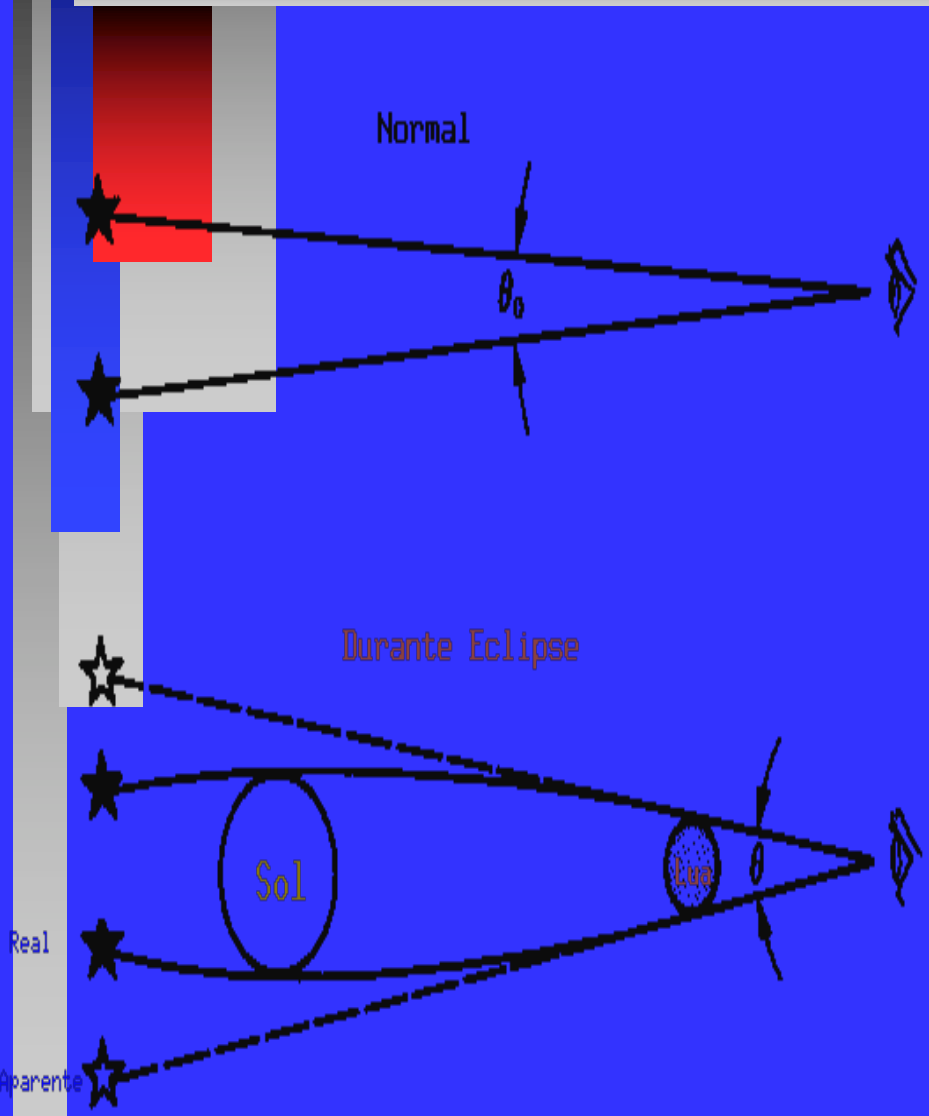
Eclipse

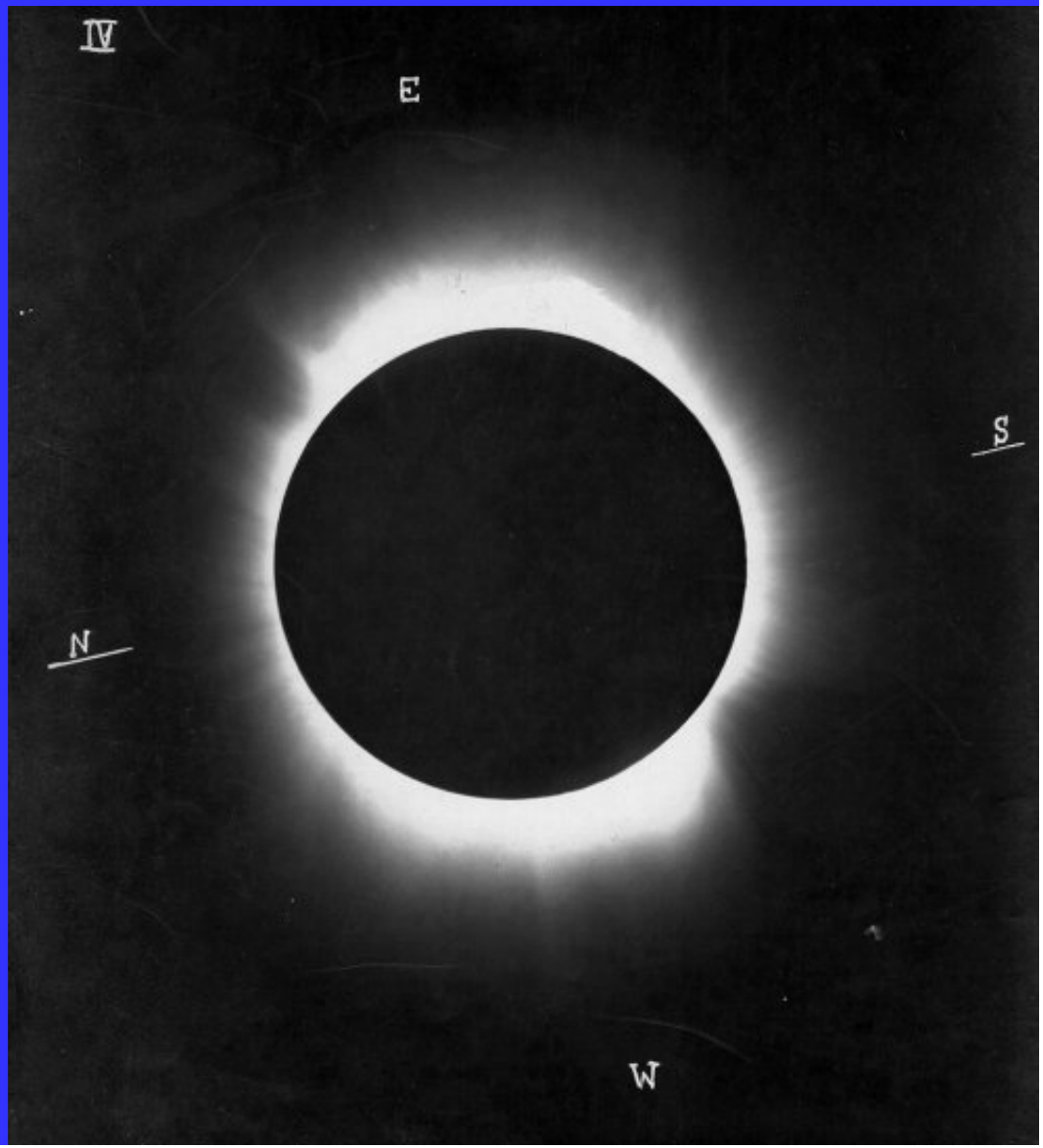
29 de maio de 1919



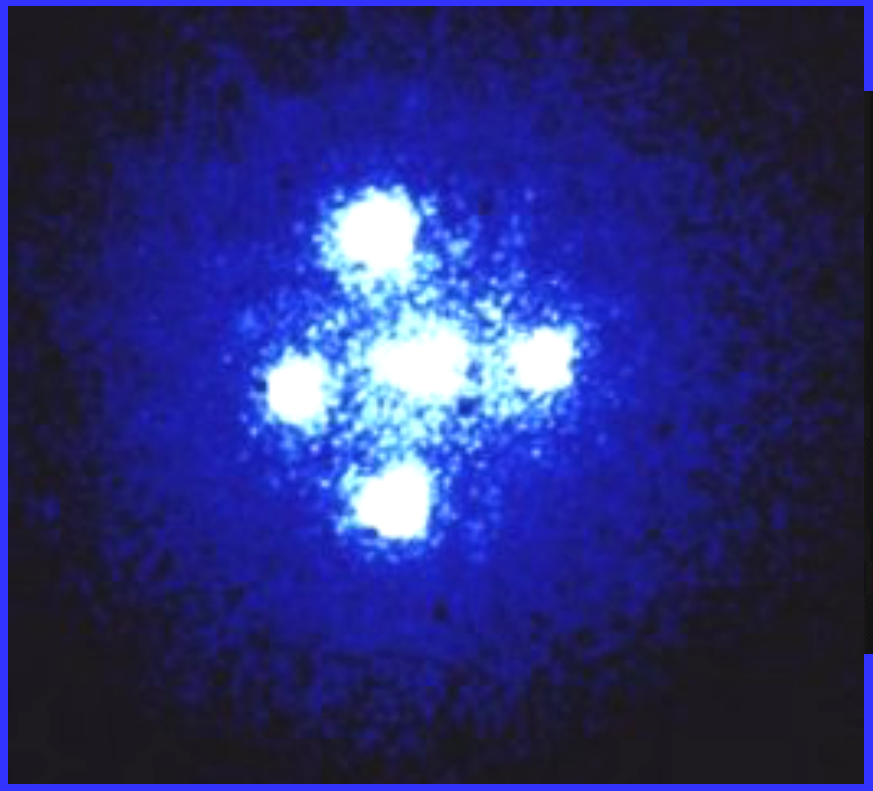


Eclipse em Sobral, CE, 29 maio 1919





Lente Gravitacional

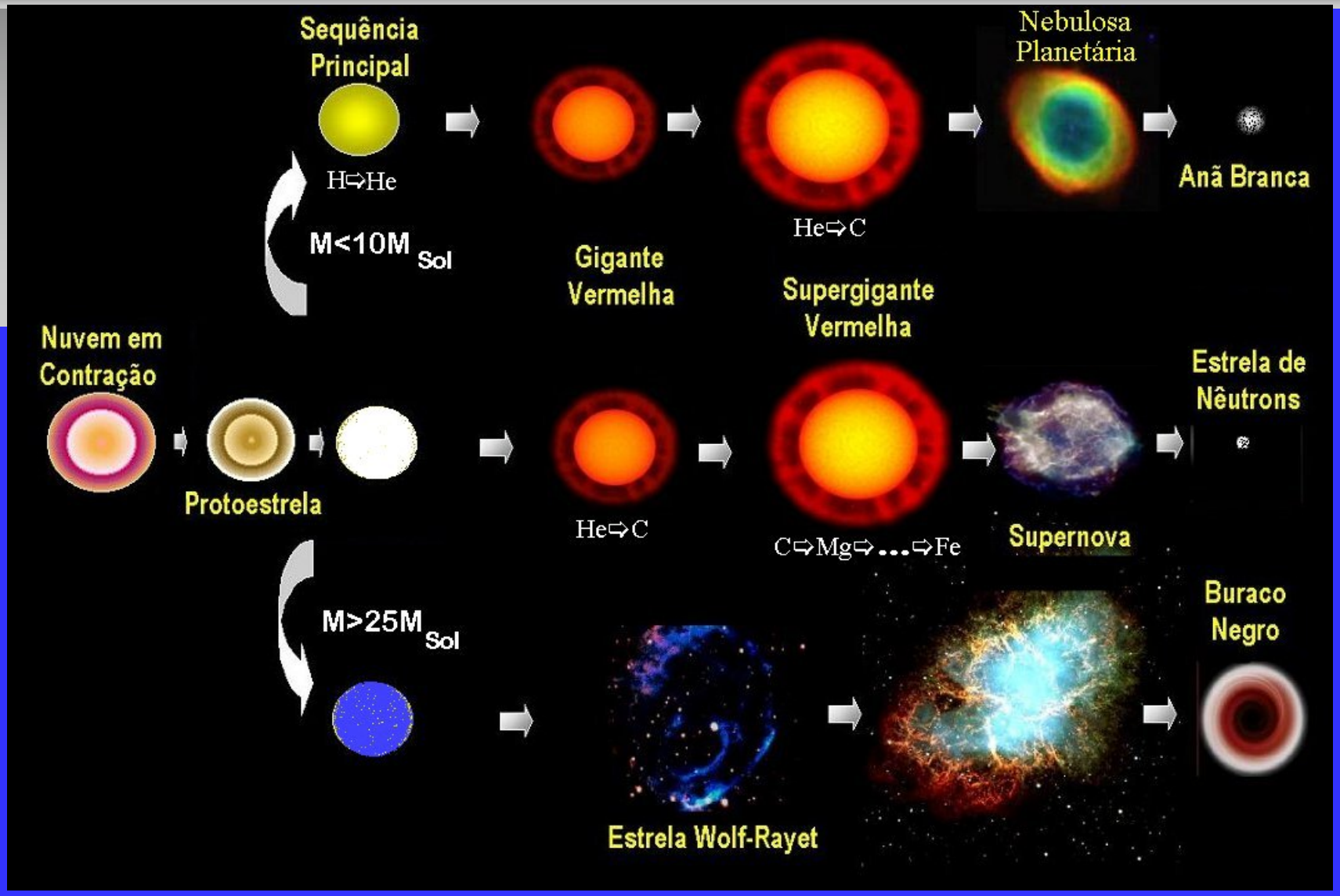


Cruz de Einstein

(quasar a 8 bilhões de anos-luz imageado por galáxia a 400 milhões de anos luz)

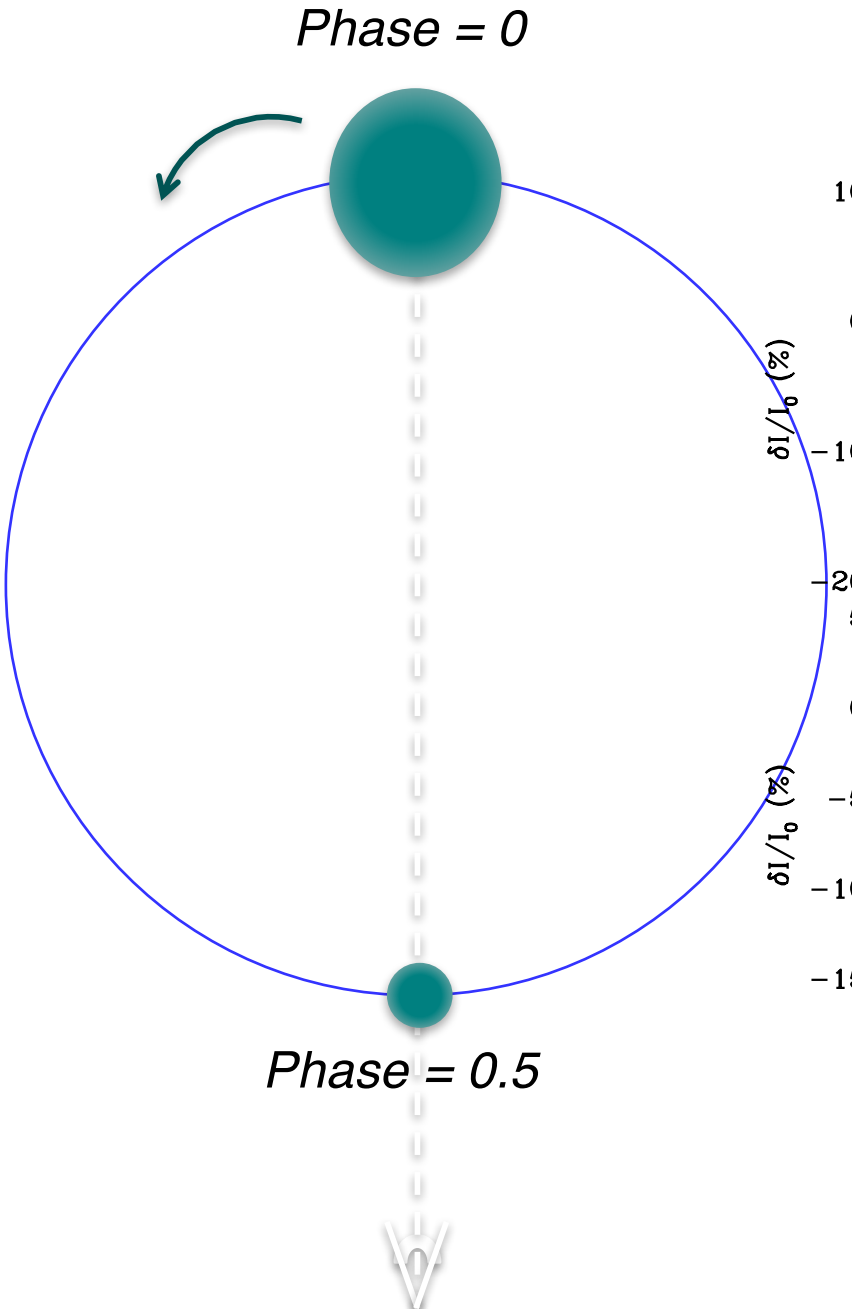
Lente Gravitacional 0024+1654

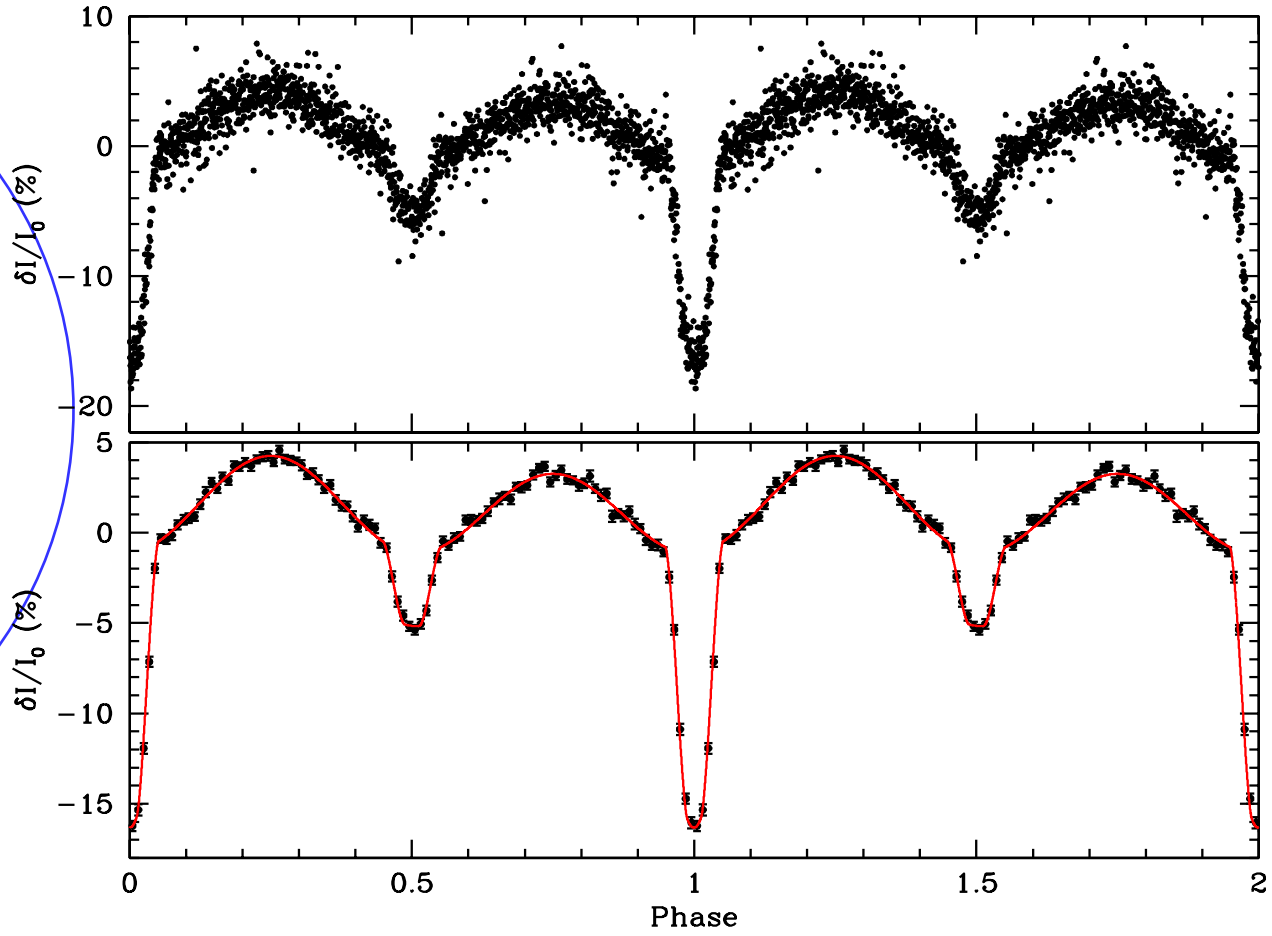
Evolução estelar



Anãs Brancas

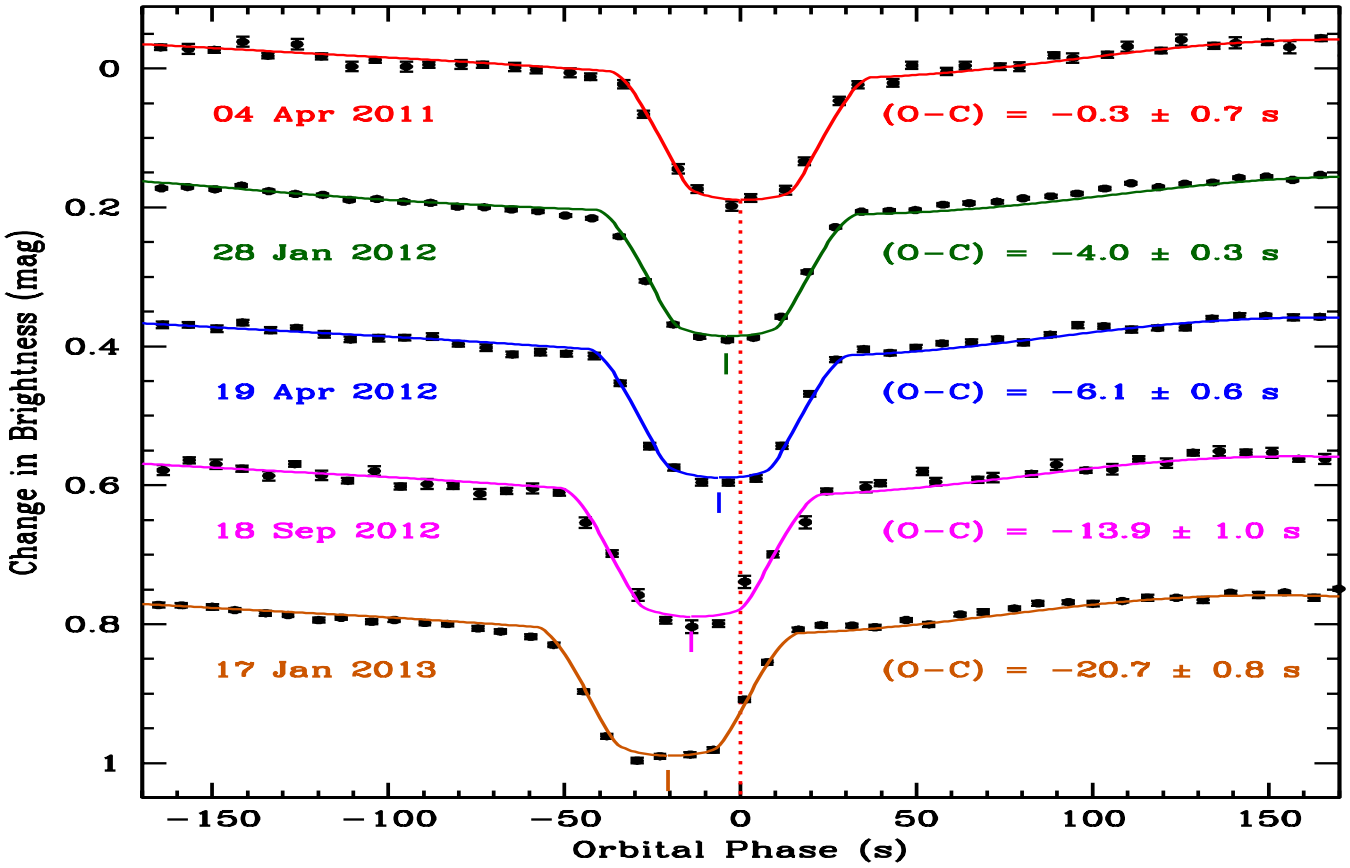
J0651+2844: 12.75 min ab+ab

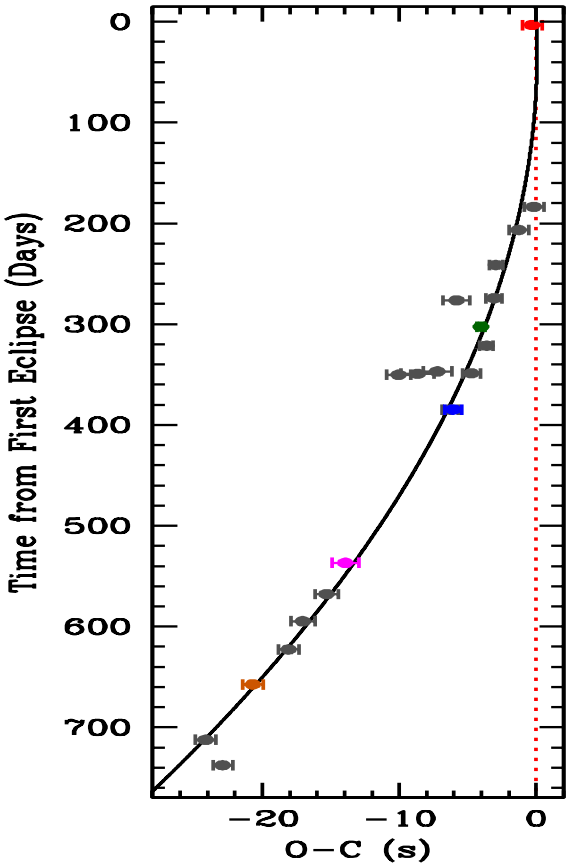




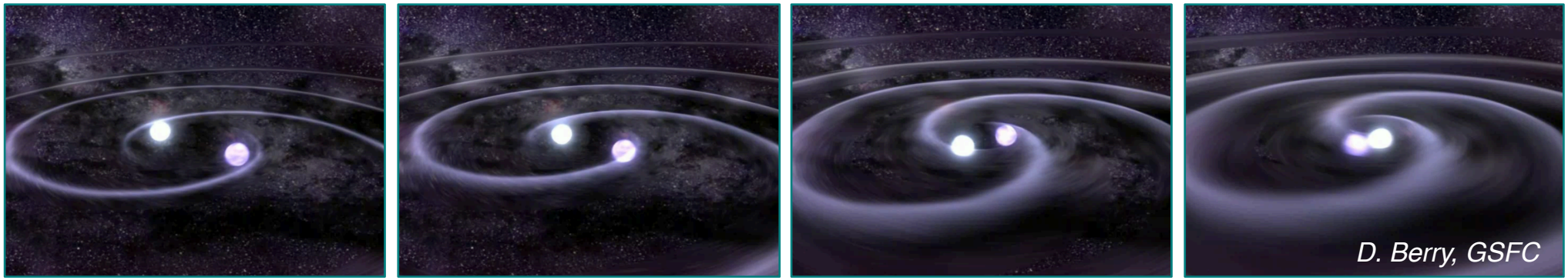
Hermes et al. 2012

Evidência de Ondas Gravitacionais

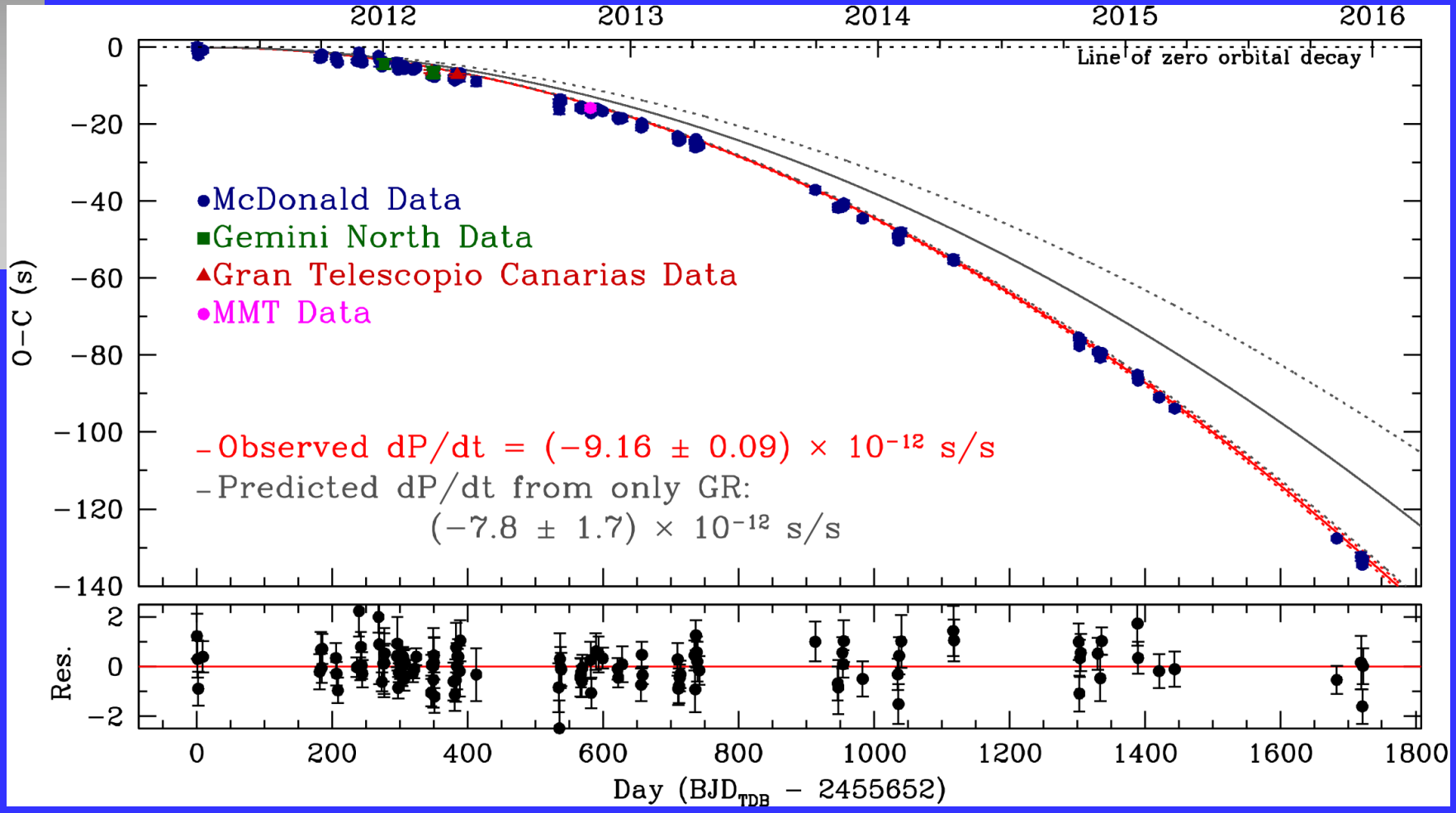




RG: dP_{orb}/dt = (-0.26 ± 0.05) ms/ano - observado (-0.28 ± 0.03) ms/ano

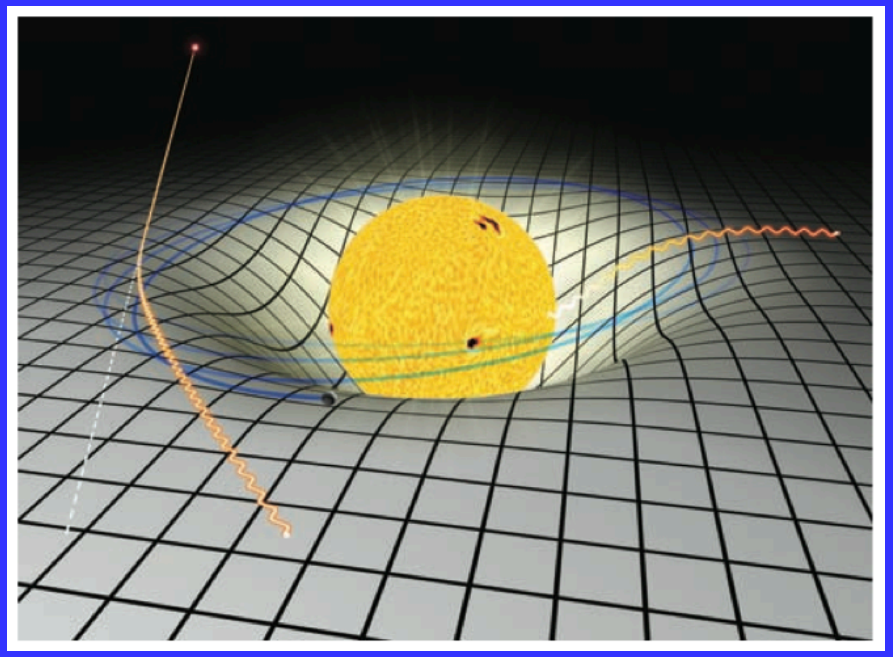


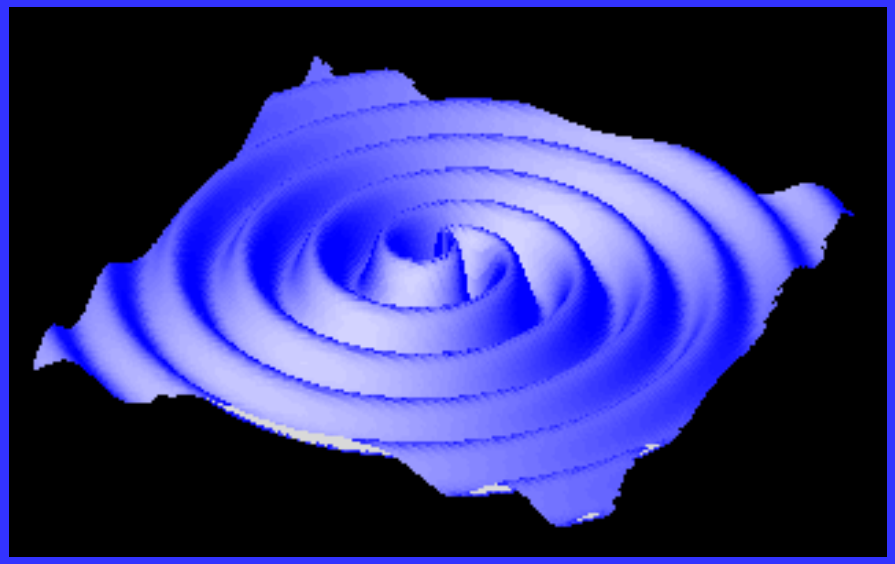
Relatividade Geral está certa!



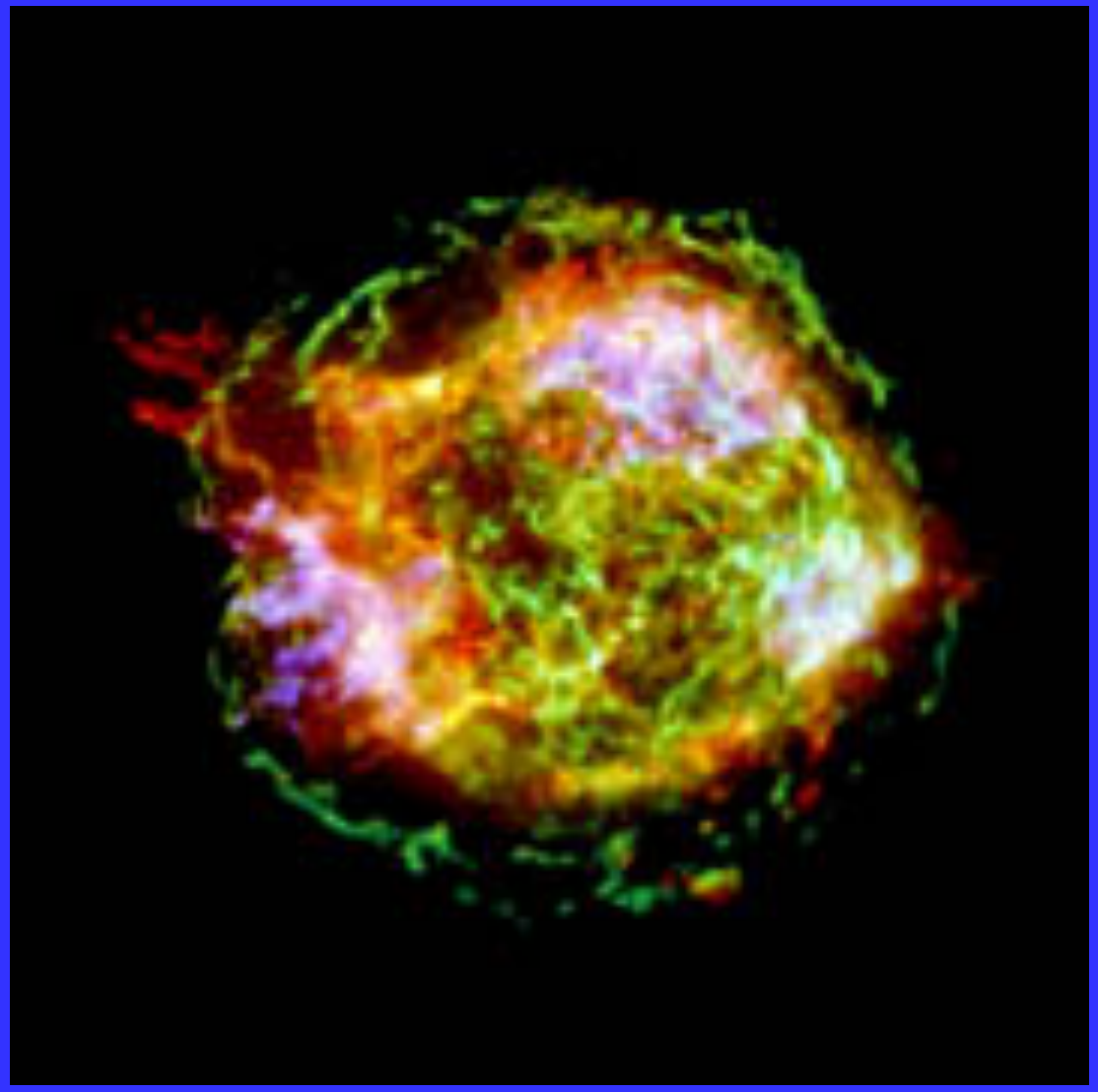
Ondas Gravitacionais

- *Gravidade deforma o espaço*
- *Massas em movimento emitem ondas*
- *Ondas carregam energia*
- *Perda de energia reduz a órbita*
- *Ondas gravitacionais ($\Delta r/r \sim 10^{-22}$)*

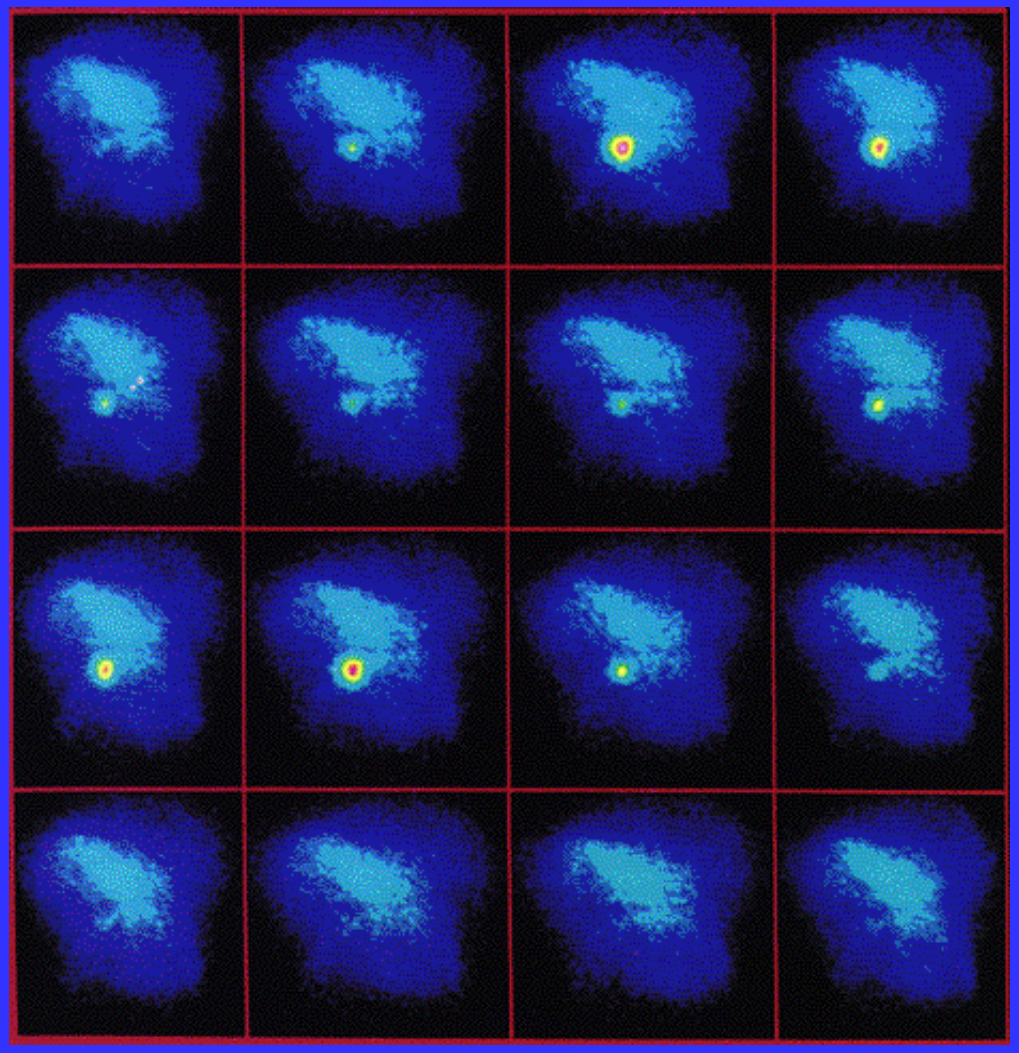




Explosão de supernova

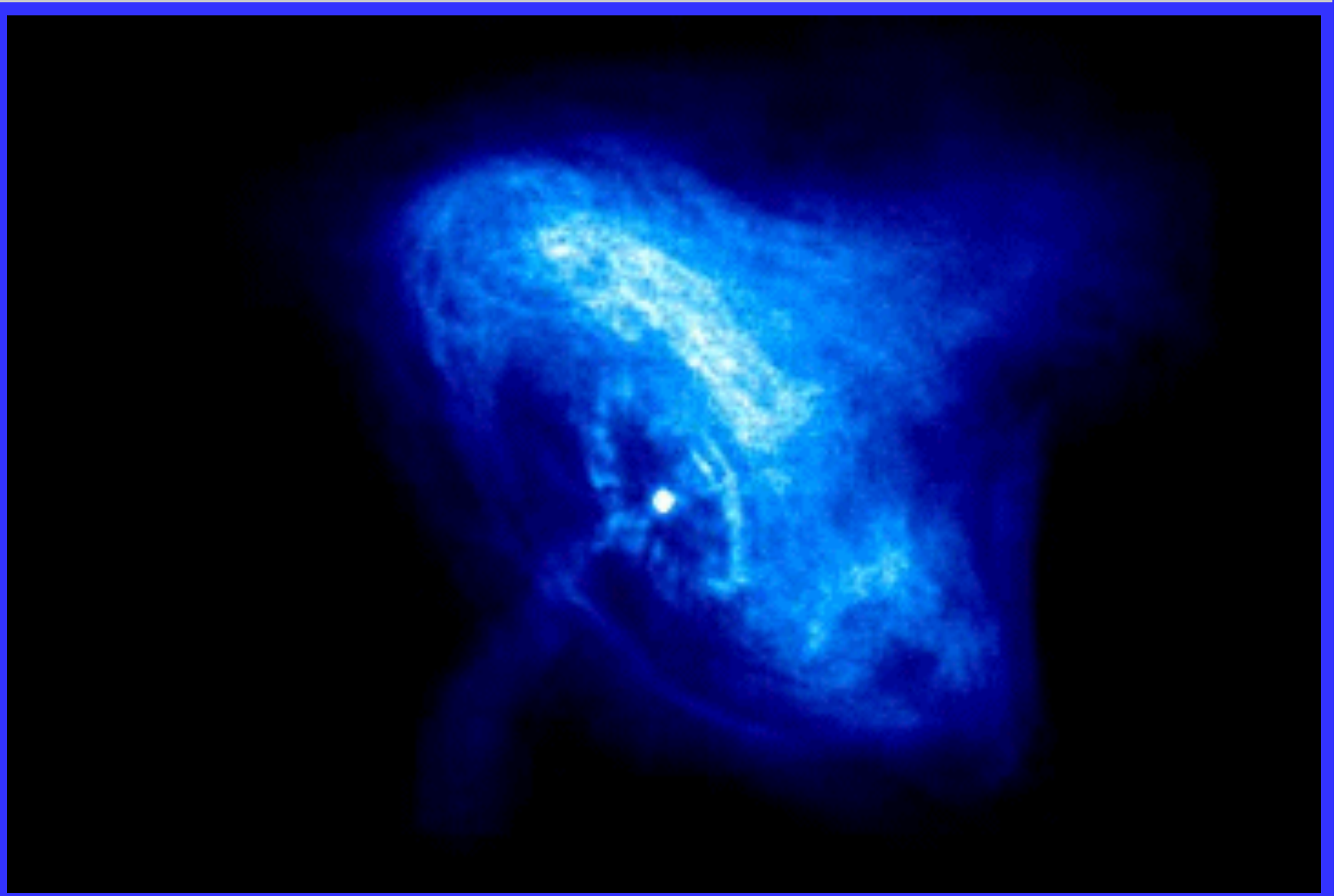


Pulsar da Nebulosa do Caranguejo (SN1054)



Raio-X

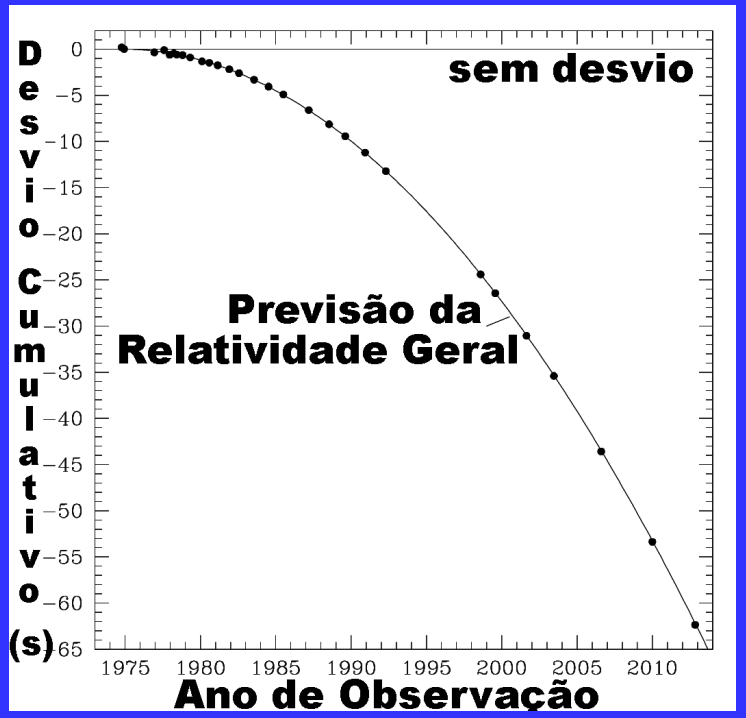
Pulsar de 1054



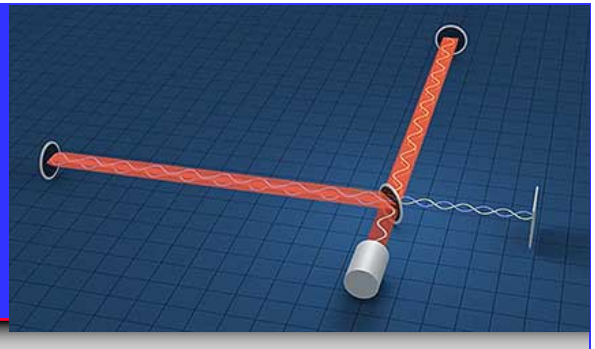
Pulsar binário PSR1913+16

- *Duas estrelas de nêutrons*
- *Período orbital = 7,75 horas*
- *Período de rotação do pulsar 59 milisegundos*
- $\Delta P/\Delta t = (76{,}0 \pm 0{,}3)\ \mu s/ano$

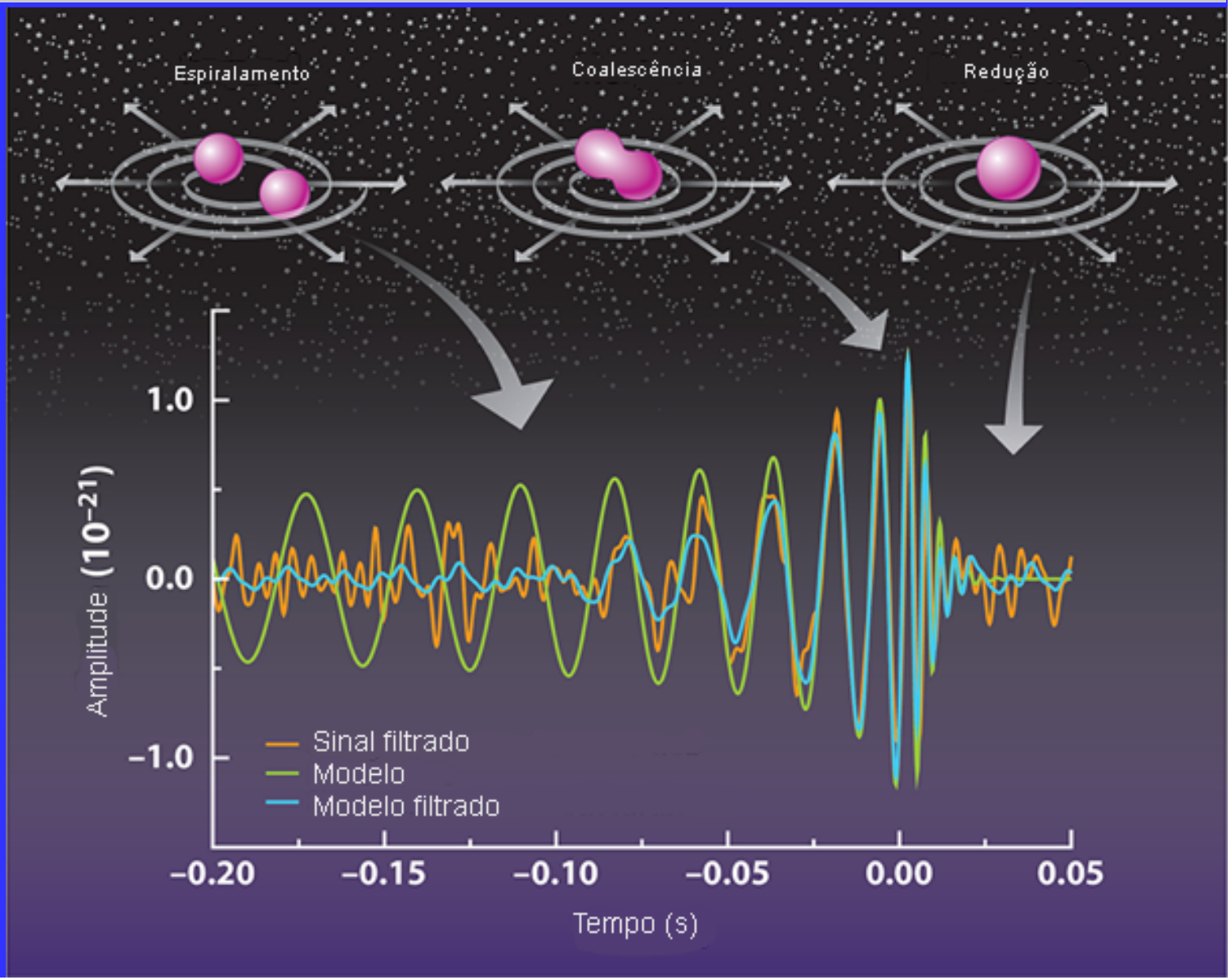
Incerteza na Relatividade *Geral é menor que $1/10^{18}$*



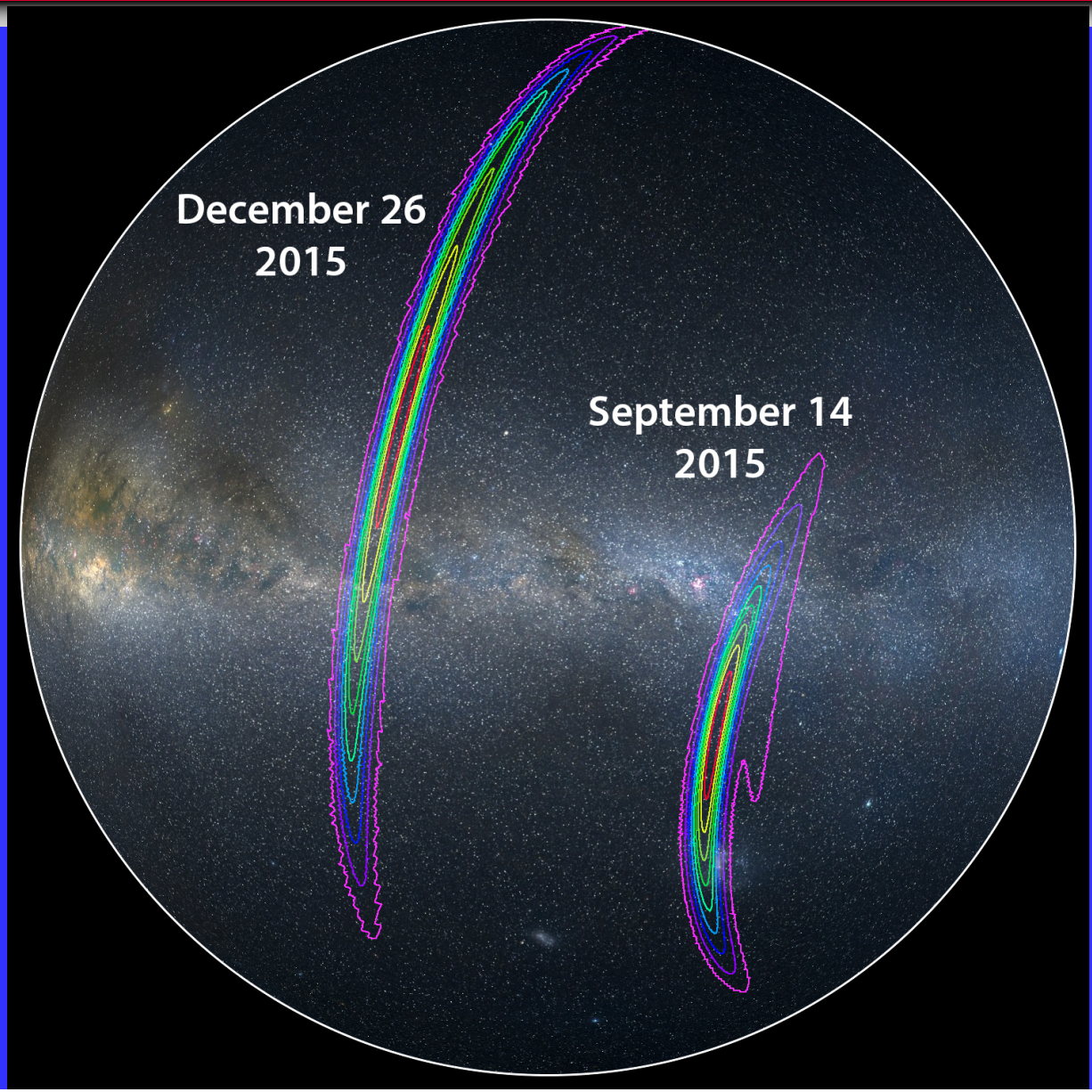
LIGO 14 set 2015



Colisão de BNs
34 ± 4 e
30 ± 4 M_{Sol}



LIGO

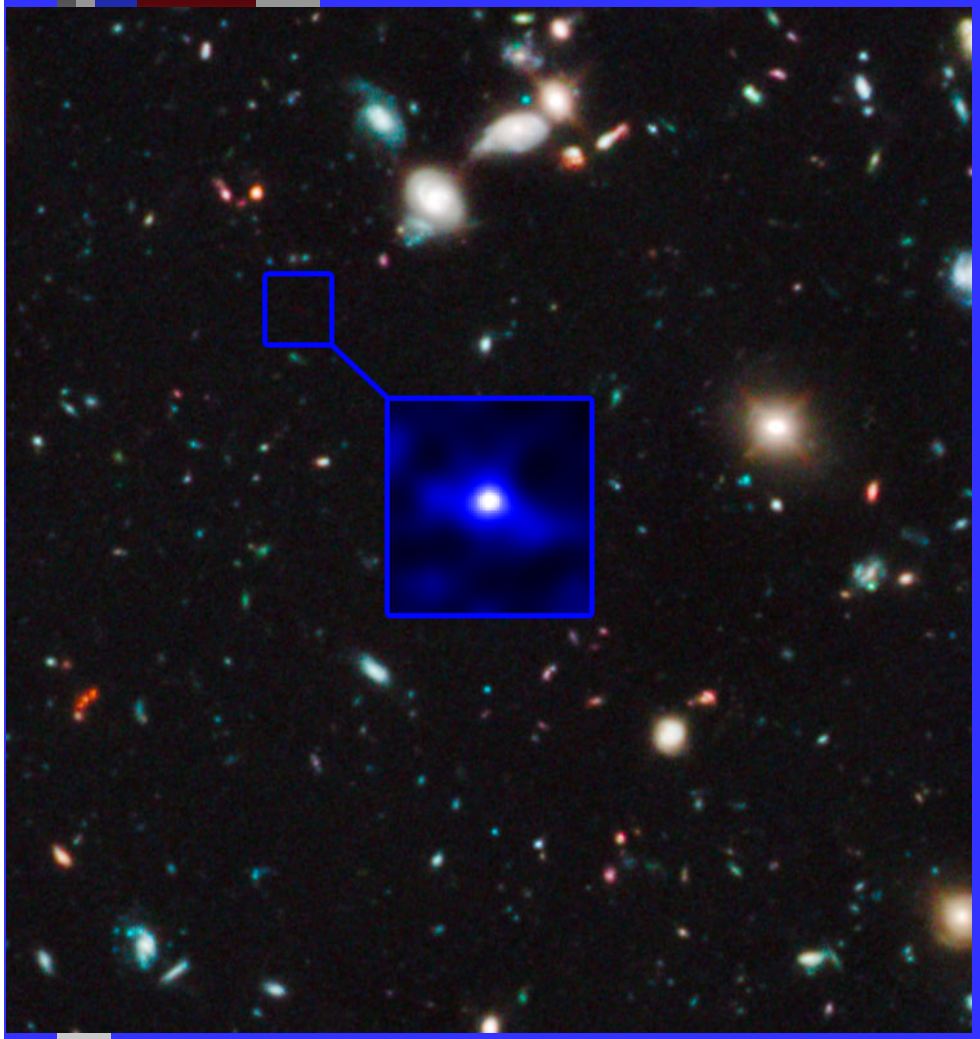


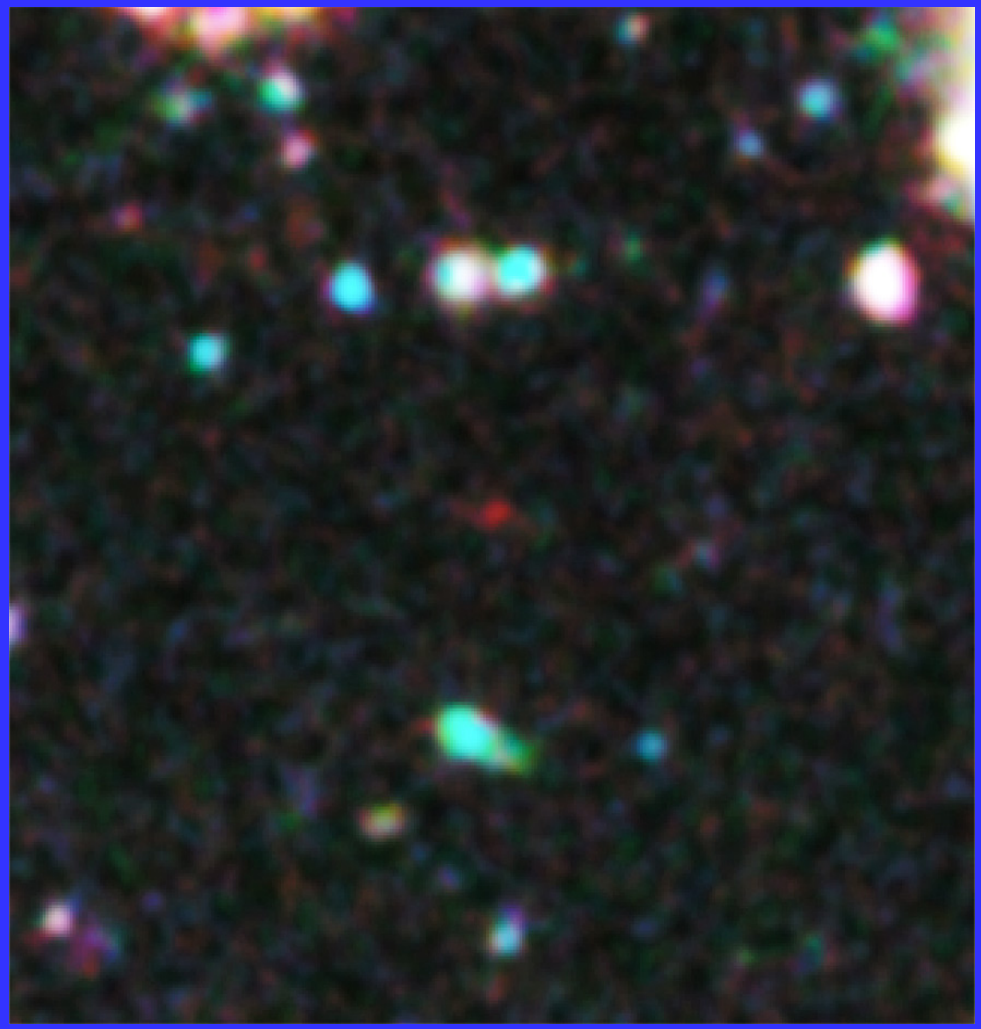
14 Sep 2015
35+30 M_{Sol}

26 Dez 2015
8+14 M_{Sol}

Z=11,9 d=13,42 bilhões de a.l.

HST UDFj-39546284





Bouwens et al. 2013, ApJ, 765, L16B

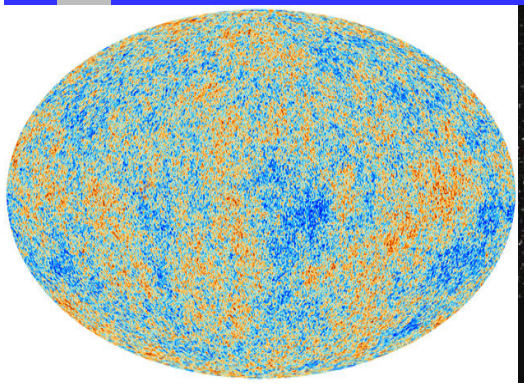
Universo é finito,

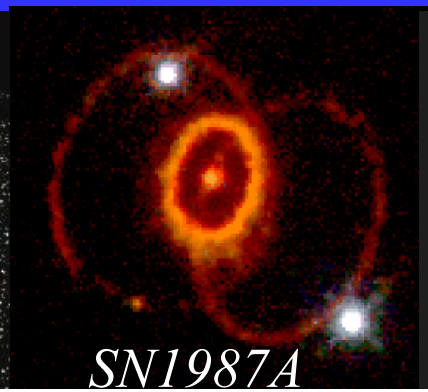
Qual é o tamanho do horizonte?

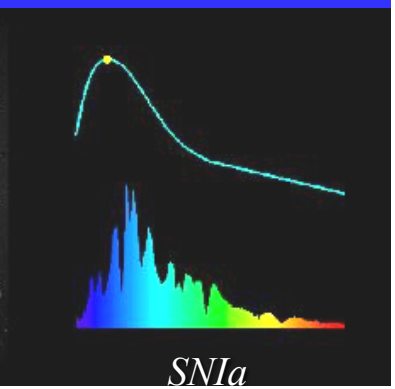
idade x c

Idade do Universo em 2016

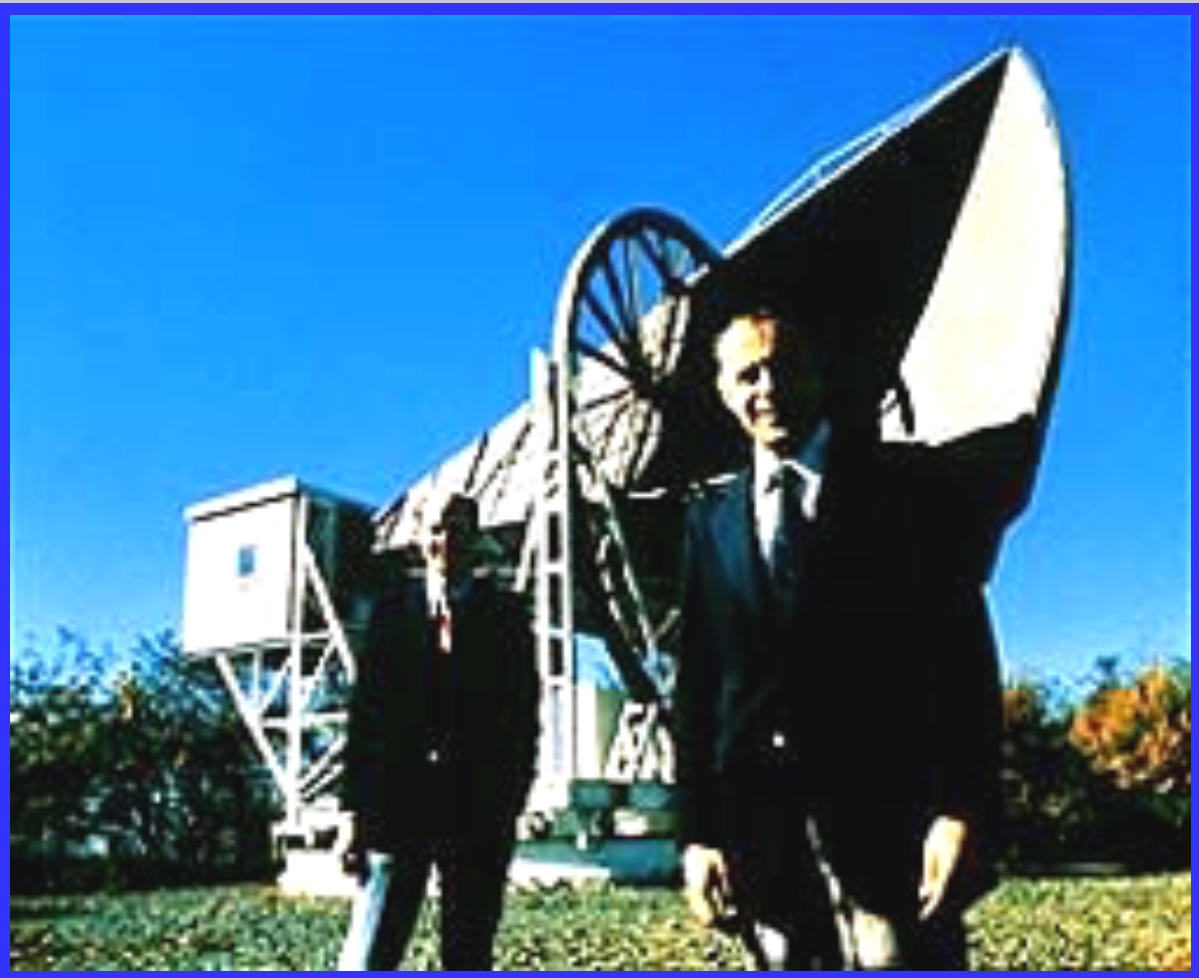
- *Espectro da Radiação do Fundo do Universo* =*(13,75±0,08)Ganos*
- *Taxa de Expansão do Universo - Idade: 1/H* = *(13 ± 1) Ganos*
- *Cúmulos Globulares - Idade:* *(13,2 ± 1,5) Ganos*
- *Decaimento Radiativo - Idade:* *(12,5 ± 3) Ganos*
- *Esfriamento das Anãs Brancas - Idade:* *(12,7 ± 0,7) Ganos*
- *Distância às Supernovas Tipo I - Idade:* *13.0 ±1.2 (0.72/h)Ga,Λ*







Arno Penzias e Robert Wilson 1964



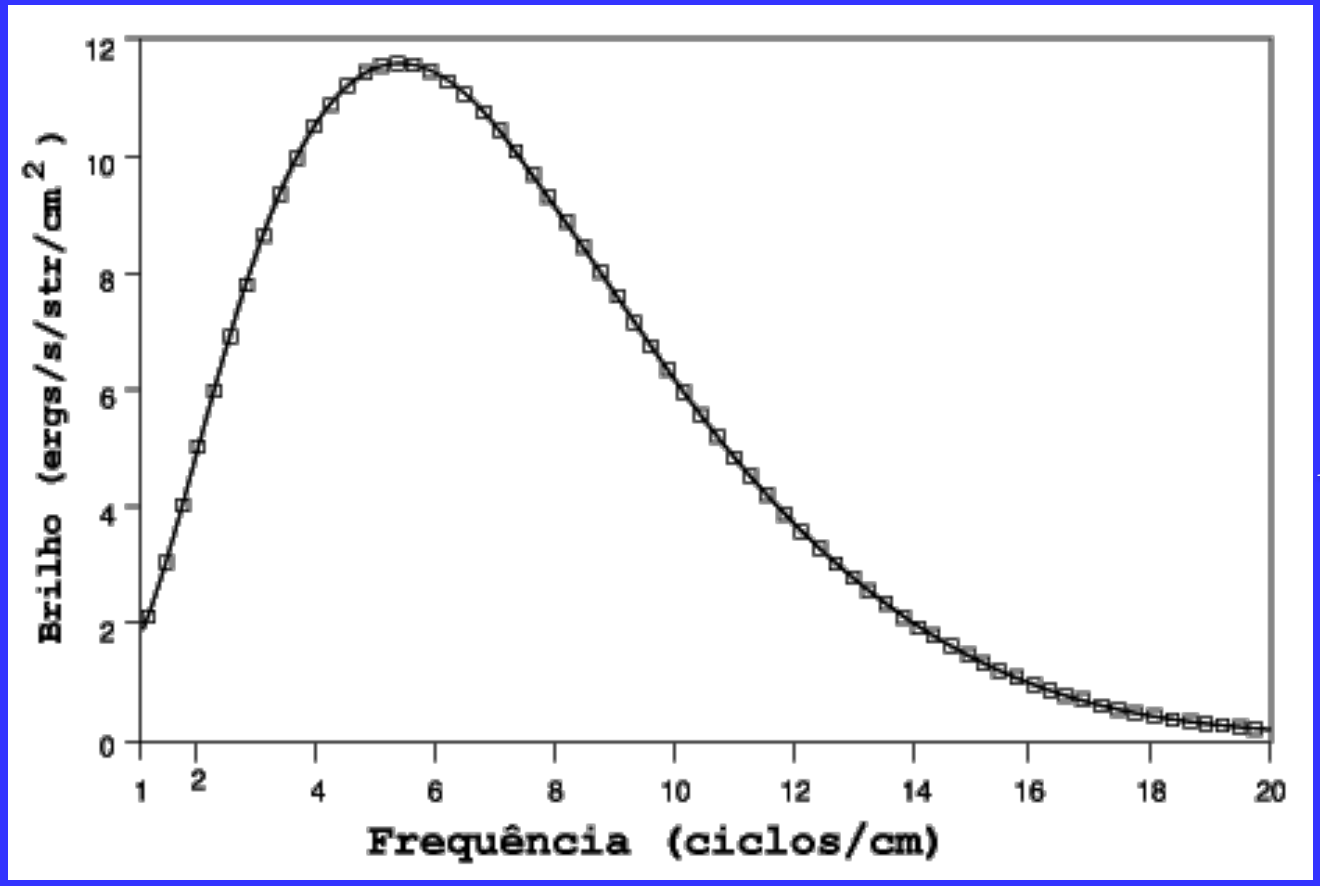
Radiação do Fundo do Universo

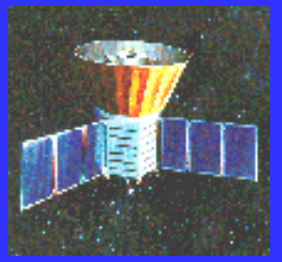
George Gamow

Robert Herman & Ralph Alpher

1948

Distribuição de Intensidades COBE





1989

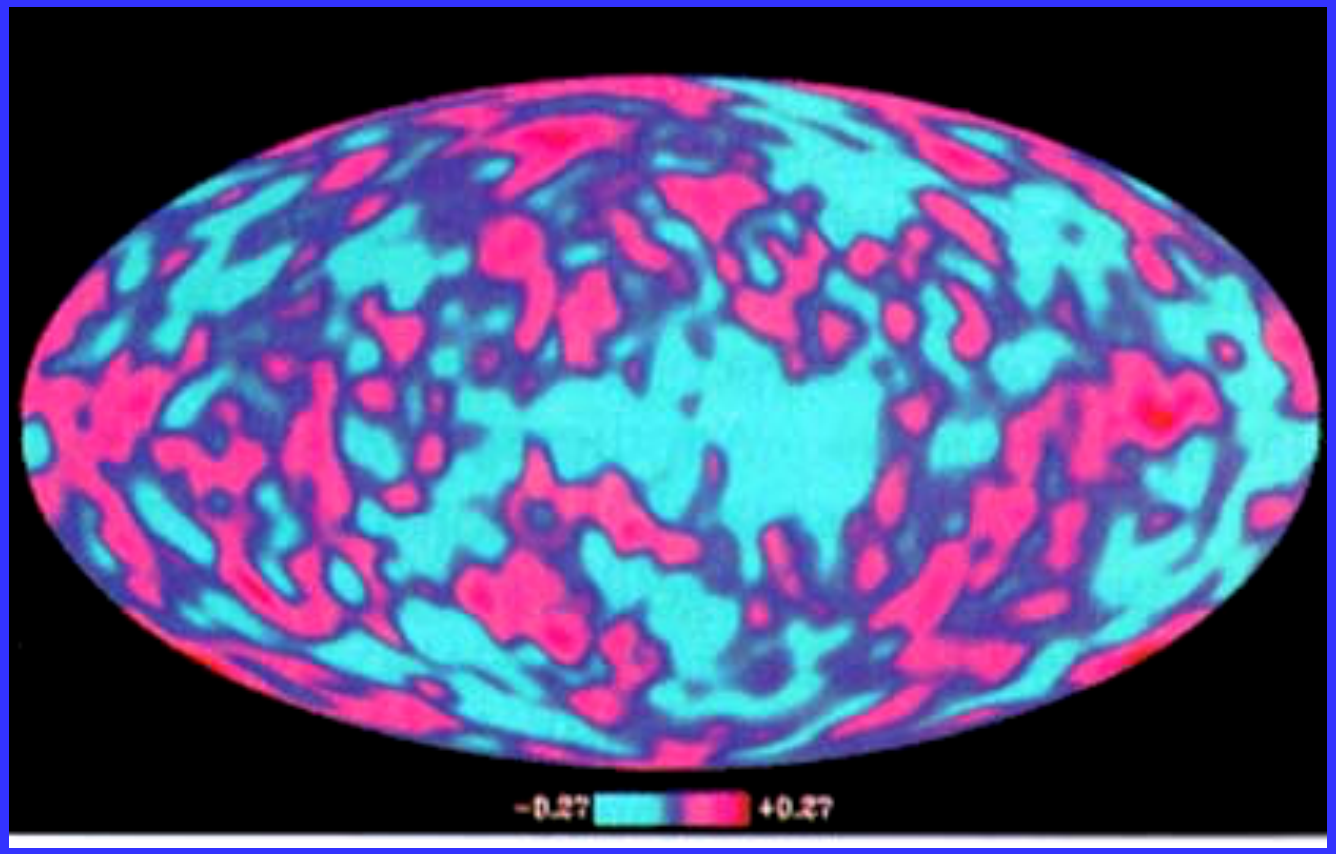
Max Planck

2,726 K

Universo era quente e pequeno no passado: Big Bang

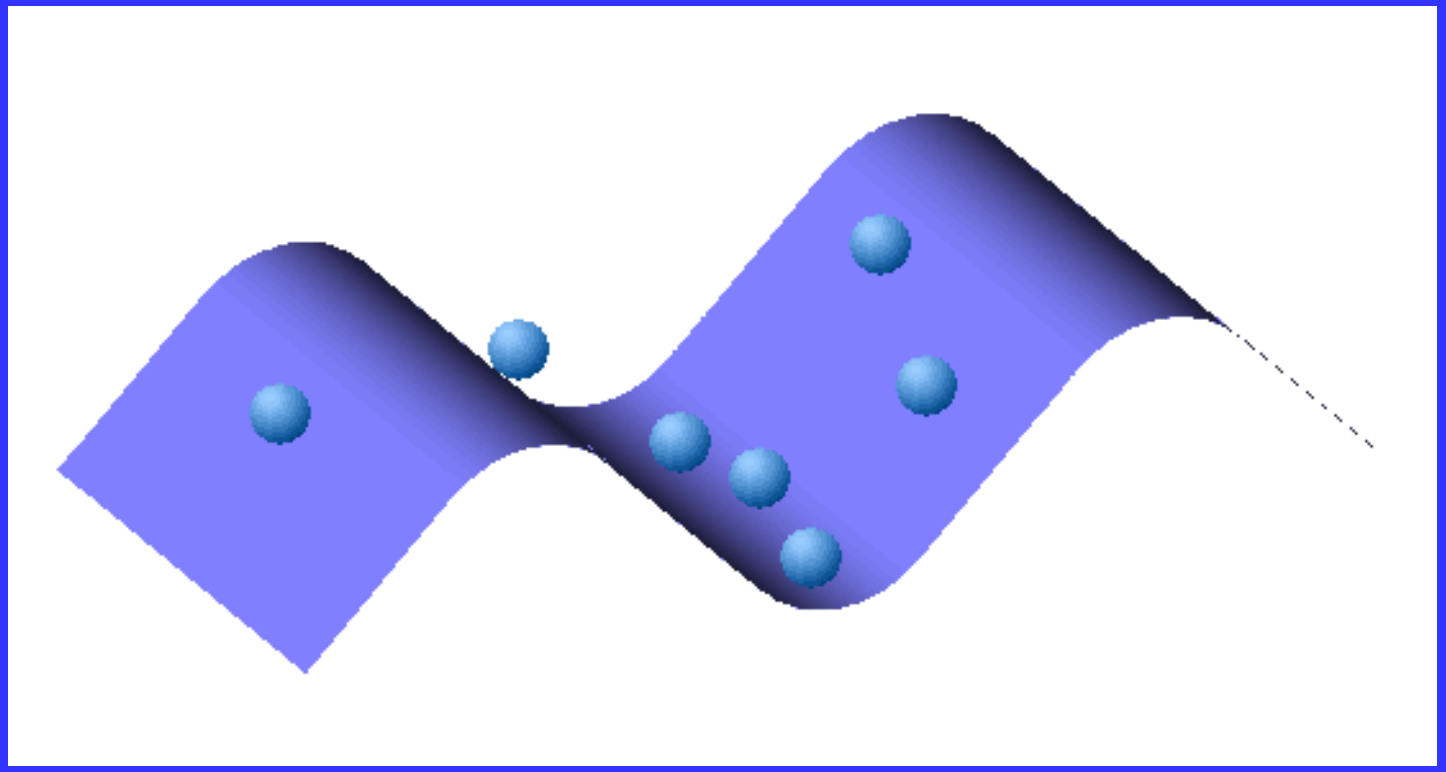
COBE - Distribuição de Intensidades

Cosmic Background Explorer



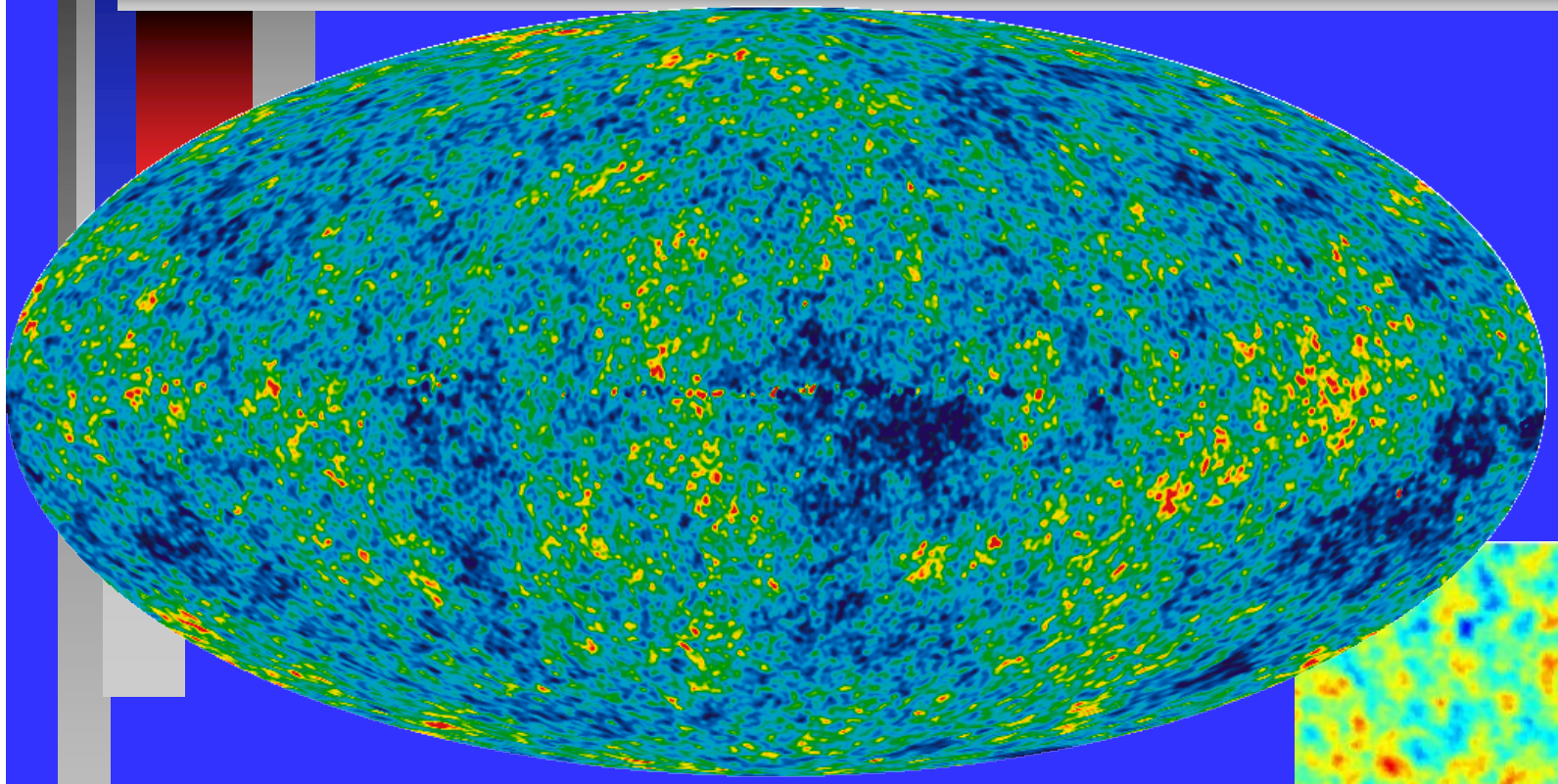
Diferença de cores representa
1 parte por milhão

Instabilidade gravitacional

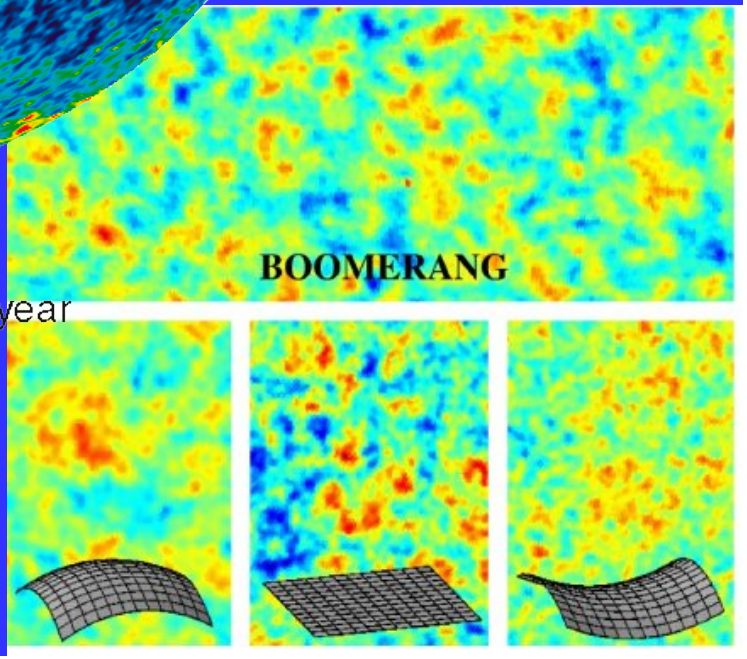


WMAP Radiação do Fundo

Wilkinson Microwave Anisotropy Probe



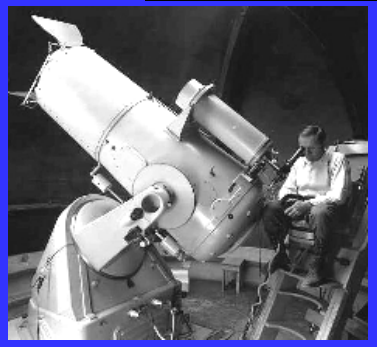
WMAP 5-year



Matéria Escura

$$\rho_{critica} = \frac{3H^2}{8\pi G} = 10^{-29}\ g/cm^3$$

$$\rho_{obs} = 2 \times 10^{-31}\ g/cm^3$$



Fritz Zwicky 1930

Energia Gravitacional = Energia Cinética

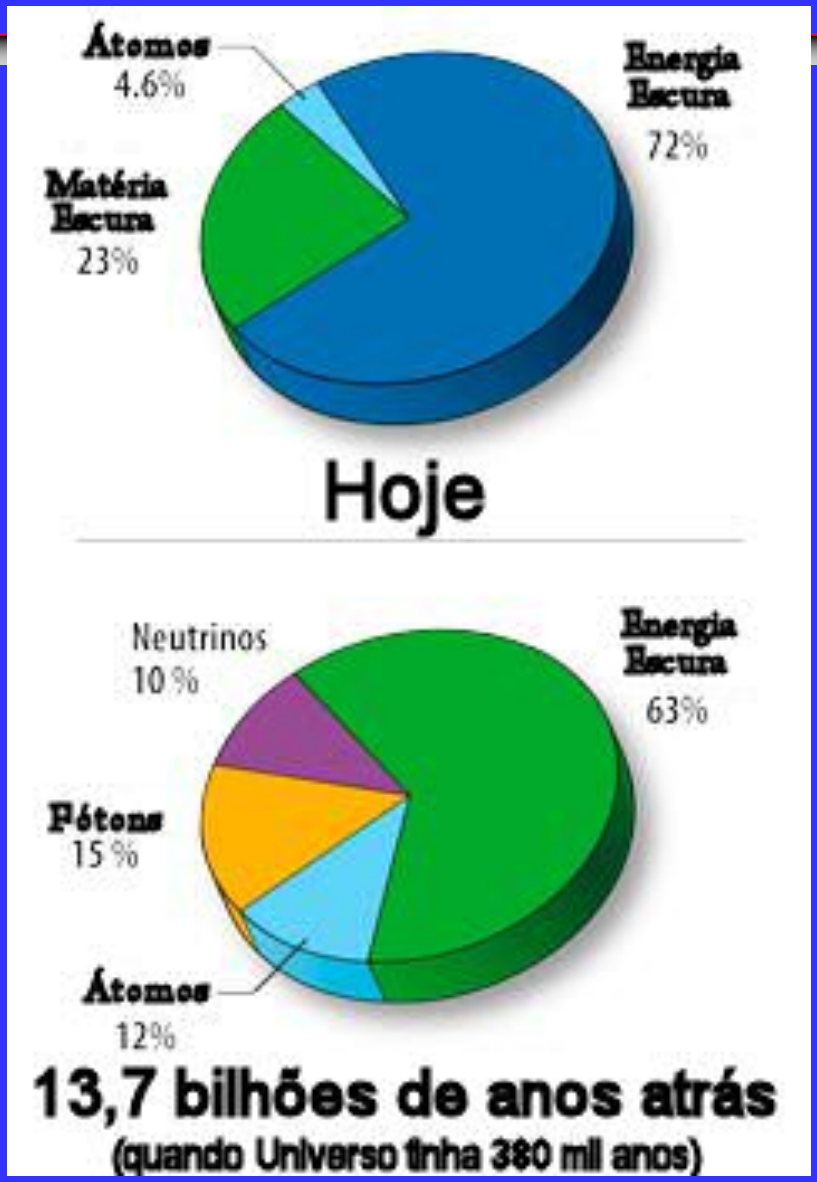
$\rho_{mat} = (0.19 \pm 0.06)\ \rho_{critica}$

Matéria Escura ~ 10 Matéria Luminosa

Energia escura 1998

SNIa

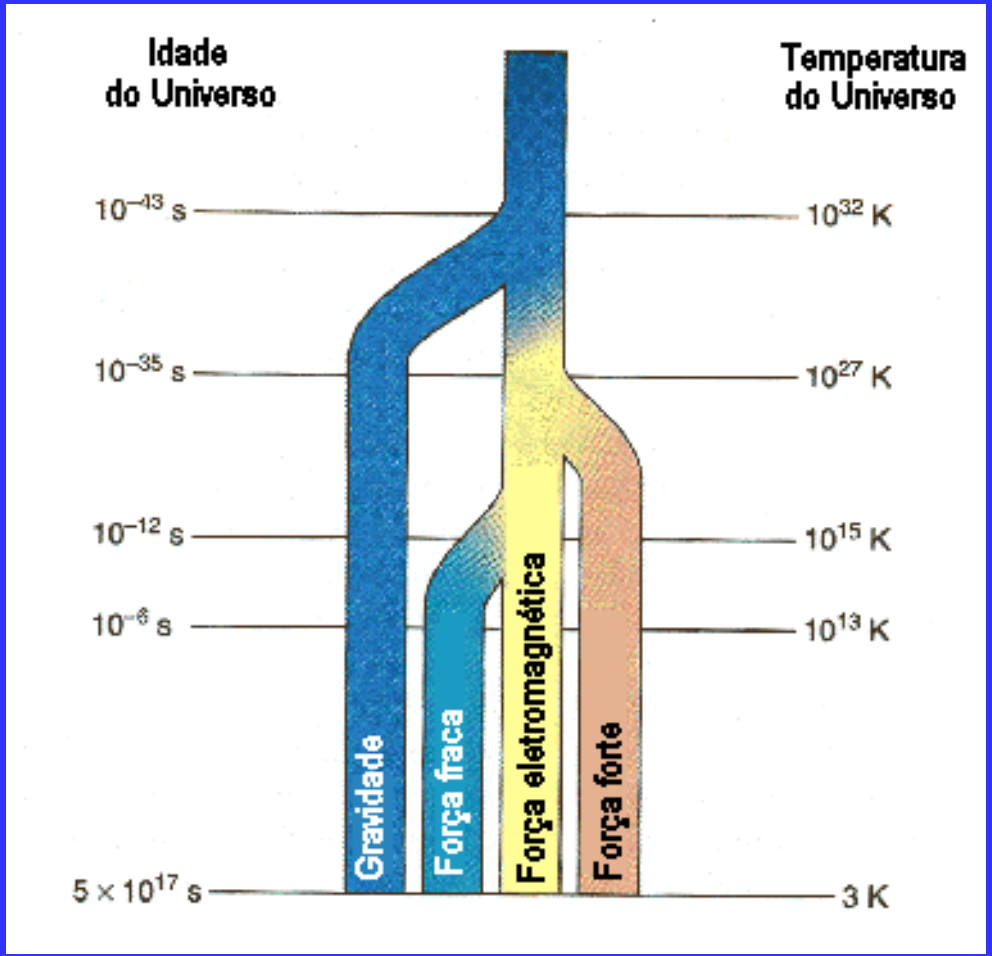
Energia Total do Universo



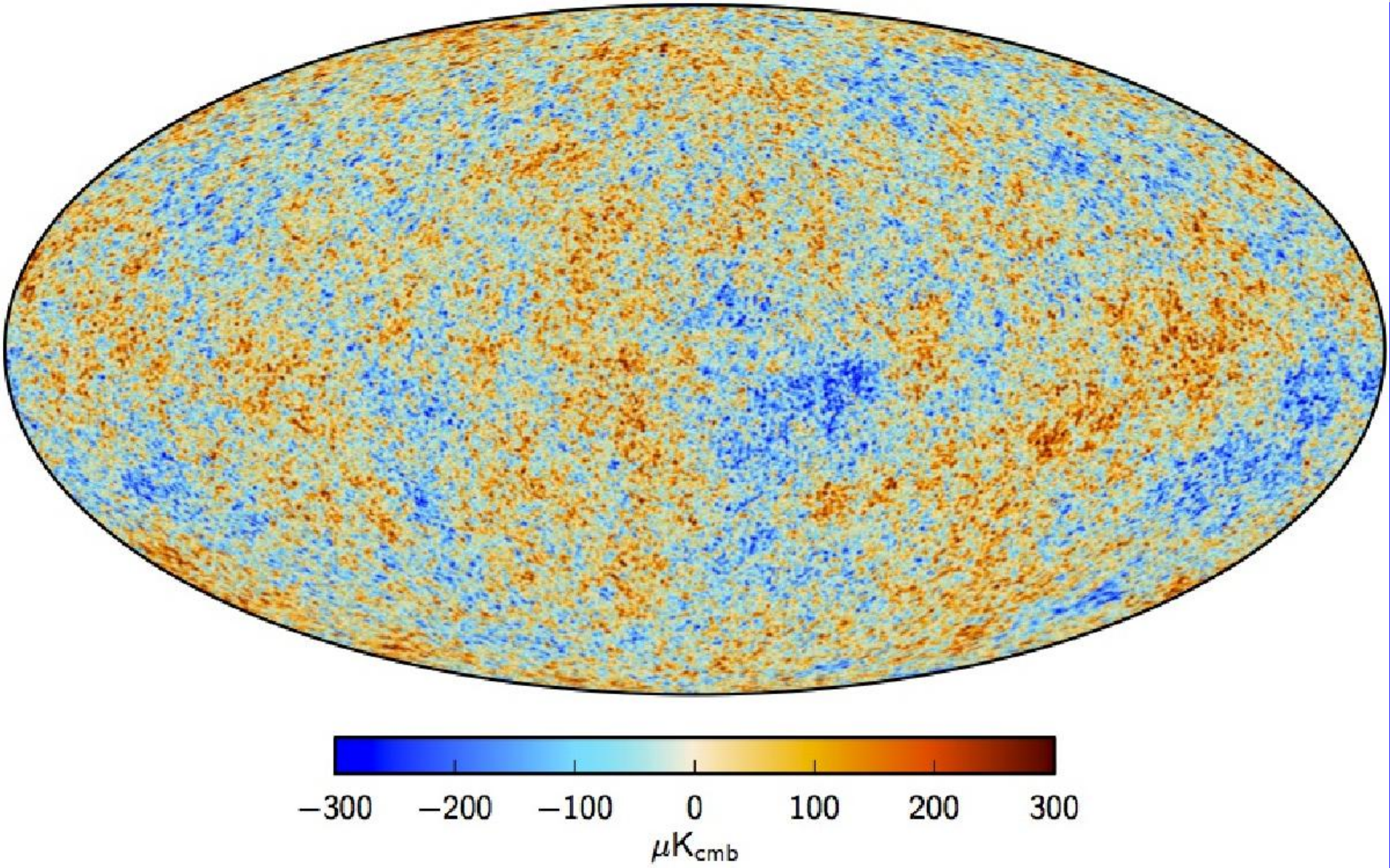
Cronologia resumida do Universo

- *Big-Bang + Inflação + formação das partículas (3m 48s)*
- *380.000 anos: desacoplamento matéria e radiação, formação dos primeiros átomos*
- *380.000.000 anos: formação das primeiras estrelas*
- *8,7 bilhões de anos: formação do Sistema Solar*
- *13,7 bilhões de anos: época atual*
- *18 bilhões de anos: Sol vai evoluir para gigante vermelha, nebulosa*

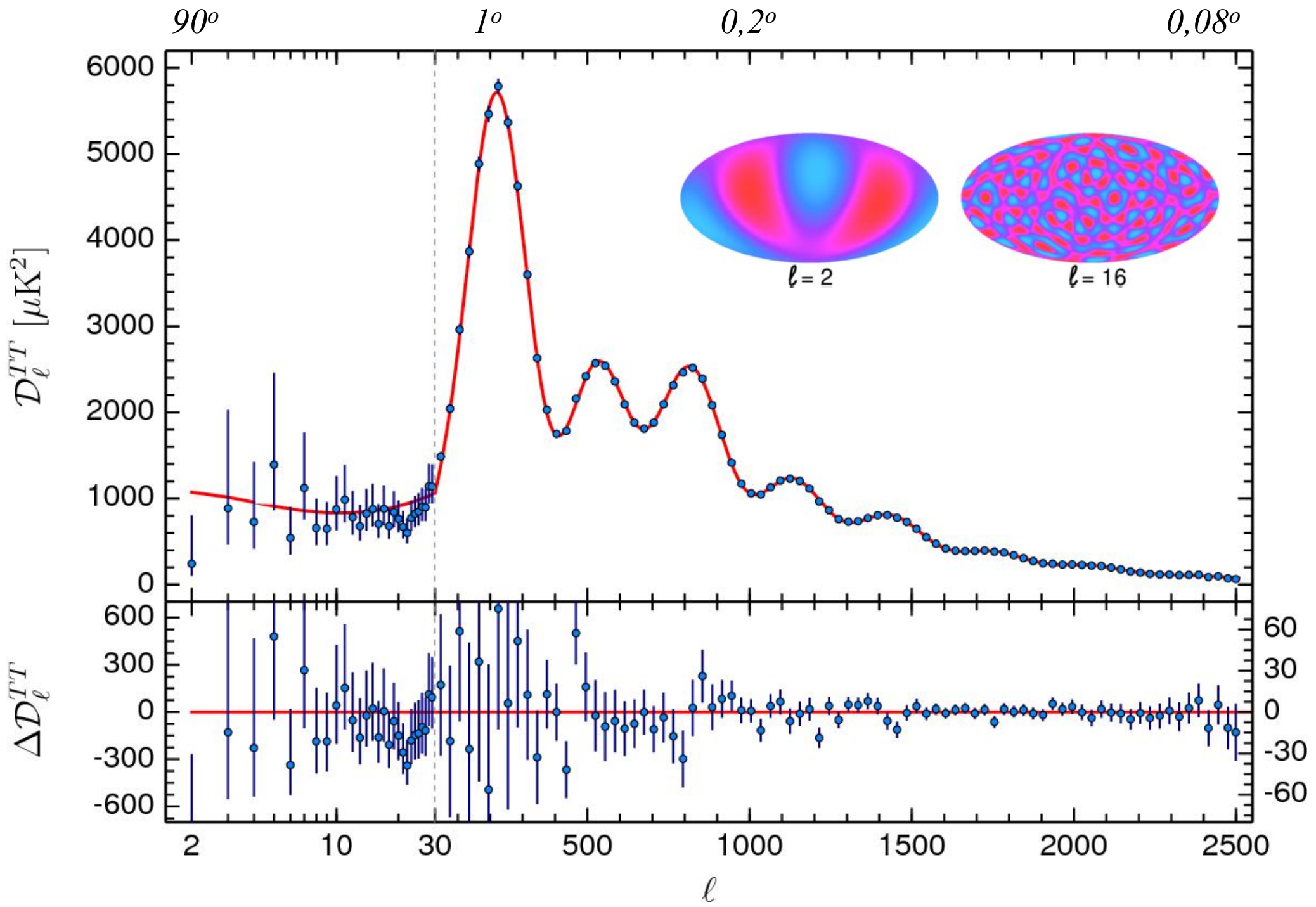
Evolução da temperatura



Planck 2016



Escala Angular das Diferenças



Linha do Tempo

Evolução Estelar

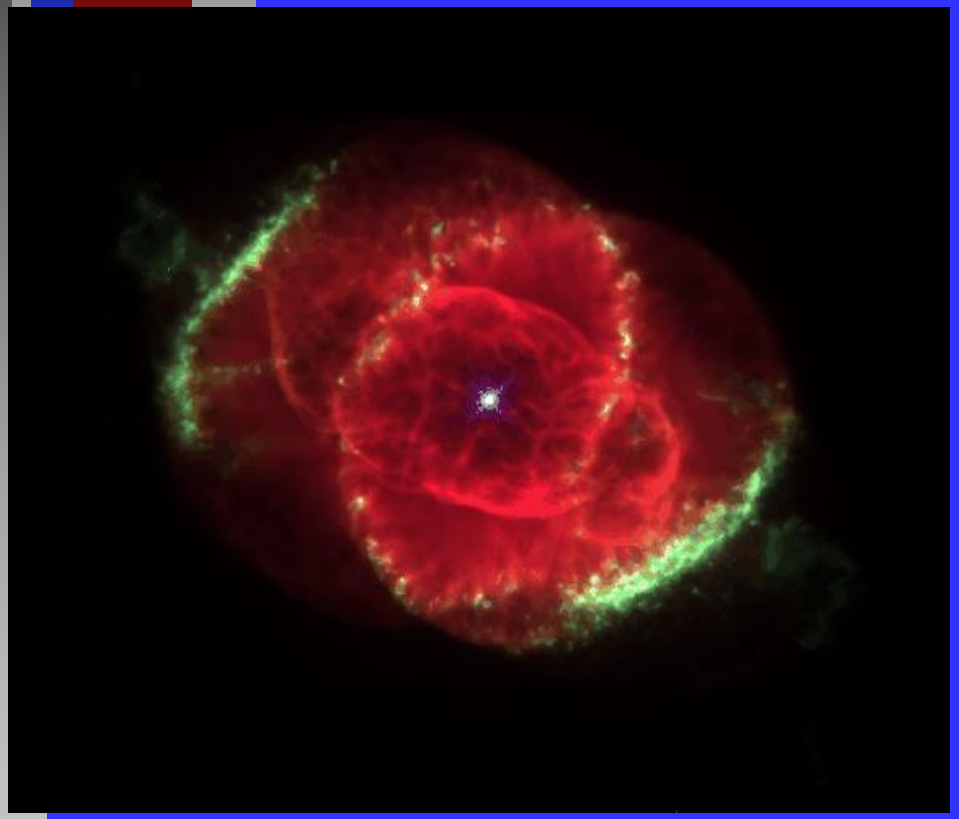
Massa < 10 M_{sol} : Anã branca

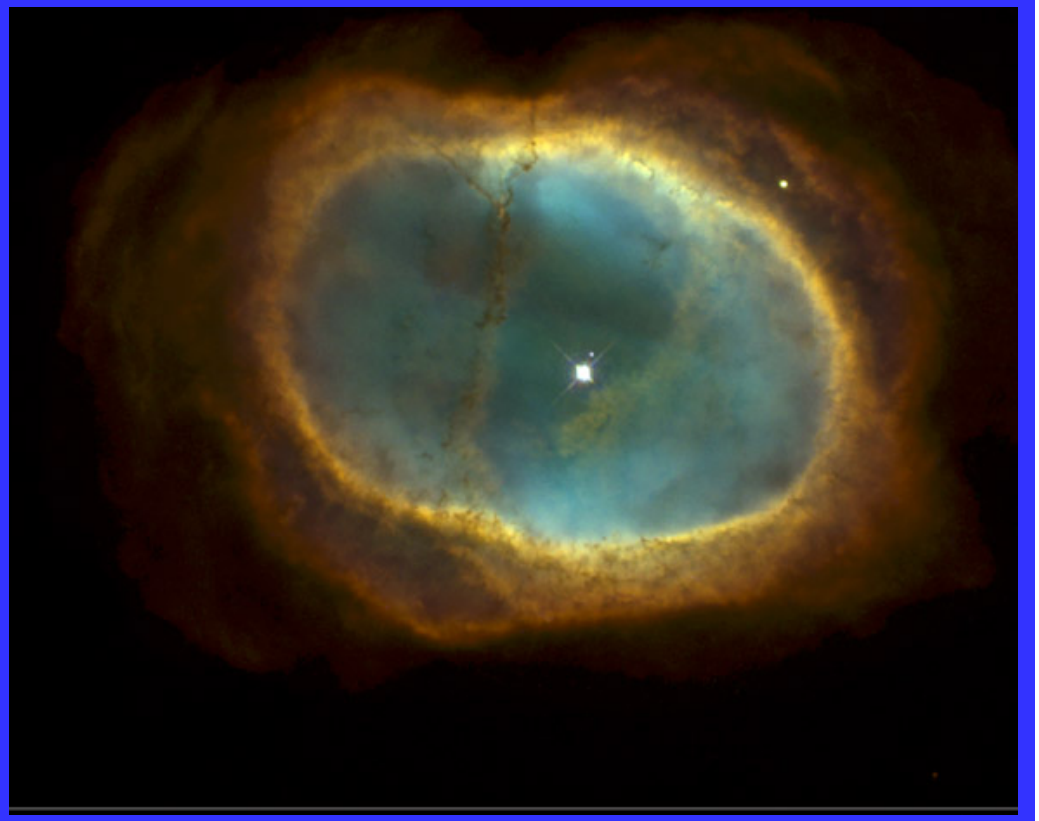
10 M_{sol} < Massa < 25 M_{sol} : Estrela de Nêutrons

Massa > 25 M_{sol} : Buraco Negro

Nebulosas Planetárias

observadas pelo Telescópio Espacial





Métodos de Datação do Universo

Expansão

Taxa de Expansão

Distância às Galáxias

Distância às Estrelas

Anãs Brancas

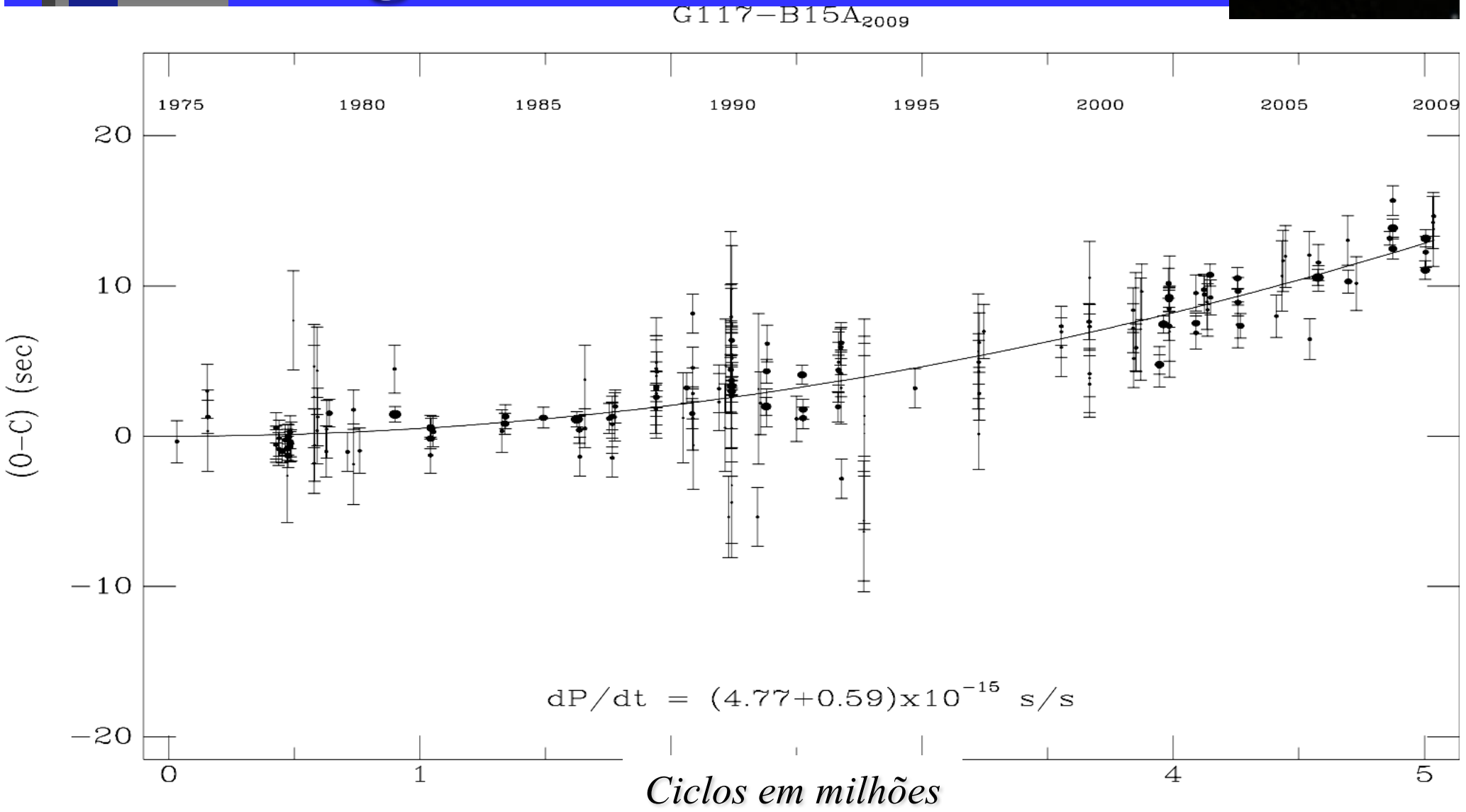
Anãs Brancas Mais Frias

Taxa de Esfriamento das Anãs Brancas

Estrutura das Anãs Brancas

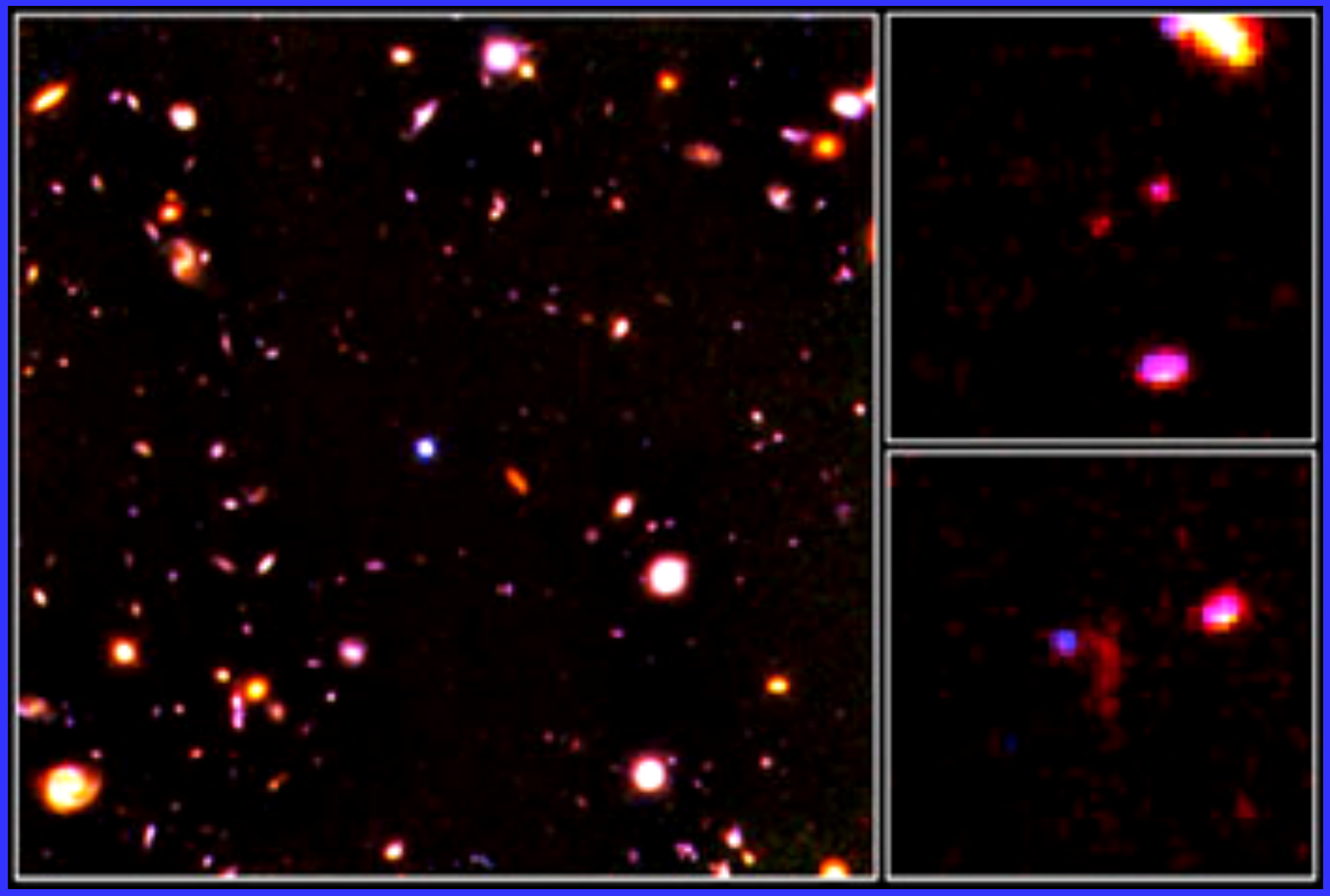
Sírius e Anã Branca

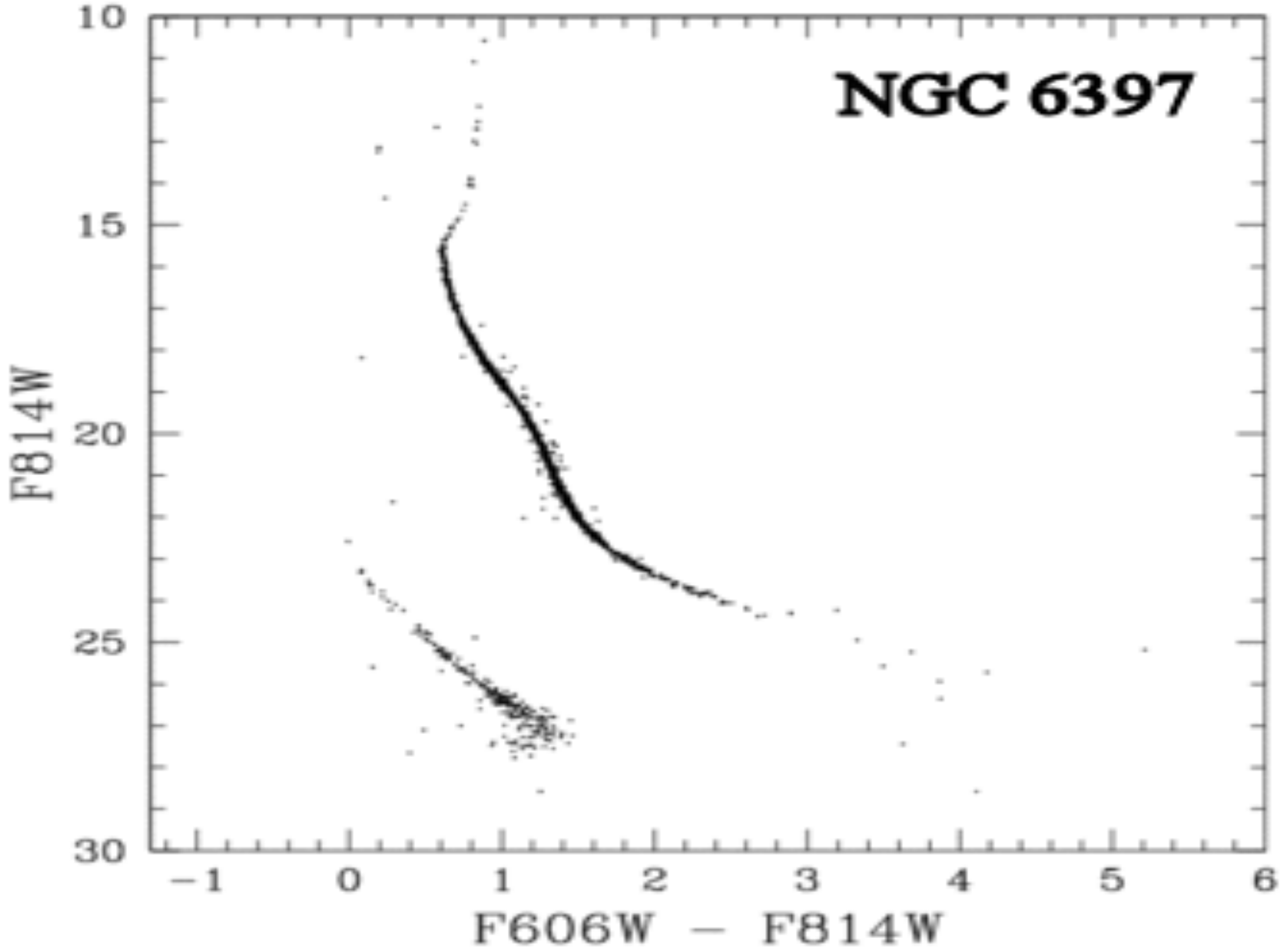
O relógio mais estável conhecido



Muda 1s a cada 10 milhões de anos!

HST: Galáxias formaram-se 1 Gano depois do Big-Bang

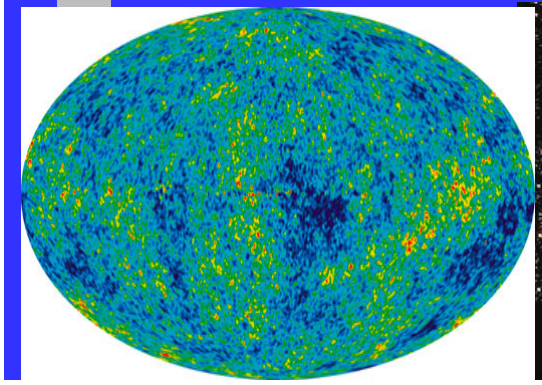


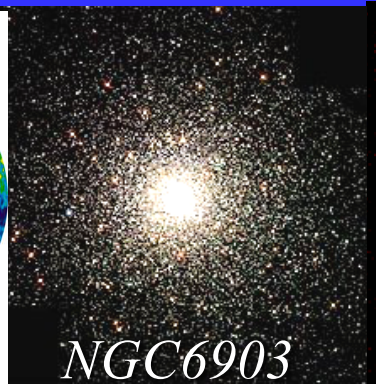

NGC 6397
F814W
F606W − F814W
10
15
20
25
30
−1
0
1
2
3
4
5
6

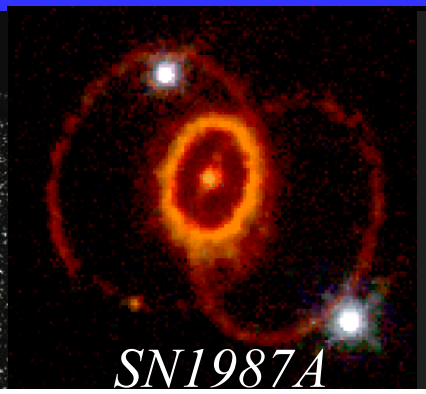
Idade do Universo em 2009

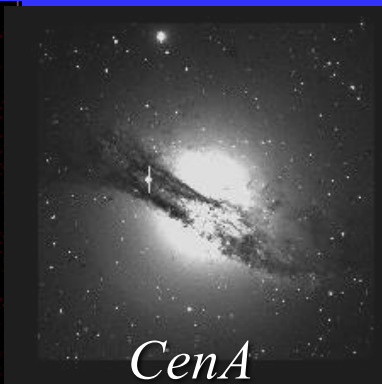
Enquanto há 20 anos somente as anãs brancas indicavam idades menores que 15 bilhões de anos:

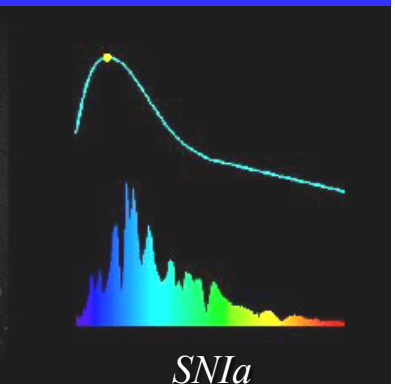
- *Espectro da Radiação do Fundo do Universo = (13,73±0,12)Ganos*
- *Taxa de Expansão do Universo - Idade: 1/H = (13 ± 1) Ganos*
- *Cúmulos Globulares - Idade: (13,2 ± 1,5) Ganos*
- *Decaimento Radiativo - Idade: (12,5 ± 3) Ganos*
- *Esfriamento das Anãs Brancas - Idade: (12,7 ± 0,7) Ganos*
- *Distância às Supernovas Tipo I - Idade: 13.0 ±1.2 (0.72/h)Ga,Λ*







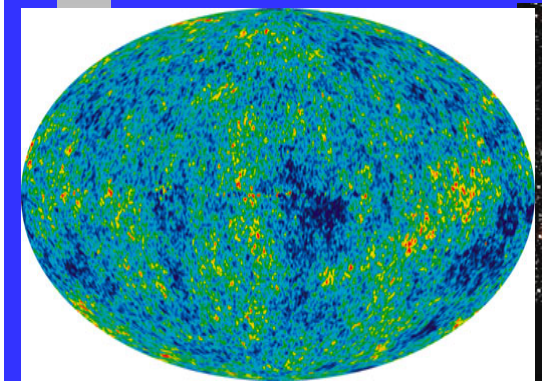


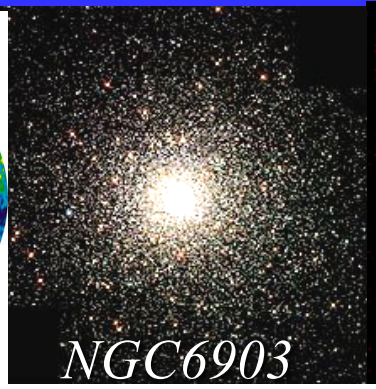


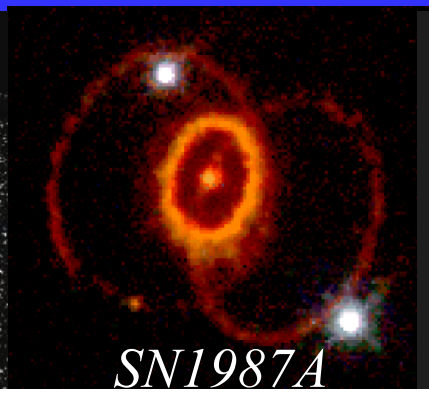
Age of the Universe 2014

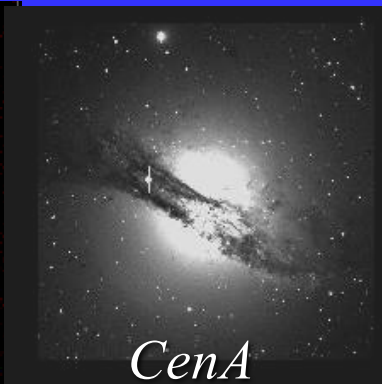
25 years ago only de Vaucouleus and white dwarfs gave Ages smaller than 15 billion years

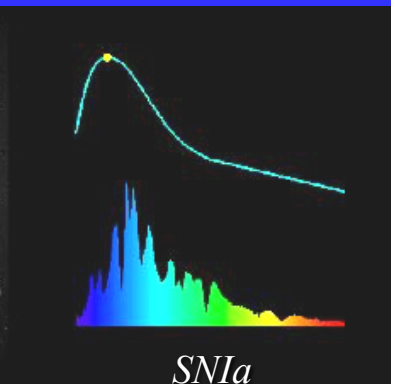
•Planck	(13.798±0.037) Gyr
•1/H	(13 ± 1) Gyr
•Globular Clusters	(13.2 ± 1.5) Gyr
•Radioactive Decay	(12.5 ± 3) Gyr
•While Dwarf Cooling	(13.5 ± 0.7) Gyr
•Distance to SNIa	13.0 ±1.2 (0.72/h)Gyr,Λ











Energia escura 1998

SNIa

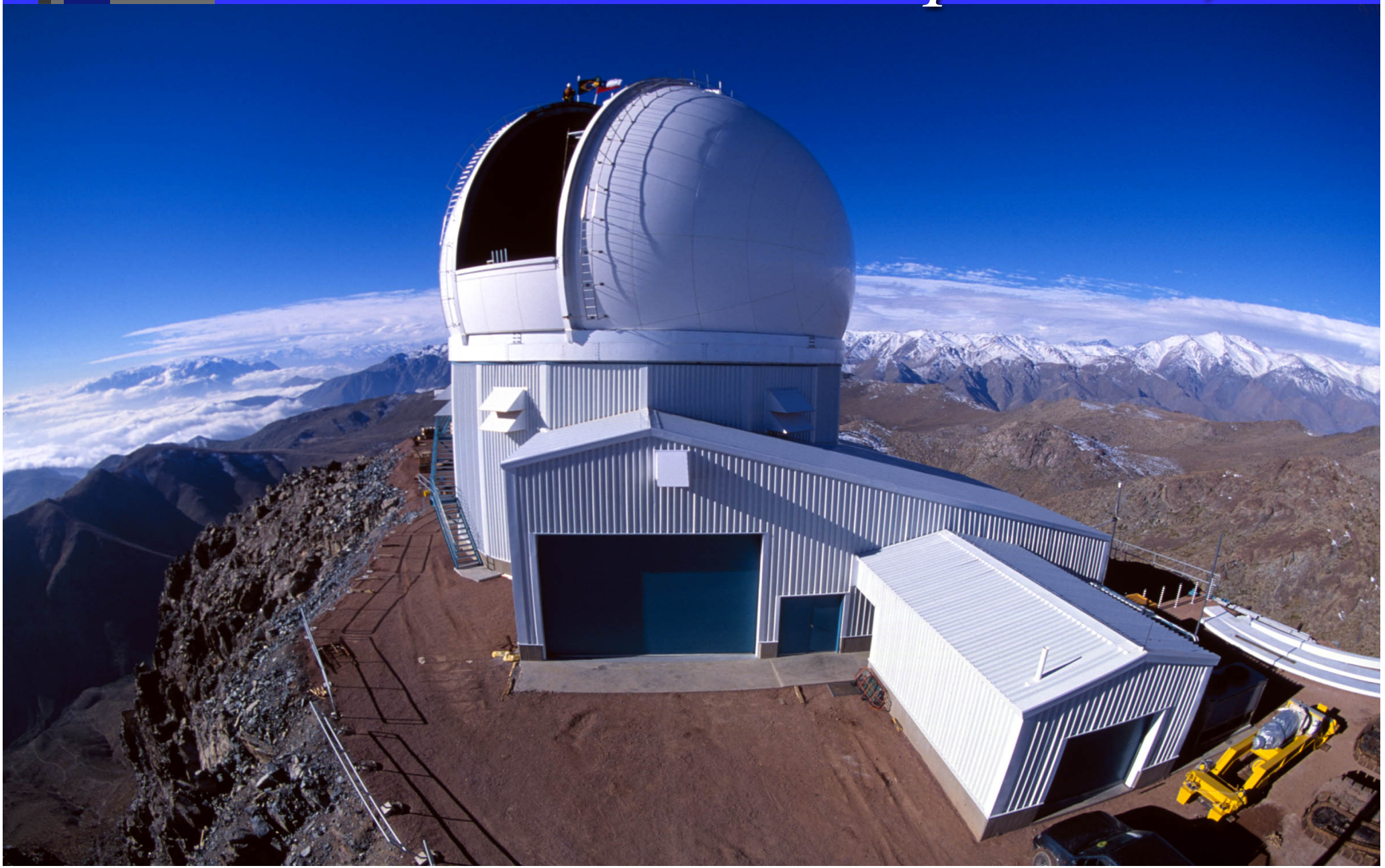
A Astronomia no Brasil

Laboratório Nacional de Astrofísica
1981
1,6m

Observações: telescópio de 1,6 m
Laboratório Nacional de Astrofísica

Brasópolis, MG

SOAR – 31% de telescópio de 4,1m

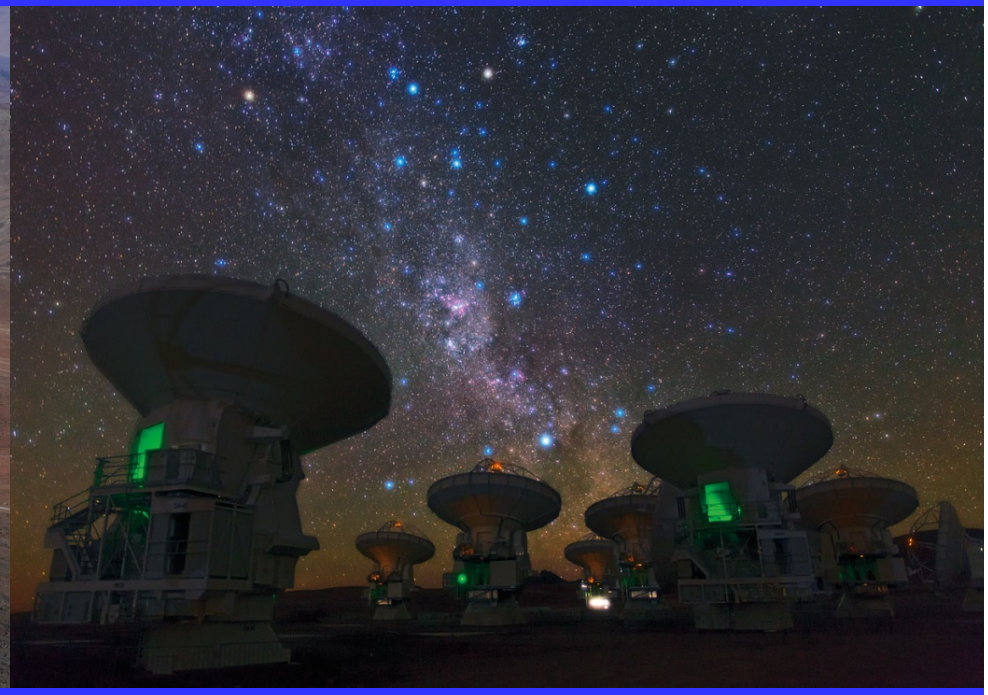


Gemini: 2 telescópios de 8m (5%)

Mauna Kea: Havaí
1999

Cerro Pachon: Chile
2000

European Southern Observatory



ESO Paranal: 4x8.2m e ALMA

That's all folks!