



Cosmologia com python

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clearnightsrthebest.com



Episódio II- O lado escuro do Universo



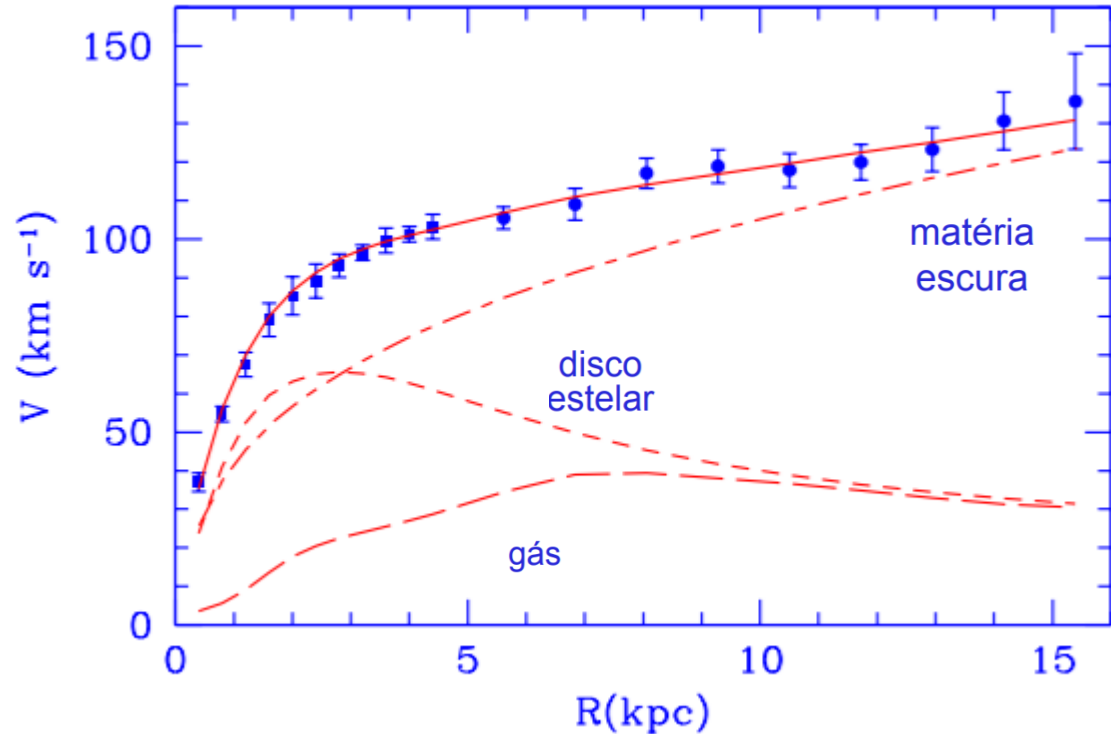
Curva de Rotação de Galáxias

$$G \frac{M(r)}{r^2} = \frac{[V(r)]^2}{r}$$

[10.1046/j.1365-8711.2000.03075.x](https://doi.org/10.1046/j.1365-8711.2000.03075.x)



$$M_{Halo} \approx 3 - 10 M$$



Lentes Gravitacionais

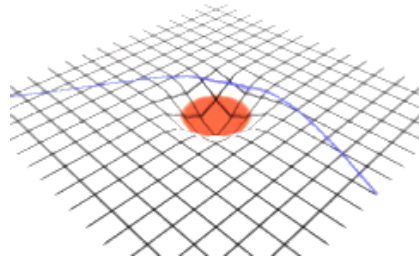
“Telescópios para enxergar a matéria escura”



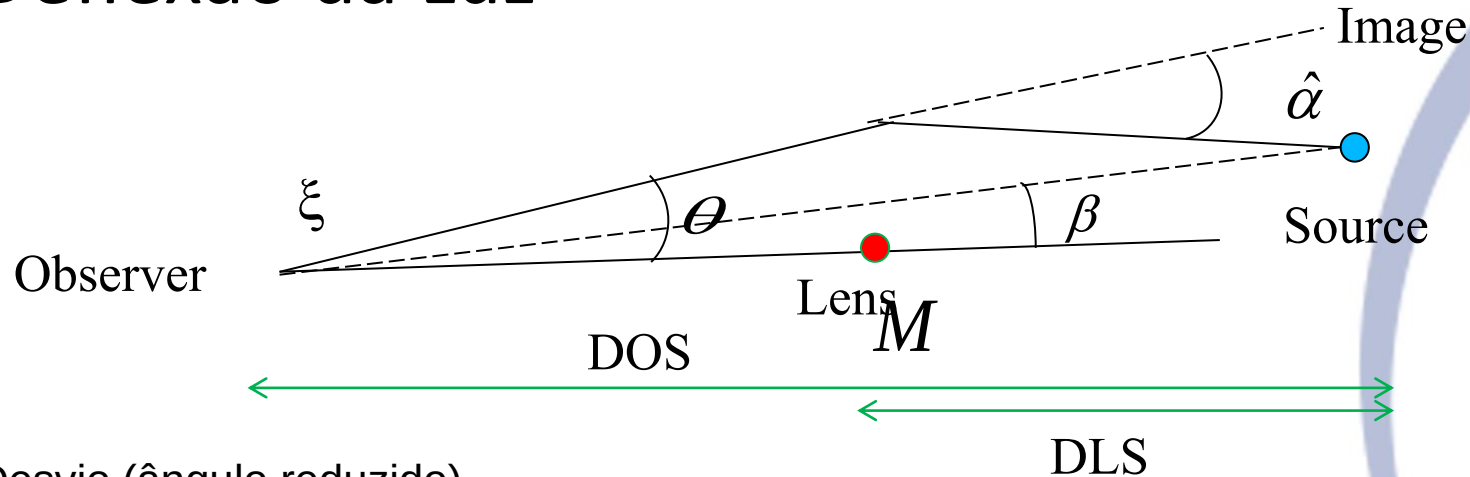
Breve História...

- Teoria
- 1783: Cavendish calcula o desvio “newtoniano” da luz
- 1905: Einstein propõe a relatividade restrita
- 1911: Obtém o desvio da luz
- (igual ao newtoniano)
- 1915: Teoria da relatividade geral

$$G_{\mu\nu} = \kappa T_{\mu\nu}$$



Deflexão da Luz



Desvio (ângulo reduzido) causado por uma fonte pontual (efeito previsto pela relatividade Geral:

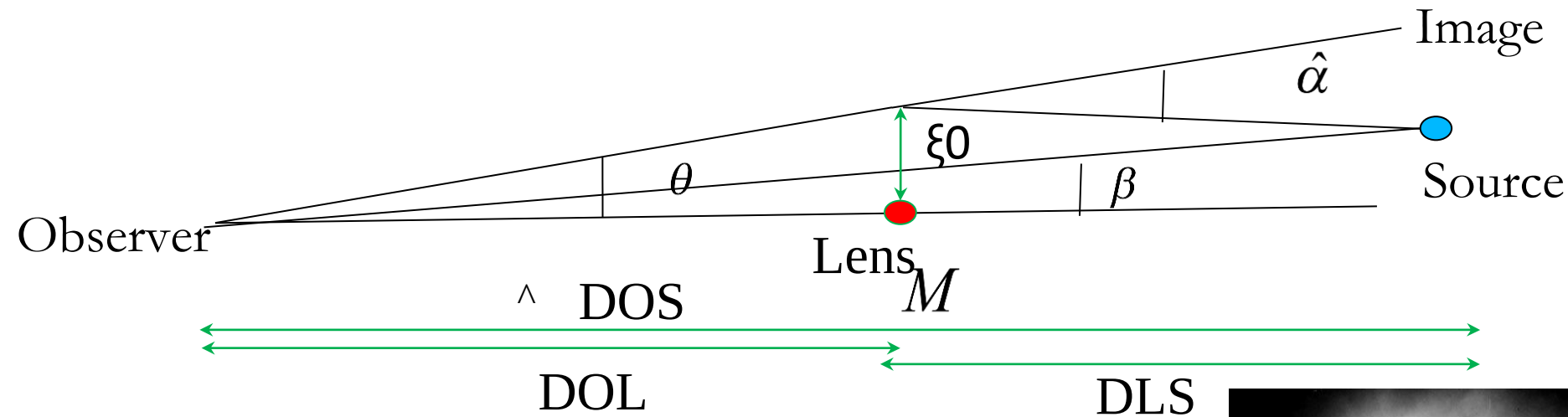
$$\alpha = \frac{D_{ls}}{D_{os}} \frac{4GM}{c^2 \xi}$$

Equação da Lente:

$$\beta = \theta - \alpha$$

Efeito Acromático e depende das distâncias entre observador e fonte e lente e fonte

Gravitational Lensing

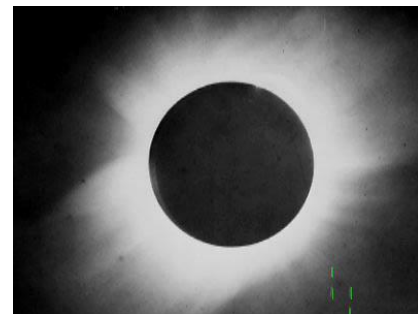


Lens Equation

$$\beta = \theta - \hat{\alpha} \frac{D_{ls}}{D_{os}}$$

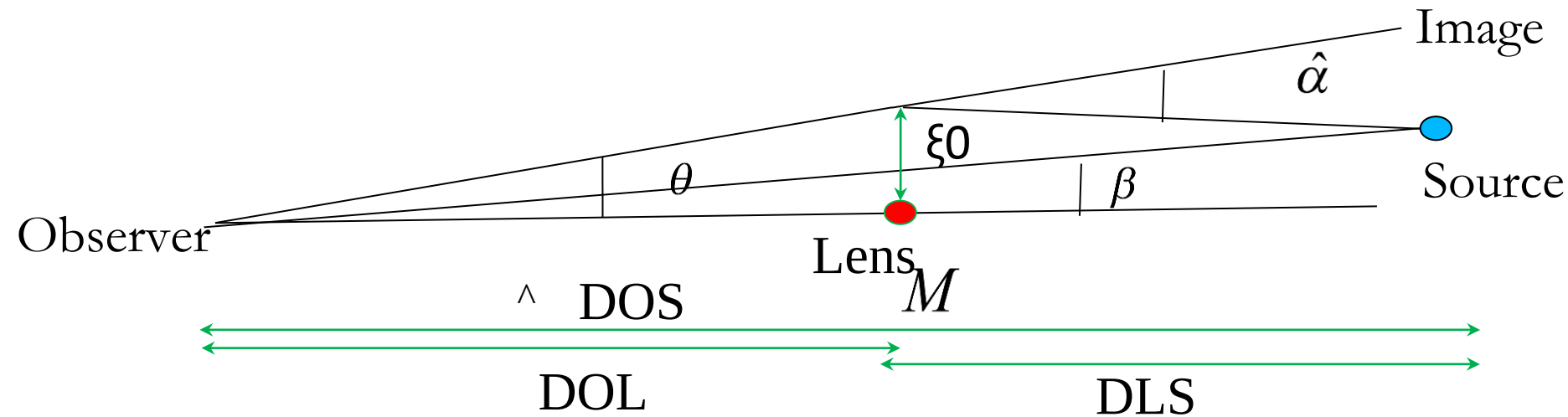
Einstein Radius

$$\theta_E = \left(\frac{4GM}{c^2} \frac{D_{LS}}{D_L D_S} \right)^{1/2}$$



A. Einstein

Gravitational Lensing



Deflection angle

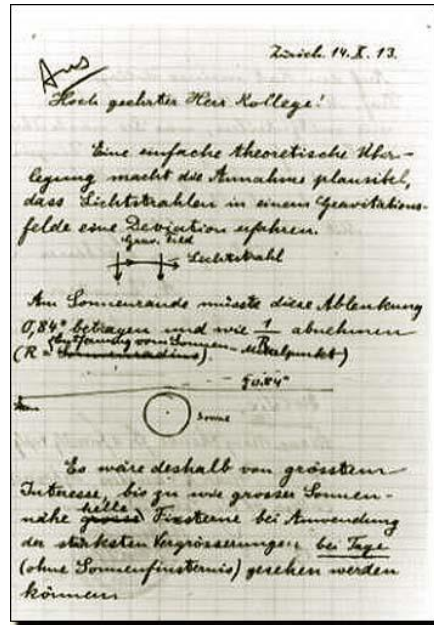
$$\hat{\alpha} = \frac{2}{c^2} \vec{\nabla}_{\xi} \psi(\vec{\varepsilon})$$

The projected potential
(weak field)

$$\psi = \int_0^{\infty} \phi(\vec{\varepsilon}, z) dz$$

Deflexão da Luz

- 1912: Einstein sugere que astrônomos meçam o desvio da luz



Deflexão da Luz

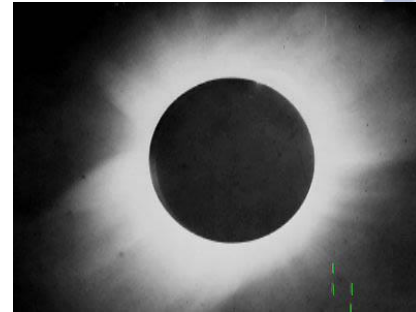
- 1912: Expedição Brasileira e Argentina para observar eclipse no Brasil em Passa quatro, Alfenas e Cristina (mg) e em Cruzeiro (SP)



Deflexão da Luz

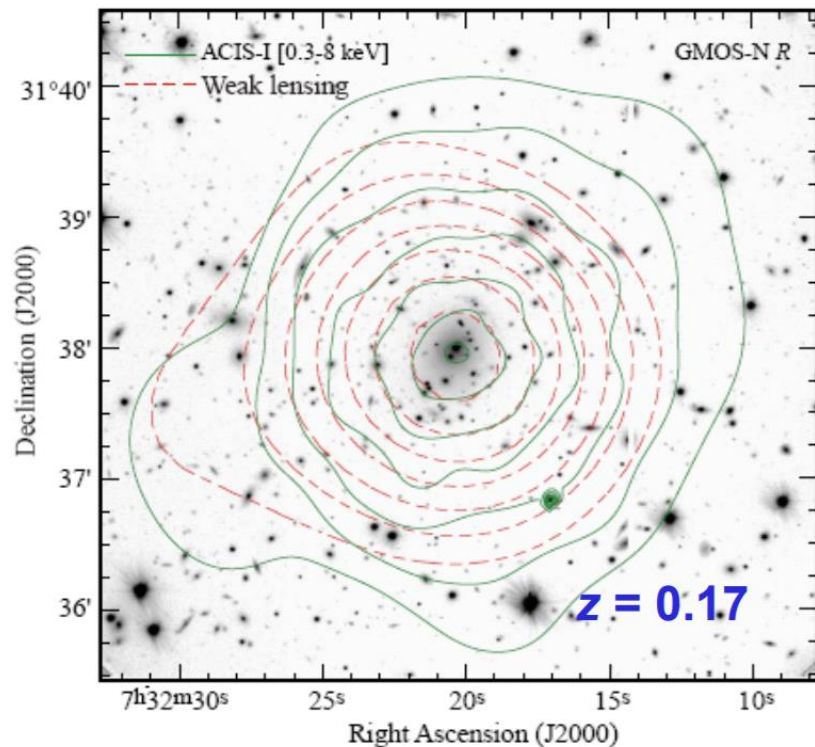
Detecção

- ❑ 1912: Expedição Argentina para observar eclipse no Brasil
 - ❑ Choveu
- ❑ 1914: Expedição de Erwin Freundlich para observar eclipse na Criméia
 - Acabarem presos por causa da primeira guerra mundial
- ❑ Sobral 1919: Desvio da luz



“A pergunta que a minha mente formulou foi respondida pelo céu ensolarado do Brasil”

A. Einstein



efeito fraco de lente
gravitacional

- emissão de raios-x

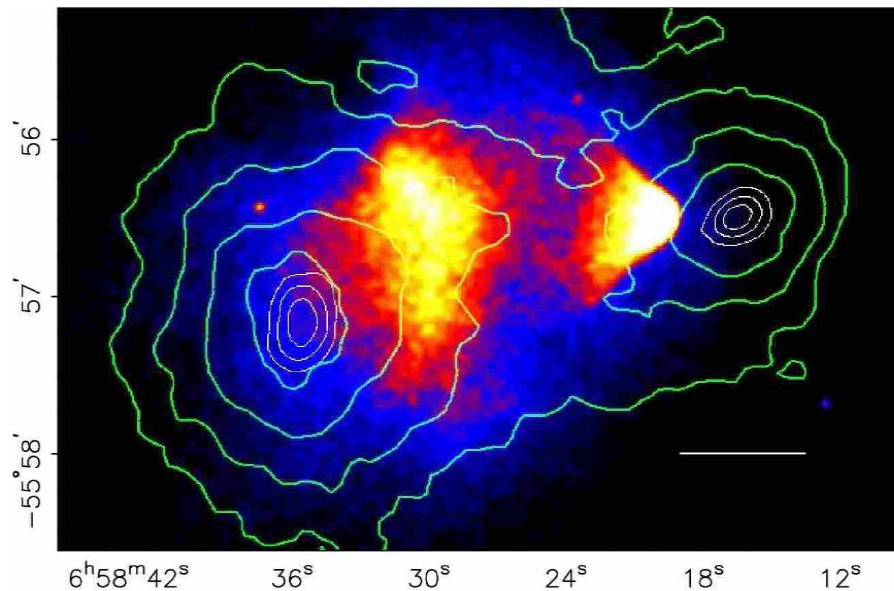
- dispersão de
velocidades

" concordam em $\sim 20\%$
(para aglomerados relaxados)
A matéria escura é 80%
da matéria total
(e $M_{\text{gas}} \sim 20 \times M_{\text{estrelas}}$)

A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER *

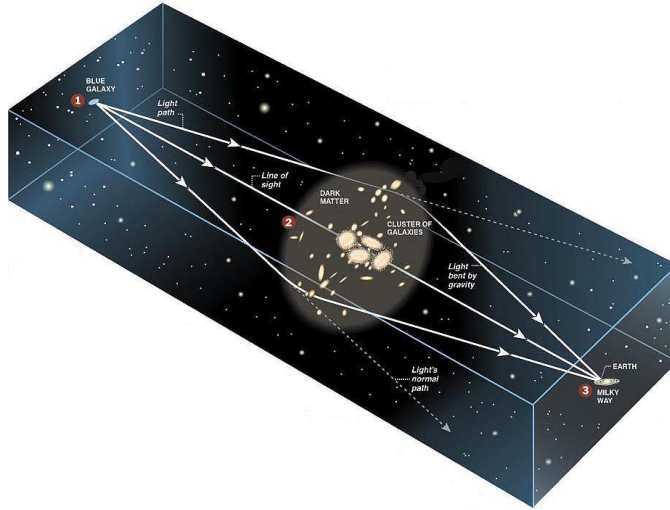
DOUGLAS CLOWE¹, MARUŠA BRADAČ², ANTHONY H. GONZALEZ³, MAXIM MARKEVITCH^{4,5}, SCOTT W. RANDALL⁴,
CHRISTINE JONES⁴, AND DENNIS ZARITSKY¹

ApJ Letters in press

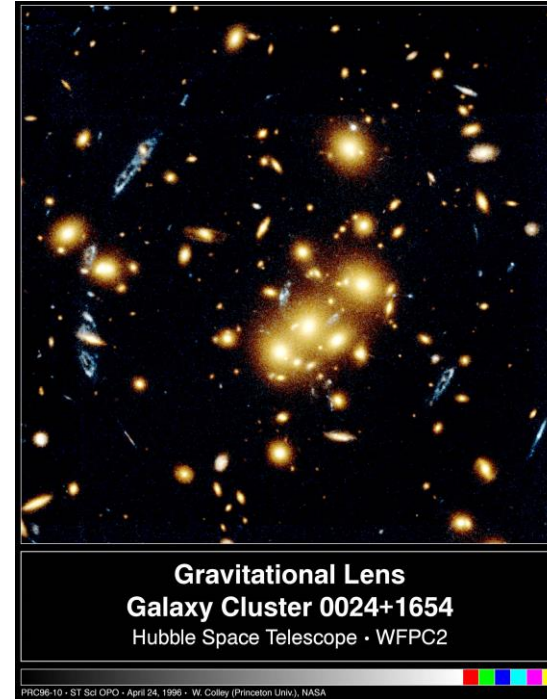


astro-ph/0608407

Lentes Gravitacionais: Efeito Forte

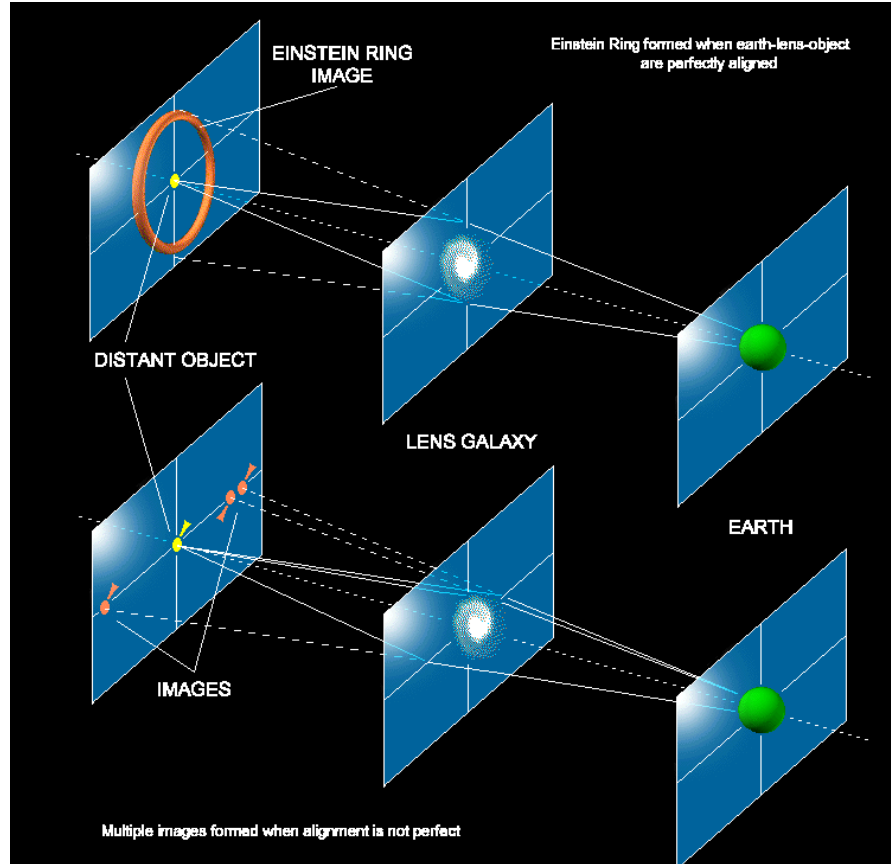


“Deformação” da trajetória da luz pelo espaço-tempo curvo.

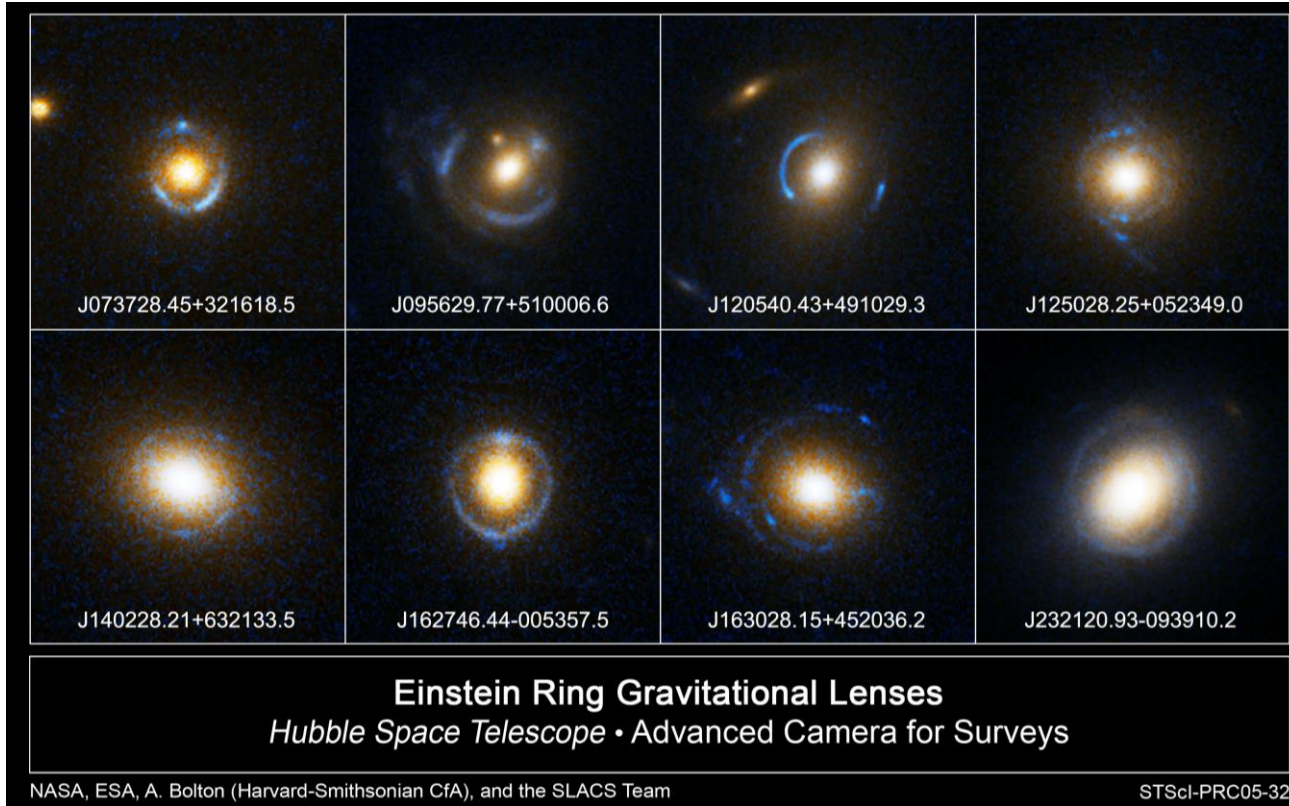


Imagens Múltiplas e Arcos

Anéis de Einstein



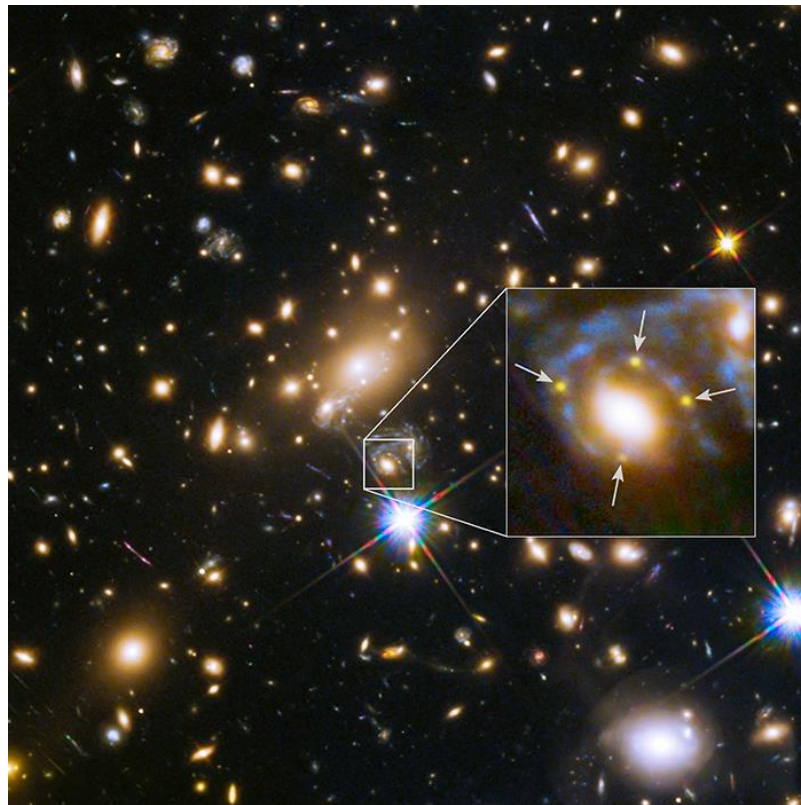
Anéis de Einstein



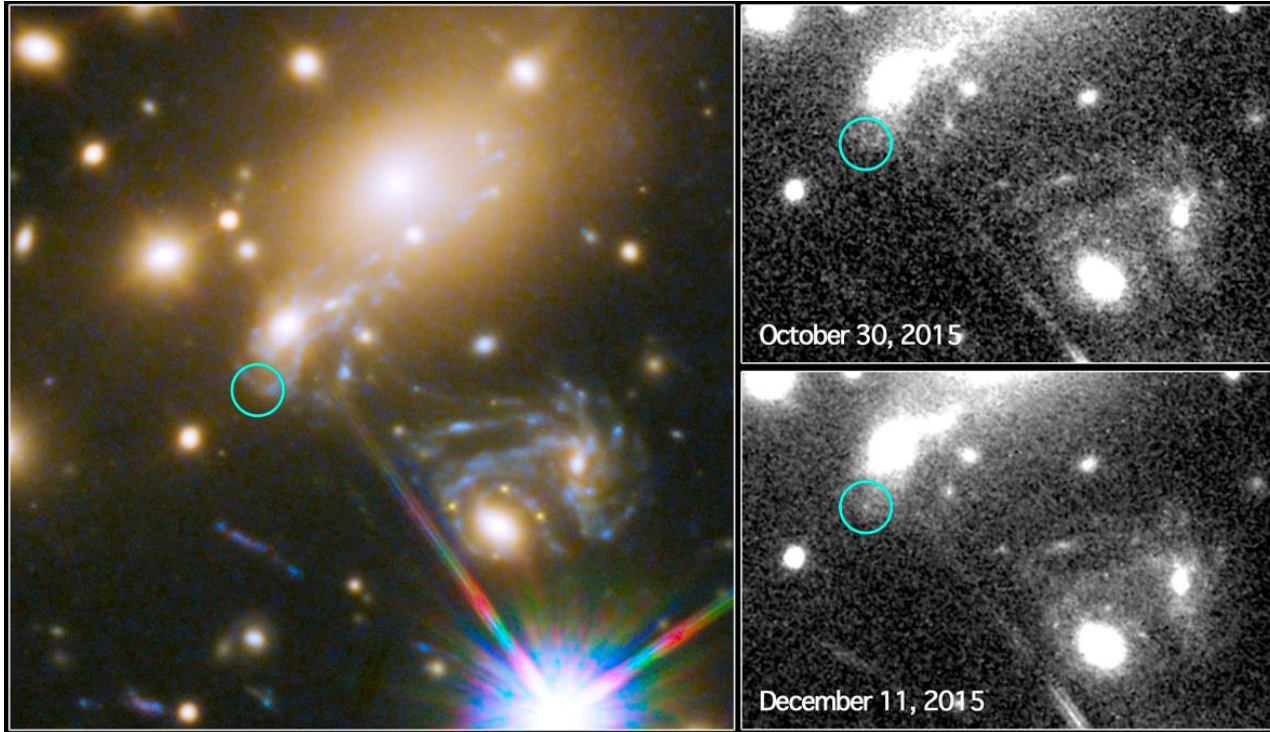
SN Refsdal



SN Refsdal



SN Refsdal



$$H^2 = H_0^2 \left(\Omega_{m,0}(1+z)^3 + \Omega_{r,0}(1+z)^4 + \Omega_{X,0}(1+z)^{3(1+w_X)} + (1-\Omega_0)(1+z)^2 \right)$$

$$H = H_0 E(z)$$

$$E(z) = \left[\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\lambda 0} \right]^{1/2}$$

$$H = \dot{a}/a \text{ e } a = (1+z)^{-1}, \quad H = -\frac{\dot{z}}{1+z}$$

$$dD_p = -cdt$$

$$dD_p = D_H dz / [(1+z)E(z)]$$

$$E(z) = \left[\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\lambda0} \right]^{1/2}$$

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$$D_p = D_H \int_{z_1}^{z_2} \frac{dz'}{(1+z')E(z')}$$

$$E(z) = \left[\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\lambda 0} \right]^{1/2}$$

$$H = \dot{a}/a \text{ e } a = (1+z)^{-1},$$

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$$D_p = D_H \int_{z_1}^{z_2} \frac{dz'}{(1+z')E(z')}$$

$$dD_p = (R/R_0) dD_c$$

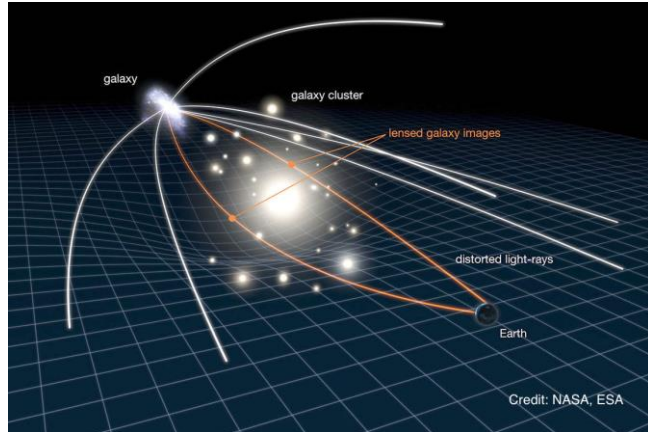
$$D_c = D_H \int_{z_1}^{z_2} \frac{dz'}{E(z')}$$

Distancias

$$E(z) = \left[\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\lambda0} \right]^{1/2}$$

$$H = \dot{a}/a \text{ e } a = (1+z)^{-1},$$

$$H = -\frac{\dot{z}}{1+z}$$



$$D_c = D_H \int_{z_1}^{z_2} \frac{dz'}{E(z')}$$

$$ds^2 = c^2 dt^2 - R(t)^2 \left[\frac{d\sigma^2}{1 - k\sigma^2} + \sigma^2 (d\theta^2 + \sin^2 \theta d\phi^2) \right]$$

$$\Delta\theta = \frac{D}{D_A}$$

$$D = R\sigma\Delta\theta$$

$$D_A = \frac{R_0\sigma}{1+z} :$$

$$D_A = \frac{d_M(z)}{1+z} :$$

Einstein Radius Cosmology

$$E(z) = \left[\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\lambda 0} \right]^{1/2}$$

$$D_c = D_H \int_{z_1}^{z_2} \frac{dz'}{E(z')}$$

$$\Delta\theta = \frac{D}{D_A} \quad D_A = \frac{d_M(z)}{1+z} :$$

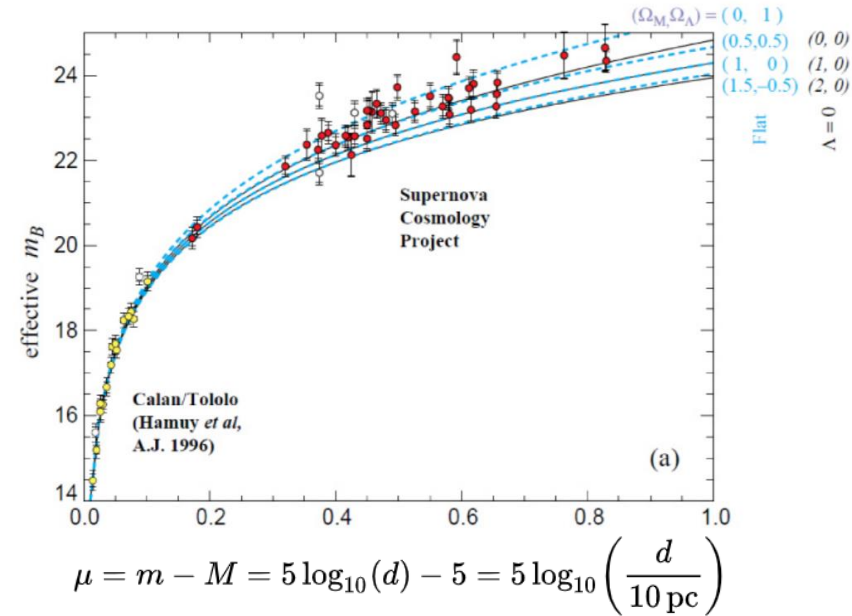
$$\theta_E = 4\pi \frac{D_A(z, z_s)}{D_A(0, z_s)} \frac{\sigma_{SIS}^2}{c^2}$$

$$\frac{D_{ds}}{D_s} = \frac{\int_{z_d}^{z_s} [dz' / E(z'; \mathbf{p})]}{\int_0^{z_s} [dz' / E(z'; \mathbf{p})]}$$

$$\frac{D_{ds}}{D_s}{}_{obs} = \frac{c^2 \theta_E}{4\pi \sigma_{SIS}^2}$$

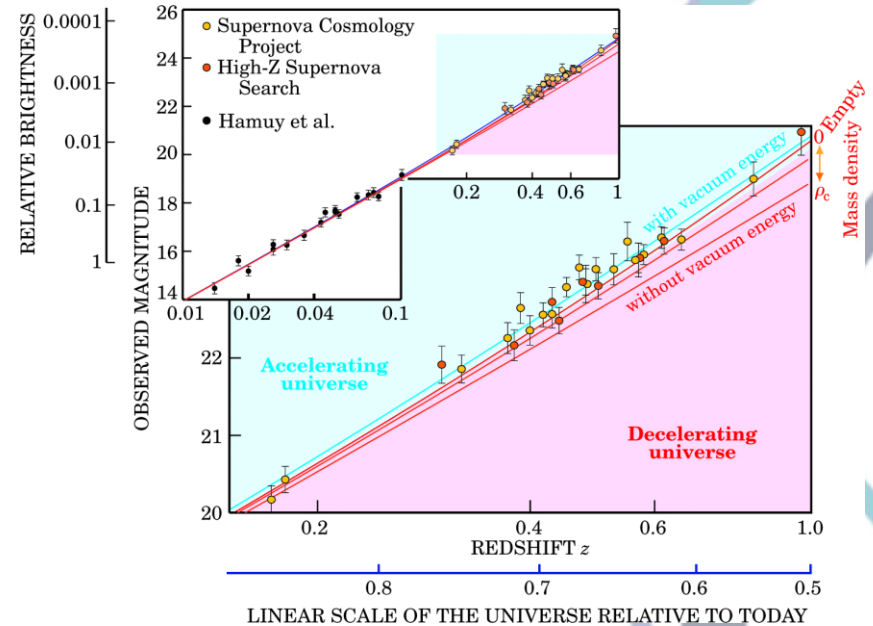


Accelerating expansion



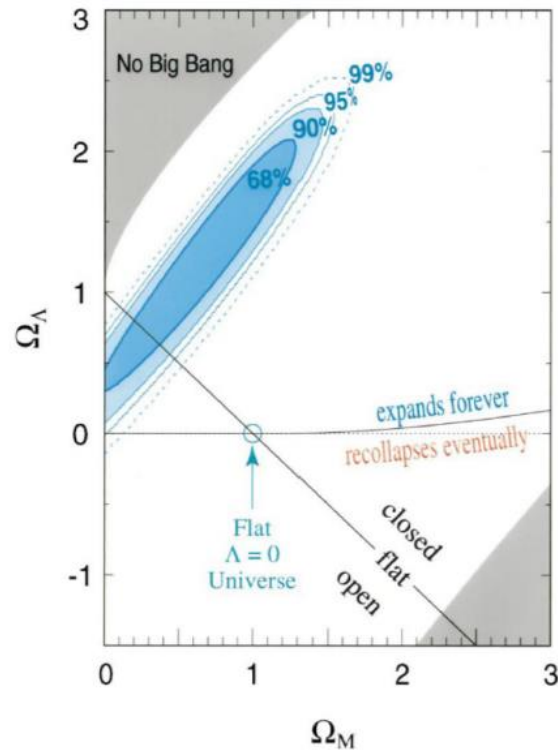
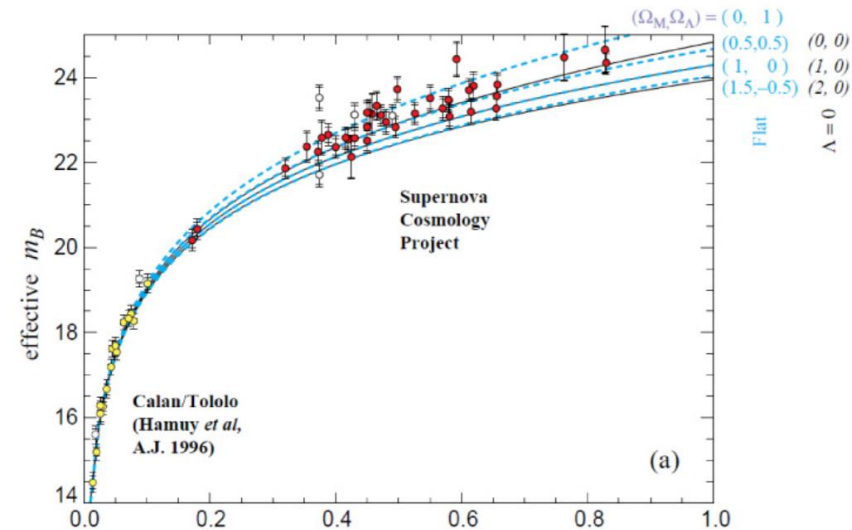
Scientific Background on the Nobel Prize in Physics 2011

THE ACCELERATING UNIVERSE

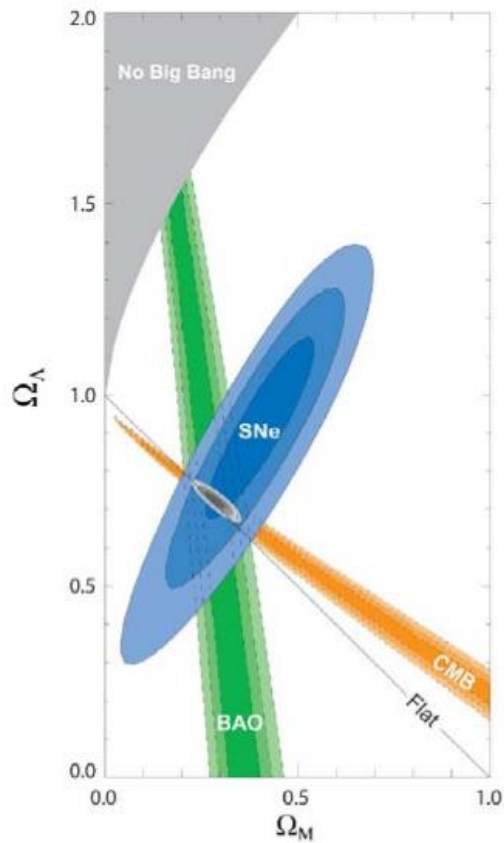
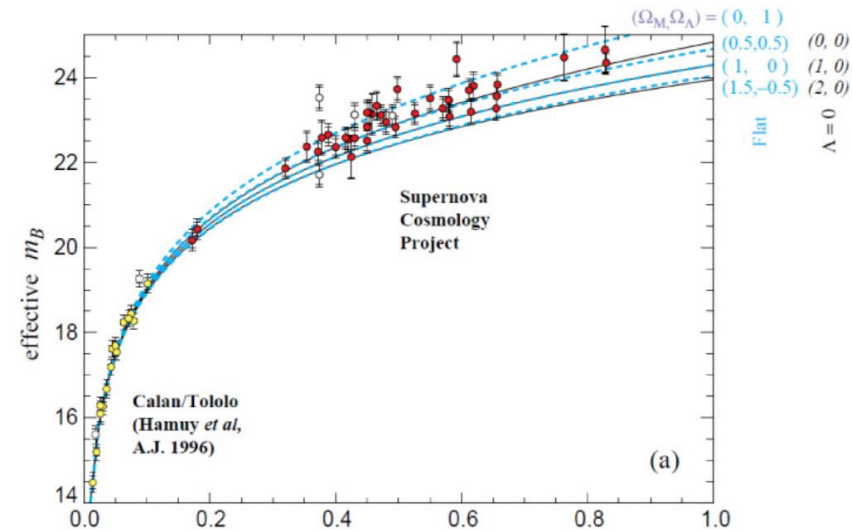


<https://physicstoday.scitation.org/doi/10.1063/1.1580050>

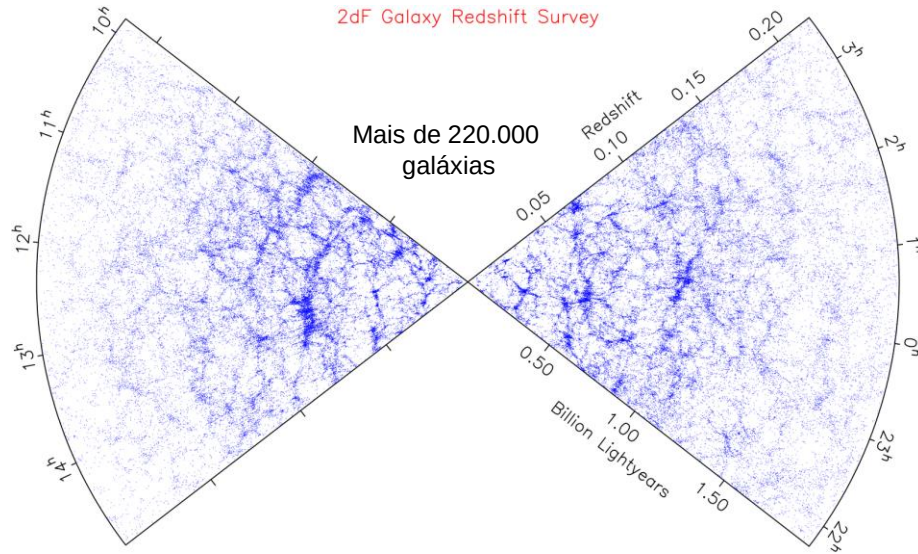
Accelerating expansion



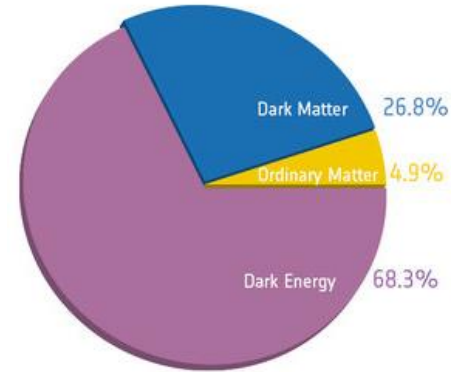
Accelerating expansion



Ingredientes do Modelo de Universo

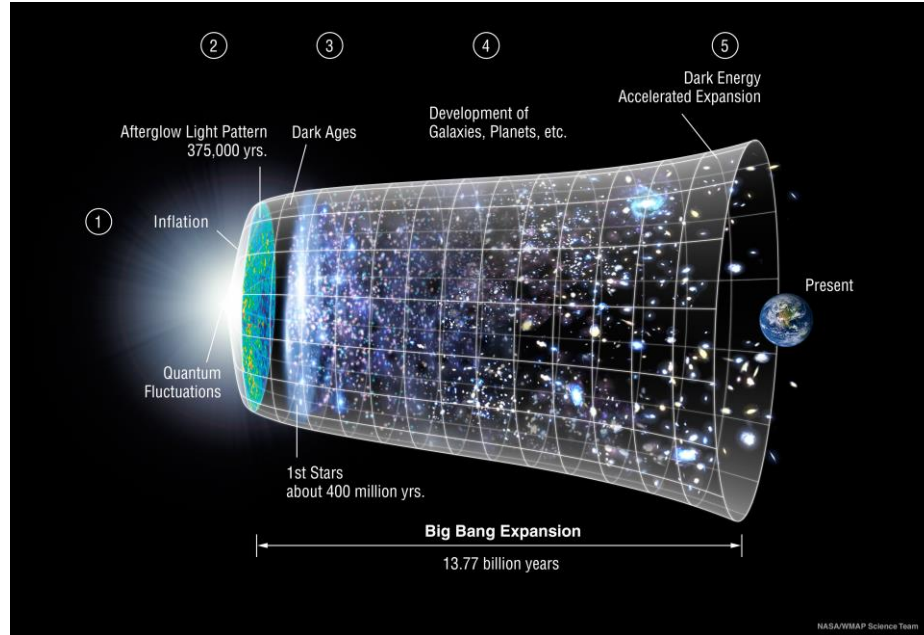


Universo é aproximadamente homogêneo e isotrópico em grandes escalas e está em expansão

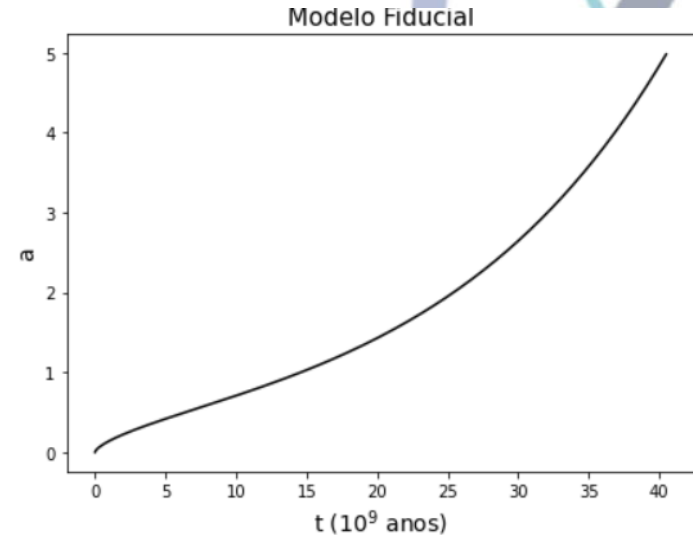


Credito: Planck Collaboration e and ESO

Concordance Model



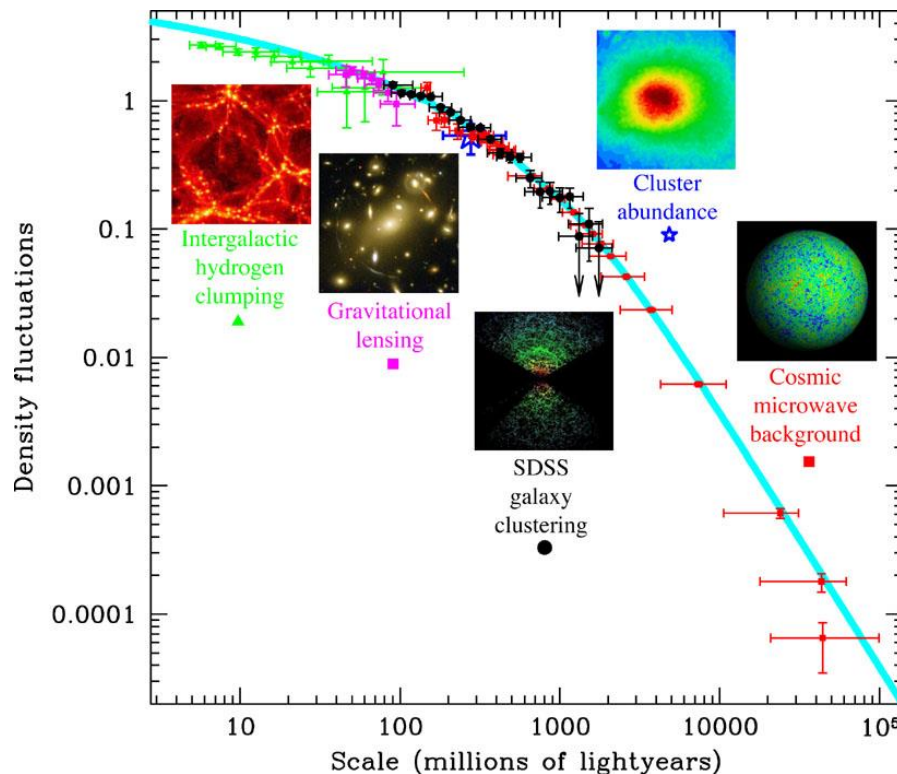
- o Big-Bang e a inflação
- a era da radiação
- a era da matéria
- a era da energia escura



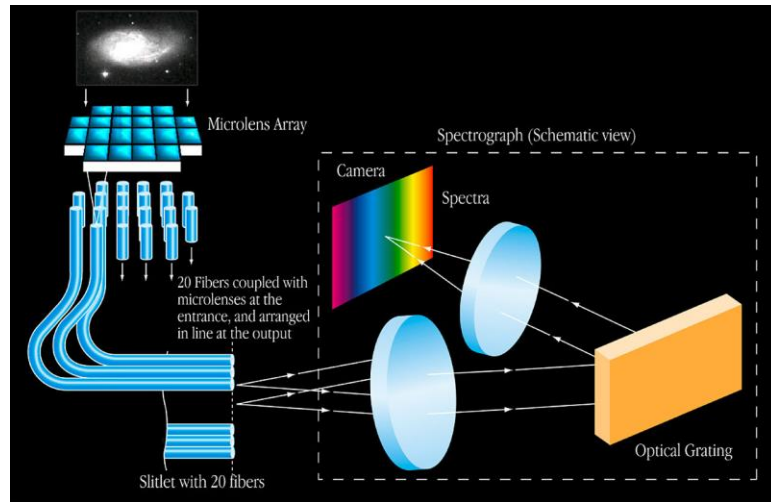
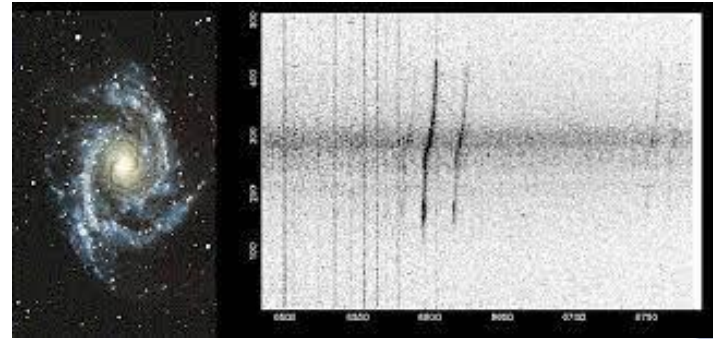
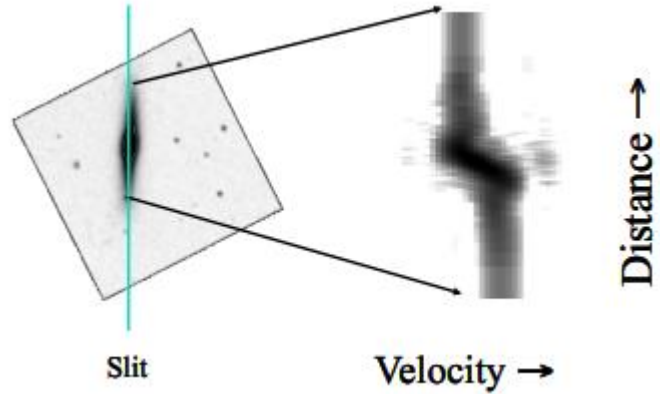
The Universe is not completely homogeneous

$$\delta(\vec{r}, t) = \frac{\rho(\vec{r}, t) - \bar{\rho}(t)}{\bar{\rho}(t)}$$

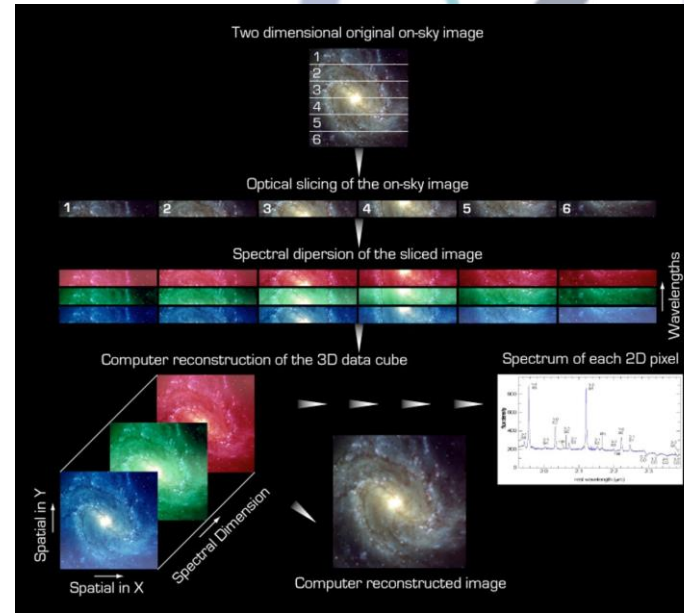
$$\delta_{obs}(\vec{r}) = \frac{n(\vec{r}) - \bar{n}(\vec{r})}{\bar{n}(\vec{r})}$$



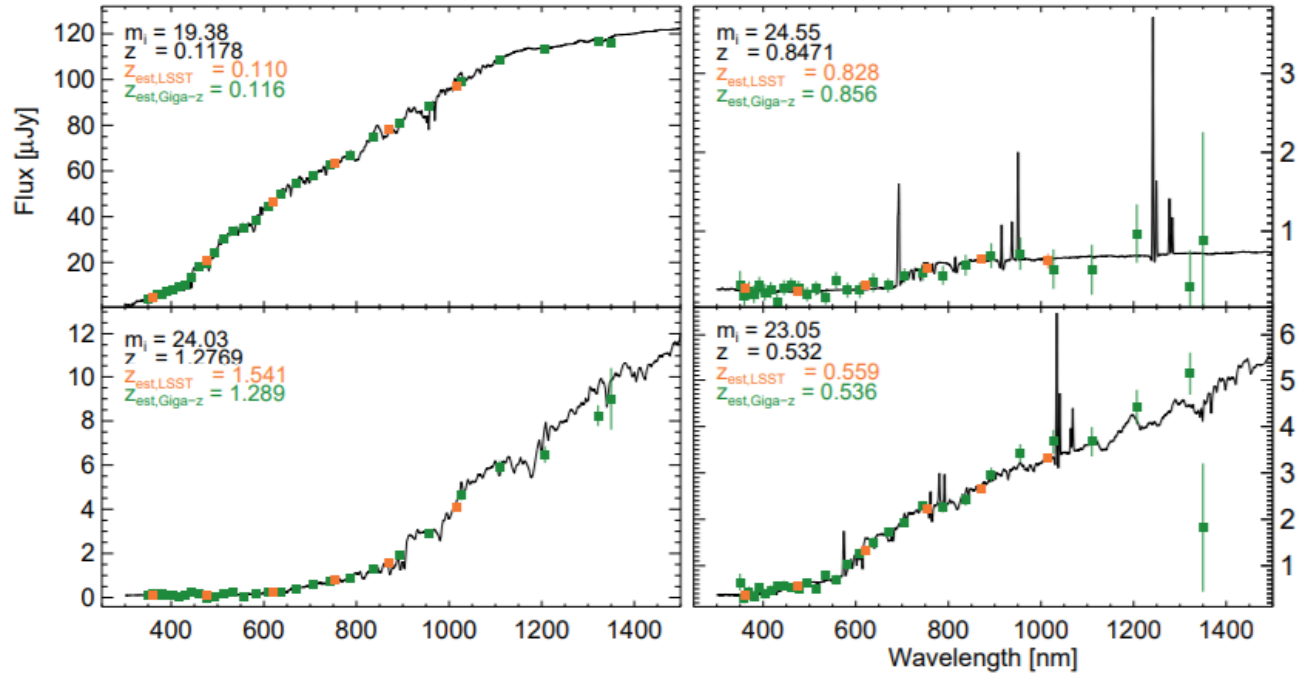
We need a huge number of z's ...



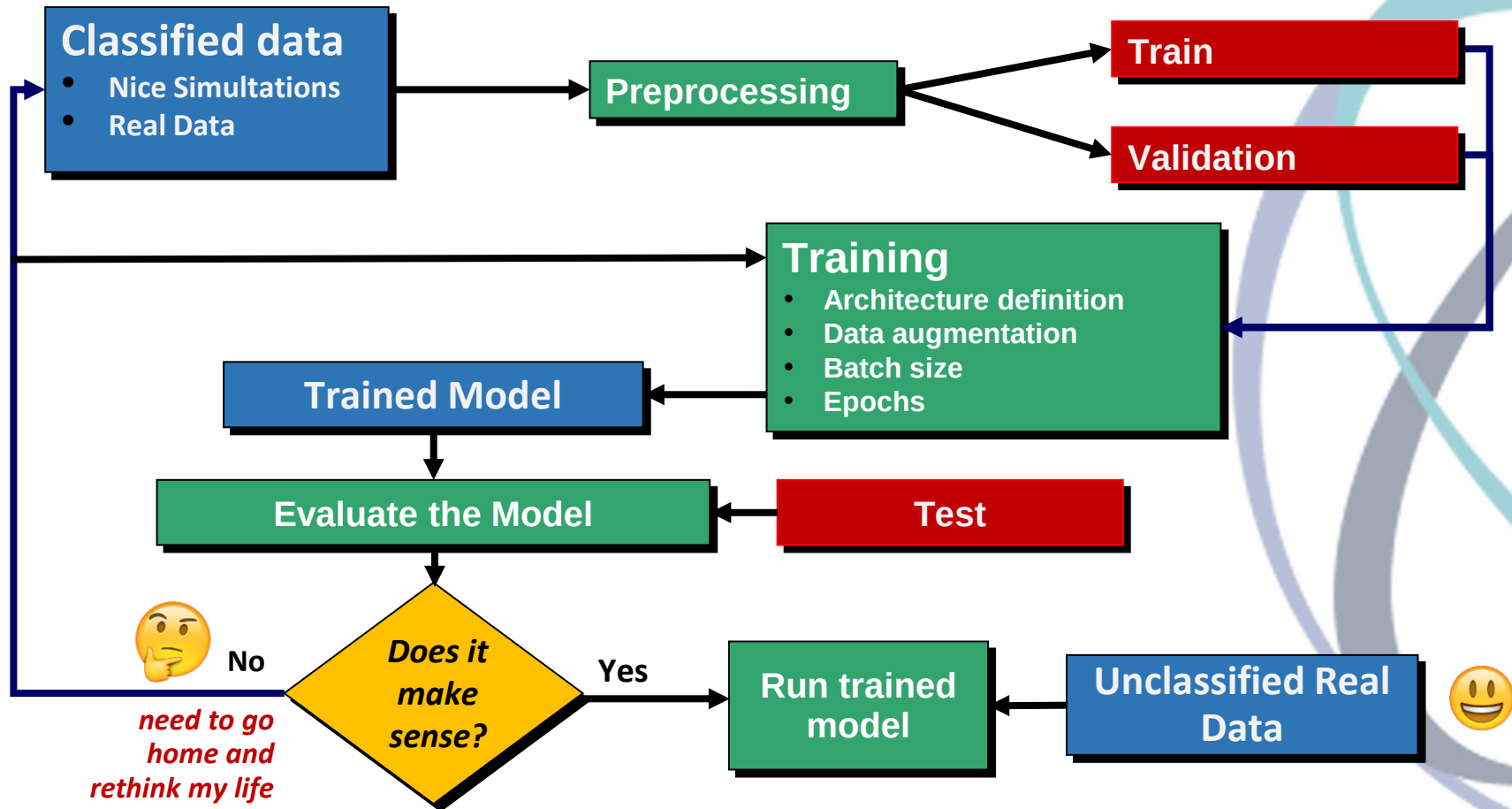
Credit: ESO



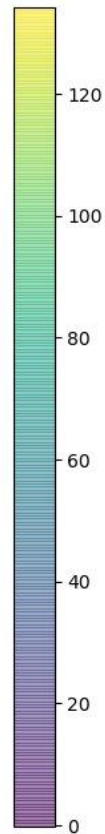
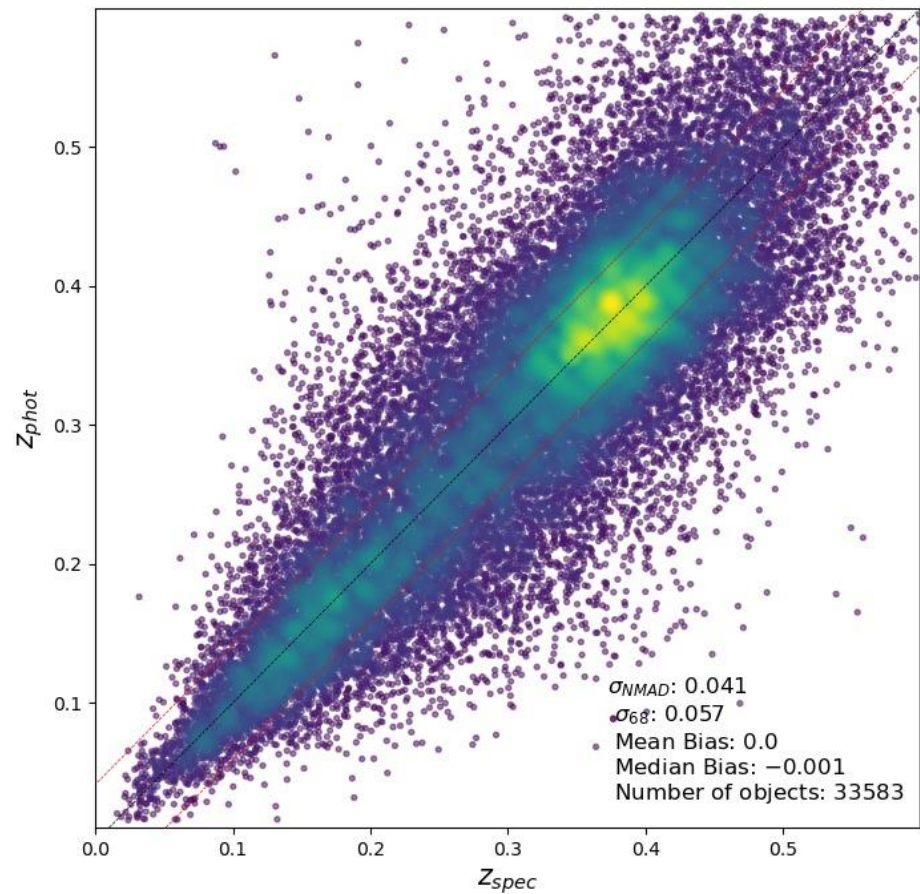
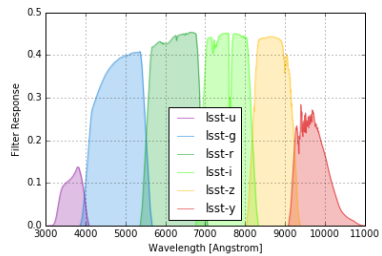
Photometric redshifts



ML: Workflow Supervised



Photometric redshifts





Cosmologia com python

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