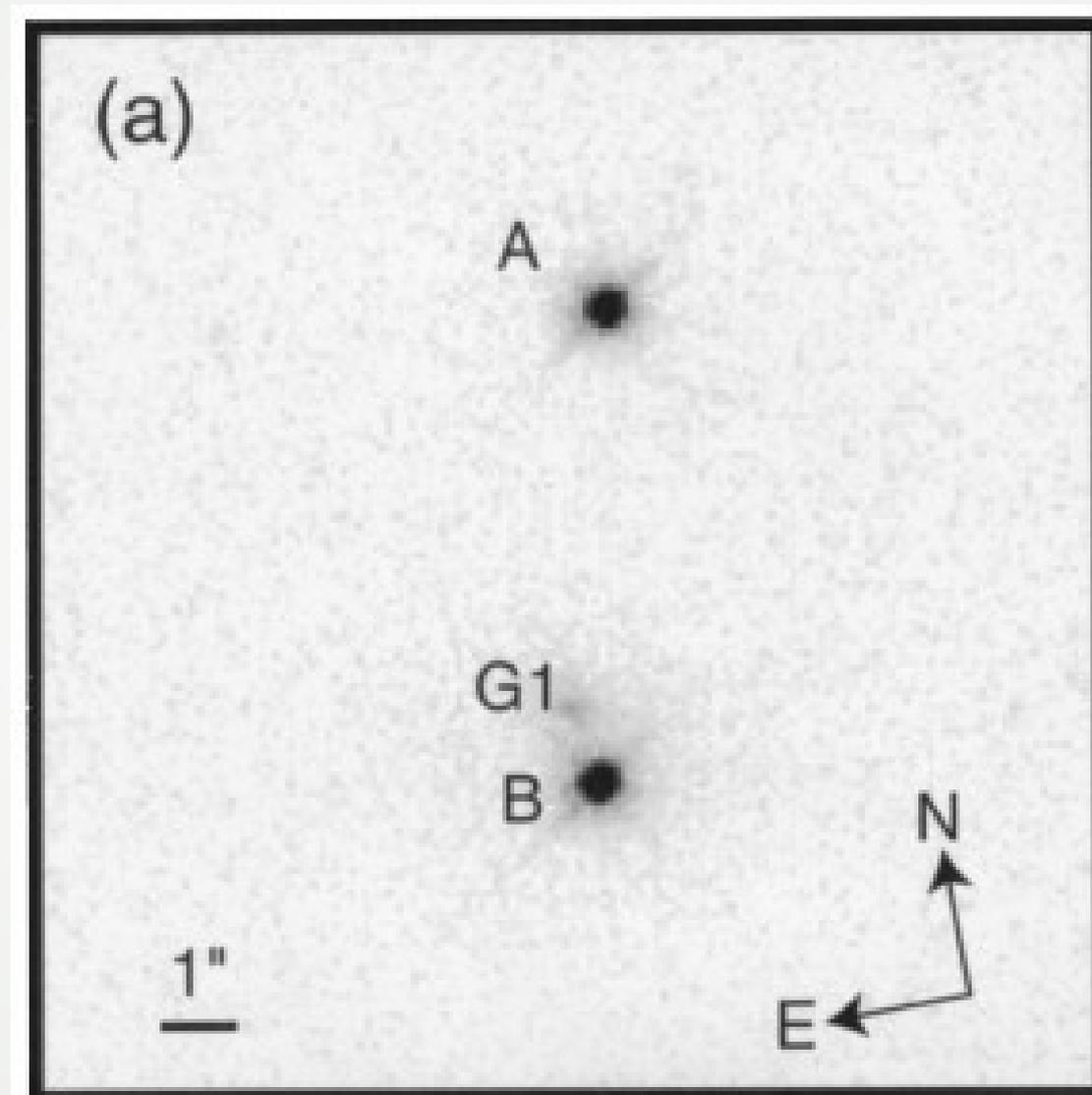


# Preučevanje vesolja s kvazarji

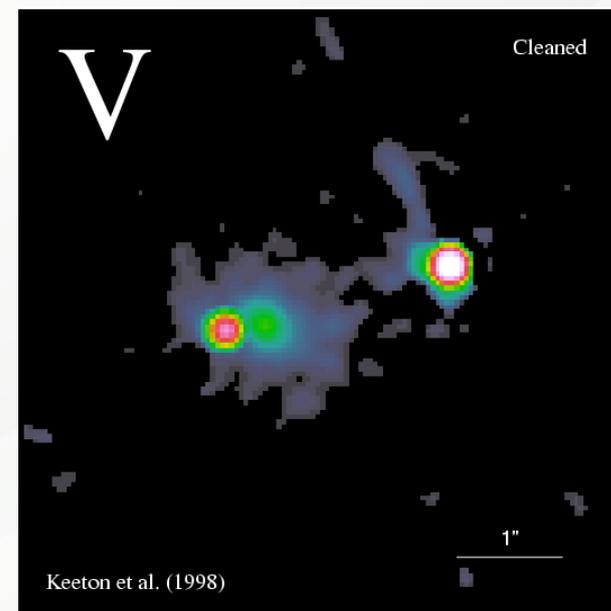
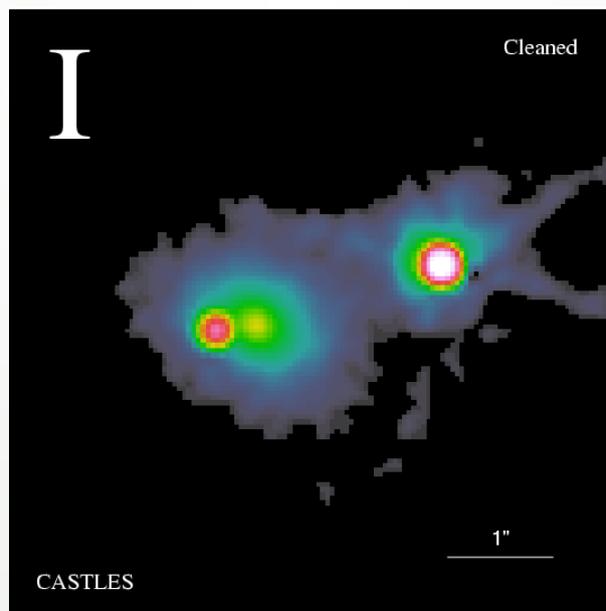
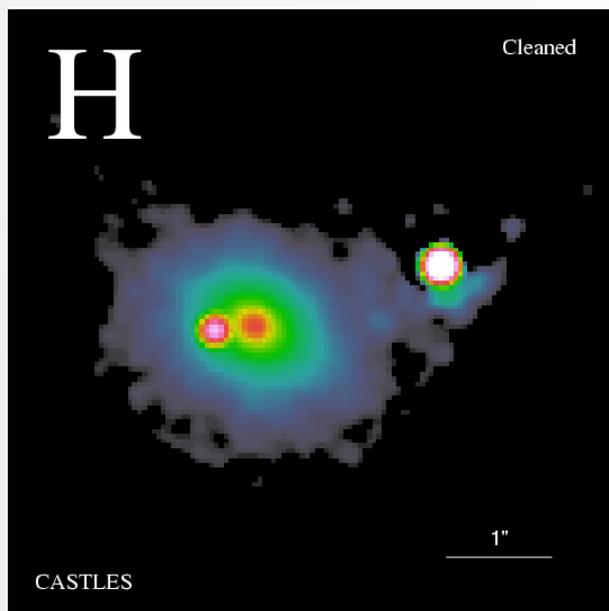
Gravitacijsko lečenje in kvazarji

Viri: Jones, Lambourne (Chap. 4), Carroll, Ostlie (Chap. 28)

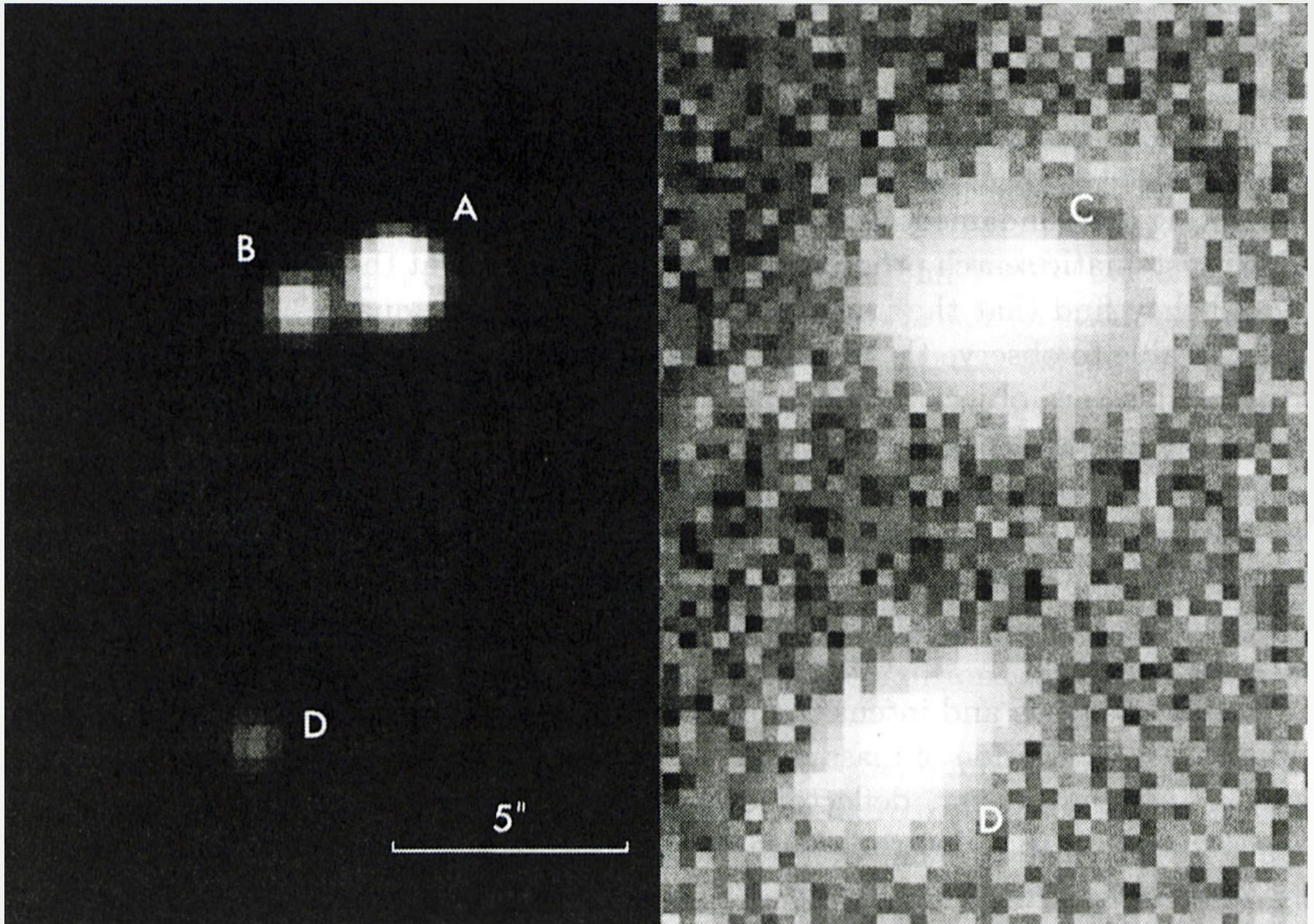
# Gravitacijsko lečeni kvazarji



Pogled na dvojni kvazar Q0957+561 (The Twin Quasar), med slikama kvazarja A in B je galaksija G1, ki deluje kot gravitacijska leča (Bernstein et al. 1997)



Kvazar Q0142+100 (Munoz et al. 1999; slika vesoljskega teleskopa Hubble).



Kvazar UM 673 (slika ESO; spektra iz Smette et al. 1992).

# Gravitacijsko lečenje

- kotni Einsteinov radij

$$\theta_E = \left( \frac{4GM}{c^2} \frac{D_{ls}}{D_{ol}D_{os}} \right)^{1/2}$$

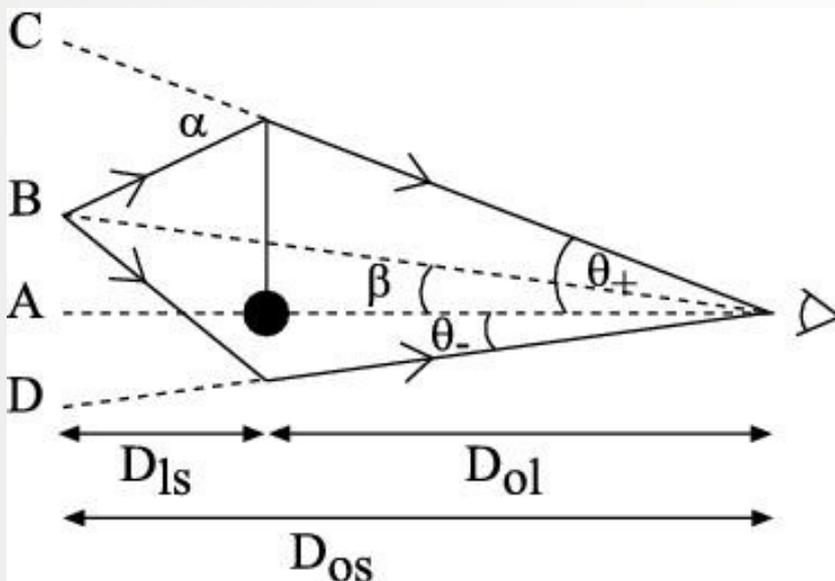
- enačba leče

$$\theta^2 - \beta\theta - \theta_E^2 = 0$$

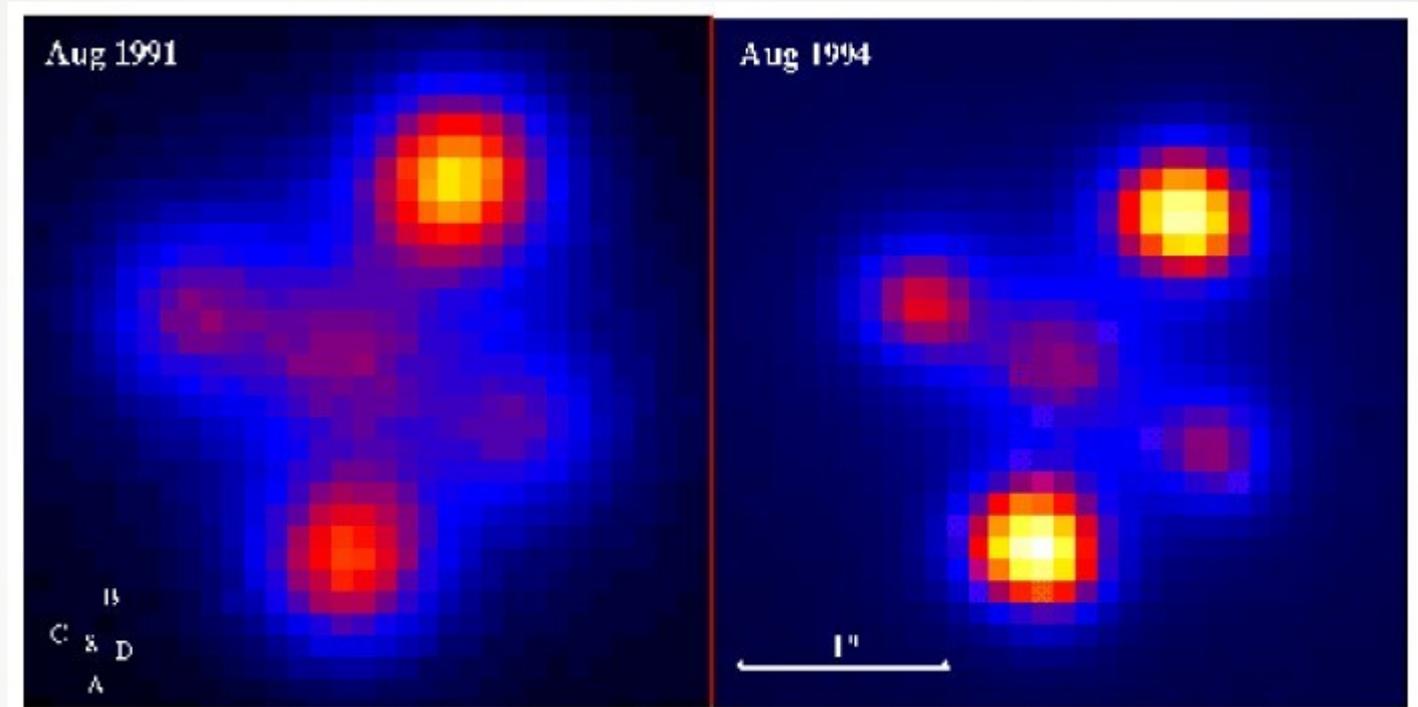
- masa leče

$$\beta = \theta_1 + \theta_2; \theta_1 < 0$$

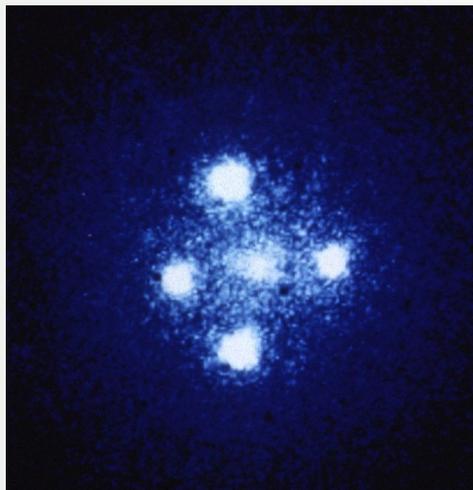
$$M = -\frac{\theta_1\theta_2 c^2}{4G} \left( \frac{D_{ol}D_{os}}{D_{ls}} \right)$$



# Einsteinov križ

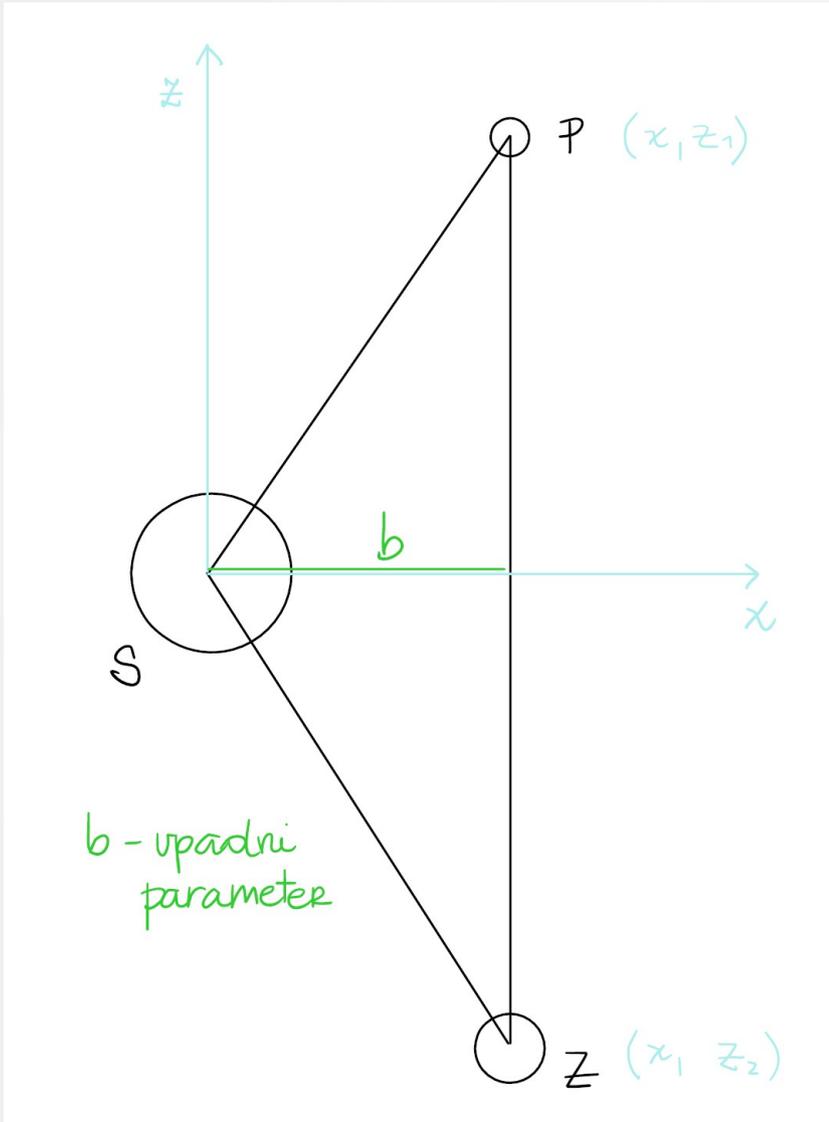


Two images of the quadruple quasar Q2237+0305 separated by three years. It is obvious that the relative brightnesses of the images change. Image B is clearly the brightest one in the left panel, whereas images A and B are about equally bright in the right panel. (Credits: Geraint Lewis.)



Einsteinov križ Q2237+030  
(NASA, ESA, and STScI)

# Gravitacijski časovni zamik



$$\frac{dr}{dt} = c \sqrt{1 + \frac{2\Phi(r)}{c^2}}$$

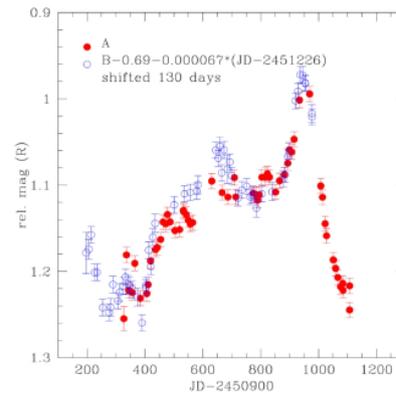
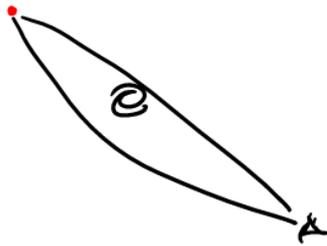
- Newtonov približek za grav. časovni zamik
- posebna teorija relativnosti
- gibanje v bližini sferno simetrične mase

$$\frac{dr}{dt} = c \sqrt{1 - \frac{2GM}{rc^2}} \simeq c \left(1 - \frac{GM}{rc^2}\right)$$

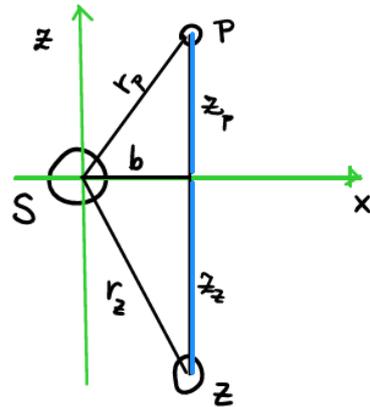
$$dt = \frac{dr}{c} \left(1 - \frac{GM}{rc^2}\right)^{-1} \simeq \frac{dr}{c} \left(1 + \frac{GM}{rc^2}\right)$$

Rešitev:

$$\Delta t = \frac{z_2}{c} - \frac{z_1}{c} + \underbrace{\frac{GM}{c^3} \ln \left( \frac{z_2 + \sqrt{z_2^2 + b^2}}{z_1 + \sqrt{z_1^2 + b^2}} \right)}_{\delta t}$$



### Gravitacijski časovni zamik



$$v(r) = c \sqrt{1 + \frac{2\phi(r)}{c^2}}$$

(posebna teorija relativnosti)

$$b \ll |z_z|, |z_p|$$

$$r_z = \sqrt{z_z^2 + b^2}$$

$$r_p = \sqrt{z_p^2 + b^2}$$

$$r = \sqrt{z^2 + b^2} \quad (\text{splošno})$$

$$\phi(r) = -\frac{GM}{r}$$

$$v(r) = c \sqrt{1 - \frac{2GM}{rc^2}}$$

$$v(r) = \frac{dz}{dt} = c \sqrt{1 - \frac{2GM}{rc^2}}$$

$$\sqrt{1 - \xi} = 1 - \frac{\xi}{2}$$

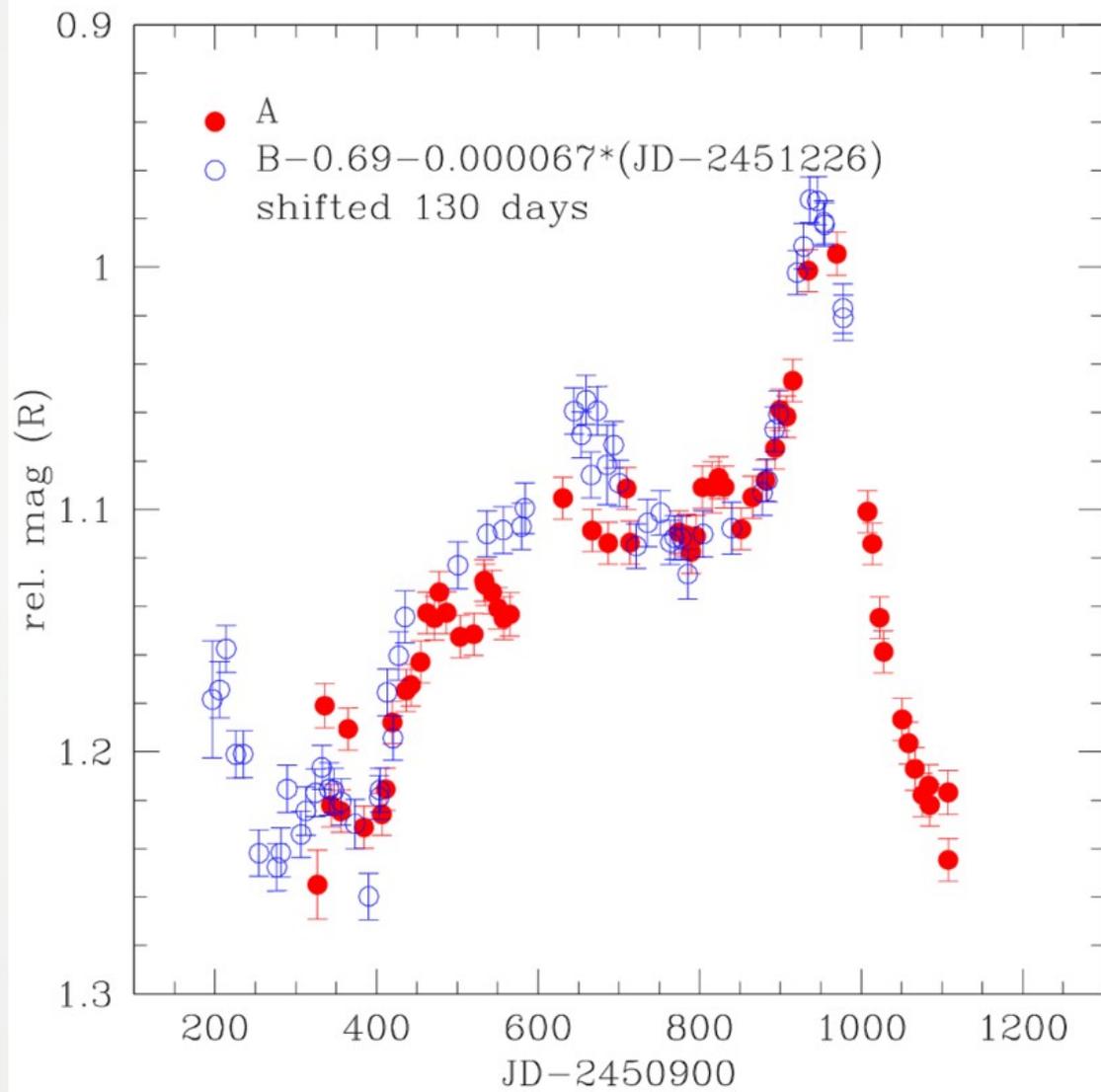
$$\approx c \left(1 - \frac{GM}{rc^2}\right)$$

$$= c \left(1 - \frac{GM}{\sqrt{z^2 + b^2} c^2}\right)$$

$$\int \frac{dx}{\sqrt{x^2 + a^2}} = \ln(\sqrt{x^2 + a^2} + x)$$

$$dt = \frac{dz}{c} \left(1 - \frac{GM}{\sqrt{z^2 + b^2} c^2}\right)^{-1} \approx \frac{dz}{c} \left(1 + \frac{GM}{\sqrt{z^2 + b^2} c^2}\right)$$

$$\int_{t_p}^{t_z} dt = t_z - t_p = \int_{z_p}^{z_z} \frac{dz}{c} \left(1 + \frac{GM}{\sqrt{z^2 + b^2} c^2}\right) = \frac{z_z}{c} - \frac{z_p}{c} + \frac{GM}{c^3} \ln \left( \frac{z_z + \sqrt{z_z^2 + b^2}}{z_p + \sqrt{z_p^2 + b^2}} \right)$$



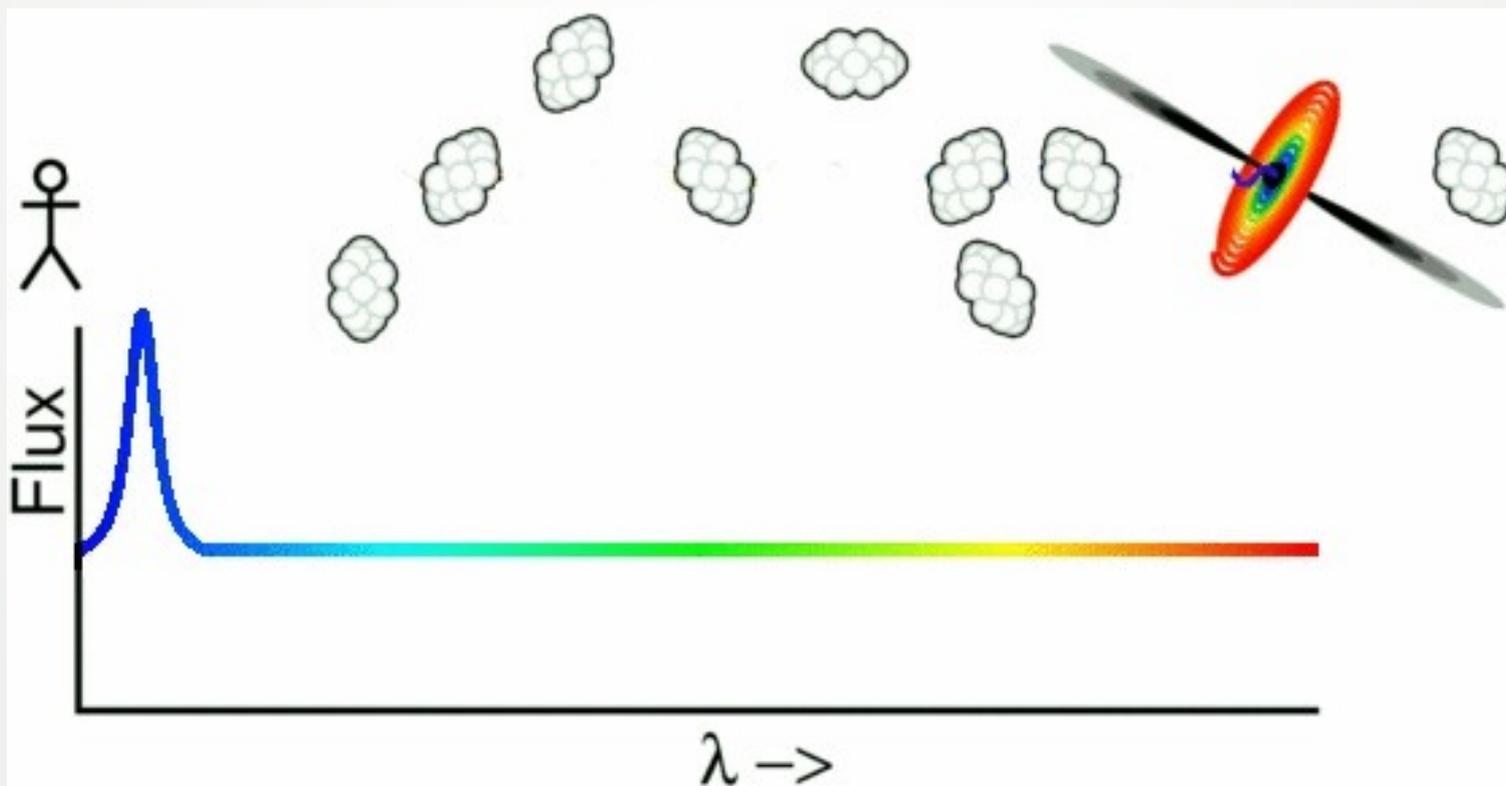
# Preučevanje vesolja s kvazarji

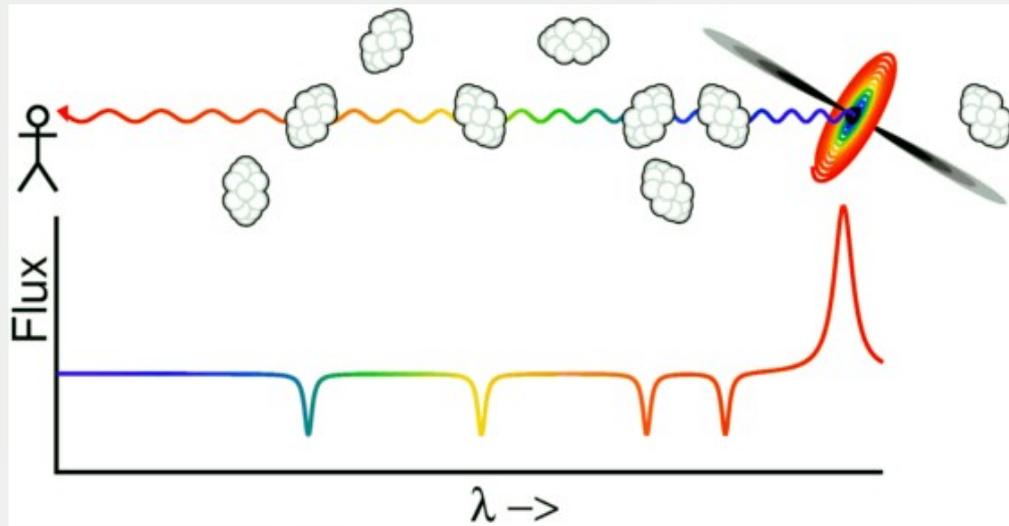
Lyman $\alpha$  gozd

**Viri:** Jones, Lambourne (Chap. 4), Carroll, Ostlie (Chap. 28)

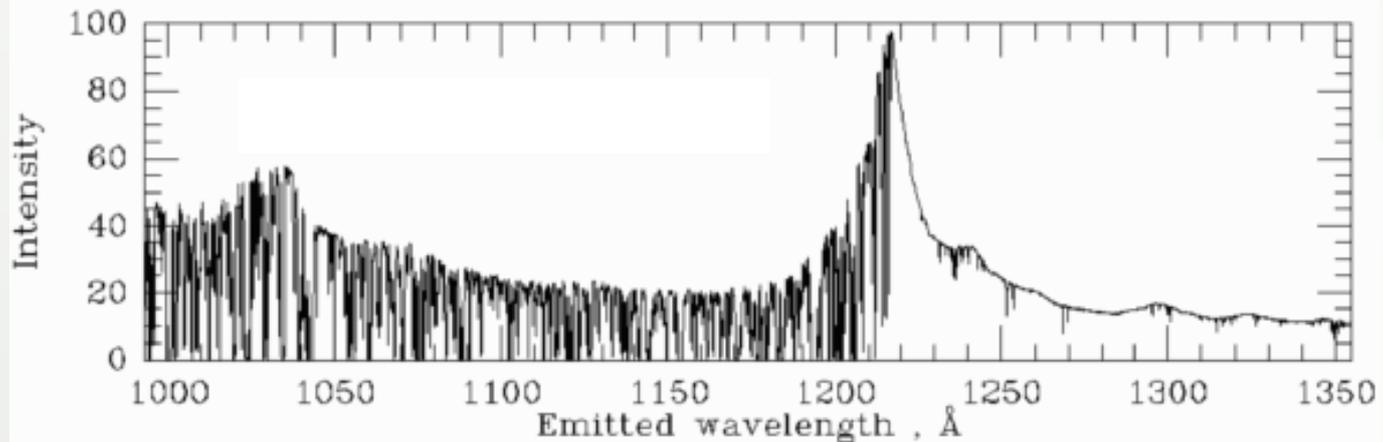
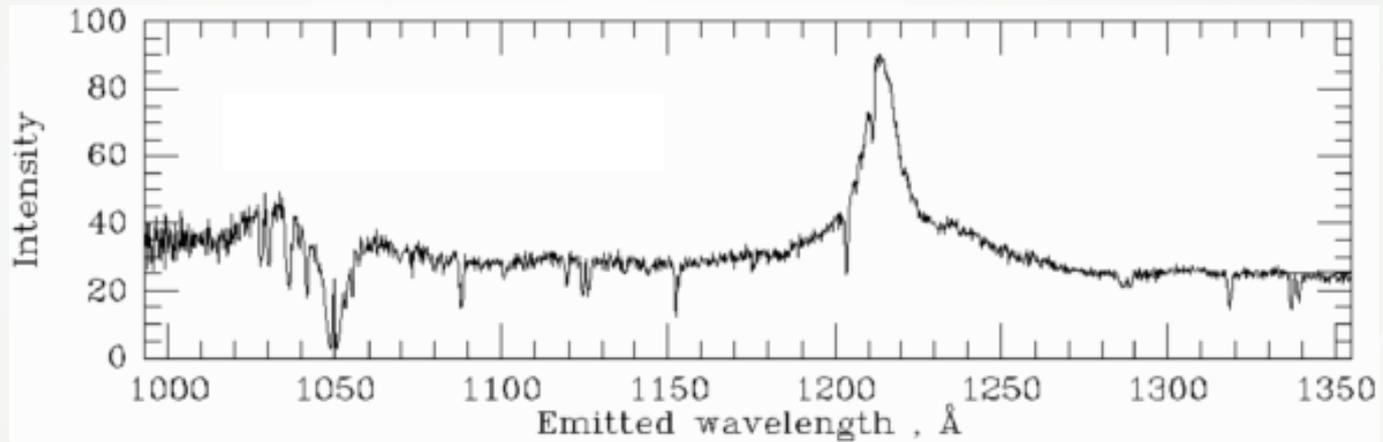
# Lyman $\alpha$ gozd

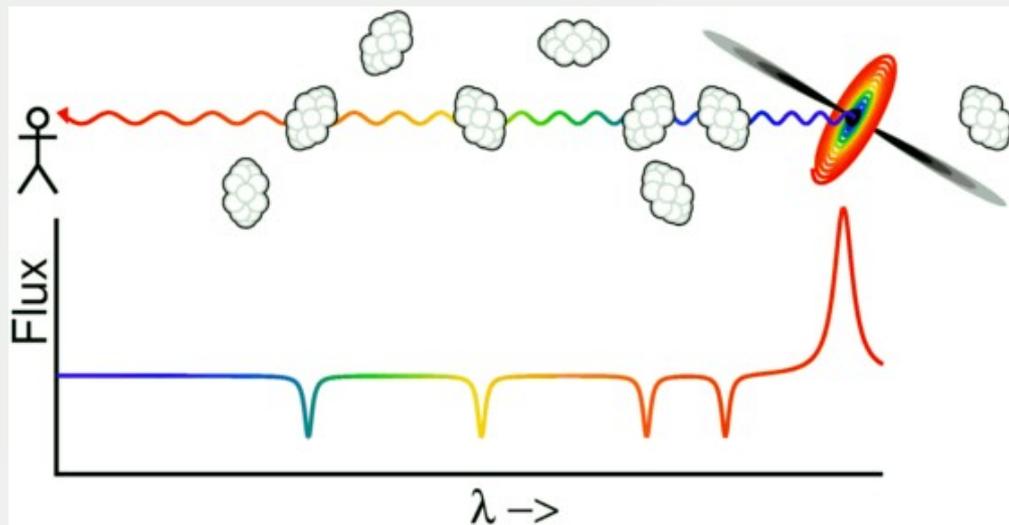
- Lyman  $\alpha$ : prehod med  $n=1$  in  $n=2$ ,  $\lambda=121.6$  nm
- kozmološki rdeči premik: 
$$\frac{\lambda_{obs}}{\lambda_{em}} = 1 + z$$



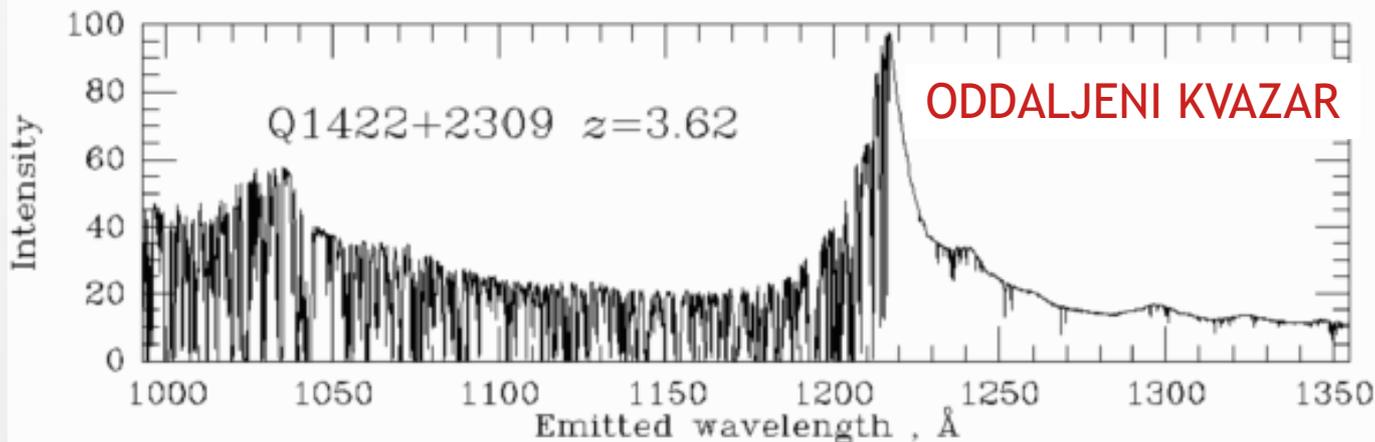
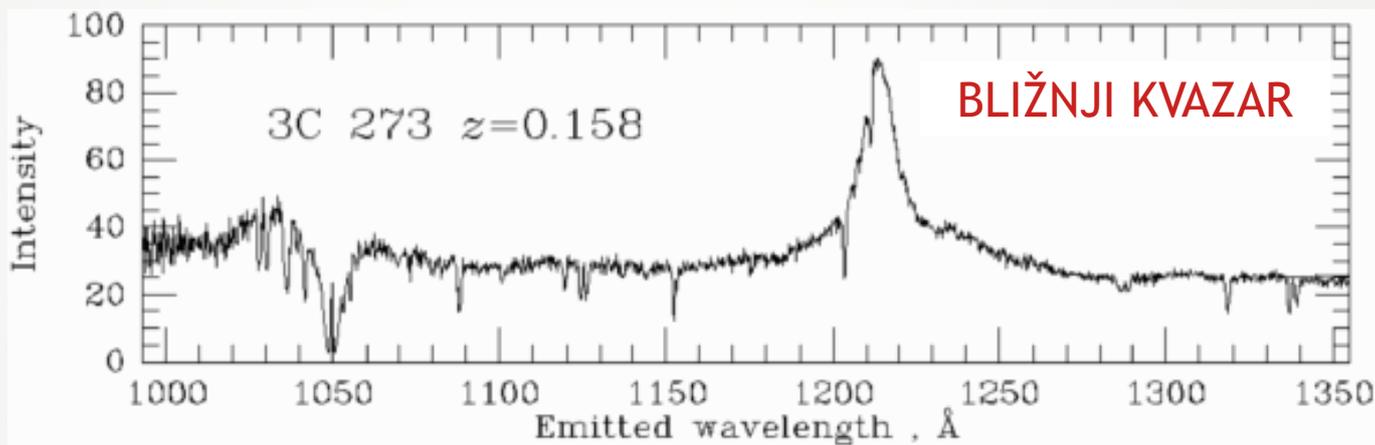


# Lyman $\alpha$ gozd

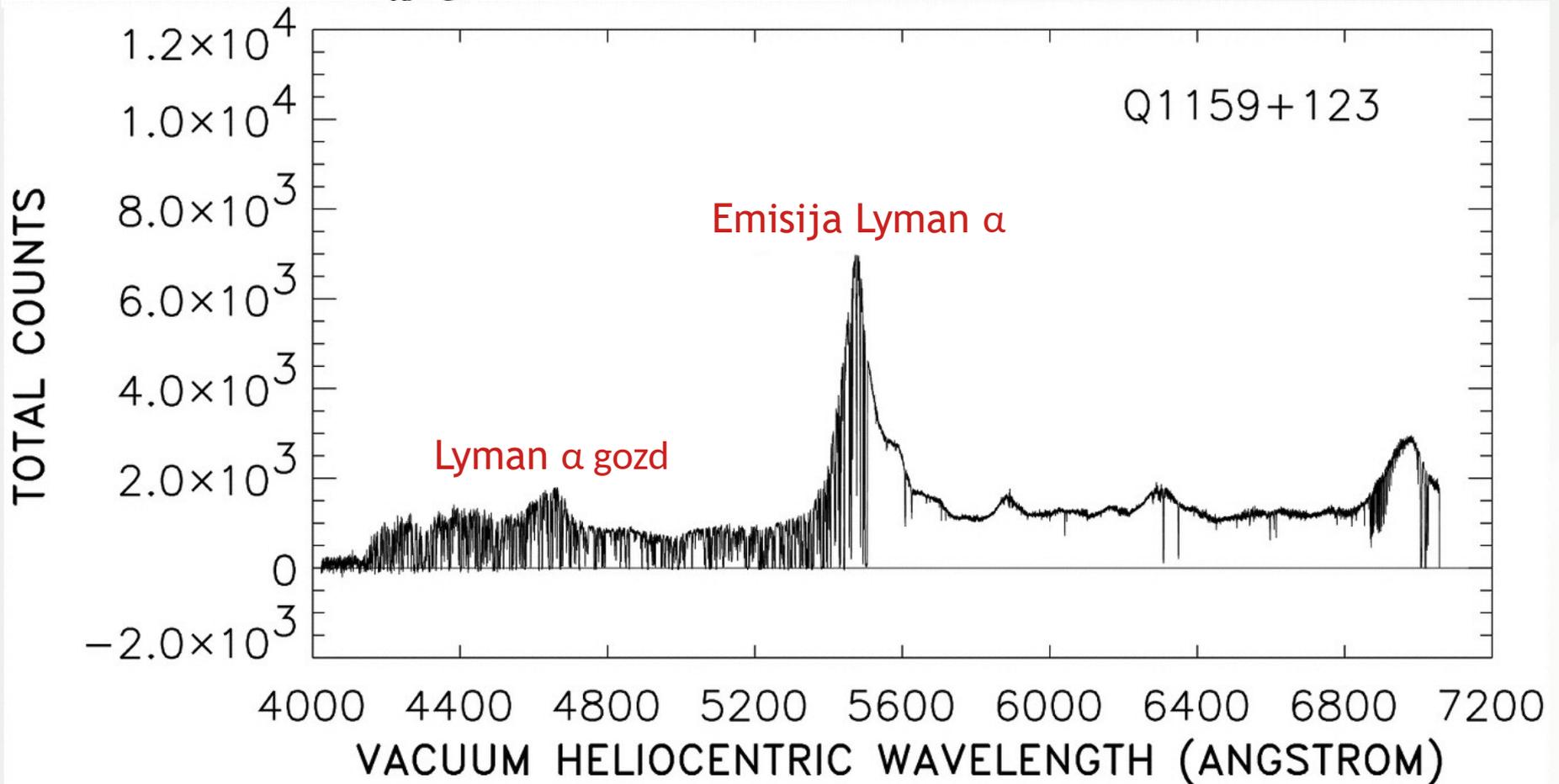
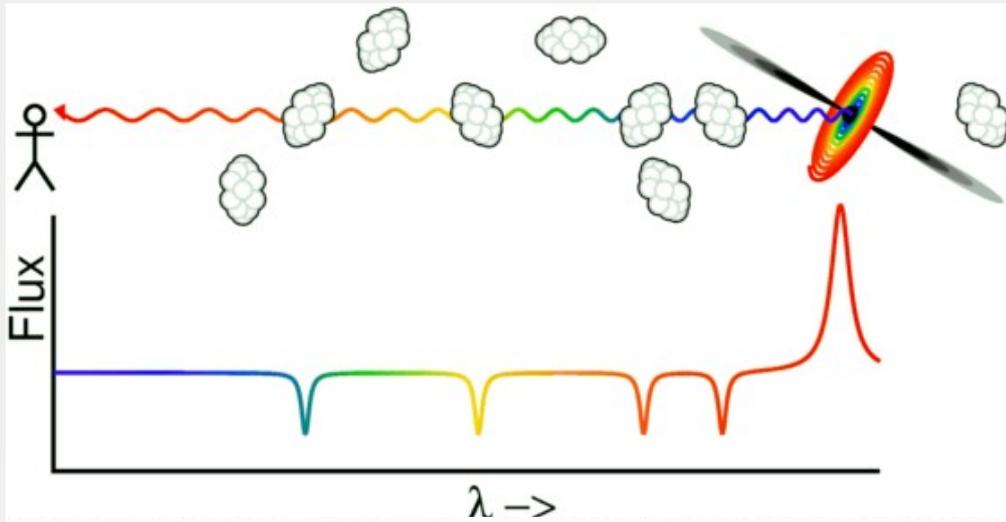


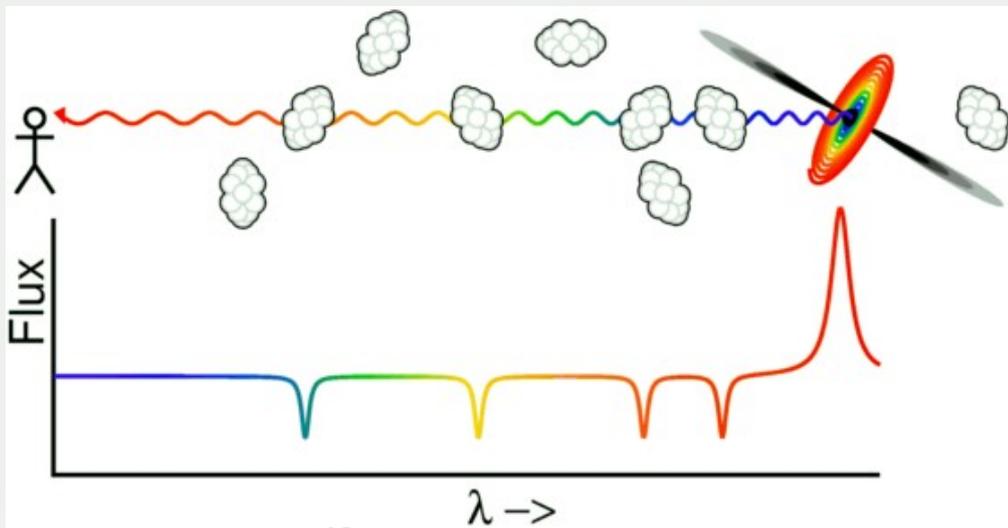


# Lyman $\alpha$ gozd



# Lyman $\alpha$ gozd





# Lyman $\alpha$ gozd

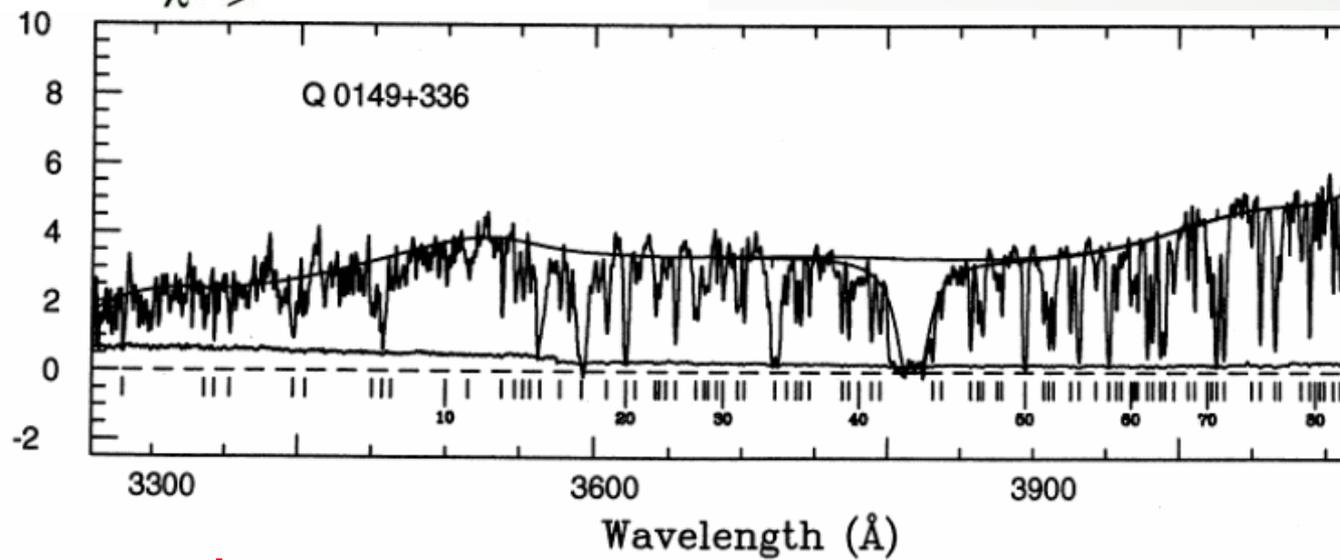


FIG. 1a

