

# II. OPAŽAČKA KOZMOLOGIJA

## II.1 Vidljive i tamne sastavnice svemira

## II.2 Hubbleova konstanta kao prvi kozмолоški parametar

*Expansion of the universe*

Cluster  
nebula in



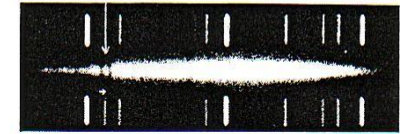
Virgo

Distance in  
light-years

78,000,000

Redshifts

H + K

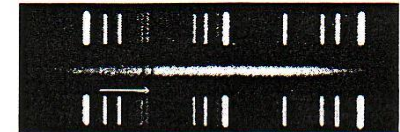


1,200 km s<sup>-1</sup>



Ursa Major

1,000,000,000

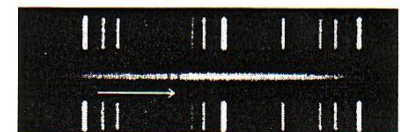


15,000 km s<sup>-1</sup>



Corona  
Borealis

1,400,000,000

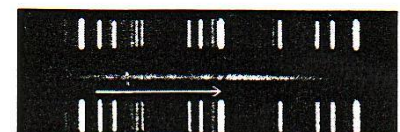


22,000 km s<sup>-1</sup>



Bootes

2,500,000,000



39,000 km s<sup>-1</sup>



Hydra

3,960,000,000

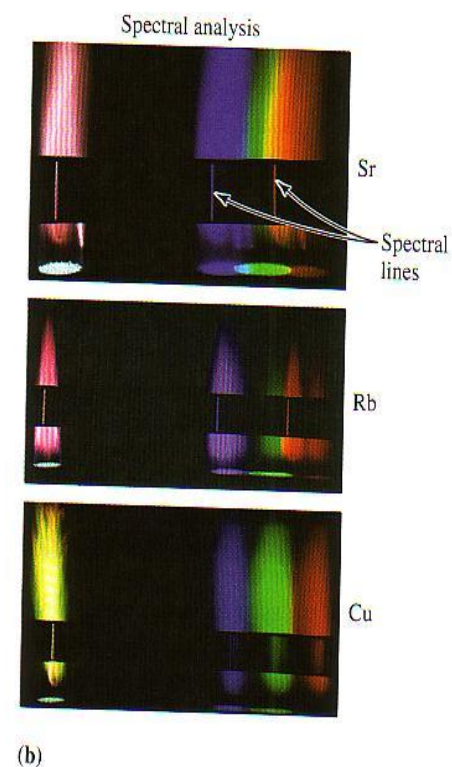
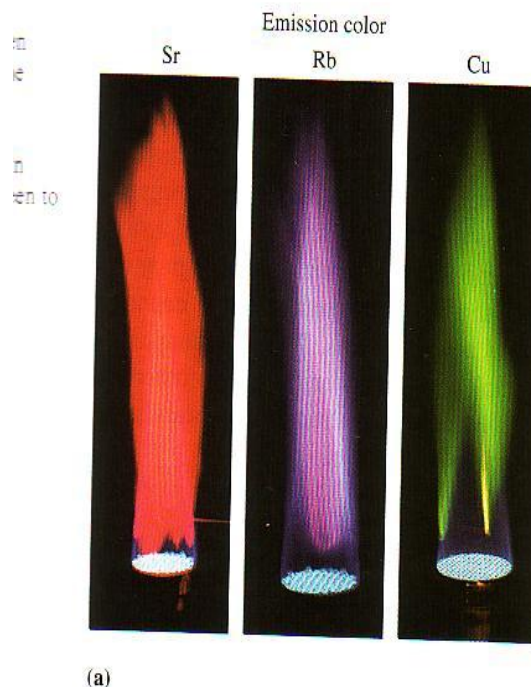


61,000 km s<sup>-1</sup>

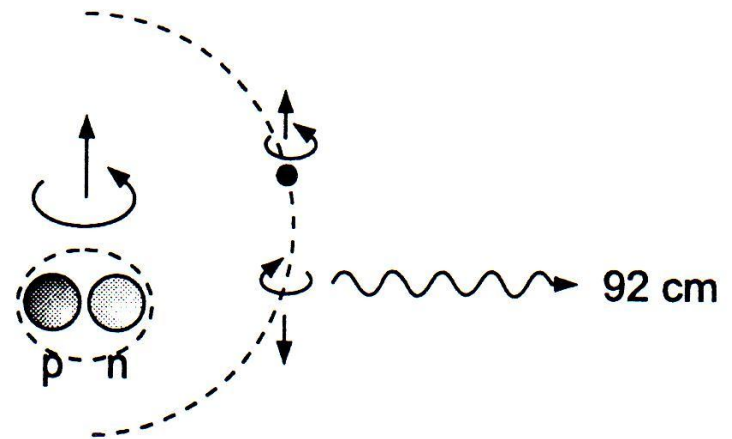
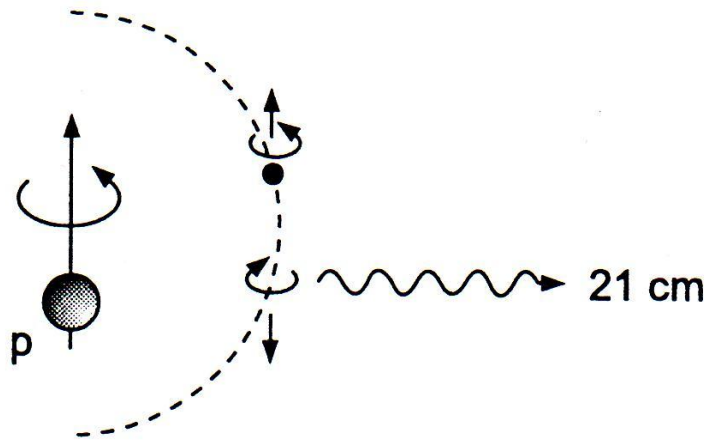
# 1. Spektralna analiza G. Kirchoff (1860)

Tamne linije

Isti kemijski elementi  
na nebu i na Zemlji

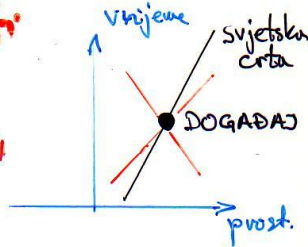


# TAMNE SPEKTRALNE LINIJE MIKROVALNE ASTRONOMIJE (FEČ, STR. 115)

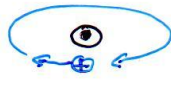


# Prostor-vrijeme Specijalne relativnosti

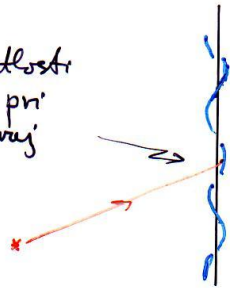
→ Svaki DOGAĐAJ ima svoj SVJETLOSNI STOŽAC



→ primjer svjetloske crte Sunca i Zemlje



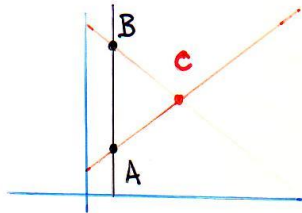
Zraka svjetlosti zakrenu se pri prolasku kraj Sunca!



→ Sa zvijezdama smo povezani svjetlošću → u prostoru-vremenu naša udaljenost od zvijezda je nula.

(najkraća udalj. A-B ide preko C!)

$$(\text{prost.-vrem. udalj.})^2 = (\text{vrem. udalj.})^2 - (\text{prost. udalj.})^2$$



→ problem svemirskih putovanja  
- ne postoji za elem. čestice koje su izvor informacija ("svemirski glasnici")

## Dopplerov pomak u STR

1<sup>o</sup>) U nerelativističkoj fizici, ukoliko se izvor valova udaljava od opažača (na ⊕) brzinom  $v$ , tijekom vrem. intervala  $dt'$  udaljenost između izvora i opažača naraste od  $cdt'$  na  $(c+v)dt'$

⇒ vremenski interval između strazanja dva brjega / otkucanja "atomskog sata" je

$$\Delta t = \left(1 + \frac{v}{c}\right) dt' \quad (1)$$

2<sup>o</sup>) U sustavu na Zemlji opažamo sat koji se udaljuje brzinom  $v$  u smjeru  $x'$ -osi. U sustavu mirovanja sata otkucaji su razdvojeni intervalom  $d\tau = dt = \frac{1}{\nu}$

→ u sustavu Zemlje  $\left\{ \begin{array}{l} \text{vrem. } dt' \\ \text{prost. } dx' = v dt' \end{array} \right.$

1/2 invarij.  $d\tau^2 = d\tau'^2$

$$d\tau = d\tau' = \sqrt{dt'^2 - \frac{dx'^2}{c^2}} = \sqrt{1 - \left(\frac{v}{c}\right)^2} dt'$$

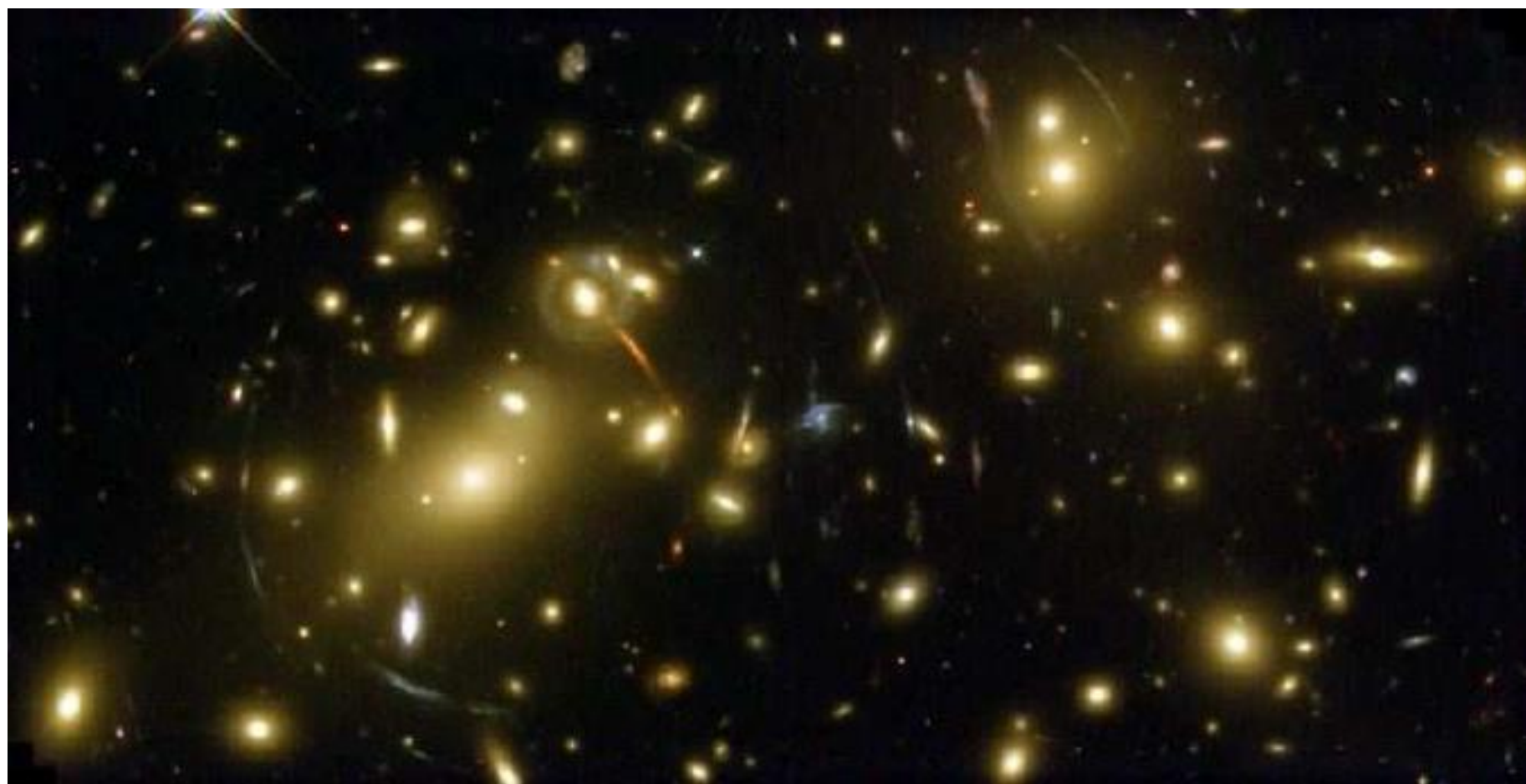
⇒ relativistička dilatacija

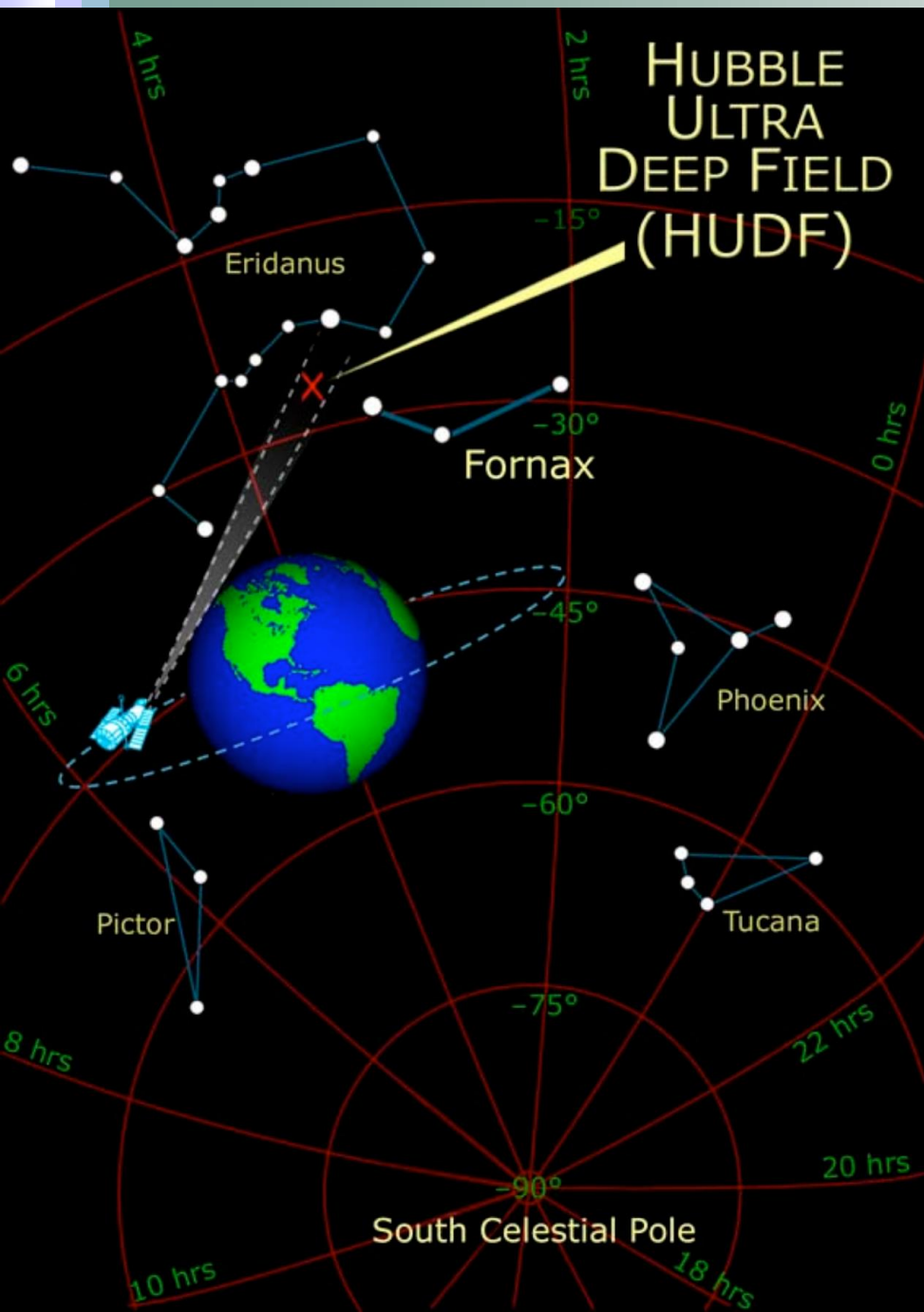
$$dt' = \frac{dt}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \quad (2)$$

$$\frac{\lambda_0}{\lambda} = \frac{v}{v_0} = \frac{\Delta t}{dt} = \frac{1 + v/c}{\sqrt{1 - (v/c)^2}}$$

$$z = \frac{\lambda_0 - \lambda}{\lambda} = \frac{\lambda_0}{\lambda} - 1 = \left(\frac{c+v}{c-v}\right)^{1/2} - 1 \rightarrow \frac{z}{0.5} \quad (v \ll c)$$

# GALAKTIČKI SVEMIR



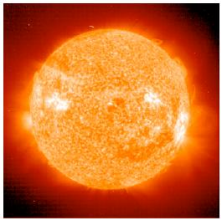


**Hubble Ultra Deep Field**



NASA, ESA, S. Beckwith (STScI) and The HUDF Team

# DOSEG NAŠEG POGLEDA



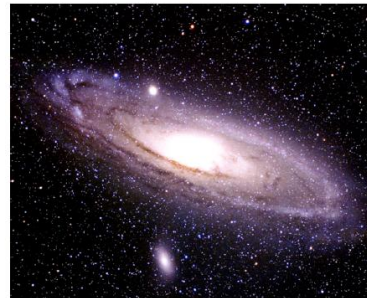
We see the Sun as it was  
8 minutes ago



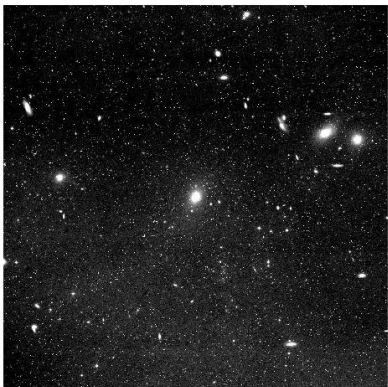
We see the nearest star Proxima Centauri, as it was 4 years ago



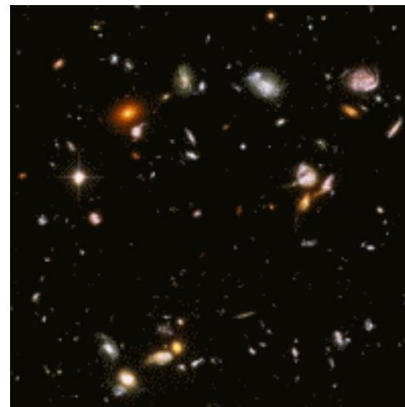
We see the Galactic centre as it was  
30,000 years ago



We see our nearest galaxy Andromeda as it was  
2 million years ago



We see the Virgo cluster as it was  
50 million years ago



We see galaxies in the Hubble Ultra Deep Field as they were upto  
12 billion years ago

# IZVAN VIDLJIVOG I OPSERVABILNOG

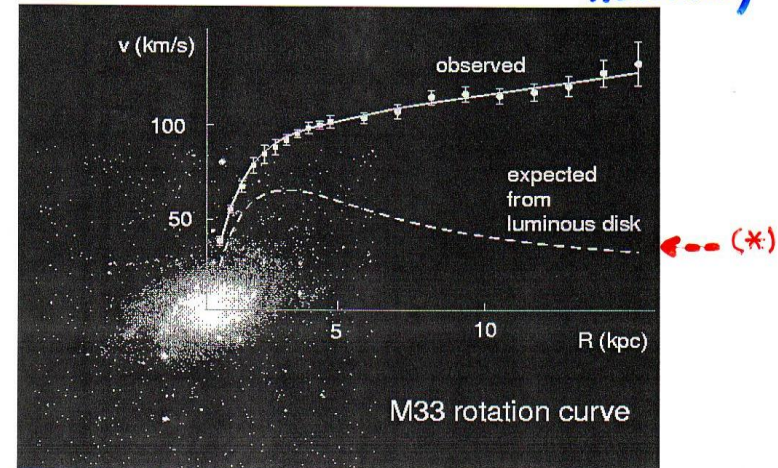


"Ill tell you what's beyond the observable universe -- lots and lots of unobservable universe."

# Karakteristične brzine osobnih gibanja

- Tamna tvar galaktičkih haloa
- na temelju Dopplerovih pomaka linija neutralnog vodika u haloima

**TAMNA TVAR**  
**BARIONSKA** (machi u galaktičkim haloima)



Newtonova gravitacija (masa  $m$  u kruženju na udaljenosti  $r$ )

$$\frac{m v^2}{r} = G_N \frac{m M(r)}{r^2}$$

- za masu koncentriranu u središtu galaktike očekujemo  $v \propto r^{-1/2}$  (\*)

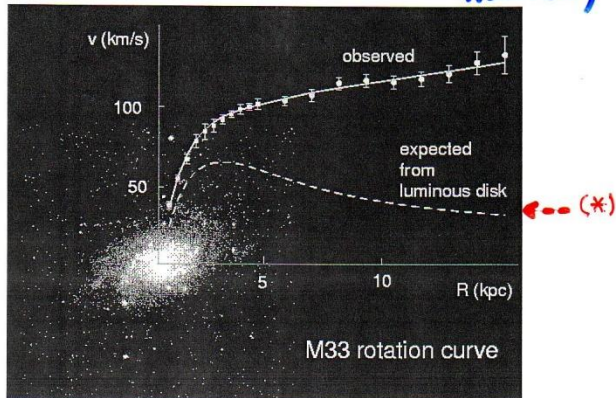
- opaženo  $v \approx \text{konst.}$  daje  $M(r) = \frac{v^2}{G_N} r \Rightarrow$  gustoća mase  $\rho(r) \propto r^{-2}$

dok bi opadanje svjetline (luminositeta) tražilo eksponencijalni pad!

# ZAGONETKA TAMNE TVARI

## TAMNA TVAR

BARIONSKA (malo u galaktičkim halovima)



Einsteinovi prstenovi oko grozdova galaktika

Newtonova gravitacija (masa  $m$  u kruženju na udaljenosti  $r$ )

$$\frac{m v^2}{r} = G_N \frac{m M(r)}{r^2}$$

- za masu koncentriranu u središtu galaktike očekujemo  $v \propto r^{-1/2}$  (\*)

- opaženo  $v \approx \text{konst.}$  daje

$$M(r) = \frac{v^2}{G_N} r \Rightarrow \text{gustoća mase } \rho(r) \propto r^{-2}$$

dok bi opadanje sjajline (luminositeta) trebalo eksponencijalni pad!

Lensing Galaxy



# BLISKE GALAKTIKE MEĐUDJELUJU

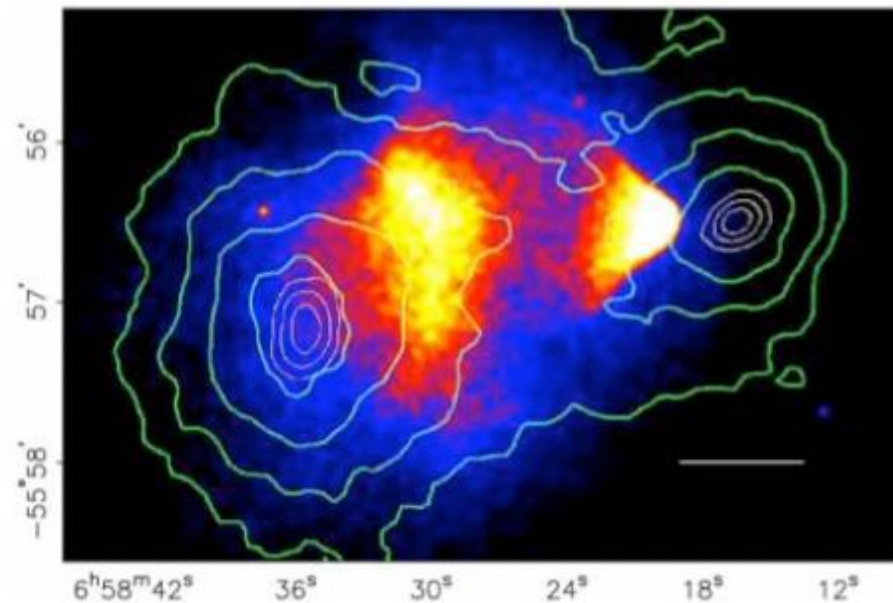
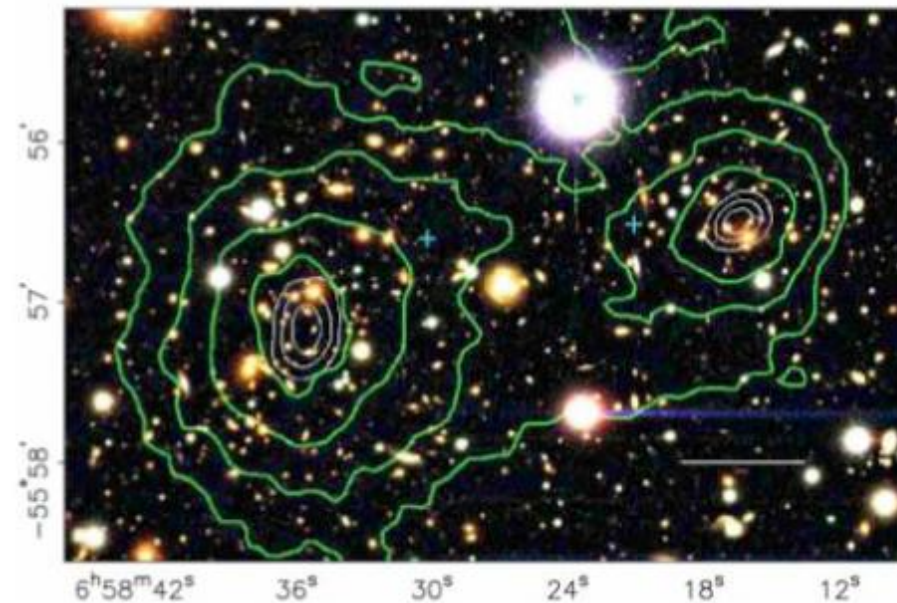
Galaxies NGC 2207 and IC 2163



# SUDARI GALAKTIČKI GROZDOVA ...

D. Clowe et al., astro-ph/0608407  
Collision in 1E0657-558 = bullet cluster

Weak lensing  $\Rightarrow$  Mass not centered on gas  
 $\Rightarrow$  Dark Matter exists



# KAO NAZNAKA TAMNE TVARI

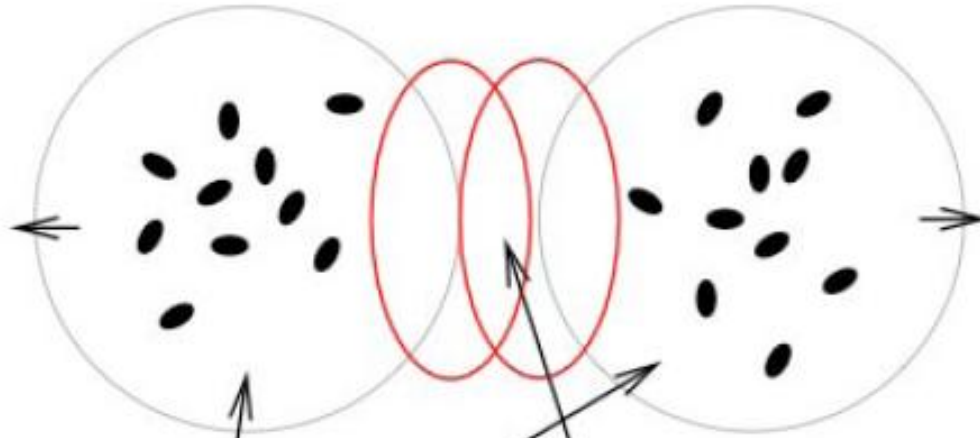
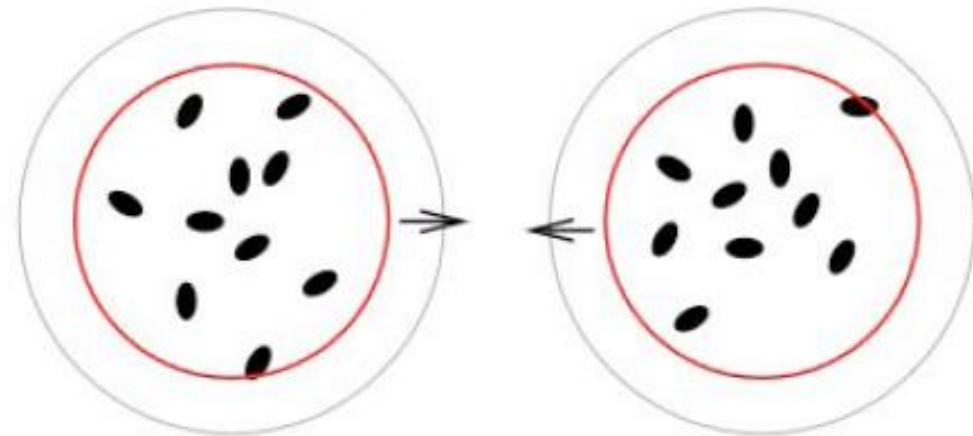
Before Collision

CDM and baryons  
superimposed

After Collision

CDM here and here

Baryons mostly here (gas)



# A. Penzias i R. Wilson (1965)

signal u mirkovalnom području iz svih smjerova neba

**Potvrda  
predviđanja  
Georga Gamowa  
(1948)  
-pozadinskog  
zračenja od 5K  
-prvotne  
nukleosinteze  
(25% He)**



# POZADINSKO MIKROVALNO ZRAČENJE

1965



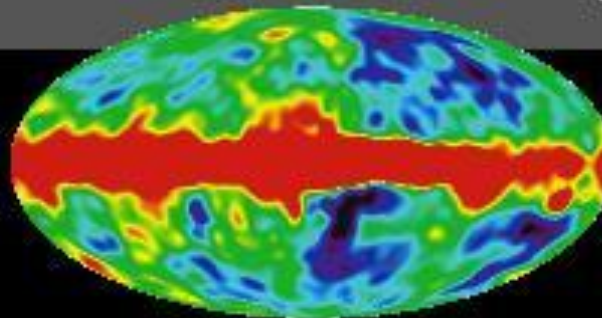
Penzias and  
Wilson



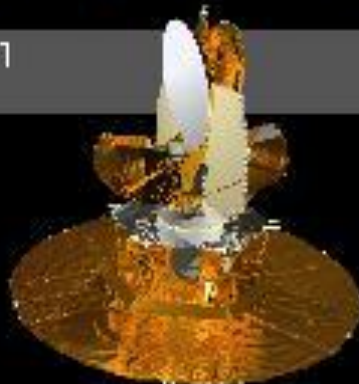
1992



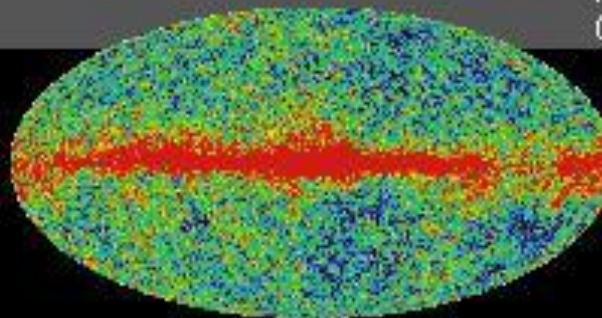
COBE



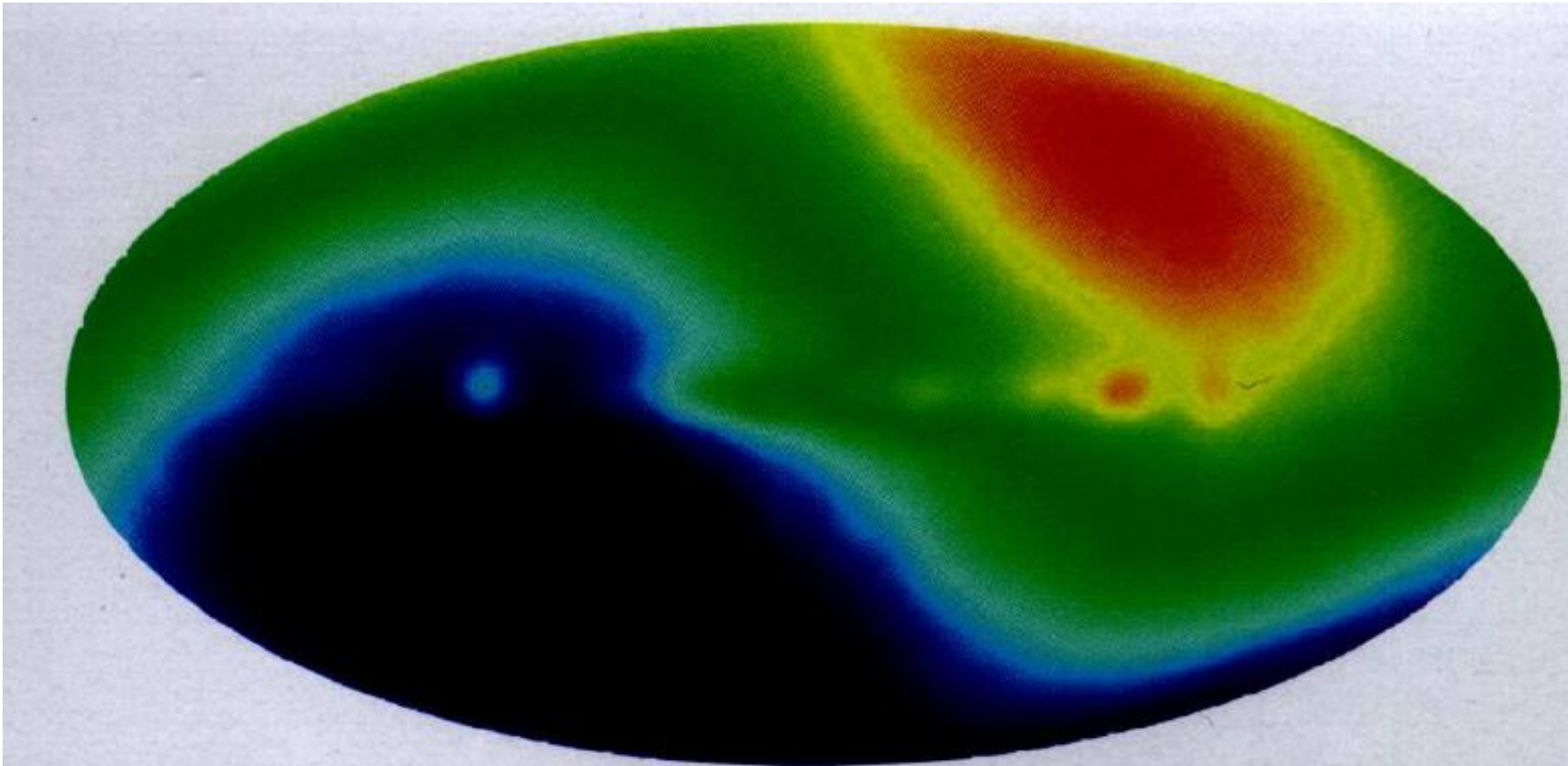
2001



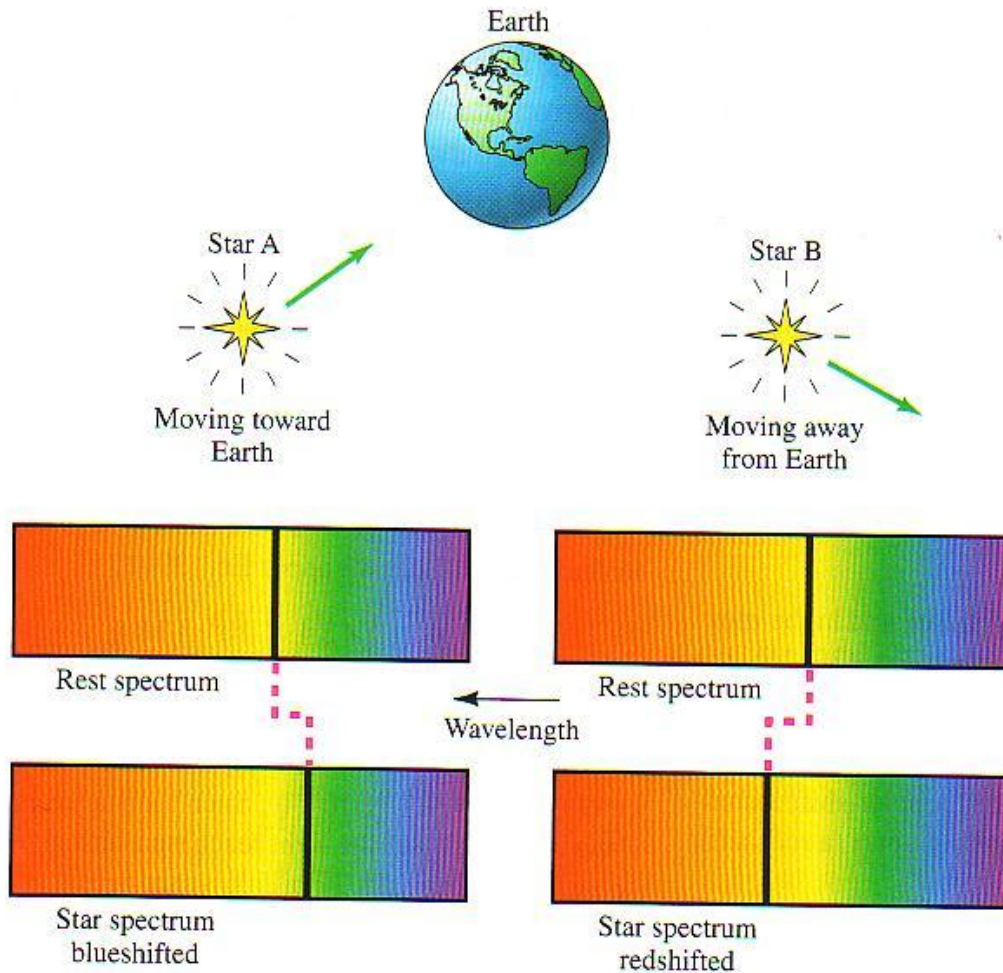
MAP  
(Simulated)



**DIPOLNA ANIZOTROPIJA CMB-a**  
(COBEovo mjerjenje  $v=371(1)\text{km/s}$   
odgovara razlici 3 mK)



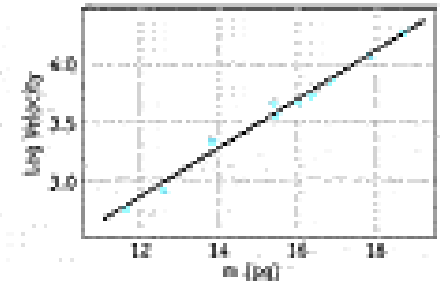
# Edvin Hubble ustanovljava svemir u širenju



## DISCOVERY OF EXPANDING UNIVERSE



Edwin Hubble



Mt. Wilson  
100 Inch  
Telescope

## 2. Porijeklo svemirskih crvenih pomaka

- Dz. 2.1: Dopplerovi pomaci
- Dz. 2.2: Gravitacijski crveni pomaci
- Izvangalaktički crveni pomaci

### EKSPANZIJA SVEMIRA

Kako protumačiti opažene crvene pomake spektralnih crt

◇ Dopplerova formula za male brzine ( $v \ll c$ )

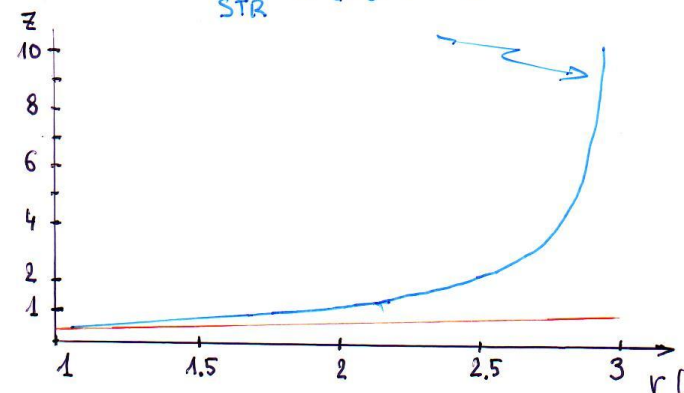
$$\frac{\lambda_o(\text{opaženo})}{\lambda(\text{emitirano})} = 1 + v/c$$

$$z = \frac{\lambda_o - \lambda}{\lambda} = \frac{v}{c}$$

(vrijedi za  $z \ll 1$ )

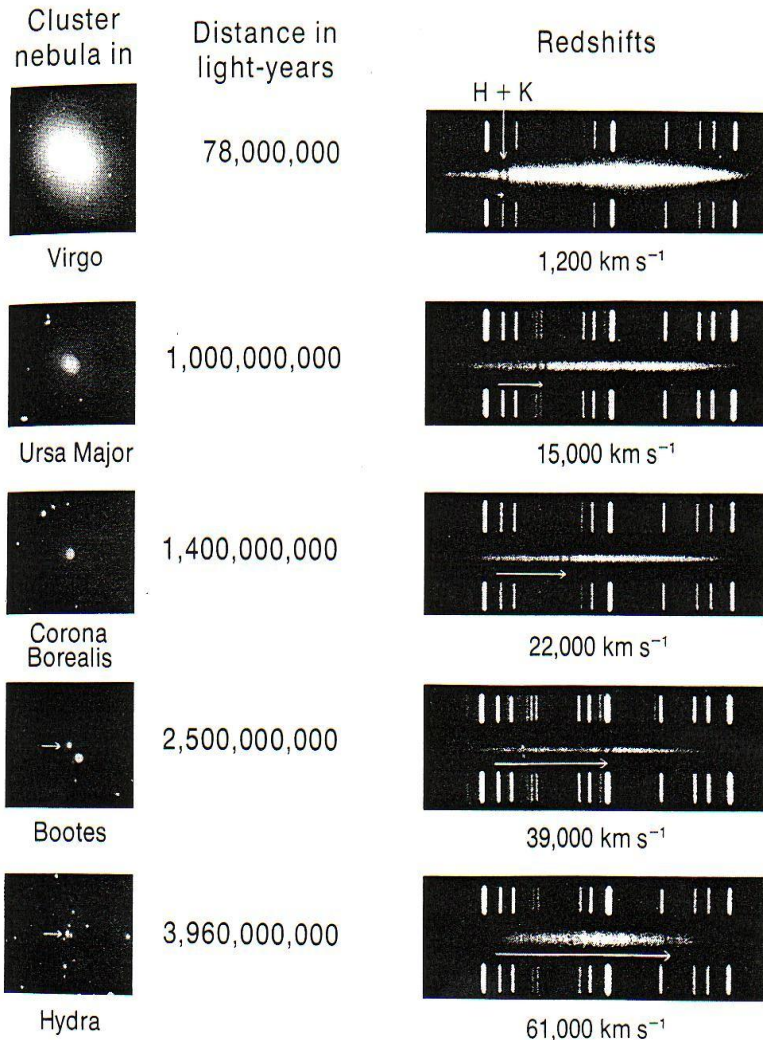
Relativistička formula

$$z|_{\text{STR}} = \left( \frac{c+v}{c-v} \right)^{1/2} - 1$$

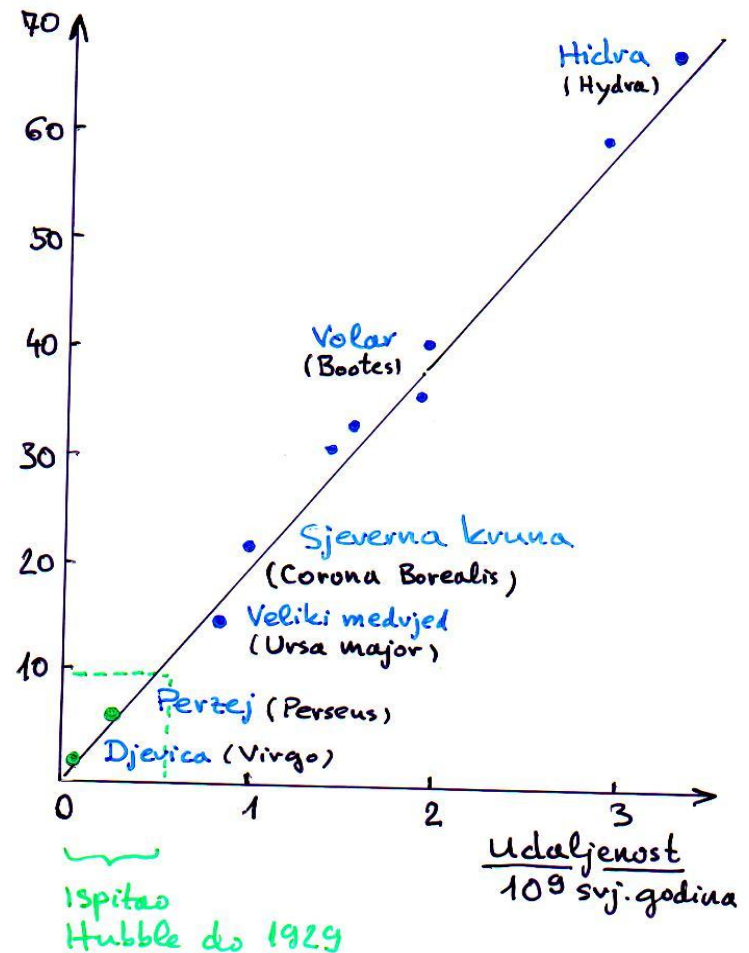


# Zakon: $z$ /udalj.(expt) & $v$ /udalj.(teor)

Expansion of the universe



Brzina udaljanja / 10<sup>3</sup> km/s



Kad god  
ugledam  
Edwina, on od  
mene bježi!

Praktični oblik  
Hubbleovog  
zakona

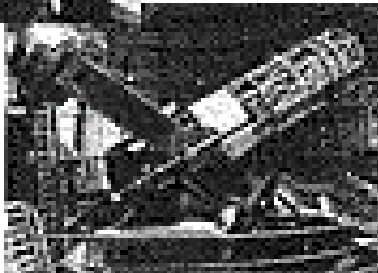
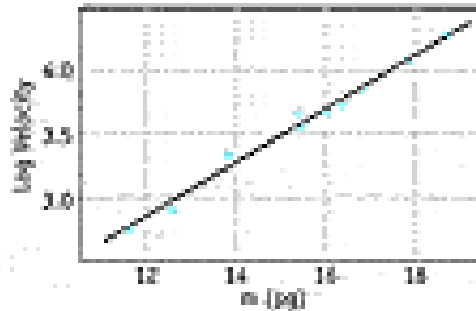


# Ekspanzija samog prostora

## DISCOVERY OF EXPANDING UNIVERSE



Edwin Hubble



H.L. Wilson  
100 Inch  
Telescope

Opaženi zakon "crveni pomak - udaljenost"

$$z = \text{konst.} \times \text{udaljenost}$$

uz pretpostavku da su crveni pomaci  
uzrokovani Dopplerovim (nerelativističkim)  
učinkom ( $v = z \cdot c$ )

$$v = z \cdot c = H_0 \cdot D$$

Hubble-ova konstanta (opisuje ŠIRENJE)

$$H_0 = \begin{cases} 530 \text{ km s}^{-1} \text{ Mpc}^{-1} & (\text{originalno}) \\ (50 - 100) \text{ km s}^{-1} \text{ Mpc}^{-1} & (\text{danas}) \end{cases}$$

$$H_0 = 100 h_0 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$(h_0 = 0.5 - 0.8) \rightarrow [0.72 \pm 0.07]$$

Cefeide, SNe:  $h_0 = 0.72(18)$  / WMAP:  $h_0 = 0.71$  [Turner, Feb. 2002]

◊ Izvan galaktički crveni pomaci  
nisu rezultat Dopplerovog učinka.

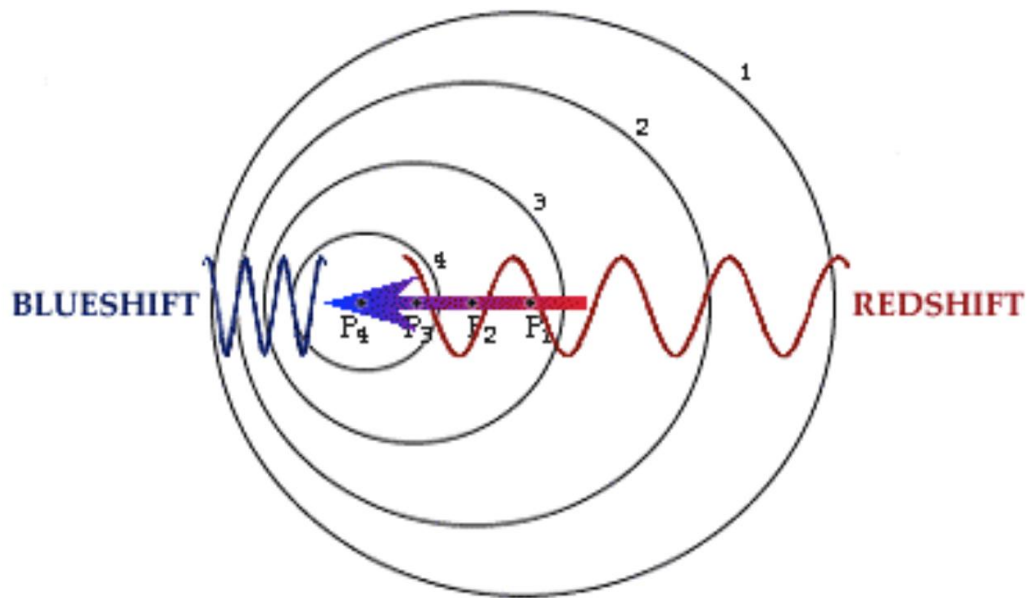
(spoznaja Howard-a Robertson-a i  
Georges-a Lemaitre-a krajem 20-tih  
→ otkriće svemirske EKSPANZIJE !)

Video lecture

Rocky (Kolb)

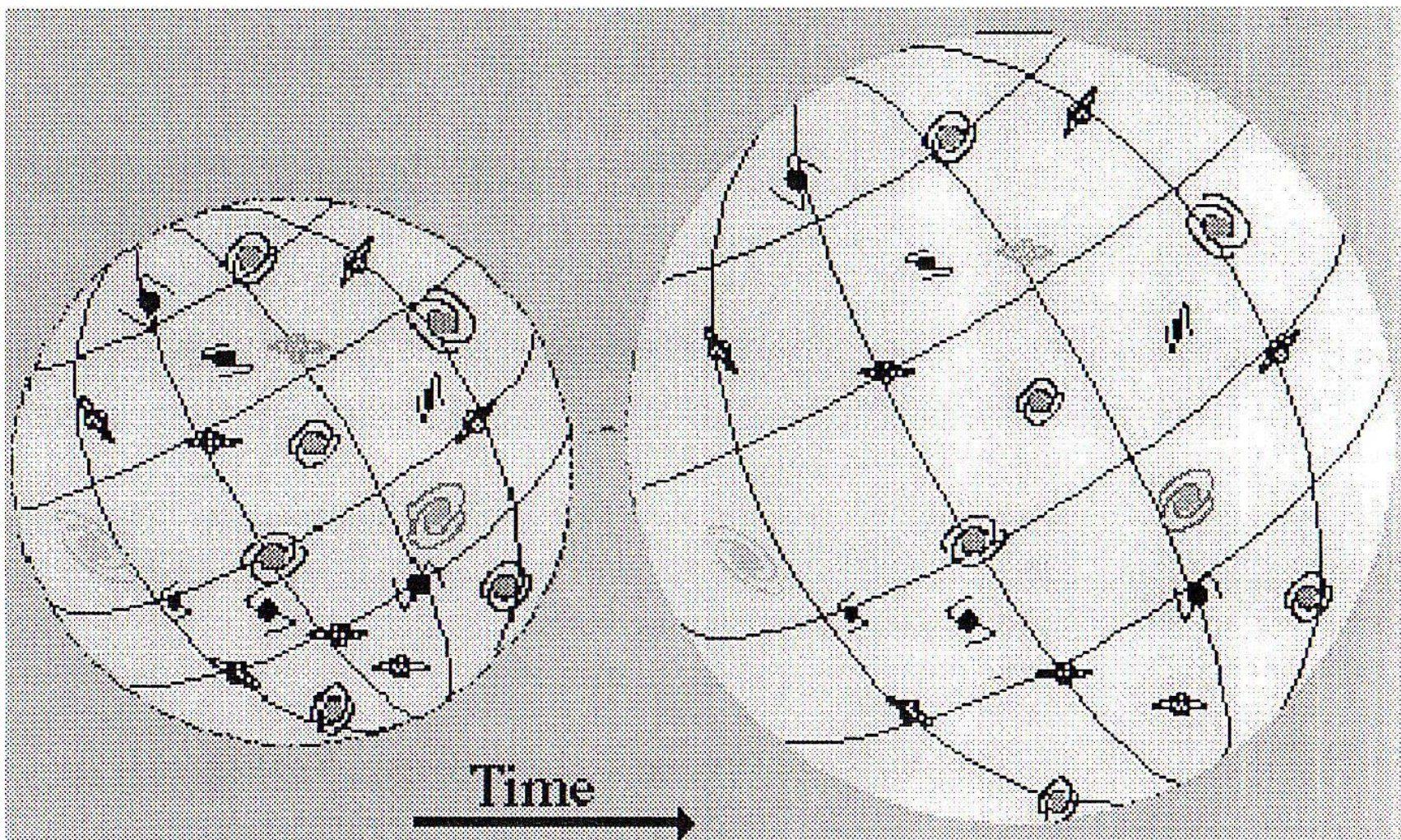
CERN 2002

# DOPPLER? OPREZ ZA ZAKRIVLJENI PROSTOR!



*"I love hearing that lonesome wail of the train whistle as the magnitude of the frequency of the wave changes due to the Doppler effect."*

# Svemir kao balon u napuhivanju



## DISKUSIJA:

"Olbersov paradoks":

Zašto je noćno nebo tamno?

## VJEŽBE:

2.1 Relativistička

Dopplerova Formula

2.2 Porijeklo dipolne anizotropije CMB-a

2.3 Sinkronizacija GPS-a Putem STR & OTR

## INERCIJALNI sustavi STR

- povezani Lorentzovim potiscima i rotacijama

- nalazimo ih unutar galaktika, koje možemo predočiti kružićima papira pričvršćenih na "EKSPANDIRAJUĆI PROSTOR" - plihu balona koji se napuhuje

