25. maj – Dan brisače

Štoparski vodnik po Galaksiji ve o brisačah povedati kar dosti stvari: Brisača, pravi, je takole približno naj – naj najkoristnejša stvar, ki si jo medzvezdni popotnik lahko omisli.

(Štoparski vodnik po galaksiji, prevedel Alojz Kodre)

Kozmologija

Osnovni parametri za opis vesolja

Viri: Jones, Lambourne (Chap. 5)

originalne prosojnice prof. Gomboc, dopolnitve in spremembe D. Fabjan

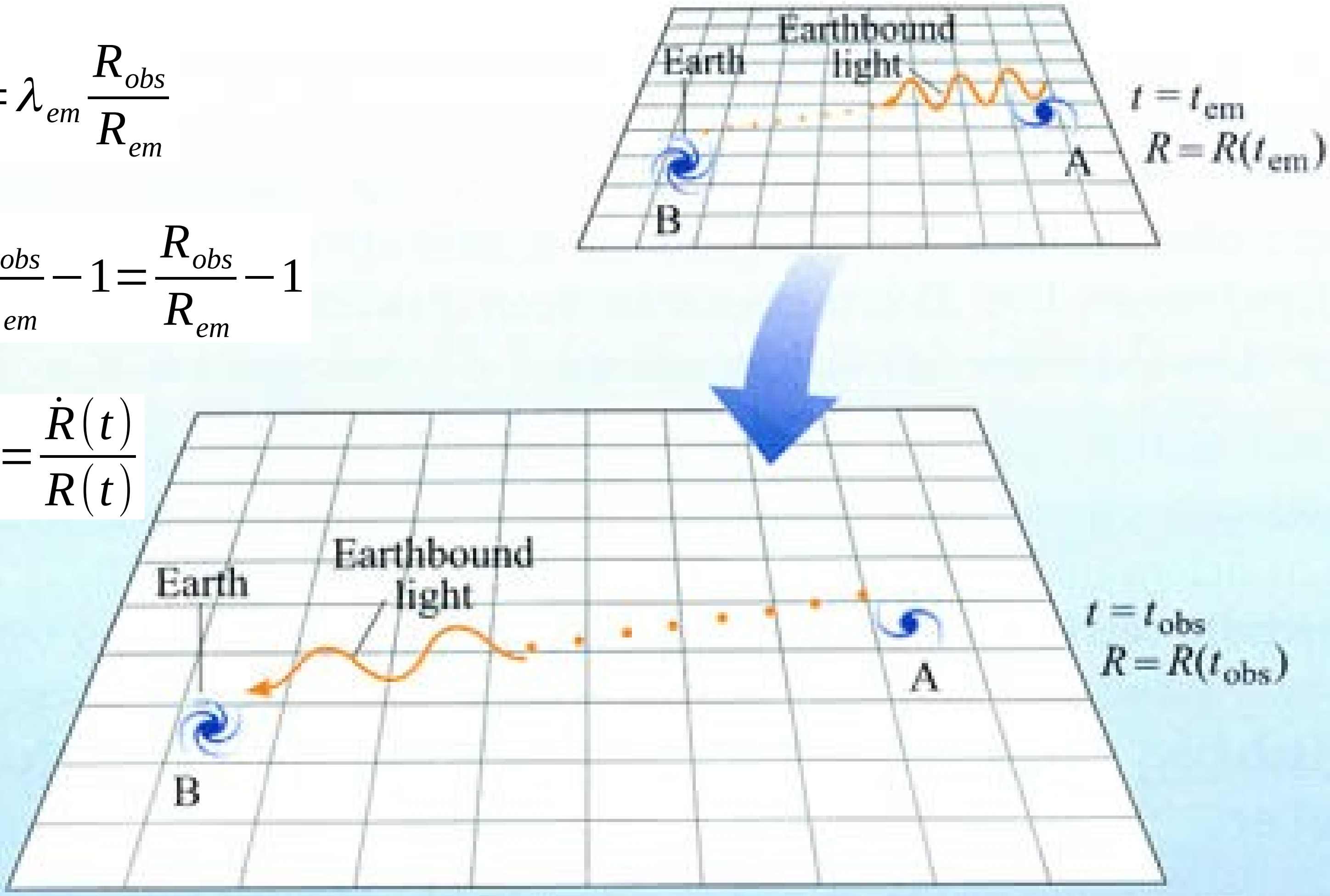
- Hubblov parameter
  - parameter pojemka q_0 - sistematična odstopanja od Hubblovega zakona
- Kritična gostota in parameter gostote
- Hubblov čas in starost vesolja

Kozmološki rdeči premik in H(t)

$$\lambda_{obs} = \lambda_{em} \frac{R_{obs}}{R_{em}}$$

$$z = \frac{\lambda_{obs}}{\lambda_{em}} - 1 = \frac{R_{obs}}{R_{em}} - 1$$

$$H(t) = \frac{\dot{R}(t)}{R(t)}$$



Hubblov parameter H(t) predstavlja hitrost spreminjanja R(t) glede na vrednost ob času t

Sistematična odstopanja od Hubblovega zakona

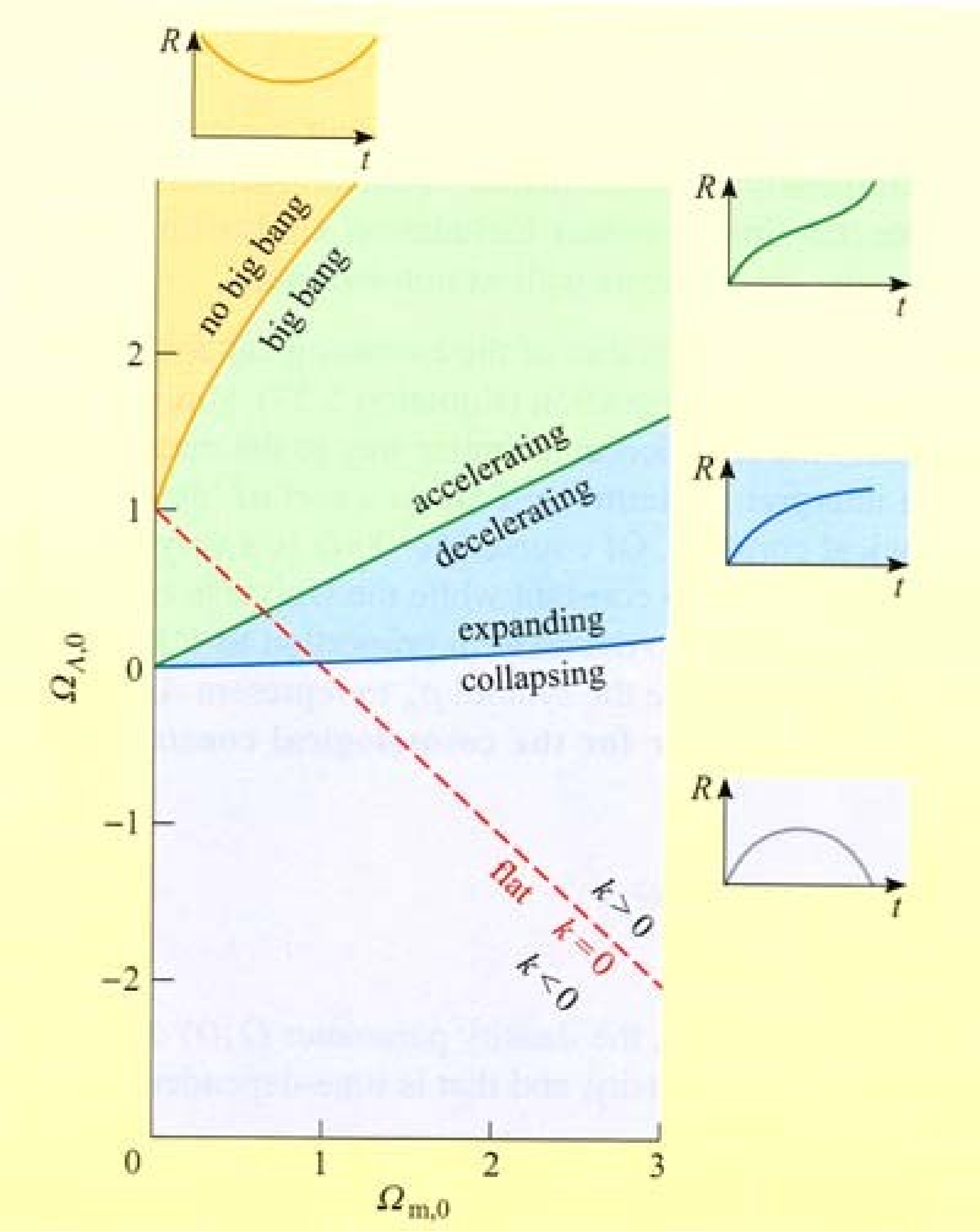
- parameter pojemka q_0

$$q(t)=\frac{-R(t)}{\dot{R}(t)^2}\ddot{R}(t)$$

- odstopanja Hubblovega zakona na večjih oddaljenostih

$$d=\frac{c\,z}{H_0}\left[1+\frac{1}{2}(1-q_0)z\right]$$

Kritična gostota in gostotni parametri



$$\rho_c = \frac{3\,H(t)^2}{8\,\pi\,G}$$

$$\rho_c(t_0) \sim 10^{-26}\,kg\,m^{-3}$$

$$\Omega_m = \frac{\rho(t)}{\rho_c(t)}$$

$$\Omega_\Lambda = \frac{\rho_\Lambda(t)}{\rho_c(t)} \qquad \rho_\Lambda = \frac{\Lambda c^2}{8\,\pi\,G}$$

$$\Omega_m + \Omega_\Lambda - 1 = \frac{k\,c^2}{R^2\,H^2}$$

$$q(t) = \frac{\Omega_m}{2} - \Omega_\Lambda$$

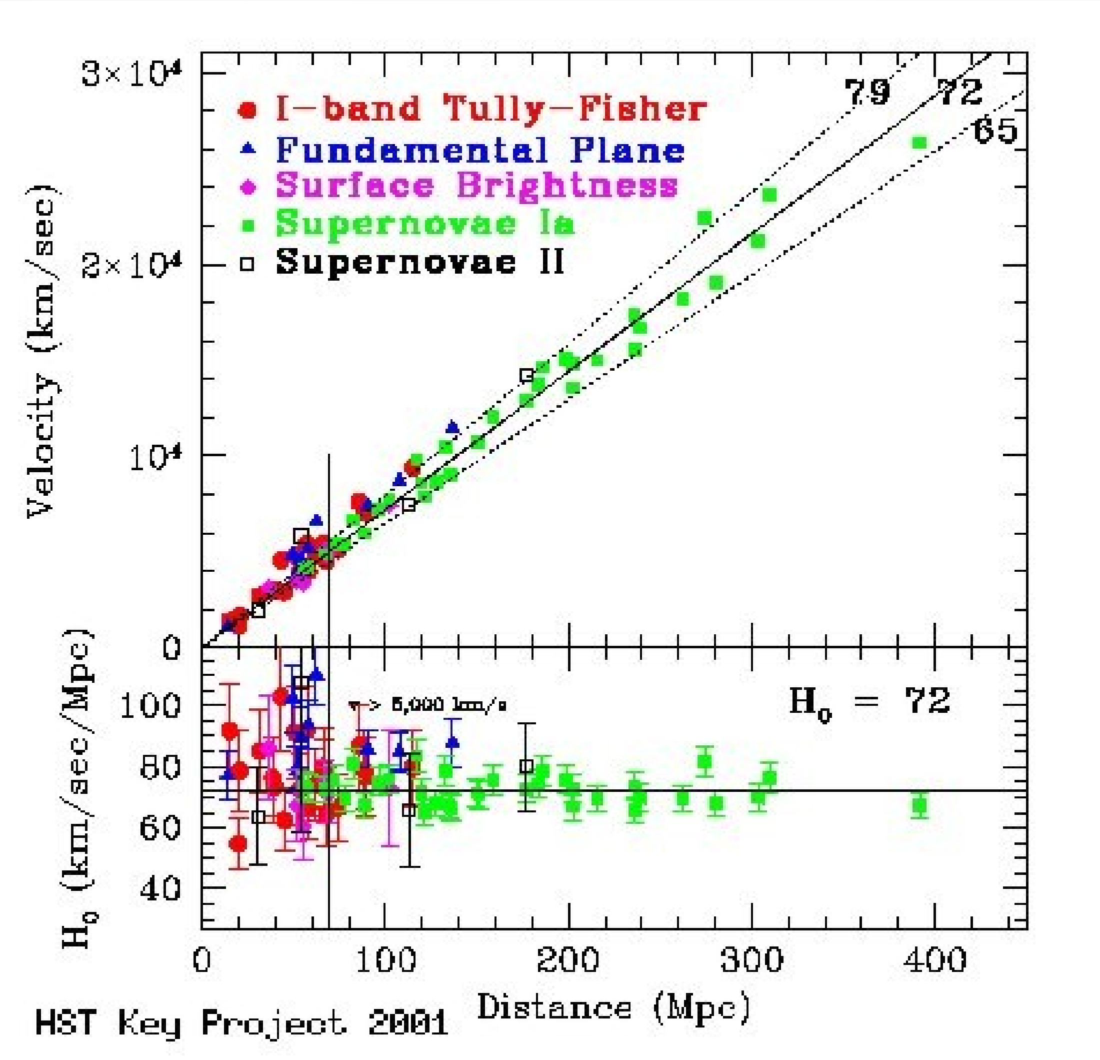
Kozmologija

Opazovalna kozmologija

Viri: Jones, Lambourne (Chap. 7)

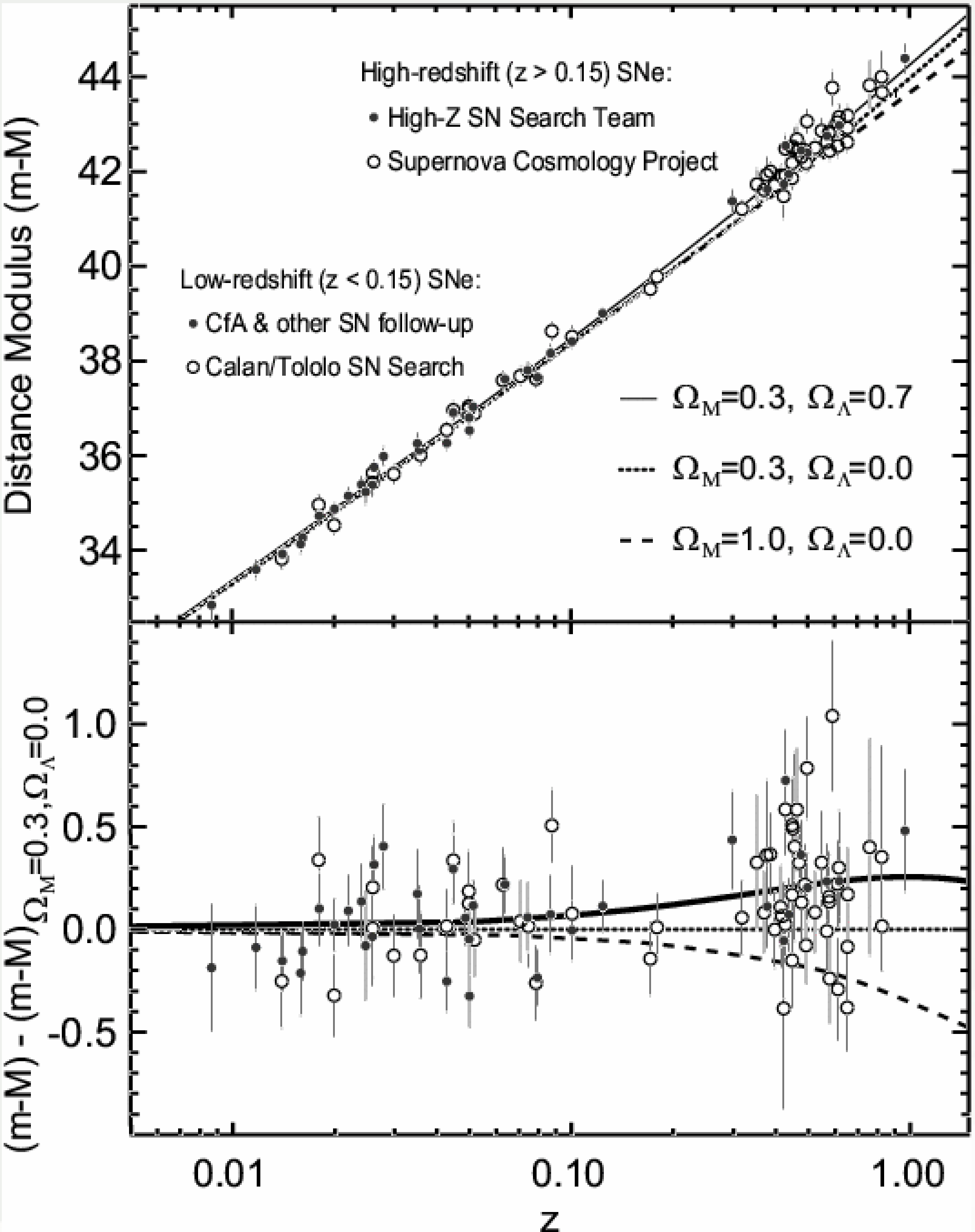
originalne prosojnice prof. Gomboc, dopolnitve in spremembe D. Fabjan

Meritve Hubblove konstante



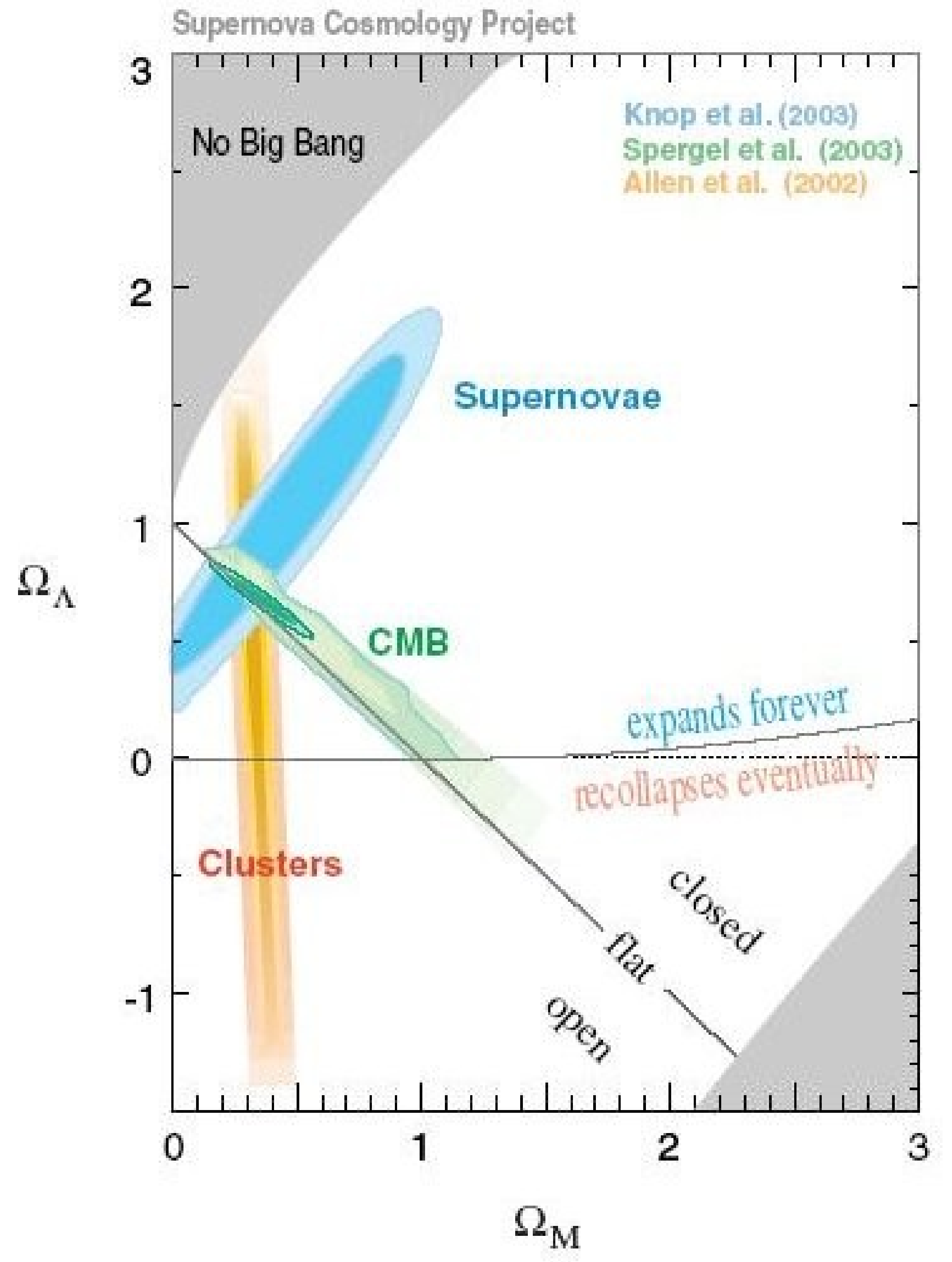
HST Key Project, Freedman et al. (2001)

Meritve parametra pojemka q_0



$-0.6 < q_0 < 0$

Meritve parametrov gostote



Meritve parametrov gostote

"svetla" snov (zvezde)	Ω_{lum} h = 0.002-0.006
galaksije	Ω_{gal} > 0.03-0.05
prvinska nukleosinteza	Ω_b h^2 = 0.019+/-0.001
jate galaksij	Ω_M = 0.1 - 0.3
jate galaksij (SZ učinek)	Ω_M h = 0.22+0.05-0.08
prasevanje	Ω_γ h^2 = 2.5x10^{-5}
nevtrini	Ω_ν h^2 = 1.7x10^{-5}

Kozmologija

Prapok in zgodnje vesolje

Viri: Jones, Lambourne (Chap. 7)

originalne prosojnice prof. Gomboc, dopolnitve in spremembe D. Fabjan

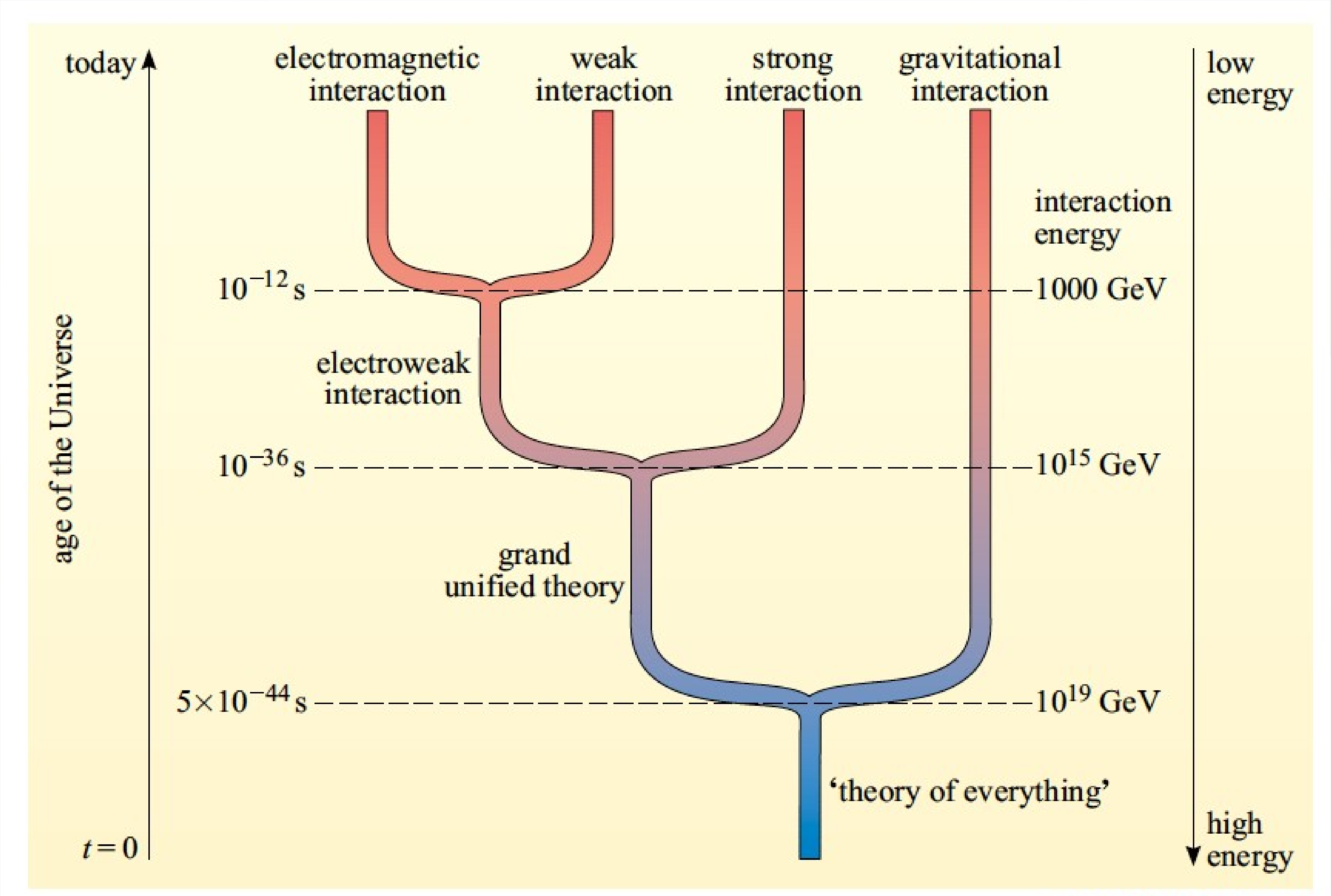
Zgodnje vesolje

- širjenje, prasevanje – nekoč manjše, vroče
- $t=0$, $a(t) = 0$
- eksperimentalne omejitve: $T<10^{15}$K, $t>10^{-9}$ s (v pospeševalnikih)
- opis s fizikalnimi teorijami:
  - kvantna fizika (standardna teorija delcev)
  - splošna teorija relativnosti
  - nimamo še kvantne gravitacije
- teorija vsega --> Planckova razdalja in čas:

$d_{Planck}= (Gh/2\pi c^3)^{1/2}=1.6\times10^{-35}$ m

$t_{Planck}=(Gh/2\pi c^5)^{1/2}=5.4\times10^{-44}$ s

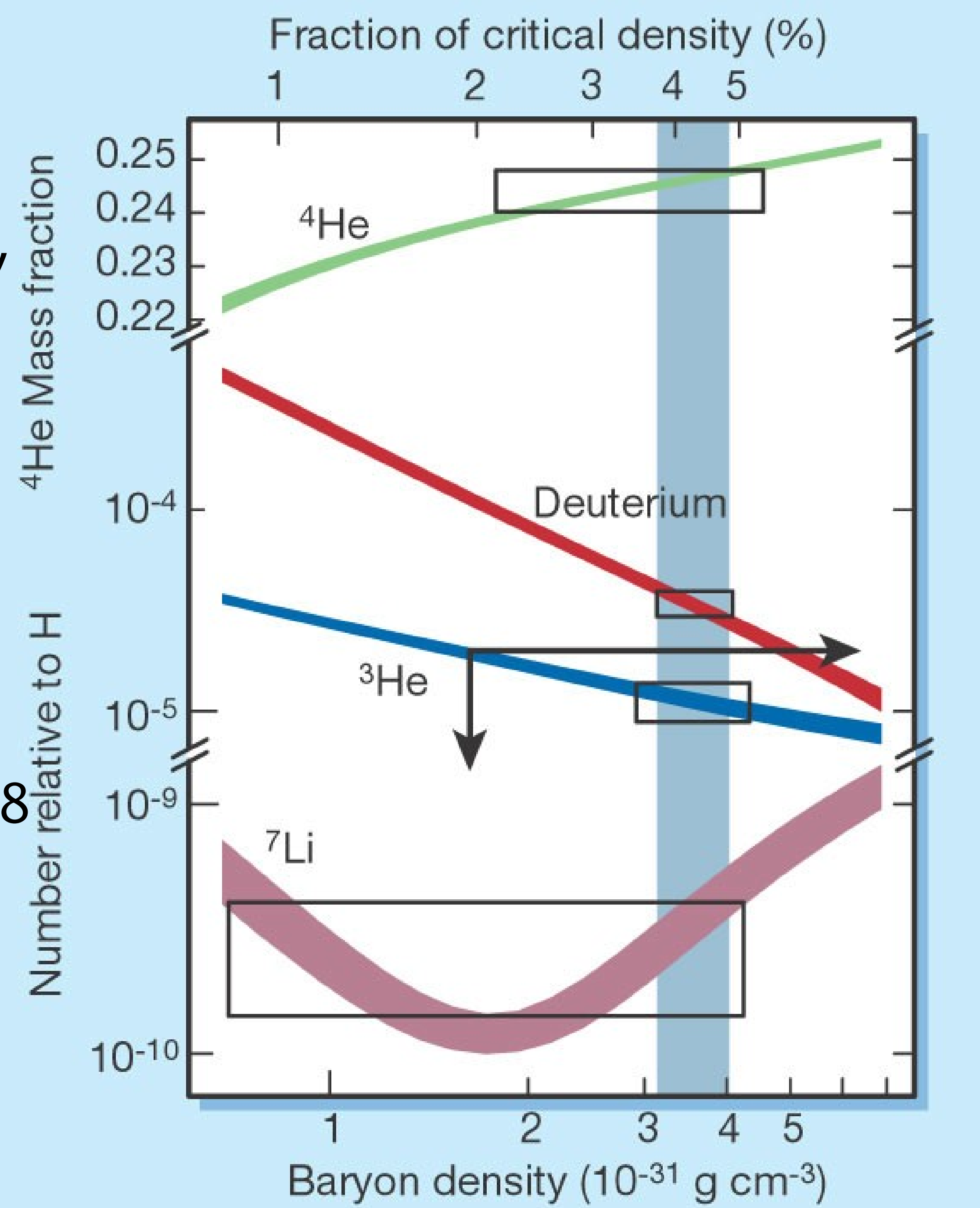
teorija vsega in poenotenje



Primordialna nukleosinteza

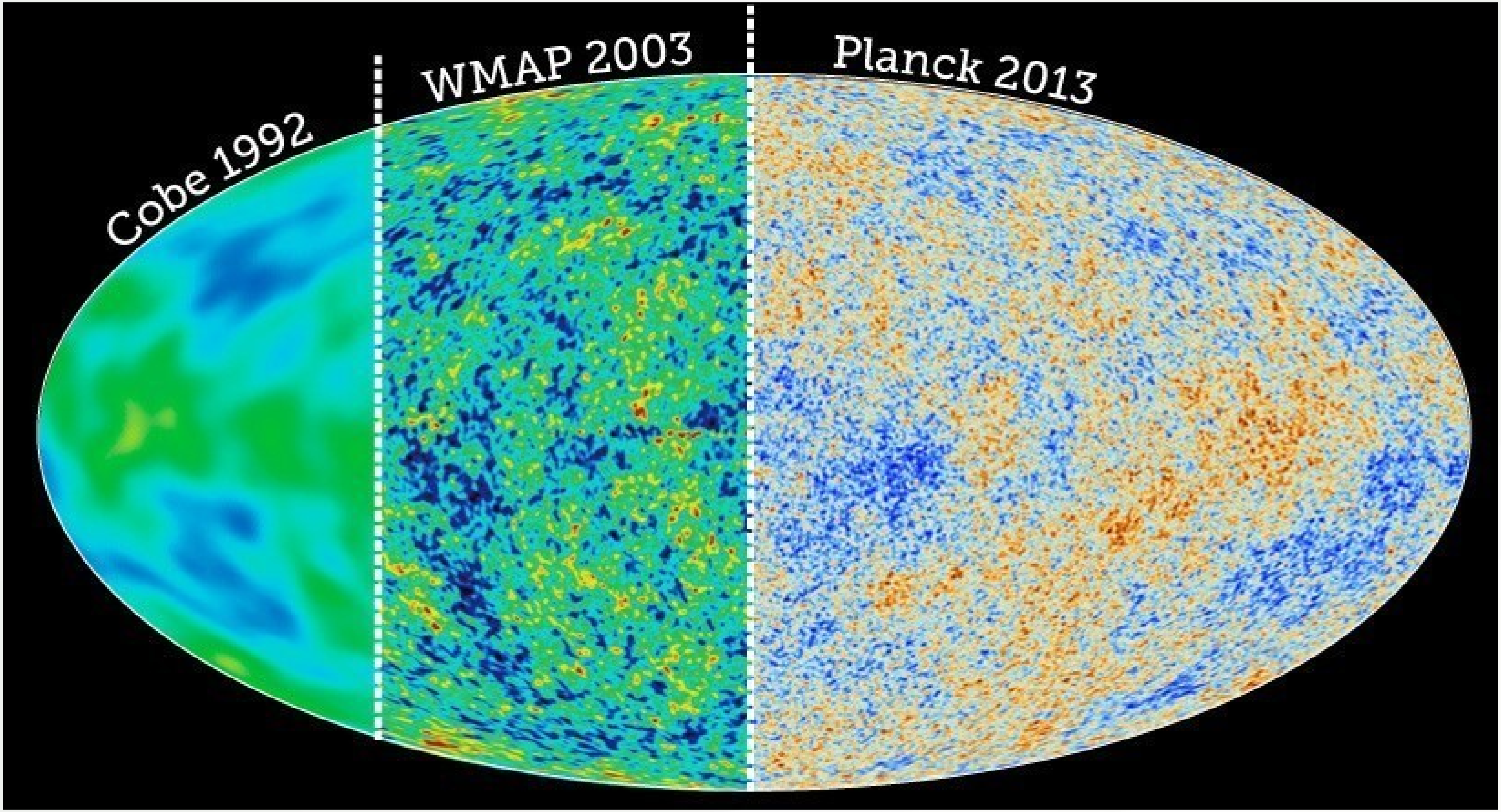
- $t < x \cdot 100$ s; $T > x \cdot 10^8$ K; $E > x \cdot 10^4$eV
- Nastajajo atomska jedra:
  večina n gre v He, malo v
  litij, berilij, devterij
- ni elementov > Be
  ker ni stabilnih jeder z A=5 ali 8
  (rabili bi trojni alfa proces)
- vesolje se širi

Li: ${}^4_2He + {}^3_1H \rightarrow {}^7_3Li + \gamma$

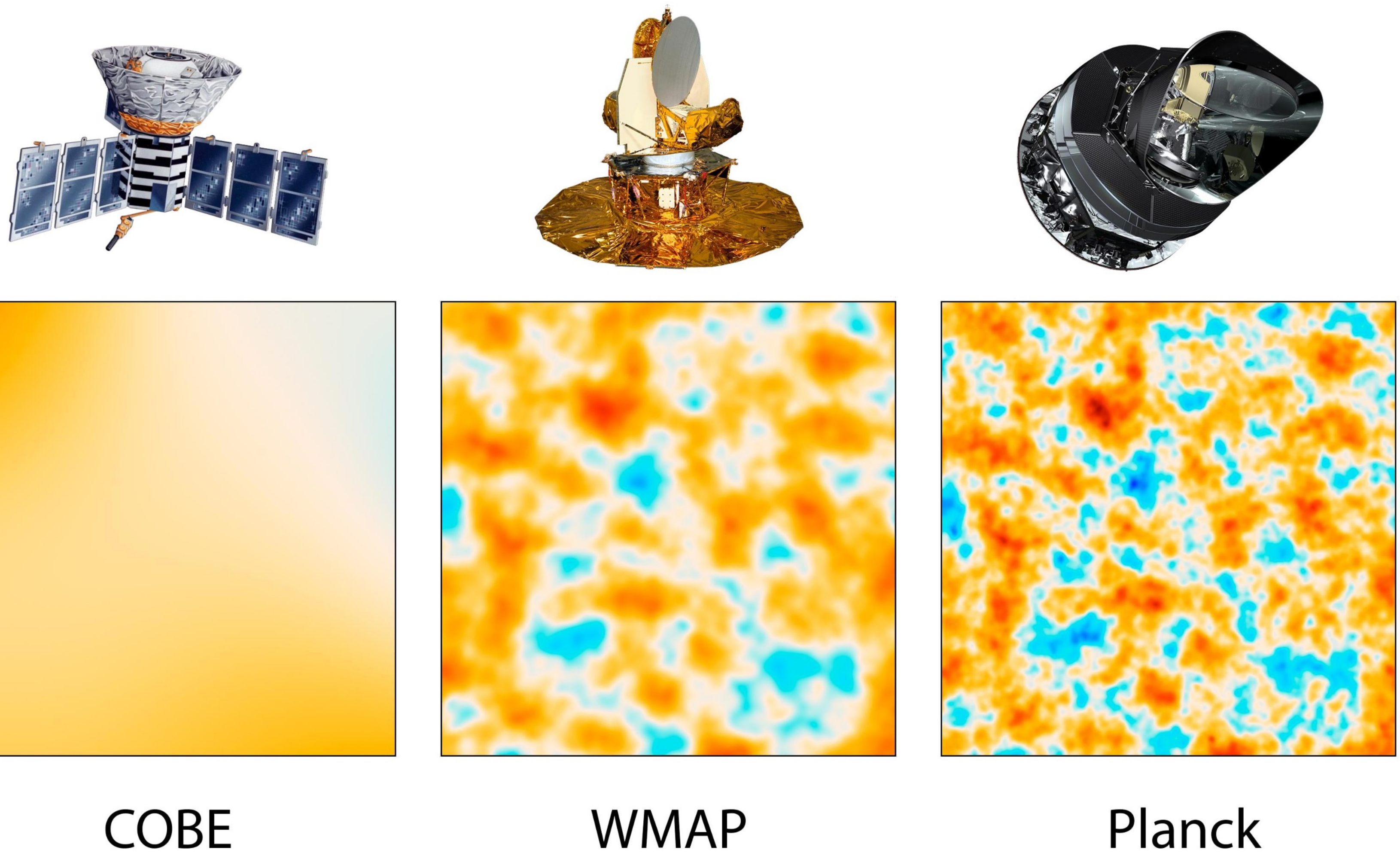


Charbonnel (2002), *Nature*

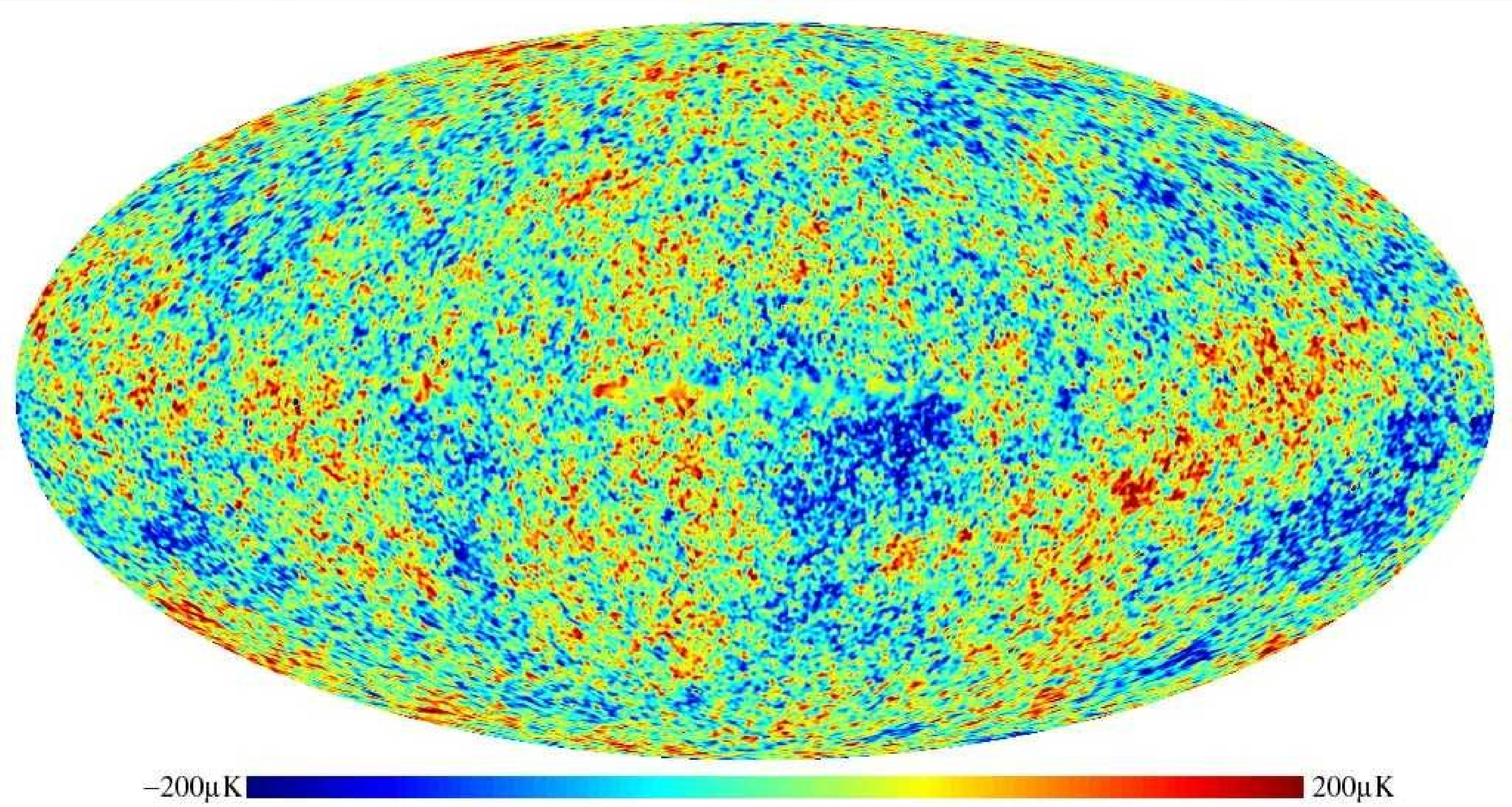
Kozmično mikrovalovno sevanje ozadja



Anizotropije v prasevanju

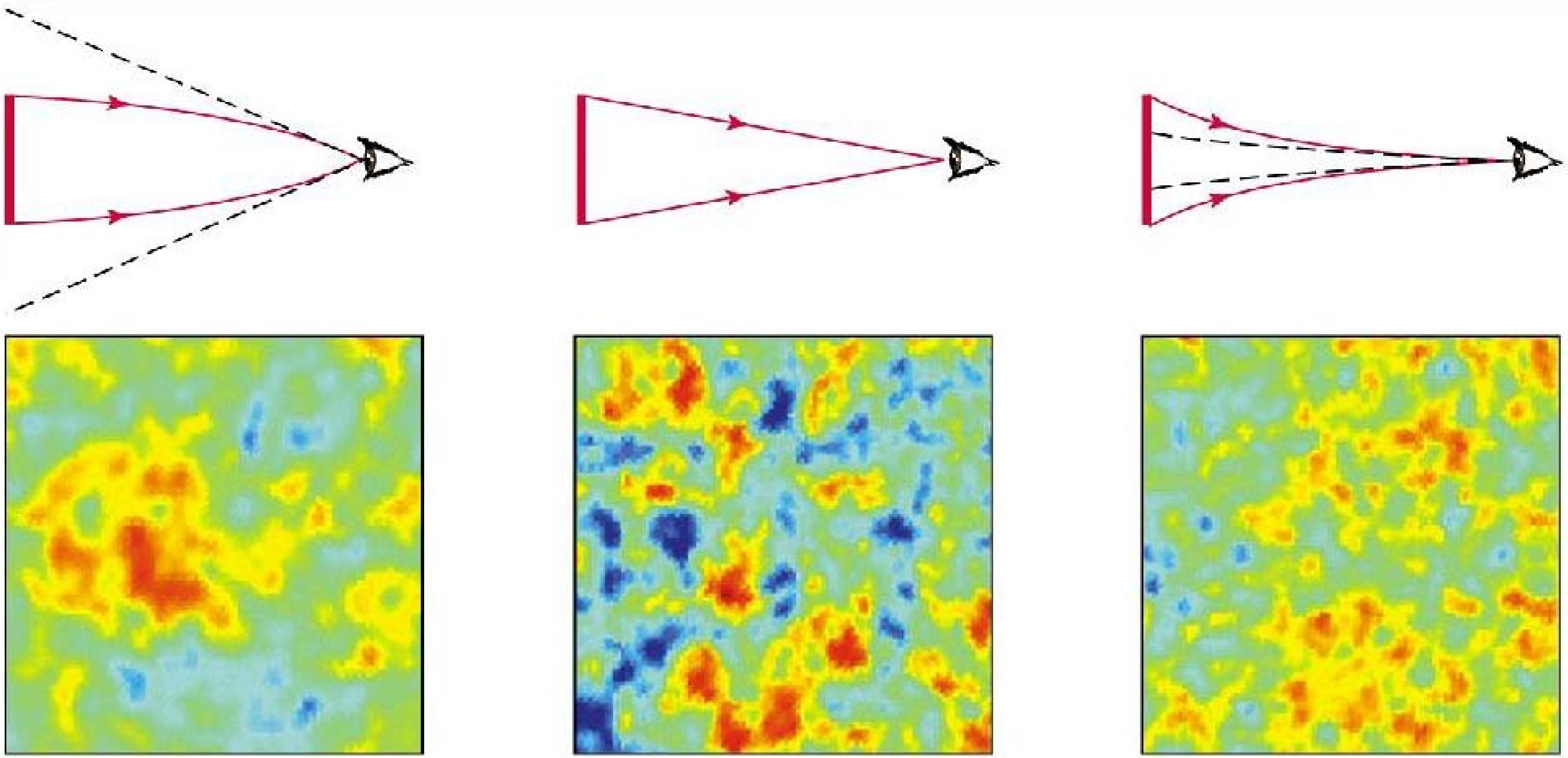


Anizotropije v prasevanju



$$\frac{\delta T}{T} \sim 10^{-5}$$

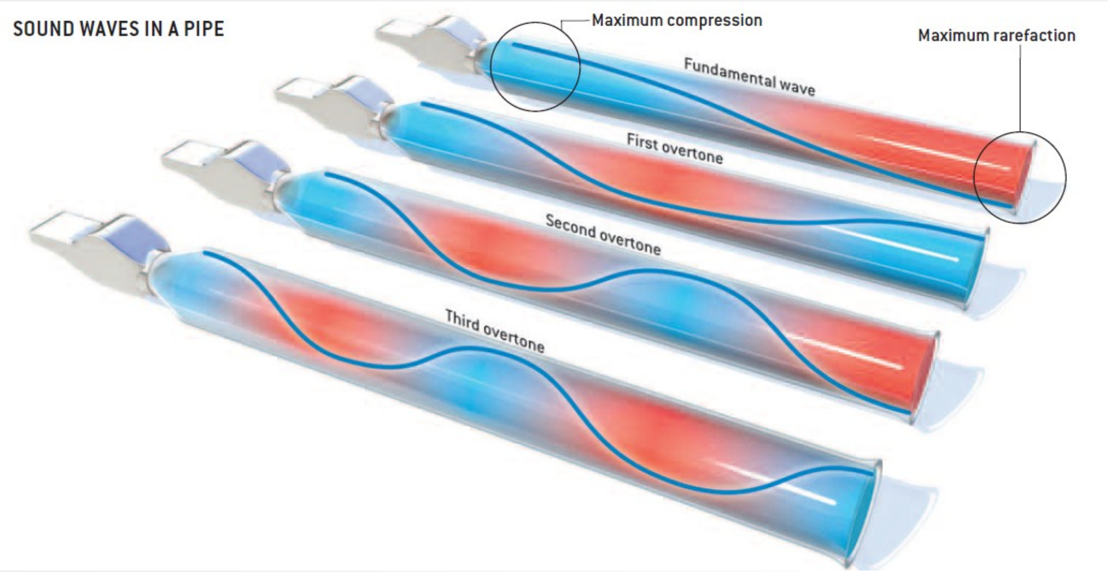
Anizotropije v prasevanju

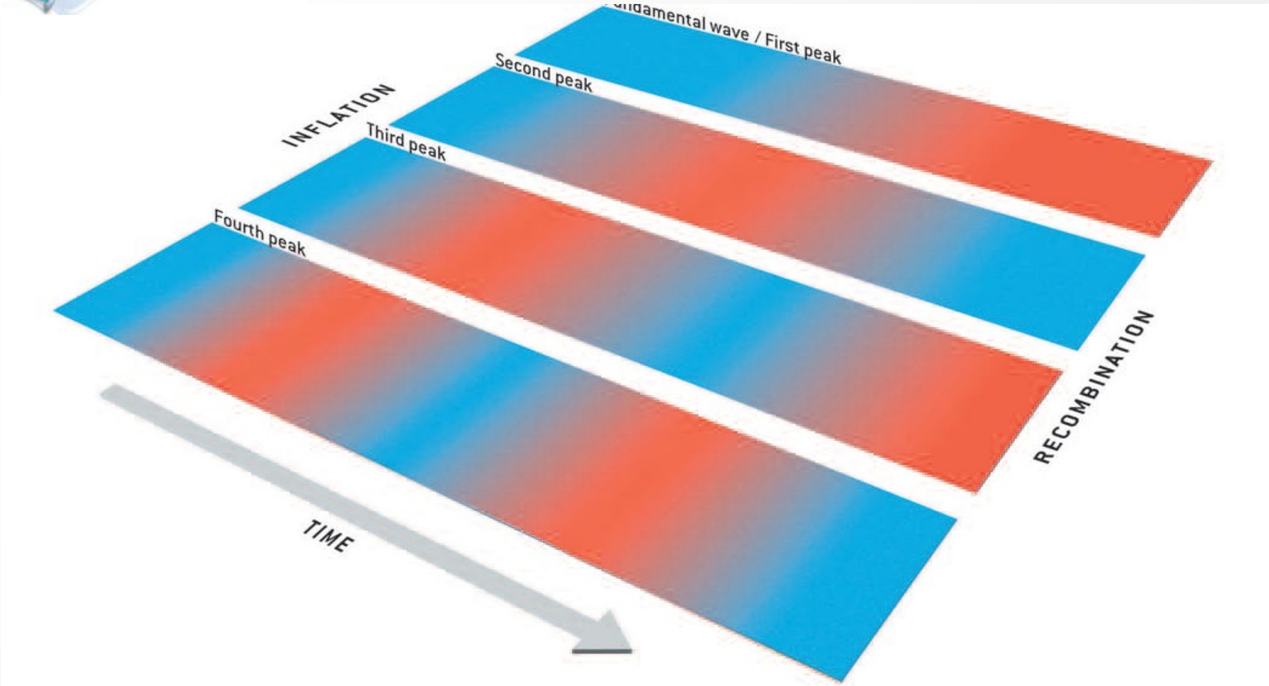


a If universe is closed, "hot spots" appear larger than actual size

b If universe is flat, "hot spots" appear actual size

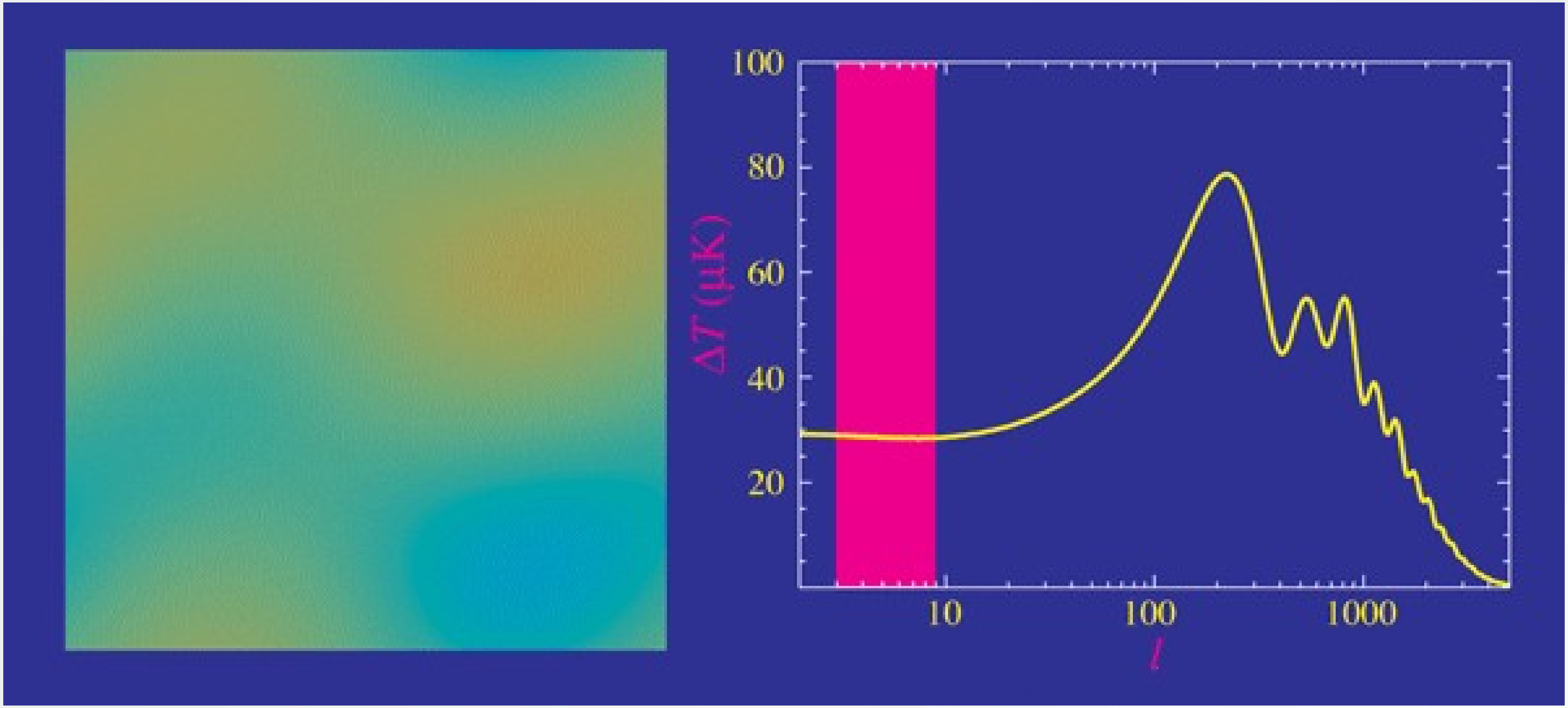
c If universe is open, "hot spots" appear smaller than actual size





Wayne Hu, Martin White
The cosmic symphony
http://background.uchicago.edu/~whu/Papers/HuWhi04.pdf

Anizotropije v prasevanju



Animacija Wayne Hu

The CMB sound spectrum
http://people.virginia.edu/~dmw8f/BBA_web/unit05/unit5.html

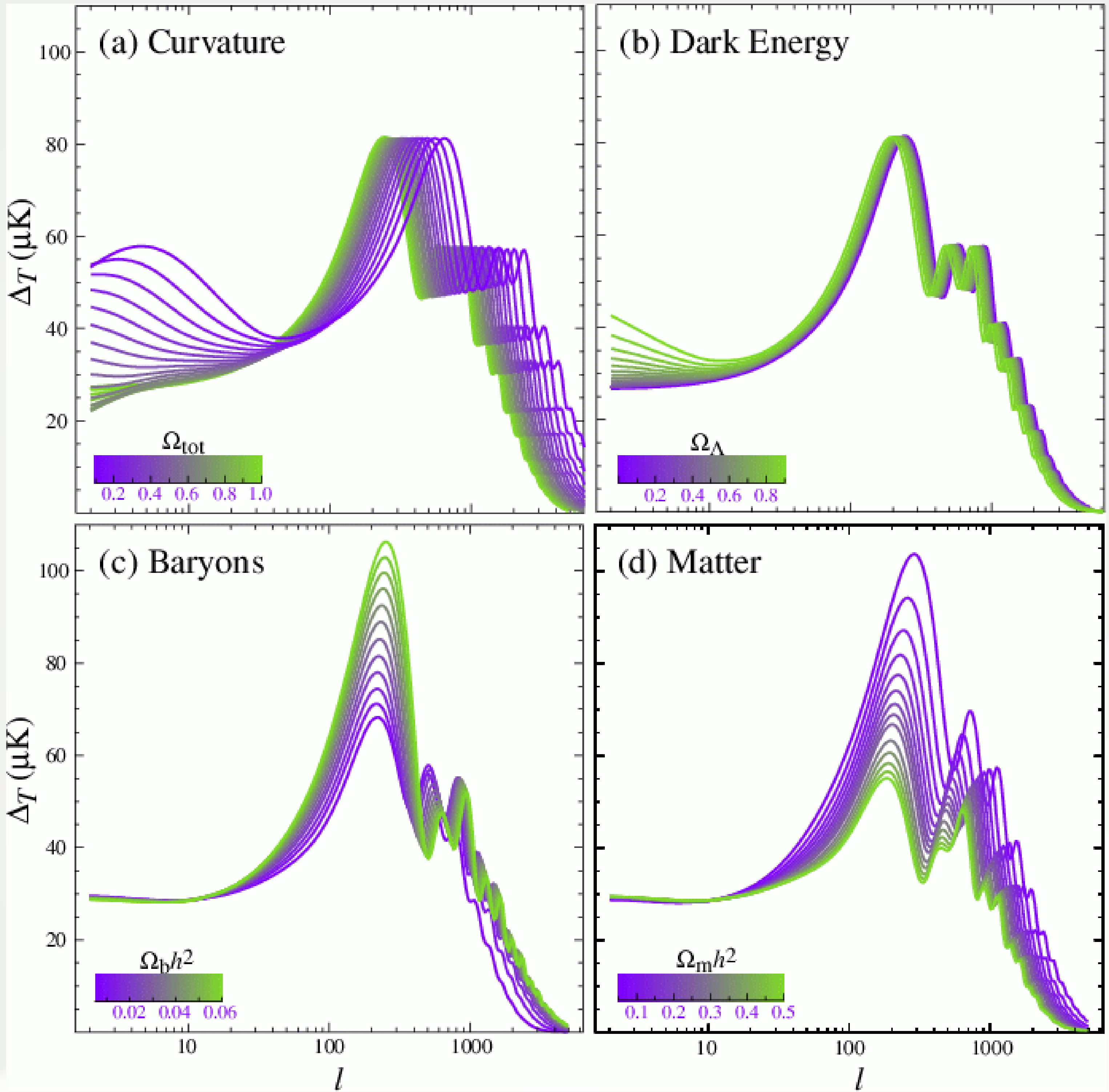
Anizotropije v prasevanju

- relativistični barionsko-fotonski plin

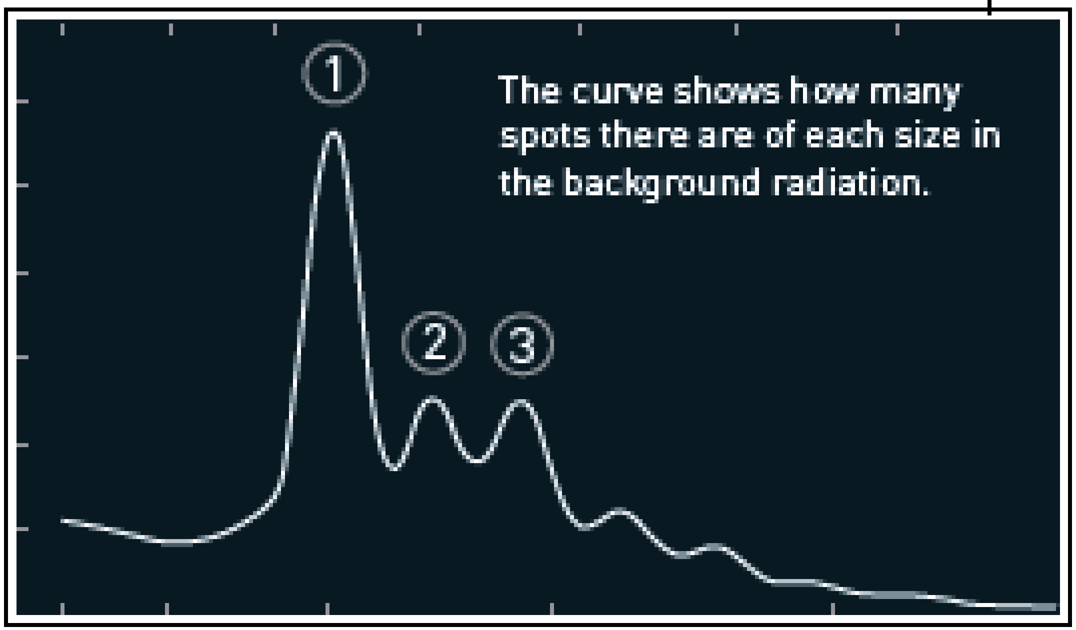
  tlak $P = \frac{\rho c^2}{3}$ hitrost zvoka $c_s = \sqrt{\frac{P}{\rho}} = \frac{c}{\sqrt{3}}$

  - λ zvočnih valov: $\lambda = c_s \tau$
  - ob času rekombinacije med območjema z večjo in manjšo gostoto: $\lambda = 2 c_s t_{rec} = \frac{2 c t_{rec}}{\sqrt{3}}$

The CMB sound spectrum
http://people.virginia.edu/~dmw8f/BBA_web/unit05/unit5.html



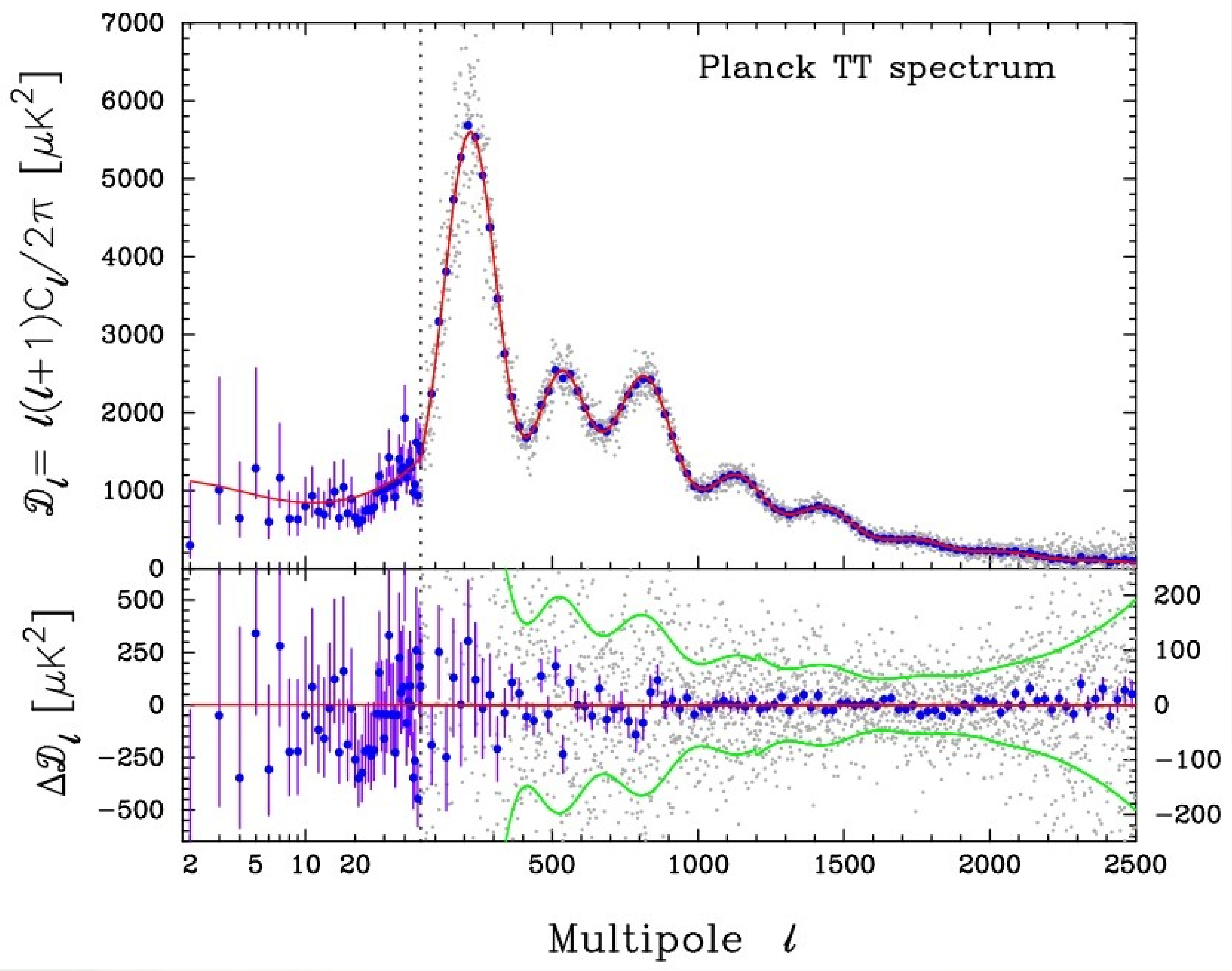
(a) Curvature
(b) Dark Energy
(c) Baryons
(d) Matter
Δ_T (μK)
l
Ω_{tot}
0.2 0.4 0.6 0.8 1.0
Ω_Λ
0.2 0.4 0.6 0.8
$\Omega_b h^2$
0.02 0.04 0.06
$\Omega_m h^2$
0.1 0.2 0.3 0.4 0.5
20 40 60 80 100
10 100 1000



1. The first peak shows that the universe is geometrically flat, i.e. two parallel lines will never meet.
2. The second peak shows that ordinary matter is just 5% of the matter and energy in the universe.
3. The third peak shows that 26% of the universe consists of dark matter.

From these three peaks, it is possible to conclude that if 31% (5%+26%) of the universe is composed of matter, then 69% must be dark energy in order to fulfil the requirement for a flat universe.

Anizotropije v prasevanju



Kozmologija

Odprta vprašanja

Viri: Jones, Lambourne (Chap. 8)

originalne prosojnice prof. Gomboc, dopolnitve in spremembe D. Fabjan

Narava temne snovi

- 15% snovi barionske (vidne in nevidne), večina snovi nebarionske
- kandidati za temno snov:
  - barionska: MACHO (MAssive Compact Halo Objects)
  - nebarionska (hladna):
    - WIMP (Weakly interactive massive particles)
    - nevtrini
    - supersimetrični delec
- Alternativna teorija: MOdified Newtonian Dynamics – MOND

Narava temne energije

- nasprotuje gravitaciji (deluje kot negativni tlak)

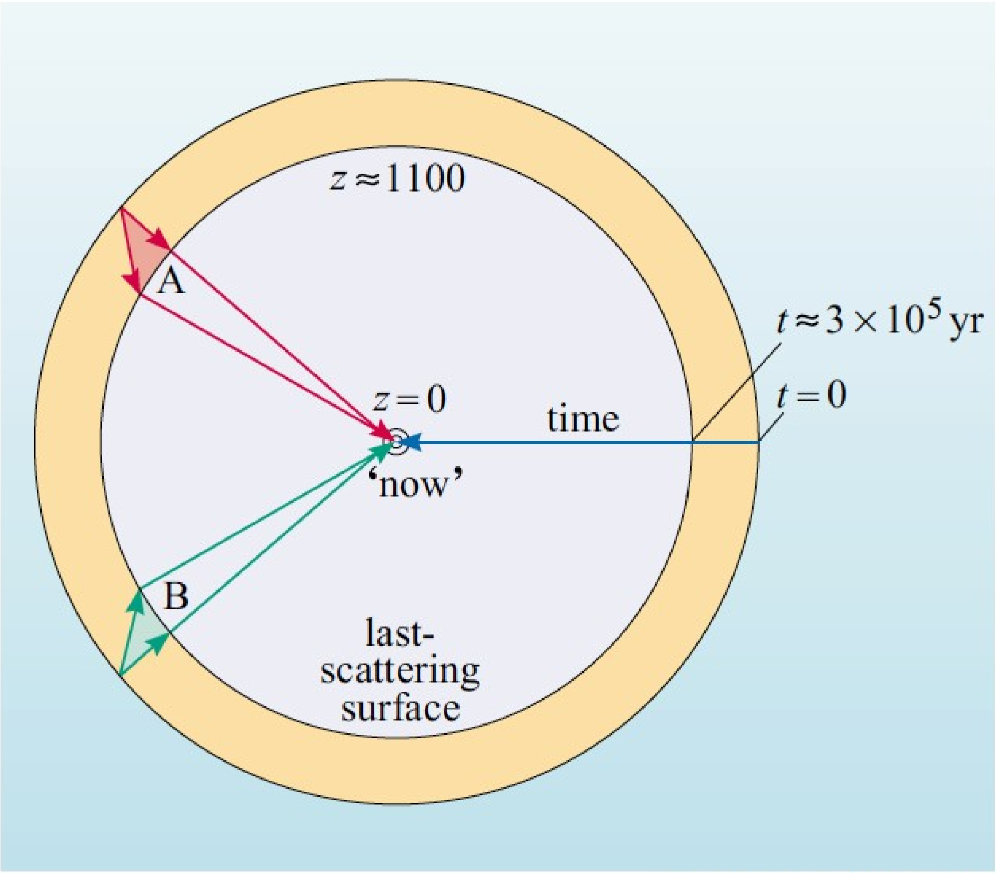
- kozmološka konstanta Λ
- energija vakuma (glej Casimirov efekt)
  - $m_{Pl} \sim 3x10^{19}$ GeV oz. 10^{97} kg m^{-3} vendar $\rho_{\Lambda} \sim 6x10^{-27}$ kg m^{-3} --> **faktor 10^{120} razlike**
- kvintesenca
  - gostota energije se spreminja s časom in lego

Problem horizonta in ravnosti

- teorija velikega poka ne pričakuje enakomernosti prasevanja na skalah >2°
- območji A in B nista bili v "kavzalnem" stiku

>> zakaj imata enako T?

- fizični kontakt območij, ki so bila v termičnem ravnovesju na začetku vesolja
- fizično oddaljevanje območij zaradi širjenja vesolja in ne zaradi potovanja fizičnega signala



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INFLACIJA

Problem horizonta in ravnosti

- če je danes $\Omega_0 = 1$ je moralo biti ravno tudi na začetku vesolja

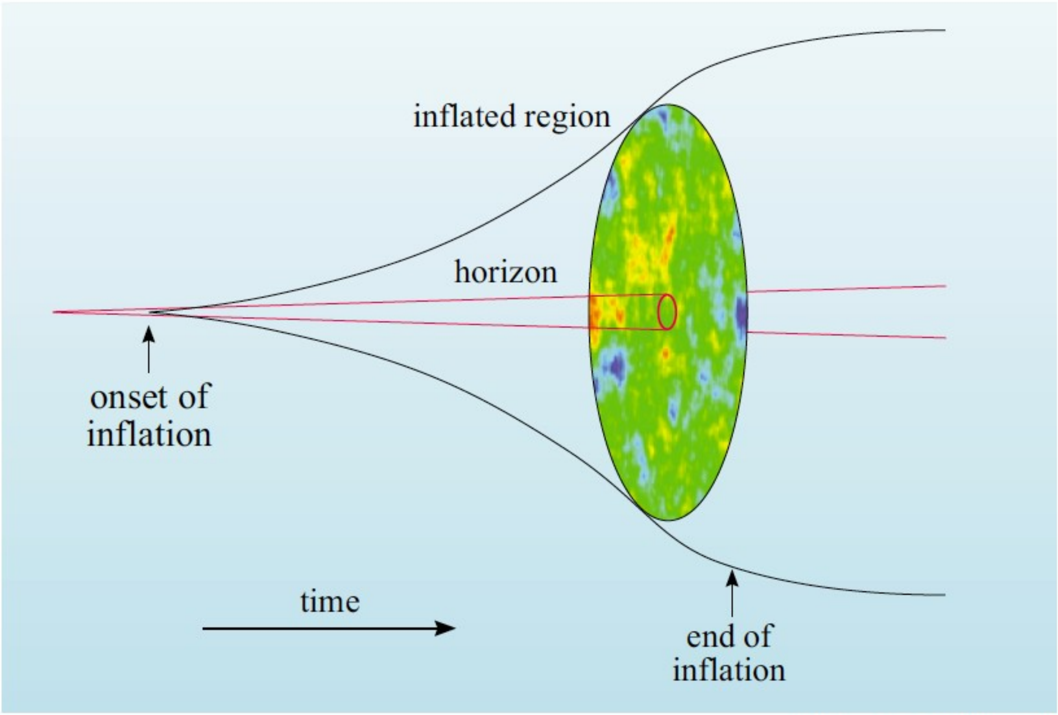
INFLACIJA

$$\left(1-\frac{1}{\Omega}\right)=(1+z)^{-1}\left(1-\frac{1}{\Omega_0}\right)$$

za katerokoli vrednost gostotnega parametra danes
bo za dovolj visoke z gostotni parameter --> 1

Nastanek struktur

- Zakaj vesolje ni popolnoma uniformno? Kako so nastale prvinske fluktuacije?
- Kvantne fluktuacije med inflacijo povzročijo makroskopske razlike v gostoti



Materija in antimaterija

- Zakaj vsebuje vesolje več materije kot antimaterije?

Antropično vesolje

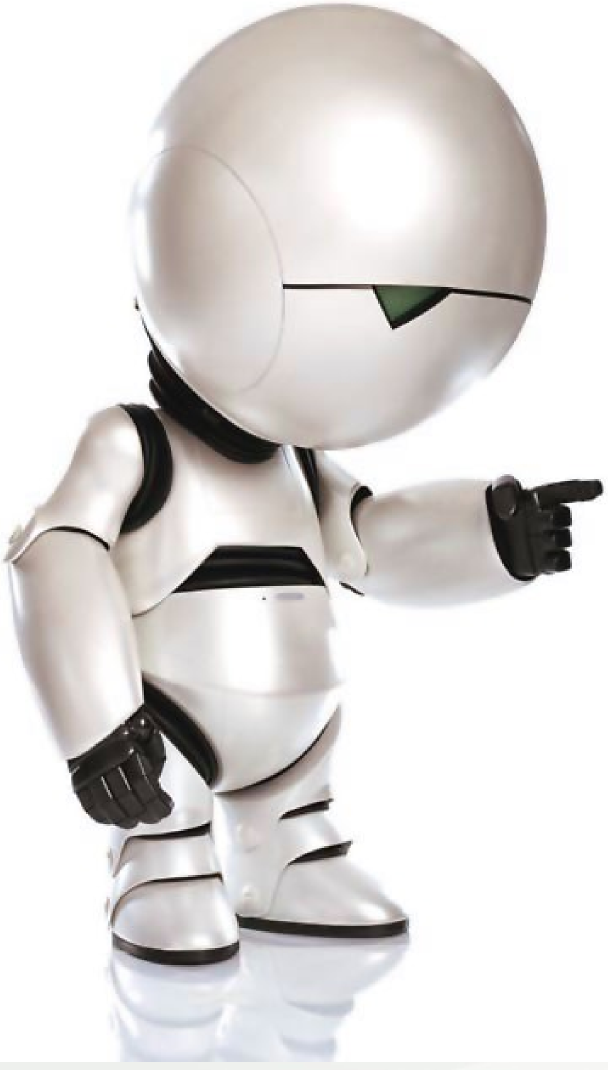
- Zakaj je vesolje tako kot je?

Ker smo tu, da se lahko o tem sprašujemo!

- šibko antropično načelo
- močno antropično načelo

Imagine a puddle waking up one morning and thinking, 'This is an interesting world I find myself in — an interesting hole I find myself in — fits me rather neatly, doesn't it? In fact it fits me staggeringly well, must have been made to have me in it!' This is such a powerful idea that as the sun rises in the sky and the air heats up and as, gradually, the puddle gets smaller and smaller, it's still frantically hanging on to the notion that everything's going to be alright, because this world was meant to have him in it, was built to have him in it; so the moment he disappears catches him rather by surprise.

Douglas Adams on the Anthropic Principle
Cited in A Devil's Chaplain by Richard Dawkins (Houghton Mifflin Harcourt: 2004), p.169.



DON'T PANIC