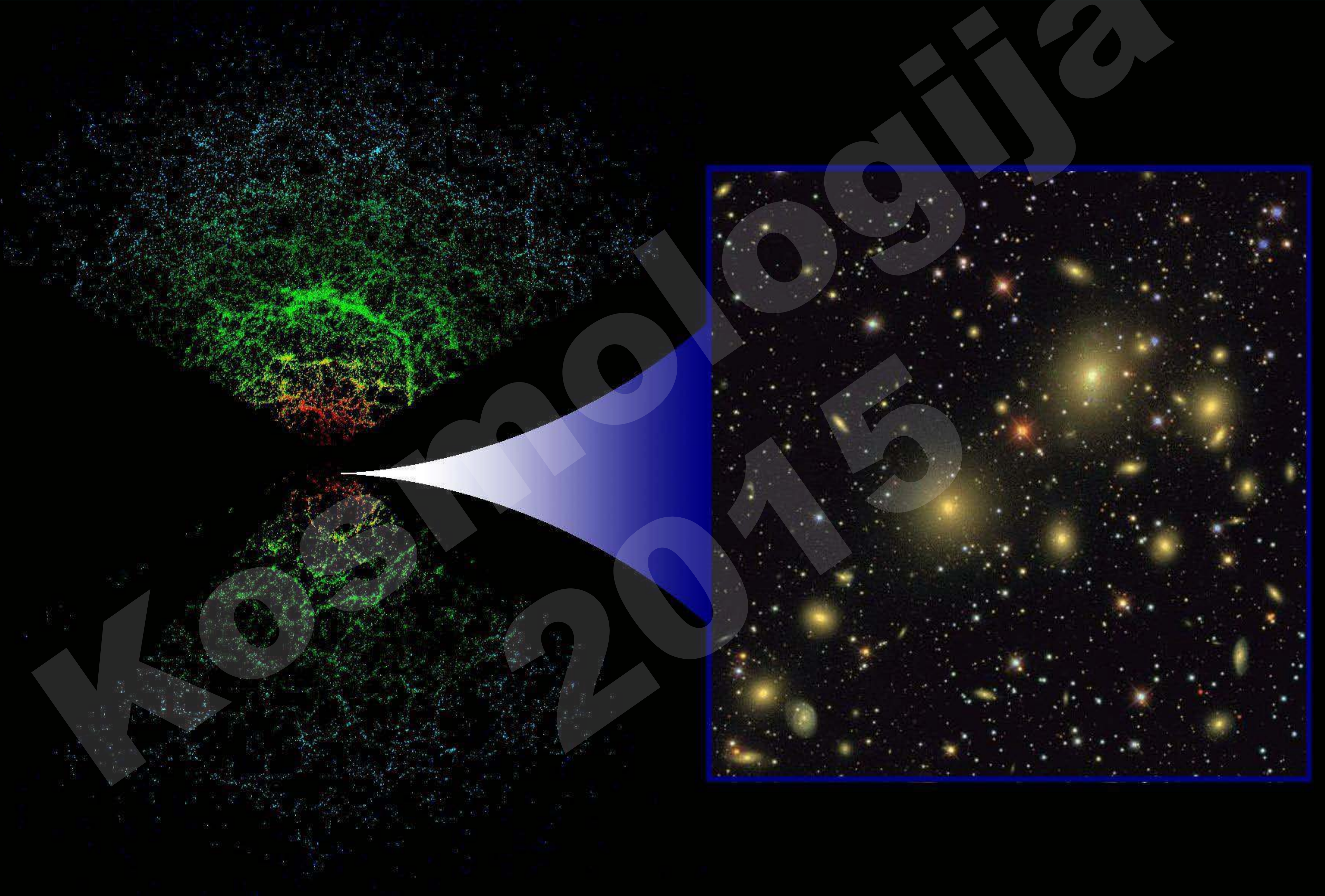
Tamna energija i multiverzum

17. 07. 2015.



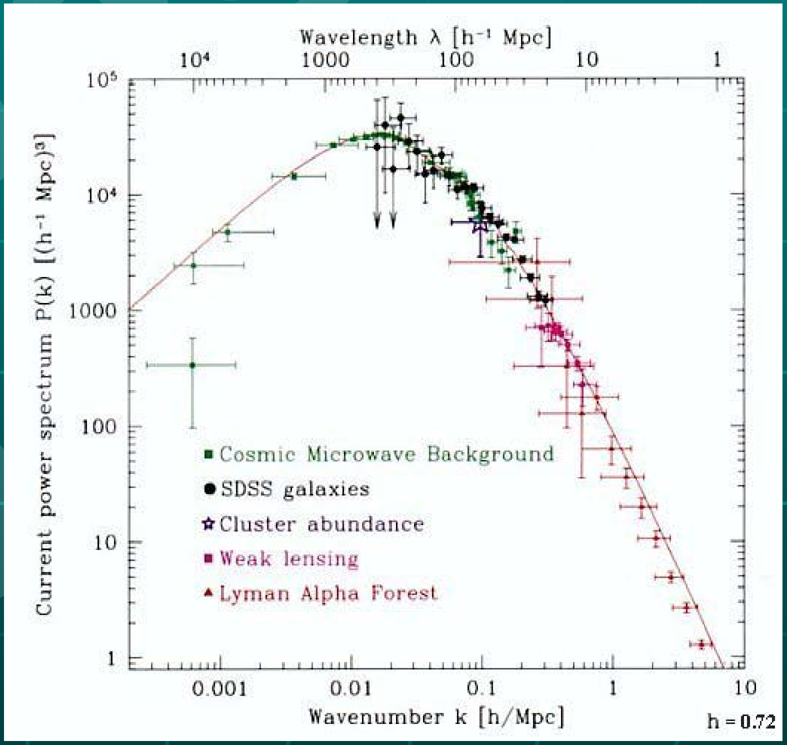
Šta pokušavamo da objasnimo u kosmologiji?

- Formiranje strukture opisane **spektrom primordijalnih fluktuacija** *P(k)*

$$\xi(r) = \frac{1}{2\pi^2} \int k^2 P(k) \frac{\sin(kr)}{kr} dk$$

gde je

$$dP = \left[1 + \xi(\vec{r}, t)\right] \rho \, dV$$

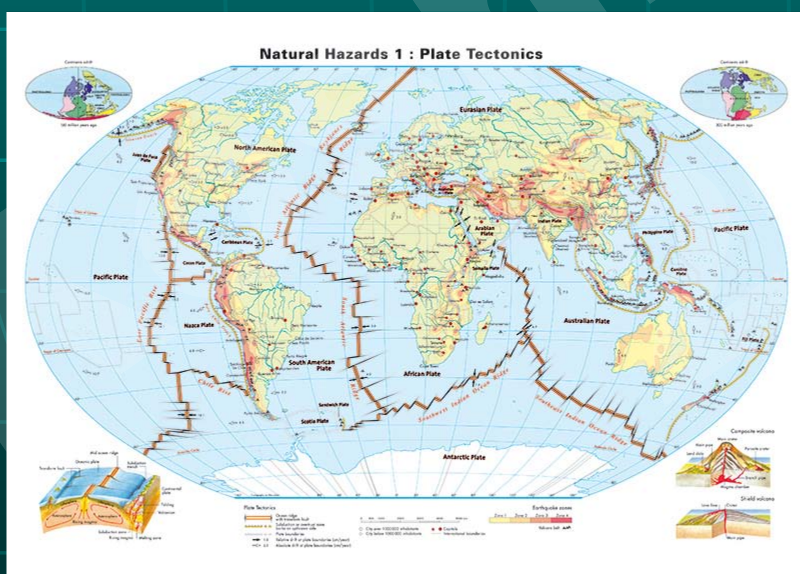


$$P(k) \propto k^n$$

- Dva **različita** pitanja:
  - Iz kojih dinamičkih zakona proističe posmatrani PS?
  - Zašto PS izgleda baš tako?

Delikatnost “zašto” pitanja...

1. Zašto je Zemlja okrugla?
2. Zašto Zemlja ima 7 kontinenata?

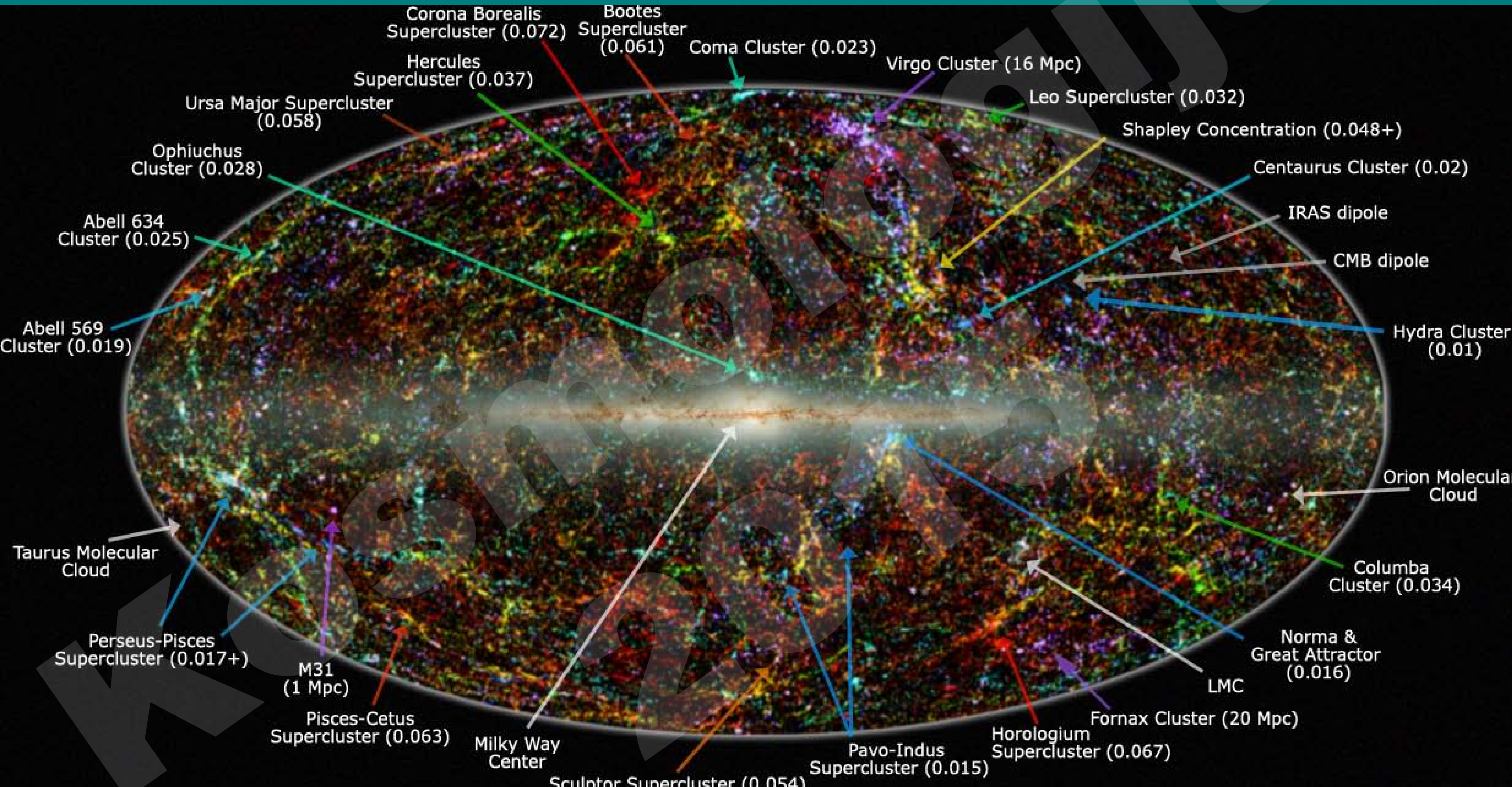


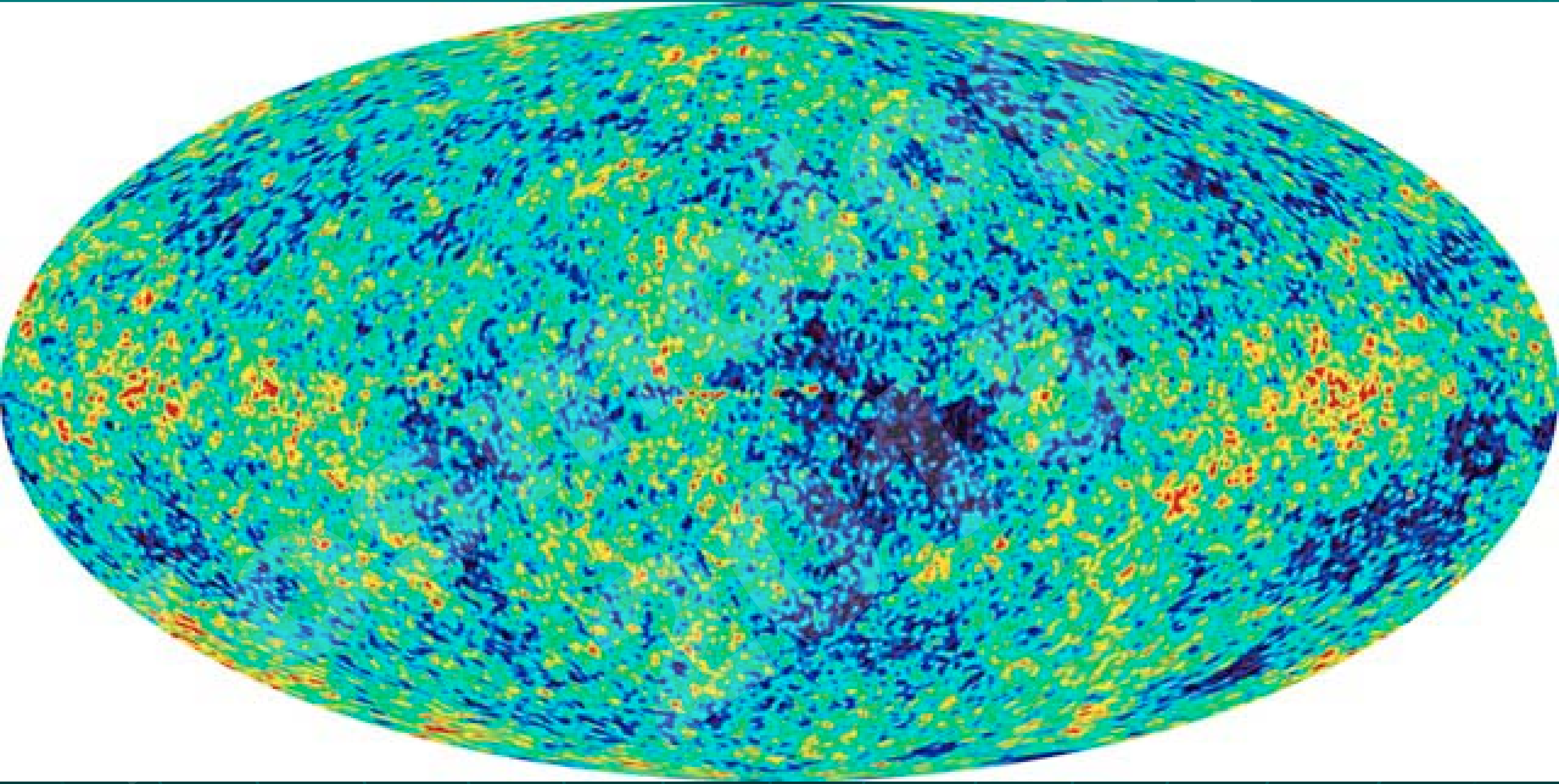
“Klasični” argumenti iz finog podešavanja

- Hoyle (oko 1953): 3α reakcija
- Dicke (1961): posmatračka selekcija
- Carter (1974): antropički principi
- Weinberg (1987): fino podešavanje Λ
- Leslie, Bostrom, Hogan (cca. 2000): antropički principi su **posmatrački selekcioni efekti**

Antropički princip(i)

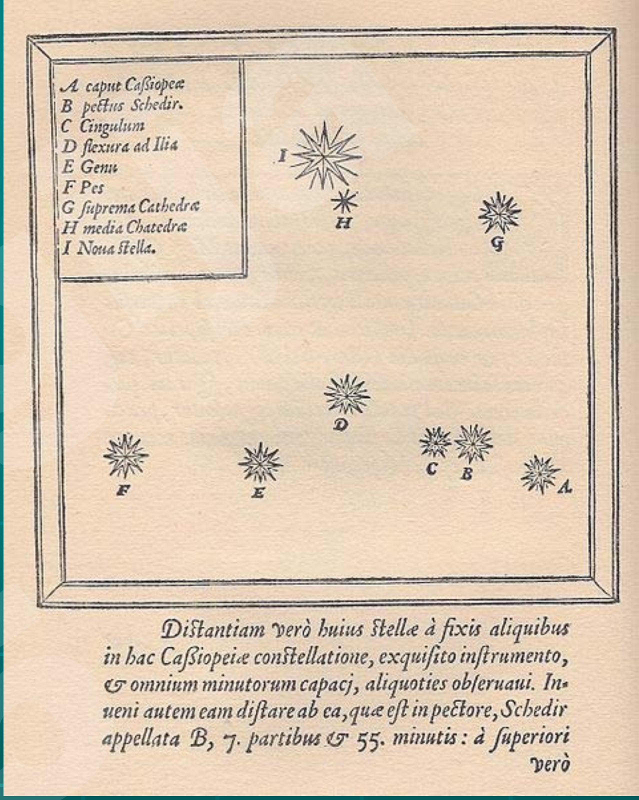
- **Slabi antropički princip (WAP; Karter 1974):** izmerene vrednosti fizičkih i kosmoloških veličina **nisu podjednako verovatne**, već su ograničene zahtevom da postoje mesta gde život baziran na ugljeniku može evoluirati, i zahtevom da univerzum bude dovoljne starosti da se to **već dogodilo**.
- Fizičke, hemijske, geološke, itd. preduslove za nastanak života i inteligencije nam daje astrobiologija.
- WAP je **informativna** tautologija!
- Veoma brojna “fina podešavanja” su empirijske činjenice
- Interpretaciju daje **bajesovski pristup verovatnoći**


Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Orion Molecula Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
M31 (1 Mpc)
Norma & Great Attractor (0.016)
LMC
Pisces-Cetus Supercluster (0.063)
Fornax Cluster (20 Mpc)
Milky Way Center
Horologium Supercluster (0.067)
Pavo-Indus Supercluster (0.015)
Sculptor Supercluster (0.054)

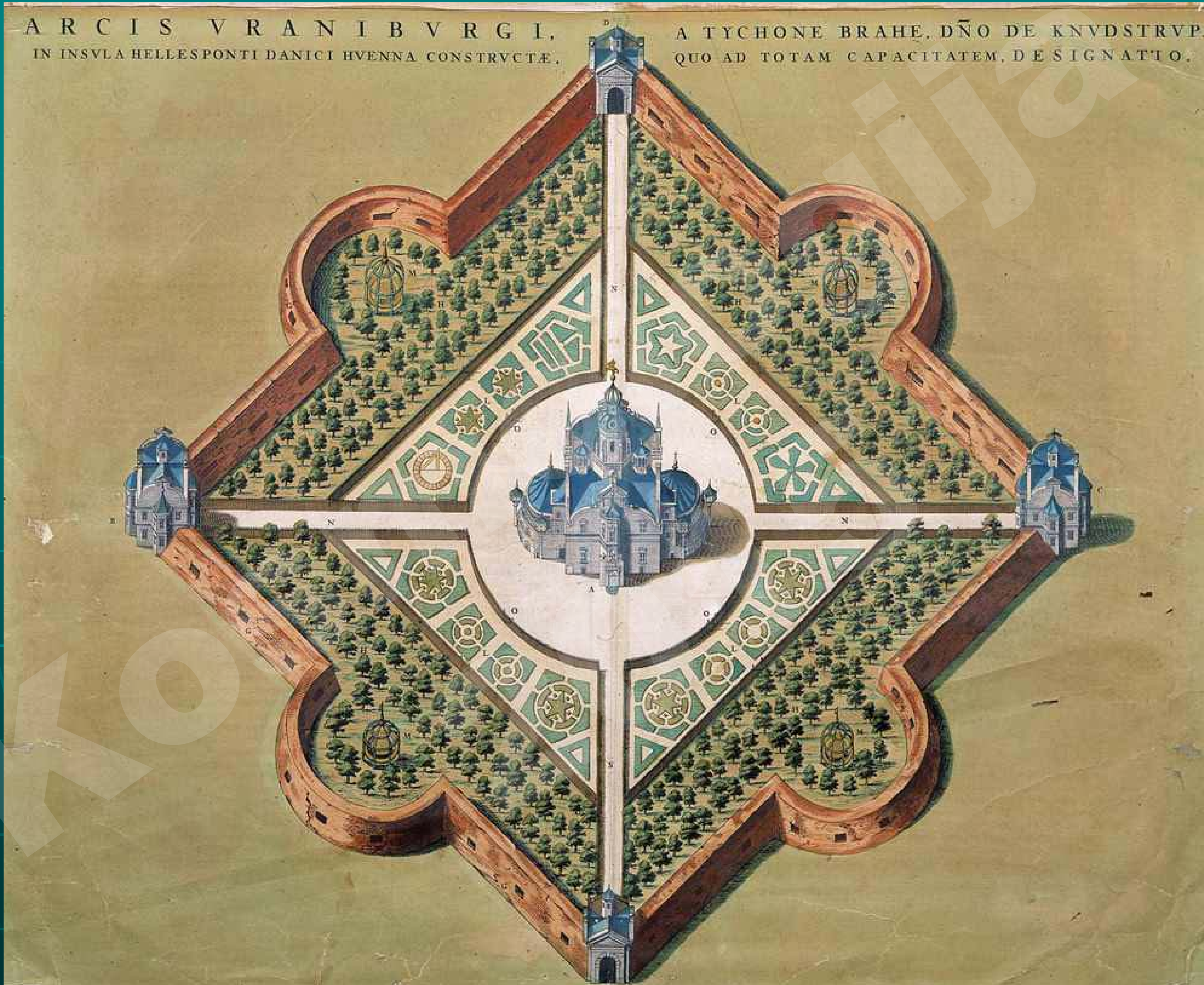


SN Ia kao početak moderne astronomije

- 6. 11. 1572. – nova zvezda!
- Tiho de Brahe: *De nova et nullius aevi memoria prius visa stella* (1573)
- Bade i Cviki (1934): *On super-novae*
- **Sjajan** primer istorijske kontingencije...

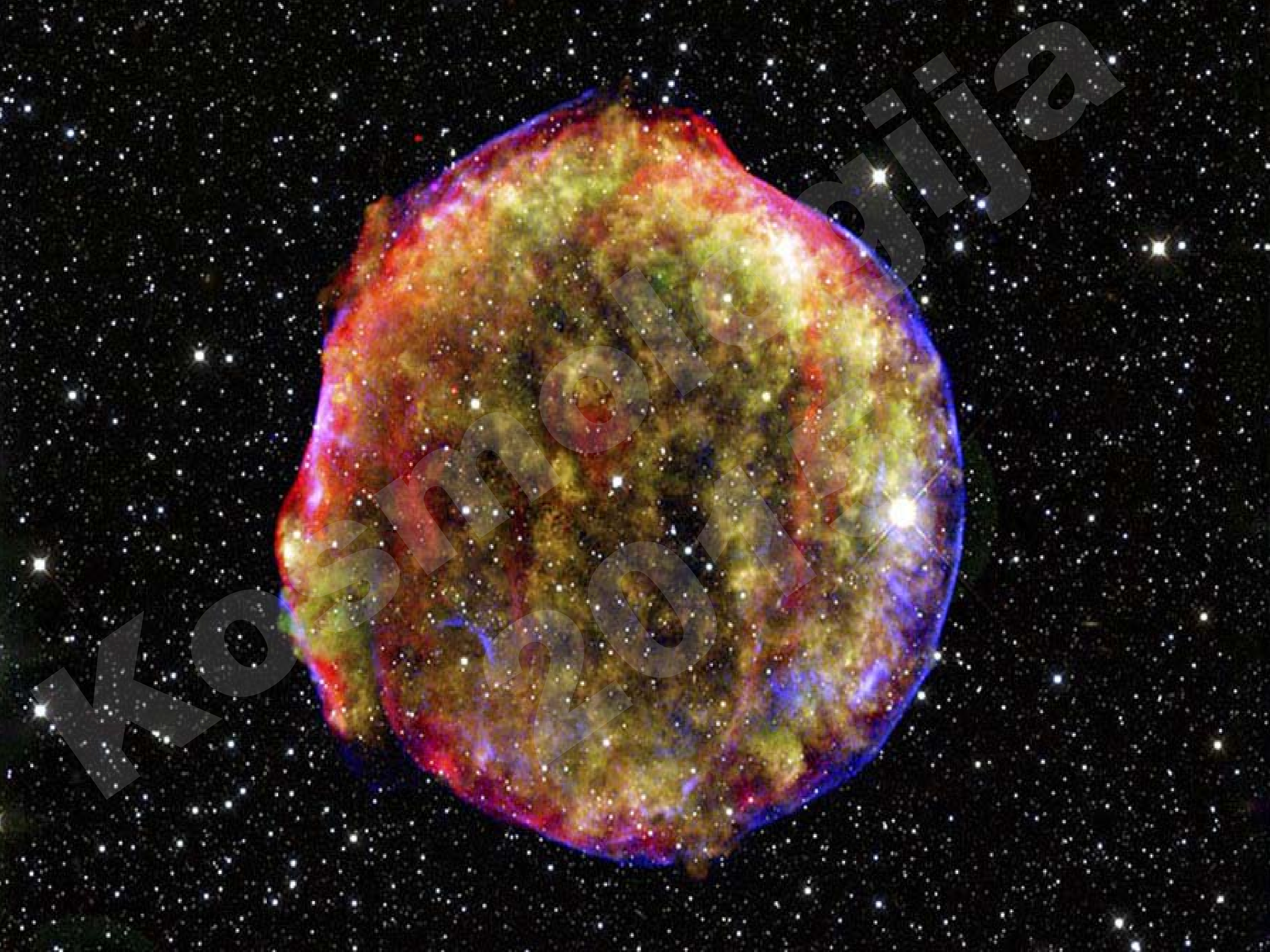


Diſtantiam verò huius ſtellæ à fixis aliquibus in hac Caßiopeiæ conſtellatione, exquiſito inſtrumento, & omnium minutorum capacj, aliquoties obſeruaui. Inueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir appellata B, 7. partibus & 55. minutis: à ſuperiori verò


ARCIS VRANIBVRGI,
IN INSVLA HELLESPONTI DANICI HVENNA CONSTRVCTÆ,
A TYCHONE BRAHE, DÑO DE KNVDSTRVP,
QUO AD TOTAM CAPACITATEM, DESIGNATIO.

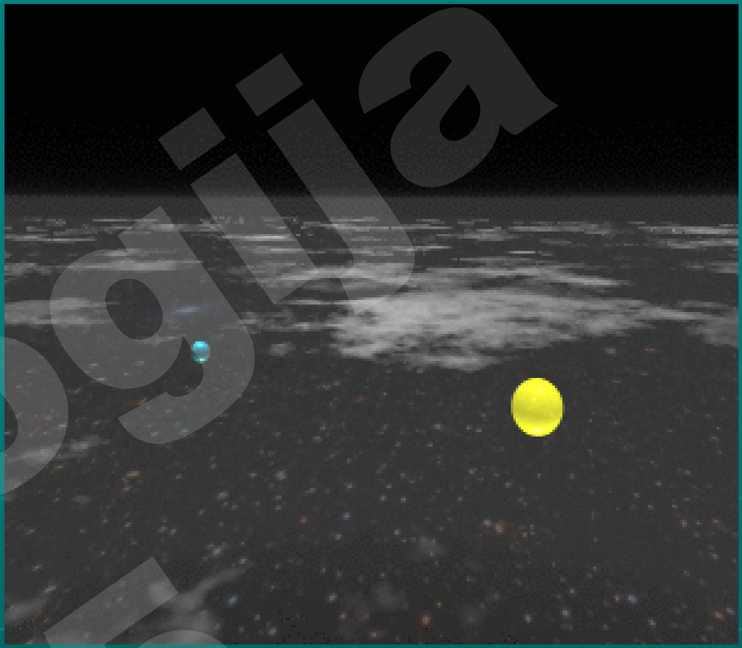
Otac posmatračke astronomije

- 1573-1597: opservatorija na Hvenu
- 1577: “Translunarna” kometa
- 1587: Tihonički sistem sveta
- Ključna posmatranja Marsa…



Svetlosni eho

- 1936: prvo posmatranje
- 2002: V838 Monoceros
- Potrebne refleksione magline
- 2008: Tihova zvezda!



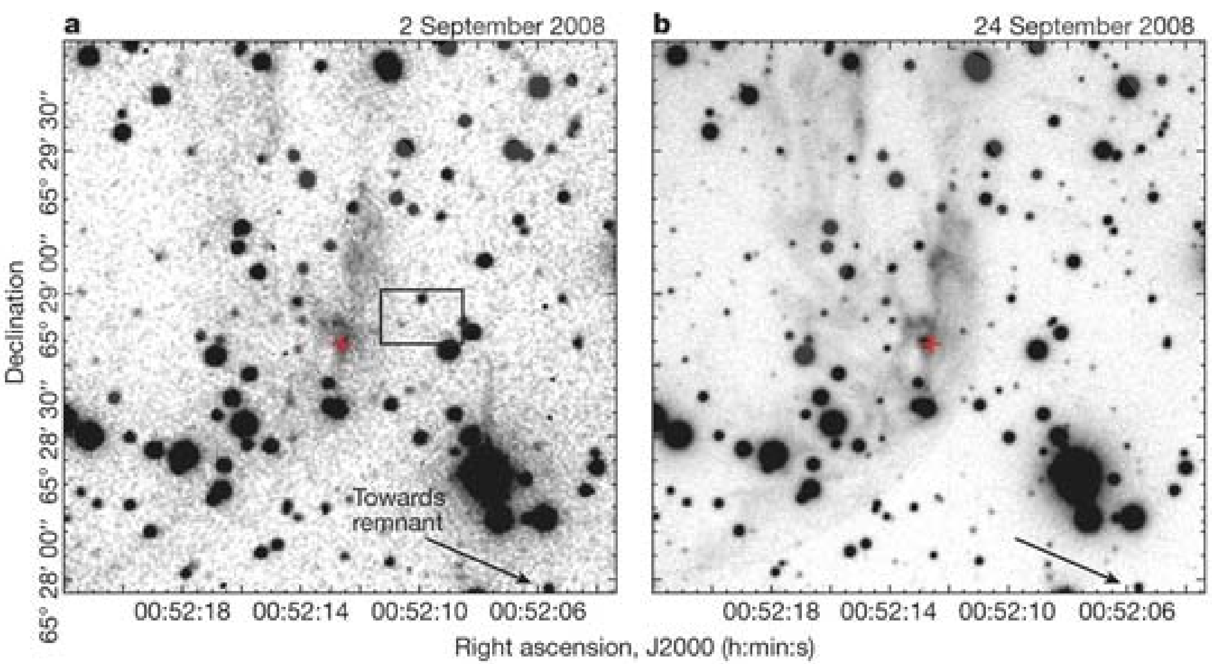


Figure 1 | Optical images of the SN 1572 light echo. **a**, **b**, R-band images of the same 120 × 120-arcsec^2 area. The corresponding observing epochs are labelled. The position of the brightness peak in the first epoch is marked for reference (red cross). The rectangle shown in **a** indicates the location of a previous light-echo detection[15]. The vector towards the remnant of SN 1572 is indicated (arrow). The respective seeings for **a** and **b** were 1.5 and 0.9 arcsec, full-width at half-maximum. The integration times of the two images were 20 and 12 min, respectively. Image reduction was performed using standard methods with the Image Reduction and Analysis Facility software.

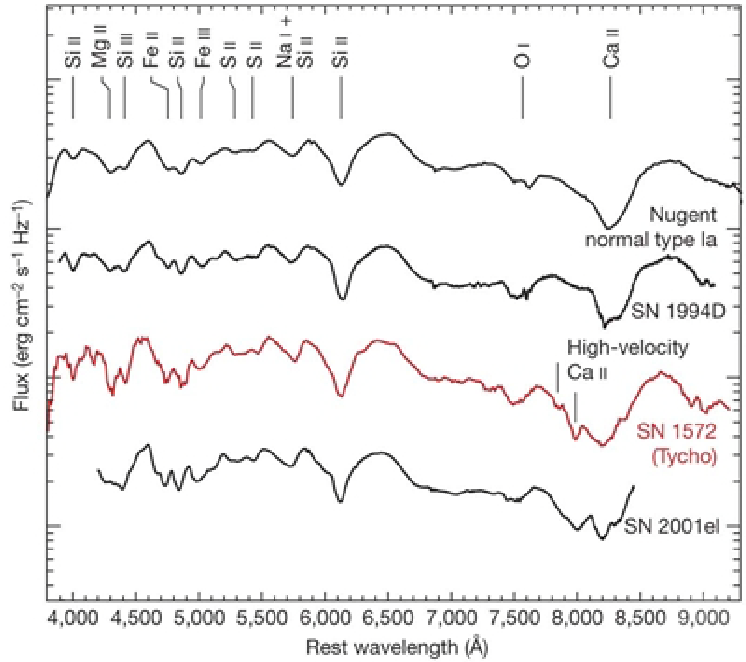


Figure 2 | Spectrum of SN 1572 and comparison spectra of normal type Ia supernovae. Important spectral features are marked. The spectra are plotted logarithmically in flux units and shifted for clarity. The spectrum was obtained with two grisms in the blue ($\lambda < 5000$ Å) and red ($\lambda > 5000$ Å). Total integration time was 4 h: 2.5 h for the red channel and 1.5 h for the blue channel. The spectrum was extracted from a 2.8×2.0-arcsec^2 aperture (position angle 81°) positioned at the echo brightness peak and then binned to a resolution of 11.2 Å per pixel and smoothed by taking a moving average over five pixels. Flux calibration was performed against the standard star G191B2B, which was observed at comparable airmass. The uncertainty in the flux calibration is 15%. Atmospheric A-band and B-band absorptions were removed using the stellar spectrum of a K star observed in the same slit as the echo. The spectrum was then corrected for the colour dependence of the scattering process for a scattering angle of $\theta = 84°$ and de-reddened for a foreground extinction of $A_V = 4.2$ mag. The scattering angle of $\theta = 84°$ results from the light-echo geometry: because all echo emission at a given epoch is located on an ellipsoidal sphere with the Earth and SN 1572 at its foci, the echo geometry can be accurately determined. For a distance range to the Tycho remnant of 2.3–2.8 kpc, the distance and scattering angle of the echo knot are $d = 460 \pm 45$ light yr and $\theta = 90° \pm 5°$, respectively. For a larger distance of 3.8 kpc, the scattering angle is smaller, $\theta = 67°$, leading to a slightly redder corrected spectrum. However, a slight increase of the adopted foreground extinction by $\Delta A_V = 0.08$ mag compensates for this effect. The comparison spectra have been obtained from the time average of light-curve-weighted spectra at days −5, −4, −2, +2, +4, +10, +11, +24, +50, +76 for SN 1994D and days −9, −4, +1, +9, +18, +40 for SN 2001el (refs 26, 27).

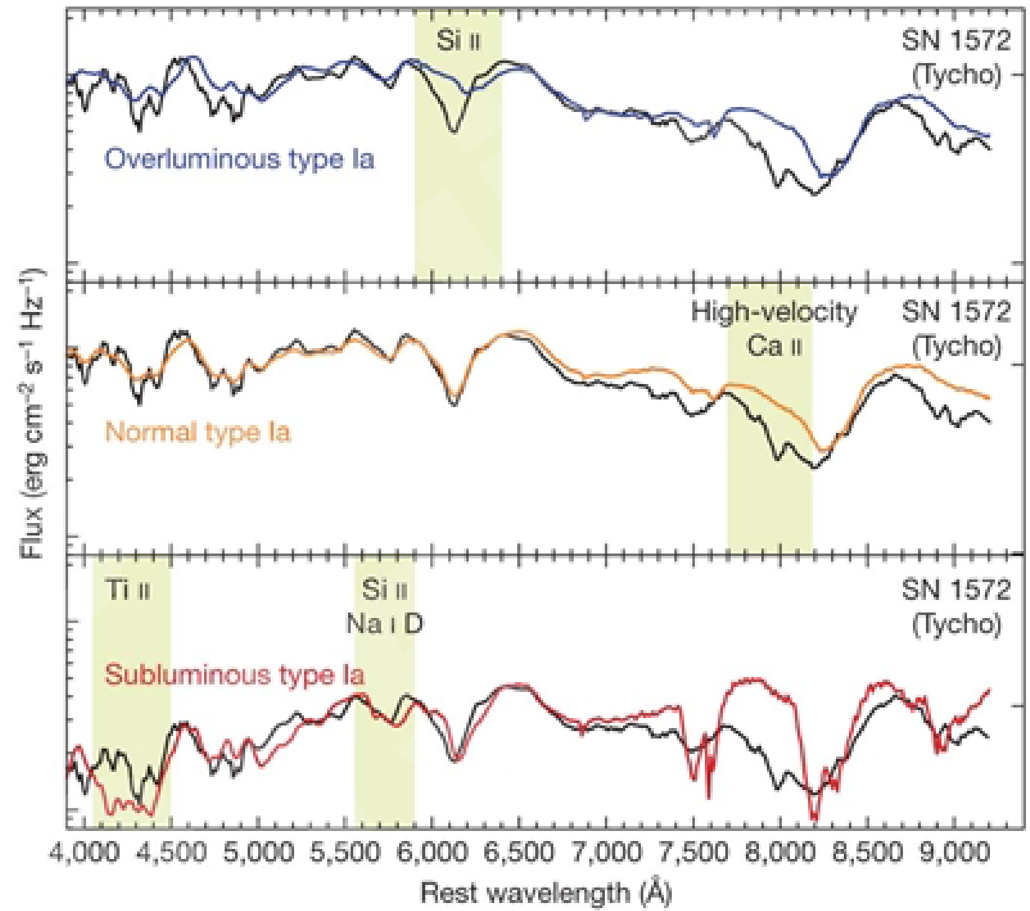
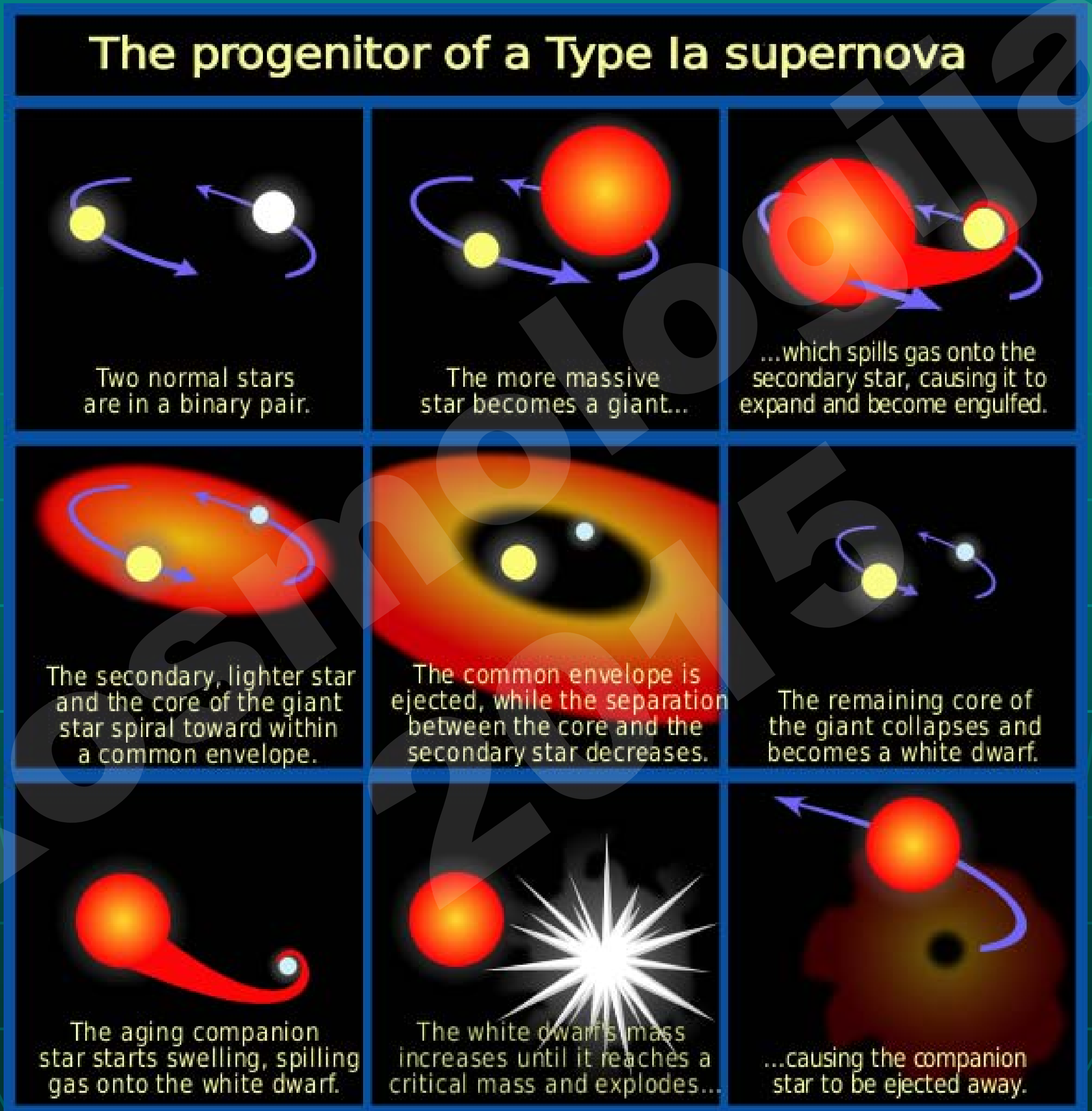
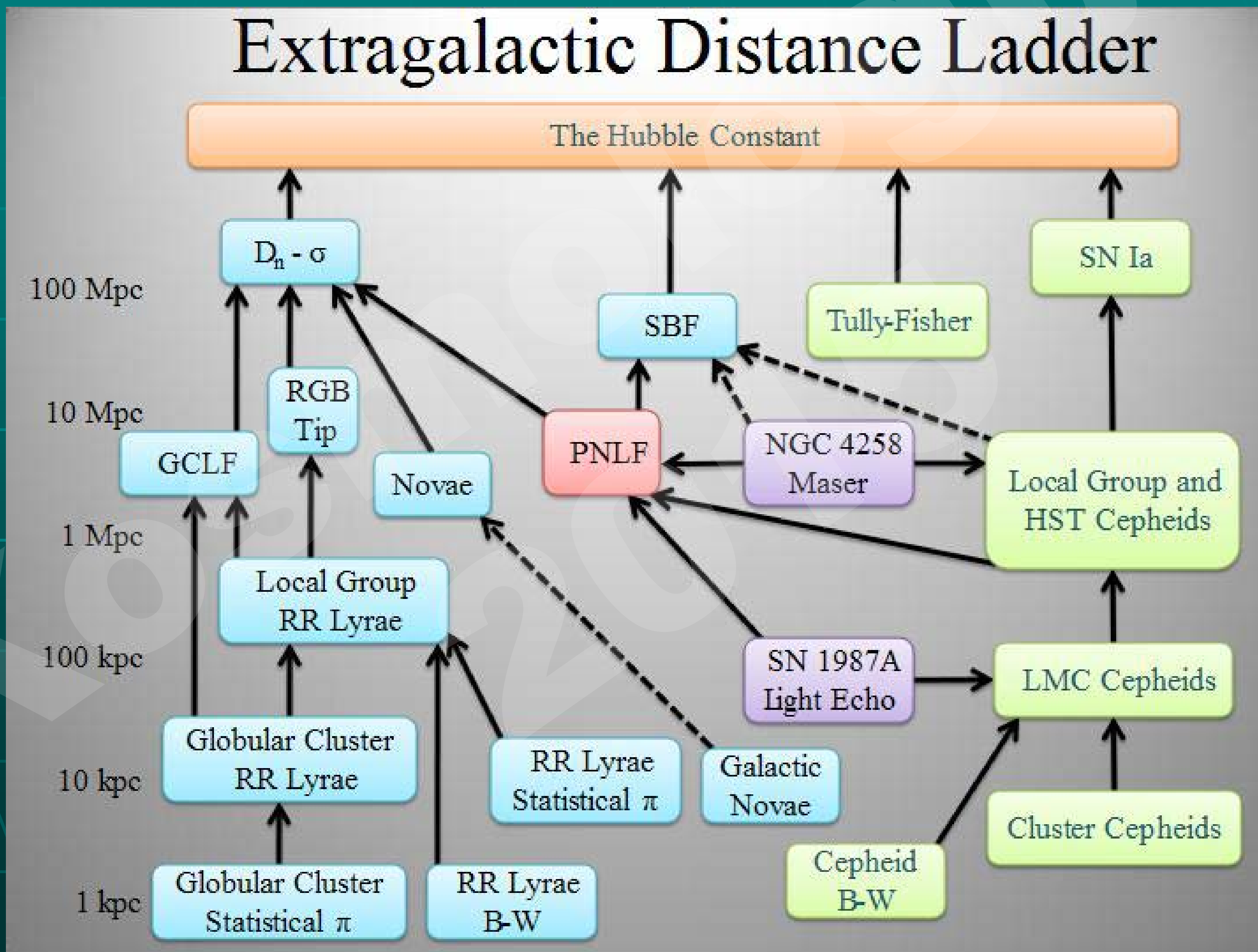


Figure 3 | Comparison of SN 1572 with type Ia supernovae of different luminosities. Spectral templates of subluminous, normal and overluminous type Ia supernovae are shown in comparison with the spectrum of SN 1572. The spectrum of SN 1572 has been corrected for a scattering angle of $\theta = 84°$ and a foreground extinction of $A_V = 4.2$ mag as described for Fig. 2. The comparison spectra have been derived as the time averages of spectral series[19] over days 0–90 after explosion and scaled to the spectrum of SN 1572. Specific features typical of the three subtypes are indicated. For the comparison with the intrinsically redder subluminous template, the spectrum of SN 1572 was de-reddened for a foreground extinction of $A_V = 3.9$ mag.


The progenitor of a Type Ia supernova
Two normal stars are in a binary pair.
The more massive star becomes a giant...
...which spills gas onto the secondary star, causing it to expand and become engulfed.
The secondary, lighter star and the core of the giant star spiral toward within a common envelope.
The common envelope is ejected, while the separation between the core and the secondary star decreases.
The remaining core of the giant collapses and becomes a white dwarf.
The aging companion star starts swelling, spilling gas onto the white dwarf.
The white dwarf's mass increases until it reaches a critical mass and explodes...
...causing the companion star to be ejected away.

Merenje udaljenosti...



Nobelova nagrada za fiziku 2011.

- Za “**otkriće ubrzanog širenja svemira kroz posmatranja udaljenih supernovih**” (Švedska kraljevska akademija)

Laureati

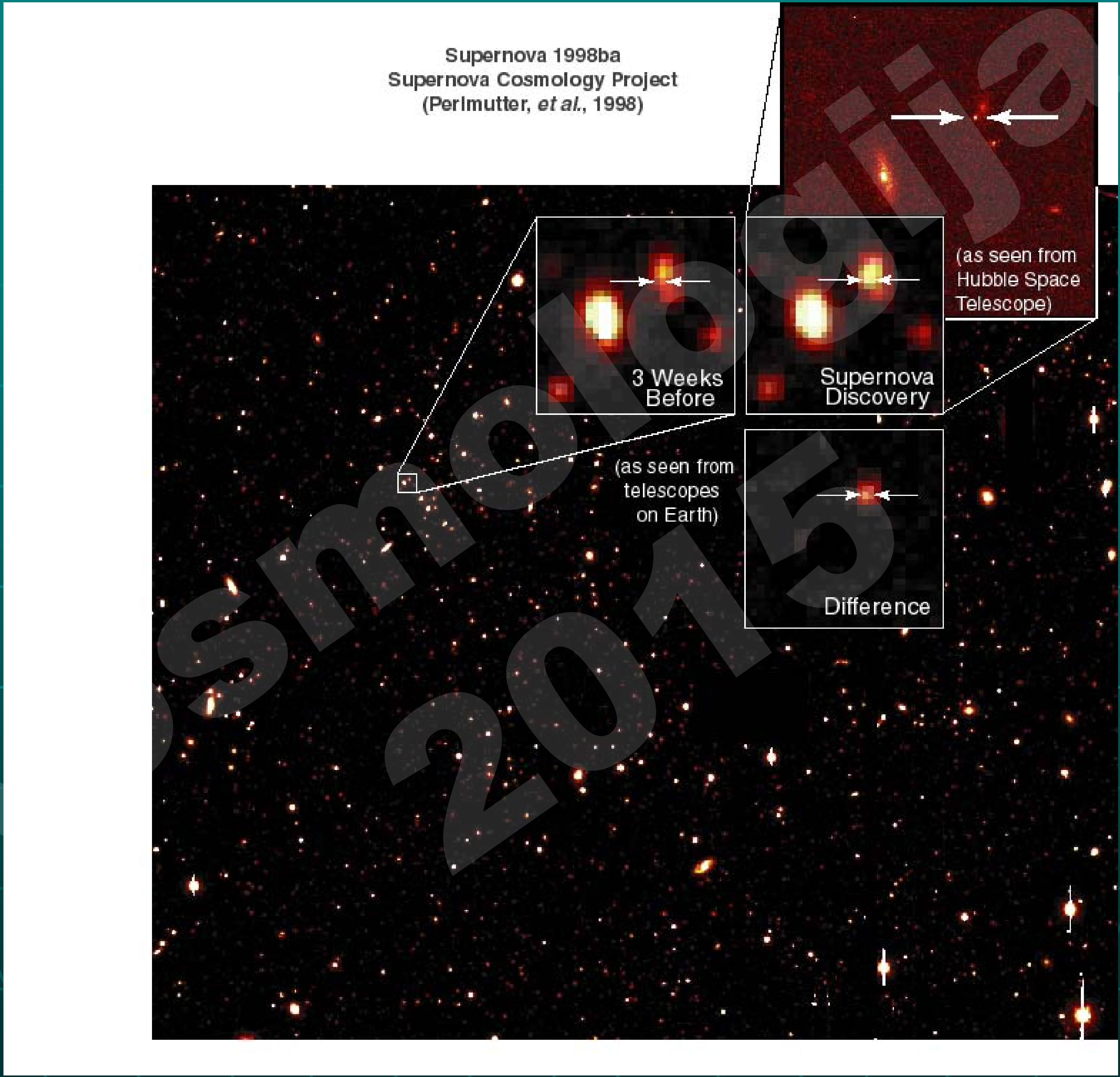
Sol Perlmuter
(1959)

Adam Ries
(1969)

Brajan Šmit
(1967)

Dva velika projekta

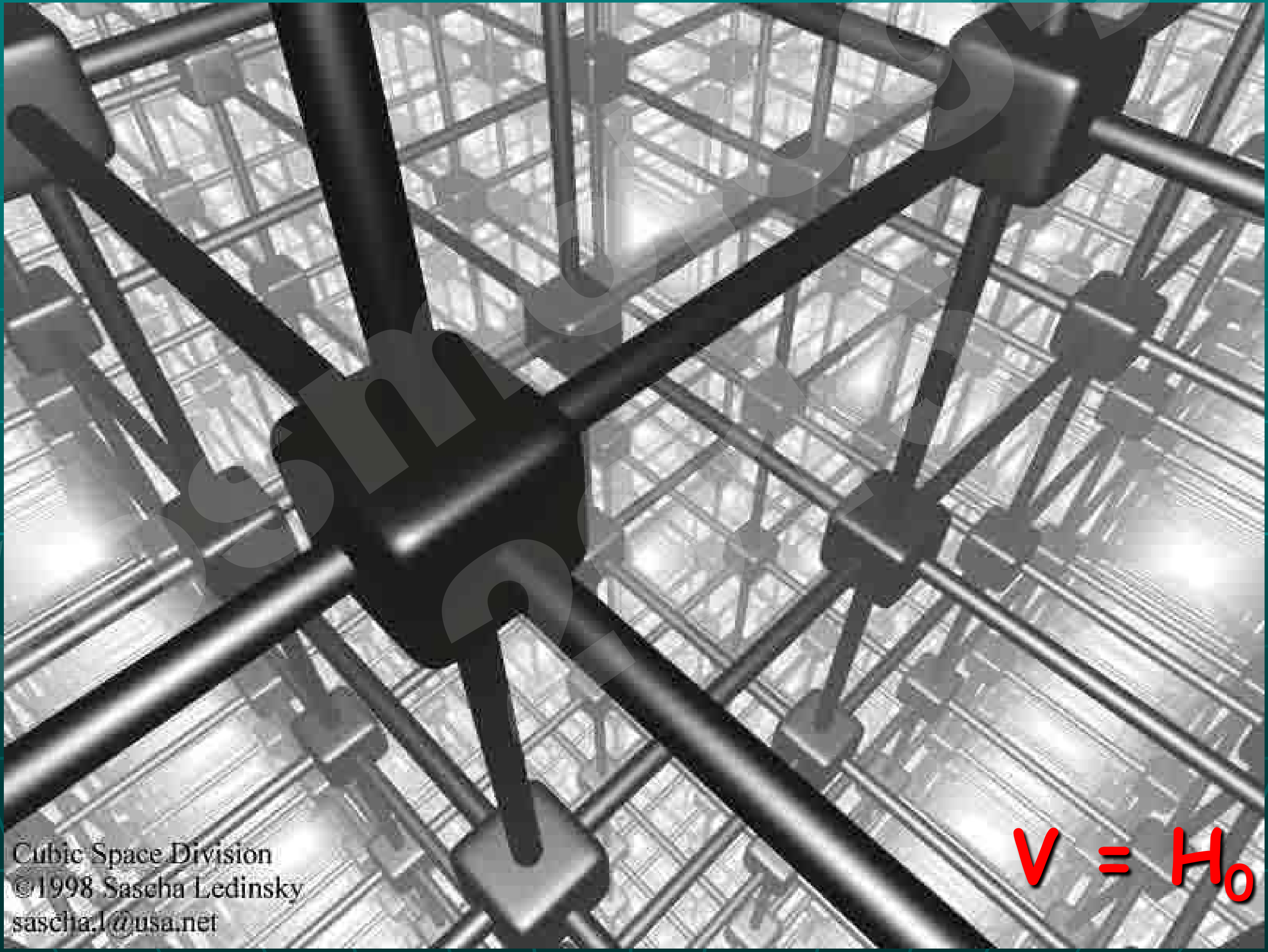
- **Supernova Cosmology Project** 1988-1998: 31 istraživač (USA, UK, Australija, Čile, Francuska, Španija, Švedska); lider: Sol Perlmuter (LBNL)
- **High-z Supernova Search Team** 1994-1998: 20 istraživača (USA, Australija, Čile); lider: Brajan Šmit (Harvard → Mt. Stromlo)


Supernova 1998ba
Supernova Cosmology Project
(Perlmutter, *et al.*, 1998)
3 Weeks Before
Supernova Discovery
(as seen from Hubble Space Telescope)
(as seen from telescopes on Earth)
Difference

Ključne publikacije

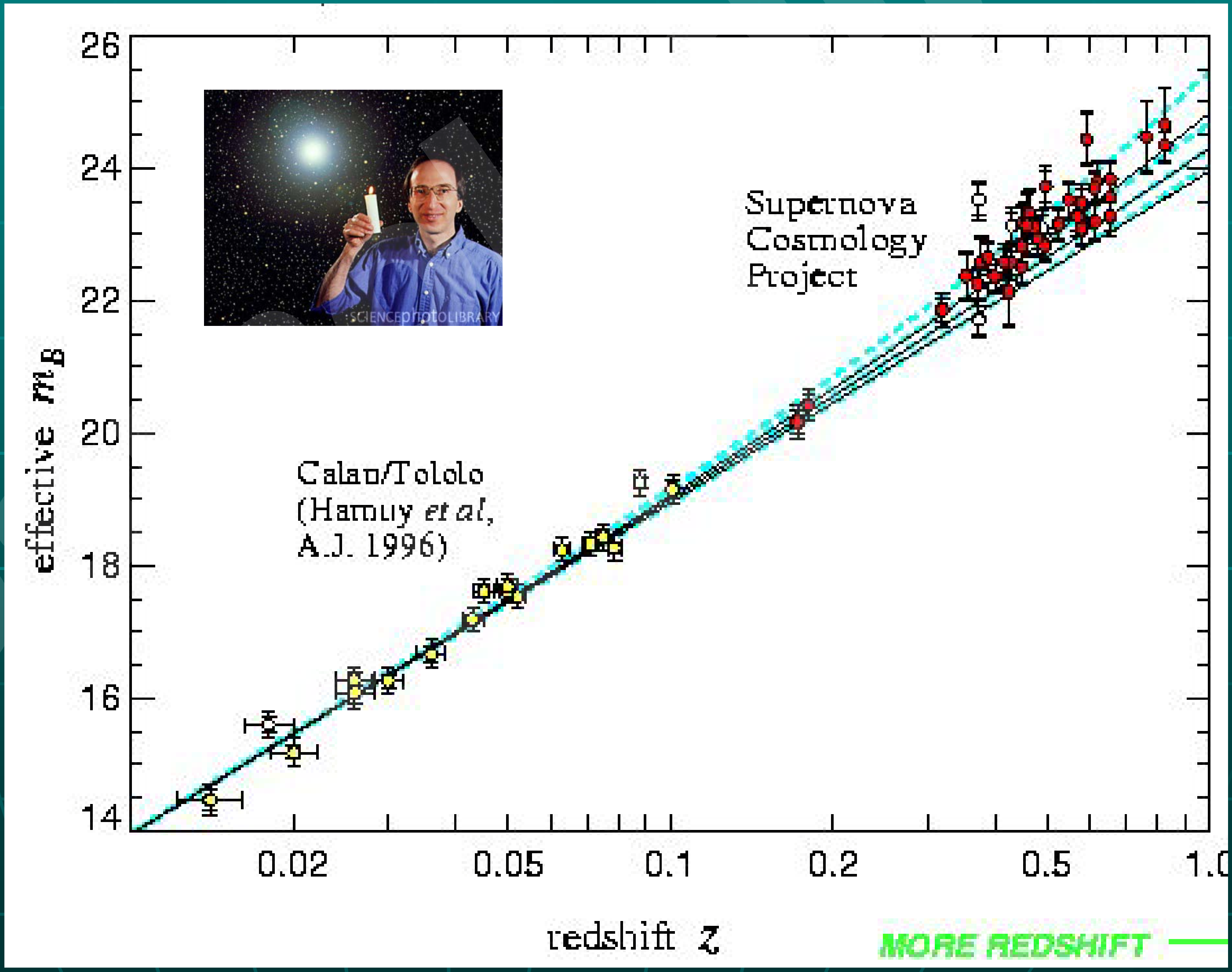
- S. Perlmutter et al. 1998, "Discovery of a supernova explosion at half the age of the Universe," *Nature* **391**, 51-54.
- A.G. Riess et al. 1998, "Observational evidence from supernovae for an accelerating universe and a cosmological constant," *Astronomical Journal* **116**, 1009-1038.
- S. Perlmutter et al. 1999, "Measurement of Ω and Λ from 42 high-redshift supernovae" *Astrophysical Journal*, **517**, 565-586.

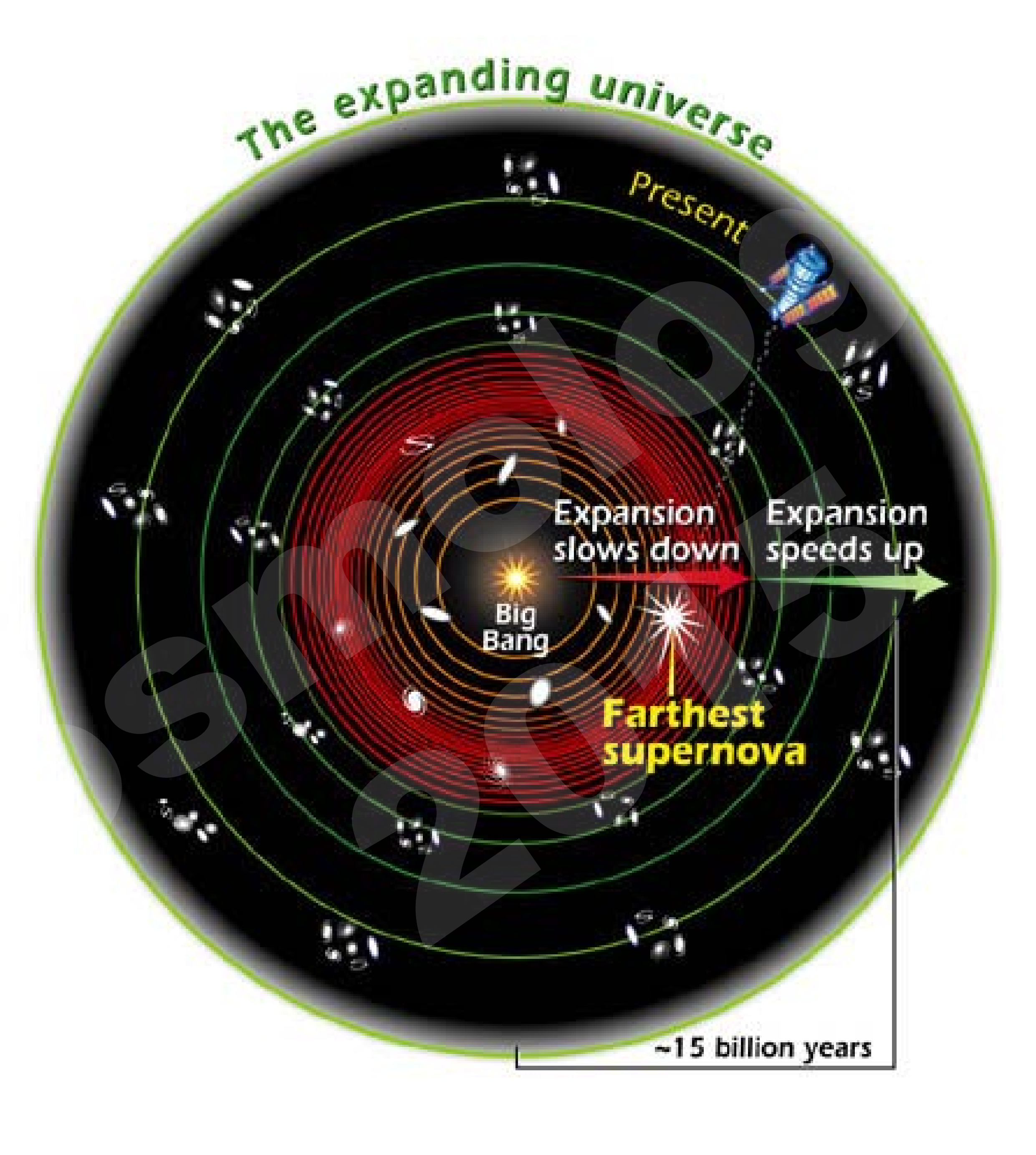
Ali šta to zapravo znači?



$V = H_0 \times D$

“Prošireni” Hablov zakon





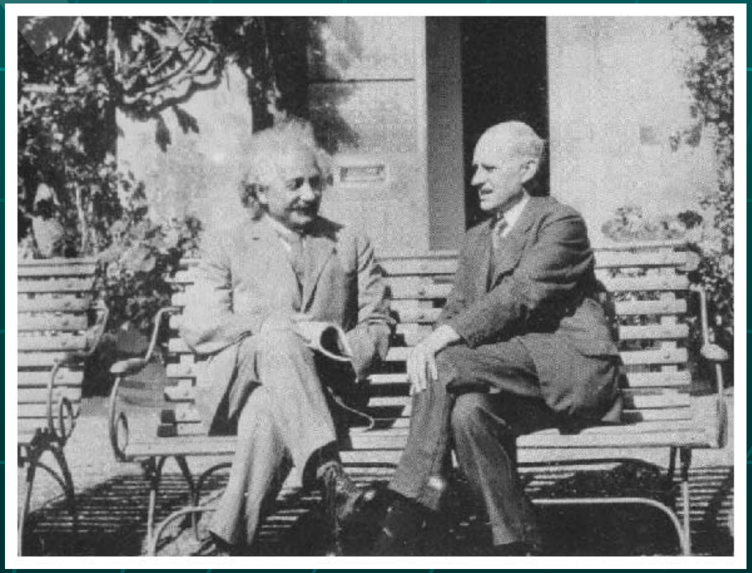
The expanding universe
Present
Expansion slows down
Expansion speeds up
Big Bang
Farthest supernova
~15 billion years

“Najveća greška mog života...”

- Ajnštajn 1917: kosmološka konstanta
- De Siter 1917: eksponencijalno šireći svemir
- Edington 1925: nestabilnost Ajnštajnovog svemira
- Habl 1929: širenje svemira

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \lambda g_{\mu\nu} = -\kappa T_{\mu\nu}$$

$$\frac{A}{R^2} + BR = 0$$



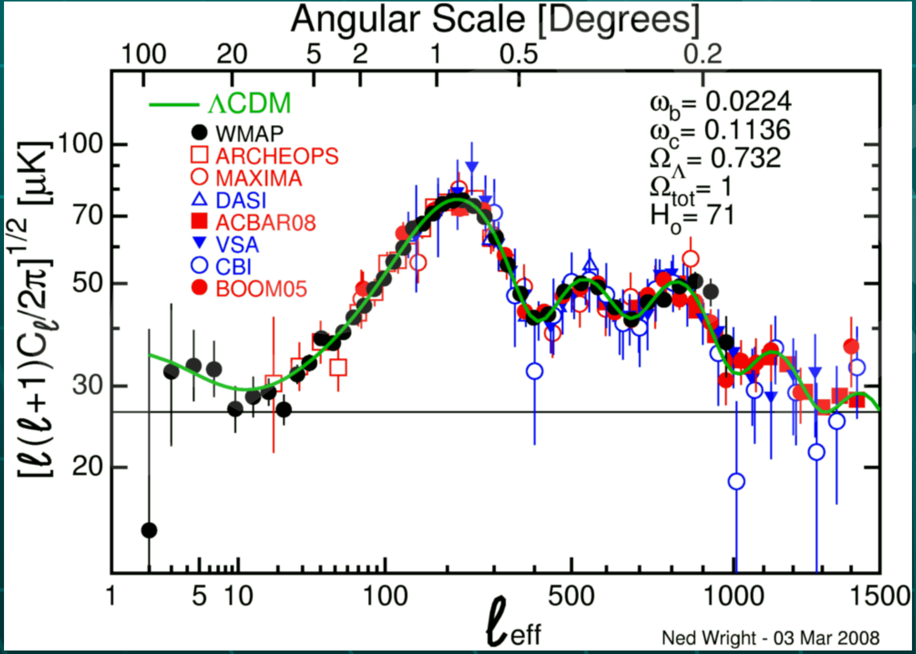
Povratak tamne energije

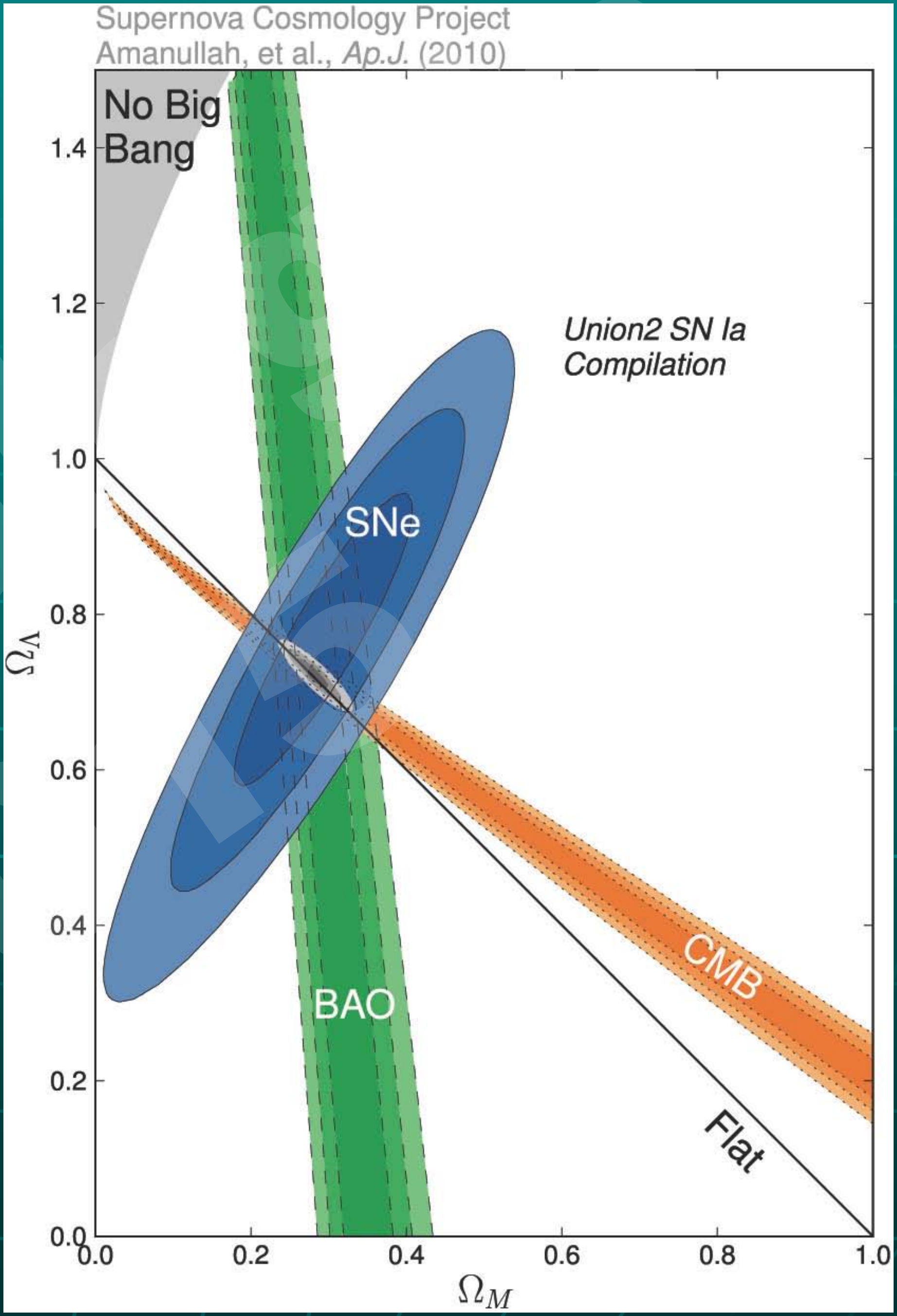
- "Prvi problem starosti" (1929-1944)
- "Novi problem starosti" (od 1970-tih)
- Tinsley & Gunn (1975):

  New data on the Hubble diagram, combined with constraints on the density of the Universe and the ages of galaxies, suggest that the most plausible cosmological models have a positive cosmological constant, are closed, too dense to make deuterium in the big bang, and will expand for ever.

Generali posle bitke…

- "Saglasnost" nezavisnih testova…





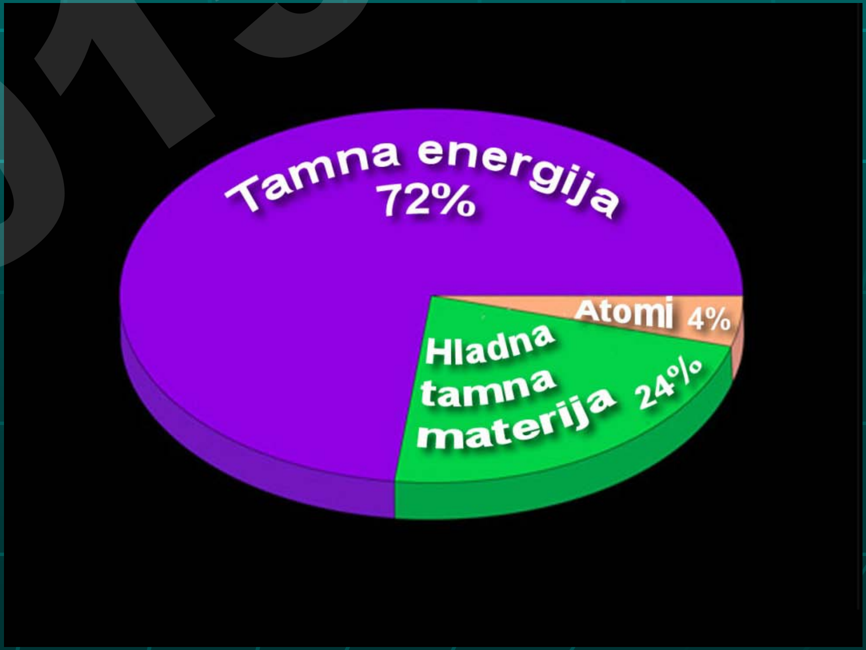
Šta je “zapravo” tamna energija?

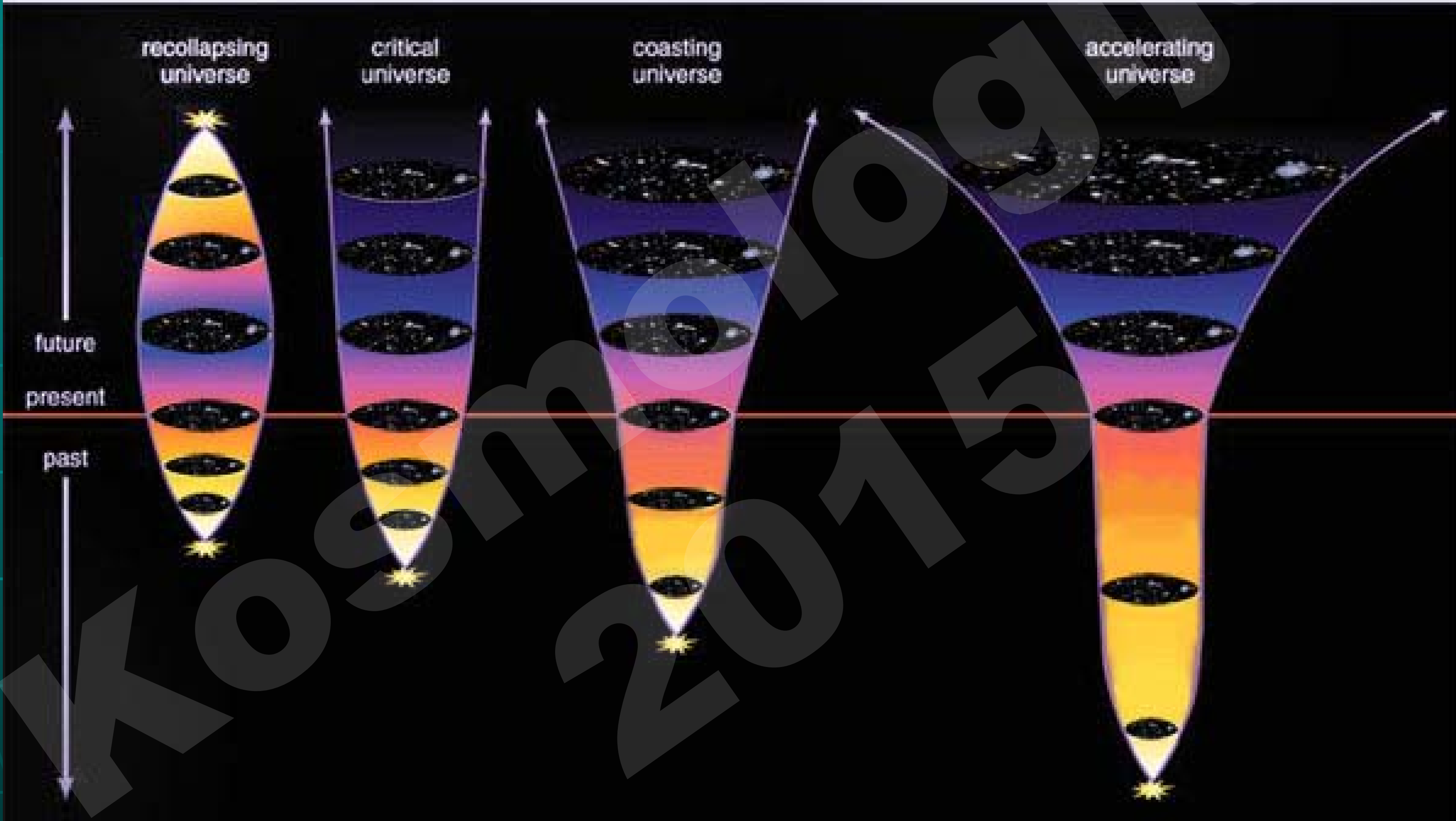
- Egzotična jednačina stanja:

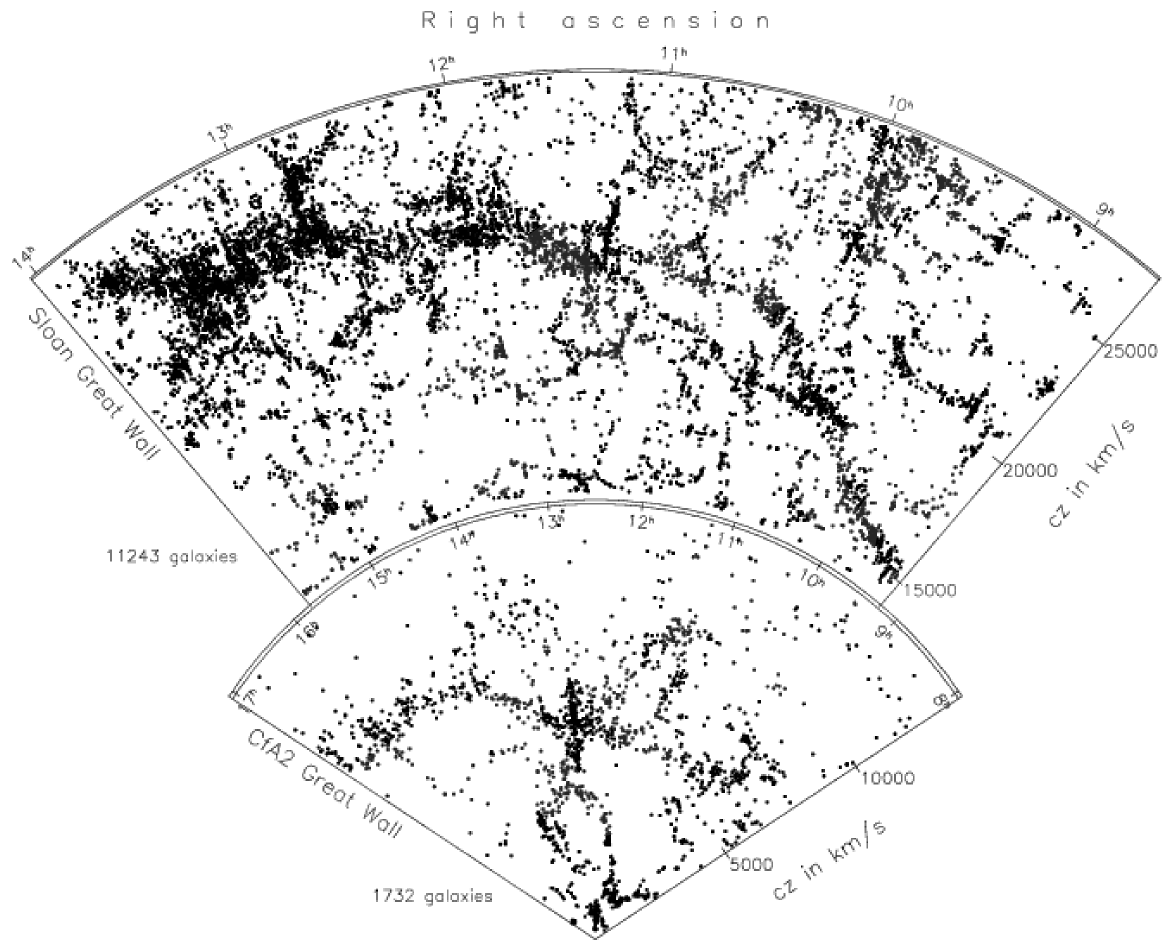
$$P = -w\rho$$

$$w \begin{cases} <1, & \text{ćaspTEdaju} \\ =1, & \text{kosmološka konstanta} \\ >1, & \text{fantomska energija} \end{cases}$$

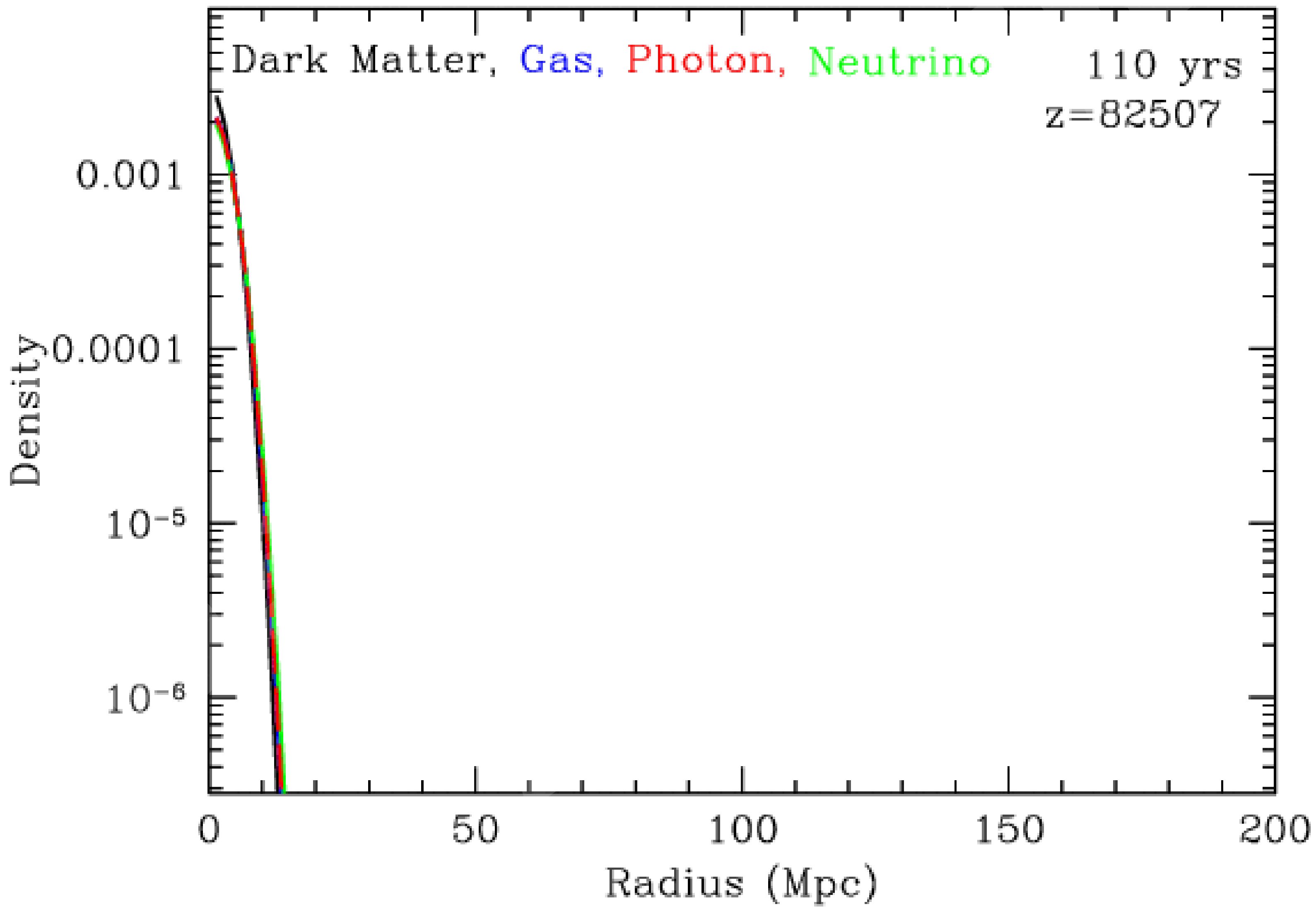
- “Dinamička” tamna energija – kvintesencija
- WMAP rezultat: w = 1.1 ± 0.14




recollapsing universe
critical universe
coasting universe
accelerating universe
future
present
past

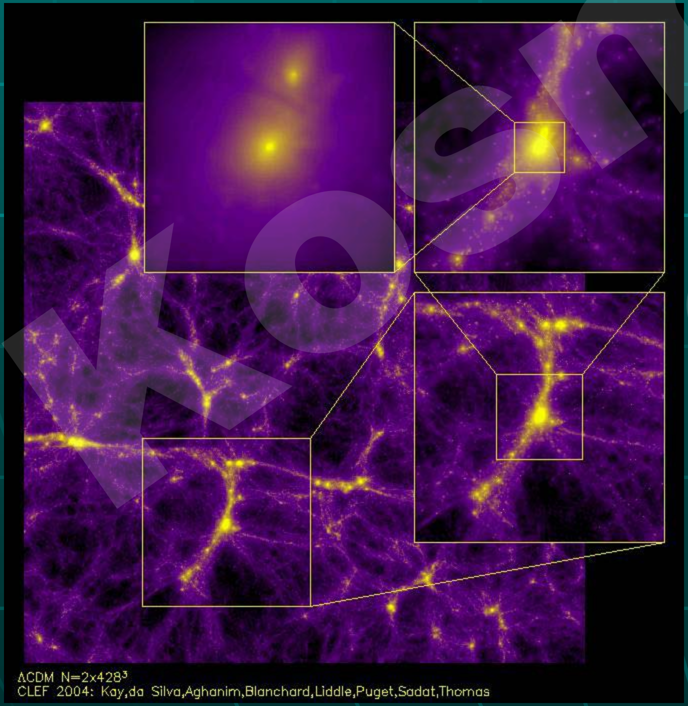


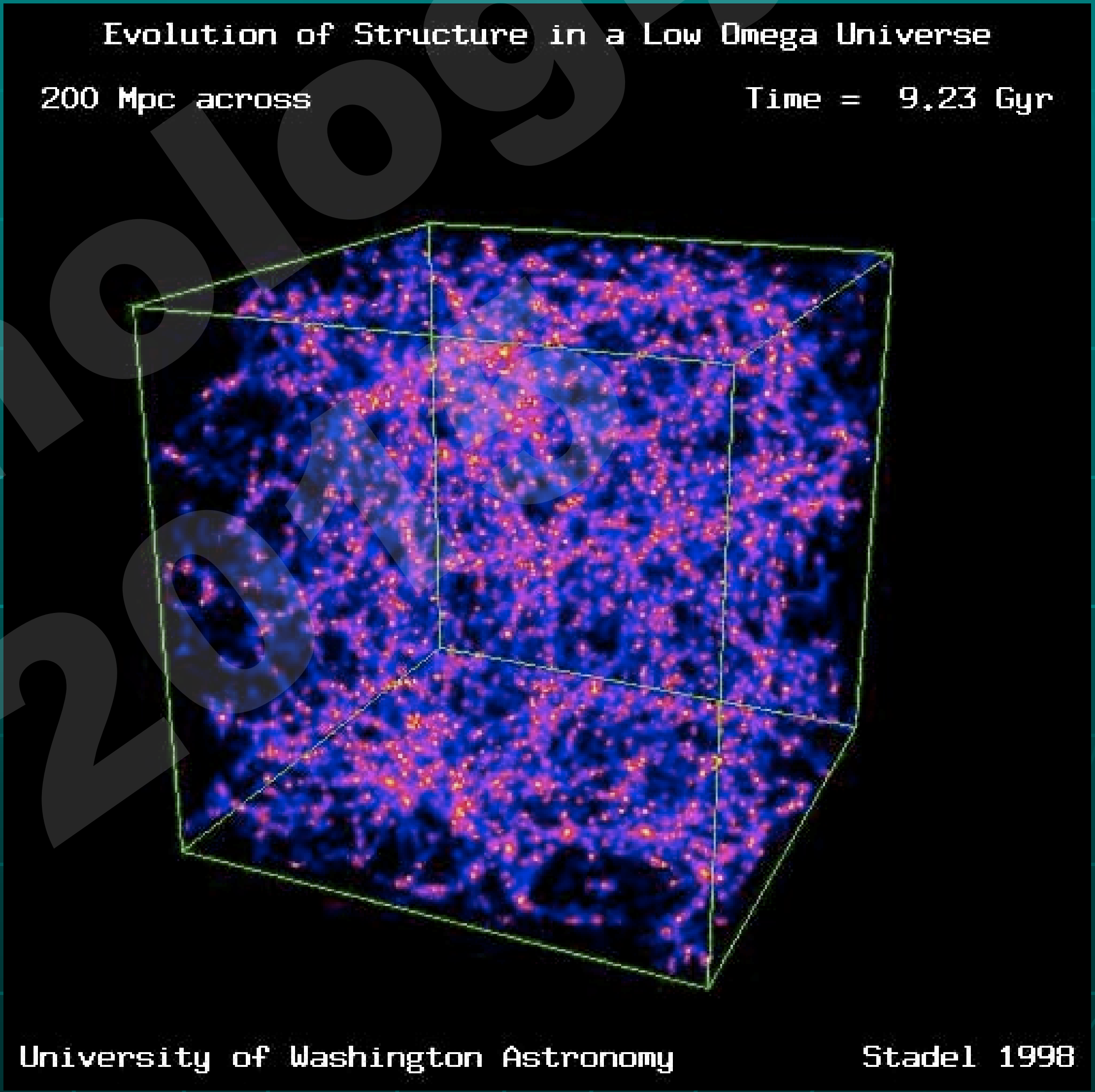
Right ascension
12h
11h
10h
13h
9h
14h
Sloan Great Wall
25000
20000
cz in km/s
11243 galaxies
15000
13h
12h
11h
14h
10h
15h
16h
9h
8h
CfA2 Great Wall
10000
5000
cz in km/s
1732 galaxies

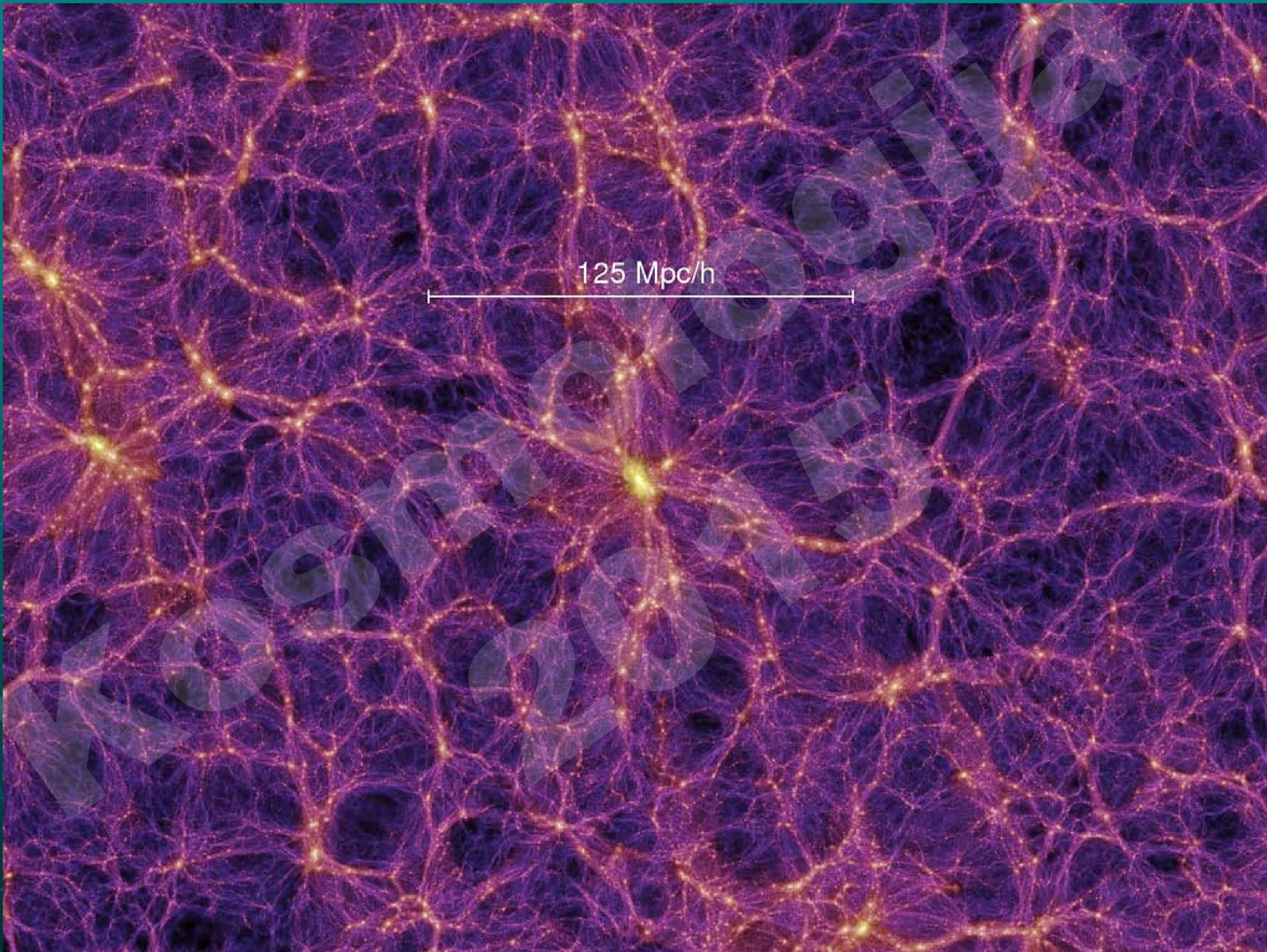

Dark Matter, Gas, Photon, Neutrino
110 yrs
z=82507
0.001
0.0001
10⁻⁵
10⁻⁶
Density
0
50
100
150
200
Radius (Mpc)

Simulacije nastanka strukture

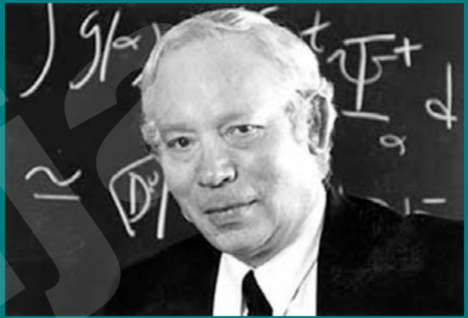
- Ubacimo “sastojke” svemira u mašinu...
- Najvažnije: vrsta i količina tamne materije
- **ΛCDM** – nova paradigma






125 Mpc/h

Weinberg (1987) – novi “žanr” antropičkog rasuđivanja



- Sledeći ideje Banksa, Abbotta i Lindea (1986) $\Rightarrow$ antropičko ograničenje na Λ
- Za Λ < 0, $|\Lambda|^{-\frac{1}{2}} \geq t_*$
- Za Λ > 0, antropički uslov: ne sme deformisati PS toliko da spreči formiranje galaksija
- U prvom redu teorije perturbacija

$$\left(\frac{da}{dt}\right)^2 + \Delta k = \frac{8\pi G}{3} a^2 \left(\rho + \Delta\rho + \rho_\Lambda\right)$$

$$\Omega_\Lambda \equiv \frac{8\pi G}{3H_0^2}\rho_\Lambda$$

- $\Rightarrow$ $\rho_\Lambda < \frac{500}{729}\tilde{\rho}$

U praksi: $\rho_\Lambda / \rho < 125$

I dalje veliki limit, ali Weinberg je bio krajnje pozitivan!

Multiverzum: bogatstvo različitosti

"Master" jednačina za antropički pristup

- Verovatnoća da neki posmatrač bilo gde u multiverzumu izmeri karakteristiku *X* :

$$p(X) = \frac{\sum_n \sigma_n(X) V_n \rho_n^{\text{obs}}}{\sum_n V_n \rho_n^{\text{obs}}}$$

- V_n je prostovremenska zapremina, ρ_n^{obs} gustina posmatrača i

$$\sigma_n = \begin{cases} 1, & \text{if universe } n \text{ has property } X \\ 0, & \text{otherwise} \end{cases}$$

Pitanje: Kako odrediti ρ_n^{obs} za neku konkretnu niskoenergetsku fiziku?

Odgovor: Kroz bolje razumevanje astrobiologije!