Эволюция Вселенной в ОТО.

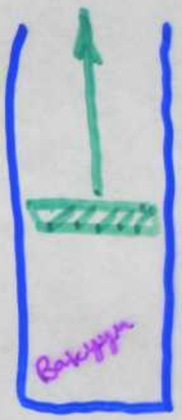
$$R_{ik} - \frac{1}{2} g_{ik} R - \Lambda g_{ik} = \varkappa T_{ik} \quad , \quad \varkappa = \frac{8\pi G}{c^2}$$

Λ – космологическая постоянная

Λg_{ik} – лоренц-инв – космологический член.

$\Lambda \neq 0 \Rightarrow$ вакуум обладает опр-ой плотностью гравитирующей массы, $\rho_v = \dfrac{c^2 \Lambda}{8\pi G}$

$dE = d(\varepsilon_v V) = -P_v dV$, $\varepsilon_v = \rho_v c^2$, $P = -\varepsilon_v$ $(\varepsilon_v > 0) \Rightarrow P < 0$ – натяжение

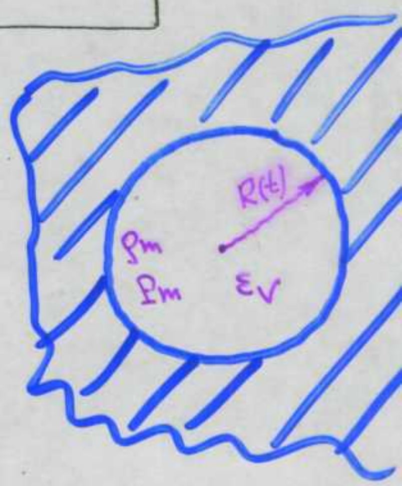


$$\frac{d^2 R}{dt} = -\frac{4\pi G}{3 \cdot c^2} R\,(\varepsilon + 3P) \rightarrow +(\varepsilon_v + 3P_v)$$

$$= -\frac{4\pi G}{3c^2} R\,(\varepsilon_m + 3P_m + \varepsilon_v + 3P_v) = -\frac{4\pi G}{3c^2} R\,(\varepsilon_m + 3P_m - 2\varepsilon_v)$$

$$\boxed{\frac{d^2 R}{dt^2} = -\frac{4\pi G}{3c^2} R\,(\varepsilon_m + 3P_m - 2\varepsilon_v)}$$

Как и прежде $\times \frac{dR}{dt}$ и $\int$



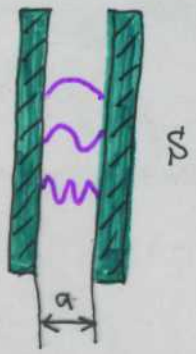
$$\frac{1}{2}\left(\frac{dR}{dt}\right)^2 = \frac{4\pi G R^2}{3c^2}(\varepsilon_m + \varepsilon_v) + \frac{Kc^2}{2}$$

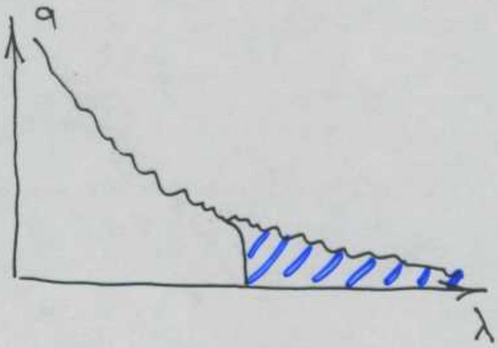
$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}(\rho_m + \rho_v) + \frac{Kc^2}{R^2}$$

$$(K = 0, \pm 1)$$

Эффект Казимира

1948 г, Казимир.



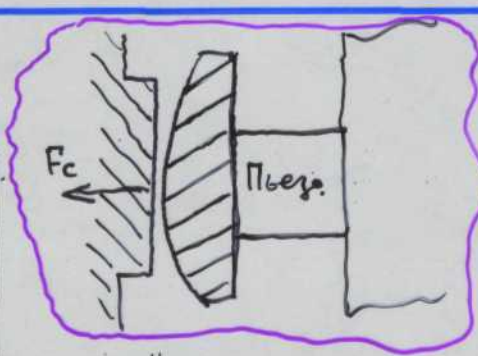


1958, Sparnaay.

Первая попытка наблюдения. 100% ош.

$$\boxed{\frac{F(a)}{S} = 0.016\,\frac{1}{a^4}\ \text{dyn}\,(\mu m)^4/\text{cm}^2}$$ (≃ 10^{-7} Н, 1 μm, S = 1 cm

1996, S.K. Lamoreaux



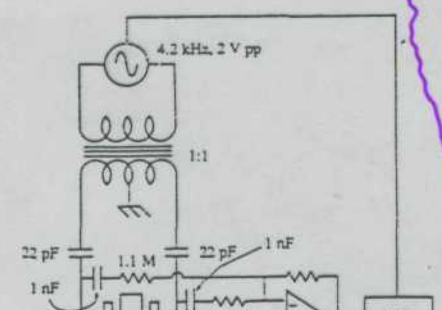


FIG. 1. Schematic of the apparatus. The vacuum vessel dimensions are 55 cm diam by 110 cm tall. The solenoid activated plunger was used to press the plates gently together (during alignment): after such pressing, the plates could be brought much closer.

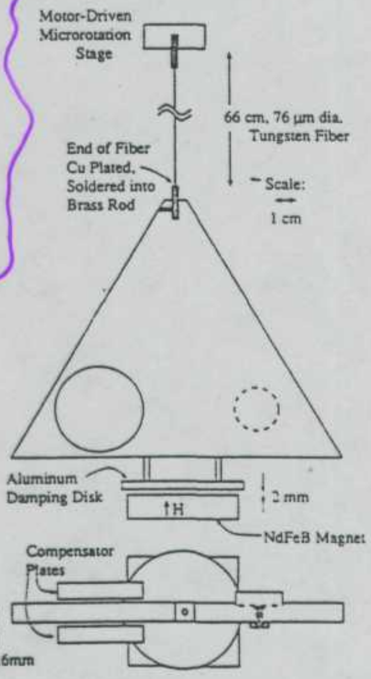


FIG. 2. Details of the pendulum. The body has t
397 g. The ends of the W fiber were plated with a C
solution; the fiber ends were bent into hairpins of 1
and then soldered into a 0.5 mm diam, 7 mm dee
the brass rods. Flat-head screws were glued to the
the plates; a spring and nut held the plates firmly ag
supports, and ensured good electrical contact.

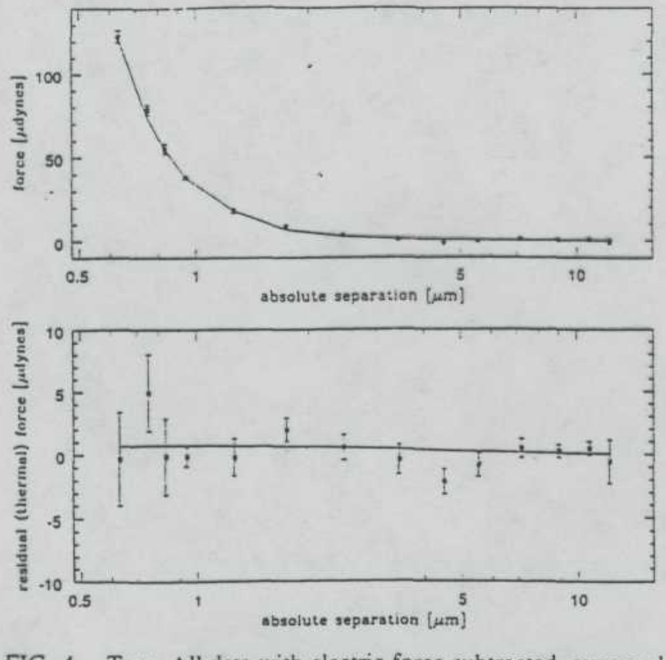
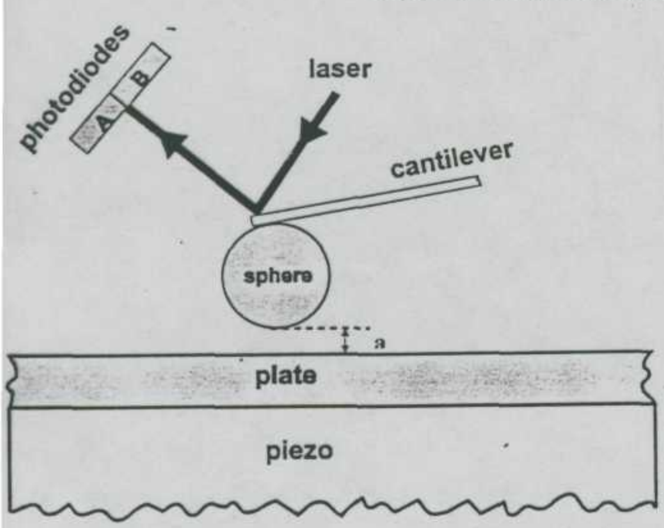
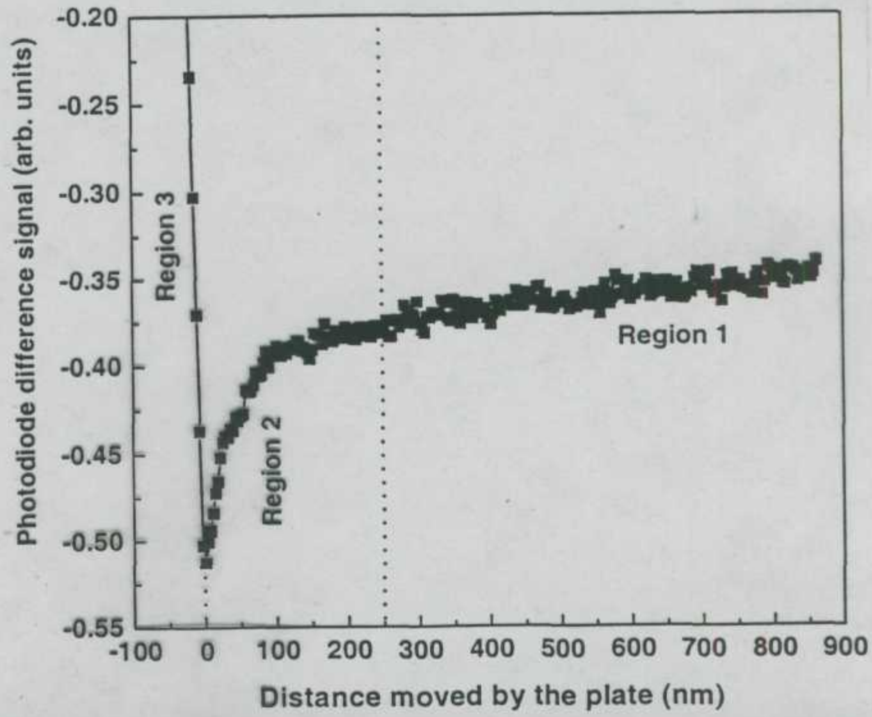
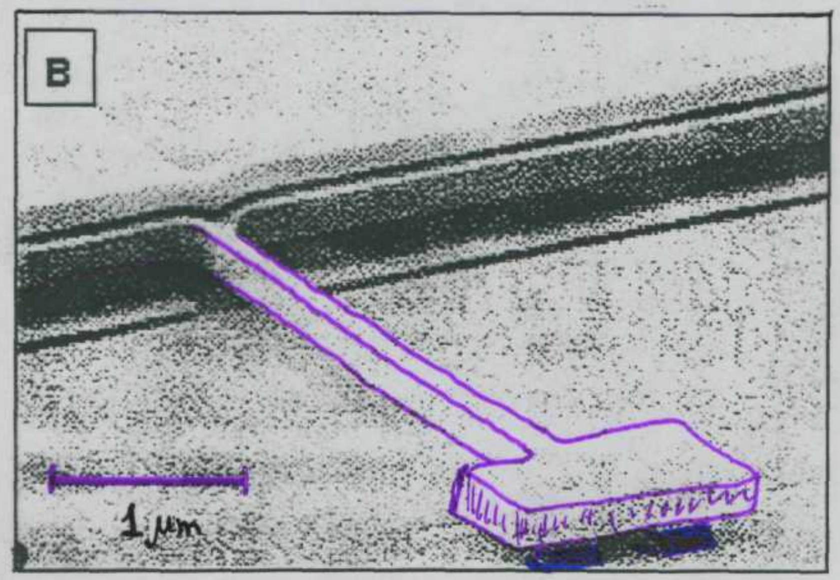
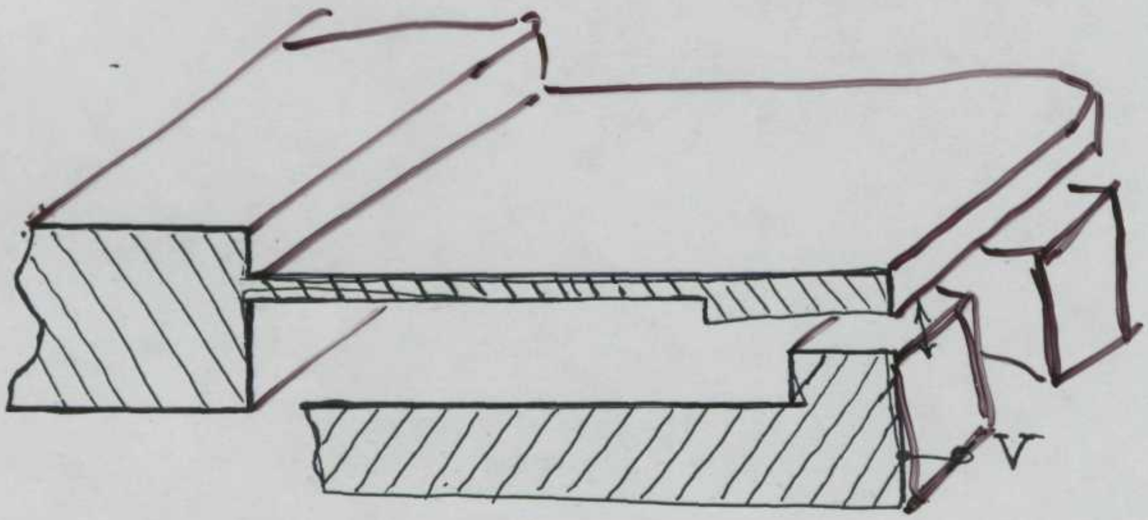


FIG. 4. Top: All data with electric force subtracted, averaged into bins (of varying width), compared to the expected Casimir force for a 11.3 cm spherical plate. Bottom: Theoretical Casimir force, without the thermal correction, subtracted from top plot; the solid line shows the expected residuals.






B
1 µm


V

Космологические параметры.

$$H = h \cdot H_0$$

$$\Omega_i = 8\pi G \rho_i / (3H_0^2) \quad ; \quad H_0 = 100 \text{ км/с/Мпк}$$

$$\Omega_i = \frac{\rho_i}{\rho_c}$$

$\Omega_i h^2$ – физическая плотность, независящая от H_0.

Ω_b – плотность барионов.

Ω_c – плотность холодного невидимого в-ва.

$\Omega_m = \Omega_b + \Omega_c$ – плотность материи. (полная)

Ω_Λ – плотность космологической константы.

$\Omega_{tot} = \Omega_m + \Omega_\Lambda$ – полная плотность

C_{10} – амплитуда флук-ий плотности (начальных)

n_s – параметр спектра начальных возмущений

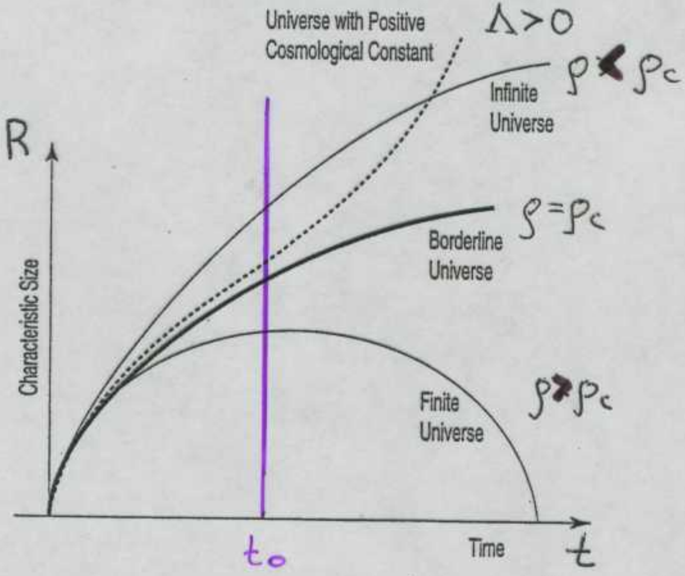
$$P(k) \sim k^{n_s}$$

τ_c – оптическая толщина эпохи реионизации.

Между этими параметрами $\exists^T$ корреляция и иногда часть из них фиксируют.

Инфляционная модель – основная в настоящее время:

$\Omega_{tot} = 1$ – инфляция даёт плоскую геометрию


Universe with Positive Cosmological Constant
$\Lambda > 0$
$\rho < \rho_c$
Infinite Universe
R
Characteristic Size
$\rho = \rho_c$
Borderline Universe
Finite Universe
$\rho > \rho_c$
t_0
Time
t

Исследование глобальных свойств Вселенной.

Ω_b - ?

Ω_Λ - ? $\qquad\qquad \Omega_{b,\Lambda} = \dfrac{\rho_{b,\Lambda}}{\rho_c}$

$\Omega_{tot} = \Omega_b + \Omega_\Lambda$ - ?

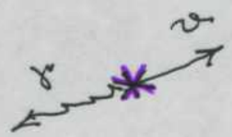
- Поиск отклонений от закона Хаббла
- Измерение кривизны пространства Вселенной

\- - -

Supernova Cosmology Project (SCP, 1988 г)

Исследование сверхновых Ia (стандартная свеча)

Измерение светимости SN Ia в зависимости от z.



$$z = \frac{\omega_{исп} - \omega_{прин}}{\omega_{исп}}, \in [0; 1]$$

3

$$\Delta = \frac{\lambda_{прин} - \lambda_{исп}}{\lambda_{исп}}, \in [0; \infty]$$

$$z = \frac{\Delta}{1 + \Delta} \quad ; \quad \Delta = \frac{z}{1 - z} \quad . \quad z \leftrightarrow \Delta$$

- Светимость в астрономии измеряется в log единицах — звёздных величинах. (ярче объект — меньше ЗВ)

$$m(z) = M + 5\log d_L(z, H_0, \Omega_M, \Omega_\Lambda) + 25$$

M - абсолютная звёздная величина (объект на рас. 10 п

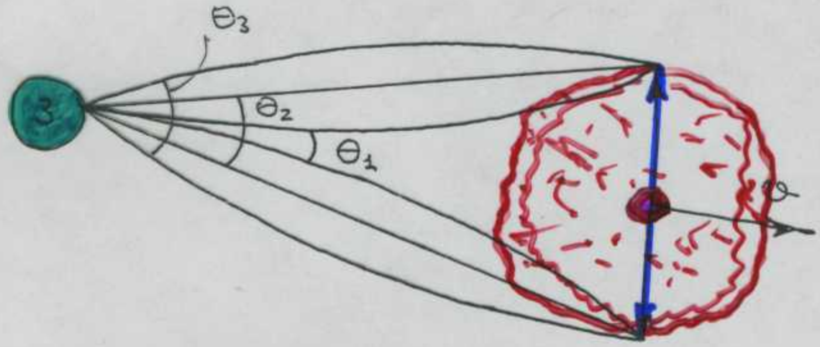
SCP (1988 - 1998 →)

На всех континентах. $D_{тел} > 2.5$ м

CCD $(4 \times (2048 \times 2048)$

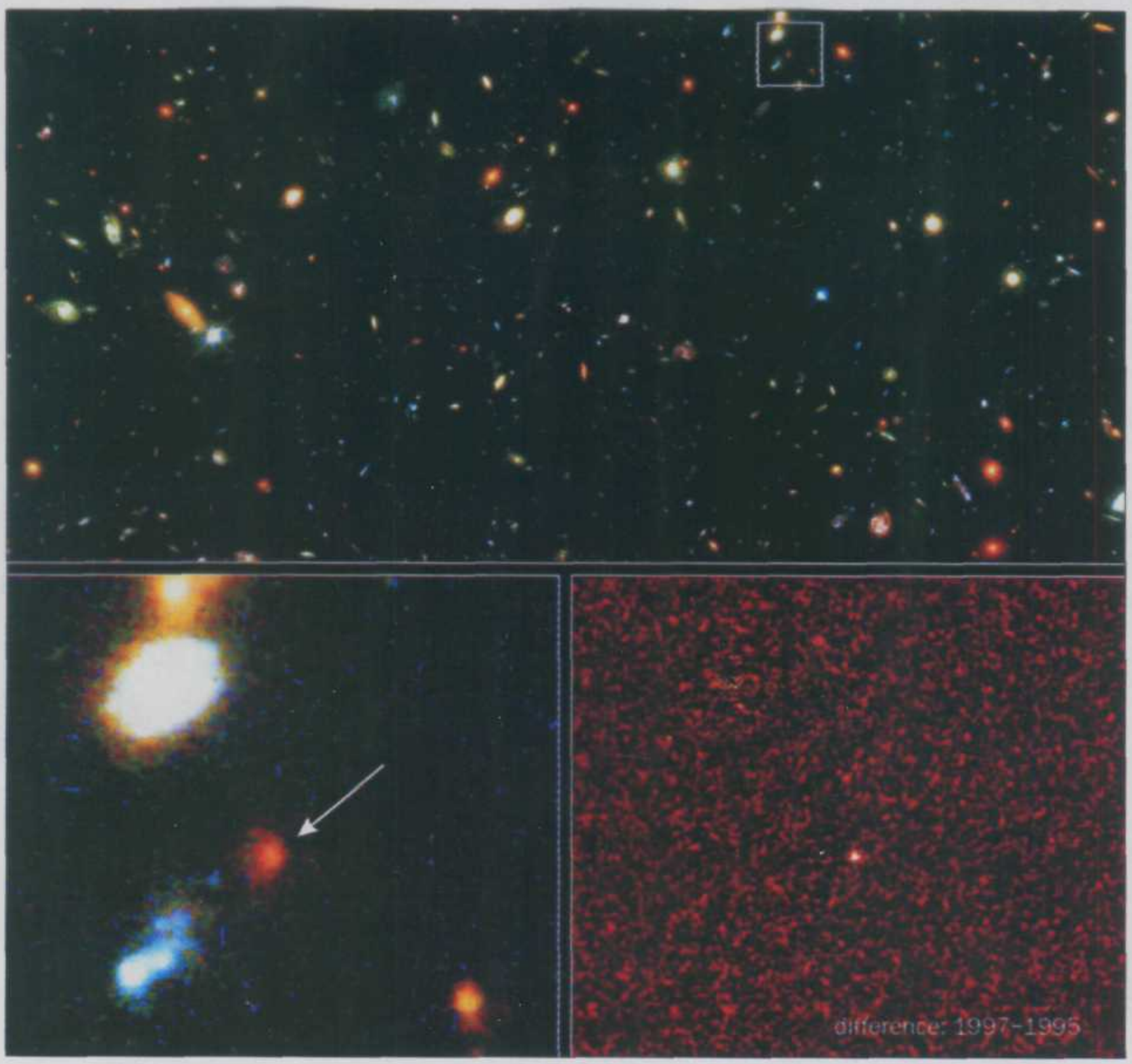
1988: 1 (SN Ia); $z = 0.31$

1998: >75 (SN Ia); $z = 0.18 \div 0.86$ (0.92)

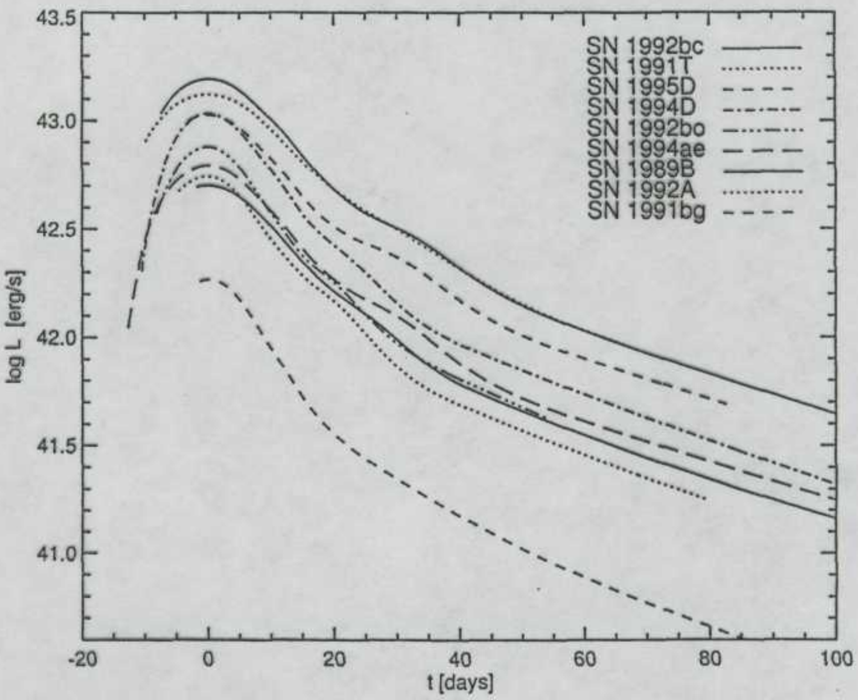


$$\Omega_{tot} = \Omega_b + \Omega_\Lambda$$

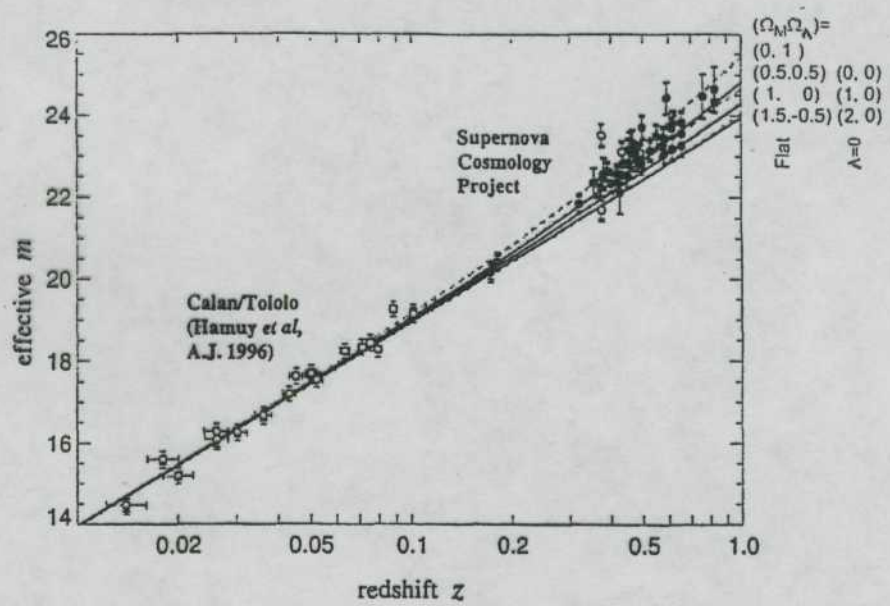
$$\Theta_1 < \Theta_2 < \Theta_3$$



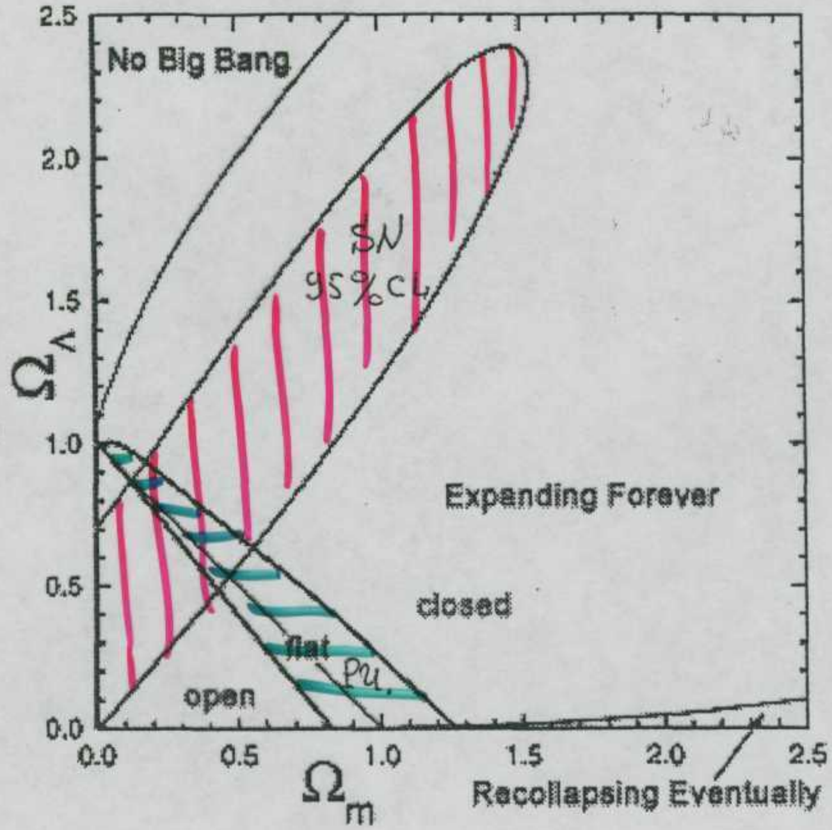
The detection and analysis of the most distant supernovae shows they are further away than expected, leading to the notion of some form of "dark energy" accelerating the expansion of the universe. These images from NASA's Hubble Space Telescope show supernova 1997ff in its cosmic neighbourhood (top), home galaxy (left), and the dying star itself (right). (NASA and A Riess, STScI.)



Bolometric light curves of nearby SNe Ia (Contardo et al. 1999).

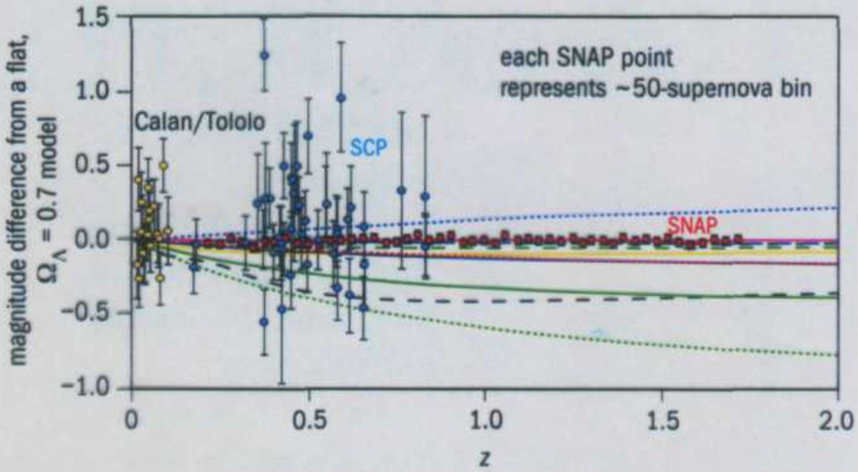


(a) Hubble diagram for 42 high-redshift Type Ia supernovae from the Supernova Cosmology Project, and 18 low-redshift Type Ia supernovae from the Calán/Tololo Supernova Survey, after correcting both sets for the SN Ia light-curve width-luminosity relation. The inner error bars show the uncertainty due to measurement errors, while the outer error bars show the total uncertainty when the intrinsic luminosity dispersion, 0.17 mag, of light-curve-width-corrected Type Ia supernovae is added in quadrature. The unfilled circles indicate supernovae not included in the primary analysis. The horizontal error bars represent the assigned peculiar velocity uncertainty of 300 km s^{-1}. The solid curves are the theoretical $m_B^{\text{effective}}(z)$ for a range of cosmological models with zero cosmological constant: $(\Omega_M, \Omega_\Lambda) = (0,0)$ on top, $(1,0)$ in middle and $(2,0)$ on bottom. The dashed curves are for a range of flat cosmological models: $(\Omega_M, \Omega_\Lambda) = (0,1)$ on top, $(0.5, 0.5)$ second from top, $(1,0)$ third from top, and $(1.5,\text{-}0.5)$ on bottom.



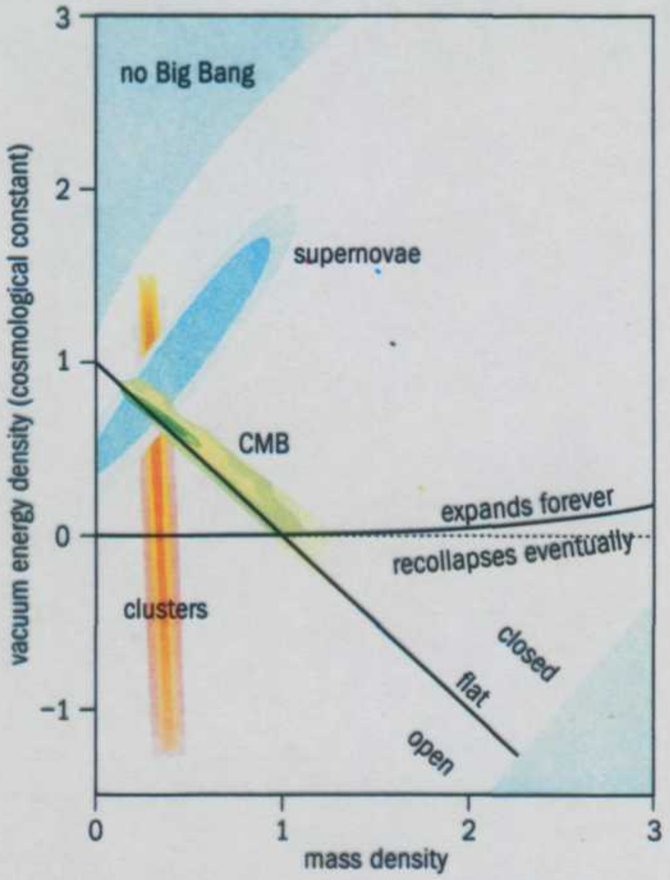
Основные результаты:

- 1. $\Lambda \neq 0$, Λ существенно больше нуля!
- 2. $t_{\text{Всел.}} = (14.5 \pm 1.0) \cdot 10^9$ лет
- 3. Вклад космологической постоянной (энергии вакуума) в плотность энергии Вселенной доминирует!
- 4. Вселенная расширяется ускоренно ↗



Future data, here simulated, of binned distance-redshift measurements from SNAP, will allow detailed exploration of the nature of dark energy. In particular, we will gain clues to the underlying physics from the time variation of the dark-energy properties. The curves show a variety of high-energy physics models in the literature (adapted from Weller and Albrecht 2002).

Cutaway view of the SNAP satellite, showing its major elements. The 2 m telescope can precisely find and observe supernovae more than 10 billion light-years away. The wide-field, half-billion pixel imager and spectrograph accurately characterize their properties, calibrating the supernovae for use as cosmological "standardized candles". (Lawrence Berkeley National Laboratory.)



Since the discovery, through Type Ia supernovae, that the expansion of the universe is accelerating and dominated by something like a vacuum energy density, this and other methods have added strong confirmation (supernova data: R Knop et al. *2003; CMB: D Spergel* et al. *2003; clusters: S Allen* et al. *2002). Today the picture is of a spatially flat universe consisting of only 30% dark matter and baryons, while 70% acts like an accelerating cosmological constant or dark energy.*