



Dark Matter

A. N. Baushev

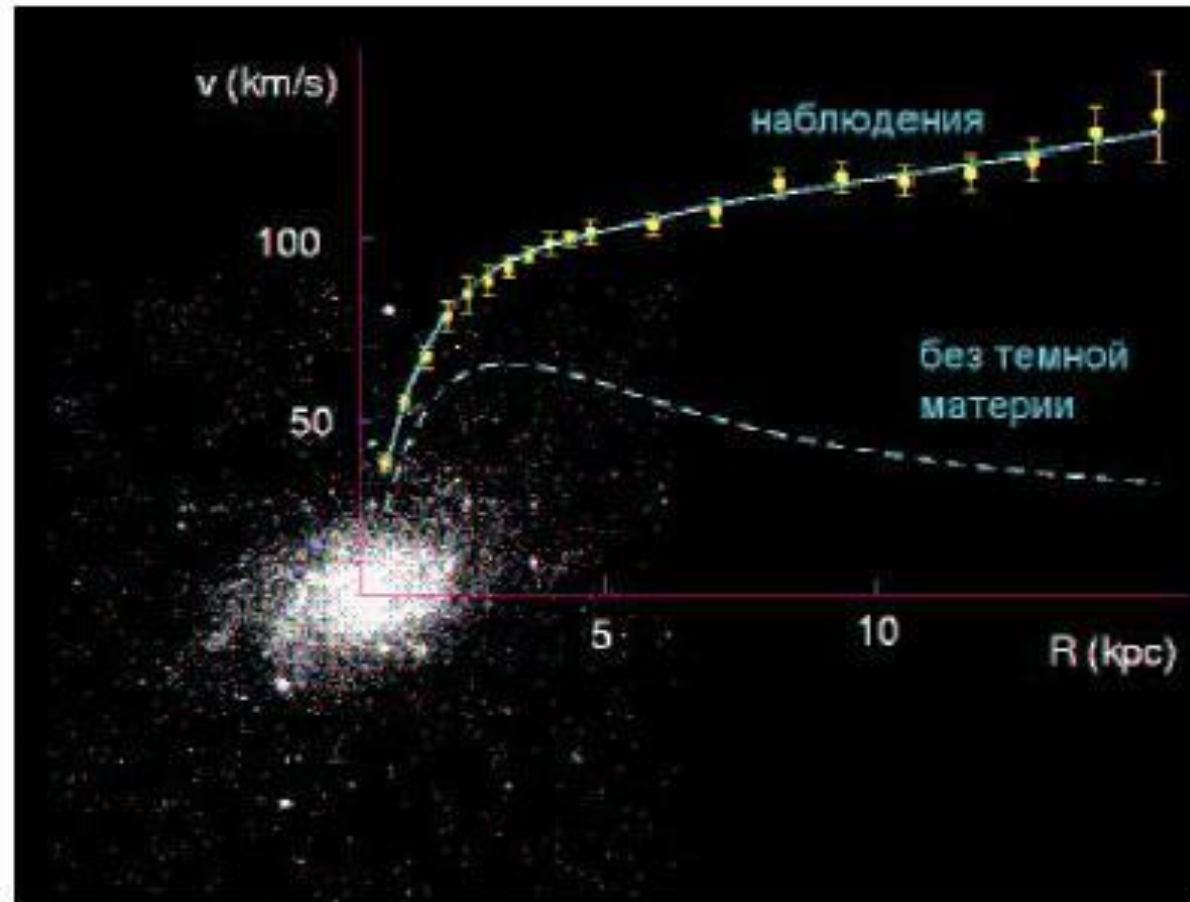
- 1933,
F.Zwicky



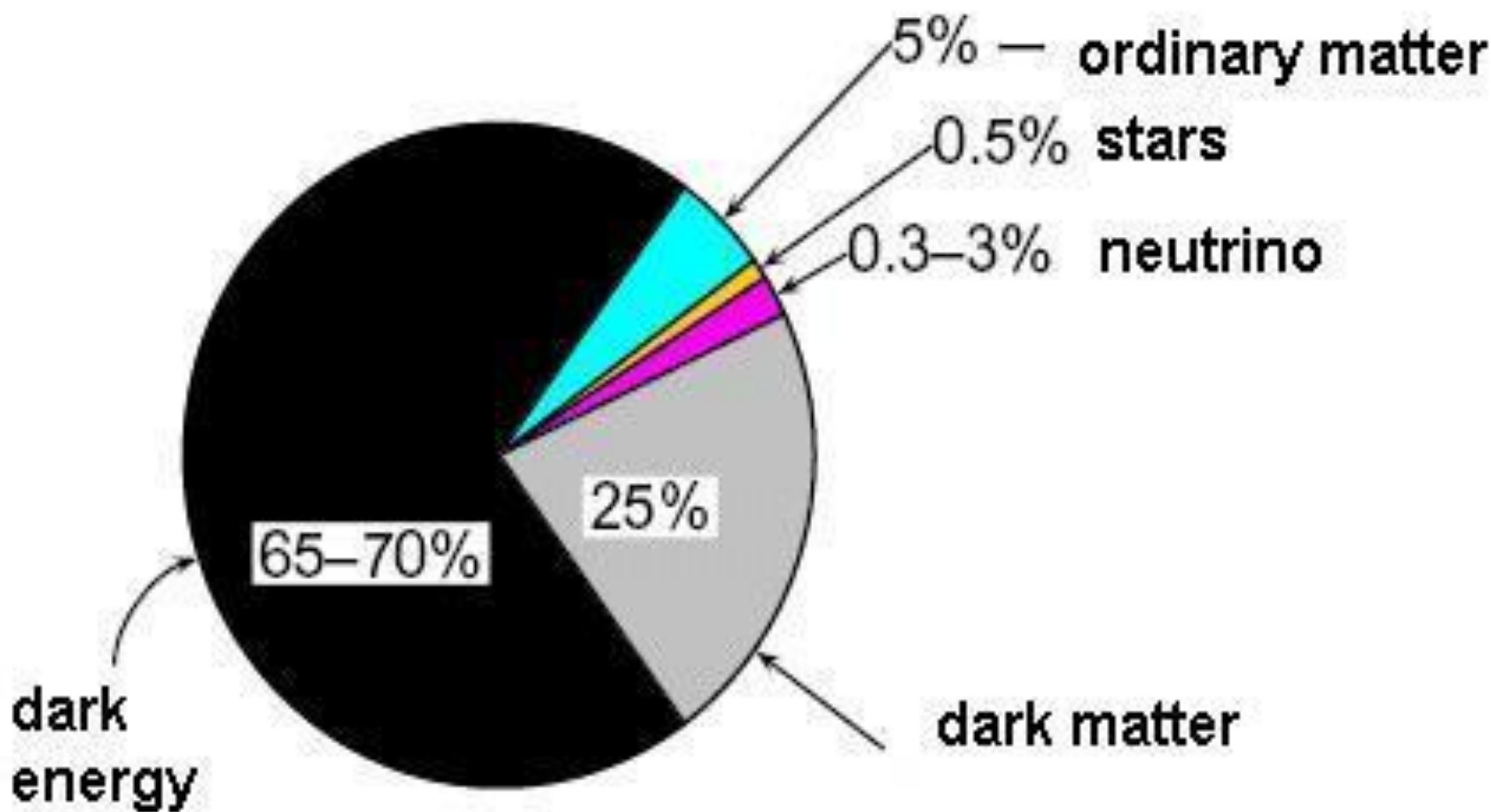
V. Rubin (optics)
A. Bosma (radio)

$$M(r) \approx \frac{r v_r^2(r)}{k}$$

$$v_r \propto r^{-1/2}$$



- Gas
- Star evolution remnants
- Jupiters
- Modified gravity



Friedmann universes

$$ds^2 = dt^2 - a^2(t) \left[d\chi^2 + \chi^2 (d\zeta^2 + \sin^2\zeta d\xi^2) \right]$$

$$ds^2 = dt^2 - a^2(t) \left[d\chi^2 + \sin^2\chi (d\zeta^2 + \sin^2\zeta d\xi^2) \right]$$

$$ds^2 = dt^2 - a^2(t) \left[d\chi^2 + \text{sh}^2\chi (d\zeta^2 + \sin^2\zeta d\xi^2) \right]$$

$$ds^2 = dt^2 - a^2(t) dl^2$$

$$ds^2 = dt^2 - dl^2$$

Friedmann

equations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3} \rho - \frac{\kappa}{a^2}$$

$$\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + p) = 0$$

Equation of
state

$$p = \alpha\rho$$

1) Relativistic matter

$$p = \frac{1}{3} \rho \quad \rightarrow \quad \alpha = \frac{1}{3}$$

$$T^{ik} = \begin{pmatrix} \rho & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix}$$

2) Non-relativistic matter

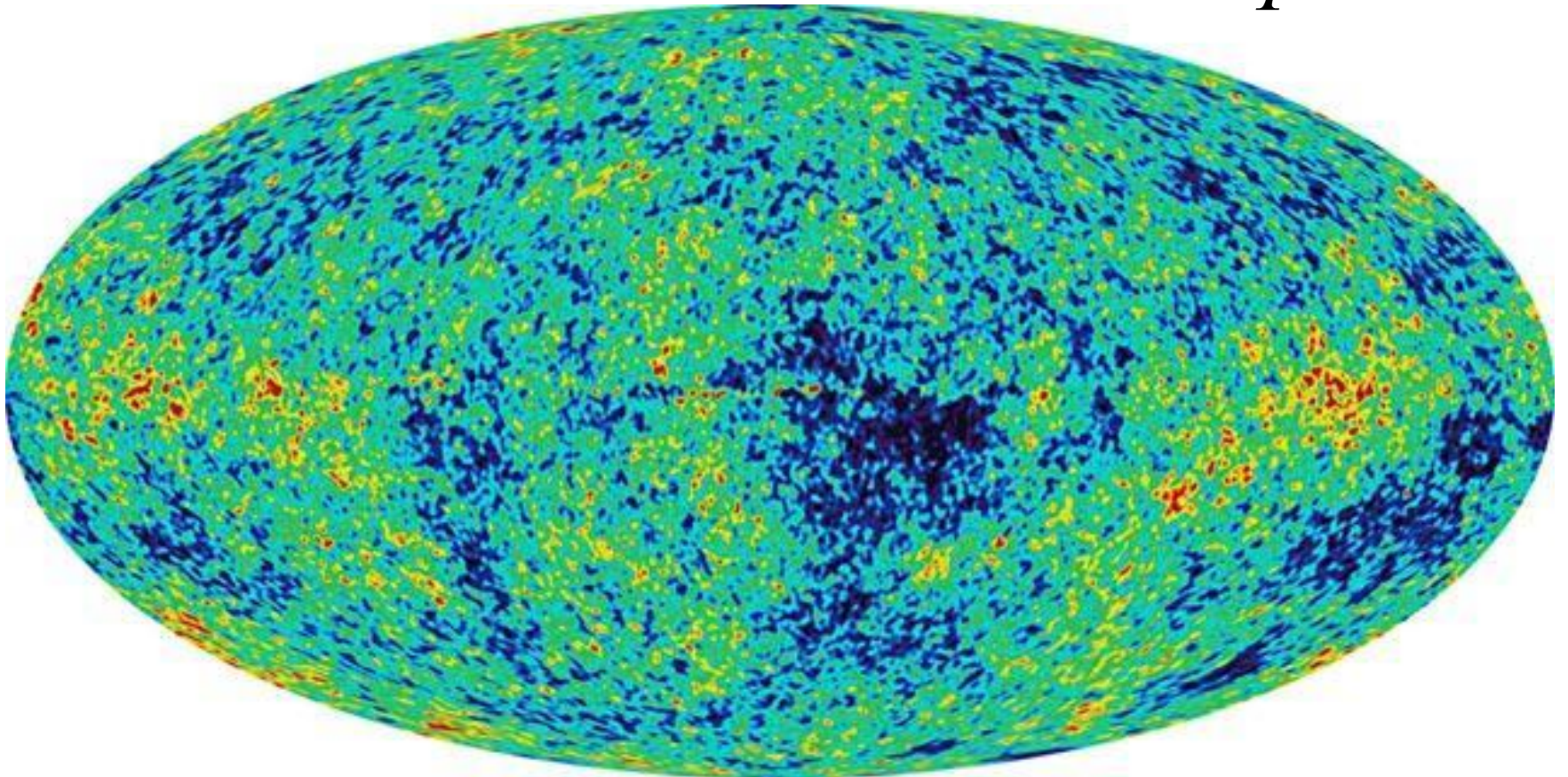
$$p = 0 \quad \rightarrow \quad \alpha = 0$$

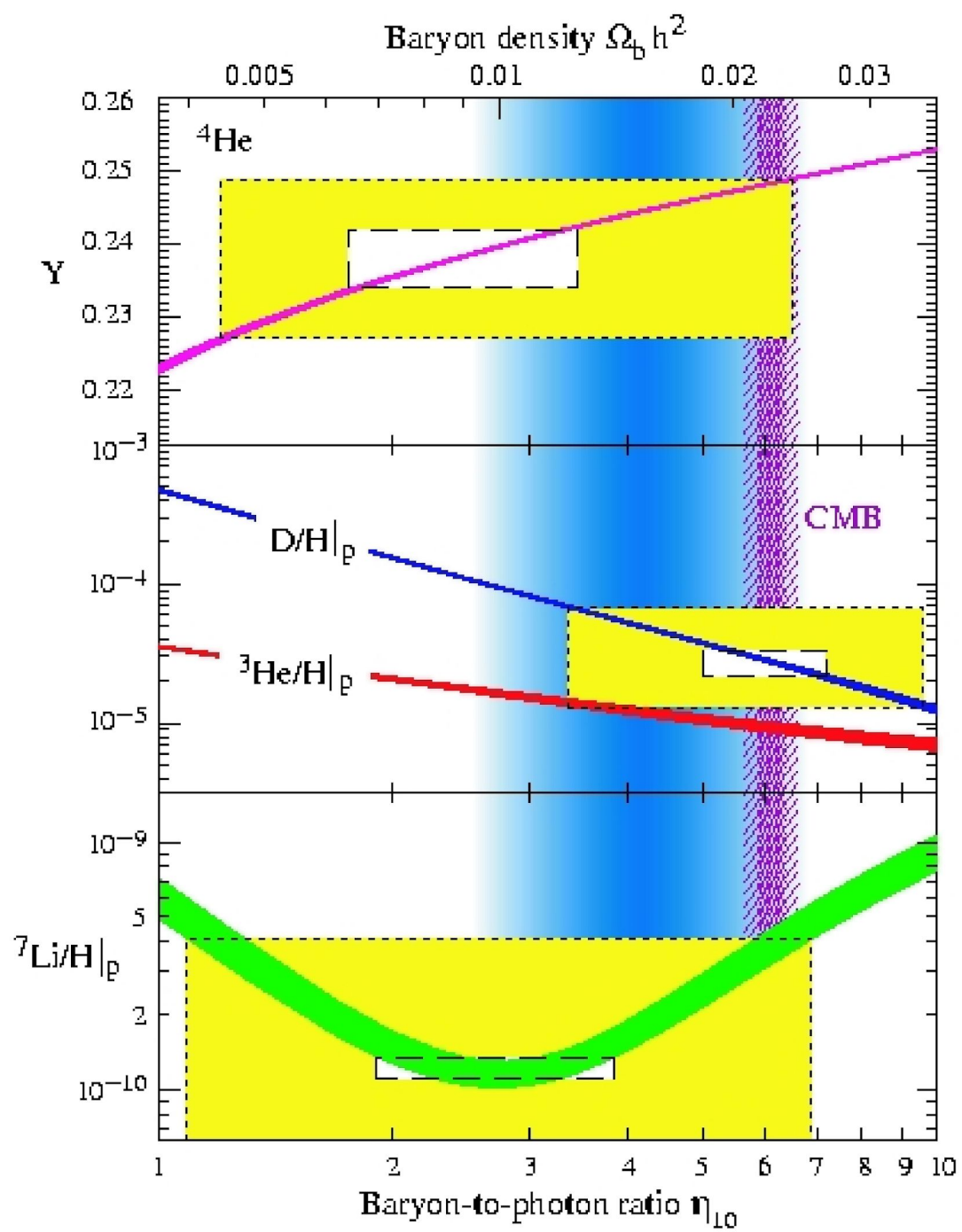
3) The cosmological constant

$$p = -\rho \quad \rightarrow \quad \alpha = -1$$

Relic radiation anisotropy

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

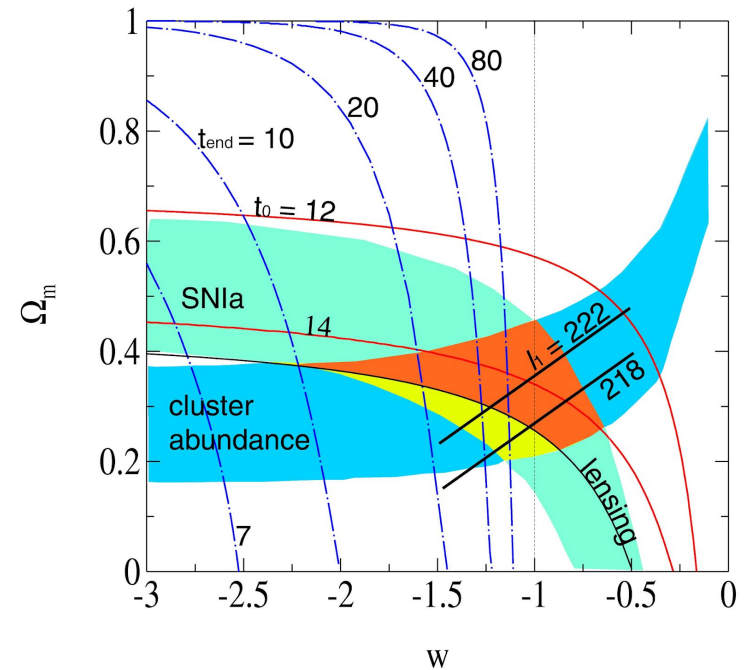




Dark matter vs. Dark energy

$$p = \alpha\rho$$

$$p = -\rho$$



$$\frac{dp}{dr} = - \frac{(p + \rho)(m + 4\pi r^3 p)}{r(r - 2m)}$$

Candidates

$$\langle \sigma v \rangle \approx \frac{3 \times 10^{-27} \text{ cm}^3 \text{ s}^{-1}}{\Omega_\chi h^2} \quad \Omega_\chi \boxtimes 0.25, \quad h \boxtimes 0.7$$

- 1) Weakly Interacting Massive Particles (WIMP)
- 2) Extremely weakly interacting particles (EWIP)
- 3) Low-massive black holes
- 4) Something else

Dark matter structure

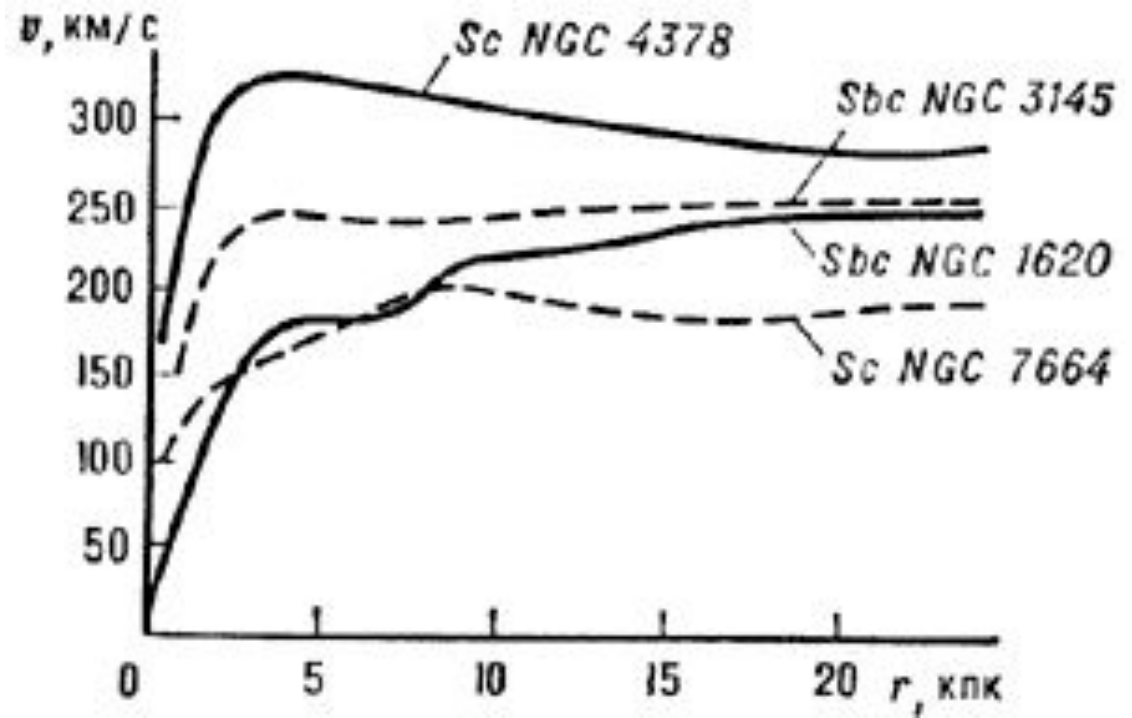
$$\boxtimes 0.3 \frac{GeV}{cm^3}$$

$60 GeV$

$$\boxtimes 0.005 cm^{-3}$$



$$v_r \propto \text{const}$$



$$M(r) \propto r$$

$$n(r) \propto \rho(r) \propto r^{-2}$$

$$n(r) \propto \rho(r) \propto r^{-1.8}$$

$$M = \int \rho(r) 4\pi r^2 dr \propto \int r^{0.2} dr$$

$$N = \int \frac{1}{2} \langle \sigma v \rangle n^2 4\pi r^2 dr \propto \int r^{-1.6} dr$$

Relic radiation anisotropy

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

