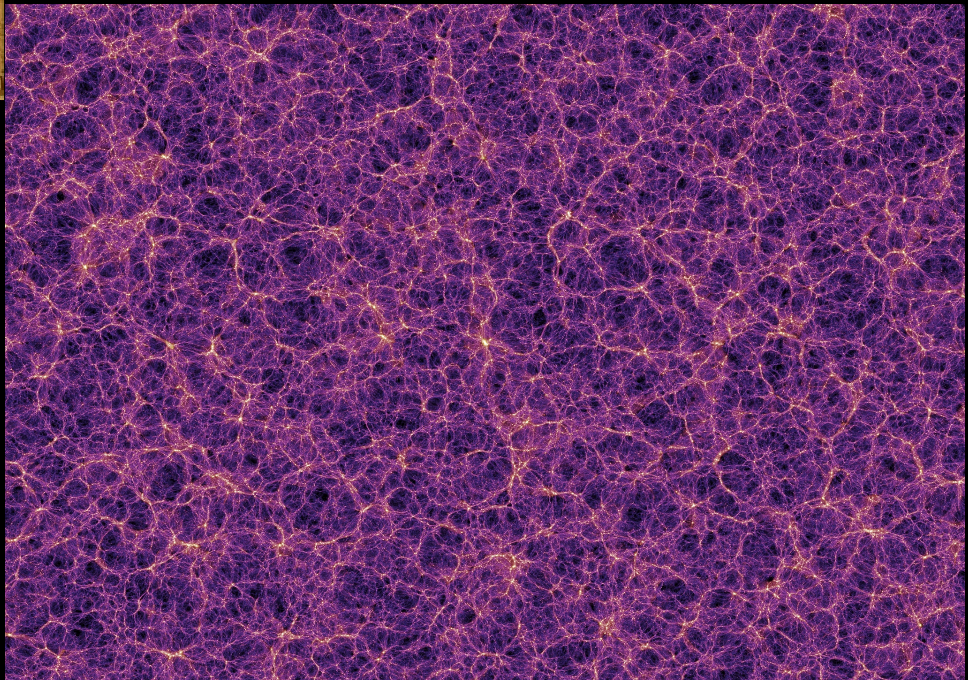
TEMNA STRAN VESOLJA



Vid Iršič
FMF, UL

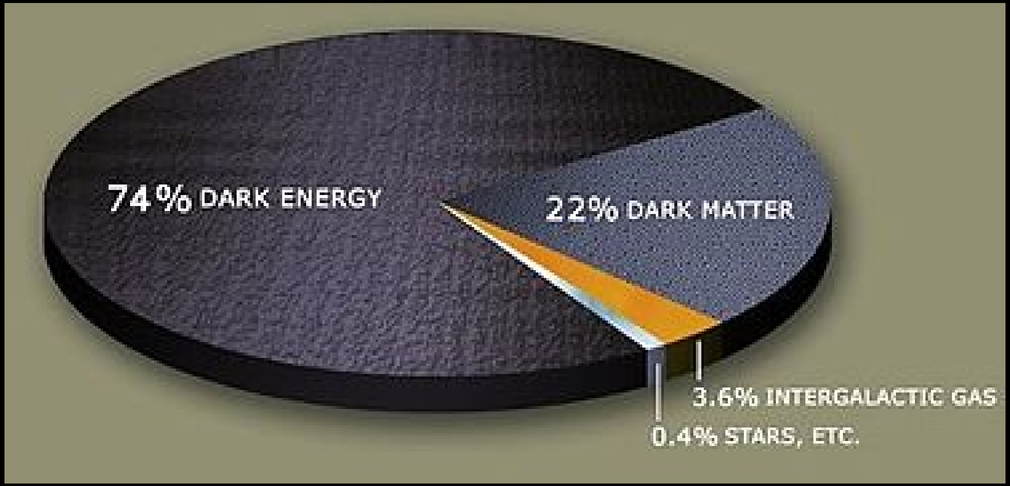
Temna snov in temna energija

Temna snov

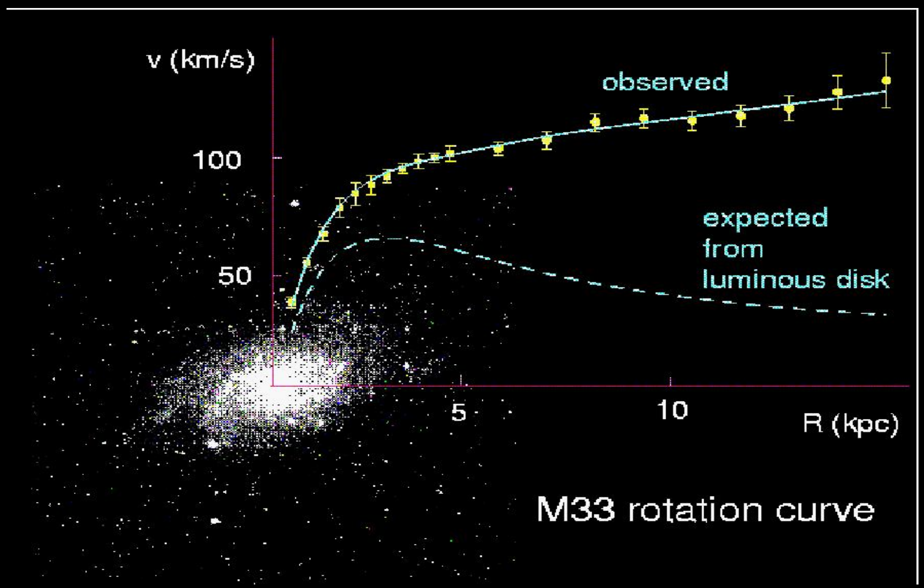
- Rotacijske krivulje galaksij
- Razpršenost hitrosti galaksij
- Opazovanje X žarkov v jatah galaksij
- Gravitacijsko lečenje
- Prasevanje
- LSS – razvoj velikih struktur v vesolju (BAO vrh, Lyman alfa gozd, korelacije v porazdelitvi galaksij)

Temna energija

- Supernove tipa Ia
- Prasevanje
- Razvoj struktur v poznem vesolju
- Integrirani Sachs-Wolfeov (ISW) efekt



Temna snov - rotacijske krivulje galaksij

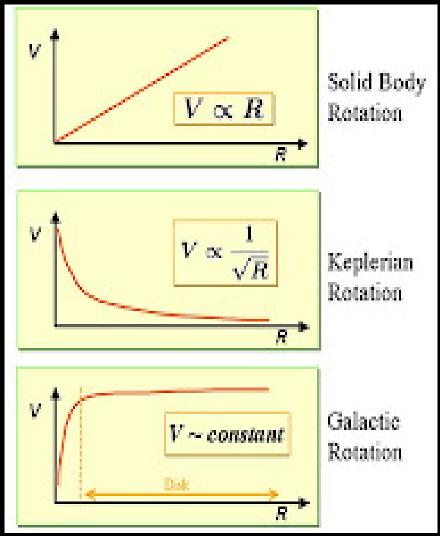


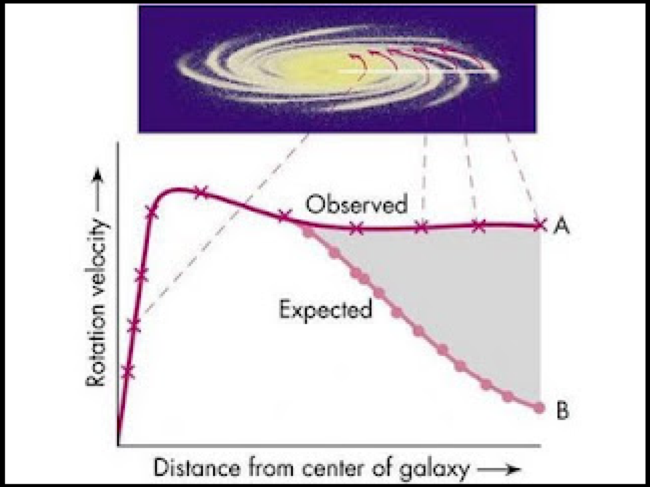
$$F_{\text{centripetal}} = F_{\text{gravity}}$$

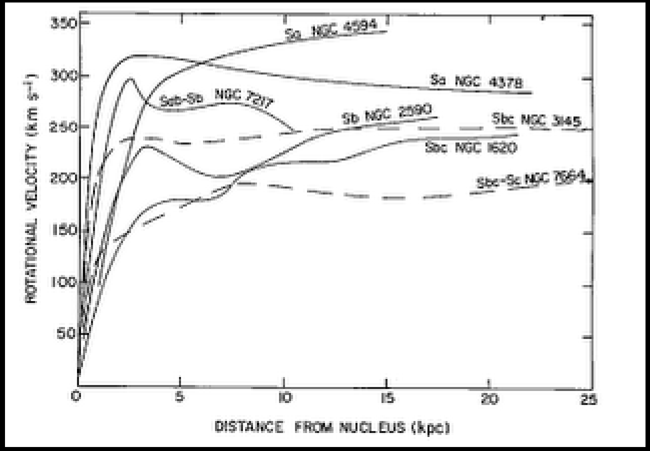
$$\frac{mv_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

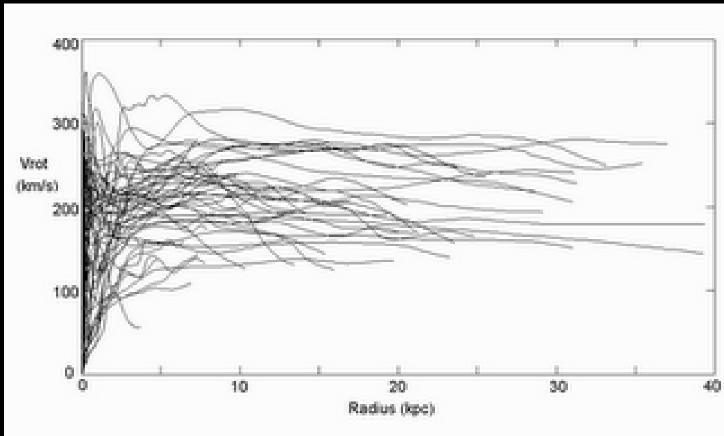
$$v_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$

$$\frac{M(r)}{r} \to \text{const} \quad (r >> r_{core})$$









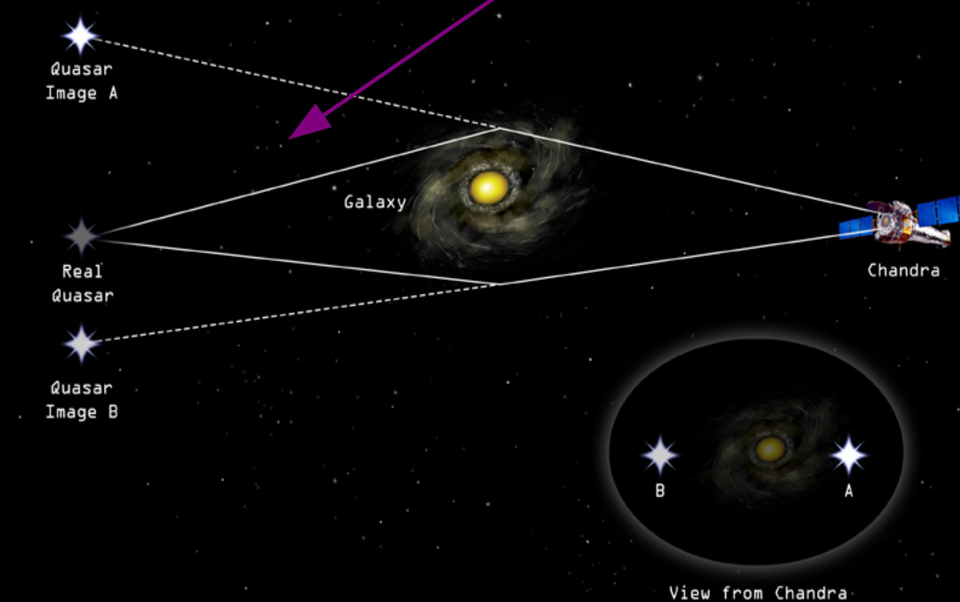
Temna snov – gravitacijsko lečenje

Abell 2128

Odklon za točkasto maso: $\alpha = \frac{4GM}{c^2 R}$

Odklon za masno porazdelitev:

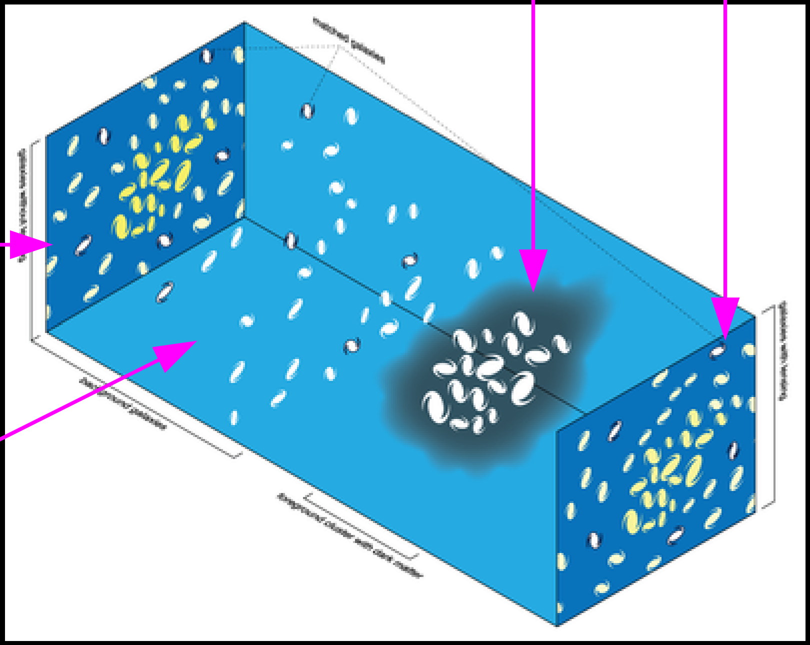
$$\boldsymbol{\alpha} = \frac{4G}{c^2} \int \frac{\Sigma(\mathbf{R})}{R^2} d\mathbf{R}$$



Opazovana lečena projekcija

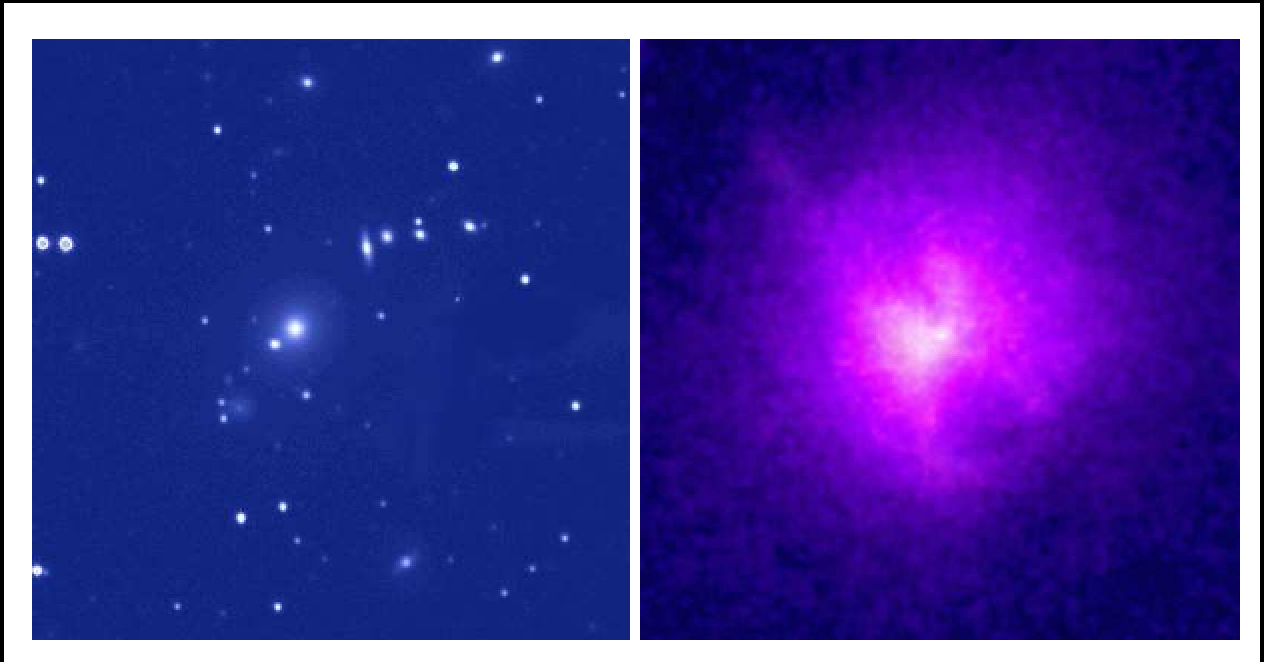
Leča: temna snov + plin + galaksije

Opazovana projekcija



Opazovane galaksije

Temna snov – Jate galaksij in X žarki



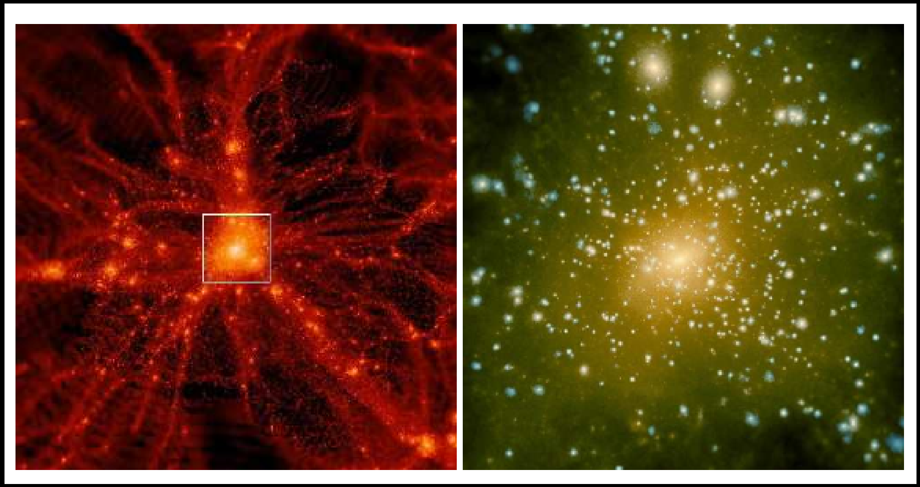
Temperature plina v jatah galaksij:

$T \sim 10^7$ K

Hidrodinamično ravnovesje:

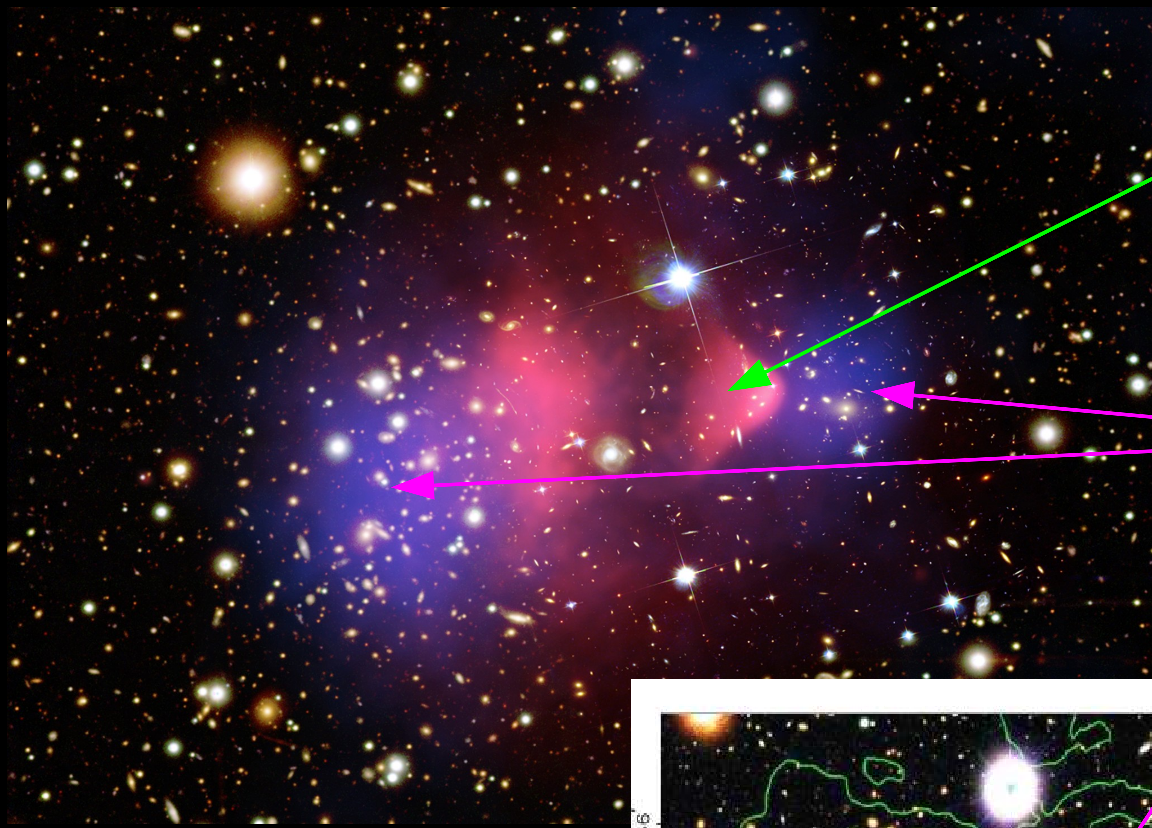
$$M_T(r) = -\frac{kT(r)r}{G\mu m_p}\left(\frac{d\ \ln\ \rho_{gas}}{d\ \ln\ r} + \frac{d\ \ln\ T}{d\ \ln\ r}\right)$$

Hydra A: (levo) optični posnetek iz La Palme;
(desno) X žarki posneti z satelitom Chandra



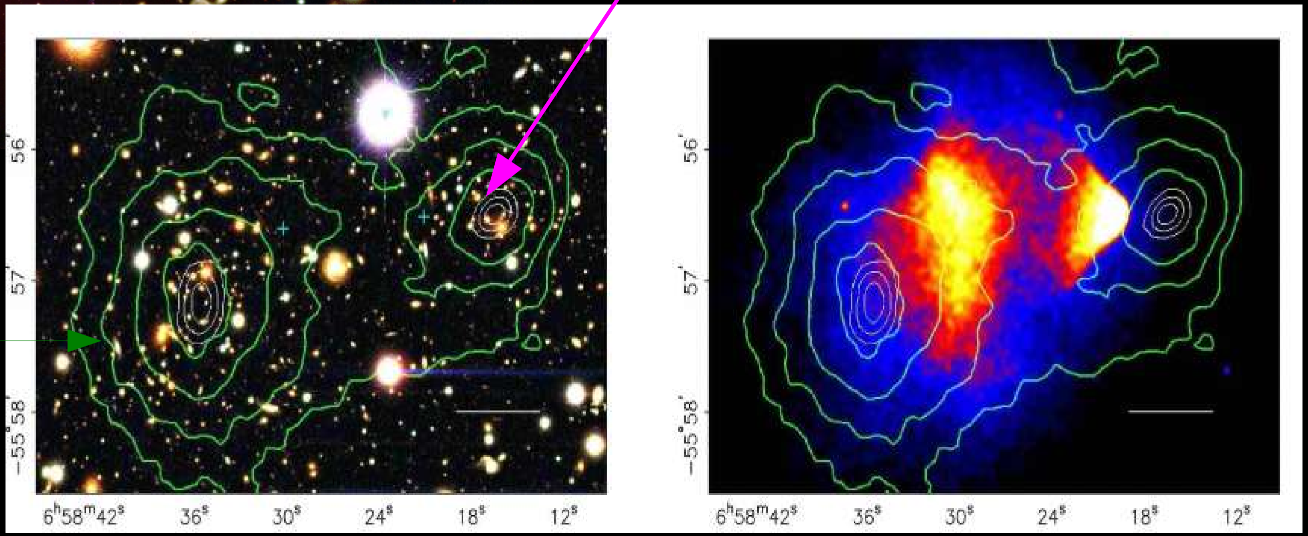
Modeli evolucije jat galaksij podajo relacijo med temperaturo (in tlakom, entropijo) plina v jati in celotno maso jate, ki je potrebna, da drži celoten gravitacijski sistem vezan.

Temna snov – Jata galaksij “Metek”



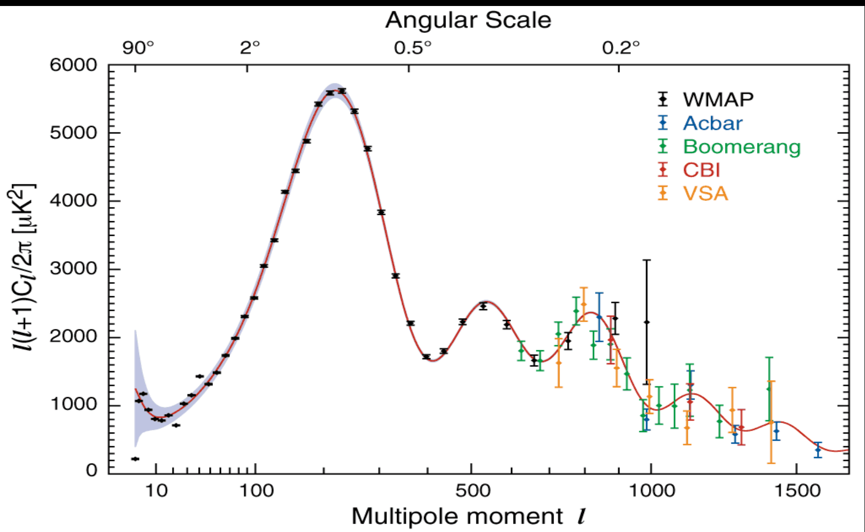
Vroč plin (X žarki)

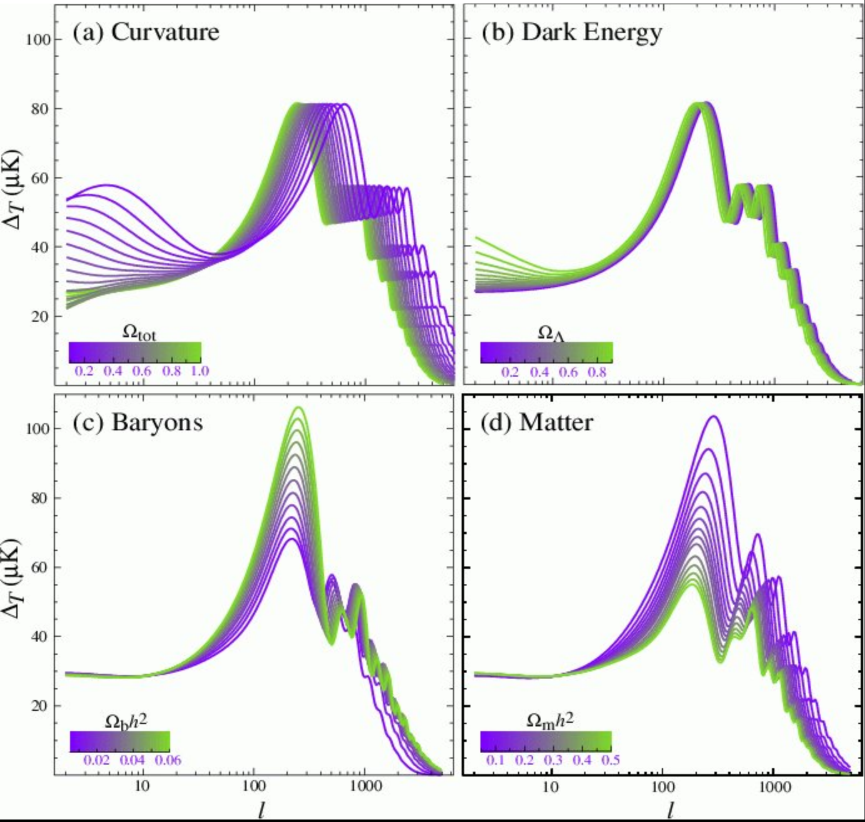
Večina mase:
temna snov

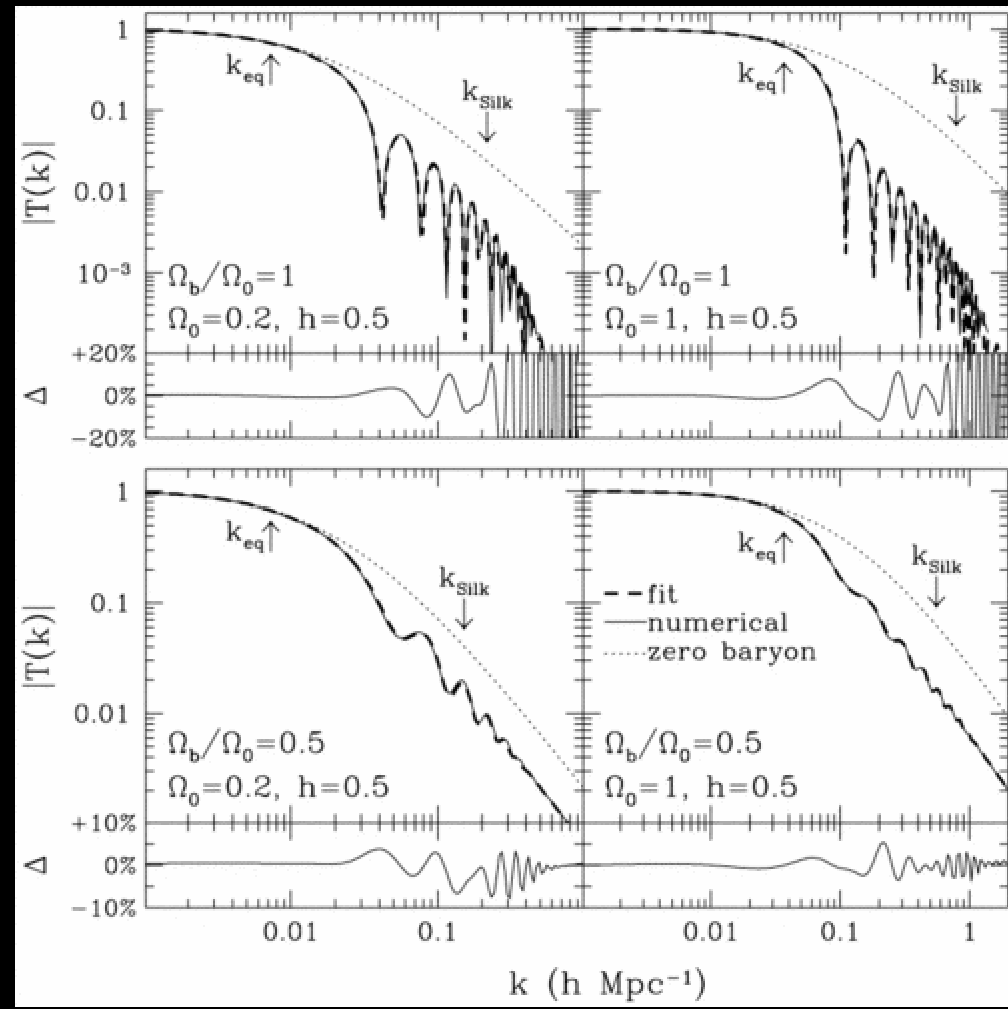


Ovojnice
enake gostote

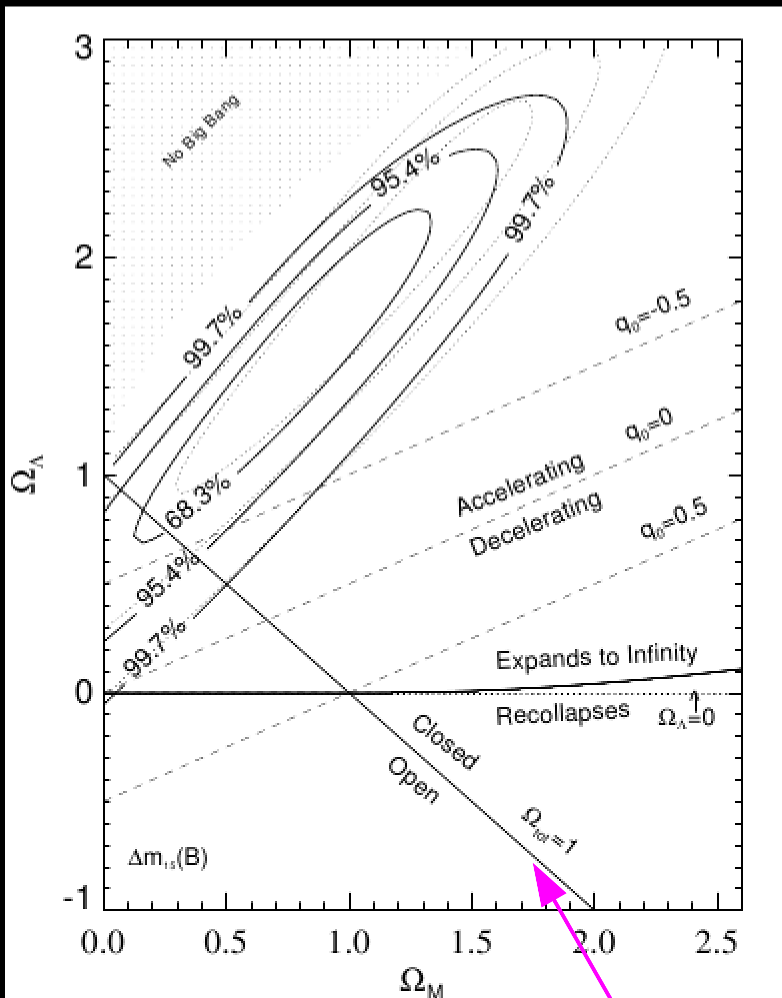
Temna snov – Prasevanje

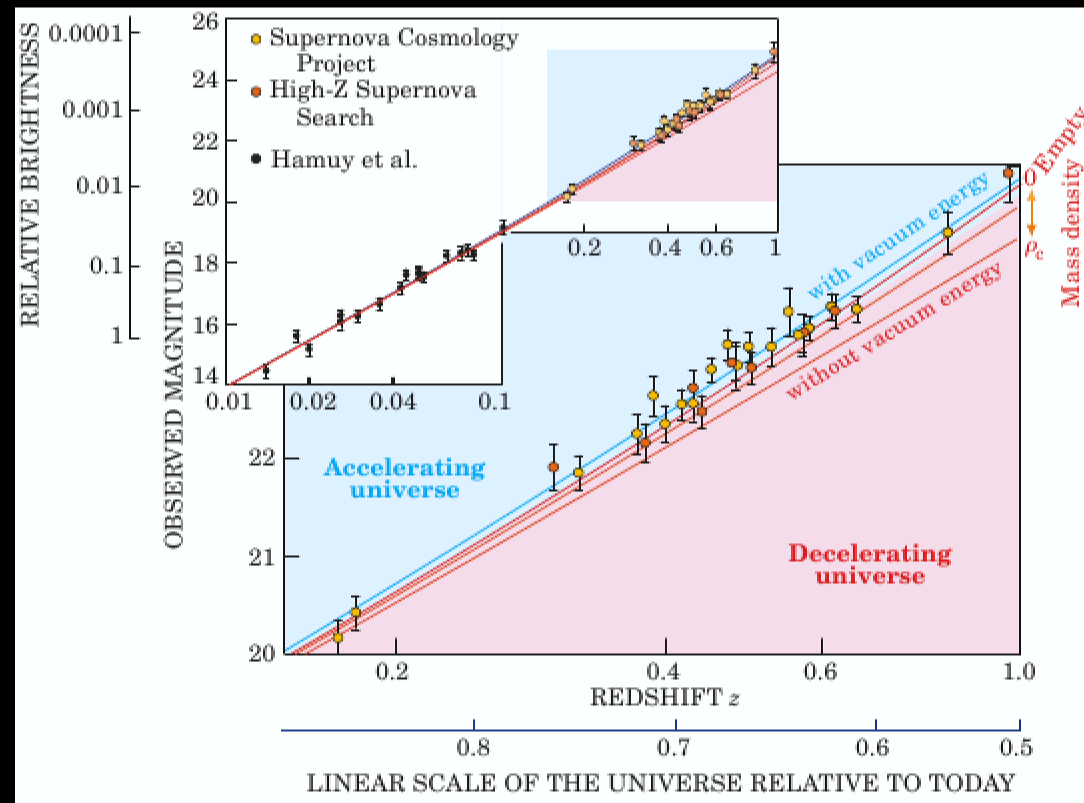






Temna energija – supernove tipa Ia





$$m - M = 5\log_{10}\left(\frac{d_L}{\mathrm{Mpc}}\right) + 25,$$

$$\chi(z) = \int_0^z \frac{dz'}{H(z')}.$$

$$d_L(z) = (1+z)\begin{cases} \frac{1}{\sqrt{k}}\sin(\chi(z)\sqrt{k}) & k>0 \\ \chi(z) & k=0 \\ \frac{1}{\sqrt{-k}}\sinh(\chi(z)\sqrt{-k}) & k<0 \end{cases}$$

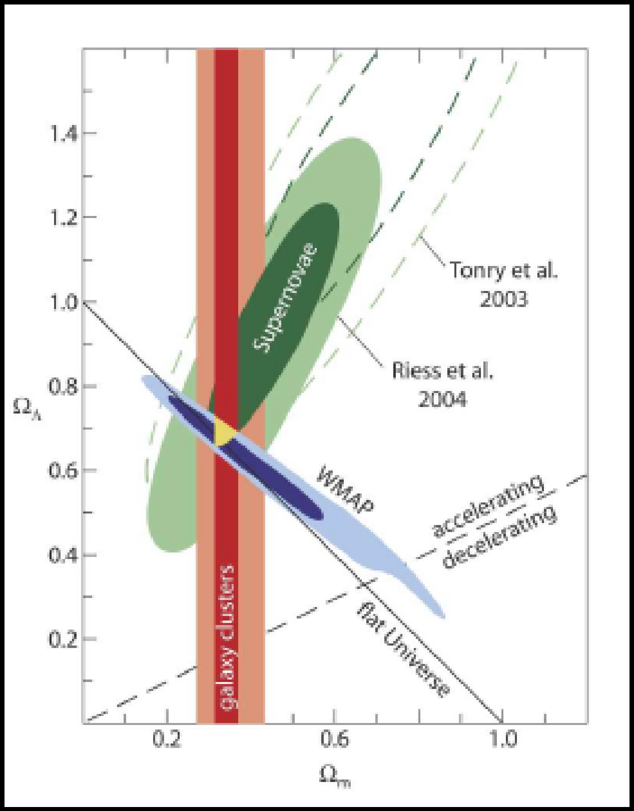
$$\left(\frac{H}{H_0}\right)^2 = \frac{\Omega_m}{a^3} + \frac{\Omega_k}{a^2} + \Omega_\Lambda,$$

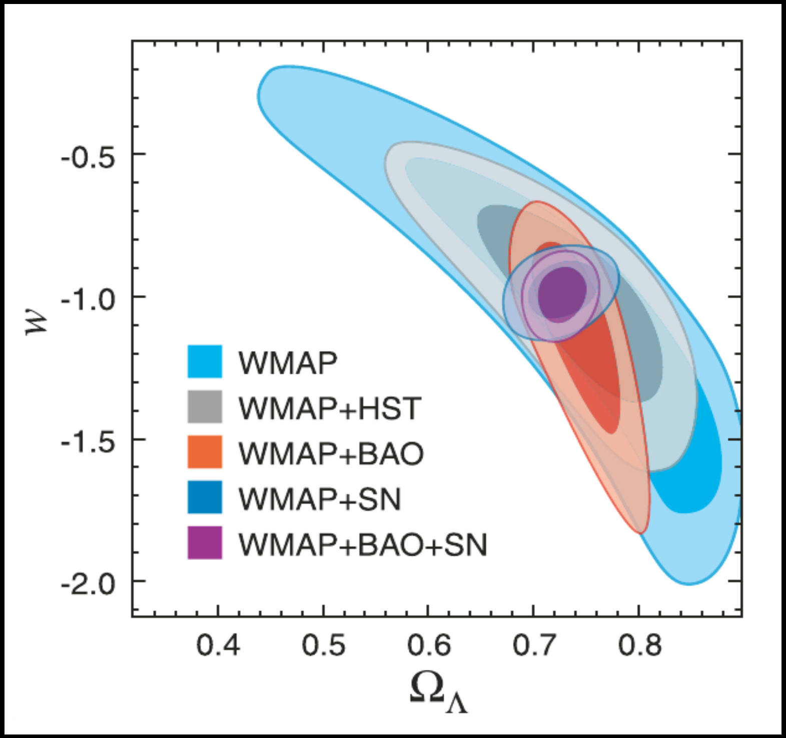
k=0

$$\Omega_k = -k/H_0^2$$

$$1+z = 1/a$$

Lastnosti temne snovi in temne energije





$$w = \frac{p}{\rho c^2}$$

$$\Omega_m = 0.275 \pm 0.015, \qquad \Omega_\Lambda = 0.725 \pm 0.016.$$

$$\Omega_{cdm} = 0.228 \pm 0.015, \qquad \Omega_\Lambda = 0.727 \pm 0.016.$$

Narava temne snovi in temne energije

Temna snov

- WIMP (angl. Weakly Interacting Massive Particles) – šibko sklopljeni masivni delci
- Supersimetrični partnerji, težki sterilni nevtrini, lahko nevtrini, itd.
- Ločimo 3 tipe: CDM (hladna), WDM (topla), HDM (vroča) – glede na njihovo maso/hitrost
- Alternativne teorije: teorija strun, kvantna gravitacija, MOND (popravljena Newtonova teorija)

Temna energija

- Kozmološka konstanta
- Kvintesence, k-esence, vektorska inflacija – temna energija kot tekočina
- Višje dimenzije, M-Brane, f(R) teorije, TeVeS, masivna skalarna polja, Brans-Dicke teorije ← znanstvena fantastika :-)

Temna energija - teorije
(hic svnt dracones)

Kozmološka konstanta – energija vakuuma

$$\rho_\Lambda \equiv \frac{\Lambda c^2}{8\pi G} \propto \int^{\Lambda_c} d^3p \frac{1}{2}\sqrt{p^2+m^2} \sim \Lambda_c^4$$

$$\rho_\Lambda \sim M_{pl}^4 \sim 10^{73}\ \mathrm{GeV}^4$$
$$\rho_{de}^{obs} \sim 10^{-47}\ \mathrm{GeV}^4$$

Einsteinova splošna teorija gravitacije

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2\kappa}(R-2\Lambda)+\mathcal{L}_m\right]$$

$$\kappa = 8\pi G/c^4$$

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}(T_{\mu\nu}+T_{\mu\nu}^{\mathrm{vac}})$$

+ FRW metrika

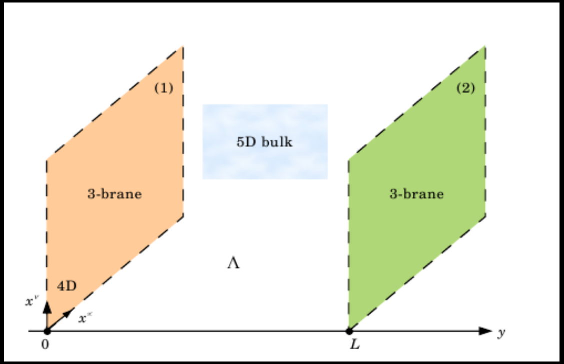
$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu = -c^2dt^2 + a^2\left[\frac{dr^2}{1-kr^2}+r^2\left(d\theta^2+\sin^2\theta d\varphi^2\right)\right]$$

$$\left(\frac{H}{H_0}\right)^2 = \frac{\Omega_m}{a^3}+\frac{\Omega_k}{a^2}+\Omega_\Lambda,$$

Višje dimenzije – Randall-Sundrum model

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

$$A(y) = k|y|$$



Kvintesence

$$S = \int d^4x\sqrt{-g}\left[\partial_\mu\phi\,\partial^\mu\phi - V(\phi)\right]$$

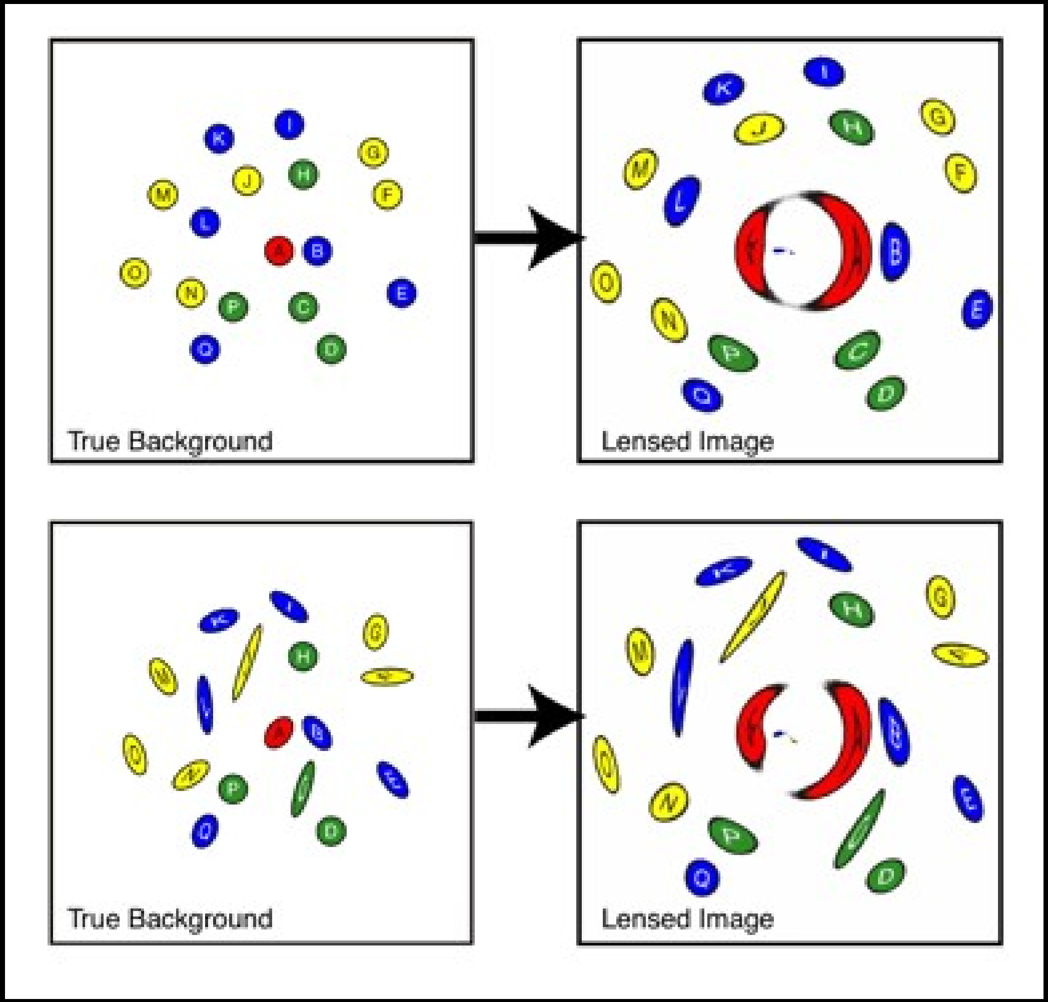
Brans-Dicke teorija

$$S = \int d^4x\sqrt{-g}\left[\frac{c^4}{16\pi}\left(\varphi R + \omega\frac{\partial_\mu\varphi\,\partial^\mu\varphi}{\varphi}\right)+\mathcal{L}_m\right]$$

$$G^{-1} \sim \varphi$$

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2\kappa}(\phi R + f(\phi)) + \mathcal{L}_m\right]$$

Hvala za pozornost! :-)



$$\mathcal{A} = \frac{1}{16\pi}\int\left(\phi R + \omega\frac{\phi_\mu\phi^\mu}{\phi}\right)\sqrt{-g}d^4x + \int T\sqrt{-g}d^4x.$$

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = -\frac{8\pi}{\phi}T_{\mu\nu} - \frac{\omega}{\phi^2}\left(\phi_\mu\phi_\nu - \frac{1}{2}g_{\mu\nu}\phi^\alpha\phi_\alpha\right) - \frac{1}{\phi}(\phi_{\mu\nu} - g_{\mu\nu}\Box\phi).$$

$$\frac{\dot{a}^2}{a} + \frac{k}{a^2} = \frac{8\pi}{3}\frac{\rho}{\phi} - \frac{\dot{\phi}}{\phi}\frac{\dot{a}}{a} + \frac{\omega}{6}\frac{\dot{\phi}^2}{\phi^2}$$

$$\dot{\phi} = \frac{1}{a^3}\frac{8\pi}{2\omega+3}\int_0^t(\rho - 3p)a^3dt + \frac{v_0}{a^3},$$