Scalaron the Mighty

Dmitry Gorbunov, A. Panin

Institute for Nuclear Research, Moscow, Russia

16th International Seminar on High Energy Physics,
Kolomna, Russia, 08.06.2010

In a few words...

We show that

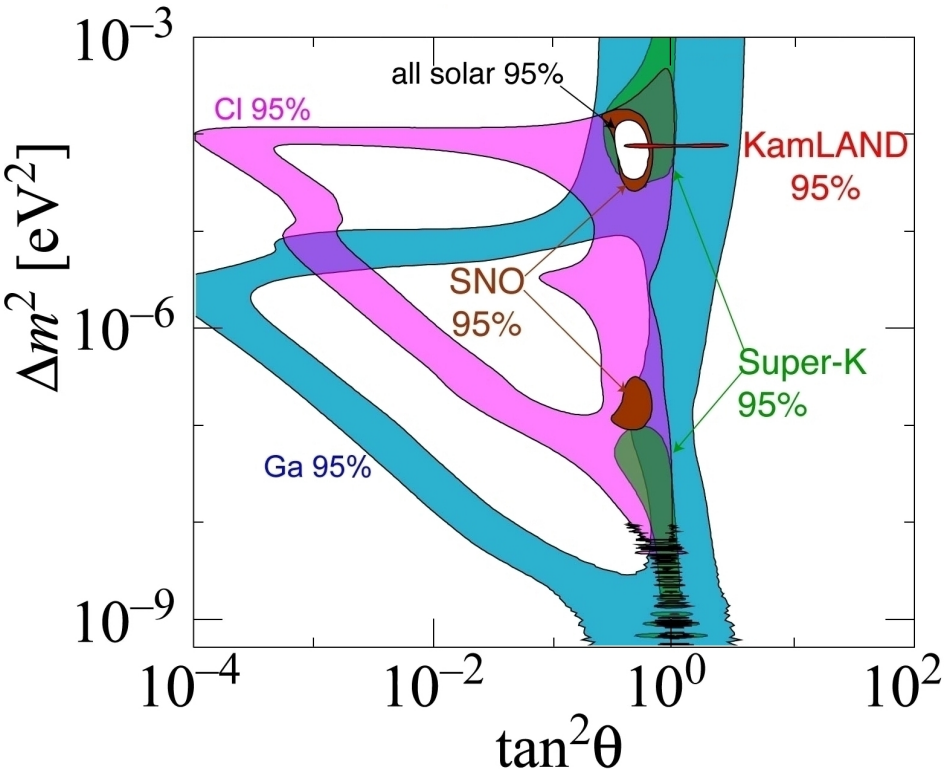
in R^2-inflation
the most universal interaction
— gravity —
fully responsible for the reheating
is also capable of producing

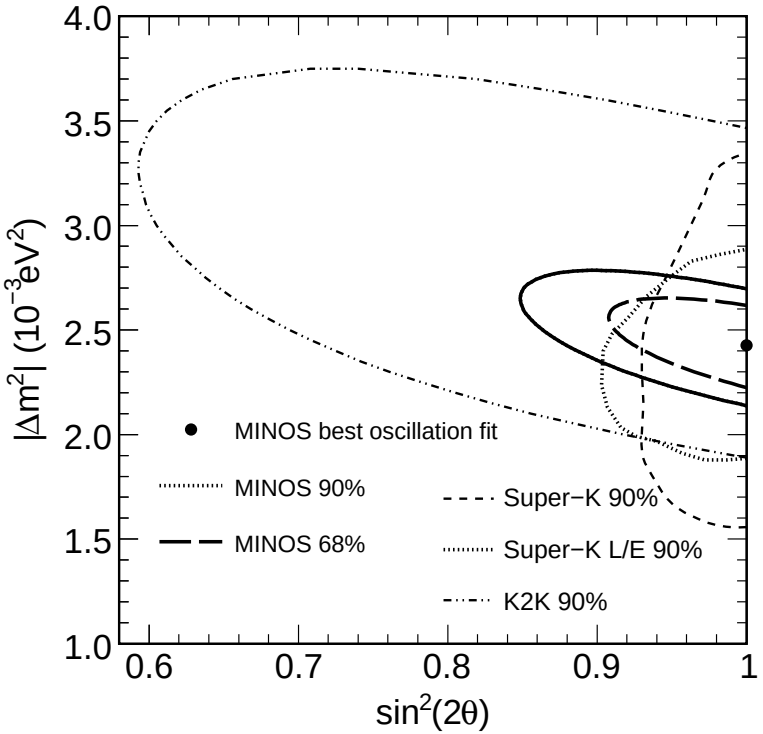
dark matter (free heavy fermions)
and
baryon asymmetry (leptogenesis via see-saw sterile neutrinos)

Outline

Outline

Neutrino Oscillations: Masses and Mixing



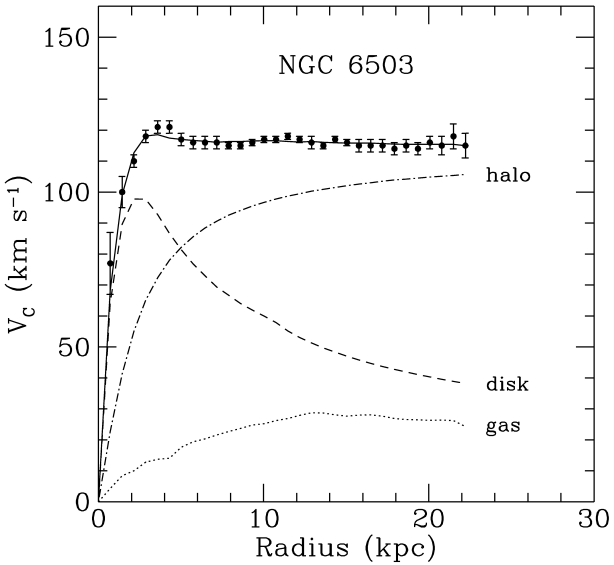


http://hitoshi.berkeley.edu/neutrino/

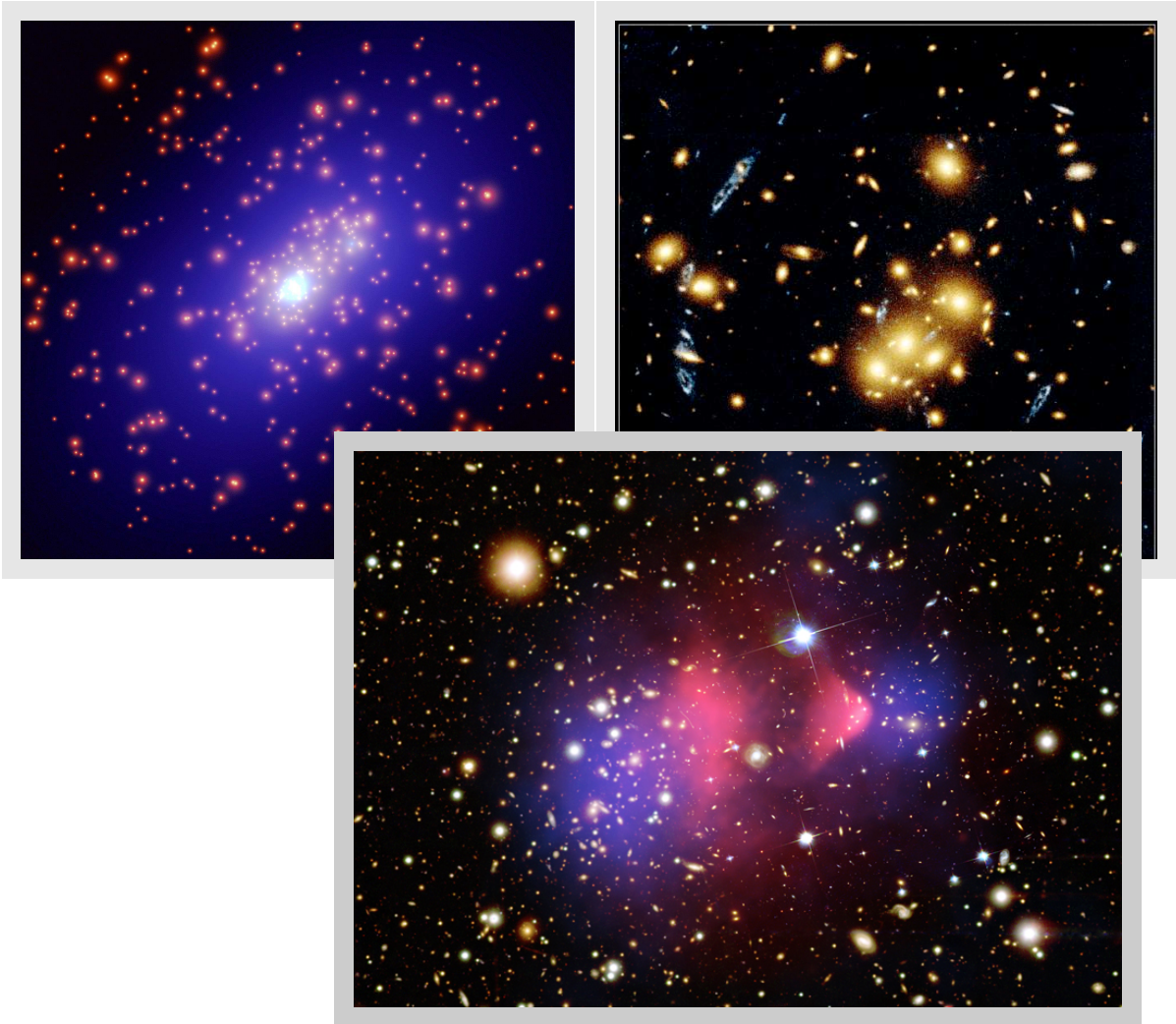
arXiv:0806.2237

Baryons and Dark Matter in Astrophysics

Rotation curves



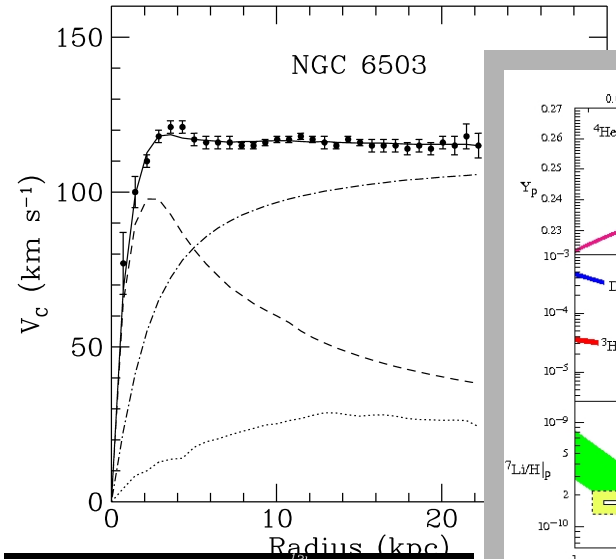
Gravitational lensing



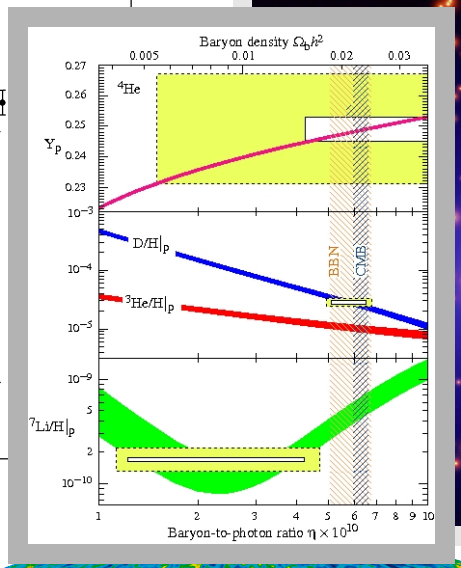
"Bullet" cluster

Baryons and Dark Matter in Cosmology

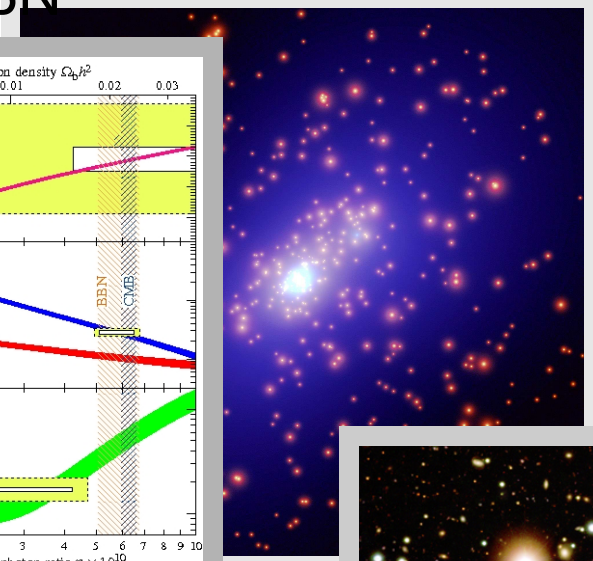
Rotation curves

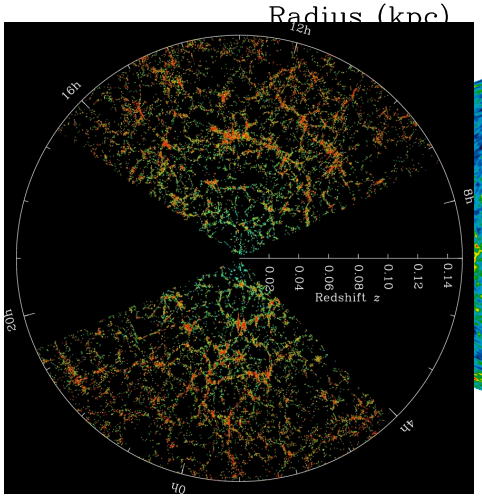


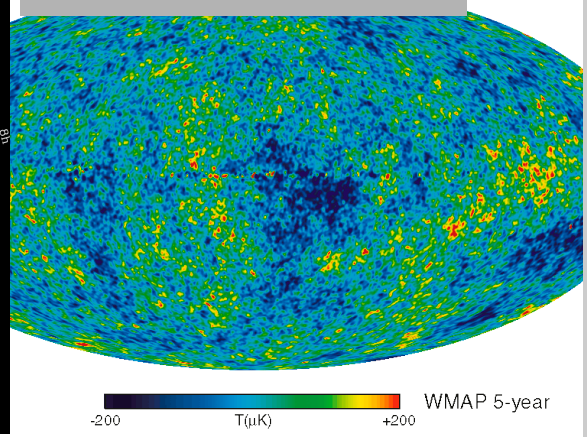
BBN



Gravitational lensing





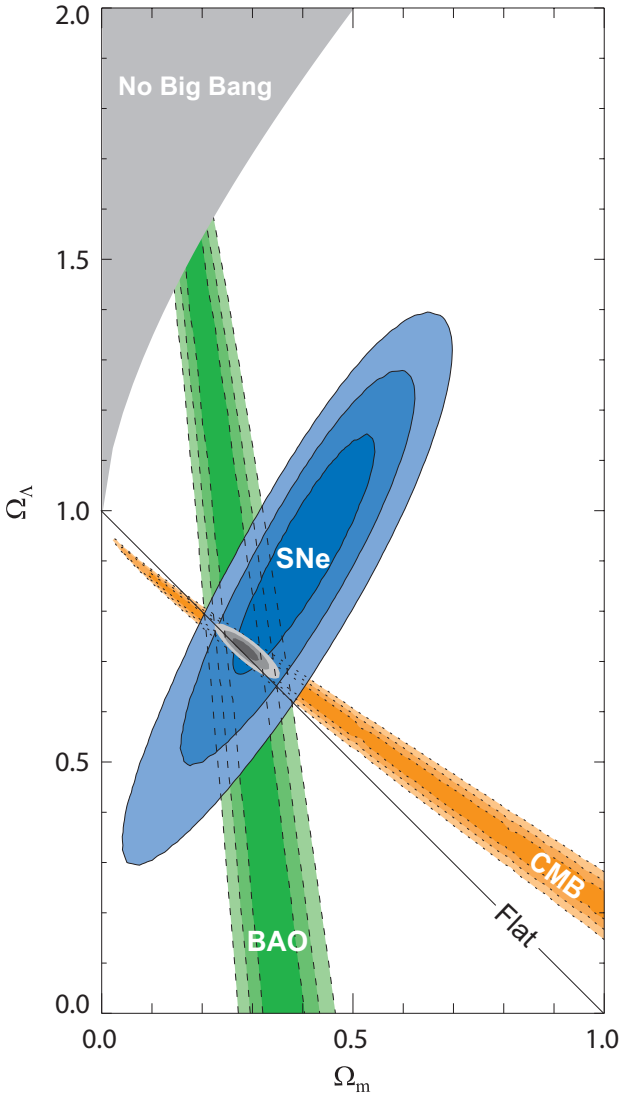


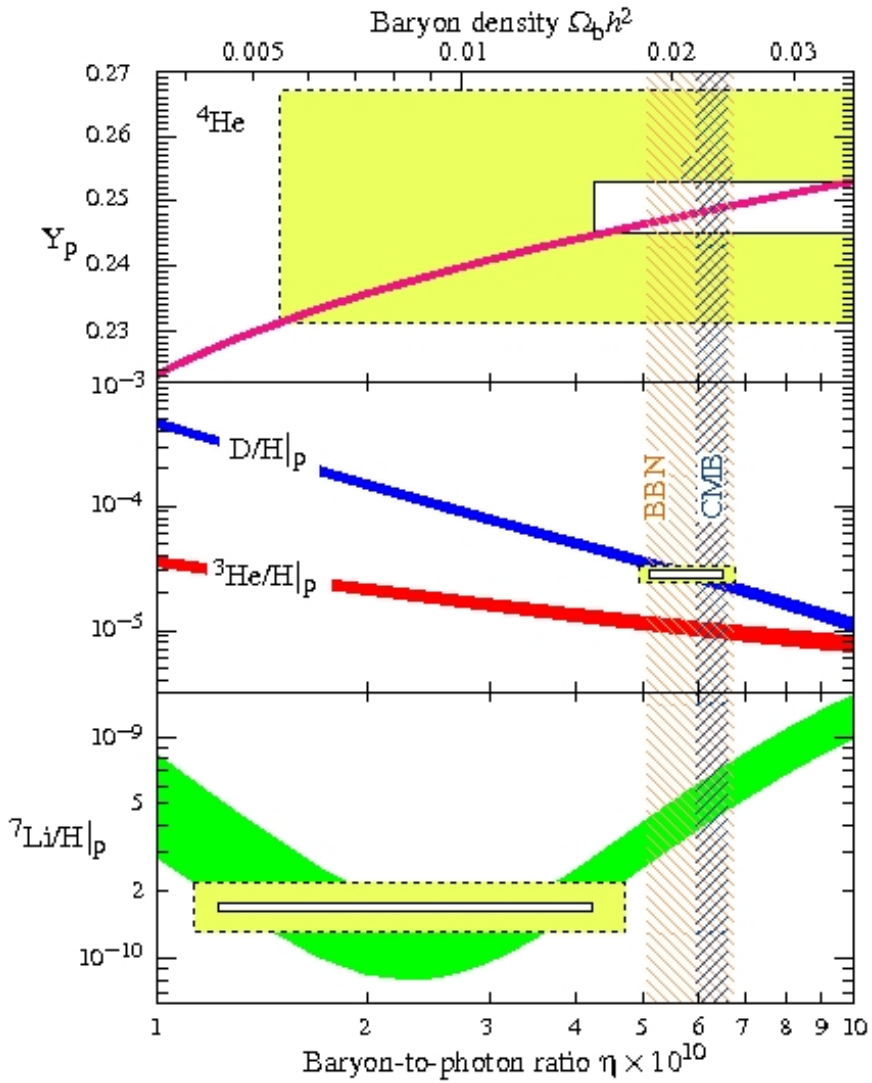
Structures

CMB fluctuations

"Bullet" cluster

Cosmological parameters: $\Omega_{DM} = 0.22$, $\Omega_B = 0.046$

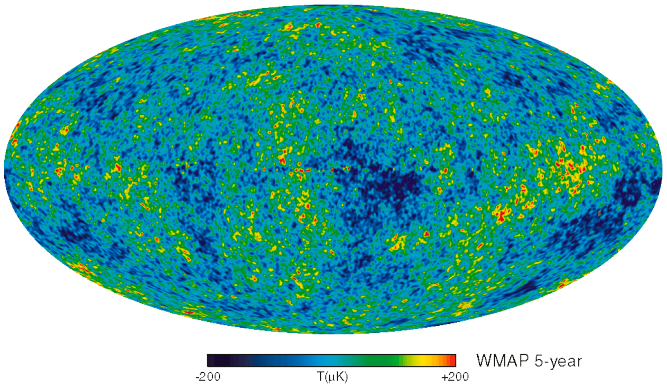


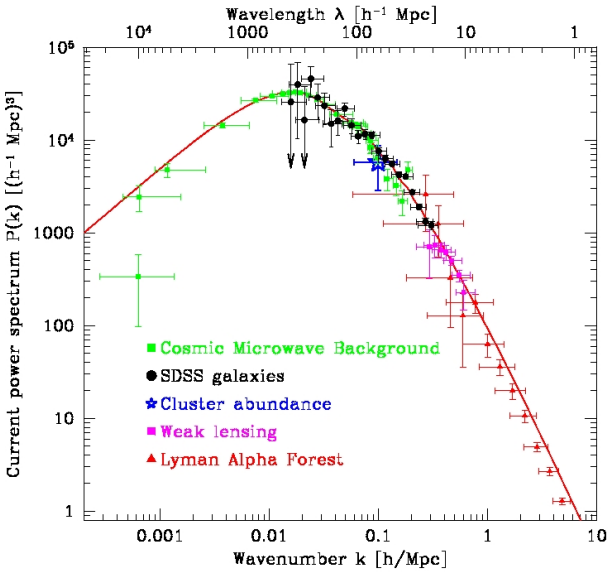


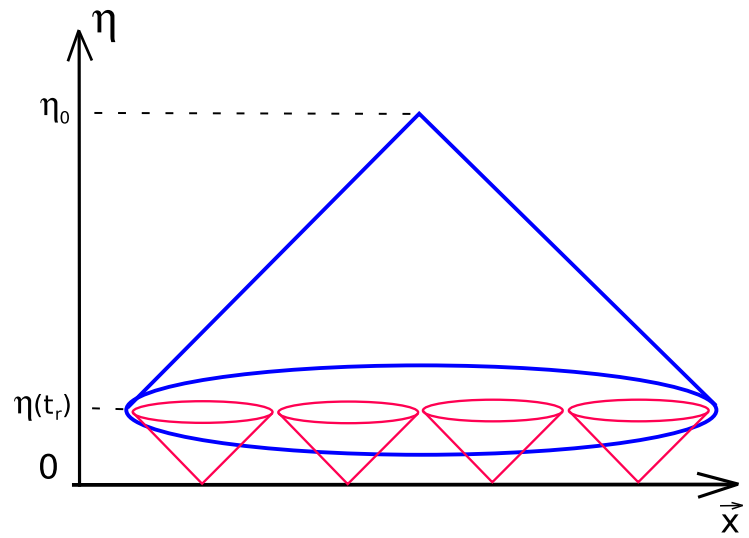
arXiv:0804.4142

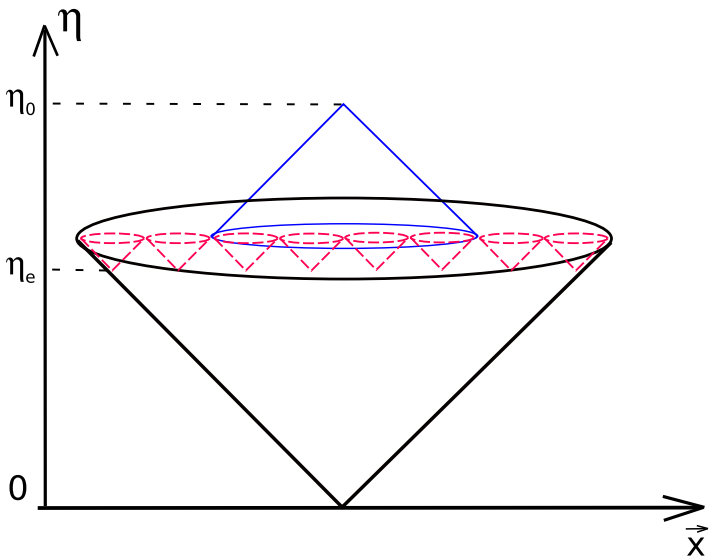
http://pdg.lbl.gov

Inflationary solution of Hot Big Bang problems









True Extension of the Standard Model should

- Reproduce the correct neutrino oscillations
- Contain the viable DM candidate
- Be capable of explaining the baryon asymmetry of the Universe
- Have the inflationary mechanism operating at early times

Outline

Inflation: R^2 term

$$S^{JF} = -\frac{M_P^2}{2}\int\sqrt{-g}\,d^4x\left(R-\frac{R^2}{\mu^2}\right)+S^{JF}_{matter}\,,$$

Jordan Frame $\rightarrow$ Einstein Frame

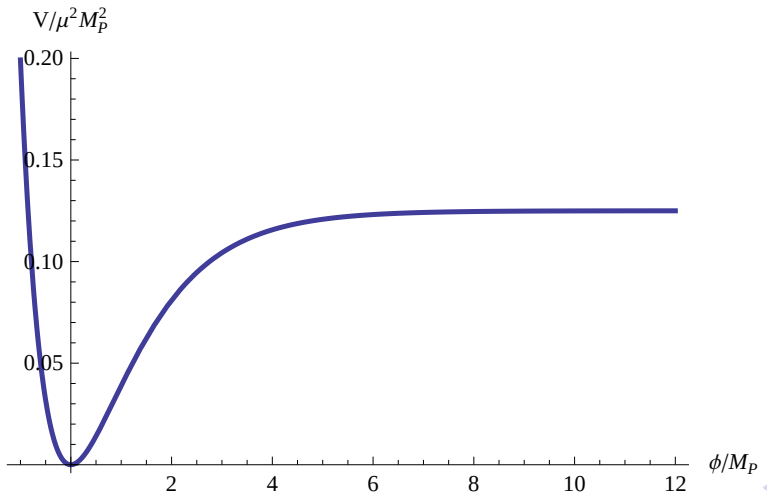
A.Starobinsky (1979,1980)

$$g_{\mu\nu}\rightarrow\tilde{g}_{\mu\nu}=\chi\,g_{\mu\nu}\,,\qquad \chi=\exp\left(\sqrt{2/3}\,\phi/M_P\right)\,.$$

$$S^{EF}=\int\sqrt{-\tilde{g}}\,d^4x\left[-\frac{M_P^2}{2}\,\tilde{R}+\frac{1}{2}\,\tilde{g}^{\mu\nu}\,\partial_\mu\phi\,\partial_\nu\phi-\frac{\mu^2M_P^2}{8}\left(1-\frac{1}{\chi(\phi)}\right)^2\right]+S^{EF}_{matter}\,,$$

generation of (almost) scale-invariant scalar perturbations from freezed in quantum fluctuations

$\delta\rho/\rho\sim 10^{-5}$ requires
$\mu=\sqrt{6}\,m_\phi\approx 3.2\times 10^{-5}\,M_P$



Post-inflationary Reheating: provided by gravity

$$S^{JF}_{matter} = S(g_{\mu\nu}, \varphi, A_\mu, \dots) \to S^{EF}_{matter} = S(\tilde{g}_{\mu\nu}, \varphi, A_\mu, \dots)$$

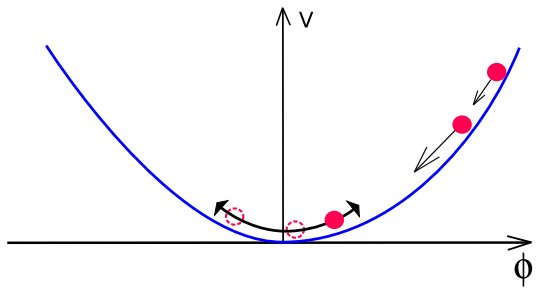
$$g_{\mu\nu} \to \tilde{g}_{\mu\nu} = \chi\, g_{\mu\nu}\,, \qquad \chi = \exp\left(\sqrt{2/3}\,\phi/M_P\right)\,.$$

for free (in the Jordan frame) scalar and fermion field:

$$S^{EF}_s = \int \sqrt{-\tilde{g}}\, d^4x \left(\frac{1}{2}\,\tilde{g}^{\mu\nu}\partial_\mu\tilde{\varphi}\partial_\nu\tilde{\varphi} - \frac{1}{2\chi}\, m_s^2\tilde{\varphi}^2 - \frac{\tilde{\varphi}^2}{12\,M_P^2}\,\tilde{g}^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - \frac{\tilde{\varphi}}{\sqrt{6}\,M_P}\,\tilde{g}_{\mu\nu}\partial_\mu\tilde{\varphi}\partial_\nu\phi \right)\,,$$

$$S^{EF}_\psi = \int \sqrt{-\tilde{g}}\, d^4x \left(i\bar{\tilde{\psi}}\tilde{\gamma}^\mu\partial_\mu\psi - \frac{m_\psi}{\sqrt{\chi}}\,\bar{\tilde{\psi}}\tilde{\psi} \right)\,.$$

$$\varphi \to \tilde{\varphi} = \chi^{-1/2}\,\varphi\,, \quad \psi \to \tilde{\psi} = \chi^{-3/4}\,\psi$$



Reheating: decay of scalarons

$$\rho_\phi = m_\phi^2 \phi^2/2 = m_\phi n_\phi \to \rho_{rad} \propto T^4$$

$$\Gamma_{\phi\to ss} = \frac{m_\phi^3}{384\pi M_P^2}\left(1-2\,\frac{m_s^2}{m_\phi^2}\right)^2 ,$$

$$\Gamma_{\phi\to\bar\psi\psi} = \frac{m_\phi\, m_\psi^2}{12\pi M_P^2} .$$

$$T_{reh} \approx 1.3\times 10^{-2}\times g_*^{-1/4}\cdot\left(\frac{N_{scalars}\,\mu^3}{M_P}\right)^{1/2} ,$$

astro-ph/0612569

for the SM with 4 scalar degrees of freedom:

$$T_{reh} \approx 4\times 10^9\ \mathrm{GeV}$$

Outline

Dark Matter generation in scalaron decays

The same universal messenger: gravity

$\rho_\phi = m_\phi^2 \phi^2/2 = m_\phi n_\phi \to \rho_{DM} = m_{DM} n_{DM}$

$$\Gamma_{\phi\to ss} = \frac{m_\phi^3}{384\pi M_P^2}\left(1-2\,\frac{m_s^2}{m_\phi^2}\right)^2 ,$$

$$\Gamma_{\phi\to\bar\psi\psi} = \frac{m_\phi\, m_\psi^2}{12\pi M_P^2} .$$

$$m_s = 20\ \mathrm{keV}\times\left(\frac{3.2\times10^{-5}\,M_P}{\mu}\right)^{1/2}\left(\frac{N_{scalars}}{4}\right)\left(\frac{106.75}{g_*}\right)^{3/4}\left(\frac{\Omega_{DM}}{0.223}\right) ,$$

$$m_f = 10^7\ \mathrm{GeV}\times\left(\frac{\mu}{3.2\times10^{-5}\,M_P}\right)^{1/2}\left(\frac{N_{scalars}}{4}\right)^{1/3}\left(\frac{106.75}{g_*}\right)^{1/4}\left(\frac{\Omega_{DM}}{0.223}\right)^{1/3} .$$

Heavier stable particles are excluded!

Outline

Seesaw neutrinos from scalaron decays

The same universal messenger: gravity

$\rho_\phi = m_\phi^2 \phi^2/2 = m_\phi n_\phi \rightarrow \rho_N = m_N n_N$

$$\mathscr{L}^{JF} = i\bar{N}_I \gamma^\mu \partial_\mu N_I - y_{\alpha I} \bar{L}_\alpha N_I \tilde{\Phi} - \frac{M_I}{2} \bar{N}_I^c N_I + h.c.$$

$$\frac{n_{N_I}}{s}(T_{reh}) = 0.7 \times 10^{-3} \times \left(\frac{M_I}{5 \times 10^{12}\ \mathrm{GeV}} \right)^2 .$$

seesaw mechanism:

$$m_{\nu\ \alpha\beta} = -\sum_I y_{\alpha I} \frac{v^2}{M_I} y_{\beta I} ,$$

neutrino of $M_N > 10^{10}$ GeV decays before reheating:

$$\Gamma_{N_I} = \frac{M_I}{4\pi} \sum_\alpha |y_{\alpha I}|^2 \sim \frac{\sqrt{\Delta m^2_{atm}}}{2\pi} \frac{M_I^2}{v^2} .$$

Lepton asymmetry from seesaw neutrino decays

Only the lightest sterile neutrino contribution ($l = 1, 2$, $M_1 \ll M_2$) is enough

$$\delta_L = \frac{\Gamma(N_1 \to hl) - \Gamma(N_1 \to h\bar{l})}{\Gamma_{N_1}^{tot}} \lesssim \frac{M_1 \sqrt{\Delta m^2_{atm}}}{6\pi v^2}$$

an order of magnitude estimate for the asymmetry right before the reheating

$$\Delta_L = \frac{n_L}{s} = \delta_L \cdot \frac{n_{N_1}}{s} \lesssim 1.7 \times 10^{-7} \times \left(\frac{M_1}{5 \times 10^{12}\ \mathrm{GeV}} \right)^3 .$$

Outline

Summary

Simple inflationary model R^2
extended by three sterile fermions (neutrinos)
explains

- active neutrino masses and mixing angles
- DM as 10^7 GeV free fermions
- baryon asymmetry via leptogenesis with seesaw sterile neutrinos of 10^{12}-10^{13} GeV

All this is due to universal coupling of scalaron to matter provided by gravity