Particle production in Starobinsky model of dark energy

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★ $M = 3 \times 10^{13}$ GeV is appropriate for the Starobinsky inflation

A. A. Starobinsky, "Disappearing cosmological constant in f(R) gravity," JETP Lett. **86**, 157 (2007) [arXiv:0706.2041 [astro-ph]]

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$$V(\phi) = \frac{M_P^2}{2F'(R(\phi))^2} \left(RF'(R) - F(R) \right) ,$$

$$F'(R) = e^{2\phi/(\sqrt{6}M_P)} \to R(\phi)$$

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The scalaron mass:

$$\boxed{m^2 = V''_{eff}(\phi_{min})}$$

Scalaron as a chameleon

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★ In a paper E. V. Arbuzova, A. D. Dolgov and L. Reverberi, "Particle Production in $f(R)$ Gravity during Structure Formation," Phys. Rev. D **88**, no. 2, 024035 (2013) [arXiv:1305.5668 [gr-qc]] the calculation of particle production was carried in the Jordan frame. But the choice of initial conditions – pure GR solution – look questionable. We calculate the number of created particles starting from more realistic vacuum initial conditions.

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- Vacuum initial conditions at $t = 0$:

$$\phi = 1/\sqrt{2\omega}, \quad \dot{\phi} = -i\omega\phi, \quad \omega = \sqrt{k^2 + m_0^2 e^{2\beta t}}$$

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$$n_p = 8.7\cdot 10^{-87}\mathrm{cm}^{-3}\cdot\frac{(n+1)^2}{\sqrt{12n(2n+1)}}\left(\frac{\lambda}{2}\right)^n\alpha^{n+2}$$

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- star formation in our galaxy

Star formation in our galaxy

Star formation starts in the cloud of the Jeans length with density

$$\frac{\rho_0}{\rho_\Lambda} = \alpha = 3.7 \cdot 10^{16} \left(\frac{M_\odot}{M_*}\right)^2 \left(\frac{T}{100K}\right)^3 .$$

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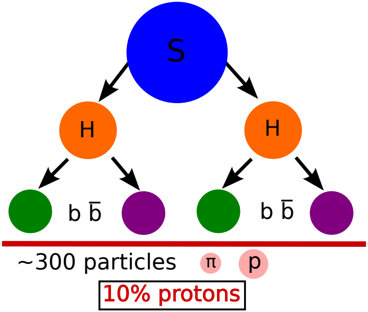
The spectrum has a cutoff at $m \sim M$

Products of scalaron decays: UHE protons



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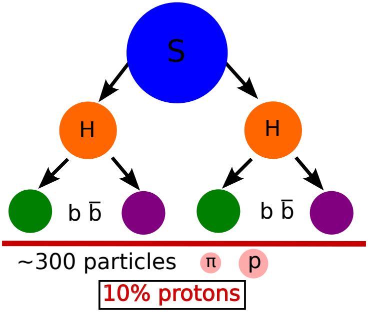

Proton mean free path in the contracting protostar with radius R:

$$\frac{\lambda_p}{R} = 0.05 \frac{M_*}{M_\odot} \left(\frac{T}{100\,K} \right)^{-2}$$

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- $N_b \sim 300$ – full number of produced particles
- n_p – scalaron number density
- R – star radius
- $r \sim 10$ kpc – average distance in our galaxy
- t_J – the time of exponential contraction (free fall)
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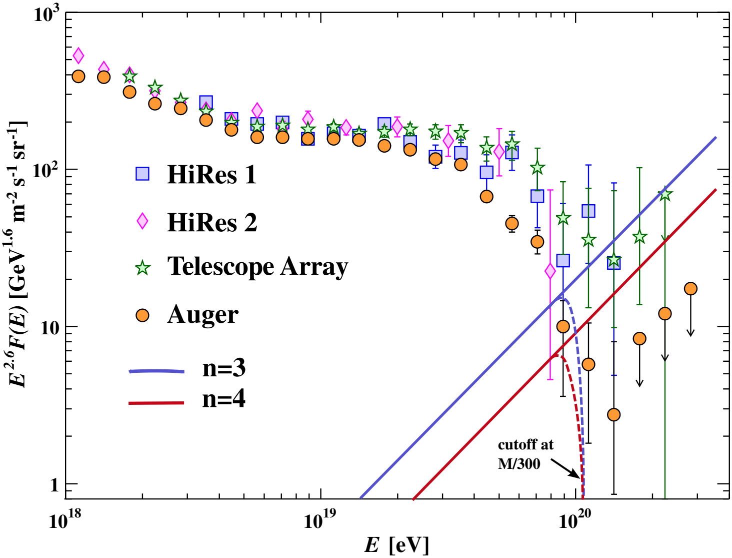
UHE CR spectrum



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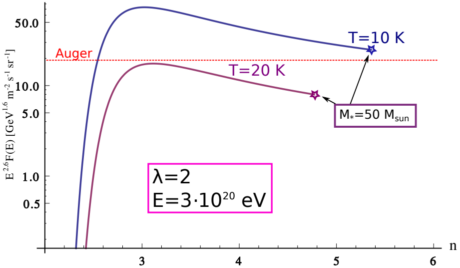

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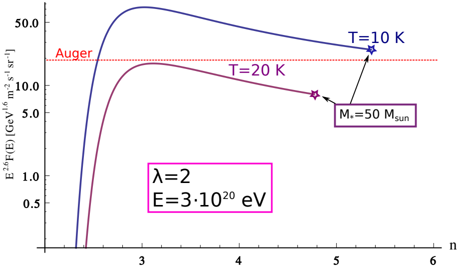

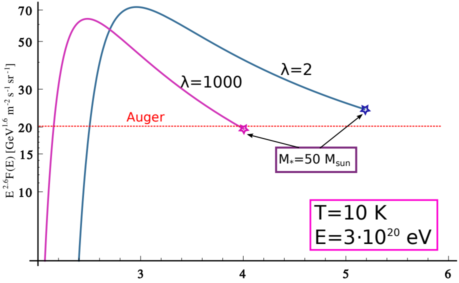

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- A calculation of the scalaron creation in contracting objects based on vacuum initial conditions was carried out.
- The proton flux from the star formation processes in our galaxy may give a significant impact to the UHE CR quadrupole anisotropy.
- For some values of the parameter n ($n = 3 \div 6$) we can conclude that maximal scalaron mass M must be $M < 9 \times 10^{13}$ GeV.

Thanks for your attention!