A brief overview of astro-particle physics

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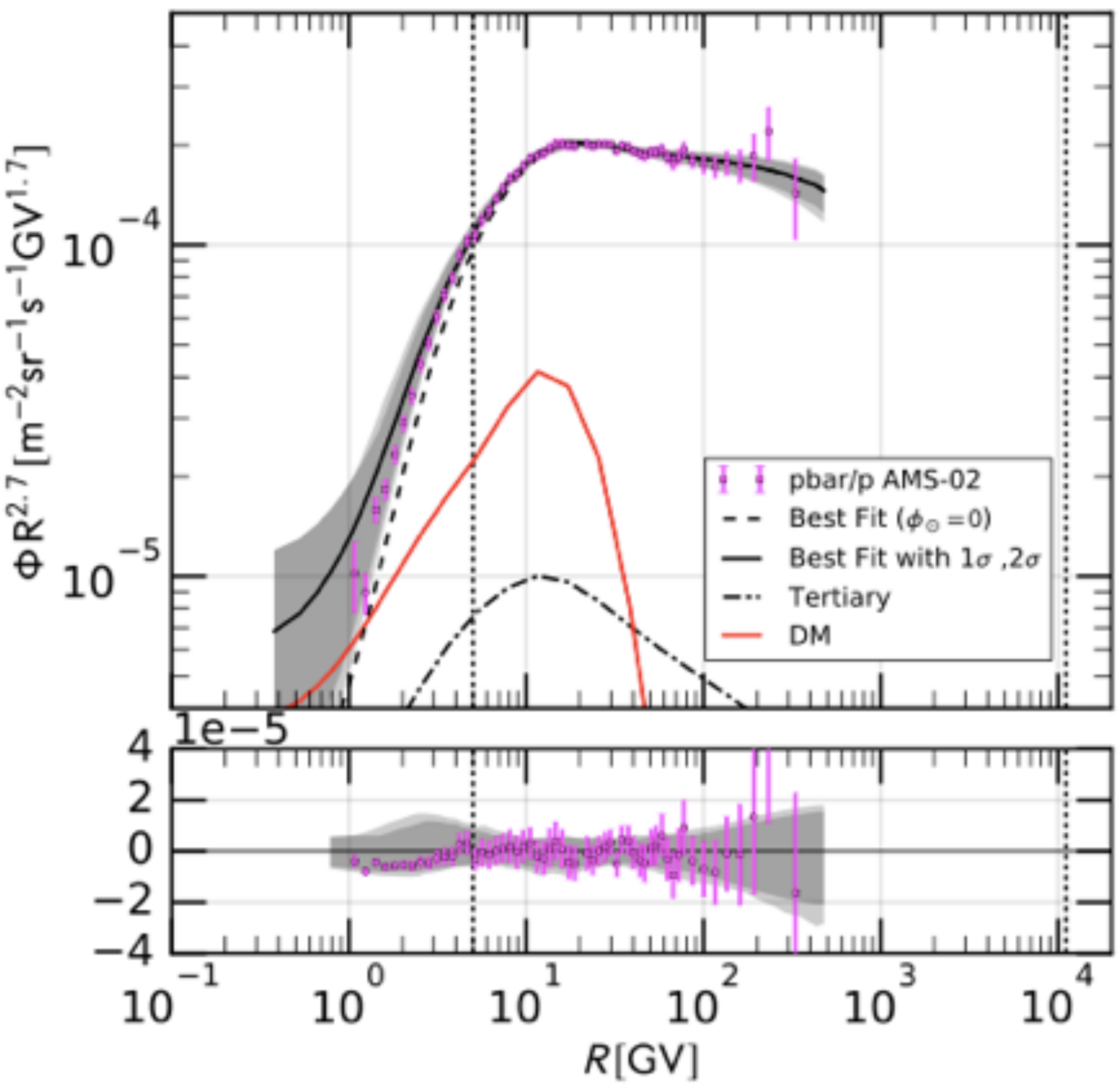
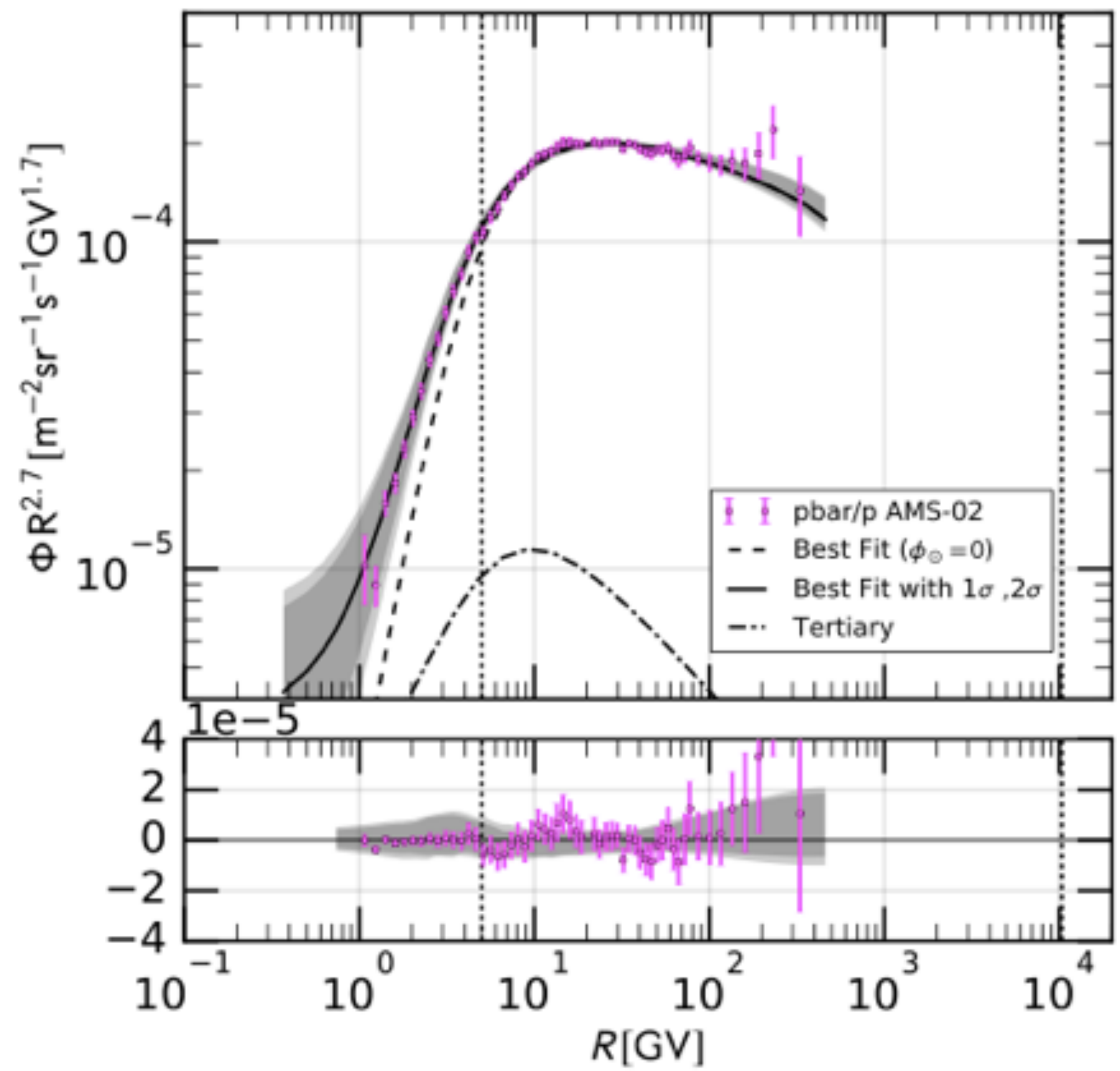
Signal for DM in AMS-02 antiproton flux measurement

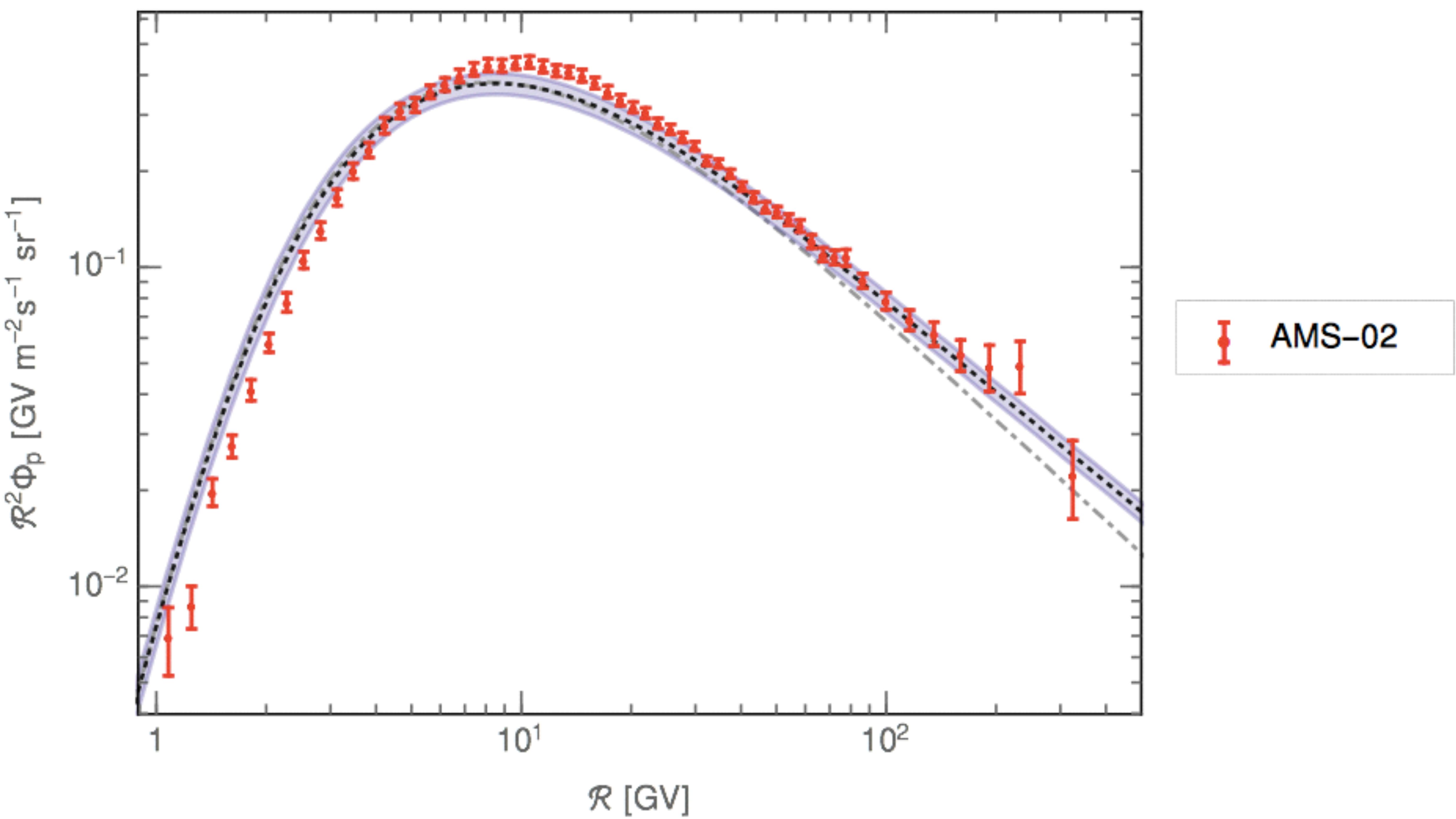
M. Aguilar et al. (AMS), Phys. Rev. Lett. 117 (2016)



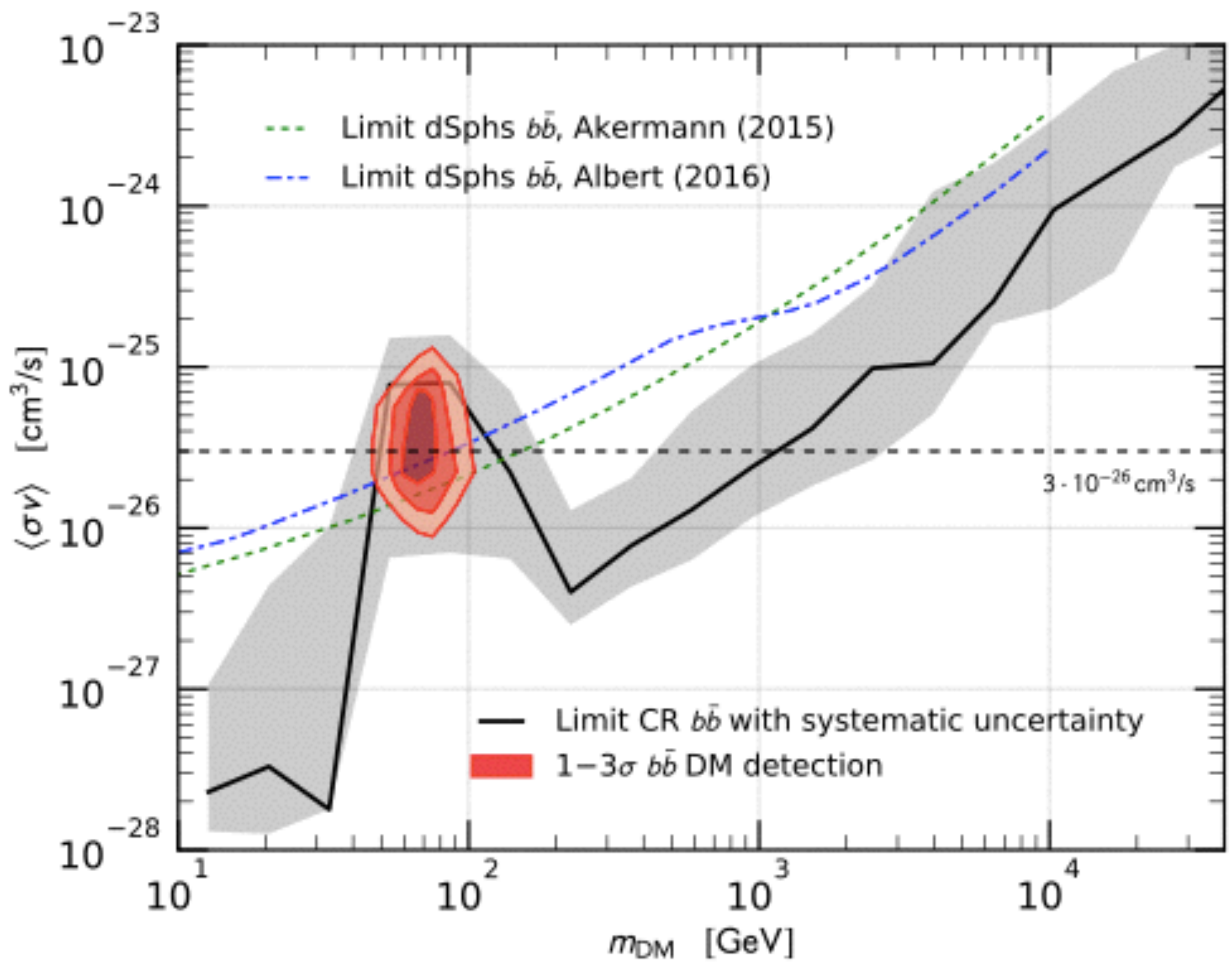


Cuoco, Krämer, Korsmeier, Phys , Rev Lett (2017),
Cuia,Yuana, Tsaib, Fan, Phys, Rev Lett (2017)

2-sigma discrepancy between secondary antiproton prediction and AMS-02 measurement

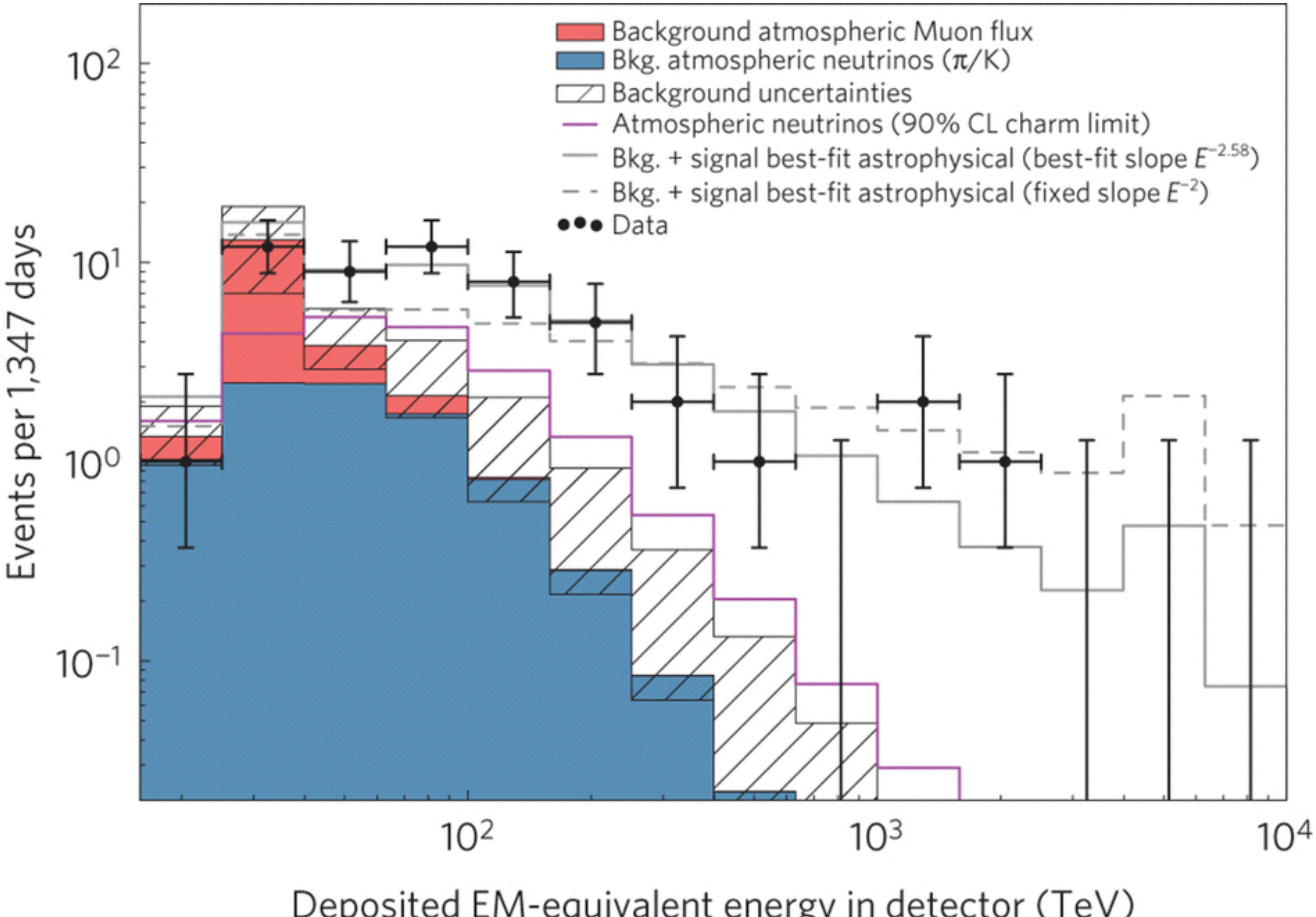


M.W.Winkler , JCAP (2017)



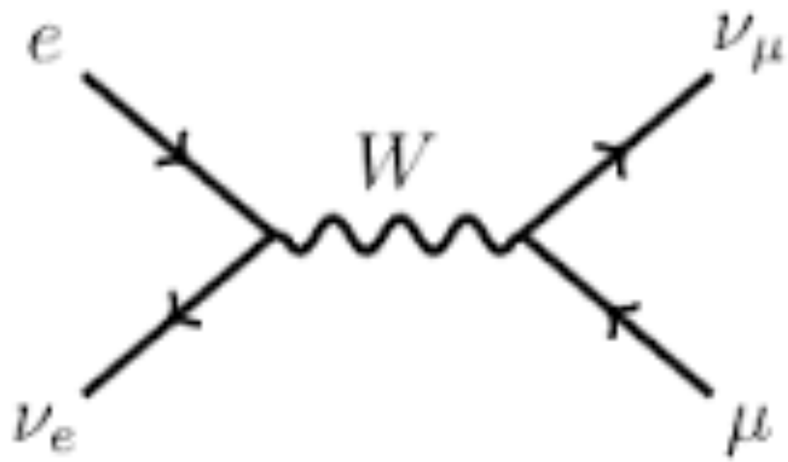
Cuoco, Krämer, Korsmeier, Phys , Rev Lett (2017),
Cuia,Yuana, Tsaib, Fan, Phys, Rev Lett (2017)

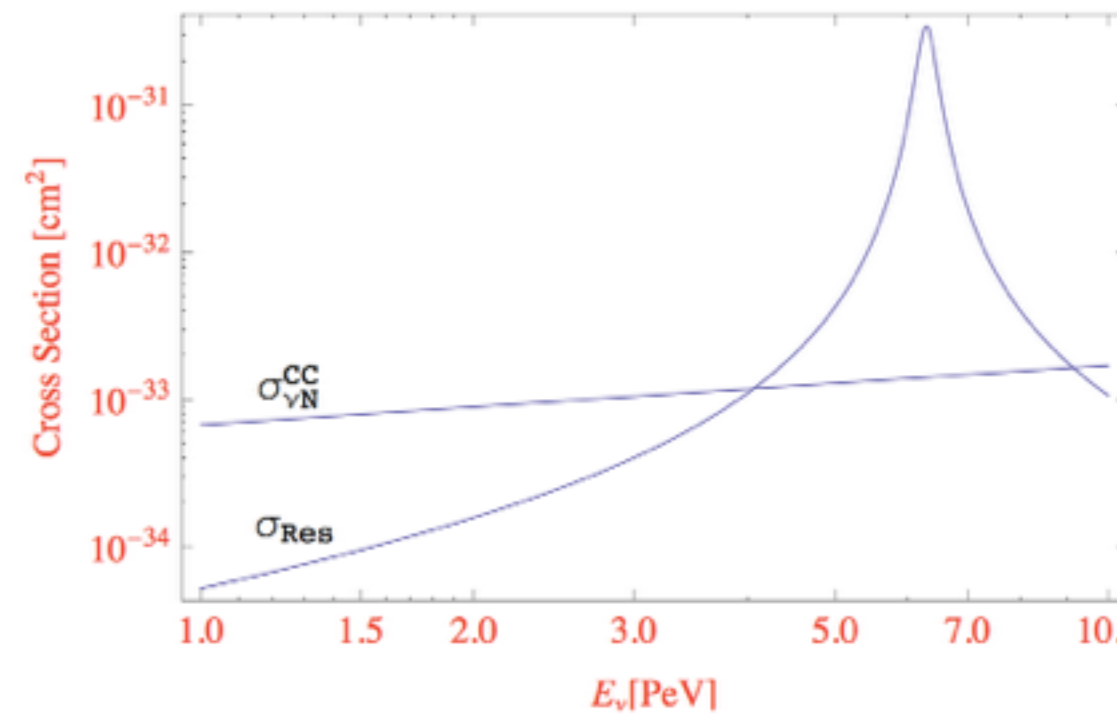
IceCube neutrino spectrum



Halzen, Nature Physics (2016)

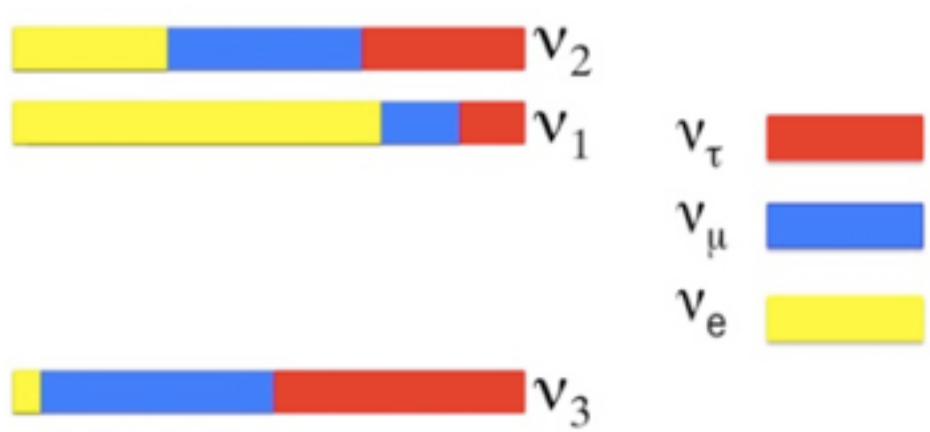
Whys hasn't the Glashow resonance been observed at IceCube





Pakvasa, Joshipura, SM, Phys Rev Lett (2013)

Neutrino decay to the ν_3 mass eigenstate



Explanation of the 1-2 PeV IceCube neutrinos

- Decay of PeV DM with lifetime of ~10^29 sec.

Borah, Dasgupta, Dey, Patra, Tomar, (2017).

Bhattacharya, Gandhi, Gupta, Mukhopadhyay, JCAP (2017).

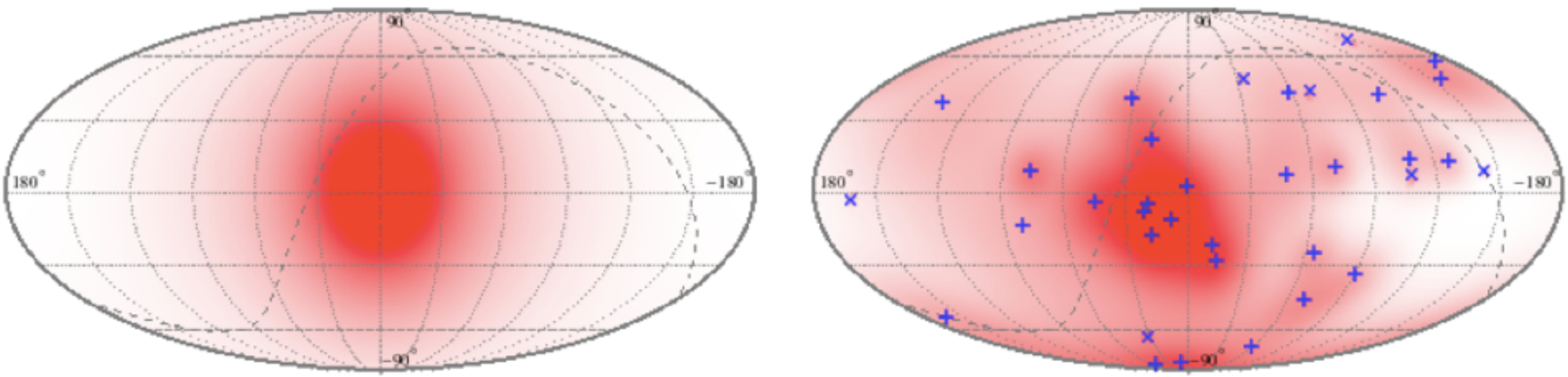
- Resonant production of new particle with mass in the range 600-800 GeV.

Leptoquarks:
Barger and Keung Phy Lett B (2013)

Dey and SM JHEP (2016)

R-parity violating SUSY:
Bhupal Dev, Ghosh, Rodejohann Phy Lett B (2016)

Direction of PeV IceCube neutrinos correlated with DM density in the galaxy

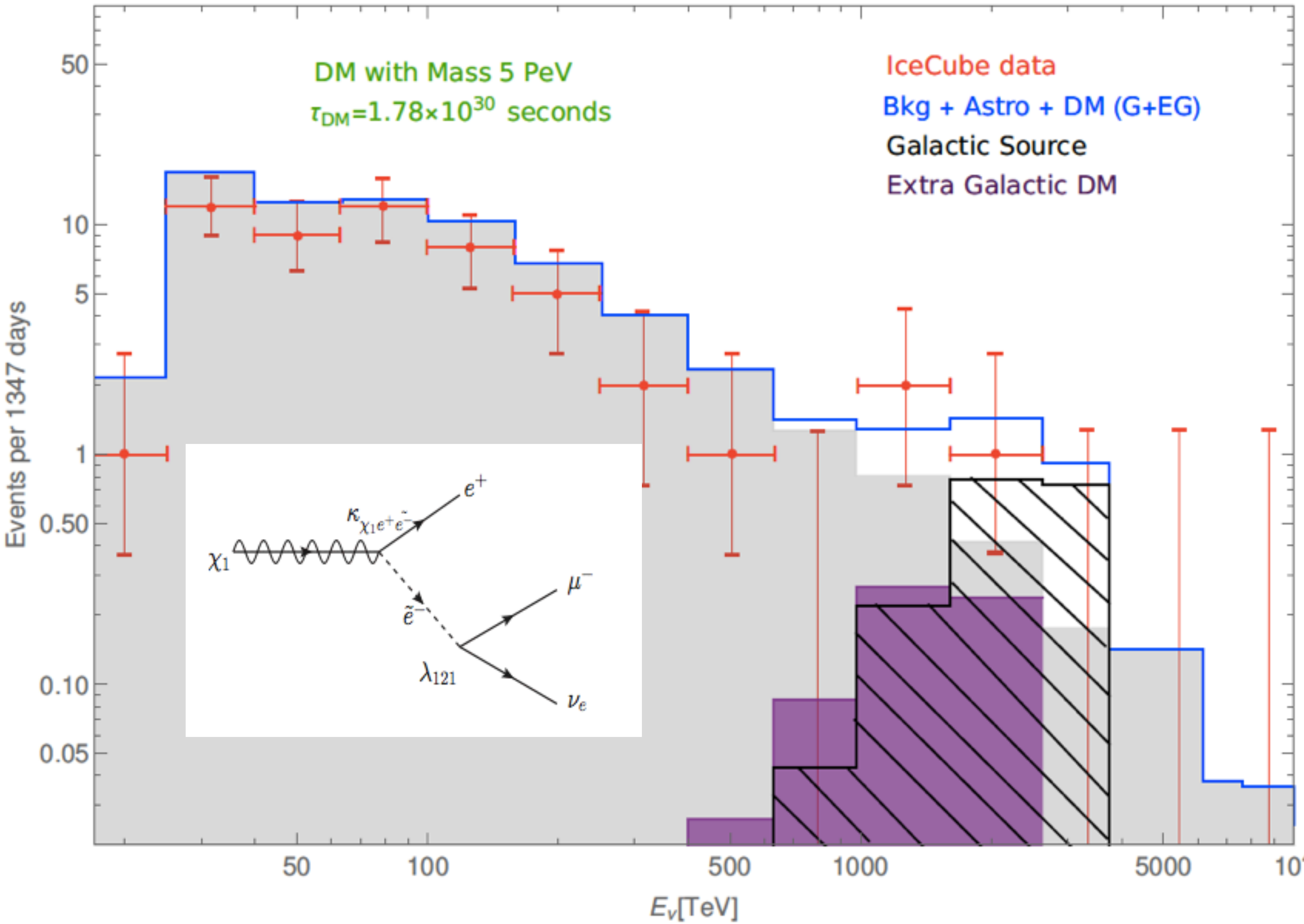


(a) PDF of DM decay

(b) PDF of IceCube data

Esmaili, Kang, Serpico , JCAP (2014)

PeV scale DM decay

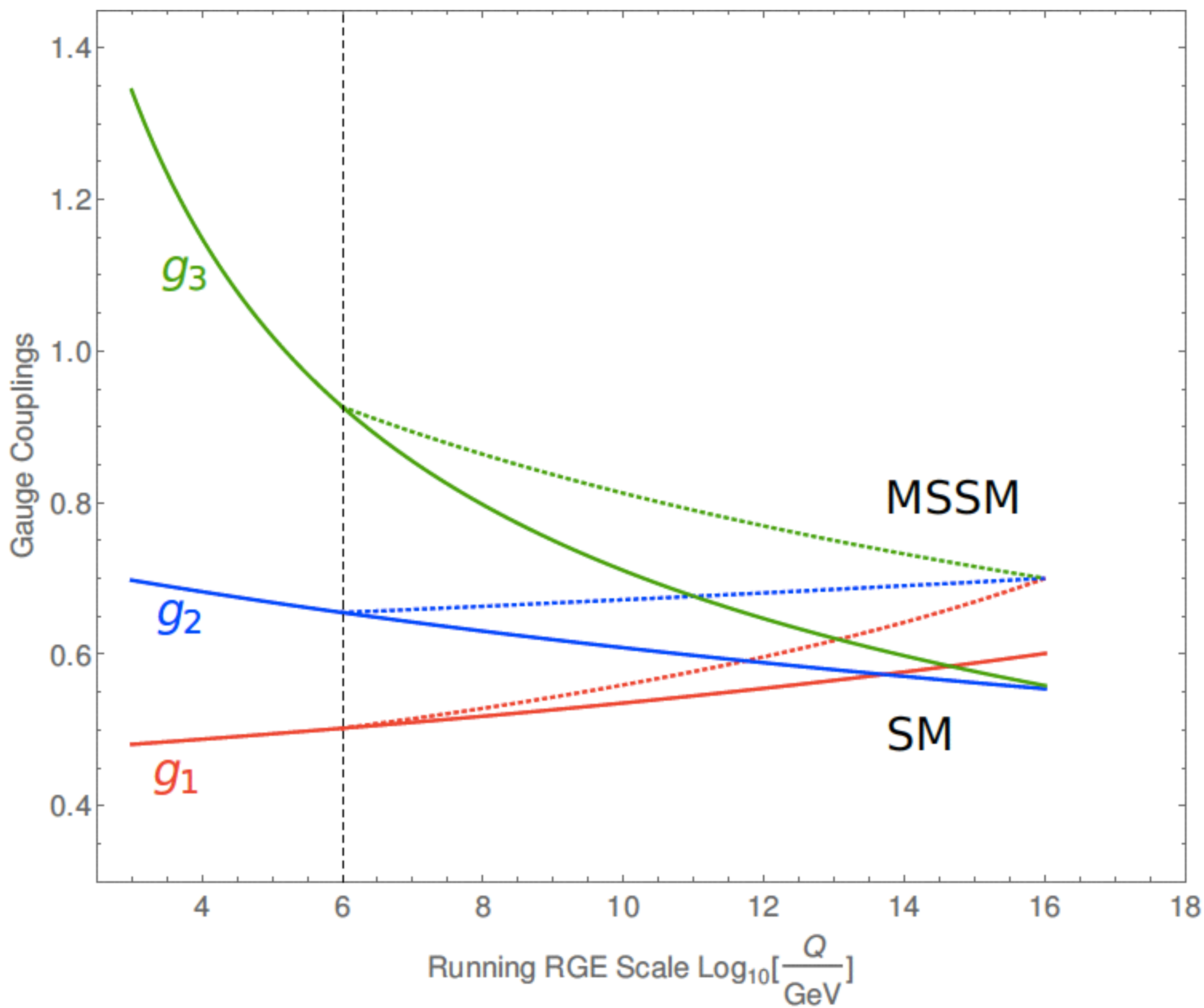


PeV scale SUSY spectrum

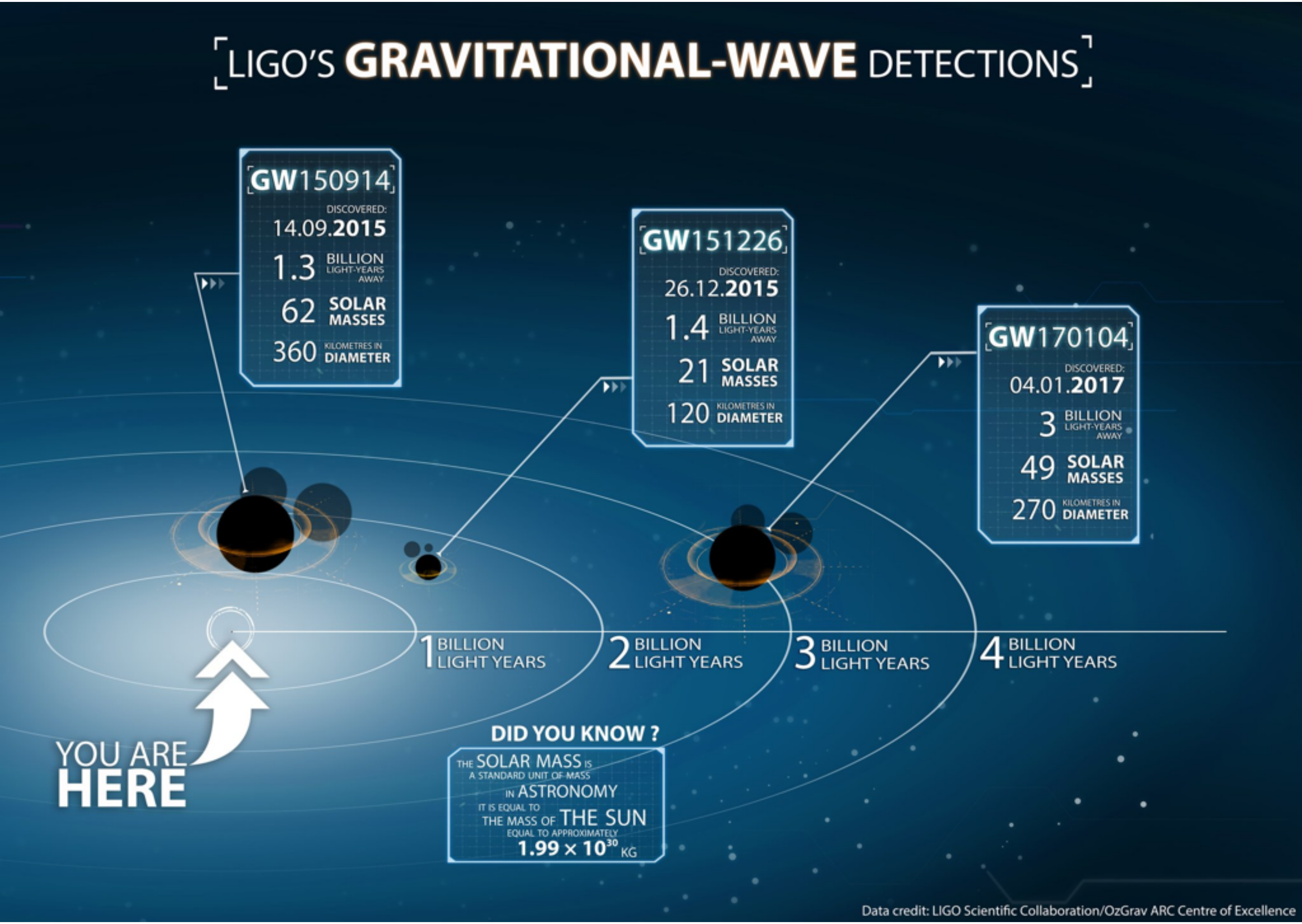
Najimuddin Khan

$\tan\beta$	Masses in PeV			RPV couplings		DM mass in PeV
	m_0	$M_{1/2}$	A_0	λ''_{121}	λ_{121}	
1.8	10	8	-15.42	3.56×10^{-22}	1.58×10^{-28}	5

SUSY Fields		Masses in PeV
$\tilde{d}_{iL,R}$	$(i = d, s, b)$	$M_{\tilde{d}_{i,L,R}} \approx (11.22,\ \ 12.53)_d \quad (12.53,\ \ 12.53)_s \quad (13.05,\ \ 13.05)_b$
$\tilde{u}_{iL,R}$	$(i = u, c, t)$	$M_{\tilde{u}_{iL,R}} \approx (8.45,\ \ 11.22)_u \quad (12.61,\ \ 12.61)_c \quad (13.05,\ \ 13.05)_t$
$\tilde{e}_{iL,R}$	$(i = e, \mu, \tau)$	$M_{\tilde{e}_{iL,R}} \approx 10.32,\ \ 10.32)_e \quad (10.32,\ \ 10.78)_\mu \quad (10.78,\ \ 10.78)_\tau$
$\tilde{\nu}_i$	$(i = e, \mu, \tau)$	$M_{\tilde{\nu}_i} \approx (10.78)_e \quad (10.78)_\mu \quad (10.78)_\tau$
h		$M_h \approx 124$ [GeV]
H		$M_h \approx 17.53$
A^0		$M_{A^0} \approx 17.53$
H^-		$M_{H^-} \approx 17.53$
$\tilde{g}_i$	$(i = 1...8)$	$M_{\tilde{g}_i} \approx 11.44$
$\tilde{\chi}^0$	$(i = 1...4)$	$M_{\tilde{\chi}_1}(DM) \approx 5.00 \quad M_{\tilde{\chi}_2} \approx 7.37 \quad M_{\tilde{\chi}_3} \approx 10.21 \quad M_{\tilde{\chi}_2} \approx 10.21$
$\tilde{\chi}^-$		$M_{\tilde{\chi}_1^-} \approx 7.37 \quad M_{\tilde{\chi}_2^-} \approx 10.21$



Najimuddin Khan- PeV Scale Susy


LIGO'S GRAVITATIONAL-WAVE DETECTIONS
GW150914
DISCOVERED: 14.09.2015
1.3 BILLION LIGHT-YEARS AWAY
62 SOLAR MASSES
360 KILOMETRES IN DIAMETER
GW151226
DISCOVERED: 26.12.2015
1.4 BILLION LIGHT-YEARS AWAY
21 SOLAR MASSES
120 KILOMETRES IN DIAMETER
GW170104
DISCOVERED: 04.01.2017
3 BILLION LIGHT-YEARS AWAY
49 SOLAR MASSES
270 KILOMETRES IN DIAMETER
1 BILLION LIGHT YEARS
2 BILLION LIGHT YEARS
3 BILLION LIGHT YEARS
4 BILLION LIGHT YEARS
YOU ARE HERE
DID YOU KNOW ?
THE SOLAR MASS IS A STANDARD UNIT OF MASS IN ASTRONOMY
IT IS EQUAL TO THE MASS OF THE SUN
EQUAL TO APPROXIMATELY 1.99×10^{30} KG
Data credit: LIGO Scientific Collaboration/OzGrav ARC Centre of Excellence

There is no dispersion or absorption of gravitational waves in an ideal fluid medium.

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu - p g_{\mu\nu}$$

Ehlers, Prasanna, Breuer, 1987

No absorption or dispersion of gravitational waves by CDM, HDM, Dark energy, Chaplygin gas etc however fluids with shear viscosity absorb gravitational waves

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu - p g_{\mu\nu} - 2\eta\,\sigma_{\mu\nu} - \xi\,\theta(u_\mu u_\nu + g_{\mu\nu})$$

Shear viscosity

Bulk viscosity

Goswami, Chakravarty, SM, Prasanna Phys Rev D (2017)

FRW metric with tensor perturbations

$$ds^2 = a(\tau)^2[d\tau^2 - (\delta_{ij} + 2\,h_{ij})\,dx^i dx^j]$$

From Einstein's equation we get

$$h_{ij}^{''} - \nabla^2 h_{ij} + 2\mathcal{H}\,h_{ij} = -16\pi a^2\,\eta\,\sigma_{ij}$$

The shear perturbations in velocity are caused by gravitational waves

$$\sigma_{ij} = h_{ij}^{'} + \mathcal{H}\,h_{ij}$$

In a viscous medium gravitational waves are damped

$$h(t,r) = \frac{A_0}{r} e^{-16\pi G\,\eta\,r}$$

Gravitational wave amplitude of inspiraling BH pair

$$A_0 = 2(4\pi)^{1/3}\ \frac{G^{5/3}}{c^4}\ f^{2/3}\ M_{ch}^{5/3}$$

$$M_{ch} = \frac{(m_1\,m_2)^{3/5}}{(m_1+m_2)^{1/5}} = \frac{c^3}{G}\left[\frac{5}{96}\pi^{-8/6} f^{-11/3}\dot{f}\right]^{3/5}$$

Need independent determination of source distance to measure shear viscosity of the dark matter

Bound on shear viscosity from GW150914

If the amplitude can be predicted with a 1% accuracy

$$\eta \times 16\pi G \times 410\mathrm{Mpc} < 0.01$$

$$\Rightarrow \eta < 5 \times 10^{-7}\,\mathrm{GeV}^3 = 6 \times 10^6\ \mathrm{Pa\,sec}$$

Goswami, Chakravarty, SM, Prasanna (2017)

Shear viscosity of self-interacting dark matter

$$\eta = \frac{1}{3}\ m\ n\ v\ l$$

Mean free path
$$l = \frac{1}{n\ \sigma}$$

Typical cross section of SIDM in galaxies and clusters

$$\frac{\sigma}{m}\ \sim\ \frac{\mathrm{cm}^2}{\mathrm{gm}} = 2\ \frac{\mathrm{barn}}{\mathrm{GeV}}$$

$$\Rightarrow \eta\ \sim\ 10^{-7}\mathrm{GeV}^3 = 10^6\ \mathrm{Pa\ sec}$$

Solving the core-cusp and missing satellite problems of ΛCDM model with

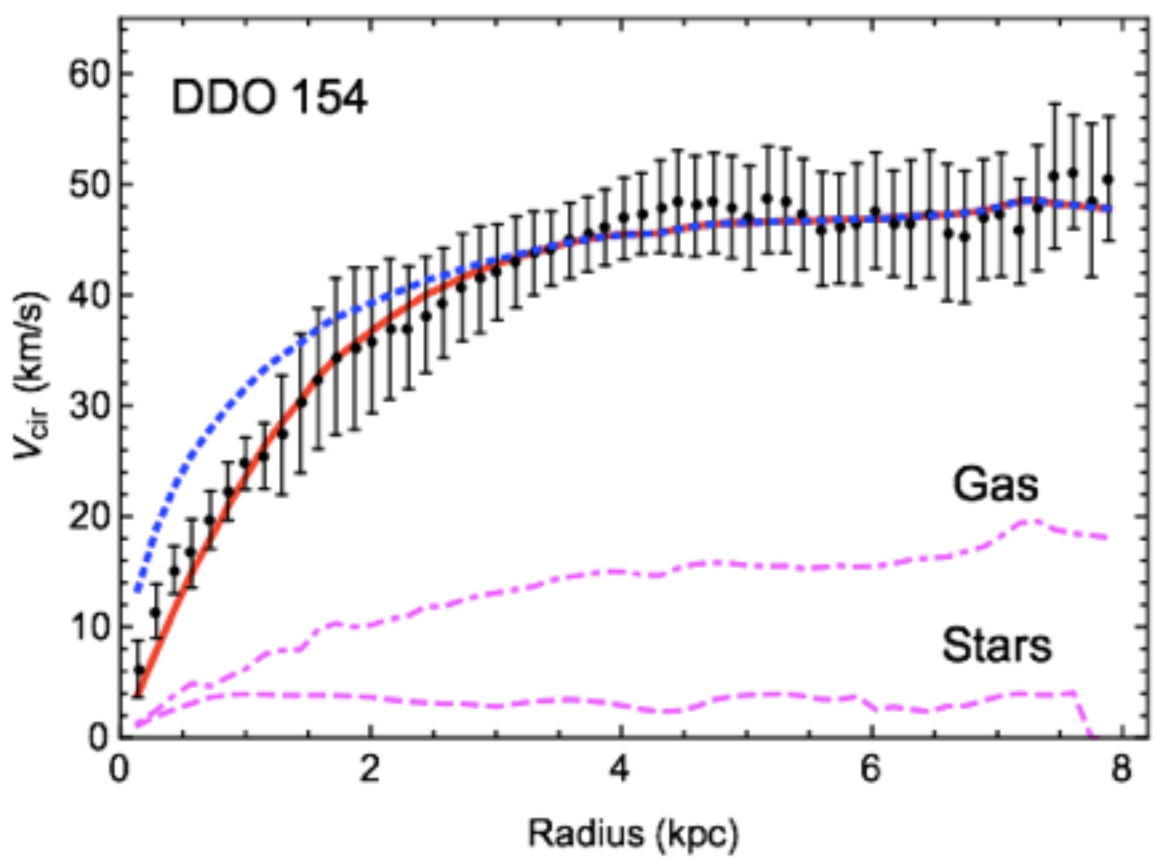
- Self-Interacting dark matter (SIDM)
- Warm dark matter (WDM)
- Fuzzy dark matter (FDM)

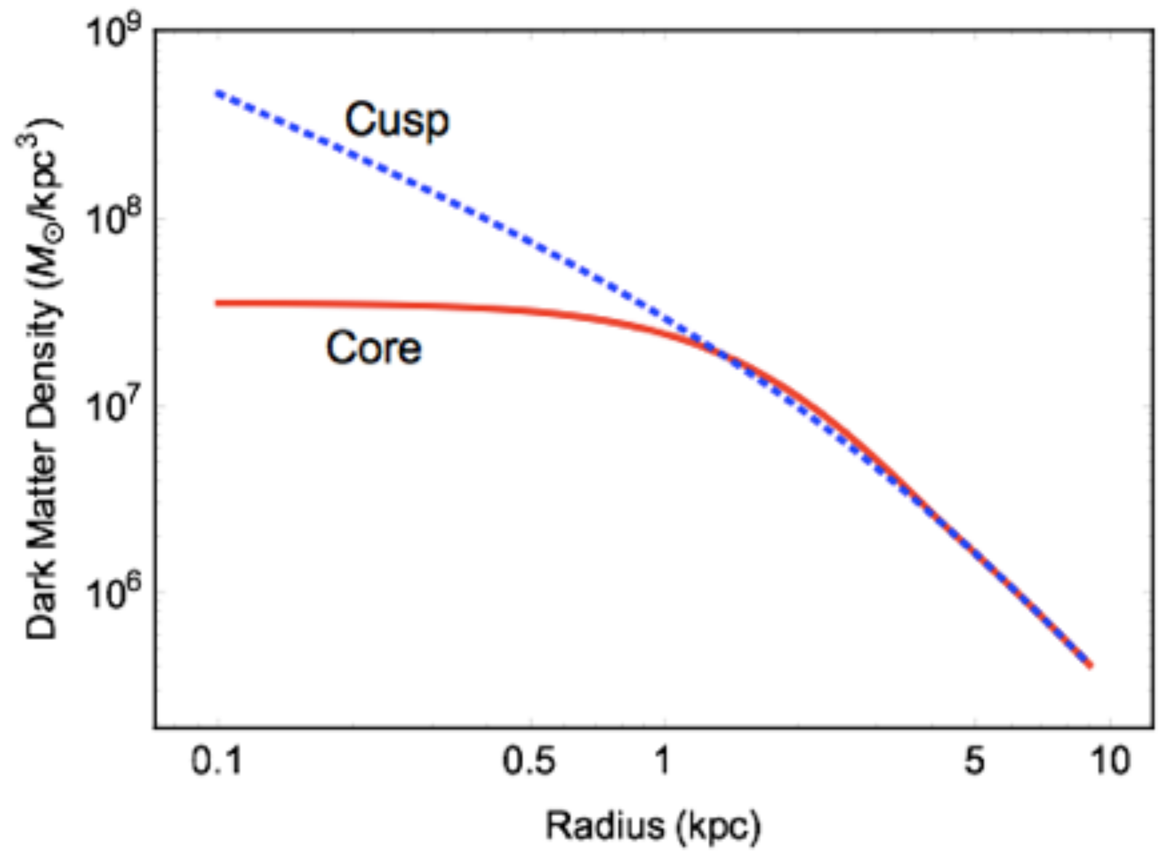
and more…

Self Interacting Dark matter -

Spergel and Steinhardt, Phys.Rev.Lett. 84, 3760 (2000)

$$\sigma/m \sim 1\ \mathrm{cm}^2/\mathrm{g} \approx 2 \times 10^{-24}\ \mathrm{cm}^2/\mathrm{GeV}$$

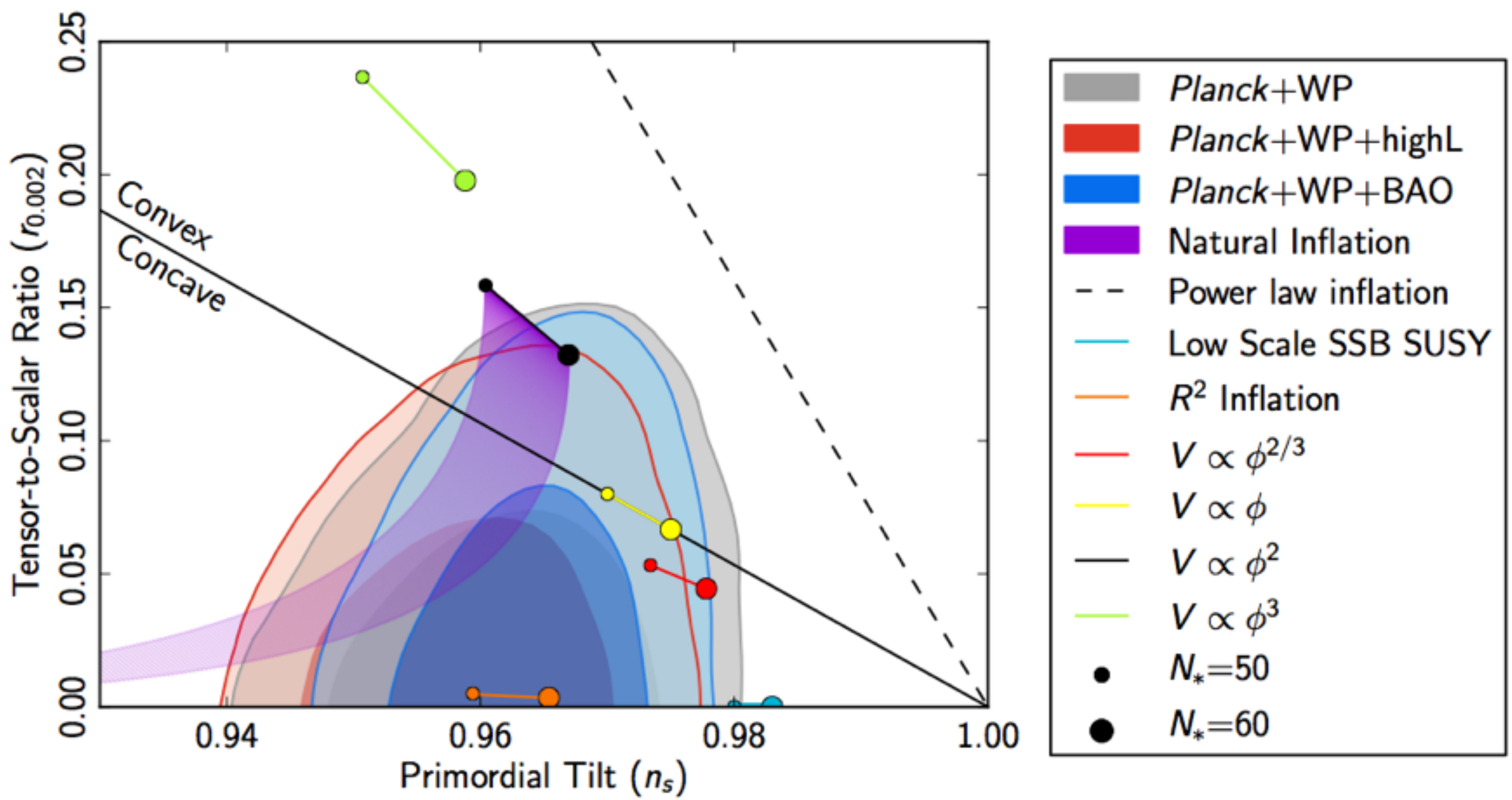




Tulin and Yu, 1705.02358

There is a possibility that SIDM may be defected via gravitational waves

Inflation models compatible with CMB data



Starobinsky model

$$S_{\mathrm{S}} = \frac{1}{2}\int \mathrm{d}^4x\sqrt{-g}\,\left(M_{\mathrm{p}}^2 R + \frac{1}{6M^2}R^2\right)$$

Jordan frame

$$S_{\mathrm{S}} = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{M_{\mathrm{p}}^2}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{3}{4}M_{\mathrm{p}}^4 M^2\left(1 - e^{-\sqrt{\frac{2}{3}}\phi/M_{\mathrm{p}}}\right)^2\right]$$

Einstein frame

$$n_s - 1 \approx -\frac{2}{N},\;\; r \approx \frac{12}{N^2}$$

$$M \simeq 10^{-5}\,, \quad N = 55$$

Higgs Inflation

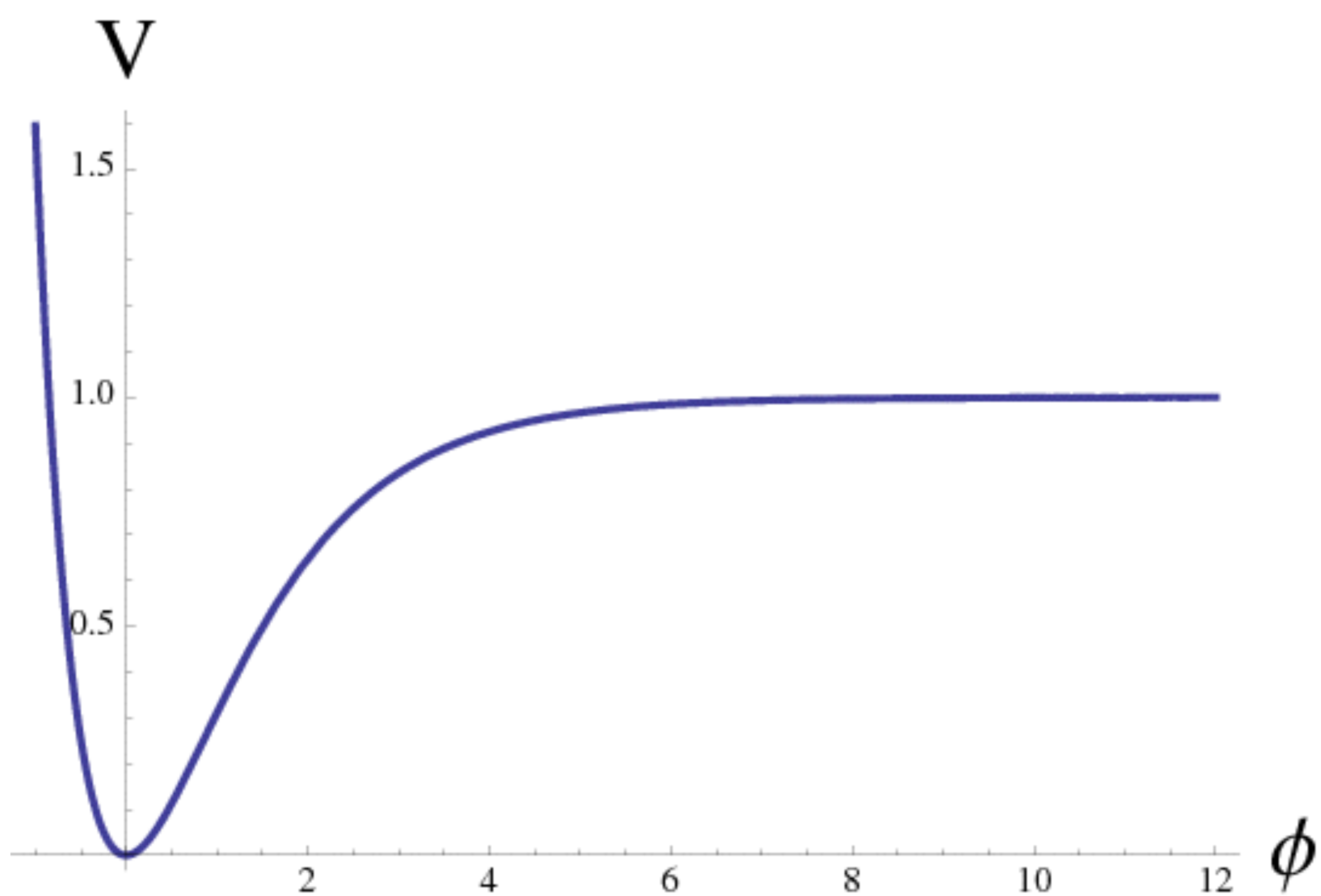
$$S_{\mathrm{HI}} = \int \mathrm{d}^4x\sqrt{-g}\left(\frac{M_{\mathrm{P}}^2}{2}R + \frac{1}{2}\xi h^2 R - \frac{\lambda}{4}h^4\right)$$ Jordan frame

Potential in the Einstein frame

$$V(\phi) = \frac{\lambda M_P^4}{4\xi^2}\left(1 - e^{-\sqrt{\frac{2}{3}}\phi/M_{\mathrm{P}}}\right)^2$$

$$\xi \sim 49000$$

Plateau potential



SUGRA Inflation

Kahler potential $\quad K(\phi_i, \phi_i^*)$

Superpotential $\quad W(\phi_i)$

$$\mathcal{L}_{kin} = -K_{ij^*} g^{\mu\nu} \partial_\mu \phi^i \partial_\nu \phi^{*j}$$

$$K_{ij^*} = \frac{\partial^2 K}{\partial \phi^i \partial \phi^{*j}}.$$

Scalar potential

$$V(\phi_i, \phi_i^*) = V_F(\phi_i, \phi_i^*) + V_D(\phi_i, \phi_i^*).$$

F term potential

$$V_F = e^K \left[D_{\phi_i} W K^{ij^*} D_{\phi_j^*} W^* - 3|W|^2 \right]$$

$$M_P = 1$$

$$K^{ij^*} \equiv K_{ij^*}^{-1}$$

$$D_{\phi_i} W = \frac{\partial W}{\partial \phi_i} + \frac{\partial K}{\partial \phi_i} W.$$

D-term potential

$$V_D = \frac{1}{2} \left[Re f_{ab}^{-1}(\phi_i) \right] D^a D^b$$

$$D^a = -g \frac{\partial G}{\partial \phi_k} (\tau^a)_k^l \phi_l$$

$$G(\phi_i, \phi_i^*) \equiv K(\phi_i, \phi_i^*) + \ln W(\phi_i) + \ln W^*(\phi_i^*),$$

SUGRA Model of Starobinsky potential

Ellis, Nanopoulos, Olive , PRL, 2013

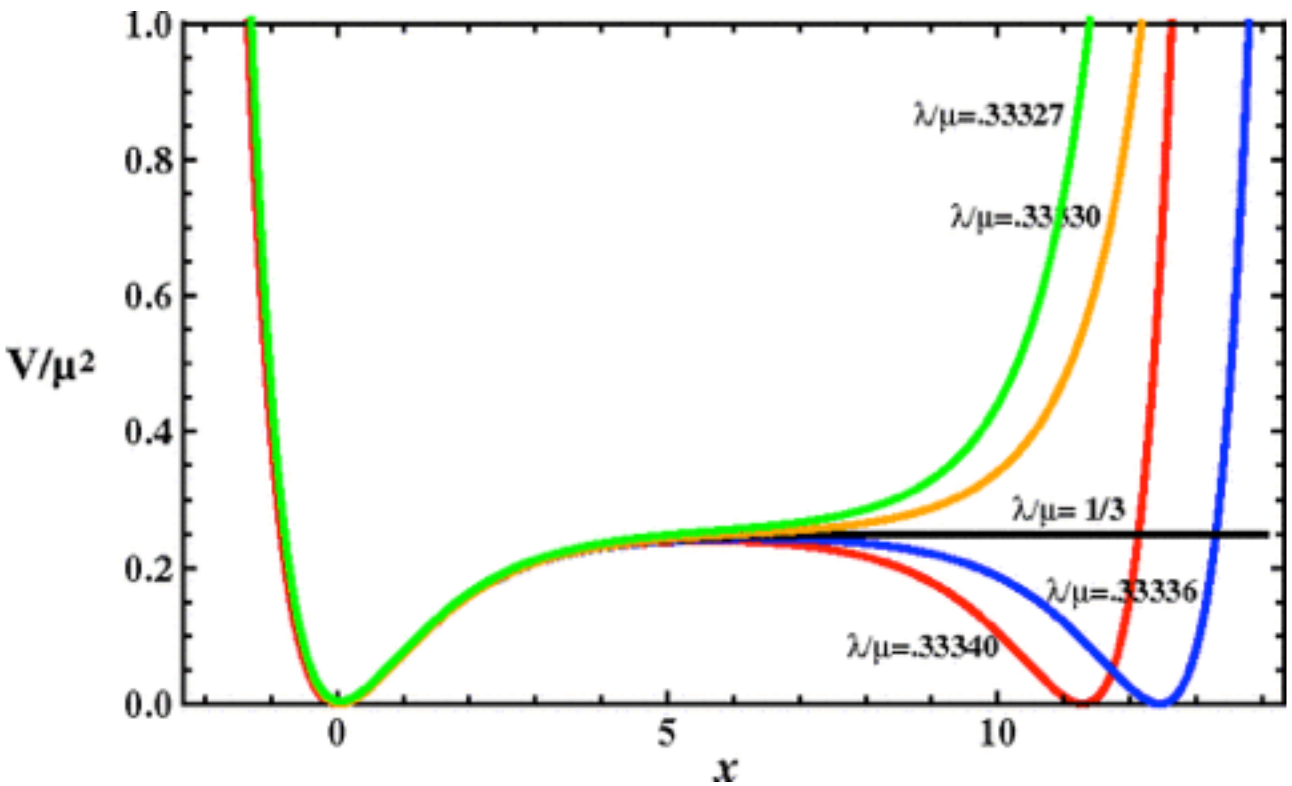
$$K = -3\ln\left[T + T^* - \frac{\phi\phi^*}{3}\right]$$

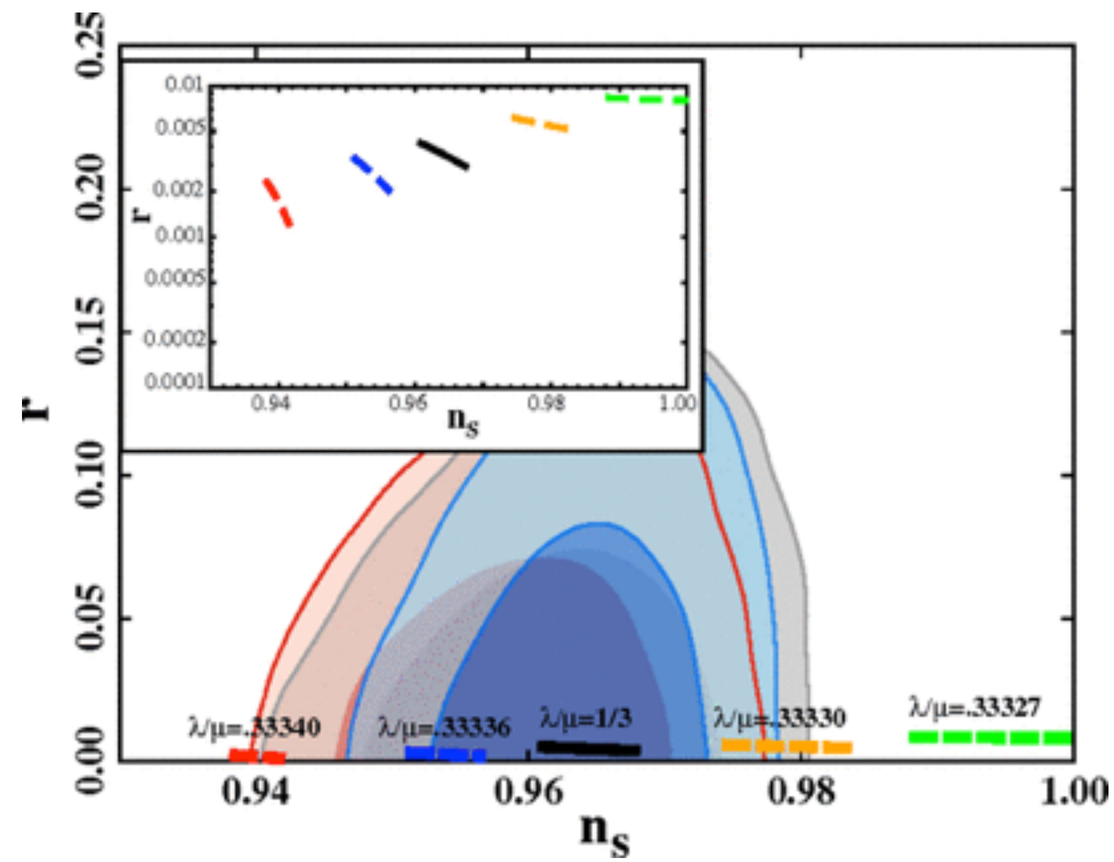
$$W = \frac{\hat{\mu}}{2}\Phi^2 - \frac{\lambda}{3}\Phi^3$$

$$\mathcal{L}_{eff} = \frac{1}{(c - |\phi|^2/3)^2}\left[c|\partial_\mu\phi|^2 - \hat{V}\right]$$

$$\phi = c\sqrt{3}\tanh\frac{\chi}{\sqrt{3}}$$

$$V_F = \frac{\mu^2}{4}\left(1 - e^{-\sqrt{\frac{2}{3}}x}\right)^2$$





No scale SUGRA SO(10) derived Starobinsky Model of Inflation

Ila Garg and SM , Phys Lett B751 (2015)

$$W = \frac{m_\Phi}{4!}\Phi^2 + \frac{\lambda}{4!}\Phi^3 + \frac{m_\Sigma}{5!}\Sigma\overline{\Sigma} + \frac{\eta}{4!}\Phi\Sigma\overline{\Sigma} + m_H H^2 + \frac{1}{4!}\Phi H(\gamma\Sigma + \bar{\gamma}\overline{\Sigma})$$

$$K = -3\ln(T + T^* - \frac{1}{3}(\frac{1}{4!}\Phi^\dagger\Phi + \frac{1}{5!}\Sigma^\dagger\Sigma + \frac{1}{5!}\overline{\Sigma}^\dagger\overline{\Sigma} + H^\dagger H))$$

$SO(10)$ scalar representations

$\mathbf{210}(\Phi_{ijkl})$ $\mathbf{126}(\Sigma_{ijklm})$ $\mathbf{10}(H_i)$,

Some intermediate symmetries like Pati-Salam do not give successful plateau inflation

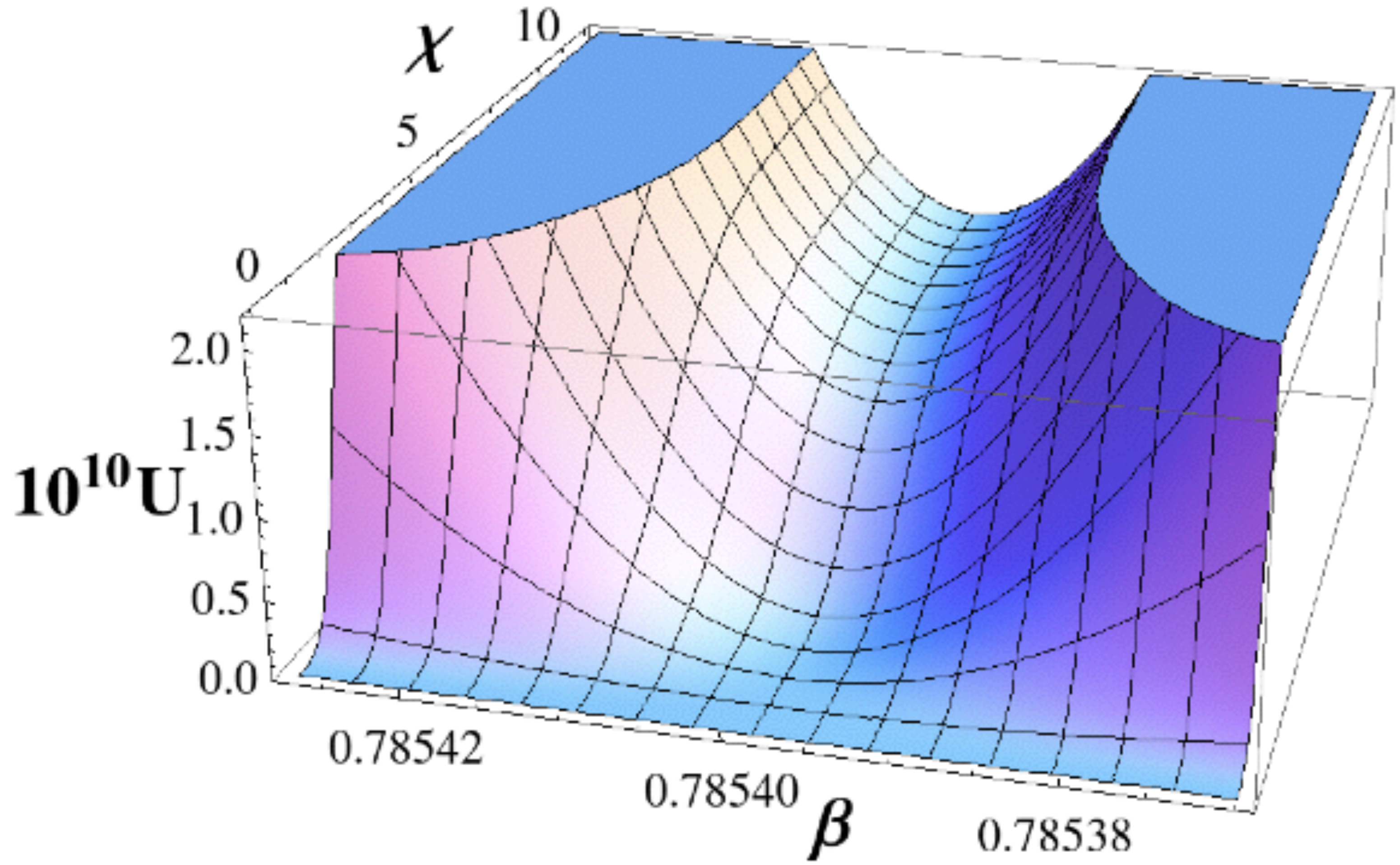
Plateau inflation in SUGRA- MSSM

G.K.Chakravarty, G. Gupta, G. Lambiase, S.M., Phys Lett B 2015

$$K = 3M_p^2 \ln\left[1 + \frac{1}{3M_p^2}\left(H_u^\dagger H_u + H_d^\dagger H_d\right)\right]$$

$$W = \mu(H_u \cdot H_d) + \lambda \frac{(H_u \cdot H_d)^2}{M_p} \exp\left(\frac{H_u \cdot H_d}{M_p^2}\right)$$

$$H_u = \begin{pmatrix} \phi_u^+ \\ \phi_u^0 \end{pmatrix}, \quad H_d = \begin{pmatrix} \phi_d^0 \\ \phi_d^- \end{pmatrix}$$



$$\lambda \simeq 3.8 \times 10^{-8}$$

$$r \simeq 0.00337, \; n_s \simeq 0.966$$

Plateau Inflation in R-parity Violating MSSM

G.K. Chakravarty, U. K. Dey, G. Lambiase, S.M., Phys Lett B (2016)

$$K = 3\ln\left[1 + \frac{1}{3M_p^2}\Big(L^\dagger L + H_u^\dagger H_u + H_d^\dagger H_d + H_d^\dagger L + L^\dagger H_d\Big)\right] + ZZ^* - \frac{(ZZ^*)^2}{\Lambda^2}$$

$$W = \mu_1 L\cdot H_u + \mu_2 H_u\cdot H_d + \Delta M_p^2 + \mu_z^2 Z + \frac{\lambda_1}{M_p}(L\cdot H_u)^2 \exp\left(\frac{-L\cdot H_u}{M_p^2}\right) + \frac{\lambda_2}{M_p}(H_u\cdot H_d)^2 \exp\left(\frac{H_u\cdot H_d}{M_p^2}\right)$$

SUSY -perhaps with heavy spectrum may find most useful application in inflation ..

Thank You