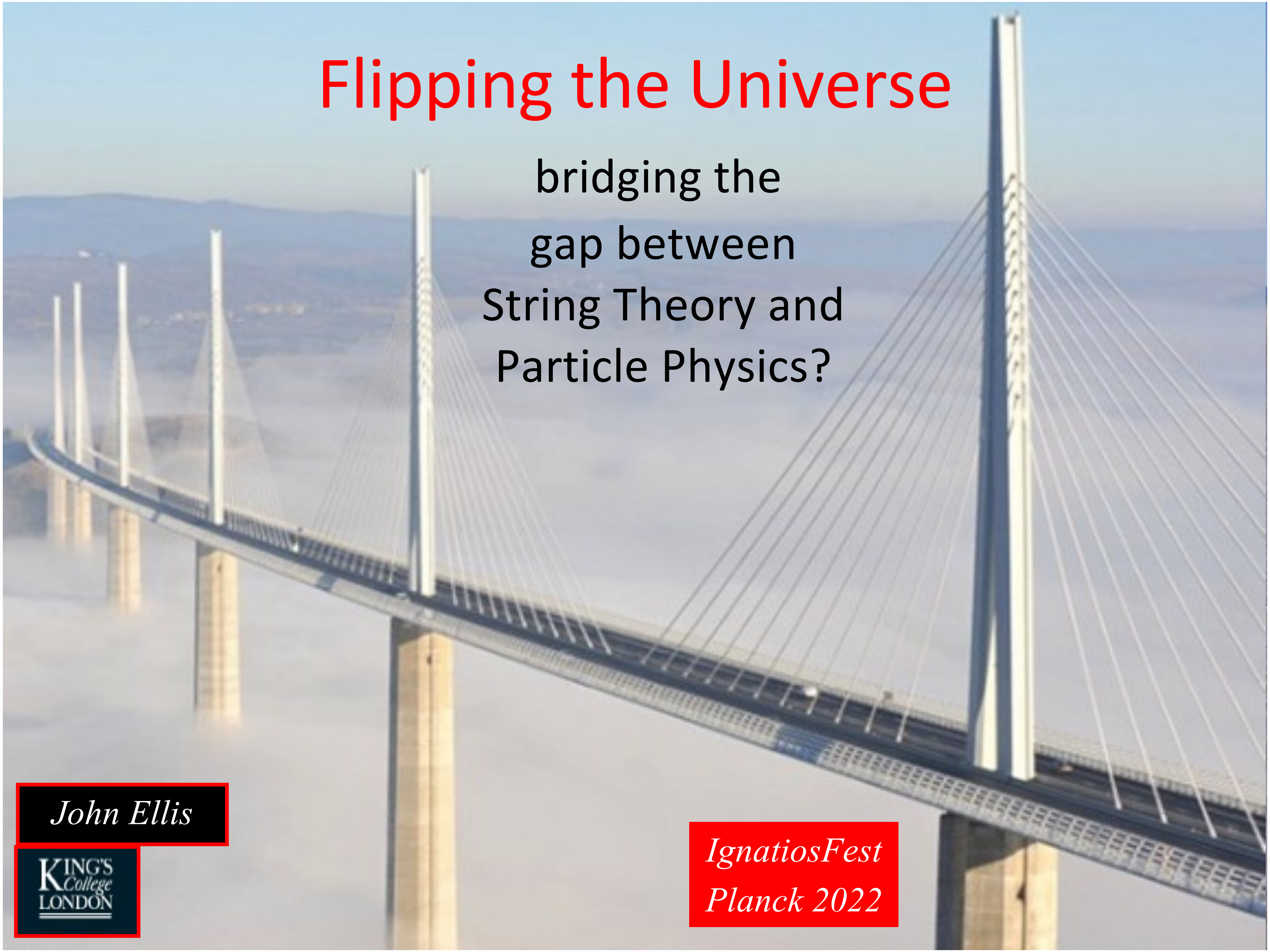

Flipping the Universe

bridging the
gap between
String Theory and
Particle Physics?

John Ellis

KING'S College LONDON

IgnatiosFest
Planck 2022

Early Papers with Ignatios

35 years already!

Striving to link string theory with accessible particle physics:

Model-building, time-dependent cosmological solutions

The Low-energy Effective Field Theory From Four-dimensional Superstrings
Ignatios Antoniadis (CERN and Crete U.), John R. Ellis (CERN), E. Floratos (Crete U.), Dimitri V. Nanopoulos (Wisconsin U., Madison), T. Tomaras (Crete U
(Feb, 1987)
Published in: *Phys.Lett.B* 191 (1987) 96-102
DOI cite 89 citatio

On the Possibility of Avoiding Singularities by Dilaton Emission
Ignatios Antoniadis (CERN), G.F.R. Ellis (CERN), John R. Ellis (CERN), C. Kounnas (LBL, Berkeley), Dimitri V. Nanopoulos (Wisconsin U., Madison) (Feb, 1987)
Published in: *Phys.Lett.B* 191 (1987) 393-398
DOI cite 9 citatio

Supersymmetric Flipped SU(5) Revitalized
Ignatios Antoniadis (CERN), John R. Ellis (CERN), J.S. Hagelin (Maharishi U. of Management), Dimitri V. Nanopoulos (Wisconsin U., Madison) (May, 1987
Published in: *Phys.Lett.B* 194 (1987) 231-235
DOI cite 584 citatio

Universality of the Mass Spectrum in Closed String Models
Ignatios Antoniadis (CERN), John R. Ellis (CERN), Dimitri V. Nanopoulos (Wisconsin U., Madison) (Aug, 1987)
Published in: *Phys.Lett.B* 199 (1987) 402-406
DOI cite 50 citatio

GUT Model Building with Fermionic Four-Dimensional Strings
Ignatios Antoniadis (CERN), John R. Ellis (CERN and SLAC), J.S. Hagelin (Maharishi U. of Management), Dimitri V. Nanopoulos (Wisconsin U., Madison) (Dec, 1987)
Published in: *Phys.Lett.B* 205 (1988) 459-465
pdf links DOI cite 218 citatio

An Improved SU(5) x U(1) Model from Four-Dimensional String
Ignatios Antoniadis (CERN), John R. Ellis (CERN), John S. Hagelin (Maharishi U. of Management), Dimitri V. Nanopoulos (Wisconsin U., Madison) (Mar, 1988)
Published in: *Phys.Lett.B* 208 (1988) 209-215, *Phys.Lett.B* 213 (1988) 562 (addendum)
DOI cite 232 citatio

Cosmological String Theories and Discrete Inflation
Ignatios Antoniadis (CERN), C. Bachas (CERN), John R. Ellis (CERN), Dimitri V. Nanopoulos (Wisconsin U., Madison) (May, 1988)
Published in: *Phys.Lett.B* 211 (1988) 393-399
DOI cite 311 citatio

An Expanding Universe in String Theory
Ignatios Antoniadis (Ecole Polytechnique), C. Bachas (Ecole Polytechnique), John R. Ellis (CERN), Dimitri V. Nanopoulos (Texas A-M) (Nov, 1988)
Published in: *Nucl.Phys.B* 328 (1989) 117-139
DOI cite 319 citatio

The Flipped SU(5) x U(1) String Model Revamped
Ignatios Antoniadis (CERN), John R. Ellis (CERN), J.S. Hagelin (CERN), Dimitri V. Nanopoulos (CERN) (Jul, 1989)
Published in: *Phys.Lett.B* 231 (1989) 65-74
DOI cite 565 citatio

Generalised No-Scale Structure

Volume 191, number 1,2 PHYSICS LETTERS B 4 June 1987

THE LOW-ENERGY EFFECTIVE FIELD THEORY FROM FOUR-DIMENSIONAL SUPERSTRINGS

I. ANTONIADIS [1,2], John ELLIS, E. FLORATOS [1], D.V. NANOPOULOS [3] and T. TOMARAS [1]

CERN, CH-1211 Geneva 23, Switzerland

Received 25 February 1987

We derive the low-energy effective supergravity field theory obtained from a fermionic formulation of four-dimensional superstrings. It contains a single dilaton supermultiplet parametrizing an SU(1, 1)/U(1) manifold, three self-conjugate sets of matter supermultiplets parametrizing SO(m, 2)/SO(m)×SO(2) manifolds, and chiral matter supermultiplets parametrizing a product of SU(M, 1)/SU(M)×U(1) manifolds. We derive the Yukawa couplings of the theory and identify some of the self-conjugate matter fields as Higgses. We also discuss the possible pattern of supersymmetry breaking.

Crucial for cosmological model-building
(no Planck-scale holes in the effective potential):
Basis for supersymmetric models of inflation (later)

Our Biggest Hit!

Volume 194, number 2 PHYSICS LETTERS B 6 August 1987

SUPERSYMMETRIC FLIPPED SU(5) REVITALIZED

I. ANTONIADIS [1], J. ELLIS
CERN, CH-1211 Geneva 23, Switzerland

J.S. HAGELIN
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and

D.V. NANOPOULOS
Physics Department, University of Wisconsin, Madison, WI 53706, USA

Received 16 May 1987

We describe a simple $N=1$ supersymmetric GUT based on the group $SU(5)\times U(1)$ which has the following virtues: the gauge group is broken down to the $SU(3)_C\times SU(2)_L\times U(1)_Y$ of the standard model using just **10**, $\overline{\mathbf{10}}$ Higgs representations, and the doublet–triplet mass splitting problem is solved naturally by a very simple missing-partner mechanism. The successful supersymmetric GUT prediction for $\sin^2\theta_w$ can be maintained, whilst there are no fermion mass relations. The gauge group and representation structure of the model may be obtainable from the superstring.

Resurrection of flipped SU(5): motivated by possibility of derivation in weakly-coupled heterotic string theory, because no need of adjoint (or larger) Higgs representation

Flipped SU(5) GUT

Antoniadis, JE, Hagelin & Nanopoulos, 1987

- Extend GUT SU(5) with additional U(1) [motivated by string theory]

- "Flipped" fermion assignments to representations:

$$\bar{f}_i(\bar{\mathbf{5}}, -3) = \{U_i^c, L_i\} \ , \quad F_i(\mathbf{10}, 1) = \{Q_i, D_i^c, N_i^c\} \ , \quad l_i(\mathbf{1}, 5) = E_i^c \ , \quad i = 1, 2, 3$$

- Break GUT symmetry with 10-dimensional Higgses, electroweak symmetry with 5-dimensional Higgses:

$$H(\mathbf{10}, 1) = \{Q_H, D_H^c, N_H^c\} \ , \qquad \bar{H}(\bar{\mathbf{10}}, -1) = \{\bar{Q}_H, \bar{D}_H^c, \bar{N}_H^c\}$$

$$h(\mathbf{5}, -2) = \{T_{H_c}, H_d\} \ , \qquad \bar{h}(\bar{\mathbf{5}}, 2) = \{\bar{T}_{\bar{H}_c}, H_u\}$$

- Superpotential:

$$W = \lambda_1^{ij} F_i F_j h + \lambda_2^{ij} F_i \bar{f}_j \bar{h} + \lambda_3^{ij} \bar{f}_i \ell_j^c h + \lambda_4 H H h + \lambda_5 \bar{H} \bar{H} \bar{h}$$
$$+ \lambda_6^{ia} F_i \bar{H} \phi_a + \lambda_7^a h \bar{h} \phi_a + \lambda_8^{abc} \phi_a \phi_b \phi_c + \mu_\phi^{ab} \phi_a \phi_b \ ,$$

First Version of Stringy Flipped SU(5)

Volume 205, number 4 PHYSICS LETTERS B 5 May 1988

GUT MODEL-BUILDING WITH FERMIONIC FOUR-DIMENSIONAL STRINGS ☆

I. ANTONIADIS [a,1], John ELLIS [a,b], J.S. HAGELIN [c] and D.V. NANOPOULOS [d]

[a] *CERN, CH-1211 Geneva 23, Switzerland*
[b] *Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94305, USA*
[c] *Maharishi International University, Fairfield, IA 52556, USA*
[d] *University of Wisconsin, Madison, WI 53706, USA*

Received 7 January 1988

We report a first attempt at model-building using the fermionic formulation of string theories directly in four dimensions. An example is presented of a supersymmetric flipped $SU(5) \times U(1)$ model with three generations and an adjustable hidden sector gauge group. The simplest version of the model contains most of the Yukawa couplings required by phenomenology, but not all those needed to give masses to quarks or conjugate neutrinos. These defects may be remedied in a more general version of the model.

First candidate unified "Theory of Everything":
derived using fermionic formulation of weakly-coupled heterotic string
(Antoniadis, Bachas and Kounnas[†])

Refined Version of Stringy Flipped SU(5)

Volume 231, number 1,2 PHYSICS LETTERS B 2 November 1989

THE FLIPPED SU(5)×U(1) STRING MODEL REVAMPED

I. ANTONIADIS [1], John ELLIS, J.S. HAGELIN [2] and D.V. NANOPOULOS [3]
CERN, CH-1211 Geneva 23, Switzerland

Received 21 July 1989

We present a refined version of our three-generation flipped SU(5)×U(1) string model with the following properties.
– The complete massless spectrum is derived and shown to be free of all gauge and mixed anomalies apart from a single anomalous U(1).
– The imaginary part of the dilaton supermultiplet is eaten by the anomalous U(1) gauge boson, and the corresponding D-term is cancelled by large VEVs for singlet fields that break surplus U(1) gauge factors, leaving a supersymmetric vacuum with an SU(5)×U(1) visible gauge group and an SO(10)×SO(6) hidden gauge group.
– There are sufficient Higgs multiplets to break the visible gauge symmetry down to the standard model in an essentially unique way.
– All trilinear superpotential couplings have been calculated and there are in particular some giving m_t, m_b, $m_\tau \neq 0$.
– A renormalization group analysis shows that $m_t < 190$ GeV and $m_b \simeq 3m_\tau$.
– Light Higgs doublets are split automatically from heavy Higgs triplets, leaving no residual dimension-five operators for baryon decay, and the baryon lifetime $\tau_B \sim 2\times10^{34\pm2}$ yr.
– There are no tree-level flavour-changing neutral currents, but $\mu\to e\gamma$ may occur at a detectable level: $B(\mu\to e\gamma)\sim10^{-11}$–$10^{-14}$.

Our second-biggest hit!

Nuclear Physics B328 (1989) 117–139
North-Holland, Amsterdam

Meanwhile Back in the Universe

AN EXPANDING UNIVERSE IN STRING THEORY

I. ANTONIADIS and C. BACHAS

Centre de Physique Theorique, Ecole Polytechnique, 91128 Palaiseau, France

John ELLIS

CERN, Geneva, Switzerland

D.V. NANOPOULOS

Physics Department, Texas A&M University, College Station, Texas, USA

Received 14 April 1989

Time-dependent model of cosmology based on non-critical string theory

We present solutions of the bosonic, heterotic and type II string theories, whose space-time manifold is a linearly expanding homogeneous and isotropic universe. These solutions are obtained by giving a background charge to the time coordinate on the world-sheet. We find the spectrum, demonstrate positivity of the Hilbert space up to the second excited level, and construct modular-invariant partition functions. The central charge of transverse excitations is a free parameter that controls the asymptotic density of states; the critical dimension and gauge group can in particular be made arbitrarily large. We show how to construct dual, factorizable, energy-conserving amplitudes in this background, discuss their interpretation and comment on the initial singularity and flatness problems in the light of our results.

Not Forgetting …!

LEP data and the light gluino window

I. Antoniadis [a], John Ellis [b] and D.V. Nanopoulos [c, 1]

[a] *Centre de Physique Théorique, Ecole Polytechnique, F-91128 Palaiseau, France*
[b] *Theory Division, CERN, CH-1211 Geneva 23, Switzerland*
[c] *Center for Theoretical Physics, Department of Physics, Texas A & M University, College Station, TX 77843-4242, USA and Astroparticle Physics Group, Houston Advanced Research Center (HARC), The Woodlands, TX 77831, USA*

Received 28 March 1991

String threshold corrections and flipped SU(5)

I. Antoniadis [a,b], John Ellis [b], R. Lacaze [c] and D.V. Nanopoulos [d,e,b]

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Received 8 July 1991

The price of deriving the standard model from the string

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[d] *Astroparticle Physics Group, Houston Advanced Research Center (HARC), The Woodlands, TX 77381, USA*

Received 8 August 1991

Unification bounds on the possible $N = 2$ supersymmetry-breaking scale ⋆

I. Antoniadis [a,b], J. Ellis [b], G.K. Leontaris [c]

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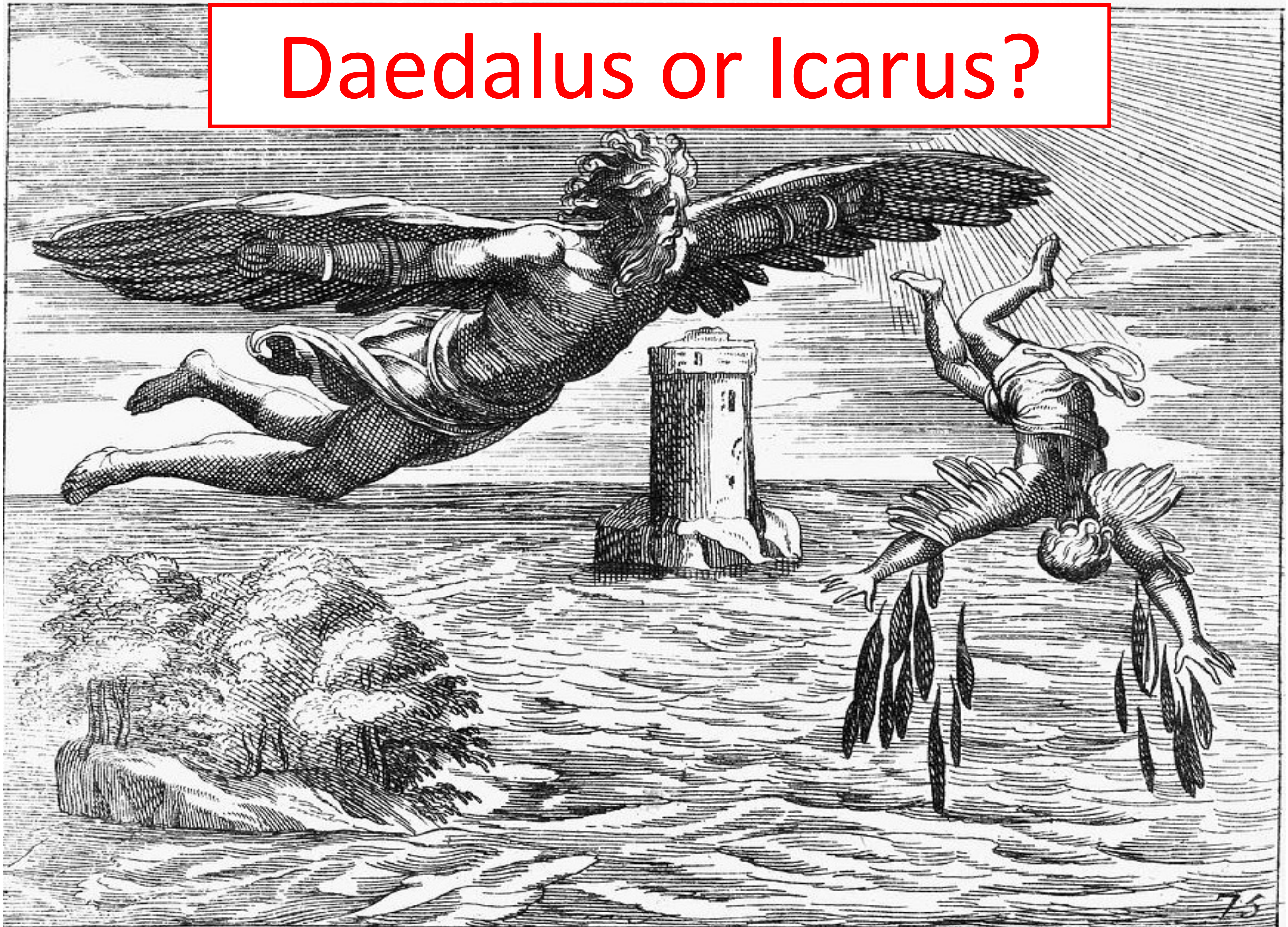
[c] *Theoretical Physics Division, Ioannina University, GR-45110 Ioannina, Greece*

Received 17 January 1997
Editor: R. Gatto

Key issues in the phenomenology of strings and supersymmetry

Daedalus or Icarus?



DEDALE PERD SON FILS ICARE

Flipped

Almost

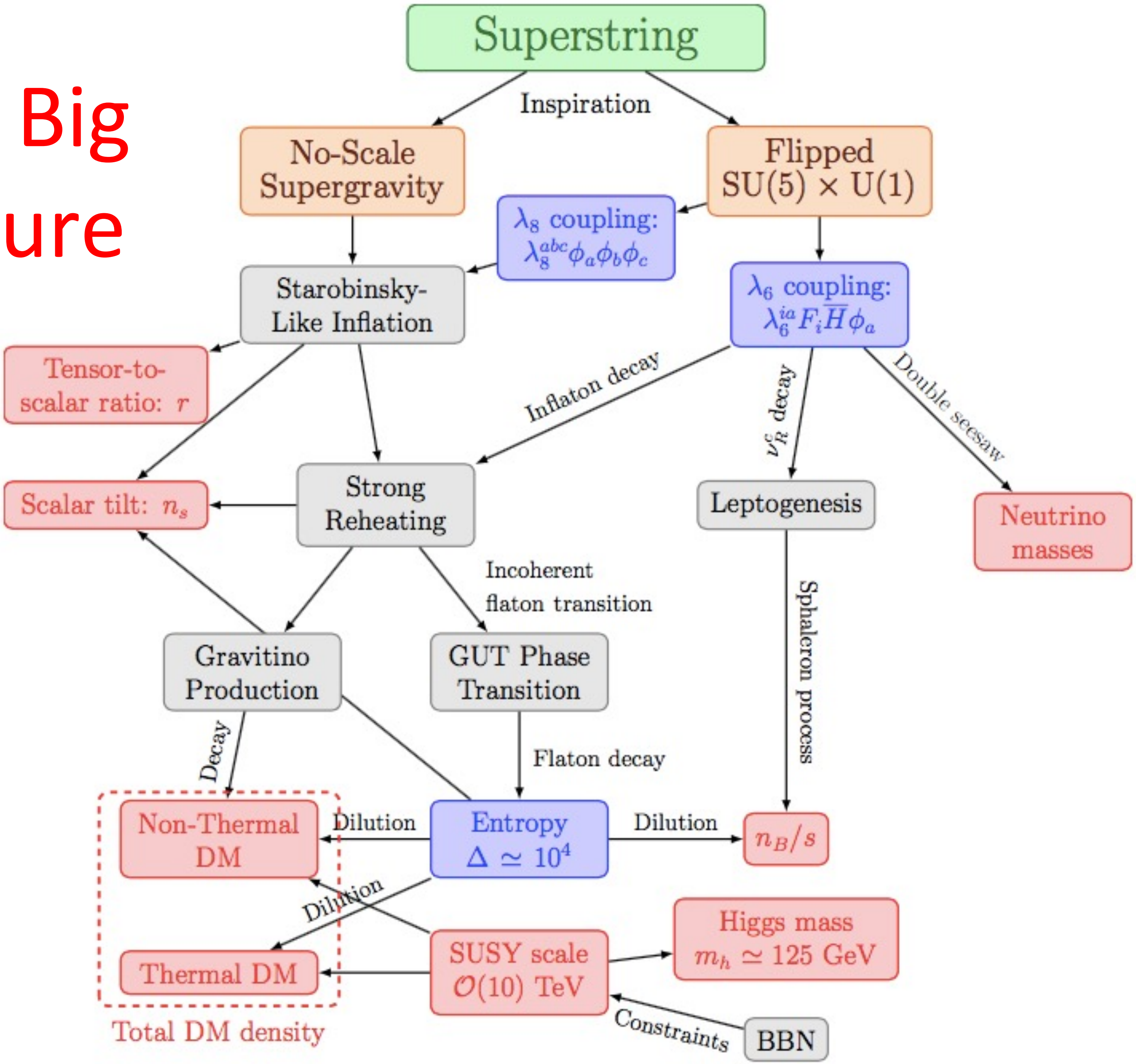
A Model of Everything

Below the Planck Scale

- Simple GUT models (SU(5), SO(10)) not obtained from weakly-coupled string
  - They need adjoint Higgs, …
- **Flipped SU(5)×U(1) derived**, has advantages
  - Small (5-, 10-dimensional) Higgs representations
  - Long-lived proton, neutrino masses, leptogenesis, …
- Construct model of Starobinsky-like inflation within flipped SU(5)×U(1) framework

JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1910.11755

The Big Picture



JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1910.11755

The Big Picture

JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1910.11755

Inflation Cries out for Supersymmetry

- Want "elementary" scalar field
  (at least looks elementary at energies << M_P)
- To get right magnitude of perturbations
  prefer mass << M_P
  (~ 10^{13} GeV in simple ϕ^2 models)
- And/or prefer small self-coupling $\lambda << 1$
- **Both technically natural with supersymmetry**

JE, Nanopoulos, Olive & Tamvakis 1983

Inflation cries out for Supergravity

- Stabilize ‘elementary’ scalar inflaton

  (needs mass << m_P and/or small coupling)
- **Supersymmetry**
- The only good symmetry is a local symmetry

  (cf, gauge symmetry in Standard Model)
- **Local supersymmetry = supergravity**
- Early Universe cosmology needs gravity
- **Supersymmetry + gravity = supergravity**

No-Scale Supergravity Inflation

- **Supersymmetry + gravity = Supergravity**
- Include conventional matter?
- Potentials in generic supergravity models have ‘holes’ with depths ~ – M_P^4
- Exception: **no-scale supergravity**
- **Appears in compactifications of string**
- Flat directions, scalar potential ~ global model + controlled corrections

Cremmer, Ferrara, Kounnas & Nanopoulos, 1983

Witten, 1985

JE, Enqvist, Nanopoulos, Olive & Srednicki, 1984

JE, Nanopoulos & Olive, arXiv:1305.1247, 1307.3537, …

Old No-Scale Supergravity Model of Inflation

Volume 152B, number 3,4 PHYSICS LETTERS 7 March 1985

No 'holes' in effective potential with negative cosmological constant

SU(*N*, 1) INFLATION

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and

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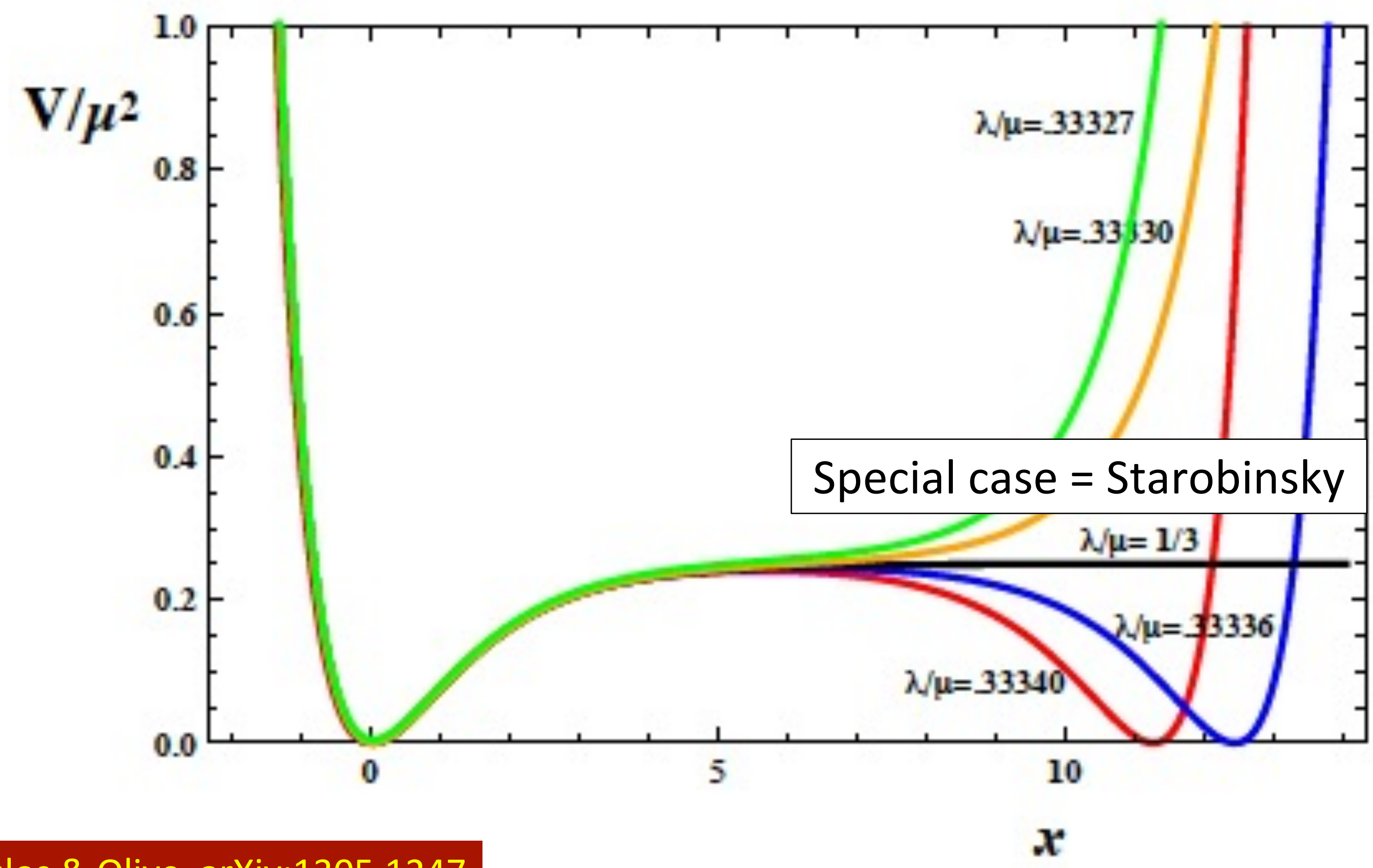
Received 7 December 1984

JE, Enqvist, Nanopoulos, Olive & Srednicki, 1984

We present a simple model for primordial inflation in the context of SU(N, 1) no-scale $n = 1$ supergravity. Because the model at zero temperature very closely resembles global supersymmetry, minima with negative cosmological constants do not exist, and it is easy to have a long inflationary epoch while keeping density perturbations of the right magnitude and satisfying other cosmological constraints. We pay specific attention to satisfying the thermal constraint for inflation, i.e. the existence of a high temperature minimum at the origin.

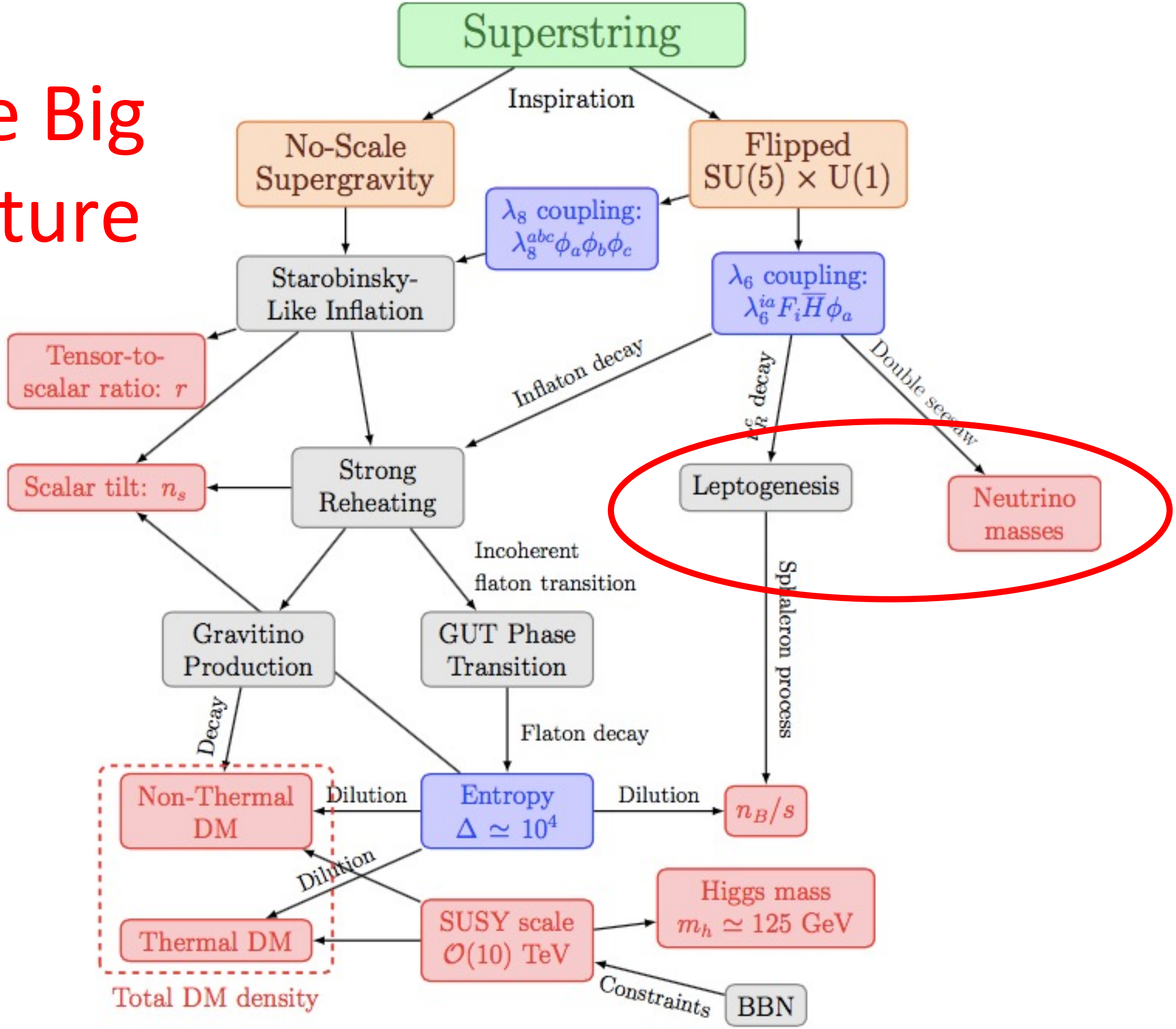
No-Scale Supergravity Inflation

- Inflationary potential for $\lambda \simeq \mu/3$



JE, Nanopoulos & Olive, arXiv:1305.1247

The Big Picture



JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1906.08483, 1910.11755

Neutrino Masses & Mixing

- Neutrinos couple to singlet scalars:

$$W = \sum_{i=1}^{3} \lambda_2^i \nu_i^c L_i H_d + \sum_{a=0}^{2} \mu^a \phi_a^2 + \sum_{i,a} \lambda_6^{ia} \nu_i^c \nu_{\bar{H}}^c \tilde{\phi}_a$$

- Neutrino mass matrix:

λ_6 key parameter in flipped SU(5)

$$\mathcal{L}_{\text{mass}} = -\frac{1}{2} \begin{pmatrix} \nu_i & \nu_j^c & \tilde{\phi}_a \end{pmatrix} \begin{pmatrix} 0 & \lambda_2^{ij} \langle \bar{h}_0 \rangle & 0 \\ \lambda_2^{ij} \langle \bar{h}_0 \rangle & 0 & \lambda_6^{ja} \langle \tilde{\nu}_{\bar{H}}^c \rangle \\ 0 & \lambda_6^{ja} \langle \tilde{\nu}_{\bar{H}}^c \rangle & \mu^a \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_j^c \\ \tilde{\phi}_a \end{pmatrix} + \text{h.c.}$$

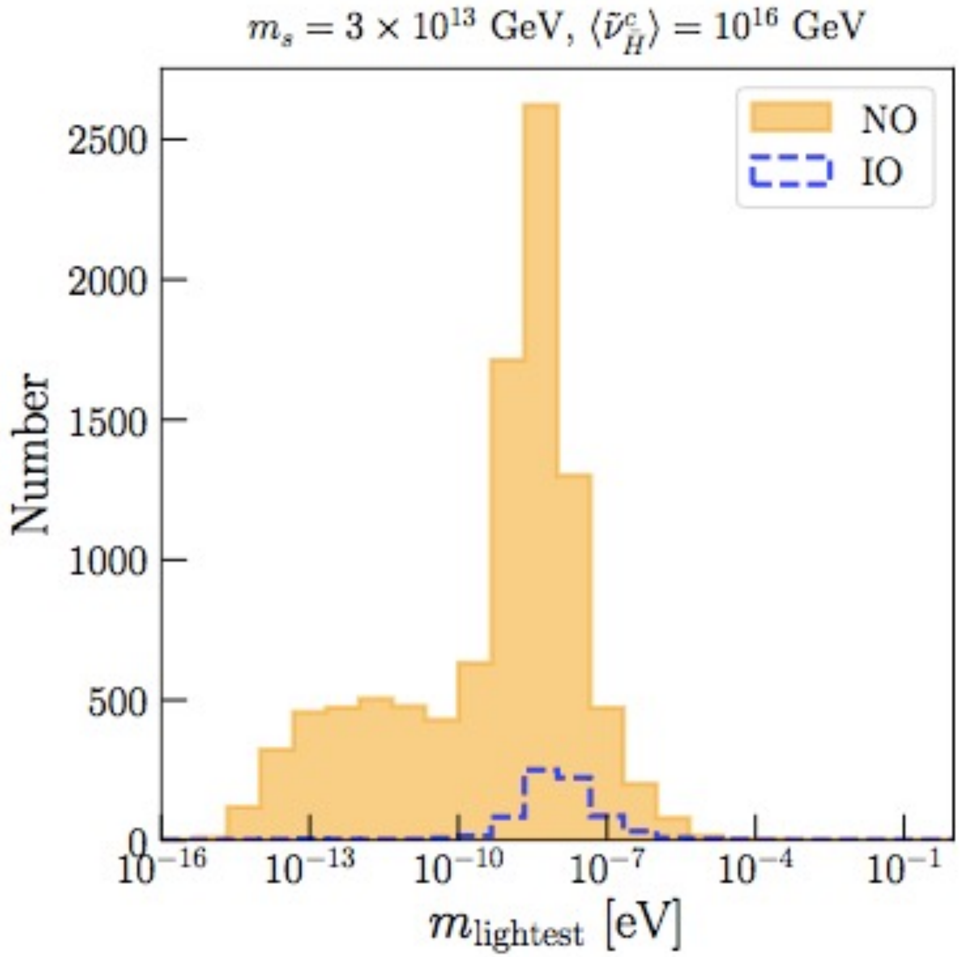
- Double seesaw for heavy & light neutrinos:

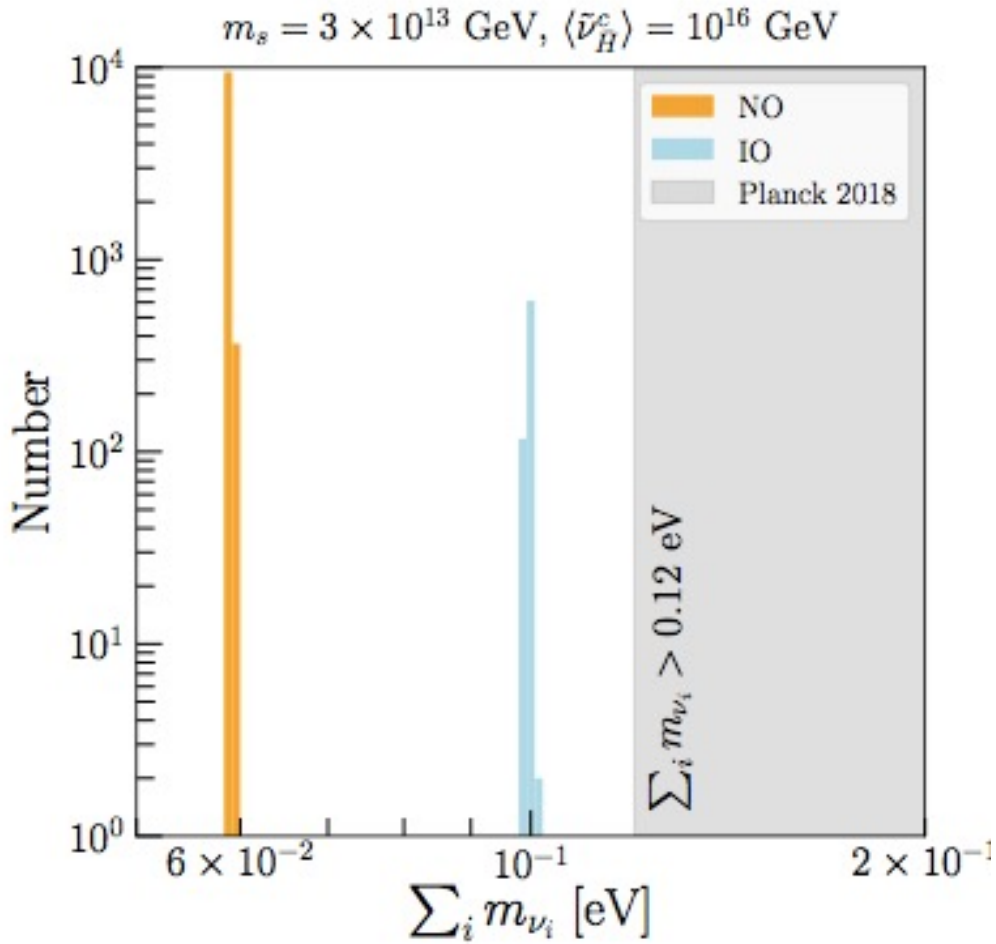
$$(m_{\nu^c})_{ij} = \sum_{a=0,1,2} \frac{\lambda_6^{ia} \lambda_6^{ja}}{\mu^a} \langle \tilde{\nu}_{\bar{H}}^c \rangle^2 \qquad (m_\nu)_{ij} = \sum_k \frac{\lambda_2^i \lambda_2^j (U_{\nu^c})_{ik} (U_{\nu^c})_{jk} \langle \bar{h}_0 \rangle^2}{(m_{\nu^c}^D)_k}$$

JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1910.11755

Light Neutrino Masses

Normal ordering vs inverse ordering





JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:1910.11755

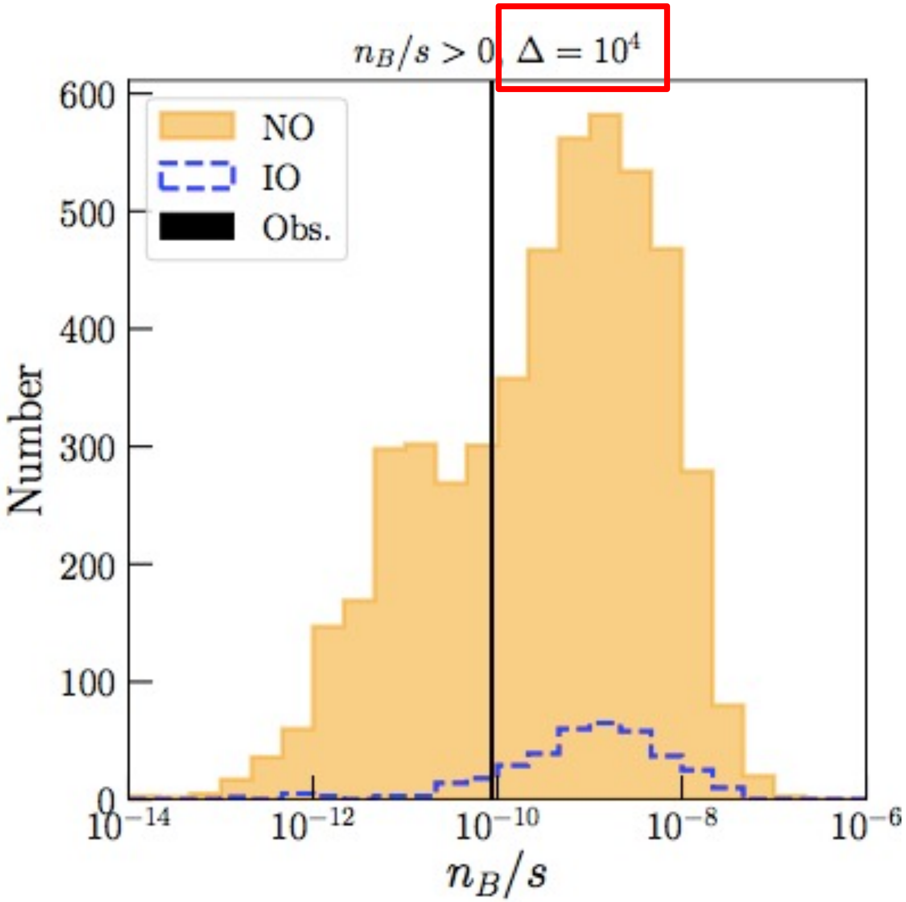
Cosmological Baryon Density

- Generated by CP violation in heavy neutrino decay

$$\frac{n_B}{s} = -\frac{28}{79} \cdot \frac{135\zeta(3)}{4\pi^4 g_{\rm reh}\Delta} \sum_{i=1,2,3} \epsilon_i \ ,$$

$$\epsilon_i = \frac{1}{2\pi} \frac{\sum_{j\neq i} {\rm Im}\left[\left(U^\dagger_{\nu^c}(\lambda_2^D)^2 U_{\nu^c}\right)^2_{ji}\right]}{\left[U^\dagger_{\nu^c}(\lambda_2^D)^2 U_{\nu^c}\right]_{ii}} g\left(\frac{m^2_{\nu^c_j}}{m^2_{\nu^c_i}}\right)$$

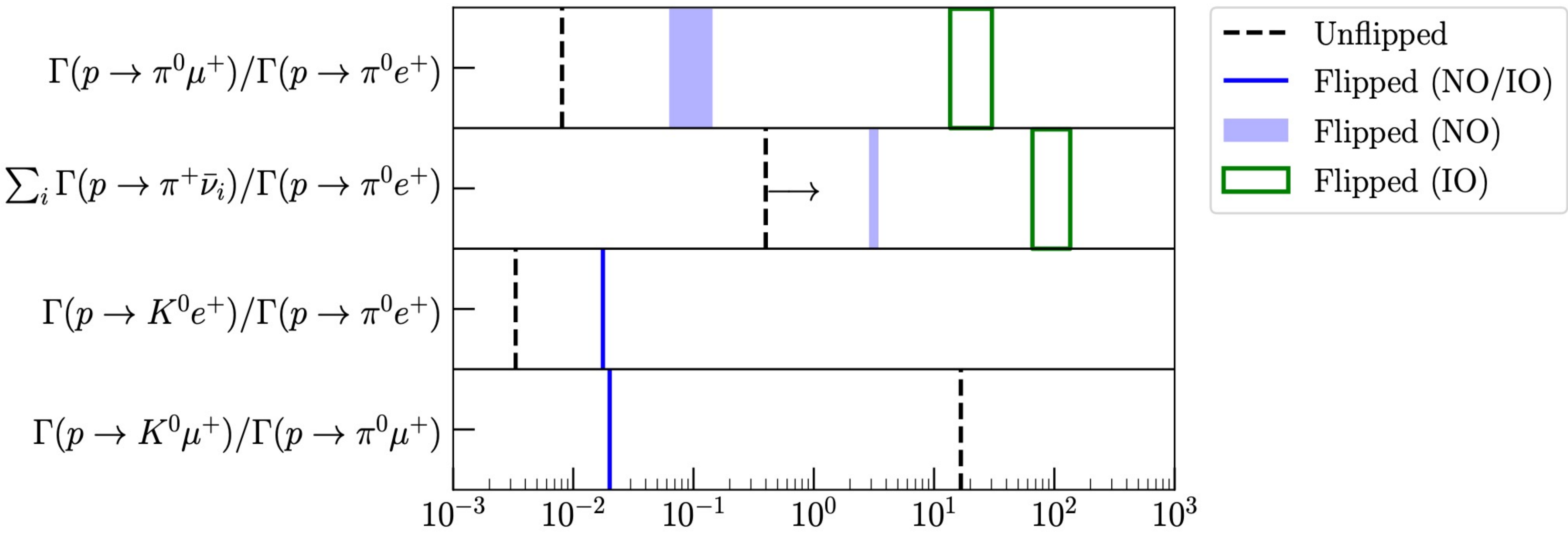
$$g(x) \equiv -\sqrt{x}\left[\frac{2}{x-1} + \ln\left(\frac{1+x}{x}\right)\right] .$$



Correct amount with appropriate entropy gain $\Delta \geq 10^4$

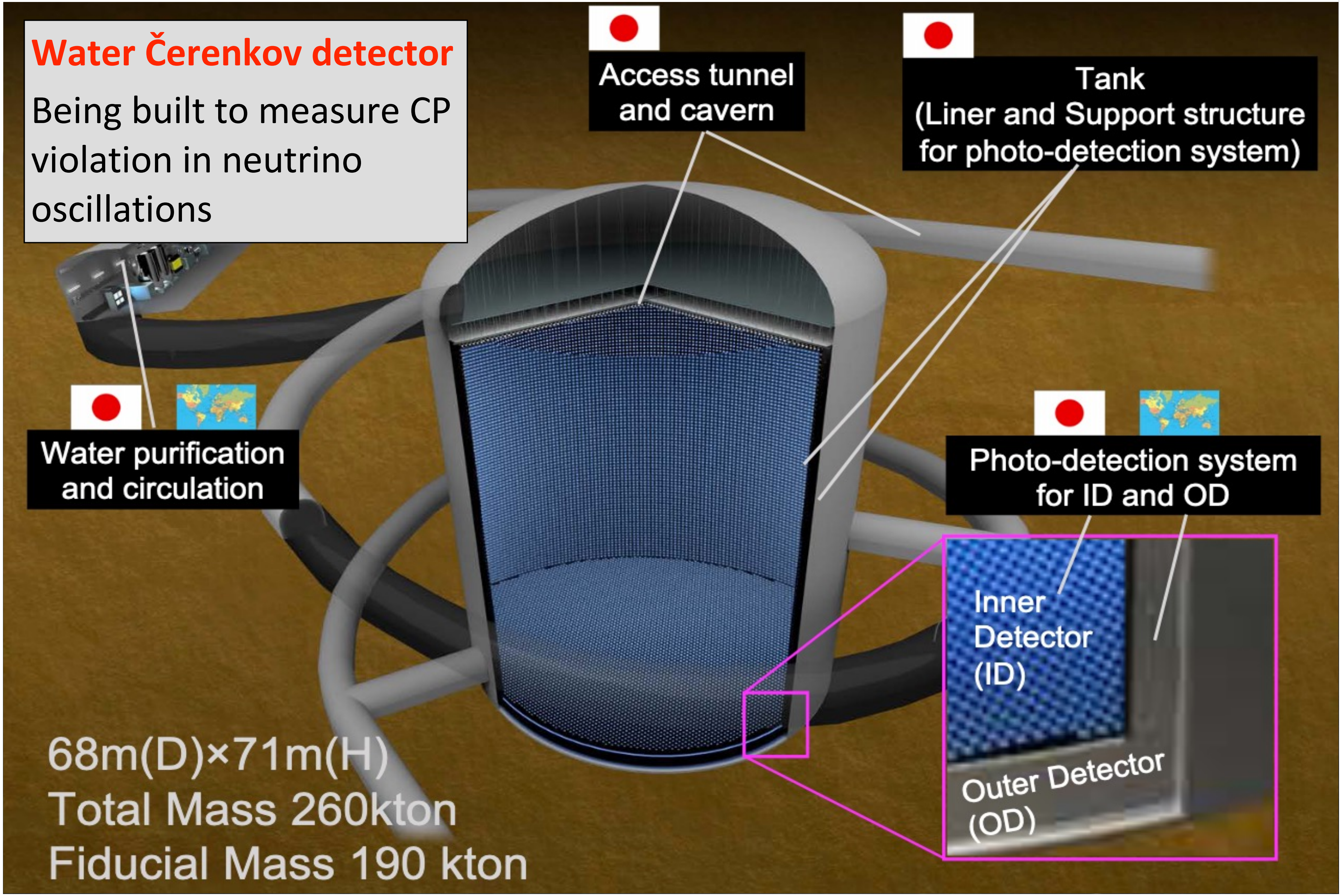
JE, Garcia, Nagata, Nanopoulos & Olive, arXiv:2003.03285

B Decay in Flipped SU(5) vs Unflipped



Probing different decay modes can distinguish between different models

Hyper-Kamiokande Experiment

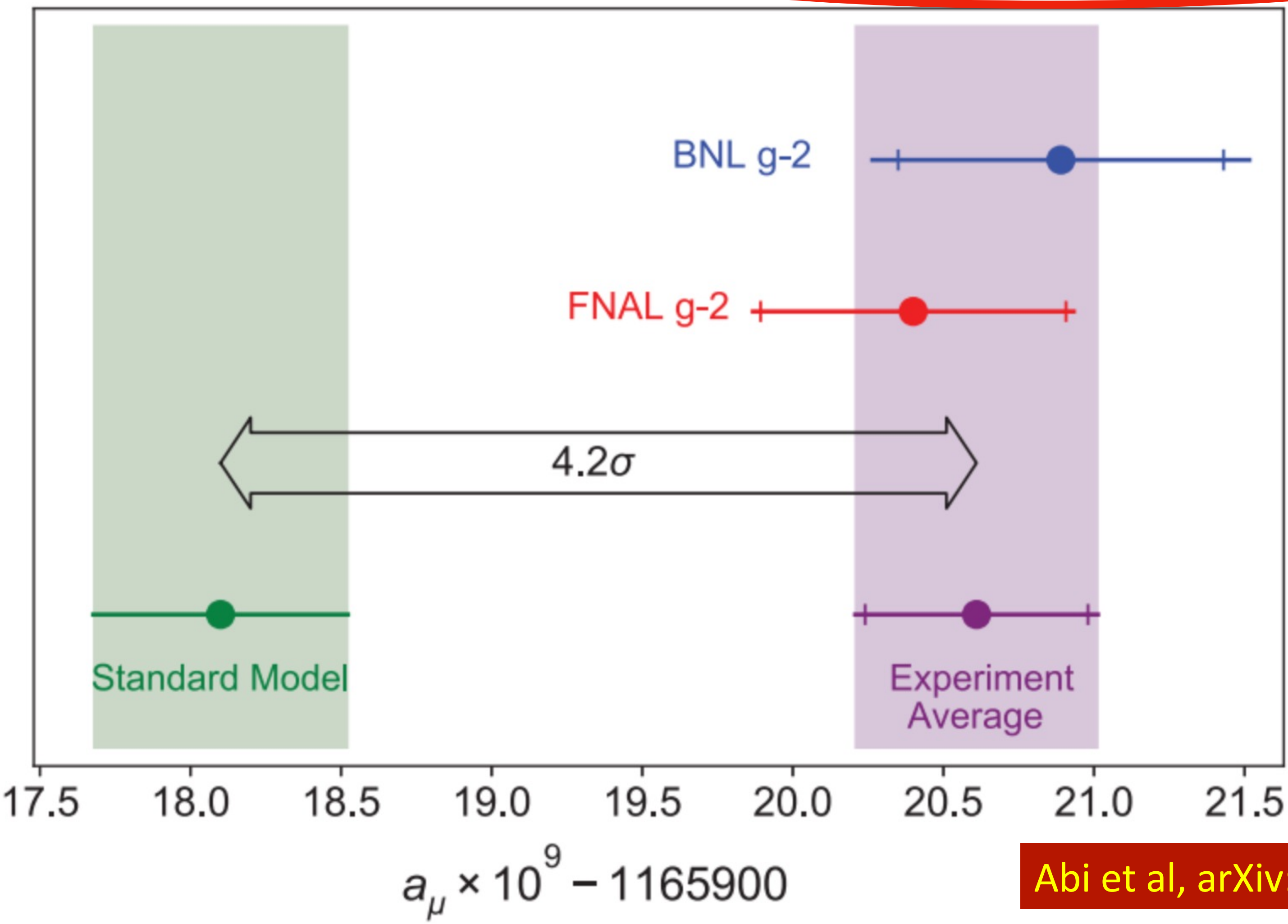


Fermilab Measurement of $g_\mu - 2$

FNAL result: $a_\mu(\text{FNAL}) = 116\,592\,040(54) \times 10^{-11} \quad (0.46\,\text{ppm})$

Combined result: $a_\mu(\text{Exp}) = 116\,592\,061(41) \times 10^{-11} \quad (0.35\,\text{ppm})$

Difference from Standard Model: $a_\mu(\text{Exp}) - a_\mu(\text{SM}) = (251 \pm 59) \times 10^{-11}$



Abi et al, arXiv:2104.03281

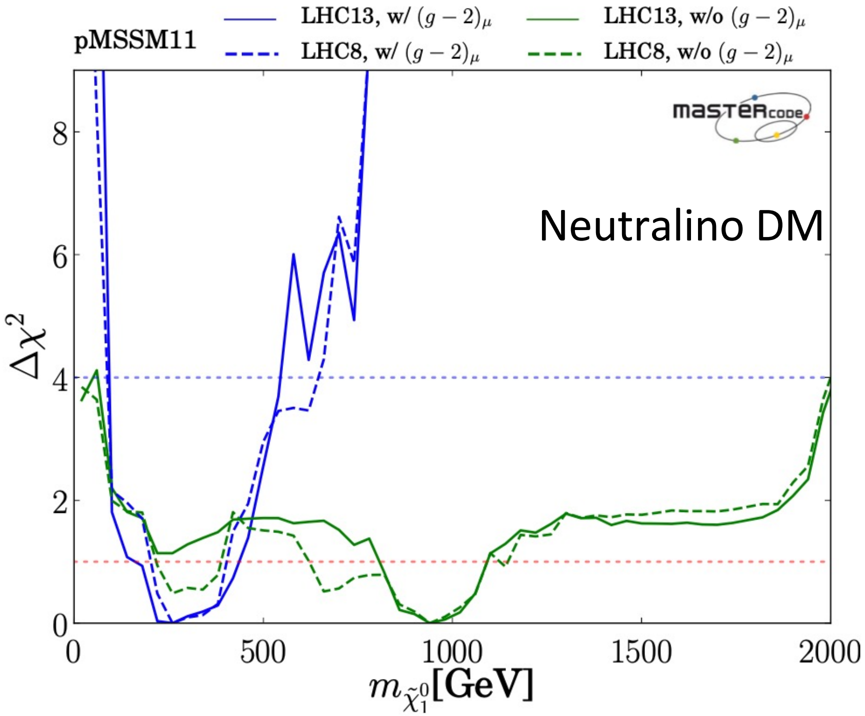
Interpretation Papers

2104.05685	Vector LQ	B	Du	
5656	L_\mu - L_\tau	DM	Borah	
5006	B_q - L_\mu	B	Cen	Leptoquarks
4494	LFV	LFV	Li	
4503	Pseudoscalar	DM, H decays	Lu	Extra U(1)
4456	2HDM	DM	Arcadi	
3542	B-LSSM	H decays	Yang	Extra Higgs
3701	Leptophilic spin 0	H factory	Chun	
3839	SUSY	HL-LHC	Aboubrahim	Supersymmetry
3691	Survey	DM, LHC	Athron	
3705	Seesaw	g_e	Escribano	Axion
3699	Gauged 2HDM	B	Chen	
3239	SUSY	Gravitino DM	Gu	
3284	NMSSM	DM	Cao	
3262	GUT-constrained SUSY	DM, LHC	Wang	
3292	MSSM	CPV	Han	
3296	lepton mass matrix	Flavour	Calibbi	
3280	Z_d	Cs weak charge	Cadeddu	
3334	E_6 3-3-1	H stability	Li	
3242	\mu-\tau-philic H	\tau decays, LHC	Wang	
3259	Anomaly mediation	DM	Yin	
3245	pMSSM	DM, fine-tuning	Van Beekveld	
3274	NMSSM	DM, AMS-02 pbar	Abdughani	
3290	MSSM	DM	Cox	
3367	2HDM	V-like leptons	Ferreira	
3267	Axion	Low-scale	Buen-Abad	
3340	L_\mu - L_tau	AMS-02 positrons	Zu	
3282	ALP	V-like fermions	Brdar	
3301	Lepton portal	DM	Bai	
3276	Dark axion portal	Dark photon	Ge	
3491	GmSUGRA	LHC	Ahmed	
3227	2HDM	LHC	Han	
3302	SUSY	small \mu	Baum	
3238	Scalar	DM, p radius	Zhu	
3489	\mu \nu SSM	B, H decays	Zhang	
3287	pMSSM	ILC	Chakraborti	
3228	DM	B, H decays	Arcadi	

890	Radiative seesaw		Chiang
2103.13991	Scalar LQ	B, H decays	Greljo
2012.11766	DM		D'Agnolo
2012.07894	Axions		Darmé
1812.06851	Charmphilic LQ		Kowalska
2104.04458	GUT-constrained SUSY	DM	Chakraborti
5730	LQ + charged singlet	B, Cabibbo	Marzocca
6320	L-R symmetry		Boyarkin
6858	L_\mu - L_\tau	\nu masses	Zhou
6854	D-brane	U(1), Regge	Anchordoqui
6656	vector LQ	B	Ban
7597	SUSY	LHC, landscape	Baer
7047	3HDM	Fermion masses	Carcamo
7680	Leptophilic Z'	Global analysis	Buras
8289	Custodial symmetry	Light scalar + pseudoscalar	Balkin
9205	U(1)D	Neutrino mass	Dasgupta
8819	Lepton non-universality	Naturalness	Cacciapaglia
8640	2x2x1	Higgses, heavy nus	Boyarkina
8293	Multi-TeV sleptons in FSSM	Extended H, tau decays	Altmannshofer
10114	SO(10)	Yukawa unification	Aboubrahim
7681	U(1)B-L	DUNE	Dev
10324	Gauged lepton number	Dark matter	Ma
10175	2HDM	Lighter Higgs?	Jueid
11229	LQ	Matter unification	Fileviez
15136	U(1)	HE neutrinos, H tension	Alonso
2105.00903	Anomalous 3-boson vertex	W mass	Arbuzov
7655	U(1)T3R	RK(*)	Dutta
8670	Leptoquark	nu mass, LFV	Zhang

$g_\mu - 2$ in Phenomenological Supersymmetry (pMSSM11)

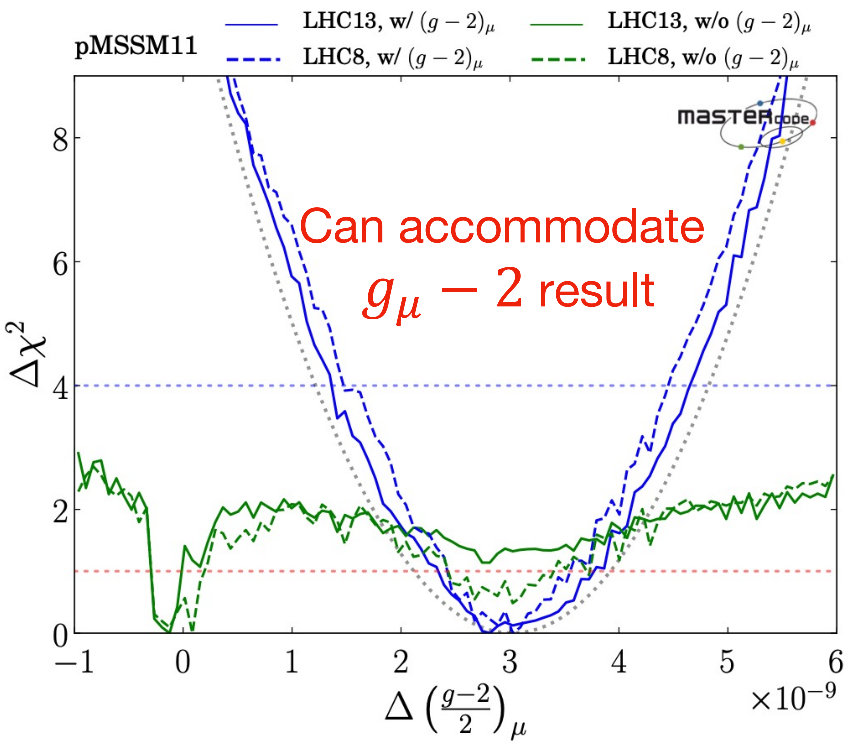
No relation between squark/gluino masses and slepton/neutralino masses

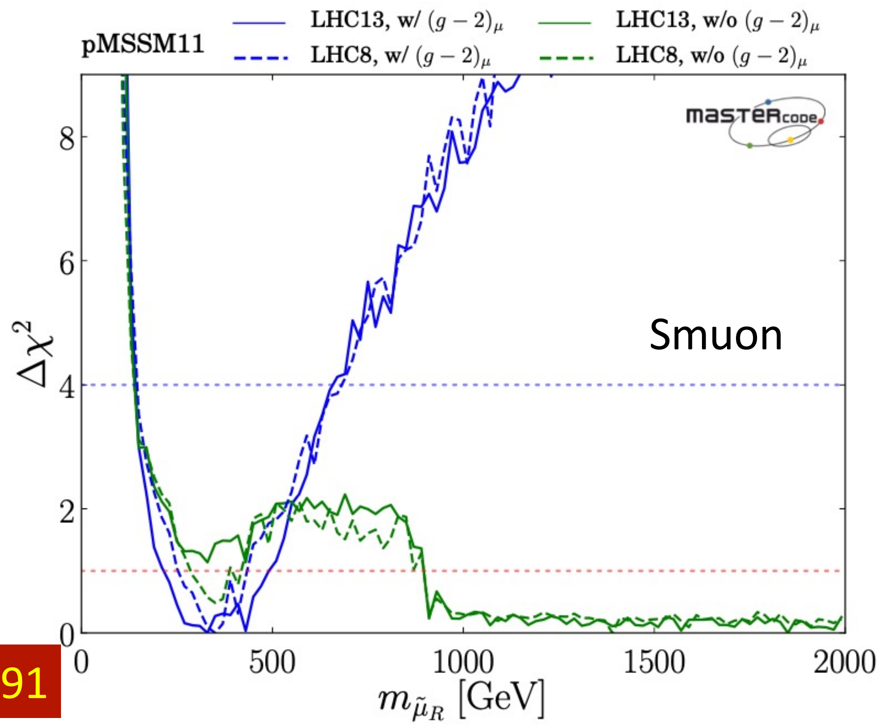


No problem accommodating BNL/FNAL result

Neutralino DM, smuon masses $\sim 300/400$ GeV

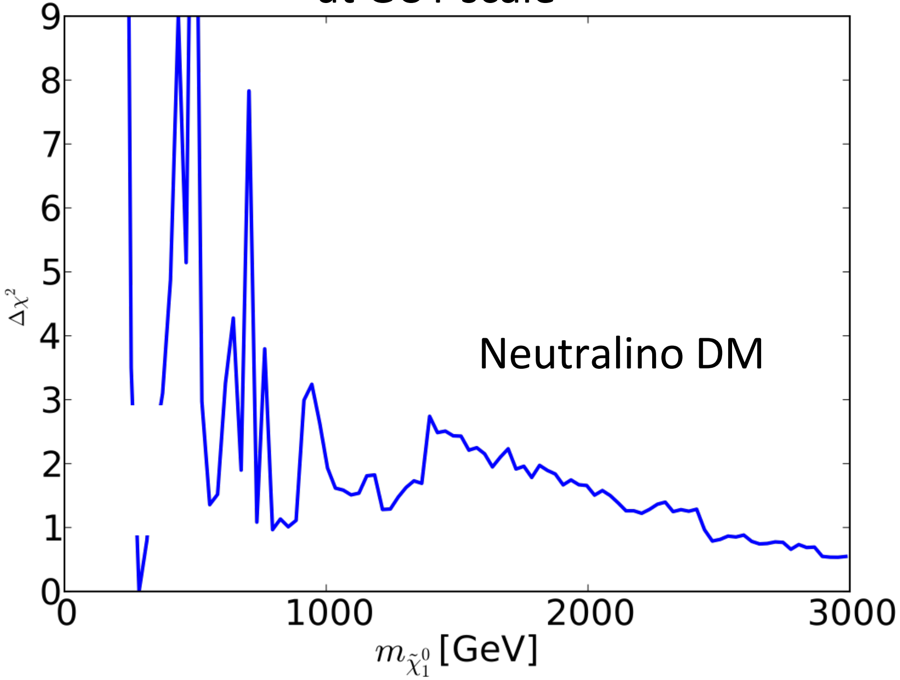
MasterCode, E. Bagnaschi, …, JE et al, arXiv:1710.11091





$g_\mu - 2$ in Supersymmetric SU(5) GUT
(CMSSM)

Assume universality between squark & slepton, and between gluino and electroweakino masses at GUT scale

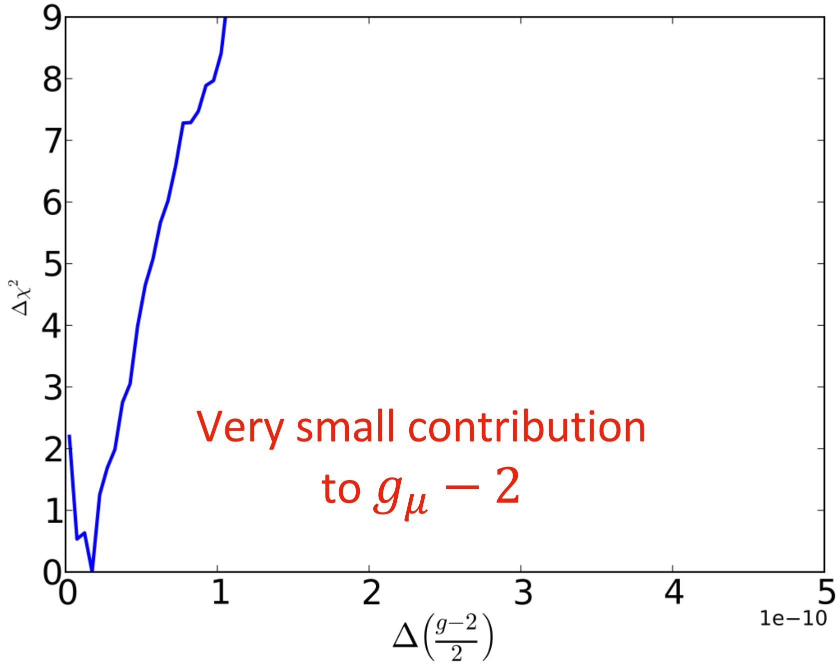


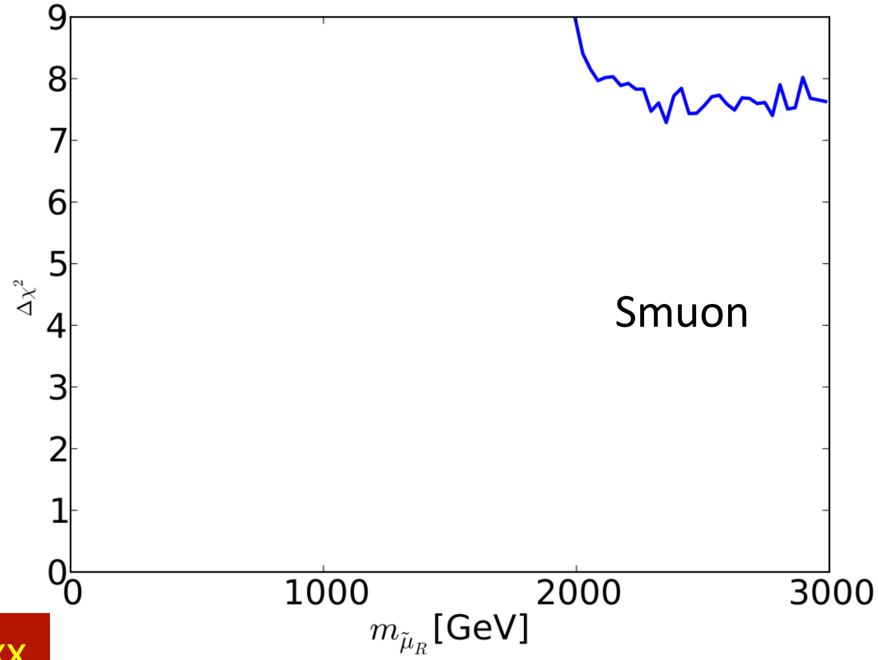
Scenario relates squark/gluino masses to slepton/neutralino masses

Cannot accommodate BNL/FNAL result

Smuon masses $\gtrsim$ 4 TeV

MasterCode, E. Bagnaschi, …, JE et al, arXiv:2108.xxxxx





Flipped SU(5) GUT

- Extend GUT SU(5) with additional U(1) [motivated by string theory]

Antoniadis, JE, Hagelin & Nanopoulos, 1987

- "Flipped" fermion assignments to representations:

$$\bar{f}_i(\bar{\mathbf{5}}, -3) = \{U_i^c, L_i\}\ , \quad F_i(\mathbf{10}, 1) = \{Q_i, D_i^c, N_i^c\}\ , \quad l_i(\mathbf{1}, 5) = E_i^c\ , \quad i = 1, 2, 3$$

- Break GUT symmetry with 10-dimensional Higgses, electroweak symmetry with 5-dimensional Higgses:

$$H(\mathbf{10}, 1) = \{Q_H, D_H^c, N_H^c\}\ , \qquad \bar{H}(\bar{\mathbf{10}}, -1) = \{\bar{Q}_H, \bar{D}_H^c, \bar{N}_H^c\}$$

$$h(\mathbf{5}, -2) = \{T_{H_c}, H_d\}\ , \qquad \bar{h}(\bar{\mathbf{5}}, 2) = \{\bar{T}_{\bar{H}_c}, H_u\}$$

Lightest neutralino & lighter smuon can have small masses

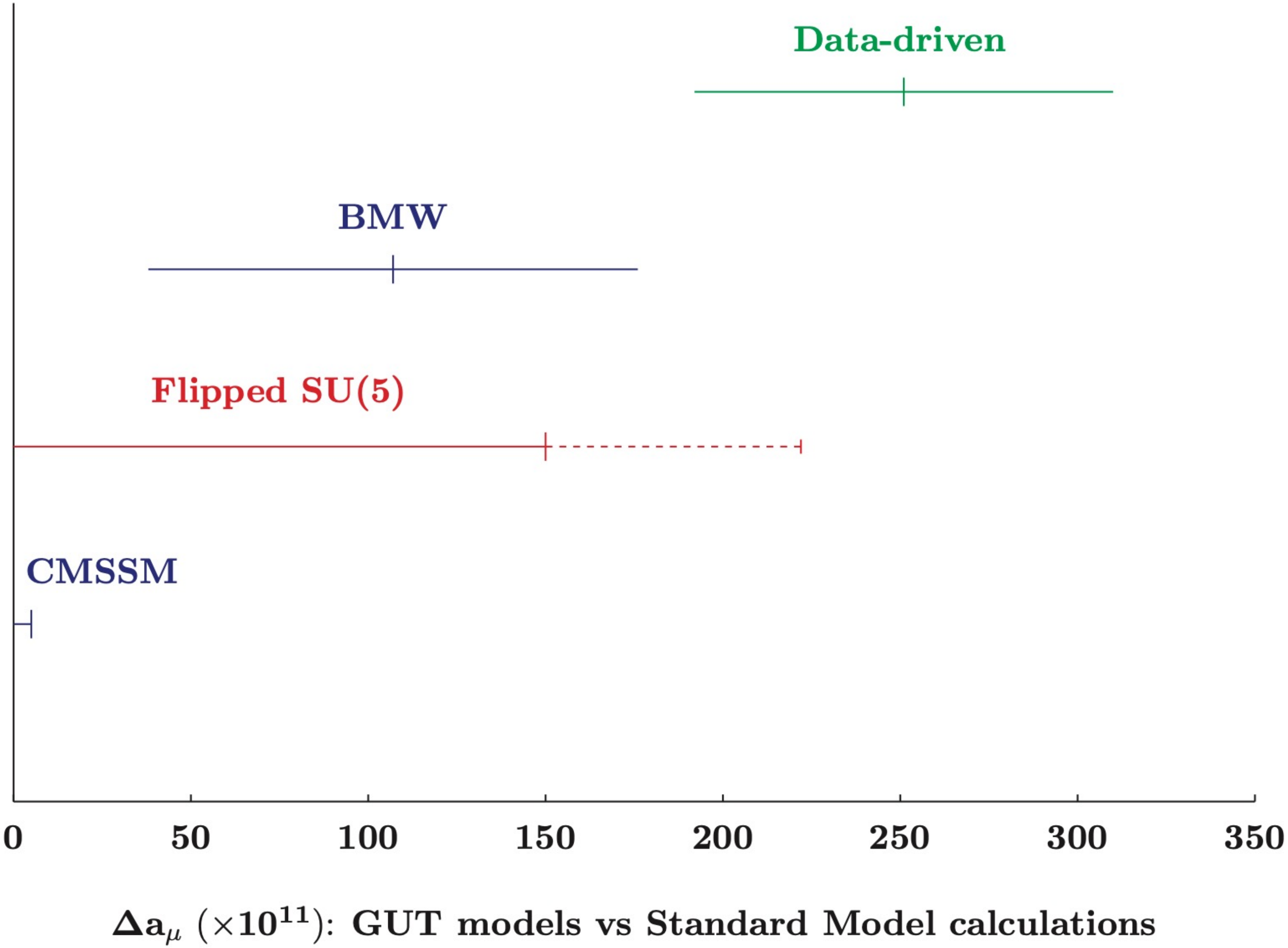
- Superpotential:

$$W = \lambda_1^{ij} F_i F_j h + \lambda_2^{ij} F_i \bar{f}_j \bar{h} + \lambda_3^{ij} \bar{f}_i \ell_j^c h + \lambda_4 H H h + \lambda_5 \bar{H} \bar{H} \bar{h}$$
$$+ \lambda_6^{ia} F_i \bar{H} \phi_a + \lambda_7^a h \bar{h} \phi_a + \lambda_8^{abc} \phi_a \phi_b \phi_c + \mu_\phi^{ab} \phi_a \phi_b\ ,$$

- Scan free parameters of model:

$$M_5,\ M_{X1},\ m_{10},\ m_5,\ m_1,\ \mu,\ M_A,\ A_0,\ \tan\beta$$

$g_\mu - 2$ in CMSSM & Flipped SU(5) vs BMW Lattice, Data-Driven Calculations



JE, Evans, Nagata, Nanopoulos & Olive, arXiv:2107.03025

$g_\mu - 2$ in Flipped SU(5)

Parameters & predictions at best-fit point

Input GUT parameters (masses in units of 10^{16} GeV)		
$M_{GUT} = 1.00$	$M_X = 0.79$	$V = 1.13$
$\lambda_4 = 0.1$	$\lambda_5 = 0.3$	$\lambda_6 = 0.001$
$g_5 = 0.70$	$g_X = 0.70$	$m_{\nu_3} = 0.05$ eV
Input supersymmetry parameters (masses in GeV units)		
$M_5 = 2460$	$M_1 = 240$	$\mu = 4770$
$m_{10} = 930$	$m_{\bar{5}} = 450$	$m_1 = 0$
$M_A = 2100$	$A_0/M_5 = 0.67$	$\tan\beta = 35$
MSSM particle masses (in GeV units)		
$m_\chi = 84$	$m_{\tilde{t}_1} = 4030$	$m_{\tilde{g}} = 5090$
$m_{\chi_2} = 2160$	$m_{\chi_3} = 5080$	$m_{\chi_4} = 5080$
$m_{\tilde{\mu}_R} = 101$	$m_{\tilde{\mu}_L} = 1600$	$m_{\tilde{\tau}_1} = 1010$
$m_{\tilde{q}_L} = 4470$	$m_{\tilde{d}_R} = 4250$	$m_{\tilde{u}_R} = 4170$
$m_{\tilde{t}_2} = 4410$	$m_{\tilde{b}_1} = 4170$	$m_{\tilde{b}_2} = 4400$
$m_{\chi^\pm} = 2160$	$m_{H,A} = 2100$	$m_{H^\pm} = 2100$
Other observables		
$\Delta a_\mu = 150 \times 10^{-11}$	$\Omega_\chi h^2 = 0.13$	$m_h = 122$ [illegible]
Normal-ordered ν masses:	$\tau_{p\to e^+\pi^0}\|_{\rm NO} = 1.1 \times 10^{36}$ yrs	$\tau_{p\to\mu^+\pi^0}\|_{\rm NO} = 1.1$ [illegible]
Inverse-ordered ν masses:	$\tau_{p\to e^+\pi^0}\|_{\rm IO} = 3.2 \times 10^{37}$ yrs	$\tau_{p\to\mu^+\pi^0}\|_{\rm IO} = 2.3 \times 10^{36}$ yrs

Opportunities to search for light smuon, neutralino at LHC
Other sparticles too heavy?

Get good CDM density without even trying!

JE, Evans, Nagata, Nanopoulos & Olive, arXiv:2107.03025

Refrain from “Supersymmetry” by Arcade Fire:

I know you're living in my mind
It's not the same as being alive

My Message to Ignatios:

Keep on Flipping!