IR-UV Mixing and Swampland Conjectures

Luis Ibáñez

(Collaboration with A.Castellano and A. Herráez, hep-th/2112.10796)

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This talk is dedicated to the memory of my friend and collaborator **Graham Ross**

CERN COURIER JANUARY/FEBRUARY 2022

A deep and original thinker

Graham Ross, a distinguished Scottish theorist who worked mainly on fundamental particle physics and its importance for the evolution of the universe, passed away suddenly on 31 October 2021.

Born in Aberdeen in 1944, Graham studied physics at the University of Aberdeen, where he met his future wife Ruth. In 1966 he moved to Durham University where he worked with Alan Martin on traditional aspects of the strong interactions for his PhD. His first postdoctoral position began in 1969 at Rutherford Appleton Laboratory (RAL). It was around the time that interest in gauge theories began to flourish, for which he and Alex Love were among the first to investigate the phenomenology. He continued working on this theme after he moved to CERN in 1974 for a two-year fellowship. Among the papers he wrote there was one in 1976 with John Ellis and Mary Gaillard suggesting how to discover the gluon in three-jet events due to "gluestrahlung" in electron–positron annihilation. This proposal formed the basis of the experimental discovery of the gluon a few years later at DESY.

After CERN, Graham worked for two years at Caltech, where he participated in a proof of the factorisation theorem that underlies the application of perturbative QCD to hard-scattering processes at the LHC. He then returned to the UK, to a consultancy at RAL held jointly with a post at the University of Oxford, where he was appointed lecturer in 1984. Here he applied his expertise on QCD in collaborations with Frank Close, Dick Roberts and also Bob Jaffe, showing how the evolution of valence quark distributions in heavy nuclei are in effect rescaled relative to what is observed in hydrogen and deuterium.

Wadham College

Graham was a pillar of Oxford's particle theory group.

This work hinted at an enhanced freedom of partons in dense nuclei.

In 1992 Graham became a professor at Oxford, where he remained for the rest of his career as a pillar of the theoretical particle-physics group, working on several deep questions and mentoring younger theorists. Among the many fundamental problems he worked on was the hierarchical ratio between the electroweak scale and the Planck or grand-unification scale, suggesting together with Luis Ibañez that it might arise from radiative corrections in a supersymmetric theory. The pair also pioneered the calculation of the electroweak mixing angle in a supersymmetric grand unified theory, obtaining a result in excellent agreement with subsequent measurements at LEP. Graham wrote extensively on the hierarchy of masses of different matter particles, and the mixing pattern of their weak interactions, with Pierre Ramond in particular, and pioneered phenomenological string models of particles and their interactions. In recent years, Graham worked on models of inflation with Chris Hill, his Oxford colleagues and others.

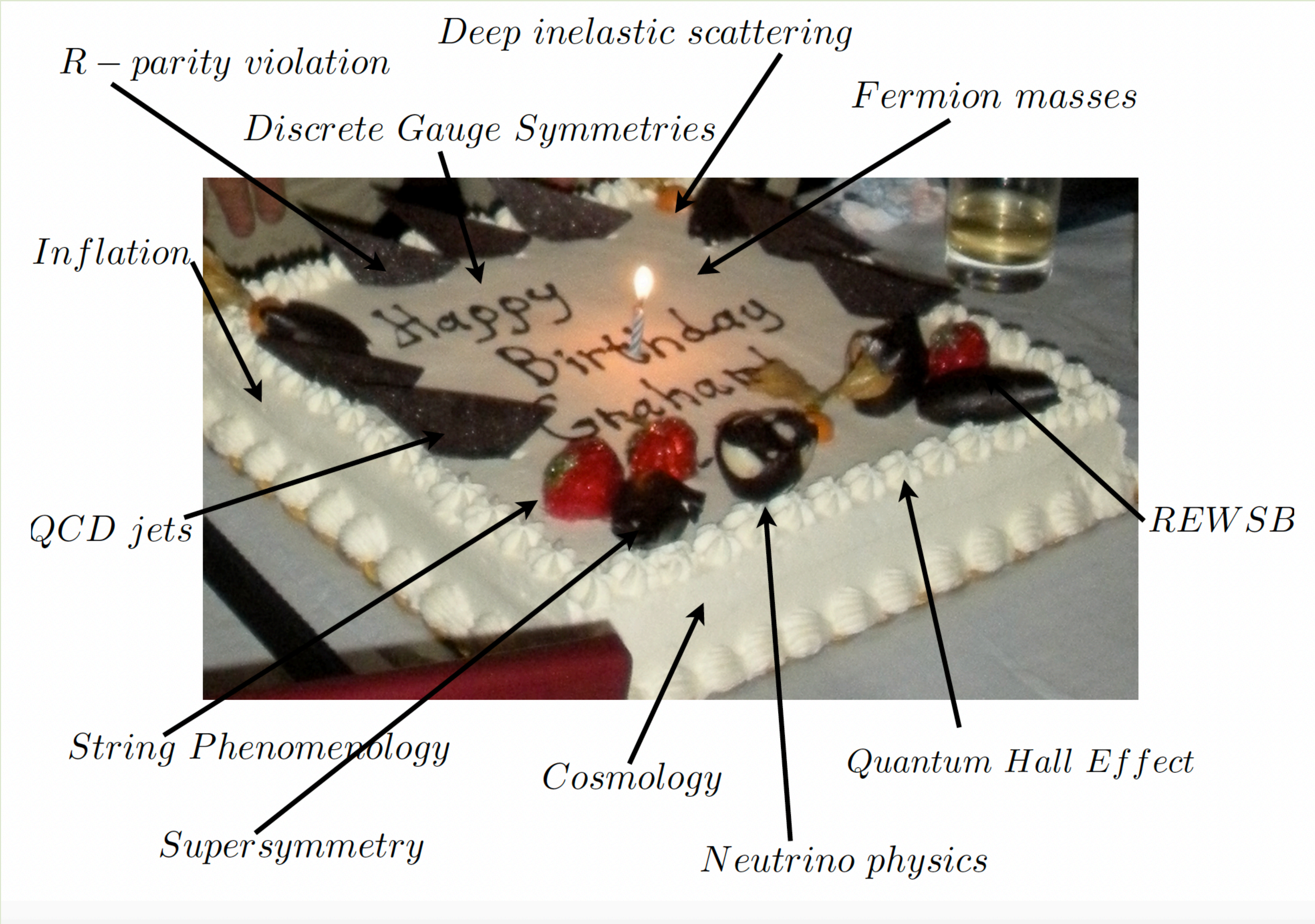
Among his formal recognitions were his election as fellow of the Royal Society in 1991 and his award of the UK Institute of Physics Dirac Medal in 2012. The citation is an apt summary of Graham's talents: "for theoretical work developing both the Standard Model of fundamental particles and forces, and theories beyond the Standard Model, that have led to new insights into the origins and nature of the universe".

Graham had a remarkable ability to think outside the box, and to analyse new ideas critically and systematically. His work was characterised by a combination of deep thought, originality and careful analysis. He was never interested in theoretical speculation or mathematical developments for their own sakes, but as means towards the ultimate end of understanding nature.

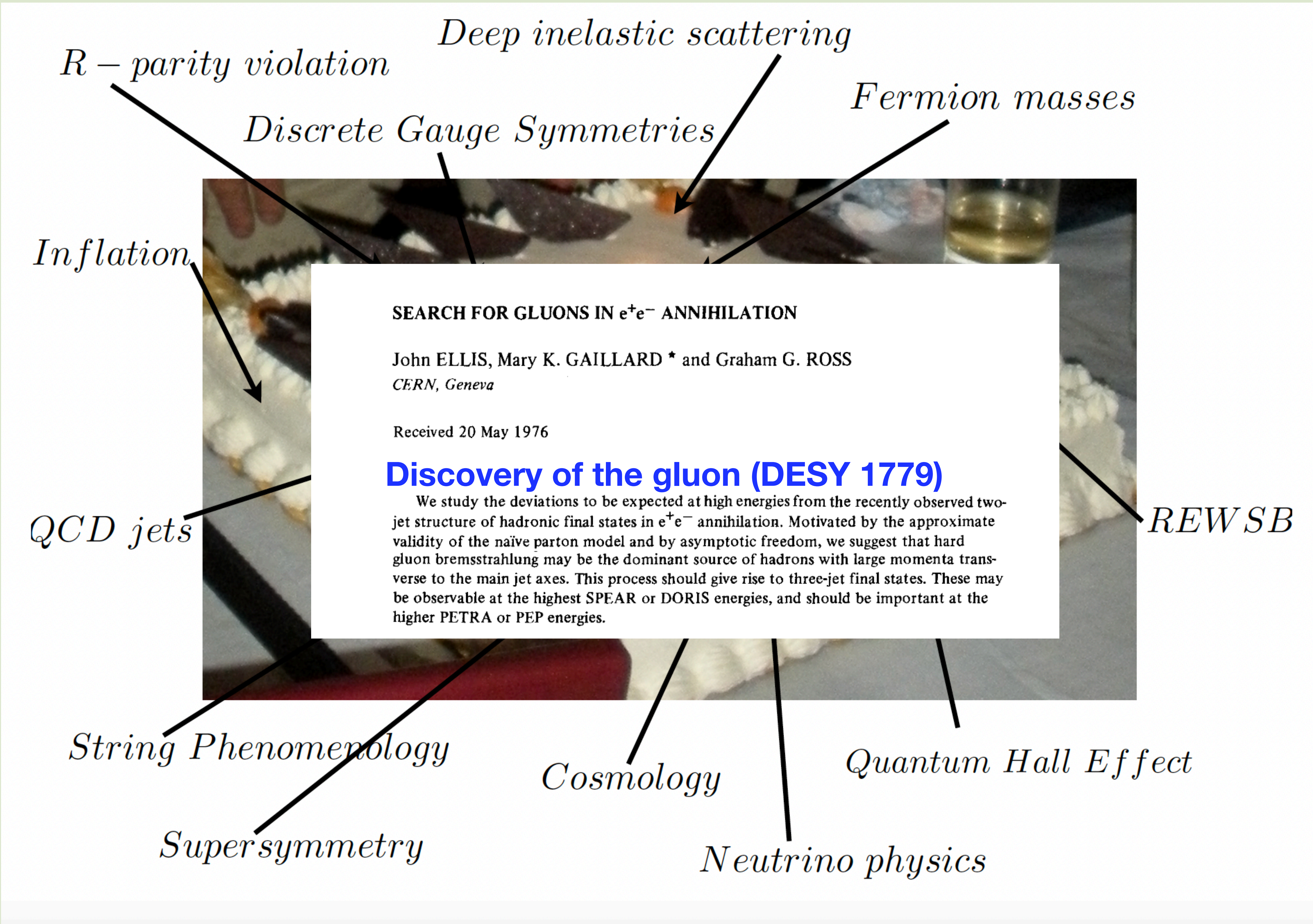
Many theoretical physicists are competitive and pursue their ambitions aggressively. But this was not Graham's way. Pursuing his ambitions with persistence and good humour, he was greatly admired as a talented physicist but also universally liked and admired, particularly by the many younger physicists whom he mentored at Oxford. He was a great teacher and an inspiration, not just to his formal students but also his daughters, Gilly and Emma, and latterly his grandchildren, James, Charlie and Wilfie.

John Ellis *King's College London/CERN,* **Frank Close** *and* **Subir Sarkar** *University of Oxford.*

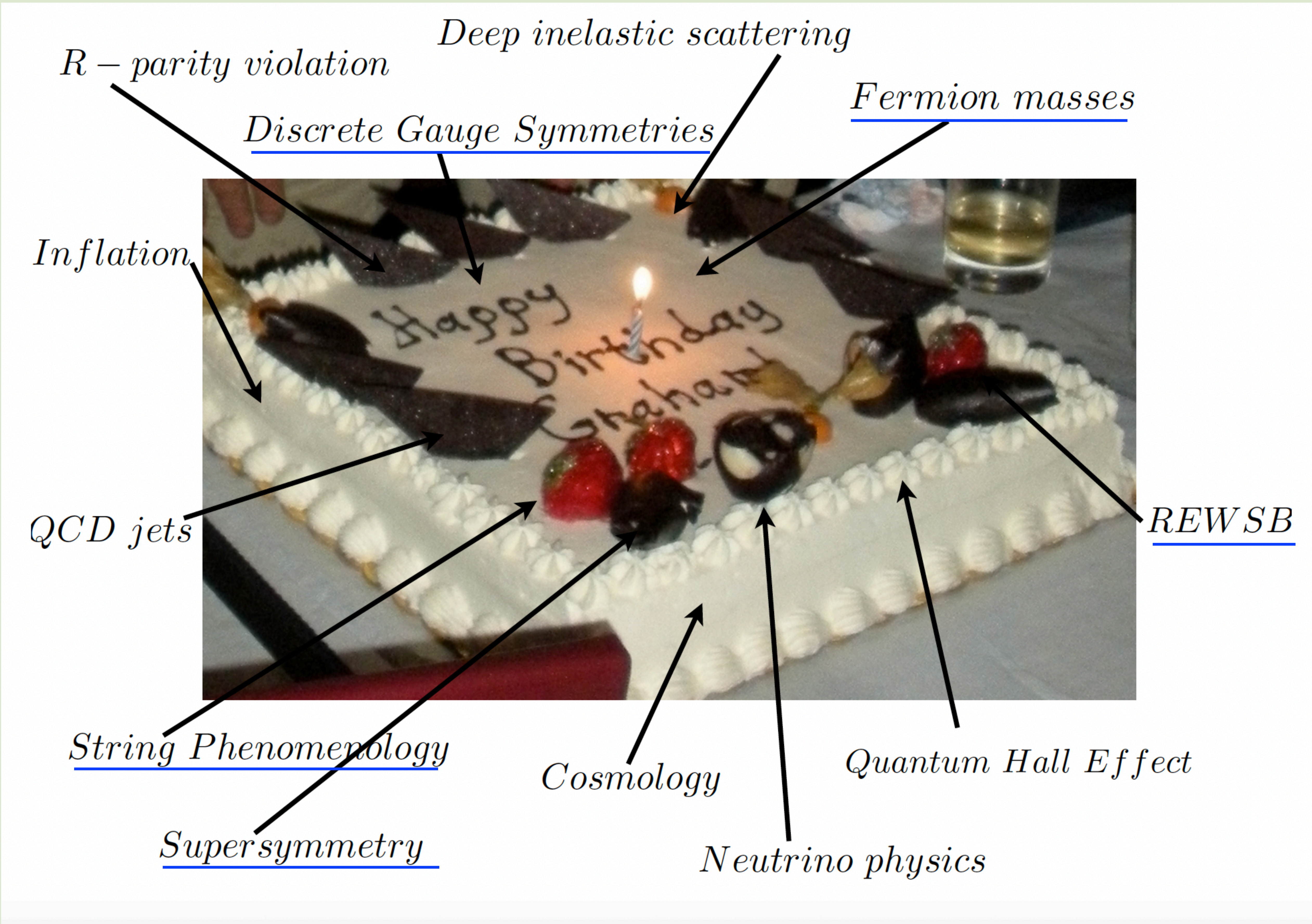
A transparency in 2011 Grahams ‘retirement’ fest

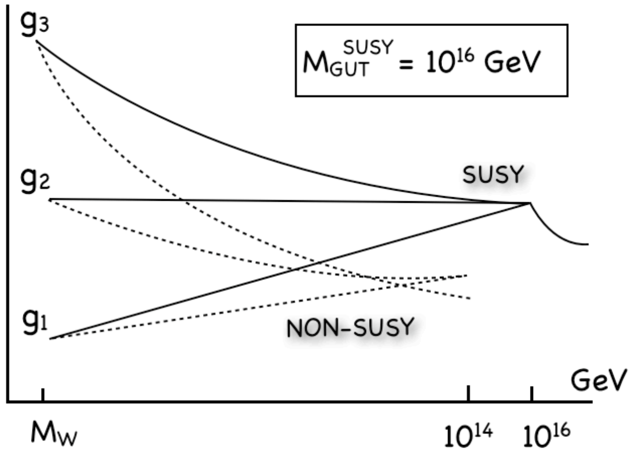


A transparency in 2011 Grahams 'retirement' fest



A transparency in 2011 Grahams 'retirement' fest





LOW-ENERGY PREDICTIONS IN SUPERSYMMETRIC GRAND UNIFIED THEORIES

L.E. IBÁÑEZ and G.G. ROSS
Department of Theoretical Physics, Oxford, OX1 3NP, England

Received 27 July 1981

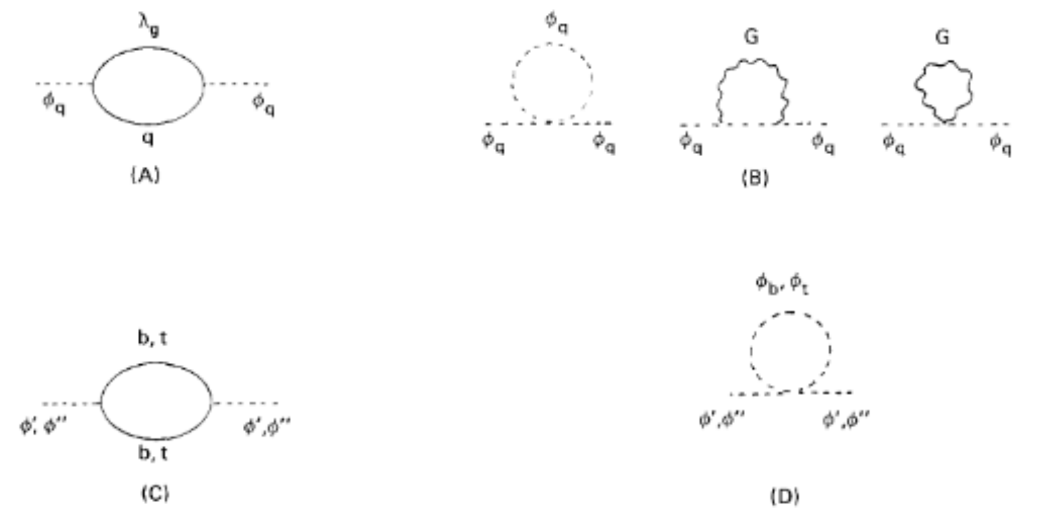
Globally supersymmetric theories provide a solution to the gauge hierarchy problem without the need for a strongly interacting sector. We consider various such theories which generalise the standard SU(3) × SU(2) × U(1) model and compute their predictions for the unification scale M_X, $\sin^2\theta_W$ and fermion mass ratios.

$SU(2)_L \times U(1)$ SYMMETRY BREAKING AS A RADIATIVE EFFECT OF SUPERSYMMETRY BREAKING IN GUTs

Luis IBÁÑEZ [1] and Graham G. ROSS [2]
Department of Theoretical Physics, Oxford OX1 3NP, UK

Received 7 January 1982

It is shown how in a globally supersymmetric SU(3) × SU(2) × U(1) model supersymmetry breaking can, via radiative corrections, induce an effective Higgs potential which spontaneously breaks SU(2) × U(1) to $U(1)_Q$. We discuss the spectrum of the resulting theory particularly the many new fermions and scalar particles which should be produced by the next generation of accelerator. The inclusion of the model in supersymmetric GUTs is considered and a model is constructed in which no unnatural adjustment of parameters is required.



$$M^2_{\phi_q} = (8/3\pi)\,\alpha_{QCD} M^2_{ss} \ln(\Lambda^2/M^2_{ss}).$$

positive $m^2_{\tilde q}$

$$\mu^2_{\phi',\phi''} = -(3/4\pi^2) h^2_{t,b} M^2_{\phi_q} \ln(\Lambda/M_{\phi_q}),$$

Spontaneous EW breaking

Discrete gauge symmetry anomalies

L.E. Ibáñez
CERN, CH-1211 Geneva 23, Switzerland

and

G.G. Ross
Department of Theoretical Physics, Oxford OX1 3NP, UK

Received 18 February 1991

(i) Cubic $\mathbb{Z}_N^3$ anomaly cancelation condition

$$\sum_i (q_i)^3 = rN + \tfrac{1}{8}\eta s N^3, \quad r, s \in \mathbb{Z},$$

where $\eta = 1, 0$ for N = even, odd.

(ii) Mixed $\mathbb{Z}_N$–gravitational anomalies

$$\sum_i (q_i) = r'N + \tfrac{1}{2}\eta s' N, \quad r', s' \in \mathbb{Z}.$$

(iii) Mixed $\mathbb{Z}_N$–SU(M)–SU(M) anomalies:

$$\sum_i T_i(q_i) = \tfrac{1}{2} r'' N, \quad r'' \in \mathbb{Z}.$$

Fermion masses and mixing angles from gauge symmetri

Luis Ibáñez [a], Graham G. Ross [b,*]
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Received 26 April 1994
Editor: R. Gatto

Discrete gauge symmetries must be anomaly free

…he was a pioneer of string phenomenology, e.g.

Nuclear Physics B278 (1986) 667–693
North-Holland, Amsterdam

A THREE-GENERATION SUPERSTRING MODEL
(I). Compactification and discrete symmetries

Brian R. GREENE, Kelley H. KIRKLIN, Paul J. MIRON and Graham G. ROSS
Department of Theoretical Physics, University of Oxford, 1 Keble Road, Oxford, UK

Received 24 March 1986

We present the preliminary analysis of a three-generation heterotic superstring-inspired model. A detailed mathematical description of the manifold of compactification is given, along with a determination of its Hodge numbers and of the associated light supermultiplet structure. For a particular choice of vacuum moduli we derive this manifold's symmetry and groups, and determine their action on the massless fields in the theory. These transformation properties shall be shown, in a companion paper, to give rise to a model with interesting phenomenological properties.

…first phenomenological study
of a 3-generation
CY heterotic compactification

Gauge coupling running
in minimal SU(3)×SU(2)×U(1) superstring unification

Luis E. Ibáñez, Dieter Lüst
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Graham G. Ross
Department of Physics, 1 Keble Road, Oxford OX1 3NP, UK

Received 20 September 1991

(0, 2) HETEROTIC STRING COMPACTIFICATIONS FROM N=2 SUPERCONFORMAL THEORIES

A. FONT
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M. MONDRAGÓN
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F. QUEVEDO
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and

G.G. ROSS
Department of Theoretical Physics, Unversity of Oxford OX1 3NP, UK

…and many other contributions to the area.….

(e.g. collaborations with Lukas, Lutken, Leontaris, Ghilencea,….)

ALBUM

…Some pictures…..

…Planck 2010, Geneva…..

…Madrid, ‘Is SUSY alive and well’ worshop, 2016…..

Graham Fest, Oxford 2011

Corfu 2009

CERN 1987

‘Auberge des Chasseurs’, close to Geneva, summer 2019….then COVID came

Many theoretical physicists are competitive and pursue their ambitions aggressively. But this was not Graham's way. Pursuing his ambitions with persistence and good humour, he was greatly admired as a talented physicist but also universally liked and admired, particularly by the many younger physicists whom he mentored at Oxford. He was a great teacher and an

Close,Ellis,Sarkar

Thanks very much
Graham for your
friendship
and for your
great physics !!!!!!!

Sadly, we suffer another shock
with the death of Costas…..

IR-UV Mixing and Swampland Conjectures

Luis Ibáñez

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QG and UV-IR connection

- Traditionally (Wilson) one parametrizes effects of QG on an EFT

$$\mathcal{L}_{\mathrm{EFT,QG}} = \mathcal{L}_{\mathrm{EFT}} + \sum_{n=D}^{\infty} \frac{\mathcal{O}_n}{M_D^{n-D}}$$

UV and IR scales otherwise unrelated

- But there are hints that this procedure is incorrect in the presence of QG e.g.
  - Duality symmetries map light to heavy modes
  - BH high energy scattering

- The precise relation between UV and IR in QG yet to be elucidated. A simple parametrization in an EFT could be provided by

$$\Lambda_{UV} \lesssim \Lambda_{IR}^{\delta} M_D^{1-\delta} \quad , \quad \delta < 1$$

$M_D = D - dimensional\ Planck\ scale$

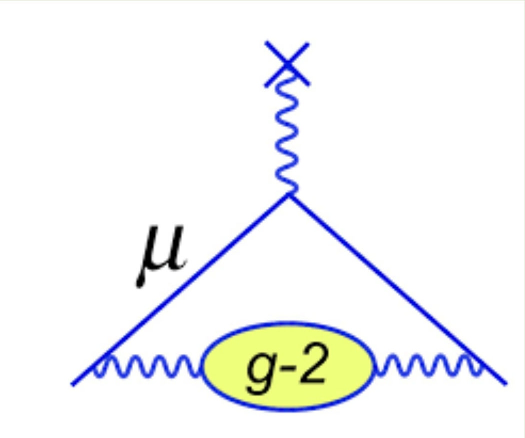
UV and IR scales correlated

$(constraint\ trivial\ as\ M_D \longrightarrow \infty : Swampland)$

$$\Lambda_{UV} \lesssim \Lambda_{IR}^{\delta} M_D^{1-\delta} \quad , \quad \delta < 1$$

- Such correlation was first proposed by Cohen, Kaplan and Nelson (1999) (see also Banks+Drapper (2019), Cohen-Kaplan (2019)) based on holographic arguments (CKN famous, > 1100 citations…!)

- They argued this type of correlations would have an impact in SM Feynman graph computations like e-g (g-2)



They vary $\Lambda_{UV}, \Lambda_{IR}$ to estimate minimal size of corrections

- Not clear what the UV cut-off is and how it can vary as we vary the IR. Not clear how the # QFT states as depleted as Λ_{IR} decreases

- We revaluate holographic constraints in the context of the Swampland ideas, which lead to a reinterpretation of the cut-offs $\Lambda_{UV}, \Lambda_{IR}$

- We argue that in QG one should identify Λ_{UV} *with the 'species' scale*

- This provides for an understanding of why Λ_{UV} *decreases as* $\Lambda_{IR} \to 0$ (due to the emergence of towers of states)

- We find 'covariant entropy bound' (Bousso) implies:

$$M_{\rm tower} \lesssim \Lambda_{\rm IR}^{2\alpha_D} M_D^{1-2\alpha_D}$$

$$\alpha_D = \frac{D-2+p}{2p(D-1)}$$

$(p\ parametrizes\ density\ of\ tower)$

- In AdS, natural to take $\Lambda_{IR} \sim L_{AdS}^{-1} \longrightarrow$ *'AdS distance conjecture'*

Lust,Palti,Vafa 2019

- We comment on application to the dS case and the universe

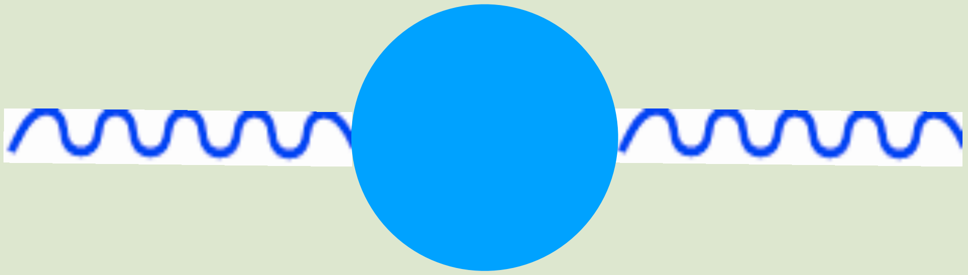
$(related\ holographic\ application\ to\ the\ distance\ conjecture : talk\ by\ J.Calderon)$

- Caveat: our use of holographic bounds will be mostly heuristic

The species scale

Dvali, 2010

- Loop corrections to Newton's constant



$$\frac{1}{\Lambda_{QG}^{D-2}} \sim \frac{N}{M_D^{D-2}}$$

- Scale Λ_{QG} at which QG effects can no longer be ignored

- N is the number of species (degrees of freedom in loop)

- In large moduli limits of QG and Strings examples those species come in towers of KK or string states

- Note as N grows , the scale of QG $\Lambda_{QG} \longrightarrow 0$

- Λ_{QG} is in general moduli dependent

Towers of states

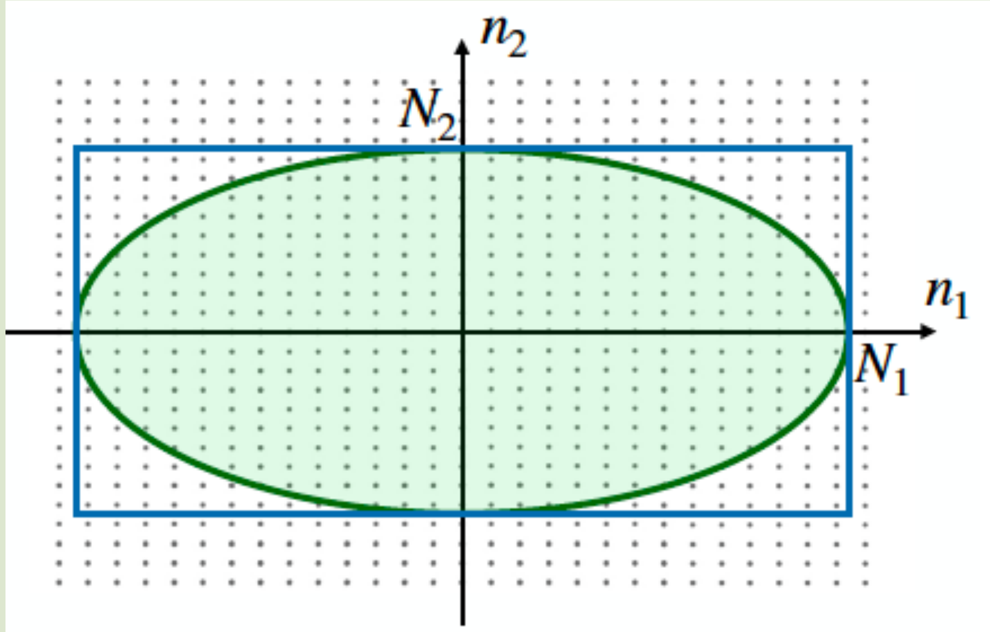
- One can parametrise the masses of the states in the towers

$$M_n = n^{1/p} M_{tower} \qquad \Lambda^p = N M_{tower}^p$$

Examples:

- One single KK tower: p=1 , N is the number of species
- Two towers

$$M^2_{n_1,n_2} = n_1^{2/p_1} M^2_{tower,1} + n_2^{2/p_2} M^2_{tower,2}$$



$$N_{esp} \simeq N_1 N_2 \qquad \Lambda_{QG} \sim \frac{M_D}{(N_1 N_2)^{1/(D-2)}}$$

$$M_{tower} \equiv (M^{p_1}_{tower,1} M^{p_2}_{tower,2})^{1/p} \qquad p = p_1 + p_2$$

$$\Lambda^p = M^p_{tower} N$$

e.g. 2 KK towers with same mass scale M_{tower} p=2

- Other example: KK step much smaller than scale

(well known example D0-D2 states in Type IIA 4D N=2 at large Kahler moduli)

$$N_1 \gg N_2 \sim 1 \qquad M_{tower,1} \ll M_{tower,2} \sim \Lambda_{QG}$$

$$M^2_{n_1,n_2} \;=\; n_1^{2/p_1}\; M^2_{tower,1} \;+\; n_2^{2/p_2}\; M^2_{tower,2} \;\sim\; n_1^2 M^2_{tower,1} \;+\; M^2_{tower,2}$$

$$p_1 \;=\; 1 \;,\; p_2 \;=\; \infty \qquad\qquad N_{esp} \sim N_1$$

- String tower: $M_n \;=\; n^{1/2}\; M_{string} \;\;;\;\; \Lambda \;\sim N^{1/2}\; M_{string}$

However $N_{esp} \sim e^{\sqrt{N}} \;\longrightarrow\; p = \infty$ (not p=2)

The number of levels N is of order $log(N_{esp})$:

$$\Lambda_{QG} \sim M_{string}$$

• For k KK-like towers one can define an effective (geometric average) tower mass:

$$M_{tower} = (M_1^{p_1} ... M_k^{p_k})^{1/p} \qquad p = \sum p_i$$

• Then $\Lambda_{UV}^p = M_{tower}^p N \qquad N = \Pi_i N_i$

and using the species scale expresion:

$$\Rightarrow \boxed{\Lambda_{UV} = M_{tower}^{p/(D-2+p)} M_D^{(D-2)/(D-2+p)}}$$

(valid also for a string tower $p = \infty$)

• The species scale is not directly related to the lightest tower scale but rather to the 'geometric average' of the scales

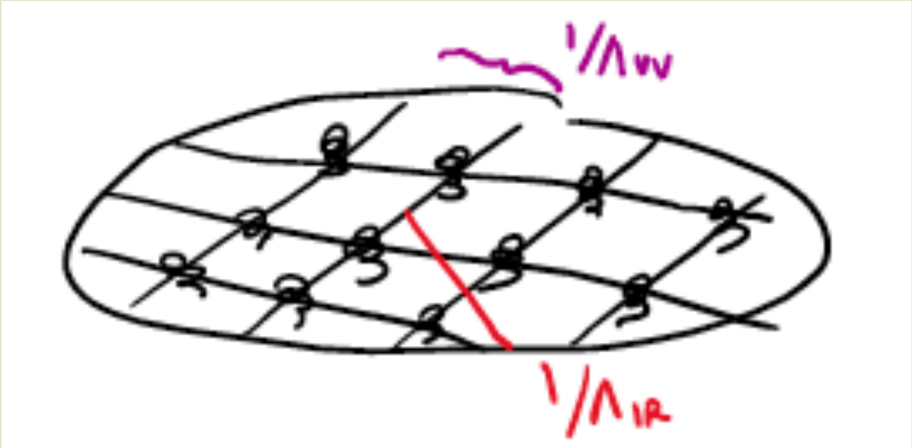
Holography and UV/IR connection

• The argument for a UV-IR connection will be based in the covariant entropy bound (Bousso (1999)) as applied to a spherical surface

• Beckenstein 1981: ' The entropy in a region of space is bounded by the BH entropy that can be stored in a region of the same size'

$$EFT\ with\ UV\ cut-off\ \Lambda_{UV}$$

$$Sphere\ of\ radius\ L = 1/\Lambda_{IR}$$



• Maximal field theoretical entropy (extensive):

$$S_{EFT} \sim (\Lambda_{UV} L)^{D-1}$$

• Blackhole entropy (like the surface) $S_{BH} \sim L^{D-2} M_D^{D-2}$

CKN , 1999

$$S_{EFT} \leq S_{BH} \quad \Longrightarrow \quad \boxed{\Lambda_{UV} \lesssim (\Lambda_{IR})^{\frac{1}{D-1}} M_D^{(D-2)/(D-1)}}$$

Explicit UV-IR connection $Note\ trivial\ if\ M_D \to \infty\ (Swampland-like)$

Comments:

$$\Lambda_{UV} \lesssim (\Lambda_{IR})^{\frac{1}{D-1}} M_D^{(D-2)/(D-1)}$$

• As we make the box large, the UV cut-off must go down. But how?

• We argue that in QG we should identify Λ_{UV} with the species scale:

$$\Lambda_{UV} \sim \frac{M_D}{N^{1/(D-2)}} \Longrightarrow N \gtrsim L^{(D-2)/(D-1)}$$

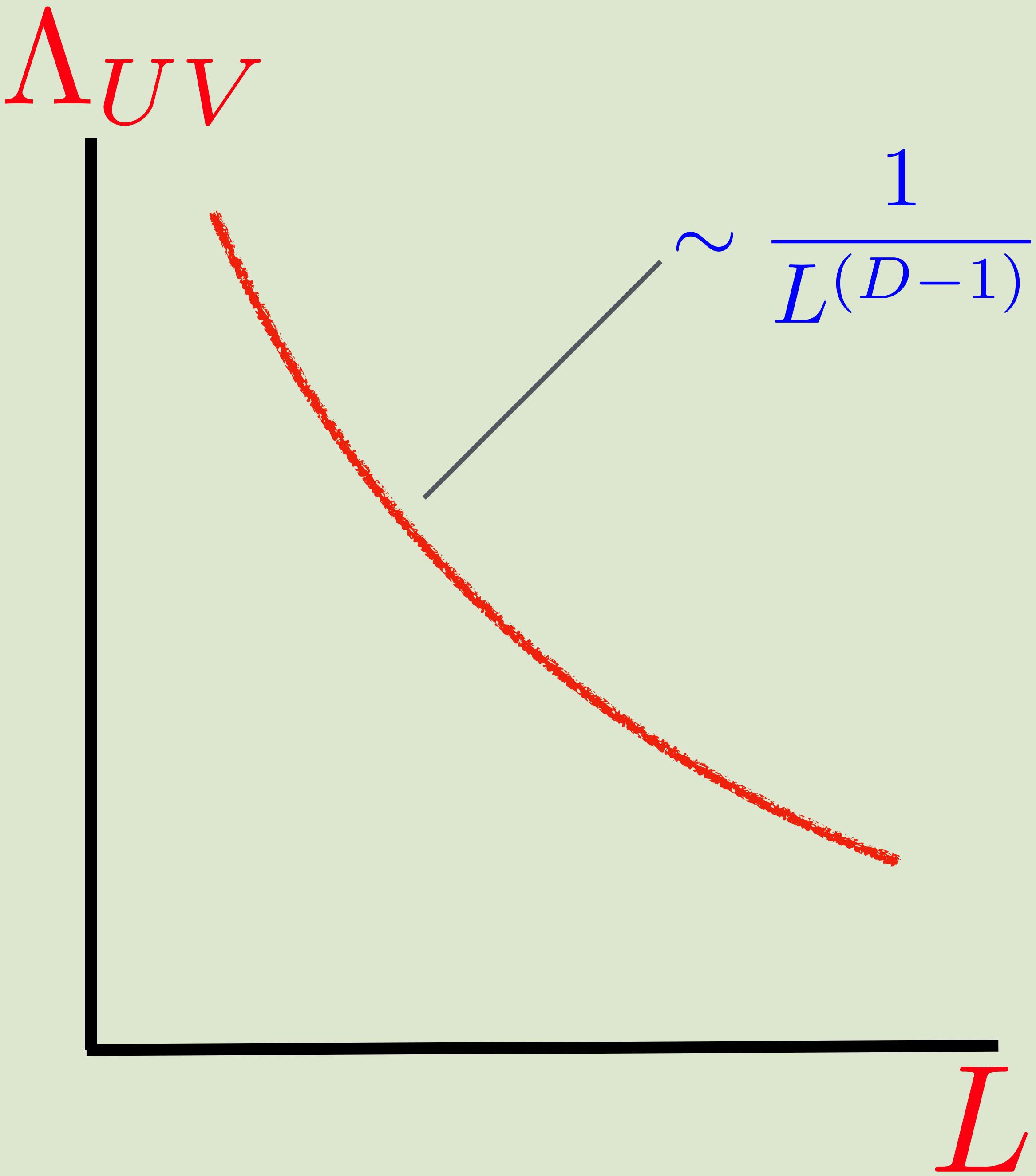
L.I.,Castellano,Herraez, 2021

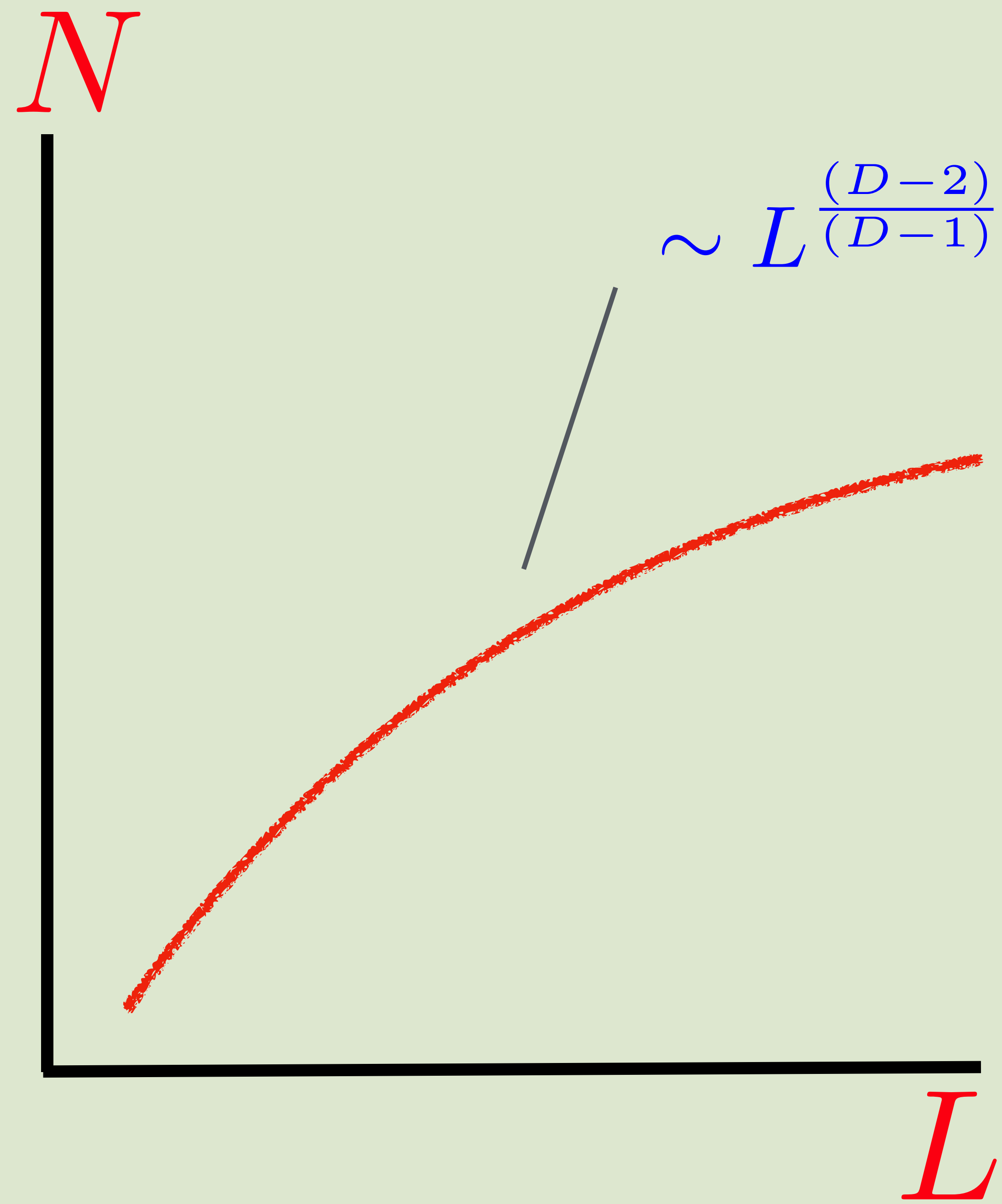
As L grows more and more particles below the species scale: Suggestive of Towers

• May be understood as a smooth transition from an extensive to a holographic entropy: allow Λ_{UV} to depend on L :

$$dS_{BH} \sim (\Lambda_{UV}(L))^{D-1} d(L^{D-1}) \sim (\Lambda_{UV}(L))^{D-1} L^{D-2} dL$$

extensive S becomes holographic if $\Lambda_{UV}^{D-1}(L) \sim \frac{1}{L}$ as above





to mantain $S_{EFT} \lesssim S_{BH}$ *as L grows :*

the cut−off must go down (which happens due to emergence of towers of species)

• Asume that the increasing number of species comes in towers as in QG examples. Combining:

$$\Lambda_{UV} \lesssim (\Lambda_{IR})^{\frac{1}{D-1}} M_D^{(D-2)/(D-1)}$$

$$\Lambda_{UV} = M_{tower}^{p/(D-2+p)} M_D^{(D-2)/(D-2+p)}$$

L.I.,Castellano,Herraez, 2021

$$M_{tower} \lesssim \Lambda_{IR}^{2\alpha_D} M_D^{1-2\alpha_D}$$

$$\alpha_D = \frac{D-2+p}{2p(D-1)}$$

depends on tower structure

$$One\ has\ in\ general\ M_{tower} \sim \Lambda_{IR}^{2\alpha}\ \ with$$

$$\alpha_D = \frac{D-2+p}{2p(D-1)} \leq \alpha \leq (D-1)\alpha_D$$

$from\ \Lambda_{IR}, M_t \lesssim \Lambda_{UV}$

Natural application: AdS distance conjecture

(Will not discuss here the possibility of gravitational collapse considered by CKN, which leads to somewhat analogous results, although somewhat different α_D see paper)

AdS distance conjecture

- Consider a family of AdS vacua with c.c. $V_0 \longrightarrow 0$

Lust,Palti,Vafa 2019

Then an infinite tower of states with characteristic scale m_{tower} must exist

$$m_{tower} \sim |V_0|^{\alpha} M_D^{1-D\alpha}$$

Strong version: $\alpha = \frac{1}{2}\ in\ SUSY\ theories$ (no scale separation)

Also conjectured that in general $\alpha \geq \frac{1}{2}$

Also that it is valid for dS with $\alpha < \frac{1}{2}$

Holography and the AdS distance conjecture

- In AdS there is a natural infrared cut-off: $L_{AdS} \sim |\Lambda_{c.c.}|^{-1/2}$

Taking $\Lambda_{IR} \sim |\Lambda_{c.c.}|^{-1/2} \sim |V_0|^{-1/2}$ holographic bound gives:

$$M_{tower} \lesssim |V_0|^{\alpha_D} M_D^{1-D\alpha_D} \qquad \alpha_D = \frac{D-2+p}{2p(D-1)}$$

- Remarkably, this reproduces the AdS distance conjecture

However here M_{tower} is the 'average' tower mass scale (not always=lightest mode scale) and we have specific bounds

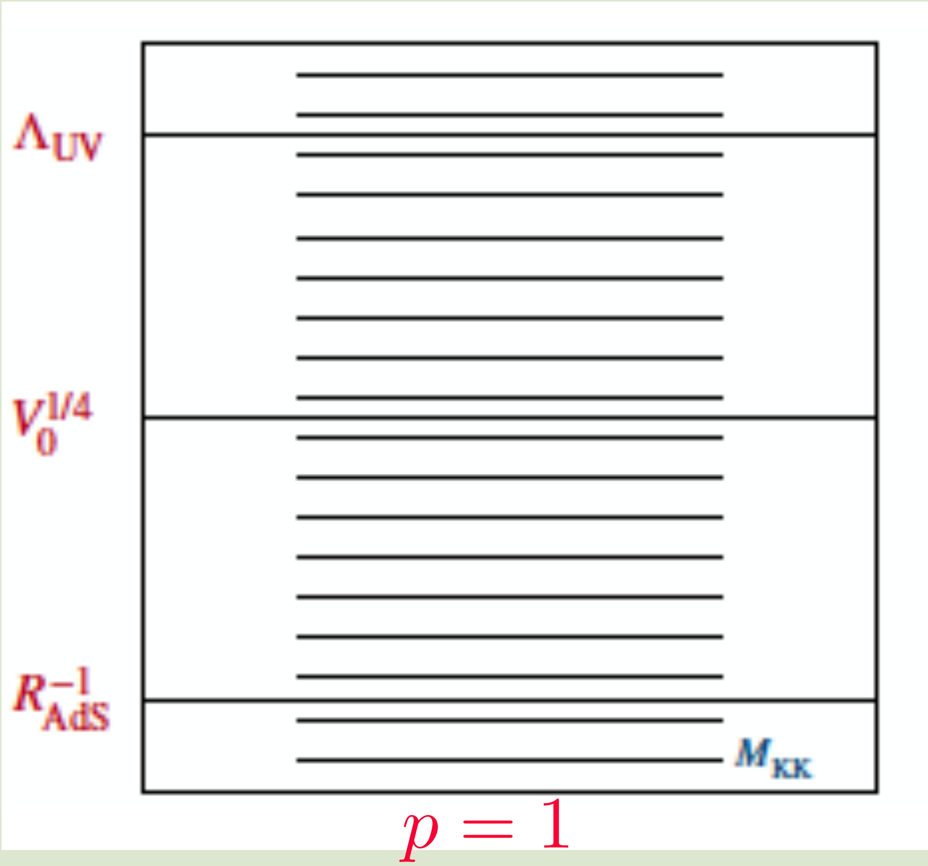
- The AdS distance conjecture may be understood in holographic terms:

As $V_0 \to 0$ the species scale (and associated towers) become light to avoid the associated entropy to be too large violating Bekenstein bound

L.I.,Castellano, Herráez, 2021

Thus depending on p:

$$\frac{1}{2(D-1)} \leq \alpha_{min} \leq \frac{1}{2}$$

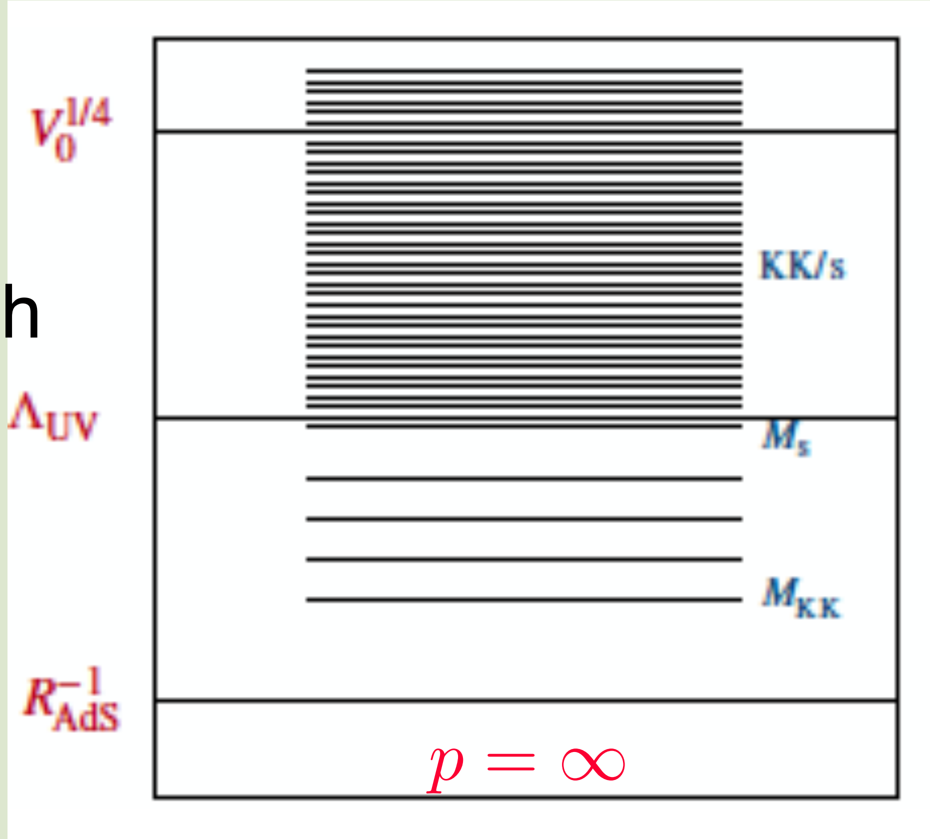


Note for $p = 1$, $\boxed{\alpha \geq \frac{1}{2}}$ *for any dimension D*

no scale separation: EFT makes no sense

For limit (e.g. strings) $p = \infty$, $\boxed{\alpha \geq \frac{1}{2(D-1)}}$

allows for scale separation



This is the case of DGKT-CFI 4D N=1 models in which

$$Geometric\ M_{tower} \sim M_{string}$$

$$In\ 4D: \quad \alpha \geq \alpha_D\ with\ \frac{1}{6} \leq \alpha_D \leq \frac{1}{2}$$

Scale separation not necessarily forbidden based on these holographic arguments

The distance and dS rate constants λ, c

L.I.,Calderon,Castellano,Herráez, 2022

- Interesting results may also be obtained for the distance conjecture if we make use of the 'local dynamical cobordism' of (see parallel talk by J. Calderón).

Angius,Calderon,Delgado, Huertas,Uranga, 2022

- Taking $L = exp(\Delta(D-1)^{1/2}/(D-2)^{1/2})$ one obtains

$$m_{tower} \sim e^{-\lambda\Delta}$$

$$\lambda = 2\alpha(D-1)^{1/2}/(D-2)^{1/2} \longrightarrow \boxed{\frac{1}{[(D-1)(D-2)]^{1/2}} \leq \lambda_{min} \leq \left(\frac{D-1}{D-2}\right)^{1/2}}$$

which is in agreement with string theory examples in the literature

Grimm et al.(2018), Gendler,Valenzuela(2021),Andriot et al,(2020), Etheredge et al (2022),….

- For the dS coefficient c, one obtains an upper bound

$$V' \geq c\, V$$

$$V \sim M_{tower}^{1/\alpha} \sim e^{-\lambda\Delta/\alpha} \qquad c \leq \frac{\lambda}{\alpha} \longrightarrow \boxed{c \leq 2\left(\frac{D-1}{D-2}\right)^{1/2}}$$

which is (D-1) times larger than the TCC lower bound

Bedroya,Vafa, 2020

Comparison to gravitino conjecture

- It is interesting to compare also to the range allowed by the gravitino conjecture (see A. Castellano parallel talk)

$$M_{tower} \sim m_{3/2}^{\delta} M_p^{1-\delta} \qquad as\ m_{3/2} \rightarrow 0$$

Castellano,Font,Herráez,L.I., 2021
Cribiori,Lust,Scalisi, 2021

- It was found for 4D N=1 sugra vacua

$$\frac{1}{3} \leq \delta \leq 1$$

- In SUSY-AdS vacua $m_{3/2} = \frac{V_0^{1/2}}{\sqrt{3} M_p}$ so comparing with $M_{tower} \sim V_0^{\alpha}$

$$\alpha = \frac{\delta}{2} \longrightarrow \qquad \frac{1}{6} \leq \alpha \leq \frac{1}{2}$$

which is in agreement with the lower bounds we find here $\frac{1}{6} \leq \alpha_D \leq \frac{1}{2}$

dS vacua and our universe

- One can also argue that in dS space there is a natural infrared cut-off provided by the dS cosmological horizon $L_{dS} \sim V_0^{-1/2}$

The EFT entropy cannot exceed the Gibbons-Hawking bound:

$$S_{EFT} \leq S_{GH} \sim L_{dS}^{D-2}$$

- Then similar bounds as for AdS are obtained:

$$M_{tower} \lesssim V_0^{\alpha_D} M_D^{1-D\alpha_D}$$

- Thus as $V_0 \to 0$ towers of states are expected, as in AdS.

- The validity of this conjecture for dS was already suggested in the original formulation of AdS conjecture

Lust,Palti,Vafa 2019

- There is another relevant IR scale which is the size of the potential $V_0^{1/4}$

- One possible argument in favour of taking $\Lambda_{IR} \sim V_0^{1/4}$ may be the 'Festina Lente' conjecture. Any U(1) charged particle in dS must obey

Montero, van Riet, Venken(2019)

$$\frac{m}{2^{1/4} g} \geq V_0^{1/4}$$

it has been claimed it may also apply to neutral particles related to neutrinos

- Given the experimental fact that $m_\nu \sim V_0^{1/4}$, its inverse is also the length such that all Compton lengths of the Standard Model particles fit in

note that in our universe with $V_0^{1/4} \simeq 10^{-3} eV$

$$\Lambda_{IR}^{(1)} \equiv \frac{V_0^{1/2}}{M_p} \qquad \Lambda_{IR}^{(2)} \equiv V_0^{1/4}$$

$$\Lambda_{IR}^{(1)} \sim 10^{-30} eV \ll \Lambda_{IR}^{(2)} \sim 10^{-3} eV \sim m_\nu$$

Smallness of V_0 suggests there could be possible towers in our universe

Lust,Palti,Vafa 2019

Using $\Lambda_{UV} \sim \Lambda_{IR}^{1/3} M_p^{2/3}$, $M_{tower} \sim \Lambda_{IR}^{2\alpha} M_p^{1-2\alpha}$ $1/6 \leq \alpha \leq 1/2$

	Λ_{IR}	Λ_{UV} $(\forall\alpha)$	M_{tower}	$\alpha = 1/2$	$\alpha = 1/4$	$\alpha = 1/6$
$\Lambda_{IR}^{(1)} = \frac{V_0^{1/2}}{M_p}$	$=10^{-30}$ eV	10^{-2} GeV	M_{tower}	10^{-30} eV	10^{-3} eV	10^{-2} GeV
$\Lambda_{IR}^{(2)} = V_0^{1/4}$	$=10^{-3}$ eV	10^{8} GeV	M_{tower}	10^{-3} eV	$10^{3.5}$ GeV	10^{8} GeV

- $\Lambda_{IR}^{(1)}$ leads to too low species scale: $\Lambda_{UV} \sim 10^{-2}\ GeV$
- $\Lambda_{IR}^{(2)}$ leads to a fundamental intermediate scale $\Lambda_{UV} \sim 10^{8}\ GeV$

The tower scale ranges from the neutrino and EW scales to the cut-off depending on the value of α

see also: Rudelius(2021)

Montero,Vafa,Valenzuela(2022); Montero's talk

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vanishing higgs potential?

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$m_{KK} \sim m_\nu$?

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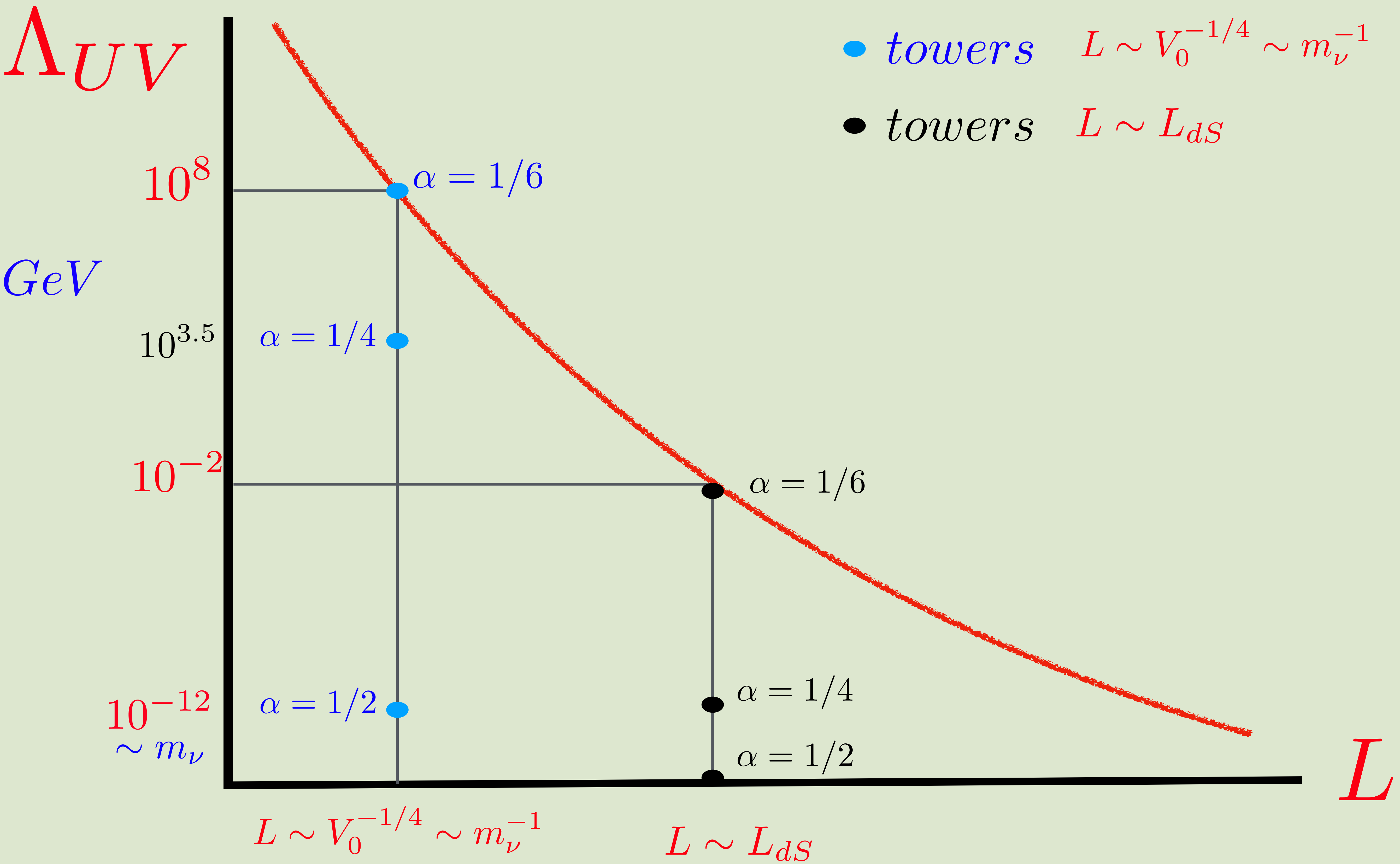

Conclusions

• The existence of UV-IR connections seems to be an important property of EFT's consistent with QG.

• We have described how applying the Bekenstein entropy bound on such EFT's, one can derive such a connection, implying Swampland constraints like, in particular, the AdS distance conjecture with

$$\frac{1}{2(D-1)} \leq \alpha_{min} \leq \frac{1}{2}$$

• Similar constraints with same α are obtained for dS vacua

• Results also suggest for the distance conjecture and dS parameters

$$\frac{1}{[(D-1)(D-2)]^{1/2}} \leq \lambda_{min} \leq \left(\frac{D-1}{D-2}\right)^{1/2}$$

$$c \leq 2\left(\frac{D-1}{D-2}\right)^{1/2}$$

• A bold application to our present universe with $\Lambda_{IR} = V_0^{1/4} \sim 10^{-3} eV$ suggests the existence of a fundamental scale at $\Lambda_{UV} \sim 10^8\ GeV$

Independently, towers of particles may exist in our universe with scales

$$10^{-3} eV \lesssim M_{tower} \lesssim 10^8\ GeV$$

Thank you !!

Swamp

land

Hieronymus Bosch