Title: Weak Gravity Conjecture From Amplitudesâ€™ Positivity

Speakers: Brando Bellazzini

Collection: Cosmological Frontiers in Fundamental Physics 2019

Date: September 03, 2019 - 2:45 PM

URL: http://pirsa.org/19090020

Abstract: I will show how to derive new positivity bounds for scattering amplitudes in theories with a massless graviton in the spectrum in four spacetime dimensions. The bounds imply that extremal black holes are self-repulsive, M/|Q|

Weak Gravity Conjecture from Amplitudes' Positivity

Brando Bellazzini

based on arXiv 1902.03250 BB, J.Serra, M. Lewandowski

Perimeter Institute, September 3rd 2019

"I wanted to quit physics,
but then I learned EFT
and everything started to make sense"

-Nima Arkani-Hamed-

"I am a particle physicist:
I think in terms of EFT all the time"

-Gia Dvali-

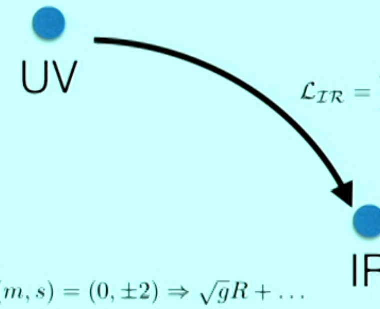
"Effective Field theory: the single most powerful organising principle in the zoo of quantum field theories."

-Slava Rychkov-


"I am a particle physicist;
I think in terms of EFT all the time"

"I wanted to quit physics,
but then I learned EFT
and everything started to make sense"

-Nima Arkani-Hamed-



$$\mathcal{L}_{\mathcal{IR}} = \sum_i c_i \frac{\mathcal{O}_i(x)}{\Lambda_{UV}^{\Delta-4}}$$

$(m, s) = (0, \pm 2) \Rightarrow \sqrt{g}R + \dots$

EFT-gravity: business as usual…

…but
black hole information,
acceleration universe
hierarchy problem ?!

"I am a particle physicist:
I think in terms of EFT all the time"

-Gia Dvali-

-Slava Rychkov-

"Effective Field theory: the single most powerful organising
principle in the zoo of quantum field theories."

"I wanted to quit physics,
but then I learned EFT
and everything started to make sense"

-Nima Arkani-Hamed-

UV

IR

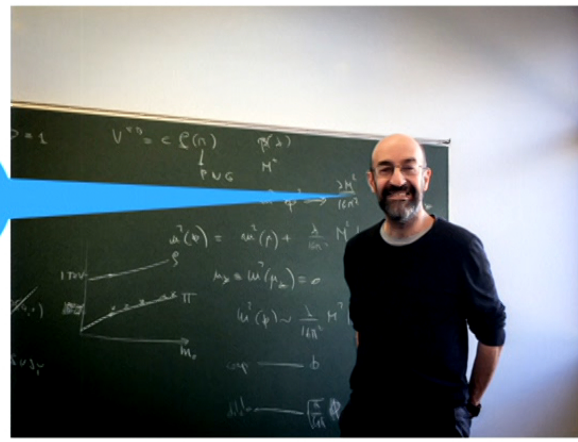
$$\mathcal{L}_{IR} = \sum_i c_i \frac{\mathcal{O}_i(x)}{\Lambda_{UV}^{\Delta-4}}$$

$$(m, s) = (0, \pm 2) \Rightarrow \sqrt{g}R + \dots$$

EFT-gravity: business as usual…

…but
black hole information,
acceleration universe
hierarchy problem ?!

"the world
is not
a crappy metal"



-Riccardo Rattazzi-

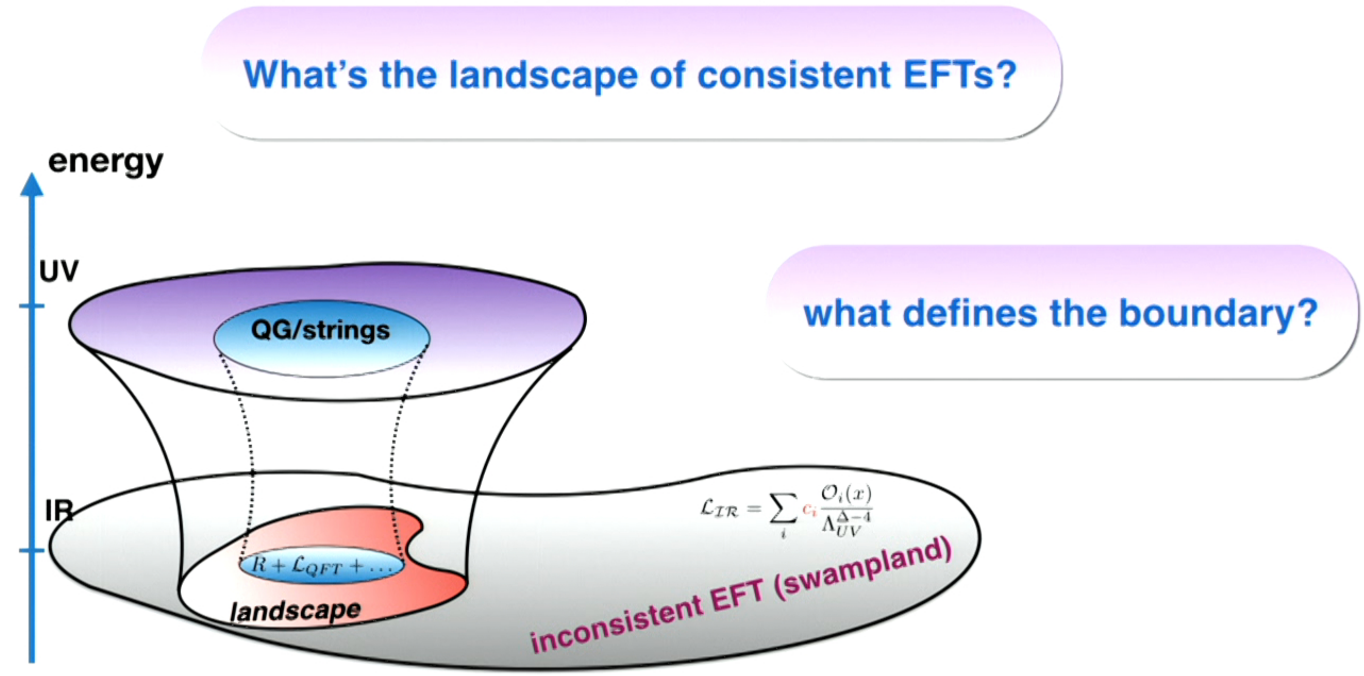
e physicist:
EFT all the time"

-Gia Dvali-

-Slava Rychkov-

"Effective Field theory: the single most powerful organising
principle in the zoo of quantum field theories."

Swampland Program



- Not every IR theory can be embedded in a consistent UV-theory

Weak Gravity Conjecture

N. Arkani-Hamed, L. Motl. A. Nicolis, C. Vafa hep-th/0601001

in any QG theory that reduces to
gravity+U(1) gauge theory in deep IR

graviton and photon
the only massless particles
(e.g. our universe)

→

$\exists$ state with $|Q| > \frac{M}{\sqrt{2}M_{Pl}}$

$Q = q \cdot g = \text{charge} \times \text{gauge coupling}$

"gravity is the weakest force"

"gravitational attraction is weaker than U(1) repulsion force
for certain states in the spectrum"

Weak Gravity Conjecture

N. Arkani-Hamed, L. Motl. A. Nicolis, C. Vafa hep-th/0601001

in any QG theory that reduces to
gravity+U(1) gauge theory in deep IR

graviton and photon
the only massless particles
(e.g. our universe)

→

$\exists$ state with $|Q| > \dfrac{M}{\sqrt{2}M_{Pl}}$

$Q = q \cdot g = \text{charge} \times \text{gauge coupling}$

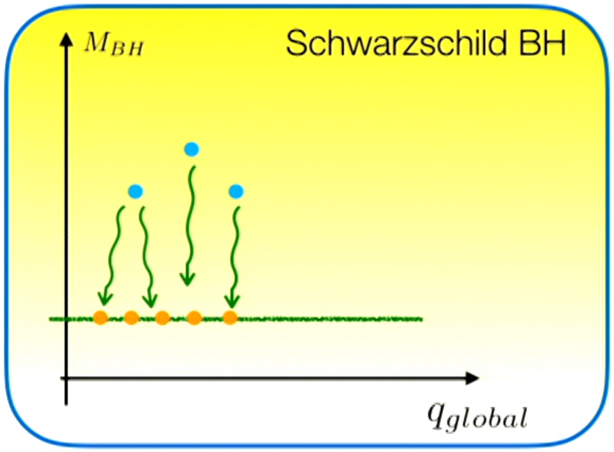
"gravity is the weakest force"

"gravitational attraction is weaker than U(1) repulsion force
for certain states in the spectrum"

it looks beyond EFT reasoning:
as g—>0 the theory should get better, not break down

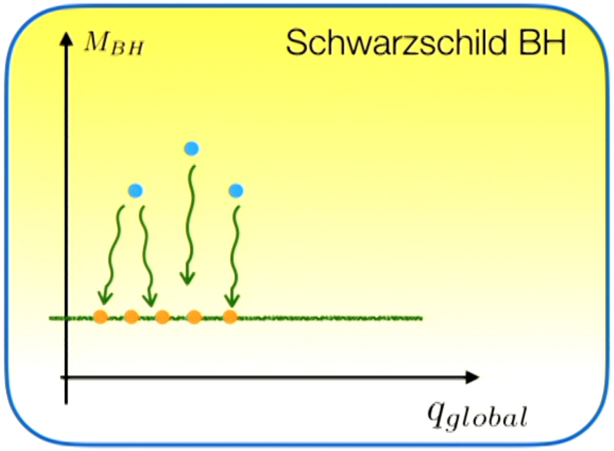
WGC Motivations: I

- No exact Global Symmetry in QG



WGC Motivations: I

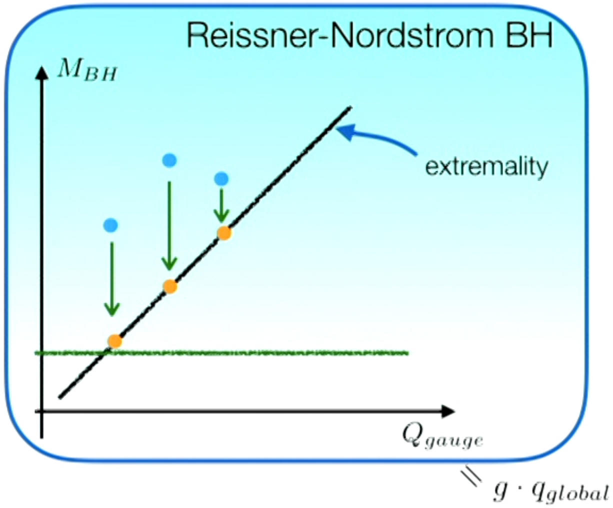
- No exact Global Symmetry in QG



WGC: $|Q| > \frac{M}{\sqrt{2}M_{Pl}}$

=no faking global by arbitrary small g

“ban of cheap tricks”

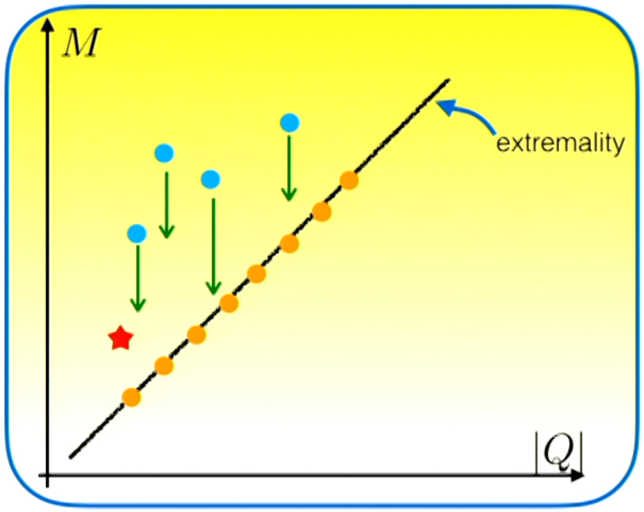


and no huge degeneracy of states

e.g. $\left.\begin{matrix} M \sim 10 M_{Pl} \\ g \sim 10^{-100} \end{matrix}\right\} \longrightarrow N \sim 10^{100}$

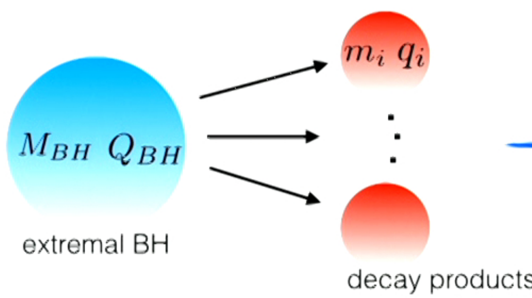
WGC Motivations: II

- avoid infinitely many stable remnants unprotected by symmetry



- RN-BH
- extremal BH
- Hawking evaporation
- decay product

if WGC false: extremal BH's can't decay further



$$\sum_i m_i = \sum_i \frac{m_i}{|q_i|}|q_i| > \frac{M_{BH}}{|Q_{BH}|}\sum_i |q_i| > M_{BH}$$

kinematically forbidden

WGC Motivations: III & IV

- no counter-example from string theory compactifications

....but 10^{500} vacua, hard to extract general lessons

- unitarity and causality

....in retrospect, see our proof

WGC proof: Strategy

$\exists$ state with $|Q| > \frac{M}{\sqrt{2}M_{Pl}}$

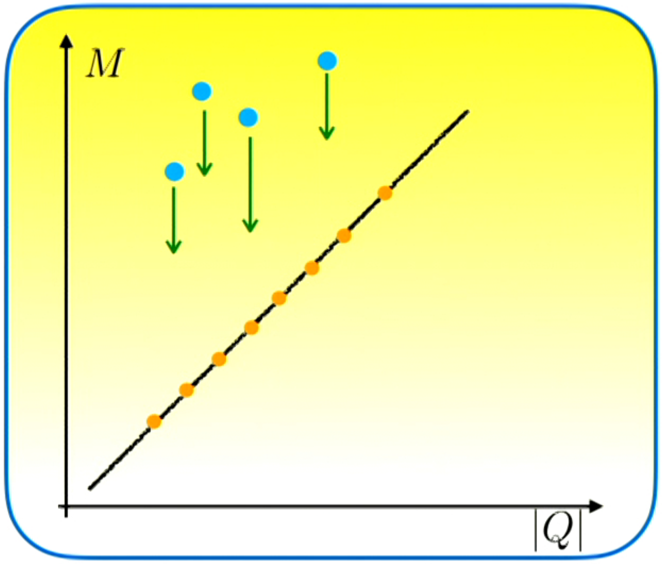
"existential statement"

put forward a natural candidate we know is in the spectrum

Extremal Black Holes!

extr. condition $Q_{BH} = M_{BH}$ **true only asymptotically**, the least irrelevant operators dominant

$$S = \int d^4x \sqrt{-g}\left(\frac{M_{pl}^2}{2}\mathcal{R} - \frac{1}{4}F^2 + \dots\right)$$



WGC proof: Strategy

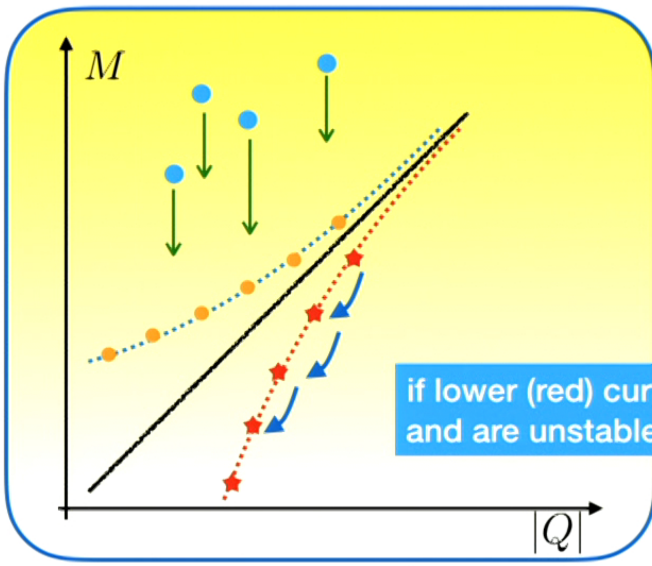
$$\exists \text{ state with } \quad |Q| > \frac{M}{\sqrt{2}M_{Pl}}$$

"existential statement"

put forward a natural candidate
we know is in the spectrum

Extremal Black Holes!

extr. condition $Q_{BH} = M_{BH}$ **true only asymptotically**, the least irrelevant operators dominant



$$S = \int d^4x \sqrt{-g}\left(\frac{M_{pl}^2}{2}\mathcal{R} - \frac{1}{4}F^2 + \dots\right)$$

$|F_{grav}| = |F_{EM}|$

classical effects balanced!
room for irrelevant op!

if lower (red) curve, extr. BH's satisfy WGC and are unstable to decay to smaller ones!

need to look at higher-dim operators

Refined Extremality

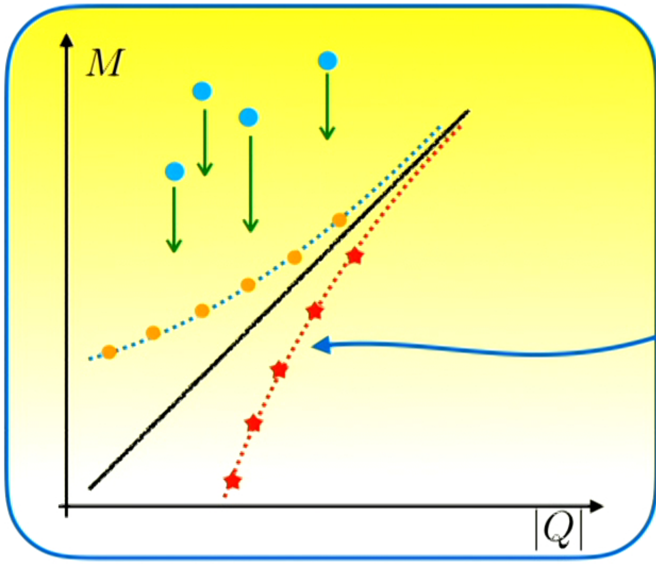
Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$

$$\left(\frac{|Q|\sqrt{2}}{M/M_{Pl}}\right)_{extr.} = 1 + \frac{4}{5}\frac{(4\pi)^2 M_{Pl}^2}{M^2}(2\alpha_1 - \alpha_3)$$

Y. Kats, L. Motl, M. Padi hep-th/0606100

REFINED EXTREMALITY

Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$



$$\left(\frac{|Q|\sqrt{2}}{M/M_{Pl}}\right)_{extr.} = 1 + \frac{4}{5}\frac{(4\pi)^2 M_{Pl}^2}{M^2}(2\alpha_1 - \alpha_3)$$

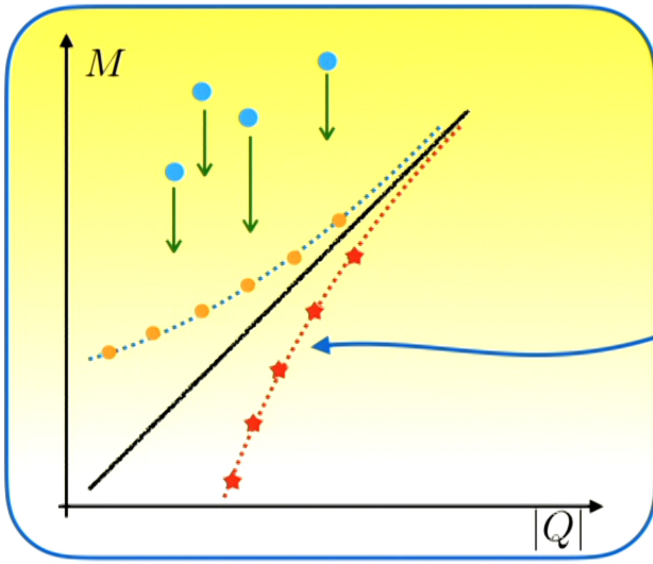
Y. Kats, L. Motl, M. Padi hep-th/0606100

proof reduces to show $2\alpha_1 - \alpha_3 > 0$

how to show that certain Wilson coefficients are always positive?

Refined Extremality

Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$



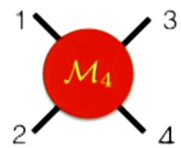
$$\left(\frac{|Q|\sqrt{2}}{M/M_{Pl}}\right)_{extr.} = 1 + \frac{4}{5}\frac{(4\pi)^2 M_{Pl}^2}{M^2}(2\alpha_1 - \alpha_3)$$

Y. Kats, L. Motl, M. Padi hep-th/0606100

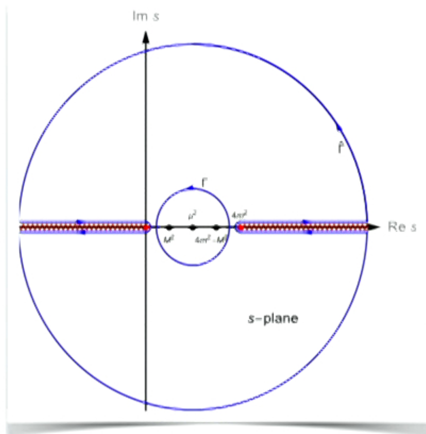
proof reduces to show $2\alpha_1 - \alpha_3 > 0$

how to show that certain Wilson coefficients are always positive? **use amplitudes' positivity**

UV-IR connection: Positivity



Analyticity, Crossing, Unitarity, Locality



schematically

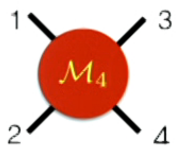
$$\mathcal{M}''(2\to 2)\big|_{IR} = \int_0^\infty \frac{ds}{s^3}\sigma_{12\to\text{anything}}(s) > 0$$

IR-side UV-side

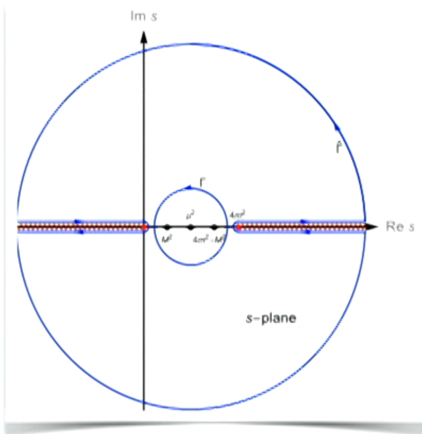
s^2-terms are strictly positive

Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi hep-th/0602178
BB 1605.06111

UV-IR connection: Positivity



Analyticity, Crossing, Unitarity, Locality



schematically

$$\mathcal{M}''(2 \to 2)\big|_{IR} = \int_0^\infty \frac{ds}{s^3} \sigma_{12 \to \text{anything}}(s) > 0$$

IR-side UV-side

s^2-terms are strictly positive

Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi hep-th/0602178
BB 1605.06111

paradigmatic example

$$\pi \to \pi + \text{const} \qquad \mathcal{L} = \frac{1}{2}(\partial_\mu \pi)^2 + \frac{c}{\Lambda^4}(\partial_\mu \pi)^4 + \ldots \longrightarrow \mathcal{M}(\pi\pi \to \pi\pi)(s, t=0) = cs^2 \longrightarrow c > 0$$

c<0 in the swampland

POSITIVITY: APPLICATIONS

Goldstone U(1) Euler-Heisenberg

Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi hep-ph/0602178
de Rham, Melville, Tolley, Zhou 1804.10624

Dilaton & a-theorem

Komargodski Schwimmer 1107.3987
Luty, Polchinski, Rattazzi 1204.5221

Composite Fermions (and Goldstini)

Bellazzini, Riva Serra Sgarlata 1706.03070
Bellazzini, F. Riva 1806.09640

Goldstini R-axion

Dine Festuccia Komargodski 0910.2527
Bellazzini 1605.06111
Bellazzini, Mariotti Redigolo Sala 1702.02152

Quantum Gravity

Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi hep-ph/0602178
Bellazzini, Cheung Remmen, 1509.00851
Bellazzini, Serra, Lewandowski 1902.03250

Galileon & massive gravity

Cheung, Remmen 1601.04068
Bellazzini 1605.06111
de Rham, Melville, Tolley, Zhou 1702.08577
Melville Noller 1904.05874
Bellazzini Riva Serra Sgarlata 1710.02539
Bellazzini, Serra, Lewandowski 1902.03250

Higher spins

Bellazzini Riva Serra Sgarlata 1903.08664

Gauge Boson scattering

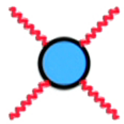
Falkowski, Rychkov, Urbano 1202.1532
Distler, Grinstein, Porto, Rothstein hep-ph/0604255
Low Rattazzi Vichi 0907.5413
Remmen Rodd 1908.09845
Zhou Zhang 1808.00010

Higher n-points Amp

Chandrasekaran, Remmen, Shahbazi 1804.03153

and many others...

Euler-Heisenberg:



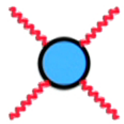
$$\alpha_1 \frac{e^4}{16\pi^2\Lambda^4}\left(F_{\mu\nu}F^{\mu\nu}\right)^2 + \alpha_2 \frac{e^4}{16\pi^2\Lambda^4}\left(\tilde{F}_{\mu\nu}F^{\mu\nu\nu}\right)^2$$

linear polarization basis

$$\mathcal{M}(\uparrow\uparrow;\uparrow\uparrow) = |n|^2\alpha_1\, s^2 \qquad \alpha_1 > 0$$

$$\mathcal{M}(\uparrow\downarrow;\uparrow\downarrow) = |n|^2\alpha_2\, s^2 \qquad \alpha_2 > 0$$

Euler-Heisenberg:



$$\alpha_1 \frac{e^4}{16\pi^2\Lambda^4}(F_{\mu\nu}F^{\mu\nu})^2 + \alpha_2 \frac{e^4}{16\pi^2\Lambda^4}\left(\tilde{F}_{\mu\nu}F^{\mu\nu\nu}\right)^2$$

linear polarization basis

$$\mathcal{M}(\uparrow\uparrow;\uparrow\uparrow) = |n|^2\alpha_1\, s^2$$
$$\mathcal{M}(\uparrow\downarrow;\uparrow\downarrow) = |n|^2\alpha_2\, s^2$$

$\rightarrow$ $\alpha_1 > 0$, $\alpha_2 > 0$

almost what we want!!

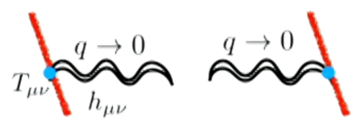
??

$$2\alpha_1 - \alpha_3 > 0$$

Maxwell-Einstein EFT:

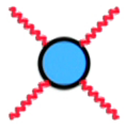
$$\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$$

$$\mathcal{M}(\uparrow\uparrow;\uparrow\uparrow) = -\frac{s^2}{M_{Pl}^2 t} + \text{ regular terms}$$
$$\mathcal{M}(\uparrow\downarrow;\uparrow\downarrow) = -\frac{s^2}{M_{Pl}^2 t} + \text{ regular terms}$$



universal coulomb sing.
by equivalence principle
swamp info of Wilson Coeff.

Euler-Heisenberg:



$$\alpha_1 \frac{e^4}{16\pi^2\Lambda^4}\left(F_{\mu\nu}F^{\mu\nu}\right)^2 + \alpha_2 \frac{e^4}{16\pi^2\Lambda^4}\left(\tilde{F}_{\mu\nu}F^{\mu\nu\nu}\right)^2$$

linear polarization basis

$$\mathcal{M}(\uparrow\uparrow;\uparrow\uparrow) = |n|^2 \alpha_1 s^2$$
$$\mathcal{M}(\uparrow\downarrow;\uparrow\downarrow) = |n|^2 \alpha_2 s^2$$

$$\alpha_1 > 0 \qquad \alpha_2 > 0$$

almost what we want!!

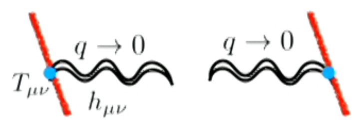
??

$$2\alpha_1 - \alpha_3 > 0$$

Maxwell-Einstein EFT:

$$\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$$

$$\mathcal{M}(\uparrow\uparrow;\uparrow\uparrow) = -\frac{s^2}{M_{Pl}^2 t} + \text{ regular terms}$$
$$\mathcal{M}(\uparrow\downarrow;\uparrow\downarrow) = -\frac{s^2}{M_{Pl}^2 t} + \text{ regular terms}$$



universal coulomb sing.
by equivalence principle
swamp info of Wilson Coeff.

REGULATE THE FORWARD SCATTER.

$$\mathcal{M}(\text{forward}) = -\frac{s^2}{M_{Pl}^2 t} + \dots$$

an IR singularity,
i.e. volume divergence,
graviton probing arbitrarily large space

how to regulate it
and extract bounds at finite Mpl?

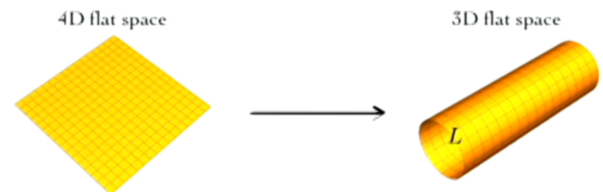
REGULATE THE FORWARD SCATTER.

$$\mathcal{M}(\text{forward}) = -\frac{s^2}{M_{Pl}^2 t} + \ldots$$

an IR singularity,
i.e. volume divergence,
graviton probing arbitrarily large space

how to regulate it
and extract bounds at finite Mpl? reduce space!

graviton is not dynamical in 3D: hence no 1/t pole



dof's is the continuous
the cylinder->4D space limit is smooth
L—>infinity at the end

2-dof 0-dof 1-dof 1-dof

$$d\hat{s}_4^2[\hat{g}_{MN}] = e^{\sigma} ds_3^2[g_{\mu\nu}] + e^{-\sigma}\,(dz + V_\mu dx^\mu)^2$$

$$\hat{A}_M dx^M = A_\mu dx^\mu + \Phi\, dz$$

2-dof 1-dof 1-dof

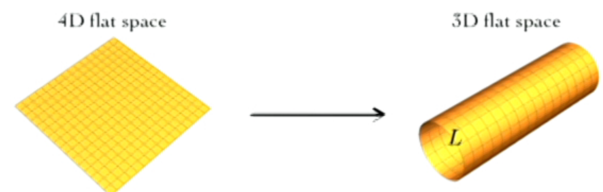
REGULATE THE FORWARD SCATTER.

$$\mathcal{M}(\text{forward}) = -\frac{s^2}{M_{Pl}^2 t} + \dots$$

an IR singularity,
i.e. volume divergence,
graviton probing arbitrarily large space

how to regulate it
and extract bounds at finite Mpl? **reduce space!**

graviton is not dynamical in 3D: hence no 1/t pole



$$\begin{aligned} S = L \int d^3x \sqrt{-g} \Big\{ & \frac{m_{\rm Pl}^2}{2} \left(R - \frac{1}{2}(\partial\sigma)^2 - \frac{1}{4} V^2 \right) \\ & - \frac{1}{4}(1-\sigma)F^2 - \frac{1}{2}(1+\sigma)(\partial\Phi)^2 - \frac{1}{2} F_{\mu\nu} V^{\mu\nu} \Phi \\ & + \frac{\alpha_1}{4 m_{\rm Pl}^4} \left(F^2 + 2(\partial\Phi)^2 \right)^2 + \frac{\alpha_2}{m_{\rm Pl}^4} \left(\epsilon^{\mu\nu\rho} F_{\mu\nu} \partial_\rho \Phi \right)^2 \\ & + \frac{\alpha_3}{m_{\rm Pl}^4} \left[F_{\rho\mu} F^{\rho\nu} F^{\mu\sigma} F_{\nu\sigma} - \frac{1}{2} F^4 - (\partial\Phi)^4 + \frac{1}{2} F^2 (\partial\Phi)^2 \right] \\ & - \frac{\alpha_3}{m_{\rm Pl}^2} \left(F_{\rho\mu} F^{\rho}{}_{\nu} - \partial_\mu \Phi \partial_\nu \Phi \right) \nabla^\mu \nabla^\nu \sigma \\ & - \frac{\alpha_3}{m_{\rm Pl}^2} F_{\mu\nu} \partial_\rho \Phi \left(\nabla^\rho V^{\mu\nu} + g^{\mu\rho} \nabla_\alpha V^{\nu\alpha} \right) \Big\}, \end{aligned} \tag{14}$$

2-dof 0-dof 1-dof 1-dof

$$d\hat{s}_4^2[\hat{g}_{MN}] = e^{\sigma} ds_3^2[g_{\mu\nu}] + e^{-\sigma} \left(dz + V_\mu dx^\mu\right)^2$$

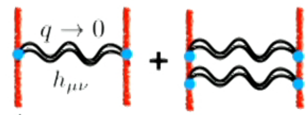
$$\hat{A}_M dx^M = A_\mu dx^\mu + \Phi\, dz$$

2-dof 1-dof 1-dof

Forward Amplitudes

1) tensor modes (known exactly…)

$$\mathcal{M}_{3D}(t \ll s) = -\frac{s^2}{t + s^2/(16L^2M_{Pl}^4)}\frac{1}{M_{Pl}^2 L} =$$



$+ \ldots =$

short-distance: recover 4D

$$\frac{-s^2}{tM_{Pl}^2 L} \quad 1/L^2 \ll t \ll s \ll M_{Pl}^2$$

$$\text{const} \quad t \ll 1/L^2$$

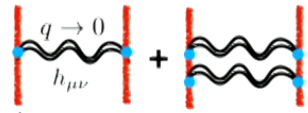
long-distance: regular

Ciafaloni '92, Deser McCarthy, Steif '94 , 't Hooft '88, … Φ , A_μ

Forward Amplitudes

1) tensor modes (known exactly…)

$$\mathcal{M}_{3D}(t \ll s) = -\frac{s^2}{t + s^2/(16L^2M_{Pl}^4)}\frac{1}{M_{Pl}^2 L} =$$



+…=

short-distance: recover 4D

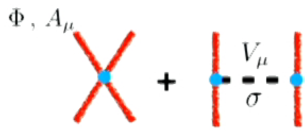
$$\frac{-s^2}{tM_{Pl}^2 L} \quad 1/L^2 \ll t \ll s \ll M_{Pl}^2$$

$$\text{const} \quad t \ll 1/L^2$$

long-distance: regular

Ciafaloni '92, Deser McCarthy, Steif '94 , 't Hooft '88, …

2) dilaton, gravi-photon & contact

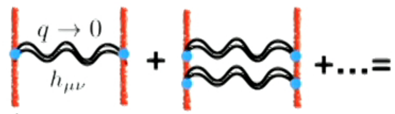


$$+ \ldots = \frac{2s^2}{M_{Pl}^2 L}(2\alpha_1 \pm \alpha_3)$$

Forward Amplitudes

1) tensor modes (known exactly…)

$$\mathcal{M}_{3D}(t \ll s) = -\frac{s^2}{t + s^2/(16L^2 M_{Pl}^4)} \frac{1}{M_{Pl}^2 L} =$$



short-distance: recover 4D

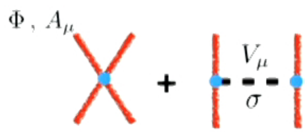
$$\frac{-s^2}{t M_{Pl}^2 L} \quad 1/L^2 \ll t \ll s \ll M_{Pl}^2$$

$$\text{const} \quad t \ll 1/L^2$$

long-distance: regular

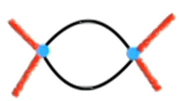
Ciafaloni '92, Deser McCarthy, Steif '94 , 't Hooft '88, … Φ, A_μ

2) dilaton, gravi-photon & contact



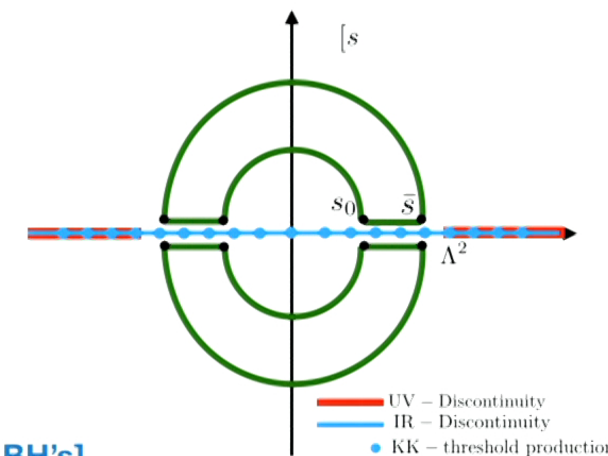
$$+\ldots = \frac{2s^2}{M_{Pl}^2 L}(2\alpha_1 \pm \alpha_3)$$

3) KK modes



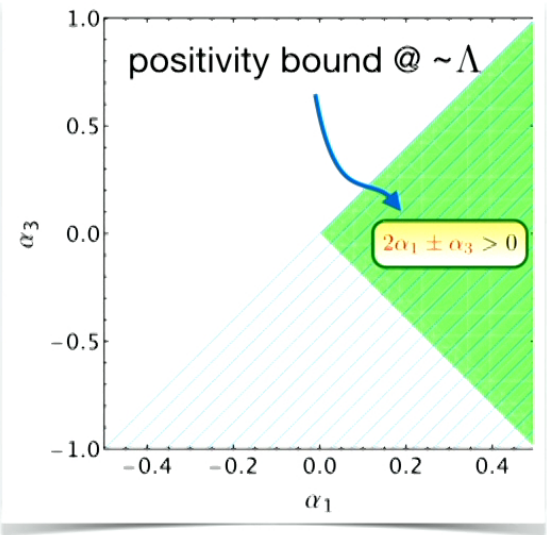
$$+\ldots = \sum_n \frac{a s^2}{L M_{Pl}^4 n} = s^2 \frac{2a}{L M_{Pl}^4} \log \frac{\Lambda^2}{\bar{s}}$$

just (positive) running!
[trivial WGC for asymptotically large BH's]



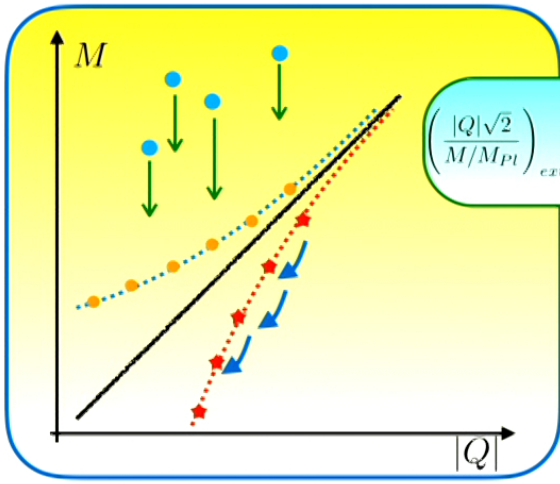
Black Hole WGC

Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$

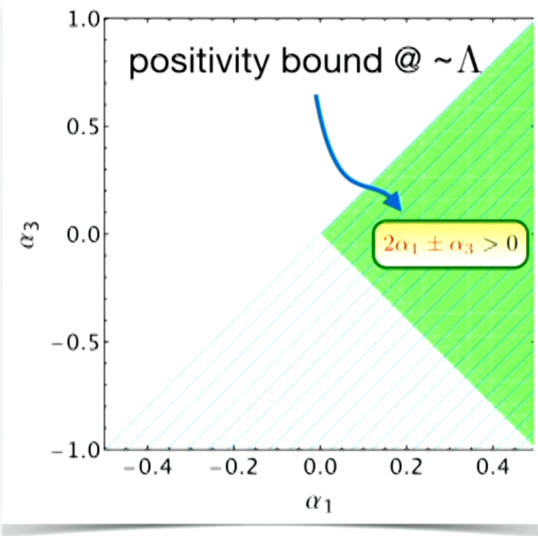


Black Hole WGC

Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$

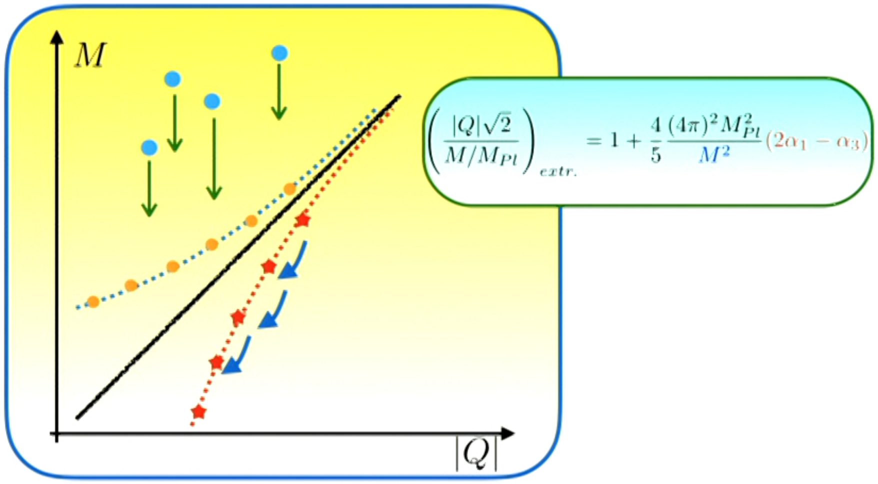


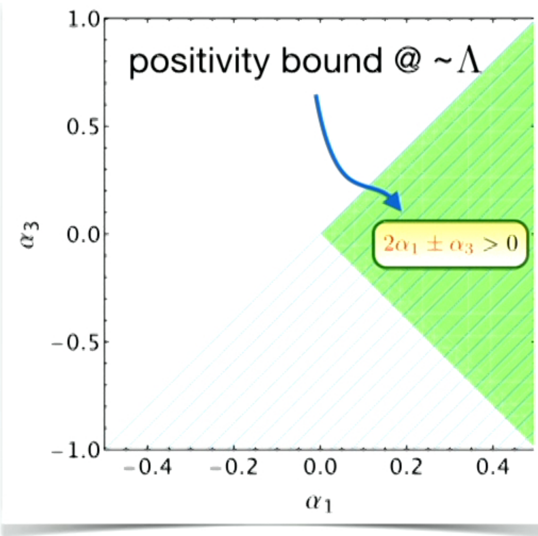
$$\left(\frac{|Q|\sqrt{2}}{M/M_{Pl}}\right)_{extr.} = 1 + \frac{4}{5}\frac{(4\pi)^2 M_{Pl}^2}{M^2}(2\alpha_1 - \alpha_3)$$



Black Hole WGC

Maxwell-Einstein EFT: $\mathcal{L} = \frac{M_{Pl}^2}{2}\mathcal{R} - \frac{1}{4}F_{\mu\nu}^2 + \frac{\alpha_1}{4M_{Pl}^4}(F_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_2}{4M_{Pl}^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2 + \frac{\alpha_3}{2M_{Pl}^2}F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \ldots$





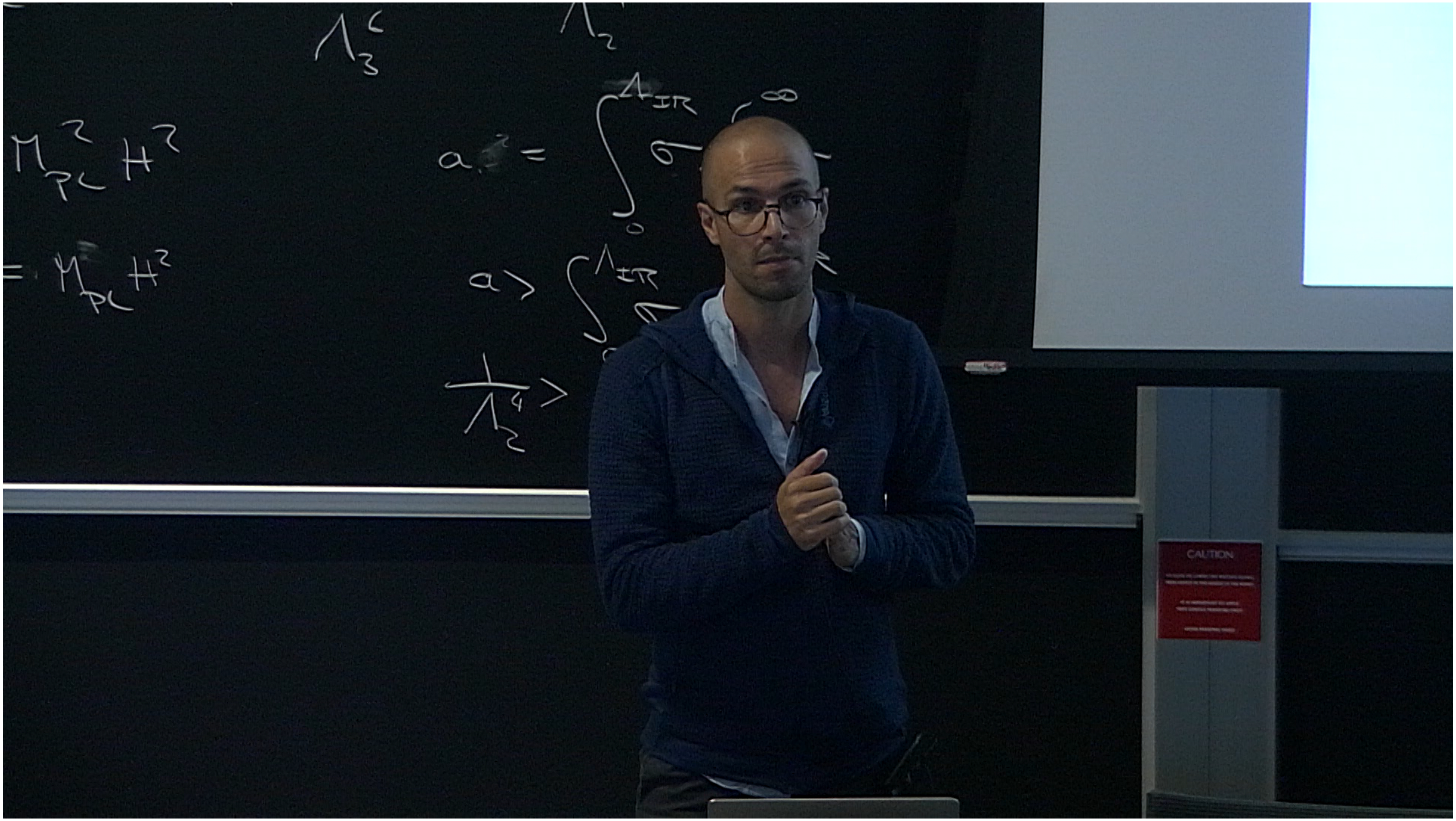
extr. BH's live on the lower curve, do satisfy WGC |Q|>M (are self-repulsive) and are unstable to decay to smaller ones!

Conclusions

* Not all EFTs are created equal: some are born in the swampland
  (UV-progenitors break either unitarity, causality, Lorentz of scattering amplitudes)

* Regulating the coulomb sing. we derived new positivity bounds in gravitational theories:
  * extremal Black holes actually have $|Q|>M$ once higher-dim. operators included
  * they are self-repulsive and unstable
  * provide explicit state obeying the WGC
    trivialising the WGC, devoided of predicting powers, just EFT+causality+unitarity

* Other applications: can rule out bunch of EFT used in cosmology
  (e.g. Galileons cutoff~ 1/(10^7 km), massive gravity,…)


CAUTION