

Positivity Constraints on Self-interacting Dark Matter

Scott Melville

Positivity Constraints on Self-interacting Dark Matter

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1. Only some non-renormalizable theories have UV completions
2. Only some dark matter interactions have UV completions

- Self-Interactions Resolution to small scale issues with CDM
- Effective Field Theory Low energy theories are non-renormalizable
- Constraining SIDM Not all DM interactions have UV completions



Tulin, Yu, 1705.02358
Dark Matter Self-Interaction and Small Scale Structure

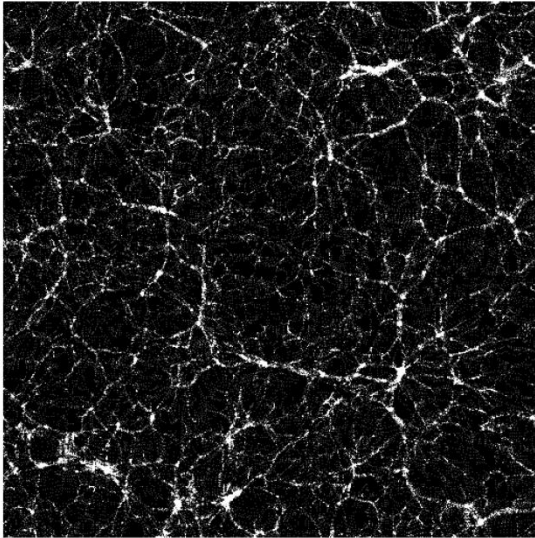
Babichev et al, 1607.03497
Heavy spin-2 dark matter

Adams et al., hep-th/0602178
Causality, Analyticity and an IR Obstruction to UV Completion

SM, de Rham, Tolley, Zhou 1702.06134, 1706.02712
Positivity Bounds for Effective Field Theories

Self Interactions

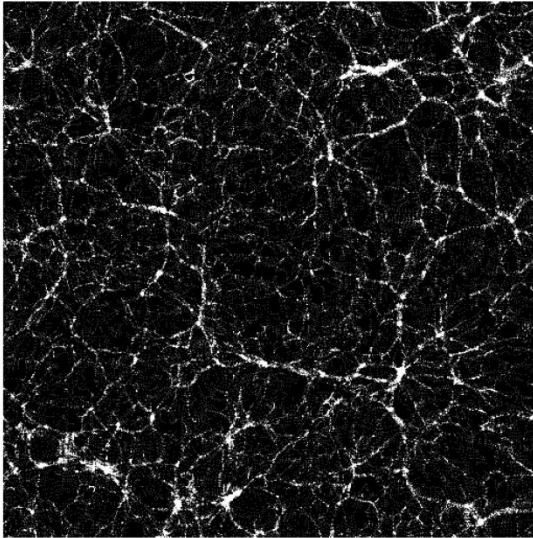
Dark Matter on Small Scales



- cusp-core
- missing satellite
- too-big-to-fail
- diversity problem

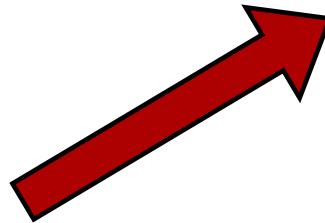
[see 1705.02358 for review]

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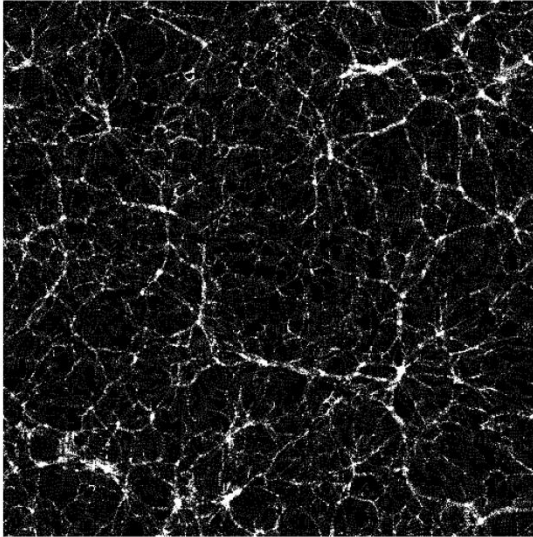
[see 1705.02358 for review]



Better Simulations
of known physics

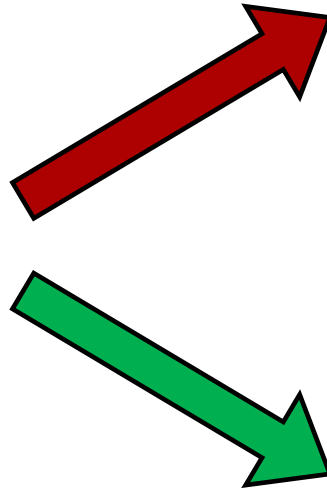
[see 1606.07790 for review]

Dark Matter on Small Scales



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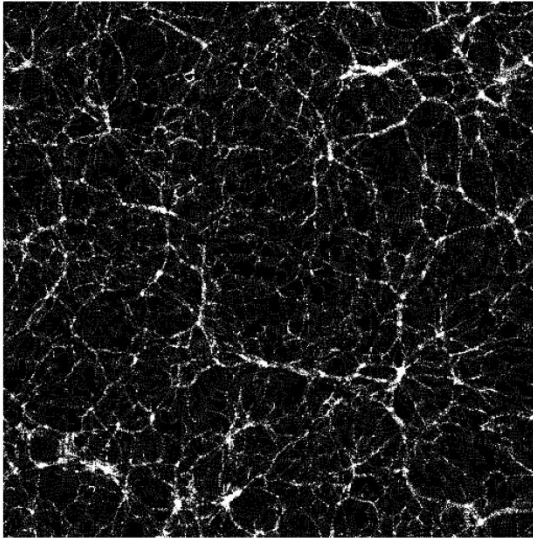
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Dark Matter
Self-Interactions!

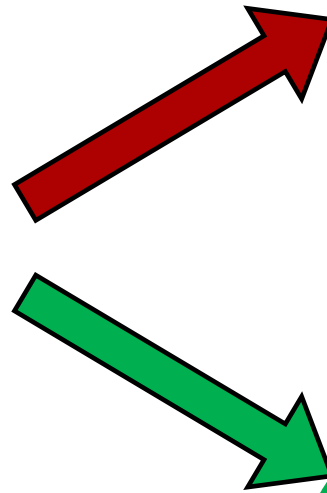
[astro-ph/9909386]

Dark Matter on Small Scales



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[see 1705.02358 for review]



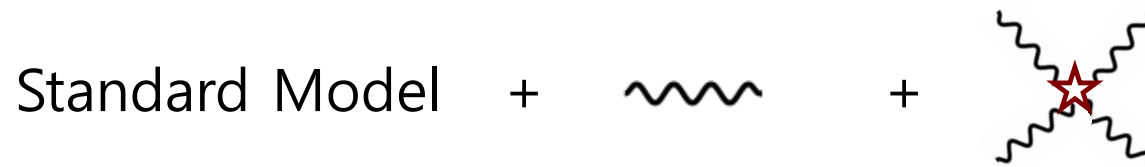
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Dark Matter
Self-Interactions!

[astro-ph/9909386]

Self-Interacting Dark Matter



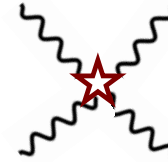
Self-Interacting Dark Matter

Standard Model

+

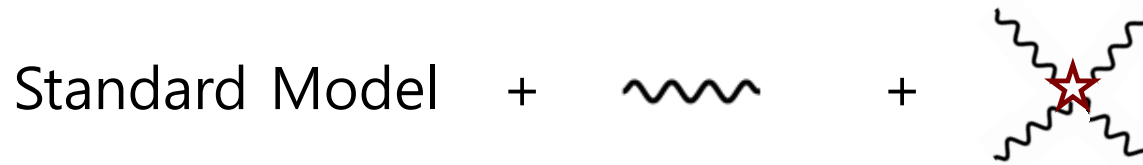


+



- Massive Spin-1 [1510.08063, ...]
- Massive Spin-3/2 [1704.01904, ...]
- Massive Spin-2 [1607.03497, 1708.06764, ...]
- Combinations [1701.07747, 1709.05128, 1803.01866, ...]

Self-Interacting Dark Matter

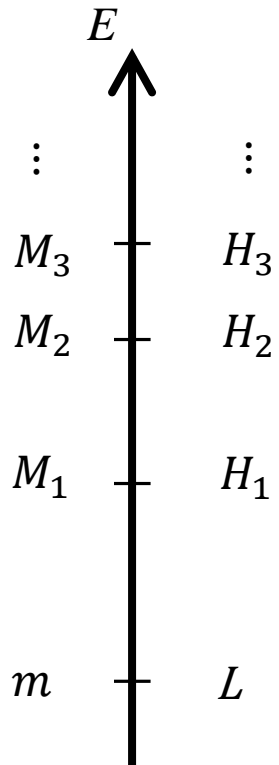


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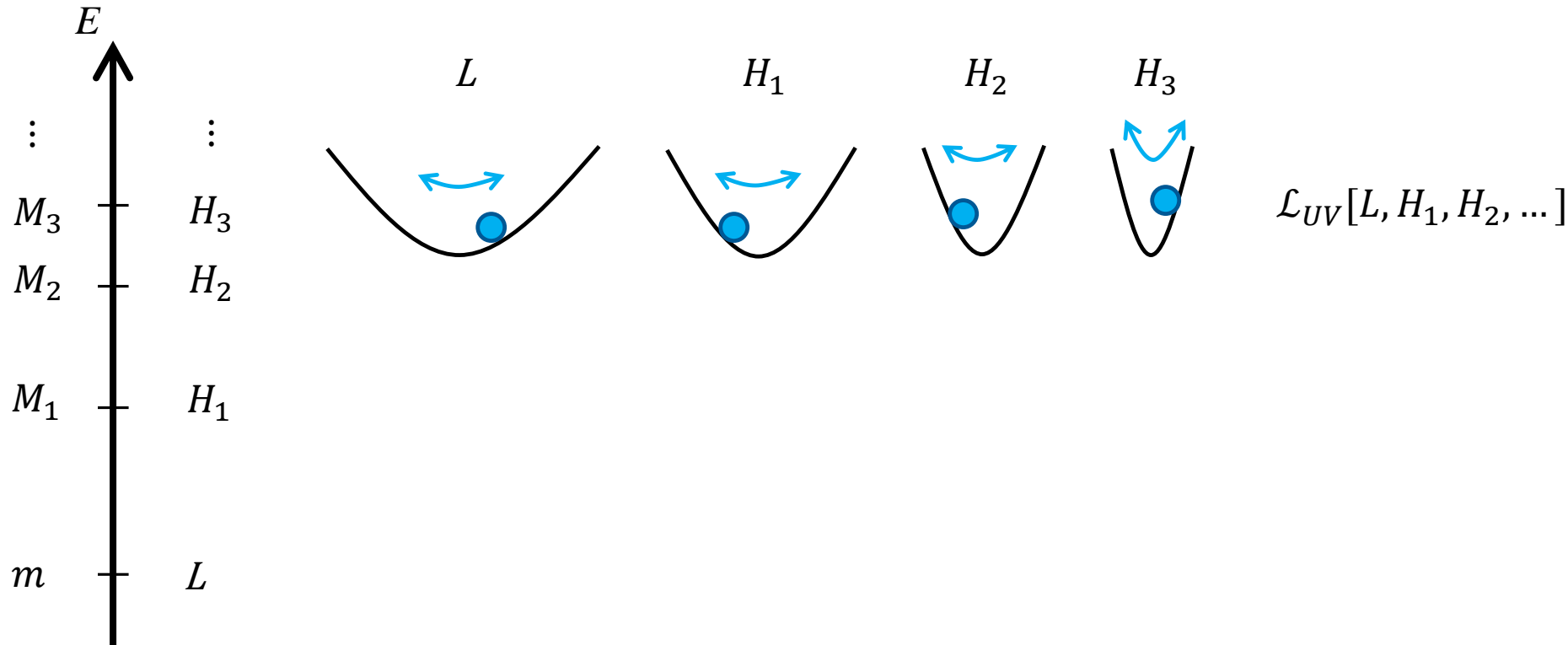
Massive spinning particles have broken gauge invariance at low energies, and are described by Effective Field Theory

Effective Field Theory

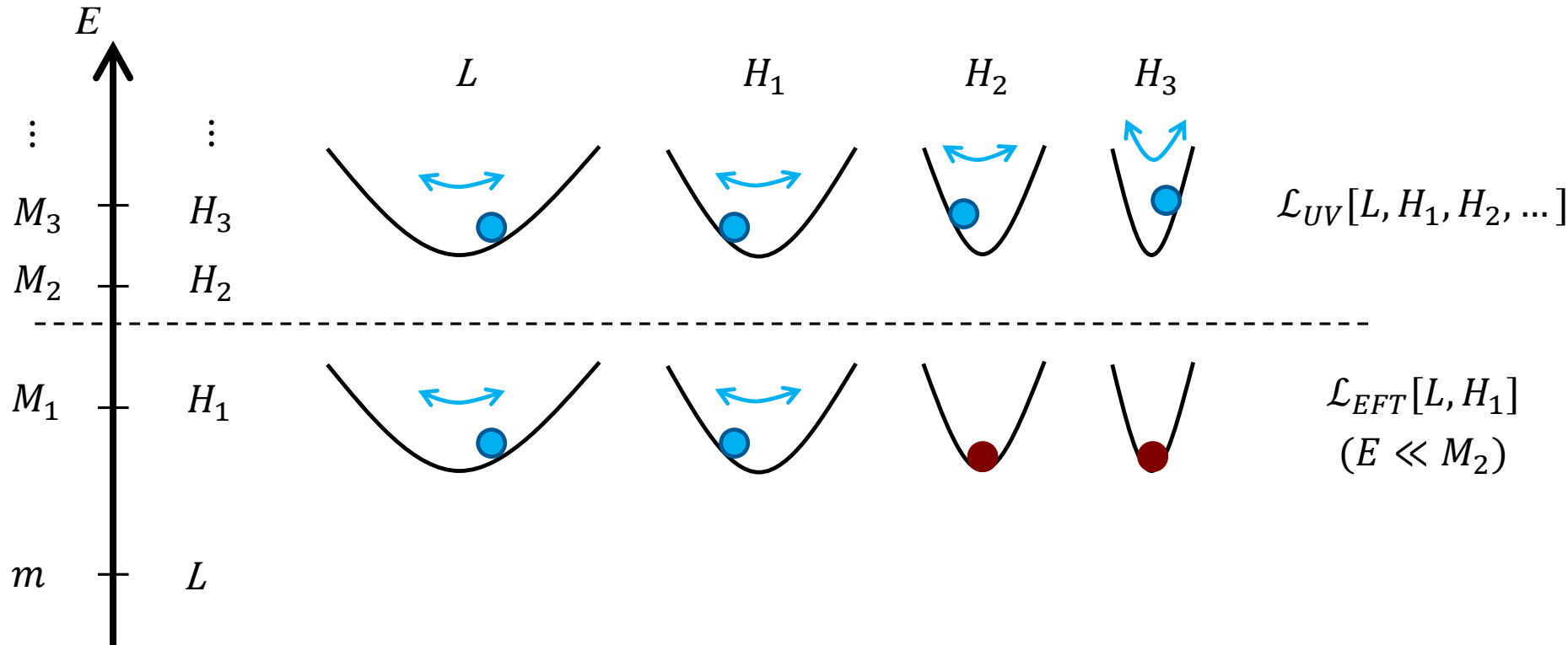
Low Energy EFT



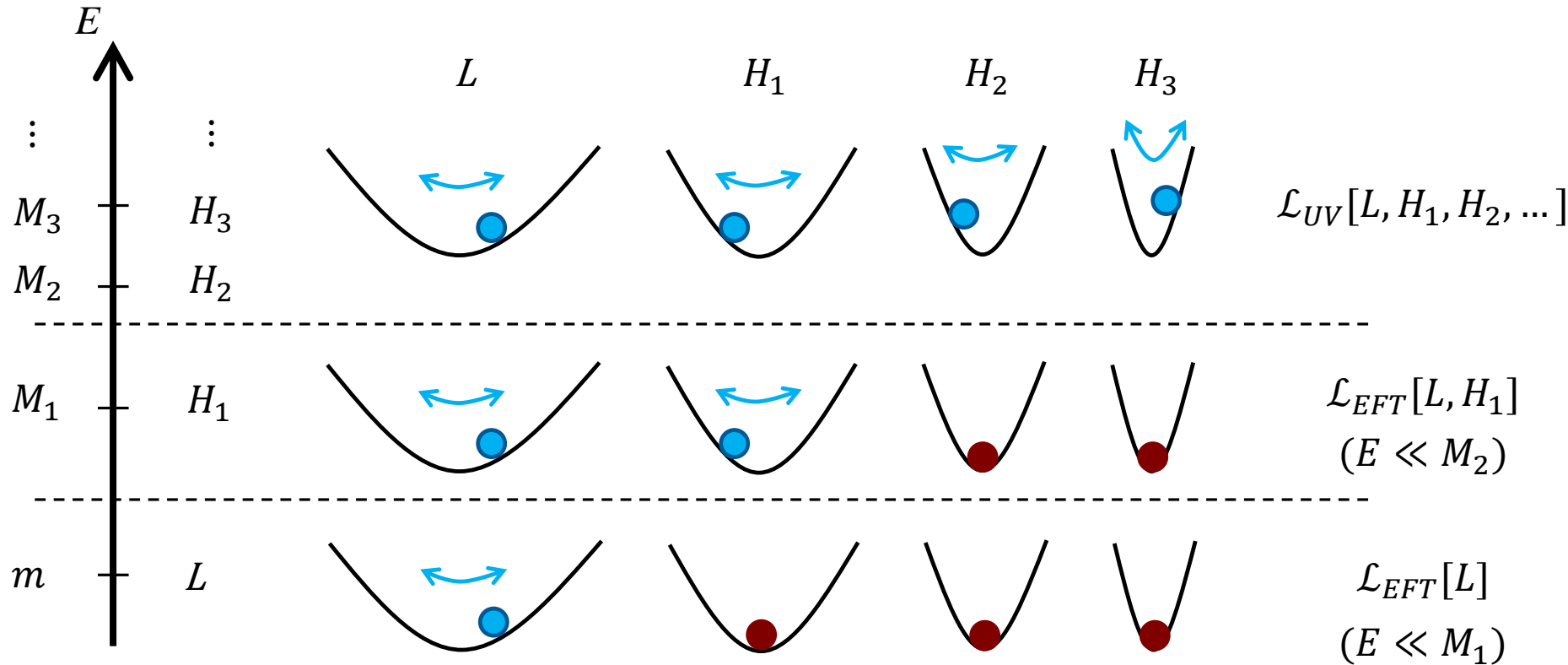
Low Energy EFT



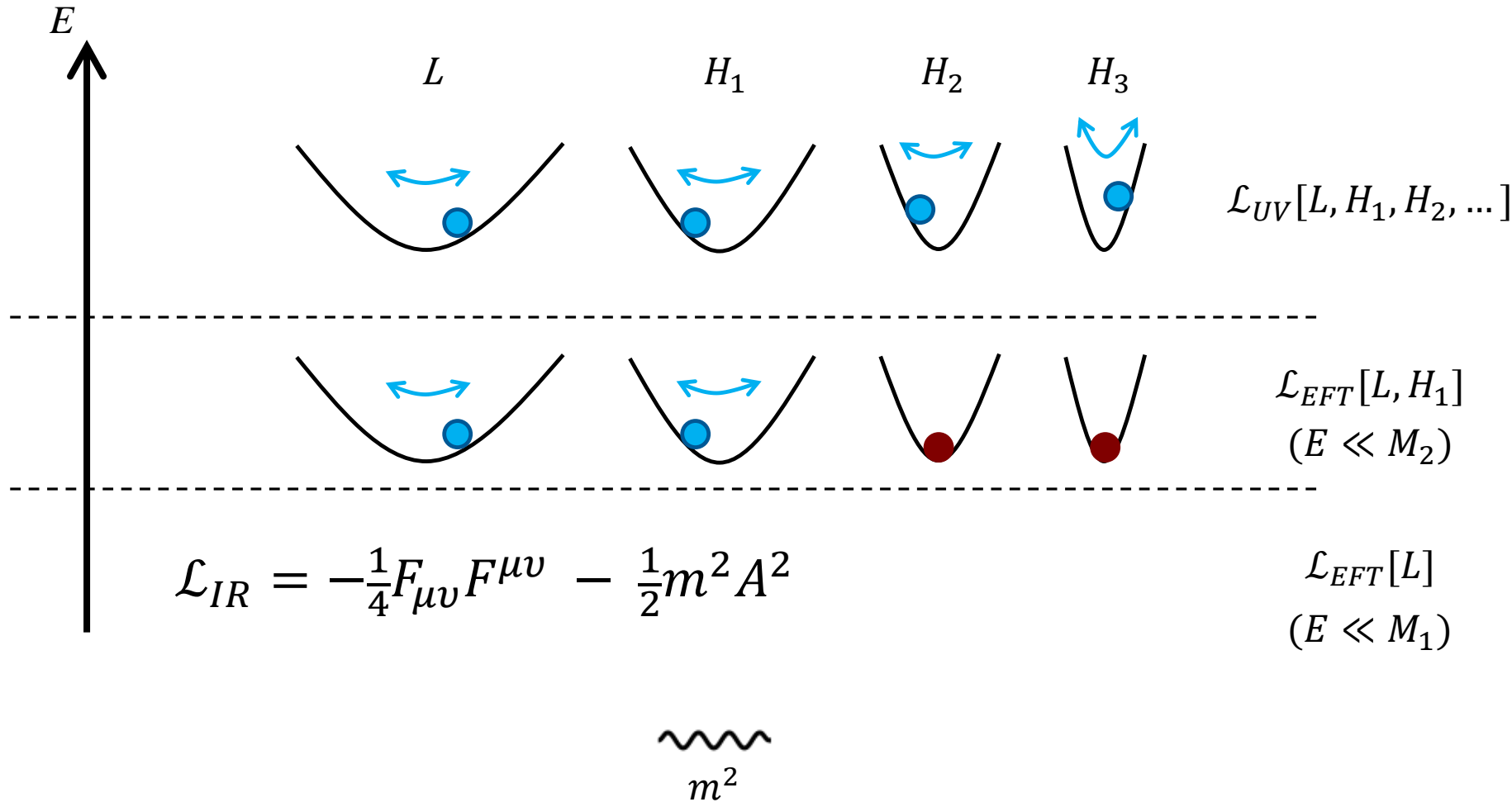
Low Energy EFT



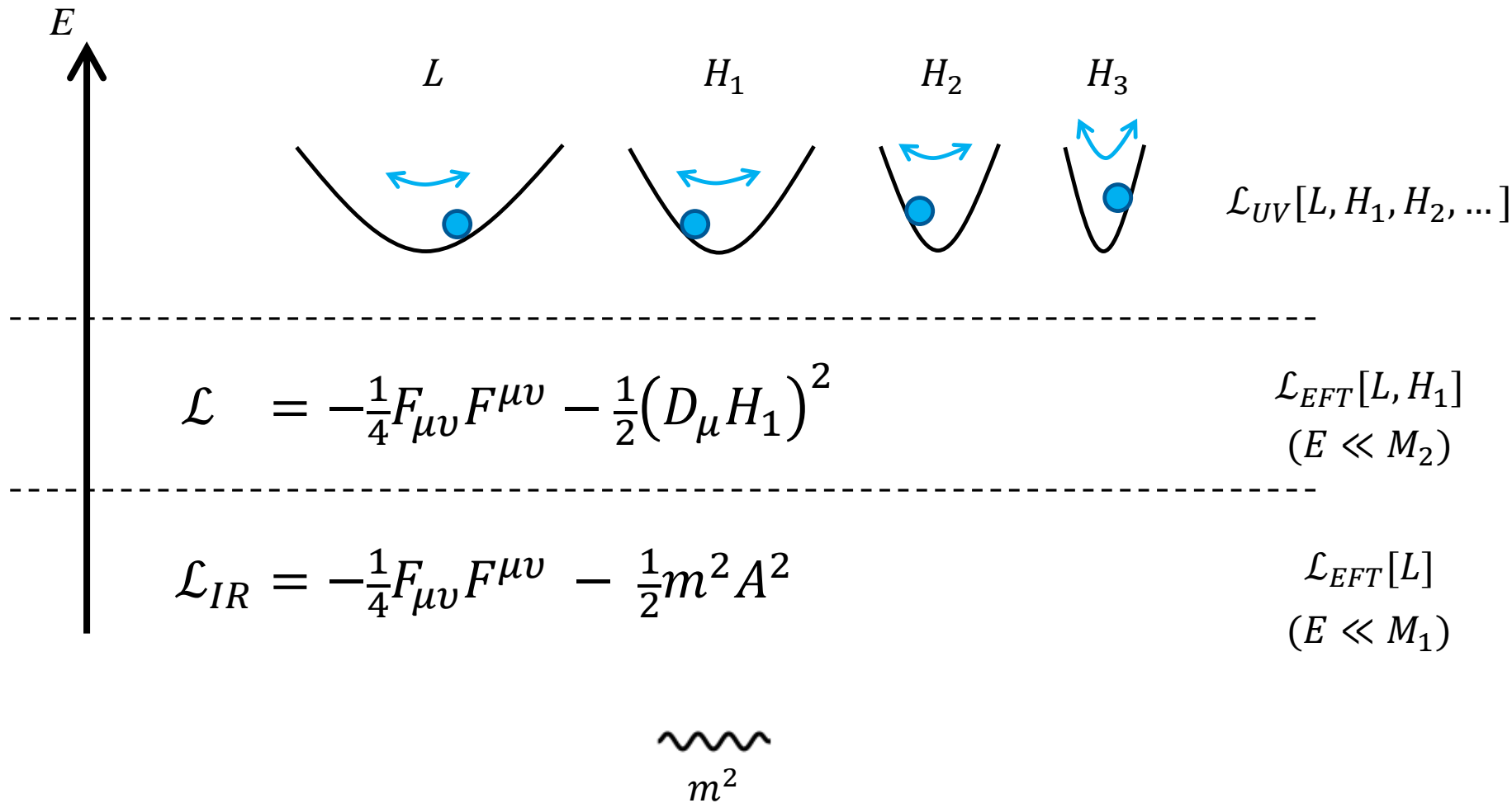
Low Energy EFT



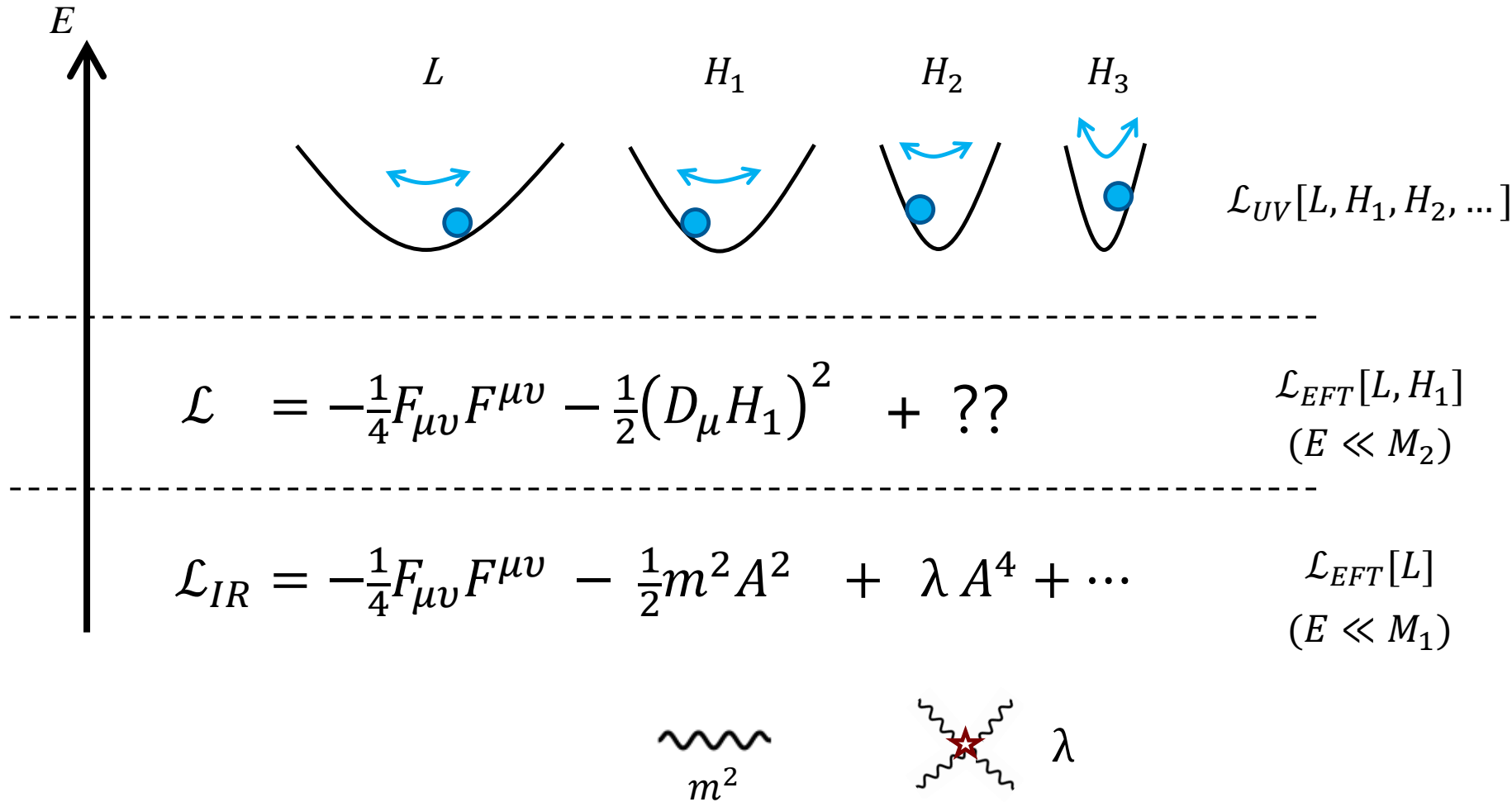
Low Energy EFT



Low Energy EFT



Low Energy EFT



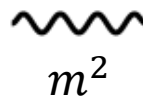
Low Energy EFT

E

$$\mathcal{L}_{UV} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(D_{\mu}H_i)^2 + \alpha H_2 D^2 H_1 \quad \mathcal{L}_{UV}[L, H_1, H_2, \dots]$$

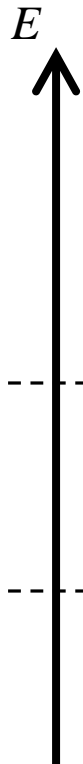
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(D_{\mu}H_1)^2 + \frac{\alpha^2}{2M_2^2} (D^2 H_1)^2 \quad \mathcal{L}_{EFT}[L, H_1] \\ (E \ll M_2)$$

$$\mathcal{L}_{IR} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m^2 A^2 + \lambda A^4 + \dots \quad \mathcal{L}_{EFT}[L] \\ (E \ll M_1)$$



Low Energy EFT


E

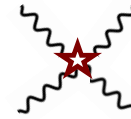


$$\mathcal{L}_{UV} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(D_\mu H_i)^2 + \alpha H_2 D^2 H_1 \quad \mathcal{L}_{UV}[L, H_1, H_2, \dots]$$

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(D_\mu H_1)^2 + \frac{\alpha^2}{2M_2^2} (D^2 H_1)^2 \quad \mathcal{L}_{EFT}[L, H_1] \quad (E \ll M_2)$$

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 m^2




$$\lambda = \frac{\alpha^2 \langle H_1 \rangle^2}{2M_2^2} > 0$$

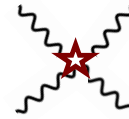
Low Energy EFT

 E

$$\mathcal{L}_{UV} = \quad ???$$

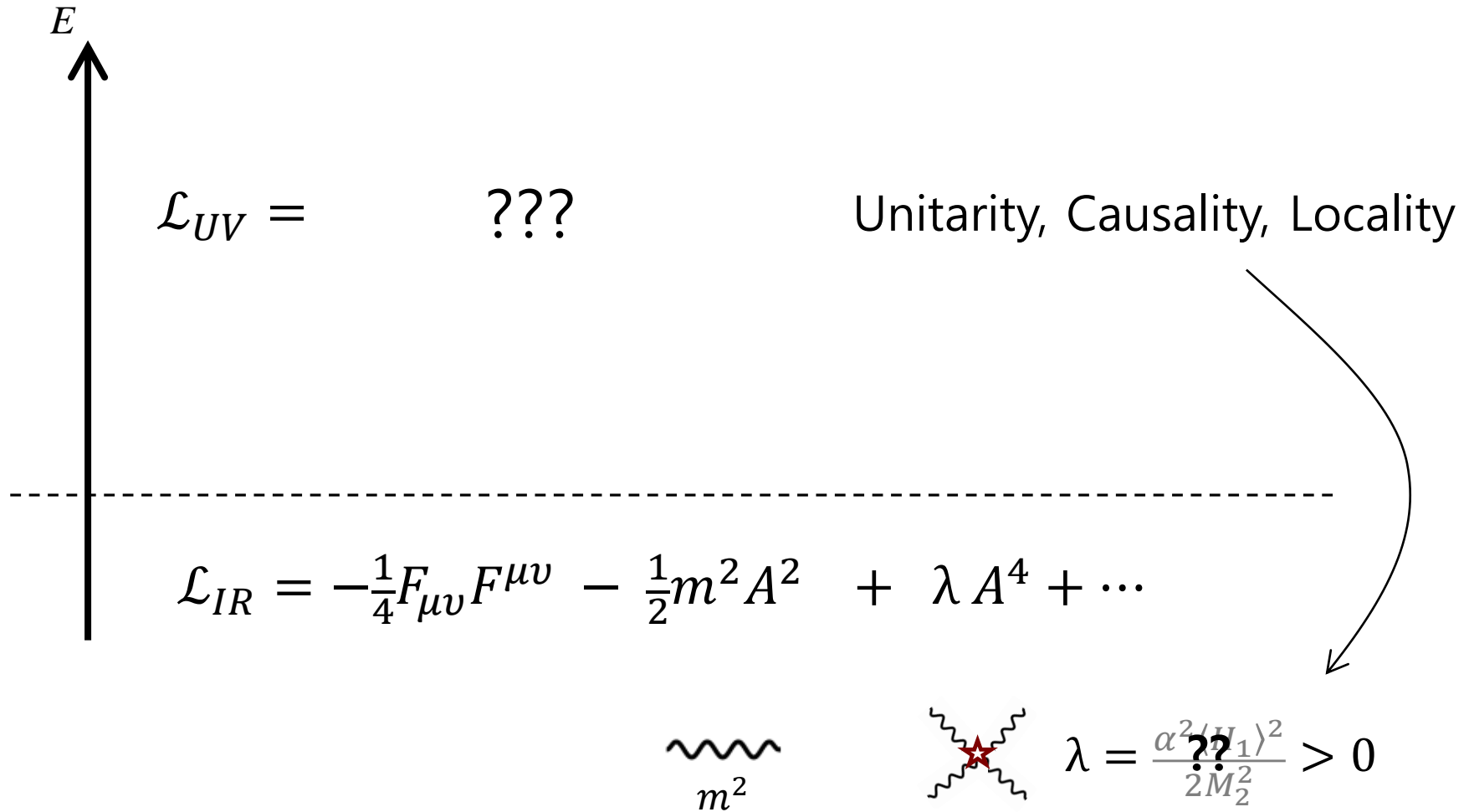
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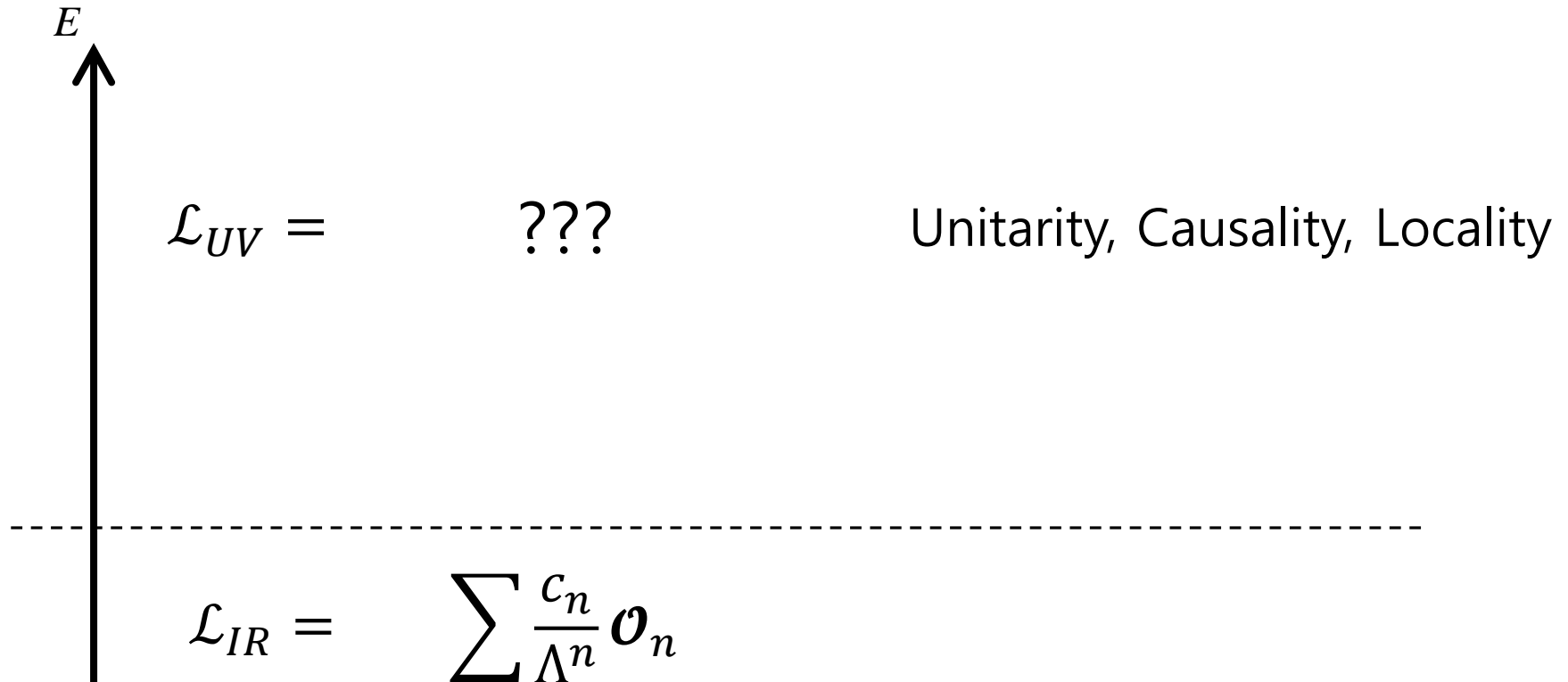
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Low Energy EFT



Positivity Bounds

[hep-th/0602178, 1702.06134, 1706.02712]



Positivity Bounds

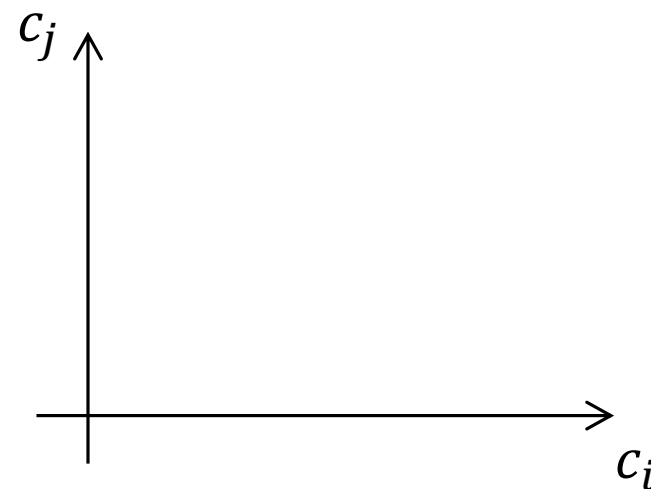
[hep-th/0602178, 1702.06134, 1706.02712]

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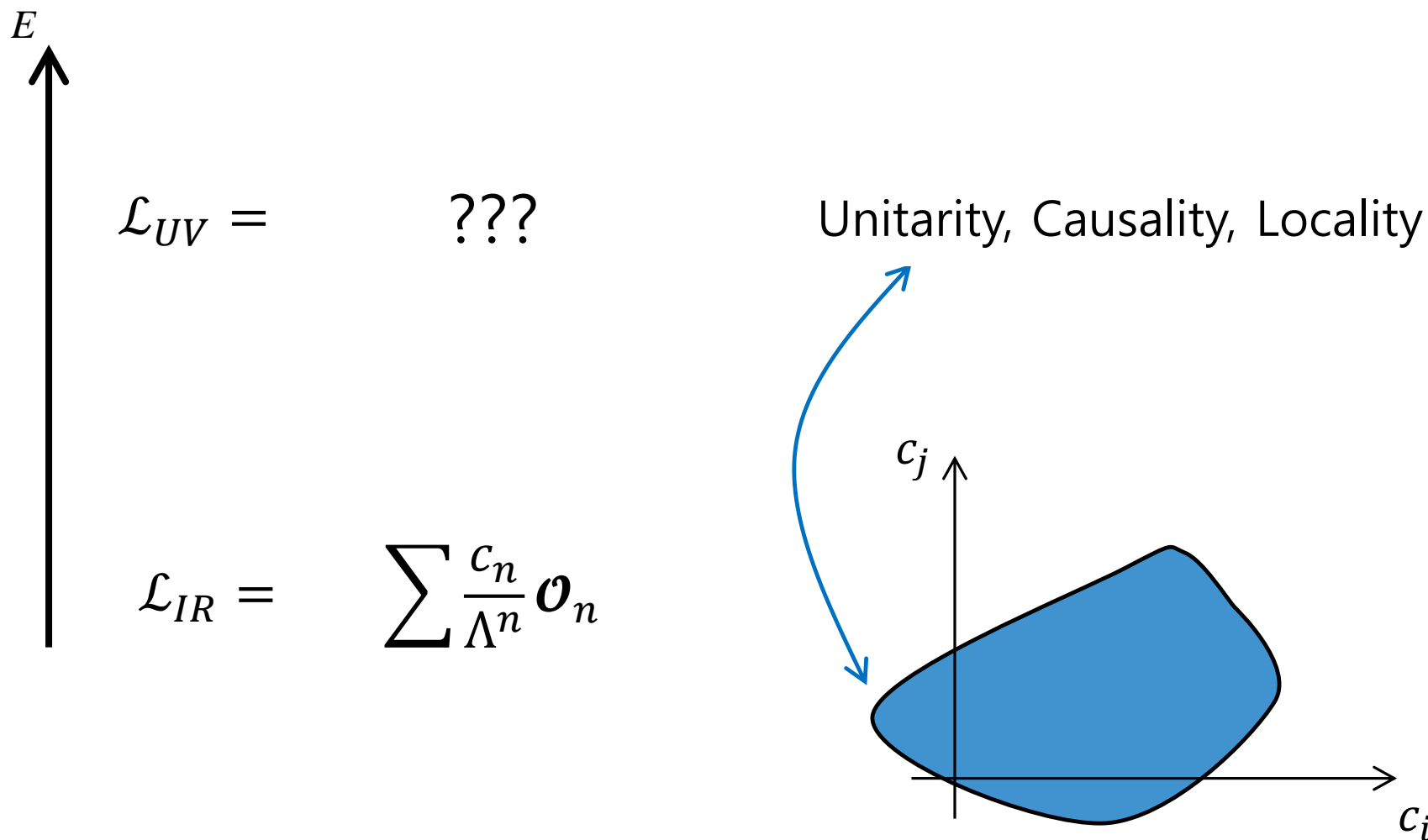
Unitarity, Causality, Locality

$$\mathcal{L}_{IR} = \sum \frac{c_n}{\Lambda^n} \mathcal{O}_n$$



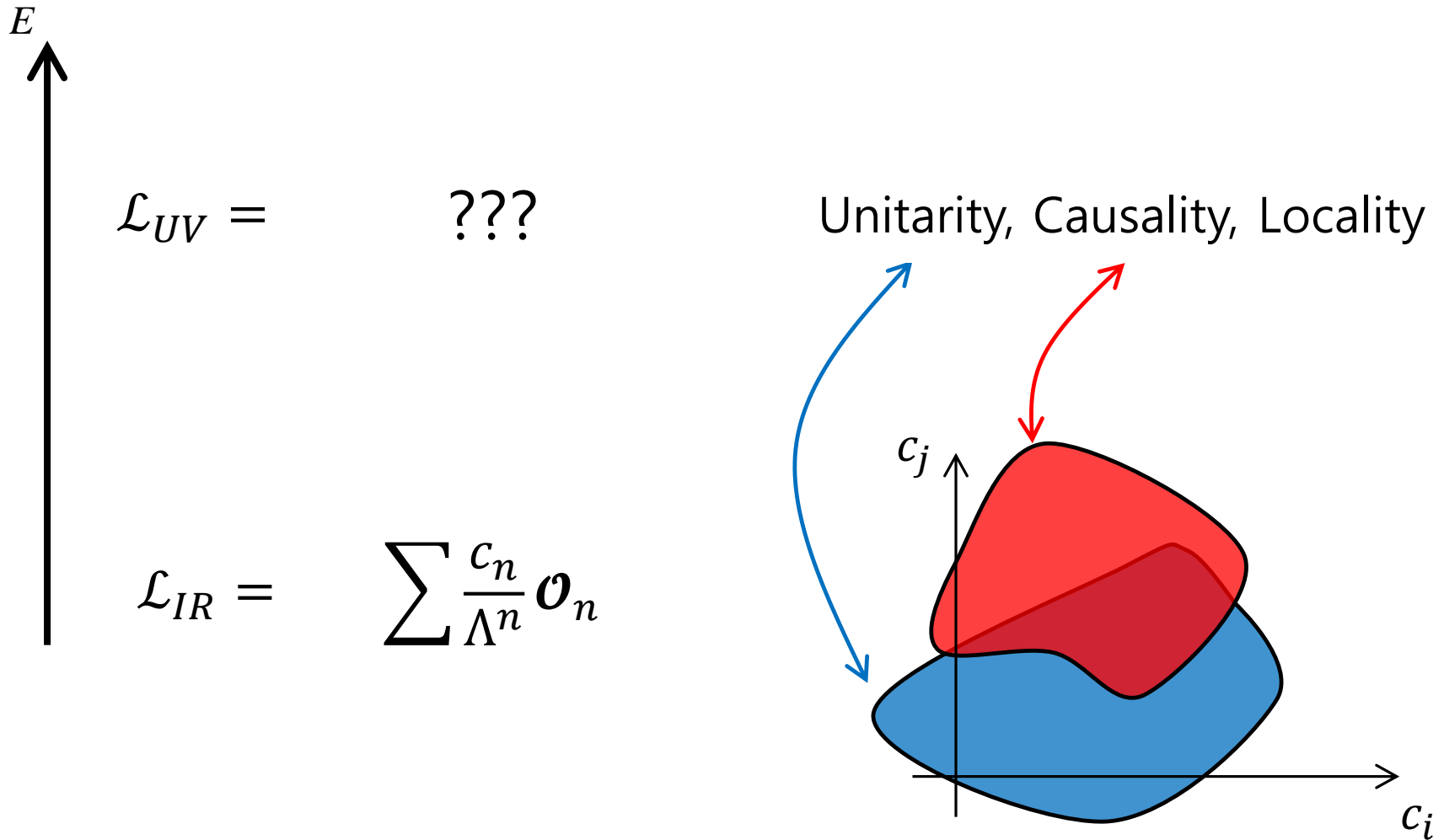
Positivity Bounds

[hep-th/0602178, 1702.06134, 1706.02712]



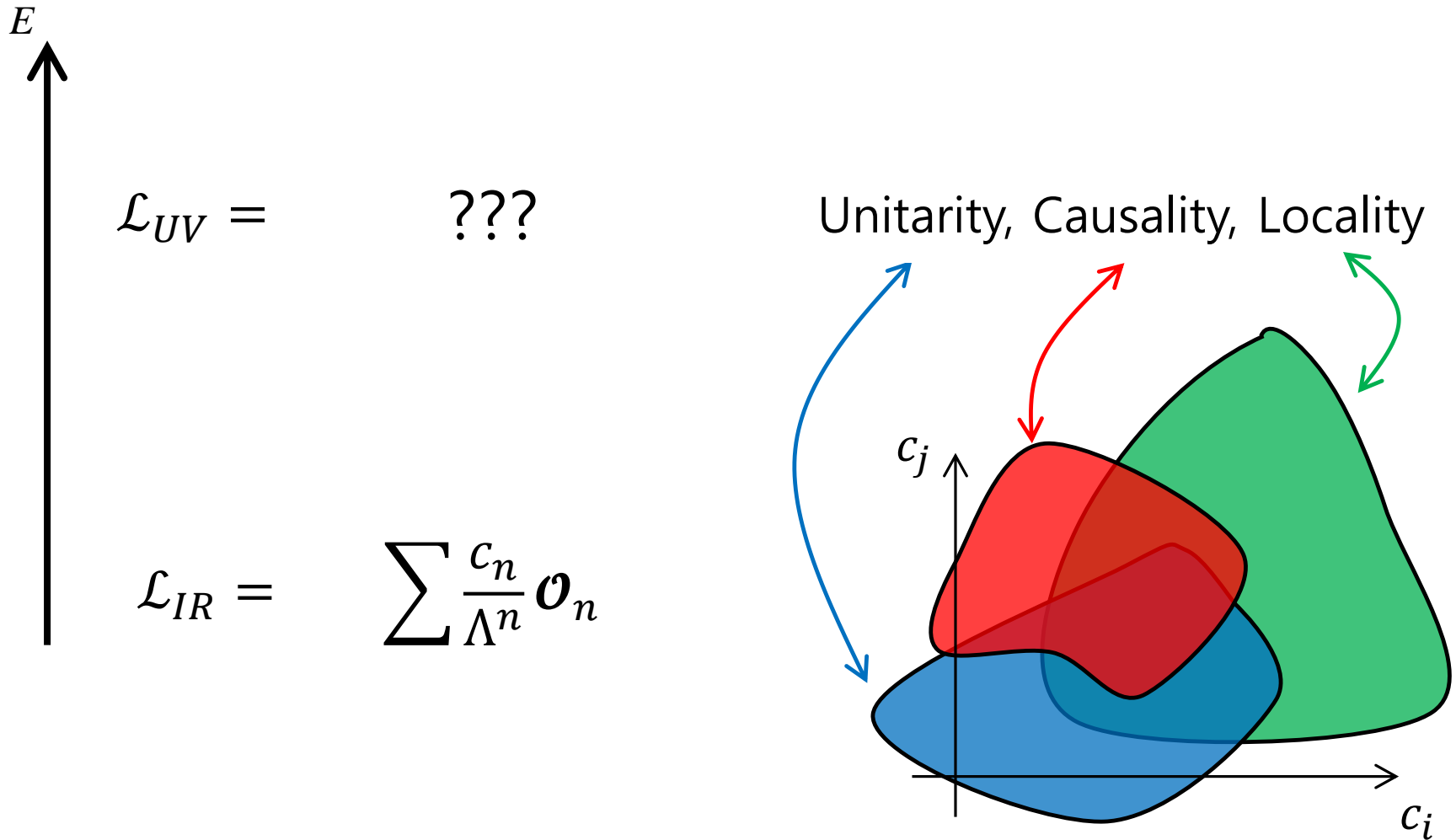
Positivity Bounds

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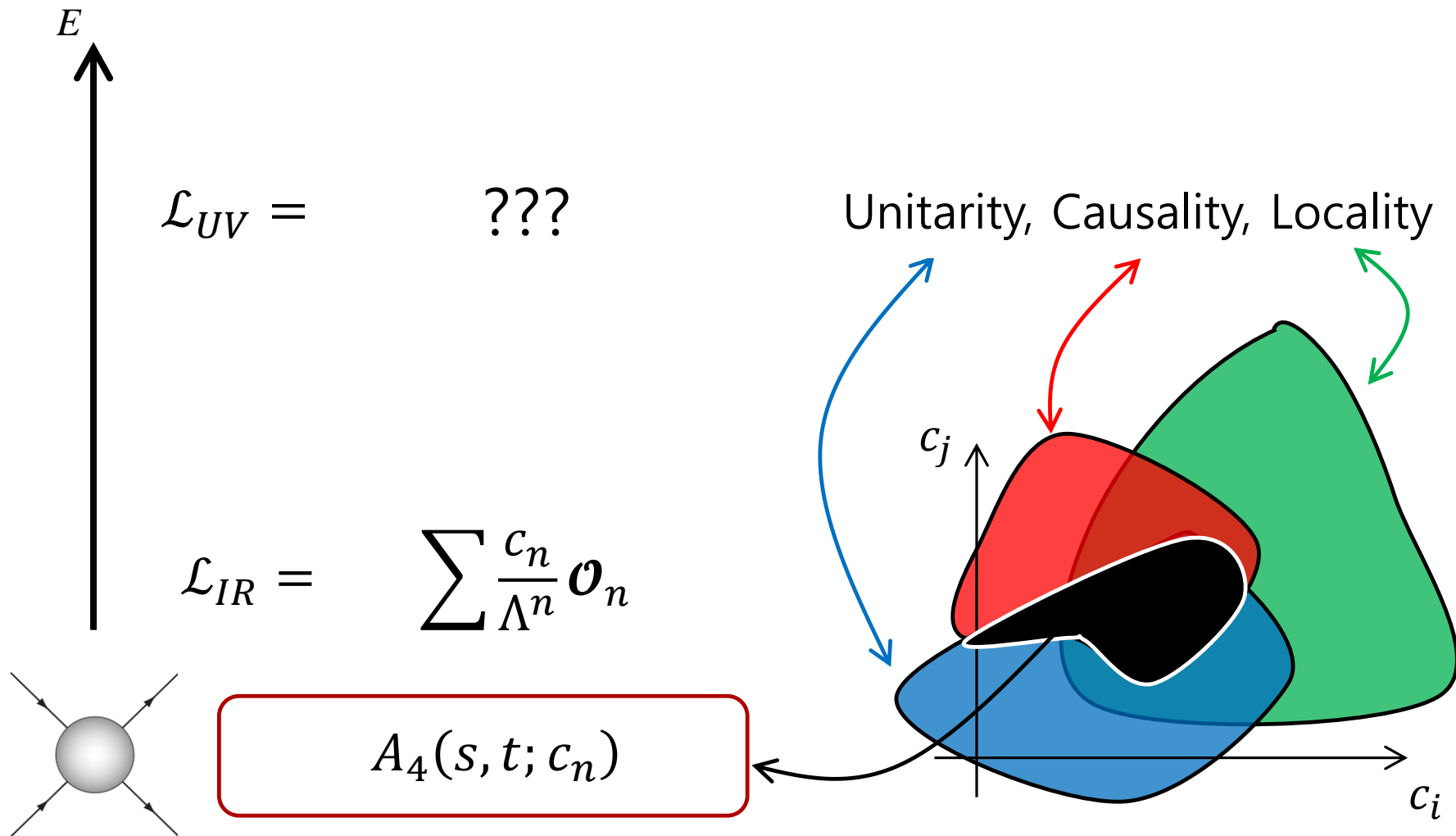
Positivity Bounds

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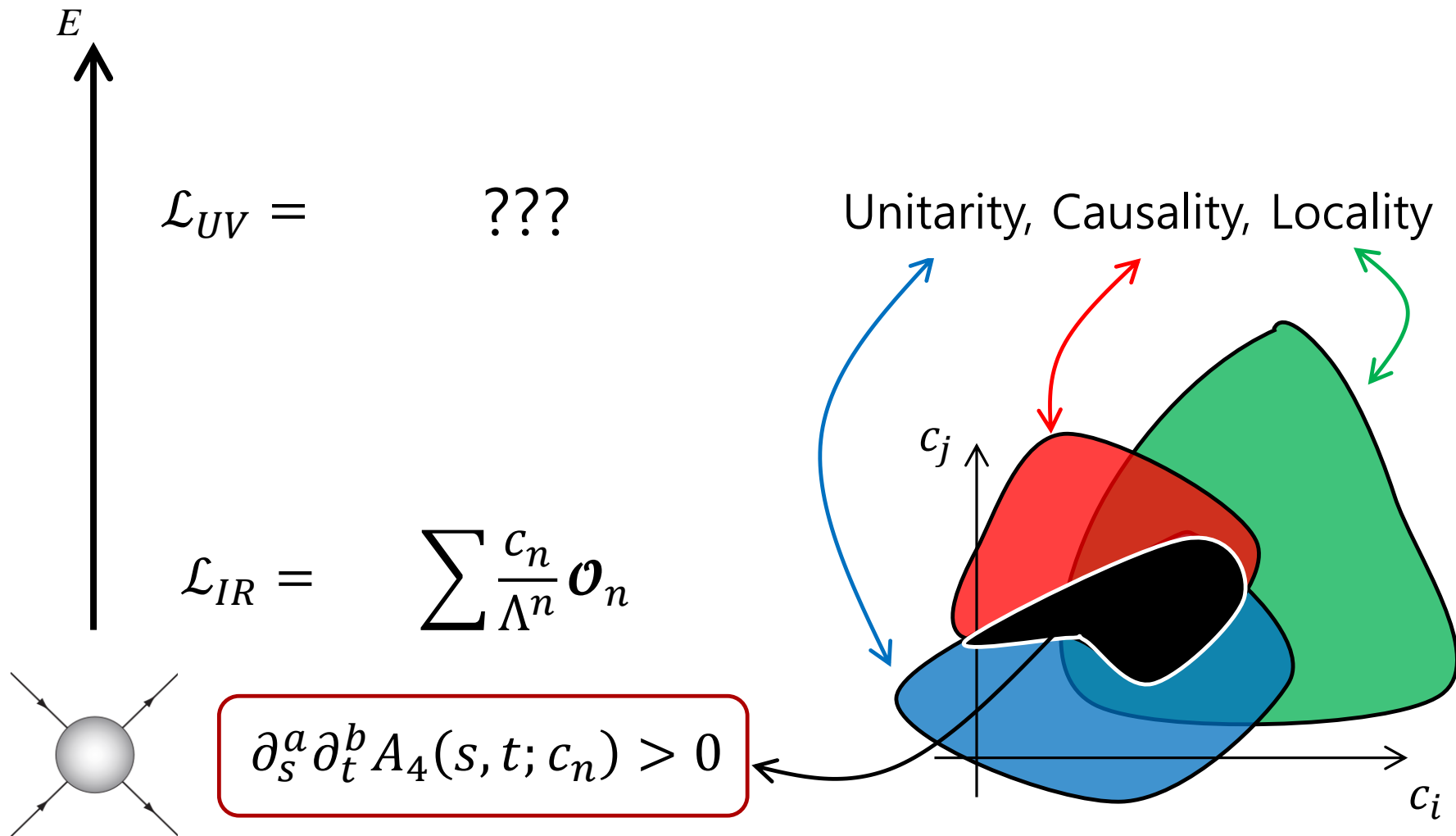
Positivity Bounds

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Positivity Bounds

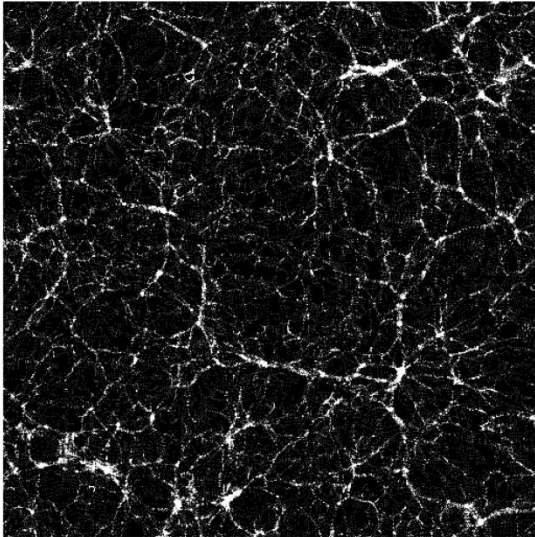
[hep-th/0602178, 1702.06134, 1706.02712]



Constraining Dark Matter

Self-Interacting Dark Matter

[1705.02358]



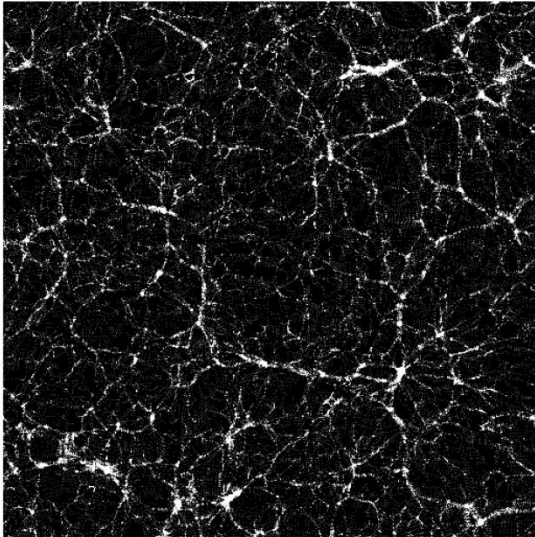
- cusp-core
- missing satellite
- too-big-to-fail
- diversity problem

Self-Interacting Dark Matter

[1705.02358]

to resolve small
scale problems
in simulations

$$0.1 \text{cm}^2/\text{g} < \frac{\sigma}{m}$$



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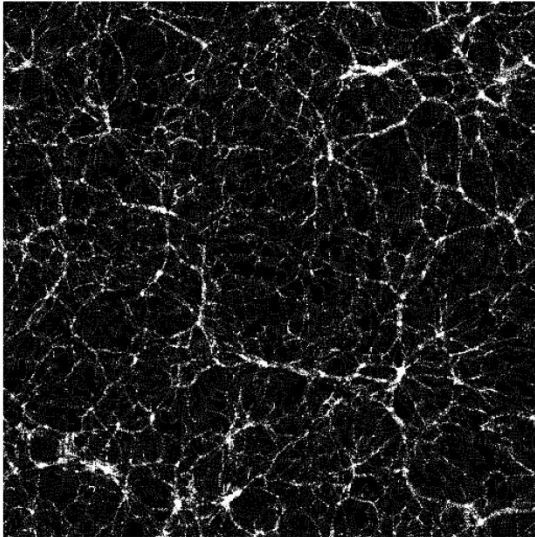
Self-Interacting Dark Matter

[1705.02358]

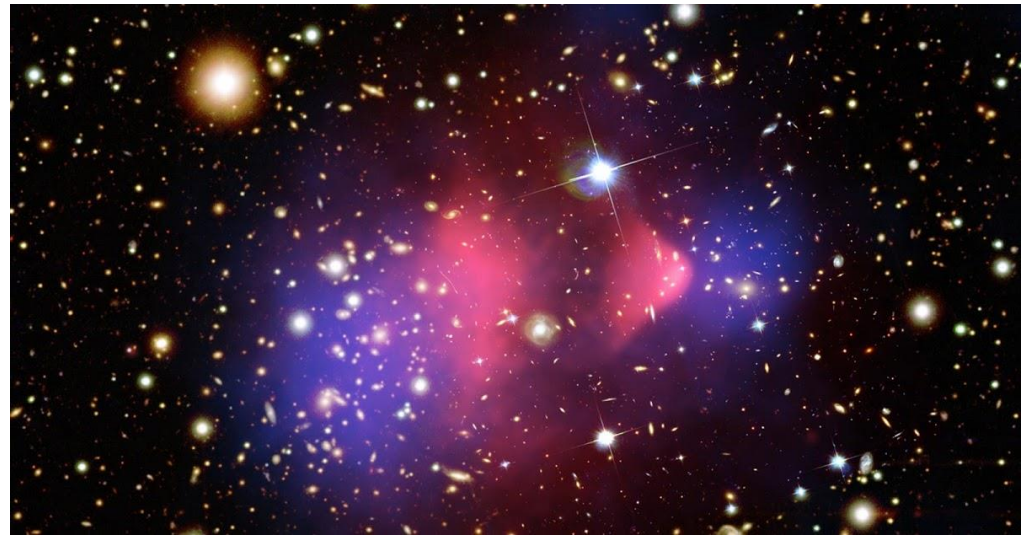
to resolve small
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in simulations

$$0.1 \text{cm}^2/\text{g} < \frac{\sigma}{m} < 1 \text{cm}^2/\text{g}$$

to match observations



- cusp-core
- missing satellite
- too-big-to-fail
- diversity problem



- bullet cluster
- halo ellipticity
- substructure mergers
- merging clusters

Self-Interacting Dark Matter

[1705.02358]

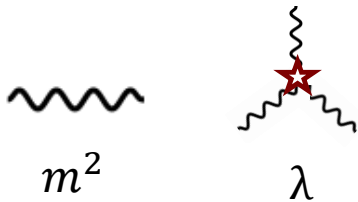
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Massive Spin-2

[1607.03497, 1708.06764]



Self-Interacting Dark Matter

[1705.02358]

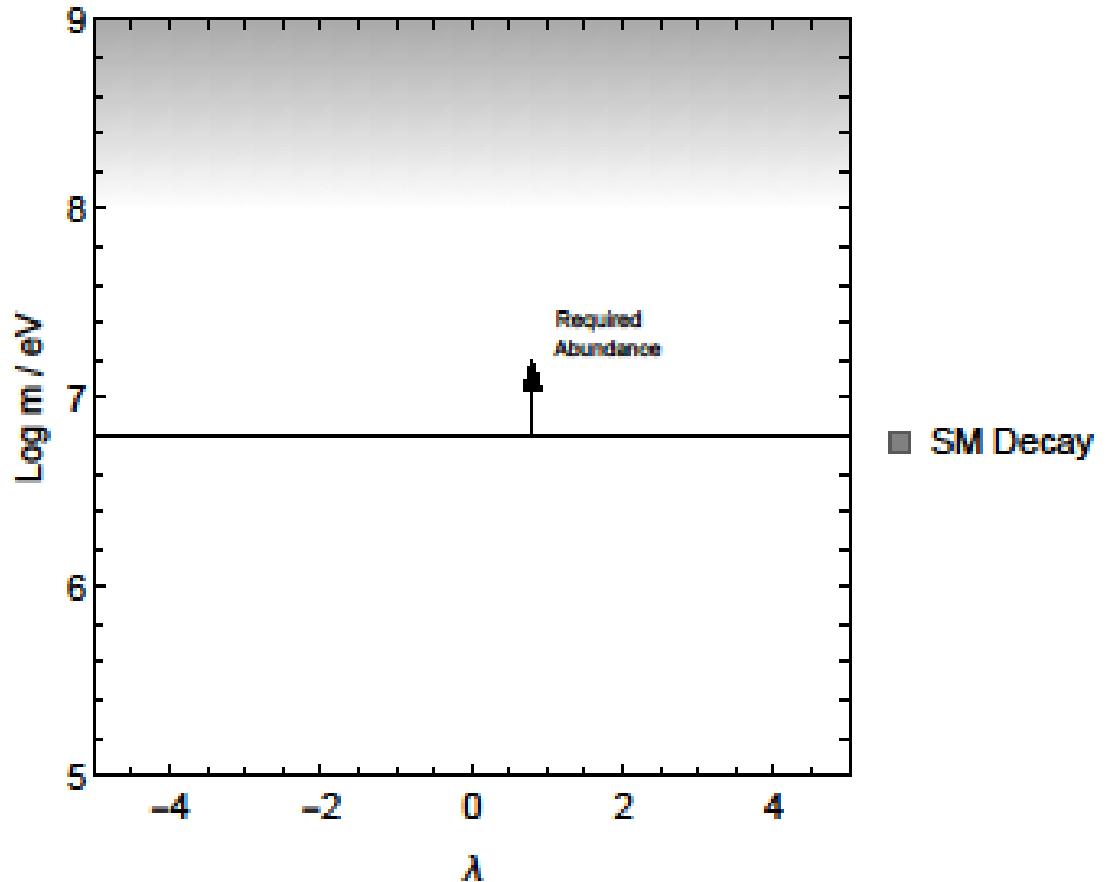
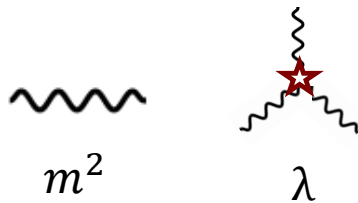
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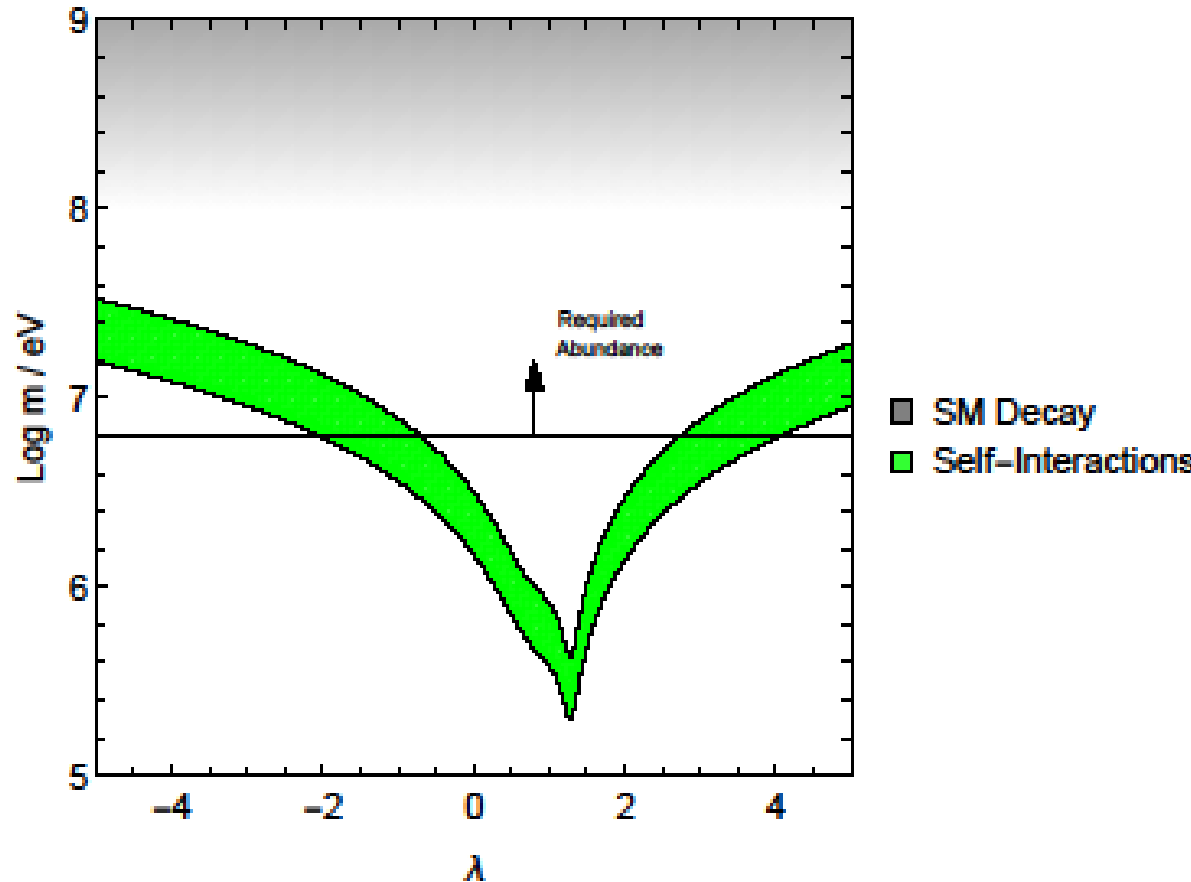
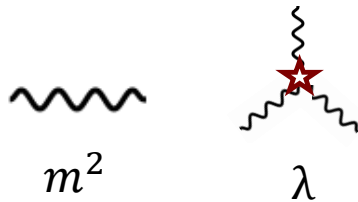
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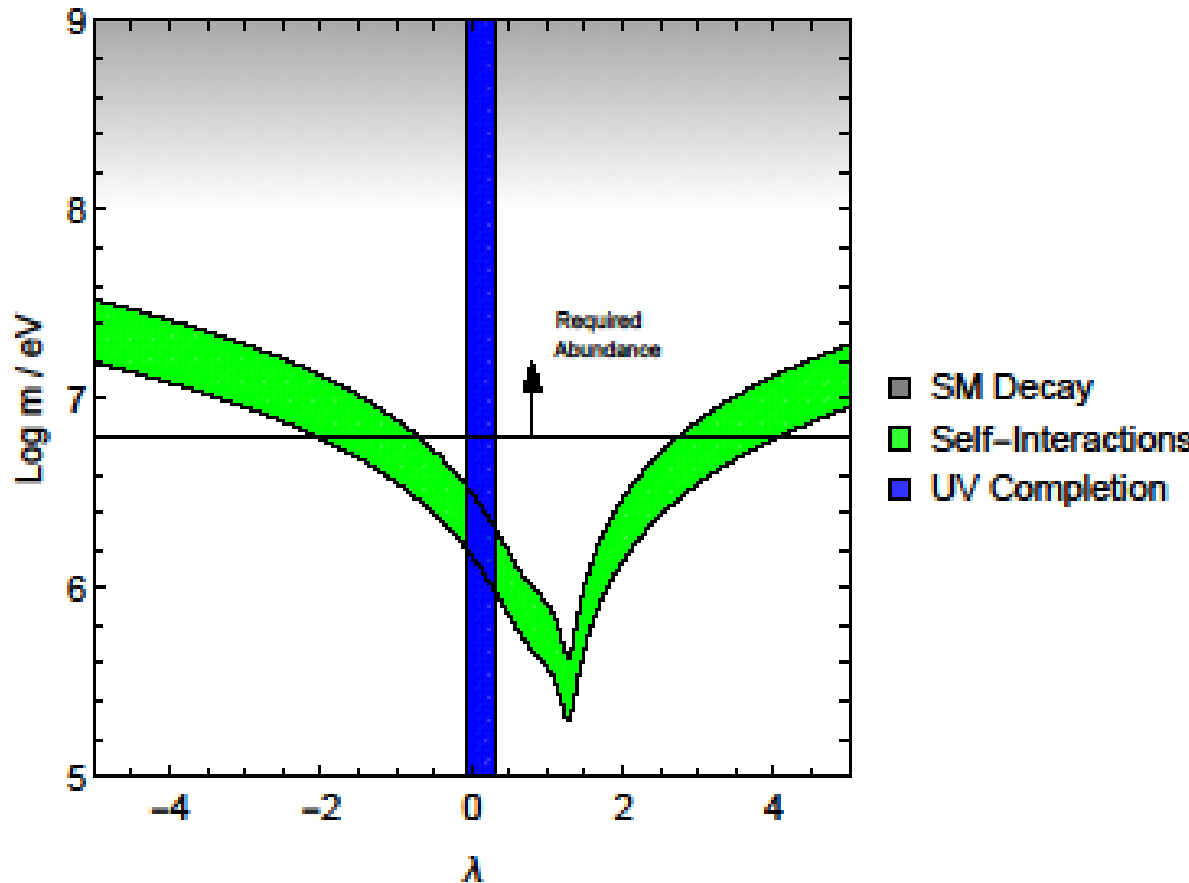
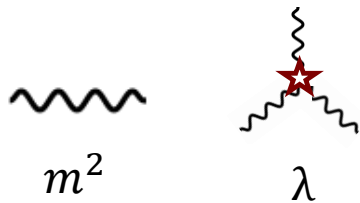
to resolve small
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[1607.03497, 1708.06764]



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[1705.02358]

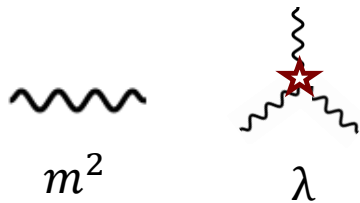
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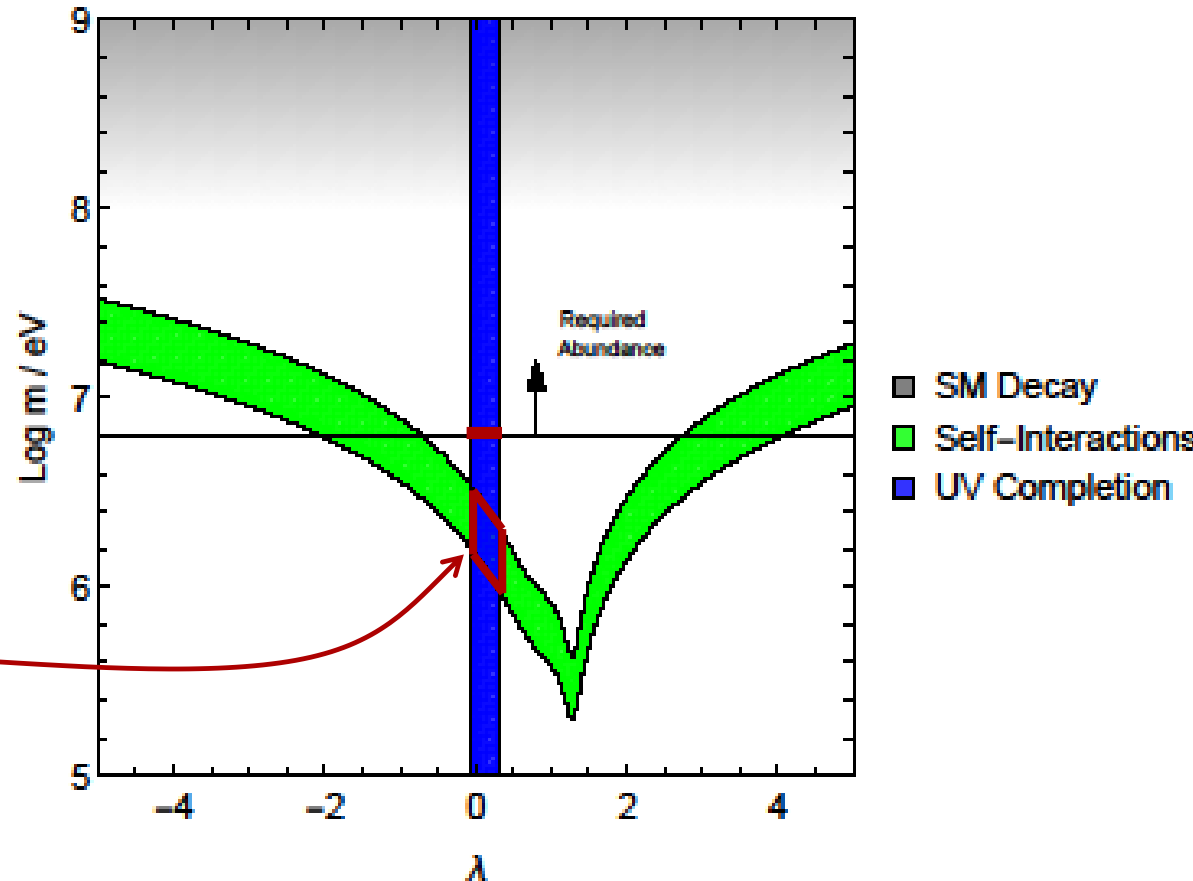
to match observations

Massive Spin-2

[1607.03497, 1708.06764]



Sufficiently self-interacting
spin-2 particle with a
UV completion **cannot**
be dark matter today

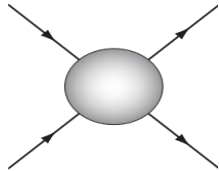


Summary

Only some Effective Fields Theories have UV Completions

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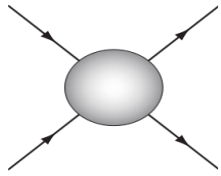


$$\partial_s^a \partial_t^b A_{IR}(s, t; c_n) > 0 \quad \Leftrightarrow \quad A_{UV} \text{ exists}$$

→ Energy

Summary

Only some Effective Fields Theories have UV Completions



$$\partial_s^a \partial_t^b A_{IR}(s, t; c_n) > 0 \quad \Leftrightarrow \quad A_{UV} \text{ exists}$$

→ Energy

to resolve small
scale problems

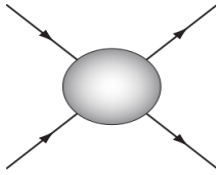
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to match observations

Only some DM Interactions
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Energy

to resolve small scale problems

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