The Pursuit of Ugly Models

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Introduction

High energy physics is changing since we have found no hints of any new physics at the LHC

1. reevaluation of guiding principles and theoretical foundations
2. creative model-building and data analysis

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High energy physics is changing since we have found no hints of any new physics at the LHC

1. reevaluation of guiding principles and theoretical foundations
2. creative model-building and data analysis
3. models being developed and tested are not ideal
   - there is no low-hanging fruit

Introduction

AIMs:

1. The standards of pursuit have shifted in response to the current research context
2. Researchers should pursue models that are:
    2.1 currently testable
    2.2 provide a radically novel approach

Overview

1. Theoretical Virtues and Pursuitworthiness
   - Theory Choice
   - Pursuitworthiness
2. Ugly Models
   - Neutralino DM
   - Relaxion
   - Repulsive Gravity
3. Lessons
   - Context Dependence of Pursuit

Overview

Kuhn (1974)

- Accuracy, Consistency, Simplicity, Scope, Fruitfulness
  - not because they are exhaustive, but "they are individually important and collectively sufficient to indicate what is at stake" (p. 357)
  - meaning and assessment of these criteria are still subjective

Theory choice question:

Which theory to tentatively believe is true, to accept as a piece of established scientific knowledge, etc.?

- epistemic
- about the features a theory should have if it is true

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Pursuit question:

Which empirically underdetermined model to work on, which models are most worthy of further investigation?

- partly epistemic, but mostly pragmatic
- about the features most expedient for short-term progress

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Pursuitworthiness

Shift focus from justification of acceptance → justification of pursuit

- not necessarily about truth or realism
- short timescale decisions
- better justify what is actually worked on

Pursuitworthiness

Explicit distinction traced back to Laudan (1977)

- pursuit can include refining a hypothesis empirically, developing it theoretically by solving conceptual problems, etc.
- one can be justified in working on theories with serious conceptual or empirical problems
  - due to their resources to potentially solve otherwise unsolved problems

Pursuitworthiness

"Scientists need to justify which hypotheses are worth investigating in order to prioritize their resources. Justifying pursuit is, essentially, a decision-theoretic problem of how to optimize the epistemic output of science."

(Nyrup, 2015, p. 753)

Pursuitworthiness

"the decision to pursue an investigation seems to depend on a weighting of at least three factors; the interest of the hypothesis, its plausibility, and it ease of test. . . belief in the truth of a hypothesis or in the experimental results is also not a requirement of further theoretical work."

(Franklin, 1993, p. 106)

Pursuitwortiness

"a hypothesis can act as a stimulus for further work even if one were skeptical of both the hypothesis and the evidence supporting it."

(Franklin, 2016, p. 82)

Pursuitworthiness

"I suggested several reasons why a scientist might choose to further investigate, or to pursue, a hypothesis. These included the interest and importance of the hypothesis; its plausibility, based on existing evidence, on its resemblance to other successful theories, or on its mathematical properties; the fact that it fit in with an ongoing research program; and its ease of test, in which I include the conceptual simplicity of the test, which differs from the technical experimental details of the test, which might be quite complex; and whether or not the experiment can be performed with either existing apparatus or with small modifications of it, or with a relatively modest investment in a new apparatus."

(Franklin, 2016, p. 80)

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- such a disjunction can scarcely be wrong

Pursuitworthiness

"If we estimate that testing the hypothesis will be easy, of potential interest, and informative, then we should give it a high priority"

(McKaughan, 2008, p. 457)

talking about Pierce on the pursuitworthiness aim of abduction and IBE.

- uncontroversial, but how to unpack this?

Pursuitworthiness

Decision theoretic model:

$$\begin{aligned} EEV(p(H)) = {} & EV(a(H)\,\&H)\cdot Pr(a(H)\mid H\,\&p(H))\cdot Pr(H) \\ & + EV(a(H)\ \&\ {\sim}H)\cdot Pr(a(H)\mid {\sim}H\,\&p(H))\cdot Pr({\sim}H) \\ & + EV(r(H)\ \&H)\cdot Pr(r(H)\mid H\,\&p(H))\cdot Pr(H) \\ & + EV(r(H)\ \&\ {\sim}H)\cdot Pr(r(H)\mid {\sim}H\,\&p(H))\cdot Pr({\sim}H). \end{aligned}$$

where $EEV(p(H))$ is the expected epistemic value of pursuing H, based on the probabilities of accepting $a(H)$, rejecting $r(H)$, or remaining agnostic $\neg a(H) \wedge \neg r(H)$, conditionalized on the truth of H

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- entirely epistemic
- does not highlight features that seem to be most important in this context

Ugly Models: Two Examples

1. WIMP Dark Matter: **singlino-like neutralino** model
   - LSP of next-to-minimal supersymmetry
   - Major sin: ad hoc, complex
2. Higgs Naturalness: **relaxion** model
   - axion-like field coupled to inflation
   - Major sin: inconsistent, ad hoc

Overview

Ugly Model: Singlino-like neutralino

How did we get here?

1. Try WIMP DM solution
   - adds light, stable particle
2. Try minimal SUSY—MSSM
   - adds a new superparticle for every SM particle (plus some Higgses)
   - LSP (neutralino) is light and stable, minimal, predictive, LHC-accessible, could solve other problems

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(Abdallah and Khalil, 2016; Badziak et al., 2017)

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   (Abdallah and Khalil, 2016; Badziak et al., 2017)
3. Try next-to-minimal SUSY—NMSSM
   - adds a Higgs singlet, increases singlino and neutralino states, removes the μ-problem

Ugly Model: Singlino-like neutralino

Why ‘ugly’?

- just a step taken in order to accommodate negative data
- less simple, more complex, more calculationally involved
- proposed new non-SM-like Higgses (highly constrained by data)
- resides in tiny parameter space
  - parameter space is scanned numerically, viable ranges of parameter combinations selected
  - 2500 combinations

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  - parameter space is scanned numerically, viable ranges of parameter combinations selected
  - 2500 combinations out of 20 million sampled

(Mou et al., 2018)

- a remote possibility, but that's enough to make it pursuitworthy

Overview

Ugly Model: Relaxion

A class of solutions that involve no new dynamics at the weak scale

- the SM Higgs stays as is
- an axion that couples to the Higgs and an arbitrary inflation sector can create a slow rolling periodic potential that selects a light mass for the Higgs

Ugly Model: Relaxion

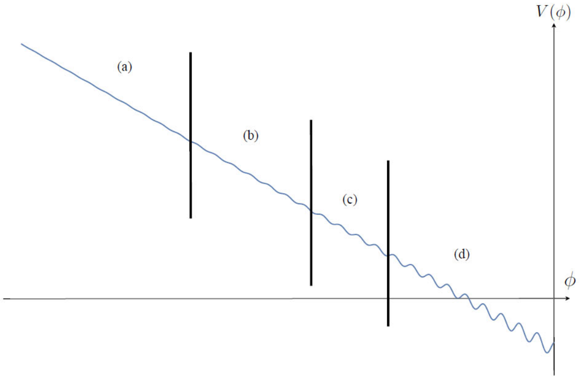

FIG. 2: A close up of the region of ϕ's potential as the barriers appear. The evolution in these regions are (a) classical rolling dominated, (b) dominated by quantum fluctuations in the steps but classical rolling between steps, (c) classically stable, but quantum fluctuations/tunneling rates shorter than N e-folds, and (d) classically stable, quantum transition rates longer than both N e-folds and 10 Gyr. Again, for clarity, the potential is not to scale.

Ugly Model: Relaxion

"During inflation, ϕ will slow-roll, thereby scanning the physical Higgs mass. At some point in the ϕ potential, the quadratic term for the Higgs crosses zero and the Higgs develops a vacuum expectation value. As the Higgs vev grows, the effective heights of the bumps, Λ^4, in the periodic potential grow. When the bumps are large enough they become barriers which stop the rolling of ϕ shortly after m_h^2 crosses zero. This sets the Higgs mass to be naturally much smaller than the cutoff"

(Graham et al., 2015, p. 3)

Ugly Model: Relaxion

Why 'ugly'?

- ad hoc
  - Higgs potential was ad hoc, so here is an explanation of that just-so potential with another just-so potential
- pushed to the fringes of parameter space for the axion-like particle
  - not a true axion (won't solve CP problem)
- inconsistent with cosmological models
  - instead of 40 e-foldings, one needs 10^{40}

Model Choice

Chosen models may be:

- ad hoc
- narrow empirical scope (solving one rather than many problems)
- highly constrained (only possible at edges of parameters spaces)
- fine-tuned, artificially restricted (choosing values just so)
- less simple than alternatives that have been ruled out
- more difficult to calculate than alternatives that have been ruled out
- less detectable than alternatives that have been ruled out
- inconsistent with other models
- not compatible with data in a broader scope

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  - we need to be able to test the model with current apparatus
  - we need to take new approaches
- They do not conform to traditional notions of beauty

Overview

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New Desiderata

What are the features of the most attractive models? What is driving pursuit?
Desiderata:

- represent a class of possible solutions to **a** problem
- immediately and easily testable
- novel, but like really new

New Desiderata

Testability

- makes clear predictions, achievable energies, already in existing data, makes use of existing facilities
- some models are being pursued for almost no other reason than that they can be easily tested
  - Repulsive Gravity

Novelty

- traditional model building has not been creative enough, radically new approaches are needed
- relaxion would never have been proposed 20 years ago
  - what is pursuitworthy changes

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Now, these are essentially sufficient conditions for pursuit

Conclusions

- There is a change of virtues and a shift in standards
- It is the research context that determines what is most worthy of pursuit
  - A static epistemic model (Nyrup) does not capture this

These models are pursuitworthy, but they don't exemplify many epistemic virtues

Thank you

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