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ORIGINAL ARTICLE

An Argument for the Extrinsic Grounding of Mass

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Abstract Several philosophers of science and metaphysicians claim that the dispositional properties of fundamental particles, such as the mass, charge, and spin of electrons, are ungrounded in any further properties. It is assumed by those making this argument that such properties are intrinsic, and thus if they are grounded at all they must be grounded intrinsically. However, this paper advances an argument, with one empirical premise and one metaphysical premise, for the claim that mass is extrinsically grounded and is thus an extrinsic disposition. Although the argument concerns mass characterized as a disposition, it applies equally well whether mass is a categorical or dispositional property; however, the dispositional nature of mass is relevant to some important objections and implications discussed.

1 Introduction

Any instance of a dispositional property seems grounded in some further property of the object bearing the disposition. For example, the micro-structural property of a vase appears to ground the fragility of the vase. The grounding property serves as the causal basis for fragility manifesting when triggered in the appropriate circumstances, and also grounds the continuous instantiation of that token of the property of fragility when it is not manifesting (i.e., when the vase is not breaking). According to one theory, dispositions are identical to their categorical grounding properties, thus an instance of fragility is identical to the vase's micro-structural property.[1] On another theory, dispositions are realized by but not identical to

[1] For example, Heil (2003, p. 111) maintains this view.

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categorical properties, thus an instance of fragility is realized by the vase's micro-structural property.[2]

Both theories presuppose that instances of dispositions continuously exist during non-manifesting periods because they are grounded. Are ungrounded dispositions possible? Stephen Mumford (2006, pp. 471–480), George Molnar (2003, pp. 131–137), and Brian Ellis (2001, pp. 114–115) argue that instances of mass, charge, and spin of fundamental particles exemplify ungrounded dispositions.

This paper challenges the claim that tokens of mass of fundamental particles are intrinsic, ungrounded dispositions. I argue that mass is an extrinsic property, and specifically that mass is grounded extrinsically in the Higgs field,[3] a scalar field posited by the Standard Model of physics. This thesis negates a core assumption made by proponents of ungrounded dispositions that properties of fundamental particles are intrinsic. Although my argument concerns mass characterized as a disposition, it applies equally well whether mass is a categorical or dispositional property; however, developing the argument the way I do clarifies some important implications that I will address.

I proceed as follows. Section 2 explains key definitions required throughout the paper. Section 3 more precisely states my thesis and the thesis my argument challenges. Section 4 develops the argument from the Higgs field, containing one empirical premise (that the Higgs field grounds the mass of fundamental particles) and one metaphysical premise (that the relation between the Higgs field and fundamental particles fits a plausible notion of extrinsicness and extrinsic grounding). Section 5 discusses three important objections to the argument. Section 6 discusses three implications of the argument, including a discussion of the relationship between my main claim and the conception of ultra-grounding advanced by Rom Harré (1986). Section 7 offers concluding remarks.

2 Grounding: Intrinsic and Extrinsic

The first definition is that, for any disposition token, F:

> *Grounds of* $F =_{df}$ that property or property-complex, G, distinct from F upon which F ontologically depends for its continuous existence (or, being).[4]

The intuitive idea is that the grounding properties of F are those that, if eliminated, would result in the simultaneous elimination of F as well.[5] It must be simultaneous otherwise the relation might be a causal relation, not one of ontological dependence.

[2] For example, Prior et al. (1982) maintain this view.

[3] The Higgs field is named after Peter Higgs, who first posited its existence.

[4] Thanks to two anonymous reviewers for helping me refine my definition of 'grounding' and other definitions.

[5] Supposing that F is multiply realizable, such that F could have several distinct, complete grounds, then the very same F could gain another grounds upon losing the original grounds. So it should be added that if the all of the possible multiply realizing grounding properties of F are eliminated, this would result in the elimination of F (Thanks very much to an anonymous reviewer for pointing out the possibility of the multiple realization of F).

Furthermore, *G* must be distinct from *F* otherwise every property is grounded in itself, or "self-grounded" (Mumford 2006, p. 486), which just means that it is ungrounded in distinct properties and sufficient for its own being. The definition above applies straightforwardly to properties in general, but as I apply it to dispositions *G* accounts for *F*'s continuous existence during non-manifestation periods (e.g., the micro-structural properties of a vase account for the vase's fragility when not manifesting). Additionally, if *G* is not a single property but a property-complex, i.e., a set of two or more properties distinct from *F*, then each property in the complex constitutes a partial ground of *F*.

If *F* is grounded, then *G* is instantiated *either* (1) solely by the object, *a*, bearing *F* (e.g., for a fragile vase, V, *G* is instantiated solely by V), *or* (2) collectively by *a* and some other object(s) or the environment *a* inhabits. Thus, *F* can have partial grounds in multiple, distinct properties, some of which may not be intrinsic properties of the object that bears *F*. This suggests that *F* may not be an intrinsic property because *G* is not intrinsic to the object bearing *F*. I address this possibility in further detail below after discussing the intrinsic/extrinsic distinction, in developing two conceptions of grounding.[6]

'Grounds of *F*' is often used synonymously with 'causal basis of *F*' in discussion of dispositions, but I have three reasons for using the former term. First, Mumford (2006, p. 479) and Molnar (2003, p. 131) use the term 'grounds'.[7] Second, 'grounds of *F*' highlights the notion of what *F* ontologically depends upon, whereas 'causal basis of *F*' highlights the notion of what is causally relevant to *F*'s manifestation in the appropriate circumstances, not necessarily what *F*'s continuous instantiation depends on. Third, it is possible that *F*, of object *a*, might be partially grounded in properties of some object *b* or environment *e* that does not bear *F*, yet properties of *b* or *e* are not causally relevant to the manifestation of *F*, such that they do not form a causal basis for *F*. Thus, the notions of grounds and causal basis may come apart in the case of some dispositions.[8]

Moving to the intrinsic/extrinsic distinction, I take the following claim offered by Molnar (2003, p. 39) as fundamentally correct: "the deepest intuition concerning 'intrinsic' is that the intrinsic properties are those the having of which by an object in no way depends on what other objects exist." This echoes Michael Dunn's (1990, p. 178) intuitive characterization that "Metaphysically, an *intrinsic* property of an object is a property that the object has by virtue of itself, depending on no other thing." These characterizations imply that an extrinsic property of an object is one that depends on the existence of another object or objects, or a specific environment.

[6] The supervenience relation may be thought to be the same relation as that of grounding, but this is not the case. Assume a standard conception of supervenience, following Davidson (1970): (1) no two things are alike in all *B* respects but differ in some *A* respect, and (2) nothing alters in an *A* respect without altering in some *B* respect, hence *A* properties supervene on *B* properties. Supervenience may suggest, but does not entail, that one property is the grounds of another. For, two otherwise unrelated properties, on opposite sides of the universe, may share a supervenient relationship if they co-vary according to conditions (1) and (2).

[7] Every contention Mumford and Molnar make, to my knowledge, seems consistent with 'grounds' being synonymous with 'casual basis'.

[8] Handfield (2008, p. 298) distinguishes between the supervenience base of a disposition and the causal basis for the manifestation of a disposition, similar to my distinction between grounds and causal basis.

Thus, for a disposition token F (or, any property token), objects a and b, and environment e, I assume the following definitions:

F is intrinsic $=_{df}$ object a's instantiating F is ontologically independent of any properties either of another distinct, existent object b non-overlapping with a, or of a's environment e.
F is extrinsic $=_{df}$ object a's instantiating F ontologically depends on some property or property-complex of a distinct, existent object b or of a's environment e.

The definitions require that a, b, and e, are distinct from each other, such that the existence of the objects (and the environment) are independent of each other. I intend only for these definitions to capture a range of platitudes about intrinsic and extrinsic properties; moreover, I assume for my purposes in this paper that they are consistent with the duplication conception of intrinsic properties, advanced by Rae Langton and David Lewis (1998, p. 337).[9]

The three definitions established thus far imply supplementary notions of property grounding. Putting the intrinsic/extrinsic distinction and the notion of grounding together, if F is intrinsic *and* grounded, then F is intrinsically grounded; and, if F is extrinsic *and* grounded, then F is extrinsically grounded. If F is grounded in other properties, then whether F is intrinsically or extrinsically grounded turns on what objects F's grounding properties belong to. An intrinsically grounded property is ontologically grounded solely in some property or property-complex of the object bearing it; and an extrinsically grounded property is partially ontologically grounded in a property or property-complex of the environment or of some object(s) other than the object bearing the property in question. So I will use these definitions:

F is intrinsically grounded $=_{df}$ F, an intrinsic property borne by object a, is ontologically dependent solely on some intrinsic property or property-complex, distinct from F, of a.
F is extrinsically grounded $=_{df}$ F, an extrinsic property borne by object a, is partially ontologically dependent on some other property or property-complex, G, not possessed by a.

Notice that F cannot be fully intrinsically grounded without also being an intrinsic property token of a. However, if F, instantiated by a, depends on a property token not borne by a, then F is an extrinsic property and also extrinsically grounded (because it is partially grounded in properties not borne by a). In other words, the fact of F being an extrinsic property token, of a, requires ontological dependence on a non-F property not borne by a. In sum, being extrinsic and extrinsically grounded

[9] Langton and Lewis (1998, p. 337) hold that "a property is *intrinsic* iff it never can differ between duplicates; iff whenever two things (actual or possible) are duplicates, either both of them have the property or both of them lack it." To relate this to my definition: if an object x that is duplicated in a world where x is the sole occupant, then x will have instances of the same type of properties as the original object in the actual world; intuitively this is because x's having those properties does not depend on any properties of distinct, existent objects, per my definition.

comes as a package deal, whereas being intrinsic and intrinsically grounded does not.[10]

The above notions of grounding, extrinsicness, and extrinsic grounding suggest a useful, straightforward test, which I will call the 'E-grounding test', for whether a property token should be considered extrinsic. The E-grounding test is this: if it is found that F is instantiated only when G is simultaneously present and F ceases to be instantiated when G ceases to be instantiated, where G is not instantiated solely by the object bearing F (recall that if G is a property-complex, *part* of the complex might be instantiated by the object bearing F), then it appears that F is extrinsically grounded and is thus an extrinsic property. Additionally, we can adopt the duplication test (Langton and Lewis 1998, p. 337) for whether a property is intrinsic: if F is intrinsic, then any duplicate of the object bearing F, regardless of its environment or relation to other objects, will have F. That is, in all the possible worlds in which a perfect duplicate of the object exists, the object possesses F. If a property fails to pass the duplication test, this implies that it is extrinsic (and thus also extrinsically grounded). I employ the E-grounding test and duplication tests in defending the argument from the Higgs field that mass is extrinsically grounded.

Given the notion of extrinsic grounding, we can now distinguish between two types of extrinsic grounding (and thus two ways a property may be extrinsic), each indicating a sufficient condition for the obtaining of extrinsicness. The first kind is:

[10] It should help, as an anonymous referee kindly pointed out to me, to explicitly set out which combinations of intrinsic/extrinsic and intrinsically grounded/extrinsically grounded work and which do not work:

1. Extrinsic and extrinsically grounded: This is possible, and it appears that if F is an extrinsic token property then it is necessarily extrinsically grounded (more on this later in the footnote).

2. Extrinsic and (fully) intrinsically grounded: This does not seem possible, because if F is extrinsic, then it will be dependent on some properties not instantiated by the object possessing F (though F might still be partially intrinsically grounded).

3. Intrinsic and intrinsically grounded: This is possible, though the claim that F's being intrinsic necessarily requires intrinsic grounds is clearly denied by proponents of the Ungrounded Dispositions Thesis (see Sect. 3 of this paper).

4. Intrinsic and extrinsically grounded: This does not seem possible, for it violates the independence requirement for being an intrinsic property token.

The same anonymous reviewer further remarks that it is an odd logical implication that, per the conceptions I advance, being extrinsic entails being extrinsically grounded (whereas being intrinsic and intrinsically grounded are logically independent, notably if fundamental properties are intrinsic but ungrounded). The reviewer gives the following example: the property of *being a parent*, P, is extrinsic, since to be instantiated it requires a child. But is P grounded partially (and thus extrinsically) in that child? Perhaps not, since parenthood is a relation between parent and child, but not grounded in them; it doesn't depend, for instance, on any microstructures of the parent and child, the reviewer suggests. My response is twofold. First, while interesting, this may not matter to my main argument. All I really need is the implication to go the other way: a property token, F, being extrinsically grounded entails that F is extrinsic, such that, if mass is extrinsically grounded, then mass is extrinsic (and this is how I defend premise two of my main argument in Sect. 3). Second, it seems equally plausible to me that, strictly speaking, P does indeed require an existent child, and so P is extrinsically grounded. Why? If someone's child (or children) no longer exists, then the property he or she instantiates is *being a former parent*, not *being a parent*. The person *was* a parent, but no longer is. This may seem a bit unpalatable, but it's not wildly counter-intuitive. Compare the idea that when a woman's husband no longer exists, she ceases to be a wife and becomes a widow—she ceases to instantiate the property of being a wife and begins instantiating the property of being a widow. (Thanks to the anonymous referee who prompted this entire footnote.).

Extrinsic grounding [object] $=_{df}$ *F*, an extrinsic property of *a*, is grounded at least partially in some property or property-complex of another object *b* (or multiple objects *b*, *c*…).

Traditional relational properties meet this condition: e.g., object *a* has the property, *T*, of being twenty feet from object *b*. *T* is grounded not just in *a*'s location but also in *b*'s location, so *T*'s existence depends on a property not belonging to *a*. For a dispositional property, take the example of a key offered by Jennifer McKitrick (2003a, p. 159): a key's disposition, *D*, to open a door, *x*, depends on the nature of the lock in *x*. If the key fits the lock, then the key has *D*; change the lock in *x*, and now the key does not have *D*. Thus, *D* is an extrinsic disposition and *D* is extrinsically grounded [object].

The other important sense of extrinsic grounding, and the one directly relevant to the argument of Sect. 4, involves the environment inhabited by the object bearing *F*:

Extrinsic grounding [environment] $=_{df}$ *F*, an extrinsic property of object *a*, is grounded at least partially in some property or property-complex of the environment *e* inhabited by *a*.

This is the most important notion for the argument from the Higgs field in Sect. 4. McKitrick (2003a, pp. 159–160) and Stephen Yablo (1999, p. 611) offer the disposition weight as an example of an extrinsic disposition. The weight of an object *a* varies depending on the strength of the gravitational field inhabited by *a*. Moreover, intrinsic duplicates would differ in weight in different gravitational fields. Since a gravitational field is something which an object inhabits, I suggest that it is plausibly considered part of *a*'s total environment (not just something in *a*'s environment, as with another object), and thus properties of it are environmental properties relative to *a*. Thus, the weight of *a* is extrinsically grounded [environment]. I will reference this example in elaborating the argument from the Higgs field in Sect. 4.

3 Ungrounded Dispositions and the Intrinsic Assumption

Mumford (2006, pp. 471–480), Molnar (2003, pp. 131–137), and Ellis (2001, pp. 114–115) support the Ungrounded Dispositions Thesis[11]:

UDT: (a) Fundamental particles, e.g., electrons, possess ungrounded dispositions, and (b)(1) mass, (2) charge, and (3) spin of fundamental particles exemplify ungrounded dispositions.[12]

[11] The main argument for UDT, what I call the Argument from Physics, is roughly this: (i) properties of fundamental particles are dispositions; (ii) fundamental particles are metaphysically simple, containing no micro-components and thus no properties of micro-components that could ground their dispositions; thus, (iii) the dispositions of fundamental particles are not grounded in any distinct properties, although they endure through non-manifestation periods. Mumford (2006) presents the Ungrounded Argument, a fully developed and explicit formulation of the argument for ungrounded dispositions based on physics; see Williams (2009) for a critique.

[12] Thanks to an anonymous reviewer for suggesting formulating UDT with two sub-claims, and for also pointing out that some dispositions of fundamental particles are arguably not fundamental properties, e.g., the charge-to-mass ratio of fundamental particles is non-fundamental because it depends on mass and

UDT challenges the Global Groundedness Thesis that all dispositions are grounded, as advanced by Elizabeth Prior et al. (1982).

Are properties of fundamental particles really *dispositions*? Mumford (2006, p. 476) cites Alan Isaacs (2000) as identifying such properties as dispositional and giving them disposition-laden definitions. Ellis (2002, p. 47) and C. B. Martin (1993, p. 184) argue that such properties are dispositional. Also, these properties satisfy typical characteristics of dispositions, e.g., they have manifestations and counterfactuals are true of them.[13] Thus, I will assume that mass, charge, and spin are indeed dispositions.[14]

In arguing for UDT, supporters presuppose the following significant and intuitively plausible claim:

> *Intrinsic Assumption*: Any disposition, F, of a fundamental particle, a, is an intrinsic property of a, and therefore *if* F is grounded, then it is intrinsically grounded by some non-F property of a.

Molnar (2003, pp. 102–107) argues for the intrinsicness of all dispositions, and he separately argues against extrinsic dispositions (Molnar 2003, pp. 108–110). Ellis (2001, p. 31) seems to accept the intrinsicness of dispositions of fundamental particles, since he thinks the real essences of objects (which presumably include fundamental particles) are defined in terms of their intrinsic properties. Additionally, Ellis (2001, p. 28) specifically accepts the intrinsicness of mass, although he thinks this is not an a priori truth because we should let physical theory guide our

Footnote 12 continued
charge. Proponents of UDT cite what appear to be fundamental properties (mass, charge, spin) as examples of ungrounded dispositions. It is an implication of my argument in this paper that mass is not fundamental, but the disposition of particle a to gain mass may be fundamental. I discuss this further in Sects. 4, 5, and 6.

[13] Here it is useful to refer to the marks of being a disposition, discussed by McKitrick (2003a, p. 157), which are prevalent throughout the literature on dispositions as McKitrick (2003a, pp. 156–157) notes. The marks of being a dispositional property, where D is a disposition, are: (1) D has a characteristic manifestation when appropriately stimulated; (2) D requires triggering or activation in the appropriate circumstances; (3) a counterfactual statement typically holds true of the object, x, bearing D; (4) an overtly dispositional locution holds true of x. These marks are not definitive; they are simply indicators of being a disposition, or useful ways of identifying dispositions. We can apply these indicators of being a disposition to the mass of an electron, for example, concluding that mass is probably a disposition: (1) a characteristic manifestation of mass is the resistance of acceleration when an acceleration force is applied to the object bearing mass, (2) the manifestation of mass requires triggering by an acceleration force (3) 'if an electron were pushed, it would resist acceleration' is true of electrons, and (4) electrons are said to have the tendency (i.e., disposition) to resist acceleration.

[14] It is possible that properties of fundamental particles are categorical, but my main argument aims to show that mass is extrinsically grounded whether it is categorical or dispositional. I frame my critique of UDT in terms of dispositions primarily because (1) the principal proponents of UDT categorize properties of fundamental particles that way, (2) mass does seem to be dispositional (see, e.g., Ellis 2002, p. 47; Isaacs 2000), and (3) in two of the implications I discuss the dispositional nature of mass plays an important role.

understanding of which properties are intrinsic v. extrinsic (which is exactly what I do, regarding mass, in this paper). Finally, Mumford (2006, pp. 479–480) gives this formulation of the Intrinsic Assumption: "The grounds of a dispositional property can be found only among the lower-level components or properties of that of which it is a property." Grounding in lower levels is equivalent to micro-grounding (a kind of intrinsic grounding), because by "lower-level" of an object, x, Mumford means components spatiotemporally contained by x (that could ground properties), or properties of x that could serve as the supervenience base for grounding further properties. This implies that an object, x, having a lower-level l, has l intrinsically. If there are grounds for F, then necessarily these grounds are components or properties of x, and not dependent on other objects or anything beyond x itself. Thus, like Molnar and Ellis, Mumford advocates the Intrinsic Assumption. While these philosophers accept the Intrinsic Assumption, they do not think that such dispositions of fundamental particles are *intrinsically grounded* in any further properties of the particles bearing the dispositions (per the definitions of Sect. 2). Hence, this is why they accept UDT.

I challenge the Intrinsic Assumption and thus UDT by arguing that mass is an extrinsic property of fundamental particles, and specifically that mass is extrinsically grounded [environment]. While proponents of UDT cite the properties listed in UDT(b), I argue that UDT(b)(1) is false, thus negating the Intrinsic Assumption. The argument may only show that one disposition of fundamental particles is grounded, but this claim should not be understated. By highlighting the possibility of extrinsic grounding, the argument from the Higgs field raises a specter of doubt about UDT(b)(2), (b)(3), and thus UDT(a).

To further emphasize the importance of my thesis, note that Alexander Bird (2007, p. 30) observes that the examples of extrinsic (and thus extrinsically grounded) dispositions offered by McKitrick (2003a), such as weight discussed in Sect. 2, all involve so-called abundant properties but not sparse properties such as mass.[15] So, her case for the extrinsic dispositions thesis (that some dispositions are extrinsic) only negates a restricted version of the intrinsic dispositions thesis (that all dispositions are intrinsic), limited to abundant properties. By contrast, if my thesis is correct then a more inclusive version of the intrinsic dispositions thesis is false, since mass appears to be a good candidate for a sparse disposition. While weight seems like an abundant disposition, Bird (2007, p. 30) offers that "it is tempting to regard mass as the real and natural property" and therefore the sparse property, implying that while weight may be extrinsic mass remains intrinsic. I suggest otherwise.

[15] Lewis (1986, p. 59) distinguishes sparse properties from abundant properties. The sparse properties are the natural properties, those typically discovered and discussed by various sciences, especially fundamental physical properties. The abundant properties are non-natural properties, including all sorts of disjunctive properties.

4 The Argument from the Higgs Field

The argument from the Higgs field concludes that all instances of the disposition mass of fundamental particles are extrinsically grounded [environment].[16,17] I use the term 'mass', but given Einstein's equivalence principle the argument is relevant to both inertial mass and gravitational mass. I address this more in Sect. 5, since it seems that the Higgs field is only clearly relevant to inertial mass.

The argument contains two premises. The empirical premise issues from the Standard Model of physics, upon which testable empirical predictions are made concerning the nature of fundamental particles. The metaphysical premise invokes the notion of extrinsic grounding [environment] defined in Sect. 2. I will defend and explain each premise upon introducing it. Here is the first premise:

(1) The disposition *mass* of any fundamental particle, *a*, is generated by *a*'s immersion in the Higgs field.

The Standard Model of physics assumes the existence of the Higgs field, a scalar field that "permeates all of space" and "endows particles with mass" (Max Jammer 2000, p. 162). The Higgs field explains why particles resist acceleration: "mass is not 'generated' in the particle by a miraculous *creatio ex nihilo*," rather it is "transferred to the particle from the Higgs field, which contained it in the form of energy" (Jammer 2000, p. 163). The energy in the Higgs field gives all the particles immersed in it a mass value, which will differ between kinds of particles.

Since particles must be situated in the Higgs field in order to obtain mass, it is reasonable to conclude that some property or property-complex of the Higgs field, call this F_H, is necessary for a given particle, *a*, to gain and thus possess mass. F_H is not the only property of the Higgs field, for it is plausible to categorize the Higgs field as a particular that possesses a set of properties; e.g., it is coextensive with spacetime, it is disposed to give particles mass (this is F_H), and it is characterized by various mathematical equations.[18]

Besides F_H, it is also necessary that some property of *a*, call this F_m, disposes particle *a* to gain mass while immersed in the Higgs field. Per the Standard Model, all of the known fundamental particles, except photons,[19] acquire potential energy and thus acquire a certain mass, in accordance with the mass-energy relation (Jammer 2000, p. 162).[20] A stronger interaction between a particle and the Higgs

[16] According to Haisch et al. (2001, p. 393), when we detect the Higgs boson (the particle constituent of the Higgs field) a legitimate question concerning "whether the inertia of matter as a reaction force opposing acceleration is an intrinsic or extrinsic property of matter" will remain. My argument aims to show that the Higgs field-particle relation implies that mass is extrinsic and extrinsically grounded.

[17] Psillos (2006, pp. 153–154) briefly discusses the Higgs boson in drawing attention to the inconclusiveness of theoretical physics regarding the question of whether fundamental dispositions are grounded or not. Psillos, however, does not specifically argue for the extrinsic grounding of mass as I do.

[18] See Peskin and Schroeder (1995, pp. 781–800), and Zee (2003), for the mathematics of the Higgs field.

[19] Photons are mass-less since they move through the Higgs field "completely unhindered" (Greene 2004, p. 263).

[20] In accordance with Einstein's equation, $E = mc^2$, a "store of energy can be thought of as a source of inertial mass" just as "inertial mass can be thought of as a store of energy" (Jammer 2000, p. 163, footnote 51).

field yields a more massive particle. With the introduction of F_m, an important issue arises: if my argument is sound (with the metaphysical premise remaining to be explained), then UDT proponents can simply replace mass with F_m in UDT (b)(1). I will fully address this objection in Sect. 5, but for now I note the following: although this may preserve a modified UDT, it does not minimize the importance of the conclusion that *mass*, a sparse property traditionally assumed to be intrinsic, is extrinsic.

My explanation of premise (1) established the relevance of the Higgs field, and specifically F_H, to the instantiation of mass in fundamental particles. My explanation and defense of premise (2) next will shed further light on premise (1). Moving to the second premise:

> (2) The nature of the relation between a fundamental particle, a, and the Higgs field meets the conditions of extrinsic grounding [environment].

Examining this premise is crucial for the claim that mass is an extrinsic property of a grounded in F_m and F_H, and not simply an intrinsic property of a.

The leading idea behind premise (2) is that a's possessing mass ontologically depends upon a property of the environment inhabited by a. The Higgs field is a part of the environment of a and exists independently of a. Since it appears true that if a were not immersed in the Higgs field a would be mass-less, and if a were removed from the Higgs field (or the Higgs field vanished) it would immediately lose mass, then F_H (the relevant property of the Higgs field) is a partial ground, along with F_m (the relevant property of a) of mass. Collectively, F_H and F_m constitute a property-complex, G, necessary and sufficient for a instantiating mass.

To help further explain the relationship between a particle and the Higgs field, and defend the claim that mass counts as being extrinsically grounded [environment], I will discuss three analogies that have been offered by others. Jammer (2000, p. 163) offers an analogy formed by Martinus J. G. Veltman (1986) to help explain the nature of this relation:

> The way particles are thought to acquire mass in their interactions with the Higgs field is somewhat analogous to the way pieces of blotting paper absorb ink. In such an analogy the pieces of paper represent individual particles and the ink represents energy, or mass. Just as pieces of paper of different size and thickness soak up varying amounts of ink, different particles "soak up" varying amounts of energy or mass. The observed mass of a particle depends on the particle's "energy absorbing" ability, and on the strength of the Higgs field in space.

To clarify this analogy, imagine that the ink field permeates all of spacetime, thus the pieces of paper are always actually immersed in the field. The paper pieces, regardless of their size or thickness, become fully soaked with ink up to the point of their individual capacities. What being fully soaked means is relative to the size and thickness of the piece of paper, and this parallels the idea that each kind of particle gains a different amount of energy (and thus mass) from the Higgs field, relative to the kind of particle in question. Although the analogy does suggest the general point that whether a possesses the disposition mass depends on a's being immersed in the

Higgs field and thus on F_H, the phrase "soak up" in the analogy may indicate a causal process between the Higgs field and particle a, not necessarily one of grounding.

Recall the claim that the weight of some object, x, is extrinsically grounded [environment] in the relevant property of a gravitational field. In this case, the mere co-existence of the gravitational field with x makes a property-difference in x. Yet, though this seems clearly like a case of an extrinsic disposition as McKitrick (2003a, pp. 159–160) and Yablo (1999, p. 611) maintain, it is not implausible to also characterize this situation as the gravitational field causing x to gain a weight disposition. But the 'causing' happens with immediacy. The nature of the relation in this case is not one of typical causal interaction, like causing an object to have a different shape.

While the ink analogy nicely captures the idea that different particles will gain different masses, two further analogies capture the idea that it is a's existing in the mere presence of the Higgs field that immediately gives a mass. Gordan Kane (2003, p. 74) suggests that the way particles interact with the Higgs field is similar to the resistance people will experience when wading through water. Brian Greene (2004, p. 261) imagines a particle's resistance to the Higgs field akin to how "a vat of molasses resists the motion of a Ping-Pong ball that's been submerged" in the molasses. It must be emphasized that in these two analogies it is not the actual, manifested resistance (experienced by the person and by the Ping-Pong ball) that represents mass, rather it is the disposition to experience that resistance that is mass. It is when there is something in the environment of the object (the person, or the Ping-Pong ball) to actually resist its motion that the object can be correctly said to have the disposition to resist; when it is actually experiencing resistance then its disposition to resist is manifested. Otherwise, when the appropriate environment does not obtain, the object merely has the disposition to gain the disposition to resist. Similarly, x can gain the disposition of having a certain weight when x is present in a gravitational field, but otherwise x merely has the disposition to gain the disposition weight (and that is a different disposition). Thus, regarding mass, it is particle a's existing in the mere presence of the Higgs field that makes it true that a has the disposition mass. If a force is actually applied to a while in the Higgs field, then a manifests its disposition mass.

It is the property F_H exerting its influence on a, thus activating F_m, such that a gains mass.[21] Similarly, x existing in a certain gravitational field activates x's disposition to gain a specific weight. I suggest that if weight counts as extrinsically grounded [environment] due to the necessity of an object being situated in a gravitational field in order to have a specific weight, then this enhances the plausibility that mass is extrinsically grounded [environment] due to the necessity of a particle being situated in the Higgs field. If weight counts, then mass counts.

The conclusion I want to draw at this point is that, so long as a, bearing F_m, exists in the presence of F_H, a can correctly be said to have the further disposition mass. Applying the E-grounding test formulated in Sect. 2, it appears that the mass of a is

[21] This is a different sense of 'activate' than is typically used in discussing the triggering of dispositions, such as the triggering of fragility, but this seems due to the fact that we are discussing the gaining of further dispositions.

instantiated only when a is in the presence of F_H in a's environment, and a would cease to possess mass if F_H were to cease to be instantiated; thus, mass is extrinsically grounded [environment].

To clarify further the metaphysical nature of the particle-Higgs field interaction, in terms of the F_m-F_H relation, particle a has a disposition F_m to interact with the Higgs field. F_m might be intrinsic to a, but it alone is not sufficient grounds for a's having mass; F_m is a disposition to gain the disposition mass. F_m is triggered when a is immersed in the Higgs field, entering the proper relation to F_H, and thus a gains mass. However, a's immersion in the Higgs field does not mean it continuously manifests mass, since the manifestation of mass further requires a triggering event itself (e.g., the acceleration of a). The immersion is just what gives a mass, which a manifests when subject to an acceleration force.

Note that the general relation between the F_H and F_m does not determine the *particular* mass of a. Rather, it determines *that* particle a possesses some mass given how a moves through the Higgs field; this is supported by Jammer (2000, p. 163) and Greene (2004, p. 262). The manner in which a particle moves through the Higgs field depends on additional properties borne by particular types of particles. If a given particle had the disposition to interact with the Higgs field differently than it actually does, because of a different set of properties besides F_m, then it would have a different mass; but, it would still have some mass value.

Empirical research will further reveal the nature of the Higgs field. But I have attempted to give a plausible metaphysical description consistent with the stated analogies and based on plausible definitions, of how F_H and F_m constitute a grounding base for mass. Given premises (1) and (2), this conclusion follows:

(3) Thus, the mass of fundamental particles is extrinsically grounded [environment]. [From (1) and (2)]

This directly challenges the Intrinsic Assumption and UDT(b)(i), by establishing that at least one disposition, mass, of fundamental particles is extrinsically grounded. This conclusion exemplifies the more general thesis that a disposition, F, of a fundamental particle, a, may be grounded either in a property or property-complex of another object, b, distinct from a, or in a property or property-complex of a's environment, hence F is not intrinsic to a.

Another way to formulate the argument involves employing McKitrick's (2003a, p. 155) conception of extrinsic dispositions, according to which two qualitatively identical objects, x and x_1, can differ with respect to having dispositions when x and x_1 are located in different environments, even if the laws of nature are fixed.[22] Applying this notion of extrinsicness to the case of mass, suppose object x is located in an environment with the Higgs field, and object x_1 is not so located. Object x will have mass, and object x_1 will not. Thus, mass is an extrinsic disposition, and thus mass is extrinsically grounded [environment].[23] The upshot of this reasoning is that

[22] Some supporters of the intrinsic dispositions thesis (that all dispositions are intrinsic) think that perfect duplicates subject to different laws of nature could have different dispositions (e.g., Lewis 1997).

[23] Does the Higgs field's capacity to ground mass in particles require the laws of nature to be a certain way? It seems not. The Higgs field may have had a different value if the laws of nature were different (if, for instance, events at the beginning of the universe were different), yet the Higgs field would still have

mass does not meet the duplication condition of intrinsic properties formulated by Langton and Lewis (1998, p. 337). For, all the possible worlds in which a perfect duplicate of *a* exists, *a* does not possess mass. In worlds sans the Higgs field, *a* may possess F_m but not mass.

I will now discuss three important objections to, and three important implications of, the argument from the Higgs field.

5 Objections and Replies

One objection, mentioned at the start of Sect. 4, is that the Higgs field is only relevant to inertial mass. To clarify, there is inertial mass and gravitational mass. Inertial mass is the property by which a particle resists acceleration. Gravitational mass comes in two varieties: the capacity to be acted upon by a gravitational field of a specified strength, i.e., passive gravitational mass, and the capacity to generate a gravitational field, i.e., active gravitational mass.[24] It appears that the Higgs field only implies the extrinsic grounding of inertial mass, since the interaction between particles and the Higgs field involves the acceleration of particles through the Higgs field. If so, then the argument from the Higgs field shows nothing new, because as Bird (2007, p. 125) notes, according to the special theory of relativity inertial mass is extrinsic while nobody "has suggested that charge, rest mass, and spin are not intrinsic." (By 'rest mass' I assume is meant gravitational mass.)

In response to the first objection, according to Einstein's equivalence principle inertial mass and passive gravitational mass are physically (though not logically) indistinguishable and thus equivalent. Given that "the equivalence principle of general relativity asserts that the force felt from accelerated motion and from a gravitational field are indistinguishable," Greene (2004, p. 518), distinguishing between gravitational mass in general and inertial mass, thus concludes that "the Higgs field is relevant for both kinds of mass." The equivalence between passive gravitational mass and inertial mass may be contingent, but such equivalence comes in the same world (the actual world) as the Higgs field exists. In sum, the argument from the Higgs field implies that at least *passive* gravitational mass, besides inertial mass, is extrinsically grounded [environment]. But given the distinction between active and passive gravitational mass, it may be that the Higgs field is not relevant to *active* gravitational mass. This is an important issue remaining for exploration, though I will not address it further in this paper.

The second objection is that the Higgs field is a theoretical posit not based on empirical evidence, thus premise (1) is dubious.

In response, the Standard Model of physics, perhaps the most successful empirical theory in the history of science, predicts the existence of the Higgs field.

Footnote 23 continued
existed and been responsible for the of particles. See Greene (2004, pp. 254–263) for a discussion of the different values the Higgs field could have depending on early events in the formation of the universe.

[24] Thanks to an anonymous reviewer for pointing out the distinction between passive and active gravitational mass.

Specifically, the Standard Model predicts the existence of the Higgs boson, the particle constituent of the Higgs field. Although the Higgs boson has not been found yet, the 1983 discovery of the W^+, W^-, and Z bosons at CERN[25] gives plausibility to the claim that it will be found, and thus confirm the Higgs mechanism (Jammer 2000, p. 163). Furthermore, Kane (2003, p. 74) argues that the expected mass of the Higgs boson is less than about 200 giga-electron-volts, and the fact that there is a predicted answer at all is "strong evidence that the Higgs exists," since "A similar type of prediction proved accurate for the top quark mass." With the construction of the Large Hadron Collider, a powerful particle accelerator operated at CERN, claims about the existence of the Higgs boson have now entered the empirical testing phase. Given the empirical plausibility of the Higgs field, the metaphysical Intrinsic Assumption looks overly presumptuous.

The third objection questions the significance of the conclusion of the argument from the Higgs field in relation to UDT. Supposing that the argument from the Higgs field is sound, the worry is that any given token of F_m is intrinsic and therefore F_m takes the place of mass in UDT (b)(1) as a fundamental, intrinsic property (disposition). Thus, those who argue for the truth of UDT can revise, but still keep, the core of their thesis. In response to this worry, first I will emphasize exactly what I take the argument from the Higgs field to show, and why it is important *regardless* of the intrinsic/extrinsic status of F_m. Second, I will suggest that the argument from the Higgs field casts some doubt on the claim that F_m is intrinsic. Finally, I will offer some speculative reasons as to why F_m may, indeed, not be intrinsic.

First, regardless of the intrinsic/extrinsic status of F_m, I want to emphasize that the argument from the Higgs field shows that a *sparse* property (mass), though not necessarily a fundamental one, is extrinsic. Mass is supposed to be a paradigm case of an intrinsic, sparse property, exemplifying the assumption that sparseness and intrinsicness go together. I address this point further in Sect. 6, but it suggests a second point of response, as follows, to the third objection.

If *mass* is not intrinsic, this at least gives us some reason to suspect that other sparse dispositions (and sparse categorical properties, if there be any) of fundamental particles are not intrinsic. That is, the surprising claim that mass is extrinsic is suggestive of the idea that other sparse properties, perhaps F_m too, are extrinsic, awaiting some further metaphysical argument or empirical discovery. To insist that F_m *must* be intrinsic, and thus that F_m simply replaces mass in UDT, is a manifestation of a metaphysical bias against extrinsic fundamental properties. The argument from the Higgs field should diminish the bias that sparse properties are intrinsic properties. Thus, a plausible lesson to draw from the argument from Higgs field is to take an agnostic stance, awaiting further evidence while carrying forward no metaphysical presuppositions regarding the intrinsic/extrinsic status of the properties of fundamental particles, since those presuppositions have been revealed to be fragile. If the above arguments are sound, then consider that, regarding mass-

[25] The name "CERN" stands for the French Conseil Européen pour la Recherche Nucléaire, or European Council for Nuclear Research (from the CERN website, http://public.web.cern.ch/public/en/About/Name-en.html).

related properties, weight depends on *mass plus gravitational fields* and mass depends on F_m *plus the Higgs field*. So, perhaps F_m depends on F_{m2} *plus some Higgs-like field*.

The last consideration in the previous paragraph suggests (beyond the mere *suspicion* created by the argument from the Higgs field) the following, speculative, reasons to doubt that F_m is intrinsic. My suggestion is that doubts about F_m being intrinsic arise both in cases where F_m is a fundamental property of a particle a, and where F_m is not a fundamental property of a. In the first case, F_m may be a fundamental property yet not intrinsic to a if some kind of holism about the grounding of fundamental properties is true. On this view, fundamental properties form an inter-dependent grounding web, where the instantiation of any given fundamental property like F_m depends on the instantiation of other fundamental properties. The scope of the grounding web may be limited in various ways, but insofar as it includes any properties beyond a given particle instantiating F_m, then that instance of F_m will be extrinsically grounded. In the second case, F_m may not be fundamental, but dependent on F_{m2} plus a Higgs-like field, which in turn depends on F_{m3} plus a Higgs-like field, and so on *ad infinitum*. In short, there may be an infinite base of mass-related properties, each extrinsically grounded in fields in the way weight and mass are grounded. (Note that I am assuming that the particle a, bearing mass and F_m, is fundamental, whereas the mass-related properties of a may not be fundamental. That is, I am concerned only with the question of the fundamentality of properties, which may *not* mirror that of the property-bearers.) On this view, there exists an infinity of descending, extrinsically grounded (and thus extrinsic) mass-related properties. This could be true of non-mass related properties as well, but my concern here is only with mass-related properties, e.g., mass, F_m, F_{m2}, etc. This possibility is no more surprising than, say, the perplexities of quantum mechanics.

In support of this possibility, some philosophers and physicists have argued that there is no fundamental level of reality—that there are infinite levels of microstructure (e.g., see Schaffer 2003 and Dehmelt 1989).[26] I am invoking that general idea as a response to the objection that F_m is intrinsic, and specifically that there may be no fundamentality vis-à-vis properties, and (more specifically) vis-à-vis mass-related properties. If there are infinite levels of mass-related properties, and the mass-related properties at the start of the sequence (weight, mass) are extrinsically grounded in fields, then maybe there are corresponding grounding fields for each further mass-related property in the infinite series of levels. That is, it is possible that each mass-related property at each *more fundamental* property level is extrinsically grounded by a corresponding field at that level.

This speculative response, if remotely plausible, at least undermines some of the motivation for modifying UDT, with F_m in the place previously occupied by mass.

[26] Schaffer (2003, p. 505) concludes that we have no evidence for a fundamental level. He finds that "there are at least two perfectly good conceptions of the hierarchy of nature: fundamentality and infinite descent. The empirical evidence to date is neutral as to which structure science is reflecting. And so, concerning the proposition that there exists a fundamental level of nature, one should withhold belief" (Schaffer 2003, pp. 505–506). Dehmelt (1989) theorizes that there are infinite levels of structure below the electron. See also Georgi (1989, p. 456).

In essence, this strategy moves beyond questioning the Intrinsic Assumption, into questioning the further assumption we might call Fundamentality (the thesis that there must be fundamental properties, which I have restricted to discussing solely in terms of mass-related properties). Though beyond the scope of further exploration in this paper, challenges to Fundamentality are worth pursuing.

6 Implications of the Argument

This section discusses three important implications of the argument from the Higgs field: that mass is not fundamental but F_m is; that mass may still lack a distinct causal basis even though it is grounded; and the vindication of ultra-grounding, a notion introduced by Harré (1986, p. 295).

First, because mass is grounded this implies it is not a fundamental property. (This does not necessarily imply, however, that F_m is fundamental. Consider that there may be no fundamental properties since there may be no fundamental level of reality, as discussed in Sect. 5). According to the argument from the Higgs field, mass is non-fundamental because it is ontologically dependent on F_m and F_H. Yet, mass remains an excellent candidate for a sparse, fully natural property. Bird (2007, p. 13) holds that the sparse—or "fully natural" since Bird (2007, p. 9) considers 'sparse' and 'natural' interchangeable—properties "include *at least* [my emphasis] the fundamental properties," suggesting that some *non*-fundamental properties are still natural, sparse properties. If mass still counts as sparse, this is significant since it extends McKitrick's (2003a) extrinsic dispositions thesis beyond abundant dispositions to include at least some sparse dispositions.

Second, besides beyond sparse, there remains a good case for mass counting as what McKitrick (2003b) calls a 'bare disposition', a disposition with no distinct causal basis for manifesting, other than itself. On this view, a bare disposition is its own causal basis for manifesting. This is an important claim, for it is a necessary condition for dispositional essentialism, for example as advocated by Bird (2007). The fact that bare dispositions serve as their own causal bases does not prevent them from being grounded in distinct properties, provided there is a metaphysical distinction between causal bases and grounds, per the suggestion in Sect. 2. Thus, if F_H and F_m are the grounds of mass, they need not be a causal basis for manifestations of mass. This is the case provided that F_H and F_m do not receive the stimulus—mass alone receives it and thus is responsible for its manifestations. Thus, if this is correct, then mass is a case of an *extrinsically grounded bare disposition*. This is consistent with the grounding properties (F_m and F_H) of mass also counting as bare dispositions, although they may be intrinsic properties of their bearers (particle a, and the Higgs field, respectively). (However, in Sect. 5, I challenged the assumption that F_m is intrinsic). Hence, taking into consideration the first and second implications, F_m and F_H are ungrounded, (perhaps) intrinsic, bare, sparse, dispositions, while mass is an extrinsically grounded, bare, sparse, disposition.

The final important implication is that the argument from the Higgs field vindicates the idea of ultra-grounding, introduced by Harré (1986, p. 295): a given

property may be grounded in "a property [or properties] of the universe as a whole." Ultra-grounding opposes the micro-grounding (grounding in lower-level parts or properties of parts, of an object) implied by the Intrinsic Assumption. On the ultra-grounding view, "The powers of parts are explained by reference to the powers of the whole" (Harré 1986, p. 286). Ultra-grounding is dismissed by UDT proponents such as Mumford (2006, p. 478) and Molnar (2003, pp. 132–135). Mumford (2006, p. 478), for example, explicitly rules this out because "there is insufficient description or justification and ultra-grounding appears a *deus ex machina* for the avoidance of the very notion of ungroundedness" contended by UDT. Furthermore, Mumford (2006, p. 478) flaunts the widespread support (due to its success) in favor of the micro-reductive program, "whereas ultra-grounding has no such advocates."

As an example of ultra-grounding, Harré (1986, p. 295) offers Mach's Principle, the claim that an object's mass is determined by the total distribution of mass and energy in the rest of the system of which the object is a member.[27] Moreover, Harré and Madden (1975, pp. 161–185), as well as Harré (1986, p. 196), suggest fields as possible ultra-grounding mechanisms. On ultra-grounding, Harré (1986, p. 196) suggests that all dispositions would ultimately be grounded in occurrent properties "embracing such matters as the quantity and distribution of energy fields."[28] Given these claims, the following rough analysis of ultra-grounding appears plausible: a disposition, F, of an object, a, is ultra-grounded if and only if the grounds of F includes a property or property-complex of the whole physical environment (as opposed to just one region of it) in which a participates or exists. Thus, the ultra-grounds are not possessed by some other particular object, but by the whole that a is part of (where the whole is the universe), which intuitively counts as a part of a's environment. Ultra-grounding, I suggest, is a kind of extrinsic grounding [environment]. On ultra-grounding, F is partially grounded in a property or property-complex of a's whole physical environment.

Since the Higgs field permeates all of spacetime, this suggests its properties qualify as ultra-grounding properties. My contention is that the universe possesses the property of being permeated by the Higgs field, and thus the universe has the capacity to give individual fundamental particles mass. More specifically, the universe possesses the relevant property F_H of the Higgs field, as discussed in Sect. 4. I assume that F_H is a property that the Higgs field, and thus the universe, possesses everywhere, per the understanding of the Higgs field issued by the Standard Model. Any given particle a could be immersed anywhere and have the

[27] Molnar (2003, p. 133) discusses this example but thinks it is insufficient to justify ultra-grounding.

[28] Energy fields, e.g., gravitational fields and electromagnetic fields, have far-reaching spatial extension and so could ground many types of dispositions of fundamental particles, as the argument from the Higgs field tries to show with mass. Interestingly, another species of Higgs field, the electroweak Higgs, is thought by some physicists to unify the electromagnetic and weak nuclear forces (Jammer 2000, p. 162), suggesting the possibility of an ultimate grounding field. It seems that fields represent a distinct possibility for the ultra-grounding of dispositions. The particle interpretation of Quantum Field Theory (QFT) takes particles and their properties as the basic ontological elements, but significant problems exist for the particle interpretation (see Kuhlmann 2006, and Harré 1986, pp. 261–280). The alternative is the field interpretation of QFT, which holds that fields and their properties are ontologically fundamental. On the field interpretation of QFT, we can ascribe energy and momentum to fields where no particles are present (Kuhlmann 2006, §5.1.2).

same mass, so a's mass depends on F_H everywhere, hence this phenomenon should be considered an instance of ultra-grounding. Moreover, H's existence is distinct from and not possessed by any fundamental particles, and thus is not an intrinsic property of any such particles. Therefore, the extrinsic grounding [environment] of mass appears to exemplify ultra-grounding. Therefore, ultra-grounding is not only a live metaphysical and physical possibility, but an actuality according to the argument from the Higgs field.

7 Concluding Remarks

To argue convincingly for UDT one must find reasons to exclude the possibility of extrinsic grounding and thus to maintain the Intrinsic Assumption. However, given the argument from the Higgs field for the extrinsic grounding [environment] of mass, the Intrinsic Assumption is false. The moral I want to draw is to look beyond the objects and particles bearing dispositions, to properties of their environment and of other objects, in exploring the ontological grounds of dispositions. I suggest that we should accept that all dispositions are intrinsically *or* extrinsically grounded in one way or another before accepting that they are ungrounded.

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References

Bird, A. (2007). *Nature's metaphysics: Laws and properties*. Oxford: Oxford University Press.

Davidson, D. (1970). Mental events. In D. J. Chalmers (Ed.), *Philosophy of mind: Classical and contemporary readings* (pp. 116–125). Oxford: Oxford University Press.

Dehmelt, H. (1989). Triton,…Electron,…, Cosmon…: An infinite regression? *Proceedings of the National Academy of Sciences, 86*, 8618–8619.

Dunn, J. M. (1990). Relevant Predication 2: Intrinsic properties and internal relations. *Philosophical Studies, 60*, 177–206.

Ellis, B. (2001). *Scientific essentialism*. Cambridge: Cambridge University Press.

Ellis, B. (2002). *The philosophy of nature: A guide to the new essentialism*. Chesham: Acumen.

Georgi, H. (1989). Effective quantum field theories. In P. Davies (Ed.), *The new physics* (pp. 446–457). Cambridge: Cambridge University Press.

Greene, B. (2004). *The fabric of the cosmos: Space, time, and the texture of reality*. New York: Random House.

Haisch, B., Rueda, A., & Dobyns, Y. (2001). Inertial mass and quantum vacuum fields. *Annalen der Physik, 10*(5), 393–414.

Handfield, T. (2008). Unfinkable dispositions. *Synthese, 160*, 297–308.

Harré, R. (1986). *Varieties of realism: A rationale for the natural sciences*. Oxford: Blackwell.

Harré, R., & Madden, E. H. (1975). *Causal powers*. Oxford: Blackwell.

Heil, J. (2003). *From an ontological point of view*. Oxford: Oxford University Press.
Isaacs, A. (2000). *Oxford dictionary of physics* (4th ed.). Oxford: Oxford University Press.
Jammer, M. (2000). *Concepts of mass in contemporary physics and philosophy*. Princeton: Princeton University Press.
Kane, G. (2003). The dawn of physics beyond the standard model. *Scientific American*, *288*(6), 68–75.
Kuhlmann, M. (2006). Quantum field theory. *The Stanford Encyclopedia of Philosophy* (Fall 2006 Edn), Edward, N. Z. (Ed.), http://plato.stanford.edu/archives/fall2006/entries/quantum-field-theory/.
Langton, R., & Lewis, D. (1998). Defining 'Intrinsic'. *Philosophy and Phenomenological Research*, *58*(2), 333–345.
Lewis, D. (1986). *On the plurality of worlds*. Oxford: Blackwell.
Lewis, D. (1997). Finkish dispositions. *Philosophical Quarterly, 47*, 143–158.
Martin, C. B. (1993). Power for realists. In J. Bacon, K. Campbell, & L. Reinhardt (Eds.), *Ontology, causality, and mind: Essays in honour of D. M. Armstrong* (pp. 175–186). Dordrecht: Kluwer.
McKitrick, J. (2003a). A case for extrinsic dispositions. *Australasian Journal of Philosophy, 81*(2), 155–174.
McKitrick, J. (2003b). The bare metaphysical possibility of bare dispositions. *Philosophy and Phenomenological Research, 66*(2), 349–369.
Molnar, G. (2003). *Powers: A study in metaphysics*. Oxford: Oxford University Press.
Mumford, S. (2006). The ungrounded argument. *Synthese, 149*, 471–489.
Peskin, M. E., & Schroeder, D. V. (1995). *An introduction to quantum field theory*. New York: Harper Collins.
Prior, E., Pargetter, R., & Jackson, F. (1982). Three theses about dispositions. *American Philosophical Quarterly, 19*, 251–257.
Psillos, S. (2006). What do powers do when they are not manifested? *Philosophy and Phenomenological Research, 72*(1), 137–156.
Schaffer, J. (2003). Is there a fundamental level? *Noûs, 37*(3), 498–517.
Veltman, M. J. G. (1986). The Higgs Boson. *Scientific American*, *255*(5), 88–94.
Williams, N. (2009). The ungrounded argument is unfounded: A response to mumford. *Synthese, 170*, 7–19.
Yablo, S. (1999). Intrinsicness. *Philosophical Topics, 26*, 590–627.
Zee, A. (2003). *Quantum field theory in a nutshell*. Princeton: Princeton University Press.