Whence *Ontological* Structural Realism?

Juha Saatsi

Abstract I scrutinize (a) the alleged dichotomy between *epistemic* and *ontological* forms of structural realism, and (b) the considerations used to motivate the ontic variety over the epistemic. I argue that there's nothing in the traditional realism debate that calls for ontological structural realism.

1 Introduction

In the scientific realism debate there's a distinction made between *epistemic* and *ontological* varieties of structural realism. 'Ontic' Structural Realism (OSR) is motivated by considerations from the foundations of physics, and it is characterised as metaphysics. Epistemic Structural Realism (ESR), by contrast, represents a 'mere' epistemological refinement to 'standard' realism. I will focus on OSR's *motivations*, and the claim that ESR doesn't offer a far-reaching enough structuralist alternative to standard realism. I will argue that the advocates of OSR have failed to motivate it as an *alternative* to ESR and other 'non-standard' forms of realism. Although there's incentive to move away from object-oriented standard realism, there's no need to go as far as OSR.

2 What ESR is (not)

There is a natural motivation for epistemic structural realism: the possibility of having 'the best of both worlds' (Worrall 1989) in the realism debate by combining the realist's optimistic image of science with the historical fact of radical theory shifts.

Juha Saatsi
Department of Philosophy, University of Leeds, Woodhouse Lane, Leeds LS2 9JT, UK.
e-mail: J.T.Saatsi@leeds.ac.uk

ESR purports to offer a principled way of identifying the *structural content* of a theory in such a way as to ensure cumulative continuity in the (structural) truth content of theories across radical theory shifts.

The structuralist intuition springs from the fact that in various historical theory-shifts there are crucial mathematical equations that are carried over either intact or, more typically, as one set of equations being a limiting case of the other. Worrall's suggestion was to take the theoretical continuity manifested as such formal mathematical correspondence to be the locus of realist commitment. This is a cogent structuralist intuition. But there remains much to be clarified to turn the intuition into a credible argument.

First of all, the structuralist needs to ensure that the kind of continuity in focus really has to do with the *realist* rather than empiricist content. (van Fraassen 2006) Worrall (1989, 1994) simply cites Fresnel's equations for the amplitudes of reflected and refracted polarized light, to point out that they are truly identical to those resulting from Maxwell's theory. But this is not enough. The motivation for going beyond empiricist commitments—the No Miracles argument—entails that we should be able to *explain* the success of the predecessor theory from the vantage point of the successor, in terms of truth-tracking theoretical content. This surely demands more than pointing out that the equations the two theories ultimately yield—the equations that are used to test the theory—are equivalent or stand in some limit-correspondence. What it demands, rather, is that we can account for the *derivation* of Fresnel's equation in terms of Maxwell's theory. For there much to Fresnel's theorising besides 'the Fresnel equations' which represent only the very end result of his theorising, and the plausibility of the realist image, structural or otherwise, comes in part from fulfilling the intuition that success of a theory is connected to its approximate truth in a 'non-miraculous' fashion. This means that we should really be considering the relationship between the *derivations* by which the corresponding equations are arrived at in the respective theoretical frameworks. When these derivations are taken into account it is not clear that this relationship is best understood in structural terms. (Cf. Saatsi 2005, 2008)

Another point to press the epistemic structural realist on concerns the sense in which one structure can be said to approximate another. Mere appeal to 'the general correspondence principle' leaves this too open. The worry is that without a precise sense in which one structure corresponds to another we end up finding mathematical continuity where we want it. Even in the cases of intuitively appealing limit-correspondence we often have grave mathematical discontinuities that mark the theoretical revolution. (See Redhead 2001, p. 346) Such discontinuities in the evolution of theoretical structures can perhaps be dismissed on the grounds that they are immaterial to the explanation of the success of the antecedent theory from the later perspective, but such claims need to be made on case-by-case basis and only after carefully scrutinising the nature of the particular structural (dis-)continuity in question.

For these (and other) reasons the thesis of ESR needs sharpening. Nevertheless, the epistemological *motivation* for structural realism is valid. The project of first making the structuralist proposal more precise and then comparing it to various

instances of historical theory change is well-defined and intuitively cogent one. According to this position, if successful, "all that we know of the world is its structure, as exemplified in our scientific theories, and the 'nature' of the underlying elements (physical objects) remains 'hidden' in some sense." (Cei and French, 2006, p. 634)

The ESR position has been recently misinterpreted by Cei and French (2006), who read Worrall's 'hidden natures' as a kind of *Ramseyan Humility* that David Lewis (forthcoming) advocates. According to Lewis even 'the final theory' of science, taken as fully true, would leave the true nature of things hidden from us. This reading creates certain problems for ESR that Cei and French then use to motivate the alternative OSR. Their argument for preferring OSR over ESR fails due to misinterpreting ESR's sense of epistemic humility. The appropriate sense is the following. Our successful theories have often radically changed, so we are not in a position to commit to the full truth of our present theories. Rather, we should commit to our present theories being partially true in some 'structural' sense. With a suitable nature–structure distinction at hand we can say that our present theories, whether final or not, describe the structure of the world correctly, but not its nature. Our theories describe various properties of the worldly furniture and processes, and these properties describe a possible way the nature of these things could be. But we do not *know* that our world is a world of that kind. What we do know, however, is that the structure of our world—whatever its nature is—is such that it is correctly described by our theories. This sense of epistemic humility straightforwardly relates to the problem that rises from the history of science: most our current theories are probably not final ones—something that is also supported by the grand difficulties in making our theories fit together—and even if one of our theories is a final theory (for its domain) in some sense, we are simply not in a position to claim that we know that.

I take ESR to be a well-motivated, somewhat programmatic realist alternative. The advocates of OSR take this as their starting point, and then offer two distinctive sources of motivation for going beyond ESR. One turns on a particular kind of underdetermination arguably exhibited by some of our best theories, seriously impeding any substantial realist commitments. The other source of inspiration comes from witnessing certain structuralist themes in the philosophy of physics, and develops into an argument by adopting a particular perspective on the relationship between metaphysics and epistemology. These two motivations for OSR are scrutinised in the next two sections.

3 Metaphysical Underdetermination

James Ladyman asked about structural realism: 'is it metaphysics or epistemology?' (1998, p. 410) As explicated above the answer seems clear: it is epistemology. There is, however, an interesting argument that at first seems to lead to a different conclusion.

3.1 The argument

Consider the challenge of providing a realist interpretation of quantum mechanics. Setting aside the problems with the collapse of the wave function to begin with, the realist should say of this most successful mature theory that it is probably approximately true in its claims about the unobservable world. So quantum particles, for example, are approximately like the theory tells us they are. But what does the theory tell us, *exactly*? Statistical behaviour of particles has been taken to be the key to their metaphysical nature. The behaviour of an assemblage of quantum particles is correctly described by either Bose–Einstein or Fermi-Dirac statistics, whilst Maxwell-Boltzmann statistics describes the behaviour of classical particles. What accounts for these differences in statistics?

According to our best understanding of quantum theory these particles can just as well be *individuals* ('cheese') or *non-individuals* ('chalk'), this metaphysical nature of the quantum objects being underdetermined by the theory. Both interpretations of the physics are equally compatible with the phenomena as well as the formalism. (French 1989, 1998; Huggett 1997; French and Rickles 2003; French & Krause 2006) So the realist is arguably in a pickle: she wants to say that the nature of quantum particles is as the theory says it is, but the theory doesn't say what it is!

> We need to recognise the failure of our best theories to determine even the most fundamental ontological characteristic of the purported entities they feature. It is an *ersatz* form of realism that recommends belief in the existence of entities that have such ambiguous metaphysical status. What is required is a shift to a different ontological basis altogether, one for which questions of individuality simply do not arise. (Ladyman, 1998, p. 419–420)

I will now try to unpack this argument, assuming that there indeed is such *metaphysical underdetermination* at least with respect to some entities featured in our best physical theories.[1] How should the realist react? Also, I follow Ladyman & French in taking *standard realism* to have the following metaphysical dimension: the ability to spell out our realist commitments in terms of objects, or entities, that exist.[2] I do not take such metaphysical dimension to be a well-motivated part of realism. What I aim to show after explicating the argument from metaphysical underdetermination is that the move from standard realism to ontic structural realism is unnecessarily radical and not supported by the premise of metaphysical underdetermination. It is natural to respond to the challenge by reducing the metaphysical dimension of standard realism, instead of adopting a radically alternative structuralist ontology.

But first, let's clarify the challenge itself: what *is* metaphysical underdetermination? For one thing, it is clearly different from the standard underdetermination

[1] Ladyman (1998), French & Ladyman (2003) and French & Rickles (2003) defend this premise particularly for quantum particles and quantum fields, and tentatively point towards the nature of spacetime. Pooley (2006) dissents, especially regarding the underdetermined status of spacetime points. See also Redhead & Teller (1992) and Saunders (2003b) for criticism of the underdetermination thesis, and French & Krause (2006) for further defence.

[2] Psillos (1999), for example, represents standard realism thus characterised for Ladyman & French. French (2006) has called this 'object oriented' realism.

objection to realism, according to which the realist cannot justify her commitment to *any* theoretical proposition P since there is always an empirically equivalent incompatible theory which says $P^{\dagger}$ (incompatible with P). It is the rampant nature of this kind of underdetermination that (allegedly) makes it such a serious objection. If underdetermination was more limited in scope, so that only *some* theoretical propositions had empirically equivalent competitors, then realism about those parts of theories that are not thus underdetermined would be an option, at least prima facie. (Psillos, 1999, p. 167) Metaphysical underdetermination is different from empirical underdetermination by virtue of not being rampant. Rather, the former has a very limited scope: it is only the metaphysical nature of quantum particles (and whatever else leads to a similar predicament) that is underdetermined. So, prima facie, we should consider placing realist commitments to the common denominator, to whatever is common to both individuals-based and non-individuals-based interpretations of quantum physics, say.

But this strategy, the argument continues, is at a risk of leading to mere 'ersatz' realism. The worry is that in order to spell out one's realist commitments one needs to appeal to metaphysical natures. This follows directly from the metaphysical dimension of standard realism: to say that such-and-such entities exist requires that one spells out what an *entity is*. So, for example, if one says that 'According to QED there exist spin-half *particles* with charge *e*', one implicitly appeals to a metaphysical imagery (extrapolated from our experience of the macroworld) of point-like objects with properties mass, spin, etc., to give cognitive content to one's assertion. Assertions

(S) There are spin-half particles with charge *e* and other properties as described by QED.
(S') There are hard elastic orange balls of the diameter of 24 centimeters, with a black stripe contouring around the ball.

are read on a par according to standard realism: they both assert the existence of some objects with some properties. Basketballs are observable, electrons are not, but we have good reasons to believe in the existence of both. So far so good. But the ontic structuralist points out that our epistemic grasp of the *very objecthood* of electrons, according to the argument from metaphysical underdetermination, is on a shaky ground. Therefore, S expresses no cognitive content beyond the surface semantic analogy which only pays lip service to the curious symmetry properties of the mathematical representation of quantum particles.

Hence, there is an acute challenge with *theoretical* posits the metaphysical nature of which is underdetermined by the physics. The challenge is that the content of prototypical realist assertions regarding our knowledge of quarks and electrons, say, is *deflated* unless the realist is able to specify 'the most fundamental metaphysical categories' exemplified by the referents of 'quark' and 'electron'. The standard realist, not willing to tackle these subtle issues posed by the foundations of physics, is merely offering a cheap simulacrum of knowledge of the quantum world, based on an extraneous metaphysical image given in terms of categories derived from our experience of the macroworld. Such realism is arguably 'ersatz' in that it does

not succeed in capturing any actual realist commitment regarding our best theories. What allegedly *could* save the realist, however, is ontological commitment to *structure* (as opposed to (non-)individual objects with properties) as the fundamental metaphysical category.

3.2 Resisting the argument

There are several points to be made in response to the above argument.

A. Common Denominator: From Entities to Properties

If the standard realist is unable to choose between the metaphysically underdetermined options, are her realist commitments really as empty as the 'ersatz' charge suggests? Is ontological structuralism a natural solution to her alleged predicament?

French and Ladyman press the standard realist on the nature of quantum particles:

> [T]he (standard) realist is unable to give a *full answer* to [the question:]'what is a quantum object?', where a 'full' answer will involve the metaphysical nature explicated in terms of such fundamental categories as individuality, identity, etc. Van Fraassen rightly sees this as a challenge to standard realism (and it is regrettable that the standard realist has not seen fit to respond) expressing his conclusion as a waving 'good-bye to metaphysics' (1991, 480–482), leaving the field clear for constructive empiricism. (2003, p. 36, my italics)

So realism without adequate metaphysics succumbs to anti-realism. But to demand a *full* answer is to demand too much. Van Fraassen (as I read him) sees the kind of metaphysical underdetermination at issue to set a challenge for full-blown metaphysics, not realism per se. Various degrees of realist confidence regarding our inductive practices can be defended whilst sharing van Fraassen's distaste for wholesale metaphysics.[3]

Nevertheless, French & Ladyman insist that 'if the realist refuses to be drawn on the metaphysics at least at the level of individuality versus non-individuality then how are we supposed to make sense of the impact of quantum mechanics?' (*ibid.*, 50) I will look at the impact of quantum statistics below, but let's first consider this challenge in the abstract. There is an ambiguity here: there are two separate explanatory endeavours at stake for the realist. How can she explain (E1) the success of the theory by its *partial* truth; and (E2) what the world could be like to make the theory true *simpliciter*? The latter challenge asks what the world *could be* like according to our theory *read literally*, whilst the former asks what the world

[3] Exactly how realism and metaphysics are related is a difficult question, of course. It is undeniable that *some* metaphysical assumptions play a role in scientific heuristics and decision-making, and perhaps *some* are required to deal with a different kind of underdetermination (Jones, 1991 vs. McMullin, 1992). I don't want to belittle these issues, but it is justified to bracket them here in order to focus purely on the argument from metaphysical underdetermination.

must be like according to our theory in order for the success of science (and of that theory in particular) not to appear 'miraculous'. Neither of these challenges is made insuperable by the metaphysical underdetermination at hand.

Regarding (E2), the realist can simply take different metaphysical frameworks to paint different meaningful images of how the world *could* be. Whether we have (ever could have) grounds to choose between such images—the very possibility and limits of metaphysical knowledge—is a different question, of course.[4] Regarding (E1), the realist's response depends on her general characterisation of her realist commitments. What does it take to philosophically explain the success of a scientific theory in the spirit of scientific realism? How is the explanatory, truth-tracking theoretical content to be delineated in the first place? Such questions surface in connection with the 'pessimistic induction', and the realist—by virtue of not being ultra-optimistic about our current science—tries avoid the force of the pessimistic historical record by appealing to some kind partial truth. I have urged elsewhere that this notion should be analysed in terms of theoretical *properties* responsible for successful derivations in science. (Saatsi, 2005) This conception of realist commitments is appropriate in the present context, too, since knowledge of these success-fuelling properties can be independent of having knowledge (or not) of the nature of reality in terms of the fundamental metaphysical categories relevant to the explanandum (E2) above. (I will illustrate this below with quantum statistics.) We can answer the question (E1) without taking a stance regarding the metaphysically underdetermined alternatives because the relevant explanatory, success-fuelling properties are shared by the competing metaphysical interpretations. We need to reject the intuition that the realist must engage in metaphysics to the extent that she can spell out her commitments in terms of *fundamental* metaphysical categories.

B. The Impact of Quantum Statistics

What, then, *can* a realist claim to know of quantum particles? How can these realist commitments be spelled out without reference to fundamental metaphysical categories? Consider, to begin with, a feasible metaphysical underdetermination vis-à-vis the nature of spacetime. The realist wants to explain the success of the general theory of relativity by claiming it to have correctly identified the curvature of spacetime as the source of gravitational phenomena. Explaining the successful accommodation of the precession of the Mercury perihelion in these terms is independent of the metaphysical question of whether the spacetime points of the substantivalist interpretation of GTR are to be understood *haecceitistically* or *anti-haecceitistically*.[5]

---

[4] Some argue that the realist is committed to optimism about the possibility metaphysics by virtue of appealing to the inference to the best explanation, for example. (Hawley, 2006) I find these arguments problematic, but this doesn't matter here. What matters is that there is a *further issue* as to what extent realism and metaphysics are connected. And further issues need further arguments.

[5] The realist explanation of this success actually is independent of the existence or otherwise of spacetime *points* altogether, as corresponding to points of the mathematical manifold of a GTR model. The realist can remain agnostic of the 'fine-structure' of spacetime at the Planck-scale,

In both of these metaphysical pictures the theory is true about the crucial unobservable features of the world, so that the concepts of curvature and geodesic, for example, similarly apply to properties of substantival spacetime. This kind of metaphysical underdetermination is quite different from the more old-fashioned empirical underdetermination regarding spacetime theories: one theory having a curved spacetime and the other having extra forces in its ontology. In the face of such underdetermination we really may not know what to believe in. Not so in the case of metaphysical underdetermination: we just believe that the theory correctly describes how spacetime is curved.

This case illustrates how metaphysical underdetermination can fall outside of natural realist commitments. But there is a crucial disanalogy to the case of quantum statistics: the underdetermined alternatives in the spacetime case—haecceitism and anti-haecceitism with respect to spacetime points—concern the modal *identity* of spacetime points, not their *individuality*. (Pooley 2006) Nevertheless, the lesson generalises. We can account for the the success of quantum statistics without reference to the metaphysical nature of particles. The explanation is subtle, and I refer to Saunders (2006) for details. The gist of the explanation turns on the probability measure on quantum state space: the *discreteness* of this measure makes a crucial difference in how the states are counted under permutation symmetry. Saunders demonstrates how the difference between classical and quantum statistics arises from the fact that the probability measure is continuous for classical state space, whilst being discrete for quantum state space, even if both classical and quantum particles are assumed to be indistinguishable and permutation symmetry is applicable to both. (Permuting indistinguishable particles under permutation symmetry is taken to yield the very same state.) The realist does not have to deny that there may be different metaphysical explanations, underdetermined by the physics, for this crucial difference between classical and quantum systems. But these metaphysical musings go beyond what is required by the realist to explain 'the impact of quantum mechanics', as far as the explananda (E1) is concerned. Regarding this aspect of quantum mechanics, the realist is committed to the characteristic discreteness of the quantum world—a property of quantum systems. Although this undeniably only scratches the surface of what the realist needs to say about quantum mechanics, it does address the source of the argument from metaphysical underdetermination.

C. Is Metaphysical Underdetermination Coherent?

Let's return to the two explananda (E1) and (E2), above. It seems that even at the level of (E2) the underdetermination does not motivate the radical step to OSR, regarded as 'offering a reconceptualisation of ontology, at the most basic metaphysical level, which effects a shift from objects to structures' (*ibid.*,p. 37). Such a *metaphysical* project is in itself fully legitimate, of course, but cannot in my view gain any extra impetus from the metaphysical underdetermination. An ontological struc-

---

only maintaining that the coarse-grained macrofeatures that emerge from the ultimate quantum theory of gravity are correctly described by GTR.

turalist conclusion (regarding (E2)) could perhaps be be argued for by saying that structuralist metaphysics provides the *only* way to make sense of the notion of objecthood at the level of quantum particles. (Saunders 2003*a*, 2003*b*)[6] But this is not the claim presently evaluated. Indeed, such a claim directly contradicts the underdetermination premise which is conditional on both horns being intelligible bona fide possibilities. If anything, it seems that the structuralist proposal only makes matters worse, for with such an alternative structuralist ontology available there would be three instead of two to choose from![7] The choice between these would presumably be done on the grounds of general metaphysical preferences. This, indeed, is another difference between metaphysical and empirical underdetermination; if one (*pace* van Fraassen) is optimistic about metaphysical reasoning in general, then arguably metaphysical underdetermination *can be broken* by considerations that go beyond physics and belong to philosophy simpliciter.

* * *

I conclude that the motivation gained from the metaphysical underdetermination for structural realism, and for ontological structural realism in particular, is highly problematic. I will next briefly look at an oblique line of enquiry that is sometimes taken to provide further grounds for OSR, or even for taking OSR to supplant ESR.

4 Structuralism in Philosophy of Physics

I now want to argue in more general terms for a distinction to be made between two levels of structuralist philosophy often run together in a synergistic fashion.[8]

One family of structuralist thought belongs to the philosophy of physics proper: the unifying theme is the conviction that the ontology of physics is best conceived in structural terms. Very broadly speaking this movement can be characterised as an attempt to shift one's ontology away from objects, as traditionally conceived, and towards structures *relationally* understood. A different set of structuralist ideas belongs to epistemology, and concern the question of what we can claim to know of the (mind independent) world. Although there are eminent historical figures to draw on (e.g. Russell 1927), in the contemporary context the epistemological motivation, as outlined in section 2, boils down to something quite specific.

---

[6] Ladyman and Ross (2007) perhaps also argue for this claim, having shifted away from the argument from metaphysical underdetermination.

[7] It has been suggested that the individuals and non-individuals packages could be viewed as different representations of the common 'structuralist core' but this intuition must be substantiated in order to show how the underdetermined options go over and above the common core, instead of just being metaphysical alternatives.

[8] It is not always easy to prise apart the different motivations running in parallel, but in my view an illegitimately close connection between different structuralist motivations is implied in Ladyman (1998), French & Ladyman (2003), Saunders (2003b), Lyre (2004), and French & Rickles (2006), for example.

On the face of it, it is not easy to say exactly how structuralism in the philosophy of physics should interact with this epistemological idea. One might at first think that if the preferred ontology of physics is structural—so that one is an ontological structural realist at the level of philosophy of physics—then one must also be a structuralist with respect to one's epistemological scientific image, since all theoretical truths are ultimately truths about structure. But the connection isn't this straightforward. After all, the structuralist ontology is inspired by metaphysical questions regarding a *literal* reading of our best theories—questions such as: what are the spacetime points quantified over in GTR like; how to understand the nature of quantum particles in the face of the permutation symmetry, or the gauge symmetry behind the Bohm-Aharonov effect. The epistemological humility of the realist image, on the other hand, is based on the belief that our theories may only be *partially* true. Therefore the notion of partial truth adopted by the realist can affect whether or not a literal reading of our present theories has input on the realist's epistemic commitments. For example, it might be part of the realist image that there really is a curved spacetime and that free particles move along the shortest paths as mathematically represented by geodesics on a manifold—i.e. the theoretical terms 'curvature of spacetime' and 'shortest path' do refer—irrespective of whether the most fundamental spacetime ontology consists of dimensionless points or of something else completely. GTR might be a true representation of the curvature properties of spacetime whilst being a false representation of its 'fine structure'. Indeed, being a classical (non-quantised) theory this is most probably the case, as acknowledged by an epistemically cautious realist. Whether or not there is an argument for interpreting GTR substantivalism in structuralist terms, it is not clear what ramifications this argument should have on such a realist.

This example is enough to sever intimate link between ontological and epistemological structuralism. Structuralism in metaphysics might be appropriate for an interpretation of some theory T, but if the realist is only committed to T being partially true it is not clear what epistemological lessons we should draw from the metaphysics. The realist only needs the resources required to capture those aspects of the world that were latched onto by the scientific practice in producing the successes of T_S. I believe that those features can be described independently of the underlying 'fundamental metaphysical categories'.

5 Conclusion

Several considerations for various forms of structural realism have been recently advanced in the quickly burgeoning literature. There is growing need to draw critical distinctions in order to regiment the multifaceted debate: too often different senses of 'structure' and 'structuralism' are confusingly placed under one and the same heading. Here I have attempted to make some headway with this clarificatory task, by focusing on different *motivations* for adopting a form of structural realism. If correctly interpreted, the original epistemic strand of structural realism is a well

motivated, if still somewhat programmatic position. What has been hailed by some as the radical alternative—the ontic version of structural realism—is rather weakly motivated in comparison. Whilst there is most certainly room for various forms of structuralism in metaphysics and philosophy of physics, the links between the various considerations are most subtle than is currently acknowledged in the literature.

Acknowledgements I wish to thank Steven French and Angelo Cei for helpful correspondence.

References

Cei A, French S (2006) Looking for Structure in all the wrong places: Ramsey sentences, multiple realizability, and structure. Studies in History and Philosophy of Science 37:633–655

van Fraassen BC (1991) Quantum Mechanics: An Empiricist View. Oxford University Press, Oxford

van Fraassen BC (2006) Structure: Its Shadow and Substance. British Journal for the Philosophy of Science 57(2):275–307

French S (1989) Identity and Individuality in Classical and Quantum Physics. Australasian Journal of Philosophy 67:432–446

French S (1998) Identity and Individuality in Quantum Theory. Stanford Encyclopedia of Philosophy

French S (2006) Structure as a weapon of the realist. Proceedings of the Aristotelian Society 106:1–19

French S, Krause D (2006) Identity and Individuality in Modern Physics. Oxford University Press, Oxford

French S, Ladyman J (2003) Remodelling Structural Realism: Quantum Physics and the Metaphysics of Structure. Synthese 136(1):31–56

French S, Rickles D (2003) Understanding Permutation Symmetry. In: Brading K, Castellani E (eds) Symmetries in Physics: Philosophical Reflections, Cambridge University Press, Cambridge, pp 212–238

French S, Rickles D (2006) Quantum Gravity Meets Structuralism: Interweaving Relations in the Foundations of Physics. In: Structural Foundations of Quantum Gravity, Oxford University Press, Oxford

Huggett N (1997) Identity, Quantum Mechanics and Common Sense. Monist 80:118–130

Jones R (1991) Realism about what? Philosophy of Science 58:185–202

Ladyman J (1998) What is Structural Realism? Studies in History and Philosophy of Science 29A(3):409–424

Ladyman J, Ross D (2007) Every Thing Must Go: Metaphysics Naturalized. Oxford University Press, Oxford

Lewis D (Forthcoming) Ramseyan humility. In: Braddon-Mitchell D, Nola R (eds) The Canberra Plan

Lyre H (2004) Holism and structuralismin U(1) gauge theory. Studies in History and Philosophy of Modern Physics 35:597–624

Pooley O (2006) Points, Particles, and Structural Realism. In: French S, Rickles D, Saatsi J (eds) The Structural Foundations of Quantum Gravity, Oxford University Press, Oxford

Psillos S (1999) Scientific Realism: How science tracks the truth. Routledge, London

Redhead M (2001) The Quest of a Realist. Metascience 10:341–347

Redhead M, Teller P (1992) Particle labels and the theory of indistinguishable particles in quantum mechanics. British Journal for the Philosophy of Science 43:201–218

Saatsi J (2005) Reconsidering the Fresnel-Maxwell case study. Studies in History and Philosophy of Science 36:509–538

Saatsi J (2008) Eclectic realism—the proof of the pudding: a reply to Busch. Studies in History and Philosophy of Science Forthcoming

Saunders S (2003a) Physics and Leibniz's Principles. In: Brading K, Castellani E (eds) Symmetries in Physics: Philosophical Reflections, Cambridge University Press, Cambridge, pp 289–308

Saunders S (2003b) Structural Realism, Again. Synthese 136(1):127–133

Saunders S (2006) On the explanation for quantum statistics. Studies in the History and Philosophy of Modern Physics 37:192–211

Worrall J (1989) Structural Realism: The Best Of Both Worlds? Dialectica 43:99–124