

Detecting the Dark

Indirectness & Dark Matter Epistemology

Niels C.M. Martens

Freudenthal Institute & Descartes Centre, Utrecht University

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Have we detected cosmological dark matter, beyond neutrinos? What does it mean to detect dark matter? In this chapter we partially unpack this question, in two ways. Firstly, by focusing on the various ways in which dark matter (DM) detections can be indirect.¹ This is important because when physicists label a detection as indirect, one may be tempted to interpret that as the detection being epistemically inferior—in the sense of producing less reliable knowledge—compared to direct or less indirect detections of the same target entity (Elder, 2025; Skulberg and Elder, forthcoming).² Similar attributions of epistemic inferiority do, after all, tend to be made, more generally, about mere observations (in astronomy) as compared to experiments (in terrestrial physics) (Hacking, 1989).³ Secondly, we hone in on what it means

¹This chapter thus focuses on the question “Is there a difference, in degree or even in kind, between purely-DM astronomical objects vs. luminous astronomical objects vs. collider-produced DM particles vs. cosmic DM particles reaching the surface of the earth, in terms of a) the directness of their observation (or, more generally, the epistemic access we have to these objects), and b) the logic of justification for/confirmation of their existence?” in Martens et al. (2022); see also a similar question in (Antonioni, 2023, p.634).

²I am not claiming here that dark matter physicists typically and/or explicitly present detections that they label as direct detections as being more reliable (e.g. more robust) than detections that are labeled as indirect. However, since such connotations do appear in other contexts, e.g. the direct detection of gravitational waves or black holes (Elder, 2025; Skulberg and Elder, forthcoming), one could easily be tempted to import such connotations in the dark matter context.

³See Shapere (1993) for an optimistic reply to Hacking’s pessimism. Explicitly, the

to detect dark matter by comparing ‘detecting-that’ dark matter exists to ‘detecting-which’ dark matter entity exists.

The main claims of this chapter are: 1) all potential detections of dark matter are more or less indirect (in the inferential sense of indirectness that might have epistemic ramifications)—one should be very surprised that the term ‘direct dark matter detection’ exists in the first place, given that it is supposed to be a dark or rather invisible form of matter; 2) (almost) no potential dark matter detection deserves to be called an experiment, in the sense that an experiment might be epistemically superior to a mere observation; 3) a direct comparison of the degree of indirectness of two potential detections of dark matter is typically neither possible in any useful quantitative sense nor particularly important; and 4) although I do not argue for this here, none of the above is particularly worrisome since these situations are commonplace in much of the natural sciences, or at least in astronomy. Instead, 5) different detection methods of dark matter are best construed as epistemically complementary; it is their combination that would achieve epistemic superiority over any single detection method. Rather than each detection method (potentially) providing us with the same knowledge of dark matter but with different degrees of trustworthiness, the various ways in which dark matter detections are indirect teach us different things about dark matter in each case. Finally, 6) detecting-that and detecting-which are strongly (semantically) intertwined in the specific dark matter context.

worries of pessimists like Hacking are that we cannot manipulate the astronomical target system. However, a) even though we can manipulate protons at the LHC (see main text), it is not like we can spray things with dark matter either, and surely a DM detection at the LHC could happen in an epistemically robust sense; b) many manipulations that we might want in experiments are simply not practically possible, e.g. because they are too expensive or would destroy the planet—luckily the cosmic laboratory ([Anderl, 2016](#)) provides us with some amazing samples of extreme initial conditions. Thus, it seems to me that part of what actually motivates the pessimists is the indirectness of astronomical knowledge. This chapter argues that this is a red herring. What is more interesting and fruitful is looking at the inferential chain on a case-by-case basis (e.g. is the whole chain gravity-mediated or not; does it lead to detection-which or only detection-that §17.4)—for instance in the spirit of Boyd’s enriched evidence ([Boyd, 2018](#)).

17.1 Types and degrees of indirectness

Before introducing and discussing various types of searches or (potential) evidence for dark matter, let us distinguish two senses in which a detection might be indirect, without claiming that this constitutes an exhaustive taxonomy of the indirectnesses of detection.⁴

Geographical or physical indirectness: A detection or observation of a physical entity or phenomenon can be more or less indirect in virtue of there being a chain of intermediary entities (“messengers”) between the target system and the detector (see chapter 23 regarding the range of messengers). This geographical inaccessibility of the target system might be due to it being distant, as with a black hole, or it being detectable via secondary products/effects only, as with primary cosmic rays decaying into secondary cosmic rays upon hitting the atmosphere, before those are eventually detected on the surface of the earth. A detection is geographically direct only if there are no intermediary entities.⁵

Logical or inferential indirectness: A shorter or longer inference chain, causal or otherwise, is required to arrive from the raw data at the conclusion that a physical entity or phenomenon has been detected or observed.

There are a few immediate things to note about this distinction. Firstly, while physical indirectness implies logical indirectness, the converse is not the case. A long inference chain may be required even for tabletop experiments, for instance if the target system is sufficiently small. Secondly, both types of indirectness are (at best) matters of degree, rather than binary notions. Even most empiricists have long since moved on from the idea of a binary distinction between direct and indirect observations, in the wake of the critical response to Van Fraassen’s (1980) dichotomy between observable and theoretical terms. In fact, even viewing indirectness as a matter of degree

⁴See for instance Shapere (1982); Franklin (2017); Skulberg and Elder (forthcoming) for some alternative notions of indirectness.

⁵Shapere (1982) would also call an observation direct if the intermediaries are transmitted without interference. On this account, even ‘indirect dark matter detections’ (see main text) would have counted as direct if the standard model decay/annihilation products would not incur any interference on their way to earth.

is too strong, as it suggests that we can determine whether one method is twice or three times as indirect as another. A (partial) ordering rather than a degree of indirectness is more realistic. Thirdly and relatedly, inferential indirectness is tantamount to theory-ladenness or model-dependence. Again, one of the core lessons of 20th century is that this is not something inherently worrisome, and fortunately so, since it is inherent in most if not all of science, despite the wishes of inductivist empiricists (Tal (2012); Elder (2024); and see the other chapters in Part IV).

17.2 Types of dark matter detections

Let us now move on to introducing the main types of (potential) dark matter detection. The first three are the non-gravitational methods, consisting of so-called production at colliders, ‘direct detection’, and ‘indirect detection’ (Figure 1).

Firstly, in particle colliders, such as the Large Hadron Collider at CERN, standard model particles or entities made up out of standard model particles are accelerated to collide with one another, creating (other) standard model particles that are detected by a detector surrounding the beam trajectory. If the total energy of the collision products does not add up to that of the initial particles, one may infer from this missing energy additional, unseen collision products: new dark particles (beyond the known dark particles: neutrinos).

Secondly, so-called ‘direct detection’ efforts, often referred to as direct detection experiments, use some material that is expected to be sensitive (i.e. interact non-gravitationally) to certain classes of dark matter particles (for instance Weakly Interactive Massive Particles, WIMPs, that do interact non-gravitationally, albeit weakly, with standard model particles) as the Earth moves through the dark matter halo of our Milky Way galaxy. Typical such “experimental techniques” include cryogenic crystal detectors, crystal scintillator “experiments”, and Noble gas scintillators. A prominent example is the series of XENONnT “experiments”,⁶ using increasing amounts of liquid Xenon. By measuring recoils, the experiments aim to constrain the two-parameter space of the mass and cross-section of dark matter particles traveling through and interacting with the Xenon tank, as well as the local dark matter density.

⁶xenonexperiment.org

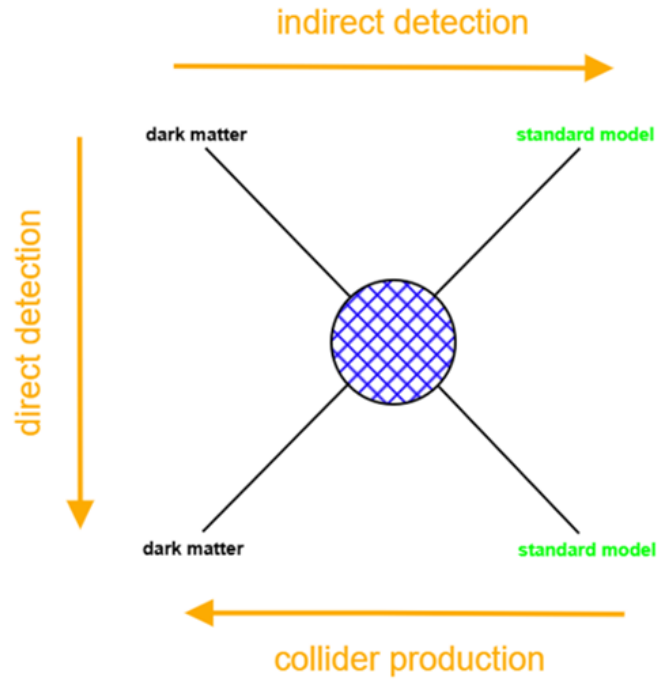


Figure 1: Schematic representation of various ways of detecting dark matter, depending on the direction in which one reads this Feynman diagram of dark matter and standard model particles. Note that the number of dark matter and standard model particle lines may differ from two, respectively; for instance, indirect detection methods also focus on dark matter decays, i.e. a single dark matter line on the left.

Thirdly, so-called ‘indirect detection’ methods scan the night sky for standard model particles/radiation that are either the decay products of individual dark matter particles or annihilation products of two (or more) dark matter particles. As we observe many other such particles or radiation with our telescopes, the focus is on finding spots with an overabundance of such particles that cannot be explained in terms of non-dark-matter sources. Inferences are thus highly dependent on knowledge of the backgrounds. On the one hand we need the cosmological dark matter to be approximately stable on cosmological time-scales; on the other hand we need it to not be completely stable if we want to be able to use indirect detection efforts that aim to detect decay products. Null results of indirect detection efforts of decay products place constraints on the half-life of dark matter candidates. In the case of annihilation products, indirect detection efforts aim to constrain the two-parameter space of the mass and annihilation cross-section of dark matter particles in various regions of the universe.

Finally, distinct from these three non-gravitational methods, there is a host of astronomical or cosmological gravity-mediated detections of dark matter, which tend to focus less on the particle nature of dark matter (e.g. cross section or mass), often treating dark matter as a fluid instead. As a result, they severely underdetermine for instance the mass of the underlying dark matter candidate, allowing for a mass range spanning up to 90 orders of magnitude (Bertone and Tait, 2018)! At the smaller, astronomical end of the scales involved in such detections, measurements of galaxy rotation curves are used to infer the distribution of dark matter in and near the galaxy, i.e. the shape of the dark matter halo.⁷

At the intermediate scale, we find that the dynamics of galaxies within whole galaxy clusters is used to infer the density distribution of dark matter within those galaxy clusters. Perhaps the most famous such cluster in this context is the Bullet cluster pair. The observations of this pair are being interpreted as the two (sub)clusters having collided, with the stars (observable in the optical range) being hardly hindered, as opposed to most of the baryonic matter, in the form of the hot gas (observable in the X-ray range), which is being slowed down by the collision. Gravitational lensing, however,

⁷Interesting further avenues to explore in terms of analysing the senses of indirectness involved, but which are unfortunately outside the scope of this chapter, include dark galaxies (Weisberg et al., 2018), the Bullet cluster (Clowe et al., 2006), gravitational-wave-mediated detections of ultralight dark matter boson clouds near black holes (Miller et al., 2021), and dark photons.

does not track the massive baryonic matter, but the stars, suggesting that much of the mass of the cluster is in the form of dark matter which is unhindered by the collision as the stars rather than separating from them by slowing down with the more massive chunk of baryonic matter/ hot gas.

At both the scales of galaxies and of galaxy clusters, gravitational lensing can be used more generally to infer the density distribution of dark matter of a target system, such as a galaxy or galaxy cluster, in between a light source and Earth.

Finally, the cosmic microwave background can be used to constrain cosmological parameters including the dark matter contribution to the total energy budget of our universe. The current structure of our universe has a bottom-up origin: small density fluctuations (anisotropies) in the early universe acted as gravitational seeds for the structure observed today, such as galaxies. However, such gravitational clumping of the known baryonic matter in our universe could only have started after the ‘moment’ of recombination of electrons and protons into neutral hydrogen some 10^5 years after the big bang, which would not leave sufficient time to develop the structure we observe today. This problem can be solved by adding dark matter to our universe, which is able to start clumping before recombination. Imprints of this process appear on the cosmic microwave background, the photons escaping at the time of recombination. This has allowed determining that 27% of the cosmic energy budget stems from dark matter.

We already start to see that the various detection methods are best understood not as competing (e.g. in terms of being the most direct detection and therefore the epistemically superior detection), but as *epistemically complementary* (Klasen et al., 2015; Bauer et al., 2015; De Baerdemaeker, 2021; Boveia et al., 2024; Skulberg and Elder, forthcoming): they each hone in on different aspects of dark matter.⁸ Astronomical and cosmological measurements of dark matter have determined the total mass of dark matter in our universe, as well as the density distribution of the dark matter fluid at various scales. These detections are all gravity-mediated, and as such are not very well suited for determining the underlying nature of dark matter⁹—arguably even opening the door to modified gravity alternatives to dark

⁸The downside of this complementarity is that it restricts the use of robustness arguments (Antoniou, 2023).

⁹This is not to say that there is no interaction between cosmological and particle physics constraints. For instance, the shape of the dark matter halo (i.e. the discrepancy between the observed shape and predicted shape from large scale structure simulations known

matter (Martens et al., 2022). Production, ‘direct detection’ and ‘indirect detection’ would be better suited at constraining the underlying nature of dark matter, e.g., in case dark matter is a particle, its mass and various cross-sections. The elephant in the room, however, is that these three types of detection have so far only produced null results for detecting cosmic dark matter beyond neutrinos, and so have only ruled out parts of parameter space.

17.3 Indirectnesses of dark matter detections

In this section we evaluate the indirectness of the various types of (potential) dark matter detections introduced in the previous section, with an eye on whether any one such detection would be epistemically superior over any other, less direct detection.

17.3.1 ‘Direct’ and ‘Indirect’ Detections

A natural starting place is those two types of detections that are explicitly named in terms of their putative (in)directness: ‘direct detection’ and ‘indirect detection’ of dark matter. This nomenclature is only obviously appropriate in the sense of geographical (in)directness. Only in the case of ‘direct detection’ does the target system itself, the dark matter particle, reach the detector. In the case of ‘indirect detection’ the target system annihilates or decays at a distant location, with the annihilation or decay products acting as intermediary entities (“messengers”) that travel towards our detector. However, geographical (in)directness does not, in any direct way, adjudicate epistemic superiority.

Firstly, as emphasised in section 17.1, geographical directness does not imply inferential directness—and it is inferential directness, if anything, that might confer epistemic superiority. Detecting dark matter with a large tank of fluid Xenon does not at all come close to old school observation with the unaided senses.¹⁰ Optimising the signal-to-noise ratio depends on a large

as the core-cusp problem) places constraints on the self-interaction cross section of dark matter particles.

¹⁰The type of direct detection method that may come closest is the bubble chamber, but they have mostly been superseded by the scintillation and crystal methods mentioned in the main text.

variety of factors. It depends on the extent to which one is able to clean (De Swart and Mol, 2025) and shield the detector, and how well one understands the remaining backgrounds (radioactivity of both the surroundings and the detector itself, cosmic rays, etc.), e.g., how one models the remaining backgrounds in order to make statistical inferences. Notably, we are now reaching the neutrino floor, i.e. the theoretical lower-limit on WIMP dark matter models that are discoverable given the uneliminable interference from the background cosmic neutrino noise. Optimising the signal-to-noise ratio also depends on how well one is able to model the signal, for instance the local dark matter velocity distribution. Traditionally one assumes the Standard Halo Model, in other words isotropic velocities following a truncated Gaussian, but refinements to this model have recently been proposed (Evans et al., 2019). Hence, not only are ‘direct dark matter detections’ rather logically/inferentially indirect, the inferences involved are not distinct from those involved in ‘indirect dark matter detections’ in that they concern only well-trusted terrestrial physics. Also ‘direct dark matter detection’ requires astronomical modeling.

Secondly, even once we have accepted that (in)directness is not a binary notion, it is still not the case that the geographical directness of ‘direct dark matter’ detections makes those detections—in any obvious or automatic manner—inferentially *more* direct than those of ‘indirect dark matter detections’. It is far from obvious that, in general, there could be any clear-cut way of comparing degrees of indirectness across detection methods (Elder, 2025, p.7). It can be difficult or even impossible to count the number of inferences, and even if that is possible for a specific approach or paper or detector, a different approach or paper or detector may use a different chain of inferences.¹¹ Moreover, not all inference steps are epistemically on a par, in that they would be equally robust or trustworthy, as they may depend on different background theories, or models with more or fewer parameters, and/or with larger uncertainties in those parameters. Jreige (2024) argues that the model-dependence of ‘direct detection experiments’ is sufficiently severe to make it difficult to compare results even just across various direct detection experiments (see also the discussion in Antoniou (2023)).

Although it would be out of the scope of this chapter to attempt to quantify the specific difference in inferential indirectness between, say, the

¹¹Different inference chains may not even agree on the conclusion, one notorious example being the Hubble tension.

XENONnT ‘direct detection’ experiment in the Gran Sasso Mountains of Italy versus the PAMELA satellite (i.e., an ‘indirect detector’) in Earth’s orbit, I expect that this would be a futile endeavour in any case. Even more so if this is then to be translated into a comparative degree of epistemic trust in each (potential) detection. PAMELA simply uses very *different* inferences. For instance, PAMELA famously detected an excess of positrons from the Galactic halo in the range 10-60 GeV. It was tempting to interpret this as resulting from dark matter annihilation (of WIMPs). However, this requires sufficient understanding of modeling alternatives, as the excesses might also be explained by pulsar or supernova remnants. In 2017 the High-Altitude Water Cherenkov Observatory (HAWC) indeed found that the positron flux from the nearest two pulsars could account for the excess instead of dark matter annihilation (Hooper et al., 2017). Another famous hunting ground for other ‘indirect dark matter detectors’ is the Galactic center, where we would expect large amounts of dark matter annihilations.¹² However, identifying any observed flux as excess, in other words as signal rather than noise, is extremely difficult as the Galactic center is very bright and not sufficiently well understood, so that results are heavily dependent on how one models the Milky Way. In sum, there is no general, unique, model-independent way of claiming that one method is more inferentially direct than another, in the sense that it would be epistemically superior.¹³

A final attempt to bestow the status of a direct detection or experiment on ‘direct detection’ methods might come from arguing that we have better epistemic control over such detectors than over those used for ‘indirect detections’, in the sense that only ‘direct detection’ instruments can be treated as black boxes. Elder (2025) considers something along these lines in the context of detecting gravitational waves either via an interferometer like LIGO-Virgo or via decaying orbits of binary systems such as the Hulse-Taylor(-Weisberg) binary. In the dark matter context however, at first glance it is the ‘indirect detection’ instruments such as telescopes that deserve to be treated as black boxes—because they have been successfully used in many other contexts to detect radiation and standard model particles—more so than ‘direct detection’ instruments, as the latter have not successfully detected cosmic dark

¹²The high mass range of dark matter that could be present there would not be reachable with terrestrial colliders, reiterating the complementarity of these different methods.

¹³And if we were to compare ‘direct’ versus ‘indirect’ methods in terms of the regions of parameter space they would access, it would arguably be the ‘indirect’ detections that come out on top (Mambrini and Muñoz, 2004).

matter so far (at least not in the sense of unambiguously discovering a new signal). Epistemic trust (in having control over these instruments) would then go to the former over the latter. One may attempt to push back against this in two ways. Firstly, if we widen our definition of the detector to include not only the telescope but also the messengers, this seems to reduce the epistemic trust in ‘indirect detectors’.¹⁴ Secondly, we arguably do have some reason to treat ‘direct detection’ instruments as black boxes, since they are based on similar techniques that did detect the only dark particle that has been confirmed: neutrinos (De Baerdemaeker, 2021). As it stands, epistemic control does not clearly favour one of these methods over the other.

17.3.2 Colliders

Let us now turn to dark matter production at colliders. Such detections may seem geographically direct, but only in the trivial sense that the target system is produced at the collider itself: there is no ‘dark matter in the cosmic wild’ involved at all, so if cosmological dark matter is the target system rather than synthesised dark matter then in that sense colliders access that target system more indirectly than the other methods. In any case, such a potential detection would still be inferentially indirect, although the inferences take the opposite form of those of ‘indirect DM detections’: rather than inferring dark matter from some excess, it would be inferred from missing energy. The produced dark matter particles do not interact with the detector. Rather, if one detects all the standard model particles that are the output of the collision, and the total energy is less than that of the input, one may attempt to *infer* (from energy conservation and by using many simulations of the detectors and collisions (Boge, 2024)) that some dark particle must have been among the output.

17.3.3 Experiments?

Could any of these three non-gravitational detection methods be considered an experiment—perhaps even such that it thereby comprises epistemic superiority? Of these three, it is instruments falling under the ‘direct detection’ category that are most often called experiments (e.g. xenonexperiment.org;

¹⁴I would like to thank Siska de Baerdemaeker for pointing this out. See also the discussion in (Elder, 2025).

see also (Jreige, 2024)).¹⁵ If the distinction between (active) experiment and mere (passive) observation is to be understood in terms of only the former involving intervention on/manipulation of/interference with the (initial conditions of the) target system, then ‘DM direct detection’ instruments are not experiments—nor are ‘indirect detections’.¹⁶ Although the target system (the dark matter particle) would reach the detector in the former case—analogue to the Pierre Auger *Observatory* detecting secondary cosmic rays via its water tanks—where it does not in the latter—analogue to the Pierre Auger *Observatory* detecting cosmic rays via its fluorescence detectors/telescopes—neither method involves manipulating the dark matter target system. Do particle colliders then constitute a *dark matter* experiment? Also no. We do manipulate the initial conditions, but those contain e.g. only protons, not yet dark matter. It goes without saying that the astronomical/cosmological detections do not constitute experiments. Dark matter experiments (almost)¹⁷ do not exist.

17.3.4 Gravity-mediated Detections

Finally, we turn to astronomical and cosmological detections. These are of course not geographically direct. They are inferentially indirect in that they depend on many astronomical and cosmological modeling assumptions, but we have seen that is also the case for ‘direct’ and ‘indirect detections’. (Not so for collider production, but that is because that method synthesises dark matter rather than discovers dark matter out in the wild. The only, extremely indirect connection that such methods would have with cosmic dark matter would be to tell ‘direct and indirect methods’ what mass and cross section to look for.) A quantitative comparison of any degree of indirectness arising from these astronomical/cosmological assumptions is problematic for the reasons already mentioned. What is more interesting is the qualitative

¹⁵De Baerdemaeker (2021) refers to all three types of non-gravitational detections as experiments.

¹⁶This definition may be too strict (Jamee Elder, personal communication). If one places a particle at different locations and with different initial velocities in an external gravitational field, and measures its behaviour to learn about the gravitational field, one may still wish to consider this a *gravitational experiment*, even though the gravitational field is not being manipulated.

¹⁷Boyd (2023) discusses one interesting potential counterexample, the Axion Dark Matter eXperiment (ADMX), where a strong magnetic field is attempting to intervene on dark matter axions expected to be present in a laboratory microwave cavity.

difference between these methods: as mentioned in section 17.2, where astronomical and cosmological detection methods shine is in determining the energy density distribution (or total cosmological energy), whereas the three non-gravitational methods shine at determining the microphysical nature of dark matter (if it is a particle), such as its mass and various cross-sections. However, even that distinction is not strict: DM halo shapes inferred from Galaxy rotation curves constrain the self-interaction cross section, ‘indirect detection methods’ also point us towards the direction of dark matter dense regions (albeit at a more local scale), and ‘direct detection methods’ are sensitive to the density of the DM halo at Earth.¹⁸ Nonetheless, this discussion highlights once more the complementary rather than competitive epistemology of the various detection methods.

17.4 Detecting what?

Let us return to our main question—what does it mean to detect dark matter?—but instead of focusing on the indirectness(es) of such detections, we turn to the distinction between what we have called ‘detecting-that’ dark matter exists versus ‘detecting-which’ type of dark matter exists.

We first consider this distinction in a different context, to serve both as an illustration of the distinction and as a contrast case. Should we be realists about Newtonian absolute masses, i.e. monadic properties in virtue of which mass ratios obtain, or only about the mass ratios (Dasgupta, 2013; Martens, 2024)? There is something elusive about absolute masses, as they are represented by numerical quantities combined with an arbitrary unit. Whereas we can communicate the number of fingers on a glove in an objective manner, as it is a dimensionless number, communicating its mass includes this conventional aspect. After all, if we would consider another possible world with all masses multiplied by the same factor (conceptually/kinematically; we leave out dynamics for a moment), nothing qualitative would change, as all their relations (ratios) stay the same (so-called “kinematic comparativism”). The only way to identify a mass across these worlds (which mass in the other world does *this* mass here correspond to?) would be if they had a further non-qualitative, primitive this-ness (“quiddity”). However, even though we cannot say *which* specific mass (quiddity) *this* planet has, it is still meaningful

¹⁸The WIMP miracle might be construed as another example of cosmological constraints interacting with the particle properties of dark matter.

to ask—now we bring in the dynamics, i.e. Newtonian gravitation—whether we can detect-*that* (varying) the absolute mass is empirically relevant (in the sense of producing an observationally distinct possible world) and thereby real. (I have argued elsewhere that the answer is yes ([Martens, 2024](#)).) So, in this case 1) detecting-which and detecting-that come apart, but 2) that is not a problem for realism, because the failure to detect-which leaves out only a tiny aspect of absolute mass (its quiddity). In fact, one might even argue that we should get rid of that elusive aspect of mass altogether, so-called sophisticated substantivalism ([Jacobs, 2023](#)).

How does the detecting-that vs detecting-which distinction apply to dark matter? According to [Jreige \(2024\)](#), ‘direct detection’ setups play a dual role: detecting (the existence of) the dark matter particle, and detecting its properties, e.g. its mass (range). Despite the supposed conceptual distinction between these two senses of detecting dark matter, their experimental degeneracy—one cannot first determine that dark matter has been detected rather than for instance dark energy, and only then determine the dark matter mass—in the specific context of ‘direct detection’ setups is taken to be an unfortunate problem for those setups. This gives me the impression that Jreige thinks it could have been otherwise, or may even be otherwise in the context of other detection methods. However, I take this empirical degeneracy to be universal within the dark matter context, since the detect-that vs detect-which distinction is not as clear-cut for dark matter as it was for absolute masses.

The (implicit) narrative in many textbooks is that the above mentioned astronomical and cosmological phenomena constitute a detection-that dark matter exists, with the three types of non-gravitational detection methods promising to detect-which dark matter candidate obtains. However, I find it difficult to clearly distinguish this from a narrative that takes the astronomical and cosmological phenomena to detect-that there are empirical discrepancies between observations and predictions of a theory that uses only luminous matter and general relativity. Within this narrative, someone who already proclaims realism about dark matter is saying something that does not seem to amount to much more than “I believe in that stuff, whatever it is, that will be found out to underlie these phenomena; let us proactively call it dark matter”.

We need the complementarity (not any supposed directness) of at least some additional non-gravitational detection methods to detect-which dark matter particle (or other entity, or even a modification of gravity) under-

lies these observables. Narrowing this vague dark matter concept in such a way would (only) then, simultaneously with the detection-which, collapse ‘detecting-that there are empirical discrepancies’ into ‘detecting-that dark matter exists’ (Martens, 2021), vindicating (all aspects of) realism about dark matter. In sum, whereas ‘detecting-that (varying) absolute mass is an empirical difference-maker’ is clearly conceptually distinct from ‘detecting-which quidditistic mass obtains’ but in such a way that failing to achieve the latter provides no obstacle for realism, ‘detecting-that’ and ‘detecting-which’ are much more semantically intertwined in the case of dark matter, such that both would need to coincide in order to substantiate realism.

17.5 Conclusion

This chapter has argued that there is (almost) no such thing as a dark matter experiment, there are only dark matter detections, and all such potential detections are more or less inferentially indirect. Moreover, detecting-that (dark matter exists) and detecting-which (dark matter candidate is the correct one) are strongly intertwined in the dark matter context. None of this warrants epistemological pessimism though. We should worry less about the (inferential and physical) indirectness of dark matter detections; shifting focus to the epistemic complementarity of the various dark matter detection methods provides a more optimistic outlook. That being said, an avenue worth exploring is the applicability of other notions of directness and indirectness in the dark matter context (e.g. along the lines of Skulberg and Elder (forthcoming)), such as the sense in which the Bullet cluster is presented by Clowe et al. (2006) as a “direct empirical proof of the existence of dark matter”.¹⁹

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¹⁹It would be particularly interesting to analyse to what extent the claimed directness of the Bullet cluster evidence falls under what Skulberg and Elder (forthcoming) call the “unambiguous signatures” view.

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