Scientific Realism and Dark Matter: Conflicts In Theory Confirmation

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Abstract

Scientific realism is in part characterized by its epistemic commitment to unobservables posited in science. To support such epistemic commitments, some realists have argued that explanatory or theoretical virtues that operates in tandem with inference to the best explanation can constitute theory confirmation. I argue that there is a tension in the realist epistemology between the idea that such virtues constitute theory confirmation and the idea that empirical discovery or detection of scientific objects constitute significant theory confirmation. In particular, I argue that the application of the realist framework in certain scientific contexts yields a realist judgment towards *undiscovered* objects. Given such a judgement, the potential empirical discovery or detection of such objects would provide no additional epistemic warrant. The resulting picture is that the realist epistemology suggests that science in principle does not need to detect or discover its hypothesized objects in order to conclusively confirm their existence. In order to avoid this situation, I argue that realists should incorporate degrees of belief and a program of meta-empirical confirmation theory into their overall framework.

1 Introduction

The project of scientific realism aims at establishing that we have rational reasons to believe that empirically successful theories in science are true and that their terms refer to existing objects. For some proponents of this view, the epistemic aims of realism is supported by inference to the best explanation (IBE). According to this inference we have rational warrant to believe that the theory that best explains, by virtue of a set of explanatory virtues, some collected data is true. A given theory then, receives epistemic support from the application of IBE. Another approach to account for the way in which evidence supports

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theory is Bayesian confirmation theory. According to this framework, a theory gets confirmation only if the probability of the theory given the evidence is greater than than the prior probability of the theory, i.e. its probability before considering the evidence. While scientific realism is not incompatible with probabilistic reasoning in terms of its overarching aims, some realists have nevertheless argued against using it in their epistemology:

> Bayesian reasoning does not have rules of acceptance. On a strict Bayesian approach, we can never detach the probability of the conclusion of a probabilistic argument, no matter how high this probability might be. So, strictly speaking, we are never licensed to accept a hypothesis on the basis of the evidence. (Psillos 2009, 195)

One can clearly see how there is a tension between the project of providing epistemic criteria for accepting a theory as being true via IBE and the "naked" probabilistic conclusions given by Bayesianism. IBE, or what I will call abductivism, can then be viewed as an alternative to Bayesianism, Hypothetico-deductivism and Inductivism as an account of theory confirmation and the relation between evidence and theory.

In this paper, I argue that the Abductivist framework set up by Psillos (1999, 2000, 2007, 2009) in certain situations fail to attribute epistemic significance to the empirical detection of a theory's central objects. It does this because there are contexts in which the application of abductivism leads to realist commitments about the central objects of a theory despite the fact that they have not yet been discovered. The structure of the paper is as follows: First, I outline the notion of empirical confirmation by discovery and its epistemic significance. I move on to present the epistemic framework - abductivism - of scientific realism given by Psillos. I apply this framework to the dark matter hypothesis and show that it results in a realist judgment with respect to dark matter despite the absence of its discovery. I argue that since dark matter has yet to be empirically confirmed in terms of discovery, abductivism implies that its potential experimental detection in the future would have no discernible effect on the epistemic status of the hypothesis - if we should already believe that dark matter is real, its discovery is epistemically impotent with respect to belief in its existence. I consider a possible rejoinder that realists may offer to resolve the tension but conclude that it leads to too costly problems elsewhere in the realist project. In the final sections, I propose that realists could restore the epistemic significance of empirical detection by integrating features of Bayesianism, specifically degrees of belief, into their framework as well as integrating the program of Meta-Empirical Confirmation (MEC) into their epistemology.

2 Discovery and empirical confirmation

Fundamental physics has for the majority of the 20th century been a success story. Theories were constructed and tested empirically, pushing our understanding of the world forward at a staggering pace. Particle colliders were built to test theories in particle physics, astronomical observatories were constructed to provide new data about the universe against which theories were tried, and a variety of experimental tests of general relativity was conducted. This process of empirically testing theories may be viewed as the ultimate arbiter for belief in the (approximate) truth of those theories within the scientific community. Even though scientists might have theoretical grounds for holding a particular theory to be more viable than a rivalling theory prior to any testing by empirical data, such theoretical grounds are rightly considered to be less epistemically probative than empirical confirmation. There is a reason why physicists are seen celebrating experimental results with a standard deviation $\geq 5\sigma$, or that vast amounts of funding is directed towards building experimental facilities like the LHC in CERN, the Tevatron collider at Fermilab or the LIGO and VIRGO gravitational wave detectors - discovery and detection is our most powerful epistemological tool to empirically confirm a theory. In virtue of the fact that discovery plays this important epistemic role in scientific theory assessment, the standards of statistical certainty have become increasingly higher. Franklin (2013) describes the progressive increase of statistical certainty in physics as a way to epistemically grade results and distinguish between 'discovery' and 'observation' on the one hand, and 'evidence for' on the other. In physics journals and communities results $\geq 5\sigma$ are required to call something an 'observation' or 'detection', while results $< 5\sigma$ are labelled 'evidence for'. This distinction indicates two things: i) that empirical confirmation is held as the highest standard of theory assessment and; ii) that detection and observation is the gold standard of empirical confirmation. Any reasonable philosophy of science then, should attribute proper epistemic significance to empirical confirmation.

3 Scientific realism

Sophisticated forms of scientific realism holds that we ought to believe in the reality of entities in so far as they are indispensable for the predictive success of a scientific theory. The most developed account of this brand of realism has been defended by Psillos, who has constructed an intricate and powerful realist framework which contains defenses against the objection that inference to the best explanation is not a legitimate epistemic inference from van Fraassen (1989), solutions to the pessimistic meta-induction by Laudan (1981), and to problems of transient underdetermination from Stanford (2006). One of the tenets in realist defenses, also present in Psillos' own, is the idea that explanatory or theoretical virtues has a bearing on the confirmation and truth of a scientific theory. (Psillos 1999, 171) This idea is expressed most clearly in tandem with the epistemic merits of IBE.

3.1 Scientific realism and IBE

As a means to retrieve knowledge beyond the observable world, realists have claimed that explanatory reasoning, or IBE, is the best option. IBE is understood by realists to be an ampliative method which confers warrant to believe that the best explanation of the evidence is true. (Psillos (1999, 2000, 2007, 2009), Kitcher (1995)) Below follows a general schema of the inference:

> D is a collection of data (facts, observations).
>
> H explains D. (H would, if true, explain D.)
>
> No other hypothesis can explain D as well as H does.
>
> ---
>
> Therefore, H is (probably) true. (Psillos 2007, 442-3)

Whether or not we ought to believe that IBE is epistemically defensible has been one of the core issues in the realism/anti-realism debate for the past 20 years or so. van Fraassen (1980) argues that the proposed explanatory connection between empirical success and truth fails to be established since two mutually exclusive theories can be equally empirically successful. Explanatory goodness then, is not a reliable guide to truth. Fine (1991) argues that the only justification available for IBE is viciously circular since it involves a failure to receive any external warrant: only IBE can justify IBE. While friends of IBE like Psillos and Kitcher (see also Douven (2002) and Bird (2006)) have mitigated some of these worries, one may still worry whether IBE overshoots the aim explanationists intends to use it for. One of the big promises that explanationism aims to deliver on is epistemic optimism: we have license to be epistemically optimistic with respect to sciences' capability of reaching beyond the limits of our senses and deliver knowledge about the world. While it is tempting to accept the offer of bona fide knowledge about the external world, epistemic optimism comes at the price of epistemic risk. The next section describes Psillos' view on the trade-off between epistemic warrant and epistemic risk.

3.2 Ampliation and Epistemic Warrant

IBE is an ampliative inference. For an inference to be ampliative just means that it outputs conclusions which are logically stronger than the premises it uses as input. The most commonly known ampliative inference is of course regular enumerative induction, where the amplification is mostly thought of as purely quantitative. IBE is an inference that is explicitly used in philosophical argument, for example in the familiar no-miracles argument for scientific realism as given by Putnam (1975) and Boyd (1980), but it is also used in science. Being an empirical endeavor, science regularly deal with generalisations and universal laws and contains theories which infers causes beyond the observational evidence. These are practices for which ampliative inferences lend themselves well. There is, however, a downside to ampliation. The content-increasing nature of ampliation means that its conclusions are susceptible to being false. Scientists are not usually interested in universal laws if they are false or in postulated entities which are not real.[1] While strictly false theories like Newtonian mechanics have their rightful place in the history of science, and can be seen as important stepping stones to a complete picture of reality, they are no longer contenders for being true. This is not to say that scientist have completely abandoned it - its reliability in contexts where it is a limiting case is still intact - but from the perspective of scientific realism, it is abandoned as a contender for being true. Under the realist assumption that ultimately, science is not in the business of aiming at false theories, it simply isn't enough for an inference to be ampliative, it also needs to be epistemically probative. In his defense of IBE as a rational epistemic tool of science and scientific realism, Psillos argues that ampliation and epistemic warrant are two desiderata in the definition of the abstract characterisation of the scientific method:[2]

> Any attempt to characterise the abstract structure of scientific method should make the method satisfy two general and intuitively compelling desiderata: it should be ampliative and epistemically probative. (Psillos 2009, 173-4)

The need for ampliation is simply that it is necessary if science is supposed to go beyond what we already know based on ordinary sensory experience. The extra content is precisely what epistemic warrant is needed for. In his (2009) book, Psillos provides an analysis of how enumerative induction and the hypothetico-deductive method fares with respect to the two desiderata. Enumerative induction is argued to satisfy epistemic warrant, but only in a quantitative way. If all observed A's are B, then we may infer that the amplified conclusion that all A's are B's is epistemically warranted. While ampliation is clearly involved, it may be characterised as 'horizontal', meaning that the content that is being increased is restricted to the *kind* of entity which one already have observed, so one is not able to infer anything beyond the kind of entity one already know to be observable. It is not able to introduce new ontology, for example, and so is not ampliative in that particular sense. The H-D method is argued to be compatible with both 'vertical' ampliation and epistemic warrant, but is, according to Psillos, too epistemically permissive: it has no discriminatory function viz-á-viz two (or more) hypotheses which deductively entail the empirical data. The consequence is that the application of the H-D method selects both (or all) hypotheses which deductively entail the empirical data, leading to an underdetermination problem. In Psillos' terminology, enumerative induction is minimally ampliative and maximally epistemically probative, while the H-D method is maximally ampliative but minimally epistemically probative. The analysis of the methods with respect to the desiderata highlights the dynamic between ampliation and epistemic warrant:

[1] Scientists can, of course, be instrumentalists about theories in the sense that the reality of the objects postulated in a theory is secondary to its utility as a predictive tool. In quantum physics, for example, this stance has been legio for the past 50 years or so.

[2] One might reasonably argue that the project of finding a universal schema for 'the scientific method' died with logical positivism (see Earman (1992) and Andersen and Hepburn (2020)), but this issue is orthogonal to the issues currently discussed here.

> [A]mpliation is inversely proportional to epistemic warrant. This is clearly not accidental, since ampliation amounts to risk and the more the risk taken, the less the epistemic security it enjoys. (Psillos 2009, 182)

What is needed, according to Psillos, is a healthy balance between sufficient ampliative strength and sufficiently robust epistemic warrant. It should come as no surprise that Psillos argues that IBE strikes precisely this balance.

3.3 IBE, epistemic warrant and ampliation

The problem with the H-D method - that it can't discriminate between multiple hypotheses from which the empirical data could be derived - is precisely the issue Psillos argues that IBE has the resources to deal with. This evaluative function is grounded in the comparing of hypotheses with respect to a number of theoretical/explanatory virtues:

> Those hypotheses are ranked higher which a) explain all the facts that led to the search for hypotheses; b) are licensed by the existing background beliefs; c) are, as far as possible, simple; d) have unifying power, e) are more testable, and especially, are such that entail novel predictions. (Psillos 2000, 65)

That IBE can discriminate between hypotheses by selecting for their explanatory virtues does of course not itself imply that the explanation that ranks highest is epistemically warranted. In order to achieve epistemic warrant, Psillos uses elimination of doubt with respect to the best explanation. That is, he uses the absence of defeaters to provide prima facie epistemic warrant for the best explanation. The two kinds of defeaters in play are *rebutting* and *undercutting* defeaters. A rebutting defeater may simply be an observation that refutes the hypothesis in question, and an undercutting defeater can be that several other hypotheses can derive the evidence, making the probability that the considered hypothesis is true significantly smaller.[3] With respect to rebutting defeaters, Psillos claims that since IBE, unlike the H-D method, is not an inference where the evidence must be entailed by the hypothesis, one may attribute the inconsistency between observation and hypothesis to one of the auxiliaries. While this may seem like gerrymandering, Psillos claims that unless there is some other reason for abandoning the best explanation (perhaps the new observation renders an alternative hypothesis the best explanation, or perhaps there are reasons to think that new explanations will supersede the currently best one), it is still rational to stick with the best explanation.[4] With respect to undercutting defeaters, Psillos argues that it is a problem which only marginally affects IBE. Not every hypothesis that can derive the evidence offers any coherent explanation of it, so only the hypotheses which both entails and explains the evidence

[3] Psillos description of rebutting looks very much like ordinary falsification.

[4] In this respect, Psillos' framework is reminiscent of Lakatos' program, where the core theories are protected.

will survive an initial screening. The ones that do will be evaluated with respect to the above explanatory virtues. We may then have a set of alternative hypotheses which explains the evidence worse, in which case their presence cannot be seen as epistemically undercutting the best explanation. Interestingly, Psillos only briefly addresses the problem of unconceived alternatives (PUA) given by Stanford (2006). PUA can be characterized as the anti-realist argument that combine underdetermination and the pessimistic meta-induction. Underdetermination is the idea is that a theory T is undermined by the fact that there exist several alternative theories which are empirically equivalent to T, i.e. that they are all equally compatible with the (available) empirical data. The pessimistic induction is the argument that many of the scientific theories believed to be true in the past have been rendered false, warranting the conclusion that current scientific theories are likely to face the same fate. PUA combines these to argue that many theories in the history of science believed to be true were thought to have no alternatives. These theories were later surpassed by newly conceived ones. A pessimistic induction is then made to the conclusion that current scientific theories are likely to have unconceived alternatives compatible with the empirical data. Stanford's argument targets Psillos' characterization of IBE because it latches on to the worry that the theory space containing empirically equivalent alternatives is likely to also contain theories that explains the evidence equally well or better than the theory currently selected by IBE. As a response, Psillos argues that "given the information available at a time t, it is reasonable to infer to the best available explanation H of the present evidence even if there may be even better possible explanations of it." (Psillos 2009, 193) I cannot see how this sufficiently blocks PUA since information about the likelihood that there might be equal or better explanations in theory space should act as an undercutting defeater of the inferred theory in and of itself, especially so since the inference is made to its truth. Given that PUA is an argument that aims to raise the likelihood for unconceived alternatives, if it succeeds then PUA provides precisely the kind of information that would constitute an undercutting defeater with respect to applications of IBE. As will become apparent in later sections, PUA is related to the central argument in this paper, that abductivism undermines the epistemic value of empirical detection, and so will be revisited there.

Taking stock, we have an epistemic framework - abductivism - that takes IBE to be the best characterization of the scientific method, involving the two defeaters undercutting and rebutting. IBE then, uses theoretical or explanatory virtues such that, in the absence of defeaters, we are licensed to believe that the theory that scores the highest with respect to those virtues is (approximately) true. The role played by the theoretical virtues, then, is confirmatory:

> The rivals of realism, typically, deny that explanatory power has anything to do with confirmation and truth: theoretical virtues are pragmatic, rather than epistemic. Realists, typically, defend the view that these theoretical virtues have epistemic force because they are part and parcel of rational scientific judgement. (Psillos 1999,

171)

Confirmation via explanatory/theoretical virtues is then taken to license epistemic optimism viz-á-viz the theoretical constituents of the theory such that we should think that they are real. (Psillos 1999, 185) The remainder of the paper applies abductivism to the dark matter hypothesis and shows that the idea that theoretical virtues can provide sufficient confirmation for realism undermines the role of confirmation by empirical discovery or detection.

4 The astrophysical case for dark matter

Rougly, one may treat the dark matter hypothesis as the theoretical paradigm committed to the idea that there is a kind of non-baryonic matter that interacts gravitationally but not electromagnetically.[5] The term 'dark matter' is commonly attributed to the Swiss astronomer Fritz Zwicky's speculative explanation of the discrepancy between the observed rotational velocity and the calculated gravitational potential of the luminous mass in the coma cluster. The extra gravitational potential, he thought, must be due to some unseen 'dunkle materie'. At the time, he didn't constrain his speculation to non-baryonic matter, but the general idea that additional low-luminous matter could explain the observed dynamics as well as the coining of the phrase was enough to retrospectively treat Zwicky's work as the start of the modern history of dark matter. A lot has happened since Zwicky's first inference to dark matter, but I will focus on three salient pieces of evidence in the literature: galaxy cluster dynamics, flat rotation curves, and large structure formation. This covers both the astrophysical and the cosmological evidence for dark matter and is sufficient to show that realists overstate their epistemic optimism with respect to dark matter in the subsequent analysis. I will largely follow the description of the evidence as given by Bertone and Hooper (2018).

4.1 Galaxy cluster dynamics

In the 1930's, Zwicky (1933) made a first attempt to determine the mass in the coma cluster by applying the virial theorem to it. The first step was to estimate the mass of the cluster to be the product of the number of observed galaxies within it (800), with an average galaxy mass of 10^9 solar masses - a number which was an approximation by Hubble. By estimating the size of the cluster (10^6 light-years) he could determine the potential energy of the system in order to calculate its kinetic energy and ultimately its velocity dispersion. The velocity dispersion for 800 galaxies of 10^9 solar masses in a sphere 10^6 light-years across should be 80km/s, but the number Zwicky ended up with was 1000km/s. In applying the virial theorem, he concluded that the amount of total mass present in the coma cluster was much higher than its luminous mass.

[5] I'm not considering here the recently (re)emerging proposal by Bird et al. (2016) which suggests that dark matter could consist of primordial black holes.

Even as a first approximation, the high discrepancy implies that the dynamics of galaxy clusters exhibit properties that where inconsistent with general relativity - at those high velocities, the galaxies should not be bound together in a cluster by the gravitational effects of their luminous masses, but should simply disperse from each other. Additional observations and measurements carried out by, amongst others, Smith (1936) and Schwarzschild (1954) further emphasized a high mass-to-light ratio in galaxy clusters, adding to the emerging problem of mass discrepancy in accounting for galaxy cluster dynamics. In short, the luminous matter we could observe was not nearly enough to account for the gravitational bond manifested in galaxy clusters with the exhibited velocity dispersion. Although several hypotheses were entertained as explanations of the observed discrepancy in the mid 20th century, in the 1970's the dark matter hypothesis emerged as the most plausible candidate to explain the observed mass-to-light discrepancy. (de Swart et al. (2017))

4.2 Flat rotation curves

In 1970, Rubin and Ford Jr (1970) used an image tube spectograph built by Ford in order to make observations of the Andromeda galaxy (or M31). Previous observations had been made using radio telescopes, but the improved accuracy of Ford's spectograph enabled a qualitatively increased measurement of the galaxy's rotation curve.

The rotation curve of a galaxy is roughly the plotted orbital speed of stars and gas as a function of their distance from the galactic center. In smaller systems, such as our solar system, the orbital speed declines with distance so that planets close to the sun orbit faster than planets further away. When analyzing the rotation curve of the Andromeda however, Rubin and Ford obtained a 'flat' rotation curve, meaning that the orbital speed of the stars and gas in it did not decline with increasing distance from the galaxy center.

The rotation curves of two additional galaxies were plotted by Roberts and Rots (1973), increasing the probability of a systematic discrepancy between expectation and observation, and in the late 1970's, Bosma (1978) published the results, and accompanying rotation curves, from radio observations of 25 galaxies, most of which displayed flatness out to the largest observed radii (Fig. 1). Once again observations had established a discrepancy between observed luminous mass and gravitational effects in the dynamics of astrophysical systems.

Roughly, the phenomena displayed by the two astrophysical systems described above imply an exclusive disjunction: either general relativity breaks down at some arbitrary scales, or there exist some additional low-luminous matter in these systems. The first explicit suggestions involving additional low-luminous or "hidden" matter that would explain flat rotation curves were made in the 1970's, following the work of Rubin and Ford (Freeman (1970); Rogstad and Shostak (1972); Einasto et al. (1974)). Faber and Gallagher (1979) reviewed the status of mass-to-light discrepancies in galaxies, in the abstract saying that "After reviewing all the evidence, it is our opinion that the case for invisible mass in the universe is very strong and becoming stronger". The viability of the

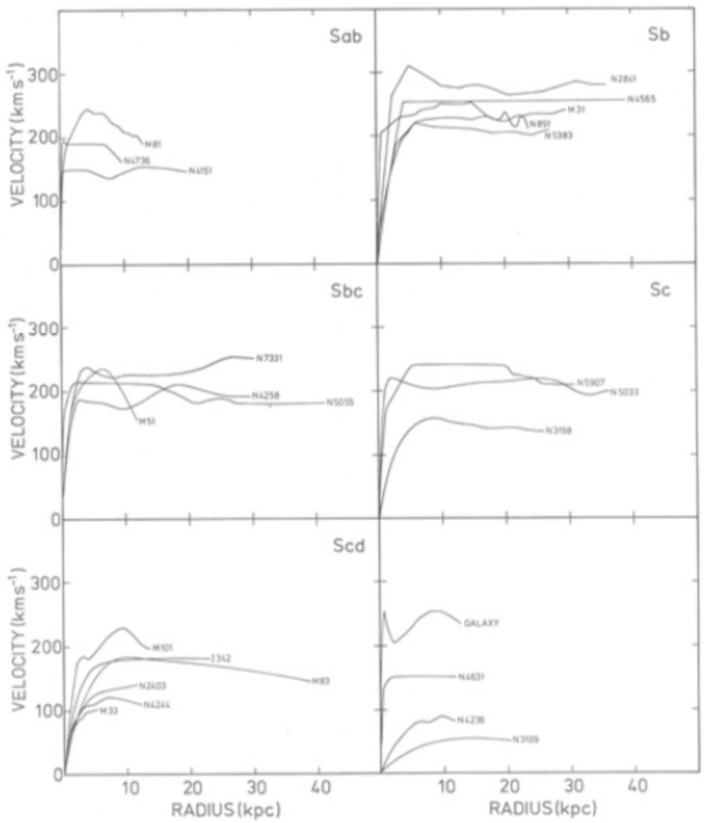

Figure 1: The rotation curves of 25 galaxies plotted by Bosma (1978), from Bertone and Hooper (2018)

dark matter hypothesis as an explanation to the observed phenomena began to gain momentum.

4.3 Dark matter and IBE

The realist position entertained in this paper argues that the best characterization of the scientific method is IBE. Since IBE is a method of inference that selects between a set of hypotheses compatible with the data, one needs to address the offered alternatives to the dark matter hypothesis. With respect to explaining galaxy cluster dynamics, there were a number of competitors in the running:

> Indeed, well into the late 1960s and early 1970s many different solutions to the cluster discrepancies were discussed. These included

ideas about possible regions of ionized hydrogen; the existence of a large number of dwarf galaxies; changes to the law of gravity; a large density of gravitational radiation; cosmologically created black holes; the notion that separate field galaxies could have been mistaken for cluster members; the presence of massive neutrinos; or, finally, the possibility of observational errors. (de Swart et al. 2017, 3)

Similarly, the measured flat rotation curves in the 1970's were not ubiquitously argued to be evidence for dark matter. The two observations were rather treated separately, having many proposed separate solutions. The dark matter hypothesis only became the leading explanation to the observed anomalies after Ostriker et al. (1974) had proposed a cosmological framework in which the missing mass explanation unified them. de Swart et al. (2017) argues that the turn from observational anomalies to evidence was rooted in the fact that the additional matter provided by the dark matter hypothesis helped cosmological models satisfy a philosophically desirable closed universe ($\Omega = 1$). This would suggest that the epistemic boost given to the dark matter hypothesis was non-empirical in the sense that the reasons given for its epistemic viability turned on theoretical work in cosmology, driven by a desire for a closed universe. Whatever the underlying motivations might have been, synthesizing the two problems and giving them a single explanation is important to the application of IBE, given that it operates with both unification and simplicity. Instead of treating cluster dynamics and galaxy dynamics as two issues with two different data sets, there is now a single data set that was best explained by the dark matter hypothesis:

> There are reasons, increasing in number and quality, to believe that the masses of ordinary galaxies may have been underestimated by a factor of 10 or more. (Ostriker et al. 1974, L1)

For the purposes of applying IBE in this context, having a single explanation which unifies the phenomena by reasoning that the dynamic behavior in the two systems is simply different manifestations that share a common feature - the presence of additional low-luminous mass - is key. Instead of having separate explanations for each astrophysical system, there was now a single unified one. The dark matter hypothesis explains both observations, it is licensed by existing background beliefs in terms of being compatible with general relativity, it is simple and unified the cause of the phenomena. It is precisely the hypothesis that would be selected by IBE, in which case the realist would say that we should believe that the dark matter hypothesis is true and that dark matter exist, despite the fact that dark matter is undiscovered:

> Not only has dark matter never been observed in accelerators, it has also not been seen in direct detection experiments (in which the recoil energy of a nucleus impacted by a dark matter particle is observed) or in indirect detection experiments (in which the debris from dark matter annihilations in space are observed). (Dodelson 2011, 2)

If we take the realist epistemology seriously, this means that the detection (direct or indirect) of dark matter is epistemically redundant for a realist judgments with respect to its existence. The evidential situation is such that the application of IBE outputs the dark matter hypothesis as (approximately) true, entailing that dark matter exist. In this situation, and others like it, treating theoretical and explanatory virtues as theory confirmation in conjunction with IBE makes empirical confirmation in terms of discovery and detection epistemically redundant.

4.4 MOND as a defeater

The realist commitment to the existence of dark matter was generated by the application of IBE to the evidential situation as described above. There is, however, an alternative theoretical framework that can derive and explain some of the data to which the dark matter hypothesis was offered as an explanation. If true, this would constitute an undercutting defeater as defined in the realist epistemology, which in turn would eliminate the realist commitment to dark matter. The core idea in the alternative framework is that general relativity's description of the dynamics of mass and spacetime breaks down at certain scales (associated with the astronomical systems described above), and that we should replace it with a different set of laws. The first set of theories that seriously explored the possibility of replacing general relativity was proposed by Milgrom (1983). The core idea was to account for the problem of missing mass in galaxies, i.e. accounting for flat rotation curves, by replacing Newton's second law, $F = ma$, in very low acceleration limits with $F = ma^2/a_0$. For this reason, Milgrom's theory and its succeeding variants are usually called Modified Newtonian Dynamics, or MONDs. It replaces Newtonian behaviour at low accelerations with "deep MOND" behaviour, meaning that high accelerations systems (such as our solar system) acts according to classic Newtonian gravity but low acceleration systems (such as galaxies) behaves according to modified gravity. In the early days, MOND had two major problems: i) reconciling its formal proposals with the conservation of momentum, energy, and angular momentum, and; ii) explaining relativistic phenomena such as gravitational lensing and cosmological expansion. In attempting to solve these problems, MOND theories went through several theoretical developments, resulting in Bekenstein's (2004) relativistic MOND-theory TeVeS (Tensor-Vector-Scalar gravity). TeVeS is dynamical enough to potentially be consistent with gravitational lensing and galaxy rotation curves, and is considered to be the most promising theory rival to dark matter. Importantly, MOND theories reject the idea that there is any missing matter - all gravitational effects that we observe is caused by baryonic mass. So what we might call 'dark matter effects' is in this framework attributed to baryonic matter, predicting a correlation between the two in systems with low acceleration with remarkable precision. MOND theories, then, can potentially suspend realist commitments to dark matter by undercutting it. As we will see, however, there are explanatory reasons to reject MOND theories in favour of a dark matter explanation.[6]

4.5 Large structure formation

In the 1960's, Penzias ans Wilson's serendipitous discovery of the cosmic microwave background (CMB) ushered in the modern era of precision cosmology. The CMB consists of the extremely redshifted light emitted in the very early stages of our universe. With the increasing quality of data provided by COBE, WMAP, and Planck, the emerging image resulting from the first free light in the history of the universe has become increasingly clearer. When analysing this data, cosmologists and astrophysicists have observed extremely small differences in temperature between different spots in the otherwise smooth and homogeneous CMB. These temperature anisotropies in the CMB is associated with fluctuations in matter-density. Lower temperatures corresponds to higher densities, and higher temperatures to lower densities. In the ΛCDM model (where Λ= dark energy and CDM is cold dark matter), the density fluctuations themselves are explained as a result of random quantum fluctuations which were amplified by the gravitational effects of baryonic matter and dark matter. Gravity pulled all matter inward, and radiation pressure due to the photons pushed baryonic matter outward, causing the fluctuations to oscillate which in turn made sound waves propagate - an effect known as Baryonic Acoustic Oscillation. Since dark matter does not interact electromagnetically, it could exert gravitational influence without being affected by the radiation pressure, causing 'gravitational wells' which attracted baryonic matter (Hu and White (2004)). As the universe expanded, it also cooled, and at a certain threshold, known as the time of recombination, the universe was cool enough for previously free electrons to couple with protons to form neutral hydrogen atoms. Since the electrons could no longer interact with photons, this process enabled photons to travel freely (this light is what comprises the CMB). The matter-densities due to the Baryonic Acoustic Oscillations remained in their current state, 'frozen' as it were, providing the initial seed structure of the large scale matter-distribution we see today in the form of galaxies and galaxy clusters (Eisenstein and Hu (1998)). Without the gravitational influence of (cold) dark matter, the formation of the measured fluctuations of matter-density cannot be explained, and consequently, present day observations of large structures cannot be explained. In fact, predictions by the cosmological model ΛCDM and the measured large scale structure data from the Sloan Digital Sky Survey (SDSS) are in remarkable agreement:

> The imprint of the acoustic oscillations on the low-redshift cluster-

[6]There are a number of observations that have been used in attempts to falsify MONDs, for example the decoupling of baryonic matter and gravitational potential in the the Bullet cluster collision (Clowe et al. (2006)) or potential dark matter free galaxies exhibiting Newtonian dynamical behavior (van Dokkum et al. (2018, 2019)). Although these observations may prove to be important pieces of evidence in settling the score, there are currently some attempts of accommodating the observations within a MONDian paradigm. An analysis with respect to the ultimate impact of this evidence on MONDs will have to wait.

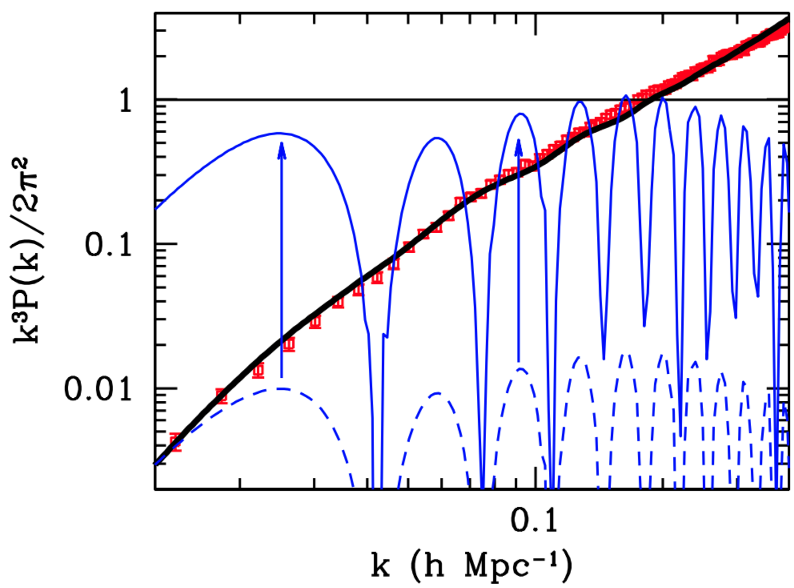

Figure 2: The matter power spectrum, from Dodelson (2011). Red error bars are data from SDSS, the thick black line is the prediction of ΛCDM assuming general relativity and dark matter exceeding baryonic matter by a factor of 6. Dotted blue line is a dark matter free model, the solid blue line is a relativistic MOND model (TeVeS).

> ing of matter is a generic prediction of CDM cosmological theory (Peebles and Yu 1970; Bond and Efstathiou 1984; Holtzmann 1989; Hu and Sugiyama 1996). Our detection confirms two aspects of the theory: first, that the oscillations occur at $z \gtrsim 1000$, and second that they survive the intervening time to be detected at low redshift. The small amplitude of the features requires that there exists matter at $z \sim 1000$ that does not interact with the photon-baryon fluid, i.e. dark matter. Eisenstein et al. (2005)

The agreement between the data received from the CMB and SDSS and the predicted values by ΛCDM needs to be reproduced by a MOND theory in order to be a viable alternative to dark matter and general relativity. However, the predicted matter power spectrum associated with Baryon Acoustic Oscillations by relativistic MONDs are, as Dodelson (2011) says "in violent disagreement with the data" (Fig.2).

We may draw the conclusion that the phenomena of Baryonic Acoustic Oscillations not only is a remarkable prediction of the ΛCDM in which dark matter is an indispensable component, but also that the dark matter hypothesis subsumes yet another observed data set within its explanatory scope, one which is not explained by the rivalling theoretical framework of modifications to gravity. For this reason, one can once again apply IBE to the extended data and add novel predictive success for the dark matter hypothesis to increase its ranking against the competition. I think there can be no doubts with respect to whether or not the realist should be committed to the existence of dark matter despite the fact that it has eluded every experimental attempt of discovery. The issue for realists regarding the MOND vs dark matter situation is their characterization of acceptance and truth. Once one has ranked how well the two alternative hypotheses perform in relation to the available data and background theory, the highest ranked hypothesis will be accepted as true. Since IBE, as characterized in Psillos' realism, does not admit of degrees of belief, this means that the empirical detection of dark matter is superfluous to the rejection of MOND - if we should accept that the dark matter hypothesis is true, we should also accept that MOND is false.

5 A realist rejoinder

In response to the argument that abductivism fails to attribute epistemic significance to the possible discovery or detection of dark matter, realists might invoke a distinction between astrophysical or cosmological dark matter and particle physics dark matter. That is to say, they might say that the explanatory virtues exhibited by dark matter with respect to the evidence from astrophysics and cosmology does warrant realism about dark matter, but only as a general existential quantifier. Since there is no evidence at all with respect to dark matter in particle physics, there is no warranted belief that targets any specific particle candidate in the class of possible contenders. While there are some constraints imposed on the class of possible dark matter particle candidates given by the astrophysical and cosmological evidence as well as from unsuccessful direct detection experiments, there is still a large number of different theoretical possibilities left, ranging from supersymmetric particles, extra dimensions, weak neutrinos, hidden sector self-interacting dark matter, and so on. Given the rather large class of dark matter candidates, the realist can point to a very important and significant way in which empirical confirmation by way of discovery can impact the epistemic status of dark matter - it tells us about the nature and properties of dark matter. There is no reason to be realist about anything more specific than the existential statement that there is some x such that it causes the phenomena we observe, and therefore there is no tension between the ideas that the existence of certain objects can be confirmed via their explanatory virtues and the idea that the nature of such objects gets confirmed in the process of empirical discovery. This response can be indirectly accessed via Psillos (1999) discussion on the causal theory of reference of theoretical terms over theory change:

> [I]t is one thing to assert that *there is* an entity to which a term t refers, quite another matter to find out the exact nature of this

> entity, and hence to specify the correct description to associate with the term t used to refer to this putative entity. (Psillos 1999, 283)

I argue that there are at least two reasons for rejecting the realist rejoinder. The first is that it relies too much on the fact that there is a large class of possible dark matter particle candidates. Since this fact is contingent it does little to reject the principled argument that confirmation by explanatory virtue outstrips the need for confirmation via detection. The second is that such a move is connected to a theory of reference which brings with it a host of problems for realists with respect to theory change.

5.1 Trivial referential success and theory change

One of the problems facing realism is how theoretical terms can be taken to successfully refer in light of substantial theory change. The realist project is premised on a connection between empirical success and truth, and since the successful reference of theoretical terms to ontologically robust objects is a natural consequence of this connection, successful reference in theory change is a vulnerable point in the realist framework. The argument against realism is that there are theoretical terms in past theories which, despite being empirically successful, were nevertheless not referring to anything at all. Laudan (1981) has perhaps most forcefully pushed this point against realists, arguing that past successful theoretical terms such as "luminiferous aether" are now abandoned and considered non-referring.[7] As a response to Laudan's argument, realists adopted a causal theory of reference that they thought could strengthen referential success in cases where a term was successful but still abandoned.[8] According to causal models of reference, references are fixed existentially, usually by simple ostension (Psillos (1999)). Given that ostension is a poor way to fix references to unobservable objects, we may substitute it for the assumption that the cause of some observed phenomena is associated with, in Psillos' terms, a 'physical magnitude'. Given that we observe some phenomena with an unknown cause, we can associate a physical magnitude to the cause with a term t. This moment is then taken to be the introduction of the term t which refers to the physical magnitude responsible for causing the phenomena. We now have a causal theory of reference that seem to fix the *existential* reference of the term 'dark matter' as being introduced in order to explain the cause of galaxy cluster dynamics. We may say then that this condition states that there is a physical magnitude, an object or a structure, to which 'dark matter' refers. The nature and properties of that physical magnitude, however, can remain unspecified or be updated once theoretical or empirical work has been done. For instance, in the early 1900's, the use of 'dark matter' picked out a particular class of objects:

> [A]stronomers at the time [1930's] were open to the possibility that large amounts of dark matter might be present in astrophysical

[7] See also Lyons (2006), Stanford (2003), and Elsamahi (2005).
[8] See Hardin and Rosenberg (1982) and Laudan (1984) for exchanges in this debate.

> systems, in the form of "extinguished stars, dark clouds, meteors, comets, and so on", as Lundmark writes in 1930." (Bertone and Hooper 2018, 18)

The modern use of the term rules out precisely those objects in favour of some exotic non-baryonic particle(s). On a purely causal account of reference, there is no tension between the early and the later use of the term since they both satisfy the same causal role played by the term - exerting gravitational influence. The causal account, however, makes successful reference too easy to get. The early use of 'dark matter' referred to low-luminous macroscopic objects made of ordinary (baryonic) matter and the modern use refers to non-luminous, microscopic non-baryonic matter. Given that the two descriptions of dark matter share no salient content with respect to the properties of the object, the continuing referential success of 'dark matter' in terms of fixing the reference existentially is inconspicuous. Laudan (1984) argues against the causal account of reference on precisely those grounds - if reference is fixed purely as an existence claim of an object as the cause of some phenomena, then the success of that reference is guaranteed despite the fact that theoretical changes over time attribute radically different properties to the object. Referential success then, becomes a trivial matter, because the causal theory of reference is tailor made to succeed. Additionally, Laudan's argument in this context implies that it would mean that Zwicky, Poincaré and others who used the term 'dark matter' in the early 1900's were actually referring to non-baryonic non-luminous particles all along, which is clearly false. A purely causal account of reference will simply not do. Psillos, well aware of the issues related to such an account, adds a descriptive component to his theory of reference:

1. A term t refers to an entity x if and only if x satisfies the core causal description associated with t.
2. Two terms t' and t denote the same entity if and only if (a) their putative referents play the same causal role with respect to a network of phenomena; and (b) the core causal description of t' takes up the kind-constitutive properties of the core causal description associated with t. (Psillos 1999, 296)

The descriptive addition specifies that there must be some properties attributed to the object such that it can play its stipulated causal role. But the kind-constitutive properties associated with the core causal description of dark matter must necessarily be informed by theory, and therefore go beyond the mere existential claim that dark matter exists. It appears as though a defense of the existential claim is coupled with the purely causal theory of reference which, by realists own admission, is insufficient to handle problems associated with theory change. Furthermore, one may worry about how to assess the core causal description of dark matter in the first place, and whether there is some overlap in the kind-constitutive properties assigned to such descriptions between the theorizing of its nature in the early 20th century and current hypotheses.

The history of dark matter is interesting as a special case of theory change since one may treat the ontological disparity between the early theorizing about its nature and the current theorizing as sufficient enough to categorize them as different hypotheses altogether. On such a reading the term 'dark matter' as used by Zwicky and others would be considered an abandoned term and not continuous with the term as it is used today. On the other hand one may take the perspective of the development of the dark matter hypothesis as analogous to the development of the atomic model, where the term 'atom' can be considered referentially stable despite underlying changes in the ontology. But does the realist have the semantic resources to deal with this special case? If we take the ontological disparity between theories in the 1930's and now as sufficient for treating them as different hypotheses, we can represent the difference between the usage of the two terms as t for non-luminous non-baryonic microscopic matter and t' for low-luminous macroscopic ordinary mass. Under this interpretation condition 2 (b) in the causal-descriptive theory of reference is fulfilled because the putative reference of t plays precisely the same causal role that the putative reference of t' was supposed to play. With respect to 2 (b) however, things are not so clear. Kind-constitutive properties are according to Psillos a set of properties that the object necessarily must have in order to play its causal role. Two questions now arise. The first is how scientists can determine which properties an object which they have not yet detected must necessarily have? The second is whether there is any sufficient overlap in the kind-constitutive properties associated with t' and the ones associated with t? The former question suggests that scientists can, based on their current background knowledge, find out the properties of an undiscovered object by reason alone which by its own is unreasonable. The latter question is concerning because the only overlap between the kind-constitutive properties of the putative entities of t and t' that one might reasonably argue exist is that they both should have the property of effecting the dynamics of spacetime. Besides echoing the problems of the causal theory, that the conditions for success is too easy to get when the criterion is too vague, the kind-constitutive properties now just looks like the causal role of the terms - what role does the kind-constitutive properties play in the causal-descriptive account if they collapse into the causal role? In addition, this could also mean that the structural changes to theories of gravity proposed by theories like MOND would also count as denoting the same entity, given that it is also captured in the kind-constitutive property of having an effect on the dynamics of spacetime.

These are interesting and specific semantic problems for realism with respect to the dark matter case and theory change, but for now, it is sufficient to point out that the realist rejoinder is coupled with a purely causal theory of reference which puts them in trouble regarding the general semantic issues of theory change. This constitutes a good reason for rejecting the rejoinder.

5.2 Contingency, Completeness, and the case of Isomers

The interest in dark matter was for a long time during the 20th century restricted to scientists working in cosmology and astronomy, where the scientific status of at least the former had not been successfully established (de Swart (2020)). The realization that the missing matter could be constituted by some exotic form of particle(s) became a valid and important research question within the particle physics community in the 1980's, and has since emerged as the most promising avenue for dark matter research (Bertone and Hooper 2018, 31). The initial space of possibilities for what dark matter could be was by in large only restricted by compatibility with the known laws of physics. Explanations of the anomalies included suggestions that low-luminous astrophysical objects like brown dwarfs, neutrino stars or black holes could account for the observed gravitational effects. The different suggestions premised on the idea that larger objects consisting of baryonic matter could constitute dark matter was collected under the heading "MACHOs", short for massive astrophysical compact halo objects. Although MACHOs have not been completely ruled out as being responsible for some of the mass budget of the universe, there "is a consensus today that MACHOs do not constitute a large fraction of the dark matter" (Bertone and Hooper 2018, 44).[9] The currently explored space of possibilities then, has been restricted by both observations and theoretical considerations to rule out baryonic massive objects.[10] Does this mean that realists are committed to the theoretical paradigm in which dark matter is a particle with properties within a specified parameter space? Even if that is so, they may still claim that their commitment is epistemically safe given that theory space is still relatively large. This epistemic safety, however, is only circumstantial and is not an effect of the realist epistemology, but rather of the contextual elements of the situation.

The fact that theory space with respect to dark matter candidates has continuously diminished demonstrates that the set of possible theoretical alternatives with respect to dark matter (or any theory) is merely a contingent feature of the situation. If scientists continue to rule out alternatives, consequently shrinking theory space, a situation may arise in which there is only one possible candidate left that can explain all the data. Supposing that dark matter has not yet been directly or indirectly detected at such a point, we can more clearly see how there is a principled reason to think that confirmation via explanatory virtues outstrips the epistemic value of empirical confirmation via discovery. In fact, there is an explicit reason to think that in such a situation, realists would be forced to accept that conclusion:

> *Completeness*: Suppose only one explanatory hypothesis H explains all data. That is, all other competing explanatory hypotheses fail to

[9]See Bertone and Hooper (2018) for two salient pieces of evidence supporting this conclusion.

[10]Again, Bertone and Hooper (2018, 43) briefly describes the theoretical and observational reasons that impacted the restrictions on mass and self-annihilating cross sections.

> explain some of the data, although they are not refuted by them. H should be accepted as the best explanation. (Psillos 2009, 184)

Completeness is taken to be an explanatory virtue by which we may judge competing hypotheses against each other in applying IBE. As we have seen, it can be applied at the level of theoretical paradigms so as to distinguish between the dark matter hypothesis and modifications of gravity, yielding a realist judgement with respect to dark matter. In order to defend the limited existential claim, realist may resist the application of *completeness* internally to the dark matter paradigm as a way to discriminate between different hypotheses about the nature of dark matter and its properties. The possibility of doing so, however, is necessarily linked with contingent facts of our knowledge about the state of theory space. If a situation arises in which we have only one dark matter candidate left, the application of *completeness* at the level of theoretical paradigms will automatically select that theory, which provides a description of the nature and properties of dark matter. The consequence is that the application of IBE amounts to a realist commitment with respect to that theory, regardless of whether dark matter has been empirically discovered or not. In order to demonstrate that the hypothesized situation in the dark matter context is not merely a philosophical possibility but rather a situation that scientists may indeed face, one can consider an analogous situation with respect to explaining isomers in the case of scientific atomism.

5.2.1 Isomers

At the turn of the last century, the scientific community were debating the epistemic credentials of the theory of scientific atomism.[11] Critics of atomism argued, amongst other things, that the principled divide between the observable and the unobservable rendered atomism a theory that could never be conclusively confirmed, given that its core postulates were microphysical. Atomism, according to this line of criticism, was a speculative theory with instrumental value at best. Exponents of atomism claimed that its predictive success and explanatory power should amount to significant epistemic support for the theory. One, for our purposes, particularly interesting argument in favour of atomism comes from late 19th century chemistry - the explanation of isomers.

Isomers are chemical compounds that consist of the same elements in equal proportions but that nevertheless differ in their chemical properties. This peculiar phenomenon in chemistry needed to be explained, and attempts at doing so came from an atomist perspective. Both Le Bel (1874) and Van't Hoff (1874) theorized that if atoms were differently spaced in the molecular bonds in the different isomers, this would explain the difference in chemical behavior. Interestingly, the phenomenon of isomers appeared to only be explained by atomism:

> First, in the absence of spatial positioning there seemed to be no degree of freedom available at all to represent differences between sub-

[11] I refer to Dawid (2020) for a full case analysis of the situation with respect to the confirmational aspects of scientific atomism.

> stances that consisted of the same elements with same proportions. Second, as had been observed by Louis Pasteur, different isomers of salts of tartaric acid rotated the polarization axis of polarized light in different ways. Given that light polarization was understood to be a spatial phenomenon, it seemed difficult to imagine any physical representation of the effect of isomers on polarization that was not based on spatial characteristics of the differences between the isomers themselves. Once one conceded that the spatial characteristics of the substance were crucial in both cases, it was exceedingly difficult to imagine a representation of the spatial characteristics of isomers that was not based on an atomist perspective. (Dawid 2020, 8) [12]

In cases such as these, *completeness* could be applied to atomism in order to yield a realist commitment to the existence of atoms even though no atoms had been empirically detected. The situation implies that the later empirical detection of atoms would have amounted to an epistemically non-significant instance of confirmation. The case of isomers show that a context in which theory space is restricted to a single theory with no discernible alternatives is a very live possibility in science. Presented with such situations, the realist epistemology will treat the explanatory virtues of a theory as sufficient for conclusive confirmation of that theory with respect to its central objects and their properties. It becomes clear then, that there is a principled tension between the confirmatory role played by explanatory virtues and the confirmatory role played by empirical detection.

6 A probabilistic turn

At this stage the issues related to PUA becomes relevant again, but in a rather unexpected way. Given the above arguments, one way for the realist to resist the charge of undermining the epistemic value of empirical detection is to claim that, unless scientists detect the central objects of a theory, there is always a chance that an unconceived alternative is the true theory. In such cases, there is still room for empirical detection to make an epistemic difference. But as we saw in previous sections, PUA is an anti-realist argument which can be used to weaken IBE on precisely those grounds. This seems to leave the realist at an impasse: either they accept that abductivism trivializes the epistemic value of empirical detection, or they accept that unconceived alternatives undercuts the probative force of IBE. I think realists could do well to look at probabilistic reasoning in order to address both the problem of unconceived alternatives as well as the problem of undermining empirical detection. Once one accepts degrees of

[12]The scientific reasoning in the quote can be taken to constitute a non-empirical way to assess the theory in question, atomism, relative to its alternatives given certain restrictions on background knowledge (that alternatives had to account for polarization effects for example). As Dawid argues, no alternatives reasoning in the isomer case was in part responsible for assessing the viability of atomism in lieu of the empirical detection of its central objects.

belief, one of the tenets in Bayesianism, there is no risk that confirmation via explanatory virtues outstrips the confirmatory role of detection simply because one does not need to assert the truth of a hypothesis in response to the evidence. So long as the probability of the hypothesis is lower than 1, there is always room to increase its probability. The question is how, more precisely, probabilistic reasoning can help the realist without also undermining its central promise of epistemic optimism.

6.1 Non-empirical theory confirmation

If it is a fact that a given hypothesis is simpler, explains more facts, is more compatible with background data et.c. relative to its rivals, it is not an empirical fact that is logically connected to the content of the hypothesis itself. That facts which are logically unrelated to the internal structure of a hypothesis can have an impact on the confirmation of a hypothesis is not sui generis in realist epistemologies. Dawid (2013, 2015, 2016) has developed and defended an account of non-empirical theory assessment that addresses situations in which the data needed to evaluate a theory empirically lies far beyond the current limits of experimental physics. In such situations Dawid argues that we can nonetheless assess the theory's viability by analyzing its non-empirical features. In this framework, the usual virtues such as simplicity, unification, fecundity and elegance are not the driving force of the analysis. Instead, Dawid argues for three distinct ways that non-empirical facts can bear on the confirmation of a theory: the no-alternatives argument, the argument of unexpected explanatory interconnections, and the meta-inductive argument. I will follow Dawid and refer to the application of one or a combination of these as an instance of meta-empirical confirmation (MEC). Could MEC be integrated in or added to the realist overall epistemology in order to address PUA as well as the problem of undermining detection? As we will see, the degree to which it can depends on the context and particulars of the situation. Before we can address the contexts in which it can, it is important to note that Dawid's aim is not to claim that MEC is equivalent with, or a substitution of, empirical confirmation:

> [T]he distinction between MEC [Meta-Empirical Confirmation] and empirical confirmation remains of crucial importance today because it indicates a substantial difference in confirmation strength. Empirical confirmation remains the only path to conclusive confirmation. MEC is a second-best option that can be deployed under specific circumstances as long as empirical confirmation is not forthcoming. Even on the most optimistic current view on MEC this point remains undisputed. (Dawid 2020, 15-16)

The reason why the distinction between MEC and empirical confirmation does not collapse in the way that I have argued that it does for the realist is because MEC is not taken to aim at assessing the *truth* of a theory. Instead, MEC is a way of assessing the *viability* of a given theory (Dawid 2017, 8-9).

The viability of a theory is of course not necessarily coupled with any realist commitment to it, so the distinction is in no danger of collapsing. MEC, seen in this way, is utilized to support substantially weaker claims than the realist wishes to make. This, however, does not mean that the realist cannot use the core concepts in MEC in combination with IBE and explanatory virtues to good effect. The rational behind doing so would be two-fold. Firstly, MEC is a framework that specifically aims to provide (some degree of) confirmation to a hypothesis by analysing the state of theory-space. Such a framework can aid the realist with respect to PUA. Secondly, it couches confirmation probabilistically, in degrees of belief, which opens up the gap between confirmation via explanatory virtues and confirmation via empirical detection. If realists could successfully integrate MEC in their overall framework, this would fix two serious problems in their epistemology.

6.2 The no-alternatives argument and realism

As we have seen, scientists may find themselves in a situation in which all the known dark matter candidates except for one have been ruled out. In such situations the application of *completeness* and IBE prompted the realist conclusion that the remaining hypothesis is true.[13] This was worrying because it shows that the realist idea that theoretical and explanatory virtues can have a confirmatory impact on a theory in some contexts imply that empirical confirmation is unnecessary or redundant for conclusive confirmation. At this point, unconceived alternatives presented an unwelcome way out for the realist: if there are reasons to think that there are unconceived alternatives to the known dark matter candidates, the empirical detection of the remaining dark matter candidate would have an impact on its confirmation. Recognizing that there are reasons to think that there are unconceived alternatives is of course problematic precisely because it blocks the epistemic warrant to believe that the confirmed dark matter hypothesis is probably true. Only if we had reason to think that the number of alternatives is close to zero would the epistemic warrant be justified. This is where the no-alternatives argument enters the picture. Let's start with a brief explication of the general concepts involved in the no-alternatives argument.[14] For an H to have no alternatives means that:

> Scientists have looked intensely and for a considerable time for alternatives to a known theory H that can solve a given scientific problem but haven't found any. This observation is taken as an indication of the viability of theory H. (Dawid 2017, 17)

Even though Dawid speaks of the probability that a theory is viable, it makes no structural difference would the realist simply substitute it for truth.

[13]In such contexts IBE looks more like what Bird (2006) calls 'Inference to the only explanation'.

[14]For proofs and a thorough Bayesian analysis of the no-alternatives argument, see Dawid et al. (2015).

Let $Y_k = \{Y = k\}$ be the expression that there are k number of alternatives that satisfy the following conditions: fulfill a set of theoretical constraints $\mathcal{C}$, explain existing data $\mathcal{D}$, and give predictions for future experimental outcomes $\mathcal{E}$. If we assume that Y takes a value in the natural numbers, and that F_A expresses the fact that no alternative H' satisfying $\mathcal{C}$, $\mathcal{D}$, and $\mathcal{E}$, has been found, then: $P(H|F_A) > P(H)$. That is, F_A confirms H. The degree to which F_A confirms H depends mainly on the number of alternatives.[15] If the number of alternatives is low, confirmation is stronger, if it is high, confirmation is weaker. The prior assigned to the value of Y_k can be determined by meta-induction. The meta-inductive argument provides reason to think that existing alternative explanations to why scientists haven't found an alternative theory, for instance that scientists are not clever enough, are improbable:

> [I]f scientists have been so successful in finding viable theories in the past, it seems less plausible to assert that they are not clever enough for doing the same this time. Therefore, MIA can turn NAA into a method of significant confirmation. (Dawid 2016, 14)

MIA then, sets the prior probabilities of alternative explanations to F_A sufficiently low as to increase the probability of H. The no-alternatives argument addresses Stanford's worry that we have inductive reasons to think that there are unconceived and empirically equivalent alternatives to any given theory by providing reasons to think the opposite. For the realist, this means that the successful application of NAA safeguards the epistemic warrant of IBE in relation to the known alternatives. If we have reason to think that there are few or no unconceived alternatives, the probability that the true theory is amongst the known ones and is selected for by IBE is greater than it would be without those reasons. It also respects the epistemic relevance of empirical detection simply because detection reduces the number of known and unknown alternatives.

One may re-frame and recap the issue as following. With respect to the dark matter hypothesis, NAA can currently only be applied on the level of theoretical paradigms. Scientists have been trying to find alternatives to the dark matter hypothesis for over 30 years and still it is only MONDs that have been in the running. If it turns out that no relativistic MOND model satisfies $\mathcal{C}$, $\mathcal{D}$, and $\mathcal{E}$, realists could take this to amount to an NAA mode of confirmation of the dark matter paradigm. However, since alternatives *within* this paradigm are many, NAA cannot be applied internally, which again leads to the core problem of how to account for realism in this internal context without ending up in the semantic problems described in section 5.1, or to see the resurfacing of the main issue addressed in this paper: that one of the dark matter candidates receives an increase in explanatory power or unification via some new observation and forces the realist to conclude that its true. Again, allowing for degrees of belief is the

[15] Other factors are accounted for in the original argument: "We should also note that the value of F_A — that scientists find/do not find an alternative to H — does not only depend on the number of available alternatives, but also on the difficulty of the problem, the cleverness of the scientists, or the available computational, experimental, and mathematical resources" (Dawid et al. 2015, 10)

obvious candidate for the realist. Once one introduces degrees of belief, there is room for confirmation via both theoretical or explanatory virtues and empirical detection, and in conjunction with MEC, this would substantially strengthen the realist framework.[16]

7 Summary

In this paper, I argued that the application of contemporary scientific realist epistemology to the dark matter hypothesis in cosmology highlighted a (principled) tension between the canonical idea that a theory is conclusively confirmed by the empirical detection of its central objects, and the idea that a theory can be confirmed by its theoretical and explanatory virtues. Realism, I argued, implies that empirical detection is not necessarily confirmatory because in some cases the application of theoretical virtues has already provided all the epistemic warrant we need. I explored a possible realist response to the argument - that realism was epistemically warranted only with respect to the existence of the entity, not its nature and properties - but concluded that such a general claim was hard to reconcile with the semantic theories regarding successful reference that realists have developed in response to challenges from theory change. Developing the realist response also made the problem of unconceived alternatives reappear in a, for the realist, new context. I then explored if abductivism could be strengthened by embracing degrees of belief as well as a program of meta-empirical confirmation, or MEC. The integration of the two looked promising for two reasons: i) degrees of belief principally upholds the relevance of empirical detection, and; ii) MEC strengthens IBE with respect to the known alternatives by addressing the problem of unconceived alternatives.

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[16]There are a number of ways that realists can introduce degrees of belief to their overall framework. For examples see: Henderson (2013), Weisberg (2009), and Vickers (2019).

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